Report 1: Summary Report

Gippsland Lakes/90 Mile Beach Local Coastal Hazard Assessment Project

April 2014

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PROJECT DETAILS

Project Name	Gippsland Lakes/90 Mile Beach Coastal Hazard Assessment
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EXECUTIVE SUMMARY

Introduction

The overall objective of the Gippsland Lakes Coastal Assessment is to identify and assess the coastal erosion and inundation hazards within the study area under both present and future climate change conditions.

The physical impact of these hazards has been has broadly investigated for the Gippsland Lakes and Ninety Mile Beach coastal systems, and assessed in greater detail at designated representative locations across the study area.

The information developed by this project will assist in planning for and managing the projected impacts of climate change in the study area. It will inform management agencies and allow them to better identify and define triggers as the basis for short, medium and long term management responses.

The study was undertaken for the Department of Environment and Primary Industries (DEPI). Throughout the study there has been significant interaction and engagement with the Project Steering Group (PSG) and the Technical Review Panel (TRP), comprising members from State and local agencies as well as independent technical experts. This process has benefited the study outcomes enormously by ensuring that issues relevant to stakeholders have been raised and addressed where possible throughout the course of the study.

The term “coastal hazard” is generally used to describe physical changes/impacts to the natural environment which are significantly influenced by coastal processes, such as:

- **Coastal erosion and accretion** - the retreat or advancement of the coastal shore
- **Inundation** – flooding of areas due to river inflows or sea storms
- **Aeolian (wind) transport of sediments** – the formation or erosion of sand dunes

The scope of this study is limited to the potential magnitude and extent of existing coastal hazard impacts, and those associated with climate change. The assessment does not consider the relative consequence of these impacts on assets or social and environmental values. The study does therefore not constitute a full risk assessment where both consequence and likelihood would be addressed.

The Victorian Coastal Strategy (Victorian Coastal Council, 2008) requires planning for sea level rise of not less than 0.8 m by 2100, which is reflected in the three sea level rise scenarios up to 0.8 m that have been specified by the PSG and considered in this study, as shown in the table below.

Table A Scenario and Event Combinations Considered in Hazard Assessment

Scenario	SLR likelihood at different timeframes				SLR (m)	Wave and Storm Surge (AEP %)	Gippsland Lakes Flood (AEP%)[1,2]
	Current	2040	2070	2100			
1	Likely	Virtually certain			0	2%	10%
2	About as likely as not	Likely	Virtually certain		0.2	2%	10%
2a	About as likely as not	Likely	Virtually certain		0.2	2%	1%
3	Unlikely	About as likely as not	Likely	Virtually certain	0.4	1%	10%
4		Exceptionally unlikely	Unlikely	About as likely as not	0.8	1%	10%

1 Note: In some cases catchment flows are not applicable and so not considered, along 90 Mile beach for example.
2 Note: Flood level frequency in the Gippsland Lakes depends on a combination of river inflows, wind, coastal storm surge and tide.

Hazard Assessment Overview

Inundation Hazard

A hydrodynamic model of the Gippsland Lakes Basin, up to approximately 3 m AHD in elevation, and the coastal offshore area surrounding Lakes Entrance was developed. This model was calibrated to measured water levels within the Lakes, including a number of historic flood events. The calibration demonstrated that the model was able to adequately represent water levels in the Lakes for a range of conditions including major floods.

The results of the inundation modelling show the maximum changes to flood levels (due to SLR) are at Lakes Entrance and in the western end of Lake Reeve, towards Seaspray. At Lakes Entrance, the greater change in depth is due to the connectivity with the ocean through the entrance. The increased depths in Lake Reeve are attributable to the higher mean sea level exceeding a threshold topography height. This results in flood flow spilling over this natural threshold, allowing inundation to penetrate further along Lake Reeve to the west, filling low areas that were previously not hydraulically connected to the main lakes. The predicted change in the 10% AEP flood levels in the Gippsland Lakes between the existing and 0.8 m SLR scenario is displayed in Figure A.

The results suggest that flood impacts increase more rapidly at Lakes Entrance than at either Paynesville or Loch Sport for a given increment of SLR. This is because there are larger areas of Lakes Entrance that are only slightly elevated above the current flood level compared to the other towns. Hence a small increase in flood level can engage a larger additional area of inundation in Lakes Entrance then elsewhere.

Detailed documentation on the hazard scenarios, methodology, results and findings are provided in Report 02: Inundation Hazards.

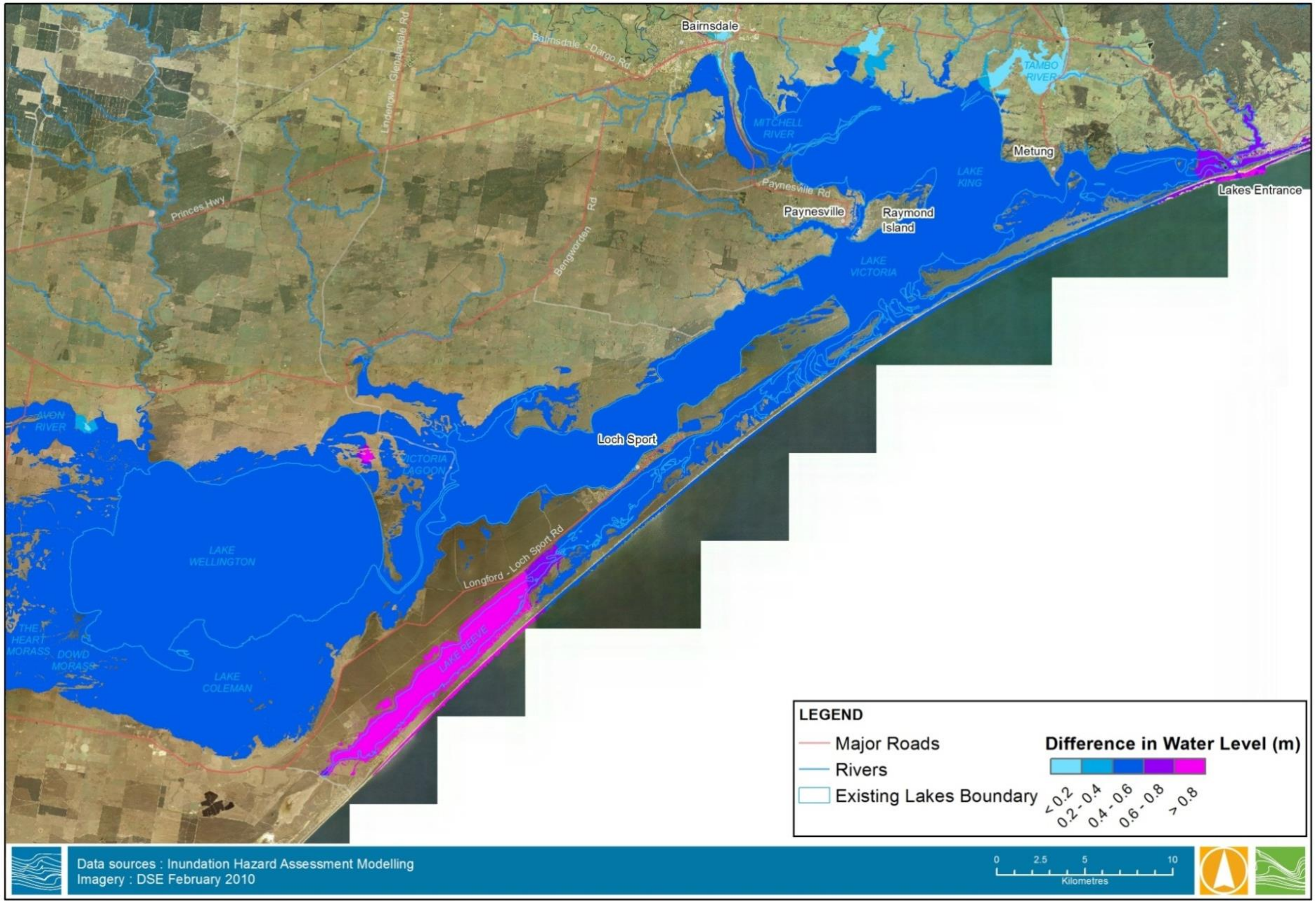


Figure A **Increase in Peak Flood Level for the 10% AEP Flood (Existing vs 0.8 m SLR scenario)**

Lake Shoreline Erosion Hazard

Shoreline erosion within the Gippsland Lakes is a function of a wide range of factors, including the physical form, environmental aspects such as waves and currents, and biological character which includes vegetation communities and land use. The magnitude of the forcing factors in relation to each other varies around the lakes shoreline. In order to combine quantitative assessments of forcing factors such as wave and current conditions with qualitative assessments such as geology and vegetation characteristics, a weighted score-based spatial framework was developed and validated against documented erosion impacts.

The erosion susceptibility rating results show that much of the current shoreline, rated as "high" susceptibility, has the potential to erode under present mean sea level conditions. There are far fewer areas identified with "very high" susceptibility to erosion which is considered within the rating system to indicate active erosion. These results should be considered in the context of the current vegetation communities and that present or future impacts of salinity on these communities were not part of the scope of this study.

Overall, the sea level rise assessment indicates a general increase in the level of shoreline erosion susceptibility throughout the Gippsland Lakes. Those areas most affected by sea level are the shoreline of Lake Wellington, the Lake Reeve lagoon system behind the outer coastal barrier south of Sperm Whale Head, the shoreline of Lake King from Paynesville to the Nicolson River, and the areas around Reeve Channel and Lakes Entrance.

The 0.9 m AHD contour is indicative of the likely future shoreline location under 0.8 m SLR. This does not take account of any sediment or vegetation response to increased mean water levels but does highlight areas where significant shoreline changes are likely in the future. This includes the southern and western shores of Lake Wellington, the western end of Lake Victoria, the southern shore of Lake King and many of the low islands near the entrance to Bunga Arm and along Reeve Channel between Metung and Lakes Entrance.

Based on the erosion susceptibility ratings, estimated erosion rates and the potential inundation extent, a zone of likely shoreline hazard for the Gippsland Lakes shoreline has been developed for the 0.8 m SLR scenario. The hazard zone map (Figure B) for the lakes shows the erosion hazard zone, representing the area of likely shoreline erosion and realignment, corresponds more closely (at the study area scale) to the 0.9 m inundation line than the susceptibility ratings. This is because of the relatively low erosion rates compared to the potential shoreline migration due to SLR.

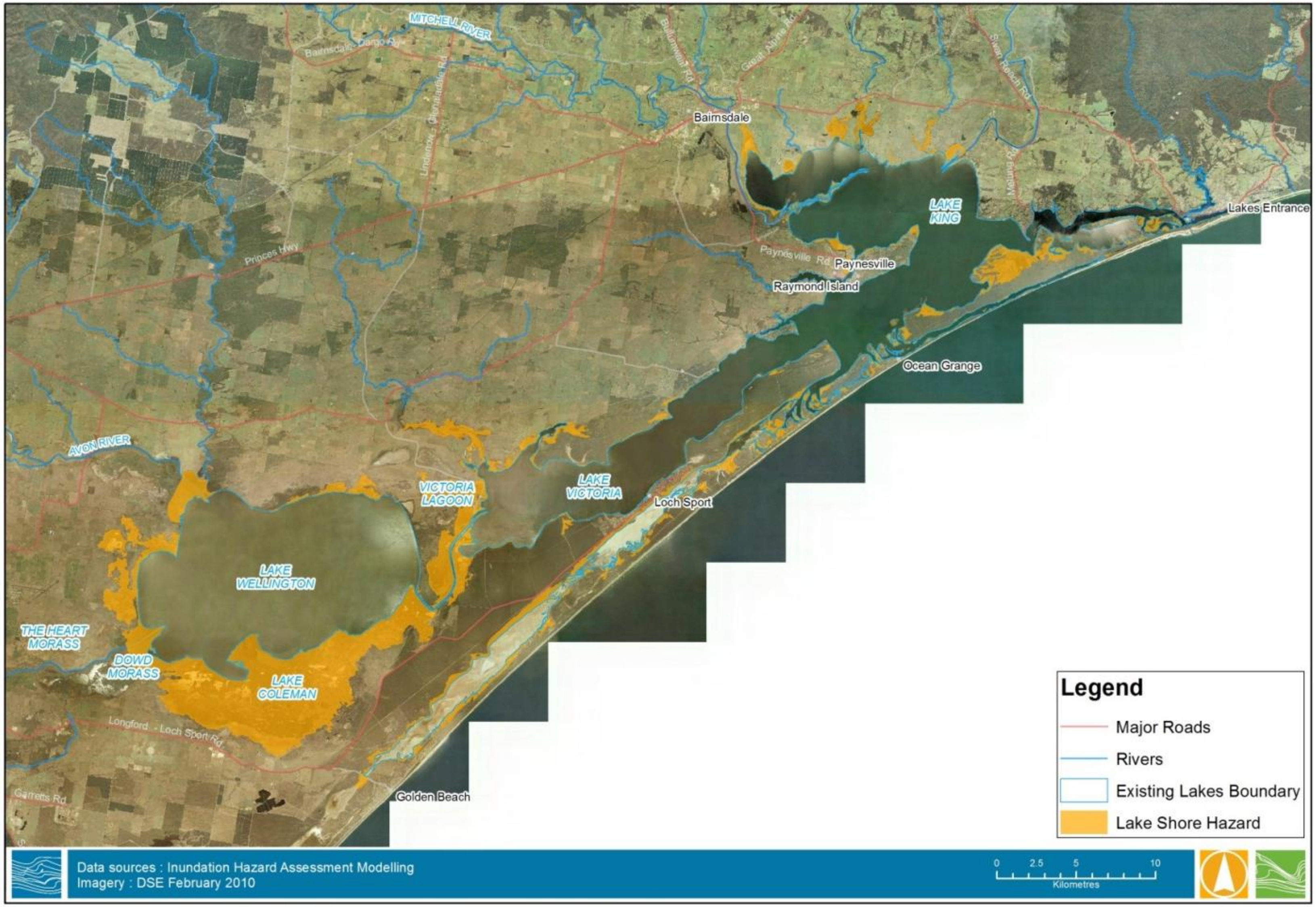


Figure B **Gippsland Lakes Shoreline Hazard Extent, 0.8 m SLR Conditions**

Outer Barrier Coastal Hazard

The 'Outer Barrier' is a long, narrow sand dune developed by wave and wind-blown sand and vegetation growth. It extends continuously (except for the artificial entrance at Lakes Entrance) along the entire length of the study area from Seaspray to Red Bluff. The seaward shore of the Outer Barrier is known as the Ninety Mile Beach.

The sandy sediments comprising the Outer Barrier are subjected to the weather and ocean processes of Bass Strait and the South Tasman Sea. The Outer Barrier is therefore a highly dynamic landform, influenced by multiple processes operating over a very wide range of spatial and temporal scales. To integrate these processes, the assessment included the following components:

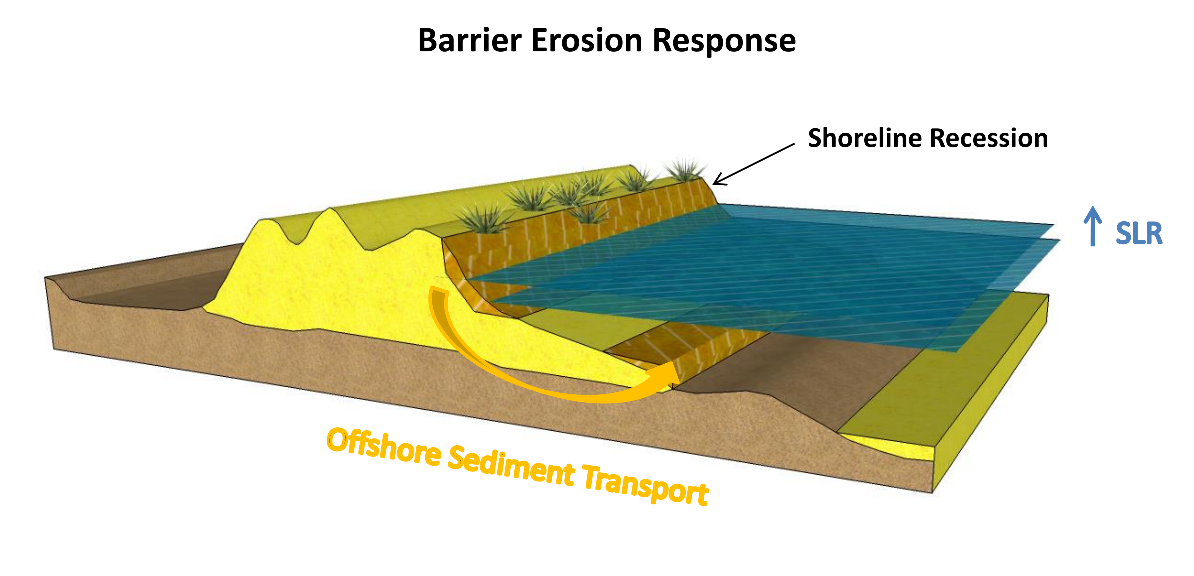
- Analysis of the geomorphology of the Outer Barrier, including its evolution over the last 10,000 years;
- Classification of the Outer Barrier into geomorphic units;
- Analysis of the meteorological and oceanographic processes that can impact the Outer Barrier;
- Review and analysis of the contemporary coastal processes and historical coastal hazard impacts along the Outer Barrier;
- Analysis of the mechanisms and potential extent of the responses of coastal barriers to increased sea levels;
- Analysis of the potential extent of coastal hazard impacts due to sea level rise;
- Evaluation of the uncertainty in the coastal hazard analysis and testing of sensitivity;

The type, variability, extent and timing of coastal hazard impacts that could be expected within the various geomorphic units of the Outer Barrier are closely related to the mechanism of barrier response. There are two primary modes of barrier response that characterise the likely coastal hazards under future sea level rise. These are *barrier erosion* or *barrier translation* as listed below and shown conceptually in Figure C.

- **Barrier Erosion –** The barrier is eroded from the seaward face and sediment is lost offshore until the profile is translated shoreward and upward;

- **Barrier Translation –** The entire barrier migrates landward without significant loss of sediment. This occurs through erosion of the shoreface and deposition of this sediment behind the barrier by the process of washovers and through aeolian (wind) transport.

The key difference between the two mechanisms, from a hazard impact point of view, is that the barrier translation response is generally expected to result in much greater landward incursion of coastal hazard impacts than the barrier erosion response.



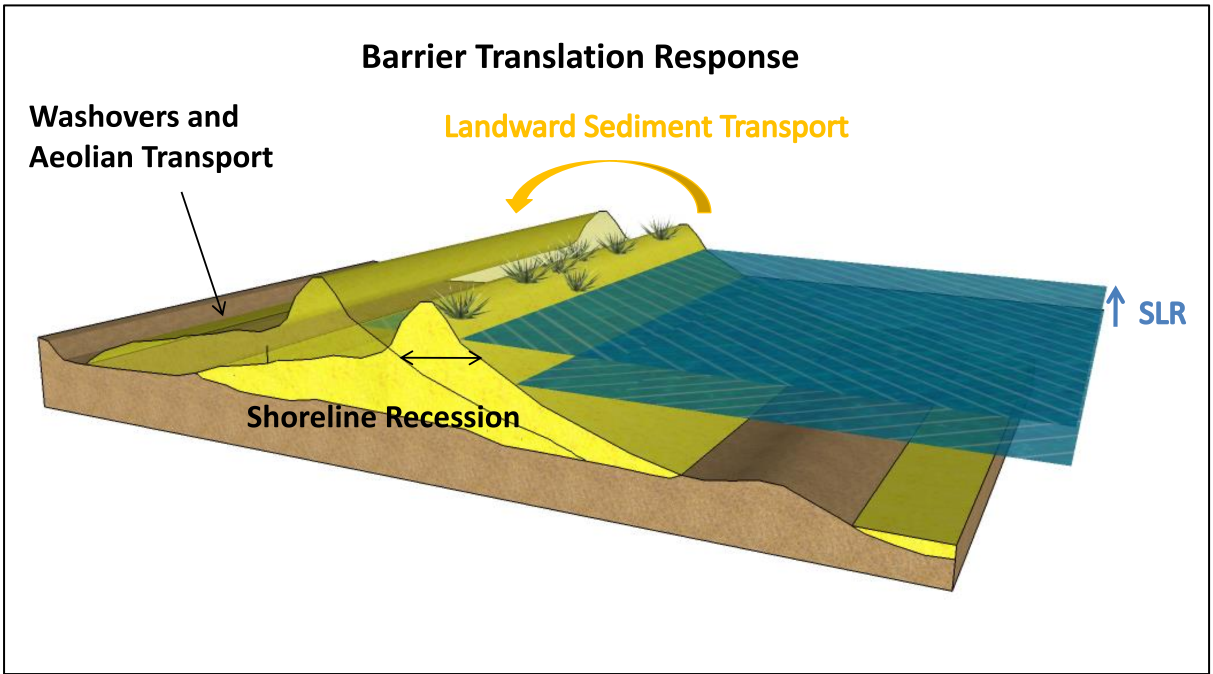


Figure C Mechanisms of Equilibrium Profile Adjustment along 90 Mile Beach

A major factor impacting the susceptibility of the Outer Barrier is the existing volume and width of the barrier itself. The Outer Barrier was analysed along its entire length to determine the change in crest height and volume per unit length. This data highlighted:

- The significant variation in the volume of sand within the barrier along its length. This represents the amount of sand that would need to be transported (by waves and/or wind) to completely erode the barrier at any location. The volume/per unit length of barrier varies from a minimum of around 200 m^3/m at Seaspray to over 4,000 m^3/m near Paradise Beach
- The large change in barrier dune height over the study length. This is an indication of the amount of erosion (by wave and/or wind) required to reduce the barrier crest to a point where overwash may occur. The barrier height varies from around 5 m AHD near Seaspray to over 20 m AHD near Golden Beach.

Taking into account these key erosion mechanisms and the physical structure of the barrier along its length, the potential Outer Barrier coastal hazard impact was determined as shown in Figure D.

Detailed documentation on the hazard scenarios, methodology, identified hazard processes and hazard extents are provided in Report 03: Coastal Barrier Hazards.

