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BELLARINE PENINSULA – CORIO BAY LOCAL COASTAL HAZARD ASSESSMENT

INUNDATION REPORT

VICTORIA State Government | Environment, Land, Water and Planning

CITY OF GREATER GEELONG

Borough of Queenscliffe
Queenscliff & Point Lonsdale, Victoria, Australia

CORANGAMITE CMA

Bellarine Bayside Coastal Management

BARWON COAST

Inundation Report

Bellarine Peninsula - Corio Bay Local Coastal Hazard Assessment

Prepared for
City of Greater Geelong & Stakeholders

December 2015

Cardno
Shaping the Future

Document Information

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Executive Summary

Introduction

Cardno was commissioned by the City of Greater Geelong (CoGG), the Department of Sustainability and Environment (DSE) (now the Department of Environment and Primary industries (DELWP), the Corangamite Catchment Management Authority (CCMA), the Department of Planning and Community Development (DPCD) and the Borough of Queenscliffe (BoQ) to undertake the Bellarine Peninsula - Corio Bay Local Coastal Hazard Assessment (Bellarine Peninsula – Corio Bay LCHA). These organisations make up the Project Control Group (PCG). This study is one of four Local Coastal Hazard Assessments undertaken in Victoria through collaborative partnerships with local stakeholder agencies and was initiated through the DSE (now DELWP) Future Coasts Program.

The Bellarine Peninsula – Corio Bay LCHA study area includes the entire Bellarine Peninsula and the northern side of Corio Bay, from Point Wilson in the north, to Breamlea in the south. The key aim of this study is to provide a comprehensive understanding of the extent of coastal hazards and the impacts on the coastal environments within the study area. This was done by addressing coastal, estuarine/riverine and climate-change challenges by defining the possible magnitudes and extents of the hazards in a considered and robust manner. This provides information for local land managers regarding their sections of the coast, and provides a basis to identify additional studies to be carried out in the future. This will ensure councils and land managers are prepared for future hazard and climate-change related challenges, and to inform strategic planning and decision making.

It is intended that this study will inform subsequent risk and mitigation assessments, which will guide the prioritisation and implementation of management actions. This will ensure best use of existing coastal management budgets, and also provide information to gain external funding where possible.

Study Area

The study area consists of a variety of coastal environments. The Bass Strait open coast section of the study area is generally a high-energy environment with a relatively consistent wave climate, shallow nearshore bathymetries, consolidated dunes/cliffs and unconsolidated dunes ranging in elevation from 2 to 30 m AHD. Headlands and rocky foreshores have fixed the ends of the local beaches, and characteristic arc and zeta curve shaped beaches lie between the fixed points. The key hazard along the open coast is erosion. Inland at Breamlea and Barwon Heads there are low-lying land areas vulnerable to inundation.

The entrance to Port Phillip Bay is a complex environment dominated by swells and strong currents. Within the bay the tidal range is lower than that in Bass Strait. The influence of swell decreases with distance from the bay entrance and the resulting environment is quite different. The wave climate is dictated by wind, meaning wave heights are fetch-limited. Due to sedimentation, water depths on the western side of the bay are shallow near the Great Sands, resulting in lower (depth-limited) wave heights.

In the vicinity of the entrance, the Lonsdale Bight coastline consists of high cliffs, long sections of protection structures (seawall and revetment) and dunes. The key hazards are erosion, overtopping of the protection structures and inundation of the low-lying areas around Queenscliff and Swan Bay. Further north along the St. Leonards and Portarlington coast the shoreline elevation is low, leaving some discrete areas vulnerable to inundation and erosion during storm events. The Clifton Springs coast from Portarlington to Geelong consists of cliffs with narrow beach widths at the base. The hazards here are mostly slope stability related, with some low-lying areas vulnerable to inundation. The coastal processes are dominated by wind, wind-waves and currents. The Corio Bay area is very low energy in comparison to the rest of the study area. Wave heights are more significant during north easterly wind events, due to the greater fetch from this sector. The northern Corio Bay area is also low energy, the energy increases slightly towards Point Wilson, due to the exposure to the wider bay. The shoreline is mostly rocky with a low-lying hinterland behind.

Methodology

A site visit and review of all relevant data sets and previous studies was undertaken early in the study. After consultation with the Project Control Group (PCG) and technical reviewers, the methodology was refined to ensure the most appropriate methods were undertaken to deliver the desired project outcomes. Due to differing landscapes and levels of hazard and potential risk, the appropriate scale and resolution of the modelling was determined for each study compartment.

The initial modelling considered waves and water levels throughout the study area, which enabled the determination of design conditions for subsequent inundation modelling. Inundation hazards were determined using hydrodynamic and static modelling (for less complex areas). Due to the nature of the differing coastal environments there were some limitations within the inundation assessments of this study, and these were considered and reported on within the findings

Key Findings

The results and findings of the inundation assessments, as well as the hazard maps are presented for the study compartments where necessary. The study findings show that the level of hazard is markedly different between locations. The following sections provide commentary of the key findings for each compartment. Figure ES 1 shows the locations of study compartments, with the boundaries of the hydrodynamic models.

Compartment 1: Breamlea to Blue Rocks

The present day inundation vulnerability to a 1% annual exceedance probability event (AEP) with 0.0 m sea-level rise (SLR) is low. Under this and the 0.2 m SLR scenario, the areas of inundation are mostly low-lying floodplain areas, therefore the impacts to habitat are potentially of significance. It is not until the events with the higher sea-level rise scenarios that infrastructure and assets are impacted.

The local habitat resilience to saline inundation should be assessed, and areas of appropriately elevated land mapped for future areas.

A key location to note is the beach access at Bancoora Beach, which has the potential to become a breach location in future for inundation of the hinterland. The timing of this is uncertain. Regular monitoring of the beach is required to allow coastal managers to track any significant changes that would prompt a management response. The amenity use of this area is likely to increase in future also, therefore the formalisation of the access may be necessary to minimise future anthropogenic impacts.

Compartment 2: Blue Rocks to Barwon Estuary

The inundation vulnerability to this section of coast is low due to the high dune/cliff elevations, however regular monitoring of the far western end of the beach (which is lower) will aid in tracking morphological change. This may be of significance to the inundation vulnerability in future.

Compartment 3: Barwon Heads, Barwon Estuary and Lake Connewarre

Riverine flood inundation has been investigated in the past, however focused solely on riverine inundation. This assessment considered the saline inundation primarily, and coincidence of this with riverine events. An assessment of the coincidence of these two factors was undertaken, it was found that storm-tide inundation and peak riverine flows due to high rainfall do not occur at the same time. The assessment therefore included two higher frequency flood events, an annual peak flow and a 10% AEP flood event, with the less frequent 1% AEP coastal event.

The saline inundation potential for Barwon Heads is less significant than previously assessed (Future Coast, 2011). In a 1% AEP event with a catchment baseflow the low-lying areas of the estuary shoreline are inundated. These are mostly areas of habitat. In events with sea-level rise above 0.2 m, the flood extents become more significant. In a 1% AEP event with a 10% AEP catchment flow for the present day (i.e. 0.0 m SLR) the flood extent is greater than the equivalent baseflow case. The inundation is likely to impact the eastern bank of the river, at Ocean Grove, where the low shore protection is likely to be overwashed. Note, the shore protection here is not forming a consistent barrier and appears to have been designed to minimise shoreline movement on the river bend, rather than flood protection. On the western bank of the river (Barwon Heads) the inundation potential increases with increases in sea-level rise.

Compartment 4: Ocean Grove to Point Lonsdale

This section of coast is subject to erosion hazards and overtopping at the Ocean Grove seawall. This will have implications for future risk assessments. It is recommended that closer monitoring of the beach is undertaken to track coastal change and provide better background information for future assessments.

The seawall at Ocean Grove Main Beach is providing a high standard of protection to the hinterland presently. Overtopping volumes are generally low for the present day. Beach levels at the toe of the seawall are likely to decrease due to scour erosion, therefore increasing the depth of water at the toe of the structure during storm conditions. This in turn will allow larger waves to penetrate further inshore and increase overtopping. The rate of loss of beach volume is currently unknown, and should be monitored to inform future assessments.

Compartment 5: Point Lonsdale to Point Edwards

This section of coast is subject to overtopping and inundation hazards. An assessment of the overtopping of the shore protection (seawall and revetments) was undertaken for Lonsdale Bight. This showed quite a significant hazard for the present day and in future with sea-level rise increases. The results are consistent with visual inspection of the area and information from the asset managers, the seawall is regularly repaired due to the effects of direct wave impact. Through time the incidence of damage due to wave impact is likely to increase, therefore continued maintenance and upkeep in this area is vital. The overtopping hazard decreases further around Lonsdale Bight due to the change from vertical seawall to revetment (which also increases in elevation from Lawrence Road) as well as a general decrease in wave energy with distance from the bay entrance.

Inundation is likely to be the overriding hazard for the Queenscliff area, more specifically, Fisherman's Flats. The Fisherman's Flats shoreline is significantly lower than the rest of the Queenscliff area; therefore any inundation is likely to originate from there. The shore protection is in very poor condition in some locations, and not forming a consistent barrier. The newly upgraded marina shoreline is approximately 0.5 to 1 m higher.

The lowest areas of Fisherman's Flats already pool runoff in high rainfall events, thus the inclusion of saline inundation will increase the vulnerability, although similarly to the Barwon Estuary the likelihood of the two hazards occurring together is low. The stormwater pumping infrastructure has been upgraded recently to address the runoff issues. It is recommended that investigation into management options to mitigate the effects of saline inundation in this location should occur in the near future.

At the southern end of Swan Bay, an assessment of the inundation of Lakers Cutting and the Lonsdale Lakes development was undertaken. The inundation vulnerability also extends to the Bellarine Highway and properties in the vicinity of Murray Road. The extent of inundation of this area becomes significant under a 1% AEP event with 0.2 m SLR. In this event, a low section of the railway embankment overtops west of the Marine Discovery Centre, possibly impacting a small number of properties along Murray Road. The timing and depth of inundation for this area during this event is likely to be low; this should be considered in subsequent risk and mitigation studies. In a 1% AEP event with 0.5 m SLR, the flood extents increase significantly. It is recommended that the railway embankment is further investigated, particularly the permeability, as with minor adaptation (e.g. valving of culverts and removal of drainage channels) this could aid in inundation mitigation during lower events. Under higher sea-level rise events, the embankment would likely be overwashed. This will impact the Bellarine Highway.

For Swan Bay, the inundation hazards are less significant. There is little development around the bay, thus the key issues will likely be related to habitat resilience. The surrounding land areas rise gradually to higher land, therefore there appears to be nothing inhibiting any natural roll-back with sea-level rise.

Compartment 6: Point Edwards to Portarlington

The key inundation hazard area is at Salt Lake. There is a narrow section of shoreline between the lake and the coast, this is likely to overwash in a 1% AEP event with 0.0 m SLR via low sections in the road. In the higher sea-level rise scenarios, the shoreline is below the storm-tide level. It is recommended that risk and mitigation studies are undertaken in the near future for here.

From indented head to Portarlington the coast becomes more exposed to wave impacts, thus, erosion issues are more significant rather than inundation.

From Portarlington to Ramblers Road, the coast is vulnerable to inundation. Similar to the previous coastal section the exposure to the prevailing winds and waves is more significant here. The hinterland elevations at the Esplanade are low, and east of the pier are low, and decrease further moving west past the Bellarine Bayside foreshore to Ramblers Road. It is recommended that risk and mitigation studies are undertaken in the near future to address the inundation issues at Ramblers Road.

Compartment 7: Portarlington to Point Henry

The inundation hazard along this section of coast is relatively low, the key location for inundation is near the Sands Caravan Park, however at the base of the cliffs around Clifton Springs there may be some impact to infrastructure in high water events.

Compartment 8: Stingaree Bay to Geelong (South Corio)

The ground elevation in this area are very low, thus, inundation is a key hazard. In a 1% AEP event with 0.0 m SLR some fringe areas of the shoreline are impacted, mostly habitat around Point Henry. The salt pans are also likely to inundate, however this is of no consequence. In a 1% AEP event with 0.5 m SLR, the flood extents become more significant, potentially impacting some roads. Properties around Newcomb and Moolap are likely to be impacted by inundation in sea-level rise scenarios of 0.8 m and above.

The inundation vulnerability around Geelong is low. The shoreline is heavily modified, protection structures exist from east of Eastern Beach to Western Beach, mostly vertical seawalls. An overtopping assessment was undertaken and the vulnerability is high, however the consequences of overtopping inundation are likely to be low as long as the ongoing maintenance of the structures and active management of the foreshore is continued.

Compartment 9: North Corio Bay to Point Wilson

Beyond the Moorpanyal cliffs the ground elevation in this area is again very low, thus, inundation is likely to be the overriding hazard. Areas of foreshore are impacted in a 1% AEP event with 0.0 m SLR, these are mostly habitat areas. As sea-level rise increases, public infrastructure is also likely to be impacted, such as roads and storm water infrastructure.

The environmental value of this area is significant with large areas of rare habitat. Resilience studies and mapping of appropriate future habitat areas based on ground elevation and future inundation frequency should be undertaken.

Area wide management recommendations

The following are general recommendations for the overall study area that may aid in reducing the uncertainty of the finding of this study, as well as aid coastal mangers in their future management undertakings:

- Establishment of a thorough monitoring program that is consistent between management organisations, beach profiling will be a key aspect of this. This should be undertaken in conjunction with DELWP.
- Recommend that this study is updated every 5-10 years to incorporate revised sea-level rise guidance and measured increases, monitoring findings to ensure better certainty in the inundation hazard assessments and review and consider coastal management changes where action has been taken and works carried out.
- Investigations of groundwater to be undertaken in future assessments.
- Monitoring and additional work to fill data gaps (see next section).

Further Work to Fill Data Gaps

Each area’s results section gives some advice as to the data requirements for further studies. This will greatly aid in reducing the levels of uncertainty within this study. The reliability of the hazard studies stems from the quality and quantity of data available to carry out the coastal hazard assessment.

There are two overarching uncertainties related to these assessments, the lack of thorough and recent background data sets and the methods used in determining the present and future hazard extents. The following will aid in reducing uncertainty, and provide information to update the findings of this study in future.

Beach profiling

Beaches provide the primary protection against the erosive effects of the sea at many places in the study area. The condition of beaches is thus an important factor in coastal hazards definition. There is lack of beach profile data available for the study area, as well as much of the Victorian coast. This will be vital in determining the short and long-term change of beaches, and better inform hazard studies in future.

Beach profile information will greatly reduce the uncertainty related to the profiles used in this study, and to monitor future change. Profiles were taken from LiDAR data flown in 2007 (DSE, 2007). The uncertainty associated with this relates to the following:

- where anything has changed since 2007, e.g. landforms, structures, roads, car parks, developments.
- where shoreline position has advanced or retreated since the LiDAR was flown.

Beach profiling can be carried out using a number of methods e.g. surveyors, RTK GPS, photogrammetry (from regular aerial images, possibly collated by unmanned aerial vehicles, “drones”), profiles from high resolution LiDAR (potentially costly due to frequency required for thorough monitoring).

LiDAR & Bathymetry

The regularity of capture of airborne laser data sets is dictated by available funds to do so. Progressions in technology mean the costs associated with these technologies are coming down over time. Annual (ideally) or biennial capture and processing in future would provide essential information that would aid in baywide coastal management, as well as the wider Victorian coast, and this is recommended.

Aerial imagery

Aerial images are captured for the study area intermittently; it is recommended this is continued in future, preferably yearly. If a thorough program of beach monitoring, particularly beach profiling, is not undertaken, then photogrammetry methods using the aerial images may be useful to monitor shoreline change. This will be a less certain method; however in lieu of any others will be useful.

Further Coastal Management Studies

This study identified and informed about hazards in a wide context. The next step in the coastal management process for the Bellarine will be to investigate the most at risk areas in terms of assets, both built and natural and determine and prioritise mitigation actions. Future tasks will likely include:

- Compilation of asset registers within the defined hazard areas and investigate the risk to key assets based on likelihood and consequence (AS/NZS ISO 31000:2009 Risk Management Techniques);
- Determination of options to manage and minimise the risk and evaluate these options using the quadruple bottom line method, considering technical, social, environmental and economic implications of each to determine a prioritised, costed and responsibility stated list of coastal management actions for State and local government as well as local land managers.
- Actions should be compiled into new coastal zone management plans for each area, which will address a wider range of coastal related issues (not just technical) or incorporated into revised versions of the current coastal management plans. Part of the review process should be the revisiting of previous management plan actions to determine which actions have and have not been undertaken and why, their effectiveness, and any implementation issues experienced by local managers. This will aid in informing and guiding future management practices. This is key to a process of effective adaptive management.

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Figures

NOTE - The inundation hazard figures within Section 6 have clickable PDF layers, meaning each inundation extent scenario layer is able to be clicked on and off. In Adobe, clicking the layers icon on the left of the page will activate the layers, or Ctrl-L for other software.

GLOSSARY

ABBREVIATION	DEFINITION
AEP	Annual Exceedance Probability
AHD	Australian Height Datum The Australian Height Datum is a geodetic datum for altitude measurement in Australia, "In 1971 the mean sea level for 1966-1968 was assigned the value of zero on the Australian Height Datum at thirty tide gauges around the coast of the Australian continent"
ARI	Annual Recurrence Interval
Astronomical tides	The fall and rise of sea levels caused by the gravitational effects of the Earth, Sun and Moon, without any atmospheric influences.
BCCoM	Barwon Coast Committee of Management
BBFCoM	Bellarine Bayside Foreshore Committee of Management
Beach berm	A nearly horizontal plateau on the beach face formed by the deposition of beach material by wave action. The berm area is often eroded during storms and reformed in periods of gentler wave activity.
BoQ	Borough of Queenscliffe
CoGG	City of Greater Geelong
Conservative / conservatism	This refers to overestimation in an assessment (or overdesigning in engineering) to ensure a 'worst case scenario' is considered for additional safety and caution, but also to account for uncertainty i.e. 'the unknown', taking a "cautious" approach. Contrast with underestimation which may lead to management actions which are not sufficient.
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	digital elevation model
DEPI	Victorian state government Department of Environment and Primary Industries
Directions	Have been given as bearings in degrees clockwise from True North or as compass points (e.g. east = 90°T). Directions for currents have been specified using the oceanographic convention as the "going to" direction. Wind and wave directions are referred to by the meteorological convention as "coming from". There may be occasions where directions are referred to in an alternative convention and the convention is indicated in the relevant text;
DSE	Victorian state government Department of Sustainability and Environment
Ebb tide	Outgoing or receding tidal current, (that is, when water is flowing away from the shore line) leading to low tide.
Fetch	The maximum distance over water that winds of a constant speed and direction can generate waves. Areas such as Port Phillip Bay are defined as fetch-limited meaning that wave heights will always be restricted by the area over which wind can blow.
High water	Maximum height reached by a rising tide.
High water mark	The highest level that water has reached up the beach, also known as the "strand line" for the seaweed and debris that are stranded at this point. It is a line which can often be identified in aerial photographs.

ABBREVIATION	DEFINITION
Hs, (m)	Significant wave height The significant wave height is originally defined as the average height of the largest one third of the waves in a given record. With the advent of digital processing techniques and spectral analysis of wave records, the significant wave height is now commonly defined as $Hs=4\sqrt{m0}$ where m0 is the variance of the wave spectrum or the "zero order moment". For the purposes of this study the definition based on variance is used. For practical purposes, the significant wave height is close to the value reported by an experienced observer making visual observations of the wave height.
Intertidal	The range between the mean higher high water and mean lower low water lines.
IPCC	Intergovernmental Panel for Climate Change
LADS	Laser Airborne Depth Sounding
LiDAR	Light Detection and Ranging. This is a remote sensing technology that measures distance by use of a laser. Alternatively it can also mean a topographic dataset created by using this method.
NTC	National Tidal Centre
PCG	Project Control Group
PoMC	Port of Melbourne Corporation
Ramsar	Convention on Wetlands of International Importance signed in Ramsar, Iran in 1971.
Saline inundation	This is inundation by sea water, as opposed to riverine flooding by fresh water.
SLR	Sea-level rise
Spit	A finger-like depositional landform that extends (often perpendicular) from the coast into a body of water.
Storm surge	A combination of barometric set up, wind set-up, and coastal trapped-waves leading to an increase in sea level above the predicted tide.
Storm-tide	A storm-tide is an extreme sea-level event during a storm, the combination of a high astronomical tide and a storm surge.
STL	Storm-tide Level. The combination of astronomical tide and storm surge and thus the sea-level anticipated or measured during a storm event.
Swell	Waves which have travelled away from the area where they were generated such as a remote storm system. Often appearing as a series of regular spaced waves of unbroken appearance. The waves may have travelled many 100's of kilometres from their point of origin.
Tidal current	Movement of water associated with the rise and fall of the tides
VRCA	Victorian Regional Channels Authority
Wave direction	Direction from which the waves are coming from and are given as the bearing, in degrees, clockwise from true north.
Wave height, H, (m)	The vertical distance in metres between the crest (top) and trough (bottom) of a wave.
Wave setup	This is an increase in the mean water-level due to the presence of waves.
Wave runup	This is the extra height or extent that broken waves reach as they run up the beach.

1 Introduction

Cardno was commissioned by the City of Greater Geelong (CoGG), the Department of Sustainability and Environment (DSE) (now the Department of Environment, Land, Water & Planning (DELWP), the Corangamite Catchment Management Authority (CCMA), the Department of Planning and Community Development (DPCD) and the Borough of Queenscliffe (BoQ) to undertake the Bellarine Peninsula Corio Bay Local Coastal Hazard Assessment (Bellarine Peninsula – Corio Bay LCHA). These organisations make up the Project Control Group (PCG). This study is one of four Local Coastal Hazard Assessments being undertaken in Victoria through collaborative partnerships with local stakeholder agencies and was initiated through the DSE (now DELWP) Future Coasts Program.

The Bellarine Peninsula - Corio Bay LCHA study area includes the entire Bellarine Peninsula and the northern side of Corio Bay, from Point Wilson in the north, to Breamlea in the south (Figure 1-1). The study provides a comprehensive understanding of the extent of coastal hazards and their impacts on the coastal environments within the study area. It assesses coastal inundation, while considering the effects of climate change, as well as combined incidence of catchment flooding and coastal inundation. The developed data sets from this study will enable the derivation of hazard maps and allow management agencies to use these outputs as tools to aid in assessing, identifying and managing risk to coastal infrastructure and environmental values through strategic, statutory and business planning processes.

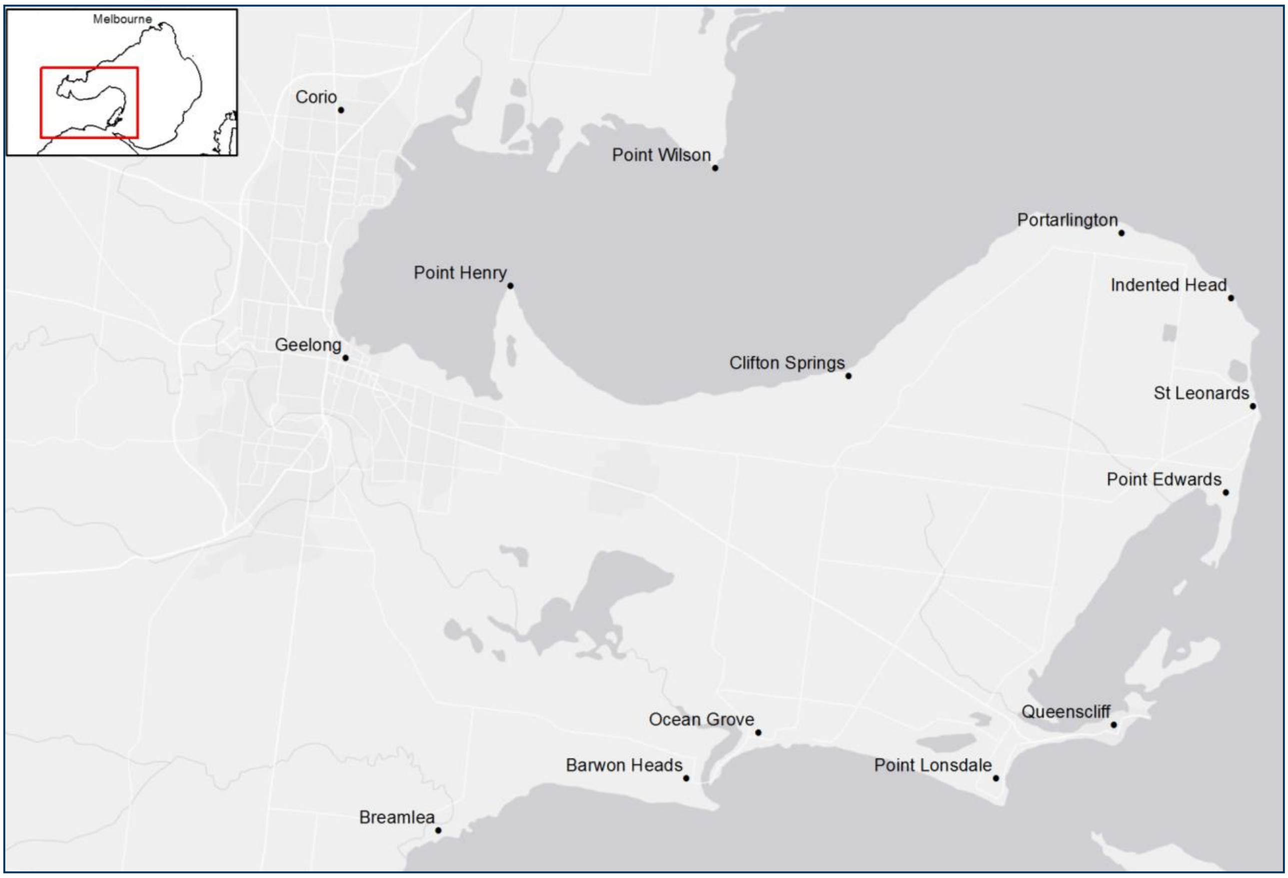


Figure 1-1 Bellarine Peninsula - Corio Bay LCHA study area

1.2 Purpose

The Bellarine Peninsula - Corio Bay LCHA is one of four pilot studies investigating coastal hazards and climate change implications along the Victorian coast. The other studies are:

- Port Fairy
- Gippsland Lakes / Ninety Mile Beach

- Westernport Bay

These pilot studies will be used in the development of mechanisms to facilitate planning for coastal climate change adaptation (DPCD, 2012). Through consultation with DSE (DELWP), councils and key stakeholders, tailored local responses to sea-level rise will be developed to aid future planning and decision-making.

The Bellarine Peninsula - Corio Bay LCHA study builds on the previous understandings of coastal hazards within the study area, as well as providing information to build capacity to deal with future issues.

The study seeks to address coastal, estuarine/riverine and climate-change challenges by defining the possible magnitude and extent of the hazards in a considered and robust manner. The aim is to advise local land managers regarding their sections of the coast, and provide a basis to identify additional studies to be carried out in the future. This will ensure councils and land managers are prepared for future hazard and climate-change related challenges, and to inform strategic planning and decision making.

It is intended that this study will also inform future risk assessments in the determination of priority coastal areas, guiding the prioritisation and implementation of adaptation responses. This will aid in minimising the effects of coastal inundation and climate change on people, property and the environment.

1.2.1 Context of the Hazard Study

The information contained in this report is the commencement of a three-step process of coastal zone management planning. The intention of this report is to identify and provide information about inundation hazards, and is the first step in the development of a sound coastal management framework that:

- is functional on a day to day basis – to ensure coastal managers have a thorough understanding of the coastal processes affecting their shorelines, as well as the wider area, to enable them to respond effectively;
- builds capacity for future challenges – providing technical information to assist in management of future risks, to assist in the implementation of suitable adaptation responses which effectively utilise resources for reducing risk; and,
- provides information that will enable the establishment of an adaptive management process – ensuring managers review the suitability of management plans and, in particular, regularly review the climate change and sea-level rise science. Management procedures need to be monitored and revised to ensure the long-term capacity of any adaptation responses.

Subsequent steps in the development of a coastal management framework (beyond the scope of this study) will include risk assessments that will relate the hazard information in this document to assets and values, after which management options and adaptation responses are evaluated to minimise the effects of the hazards on said assets and values. This study also identifies what additional studies are required to fill data gaps.

1.3 Aims & Objectives

The aims of this study are to:

- Provide an improved understanding of the processes that are shaping the coast along the Bellarine Peninsula and Corio Bay, now and into the future, considering the impacts of climate change.
- Provide data sets which will assist in predicting the coast’s susceptibility to inundation. These will provide information that will directly inform regional, township and local strategic planning, including adaptation planning processes.
- Build the collective capacity and depth of knowledge of land managers and decision makers to use the data sets that are generated to plan for and respond to coastal inundation and identified risks.

A number of coastal vulnerability assessments have been done at individual property scale within the study area, therefore, another key outcome of this study will be to minimise the requirement for individual property scale assessments.

1.3.1 Legislative Framework

The Victorian Coastal Management Act was established in 1995. The Act is intended to provide for the establishment of the Victorian Coastal Council, Regional Coastal Boards, provide for co-ordinated strategic planning and management. It also provides for the preparation and implementation of management plans for coastal Crown land and a co-ordinated approach for approving Crown land development.

The Victorian Coastal Strategy (VCC, 2008) was established in 2008 under the Victorian Coastal Management Act. The Strategy is a four part document that provides for and gives guidance on:

- the protection of significant environmental and cultural values
- integrated planning and direction for the future
- sustainable use of coastal resources; and
- suitable development on the coast.

A new consultation draft of the Victorian Coastal Strategy was released in September 2013 (VCC, 2013). The final document was released in 2014.

Some other key planning documents for the study region include:

- Waterfront Geelong Coastal Action Plan (Central Coastal Board, 2004)
- Corio Bay Coastal Action Plan (Central Coastal Board, 2005)
- Queenscliff Coastal Management Plan (Robin Crocker & Associates et al, 2006)
- Clifton Springs Coastal Management Plan (Thompson Berrill Landscape Design, 2008)
- Breamlea Foreshore Masterplan (Thompson Berrill Landscape Design, 2009)
- Buckley Park Coastal Management Plan (CDA Design Group, 2006)
- Ramblers Road Foreshore Management Plan (Thompson Berrill Landscape Design, 2007)
- Point Henry Foreshore Management Plan (Thompson Berrill Landscape Design, 2006)
- Limeburners Bay Management Plan (Insight Leisure Planning, 2008)

1.4 Project Partners

A partnership between the relevant organisations from the study area was formed as part of this project. The Project Control Group (PCG) is made up of the following organisations:

- Department of Environment, Land, Water & Planning (DELWP) (Chair),
- Corangamite Catchment Management Authority (CCMA)
- City of Greater Geelong (CoGG)
- Borough of Queenscliffe (BoQ)
- Bellarine Bayside Foreshore Committee of Management (BBFCoM)
- Barwon Coast Committee of Management (BCCoM)

The City of Greater Geelong acts as Project Manager, on behalf of the Bellarine Peninsula – Corio Bay LCHA Project Control Group. The PCG also established a Project Reference Group and a Technical Reference Group to assist in the project. A Senior Strategic Partnership Group (SSPG) that consists of the same organisations as the PCG plus the Department of Planning and Community Development was also established to provide high-level strategic oversight.

1.5 Project Methodology

A schematic outline of the project methodology is shown in Figure 1-2. This shows three concurrent, interlinked streams, although all the cross-linkages are not shown. On the left is the project management and reporting stream, in the centre the geomorphology and history and, on the right, the modelling. The final two stages, the

Risk Assessments and Adaptation Responses are not part of the Hazard assessment and form bodies of work for future investigations.

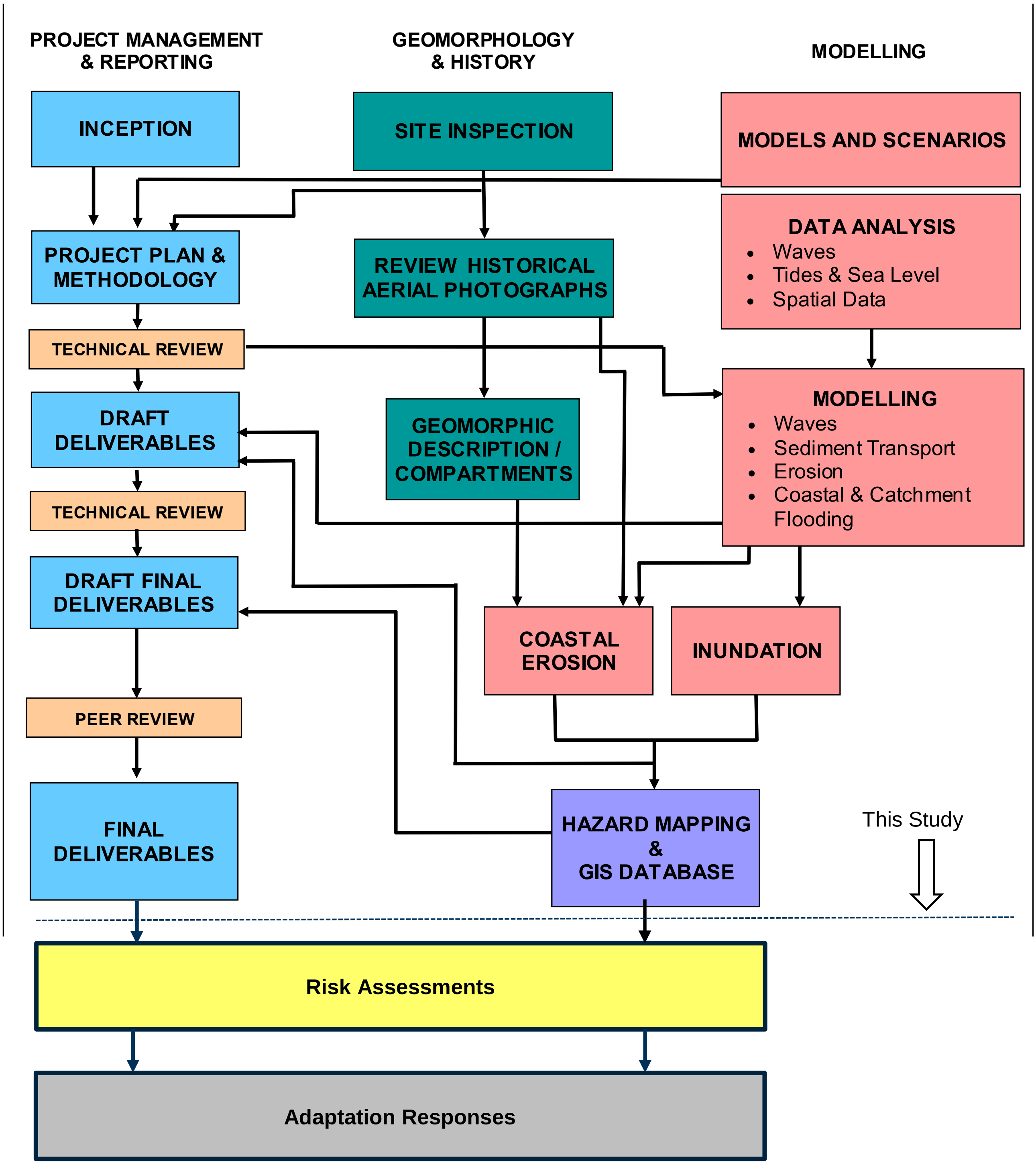


Figure 1-2 Schematic outline of the project methodology

The modelling considers waves and water levels throughout the study area, which enables the determination of design conditions for subsequent modelling. The geomorphology and history stream considers previous work to characterise the study area in terms of geology, land forms, shoreline types and geomorphic processes. This also includes the assessment of historical aerial imagery which enables shoreline change to be tracked over time to determine what changes may potentially happen in the future, based on what has happened in the past. The project management and reporting stream includes the project deliverables and the peer review process.

1.6 Scope of this document

This document follows on from the Scoping Document (Appendix A) produced in the initial phase of the project.

Section 1 (this section) gives a general introduction to the project.

Section 2 presents the review of relevant information and literature in the development of the project.

Section 3 gives a brief overview of the geomorphic development of the area and the local coastal processes.

Section 4 presents the study investigations and determination of design conditions.

Section 5 presents the methodology for the inundation hazard assessment.

Section 6 presents the results of the inundation hazard assessments by location.

Section 7 presents the overall conclusions and recommendations of the study.

2 Literature Review and Available Data

2.1 Previous Studies

A data assimilation project was commissioned by DSE (now DELWP) prior to the commencement of the Bellarine Peninsula - Corio Bay LCHA. The purpose of this project was to locate and compile all the relevant data and information that would be required to undertake the coastal hazard and climate change assessment.

The assimilation project information formed the basis of the current review. The information provides a thorough record of previous studies carried out in the region up to 2011. Any missing information or data available since then has been incorporated into this review.

Figure 2-1 presents the database structure and information categories available from the assimilation project. This information has been reviewed to determine relevance and usefulness, and, combined with the information gathered through the site inspection and Cardno's previous local experience, establishes a contemporary understanding of the historic development, and contemporary hydrodynamic and geomorphic processes operating within the study area.

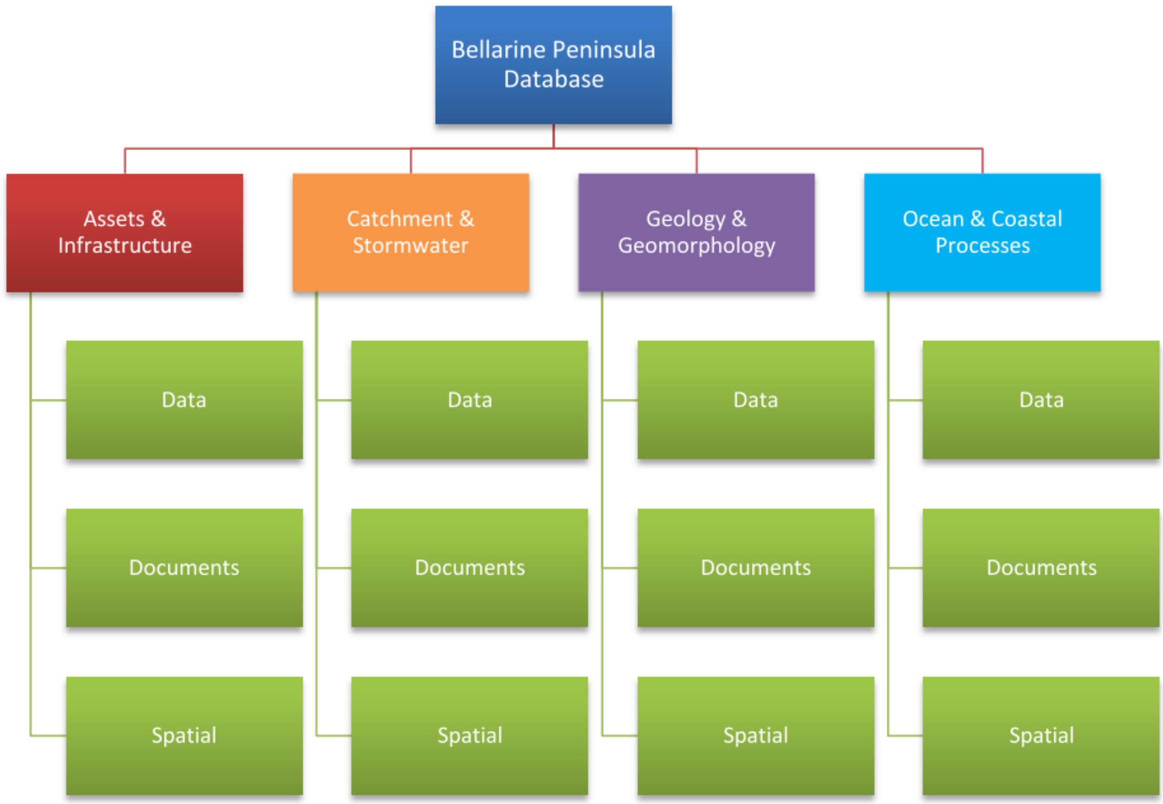


Figure 2-1 Categories of information available from the assimilation project (Water Technology, 2011)

2.2 Key documents

The assimilation project database compiled by Water Technology (2011) contains more than 300 individual datasets, reports, books, aerial photographs, CAD and image files. Although all the collated information is in some way relevant to the hazard study, certain components are more relevant and useful than others. There are a number of recent reports and papers for the study area which can be considered key documents in developing a thorough understanding of the coastal processes and geomorphology. The following sections provide a summary of the key documents by topic; Section 3 provides a commentary of the understanding gathered from the review of these (and other) documents and papers.

2.2.1 Coastal Processes

- *Great Sands and Adjacent Coast and Beaches (Cardno, 2011a)*

This report was prepared as part of the Port of Melbourne Corporation (PoMC) Channel Deepening Project and is a detailed look at the hydrodynamic processes operating in the southern reaches of Port Phillip Bay.

- *Great Sands Sediment Transport Modelling (Cardno, 2011b)*

This report was prepared as part of the PoMC Channel Deepening Project and considers the sediment transport mechanisms, pathways and volumes entering the southern reaches of the Bay.

- *Bellarine Coastal Processes Study (Cardno, 2011c)*

This study was commissioned by the Bellarine Bayside Foreshore Committee of Management (BBFCoM) and Department of Sustainability and Environment (DSE) to look at coastal processes in the eastern section of the Bellarine Peninsula, from Ramblers Road to Edwards Point From this, at risk areas were identified and management strategies suggested to mitigate risk.

- *Geelong Coastal Process Study (Lawson and Treloar, 2004)*

This provides a thorough understanding of the physical conditions and processes in and around Geelong. Waves and sediment transport were modelled, with an assessment of historical aerial photography to determine any shoreline change over the 57 years from 1944 to 2001. The study concluded that the study area coastal processes are dominated by low but persistent wave-energy. It also concluded that sections of the study area are naturally susceptible to erosion with headlands in particular and beaches between Portarlington and Point Richards eroding at various rates.

- *Portarlington Safe Harbour – Coastal Process Investigation (Water Technology, 2007)*

This report was prepared by Water Technology for Parks Victoria and investigated the coastal process at Portarlington in relation to the development of options for the safe harbour. The report includes the results of hydrodynamic modelling, wave modelling, wave climate analysis for littoral transport and aerial photography comparisons for Portarlington.

The results showed a net westward sediment transport rate of about 1,000 - 2,000 m^3/yr over the summer months and close to neutral in winter. The net westerly transport is significantly lower than the 2 to 4 years average maintenance dredging of 21,000 m^3. The presence of the harbour disrupts the longshore transport, thus reducing the volume available for beach replenishment. The study also showed that the circulation at Portarlington is dominated by tidal currents and that wind-driven currents have minor impact. Comparisons of the aerial photography from 1950 to 2001 pointed out that, in the immediate lee of the breakwater, the coastline is gradually advancing but between Portarlington and Point Richards the coastline is retreating. The report broadly discusses the impact of climate change. As mitigation options, the study proposed a combination of sand by-passing, beach nourishment and groyne construction. The report includes a concept plan of the harbour development.

- *Queenscliff Pier Coastal Processes Review, (Water Technology, 2008)*

This report reviewed the coastal processes in the vicinity of and implications for the Queenscliff Pier. The report concluded that the existing shoreward end of the Pier will continue to be buried periodically by sand. The report analysed the historical hydrographic survey and aerial photography. Comparison of 1993, 2006 and 2008 hydrographic surveys showed no significant shallowing trend in the offshore areas in the vicinity of the Queenscliff Pier. A review of the coastline from 1939 to 2007 showed a gradual progression of the coastline with movement of approximately 25 m offshore at the location of the Pier between 2001 and 2007.

- *Portarlington Beach Renourishment- Beach Monitoring (Oldfield Consulting Australasia, 2012)*

As a part of the ongoing program of Department of Sustainability and Environment for renourishment of beaches around Port Phillip Bay, BBFCoM engaged Oldfield Consulting Australasia to conduct monitoring of the renourished beach. The monitoring included regular level surveys over a period of 15 months starting in November 2012 over a beach length of 2 km between Portarlington Pier and Point Richards. The initial survey reported that the beach had a relatively flat slope of about 1 vertical to 50 horizontal. Within two months, the survey showed that beach slope had changed typically less than 4% from the baseline; however, the survey confirmed that sand was being transported offshore from the swash zone. Along the beach renourishment site, the total volume of sand was reported to be reduced by 0.4%. It indicated longshore transport towards west over the two-month period.

2.2.2 Flooding

- *Portarlington East Drainage / Flood Study, (BMT WBM, 2009)*

The City of Greater Geelong (CoGG) engaged BMT WBM Ltd. (BMT WBM) to undertake an assessment of stormwater flooding within the Portarlington East drainage catchments and to investigate the flood management options. The study identified the number of flooded properties for 1%, 5% and 20% Annual Exceedance Probability (AEP) for “within property” and “above floor level”. The study estimated a maximum of 334 properties will be inundated for a 1% AEP event and water will rise above the floor level in 12 properties for the same event. The report also produces Hazard mapping where safety is defined in terms of depth, velocity and velocity times depth product. The Portarlington Golf Course, the retarding basins between Fisher Street and Gellibrand Street, the retarding basin at Fairfax Street and Seaforth Drive in addition to the main drainage paths have been specified as unsafe in a 1% AEP flood. The study provided structural and non-structural mitigation schemes.

- *1920 Barwon Heads Road Coastal Vulnerability, Flooding and Stormwater Assessment, (BMT WBM, 2009)*

This study adopted 1.65 m above MSL as 100 year ARI (1%AEP) storm-tide level at Barwon Heads based on CCMA (2005). Given that the natural dune level and the levee level at the northern end of the Murtnaghurt Lagoon are at 3.0 m AHD, the study found that the property, 1920 Barwon Heads Rd is not likely not be inundated in present or future sea-level rise scenarios.

- *Barwon Heads Drainage Flood management Plan (WBM Oceanics 2005)*

The City of Greater Geelong (CoGG) engaged WBM Oceanics Australia (WBM) to assess stormwater flooding within Barwon Heads and to investigate flood management options. The study includes XP-RAFTS200 hydrological modelling and TUFLOW 2D hydraulic modelling to assess the existing flooding characteristics. The study identified the number of properties inundated above floor level for 5, 20 and 100 year Average Recurrence Interval (ARI). It was found that the 100 year ARI event is likely to inundate 61 properties above floor level. The downstream tail-water level in the Barwon River was set to 1.45 m AHD for all events. As a mitigation option, the report mentioned three mitigation schemes included structural and non-structural elements. The study also selected a preferred mitigation strategy through consultation with the City of Greater Geelong (CoGG).

- *Barwon River Estuary Flood Study (Corangamite CMA, 2005)*

This report looks at the occurrence and implications of a 1% AEP surge / flood event. The study adopted GHD (1997) 1% AEP peak tide level of 2.4 m AHD as the tail-water level which allow 0.2 m for expected greenhouse effect over 30 years. This level was achieved through joint probability of both astronomical and meteorological tide. The study used HecRas hydraulic modelling to determine the flood profiles for both 1% AEP tidal surge and 1% AEP catchment flows, however not the combination (i.e. joint probability) of the two. The study used 1,400 m^3/s as the 1% AEP peak flow at Lake Connewarre. It used the maximum of the tidal or river flows at cross-sections along the river. The adopted flood levels were the maximums from each.

- *Geelong Flood Mitigation Strategy (GHD, 1997)*

This was a broad-scale assessment of flooding from the confluence of the Barwon and Moorabool Rivers in Geelong through Lakes Reedy and Connewarre, to Barwon Heads. The study looked at the frequency of flooding, flood extents and risk, mitigation strategies and costs. The study found that improved flood warning, public education and development controls would reduce the flood risk into the future. It also recommended a levee be constructed at an industrial estate in South Geelong (Factories St. to Wood St.).

- *Newcomb – Whittington Drainage / Flood Study (BMT WBM, 2011)*

The City of Greater Geelong (CoGG) engaged BMT WBM to assess the stormwater flooding and to investigate the mitigations options for the Newcomb and Whittington areas of Geelong. The study used a RORB hydrological model and TUFLOW 2D hydraulic model. The report identified the existing flood characteristics for 20%, 10%, 5% and 1% AEP flood events. The number of properties inundated was assessed to be 2696 and 65 for “within property” and “above floor level” respectively for 1% AEP events. The report also presented the Hazard mapping for the same events. Properties located on Geelong – Portarlington Road west of Wilsons Road were identified to have unacceptable hazard levels in the 1% AEP event. Within the residential area, unacceptable hazard levels were reported to be contained within road reserves. The study provides a full range of structural and non-structural flood mitigation schemes and selected the preferred scheme through consultation with CoGG.

2.2.3 Geology and Geomorphology

- *Changes to the Coastline of Port Phillip Bay (Bird, 2011)*

This report gives a good overview of the historic development, processes and geomorphology of Port Phillip Bay, as well as the potential changes and shoreline responses due to climate change and sea-level rise.

- *Murtnaghurt Lagoon, Bellarine Peninsula & Related Landforms (Rosengren, 2009)*

This report details the geology and geomorphology of the Bellarine Peninsula, particularly the open coast.

- *Buckley Park Foreshore Reserve Murtnaghurt Lagoon, Bellarine Peninsula & Related Landforms (Rosengren, 2010)*

This describes the physical environment around the Buckley Park Foreshore region, from Ocean Grove to Point Lonsdale, including local geology and landscape development, geomorphology and coastal processes.

2.2.4 Climate Change and Sea Level Rise

- *The effect of climate change on extreme sea levels along Victoria’s coast (McInnes et.al., 2009a)*

This report was prepared by CSIRO for DSE as part of the Future Coasts Program. The report determines extreme surge and storm-tide levels for the coast and the hazard implications of these, in terms of inundation. It assesses current and future climate conditions and sea-level rise to determine at risk areas.

- *The effect of climate change on extreme sea levels in Port Phillip Bay (McInnes et.al., 2009b)*

This report is similar to the above, for the Port Phillip Bay area.

- *Victorian Coastal Strategy 2014 (Victorian Coastal Council, 2014)*

The *Victorian Coastal Strategy 2014 (previous Strategy versions 1997, 2002 and 2008)* is required under the *Coastal Management Act 1995* to provide long-term planning advice and directions for management of the Victorian coast for the next 100 years. Application of the strategy is a requirement within the State Planning Policy Framework for all coastal municipalities. The Victorian Coastal Council has identified five significant issues facing the coast that require specific attention. They are:

   – Managing population growth
   – Adapting to a changing climate
   – Managing coastal land and infrastructure
   – Valuing the natural environment

- Integrating marine planning

2.3 Key Data Sets

The key data sets used in this assessment include:

- Point Nepean wave data (PoMC)
- Tidal level data (PoMC, NTC and VRCA)
- DSE (DELWP) LiDAR (2007)
- DSE (DELWP) Bathymetry data (2009)

A number of additional wave and water level datasets exist and have also been utilised, however most are short term (less than two years), and therefore are used for confirmation and checking rather than model validation.

3 Coastal Processes & Environment Review

3.1 Evolution of the Bellarine Peninsula

Rosengren (2009, 2010) provides a detailed overview of the geology and geomorphology of the Bellarine Peninsula.

Deep drilling and geophysical surveys show that the Bellarine Peninsula has a basement of sedimentary rocks but also extensive areas of volcanic rocks which are buried by younger sediments. Sediments were deposited in river channels, floodplains and freshwater lakes about 100 million years ago and occur at the surface along the coastal slopes between Clifton Springs and Portarlington (Rosengren, 2010).

Over the last 20 million years the Bellarine has undergone complete or partial marine submergence on several occasions. The entire peninsula was inundated by the mid Miocene (23 – 5.3 million years ago) and the coastline was then situated as far inland as Meredith. The sea retreated during the Pliocene (5.3 – 2.5 million years ago) and left a thin deposit of sand behind. Following the tectonic uplift in the Pliocene, the coast between Torquay and Ocean Grove comprised a large funnel-shaped embayment, narrowing towards a wide channel that ran to Corio Bay. The embayment was shallow, with a floor of Tertiary (65 – 2.6 million years ago, mostly Miocene) sediments. Changing sea levels associated with the continued retreat of the sea constructed a series of small barriers and lakes throughout the embayment, resulting in the deposition of a series of dense shell beds and minor sands, which now underlie the Connewarre Lake system. During the last inter-glacial period, about 125,000 years ago, sea levels were generally about 6 m higher than present (Dahlhaus, 2010).

As a result of local tectonic uplift, the Bellarine Peninsula is an area of higher relief inside the Port Phillip Bay Sunkland. This uplifted area is dominated by a well-defined undulating low plateau and hills (less than 150 m elevation) of broad crests and gentle convex slopes with steeper slopes above some drainage lines (Rosengren 2009, 2011).

Rosengren differentiates three main terrain units, shown in Figure 3-1. These terrain units include:

- an eastern area between Leopold, Portarlington and Ocean Grove of undulating low hill and plateau, (near Bellarine Upland);
- a fringe of gently undulating sloping lowland enclosing Swan Bay (south east of Bellarine Upland);
- a broad area of lowland (Moolap and Connewarre Lowland) extending between Stingaree Bay at Geelong to the Bass Strait coast at Breamlea.

The development of the open coast side of the peninsula has seen periods of volcanic activity and deposition. Lava flows from Mt. Dundeed between 1 and 2 million years ago left a base formation of volcanic material that has underlain the present geomorphology near the Breamlea and Barwon areas. Fluvial processes subsequently shaped the lowland areas during low sea-level periods. During this time the Barwon River possibly met the ocean further east towards Ocean Grove. During the Holocene when sea-levels were higher, the ocean and Corio Bay re-established a seaway across the Moolap Lowland, first established during the previous interglacial period (Rosengren, 2009). Falling sea levels and sedimentation closed the seaway within approximately the last 5,000 year, and gave rise to the Barwon estuary, Reedy Lake and Lake Connewarre. The alternating sea levels formed natural levee systems, and has allowed Reedy Lake to develop as a freshwater wetland.

