Foreshore Management Plan for the Swan River Estuary in the Western Suburbs of Perth

For the Western Suburbs Regional Organisation of Councils (WESROC)

Seashore Engineering Pty Ltd
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Western Suburbs Regional Organisation of Councils

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Disclaimer

(1) The document articulates foreshore management and adaptation approaches recommended by Seashore Engineering. The report is intended to inform, not dictate, future management approaches implemented by foreshore managers. It does not replace the management and decision-making process used by Local Government Authorities (LGAs) that may be influenced by community consultation, financial priorities and the broader scope of LGA management responsibilities.

If an LGA selects an alternate management pathway for a site than documented in this report, it is recommended to also update the planned monitoring, capital and maintenance requirements.

The opinions contained within the report do not necessarily represent the views of the Department of Parks and Wildlife Rivers and Estuaries Division.

(2) From 1 July 2016, any reference to the foreshore managed by the City of Subiaco should be read as managed by the City of Perth following enactment of the *City of Perth Act 2016*.

EXECUTIVE SUMMARY

The Western Suburbs Regional Organisation of Councils (WESROC) includes the Towns of Claremont, Cottesloe and Mosman Park, the Shire of Peppermint Grove and the Cities of Nedlands and Subiaco. WESROC works as a voluntary partnership on projects across, or on shared boundaries, and to address cross-boundary regional issues. This Study was commissioned by WESROC, and co-funded with the Department of Parks and Wildlife Rivers and Estuaries Division, to obtain a regional management plan for the 16.1km of estuarine foreshore managed by the councils. The Town of Cottesloe is the only council without estuarine foreshore and therefore not involved in the project.

The WESROC foreshore is experiencing problems with erosion and river wall collapse. Estuarine vegetation restoration programs have had varying success. Since 1985, foreshore management in the WESROC area has typically been reactive and on a small scale. Many of the structures installed prior to 1985 by the Public Works Department have reached the effective end of their structural life and require either major repair or changes to management practices. Many of the foreshores have previously been modified by dredging and reclamation, including sand placement to form recreational beaches. Extensive retreat since the mid-1980s has coincided with a policy shift away from dredging. The foreshore has been further impacted by extended periods of high water levels, a number of severe storms and year-to-year variations in the prevailing weather systems, with response also impacted by the extensive previous modifications.

This WESROC foreshore management plan (FMP) has been prepared to assist local governments protect and enhance riverbanks. It is intended to assist planning for foreshore structure maintenance, renewal and capital works over a range of time-scales and to help forecast funding needed to undertake the works. The plan attempts to reduce the reliance upon reactive management. Proposed present and future management required consideration of existing management and adaptation pathways, with an aim to develop and improve foreshore resilience. Management recommendations are required at an asset level to facilitate successful delivery of on-ground projects.

Approach

Physical evidence regarding foreshore dynamics was considered through a vulnerability framework over three time frames. This allowed focus on different elements of management, nominally being:

- < 5 years which provides a risk management context, by considering the present state of the foreshore and sensitivity to acute events;
- 5-25 years which indicates management pathways, considering dynamics, life-cycle of existing stabilising structures and actions to increasing foreshore resilience; and
- > 25 years which provides an adaptation strategy, considering uncertainty related to future management choices and longer-term process variability. Scenarios considered over this scale indicate potential pathways to improve foreshore resilience.

Use of the three time frames supported identification of conflicts or constraints between short to medium-term management actions and medium to long term plans or options. Information in this foreshore management plan included actions to improve foreshore resilience over the three time frames, monitoring requirements, issues to be resolved and works that may constrain long term strategies.

The study used the segment-scale spatial framework used by the Department of Parks and Wildlife Rivers and Estuaries Division (Parks and Wildlife), with 26 segments in the WESROC area, facilitating ease of communication for *Riverbank* funding applications.

A key outcome of the evidence-based assessment of dynamics was recognition that much of the observed change was related to previous modifications to the foreshore and existing structures. Within this context, a deeper understanding of the historic decision-making and apparent consequences was developed to support the interpretation of appropriate future interventions.

WESROC Foreshore Management and Adaptation Themes

Key local themes identified as prevalent along the WESROC foreshore include:

- Insufficient maintenance;
- Reactive management;
- Structures reaching the end of their functional life;
- Foreshore resilience issues related to surface drainage and irrigation;
- Trampling by pedestrians and vessel launching/retrieval;
- Conflicting uses and values;
- Continued foreshore response to historic works; and
- The need for improved communication with other stakeholders for foreshore management, asset maintenance and planning, including the Water Corporation and leaseholders.

Issues identified relevant to State Government

Anticipated foreshore management requirements for WESROC indicate a number of significant issues that are difficult to address at a Local Government level, but may have potential for better or more efficient management through the involvement of State Government agencies. It is recommended that WESROC should engage in strategic discussions with the appropriate organisations, and where appropriate, actively lobby for support using its leverage as a collection of councils. Five challenges were identified with recommendations to address each included below.

Interactions with private ownership

Existing foreshore management is constrained by interactions with private ownership of land or assets near the foreshore. On foreshores with alternating public and private foreshore ownership, the transfer of stresses due to discontinuous foreshore management obscures responsibilities for management and cost-sharing and potentially causes litigious situations. The issue for private ownership landward of a narrow foreshore reserve is that owners may expect that the LGA will protect their properties at public expense, particularly where it is deemed to provide public foreshore access. Management of these foreshores is further restricted by existing funding arrangements for stabilisation works, which exclude management of privately-owned foreshores. This issue extends to other foreshores around the state and therefore it is recommended that WESROC liaise with the Western Australian Local Government Association (WALGA) regarding up-to-date and effective practices related to private foreshore ownership issues, including a clear understanding of legal positions and obligations.
Recommendation: *Legal clarification should be sought by WESROC on the relative obligations of LGAs for foreshores with interactions with private ownership and their capacity to obtain funding to support protective efforts (such as Special area rates under Section 6.37 of the Local Government Act 1995).*

Ceding and vesting of privately-owned foreshore

Ceding and vesting of privately owned land by the Western Australian Planning Commission (WAPC) to form a foreshore reserve is triggered by the subdivision process, and often results in high maintenance costs for an LGA due to access constraints and piecemeal treatments; with no improved foreshore access for the public. This is particularly relevant to potential ongoing costs for the City of Nedlands, Town of

Claremont, Town of Mosman Park, Parks and Wildlife and the WAPC. Presently, WAPC will continue to cede land and vest it with an LGA through the subdivision process, and in the context of the Metropolitan Region Scheme (MRS) and Section 152 of the *Planning and Development Act 2005*. This is supported by the Parks and Wildlife Policy SRT/EA2 on Foreshore Reserves. One possible outcome to reduce this issue is to conduct an MRS amendment at the scale of WESROC. Other LGAs along the Swan and Canning Rivers, as well as coastal LGAs, are similarly affected by this policy and may also seek to avoid further vesting of narrow foreshores with LGAs.

Recommendation: *WESROC should consider its position with respect to this policy and if deemed appropriate, liaise with LGAs along the Swan and Canning Rivers and WALGA to collectively approach the Department of Parks and Wildlife Rivers and Estuaries Division, the Minister for Planning and the WAPC to review this approach of vesting land along narrow or eroding foreshores*

Material disposal costs

High costs of disposal of dredged spoil and existing walling, partly due to the recent increase in the landfill levy, are likely to prejudice future management options, tending toward building additional structures riverward of the existing walling. This additional reclamation reduces the foreshore resilience and potentially increases lifetime management costs. A broader range of management solutions could be developed if a reduced cost disposal option existed for historic river walls and reclaimed foreshores. There may be opportunities to substantially decrease material disposal costs if the entire existing foreshore walling (or a substantial part thereof) is considered, instead of looking at disposal of small sections.

Recommendation: *WESROC should liaise with the Department of Environmental Regulation (DER) regarding methods to reduce the costs of disposal of existing foreshore treatments previously undertaken by State Government departments. This could include a special exemption for the landfill levy and an appropriate strategy for reducing costs associated with identification, testing and disposal.*

Availability of sand for renourishment

WESROC includes many artificial foreshores and beaches which require ongoing renourishment, with a high expense due to restrictions on dredging since 1985 and suitable quarries becoming increasingly distant from the WESROC area over recent decades. A reliable and cost-effective source of sediment is required to maintain these beaches. An option that should be pursued further is the extraction of sediment accumulating in the river pools on the Avon River. Existing studies have focused on the viability of extracting sediment from these pools for the construction industry; however, it is preferred to maintain the sediment within the broader river system. Consultation with the Whadjuk Regional Corporation is required because the excavation will cause disturbance to a recognised Site (3536).

Recommendation: *Consideration should be given to a state agency lead study to determine how river pools on the Avon River could be a viable source of renourishment material for the beaches on the Swan-Canning River System. The study should consider (i) approval under Section 18 of the Aboriginal Heritage Act 1972, (ii) funding arrangements, including Local Government contributions, and (iii) resolve the potential conflict for the sand with the construction industry.*

Strategic funding allocations

The projected funding requirement for WESROC erosion mitigation is substantial, with high costs for both capital and maintenance activities. Collaborative agreements with Parks and Wildlife, such as the Nedlands River Wall Foreshore Restoration agreement, demonstrate pathways to address the issues associated with sourcing funds for large capital works within electoral cycles and the financial pressure to defer maintenance. Collaborative agreements are likely to be required for a number of LGAs given that renewal of many assets will be needed in the next five years.

Recommendation: *Collaborative agreements should be sought by Parks and Wildlife for large areas of walling works to provide greater flexibility in establishing project timelines rather than an annual grant scheme.*

Foreshore Management Plan per Segment

Information is provided to assist in planning for capital works, maintenance works and monitoring immediately, as well as for the medium- and longer-term. Key management statements for each LGA are noted below with reference to the corresponding sections of this plan containing management recommendations.

City of Subiaco

The management plan for the City of Subiaco is presented in Section 6.2 with detailed recommendations per segment in Appendix C.6. Maintenance of the JH Abrahams Reserve walling is a management focus given the age of the walling, toe undermining due to bed-level lowering, the reduction of walling porosity during 2003-2006 maintenance and the age of drain infrastructure. In the medium-term, the feasibility of pocket beaches should be further assessed in JH Abrahams Reserve when planning the walling renewal. The Qantas boat ramp should not be upgraded, with launching traffic directed to the boat ramp on the north side of Pelican Point. Management options for the eroding foreshore to the east of the boat ramp requires resolution with Parks and Wildlife. Maintenance and renewal of walling in southern JH Abrahams Reserve require joint planning with the City of Nedlands.

City of Nedlands

The management plan for the City of Nedlands is presented in Section 7.2 with detailed recommendations per segment in Appendix D.6. Six of the 11 segments correspond to the walled foreshore, which is approaching the end of its life in many areas. The focus is maintaining the existing use for as long as possible, replacing the worst sections with a longer-term solution and fencing failing areas until scheduled works can be undertaken. The preferred option for this foreshore is a rock revetment with a smooth continuous alignment. It is recommended to remove the existing walling and construct slightly landward of the existing walling with considerations of staging and transitions required. Resilience can be improved through inclusion of a scour toe, splash zone at the crest and deeper embedment. In areas with private property interactions along Jutland Parade and Victoria Avenue it is recommended to encourage neighbouring private property owners to develop collective long-term plans, with consideration of safety and access, and for the City to develop more detailed planning controls and guides. The cliffed foreshores of Point Resolution Reserve require short-term management to address safety concerns and in the medium- to longer-term prevention of foreshore access. Maintenance and renewal of northern Charles Court Reserve will require joint planning with the City of Subiaco. Management of the foreshore at Watkins Road will require joint planning with the Town of Claremont management of the foreshore at Mrs Herberts Reserve.

Town of Claremont

The management plan for the Town of Claremont is presented in Section 8.2, with detailed recommendations per segment in Appendix E.6. The main approach for this foreshore is to improve resilience by allowing landward migration and improving the smoothness and continuity of the foreshore alignment. Recommended management actions include backpassing sediment accumulated at Claremont

Yacht Club and renourishing beaches using externally sourced sediment. Management of the foreshore at Mrs Herberts Park will require joint planning with the City of Nedlands management of the foreshore at Watkins Road.

Shire of Peppermint Grove

The management plan for the Shire of Peppermint Grove is presented in Section 9.2, with detailed recommendations per segment in Appendix F.6. A management focus is walling maintenance given the age of the walling, including focus on the base of structures and near drains. Key immediate issues for the Shire are associated with erosion enhanced by trampling, drainage and surface runoff; particularly south of Leake Street. Focal points for recreational access are required. Sediment management will also be required with backpassing and renourishment using externally-sourced sand. Management of the foreshore south of Royal Freshwater Bay Yacht Club requires joint planning with the Town of Mosman Park for the broader Mosman Bay, including the boat ramp.

Town of Mosman Park

The management plan for the Town of Mosman Park is presented in Section 10.2, with detailed recommendations per segment in Appendix G.6. In the short-term, the main focus for the Town of Mosman Park is undertaking works within Mosman Bay (wall renewal and boat ramp) and addressing the failed walling under Mosmans Restaurant. Maintenance is required to extend the life of the walling for as long as possible, with two sections requiring immediate replacement with sufficient embedment to achieve the longer-term strategy. The walling selected should have sufficient embedment now to tolerate raising the walling by up to 0.5m in future to allow for improved resilience to high water levels. The design incorporates the option for future beach renourishment by allowing for minor retreat, rather than extending the walling further riverward. A number of other key recreation areas at Swan Canoe Club, the Coombe, Green Place, Chidley Point Reserve, Minim Cove jetty and Milo beach also require management via renourishment, sand backpassing and structure maintenance. Most of these sites have access limitations that require consideration for ongoing management given the expense of operating from a barge. Most cliff areas are recommended to be allowed to retreat, with actions required to address foreshore access and safety hazards. Management of the foreshore in Mosman Bay requires joint planning with the Shire of Peppermint Grove.

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Appendices C to G are provided as separate attachments.

Glossary

Term	Definition
Adaptation	Adjusting management in response to changing environmental conditions. Adaptation responses can be adjusting physical structures or management actions, modifying planning controls or undertaking new management actions. Adaptation is often considered in estuarine foreshore management to account for projected mean sea level rise and climate change. Further information on adaptation is available from the National Committee for Coastal and Ocean Engineering (2012).
Australian Height Datum (AHD)	The vertical datum that sets mean sea level as zero elevation. Mean sea level was determined from observations recorded by 30 tide gauges around the coast of the Australian continent for the period 1966–1968.
Average Recurrence interval (ARI)	The average or expected value of the periods between exceedances of a given measure (eg water level) over a given duration. It is implicit in this definition that the periods between exceedances are generally random.
Backpassing	Mechanically shifting sediment from one end of a beach/bay to the other, normally from a point of accumulation to a point of erosion.
Bar	Sand, gravel or cobble deposit found on the bed of a stream that is often exposed only during low water levels
Dredging	The process of excavating sediment from the riverbed.
El Niño	A fluctuation in atmospheric pressure, ocean temperatures and rainfall associated with warming of the oceans in the equatorial eastern and central Pacific.
Gabion	Steel wire-mesh cage to hold stones or crushed rock to protect a bank from erosion
Groyne	A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift and therefore slow erosion of the shore immediately updrift.
Geology	The science that deals with the dynamics and physical history of the earth, the rocks of which it is composed, and the physical, chemical, and biological changes that the earth has undergone or is undergoing
Geomorphology	That branch of geography which deals with the form of the Earth, the general configuration of its surface, the distribution of the land and water; or the investigation of geologic changes through the interpretation of topographic forms
Inundation	When high water levels and waves cause flooding of normally dry land. This can impact on foreshore vegetation or structures and curtails amenity. In estuarine reaches, the inundation level is largely determined by the summation of tides, surges and wave excursion over land. Inundation can occur from fluvial flooding.
La Niña	La Niña refers to the extensive cooling of the central and eastern tropical Pacific Ocean, often accompanied by warmer than normal sea surface temperatures in the western Pacific, and to the north of Australia. La Niña events are correlated with stronger Leeuwin Currents and higher mean sea levels in the Swan (Eliot 2012).
Renourishment	A process by which sediment (usually sand) lost through longshore drift or erosion is replaced on a foreshore with coarse sand.
Resilience	Foreshore resilience is defined as the foreshore’s capacity to tolerate and adjust in response to changing environmental conditions.
Revetment	An inclined structure that provides a protective covering on an embankment of earth designed to maintain the slope or protect it from erosion
Rock revetments	A system of graded, interlocked, quarried armour stone applied to a bank on an incline to absorb erosive forces and stabilise the adjacent foreshore
Sandbar	A depositional area composed primarily of sand
Scour	Erosion due to flowing water, usually considered as being localised as opposed to general bed degradation

1. Introduction

The Western Suburbs Regional Organisation of Councils (WESROC) includes the Towns of Claremont, Cottesloe and Mosman Park, the Shire of Peppermint Grove and the Cities of Nedlands and Subiaco. WESROC was established in 1995. WESROC works as a voluntary partnership on projects across, or on shared boundaries, and to address cross-boundary regional issues. This Study was commissioned by WESROC, and co-funded with the Department of Parks and Wildlife Rivers and Estuaries Division (herein Parks and Wildlife, previously Swan River Trust), to obtain a regional management plan for the 16.1km of estuarine foreshore managed by the councils (Figure 1-1). The Town of Cottesloe is the only council without estuarine foreshore and therefore not involved in the project.

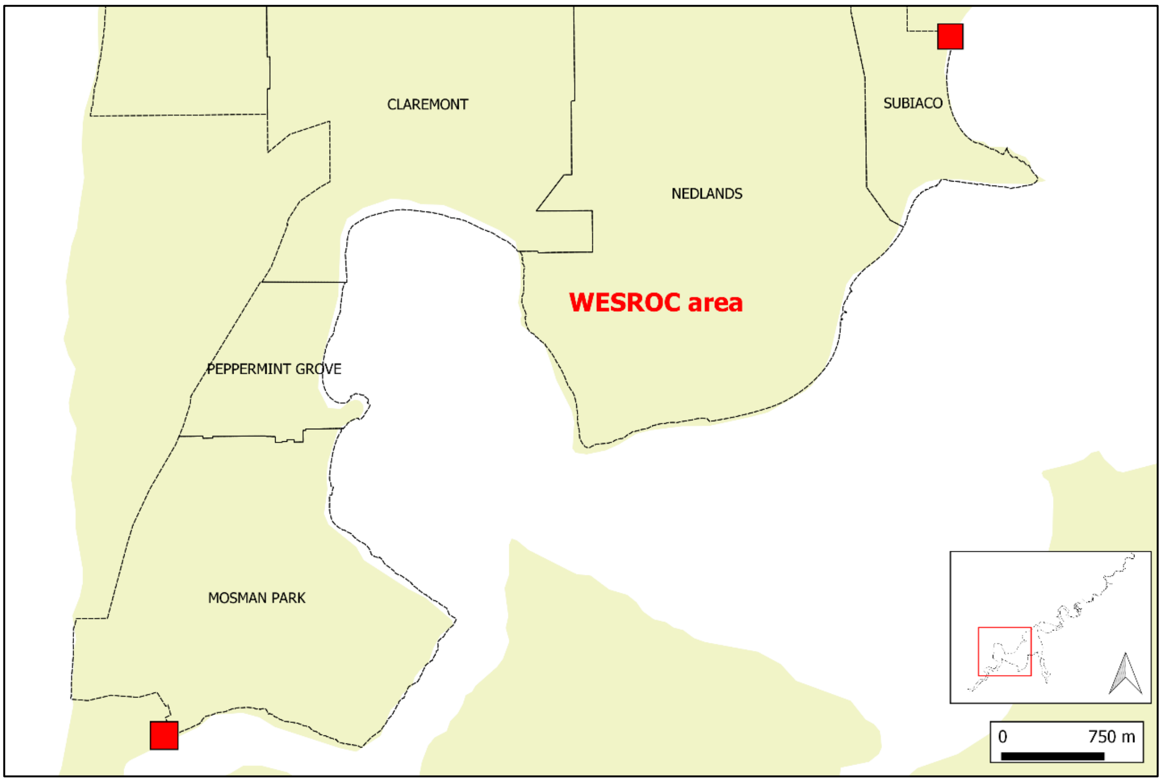

Figure 1-1: WESROC Study Area

The WESROC foreshore is experiencing problems with erosion and river wall collapse. Estuarine vegetation restoration programs have had varying success. Since 1985, with the disbanding of the Public Works Department (PWD), foreshore management in the WESROC area has typically been on a small scale. This has often been reactive, in response to severe storm events or local structural failures. Many of the structures installed prior to 1985 by the Public Works Department have reached the effective end of their structural life and require either major repair or changes to management practices. Many of the foreshores have previously been modified by dredging and reclamation, including sand placement to form recreational beaches. Extensive retreat since the mid-1980s has coincided with a policy shift away from dredging.

Additional erosive pressure has occurred recently through an extended period of high water levels, associated with several different phenomena (Eliot 2012). The most significant of these has been the extremely high mean water level associated with the unheralded 2011-2012 la Nina climate phase (BoM 2012), which caused water levels almost 0.3m higher than normal and has resulted in extensive erosion issues all the way along the Western Australian coast.

Extreme weather events, potential climate variability and potential foreshore response in the context of previous foreshore modifications are considered in the vulnerability assessment of the WESROC foreshore. This assists in determining a best-practice adaptation approach, ensuring the constituent local governments satisfy due diligence in decision-making and ensure future costs and potential liabilities are minimised.

Vulnerability to extreme weather events is considered as a combination of the likelihood and magnitude of the events themselves, in conjunction with the potential foreshore response. The potential foreshore response is placed in the context of previous works (historic dredging, reclamation, renourishment and structures) due to the extensive modification of this foreshore. In addition, future foreshore response considers responses below the Mean High Water Mark with modifications to terraces often a significant cause of foreshore erosion.

In the context of this study, foreshore vulnerability has been considered as the sensitivity of identified objectives and assets to foreshore dynamics. Vulnerability may need to consider both natural foreshore pressures and the effects of imposed changes, given that many structural foreshore assets, and associated reclamation projects, have direct effect on foreshore dynamics.

Proposed present and future foreshore management requires consideration of management and adaptation. An evidence-based approach can be used to determine management needs based on a review of foreshore performance and infrastructure condition and function in the context of observed environmental conditions. Requirements of foreshores to tolerate extreme events also require evaluation. For future plans, adaptation may be required to respond to changing infrastructure/foreshore use, the effects of adjacent foreshore management and changing environmental conditions.

Adaptation planning for the WESROC foreshores considers these possible changes, and identification of appropriate management or infrastructure responses. Where it is cost-effective to accommodate potential changes through present-day actions that are long-lasting, it should be directly included, otherwise it requires a monitoring framework and set of management triggers to be identified. Because it does not necessarily involve active management, effective adaptation planning should generally consider a broad range of possible future outcomes, a large change in facility use or long-term foreshore evolution. The key aim of adaptation planning is to develop foreshore resilience.

1.1. OBJECTIVES

This Study aims to provide a foreshore management plan (FMP) for the WESROC foreshore to assist local governments protect and enhance riverbanks. It is intended to assist planning for foreshore structure maintenance, renewal and capital works over a range of time-scales and to help forecast funding needed to undertake the works. The plan is intended to reduce the reliance upon reactive foreshore management. Proposed present and future management required consideration of existing management and adaptation pathways, with an aim to develop and improve foreshore resilience. Management recommendations are required at an asset level to facilitate successful delivery of on-ground projects.

The project objectives are to:

1. Complete a detailed vulnerability assessment of the foreshore;
2. Identify tailored solutions for each local government area according to risk and priority; and

3. Produce a regional management plan with specific options for each council, to allow delivery of successful on-ground projects.

1.2. REPORT STRUCTURE

The structure of the foreshore management plan is separated into five main components:

- Contextual information at the WESROC scale;
- The method used for the vulnerability assessment;
- Context and vulnerability at the Local Government Association (LGA) scale;
- Foreshore adaptation and management plans at the LGA scale; and
- Collective WESROC issues relevant to State Government agencies.

Most information is presented at a consistent spatial framework of segments (see Section 2 for definition) for consistency with Parks and Wildlife management structures.

At the LGA scale, information included for context and assessing vulnerability includes:

- Processes overview;
- Impacts of historic works, as well as previous and existing plans;
- Site issues and constraints;
- Observed change;
- Structure condition and function comparison, as well as photo comparisons;
- Foreshore controls and sensitivities;
- Scenarios and impacts;
- Values and foreshore uses in the short- and long-term;
- Vulnerability across three time-scales of existing vulnerability (1-5 years), progressive change to vulnerability (5-25 years) and scenarios for changing vulnerability (>25 years);
- Application of the *Best Management Practices for Foreshore Stabilisation* (SRT 2009) to identify which stabilisation techniques should be considered further; and
- A description of possible foreshore interventions to improve foreshore resilience.

This information was used to derive a management and adaptation sequence per segment of foreshore following the same three time-scales linked to risk mitigation (1-5 years), management pathways (5-25 years) and adaptation strategy (>25 years). At the LGA scale, foreshore adaptation and management options are presented in the format of:

- Works for each segment in individual tables. Each table includes:
  (1) foreshore management goals, capital works and maintenance requirements.
  (2) requirements for monitoring linked.
  (3) details of issues to be resolved, and works to be avoided, to ensure the recommended management sequence may be achieved.
  (4) simple cost estimates for capital works, maintenance works and a 25-year total with no future cost adjustments.
- LGA-specific plan for ongoing monitoring to review requirements for foreshore maintenance, management and triggering adaptation.
- LGA-specific implementation summary of the capital and maintenance works recommended for the first five years of management.
- Works dependences per LGA.

For each LGA, information is presented in a report section (6-10) and an appendix (C-G).

2. Swan River Context

All analyses, management plans and reporting are undertaken using the segment and sub-segment spatial framework used by Parks and Wildlife for management of the Swan and Canning Rivers (Talis 2012). This facilitates greater ease of communication with Parks and Wildlife for support and *Riverbank* funding application. The foreshore was first separated into a reach level which had origins in the *Foreshore Assessment and Management Strategy* and *Best Management Practices for Foreshore Stabilisation* (SRT 2008, 2009), with reaches linked to geomorphology. Reaches were separated according to a significant barrier to alongshore sediment transport, if the shore changed aspect by more than 45^{o} or where a perceptible change in active stresses was observed (Damara WA 2007a). In 2012, segments were refined from the reaches for use in an Asset Management System (AMS) for proactive and structured system of foreshore management. The segment definition ensured separation at suburb boundaries, one segment for each side of the river and an attempt to have segment lengths between 200m and 1000m.

The 30 reaches from these previous studies are modified into 26 segments for the WESROC area (Table 2-1; Figure 6-1; Figure 7-1; Figure 8-1; Figure 9-1; Figure 10-1). Two are within the City of Subiaco, 11 within the City of Nedlands, three in the Town of Claremont, three in the Shire of Peppermint Grove and seven in the Town of Mosman Park. Information from previous assessments (Damara WA 2007a, b, c; SRT 2008, 2009) has been adjusted to the new segment and sub-segment format.

Table 2-1: Parks and Wildlife Riverbank Segments within WESROC

<table>
<tr><th>Segment</th><th>Length (m)</th><th>LGA</th><th>Map</th></tr>
<tr><td>SRCra05 Matilda Bay Reserve Look out</td><td>752</td><td>City of Subiaco & DPaW</td><td rowspan="2">Figure 6-1</td></tr>
<tr><td>SRCra06 JH Abrahams Reserve</td><td>423</td><td>City of Subiaco</td></tr>
<tr><td>SRNed01 Charles Court Reserve</td><td>567</td><td rowspan="11">City of Nedlands</td><td rowspan="11">Figure 7-1</td></tr>
<tr><td>SRDal01 Birdwood Park</td><td>427</td></tr>
<tr><td>SRDal02 Paul Hasluck Reserve</td><td>284</td></tr>
<tr><td>SRDal03 Paul Hasluck Reserve-Sadlier Street</td><td>233</td></tr>
<tr><td>SRDal04 Beaton Park</td><td>521</td></tr>
<tr><td>SRDal05 Iris Avenue</td><td>316</td></tr>
<tr><td>SRDal06 Adelma Place</td><td>835</td></tr>
<tr><td>SRDal07 Point Resolution reserve</td><td>152</td></tr>
<tr><td>SRDal08 Point Resolution Reserve, Jutland Pde</td><td>537</td></tr>
<tr><td>SRDal09 Bishop Road Reserve</td><td>766</td></tr>
<tr><td>SRDal10 Watkins Road</td><td>325</td></tr>
<tr><td>SRCla01 Mrs Herberts Park</td><td>408</td><td rowspan="3">Town of Claremont</td><td rowspan="3">Figure 8-1</td></tr>
<tr><td>SRCla02 Jetty Rd</td><td>427</td></tr>
<tr><td>SRCla03 Bethesda Hospital</td><td>1,003</td></tr>
<tr><td>SRPep01 Scotch College BoatShed Forrest St</td><td>533</td><td rowspan="3">Shire of Peppermint Grove</td><td rowspan="3">Figure 9-1</td></tr>
<tr><td>SRPep02 Manners Hill Park Keane St</td><td>777</td></tr>
<tr><td>SRPep03 Keanes Point Reserve</td><td>300</td></tr>
<tr><td>SRMos01 Mosman Bay Park, Mosman Tce</td><td>465</td><td rowspan="7">Town of Mosman Park</td><td rowspan="7">Figure 10-1</td></tr>
<tr><td>SRMos02 Bay View Park,View Tce</td><td>907</td></tr>
<tr><td>SRMos03 Chidley Point Reserve, Chidley Wy</td><td>917</td></tr>
<tr><td>SRMos04 MosPark GolfClubHouse, Marshall Dr</td><td>550</td></tr>
<tr><td>SRMos05 Point Roe Park, John Lewis Rise</td><td>822</td></tr>
<tr><td>SRMos06 Minim Cove Park</td><td>428</td></tr>
<tr><td>SRMos07 Garungup Park, Hutchinson Av</td><td>724</td></tr>
</table>

2.1. GEOLOGY AND GEOMORPHOLOGY

Geomorphology includes description of the landforms being managed in the context of the processes that shape them and the sediments of which they are comprised. Together, the three components (landforms, processes and sediments) constitute a morphodynamic system in which forced alteration of one will have consequences for the form and function of the other two. In this context, sound foreshore planning and management maintains the attributes of the foreshore in a manner that minimises unnecessary disturbance to the system and/or accrual of maintenance costs.

Management of estuarine and coastal systems has repeatedly illustrated the need to work within the framework of natural dynamics as a first principle, rather than engineering to prevent change. This does not mean a negation of a potential requirement for engineering work but the need to place such work in a local context and full understanding of the processes of environmental change. On this basis, an early step for foreshore management is to identify active foreshore processes and determine appropriate strategies to minimise negative impacts. One of the most significant foreshore processes experienced in the WESROC area is geomorphic change – including erosion, accretion and reshaping of foreshore landforms; in the context of engineering modifications.

Geomorphic processes are those driving the development of landforms, and may involve chemical, mechanical or biophysical actions. Within an estuarine setting, biophysical actions are strongly apparent: hydraulic stresses are developed through waves and currents; landform response is strongly affected by vegetation and, in some cases, through production of biogenic sediments. Due to the dominance of these biophysical actions, they are used as a foundation for geomorphic assessment.

Overall, large-scale sedimentary features tend to respond to the long-term prevailing conditions, moving towards a stable morphology in most circumstances (de Vriend *et al.* 1993; Cowell & Thom 1994). However, foreshores may also be susceptible to short-term change that requires ongoing management. Hence, interpretation of shorelines normally characterise their structure with respect to either prevailing conditions or response to short-period forcing, such as storms and floods (Komar & Enfield 1987; Camfield & Morang 1996; Galgano *et al.* 1998).

Due to the enclosed nature of estuaries there is both an exposed and a sheltered section of shore for any wind direction. Hence, there is a wide range in the frequency with which different parts of the foreshore are exposed to energetic conditions. Furthermore, estuaries are typically comprised of diverse materials, with differing degrees of mobility. In locations that are sheltered from common (prevailing) conditions, comparatively high-energy conditions are experienced only under unusual circumstances. Low levels of foreshore reworking during prevailing conditions can determine that the features produced during unusual (extreme) events are retained for an extended period. Similarly, an environment subject to low energy or with low mobility is more likely to retain the effects of animal or human actions, including installation of built structures. Landforms require different management dependent on if they are generated by prevailing conditions, extreme events or through the influence of humans.

Each landform supports a variety of small secondary forms that provide evidence of the manner in which the larger scale landforms are changing in response to variation in the local wind, water level and wave regimes at a variety of time scales (Jackson *et al.* 2002; Prats 2003).

2.1.1. Geology

The geology of the Perth Region is divided by the Darling Scarp between the Yilgarn Block to the east (Precambrian granites) and the Perth Basin to the west, with mostly Cretaceous limestone (Gozzard 2007). The geology of the Swan River is one of the most important factors influencing the morphologic response to tidal, fluvial and wind forcing; in conjunction with the influence of historic modifications. Much, if not all, of the lower estuary is formed by depressions within the calcarenite Tamala Limestone (Gozzard 2007) of Pleistocene marine and aeolian origin overlying the older, Cretaceous sediments.

Rocky features are effectively immobile and create a practical limit to erosive forces, causing redirection of the main flow channels or capture of sediments. The estuarine channel (to Point Walter Spit) experiences a number of sharp turns associated with limestone cliffs. The inside of these turns are generally characterised by low-profile lobate sandy features of Recent (Holocene) Age, including Chidley Point and Point Roe. Isolated limestone features can be found along the margins of the WESROC foreshore, including prominent cliff features at Minim Cove, near the Coombe, Freshwater Bay and at Point Resolution (Figure 2-1a), inter-tidal platforms at Point Resolution and northern Keanes Point (Figure 2-1b) and sub-tidal platforms at Nedlands and Pelican Point.

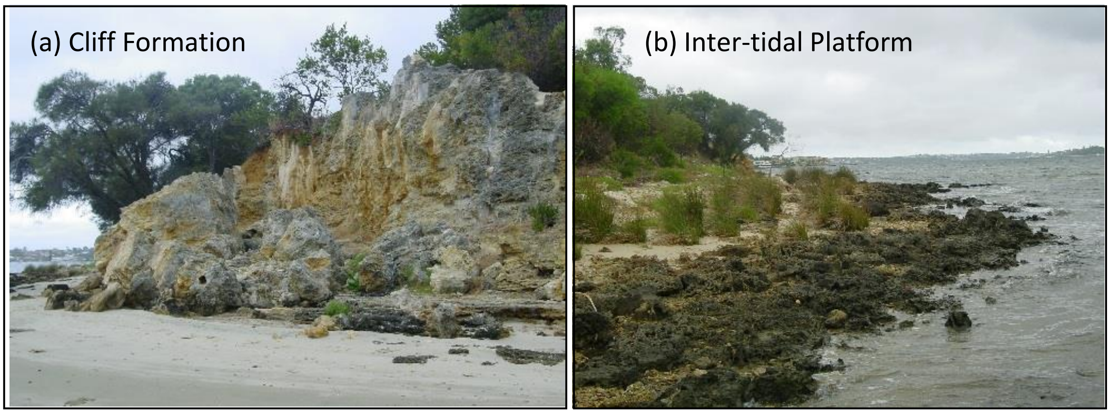

Figure 2-1: Tamala Limestone Formations

The segments in the WESROC area with rock outcropping along the shore include:

- Cliffs and rock outcrops at various levels in Dalkeith for the five segments between SRDal06 to SRDal10. This includes presence of rock cobble on the beaches near Point Resolution which is reworked sub-tidal rock platform;
- Sub-tidal rock in SRCla01;
- Cliffs and caves along western Freshwater Bay in SRCla03 and SRPep01, including Devil's Elbow;
- Keanes Point with the Royal Freshwater Bay Yacht Club (RFBYC) reclamation works obscuring the rocky features in SRPep02 and SRPep03. Construction on the northern side of Keanes Point requires consideration of tie-ins to the inter-tidal rock platform; and
- Cliffs, karst features, caves (e.g. Chine), remnant quarries and steep embankments (many are modified) with rock outcrops at the toe are located intermittently along the Mosman Park foreshore for six segments between SRMos02 and SRMos07.

The rock features in Subiaco and Nedlands are sub-tidal.

The susceptibility and instability of rock features to human impacts requires consideration, along with consideration of safety in proximity of cliffs and caves. Pedestrian access underneath cliffs on public land occurs in Shire of Peppermint Grove and Point Resolution (City of Nedlands) with ongoing monitoring and maintenance required to manage public liability related to cliff collapse or falling from steep slopes. Susceptibility and instability of the cliffs and steep embankments requires consideration for any construction on and above limestone/sandstone features, which includes excavating into cliffs, pool discharge and stormwater management. Any erosion mitigation structures adjacent to naturally occurring rock require consideration of the rock stability for tie-ins both alongshore and at the toe for areas with inter-tidal or sub-tidal rock platforms. Prediction of future cliff susceptibility requires consideration of potential narrowing and lowering of beaches and terraces at the base of cliff features.

Several gently undulating shorelines define the northern area of the main basin of Melville Water. Termination points of these lines include rocky headlands at Point Resolution and Keanes Point; sandy spits or shoals at Armstrong Spit (now dredged) and Pelican Point. These transition points define regions of significant change in hydraulic forcing, resulting in zones of ongoing accretion or deposition. For the intervening sections of shoreline alongshore transport is nearly in balance, although possibly producing a net transfer between the end points. This balance is further impacted by engineering modifications.

The WESROC area is comprised of generally sandy sediments, with some sand flats and spits. The sediments range from fine dark grey mud, to coarse shell and pebble beds, to yellow Karrakatta sands, to sand flats and sills (Thurlow *et al*. 1986).

Further information on the geology of the area is available in geological processes sections for Precincts 2-4 in the *Landscape Description* (SRT 1997), the sections on Mosman Park and Peppermint Grove in *Geology and Landforms of the Perth Region* (Gozzard 2007 pp27-35) and cliff stability reports (eg. Golder & Associates 2015).

Landforms in the river are constrained by geological controls as well as the bathymetric structure (Figure 2-2). The WESROC foreshore includes areas of sub-tidal terraces, which are shallow areas of mobile sediment, with many perched on rock platforms. The varied nature of the width and grade of the terrace alters the hydrodynamic forcing. The terrace is an active part of the sediment transfer system with wholescale terrace level adjustment in response to longer-term variability in hydrodynamic forcing, as well as providing connectivity to adjacent sections of foreshore. The terrace also provides a role in supporting secondary geomorphic features, such as sand bars along Nedlands, to accommodate shorter-term variability in hydrodynamic processes. Connectivity between the terrace and the foreshore is impacted in many areas due to dredging and walling. Two large shoals are present in the WESROC area in Rocky Bay (flood tide shoal) and Freshwater Bay (Karrakatta bank). The shoal in Rocky Bay has altered its structure in response to the 1971 navigation channel dredged adjacent to Preston Point, with increased shoaling to the northeast potentially impacting on segment SRMos07.

2.1.2. Geomorphology

Planform

The three-dimensional shape of terrestrial features reflects an interaction with forcing conditions and often expresses the internal structure of the materials comprising the feature. Landforms are distinct sections of the terrestrial structure, commonly defined by the effective domain of a dynamic process. This may simply be a change in slope, or a zone over which wave-induced sediment transport occurs. Along a shore, a distinction is normally made between cross-shore and plan-form landforms, although in most cases features are three-dimensional in space and responsive in time (Prats 2003).

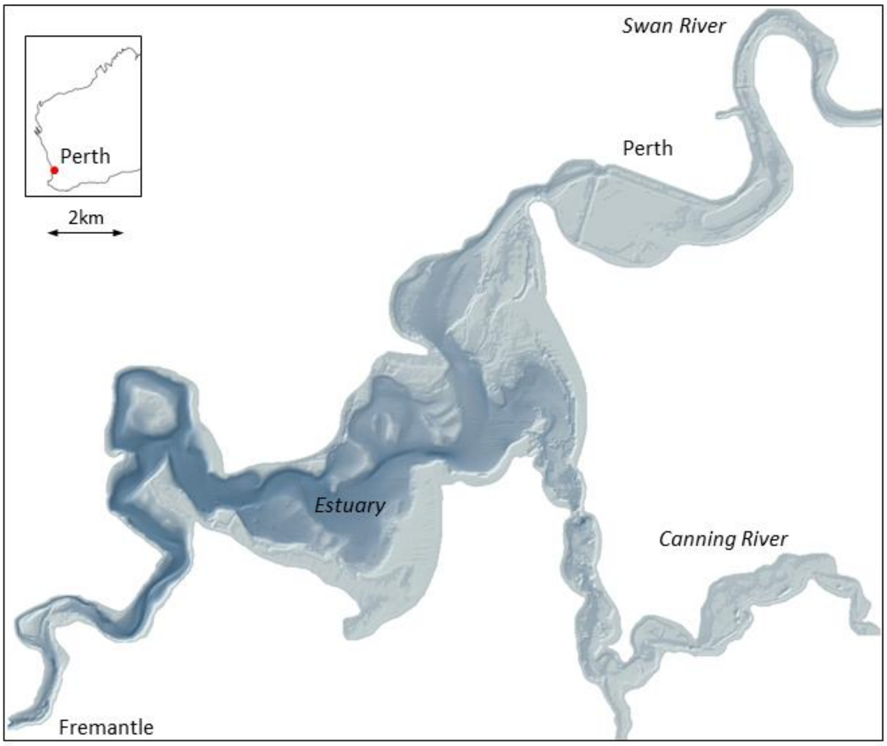

Figure 2-2: Digital Terrain Model Derived from 2010-2011 Bathymetry (Source: Parks and Wildlife)

Estuarine foreshores often differ significantly from open coast shorelines and may be poorly represented by geomorphic classifications developed for high-energy beaches (Eliot et al. 2006; Nordstrom & Jackson 2012). The most significant difference is produced by the restricted wave climate and its relatively large variation over small spatial extents. This may produce alongshore discontinuity and enhance the scale of cross-shore features.

Within the lower Swan River estuary, cementation of sand, rock and shell plays an important role in the structure, development and dynamics of the estuarine landforms. This includes sections of erosion resistant limestone cliff, zones of more loosely cemented shell and sand, emergent portions of sub-tidal rock platforms and deposits of cohesive mud. Resistant sections of foreshore may influence stability of adjacent shores by directly providing wave shelter, or by restricting the volume of sediment available for transport.

When considered in plan form at a large scale, the WESROC foreshore is comprised of a series of curvilinear sections. The plan form, in combination with the bathymetry (Figure 2-2), provides a diagnostic indicator for the key active processes along various sections of foreshore. Most of the WESROC foreshore has been heavily modified since European settlement (Section 2.3.3), with the modified foreshores often not in balance with prevailing environmental conditions.

Plan forms across the WESROC foreshore give an indication of the general amplitude of sediment transport and the corresponding shoreline variability (Figure 2-3). Modifications to these general planform characteristics are attributed to sub-tidal dredging, with dredging immediately adjacent to the foreshore in some segments.

Relatively linear plan forms, such as Dalkeith, generally indicate high levels of current activity and particularly alongshore sediment transport, which may be caused by tidal flows or incident wave action.

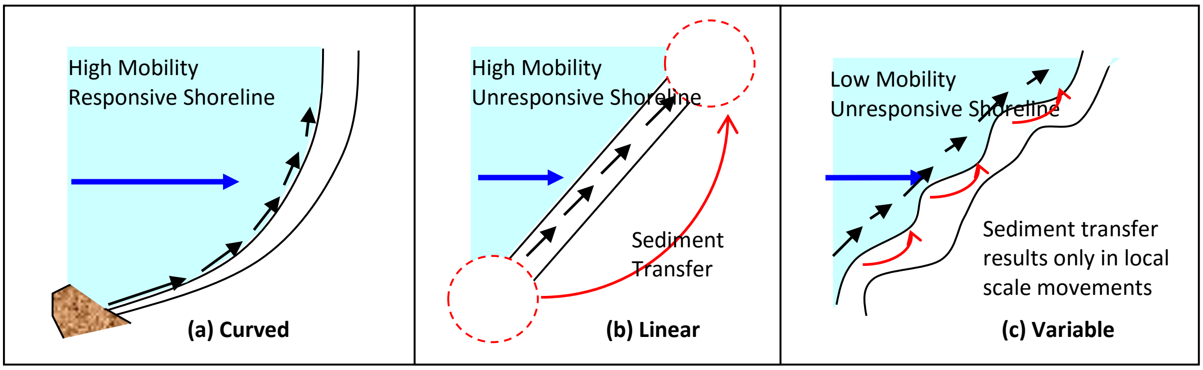

Figure 2-3: Plan Form Characterisation

In addition to overall plan form, the terminus of a curvilinear section is an important geomorphic feature and often subject to enhanced shoreline variability. Sharp changes of foreshore aspect are characteristic at rocky shore features; such as Butler's Hump (Keane's Pt) and Point Resolution. Between Fremantle and Freshwater Bay, rock features on the outer curve control all sharp changes in direction of the estuary entrance channel. Pelican Point is a shallow sedimentary feature overlying a limestone ridge.

Landforms

When considered in cross-section, a foreshore profile normally varies dramatically in gradient, vegetation and structure between the deepest parts of the estuary up to dry land, typically over a scale of 10-100 metres. Variation along the estuary foreshore is often more subtle, demonstrated by the use of segments for which a "typical" profile may be considered representative for 100-1,000 metres.

A basic indication of the changes across a segment is given by its curvature, relative to incident stresses and points of resistance, such as headlands (Hsu & Silvester 1996). A linear segment is suggestive of relatively uniform stresses or continuous sediment transport. A concave feature normally forms in response to the pattern of refraction behind a sheltering feature, or relative lag of sediment supply.

For the purpose of describing foreshore behaviour and likely response to future conditions, the foreshore profile has been broken up into a number of sections (Figure 2-6 and Table 2-2).

In some parts of the estuary, sub-tidal terraces occur, which are extensive shallow areas of mobile sediment. The shallow nature of this landform acts to dissipate wave energy through breaking and friction. Many sub-tidal areas of the WESROC foreshore have been dredged.

Smaller landforms occur in combination with the primary landforms, including bars, ripples, ridges, sheets and fans. These features are commonly ephemeral, in response to changing conditions (Prats 2003). The structure and duration of such features is indicative of the patterns of change occurring along a foreshore reach and may be used to interpret the active processes.

Further discussion of geomorphology is included in Section 2.2.2.

2.2. DRIVING PROCESSES

The functions performed by the Swan River foreshore region, including environmental, cultural, recreational, aesthetic and commercial utilities, provide significant value to the surrounding WESROC area. This interface between terrestrial and marine activities is a highly dynamic zone, affected by relative movements of both land (sediment erosion and accretion) and water (tides, surges, resonant phenomena, etc.). The foreshore's susceptibility to change due to these dynamic processes is determined by environmental forcing, landform stability (including the presence of vegetation) and, along much of the region in question, by the presence of structures built to retain foreshore sediments. Further change may be brought about through the imbalance of sediment transport, regardless of the foreshore capacity to resist wave and current action.

Relative movement of the foreshore has an effect on human amenity when the land-water interface moves into the land profile, as most human activity and infrastructure will be contained within this landward profile. Use of this model demonstrates that the two of the most important factors to consider in foreshore management are erosion and inundation, where the latter may include wave run-up effects. Accretion is significant for navigation, mooring and causing ponding of stormwater runoff. Unless material is physically removed from a foreshore, erosion and accretion are balanced, as the eroded material must be moved to a different location. However, the perception of erosion is enhanced by the total change in amenity produced by the movement.

This section (2.2), and Appendix A, provides information on driving processes, including hydrodynamic forcing, sediment transport, profile response and inundation. Much of the information is derived from previous reports (Damara WA 2007a, b, c, Eliot 2012, Damara et al. 2014, Damara WA 2012a, b).

2.2.1. Driving Processes Overview

The Swan-Canning River System is a very low energy environment. Following the classification scheme of wave, tide and runoff dominance, the system is wave-dominated (Harris *et al*. 2002). Whilst this classification is most relevant to the ocean entrance of the estuary, it also reflects on the energetics of the internal basins, with low river flows ($10m^3/s$ mean to $300m^3/s$ maximum), microtidal conditions (1.1m astronomical tide range) and frequent strong wind conditions (wind speeds >25 knots occur on average once per week).

Hydrodynamics caused by environmental forcing (wind, waves, rainfall-runoff, oceanic water levels) varies according to the location within the estuarine system and the local bathymetric structure (Figure 2-2). A general progression for estuaries with basins is from runoff dominated behaviour in the upstream channels, wind-dominated behaviour in the estuarine basin and tidal exchange dominance through the entrance channel. A key role of the basin is to provide damping of flows from either direction, and therefore transitionary features occur at the upstream and downstream limits of the basin. The Swan-Canning River System is consistent with this general pattern, with Point Walter and the Causeway marking the areas of transition (Figure 2-4).

The WESROC area can effectively be separated into the entrance channel, Freshwater Bay and Melville Water (Figure 2-5). Flows are strongest in the channel areas, with waves being most energetic in the basins.

Information on water levels, winds, waves, currents and stormwater drainage is summarised below, with further detail contained in Appendix A. The information in Appendix A is used in developing the erosion mitigation options and foreshore management plan.

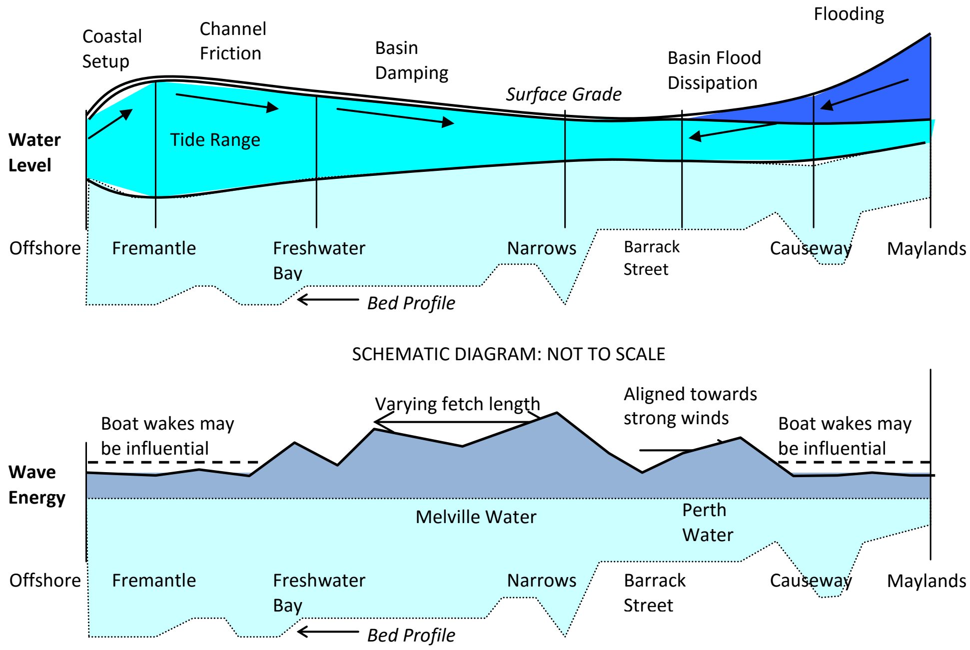

Figure 2-4: Spatial Variation of Water Levels and Waves within the Lower Swan River (Schematic diagram only)

Figure 2-5: Principal Basins, Channels and Dominant Winds
Principal basins and channels are segregated by yellow lines

Water levels

Water levels within the estuary determine the elevation at which surface wave action may occur, controlling inundation and structure overtopping. Information on water levels, tides and floods is provided in Appendix A.1. River flooding, although significant upstream, is reduced by broad reaches of the river and is generally a minor influence downstream of the Causeway. A recent study (URS 2013a) found the 100 year ARI fluvial flood would be an approximately similar level to that estimated for oceanic inundation, with emphasis for design and adaptation focused on oceanic water levels. The WESROC foreshore is microtidal with a maximum astronomical tidal range of 1.1m, with up to 0.15m variability due to the 18.6 year lunar nodical cycle. The very low tidal range enables other (non-tidal) sea level processes to contribute to a total water level range of 2.15m at Fremantle, which is almost twice the astronomic tidal range. Shifts in mean sea level can also occur by up to 0.3m seasonally and 0.3m inter-annually due to the El-Nino / la Nina climate cycle. Recent elevated mean sea levels between 2008-2012 have been associated with a strong La Nina event, while a decrease in mean sea level between 2014-2015 is associated with a shift to an El Nino phase. Extreme water levels are generally restricted to between May-July, when seasonal peaks for mean sea level, surge and tide are in phase. The design water levels used for the WESROC foreshore are +1.1mAHD for the 10 year ARI and +1.3mAHD for the 100 year ARI based on numerous previous studies that generate values in this approximate range (Scott 1977, McMullen 2012, Haigh *et al.* 2012, URS 2013a, this study).

Winds

Winds generate waves, setup and wind-driven circulation patterns as energy is transferred across the water surface (Appendix A.2). Prevailing winds are the land-sea breeze system with a broader directional range of winds in Melville water than the open ocean. Weakening of the land-seabreeze system occurs during winter months with a dominance of winter westerlies between June and September. There is inter-annual variability in the wind climate which impacts net sediment transport directions for the foreshore. Winds at Swanbourne were used to define directional estuarine extreme wind climate used to estimate wind waves for design. Wind speeds were estimated for each segment for 3, 10, 30 and 100 year ARI, for each semi-cardinal direction, with speeds ranging from 36 to 72 knots.

Waves

Wave action in the WESROC area is generated from a combination of wind waves and boat wakes (Appendix A.3). For most of the WESROC foreshore it is assumed wind wave levels are appropriate for design of erosion mitigation structures, with longer periods incorporated to allow for boat wakes. Wind waves are influenced by diurnal (i.e. sea breezes), seasonal and inter-annual variability in the wind climate. This contributes to variability in foreshore processes, patterns of erosion and accretion, yacht club sedimentation and stress on the toe of structures. Wind waves were estimated for each segment for 3, 10, 30 and 100 year ARI with heights ranging from 0.5m to 1.3m. The longer period of boat wakes (4s) increases the erosion potential of the waves, including bed scour and loss of material through structures, and the amount of overtopping that occurs. Boat wakes are also considered in their contribution to alongshore sediment transport, due to the acute direction of wake travel outside the range of prevailing wind-wave directions and their capacity for relatively large size.

Currents

There is no sustained program for measurement of currents within the WESROC area, due largely to their localised nature (Appendix A.4). Currents produce stresses on the bed and provide a means of transport for any material suspended within the water column. Currents generally follow bathymetry and increase in areas of constriction, whether they are horizontal constraints (i.e. entrance channel) or depth limited areas. Areas where the currents are lower generally allow deposition to occur and higher currents may erode the bed if its material is mobile. Currents have been measured in the entrance channel with a maximum measured speed of 0.91m/s. Current speeds are anticipated to be lower than this for the WESROC area, although local focussing occurs where there is a projection into the river such as Pelican Point. Areas of locally enhanced currents will be considered for designs in the tidal gorge, where there are rapid changes in flow channel curvature, through dredged channels and across sand spits and shoals.

Stormwater drainage

There are 56 stormwater drains on public land ranging from diameters of 0.15m to 1.15m (after Damara WA 2015; Figure 2-14). Information on rainfall, runoff and catchment areas is required to determine the design or adaptation of a drain. However, a standard approach should not be undertaken and applied to all drain locations in the WESROC area. Three separate calculations are required to balance the bed scour from the pipe in the context of sediment resupply from adjacent foreshores, and the consequences of overbank flow. The calculations are balanced dependent on the acceptable areas of erosion on the foreshore, as well as consideration of drain function with potential rising mean sea level. Investigations of drain function will consider mean sea levels where blow-back, choking and flooding may occur. Further information on these calculations is included in Appendix A.5.

2.2.2. Foreshore Processes

The information in this section on foreshore processes should be read in conjunction with Section 4 which considers the implications of foreshore processes for foreshore management and adaptation.

The foreshore is the interface between the marine and terrestrial environments, with the relative degree of marine exposure influencing amenity and function. Such influences include determination of the zone supporting riparian vegetation; or the landward distance appropriate for pedestrians to avoid wave action. The degree of marine exposure is dynamic, due to tides, weather, changing vegetation, movement of foreshore sediments, or human activities.

The foreshore profile may be divided schematically into a number of zones (Figure 2-6, upper) including the bed, margin, terrace, lower shore, mid-shore, upper shore and adjacent zone. Each of these zones has distinctive behaviour and geometry that is related to the relative influence of waves, currents and water levels (Table 2-2). The result is that there is spatial variation of stressors, such as inundation, undermining, smothering or wave loading, upon features depending on which part of the profile they are located (Figure 2-6, lower).

The short spatial range over which foreshore stresses vary significantly makes the location on the profile important for any feature, whether natural such as sedges, or artificial such as walling. Features intolerant of inundation, undermining, smothering or hydrodynamics stresses may be damaged or fail due to relative movements of the profile. Consequently, the relative importance of foreshore processes can be broadly related to the following classes:

1. Processes that cause the profile to relocate;
2. Processes that cause the profile to alter, while retaining the same general location;
3. Processes that do not affect the profile, only any features located on the profile.

The importance of profile movement is largely determined by the narrow width of the hydraulic zone within the lower Swan River estuary. For a typical foreshore width of 20-30m changing at 0.5m per year, which represents relatively slow movement, existing terrestrial locations may become wholly marine within typical planning time frames.

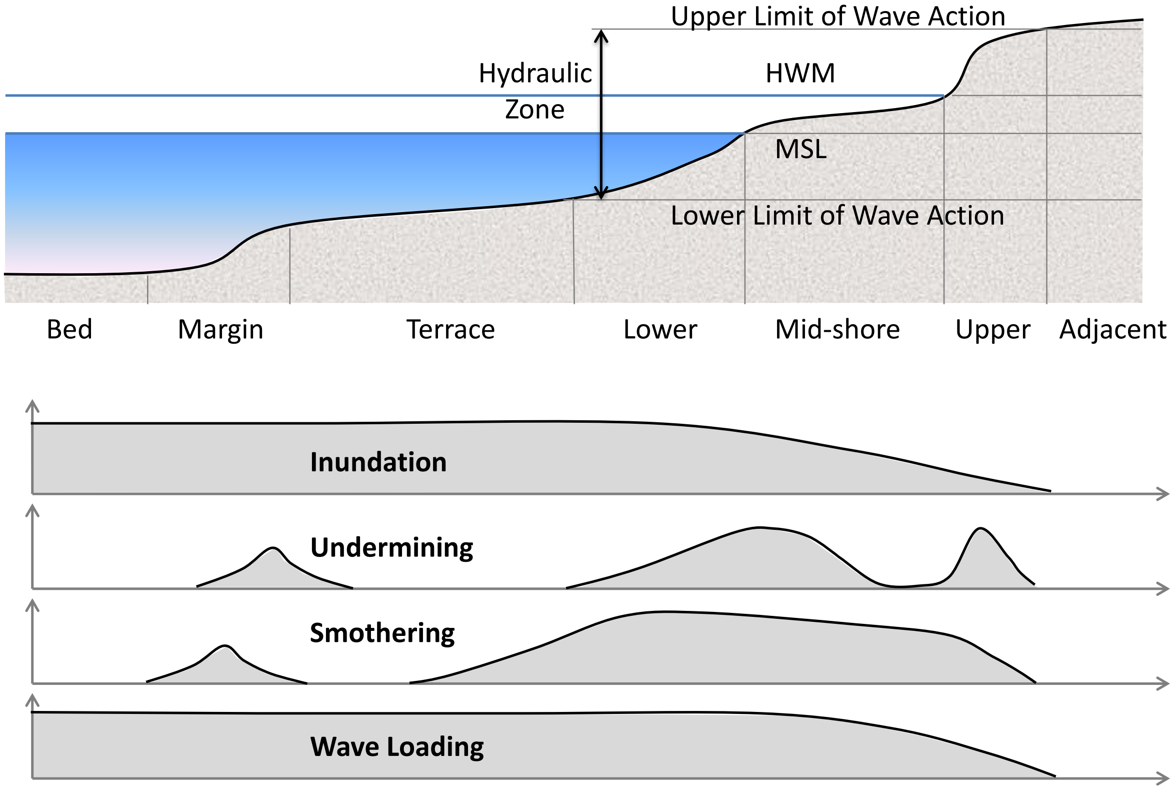

Figure 2-6: Profile Zones and Spatial Distribution of Foreshore Pressures

Table 2-2: Description of Profile Zones (Figure 2-6)

Profile Zone	Position	Influence on Foreshore Dynamics
Bed	Area riverward of the lower limit of wave influence	Typically outside the influence of ambient wave conditions. Sediment dynamics are largely determined by currents, which may be tidal, wind-driven or fluvial in character.
Terrace Margin	Steep gradient area riverward of terrace	Gradient alters the balance of cross-shore sediment transport and encourages transport along the margin, which may be distinct from transport along the shore.
Terrace	Low gradient area riverward of shore	Low gradient of terrace smooths out variations in sediment transport. Shallow depths limit ambient wave energy and wave direction.
Lower Shore	Lower limit of wave influence (or landward limit of terrace) to MSL	Experiences almost continuous wave action with ambient tendency for material to be pushed shoreward, which may be balanced by flattening under energetic wave conditions.
Mid-shore	Mean sea level to high water mark	Experiences almost continuous wave action and intermittent inundation. Highly dynamic zone, responding to the active level of stress, often changing gradient due to active tides and waves.
Upper Shore	High water mark to limit of wave action	Outside normal hydraulic action, and responds to extreme conditions, including high wave action or flooding. For low energy systems, usually erodes progressively, unless aeolian processes are active.
Adjacent Zone	Above limit of wave action	Outside river or estuarine stresses. Elevation influences scarp height and the potential rate of sediment supply if the upper shore erodes.

Considerable cross-shore movement of foreshore material may occur without causing change to the profile position (Figure 2-7). Typically the profile 'flattens' under energetic wave conditions and progressively steepens under lower energy ambient conditions. Material transfer may also occur due to changes in water level, including tidal variation (fortnightly, semi-annual or inter-annual) and mean sea level variation (annual or inter-annual). Sediment is transferred between the lower, mid and upper shore zones through waves and currents. Change typically occurs as an event-recovery sequence, with seasonal or inter-annual variation of the time between erosion events causing corresponding longer-term cycles of foreshore fluctuation.

Cyclic behaviour is also common through alongshore transport on a seasonal basis, where the foreshore position responds to changes in wind-wave direction. The overall behaviour is affected by any compartmentalisation of the foreshore, as sediment pushed towards any barrier to transport will cause the foreshore to change in orientation, reducing its tendency to move in the same direction.

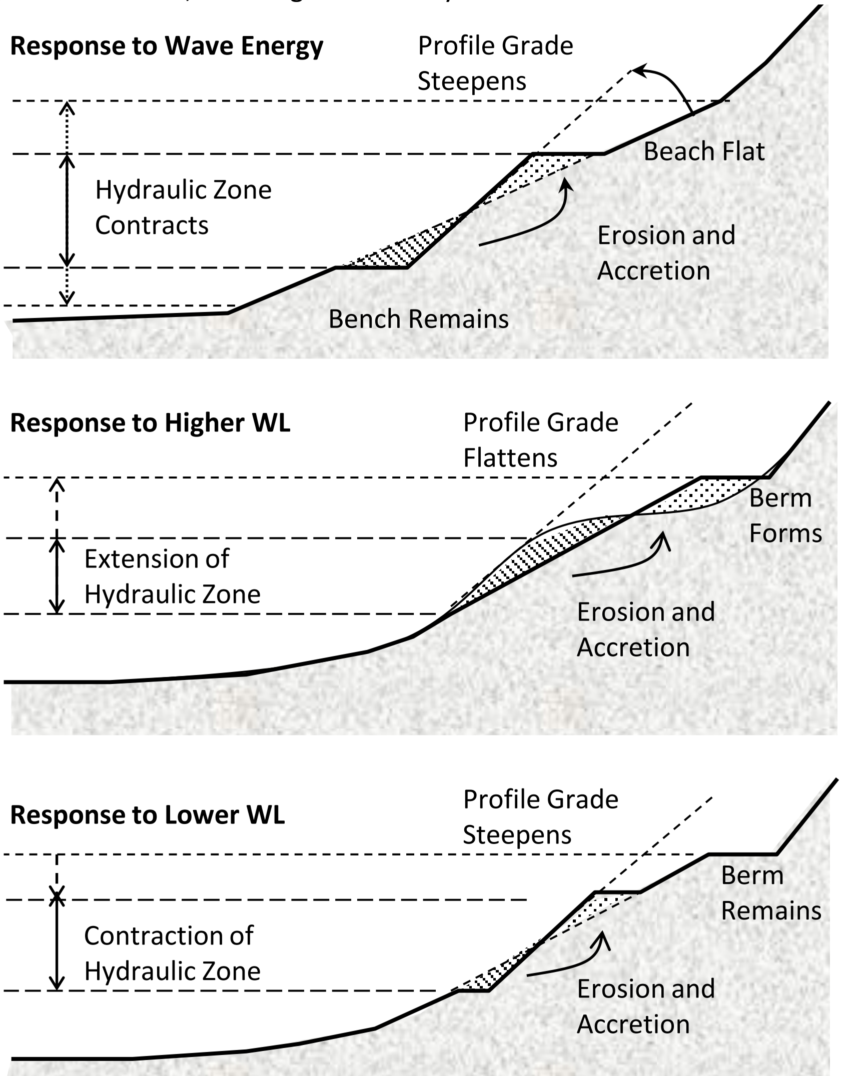

Figure 2-7: Common Profile Adjustments to Changing Conditions

Fluctuations of the profile due to cyclic movement of material (either cross-shore or alongshore) provide high opportunity for undermining or smothering within the hydraulic zone, particularly the lower and mid-shore zones. Features that are located within this area must be robust to survive, whether artificial or natural. As a consequence, most riparian vegetation is located in the upper shore zone.

Due to the highly dynamic nature of the marine and estuarine environment, sediment transport appears to be a stochastic (almost random) process, with overall transport the end result of a great many movements backwards and forwards. The overall rate of transport is significantly enhanced in situations where it is biased in one direction. For example, if a section of beach is excavated, then material is readily pushed into the hole, but does not leave the hole easily. As a result, the rate of accumulation within the hole is significantly greater than the longer-term net transport of sediment along the foreshore. This difference will cause transitory localised erosion (near-field effect), which gradually spreads over a wider area. The near-field effect is important for a number of common foreshore features, including pocket beaches and drains. It may also come into play for short-term sediment transport processes, such as storm-induced erosion.

The large difference of active stresses from the hydraulic zone to the zone above (and to a lesser extent for the zone below) means that movement of the profile may have significant impact on the stability of any features, whether natural or artificial. Longer-term change to the position of the profile can be developed through sediment volume moving into or out of the hydraulic zone (lower to upper shore). This may involve transfer of sediment alongshore or cross-shore. A range of processes may affect the foreshore sediment volume (Figure 2-8). These include sediment movement off the foreshore hydraulic zone due to unusually strong or persistent conditions; destabilisation of the upper profile due to vegetation loss, overbank flow or trampling; sediment trapping due to structures; and potential destabilisation of the lower shore if stormwater drainage is weakly controlled (Damara WA 2007a; SRT 2008).

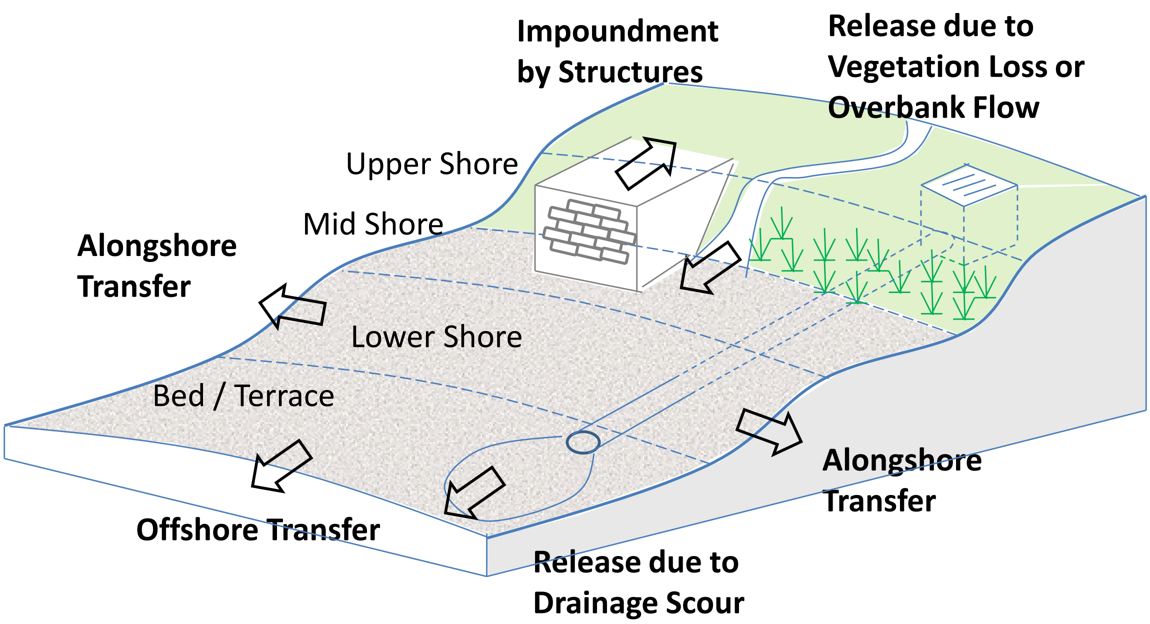

Figure 2-8: Processes Causing Foreshore Volume Change

The main natural mechanism for changes to foreshore sediment volume is brought about by alongshore sediment transport, caused when currents and waves actively transport material along the foreshore. The transport rate is determined by the mobility of bed material, speed of the current, wave angle and the quantity of material suspended in the water column. It is important to recognise that these conditions only determine sediment transport potential, as a section of foreshore with little mobile sediment will have low transport rates regardless of the waves or currents. Change is brought about by the *net transport rate*, which is the sum of sediment volumes moving both in and out of a given area. For sections of estuary bed or foreshore that retain relatively homogeneous form and shoreline aspect, transport rates will be similar, resulting in low rates of change. Consequently, alongshore transport is most important where there are transitions of the foreshore aspect, bank material or incident wave conditions. As a result, the most dynamic parts of an extended linear section of foreshore are normally its end points.

Within the lower Swan River estuary, the available water surface length over which wind waves can develop (fetch) varies systematically along the shore, producing changes to incident wave conditions and corresponding differences in prevailing sediment transport bias, according to foreshore orientation. Analysis of the wind directional distribution, available fetches and foreshore orientation has been undertaken, to evaluate the areas in which potential sediment transport is likely to converge, promoting accretion; or diverge, promoting erosion (Figure 2-9). The analysis of potential erosion and deposition zones does not take into account the shore type or effects of currents, which are particularly important at points of constriction. Zones at which prevailing sediment transport paths diverge or converge are noted by an un-circled dot. Circled dots identify areas where potential sediment transport changes in magnitude, which may cause a tendency for erosion (increasing transport rate) or accretion (decreasing transport rate).

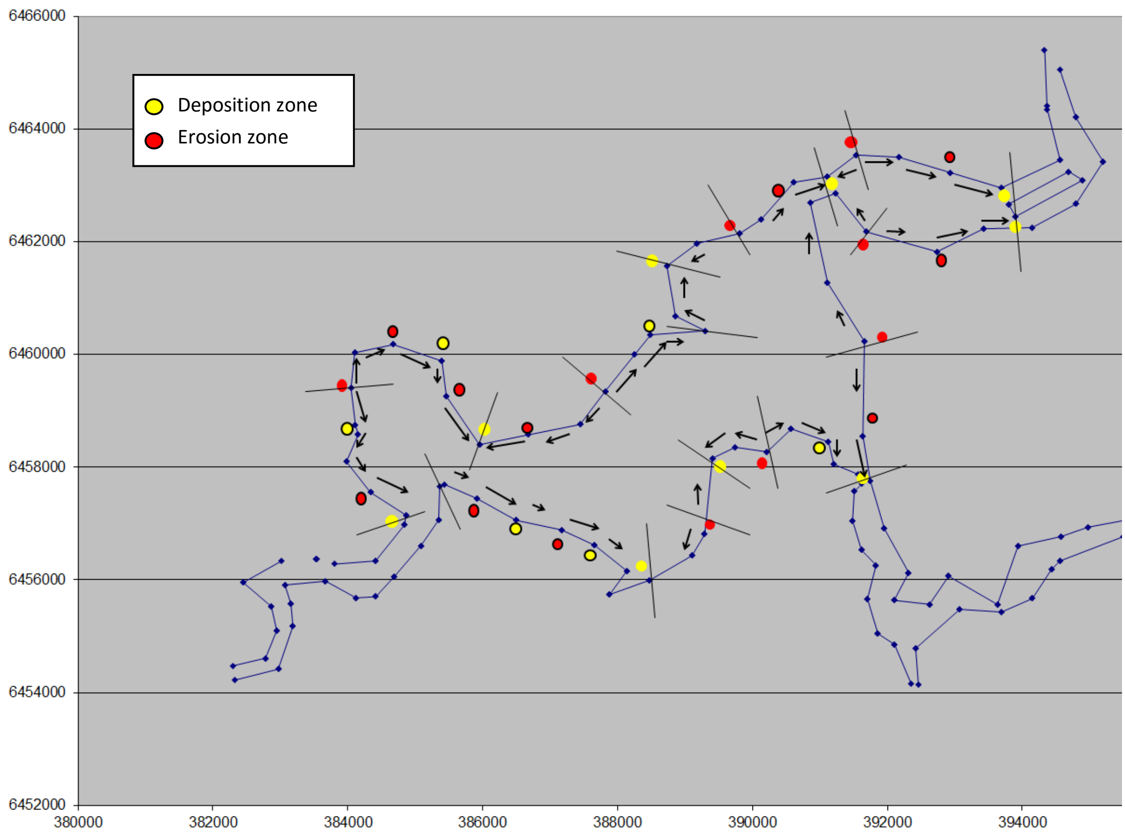

Figure 2-9: Potential Erosion and Deposition Zones

Areas along the WESROC foreshore for which the analysis suggests potential for ongoing erosion and accretion are listed in Table 2-3. The pattern of erosion and accretion is generally consistent with naturally occurring foreshore features around the Swan River, including spits at areas of transport convergence and cliffs at areas of transport divergence. However, comparison of historic foreshore changes indicates that there are substantial local influences, particularly where historic works of dredging and foreshore reclamation have been undertaken (see Section 2.3.3).

Table 2-3: Zones of Potential Erosion and Accretion Based on Wave Fetch Analysis

	Area	Shore Type	Comment
Erosion Zones	Claremont	Rocky	
	Nedlands	Reclaimed, Walled	Stressed walling
Accretion Zones	Chidley Point	Sandy Lobe	Stripped by current
	Point Resolution	Sandy Lobe	Stripped by current
	J H Abrahams	Sub-tidal flat	Accreting
	Matilda Bay N	Sub-tidal flat	Offshore deposition

In addition to foreshore movements, both natural and artificial features located on the upper part of the profile may be subject to short-term stresses due to high water levels and waves. This can impact on foreshore vegetation or structures and severely curtail amenity. The area affected by water movement is determined by inundation (tide and surge) combined with the capacity for wave excursion over land (Figure 2-10). Wave action is strongly influenced by the profile grade and the permeability of the surface over which waves run up.

For estuary beaches, waves washing over the beach tend to percolate through the sand and dissipate wave energy; although walls and revetments are generally higher than beaches, they have lower permeability, allowing waves to run up further.

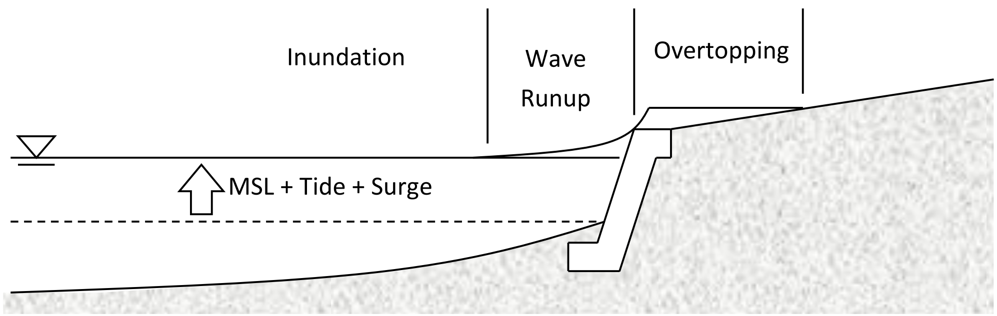

Figure 2-10: Schematic for Inundation and Overtopping

As a combination of water level and wave action, flooding effects vary significantly around the lower estuary, depending upon the degree of wave exposure and the joint probability of surge and wave direction. In general terms, west facing shores experience the greatest flooding, as westerlies are associated with positive oceanic surge and are most severe during winter (Department of Defence 2010), which is also when mean water levels are high.

Most of the existing erosion mitigation structures in the WESROC area have elevations below +1 mAHD (<10-year ARI) and are susceptible to inundation (Damara WA 2015; example Figure 2-11).

A preliminary analysis of flood hazard was previously undertaken, based upon hindcast waves and estimated extreme water levels, with consideration of shore type (Damara WA 2007a, c). For the purpose of this assessment, wave runup was based upon the shore type (Table 2-4).

The limit of flooding upon lower Swan River foreshores was evaluated by applying estimated vertical levels to the existing topography. It is recognised that in a number of areas, there is likely to be a geomorphic change or ongoing adaptation. The flood assessment indicated that several zones along the WESROC foreshore are susceptible to inundation during either coastal flooding or severe wave events (Table 2-5).