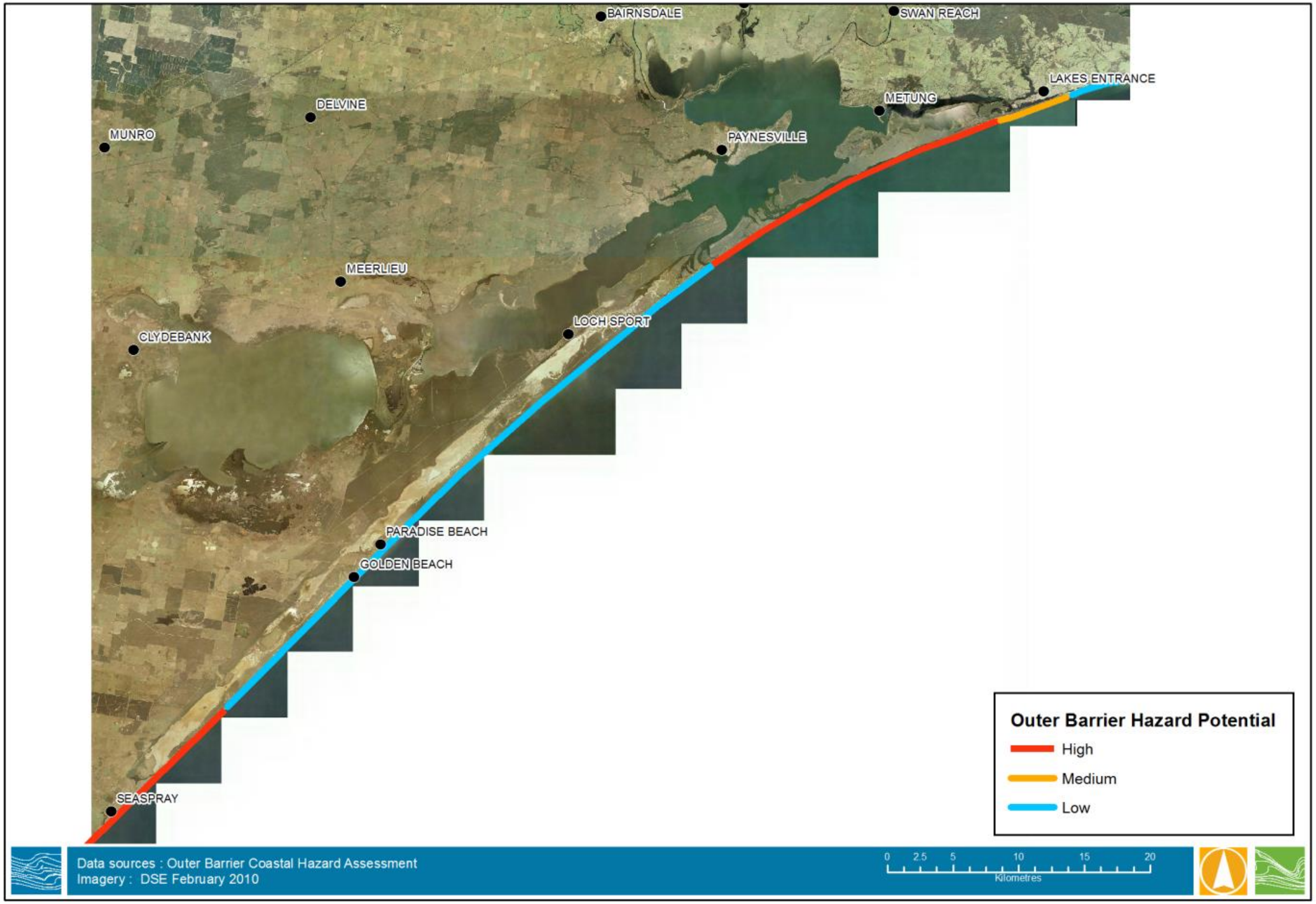


Figure D **Outer Barrier Coastal Hazard Impact Potential**

Representative Locations

Five representative locations within the study area were selected for additional detailed analysis and assessment of potential hazard impacts. The selection of the representative locations was based on their physical setting, existing susceptibility to coastal hazard impacts and through consultation with the Project Steering Group.

The representative locations selected for additional detailed analysis were:

- Lakes Entrance
- Paynesville
- Loch Sport
- Bunga Arm
- Seaspray

Summary of the Key Hazards at Representative Locations

The key hazards identified for each of the representative locations are summarised below. Figures E to I provide a summary of the overall hazard study outputs for each representative location.

Lakes Entrance

- Lakes Entrance is currently subjected to inundation during a 10% AEP flood event. Inundation extents are predicted to increase with increasing mean sea level, with peak flood levels predicted to increase at a rate of approximately 0.9 times the amount of sea level rise.
- Recession of the Outer Barrier at Lakes Entrance is expected to accelerate with increasing mean sea level. A critical tipping point could occur between 0.4 and 0.8 m SLR, when barrier overwash is likely to increase in frequency, leading to significantly larger hazard extents.

Paynesville

- The key hazard at Paynesville is expected to be inundation. Peak flood levels are predicted to increase by approximately 0.65 times the rise in mean sea level.

Loch Sport

- Peak flood levels at Loch Sport were predicted to increase at approximately 0.65 times the rise in mean sea level. Increases in inundation extent were minimal when compared to Lakes Entrance and Paynesville due to the higher elevations of land surrounding Loch Sport.

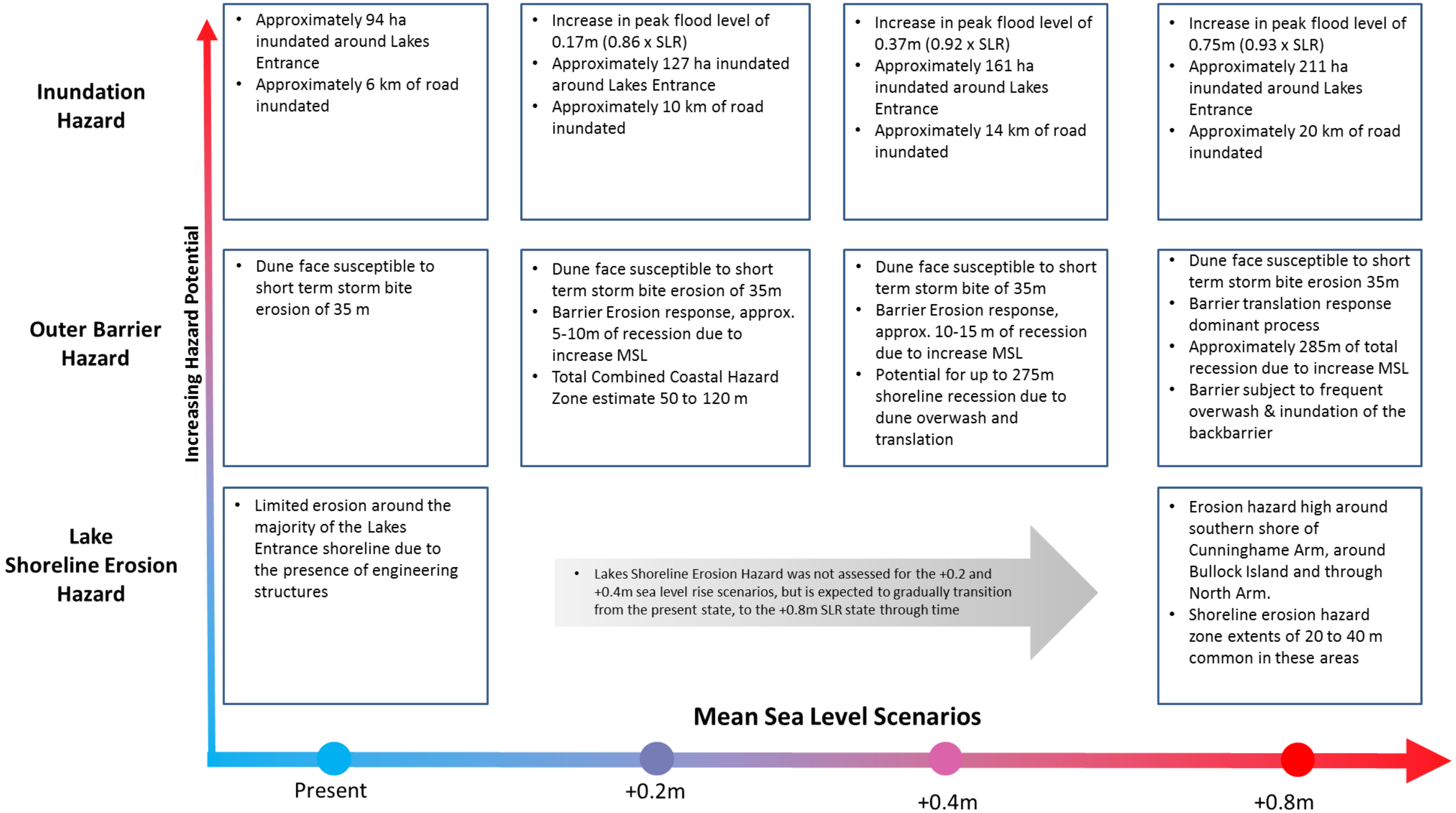
Bunga Arm

- Recession of the Outer Barrier at Bunga Arm is expected to accelerate with increasing mean sea level. A critical tipping point could occur between 0.4 and 0.8 m SLR, when barrier overwash is likely to increase in frequency, leading to significantly larger hazard extents.
- Peak flood levels are predicted to increase by approximately 0.65 times the rise in mean sea level.

Seaspray

- Recession of the Outer Barrier at Bunga Arm is expected to accelerate with increasing mean sea level. A critical tipping point could occur between 0.4 m and 0.8 m SLR, when barrier overwash is likely to increase in frequency, leading to significantly larger hazard extents.
- For 0.8 m SLR, inundation of low lying areas around Seaspray from Lake Reeve is predicted to occur during a 10% AEP flood event in the Gippsland Lakes.

Lakes Entrance



Summary of the Key Hazards at Lakes Entrance

- Lakes Entrance is currently subjected to inundation during a 10% AEP flood event. Inundation extents have been shown to increase with increasing mean sea level, with peak water levels increase at approximately 0.9 times the amount of sea level rise.
- Recession of the outer barrier accelerates with increasing mean sea level. A critical tipping point is expected to occur between 0.4 and 0.8m SLR, when barrier overwash is likely to increase in frequency, leading to significantly larger hazard zones.

Description of Scenarios

- **Inundation Hazards:** The inundation simulation results are based on a 10% AEP flood event with the associated sea level rise
- **Outer Barrier Hazards:** Based on 0.2, 0.4 and 0.8m increase in mean sea level
- **Shoreline Erosion Susceptibility:** Based on a 0.8 m increase in mean sea level

Figure E Summary of Coastal Hazard Assessment at Lakes Entrance

Paynesville

Increasing Hazard Potential

	Present	+0.2m	+0.4m	+0.8m
Inundation Hazard	• Approximately 59 ha inundated around Paynesville/Raymond Island • Approximately 6 km of road inundated	• Increase in peak water levels of 0.12m (0.58 x SLR) • Approximately 69 ha inundated around Paynesville/Raymond Island • Approximately 7 km of road inundated	• Increase in peak water levels of 0.26m (0.65 x SLR) • Approximately 78 ha inundated around Paynesville/Raymond Island • Approximately 8 km of road inundated	• Increase in peak water levels of 0.54m (0.67 x SLR) • Approximately 98 ha inundated around Paynesville/Raymond Island Approximately 11 km of road inundated
Lake Shoreline Erosion Hazard	• Low erosion susceptibility around the majority of the Paynesville shoreline due to the presence of engineered structures and fringing vegetation.	• Lakes Shoreline Erosion Susceptibility was not assessed for the +0.2 and +0.4m sea level rise scenarios, but is expected to gradually transition from the present state, to the +0.8m SLR state through time		• Erosion hazard is high on the north side of Raymond Island and to the north of Paynesville, with a hazard zone up to 100m wide. • Erosion hazard zone depths are generally around 20m at the town and on the southern side of Raymond Is
Outer Barrier Hazard	• Paynesville is located on the northern side of Lake Victoria, well away from the outer barrier (6.5km). Hence it is not considered liable to Outer Barrier erosion hazard	• Paynesville is located on the northern side of Lake Victoria, well away from the outer barrier (6.5km). Hence it is not considered liable to Outer Barrier erosion hazard	• Paynesville is located on the northern side of Lake Victoria, well away from the outer barrier (6.5km). Hence it is not considered liable to Outer Barrier erosion hazard	• Paynesville is located on the northern side of Lake Victoria, well away from the outer barrier (6.5km). Hence it is not considered liable to Outer Barrier erosion hazard, even under a 0.8m SLR case.

Mean Sea Level

Summary of the Key Hazards at Paynesville

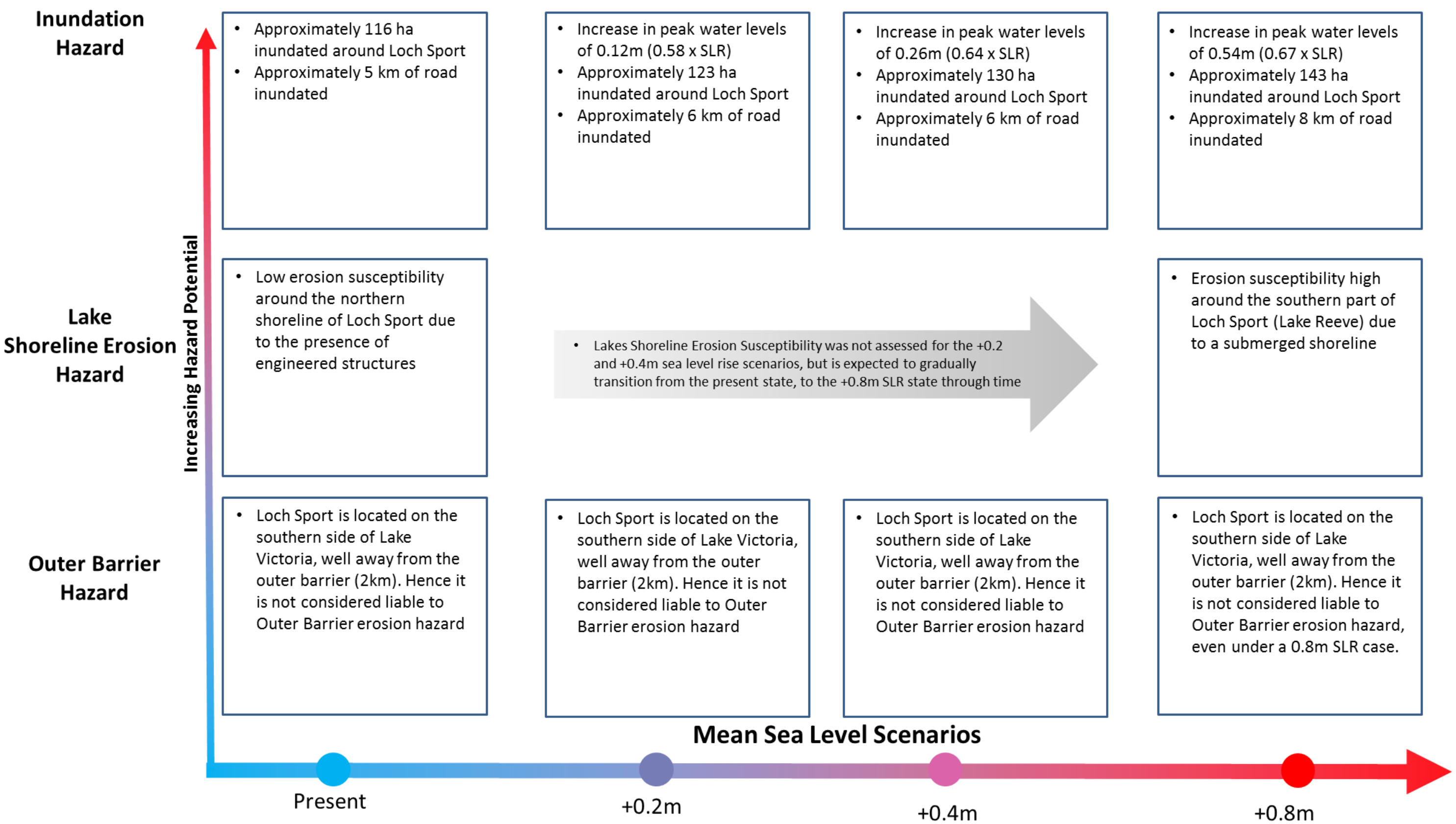
- The key hazard at Paynesville is inundation. Peak water levels increase by approximately 0.65 time the rise in mean sea level for both the 10% and 1% AEP flood events. A large increase in the number of properties flooded is expected between the present and 0.2m of sea level rise scenarios, and increasing through higher mean sea levels, albeit at a slower increase rate.

Description of Scenarios

- **Inundation Hazards:** The inundation simulation results are based on a 10% AEP flood event with the associated sea level rise
- **Shoreline Erosion Susceptibility:** Are based on the existing and 0.8m increase in mean sea levels

Figure F Summary of Coastal Hazard Assessment at Paynesville

Loch Sport



Summary of the Key Hazards at Loch Sport

- The key hazard at Loch Sport is Inundation. Similarly to Paynesville, peak flood water levels at Loch Sport were shown to increase at approximately 0.65 x the rise in mean sea level. Increases in inundation extent were minimal when compared to Lakes Entrance and Paynesville due to the steeper sloping land surrounding Loch Sport

Description of Scenarios

- **Inundation Hazards:** The inundation simulation results are based on a 10% AEP flood event with the associated sea level rise
- **Shoreline Erosion Susceptibility:** Are based on the existing and 0.8m increase in mean sea levels

Figure G Summary of Coastal Hazard Assessment at Loch Sport

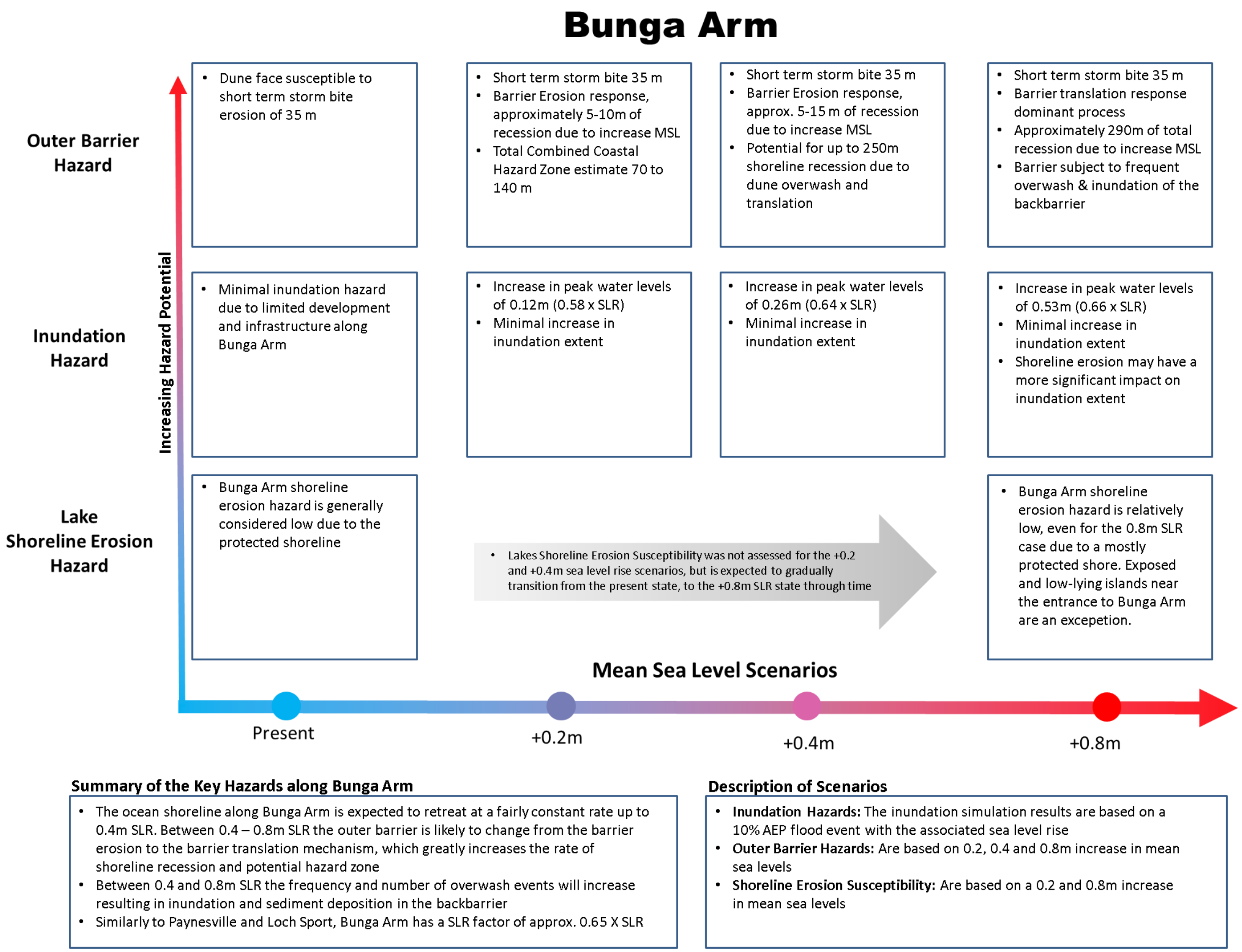
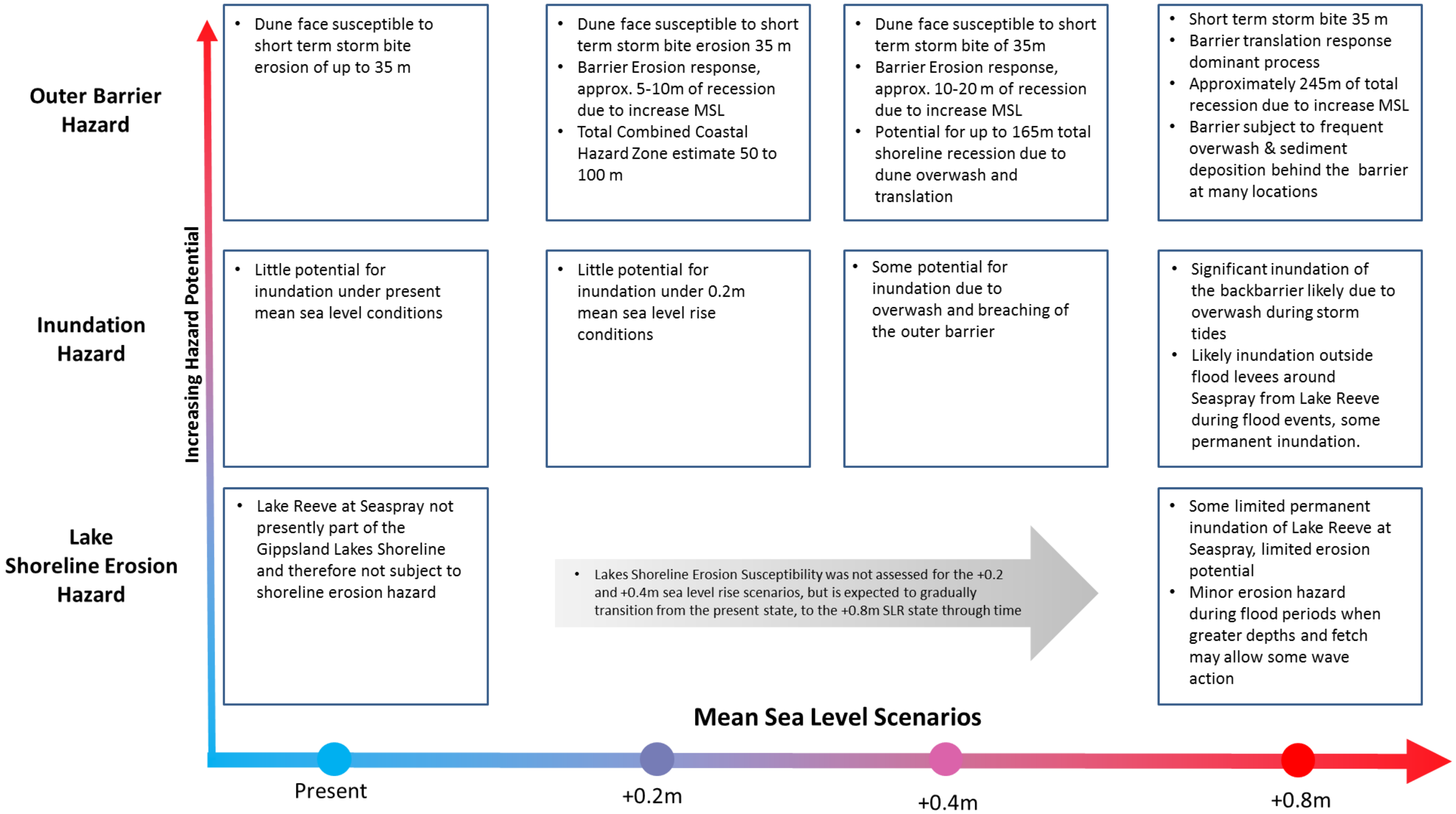


Figure H Summary of Coastal Hazard Assessment at Bunga Arm

Seaspray



Summary of the Key Hazards at Seaspray

- The shoreline at Seaspray is expected to retreat at a fairly constant rate up to 0.4m SLR.
- Between 0.4 – 0.8m of SLR the outer barrier is likely to respond to increased mean sea levels through the barrier translation mechanism, greatly increasing shoreline recession
- Between 0.4 and 0.8m of SLR the frequency and number of barrier breach and overwash events will increase resulting in inundation of the back barrier
- For 0.8m SLR, inundation from Lake Reeve occurs during a 10% AEP flood event in the Gippsland Lakes.