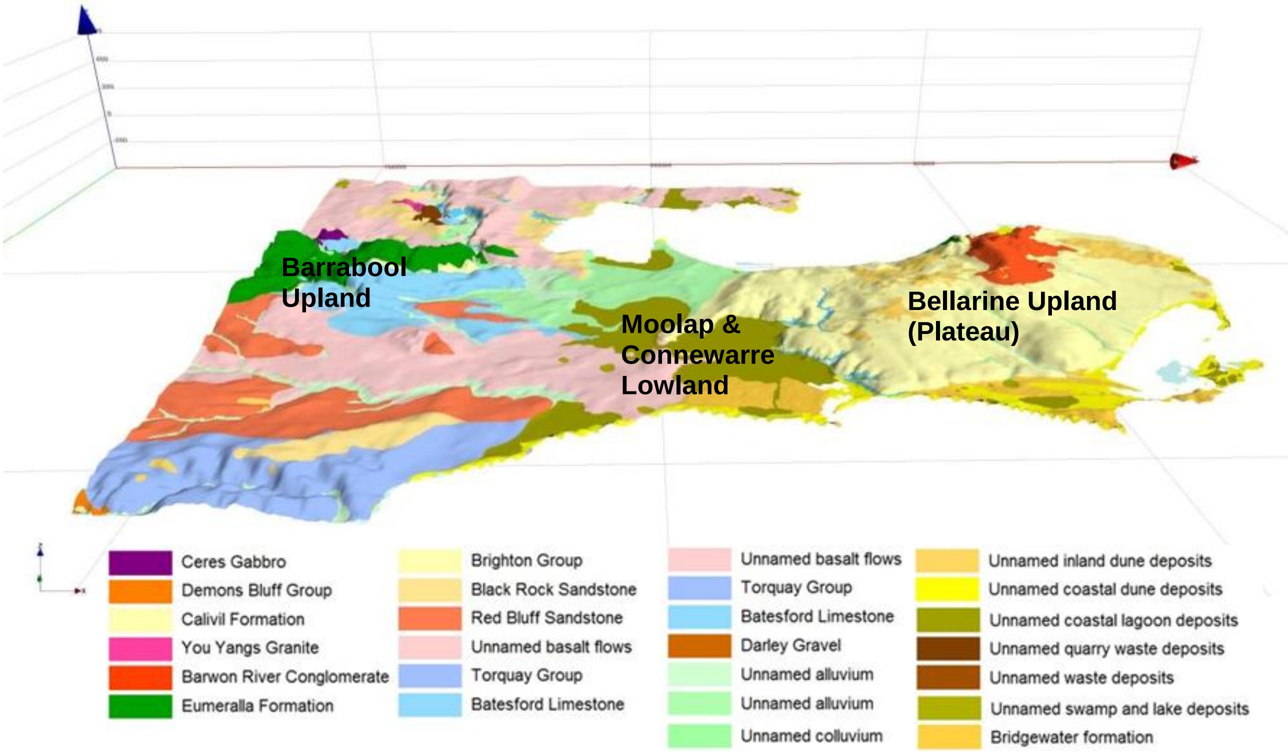


Figure 3-1 The geology of the Bellarine Peninsula, over a 3D digital elevation model (adapted from Dahlhaus, 2010)

Along the coast, the lowering of sea-levels and aeolian sedimentation led to the formation of the high calcarenite cliffs and lower ridges. Over time these were overlain by sand to form the dune formations that are present today. The calcarenite ridge would have restricted the flow of the Barwon River, until such time that the river was able to breach the ridge and form the estuary entrance closer to the current location. Refraction and sedimentation processes then began shaping the curved spit on the Ocean Grove side of the Barwon River. This allowed the formation of the large deltaic complex beyond the river mouth, which was subsequently colonised by mangrove and saltmarsh species. Evidence suggests that there has been some rapid sedimentation within Lake Connewarre within the last 150 years which has shallowed the basin significantly (Rosengren, 2009).

The dominant sediment transport direction along the Bass Strait coast is from the south-west to the north-east. This trend has shaped the shoreline into characteristic crescent shapes between ‘hard points’ (i.e. rocky outcrops, headlands) in some locations. The beaches are generally low angle sandy beaches backed by dunes which advance and recede in response to natural processes. During the site visit in April 2013, the foredunes appeared to be in an erosional trend, with scarped frontal dunes due to recent storm activity. The dunes have a calcarenite core in many locations; however, the depth at which it occurs within the dune is uncertain except where dune blow-outs have left the core exposed. Depending on location, the height of the dunes/cliffs can be greater than 20 m, and wider than 100 m.

Within Port Phillip Bay the study area coastline extends from east of Point Lonsdale to Point Wilson. The shoreline consists largely of soft rock shorelines, bluffs and cliffs lined with narrow sand and rocky beaches. The bathymetry is largely very shallow, especially in the vicinity of The Sands. This is the flood-tidal delta of the Port Phillip Bay entrance. The shoreline is largely modified and developed, and in some locations very low lying.

3.2 Contemporary Processes

The following sections detail the area-wide physical processes occurring within the study area based on the review of previous work. Note, no assessment of groundwater and cliff stability has been undertaken, nor the implications of climate change and sea-level rise on these processes; however, where necessary, recommendations are made in the conclusions (Section 7) to note that these issues may be relevant, and require further investigation.

3.2.1 Tides

The astronomical tides in the study area vary, with Bass Strait having semi-diurnal with a diurnal inequality, meaning there are approximately two tidal cycles each day; with one having a larger range than the other, whereas in Port Phillip Bay north of the Heads, the tides are classified as diurnal, with one major tidal cycle each day (definitions from ANTT, 2014). The change in tidal character results in different sets of tidal planes being used to describe the tides in the two areas. Hence, in Table 3-1, which displays the tidal planes at Lorne, Queenscliff and Geelong (ANTT 2013, and PoMC, 2013) referenced to AHD, there are different values for Lorne and for Queenscliff and Geelong which are inside the bay. The tidal range for the open coast is 1.8 m in the Bass Strait at Lorne. At Geelong, the tidal range is 0.9 m.

Table 3-1 Astronomical Tides (ANTT, 2013 & PoMC, 2013)

Tide	Lorne m AHD	Queenscliff m AHD	Geelong m AHD
Highest Astronomical Tide (HAT)	1.3		0.7
Mean High Water Spring (MHWS)	0.8		
Mean Higher High Water (MHHW)		0.5	0.4
Mean High Water Neap (MHWN)	0.4		
Mean Lower High Water (MLHW)		0.1	0.1
Australian Height Datum	0.0	0.0	0.0
Mean Higher Low Water (MHLW)		-0.1	-0.1
Mean Low Water Neap (MLWN)	-0.4		
Mean Lower Low Water (MLHW)		-0.4	-0.5
Mean Low Water Spring (MLWS)	-0.8		
Lowest Astronomical Tide (LAT)	-1.5		-0.6

Tidal data is available from a number of tide gauges owned by the Port of Melbourne Corporation (PoMC), Victorian Regional Channels Authority (VRCA) or National Tidal Centre (NTC), relevant to the study area, Table 3-2. The most relevant to this study are located at Lorne, Point Lonsdale, Queenscliff, Point Richards and Corio. This data was used to determine and confirm surge and storm-tide levels for the study area. Section 4.3.1 and Appendix A detail the methodology for determining storm-tide levels.

Table 3-2 Tide Gauges within the wider study area

Location	Owner / operator
Lorne	PoMC
Point Lonsdale	PoMC
Queenscliff	PoMC
Hovell Pile	PoMC
West Channel Pile	PoMC
Point Richards Beacon	VRCA
Corio #9 Beacon	VRCA
Fawkner Beacon	PoMC
Williamstown	PoMC
Portland	NTC

3.2.2 Wind

Bass Strait and Port Phillip Bay lie on the boundary between the westerly-wind belt of the southern hemisphere and the subtropical trade-wind belt. In summer, the trade-wind belt moves southward with the thermal equator and the belt of variable winds is also moved further south. Hence, the path of the pressure systems across Australia is further south in summer than in winter and, as the land areas heat and become low-pressure areas, winds near the earth's surface blow mainly from sea to land. Conversely, in winter, the land is covered by high pressure, and the winds blow mainly outward from land to sea. The impact of these systems on the study area is that in winter, June to August, the most prevalent winds are northerlies; while in summer, December to February, southerly winds, south east to south westerly are prevalent. Spring and autumn represent a transition between the two dominant seasons and the wind patterns are a mixture of the summer and winter patterns. Historical wind data has been obtained from the anemometer at Point Wilson Jetty, from 1991 to 2010. Annual and seasonal-average wind roses have been derived from the data, Figure 3-2. The same data are presented as frequency of occurrence in Table 3-3. The strongest winds are from the north and west. The most frequently occurring wind directions are the north, west and south.

Wind is a particularly important component within the Port Phillip Bay area as waves are fetch-limited, meaning they are generated by local winds and the wave height is limited by the distance over water that the wind can blow, i.e. the fetch.

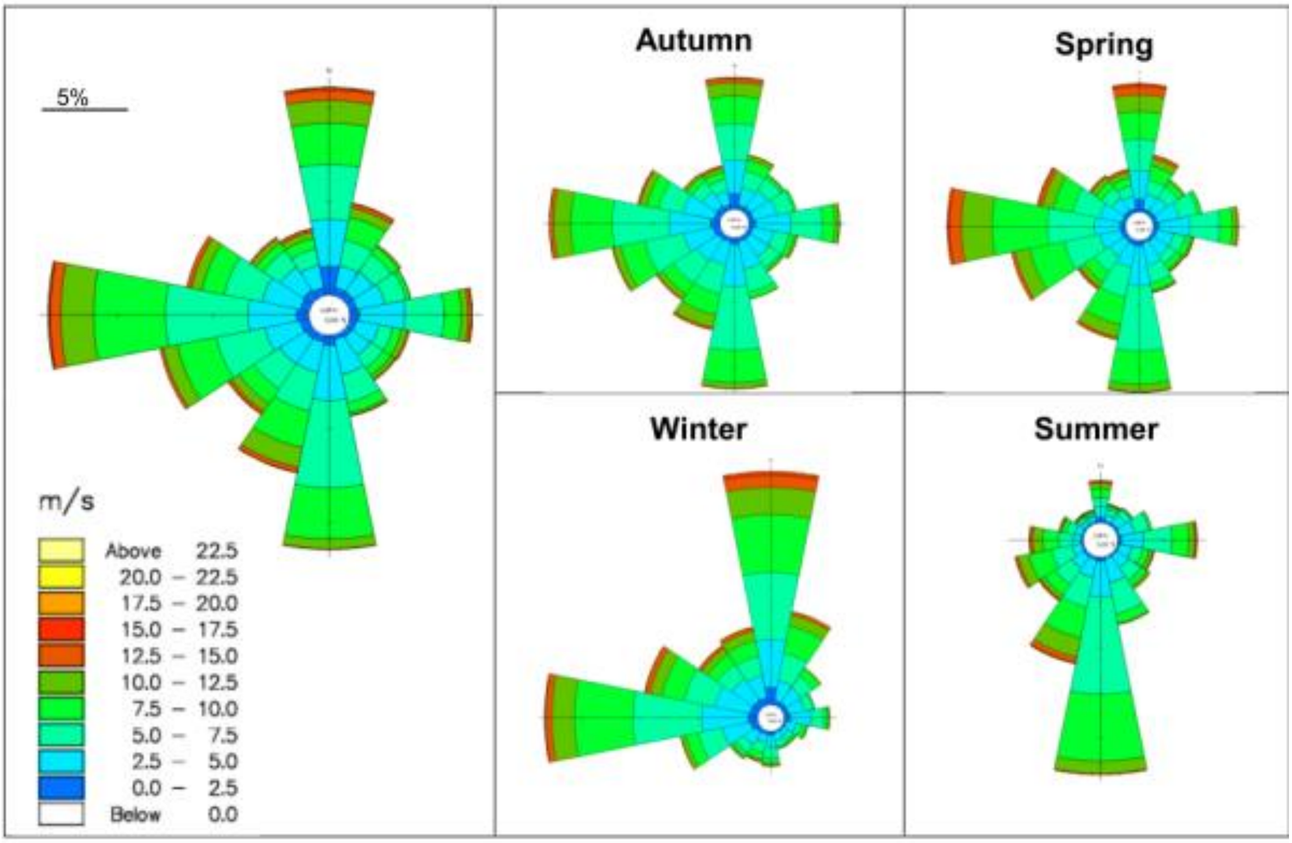


Figure 3-2 Point Wilson wind speeds and directions - overall and seasonally (1991-2010, BOM)

Table 3-3 Wind matrix showing percentage occurrence of speed and direction (1991-2010, BOM)

Direction (°)		Wind Speed (m/s)									Total (%)
		0.0+	2.5+	5.0+	7.5+	10.0+	12.5+	15.0+	17.5+	20.0+	
N	348.75 - 11.25	0.80	2.02	2.27	1.90	0.96	0.42	0.10	0.04	-	8.51
NNE	11.25 - 33.75	0.38	1.26	1.40	1.07	0.44	0.13	0.03	0.01	-	4.73
NE	33.75 - 56.25	0.45	1.34	0.97	0.41	0.09	0.01	-	-	-	3.26
ENE	56.25 - 78.75	0.76	2.61	1.89	0.55	0.11	0.01	-	-	-	5.94
E	78.75 - 101.25	0.30	1.52	1.28	0.68	0.30	0.10	0.01	-	-	4.20
ESE	101.25 - 123.75	0.23	1.25	1.04	0.54	0.23	0.05	0.01	-	-	3.36
SE	123.75 - 146.25	0.21	1.14	1.12	0.48	0.19	0.04	-	-	-	3.18
SSE	146.25 - 168.75	0.36	2.61	3.42	1.41	0.22	0.02	-	-	-	8.04
S	168.75 - 191.25	0.42	2.05	3.64	2.36	0.53	0.08	0.01	-	-	9.10
SSW	191.25 - 213.75	0.32	1.63	2.32	1.89	1.02	0.26	0.03	0.01	-	7.49
SW	213.75 - 236.25	0.30	1.46	1.56	1.04	0.46	0.14	0.03	0.01	-	5.00
WSW	236.25 - 258.75	0.56	2.75	3.87	3.32	1.40	0.39	0.06	0.01	-	12.36
W	258.75 - 281.25	0.35	1.77	2.43	2.19	1.14	0.36	0.07	0.02	-	8.33
WNW	281.25 - 303.75	0.40	1.86	1.91	1.32	0.71	0.26	0.05	0.01	-	6.52
NW	303.75 - 326.25	0.38	1.28	1.03	0.60	0.33	0.10	0.02	0.01	-	3.75
NNW	326.25 - 348.75	0.52	1.79	1.66	1.25	0.69	0.27	0.06	0.01	-	6.26
Bin Totals (%)		6.74	28.35	31.81	21.02	8.82	2.65	0.48	0.13	0.01	100.0
Exceedence (%)		100.0	93.26	64.91	33.10	12.08	3.26	0.62	0.14	0.01	

3.2.3 Currents

There is a significant reduction in the tidal range between Bass Strait and the body of the bay. The majority of this change takes place at The Entrance. Previous work on tidal currents throughout the bay was carried out as part of the Port of Melbourne Corporation Channel Deepening Project investigations (Cardno Lawson Treloar, 2007a).

The tidal currents show a marked variation in the bay with current speeds exceeding 3.5 m/s in Port Phillip Bay Heads, over 1 m/s in the South of the Bay channels, and generally below 0.2 m/s in the body of the bay north of the Sands. As a result, tidal currents are important to coastal processes and sediment movement in The Entrance and the Sands, but are less significant in other areas.

For the portion of the bay which is north of the Sands and adjacent to the study area, the tidal currents are weak with speeds of less than 0.2 m/s, with a slight increase in speed closer to the Sands. At CSIRO's Great Sands location, Walker (1997) reports tidal current speeds just above 0.1 m/s. Close to the Sands, the tidal currents increase near the northern ends of the channels and there are eddies created, particularly on the flood tide near the ends of Symonds Channel and to the north-east of Hovell Pile (Prytz & Heron, 1994).

Cardno (2011c) found that during storms, current magnitudes of approximately 0.3 - 0.6 m/s could occur at Point Richards, Point George and south of St. Leonards Pier.

Little previous work has been undertaken for the open coast in terms of hydrodynamics and no current measurements are available away from the Port Phillip Bay area and the Heads.

3.2.4 Waves

The wave climate varies throughout the study area, from smaller wind-generated waves in Port Phillip Bay, to larger Bass Strait swell waves along the open coast.

Within the bay, waves rarely exceed 1 m in height in the study area. However, with strong winds from certain directions, and depending on water depth, they are able to produce wave heights in excess of 1 m. Analysis of wind directions and frequency show that winds rarely occur from the direction of the greatest fetch (north-east), therefore the occurrence of waves from that direction is similarly infrequent. The presence of the Great Sands (Figure 3-5) limits the wave energy reaching the shoreline of the east coast of the Bellarine Peninsula. Similarly, in Swan Bay, the water depths are very shallow with large areas of seagrass. This results in a very low wave-energy environment.

Waves near the entrance to Port Phillip Bay have been studied in the past, and detailed models exist that have provided information relating to swell penetration through the entrance, as well as the effect of the flood and ebb currents on the entrance wave climate.

The open coast and Lonsdale Bight shoreline of the Bellarine Peninsula receive waves from Bass Strait. Measurements of the waves in Bass Strait have been made by PoMC at a site approximately 8 km south east of Point Nepean since 2003. The wave climate is dominated by swell with about 92% of the waves coming from the south south-west and south west with a most frequent direction of around 213° (Figure 3-3). This is the direction of waves that are able to propagate through the gap between Cape Otway and King Island from the Southern Ocean and arrive at the coast as swell. Waves with a significant wave height greater than 3 m come from a narrow directional band around the average direction. The largest waves occur when the local wind comes from the same direction as the swell. Some wind-waves come from the south south-east, but these are relatively infrequent.

The measured significant wave height reaches 6.4 m, with at least 50% of the waves being between 1 and 2 m. The average significant wave height over all seasons at this location is 1.7 m. Seasonally, the average wave height drops to 1.6 m in summer and autumn and returns to 1.7 m during winter and spring. The dominant spectral-peak wave period is between 10 and 16 s with an average period of 12.8 s. The average varies from 11.7 s in summer to 13.6 s in winter.

The wave climate changes along the open coast (Bass Strait) of the study area depending on:

- distance west from Port Phillip Bay Heads as the wave heights generally decrease towards the west due to sheltering by Cape Otway and refraction of the waves in towards the coast;
- the location of offshore banks;
- the orientation of the shoreline in relation to the dominant swell direction; and,
- where headlands provide shelter in relation to the dominant swell direction.

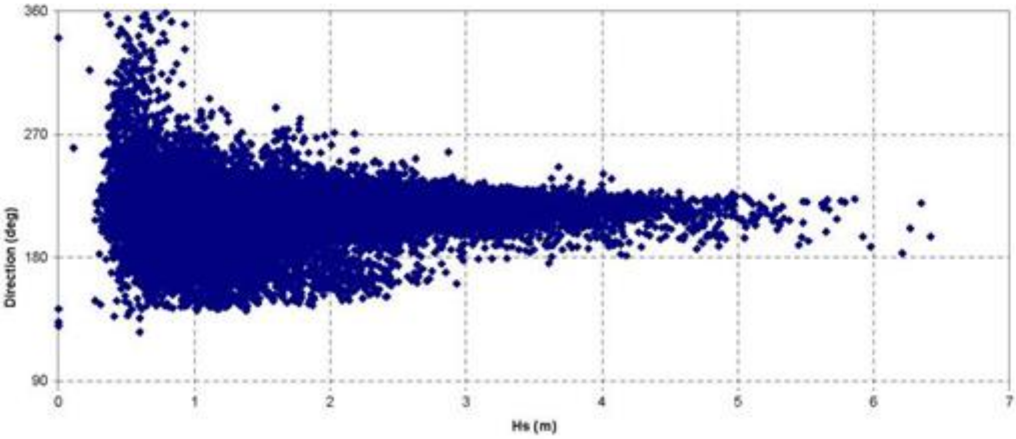


Figure 3-3 Wave direction vs. significant wave height (H_s) at the PoMC Point Nepean wave buoy (Cardno, 2011a)

Thirteenth Beach and the Buckley Park coast are almost perpendicular to the dominant wave direction, and experience the highest wave conditions within the study area. Rocky outcrops and shore platforms offer some protection to certain parts of the shoreline. Ocean Grove and the Barwon River entrance are sheltered by Barwon Head. The wave modelling and determination of design wave conditions for this assessment are presented in Section 4.3.2.

3.2.5 Storm Surge

Storm surges occur during storm events where meteorological forcing of wind, atmospheric pressure and wave set-up leads to an increase in sea-level over a number of days. Subtracting the predicted water-level variation due to the astronomical tide from the observed water-level record determines the tidal residual. This provides an estimate of the magnitude of the meteorological component in the observed water-level variations. Positive tidal-residuals are commonly referred to as storm surge.

The meteorological forcing can cause very long period waves to move across the ocean and, in particular, along the edge of continents where they interact with the continental shelf to form “shelf waves”. There are a number of types and propagation modes for such waves and all involve a variation in sea level at the coast. Since all these mechanisms combine to make up the water-level variations other than the astronomical tides, they have been grouped under the term storm surge in this report since their combined effect will be greatest during a storm event. CSIRO determined surge heights under various exceedance probabilities (McInnes *et. al*., 2009a,b). This was done for a number of locations along the Bass Strait coast (where tide gauges exist) as well as twelve locations in Port Phillip Bay, from Point Lonsdale to Sorrento. Relevant locations for this study include Lorne on the open coast and Point Lonsdale, Queenscliff and Geelong within the bay.

Figure 3-4 shows the 1 in 100 year (i.e. 1% AEP) surge heights for Port Phillip Bay and the Bass Strait coast. These levels were determined through hydrodynamic modelling of surge events, forced with wind and atmospheric pressure. The data set used to determine these values was for 38 years from 1966 to 2003, therefore an extremal analysis was undertaken to obtain values for the less frequent surge events.

A combination of large positive tidal-residuals with high astronomical-tides results in extreme water-levels. This is termed a ‘storm-tide’. Values of extreme storm-tide levels for the study area are discussed in Section 4.3.1.

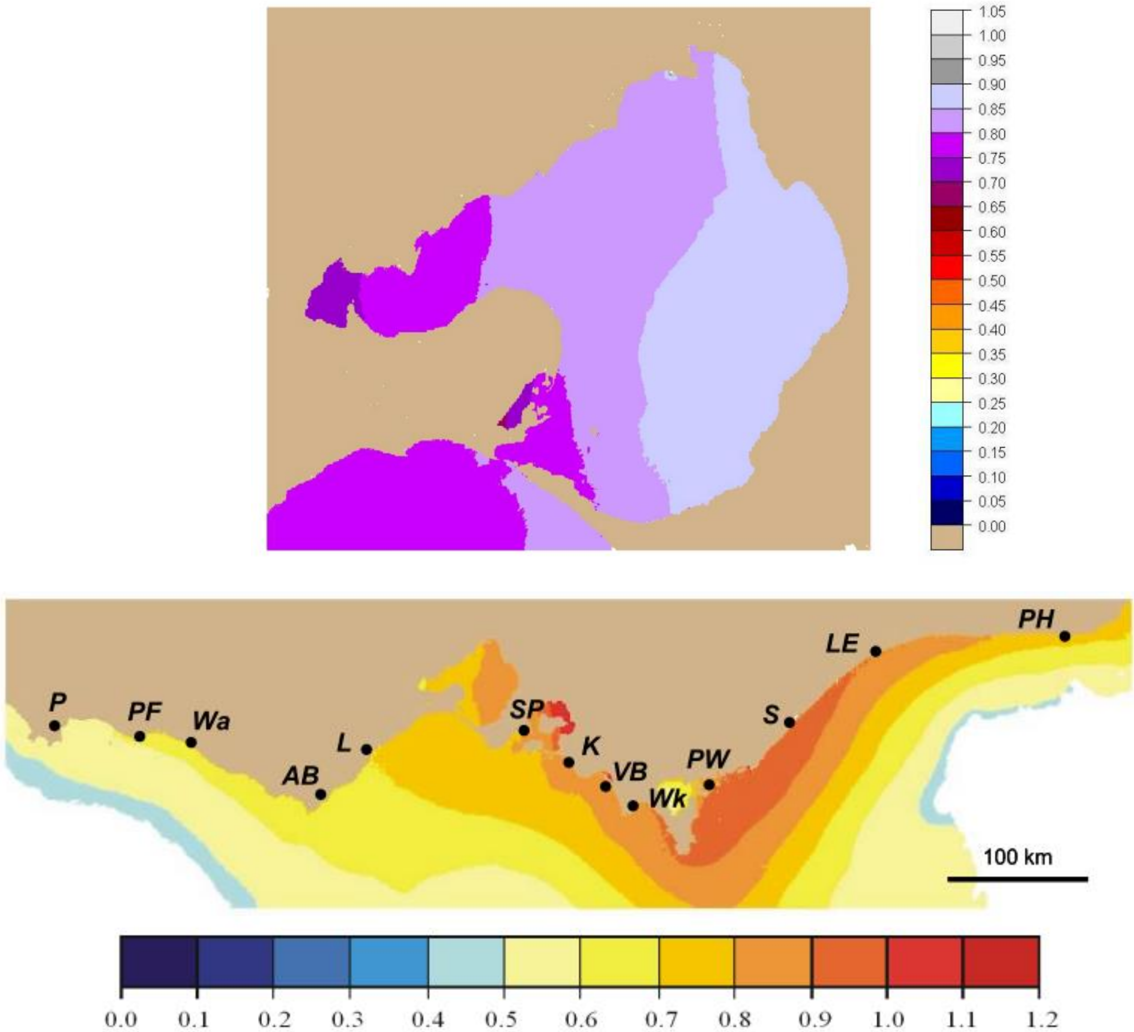


Figure 3-4 Spatial pattern of the 1 in 100 (1% AEP) year storm surge height for Port Phillip Bay and Bass Strait (McInnes *et.al.*, 2009a,b)

3.2.6 Bathymetry

The entrance of Port Phillip Bay is a region of extremes, with the bathymetry including a 100 m deep canyon and relatively shallow banks. Water entering or leaving Port Phillip Bay thus flows over areas of greatly varying depths and the result is a highly turbulent flow with large eddies. The area is characterised by very strong tidal-currents and sometimes very rough wave conditions.

Immediately behind the entrance is the Great Sands. The major features of the entrance and Great Sands, including the channels, are shown in Figure 3-5. Due to the size and shallow bathymetry of the area, the sands dampen any wave activity approaching through the entrance and also result in any locally derived wind waves being depth limited.

The open coast bathymetry consists of a low angle sandy substrate with rocky reefs scattered offshore of the cliffed areas.

Little information is available to describe the nature of the seabed and bathymetry, the LADS DEM of the bathymetry is presented in Figure 3-6.

Figure 3-5 Great Sands (Cardno, 2011b)

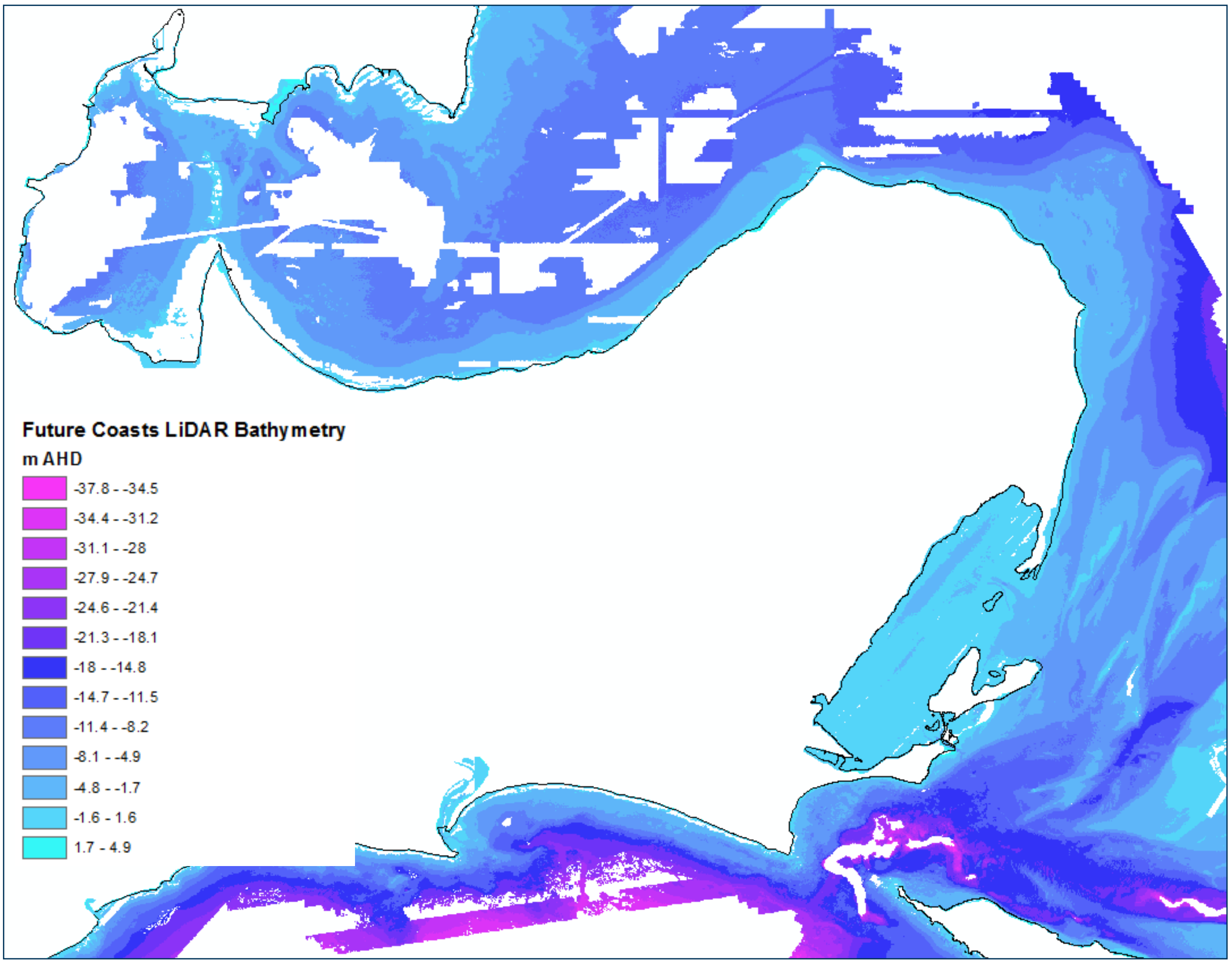


Figure 3-6 2008 Future Coasts LADS bathymetry DEM (NB. white space offshore indicates data gaps)

3.2.7 Sediments

Sediment samples were taken along the open coast beaches during the April 2013 site visit, from the dune and swash zone of the beach, at sites shown in Figure 3-7. Sediment samples are analysed to determine the particle size distribution, which contributes to the erosion assessment by factoring in the 'moveability' of different grain-sized material.

Generally, sediment grain-sizes range from coarse to fine sands depending on the location within the study area (Table 3-4 and Figure 3-8). For the open coast, samples containing the most fines were taken from the dunes near the Ocean Grove Spit and Ocean Grove Main Beach. It is likely that some of the finer material at these locations has been sourced from the estuary. The coarsest samples are located near Point Lonsdale, Thirteenth Beach and Breamlea. These are the highest energy locations, and where there are eroding cliffs. The Ocean Grove Spit swash sample is also relatively coarse, possibly due to proximity to the bluff.

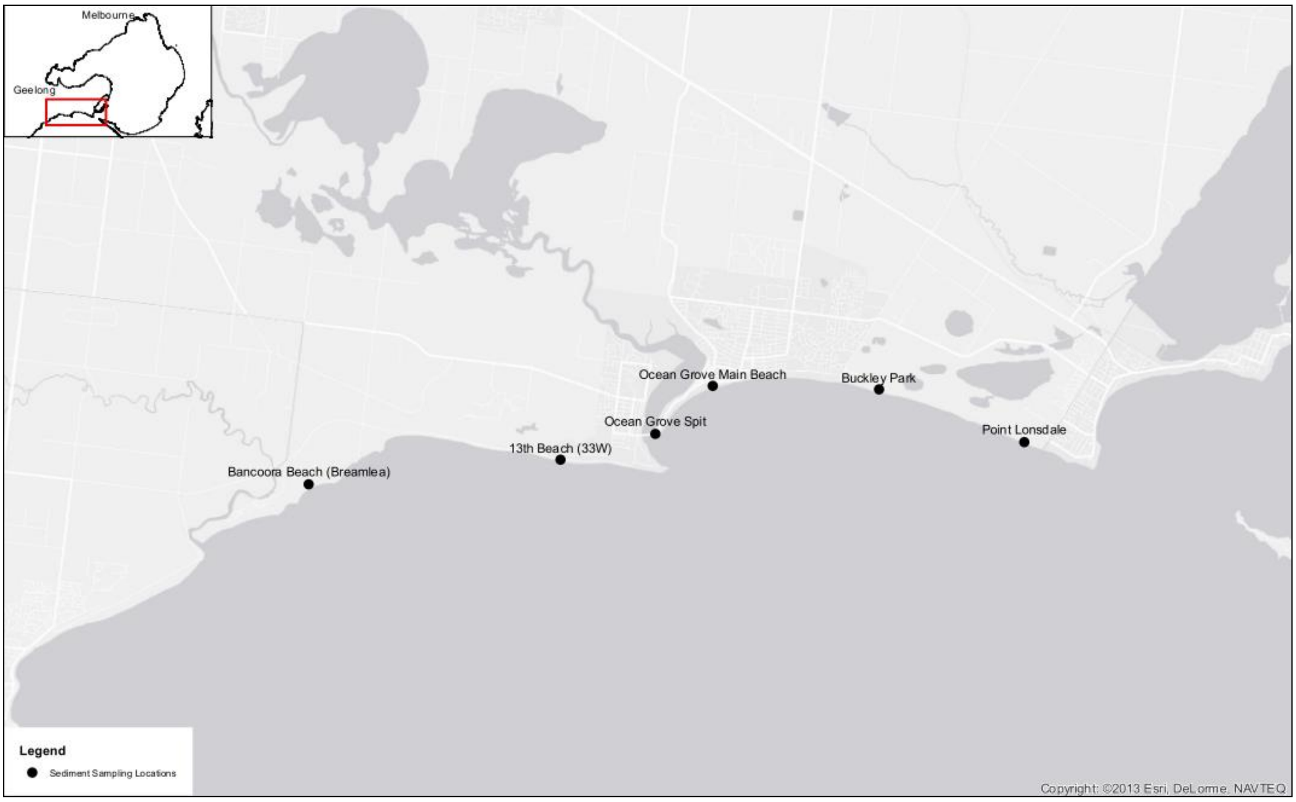


Figure 3-7 Sediment samples locations

Table 3-4 Sediment sampling

Beach location	Location
Swash	Point Lonsdale – dune blowout & cemented dune area
Dune	
Swash	Buckley Park Foreshore
Dune	
Swash	Ocean Grove Main Beach
Dune	
Swash	Ocean Grove Spit
Dune	
Swash	Thirteenth Beach (33W marker sign post)
Dune	
Swash	Bancoora Beach (Breamlea)
Dune	

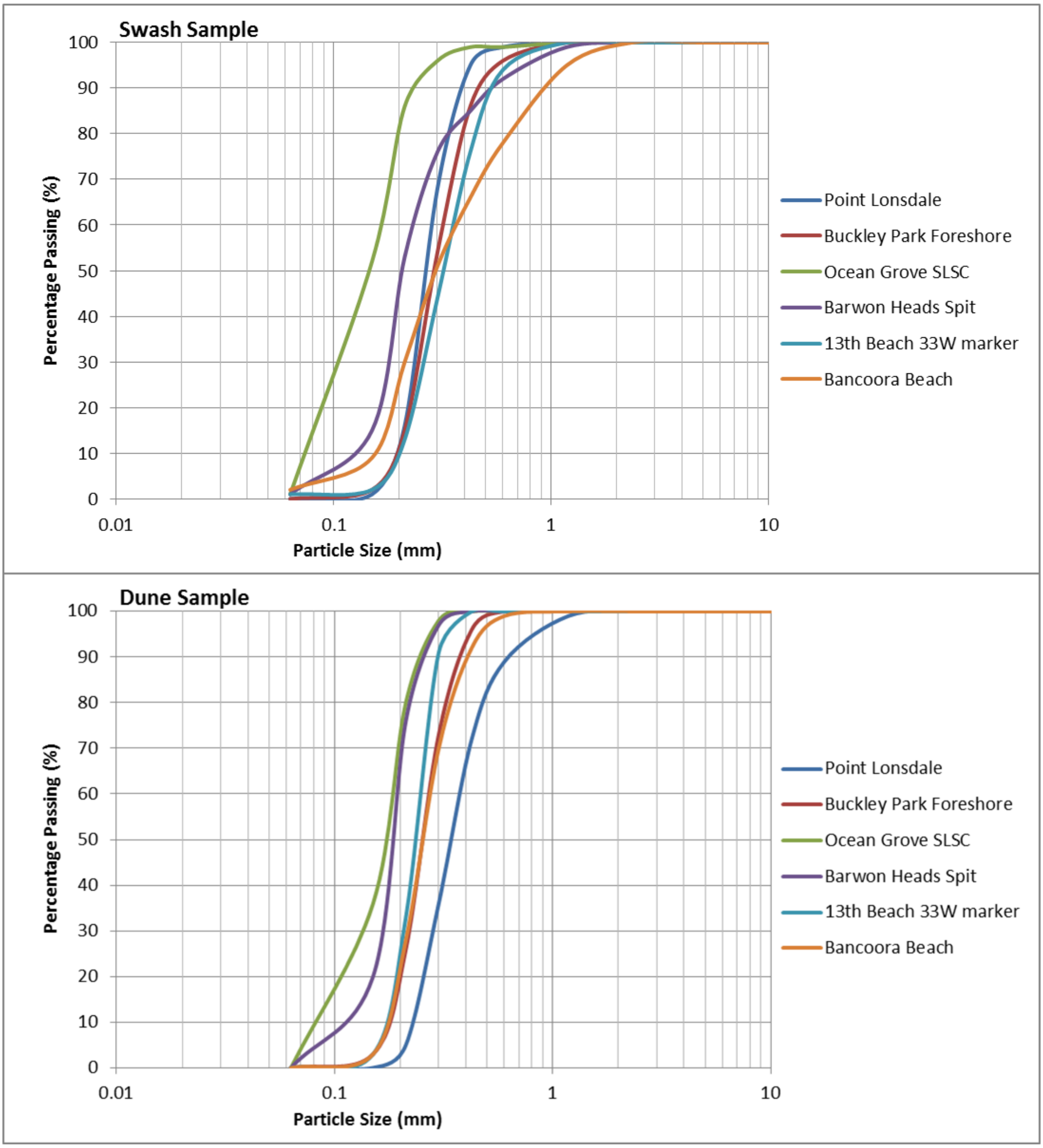


Figure 3-8 Open coast sediment grain sizes for dune and swash zones

Sediment analyses have been undertaken previously for areas within Port Phillip Bay. Generally, the grain size differs quite markedly from location to location as shown in Figure 3-9 and Table 3-5.

Figure 3-9 Sediment sample and profile locations and net sediment transport directions (Cardno, 2011c)

Table 3-5 Grain sizes (D_{50}) for Port Phillip Bay beaches (Cardno, 2011c) - location points on Figure 3-9.

Location	Location Point	Grain size (mm)
Geelong	n/a	0.13
Ramblers Road	2	0.54
	4	0.97
	5	0.97
	7	0.71
	9	0.71
Esplanade, Portarlington	13	0.52
	15	0.27
	17	0.41
	19	0.65
Indented Head	20	0.65
	22	0.25
	24	0.41
	25	0.41
	26	0.41
	27	1.03
	29	0.43
	30	0.43
Salt Lagoon	33	0.24
	34	0.24
	36	0.27
St Leonards	38	0.30
	39	0.30
	41	0.28
	42	0.28
	43	0.28
	45	0.24
	46	0.24

3.2.8 Sediment transport

Sediment transport near the entrance to Port Phillip Bay (The Entrance) has been studied previously (Cardno, 2011b). Sediment is moving along the Bass Strait coast from west to east and it is estimated that approximately 400,000 m³/yr of sand reaches Point Lonsdale from the west. This value was estimated using expert judgement, knowledge of the area and the yearly volumes of sediment dredged from The Cut at Queenscliff. The source of this material is likely to be a combination of beach-dune erosion in the study area and areas further west of the study area through the dominant sediment transport pathway. Material is also likely to come from offshore, as well as riverine inputs.

Approximately half of the 400,000 m³/yr is thought to be carried offshore by the ebb tide or into the Entrance Deep. There are then two pathways for sand moving into the bay from Point Lonsdale. It is estimated that between 50,000 and 80,000 m³/yr are moved by wave-generated longshore currents along the beaches of Lonsdale Bight. A further volume of the same order is moved across Lonsdale Bight outside the surf zone, but in depths of less than 15 m under the action of the tidal currents and waves. There are obviously much larger gross movements, but this is an estimate of the net annual movement.

The sand transported across Lonsdale Bight offshore is assumed to be carried by the tidal currents with additional sediment put into suspension by wave activity. The sea bed in a large proportion of this area is rocky with a veneer of sand (Vantree, 1998), suggesting that the energy available for sediment transport exceeds the sediment supply. This reduces the sensitivity of the transport to small changes in the energy.

When the sand reaches Shortland Bluff, some is carried further north within the littoral system to Queenscliff Creek where dredging records indicate an accumulation of approximately 82,000 m³/yr (unpublished records, Parks Victoria, 2006). Some of the sand reaching Shortland Bluff is likely to be carried further into the bay by tidal streams and longshore currents, some will be carried out into the deeper water by the ebb tide currents and eventually out of the bay. The estimated patterns of sediment transport through the heads are indicated in Figure 3-10.

Much of the sand which heads north past Queenscliff probably makes its way into the Great Sands, and some of this would move on to the beaches of the north east Bellarine Peninsula. There is little natural accretion evident along the majority of the beaches within the bay, which would imply that sand is shoaling with minimal transport to local beaches. There is little evidence to support significant accretion of the Great Sands themselves. This sand may be available to supply nearby beaches with SLR, however at present there is no evidence that the dominant wave directions are able to facilitate this. The dredging at Queenscliff and pumping to the southern shore of Swan Island (a sink) also contributes to the lesser volume of sand able to be transported north during the summer.

Sediment transport along the St. Leonards and Portarlington shorelines was assessed as part of the Bellarine Coastal Process Study (Cardno 2011c). The net sediment transport directions are shown in Figure 3-9.

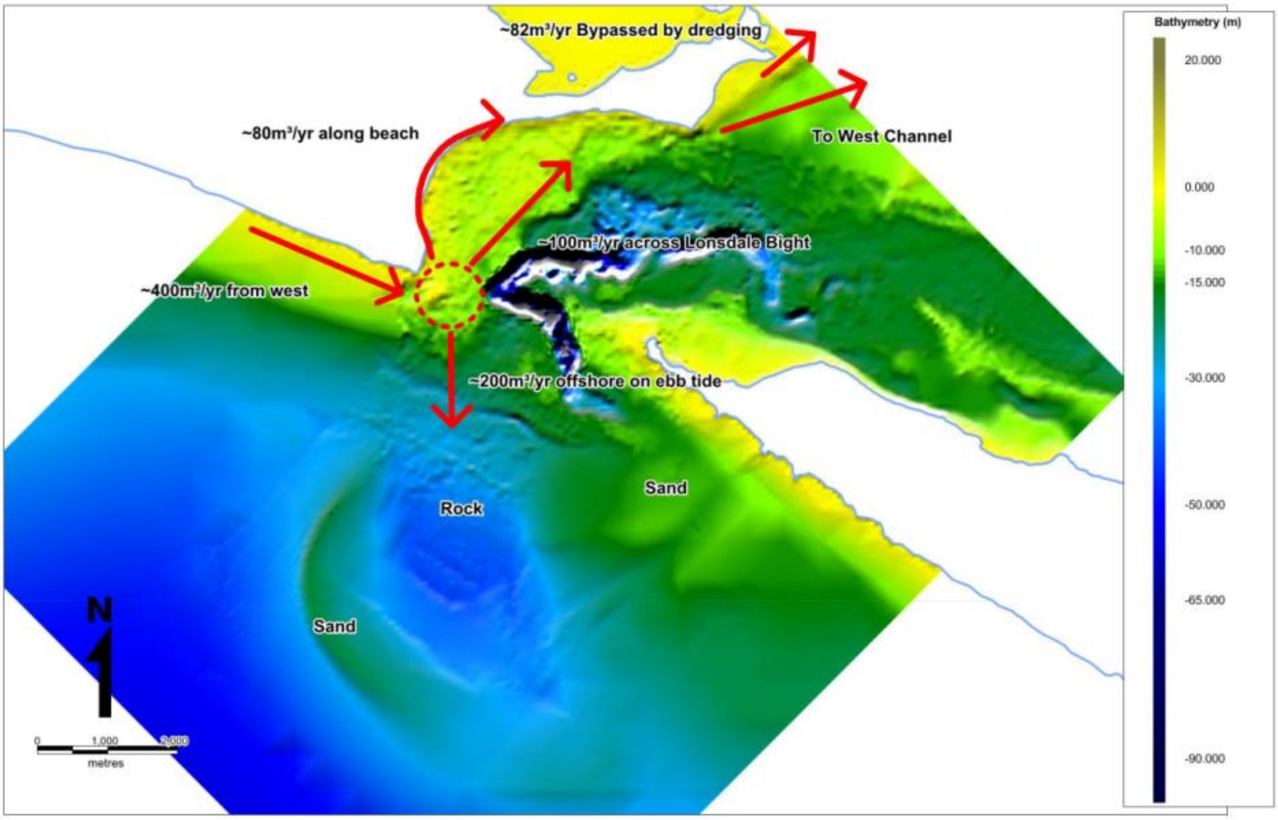


Figure 3-10 Sediment transport near the entrance of Port Phillip Bay (Cardno, 2011b)

3.3 Climate Change

Dealing with the effects of climate change will arguably be the biggest challenge coastal managers will face in the future. The effects of climate change are already becoming apparent, and will increase over time. There are four key climate-change related impacts that will affect the coastal environment:

- sea-level rise;
- increasing storm activity;
- increasing rainfall and catchment flows; and

- increasing groundwater tables.

The Intergovernmental Panel on Climate Change (IPCC) is the international scientific body that compiles and evaluates global studies on climate change. The fourth assessment by the IPCC was released in 2007 and gave information on global warming related to emissions scenarios, and particularly relevant is the advice and guidance on projected sea-level rise. The IPCC projected sea-level rise of between 0.18-0.59 m by 2090-2099 in this assessment. However, the upper values of sea-level rise (e.g. 0.59 m) projected by the models were not considered to be upper bounds of possible sea-level rise by 2099. The fifth assessment by IPCC was released late in 2013. This gives a range of values for each Representative Concentration Pathways (RCP) scenario that relates to estimated global temperature increases. Estimates for the low RCP scenario are 0.26 - 0.54 m by 2100, whilst the highest RCP scenario estimates a rise in sea-level of between 0.53 - 0.97 m by 2100.

With the majority of the Australian population living within close proximity to the shoreline, the implications of sea-level rise are numerous and varied. The first pass national assessment of climate change risks (DoCC, 2009) identified assets to a value of approximately $63 billion at risk with a static water-level increase of 1.1 m. The second-pass Future Coast assessment (Lacey & Mount, 2011) used a static inundation modelling method to determine potential inundation extents under various sea-level rise scenarios. Static inundation modelling uses known water-levels and topographic elevations to determine potential maximum inundation extents. This is a relatively simple method and provides an indication of inundation, but includes significant uncertainty.

Work done recently by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has furthered the knowledge of climate change and sea-level rise risk in Australia. In Victoria, relevant reports include two CSIRO reports that detail the effects of climate change on extreme sea-levels for the Victorian Coast and Port Phillip Bay (McInnes *et. al.*, 2009 a,b).

At present, research into wave height increases in response to climate change has been inconclusive; therefore no increase in the magnitude of future storms has been incorporated in this study.

3.3.1 Sea-Level Rise

Climate change implications on the coast are mostly in relation to rising water-levels. This is a complex process that is thought to be the result of naturally fluctuating global temperature variations, exacerbated by anthropogenically induced global warming. Increases in greenhouse gases result in increases in global temperatures (the greenhouse effect), and the heat causes water to expand. The increase in temperatures also results in the melting of ice caps. The overall effect is an increase in static water-levels in most coastal areas of the world.

Although varying degrees of confidence relating to climate change projections exist, long-term tide gauge records around the world have shown steady increases in static water-levels over the last 50 to 100 years which should be considered and planned for regardless of the climate change debate. In Victoria, recent measured net rates of sea-level rise have ranged between approximately 1.3 and 2.8 mm/yr (http://www.bom.gov.au/oceanography/projects/abslmp/reports_yearly.shtml). However, as the effects of global warming become more apparent, the rates are expected to increase, especially toward the end of this century. Thus, the IPCC sea-level rise estimates vary depending on differing emissions and temperature scenarios, which in turn results in a very wide range of sea-level rise estimates that need to be considered in hazard assessments. For the purpose of this study, six sea-level rise benchmarks have been considered to ensure the wide range of sea-level rise scenarios are considered, these are 0.0 m, 0.2 m, 0.5 m, 0.8 m, 1.1 m and 1.4 m relative to 1990 levels. The amount of sea-level rise that has occurred since 1990 has not been removed from the benchmarks for this study.

A key difference between this study and others carried out in Australia is that the year that the sea-level rise benchmark is likely to occur has not been stated. The aim of this is to avoid tying the scenarios to a given time in the future, but rather to say that if a given amount of sea-level rise occurs, this will be the consequence. This allows some flexibility with future assessments, but also removes some of the uncertainty associated with having a line on a map that states the shoreline may be in a certain place at a certain time. For locations where more comprehensive background data sets exist, this may be appropriate; however, given the levels of certainty within this study, it is not considered the best approach.

4 Study Investigations

4.1 Compartments

The study area includes the entire Bellarine Peninsula and the northern side of Corio Bay, from Point Wilson in the north, to Breamlea in the south.

The study area was divided into compartments based on the geomorphology and observed processes. An outline of the study compartments was presented within the project brief. It was necessary to reassess these on a local scale based on the local topography, control structures and potential flooding. The localised study compartments for each area are indicated in Figure 4-1 and Table 4-1.

The key locations and/or sub-locations were identified within each coastal compartment based on stretches of the coast separated by:

- a river or creek entrance, or headland, which formed a clear boundary;
- a difference in substrate e.g. rocky shore compared with sandy;
- a section where the wave or wind climate direction is likely to be significantly different to the adjacent;
- differing rates of change compared with the surrounding shoreline e.g. due to beach renourishment or other localised modification;
- long sections of wall or revetment protecting the shoreline.

4.1.1 Identification of Hazards and Determining Priority

A brief scoping exercise was undertaken during the initial phase of the project to identify issues and areas of concern to enable the prioritisation of the assessment. The original methodology was refined to ensure the most appropriate methods were undertaken to deliver the desired project outcomes.

Table 4-1 shows the key features which have distinguished the location and sub-locations for each compartment. Where there is no significant difference in geomorphology the compartment locations are differentiated by the dominant coastal processes in the vicinity, e.g. the shoreline may be orientated so that the dominant wave direction is different from the adjacent; therefore the boundary or forcing conditions would be different. Table 4-1 notes the likely hazards in the area, as well as some of the key assets near the shoreline that may be impacted in future. These include public and private property, infrastructure e.g. roads, water, sewerage and services such as power and telephone lines.

Generally, the priority is based on the proximity of assets and information received from stakeholders. The high-priority areas are often where numerous assets are located near the shoreline, or areas of low-lying land. Areas of moderate priority may also have assets, however fewer in number, or may be areas of habitat or cultural significance. The low-priority areas are generally low-use areas with little development or assets, and/or which are unlikely to be impacted significantly.

Note, the priority descriptions do not translate to the risk for nearby assets. The scope of this project is to identify hazards, especially in the vicinity of assets that may potentially be affected, rather than determine the risk. This will carried out in subsequent projects.