Table 2-4: Influence of Shore Type on Runup and Overtopping

Shore Type	Wave Runup (vertical extent)	Overtopping (horizontal extent)
Beach	0.5 H	Not applicable
Revetment or Rock Platform	H	(H-f) / (m+0.1)
Wall or Rocky Cliff	1.5 H	(H-f) / (m+0.1)

Table 2-5: Zones Susceptible to Inundation along the WESROC Foreshore

Foreshore Area	Facilities	Hazard
Claremont Foreshore	Claremont Yacht Club	Moderate
Claremont Colleges	Boat Sheds	Low
Point Resolution	Private Lots (not affecting buildings)	Very Low
Nedlands Foreshore	Yacht Clubs; Tawarri Lodge	Moderate

Figure 2-11: Example of Existing Erosion Mitigation Structures Below +1mAHD
Top left: Jojos, Top right: Chester Road, Bottom left: Keanes Point, Bottom right: Mosmans

Drainage of the overtopping water may place considerable stress on estuarine foreshore protection structures. For flat land behind the walling, such as Nedlands foreshore, waves may travel relatively long distances before dissipating.

The use of the foreshore area naturally exposes some areas to inundation risk. However, techniques to mitigate inundation are likely to affect foreshore amenity, management requirements or susceptibility to different processes. The effects of mitigation techniques need to be considered in the context of the likelihood and implications of inundation impacts. Although each option needs to be specifically considered on a site by site basis, some general aspects to be considered with each are discussed in Table 2-6.

Table 2-6: Inundation mitigation techniques (After Damara WA 2007a, b) excluding adaptation options

Mitigation Technique	General Considerations
1. Do Nothing	• Increased inundation likely under periods of higher mean sea level • Existing patterns of erosion or accretion need to be considered
2. Raise Ground Levels	• Reduces foreshore amenity • Very expensive when applied to large areas • Requires a means for material retention (e.g. walling)
3. Widen Foreshore	• Reduces river amenity • May restrict flows and increase flooding in some areas • Requires a means for material retention or renourishment program
4. Construct Walling	• High capital cost and potential for ongoing maintenance • Enhanced wave reflection & potential overtopping • Consider need for wave recurve system
5. Construct Revetments	• High capital cost and some ongoing maintenance • Potentially high wave runup
6. Wave Dissipation	• Vegetation treatments are only suitable for low wave climates • Loss of foreshore amenity
7. Drainage	• Reduced foreshore amenity

2.3. HISTORIC MANAGEMENT, GOVERNANCE AND WORKS

Further information relevant to developing a foreshore management and adaptation plan for the WESROC area includes previous management plans, governance and a description of previous trends in historic engineering works and associated foreshore response.

2.3.1. Previous Management Plans

The two previous broad-scale foreshore management plans or strategies produced by Parks and Wildlife (previously the Swan River Trust) that influenced management of the WESROC area include the *Foreshore Assessment and Management Strategy* (FAMS: SRT 2008) and *Best Management Practices for Foreshore Stabilisation* (BMP: SRT 2009). The *FAMS* provided rationale for allocation of Parks and Wildlife *Riverbank* funding for revegetation and erosion mitigation works. The BMP provided guidance for approaching erosion mitigation works, choosing appropriate options and maps of minimum levels of mitigation required. A recent revision of management priorities for erosion mitigation structures and drains was undertaken and will also be considered in this study (Damara WA 2015).

Additional management plans exist for segments with walling or managed foreshores that guide management practices undertaken by each foreshore manager (LGA/Parks and Wildlife). These are listed per segment in Appendices E.2, F.2, G.2, H.2 and I.2. Information contained within the existing plans will be considered in development of the foreshore management and adaptation plan.

2.3.2. Governance

The two principle agencies that will be involved in the planning process for any future works along the publicly owned land of the WESROC foreshore are the relevant LGA and Parks and Wildlife (Section 12 of the *Swan and Canning Rivers Management [SCRM] Act 2006*). For non-HWM private property, the LGA is jointly responsible with Parks and Wildlife for the care, control and management of the shoreline and for the maintenance of any erosion mitigation structures within 2m above and below the high water mark (12.3 in *SCRM Act 2006*). Matilda Bay and Pelican Point are managed by a separate division of the Department of Parks and Wildlife, rather than the City of Subiaco, and were considered beyond the scope of this project.

Any works in the Development Control Area (including the river and adjoining parks and reserves) require planning and development approval from Parks and Wildlife outlined in the Development Control Procedures 2016. There are some exceptions for small maintenance works, with details in the documentation. The proponent of any works should read and follow the latest permit application process for Development Control Approvals on the Parks and Wildlife website along with planning policies, such as those relating to river retaining walls.

Other specific agencies that may be involved in the planning process include (after SRT 2012a) the:

- Western Australian Planning Commission (WAPC) for any resumption of private property abutting the foreshore.
- Department of Parks and Wildlife for any works in proximity to Matilda Bay or the Marine Park at Pelican Point (Marine Parks and Reserves Authority).
- Water Corporation for sewage, sewerage, overflow tanks and large stormwater drains.
- Main Roads for any large stormwater drains, if required under their jurisdiction.
- Department of Environment Regulation (DER) provides review and advice related to potential contamination and acid sulphate soils (Contaminated Sites Branch).
- Department of Aboriginal Affairs (previously Department of Indigenous Affairs) is involved to obtain approval for any works likely to permanently alter the river bed, foreshore or adjacent Aboriginal Heritage site. It is anticipated that the Whadjuk Regional Corporation will soon be the main contact for this area under Native Title, replacing the South West Aboriginal Land and Sea Council. It is recommended to commence consultation early in the planning process.
- Department of Transport should be consulted for works related to navigation and incident response.
- Office of the Environmental Protection Authority (OEPA) for large-scale projects incorporating dredging. Any proposals for dredging may be required to be referred to the OEPA under Part IV, Division 1, Section 38 of the *Environmental Protection Act 1986 (EP Act 1986)*. It is recommended every project and potential issues are discussed with the OEPA at a pre-referral meeting, where informal advice is provided on whether a referral would be required.
- Department of Water is responsible for protecting water quality.
- Department of Health is involved to protect human health from the adverse impacts of dredging, such as potential contaminants in the water and in sediments on recreational beaches.

Many management decisions will also require consideration of leaseholders in the area, such as the yacht clubs, or private property owners.

2.3.3. State Level Policy

The main State level legislation, policies and strategies that may be relevant to this Foreshore Management Plan for the WESROC area as per June 2015 include:

- *Swan and Canning Rivers Management Act 2006 (SCRM Act 2006) and Amendment Bill 2014.*
- *Swan and Canning Rivers Management Regulations 2007* and *Swan and Canning Rivers Management Amendment Regulations 2012.*
- State Planning Policy 2.10 Swan-Canning River System (WAPC 2006).
- Development Control Procedures 2016.
- Swan and Canning Rivers Foreshore Assessment and Management Strategy (FAMS) (SRT 2008).
- Draft River Protection Strategy 2012 (SRT 2012a).
- Guidelines for developing foreshore management plans in the Swan Canning Riverpark 2012 (SRT 2012b).
- Environmental and Heritage Acts:
    - *WA Aboriginal Heritage Act 1972*, Aboriginal Heritage Regulations 1974, *Native Title Act 1993* and Whadjuk People Indigenous Land Use Agreement.
    - *Heritage of Western Australia Act 1990.*
    - *Environmental Protection Act 1986.*
    - And not particularly relevant as of September 2013 is the *Environmental Protection and Biodiversity Act 1999*.
    - *Conservation and Land Management Act 1984.*

Parks and Wildlife are able to provide a co-contribution to erosion mitigation works on public land along the foreshore through the Riverbank program. Since 2002, Riverbank funding has been used for foreshore protection and rehabilitation works on public land, with funding matched by riverside local government authorities. Riverbank funding is available through an annual grants application process and through a proactive program where State and local government agencies are approached to develop partnerships and project plans for sites identified by Parks and Wildlife as high priority sites.

2.3.4. Historic Works and Foreshore Response

Foreshore response to engineering works may often occur over extended time frames, particularly if the works create a small change to net alongshore sediment transport patterns or pathways, or disrupts processes that are occasional but significant such as short-term reversal of transport direction. In general, larger-scale engineering works cause greater foreshore response, over extended time frames. However, previous investigations within the Swan River indicated that small local works may have equivalent effects on estuarine beach stability as larger more distant works.

The WESROC foreshore is highly modified and there is evidence that response to some engineering works continues to influence present day behaviour. In some cases, the response continues despite original structures being removed, as the sedimentary features built-up by the structure throughout its installation progressively evolve.

The changing context of historic foreshore modifications is provided in Table 2-7 through a summary of the evolution of environmental regulations and management practices across the river. Further detail of historic modifications for each segment is provided in Sections 6.1.3, 7.1.3, 8.1.3, 9.1.3 and 10.1.3.

A discussion of present and future foreshore dynamics necessitates incorporating the impacts of the historic modifications, due to the role of these features to influence behaviour on many sections of the foreshore. Designing future management and adaptation options requires consideration of where historic modifications have been undertaken, how they are impacting present foreshore dynamics and how the works may be altered in future, particularly where the original objective has changed.

Sediment management

Foreshore sediments have been mechanically moved from locations where they were naturally deposited through various programs of dredging, renourishment, sand harvesting and backpassing. These actions may create spaces into which other sediment may be subsequently moved by natural processes, or place material in a configuration that is not subject to natural recovery if it is disturbed. Due to the relatively slow rate of change prevalent along the estuary foreshore, the influence of historic sediment management on foreshore behaviour may be extended, sometimes for decades. For some situations, sediment management may create features that are unstable only under rare conditions, which may therefore cause a sudden response after a long period of apparent stability.

Changes in types and extent of sediment management have changed with societal and population developments, along with the implementation of various management policies. The changes are summarised in Table 2-7 along with the main institutions focused on dredging to support infrastructure or amenity objectives up to 1985, with subsequent focus on foreshore stabilisation. Dredging has been undertaken along much of the WESROC foreshore, with key objectives to provide road reserves through foreshore reclamation, improve navigation, reduce flood risk, infill wetlands for mosquito control, and landfill to provide recreation areas (Riggert 1978; Le Page 1986; PWD records). Dredging had largely ceased in the WESROC area by the early 1970s, except to provide yacht club mooring areas or to maintain navigable access to jetties and other facilities affected by shoaling.

A significant shift away from dredging occurred in the mid-1980s with break-up of the PWD in 1985, the sale or scrapping of State Government dredge vessels and increased focus on environmental management. Relevant legislation changes included the *EP Act 1986*, amendment of the *Land Drainage Act* restricting floodplain filling and creation of the *Swan River Trust Act 1988* (in addition to the *Waterways Conservation Act 1976*). This period generated a policy for the '*Guidelines and Explanation for Dredging and Disposal of Dredge Material in the Swan River System*', which restricted dredging other than for navigation. From the mid-1980s the preference for erosion control methods was for natural vegetation (Thurlow *et al.* 1986).

Since 1985 the contemporary focus for sediment management has involved local excavation, backpassing and import of renourishment material. Historic information on sediment management from WESROC foreshores is limited due to fragmented and incomplete records. Sources have noted backpassing material from one end of a beach to the other (e.g. Mosman Bay 1995 from north to south), areas of sediment accumulation along the river (causing other problems), and import of sand from quarries or river pool excavations on the lower Avon River. The practice of locally hauling sand from areas of sediment accumulation in the Swan River (e.g. Johnston Parade in Peppermint Grove) to eroding areas (e.g. Claremont beach) has reduced since 2007.

Historic Works

The most significant human impact on the Swan River was construction of Fremantle Harbour, as removal of the rock bar (1897) and associated harbour basin expansions (1892-1962) altered the estuary's tidal hydraulics. Examples of dredging for navigational purposes within or near to the WESROC area include Qantas boat ramp area for Catalina flying boats (1936), Armstrong spit for navigation after creation of Perth

Flying Squadron Yacht Club (PFSYC; 1969), dredging of an alternative channel across Rocky Bay (1971), and modifications to Point Walter spit.

A major reclamation dredging project was undertaken to develop a continuous road reserve along the northern foreshore between Fremantle and Perth, with the work along Nedlands, Pelican Point and Crawley occurring between 1936 and 1938 (Figure 2-12). Publicised benefits of the works were to minimise algae, control mosquitos, improve public health by reducing stagnant water and sewage filter beds, improve camping facilities and provide area for recreation. Dredge areas were based on absence of rock and minimising distance from shore to maximise dredging efficiency. The plan for the road was abandoned in 1938, with works not extending further downstream.

Smaller scale reclamation and dredging projects undertaken in the WESROC area were mainly related to yacht club development, with several other projects to improve foreshore amenity, for mosquito control or maintenance dredging for navigation. Available records have identified works at UWA boat shed in Matilda Bay (pre-1954), Matilda Bay swimming jetties (1972), northern Pelican Point for Royal Perth Yacht Club (1954), Nedlands Yacht Club (NYC; 1959), Armstrong spit associated with PFSYC (1969), Claremont (1930s, foreshore nourishment), Royal Freshwater Bay Yacht Club (RFBYC; pre-1953, 1967), Mosman Bay beach (1964) and Chidley Point (1964). Limited information regarding dredging history at yacht clubs has been obtained.

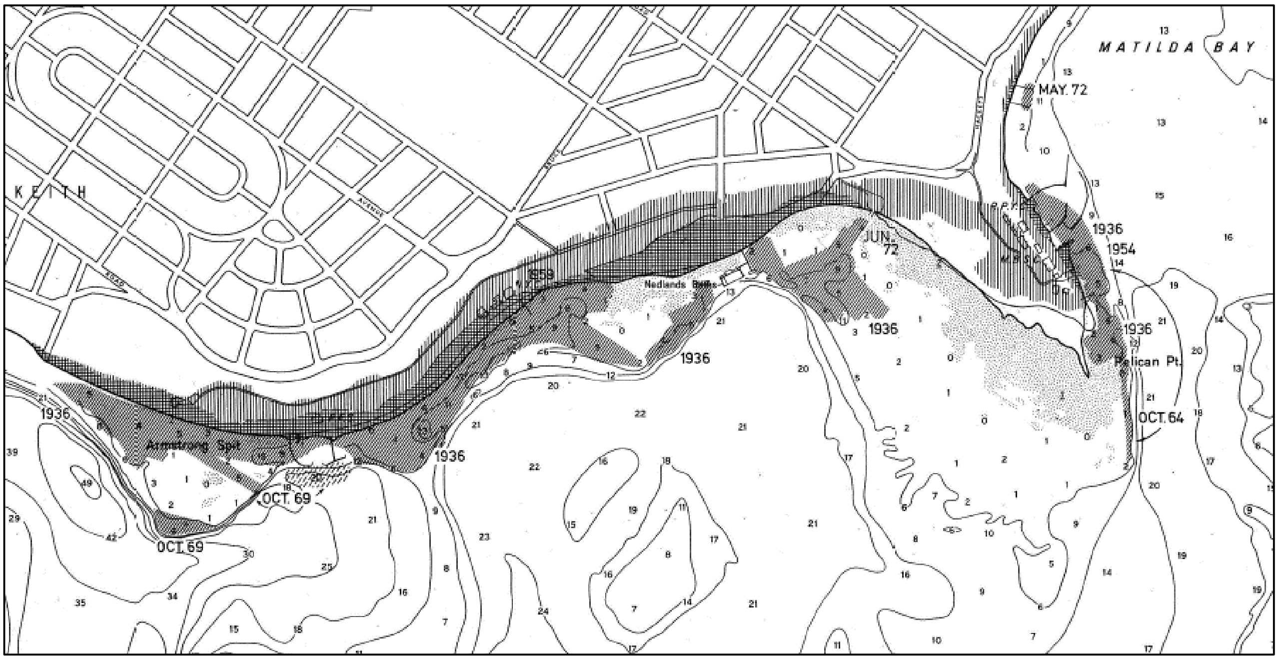

Figure 2-12: Historic Dredging and Reclamation to 1978 (extract PWD 41264-06-01)

Table 2-7: Change in Society, Institutions and River Management Responses

Period	Approx Dates	Notes on Society Related to River	Management Responses	Main Institutions
Pre-settlement	Pre-1829	River provided natural resources Spiritual value	-	-
Early Colonial	1829-1850	Establishing colony, low population, few resources. River was the major means of transport.	Attempts to cross the river and create navigation routes through Perth flats. Floodplain drained for market gardens.	Landowners
Penal Colony	1850-1870	Limited population, cheap manpower	Private landings Small-scale dredging and navigation including channels in the Canning River	Public Works. Local Works Boards starting
Gold Rush	1870-1895	Growing population. Improved resources, technology. Greater use of roads. Industrial land uses commenced. Government dredge first used in 1872, later called Black Swan.	Quarrying, navigation and jetties. Mechanised vessels made river transport and dredging easier, but required improved landings. Canning River navigation channels (Hutchison & Davidson 1979). Fremantle Harbour (1897)	Local Works Boards.
Industrial Focus (Fremantle Harbour open)	1895-1925	Pressure to build self-sufficiency Industrial land uses were dominant	Major foreshore works in Perth Water. Extensive foreshore walling Start of larger-scale river transport access, including ferries with many landings constructed using locally sourced rock from adjacent cliffs or riverbed. Landfill and drainage Dredging for construction materials commenced Dredging to reduce flood levels at Guildford. Improvements to foreshore camping areas for recreation.	Civil Authorities PWD started
Flood Response	1925-1950	Re-evaluation of river management *Swan River Improvement Act 1925* Gazetted	River straightening and deepening program Levee bank building Reclamation and fill for mosquito control Reclamation for Riverside Drive from Perth to Fremantle along northern bank. Dredging to reduce flood levels at Guildford. De-snagging Reclamation for road construction. Damming (Mundaring Weir 1902)	Dominance of PWD (including Swan River Reference Committee from 1943)
Navigation and transport	1950-1975	Post-war planning and development (1955 Stephenson-Hepburn Plan) *Swan River Conservation Act 1958* Gazetted	Roads, jetties and yacht clubs. Dredging and reclamation for roads, land development and recreation. Avon River Training Scheme. Dredging for flood control with sand mining for construction achieving the same benefit.	Dominance of Public Works Department
Rec-reational	1975-1985	Dramatic increase in boat use (& yacht clubs) with corresponding boat wake issues *Waterways Conservation Act 1976* Gazetted	Extensive provision of minor protective works to resist foreshore erosion Continued application of de-snagging (for safety) Consolidation of boat ramps and expansion of yacht clubs First foreshore renourishment with quarried sand to establish recreational beaches (1976).	PWD (ceased 1985) Department of Conservation & Environment Swan River Management Authority (1977)
Environ-mental	1986-Now	River stresses became increasingly apparent. Understanding of complex ecological issues through Peel-Harvey eutrophication Sale of PWD dredge and break up of PWD *Environmental Protection Act 1986* Gazetted *Swan River Trust Act 1988* Gazetted Swan River Management Strategy (1988). Amendment of Land Drainage Act *Native Title Act 1993*	More detailed scientific evaluation. Policies/guidelines restricting dredging except for maintenance of navigation (including Aboriginal Site 3536). Restrictions on filling the floodplain. Restrictions on hard erosion mitigation structures and jetties. Trust Works Depot (and River*bank* from 2002) assist with minor protective works to resist foreshore erosion, including renourishment of previously reclaimed foreshore. Includes backpassing and haulage from 1990, reduced scope since 2007.	Department of Environment. EPA. Swan River Trust (1989)
Present	Now	Responding to history of previous management Facing sustained La Nina and potential long-term variability in mean sea level and winds Applying foreshore reserve approach more seriously. Incorporate Indigenous values High disposal costs	Ongoing retreat adjacent to structures, dredged and reclaimed areas has resulted in new structures and structure extensions. Enhanced response in periods of high mean sea level. Limiting excavation to 600mm due to indigenous heritage is resulting in overdesign. Lack of affordable sand for renourishment. High disposal costs which limits capacity for retreat and causing construction riverward or over of existing failing structures (deferring costs).	LGA Parks and Wildlife Rivers and Estuaries Division (2015, was Swan River Trust)

Existing Situation
There is insufficient local accumulation of sediment on the river foreshores to maintain existing beaches in the WESROC area and the broader Swan-Canning River System. The volume available for excavation and haulage is unlikely to satisfy the ongoing small renourishment tasks. It is likely to be beneficial to investigate sourcing material from the Avon River pools in a subsequent study following the recommendations in Section 5.

Dredging, renourishment, mining of sediment and backpassing create future management issues. If dredging is undertaken in a method that creates a hole, or disrupts the hydraulic connectivity with the adjacent bed, sediment may be funnelled off beaches into the holes. This would also limit the future effectiveness of renourishment without associated sediment retaining structures. Examples where this occurs is near UWA boat shed and the swimming jetties in Matilda Bay, southern Matilda Bay near the boat ramp, the pocket beaches at NYC, south of RFBYC in northern Mosman Bay, at Mosmans in southern Mosman Bay and Chidley Point. Dredging may also restrict the onshore supply of sediment if the connection to the foreshore is severed, such as Eastern Pelican Point and Armstrong spit. Dredging often modifies local wave energy and currents which alters the stresses on walling as well as sediment transport patterns. An example of this is the focused ferry boat wake energy immediately upstream of PFSYC.

Maintaining beaches using haulage, backpassing or local excavation of sediment is partially restricted by availability of sand and conflicting foreshore use. Nourishing an eroding area near a yacht club is often discouraged due to shoaling within mooring areas, even if the material is backpassed from the terminal end of a beach system. Excavating sediment from an accreting beach for use on eroding foreshores elsewhere on the river may cause future problems as beach dynamics and erosive pressures may change over time, with a beach that was a source of sand becoming sand-deficient (e.g. Mosman Bay). Creating and sustaining reclaimed or renourished foreshores creates public expectations for a 'beach' to be present permanently and any erosion and the presence of scarps is a problem. This may result in expectations that any reclaimed foreshores should be sustained by walling as erosion is unacceptable.

<u>Fixed Structures in the River</u>
Fixed structures within or extending into the river may impede the existing hydraulics (waves and currents), which therefore modifies sediment transport. Typically this results in shore realignment, where the modified sediment transport is offset by accretion and corresponding erosion. However, for structures which have greater spatial influence or on foreshore where sand movement alternates seasonally, the structure may partition the foreshore, potentially resulting in a greater cross-shore scale of response and a prolonged time frame for foreshore adjustment. Examples of fixed structures that affect foreshore behaviour include groynes and retaining walls for foreshore reclamation, which occur at boat ramps, yacht club hardstand areas and jetty abutments. The effect of permeable structures, such as jetties and yacht club moorings, is typically reduced as there is less disruption of existing hydraulics. However, as they often extend much further into the river than impermeable structures, their overall effect may be comparable.

Construction of fixed structures that project into the river (as opposed to reclamation along shore) is comparatively limited along the WESROC foreshores, typically being small scale if built from impermeable structures (landings, abutments or short groynes) or deliberately permeable for larger scale facilities (jetties and yacht clubs).

The first known reclaimed sections of foreshore with walling extending into the river were those used to provide landing and offloading points at jetties at Keanes Point (pre-1906), Mosman Bay (1906) and Nedlands prior to 1933 (now part of existing walling).

Many swimming baths and early yacht clubs had limited impact on the foreshores as they were piled structures. Subsequently infrastructure was constructed that extended further riverward, mainly for yacht clubs or other navigation purposes. This has impacted sediment transport and has been compounded by the combination of associated dredging modifying local wave and current patterns. Examples include UWA boat shed (immediately north of study area), yacht clubs and groynes on northern Pelican Point, NYC, PFSYC, edge of reclamation at Iris Avenue, Chester Road car park, CYC, Christchurch Grammar boat shed, Keanes Point reclamation for RFBYC, Mosman Bay jetty and extension to Swan Canoe Club, the Coombe, Green Place, the discharge outlet for CSR, remnant abutments for shipping of quarried rock in Rocky Bay. It is possible that some private properties fronting the river (e.g. Jutland Parade, Victoria Avenue and between the Coombe and Green Place) may have walling that extends riverward if erosion continues or there are periods of sustained higher mean sea level.

Vertical or near-vertical walling

Hard infrastructure placed in the hydraulic zone along the foreshore can transfer erosion stress to the toe of the walling and to the adjacent foreshore. If erosion stress is transferred to adjacent shores there is a common trend of foreshore managers wanting to extend hard structures further alongshore, which may eventually result in an entirely walled foreshore.

Most of the vertical or near-vertical walling in the WESROC foreshore is associated with some form of reclamation or renourishment. These sections of foreshore have had low-lying swamps, bays, spits and banks replaced with high vertical features that break the capacity for cross-shore exchange of sediment. This leads to bed level lowering riverward of the reclaimed foreshore held by structures as the supply of sediment from landward is blocked. Bed level lowering is further exacerbated by additional energy transmitted as a result of dredge areas reducing wave energy dissipation, less wave breaking due to a lowering of shallow areas, dredge areas blocking onshore supply (e.g. Armstrong Spit) in conjunction with local scour attributed to wave reflection from the vertical walling.

Walling located within a bay may restrict the capacity of the foreshore to adjust to inter-annual variability in seasonal wind and sediment transport patterns. If the walling does not extend throughout the bay the foreshore adjustment in response to inter-annual variability may result in erosion adjacent to the structures.

Hard erosion mitigation structures within the hydraulic zone of the WESROC foreshore are shown in Figure 2-13. These are the structures on public land, excluding yacht clubs and private property.

Figure 2-13: Publicly-owned Structures

<u>Stormwater drainage</u>

Stormwater drainage to the river can cause localised scour and erosion, delta formation, interruption of alongshore sediment transport patterns, water quality issues through nutrient transfer and can enhance loss of renourished sediment from the desired location.

Formalised stormwater drainage to the Swan River has changed over time, with a number of large drains including northern Matilda Bay, JH Abrahams Reserve, Jetty Road (Claremont) and Keane Street as well as smaller drains (Figure 2-14). Formation of sand bars at JH Abrahams Reserve and Jetty Road Claremont contribute to water quality concerns and require active sediment management. Some drains have insufficient capacity for high flows (e.g. southern Mosman Bay) with overbank flow or have headwalls or scour aprons that exacerbate erosion of adjacent banks (e.g. northern Freshwater Bay).

Figure 2-14: Drains

2.4. WHADJUK HERITAGE

The Whadjuk people have had a connection to the Swan and Canning Rivers for a long time, including to the WESROC foreshore. The whole riverbed of the Swan and Canning Rivers is a recognised Aboriginal Site (Site 3536) on mythological grounds. The connection to the river has been formally recognised under the *Aboriginal Heritage Act 1972,* the *Native Title Act 1993* and most recently through The South West Native Title Settlement 2015. Under the settlement a *Whadjuk People Indigenous Land Use Agreement* has been prepared which covers the Swan and Canning Rivers.

Some broad information regarding Whadjuk heritage of the area is included in many resources, a few of which are listed below:

- *Swan River System Landscape Description* (SRT 1997);
- *Indigenous history of the Swan and Canning rivers* (Hughes-Hallett 2000);
- *Rivers of Emotion: Derbarl Yerrigan and Djarlgarro Beelier / the Swan and Canning Rivers* (Broomhall & Pickering 2012);
- Relation to recognised Sites such as the riverbed (Site 3536), with simple details of Sites on the Aboriginal Heritage Inquiry System (http://maps.dia.wa.gov.au/AHIS2/); and
- Information prepared for site specific investigations such as at JH Abrahams Reserve under the *Aboriginal Heritage Act 1972* (Parker and Parker 2002). This is required for many projects.

Some placenames used within the WESROC area have been extracted in Figure 2-15.

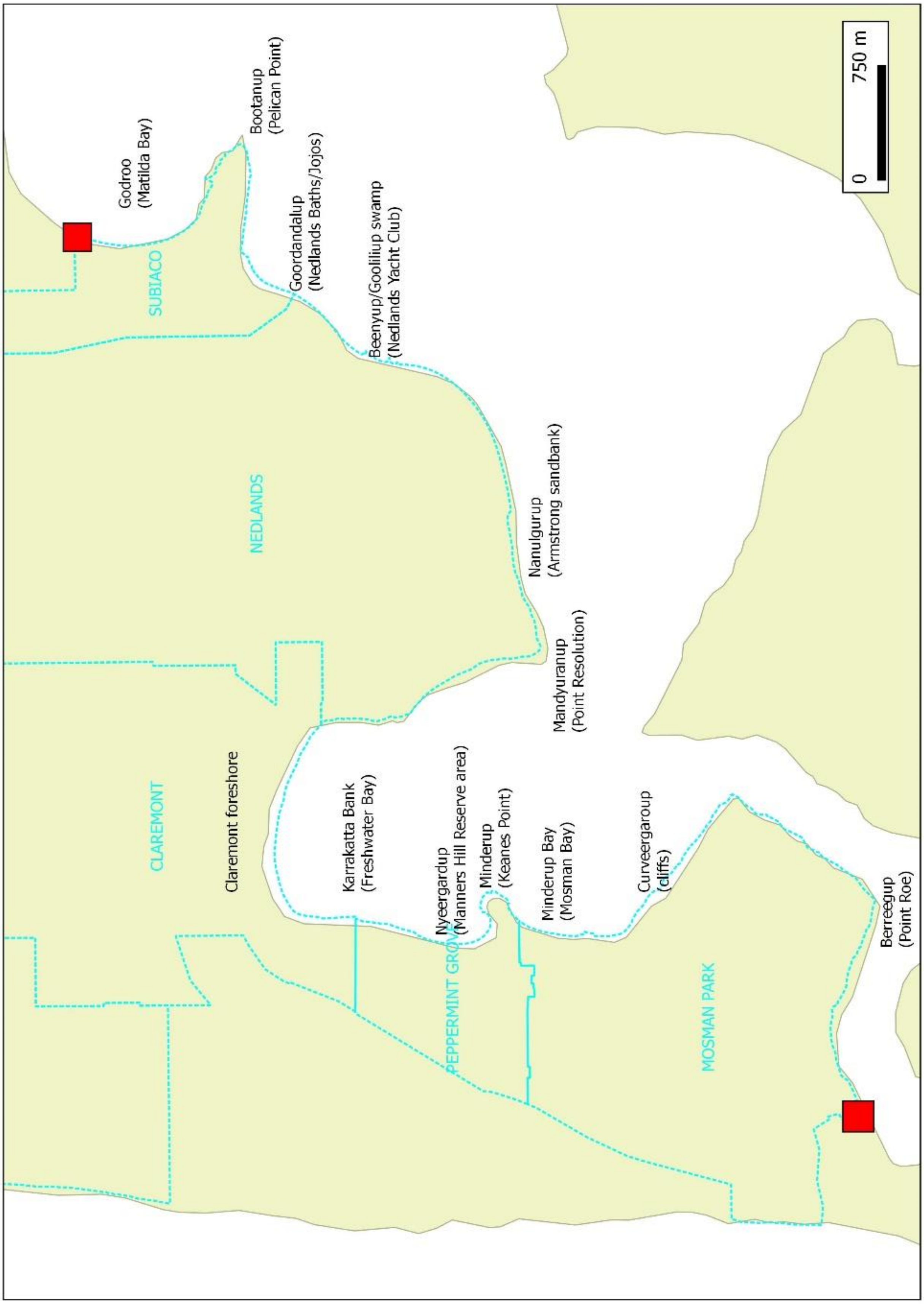

Figure 2-15: Noongar names (after SRT 1997)

The existing process for foreshore management is that the land user, which in this case is a WESROC LGA, determines if their foreshore plans are likely to impact on a Site. The impact is determined by two factors, how disturbed is the site and how disturbing are the proposed works. If the impact to a Site is unavoidable, for example replacing an existing wall with another structure when infrastructure is to landward, the consent of the Minister for Indigenous Affairs may be sought under section 18 of the *Aboriginal Heritage Act 1972* to impact the Site by giving notice to the Aboriginal Cultural Material Committee (ACMC). The notice should be accompanied by the information as to the intended use of the land and sites on the land. The process of consultation with the Whadjuk Regional Corporation will require clarification in 2016.

The Department of Aboriginal Affairs (DAA) are the contact agency for issues related to the *Aboriginal Heritage Act 1972*. The Department works to protect and manage places of significance, through provision of advice related to Aboriginal heritage management and maintains a Register of Aboriginal Sites. It is recommended an LGA contact the DAA for any planned foreshore works at an early stage of the project (e.g. concept stage).

This WESROC FMP is a strategic document. Any works by individual councils will follow the consultation process under the *Aboriginal Heritage Act 1972.* A strategic overview was presented to the Whadjuk Native Title Group for their guidance on 18 August 2015.

During this meeting a number of items were raised with regard to reducing the overall impact of works on the foreshore across the broader river system. At present, there are a number of guidelines to minimise impacts on a Site, including restricting excavation of the riverbed. It may be worth discussing some overall principles with the Whadjuk Regional Corporation to obtain their input to other aspects of river management, which may assist with decision-making for WESROC councils.

Some questions to be resolved may include:

1. What is your goal for overall foreshore management? Is it overall reduced impact on the foreshore?
2. What do you think of backpassing of sediment? This is the moving of sand from one end of a bay to the other.
3. When trying to maintain a beach that is eroding would it be possible to take sand from somewhere else in the river where the sand is accumulating?
4. If it is not feasible to remove a structure, is it ok to replace like for like?
5. In areas where the riverbed Site (3536) is already disturbed by a previous structure what is an acceptable amount of excavation when replacing with a new structure, considering excavation is required to remove the existing structure?
6. Is it ok to allow some foreshore to erode?
7. For drainage management, is it possible to undertake local sediment clearing and use of flexible scour toes?
8. Many beaches are eroding. We would like to discuss where to source sand for top-up of the beaches. Would sediment accumulated in the pools of the Avon River be acceptable, given the sand would stay in the river system? Harvesting this sediment would improve the ecological function of the river pools.

These queries relate directly to possible management solutions identified for the WESROC foreshore and are also applicable to other areas of the Swan and Canning Rivers.

3. Vulnerability Assessment Methods

In the context of this study, foreshore vulnerability has been considered as the sensitivity of identified objectives and assets (including potential assets) to foreshore dynamics, which includes both movements of foreshore sediments and the estuary water body through wave action or flooding. The history of foreshore management on the Swan River demonstrates that many structural foreshore assets, and associated reclamation projects, have direct effect on foreshore dynamics. Therefore vulnerability considers both natural foreshore pressures and the effects of imposed changes.

The general approach to a vulnerability assessment is to apply an imposed change or event (such as a severe storm) and to determine the impact upon values, which may be monetary, social, environmental or other. This has been enhanced through risk management frameworks, such as ISO 31000, to incorporate management interventions (risk mitigation), using likelihood and value of impact to provide risk prioritisation (Figure 3-1). Further refinement, mainly to cope with forecast uncertainty, has been developed through the use of adaptive management systems, applied to environmental management through ISO 14001 since 1992. Risk management and adaptation frameworks are popularly applied to climate change assessment, although the approaches are valid for any dynamic system such as the coast, even over sub-decadal time scales.

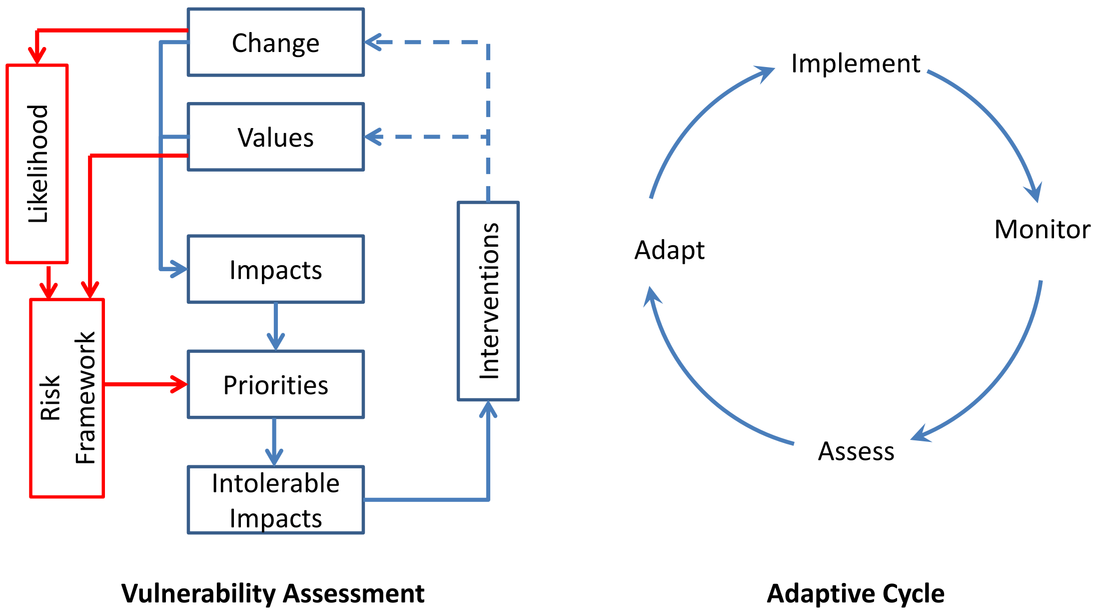

Figure 3-1: Vulnerability Assessment Framework and Adaptive Cycle

Interpretation of foreshore vulnerability is time-dependent (Table 3-1). When considered over short time scales, such as the next 1-5 years, the present state of the foreshore and the sensitivity to acute events is considered, leading to identification of appropriate forms of risk mitigation. Over longer time frames the effects of foreshore dynamics, including erosion, accretion and the life-cycle of foreshore stabilising structures have greater influence and are considered when developing a foreshore plan. Over time frames of greater than 25 years, there is considerable uncertainty regarding the future state of the foreshore, which is likely to be significantly affected by management over time and longer-term process variability. Consequently, it is appropriate to consider foreshore vulnerability to scenarios possibly affecting the foreshore, to develop an overall foreshore strategy.

Table 3-1: Vulnerability Assessment Time Frames

Time Frame	Typical	Objective	Sensitivity	Outcome
Short	1-3 years	Risk management	Acute events [1]	Risk mitigation
Moderate	3-25 years	Planning	Trends	Management pathways
Long	> 25 years	Strategy	Scenarios	Adaptation strategy

Note: 1. Acute events may include storm erosion or flooding, failure of infrastructure stabilising the foreshore or the imposition of new infrastructure.

Foreshore vulnerability was assessed for each segment over short, moderate and long time frames. Although vulnerability over short time frames may guide the most immediate management interventions, there is a need to consider the potential consequences over longer term. Potential interventions were evaluated using foreshore vulnerability assessment methods over moderate and long time frames.

The vulnerability assessment required the application of five steps to each foreshore segment (Table 3-2).

Table 3-2: Vulnerability Assessment (VA) Steps

Step 1	Establish values
Step 2	Evaluate foreshore change
Step 3a	Short-term VA
Step 3b	Moderate-term VA
Step 3c	Long-term VA

Step 1 – Establishing Values

Values are anything that has intrinsic worth to the managing agency (or its community). Worth can be considered from commercial, infrastructure, amenity, environmental, cultural, social or safety perspectives.

A summary of values applicable to each segment has previously been developed through the *Best Management Practices for Foreshore Stabilisation* (SRT 2009), which has been used as a preliminary basis for valuation (Section 3.1). However, refinement was required to develop a foreshore plan. This included:

- Identification of foreshore walling and associated structures based on the Foreshore Asset Management program by Parks and Wildlife;
- Review of values based upon existing foreshore management plans;
- Information provided through interviews with WESROC council staff; and
- Site assessment.

Values for each segment were identified as either objectives (values which are not place-specific such as recreational amenity) or assets, which include both infrastructure and non-infrastructure assets.

Step 2 – Evaluating Foreshore Change

Foreshore response varies from site to site even under identical conditions. This may be due to foreshore aspect (exposure), the presence of vegetation or structures affecting foreshore stability or the spatial pathway for sediment movement. Consequently, an evidence-based approach towards identifying foreshore sensitivity was adopted, which uses historically observed behaviour and existing landforms to evaluate foreshore response. Possible thresholds at which previous behaviour is unlikely to continue (i.e. tipping points) was determined through evaluation of foreshore and infrastructure geometry, such as the depth to undermining, or the change in foreshore position that may significantly change the effect of a rock feature on alongshore sediment transport.

An indication of net alongshore sediment transport at the segment scale has previously been developed through analysis of hindcast wave conditions, with a basic validation based on observed behaviour at zones of expected transport convergence or divergence (Damara WA 2007b; Appendix A). This information, combined with knowledge of existing sand bodies along the foreshore, was used as a basis for interpreting historic behaviour and response to foreshore structures.

In addition to the overall (long-term) behaviour, the sensitivity of the foreshore to unusual observed conditions was used to describe the possible 'vectors' for future change. Key features evaluated included:

- Observed severe storm events which provide an indication of how the foreshore segment may respond to subsequent storm events;
- Inter-annual variability of wind conditions (mainly linked to La Nina conditions) which provide an indication of how variation in prevailing wind or alongshore sediment supply may affect each foreshore segment;
- Higher water levels occurring from 2008 through 2012 which may provide an indication of how the foreshore segment responds to stress, including showing where sediment is captured or where supply may lag.

Due to the extensively managed nature of the WESROC foreshore, it is acknowledged that much of the observed change is in response to foreshore structures and reclamation. The possible effectiveness of existing and future structures required distinguishing, where possible, between historic larger scale foreshore processes and the structural response.

In general, larger scale processes are more difficult to permanently influence through intervention. For example protective structures rarely prevent alongshore transport, instead relocating the zones of accretion and erosion. They commonly require large scale and expensive engineering works. In contrast, the most achievable interventions are typically small scale, with limited response. Identification of the response to a historic intervention considered both the near-field response (such as local foreshore realignment, normally within a few years) and the far-field response (change to sediment transport patterns, giving sustained change).

As foreshore structures represent some of the most likely assets to be affected by foreshore dynamics, it was appropriate to consider their relative structural performance. Structures photographed during the *FAMS* project (SRT 2008) in 2003-2004 were compared with present day condition (2014) to determine the relative performance of the structures over the last decade, acknowledging structure life-cycles and maintenance where known. This performance, in conjunction with structure and foreshore levels, was used to help inform appropriate structural adaptation and appropriate maintenance. All structures on public land were surveyed and assessed for condition and function in December 2014, with the information used in this project.

Step 3a – Vulnerability over Short Time Frames

The objectives and assets along each foreshore segment were evaluated to determine the local sensitivity. Foreshore vulnerability over short time frames was evaluated by considering the acute events of:

- Erosion – potential for erosion was determined based on the existing foreshore state, previously estimated wave conditions for the lower Swan River (Damara WA 2007b, Figure 12-14), and water levels (Damara WA 2007c; Eliot 2012; McMullen 2012; URS 2013a);
- Accretion or smothering – potential for accretion or smothering was determined based upon existing foreshore state, sand or wrack presence and the capacity for wave overwash to occur;
- Undermining – potential for a short-term bed scour, such as caused by wave reflection from a wall or runoff from a large stormwater drain network;
- Shoaling – potential for shallowing to affect foreshore values was determined based on the sensitivity of values and available evidence from the existing foreshore state;
- Inundation – potential for inundation was determined based upon the available water level and wave studies (Damara WA 2007b; Damara WA 2007c; Eliot 2012; McMullen 2012; URS 2013a);
- Structure loss – reliance of foreshore stability upon existing infrastructure was identified by the foreshore geometry and observed patterns of change;
- Installation of a new structure – where a new structure may cause increased foreshore dynamics, through near-field sediment capture or disruption of alongshore sediment transport.

Potential interventions to address key areas of sensitivity were determined. These were considered in the context of moderate and longer time frames.

Step 3b – Vulnerability over Moderate Time Frames
Evaluating vulnerability over moderate time frames was similar to the approach used for short-term vulnerability assessment, with the following exceptions:

- The effect of existing foreshore trends was projected forward;
- The role of structures that may be affected by degradation was considered;
- The role of possible intervention identified in Step 3a was considered.

As the foreshore response over time is influenced by episodic weather events, ongoing foreshore management, the life cycle of foreshore structures and potential behavioural tipping points, it is impractical to provide a time-based forecast of foreshore structure response. Instead, projected changes were used to provide a pathway for change and appropriate response, therefore allowing identification of thresholds suitable to guide implementation of foreshore management actions.

Step 3c – Vulnerability over Long Time Frames
Long-term vulnerability assessment intends to develop a strategy for adaptive response, and essentially deals with uncertainty surrounding future conditions. Consequently, rather than evaluate response to a 'set' change, the vulnerability assessment involved determining levels of change for which the existing (or proposed) values will require intervention. Scenarios considered included:

- Proposed or potential interventions for foreshore management (including dredging);
- Progressive coastal change (alongshore sediment transport);
- Isolation of sediment supplies;
- Change to prevailing wind conditions;
- Bed lowering;
- Sea level fluctuations;
- Changing incidence of boat wakes; and
- Impacts of stormwater management, including extreme runoff.

Development of an appropriate strategy included consideration of how any necessary intervention may affect the identified values within the foreshore segment, or change the relative response to other possible sources of foreshore change. Relationships between segments were considered at this scale.

3.1. METHOD OF ASSESSING VALUE IN BMP

Existing and future foreshore management requires consideration of the foreshore and asset values. A simple assessment of values was undertaken previously (SRT 2008, 2009) on a reach scale using existing datasets, as well as an overview of infrastructure to landward. This values assessment is summarised below and is applied as the initial basis for possible interventions for the foreshore. This method was applied to cover the whole Parks and Wildlife management area using existing datasets, with further refinement required for specific segments.

At the WESROC scale, the SRT (2009) assessment of values was prepared for use in a decision support framework to determine appropriate stabilisation techniques for further investigation at a site (Appendices C.5, D.5, E.5, F.5 and G.5). A risk to the value was assessed if the foreshore was not stabilised, by rating the value and rating a likelihood. This included values of (Table 3-3):

- Existing **infrastructure**;
- **Public safety**, incorporating both the potential magnitude of the injury and whether there is any management of the hazard (e.g. fencing, signage);
- **Amenity**, incorporating frequency and type of foreshore use, along with the amount of space available for the foreshore use; and
- **Environment** (vegetation only), incorporating potential damage to vegetation at a site with conservation or biodiversity value and the associated vegetation condition.

Likelihood was assessed in terms of likely timeframe that any element of these four values may be threatened by foreshore instability, excluding inundation hazard.

Table 3-3: Loss of four values from BMP (SRT 2009)

Rank		Value of existing infrastructure	Potential loss of safety value	Potential loss of amenity value	Potential loss of environmental (vegetation) value[1]
High	4	>$100,000	Major injury and unmanaged hazard	Permanent interruption of high-use foreshore activities	High conservation value and good/moderate condition vegetation
Med-ium	2	$10,000-$100,000	Major injury with hazard management or minor injury without hazard management	Reduced area for, or temporary interruption of, high-use foreshore activities; or interruption of rare activities	Moderate conservation value with any vegetation condition; or high conservation value and poor condition vegetation
Low	1	<$10,000	Injury requires hazard management to be bypassed	Foreshore activities can be relocated within the precinct	No conservation value with good condition vegetation
Neg-ligible	0	$0	No hazard management required	No disruption of, or no, foreshore activities	No conservation value and poor/moderate condition vegetation

Note 1: Environmental value has been defined according to vegetation condition and the conservation or biodiversity value of the site. These categories have been defined in FAMS (SRT 2008). The rationale is that a site of conservation value with good condition vegetation is of most value.

Further detail on how the ranking of value was achieved is included below. This used two other datasets:

- MGT_ZONE: Management zone was defined according to the vegetation assessment characterisation (SRT 2008) and extended to incorporate further infrastructure such as yacht clubs. The vegetation assessment categorised this as infrastructure, active, passive and natural.
- CS_SPACE: Cross-shore space restriction (land, water, land-water, none). Restricted horizontal distance for foreshore stabilisation options relative to a general mean water level (MWL) and: (1) Land restriction = landward extent of amenity; (2) Water restriction = navigable boundary (or deep water); (3) Land and water restriction = both (e.g. steep foreshore and deep); (4) None = no cross-shore space restrictions.

Values were further refined per LGA and segment to suit the level of detail required for this foreshore management and adaptation plan. Values were documented per segment based on discussion with LGA officers, field visits, structure condition and function assessments, existing documentation on values, aerial imagery and site photo analysis. Whadjuk values related to improving ecosystem function were also incorporated where possible. The values information is included per LGA in Sections 6 to 10.

4. Process Considerations for Foreshore Management and Adaptation

This section should be read in conjunction with Section 2.2.2 on Foreshore Processes.

Foreshore dynamics are significant for both active foreshore management and ongoing adaptation. The back and forth movement of sediment (both cross-shore and alongshore) means that the stability of any part of the foreshore is influenced by the availability of sediment from its surrounds. Reducing the mobility of any part of the foreshore will therefore cause adjustment of both the profile shape (cross-shore) and the plan form (alongshore). This operates in conjunction with foreshore variability caused by environmental conditions.

Historically, particularly before 1985, the negative impacts of foreshore movement were extensively managed through the use of engineering works including renourishment, walling, construction of groynes and slope stabilisation. The main objective of these works is to locally reduce the mobility of foreshore sediment within the hydraulic zone. However, reducing the mobility of sediment will ultimately disrupt the overall net gradual drift of sediment that is common along most of the foreshore areas (Figure 4-1). Disruption may be further exacerbated by other works such as dredging and installation of drains, which may cause a net loss of sediment from the foreshore.

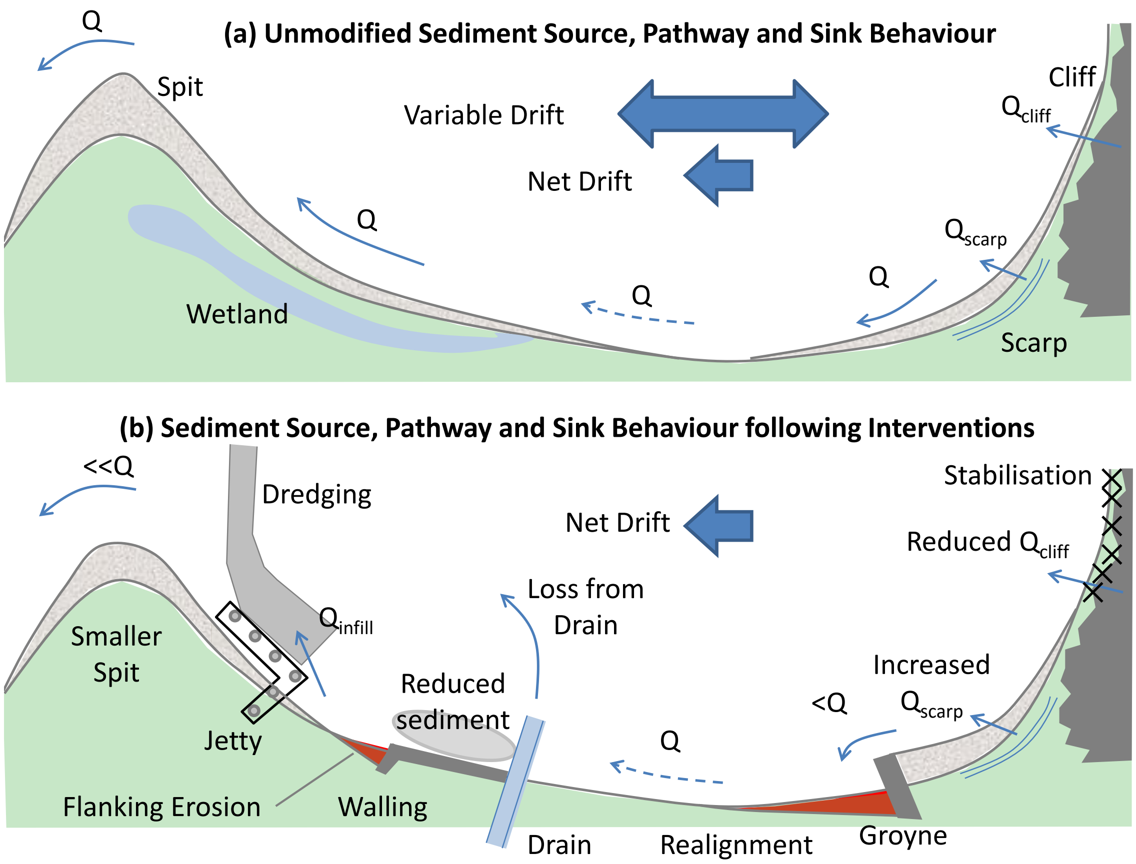

Figure 4-1: Effect of Foreshore Works on Sediment Source, Pathway and Sink Behaviour

The importance of net sediment drift is that it provides a mechanism to compensate for varying foreshore sediment demand, particularly as a function of weather conditions. The larger the drift available, the greater capacity for foreshore recovery after a storm erosion event. This principle is relevant at both short and long time scales and different sorts of foreshore impacts, with *larger volumes of mobile sediment* being a key means of enhancing foreshore resilience.

The main approach towards maximising the available sediment drift along a section of foreshore is to move towards *hydraulic smoothness*. This is a foreshore plan form with a limited number of projections or changes in foreshore orientation, preferably developed in a configuration that maintains even net sediment transport due to waves and currents.

A primary consideration for any section of foreshore is the *net sediment balance*, being the overall difference between the volume of sediment coming in and that which is leaving. The maximum area that can be protected from erosion, without merely transferring the erosion to another area, is determined by this net supply. Under situations where there is a net sediment loss, there will be overall erosion unless material is imported. On parts of the Swan River, including Como and Attadale foreshores, net sediment loss was historically addressed through massive one-off dredging and foreshore renourishment programs, which were effective for decades but ultimately have a limited life.

The imbalance of sediment supply and loss can be significantly affected by interrupting active sources. Stabilisation works, including cliff stabilisation, planting of riparian vegetation or construction of walling at an eroding scarp, may act to reduce the volume of sediment being supplied to the wider foreshore. In all cases, stabilisation of an eroding area will result in reduced supply somewhere else, therefore *transferring the erosive pressure*. A key objective is therefore to transfer the pressure to a section of foreshore where it is likely to have less impact, ideally where it is offset by a previous tendency for accretion.

At a more local scale, sediment transfer between the upper and lower parts of the hydraulic zone commonly occurs in response to storm erosion and recovery cycles. Foreshore stabilisation, which is normally concentrated in the upper part of the hydraulic zone, reduces the capacity for transfer, and either causes progressive deepening in front of the stabilisation, or greater pressure on the areas that are not stabilised. Foreshore areas without stabilisation effectively act as the ‘pressure valve’ to cope with foreshore sediment demand as it varies with environmental conditions.

In practical terms, the objective of maximising hydraulic smoothness is only an ideal, as there are a large number of existing works and features that influence the foreshore behaviour and are important for foreshore amenity. However, a greater understanding of how they influence the foreshore may support better management. Some general principles to be considered include:

- Foreshore stabilisation works typically increase variability of the adjacent areas, whether through downdrift erosion, or steepening in front of the structures;
- Consideration of net sediment drift, where it occurs, may be important for the location of structures. In general, interruptions to sediment transport towards the updrift end may affect a greater length of foreshore. Permeable structures with piled foundations are preferred for updrift areas.
- Foreshore dynamics may be exacerbated by interactions between the effects of multiple structures. A principle of nodal development may possibly reduce total impact.

5. WESROC Issues Relevant to State Government Management

Anticipated foreshore management requirements for WESROC indicate a number of significant issues that are difficult to address at a Local Government level, but may have potential for better or more efficient management through the involvement of State Government agencies. It is recommended that WESROC should engage in strategic discussions with the appropriate organisations, and where appropriate, actively lobby for support using its leverage as a collection of councils. Five challenges identified include:

- Interactions with private ownership;
- Resumption of privately-owned foreshore;
- Material disposal costs;
- Availability of sand for renourishment;
- Strategic funding allocations.

Each of these issues is summarised below.

Interactions with private ownership

Existing foreshore management is constrained by interactions with private ownership of land or assets near the foreshore. A perceived requirement for mutual non-interference limits the capacity for holistic foreshore management. This is further restricted by existing funding arrangements for foreshore enhancement or stabilisation works, which exclude management of privately-owned foreshores. Definition of foreshore reserves partly addresses this issue, although its effectiveness is compromised where the trigger for land resumption results in piecemeal reserve allowances.

On foreshores with alternating public and private foreshore ownership, the transfer of stresses due to discontinuous foreshore management obscures responsibilities for management and cost-sharing and potentially causes litigious situations.

The issue for private ownership landward of a narrow foreshore reserve is that owners may expect that the LGA will protect their properties at public expense, particularly where it is deemed to provide public foreshore access. In this way, private landowners may expect to be insulated from erosive stresses, at no cost. Management of these foreshores is further restricted by existing funding arrangements for stabilisation works, which exclude management of privately-owned foreshores.

Increased density of development on these foreshores with private and public ownership can result in a loss of access to the lower foreshore increasing the cost of any maintenance to erosion mitigation structures as a barge may be required to undertake the work.

This issue extends to other foreshores around the state and therefore it is recommended that WESROC liaise with the Western Australian Local Government Association (WALGA) regarding up-to-date and effective practices related to private foreshore ownership issues, including a clear understanding of legal positions and obligations.

Recommendation: *Legal clarification should be sought by WESROC on the relative obligations of LGAs for foreshores with interactions with private ownership and their capacity to obtain funding to support protective efforts (such as Special area rates under Section 6.37 of the Local Government Act 1995).*

Ceding and vesting of privately-owned foreshore

Ceding and vesting of privately owned land by the Western Australian Planning Commission (WAPC) to form a foreshore reserve is triggered by the subdivision process, and often results in high maintenance costs for an LGA due to access constraints and piecemeal treatments; with no improved foreshore access for the public. This is particularly relevant to potential ongoing costs for the City of Nedlands, Town of Claremont, Town of Mosman Park, Parks and Wildlife and the WAPC.

Section 152 of the *Planning and Development Act 2005* and the *Land Administration Act 1997* includes provision for this vesting of privately owned land. This is supported by the Parks and Wildlife Policy SRT/EA2 on Foreshore Reserves. In most cases, the WAPC transfer management to the LGA through a management order, which may be supported by an Area Assistance Grant for capital works. Although this is arguably a significant tool to provide an effective buffer, the nature of subdivision along the WESROC foreshore is erratic and generally slow, and it may take many years before a sufficient length of foreshore reserve is established to support effective erosion protection. The subdivision process often reduces foreshore access and in many cases results in construction of assets closer to the shore. Until a suitable distance of foreshore reserve is established with appropriate access, a partly publicly-owned foreshore is likely to have much higher management costs.

Presently, WAPC will continue to cede land and vest it with an LGA through the subdivision process, and in the context of the Metropolitan Region Scheme (MRS). One possible outcome to reduce this issue is to conduct an MRS amendment at the scale of WESROC. Other LGAs along the Swan and Canning Rivers, as well as coastal LGAs, are similarly affected by this policy and may also seek to avoid further vesting of narrow foreshores with LGAs.

Recommendation: *WESROC should consider its position with respect to this policy and if deemed appropriate, liaise with LGAs along the Swan and Canning Rivers and WALGA to collectively approach the Department of Parks and Wildlife Rivers and Estuaries Division, the Minister for Planning and the WAPC to review this approach of vesting land along narrow or eroding foreshores.*

Material disposal costs

A substantial portion of the WESROC foreshore areas were developed through a process of walling and reclamation using spoil dredged from the river. Much of the original walling is well beyond its structural life and requires replacement. Removal of either the dredged spoil or the original walling is a potentially expensive process, including the costs of testing, transport and land-filling.

High costs of disposal of dredged spoil and existing walling, partly due to the recent increase in the landfill levy, are likely to prejudice future management options, tending toward building additional structures riverward of the existing walling. This additional reclamation, although at a much smaller scale than original works, continues to harden the foreshore, reducing the resilience of the foreshore system to changing conditions and potentially increasing lifetime management costs. Burying the existing structures under another layer also increases the inertia for subsequent foreshore redevelopment and enhancement. This is particularly the case for asbestos and contaminated soils, as building over relatively small features will substantially increase the 'at risk area' for any subsequent remediation. A broader range of foreshore management solutions could be developed if a reduced cost disposal option existed for historic river walls and reclaimed foreshores.

There may be opportunities to substantially decrease material disposal costs if the entire existing foreshore walling (or a substantial part thereof) is considered, instead of looking at disposal of small sections.

Recommendation: *WESROC should liaise with the Department of Environmental Regulation (DER) regarding methods to reduce the costs of disposal of existing foreshore treatments previously undertaken by State Government departments. This could include a special exemption for the landfill levy and an appropriate strategy for reducing costs associated with identification, testing and disposal.*

Availability of sand for renourishment

A reliable and cost-effective source of sediment is required to maintain artificial beaches in the WESROC area. An option that should be pursued further is the extraction of sediment accumulating in the river pools on the Avon River.

WESROC includes a number of artificial foreshores and beaches created between the 1930s and 1970s mainly through dredging of the riverbed and placement onshore (see Section 2.3). Since the 1980s, some of these features have been partly sustained through small-scale sand relocation. However, it is apparent that there is insufficient material accumulating along parts of WESROC foreshore to balance those areas which have experienced erosion. Importation of quarried coarse river sand is typically used as a cost-comparison with alternative forms of foreshore management, although the costs of this source have substantially increased with suitable active quarries becomingly increasingly distant from the WESROC area over recent decades.

The relative cost of sand importation may be offset where there is a recognised benefit to sand removal. A study commissioned by the Department of Water identified the economic viability of excavation on the Avon River, with more than two million cubic metres of material (gravel/sand/silt) accumulated in 26 pools between Beverley and the Avon River National Park (ACE & VRA 2007). Additional studies to investigate processes and assess priority sites have been undertaken (ACC 2008; Department of Water 2007; JDA 2008).

Use of excavated material from the river pools for renourishment in the lower Swan River may be economically feasible if a joint funding agreement is sought with local governments, Parks and Wildlife, State NRM groups and the Department of Water. Potential limitations to the project include potential for high silts and clays in some pools, trucking distances, competition for material from industry and expense to separate the useful coarse sand from the finer silts and clays, which have high concentrations of phosphorus (0.8kg/m^3; *Nordstrom M. pers. comm*). Consultation with the Whadjuk Regional Corporation is required because the excavation will cause disturbance to a recognised Site (3536).

Recommendation: *Consideration should be given to a state agency lead study to determine how river pools on the Avon River could be a viable source of renourishment material for the beaches on the Swan-Canning River System. The study should consider (i) approval under Section 18 of the Aboriginal Heritage Act 1972, (ii) funding arrangements, including Local Government contributions, and (iii) resolve the potential conflict for the sand with the construction industry.*

Strategic funding allocations

The projected funding requirement for WESROC foreshore erosion mitigation is substantial, with high costs for both capital and maintenance activities. This expense is partly a legacy from extensive works by the PWD and preceding local government road boards. There is a strong community expectation that the foreshore should be maintained in an equivalent state. However, costs to maintain the foreshore position and existing uses are substantially higher than in the 1930s-1960s construction heydays. At the time, relatively low cost was achieved by:

- Using government-owned machinery;
- Using depression period labour for much of the original walling;
- Sourcing basic raw materials locally from government owned cliffs, quarries and dredging with short transport distances;
- Limited approvals requirements;
- No costs to remove and dispose of existing works and disposal fees.

These methods of economy are not available to present works, and most projects are assessed based upon commercial rates from external contractors.

The high costs of foreshore erosion mitigation and the uncertainties associated with future hazards complicate decision-making at a local government level. In particular:

- There are financial benefits to deferring maintenance on a dilapidated structure, provided the corresponding risk is deemed acceptable;
- The time frames required to accumulate funds necessary for refurbishment are much longer than the electoral cycle and therefore often difficult to accumulate;
- Opportunities constrained by electoral cycles or short-term funding accumulation require piecemeal redevelopment, which may produce inefficiencies due to staging.

Parks and Wildlife have shared responsibility for management of publicly owned foreshores (Section 2.3.2) with the local LGA and six other State Government Agencies. Private land is excluded. As part of this shared responsibility, Parks and Wildlife has adopted a position of co-funding (dollar for dollar) large asset renewal works (Section 2.3.3) under the Riverbank program. However, investment in operational, maintenance of asset upgrade for foreshore assets is the responsibility of foreshore land managers and not Parks and Wildlife.

Collaborative agreements with Parks and Wildlife, such as the Nedlands River Wall Foreshore Restoration agreement, demonstrate pathways to address the issues associated with sourcing funds for large capital works within electoral cycles and the financial pressure to defer maintenance. Collaborative agreements are likely to be required for a number of LGAs given that renewal of many assets will be needed in the next five years.

Recommendation: *Collaborative agreements should be sought by Parks and Wildlife for large areas of walling works to provide greater flexibility in establishing project timelines rather than an annual grant scheme.*

6. City of Subiaco

Information for the foreshore managed by the City of Subiaco is separated into two sections and Appendix C, all focused on the two segments of foreshore (Figure 6-1; Table 2-1). The first section (6.1) provides context for recommended management, vulnerability and a previous consideration of possible interventions (BMP 2009). The second section (6.2 and Appendix C.6) provides a discussion of possible interventions and more detail on the preferred foreshore management and adaptation sequences and plans, including tables per segment noting maintenance and capital works that could be undertaken in the short-, medium- and longer-terms.

The foreshore management plan for the City of Subiaco is presented in Section 6.2 with detailed recommendations per segment in Appendix C.6. Maintenance of the JH Abrahams Reserve walling is a management focus given the age of the walling, toe undermining due to bed-level lowering, the reduction of walling porosity during 2003-2006 maintenance and the age of drain infrastructure. In the medium-term, the feasibility of pocket beaches should be further assessed in JH Abrahams Reserve when planning the walling renewal. The Qantas boat ramp should not be upgraded, with launching traffic directed to the boat ramp on the north side of Pelican Point. Management options for the eroding foreshore to the east of the boat ramp requires resolution with Parks and Wildlife. Maintenance and renewal of walling in southern JH Abrahams Reserve require joint planning with the City of Nedlands.

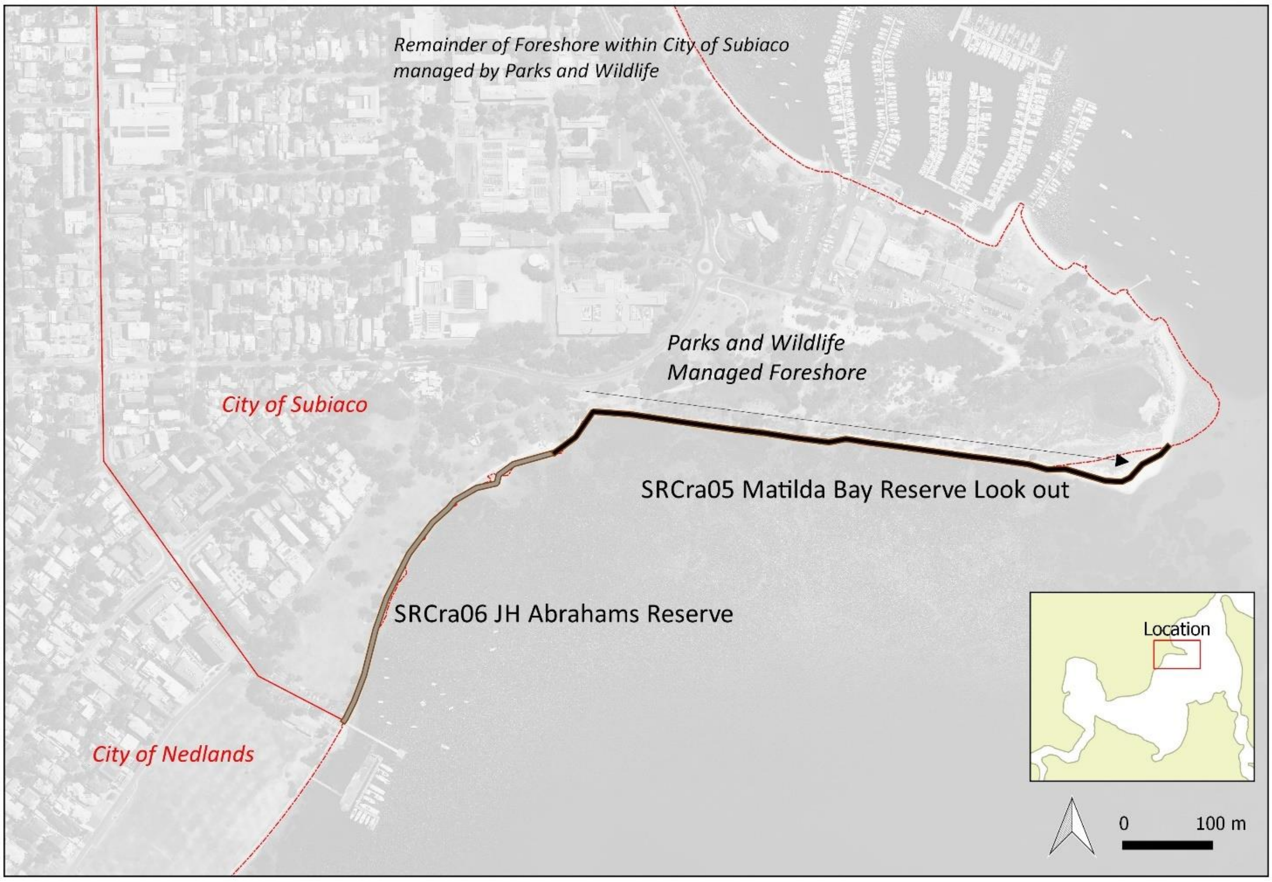

Figure 6-1: City of Subiaco Segments

6.1. CONTEXT AND VULNERABILITY

6.1.1. Process Overview

Segment SRCra05 (Pelican Point, largely managed by Parks and Wildlife)

The Pelican Point section has been modified through reclamation to infill low-lying areas (1930s) and has been partially isolated from the JH Abrahams foreshore due to dredging of an approach channel to the boat ramp. Sediment transport and supply to the Pelican Point foreshore would historically have come from the south, with some reversal during strong easterlies. The contemporary sediment supply to the Pelican Point foreshore is mainly provided from the adjacent terrace to the south, and sediment bypassing immediately adjacent to the boat ramp. Exchange is reduced due to the sediment sink of the boat ramp approach channel (1936, 1972).

The altered sediment supply and extension of the car park facilities and walling riverward has contributed to rotation of the foreshore of Pelican Point and more than 30m of retreat east of the boat ramp car park, with seasonal reversals.

Runoff from the carpark down the boat ramp contributes to local scour.

Accumulation at the eastern end of Pelican Point is sheared by tidal currents, producing a southeastwards curving spit. There may be periods in the future where the pond is breached, with formation of ebb and flood tidal shoals.

Segment SRCra06 (JH Abrahams Reserve)

A series of modifications have been made to this foreshore, including nearshore dredging, reclamation, walling, small groynes and large stormwater drains. A net northwards alongshore sediment transport is seasonally reversed during strong easterlies. However, construction of Perth Flying Squadron Yacht Club (City of Nedlands area) in 1969 has effectively prevented ongoing sediment supply, producing net erosion and bed-level lowering along the JH Abrahams Reserve. There was a lag between the last renourishment adjacent to the walling (possibly 1969) and the loss of an ongoing sediment supply to the north as pulses of sediment migrated along the walling.

Some sediment is transferred onshore from the terrace and some sediment is bypassed to the west from Pelican Point, immediately adjacent to the boat ramp. However, the supply from the terrace was reduced by the disconnect due to dredging north of the jetty (1936) and at the boat ramp (1936, 1972). Sediment is generally transferred north with accumulation at the three large drains and the boat ramp. The volume of sediment adjacent to the walling varies seasonally and inter-annually. Runoff from the carpark down the boat ramp contributes to local scour.

The dynamics of the JH Abrahams foreshore is complicated by the presence of a low-level rock shelf in non-dredged areas that provides a perched beach structure, which is seasonal in nature, and can contribute to the future smothering of the drains and boat ramp.

Ongoing stress to walling is anticipated immediately adjacent to the dredged area abutting the walling upstream of the jetty. A wholescale lowering of the terrace is expected for this area with short periods of accumulation at the groynes, drains and the boat ramp.

6.1.2. Previous and Existing Plans

The existing management plan for the City of Subiaco managed foreshore is the *JH Abrahams Management Plan* (Ecoscape 2003). The main recommendations related to foreshore management in the document were to:

- Undertake structural assessment of the seawall to determine condition.
- Instigate planting of rushes along the front of the wall in specific sections as a trial.
- Monitor beach levels at eastern end of the reserve to consider turning the area into a beach.

The renewal of this management plan should reconsider the assumption that the bed level adjacent to the walling is rising with time (it is lowering) and that sedge riverward of the walling will survive.

In the *Foreshore Assessment and Management Strategy* (SRT 2008) the section of foreshore from Pelican Point to Nedlands Foreshore was identified as a moderate priority, priority 2, in terms of urgent investment in foreshore stabilisation works. The main recommendations for the foreshore were to develop a plan for monitoring and maintenance of structures, undertake renourishment where appropriate and to address the likelihood of increased flooding and inundation in flood prone areas.

Walling maintenance has been undertaken in 2003, 2005, 2006 and 2013 for the majority of the foreshore, excluding the downstream 20m (Figure 6-8).

The constraints to future works as a result of previous and existing plans are:

- Location of path above walling restricting capacity to monitor and maintain walling;
- Water Corporation plans for the three Princess Road main drains;
- Maintenance plans for walling to consider previous maintenance undertaken as the use of concrete infill to landward has transferred erosion stresses;
- Assumed requirement of a beach adjacent to the boat ramp walling at WA Kite Surfing Association agreed launching area;
- Agreement required with City of Nedlands regarding any modification to car park, stairs and walling at southern end of JH Abrahams Reserve; and
- Jojo's/Acqua Viva expansions.

6.1.3. Historic Works

The City of Subiaco foreshore was initially a gentle-grade sandy foreshore, adjoining a terrace, with the original foreshore position located up to 80m landward of the reclaimed position. The terrace was partially exposed during low tides. Extensive modifications were undertaken in 1936 to 1938 with dredging close to shore to infill the Pelican Point swamp area and to create a smooth, walled foreshore. The reclamation was undertaken to reduce mosquito breeding, reducing the accumulation of sewage from Perth and to allow the future construction of the Perth to Fremantle Road. Further modifications have been undertaken for boat launching and catalina flying boats, recreation and beautification.

This section should be read in conjunction with Section 2.3 which includes a summary of how environmental regulations and management practices across the river have changed over time.

An overview of some changes and issues in the foreshore section managed by City of Subiaco are included in Figure 6-2. Key changes in relation to foreshore management are listed in Table 6-1 with context provided with aerial images of 1953, 1965, 1983, 2014 per segment (Figure 12-17 to Figure 12-18 in Appendix C.1). The aerial imagery of 1953 does not show the foreshore before the large-scale reclamation with further context provided by Figure 6-3 to Figure 6-5. The long-term controls on beach position and sediment transport on this foreshore are the reclaimed walling, dredging, boat ramp and drains.