Description of Scenarios

- **Inundation Hazards:** The inundation simulation results are based on a 10% AEP flood event with the associated sea level rise
- **Outer Barrier Hazards:** Are based on 0.2, 0.4 and 0.8m increase in mean sea levels

Figure I **Summary of Coastal Hazard Assessment at Seaspray**

Conclusions

Outer Barrier Coastal Hazard

- The type, variability, extent and timing of the coastal hazard impacts along the Outer Barrier have been identified as being closely related to the mechanism of barrier response that is experienced for a given magnitude of sea level rise (i.e. barrier erosion or barrier translation)
- Investigations suggest the Outer Barrier at Seaspray, Bunga Arm and Eastern Beach is likely to be susceptible to overwash and barrier translation processes for sea level rise of greater than approximately 0.4 m.
- Overwash/barrier translation at these locations would be expected to result in coastal hazard impacts extending many hundreds of metres landward of the present shoreline.

Inundation Hazards

- At a broad scale, only relatively minor, local changes in inundation extents are predicted around the majority of the Gippsland Lakes for 10% AEP design flood events combined with sea level rise up to 0.8 m. The exceptions to this are the south-western end of Lake Reeve, where large increases in inundation extents are predicted for sea level rise scenarios greater than 0.4 m and
- For the majority of the Gippsland Lakes, the SLR Response Factor is predicted to be approximately 0.65, which closely approximates the relationship between storage and elevation of the Gippsland Lakes Basin.
- At Lakes Entrance the SLR Response Factor is predicted to be approximately 0.9 due to the proximity to the ocean entrance and subsequent greater influence of tidal and coastal water levels on flood behaviour.
- The floodplain around Seaspray is predicted to become susceptible to inundation from Gippsland Lakes floods with a 10% AEP flood and 0.8 m of sea level rise. Under these conditions, flooding from the east via Lake Reeve is not predicted to result in peak levels of sufficient height to overtop the levees surrounding Seaspray. It is noted that flooding from Merriman's Creek, to the west and north of Seaspray, was not assessed as part of this project. Merriman's Creek flooding has been assessed in a previously study (Cardno Lawson Treloar, 2010).

Lake Shoreline Erosion Hazard

- The lake shoreline hazard assessment indicates a general increase level of shoreline erosion susceptibility throughout the Gippsland Lakes due to sea level rise. Those areas most affected by increases in erosion susceptibility, and hence likely to experience significant erosion hazard under sea level rise conditions, are the shoreline of Lake Wellington, Lake Reeve behind the outer coastal barrier south of Sperm Whale Head, the shoreline of Lake King from Paynesville to the Nicolson River, and the areas around Reeve Channel and Lakes Entrance.
- The shoreline erosion hazard around the townships of Lakes Entrance, Paynesville and Loch Sport are, to a significant extent, mitigated by the presence of shoreline protection structures. Should these structures not be maintained or removed, then the shorelines around these towns may become susceptible to erosion hazard.

Monitoring

- Initial coastal and shoreline profile data has been collected. This data, when compared to previous LiDAR survey, demonstrated profile change at a number of locations. The use of high-accuracy mobile GPS equipment proved efficient and flexible in allowing features to be levelled around the study area.
- A review of potential monitoring parameters and techniques has been undertaken. These have led to preliminary recommendations for future monitoring to inform coastal hazard assessments and adaptation.

Recommendations

Inundation Hazard

- A Water Level Frequency Analysis should be undertaken for the main townships of the Gippsland Lakes to aid understanding of the full range of SLR impacts on these communities. This project has assessed the impact of SLR on flood levels due to large floods within the Gippsland Lakes. However, it has also been highlighted that there is a need to further understand the potential changes to the frequency of inundation associated with smaller flood and coastal water level events with sea level rise in the Gippsland Lakes.
- The flood modelling in this study has been undertaken to provide a reliable indication of the impact of sea level rise and climate change on flood levels within the Gippsland Lakes. It does not however constitute a full flood study. Further work in the refinement of model calibration parameters and boundary conditions could be undertaken to provide outputs that meet the requirements of a full flood study, such that the results could be applied to set levels for future land-use planning.
- Further to the above point, analysis of the impacts of 0.8 m SLR on the 1% AEP design flood scenario (or set of scenarios) within the Gippsland Lakes, along with sensitivity analysis around the uncertainties for this event could be undertaken. This would improve the information available to authorities to assess impacts at the 2100, 0.8 m SLR planning horizon.
- The impact of climate change on salinity within the Gippsland Lakes is of major ecological importance. Changes to the salinity regime could influence the biota within the lakes including fringing vegetation and related aspects such as algae and the entire food web. The existing hydrodynamic model can be utilised to investigate salinity impacts in the future.
- The sensitivity of entrance dynamics was not able to be investigated by this study. The interaction of tides, floods and dredging of the entrance and surrounds potentially has significance and could be investigated through further modelling and data collection.

Outer Barrier Coastal Erosion Hazard

- Only approximately 5% of the Outer Barrier was covered by historical aerial photography that was available for the study. The collation and analysis of additional historical aerial photography would assist in understanding the underlying shoreline variability and trends along the Outer Barrier.
- Ongoing survey of the Outer Barrier through either repeat transect surveys or other airborne remote sensing techniques should be undertaken to develop a longer and higher resolution time-series of elevations and geomorphological change along the Outer Barrier.
- Very limited dating of the sediments of the Outer Barrier currently exists. Additional, precise dating of the Outer Barrier sediments would improve the understanding of the evolution of this landform and assist in interpreting likely future rates of change.

Shoreline Erosion Hazard

- A key knowledge gap for this study is the impact of salinity on the vegetation communities of the Gippsland Lakes shoreline and how this may impact on the current ability of these shorelines to mitigate erosion susceptibility. This may be investigated in future through monitoring of vegetation and application of the hydrodynamic model, modified to resolve salinity dynamics.
- There is considerable uncertainty surrounding the potential impact of climate change on wind speeds and directions. There is currently no reliable guidance available on such changes. The hydrodynamic models used for this study could be modified to test the sensitivity of the system to a wide range of potential climate change conditions, including the impact of altered wind conditions.

Monitoring

- Annual monitoring for the baseline coastal profile transects identified in Report 5: “Coastal Monitoring" will assist understanding of the long term erosion/deposition trends within the study area and would aid in reducing the uncertainty in the long term trends identified within this project.
- The monitoring of profiles as well as shoreline location should allow for the calculation and verification of erosion rates in the future. This will allow for better estimation of future shoreline hazard estimation around the lakes in particular.
- The collection of profile surveys should coincide with imagery capture if possible to maximise the value of both data sets.
- Improved mapping of shoreline EVCs that differentiates between reed beds and the scrubland would enable the impact of changes to reed bed extent to be quantified.
- Monitoring of parameters such as vegetation and salinity will allow for the links between shoreline erosion and ecological characteristics to be better understood.
- Monitoring of the extent of specific high value reed beds (such as the western shore of Lake Wellington) along with salinity measurements to assess responses to salinity and enhance understanding of responses to these systems to change
- Erosion monitoring throughout the lakes system covering a range of shoreline types, environmental conditions (exposed to waves/currents), and vegetation communities.
- Better co-ordination and sharing of monitoring responsibilities and data between agencies will result in a greatly improved overall outcome for the Gippsland Lakes. The agreed nomination of a lead agency to co-ordinate these activities would be highly beneficial.

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GLOSSARY

Australian Height Datum (AHD)	A common national plane of level corresponding approximately to mean sea level
ARI	Average Recurrence Interval: Over a long period, the average interval between occurrences above a certain magnitude flood or rainfall event
Aeolian	The transport of sediment by winds through suspension, saltation (bouncing or skipping) and creeping (sliding) along a surface
AEP	Annual Exceedance Probability: The measure of the likelihood (expressed as a probability) of an event equalling or exceeding a given magnitude in any given year
Astronomical tide	Water level variations due to the combined effects of the Earth's rotation, the Moon's orbit around the Earth and the Earth's orbit around the Sun
Calibration	The process by which the results of a computer model are brought to agreement with observed data
Exceedance Probability	The probability of an extreme event occurring at least once during a prescribed period of assessment is given by the exceedance probability. The probability of a 1 in 100 year event (1% AEP) occurring during the first 25 years is 22%, during the first 50 years the probability is 39% and over a 100 year asset life the probability is 63%
Equilibrium Profile	An equilibrium profile is the stable cross-section profile of a section of beach that balances the locally available sand and beach geometry with prevailing wave forces and sea levels
Geomorphology	The study of the origin, characteristics and development of land forms
Hydrodynamic Model	A numerical model that simulates the movement of water within a defined model area
LiDAR	Light Detection and Ranging, sometimes also referred to as ALS (aerial laser scanning). This is a remote sensing survey technology that measures distance by illuminating a target with a laser and analysing the timing of the reflected light to determine a 3D location (when coupled with accurate 3D positioning of the aircraft).
MSL	Mean Sea Level
Neap Tides	Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean).
Sea Level Rise (SLR)	A permanent increase in the mean sea level
SLR Response Factor	The SLR Response Factor is a non-dimensional factor that describes the relative increase in lakes flood water level to a given sea level rise scenario. For example, a SLR Resposne Factor of 0.5 represents an increase in a given flood level of 0.5 x a given SLR scenario.
Spring Tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean)
Storm Surge	The increase in coastal water levels caused by the barometric and wind set-up effects of storms. Barometric set-up refers to the increase in coastal water levels associated with the lower atmospheric pressures characteristic of storms. Wind set-up refers to the increase in coastal water levels caused by an onshore wind

	driving water shorewards and piling it up against the coast
Storm tide	Coastal water level produced by the combination of astronomical and meteorological (storm surge) ocean water level forcing
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides
Tides	The regular rise and fall in sea level in response to the gravitational attraction of the Sun, Moon and Earth

1. INTRODUCTION

1.1 Overview

The overall objective of the Gippsland Lakes and Ninety Mile Beach Local Coastal Hazard Assessment is to identify and assess the coastal erosion and inundation hazards within the study area under both present and future climate change conditions.

The study has broadly investigated key coastal processes and hazards for the Gippsland Lakes and Ninety Mile Beach coastal systems. The physical impact of these hazards has been assessed in greater detail at designated representative locations across the study area, and for representative climate change/sea level rise scenarios.

This work provides an improved understanding of the extent of existing and future coastal hazards and their physical impacts for both the Gippsland Lakes and Ninety Mile Beach coastal environments. This has been achieved through the description of potential erosion, coastal inundation and the impact of catchment flooding events.

The information developed by this project will assist in planning for and managing the projected impacts of climate change in the study area. It will inform management agencies and allow them to better identify and define triggers as the basis for short, medium and long term management responses.

1.2 Structure of the Study and Reporting

The study has been conducted in three distinct stages with the outputs broken into 5 reports as shown in Figure 1-1. The data review and confirmation of scope, along with identification of representative locations was undertaken in the initial phase of the project. This was followed by period of detailed technical assessments of the identified coastal hazards. Finally, the study reporting has documented the findings of the project.

Throughout the study there has been significant interaction and engagement with the Project Steering Group (PSG) and the Technical Review Panel (TRP). This process has benefited the study outcomes enormously by ensuring that issues relevant to stakeholders have been raised and addressed where possible throughout the course of the study.

The detailed technical assessments of erosion and inundation hazards have been undertaken to provide a knowledge base that under-pins the results of the study. Each technical assessment has considered the potential relative changes and extents of erosion and/or inundation hazards under existing sea level and three future sea level rise conditions; +0.2, +0.4 and +0.8 m as specified by the PSG. It is noted that in the recently released IPCC AR5 Summary for Policy Makers (2013) document that future sea level rise in excess of 0.8 m by 2100 is predicted for two of the greenhouse gas emission scenarios. However, 0.8 m remains within the predicted range, and therefore is still considered appropriate.

This document forms the study summary report and is the first of 5 reports produced for the project. It should be read in conjunction with the accompanying technical reports, which contain further details of the assessment methods, analysis and results for each component of the project. The complete set of reports is listed and described below.

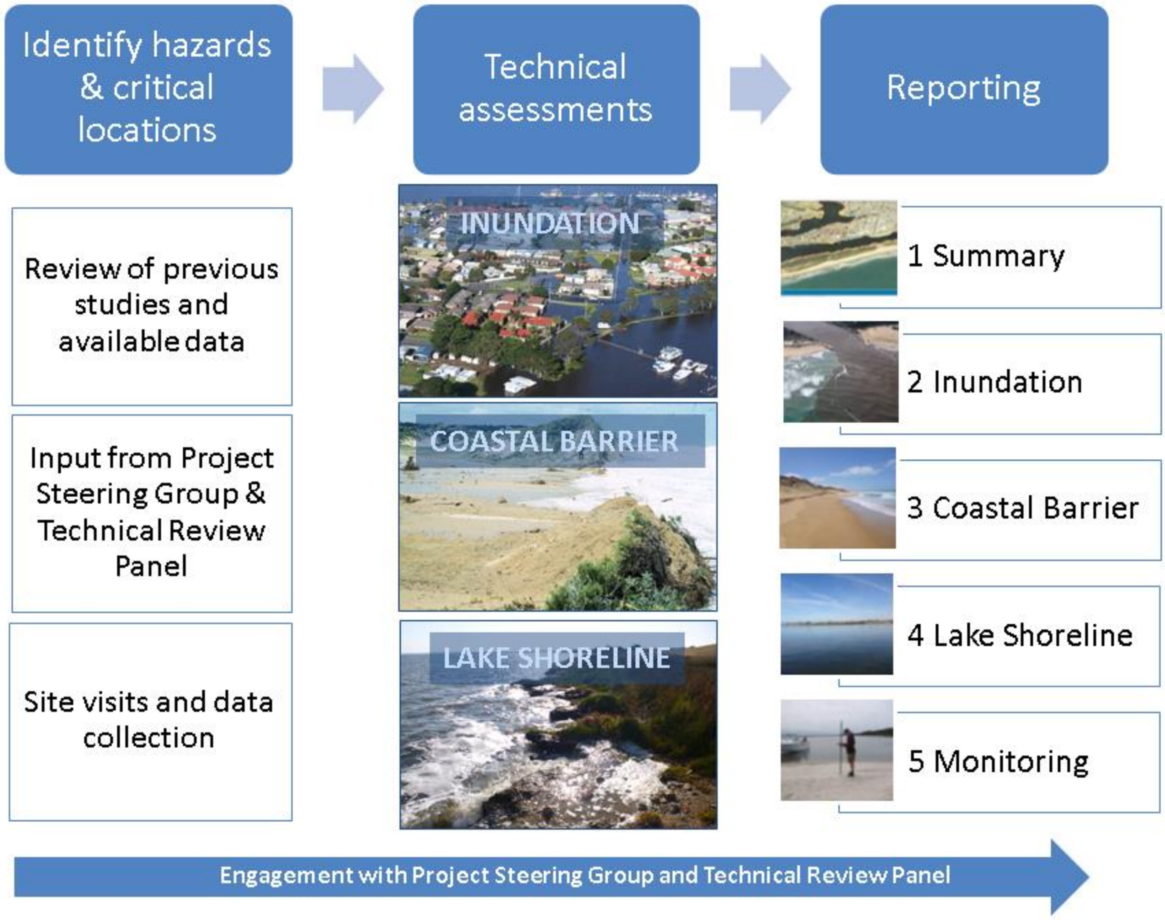


Figure 1-1 Schematic of Study Process and Outputs

Report 1 – Study Summary and Recommendations: This report provides a summary of the coastal and inundation hazard investigations and recommendations developed for the Gippsland Lakes Coastal Assessment. This report covers the study area as a whole as well as details for each of the representative locations.

Report 2 - Inundation Hazard Report*:* The inundation hazard assessment details the relative change in magnitude, extent and various metrics of inundation impact for large flood events under the three sea level rise scenarios in combination with storm surge and tidal effects. This analysis has been undertaken broadly for the Gippsland Lakes, and more specifically for identified representative locations.

Report 3 - Outer Barrier Coastal Hazard: The outer barrier coastal hazard assessment provides an analysis of the prehistoric, historic and contemporary processes and hazards along the outer barrier, incorporating the Ninety Nile Beach and the potential impact of sea level rise on the nature and extent of coastal hazards along this landform.

Report 4 - Lakes Shoreline Erosion Hazard: The shoreline erosion hazard assessment characterises the Gippsland Lakes shoreline in regards to its erosion susceptibility, which is then related to erosion hazard. This report provides an assessment as to the potential change in erosion hazard under higher mean sea level scenarios.

Report 5 - Coastal Monitoring: Coastal and Lake shoreline survey profiles have been established at multiple locations within the study area to provide a basis for a future coastal monitoring program to track ongoing coastal change.

1.3 Study Area

The study area extends along the Ninety Mile Beach from Seaspray to Red Bluff, and inland encompassing the Gippsland Lakes and associated floodplain areas to approximately 3 m above mean sea level as shown in Figure 1-2. The area incorporates two local government areas, Wellington Shire and East Gippsland Shire. Various aspects of responsibility for the management of the lakes and associated shoreline are shared amongst a number of agencies including the Department of Environment and Primary Industries (DEPI), Parks Victoria, Gippsland Ports, the Gippsland Coastal Board and; East and West Gippsland Catchment Management Authorities.

Detailed descriptions of the Gippsland Lakes, its communities and environment are available in previous reports such as ECOS (2008). A brief overview of the Gippsland Lakes is provided below.

1.4 Overview of the Gippsland Lakes

The Gippsland Lakes is a large complex of lakes, rivers and fringing wetlands located on Victoria's east coast, connected to the sea near its eastern-most extent by an artificially maintained entrance. It consists of a series of large coastal lagoons (lakes) formed behind a coastal barrier dune system, of which the ocean shore forms the Ninety Mile Beach. The lakes are fed by seven significant rivers draining a total catchment area of approximately 20,000 km^2 and surrounded by numerous fringing wetlands that are most developed along the lower, estuarine reaches of the rivers. The main Lakes are described below.

Lake Wellington – Is the western most lake and has a surface area of approximately 148 km^2. It is the freshest of the lakes and is fed by the Latrobe, Thomson, Macalister and Avon Rivers.

Lake Victoria - Is linked to the Lake Wellington by the narrow, meandering McLennan Strait. Lake Victoria has an elongated lake shape and a surface area of approximately 75 km^2. There are no rivers flowing directly into Lake Victoria.

Lake King - Lake King, the most easterly of the main lakes and is fed by the Nicholson, Mitchell and Tambo Rivers. It has a surface area of approximately 98 km^2.

All the main lakes are shallow with the mean depth of Lake Wellington only 2.6 m and the deepest parts of Lakes Victoria and King only 9-10 m. The salinity in the lakes varies significantly from quite fresh at the western end of Lake Wellington to marine near Lakes Entrance in the east. The salinity varies seasonally and year-to-year depending on the amount of freshwater inflow from the rivers. Turbidity varies with salinity and is generally high in the west and very low in the east.

Due to its large area and the diversity of habitats, the Gippsland Lakes system supports a wide range of ecosystem goods and services which in turn support important socio-economic values. These include market goods and services such as commercial fisheries and tourism and non-market recreation services including visual amenity, wildlife and biodiversity.

There are a number of towns on the Gippsland Lakes including Lakes Entrance, Metung, Paynesville and Loch Sport. Bairnsdale and Sale are located on the Mitchell and Thompson Rivers respectively, which flow into the lakes. There are a number of other smaller towns or areas of housing near the lake shore such as Ocean Grange, Holland's Landing and Eagle Point.

At the western end of the Ninety Mile Beach there are a number of small coastal towns such as Seaspray, The Honeysuckles, Golden Beach and Paradise Beach.

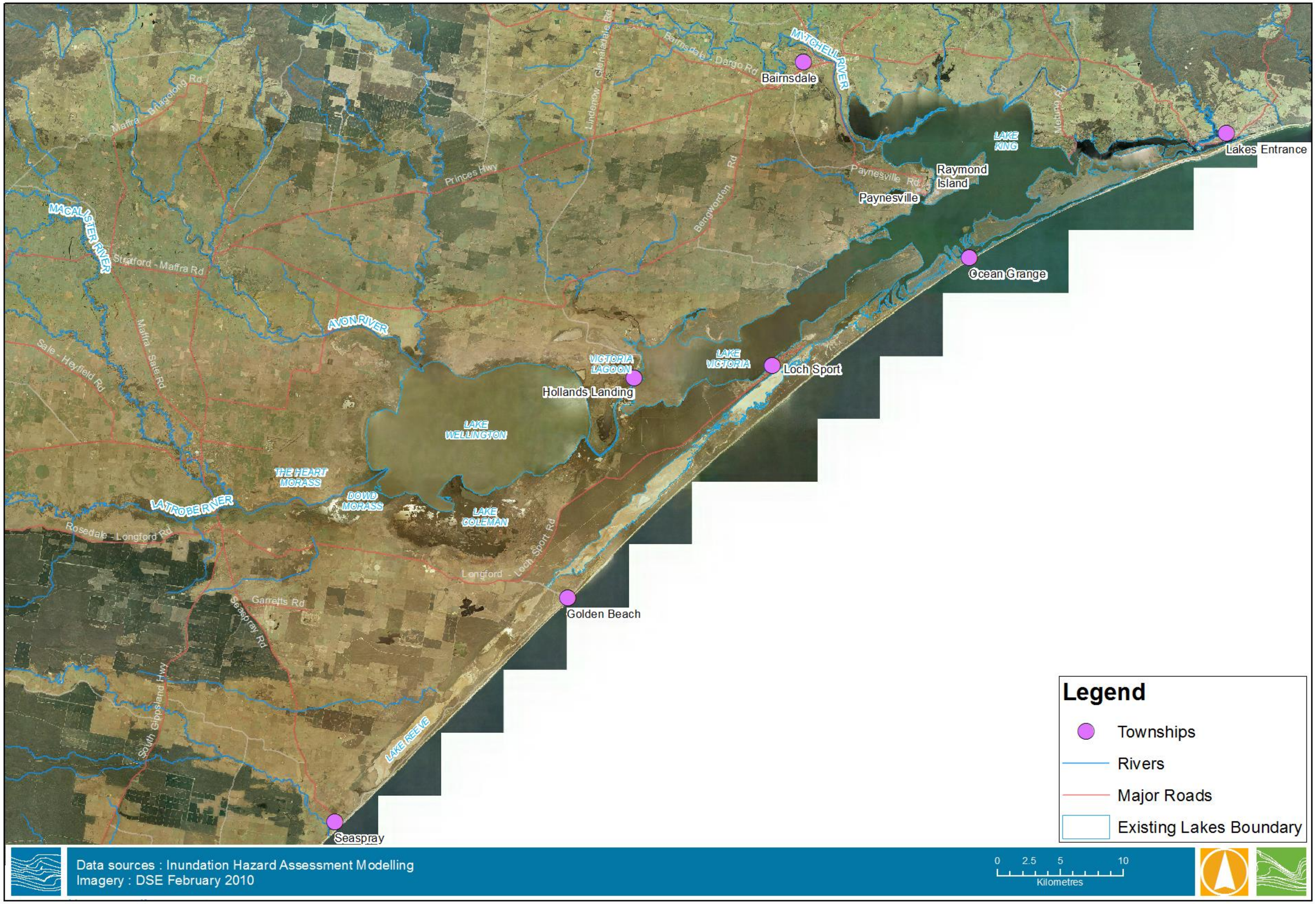


Figure 1-2 **Key Locations within the Study Area and Approximate Study Boundary**

1.5 Geological and Geomorphic Context

1.5.1 The Gippsland Basin

The Gippsland Basin is one of the largest sedimentary basins of southern Australia. It comprises a series of sediment-filled tectonic depressions extending east and south of the South Gippsland Hills and for several hundred kilometres onto the Bass Strait continental shelf (Figure 1-3).