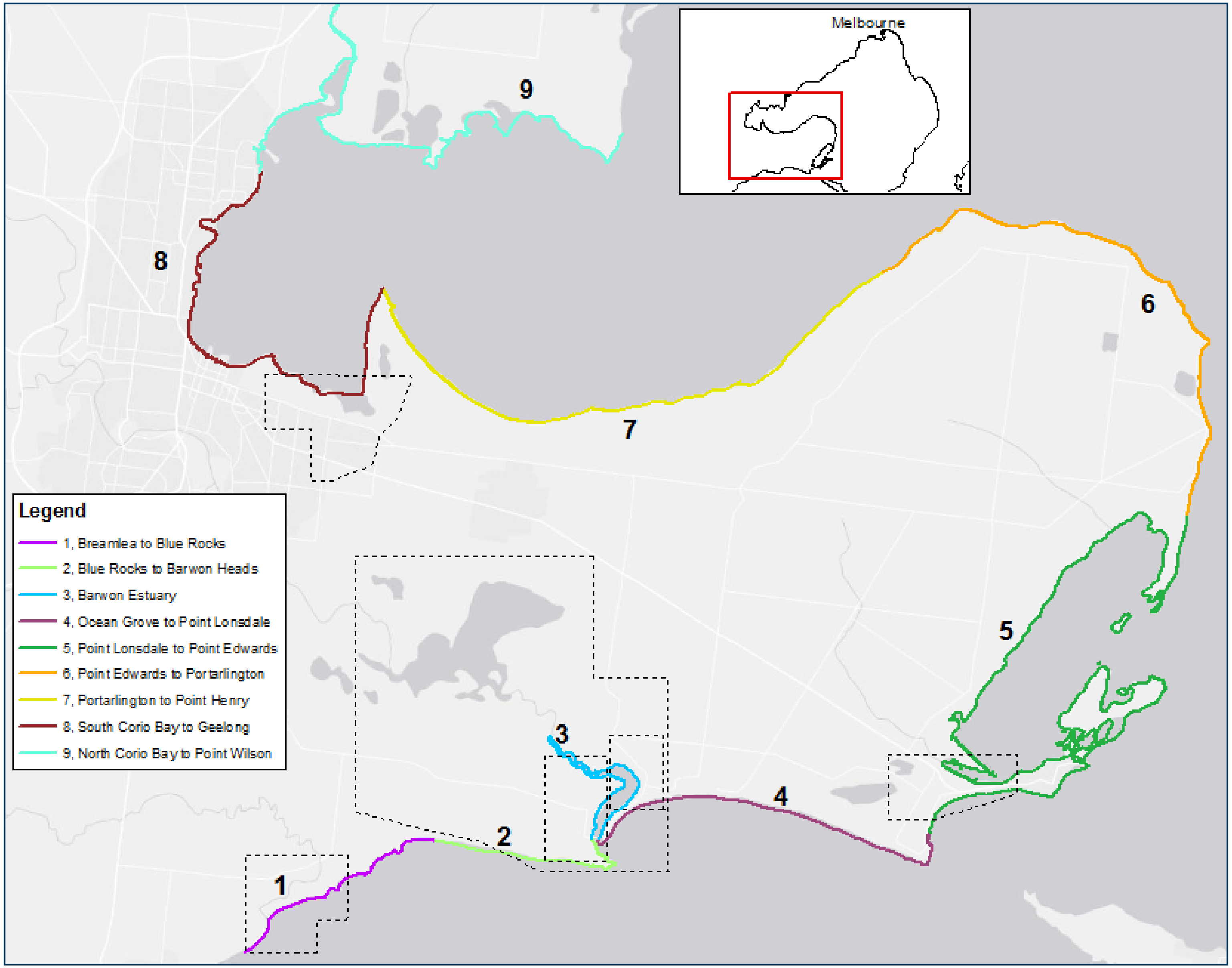


Figure 4-1 Study Compartments and inundation hydrodynamic model (SOBEK) grid boundaries

Table 4-1 Study compartments, issues, assets and priority (Note: SW - Stormwater; PW - Potable Water)

<table>
<tr><th rowspan="2">Compartment</th><th rowspan="2">Location</th><th rowspan="2">Sub-location</th><th rowspan="2">Features for division</th><th rowspan="2">Key issues</th><th colspan="2">Nearby Assets</th><th rowspan="2">Priority</th></tr>
<tr><th>Public</th><th>Private</th></tr>
<tr><td rowspan="5">1. Breamlea to Blue Rocks</td><td rowspan="2">Thompson Creek</td><td>Thompson Creek and Entrance</td><td>Estuarine creek area to be flood modelled</td><td>Inundation
Erosion</td><td>Saline habitat, dunes (open coast)
Infrastructure - roads, Stormwater (SW) , Potable water (PW), beach accesses
Services - Electricity, Gas</td><td>Residential properties
Agricultural land</td><td>High</td></tr>
<tr><td>Breamlea Beach</td><td>Open coast sandy beach</td><td>Erosion</td><td>Dunes
Infrastructure - roads, car parks, SW, PW, beach accesses
Services - Electricity, Gas</td><td>Residential properties
Agricultural land</td><td>Medium</td></tr>
<tr><td rowspan="2">Surf Club Lane</td><td>Buckleys Bay</td><td>Could be considered a pocket beach as located between two rocky outcrops – potentially limiting longshore drift. Foreshore is combination of sand and cobble / boulder sized volcanic rocks.</td><td>Erosion</td><td>Dunes
Caravan park
Services - Electricity, Gas</td><td></td><td>Medium</td></tr>
<tr><td>Bancoora Beach</td><td>Sandy beach located between two rocky outcrops, with sandy shore.</td><td>Inundation (potential breach)
Erosion</td><td>Dunes
SLSC and tower
Infrastructure - roads, car parks, SW, PW, beach accesses
Services - Electricity, Gas</td><td>Agricultural land</td><td>High</td></tr>
<tr><td colspan="2">Black Rock Road</td><td>Rocky shoreline, no sandy beach</td><td></td><td>Sewerage outfall</td><td></td><td>Low</td></tr>
<tr><td>2. Blue Rocks to Barwon Heads</td><td colspan="2">13th Beach</td><td>Long stretch of sandy beach, some calcarenite outcrops</td><td>Erosion
Potential future breach</td><td>Dunes
SLSC
Infrastructure - road (in very close proximity to dune scarp), car parks, SW, PW, beach accesses</td><td>Golf course
Residential properties</td><td>High</td></tr>
</table>

Compartment	Location	Sub-location	Features for division	Key issues	Nearby Assets: Public	Nearby Assets: Private	Priority
					Services - Electricity, Gas		
3. Barwon Heads, Barwon Estuary and Lake Connewarre	West Bank (Barwon Heads township)		Heavily populated western shoreline of the lower estuary, with multitude of differing shoreline protection methods.	Overwashing Overtopping (outer channel only) Inundation	Saline habitat Shore protection structures Foreshore reserve Caravan park & football oval Village Park Infrastructure - roads, bridge, car parks, SW, PW, beach accesses, boat ramps Services - Electricity, Gas	Golf course Wildlife Sanctuary Residential properties Commercial properties	High
	East Bank (Ocean Grove)		Heavily populated eastern shoreline of the lower estuary, with some differing shoreline protection methods and natural shoreline	Overwashing Inundation	Saline habitat Shore protection structures Caravan park, camping area Infrastructure - roads, bridge, car parks, SW, PW, beach accesses, boat ramps, sewerage Services - Electricity, Gas	Residential properties Commercial properties Equestrian centre	
	Lower Barwon		Similar to the east and west bank, however modelled in combination at a coarser resolution.	as above	as above	as above	
	Lake Connewarre		- Natural river / estuary shoreline - Less tidal influence	Riverine flooding	Saline habitat Weir structure Infrastructure - roads, SW, PW Services - Electricity, Gas	Residential properties Commercial properties Agricultural land	
4. Ocean Grove to Point Lonsdale	Ocean Grove		Long sandy beach – note section of vertical seawall at SLSC that will result in different rates of erosion from the adjacent beaches,	Erosion + scour Overtopping	Dunes - steep scarps in some areas Shore protection structure	Residential properties	High

Compartment	Location	Sub-location	Features for division	Key issues	Nearby Assets		Priority
					Public	Private	
			particularly related to scour (toe and terminal). Grants lookout - some cliff erosion and possibly runoff issues. Rock revetment near 13W		Foreshore reserves SLSC Infrastructure - roads, car parks, SW, PW, beach accesses Services - Electricity, Gas	Commercial properties	
	Barwon Coast / Buckley Park		Long stretch of sandy beach – however dune area consists of aeolian sediments, calcarenite outcrops and some cemented sections of sand dune.	Erosion Cliff instability	Dunes Shore protection structures Foreshore reserves – Buckley Park Infrastructure - roads, car parks, SW, PW, beach accesses Services - Electricity, Gas	Residential properties Commercial properties	Medium
5. Point Lonsdale to Point Edwards	Lonsdale Bight	Cliffs	More significant as a geotechnical hazard area	Erosion Cliff instability	Lighthouse Infrastructure - roads, car parks, SW, PW, beach accesses Pier	Toc H Camp	Medium
		Vertical Wall + groynes	Similar processes, however differing shoreline protection methods likely to have a marked difference in cross and longshore sediment transport processes and rates.	Overtopping	Shore protection structures Cemetery Infrastructure - roads, car parks, SW, PW, beach accesses Services - Electricity, Gas Caravan parks Sports Ground Primary School	Residential properties Commercial properties	Medium
		Rock Revetment		Overtopping			Medium
		Dog beach	Natural sandy beach – high dunes Terminal scour at end of revetment.	Erosion	Dunes Foreshore reserve		Medium

Compartment	Location	Sub-location	Features for division	Key issues	Nearby Assets		Priority
					Public	Private	
	Queenscliff (Port Phillip Bay coast side)		Natural sandy beach with pier structures	Inundation Erosion	Caravan parks Infrastructure - roads, car parks, SW, PW, beach accesses Services - Electricity, Gas Pier Foreshore reserve & park	Residential properties Commercial properties Sports Club	Medium
	Swan Island (Port Phillip Bay coast side)		Natural sandy beach – renourished with dredge spoil from Queenscliff	Inundation Erosion	Dunes	Defence site	Medium
	Queenscliff (Fisherman's Flats)		Low-energy frontage with quay and seawalls	Inundation	Infrastructure - roads, car parks, rail line, SW, PW, beach accesses Services - Electricity, Gas Shore protection structures Quay walls Ferry terminal Boat ramps	Residential properties Commercial properties	High
	Swan Bay		Mostly natural low-energy shoreline.	Inundation	Infrastructure - roads, car parks, SW, PW, access ways Services - Electricity, Gas Boat ramps Holiday Park Ramsar Wetland	Residential properties Commercial properties Agricultural land Golf Course	Medium
	Lakers Cutting – Lonsdale Lakes Estate		Low-lying land area with flood route fed through series of channels.	Inundation	Infrastructure - roads, SW, PW, access ways Services - Electricity, Gas	Residential properties Commercial properties	High

Compartment	Location	Sub-location	Features for division		Key issues	Nearby Assets		Priority
						Public	Private	
6. Point Edwards to Portarlington	St Leonards		Section of sandy coast oriented north to south, some short defended sections, and some timber groynes.	The scope of studies have been reduced for these areas due to a number of existing contemporary studies.	Inundation Erosion	St Leonards Faunal Reserve Caravan park Holiday park Pier / Harbour Hypersaline habitat (Salt Lagoon) Infrastructure - roads, car parks, SW, PW, beach accesses Services - Electricity, Gas Shore protection structures	Residential properties Commercial properties	Medium
	Portarlington		Very narrow beach and low-lying land		Inundation Erosion	Infrastructure - roads, car parks, SW, PW, beach accesses Services - Electricity, Gas Shore protection structures	Residential properties Commercial properties	Medium
	Bellarine Bayside Shore		Artificially renourished beach		Inundation Erosion	Holiday park Infrastructure - roads, car parks, SW, PW, beach accesses Services - Electricity, Gas Renourished beach	Residential properties Commercial properties	High
7. Portarlington to Point Henry	Ramblers Road		Very low-lying section of beach that alternates between a low and moderate energy regime dependent on wind direction.		Inundation Erosion	Foreshore reserve Saline and freshwater habitat Infrastructure - roads, car parks, SW, PW, beach accesses Services - Electricity, Gas Boat ramp / harbour	Residential properties	High

Compartment	Location	Sub-location	Features for division	Key issues	Nearby Assets		Priority
					Public	Private	
	Clifton Springs		Low to medium energy environment	Inundation Erosion Cliff instability	Shore protection structures Infrastructure - roads, car parks, SW, PW, beach accesses Services - Electricity, Gas Boat ramps Heritage sites	Residential properties Commercial properties	Medium
	Point Henry		Very narrow beach and low-lying land, low-energy environment	Inundation Erosion	Saline habitat Foreshore reserve Infrastructure - roads, car parks, SW, PW Caravan Park Services - Electricity, Gas	Smelter works Commercial properties	Medium
8. Stingaree Bay to Geelong (South Corio Bay)	Newcomb and Moolap		Low-lying low-energy environment, hinterland landward of a series of levees potentially at risk.	Inundation	Saline and freshwater habitat Infrastructure - roads, car parks, SW, PW. Services - Electricity, Gas Public reserves Cemetery	Residential properties Commercial / industrial properties	High
	Geelong	Eastern Beach	Renourished section of beach amongst walled coastline.	Inundation Erosion	Foreshore reserve Marina Heritage sites Infrastructure - roads, car parks, SW, PW. Services - Electricity, Gas	Commercial properties	Medium
		Western Beach	Seawalls, revetments, piers etc.	Overtopping Inundation			

Compartment	Location	Sub-location	Features for division	Key issues	Nearby Assets		Priority
					Public	Private	
9. Geelong to Point Wilson (North Corio Bay)	North Geelong	North Shore	Some high cliffs, industrial port areas – quays, seawalls etc.	Overtopping Inundation Cliff instability	Foreshore reserve Infrastructure - roads, car parks, SW, PW Services - Electricity, Gas	Residential properties Commercial / industrial properties	Medium
		Shell Foreshore	Some natural coast, Shell pier and number of outfalls. Areas of saline habitat.	Inundation		Commercial / industrial properties	
	Limeburners Lagoon		Low-lying floodplain area, with creek and shallow lagoon.	Inundation	Saline habitat Foreshore reserve Infrastructure - roads, car parks, SW, PW Services - Electricity, Gas	Residential properties Commercial / industrial properties	Medium
	Avalon Beach		Former saltpan site area, very low-lying, little dune protection. Row of properties. Significant habitat area.	Inundation Erosion	Saline habitat Infrastructure - roads, SW, PW Services - Electricity, Gas	Residential properties Commercial / industrial properties	Medium
	Point Wilson		Mostly natural rocky foreshore with low-lying hinterland.	Inundation	Saline habitat Infrastructure - roads, SW, PW Services - Electricity, Gas	Commercial / industrial properties	Medium

4.2 Modelling Approaches

The various landscapes around the Bellarine area require differing modelling approaches at differing resolutions. During the scoping phase of the project, areas of concern were identified. These were visited during the site inspection and potential flooding mechanisms were confirmed. Additional information for model detail was also gathered during the site visit, including potential flood paths that may not have been detected by the LiDAR, and the presence and condition of defences that were not included in the structures database. From this, the appropriate scale and resolution of modelling was determined for each compartment. Where recent detailed modelling was available, the scope of modelling was reduced accordingly. The modelling approaches are noted in Table 4-2.

Table 4-2 Modelling techniques

Hazard	Techniques employed
Wave modelling	SWAN
Wave setup and runup	LITPROF and empirical calculations
Flooding / inundation	SOBEK for complex river / estuary environments
	Coastal inundation through static modelling – for less complex areas
Overtopping	EurOtop

The inundation modelling includes both dynamic and static modelling approaches. Dynamic modelling simulates the movement of water through the environment by accounting for the flow paths, friction of various surfaces and the time variation of sea-level and river flows. The dynamic methods are applied to the higher priority locations and where flow paths are more complex. The static modelling refers to the horizontal projection of the peak water-level across the terrain based on land elevation (i.e. “bathtub” method). This method is applicable for the medium and low-priority locations, where there are less complex inundation mechanisms e.g. low-lying areas with little or no dune and no defences. The static inundation does, however, include consideration of flow paths where possible and information relating to the event under which the inundation would be expected to occur, including the standard of protection of any foreshore structures.

Future tidal levels were also used to give an indication of the possible future shoreline location for low-lying areas.

Overtopping discharge volumes are given for information and to determine potential failure mechanisms and timeframes. The stated volumes should be checked if required for design purposes.

4.3 Determination of Design Conditions

4.3.1 Storm-Tide Levels

CSIRO (2009a,b) has produced storm-tide levels for Port Phillip Bay and the open coast of Victoria, these are presented in Table 4-3.

Table 4-3 1% AEP storm-tide levels (CSIRO, 2009a,b)

Locations	Surge (m)	Storm-tide (m AHD)
Lorne	0.70	1.69
Point Lonsdale (tide gauge)	0.84	1.41
Queenscliff	0.83	1.23
Geelong	0.76	1.06

4.3.2 Wave Climate

4.3.2.1 Open Coast

To determine wave conditions along the open coast, a global WaveWatchIII wave model was used to compute the wave conditions along the boundary of a coarse SWAN model. The SWAN model extended from Cape Otway to Wilson's Promontory. Within the coarse grid a finer resolution grid was nested from which model results were extracted at points in 10 m water depth along the study area coastline. The model was run for 85 storm events spanning 33 years from 1979 to 2011 from which extreme conditions and the variation in wave climate along the open coast could be determined.

The wave climate for the open coast was determined by deriving the relationship between the model-derived values at Point Nepean and each extraction location from Breamlea to Point Lonsdale. An additional relationship between the modelled and measured data for Point Nepean was then derived from which the wave climate at each location was determined. It was assumed that the wave period remained constant for all locations.

An extremal analysis was performed to determine the AEP for significant wave heights (Hs) at Point Nepean, Table 4-4. The same relationship used to determine the wave climate for each extraction point was also used to determine the extreme values for the open coast at 30 locations. These values were used to inform the subsequent joint probability assessment to determine the final design conditions for the hazard modelling. Appendix A gives more details of the wave analysis.

Table 4-4 Extreme wave heights for Point Nepean

AEP	Adopted Hs Values (m)
100%	5.6
20%	6.2
10%	6.6
5%	7.0
2%	7.6
1%	8.0

4.3.2.2 Port Phillip Bay

The wave climate within Port Phillip Bay was available from models used in past projects with minor editing to grid coverage, and inputs. As swell from Bass Strait penetrates only a short distance through the entrance of Port Phillip Bay (Cardno, 2011), waves in the study area within the bay are generated by local winds (i.e. fetch-limited waves). A wave climate for the study area from Edwards Point to Avalon was derived using measured wind data from Point Wilson. The wave climate was obtained by applying a 1% AEP wind in the model, from various directions, based on Australia design wind standards (AS/NZS 1170.2:2011).

An additional dataset of measured wave heights off Portarlington was received from Water Technology for March 2010 to March 2011. This data was from a pressure gauge and was used as a check on the wave heights in the Portarlington area. This was not a formal model validation exercise.

Due to the dominance of the current fields near the heads area and the swell conditions, the corresponding wave climate from Point Lonsdale to Edwards Point was modelled under flood-tide conditions with swell applied to the model boundary.

4.3.3 Catchment flows

The effect of climate change on catchment flows is currently the subject of much debate. Although rainfall events are predicted to become more intense, the effect of other hydrological drivers, such as soil moisture, evaporation, and infiltration are less well defined. For the coastal hazard from flooding to be increased, the catchment flows must also occur simultaneously with the peak tide and storm-surge levels. For the Barwon River, analysis indicates no correlation between flood flows and storm surge in the long-term data record (Swan et. al., 2010). For most catchments along the Bellarine Peninsula, short duration storms (in the order of up to 6 hours) are likely to be the storms that will produce the highest run off. These are generally thunderstorm type events that are not associated with high storm-surge levels.

Catchment flows have been assessed for the Barwon River, upstream of Lake Connewarre. Two inflow scenarios have been assessed (Table 4-5). One is a constant flow calculated as the 99th percentile daily average flow in the Barwon River based on four years of measured flows. This flow, which is 87 m^3/s, was applied for all sea-level rise events. The second inflow was the 10% AEP flood event, which was timed to coincide with the peak 1% AEP storm-tide level in the Barwon Estuary for the 0.0 m, 0.8 m and 1.4 m SLR scenarios. The probability of the 10% AEP catchment flow case occurring at the peak of a storm surge is extremely low; hence the high daily-average flow case has been the focus of the modelling, with the 10% AEP catchment flow case assessed for sensitivity. Assessment of the high daily-average flow case with the 1% AEP storm-tide inundation event also allows the implications of the storm-tide inundation to be assessed independently. The results are presented to give an indication of the possible maximum impact should this very rare combination of events occur. The magnitude of the 10% AEP catchment flow event is 670 m^3/s and the adopted hydrograph shape (based on the January 2011 flood event) is shown in Figure 4-2. For other locations, the effects of catchment flows are less significant, and therefore have not been incorporated

Table 4-5 Study modelling scenarios + catchment flows for Barwon hydrodynamic models

Storm Event	+ Catchment flow	+ SLR (m)					
1% AEP	high daily-average flow	0	0.2	0.5	0.8	1.1	1.4
1% AEP	10% AEP (sensitivity)	0			0.8		1.4

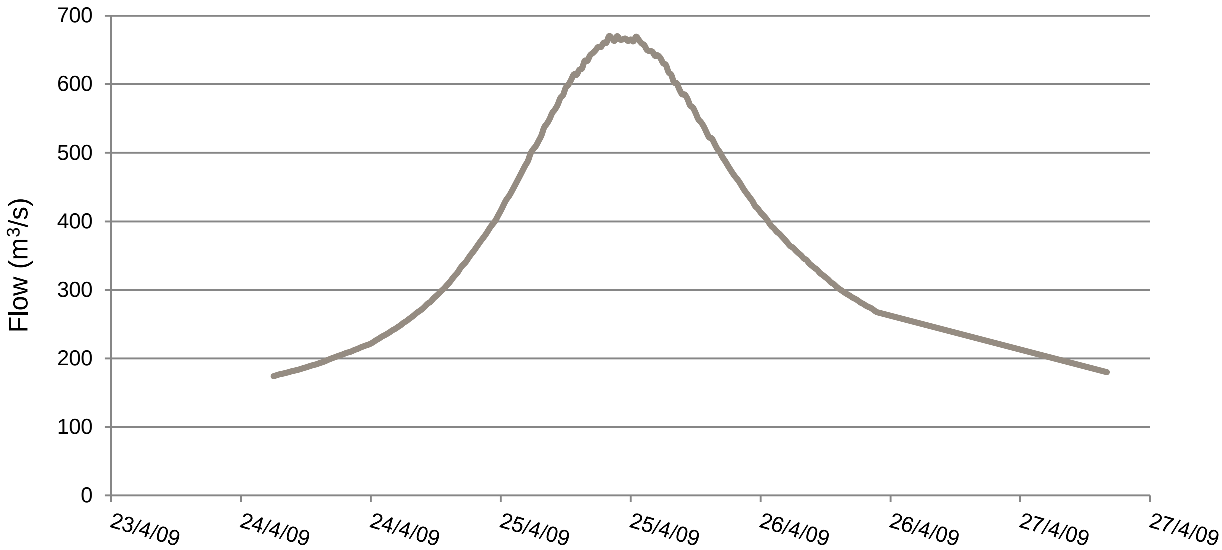


Figure 4-2 Barwon River inflow - 10% AEP catchment flow (arbitrary dates)

4.3.4 Joint Probability

The 1% AEP wave and storm-tide level values were determined independently, and brought together in a joint probability analysis to produce a 1% AEP event. The likelihood of the two extremes occurring at the same time is very low, far in excess of an event that would be statistically likely to occur with a 1% annual probability. Although this is not the most conservative case for a hazard assessment, part of the scope of this project was to provide a more refined estimate of conditions and resultant hazards compared to previous work (i.e. Future Coast). Also, the results of this study are for inundation and coastal erosion hazard management purposes, not detailed design, therefore the inherent uncertainties that are associated with bivariate analysis are considered acceptable.

A methodology similar to that of Galiatsatou and Prinos (2011) and Shand *et. al.* (2012) was undertaken. The long-term records of waves and water levels and residuals were used in the joint probability assessment, long-term concurrent data records were only available for the open coast. Two sets of design conditions were determined for consideration in subsequent assessments, a worst case condition for wave impact (Table 4-6) and a case for overtopping / inundation analysis (Table 4-7). A number of test cases and sensitivities were carried out for the erosion modelling. The wave impact conditions (a larger water level with lower storm-tide level) was not used due to the shallow nearshore bathymetry. The depth-limited waves appeared to be unable to penetrate inshore in the model, especially in combination with a lower joint probability storm-tide level. The most appropriate condition to be used along the open coast was the worst case overtopping / inundation condition. Only under these conditions were water levels of sufficient elevation to allow waves to reach the shoreline and have a significant erosional effect.

Similarly to the waves and water-level assessments, the joint probability assessment was undertaken on the Point Nepean waves, with the SWAN model results used to transform the conditions to a variable climate along the open coast. The transformed joint probability wave-height values are summarised in Table 4-8. There were 30 open coast wave extraction points and 60 Port Phillip Bay wave extraction points established to produce the variable wave climate. The raw values for all wave points are presented in Appendix B.

Table 4-6 Joint probability conditions (worst case wave impact) plus sensitivity values

% AEP	Sensitivity A			Design			Sensitivity B		
	Hs (m)	**Ts (s)**	**STL (m AHD)**	**Hs (m)**	**Ts (s)**	**STL (m AHD)**	**Hs (m)**	**Ts (s)**	**STL (m AHD)**
10	6.1	11	0.89	6.2	11.2	0.77	6.4	11.4	0.64
1	7.4	13	1.30	7.6	13.5	1.19	7.7	14.0	1.05

Table 4-7 Joint probability conditions (worst case inundation / overtopping) plus sensitivity values

% AEP	Sensitivity A			Design			Sensitivity B		
	Hs (m)	**Ts (s)**	**STL (m AHD)**	**Hs (m)**	**Ts (s)**	**STL (m AHD)**	**Hs (m)**	**Ts (s)**	**STL (m AHD)**
10	4.4	9	1.25	4.0	8.6	1.27	3.6	8.3	1.29
1	5.7	9.6	1.63	5.2	9.3	1.65	4.7	9.1	1.66

To determine variable storm-tide levels for Barwon and Point Lonsdale (Rip Bank), the differences in tidal ranges along the open coast were applied. The storm-tide levels (STL) within the study area are presented in Table 4-8.

For input into the models, tidal curves and wave curves were required for the design-storm period duration of 4 days. This was based on the Anzac Day storm of 2009, which is the largest most recent storm for which measured records at multiple locations exist. The actual tidal cycle data for the two days before the storm and two days after was used for each location, with the magnitude of the peak of the storm increased to the maximum STL and wave height (as a range for each area) values presented in Table 4-8. The design storm for the erosion assessment was this storm applied twice, to simulate the effects of two design-storms.

Table 4-8 1% AEP event wave and storm-tide joint probability conditions for the study area

Location	Waves (Hs)	1% AEP Storm-tide levels					
		0.0 m SLR	0.2 m SLR	0.5 m SLR	0.8 m SLR	1.1 m SLR	1.4 m SLR
	m	(m AHD)	(m AHD)	(m AHD)	(m AHD)	(m AHD)	(m AHD)
Breamlea	4.1 - 4.4	1.75	1.95	2.25	2.55	2.85	3.15
Barwon Heads	3.0 - 4.6	1.77	1.97	2.27	2.57	2.87	3.17
Rip Bank	4.6	1.75	1.95	2.25	2.55	2.85	3.15
Point Lonsdale (Tide gauge)	1.6	1.38	1.58	1.88	2.18	2.48	2.78
Lonsdale Bight	0.9 - 1.4	1.29	1.49	1.79	2.09	2.39	2.69
Swan Bay & Lakers Cutting (West Channel Pile)	n/a	1.06	1.26	1.56	1.86	2.16	2.46
Queenscliff	0.87 - 1.1	1.20	1.40	1.70	2.00	2.30	2.60
Portarlington & St. Leonards	0.78 - 1.6	1.09	1.29	1.59	1.89	2.19	2.49
Geelong	0.47 - 0.81	1.03	1.23	1.53	1.83	2.13	2.43
Point Wilson	0.45 - 0.78	1.06	1.26	1.56	1.86	2.16	2.46

4.4 Hazard Definitions

Hazard definition refers to the various factors that have contributed to the inundation extents that are the key outputs of this project.

Studies use differing approaches in determining what constitutes a hazard zone. After consultation with the PCG and technical reviewers, the inundation hazards have been defined in Table 4-9. The following sections give more detailed accounts of each of these parameters, how they are calculated and incorporated into the hazard assessment.

Table 4-9 Inundation hazard definition

Present Day Scenario	Sea level rise scenarios				
1% AEP event inundation extent	1% AEP event inundation extent + 0.2 m SLR	1% AEP event inundation extent + 0.5 m SLR	1% AEP event inundation extent + 0.8 m SLR	1% AEP event inundation extent + 1.1 m SLR	1% AEP event inundation extent + 1.4 m SLR

5 Inundation Hazard Assessment

This section presents the process in determining the inundation extents under the various sea-level rise scenarios. Two modelling approaches were adopted. In more complex areas dynamic flood models were used, these models consider overland spreading, flow through engineered structures, saline and freshwater inputs, topographic features and shore protection and use time-varying input conditions.

For low-lying land where the mechanisms for coastal inundation are simpler, a static model was used to determine potential inundation extents. This assumes that the elevated storm-tide level will be able to overwash the shoreline or defences and flood the hinterland. This technique considers flood routes, but not the rate of overland spreading, ground absorption etc. This makes extents more conservative than may occur in reality, and represents a worst-case inundation extent for the water levels used. The assessment also considers shore protection, and under which scenario water is able to breach the shoreline.

The mechanisms for coastal inundation throughout the study area are varied due to the differing landscapes, as shown in Table 5-1.

Table 5-1 Possible mechanisms of inundation for the coast and rivers / estuaries

Location	Mechanism
Coast	Overwashing of low dunes / shoreline
	Breaching of dune due to erosion and elevated water levels
	Overtopping and/or failure of shore protection structures
River / estuary	Overwashing or overtopping of the shoreline
	Overwashing or overtopping of shore protection structures
	Breaching of shore protection due to structural failure
	Backflow thorough stormwater infrastructure

5.1.2 Hydrodynamic modelling

The detailed hydrodynamic modelling was carried using SOBEK. Grids were set up for the four key inundation risk locations as shown in Table 5-2 and Figure 5-1, with the grid size of each modelled area. Note, the smaller the grid size, the more detailed the model.

Table 5-2 SOBEK modelling locations and model grid sizes

Area	Location	Grid size
Barwon Estuary	Barwon Heads / West Bank	4 m
	Ocean Grove / East Bank	4 m
	Lower Barwon	20 m
	Lake Connewarre	40 m
Breamlea	Thompson Creek & Entrance	20 m
Lakers Cutting	Lakers Cutting, Lonsdale Lakes Estate, Lake Victoria	4 m
Newcomb & Moolap	Salt pans and landward	4 m

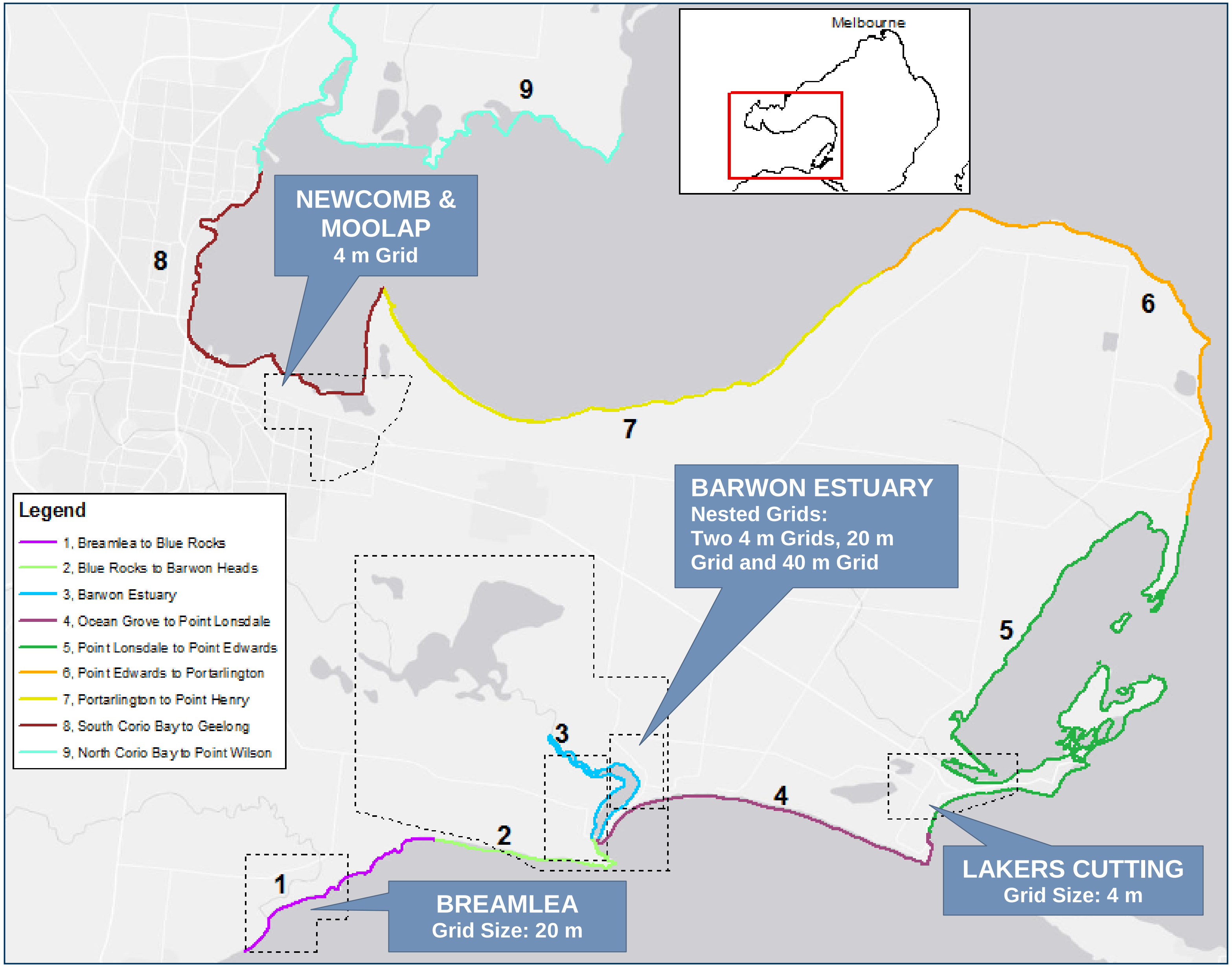


Figure 5-1 Study Area Compartments and SOBEK modelling locations

An assessment of the structures within each modelled area was undertaken prior to set up of the models to decide which were relevant to be incorporated. The majority of the protection structures identified were low retaining walls or revetments on the estuary shores, therefore these were incorporated as topographic features rather than formal structures (and where appropriate, additional roughness was added). Significant shore-protection structures were incorporated as structures in the model where inclusion as a topographic feature was not appropriate e.g. the Barwon levee. These were then checked for elevation against survey data and the LiDAR. Other structures that were necessary to be incorporated were the culverts, pipes and drains. These are to ensure water is transmitted through areas where topographical features may form a barrier in the model.

5.1.2.2 Durations of storm-tide events

The 1% AEP storm-tide data for each of the Barwon Estuary, Breamlea, Newcomb / Moolap and Lakers Cutting areas spanned four days (Figure 5-2). This storm-tide was used for each of the six sea-level rise scenarios. The figure illustrates the tidal base-data used for each location. Note there is slight difference between the storm-tide peaks for Breamlea and Barwon Estuary, with Barwon Estuary being slightly higher. This base data was then raised as required for each sea-level rise scenario. Each of the six scenarios were run dynamically for at least one tidal cycle in order to capture the peak event. Storm-tide events were applied to their respective models at the ocean boundary.

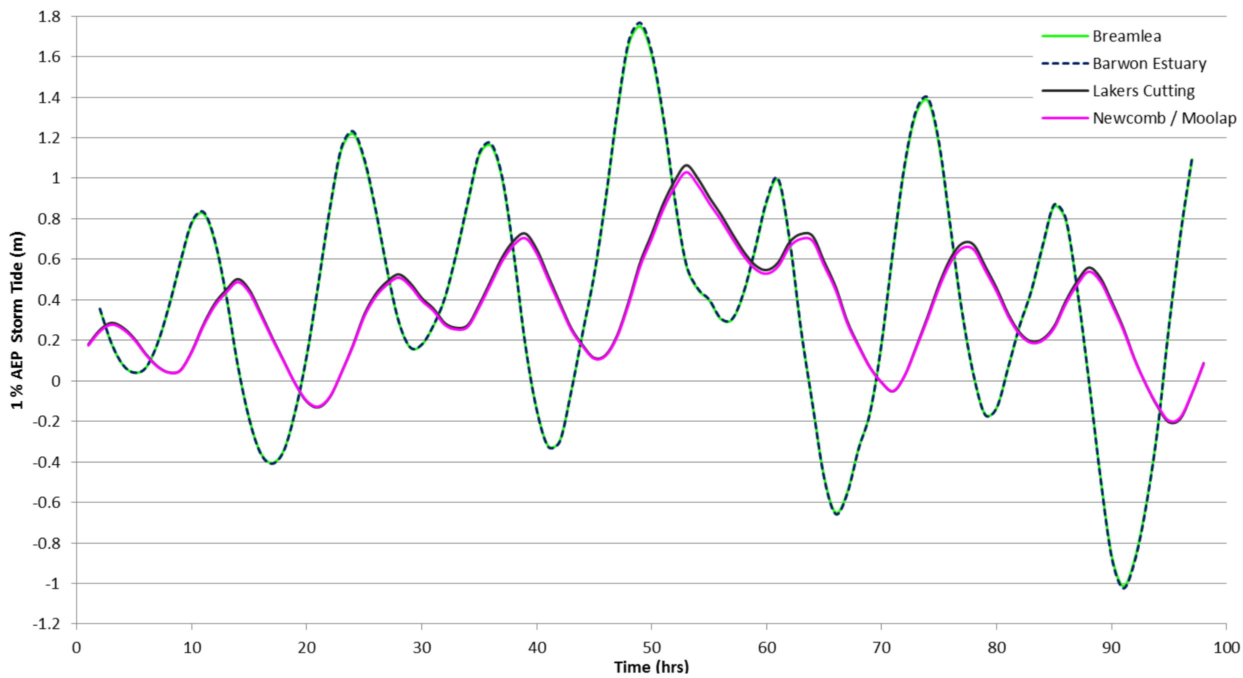


Figure 5-2 Storm-tide sea-level curves used in the hydrodynamic modelling

5.1.3 <u>Static Inundation Modelling</u>

Static-model inundation was carried out for nine areas, Queenscliff, Swan Bay, St Leonards, Indented Head, Portarlington, Ramblers Road, the Sands Caravan Park area and northern Corio Bay (Avalon Beach and Point Wilson). All of these areas are very low-lying, with little protection from oceanic inundation, especially in the long term.

This inundation modelling uses the LiDAR DEM with the storm-tide levels to predict potential flood extents. Although this method provides less certainty than the hydrodynamic modelling, it still gives a sound indication of potential inundation extents under the various scenarios, especially for areas of low-lying land where flooding mechanisms are less complex.

The storm-tide levels presented in Table 4-8 were used in conjunction with the LiDAR digital elevation model to determine extents based on land elevation. These extents were then edited to account for possible flow paths where necessary to ensure all areas shown to flood were in some way connected to the flooding source.

5.2 Uncertainty

The type of assessment undertaken in this project has some inherent uncertainties that must be documented. This is to ensure that users of the information understand the limitations, and this is kept in mind when using the information to inform subsequent assessments. Each assessment has its own uncertainty and there are some generalised project-related uncertainties which are noted in Table 5-3. It is worth nothing that this type of assessment is indicative and uses the best scientific practice to produce the best outcomes possible with the information available. The results are fit for a defined purpose (refer Section 1), but are not to a level of detail to facilitate detailed design. The purpose of this study is to inform strategic flood and erosion management decisions and provide an insight into what may happen in future.

Table 5-3 Sources and implications of project uncertainties

	Type	Information	Implications	How overcome
DATA	Topographic LiDAR	The most recent LiDAR available was flown in 2007. The data are available at 1 m horizontal resolution, and were re-processed from the original level 2 classification into level 3 for input to a higher accuracy Intergovernmental Committee on Surveying & Mapping (ICSM) Level 3 classification.	The horizontal accuracy of the LiDAR data is +/- 35 cm, the vertical accuracy +/- 10 cm (RMSE 68% conf.). The implications of this are that the height of any given point *could* on average be approximately 10 cm above or below the height stated in the dataset. The implication is that, potentially, cross-shores profiles extracted based on the LiDAR could be incorrect, and flood and erosion extents could be over or underestimated. - Locations that have been significantly modified through works (e.g. Queenscliff marina) will not show within the LiDAR data.	Elevations were checked against survey data or construction drawings (where available) for vertical accuracy and manually checked and modified where possible for horizontal alignment.
DATA	Bathymetric data	The most recent bathymetric (LADS) data was collected in 2009 / 2010. The data set has some gaps within the study area, these are largely due to turbidity of the water during data capture (the LADS laser could not penetrate the water to the seabed).	The horizontal resolution of the data is 2.5 m, the horizontal accuracy is +/- 1.62 m, the vertical accuracy is +/- 0.26 m at 68% confidence, or better. The implications of the data are similar to those documented for the Topographic LIDAR data. The depth and slope for the nearshore zone has an effect on the wave modelling outputs, and therefore has an effect on the erosion modelling. A deeper or steeper bathymetry would mean wave conditions would be underestimated, and modelled erosion extents could possibly be further inland than presented. The data gaps are quite vast in the nearshore zone.	Some hydrographic data exists for the offshore areas, however this is rather old and relatively uncertain in itself. The bathymetric data was given consistency checks, and where data was missing, profiles were checked against hydrographic charts (where possible) or profiles linearly interpolated to fill data gaps.

	Type	Information	Implications	How overcome
DATA	Waves	Measured wave data is available for two locations: - Point Nepean has 10 years of relatively continuous Wave buoy data (PoMC) - 1 year of measured wave height information was gathered using a pressure gauge near Portarlington (Water Technology, 2008).	There is very little data to validate wave models and the time span is too short to obtain more certain extreme events. Pressure gauge wave data is relatively uncertain, and also has no associated directions. Data set not likely to be appropriate for validation of PPB model.	No additional data at nearby locations is available to validate / compare the local measured data.
	Tidal	20+ years of tidal data exists for the main tidal stations.	The data record is insufficient to provide fully certain values for extreme storm-tides. The locations of some tide gauges can introduce some uncertainty, e.g. Point Lonsdale is behind a rock shelf within the PPB entrance therefore is not representative of the open coast conditions.	Extremes determined using the tidal data were compared to known storm-tide events for consistency. Point Lonsdale open coast STLs are based on tides at Rip Bank (i.e. outside the entrance) rather than the Point Lonsdale tide gauge.
	Coastal protection structures	Coastal protection structures were captured by the DSE Future Coasts Program, using DSE aerial imagery. It was identified that some protection structures were not captured initially. This was most likely because they could not be identified on the available aerial photography. Structure crest elevation, residual life and general condition is also uncertain / unknown in some locations.	Missing structures or structures that are present but in poor condition (that is unknown) will affect the inundation modelling, possibly flooding areas unnecessarily, or not allowing areas to flood that in reality might. Uncertainty about elevation will have similar implications to the above.	Members of the project reference group assisted with adding additional information. Structures with no crest elevation information were check with LiDAR and local stakeholders.
	Aerial imagery	The most recent aerial imagery was flown in 2012. Historical imagery also exists for some areas from as early as the 1930s. The ortho-rectification process and digitising of shorelines can introduce error. The level of error depends on the accuracy of ortho-rectification and scale at which shorelines are digitised. Ortho-rectification quality depends to some extent on the number and quality of reference points	Depending on the degree of horizontal error, this has an effect on the position of the shoreline at the time of capture and therefore values used for calculating coastal change. It must also be noted that historical aerial images used in this study provide only a snapshot in time. Typically, it is not known if the image was taken during a calm or stormy period or before or after a coastal storm. This could lead to a false impression of a 'stable' shoreline.	Images were provided by the client (DELWP) and checked against existing information, and between images of different years. No significant issues could be identified and images were utilised as supplied.

	Type	Information	Implications	How overcome
DATA	Geology	Surface Geological Mapping is available at 1:250,000 scale for the entire Bellarine Peninsula.	The accuracy of the dataset and level of information available for sub-surface geology does not allow for a fully accurate assessment of the possible available erodible (sand) volume of the open coast dunes/cliffs.	All available information, such as reports containing more localised information (e.g., Rosengren, 2010) were utilised in the assessment. This included information about calcarenite along the open coast between Barwon Heads and Point Lonsdale.
DATA	Geotechnical information	A number of geotechnical assessments have been undertaken for the study area previously. The scope of these studies differs from the current study, therefore the information within has limited use as part of this assessment.	The studies have been carried out for the 'present day', no sea-level rise scenarios have been considered. It may be more appropriate to link future geotechnical hazards to inspection by professional engineers, once significant change is determined through regular impaction by land managers.	Geotechnical assessment is beyond the scope of this project, however where necessary it will be noted that future hazard and risk will be linked directly to engineer inspections.
MODELLING	SWAN Modelling Bass Strait	Modelling of waves in Bass Strait for relationship with Point Nepean measurements depended on bathymetry beyond the LADS coverage area and may not be accurate. Hindcast for extreme events has limited validation and only spans 33 years. There is 10 years measured wave data from Point Nepean.	There is moderate to high uncertainty in the extreme wave conditions, the limited data used could over or underestimate the extreme values calculated, which would have an effect on the erosion hazards determined. More data would increase confidence levels.	The values used were checked using the limited measured data, but this has too short a span to provide high certainty. There are no data to validate the modelled relationships with the Point Nepean measurements and the study area. Both remain sources of uncertainty.
MODELLING	SWAN Modelling Port Phillip Bay	No detailed data for directional waves available to validate modelling. Hindcasting has been used to obtain extreme events, but that is limited since there are only 22 years of wind fields available at Point Wilson.	Waves are fetch limited, but effects of bottom friction and depth-limited wave breaking provide significant uncertainty. Therefore, the extreme conditions could be over or underestimated in individual locations, which would have an effect on the erosion hazards determined.	Consistency checked (not validated) against Water Technology (2008) measured waves at Portarlington.
MODELLING	Inundation Modelling (Static)	Depends on the accuracy of the LiDAR DEM and potential flow paths. Depends on accuracy of design water levels.	Results likely to be conservative (overestimate inundation) for given water levels, as overland flow etc. are not considered.	Manual checking where possible of elevations and extents, cross-referenced against anecdotal information.

	Type	Information	Implications	How overcome
MODELLING	Inundation Modelling (Dynamic)	Depends on the accuracy of the LiDAR DEM and structure information. Requires friction factors for overland flow. Depends on accuracy of design water levels.	Results likely to be less conservative than the static model method.	Manual checking where possible, cross-referencing against anecdotal information. Timing of inundation is a good addition of information to aid in subsequent risk assessments.
	Storm events	Only one AEP event has been considered as the design scenario (a 1% AEP). This is a rare and significant event. More frequent events with a lesser impact are likely to occur, however, the implications of these, although possibly also significant, are not presented.	More frequent events, although smaller in magnitude have the potential to have a significant effect, especially in very low-lying or exposed areas. The concentration on a large infrequent event limits the amount of information available for short term management planning.	Where there is significant impact under a 1% AEP event with 0.0 m SLR, it may be necessary to assess more frequent return periods in subsequent assessments, especially where consequential risk may be significant.
Mapping	Inundation hazard maps (static)	The inundation layers present the maximum extent based on the LiDAR topography, the detail of this is limited by the background data as well as the processing of data. Where areas of inundated land at relevant elevations are located but not connected (flood path), these are edited out, however not at a resolution to remove all. Only large significant areas were removed.	Some low-lying areas not connected could appear to be flooded with no connection to the ocean. In reality, these may be filled with runoff, so the significance is potentially low, but an uncertainty nonetheless.	Maps are checked for connectivity, large obvious unconnected inundated areas are removed.
	Inundation hazard maps (hydro-dynamic)	The areas are gridded to cells; therefore the extent is based on a series of grid-sized square cells.	May be some slight elevation differences within the gridded cells, however only significant for the lower resolution models with larger grid cell sizes.	A prioritising exercise was undertaken early in the project, where the more detailed areas were targeted for a higher resolution model assessment (smaller grid cells).

5.3 Interpreting the Hazard Results

The nature of the Bellarine environment means that standard methods of coastal hazard evaluation are at times not applicable, therefore, the hazard figures must be viewed with the corresponding text to gather the best understanding of the processes operating, and the uncertainty associated with the processes and methodology. Also, a new method for the presentation of future scenarios has been undertaken linked to sea-level rise increments rather than a specific year to reduce the uncertainty related to the rates of sea-level rise and the prediction of future inundation extents. The use of sea-level rise triggers is detailed in the following sections.

5.3.1 Trigger Points

The Scoping Document (Appendix A) detailed the intention of this study to consider trigger points in relation to hazards, rather than tying scenarios to a specific year. This includes producing maps that show potential inundation extents based on various sea-level rise scenarios, regardless of a year. This is in contrast to producing hazard maps that appear to 'predict' the position of the shoreline in a particular year, or the frequency and extent of inundation in a particular year. Generally, the better the background data, the better and more certain the assessment can be. For the Bellarine area, there are few thorough and consistent background datasets available, making a move to trigger points more reasonable and flexible. Although this is not common for hazard assessments, uncertainty related to the lack of background data and future rates of sea-level rise means that the prediction of a shoreline position or frequency of inundation in future years is too uncertain. This use of trigger points also allows for new data, particularly new rates of sea-level rise, to be incorporated as they become available. This will increase the certainty of assessments and provide additional confidence to managers that the planning decisions they are making are appropriate.

The triggers presented are tailored to each location based on the nature of the site, and knowledge of the site. The triggers are likely to be superseded when risk, options and mitigation studies are undertaken, or will remain valid for locations that are of lower priority, where subsequent studies won't be undertaken for a number of years. It is recommended that risk assessment and planning be undertaken before the triggers are met.

The triggers are categorised into planning/investigation triggers and physical triggers. Planning triggers relate to an inundation extent under a particular sea-level rise scenario that alerts to a need for additional investigation and a potential management response. This is to ensure that land managers have a reasonable indication of when work needs to be started to address a forthcoming hazard. The physical triggers are to initiate a response to an imminent hazard, this may override a management trigger, e.g. if a storm of a magnitude greater than the modelled scenario was to occur, this may initiate an immediate emergency management response. In this context, actions are ways to mitigate against the effects of storms and increases in sea-level, either works or planning and management actions.

The aim is to allow managers to better prioritise responses, to make best use of coastal management funds and resources.

5.3.1.1 Inundation Triggers

There are large areas of low-lying land throughout the study area. At present, these areas are only inundated under extreme events. With increases in sea-level, the frequency of inundation is likely to increase, with some areas likely to become tidal. Land managers require information as to when they should start taking action to mitigate the effects of this potential inundation. Note, that this is based on the occurrence of a 1% AEP event, the triggers provided do not account for events in excess of a 1% AEP. The assessment presents two inundation triggers:

Inundation trigger A - this is to trigger a management response when the measured sea-level rise reaches a certain threshold. Investigation or action should be taken to mitigate against the potential effects of the increase in sea-level. In this context, actions are ways to mitigate against the effects of storms and increases in sea-level, either works (e.g. protection) or planning and management actions (e.g. retreat).

When assessing inundation risk to assets (subsequent to this study), frequency of inundation (i.e. the likelihood) and the consequences will be considered. For example, a property that is inundated, on average, once every 100 years (i.e. in a 1% AEP event) may be considered to be a tolerable risk, however, a property that was inundated yearly, would not. Therefore it is appropriate to determine under which sea-level rise scenario the hazard becomes too great and needs to be dealt with. This will be different for different types of assets. The trigger tables give an indication of when action is required by land managers related to increases in local measured increases in sea-level. It is also noted, that the difference in saline and freshwater inundation should be considered when addressing inundation of certain assets, particularly natural assets, i.e. habitats, as resilience will be dependent on physiological tolerances. This finer detail will be part of the scope of subsequent studies that arise; however, this study initiates the process by identifying which events and sea-level rise scenarios trigger a response. Following from this, risk assessments and determination of adaptation responses will combine all relevant hazard and asset information to address the issues and environment as a whole.

5.4 Prediction of Inundation Events

5.4.1 Warning and prediction of storm-tide

Along the south coast of Australia sea-level variations over longer time-scales are related to meteorological systems which move from west to east. The corresponding sea-level variations also migrate from west to east as demonstrated by Provis and Radok (1979) and illustrated in the monthly reports from the National Tidal Centre for the Australian Baseline Sea-level Monitoring Project. It would be useful in terms of emergency services if the water levels associated with such storm events could be predicted in advance.

Previous unpublished work by Cardno determined that the sea-levels from Portland could be used to predict the water level at Geelong 18 hours in advance. In order for such predictions to be determined for the study area, reliable tide-gauge data must be obtained. The closest long-term reliable tide gauges to the study area are located at Lorne and Queenscliff.

In order to determine if sea-level rise under storm condition could be predicted in advance, the measured sea-levels at Portland and Lorne were compared. Non-tidal variations in sea-level are defined by determining the difference between the measured and predicted sea-level, that is, by the residual. As storms travel from west to east, the residual at Portland should therefore be an indication of potential surge to be added to the predicted tide at Lorne.

The initial time lag between Portland and Lorne was determined using a lagged cross-correlation based upon the residual at Portland and the non-tidal water level at Lorne. This indicated that it took seven hours for sea-level variations measured at Portland to reach Lorne.

In order to provide the best prediction algorithm, a technique known as “Artificial Neural Networks” was applied. This is a method of using multi-variable correlations to find relationships between one set of variables and another. The main feature of the method is the use of a set of “hidden” variables in the correlation which allows for a better fit.

One of the disadvantages of predicting sea-level with a neural network program is that the prediction algorithm is relatively complicated. In order to simplify the process for operational purposes, the possibility of using a simple addition of the residual from Portland seven hours earlier to the predicted tide at Lorne was investigated. The results of this prediction in comparison to the predicted sea-level and actual measured sea-level at Lorne are shown in Figure 5-4 for a storm event.

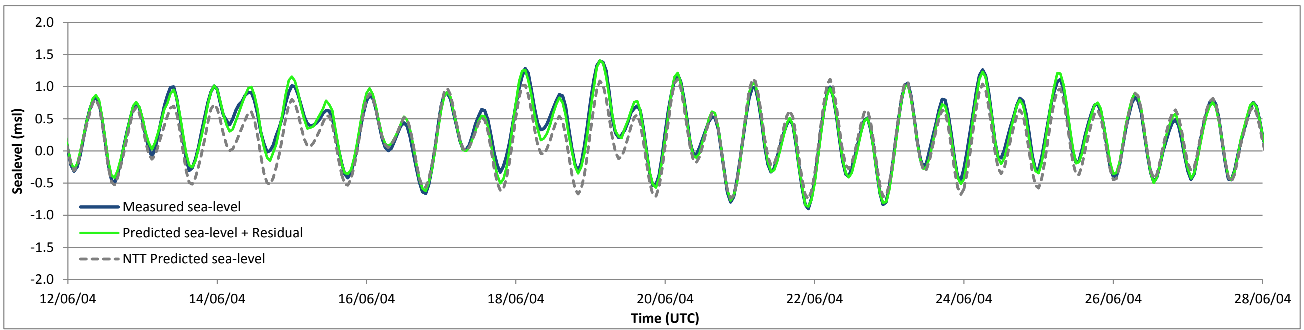


Figure 5-3 Comparison of ANTT predicted, actual measured and predicted sea-level at Lorne using the Portland residual seven hours earlier added to the Lorne predicted tide.

The data in Figure 5-3 shows that the simple method provides a useful prediction of the timing and height of the storm-tide. Comparison with the more complex neural network predictions showed that the simpler system performed as well for practical purposes and hence this method is recommended. A cross-correlation of the measured sea-levels and those from the simplified prediction method are shown in Figure 5-4.

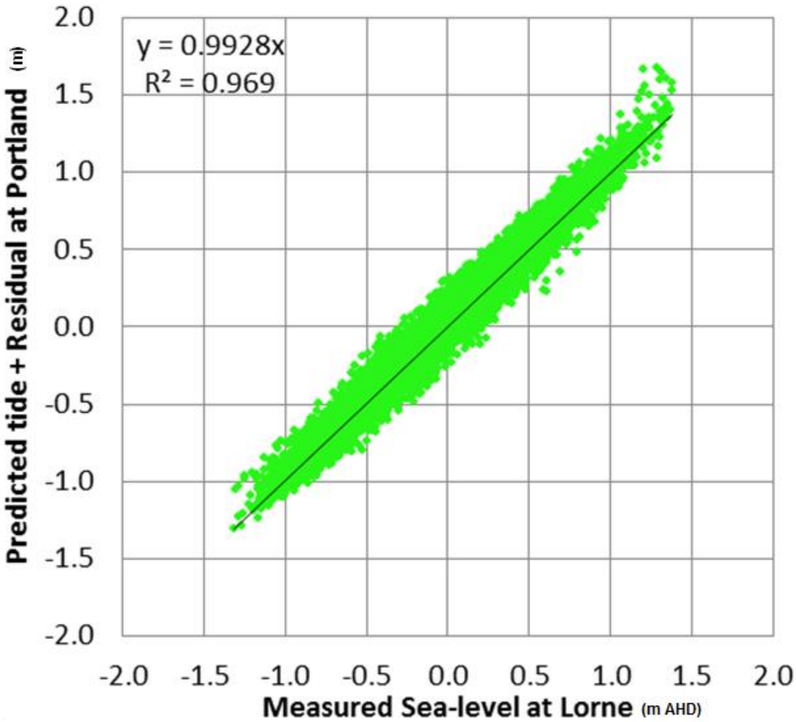


Figure 5-4 Cross-correlation of measured sea-level at Lorne with predicted sea-level using tide + residual

The statistics of the differences between the measurements and the Portland-residual prediction method using all the available data in 1994, 2001 and 2004 are shown in Table 5-4. The statistics of the difference indicate that by taking the Portland residual seven hours prior and adding it to the predicted tide level at Lorne, an accuracy of typically much less than 0.1 m can be achieved. In fact, 98% of the predicted values for each year examined differ by less than 0.1 m from the observed value. This indicates that the sea-level at Lorne under storm-surge conditions can be predicted to an accuracy of 0.1 m by adding the residual from Portland seven hours prior to the predicted Lorne tide level, e.g. sea-level at Lorne (10:00) = Predicted Lorne tide level (10:00) + Portland residual (03:00).

Table 5-4 Statistics of the difference between the measured sea-level at Lorne and the predicted sea-level using the Portland residual for 1994, 2001 and 2004.

Difference in predicted water level and measured water level	1994	2001	2004
Average	0.01	0.01	0.00
Maximum	0.14	0.15	0.11
Minimum	-0.14	-0.20	-0.13
Standard Deviation	0.03	0.03	0.03
1st percentile	-0.08	-0.07	-0.09
5th percentile	-0.05	-0.05	-0.06
95th percentile	0.06	0.05	0.05
99th percentile	0.09	0.08	0.08

The sea-level at Lorne is applicable to storm-tide levels at Barwon Heads and Ocean Grove. For flooding at Queenscliff and Point Lonsdale, the residual from Portland should be added to the predicted tide at Queenscliff.