Table 6-1: Historic modifications relevant to present-day foreshore management

Segment	Modification	Date
SRCra05 Matilda Bay Reserve Look out	Dredging: • Dredging on north side of Pelican Point (Figure 6-3) to raise level of Pelican Point for mosquito control. • Channel dredged 25m wide at Qantas boat ramp • Channel widened to 35m at Qantas boat ramp	1936 1936 1972
	Reclamation/renourishment: • Broader segment infilled and modified for mosquito control with subsequent extensive reworking. • Assumed some renourishment has been undertaken east of boat ramp walling.	1936
	Boat ramp, car park (no drainage) and walling: • Boat ramp and concrete car park (channel dredged 1936). • Expected upgrade to car park and boat ramp when dredge channel to boat ramp widened. • Extension E with 3-layer limestone block + stairs • Extension E with 2-layer limestone block • Eastern walling shifted 2.5m landward • Maintenance of walling abutting car park by retrofitting foundations and regrout.	1936-1939. 1972 Pre-1995 Unknown 2004-2006 2007-2008
	Path: • 8m landward of walling • Decking and path connecting car park and Pelican Point • Moved 10m landward in Kite surf launching area	Pre-1995 2006-2008 2011-2014
	Fence to distinguish bird nesting area and controlling shoreline position.	Installed pre-1981 and removed ≈2008
SRCra06 JH Abrahams Reserve	Dredging/reclamation: • Large scale dredging for reclamation (Figure 6-3, Figure 6-4). • Dredging to widen channel to 35m at Qantas boat ramp.	1936 1972
	Walling (see Figure 6-8 for extent of maintenance): • Installed to retain dredged material for reclamation. Unknown if replaced. • Maintenance of 100m of walling • Maintenance of 198m of walling • Maintenance of ≈112m of walling • Maintenance of 30m of walling	≈1936 2003 2005 2006 2013
	Three small groynes installed to maintain lower beach	Pre-1995
	The six drains were extended to their present locations in conjunction with the large-scale foreshore reclamation. The three Water Corp. drains at Princess Road have been upgraded in this time. Also sewage overflow tanks located 100m landward.	1936-1938. Princess Rd upgrades assumed. Sewage overflow tanks 1995-2000.
	Car park and stairs to the foreshore at southern boundary (no local drainage)	Pre-1922, Pre-1953, widened 1970s, 1990s
	Path above walling	Pre-1995

Figure 6-2: Some issues and modifications for the foreshore managed by City of Subiaco

Figure 6-3: Historic modifications overview for City of Subiaco

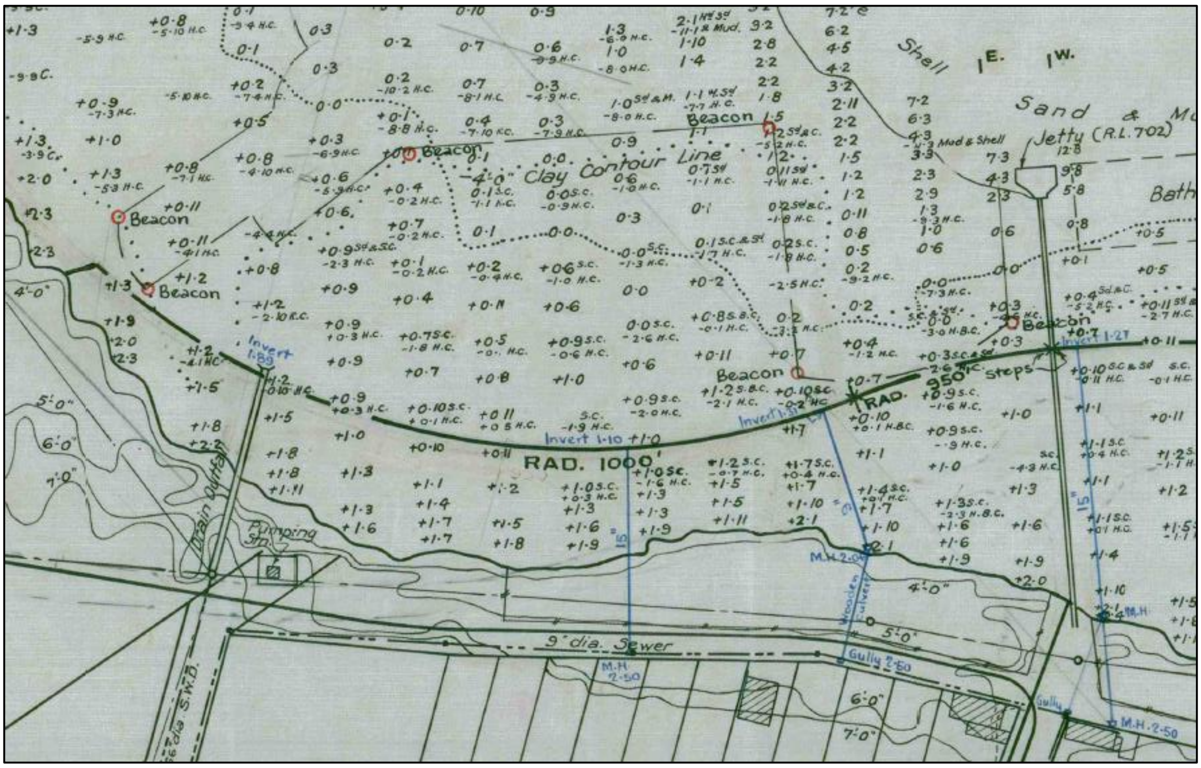

Figure 6-4: 1936-1938 Dredging, Reclamation and Drainage extension in SRCra06 (PWD 29200-4-1)

6.1.4. Site Issues and Constraints

Details of issues and constraints for the two segments managed by the City of Subiaco are included in Table 12-9 (Appendix C.2). This is in addition to some further broader issues of:

- The requirement for foreshore management decisions in the north to be made in conjunction with the Department of Parks and Wildlife, due to the proximity to the Swan Estuary Marine Park and the A Class Nature Reserve.
- Water Corporation has large drains discharging at JH Abrahams Reserve with sediment bars blocking flow and causing water quality issues. City of Subiaco advised the area around the drains is regraded at least once per year by Parks and Wildlife.
- Resourcing for future works.
- Stakeholder conflict varies along the foreshore with notes included in addition to passive recreational users of the foreshore.
  - Works in and around Qantas boat ramp need to be considered in the context of the impact on the Swan Estuary Marine Park and future foreshore retreat.
  - JH Abrahams Reserve has conflicting use of avoiding sedimentation at both segment extents (boat ramp and Nedlands Jetty), stormwater management, maintenance of the path adjacent to the wall, users of the Nedlands car park and private property owners to landward.
  - The WA Kite Flyer Association allows a 280m length for kite launching in segment SRCra05 that can conflict with bird foraging in the Swan Estuary Marine Park. This association also requires works to only be undertaken that permit future kite launching, such as avoiding the use of rock which may tear the kites.
  - Recommendations for management incorporate the harvesting of sediment from the Royal Perth Yacht Club (RPYC). The RPYC would likely appreciate harvesting of sediment from the

east for renourishment to reduce sedimentation, with Mounts Bay Sailing Club and the Sea Scouts possibly not supporting the initiative.

- Path is adjacent to walling in JH Abrahams Reserve, with shotcrete applied to landward of the wall for some sections, obscuring capacity to detect erosion and prioritise maintenance.
- Foreshore presently responding to historic dredge areas <20m from the shore and altered structural controls. Consider impact of altering any structural controls in future as modifications could cause rapid erosion.
- Indigenous approval discussions required for any dredging or haulage, including potentially extracting sediment from accumulation in the eastern berth area of RPYC and within the groyne field on northern Pelican Point. The study by Parker and Parker (2002) should be considered.
- Changing far-field forcing of boat wakes.
- There are two significant trees within the broader foreshore area that will require consideration if pursuing pocket beaches or foreshore retreat. These are located approximately 30m landward of the three Water Corporation drain outlets. Further information is available in the City of Subiaco (2014) Register of Significant Park Trees, with a total of 25 significant trees within JH Abrahams Reserve. The majority of these are original remnant trees (e.g. *Melaleuca rhaphiophylla* and *Eucalyptus rudis*) or the progeny of remnant trees that are likely to have genetic diversity unique to the area.

6.1.5. Observed Change

The City of Subiaco managed foreshore is presently responding to previous reclamation and walling, in conjunction with drainage and surface runoff (Figure 6-5). It is also responding to inter-annual variability in winds, water levels and sediment supply.

Some observed changes include:

- Overall bed level lowering since the 1970s.
- Reduction in sediment supply from the south due to dredging and cessation of supply from the beach adjacent to the terrace in dredged areas.
- Sediment is generally transferred north with accumulation at the three large Water Corporation drains and the boat ramp, with some sediment trapped at the low-level groynes. The volume of sediment adjacent to the walling varies seasonally and inter-annually, particularly in the presence of the low-level rock shelf in non-dredged areas.
- The path above the walling at JH Abrahams Reserve, and maintenance works since 2001 that have reduced permeability, has promoted bed-level lowering as erosion stress is transferred to lower on the structure.
- The downstream extent of the walling, adjacent to Nedlands jetty car park, is slumping.
- Uncontrolled pedestrian and kite surf launching access contributing to erosion.
- Runoff scour occurs at both car parks due to a lack of drainage management with surface runoff down the stairs and boat ramp, contributing to erosion.
- Rotation of southern Pelican Point foreshore has resulted in retreat of 30m east of boat ramp since 1953, with some seasonal reversals. This is caused by reduced sediment supply from the south and west, accumulation of sediment on SE Pelican Point from previous reclamation with broad foreshore realignment– as well as reflection off walling adjacent to car park. The recurved spit encompassing the pond/lake on Pelican Point has breached during high water level events during La Nina.
- Seagrass wrack continues to accumulate along this foreshore.

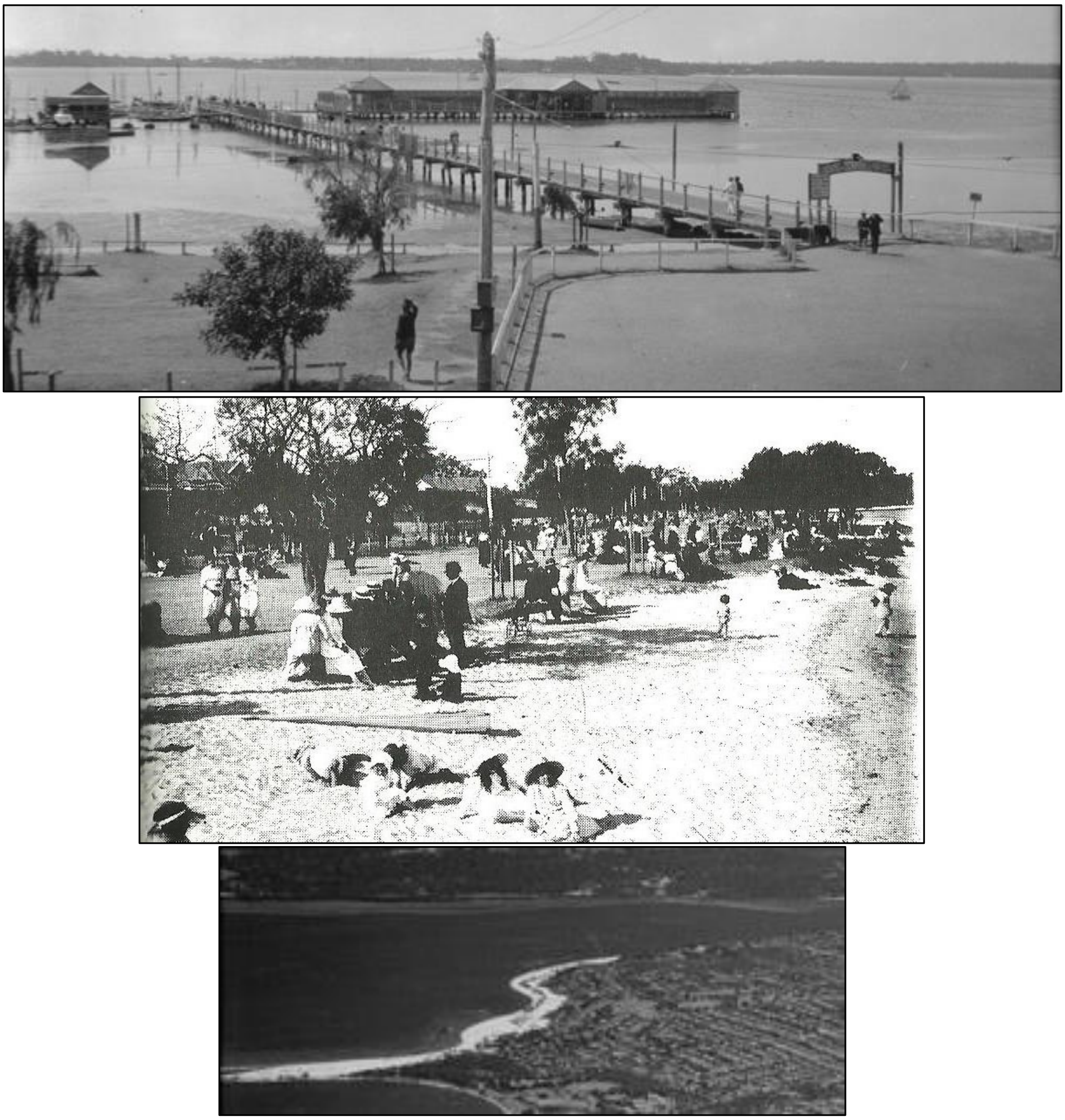

Figure 6-5: Historic Subiaco Foreshore Images
Top: Nedlands jetty and baths 1922 (Orloff and SLWA). Centre: Esplanade foreshore 1916 (Clarke 1993). Bottom: 1930s reclamation ca 1939 (Gore and SLWA).

6.1.6. Structure Condition and Function Comparison

Previous assessments of structure condition and function have been used in preparation of the foreshore management and adaptation approach for City of Subiaco. The details of the 2004 and 2014 assessments are included in Appendix C.3 with tables of structure condition and short-term maintenance comments in Appendix C.4. Drains were only assessed in 2014 if they were contained within other foreshore structures.

6.1.7. Foreshore Controls and Sensitivities

The foreshore controls and sensitivities for the City of Subiaco managed foreshore include:

- Response to reduced sediment supply and sensitivity to dredged areas.
- Reclaimed foreshore walling providing fixed control for Pelican Point foreshore to the east.

- Modified foreshore. Dredged areas adjacent to walling in the southern area limit the capacity to return to a gentle grade foreshore in this area.
- Sensitive to future bed level lowering. The combination of the path above the wall and maintenance infill behind walling with shotcrete/concrete contributes to a more rigid and impervious structure which transfers erosion stress to the bed adjacent to the wall.
- Any replacement walling in the approximately present location will be low-elevation as it is impractical to raise elevation of the fill areas to landward.
- Underlying rock substrate to be considered in future plans.
- Path adjacent to walling obscures identification of voids behind walling.
- Water Corporation drains invert levels unlikely to be raised due to elevation limitations to landward. The flow from these drains provides a control to the adjacent foreshore as sediment is trapped in a delta and storm bar.
- Surface runoff including managed runoff at the three Water Corporation drains and two local drains, as well as unmanaged runoff at Nedlands jetty car park, at the southern section of collapsing walling on JH Abrahams Reserve and at the Qantas boat ramp.
- Potential acid sulphate soils to landward.

The foreshore managed by the City of Subiaco is walled, with existing levels shown in Figure 6-6 and Figure 6-7, with photos in Appendix C.7. The eastern extent of the reclamation, and subsequently installed walling, transfers erosion stress to the foreshore to the east.

The original walling to retain the reclaimed foreshore was constructed in 1936 and it is unknown when the walling was replaced. Based on the style, similar to the 1940s Mosman Bay and Peppermint Grove walls it is possible the walling is original or was constructed in the 1950s. An additional section of concrete footing, shown in green in Figure 6-7, was likely added later. The CoS undertakes maintenance on this walling. Based on records provided by CoS, the approximate extent of maintenance and type of works undertaken are demonstrated in Figure 6-8 and Figure 6-9.

Maintenance in 2003-2006 focused on infilling the space landward of the uneven small limestone blocks with concrete using two different methods. The use of shotcrete or infilling with concrete provides a layer of binding concrete to landward, effectively forming a new wall behind. It is likely to lengthen the life of the wall, but restricts the capacity for future maintenance. Any voids will now create a larger void until the section of wall fails, increasing the required inspection frequency and likely increasing the scale of the next failure. The method of infilling to landward with concrete requires filling all voids, rather than concrete on dirt which only provides a cap to the cavity. It is likely the method used in February 2003 (Figure 6-9) will have a shorter longevity to the 2005-2006 approach, due to applying a shotcrete layer rather than a binding concrete layer vibrated into gaps. Any voids will increase cavitation. In many areas, including the area of works in 2013, the riverward side has been regrouted with some new blocks. It appears no works have been undertaken on the structure toe.

The walling at the boat ramp car park (SRCra05.B01) was constructed with insufficient embedment. Works were undertaken (2006-2007) to infill concrete under the toe of the walling and to shift the eastern extent of the walling 2.5m landward after it failed.

Figure 6-6: Qantas Ramp Car Park Walling (SRCra05.B01) Levels - January 2015 (on 2014 image)

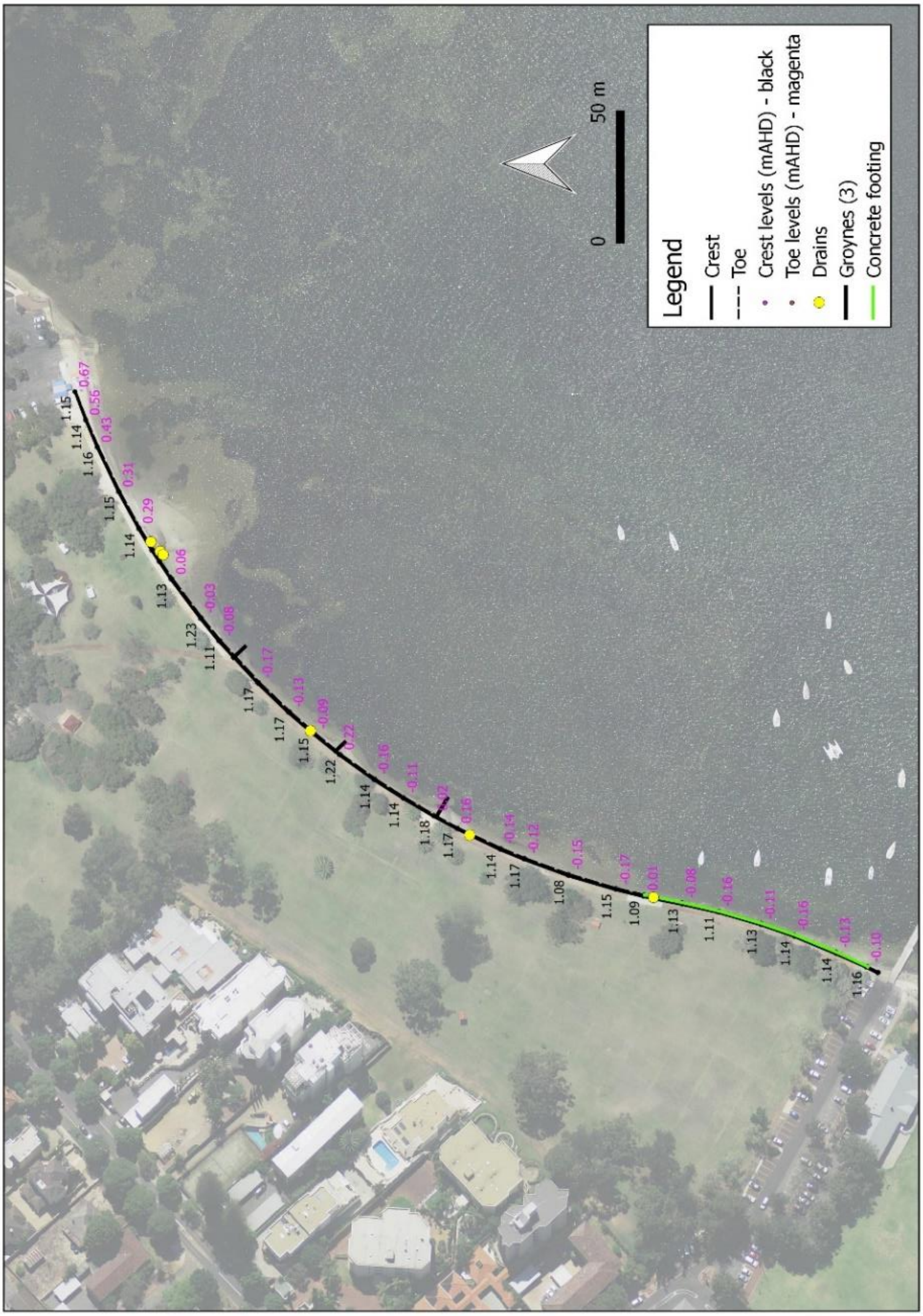

Figure 6-7: JH Abrahams Reserve Walling (SRCra06.B01) Levels - January 2015 (on 2014 image)

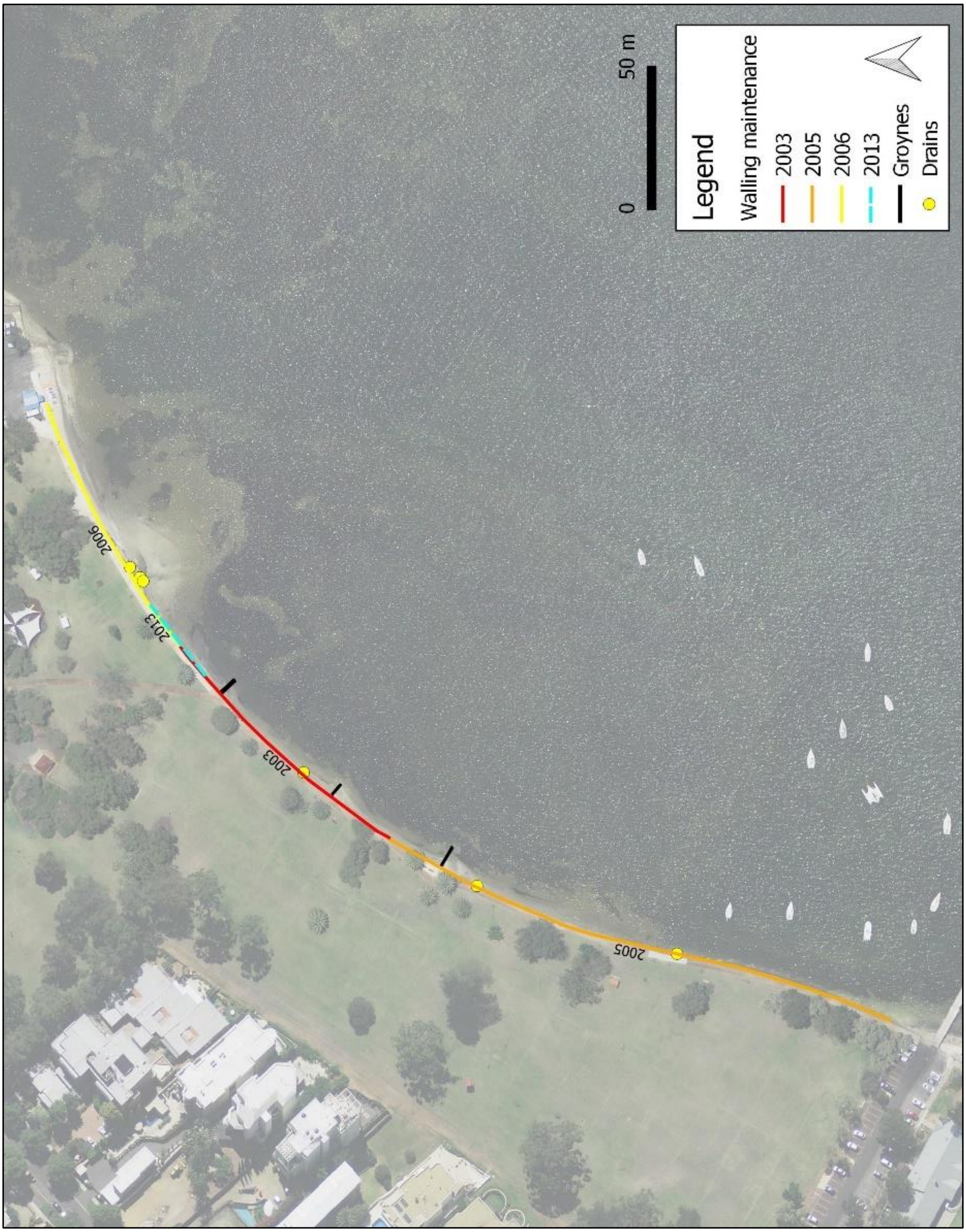

Figure 6-8: Assumed spatial extent of maintenance works at SRCra06 – JH Abrahams Reserve

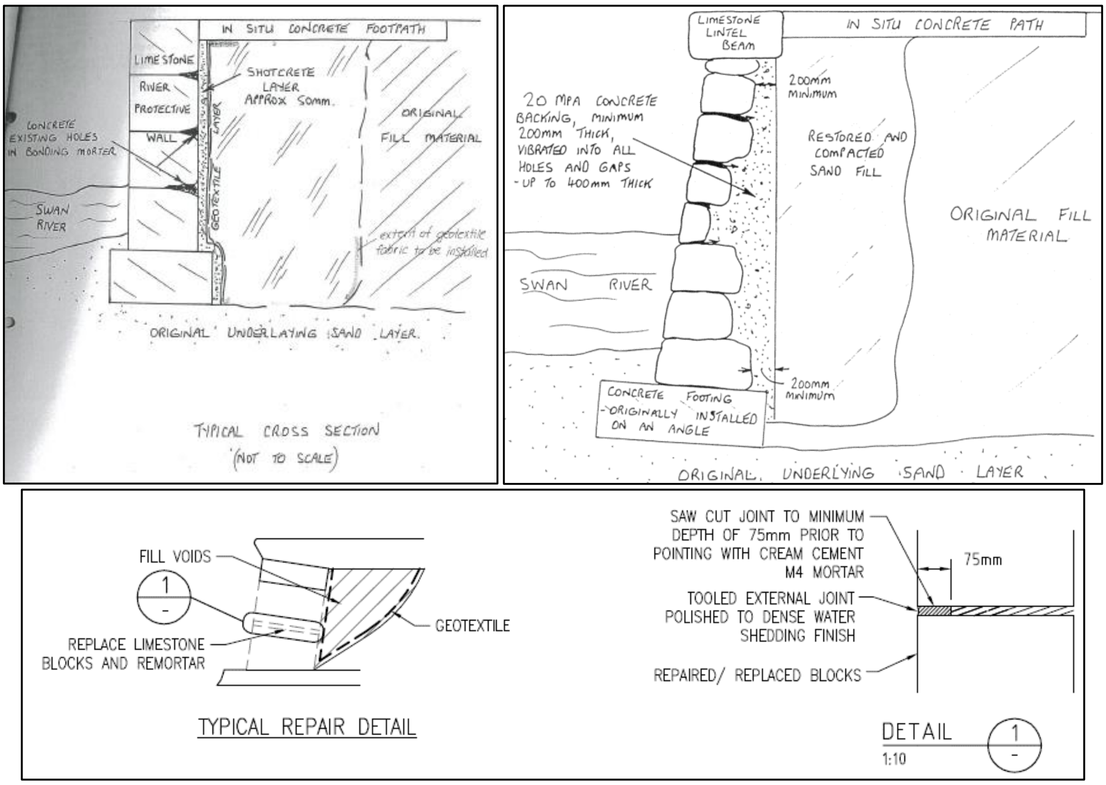

Figure 6-9: Walling Maintenance at SRCra06.B01 JH Abrahams Reserve
Top Left: 100m in February 2003 (CoS 2003), note this is not representative of the actual walling. Top Right: 198m in February 2005 and assumed 112m in 2006 (CoS 2005, 2007). Bottom: 30m in 2013 (MP Rogers & Associates 2013)

The broader foreshore landward of the walling is relatively low-lying with 10-20m width until +1.4mAHD (Figure 6-10), as well as the level of the car park at Qantas boat ramp. The top of the walling is approximately +1.1mAHD which corresponds to the 10-year ARI still water level. Raising walling as a method of mitigating future vulnerability to increased mean sea level is not considered viable due to the large area to landward requiring infill.

Foreshore structure and drain maintenance requirements provides another foreshore sensitivity for the City of Subiaco. If adequate maintenance is not undertaken it may lead to failure, which can transfer erosion stress. Tables of the condition and potential maintenance of the walling and drains were prepared by Damara WA (2015) for the Parks and Wildlife at a broad scale (Table 12-11 and Table 12-12; Appendix C.3). Some of the information has been refined for consideration of the moderate to longer-term vulnerabilities and planning requirements (Section 6.2), particularly given the subsequent information provided by the City of Subiaco regarding maintenance works undertaken since 2003 (Figure 6-8 and Figure 6-9).

Figure 6-10: Topography and Bathymetry in the City of Subiaco managed foreshores

6.1.8. Scenarios and Impacts

The scenario at present is:

- Continued stress at structure toe with loss of material under footing, particularly adjacent to dredged areas.
- Bed level lowering increases wave energy transmission to walling, increases reflection and feedback on local scour adjacent to walling.
- Increased risk of cavitation damage behind walling due to concrete infill to landward and difficulty to identify when it is occurring due to the path location adjacent to the wall.
- Ongoing maintenance requirement for walling, with southern 15m section most likely to fail.
- Foreshore retreat and structure at Qantas boat ramp car park restricts alongshore sediment transport with erosion focused adjacent to this walling.
- Continued inter-annual discrepancy in onshore transfer of sediment, seasonal and net sediment transport, and rates of accumulation of sediment at the drains, the boat ramp and in the eroding foreshore to the east.
- Ongoing local erosion stress associated with drain scour and unmanaged runoff.
- Water-logging of parklands, with recent irrigation upgrade improving this issue.

The scenario of increased mean sea level could result in the potential responses outlined in Section 6.1.10 in the >25 year category.

Further scenarios to consider are works undertaken that may further reduce sediment supply to the foreshore and removing sections of the walling and replacing with two to three pocket beaches. It is assumed that the boat ramp would not be upgraded to a larger facility.

6.1.9. Values and Foreshore Uses Considered (Short- and Long-Term)

The foreshore values and uses for the City of Subiaco managed foreshore include:

- Maintain existing where possible.
- Maintain lawn.
- Ensure space for kitesurfers to layout kites, with present allocation of 280m length east of Qantas ramp car park. Future works should not incorporate structures that could tear kites.
- Balancing the various requirements of kitesurfers and windsurfers.
- Maintain drain function with particular focus on the Princess Road main drains.
- Existing recreation focus is above the walling, with exceptions in the area of the boat ramp with kitesurfers, windsurfers, stand up paddle-boarders and children playing in the sand.
- Allow for an expanded playground with consideration of increased interaction with the river.
- Maintain boat ramp function for launching kayaks and small dinghies. Facility should not be upgraded considering the large boat launching facility 500m to the north.
- Path requires connection along foreshore for recreational use.
- Whadjuk values are to increase ecological function and reduce walling hardness.
- Ensuring space is available for bird roosting, feeding and nesting. Maintain integrity and function of Bush Forever Site 402 and the Swan Estuary Marine Park. Consideration is required for the natural evolution of Pelican Point in response to historic modifications.
- Accumulation of seagrass wrack may be a cause of ongoing complaints.
- Maintain moorings with pressure for dinghy storage and launching areas to access moorings.
- Maintain significant trees.

As the population density increases it is anticipated there will be increased use of this foreshore.

6.1.10. Vulnerability

Existing vulnerability (0-5 years)

Inundation of the walling occurs for most of the walling in a 10-year ARI still water level (+1.1 mAHD) if no waves and no mean sea level shift (Figure 6-6 and Figure 6-7). Inundation increases during La Nina events due to an increase in mean sea level. Waves will contribute to scour of material under the toe, erosion through gaps in the walling, cavitation under the path, and erosion landward of the path due to overtopping. Local ponding occurs on low points in the path. Inter-annual variability in the water level, wind and wave climate contributes to sediment accumulation at the groynes, drains and the boat ramp as well as erosion adjacent to the boat ramp walling. Waves are 0.9 to 1.2m Hs (3-year to 100-year), with long-period boat wakes also occurring at the site.

The section of walling most susceptible to damage is the southern 15m which has not had extensive maintenance undertaken (Figure 6-8). The walling is folding in on itself with block units collapsing landward, coping rotating riverward, a lowering of the total wall level and a loss of grout. Some patching of the coping has been undertaken, but it is insufficient, with damage exacerbated by unmanaged runoff from the car park.

Other sections of walling susceptible to damage are areas where:

- grout had eroded between the wall and the coping;
- walling is adjacent to the deeper bed with reduced onshore supply and toe undermining;
- walling is less permeable due to maintenance undertaken with erosion stress at the toe;
- bed level lowering east of the boat ramp could cause further settling and structural damage;
- walling is adjacent to drains, particularly where drains discharge onto or in to the wall;
- the palm tree is close to the wall and more frequent regrouting is required due to piping of water by roots; and
- coping is rotating landward creating a lower elevation area to store overtopped water. Cuts in the coping provide a focal area for damage.

Focal erosion occurs in the vicinity of the three Water Corporation drains, with vulnerability to a sand bar blocking low flow events particularly when a storm bar accumulates inside the drain pipes. The blocking of flow could result in poor water quality in the pipes and local reduction in drainage capacity. The storm bar and delta around the three drains traps water which contributes to local algal blooms.

The foreshore east of the ramp car park is vulnerable to erosion due to altered sediment supply, the walling interrupting the hydraulic smoothness and the accumulation of sediment on southeast Pelican Point. The beach experiences seasonal reversals and inter-annual variation in levels.

Further vulnerability is associated with:

- Drainage leaks;
- Unmanaged surface runoff at Nedlands car park steps, boat ramp, boat ramp car park and at holes cut in the wall coping;
- Removal of any sand accumulating at the drains and boat ramp from the system for use in other foreshore areas. Sediment should be maintained within the area and transferred east of the boat ramp car park;

- A large storm event that scours sediment from under the structure toe; and
- Construction of any new structure that impedes alongshore sediment transport.

Progressive change to vulnerability (5-25 years)

It is expected the walling will reach the end of its functional life during this time period. Drainage pipes will likely require renewal through length of pipe as they were placed during foreshore reclamation works in the 1930s. Breakage and leaking promotes local walling weakness.

Some of the vectors for vulnerability described are likely to increase in magnitude. This will include increased:

- Erosion at the toe of structures, through structures and east of the car park walling as the foreshore continues to respond to the historic works.
- Recreation use and creation of focal erosion areas due to uncontrolled access.
- Runoff into drains with less recharge in the catchment as density increases in the CoS. This will result in increased scour at drains and in areas of unmanaged runoff.
- Storm bar and delta accumulations at the Water Corporation drains.

A further source of vulnerability is due to staging of the walling replacement. The tie-in areas have the highest susceptibility to damage, with adequate temporary tie-ins to be designed.

The foreshore is also vulnerable to the erosion mitigation works undertaken by City of Nedlands immediately downstream as part of their plans for asset renewal.

Scenarios for changing vulnerability (>25 years)

Longer-term planning considers the scenario of increased mean sea level. This could increase the foreshore vulnerability to:

- Increased water-logging of parklands.
- Bed level lowering and stress at structure toe. Loss of material under the footing.
- Increased overtopping, cavitation and slumping of path. Without frequent monitoring and maintenance the walling could collapse. Increased mean sea level may coincide with required renewal of the walling.
- Blowback and choking at Princess Road drains due to low invert levels and high elevation sand bars blowing the flow.
- Erosion enhanced east of boat ramp car park with undermining of walling and end-effects.

6.2. FORESHORE MANAGEMENT AND ADAPTATION SEQUENCES AND PLANS

The possible interventions for the City of Subiaco are described according to the vulnerability assessment time-frames linked to risk mitigation, management pathways and an adaptation strategy (Table 3-1). This information is presented for each segment (Figure 6-1), with a summary of scheduling, monitoring requirements for adaptation triggers and works summary for the 0-5 year time-frame provided for the whole LGA.

Initially, the decision-support framework was applied, according to the method described in Section 3.2 of SRT (2009), to refine which stabilisation techniques should be considered further. Details of this application is included in Appendix C.5.

6.2.1. Possible Interventions

Maintenance and capital works for the sections of walled foreshore managed by the City of Subiaco are discussed in the context of improving foreshore resilience. Improving resilience on a walled foreshore includes considering greater capacity to tolerate increased wave energy, lower bed levels adjacent to the walling and higher rates of overtopping.

The City has actively maintained the walling through programs of re-grout, backfilling with concrete and repair, which has significantly extended the structural life of the walling. However, in many sections the walling life can be extended with further maintenance. In some locations the structural life of the limestone block walling has been exceeded with limited opportunity to extend it further through modification of the existing structures due to the nature of previous maintenance (CoS 2007; Damara WA 2015). In the 5-25 year period it is anticipated that sections of the existing walling will require replacing. Financial constraints determine that it is unlikely to achieve replacement as a single work, and therefore short-term enhancement may be suitable where it can be achieved.

This guidance is applicable to both short-term enhancement and to longer-term treatment of the foreshore.

Design elements that need to be considered in both instances include:

- The structural integrity of the walling itself;
- Progressive deepening of the river bed in the southern areas, which has compromised the effectiveness of the wall to retain sediment;
- Implications of low foreshore elevation for material retention, including both overtopping and inundation.

<u>Short-term enhancement and management</u>

Actions to extend the structural life for less-compromised sections of walling should focus on regrout, lifting the path and infilling cavities (when identified), improving drainage to landward or providing an improved toe and scour toe (reducing undermining).

In the sections where undermining is occurring, maintenance works at the toe may be undertaken following recommendations in Table 12-11 (Damara WA 2015). Jetting of cement grout under the existing toe and installation of a rock scour toe may be useful for reducing the loss of material under the structure, but will require later excavation when wall replacement is required. Maintenance items require consideration in terms of expense ahead of possible wall replacement.

The effects of overtopping and inundation are considered relatively minor under present conditions, and where the walling is above +1.0m AHD, shifting the path away from the wall crest and backfilling using free-draining but erosion resistant material (e.g. gravel, possibly with geotextile) may be cost-effective. The shifting of the path to landward may be undertaken when sections of walling are replaced.

Ponding on the foreshore landward of the path presently occurs. If lowering of the path level and adjacent land levels continues to occur, the capacity of water accumulated landward of the wall to scour sections of the foreshore when it drains ultimately require a more formal drainage system. The low level of the walling and the impervious nature of the concrete-lined (2003-2006 maintenance) limestone block walling (Figure 6-9) determine that a drainage conduit system, rather than a through flow system, may be appropriate (e.g.

megaflo). This is difficult to retrofit as the path needs to be lifted, conduits need to be installed landward of the concrete fill behind the wall, and outlets need to be drilled to establish a drainage path to the river. This is not presently considered a cost-effective approach. Instead, it is recommended that drainage be incorporated in the design of the walling renewal.

Capital works

The foreshore has experienced (in general) progressive lowering of the river bed in the southern areas, with consequent increased stress on the river walling. Further progressive lowering should be expected to occur, unless the walling is modified. Bed lowering and structural degradation have both contributed to maintenance cost increases. The access for reliable maintenance funding from the City of Subiaco should be acknowledged within the design principles. Walling should be designed using appropriate design criteria, for resilience to changing bed conditions and have an acceptable allowance for ongoing maintenance.

The capacity of any capital works to enhance existing pressures should be clearly recognised and incorporated into design, most particularly those which may increase seabed lowering.

Some design elements that may improve resilience when determining long-term capital works are listed below, along with their associated objectives.

Design Element	**Objective**
1. Limit riverward extension	Limit river bed lowering due to structure
2. Use inclined wall to reduce wave effects	Limit river bed lowering & reduce overtopping
3. Increased walling embedment	Greater resilience to river bed lowering
4. Incorporate flexible scour toe	Greater resilience to river bed lowering
5. Move path away from walling	Improved maintenance & drainage capacity
6. Raise wall crest level *	Greater resilience to overtopping & inundation
7. Manage drainage for the foreshore surface	Greater resilience to overtopping & inundation
8. Increase walling permeability	Greater resilience to overtopping & inundation
9. Design for fully saturated foreshore	Greater resilience to inundation

* Although raising the wall level is an appropriate method to improve resilience to overtopping and inundation, it is challenged in this case by the low foreshore level. Water that accumulates behind the wall will drain, either downwards or horizontally across the walling. Increasing the wall level reduces the incidence of flooding, but increases the capacity to trap water under an exceedance event and reduces horizontal drainage, typically transferring flow along the wall to low points. This effect is typically offset by incorporating a surface drainage system within the walling. Downwards drainage may be enhanced through the ground treatment, such as gravel, including improved wall permeability.

Three walling options have been considered for discussion here, with only the limestone block walling costed for these segments in Section 6.2:

1. Limestone block walling;
2. Build revetment riverward of the existing walling. This is only discussed in this section and neglected as an option for the recommended works for this section of foreshore; and
3. Build revetment, retaining the (toe) position of the existing walling.

Partial retreat of the foreshore to incorporate pocket beaches is also discussed.

Option 1 is for an inclined limestone block wall. This would address resilience design elements (1), (2), (3), (4), (5), (7) and (9). The inclined wall would be a gravity wall structure, compared to the present single block wall. The wall would require a scour toe, sufficient embedment and drainage to landward. Shifting the path landward will increase the capacity to undertake maintenance work on the walling and to encourage drainage capacity through use of a broad splash zone and gravel infill. In general, an inclined limestone block wall is a less resilient structure than a revetment as it lacks self-stabilising mobility. As the inclined wall is similar to the existing walling type, there is capacity to construct it to landward and it can easily transition with the stairs, drainage and the boat ramp due to having a narrower footprint than a revetment. Removal of the existing walling has a high cost and should only be undertaken when required (i.e. failure has occurred).

Option 2 is presently an option considered by the City of Nedlands to the south, and if pursued by CoN will require consideration for connection to JH Abrahams Reserve walling. The placement of a rock revetment riverward of existing walling addresses resilience design elements (2), (3), (4) and (9). The practice of building in front of existing walling effectively defers future disposal costs, and limits the capacity for a revetment to act as a permeable structure. It is not recommended for this section of foreshore as there is capacity to retreat to landward, and the extension of the structure riverward will enhance scour at the toe. If this option is pursued it is recommended to further consider:

- Sufficient embedment of the rock revetment, with potential inclusion of a scour toe, in areas with a deeper bed (see Figure 6-7 and Figure 6-10 for indicators of bed level differences);
- Implications of the new riverward position, particularly if the wall is constructed in sections. This may enhance the rate of bed lowering and transfer erosion stress to different parts of the foreshore;
- Potential actions to improve management of overtopping or inundation waters (e.g. surface drainage, or improving permeability through the remnant wall) (expected);
- The practicalities and relative costs of maintenance for this specific type of revetment landward of the remnant wall compared to a standard 2-layer revetment;
- Drain extensions; and
- Length and detail of transitions needed to tie-in with existing walling and drains.

Option 3 holds the position of the existing wall toe, with retreat of the upper foreshore through excavation to allow for an inclined revetment to extend landward. This would address resilience design elements (1), (2), (6), (7), (8) and (9). This option may also be pursued by the City of Nedlands to the south. The structure would require a broad splash zone and subsurface drainage. Between the revetment crest and the path, the broad splash zone could incorporate a swale behind the splash zone or a wide revetment crest with smaller rocks to landward. This would also require careful transitions to existing nodal locations, such as the stairs, Nedlands jetty, the Water Corporation drains and the boat ramp.

<u>Transition</u>

The southern section of the JH Abrahams Reserve walling requires a transition with the steps, the Nedlands jetty and the renewal works undertaken in future with the City of Nedlands. It should be noted the preferred option for the City of Nedlands and its ratepayers is a rock revetment, and if the revetment is constructed riverward of the existing walling the toe will be located 5-7m riverward of the existing walling location. The transition between the two types of hard structures will require joint agreement between the City of Nedlands and City of Subiaco.

Pocket beaches or future foreshore retreat

The area where dredging was not undertaken (see shallow area in Figure 6-10) provides an opportunity for future foreshore retreat. Pocket beaches, constrained between headlands encompassing drains, are considered possible adjacent to the terrace as there is capacity for sediment exchange with the terrace, there is alongshore transport at the site and there is no land-use restriction immediately to landward. This will likely increase foreshore use in the area and could provide a direct connection with a future expanded adventure playground. Important considerations include the high cost of disposal of this excavated material, acid sulphate soil risk, beach maintenance and management of accumulated seagrass wrack.

East of Qantas boat ramp car park

Works to **increase foreshore resilience to erosion pressures** for the eastern car park walling, the walling in the kite surfing launch area and the small beach include:

- Caution with raising any of the walling (when the increased height of the walling increases wave reflection) or extending the toe of the structures further riverward as this will transfer erosion stresses riverward and increase the rate of erosion on the adjacent foreshores.
- Upgrade the structure toe as required should erosive trends continue. Walling may require reconstruction with a deeper toe embedment.
- Beach renourishment. Backpassing sediment from elsewhere on Pelican Point is a useful source of material to address the erosion adjacent to the reclaimed foreshore. Externally sourced sediment is likely to be required in future.
- Reducing focal areas of erosion associated with unmanaged surface runoff and trampling (to east of the extent of the walling).
- In the longer-term (>25 years), as the erosion pressures increase, it recommended to increase the hydraulic smoothness in this area. The corners of the walling could be smoothed and the low-wall constructed with an improved transition to the adjacent sandy foreshore as it retreats. Plans for retreat of the walling should be considered in the longer-term. Renourishment with externally sourced material is also likely to be required.

Works to avoid

Some options were not considered due to **decreasing the resilience** of the broader foreshore. This includes:

- Planting of tall trees across the foreshore. This is partly because private property owners may vandalise the trees if river views are restricted. The main reason this is not recommended immediately adjacent to the walling is that the tree roots will cause localised damage due to piping of water. This increases the local regrout maintenance required.
- Planting of vegetation riverward of the walling, such as previously recommended in 2003, because the reflection and bed level fluctuations would cause sedge death.
- Extending toe of walling further riverward.
- Boat ramp upgrades as this will contribute to further erosion of the foreshore east of the boat ramp car park. Also increased boat use of the area may lead to enhanced scour.
- Raising walling level east of Qantas boat ramp as this will transfer erosion stresses riverward and increase the rate of erosion on the adjacent foreshores when the increased height of the walling increases wave reflection.
- Extending walling east of Qantas boat ramp as this will continue to increase the rate of erosion into the Marine Park.
- Works to trap sediment, such as a groyne, in the area adjacent to the Qantas boat ramp walling as this will decrease the hydraulic smoothness and transfer the erosion stress into the Marine Park.

- Investment in interactive paths or platforms on southern Pelican Point due to the migratory and unknown evolution of this foreshore. Any tourist or educational infrastructure should be located inland of anticipated migratory landforms or be stumped with sufficient embedment to tolerate erosion.

6.2.2. Works for Each Segment

Potential risk mitigation, management pathways and adaptation strategies are presented for each segment linked to time-frames of 0-5 years, 5-25 years and >25 years (Table 3-1). The shortest timescales consider the present state of the foreshore and sensitivity to acute events. The medium-term timescales consider foreshore dynamics, life-cycle of existing stabilising structures and increasing foreshore resilience. For time-frames greater than 25 years there is uncertainty related to future management choices and longer-term process variability. Scenarios possibly affecting the foreshore are considered at this scale in the context of improving resilience where possible.

The foreshore management and adaptation sequences are presented for each foreshore segment in Appendix C.6 (Table 12-14 to Table 12-16, with two options for SRCra06). Each table includes:

- A foreshore management goal, capital works and maintenance requirements for each of the three timeframes.
- Requirements for monitoring linked to identification of maintenance requirements, refining budgets and triggering foreshore management actions and adaptation.
- Details of issues to be resolved, and works to be avoided, to ensure the recommended management sequence may be achieved.
- Simple cost estimates (Appendix B) for capital works, maintenance works and a 25-year total with no future cost adjustments.

A summary of the foreshore management goals for the three timescales for each segment is provided in Table 6-2.

It should be noted that other than the Water Corporation drains, three local drains and some power services in the Nedlands jetty car park there are no key services located within the foreshore reserve based on a Dial Before you Dig query.

Table 6-2: Summary of Management Goals for each Segment in the City of Subiaco
Detail for each segment is included in relevant tables in Appendix C.6

Segment (Table with detail in Appendix C.6)	**Short-term (risk management) for 0-5 years**	**Medium-term (planning) for 5-25 years**	**Long-term (strategy) for >25 years**	**25-year cost. Not indexed (2015 costs)**
SRCra05 Matilda Bay Reserve Look out (Table 12-14)	Maintain existing walling and beach position as long as possible. Allow foreshore on Pelican Point to retreat.	Maintain existing walling and foreshore use as long as possible. Allow foreshore on Pelican Point to retreat.	Partial retreat of walling, improve hydraulic smoothness. Ongoing retreat of foreshore on Pelican Point.	≈$350k

Segment (Table with detail in Appendix C.6)	**Short-term (risk management) for 0-5 years**	**Medium-term (planning) for 5-25 years**	**Long-term (strategy) for >25 years**	**25-year cost. Not indexed (2015 costs)**
SRCra06 JH Abrahams Reserve – Option 1 Hold the Line Scenario (Table 12-15)	Maintain existing walling as long as possible.	Reconstruct walling as a limestone block gravity wall, or equivalent, with deeper embedment. Move path landward.	Hold line with inclined walling. Loss of permanent beach in many areas. Eventual retreat.	≈$2M
SRCra06 JH Abrahams Reserve – Option 2 Partial retreat and pocket beaches (Table 12-16)	Maintain existing walling as long as possible.	Create sections with pocket beaches. For remaining, reconstruct walling as a limestone block gravity wall, or equivalent, with deeper embedment.	Maintain pocket beaches and walling. Eventual retreat of remaining walling.	≈$2.75M

6.2.3. Ongoing Monitoring Requirements

It is recommended that the City of Subiaco organise the following ongoing monitoring to plan and review requirements for foreshore maintenance, management and adaptation triggers. The information included in Table 6-3 is a council-wide summary of the information in the tables within Section 0.

Table 6-3: Monitoring Requirements for City of Subiaco

Monitoring technique	**Spatial coverage**	**Frequency**
1.1 **Inspections of the face of walling** (walk in water). (i) Pre-wall upgrade: 6- to 12-weekly inspection and tapping path to hear if any hollows. Check damage around drains. (ii) Following sections of replaced walling: Post-event and annual inspections. (iii) Long-term: Post-event and twice-yearly inspections.	All hard walling in SRCra05 and SRCra06	Pre-wall upgrade: 6- to 12-weekly. Post-wall upgrade: post-event and annual.
1.2 **Tabulate maintenance records** undertaken **at JH Abrahams Reserve** on the grout, walling, path, infill of gravel to landward (post-replaced walling) and drain bar excavation (Water Corp.), including dates and details of the works. If **pocket beaches** are constructed also note the renourishment rates, seagrass wrack accumulation, beach reworking and seagrass wrack clearance.	JH Abrahams Reserve (SRCra06)	When works are undertaken.
1.3 Tabulate records of works undertaken adjacent to **Qantas boat ramp car park** on walling maintenance and renourishment rates, including dates and details of the works.	Hard walling and foreshore area 250m east of car park (SRCra05)	When works are undertaken.
1.4 Following sections of replaced walling, undertake **inspections of gravel levels** landward of the walling.	Sections of replaced walling in JH Abrahams Reserve (SRCra06).	Post-event and 12-weekly

Monitoring technique	Spatial coverage	Frequency
1.5 **Photos at 50m intervals** from upstream to downstream	Whole CoS managed foreshore starting in Parks and Wildlife area 500m E of car park.	Annual in December/January.
1.6 **Photos of beach widths** at fixed locations to identify seasonal variability, renourishment and adaptation requirements.	Fixed locations at car park in SRCra05 facing E to monitor beach and in SRCra06 at headlands if pocket beaches constructed.	Monthly.

6.2.4. Implementation and Management Summary (0-5 years)

A council-wide summary of the capital and maintenance works recommended for the first five years of management are included in Table 6-4. This summarises key information in the tables within Section 0. Further detail is included in the segment-specific tables (Table 12-14 to Table 12-16). Monitoring recommendations are included separately in Table 6-3 and are not costed in the table below.

Table 6-4: Implementation Summary for City of Subiaco (1-5 years)

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
Year 1	None required	$0	3.1 **Regrout** focal areas including near tree roots and drains in JH Abrahams Reserve walling.	$7.5k
			3.2 **Clear sand bar at Princess Rd drains** and sand accumulated within the drains (≈monthly near neap tides). Transfer to N.	Water Corp. in-kind
			3.3 **Maintain path** adjacent to walling in JH Abrahams Reserve	Separate CoS budget item.
			3.4 **Maintain infrastructure above walling** east of Qantas boat ramp in SRCra05	Separate CoS budget item.
Year 2	2.1 **Walling reconstruction for S 50m walling at JH Abrahams Reserve** OR 2.1 **Walling maintenance for S 15m**	$220k (exc. Works on car park and steps) OR $60k (exc. Works on car park and steps)	3.5 **Maintenance of main drains** (.D01, .D03 in Table 12-12) and 5m of damaged wall N of .D01. Regrout wall to the toe (sand excavation), address slumping, lifted path and cracked pipes.	Water Corp. in-kind
			3.6 **Maintenance for CoS drains** (.D05, .D06 in Table 12-12). Includes repairing pipes, regrouting wall, D06 footing repair. Regrout only if planning on upgrading wall.	~$7k (Unknown)
			3.7 **Clear sand bar at Princess Rd drains** and sand accumulated within the drains (≈monthly near neap tides). Transfer to N.	Water Corp. in-kind
			3.8 **Maintain path** adjacent to walling in JH Abrahams Reserve	Separate CoS budget item.
			3.9 **Maintain infrastructure above walling** east of Qantas boat ramp in SRCra05	Separate CoS budget item.
			3.10 **Beach renourishment** in kite surf launching area with material excavated from RPYC, approximately 420m^3. Harvest material accumulated in RPYC around the groyne.	~$7k

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
Year 3	None required	$0	3.11 **Address undermined toe** of JH Abrahams Reserve walling by excavating bed, cement grout under toe (lowest summer tides) and rebuild a small rock toe. ≈50m walling, depends on timing of walling renewal.	*≈$15k for 50m.*
			3.12 **Clear sand bar at Princess Rd drains** and sand accumulated within the drains (≈monthly near neap tides). Transfer to N.	Water Corp. in-kind
			3.13 **Maintain path** adjacent to walling in JH Abrahams Reserve	Separate CoS budget item.
			3.14 **Regrout** walling east of boat ramp **in SRCra05**	~$7.5k
			3.15 **Maintain infrastructure above walling** east of Qantas boat ramp in SRCra05	Separate CoS budget item.
Year 4	None required	$0	3.16 Patching of gaps in blocks for **groynes** at JH Abrahams Reserve.	*$3k + in kind-labour*
			3.17 **Clear sand bar at Princess Rd drains** and sand accumulated within the drains (≈monthly near neap tides). Transfer to N.	Water Corp. in-kind
			3.18 **Maintain path** adjacent to walling in JH Abrahams Reserve	Separate CoS budget item.
			3.19 **Maintain infrastructure above walling** east of Qantas boat ramp in SRCra05	Separate CoS budget item.
Year 5	None required	$0	3.20 **Regrout** walling. Includes removing grout and reapplication of M4 grade with smooth finish. Dig up path and refill to landward with gravel as needed.	*$25k assuming no path excavation.*
			3.21 **Clear sand bar at Princess Rd drains** and sand accumulated within the drains (≈monthly near neap tides). Transfer to N.	Water Corp. in-kind
			3.22 **Maintain path** adjacent to walling in JH Abrahams Reserve	Separate CoS budget item.
			3.23 **Maintain infrastructure above walling** east of Qantas boat ramp in SRCra05	Separate CoS budget item.

6.2.5. Works Dependencies

Some management and adaptation works should only be undertaken once another management task has been undertaken. The main works dependencies within CoS include:

- Walling upgrade in in JH Abrahams Reserve in SRCra06 requires decision on if pocket beaches will be pursued before final design and works commence;
- Drain upgrades and renewal should wait until plans for walling or walling and pocket beaches are confirmed for JH Abrahams Reserve in SRCra06. Timing of drain upgrade should link to timing of required drain renewal;
- Walling upgrade in JH Abrahams Reserve in SRCra06 requires transition and consideration of works to be undertaken in northern City of Nedlands;
- Feasibility of pocket beaches will require some reuse of excavated bank material as costs of disposal of old dredged material is approximately 2/3 of project cost; and

- Securing the sediment in and adjacent to RPYC for use in ongoing backpassing operations.

Many maintenance and capital works recommendations in Table 12-14 to Table 12-16 and Table 6-4 require certain issues to be resolved or certain works to be avoided. The segment-specific tables (Table 12-14 to Table 12-16) should be consulted for this information as many works are dependent on these issues being resolved or specific works being avoided.

The staging of capital and maintenance works is broadly outlined in the segment-specific tables and for the first five years in Table 6-4. It is recommended the City of Subiaco prepare a Gantt chart to allocate their own prioritisation of works and works dependencies. This chart could be updated when a management decision (e.g. creating a new recreation node) alters the broader management plan. Works prioritisation will be linked to funding availability and the Gantt chart should be revised annually following the budget allocation.

7. City of Nedlands

Information for the foreshore managed by the City of Nedlands is separated into two sections and Appendix D, all focused on the 11 segments of foreshore (Figure 7-1; Table 2-1). The first section (7.1) provides context for recommended management, vulnerability and a previous consideration of possible interventions (BMP 2009). The second section (7.2 and Appendix D.6) provides a discussion of possible interventions and more detail on the preferred foreshore management and adaptation sequences and plans, including tables per segment noting maintenance and capital works that could be undertaken in the short-, medium- and longer-terms.

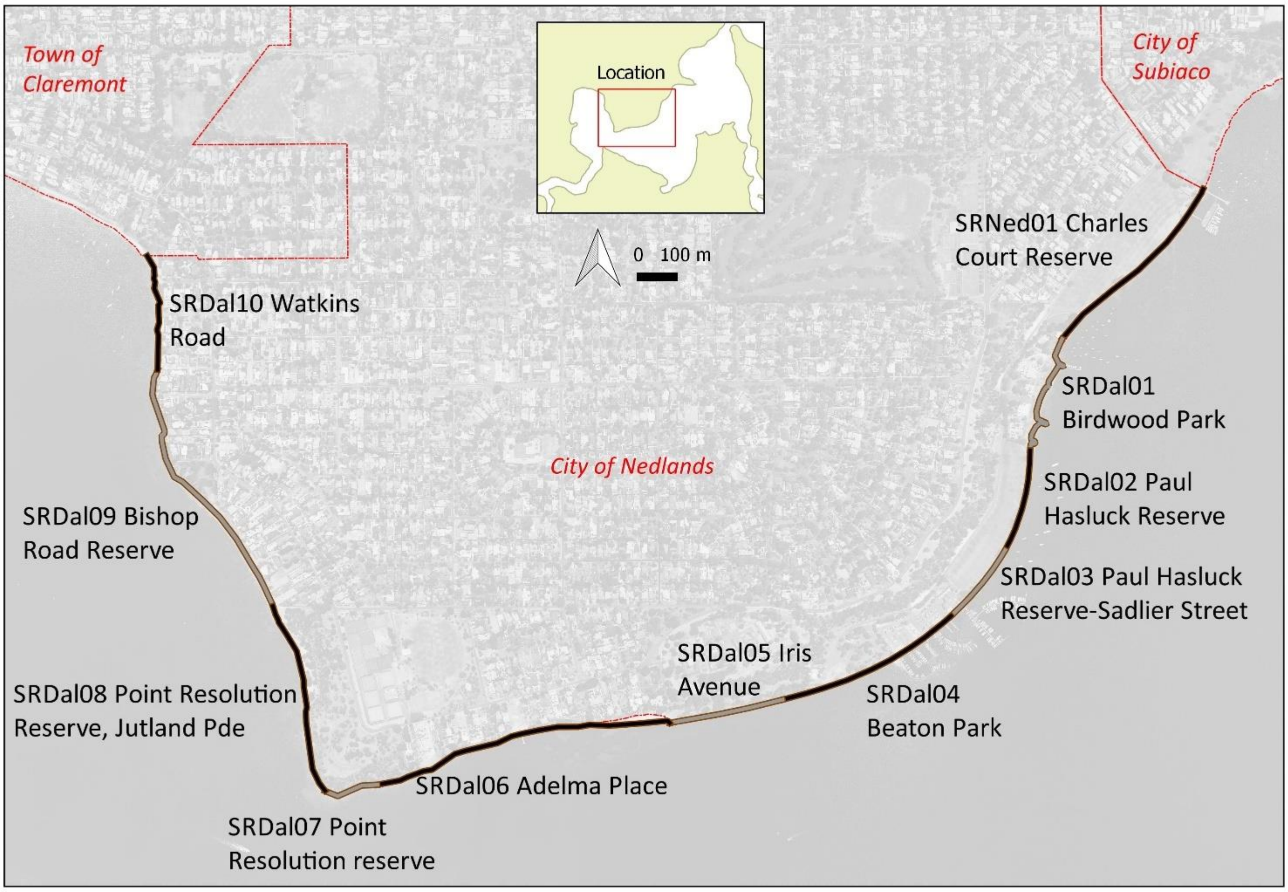

Figure 7-1: City of Nedlands Segments

The foreshore management plan for the City of Nedlands is presented in Section 7.2 with detailed recommendations per segment in Appendix D.6. Six of the 11 segments correspond to the walled foreshore, which is approaching the end of its life in many areas. The focus is maintaining the existing use for as long as possible, replacing the worst sections with a longer-term solution and fencing failing areas until scheduled works can be undertaken. The preferred option for this foreshore is a rock revetment with a smooth continuous alignment. It is recommended to remove the existing walling and construct slightly landward of the existing walling with considerations of staging and transitions required. Resilience can be improved through inclusion of a scour toe, splash zone at the crest and deeper embedment. In areas with private property interactions along Jutland Parade and Victoria Avenue it is recommended to encourage neighbouring private property owners to develop collective long-term plans, with consideration of safety and access, and for the City to develop more detailed planning controls and guides. The cliffed foreshores of Point Resolution Reserve require short-term management to address safety concerns and in the medium- to longer-term prevention of foreshore access. Maintenance and renewal of northern Charles Court Reserve will require joint planning with the City of Subiaco. Management of the foreshore at Watkins Road will require joint planning with the Town of Claremont management of the foreshore at Mrs Herberts Reserve.

7.1. CONTEXT AND VULNERABILITY

7.1.1. Process Overview

Segments SRNed01, SRDal01 to SRDal03 (Jojos to PFSYC)
This foreshore is modified with dredging, reclamation, walling and yacht clubs. A net northwards alongshore sediment transport for much of the foreshore is seasonally reversed during strong easterlies. However, construction of Perth Flying Squadron Yacht Club (PFSYC) in 1969 has effectively prevented ongoing sediment supply to the north, producing net erosion and bed-level lowering adjacent to the walling. This direction of transport is further suggested by downdrift erosion, apparent on the north side of Nedlands Yacht Club (NYC). There was a lag between the last renourishment adjacent to the walling (possibly 1969) and the loss of an ongoing sediment supply to the north as pulses of sediment migrated along the walling.

Ongoing erosion is expected for the beaches within NYC with sediment transported to the north and offshore to the dredged areas.

The dynamics of the Nedlands Foreshore are complicated by the presence of a low level rock shelf near Jojos that provides a perched beach structure, which is seasonal in character.

A separation point in the direction of sediment transport suggests that erosion along Nedlands foreshore is expected to be progressive. This has been enhanced through the provision of near-vertical walling, which causes wave reflection, and dredging in close proximity to the walling. A wholescale lowering of the terrace is expected for this area, with reduced stress in the area of rock platform.

Segments SRDal04 to SRDal07 (Royal Flying Squadron Yacht Club to Point Resolution)
This length of foreshore has been heavily modified, with extensive reclamation undertaken along its eastern section, private property infrastructure in the middle section and steep slopes with remnant quarrying in the western section. The main tidal channel arcs close to shore along Dalkeith foreshore, producing an interaction between current and wave-driven sediment transport. A net westwards wave-driven transport is locally countered to cause Armstrong Spit to develop (now dredged) and produce a tendency for erosion near Iris Avenue.

The greatest foreshore stress is apparently produced where the tidal channel is close to shore along Edward Bruce Park. This marks the end of the reclamation walling and has been a persistent zone of erosion. The small beach west of Iris Avenue is expected to progressively erode, which may require further extension of the revetment structure.

The walling between Royal Flying Squadron Yacht Club and Iris Avenue is under stress due to exposure to high-energy waves, local dredging adjacent to the walling, wholescale lowering of the terrace and blockage of the local sediment supply from Armstrong Spit due to dredging (1936 and 1969).

Private property walling will continue to add erosive pressure to adjacent foreshores through interruption of hydraulic smoothness and reduced sediment availability for the cross-shore balance for variations in foreshore sediment demand.

The area adjacent to point resolution has a supply of material from the sub-tidal rock platform and eroding cliffs and steep banks.

Segments SRDal08 to SRDal10 (Point Resolution to northern extent of Dalkeith)
Prevailing wind conditions and available fetches suggest that there is potential for a clockwise transport of sediment from the north to Point Resolution. Local variations in shore alignment suggest a tendency for erosion near Waratah Place and accumulation in the three dune areas north of Point Resolution. These patterns are matched by steep bathymetric contours with rock features for the “erosive” locations; with flatter grades for “accretionary” zones. A sand spit is not present at Point Resolution, which suggests that the rate of sediment transport due to currents is greater than the wave-driven alongshore sediment transport.

The small pocket beaches between Claremont and Point Resolution have limited sediment supply. Consequently, they may be expected to respond to seasonal patterns of accretion and erosion. The low topography of these beaches makes them subject to inundation.

Private property walling will continue to add erosive pressure to adjacent foreshores through interruption of hydraulic smoothness and reduced sediment availability for the cross-shore balance for variations in foreshore sediment demand.

7.1.2. Previous and Existing Plans

The existing management plans for the City of Nedlands foreshore is covered by a series of six reports (URS 2013b; MP Rogers & Associates 2013, 2015; City of Nedlands 2013, 2014; Golder & Associates 2015). A further report prepared in 2003 also contains useful information for foreshore management (Damara WA 2003). The reports cover:

- Walling;
- Cliffs; and
- Point Resolution Reserve and Bishop Road Reserve.

No information was included in these reports on management actions required along the foreshore with HWM private property or a narrow foreshore reserve with private property to landward along Jutland Parade and Victoria Avenue.

The **walled sections** (SRNed01, SRDal01 to SRDal05) between Nedlands jetty and Iris Avenue (URS 2013b, MP Rogers & Associates 2013, 2015). The URS study provided guidance for future foreshore stabilisation options along the length and was used to obtain funding support from Parks and Wildlife. The preferred option for most of the foreshore is a rock revetment with that treatment released for public comment and a submission to the Minister of Indigenous Affairs. A concept design for a rock revetment has been prepared for use in Beaton Park (SRDal04 and SRDal05) which extends the revetment riverward of the existing concrete panel walling (MP Rogers & Associates 2015). The feasibility of replacing some walling with pocket beaches was investigated by MP Rogers & Associates (2013) with a scope of considering beaches that are exposed to wave action, rather than Mediterranean-style beaches which are more sheltered from incident wave energy. An all abilities playspace has been approved for installation at Beaton Park (SRDal04) landward of the walling.

City of Nedlands and Parks and Wildlife have a collaborative agreement for Nedlands River Wall Foreshore Restoration. This has resulted in a broad plan for selection of the treatment type (URS 2013b) and a concept design for the first area of replacement revetment (MP Rogers & Associates 2015). The replacement of the walled section in parts of SRDal04 Beaton Park and parts of SRDal05 Iris Avenue been agreed in Riverbank project P16NL01 Nedlands Riverwall Foreshore Restoration Implementation Year 1, which included a project plan, designs and funding arrangement for a rock revetment. Any future works as part of this plan should consider:

- Accounting for different forcing associated with large dredge areas immediately adjacent to foreshore. Additional reinforcement likely required in these areas.
- Overall bed level lowering riverward of walling (since 1960s) has resulted in many structures demonstrating insufficient embedded. Works to consider future bed lowering in design.
- Works to consider any future dredging expansion associated with yacht club expansions/operations.
- Tying in different types of walling required to be undertaken with hydraulically smooth transitions.
- Locating vertical walling in areas of sediment transport deficit is likely to place the structures under additional stress.
- Investing in high value path infrastructure immediately above or landward of walling will require ongoing maintenance funding commitments.

Management actions for **cliffs** in the City of Nedlands was prepared in a recent study by Golder & Associates (2015). This includes stabilisation at the toe for some of the cliffs.

Management plans for the **natural areas** of foreshore, in particular Point Resolution Reserve and Bishop Road Reserve are described in documents prepared by the City of Nedlands (2013, 2014). This includes recommended revegetation and bioengineering at Point Resolution with annual maintenance of previous rehabilitation efforts (City of Nedlands 2014). The broader *Natural Areas Management Plan* (City of Nedlands 2013) provides particular information related to foreshore access, with existing pathways to be maintained, beach fencing to be maintained every 18 months and for geotechnical surveys to be undertaken at the cliffs every 5 years. These plans do not discuss the possibility of allowing the steep foreshores to erode and restricting access to the foreshore at Point Resolution Reserve.

In the *Foreshore Assessment and Management Strategy* (SRT 2008) the section of foreshore from the City of Subiaco border to Point Resolution Reserve was identified as a moderate priority, priority 2, in terms of urgent investment in foreshore stabilisation works. The main recommendations for the foreshore were to consider appropriate stabilisation works and develop a plan for monitoring and maintenance of structures, with a lower priority for addressing inundation and identifying mechanisms for sourcing funds to support maintenance works. The section of foreshore from Point Resolution to the Claremont Cliffs (half in the Town of Claremont) was identified as a low priority, priority 3, in terms of urgent investment in foreshore stabilisation works. The main recommendations for the foreshore were to address the likelihood of increased flooding and inundation in prone areas and undertake renourishment where appropriate.

Any plans that incorporate hard structures in the Nedlands walling area (SRNed01, SRDal01 to SRDal05) should consider the conditions suggested by the Minister of Indigenous Affairs which were recommended to be adhered to throughout the project and during construction (referred to in URS 2013b). This was not made available for the present study. Any revised plans recommended in this study should be referred to the Minister under a Section 18 notice.

The constraints to future works as a result of previous and existing plans are:

- Walled foreshores:
    - Approved plans of rock revetments as replacement for existing walling with concept design of revetment extending further riverward. Further consideration is required for transitions between stages of works and the alongshore variability of the design due to varied erosion stress including bed level lowering;
    - Feasibility study of pocket beaches was not requested to consider Mediterranean style beaches which may be suitable for certain areas of foreshore;
    - Location of recently upgraded concrete coping above walling in SRDal05 restricts the capacity to monitor and maintain voids behind the walling;
    - Maintenance plans for concrete walling to consider previous maintenance undertaken in terms of transferring erosion stress;
    - Existing drains within the walling;
    - Agreement required with City of Subiaco regarding any modification to car park, stairs and walling at northern end of Nedlands Foreshore Reserve 1 Reserve;
    - Jojo's/Acqua Viva expansions;
- Existing drainage from steep foreshores;
- Yacht club expansions or modifications;
- Unconstrained pedestrian access;
- Plans to protect eroding foreshores in natural areas rather than consider allowing retreat. Bioengineering, used at Point Resolution, could be incorporated as part of a managed retreat strategy. Limiting pedestrian access along the foreshore at Point Resolution may be required;
- The legacy of development of private properties along the foreshore of Jutland Parade and Victoria Avenue. Existing and future developments on private property are a constraint for future management and provision of pedestrian access along the foreshore; and
- Joint management with Town of Claremont required for works at Watkins Road.

7.1.3. Historic Works

The initial condition of the City of Nedlands foreshore included a broad, low elevation, and vegetated sandy and swampy foreshore to the east, as well as a steeper foreshore abutted by sandy beaches in the west. The main separation point is located at the limestone cliffs, outcrops and rock platforms of Point Resolution. The foreshore was a common feature adjoining terraces, rocky platforms and sandy shoals that were partially exposed during low tides; these shoals provided sediment exchange to the beaches along the length of the foreshore. Modifications have been undertaken over time for purposes such as navigation, quarrying of construction materials at Point Resolution, beautification, recreation, camping, boat launching, yacht club use, as well as various modifications performed by private property owners.

Extensive modifications were undertaken from 1936 to 1938 between the old Nedlands baths and Iris Avenue, including dredging close to shore to create a smooth walled foreshore. The reclamation was undertaken to reduce mosquito breeding and the accumulation of sewage from Perth, and to allow the future construction of the Perth to Fremantle Road. Further modifications have been undertaken for yacht club expansions, recreation, and walling upgrades, resulting in a reclaimed foreshore that is 20-120m riverward of the pre-reclaimed foreshore. The dredged channels and foreshore walling have discontinued the onshore supply of sediment along most of the walled foreshore.

This section should be read in conjunction with Section 2.3.1 which includes a summary of how environmental regulations and management practices across the river have changed over time.

An overview of some changes and issues in the City of Nedlands are included in Figure 7-2. Key changes in relation to foreshore management are listed in Table 7-1 with context provided through aerial images of 1953, 1965, 1983, 2014 per segment (Figure 12-27 to Figure 12-36). Bioengineering and revegetation works have not been included. Further historic images are included in Section 7.1.5. Additional maintenance work undertaken on the walling is noted in Section 2.2 of the URS (2013b) condition assessment study.

Further information on structure designs and drawings were not available for this project. For the preparation of any concept and detailed designs it is recommend to review the documents listed in Section 2 of the URS (2013b) condition assessment study.

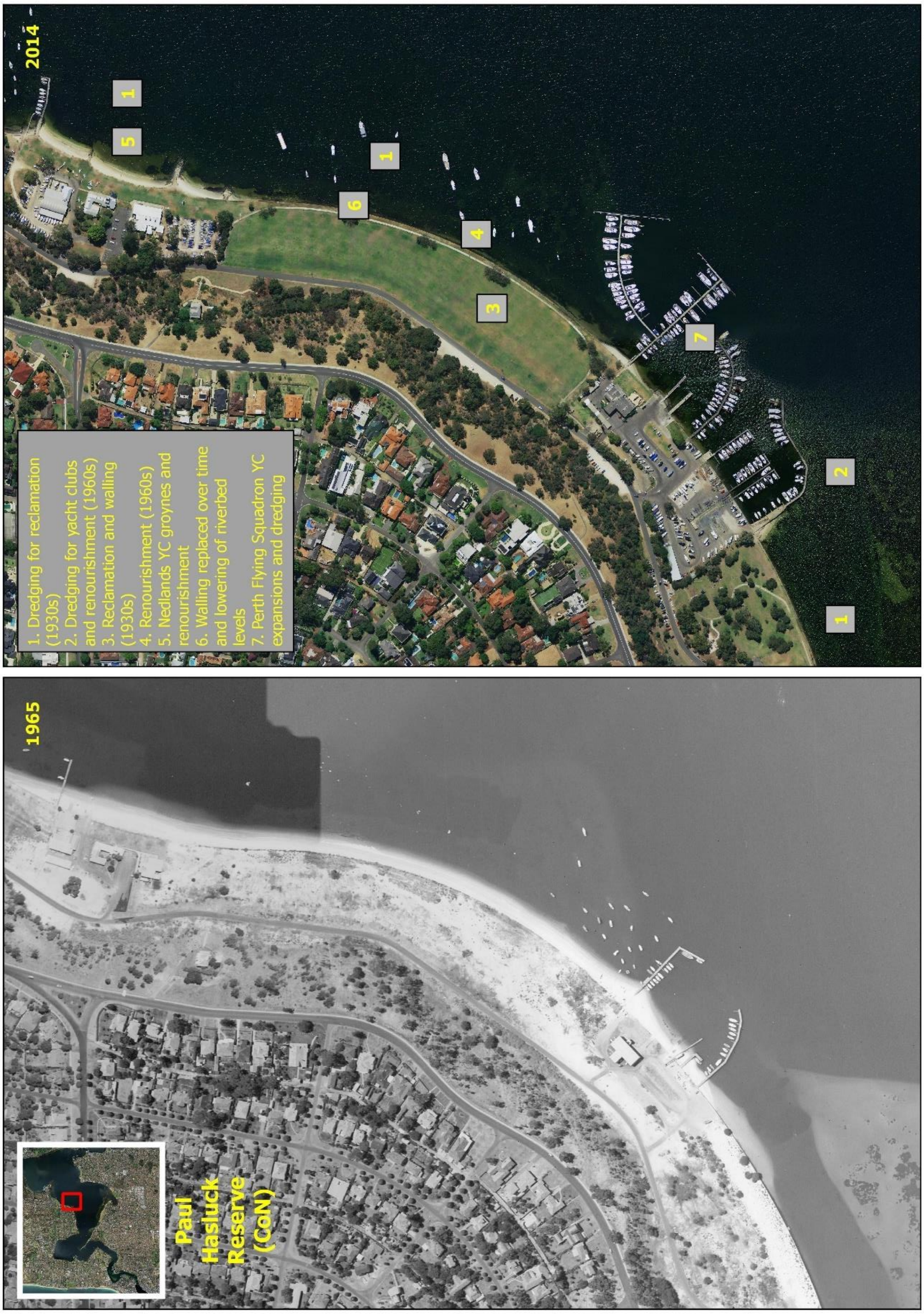

Figure 7-2: Some issues and modifications for Paul Hasluck Reserve

Table 7-1: Historic modifications relevant to present-day foreshore management (excluding maintenance listed in URS 2013b)

Segment	Modification	Date
SRNed01 Charles Court Reserve	Reclamation of the whole foreshore with 10-130m reclamation and a further 100m of fill to raise levels. Retained by walling with 3 drains extended to river. Local dredging.	1935-1936
	Limestone block wall on concrete toe. Shotcrete application	1940s 1990s
	Car park sealed Car park expanded with no consolidated drainage	Pre-1965
SRDal01 Birdwood Park	Reclamation of the whole foreshore with 50m reclamation and a further 70m of fill to raise levels. Retained by walling (replaced ≈1960s). Local dredging.	1935-1936
	Reclamation, renourishment with groynes extending 3-18m riverward	1959
	Groynes (N to S): 36m 10m encasing drain 36m Stub groyne (tyres) 13m Boat ramp	 1970, 1981, 1983-1995 (jetty) 1995-2003 1991 1983-1995 1993
	Renourishment (assumed more undertaken)	1959 1995
SRDal02 Paul Hasluck Reserve	Dredging adjacent to shore for whole length, widening towards downstream, with walling. Local dredging	1936
	S section of inclined wall replaced with vertical limestone block wall	2009
SRDal03 Paul Hasluck Reserve-Sadlier Street	Wholescale reclamation with walling (wall for whole segment length with one small patch of vertical limestone walling). Local dredging.	1936
	Boat ramp (10m)	1983
	Concrete block groyne (16m), damaged and bypassing	1995
SRDal04 Beaton Park	Wholescale reclamation with walling. Local dredging and interruption of Armstrong spit.	1936
	Armstrong spit for altered PFSYC and navigability, jetties	1969
	Groyne (45m) covered in shotcrete Boat ramp (10m)	1970 1983
SRDal05 Iris Avenue	Wholescale reclamation and local dredging. Retained with walling.	1936
	Downstream extent has roughly constructed limestone groyne	
SRDal06 Adelma Place.	Remnant jetties (small groynes) along much of this foreshore. Still providing some control.	Pre-1953
	HWM private wall extending riverward, with ongoing modifications.	Pre-1953 originally

	Reclamation (30m) at upstream end, with walling and groyne. Local dredging.	1936
SRDal07 Point Resolution reserve	Quarrying of limestone	Pre-1920s
	Old plans for dredging (no confirmation)	
	Stairs	Pre-1965
	Bioengineering	2011-2012
SRDal08 Point Resolution Reserve, Jutland Pde	Old convict camp bath	Historic
	Bioengineering	2014
SRDal09 Bishop Road Reserve	Private property erosion mitigation structures	Pre-1965 for property with garden, then progressive expansion.
	Bishop Road Reserve access	Pre-1953
SRDal10 Watkins Road	Private property erosion mitigation structures	1965-1974 in the S, with progressive expansion.
	Extension of Watkins Road to lower foreshore	≈1974, consolidated 2004/2006. Foreshore stabilisation works 2015.