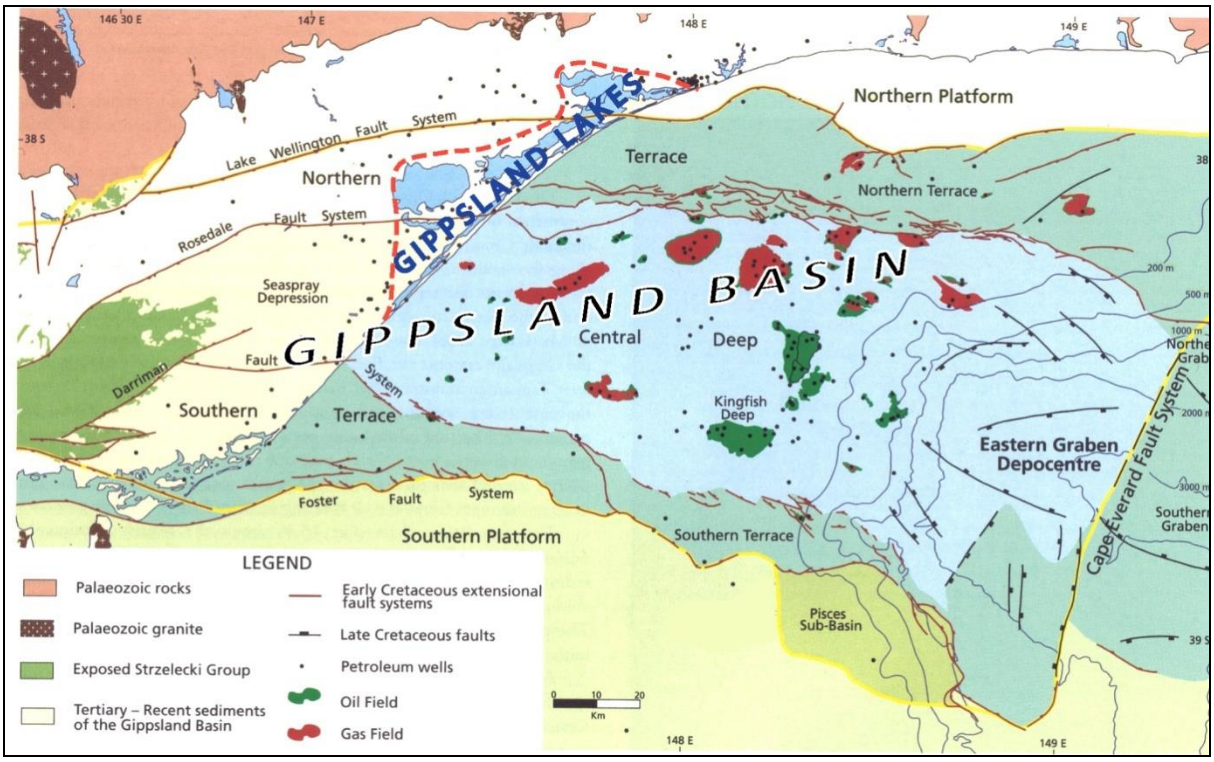


Figure 1-3 Gippsland Basin and Gippsland Lakes (after Invalid source specified.**)**

1.5.2 The Gippsland Lakes

The Gippsland Lakes complex is a former marine embayment established during periods of higher sea levels, now enclosed and partly filled by a sequence of coastal sand barriers and lake, swamp and fluvial deposits. These deposits and associated landforms, developed during episodes of higher and lower sea level, comprise the largest coastal barrier and lagoon system on the Australian coast, Figure 1-4.

An overview of the geomorphic features associated with the Lakes is provided in Section 3.3.3 of this report. Aspects related to the coastal barriers, particular the outer barrier are detailed in Report 3: Outer Barrier Coastal Hazards.

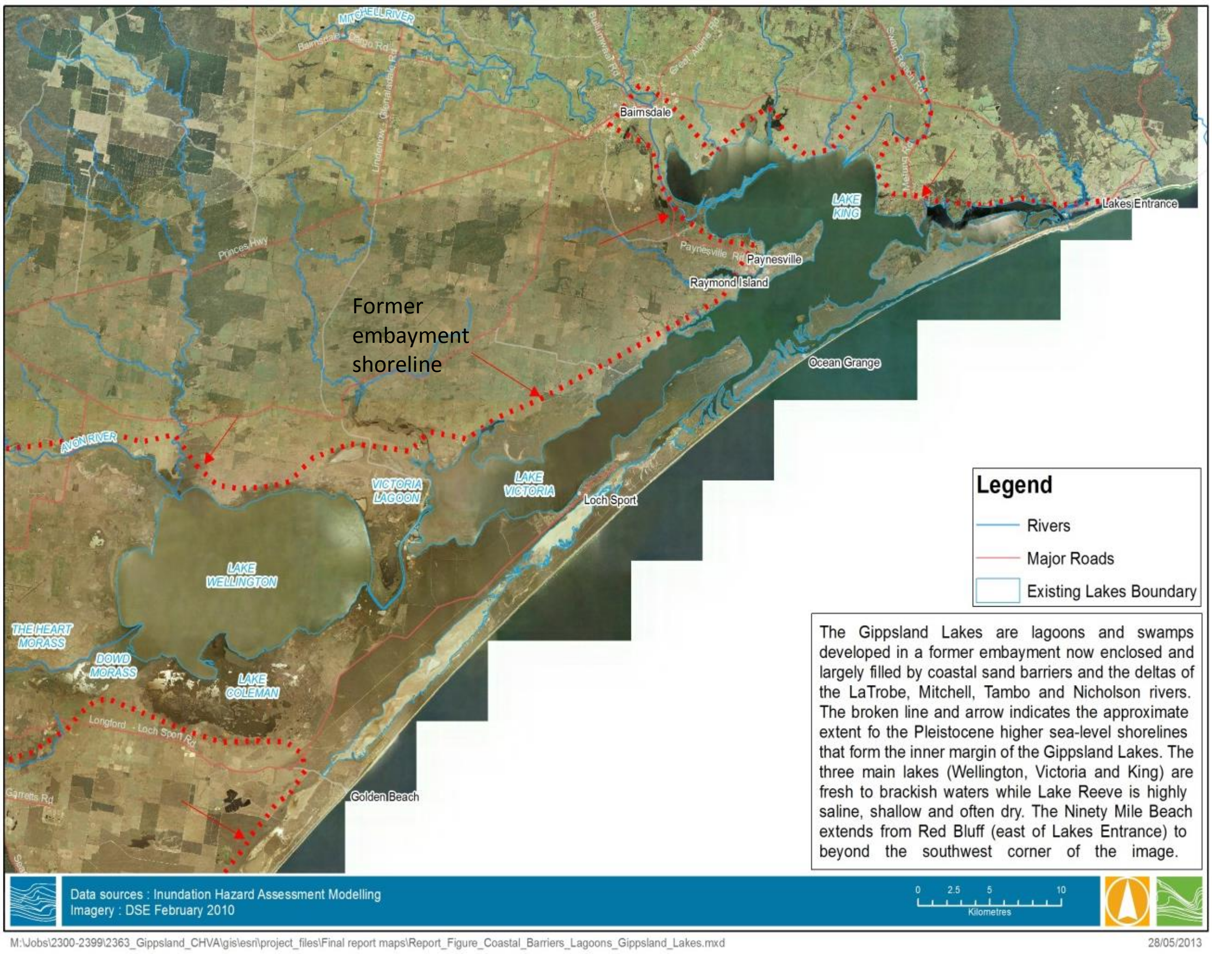


Figure 1-4 Coastal barrier and lagoons of the Gippsland Lakes

1.6 Background Investigations

1.6.1 Previous Work

There is a wealth of existing knowledge on the Gippsland Lakes from previous investigations and reports over the past 30 years. A review of previous work was undertaken and the following are considered to be the key previous studies relevant to the assessment of inundation and erosion hazards within the study area:

Gippsland Climate Change Study

The Gippsland Coastal Board commissioned a series of investigations as part of the Gippsland Climate Change Study to inform coastal planners and managers of the potential impacts of sea level rise, climate change and coastal subsidence on the Gippsland coastline.

The study was undertaken in the following two main phases:

Phase 1

The first phase comprised a series of technical studies undertaken by CSIRO Marine and Atmospheric Research to evaluate the impact of climate change on regional sea levels and weather patterns on the Gippsland Coastline. The research program was undertaken which included the following three main stages:

Stage 1 (McInnes, Abss, & Bathols, 2005) involved an assessment of climate model simulations in terms of changes to weather conditions (e.g frequency and intensity of storms) and synoptic weather events that are conducive to storm surge formation on the East Victorian coastline.

Stage 2 (McInnes, Macadam, Hubbert, Abss, & Bathols, 2005)assessed the impacts of future wind speed changes on storm surges along the eastern Victorian coastline. Hydrodynamic modelling and statistical analysis of extreme sea level events was used to develop spatial predictions of storm surge recurrence intervals including sea level rise and climate change on the East Victorian coastline

Stage 3 (McInnes, Macadam, & Hubbert, 2006) assessed the impact of climate change on sea level heights and inundation at a higher spatial resolution for Corner Inlet and the Gippsland Lakes. The study provided estimated storm tide return levels for a number of representative locations within the Gippsland Lakes due to the combination of astronomical tide, storm surge and wind setup, however the influence of streamflows was not included.

Phase 2 (Ethos NRM; Water Technology, 2008)

The Phase 2 study assessed the coastal geological characteristics and the potential for erosion of the Gippsland coast. Using climate change predictions at the time, it determined the likely changes to coastal sediment transport (sand movement) patterns along the coast. Possible effects of sea level rise and subsidence on physical assets and natural values along the coast were identified.

Gippsland Lakes Flood Level Modelling Project (Grayson, et al., 2004)

The Gippsland Lakes Flood Modelling Project (GLFMP) comprised a significant body of technical work to establish design flood levels for the Gippsland Lakes taking into account the range of physical influences on the Lakes water levels including streamflow, wind and ocean levels. A stochastic method was utilised to simulate long sequences of combined rainfall, wind and atmospheric pressure. Mont Carlo simulations with a one dimensional hydrodynamic model of the Gippsland Lakes were then undertaken to estimate the probability distribution of extreme water levels in the Gippsland Lakes.

The study did not consider the potential impact of sea level rise and climate change on extreme water levels in the Gippsland Lakes. The modelling methodology adopted for the GLFMP was identified as useful for integrating the effects of changes in rainfall, sea level atmospheric pressure and wind, however, it was noted that detailed information on expected changes to these forcing would be needed to enable the modelling method to be applied.

Gippsland Lakes Shore Erosion & Revegetation Strategy (Coastal Engineering Solutions; Geostudies; Shearwater Associates; Crossco Australia, 2002)

The Gippsland Lakes Shore Erosion and Revegetation Strategy investigations were commissioned by the Gippsland Coastal Board (GCB). The objectives of the strategy were to identify the extent of lakeshore erosion since the 1930's and to identify and prioritise areas for protection. The study included detailed field inspections to determine shore and vegetation types and analysis of historical aerial photography to delineate extents of shoreline change. An Appendix to the main report provides an assessment of the potential response of the lake shorelines to changes in mean sea level and salinity associated with climate change. The Appendix broadly considers potential changes in terms of vegetation types, groundwater levels, salinity and waves to identify how the lake shorelines could be expected to respond. Detailed analysis and mapping of potential erosion hazard extents under sea level rise/climate change scenarios was however not undertaken.

Gippsland Lakes / 90 Mile Beach Coastal Hazard Assessment, Component 1 - Background Data Assimilation and Gap Analysis (Worley Parsons, 2012)

The Data Assimilation and Gap Analysis was the first stage in the Local Hazard Assessment for the Gippsland Lakes and 90 Mile Beach. The objectives of this study were to locate and collate all available information on relevant coastal and catchment processes for use in the current coastal hazard assessment, and to identify any data gaps. The study produced a database of information and references to data that was of relevance to this coastal hazard study.

1.7 Monitoring

1.7.1 Data Collection

Coastal and Shoreline Profiles

A series of coastal and lake shoreline profile surveys have been undertaken within the study area to establish and document a first round of monitoring records. This data will enable future coastal and shoreline changes to be tracked, improving understanding of the processes themselves as well as the impact of future SLR over time. Details of the coastal data collection are provided Report 5: Coastal Monitoring.

The coastal and shoreline profiles were surveyed using a differential GPS (dGPS). The dGPS receiver provides horizontal and vertical accuracies of ± 0.1 m. The coastal and shoreline profile surveys have been provided in GDA zone 55 coordinates. Vertical elevations are relative to AHD. The coastal and shoreline profile surveys were undertaken on the 15-16th October 2012 and 3-4th February 2013.

Coastal and lake shoreline profiles have been undertaken at the following locations:

Outer Barrier Coastal Profiles

- Seaspray (Western & Eastern)
- Bunga Arm (1st and 2nd Blowholes)
- Eastern Beach (East of Lakes Entrance)

Lake Shoreline Profiles

- *Bunga Arm*
- *Paynesville*
- *Metung*
- *Lakes Entrance*
- *Loch Sport*

Examples of the coastal profile outputs are provided in Figure 1-5 and Figure 1-6 below.

Figure 1-5 Example Monitoring Location - 1st Blowhole Coastal Profile Location (15-1-2012)

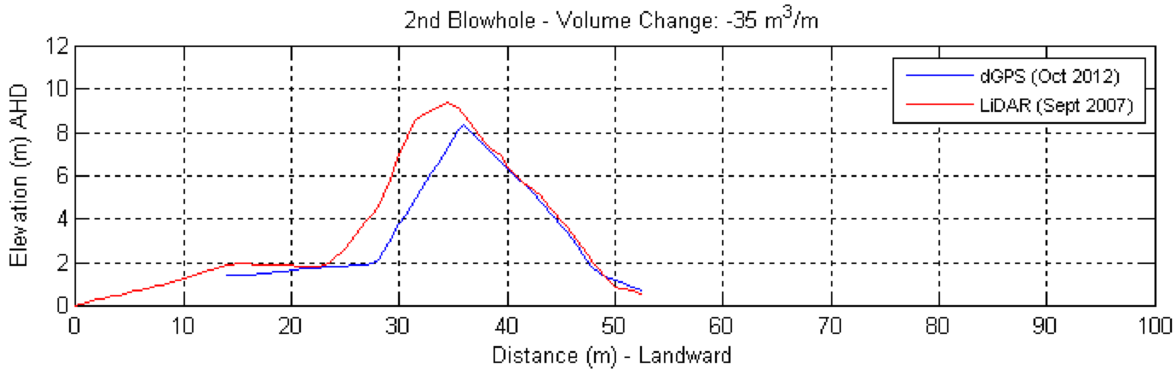


Figure 1-6 Example Monitoring - 2nd (Eastern) Blowhole Coastal Profile

Sediment Sampling

In order to inform the Outer Barrier hazard assessment, sediment samples were collected from Seaspray and Paradise Beach. Samples were collected from the mid face of the dune and the swash zone at both locations. The particle size distributions of the samples were assessed via sieving analysis. The particle size distributions were used in the calculation of sediment transport rates and profiles dynamics.

1.8 Representative Locations and Key Physical Processes

During the initial phase of the study representative locations were identified and confirmed with the PSG. The representative locations are areas of particular interest that have been the focus of more detailed assessment and reporting compared to the study area as a whole. This recognises that the scale of the study area is such the detailed reporting around the whole shoreline of the Lakes and along the whole coastline of the 90 Mile Beach is impractical. In addition it is possible to provide results at locations that can be considered representative of the impacts over broader sections of the study area. Each of the representative locations was then assessed according to its individual importance in terms of coastal hazard as well as the extent to which that location represents a unique set of physical circumstances relevant to other parts of the overall system.

The 5 selected representative locations are shown in Figure 1-2 and described below, along with the key hazards and processes at each site. Table 1-1 provides a summary of the study investigation methods applied for each area of interest.

Lakes Entrance

Lakes Entrance is particularly vulnerable to flooding due to the intensity of the development in the township, low elevations and proximity to the ocean entrance and associated tidal influence which can amplify flood levels locally. Within the Gippsland Lakes, the significant tidal influence on flood levels is unique to Lakes Entrance. The flood level vulnerability of Lakes Entrance is such that flooding of roads and properties begins at around 0.9 – 1.0 m AHD. Low level inundation hazards begin primarily through surcharging of the stormwater network. Large increases in flood inundation extents and numbers of properties impacted occurs at flood levels above approximately 1.1 m AHD at Lakes Entrance.

The township is located on the remnants of a prior barrier dune which is over 15,000 years old. Significant sections of the township have been filled during development over the past century and the shorelines around Lakes Entrance are now engineered with sea walls and revetments. Due to the confined nature of the lakes (North Arm and Cunninghame Arm) in this area, waves are significantly limited by area of open water. Ocean swells and waves are not able to penetrate the entrance due to the restricted opening.

Before the creation of the permanent entrance in 1889, an ephemeral entrance existed to the east of Lakes Entrance that was connected to the main body of the Gippsland Lakes along Cunninghame Arm. It is also useful to note that the Outer Barrier dune in the vicinity of the Golf Course at the eastern end of the town was breached during a storm in 1979, however this process has not been observed during significant storms events since that time.

Lakes Entrance is unique in terms of the extent of the historical changes that have occurred to the shorelines/barriers in this area. It is liable to flooding under present conditions and therefore highly vulnerable to the potential hazards posed by sea level rise. Whilst the sandy shores around Lakes Entrance are inherently susceptible to wave and wind transport, the overall erosion hazard is considered less significant than the inundation hazard at this location. Figure 1-7 shows a schematic of the Lakes Entrance representative location along with the key processes.

Figure 1-7 Lakes Entrance Representative Location and Key Coastal Processes

Paynesville and Raymond Island

The township of Paynesville is located on the edge of a bluff marking the extent of a former cliffed coastline that existed during a period of higher sea level. In front of the bluff, a low terrace and associated shoreline extends out into the Lakes. Raymond Island is a remnant of an 'inner sandy barrier' that built out in front of the earlier cliffed coastline.

The communities of Paynesville and Raymond Island are vulnerable to flooding. Raymond Island is particularly vulnerable as the island can become isolated if operation of the ferry is restricted due to floods or other interruptions. Paynesville is relatively close to the outlet of the Mitchell, Nicholson and to a lesser extent Tambo Rivers. These rivers all have the potential to significantly impact flooding in the lakes.

This location is considered unique in that the shorelines are comprised of two distinctly different landforms and geology. The way in which these shorelines respond to sea level rise may therefore be significantly different.

The sandy shores of the southern-facing coastline are subject to larger waves than the north-facing shores which comprise more silts and shallow marsh. This is partly due to a longer stretch of open water to the south-west along Lake Victoria and the prevalence of summer sea-breezes. The north-facing shores are susceptible to erosion as the vegetation that binds the silty material together is sensitive to salinity and hence small rises in sea level.

The hazards at this location are expected to be driven by a combination of erosion and inundation impacts. Figure 1-8 shows a schematic of the Paynesville representative location along with key processes.

Figure 1-8 Paynesville & Raymond Island Representative Location and Key Coastal Processes

Loch Sport

The township of Loch Sport is located on the inner barrier. The meandering of pre-historic rivers between the inner barrier and the bluff to the north during low sea level periods has eroded sections of the inner barrier at Loch Sport. Subsequently, only a relatively small barrier now exists between Lake Victoria and Lake Reeve. The majority of the Lake Victoria shoreline at Loch Sport is now managed by the construction of groynes which have trapped eastward drifting sand.

Much of the township is located above 3 m AHD and is therefore not particularly vulnerable to flooding under existing sea level conditions.

The lake shore at Loch Sport is subject to waves with significant exposure from the north-east and south-west directions. Whilst there is presently no quantitative data regarding the level of vulnerability of this area to coastal erosion, the existence of significant groyne construction indicates there have been issues in the past.

The anecdotal evidence of shoreline stability issues and the positioning of the township on the southern shore of the lakes provide a unique set of circumstances for this location. Although Loch Sport is approximately midway between the western and eastern rivers, flood levels here are more closely tied to the levels in Lake King/Paynesville than Lake Wellington. Figure 1-9 shows a schematic of the Loch Sport representative location along with the key processes.

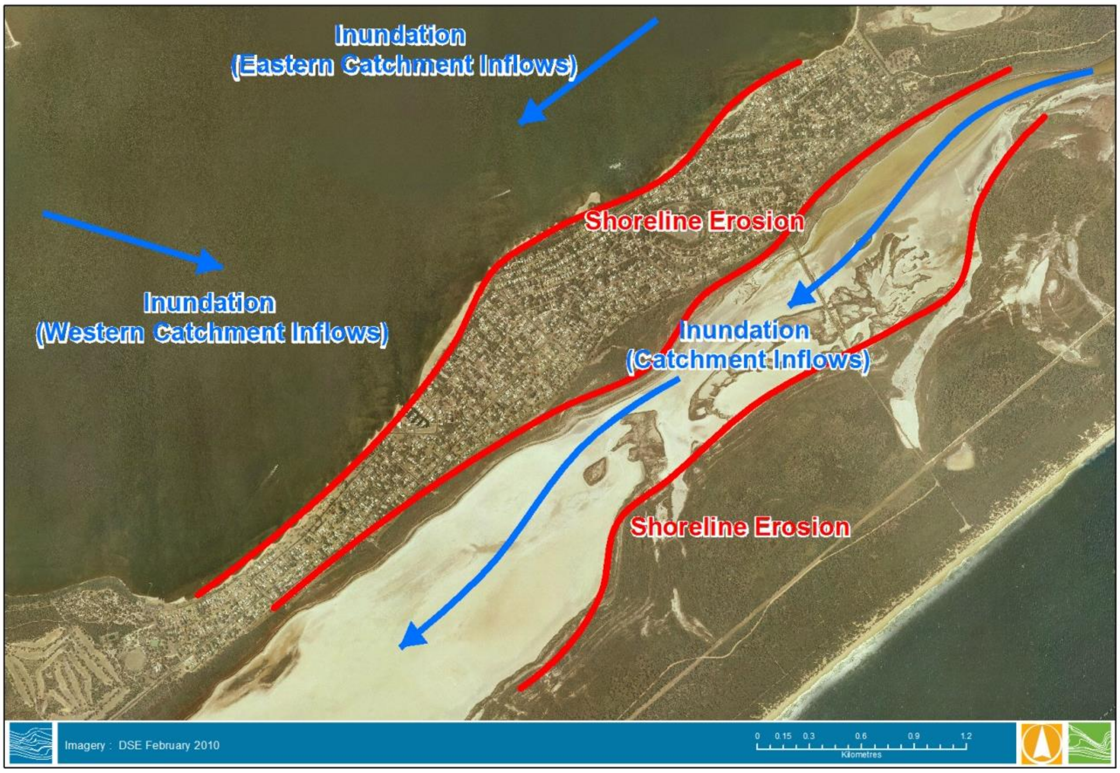


Figure 1-9 Loch Sport Representative Location and Key Coastal Processes

Bunga Arm/Blowholes

In this section of the Ninety Mile Beach, the outer barrier separates the ocean from Bunga Arm, a narrow lagoon that runs parallel to the coast for approximately 15 km from Ocean Grange, east towards Lakes Entrance. The Bunga Arm lagoon is a prior entrance channel to the Gippsland Lakes that was deflected eastward by waves and sand movement and finally sealed within the last 3,000 to 4,000 years. The outer barrier is very narrow in sections along Bunga Arm. At two locations known as the '1st' and '2nd' Blowholes, the dune volume and crest elevation are relatively low. Anecdotal accounts report that the barrier was breached at the 2nd Blowhole in the early 1950's following a severe storm event (pers comm. Eric Bird).

The Bunga Arm/blowholes location provides a representative location for evaluation of the potential for barrier overwash processes to occur. Evaluation of this site can lead to understanding of the potential impact of overwash on flood levels in the Lakes in the event that an ephemeral entrance develops in Bunga Arm due to sea level rise. Figure 1-10 shows a schematic of the Bunga Arm representative location along with the key processes.