This prediction system should provide emergency managers with useful information in the planning of evacuations and emergency response, if inundations events are likely to cause significant flood depths for a significant amount of time.

5.4.2 Duration of inundation events

The hydrodynamic models were thematically mapped to demonstrate the duration of time for which the inundation water depth at a point remained above a threshold of 0.3 m. These results highlight the fact that inundation arising due to storm-tides only lasts for a short period of time. The results of the inundation timing assessments are presented for each location where a hydrodynamic inundation assessment has been carried out, in Section 6. This information will aid in subsequent risk, options and mitigation assessments.

6 Results by Location

Due to the differing coastal management organisations that oversee the various sections of coast, the results are presented by location for ease of reference. The following sections give a brief overview of the site-specific characteristics of the study locations, and the results of the inundation hazard assessments. An overview of the entire study area is shown in Figure 5-1.

6.1 Compartment 1: Breamlea to Blue Rocks

This section of coast is managed by the City of Greater Geelong. The Breamlea area includes Thompsons Creek (and the adjacent creek hinterland), the beach, dunes and rocky shore to Blue Rocks (Figure 6-1). The creek is a low-energy water body that meanders through the very low-lying and very flat floodplain hinterland. To the west of the creek entrance there is a large area of saline wetland habitat fed by the creek through a culvert under the road. The inner bends of the creek are armoured with low rock retaining-wall structures. These are in place for erosion control along the creek and to minimise any further movements of the channel, and will not protect against inundation. There is only one road in and out of the Breamlea settlement, and this is likely to be at risk in future inundation scenarios.

The Breamlea beaches are relatively wide, low angle, low-tide terrace beaches (Short, 1996). The wave conditions are swell dominated, and the shoreline is afforded some protection from the dominant south-westerly swells due to Point Impossible (west of the Thompsons Creek entrance) and the orientation of the shoreline. The Breamlea barrier dune ranges in height from 0 m AHD to over 20 m AHD, the inner landward side is covered with private dwellings. The north-east end of the beach is held by volcanic boulders, probably eroded from the inland volcanic area of Mt. Duneed.

Figure 6-1 Compartment 1: Breamlea to Blue Rocks + cross-shore profiles (in red)

East of Breamlea, similar volcanic boulders have fixed the shorelines at each end of Buckley's Bay and Bancoora Beach. Both beaches exhibit a characteristic crescent shape between the fixed ends and each is slightly skewed to the east, indicating the dominant littoral drift is from the south-west, to north-east. Sediments taken from Bancoora Beach show that the dune sample is mostly fine sediment, with the swash sample containing more medium and coarse grain sizes.

6.1.2 Methodology - Inundation Hazard Assessment

The SOBEK model used a grid size of 20 m; this was considered sufficient for the level of detail required (Figure 6-2). Key development features such as roads, levees and shore protection structures were checked to ensure they were picked up as topographic features, and were refined where necessary. No formal protection structures exist in this area; therefore the low retaining walls that line the eastern bank of the creek were checked within the underlying topography for elevation. Culverts were incorporated beneath the road in two locations:

- where Blackgate Road crosses Thompson Creek; and
- near the intersection of Blackgate and Breamlea Roads.

In addition to these, four culverts were identified along the boundary between Thompson Creek and the local properties and incorporated them into the model. The tidal boundary was applied at the mouth of the Thompsons Creek. The model was run for the 1% AEP storm-tide case in combination with a number of sea-level rise scenarios to determine the extent of inundation that would arise. The adopted storm-tide levels are shown in Table 6-1.

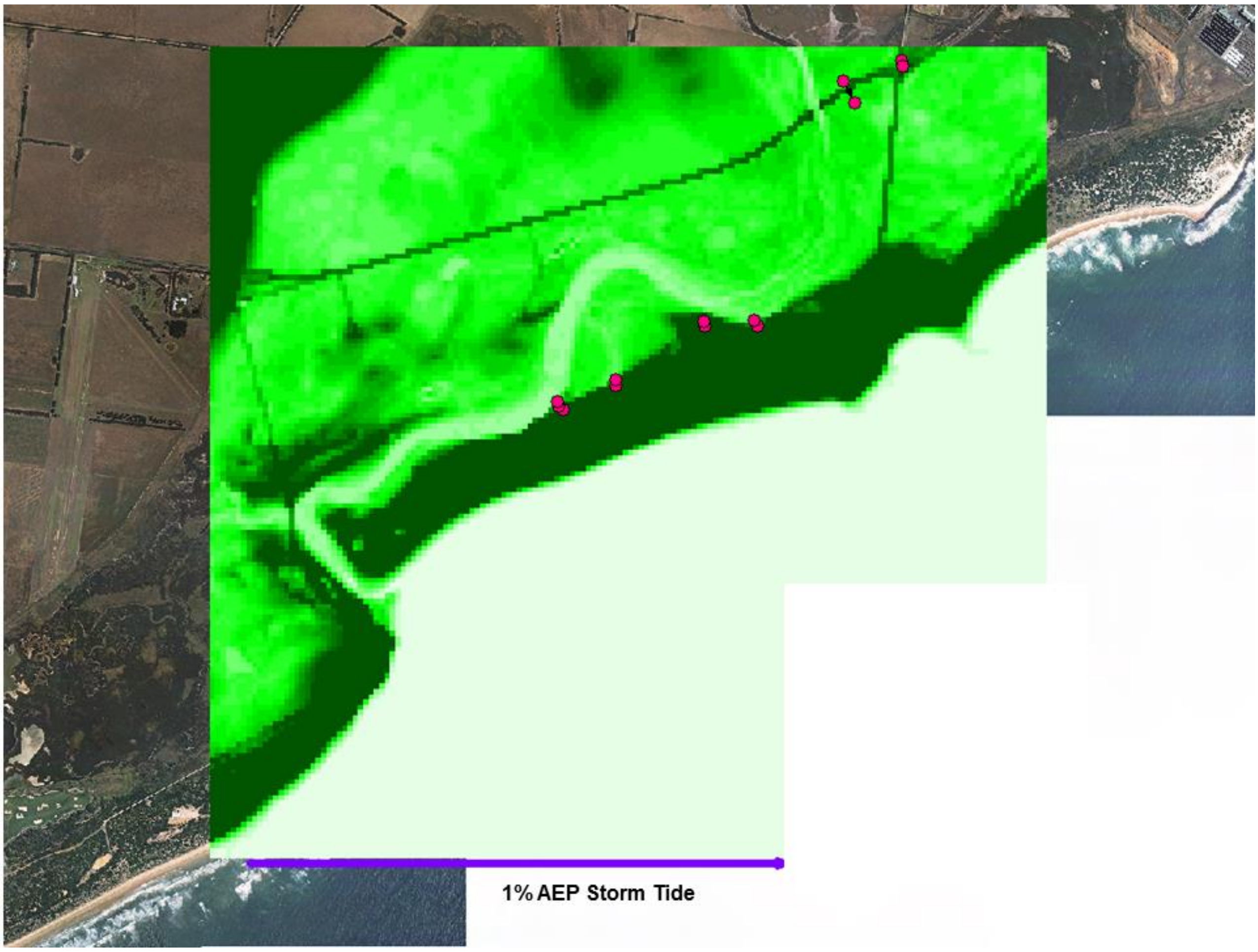


Figure 6-2 Extent of Breamlea model, showing river and tidal inflows and culvert locations (pink circles)

Table 6-1 Adopted storm-tide levels for Breamlea area

	0 m SLR	0.2 m SLR	0.5 m SLR	0.8 m SLR	1.1 m SLR	1.4 m SLR
Storm-tide level (m AHD)	1.75	1.95	2.25	2.55	2.85	3.15

6.1.3 Results

The hydrodynamic inundation results are presented in Figure 6-3. The largest impact is seen in a 0.8 m increase in sea-level where large areas north of the river become inundated. The duration for inundation of Breamlea is in Figure 6-4. This figure is to aid in subsequent risk assessments to show that although the area inundated is large, the duration of inundation for most areas is low.

6.1.4 Implications for Coastal Management

Three specific locations (identified in Figure 6-3 by the red dots) and the conditions under which they are inundated have been included in Table 6-2. Properties north of the creek, but south of Blackgate Road are likely to be affected under a 1% AEP event with 0.5 m of sea-level rise. The Horwood Drive area south of the creek is an area of higher topography than areas north of the creek. This area is only likely to inundate under a 1% AEP event with 1.4 m of sea-level rise. This will affect access to the properties along Horwood Drive and potentially some of the lower lying properties.

Table 6-2 Critical inundation locations identified in the Breamlea model

Critical Location	Event Resulting in Inundation
North of Blackgate Road	1 % AEP and 0.50 m SLR
Point Impossible (Minya Lane)	1 % AEP and 0.80 m SLR
South of Horwood Drive	1 % AEP and 1.40 m SLR

The main erosion hazard in this compartment is the beach access track at Bancoora Beach. At present the elevation of the dune in this location is enough to limit coastal inundation during storm events. Recent core samples show that the unconsolidated sediment in this area is able to erode to a depth approximately 4 m below present elevation (which ranges from 4.1 - 4.4 m AHD). With increases in sea-level rise greater than 0.5 m, the erosion here is likely to be sufficient to erode the beach back far enough that, under a 1% AEP event, water may overwash the dune at the low section, and inundate the hinterland. Further investigation is required to examine the results of the core sampling and hence the susceptibility of the dune to erosion, especially when coupled with the incidence of riverine flooding. Increases in foot traffic using this beach access will also need to be considered as this will increase the anthropogenic induced erosion in this area. The management triggers are presented in Table 6-3.

Table 6-3 Inundation triggers - Thompson Creek to Blue Rocks

Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation	Storm-tide inundation of low floodplain	1 % AEP event + 0.2 m SLR	A) Investigation and planning / management required when measured increases in sea-level rise reach 0.05 - 0.1 m above 1990 sea-levels **and** A) Public road infrastructure subject to hazard under 1 % AEP event + 0.5 m SLR.

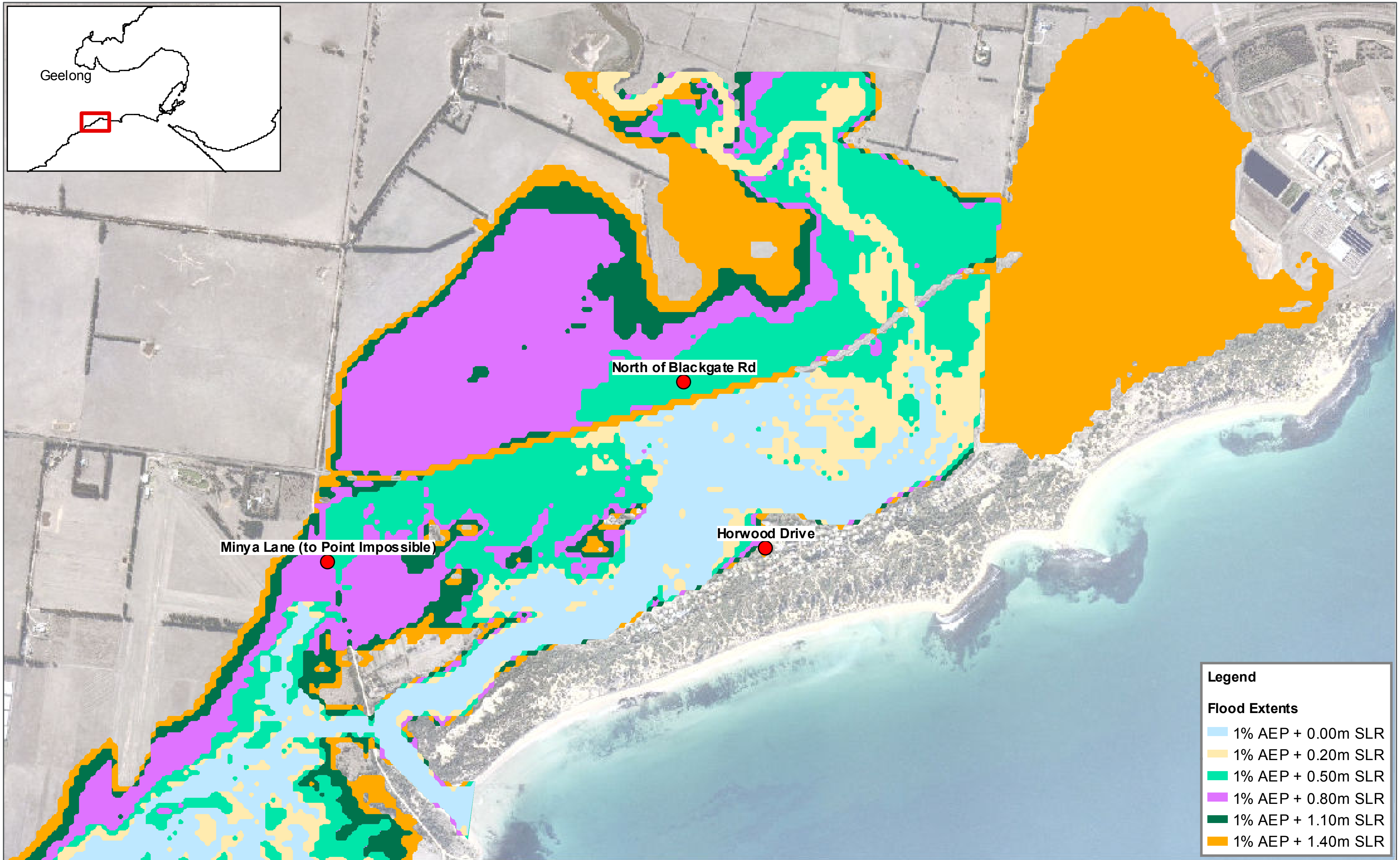
6.1.5 Further investigations & recommendations

- Monitoring of the beaches in this compartment (e.g. profile surveys) is recommended to more closely document the rates of change along the beach, particularly at Bancoora Beach near the beach access. This will provide better background information to inform more detailed future assessments. Frequency of profiling will depend on available funds and resources, suggest teaming with DELWP to determine how best to approach the monitoring. Generally, the following is recommended:

  - profiling at the end of each season (or at least summer and winter), as well as after significant storm events
  - profiles at one or two key locations, and/or where there is a significant change in the beach morphology, and/or where shore protection backing the beach occurs or changes
  - photographs of the shoreline taken at the same times as profiles are surveyed, preferably at fixed and known sites facing the same direction.
- Planning in relation to future trends of usage at Bancoora Beach. Increased foot traffic will further erode the beach access, it may be necessary to formalise the access depending on review of use.

6.1.6 Further studies

- Compile an asset register based on the extents of the erosion and inundation.
- Undertake a risk assessment.
- Determine and evaluate options to reduce / mitigate risk using a quadruple bottom-line assessment, and the necessary timeframes to rank priority.
- Determine works schedules for future years. This could be done as part of an updated local management plan, incorporating the preferred mitigation option findings.



Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-10
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Breamlea_with_critical_locations_2.mxd 01

Figure 6-3

1:18,000 Scale at A4

Metres
0 250 500 750

Bellarine Peninsula - Corio Bay LCHA

BREAMLEA

COASTAL INUNDATION MAPPING - HYDRODYNAMIC MODEL

1% AEP EVENT + SEA LEVEL RISE (SLR)

Cardno

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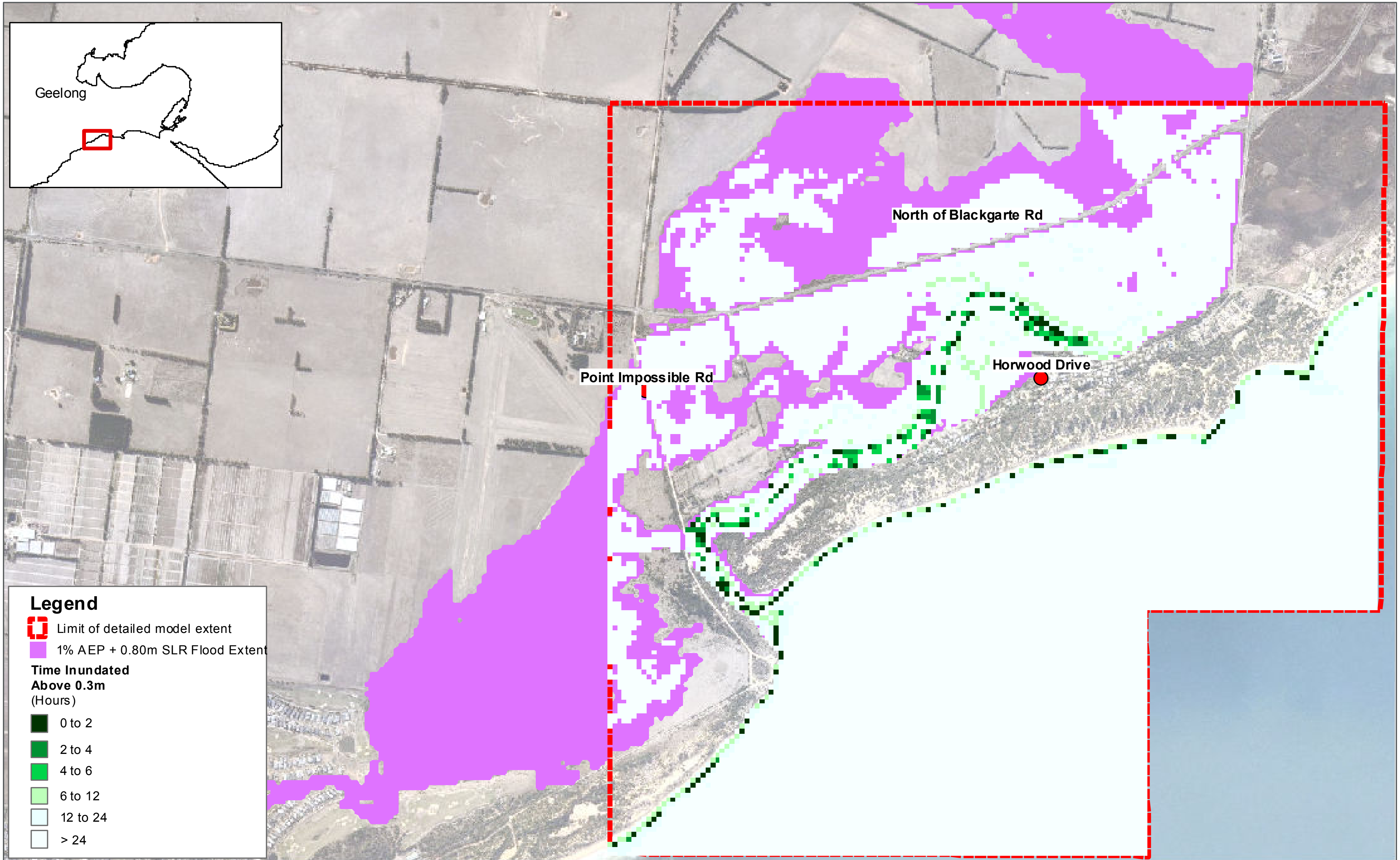

Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-07
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Breamlea_time_of_inundation.mxd 01

Figure 6-4

1:20,000 Scale at A4

Metres: 0, 250, 500, 750

Bellarine Peninsula - Corio Bay LCHA

BREAMLEA

COASTAL INUNDATION MAPPING - HYDRODYNAMIC MODEL 1% AEP EVENT + SEA LEVEL RISE (SLR)

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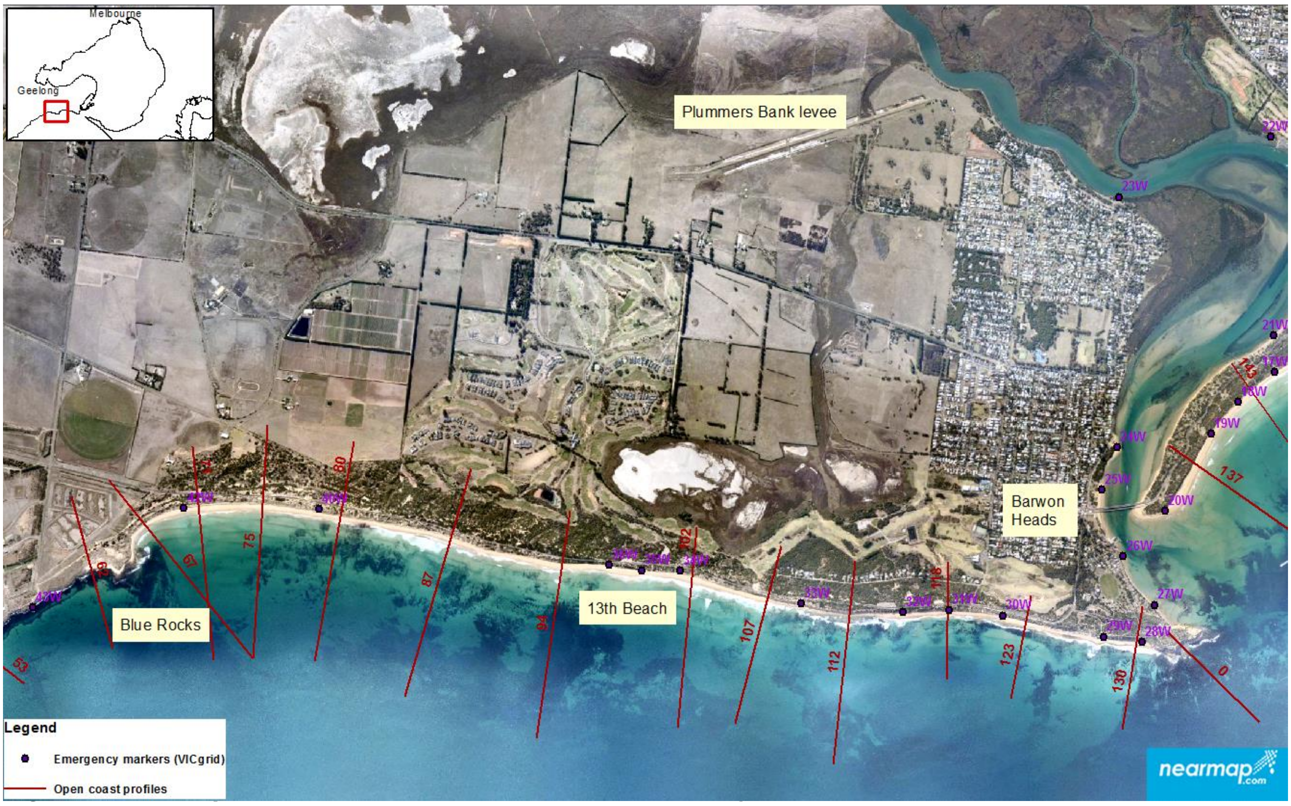
6.2 Compartment 2: Blue Rocks to Barwon Estuary

This section of coast is managed by the Barwon Coast Committee of Management and is a 6.5 km section of beach from Blue Rocks to Barwon Heads (Figure 6-5). West of Blue Rocks, Barwon Water manages the foreshore directly fronting the water treatment facility (between BHCoM and CoGG managed sections).

Thirteenth Beach is backed by high dunes/cliffs with steep, almost vertical, scarps at the central and eastern ends of the beach. The nature of the dune/cliff features is not clear due to the unknown level of cementation or calcarenite in these features. The elevation of the dunes/cliffs ranges from approximately 5 m at the western end, to almost 30 m at the eastern end. There are exposed sections of calcarenite within the dune that appear to have fixed the shoreline position to some extent. Beneath the eroding calcarenite cliffs, scree has accumulated providing some natural protection to the base of the cliffs in this area. Shoreward of the calcarenite sections, some rocky reefs exist which are acting to reduce the wave energy in the nearshore zone. The shoreline is almost perpendicular to the dominant wave direction and this one of the most high energy areas in the study area. The beach width is relatively uniform, with only slightly narrower sections where the cliffed areas are fixed in place. This would indicate that the flux of sediment passing along the beach is relatively constant. The dominant sediment transport is west to east, and waves push sediment around Barwon Heads, where it is either deposited on and around the Barwon River ebb delta, or bypasses towards the Ocean Grove spit and Ocean Grove Main Beach. Some sediment is also likely to be imported into the estuary on incoming tides.

Behind the beach is Murtnaghurt Lagoon, a naturally segmented basin formerly connected to the Barwon River channel through a relict channel that is now disrupted by Plummer's Bank. This is a 4 m high levee constructed in the 1950s to protect against 'back door' flooding of the Barwon Heads township (Rosengren, 2009). The likelihood of the dune/cliff breaching and flooding the low-lying hinterland and the lagoon is very low due to the elevation and volume of the dunes/cliffs.

No inundation maps were produced for this area, as there is no inundation hazard risk to the hinterland from the coast. Possible flooding of this area and Murtnaghurt Lagoon is discussed in the Barwon Heads and Lake Connewarre model section.



6.3 Compartment 3: Barwon Heads, Barwon Estuary and Lake Connewarre

The wider Barwon area is shown in Figure 6-6. The bluff west of the Barwon River entrance protects much of the shore east of here. Waves refract and energy dissipates as they approach the Ocean Grove shoreline, reducing wave heights. The Barwon Heads township is on the western bank of the river. The western bank is protected by a series of high vertical timber and masonry retaining walls. These protect the hinterland properties against high river and coastal flooding events. The elevations of the walls range from 1.6 m to over 3 m AHD with numerous properties lying behind. There is also a section near Ozone Road that has no formal protection; however this backs on to high ground.

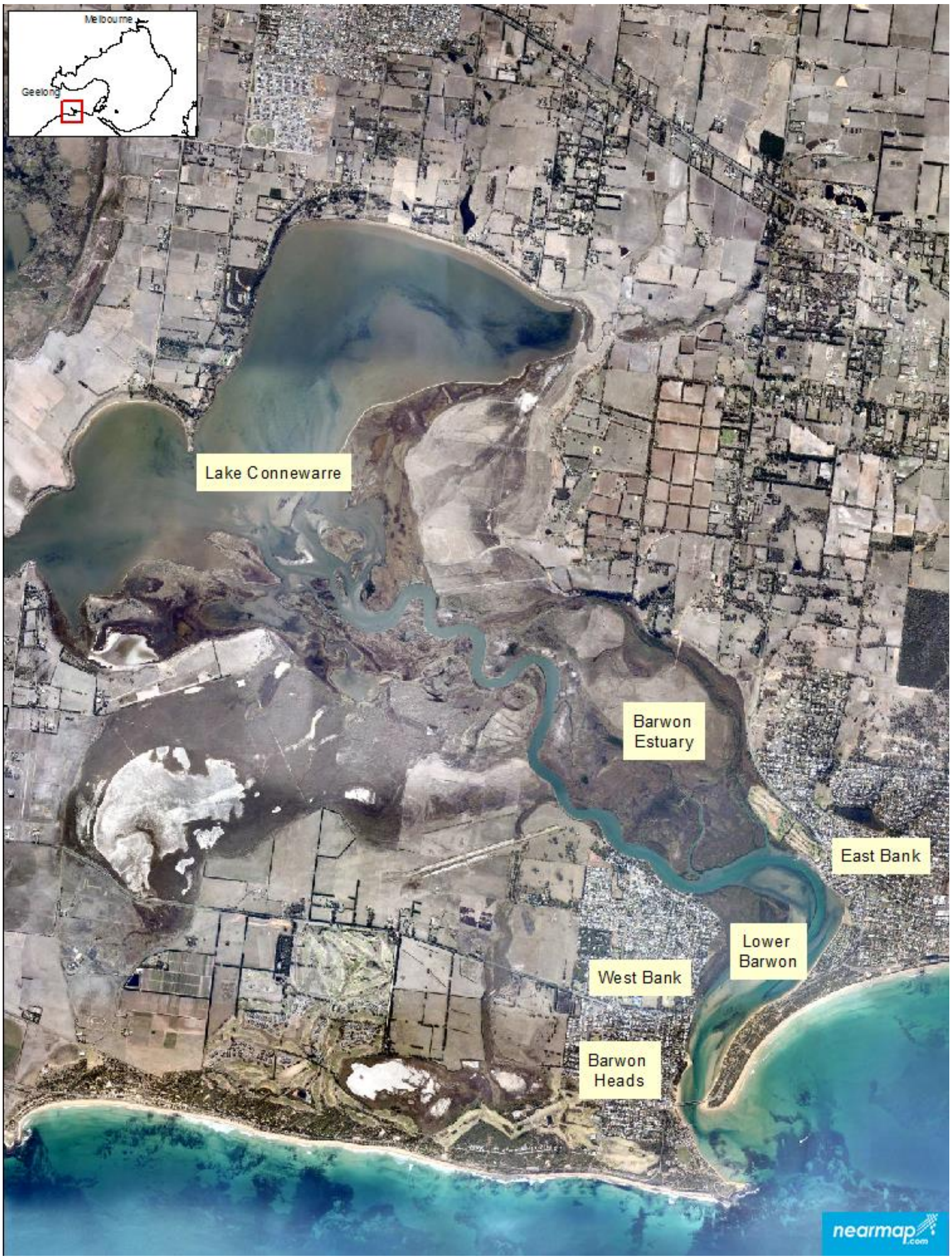


Figure 6-6 Compartment 3: Barwon Heads, Barwon Estuary and Lake Connewarre

The estuary fringes are characterised by very fine muddy sediment, indicative of a low-energy environment. The Ocean Grove spit is protecting the inner reaches of the estuary from wave energy which has allowed the establishment of extensive areas of saline habitat, such as mangroves and saltmarsh. The historic imagery shows some migration of the low water channel which may have contributed to the localised bank erosion. The western bank (Barwon Heads township) is fronted by a series of mostly vertical retaining walls (Figure 6-7a). The eastern bank of the river (Ocean Grove) has erosion protection in the form of a low rock revetment (Figure 6-7b); however this will have little effect against inundation.

The Ocean Grove spit has evolved through the alternate ocean and river pressures. Waves refract around the bluff and deposit sediment in a curved spit, whilst the flowing river contributes to spit formation from the inside. In the past, the spit migrated in response to changing conditions, however now it is largely fixed in place by rock work.

Figure 6-7 (a) vertical retaining wall - western bank Barwon River (b) erosion protection - eastern bank Barwon River (Ocean Grove)

6.3.2 Methodology and modelling

6.3.2.1 Inundation hazard assessment

The Barwon River model and the tidal inflow locations are provided in Figure 6-8. The red, green and blue areas in indicate the different grid sizes which were used in the models, as listed in Table 5-2. The Barwon model was initially set as a 40 m grid (indicated in red) covering the wider Barwon Connewarre area. The large grid-cell resolution was required due to the size of the area as it must capture the storage characteristics of Lake Connewarre. Finer resolution is required to appropriately reproduce features in the township areas. As a result, three nested grids were incorporated to ensure greater detail at the relevant locations, such as the residential areas on the eastern and western banks of the river. One grid was a 20 m resolution (indicated in green) covering Barwon Heads, Ocean Grove and the Barwon River to appropriately assess the estuary entrance conditions to Lake Connewarre. Two 4 m resolution grids (indicated blue) covered Barwon Heads and Ocean Grove individually providing a model that is able to assess the expected impact of sea-level rise on individual properties in the townships. Key development features such as roads and shore protection structures were checked to ensure they were picked up as topographic features, and were refined where necessary. Culverts and pipes located along the main drainage path were incorporated into the model, as indicated by the pink dots in Figure 6-8.

As discussed in Section 4.3.3, the Barwon model was run with the 1% AEP storm-tide case in conjunction with a constant 99th percentile average daily flow (87 m^3/s) in the Barwon River. As with the Breamlea model the modelling was undertaken for a number of sea-level rise scenarios. Additional ‘high flow’ model runs were also undertaken for the 0.0 m, 0.8 m and 1.4 m SLR scenarios where the 10% AEP riverine flood event in the Barwon River was timed to coincide with the peak 1% AEP tide level in the Barwon Estuary.

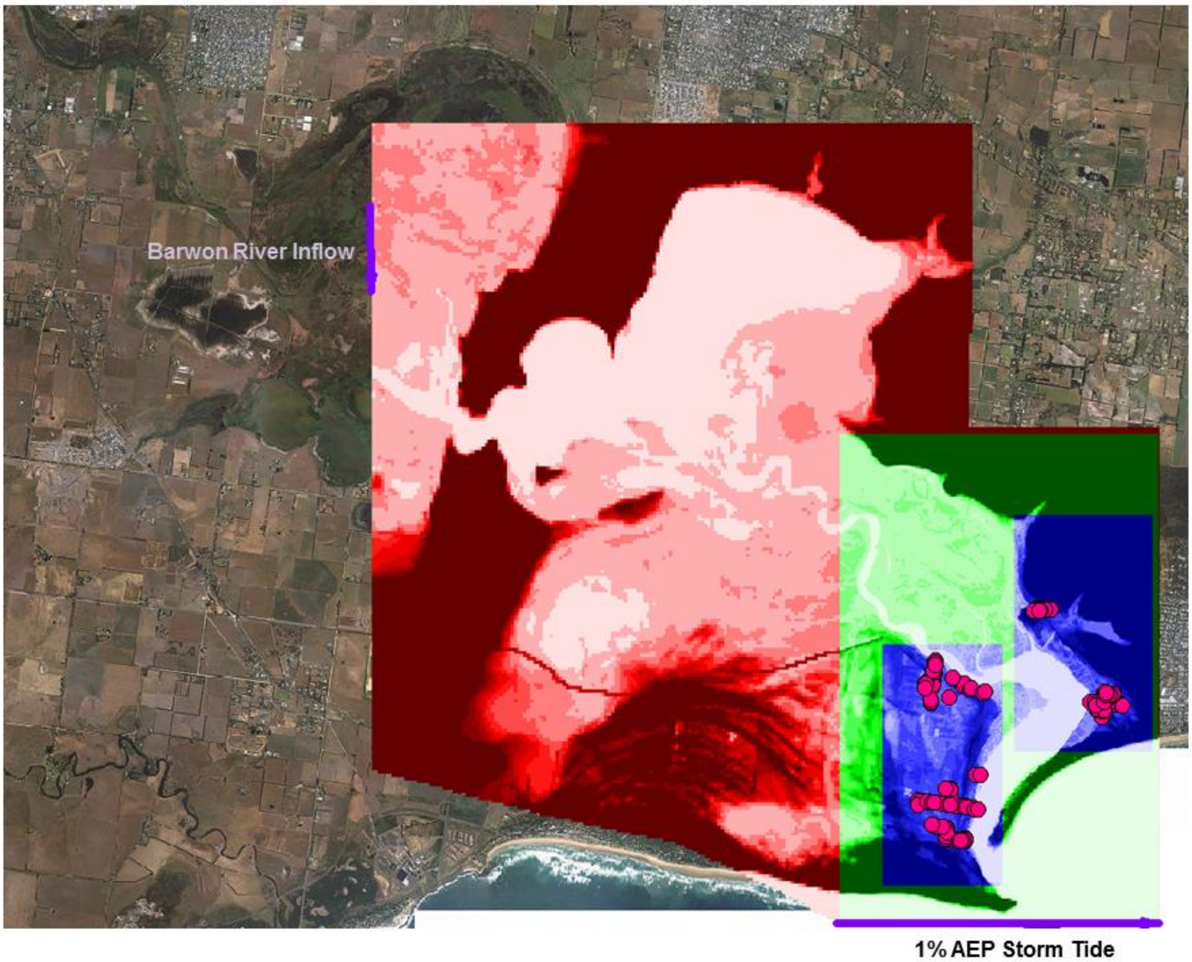


Figure 6-8 Extent of Barwon River model, showing river and tidal inflows and culvert locations (pink circles)

6.3.3 Results

This area is subject to riverine and coastal inundation. Previous studies have shown a significant risk to assets and the hinterland from riverine flooding; therefore the implications of coastal inundation coupled with riverine flooding have been investigated for this study. The probability of the joint occurrence of a 1% AEP storm-tide event and a 10% catchment flow event is very low, therefore a 99th percentile average daily flow baseflow was favoured as the design event. This also gave the opportunity to determine the coastal inundation risk (almost) independently of the catchment flows. To ensure consistency with the scope, a 10% AEP catchment flow sensitivity was also undertaken for selected scenarios.

The inundation extents to for the 1% AEP storm-tide case in conjunction with a baseflow in the Barwon River in combination with various sea-levels is presented in Figure 6-9a. Inundation resulting from the 1% AEP storm-tide case in conjunction with a 10 % AEP catchment flow in the Barwon River is presented in Figure 6-10a. Key locations within the modelled area have been included in the hazard figures, for both flow cases.

The main differences between the flood extents arising from each flow case through the Barwon River occur in the 1% AEP events with 0 m SLR. Under the 10% catchment flow case, the flood extent on the eastern bank of the river near is greater than under the baseflow case, near the caravan park. The differences in extents due to catchment flows on the western bank of the river are less significant for the present day scenario. On the western side of the river, River Parade will be inundated under present day sea- level conditions (0.0 m SLR) if a 1% AEP storm-tide and 10% AEP catchment flow were to coincide. Under a 1% AEP storm-tide and 10% AEP catchment flow event, a low section of River Parade east of Minah St is likely to be overwashed. This would allow flood waters to penetrate inland impacting more of the Barwon Heads township.

As the sea-level rise scenarios increase, so do the flood extents. The overall vulnerability in future is likely to be more significant on the eastern bank of the river at Ocean Grove, due to the low land levels and lack of appropriate shore protection designed for inundation purposes.

Table 6-4 Locations impacted by inundation as identified by the hydrodynamic modelling

Location	Constant flow 87m^3/s in Barwon River	10 % AEP in Barwon River
Over dunes towards Talbot Street	1 % AEP and 0.0 m SLR	Simultaneous 1% AEP + 0.0 m SLR
South West of salt marsh	1 % AEP and 0.0 m SLR	Simultaneous 1% AEP + 0.0 m SLR
Peers Crescent	1 % AEP and 0.0 m SLR	Simultaneous 1 % AEP + 0.0 m SLR
Riverside Road	1 % AEP and 0.5 m SLR	Simultaneous 1 % AEP + 0.0 m SLR
North West of salt marsh	1 % AEP and 0.5 m SLR	Simultaneous 1 % AEP + 0.0 m SLR
Barwon Heads Ocean Grove Road	1 % AEP and 0.5 m SLR	Simultaneous 1 % AEP + 0.0 m SLR
River Parade	1 % AEP and 0.8 m SLR	Simultaneous 1 % AEP + 0.0 m SLR
Wallington Road	1 % AEP and 0.8 m SLR	Simultaneous 1 % AEP + 0.0 m SLR
Ozone St	1 % AEP and 0.8 m SLR	Simultaneous 1 % AEP + 0.8 m SLR
Punt Street	1 % AEP and 0.8 m SLR	Simultaneous 1 % AEP + 0.8 m SLR
Flinders Parade	1 % AEP and 0.8 m SLR	Simultaneous 1 % AEP + 0.8 m SLR
Grove Road	1 % AEP and 1.1 m SLR	Simultaneous 1 % AEP + 1.1 m SLR
Dare St	No inundation	Simultaneous 1 % AEP + 0.0 m SLR
South of River Parade	No inundation	Simultaneous 1 % AEP + 1.4 m SLR

6.3.4 Implications for Coastal Management

Should a 10 % AEP riverine flood coincide with a 1 % AEP storm-tide both sides of the river will be impacted under present day sea-levels. Although the probability of such events coinciding is very low, it is recommended that prior to predicted high Barwon River flows the sea-levels at Portland be examined to ascertain whether a storm-tide is likely to occur, and the timing of this in relation to the expected peak river flows. Section 5.4.1 discusses how the sea-level at Portland can be used to give an indication of the sea-level at the mouth of the Barwon Estuary to warn against potential storm-tide events.

The newly upgraded stormwater pumping station at Barwon Heads along Clifford Parade will aid in managing the effects of river, saline and runoff induced flooding. This area is a low-lying depression that pools water, and three high-capacity pumps have replaced the previous single pump. Although this does not affect the hazard vulnerability, this should be considered in subsequent risk and mitigation assessments. The management triggers are presented in Table 6-5.

Table 6-5 Management triggers - Barwon Heads, Barwon River and Lake Connewarre

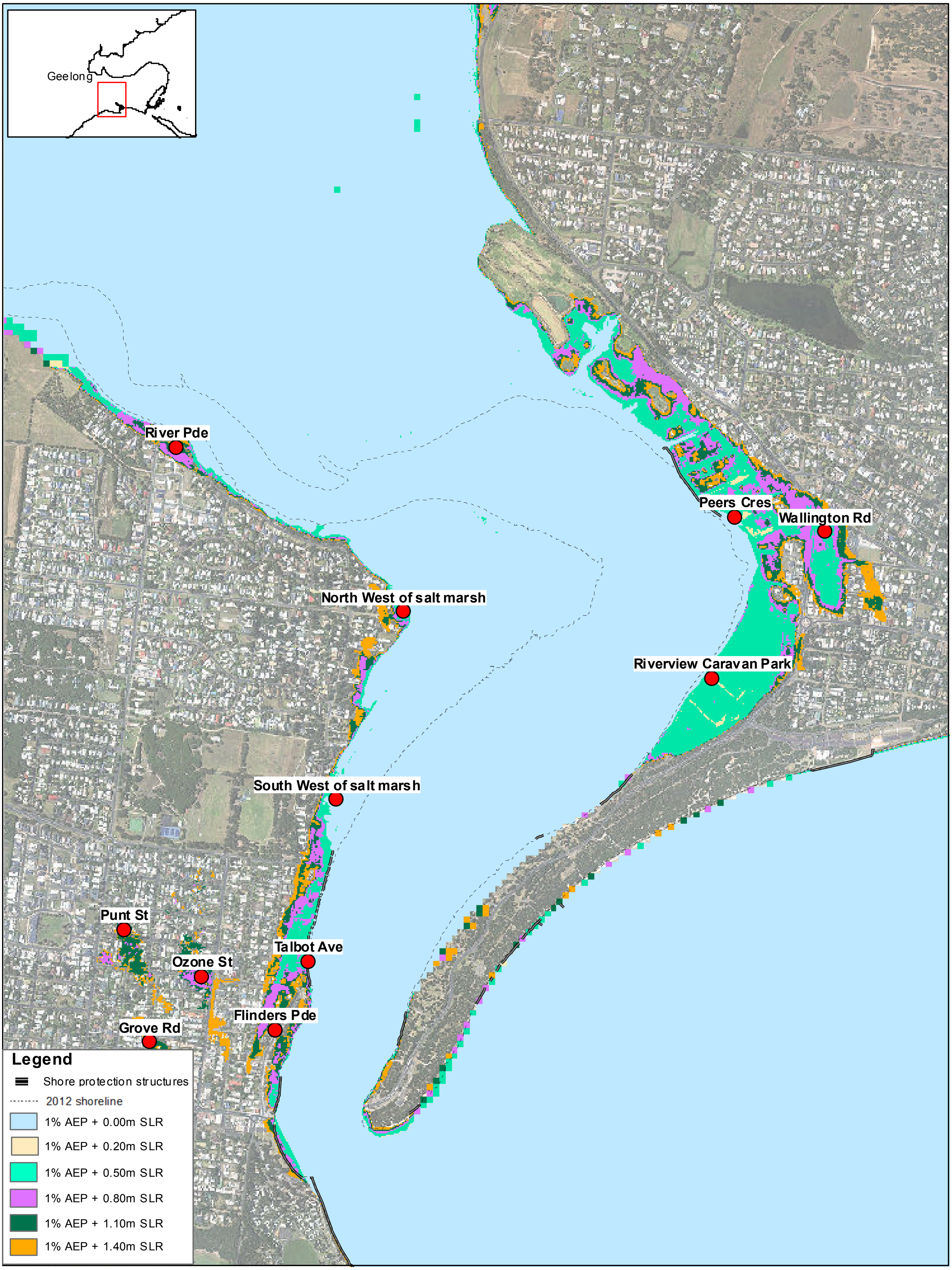
Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation of western river bank (River Parade)	Overwashing of shoreline and shore protection by elevated storm-tide levels + backflow through stormwater infrastructure	1 % AEP storm-tide + baseflow + 0.5 m SLR 1 % AEP storm-tide + 10 % AEP catchment flow + 0.2 m SLR (minor impact) 1 % AEP storm-tide + 10 % AEP catchment flow + 0.5 m SLR (major impact)	A) Investigation and planning / management action required when measured increases in sea-level are in excess of 0.2 m above 1990 sea-levels **and** Sea-level at Portland should be examined in order to predict any possible storm-tide level (see Section 5.6.1) when high flows are expected within the Barwon River.
Inundation of eastern river bank (Riverside Road)	Overwashing of shoreline and shore protection by elevated storm-tide levels	1 % AEP storm-tide + baseflow + 0.2 m SLR 10 % AEP riverine flood + 1 % AER storm-tide at present day sea-level	A) Investigation and planning / management action required when measured increases in sea-level are in excess of 0.5 m above present day levels **and** Sea-level at Portland should be examined in order to predict any possible storm-tide level (see Section 5.6.1) when high flows are expected within the Barwon River.

6.3.5 Further investigations and recommendations

- More thorough surveying of shore protection structures to determine crest levels, the ground elevation at the toe of the structures and general condition. Elevations based on LiDAR were used, and this is a significant uncertainty.
- Continue maintenance of shore protection structures, and investigate ways to improve the standard of protection of these in future.
- Formalise the protection structures on the eastern river bank at Ocean Grove for flood protection purposes in future.
- Sea-level at Portland should be examined in order to predict any possible storm-tide events when high flows are expected within the Barwon River.
- An assessment of the resilience of the estuary saline habitats to increases in sea-level, and identify appropriate areas of land (based on elevation and potential future frequency of inundation) as compensatory habitat areas for the areas that may be lost due to sea-level rise.

6.3.6 Further studies

- Compile an asset register based on the extents of the inundation.
- Undertake a risk assessment.
- Determine and evaluate options to reduce / mitigate risk using a quadruple bottom-line assessment, and the necessary timeframes to rank priority.
- Determine works schedules for future years. This could be done as part of an update to the local management plan incorporating the preferred mitigation option findings.



Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-03-01
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Barwon_low_flow_inundation_critical_locations.mxd 01

Figure 6-9(a)
1:16,000 Scale at A4
Metres
0 100 200

Bellarine Peninsula - Corio Bay LCHA
BARWON ESTUARY
COASTAL INUNDATION MAPPING - HYDRODYNAMIC MODEL
1% AEP EVENT + BASEFLOW + SEA LEVEL RISE (SLR)

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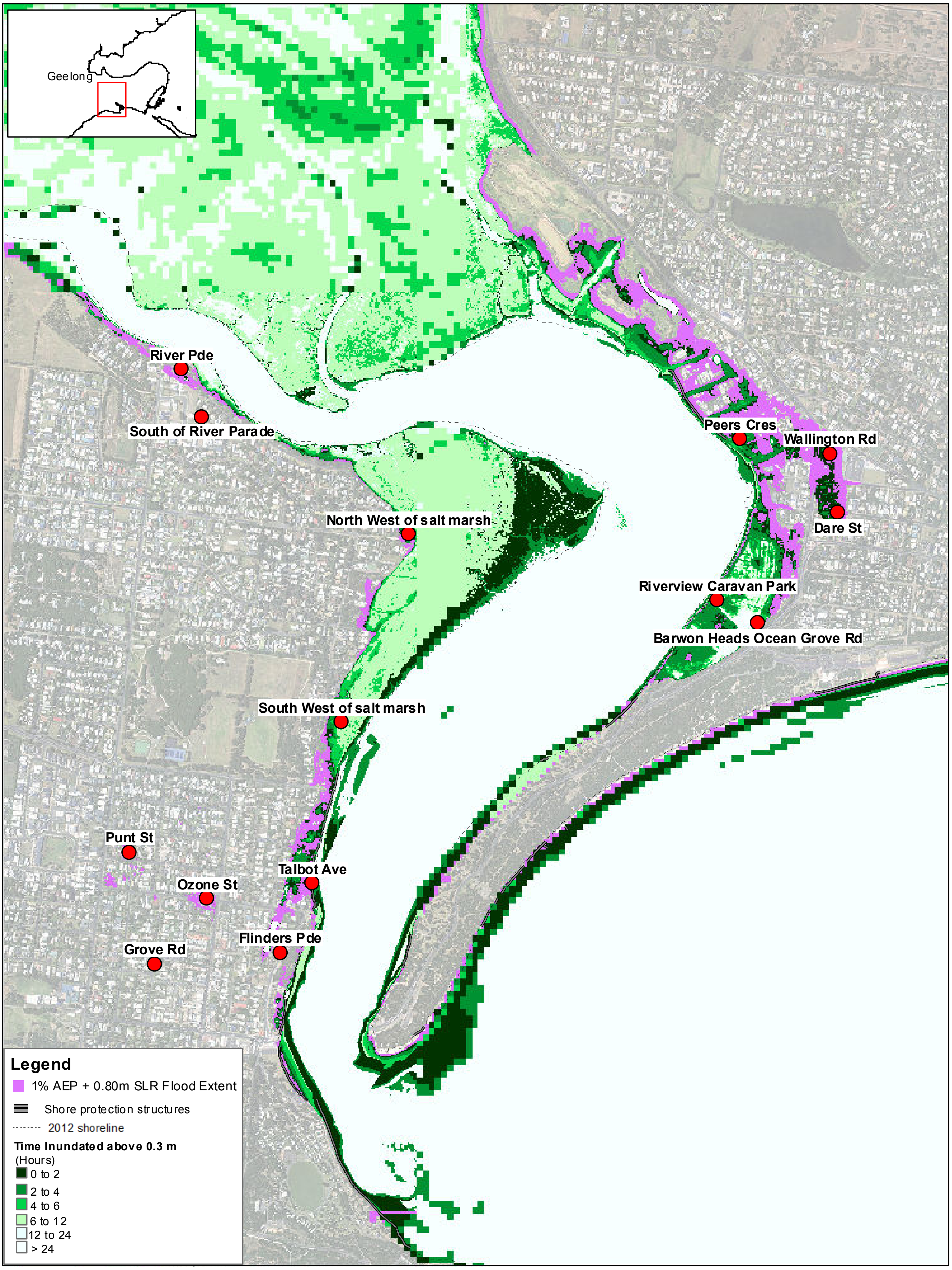

Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-03-01
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: BarwonBase_inundation_timing_v2.mxd 01

Figure 6-9(b)
1:16,000 Scale at A4
Metres
0 100 200

Bellarine Peninsula - Corio Bay LCHA
BARWON ESTUARY - TIMING OF INUNDATION
COASTAL INUNDATION MAPPING - HYDRODYNAMIC MODEL
1% AEP EVENT + BASEFLOW + SEA LEVEL RISE (SLR)

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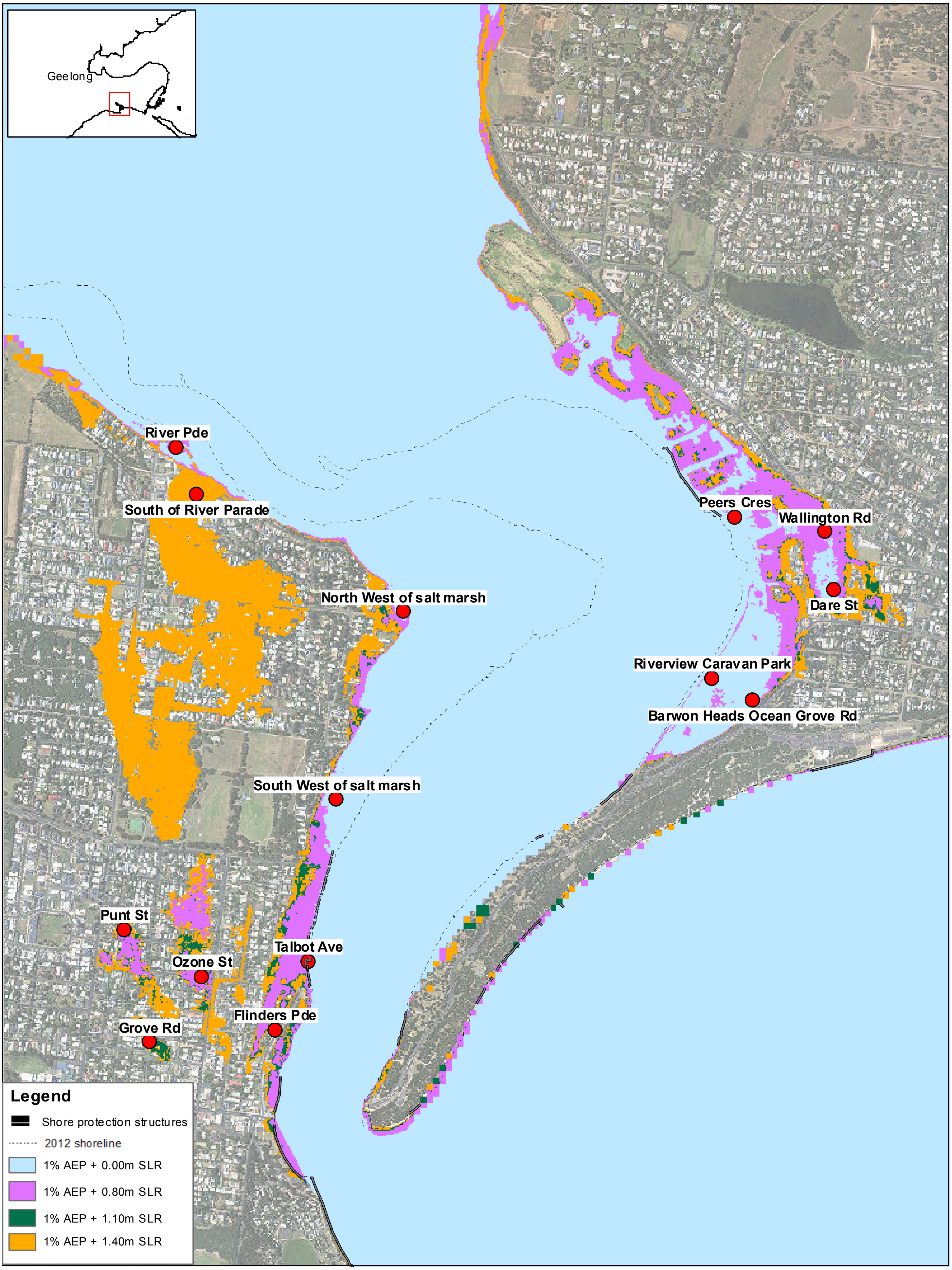

Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-03-01
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Barwon10%_inundation_critical_locations_v3.mxd 01

Figure 6-10(a)
1:16,000 Scale at A4
Metres 0 100 200

Bellarine Peninsula - Corio Bay LCHA
BARWON ESTUARY

COASTAL INUNDATION MAPPING - HYDRODYNAMIC MODEL
1% AEP EVENT + 10% AEP FLOOD + SEA LEVEL RISE (SLR)

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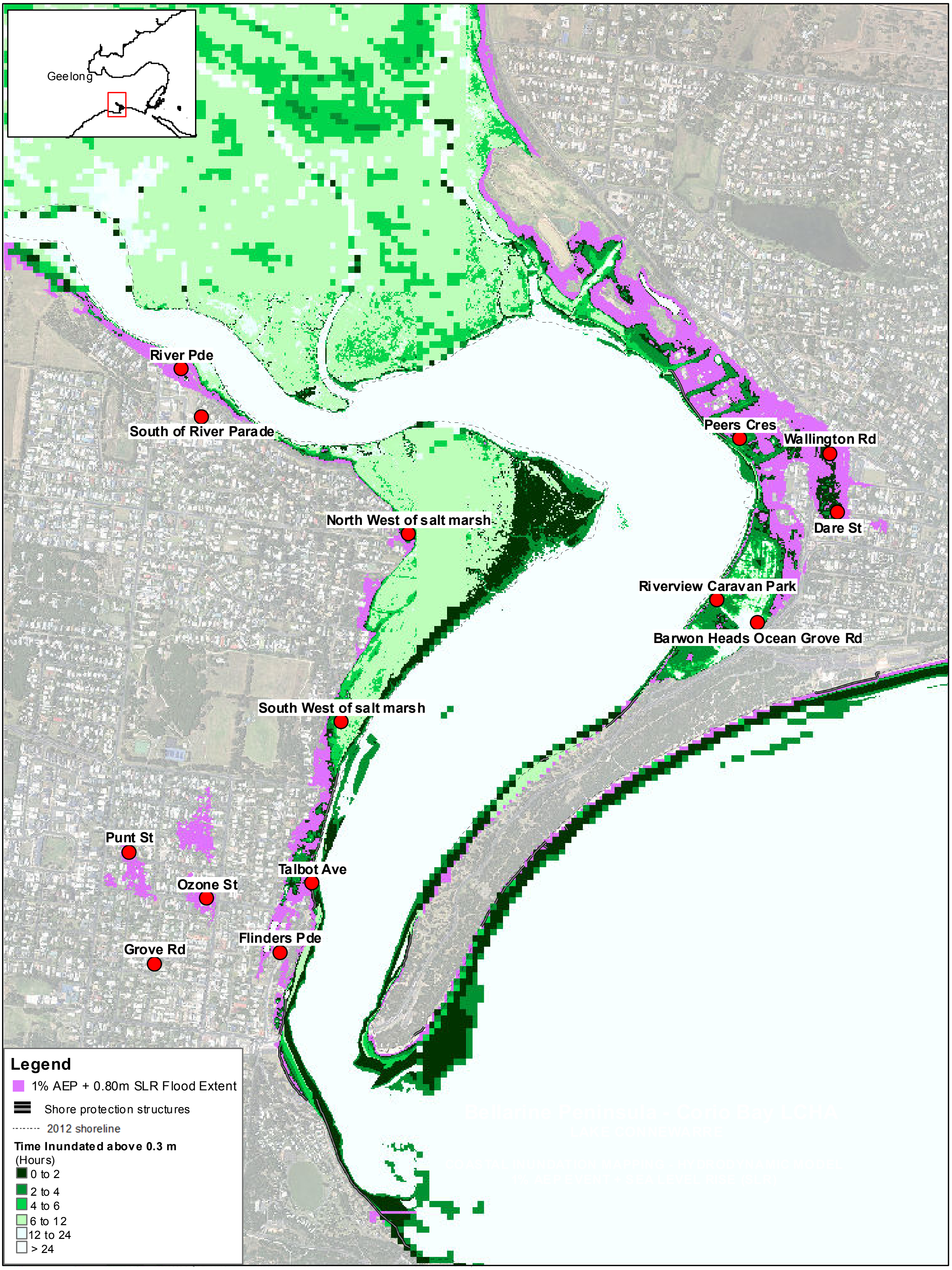

Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
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Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Barwon10%_inundation_timing_v2.mxd 01

Figure 6-10(b)
1:16,000 Scale at A4
Metres
0 100 200

Bellarine Peninsula - Corio Bay LCHA
BARWON ESTUARY - TIMING OF INUNDATION
COASTAL INUNDATION MAPPING - HYDRODYNAMIC MODEL
1% AEP EVENT + 10% AEP FLOOD + SEA LEVEL RISE (SLR)

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6.4 Compartment 4: Ocean Grove to Point Lonsdale

This section of coast is managed by the Barwon Coast Committee of Management. The beach is fixed between two headlands, the Barwon Head in the west, and Point Lonsdale to the east (Figure 6-11). The western end of the beach near the river entrance (Ocean Grove Spit) is very flat and wide, with well-developed dunes that have a good covering of vegetation. A relict low timber wall provides some additional protection to the dunes, and has encouraged the development of a low sparsely vegetated berm seaward of the toe of the dune. Offshore, the bathymetry is very shallow, and wave conditions are lower energy than other regions of the Barwon coastline. The exposure to the dominant south-westerly swells is limited due to the protection of Barwon Head and shallow offshore reefs.