7.1.4. Site Issues and Constraints

Details of issues and constraints for the 11 segments in the City of Nedlands are included in Table 12-17 and Table 12-18 (Appendix D.2). This is in addition to some further broader issues of:

- Resourcing for future works. This is addressed for part of the CoN foreshore, with a collaborative agreement now raised with Parks and Wildlife for the six upstream segments.
- Stakeholder conflict in the reclaimed sections of foreshore covered by the collaborative agreement (SRNed01 to SRDal05). Conflicts include requirements to minimise sedimentation at PFSYC, NYC and at Jojo's pens; with wanting to ensure sufficient embedment of walling and maintaining a beach at NYC. Holding the position of the reclaimed foreshore with walling is a high long-term expense, yet shifting the walling to landward will generate conflict with the Rugby club and other users of sporting reserves, as well as the yacht club operations, Tawarri and pedestrians. It is assumed pedestrians would like a continuous path along the foreshore where possible. It is understood there is a desire to maintain walling in many locations along this foreshore. See comments below for future works.
- Stakeholder conflict in the remaining foreshore area relates to private property owners, City of Nedlands and recreational users having different views on appropriate foreshore use. The most likely ongoing conflict is continued foreshore access between Iris Avenue and Mrs Herberts Park (Town of Claremont).
- Sections with High Water Mark private property ownership. This creates stakeholder conflict between the private property owners and the City of Nedlands, particularly in areas where partial resumption of the foreshore reserve has occurred. Further information is provided below.
- Lower foreshore is still responding to previous dredging along the upstream segments of SRNed01 Charles Court Reserve to SRDal05 Iris Avenue.
- Any works that will create new or altered longshore controls require consideration of wider impacts.
- Stability of cliffs and steep slopes is a concern along the foreshore from Point Resolution to Bishop Road Reserve (SRDal06 to SRDal09). Bioengineering has recently been used to stabilise the cliffs. Erosion of cliffs and steep slopes provides a local source of sediment for the beaches and

foreshores. However, unstable cliffs are a safety concern due to public use of the foreshore between Bishop Road Reserve and Point Resolution Reserve.

- Stormwater management from the car park in the north (SRNed01 Charles Court Reserve) and the roads landward of the downstream segments (SRDal09 Bishop Road Reserve and SRDal10 Watkins Road). This is also relevant to areas with uncontrolled runoff from cul-de-sacs and areas with steep foreshore access.
- Capacity for sandy foreshores to migrate landward restricted in areas with walling within the hydraulic zone.
- Walling in sections within SRDal01 Birdwood Park, SRDal03 Paul Hasluck Reserve-Sadlier Street and SRDal05 Iris Avenue is approaching the end of its functional life.
- Uncontrolled access to the foreshore is contributing to erosion, runoff scour and also to the formation of blowouts (and loss of sediment from the beach) for the segments around Point Resolution (SRDal06 Adelma Place, SRDal07 Point Resolution reserve, SRDal08 Point Resolution Reserve, Jutland Pde).
- Stabilising blowouts along SRDal08 without harvesting the sediment is a missed opportunity for obtaining a source for renourishment on adjacent eroding sections of foreshore.
- Future population pressure for path along foreshore connecting Iris Avenue to Mrs Herberts Park (Town of Claremont).
- Indigenous approval discussions required for any dredging or renourishment works, including harvesting sediment from southern Dalkeith foreshore (SRDal08 Point Resolution Reserve, Jutland Pde).
- Changing far-field forcing of boat wakes.

<u>Liability for erosion mitigation when ceding and vesting HWM Private Property (Section 5)</u>
Ceding and vesting, part or all of, the foreshore reserve along Jutland Parade and Victoria Avenue with the City of Nedlands may create ongoing issues related to erosion mitigation on adjacent private properties with an unclear definition of liability for damages or conducting management works.

The riverward portion of privately owned land is presently ceded along the foreshore during the subdivision process. The ceding process is that WAPC transfers the property to the State of Western Australia under the Transfer of Land Act (TLA), then the Department of Lands take the property out of the TLA and create it as a reserve under the Land Administration Act (LAA), and then the management order is issued to the City of Nedlands, with the land vested with the City of Nedlands. Section 152 of the *Planning and Development Act 2005* and the *Land Administration Act 1997* includes provision for this vesting of privately owned land. This is supported by the Parks and Wildlife Policy SRT/EA2 on Foreshore Reserves. A management order may only be issued over land reserves, or a lease is established by the City for a set period. This enables the WAPC to provide Area Assistance Grants. However, a lease is only issued on the basis that a management order will be established following expiry of the lease. Area Assistance Grants are only available for capital upgrades to properties leased or with a management order held by the City of Nedlands. Grants for capital works, not maintenance, may be up to $500,000 at an individual site provided over 5 years (maximum of $100,000 per year) based on a 50% contribution by WAPC and 50% by the City of Nedlands.

Once a section of foreshore reserve has been ceded from a private property along Jutland Parade or Victoria Avenue (and adjacent cul-de-sacs) and a management order is provided to the City of Nedlands, the City will essentially be responsible for erosion mitigation structure for the private property to landward. Funding for erosion mitigation structures on private property is not permitted under Government grants through the Parks and Wildlife Riverbank program (under the *SCRM Act 2006 and Guidelines 2007*). Therefore, any base structure constructed by Parks and Wildlife/City of Nedlands (e.g. for a path[1]) would seem to provide erosion mitigation to private property landowners at no cost to the owners as the base structure would be on publicly owned land. As the landowner or land manager of a foreshore lot is responsible for maintenance this would also mean the City of Nedlands is responsible for both maintenance of the path and erosion mitigation structures.

At present, the foreshore reserve of each lot will progressively be ceded by the WAPC (if any property is subdivided) and possibly leased by the City of Nedlands or the City may be provided a management order. Consideration of tie-ins of erosion mitigation options between properties will be required with some situations with co-contribution by private property owners and the City of Nedlands. The land manager of the publicly owned property (City of Nedlands or WAPC) is not likely to be responsible for the costs of providing erosion mitigation for the private property to landward, protecting private property adjacent along the foreshore or damage to erosion mitigation structures on adjacent land as erosion is occurring due to natural processes. It is unclear on who is responsible for maintaining erosion mitigation structures constructed prior to resumption of the land. Further legal advice should be sought on this topic.

The present situation is that WAPC will continue to cede land and vest it with an LGA through the subdivision process (Section 5). WESROC should consider its position with respect to this policy and if deemed appropriate, liaise with LGAs along the Swan and Canning Rivers and WALGA to collectively approach the Department of Parks and Wildlife Rivers and Estuaries Division, the Minister for Planning and the WAPC to review this approach of vesting land along narrow or eroding foreshores. This is recommended in the context of potential ongoing costs for the City of Nedlands, Town of Claremont, Town of Mosman Park, Parks and Wildlife and the WAPC.

The subdivision process often reduces foreshore access and in many cases results in construction of assets closer to the shore. This is relevant for the foreshore along Jutland Parade and Victoria Avenue for maintenance of erosion mitigation structures. Historic access to the lower foreshore has been restricted by the continued housing developments. Often when a house was demolished a retaining wall was placed on the foreshore, and the house was constructed closer to the river encompassing more of the block width without sufficient foreshore access for machinery to undertake maintenance on the retaining walls. Future maintenance costs may incur a surcharge related to obtaining access to the foreshore.

7.1.5. Observed Change

The City of Nedlands foreshore is presently responding to previous reclamation works at the northern and southern extents of broad bays, including walling, dredging and renourishment, in conjunction with drainage and surface runoff. In addition to these anthropogenic changes, it is also responding to inter-annual variability of naturally occurring processes, including winds, water levels and sediment supply.

[1] If a piled-boardwalk was constructed for a path in future it would not provide erosion mitigation for the private property owners to landward. It is assumed capital and maintenance funding would continue to be required from the private property owners for erosion mitigation structures. There would likely be increased cost due to access constraints provided by the presence of the boardwalk. Further advice is required to determine who is responsible for erosion control works if a boardwalk abutted a private property boundary.

The foreshore has been separated into two sections, one that is fronted with walling and another containing all remaining lengths of foreshore. This separation facilitates ease of discussion around the processes and interactions that are occurring at each of these sections. These sections include the following segments:

- Nedlands walling section (SRNed01, SRDal01 to SRDal05)
- Nedlands remaining foreshore (SRDal06 to SRDal10)

Observed changes are discussed on the basis of this section separation.

<u>Nedlands walling sections (SRNed01, SRDal01 to SRDal05)</u>

- Reclaimed and walled foreshore. Sections of wall replaced with time with grouted limestone block wall on large concrete footing replaced with precast concrete panels (same footing).
- Loss of beaches, bed level lowering adjacent to structures. Lowering of foreshore occurring in response to reflection from walling, dredged areas adjacent to walling and cessation of many original sand feeds (dredged through spits/bars). Figure 7-3 demonstrates the amount of sand on foreshore in 1970 with NYC in the foreground and Jojos in the background.
- Many beach/bed levels fluctuate seasonally. Artificial beach at NYC is sustained by renourishment.
- Overtopping.
- Loss of material through the structure.
- Addition of shotcrete transferring erosion stress to the bed as loss of material restricted through the structure.
- Ongoing backfill occurs behind sections of walling.
- Toe of walling now at insufficient depth due to bed level lowering. Many sections of concrete panel walling approaching end of functional life with limestone block walling sections still functioning (toe upgrade required).
- Transition at downstream end is a source of ongoing erosion stress.
- Infrastructure investment landward of walling limits capacity to retreat.

<u>Remaining Nedlands foreshore (SRDal06 to SRDal10)</u>

- The position of the beach at the reclaimed foreshore's western end (Iris Avenue) fluctuates seasonally. This beach covers a broader alongshore section of foreshore than in the 1950s and 1960s.
- Along Jutland Parade many private jetties have been removed. Sediment loss has occurred in the west, with sediment accumulation to the east. This accumulation is impounded against the groyne holding the reclaimed foreshore in place. Subdivision has occurred along this length of foreshore, creating the need for more erosion mitigating structures to protect the increased number of houses along the eroding western end.
- Trampling by pedestrians and surface runoff from paths is creating erosion pressure in Point Resolution Reserve. Sediment from the beach on the western facing shore is lost to a series of three blowouts associated with pedestrian access locations.
- Ongoing retreat of the lower foreshore is evident at Point Resolution reserve, particularly in areas adjacent to the cliffs and on the southern side, with recent mitigating actions including bioengineering.
- Property subdivision is occurring along Victoria Ave, between Point Resolution Reserve and Bishop Road Reserve, which is resulting in increased housing closer to the foreshore. This is reducing the capacity for the foreshore to respond to naturally varying conditions.

- Net retreat of the foreshore is occurring along Victoria Avenue between Waratah Place and Watkins Road. Private property subdivision has occurred, and some newer houses are located closer to the river. Surface runoff from roads is contributing to local erosion, along with the transfer of erosion stress due to privately owned erosion mitigation structures.
- Private property walling continues to add erosive pressure to adjacent foreshores along Jutland Parade and between Waratah Place and Watkins Road, particularly those that extend riverward.
- Continuous foreshore access for pedestrians from Iris Avenue to Watkins Road is now only achievable during low tide.

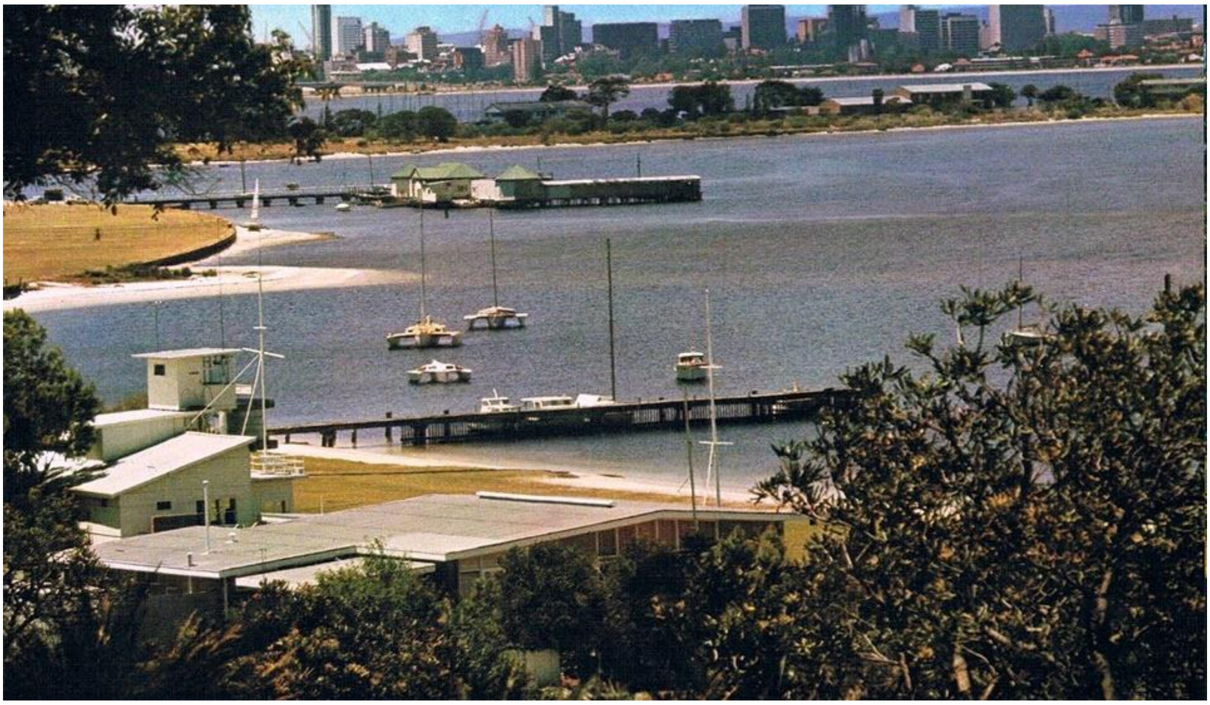

Figure 7-3: Nedlands foreshore 1970 (Reference unknown)

7.1.6. Structure Condition and Function Comparison

Previous assessments of structure condition and function have been used in preparation of the foreshore management and adaptation approach for City of Nedlands. The details of the 2004 and 2014 assessments are included in Appendix D.3 with tables of structure condition and short-term maintenance comments in Appendix D.4. Drains were only assessed in 2014 if they were contained within other foreshore structures.

7.1.7. Foreshore Controls and Sensitivities

The foreshore controls and sensitivities for the City of Nedlands foreshore include:

- Modified foreshore. Dredged areas adjacent to walling sections (Figure 7-4) limit the capacity to return to historic gentle grade foreshore (Figure 7-5; Figure 7-6; Figure 7-7). Location of dredged areas and rock substrate to be considered in future plans. The location and influence of historic walling controls the walling performance, for example the historic jetty siding (seen in Figure 7-7 in 1933) is still a part of structure SRDal03 Paul Hasluck Reserve–Sadlier Street.B01 (Figure 12-53; Figure 12-54 in Appendix D.7) and an area of poor condition.
- Walled sections are sensitive to bed lowering, future loss of material to dredged areas and wave reflection from walling. Previous works (shotcrete) have caused focusing of erosion at, and under, the wall toe.

- Public resistance to landward migration of the walled foreshore due to existing foreshore uses (rugby club pitches, Tawarri function centre, yacht clubs and general public recreation).
- The eastern extent of the reclaimed walling section provides fixed control for the foreshore to the west, adjacent to private properties on Jutland Parade.
- Any replacement walling along the walled section will be low-elevation as it is impractical to raise elevation of fill areas to landward.
- Path directly above walling in the western portion of the walled section obscures identification of voids behind the walling.
- Walling, or other erosion mitigation structures, requires adequate tie-ins and transitions or the focal erosion will occur at the points of transition.
- Irrigation adjacent to walling contributes to local damage and failure.
- Potential acid sulphate soils to landward of parts of the walled section.
- Surface runoff, linked to increased development along the Jutland Parade and Victoria Avenue foreshore, is impacting negatively in this area. This includes managed runoff at Waratah Place and Adams Road as well as unmanaged runoff along low points in paths on Point Resolution Reserve. Paths include those in Bishop Road Reserve, at Bishops Road, Adams Road (overflow) and Watkins Road. Further erosion from unmanaged runoff is occurring at private properties along Victoria Avenue between Bishop Road and Watkins Road, which also includes burst and exposed irrigation or drainage pipes.
- Steep banks and cliffed areas are controlled by, and are sensitive to, the characteristics of the banks (ie strength of foreshore material), the quantity of sand or talus at the toe of the cliffs/banks, groundwater, surface water modifications from land use above and focal drainage pathways. Structures placed at the toe of steep banks to reduce local damage can transfer stress to adjacent foreshores with increased local safety hazard.
- Underlying rock platforms limiting the capacity for excavation if wanting to place structures.
- Position and type of existing erosion mitigation structures on private property, or resumed riverward portions of private property, can transfer erosion stress to adjacent properties. Future works on Jutland Parade and Victoria Avenue are limited by adequate foreshore access and works undertaken by adjacent landholders.

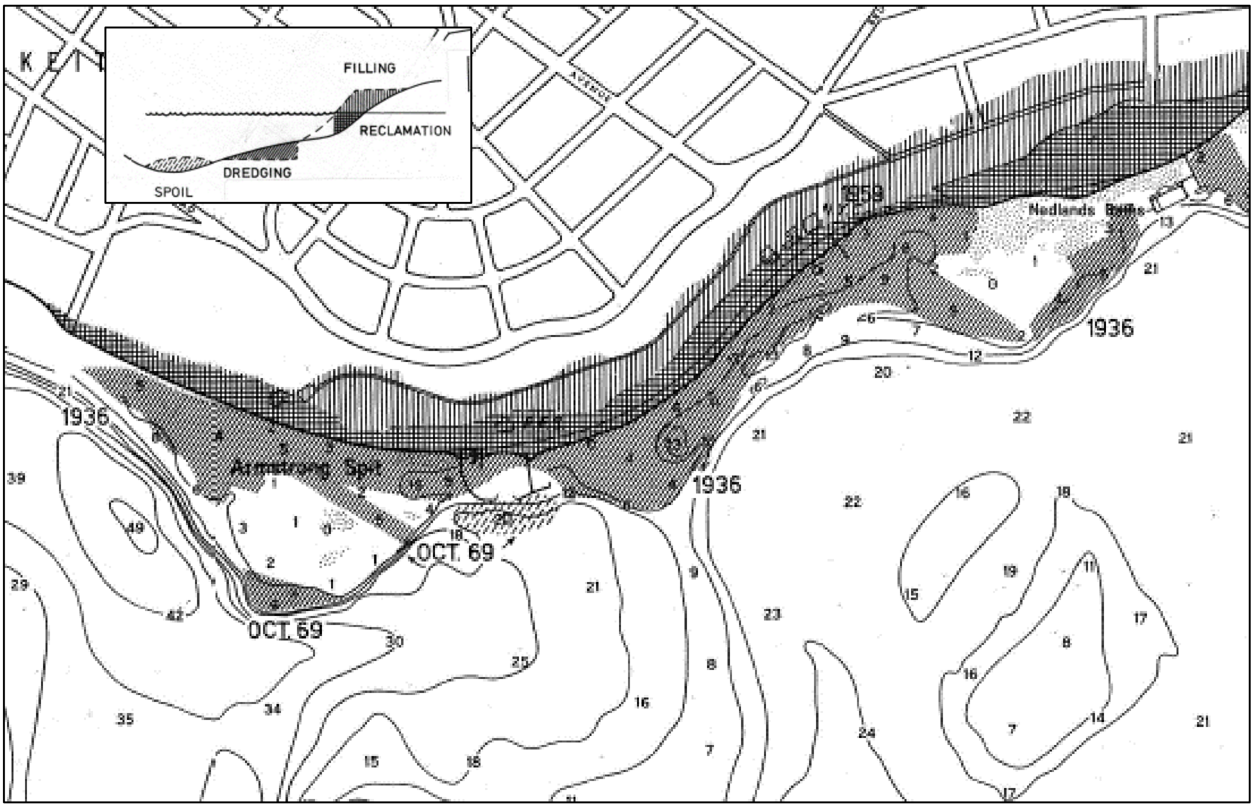

Figure 7-4: Historic Dredging and Reclamation to 1978 (extract PWD 41264-06-01)

Figure 7-5: Nedlands foreshore overlooking Jojos (Nedlands baths) in 1920 (Lund and SLWA)

Figure 7-6: Nedlands foreshore near Armstrong Spit in 1922 (Lund and SLWA)

Figure 7-7: Nedlands foreshore overlooking the jetty and Nedlands baths in 1922 (Lund and SLWA)

Figure 7-8: Nedlands foreshore overlooking Nedlands jetty in 1933 (Lund and SLWA)

Nedlands Walling (SRNed01, SRDal01 to SRDal05)
The walled foreshore between Nedlands jetty (Jojojs/Aqua Viva) and the groyne at Iris Avenue is comprised of four broad structure types including concrete panel walling (Figure 7-9), groynes (Figure 7-10), inclined limestone block walling (Figure 7-11) and vertical limestone block walling (Figure 7-12). Photos of the structures are included in Appendix D.7. Existing wall levels are shown in Figure 7-13, demonstrating dredged areas on 1965 imagery in Figure 7-14 and compared to topographic and bathymetric levels in Figure 7-15.

The walling is retaining a reclaimed foreshore with erosion stress transferred to the toe, at structure transitions and to the west of the terminal groyne into Adelma Place (SRMos06). All of the walling is subject to inundation which requires some management of overtopping immediately to landward.

The alignment of the existing walling along Nedlands foreshore was created in 1935-1936 to retain dredged material. Walling existed in small areas before this time for jetty landings (e.g. Figure 7-8). The initial 1935-1936 walling failed because of insufficient embedment (source Trove newspaper articles 1940s), which may have been subsequently replaced with the grouted limestone block wall on a large concrete toe with small scour toe (Figure 7-11) or concrete panel walling (Figure 7-9). Some sections of old walling were replaced in the early 1980s with concrete panel walling on the existing concrete toe (Figure 7-9). The addition of the groynes and renourished beaches at Nedlands Yacht Club was through a process of gradual upgrades, with the first groyne constructed to the north in 1970, two other groynes added in 1991 and a disabled boat ramp installed in 1993. The groynes are constructed of loose limestone rock with tractor tyre cores infiled with sand.

Ongoing maintenance is undertaken on the walling, often reactive to damage or failure. Shotcrete was applied along most sections of the walling in 1996, transferring erosion stress to the join between the panel and the large concrete base. A section of concrete panel walling was replaced with vertical limestone block walling (part SRDal02) in 2009 without upgrading the structure toe, which transfers erosion stress to the toe. The groynes were upgraded in 1997, with shotcrete previously applied that was neither comprehensive nor strategic. General walling maintenance has included infilling of voids landward of the structure with granular fill or concrete, infilling cavities behind the concrete panel walling with geotextile lined sediment, shotcrete and replacement of failed panels with grouted rocks.

Foreshore structure and drain replacement and maintenance requirements provides one of the greatest foreshore sensitivities for the CoN. As many sections of the walls are approaching the end of their structural life, if adequate maintenance is not undertaken it may lead to failure, which can transfer erosion stress. The timing of maintenance should be assessed in relation to anticipated timing of walling replacement. Tables of the condition and potential maintenance of the separate wall sections and most drains were prepared by Damara WA (2015) for Parks and Wildlife at a broad scale (Table 12-20 and Table 12-21; Appendix D.3), with condition also assessed by URS (2013b). Some of the information has been refined for consideration of the moderate to longer-term vulnerabilities and planning requirements (Section 7.2). It has been refined based on further information obtained from CoN regarding maintenance work undertaken since 2003 (URS 2013b) and the revetment concept plan (MP Rogers & Associates 2015) for SRDal04/SRDal05.

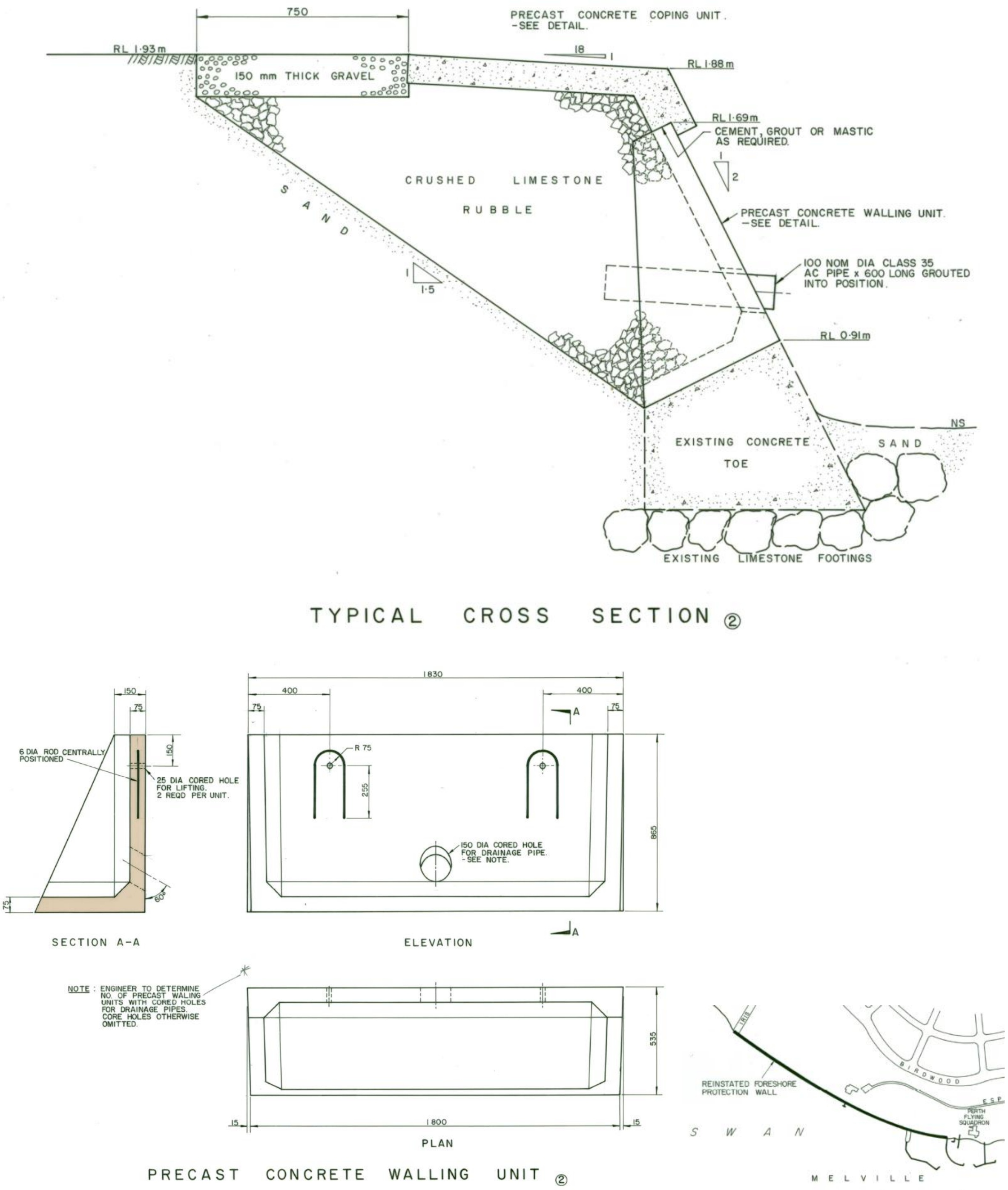

Figure 7-9: Example of concrete panel walling, in place from PFSYC to Iris Avenue (PWD 1982)

Figure 7-10: NYC with groynes and beaches riverward of old walling

Figure 7-11: Inclined limestone block walling north of NYC with concrete panels on old footings

Figure 7-12: Section of new vertical limestone block walling constructed on existing footings

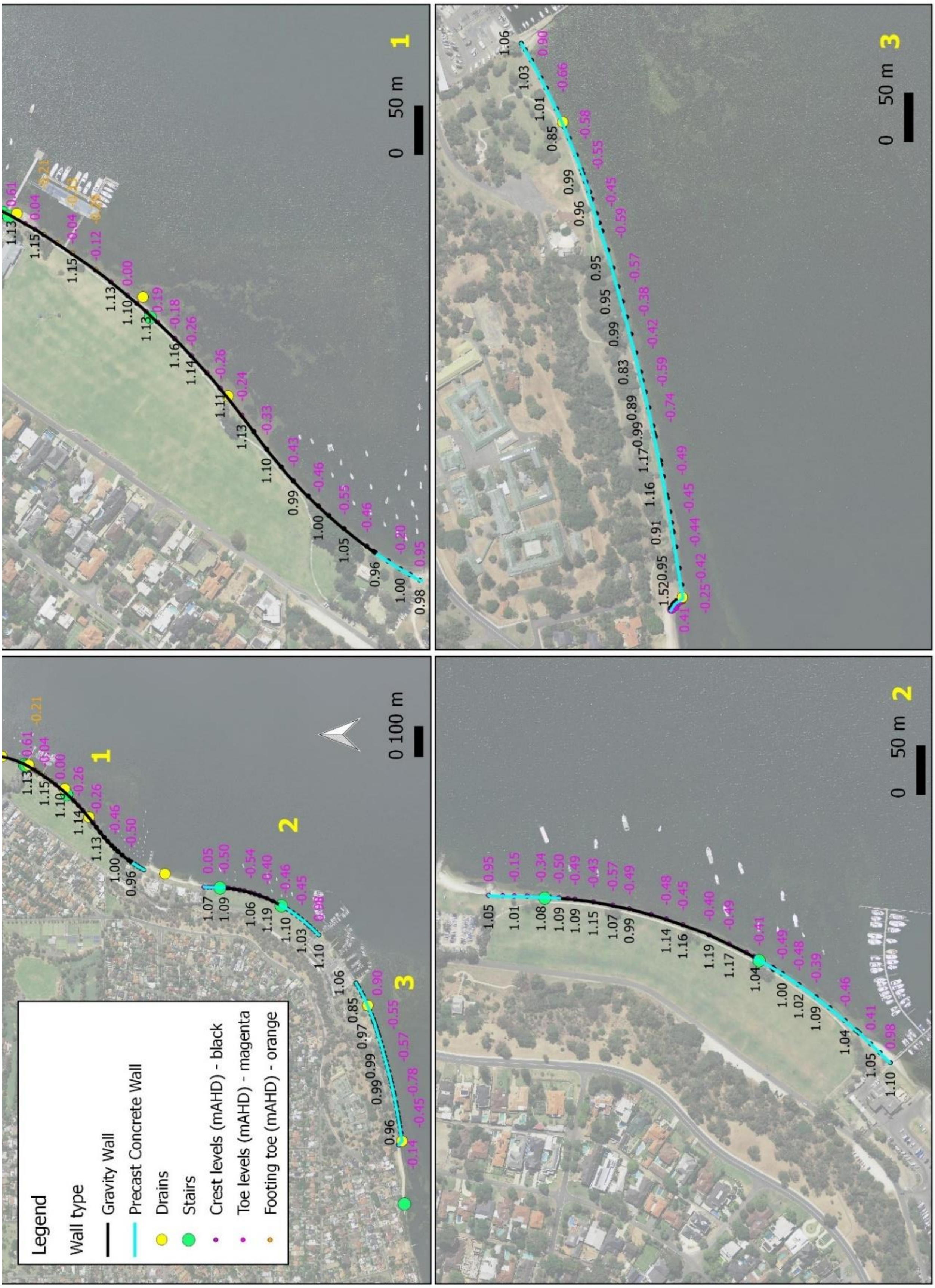

Figure 7-13: Nedlands Walling Levels - January 2015 (on 2014 image)

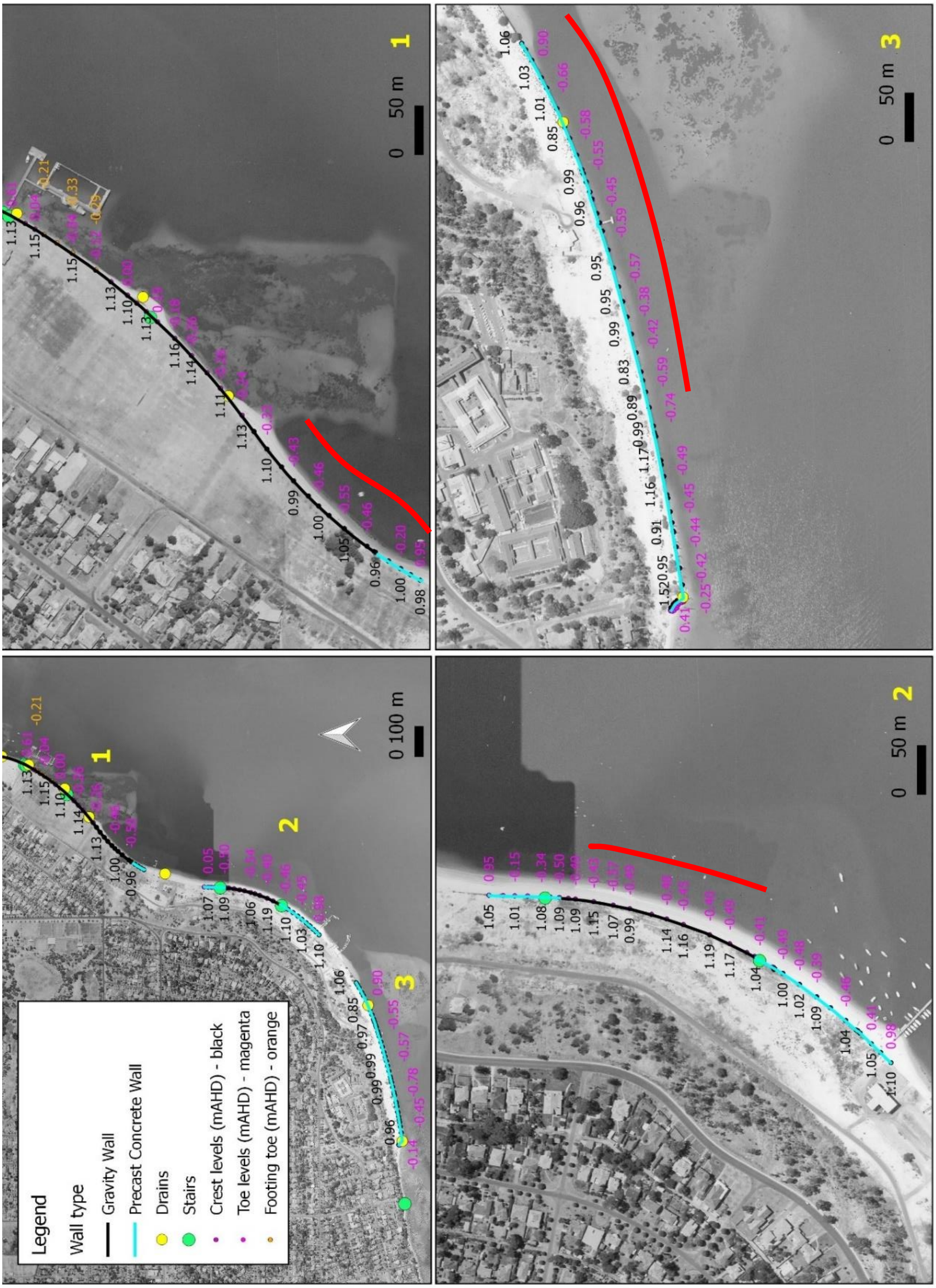

Figure 7-14: Nedlands Walling Levels - January 2015 (on 1965 image)
Red lines indicate dredged areas close to shore. This does not include 1969 dredging at PFSYC.

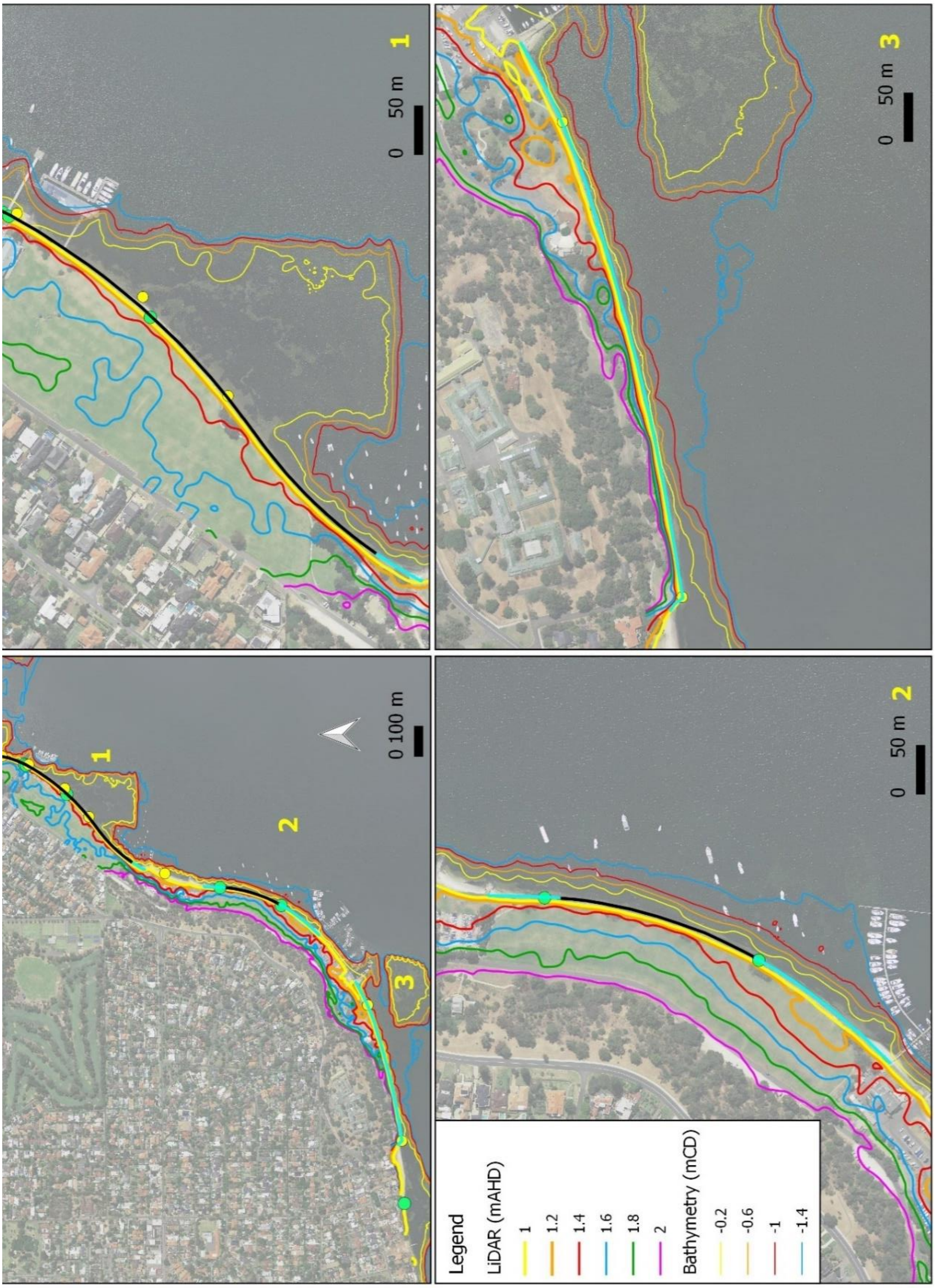

Figure 7-15: Topography and Bathymetry near Nedlands Walling

7.1.8. Scenarios and Impacts

The scenario at present is:

- Continued stress at structure toe along Nedlands walling section with loss of material under footing.
- Bed level lowering increases wave energy transmission to walling, increases reflection and feedback no further bed level lowering adjacent to walling.
- Ongoing failure of sections of concrete panel walling due to end of functional life (some built 1982).
- Wall overtopping during storm events.
- Continued degradation of aged walling on private properties, or resumed sections of private properties, along Jutland Parade and Victoria Avenue.
- Ongoing local erosion stress associated with drain scour and unmanaged runoff from low points in paths and from roads.
- Ongoing local erosion stress due to trampling.
- Sediment loss from the beach on western Point Resolution Reserve in the areas of pedestrian access.
- Ongoing erosion stress along western Jutland Parade and the south facing section of Point Resolution Reserve, with local stress enhanced adjacent to walling located further riverward.
- Continued narrowing of the foreshore around Point Resolution, with increased hydraulic activity at the base of the cliffs and rock outcrops.
- Ongoing erosion stress along the Victoria Avenue foreshore between Bishop Road and Watkins Road, with local stress enhanced adjacent to walling located further riverward and in areas of unmanaged surface runoff.
- Continued inter-annual discrepancy in onshore transfer of sediment, seasonal and net sediment transport.

The scenario of increased mean sea level could result in the potential responses outlined in Section 7.1.10 in the >25 year category.

A further scenario to consider is further expansion of yacht club jetties, pens and hardstand areas. Retreat will be considered, through use of pocket beaches, in areas of reclaimed foreshores not used as sporting fields.

7.1.9. Values and Foreshore Uses Considered (Short- and Long-Term)

The foreshore values and use for the Nedlands walling foreshore includes:

- Recreation landward of the walling includes the path, walking, rugby playing fields, play equipment, skate park, seating above walling, Tawarri, rugby club. There will be increased difficulty to maintain the playing fields in future if higher mean sea level due to increased ponding as a result of rising groundwater levels.
- No beach required riverward of walling, which is unable to be sustained.
- Nedlands Jetty and Jojos.
- Maintain boat pens at Jojos, NYC and PFSYC.
- Maintain boat launching facilities at yacht clubs.
- Maintain walling, and beach at NYC, for continued operations of yacht clubs.
- Maintain moorings, with likely pressure in future for further dinghy storage and launchings for moorings.

- Maintain lawn above structure.
- Transition to private property and beach to downstream to be considered.
- Minimise change.
- Drainage of parkland, Esplanade and car parks/yacht club areas.
- Whadjuk values of returning foreshore to more natural conditions with reduced walling.

The foreshore values and use for the remaining City of Nedlands foreshore (SRDal06 to SRDal10) include:

- Maintain access to the foreshore from car parks at access roads, the stairs at Point Resolution and the ramp at Bishop Road Reserve.
- Cliff stability from a safety perspective (Golder and Associates 2015).
- Recreation use which is general beach use and walking along the foreshore. The capacity to walk along the foreshore will require review in future due to the narrowing of the foreshore riverward of private property and cliff stability.
- Maintain walling, land, views, boat ramps, jetties and boatsheds for foreshores with HWM private property (SRDal06, SRDal09, SRDal10) or narrow foreshore reserves with private property to landward.
- Foreshore management should not defer erosion/inundation risks to local private property owners. Private property owners should not defer risk to the foreshore reserve.
- Maintain Bush Forever site 221 (SRDal06 to SRDal08), Point Resolution Reserve (A Class Reserve) and Bishop Road Reserve.
- Maintain European Heritage with site of quarry and convict camp at Point Resolution.
- Maintain significant trees, mainly on private property.
- Maintain dinghy storage/kayak launching near Watkins Road (SRDal10).
- Maintain access to Mrs Herberts Reserve foreshore at Watkins Road for private property owners. Alternate access routes to be considered as the long-term plan for improved foreshore resilience will be the retreat of this road.
- Drainage function to minimsie road flooding, with improvements required to reduce overbank flow.
- Whadjuk values of returning foreshore to more natural conditions with reduced walling.
- Consider ecological benefits of occasional seagrass wrack accumulation.

7.1.10. Vulnerability

Existing vulnerability (0-5 years)

Nedlands walling (SRNed01, SRDal01 to SRDal05)

The majority of the of walling would be inundated in a 10-year ARI still water level (+1.1mAHD) if no local wind setup, waves and no mean sea level shift (Figure 7-13). Inundation increases locally from wind setup and waves across Melville Water. Inundation increases during La Nina events due to an increase in mean sea level. Waves will contribute to scour of material under the structure toe, erosion through gaps in the walling and at the crest of the walling due to overtopping. Waves are 0.8m/0.9m to 1.0/1.1m H_s (3-year to 100-year), with large long-period boat wakes also occurring frequently at the site.

Toe exposure and undermining is occurring for many sections of the foreshore, leaving the structure vulnerable to damage and failure. Bed levels at the toe in many areas in the order of -0.4mAHD to -0.6mAHD and are generally inundated in most water levels. The bed level lowering that has occurred since the 1970s has resulted in the majority of the walling having insufficient embedment. Existing walling levels at the crest and toe/beach surface level (whichever was exposed) are shown in Figure 7-13.

Many sections of walling are approaching the end of the functional life, as described in URS (2013b) and in the structure assessments undertaken by Damara (2015; Table 12-20 in Appendix D.3). The segments with walling that may require replacement in the 0-5 year period is SRDal01 (immediately north of NYC), SRDal03 and the worst sections of walling in SRDal04 and SRDal05.

The present walling was designed when there was more sediment at the toe of the structures. Replacement structures will require sufficient embedment to sustain the increased hydraulic forcing associated with the bed level lowering.

The drainage pipes will require replacement through the length of the pipe as it was placed during the foreshore reclamation works in the 1930s. Breakage and leaking of these pipes promotes localised weakness in the walling.

Other sections of walling susceptible to damage are areas where:

- walling is adjacent to the deeper dredged sections with toe undermining;
- grout has eroded in the lower part of the structure for limestone block walling sections;
- insufficient stability at the toe;
- where shotcrete has transferred erosion stress to the toe;
- walling is adjacent to drains, particularly where drains discharge in the wall, or directly on the face;
- in areas where the structure was poorly built;
- where irrigation pipes and sprinklers are located adjacent to walling; and
- there are stairs.

Further vulnerability is associated with:

- drainage leaks;
- unmanaged surface runoff at Nedlands car park steps;
- A large storm event that scours sediment from under the structure toe;
- construction of any new structure that impedes alongshore sediment transport or extends further riverward than the existing structure; and
- inter-annual variability in the water level, wind and wave climate contributing to changing levels of sediment at the structure toe.

A further source of vulnerability is due to staging of the walling replacement with rock revetments. The tie-in areas have the highest susceptibility to damage, with adequate temporary tie-ins to be designed. If any new walling works extend further riverward, such as is planned for the replacement rock revetments, additional consideration is required for stabilising the toe of adjacent structures to account for transfer of erosion stress.

The beaches at Nedlands Yacht Club are susceptible to erosion, which is enhanced during periods of higher mean sea level.

Cliffed areas

Foreshore is sensitive to the overall loss of sediment and talus at the base of the steep foreshores which is likely to increase with possible mean sea level rise. Rates of slip failure and cliff collapse likely to increase with increased mean sea level rise. The cliffs and steep foreshores are vulnerable to local focused surface runoff in response to increased land use through paths, car parks and private property developments. Some sections of foreshore may require managed retreat.

Areas with HWM private property or private property landward of a narrow foreshore reserve
The vulnerability of the City of Nedlands to management difficulties at HWM private property or private property landward of a narrow foreshore reserve are outlined in Section 7.1.4 and Section 5. This includes issues to do with liability, transfer of erosion stress to publicly owned land and restricted public access in future. The increased density of development along Jutland Parade and Victoria Avenue will result in restricted access to the foreshore for maintenance of erosion mitigation structures, incurring a surcharge for maintenance to obtain access to the foreshore.

The foreshore along Jutland Parade and northern Victoria Avenue is sensitive to the overall loss of sediment on the lower beach, partly attributed to the influence of erosion mitigation structures, and narrowing of the terrace which is likely to increase with possible mean sea level rise. Undermining of structures is likely to continue with potential structural failure, with a greater reliance on more frequent maintenance. Flanking erosion is anticipated to occur adjacent to structures, with enhanced damage at the transitions between different mitigation techniques on adjacent properties. Many of the structures are vulnerable to damage or failure due to insufficient, or inappropriate, maintenance. Erosion due to overtopping has increased due to the narrowing of the foreshore.

Focal erosion occurs in the vicinity of drains, as well as due to overbank flow in other areas, such as at Bishop Road, Adams Road and Watkins Road. The recent bioengineering application at Watkins Road does not address the overbank runoff contribution to local erosion.

<u>Progressive change to vulnerability (5-25 years)</u>
It is expected that many sections of the walling will reach the end of its functional life during this time period. Drainage pipes will require renewal through the length of pipe simultaneously.

Some of the vectors for vulnerability described are likely to increase in magnitude. This will include increased:

- Erosion at the base of structures, through structures and due to flanking erosion adjacent to structures as the foreshore continues to respond to historic works. Erosion due to overtopping of low structures will also increase for some locations, particularly where the beach is narrowing.
- Runoff into drains, drainage pits and over the banks with less recharge in the catchment as density increases in the City of Nedlands This will result in increased scour at drains and in areas of unmanaged runoff.
- Rate of grout weathering.
- Bed level lowering adjacent to structures.
- Foreshore narrowing and raising for areas with beaches, which may include local blockages of drains.
- Continued loss of sediment and talus at the base of the steep foreshores, providing a safety hazard for pedestrians.
- Transfer of erosion stress at the tie-in areas following partial replacement of the existing structures.

The City of Nedlands foreshore is also vulnerable to any plans for works at the yacht clubs and at Nedlands jetty, as well as upgrades and improvements at private properties.

Scenarios for changing vulnerability (>25 years):
Longer-term planning considers the scenario of increased mean sea level. This could increase the foreshore vulnerability to:

- Increased bed level lowering and stress at structure toe along the Nedlands walling section, loss of material under footing, panel blowout, wall slumping and local collapse.
- Increased overtopping of Nedlands walling structures, loss of material behind structure or undermining of the path/coping immediately above the structure.
- Increased ponding and groundwater pressures on landward side of structure in reclaimed foreshore.
- Erosion enhanced at NYC beaches.
- Continued foreshore narrowing along Jutland parade foreshore.
- Increased cliff instability around Point Resolution and enhanced erosion on southern Point Resolution Reserve requiring restricted pedestrian access.
- Raising and landward migration of the storm bar along Victoria Avenue foreshore between Point Resolution Reserve and Bishop Road Reserve.
- Continued foreshore narrowing along Victoria Avenue foreshore between Bishop Road and Watkins Road. If northwards sediment transport is limited at Watkins Road due to foreshore narrowing and erosion mitigation works, it may lead to erosion of Mrs Herberts Park foreshore.

7.2. FORESHORE MANAGEMENT AND ADAPTATION SEQUENCES AND PLANS

The possible interventions for the City of Nedlands are described in further detail according to the vulnerability assessment time-frames linked to risk mitigation, management pathways and an adaptation strategy (Table 3-1). This information is presented for each segment (Figure 7-1), with a summary of scheduling, monitoring requirements for adaptation triggers and works summary for the 0-5 year time-frame provided for the whole LGA.

Initially, the decision-support framework was applied, according to the method described in Section 3.2 of SRT (2009), to refine which stabilisation techniques should be considered further. Details of this application is included in Appendix D.5.

7.2.1. Possible Interventions

Possible maintenance and capital works for the City of Nedlands foreshore are discussed in the context of improving resilience of the foreshore to erosion (chronic and acute), shifting mean sea levels, structure degradation, increased surface runoff and inter-annual variations in wind direction. Any interventions account for the foreshore response to historic works and management actions. Possible interventions are discussed on a spatial basis separated at Iris Ave, delineating the reclaimed wall section as separate from the remaining CoN foreshore, rather than applying generic principles across the CoN foreshore. This method of separation creates higher confidence in recommended interventions due to variations in historic modifications, land use, land ownership and exposure to hydrodynamic forcing.

The majority of the discussion focuses on the walled section of foreshore, covering segments SRNed01 and SRDal01 to SRDal05, as this section is managed by the CoN, with no joint management with private property owners. This walled section is also the area where there has been the highest investment in infrastructure for recreational use, and the area that will require the highest capital works expenditure for future erosion mitigation.

It is not considered feasible to maintain all of the existing uses across the broader CoN foreshore in the longer term, and it is recommended to consider future retreat in some areas, altered foreshore use in others, and increased investment in erosion mitigation for private property owners.

Nedlands Walling (SRNed01, SRDal01 to SRDal05)
Walling along Nedlands foreshore was originally built by the PWD through several phases of walling and reclamation. Management of the walling has subsequently been undertaken by the City of Nedlands. The City has actively maintained the walling through programs of filling and spot repair, which has significantly extended the structural life beyond its design, with a low operational cost but resulting in gradual structural degradation. Condition assessment and review of the walling has identified that the structural life of the walling has been exceeded and there is limited opportunity to extend it substantially through modification of the existing structures (Damara WA 2003, URS 2013b, MP Rogers & Associates 2015, and Damara WA 2015). All reviews conducted have indicated the overall need to replace many sections of the existing walling, in preference to modification and maintenance. However, financial constraints determine that it is unlikely to achieve replacement as a single work, and therefore short-term enhancement may be suitable where it can be achieved.

This guidance is applicable to both short-term enhancement and to longer-term treatment of the foreshore.

Design elements that need to be considered in both instances include:

- The structural integrity of the walling itself;
- Progressive deepening of the river bed, which has compromised the effectiveness of the wall to retain sediment;
- Implications of low foreshore elevation for material retention, including both overtopping and inundation.

Short-term enhancement and management
It is recommended to immediately fence off sections of walling that are failing to ensure public safety.

Actions to extend the structural life for less-compromised sections of walling should either focus on improving drainage to landward (reducing scour behind the wall) or providing an improved toe and scour toe (reducing undermining).

In some sections the life of the concrete panel walling can be extended by undertaking some maintenance works at the toe and backfill with geotextile, with further recommendations in the AMS (Damara WA 2015) tables included in Table 12-20 (Appendix D.4).

Jetting of concrete under the existing toe and installation of a rock scour toe may be useful for reducing the loss of material under the structure, but will require excavation again when pursuing the next option. These maintenance items require consideration in terms of expense in relation to timing of future works.

The effects of overtopping and inundation are considered relatively minor under present conditions, and where the walling is above +1.0m AHD, backfill using free-draining but erosion resistant material (e.g. gravel, possibly with geotextile) may continue to be cost-effective.

It is understood that ponding on the foreshore land is not considered an issue by the City, but the capacity of water accumulated landward of the wall to scour sections of the foreshore when it drains may ultimately require a more formal drainage system. The low level of the walling and the impervious nature of the concrete panel walling determine that a drainage conduit system is appropriate (e.g. megaflo). However, this is difficult to retrofit as it needs to be installed landward of the concrete panels, with disturbance of the existing panels (say every 5th panel) to establish a drainage path to the river. This is not presently considered a cost-effective approach.

Capital works

The foreshore has experienced (in general) progressive lowering of the river bed, with consequent increased stress on the river walling. Further progressive lowering should be expected to occur, unless the walling is modified. Bed lowering and structural degradation have both contributed to maintenance cost increases. The relative difficulty for obtaining reliable maintenance funding should be acknowledged within the design principles, say by using high design criteria and structures that are resilient to changing bed conditions.

The capacity of any capital works to enhance existing pressures should be clearly recognised and incorporated into design, most particularly those which may increase seabed lowering.

Some design elements that may improve resilience when determining long-term capital works are listed below, along with their associated objectives.

Design Element	Objective
1. Limit riverward extension	Limit river bed lowering due to structure
2. Use inclined wall to reduce wave effects	Limit river bed lowering & reduce overtopping
3. Increased walling embedment	Greater resilience to river bed lowering
4. Incorporate flexible scour toe	Greater resilience to river bed lowering
5. Move path away from walling	Improved maintenance & drainage capacity
6. Raise wall crest level *	Greater resilience to overtopping & inundation
7. Manage drainage for the foreshore surface	Greater resilience to overtopping & inundation
8. Increase walling permeability	Greater resilience to overtopping & inundation
9. Design for fully saturated foreshore	Greater resilience to inundation

* Although raising the wall level is an appropriate method to improve resilience to overtopping and inundation, it is challenged in this case by the low foreshore level. Water that accumulates behind the wall will drain, either downwards or horizontally across the walling. Increasing the wall level reduces the incidence of flooding, but increases the capacity to trap water under an exceedance event and reduces horizontal drainage, typically transferring flow along the wall to low points. This effect is typically offset by incorporating a surface drainage system within the walling. Downwards drainage may be enhanced through the ground treatment, including improved wall permeability.

Further information is required on the leasing and funding arrangements for yacht clubs to maintain their walling and the groynes and beaches at NYC. It is not recommended the City of Nedlands be wholly responsible for the costs of maintaining these facilities; however, costs have been included here in City of Nedlands allocations for further discussions with yacht clubs regarding resourcing future foreshore management. Resourcing discussions should address Section 12 of the *SCRM Act 2006* and also seek contribution from the yacht clubs.

Four walling options have been considered (with one or two options costed per foreshore segment), three being revetments and one being block walling:

1. Build revetment riverward of the existing walling;
2. Build revetment, retaining the (toe) position of the existing walling;
3. Build revetment with berm, retaining the (toe) position of the existing walling;
4. Limestone block walling.

Option 1 is presently preferred by the City of Nedlands and a concept design has been prepared by consultants. This design addresses resilience design elements (2), (6) and (9). The practice of building in front of existing walling effectively defers future disposal costs, and limits the capacity for the revetment to act as a permeable structure. If this option is pursued it is recommended to further consider:

- Deeper embedment of the rock revetment, with potential inclusion of a scour toe, in areas with a deeper bed (see Figure 7-13 for indicators of bed level differences);
- Implications of the new riverward position, particularly if the wall is constructed in sections. This may enhance the rate of bed lowering and transfer erosion stress to different parts of the foreshore;
- Potential actions to improve management of overtopping or inundation waters (e.g. surface drainage, or improving permeability through the remnant wall);
- The practicalities and relative costs of maintenance for this specific type of revetment landward of the remnant wall compared to a standard 2-layer revetment;
- Length and detail of transitions needed to tie-in with existing walling;
- Any concerns with the revetment elevation being 0.5m above the existing foreshore level.

Option 2 holds the position of the existing wall toe, excavating the upper foreshore to allow for an inclined revetment to extend landward. This would address resilience design elements (1), (2), (6), (7), (8) and (9).

Removal of the existing walling has a high cost, and therefore may not be immediately feasible. However, this would allow construction of a layered revetment with integrated drainage. The low elevation structure would require a broad splash zone and subsurface drainage. The broad splash zone could incorporate a swale behind the splash zone and path or a wide revetment crest with smaller rocks to landward. This would also require careful transitions to existing nodal locations, such as yacht clubs.

Option 3 incorporates a berm within the revetment, creating a ‘stepped’ structure. This is otherwise similar to option 2, and addresses resilience design elements (1), (2), (6), (7), (8) and (9).

This option is included in areas where some connection is desired with the lower foreshore, such as in the Nedlands Foreshore 1 area. The crest of this revetment would extend further landward than the second option, but would be similar in all other aspects.

Option 4 is for a stepped limestone block wall. This would address resilience design elements (1), (6), (7) and (9).

A stepped wall would require a scour toe, sufficient embedment and drainage to landward. In general, a limestone block wall is a less resilient structure than a revetment. It is noted that the preferred option for this foreshore for the City of Nedlands and its ratepayers is a rock revetment.

Transition
The southern section of Nedlands foreshore walling presently does not have a smooth plan form, which creates local areas of higher foreshore stress. A new rock revetment in this area could be constructed to smooth this transition, which would require removal of some parkland areas and trees, a larger tie-in area with gentle grade in the reserve adjacent to the private properties, regrading of the beach area and renewal of the Iris Avenue drain.

Pocket beaches or future foreshore retreat
MP Rogers & Associates (2013) undertook an assessment, as required in the project scope, of the potential for replacing some walling with pocket beaches exposed to wave action. Their project scope did not include consideration of Mediterranean-style beaches with the beaches sheltered from incident wave energy by shore parallel structures. This style of beach is likely to be more feasible along this reclaimed foreshore as the sand will not be rapidly dispersed along the terrace during periods of storminess of high mean sea level. Design of any pocket beaches or Mediterranean-style beaches requires consideration of future foreshore retreat, existing land use to landward, high cost of disposal of the existing walling and land, beach maintenance, acid sulphate soil risk, management of accumulated seagrass wrack, as well as the potential for loss to the terrace and infill of dredge holes.

Remaining Nedlands Foreshore Segments (SRDal06 to SRDal10)
The possible interventions in this area are discussed in relation to private property, cliffs, foreshore access, drainage and western Point Resolution Reserve.

Private property
A series of approaches are possible to improve the foreshore management of the foreshores with HWM private property or private property immediately landward of a narrow foreshore reserve. The measures attempt to improve foreshore resilience now with considerations of holding the line and progressive retreat in the longer-term.

One aspect is encouraging private property owners of (i) Jutland Parade (SRDal06) and (ii) Victoria Avenue from Bishop Road to Watkins Roads (SRDal09 and SRDal10) to develop and implement a strategic plan for erosion mitigation. A separate plan would be required for Jutland Parade and Victoria Avenue. Erosive pressure on these foreshores are likely to continue. Piecemeal management of the problem increases the stress on the adjacent foreshore and costs for mitigation. Plan to consider transitions between adjacent structures, staging, local areas of retreat, tie-in to underlying rock and foreshore access. Design principles should consider continuity and hydraulic smoothness and avoid foreshore reclamation.

Planning controls could be developed by the City of Nedlands to define development setbacks. A setback could be defined for riverfront properties on Jutland Parade to support foreshore movement. A setback is also appropriate for 148 to 160A Victoria Avenue to support foreshore movement, allowing the beach to fluctuate in its position or migrate landwards.

The City of Nedlands should also develop access plans to ensure erosion mitigation structures can be maintained for each riverfront property along Jutland Parade and Victoria Avenue, excluding reliance of access via Watkins Road for the medium-term. The plan should guide requirements for subdivisions to ensure access is maintained and be revised often.

Preparation of plans and development of planning controls should allow for progressive retreat. It is anticipated private property owners will hold the line where possible with a loss of permanent beach in parts of Jutland Parade and northern Victoria Avenue. In southern Victoria Avenue and parts of Jutland Parade erosion will continue into the development setback area.

In the longer-term foreshore access may be limited riverward of some private properties with further discussion below in 'foreshore access for recreation'.

Cliffs
There are four sections of cliffs in segments SRDal06 to SRDal10. A recent study by Golder & Associates (2015) provides recommendations for cliff stabilisation, which should be considered in the context of the feasibility of maintaining recreation access under the cliffs. In the interests of improving overall foreshore resilience it is generally recommended to allow the base of cliffs or steep slopes to continue to erode. The eroded material contributes to talus and sediment at the base of cliffs and on the terrace, which provides a measure of self-stabilisation. This material may also be available to adjacent foreshores. The timing of restricting access to allow the cliffs to erode is discussed in 'Foreshore access for recreation' below.

In the short-term any bioengineering should be maintained, with signage installed and toe protection of cliffs in SRDal07 (Locality 3) and SRDal09 (Locality 4) following recommendations by Golder & Associates (2015).

Once managed retreat is agreed upon for the steep foreshores the following requires consideration to facilitate the retreat:

- Restricting access for public safety at the base and along the top of the cliffs and steep slopes. This may require fencing, signage and revegetation efforts.
- Public awareness of managed retreat. This is particularly relevant to concerns that may be raised from boat users. Information may be required to be posted to the City of Nedlands and Parks and Wildlife websites.
- Improved surface drainage management above steep slopes and cliffs to reduce slip failure, cliff collapse and scour as a result of surface runoff.

Investment in infrastructure at the crest of these eroding steep foreshores should be avoided.

Foreshore access for recreation
In the short-term the existing foreshore access is maintained with steps at Point Resolution Reserve requiring an upgrade.

Plans should be developed now for long-term public foreshore access restrictions in a number of places along the foreshore. This is required to address safety under unstable cliffs and due to the narrowing of beaches riverward of private property. In the short-term signage should be installed regarding the safety hazard for accessing the foreshore in front of private properties between Adelma Place and 68 Jutland Parade. In the longer term:

- Plan for, and implement, long-term public foreshore access restrictions between Adelma Place and 68 Jutland Parade.
- Extend restrictions for foreshore access from between Adelma Place and 68 Jutland Parade to the north of the cliffs in Point Resolution Reserve. This will require a cost-benefit analysis of maintaining pedestrian access. The analysis should consider the capital and maintenance costs of

bioengineering and other works required to stabilise the cliff toe and steep foreshore, as well as the risk of injury.

- Access may require restriction around the Bishop Rd Reserve cliffs.

Drainage

Improved management of surface runoff is required from the paths in Point Resolution Reserve, at Waratah Place, Watkins Road and Adams Road. In the longer-term the drain invert level at 148 Victoria Avenue may require raising with the pipe discharging higher on the bank and would likely incorporate a loose rock scour toe at the base of the drain.

Point Resolution Reserve

Point Resolution Reserve has steep slopes, cliffs and a long beach section. The steep sections of foreshore are presently maintained by bioengineering. The southern side and cliffs may have access restricted to allow for the banks to erode and supply material to the lower foreshore and terrace without causing a safety hazard (see 'Foreshore access for recreation' and 'Cliffs' above). Maintenance of the bioengineering, stairs and installation of toe stabilisation of cliffs will only be undertaken until foreshore access is restricted. The beaches along the western foreshore of Point Resolution Reserve should be allowed to migrate upwards and landwards, with some sediment harvested from blowouts/dunes used to create a storm bar and revegetate. Sand accumulated in the blowouts/dunes along a 200m length of foreshore can be harvested with approximately 2,000m^3 of sand available. Any material harvested should be used to create a storm bar and swale, with revegetation, ensuring the remaining dunes/blowouts/access paths are not planted with sedge. These locations will provide an ongoing source of sediment and should not be vegetated.

<u>Works to avoid</u>

Some options were not considered due to **decreasing the resilience** of the broader foreshore. The detail for each segment is contained in the tables in Appendix C.6. Some general statements of works to avoid that apply to more than one segment in the City of Nedlands include:

- Constructing erosion mitigation structures on a part of a foreshore that do not match or tie-in to the long-term plans for (i) the broader Nedlands walling section, (ii) Jutland Parade) and (iii) northern Victoria Avenue. Installation of structures that transfer erosion stress to adjacent private properties should be avoided.
- Infrastructure placed within 10m (notional, varies) landward of the crest of existing structures that restricts the capacity for future structure maintenance to be undertaken or partial retreat of the structure crest.
- Undertaking works that reduce the permeability of structures.
- Undertaking large toe stabilisation works for structures likely to be removed or replaced in the next 5 years as this increases the amount of excavation required for future works.
- Irrigation pipes adjacent to erosion mitigation structures or on upper parts of steep foreshores.
- Deepening and expansion of dredged areas and boat pens at yacht clubs.
- Works that improve access to the base of unstable cliffs, or stabilising the base of eroding cliffs or steep banks, without a costed long-term plan to address safety hazards and feasibility of foreshore access.
- Large-scale renourishment works along foreshores adjacent to private properties because the material is unlikely to provide a stable protective buffer for private property.
- Foreshore reclamation on private properties.

- Subdivision of private properties that restricts the capacity for foreshore access for structure maintenance.
- Works on the lower foreshore that can only be maintained from a barge.
- Stabilising blowouts in SRDal08 without harvesting sediment for renourishment of the lower foreshore.

7.2.2. Works for Each Segment

Potential risk mitigation, management pathways and adaptation strategies are presented for each segment linked to time-frames of 0-5 years, 5-25 years and >25 years (Table 3-1). The shortest timescales consider the present state of the foreshore and sensitivity to acute events. The medium-term timescales consider foreshore dynamics, life-cycle of existing stabilising structures and increasing foreshore resilience. For time-frames greater than 25 years there is uncertainty related to future management choices and longer-term process variability. Scenarios possibly affecting the foreshore are considered at this scale in the context of improving resilience where possible.

The foreshore management and adaptation sequences are presented for each foreshore segment in detail in Appendix D.6 (Table 12-23 to Table 12-33). Each table includes:

- A foreshore management goal, capital works and maintenance requirements for each of the three timeframes.
- Requirements for monitoring linked to identification of maintenance requirements, refining budgets and triggering foreshore management actions and adaptation.
- Details of issues to be resolved, and works to be avoided, to ensure the recommended management sequence may be achieved.
- Simple cost estimates (Appendix B) for capital works, maintenance works and a 25-year total with no future cost adjustments.

A summary of the foreshore management goals for the three timescales for each segment is provided in Table 7-2.

Works should be undertaken with consideration of local drainage, water supply, gas, electricity and telecommunications services. They are located in many car park and cul-de-sac areas, based on Dial Before you Dig queries.

Table 7-2: Summary of Management Goals for each Segment in the City of Nedlands
Detail for each segment is included in relevant tables in Appendix D.6

Segment (Table with detail in Appendix D.6)	**Short-term (risk management) for 0-5 years**	**Medium-term (planning) for 5-25 years**	**Long-term (strategy) for >25 years**	**25-year cost. Not indexed (2015 costs)**
SRNed01 Charles Court Reserve (Table 12-23)	Extend life of existing walling as long as possible.	Reconstruct structure (in three stages) as a revetment with splash zone and scour toe, minor retreat, deeper embedment. Move path landward	Hold line with revetment. Loss of permanent beach. Eventual retreat.	≈$3M

Segment (Table with detail in Appendix D.6)	**Short-term (risk management) for 0-5 years**	**Medium-term (planning) for 5-25 years**	**Long-term (strategy) for >25 years**	**25-year cost. Not indexed (2015 costs)**
SRDal01 Birdwood Park (Table 12-24)	Replace exposed concrete panel walling in the north and maintain existing NYC use.	Maintain existing use at NYC.	Retreat within NYC through removal of walling, extending groynes landward and regrading foreshore.	≈$1.2M
SRDal02 Paul Hasluck Reserve (Table 12-25)	Extend life of existing walling as long as possible.	Maintain existing limestone block walling as long as possible. Eventual replacement with revetment with splash zone and scour toe, minor retreat, deeper embedment. Move path landward.	Hold line with revetment. Eventual retreat.	≈$1.7M
SRDal03 Paul Hasluck Reserve-Sadlier Street (Table 12-26)	Replace most of the walling, excluding PFSYC.	Maintain new revetment and replace wall within PFSYC.	Hold line with revetment as long as possible. Eventual retreat N of PFYSC. Maintain approximate position of PFYSC.	≈$1.1M
SRDal04 Beaton Park (Table 12-27)	Replace worst sections of walling with a rock revetment, consider fencing other areas and undertaking emergency repairs when needed.	Replace walling with revetment. Replace wall within PFSYC.	Hold line with revetment as long as possible. Eventual retreat, maintaining approximate position of PFYSC.	≈$2.5M (no allocation to PFSYC).
SRDal05 Iris Avenue (Table 12-28)	Replace the worst section of walling and restrict foreshore access to other damaged sections.	Replace remaining revetment and improve transition to the west. Maintain replaced revetments.	Hold line with revetment as long as possible. Eventual retreat with altered foreshore use.	≈$2.9M.

Segment (Table with detail in Appendix D.6)	**Short-term (risk management) for 0-5 years**	**Medium-term (planning) for 5-25 years**	**Long-term (strategy) for >25 years**	**25-year cost. Not indexed (2015 costs)**
SRDal06 Adelma Place (Table 12-29)	Encourage private property owners to develop long-term plans. Develop some planning controls. Address foreshore access and safety.	Manage/limit foreshore access. Avoid creating additional erosion pressure with private property redevelopment	Restrict foreshore access and maintain beach at the east.	≈$1.2M [1]
SRDal07 Point Resolution reserve (Table 12-30)	Address foreshore access and safety, maintain bioengineering	Manage/limit foreshore access.	Restrict foreshore access and focus management efforts on the upper foreshore.	≈$1M [1]
SRDal08 Point Resolution Reserve, Jutland Pde (Table 12-31)	Address foreshore access and safety.	Manage/limit foreshore access for southern foreshore in cliffed area. Continue to facilitate landward migration of northern 310m of foreshore.	Restrict foreshore access in cliffed and steep areas. Allow for progressive retreat in northern 310m.	≈$860k [1]
SRDal09 Bishop Road Reserve (Table 12-32)	Encourage private property owners to develop long-term plans, including provision of space for an erosion buffer in the south.	Disperse stress along eroding foreshore, manage drainage and avoid creating additional erosion pressure with private property redevelopment.	Private property owners to hold the line in the north with loss of permanent beach. In the south, progressive retreat into the development setback area.	≈$260k
SRDal10 Watkins Road (Table 12-33)	Improve drainage management and encourage private property owners to develop long-term plans.	Disperse stress along eroding foreshore.	Private property owners assumed to hold the line. Loss of permanent beach in many areas.	≈$260k-$305k with not all maintenance included.

Note: 1. Not all works required if recreation and pedestrian access is limited sooner

7.2.3. Ongoing Monitoring Requirements

It is recommended that the City of Nedlands organise the following ongoing monitoring to plan and review requirements for foreshore maintenance, management and adaptation triggers. The information included in Table 7-3 is a council-wide summary of the information in the tables within Section 7.2.1.

Table 7-3: Monitoring Requirements for City of Nedlands

Monitoring technique	Spatial coverage	Frequency
1.1 **Inspections of the face of erosion mitigation structures** (walk in water) and surface behind structure. This includes walling, revetments, groynes, breakwaters, splash zone, scour toes, bioengineering, cliff toe works and fixed access stairs.	All hard walling/ revetments/ structures in SRNed01, SRDal01 to SRDal05. Stairs in SRDal07. Bioengineering and cliff toe stabilisation works in SRDal06 to SRDal10.	Post-event and annual
1.2 **Inspection of drains** and drainage pits	148 Victoria Ave, Bishop Rd and Waratah Pl, Adams Road and Watkins Road (once installed)	Before the first winter rains and mid-winter.
1.3 **Photos at 50m intervals** from upstream to downstream. Used to monitor structure condition, foreshore changes and beach stability. Additional photos can focus on areas with toe undermining, structure transitions, near drains and near failure points. Photos taken in both directions at pocket beaches.	Whole CoN managed foreshore	Annual
1.4 **Tabulate capital and maintenance works records** undertaken on any stabilisation works on CoN land, including dates and details of the works. This includes renourishment, groynes, revetments, walling, bioengineering, clearing of wrack, drainage, managing overbank runoff, infill of material to landward of structures, cliff stabilisation and scour toes	Whole CoN managed foreshore	When works are undertaken
1.5 **Photos of beach widths** taken from both directions at each groyne/breakwater to identify adaptation requirements and beach performance.	Fixed locations in SRDal01 (NYC) and SRDal04 (if pocket beaches constructed)	Quarterly (3 months)
1.6 Encourage **private property owners** to collectively arrange **inspections** of foreshore walling and cliff stability assessments (for properties with cliffs).	Walling and cliff along sections of private property within CoN including SRDal06 (Adelma Pl to 68 Jutland Pde), SRDal09 and SRDal10 (Victoria Ave).	Post-event and annual, and 3-yearly respectively
1.7 **Monitoring of cliff stability** as recommended by Golder (2015).	SRDal06 to SRDal10	2-3 yearly and post-fire

7.2.4. Implementation and Management Summary (0-5 years)

A council-wide summary of the capital and maintenance works recommended for the first five years of management are included in Table 7-4. This summarises key information in the tables within Section 7.2.1. Further detail is included in the segment-specific tables (Table 12-23 to Table 12-33). Monitoring recommendations are included separately in Table 7-3 and are not costed in the table below.

The capital works identified for the first five years is in the order of $4M to $5M due to the number of sections of walling approaching the end of their functional life. Six individual sections of walling replacement total $3.4M. The schedule below has been developed to ensure this is distributed as between $330k and $895k in an individual year. It is recommended the City of Nedlands modify this schedule to suit their funding structures and needs, along with the condition of each section of walling.