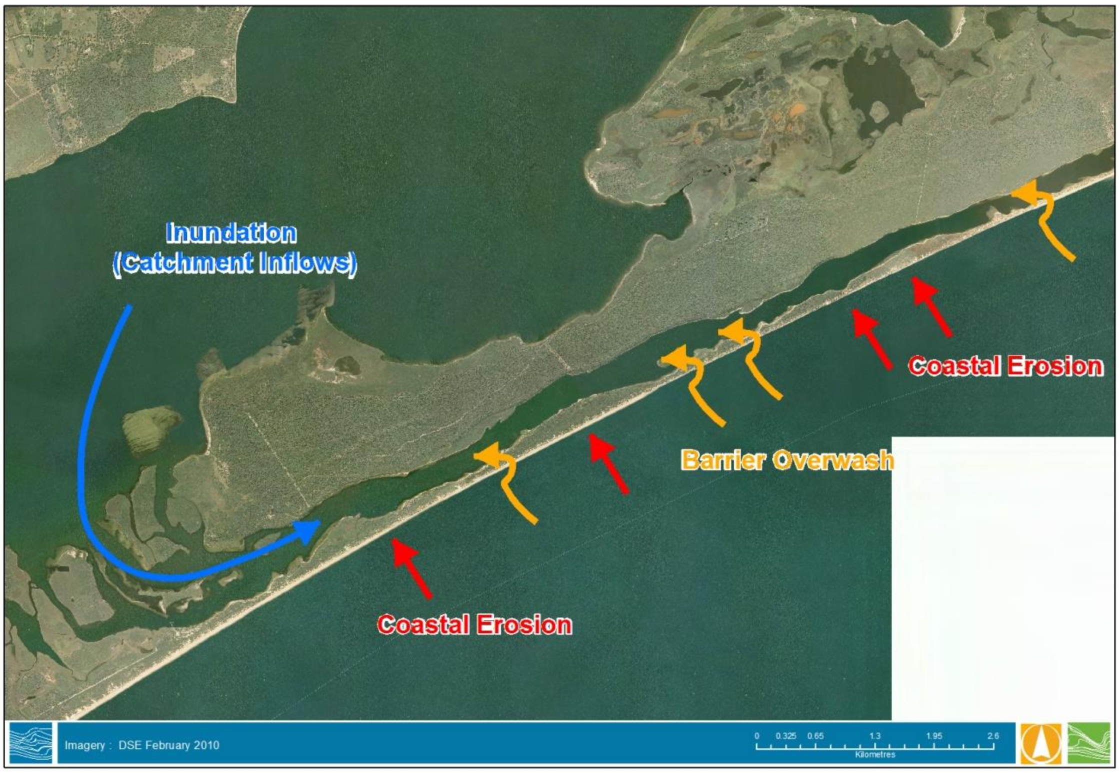


Figure 1-10 Bunga Arm/Blowholes and Key Coastal Processes

Seaspray-Honeysuckles

The outer barrier at Seaspray and Honeysuckles is comprised of a single low and narrow fore-dune overlying lagoon/estuarine mud and peat. Behind the barrier landforms are variable; in places there is a sandy plain of low relief while elsewhere there are the lagoon shores of Lake Reeve and remnant tidal channels which lie less than 0.5 m above present day sea level. Documents relating to the early management of the Prospect Reserve at Seaspray make reference to the exposure of the reserve to over-washing of the barrier and subsequent inundation and drifting sand hazards. The historical aerial photography of the area indicates that significant recession of the barrier has occurred, particularly over the last decade.

Seaspray is considered a representative location in the study area due to the extent of the physical hazards that could potentially occur due to sea level rise and the public and private assets that could be exposed. Figure 1-11 shows a schematic of the Seaspray representative location along with the key processes.

Figure 1-11 Seaspray/Honeysuckles Representative Location and Key Coastal Processes

Table 1-1 Summary of Study Investigation Process for Each Area of Interest

Area of Interest	Costal Hazard Issues (Erosion, Inundation etc)	Physical Drivers (what are the natural or other forces influencing these hazards)	Characterisation Method (what methods were used to address these issues)	Assessment (how was each hazard reported)	Sensitivity Testing (what stress testing can we apply to understand the sensitivity of the system to alternative forcing)
Lakes Entrance ***near ocean entrance***	• Inundation of township via flood and/or storm-tide • Erosion of ocean beach and dune • Overtopping of dune	• Flood level response to sea level rise and river inflows • Bass Strait waves with sea level rise, long-shore and cross-shore sand movement under sea level rise • Bass Strait waves and sea level rise, sand transport, dune vegetation types	• Gippsland Lakes flood model • Ocean wave model, sand transport models, review of data and reports on barrier formation and evolution • Flood model of dune overtopping, qualitative assessment of dune susceptibility	• Mapping of flood extents and flow velocities • Cross-shore profiles with sea level rise and storm erosion, mapping of estimated shoreline recession, schematics of key physical processes • Mapped overtopping scenario extents, animation of overtopping case, mapped susceptibility zones	• Subsidence and/or barrier dune breach events • Changes to wind patterns • Changes to vegetation (type, abundance)
Paynesville & Raymond Island ***lake site near a river discharge***	• Inundation of township via flooding • Lake shoreline erosion	• Flood level response to sea level rise and river inflows • Lake waves with sea level rise, currents, shoreline geology and vegetation type/cover, land-use and artificial structures	• Gippsland Lakes flood model • Lakes wave model, lakes flood model, review of geology, vegetation, and land-use data and reports on shoreline environment (lake shoreline susceptibility assessment framework)	• Mapping of flood extents and flow velocities • Tables and map layers of various input risk factors leading to a physical, environmental and biological risk score for the shoreline	• Subsidence and/or barrier dune breach events, changes to river flows • Potential impact of subsidence, status without man-made structures
Loch Sport ***lake site distant from a river discharge***	• Inundation of township via flooding • Lake shoreline erosion	• Flood level response to sea level rise and river inflows • Lake waves with sea level rise, currents, shoreline geology and vegetation type/cover, land-use and artificial structures	• Gippsland Lakes flood model • Lakes wave model, lakes flood model, review of geology, vegetation, and land-use data and reports on shoreline environment (lake shoreline susceptibility assessment framework)	• Mapping of flood extents and flow velocities • Tables and map layers of various input risk factors leading to a physical, environmental and biological risk score for the shoreline	• Subsidence and/or barrier dune breach events, changes to river flows • Potential impact of subsidence, status without man-made structures
Steamer Landing/Blowholes ***open coast, no township***	• Erosion of ocean beach and dune • Overtopping of dune, breach in barrier	• Bass Strait waves with sea level rise, long-shore and cross-shore sand movement under sea level rise • Bass Strait waves and sea level rise, sand transport, dune vegetation types	• Ocean wave model, sand transport models, review of data and reports on barrier formation and evolution • Flood model of dune overtopping, qualitative assessment of dune susceptibility	• Cross-shore profiles with sea level rise and storm erosion, mapping of estimated shoreline recession, schematics of key physical processes • Mapped overtopping scenario extents, animation of overtopping case, mapped susceptibility zones	• Subsidence and/or barrier dune breach events • Impact of breach on lake flood levels
Seaspray-Honeysuckles (proposed representative location) ***open coast near a township***	• Inundation of township via flood from Lake Reeve, overtopping levees • Erosion of ocean beach and dune • Overtopping of dune	• Flood level response to sea level rise and river inflows • Bass Strait waves with sea level rise, long-shore and cross-shore sand movement under sea level rise • Bass Strait waves and sea level rise, sand transport, dune vegetation types	• Gippsland Lakes flood model • Ocean wave model, sand transport models, review of data and reports on barrier formation and evolution • Flood model of dune overtopping, qualitative assessment of dune susceptibility	• Mapping of flood extents and flow velocities • Cross-shore profiles with sea level rise and storm erosion, mapping of estimated shoreline recession, schematics of key physical processes • Mapped overtopping scenario extents, animation of overtopping case, mapped susceptibility zones	• Subsidence and/or barrier dune breach events • Changes to wind patterns • Changes to vegetation (type, abundance)

Area of Interest	**Costal Hazard Issues (Erosion, Inundation etc)**	**Physical Drivers (what are the natural or other forces influencing these hazards)**	**Characterisation Method (what methods are we using to address these issues)**	**Assessment (how will each hazard be reported)**	**Sensitivity Testing (what stress testing can we apply to understand the sensitivity of the system to alternative forcing)**
Whole of the Gippsland Lakes	• Permanent or episodic inundation of fringing coast and wetlands via flooding • Lake shoreline erosion	• Flood level response to sea level rise and river inflows • Lake waves with sea level rise, currents, shoreline geology and vegetation type/cover, land-use and artificial structures	• Gippsland Lakes flood model • Lakes wave model, lakes flood model, review of geology, vegetation, and land-use data and reports on shoreline environment (lake shoreline susceptibility assessment framework)	• Mapping of flood extents and flow velocities • Tables and map layers of various input risk factors leading to a physical, environmental and biological risk score for the shoreline	• Subsidence and/or barrier dune breach events, changes to river flows • Potential impact of subsidence, status without man-made structures
Whole of 90 Mile Beach	• Erosion of ocean beach and barrier dune • Overtopping of dune, breach in barrier	• Bass Strait waves with sea level rise, long-shore and cross-shore sand movement under sea level rise • Bass Strait waves and sea level rise, sand transport, dune vegetation types	• Ocean wave model, sand transport models, review of data and reports on barrier formation and evolution • Flood model of dune overtopping, qualitative assessment of dune susceptibility	• Cross-shore profiles with sea level rise and storm erosion, mapping of estimated shoreline recession, schematics of key physical processes • Mapped overtopping scenario extents, animation of overtopping case, mapped susceptibility zones	• Subsidence and/or barrier dune breach events • Impact of change in mechanism of shoreline change from dune retreat to dune washover

2. HAZARD DEFINITION

2.1 Terminology

The term coastal hazard is generally used to collectively describe physical changes/impacts to the natural environment which are significantly driven or influenced by coastal or oceanographic processes. Coastal hazards can include a range of processes that result in physical impacts to the natural environment such as:

- **Coastal erosion and accretion** - the retreat or advancement of the coastal shore
- **Inundation** – flooding of areas due to river inflows or sea storms
- **Aeolian (wind) transport of sediments** – the formation or erosion of sand dunes

The scope of this study is limited to the potential magnitude and extent of coastal hazard impacts associated with sea level rise/climate change in the study area. The assessment does not consider, nor make judgements as to the relative consequence of these potential hazard impacts on assets or social and environmental values. The study does therefore not constitute a full risk assessment where both consequence and likelihood are addressed.

Due to the dominant influence of catchment generated flows on flooding within the Gippsland Lakes, this study differentiates inundation hazards from coastal hazards. For this study, inundation hazards therefore primarily relate to the potential impact of sea level rise/climate change on water level conditions driven by major catchment generated flood flows into the Gippsland Lakes.

The type and scale of physical processes that give rise to erosion hazards vary substantially between the open coast shoreline (90 Mile Beach) and the shorelines of the Gippsland Lakes. For this reason, the erosion hazards for these two shoreline types have been considered separately, using different assessment methodologies.

2.2 Consideration of Spatial and Temporal Assessment Scales

The assessment of potential coastal hazard impacts has required the assessment of a wide range of physical processes. These physical processes operate and influence the study area over a range of spatial and temporal scales that can vary by several orders of magnitude. This influences the level of certainty and precision that can be reasonably applied to estimates of the severity and extent of coastal hazard impacts within the study area.

The schematic in Figure 2-1 illustrates the relationship between different processes and timescales. The left hand side shows the range of spatial and temporal scales over which relevant physical processes and associated coastal hazard impacts have manifest within the study area over time, leading to the present coastline.

The right hand side of Figure 2-1 provides an overview of the spatial and temporal scales over which current models of coastal processes are considered applicable. This shows that over relatively short temporal scales of days to years, and spatial scales of square metres to kilometres, process based models can provide a good understanding of physical behaviour/impacts.

Additionally, over very long temporal scales and large spatial scales, conceptual models of coastal geomorphic behaviour and landform evolution currently provide a reasonable framework for understanding the potential physical changes/impacts at these scales.

For planners, managers and engineers, the temporal scales relevant for planning and implementing management responses to climate change (and the long term impacts of these measures) may range from decades to centuries. Over these intermediate temporal scales, the extent of the physical changes/impacts and their rate of change is dynamic. They result from the complex interaction of a wide range of stochastic processes that cannot be accurately simulated or predicted at these time scales.

To overcome these limitations, the assessment methodologies endeavour to upscale the process-based models/results and downscale the geomorphic understanding of relevant physical behaviour. This approach provides an assessment of the potential coastal change and hazard impacts at time-scales relevant to planning, engineering and management, as highlighted in Figure 2-1 below.

Where significant uncertainty surrounds the potential rate or magnitude of change of a physical process or behaviour, the sensitivity of that process on coastal hazard impact has been tested. The resulting sensitivity outputs provide guidance for decision making and risk management in the future.

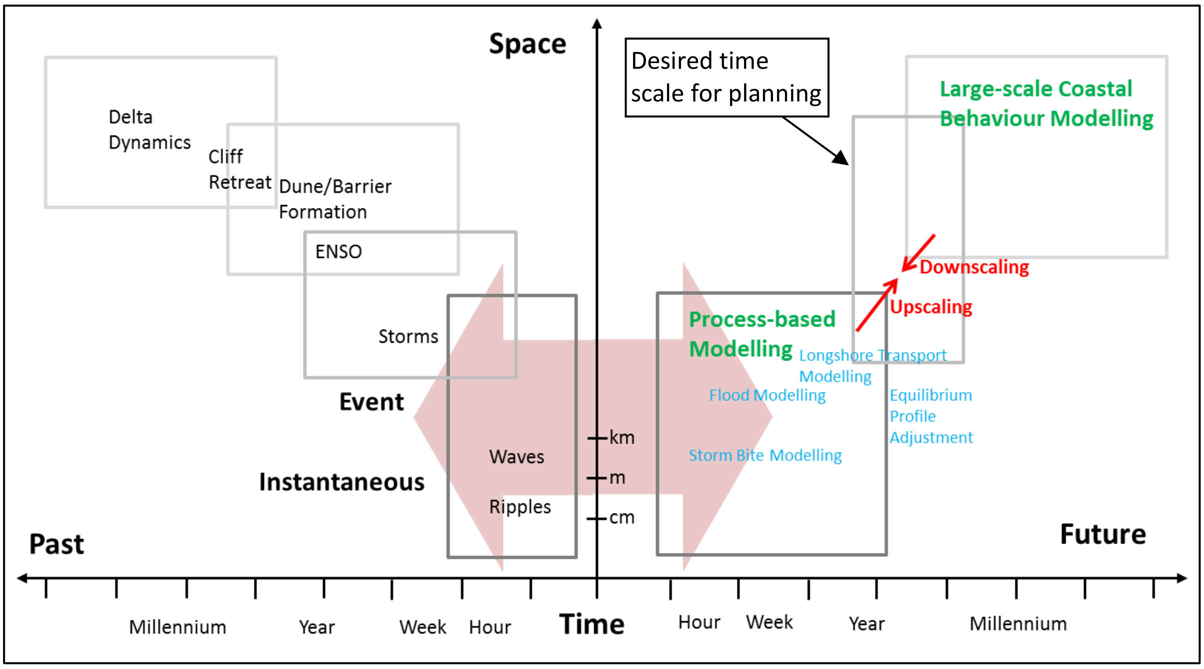


Figure 2-1 **Schematic of geomorphic processes and responses, highlighting the range of spatial and temporal scales over which they are considered (Adapted from Woodroofe, (2002)).**

2.3 Hazard Scenarios

Coastal hazard impact assessments have been undertaken for a number of discrete climate change/sea level rise scenarios. For each of these scenarios, the potential coastal hazard impacts have been assessed for a defined number of event probabilities (likelihoods). The scenario and event combinations are summarised in Table 2-1 below. These are primarily derived from the Victorian Coastal Hazard Guide (DSE, 2012) which in turn draws on the Victorian Coastal Strategy (Victorian Coastal Council, 2008) for guidance with respect to sea level rise. The Victorian Coastal Strategy (Victorian Coastal Council, 2008) requires planning for sea level rise of not less than 0.8 m by 2100, which is reflected in the three sea level rise scenarios up to 0.8 m that have been specified by the PSG and considered in this study. These scenarios are also consistent with the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, Working Group 1.

The use of scenarios in this assessment enables the relative rate and extent of potential change in the coastal hazard impacts in the study area to be more readily compared between the climate change/sea level rise scenarios and existing conditions.

Table 2-1 Scenario and Event Combinations Considered in Hazard Assessment

Scenario	SLR likelihood at different timeframes				SLR (m)	Wave and Storm Surge (AEP %)	Gippsland Lakes Flood (AEP%)[1,2]
	Current	2040	2070	2100			
1	Likely	Virtually certain			0	2%	10%
2	About as likely as not	Likely	Virtually certain		0.2	2%	10%
2a	About as likely as not	Likely	Virtually certain		0.2	2%	1%
3	Unlikely	About as likely as not	Likely	Virtually certain	0.4	1%	10%
4		Exceptionally unlikely	Unlikely	About as likely as not	0.8	1%	10%

1 Note: In some cases catchment flows are not applicable and so not considered, along 90 Mile beach for example.

2 Note: Flood level frequency in the Gippsland Lakes depends on a combination of river inflows, wind, coastal storm surge and tide.

3. HAZARD ASSESSMENT OVERVIEW

The following sections provide a brief overview of the predicted changes to erosion and inundation hazards at a broad, study area scale from the results of the technical assessments.

3.1 Inundation Hazard

3.1.1 Introduction

A number of townships adjacent to the Gippsland Lakes shoreline have areas of relatively low elevation that are vulnerable to inundation. In order to understand inundation hazard, an analysis of the processes contributing to flood levels and how they change under increased mean sea level has been undertaken.

The extent of the inundation hazards resulting from floods in the Gippsland Lakes, under current sea level, is generally well understood.

The exceedance probabilities of flood levels have been previously assessed in detail as part of the Gippsland Lakes Flood Level Modelling Project (Grayson, et al., 2004). However there is currently no information on the potential impact of higher mean sea levels on the extent of catchment driven, flood inundation within the Gippsland Lakes.

A detailed hydrodynamic modelling analysis was therefore undertaken to predict the impact that changes in mean sea level could have on flood behaviour within the Gippsland Lakes. The details of the flood model set-up, calibration and results are presented in *Report 2: Inundation Hazard*.

3.1.2 Method

A hydrodynamic model of the Gippsland Lakes Basin, up to approximately 3 m AHD in elevation, and the coastal offshore area surrounding Lakes Entrance was developed. This model was calibrated to measured water levels within the Lakes, including a number of historic flood events. Calibrating the hydrodynamic model consisted of simulating the model with measured and/or modelled river inflow data, winds, tide and coastal ocean levels, and comparing the modelled water levels to measured data at a number of locations throughout the lakes.

The calibration showed that the model was able to recreate, with sufficient accuracy, typical or ambient water level variations, as well as major flood conditions. The calibration process demonstrated that the hydrodynamic model is an appropriate tool for predicting the impact of sea level rise on flood conditions in the Gippsland lakes.

A range of flood levels and associated exceedance probabilities has previously been determined as part of the Gippsland Lakes Flood Level Modelling Project (Grayson, et al., 2004). The Gippsland Lakes Flood Level Modelling Project statistically generated 3,000 artificial streamflow, coastal water level and wind scenario cases. From the 3,000 total cases, a sub-set of 329 large flood cases were identified, and used as the basis for determining design flood levels.

The streamflow, coastal water level and wind cases which resulted in representative 10% AEP (10 year ARI) and 1% AEP (100 year ARI) flood levels were extracted from the Gippsland Lakes Flood Level Modelling Project data set and used as boundary conditions for the hydrodynamic model developed for this project.

The 10% AEP flood case was simulated for present mean sea level and for +0.2, 0.4 and 0.8 m sea level rise conditions. The 1% AEP design flood case was simulated for the present mean sea level and +0.2 m sea level rise conditions.

Three additional scenarios were also simulated in the hydrodynamic model to test the sensitivity of predicted flood levels, due to uncertainty relating to the following:

- Potential overwash of the outer barrier and creation of an additional ephemeral entrance to the Gippsland Lakes due to sea level rise;
- Changes to catchment flood hydrology due to climate change; and
- Land subsidence associated with aquifer deflation.

Figure 3-1 displays the conceptual methodology used to assess inundation hazards in the Gippsland Lakes.

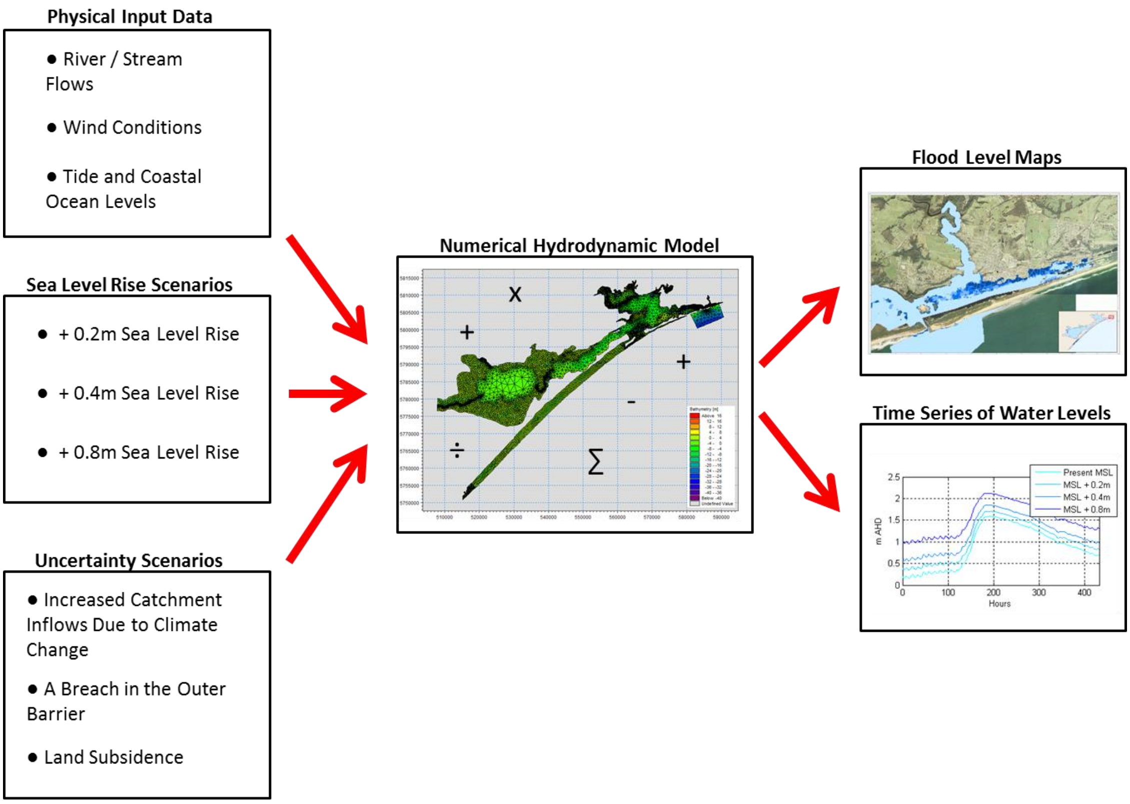


Figure 3-1 **Conceptual Process by which the Inundation Hazards within the Gippsland Lakes were Assessed**

3.1.3 Results Overview

The results from the hydrodynamic modelling were processed to develop a range of outputs representing various aspects of inundation hazard to allow comparison of current and future conditions due to sea level rise.