Further east towards Ocean Grove main beach, the beach narrows and steepens slightly. The dunes are high, ranging in elevation from 4 m to 15 m AHD. This section is also where the bathymetry changes from the very shallow ebb delta influenced region to the normal swell / wave influenced type of open coast. It is out of the immediate lee of the headland and thus the wave heights and energy increases towards Point Lonsdale. The dune face is scarped in contrast to the western end, indicating an increase in the wave energy able to penetrate this section of the beach. There is little berm development, and vegetation is returning to the dune scarp which would indicate wave events of the magnitude required to erode this section of dune are not common.

Ocean Grove main beach is similar in nature to the section previously noted, with the addition of a vertical timber and concrete retaining wall in front of the Surf Lifesaving Club. This 200 m wall was upgraded recently, and is positioned approximately 6 m seaward of the toe of the dune. The effects of this seawall are already apparent, with the beach elevation and gradient immediately in front of the wall differing from the surrounding beach, and terminal scour having occurred at the eastern end. This has exposed the eastern flank of the access ramp which has been stabilised with the addition of a geotextile container wall buried at the toe of the dune. This appears to be effective at present.

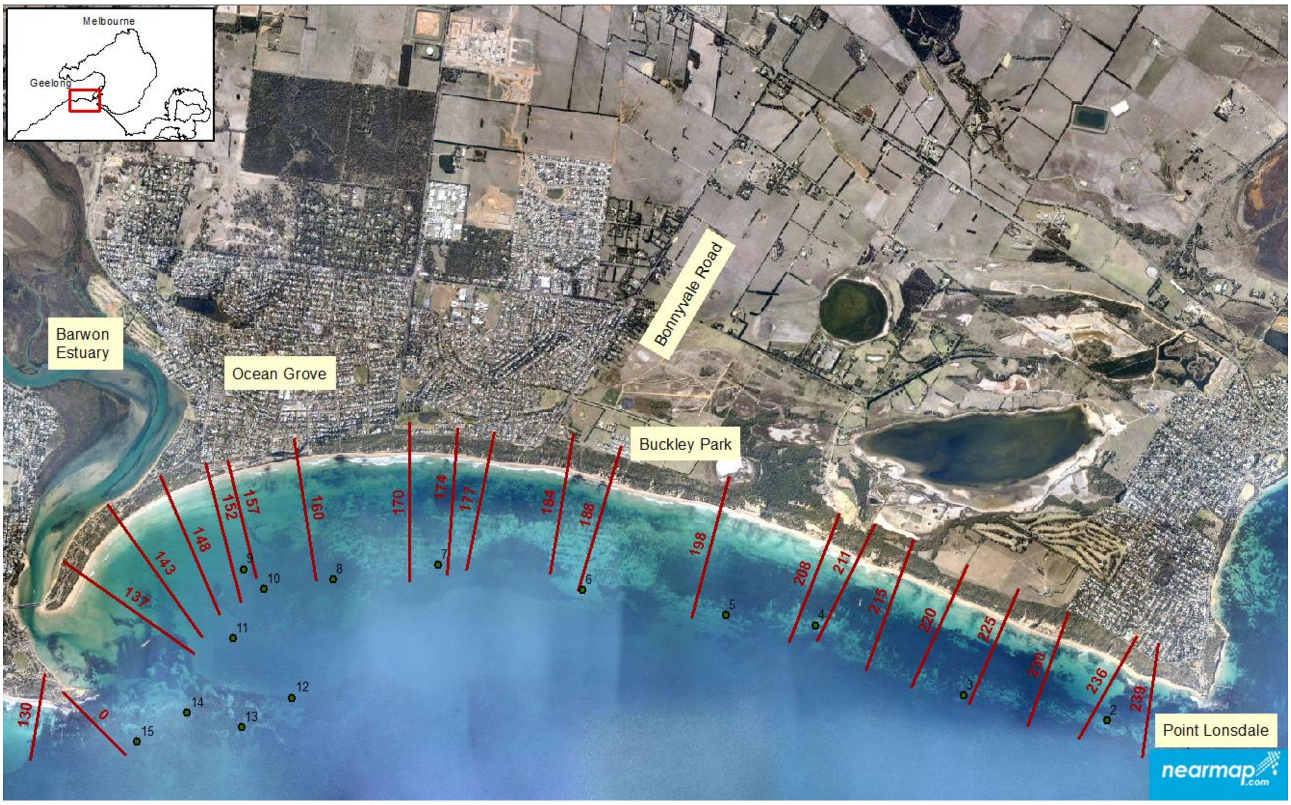


Figure 6-11 Compartment 4: Ocean Grove to Point Lonsdale + cross-shore profiles and wave points

East of the Main Beach towards the Buckley Park foreshore, the beach face steepens slightly and dune heights increase to over 20 m AHD, and are in some places over 150 m wide. Dune faces are scarped, however due to the volume of available erodible material this is of little consequence. The dune is also reasonably erosion resistant owing to a core of calcarenite. A low calcarenite ridge is exposed in some places, and where exposed, is at a similar elevation and depth within the dune system. In the absence of cores, it is sensible to assume the ridge runs in a low band approximately 30 m landward from the toe of the dune at an elevation of approximately 4.5 m AHD from Point Lonsdale west until at least Bonnyvale Road, at Ocean Grove. Upper ridges also exist within the dune, however these are at a considerable elevation and distance from the toe of the dunes/cliffs. Nearer to Point Lonsdale, higher and wider ridges of calcarenite exist, linking into the Point Lonsdale headland. The beach is very healthy and poses little to no hazard risk to the hinterland. The hazards here are more environmental, associated with dune blowouts smothering vegetation, and possibly fire risk. There is also a beach access structure from Ocean Road that may be subject to vulnerability; this has been redesigned in recent years to a piered structure, after a number of previous solid structures failed.

No inundation maps were produced for this area, as there is no inundation hazard risk to the hinterland from the coast. Possible flooding of Lake Victoria is noted in Section 6.5.

The seawall at Ocean Grove Main Beach is providing a high standard of protection to the hinterland presently. Overtopping volumes under a 1% AEP event for the present day (i.e. 0.0 m SLR) are low, less than 0.1 litres per second per metre (L/s/m). For 1 % AEP events with sea-level rise greater than 0.5 m, overtopping discharge volumes increase to greater than 5 L/s/m. This discharge would not be expected to be sufficient cause the structure to fail if it is maintained to the current standard; however, this discharge would increase the risk to the pavements and promenades behind, as well as any nearby pedestrians (Table 6-7 gives some information on overtopping discharges). Beach levels at the toe of the seawall are likely to decrease due to scour erosion, therefore increasing the depth of water at the toe of the structure during storm conditions. This in turn will allow larger waves to penetrate further inshore and increase overtopping. The rate of loss of beach volume is currently unknown, and should be monitored to inform future assessments.

6.5 Compartment 5: Point Lonsdale to Point Edwards

6.5.1 Locations Overview

This section of coast is managed by the Borough of Queenscliffe and extends from Point Lonsdale back beach (open coast) to Swan Bay as shown in Figure 6-12. This section of coast consists of steep eroding cliffs, various shore protection methods, sandy beaches and the Swan Bay area.

6.5.1.1 Point Lonsdale & Lonsdale Bight

The headland at Point Lonsdale is formed of Pleistocene calcarenite and has fixed the entrance of Port Phillip Bay on the western side. Shore platforms have formed at the base of the cliffs and provide some protection to the base of the cliffs. Within the bay, the cliffs line the shore until the Point Lonsdale township where the elevation drops, and a sandy beach has formed between Point Lonsdale and Shortland Bluff, where another significant outcrop of calcarenite exists and has again fixed the position of the shore.

It has been estimated that approximately 200,000 m^3 of sediment passes around Point Lonsdale from Ocean Grove in a year (Cardno, 2011a); however with strong tidal currents and southern swells penetrating the bay as far as The Sands, this material rapidly moves through Lonsdale Bight. Significant shore protection structures exist for most of Lonsdale Bight. A bluestone seawall was constructed in front of the township in the early 1900s to limit recession. A recurved lip is fixed to the structure approximately two thirds of the way up the front face to deflect wave energy (Figure 6-14b). The condition of the seawall now is 'moderate' according to the DSE (now DELWP) structures database. Issues with run-off have seen the wall crack in some locations and works have been carried out to allow water to pass through the structure. The effects of wave impact are also very visible in some locations with bricks and mortar removed and repaired both in the frontal wall section, and the wall behind the promenade (Figure 6-14a). The promenade is also cracking indicating some possible subsidence (Figure 6-14d).

The masonry wall was extended a number of times. As time passed, due to the terminal scour effects, it was seen as necessary to construct further rock revetments to limit the recession and protect the assets behind. There are visible 'step backs' along the Lonsdale Bight as the wall and revetment have been extended over the century (Figure 6-13). The end of the revetment is now at Dog Beach, where terminal scour has resulted in local recession the beach of more than 20 m. This recession is now stable, and since 1996 the scarp has not receded significantly.

6.5.1.2 Queenscliff

The coastal section of Queenscliff from Shortland Bluff to the Queenscliff Creek decreases in elevation from 15 m at the bluff to less than 2 m further north. The base of the bluff has been stabilised with a masonry seawall. A narrow strip of beach exists in front of a vegetated dune. The dune is low-lying and approximately 30 m wide at the narrowest section near the Pilots Jetty, and 130 m wide at the north-eastern end of the beach near the ferry terminal. Construction of the training walls and harbour works has resulted in a large accumulation of sand as far back as the Queenscliff Pier and Port Phillip Bay Sea Pilots Jetty. Much of the foreshore land is now occupied by developments associated with the harbour and ferry terminal. The wave energy here is lower than within Lonsdale Bight, with the bluff protecting against some of the swell energy penetrating from Bass Strait.

The maintenance of the harbour entrance has induced a significant change in the geomorphology of the Queenscliff and Swan Island areas. The narrow channel fills with northerly transported sediments; rates of approximately 80,000 to 100,000 m^3/yr have been estimated as the net flux along this section of coast based on dredging records (Cardno, 2011a). The entrance is regularly dredged and the material is pumped north where it has formed a large sand island now attached to Swan Island.

Figure 6-12 Compartment 5: Point Lonsdale to Point Edwards + cross-shore profile locations

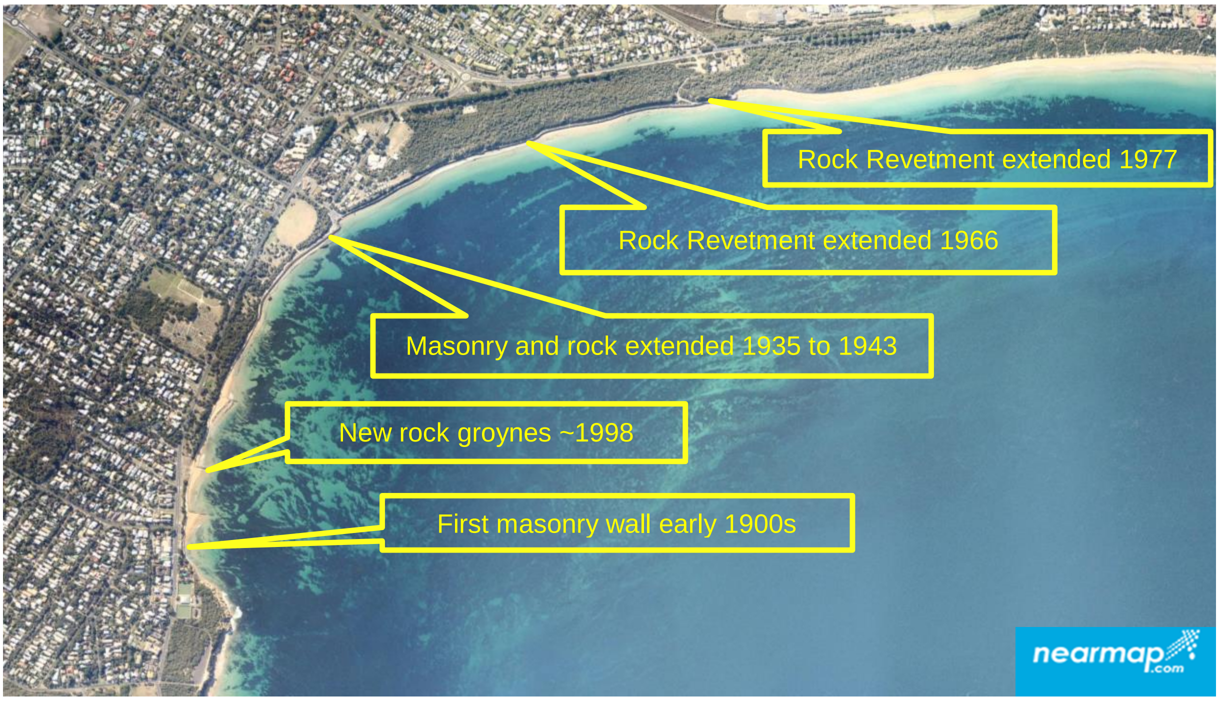


Figure 6-13 History of protection works in Lonsdale Bight (based on Bird, 2011)

Figure 6-14 (a) missing wall stones behind promenade, (b) drainage through structure, (c) lower section of wall with no recurve lip, (d) cracks in promenade

6.5.1.3 Swan Bay & Lakers Cutting

Swan Bay is an important area supporting natural wetland habitats. It is part of the Port Phillip Bay Ramsar site, and includes the wetlands fringing Swan Bay as well as the Swan and Rabbit Islands (Figure 6-12). The characteristics of this area are more like a saline lake than an estuary. The barrier islands enclose the bay and limit the tidal range and the wave energy able to enter. There are two main tidal entrances, the natural channel, just south of Edwards Point, and the Cut, an artificially created channel that originally formalised the path of the Queenscliff creek. Waves within the bay are small due to the limited fetch. The depth of the bay and extensive seagrass beds also dampen wave energy and limit the possible wave heights within the bay. At the southern end of the bay, Lakers Cutting, a former shell-grit mining site, feeds the newly established Lonsdale Lakes development canals and artificial lakes. The water enters through a series of channels and culverts beneath the roads. There is a one-way valved culvert beneath the railway embankment that feeds through underneath the Bellarine highway through another (non-valved) culvert. The passage of water into and out of the artificial lake system is indicated in Figure 6-15.

Figure 6-15 Lakers Cutting and the Lonsdale Lakes Estate - feeder channel (and flood route) in blue

6.5.2 Methodology - Inundation and Overtopping Hazard Assessments

The following design conditions were used in the inundation and overtopping assessments (Table 6-6). Both hydrodynamic and static inundation methods were employed.

Table 6-6 Design conditions for the hazard assessments

Location	Waves (Hs)	Storm-tide levels					
		0.0m m SLR	0.2 m SLR	0.5 m SLR	0.8 m SLR	1.1 m SLR	1.4 m SLR
	m	(m AHD)	(m AHD)	(m AHD)	(m AHD)	(m AHD)	(m AHD)
Point Lonsdale (RipBank, open coast)	4.55	1.75	1.95	2.25	2.55	2.85	3.15
Lonsdale Bight	0.9 -1.41	1.29	1.49	1.79	2.09	2.39	2.69
Lakers Cutting & Swan Bay (West Channel Pile)	n/a	1.06	1.26	1.56	1.86	2.16	2.46
Queenscliff	0.87 - 1.1	1.20	1.40	1.70	2.00	2.30	2.60

6.5.2.2 Overtopping Hazard Assessment - Lonsdale Bight coastal protection structures

Overtopping was calculated for the seawall and revetment sections of shoreline where assets were located behind the structures. The significant investment in these shore protection structures and the development that has occurred behind means that these structures are likely to be maintained indefinitely. Note, as sea levels increase, the maintenance requirements of these structures will also increase.

Assessing the overtopping gives an indication of which scenario results in overtopping discharges in excess of safe limits, or scenarios under which the structures may fail. For the vertical wall section, these have been calculated for the narrowest lowest sections of beach beneath the structure (i.e. not where sedimentation between the groynes has elevated the beach level), this is where the greatest water depth at the toe of the structure is able to transmit the largest waves (Figure 6-16). This will ensure the most conservative estimate of overtopping discharge (i.e. worst case). Note, the assessment was done on the lower section of the vertical seawall beneath the lower promenade, rather than the upper wall that is flush with street level. The street elevation and upper wall is approximately 1.5 m higher and should be considered in subsequent risk studies. The assessment used the Lonsdale Bight wave and storm-tide conditions (summarised in Table 6-6).

Figure 6-16 Locations of overtopping calculations at Point Lonsdale (a) vertical seawall in front of township (b) rock revetment near Lawrence Rd (Images: Google)

6.5.2.3 Queenscliff Inundation

The lack of complexity of flooding in the very low-lying foreshore area of Fisherman's Flats inside the Queenscliff Cut meant that a static inundation model was sufficient to identify the hazards. It is noted that the LiDAR used in the assessment was captured prior to the refurbishment of the Queenscliff harbour and marina. BoQ provided design drawings of the developed areas to confirm the new land levels and quay wall elevations are the same or higher than those in the LiDAR to ensure the assessment was still valid. The flow paths into the inundated area are from the Fisherman's Flats. The extents within this vicinity will need checking in future revisions of this assessment when new datasets become available. The model used the West Channel Pile design storm-tide levels as they are considered to be more representative of the inner Swan Bay and Fisherman's Flats areas (Table 6-6).

6.5.2.4 *Swan Bay inundation*

A simple static model was used for this very low and very flat area. No erosion figures have been produced for Swan Bay as the overriding hazard here is inundation.

6.5.2.5 *Lakers Cutting Hydrodynamic Inundation Model*

The model used a grid size of 4 m in order to capture the required detail. Culverts were incorporated into the model at five locations along the main drainage path identified by the pink dots in Figure 6-17. Key development features such as roads, railway embankments, drains and shore protection structures were checked to ensure they were picked up as topographic features, and were refined where necessary.

The model was run for the 1% AEP storm-tide case in combination with a number of sea-level rise scenarios to determine the extents of inundation that may arise. The model used the West Channel Pile design storm-tide levels as they are representative of the inner Swan Bay area (Table 6-6).

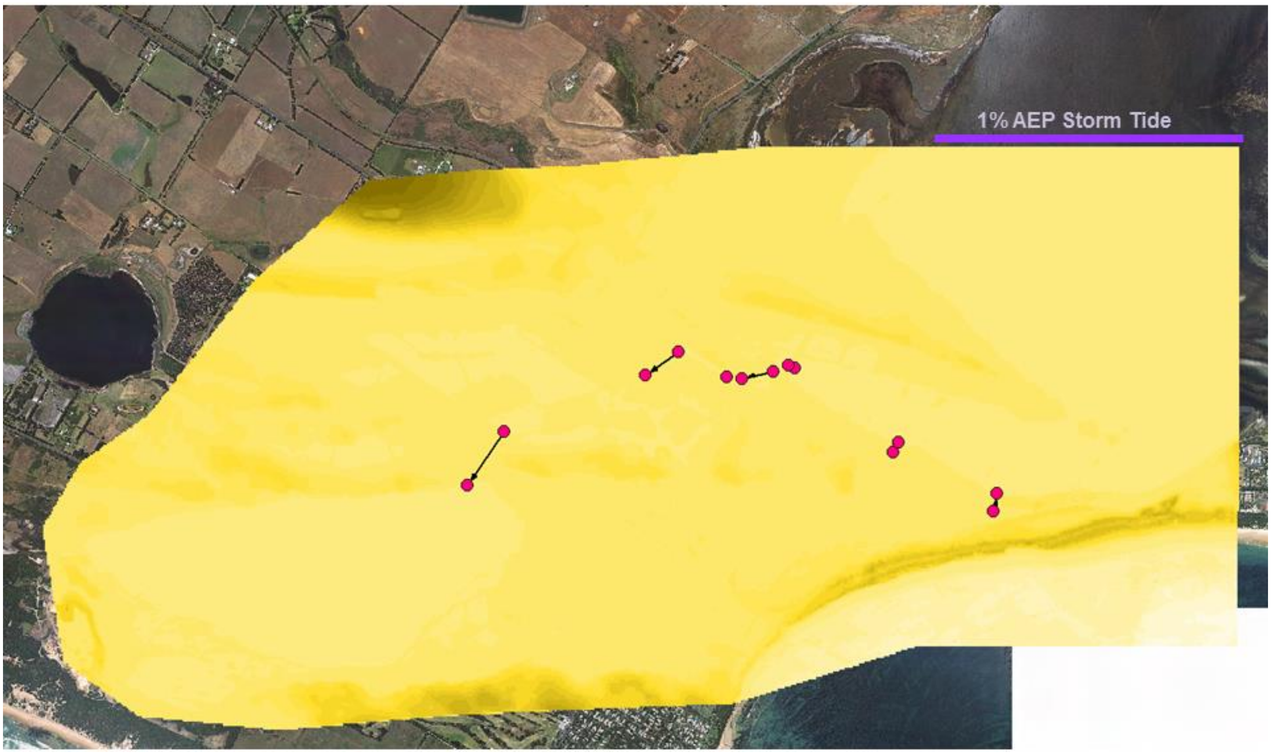


Figure 6-17 Extent of Lakers Cutting model, showing tidal inflow and culvert locations (pink circles)

6.5.3 Results

6.5.3.1 *Overtopping - Lonsdale Bight*

The results of the overtopping assessment are presented in Table 6-7. Discharges are presented in units of litres per second per metre (L/s/m). The results show that under the higher sea-level rise scenarios, the overtopping hazard of the structures increases.

Table 6-7 Lonsdale Bight Overtopping

Location	Overtopping discharge (L/s/m)					
	1% AEP + 0.0m m SLR	1% AEP + 0.2 m SLR	1% AEP + 0.5 m SLR	1% AEP + 0.8 m SLR	1% AEP + 1.1 m SLR	1% AEP + 1.4 m SLR
1	29.1	120.2	fail	fail	fail	fail
2	14.5	63.3	fail	fail	fail	fail
3	38.6	172.4	fail	fail	fail	fail
4	0.003	0.2	5.7	62.6	fail	fail
5	0.00	0.002	0.1	2.2	15.3	69.8

Key:

0.1 L/s/m = mean discharge for pedestrian safety

1 - 50 = unsafe for pedestrians

50 – 200 = very hazardous to people and vehicles, some pavement or promenade damage

>200 L/s/m = damage to paved or armoured promenade behind seawall (this could be considered a discharge that would fail a structure).

N.B. The results assume the condition and the elevation of the current structures are maintained.

6.5.3.2 Inundation - Queenscliff & Swan Bay

The inundation extent for Queenscliff (Fisherman's flats) under the 1% AEP storm tide in combination with various sea-levels is presented in Figure 6-18. This shows that under a present day inundation event, there is the potential for saline inundation of Fisherman's Flats. Note, the mechanism for flooding here will be overwashing of the very low-lying shoreline near Bay and Bridge St at Fisherman's Flats, rather than via the front beach or marina area, which are at greater elevations than Fisherman's Flats. Only under the higher sea-level rise scenarios is there the potential for flooding via these flowpaths.

The inundation extents for Lakers Cutting are in Figure 6-19. The events under which inundation occurs at select locations, identified by the red dots in Figure 6-19, have been listed in Table 6-8. The most significant impact of a 1% AEP storm-tide within Swan Bay is that shoreward of the Marine Discovery Centre and sections of Murray Road would both be inundated at the present day sea-level. The Marine Discovery Centre itself should avoid flooding below a 0.8 m rise in sea-level but the actual floor levels of the building would have to be verified to be certain. The Bellarine Highway comes under threat in a 1% AEP event with 0.5 m SLR, however, note that the road is low lying and local rainfall runoff coupled with saline inundation may cause flooding in lower events. The stormwater infrastructure should be assessed to ensure the risk of this is minimised. A figure showing the timing of inundation for Lakers Cutting is shown in Figure 6-20. This will aid in informing subsequent risk assessments.

Table 6-8 Critical inundation locations identified in the Lakers Cutting model

Location	Event Resulting in Inundation
Murray Road	1 % AEP at present day sea-level
Shoreward of Marine Discovery Centre	1 % AEP at present day sea-level
Bellarine Highway	1 % AEP and 0.5 m SLR
Emily Street	1 % AEP and 0.8 m SLR
Flinders Street	1 % AEP and 1.1 m SLR

Inundation for Swan Bay is shown in Figure 6-21 for the south western end, and Figure 6-22 for the northern end.

6.5.4 Implications for Coastal Management

6.5.4.1 Lonsdale Bight

The vertical wall sections at Point Lonsdale are subject to direct wave forces during storm conditions; this is reflected in the overtopping results. This is also consistent with visual inspection of the wall during the April 2013 site visit, which saw some sections of the bluestone façade removed during a recent storm event. This would be expected with discharges in the order of those presented for Locations 1-3 for the 0.0 m SLR scenario in Table 6-7. It is noted that the overtopping volumes relate to a failure under a SLR of 0.5 m, however, the volume discharges for the lesser SLR scenarios are still very high and would be expected to cause significant damage. Thorough maintenance of this area is required to ensure the viability of the wall. The western wall section has limited beach fronting it, making it more vulnerable to wave impact and undermining.

The revetments have a higher standard of protection in terms of overtopping discharge than the vertical seawall. This is for two reasons. Sloped (non-paved) revetments are designed to absorb wave energy, this reduces overtopping discharges. Also, wave energy dissipates as it enters Port Phillip Bay and the effects of open coast swells lessen with distance from the bay entrance. This reduces wave heights with distance from the entrance, and thus overtopping discharges. The crest elevation is higher at Location 5 and is representative of the newer section of the rock revetment beyond Lawrence Road, which also reduces the overtopping discharges. During the April 2013 site visit, it was noted that the revetments are showing some evidence of out-washing of material as it appears there is no geotextile layer beneath the armouring. This leaves the structure vulnerable to wave action, resulting in erosion of the land beneath / behind.

The management triggers are presented in Table 6-9.

Table 6-9 Management triggers - Point Lonsdale and Lonsdale Bight

Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Failure of shore protection structures (seawalls)	Failure due to wave impact, undermining, or excessive overtopping	1% AEP event + 0.5 m SLR	Investigation and planning / management action required when measured increases in sea-level are in excess of 0.1 m above 1990 levels. Although the overtopping discharges for the 1% AEP event + 0.2 m SLR scenario are not likely to be sufficient to fail the structure, they are sufficient to cause significant damage and should be planned for ahead of time.
Failure of shore protection structures (revetments)	Failure due to wave impact, out-flanking, or excessive overtopping	1% AEP event + 1.1 m SLR	The condition of the revetment is good at present, especially the newer sections. Some evidence of out-washing of the structure is visible near Dog Beach. Although the risk of failure due to overtopping is low, the out-washing needs to be monitored. Triggers related to this location should be linked to engineering inspections as well as SLR.

6.5.4.2 Queenscliff (Fisherman's Flats)

Information from Borough of Queenscliffe indicates that water pools in depressed areas during high rainfall events, and upgrades to stormwater infrastructure will be carried out to remedy this. As Figure 6-18 shows, the Fisherman's Flats area of Queenscliff is vulnerable to inundation under present day storm-tide conditions. Although some shore protection exists in the inner bay area, these are low retaining walls that are not forming a consistent barrier. They are canaled in some locations to allow for surface water to drain, however under storm-tides, these will likely become flood routes. Under the higher sea-level rise inundation events of 1.1 m and 1.4 m, flooding from the main front beach and Fisherman's Flats is expected to join.

The management triggers are presented in Table 6-10.

Table 6-10 Management triggers - Queenscliff

Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation	Over-washing of the shoreline during storm-tides, coupled with surface flooding	1% AEP event + 0.0 m SLR	A) Investigation and planning / management action required immediately.

6.5.4.3 Lakers Cutting & Swan Bay

Lakers Cutting links the southern end of Swan Bay to the newly established Lonsdale Lakes estate, the Bellarine Highway and Shell Rd. This area was dynamically modelled due to the complexity of the inundation mechanisms. This area also includes the area where the Bellarine Highway links to Flinders St in Queenscliff. This is the only way in or out of Queenscliff, other than the ferry.

The Lakers Cutting and Lake Victoria coastal inundation extents are presented in Figure 6-19. This shows a complex network of channels and overland flow paths. Under the 1% AEP event + 0.2 m SLR the inundation extent increase significantly and starts to impact shoreline assets.

For Swan Bay, the inundation hazards are less significant in the short-term. Much of the wider shoreline of Swan Bay is agricultural land, therefore asset vulnerability is low. One key area of note is the Swan Bay Holiday Park, which is positioned on the shoreline at the end of Swan Bay Rd Figure 6-21). The key issues will be related habitat resilience. The surrounding land areas rise gradually to higher land, therefore there appears to be nothing inhibiting any natural roll-back with sea-level rise.

The northern end of Swan Bay includes the southern end of St. Leonards (Figure 6-22). This area is likely to be subject to estuarine flooding from Swan Bay, as well as normal coastal inundation of the shoreline. This will occur under a 1% AEP event + 0.2m SLR, but will be most significant in a 1% AEP event + 0.5 m SLR and above, due to potential depths.

The management triggers are presented in Table 6-11.

Table 6-11 Management triggers - Lakers Cutting & Swan Bay

Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation - Lakers Cutting	Overwashing of the shoreline during storm-tides + sea-level rise	1% AEP event + 0.2 m SLR	A) Investigation and planning / management action required immediately.
Inundation / Erosion - Swan Bay	Erosion and inundation of the shoreline due to storm-tide inundation and increases in normal tidal extents + sea-level rise	1% AEP event + 0.2 m SLR	A) Investigation and planning / management action required immediately, however the mobile / adaptable nature of a Holiday Park infrastructure means this may be a lower priority. A) Investigation and planning / management action required when measured increases in sea-level reach 0.1 m above 1990 levels in relation to 'backdoor' and coastal inundation of the southern end of St. Leonards.

6.5.5 <u>Further investigations & recommendations</u>

- Regular condition assessments of the seawall and revetments should be undertaken by qualified engineers, yearly and after significant storm events.
- The rates of loss of material at the toe of the seawalls should be monitored where necessary.
- Monitoring of the beaches in this location (e.g. profile surveys, photographs) is recommended to more closely document the rates of change along the beaches. This will provide better background information to inform more detailed future assessments. Frequency of profiling will depend on available funds and resources, suggest teaming with DELWP to determine how best to approach the monitoring and the methods. Generally, the following is recommended:

  - profiling at the end of each season (or at least summer and winter), as well as after significant storm events
  - 10 - 15 profiles at key locations along Lonsdale Bight, and/or where there is a significant change in the beach morphology or where shore protection structures change
  - 5 - 10 profiles at key locations along Queenscliff Beach and Sand Island, and/or where there is a significant change in the beach morphology
  - photographs of the shoreline taken at the same times as profiles are surveyed, preferably at a fixed and known sites facing the same direction

- Management options and adaptation response planning to address the inundation vulnerability should be undertaken in the near future.
- Investigate habitat resilience and adaptability to climate change and sea-level rise for Swan Bay.
- More detailed investigation and/or modelling of the combination of inundation paths at St. Leonards.

6.5.6 Further studies

- Compile an asset register based on the extents of the inundation.
- Undertake a risk assessment.
- Determine and evaluate options to reduce / mitigate risk using a quadruple bottom-line assessment, and the necessary timeframes to rank priority.
- Determine works schedules for future years. This could be done as part of an updated local management plan incorporating the preferred mitigation option findings.

Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-19
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Swan_Bay_Qu_v2.mxd 01

Bellarine Peninsula - Corio Bay LCHA

QUEENSCLIFF - FISHERMAN'S FLATS

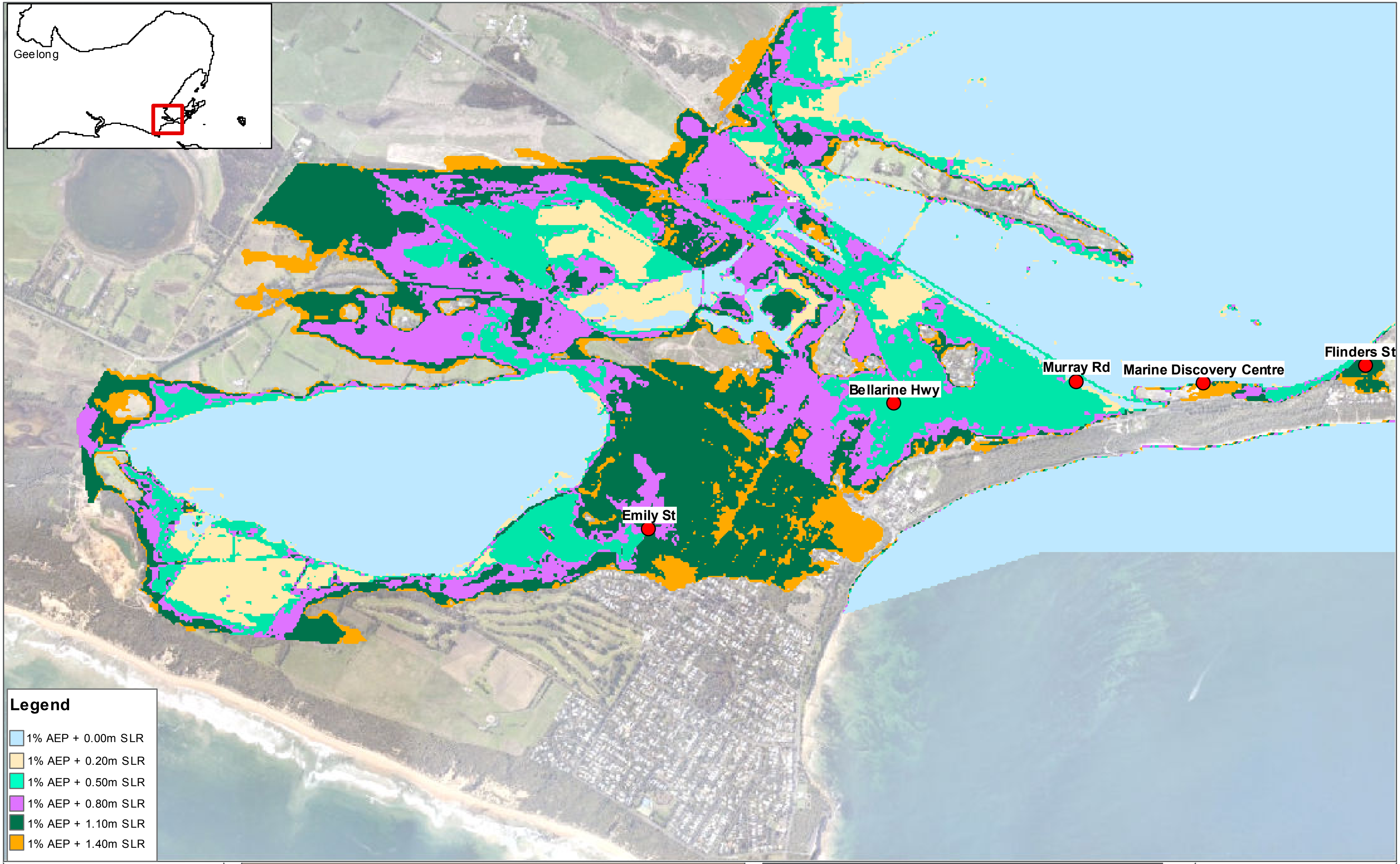
COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

Figure 6-18

1:8,000 Scale at A4

Metres
0 100 200 300 400

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Swan_Bay\Coastal_Inundation_Swan_Bay_Qu_v2.mxd



Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-19
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_SwanBay_Lakers_Cutting_v2.mxd 01

Bellarine Peninsula - Corio Bay LCHA

LAKERS CUTTING - LAKE VICTORIA

COASTAL INUNDATION MAPPING - HYDRODYNAMIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

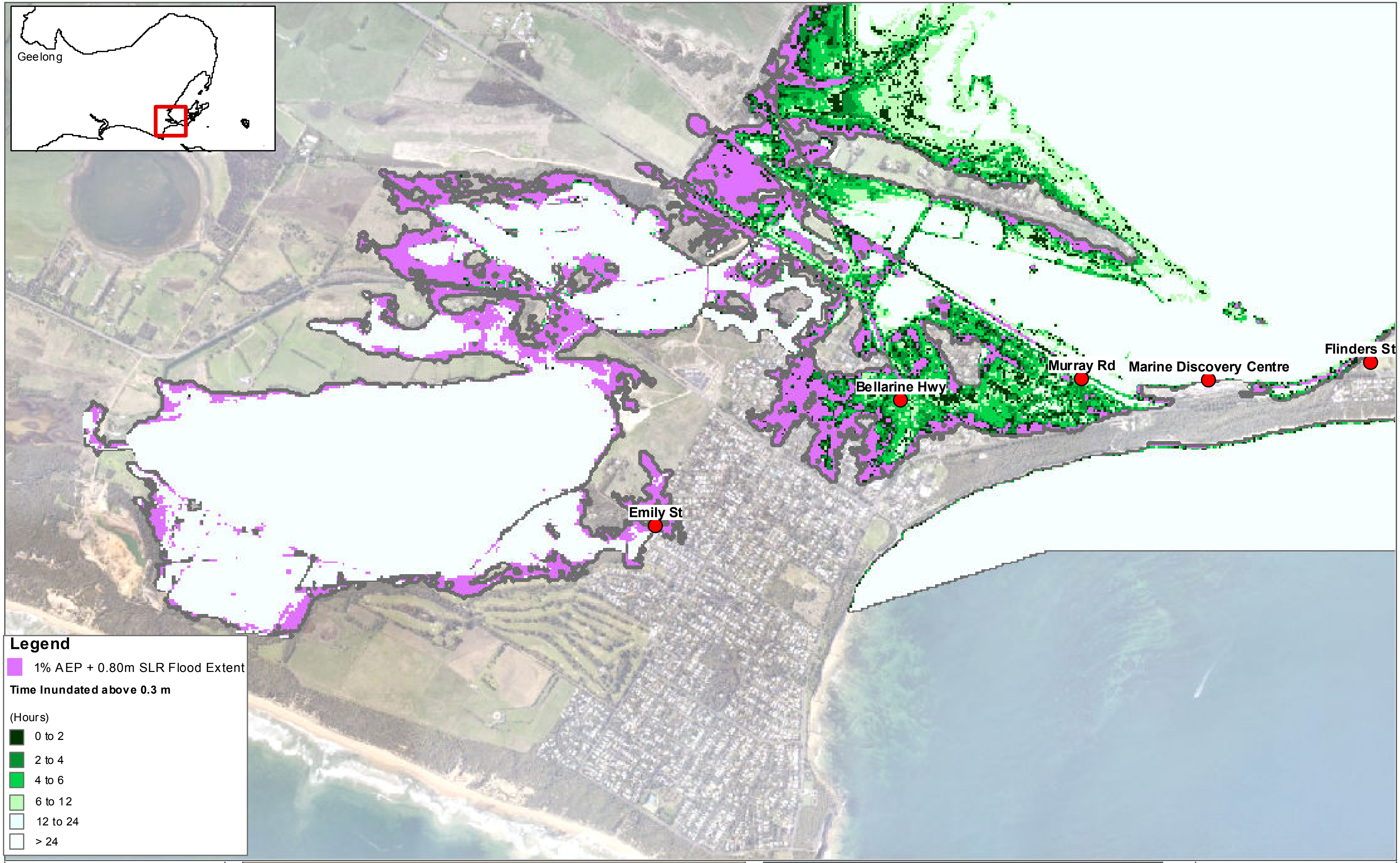
Figure 6-19

1:23,000 Scale at A4

Metres
0 200 400 600 800

Cardno

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Swan_Bay\Coastal_Inundation_SwanBay_Lakers_Cutting_v2.mxd



Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-19
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_SwanBay_LakersCutting_timing_v2.mxd 01

Bellarine Peninsula - Corio Bay LCHA

LAKERS CUTTING - LAKE VICTORIA

COASTAL INUNDATION TIMIMG - HYDRODYNAMIC MODEL
1% AEP EVENT + 0.8 M SEA LEVEL RISE (SLR)

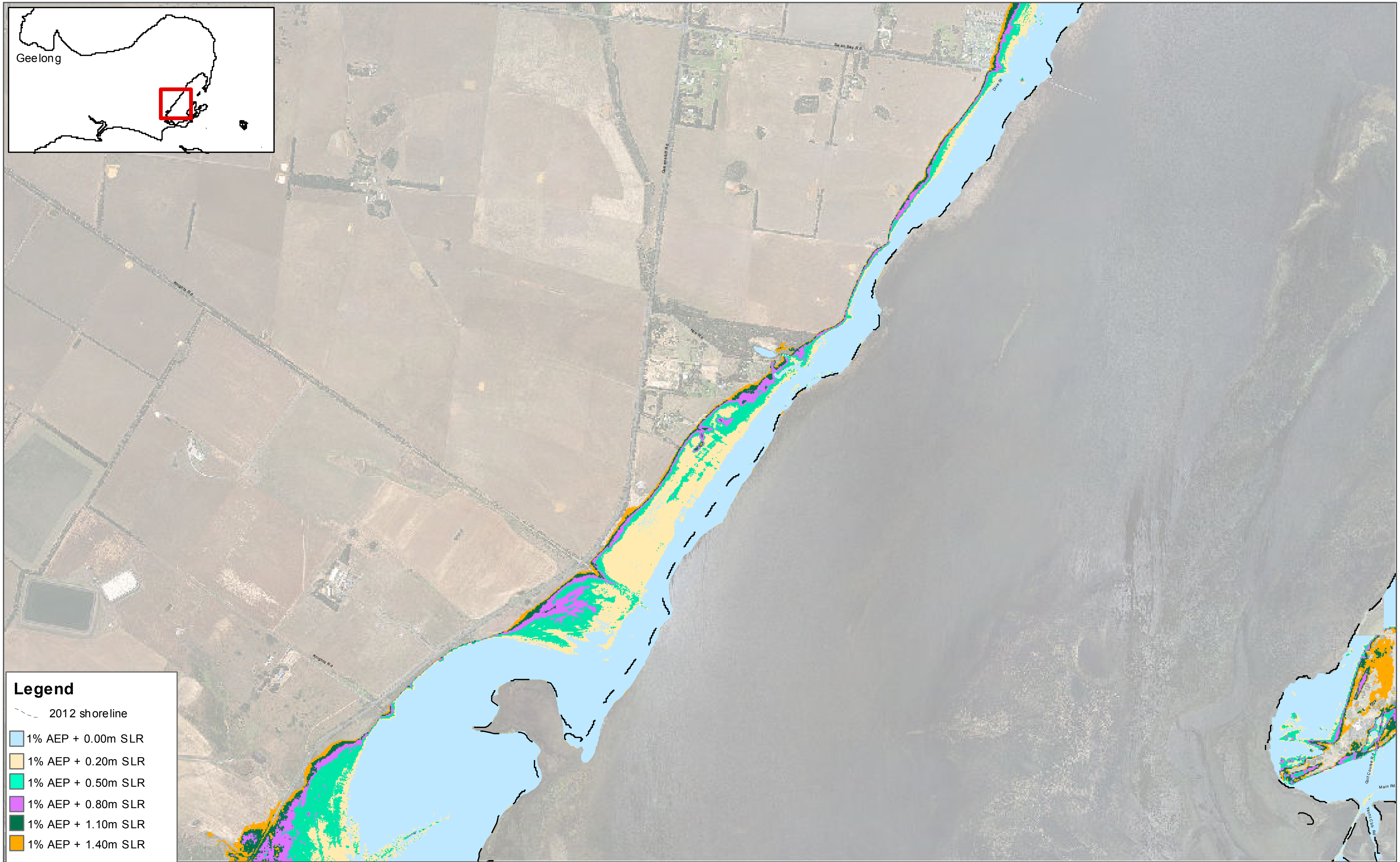
Figure 6-20

1:23,000 Scale at A4

Metres
0 200 400 600 800

Cardno

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Swan_Bay\Coastal_Inundation_SwanBay_LakersCutting_timing_v2.mxd



Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-19
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Swan_Bay_Western_Swan_bay.mxd 01

Bellarine Peninsula - Corio Bay LCHA

SOUTH WESTERN SWAN BAY

COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

Figure 6-21

1:21,000 Scale at A4

Metres

0 200 400 600 800

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Swan_Bay\Coastal_Inundation_Swan_Bay_Western_Swan_bay.mxd

Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-19
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_SwanBay_StLeo_v2.mxd 01

Bellarine Peninsula - Corio Bay LCHA

SWAN BAY (NORTH) - ST LEONARDS

COASTAL INUNDATION MAPPING - STATIC MODEL 1% AEP EVENT + SEA LEVEL RISE (SLR)

Figure 6-22

1:25,000 Scale at A4

Metres

0 200 400 600 800

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Swan_Bay\Coastal_Inundation_Swan_Bay_St_Leonards.mxd

6.6 Compartment 6: Point Edwards to Portarlington

6.6.1 Locations Overview

This section of coast is managed by the Bellarine Bayside Foreshore Committee of Management (BBFCoM), (Figure 6-23). Much of the shoreline is a very narrow strip of beach backed by eroding soft rock and some low cliffs. The shoreline is partially protected from wave action by the Great Sands. In the more exposed areas, there are some shore protection works in the form of rock revetments, timber retaining walls and geotextile container walls (near Salt Lagoon). In the south, relict timber groynes have been replaced recently along the frontage of Bell Parade to trap the southern moving sediments and widen the beaches in front the properties which run to within metres of the water's edge and are very low-lying.

Further north around Bluff Rd and Harvey Park there is more dune development, and the general elevation of the hinterland is greater.

Seaward of Salt Lagoon the beach is very narrow and eroding. The properties behind the road sit in a depression and have been inundated in the past. Salt Lagoon itself supports some rare hyper-saline habitats, and occasionally dries out totally in summer.

Indented Head shoreline has been relatively stable over time. Some additional erosion protection exists in the form of a low retaining wall south of Andersons Reserve. The northern areas appear to be accreting, with the southern end eroding. This is consistent with the sediment transport trends determined in the previous coastal process study (Cardno, 2011c). As sand moves south in this area it will accumulate on the northern side of the headland before passing around it. The lack of sand on the southern side makes this area vulnerable to wave attack.

The Esplanade, east of Portarlington, is a very low-lying soft rock foreshore that is vulnerable to inundation. It has little or no protection against the prevailing winds and waves. There is no dune protecting the hinterland, and shore protection (where present) is mostly in the form of low retaining walls that are in various states, from poor to good condition. The lack of sand on the foreshore here is characteristic of the exposed nature of the shoreline. Near-shore tidal currents also appear to be strong and sediment is being transported east and west, with little material staying on the beaches.

The Portarlington area is a combination of low-lying soft rock shorelines and low cliffs. The Bellarine Bayside foreshore west of the harbour fronts the holiday park and is a very popular tourist area in summer. The beach was renourished with approximately 16,000 m^3 of imported material in 2012 to increase beach widths and provide additional amenity. This area west of here is also vulnerable to inundation, and has been flooded due to overwashing in the past. This area is regularly monitored to track the performance of the renourishment. Beach scraping is used as a management method at the far western end of the beach. This redistributes sand from the lower intertidal zone to the upper intertidal and supratidal zones.

The Ramblers Road foreshore is a mostly low-energy environment with narrow strips of beach of medium to fine sand and coarse shell material. There is some evidence of littoral drift in an easterly direction; however this reverses during less frequent north-easterly winds. The boat ramp facilities are dredged regularly with sand recycled east to renourish nearby shorelines, or exported for use elsewhere. Saline shrub habitats occupy the areas behind the very low dunes. Beyond the vegetation, private properties are positioned near the shoreline at very low elevations. These properties have been inundated in the past due to overwashing of the low dune.

Figure 6-23 Compartment 6: Point Edwards to Portarlington + cross-shore profiles and wave points

6.6.2 Methodology - Inundation Hazard Assessment

Simple static models were set up for this section of coast. The 1% AEP event storm-tide levels used in the assessment are presented in Table 6-12.

From St Leonards to Indented Head there are two locations vulnerable to inundation, St. Leonards Lake Reserve and Salt Lake.

From Indented Head to Ramblers Road at Portarlington, there are also two very broad areas subject to inundation, from the Indented Head Esplanade to Portarlington Esplanade, and from the Bellarine Bayside shore to Ramblers Road.

Table 6-12 Storm-tide levels

	0 m SLR	0.2 m SLR	0.5 m SLR	0.8 m SLR	1.1 m SLR	1.4 m SLR
Storm-tide level	1.09	1.29	1.59	1.89	2.19	2.49

6.6.3 Results

6.6.3.1 St Leonards to Indented Head

This section of coast is vulnerable to inundation in discrete areas. It is noted that subsequent risk assessments will be required for this part of the coast to combine the hazard and risk findings in order to produce a holistic picture of the overall vulnerability.

Inundation vulnerability is presented for St Leonards Lake Reserve (Figure 6-24) and Salt Lake (Figure 6-25). The hazard is low at St Leonards Lake Reserve, impacts become more significant with sea-level rise increases over 0.2 m in a 1% AEP event. The inundation hazard at Salt Lake shows the shoreline overwashing in a present day 1% AEP event (i.e. no sea-level rise). The difference here, compared with the previous hazard maps where large section of shoreline are overwashed and inundated, is that there are three particular spots along the shoreline lower than adjacent areas that will allow inundation to occur in the present day 1% AEP event. These are shown as breach locations in Figure 6-25. This information will aid in further risk and options assessments.

6.6.3.2 Indented Head to Portarlington

There is a significant inundation hazard at Indented Head near Andersons Reserve to the Esplanade at Portarlington (Figure 6-26) and Ramblers Road (Figure 6-27). These areas are both extremely low and flat. There is little to no dune formation fronting the hinterland, and low wooden retaining walls holding the shoreline in place in some locations.

6.6.4 Implications for Coastal Management

6.6.4.1 St Leonards to Indented Head

This section of coast is vulnerable to inundation. Longshore transport of material from south to north appears to be maintaining that width and elevation of the beaches, which will aid in reducing the inundation risk. Much of the shoreline is backed by areas of foreshore reserve which provides a buffer. Behind this is the road, which is likely to be impacted in future as sea-levels rise.

Salt Lagoon is a very low-lying area. The strip of foreshore separating the Lagoon and nearby beachfront properties from the bay is narrow. Under a present day 1% AEP inundation event (0.0 m SLR), the foreshore and road (The Esplanade) is likely to be overwashed leading to inundation of the hinterland. Under higher events (i.e. 1% AEP events with more than 0.2 m SLR) almost the entire shoreline is low enough to be overwashed.

Note, the inundation extents shown are the maximum possible based on topography and the storm-tide level under each scenario, and do not consider spreading and absorption.

Management triggers are presented in Table 6-13.

Table 6-13 Management triggers – St Leonards to Indented Head

Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation (Lake Reserve)	Overwashing of the shoreline due to storm-tide inundation + sea-level rise	1% AEP event + 1.1 m SLR	A) Investigation and planning / management when measured increases in sea-level reach 0.5 m above present day levels **and/or** if significant erosion occurs lowering current foreshore levels.
Inundation (Salt Lagoon)	Overwashing of the shoreline and breaching of low protection structures due to storm-tide inundation + sea-level rise	1% AEP event + 0.0 m SLR	A) Investigation and planning / management action required immediately. The shore protection fronting the road at Salt Lagoon is low and in poor condition. Breaching in this area is likely under a 1% AEP event.