Table 7-4: Implementation Summary for City of Nedlands (1-5 years)

	Capital	**Capital Cost ($)**	**Maintenance**	**Maint. Cost ($)**
Year 1	2.1 Install **signage and toe protection for cliffs** in SRDal06 to SRDal09	$230k (4 projects)	3.1 **Drain maintenance** for 5 drains in SRNed01, SRDal01 and SRDal04	$14.5k
			3.2 **Regrout** for 229m of limestone block walling in SRDal02, focus between concrete toe and two lower limestone blocks.	$25k
	2.2. **Fencing** for safety until wall replacement works undertaken in SRDal04 and SRDal05	$10k	3.3 **Extend life of wall and delay reconstruction works** for sections of SRDal03, SRDal04 and SRDal05. Works recommended in Table 12-26 to Table 12-28 will depend on schedule for replacement and available funds.	Not costed.
	2.3 **Replace walling with revetment** for eastern 135m in SRDal05 and **shift path**	$915k	3.4 Maintain **bioengineering** for 100m of steep foreshore section in SRDal08	$20k + in-kind labour
			3.5 **Maintain path** in SRNed01, SRDal01 to SRDal05	Separate CoN budget item.
	2.4 **Discuss transition with CoS** for SRNed01	In-kind CoN planning staff	3.6 **Infill slumping** behind walling or revetment splash zone with geotextile and coarse granular fill, as required for SRNed01, SRDalo01 to SRDal05. Cost $2-3k/5m.	≈ $12k
	2.5 **Define development setbacks** for riverfront properties on (a) Jutland Parade (SRDal06) (b) 148 to 160A Victoria Avenue (SRDal09)	In-kind CoN planning staff	3.7 **Returf and maintain vegetation** near Iris Avenue and eastern end of the beach to manage pedestrian access (SRDal06)	$5k + in kind-labour
			3.8 **Rework sediment on beach** to minimise scarping in east (SRDal06)	$5k + in-kind labour
			3.9 **Maintain bioengineering** for 205m on S Point Resolution Reserve (SRDal06, SRDal07)	$25k + in-kind labour
			3.10 **Manage scour** from pathways, stairs and surface runoff in Point Resolution Reserve (SRDal06 to SRDal08)	$15k + in-kind labour
	2.6 **Develop an access plan** to ensure erosion mitigation structures can be maintained for each riverfront property for:	In-kind CoN planning staff	3.11 **Clear drains and drainage pits** at Waratah Place, Bishop Road, Adams Rd (and Watkins Rd once constructed) before the first winter rains and check mid-winter (SRDal09, SRDal10)	In-kind labour
			3.12 **Harvest sediment from blow-outs/dunes** and transfer to the beach in western SRDal08	$5k

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
	(a) Jutland Parade (SRDal06) (b) Victoria Avenue (SRDal09) (c) Victoria Avenue (SRDal10)		3.13 Maintain **drainage stabilisation works, bioengineering** and toe stabilisation at Waratah Place (SRDal09)	$4k + in-kind labour
			3.14 **Returf** Bishop Road Reserve access between path and beach, and maintain **sedge** and other vegetation at Bishop Road Reserve and south (SRDal09)	$2k + in-kind labour
Year 2	2.7 **Replace walling with revetment** for western 191m in SRNed01 and 60m N of northern NYC groyne in SRDal01 and **reconstruct path** (adjacent works in conjunction reduce cost)	$995k	3.15 **Shift Irrigation Pipes away from walling** in SRNed01, SRDal01 to SRDal05.	Separate CoN budget item.
			3.16 **Replace small failed (<7m) sections of concrete wall** with grouted limestone block walling. Cost of $13-14k / 7m of wall. Reactive to failure, but assumed in SRDal03 and SRDal05 in this year.	$27k
			3.17 **Address undermined structure toe** for 440m in SRNed01 (two wall sections).	$140k
			3.18 **Maintain path** in SRNed01, SRDal01 to SRDal05	Separate CoN budget item.
			3.19 **Infill slumping** behind walling or revetment splash zone with geotextile and coarse granular fill, as required for SRNed01, SRDalo01 to SRDal05. Cost $2-3k/5m.	≈ $12k
	2.8 **Stabilise stairs** on lower foreshore in Point Resolution Reserve (SRDal07)	$45k	3.20 **Returf and maintain vegetation** near Iris Avenue and eastern end of the beach to manage pedestrian access (SRDal06)	$5k + in kind-labour
			3.21 **Rework sediment on beach** to minimise scarping in east (SRDal06)	$5k + in-kind labour
			3.22 **Maintain bioengineering** for 205m on S Point Resolution Reserve (SRDal06, SRDal07)	$25k + in-kind labour
			3.23 **Manage scour** from pathways, stairs and surface runoff in Point Resolution Reserve (SRDal06 to SRDal08)	$15k + in-kind labour
			3.24 **Clear drains and drainage pits** at Waratah Place, Bishop Road, Adams Rd (and Watkins Rd once constructed) before the first winter rains and check mid-winter (SRDal09, SRDal10)	In-kind labour
			3.25 **Harvest sediment from blow-outs/dunes** and transfer to the beach in western SRDal08	$5k
			3.26 Maintain **drainage stabilisation works, bioengineering** and toe stabilisation at Waratah Place (SRDal09)	$4k + in-kind labour
			3.27 **Returf** Bishop Road Reserve access between path and beach, and maintain **sedge** and other vegetation at Bishop Road Reserve and south (SRDal09)	$2k + in-kind labour
Year 3	2.9 **Replace walling with revetment** for western 100m in SRDal04	$440k	3.28 **Replace small failed (<7m) sections of concrete wall** with grouted limestone block walling. Cost of $13-14k / 7m of wall. Reactive to failure, but assumed in SRDal04 this year.	$13k

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
	2.10 Install **drainage** infrastructure at **Watkins Road** in SRDal10 (order $30k-$75k dependent on works)	$60k	3.29 Maintain **bioengineering** for 100m of steep foreshore section in SRDal08	$20k + in-kind labour
			3.30 Maintain **cliff toe buttressing** in SRDal08	$15k
			3.31 **Maintain path** in SRNed01, SRDal01 to SRDal05	Separate CoN budget item.
	2.11 Develop **medium-term plan for PFSYC erosion mitigation** (SRDal04). Funding contribution expected from PFSYC	$75k	3.32 **Infill slumping** behind walling or revetment splash zone with geotextile and coarse granular fill, as required for SRNed01, SRDalo01 to SRDal05. Cost $2-3k/5m.	≈ $12k
			3.33 **Returf and maintain vegetation** near Iris Avenue and eastern end of the beach to manage pedestrian access (SRDal06)	$5k + in-kind labour
	2.12 **Encourage private property owners** to develop and implement a **plan for erosion mitigation**: (a) Jutland Pde (SRDal06) (b) Victoria Ave from Bishop to Watkins Rds (SRDal09, SRDal10) Funding encouraged by private property owners.	 $100k $100k	3.34 **Rework sediment on beach** to minimise scarping in east (SRDal06)	$5k + in-kind labour
			3.35 **Maintain bioengineering** for 205m on S Point Resolution Reserve (SRDal06, SRDal07)	$25k + in-kind labour
			3.36 **Manage scour** from pathways, stairs and surface runoff in Point Resolution Reserve (SRDal06 to SRDal08)	$15k + in-kind labour
	2.13 **Repair** or reinstall **bioengineering** in S Point Res. Reserve, including modification to paths (SRDal06, SRDal07)	$130k	3.37 **Clear drains and drainage pits** at Waratah Place, Bishop Road, Adams Rd (and Watkins Rd once constructed) before the first winter rains and check mid-winter (SRDal09, SRDal10)	In-kind labour
	2.14 Install **signage** adjacent to Adelma Pl. and 68 Jutland Pde notifying of limited access (SRDal06)	$10k + design by CoN staff	3.38 **Harvest sediment from blow-outs/dunes** and transfer to the beach in western SRDal08	$5k
	2.15 **Revegetate** to focus pedestrian access at beach near Iris Ave (SRDal06)	$10k + in-kind labour	3.39 Maintain **drainage stabilisation works, bioengineering** and toe stabilisation at Waratah Place (SRDal09)	$4k + in kind-labour
	2.16 Install **path and drainage adjacent to 68 Jutland Parade** (SRDal06). May be in the order of $40k-$80k dependent on works.	$60k	3.40 **Returf** Bishop Road Reserve access between path and beach, and maintain **sedge** and other vegetation at Bishop Road Reserve and south (SRDal09)	$2k + in kind-labour
Year	2.17 **Replace walling with revetment** for N	$915k	3.41 **Regrout** 35m of non-shotcrete limestone block walling in SRNed01	$5k

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
	190m in SRDal03 and **reconstruct path** (150m)		3.42 **Maintain groynes** in NYC (SRDal01) as required, assumed year 4.	$10k
			3.43 **Maintain and improve drains at Adams Road** (SRDal10)	$10k
	2.18 **Revegetate** (low-elevation plants landward of **new path** in SRDal03	$25k + in-kind labour	3.44 **Maintain path** in SRNed01, SRDal01 to SRDal05	Separate CoN budget item.
			3.45 **Infill slumping** behind walling or revetment splash zone with geotextile and coarse granular fill, as required for SRNed01, SRDalo01 to SRDal05. Cost $2-3k/5m.	≈ $12k
			3.46 **Returf and maintain vegetation** near Iris Avenue and eastern end of the beach to manage pedestrian access (SRDal06)	$5k + in kind-labour
	2.19 Install **fencing and spiky plants** on upper foreshore in Point Resolution Reserve to limit pedestrian access (SRDal07 and SRDal08)	$20k	3.47 **Rework sediment on beach** to minimise scarping in east (SRDal06)	$5k + in-kind labour
			3.48 **Maintain bioengineering** for 205m on S Point Resolution Reserve (SRDal06, SRDal07)	$25k + in-kind labour
			3.49 **Manage scour** from pathways, stairs and surface runoff in Point Resolution Reserve (SRDal06 to SRDal08)	$15k + in-kind labour
	2.20 Develop **medium-term plan for boat ramp** in northern NYC and if it will be a public facility.	$50k with funding allocation from NYC and CoN	3.50 **Clear drains and drainage pits** at Waratah Place, Bishop Road, Adams Rd (and Watkins Rd once constructed) before the first winter rains and check mid-winter (SRDal09, SRDal10)	In-kind labour
			3.51 **Harvest sediment from blow-outs/dunes** and transfer to the beach in western SRDal08	$5k
			3.52 Maintain **drainage stabilisation works, bioengineering** and toe stabilisation at Waratah Place (SRDal09)	$4k + in-kind labour
			3.53 **Returf** Bishop Road Reserve access between path and beach, and maintain **sedge** and other vegetation at Bishop Road Reserve and south (SRDal09)	$2k + in-kind labour
Year 5	2.21 **Replace walling with revetment** for northern 78m in SRDal02 and **reconstruct path** (40m)	$345k	3.54 Maintain **structure at the base of the stairs** in SRDal07	$3k + in-kind labour
			3.55 Maintain **drain headwall at 148 Victoria Avenue** (SRDal09)	$3k
			3.56 Maintain **bioengineering** for 100m of steep foreshore section in SRDal08	$20k + in-kind labour
			3.57 Maintain **cliff toe buttressing** in SRDal08	$15k
	2.22 Install **small scour toe** at base of 2009 limestone block walling in SRDal02	$47k	3.58 **Maintain path** in SRNed01, SRDal01 to SRDal05	Separate CoN budget item.
			3.59 **Infill slumping** behind walling or revetment splash zone with geotextile and coarse granular fill, as required for SRNed01, SRDalo01 to SRDal05. Cost $2-3k/5m.	≈ $12k

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
	2.23 **Renourish beaches** within **NYC** groynes (SRDal01)	$60k	3.60 **Returf and maintain vegetation** near Iris Avenue and eastern end of the beach to manage pedestrian access (SRDal06)	$5k + in kind-labour
	2.24 Undertake **cost-benefit analysis** to determine if **maintaining pedestrian access** along western Point Resolution Reserve in southern 230m in cliffed and steep foreshore area (SRDal08)	$50k	3.61 **Rework sediment on beach** to minimise scarping in east (SRDal06)	$5k + in-kind labour
			3.62 **Maintain bioengineering** for 205m on S Point Resolution Reserve (SRDal06, SRDal07)	$25k + in-kind labour
			3.63 **Manage scour** from pathways, stairs and surface runoff in Point Resolution Reserve (SRDal06 to SRDal08)	$15k + in-kind labour
			3.64 **Clear drains and drainage pits** at Waratah Place, Bishop Road, Adams Rd (and Watkins Rd once constructed) before the first winter rains and check mid-winter (SRDal09, SRDal10)	In-kind labour
			3.65 **Harvest sediment from blow-outs/dunes** and transfer to the beach in western SRDal08	$5k
	2.25 Install **drainage** infrastructure down access path at **Bishop Road Reserve** (SRDal09)	$5k	3.66 Maintain **drainage stabilisation works, bioengineering** and toe stabilisation at Waratah Place (SRDal09)	$4k + in kind-labour
			3.67 **Returf** Bishop Road Reserve access between path and beach, and maintain **sedge** and other vegetation at Bishop Road Reserve and south (SRDal09)	$2k + in kind-labour

7.2.5. Works Dependencies

Some management and adaptation works should only be undertaken once another management task has been undertaken. The main works dependencies within CoN include:

- Agreement and confirmation of funding structures and planned works for NYC and PFSYC before any upgrade works can be undertaken. This is also requires agreement for funding the ongoing maintenance of erosion mitigation structures;
- Consideration of works to be in southern JH Abrahams Reserve in planning works for northern SRNed01;
- Works in SRDal04 will depend on the timing of the replacement of the Tawarri jetty, if pursued;
- Feasibility of many of the recommended works, are dependent on revision of the landfill levy. Disposal costs for many projects are in the order of 25-45% of the total capital costs. This makes many of the works prohibitively expensive;
- Timing of maintenance to extend structure life, with a focus on the structure toe, depends on schedule for capital works in the walled reclaimed sections of foreshore (SRNed01, SRDal01 to SRDal06);
- Scheduled works for Point Resolution Reserve between 68 Jutland Parade and the old baths (N point of cliffed section) requires determination of when pedestrian access should be abandoned for safety. A cost benefit analysis is recommended;
- Securing sufficient funding to ensure the proposed works can be undertaken; and

- Future management of the sections of foreshore with riverfront private properties (Jutland Parade and Victoria Avenue) would be improved through the development of planning controls, access plans and coordinated strategic erosion mitigation plans.

Many maintenance and capital works recommendations in Table 12-23 to Table 12-33 and Table 7-4 require certain issues to be resolved or certain works to be avoided. The segment-specific tables (Table 12-23 to Table 12-33) should be consulted for this information as many works are dependent on these issues being resolved or specific works being avoided.

The staging of capital and maintenance works is broadly outlined in the segment-specific tables and for the first five years in Table 7-4. It is recommended the City of Nedlands prepare a Gantt chart to allocate their own prioritisation of works and works dependencies. This chart could be updated when a management decision (e.g. creating a new recreation node) alters the broader management plan. Works prioritisation will be linked to funding availability and the Gantt chart should be revised annually following the budget allocation.

8. Town of Claremont

Information for the foreshore managed by the Town of Claremont is separated into two sections and Appendix E, all focused on the three segments of foreshore (Figure 8-1; Table 2-1). The first section (8.1) provides context for recommended management, vulnerability and a previous consideration of possible interventions (BMP 2009). The second section (8.2 and Appendix E.6) provides a discussion of possible interventions and more detail on the preferred foreshore management and adaptation sequences and plans, including tables per segment noting maintenance and capital works that could be undertaken in the short-, medium- and longer-terms.

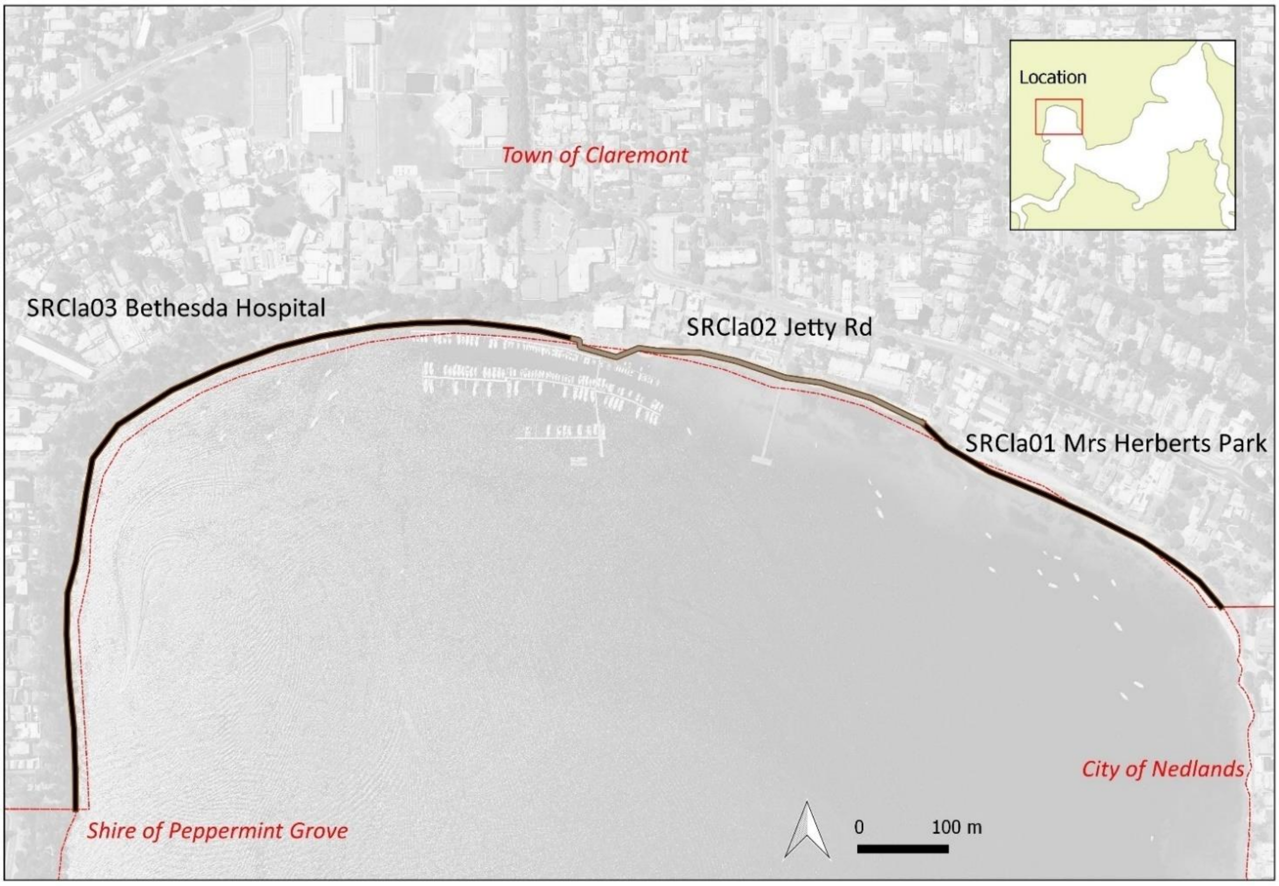

Figure 8-1: Town of Claremont Segments

The foreshore management plan for the Town of Claremont is presented in Section 8.2 with detailed recommendations per segment in Appendix E.6. The main approach is to improve resilience by allowing landward migration and improving the smoothness and continuity of the foreshore alignment. Recommended management actions include backpassing sediment accumulated at Claremont Yacht Club (CYC) and renourishment using externally sourced sediment. Management of the foreshore at Mrs Herberts Park will require joint planning with the City of Nedlands management of the foreshore at Watkins Road.

8.1. CONTEXT AND VULNERABILITY

8.1.1. Process Overview

<u>Segments SRCla01 and SRCal02 (Mrs Herberts Park to Claremont Yacht Club)</u>

There is net clockwise transport of sediment (along the terrace) due to winds, with seasonal variability. Local variations in shore alignment suggest a tendency for accumulation at Bay Road and erosion near

Waratah Place. Sediment has accumulated at CYC that would have transported to the east if the berth areas and yacht club walling were not present. This has reduced the supply of sediment to the area between the yacht club and Chester Road car park.

Reclaimed foreshores that extend riverward with hard structures (Chester Road car park, CYC hardstand area and Christchurch boat ramp) provide a control to alongshore transport, with most significant erosion occurring in vicinity of these features. Further controls to alongshore transport are provided by the drains, drain scour and groynes at Jetty Road.

Response of the foreshore is largely dependent on water level, along with some discrepancies in inter-annual wind direction and intensity. The low elevation beaches are subject to inundation.

Periods of higher mean sea level (e.g. 2011-2013 La Nina) cause overwash of the beach, creating a storm bar and swale to landward. During higher mean sea levels the Jetty Road drains are likely to have flow restricted.

Segment SRCla03 (Claremont Cliffs)
Rocky cliffs and steep banks are located between CYC and the boundary with Shire of Peppermint Grove. The section between CYC and Christchurch Boat Ramp had previously been quarried, and is presently eroding due to restricted sediment supply due to the structures extending riverward of the adjacent foreshore. Erosion downstream of Christchurch boatramp is expected to continue due to the interruption of alongshore transport by the boatramp, removal of revegetation on the steep banks and trampling.

Whilst the talus material along Claremont Cliffs is resistant to wave action, it is subject to gradual degradation and erosion.

8.1.2. Previous and Existing Plans

The majority of the foreshore was previously considered under the Freshwater Bay Management Plan (Swan River Trust 1999) and the Foreshore Management Plan (ToC 2002). In the *Foreshore Assessment and Management Strategy* (SRT 2008) the broader section of foreshore was identified as a low priority, priority 3, in terms of urgent investment in foreshore stabilisation works. The significant constraints to future works as a result of previous and existing plans are:

- Works at Watkins Road by City of Nedlands;
- Water Corporation plans for drains and sewage overflow at Jetty Road
- CYC expansions;
- Bethesda Hospital expansions; and
- Christchurch boat shed expansions.

8.1.3. Historic Works

Town of Claremont foreshore was initially a sandy beach, with outcrops of limestone backed by a vegetated slope, with cliffs in the west. Modifications have been undertaken over time for navigation purposes, beautification, recreation and yacht club use.

This section should be read in conjunction with Section 2.3 which includes a summary of how environmental regulations and management practices across the river have changed over time.

An overview of some changes and issues in the sandy foreshore section of Town of Claremont are included in Figure 8-2. Key changes in relation to foreshore management are listed in Table 8-1 with context provided with aerial images of 1953, 1965, 1983, 2014 (Figure 12-67 to Figure 12-69). Bioengineering and revegetation works have not been included. The main controls to alongshore transport along this foreshore are the car park revetment at Chester Road, CYC reclamation and the Christchurch boat ramp (smaller control).

Table 8-1: Historic modifications relevant to present-day foreshore management

Segment	Modification	Date
Upstream of SRCla01 Mrs Herberts Park	Extension of Watkins Road to the foreshore creating a control Bioengineering and rock toe at Watkins Road.	After 1983 2015
SRCla01 Mrs Herberts Park	Revetment: • Rock quarried from seabed. Riverward of present alignment • Modification in conjunction with renourishment • Consolidated in approximate present alignment • Minor reconstruction	1920 (possibly earlier) 1931 Pre-1983 ≈2003
	Renourishment east of carpark: • Unconfirmed 1920 renourishment • >10,000m^3 renourish for 360m east using sand sourced from road construction work • Other dates to be confirmed	1920 1931 Unknown
	Boat ramp	
SRCla02 Jetty Rd	Jetty Road abutments, drains and groynes	Unknown. Recent disabled access creating runoff problems
	Renourishment between Chester Road carpark and CYC (focus at CYC): • Source and volume unknown • Source and volume unknown • Source and volume unknown • Using Point Walter Spit sediment • Additional renourishment likely occurred	1995 1997 2000-2001 2004 Dates unknown
	CYC land-based modifications: • Extension riverward • Extension riverward and to east • Extension riverward • Extension to east • Extension to east and riverward • Shotcreting of walling • Installation of timber walling to east • Installation of flex-mat to east • Installation of limestone block walling to east	Pre-1953 1965 1965-1974 1979 1990s 1994 1994 1997 Pre-2014
SRCla03 Bethesda Hospital	Christchurch rowing shed rock walling (60m)	1999
	Christchurch boatramp	1979-81, repair 1997
	Bamboo removal	1999 and ongoing
	Steps from Christchurch to half-way down slope, contributing to uncontrolled access trampling	2009

Figure 8-2: Some issues and modifications for the main recreational area of Town of Claremont

8.1.4. Site Issues and Constraints

Details of issues and constraints for the three segments in the Town of Claremont are included in Table 12-34 (Appendix E.2). This is in addition to some further broader issues of:

- Resourcing for future works
- Stakeholder conflict, with four main conflicting uses for the yacht club, private property owners, recreational users (non-residents, including use of carparks) and stormwater management.
- Partial resumption of portions of private property during subdivision process has liability implications for future works. Further information is provided below.
- Future population pressure for fixed paths.
- Indigenous approval discussions required for any dredging/haulage.
- Changing far-field forcing of boat wakes.
- Foreshore is still responding to previous renourishment and modifications.
- Capacity for sandy foreshores to migrate landward restricted in areas with walling within the hydraulic zone.
- Considering any controls that limit E-W sediment transport, including incorporating existing major controls of CYC and Chester Road car park.
- Odour related to seagrass wrack.
- Stability of cliffs and steep slopes in segment SRCla03. Erosion of these steep slopes provides a local source of sediment for the beaches and foreshores.

<u>Liability for erosion, inundation and fire hazards when ceding and vesting HWM Private Property (Section 5)</u>
Ceding and vesting, part or all of, the foreshore reserve along the Town of Claremont may create ongoing issues related to erosion, inundation and fire hazards on adjacent private properties with an unclear definition of liability for damages or conducting management works.

The riverward portion of privately owned land is presently ceded along the foreshore during the subdivision process. The ceding process is that WAPC transfers the property to the State of Western Australia under the Transfer of Land Act (TLA), then the Department of Lands take the property out of the TLA and create it as a reserve under the Land Administration Act (LAA), and then the management order is issued to the Town of Claremont, with the land vested with the Town of Claremont. Section 152 of the *Planning and Development Act 2005* and the *Land Administration Act 1997* includes provision for this vesting of privately owned land. This is supported by the Parks and Wildlife Policy SRT/EA2 on Foreshore Reserves. A management order may only be issued over land reserves, or a lease is established by the Town for a set period. This enables the WAPC to provide Area Assistance Grants. However, a lease is only issued on the basis that a management order will be established following expiry of the lease. Area Assistance Grants are only available for capital upgrades to properties leased or with a management order held by the Town of Claremont. Grants for capital works, not maintenance, may be up to $500,000 at an individual site provided over 5 years (maximum of $100,000 per year) based on a 50% contribution by WAPC and 50% by the Town of Claremont.

Once a section of foreshore reserve has been ceded from a private property, and a management order is provided to the Town of Claremont, the Town will essentially be responsible for erosion mitigation structures (and toe stability on steep slopes) for the private property to landward. Funding for erosion mitigation structures on private property is not permitted under Government grants through the Parks and Wildlife Riverbank program (under the *SCRM Act 2006 and Guidelines 2007*). Therefore, any base structure constructed by Parks and Wildlife/Town of Claremont (e.g. for a path[2]) would seem to provide erosion mitigation to private property landowners at no cost to the owners as the base structure would be on publicly owned land. As the landowner or land manager of a foreshore lot is responsible for maintenance this would also mean the Town of Claremont is responsible for both maintenance of the path and erosion mitigation structures.

At present, the foreshore reserve of each lot will progressively be ceded by the WAPC (if any property is subdivided) and possibly leased by the Town of Claremont or the Town may be provided a management order. Consideration of tie-ins of erosion mitigation options between properties will be required with some situations with co-contribution by private property owners and the Town of Claremont. The land manager of the publicly owned property (Town of Claremont or WAPC) is not likely to be responsible for the costs of providing erosion mitigation for the private property to landward, protecting private property adjacent along the foreshore or damage to erosion mitigation structures on adjacent land as erosion is occurring due to natural processes. It is unclear on who is responsible for maintaining erosion mitigation structures constructed prior to resumption of the land. Further legal advice should be sought on this topic.

The present situation is that WAPC will continue to cede land and vest it with an LGA through the subdivision process (Section 5). WESROC should consider its position with respect to this policy and if deemed appropriate, liaise with LGAs along the Swan and Canning Rivers and WALGA to collectively approach the Department of Parks and Wildlife Rivers and Estuaries Division, the Minister for Planning and the WAPC to review this approach of vesting land along narrow or eroding foreshores. This is recommended in the context of potential ongoing costs for the City of Nedlands, Town of Claremont, Town of Mosman Park, Parks and Wildlife and the WAPC.

The subdivision process often reduces foreshore access and in many cases results in construction of assets closer to the shore. There may be future difficulty with accessing the foreshore along Victoria Avenue between Chester Road carpark and CYC for maintenance of erosion mitigation structures if the foreshore reserve narrows. Historic access to the lower foreshore has been restricted by the continued housing developments. Often when a house was demolished the new house/apartment building was constructed closer to the river encompassing more of the block width without sufficient foreshore access for machinery to undertake maintenance on the retaining walls or foreshore. Future maintenance costs may incur a surcharge related to obtaining access to the foreshore.

Legal advice should be sought regarding potential liability from inundation hazard along Victoria Avenue between Mrs Herberts Park and CYC.

1. Liability implications should be clarified with regards to the Town of Claremont or Parks and Wildlife input to (or rejection of) plans for inundation protection by a private property owner; and
2. Liability should be clarified in relation to increased hazard if the Town allowed the foreshore reserve to erode towards the private property boundary. If the foreshore erodes, increased wave transmission would add to the potential for overtopping and inundation damage. The act of

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[2] If a piled-boardwalk was constructed for a path in future it would not provide erosion mitigation for the private property owners to landward. It is assumed capital and maintenance funding would continue to be required from the private property owners for erosion mitigation structures. There would likely be increased cost due to access constraints provided by the presence of the boardwalk. Further advice is required to determine who is responsible for erosion control works if a boardwalk abutted a private property boundary.

allowing the foreshore to erode would therefore effectively require the private property owner to progressively modify any inundation mitigation structures (levees or walls). Is there potential liability for the Town or Parks and Wildlife to support these works, or compensation if the loss of foreshore has reduced the capacity of the existing structures to resist inundation?

Ceding and vesting of the lower section of the steep banks from CYC around through Bindaring Parade creates potential management issues for the Town of Claremont. These small portions of steep resumed foreshores have limited accessibility for the Town, as well as some of lower foreshore areas already managed by the Town. Clearing of weeds and vegetation as part of the Town's fire management practices are restricted due to bank access/stability as well as dumping of garden waste by adjacent private property owners. Legal advice should be sought to determine if the Town of Claremont would be liable if there was a fire that started in the publicly owned foreshore that caused damage to adjacent private property. The legal advice should guide the Town's fire management and prevention practices, in conjunction with staff safety for undertaking the works.

8.1.5. Observed Change

The Town of Claremont foreshore is presently responding to previous renourishment, hard structures within the hydraulic zone, yacht club operations and recreational use (Figure 8-3). It is also responding to inter-annual variability in wind and water levels. Some observed changes include:

- The foreshore is susceptible to both cross-shore and longshore patterns of sediment transport, with exchange also occurring along the terrace.
- Rotation and prevailing transport to one end of the three beach lengths (Watkins Road to Chester Road car park, Chester Road car park to Jetty Road and Jetty Road to CYC). The net change observed along the foreshores is related to seasonal and inter-annual variation in wind patterns, with sustained periods of more easterly or westerly wind drift (Section 2.2 and Appendix A.2).
- Structures that restrict alongshore sediment transport (CYC, Christchurch boat ramp, Jetty Road drain structures and Chester Road car park) create focal areas of most significant erosion. The riverward extension of structures is included in Table 8-1 and Table 12-34.
- Sediment has accumulated (since ≈1998) at the east of the CYC. This could provide a future source of sediment for backpassing operations to top up eroding areas of foreshore.
- Sedge is lost during periods of cross-shore erosion, is susceptible to trampling and is lost from the ends of the three beaches during sustained net alongshore sediment transport.
- During periods of higher mean sea level a storm bar (or beach ridge) forms due to overwash with a swale formed to landward. Water ponds in this area and drains preferentially through low points, scouring the beach. The upwards growth of the storm bar is noticeable in areas with fixed infrastructure, for example the accumulation of sediment at the base of benches. The low-elevation beaches are inundated during high water level events.
- Resistance to tall vegetation that could block views from homes.
- Unmanaged surface runoff contributing to erosion at Watkins Road (City of Nedlands), Chester Road car park, through break in kerb at Jetty Road and at CYC.
- Formation of storm bars at Alex Prior Park drain and Jetty Road drains causing ponding, with associated odour issues and water quality concerns.
- Uncontrolled pedestrian or kayak launching access is contributing to erosion, and sedge trampling, east of Chester Road car park and adjacent to Jetty Road. Trampling occurs at any gaps in the sedge. Uncontrolled access is contributing to erosion west of Christchurch boatshed where bamboo were removed and stairs (2011) extend halfway down the slope.

- Seagrass wrack has always been deposited on this foreshore.
- Ongoing foreshore retreat has been occurring in the adjacent foreshore section in City of Nedlands, in part due to construction of hard walling within the hydraulic zone restricting natural cross-shore sediment exchange. The erosion is exacerbated at Watkins Road with the road extended riverward to the foreshore after 1983 without any foreshore protection or surface runoff management. In 2015 CoN have undertaken bioengineering works to attempt to stabilise the foreshore at Watkins Road with no management of surface runoff. Works at Watkins Road will have implications for the Chester Park foreshore.
- Sediment transport along the foreshore between Jetty Road and the cliffs into SoPG has been interrupted by the reclamation and dredging at CYC (Figure 8-2 and Figure 12-69). The foreshore between CYC and Christchurch boat ramp is eroding and expected to continue to erode. Erosion will continue downstream of the Christchurch boat ramp.

Figure 8-3: Historic imagery of Claremont foreshore from State Library of WA
Top left: Hart (1906) of Claremont foreshore, Lower left: Lund (ca 1910) of Osborne steps, Right: Woldendorp (1985) obliques.

8.1.6. Structure Condition and Function Comparison

Previous assessments of structure condition and function have been used in preparation of the foreshore management and adaptation approach for Town of Claremont. The details of the 2004 and 2014 assessments are included in Appendix E.3 with tables of structure condition and short-term maintenance comments in Appendix E.4. Drains were only assessed in 2014 if they were contained within other foreshore structures, with the exception of the large drains at Jetty Road.

8.1.7. Foreshore Controls and Sensitivities

The foreshore controls and sensitivities for ToC foreshore include:

- Modified foreshore with renourishment and hard structure controls restricting alongshore transport. The hard structures limit the capacity to maintain natural sediment transport processes and will require active sand management.
- The beaches are sensitive to structures extending riverward with efforts required to improve hydraulic smoothness to reduce fluctuations in foreshore position during periods of net east/west sediment transport.
- Any works proposed in the future that provide a hard structure that extends further riverward should be considered in terms of the impact on the broader foreshore area.
- Rock substrate, either natural or modified, to be considered in any future plans.
- Response of foreshore downstream of CYC to reduced sediment supply.
- Surface runoff including managed runoff at Alex Prior Park and the Water Corporation drains at Jetty Road, as well as unmanaged runoff at Watkins Road (City of Nedlands), Chester Road car park, through break in kerb at Jetty Road and at CYC.
- Ensuring capacity for beach, and broader foreshore, to migrate landwards and upwards.
- A sensitivity is the potential works undertaken by private property owners for both erosion/inundation mitigation works as well as access to undertake the works. Some properties would already experience inundation during high water level events.

The main publicly owned foreshore-retention structure is the Chester Road car park revetment, with existing levels shown in Figure 8-4 and photos in Appendix E.7. The eastern extension of the revetment over time transfers erosion stress to the foreshore to the east. The revetment is subject to inundation over the low-crest elevation, which will require some management of overtopping immediately to landward. The potential realignment of the car park and revetment is considered as a longer-term option.

The broader foreshore of the two eastern segments is low-lying (Figure 8-5) with levels at the edge of the grass at approximately +0.6mAHD (1.3mCD) corresponding to the highest astronomical tide. The beach and grassed foreshore area would be inundated during most winters. A few private property boundaries near Jetty Road are located at elevations lower than +1 mAHD, which is lower than the 10-year ARI water level.

Foreshore structure and drain maintenance requirements provides another foreshore sensitivity for the ToC. If adequate maintenance is not undertaken it may lead to failure, which can transfer erosion stress. Tables of the condition and potential maintenance of the Chester Road car park rock revetment (and drains) and the Jetty Road drains were prepared by Damara WA (2015) for the Parks and Wildlife at a broad scale (Table 12-36 and Table 12-37; Appendix E.3). Some of the information has been refined for consideration of the moderate to longer-term vulnerabilities and planning requirements (Section 8.2).

8.1.8. Scenarios and Impacts

The scenario at present is:

- Continued inter-annual discrepancy in seasonal and net sediment transport.
- Foreshore responding to hard structures restricting alongshore sediment transport with erosion focused at ends of beaches and ongoing retreat west of CYC.
- Ongoing erosion stress associated with uncontrolled access, drain scour and unmanaged runoff.
- Inundation, ponding and scarping during storm events.

The scenario of increased mean sea level could result in the potential responses outlined in Section 8.1.10 in the >25 year category.

A further scenario to consider is further expansion of CYC jetties, pens and car parking areas. It is assumed that the small boat ramp to the west of the Chester Road car park would not be upgraded to a larger facility.

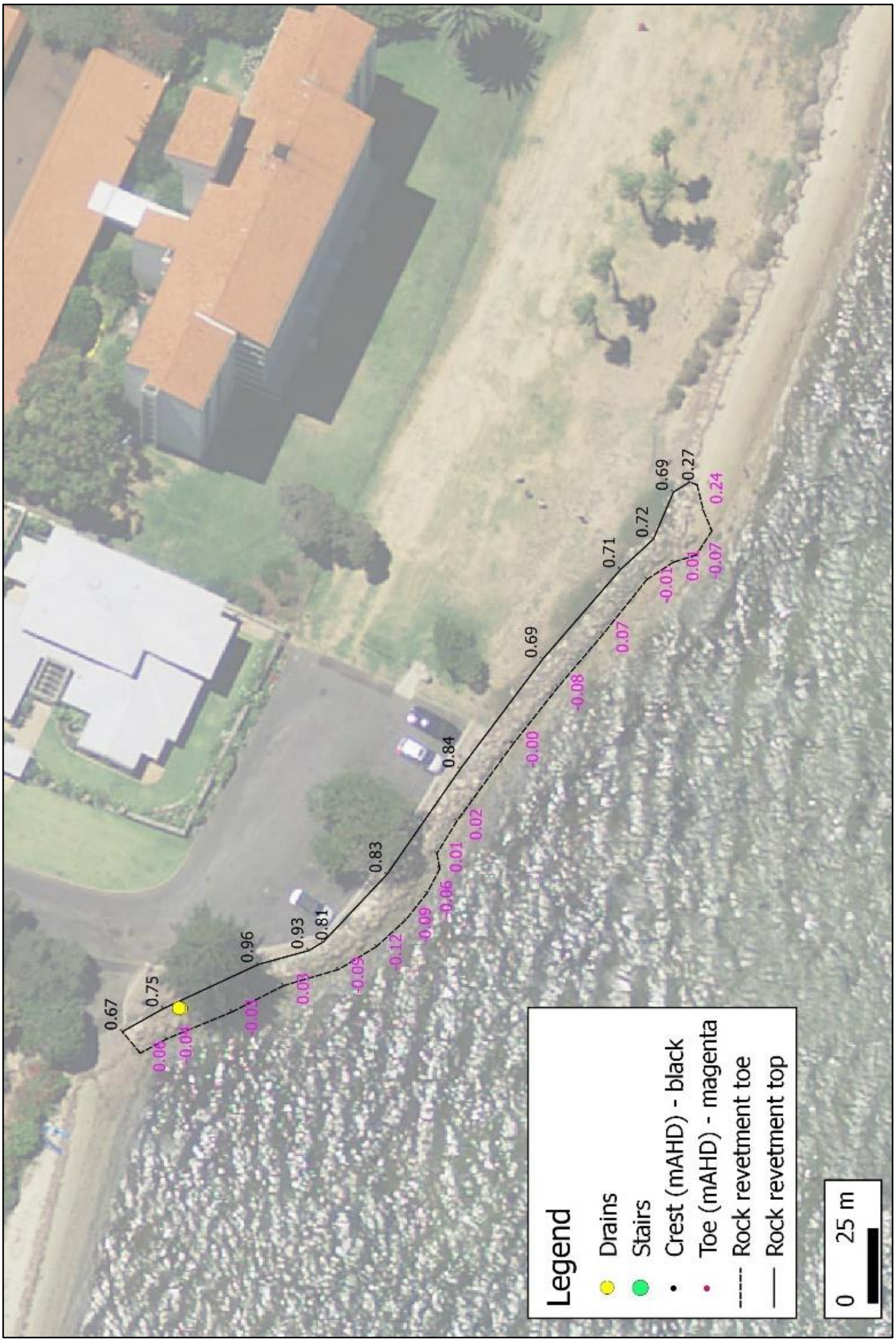

Figure 8-4: Claremont Revetment (SRCla01.B01) Levels - January 2015 (on 2014 image)

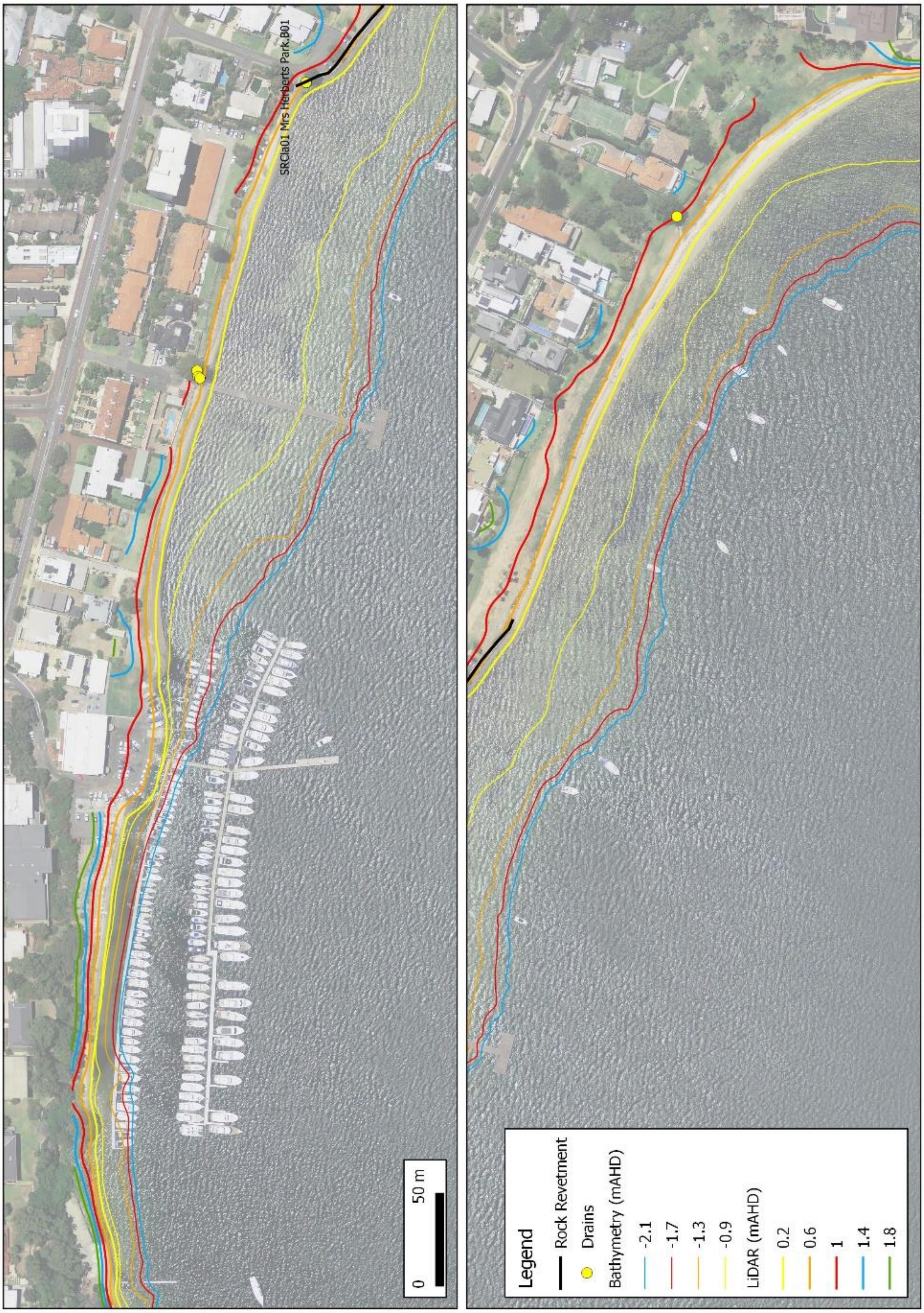

Figure 8-5: Topography and Bathymetry in central and eastern Town of Claremont

8.1.9. Values and Foreshore Uses Considered (Short- and Long-Term)

The foreshore values and uses for the Town of Claremont foreshore include:

- Recreation (not a fixed path), with continuous access along the foreshore.
- Low maintenance and sustainable management solutions through increasing foreshore resilience.
- Preference for some vegetation (trees unlikely to be supported) rather than hard structures.
- Whadjuk values to maintain ecological function, return foreshore to more natural conditions with a reduction in hard walling.
- Foreshore management should not defer erosion/inundations risks to local private property owners. Private property owners should not transfer erosion risk to the foreshore reserve.
- Maintain existing uses.
- Maintain and improve drain function at Alex Prior Park and at Jetty Road.
- Improve management of surface runoff at Watkins Road, Chester Road car park, Jetty Road and CYC.
- Maintain car parking areas at Chester Road and Jetty Road. Extending car parking to east at Chester Road could improve access to apartment block storage units.
- Maintain CYC boat pens and facilities. Any future expansion plans should be assessed for the impact on adjacent foreshores with requirements for CYC to contribute to foreshore management.
- Toilet block, sewage overflow tanks and sewage pump station at Jetty Road.
- Certain ratepayers would request improved management of seagrass wrack due to odour issues. There are ecological benefits for maintaining seagrass in the system.
- Maintain boat ramp function for launching kayaks and small dinghies at Chester Road car park. Facility should not be upgraded.
- Maintain moorings with potential future pressure for further dinghy storage and launching areas to access moorings.

Pressure to reinstate Osborne steps, or equivalent access, west/downstream of CYC should be discouraged due to high capital and maintenance costs and the inability to guarantee safe pedestrian access between Christchurch boat ramp and CYC.

8.1.10. Vulnerability

<u>Existing vulnerability (0-5 years)</u>

Inundation of beach and foreshore for events exceeding highest astronomical tide if no waves and no mean sea level shift (Figure 8-5). Inundation increases during La Nina events due to an increase in mean sea level. Waves can contribute to local scarping and erosion, erosion adjacent to hard structures and can also contribute to beach building processes through overtopping of the storm bar. Waves are 0.8/0.9 to 1.0/1.1m Hs (3-year to 100-year), with small elevation long-period boat wakes also occurring at the site.

The low crest of the Chester Road car park revetment (+0.7 to +0.96mAHD; Figure 8-4) is frequently inundated with overtopped waves contributing to erosion and damage to landward. The revetment extends riverward to the east, reducing the resilience of the adjacent foreshore to inter-annual variability in alongshore sediment transport.

The foreshore is sensitive to inter-annual variability in mean sea level and wind patterns. Foreshore resilience is reduced if the sediment transport along the foreshore and the terrace is interrupted by hard structures. The foreshore is vulnerable to any future changes in hard structures and to a lack of sand renourishment.

Focal erosion occurs in the vicinity of drains at Alex Prior Park and Jetty Road, with vulnerability to a sand bar blocking low flow events at both drains. The blocking of flow could result in runoff and scour across broader areas. In addition, the foreshore is also vulnerable to areas of unmanaged surface runoff at Watkins Road, Chester Road, Jetty Road and CYC.

Further vulnerability is associated with:

- Leaks at the Jetty road sewage pump station, with the sewage overflow tanks installed in 2009 hopefully addressing the previous leaks.
- Removal of any sand from between Watkins Road and CYC from the system for use in other foreshore areas. Sediment should be maintained within the sandy foreshore area.
- Extending or raising hard structures at CYC.
- Erosion/inundation mitigation works by private property owners.
- A large storm event that transfers sediment off the beach.

<u>Progressive change to vulnerability (5-25 years)</u>
Some of the vectors for vulnerability described above are likely to increase in magnitude. This will include increased:

- Erosion adjacent to structures as the foreshore continues to respond to the historic works.
- Recreation use, trampling of vegetation and creation of focal erosion areas.
- Runoff into drains with less recharge in the catchment as density increases in the ToC. This will result in increased scour at drains and in areas of unmanaged runoff.

A further scenario to consider is further expansion of CYC jetties, pens and car parking areas.

<u>Scenarios for changing vulnerability (>25 years)</u>
Longer-term planning considers the scenario of increased mean sea level. This could increase the foreshore vulnerability to:

- Increased inundation of the foreshore area, ponding and erosion scour at low points in the beach. This would also cause increased water-logging of the foreshore reserve.
- Increased overtopping of the car park revetment, loss of material behind the revetment and damage to the car park.
- Erosion enhanced at beach ends and adjacent to structures, with potential undermining of structures.
- Blowback and choking at drains due to low invert levels and higher elevation sand bars blocking flow.
- Potential damage to the sewage pump station.

Scenarios for changing foreshore use have not been considered.

8.2. FORESHORE MANAGEMENT AND ADAPTATION SEQUENCES AND PLANS

The possible interventions for the Town of Claremont are described in further detail according to the vulnerability assessment time-frames linked to risk mitigation, management pathways and an adaptation strategy (Table 3-1). This information is presented for each segment (Figure 8-1), with a summary of scheduling, monitoring requirements for adaptation triggers and works summary for the 0-5 year time-frame provided for the whole LGA.

Initially, the decision-support framework was applied, according to the method described in Section 3.2 of SRT (2009), to refine which stabilisation techniques should be considered further. Details of this application is included in Appendix E.5.

8.2.1. Possible Interventions

Possible maintenance and capital works for the sandy foreshores in the Town of Claremont are discussed in the context of improving resilience of the foreshore to storm events, shifting mean sea levels and inter-annual variations in wind direction. Any interventions account for the foreshore response to historic works and management actions, such as beach renourishment. The discussion focuses on the section of foreshore between Watkins Road and CYC.

The method considered as most effective to **improve the resilience of the foreshore to inundation** is the creation of a storm bar and swale with focal runoff locations. This approach encourages the onshore transport of sediment into the storm bar during periods of increased mean sea level. This approach also improves the resilience of the foreshore to erosion as the storm bar is a sacrificial feature and is easily adjusted using simple machinery.

The remaining recommended methods attempt to **improve the foreshore resilience to fluctuations in winds and erosion pressures**. This includes:

- Increasing hydraulic smoothness of the foreshore with smoother transitions between hard structures and the adjacent beach. This improves the capacity for bi-directional sediment transport adjacent to the structures. An example of this is modifying the eastern extent of the Chester Road car park revetment.
- Reducing focal areas of scour/erosion associated with drain scour, unmanaged surface runoff and trampling. Areas of focal trampling will require sediment top-up and returfing.
- Intervening in active sand management to transfer sand from accumulating areas to eroding areas if patterns are sustained for more than 3 years. The sediment should be maintained within the foreshore area between Watkins Road and CYC.
- Beach renourishment. The foreshore has been renourished since the 1920s and will require ongoing external sediment supply to improve the resilience to erosion.
- Frequent revegetation with grass (in areas of trampling and access pathways) and sedge to improve the sediment retention capacity during prevailing conditions.
- In the longer-term (>25 years), as the erosion pressures increase, it is recommended to consider raising the storm bar (and backshore between Chester Road car park and CYC) and retreat. The beach and foreshore reserve will narrow. As the foreshore narrows the Chester Road car park will effectively extend riverward compared to the adjacent foreshore, transferring erosion stress and decreasing resilience. It is recommended to narrow and extend the car park and revetment, following placement of a small groyne at CYC to trap the additional sediment that will be transported to the west. This sediment is then available for more frequent backpassing and active sediment management. Renourishment between Chester Road car park and CYC should only be undertaken once the small groyne at CYC is constructed to reduce potential sedimentation of the boat pens.

Some options were not considered due to **decreasing the resilience** of the broader foreshore. This includes:

- Walling along the foreshore to hold the line is not recommended as it will decrease resilience of the beach to erosion. The erosion pressures are transferred riverward of the structure. In addition, this will require raising of the whole foreshore area, which could increase ponding of water on private properties during high water level and rainfall events as well as promoting the lowering of the bed riverward of the walling. Amenity of the broader foreshore would be reduced.
- Raising the crest level of the rock revetment, Claremont jetty decking or the CYC walling as this will decrease the resilience of the broader foreshore to erosion. The raised walling will cause bed-level lowering at the base of the structures and increase the rate of erosion of the adjacent foreshores.
- A fixed path or piled boardwalk along the foreshore as it decreases the capacity to improve the resilience of the foreshore to erosion and inundation. A method for improving resilience is to migrate the foreshore to landward, raising the storm bar and creating a swale. The presence of a fixed path or piled boardwalk will limit this capacity, as well as creating areas of focal erosion due to surface runoff and trampling.
- Planting of tall trees across the foreshore. This is partly because private property owners may vandalise the trees if river views are restricted. The main reason this is not recommended is although the rootmass of tall trees may create increased resilience to erosion in extreme events, measures are frequently undertaken to protect a tree from falling in the river, causing greater problems. This is observed in other areas of the Swan River where the erosion mitigation works placed to protect trees transfers the erosion risk to the adjacent foreshore.
- Private property owners adding large erosion/inundation mitigation structures extending into the foreshore reserve, or are of sufficient height to limit overtopping during extreme events. This type of structures decrease the resilience of the foreshore to erosion as the erosion hazard is transferred riverward of these assets, contributing to a reduction in the beach width.

It is recommended to allow the broader foreshore between CYC and the Shire of Peppermint Grove to erode, restricting any further development to allow for retreat.

8.2.2. Works for Each Segment

Potential risk mitigation, management pathways and adaptation strategies are presented for each segment linked to time-frames of 0-5 years, 5-25 years and >25 years (Table 3-1). The shortest timescales consider the present state of the foreshore and sensitivity to acute events. The medium-term timescales consider foreshore dynamics, life-cycle of existing stabilising structures and increasing foreshore resilience. For time-frames greater than 25 years there is uncertainty related to future management choices and longer-term process variability. Scenarios possibly affecting the foreshore are considered at this scale in the context of improving foreshore resilience where possible.

The foreshore management and adaptation sequences are presented for each foreshore segment in Appendix E.6 (Table 12-39 to Table 12-41). Each table includes:

- A foreshore management goal, capital works and maintenance requirements for each of the three timeframes.
- Requirements for monitoring linked to identification of maintenance requirements, refining budgets and triggering foreshore management actions and adaptation.
- Details of issues to be resolved, and works to be avoided, to ensure the recommended management sequence may be achieved.

- Simple cost estimates (Appendix B) for capital works, maintenance works and a 25-year total with no future cost adjustments.

A summary of the foreshore management goals for the three timescales for each segment is provided in Table 8-2.

It should be noted that other than the Water Corporation drains there are no key services located within the foreshore reserve based on a Dial Before you Dig query.

Table 8-2: Summary of Management Goals for each Segment in the Town of Claremont
Detail for each segment is included in relevant tables in Appendix E.6

Segment (Table with detail in Appendix E.6)	**Short-term (risk management) for 0-5 years**	**Medium-term (planning) for 5-25 years**	**Long-term (strategy) for >25 years**	**25-year cost. Not indexed (2015 costs)**
SRCla01 Mrs Herberts Park (Table 12-39)	Improve resilience for interannual variations in MSL and winds.	Improve resilience for scenario of increased mean sea level and variability, by promoting sand to transfer onshore.	Progressive retreat to allow for mean sea level increase.	≈$350k Further $150k for car park and revetment landward migration.
SRCla02 Jetty Rd (Table 12-40)	Improve resilience for existing MSL/wind variance, and increased recreation.	Extend existing foreshore use for as long as possible.	Improve resilience of the foreshore to increased mean sea level through modifying structures, raising foreshore levels, renourishment and some retreat	≈$240k. Further $150k to construct groyne, raise foreshore level and one external renourishment campaign.
SRCla03 Bethesda Hospital (Table 12-41)	Allow lower foreshore to erode to provide a source of sediment, while managing trampling	Allow lower foreshore to erode to provide a source of sediment and ensure private property owners do not transfer erosion stress without compensation	Encourage managed retreat, or adaptation, for the lower foreshore for some private property owners.	Depends on the agreements established with private property owners and leaseholders. In-kind and lawyer costs required to establish responsibilities.

8.2.3. Ongoing Monitoring Requirements

It is recommended that the Town of Claremont organise the following ongoing monitoring to plan and review requirements for foreshore maintenance, management and adaptation triggers. The information included in Table 8-3 is a council-wide summary of the information in the tables within Section 8.2.1.

Table 8-3: Monitoring Requirements for Town of Claremont

Monitoring technique	Spatial coverage	Frequency
1.1 Tabulate records of location, rates and timing of **revegetation, backpassing and renourishment**. This includes the volumes of sediment harvested from adjacent to CYC.	CoN border to CYC (SRCla01 and SRCla02)	When works are undertaken
1.2 Tabulate records of **repairs to Chester Road** car park and rock revetment, including costs and timing.	Chester Road car park and revetment (part of SRCla01)	When works are undertaken
1.3 Tabulate records of volumes and timing of sand manually breached by ToC staff at **storm bar** associated with drain at **Alex Prior Park**.	Alex Prior Park drain (part of SRCla01)	When works are undertaken
1.4 Tabulate records of volumes and timing of drain **storm bar excavation at Jetty Road** (undertaken by Water Corporation). Also note the date and significance of any blowback at these drains.	Jetty Road drains (part of SRCla02)	When works are undertaken or when blowback occurs
1.5 Tabulate records of any known **works undertaken by private property owners**	CYC to SoPG boundary (SRCla03)	When works are undertaken or following the annual 10m photos
1.6 Tabulate **patterns of wrack accumulation** and metocean (water level, wind speed and direction) conditions surrounding wrack accumulation. Note location of wrack accumulation and take a photo. Also note dates Parks and Wildlife (ex-SRT) **cleared the wrack** and approximate volumes.	Between Chester Road and CYC (SRCla02)	When wrack accumulates and when wrack is cleared
1.7 **Engineering inspection** of Chester Road revetment	Chester Road revetment (part of SRCla01)	Annual and post-event
1.8 **Photos at 50m intervals** from upstream to downstream	Whole ToC	Annual in December/January
1.9 **Photos of beach widths** at fixed locations to identify seasonal variability and adaptation requirements	Fixed locations between CoN border to CYC (SRCla01 and SRCla02)	Monthly
1.10 **Geotechnical assessment** of toe of steep banks to determine hazards related to slip failure or bank collapse.	CYC to SoPG boundary (SRCla03)	5- to 10-yearly

8.2.4. Implementation and Management Summary (0-5 years)

A council-wide summary of the capital and maintenance works recommended for the first five years of management are included in Table 8-4. This summarises key information in the tables within Section 8.2.1. Further detail is included in the segment-specific tables (Table 12-39 to Table 12-41). Monitoring recommendations are included separately in Table 8-3 and are not costed in the table below.

Table 8-4: Implementation Summary for Town of Claremont (1-5 years)

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
Year 1	2.1 **Shift** disabled access **cut in kerb at Jetty Rd** to other side of drain pits.	$1k + in-kind labour	3.1 Manually breach the **sand bar at the Alex Prior drain** (≈monthly towards neap tides).	In-kind
			3.2 **Clear sand bar at Jetty Rd** drains (≈monthly near neap tides). Transfer to beach to E.	Water Corp. in-kind
			3.3 Maintain **sedge** between Mrs Herberts Park and CYC.	$5k pa + in-kind labour
			3.4 Maintain **grass** near Jetty Road to reduce erosion through pedestrian trampling. After minor renourishment.	$0.5k pa + in-kind labour
	2.2 **Create small drain** at low point in the Chester Road car park.	$2-3k	3.5 **Clear wrack** from the beach when agreed between ToC and Rivers and Estuaries Riverpark Unit. Either re-use in river elsewhere or bypass to W side of CYC.	Parks and Wildlife (ex-SRT) in-kind
			3.6 Backfill between **revetment crest** and car park with coarse gravel. Ideally create a wider splash zone at the crest between the top of the revetment and the car park kerbing.	$2k pa + in-kind labour (only for coarse gravel)
			3.7 **Minor renourishment** focused E of Chester Rd car park using CYC sand.	$3.5k -100 m^3 from CYC (≈2-yearly)
			3.8 **Re-grout** groynes at Jetty Road.	$2k
Year 2	2.3 **Education program** on seagrass wrack.	$5k (once)	3.9 Manually breach the **sand bar at the Alex Prior drain** (≈monthly towards neap tides).	In-kind
			3.10 **Clear sand bar at Jetty Rd** drains (≈monthly near neap tides).	Water Corp. in-kind
			3.11 Maintain **sedge** between Mrs Herberts Park and CYC.	$5k pa + in-kind labour
	2.4 **Extend stairs** to boat shed Fence/plant other pathways.	Christ-church	3.12 Maintain **grass** near Jetty Road to reduce erosion through pedestrian trampling. After minor renourishment.	$0.5k pa + in-kind labour
			3.13 **Clear wrack** from the beach when agreed between ToC and Rivers and Estuaries Riverpark Unit.	Parks and Wildlife (ex-SRT) in-kind
			3.14 Backfill **revetment crest** to car park with coarse gravel.	$2k pa + in-kind labour
			3.15 **Minor renourishment** focused at Jetty Road area using CYC sand using a dozer along the beach.	$2k - 100 m^3 from CYC (≈2-yearly)
Year 3	2.5 **Modify Chester Road car park revetment**	$10-15k (check excav-ation).	3.16 Manually breach the **sand bar at the Alex Prior drain** (≈monthly towards neap tides).	In-kind
			3.17 **Clear sand bar at Jetty Rd** drains (≈monthly near neap tides)	Water Corp. in-kind

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
	for gradual tie-in to the east	Reuse existing rock.	3.18 Maintain **sedge** between Mrs Herberts Park and CYC.	$5k pa + in-kind labour
			3.19 Maintain **grass** near Jetty Road to reduce erosion through pedestrian trampling. After minor renourishment.	$0.5k pa + in-kind labour
			3.20 **Clear wrack** from the beach when agreed between ToC and Rivers and Estuaries Riverpark Unit	Parks and Wildlife (ex-SRT) in-kind
			3.21 Backfill **revetment crest** to car park with coarse gravel.	$2k pa + in-kind labour
			3.22 **Minor renourishment** focused adjacent to Chester Road car park using CYC sand.	$3.5k -100 m^3 from CYC (≈2-yearly)
Year 4	None required	$0	3.23 Manually breach the **sand bar at the Alex Prior drain** (≈monthly towards neap tides).	In-kind
	2.6 **Guidelines and MoU** with private property owners and leaseholders in SRCla03	Not costed	3.24 **Clear sand bar at Jetty Rd** drains (≈monthly near neap tides).	Water Corp. in-kind
			3.25 Maintain **sedge** between Mrs Herberts Park and CYC.	$5k pa + in-kind labour
			3.26 Maintain **grass** near Jetty Road to reduce erosion through pedestrian trampling. After minor renourishment.	$0.5k pa + in-kind labour
			3.27 **Clear wrack** from the beach when agreed between ToC and Rivers and Estuaries Riverpark Unit.	Parks and Wildlife (ex-SRT) in-kind
			3.28 Backfill **revetment crest** to car park with coarse gravel.	$2k pa + in-kind labour
			3.29 **Minor renourishment** focused at Jetty Road area using CYC sand using a dozer along the beach.	$2k - 100 m^3 from CYC (≈2-yearly)
Year 5	None required	$0	3.30 Manually breach the **sand bar at the Alex Prior drain** (≈monthly towards neap tides).	In-kind
			3.31 **Clear sand bar at Jetty Rd** drains (≈monthly near neap tides).	Water Corp. in-kind
			3.32 Maintain **sedge** between Mrs Herberts Park and CYC.	$5k pa + in-kind labour
			3.33 Maintain **grass** near Jetty Road to reduce erosion through pedestrian trampling. After minor renourishment.	$0.5k pa + in-kind labour
			3.34 **Clear wrack** from the beach when agreed between ToC and Rivers and Estuaries Riverpark Unit.	Parks and Wildlife (ex-SRT) in-kind
			3.35 Backfill **revetment crest** to car park with coarse gravel.	$2k pa + in-kind labour
			3.36 **Minor renourishment** focused adjacent to Chester Road car park using CYC sand.	$3.5k -100 m^3 from CYC (≈2-yearly)

8.2.5. Works Dependencies

Some management and adaptation works should only be undertaken once another management task has been undertaken. The main works dependencies within ToC include:

- The installation of the short groyne at CYC should be undertaken before any renourishment with externally sourced sediment for SRCla02 and before the car park and revetment retreat in SRCla01; and
- Securing the sediment to the E of CYC for use in ongoing backpassing operations.

Many maintenance and capital works recommendations in Table 12-39 to Table 12-41 and Table 8-4 require certain issues to be resolved or certain works to be avoided. The segment-specific tables (Table 12-39 to Table 12-41) should be consulted for this information as many works are dependent on these issues being resolved or specific works being avoided.

The staging of capital and maintenance works is broadly outlined in the segment-specific tables and for the first five years in Table 8-4. It is recommended the Town of Claremont prepare a Gantt chart to allocate their own prioritisation of works and works dependencies. This chart could be updated when a management decision (e.g. creating a new recreation node) alters the broader management plan. Works prioritisation will be linked to funding availability and the Gantt chart should be revised annually following the budget allocation.

9. Shire of Peppermint Grove

Information for the foreshore managed by the Shire of Peppermint Grove is separated into two sections and Appendix F, all focused on the three segments of foreshore (Figure 9-1; Table 2-1). The first section (9.1) provides context for recommended management, vulnerability and a previous consideration of possible interventions (BMP 2009). The second section (9.2 and Appendix F.6) provides a discussion of possible interventions and more detail on the preferred foreshore management and adaptation sequences and plans, including tables per segment noting maintenance and capital works that could be undertaken in the short-, medium- and longer-terms.

The foreshore management plan for the Shire of Peppermint Grove is presented in Section 9.2 with detailed recommendations per segment in Appendix F.6. A management focus is walling maintenance given the age of the walling, including focus on the base of structures and near drains. Key immediate issues for the Shire are associated with erosion enhanced by trampling, drainage and surface runoff; particularly south of Keane St. Focal points for recreational access are required. Sediment management will also be required with backpassing and renourishment using externally-sourced sand. Management of the foreshore south of Royal Freshwater Bay Yacht Club requires joint planning with the Town of Mosman Park for the broader Mosman Bay, including the boat ramp.

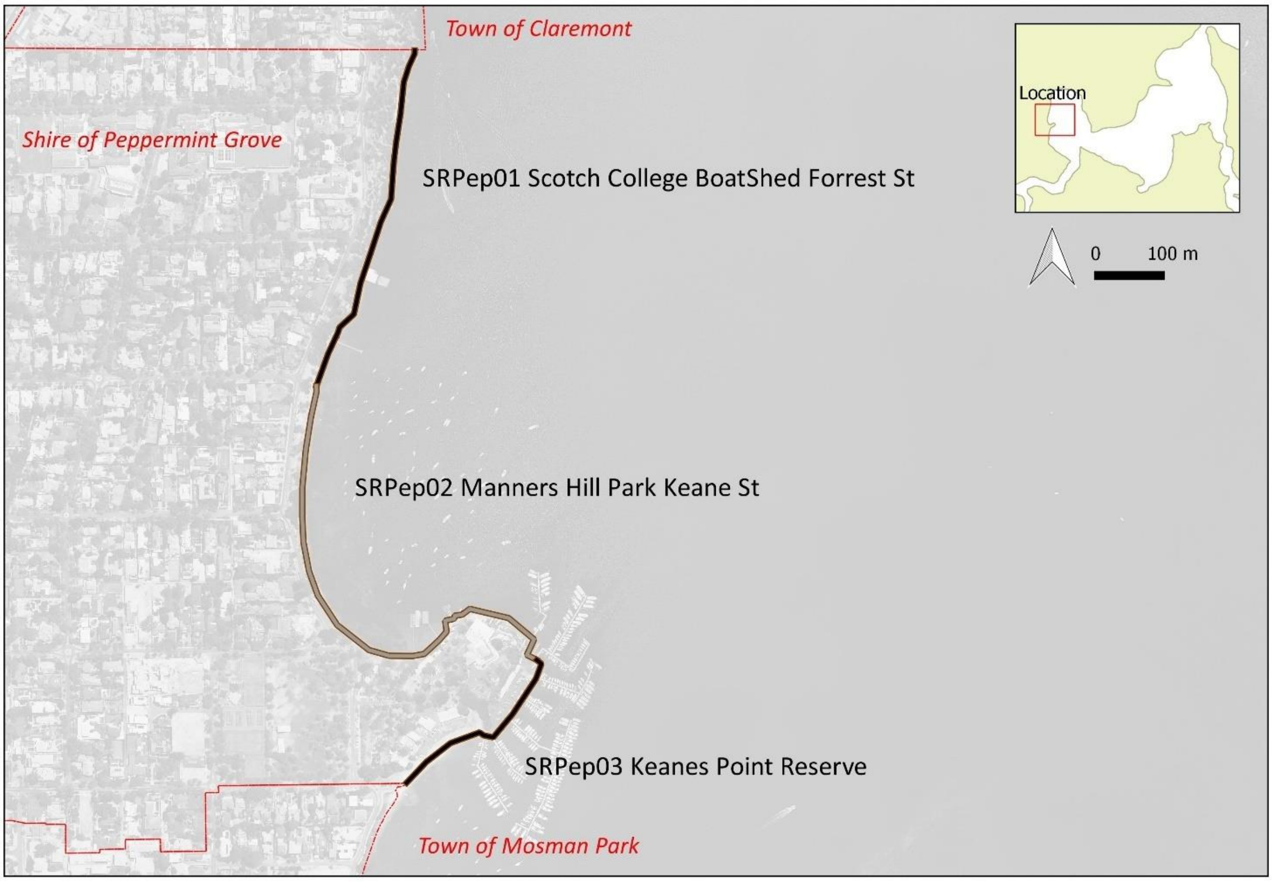

Figure 9-1: Shire of Peppermint Grove Segments

9.1. CONTEXT AND VULNERABILITY

9.1.1. Process Overview

Segments SRPep01 and SRPep02 (Claremont Cliffs to Keanes Point)

The southwest part of Freshwater Bay is a small sandy pocket beach, held in place by the rocky outcrop of Keanes Point (Butler's Hump). North of this pocket beach are rocky cliffs, which were mined during early European settlement of the Swan River. Although the wave climate suggests southwards potential sediment transport, this potential is not realised due to an absence of mobile material.

Peppermint Grove beach is a natural zone of accumulation. However, accretion is limited by the size of Butler Hump and sediment supply from the Claremont Cliffs is very low. Consequently, this may be considered a partially stable beach, which may be obscured by a lack of available records of likely historic renourishment in the south (1970s). Recently sediment has accumulated in the centre of the bay with erosion at the northern and southern section of the beach. Its low topography determines that it is subject to occasional inundation with drainage constrained by high groundwater tables.

The beach has a wall covering the southern half of the beach, with many sections of the wall reliant on a beach in front for stability as the toe is located on a sub-tidal rock platform.

The beach is responding to historic modifications including a partial blockage of supply to the south with the hardening and reclamation of Keanes Point, and removal of a structure extending riverward (tea rooms) south of Scotch College Boatshed. The tea rooms were removed in the period 1995-2003, with associated riverward migration of the beach toe and flattening of the downstream beach profile. This is contributing to erosion south of the walling, in conjunction with increased reflection due to the recent raising of the walling adjacent to the jetty.

Whilst the talus material along Claremont Cliffs is resistant to wave action, it is subject to gradual degradation and erosion. Foreshore structures, including "Lover's Walk" pathway and walling adjacent to Scotch College Boatshed, are likely to be affected by very gradual foreshore retreat.

Segment SRPep03 (Keanes Point and northern Mosman Bay)

The Shire of Peppermint Grove manages the northern section of Mosman Bay, which is part of a broader section of river mainly managed by the Town of Mosman Park. Considered at a large scale, the section from Keanes Point to Chidley Point has a tendency for material transport towards Chidley Point due to wave action. However, this section of foreshore is the upstream end of the tidal gorge, bounded on the north side by the submerged rock upon which Point Walter Spit sits. Consequently, currents will tend to deposit sediment where the flow speed reduces, in the river between Keanes Point and Point Walter Spit at the south end of Freshwater Bay.

Mosman Bay is a section of beach between the Swan Canoe Club and Keanes Point that has been isolated from a supply of sediment to the south through the construction of Mosman Jetty landing in 1912. The sediment dynamics of the bay have also been impacted by the riverward extension of Keanes Point for the Royal Freshwater Bay Yacht Club (RFBYC), and associated dredging, as well as walling to landward. The walling along Mosman Bay is reliant on the presence of a beach in front, with the last large renourishment undertaken in 1964-1967. Sand in the bay is transported from south to north, with sediment backpassed to the south of the beach until at least the mid-1990s, with accumulated sand at the north harvested for use on other beaches in the 2000s. The large renourishment program disrupted bars present on the foreshore (1953 aerial photo), which changed the bars from importing sediment to the beach to exporting sediment from the beach including to infill dredge holes. The beach structure was altered from a steeper structure to a shallow and flat structure, contributing to loss of amenity. The broader scale sediment transport processes determine that Mosman Bay may be subject to short episodes of rapid accumulation, followed by extended periods of erosion, due to the nature of the tidal gorge varying from acting as a sediment sink to a sediment source. Sediment is also lost from the beach into dredge holes along the edge of the terrace and at the northern end adjacent to the RFBYC jetties.

The northern extent of Mosman bay managed by Shire of Peppermint Grove experiences ongoing accumulation as sediment is transported from the south. This material has a long history of being harvested for backpassing to the south and exporting to other beaches. Material accumulated in this area should continue to be available for ongoing backpassing to maintain Mosman Bay.

Any future works require sufficient embedment to cater for bed movements and the bay is likely to require ongoing renourishment or backpassing.

9.1.2. Previous and Existing Plans

The existing management plan for the Shire of Peppermint Grove foreshore is the *Keane's Point Foreshore Reserve – Upgrade Strategy* (SoPG 2011), focused on the Keane's Point Reserve area (SRPep02). The main recommendations related to foreshore management in the document were:

- Repair the river wall (some patching had already been undertaken between 2006 and 2011);
- Management of stormwater and drainage into the river, with the suggestion of considering removing all drains flowing into the river to reduce the contribution to erosion;
- Re-turf degraded areas between Leake and Keane Streets;
- Construct a paved footpath that links the café to the foreshore at the bottom of Keane St, and then across to the western side of the Esplanade to join the existing footpath. A re-turfed area above a repaired river wall is considered sufficient; and
- Install new bollards for dinghy storage.

This strategy requires some review in terms of erosion patterns, northern and southern ends of the broader foreshore in the context of historic modifications and embedment of the existing structures.

The foreshore south of Keanes Point (SRPep03) requires joint management with the Town of Mosman Park. The present plans directly impacting the SoPG foreshore in this section are any plans associated with the RFBYC, as well as the existing plan for expansion of the boat ramp (including dredging of appropriate areas).

In the *Foreshore Assessment and Management Strategy* (SRT 2008) the SoPG foreshore is separated at Keanes Point (location of the RFBYC), with both sections north and south identified as low priority (priority 3) in terms of urgent investment in foreshore stabilisation works. The main recommendations for the foreshore are to monitor and maintain structures and in Mosman Bay only, and to undertake renourishment where appropriate.

The constraints to future works as a result of previous and existing plans are:

- Water Corporation sewage overflow tanks limiting opportunities for redesign of walling between Keane's Point jetty and the northern intersection of Leake Street and the Esplanade. Works cannot extend landward due to the tanks;

- Limited documentation of dredging and renourishment, restricting capacity to identify potential causes of local erosion;
- Previous maintenance works. Proposed walling maintenance plans and their outcomes will be affected by previous methods, including
    - Use of concrete infill to landward (in the north) reduces permeability, transferring erosion stress to the bed riverward of the structure and can lead to cavitation;
    - Focal re-grout on the upper portions of walling (in the south) transfers erosion stresses to the lower portion or the walling and toe (e.g. failure in Figure 9-11); and
    - If voids were not infilled sufficiently during the re-grout process these may become focal points of damage and failure.
- Existing drainage;
- Unconstrained pedestrian access, as well as kayak and stand up paddle board launching;
- Dinghy storage and launching;
- RFBYC expansions;
- The requirement for the ToMP to agree with proposed works in Mosman Bay; and
- Any works at Scotch boatshed.

9.1.3. Historic Works

The Shire of Peppermint Grove foreshore was initially a gentle grade vegetated foreshore, located between rocky outcrops and cliffs including Butler's hump (Keane's Point). Modifications have been undertaken over time for navigation purposes, beautification, recreation, camping, boat launching, drainage and yacht club use. In many areas the sandy foreshore is now located 30m riverward of the pre-reclaimed foreshore. The large walling and reclamation works in Keane's Point Reserve were undertaken in 1935. The works associated with the RFBYC were largely undertaken in 1964 and included large reclamation works that altered sediment dynamics, renourishment north and south of the RFBYC and local dredging pockets. Removal of a control to sediment transport at the tea rooms between 1995 and 2003 has contributed to erosion south of Leake St.

This section should be read in conjunction with Section 2.3.1 which includes a summary of how environmental regulations and management practices across the river have changed over time.

An overview of some changes and issues in the Shire of Peppermint Grove are included in Figure 9-2. Key changes in relation to foreshore management are listed in Table 9-1 with context provided with aerial images of 1953, 1965, 1983, 2014 per segment (Figure 12-76 to Figure 12-78). Further historic images are included in Section 9.1.5, with possible indication of previous renourishment shown in Figure 9-3.