Figure 3-2 displays an overview of the predicted change in maximum inundation extents under various sea level rise scenarios. At a broad, study-area scale, only relatively minor changes in inundation extents are discernible around the Gippsland Lakes, with the main exception being the south western end of Lake Reeve, where a large increase in inundation extent is predicted. Whilst not obvious at the broader scale, there are significant changes in flood extent for some local areas such as Lakes Entrance.

Figure 3-3 shows the increase in peak flood level for the 10% AEP flood case (0.8 m SLR minus existing peak water surface). This shows that the maximum changes to flood levels (due to SLR) are at Lakes Entrance and in the western end of Lake Reeve, towards Seaspray. At Lakes Entrance, the greater change in height is due to the connectivity with the ocean through the entrance. The increased levels in Lake Reeve are attributable to the higher mean sea level exceeding a threshold topography level. This results in flood flow spilling over this natural threshold, allowing inundation to penetrate further along Lake Reeve to the west, filling low areas that were previously not hydraulically connected to the main lakes.

The significance of local changes in inundation extents are discussed in detail for the representative locations in Section 4 of this report.

Figure 3-2 shows the variation in relative impact of sea level rise on flood levels throughout the Gippsland Lakes. This is displayed by way of a ratio of the change in peak flood level versus the change in mean sea level. This ratio has been termed the 'Sea Level Rise Response Factor' (SLR Response Factor). The SLR Response Factor provides a simple indication of the relative sensitivity of flood levels to sea level rise at various locations within the Gippsland Lakes. The variations in the SLR Response Factor relate in part to the variation in the characteristics of the elevation versus storage relationship within the Gippsland Lakes Basin.

The results show that Lakes Entrance has a SLR Response Factor of 0.9. Flood levels are therefore predicted to increase at almost the same rate as sea level rise at the eastern end of the system. However, in Lake Wellington to the west, the SLR Response Factor is only 0.3 and flood levels are predicted to only increase by approximately one third the rate of sea level rise.

Figure 3-4 shows how one indicator of inundation hazard (length of road reserve flooded) changes with increasing SLR at different locations within the Lakes. This suggests that impacts increase more rapidly at Lakes Entrance than at either Paynesville or Loch Sport, for a given increment of SLR. This is because there are larger areas of Lakes Entrance that are only slightly elevated above the current flood level compared to the other towns. Hence a small increase in flood level can engage a larger additional area of inundation in Lakes Entrance than in Paynesville or Loch Sport.

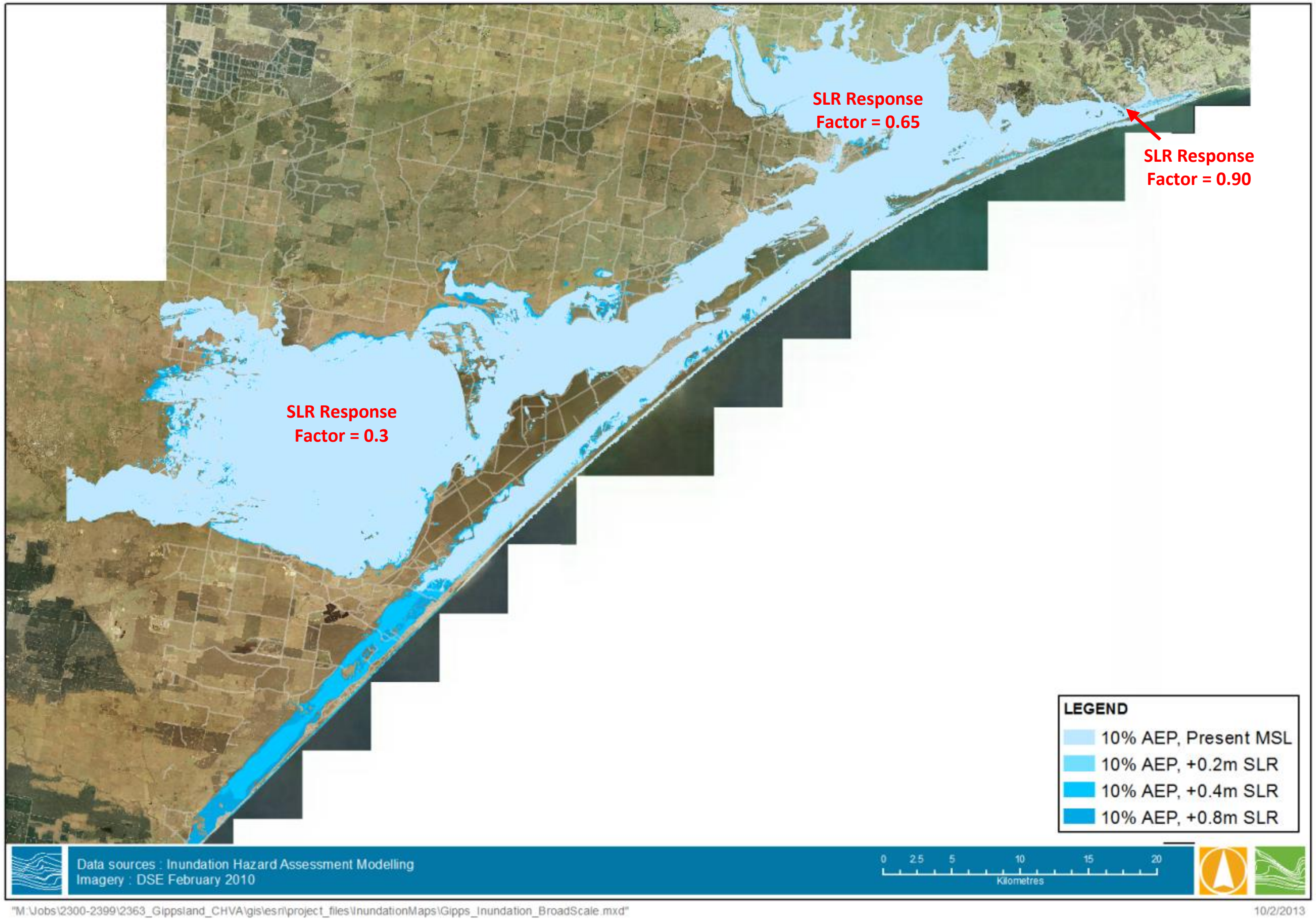


Figure 3-2 10% AEP Inundation Hazard Assessment - Broad Scale Overview, Flood Extent

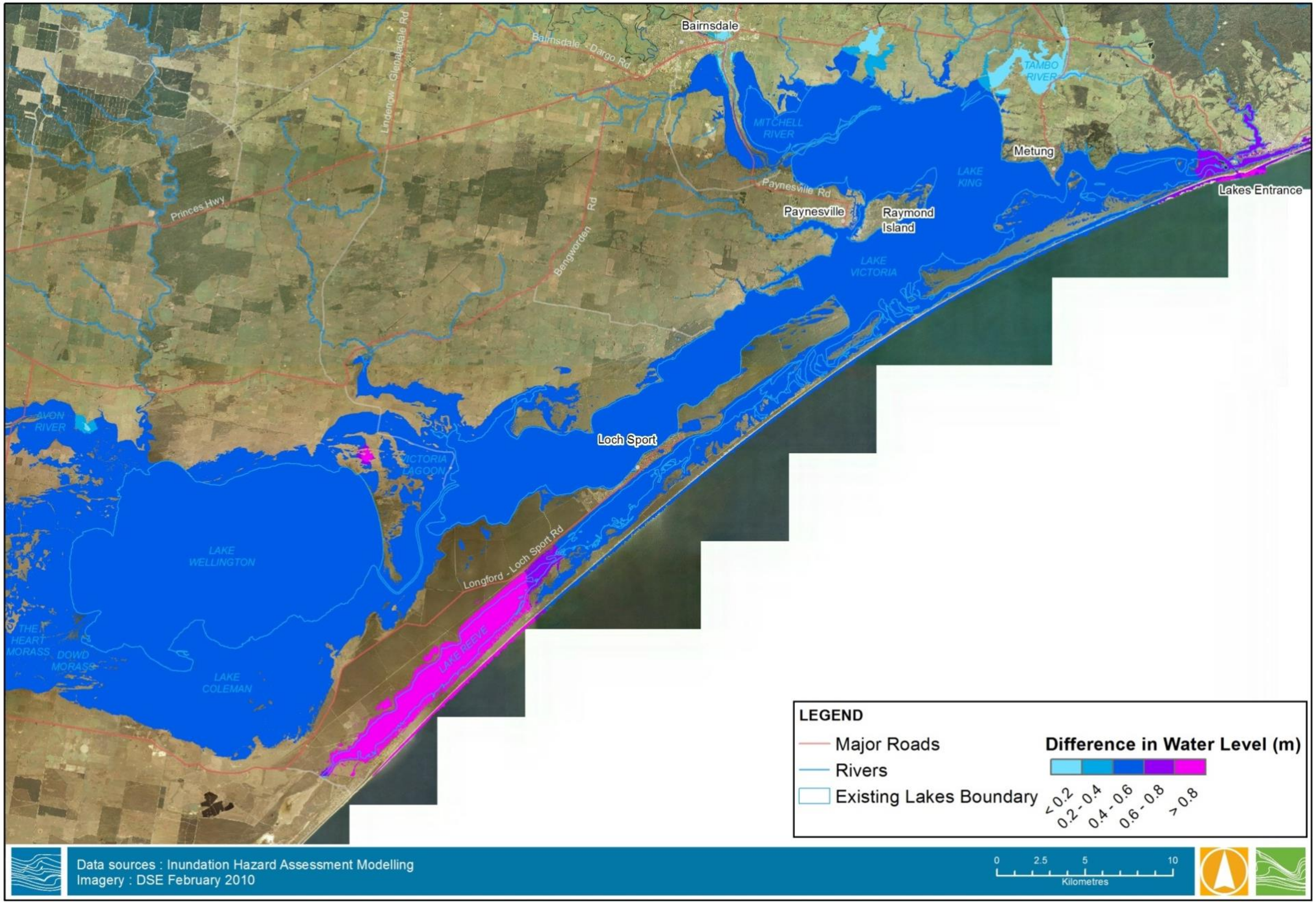


Figure 3-3 **Increase in Peak Flood Level for the 10% AEP Flood (Existing vs 0.8 m SLR scenario)**

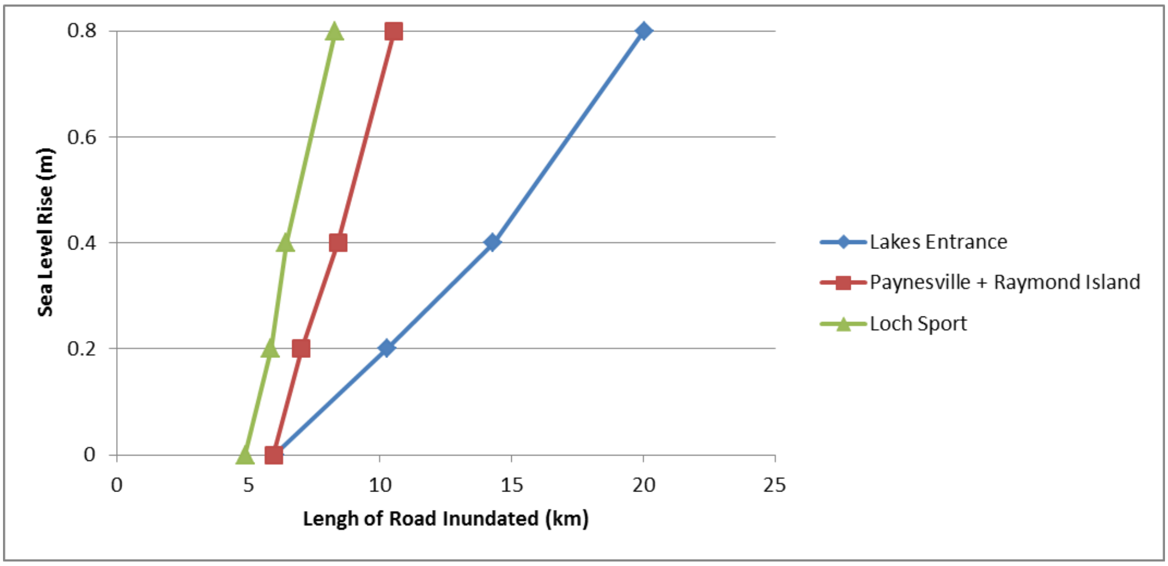


Figure 3-4 **Variation of Impact with SLR across Gippsland Lakes (10 % AEP flood)**

3.2 Lake Shoreline Erosion Hazards

3.2.1 Introduction

Shoreline erosion within the Gippsland Lakes is a function of a wide range of forcing factors, including geomorphology and physical form, environmental aspects such as waves and currents, and biological character which includes vegetation communities and land use. The magnitude of each of the forcing factors in relation to each other varies around the lakes shoreline. In order to combine quantitative assessments of forcing factors such as wave and current conditions with qualitative assessments of forcing factors such as geology and vegetation characteristics a weighted score-based spatial framework was developed.

3.2.2 Method

Overview

Details of the background and method applied for the shoreline erosion susceptibility assessment are provided in study Report 4 – Lake Shoreline Erosion Hazards. An outline of the method is provided below.

At the outset, seven principal forcing factors were identified as influencing shoreline erosion susceptibility and hazard, covering physical, environmental and biological factors. These are listed below and shown diagrammatically in Figure 3-5.

- **Physical**
    - *Fabric* – represents the geology and underlying material of the shore
    - *Form* – the physical shape of the shoreline
    - *Structures* – artificial shoreline structures such as breakwaters, sea walls or groynes
- **Environmental**
    - *Wave conditions* – the height and frequency of waves meeting the shoreline
    - *Currents* – represents the speed of flow beside the shoreline
- **Biological**
    - *Coastal vegetation* – describes the type of shoreline vegetation types
    - *Land use* – represents different risks due to residential or farm use for example

A range of datasets covering these factors were collated and converted to a raster (grid cell) system, and numeric scores assigned to each input factor. The scores for each input factor were then combined into three thematic groups of: Physical, Environmental and Biological Factors. The three thematic groups were then given individual weightings to produce an integrated shoreline erosion susceptibility mapping data layer. Figure 3-6 gives an example of one input data set, showing the results of wave modelling, used as a rating of wave exposure. This highlights that southern and eastern shores are generally more exposed to wave impacts than northern and western shores.

Validation

The results of the spatial framework used to assess Lake Shoreline Erosion Susceptibility and Hazard were compared to a detailed shoreline erosion assessment conducted by Sjerp et al. (2002), and were shown to produce good agreement over the majority of the shoreline. Differences at some of the locations were attributed to:

- Accuracy of the coordinates and location description of some observations listed in Sjerp et al. (2002),
- The difference in methods (broad-scale spatial model vs site specific observations) meaning that some results were not able to be reproduced where local factors or time varying impacts (such as erosion related to a particular storm) were significant.

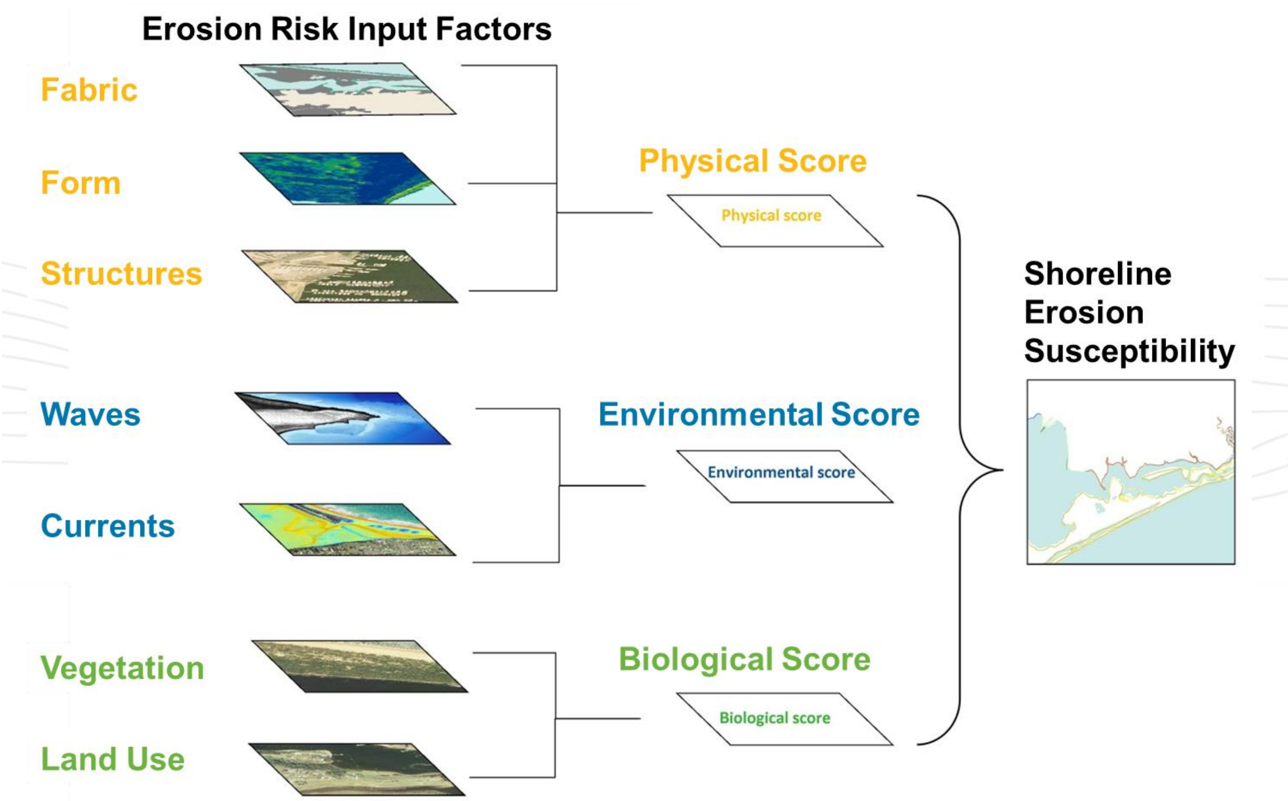


Figure 3-5 Conceptual Process for Lake Shoreline Erosion Susceptibility Assessment

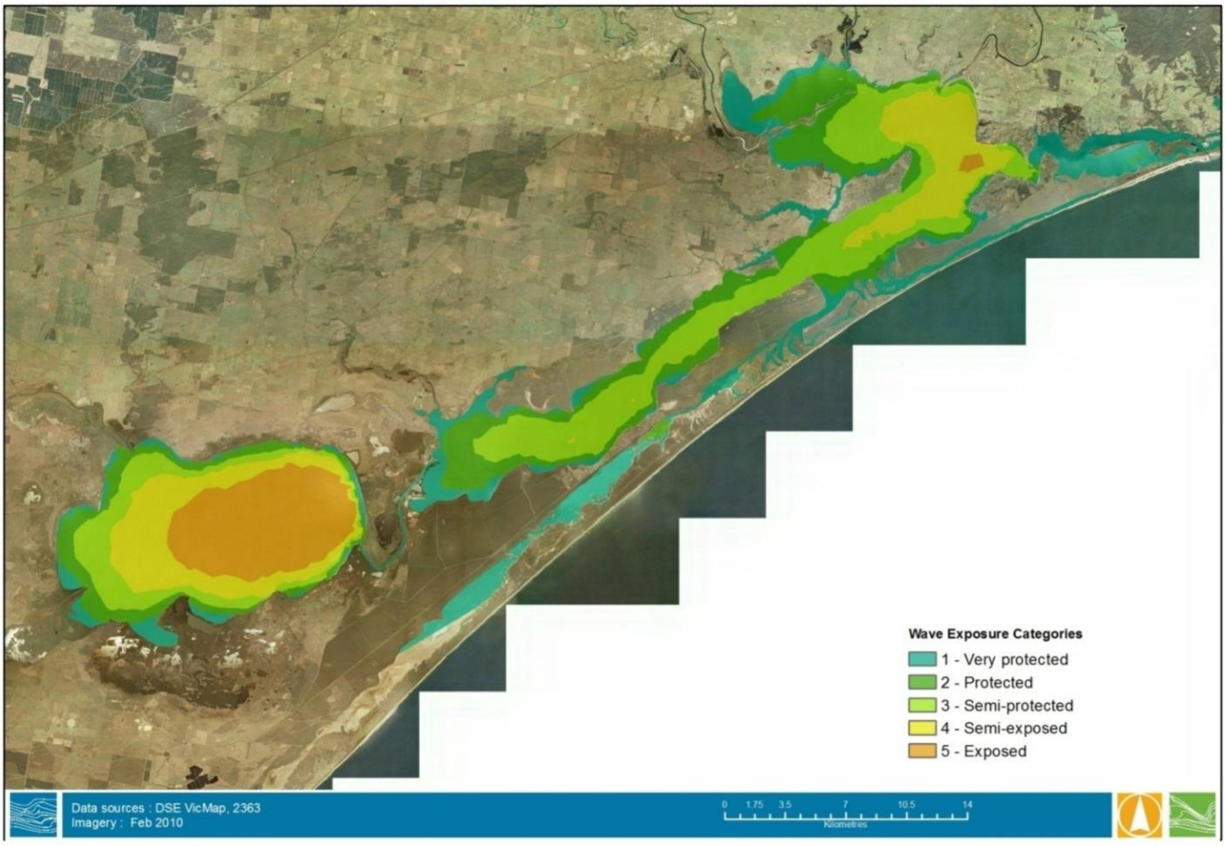


Figure 3-6 Example Input - Wave Exposure under Existing Mean Sea Level

Climate Change Assessment

Under predicted climate change conditions there are likely to be changes to the influencing components of erosion hazard as a result of higher mean water levels in the Gippsland Lakes. To assess how an increase in mean water level may alter the erosion susceptibility of the shoreline over the course of this century, the scores associated with each component were reassessed for the +0.8 m sea level rise scenario. The following key parameters were modified along with guiding assumptions.

Physical - The key physical change was the removal of all artificial structures. This is considered a conservative assumption as structures are likely to be maintained and adapted as sea level rises.

The other physical change was the application of shoreline fabric and form values at the 0.9 m AHD contour. This captured any change in shoreline sediments or slope associated with +0.8 m sea level rise. This is particularly relevant to areas of low relief such as the shoreline of Lake Wellington.

***Environmental* -** The values of wave and current exposure along the shoreline were modified based on re-modelling the wave and current simulations with +0.8 m SLR.

***Biological* -** The biological score is based on land-use and vegetation at the present shoreline. For the sea level rise scenario the biological score was modified to represent the current land use and vegetation at the 0.9 m AHD contour. Whilst some degree of retreat or adaptation of vegetation communities to sea level rise is likely, these changes were not able to be considered in this study.

3.2.3 Results Overview – Existing Conditions

The erosion susceptibility rating of the Gippsland Lakes shoreline at the study-area scale is shown in Figure 3-7 for existing conditions. Clearly much of the current shoreline, rated as "high" susceptibility, has the potential to erode under present mean sea level conditions. There are far fewer areas identified with "very high" susceptibility to erosion which is considered within the rating system to indicate active erosion.

These results should be considered in the context of the current vegetation communities and that the past, present or future impacts of salinity on these communities have not been incorporated.

A summary of the likely erosion rates associated with the erosion susceptibility ratings is provided in Table 3-1. These are relatively low rates of erosion and reflect the typically low energy shoreline environment of the Gippsland Lakes system.