6.6.5 Indented Head to Portarlington

For the area shoreline, only significant shore protection structures have been considered. The elevations of the structures are low, however, and are of no consequence to the inundation assessment. The inundation hazard is quite significant in this location.

The erosion and inundation hazards have been treated separately in this area, although the two are significantly linked and will also be linked to tide level increases with sea-level rise. This should be considered in subsequent risk assessments. Additional figures have been produced that show the mean high high water (MHHW) mark for the present day and including sea-level rise, which infers a possible shoreline position with no management intervention and no accelerated erosion. This shows that the future MHHW tidal levels with sea-level rise will advance well inland (Figure 6-28 and Figure 6-29).

Management triggers are presented in Table 6-14.

Table 6-14 Management triggers - Indented Head to Portarlington

Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation - The Esplanade	Overwashing of the shoreline and low protection structures due to storm-tide inundation + sea-level rise	1% AEP event + 0.5 m SLR	A) Investigation and planning / management when measured increases in sea-level reach 0.2 m above present day levels **and/or** if significant erosion occurs lowering current foreshore levels (identified through monitoring).
Inundation - Ramblers Rd	Overwashing of the shoreline due to storm-tide inundation + sea-level rise	1% AEP event + 0.0 m SLR	1) Investigation and planning / management action required immediately. Breaching and inundation in this area is likely under a 1% AEP event for the present day.

6.6.6 Further investigations

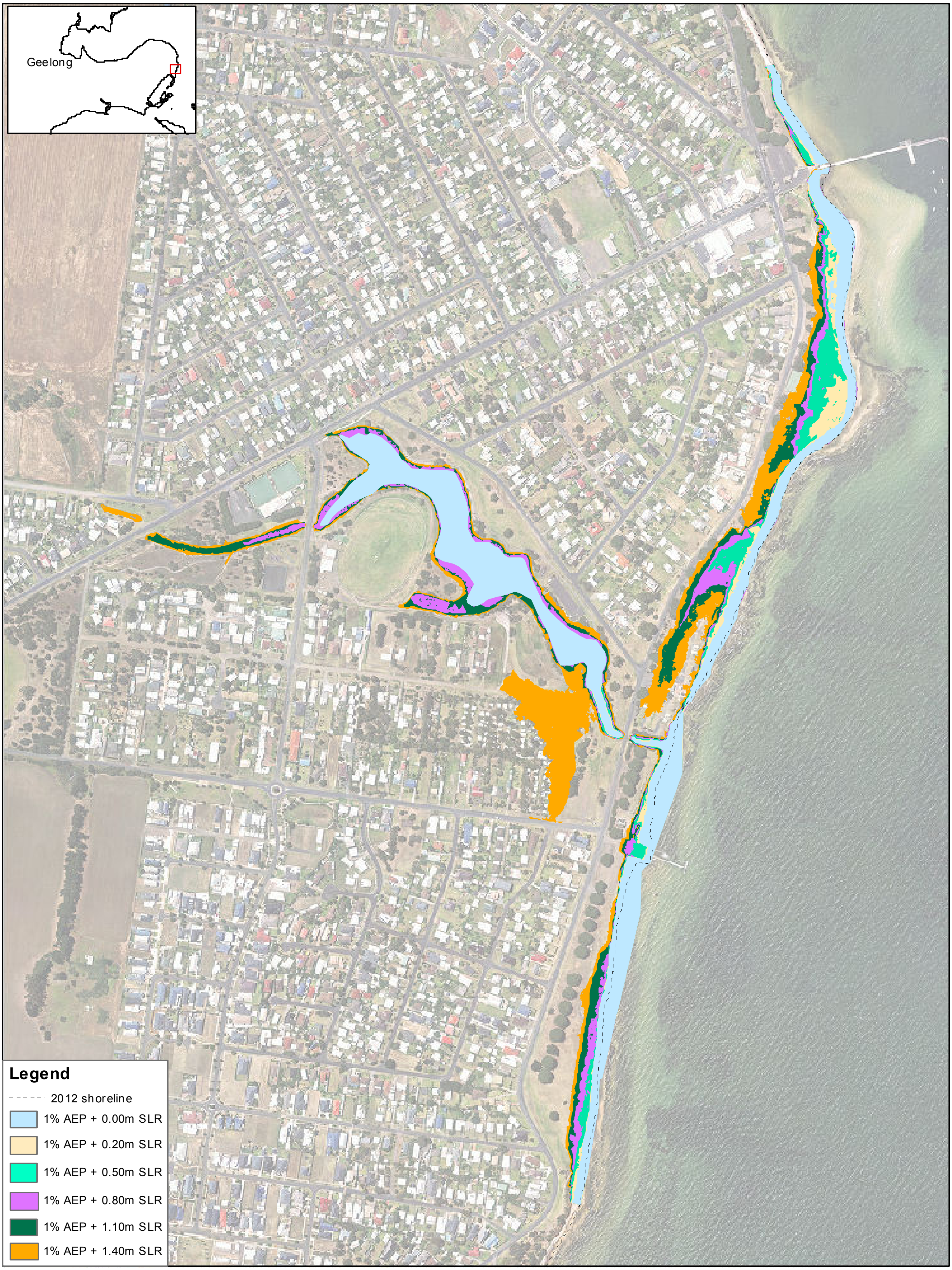
- Management options and adaptation planning to address the inundation vulnerability should be investigated in the near future for the Salt Lagoon area.
- Monitoring of the beaches in this area (e.g. profile surveys, photographs) is recommended to more closely document the rates of change along the beaches. This will provide better background information to inform more detailed future assessments. Frequency of profiling will depend on available funds and resources, suggest teaming with DELWP to determine how best to approach the monitoring and the methods. Generally, the following is recommended:
  - profiling at the end of each season (or at least summer and winter), as well as after significant storm events
  - 20 - 30 profiles at key locations from St. Leonards to Portarlington i.e. where there is already evidence of erosion (particularly near Salt Lake) or there is a significant change in the beach morphology, or where shore protection structures are present and/or change in type and elevation

  - photographs of the shoreline taken at the same times as profiles are surveyed, preferably at a fixed and known sites facing the same direction.
- Limited measured wave data exists in this area. Further measured data will aid in reducing uncertainty by qualifying modelling results.
- Determine the resilience and adaptability of the sensitive saline habitats of Salt Lagoon to inundation, and changes in salinity.
- Management options and adaptation planning to address the inundation vulnerability should be undertaken in the near future for the Ramblers Road area. This area has two management organisations (CoGG and BBFCoM) therefore an integrated approach could be developed in conjunction with DELWP.

6.6.7 Further studies

The previous Bellarine Coastal Process Study (Cardno, 2011c) provides some guidance on risk and mitigation strategies for this area; this should be consulted as a starting point.

- Compile an asset register based on the extents of the inundation.
- Undertake a risk assessment.
- Determine and evaluate options to reduce / mitigate risk using a quadruple bottom-line assessment, and the necessary timeframes to rank priority.
- Determine works schedules for future years. This could possibly be done as part of an updated local management plan (or produce one if one is not already in place) and incorporate the preferred mitigation option findings.



Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-21
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_St_Leonards_v2.mxd 01

Figure 6-24

1:7,500 Scale at A4

Metres
0 100

Bellarine Peninsula - Corio Bay LCHA

ST LEONARDS

COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

Cardno

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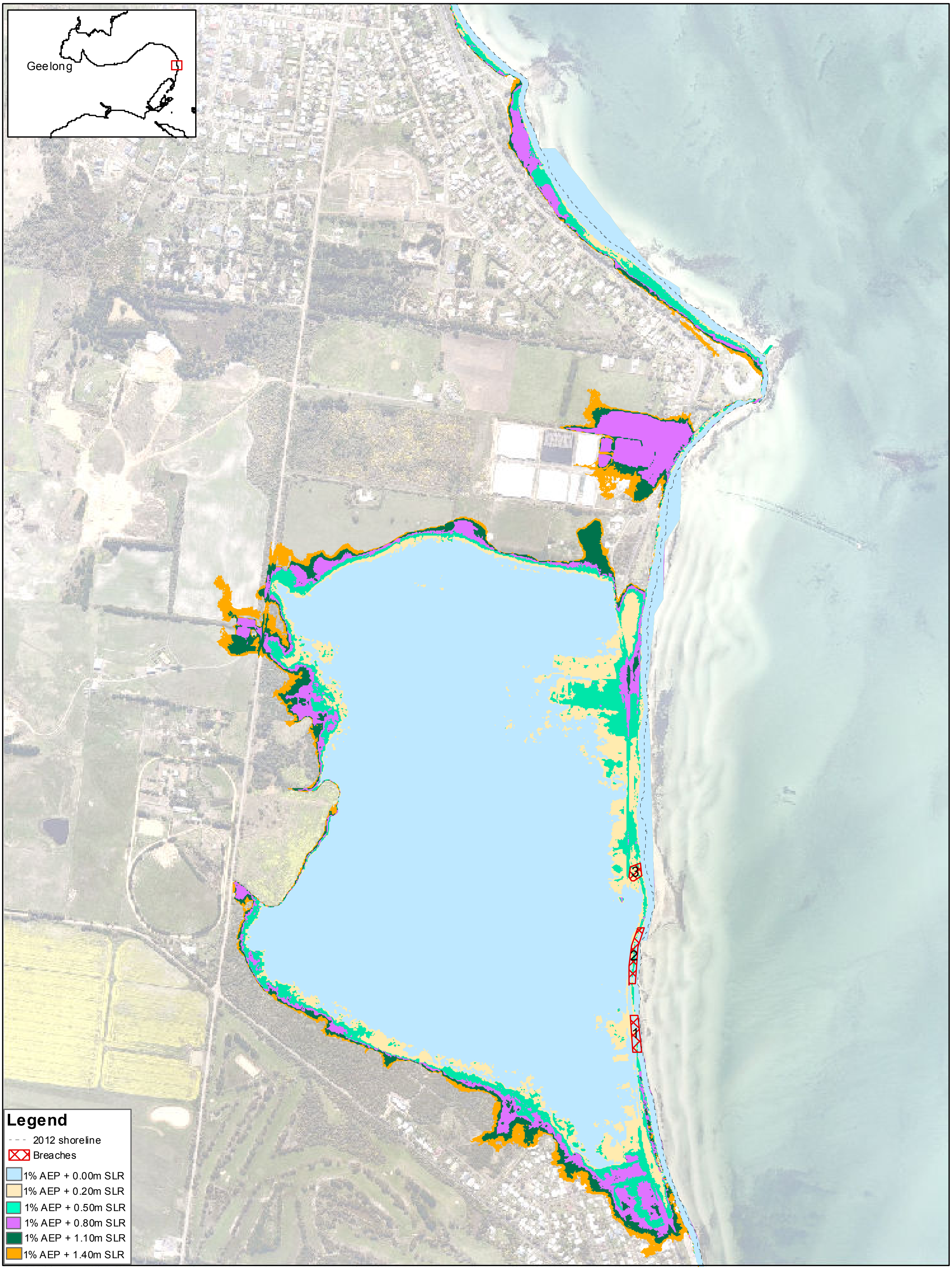


Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-21
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Salt_Lake_v2.mxd 01

Figure 6-25

1:12,500 Scale at A4

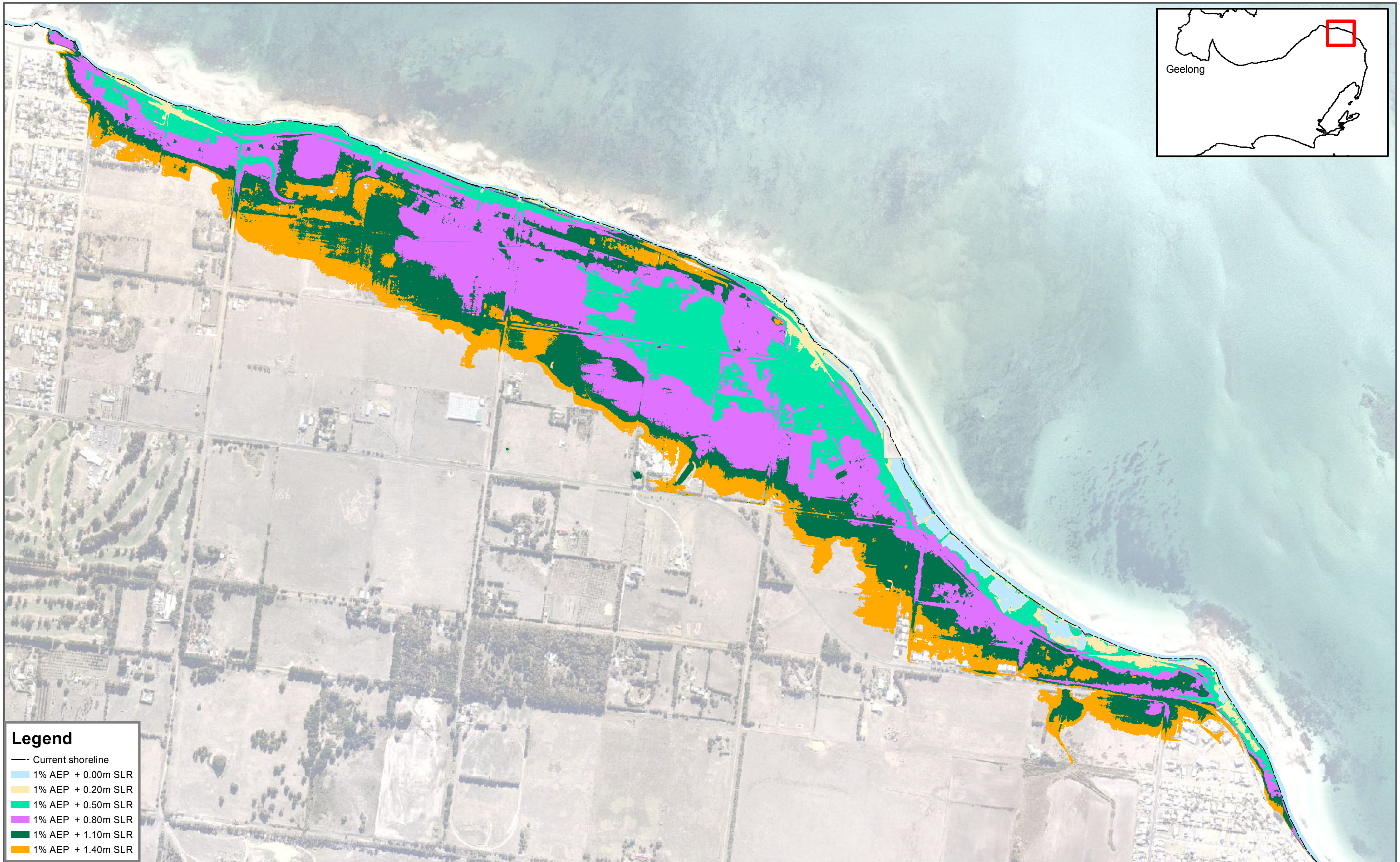
Metres
0 100 200

Bellarine Peninsula - Corio Bay LCHA

SALT LAKE - ST. LEONARDS

COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Salt_Lake\Coastal_Inundation_Salt_Lake_v2.mxd



Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-27
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Indented_Head_v2.mxd 01

Figure 6-26

1:14,000 Scale at A4

Metres
0 100 200 300

Bellarine Peninsula - Corio Bay LCHA

THE ESPLANADE - PORTARLINGTON TO INDENTED HEAD

COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

Cardno

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Portarlington\Coastal_Inundation_Indented_Head_v2.mxd

Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-03-01
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Portarlington_v2.mxd 01

N

Figure 6-27

1:16,000 Scale at A4

Metres

0 200 400 600

Bellarine Peninsula - Corio Bay LCHA

POINT RICHARDS - RAMBLERS ROAD

COASTAL INUNDATION MAPPING - STATIC MODEL

1% AEP EVENT + SEA LEVEL RISE (SLR)

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Portarlington\Coastal_Inundation_Portarlington_v2.mxd

Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-28
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Erosion_Esplanade_MHHW.mxd 01

N

Figure 6-28

1:12,000 Scale at A4

Metres
0 100 200 300

Bellarine Peninsula - Corio Bay LCHA

PORTARLINGTON - THE ESPLANADE

TIDAL LEVELS - MEAN HIGH HIGH WATER (MHHW) + SLR

Cardno

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Portarlington\Coastal_Erosion_Esplanade_MHHW.mxd

Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-28
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Erosion_Ramblers_MHHS.mxd 01

Figure 6-29

1:14,000 Scale at A4

Bellarine Peninsula - Corio Bay LCHA

PORTARLINGTON - RAMBLERS ROAD, BELLARINE BAYSIDE

TIDAL LEVELS - MEAN HIGH HIGH WATER (MHHW) + SLR

Cardno

V:\Jobs\NA49913529_CoGG_Bellarine_LCHA\GIS\MXD\Final_Mapping\Portarlington\Coastal_Erosion_Ramblers_MHHS.mxd

6.7 Compartment 7: Portarlington to Point Henry

6.7.1 Location Overview

This compartment encapsulates the wider Clifton Springs and Curlewis shoreline as shown in Figure 6-30.

Figure 6-30 Compartment 7: Portarlington to Point Henry

Much of the Clifton Springs shoreline is steeply cliffed, backed by a high plateau. There are narrow widths of sandy / rocky beach at the base. Further west towards Point Henry, the topography lowers significantly near the Sands Caravan Park. There are indigenous and cultural heritage sites along this coast.

North-east of the main settlement at Clifton Springs, there is a series of three groyne structures that extend into the bay at approximately a 60-70° angle to the shoreline. These were constructed to hold the beach in front of the cliffs near Edgewater Drive. The performance of these groynes is not ideal, and works have been undertaken recently to remedy issues with the centre groyne.

A number of geotechnical assessments have been carried out previously along this section of coast (Coffey, 2006; A.S. Miner Geotechnical, 2011). These have investigated the types of geotechnical hazards, slope instability mechanisms, risk and mitigation. The rate of cliff recession was determined using historical aerial images with rates ranging from 2 to 23 m over a 60 year period from 1947 to 2007 (A.S. Miner Geotechnical, 2011). Following on from these assessments, works have been carried out to address some of the instability issues.

Works were carried out in 2013 to stabilise the toe of the cliffed shoreline near the north-east (third) groyne, near Edgewater Drive. At the Dell, works have been carried out recently to stabilise the slopes and shoreline near the spring's historic site. Some material sourced from Point Richards was used to renourish the shoreline. At the time of writing, the renourishment appears to be having the desired effect.

Further to the west, the Clifton Springs Boat Harbour and boat ramp is dredged sporadically to maintain the navigation channel due to sedimentation. Groynes were constructed either side of the harbour to aid in capturing longshore sediments to reduce the frequency of dredging required and create areas of beach. The effectiveness of these groynes depends on the direction of the sediment transport, which is primarily towards the east. The groynes are at capacity, and sand is bypassing and entering the harbour. Also, with seasonal variation, sand is also able to enter the harbour entrance directly, especially during prolonged northerlies and north easterlies. Thus, dredging is required yearly. An additional groyne was to be constructed near the tip of the rock breakwater; however, this was opposed by the local community as it was thought it may limit accretion of sand in the down-drift areas, particularly those fronting Bayshore Avenue and Clifton Street (east of the boat harbour).

Towards Curlewis and Moolap, the shoreline elevation lowers, making this area subject to potential inundation.

6.7.2 Inundation Hazard Assessment

The main inundation hazard area is the low-lying land west of Alexander Avenue near the Sands Caravan Park. The inundation assessment was carried out with a static model, using the storm-tide level design conditions shown in Table 6-15.

Table 6-15 Design Storm-tide levels for Geelong

	0 m SLR	0.2 m SLR	0.5 m SLR	0.8 m SLR	1.1 m SLR	1.4 m SLR
Storm-tide level	1.03	1.23	1.53	1.83	2.13	2.43

The results of the inundation assessment are shown in Figure 6-31. The inundation area is concentrated near the informal man-made harbour east of the Caravan Park.

6.7.3 Implications for Coastal Management

The consequences of inundation west of the caravan park are likely to be low, so management planning here would likely be a lower priority, even though impacted by inundation under present day conditions. It is also likely that the financial costs of protecting the Sands Caravan Park area from inundation will not be affordable; therefore retreat options may be preferred in this area. This will be further investigated in subsequent risk and mitigation studies.

Management triggers are presented in **Table 6-16**.

Table 6-16 Management triggers – Clifton Springs Coast

Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation (Sands Caravan Park)	Overwashing of the shoreline due to storm-tide inundation + sea-level rise	1% AEP event + 0.0 m SLR	A) Investigation and planning / management required at present day levels. The consequences of this are likely to be low, so could be a low-priority, even though impacted by inundation under present day conditions.

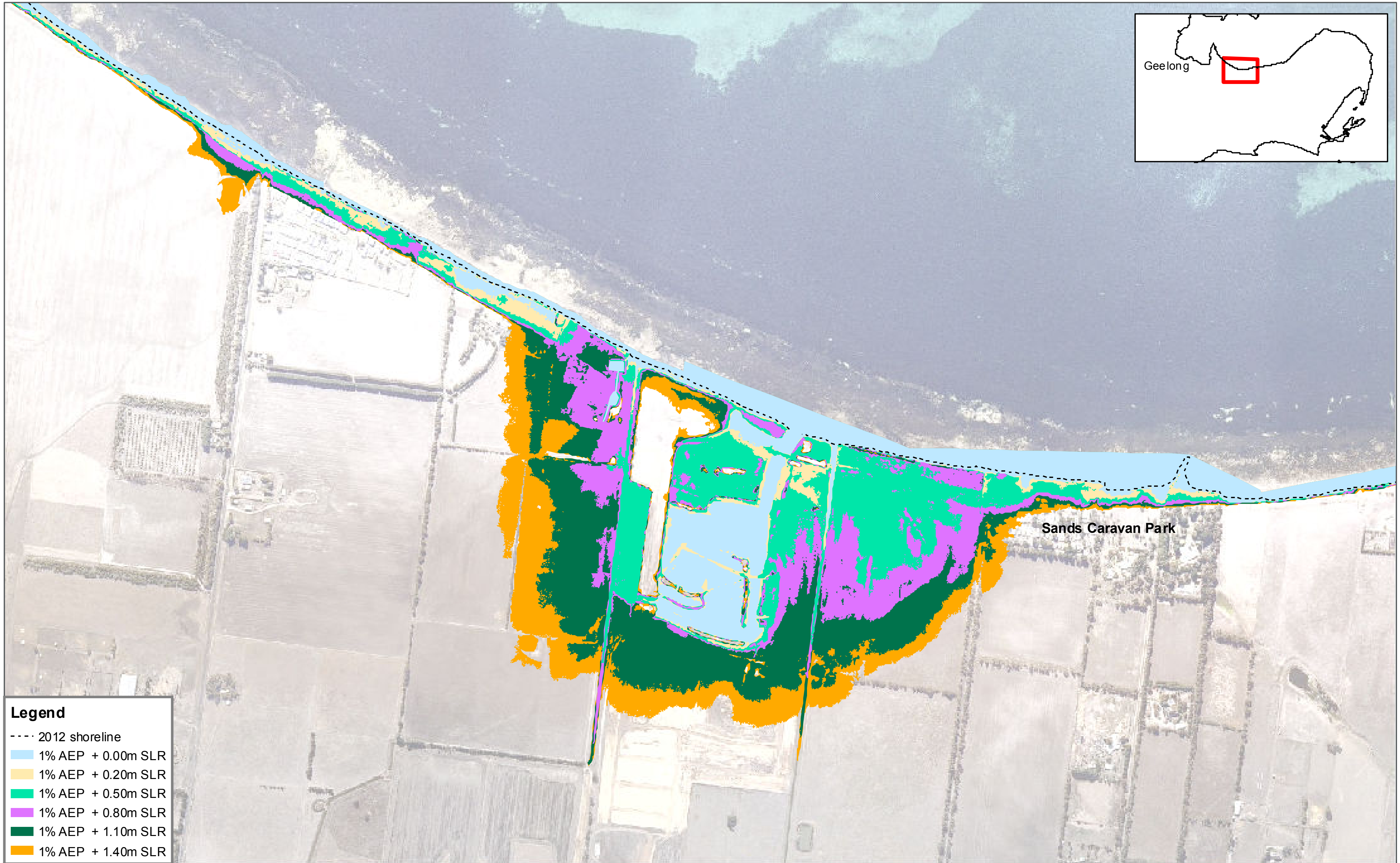
The previous geotechnical assessments consider the slope stability hazards along this shoreline (A.S. Miner Geotechnical, 2011). The report findings noted that the reduction of the beach width at the toe of the cliffs over the past 60 years had little effect on the stability of the cliffs behind, however this will change as the erosion regresses into the slopes over time. This will be exacerbated by sea-level rise. The Miner report addresses the slope hazards and risk for the present day; however, it does not consider future erosion scenarios. This should be taken into account in subsequent risk assessments, which should be undertaken in consultation with geotechnical engineers.

6.7.4 Further investigations & recommendations

- Consideration of the indigenous and heritage sites in future with respect to sea-level rise.
- Monitoring of the beaches in this location (e.g. profile surveys, photographs) is recommended to more closely document the rates of change along the beach, particularly near the boat ramp, the Dell and on either side of the new centre groyne below Edgewater Drive. This will provide better background information to inform more detailed future assessments. Frequency of profiling will depend on available funds and resources, suggest teaming with DELWP to determine how best to approach the monitoring and the methods. Generally, the following is recommended:
  - profiling at the end of each season (or at least summer and winter), as well as after significant storm events
  - 10-15 profiles at key locations along the Clifton Springs coast, and/or where there is a significant change in the cliff or beach morphology or where there are significant assets along the shoreline or behind shore protection structures
  - photographs of the shoreline taken at the same times as profiles are surveyed, preferably at fixed and known sites facing the same direction.

6.7.5 Further studies

- Undertake a risk assessment.
- Compile an asset register based on the extents of the previous cliff stability assessments and the current inundation assessment.
- Determine and evaluate options to reduce / mitigate risk using a quadruple bottom-line assessment, and the necessary timeframes to rank priority.
- Determine works schedules for future years. This could possibly be done as part of an updated local management plan incorporating the preferred mitigation option findings.



Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-26
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Sands_v2.mxd 01

N

Figure 6-31

1:10,000 Scale at A4

Metres

0 100 200 300

Bellarine Peninsula - Corio Bay LCHA

SANDS CARAVAN PARK

COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

Cardno

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6.8 Compartment 8: Stingaree Bay to Geelong

6.8.1 Location Overview

The south eastern part of Corio Bay is Stingaree Bay, where the relict saltpans and Point Henry are located; the western side is the foreshore of the City of Geelong (Eastern and Western Beach) as shown in Figure 6-32. Coastal erosion is a less significant hazard than inundation in this area, due to the low-energy conditions.

Figure 6-32 Compartment 8: Stingaree Bay to Geelong (South Corio)

6.8.1.2 Point Henry, Newcomb & Moolap

This area is a very low-lying and low-energy environment. Similar to the more eastern areas, the shoreline is very narrow with little to no dune formation to protect the hinterland. There is minimal sediment transport in this area due to a lack of material and low-wave action.

The western side of Point Henry (Stingaree Bay side) is protected by an informal rock revetment. The eastern side supports almost 20 hectares of saline habitat and small salt lagoons. At the base of Point Henry, the relict salt pans are closed in by a series of unmaintained levees. The levees do not form a consistent barrier, and have been breached to allow water to enter. These offer some protection to the hinterland; however, with increasing sea-levels and a lack of maintenance, this may be short lived. The Newcomb and Moolap residential and commercial areas lie behind the salt pans and Portarlington Rd; these are similarly very low-lying. Inundation is the key issue for this area, with flow paths from Stingaree Bay and to the east of Point Henry, as indicated by the blue arrows in Figure 6-33.

6.8.1.3 Geelong

Much of the Geelong foreshore is highly modified. The frontage is protected with seawalls and revetments, with man-made beaches to provide amenity for the community. Shorelines are narrow with little sediment supply to maintain a wide dry beach, therefore renourishments are undertaken sporadically. The dominant littoral drift is towards the west, driven by refracted waves from the Inner Harbour. The bathymetry is shallow and flat, with an abundance of fine grained sediments. The nearshore zone supports seagrass habitats.

Figure 6-33 Point Henry and Saltpans and possible inundation routes

6.8.2 Inundation Hazard Assessment

6.8.2.1 Point Henry and Newcomb / Moolap Inundation Models

A static model was constructed for Point Henry, to investigate the inundation vulnerability, and the incidence of flooding from two directions. The design storm-tide levels are presented in Table 6-17.

The hydrodynamic model for Newcomb / Moolap was set at a grid size at 4 m; this was considered sufficient for the level of detail required. Culverts were incorporated beneath the road in two locations, at the intersection of Portarlington Road and connecting the channel between Moon and Albert Streets with the salt-works channel, as shown in Figure 6-34, which also shows the tidal boundary. Key development features such as roads and levees were checked to ensure they were appropriately represented and picked up as topographic features. These were refined where necessary.

The model was run for the 1 % AEP storm-tide case in combination with a number of sea-level rise scenarios to determine the extent of inundation that would arise, as shown in Table 6-17.

Table 6-17 Design Storm-tide levels for Geelong

	0 m SLR	0.2 m SLR	0.5 m SLR	0.8 m SLR	1.1 m SLR	1.4 m SLR
Storm-tide level	1.03	1.23	1.53	1.83	2.13	2.43

Figure 6-34 Extent of Newcomb / Moolap Model showing tidal inflows and culvert locations (pink circles)

6.8.2.2 Geelong Overtopping

Overtopping calculations were undertaken for the Geelong waterfront areas fronted by structures. Four locations with vertical masonry seawalls were considered. No erosion assessment has been undertaken, as the only section of beach (Ritchie's Boulevard) is man-made and is likely to be continued to be renourished indefinitely to maintain the amenity.

Figure 6-35 Geelong overtopping calculation locations and shore protection structures

6.8.3 Results

6.8.3.1 Point Henry, Newcomb & Moolap Inundation

The static inundation map of the Moolap / Point Henry area is shown in Figure 6-36. This figure shows that under a 1% AEP event with 0.0 m SLR only the saltpans and habitat areas on the eastern fringe of Point Henry are inundated. In a 1% AEP event with 0.5 m SLR Point Henry Road is likely to be cut, the flooding in this instance is likely to be from the western side of the point, with minimal flood inundation from the eastern side. Under a 1% AEP event with 0.8 m SLR the inundation from east becomes more significant.

The Newcomb / Moolap area was modelled dynamically, as shown in Figure 6-37. The events under which inundation occurs at key locations, identified by the red dots in Figure 6-37, have been listed in Table 6-18. Inundation is largely via the large drainage channel around the western and southern edge of the salt pans. The Geelong-Portarlington Road is overwashed at the western end in a 1% AEP event with more than 0.8 m SLR. South of the Geelong-Portarlington Road, inundation is only apparent in a 1% AEP event at more than 0.8 m SLR. Above 0.8 m SLR (1.1 m and 1.4 m scenarios) water flows over the road and inundates significant areas in a 1% AEP event. West of the salt-works, the CSIRO building is located above any predicted inundation. The timing of inundation is presented in Figure 6-38.

Table 6-18 Critical inundation locations identified in the Newcomb / Moolap model

Location	Event Resulting in Inundation
West of salt works	1% AEP and 0.5 m SLR
South of Geelong Portarlington Road	1% AEP and 0.8 m SLR
South of Alcoa Road	1% AEP and 1.1 m SLR
South of High Street	1% AEP and 1.1 m SLR

6.8.3.2 Geelong Overtopping

The results of the overtopping assessment for the Geelong sea-walls are presented in Table 6-19. Discharges are presented in units of litres per second per metre (L/s/m). The results show that under the higher sea-level rise scenarios, the overtopping hazard of the structures increases. It should be noted that the wave energy in this location is generally low, although the volumes calculated are high due to increased wave heights during storm conditions; this is more related to the storm-tide level and lack of freeboard i.e. the vertical difference between the structure crest elevation and the storm-tide water elevation. Hence, the failure volumes are noted as ‘overwashed’ rather than fail, as it is unlikely the structures would fail. The calculations assume the condition and the elevation of the current structures are maintained. The calculations also assume the depth of water at the toe does not decrease over time due to sedimentation, thus, for the sea-level rise scenarios are conservative. Figure 6-39 shows the possible maximum flood extent in an overtopping event. This is a conservative indication of the extents, as a static model has been utilised, rather than a volumetric placement of the overtopping discharge volumes behind the structures based on the topography.

Table 6-19 Overtopping discharge volumes

Location	Overtopping discharge (L/s/m)					
	1% AEP + 0.0m m SLR	1% AEP + 0.2 m SLR	1% AEP + 0.5 m SLR	1% AEP + 0.8 m SLR	1% AEP + 1.1 m SLR	1% AEP + 1.4 m SLR
1	8	82.7	overwashed	overwashed	overwashed	overwashed
2	8	82.7	overwashed	overwashed	overwashed	overwashed
3	16.8	overwashed	overwashed	overwashed	overwashed	overwashed
4	44.5	overwashed	overwashed	overwashed	overwashed	overwashed

Key:
0.1 L/s/m = mean discharge for pedestrian safety
1 - 50 = unsafe for pedestrians
50 – 200 = very hazardous to people and vehicles, some pavement or promenade damage
>200 L/s/m = "overwashed", damage to paved or armoured promenade behind seawall.

6.8.4 Implications for coastal management

6.8.4.1 Point Henry, Moolap & Newcomb

The salt works levees are relict; however, they could be inspected by a qualified engineer to determine what would be required to make them effective for flood management purposes. It may be more cost effective to increase the elevation of Geelong-Portarlington Road gradually over time during routine maintenance and resurfacing, and install valves on the drains and flood routes, since the hazard is only significant in the long term. An assessment of the costs and benefits of such actions in future would be required as part of subsequent studies.

The potential development of the salt pans site is an issue in terms of the future inundation hazard, and should be thoroughly considered prior to Council granting any development consents.

Management triggers are presented in Table 6-20.

Table 6-20 Management triggers – Point Henry, Newcomb & Moolap

Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation Point Henry	Overwashing of the shoreline due to storm-tide inundation + sea-level rise	1% AEP event + 0.5 m SLR	A) Investigation and planning / management when measured increases in sea-level reach 0.2 m above 1990 levels.
Inundation Newcomb / Moolap	Inundation due to storm-tide + sea-level rise	1% AEP event + 0.8 m SLR	A) Investigation and planning / management when measured increases in sea-level reach 0.5 m above 1990 levels.

6.8.4.2 Geelong

Inundation hazards in this area are less significant, and the long-term management of the Geelong waterfront will be the key factor minimising the hazard vulnerability here. The Geelong waterfront is well protected and maintained at present. The location and importance of this as an amenity area will ensure that this is likely to continue indefinitely. The hinterland rises to higher ground, which will limit the risk posed by inundation or overtopping hazards. An increase in the crest height of the shore protection structures over time will reduce the potential hazard significantly.

Eastern and Ritchie's beaches are sporadically renourished with imported sediments. Erosion losses here are minor, and a programme of beach recycling (i.e. relocation of sediment from downdrift to updrift areas) is being established as part of a separate management project to address the effects of the littoral drift. Management triggers are presented in Table 6-21.

Table 6-21 Management triggers – Geelong

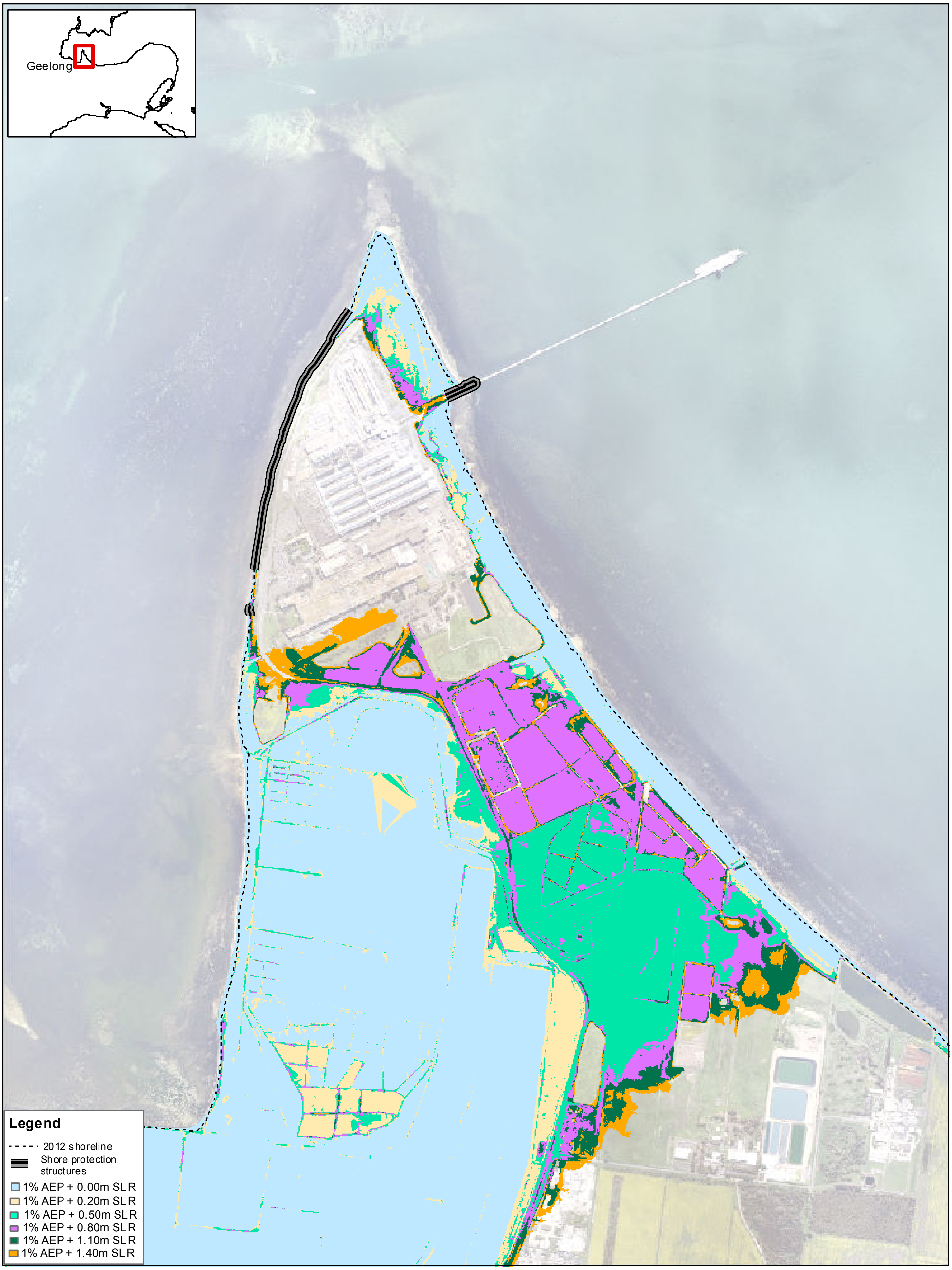
Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation	Overwashing or overtopping of the shoreline due to storm-tide inundation + sea-level rise	1% AEP event + 0.0 m SLR	A) Investigation and planning / management required at present day levels. Maintenance of coastal protection structures to continue.

6.8.5 Further investigations & recommendations

- Recommend potential developers of the Stingaree Bay salt pans precinct do further investigation prior to any development consent.
- Monitoring, inspection and continued routine maintenance of the shore protection structures.

6.8.6 Further studies

- Compile an asset register based on distance from the shoreline.
- Undertake a risk assessment.
- Determine and evaluate options to reduce / mitigate risk using a quadruple bottom-line assessment, and the necessary timeframes to rank priority.
- Determine works schedules for future years. This could be done as part of an updated version of the current management plan with the preferred mitigation option findings incorporated.



Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-26
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Inundation_PtHenry_v2.mxd 01

Figure 6-36

1:18,500 Scale at A4

Metres
0 100 200

Bellarine Peninsula - Corio Bay LCHA

POINT HENRY

COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

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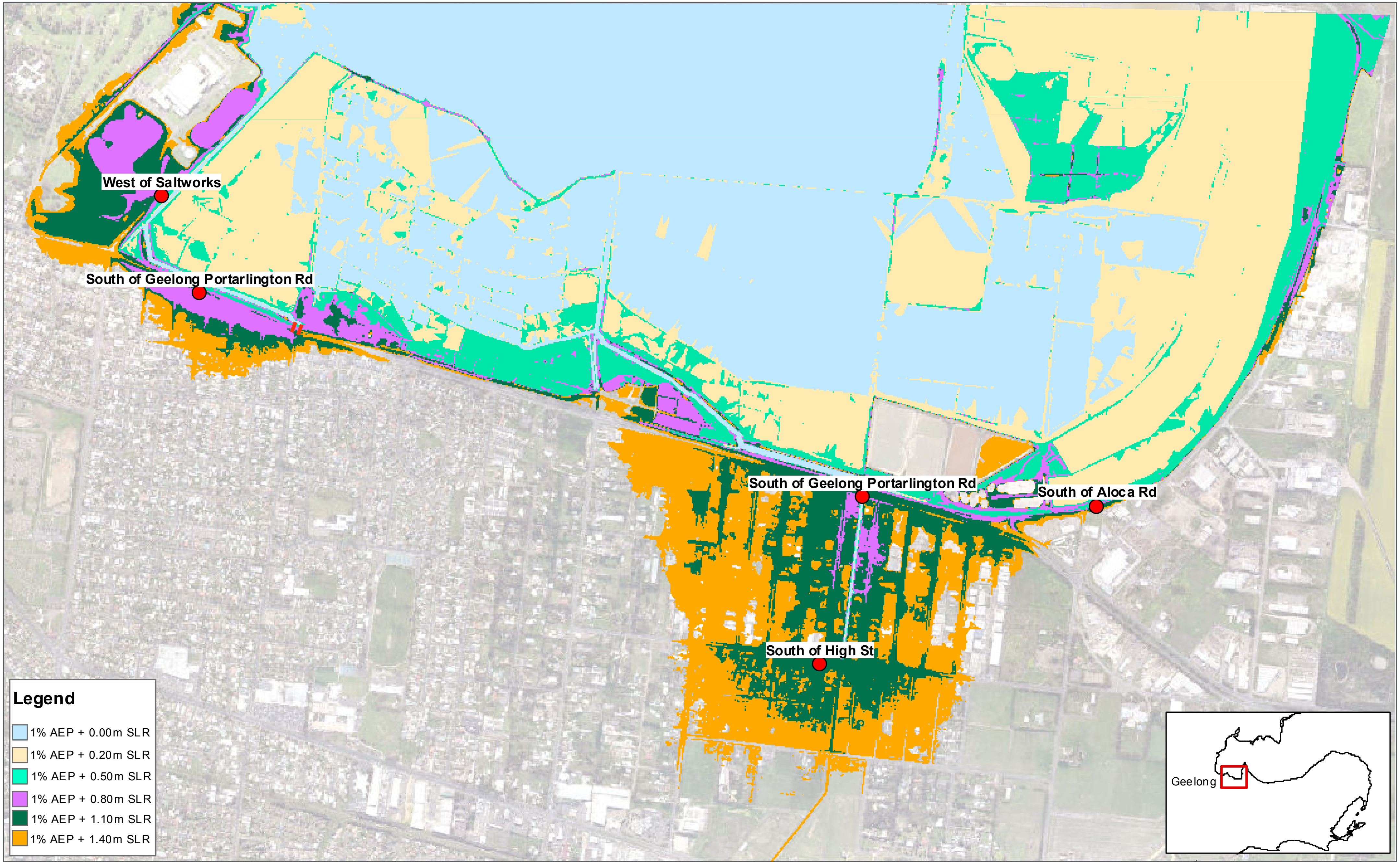

Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-26
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Inundation_Moolap_with_Critical_Locations_v2.mxd 01

Figure 6-37

1:16,000 Scale at A4

Metres
0 100 200 300 400

Bellarine Peninsula - Corio Bay LCHA
NEWCOMB - MOOLAP
COASTAL INUNDATION MAPPING - HYDRODYNAMIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

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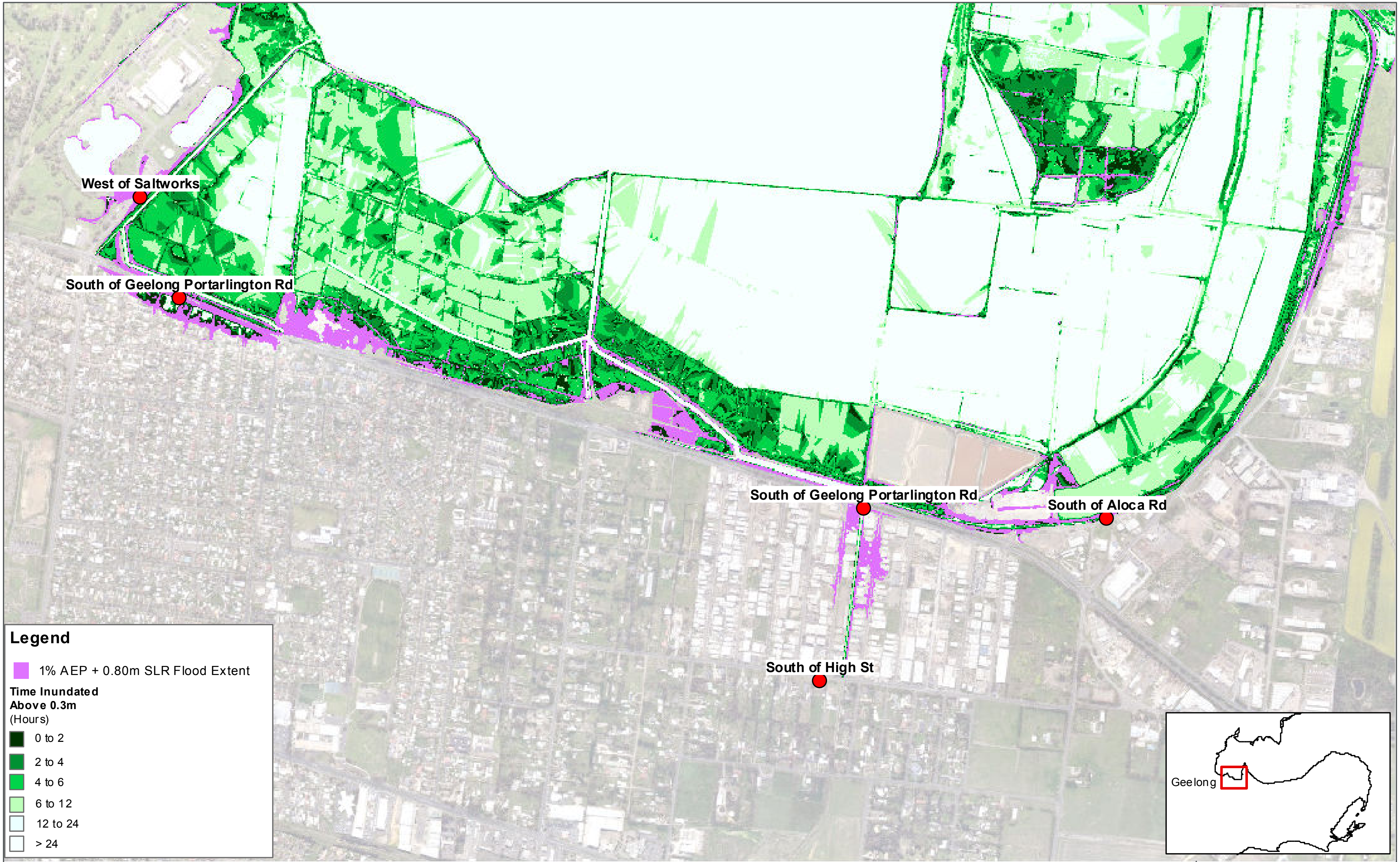


Data Sources: VICMAP nearmap

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-26
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Inundation_Moolap_time_of_inundation_v2.mxd 01

Figure 6-38

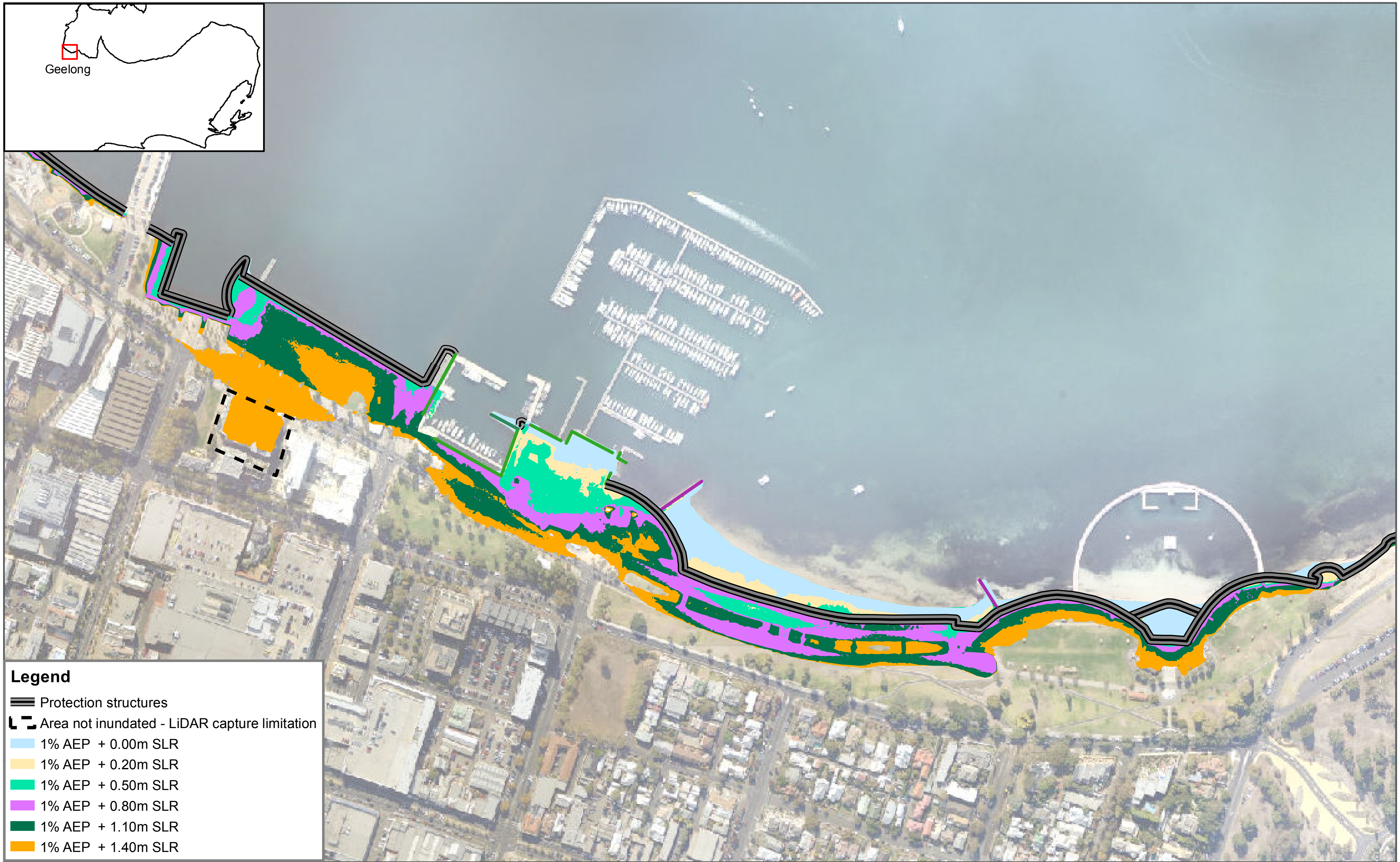
1:15,500 Scale at A4

Metres
0 100 200 300 400

Bellarine Peninsula - Corio Bay LCHA

NEWCOMB/MOOLAP - TIMING OF INUNDATION
COASTAL INUNDATION MAPPING - HYDRODYNAMIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

Cardno



Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-26
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Geelong_Waterfront.mxd 01

N

Figure 6-39

1:5,000 Scale at A4

Metres
0 50 100 150

Bellarine Peninsula - Corio Bay LCHA

GEELONG - WATERFRONT
COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

Cardno

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6.9 Compartment 9: North Corio Bay to Point Wilson

This section of coast extends from the Shell Foreshore, Limeburners Lagoon and Avalon Beach to Point Wilson (Figure 6-40). The landscape here is very low and flat. The area supports large areas of saline habitat outside the former salt pan areas and, more recently, within. Some low levees protect the hinterland from regular tidal inundation; however, these are relict from the operation of the salt pans rather than for the purpose of protecting the hinterland. They are no longer maintained and are in poor condition. Inundation is the key issue rather than erosion.

Near Point Wilson the shoreline is a low-lying soft rock shoreline. Limited access to this area means little is known. The key issues here are likely to be more inundation related, than erosion.

Figure 6-40 Compartment 9: North Corio Bay to Point Wilson

6.9.2 Inundation Hazard Assessment

The north Corio Bay area is a very low-energy environment. The shoreline is a combination of cliffs, rocky foreshores with very narrow beach widths and low angle fine grained sediment beaches with little to no dune formation. There is minimal sediment transport in this area due a lack of material and low wave action. The Avalon area is a relict saltpan site and has levees enclosing the low-lying hinterland areas behind the beach. The levees are no longer maintained and in various states of disrepair.

Due to the low complexity of the flooding mechanisms, static modelling was used to calculate inundation.

The results of the inundation assessment for the Shell Foreshore are in Figure 6-41. There is a small increase in flooding of the low-lying foreshore and along the drainage channels. The inundation hazard here is mostly to the road and stormwater infrastructure.

Saline Inundation at Limeburners Lagoon is of low significance and is shown in Figure 6-42. The ground elevations are low along the floodplain of Hovell Creek and the lagoon; however the floodplain is bounded by a steep rise to higher land limiting the inundation extent. The areas likely to be impacted are mostly the riparian habitats, with some potential impacts to Foreshore Road. The creek passes beneath the Princes Highway, however, the flood extents determined (based on the 2007 LiDAR, but with water ways inserted) do not take into account the bridge over the creek, thus show flooding of the highway, which is incorrect.

Inundation of Avalon Beach is shown in Figure 6-43. There are extensive areas of inundation of the relict saltpans under present day sea-levels including the southern section of Avalon Road. This is of little consequence in terms of flood-risk management, however, will have implications for the saline habitats that have taken over the area since decommissioning of the salt works. The levees fronting the area will provide some additional protection, however, they do not form consistent barrier. Under the higher sea-level rise scenarios, there is inundation of some salt pans in the west adjacent to Avalon Road.

East of Point Lillias, there are extensive areas which will be inundated under present-day sea-levels in a 1% AEP event. The embayment east of Point Lillias will be inundated at a sea-level rise of 0.5 m and additional areas are inundated further east as sea-level rises.

Inundation for Point Wilson is shown in Figure 6-44. There are extensive areas of the foreshore that are likely to be inundated under present-day sea-levels in a 1% AEP event. The land adjacent to the Point Wilson jetty access road is inundated and the road cut under a 1% AEP event with a sea-level rise of 0.8 m. Further north there is a low-lying area which will be inundated; however this is outside the study area.