Figure 9-2: Some issues and modifications for Freshwater Bay, Keanes Point and Mosman Bay (south of boat ramp is Town of Mosman Park)

Table 9-1: Historic modifications relevant to present-day foreshore management

Segment	Modification	Date
SRPep01 Scotch College BoatShed Forrest St	Walling under cliffs: • 2 gravel paths installed, upgrading old track • Progressive walling upgrades including stairs • Partial wall reconstruction N of Scotch boatshed	1937 Dates unknown 2011
	Walling at Scotch boat shed • Wall construction • Scotch boat shed construction and jetty • Wall upgrades	Possibly 1914 1914 Dates unknown
	Old tea rooms: • Walling • Riverward extension providing control • Removal of old tea rooms platform • Ongoing maintenance and patching • Recent reconstruction following storms and regrout	Pre-1936 Date unknown 1995-2003 Date unknown 2011
	Reclamation through mining of rocks from cliffs to create pathway. Quarrying.	Dates unknown.
SRPep02 Manners Hill Park Keane St	Walling • Log-walling • Stone walling with raising bank levels and turf • Vertical increase of 0.15m by Water Corp. (local) • Partial reconstruction at S end following storms	Pre-1935 1935 2009 2011
	Renourishment	Potentially in 1970s (unconfirmed)
	Keane's Point Jetty • Reclamation and initial alignment (16m) • Upgrade of walling and extension W	Pre-1906 1964 (unsure of date)
	RFBYC reclamation	1964
SRPep03 Keanes Point Reserve	RFBYC reclamation (including dredging >100m from shoreline)	1964
	Renourishment adjacent to RFBYC	1964
	Boat ramp to the S impeding cross shore transport	Progressive consolidation.
	Backpassing sediment to the south in Mosman Bay	Ongoing, last known documented was 1995.
	Harvesting sediment for use elsewhere in river	Ongoing by Swan River Trust 1995 until ≈2013
	Dredging of RFBYC berth areas and dredge pocket to S, (≈4,000m^3). Pocket to the S assumed to be for beach infill for RFBYC boat launching.	1964

Figure 9-3: Possible Historic Renourishment and Dredging (Source PWD 40488-1-3 1963)

9.1.4. Site Issues and Constraints

Details of issues and constraints for the three segments in the Shire of Peppermint Grove are included in Table 12-42 (Appendix F.2). This is in addition to some further broader issues of:

- Resourcing for future works.
- Stakeholder conflict north of RFBYC. Conflicts may include advice to remove/alter the toilet block and access pathways to reduce runoff erosion, yet Scotch College likely relies on the toilet block. The erosion between the two northern segments requires altered management of dinghy/kayak storage and launching, stormwater management, alongshore controls and foreshore access which may not satisfy all stakeholders. Further south any works on the walling or foreshore require consideration of stormwater management (multiple drains and overbank drainage), avoiding the Water Corporation storage tanks during construction and ensuring they are protected, kiosk operations, maintaining boat shed jetties, protection of the Moreton Bay figs, ensuring a beach is present for recreation purposes and the views of private property owners facing the foreshore.
- Stakeholder conflict south of RFBYC. The broader Mosman Bay is managed by Shire of Peppermint Grove and Town of Mosman Park, separated at the northern limit of the boat ramp. The Town manages the boat ramp with the Shire providing the car park. Management decisions for the Mosman Bay foreshore should be made in agreement with both councils. Sediment accumulating in the Shire of Peppermint Grove segment benefits the Sea Scout and RFBYC operations, with these two stakeholders potentially not supporting an initiative to harvest this sediment for backpassing to the south even though this was historically undertaken. People who launch boats at this location will resist actions that decrease the function of the boat ramp.
- Foreshore is still responding to previous active sediment management, including dredging, renourishment, backpassing and harvesting sediment from these beaches for use in other locations of the Swan River. Any works that will create new or altered longshore controls require consideration of wider impacts.
- Stability of cliffs and erosion mitigation structures in the north adjacent to path.
- Stormwater management.
- Maintenance of turnaround area immediately north of Scotch boatshed.
- There is no direct point source for recreation access as car parking is spread along the broader foreshore, which limits options to minimise trampling of erosion scarps.
- Walling in northern segment (SRPep01 Scotch College BoatShed Forrest St) is approaching the end of its functional life.
- Future population pressure for fixed paths in Manners Hill Reserve or Keanes Point Reserve. Also pressure to upgrade or improve the path in the north (SRPep01 Scotch College BoatShed Forrest St).
- Indigenous approval discussions required for any dredging/haulage, including backpassing (sourced from southern Keanes Point, and from near Irvine Street) and sourcing material for southern Freshwater Bay.
- Changing far-field forcing of boat wakes.

9.1.5. Observed Change

The Shire of Peppermint Grove foreshore is presently responding to previous reclamation works at the northern and southern extents of broad bays, including walling, dredging and renourishment, in conjunction with drainage and surface runoff (Figure 9-5, Figure 9-6, Figure 9-9, Figure 9-11). In addition to these anthropogenic changes, it is also responding to inter-annual variability of naturally occurring processes, including winds, water levels and sediment supply.

Historic aerial imagery of this site is only available from 1953, with a number of old images (Figure 9-4, Figure 9-5, Figure 9-9, Figure 9-10, Figure 9-12) used to demonstrate impacts of historic works on the foreshore.

The SoPG foreshore region has been separated into three segments for ease of analysis and interpretation. These sections are:

- SRPep01 – the segment immediately south of the Scotch Boatshed up to Leake Street.
- SRPep02 – the segment south of Leake Street, encompassing the broader Keane's Point Reserve Foreshore, up to the walling/reclamation of land to the north of RFBYC.
- SRPeP03 – the segment south of RFBYC up to Johnston Street (boat launching area).

The observed changes are also discussed on a segment basis.

<u>SRPep01 – ToC border to Leake Street</u>

- Path from Devil's elbow has been in place since the early 1900s, upgraded to 2 gravel tracks in 1937 (Figure 9-5) with subsequent upgrades and progressive reconstruction to failed walling. Most recent works were undertaken in 2011 following partial wall collapse.
- Walling between Scotch College Boatshed and new walling close to the nearby jetty is at the end of its functional life. This wall has had rock placed to riverward (making maintenance difficult) and reconstruction works in 2011 following partial collapse. Overtopping has occurred at this location.
- Increased runoff from stairs and access pathways contributes to walling damage.
- Bed level lowering adjacent to the dinghy storage area, and foreshore retreat to the south (S of Leake St) has occurred (Figure 9-7). The impacts on the foreshore to the south is discussed in SRPep02.

<u>SRPep02 – Leake Street to mid-RFBYC</u>

- Erosion is occurring to the south of the drain and dinghy storage area at Leake Street (Figure 9-7). Recent trends have caused a horizontal erosion distance of up to 5m and scarps present for 55m downstream, with some retention provided by the palm tree (Figure 9-8). Multiple pressures have contributed to this erosion, including (in no particular order):
    - Removal of the tea rooms' platform and stairs in the period 1995-2003 (Figure 9-4, Figure 9-6).
    - Raising and southwards extension of limestone block walling adjacent to the jetty in 2006-2008. The raised walling causes increased wave reflection and scour at the toe. Any beach riverward of this structure has eroded.
    - Construction of a raised scour apron for the drain, with reconstruction in 2011. A scour apron should not have a step and should be more flexible to reduce scour potential. Drain cleaning work by SoPG in 2009 may have contributed to increased flow from the drain, and increased scour potential.
    - Rock infill between the wall and drain in 2011-2014 transferred erosion pressures downdrift.
    - There is no gradual tie-in between the drain headwall and scour apron to the adjacent bank to the south.
    - Consolidation of dinghy storage above the walling contributes to trampling south of the drain to launch and retrieve the dinghies, mobilising sediment for erosion.
    - Trampling by pedestrians, kayak users and stand up paddle board users.

  - Unusual conditions from 2011-2013 during a strong La Nina with raised mean sea levels and less strong southerlies in summer. This may have reduced the amount of sediment transported from the south to prime the beaches for winter.
  - Possible previous backpassing/renourishment was undertaken at this site.
  - Installation of irrigation (and possible pipe bursts) south of drain saturating the sediment, improving the capacity for entrainment.
  - Bathymetric shallowing, possibly indication of previous dredge hole infill (Figure 9-3). Dredging may have been associated with old RFBYC (pre-1950s) or tea rooms.
- Historic foreshore was a gentle grade (Figure 9-9, Figure 9-10). Over time this area has had walling installed, partial reclamation and possible 1960s renourishment (Figure 9-3).
- Works at both ends of Freshwater Bay (RFBYC extension in S and tearooms in N) provide restrictions to sediment transport patterns.
- Net erosion occurring across foreshore, with erosion at the southern and northern ends and sediment accumulation in the centre. Grassed foreshore levels landward of walling are raising in parts due to accretion and wind-driven transport. Erosion of non-vegetated foreshore expected to continue.
- Walling is overtopped, particularly at Keane St.
- Hardening of catchment over time has increased surface runoff, causing multiple drains to contribute to elevated local scour.
- Beach is inundated in high water level events.
- Trampling occurring along broader foreshore due to large parking area creating broad access.
- S 190m of walling approaching end of structural life, with maintenance focused on the upper portion of the walling (Figure 9-11). Walling was constructed pre-1940 and was designed to have a beach at its toe. Walling now sits on rock base in many parts and the beach has eroded to the point of creating insufficient embedment for walling. This section requires more maintenance to be undertaken at the walling toe.

Figure 9-4: SRPep01 S - Historic Tea Rooms location of jetty and dinghy storage 1940s (The Grove)

Figure 9-5: SRPep01 S - Walling between Tea Rooms and Scotch Boatshed 1940s (The Grove)

Figure 9-6: SRPep01 S - Old Tea Rooms Platform Showing Steps and Lower Elevation Walling 1995 Steps provided beach position control and lower elevation walling (The Grove)

Figure 9-7: SRPep01/SRPep02 Foreshore Modifications from 1995-2014 (Source: Landgate)

Figure 9-8: Retreat in northern SRPep02 (proximate to Leake St) – 16 April 2015
Base image is broader retreat

Figure 9-9: SRPep02 Keane's Point Reserve Foreshore 1900-2014 (The Grove)

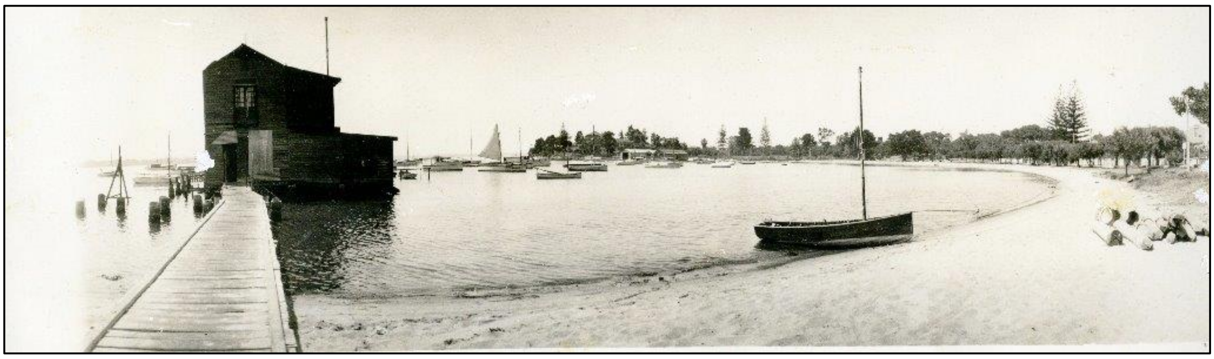

Figure 9-10: SRPep02 Keane's Point Reserve 1936 with original RFBYC, now removed (The Grove)

Figure 9-11: Example of SRPep02 Walling Failure and Maintenance (2010 Top, 2014 Base)

Figure 9-12: RBYC 1936 (Top) and 1940s (Base) (The Grove)

<u>SRPep03 – mid-RFBYC to ToMP border (boat ramp)</u>

The majority of observed change in this segment is attributed to land reclamation for RFBYC, large-scale renourishment in the 1960s, response to local dredge hole from 1960s and subsequent sediment backpassing to southern Mosman Bay (ToMP, until ca 1995) and sediment harvesting for renourishment of other portions of the Swan River (by SRT until ca 2013). The site prior to 1960 is shown in Figure 9-13, with extent of works in 1960s shown in Figure 12-78.

Figure 9-13: SRPep03, south of RFBYC before 1960s extension (The Grove)

The foreshore in this segment is accumulating, with a grassed area used by the sea scouts and RFBYC for vessel launching. This grassed level has raised over time. The accumulated sediment in this area is available for backpassing within Mosman Bay. During stormy periods scarps forms in the grass.

9.1.6. Structure Condition and Function Comparison

Previous assessments of structure condition and function have been used in preparation of the foreshore management and adaptation approach for Shire of Peppermint Grove. The details of the 2004 and 2014 assessments are included in Appendix F.3 with tables of structure condition and short-term maintenance comments in Appendix F.4. Drains were only assessed in 2014 if they were contained within other foreshore structures.

9.1.7. Foreshore Controls and Sensitivities

The foreshore controls and sensitivities for the Shire of Peppermint Grove foreshore include:

- Modified foreshore. The historic reclamation and hard structures restrict alongshore transport at the Tearooms (historically) in the north and RFBYC in the south. The RFBYC reclamation increases the sediment capture capacity for the beach to the south in Mosman Bay. Walled foreshores provide a fixed position for the foreshore, limiting natural sediment transport processes.
- Any works proposed in the future that provide a hard structure that extends further riverward, or interrupt hydraulic smoothness within the broader Keane's Point Reserve area should be considered in terms of the impact on the broader foreshore area.

- Underlying rock substrate to be considered in any future plans. This includes capacity to embed replacement structures with consideration of tie-ins of the structure toe to the rocky substrate that is above mean sea level (≈+0.3 mAHD) towards Keane's Jetty.
- Sensitivity to dredged areas, with locations of historic dredging unknown.
- Ensuring capacity for structures, and broader foreshore, to be able to migrate landwards and upwards. This requires limited investment in fixed infrastructure or new trees immediately landward of the walling. An example of this limitation is demonstrated by the Water Corporation sewage overflow tanks (Figure 9-14).
- All structures with exposed lower third vertically are sensitive to loss of grout. Maintenance work has either previously focused on regrout on the upper portions of the walling without digging out the toe area, or has used grout that is not marine grade (M4). Most of the exposed structures show movement in the lower units and at the toe, which provides a focal area for failure.
- Sensitive to future bed level lowering in SRPep01 and SRPep02. The walling in SRPep01 experiences erosion stress at the toe with limited capacity to upgrade the toe due to underlying and adjacent rocks. The walling in SRPep02 was constructed in 1935 with an adjacent beach. There is insufficient embedment of the wall toe for the bed level lowering that has occurred at this site, with insufficient reapplication of grout below summer bed levels (requires temporary beach excavation).
- Any replacement walling in the approximately present location of SRPep02 will be low-elevation as it is impractical to raise elevation of the areas to landward and it transfers flood hazard to the road.
- Resilience of walling in SRPep01 is reliant on the integrity of the grout.
- Works undertaken in proximity to Leake Street impacting on foreshore position locally and across the broader 100m foreshore to the south.
- Foreshore in the southern segment (SRPep03) is sensitive to any works undertaken by the Town of Mosman Park within Mosman Bay and at the boat ramp. It is also sensitive to harvesting of accumulated sediment for use in other sections of the river, not recommended to continue.
- Twelve drains discharge into the foreshore north of RFBYC. The drain and associated overbank flow at Keane Street cause local scour of the beach and reduce the resilience of the wall. The drains along Keane's Point Reserve foreshore that drain the Esplanade between Leake and Keane Streets cause scour of the beach levels, contribute to beach loss and ponding of water with associated water quality concerns. Drain invert levels are unlikely to be raised to elevation limitations to landward.
- Unmanaged surface runoff at stairs, from the roof at the toilets in SRPep01, low points in the road and Mosman Bay boat ramp contribute to local scour and of beaches and damage to walling.
- Focal areas of erosion are susceptible to trampling by pedestrians and vessel launching, as well as irrigation, both of which can increase rates of erosion.

Only 0.29km of the 1.61km foreshore length managed by the Shire of Peppermint Grove is sedimentary foreshore, with 0.17km of cliffs and 1.15km of walling. Existing walling levels for structures managed by SoPG are shown in Figure 9-15 and photos in Appendix F.7. Walling is transferring erosion stress to the toe and the southern extent of walling at Leake Street is transferring erosion stress to the foreshore to the south. The low elevation walling in SRPep02 (Figure 9-15 left panel) is subject to inundation, which will require some management of overtopping and runoff scour immediately to landward.

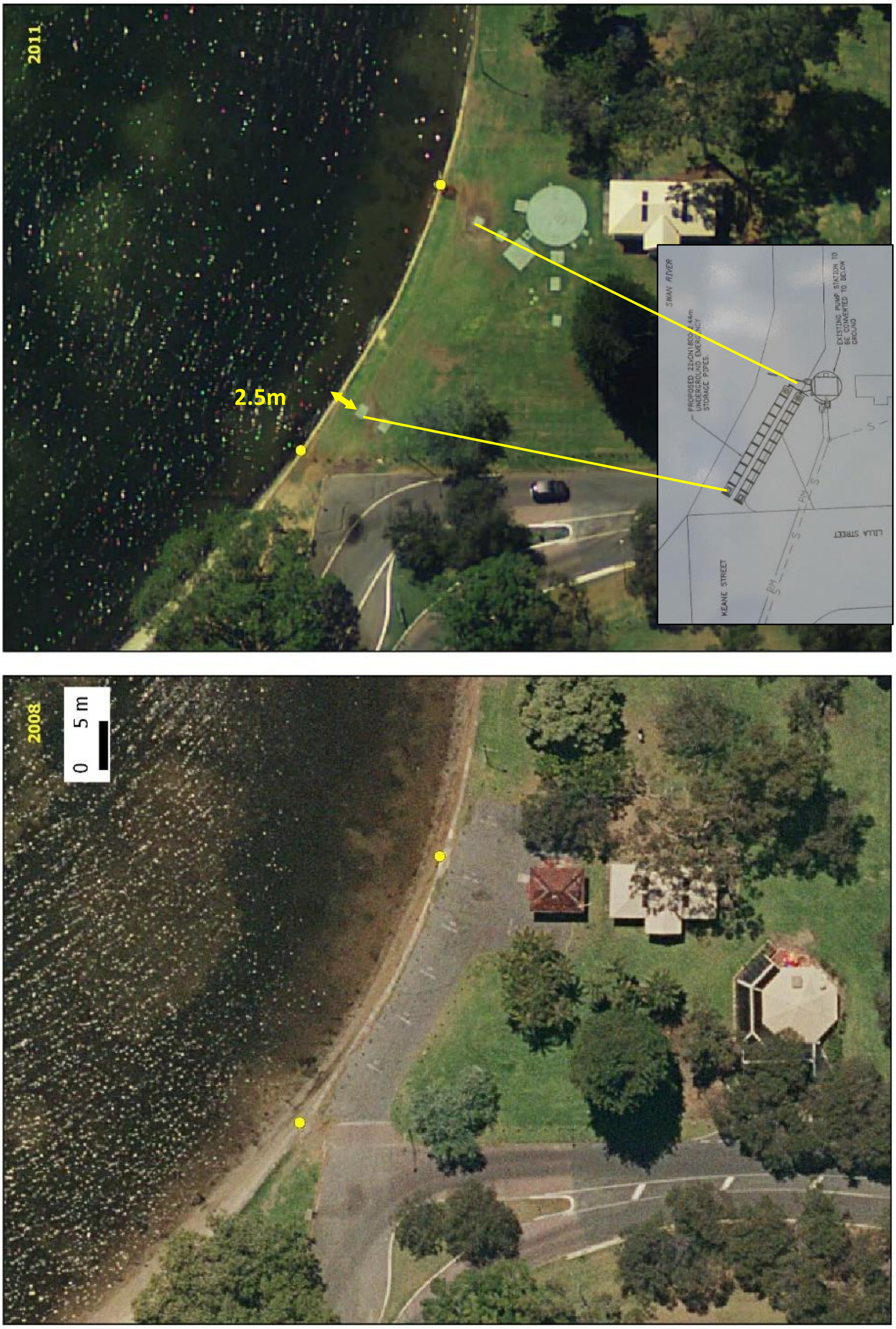

Figure 9-14: Water Corporation Storage Tanks Upgraded 2009

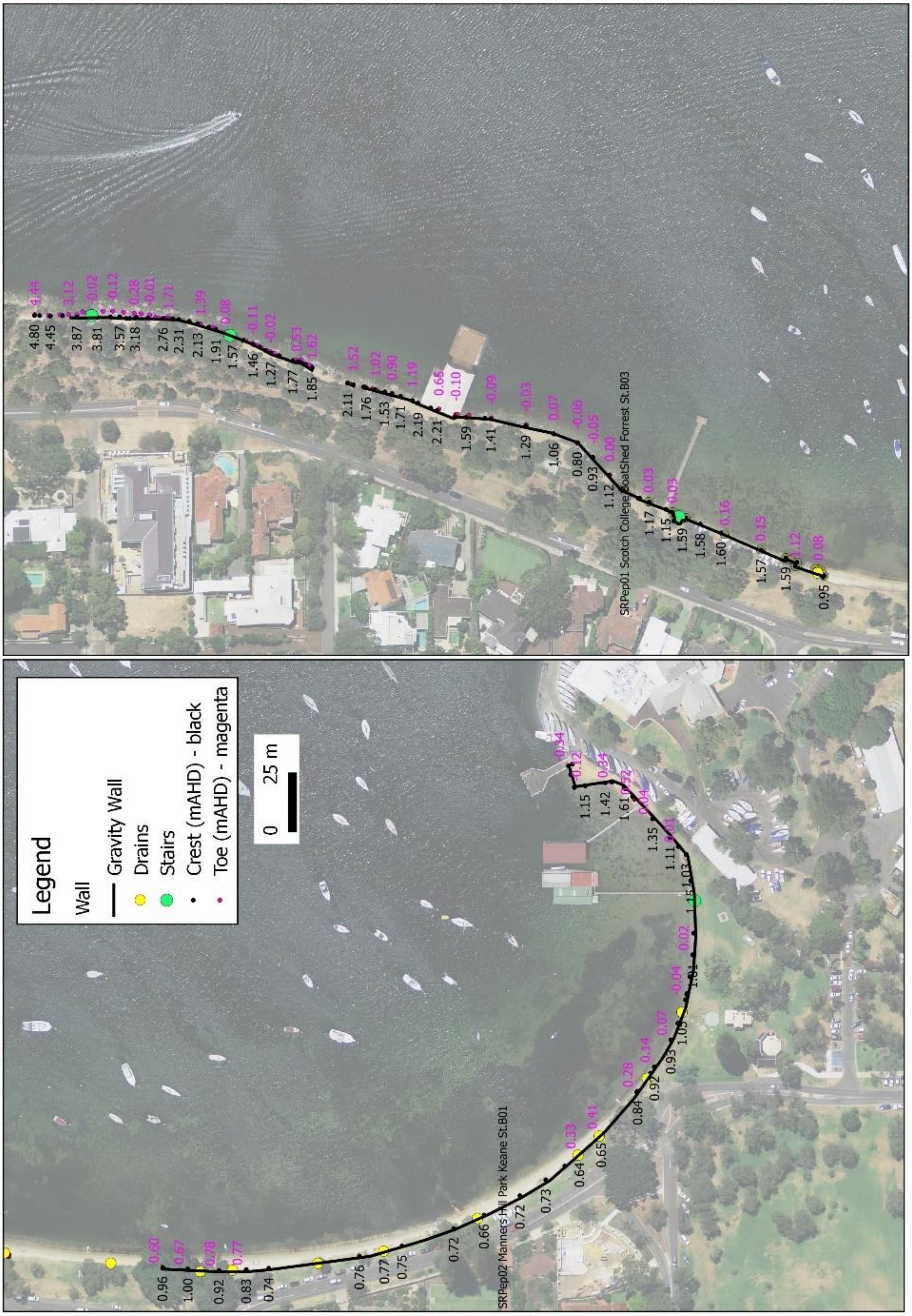

Figure 9-15: SoPG Walling Levels - January 2015 (on 2014 image)

The original walling in SRPep02 was constructed in 1935 to retain the foreshore and near the tea rooms in SRPep01 at approximately the similar time. The walling near the jetty north of Leake St was subsequently upgraded. The SoPG undertakes reactive maintenance on all of the walling. Recent maintenance has been temporary repairs when partial failure has occurred, this has included reconstruction of walling with cement placed behind and material infill (Figure 9-16; SRPep01) and regrout of displaced units (Figure 9-11; SRPep02). Ongoing reactive maintenance is anticipated.

Figure 9-16: Partial Wall Reconstruction SRPep01 (August 2011, SoPG)

The foreshore is low lying with the exception of Keane's Point (RFBYC) and the cliffed and walled foreshore north of Leake St (Figure 9-17). The foreshore in SRPep03 is 13-30m wide between the grass line and buildings, with the majority of that area <+1 mAHD. In SRPep02, the walling levels vary from ≈+1 mAHD between Keane St and the boatsheds, with crest levels decreasing to 0.64 m at northern intersection of Keane St and the Esplanade (Figure 9-15), then increasing to +1 mAHD to the north. The foreshore along the Esplanade is low-lying with road levels ≈+0.7m AHD (1.4mCD) in some parts, which is approximately Highest Astronomical Tide. The only low section of walling subject to frequent inundation in SRPep01 is the old section near the toilets with levels as low as +0.8 mAHD. Surface runoff and high river levels contribute to ponding on the roads and foreshores. The beach, grassed and low walling foreshore areas would be inundated during most winters.

Foreshore structure and drain maintenance requirements provides one of the greatest foreshore sensitivities for the SoPG. As many of the walls were constructed in the 1930s and 1940s, and are approaching the end of their structural life, if adequate maintenance is not undertaken it may lead to failure, which can transfer erosion stress. Tables of the condition and potential maintenance of the four separate wall sections and most drains were prepared by Damara WA (2015) for Parks and Wildlife at a broad scale (Table 12-44 and Table 12-45; Appendix F.3). Some of the information has been refined given the further information obtained from SoPG regarding maintenance work undertaken since 2007 and for consideration of the moderate to longer-term vulnerabilities and planning requirements (Section 9.2).

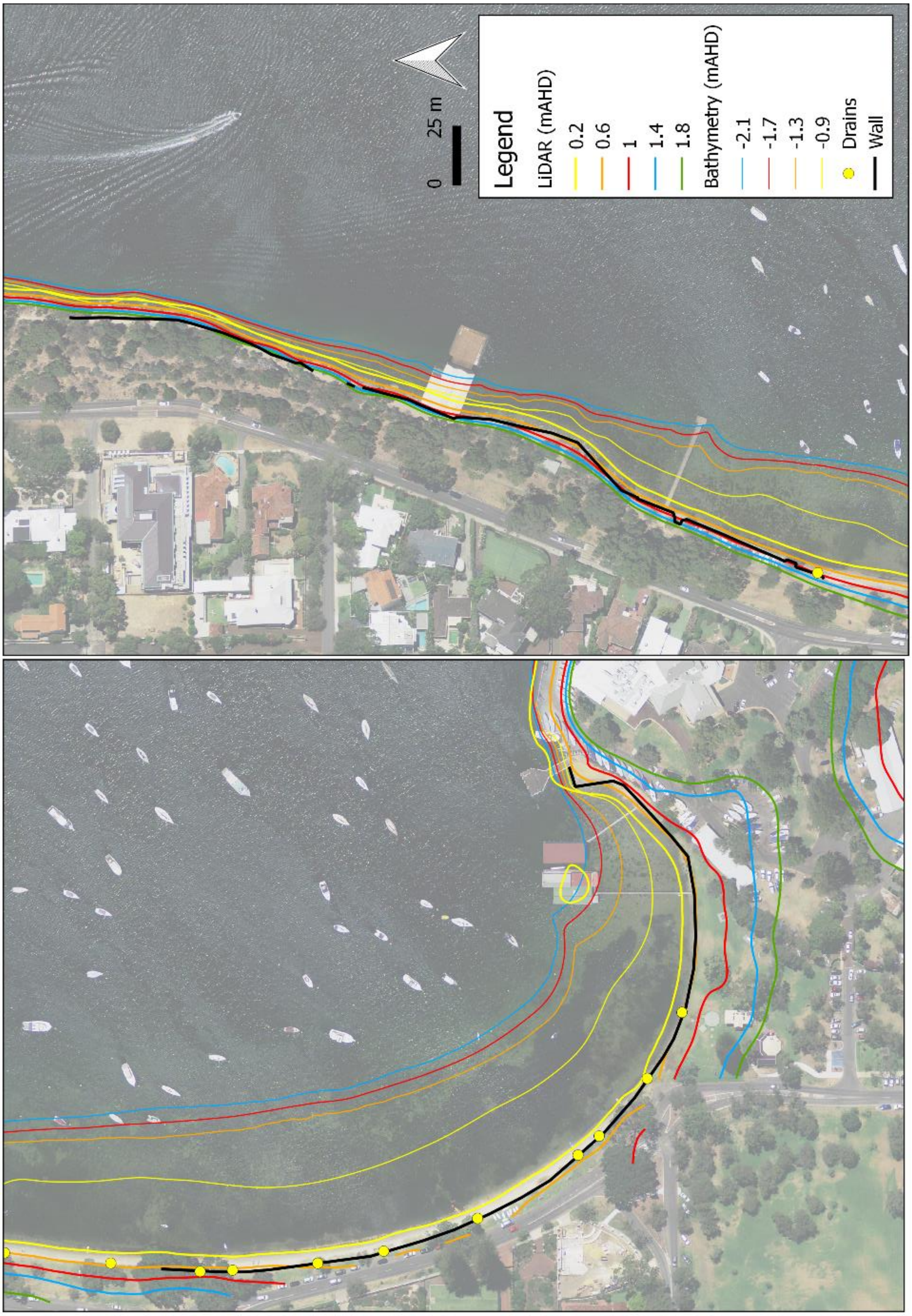

Figure 9-17: Topography and Bathymetry focusing on SRPep01 and SRPep02 in SoPG

9.1.8. Scenarios and Impacts

The scenario at present is:

- Continued degradation of aged walling, with grout weathering, block movement and loss, erosion at the toe, slumping and partial collapse during high water level events due to destabilisation from scour behind the structure.
- Ongoing maintenance requirement for the walling not fronted by a beach.
- Bed level lowering at the dinghy storage area increases wave energy transmission to walling, increases reflection and feedback on bed level lowering. Also contributes to erosion to the south.
- Increased risk of cavitation damage behind walling due to method of concrete infill to landward of patched walling. Patched walling relies on the grout integrity.
- Foreshore retreat south of the dinghy storage area, south of Leake Street.
- Continued erosion of the foreshore, with erosion at the southern and northern ends, with sediment accumulation in the centre. Foreshore is continuing to respond to hard structures modifying sediment transport.
- Wall overtopping during storm events as well as inundation of the beach and broader foreshore.
- Interaction of high river level events with surface runoff.
- Ongoing local erosion stress associated with drain scour and unmanaged runoff from stairs, low points in the road and at the boat ramp. The drain scour and unmanaged runoff causes local bed level lowering, ponding of stagnant water, local walling damage and accumulation of surface runoff along the roads at Keane Street and the Esplanade.
- Ongoing local erosion stress due to trampling, kayak and stand up paddle board launching in SRPep02.
- Sediment accumulation in SRPep03, with scarping in the grass during stormy periods.
- Continued inter-annual discrepancy in seasonal and net sediment transport.

The scenario of increased mean sea level could result in the potential responses outlined in Section 9.1.10 in the >25 year category.

Further scenarios to consider are expansions of Scotch boat shed, dinghy storage areas, RFBYC jetties and reclaimed areas, and car parking along the Esplanade. It is assumed there will be no fixed path placed along the foreshore and no works will be undertaken that further reduce the sediment exchange along the foreshore.

9.1.9. Values and Foreshore Uses Considered (Short- and Long-Term)

The foreshore values and use for the Shire of Peppermint Grove foreshore include:

- Maintain existing where possible.
- Low maintenance solutions through increasing foreshore resilience.
- Maintain significant trees (e.g. peppermint trees, Moreton Bay fig at Keane St).
- Maintain all Bush Forever sites (Bush Forever 403)
- Maintain all Native Title/Aboriginal Heritage (DAA Heritage Site – Site Swan River 3536)
- Maintain all European Heritage Sites
    - Devil’s Elbow
    - Keane’s Point Jetty
    - RFBYC clubhouse in old Keane family home
- Maintain stability of cliffs and erosion mitigation structures in SRPep01 adjacent to the path.

- Foreshore management should not defer erosion/inundations risks to local private property owners. Private property owners should not transfer erosion risk to the foreshore reserve.
- Maintain café, with consideration to rebuild facility with similar sized footprint, possibly incorporating public toilets into new building (remove older toilets).
- Existing jetties at Keane's Point and Leake Street to be maintained for recreational amenity.
- Scotch College Boatshed provides significant recreational value, with high usage rate. Associated facilities include the 24hr vehicular access via the chain gate near Leake St/Esplanade intersection.
- Parking area allowing for vehicle turnaround to be maintained at Scotch Boatshed.
- Western Power lighting on Keanes Point Reserve near boatsheds should be maintained.
- Freshwater Bay Foreshore provides significant recreational usage via groups using vegetated (turf grass) for picnics etc. Community places value on no change occurring in this area.
- Freshwater Bay Foreshore also used for other recreational purposes, including standup paddle boarding classes and other various water sports.
- Stormwater management must be carefully planned in low lying areas due to high groundwater level (i.e. significantly small buffer space for catching stormwater). Ensure surface runoff is managed well.
- Vehicular access to all foreshore areas to be retained to ensure ongoing maintenance and waste management can be performed.
- Maintenance of the Whadjuk Wardun Beeliar Bidi Walking Trail.
- Maintain boat moorings (50m from walling at Scotch College Boatshed, 80m from beach at Keane's Point Reserve).
- Maintain of kayak/dinghy launching areas, while discouraging use of jet skis.
- Maintain dinghy storage at Scotch Boatshed and Keane's Point Reserve.
- Maintenance of stairs and seating in public areas.
- Consider ecological benefits of occasional seagrass wrack accumulation.

As the population density increases it is anticipated there will be increased use of this foreshore.

9.1.10. Vulnerability

<u>Existing vulnerability (0-5 years)</u>

There are three sections of low elevation walling in the SoPG (Figure 9-15), including 30m between Scotch boatshed and the jetty (+0.8 to +1.12 mAHD), 10m north of the Leake Street drain (+0.95 mAHD) and 350m between the Moreton Bay Fig and the first boatshed (+0.64 to +1.03 mAHD). Inundation of the walling in these areas occurs for a 0.4m surge on an average high tide (+0.7mAHD) through to a 10-year ARI still water level at the highest point (+1.1 mAHD) if no waves and no mean sea level shift. Example inundation and surface drainage ponding photos from an event with a short-lived inundation peak of +1.13mAHD at Fremantle and +0.98mAHD at Barrack Street are included in Figure 9-18. Inundation increases during La Nina events due to an increase in mean sea level.

Waves contribute to local scarping and erosion of beaches, alongshore sediment transport, erosion adjacent to hard structures, scour of material at the structure toe, erosion through gaps in the grout, erosion behind structures due to overtopping and in SRPep03 can also contribute to beach building processes through overtopping of the storm bar. Waves are 0.6/0.7 to 0.7/0.9m Hs (3-year to 100-year), with small long-period boat wakes also occurring at the site.

Figure 9-18: Inundation and Surface Runoff Ponding during 20 May 2011 Storm (Source: SoPG)

The foreshore is sensitive to inter-annual variability in the water level, wind and wave climate, which contributes to varied sediment accumulation in the centre of the Keane's Point Reserve foreshore, in SRPep03 and at drains. Foreshore resilience is reduced if the sediment transport along the foreshore is interrupted by hard structures. The foreshore is vulnerable to any future changes in hard structures and to a lack of sand renourishment.

The interaction of surface runoff in the catchment, high groundwater levels, use of drainage pits and high mean sea level events results in water ponding on the Esplanade Road and overbank flow at the low point in the road and at Keane St (Figure 9-15, Figure 9-18). Focal erosion also occurs in the vicinity of the 12 drains, with vulnerability to an accumulated beach blocking low flow events for the central drains, reducing the drainage capacity. Local scour holes form that trap water with low water quality contributing to local algal growth. The two downstream drains require maintenance as water is discharging into the wall, which will contribute to local wall failure (Table 12-45).

The oldest 1936 walling is most susceptible to damage at the toe and the lower blocks, in areas with insufficient grout and in the lowest elevation locations without a beach fronting the structure. If the wall is overtopped and material is scoured from under, behind and through the structure it can lead to wall collapse, similar to what occurred in May 2011. Rates of sediment loss under, through and from behind structures is exacerbated by unmanaged runoff and reticulation.

Other sections of walling susceptible to damage are areas where:

- grout has eroded between the wall and the underlying rock pavement or rock structure north of Leake Street and towards Keane's Point jetty;
- cavitation has occurred;
- insufficient stability at the toe (e.g. Figure 9-19);
- walling is less permeable due to maintenance undertaken, with erosion stress at the toe;
- bed level lowering and loss of beach could cause further settling and structural damage;
- walling is adjacent to drains particularly where drains discharge in the wall, or directly on the face, with insufficient reapplication of grout;
- where irrigation pipes and sprinklers are located adjacent to walling; and
- there is a transition between different walling types, or between walls and rock outcrops, as these are focal areas of failure (Figure 9-19). For example the transition between the more recent limestone block wall in the dinghy storage area and the old walling near the toilets.

Figure 9-19: Some Examples of Walling in SRPep01 Requiring Maintenance (Jan. 2015)

Further vulnerability is associated with:

- Extending structures along the shore to address broad-scale erosion trends, which transfers the erosion stress to the adjacent foreshore (e.g. near Leake Street);
- Leaks from drainage and irrigation pipes, particularly relevant for irrigation located immediately adjacent to walling and edge of grassed areas;
- Unmanaged surface runoff in SRPep01 (Figure 9-20) from Devil's elbow stairs, from the toilet roofs down the stairs and a bitumen ramp, from the compacted access routes north and south of Leake Street off the Esplanade, and from the steep path above in 3 locations: 1) the stairs between the Esplanade and the jetty, 2) down the slope near the toilet and 3) drain discharge onto the path from the pathways/road above;
- Unmanaged surface runoff in SRPep02 with water flowing over the bank at the low point in the Esplanade and at the interaction of Lilla Street and Keane Street;
- Unmanaged surface runoff in SRPep03 with water flowing down the boat ramp from the surrounding road and car park, contributing to local scour;
- Overall cliff stability is influenced by groundwater behaviour and the focused surface runoff into the cliffs from the fixed paths above the cliffs;
- Removal of any sand accumulating south of RFBYC (SRPep03) for use in a foreshore area other than Mosman Bay;
- Removal of any sand accumulating in the mid-section of Keane's Point Reserve (SRPep02) for use in a foreshore area other than Freshwater Bay between Leake Street and Keane's Point;
- A large storm event that scours sediment from under the structure toe and through the lower part of the structure; and
- Construction of any new structure that impedes alongshore sediment transport.

<u>Progressive change to vulnerability (5-25 years)</u>

It is expected that many sections of the walling will reach the end of their functional life during this time period. Some of the drainage pipes may also require renewal, with age of each pipe to be determined by SoPG. Breakage and leaking promotes local walling weakness.

Figure 9-20: Examples of Unmanaged Surface Runoff in SRPep01 (Jan. 2015)

Some of the vectors for vulnerability described are likely to increase in magnitude in the 5-25 year period. This will include increased:

- Erosion at the toe of structures, through structures, between structures and over structures (in parts).
- Erosion south of Leake Street, and between Keane St/Lilla St and Keane's Point jetty, as the foreshore continues to respond to the historic works.
- Rate of grout weathering and lower block movements.
- Recreation use and creation of focal erosion areas due to uncontrolled access and vessel launching/retrieval.
- Runoff into drains and drainage pits with less recharge in the catchment as density increases in the SoPG. This will result in increased scour at drains, in areas of unmanaged runoff and ponding on the Esplanade.

A further source of vulnerability is due to staging of the walling replacement and walling works. Tie-in areas have the highest susceptibility to damage, with adequate temporary tie-ins to be designed when undertaking works in stages. If any new walling works extend further riverward, such as will be required in proximity to the Water Corporation storage tanks, additional consideration is required for stabilising the toe of adjacent structures to account for transfer of erosion stress.

The foreshore is also vulnerable to any erosion mitigation works undertaken by Town of Mosman Park to the south and any works undertaken by RFBYC.

Scenarios for changing vulnerability (>25 years)

Longer-term planning considers the scenario of increased mean sea level and increased surface runoff. This could increase the foreshore vulnerability to:

- Continued bed level lowering and stress at structure toe and lower half of the structures. Loss of material under the footing and continued slumping and partial collapse.
- Erosion enhanced at beach extents for SRPep02. Narrowing and raising of the foreshore.
- Increased overtopping of walling and on to the road at Keane Street and the low points in the Esplanade, with loss of material landward of the walling and leading to more frequent collapse. Walling renewal or upgrade is anticipated before a >0.3m mean sea level rise.
- Increased damage to walling between Scotch boat shed and Devil's elbow with more frequent closure of the path. It is anticipated the path will eventually require retreat.
- Increased choking, and some sedimentation, of drains due to low invert levels along the Esplanade (SRPep02). There will be increased ponding on the roads with runoff.
- Sediment accumulation in SRPep03 available for backpassing will be dependent on management options pursued by Town of Mosman Park.

9.2. FORESHORE MANAGEMENT AND ADAPTATION SEQUENCES AND PLANS

The possible interventions for the Shire of Peppermint Grove are described in further detail according to the vulnerability assessment time-frames linked to risk mitigation, management pathways and an adaptation strategy (Table 3-1). This information is presented for each segment (Figure 9-1), with a summary of scheduling, monitoring requirements for adaptation triggers and works summary for the 0-5 year time-frame provided for the whole LGA.

Initially, the decision-support framework was applied, according to the method described in Section 3.2 of SRT (2009), to refine which stabilisation techniques should be considered further. Details of this application is included in Appendix F.5.

9.2.1. Possible Interventions

Possible maintenance and capital works for the Shire of Peppermint Grove foreshore are discussed in the context of improving resilience of the foreshore to erosion (chronic and acute), shifting mean sea levels, increased surface runoff and inter-annual variations in wind direction. Any interventions account for the foreshore response to historic works and management actions. Possible interventions are discussed on a spatial basis from north to south, rather than applying generic principles across the SoPG foreshore. This is because of the variation in historic modifications, land use and exposure to hydrodynamic forcing.

The majority of the discussion focuses on the foreshore between Scotch boatshed and Keane's Point jetty, which covers part of SRPep01 and most of SRPep02. It is not considered possible to maintain a beach across this focal area with sand lost preferentially from one or both ends. Options will focus on renourishment across a broader area or concentrating activities in a smaller area. The remainder of the segment SRPep01 is cliffed and segment SRPep03 requires joint management with Town of Mosman Park.

It is not considered feasible to maintain all of the existing uses across the broader SoPG foreshore and it is recommended to consider future retreat in some areas.

In foreshore locations where renewal of hard structures is considered, the design elements that may improve resilience are listed below, along with their associated objectives. These are discussed where relevant below.

Design Element	Objective
1. Limit riverward extension	Limit river bed lowering due to structure
2. Use inclined wall to reduce wave effects	Limit river bed lowering & reduce overtopping
3. Increased walling embedment	Greater resilience to river bed lowering
4. Incorporate flexible scour toe	Greater resilience to river bed lowering
5. Move fixed paths away from walling	Improved maintenance & drainage capacity
6. Raise wall crest level *	Greater resilience to overtopping & inundation
7. Manage drainage for the foreshore surface	Greater resilience to overtopping & inundation
8. Increase walling permeability	Greater resilience to overtopping & inundation
9. Design for fully saturated foreshore	Greater resilience to inundation

* Although raising the wall level is an appropriate method to improve resilience to overtopping and inundation, it is challenged in this case by the low foreshore level (in parts) and the desire to maintain a beach. Water that accumulates behind the wall will drain, either downwards or horizontally across the walling. Increasing the wall level reduces the incidence of flooding from the river, but increases the capacity to trap water under an exceedance event and reduces horizontal drainage, typically transferring flow along the wall to low points. This effect is typically offset by incorporating a surface drainage system within the walling and gravel to landward, which may be difficult to retrofit in many areas of the SoPG foreshore due to constraints to landward. Raising the walling level contributes to loss of adjacent beach due to altering sediment transfers and increasing scour/reflection.

Northern SRPep01 - North of Scotch boatshed

The walls integrated with rocky outcrops in northern SRPep01 between Devil's Elbow and Scotch boatshed should be maintained for as long as possible to ensure pedestrian access for the longest feasible timespan. It is not recommended to undertake extensive works to improve structural resilience or upgrade structures in this area. Maintenance actions to extend the structural life include regrouting and placement of cut blocks to fit voids (e.g. Figure 9-19 left panel), with emphasis on the lower parts of the structure exposed to the most hydraulic activity (Table 12-44). Grout (M4 grade) should be maintained as it is holding the wall together in many areas in SRPep01. Simple reconstruction using existing materials on site is considered appropriate if local failure occurs (Figure 9-16).

The steps from the path to the river at coordinates (E N GDA94 UTM50) 384046 6459440 and 384044 6459424 require more frequent maintenance. The safety hazard and public liability provided by these steps should be considered in determining when the steps should be removed.

The cliffs should be maintained in their natural state where possible through:

- Avoiding runoff into the upper cliffs;
- Consider fencing to restrict access under overhangs for purposes of public safety and decreasing pedestrian induced destabilisation; and

- Stabilisation in areas of overhangs.

Planning for retreat of the pathway between Devil's Elbow and 5m north of the boatshed should commence in the medium-term, which will require an alternate route set back from the foreshore. The 5m distance north of the boatshed should be maintained in the long-term to maintain a vehicle turnaround area. Retreat is not anticipated within a 25-year period, triggered when holes in the path are occurring frequently with the path width less than 1.2m and a cost-benefit analysis indicates further maintenance cannot be justified. In the short- to medium-term, the path and walling will be maintained. Fencing and signage should be obtained and installed immediately when holes appear in the path until the issue is fixed. If the path width narrows to less than 1.2m the whole path should be closed for maintenance until the issue is fixed to ensure public safety.

Walling at the boatshed should be maintained as a vertical limestone block wall to ensure sufficient space is maintained for vehicles to turn around. Additional stabilisation at the toe will be required in the medium to long-term.

<u>SRPep01 - Jetty to Scotch boatshed</u>
The foreshore resilience in this area could be improved through improving hydraulic smoothness, focusing maintenance on wall transitions and low points, improving drainage management and path design. The old walling (pre-1940s), between Scotch boatshed and the new limestone walling near the jetty, has limited capacity for maintenance with large rocks dumped riverward and patchy maintenance as sections of walling have failed. Management options could include:

- Improving hydraulic smoothness by replacing the walling with a smoother faced rock revetment. Crest location would be constrained by the requirement to ensure sufficient vehicle access for Scotch boatshed. The flexible structure will require less maintenance, has the capacity to be adapted vertically and would address design elements (2), (4), (6 – for lowest sections of wall), (8) and (9). If other recommended surface runoff management measures are undertaken it will also contribute to (7). Sufficient embedment would not be able to be achieved due to the rock pavement, with a scour toe used to minimise toe movement. The underlying rock limits the construction of a gravity wall;
- Surface runoff management for Devil's elbow stairs, the toilet roofs down the stairs and a bitumen ramp, from the compacted access routes north and south of Leake Street off the Esplanade, and from the steep path above in 3 locations: 1) the stairs between the Esplanade and the jetty, 2) down the slope near the toilet and 3) drain discharge onto the path from the pathways/road above (Figure 9-20); and
- Upgrade the path simultaneous with improved surface drainage management and revetment works. The path should be well draining. Two options are a gravel/porous path that may be susceptible to vandals (CCTV could mitigate vandalism risk), or a narrow hard path with small rock drainage chutes on either side.

Short-term enhancement in this area, while designing and obtaining funds for these works, include regrout of the lower blocks in the walling, infill the scoured path and areas adjacent to the wall with geotextile-lined gravel to promote permeability and drainage. It is recommended to avoid hardening the path and infilling scoured areas with bitumen or concrete as this reduces the walling permeability.

<u>SRPep01 – Dinghy storage area to drain at Leake Street</u>

Recommended works in this area should be reviewed if an alternate management option is selected for south of the drain in the focal area of erosion. Works in this area are considered to improve the resilience locally and of the foreshore to the south, as the last upgrades have contributed to erosion to the south. The works could include:

- Reducing the height of wall in the dinghy storage area as the raised walling has contributed to erosion at the toe and transferred erosion stress downstream. If a headland control is installed for the south and a scour toe this task would not be required;
- Incorporate a splash zone above the walling with geotextile lined well-draining material with a rock surface to encourage rapid drainage of overtopped water;
- The toe of the walling is presently exposed, with increased resilience to be provided by a flexible rock scour toe (design element 4). This would be placed over the failed aesthetic placement of small cut limestone cobbles;
- Reduce local scour by replacing the large rigid step at the Leake Street drain with a flexible scour toe. The scour toe would integrate with the headland (see SRPep02 below).

The presence of this walling with dinghy storage above should be reconsidered on the longer-term if mean sea level rise of >0.4m occurs.

SRPep02 – South of drain in focal area of erosion (100m)

Works in this area require improving the resilience of the foreshore to trampling and erosion stress transfer from the section of foreshore to the north. Any works that continue to extend hard structures along the shore to the south will not improve the overall foreshore resilience as the erosion problem will be transferred further south.

Emergency works could incorporate regrading the bank to ensure the scarp is minimised.

In the short-term it is recommended to re-create the control to sediment transport and beach toe position provided by the old tea room steps that were removed 1995-2003 (Figure 9-6). A small rock headland is the suggested option, but other materials could be investigated. The headland would incorporate a sandy dinghy/kayak launching pathway to the south connecting to the dinghy storage area above the walling. The foreshore to 100m south would be regraded and renourished, with ongoing renourishment required. Access to the beach should be restricted to two locations in this area through the use of planting low-level vegetation to create focal maintenance areas. Further trees should not be planted as this will limit the capacity for future retreat.

In the longer-term, partial retreat should be considered. This will require terraced walling, or equivalent, further landward to shift the structure out of the frequently active hydraulic zone. Stairs and a broader dinghy/kayak launching pathway will be required. Broad retreat of the foreshore position is expected to the south with foreshore regrading required for aesthetics and safety.

SRPep02 – Mid- Keane's Point Reserve

This foreshore covers the beach section, with consideration required to improve resilience to erosion, including inter-annual variability in sediment transport, a sediment deficit, trampling and scour from drains and surface runoff.

An intervention to address the overall sediment deficit could be to identify a focal area for recreation and prioritise funding for improvement and sustaining a beach for that area. This is not wholly considered feasible here, with emphasis placed on maintaining a beach north of Keane/Lilla Streets. To ensure a beach is maintained near the Moreton Bay figs a program of beach renourishment and backpassing of sediment could be undertaken. If sand accumulates to levels higher than the walling the sediment can be harvested and shifted to areas of erosion further north. In the longer-term the mid-section of beach, near the Moreton Bay Figs, should be allowed to migrate landward, requiring a landward migration of structures at the back of the beach.

Focal beach access locations are required to minimise trampling by pedestrians and launching/retrieval of kayaks, stand up paddleboards and dinghies. At present this occurs anywhere between Keane Street and Leake Street due to the alongshore parking. It is recommended to create focal access pathways by replacing sections of turf with low-level vegetation to discourage access. The focal access locations will require ongoing and frequent renourishment and returfing.

Interventions are required to reduce scour of the foreshore at drains, in areas of unmanaged surface runoff from the Esplanade and to reduce flooding of the Esplanade in the <5 year ARI rainfall events. This follows from discussion of drainage in Appendix A.5. The possible interventions here include improving the short-term storage capacity and diffusing the scour impacts. Works considered were:

- Extending pipes riverward to reduce scour of the upper beach. This was disregarded as the pipes would break under forcing during extreme events and create trip hazards.
- Increase storage volume within the drainage pits to reduce the flow and ponding in a 1-year ARI event. Flushing the drainage pits also increases the storage volume. If required the drains along the foreshore could also be resized to increase flow capacity, with consideration of the suitability of the enhanced scour impacts.
- To significantly increase storage volume a slotted gutter (ie gutter with diffuser) could be used. This is not considered necessary at this stage.
- Local subsoil diffusers are recommended to be installed, such as slotted pipes with filter cloth, with sufficient capacity to discharge the 1-5 year ARI flows.
- Alternatively in the longer-term a large diffusion system could be installed in the grass across the broader Esplanade road. This would be a series of large trenches installed as a series to avoid disturbing tree roots.

In the short-term local subsoil diffusers are recommended, with increasing capacity of drainage pits in the medium-term. Long-term solutions should be selected by SoPG.

Increasing the capacity of the drainage pits will decrease the ponding on the Esplanade from 1 year ARI events. No further action is required in the short-term because flooding from surface runoff only provides a temporary restriction on access by vehicles along the foreshore and to private properties. Planning controls could be put in place now for private property redevelopment along the Esplanade to minimise river flood and surface runoff flooding hazards on the Esplanade in the longer-term. The private property owners would have a level set for future driveway minimum levels at the Esplanade to allow for future raising of the road level. An investigation would be required to determine the future height of the Esplanade based on a combined analysis of surface runoff and river inundation. Any low-lying private properties may also require emergency pumps.

Options not considered due to ***decreasing the foreshore resilience to erosion****:*

- Raising walling as this will enhance the erosion of the beach.
- Fixed path adjacent to the walling.
- Planting of more tall trees in close proximity (ie <6m) from top of walling as this limits capacity to retreat landward in future.
- Works that reduce hydraulic smoothness.
- Protecting trees with hard structures.
- Non-stumped jetties (ie no solid structures interrupting hydraulic smoothness).
- Headland controls, in the short- to medium-term, because it risks loss of beaches as it interrupts the natural sediment transport patterns along a broader bay.

SRPep02 – 190m from northern Keane St intersection with Esplanade through Keanes Point Jetty

The walling between Keane St and the Esplanade is a 190m section of wall that is low with no beach remaining adjacent to the walling at most times of the year. Toe undermining is occurring. The installation of Water Corporation sewage overflow tanks limit the capacity for walling reconstruction in this area with a 2.5m buffer available (Figure 9-14). The options considered for this area are:

- <10 years – Add a scour toe. Also could consider subsequently renourishing the foreshore.
- 10-30 years – Reclaim foreshore by building a rock rubble revetment. This should only be undertaken if SoPG is not considering one of the >30 year options.
- >30 years – Three options are considered feasible of:
    - Piled wall system, with scour toe or
    - Mass-bloc structure, with scour toe or
    - Stepped limestone block wall with steps extending riverward, with scour toe.

Any of the longer-term options of rock rubble revetment, piled wall system, mass-bloc structure or stepped limestone block wall are considered feasible, with further investigation by SoPG to identify their preferred solution.

*Options not considered due to **decreasing the resilience to erosion**:*

- Raising walling.
- Fixed path adjacent to the walling.
- Planting of tall trees in close proximity (ie <6m) from top of walling as this limits capacity to migrate landward in future.
- Works that reduce hydraulic smoothness.
- Non-stumped jetties (ie no solid structures interrupting hydraulic smoothness).

Options are also provided to reduce ponding at the intersection of the Esplanade, Keane and Lilla Streets from surface runoff and river inundation. In the short-term no action is required because flooding only provides a temporary restriction on access by vehicles along the foreshore and to private properties. In the medium-term the permeability of the wall and the land could be increased. Permeability of the land could be increased by turning the low point in the Esplanade at the Keane Street intersection into an open drain waterway, or a permeable barrier. This would require further design detail to ensure it has the load capacity for trucks. Installation of megaflo behind the wall with conduits through the wall will increase the drainage rate. Planning controls should be implemented now for private property redevelopment to ensure the Esplanade and lower Lilla/Keane Streets can be raised in future, following the description in mid-Keane's Point Reserve above.

SRPep02/SRPep03 – RFBYC

It is recommended that no further expansion of hard structures or hardstand areas is undertaken by RFBYC. RFBYC are responsible for maintenance works for all structures in their lease area.

SRPep03 – S of RFBYC hardstand to ToMP boundary
The foreshore is managed in conjunction with Town of Mosman Park, with sediment available in the area for backpassing to the south in Mosman Bay. Sediment harvesting should be undertaken to ensure safety of beach use, with a smooth grade. The rate of sediment accumulation will depend on the renourishment approach and structures used at, and south of, the boat ramp. Sediment should no longer be harvested from this area for renourishment of other foreshore areas in the river, noting the rate of removal has decreased since 2007. To ensure ongoing capacity for backpassing at this location, no further fixed infrastructure should be located riverward of the existing locations of the Sea Scouts and RFBYC buildings.

In the longer-term a spur groyne may be constructed adjacent to the RFBYC structures to minimise loss of sediment into the boat pens and improve the sediment capture capacity. Partial infill of the local dredge hole (top right panel Figure 12-78) may also slow local erosion during high water level events and long-term changes to the terrace.

9.2.2. Works for Each Segment

Potential risk mitigation, management pathways and adaptation strategies are presented for each segment linked to time-frames of 0-5 years, 5-25 years and >25 years (Table 3-1). The shortest timescales consider the present state of the foreshore and sensitivity to acute events. The medium-term timescales consider foreshore dynamics, life-cycle of existing stabilising structures and increasing foreshore resilience. For time-frames greater than 25 years there is uncertainty related to future management choices and longer-term process variability. Scenarios possibly affecting the foreshore are considered at this scale in the context of improving foreshore resilience.

The foreshore management and adaptation sequences are presented for each foreshore segment in Appendix F.6 (Table 12-47 to Table 12-49). Each table includes:

- A foreshore management goal, capital works and maintenance requirements for each of the three timeframes.
- Requirements for monitoring linked to identification of maintenance requirements, refining budgets and triggering foreshore management actions and adaptation.
- Details of issues to be resolved, and works to be avoided, to ensure the recommended management sequence may be achieved.
- Simple cost estimates (Appendix B) for capital works, maintenance works and a 25-year total with no future cost adjustments.

A summary of the foreshore management goals for the three timescales for each segment is provided in Table 9-2.

It should be noted a number of services will require consideration based on a Dial before you Dig query. This includes the Water Corporation sewage overflow tanks, Water Corporation pipes/gas/telecommunications on the landward side of the Esplanade and Water Corporation pipes under the Lilla St/Keane St intersection.

Table 9-2: Summary of Management Goals for each Segment in the Shire of Peppermint Grove Detail for each segment is included in relevant tables in Appendix F.6

Segment (Table with detail in Appendix F.6)	**Short-term (risk management) for 0-5 years**	**Medium-term (planning) for 5-25 years**	**Long-term (strategy) for >25 years**	**25-year cost. Not indexed (2015 costs)**
SRPep01 Scotch College BoatShed Forrest St (Table 12-47)	Maintain existing use north of jetty. Improve structure and foreshore resilience south of Scotch boatshed.	Improve hydraulic smoothness south of Scotch boatshed, maintain structures and use of path north of the boatshed for as long as possible (while planning for retreat).	Maintain use for as long as feasible with retreat between Devil's Elbow and Scotch boatshed and alternate use of the dinghy storage area.	≈$0.75M excluding drain upgrades
SRPep02 Manners Hill Park Keane St (Table 12-48)	Maintain assets, upgrade northern extent and create focal recreation access locations.	Progressively upgrade assets or undertake more frequent maintenance. Surface runoff management considered.	Partial retreat (where possible) with beach maintenance and renourishment focused on the central and northern areas of the foreshore.	≈$0.9-1.2M excluding drainage upgrades
SRPep03 Keanes Point Reserve (Table 12-49)	Provide a source of sediment for southern Mosman Bay and maintain existing foreshore use.	Continue to provide a source of sediment for southern Mosman Bay, while adapting to Town of Mosman Park boat ramp upgrades. Maintain existing foreshore use.	Consolidate foreshore uses to allow for partial retreat. Sediment source for southern Mosman Bay will depend on long-term management plans of ToMP.	No cost to SoPG, assuming costs of backpassing covered by ToMP, beach maintenance costs to RFBYC and Sea Scouts.

9.2.3. Ongoing Monitoring Requirements

It is recommended that the Shire of Peppermint Grove organise the following ongoing monitoring to plan and review requirements for foreshore maintenance, management and adaptation triggers. The information included in Table 9-3 is a council-wide summary of the information in the tables within Section 9.2.1.

Table 9-3: Monitoring Requirements for Shire of Peppermint Grove

Monitoring technique	**Spatial coverage**	**Frequency**

1.1 Tabulate records of dates, location, details and costs of works including **regrout, walling, path infill, drains, revegetation, backpassing and renourishment**. This includes the volumes of sediment harvested between ToMP boatramp and RFBYC.	Whole SoPG, including works by RFBYC, Sea Scouts and ToMP south of SRPep03	When works are undertaken
1.2 **Engineering inspections** of the face of walling (walk in water) and surface behind structures.	All structures in SRPep01 and SRPep02	Annual and post-event
1.3 **Photos at 50m intervals** from upstream to downstream and at areas of focal erosion, structural damage or failure	Whole SoPG, excluding RFBYC facilities	Annual in December/January
1.4 **Photos of beach widths** at fixed locations to monitor beach performance and approximate volumes of sediment harvested from SRPep03 for backpassing.	Fixed locations in SRPep02 and SRPep03	3-monthly. Also pre- and post-sediment harvesting in SRPep03

9.2.4. Implementation and Management Summary (0-5 years)

A council-wide summary of the capital and maintenance works recommended for the first five years of management are included in Table 9-4. This summarises key information in the tables within Section 9.2.1. Further detail is included in the segment-specific tables (Table 12-47 to Table 12-49). Monitoring recommendations are included separately in Table 9-3 and are not costed in the table below.

Table 9-4: Implementation Summary for Shire of Peppermint Grove (1-5 years)

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
Year 1	2.1 **Scour toe** for dinghy wall	$15k	3.1 **Stabilise informal stairs** in SRPep01 including regrout and replacement cut limestone blocks.	$10k
	2.2 **Install drainage** in SRPep01	Not costed	3.2 **Maintain path** from Devil's elbow to Leake St.	Separate SoPG item.
			3.3 **Regrout gaps in walling in SRPep01**, focused on lower half of walls and in transitions between wall types and wall/rock.	$15k
Year 2	2.3 **Reactive walling** recon in SRPep01.	≈$15k when wall fails	3.4 **Surface runoff management in SRPep01** including clearing of drains and top of scoured material.	$2k + in-kind labour
	2.4 **Works at Leake St**, inc. headland & renourish	$100k	3.5 **Maintain path** from Devil's elbow to Leake St.	Separate SoPG item.
	2.5 **Revegetate** to create focal access in SRPep02	*$20k + in-kind labour*	3.6 **Regrout walling in SRPep02**, mainly focused on lower half of walls and near drains	$10k
			3.7 **Shift irrigation pipes and sprinklers** away from walling and eroding foreshores. Avoid piping aligned along the foreshore.	$5k + in-kind labour
	2.6 **Long-term plan for S 190m**	*$30k*	3.8 **Backpass 300m^3 to ToMP** foreshore in Mosman Bay. Only following plan development for boat ramp.	$4k (ToMP cost)

	Capital	Capital Cost ($)	Maintenance	Maint. Cost ($)
Year 3	2.7 **Reactive walling** recon in SRPep02.	≈$20k when wall fails	3.9 **Surface runoff management in SRPep01** including clearing of drains and top of scoured material.	$2k + in-kind labour
			3.10 **Maintain path** from Devil's elbow to Leake St.	Separate SoPG item.
	2.8 Wall maintenance and scour toe for **S 190m**	$75k (depends on long-term plan)	3.11 **Top-up access locations and kayak ramp in SRPep02** with sand harvested from the centre of the bay ≈50m^3	$2k twice-yearly ($4k pa)
			3.12 **Revegetate** areas in SRPep02 to restrict trampling	$4k pa + in-kind labour
			3.13 **Backpass 300m^3 to ToMP** foreshore in Mosman Bay. Only following plan development for boat ramp.	$4k (ToMP cost)
Year 4	2.9 **Reactive walling** reconstruction when fails in SRPep01	≈$15k	3.14 **Surface runoff management in SRPep01** including clearing of drains and top of scoured material.	$2k + in-kind labour
			3.15 **Maintain path** from Devil's elbow to Leake St.	Separate SoPG item.
			3.16 **Top-up access locations and kayak ramp in SRPep02** with sand harvested from the centre of the bay ≈50m^3	$2k twice-yearly ($4k pa)
			3.17 **Revegetate** areas in SRPep02 to restrict trampling	$4k pa + in-kind labour
			3.18 **Backpass 300m^3 to ToMP** foreshore in Mosman Bay. Only following plan development for boat ramp.	$4k (ToMP cost)
Year 5	2.10 **Manage drainage** down boat ramp in SRPep03	Cost depend on boat ramp option and ToMP	3.19 **Maintain scour toe** in dinghy storage area and at drain scour toe at Leake St	$5k
			3.20 **Surface runoff management in SRPep01** including clearing of drains and top of scoured material.	$2k + in-kind labour
			3.21 **Maintain path** from Devil's elbow to Leake St.	Separate SoPG item.
			3.22 **Regrout gaps in walling in SRPep01**, focused on lower half of walls and in transitions between wall types and wall/rock.	$15k
			3.23 **Renourish 75m foreshore in SRPep02** south of rock headland with 200m^3 from quarry	$20k
			3.24 **Top-up access locations and kayak ramp in SRPep02** with sand harvested from the centre of the bay ≈50m^3	$2k twice-yearly ($4k pa)
			3.25 **Revegetate** areas in SRPep02 to restrict trampling	$4k pa + in-kind labour
			3.26 **Maintain flexible scour toe** in southern 190m of SRPep02	$5k
			3.27 **Backpass 300m^3 to ToMP** foreshore in Mosman Bay. Only following plan development for boat ramp.	$4k (ToMP cost)

9.2.5. Works Dependencies

Some management and adaptation works should only be undertaken once another management task has been undertaken. The main works dependencies within SoPG include:

- Maintenance for the aged walling should be considered in the context of timing of works renewal, to optimise funding allocation;
- Works planned in SRPep01 between Scotch boatshed and the jetty should be undertaken together, rather than staged. This includes integrating surface drainage management, path upgrade and replacement of the walling with a revetment;
- Works planned in southern SRPep01 and northern SRPep02 near Leake Street are reliant on the overall approved plan. This includes scour toe, headland, terraced wall, renourishment, kayak/dinghy launching ramp, drain improvements and bank regarding. The details of the works are included in Table 12-47 and Table 12-48. The timing and impact of each task should be considered in the context of all of the works at this site;
- Renourishment should only be undertaken following maintenance on the walling or scour toe to landward; and
- Works in SRPep03 between RFBYC and the ToMP boat ramp are dependent on the management options selected by ToMP.

Many maintenance and capital works recommendations in Table 12-47 to Table 12-49 and Table 9-4 require certain issues to be resolved or certain works to be avoided. The segment-specific tables (Table 12-47 to Table 12-49) should be consulted for this information as many works are dependent on these issues being resolved or specific works being avoided.

The staging of capital and maintenance works is broadly outlined in the segment-specific tables and for the first five years in Table 9-4. It is recommended the Shire of Peppermint Grove prepare a Gantt chart to allocate their own prioritisation of works and works dependencies. This chart could be updated when a management decision (e.g. creating a new recreation node) alters the broader management plan. Works prioritisation will be linked to funding availability and the Gantt chart should be revised annually following the budget allocation.

10. Town of Mosman Park

Information for the foreshore managed by the Town of Mosman Park is separated into two sections and Appendix G, all focused on the seven segments of foreshore (Figure 10-1; Table 2-1). The first section (10.1) provides context for recommended management, vulnerability and a previous consideration of possible interventions (BMP 2009). The second section (10.2 and Appendix G.6) provides a discussion of possible interventions and more detail on the preferred foreshore management and adaptation sequences and plans, including tables per segment noting maintenance and capital works that could be undertaken in the short-, medium- and longer-terms.

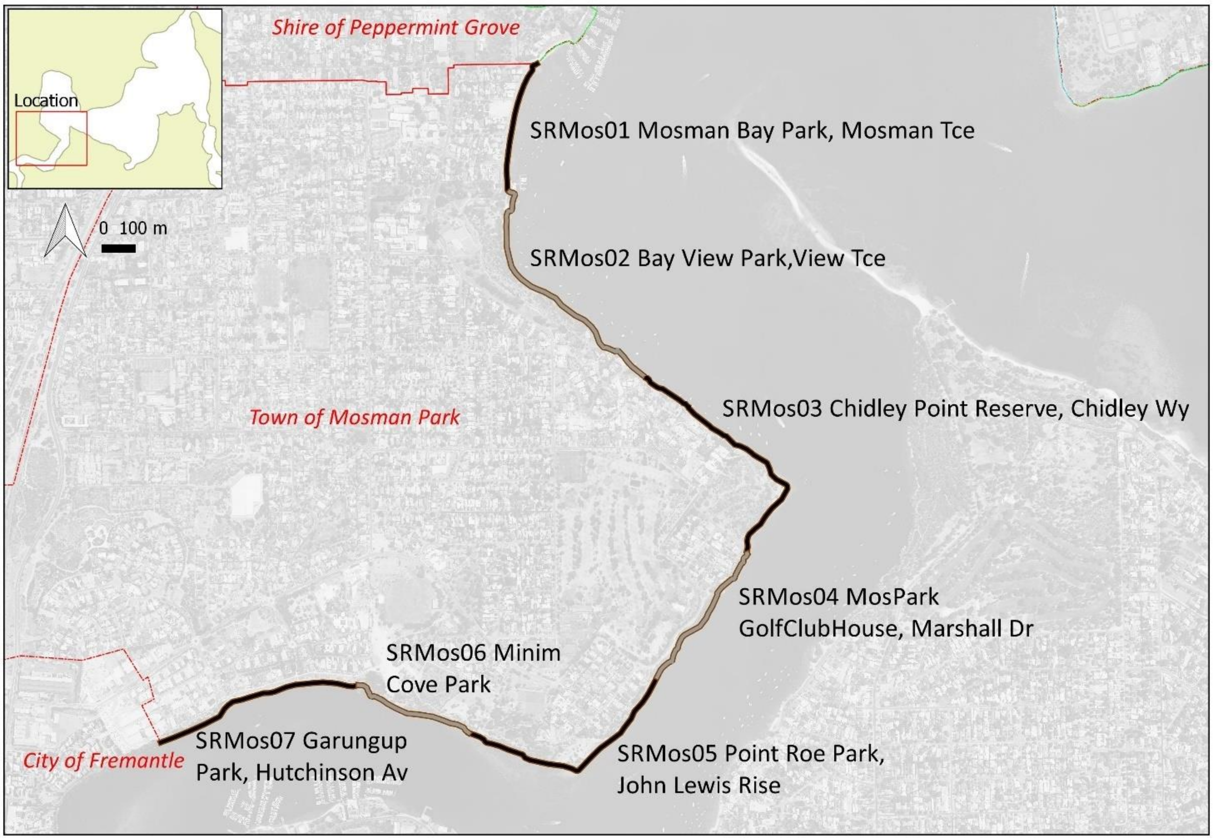

Figure 10-1: Town of Mosman Park Segments

The foreshore management plan for the Town of Mosman Park is presented in Section 10.2 with detailed recommendations per segment in Appendix G.6. In the short-term, the main focus for the Town of Mosman Park is undertaking works within Mosman Bay (wall renewal and boat ramp) and addressing the failed walling under Mosmans Restaurant. Maintenance is required to extend the life of the walling for as long as possible, with two sections requiring immediate replacement with sufficient embedment to achieve the longer-term strategy. The walling selected should have sufficient embedment now to tolerate raising the walling by up to 0.5m in future to allow for improved resilience to high water levels. The design incorporates the option for future beach renourishment by allowing for minor retreat, rather than extending the walling further riverward. A number of other key recreation areas at Swan Canoe Club, the Coombe, Green Place, Chidley Point Reserve, Minim Cove jetty and Milo beach also require management via renourishment, sand backpassing and structure maintenance. Most of these sites have access limitations that require consideration for ongoing management given the expense of operating from a barge. Most cliff areas are recommended to be allowed to retreat, with actions required to address foreshore access and safety hazards. Management of the foreshore in Mosman Bay requires joint planning with the Shire of Peppermint Grove.

10.1. CONTEXT AND VULNERABILITY

10.1.1. Process Overview

Segments SRMos01 to SRMos03 (Keanes Point to Chidley Point)

Considered at a large scale, this section has a tendency for material transport towards Chidley Point due to wave action. However, this section of foreshore is the upstream end of the tidal gorge, bounded on the north side by the submerged rock upon which Point Walter Spit sits. Consequently, currents will tend to deposit sediment where the flow speed reduces, in the river between Keanes Point and Point Walter Spit at the south end of Freshwater Bay. The effects of both currents and waves are strongly reduced along this section of shore due to the low mobility of the bank material, with most of the shore largely rocky in nature.

Mosman Bay is a section of beach between the Swan Canoe Club and Keanes Point that has been isolated from a supply of sediment to the south through the construction of Mosman Jetty landing in 1912. The sediment dynamics of the bay have also been impacted by the riverward extension of Keanes Point for the Royal Freshwater Bay Yacht Club (RFBYC), and associated dredging, as well as walling to landward. The walling along Mosman Bay is reliant on the presence of a beach in front, with the last large renourishment undertaken in 1964-1967. Sand in the bay is transported from south to north, with sediment backpassed to the south of the beach until at least the mid-1990s, with accumulated sand at the north harvested for use on other beaches in the 2000s. The large renourishment program disrupted bars present on the foreshore (1953 aerial photo), which changed the bars from importing sediment to the beach to exporting sediment from the beach, including to infill dredge holes. The beach structure was altered from a steeper structure to a shallow and flat structure, contributing to loss of amenity. The broader scale sediment transport processes determine that Mosman Bay may be subject to short episodes of rapid accumulation, followed by extended periods of erosion, due to the nature of the tidal gorge varying from acting as a sediment sink to a sediment source. Sediment is also lost from the beach into dredge holes along the edge of the terrace and at the northern end adjacent to the RFBYC jetties. Any future works require sufficient embedment to cater for bed movements and the bay is likely to require ongoing renourishment or backpassing.

The foreshore immediately south of the Swan Canoe Club revetment are steep banks, that were previously quarried in parts, which are now providing a supply of sediment to the lower foreshore.

The broader section of foreshore between the Swan Canoe Club and Chidley Point has a long history of quarrying and private property interactions with the river. In this area the terrace is deepening and narrowing. Installation of structures along the foreshore creates pockets that have reduced sediment supply. Walling also interrupts the hydraulic smoothness and reduces the amount of sediment available for the cross-shore balance for variations in foreshore sediment demand.

Segments SRMos03 to SRMos07 (Chidley Point to downstream end of WESROC area)

This section of the estuary represents the tidal gorge, which is strongly influenced by tidal flows, producing high bed and bank stresses. Tidal exchange is approximately equal throughout the tidal gorge, maintaining near equal cross-sectional area, which varies from shallow and broad at Point Preston and Point Roe, through to narrow and deep along Blackwall Reach. The overall plan-shape of the tidal gorge is apparently controlled by the presence of rock, with a series of sharp turns in the river channel associated with rocky shores.

High levels of bed and bank stress caused by the tidal currents determine that any bed sediments are subject to variations in the quantity of tidal exchange. This may vary due to flooding, tide range and mean sea level variation. For short-term variations, pulsatory sediment transport may occur. Longer-term changes cause the tidal gorge to act alternately as a sediment source or sink. Sediment demands may be made from the bed, banks and sills at either end of the gorge. During periods of enhanced flow, sediment is exported from the gorge to the sills near Point Walter and Fremantle Harbour. The foreshore in the downstream segment (SRMos07) is likely to experience terrace lowering and narrowing as the channel migrates. This migration is in response to the growth of the flood tide shoal since dredging of the Preston Point channel.

Within the tidal gorge, sedimentary features at Point Roe and Chidley Point are subject to high levels of variability. Although these features are present in the longer-term, they are an immediate source of material for short-term sediment demand. Chidley Point was nourished in 1964. Armouring of these sections will be subject to high levels of stress and must be designed to cater for dramatic changes in the volume of sedimentary material.

Many sections of the steeper foreshore between Point Roe and the City of Fremantle foreshore were historically mined and quarried. The steep foreshores of Garungup Reserve are artificial, built to provide level ground for industrial infrastructure to landward following quarrying. Slip failures occur in this area partially attributed to unmanaged surface runoff, tree growth and erosion at the toe.

Any walls constructed in this section should account for high bed level changes in the gorge, with greater embedment than other locations.

10.1.2. Previous and Existing Plans

The majority of the foreshore is not covered by a specific plan documenting long-term foreshore management. In the *Foreshore Assessment and Management Strategy* (SRT 2008) the foreshore of ToMP is incorporated in part of S.1 and S.2. Downstream of Chidley Point the foreshore is part of S.1, considered a moderate priority for investment in foreshore stabilisation works, with the associated recommendations related to the higher use foreshores of Fremantle and East Fremantle. Overall, the ToMP foreshore was identified as a low priority, priority 3, in terms of urgent investment in foreshore stabilisation works.

Management recommendations have been prepared for Mosman Bay by iwprojects *et al.* (2012), MP Rogers & Associates (2010 with review by Damara (2011)). The options presented by iwprojects considered a partial renourishment, wall construction riverward of existing walling and partial use of existing walling. The reliance on the existing walling and the construction of new walling riverward is not encouraged for a long-term strategy at this site. MP Rogers & Associates have recommended five options, with the preferred option of a groyne and partial renourishment. This approach does not address the failed walling.

The significant constraints to future works as a result of previous and existing plans are:

- Choice of emergency works in Mosman Bay in 2001;
- Plans for the boat ramp in Mosman Bay (MP Rogers & Associates). Renourishment options may be limited if the boat ramp is expanded with hard structures and a dredged channel;
- Water Corporation plans for the sewage pump station in Mosman Bay;
- Mosmans boat pens and RFBYC boat pens in terms of renourishment plans for Mosman Bay;
- Swan Canoe Club expansions;

- Population expansion above steep cliffs and implications for surface runoff and cliff stability; and
- Increased foreshore use due to improved facilities.

10.1.3. Historic Works

The Town of Mosman Park foreshore was initially a steep and rocky foreshore located in the tidal gorge with two points (Point Roe and Chidley Point) and a bay impounded upon a smaller rocky Keanes Point. There were rocky beaches and areas of sedges, near Point Roe. The main recreational beaches in the ToMP at Mosman Bay and Chidley Point were created by local dredging and renourishment. Extensive modification of the steep slopes has occurred due to quarrying. Further modifications have been undertaken over time for purposes such as navigation, industrial purposes, quarrying of construction materials, beautification, recreation, boat launching and storage, yacht club use, as well as various modifications performed by private property owners.