Table 3-1 Summary of Erosion Ratings and Likely Erosion Rates

Erosion Susceptibility Rating	Erosion Rates (based on Sjerp et al, 2002) (m/year)
Low to Moderate	<0.1
High	0.1 – 0.2
Very High	0.2 – 0.5

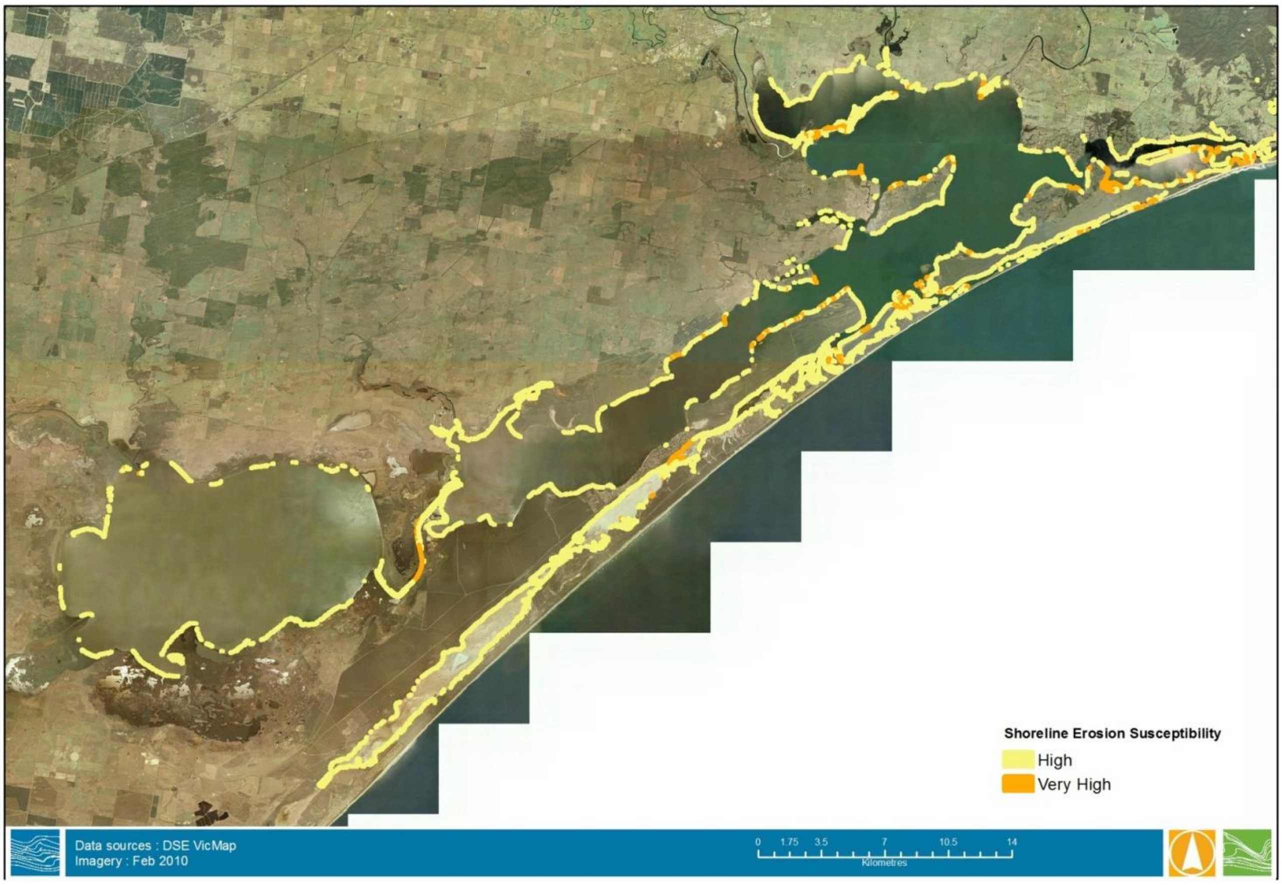


Figure 3-7 Shoreline Erosion Susceptibility for the Gippsland Lakes, Existing Conditions

3.2.4 Results Overview – Future Sea Level Rise Conditions

Overall, the sea level rise assessment indicates a general increase level of shoreline erosion susceptibility throughout the Gippsland Lakes as indicated by the magenta lines shown in Figure 3-8. Those areas most affected by sea level rise related increases in erosion susceptibility are the shoreline of Lake Wellington, the Lake Reeve lagoon system behind the outer coastal barrier south of Sperm Whale Head, the shoreline of Lake King from Paynesville to the Nicolson River, and the areas around Reeve Channel and Lakes Entrance.

The 0.9 m contour is also shown on Figure 3-8, indicating the possible future shoreline location under 0.8 m SLR. This does not take account of any sediment or vegetation response to increased mean water levels but does provide an indication of the areas where significant shoreline change are likely in the future. This includes the southern and western shores of Lake Wellington, the western end of Lake Victoria, the southern shore of Lake King and many of the low islands near the entrance to Bunga Arm and along Reeve Channel between Metung and Lakes Entrance.

Based on the erosion susceptibility ratings, the erosion rates shown in Table 3-1 and the potential inundation extent, a zone of likely shoreline hazard for the Gippsland Lakes shoreline has been developed for the 0.8 m SLR scenario. The hazard zone map for the lakes is shown in Figure 3-9. This shows the erosion hazard zone, representing the area of likely shoreline erosion and realignment, corresponds more closely (at the study area scale) to the 0.9 m inundation line than the susceptibility ratings. This is because of the relatively low erosion rates compared to the potential shoreline migration due to SLR.

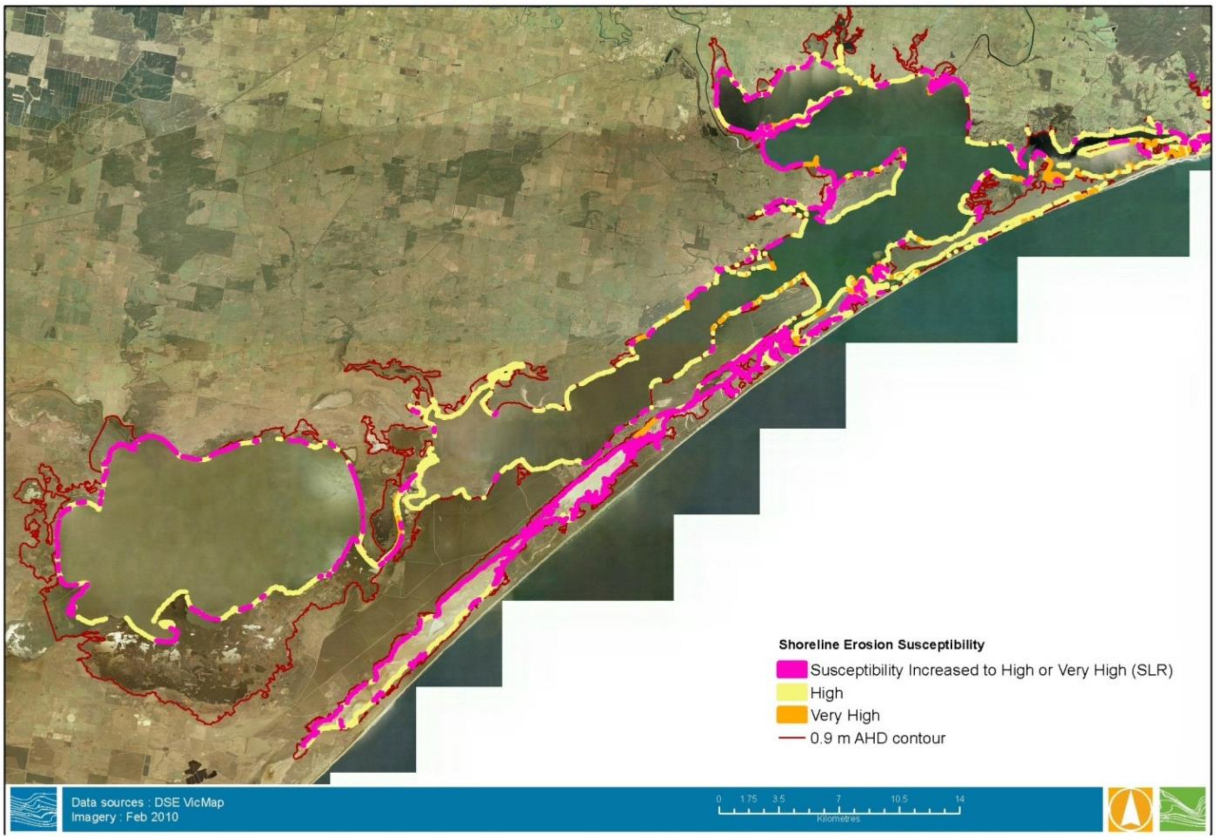


Figure 3-8 Shoreline Erosion Susceptibility for the Gippsland Lakes, 0.8 m SLR Conditions

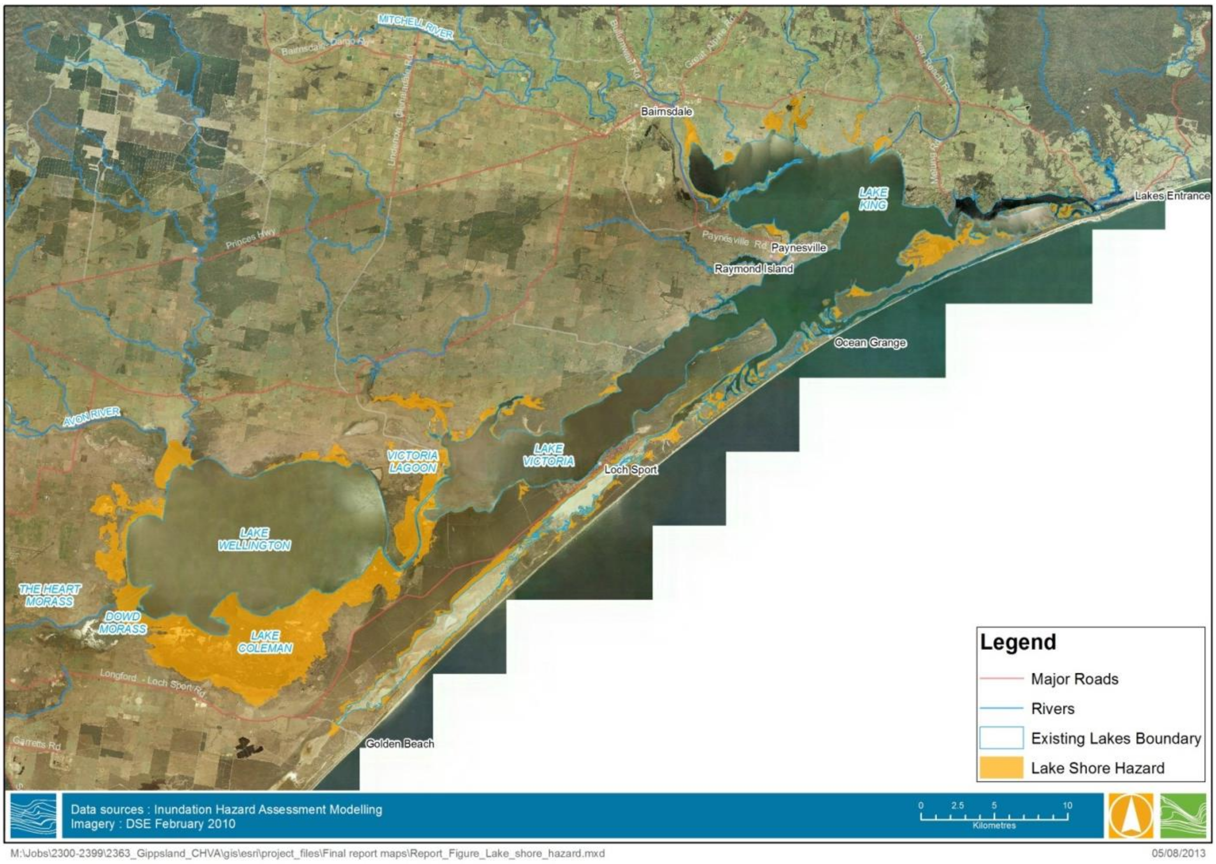


Figure 3-9 Gippsland Lakes Shoreline Hazard Extent, 0.8 m SLR Conditions

3.3 Outer Barrier Coastal Hazards

3.3.1 Introduction

The 'Outer Barrier' is a long, narrow sand dune developed by wave and wind-blown sand transport and vegetation growth. It extends continuously (except for the artificial entrance at Lakes Entrance) along the entire length of the study area from Seaspray to Red Bluff. The seaward shore of the Outer Barrier is known as the Ninety Mile Beach.

As its name suggests, the Outer Barrier provides a barrier to the extent of the coastal/marine processes and influences that can impact the Gippsland Lakes and associated landforms on its landward side. For this reason, risks posed to the Outer Barrier by sea level rise and climate change are critical for understanding the potential extent of erosion and inundation hazards more generally in the study area.

3.3.2 Method

The sandy sediments comprising the Outer Barrier are subjected to the weather and ocean processes of Bass Strait and the South Tasman Sea. The Outer Barrier is therefore a highly dynamic landform, influenced by multiple processes operating over a very wide range of spatial and temporal scales.

The assessment of coastal hazard therefore requires consideration of a range of physical processes as well as the rates and scales over which these can influence the Outer Barrier. To integrate these processes over the necessary range of temporal and spatial scales for which they are significant, the assessment method has included the following major components:

- Analysis of the geomorphology of the Outer Barrier, including its evolution over the last 10,000 years;
- Classification of the Outer Barrier into geomorphic units;
- Analysis of the meteorological and oceanographic processes that can impact the Outer Barrier;
- Review and analysis of the contemporary coastal processes and historical coastal hazard impacts along the Outer Barrier;
- Analysis of the mechanisms and potential extent of the responses of coastal barriers to increased sea levels;
- Analysis of the potential extent of coastal hazard impacts due to sea level rise; and
- Evaluation of the uncertainty in the coastal hazard analysis and testing of sensitivity;

Figure 3-10 conceptually displays the methodology used to assess the changes to coastal hazards on the Outer Barrier.

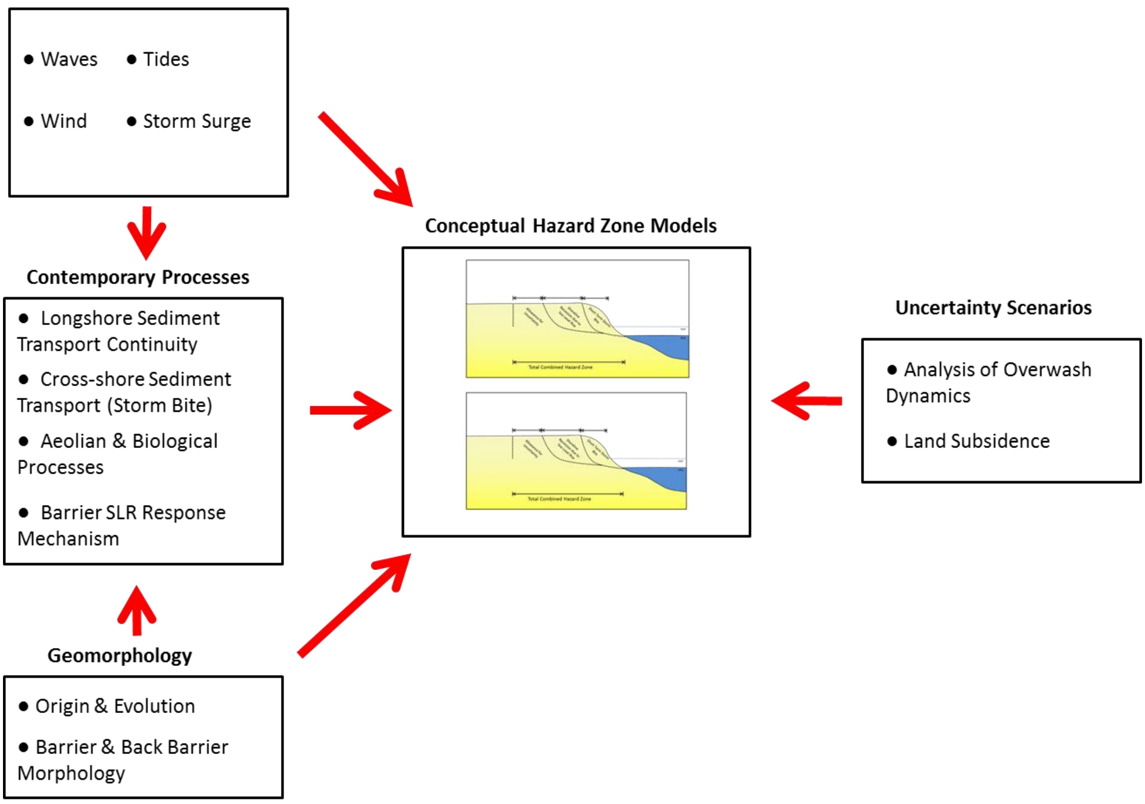


Figure 3-10 Conceptual Process by which the Coastal Outer Barrier along Ninety Mile Beach were Assessed

The detailed analysis of the processes and inputs listed above is documented within Report 2: Outer Barrier Coastal Erosion Hazards. A summary of the main components of the analysis and results are provided in the following sections.

Figure 3-11 and Figure 3-12 illustrate schematically how the above coastal hazard processes and components have been combined to define total coastal hazard extents for the barrier erosion and barrier translation response mechanisms respectively. These schematics are relevant for the interpretation of results in the representative locations section of the report.

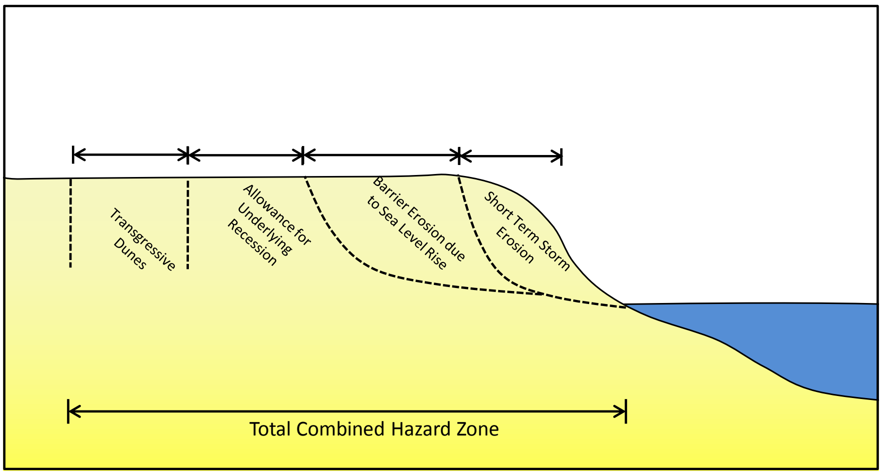


Figure 3-11 **Schematic of Coastal Hazard Components used to Determine Overall Coastal Hazard Extent for Locations/Sea Level Rise Scenarios Responding According to the Barrier Erosion Mechanism**

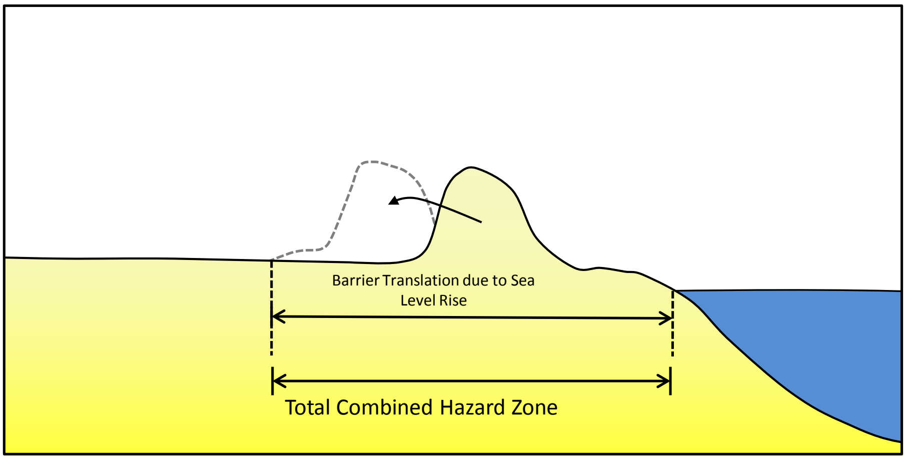


Figure 3-12 **Schematic of Coastal Hazard Components used to Determine Overall Coastal Hazard Extent for Locations/Sea Level Rise Scenarios Responding According to the Barrier Translation Mechanism**

3.3.3 Geomorphology

The Gippsland Lakes

The former embayment that contains the Gippsland Lakes is cut into a level to gently sloping surface with a basement of limestone covered by sand, clay and gravel.

During times of higher sea-levels, wave action submerged and eroded the edge of this plain, forming an active cliffed coastline (now referred to as the marginal bluff and evident at places such as Eagle Point and Nungurner). The sea extended into the major river valleys forming estuaries. At lower sea levels, the marine cliff was abandoned and streams extended beyond the former shoreline cutting deeper valleys and partly backfilling these with river-borne sediment. This sequence of submergence and emergence occurred on multiple occasions over the past 4 million years in response to global glacial and interglacial conditions. This sequence of geological events resulted in the present form of the Gippsland Lakes and Ninety Mile Beach. The key geomorphological features of the region are shown in Figure 3-13.

The Gippsland Lakes Barriers

The coast of Gippsland between Corner Inlet and Red Bluff, east of Lakes Entrance, is fringed by sand barriers of varied width, complexity and history. Terminology and interpretation of barrier history varies in the literature, however it is generally agreed that there are three groups of mostly parallel sand ridges. These have been initiated and broadly configured by wave action at different periods of sea level over the last 2 Million years.

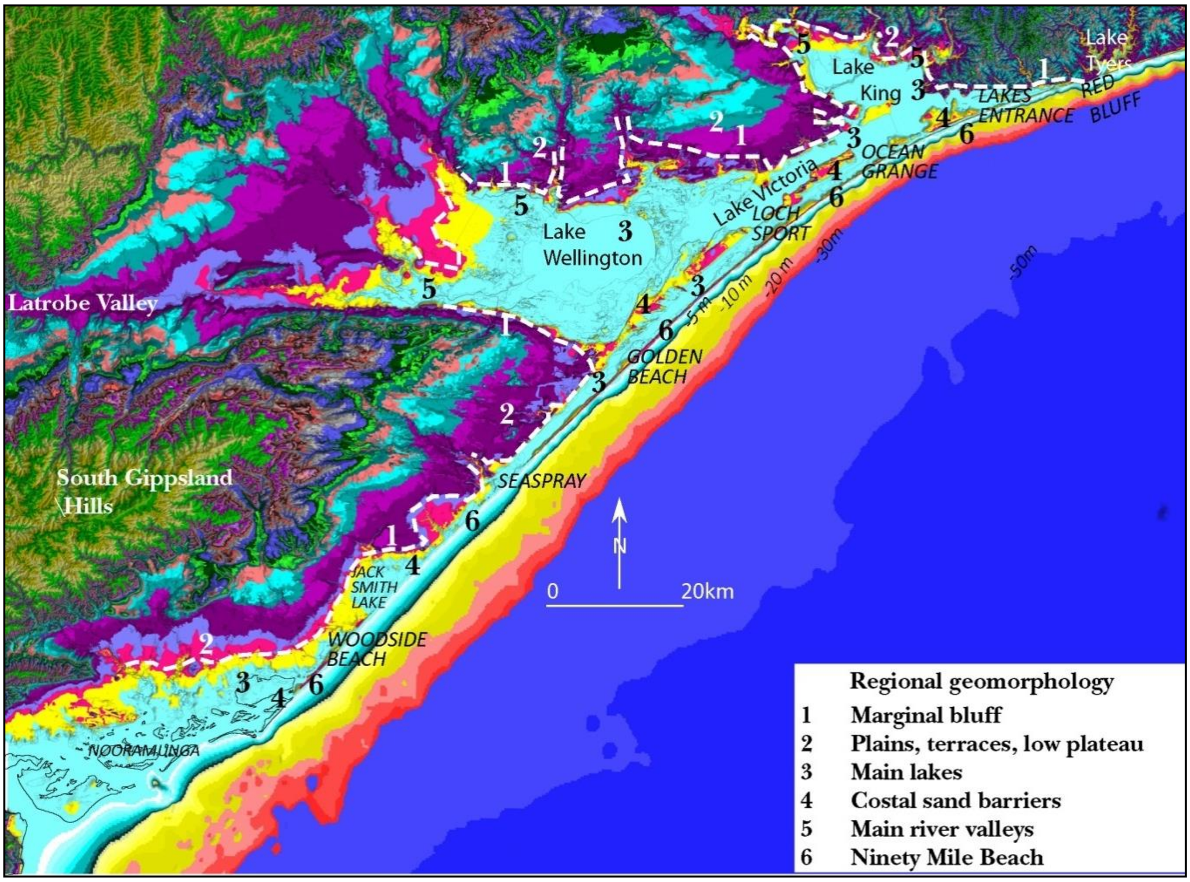


Figure 3-13 Regional Geomorphology

The three primary stages of barrier formation in the Gippsland Lakes (Bird (1965) and subsequent papers) are illustrated in Figure 3-14 and described below:

> ***Prior Barrier*** This is a remnant and discontinuous feature on the inner margin of the lakes and lies at the foot of the marginal bluff or is separated from it by a narrow waterway. It extends from the northern edge of Lake Wellington and Lake Victoria with the most prominent remnants being Banksia Peninsula and Raymond Island.
>
> ***Inner Barrier*** This is an extensive and complex group of landforms extending as a continuous broad, peninsula from near Golden Beach to Sperm Whale Head. The inner barrier system forms the southern margin of Lake Wellington and Lake Victoria.
>
> ***Outer Barrier*** The outer barrier extends continuously from the sand islands of eastern Corner Inlet to Red Bluff east of Lakes Entrance. It is the youngest of the coastal barriers and the morphology and present dynamics is highly variable. The assessment of coastal barrier hazards in this study focuses on this landform.