6.9.3 Implications for coastal management

Much of the northern Geelong coast is under private ownership (the port and Shell site). The Moorpanyal Park reserve is a high cliff area and may require geotechnical assessment in future to determine slope stability, at present there is little erosion risk. Further north along Shell Parade, the inundation vulnerability is mostly to the road and narrow strips of saline vegetation. With sea-level rise these habitats are likely to be lost in the long term as there is limited space for the shoreline and habitats to move back. There are a number of outfalls along this coast which are also likely to be impacted by rising tide levels. Similarly, the shoreline habitats along Hovell Creek may be lost in future due to rising sea-levels and a lack of appropriately elevated hinterland. There are large areas of undeveloped land along the banks of the creek, however the change in elevation between the creek and the hinterland is quite significant, and it is very unlikely the frequency of inundation required to allow new saline habitats to establish would occur in the next 100 years.

Avalon is very low and flat. There is a narrow strip of elevated foreshore and dune area that the road runs along which is at present acting as a levee, however not forming a consistent barrier. The properties along Avalon Beach are likely to be impacted in a 1% AEP event for present day sea-levels; however the flooding would be via isolated breaches and low sections in the foreshore / levee, therefore the flood levels may not be less significant. The impacts of a 1% AEP event with 0.2 m SLR may be enough to breach the elevated shoreline, more widely therefore would be a more significant inundation extent. Planning and management of the risk of this area may be required now, however, due to the nature of the environment and the flood mechanisms, risk mitigation (which will most likely be retreat) could be delayed for a number of years. This is similar for the locations further east where inundation may occur under present day conditions in a 1% AEP event, however, the consequences of inundation would likely be low, so the areas would have a low risk.

The management triggers are presented in Table 6-22. As previously mentioned, although large areas are likely to be impacted in a 1% AEP event under present day sea-levels, the perceived risk of these areas is low. Investigation of management options would be required in the near future; however the priority of this would also be low. Habitat resilience in the short-term is likely to be sufficient to withstand infrequent flood events, but should be assessed for long-term implications.

Table 6-22 Management triggers – North Corio Bay to Point Wilson

Hazard	Mechanism	Estimated scenario under which this is likely to occur	Triggers
Inundation Shell Foreshore	Overwashing of the shoreline and road due to storm-tide inundation + sea-level rise	1% AEP and 0.8 m SLR	A) Investigation and planning / management when measured increases in sea-level reach 0.5 m above 1990 levels.
Inundation Limeburner's Lagoon	Overwashing of the shoreline due to storm-tide inundation + sea-level rise	1% AEP and 0.2 m SLR	A) Investigation and planning / management when measured increases in sea-level reach 0.1 m above 1990 levels.
Inundation Avalon	Overwashing of the shoreline due to storm-tide inundation + sea-level rise	1% AEP and 0.0 m SLR	A) Investigation and planning/management required immediately, however lower priority
Inundation Pt. Wilson	Overwashing of the shoreline due to storm-tide inundation + sea-level rise	1% AEP and 0.0 m SLR	A) Investigation and planning/management required immediately, however lower priority

6.9.4 Further investigations

- Investigate habitat resilience and adaptability to climate change and sea-level rise in the long term. Undeveloped land of an appropriate elevation in relation to current and future tidal levels could be mapped and these areas zoned/designated future compensatory habitat areas, after the loss of low-lying habitat areas due to sea-level rise.
- Geotechnical assessment of the Moorpanyal cliff areas considering sea-level rise.
- Monitoring of the beaches in this location (e.g. profile surveys, photographs) is recommended to more closely document the rates of change along the shoreline. This will provide better background information to inform future assessments. Frequency of profiling will depend on available funds and resources, suggest teaming with DELWP, to determine how best to approach the monitoring and the methods. Generally, the following is recommended:
  - profiling at the end of each season (or at least summer and winter), as well as after significant storm events
  - 5 to10 profiles at key locations along the shoreline, where there is a significant change in the cliff or beach morphology and/or where there are levees and shore protection structures
  - photographs of the shoreline taken at the same times as profiles are surveyed, preferably at fixed and known sites facing the same direction.

6.9.5 Further studies

- Compile an asset register based on inundation extents.
- Undertake a risk assessment.
- Determine and evaluate options to reduce / mitigate risk using a quadruple bottom-line assessment, and the necessary timeframes to rank priority.
- Determine works schedules for future years. This could possibly be done as part of an updated local management plan incorporating the preferred mitigation option findings.

Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-27
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Shell_North_Geelong_v2.mxd 01

Figure 6-41

1:11,000 Scale at A4

Metres 0 100 200

Bellarine Peninsula - Corio Bay LCHA

GEELONG-SHELL FORESHORE

COASTAL INUNDATION MAPPING - STATIC MODEL 1% AEP EVENT + SEA LEVEL RISE (SLR)

Cardno

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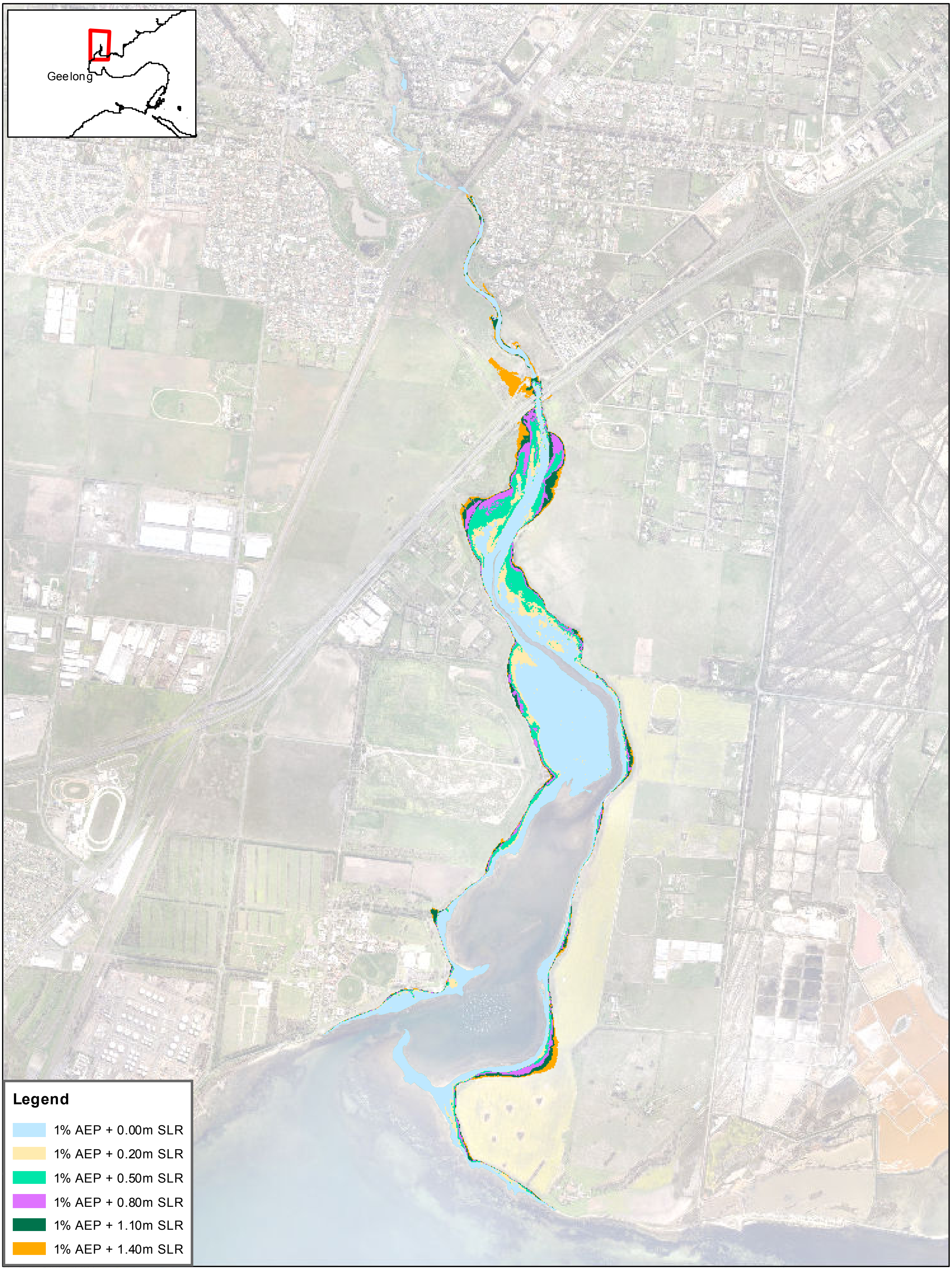

Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-27
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Limeburnersv2.mxd 01

Figure 6-42

1:30,000 Scale at A4

Metres
0 200 400

Bellarine Peninsula - Corio Bay LCHA

LIMEBURNERS BAY

COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

Cardno

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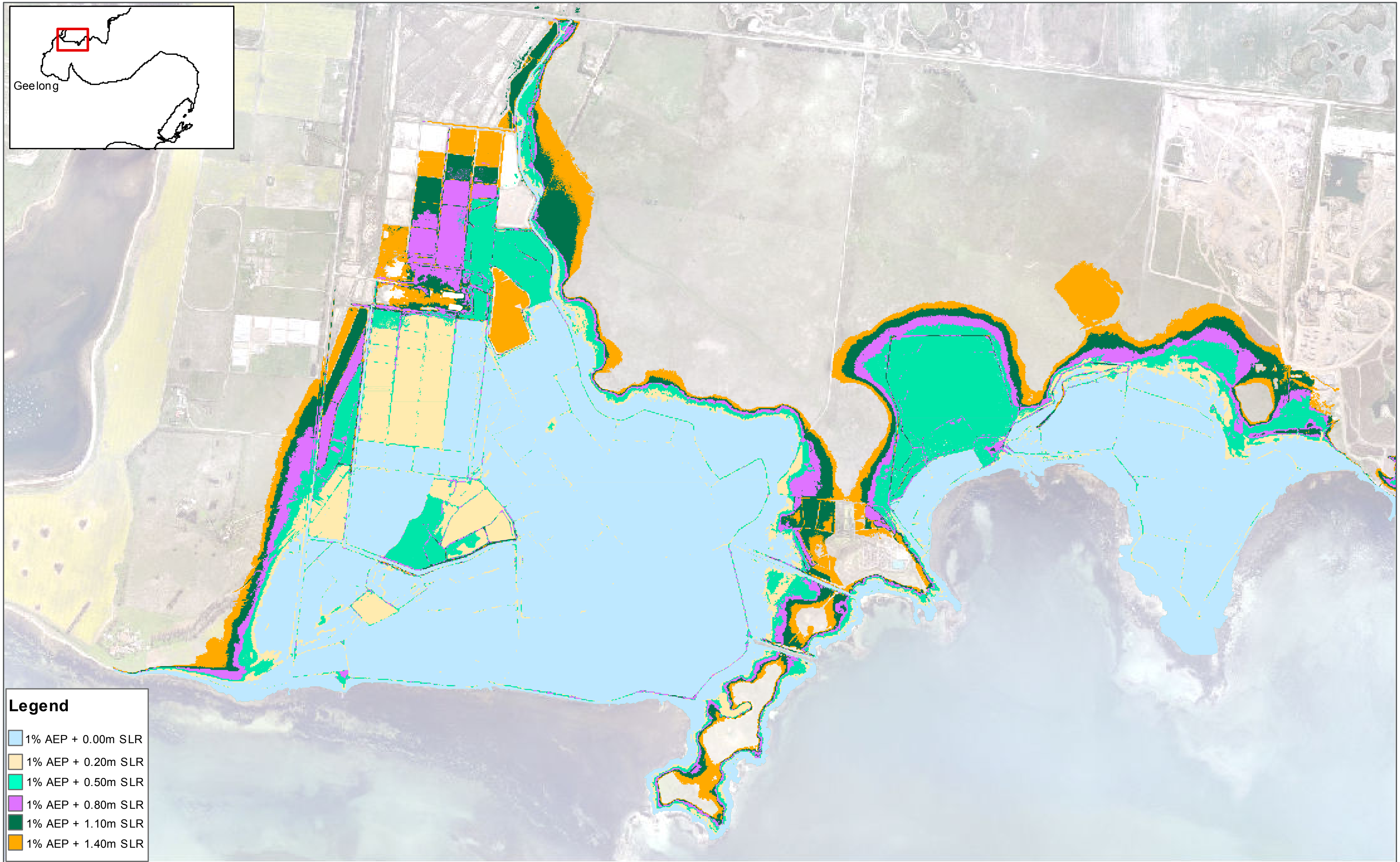

Data Sources: VICMAP

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-27
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Avalon_v2.mxd 01

Figure 6-43

1:23,000 Scale at A4

Metres
0 200 400

Bellarine Peninsula - Corio Bay LCHA

AVALON BEACH
COASTAL INUNDATION MAPPING - STATIC MODEL
1% AEP EVENT + SEA LEVEL RISE (SLR)

Cardno

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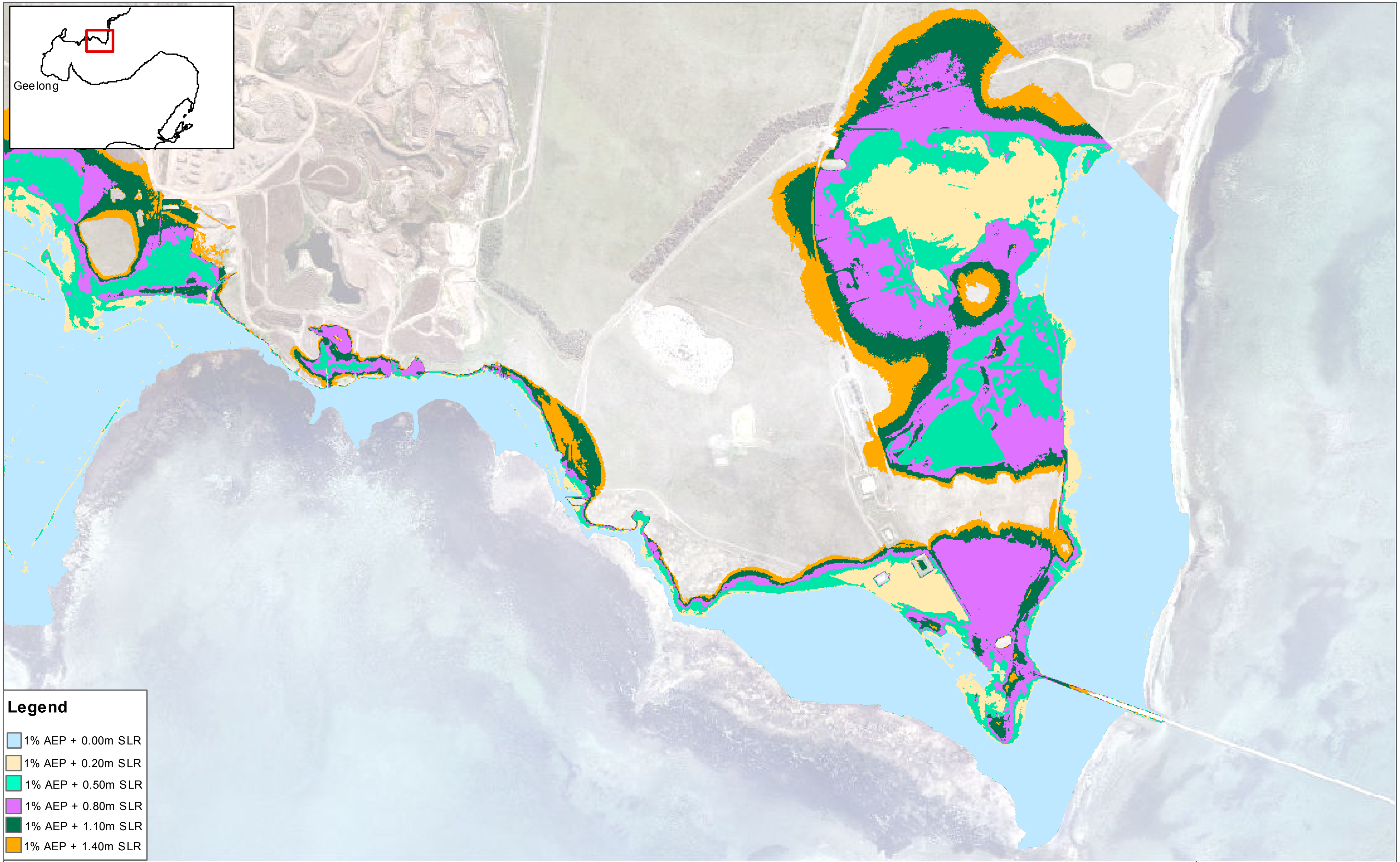

Data Sources: VICMAP nearmap.com

Map Produced by NSW/ACT (Water & Env.)
Date: 2014-02-27
Coordinate System: GDA 1994 MGA Zone 55
Project: NA49913529 (Bellarine LCHA)
Map: Coastal_Inundation_Point_Wilson_v2.mxd 01

N

Figure 6-44

1:15,318 Scale at A4

Metres

0 200 400 600 800

Bellarine Peninsula - Corio Bay LCHA

POINT WILSON

COASTAL INUNDATION MAPPING - STATIC MODEL

1% AEP EVENT + SEA LEVEL RISE (SLR)

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7 Conclusions

7.1 Overview

The purpose of this study was to assess the potential inundation hazards for the Bellarine Peninsula and Corio Bay, and provide information to aid land managers to understand the local processes and enable them to plan and formulate appropriate responses.

The study area consists of a variety of coastal environments. The Bass Strait open coast section of the study area is generally a high-energy environment with a relatively consistent wave climate, shallow nearshore bathymetries, consolidated dunes/cliffs and unconsolidated dunes, ranging in elevation from 2 to 30 m AHD. Headlands and rocky foreshores have fixed the ends of the local beaches, and characteristic arc and zeta-curve shaped beaches lie between the fixed points. Inland at Breamlea and Barwon Heads there are low-lying land areas vulnerable to inundation.

The entrance to Port Phillip Bay is a complex environment dominated by swells and strong currents. Within the bay the tidal range is lower than that in Bass Strait. The influence of swell decreases with distance from the bay entrance and the resulting environment is quite different. The wave climate is dictated by wind, meaning wave heights are fetch-limited. Due to sedimentation, water depths on the western side of the bay are shallow near the Great Sands, resulting in lower (depth-limited) wave heights.

In the vicinity of the entrance, the Lonsdale Bight coastline consists of high cliffs, long sections of seawall and revetment and dunes. The key hazards are overtopping of the protection structures and inundation of the low-lying areas around Queenscliff and Swan Bay. Further north along the St. Leonards and Portarlington coast the shoreline elevation is low, leaving some discrete areas vulnerable to inundation and erosion during storm events. The Clifton Springs coast from Portarlington to Geelong consists of cliffs with narrow beach widths at the base. The hazards here are mostly slope stability related, with some low-lying areas vulnerable to inundation. The coastal processes are dominated by wind, wind-waves and currents. The Corio Bay area is lower energy in comparison to the rest of the study area. Wave heights are more significant during north easterly wind events, due to the greater fetch from this sector; however the easterlies and nor'easters still produce waves that are able to have an effect on the shoreline. The northern Corio Bay area is also low energy, the energy increases slightly towards Point Wilson, due to the exposure to the wider bay. The shoreline is mostly rocky with low-lying hinterland behind.

A site visit and review of all relevant data sets and previous studies was undertaken early in the study. After consultation with the Project Control Group (PCG) and technical reviewers, the methodology was refined to ensure the most appropriate methods were undertaken to deliver the desired project outcomes. Due to differing landscapes and levels of hazard and potential risk, the appropriate scale and resolution of the modelling was determined for each study compartment.

The initial modelling considered waves and water levels throughout the study area, which enabled the determination of design conditions for subsequent inundation modelling. Inundation hazards were determined using hydrodynamic and static modelling (for less complex areas). Due to the nature of the differing coastal environments there were some limitations within the inundation assessments of this study, and these were considered and reported on within the findings.

7.2 Key Findings

The results and findings of the inundation assessments, as well as the hazard maps are presented for the study compartments where necessary. The study findings show that the level of hazard is markedly different between locations. The following sections provide commentary of the key findings for each compartment.

7.2.1 <u>Compartment 1: Breamlea to Blue Rocks</u>

The present day inundation vulnerability to a 1% annual exceedance probability event (AEP) with 0.0 m sea-level rise (SLR) is low. Under this and the 0.2 m SLR scenario, the areas of inundation are mostly low-lying floodplain areas, therefore the impacts to habitat are potentially of significance. It is not until the events with the higher sea-level rise scenarios that infrastructure and assets are impacted.

The local habitat resilience to saline inundation should be assessed, and areas of appropriately elevated land mapped for future areas.

A key location to note is the beach access at Bancoora Beach, which has the potential to become a breach location in future for inundation of the hinterland. The timing of this is uncertain. Regular monitoring of the beach is required to allow coastal managers to track any significant changes that would prompt a management response. The amenity use of this area is likely to increase in future also, therefore the formalisation of the access may be necessary to minimise future anthropogenic impacts.

7.2.2 Compartment 2: Blue Rocks to Barwon Estuary

The inundation vulnerability to this section of coast is low due to the high dune/cliff elevations, however regular monitoring of the far western end of the beach (which is lower) will aid in tracking morphological change. This may be of significance to the inundation vulnerability in future.

7.2.3 Compartment 3: Barwon Heads, Barwon Estuary and Lake Connewarre

Riverine flood inundation has been investigated in the past, however focused solely on riverine inundation. This assessment considered the saline inundation primarily, and coincidence of this with riverine events. An assessment of the coincidence of these two factors was undertaken, it was found that storm-tide inundation and peak riverine flows due to high rainfall do not occur at the same time. The assessment therefore included two higher frequency flood events, an annual peak flow and a 10% AEP flood event, with the less frequent 1% AEP coastal event.

The saline inundation potential for Barwon Heads is less significant than previously assessed (Future Coast, 2011). In a 1% AEP event with a catchment baseflow the low-lying areas of the estuary shoreline are inundated. These are mostly areas of habitat. In events with sea-level rise above 0.2 m, the flood extents become more significant. In a 1% AEP event with a 10% AEP catchment flow for the present day (i.e. 0.0 m SLR) the flood extent is greater than the equivalent baseflow case. The inundation is likely to impact the eastern bank of the river, at Ocean Grove, where the low shore protection is likely to be overwashed. Note, the shore protection here is not forming a consistent barrier and appears to have been designed to minimise shoreline movement on the river bend, rather than flood protection. On the western bank of the river (Barwon Heads) the inundation potential increases with increases in sea-level rise.

7.2.4 Compartment 4: Ocean Grove to Point Lonsdale

This section of coast is subject to erosion hazards and overtopping at the Ocean Grove seawall. This will have implications for future risk assessments. It is recommended that closer monitoring of the beach is undertaken to track coastal change and provide better background information for future assessments.

The seawall at Ocean Grove Main Beach is providing a high standard of protection to the hinterland presently. Overtopping volumes are generally low for the present day. Beach levels at the toe of the seawall are likely to decrease due to scour erosion, therefore increasing the depth of water at the toe of the structure during storm conditions. This in turn will allow larger waves to penetrate further inshore and increase overtopping. The rate of loss of beach volume is currently unknown, and should be monitored to inform future assessments.

7.2.5 Compartment 5: Point Lonsdale to Point Edwards

This section of coast is subject to overtopping and inundation hazards. An assessment of the overtopping of the shore protection (seawall and revetments) was undertaken for Lonsdale Bight. This showed quite a significant hazard for the present day and in future with sea-level rise increases. The results are consistent with visual inspection of the area and information from the asset managers, the seawall is regularly repaired due to the effects of direct wave impact. Through time the incidence of damage due to wave impact is likely to increase, therefore continued maintenance and upkeep in this area is vital. The overtopping hazard decreases further around Lonsdale Bight due to the change from vertical seawall to revetment (which also increases in elevation from Lawrence Road) as well as a general decrease in wave energy with distance from the bay entrance.

Inundation is likely to be the overriding hazard for the Queenscliff area, more specifically, Fisherman's Flats. The Fisherman's Flats shoreline is significantly lower than the rest of the Queenscliff area; therefore any inundation is likely to originate from there. The shore protection is in very poor condition in some locations, and not forming a consistent barrier. The newly upgraded marina shoreline is approximately 0.5 to 1 m higher.

The lowest areas of Fisherman's Flats already pool runoff in high rainfall events, thus the inclusion of saline inundation will increase the vulnerability, although similarly to the Barwon Estuary the likelihood of the two hazards occurring together is low. The stormwater pumping infrastructure has been upgraded recently to address the runoff issues. It is recommended that investigation into management options to mitigate the effects of saline inundation in this location should occur in the near future.

At the southern end of Swan Bay, an assessment of the inundation of Lakers Cutting and the Lonsdale Lakes development was undertaken. The inundation vulnerability also extends to the Bellarine Highway and properties in the vicinity of Murray Road. The extent of inundation of this area becomes significant under a 1% AEP event with 0.2 m SLR. In this event, a low section of the railway embankment overtops west of the Marine Discovery Centre, possibly impacting a small number of properties along Murray Road. The timing and depth of inundation for this area during this event is likely to be low; this should be considered in subsequent risk and mitigation studies. In a 1% AEP event with 0.5 m SLR, the flood extents increase significantly. It is recommended that the railway embankment is further investigated, particularly the permeability, as with minor adaptation (e.g. valving of culverts and removal of drainage channels) this could aid in inundation mitigation during lower events. Under higher sea-level rise events, the embankment would likely be overwashed. This will impact the Bellarine Highway.

For Swan Bay, the inundation hazards are less significant. There is little development around the bay, thus the key issues will likely be related to habitat resilience. The surrounding land areas rise gradually to higher land, therefore there appears to be nothing inhibiting any natural roll-back with sea-level rise.

7.2.6 Compartment 6: Point Edwards to Portarlington

The key inundation hazard area is at Salt Lake. There is a narrow section of shoreline between the lake and the coast, this is likely to overwash in a 1% AEP event with 0.0 m SLR via low sections in the road. In the higher sea-level rise scenarios, the shoreline is below the storm-tide level. It is recommended that risk and mitigation studies are undertaken in the near future for here.

From indented head to Portarlington the coast becomes more exposed to wave impacts, thus, erosion issues are more significant rather than inundation.

From Portarlington to Ramblers Road, the coast is vulnerable to inundation. Similar to the previous coastal section the exposure to the prevailing winds and waves is more significant here. The hinterland elevations at the Esplanade are low, and east of the pier are low, and decrease further moving west past the Bellarine Bayside foreshore to Ramblers Road. It is recommended that risk and mitigation studies are undertaken in the near future to address the inundation issues at Ramblers Road.

7.2.7 Compartment 7: Portarlington to Point Henry

The inundation hazard along this section of coast is relatively low, the key location for inundation is near the Sands Caravan Park, however at the base of the cliffs around Clifton Springs there may be some impact to infrastructure in high water events.

7.2.8 Compartment 8: Stingaree Bay to Geelong (South Corio)

The ground elevation in this area are very low, thus, inundation is a key hazard. In a 1% AEP event with 0.0 m SLR some fringe areas of the shoreline are impacted, mostly habitat around Point Henry. The salt pans are also likely to inundate, however this is of no consequence. In a 1% AEP event with 0.5 m SLR, the flood extents become more significant, potentially impacting some roads. Properties around Newcomb and Moolap are likely to be impacted by inundation in sea-level rise scenarios of 0.8 m and above.

The inundation vulnerability around Geelong is low. The shoreline is heavily modified, protection structures exist from east of Eastern Beach to Western Beach, mostly vertical seawalls. An overtopping assessment was undertaken and the vulnerability is high, however the consequences of overtopping inundation are likely to be low as long as the ongoing maintenance of the structures and active management of the foreshore is continued.

7.2.9 Compartment 9: North Corio Bay to Point Wilson

Beyond the Moorpanyal cliffs the ground elevation in this area is again very low, thus, inundation is likely to be the overriding hazard. Areas of foreshore are impacted in a 1% AEP event with 0.0 m SLR, these are mostly habitat areas. As sea-level rise increases, public infrastructure is also likely to be impacted, such as roads and storm water infrastructure.

The environmental value of this area is significant with large areas of rare habitat. Resilience studies and mapping of appropriate future habitat areas based on ground elevation and future inundation frequency should be undertaken.

7.3 Area wide management recommendations

The following are general recommendations for the overall study area that may aid in reducing the uncertainty of the finding of this study, as well as aid coastal mangers in their future management undertakings:

- Establishment of a thorough monitoring program that is consistent between management organisations, beach profiling will be a key aspect of this. This should be undertaken in conjunction with DELWP.
- Recommend that this study is updated every 5-10 years to incorporate revised sea-level rise guidance and measured increases, monitoring findings to ensure better certainty in the inundation hazard assessments and review and consider coastal management changes where action has been taken and works carried out.
- Investigations of groundwater to be undertaken in future assessments.
- Monitoring and additional work to fill data gaps (see next section).

7.3.1 Further Work to Fill Data Gaps

Each area's results section gives some advice as to the data requirements for further studies. This will greatly aid in reducing the levels of uncertainty within this study. The reliability of the hazard studies stems from the quality and quantity of data available to carry out the coastal hazard assessment.

There are two overarching uncertainties related to these assessments, the lack of thorough and recent background data sets and the methods used in determining the present and future hazard extents. The following will aid in reducing uncertainty, and provide information to update the findings of this study in future.

7.3.1.1 Beach profiling

There is lack of beach profile data available for the study area, as well as much of the Victorian coast. This will be vital in determining the short and long-term change of beaches, and better inform hazard studies in future.

Beach profile information will greatly reduce the uncertainty related to the profiles used in this study, and to monitor future change. Profiles were taken from LiDAR data flown in 2007 (DSE, 2007). The uncertainty associated with this relates to the following:

- where anything has changed since 2007, e.g. landforms, structures, roads, car parks, developments.
- where shoreline position has advanced or retreated since the LiDAR was flown.

Beach profiling can be carried out using a number of methods e.g. surveyors, RTK GPS, photogrammetry (from regular aerial images, possibly collated by unmanned aerial vehicles, "drones"), profiles from high resolution LiDAR (potentially costly due to frequency required for thorough monitoring).

7.3.1.2 LiDAR & Bathymetry

The regularity of capture of airborne laser data sets is dictated by available funds to do so. Progressions in technology mean the costs associated with these technologies are coming down over time. Annual (ideally) or biennial capture and processing in future would provide essential information that would aid in baywide coastal management, as well as the wider Victorian coast, and this is recommended.

7.3.1.3 Aerial imagery

Aerial images are captured for the study area intermittently; it is recommended this is continued in future, preferably yearly. If a thorough program of beach monitoring, particularly beach profiling, is not undertaken, then photogrammetry methods using the aerial images may be useful to monitor shoreline change. This will be a less certain method, however in lieu of any others will be useful.

7.4 Further Coastal Management Studies

This study identified and informed about hazards in a wide context. The next step in the coastal management process for the Bellarine will be to investigate the most at risk areas in terms of assets, both built and natural and determine and prioritise mitigation actions. Future tasks will likely include:

- Compilation of asset registers within the defined hazard areas and investigate the risk to key assets based on likelihood and consequence (AS/NZS ISO 31000:2009 Risk Management Techniques);
- Determination of options to manage and minimise the risk and evaluate these options using the quadruple bottom line method, considering technical, social, environmental and economic implications of each to determine a prioritised, costed and responsibility stated list of coastal management actions for State and local government as well as local land managers.
- Actions should be compiled into new coastal zone management plans for each area, which will address a wider range of coastal related issues (not just technical) or incorporated into revised versions of the current coastal management plans. Part of the review process should be the revisiting of previous management plan actions to determine which actions have and have not been undertaken and why, their effectiveness, and any implementation issues experienced by local managers. This will aid in informing and guiding future management practices. This is key to a process of effective adaptive management.

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Bellarine Peninsula - Corio Bay Local Coastal Hazard Assessment

APPENDIX A
SCOPING DOCUMENT

Draft Scoping Document

Bellarine Peninsula Corio Bay Local Coastal Hazard Assessment

NA49913529

Prepared for
City of Greater Geelong and Project Control Group

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Cardno
Shaping the Future

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1 Introduction

The Bellarine Peninsula Corio Bay Local Coastal Hazard Assessment seeks to address coastal, estuarine and climate change challenges by defining the magnitude and extent of the likely hazards in a considered and robust manner. This information will form the basis of the main project report and will be added to and developed in the coming months.

The purpose of this document is to provide a more detailed scope of the project. It presents a refined methodology, developed following the project inception meeting, the site visit and after some of the preliminary project work was undertaken. The information contained within this document will give the project team a better understanding of the processes in determining the hazard zones, as well as why specific methods are to be applied to specific locations. Once these methods are agreed, and design conditions set, the detailed modelling can commence.

Section 2 details the refined methodology and includes:

- the purpose and outcomes of the preliminary modelling;
- how the coastal and flood compartments and the priority areas were defined;

Section 3 details:

- how the storm events to be modelled and sea level rise (SLR) scenarios were defined;
- the determination of conditions

Section 4 details:

- the modelling approaches;
- the methods to be used at each location;
- any assumptions and limitations relating to the modelling.

Section 5 gives:

- an overview of the format of the main report;
- a brief update of the project standing.

2 Preliminary Assessments

After consultation with the Project Control Group (PCG) and technical reviewers, the original methodology has been refined to ensure the most appropriate methods are undertaken to deliver the desired project outcomes. Due to differing landscapes and levels of hazard and risk, the appropriate scale and resolution modelling has been determined for each study compartment. Where recent detailed modelling is available the scope of modelling has been reduced accordingly.

2.1 Coastal

2.1.1 Wave Modelling

The preliminary wave modelling for the Bellarine Coast was undertaken using SWAN. A series of storms were modelled using measured data from Pt. Lonsdale tide gauge (30 year record) and the Pt. Nepean wave buoy (10 year record) was used as forcing conditions.

2.1.2 Inundation

Cardno has undertaken a number of previous studies around the Bellarine Peninsula and thus have an up to date knowledge of certain coastal hazard and risk areas. Areas at risk to coastal inundation were discussed in the inception meeting also. To further refine the areas most at risk from coastal inundation, the Future Coast and OzCoasts 2100 1% Annual Exeedance Probability (AEP) storm tide level extents were overlain on the most recent digital elevation model. This allowed us to identify locations that required further investigation during the site visit, along with those identified by the PCG.

2.2 River/Estuarine

The areas at risk to riverine or estuary flooding were discussed at the inception meeting. Subsequent to that, basic static models were constructed to determine potential flood extents and to identify low lying areas. Some of the key low-lying areas were visited during the site inspections to check for potential breach locations, structures (e.g. outlets, culverts) and any other information that would need to be considered and/or incorporated into the detailed modelling.

2.3 Site Visit

A two day site visit was carried out by Cardno in early April. All sites were visited and local conditions and observations documented and photographed. The purpose of the site visit to gain familiarity with the site, investigate control structures and potential flood paths, as well as take sediment samples for the sediment transport calculations. Cardno staff were accompanied by local coastal managers to view areas of concern, and to learn some of the historic development of the area.

2.4 Determination of Study Compartments & Priority

An outline of the study compartments was presented by the client within the project brief. It was necessary to reassess these on a local scale based on the local topography, control structures and potential flooding or erosion mechanisms. Table 2-1 and Figure 2-1 show the study flood compartments.

The coastal compartments locations were based on stretches of coast where there were defined sections or specific processes occurring, for example:

- a river or creek entrance, or headland, which formed a clear boundary;
- a difference in substrate e.g. rocky shore compared with sandy;
- a section where the wave or wind climate direction is likely to be significantly different to the adjacent;
- differing rates of change compared with the surrounding shoreline compared to the adjacent e.g. due to beach renourishment or other localised modification;
- long sections of wall or revetment protecting the shoreline.

The priority areas were identified by in the brief, and refined once the study compartments were confirmed. The level of priority (to some extent) determines the level of detail required for the subsequent modelling. The purpose of the project is to identify hazards and delineate potential hazard zones, determining levels of risk to assets is beyond the scope. It should therefore also be noted that the priority does not translate into perceived risk or significance. The use of risk descriptors should be avoided at this stage of the project as a formal risk assessment will be undertaken subsequent to this project.

Table 2-1 shows the key features that have distinguished the compartments and sub-compartments. These are presented in Figure 2-1. Where there is no significant difference in geomorphology the compartment is differentiated due to the dominant coastal processes in the vicinity, e.g. the shoreline may be orientated so that the dominant wave direction is different from the adjacent; therefore boundary/forcing conditions would be different. The table notes the likely hazards in the area, as well as some of the key assets near the shoreline that may be impacted. These include public and private property, infrastructure e.g. roads, water, sewerage and services e.g. power and phone lines.

Generally, the priority is based on the proximity of assets. The high priority areas are often where numerous assets are located near the shoreline. Areas of moderate priority may also have assets, however fewer numbers, or may be areas of habitat or cultural significance. The low priority areas are generally low use areas with little development or assets, which are unlikely to be impacted significantly.

Table 2-1 Study Compartments (SW and PW refer to stormwater and potable water infrastructure, respectively)

Area	No.	Location	Sub-location		Features for division	Key issues	Nearby Assets		Priority
							Public	Private	
Thompson Creek to Blue Rocks	1	Thompson Creek	a	Thompson Creek and Entrance	Estuarine creek area to be flood modelled	Inundation Erosion	Saline habitat, dunes (open coast) Infrastructure - roads, SW, PW, beach accesses Services	Residential properties Agricultural land	High
			b	beach	Open coast sandy beach	Erosion	Dunes Infrastructure - roads, car parks, SW, PW, beach accesses Services	Residential properties Agricultural land	Medium
	2	Surf Club Lane	c	Buckleys Bay	Could be considered a pocket beach as located between two rocky outcrops – potentially limiting longshore drift. Foreshore is combination of sand and cobble/boulder sized volcanic rocks.	Erosion	Dunes Caravan park Services		Medium
			d	Bancoora Beach	Sandy beach located between two rocky outcrops, with sandy shore.	Inundation (potential breach) Erosion	Dunes SLSC and tower Infrastructure - roads, car parks, SW, PW, beach accesses Services	Agricultural land	High
	3	Black Rock Road			Rocky shoreline, no sandy beach		Sewerage outfall		Low
Blue Rocks to Barwon Estuary	4	13th Beach			Long stretch of sandy beach, some calcarenite outcrops	Erosion Potential future breach	Dunes SLSC Infrastructure - road (in very close proximity to dune scarp), car parks, SW, PW, beach accesses	Golf course Residential properties	High
	5	Barwon Estuary	a	West Bank	- Heavily populated western shoreline of the lower estuary, with multitude of differing shoreline protection methods	Overwashing Overtopping (outer channel only) Inundation	Saline habitat Shore protection structures Foreshore reserve Caravan park & football oval Village Park Infrastructure - roads, bridge, car parks, SW, PW, beach accesses, boat ramps	Golf course Wildlife Sanctuary Residential properties Commercial properties	High
			b	East Bank	Heavily populated eastern shoreline of the lower estuary, with some differing shoreline protection methods and natural shoreline	Overwashing Inundation	Saline habitat Shore protection structures Caravan park, camping area Infrastructure - roads, bridge, car	Residential properties Commercial properties Equestrian centre	

Area	No.	Location	Sub-location		Features for division	Key issues	Nearby Assets		Priority
							Public	Private	
							parks, SW, PW, beach accesses, boat ramps, sewerage		
			c	Lower Barwon	Similar to 5a/b, however modelled in combination at a coarser resolution.	as above	as above	as above	
			d	Lake Connewarre	- Natural river/estuary shoreline - Less tidal influence	Riverine flooding	Saline habitat Weir structure Infrastructure - roads, SW, PW Services - Elec, gas	Residential properties Commercial properties Agricultural land	
Ocean Grove to Point Lonsdale	6	Ocean Grove			Long sandy beach – note section of vertical seawall at SLSC that will result in different rates of erosion than the adjacent beaches, particularly related to scour (toe and terminal). Grants lookout - some cliff erosion and possibly runoff issues. Rock revetment near 13W	Erosion + scour Overtopping	Dunes - steep scarps in some areas Shore protection structure Foreshore reserves SLSC Infrastructure - roads, car parks, SW, PW, beach accesses Services - Elec, gas	Residential properties Commercial properties	High
	7	Barwon Coast/Buckley's			Long stretch of sandy beach – however dune area consists of aeolian sediments, calcarenite outcrops and some cemented sections of sand dune.	Erosion Cliff instability	Dunes Shore protection structures Foreshore reserves - Buckleys Infrastructure - roads, car parks, SW, PW, beach accesses	Residential properties Commercial properties	Medium
Point Lonsdale to Pt Edwards	8	Lonsdale Bight	a	Cliffs	More significant as a geotechnical hazard area.	Erosion Cliff instability	Lighthouse Infrastructure - roads, car parks, SW, PW, beach accesses Pier	Toc H Camp	Medium
			b	Vertical Wall + groynes	Similar processes, however differing shoreline protection methods likely to have a marked difference in cross and longshore sediment transport processes and rates	Overtopping	Shore protection structures Cemetery Infrastructure - roads, car parks, SW, PW, beach accesses Services - Elec, gas Caravan parks Footy oval Primary School	Residential properties Commercial properties	Medium
			c	Rock Revetment		Overtopping			Medium
			d	Dog beach	Natural sandy beach – high dunes Terminal scour at end of revetment.	Erosion	Dunes Foreshore reserve		Medium

<table>
<tr><th rowspan="2">Area</th><th rowspan="2">No.</th><th rowspan="2">Location</th><th rowspan="2">Sub-location</th><th rowspan="2" colspan="2">Features for division</th><th rowspan="2">Key issues</th><th colspan="2">Nearby Assets</th><th rowspan="2">Priority</th></tr>
<tr><th>Public</th><th>Private</th></tr>
<tr><td rowspan="5"></td><td rowspan="2">9</td><td colspan="2">Queenscliff (Port Phillip Bay coast side)</td><td colspan="2">Natural sandy beach with pier structures</td><td>Inundation
Erosion</td><td>Caravan parks
Infrastructure - roads, car parks, SW, PW, beach accesses
Services - Elec, gas
Pier
Foreshore reserve & park</td><td>Residential properties
Commercial properties
Sports Club</td><td>Medium</td></tr>
<tr><td colspan="2">Swan Island (Port Phillip Bay coast side)</td><td colspan="2">Natural sandy beach – renourished with dredge spoil from Queenscliff</td><td>Inundation
Erosion</td><td>Dunes</td><td>Military site</td><td>Medium</td></tr>
<tr><td rowspan="3">10</td><td colspan="2">Queenscliff (Fisherman's Flats)</td><td colspan="2">Low energy frontage with quay and seawalls</td><td>Inundation</td><td>Infrastructure - roads, car parks, rail line, SW, PW, beach accesses
Services - Elec, gas
Shore protection structures
Quay walls
Ferry terminal
Boat ramps</td><td>Residential properties
Commercial properties</td><td>High</td></tr>
<tr><td colspan="2">Swan Bay</td><td colspan="2">Mostly natural low energy shoreline.</td><td>Inundation
Erosion</td><td>Saline habitat
Infrastructure - roads, car parks, SW, PW, access ways
Services - Elec, gas
Boat ramps
Holiday Park</td><td>Residential properties
Commercial properties
Agricultural land
Golf Course</td><td>Medium/ High</td></tr>
<tr><td colspan="2">Lakers Cutting – Hollywood Estate</td><td colspan="2">Low lying land area with flood route fed through series of channels.</td><td>Inundation</td><td>Infrastructure - roads, SW, PW, access ways
Services - Elec, gas</td><td>Residential properties
Commercial properties</td><td>High</td></tr>
<tr><td rowspan="2">Pt Edwards to Portarlington</td><td>11</td><td colspan="2">St Leonards</td><td>Section of sandy coast oriented north to south, some short defended sections, and some timber groynes.</td><td rowspan="2">The scope of studies have been reduced for these areas due to a number of existing contemporary studies which will be updated and further developed where necessary.</td><td>Inundation
Erosion</td><td>Salt Lagoon
St Leonards Faunal Reserve
Caravan park
Infrastructure - roads, car parks, SW, PW, beach accesses
Services - Elec, gas
Shore protection structures</td><td>Residential properties
Commercial properties</td><td>Medium/ High</td></tr>
<tr><td>12</td><td colspan="2">Portarlington</td><td>Very narrow beach and low lying land</td><td>Inundation
Erosion</td><td>Holiday park
Brackish habitat (Salt Lake)
Infrastructure - roads, car parks, SW, PW, beach accesses
Services - Elec, gas
Shore protection structures</td><td>Residential properties
Commercial properties</td><td>Medium</td></tr>
</table>

Area	No.	Location	Sub-location		Features for division	Key issues	Nearby Assets		Priority
							Public	Private	
	13	Bellarine Bayside Shore			Artificially renourished beach	Inundation Erosion	Holiday park Infrastructure - roads, car parks, SW, PW, beach accesses Services - Elec, gas Renourished beach	Residential properties Commercial properties	High
Portarlington to Pt Henry	14	Ramblers Way			Very low lying section of beach that alternates between a low and moderate energy regime dependent on wind direction.	Inundation Erosion	Foreshore reserve Saline and freshwater habitat Infrastructure - roads, car parks, SW, PW, beach accesses Services - Elec, gas Boat ramp/harbour	Residential properties	High
		Clifton Springs			Low to medium energy environment	Inundation Erosion Cliff instability	Shore protection structures Infrastructure - roads, car parks, SW, PW, beach accesses Services - Elec, gas Boat ramps Heritage sites	Residential properties Commercial properties	Medium
		Point Henry and Moolap			Very narrow beach and low lying land, low energy environment	Inundation Erosion	Saline habitat Foreshore reserve Infrastructure - roads, car parks, SW, PW Caravan Park	Smelter works Commercial properties	Medium
South Corio Bay	15	Newcomb and Moolap			Low lying low energy environment, hinterland landward of a series of levees potentially at risk.	Inundation	Saline and freshwater habitat Infrastructure - roads, car parks, SW, PW. Services - Elec, gas Public reserves Cemetery	Residential properties Commercial/industrial properties	High
	16	Geelong	a	Eastern Beach	Renourished section of beach amongst walled coastline.	Inundation Erosion	Foreshore reserve Marina Heritage sites Infrastructure - roads, car parks, SW, PW. Services	Commercial properties	Medium
			b	Western Beach	Seawalls, revetments, piers etc.	Overtopping Inundation			
North Corio	17	North Geelong	a	North Shore	Some high cliffs, plus industrial port areas – quays, seawalls etc.	Overtopping Inundation	Foreshore reserve Infrastructure - roads, car parks,	Residential properties Commercial/industrial	Medium

Area	No.	Location	Sub-location		Features for division	Key issues	Nearby Assets		Priority
							Public	Private	
Bay						Cliff instability	SW, PW Services	properties	
			b	Shell Foreshore	Some natural coast, plus Shell pier and number of outfalls. Areas of saline habitat.	Inundation		Commercial/industrial properties	
	18	Limeburners Lagoon			Low lying flood plain area, with creek and shallow lagoon.	Inundation	Saline habitat Foreshore reserve Infrastructure - roads, car parks, SW, PW Services	Residential properties Commercial/industrial properties	Medium/ High
	19	Avalon			Former saltpan site area, very low lying, little dune protection. Row of properties. Very interesting habitat area.	Inundation Erosion	Saline habitat Infrastructure - roads, SW, PW	Residential properties Commercial/industrial properties	Medium
	20	Pt. Wilson			Mostly natural rocky foreshore with low lying hinterland.	Inundation	Saline habitat Infrastructure - roads, SW, PW	Commercial/industrial properties	Medium/ High

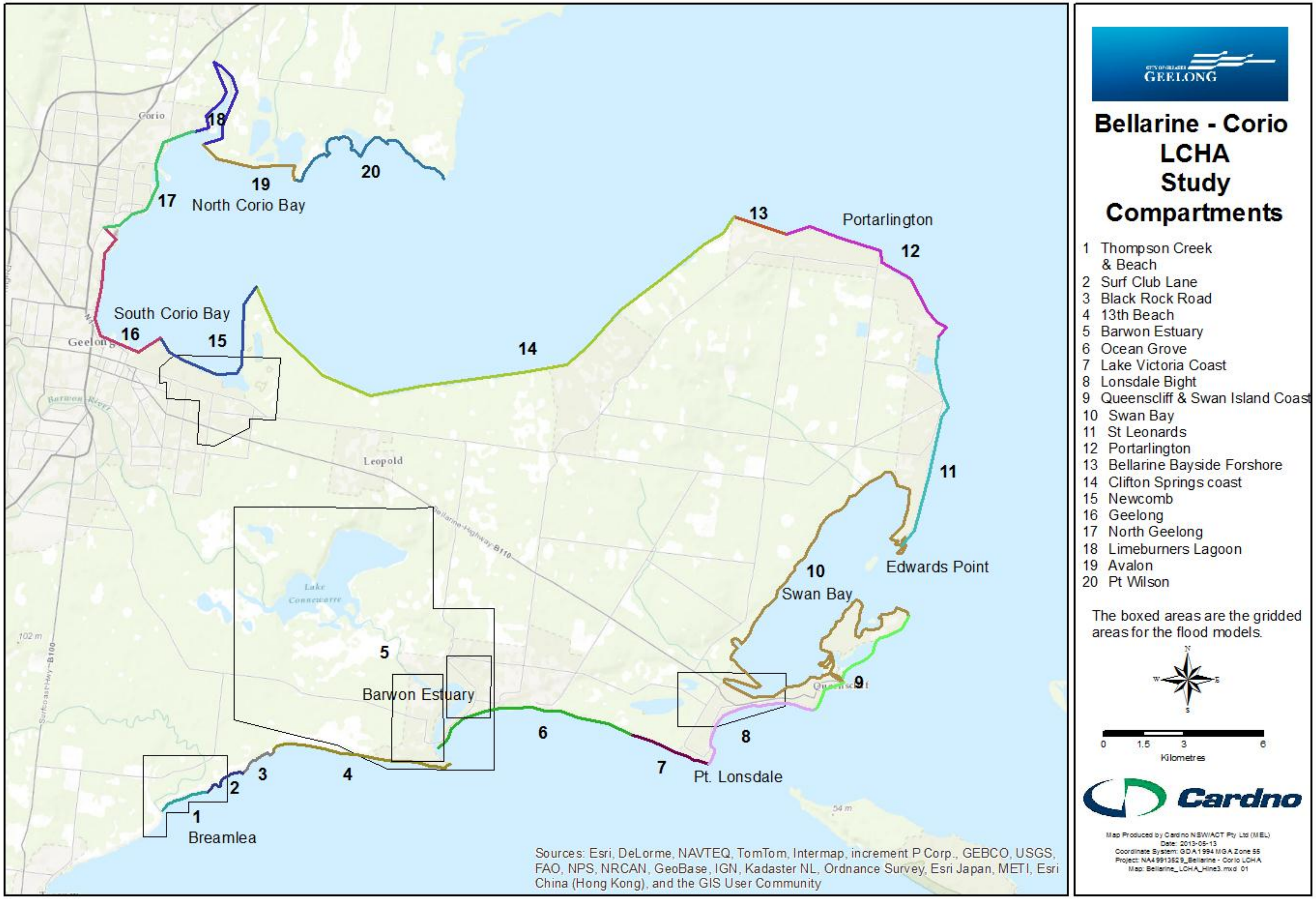

Figure 2-1 Study Compartments and flood model grid locations

3 Technical Assessments

3.1 Storm events

A table of events and descriptors was presented in the project brief to guide the selection of extreme coastal and flood events for modelling (Table 3-1). A low frequency 1% AEP storm tide and 1% AEP wave condition was to be coupled with a moderately high frequency 10% AEP catchment flow, with a number of varying sea level rise estimates included to ensure the range of SLR variations through time is considered. It is proposed to vary slightly from these to consider a 1% AEP event, coupled with a 10% AEP catchment flow. It should also be noted that the likelihood descriptions noted in the table can be misleading, and therefore will not be used. They do not describe the likelihood of the corresponding event occurring. They may have been intended to describe the resultant mapped area affected by said event. If they are required to be used in the project, they should be redefined in consultation with the PCG for appropriateness.

Table 3-1 Scenarios noted in the brief

Time period (year)				Combination of events to assess coastal hazards
Present	2040	2070	2100	
Likely	Virtually certain			1% AEP storm tide & wave height with 10% AEP catchment flows
Unlikely	About as likely as not	Likely	Virtually certain	0.2 m of sea-level rise plus 1% AEP storm tide & wave height with 10% AEP catchment flows
Very unlikely	Unlikely	About as likely as not	Likely	0.5 m of sea-level rise plus 1% AEP storm tide & wave height with 10% AEP catchment flows
		Very unlikely	About as likely as not	0.8 m of sea-level rise plus 1% AEP storm tide & wave height with 10% AEP catchment flows
			Unlikely	1.1 m of sea-level rise plus 1% AEP storm tide & wave height with 10% AEP catchment flows
			Very unlikely	1.4 m of sea-level rise plus 1% AEP storm tide & wave height with 10% AEP catchment flows

Due to climate change uncertainty, we propose to present a range of scenarios that can be applied independent of a specified time frame. This allows for changes based on variations in sea level rise and changing IPCC guidance. This will be consistent with a process of adaptive management where future decisions are based on the most up to date coastal and climate change science.

We propose a new matrix of events that would better represent local requirements (Table 3-2). It is also suggested that a higher frequency event be modelled as well to provide short term planning information. Having only one modelled AEP event gives limited information for subsequent purposes, it also does not allow for the investigation of the impact of a series of higher frequency storms, as was suggested in the project inception meeting. Therefore a 10% AEP event may be assessed as well as the 1% AEP event (time and budget pending), paired with the State Government SLR benchmarks of 0.2 m, 0.5 m, 0.8 m, 1.1 m and 1.4 m. An initial assessment shows the highest catchment flows do not coincide with surge events in this area, therefore a 10% AEP catchment flow (or lower) may be appropriate, this will be further investigated.

Note, the SLR increments noted are benchmarked against 1990 water levels. SLR around Victoria averages approximately 1mm per year, therefore equating to around 2.3cm of SLR that has occurred since that time. However for the purposes of this project, and conservatism, the 1990 will be applied to the present day water levels without removing the 2.3cm. This will also avoid confusion.

Table 3-2 Revised event and SLR scenario table

Storm Event	+ Catchment flow	+ SLR (m)					
1 % AEP	10% AEP	0	0.2	0.5	0.8	1.1	1.4
10% AEP	base flow	0	0.2	0.5	0.8	1.1	1.4

Therefore, in summary, an AEP event includes a wave component, a storm tide component, and a catchment flow component (where relevant) and a sea level rise component.

3.2 Determination of Storm Tide Levels

The CSIRO storm tide levels (STLs) determined in McInnes *et. al.* (2009, 2009b) were checked for applicability. These levels were determined through hydrodynamic modelling of surge events, forced with wind and atmospheric pressure. The data set was for 38 years from 1966 to 2003, therefore an extremal analysis was undertaken to extrapolate the lower frequency event surge and STL levels. An astronomical tide component was added to these using a Monte Carlo sampling technique. Table 3-3 shows the values from McInnes *et. al.* (2009, 2009b), these are for Lorne, Point Lonsdale, Queenscliff and Geelong. The tidal assessment for sites in and adjacent to Bass Strait used Point Lonsdale water levels rather than Lorne. These are considered not representative of the open coast, as the tide gauge is located within the entrance of Port Phillip Bay. Also the Point Lonsdale water level record is rather limited, as well as being sparsely populated at times.