This section should be read in conjunction with Section 2.3.1 which includes a summary of how environmental regulations and management practices across the river have changed over time.

An overview of some changes and issues in northern Rocky Bay (Minim Cove and Milo Beach area) of Town of Mosman Park are included in Figure 10-2. Key changes in relation to foreshore management are listed in Table 9-1 with context provided with aerial images of 1953, 1965, 1983, 2014 per segment (Appendix G.1). Bioengineering and revegetation works have not been included. The impacts of some of these historic modifications are described in the process overview above (Section 10.1.1), with the foreshore still presently responding to the historic works. The main controls to alongshore transport along this foreshore are the rock controls at Keanes Point, Chidley Point and Point Roe, along with rocky outcrops along the shore. At a smaller scale, the reclamation at Keanes Point, the Lower Mosman Bay Park, the Coombe and Green Place also provide control.

10.1.4. Site Issues and Constraints

Details of issues and constraints for the seven segments in the Town of Mosman Park are included in Table 12-50 and Table 12-51 (Appendix G.2). This is in addition to some further broader issues of:

- Resourcing for future works. This is a major constraint with insufficient funds available for proposed works in Mosman Bay (iwprojects *et al.* 2012).
- Stability of cliffs and steep slopes, including steep banks in SRMos02 and SRMos07. The steep banks in SRMos02 are eroding (with scarps >2m) partially in response to the control provided by the Mosman Bay Park revetment (>30m riverward) and Swan Canoe Club extension. Erosion of these steep slopes provides a local source of sediment for the beaches and foreshores; particularly in an area of limited public use of the lower foreshore and no infrastructure threatened above the scarps. The steep banks in the SRMos07 segment are artificial, built up to provide level ground for industrial infrastructure to landward following quarrying. The steep bank has a rock revetment (poor rock connection) with varied success for stabilising the bank toe with erosion through the structure. There are sections with slip failures, also partially attributed to unmanaged runoff, tree growth and erosion at the toe.

Figure 10-2: Some issues and modifications for northern Rocky Bay

Table 10-1: Historic modifications relevant to present-day foreshore management

Segment	Modification	Date
SRMos01 Mosman Bay Park, Mosman Tce	Wholescale renourishment	1964-1967
	Reclamation for Johnson Pde and first walling Backpassing from N to S	1900s 1900s
	RFBYC (30m) to N extending riverward Boat ramp extending riverward Mosman Bay Jetty (30m) extending riverward	1964 1906
	Removal of previous sediment via dredging Removal of old Smiths boatshed in S of segment	
	Walling for whole segment length with some walling failing	≈1900s
	Addition of cycle path 5-8m from wall crest	2005-2011
SRMos02 Bay View Park,View Tce	Dredging at N end Dredging for boat mooring at N extent of segment	1964-1967 Pre 1953
	Cut-fill from steep banks for Mosman Bay Jetty area reclamation	1906
	Drain at the Coombe extending riverward SCC/Mosman Bay Jetty retained reclamation extending riverward	
	Drain structure at the Coombe acting as a groyne	
	Walling at the Coombe Rock revetment and walling at SCC/Mosman Bay Jetty	
SRMos03 Chidley Point Reserve, Chidley Wy	Dredging ~60-90m from shore for reclamation of Chidley Point	1964
	Modifications to Point Walter Spit	
	Reclamation for Chidley Point Green Pl landing extends riverward from adjacent foreshore Private property walling	1965
	Private property walling extending riverward (including two jetties)	
	Failing landscaping wall at Chidley Pt Wall at Green Pl	
SRMos04 MosPark GolfClubHouse, Marshall Dr	Minor boatshed	
	Old foreshore access (groyne/jetty) with old boatshed (2nd most upstream property)	
SRMos05 Point Roe Park, John Lewis Rise	Minor old CSR pond for discharge	
SRMos06 Minim Cove Park	Minor foreshore modification due to historic quarry operations	
SRMos07 Garungup Park, Hutchinson Av	Possible minor dredging associated with jetties	
	Channel causing altered flood tide shoal closer to the foreshore	1971
	Altered for quarrying/industry. Artificial banks for level land above	Pre-1990
	Minor drain feature and old quarried limestone rocks	
	Large rock loose revetment partially impedes cross shore transport	

- Stakeholder conflict in Mosman Bay. The broader Mosman Bay is managed by the Shire of Peppermint Grove and Town of Mosman Park, separated at the northern limit of the boat ramp. The Town manages the boat ramp with the Shire providing the car park. Management decisions for the Mosman Bay foreshore should be made in agreement with both councils, dependent on cost and funding sources. Sediment accumulating in the Shire segment benefits the Sea Scout and RFBYC operations, with these two stakeholders potentially not supporting an initiative to harvest this sediment for backpassing to the south even though this was historically undertaken. Mosmans has previously complained (1995) regarding backpassing contributing to sedimentation of their six boat pens. People who launch boats at the ramp will resist actions that decrease the function of the boat ramp. Recreation users value a beach and pedestrian access (iwprojects *et al.* 2012) with sedimentation of adjacent facilities to be minimised. Note, ToMP has SWALSC approval for dredging a channel to the boat ramp and DAA Section 18 approval for a groyne.

- Stakeholder conflict in the remaining foreshore area relates to private property owners, Town of Mosman Park and recreational users having different views on appropriate foreshore use. Two aspects are discussed in further detail below (in the liability discussion) in relation to private property ownership and narrow foreshore buffers. Further concerns may relate to continued foreshore access and complaints that there should not be any visible erosion along the foreshore, even though this provides a source of material for adjacent foreshores.
- There are small sections of foreshore near Saunders Street with High Water Mark private property ownership. This creates potential stakeholder conflict between the private property owners and the Town of Mosman Park, particularly in areas where partial resumption of the foreshore reserve has occurred. Further information is provided below.
- Narrow buffers between the river and private property on steep slopes are present 1) from Chine Place to Chidley Point Reserve, 2) along Riverside Drive, 3) along Colonial Gardens and 4) in Rocky Bay along Hutchinson Avenue, Mathieson Avenue and Westmeath Street. Locations 3 and 4 are redevelopments on old industrial sites. The narrow buffer in these four areas could potentially result in liability for the Town of Mosman Park. Legal advice should be sought to determine if the Town would be liable if there was a fire that started in the publicly owned foreshore that caused damage to adjacent private property. The legal advice should guide the Town's fire management and prevention practices. The liability for any slope failure or cliff failure between river and private property that could cause damage to private property should be confirmed.
- Mosman bay walling (SRMos01) is approaching the end of its functional life in some areas, and it appears from its design that walling function required sediment in front of it (now eroded). Design of future works requires consideration of future foreshore response to existing dredge holes and modified stormwater management. The sewage pumping station in this section is exposed to hydraulic loading and is subject to damage or failure.
- Any works that create new or altered longshore controls require consideration of wider impacts.
- Stormwater management above steep foreshores with potential slope stability concerns.
- Future population pressure for continuous path along foreshore. Increased foreshore use is anticipated with transfer from industrial to higher density residential developments.
- Indigenous approval discussions required for any dredging or renourishment works, including backpassing along Mosman Bay.
- Changing far-field forcing of boat wakes.

<u>Liability for erosion mitigation when ceding and vesting HWM Private Property (Section 5)</u>
Ceding and vesting, part or all of, the foreshore reserve along Saunders Street (and cul-de-sacs) with the Town of Mosman Park may create ongoing issues related to erosion mitigation on adjacent private properties with an unclear definition of liability for damages or conducting management works.

The riverward portion of privately owned land is presently ceded along the foreshore during the subdivision process. The ceding process is that WAPC transfers the property to the State of Western Australia under the Transfer of Land Act (TLA), then the Department of Lands take the property out of the TLA and create it as a reserve under the Land Administration Act (LAA), and then the management order is issued to the

Town of Mosman Park, with the land vested with the Town of Mosman Park. Section 152 of the *Planning and Development Act 2005* and the *Land Administration Act 1997* includes provision for this vesting of privately owned land. This is supported by the Parks and Wildlife Policy SRT/EA2 on Foreshore Reserves.. A management order may only be issued over land reserves, or a lease is established by the Town for a set period. This enables the WAPC to provide Area Assistance Grants. However, a lease is only issued on the basis that a management order will be established following expiry of the lease. Area Assistance Grants are only available for capital upgrades to properties leased or with a management order held by the Town of Mosman Park. Grants for capital works, not maintenance, may be up to $500,000 at an individual site provided over 5 years (maximum of $100,000 per year) based on a 50% contribution by WAPC and 50% by the Town of Mosman Park.

Once a section of foreshore reserve has been ceded from a private property along Saunders Street (and adjacent cul-de-sacs) and a management order is provided to the Town of Mosman Park, the Town will essentially be responsible for erosion mitigation structures for the private property to landward. Funding for erosion mitigation structures on private property is not permitted under Government grants through the Parks and Wildlife Riverbank program (under the *SCRM Act 2006 and Guidelines 2007*). Therefore, any base structure constructed by Parks and Wildlife/Town of Mosman Park (e.g. for a path[3]) would seem to provide erosion mitigation to private property landowners at no cost to the owners as the base structure would be on publicly owned land. As the landowner or land manager of a foreshore lot is responsible for maintenance this would also mean the Town of Mosman Park is responsible for both maintenance of the path and erosion mitigation structures.

At present, the foreshore reserve of each lot will progressively be ceded by the WAPC (if any property is subdivided) and possibly leased by the Town of Mosman Park or the Town may be provided a management order. Consideration of tie-ins of erosion mitigation options between properties will be required with some situations with co-contribution by private property owners and the Town of Mosman Park. The land manager of the publicly owned property (Town of Mosman Park or WAPC) is not likely to be responsible for the costs of providing erosion mitigation for the private property to landward, protecting private property adjacent along the foreshore or damage to erosion mitigation structures on adjacent land as erosion is occurring due to natural processes. It is unclear on who is responsible for maintaining erosion mitigation structures constructed prior to resumption of the land. Further legal advice should be sought on this topic.

The present situation is that WAPC will continue to cede land and vest it with an LGA through the subdivision process (Section 5). WESROC should consider its position with respect to this policy and if deemed appropriate, liaise with LGAs along the Swan and Canning Rivers and WALGA to collectively approach the Department of Parks and Wildlife Rivers and Estuaries Division, the Minister for Planning and the WAPC to review this approach of vesting land along narrow or eroding foreshores. This is recommended in the context of potential ongoing costs for the City of Nedlands, Town of Claremont, Town of Mosman Park, Parks and Wildlife and the WAPC.

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[3] If a piled-boardwalk was constructed for a path in future it would not provide erosion mitigation for the private property owners to landward. It is assumed capital and maintenance funding would continue to be required from the private property owners for erosion mitigation structures. There would likely be increased cost due to access constraints provided by the presence of the boardwalk. Further advice is required to determine who is responsible for erosion control works if a boardwalk abutted a private property boundary.

The subdivision process often reduces foreshore access and in many cases results in construction of assets closer to the shore. This is relevant for the potential future difficulty with accessing the foreshore along Saunders Street (and adjacent cul-de-sacs) for maintenance of erosion mitigation structures. Historic access to the lower foreshore has been restricted by the continued housing developments. Often when a house was demolished a retaining wall was placed on the foreshore, and the house was constructed closer to the river encompassing more of the block width without sufficient foreshore access for machinery to undertake maintenance on the retaining walls. Future maintenance costs may incur a surcharge related to obtaining access to the foreshore.

10.1.5. Observed Change

Mosman Bay (SRMos01)

- Loss of beach, damage to structure to landward, sediment accumulation in the north.
- Foreshore responding to historic changes with extension of a headland in the south 30m riverward in 1906 for Mosmans Jetty and in the north by 30m riverward in 1964 for RFBYC. Dredged areas at the pens at Mosmans (and historically earlier than that for Smiths boatshed), at RFBYC to the north, a dredged hole west of the RFBYC pens and the dredged area on the terrace from the 1964-1967 renourishment.
- The walling is experiencing damage and sections of failure with undermining, rotation, overtopping and loss of material through the wall. Old retaining wall at back of the beach was lower and existed in the 1940s. It was more of a landscaping wall not designed to sustain full hydraulic forcing, relying on the presence of a beach to riverward. Replaced in sections in 2001 with a single layer of walling further riverward (see notes below in Section 10.1.7). The overall wall design is not appropriate for a foreshore without a beach and as such the majority of the walling is approaching the end of its functional life. Raising the walling and extending it riverward promotes wave reflection in higher water level events contributing to overall bed level lowering. Fixing the foreshore provides less capacity for foreshore response to extreme events.
- Beach has responded to modified controls in the north and south and will always rely on ongoing management. Last known transfer of material from N to S in 1995 (when Meads, now Mosmans, complained). Occasional movement of small volumes to the S, with sediment accumulated in the north harvested from the beach and taken elsewhere on the river. Backpassing to be reinstated.
- The level of the terrace and its outer slope have remained in the same positions, with erosion of the beach and on the outer margin of the terrace. This pattern of change is consistent with increased wave action on the outer terrace, with the loss of beach material more characteristics of alongshore transport.

Recreation areas

The remaining foreshore recreation areas in the ToMP are all experiencing net retreat with a narrowing and lowering of the beaches and foreshores adjacent to structures. The effective bed-level lowering is causing undermining of structures and increased pressure at the structure toe.

- SCC and lower Mosman Bay Park have lost material at the toe of the structures, increasing erosive pressure at the face and crest of the structures. Structures are approaching the end of their functional life. Recent upgrade to the SCC revetment with crushed limestone to landward.
- The Coombe area has been experiencing net retreat, with increased flanking erosion, bed level lowering adjacent to the structures and increased maintenance requirements for the structures.
- Green Place is also located in an area of net retreat, with partial failure of the aged structure and recent reconstruction, as well as bed level lowering and increased flanking erosion.

- Chidley Point is migrating with net erosion. There has been undercutting, overtopping and rotation of the landscaping limestone wall.
- The beach near Minim Cove with the jetty has not demonstrated significant change with increased vegetation to landward.
- Milo beach is also demonstrating erosion with a narrowing of the terrace.

Cliffed areas

The steep banks and cliffed areas of SRMos02 to SRMos07 have all experienced net retreat of sediment at the toe of the banks which provides an increased risk of future destabilisation. Localised cliff collapse and slip failures have occurred. Some areas, such as south of Swan Canoe Club have erosion scarps >2m in height. The cliffed and steep foreshore areas include:

- Swan Canoe Club to the Coombe (SRMos02)
- The Coombe to Green Place Reserve (SRMos02 and SRMos03)
- Green Place Reserve to Chidley Point beach (N) (SRMos03)
- Chidley Point beach (W) to Point Roe beach (N) (SRMos03 to SRMos05)
- Point Roe (W) to beyond City of Fremantle border (SRMos05 to SRMos07 and beyond).

All sections have locations with increased development above the steep slopes with changing land use. This places increased pressure to stabilise the cliffs, with stabilisation benefiting private property owners.

10.1.6. Structure Condition and Function Comparison

Previous assessments of structure condition and function have been used in preparation of the foreshore management and adaptation approach for Town of Mosman Park. The details of the 2004 and 2014 assessments are included in Appendix G.3 with tables of structure condition and short-term maintenance comments in Appendix G.4. Drains were only assessed in 2014 if they were contained within other foreshore structures.

10.1.7. Foreshore Controls and Sensitivities

The foreshore controls and sensitivities for the Town of Mosman Park are noted for Mosman Bay, other recreation areas and the cliffed areas.

Mosman Bay (SRMos01)

- Response to riverward extension of headlands by 30m in both north and south, as well as dredged areas at either extent of the beach.
- Historic renourishment (1967) material has been eroded from the beach.
- Restriction for migration of stabilisation works to landward.
- Sensitive to future loss of material to dredged areas.
- Drains and road runoff.
- Must move sewage pump station.
- New boat ramp dredged area will conflict with desire to renourish foreshore to return a beach riverward of the walling.
- Walling was insufficiently designed, presently rotating forward, slumping.
- Trees limits landward movement of structures due to root systems.
- Existing walling levels shown in Figure 10-3 with photos in Appendix G.7.

Mosman Bay walling

Previous walling maintenance works require consideration in the controls and sensitivities of the existing walling. In 2001 a 185m section of walling was constructed as a single block-wall fronting the older, lower-level grouted block walling (Figure 10-4). This diagram shows that the structure may not have been constructed consistently on appropriate footings; specifically, use of a gravity wall to resist hydraulic forcing is not appropriate without a beach to absorb wave energy.

Further sections of walling were collapsing between Mosmans and the 185m walling in 2001 (Figure 10-5), and were replaced in December 2001. A similar method of replacement to the one mentioned above was utilised for this section, and there is doubt over the sufficiency of the installed footing. Concerns over insufficient use of geotextile and coarse material to landward may also affect the integrity of the replaced walling. It is assumed that some renourishment or backpassing would have been done simultaneously with the replacement, but no records have been provided.

It should be noted that raising the walling and extending it riverward promotes wave reflection in higher water level events, contributing to overall bed level lowering. Fixing the foreshore provides less capacity for foreshore response to extreme events.

<u>Recreation areas</u>

In many of the other recreation areas the foreshore is still responding to the riverward extension of the foreshores and historic renourishment. The foreshores are sensitive the terrace and lower foreshore levels and dynamics. Many sections of walling are at the end of their structural life, with some reactive management limiting the capacity to undertake maintenance. Drainage and surface runoff is a further control for foreshore instability. Further site specific controls are noted below.

- SCC and lower Mosman Bay Park – There is a lack of setback for SCC. Rocks in front of the block wall at Lower Mosman Bay Park limit capacity to undertake maintenance. Existing wall levels shown in Figure 10-6 with photos in Appendix G.7.
- The Coombe – rocks riverward of the limestone walling limit capacity to undertake maintenance. Additional controls are surface runoff down the Coombe, loss of beach and narrowing of the lower foreshore. Existing wall levels shown in Figure 10-6 with photos in Appendix G.7.
- Green Place – part of the walling has recently been reconstructed. The narrowing of the lower foreshore is contributing to structural damage and flanking erosion. Existing wall levels shown in Figure 10-7 with photos in Appendix G.7.
- Chidley Point – the existing structure was placed to fix a migratory and artificial feature. Existing wall levels shown in Figure 10-7 with photos in Appendix G.7. This reclaimed foreshore is sensitive to interannual variability in hydrodynamic processes and sustained shifts in mean sea level.
- Beach with jetty near Minim Cove – terrace dynamics and migrating channel impact capacity for beach to be sustained in its present position.
- Milo beach – terrace dynamics and migrating channel impact capacity for beach to be sustained in its present position. Information on adjacent structures in Figure 10-8.

<u>Cliffed areas</u>

The main controls and sensitivities for the cliffed areas is the characteristics of the banks (ie strength of foreshore material), the quantity of sand or talus at the toe of the cliffs/banks, groundwater, surface water modifications from land use above and focal drainage pathways. Structures placed at the toe of steep banks to reduce local damage can transfer stress to adjacent foreshores with increased local safety hazard.

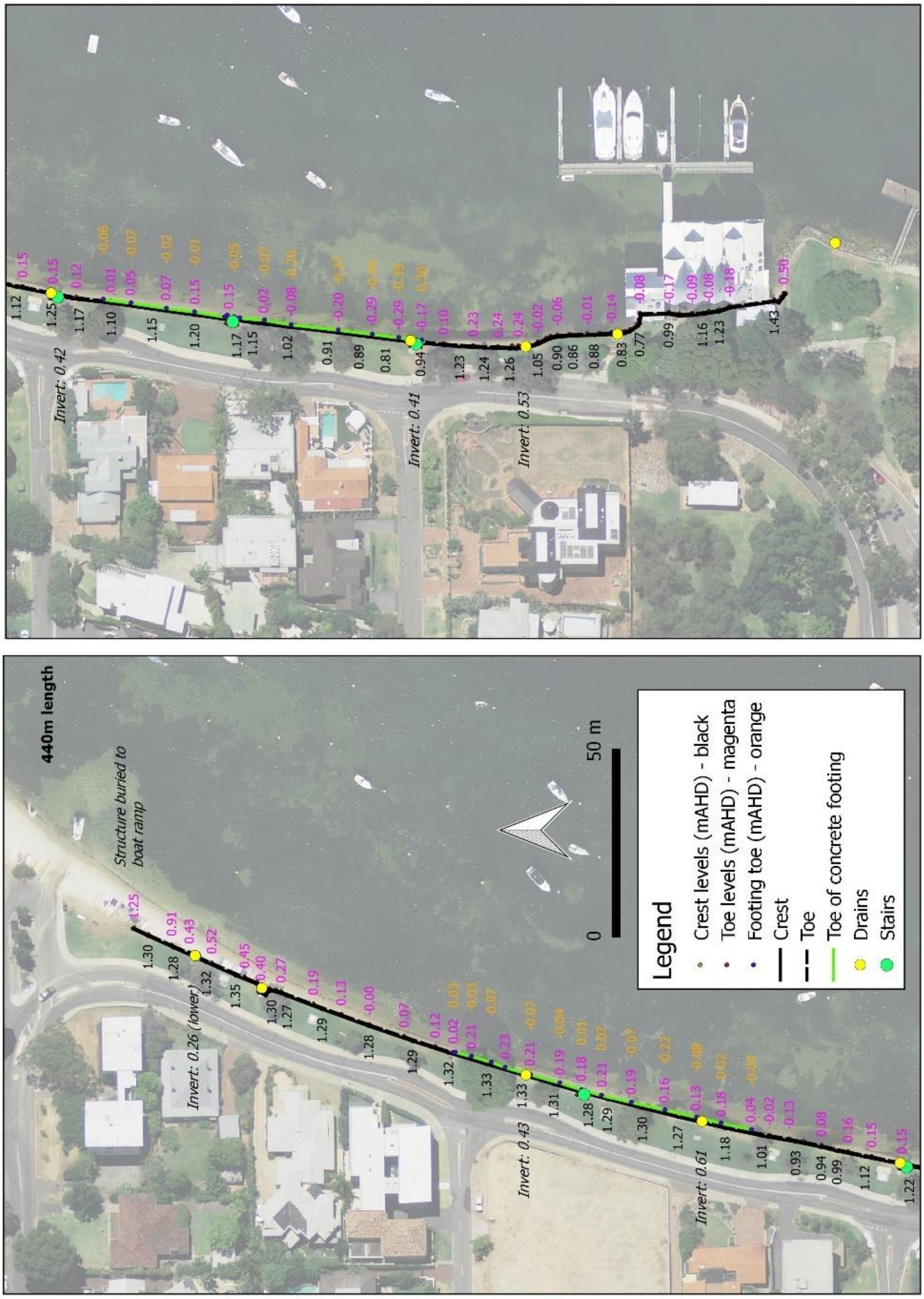

Figure 10-3: Existing walling level at the crest, toe and footing of the walling along Mosman Bay (2014)

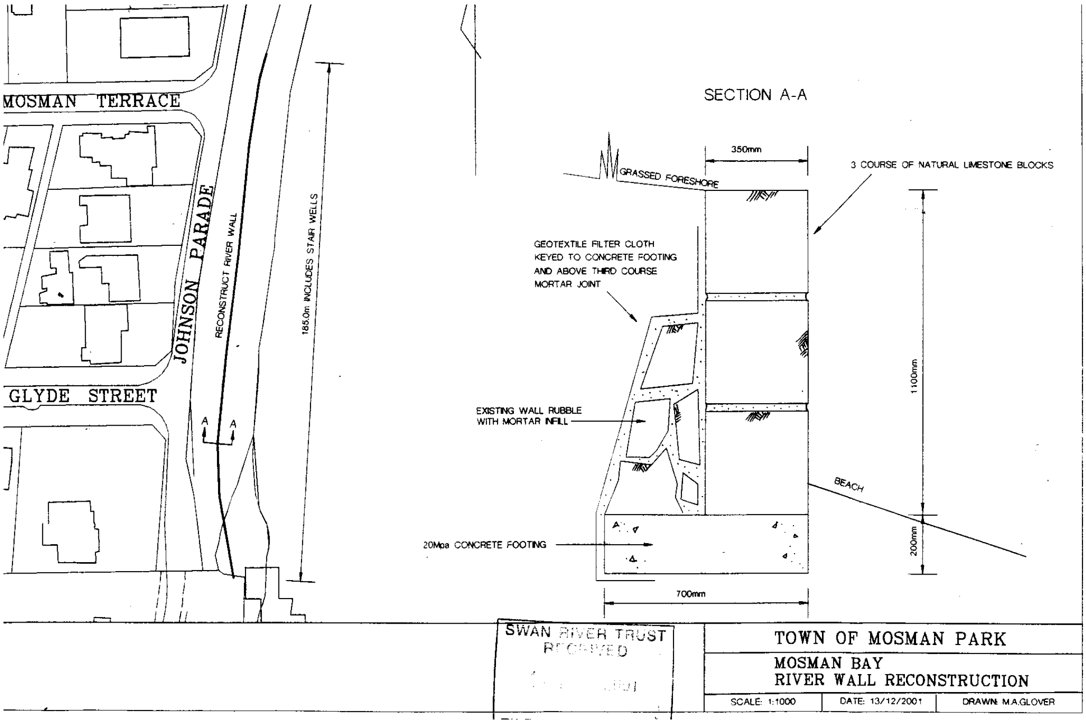

Figure 10-4: Mosman Bay river wall reconstruction design diagram (SRT 2001)

Figure 10-5: December 2001. Reconstruction of walled section between Mosmans and 185m walled section replaced in 2001 (SRT 2001)

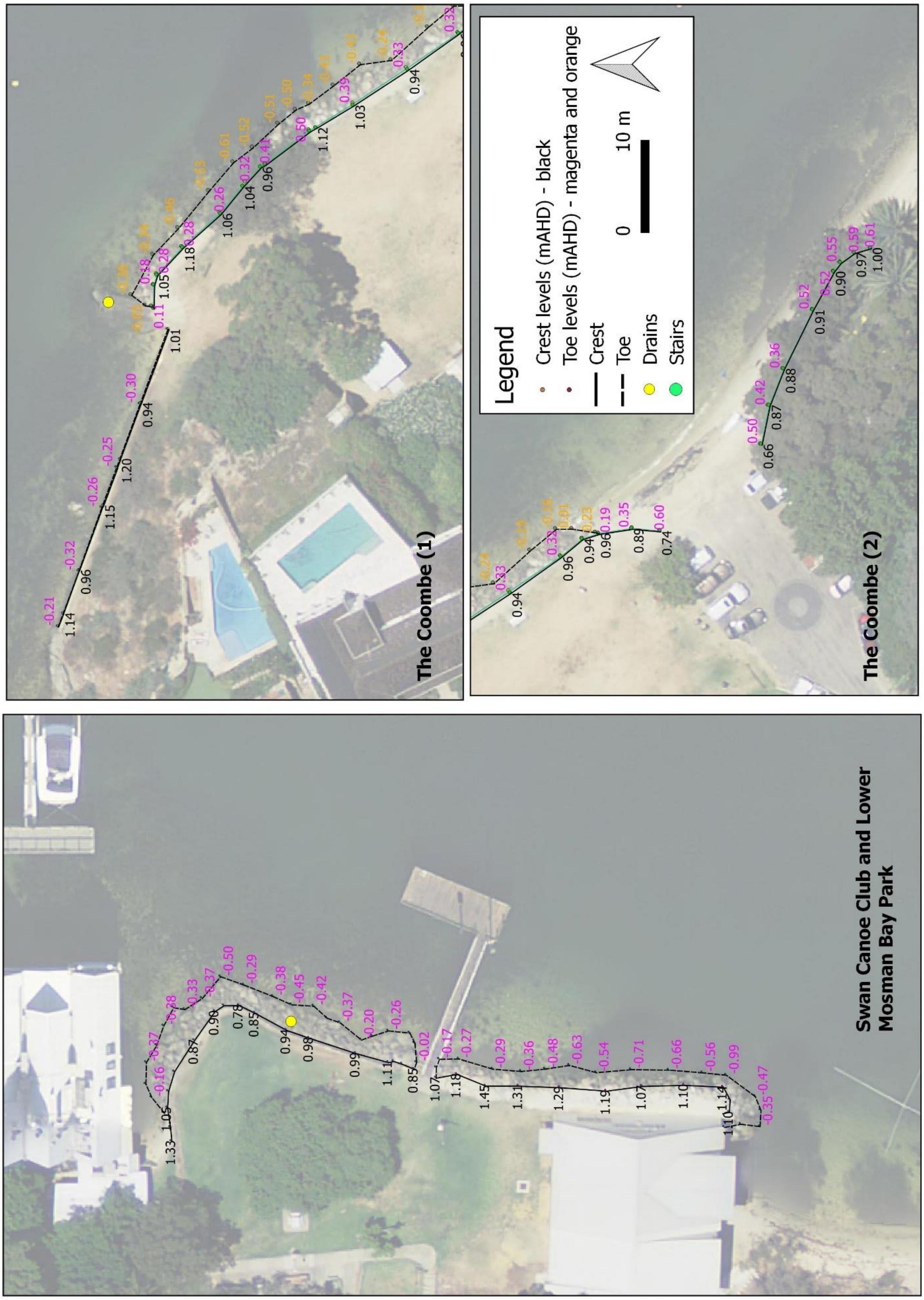

Figure 10-6: Existing walling levels in SRMos02 at SCC, Lower Mosman Park and the Coombe (2014)

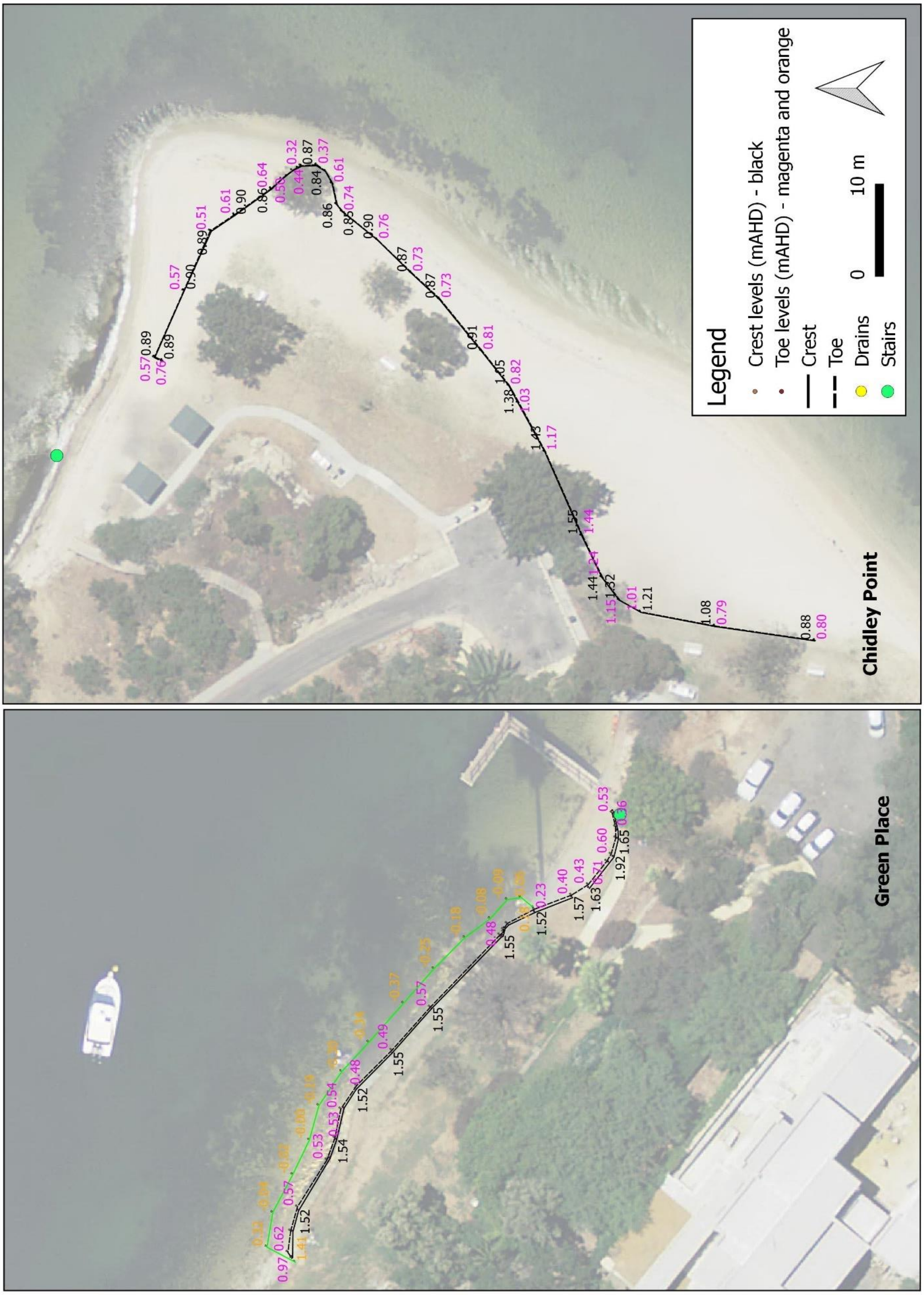

Figure 10-7: Existing walling levels in SRMos03 at Green Place and Chidley Point (2014)

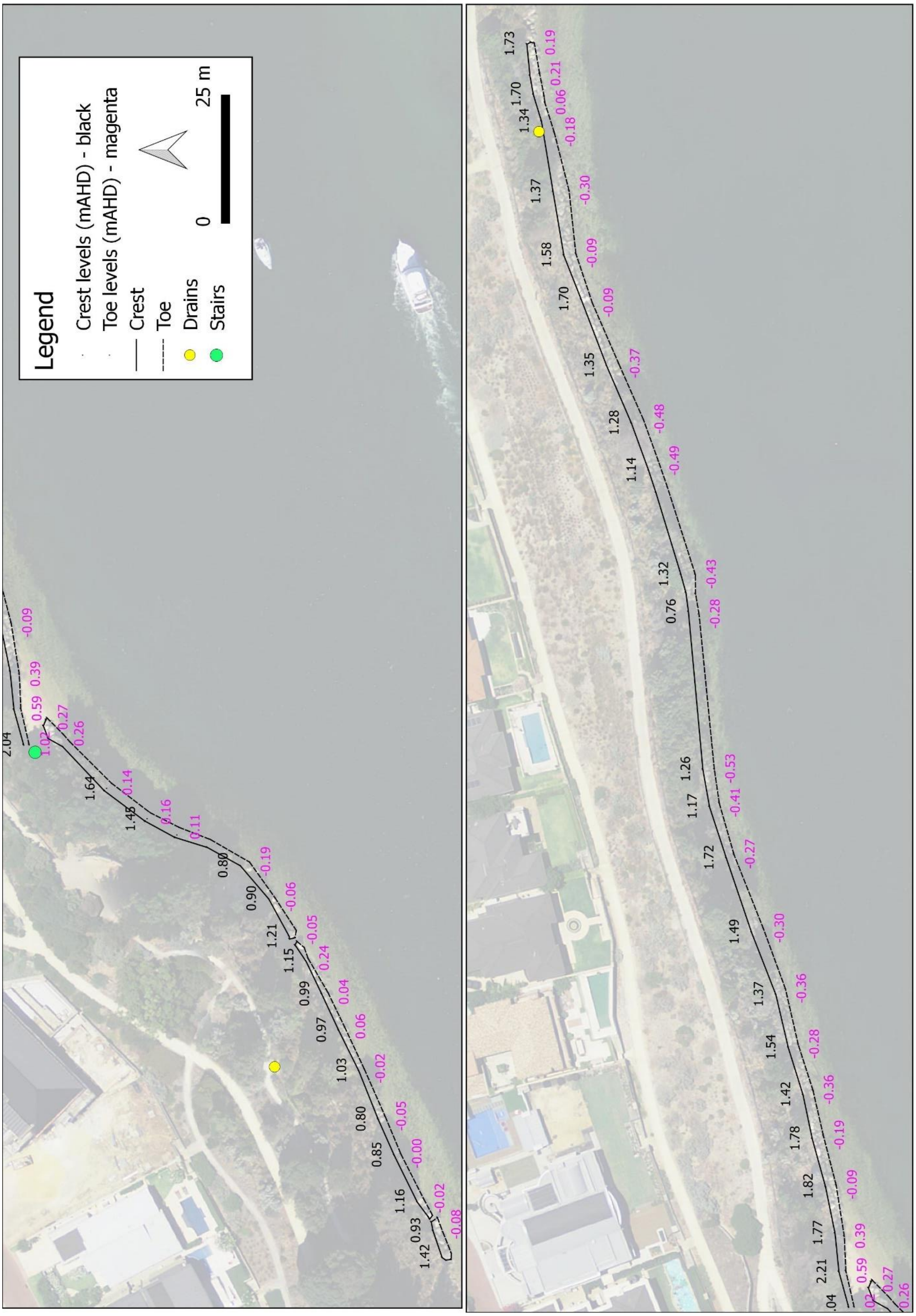

Figure 10-8: Existing walling levels in SRMos07 at Milo Beach/Garungup Park/Minim Cove (2014)

10.1.8. Scenarios and Impacts

The scenario at present is:

- Mosman Bay
  - Continued stress at the structure toe with loss of material under the footing. Continued undermining, rotation in parts and walling failure.
  - Ongoing maintenance requirement for walling, with three sections most likely to fail.
  - Continued loss of beach in Mosman Bay with sediment accumulation in the north. Beach is not maintained, with sediment harvested and taken elsewhere on the river.
  - Ongoing local wall damage associated with drain scour.
  - Anticipated failure of the sewage pump station due to direct wave attack.
  - Sedimentation of the boat ramp.
  - Sediment accumulation between the boat ramp and RFBYC.
- Continued erosion through and at the crest of structures at SCC and lower Mosman Bay Park. Ongoing loss of crushed limestone fill occurring at crest of SCC revetment.
- Continued erosion of cliff and steep scarped areas without adequate erosion mitigation structures.
- Continued erosion stress at the base of the structures at the Coombe, continued runoff scour at the end of the Coombe road and ongoing erosion stress adjacent to structures. Low structures are overtopped during storm events.
- Erosion anticipated to continue to the north of the new walling at Green Place.
- Continued inter-annual discrepancy in seasonal and net sediment transport Chidley Point Reserve, with damage to low-walling during storm events.
- Continued narrowing of the terrace near Milo Beach.

The scenario of increased mean sea level could result in the potential responses outlined in Section 10.1.10 in the >25 year category.

Further scenarios to consider are the feedback related to the increased scale of the boat ramp and dredged channel in Mosman Bay, the scenario of not maintaining the beach in Mosman Bay and modifying erosion mitigation structures to smooth hydraulic transitions. The anticipated ongoing modification to land use in the Town of Mosman Park, with increased density, is altering drainage pathways which may increase slip failures and bank instability. The implications for increased private property redevelopment at the crest of steep slopes should also be considered.

10.1.9. Values and Foreshore Uses Considered (Short- and Long-Term)

The foreshore values and uses for the Town of Mosman Park managed foreshore are noted for Mosman Bay, other recreation areas and the cliffed areas.

<u>Mosman Bay (SRMos01)</u>

There are conflicting values for the Mosman Bay foreshore, including a desire for low cost solutions.

- Beach.
- Recreation use.
- Walking above walling.
- Benches and seating above walling.
- Boat launching and maintaining new proposed dredged channel.
- Maintain boat pens at Mosmans (S) and RFBYC (N).
- Dinghy storage and launching for moorings.

- Minimise change.
- Maintain lawn above structure.
- Maintain peppermint trees.
- Maintain drain function to minimise road flooding (also reduce overflow over bank).
- In the N, ensure sea scouts are not compromised.
- Whadjuk values are to increase ecological function and reduce walling hardness.

As the population density increases it is anticipated there will be increased use of this foreshore.

Recreation areas:

- Recreation use at SCC, lower Mosman Bay Park, The Coombe, Green Place, Chidley Point, beach at the jetty (SRMos06), Milo beach. Anticipated increased use of these areas in future with an increase population density.
- Beach use at Chidley Point, beach at the jetty (SRMos06) and Milo beach. Anticipated increased use of these areas in future with an increase population density.
- Dinghy storage at the Coombe.
- Maintain lawn above structures.
- Car parking at Chidley Point and the Coombe.
- Canoe and kayak launching and storage facilities at SCC.
- Jetty at Lower Mosman Bay Park and at the beach in SRMos06.
- Maintain moorings with pressure for dinghy storage and launching areas to access moorings.
- Whadjuk values are to increase ecological function and reduce walling hardness.

Cliffed foreshores:

- Private property above in many areas with privately owned erosion mitigation structures. Some partial resumption by WAPC.
- Path and viewscapes from above.
- Car parks above.
- Vegetation and ecological function.
- Not heavy pedestrian use at the toe.
- Some fishing at base of the cliffs.

10.1.10. Vulnerability

Existing vulnerability (0-5 years)

Mosman Bay (SRMos01.B01)

Approximately 120m of the 440m walling (in three sections, all in the southern areas) would be inundated in a 10-year ARI still water level (+1.1mAHD) if no waves and no mean sea level shift (Figure 10-3). Inundation increases during La Nina events due to an increase in mean sea level. Waves will contribute to scour of material under the structure toe, erosion through gaps in the walling and at the crest of the walling due to overtopping. Waves are 0.6 to 0.8m Hs (3-year to 100-year), with small long-period boat wakes also occurring at the site.

The three sections of walling most susceptible to damage are the walling under Mosmans Restaurant, an 80m section rotating forwards and a 100m section with low-elevation. Many poor sections of walling are attributed to inadequate design and the technique of constructing new walling riverward of historic walling, as detailed in Section 10.1.7. Some sections of walling are rotating riverward and others settling due to insufficient footings and the design relying on a beach fronting the structure. Existing walling levels at the crest and at the toe/beach surface level (whichever was exposed) are shown in Figure 10-3. The levels at the base of the exposed toe in two sections is also noted.

The present walling in Mosman Bay is vulnerable if a beach is not maintained. Without renourishment the beach will continue to erode. Replacement structures will require sufficient embedment to sustain the increased hydraulic forcing.

Other sections of walling susceptible to damage are areas where:

- grout has eroded in the lower part of the structure;
- insufficient stability at the toe;
- walling is adjacent to drains, particularly where drains discharge in the wall, or directly on the face, with insufficient reapplication of grout;
- in areas where the structure was poorly built;
- there is no remaining beach fronting the walling;
- where irrigation pipes and sprinklers are located adjacent to walling; and
- there are stairs.

Further vulnerability is associated with:

- where the walling is not smooth, near the sewage pump station and at Mosmans Restaurant;
- at the sewage pump station, with the concrete structure unlikely to have been designed to sustain the hydraulic forcing it is exposed to since the beach has been eroded;
- unmanaged surface runoff from the roads, which is likely to increase in frequency with increased density of residential developments;
- removal of any sand accumulating at the boat ramp, the proposed dredged channel and accumulating in northern Mosman Bay (Town of Mosman Park) for use in a foreshore area other than Mosman Bay;
- construction of any new structure that impedes alongshore sediment transport or extends further riverward than the existing structure; and
- inter-annual variability in the water level, wind and wave climate contributing to sediment accumulation at the boat ramp.

Remaining recreation areas
Foreshore is sensitive to the overall loss of sediment on the lower beach and narrowing of the terrace which is likely to increase with possible mean sea level rise. Undermining of structures is likely to continue with potential structural failure, with a greater reliance on more frequent maintenance. Flanking erosion is anticipated to occur adjacent to structures.

The beaches are vulnerable to ongoing loss of renourished material with potential increased mean sea level. Chidley Point foreshore is migratory and should be allowed to move, avoiding fixed structures. Some sections of foreshore may require managed retreat.

Focal erosion occurs in the vicinity of drains at Lower Mosman Bay Park and the Coombe, as well as due to overbank flow in other areas, such as the Coombe and Milo Beach.

Cliffed areas
Foreshore is sensitive to the overall loss of sediment and talus at the base of the steep foreshores which is likely to increase with possible mean sea level rise. Rates of slip failure and cliff collapse likely to increase with increased mean sea level rise. In the Rocky Bay area (SRMos06, SRMos07) the foreshore is highly vulnerable to the northward migration of the river channel, partly in response to the growth of the flood tidal shoal in a different area following the 1971 Preston Point channel dredging. The cliffs and steep foreshores are vulnerable to local focused surface runoff in response to increased land use through paths, car parks and private property developments.

Progressive change to vulnerability (5-25 years)
It is expected that many sections of the walling in Mosman Bay will reach the end of its functional life during this time period. Drainage pipes may also require renewal through the length of pipe simultaneously with the age of the pipes to be determined.

Some of the vectors for vulnerability described are likely to increase in magnitude. This will include increased:

- Erosion at the base of structures, through structures and due to flanking erosion adjacent to structures as the foreshore continues to respond to historic works. Erosion due to overtopping of low structures will also increase for some locations.
- Runoff into drains, drainage pits and over the banks with less recharge in the catchment as density increase in the ToMP. This will result in increased scour at drains and in areas of unmanaged runoff.
- Rate of grout weathering.
- Narrowing of the beaches, with enhanced erosion stress in southern Mosman Bay.
- Continued loss of sediment and talus at the base of the steep foreshores.

A further source of vulnerability is due to staging of the walling replacement in Mosman Bay. The tie-in areas have the highest susceptibility to damage, with adequate temporary tie-ins to be designed. If any new walling works extend further riverward, additional consideration is required for stabilising the toe of adjacent structures to account for transfer of erosion stress.

The foreshore in Mosman Bay is also vulnerable to the plans for the boat ramp, at RFBYC and at Mosmans Restaurant. The foreshore in the Rocky Bay area (SRMos06, SRMos07) is most vulnerable to the narrowing of the terrace, possibly in relation to northward migration of the channel.

Scenarios for changing vulnerability (>25 years)
Longer-term planning considers the scenario of increased mean sea level. This could increase the foreshore vulnerability to:

- Bed level lowering and stress at the toe of structures. Loss of material under footings (if present) and slumping. Walling collapse anticipated in part of Mosman Bay if beach not maintained.
- Increased overtopping of structures, loss of material behind the structures.
- Increased slip failures and cliff collapse on steep slopes. In part due to the increased loss of sediment and talus at the base of the steep foreshores.
- Ongoing erosion stress in southern foreshore of Mosman Bay and increased sedimentation in northern foreshore of Mosman Bay. Present foreshore use restricts capacity to move. Without renourishment there will be no beach present.
- Erosion enhanced adjacent to structures.

Scenarios for changing foreshore use have not been considered. However, Town of Mosman Park should consider the implications on the foreshore due to ongoing change in land use in long-term plans.

10.2. FORESHORE MANAGEMENT AND ADAPTATION SEQUENCES AND PLANS

The possible interventions for the Town of Mosman Park are described, with the preferred options described in further detail according to the vulnerability assessment time-frames linked to risk mitigation, management pathways and an adaptation strategy (Table 3-1). The detailed information is presented for each segment (Figure 10-1), with a summary of scheduling, monitoring requirements for adaptation triggers and works summary for the 0-5 year time-frame provided for the whole LGA. Further detail is also included for each segment in Appendix G.6.

Initially, the decision-support framework was applied, according to the method described in Section 3.2 of SRT (2009), to refine which stabilisation techniques should be considered further. Details of this application is included in Appendix G.5.

10.2.1. Possible Interventions

Possible maintenance and capital works for the Town of Mosman Park foreshore are discussed in the context of improving resilience of the foreshore to erosion (chronic and acute), shifting mean sea levels, structure degradation, increased surface runoff and inter-annual variations in wind direction. Any interventions account for the foreshore response to historic works and management actions. Possible interventions are discussed on a spatial basis separated into Mosman Bay, other recreation areas (Swan Canoe Club and Lower Mosman Bay Park, the Coombe, Green Place, Chidley Point Reserve, the beach near Minim Cove jetty, Milo beach) and steep/cliffed foreshores. This separation was preferred to applying generic principles across the ToMP foreshore. This method of separation creates higher confidence in recommended interventions due to variations in historic modifications, land use, land ownership and exposure to hydrodynamic forcing.

The majority of the discussion focuses on the walling in Mosman Bay (segment SRMos01) as this is the area with the highest recreational use, is in the poorest condition and will require the highest capital works expenditure for future erosion mitigation. Mosman Bay has also been the focus of recent investigations for erosion mitigation studies (iwprojects *et al.* (2012), MP Rogers & Associates (2010 with review by Damara (2011)), with any subsequent plans recommended to consider the aspects discussed in this section.

It is not considered feasible to maintain all of the existing uses across the broader ToMP foreshore in the longer term, and it is recommended to consider future retreat in some areas, altered foreshore use in others, and increased investment in erosion mitigation for some private property owners. Possible interventions will require consideration of the increased residential development density occurring in ToMP which will alter the foreshore use and drainage patterns. In addition, access limitations will require consideration for possible interventions for some areas given the expense of operating from a barge.

<u>Mosman Bay Walling (SRMos01)</u>

Maintenance and capital works for the walled foreshore of Mosman Bay are discussed in the context of improving foreshore resilience. Improving resilience on a walled foreshore includes considering greater capacity to tolerate increased wave energy, lower bed levels adjacent to the walling (including loss of beach) and higher rates of overtopping. It is assumed the goal for this foreshore is to maintain the grassed recreation area to landward of the walling, with discussion of maintaining a beach, and improved function of the boat ramp.

Walling along the Mosman Bay foreshore was lower in elevation in the 1940s and was a landscaping-style wall not necessarily designed to sustain full hydraulic forcing, relying on the presence of a beach to riverward. The beach was sustained with renourishment in 1964, with backpassing occurring until 1995. The lack of ongoing renourishment lead to the more exposed walling starting to fail in 2000. Sections were replaced in 2001 with a single layer of walling further riverward (see notes below in Section 10.1.7). The overall wall design is not appropriate for a foreshore without a beach and as such more than 200m of the 440m of walling is approaching the end of its functional life.

The ToMP has actively maintained the walling through programs of re-grout, backfilling with builders sand and repair at drains/stairs, which has extended the structural life of the walling. However, in many sections the walling life can be extended with further maintenance such as regrout and shifting irrigation to landward. In two to three locations the structural life of the limestone block walling (or rock walling under Mosmans) has been exceeded with limited opportunity to extend it further through modification of the existing structures due to the nature of the construction riverward of historic walling (Table 12-53 in Appendix G.4; Damara WA 2015). In the 0-5 year period it is anticipated that three sections of the existing walling will require replacing, with the remainder expected in the 5-25 year period. Financial constraints determine that it is unlikely to achieve replacement as a single work, and therefore short-term enhancement may be suitable where it can be achieved and any capital works undertaken in the 0-5 year period should be adaptable and suitable to improve resilience to higher water levels.

This guidance is applicable to both short-term enhancement and to longer-term treatment of the foreshore.

Design elements that need to be considered in both instances include:

- The structural integrity of the walling itself;
- Progressive loss of beach and deepening of the river bed (enhanced in the south), which has compromised the effectiveness of the wall to retain sediment;
- Implications of low foreshore elevation for material retention, including both overtopping and inundation; and
- Allowance for a renourished beach to be incorporated if chosen to be pursued by ToMP.

Short-term enhancement and management

An urgent action item required is to address the exposure of the sewage pump station to hydraulic forcing. It is not recommended to undertake a permanent stabilisation solution as it will be recommended to shift the pump station away from the hydraulic zone. Undertaking emergency renourishment should provide some protection from the hydraulic forcing while a more permanent relocation is developed with the Water Corporation. This emergency renourishment could also be placed riverward of the failing Mosmans walling if required. The implications of this renourishment on sedimentation of the boat pens at Mosmans should be discussed with the restaurant owners.

Three sections of walling require urgent replacement include (1) 72m of walling under Mosmans, (2) 80m of walling rotating forwards, (3) 100m section of low-elevation walling. The most urgent requiring immediate maintenance is the walling under Mosmans, discussed further in the capital works section below.

Actions to extend the structural life for less-compromised sections of walling should focus on:

- Regrout to the full depth of the structure with marine grade (M4) cement including near drains;
- Shift irrigation pipes away from the walling (whole foreshore section) and plant salt- and drought-tolerant grass;
- Infilling scour holes and slumping behind walling with geotextile lining and coarse granular fill;
- Local areas of poor condition at the toe could be sustained with temporary backpassed material from the boat ramp or accumulated at RFBYC (SoPG foreshore).

Sedimentation at the boat ramp can be addressed by harvesting the sediment for backpassing to place riverward of the failing sections of walling.

Short-term works should avoid:

- any wall reconstructions that do not match or tie-in to the long-term plan;
- large toe stabilisation works as this increases the amount of excavation required when the walling is replaced; and
- investment in upgrading the Water Corporation sewage pump station in its present location as it requires relocation.

Capital works

Inadequate walling design for a foreshore without a beach has resulted in increased stress on the river walling as the beach levels were not maintained after 1995. Sediment backpassing was discontinued with sediment accumulated in the north of the bay harvested and taken elsewhere on the river. Further loss of beach and walling failure should be expected to occur. The loss of beach, bed level lowering, inadequate design and structural degradation have contributed to maintenance cost increases. The access for reliable maintenance funding from the Town of Mosman Park should be acknowledged within the design principles. Walling should be designed using appropriate design criteria, for resilience to changing bed conditions and have an acceptable allowance for ongoing maintenance.

Management recommendations by iwprojects *et al.* (2012) and MP Rogers & Associates (2010) do not address the failed and inadequate walling. The iwprojects *et al.* (2012) study recommended partial use of existing walling, wall reconstruction riverward of the existing walling (third extension riverward) and partial renourishment. The MP Rogers & Associates (2010) preferred option of a groyne near the boat ramp and partial renourishment does not address the failed walling in the mid- and southern sections.

Renewal of the hard structures in the Mosman Bay foreshore requires consideration of design elements that may improve foreshore resilience. Some aspects are presented below along with their associated objectives. The capacity of any capital works to enhance existing pressures, such as loss of beach and seabed lowering, should be clearly recognised and incorporated into design.

Design Element	**Objective**
1. Limit riverward extension	Limit river bed lowering and loss of beach due to structure

2. Use inclined wall to reduce wave effects	Limit river bed lowering and loss of beach, reduce overtopping
3. Increased walling embedment	Greater resilience to river bed lowering and loss of beach
4. Incorporate flexible scour toe OR use a renourished beach	Greater resilience to river bed lowering and loss of beach OR renourishment provides some resilience to bed level lowering
5. Raise wall crest level *	Greater resilience to overtopping & inundation
6. Manage drainage	Greater resilience to overtopping & inundation
7. Increase walling permeability	Greater resilience to overtopping & inundation

* Although raising the wall level is an appropriate method to improve resilience to overtopping and inundation, it is challenged in this case by the low foreshore level (in parts) and the inadequate toe for the wall construction.

Options not considered for further discussion were:

- No walling upgrade – this will not improve foreshore resilience as the wall will fail;
- Walling that extended further riverward without removing the existing walling – this will be the third wall extension riverward, promoting wave reflection in higher water level events and contributing to further bed level lowering and beach loss. It will require extensive embedment and provides less capacity for foreshore response to extreme events;
- Walling designed now to sustain potential higher sea levels in future (e.g. 0.5m higher structure) – this is an overinvestment not presently required and the foreshore to landward would require raising now;
- Walling that could not be adapted to improve resilience to higher sea levels in future – structures should have sufficient design at the base to allow for the wall to be raised in future without reconstruction at the toe; and
- Walling that did not permit the creation of a beach, in case the option wanted to be pursued (e.g. sheet piling or large rock revetment) – the future values for this area may return to having a beach in this location.

The main option considered for discussion is an inclined wall that ensures sufficient embedment now to allow for a future 0.5m rise in the height of the walling, without having to reconstruct the walling. Low sections of the walling would require raising now to improve resilience to existing water levels. The toe of the walling would be ideally as far landward as possible, most likely in its approximate present position, with retreat of the upper walling, to minimise disturbance to the peppermint trees to landward.

The study considers an inclined limestone block gravity wall, although other options are available. This wall design is presented as it addresses design elements (1), (2), (3), (5), (6) and (7) with an option to address (4) with either a scour toe or renourishment. The inclined wall would be a gravity wall structure, compared to the present two layers of single block wall, constructed at separate times. The wall would require extensive excavation to construct (ensuring minimal disruption to tree roots), sufficient embedment and base design to allow for a future rise in the walling, drainage to landward and either a scour toe or renourishment. In general, an inclined limestone block wall is a less resilient structure than a revetment as it lacks self-stabilising mobility. However, with sufficient construction of the base it is readily adaptable upwards in future. As the inclined wall is similar to the existing walling type, there is capacity to construct it to landward and it can transition with the stairs, drainage and the boat ramp due to having a narrower footprint than a revetment. Removal of the existing walling has a high cost and should only be undertaken when required (i.e. failure has occurred). All drains are likely to require renewal as part of the reconstruction. Raising the walling in future will require additional block units and the area to landward backfilled and regraded.

The toe of the structure may have either (1) renourishment, with spur groynes considered to assist in stabilising the renourished material or (2) a rock scour toe. If renourishment is pursued, with possible low 2-3m length groynes, some issues require resolution:

- Sedimentation rates of Mosmans pens and boat ramp channel. Consider there may be loss of pens at Mosmans and boat ramp may require long-term shift to an area with less sedimentation;
- Perceived waste of money, to be placed in context of maintaining scour toe;
- Reducing rate of beach erosion due to drainage;
- Ongoing source of material; and
- How will spurs impact on capacity to backpass material from N to S.

In the longer-term it is expected a scour toe will be required in the south and potentially along most of the foreshore.

Multiple options may be pursued along the foreshore, as considered by iwprojects *et al.* (2012), with areas of focal renourishment for recreation use rather than renourishing the broader foreshore. This renourishment would require structures to hold the sediment in position.

At Mosmans Restaurant the failing grouted rock wall presently extends further riverward than the adjacent foreshore to the north, due to subsequent modifications to the foreshore use with time. The walling previously had a beach riverward of the wall. It is recommended to replace the 72m of wall, and some of the foreshore, with a revetment that improves the hydraulic smoothness. The revetment will require additional embedment and transitions to the adjacent walling. Pedestrian access to Mosmans Restaurant will require redesign and could include a piled walkway. As discussed in the Short-Term Management above, the sewage pump station will require relocation by the Water Corporation. It is recommended to discuss with Mosmans Restaurant about potential financial contribution towards the revetment and walkway.

The plan for the wall and revetment should be prepared as soon as possible for the works to be undertaken as required and so funding can be arranged. The plan should consider the impacts of the approved design of the boat ramp and dredged channel. Ongoing wall maintenance is required, as well as renourishment/backpassing or top of the scour toe. The cost estimates provided in this plan can be used as an initial basis for funding discussions.

Transition

The southern section of the walling requires transition with the proposed revetment at Mosmans Restaurant. The northern section of the walling requires transition with the proposed boat ramp and dredged channel. Within the structure the transition to steps requires consideration.

<u>Other recreation areas</u>

Possible interventions for improving foreshore resilience in six other recreation areas in the ToMP were considered. The works generally involve maintaining existing for as long as possible and then partial retreat, including walling. Exceptions to the partial retreat is at Chidley Point and Milo Beach with interventions to possibly include beach renourishment.

It is recommended to develop a planning control over local redevelopments within a nominal distance from the foreshore (e.g. 800m) to ensure any limestone material to be excavated as part of future residential developments is made available to ToMP for foreshore stabilisation works. This would reduce the overall cost of replacement of aging erosion mitigation structures due to the distance to suitable limestone rock quarries.

If a new beach recreation zone is desired between Chidley Point and Minim Cove Jetty it is recommended to develop a long-term management plan to ensure it is feasible.

Swan Canoe Club and Lower Mosman Bay Park (SRMos02)
Foreshore resilience in this area could be improved in the longer-term by smoothing the alongshore alignment of the walling to reduce focal areas of erosive stress. This would include replacing the revetment at Swan Canoe Club with a wider revetment and retreat of the old walling alignment from the 1906 jetty placement towards Mosmans. Any planned works require consideration of the access limitations at the site. In the shorter-term the walling at Lower Mosman Bay will require ongoing regrout, possibly applied on the landward side of the walling. The crushed limestone levels landward of the Swan Canoe Club revetment will require ongoing top-up. It is recommended to discuss with Swan Canoe Club about potential financial contribution towards long-term revetment reconstruction. Works landward of the existing walling should only be approved if they do not limit the future retreat of the foreshore structures.

The Coombe (SRMos02)
Foreshore resilience in this area could be improved in the short-term through structure maintenance and management of surface run-off, with landward migration of structures in future. In the short-term, the improved surface runoff management and the removal of the riverward 2m of bitumen from the carpark will reduce beach loss due to wave reflection and runoff scour. In the medium-term realignment and partial retreat will be required, as many structures are only retaining grass, with creation of smoother transitions. The drain will require reconstruction with an allowance for further terrace bed level lowering. Sections of the car park should be removed and replaced with a renourished beach to reduce scour. It is recommended to obtain some financial contribution by the private property owner benefiting from the erosion mitigation provided by the vertical limestone block wall (SRMos02.B02). The trigger for works being undertaken is likely to be if rock is available from a local residential development. Ongoing renourishment will be required riverward of the modified carpark to maintain the beach. Any Works landward of the existing walling should only be approved if they do not limit the future retreat of the foreshore structures.

Green Place (SRMos03)
Foreshore resilience at Green Place requires maintenance of the existing, and recently replaced, structures as long as possible. Maintenance of the scour toe is restricted by access limitations to deliver the rock. In the medium-term the small block wall near the jetty is likely to require replacement. North of the existing structure will require an extension of the structure or managed retreat to address ongoing erosion concerns. In the long-term partial retreat of the walling should be considered as it is retaining a grassed area to landward. Any planned works require consideration of the access limitations at the site.

Chidley Point (SRMos03)
Foreshore resilience on this renourished foreshore could be improved by allowing the beach to migrate and avoiding placing fixed structures to stabilise the foreshore position. In the medium-term the existing low-elevation walling could be removed, with the beach renourished and ongoing backpassing. Ongoing

renourishment is required in the longer-term with consideration of partial retreat and installation of headlands.

Minim Cove Jetty (SRMos06)
The resilience of the small beach at Minim Cove Jetty will depend on the migration of the terrace and shifts in mean sea level. Ongoing renourishment is a recommended intervention to maintain a recreational beach. Access limitations require consideration in planning renourishment programs. Ensure Department of Transport are aware that if they were to dredge the flood tide shoal to assist with navigation that some dredged sediment is placed at this beach.

Milo Beach (SRMos07)
Ongoing renourishment and improved management of surface runoff down the stairs are recommended interventions for the small Milo Beach. Access limitations require consideration in planning renourishment programs as the site is only accessible from the water or via a staircase. In the longer-term, structures are likely required to maintain the beach position and slow the rate of erosion, particularly as the terrace continues to narrow and deepen. Ensure Department of Transport are aware that if they were to dredge the flood tide shoal to assist with navigation that some dredged sediment is placed at Milo Beach.

Cliffs and steep foreshores (parts SRMos02 to SRMos07).
There are five sections of cliffs and steep foreshore areas (listed in Section 10.1.5) in the Town of Mosman Park. In the interests of improving overall foreshore resilience it is generally recommended to allow the base of cliffs or steep slopes to continue to erode. The eroded material contributes to talus and sediment at the base of cliffs and on the terrace, which provides a measure of self-stabilisation. This material may also be available to adjacent foreshores.

Five points to consider in facilitating managed retreat of steep foreshores includes:

- Restricting access for public safety at the base and along the top of the cliffs and steep slopes. This may require fencing, signage and revegetation efforts.
- Public awareness of managed retreat. This is particularly relevant to concerns that may be raised from boat users. Information may be required to be posted to the Town of Mosman Park and Parks and Wildlife websites.
- Improved surface drainage management above steep slopes and cliffs to reduce slip failure, cliff collapse and scour as a result of surface runoff. In the longer-term this may require realignment of car parks at the crest of steep foreshores (eg. Caporn St in SRMos03). Planning controls should be developed to ensure surface runoff from private properties is managed to avoid destabilisation of steep slopes (SRMos03 to SRMos05).
- Slip failure in SRMos07 in northern Rocky Bay will require opportunistic repair of the existing structure, dependent on access from a barge. In the longer-term a path realignment may be required to reduce the contribution of surface runoff to slip failure.
- Addressing the requirement for the toe of some cliffs and steep banks when there is HWM private property ownership. In certain areas (Coombe and Owston Rd in SRMos02, Saunders St and Riverside Pl in SRMos03) private property owners should be encouraged to develop and implement a strategic plan for erosion mitigation. The agreement should consider long-term maintenance and funding arrangements for works on the lower foreshore. The plan should consider transitions between structures, cliff stability, staging, local areas of retreat and tie-in to underlying rock.

Investment in infrastructure at the crest of these eroding steep foreshores should be avoided.

10.2.2. Works for Each Segment

Potential risk mitigation, management pathways and adaptation strategies are presented for each segment linked to time-frames of 0-5 years, 5-25 years and >25 years (Table 3-1). The shortest timescales consider the present state of the foreshore and sensitivity to acute events. The medium-term timescales consider foreshore dynamics, life-cycle of existing stabilising structures and increasing foreshore resilience. For time-frames greater than 25 years there is uncertainty related to future management choices and longer-term process variability. Scenarios possibly affecting the foreshore are considered at this scale in the context of improving resilience where possible.

The foreshore management and adaptation sequences are presented for each foreshore segment in detail in Appendix G.6 (Table 12-57 to Table 12-63). Each table includes:

- A foreshore management goal, capital works and maintenance requirements for each of the three timeframes.
- Requirements for monitoring linked to identification of maintenance requirements, refining budgets and triggering foreshore management actions and adaptation.
- Details of issues to be resolved, and works to be avoided, to ensure the recommended management sequence may be achieved.
- Simple cost estimates (Appendix B) for capital works, maintenance works and a 25-year total with no future cost adjustments.

A summary of the foreshore management goals for the three timescales for each segment is provided in Table 10-2.

Table 10-2: Summary of Management Goals for each Segment in the Town of Mosman Park
Detail for each segment is included in relevant tables in Appendix G.6

Segment (Table with detail in Appendix G.6)	**Short-term (risk management) for 0-5 years**	**Medium-term (planning) for 5-25 years**	**Long-term (strategy) for >25 years**	**25-year cost. Not indexed (2015 costs)**
SRMos01 Mosman Bay Park, Mosman Tce (Table 12-57)	Extend life of existing walling as long as possible. Replace failed southern walling with a realigned rock revetment. Replace failing mid-segment walling with sufficient embedment for long-term strategy.	Replace remainder of walling with sufficient embedment for long-term strategy with optional beach renourishment.	Hold line and raise walling vertically by 0.5m and backfill/regrade. Loss of beach except in focal area in the north.	≈$2.4M -$2.9M with a further ~$100k assumed required for drain renewal[1,2] (resolve Mosmans contribution. Excludes boat ramp upgrade costs)
SRMos02 Bay View Park,View Tce (Table 12-58)	Extend life of existing walling near Swan Canoe Club and the Coombe as long as possible. Remove riverward 1-2m of Coombe car park. Manage surface runoff. Allow cliffs to erode and restrict access at base. Resolve arrangements for private owner contribution for cliff toe stabilisation.	Extend life of existing walling near Swan Canoe Club as long as possible, then pursue replacement. Retreat in the north towards Mosmans and wider revetment at the canoe club. Plan retreat and structure replacement at the Coombe to opportunistically take advantage of private property redevelopments (local rock source). Smooth transitions. Manage surface runoff. Allow cliffs to erode and restrict access at base.	Either undertake works near Swan Canoe Club mentioned in medium-term or maintain structures if already undertaken. Maintain new structures at the Coombe. Manage surface runoff. Allow cliffs to erode and restrict access at base.	≈$1.4M (resolve Swan Canoe Club contribution)
SRMos03 Chidley Point Reserve, Chidley Wy (Table 12-59)	Manage surface runoff and drains. Maintain existing walling at Chidley Point and Green Place as long as possible. Maintain beach at Chidley Point. Allow cliffs to erode in Chidley Point Reserve. Planning controls for managing runoff from private property at top of cliffs. Encourage private property owners to develop long-term plans for foreshore stabilisation.	Maintain walling at Green Place, replace small block wall near jetty and extend structure to north (or managed retreat). Remove walling at Chidley Point, renourish beach and allow beach to migrate with backpassing. Ongoing surface runoff management with car park modification at Caporn St. Allow cliffs to erode in Chidley Point Reserve.	Ongoing renourishment of Chidley Point with partial retreat and creation of headlands. Consider partial retreat at Green Place, or walling reconstruction. Ongoing surface runoff management. Allow cliffs to erode in Chidley Point Reserve.	≈$1.1M -$1.3M [2]
SRMos04 MosPark GolfClubHouse, Marshall Dr (Table 12-60)	Manage surface runoff and drains from Downey Rd and car parks. Allow cliffed and steep foreshores to retreat, by addressing foreshore access. Planning controls for managing runoff from private property at top of cliffs.	Allow ongoing cliff retreat with no public access to lower foreshore. Ongoing surface runoff management.	Allow ongoing cliff retreat with no public access to lower foreshore. Modify car park at bend in Downey Road to allow retreat. Ongoing surface runoff management.	≈$160k
SRMos05 Point Roe Park, John Lewis Rise (Table 12-61)	Maintain beach at Point Roe Park ensuring any recreation focal areas allow for beach migration. Allow cliff retreat by addressing foreshore access. Develop planning controls for managing runoff from private property at top of cliffs.	Ensure long-term management is feasible for creating a new beach recreation node. Maintain Point Roe beach. Allow ongoing cliff retreat.	Consider consolidating beach access at Point Roe Park. Restrict foreshore access elsewhere and allow cliff retreat.	≈$605k[2]
SRMos06 Minim Cove Park (Table 12-62)	Maintain beach at the jetty. Allow cliff and old quarry areas to retreat, by addressing foreshore access and safety. Revegetate to restrict access.	Ensure long-term management is feasible for creating a new beach recreation node. Maintain beach at the jetty. Manage/limit foreshore access elsewhere and allow retreat.	Maintain beach at the jetty (and at optional new beach node). Restrict foreshore access elsewhere and allow cliff retreat.	≈$400k [2]
SRMos07 Garungup Park, Hutchinson Av (Table 12-63)	Address surface runoff on the steep slopes. Opportunistically repair existing structure.	Continue to address surface runoff, including partial path realignment. Maintain beach. Opportunistically repair existing structure.	Local retreat and restrict access in areas of slip failure. Maintain beach with structures. Dredge flood tide shoal (DoT).	≈$1.5M - $2.9M [2,3]

Note: 1. Works costs will depend on scheduling by ToMP and optional renourishment. The option presented reduces the total 50-year cost.
2. Renourishment should be undertaken opportunistically with any maintenance dredging projects for navigation.
3. Cost estimates difficult to establish for segments where works will require materials delivery and construction from a barge.

10.2.3. Ongoing Monitoring Requirements

It is recommended that the Town of Mosman Park organise the following ongoing monitoring to plan and review requirements for foreshore maintenance, management and adaptation triggers. The information included in Table 10-3 is a council-wide summary of the information in the tables within Appendix G.6.

Table 10-3: Monitoring Requirements for Town of Mosman Park

Monitoring technique	Spatial coverage	Frequency
1.1 **Inspections of the face of erosion mitigation structures** (walk in water) and surface behind structure. This includes walling, revetments, surface behind structures, scour toes, drains, fencing and fixed access stairs (rotation and settling) and bank stability/slip failure.	All hard walling/ revetments/ structures in SRMos01, SRMos02, SRMos03 and SRMos07.	Post-event and annual
1.2 **Inspection of drains,** and drainage pits and surface runoff	SRMos01 to SRMos04 and SRMos07 at all drains, low points in car parks and paths above steep slopes.	Before the first winter rains and mid-winter.
1.3 **Photos at 50m intervals** from upstream to downstream taken at low water. Used to monitor structure condition, foreshore changes and beach stability. Additional photos can focus on areas with toe undermining, structure transitions, near drains and near failure points.	ToMP managed foreshore, excluding cliff areas captured by video (see 1.4)	Annual
1.4 Obtain **videos of foreshore under cliffs** as ideally collected by Parks and Wildlife. Alternatively, ToMP to arrange collection.	Whole ToMP managed foreshore with focus on SRMos02 to SRMos07.	5-yearly
1.5 **Tabulate capital and maintenance works records** undertaken on any stabilisation works on ToMP land, including dates and details of the works. This includes renourishment, backpassing, revetments, walling, drainage, managing overbank runoff, infill of material behind structures, fencing, scour toes, slip maintenance and revegetation.	Whole ToMP managed foreshore	When works are undertaken
1.6 **Photos of beach widths** taken from both directions at fixed locations to identify renourishment requirements and beach performance.	Fixed locations in SRMos01 (Mosman Bay), SRMos03 (Chidley Point), SRMos05 Point Roe beach), SRMos06 (near jetty) and SRMos07 (Milo Beach).	Quarterly (3 months)
1.7 Investigate **long-term trend in terrace migration** in response to historic dredging and alteration of the Preston Point channel. Use existing datasets where possible. Cost ≈$25k using existing datasets.	Point Roe to City of Fremantle (SRMos05 to SRMos07).	10-yearly
1.8 **Track any planning developments** that may produce limestone rock for use in capital foreshore works.	In local area of the Coombe (SRMos02).	Ongoing.
1.9 **Check vegetation integrity above cliffs** used to restrict access to cliffs and lower foreshore.	Above cliffs in SRMos05 and SRMos06	6-monthly

10.2.4. Implementation and Management Summary (0-5 years)

A council-wide summary of the capital and maintenance works recommended for the first five years of management are included in Table 10-4. This summarises key information in the tables within Appendix G.4. Further detail is included in the segment-specific tables (Table 12-14 to Table 12-16). Monitoring recommendations are included separately in Table 10-3 and are not costed in the table below.

Table 10-4: Implementation Summary for Town of Mosman Park (1-5 years)

	Capital	Cost ($)	Maintenance	Cost ($)
Year 1	2.1 **Urgent renourishment adjacent to sewage pump station** in Mosman Bay.	$8k.	3.1 **Maintain wall at Chidley Point** (if choosing to pursue preservation of walling). Regrout as required and reconstruc single block section when failed with improved embedment.	$20k
	2.2 **Increase hydraulic smoothness at southern end of Mosman Bay** and replace failing wall under Mosmans with a revetment. Water Corp. responsible for moving the sewage pump station (urgent).	$200k + Water Corp shift pump station.	3.2 **Maintain drainage** from Downey Rd and two car parks.	$5k
	2.3 **Develop long-term wall design** for Mosman Bay with sufficient embedment and allowance for future rise in height of walling, without having to reconstruct.	$50k	3.3 **Maintain drainage** from Caporn St and Chidley Way (at Chidley Pt and near Green Pl).	$10k
	2.4 **Shift irrigation pipes away from walling** in Mosman Bay	Separat e item	3.4 **Maintenance for large drain** (SRMos07.D01)	~$25k
	2.5 **Develop planning controls** for properties along Riverside Pl, The Coombe and Owston Rd (SRMos02), along Saunders St (SRMos03), Riverside Dr (SRMos04) to manage surface runoff.	ToMP planning officer time.	3.5 **Maintenance for aged drain** (SRMos07.D02)	~$30k.
			3.6 **Shift irrigation pipes away from top of scarp** in SRMos07	Separate item
	2.6 **Develop a planning control** over local redevelopments near the Coombe to source limestone rock	ToMP planning officer time.	3.7 **Infill slumping behind walling in Mosman Bay**	$2k/5m
	2.7 **Develop a plan** for long-term formal access to Point Roe beach.	$20k	3.8 **Backpass 300m³ sediment** to S Mosman Bay	$4k
	2.8 **Develop planning controls** for properties along Colonial Gardens to manage surface runoff onto the cliffs.	ToMP planning officer time.	3.9 **Remove sand at boat ramp** in Mosman Bay 2-weekly to monthly.	$0.5k/ month
	2.9 **Revegetate to restrict access** to lower foreshore. Includes signage.	$75k	3.10 **Ongoing infill of material behind structures** in SRMos02	$5k
	2.10 **Signage** for Russell Brown Adventure Playground to show directions to jetty (or Point Roe).	$5k + in-kind labour.	3.11 **Backpass sediment at Chidley Point**	$3k
			3.12 **Clear drains** (once installed) before first winter rains & mid-winter in SRMos07	In-kind labour

	Capital	Cost ($)	Maintenance	Cost ($)
Year 2	2.11 **Replace 80m failing section of walling (1 of 3)** in Mosman Bay with long-term plan.	$300k, excl. drains	3.13 **Remove sand bar at boat ramp** in Mosman Baywith sediment backpassed.	15k.
	2.12 **Develop plan for Swan Canoe Club and Lower Mosman Bay Park**.	$40k design.	3.14 **Maintenance on wall/revetment at Lower Mosman Park/SCC** (.B01)	$25k.
	2.13 **Develop plan for flanking erosion at Green Place** both upstream and downstream.	$5k-$10k plan	3.15 **Maintain drainage** from the Coombe and surrounding streets.	$10k
	2.14 **Discussions with City of Fremantle regarding collective runoff management** and potential slip failure in northern Rocky Bay.	In-kind ToMP planning staff.	3.16 **Maintain recreation area** at Chidley Point	Separate item
			3.17 **Top up rock scour toe at Green Place**	$15k
			3.18 **Maintain stairs to Milo Beach**	Separate item
			3.19 **Maintain path and boardwalk** in SRMos05	Separate item
			3.20 **Maintain path** in SRMos07	Separate item
			3.21 **Infill slumping behind walling in Mosman Bay**	$2k/5m
			3.22 **Backpass 300m³ sediment** to S Mosman Bay	$4k
			3.23 **Remove sand at boat ramp** in Mosman Bay 2-weekly to monthly.	$0.5k/ month
			3.24 **Ongoing infill of material behind structures** in SRMos02	$5k
			3.25 **Backpass sediment at Chidley Point**	$3k
			3.26 **Clear drains** (once installed) before first winter rains & mid-winter in SRMos07	In-kind labour
Year 3	2.15 **Develop plan for the medium-term Coombe erosion mitigation**	$40k for design.	3.27 **Regrout** Mosman Bay walling, including at drains	$25k.
	2.16 **Encourage private property owners** along the Coombe and Oswton Rd to develop and implement a strategic plan for erosion mitigation.	≈$100k	3.28 **Drain maintenance** for the 7 drains in Mosman Bay	≈ $20k.
			3.29 **Maintain drainage** from Downey Rd and two car parks.	$5k
			3.30 **Maintain drainage** from Caporn St and Chidley Wy (Chidley Pt &near Green Pl).	$10k
	2.17 **Encourage private property owners** along Saunders St and Riverside Pl to develop and implement a strategic plan for erosion mitigation	≈$100k	3.31 **Maintain path** and Wardun Beelier Bidi trail adjacent to road in SRMos04	Separate item
			3.32 **Infill slumping behind walling in Mosman Bay**	$2k/5m
			3.33 **Backpass 300m³ sediment** to S Mosman Bay	$4k
			3.34 **Remove sand at boat ramp** in Mosman Bay 2-weekly to monthly.	$0.5k/ month
	2.18 **Develop drainage plans** for the whole segment to reduce	≈$75k.	3.35 **Ongoing infill of material behind structures** in SRMos02	$5k
			3.36 **Backpass sediment at Chidley Point**	$3k

	Capital	Cost ($)	Maintenance	Cost ($)
	focused runoff leading to slip failure.			
	2.19 **Develop plan for rock toe stabilisation** if barge is available.	$50k for plan	3.37 **Clear drains** (once installed) before first winter rains & mid-winter in SRMos07	In-kind labour
Year 4	2.20 **Replace 100m second section of walling (2 of 3)** in Mosman Bay with long-term plan. Trigger: failure of 20% of the walling	$375k, excl. drains	3.38 **Maintain walling at the Coombe** (.B02, .B03).	$30k.
			3.39 **Backpass sediment at the Coombe**.	$3k
			3.40 **Maintain drainage** from the Coombe and surrounding streets.	$10k
	2.21 **Remove riverward 2m of bitumen at the Coombe**..	$10k	3.41 **Maintain vegetation** in SRMos06 to restrict access.	~$5k + in-kind labour
	2.22 **Renourish beach at the Coombe**. 210m^3 of quarry material.	$23k.	3.42 **Maintain recreation area** at Chidley Point	Separate item
			3.43 **Top up rock scour toe at Green Place**	$15k
			3.44 **Maintain stairs to Milo Beach**	Separate item
			3.45 **Backpass sediment within Point Roe beach**.	$2k
			3.46 **Maintain vegetation** to focus pedestrian access to Point Roe beach.	~$5k + in-kind labour
			3.47 **Maintain path and boardwalk** in SRMos05	Separate item
			3.48 **Maintain path** in SRMos07	Separate item
			3.49 **Infill slumping behind walling in Mosman Bay**	$2k/5m
			3.50 **Backpass 300m^3 sediment** to S Mosman Bay	$4k
			3.51 **Remove sand at boat ramp** in Mosman Bay 2-weekly to monthly.	$0.5k/ month
			3.52 **Ongoing infill of material behind structures** in SRMos02	$5k
			3.53 **Backpass sediment at Chidley Point**	$3k
			3.54 **Clear drains** (once installed) before first winter rains & mid-winter in SRMos07	In-kind labour
Year 5	2.23 **Improve management of surface runoff and drains** at the Coombe and surrounding roads.	≈$30k	3.55 **Maintain drainage** from Downey Rd and two car parks.	$5k
			3.56 **Backpass sediment at the Coombe**.	$3k
	2.24 **Improve management of surface runoff and drains** from Caporn St and Chidley Way (at Chidley Pt and near Green Pl).	≈$40k	3.57 **Maintain drainage** from Caporn St and Chidley Wy (Chidley Pt & near Green Pl).	$10k
			3.58 **Maintain path** and Wardun Beelier Bidi trail adjacent to road in SRMos04	Separate item
		$20k for plan.	3.59 **Backpass sediment within Point Roe beach**.	$2k

	Capital	Cost ($)	Maintenance	Cost ($)
	2.25 **Develop plan for Chidley Point erosion mitigation** to include removing wall renourishment.		3.60 **Maintain vegetation** to focus pedestrian access to Point Roe beach.	~$5k + in-kind labour
	2.26 **Improve management of surface runoff and drains** from Downey Rd and two car parks.	≈$30k	3.61 **Infill slumping behind walling in Mosman Bay**	$2k/5m
			3.62 **Backpass 300m^3 sand** to S Mosman Bay	$4k
	2.27 **Implement foreshore access to Point Roe beach.**	$90k	3.63 **Remove sand at boat ramp** in Mosman Bay 2-weekly to monthly.	$0.5k/ month
			3.64 **Ongoing infill of material behind structures** in SRMos02	$5k
	2.28 **Modify surface runoff locally for slip failure**. Temporary minor stabilisation works for slips.	$100k	3.65 **Backpass sediment at Chidley Point**	$3k
			3.66 **Clear drains** (once installed) before first winter rains & mid-winter in SRMos07	In-kind labour

10.2.5. Works Dependencies

Some management and adaptation works should only be undertaken once another management task has been undertaken. The main works dependencies within ToMP include:

- Large renourishment project in Mosman Bay should wait until at least the two failing sections of walling are replaced and the boat ramp is installed;
- Works at Mosman Bay, Lower Mosman Bay Park, the Coombe and Chidley Point should wait until the long-term plans are developed. This increases the urgency for these plans to be developed;
- Drain upgrades and renewal should wait until plans for walling for are prepared for Mosman Bay, Lower Mosman Bay Park and the Coombe. Timing of drain upgrade should link to timing of required drain renewal;
- There is a high expense for sites where access is restricted, requiring delivery and working from a barge (e.g. SRMos07 and Green Place). Therefore plans should be prepared and discussed with all yacht clubs, DoT, Parks and Wildlife, other councils and private property owners to ensure works may be undertaken if a dredging vessel, barge or local excavation works (quarried rock) are undertaken. For example if DoT are undertaking maintenance dredging of the migrated flood tide shoal then that material can be used for renourishment projects; and
- Securing the sediment in and adjacent to RFBYC (Shire of Peppermint Grove) for use in ongoing backpassing operations.

Many maintenance and capital works recommendations in the tables in Appendix G.6 and Table 10-4 require certain issues to be resolved or certain works to be avoided. The segment-specific tables (Appendix G.6) should be consulted for this information as many works are dependent on these issues being resolved or specific works being avoided.

The staging of capital and maintenance works is broadly outlined in the segment-specific tables and for the first five years in Table 10-4. It is recommended the Town of Mosman Park prepare a Gantt chart to allocate their own prioritisation of works and works dependencies. This chart could be updated when a management decision (e.g. creating a new recreation node) alters the broader management plan, or when a trigger for works is reached. Works prioritisation will be linked to funding availability and the Gantt chart should be revised annually following the budget allocation.

11. Conclusions

Physical evidence regarding foreshore dynamics was considered through a vulnerability framework over three time frames. This allowed focus on different elements of management, nominally being:

- < 5 years which provides a risk management context, by considering the present state of the foreshore and sensitivity to acute events;
- 5-25 years which indicates management pathways, considering dynamics, life-cycle of existing stabilising structures and actions to increasing foreshore resilience; and
- > 25 years which provides an adaptation strategy, considering uncertainty related to future management choices and longer-term process variability. Scenarios considered over this scale indicate potential pathways to improve foreshore resilience.

Use of the three time frames supported identification of conflicts or constraints between short to medium-term management actions and medium to long term plans or options. Information in this foreshore management plan included actions to improve foreshore resilience over the three time frames, monitoring requirements, issues to be resolved and works that may constrain long term strategies.

A key outcome of the evidence-based assessment of foreshore dynamics was recognition that much of the observed change was related to previous modifications to the foreshore and existing structures. Within this context, a deeper understanding of the historic decision-making and apparent consequences was developed to support the interpretation of appropriate future interventions.

Key local themes identified as prevalent along the WESROC foreshore related to management and adaptation include:

- Insufficient maintenance;
- Reactive management;
- Structures reaching the end of their functional life;
- Foreshore resilience issues related to surface drainage and irrigation;
- Trampling by pedestrians and vessel launching/retrieval;
- Conflicting uses and values;
- Continued foreshore response to historic works; and
- The need for improved communication with other stakeholders for foreshore management, asset maintenance and planning, including the Water Corporation and leaseholders.

Additional issues were observed that are difficult to address at a Local government level any may require involvement of State Government agencies. Challenges identified included:

- Interactions with private ownership;
- Resumption of privately-owned foreshores;
- High material disposal costs;
- Availability of sand for renourishment; and
- Strategic funding allocations.

Recommendations for involvement of certain State Government agencies are provided for each of these challenges.

The information presented in this report is at a contextual level and should not be taken as a detailed design. Suggested interventions and works should be revisited if:

- New large recreational infrastructure is installed;

- A significant change in foreshore use occurs;
- There is a significant change of environmental conditions; or
- New technology is available which can improve project efficiencies.

A limitation of the methodology used is that the cost estimates presented for maintenance and capital works are first-order, based upon simplified assumptions and present-day rates. The study basis used to identify recommended works is potentially sensitive to these cost estimates and it is considered appropriate to review the plans if revised cost information becomes available. A clear example of the sensitivity to cost estimates is the consequence of disposal to landfill costs, which showed a strong influence on future management options. Parks and Wildlife may be able to assist updating LGAs with respect to significant cost revisions. A final consideration for recommended interventions is that an approximate schedule is provided for maintenance and capital works; however, works should not be undertaken before they are required.

Information has been provided per LGA to assist in planning for maintenance and foreshore management immediately. This includes outlines for monitoring requirements for decision-making and an implementation summary for capital and maintenance works the next five years.

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Appendix A Additional Driving Process Information

APPENDIX A.1 WATER LEVELS, TIDES AND FLOODS

Water levels within the estuary determine the elevation at which surface wave action may occur, controlling inundation and structure overtopping. An understanding of the amplitude and frequency of high water level events is therefore essential to foreshore management and the design of estuarine structures.

Water level behaviour in the estuary has been described using the two closest tide gauges, with Fremantle downstream and Barrack Street upstream, based on previous analyses by Eliot (2012). It is noted that water levels upstream typically experience tidal dampening, with approximately a 20% reduction and 2.5 hours lag during summer months at Barrack Street, relative to Fremantle (Eliot 2012; Figure 2-4). In contrast to tides, slower sea level processes such as shelf-waves, seasonal change or inter-annual fluctuations are less affected by the estuary structure and are typically experienced almost in full throughout the estuary.

An hourly data subset for Fremantle from 1955 to March 2015 has been used to demonstrate inter-annual variability in mean sea level and high water level events (Figure 12-1a), seasonal trends of higher water levels during winter (Figure 12-1b) and a monthly pattern of mainly diurnal tides with storm surge influences (Figure 12-1c).

Oceanic water levels

The WESROC foreshore is microtidal, with mixed, mainly diurnal tides, producing one high tide each day, with a lowest to highest astronomical tidal range of approximately 1.1m at Fremantle (1.0m at Barrack Street) and an average daily tide range of approximately 0.6m (Table 12-1; Bennett 1940). Tides are modulated over monthly, seasonal and inter-annual time scales, with inter-annual fluctuations dominated by the 18.6 year lunar nodal cycle which contributes to up to 0.15m variability in tide between high and low years (Figure 12-2).

Table 12-1: Tidal Planes

		Fremantle (mAHD)	Barrack St (mAHD)
Highest Astronomical Tide	HAT	0.58 m AHD	0.55 m AHD
Mean Higher High Water	MHHW	0.2 m AHD	0.19 m AHD
Mean Lower High Water	MLHW	0.02 m AHD	-0.01 m AHD
Mean Sea Level	MSL	-0.01 m AHD	-0.03 m AHD
Mean Higher Low Water	MHLW	-0.11 m AHD	-0.11 m AHD
Mean Lower Low Water	MLLW	-0.23 m AHD	-0.22 m AHD
Lowest Astronomic Tide	LAT	-0.47 m AHD	-0.42 m AHD
Chart Datum	CD	-0.76 m AHD	-0.76 m AHD

The very low tidal range enables other (non-tidal) sea level processes to contribute to a total water level range of 2.15m at Fremantle, which is almost twice the astronomic tidal range. Non-tidal sea level processes contributing the water levels include seasonal and inter-annual mean sea level (MSL) variations, storm surge, continental shelf waves, seiching, meteotsunami and inter-annual tidal modulations (Eliot & Pattiaratchi 2007; Pattiaratchi & Eliot 2008).

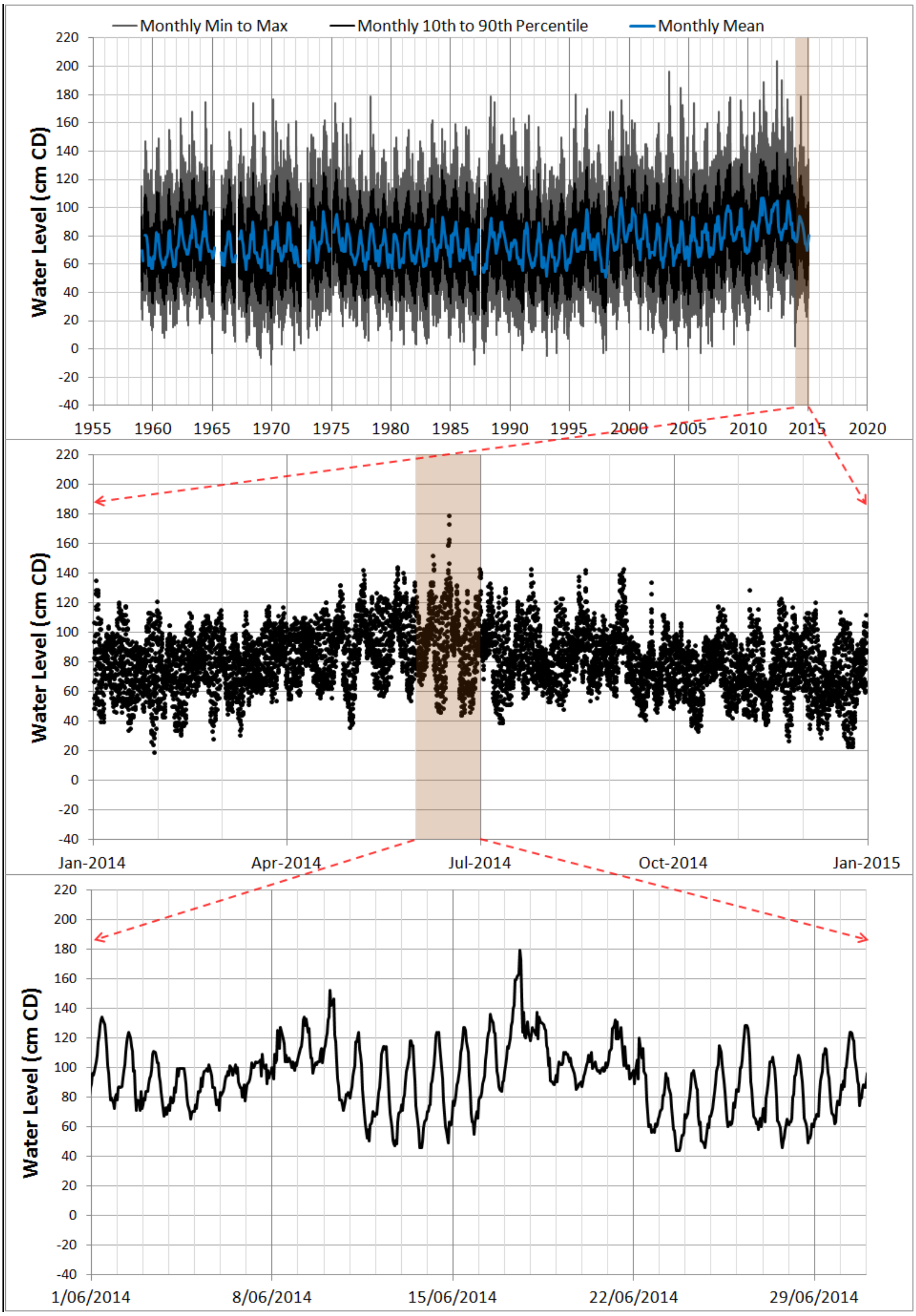

Figure 12-1: Water Levels (1959-March 2015) for Fremantle
(A) Total Record, (b) 2014 and (C) June 2014
(Source: Royal Australian Navy Hydrographic Office and Department of Transport)

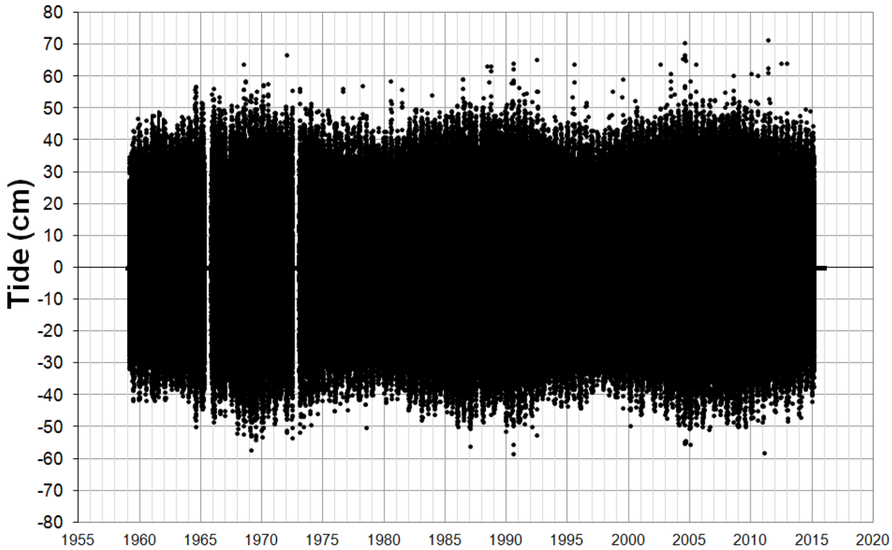

Figure 12-2: Fremantle rapidly varying water level signal (Tide Approximation)

Weather events acknowledged to cause high surge include extra-tropical or mid-latitude storms (Haigh *et al*. 2010), tropical cyclones (Fandry *et al*. 1984) and meteotsunami (Wijeratne *et al.* 2010). Winter mid-latitude storms are the most frequent of these phenomena, while tropical cyclones are comparatively infrequent, with only one cyclone travelling through the southwest per decade. More remote tropical cyclone systems may act to force water levels in the southwest during summer months (December−March) through continental shelf waves formation (Eliot & Pattiaratchi 2010).

Mean sea level variation is influenced by a combination of seasonal and inter-annual cycles as demonstrated by the monthly-running mean water level in Figure 12-1. Mean sea level variation alters the location of a relatively narrow active hydraulic zone, and influences the frequency and magnitude of high water level events.

Seasonal mean sea level variability contributes almost 0.3m of water level range, peaking in May-July and lowest in October-November. The range is not constant from year-to-year and has been demonstrated to be largely explained by barotropic variation (i.e. atmospheric pressure and winds), meaning that it is affected by relative annual storminess (Wijeratne *et al.* 2010).

Inter-annual mean sea level variability is strongly linked to the El-Nino / la Nina climate cycle, suggested by a strong correlation to the Southern Oscillation Index (Figure 12-3; Pariwono *et al.* 1986; Haigh *et al.* 2011b). Variation of approximately 0.3m may be attributed to this relationship, with higher water levels occurring during the La Nina phase. Recent elevated mean sea levels between 2008-2012 have been associated with a strong La Nina event, while a decrease in mean sea level between 2014-2015 is associated with a shift to an El Nino phase.

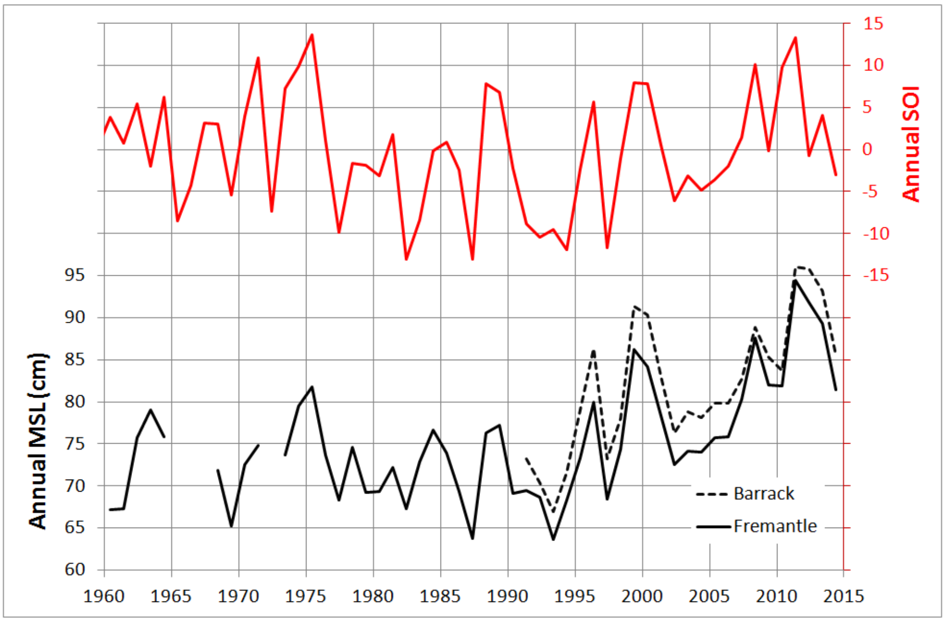

Figure 12-3: Correspondence between the Annual Means of Fremantle and Barrack Street Mean Sea Levels and Southern Oscillation Index (1959 to 2014)

<u>Extreme water levels</u>

Although storm events may occur for the majority of the year, extreme water levels are generally restricted to between May-July, when seasonal peaks for mean sea level, surge and tide are in phase (Table 12-2).

The frequency and magnitude of high water level events are particularly influenced by sources of inter-annual variability, in combination with variation between individual storm (Eliot 2012). The following two major sources of variability are identified in the Fremantle and Barrack Street records:

- Up to 0.3m of variability in the mean sea level signal between high and low years, largely corresponding to ENSO phenomenon (Eliot 2012); and
- Up to 0.15m of variability in the tidal signal between high and low years attributed to the 18.6-year lunar nodical cycle. The last peak in the cycle occurred in 2006.

Table 12-2: Summary of Seasonal Changes in Water Level Processes

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tide	Peak		Low		Peak				Low		Peak	
Surge	Low*				Peak						Low*	
MSL	Low				Peak						Low	

**Occasional tropical cyclone shelf waves during summer months (December-March)*

It is recognised the likelihood of high water level events increases during periods of elevated mean sea levels (La Nina) and highs in the lunar nodical tidal cycle and particularly when the two are in phase. The influence of the recent period of high mean sea level is evident by three of the top five events in the long-term Fremantle record occurring during 2011-2012 (Table 12-3).

The highest observed water levels at Fremantle occurred on the 10 June 2012 and was associated with a meteotsunami during the passage of a cold front (Table 12-3). The surge peak during this event was relatively short-lived which restricted upstream propagation in the estuary. Consequently, this event was only the 6th highest in the Barrack Street record.

The highest water observed water level at Barrack Street occurred on the 16 May 2003, which was also the second highest at Fremantle. This was produced by a large surge associated with a deep mid-latitude depression, combined with a high astronomic tide. Photographs showing foreshore inundation during this event are provided in Figure 12-5 to Figure 12-7.

Table 12-3: Top 10 Water Levels Events at Fremantle and Barrack Street

Fremantle (1959-2015)			Barrack St (1988-2015)	
Date	**WL (cm CD)**		**Date**	**WL (cm CD)**
10/06/2012	204		16/05/2003	192
16/05/2003	197		28/11/2012	180
28/11/2012	190		12/07/1995	174
20/05/2011	189		20/05/2011	174
9/05/2004	185		16/07/1996	173
12/07/1995	180		10/06/2012	173
4/04/1978	179		18/07/2008	172
2/06/1988	179		30/07/2008	170
17/06/2014	179		30/01/2011	169
18/07/2008	178		17/06/2014	169

Design extreme water levels have been derived at Fremantle and Barrack Street using Weibull distribution fitting (Figure 12-4), based on Petrauskas & Aagaard (1971). The water levels can be applied to the WESROC foreshore, including for structure design and adaptation planning. The 10, 20, 50 and 100 year ARI oceanic water levels are provided in Table 12-4 (Figure 12-4; Table 12-4). A comparison between levels generated from other extreme water level investigations is included in Table 12-5. Each study uses different techniques, assumptions and length of dataset. All results presented are essentially false, with values presented for Fremantle in the most recent comprehensive study (URS 2013a) used as the basis of design for this report. The levels used are 1.1mAHD for the 10-year ARI and 1.3mAHD for the 30-year ARI.

Future variability

Variability in mean sea levels can be attributed to approximately 0.4m migration of the active hydraulic zone due to El Nino-Southern Oscillation (ENSO) climate indices and the 19-year tidal cycle. Further variability is also attributed to periods of storminess. This variability in mean sea level shifts the active hydraulic zone vertically, as discussed in Section 2.2.2.

Long-term adaptation requires consideration of potential longer-term variations in mean sea level (Department of Transport 2010; SRT 2007, 2010). The most recent river-wide study considered a range of +0.2 to +1.2m (URS 2013a).

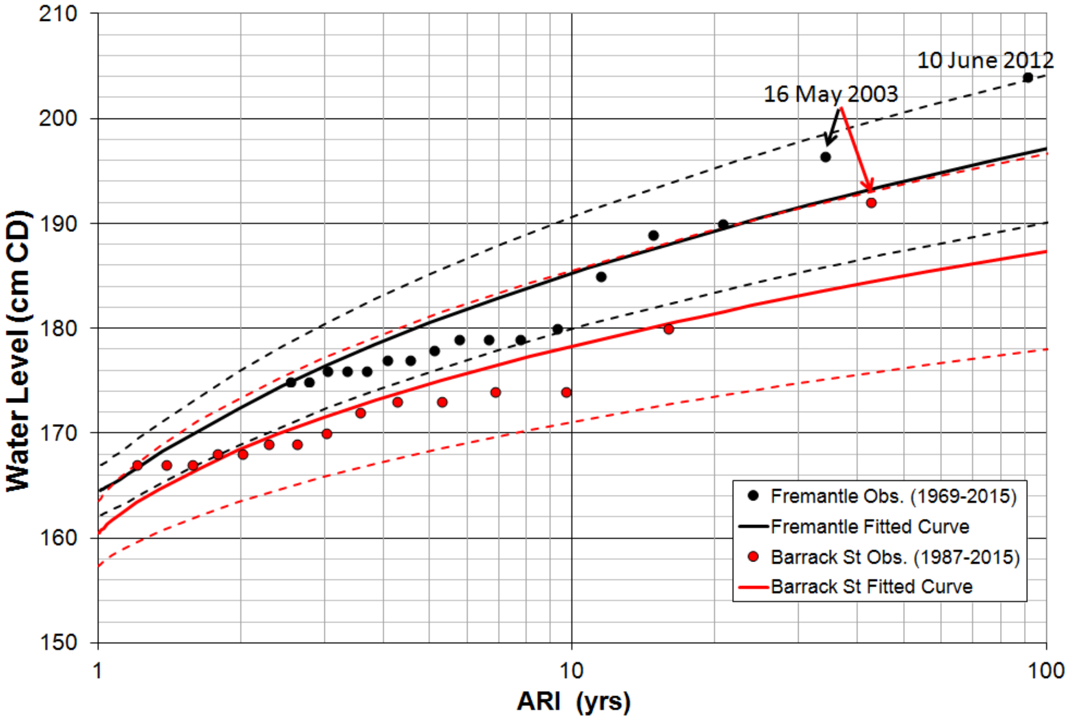

Figure 12-4: Fremantle and Barrack Street Extreme Water Levels 95% confidence intervals included

Table 12-4: Oceanic Water Level Design Levels at the 95% Confidence Interval

ARI	Fremantle	Barrack Street
10-year	1.85m CD (1.09m AHD)	1.78m CD (1.02m AHD)
20-year	1.90m CD (1.14m AHD)	1.81m CD (1.05m AHD)
50-year	1.94m CD (1.18m AHD)	1.85m CD (1.09m AHD)
100-year	1.97m CD (1.21m AHD)	1.88m CD (1.12m AHD)

Figure 12-5: Inundation at Qantas Boat Ramp 16 May 2003

Figure 12-6: Inundation at Beaton Park 16 May 2003

Figure 12-7: Inundation at Charles Court Reserve 16 May 2003

<u>Wind set-up</u>

Wind set-up is a vertical rise in water level attributed to wind stresses acting on the water surface. Wind set-up levels were estimated by URS (2013a) for the 100-year ARI scenario of 0.02m at Fremantle ranging to 0.16m at Barrack Street. The range for the WESROC area was 0.02m to 0.09m. However, it is assumed that in many areas this is an overestimate since the wind stress is transferred into wind-driven currents in estuarine areas with changes in bathymetry and foreshore direction. An exception is within northern Freshwater Bay where wind set-up would occur during strong winds with a southerly component.

Table 12-5: Comparison of Extreme Water Level Estimates Between Studies

Study	Fremantle (mAHD)		Barrack Street (mAHD)		Notes
	10-yr ARI	100-yr ARI	10-yr ARI	100-yr ARI	
This study - Table 12-4	1.09	1.21	1.02	1.12	Excludes set-up and fluvial flooding
URS (2013a)	1.10	1.31	1.10	1.82	Oceanic and fluvial combined. 100-yr ARI includes wind setup of 0.02m at Fremantle and 0.16m at Barrack Street
ACECRC	1.09	1.25	-	-	
Haigh *et al.* (2012) total water level	1.10	1.30	1.08	1.29	
Haigh *et al.* (2012) tide and residual	1.13	1.27	0.93	1.11	
McMullen (2012)	1.14	1.42	-	-	Gumbel distribution – no fluvial component.
Scott/PWD (1977)	-	-	-	0.99-1.38	Weibull distribution on 1930-1976 dataset
Fluvial only					
PWD (1977)				1.47 (Causeway)	At causeway with extreme tide
PWD (1982)	-	1.15	-	1.24	Flood only
Middelmann *et al.* (2005)	(could not interpret)	(could not interpret)		~1.6 (graph)	Used actual tidal cycle at Fremantle as boundary condition.
WAWA (1985)	-	-		~1.7 (graph)	Used 1.5mAHD at Fremantle as boundary condition. Too high.

Fluvial flooding

River flooding, although significant upstream, is reduced by broad reaches of the river and is generally a minor influence downstream of the Causeway. Since the removal of the sill at the entrance to the river in 1903, and subsequent dredging, the hydraulic connectivity to the ocean has increased with floodwaters rapidly draining in the area downstream of the Narrows and Canning Highway Bridges. The potential for river flooding was modelled in 1982, suggesting the 100 year ARI fluvial flood could generate a +1.15 mAHD level at Fremantle (PWD 1982). The recent URS (2013a) study found the 100 year ARI fluvial flood would be approximately +1.3 mAHD at Fremantle. This level is of a similar level to that estimated for oceanic water levels, with emphasis for design and adaptation focused on oceanic water levels.

APPENDIX A.2 WINDS

Winds generate waves, setup and wind-driven circulation patterns as energy is transferred across the water surface. In terms of waves, wind energy progressively increases the wave height and length until reaching a maximum for a given speed, distance or duration (USACE 2001).

There is a systematic variation of wind speed and frequency across Perth, as well as a variation in the direction-frequency pattern resulting from the structure of thermal cells and relative intensity of land and sea breezes (Damara WA 2007c). Additionally, local wind patterns may also be strongly influenced by topographic effects, such as overland sheltering.

The two most relevant wind stations to the WESROC foreshore are located on the river at Melville Water (BOM Station 9091) and on the coast at Swanbourne (BOM Station 9215). Annual speed and direction frequency distributions identify the dominant wind directions at Swanbourne (Figure 12-8) and Melville Water (Figure 12-9), which demonstrate the:

- prevalence of the land-sea-breeze system, with a broader directional range of easterlies (land-breezes) and south-westerlies (sea-breezes) at Melville Water; and
- effect of overland sheltering at Melville, with reduced frequency of winds from the NW quadrant.

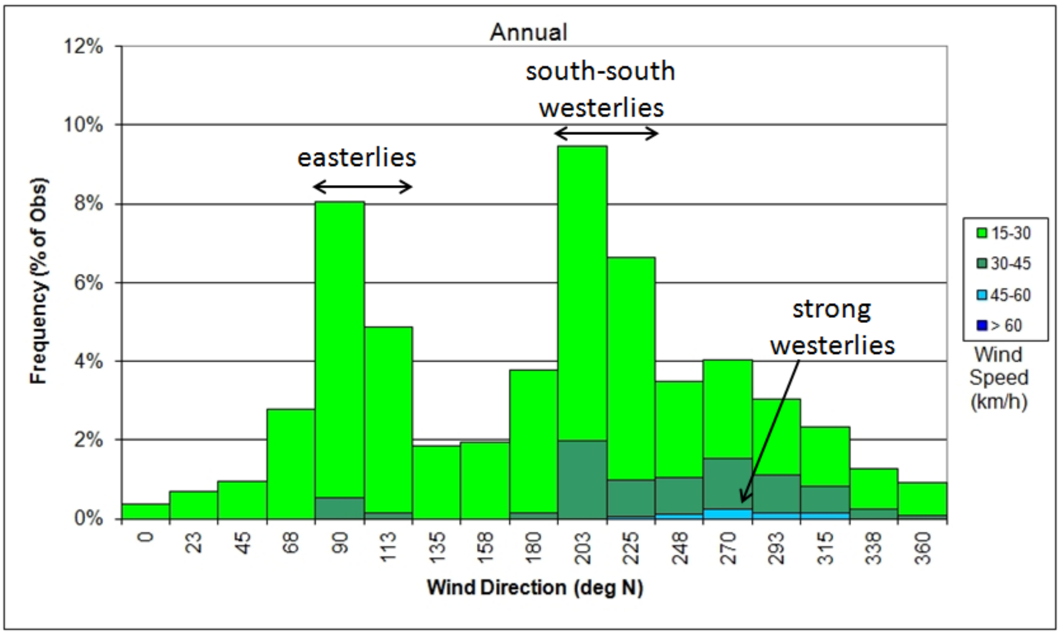

Figure 12-8: Swanbourne Wind Speed-Direction-Frequency Plot (1994 to 2014)

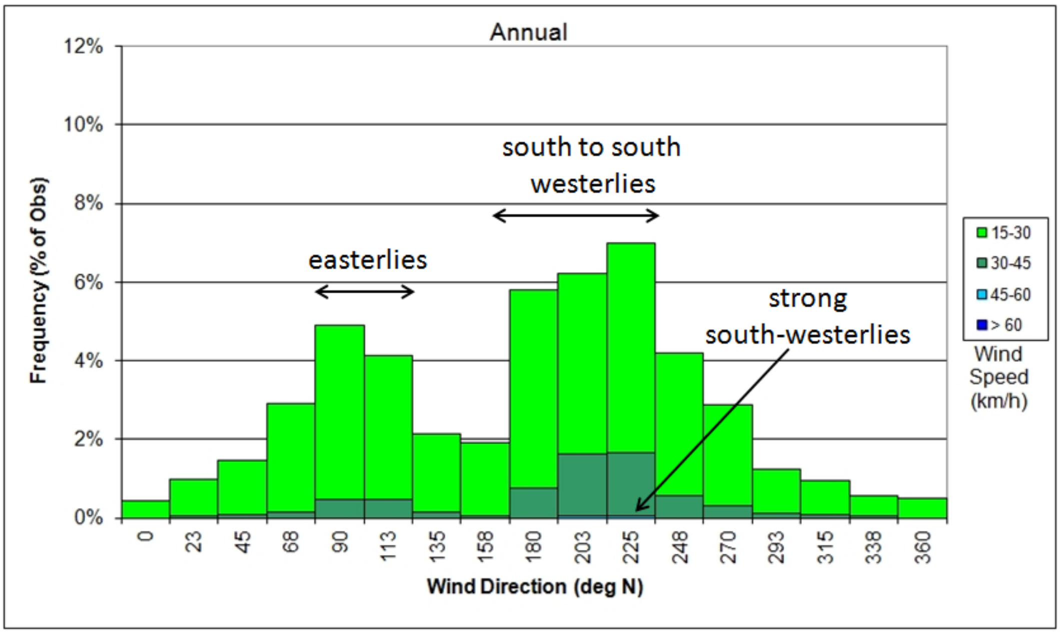

Figure 12-9: Melville Water Wind Speed-Direction-Frequency Plot (1999-2014)

The strongest wind conditions at Swanbourne are from the northwest through to southwest and are generally associated with *winter* mid-latitude storms. The strongest winds at Melville Water are generally restricted to from the south-west, largely due to overland sheltering of west to north westerly winds.

Seasonal variability in the wind climate is indicated by monthly speed and direction wind frequency distributions provided in Figure 12-10 and Figure 12-11. These demonstrate the weakening of the land-seabreeze system during winter months and a dominance of *winter* westerlies between June and September.

Inter-annual variability in the wind climate is indicated by cumulative vector wind drifts provided in Figure 12-12 and Figure 12-13. The drifts are analogous to the path a balloon would drift and are highly influenced by:

- the strength of the seabreeze system, with a net northward drift typically of all years generally associated with the southerly wind component of sea-breezes; and
- the strength and frequency of winter westerlies (storminess).

The year to year wind drifts at Swanbourne and Melville Water are not completely coherent, likely to be due to a combination of topographical effects and variations in the relative intensity of seabreeze system. Although, both locations did experienced periods of unusually low northward and high westward net wind drift during a strong La Nina event between 2010- 2013, indicating an increased dominance of easterly winds.

To provide the most appropriate estimate of winds across the lower estuary, it is appropriate to use the least sheltered wind record corresponding to the near-coast margin. On this basis, the Swanbourne wind record was used to define the directional estuarine extreme wind climate using 11 years of data (Table 12-6). This information was used to generate a wind-wave hindcast (Damara WA 2007a, 2007c) which is presented in the wave section below (Appendix A.3).

Table 12-6: Characteristic wind speeds (kn) at Swanbourne used for the wave climate

	Direction	N	NE	E	SE	S	SW	W	NW
Frequency	Weekly	16	15	19	17	20	24	25	21
	Monthly	20	19	22	20	24	27	29	27
	1-year ARI	34	30	32	31	42	47	57	47
	3-year ARI	38	36	38	38	48	53	63	52
	10-year ARI	42	39	40	41	51	57	67	56
	30-year ARI	45	41	42	43	54	61	70	60
	100-year ARI	46	45	45	48	56	62	72	61

* *Weekly and Monthly refer to the average weekly maximum and the average monthly maximum. N-year ARI (average recurrence interval) refers to the wind speed exceeded, on average once every N years. Note this is greater than the average N-year maximum.*

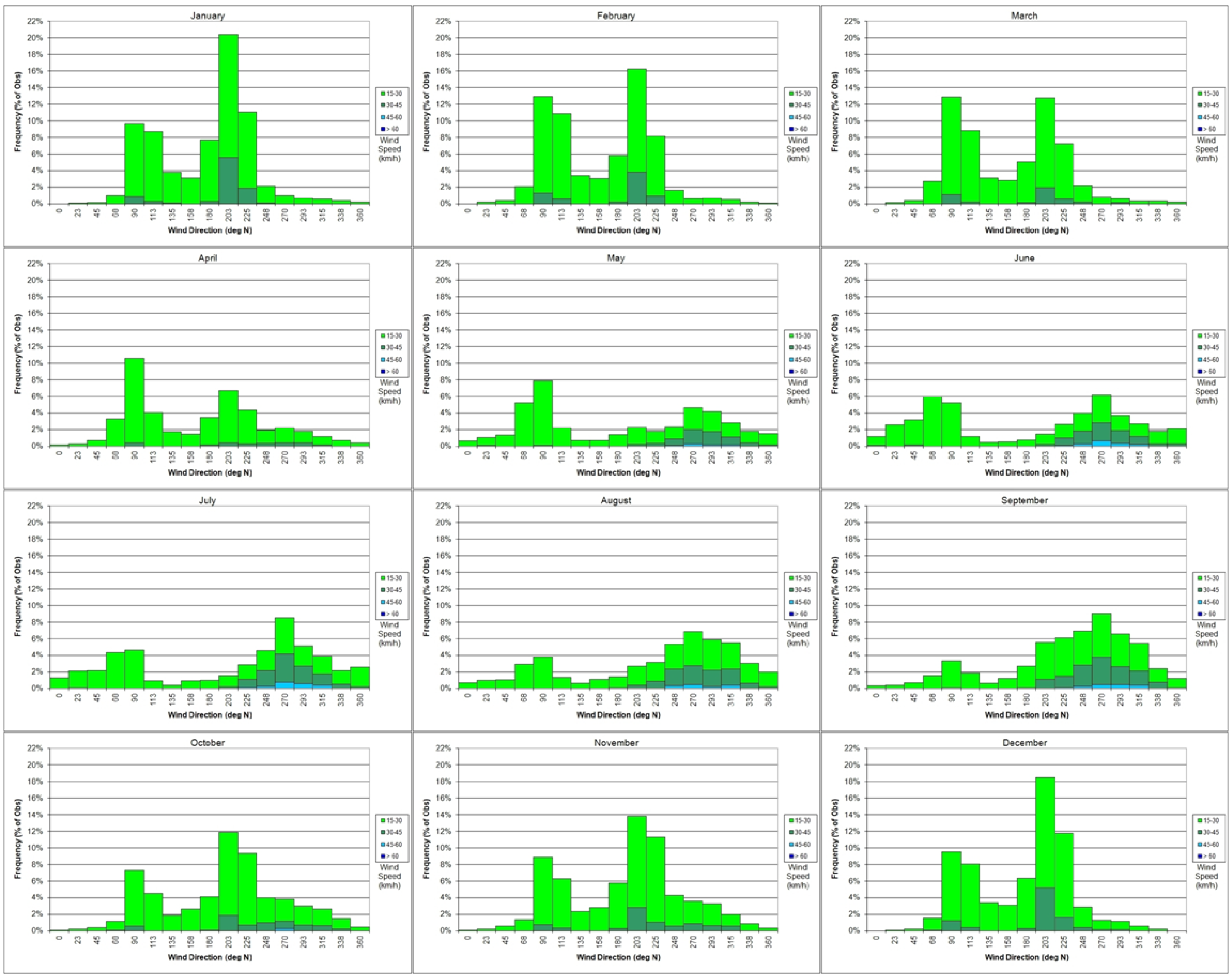

Figure 12-10: Swanbourne Monthly Wind Speed-Direction-Frequency Plots (1994-2014)

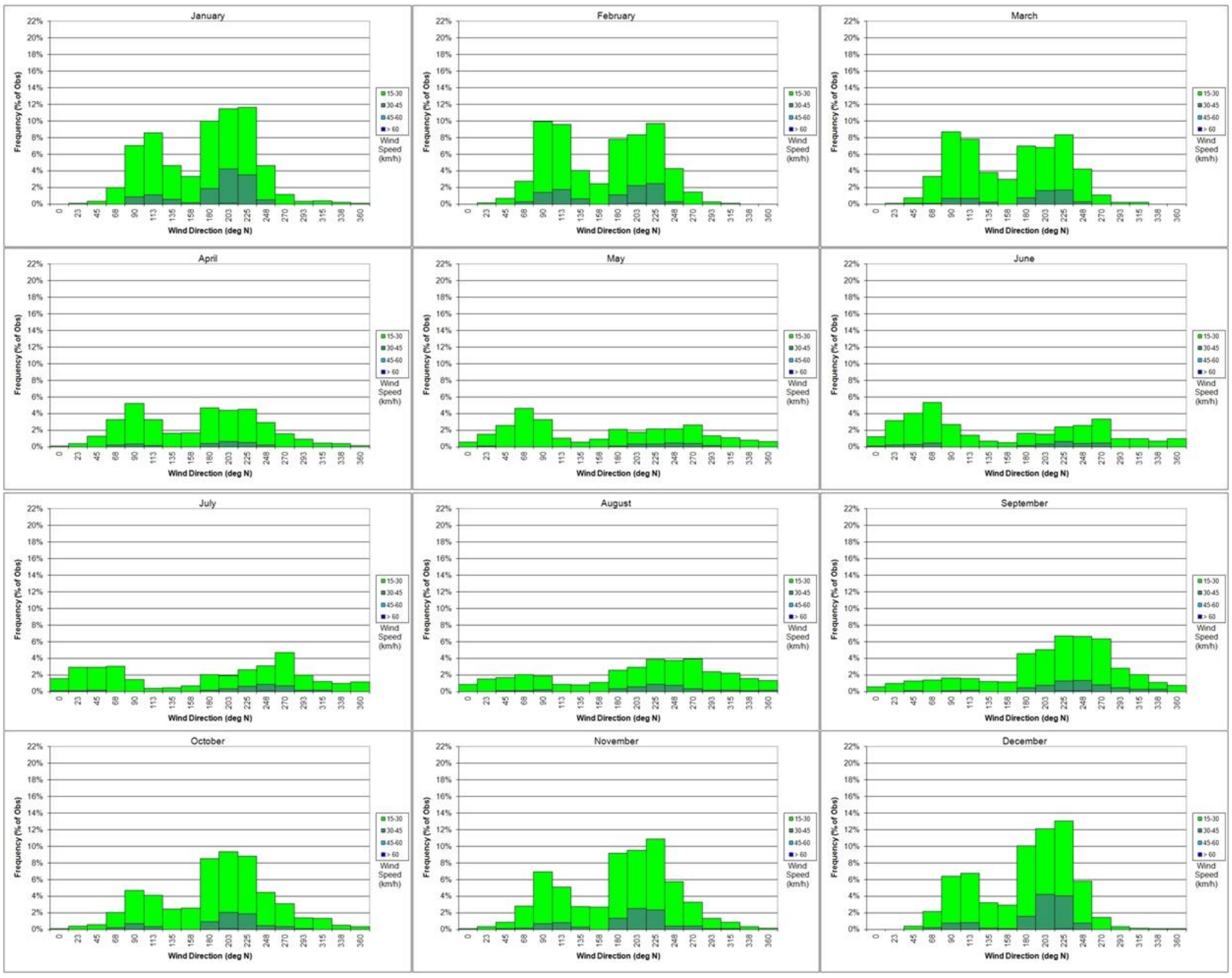

Figure 12-11: Melville Water Monthly Wind Speed-Direction-Frequency Plots (1999-2014)

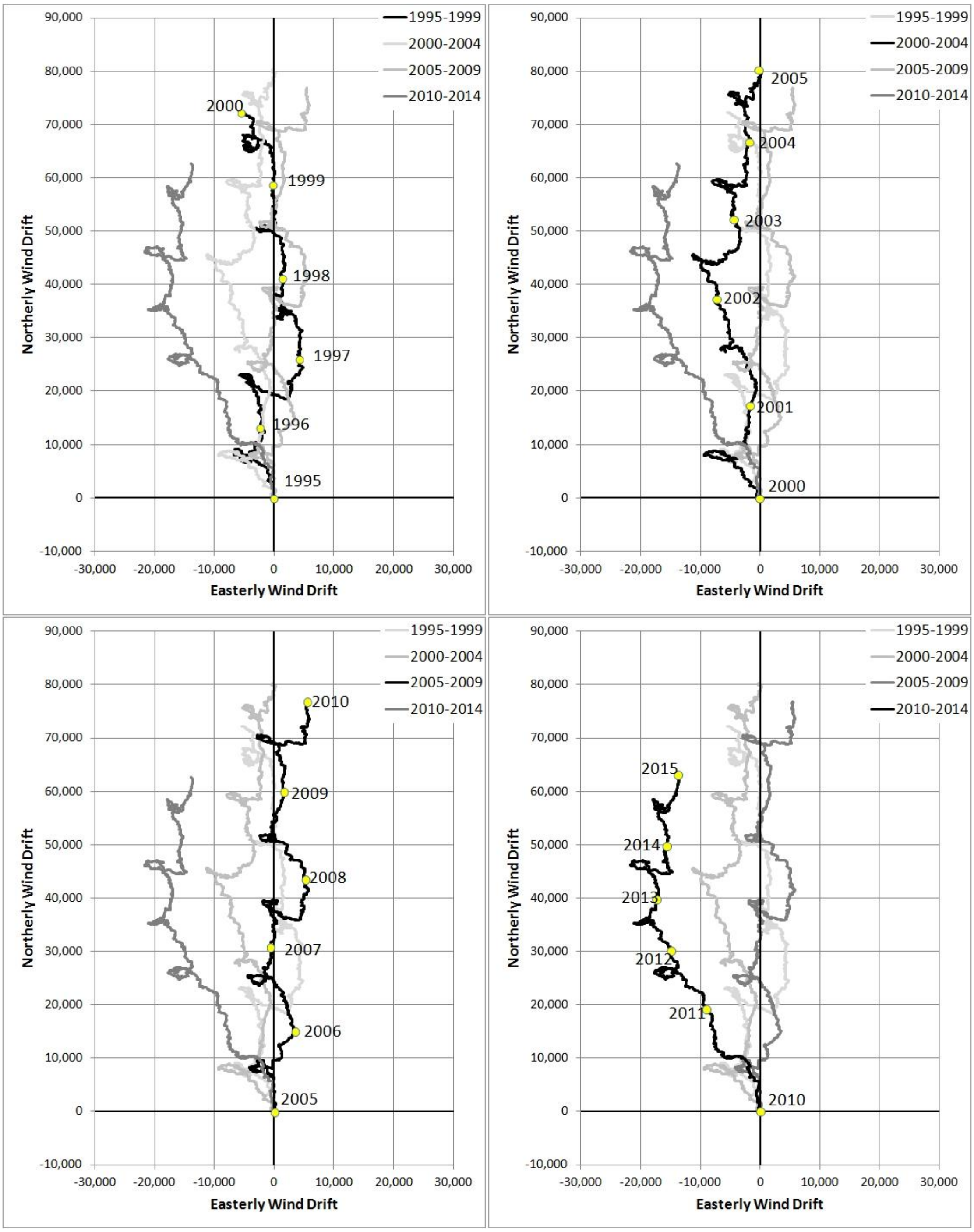

Figure 12-12: Swanbourne Wind Drift 1995-2014

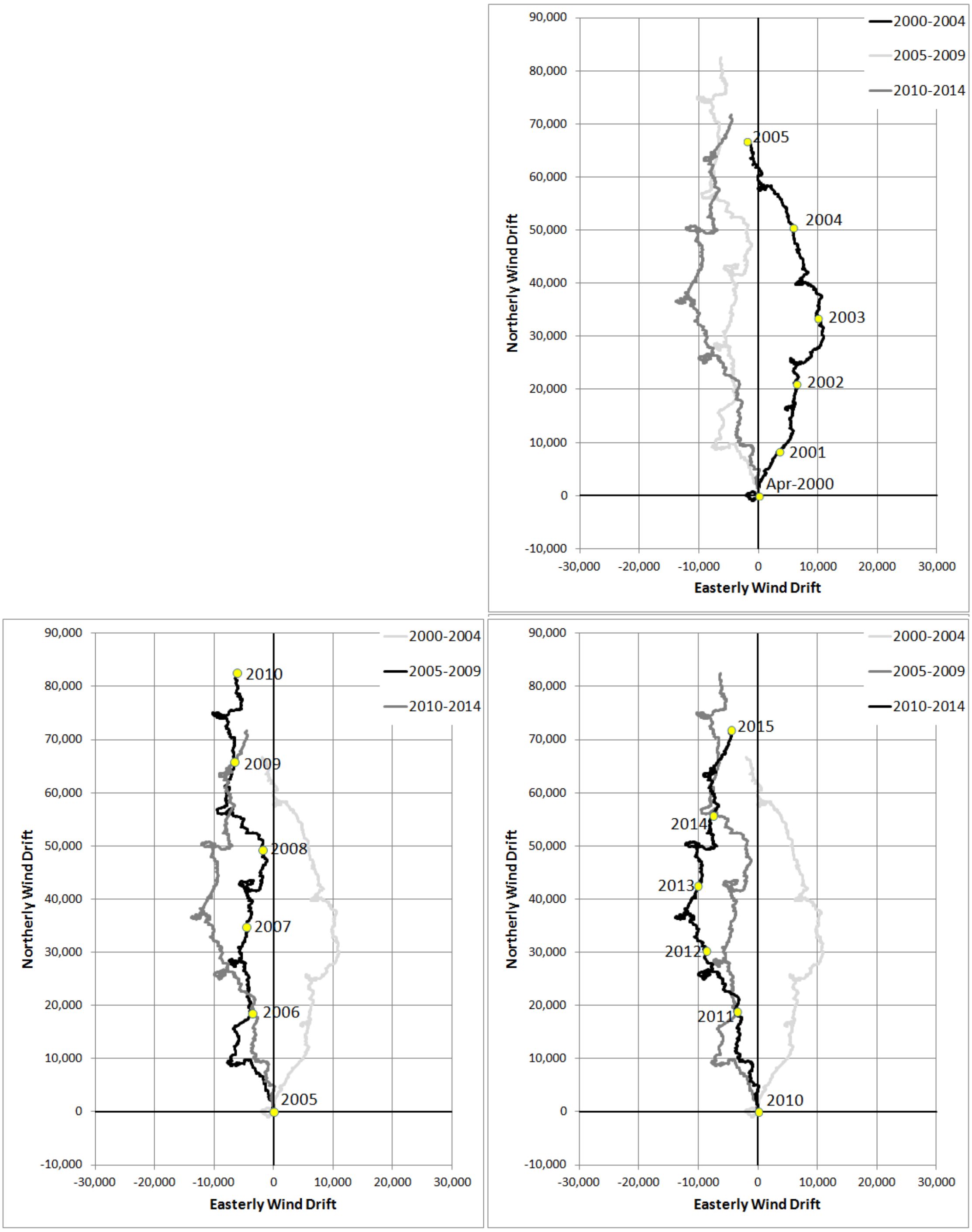

Figure 12-13: Melville Water Wind Drift 1999-2014

APPENDIX A.3 WAVES

Waves are generally the greatest physical action causing foreshore dynamics. As a wave moves towards a shore, bed friction causes the wave to shoal and break, releasing the wave energy and producing turbulent motion.

Wave action in the WESROC area is generated from a combination of wind waves and boat wakes. In general, boat wakes provide significantly less energy than wind waves, but their long period and occurrence in sheltered locations means that they may have greater impact on the foreshore (CMST 2010), particularly along the river channels.

Wind Waves

The capacity for wind wave generation within the lower Swan Estuary is determined by the strength and persistence of winds, along with the length and depth of water over which the winds blow. Due to variations in exposure for wind-wave generation, wave heights vary around the foreshore, and often along small spatial scales due to the relatively convoluted shoreline and basin structure. These variations may drive local patterns of erosion and accretion (Damara WA 2003).

Waves are influenced by diurnal (i.e. sea breezes), seasonal and inter-annual variability in the wind climate (Appendix A.2). This contributes to variability in foreshore processes, patterns of erosion and accretion, yacht club sedimentation and stress on the toe of structures.

A wind-wave hindcast was previously undertaken in 2005 (Damara WA 2007c) using the empirical formulae of the Sverdrup-Munk-Bretschneider (SMB) equations (USACE 1984) to relate wind speed, fetch length, wind duration and water depth. The steps undertaken were:

1. Selecting characteristic wind speeds at Swanbourne, in terms of frequency, at each of the semi-cardinal directions (45^{o} increments) (Appendix A.2);
2. Definition of fetch lines across the estuary basins and their corresponding depths;
3. Simplified analysis of water level conditions corresponding to design wind events;
4. Hindcasting of the significant wave heights corresponding to nominated frequency wind conditions (3, 10, 30 and 100 year ARI).

The spatial variation in the hindcasting results for the WESROC region is presented visually (Figure 12-14) and tabulated (Table 12-7).

High hindcast wave heights are generally in areas exposed to extended westerly (strongest winds) to south-westerly fetches, while lower hindcast wave are generally in areas of channel constriction and on easterly facing shorelines. The highest wave heights are at Point Resolution Reserve in Dalkeith which is exposed to a 2km westerly fetch across Freshwater Bay and the lowest is near the Mosman Park Golf Course, in Blackwall Reach. This wave information will be used in adaptation planning.

The recently estimated potential range of extreme wave periods for wind generated waves at the 100-year ARI level (based on $20ms^{-1}$ wind speed) ranged from 2-3s downstream of Nedlands and 3-4s upstream of Matilda Bay (URS 2013a Figure 9-2).

Boat Wakes

A further source of surface waves is generation from vessel wakes, which have varied significance across the WESROC area. Remote boat wakes from large vessels travelling at fast speeds along the navigation route require consideration for most of the WESROC area upstream of Keanes Point. The Mosman Park foreshore is likely also to be sensitive to all vessel wakes as it is located in a narrower river section with the vessels travelling closer to the foreshore.

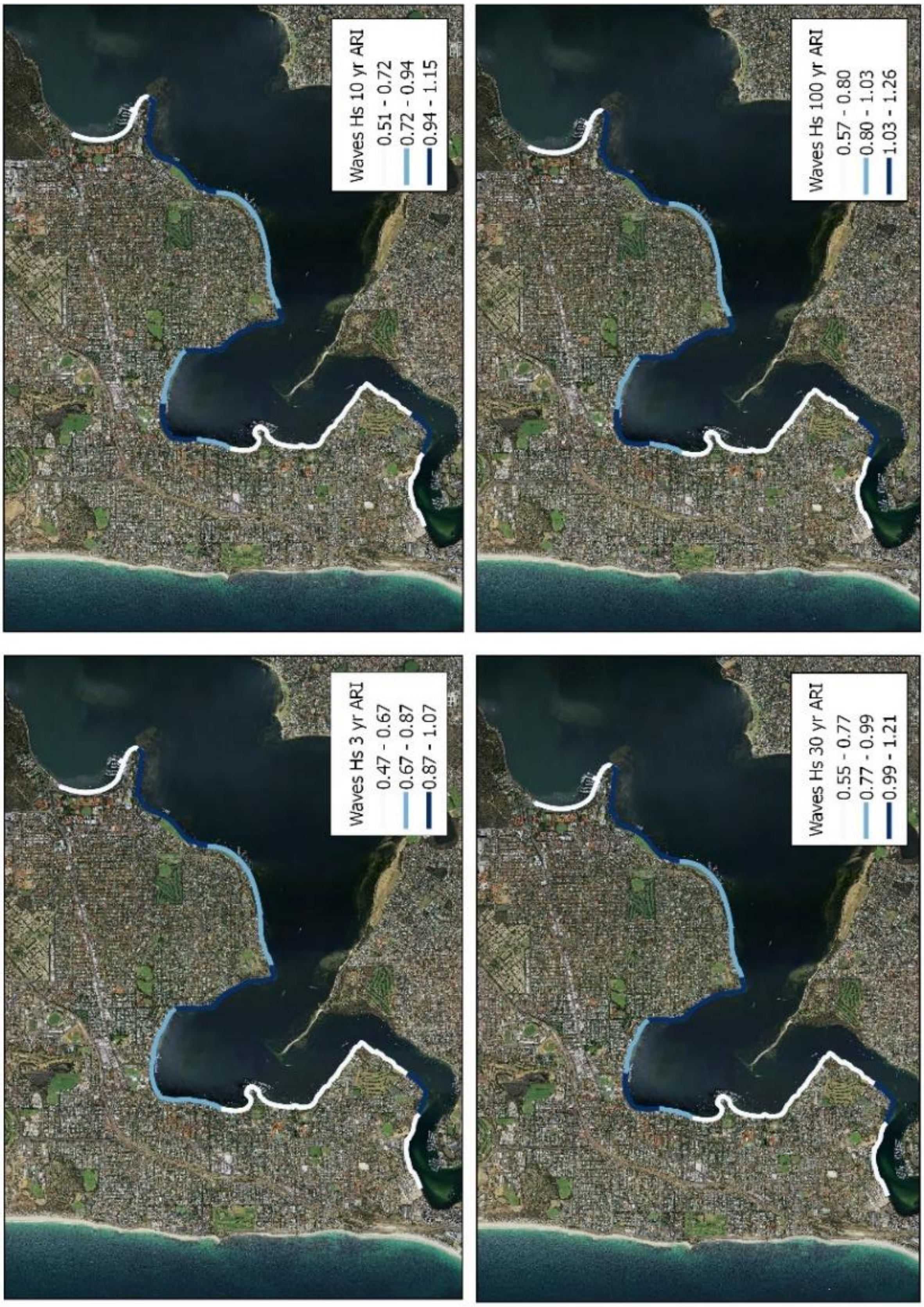

Figure 12-14: Spatial Variation in Significant Wave Height (H_s) for Design

Table 12-7: Significant Wave Height (H_s) for Design per Segment

	Hindcast Significant Wave Height (H_s) in metres			
Segment	**3 yr ARI**	**10 yr ARI**	**30 yr ARI**	**100 yr ARI**
SRCra05 Matilda Bay Reserve Look out	0.9	1.0	1.1	1.1
SRCra06 JH Abrahams Reserve	1.0	1.1	1.2	1.2
SRNed01 Charles Court Reserve	0.9	1.0	1.1	1.1
SRDal01 Birdwood Park	0.9	1.0	1.1	1.1
SRDal02 Paul Hasluck Reserve	0.8	0.9	0.9	1.0
SRDal03 Paul Hasluck Reserve-Sadlier Street	0.8	0.9	0.9	1.0
SRDal04 Beaton Park	0.8	0.9	0.9	1.0
SRDal05 Iris Avenue	0.8	0.9	0.9	1.0
SRDal06 Adelma Place	0.7	0.8	0.9	1.0
SRDal07 Point Resolution reserve	0.9	1.0	1.0	1.1
SRDal08 Point Resolution Reserve, Jutland Pde	1.1	1.2	1.2	1.3
SRDal09 Bishop Road Reserve	1.0	1.1	1.2	1.2
SRDal10 Watkins Road	0.9	1.0	1.1	1.1
SRCla01 Mrs Herberts Park	0.8	0.9	0.9	1.0
SRCla02 Jetty Rd	0.8	0.9	0.9	1.0
SRCla03 Bethesda Hospital	0.9	0.9	1.0	1.1
SRPep01 Scotch College BoatShed Forrest St	0.7	0.8	0.8	0.9
SRPep02 Manners Hill Park Keane St	0.6	0.6	0.6	0.7
SRPep03 Keanes Point Reserve	0.6	0.6	0.7	0.7
SRMos01 Mosman Bay Park, Mosman Tce	0.6	0.7	0.7	0.8
SRMos02 Bay View Park,View Tce	0.6	0.6	0.7	0.8
SRMos03 Chidley Point Reserve, Chdiley Wy	0.6	0.6	0.7	0.7
SRMos04 MosPark GolfClubHouse, Marshall Dr	0.5	0.5	0.5	0.6
SRMos05 Point Roe Park, John Lewis Rise	0.9	1.0	1.0	1.1
SRMos06 Minim Cove Park	0.6	0.7	0.8	0.8
SRMos07 Garungup Park, Hutchinson Av	0.6	0.6	0.7	0.7

Information on boat wakes has been reviewed for the Swan River in two recent studies (AMC & CMST 2009, CMST 2010). An overview of wave forcing is included here, with further detail to be obtained from these two reports. Waves are generated at the bow and stern of the vessel. The pattern of interference caused by these waves is the boat wake, which is comprised of a V-shaped pattern of waves propagating obliquely to the sailing line, with a second set of waves propagating in the same direction as the sailing line (Figure 12-15). Both sets of waves decline in size with distance away from the vessel. Boat wake formation is determined by a range of parameters including the speed of the vessel (and if it is operating at super-critical speed), water depth and hull shape. The relative size of the two wave forms and their position varies systematically as the vessel speed increases towards planing.

Boat wakes were compared for their dominance to wind waves at Quarry Point (between Matilda Bay and the Narrows – upstream of the WESROC area), with boat wakes also measured at Chidley Point (AMC & CMST 2009, CMST 2010). At Quarry Point the larger vessels produced more wave energy for many speeds above 9 knots, up to 10 times the estimated wind wave energy (CMST 2010). However, wind waves have greater significance due to the very high number of waves associated with a single ‘event’ compared with the short set of boat wakes associated with vessel passage. To achieve the same wave count as a wind event would require 500 vessels per hour. At both Quarry Point and Chidley Point the boats producing the largest wave energy were high-displacement recreational vessels (CMST 2010). Chidley Point had the largest wave energy produced by an individual vessel measured at its site, due to the large size and high speed of passing recreational vessels at Chidley Point. The five highest measurements from individual vessel passages at Chidley Point ranged from 0.53 – 0.72m wave heights and 2.5s to 4.7s wave periods. The highest cumulative energy was generated by a 0.7m wave height and 4.2s wave period (CMST 2010), which is comparable to a 3-year ARI wind-wave for many areas of the WESROC foreshore (Table 12-7), with a longer wave period. The vessel-generated wave heights or energy reaching the shore along the remainder of the WESROC foreshore was not undertaken in these studies.

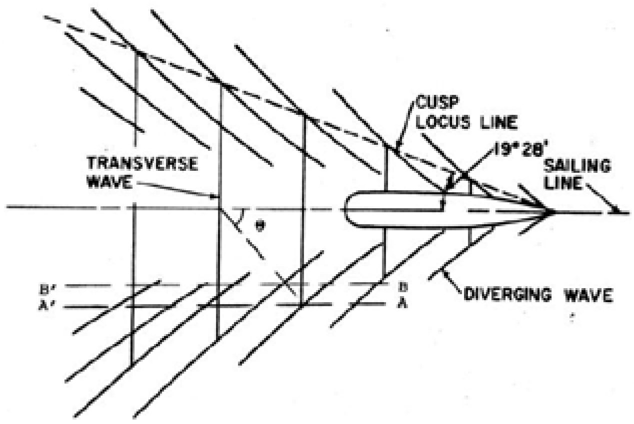

Figure 12-15: Boat Wake Generation

Methods of estimating boat wakes should be used for the design of erosion mitigation solutions at an individual site. However, methods to estimate vessel wake are empirical and should therefore be used with limited confidence. Methods may include that suggested by AMC & CMST (2009) for sub-critical speeds or using the method Damara WA has used elsewhere on the Swan-Canning. The method used by Damara WA is based on PIANC (2003) for wake generation and corresponding decay patterns. Wave heights for sub-critical wakes can be estimated using Erikson *et al.* (2003) and critical and sub-critical wakes using Wijnstra & Harris (1995). The pattern of predicted wakes is generally a peak at the critical vessel speed, followed by a linear increase with speed in the super-critical zone. The estimated boat wake height is then increased by 50% for the design of erosion mitigation structures because boat wake structures are typically steeper than wind generated waves (CIRIA *et al.* 2007). Finally some consideration is required of relative frequency of boat wakes to wind waves in determining an equivalent wave height.

For most of the WESROC study area it is assumed the wind wave levels are appropriate for design of erosion mitigation structures, with longer periods added for the boat wakes. In the narrower river sections of Town of Mosman Park, the height of waves generated by vessels is directly comparable with the extreme wind wave conditions with the vessel wakes anticipated to occur at lower water levels. However, for the WESROC foreshore between Keanes Point and Pelican Point the extreme wind wave heights (>10-year ARI) are likely to exceed boat wakes, with corrections required for wave period. Exceptions will be incorporated such as locations where local dredge holes reduce the dissipation of the wave energy, and the superposition of waves from two concurrent vessel passages.

The longer period of boat wakes increases the erosion potential of the waves, including bed scour and loss of material through structures, and the amount of overtopping that occurs.

Boat wakes are also considered in their contribution to alongshore sediment transport, due to the acute direction of wake travel outside the range of prevailing wind-wave directions and their capacity for relatively large size. Boat wakes also provide increased wave activity to redistribute sediments in response to elevated mean sea levels and historic modifications of the foreshore and terrace.

APPENDIX A.4 CURRENTS

Currents are an internal fluid response to disturbance, as the fluid attempts to equilibrate pressure gradients. The most recognisable gradient is the water surface slope, which responds by 'flowing downhill'. Forcing mechanisms include gravity (hydraulic grade or flow head), wind stress, density differences or wave energy.

Currents produce stresses on the bed and provide a means of transport for any material suspended within the water column. Currents generally follow bathymetry and increase in areas of constriction, whether they are horizontal constraints (i.e. entrance channel) or depth limited areas. Areas where the currents are lower generally allow deposition to occur and higher currents may erode the bed if its material is mobile.

Tidal gradients are generally the major source of current in the Swan River lower estuary, particularly in the entrance channel where relative strong bi-directional flow is observed (Dyer 1986). Non-tidal gradients, particularly driven by winds, storm surges and other oceanographic phenomena provide additional sources of current.

Currents in the entrance channel were measured between December 2004 to November 2006 at the at the Fremantle traffic bridge (Fremantle Port Authority), downstream of the WESROC foreshore (Figure 12-16). The record shows:

- A maximum measured current speed of 0.91 m/s on 8 August 2006 (1.77 knots) associated with a high tide (1.0m range); and
- Bi-directional flow generated by tidal gradients in the lower estuary producing two distinct directional bands of approximately 110°N (flood tide) and 290°N (ebb tide). The highest current speeds tend to occur during ebb tides (Figure 12-16).

It is recognised that recorded flows vary along the entrance channel according to cross-sectional area and configuration (Stephens & Imberger 1996).

Current speeds within the Swan River estuary basins are anecdotally much lower than in the entrance channel, although local focussing occurs where there is a projection into the river such as Pelican Point, or at throttles such as the Narrows. For the lower Swan River, the importance of currents is enhanced at a number of locations, including:

- Through the tidal gorge between Fremantle and Freshwater Bay;
- Along rapid changes in flow channel curvature, such as Armstrong Spit;
- Through dredged channels, such as Armstrong Spit and Qantas boat ramp; and
- Across sand spits and shoals, including Pelican Point and Freshwater Bay.

There is no sustained program for measurement of currents within the lower Swan River Estuary basin, due largely to their localised nature. In general, short-term current metering has been used to test and support numerical models of water circulation in the estuary (Stephens & Imberger 1996).

Wave induced currents are considered below in terms of alongshore transport, both for wind waves and boat wakes.

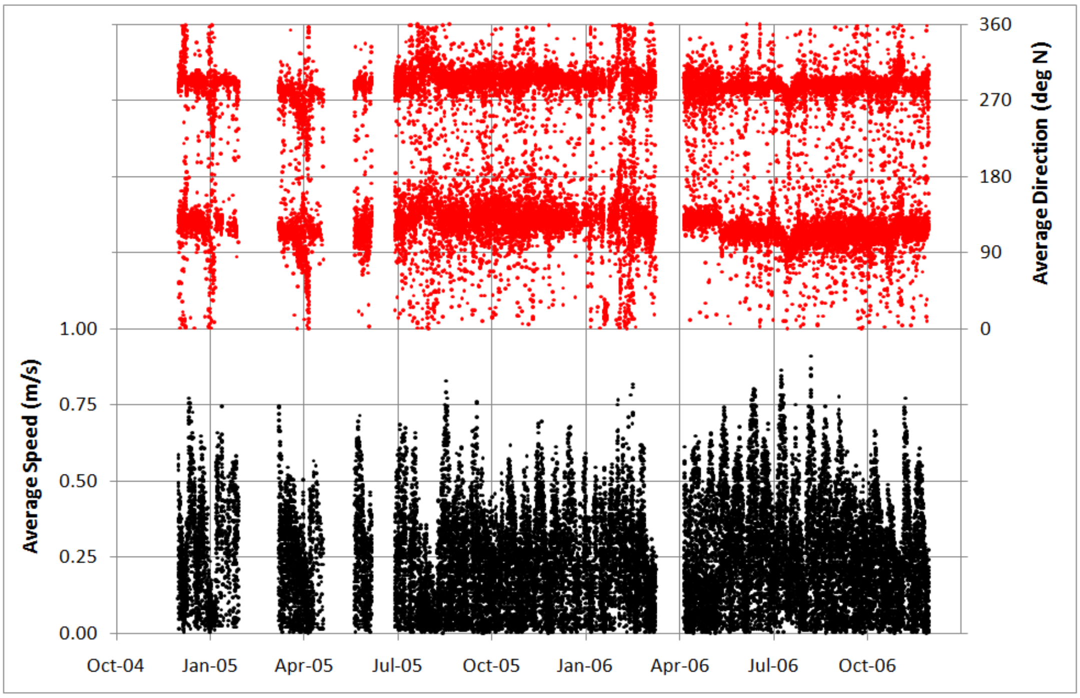

Figure 12-16: Flow Speed and Direction Time Series

APPENDIX A.5 STORMWATER DRAINAGE

Much of the stormwater network in the WESROC area discharges to the river (CZM 2010). There are 56 drains on public land ranging from diameters of 0.15m to 1.15m (after Damara WA 2015; Figure 2-14).

Some stormwater drains require modification and adaptation due to high bed scour from the pipe contributing to adjacent foreshore erosion, insufficient capacity of drains for high flows with overbank flow causing scour behind structures, associated erosion mitigation structures that are exacerbating erosion of adjacent banks or because sand bars are formed riverward of the drain contributing to water quality concerns. Some drains fronted by sand bars or those with low invert levels may potentially stop draining effectively with rising mean sea level.

Information on rainfall, runoff and catchment areas is required to determine the design or adaptation of a drain. However, a standard approach should not be undertaken and applied to all drain locations in the WESROC area. Three separate calculations are required to balance the bed scour from the pipe in the context of sediment resupply from adjacent foreshores, and the consequences of overbank flow.

The three calculations are:

1. Pipe full flow. This is approximately equivalent to the 2 to 5 year ARI. The higher the value selected the less frequently overland flow will occur with reduced scour capacity of the upper bank or landward of structures. However, higher pipe full flow will also increase the capacity for episodic scour of the riverbed at the end of the drain pipe.

2. Overbank flow. Estimates of overland flow should consider the impact and stability of the foreshore that is flooded. For example, it should be determined if there is an acceptable level of potential gully erosion or saturation of sediment behind a wall contributing to erosion through the wall (e.g. Glyde Street in Mosman Park).
3. Extreme flow variation. This analysis considers if near-field erosion response is anticipated considering the anticipated rate of bed scour from the pipe in conjunction with the rate of resupply of sediments from the adjacent terrace or foreshore to infill the scour hole. It requires consideration of the nature of the catchment, the scour point at the end of the drain pipe and if resupply is episodic or seasonal.

The three calculations are balanced dependent on the acceptable areas of erosion on the foreshore, as well as consideration of drain function with potential rising mean sea level. Investigations of drain function will consider mean sea levels where blow-back, choking and flooding may occur.

Appendix B Information Used for First Order Cost Estimates

First-order cost estimates of recommended management sequences along the WESROC Foreshore have been prepared for each LGA in tables in Appendices C6, D.6, E.6, F.6 and G.6. This information is useful only for application of funding grants and budgetary scheduling, and should be refined during project-specific design and based on similar projects undertaken by the LGA. The approach for preparing these cost estimates has included:

- developing appropriate coarse level design options;
- estimating material quantities for disposal and construction;
- identifying suitable plant and equipment for construction;
- estimating construction timeframes; and
- consideration of site constraints, including restricted access.

For each of these steps engineering judgement based on previous experience in the Swan River has been applied.

The cost-estimates consider the following cost components:

- Materials costs - based on 2015 rates for materials typically used for foreshore management in the Swan River (Table 12-8) and engineering assumptions for various other materials, including for concrete footings, path installation, drainage and others. Material costs include transport to site.
- Construction costs - based on 2015 rates for plant and equipment typically used for demolition, excavation and materials placement in foreshore management in the Swan River;
- Disposal costs - based on Red Hill Waste Management Facility tip fees which is the only commercially available facility licensed by the Department of Environmental Regulation to accept Class I to Class VF waste. Disposal costs include transport.
- Preliminaries costs - based on 15% of the material supply and construction costs. Preliminaries could include site establishment, mobilisation/demobilisation, works insurances, documentation, survey, environmental monitoring, traffic and pedestrian management; and
- Design costs - based on 5% of the material supply and construction costs for management sequences requiring design. In some areas separate design studies have been recommended and costed separately.

No cost estimates for environmental testing of material to be excavated and disposed have been included. These costs should be added to the first order cost estimates where relevant.

Table 12-8: Rates Obtained and Used in Cost Estimates

Item	Rate	Unit	Source
Materials Supply (including transport)			
Limestone Rock (Core & Armour)	\$60	per tonne	Local Supplier
Limestone Blocks (1.0m × 0.35m × 0.35m)	\$17	per block	Local Supplier
Sand Renourishment from Darling Scarp quarry *-semi-trailer truck* *-6 wheeler truck for restricted access*	 \$52 \$39	 per tonne per tonne	Local Supplier
0.75m³ Geotextile Sand Container - Standard	\$65	per GSC	Local Supplier
0.75m³ Geotextile Sand Container - Vandal Deterrent	\$130	per GSC	Local Supplier
Geotextile	\$4	per m²	Local Supplier

Item	Rate	Unit	Source
Construction			
Bobcat (Positrak)	$1,050	per day	Local Contractor
Excavator (5-8t)	$1,100	per day	Local Contractor
Site Supervisor	$100	per hour	Local Contractor
Transport			
Rock Truck (semi-trailer)	$1,450	per day	Local Contractor
Sand Truck (semi-trailer)	$1,150	per day	Local Contractor
Disposal			
Redhill Tip fees (not including transport)	$160	per tonne	Redhill Tip