A Monte Carlo sampling method will be used to reassess the tidal portion of the storm tide for Lorne, with the modelled CSIRO surge component added to that. The CSIRO surge and storm tide values are determined for four locations within the study area; therefore assumptions must be made to determine what values should be used for locations not modelled.

Since the modelled surge for the open coast is relatively uniform (see Figure 3-3), the differences in STL are likely due to tidal variation and wind setup. The tidal range increases along the coast between Lorne, Barwon Heads and The Rip, as does the 1% AEP STL (Figure 3-2). The CSIRO Pt. Lonsdale STLs are significantly lower than the Lorne values, due to the tide gauge position within the bay entrance. To determine the STLs for the open coast between Lorne and Pt. Lonsdale, the tidal component of the revised Lorne STLs will be adjusted to reflect the tidal differences to give a more accurate STL for Barwon Heads, Ocean Grove and the open coast side of Pt. Lonsdale. Appendix B describes in more detail the justification and methods for reassessing the STLs.

The inner Port Phillip Bay CSIRO values are still applicable. Within Port Phillip Bay, the tide and surge levels are relatively uniform throughout resulting in a STL that is also relatively uniform. The exception is the eastern side of Port Phillip where the surge is higher, probably due to the effects of wind set up (Figure 3-1). Therefore it is considered appropriate to use the Geelong STL values for much of the Peninsula coast, within the bay.

Table 3-3 CSIRO present day storm tide levels (McInnes *et.al.*, 2009, 2009b)

Locations	Levels	CSIRO Values		Revised Values	
		AEP 10%	AEP 1%	AEP 10%	AEP 1%
Lorne	Surge (m AHD)	0.66	0.71	0.57	0.70
	Storm tide (m AHD)	1.32	1.69	1.53	1.69
Point Lonsdale	Surge (m AHD)	0.75	0.84		
	Storm tide (m AHD)	1.16	1.41		
Queenscliff	Surge (m AHD)	0.74	0.83		
	Storm tide (m AHD)	1.04	1.23		
Geelong	Surge (m AHD)	0.7	0.76		
	Storm tide (m AHD)	0.91	1.06		

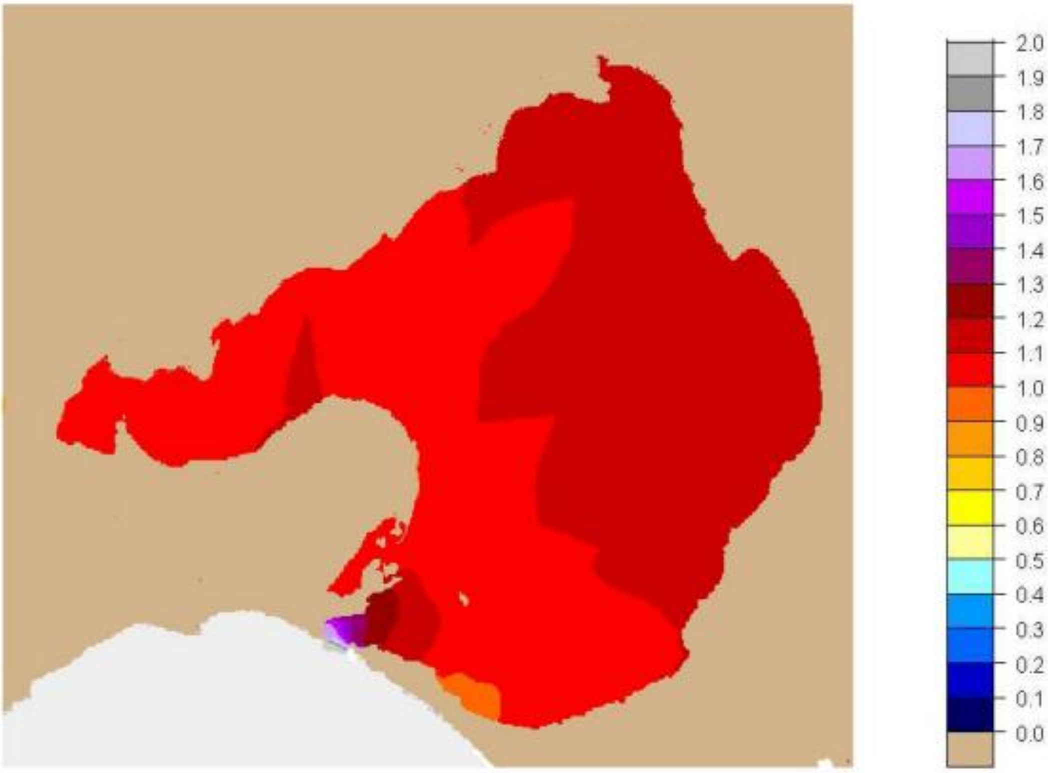

Figure 3-1 Spatial pattern of the 1 in 100 year STL for Port Phillip Bay (McInnes *et.al.*, 2009b)

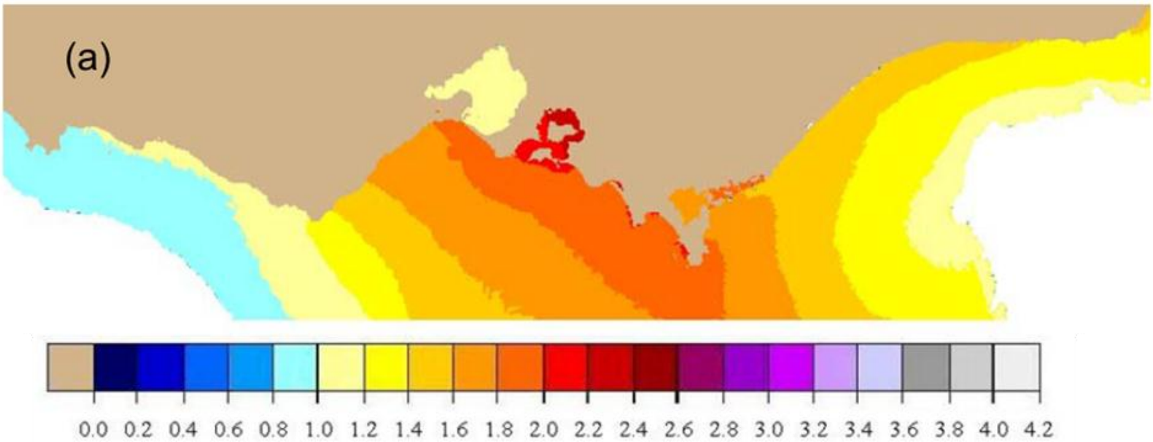

Figure 3-2 Spatial pattern of the 1 in 100 year STL for Bass Strait (McInnes *et.al.*, 2009)

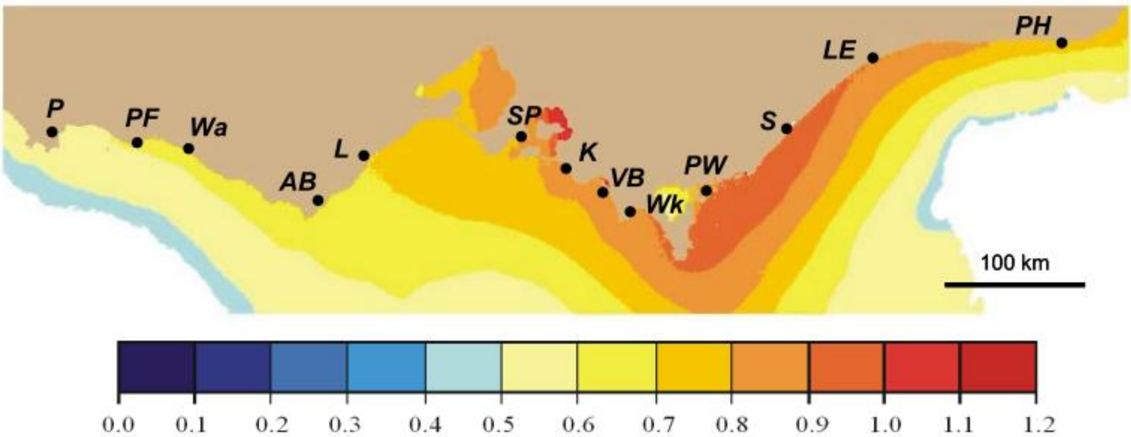

Figure 3-3 Spatial pattern of the 1 in 100 year storm surge height for Bass Strait (McInnes *et.al.*, 2009)

3.3 Wave Conditions

The Bass Strait wave conditions for the study area along the open coast are required for analysis of coastal processes and coastal erosion. A global WaveWatchIII wave model, driven by the Climate Forecast System Reanalysis (CFSR) wind fields (http://nomads.ncdc.noaa.gov/data.php?name=access#cfsr) was used to compute the wave conditions along the boundary of a coarse SWAN model. The SWAN model extends from Cape Otway to Wilson's Promontory. Within the coarse grid a finer resolution grid was nested from which model results were extracted at points in 10 m water depth along the study area coastline. The modelling system was run for 85 storm events, judged to be the most severe over the 30 years covered by the wind fields.

Extremal analysis using a Weibull distribution was performed using a separate dataset of storm peaks for the measured and modelled data. The modelled extremes analysis was based on the highest 33 storm events derived from the initial 85 runs. The 30 years of modelled data between 1979 and 2009 were used to obtain the 1% AEP wave conditions. This was compared to the extremes based on the 10 years of measured data from Point Nepean (PoMC). Table 3-4 shows the differences between the measured and modelled extremes. The modelled extremes are more conservative (higher) than the measured extremes for the less frequent events. Therefore, the most conservative value for each AEP will be adopted.

Wave conditions were extracted at appropriate points along the open coast, from east of Breamlea to Point Nepean (The Rip). The model results were used to derive relationships between the wave height for each selected location, against that at Point Nepean. These relationships can then be utilised to create a variable wave climate along the coast, based on the measured wave data at Point Nepean from 2003 to 2013 and are able to be applied to the Pt. Nepean extreme events. This is to determine extreme wave conditions for each selected location. The wave point locations are presented in Figure 3-4, each is approximately on the 10m contour.

Further stationary SWAN runs were conducted to determine how the direction varied along the open coast. These runs enabled the measured wave direction at Point Nepean to be converted for each location along the coast. The wave periods were assumed to be constant.

Table 3-4 Extreme Wave Heights for Pt. Nepean

AEP	Hs measured (m)	Hs modelled (m)	Adopted Hs Values (m)
100%	5.6	4.9	5.6
20%	6.2	6.1	6.2
10%	6.5	6.6	6.6
5%	6.7	7.0	7.0
2%	6.9	7.6	7.6
1%	7.1	8.0	8.0

The wave climate within Port Phillip Bay is available from models used in past projects, such as the Bellarine Coastal Processes Study (Cardno, 2011), the Channel Deepening Project (PoMC, 2008) as well as Eastern Beach and Clifton Springs projects. As swell from Bass Strait penetrates only a short distance through the entrance, waves within the bay are generated by wind. The wave climate can therefore be obtained by applying the probability of exceedance for wind speeds and directions to corresponding modelled stationary wave runs. An additional dataset of measured wave heights was received from Water Technology for March 2010 to March 2011. This will be used to confirm conditions in this area once they are extracted from the model in the necessary locations.

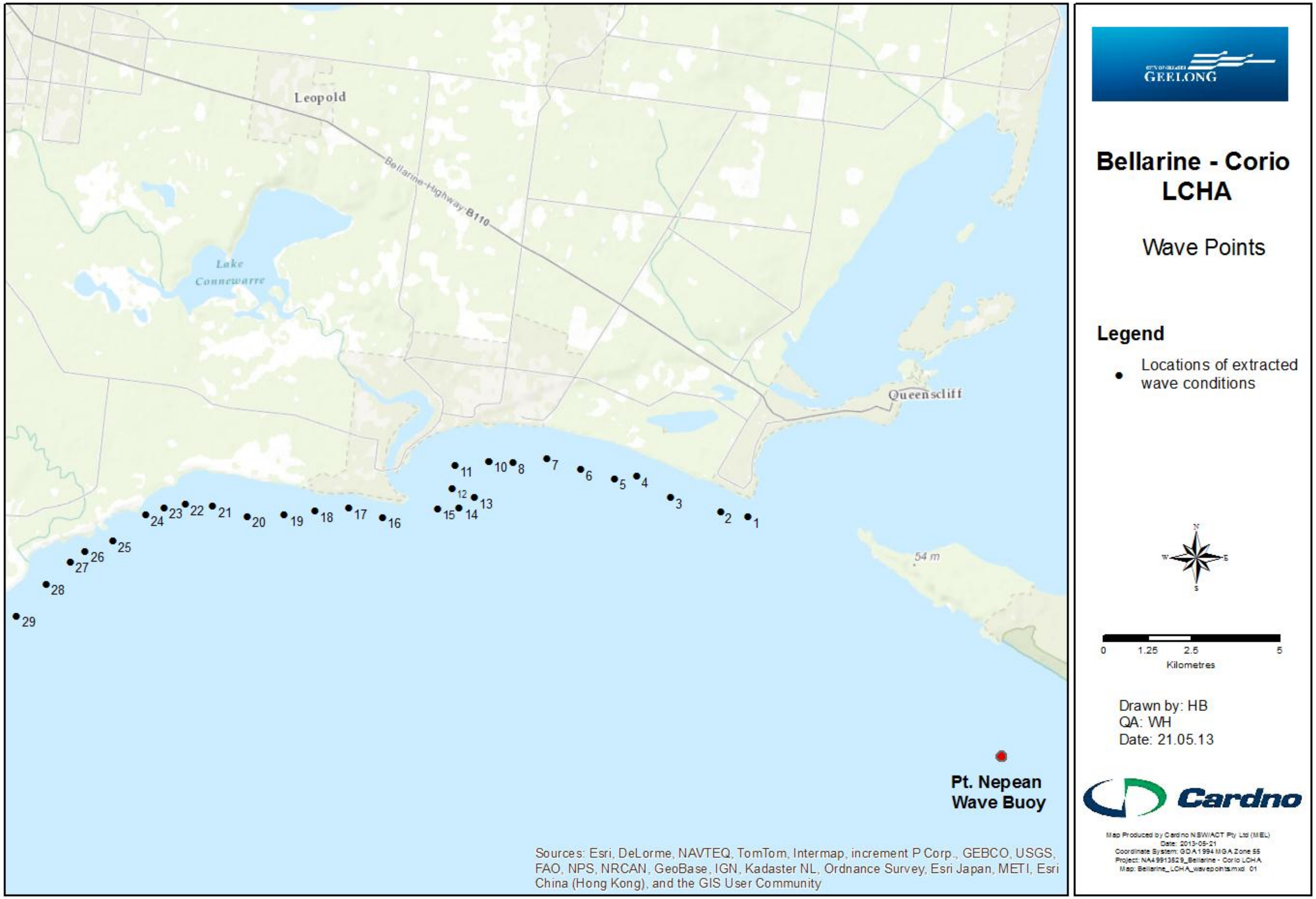

Figure 3-4 Locations of extracted wave conditions for the open coast

3.4 Joint Probability – waves, water levels, rainfall

A requirement of this project stated in the brief was to look at a 1% AEP storm tide event coupled with a 1% AEP wave height and a 10% AEP catchment flow, for a range of sea level rise scenarios for a range of years. An assessment of measured tidal (Lorne) and wave records (Pt. Nepean) showed that the largest waves do not coincide with the highest water levels. Thus, the occurrence of 1% AEP levels for both parameters in one event is considered unrealistic and overly conservative. An assessment of the measured wave heights occurring during surge events will be undertaken to determine an appropriate wave height and storm tide combination that will constitute the 1% AEP event.

A pragmatic approach to determining joint probability conditions based on measured events will be taken. This will be a similar to the method presented in Shand *et.al.* (2011). It should be noted that the design conditions are for indicative flood and erosion hazard purposes rather than for structural design. Therefore, although the level of confidence may be lower, this is considered acceptable for project purposes. It should also be noted (and will be made very clear in the final project report) that any conditions determined in this assessment are not intended for, and should not be used for, detailed design purposes.

Similarly an assessment of rainfall against surge level noted that the highest rainfall and surge also do not coincide, thus, the application of a 10% catchment flow within the 1% event is considered reasonable. This will be refined where necessary during the model development.

3.5 Design Conditions

A table of joint probability design conditions will be produced for the study area once conditions are determined through modelling and analysis. These will be presented in the final report.

3.6 Assessment of the historical aerial photography

This will be undertaken to determine any underlying rates of shoreline change over the past 70 years. Aerial photographs are available for some areas within the study area. The photographs were orthorectified by DSE and were compiled as part of a DSE historical imagery project. There is some inherent uncertainty relating to this type of assessment. The toe of the dune was traced in ArcGIS, or where the toe was not distinguishable, the seaward edge of the vegetation line. The most seaward edge of any cliff sections was also traced.

The orthorectification process and digitising of the shoreline can introduce error, as both are manual processes. Also, the sporadic times of photographs makes it difficult to qualify the results, as it is unknown whether each was taken after a long period of calm, or after a storm. Even with this uncertainty, it will still be possible to get an idea of areas that are relatively dynamic, and those relatively stable for use in subsequent assessments (with caution).

3.7 Protection structures

A database exists that includes most of the coastal protection structures in the study area. The dataset includes various parameters, e.g. reduced levels (RL), defence type, lengths, condition, priority of maintenance etc. Inspection of this data set and visual observations during the site visit concluded that some lengths of defence were missing from the database. If no survey data is available from individual land managers, the lengths and RLs will be estimated in GIS, and will be confirmed with local land managers as an informal ground-truthing exercise. For example, the revetment structures on the east bank of the lower Barwon River are not included in the database. Figure 3-5 shows the structures in the study area that are included in the database.

The condition and performance of the protection structures will be a key aspect of the erosion and inundation assessments. The database gives generic condition and design life descriptors, e.g. “poor”, “fair”; however, no estimation of the residual life is included. Within the dynamic modelling a range of hydraulic features will be incorporated to account for differences in the structures and their integrity. That is, where a structure is in place, but may be permeable due to poor condition or lack of formal design. Low retaining walls will be modelled as topographic features rather than structures.

The brief notes two modelling scenarios, one where the defences are present, and one where they are absent. The assessment of a “without defences” option can be used for the purpose of determining the potential costs and benefits of maintaining the status quo, or to justify future funding. However, for this study area, it is more appropriate to model the current situation, and, where necessary, provide indication of the event under which a defence may fail, and the resultant inundation or erosion extent, as well as including potential failure mechanisms related to trigger points. This is applicable for the protected and non-protected sections of coast. This would indicate that when storm event levels or tidal levels (once sea level rise is incorporated) exceed a certain threshold that the volumes overtopping a frontage or defence are no longer tolerable and the inundation may cause failure. Thus, some additional works may be required to ensure the risk of failure is reduced. This could be applied similarly for erosion, when event conditions cause erosion that leads to, for example, the erosion scarp getting within an unsafe distance from an asset. It may be appropriate to have two trigger distances, one to alert that the risk is increased significantly, and then another to alert that action needs to be taken imminently to reduce the risk.

For this study, it will be assumed that most of the current defences will be maintained *in situ* for the next 100 years to a “fit for purpose” standard. The current defence crest-elevations will not be increased to keep a constant freeboard in pace with sea level rise. Since the residual life of the current defences is unknown, the report will note that any defences present after 50 years would be assumed to have been rebuilt or refurbished to an appropriate standard. Recommendations relating to this, and to facilitate this will be made. We will also consider locations where a defence may not be possible to be maintained for the duration of the study period, therefore, the extent of erosion in the absence of the defence will be presented.

The volumes of overtopping discharge will be assessed for information, based on functional and tolerable limits where developments or infrastructure are immediately behind. Levee defences will also be assumed to withstand sporadic flood events and overwashing (depending on levee crest elevation) in the short term. This is consistent with GHD (1997), where the Barwon levee was “tested” during a storm event in 1995 and did not fail. In the long term, levee defences may fail in significant flood events, especially with more frequent higher magnitude storms in future. For this project, overwashing refers to the water level increasing over and above the crest of a defence in the absence of significant wave energy, as opposed to wave overtopping where it is the additional momentum associated with the wave action which results in water flowing over the structure, however both are inundation mechanisms.

The exact methods related to the aforementioned assessments and individual locations are not able to be predicted at present, they will be developed and dealt with as the project progresses.

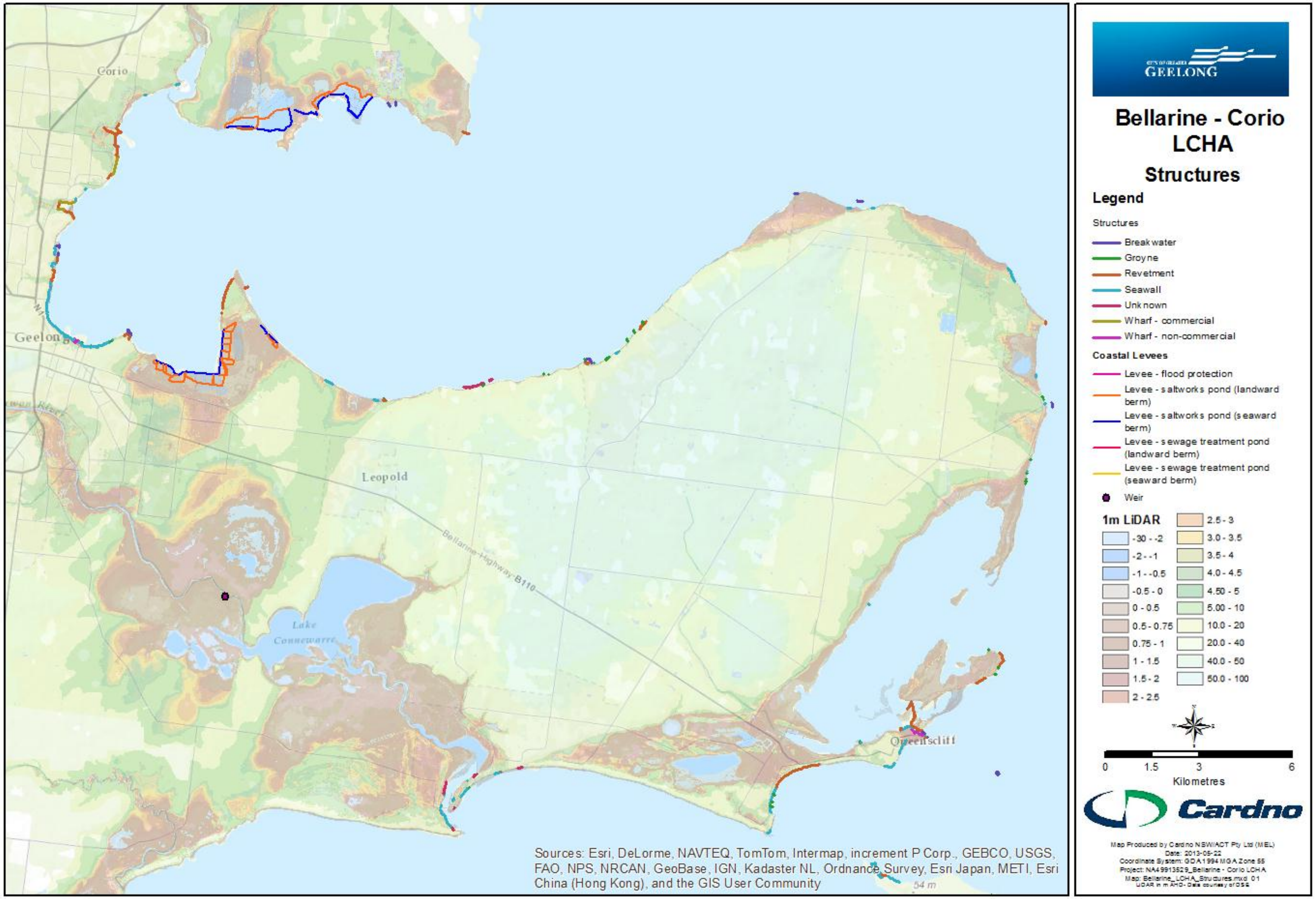

Figure 3-5 Structures within the study area

4 Modelling

The various landscapes around the Bellarine area require differing modelling approaches at differing resolutions. Information from CoGG, DSE and other local stakeholders identified their areas of concern. These were visited during the site inspection and confirmed through the preliminary modelling to ensure the potential flooding and erosion mechanisms were understood. Additional information for model detail was also gathered, including potential flood paths, presence and condition of defences etc.

The landscape consists of:

- high energy sandy beaches (open coast)
- high energy rocky beaches (open coast)
- low energy beaches (PPB)
- semi-lithified dunes/cliffs (open coast)
- cliffed areas
- low energy estuarine areas.

4.1 Modelling Approaches

Table 4-1 details the approaches and justification for each location. The subsequent sections give some more detail about the methods and assumptions.

The inundation modelling will include both dynamic and static modelling approaches. The dynamic methods are applied to the higher priority locations and where flow paths are more complex, the grid mesh size is given to indicate modelling resolution (the smaller the grid size the more detailed the model). A dynamic model includes consideration of the time taken for water to flow across the land and the limits in the volume of water which can flow due to frictional effects. It also includes variable boundary values such as including tidal variation for sea level boundaries. The static modelling refers to horizontal projection of the water level. This method is applicable for the medium and low priority locations, and where there are less complex inundation mechanisms e.g. low lying areas with little or no dune and no defences (as indicated in Table 4-1).

Table 4-1 Modelling approach by location – note merged table cells indicates where a model will cross location boundaries

Area	Location		Sub-location	Riverine Inundation modelling and grid size	Cross shore sediment transport and 'storm bite'	Longshore sediment transport	Coastal Inundation (Run-up Overtopping)	Additional Information
Thompson Creek to Blue Rocks	1	Thompson Creek	Creek & Entrance	x (20m)				Due to the high priority of this location, Thompson creek will be modelled using SOBEK using a 20m grid.
			Beach		x		x	Potential for future breaching of dunes in future to be investigated.
	2	Surf Club Lane	West beach		x		x	Rocky and sandy foreshore bound between rocky outcrops.
			Bancoora Beach		x	x	x	The potential for breaching of the dunes will be investigated, and if necessary incorporated into the Thompson Creek SOBEK model. Sandy foreshore bound between rocky outcrops.
	3	Black Rock Road					x	Rocky substrate - sewerage works outfall.
Blue Rocks to Barwon Estuary	4	13th Beach			x		x	Although in future there may be potential for the dune to breach here due to the present location of the dune scarp, it is assumed that this section of beach would be held in place to protect the road. Assumptions must be made as to the potential horizontal distance of erosion, considering the calcarenite cliffs at the eastern end.
	5	Barwon Estuary	West Channel	x (4m)				The modelling of this compartment will be done using SOBEK at varying resolutions. Numerous shore protection structures. Waves within estuary negligible, thus flooding via overwashing.
			East Channel	x (4m)				
			Lower Barwon	x (20m)				
			Lake Connewarre	x (40m)				
Ocean Grove to Point Lonsdale	6	Ocean Grove			x	x	x	Overtopping of vertical timber retaining wall, and consider potential undermining due to scour at the toe - terminal scour at each end.
	7	Barwon Coast/Buckley Park			x		x	Assumptions must be made as to the potential horizontal distance of erosion, considering the calcarenite ridge.
Point Lonsdale to Pt Edwards	8	Lonsdale Bight	Cliffs				x	Where structures are present, overtopping will be calculated and any potential 'failure' volumes will be determined for hinterland safety based on tolerable limits.
			Vertical Wall		x	x	x	
			Rock Revetment		x		x	

Area	Location	Sub-location	Riverine Inundation modelling and grid size	Cross shore sediment transport and 'storm bite'	Longshore sediment transport	Coastal Inundation (Run-up Overtopping)	Additional Information
		PPB Open coast		x		x	Terminal erosion at end of rock revetment.
	9	Queenscliff (PPB coast)		x		x	Revetment buried with sediment. Rock groyne holding the channel mouth and protecting the ferry terminal.
		Swan Island (PPB coast)		x		x	Natural rates of erosion masked by renourishment from channel dredge spoil to consider.
	10	Queenscliff (Fishermans Flats)		x		x(s)	This area currently floods during high rainfall events due to it being very low lying, with a high water table. The flooding mechanisms here are not complex and do not require a dynamic approach.
		Swan Bay		x		x(s)	The wave heights within Swan Bay are low; therefore inundation is likely to be the overriding hazard rather than erosion. Inundation will be assessed using a static model. Shoreline erosion will be assessed using a basic lake/estuary shoreline erosion model.
		Lakers Cutting – Hollywood Estate	x (10m)				This will be modelled dynamically due to the complex flow paths with a series of culverts. Special consideration when modelling the road - only entry/exit to Borough.
Pt Edwards to Portarlington	11	St Leonards		x		x(s)	Series of groynes, vertical retaining walls and some geotextile containers. Land is low lying, and defences are low, offshore sand banks providing some protection to the coast from wave climate.
	12	Portarlington		x		x(s)	Mostly low lying hinterland, low vertical retaining walls, rocky and sandy shore,
	13	Bellarine Bayside Shore		x		x(s)	Renourished at eastern end, beach scraped at western end.
Portarlington to Pt Henry	14	Ramblers Way		x	x	x(s)	This area is very low and flat and there is no significant dune or protection structure. Although calculations for storm bite will be carried out for indicative purposes, the overriding hazard here is likely to be inundation.
		Clifton Springs		x		x(s)	Groynes, boat harbour, cliffs + heritage area and renourishment of the Dell.
		Point Henry & Moolap		x		x(s)	This area is very low and flat and there is no significant dune or protection structure. The overriding hazard here is likely to be inundation.
South Corio Bay	15	Newcomb & Moolap	x (4m)	x			The overriding hazard here is likely to be inundation due to the very low lying land. There is a series of levees along the shoreline from the decommissioned salt works and a number of stormwater drainage channels that extend into the hinterland.

Area	Location		Sub-location		Riverine Inundation modelling and grid size	Cross shore sediment transport and 'storm bite'	Longshore sediment transport	Coastal Inundation (Run-up Overtopping)	Additional Information
									Therefore, a dynamic model will be used to determine the inundation hazard.
	16	Geelong	a	Eastern Beach				x(s)	A static model will determine the potential inundation extent, due to the negligible wave climate. Since much of the frontage is armoured except Eastern beach, overtopping will be calculated using EurotOp.
			b	Western Beach					
North Corio Bay	17	North Geelong	a	North Shore					
			b	Shell Foreshore					
	18	Limeburners Lagoon				x	x	x(s)	This area is very low and flat and there are no significant dune or protection structures. The overriding hazard here is likely to be inundation.
	19	Avalon				x		x(s)	
	20	Pt Wilson				x		x(s)	

4.2 Coastal Inundation

4.2.1 Wave setup & runup

The STLs already incorporate a wind setup component, therefore only wave setup is required from the modelling. The coastal inundation will be modelled using SWASH where appropriate and where the required information is available to set up the model. Where the SWASH model is unable to be applied, setup is able to be determined in SWAN or LITPACK. From this, empirical calculations can be carried out to determine the runup. This will inform areas where breaches of the dune may occur. Overtopping calculations will be carried out to give an indication of the potential volumes of water that may pass over/through a breach. From this an indicative area that may become wet can be determined based on the topography of the hinterland (volumetric placement method).

4.2.2 Overtopping

Overtopping calculations will be undertaken for locations where hard defences are present. There are a number of locations throughout the study area where the shoreline is armoured, therefore, some of the study compartments have been sub-divided to account for differences in defence, and thus, differences in modelling approach. EurotOp (2007) will be used to calculate overtopping of the various structures around the study area. If calculations are required for coastal dune breaches, assumptions will be made as to the most appropriate methods to use as well as the appropriate roughness coefficients etc. Profile slopes are able to be determined from the LiDAR/bathymetry data cross sections. Visual observations and estimations of the middle and upper beach were also made during the site inspections.

4.2.3 Overwashing

For low lying land where there are no significant defences, dunes or waves, and where the mechanisms for coastal flooding are simplistic, a static model will be used to determine potential inundation extents. This assumes that the elevated water level attributed to the storm tide will be able to overwash the shoreline or defences and flood the hinterland. This technique will consider flood routes, but will not consider overland spreading or ground absorption; however it can be assumed that during a storm/flood event, the ground will be soaked due to rainfall and storm water drains would likely be full. In more complex areas a dynamic flood modelling approach will be used (see Section 4.5).

4.3 Coastal Erosion Modelling

4.3.1 Storm bite and cross-shore transport

Where significant dunes are present, short term storm erosion will be determined using SBEACH or LITPROF. The different methods will be undertaken based on the characteristics of each site and the abilities or limitations of each model. The results of this contribute to erosion hazard delineation.

4.3.2 Longshore sediment transport

Assessment of the longshore sediment transport will be undertaken using LITDRIFT. This will determine the rates of sediment transport to determine and enable us to infer any significant cross or longshore erosion or accretion trends, and to compare with any trends in the historical aerial photography. LITLINE is able to be used to estimate future shoreline change and beach rotation based on sediment transport rates. This information will be factored into the hazard zone delineation.

4.3.3 Shoreline response to SLR

The Ranasinghe (2011) model will be investigated for appropriateness in the study area. This model required significant amounts of background data, therefore may not be appropriate in certain locations. Where this is apparent, Bruun (1962) will be used in lieu, as well as any trends or long term erosion or accretion noted from the historical aerial images.

4.4 Shoreline Evolution

The brief states that the future climate change scenarios will incorporate future shorelines. This type of assessment is inherently uncertain, and results can be misleading and alarming if not carried out sensibly. If a significant and reliable trend of erosion exists in a location, the future climate change erosion and inundation scenarios will be carried out using the predicted future shoreline, over and above the results on the present shoreline. The assumptions relating to these assessments will be documented clearly to inform of the uncertainty.

4.5 Flood Modelling

The locations at risk of river or estuarine flooding are noted in Table 4-1. This riverine inundation modelling will be carried out using SOBEK. The coarse and fine gridded areas are presented in Figure 2-1.

The Breamlea area is considered to be of high priority. The creek is a low energy environment, with low lying flood plain hinterland. The flood model will be an intermediate grid size (20m). There are two features that will be considered within the flood model, a culvert to a saline habitat area and a potential breach near the SLSC. The breach will not likely initiate until a future time period once the beach has eroded back/down enough to allow flow through, if a trend of erosion is determined here.

The lower Barwon area and Lake Connewarre will be modelled separately at a coarser resolution (20m and 40m respectively). Each of the heavily populated eastern and western banks (high priority) of the Barwon will be modelled separately at a finer resolution with nested model grids (4m). As noted previously, the estuary will be modelled assuming the current defences are in place, and will continue to be maintained at the current standard of protection.

Lakers Cutting and the Bellarine Highway will be modelled with a 10m grid. The Highway is in very close vicinity to Swan Bay, separated by a rail embankment. This is road is the only entry/exit to Queenscliff, thus is high priority. The flow path through Lakers Cutting to the Hollywood estate is complex, thus, is included in the model grid. The Murray Road area is also likely to be at risk. The Fisherman’s Flats area of Queenscliff has been left out of the dynamic model grid. Protection structures are low and in poor condition, thus, there is little to inhibit the flow of saline water to the hinterland. The area has a high water table, and presently floods during high rainfall events. Thus, the complexity of the dynamic modelling is not required here.

The Newcomb gridded area is bound by the 3.5 m AHD contour. The area is a heavily populated low lying area. The shoreline consists of a series of levee embankments in varying condition and relict saltpans. There is a large open storm water channel that drains parallel to Moon Street, and other smaller stormwater outlets along a similar orientation throughout the area. For the purposes of this study, the levees will not be modelled as a barrier. The condition of them in mostly poor, and they are no longer maintained. They also do not form one consistent barrier, as there are gaps and low sections.

For the bathymetry of the SOBEK models, it is assumed that although water levels will increase with SLR, no change in flood or ebb dominance will be incorporated. The tidal prism will likely increase, as no increase in sedimentation of the estuary will be incorporated to keep pace with sea level rise, as may happen in reality.

4.6 Hazard Definition

Studies use differing approaches in determining what constitutes a hazard zone. Usually, hazard zones will factor in the following in some combination:

- storm bite erosion;
- long term recession rates;
- some slope adjustment factor;
- recession due to sea level rise.

The primary erosion and inundation defined hazards are presented in Table 4-2. Previous studies undertaken along the Victoria coast have used two back-to-back 1% AEP events as the defined erosion hazard zone. For consistency, this will be done for this hazard assessment also. Where appropriate, the two events will use different combinations of wave conditions and storm tide, but retaining the 1%AEP occurrence level.

Where shoreline erosion occurs in areas that are not dunes (i.e. direct erosion of land or soft rock), the two lines for each AEP event will be reproduced by changing the modelling inputs to account for the changes in the profile, and use engineering judgement to apply appropriate horizontal recession distances.

The inundation hazard zones will be the horizontal flood extents of each event, with the 1% AEP event the defined inundation hazard.

Table 4-2 Primary erosion and inundation defined hazards

Hazard	Present Day Scenario	Future Scenarios				
	A1a	***A1b***	***A1c***	***A1d***	***A1e***	***A1f***
Erosion	2 x 1% AEP event storm bite erosion extent + factor for slope adjustment and RFC	2 x 1% AEP event storm bite erosion extent + 0.2m SLR + recession + factor for slope adjustment and RFC	2 x 1% AEP event storm bite erosion extent + 0.5m SLR + recession + factor for slope adjustment and RFC	2 x 1% AEP event storm bite erosion extent + 0.8m SLR + recession + factor for slope adjustment and RFC	2 x 1% AEP event storm bite erosion extent + 1.1m SLR + recession + factor for slope adjustment and RFC	2 x 1% AEP event storm bite erosion extent + 1.4m SLR + recession + factor for slope adjustment and RFC
	B1a	***B1b***	***B1c***	***B1d***	***B1e***	***B1f***
Inundation	1% AEP event inundation extent	1% AEP event inundation extent + 0.2m SLR	1% AEP event inundation extent + 0.5m SLR	1% AEP event inundation extent + 0.8m SLR	1% AEP event inundation extent + 1.1m SLR	1% AEP event inundation extent + 1.4m SLR

Note: RFC – Reduced Foundation Capacity

Additional erosion scenarios will be carried out, budget and time allowing.

Although all lines will be produced and available as spatial layers for Council use, only the scenarios in Table 4-2 will be presented in the report as maps.

4.7 Assumptions & Uncertainty

The degree of certainty is to be determined for the individual compartments in a mostly qualitatively fashion, and to some extent, quantitatively.

The qualitative process will likely include an overview on the data used to calibrate the models, i.e. the resolution of LiDAR and bathymetry data, measured versus modelled conditions, resolution of model grids.

Appropriate sensitivity analyses will be undertaken where necessary to assess quantitative uncertainty. For this project, it is likely to be the open coast wave climate. It is common practice in coastal engineering design to test an 'overload' case which increases the wave height by 10 or 20%, therefore test cases will be run where appropriate to determine how sensitive the calculations and results are to various increases or decreases (where appropriate) in design conditions and wind direction. Considering the extreme waves are calculated from modelled data, and are already considered conservative, the sensitivity will likely be reducing the wave height and assessing the implications of this.

In terms of climate change and sea level rise uncertainty, by applying the sea level rise increments regardless of year, this removes the perceived certainty surrounding the inundation and erosion extents related to the specific future years identified. It allows for some flexibility in future assessments with respect to changing sea level rise guidance and local measured rates of increase. For the few locations where there is underlying recession, a year has to be assumed to calculate the amount of recession to apply; this will be in accordance with the Victorian Coastal Council's guidelines for 2040 and 2080 sea level rise.

A register of uncertainty and limitations will be kept and presented in the final report with methods to reduce or overcome each limitation, likely through recommendations for future studies, data acquisition and monitoring that are beyond the scope of this project.

5 Project Information

5.1 Main report and presentation of results

The main project report will contain all relevant information, methods and results. This will be a technical report that is intended for an audience that is relatively familiar with the concepts of coastal science and engineering. An initial template of the report has been prepared for review and comment, this is in Appendix A. This will be developed over the course of the project.

It is likely that the final report will come with a series of appendices - this will ensure the modelling detail is available for interested parties, without making the main body of the report too technical. A number of figures will be produced at area wide resolution to present the erosion and inundation extent results for each of the SLR increments. This will likely produce in excess of 120 figures, which will be put into an appendix rather than the main text.

A shorter non-technical summary could be produced after agreement of the project findings and could be used as a public information document. This would be additional to the project scope and subject to a variation.

5.2 Project standing summary

At present (July 2013) we have completed the data processing phase of the project, and are starting to undertake the detailed modelling. The following is a breakdown of the project standing:

- the site visit has been completed and sediment samples analysed;
- the type of modelling applicable to each compartment and sub-compartment are noted for review;
- the specific modelling methods have been tested;
- detailed models are being set up;
- design joint probability water levels and wave heights are being determined;
- the aerial photography assessment is complete;
- the literature review and assessment of coastal process and geomorphology is complete.

The next project deliverable will be the draft project report, in late September.

6 References

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Bellarine Peninsula Corio Bay Local Coastal Hazard Assessment

ANNEX A (APPENDIX A) MAIN REPORT TOC

ANNEX B (APPENDIX B)
SUPPLEMENTARY TECHNICAL NOTE

Cardno
Shaping the Future

SUPPLEMENTARY TECHNICAL NOTE

Introduction

This technical note provides some of the additional technical detail to the scoping document. This document is targeted to the Technical Review Group, and details the justification for determining new storm tide levels for the open coast, instead of using the CSIRO (2009) values.

CSIRO Storm Tide Levels

An assessment of the CSIRO (2009) storm tide levels and methodology for the open coast was undertaken to determine the validity of the values for use in the Bellarine Local Coastal Hazard Assessment.

The CSIRO method is a two phase method that firstly:

- identifies surge events in the tidal record, using the tidal residuals (threshold set at 0.2 m);
- hydrodynamically models each surge event to determine the maximum modelled surge peaks;
- then uses extremal analysis to determine surge height probabilities.

The second phase uses a Monte Carlo sampling method to determine the point of the tide at which the surge would occur. This was done by:

- using a tide model to generate tidal information on a grid similar to the surge modelling;
- tidal height frequency distributions were calculated for each grid cell of the surge model;
- these were then plotted against measured tidal gauge data at Portland, Stony Point, Rabbit Island and Point Hicks to confirm the model values;
- a random high-tide height and random peak surge-height are sampled from each data set and summed to give a storm-tide level, these were ranked and then the storm-tide level Return Intervals are determined.

An assessment of the measured and modelled data at Point Lonsdale, and the measured and modelled values at Lorne showed some significant differences. The Point Lonsdale values are inappropriate to use for the open coast, as they are considered too low. This is likely due to the position of the tide gauge within the bay. A comparison of the Lorne measured and modelled values was undertaken, this showed that the CSIRO values for the more frequent events (1 in 10 and 1 in 20 ARI) may also be too low.

Storm Tide Levels for Lorne and the Open Coast

Similar to the CSIRO (2009) method, surge events were identified in the tidal records. In this area of the Bass Strait coast, storm surges are often accompanied by a phase shift in the tide (Hubbert and McInnes, 2003). This means that the tidal residual (measured minus predicted sea level for any given time) contains the result of this phase shift as well as the storm surge, and thus residuals are not a suitable way to define the storm surge for evaluating storm-tide inundation. The surge was identified in the measured data using a “tide-killer” filter (Godin, 1972). From these data, a typical surge profile was identified, that is, the shape of the surge over time before and after the peak. Figure B1 shows an example of the sea level at Lorne during a storm event and the phase shift and consequent tidal variations in the residual can be seen. Also shown is the profile of the storm surge.

The heights of the storm surges in the available data (1992 to present) were used to develop the probability distribution for the low probability (greater than 1 year ARI) events. A Monte Carlo simulation was then used to combine the surge with the astronomical tide to yield the storm tide. A prediction of the tide for 18.6 years was produced and a time within this period selected at random, this was the time of the peak surge. Similarly, a random number was used to select storm surge height based on the probability distribution. Using the typical surge profile, the surge was added to the astronomical tide for the selected time with sea levels being calculated for 24 hours either side of the selected time. The maximum sea level during this 48 hour period was then designated as the storm tide for that event. By computing a large number (100,000) events, the probability distribution of the storm-tide events was determined.

Climate Change scenario mapping

It is proposed to reference scenarios for inundation and coastal erosion to event AEP and sea-level, rather than a specific year. Thus maps would be labelled “1% AEP + 0.5m sea-level rise” where the sea-level rise is relative to 1990 levels but applied at the present day (to avoid confusion). The aim of this is to avoid tying the scenarios to a given time in the future, but rather to say that if a given amount of sea-level rise occurs, this will be the consequence. We will still include a curve like the IPCC graph, or similar, but by specifying the sea-level rise, we put the uncertainty into the timing rather than having the uncertainty attached to the level of rise for a given time. This approach can also lead to the adoption of a “tipping point” or “trigger point” approach for coastal inundation where given actions or responses can be tied to a measureable quantity, namely an increase in mean sea-level.

For erosion, the premise would be similar; however, to incorporate a value for underlying recession would be difficult, as this is directly applied on a mm/yr basis. After assessment of the historic aerial photographs in the region, the open coast has no significant trend of erosion or accretion. The coastal compartments are fixed and protected by headlands and offshore banks, thus if sediment supply is to continue along the shoreline, increased erosion will likely only be attributed to increases in static water level due to sea level rise. The only areas that exhibit an erosion trend are at Lonsdale Bight, which was due to terminal scour at the end of the seawall (which has stabilised in the last 15 year) and discrete sections of Portarlington. For the few locations where there is underlying recession, a year has to be assumed to calculate the amount of recession to apply; this will be in accordance with the Victorian Coastal Councils guidelines for 2040 and 2080 sea level rise. As well as the “trigger points” related to sea level rise, and thus, the calculated presumed inundation and erosion extent, physical “trigger points” will also be incorporated to aid in Council and land managers planning decisions, which will override any predicted extents noted.

If such an approach were adopted in planning decisions and regulations, it would remove the emotive arguments about whether or not climate change and sea-level rise is, or is going to, occur in the future. By using a trigger point, a given planning regime or change would be triggered by a change in mean sea-level and not by a point in time which has the uncertainty attached to it. For example, a development may be allowed to proceed on the basis that flood barriers were installed to prevent inundation of, say, a basement car park, possibly at some time in the future. It is easy to conceive of a situation where such barriers are not required at present and to install them at present would likely lead to their deterioration over time until they are required. If the installation is triggered by a point time, it may too early, or it may be too late due to the uncertainty in the timing of sea-level rise. If the installation were to be triggered by a given increase in mean sea-level, then the barriers would be in place when needed, and the need for them would have been established by the observed and measured rise in sea level.

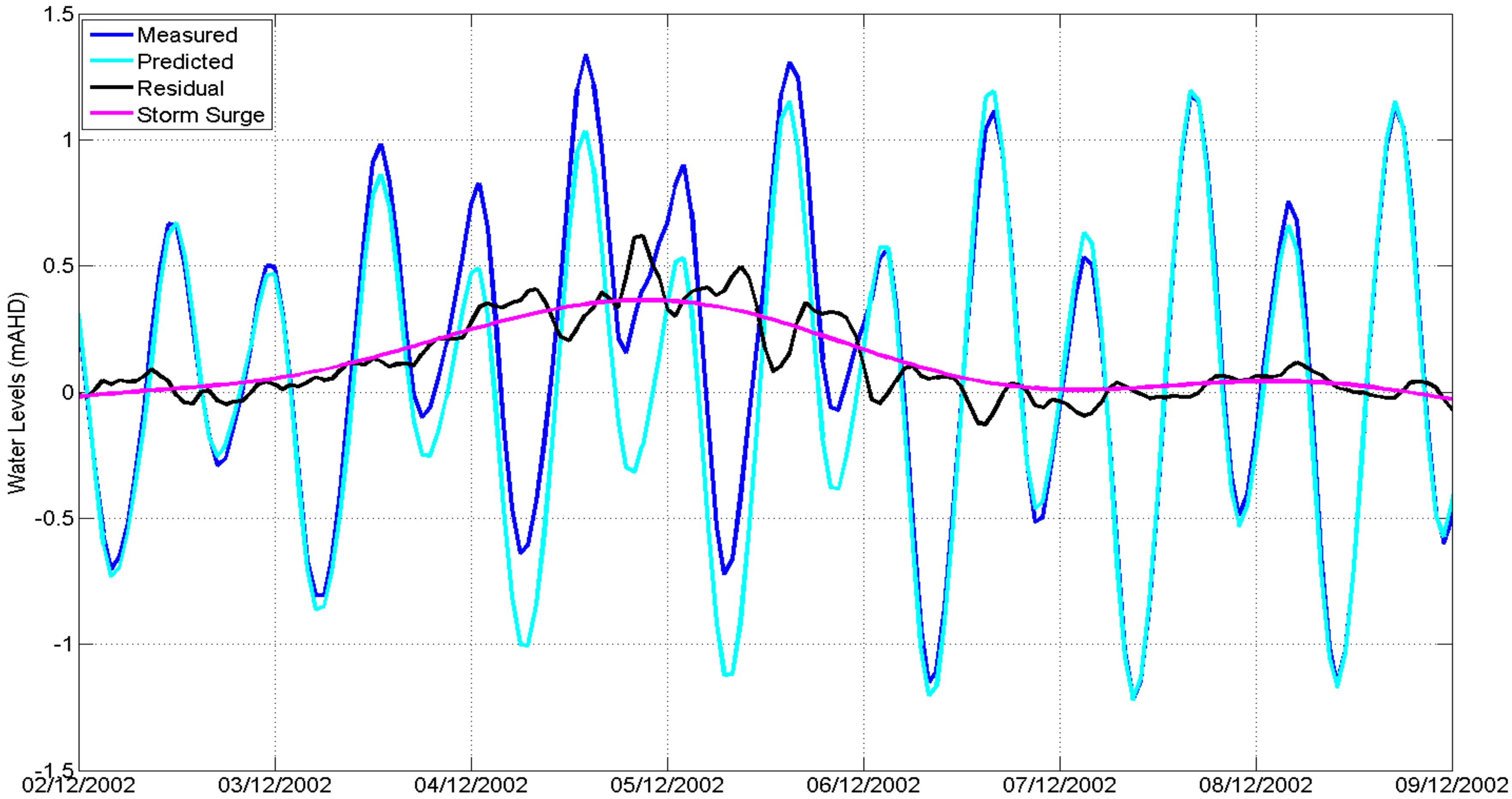

Figure B1 - Example of the tidal record at Lorne showing phase shift phenomena, the remnant tidal signal within the residuals and the smoothed surge

Figure B2 shows the storm-tide levels determined through the different methods.

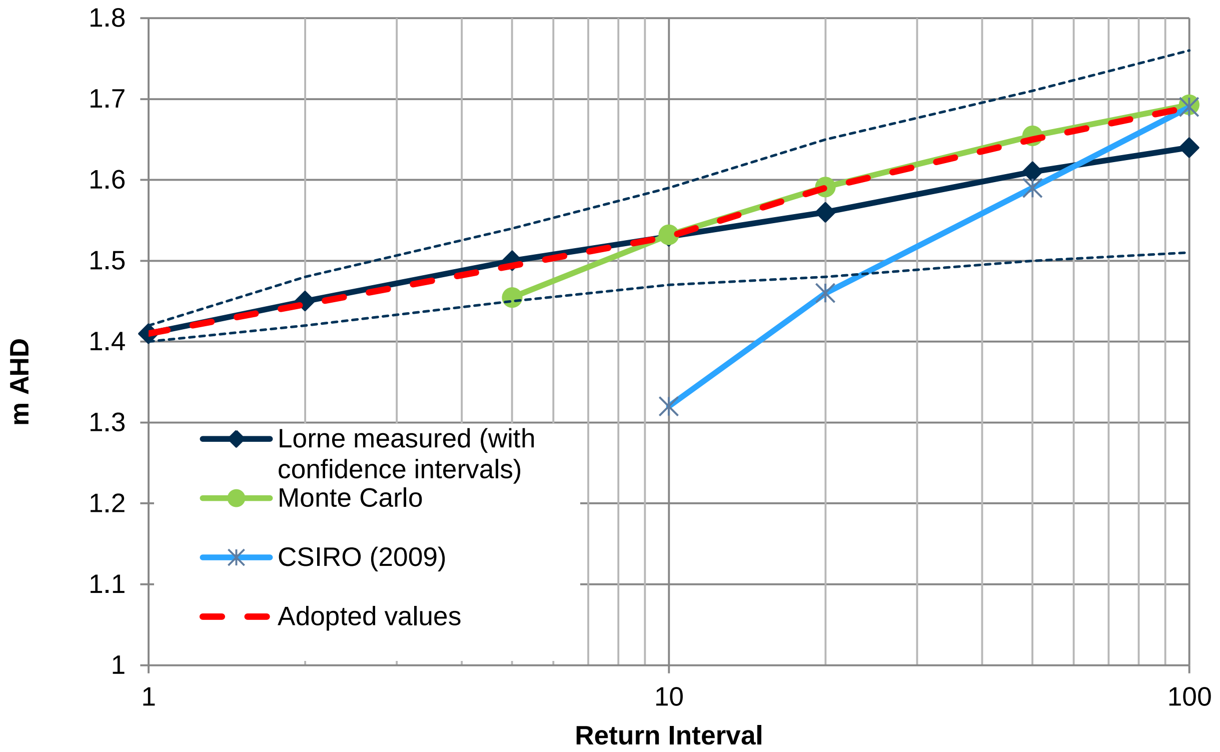

Figure B2 - STLs determined through the different methods

It was decided that the most conservative value for each return interval would be adopted as the design storm-tide condition. The values are given in Table B1. The final project values including sea level rise increments are noted in Table B2.

Table B1 - Adopted values for the Storm Tide Levels (relevant project scenarios in bold)

Method	ARI (1 in x Year)	AEP (%)	Adopted STLs (m)
Lorne measured	1	100	1.41
Lorne measured	**10**	**10**	**1.53**
Monte Carlo	20	5	1.59
Monte Carlo	50	2	1.65
CSIRO	**100**	**1**	**1.69**

Table B2 - Adopted values for the Storm Tide Levels for the project area *(CSIRO 2009 values in italics)*

Method	Present Day		0.2 (m)		0.5 (m)		0.8 (m)		1.1 (m)		1.4 (m)	
	AEP 10%	AEP 1%	AEP 10%	AEP 1%	AEP 10%	AEP 1%	AEP 10%	AEP 1%	AEP 10%	AEP 1%	AEP 10%	AEP 1%
Lorne	1.53	1.69	1.73	1.89	2.03	2.19	2.33	2.49	2.63	2.79	2.93	3.09
Barwon Heads	1.65	1.81	1.85	2.01	2.15	2.31	2.45	2.61	2.75	2.91	3.05	3.21
Point Lonsdale (Rip Bank)	1.63	1.79	1.83	1.99	2.13	2.29	2.43	2.59	2.73	2.89	3.03	3.19
Point Lonsdale (Tide gauge)	*1.16*	*1.41*	*1.36*	*1.61*	*1.66*	*1.91*	*1.96*	*2.21*	*2.26*	*2.51*	*2.56*	*2.81*
Queenscliff	*1.04*	*1.23*	*1.24*	*1.43*	*1.54*	*1.73*	*1.84*	*2.03*	*2.14*	*2.33*	*2.44*	*2.63*
Geelong	*0.91*	*1.06*	*1.11*	*1.26*	*1.41*	*1.56*	*1.71*	*1.86*	*2.01*	*2.16*	*2.31*	*2.46*