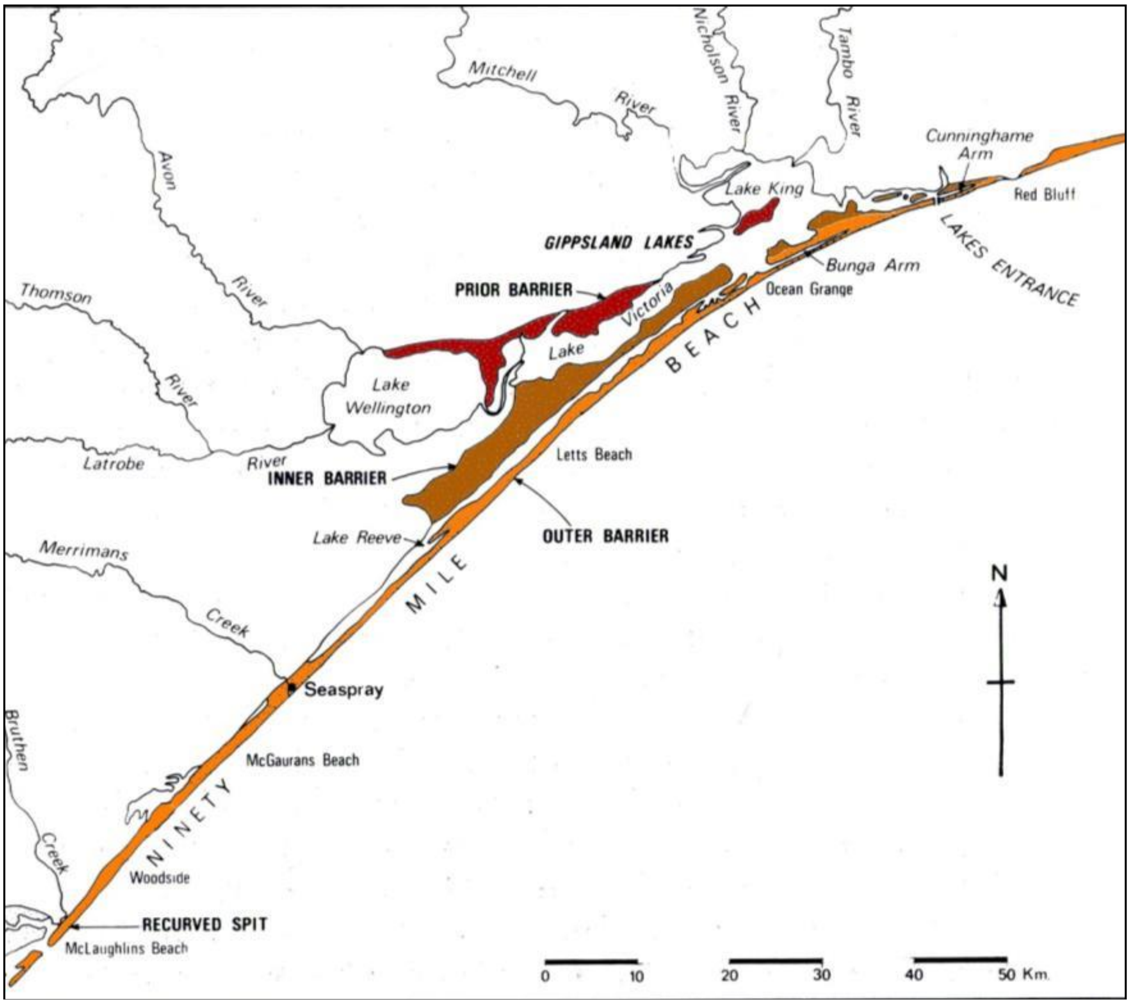


Figure 3-14 Simplified Outline of the Barrier Systems of the Gippsland Lakes, after Bird (1993).

Based on width, volume/number of ridges and the back-barrier morphology, eleven geomorphic units between Corner Inlet and Red Bluff were identified, as shown in Figure 3-17 and summarised in Table 3-2. Defining these discrete geomorphic units allowed specific characteristics of each section of coastline to be evaluated.

The volume and height of the outer barrier at different locations is considered to be a primary indicator of coastal erosion susceptibility. The data in Figure 3-17 and Table 3-2 demonstrate the variability in physical scale of the outer barrier dune system along its length. This aspect is discussed further in Section 3.3.5.

Table 3-2 Summary of Geomorphological Units of the Outer Barrier (Units 1 & 2 are not included below as they are outside of the project study area)

Unit	Barrier Morphology	Back Barrier Morphology	Max. Dune Crest Height Range (m AHD)	Barrier Volume Range (m^3/m)
Unit 3: Woodside Beach to Glomar Beach	Single narrow barrier ridge	Backbarrier terrace, lagoons and palaeo-tidal channels	2.5 – 10	250 – 1,000
Unit 4: Glomar Beach to Paradise Beach	Multiple parallel ridges. Typically 2-4 ridges, but 13 closely spaced ridges identified at Golden Beach	Lake Reeve	6.5 - 20	800 – 4,500
Unit 5: Paradise Beach to Loch Sport	Multiple parallel ridges.	Lake Reeve	10 - 18	2,100 – 4,700
Unit 6: Loch Sport to Ocean Grange	Multiple barrier ridges declining to a single ridge towards Ocean Grange	Lake Reeve and sub-parallel curving ridges, island and subaqueous banks extending into Lake Victoria	11 - 18	2,500 - 900
Unit 7: Bunga Arm	Single irregular barrier ridge	Bunga Arm lagoon	4 - 15	110 – 1,000
Unit 8: Barrier Landing	Single irregular barrier ridge	The infilled former eastern end of Lake Bunga – a sandy backbarrier with flat low sand ridges	5 - 10	250 - 850
Unit 9: Lakes Entrance	Multiple irregular barrier ridges	Cunninghame Arm	6 - 12	370 - 1,600
Unit 10: Eastern Beach to Lake Bunga	Narrow, low barrier dunes as single or in places multiple ridges	Infilled remnant of the former Reeve's River	5 - 12	200 – 1,700
Unit 11: Lake Bunga to Red Bluff	Series of Irregular ridges and hummocks	Marginal Bluff	5 – 15+	

3.3.4 Coastal Dynamics

A range of physical processes have been identified that contribute to the extent and frequency of coastal hazard impacts due to sea level rise along the Outer Barrier.

These processes are:

- Short-term storm-related erosion;
- Longshore sediment transport;
- Aeolian-biological (wind-vegetation) sediment transport; and
- Shoreline profile recession or translation due to sea level rise.

Each of these processes and the analysis undertaken to inform the study are described in detail in the accompanying technical report, Report 3: Outer Barrier Coastal Erosion Hazards. This summary report focuses on the last of the above processes, shoreline profile recession or translation, as this is considered to be the primary determinant of coastal hazard along the Outer Barrier.

The type, variability, extent and timing of coastal hazard impacts that could be expected within the various geomorphic units of the Outer Barrier are integrally related to the mechanism of barrier response that is experienced for a given increment of sea level rise. The geomorphic literature and detailed analysis of sediment processes suggest there are two primary mechanisms or modes of barrier response that characterise the likely coastal hazards under future sea level rise. These are *barrier erosion* or *barrier translation*. Figure 3-15 and Figure 3-16 show conceptual models of the two key potential barrier response mechanisms expected along the Outer Barrier as described below:

- **Barrier Erosion –** The barrier is eroded from the seaward face and sediment is lost offshore until the profile is translated shoreward and upward
- **Barrier Translation –** The entire barrier migrates landward without significant loss of sediment. This is accomplished through erosion of the shoreface and deposition of this sediment behind the barrier by the process of washovers and through aeolian (wind) transport.

The key difference between the two mechanisms, from a hazard impact point of view, is that the barrier translation response is generally expected to result in much greater landward incursion of coastal hazard impact than the barrier erosion response.

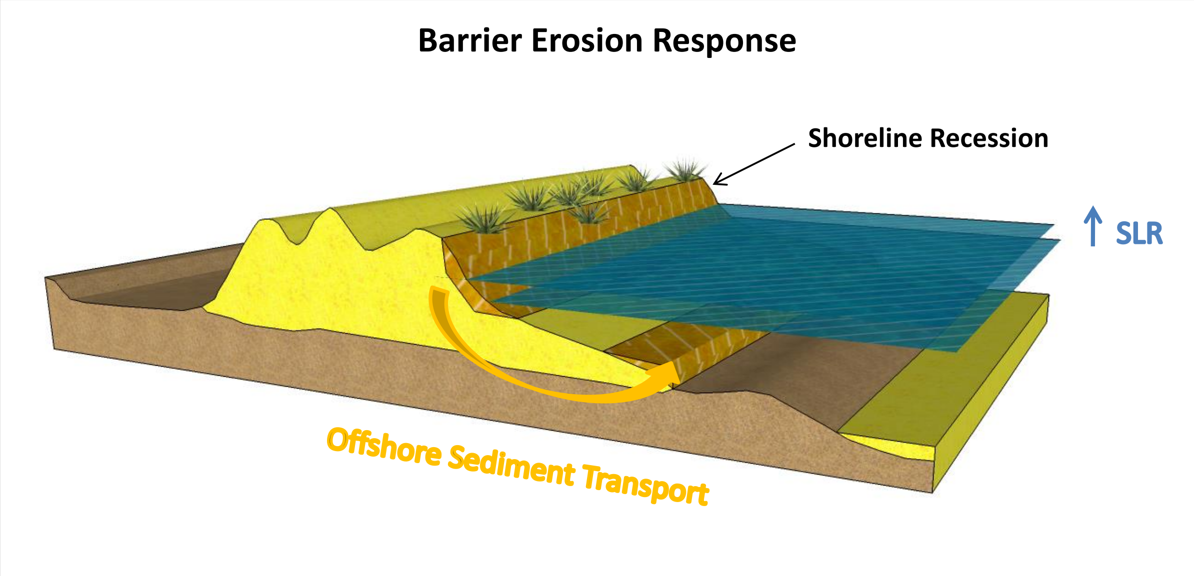


Figure 3-15 Coastal Barrier Conceptual "Barrier Erosion" Response to Sea Level Rise

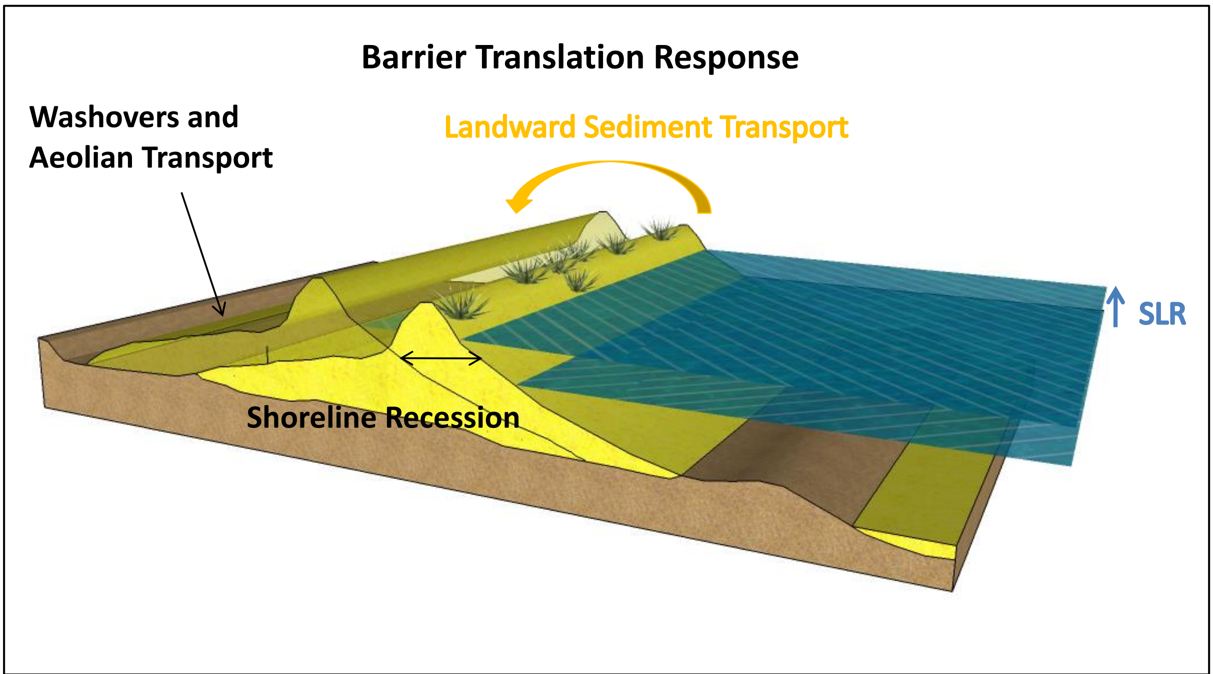


Figure 3-16 Coastal Barrier Conceptual "Barrier Translation" Response to Sea Level Rise

3.3.5 Results Overview

The coastal hazard impacts along the Outer Barrier are significantly influenced by the likelihood of the barrier response mechanism switching from an erosional response to a translation response (roll-over), beyond a given increment of sea level rise. Translation of the barrier by overwash processes results in a relatively rapid, non-linear change in the extent of the coastal hazard impacts to back barrier areas along the coast.

A major factor impacting the susceptibility of different units of the Outer Barrier is the existing volume and width of the dune formation. The outer barrier was divided into 11 geomorphic units for the purposes of the study, as shown in Figure 3-17. Figure 3-18 shows the key physical characteristics of the Outer Barrier over the 100 km length of the study area. This highlights:

- The significant variation in the volume of sand within the barrier along its length. This represents the amount of sand that would need to be transported (by waves and/or wind) to completely erode the barrier at any location. The volume/per unit length of barrier varies from a minimum of around 200 m^3/m at Seaspray to over 4,000 m^3/m near Paradise Beach
- The large change in barrier dune height over the study length. This is an indication of the amount of erosion (by wave and/or wind) required to reduce the barrier crest to a point where overwash may occur. The profile in Figure 3-18 shows the barrier height varies from around 5 m near Seaspray to over 20 m near Golden Beach.

Four locations along the Outer Barrier (Lakes Entrance, Bunga Arm/Blowholes, Paradise Beach and Seaspray), representing the major variations in the geomorphic units of the Outer Barrier in terms of the volume, width and height of the barrier have been analysed in detail using equilibrium profile modelling techniques. An equilibrium profile is the stable cross-section profile of a section of beach that balances the locally available sand and beach geometry with prevailing wave forces and sea levels.

Equilibrium profile modelling has assisted in identifying the likely mechanisms of barrier response at each representative location. That is, barrier erosion or barrier translation and the potential sea level threshold at which the barrier erosion response may evolve to one of translation.

The results of the equilibrium profile modelling, in association with geomorphic susceptibility and evidence of prehistoric and contemporary washover processes, identified that three of the four representative profile locations are likely to be susceptible to overwash for sea level rise of 0.4 m and greater.

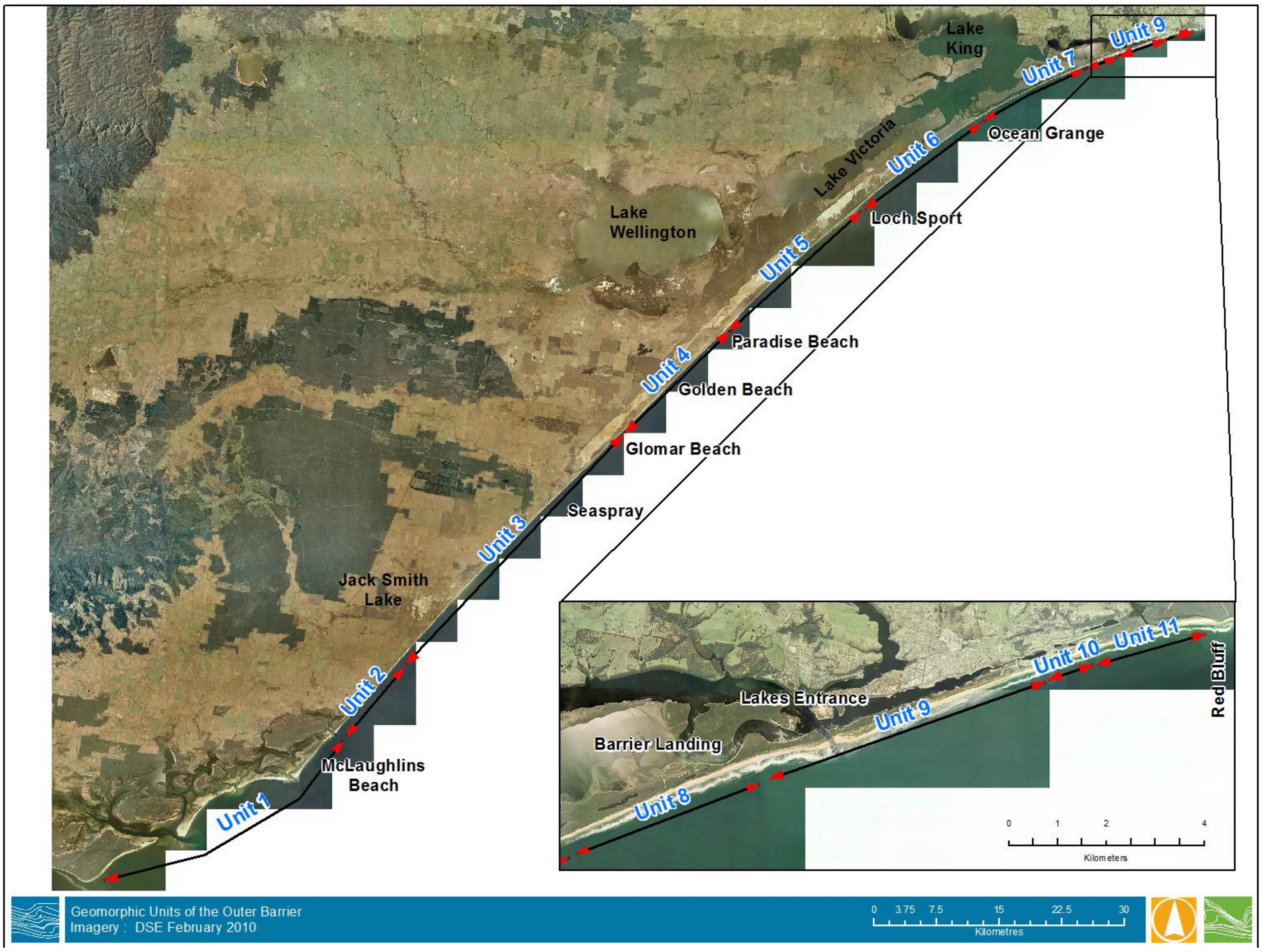


Figure 3-17 Geomorphic Units of the Outer Barrier

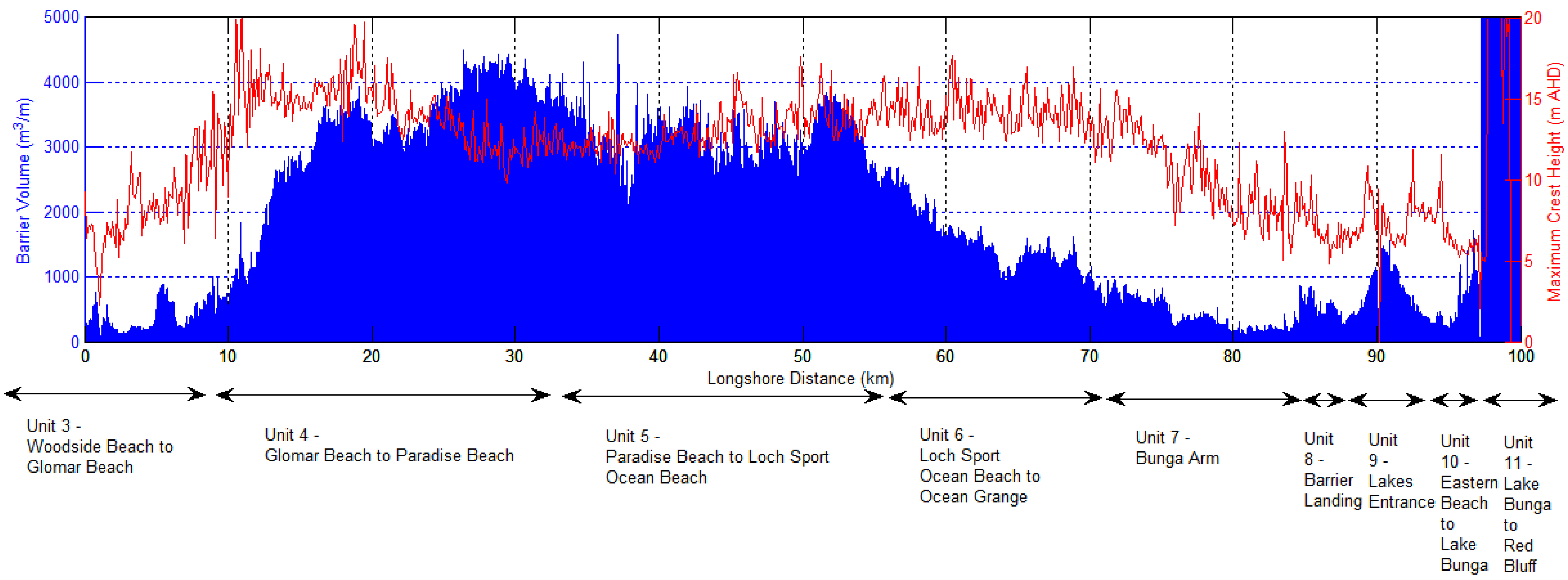


Figure 3-18 Barrier Volume and Maximum Dune Crest Height for Geomorphic Units of the Outer Barrier

Figure 3-19 displays a qualitative indication of the variation in susceptibility of the Outer Barrier to coastal hazard impacts. Higher susceptibility indicates greater likelihood and extent of barrier translation and associated overwash processes occurring due to sea level rise scenarios up to 0.8 m

Figure 3-20 displays an overview of the calculated coastal hazard zones for each sea level rise/timeframe scenario. These zones have been calculated based on the combined coastal hazards described in Report 3: Outer Barrier Coastal Erosion Hazards.

Considering Figure 3-19 and Figure 3-20 together shows that in areas where there is high susceptibility, such as Ocean Grange, there is also a larger defined hazard zone. Similarly the lower susceptibility rating at Paradise Beach corresponds to a narrower hazard zone as expected. These results are discussed further in the representative locations reporting sections.

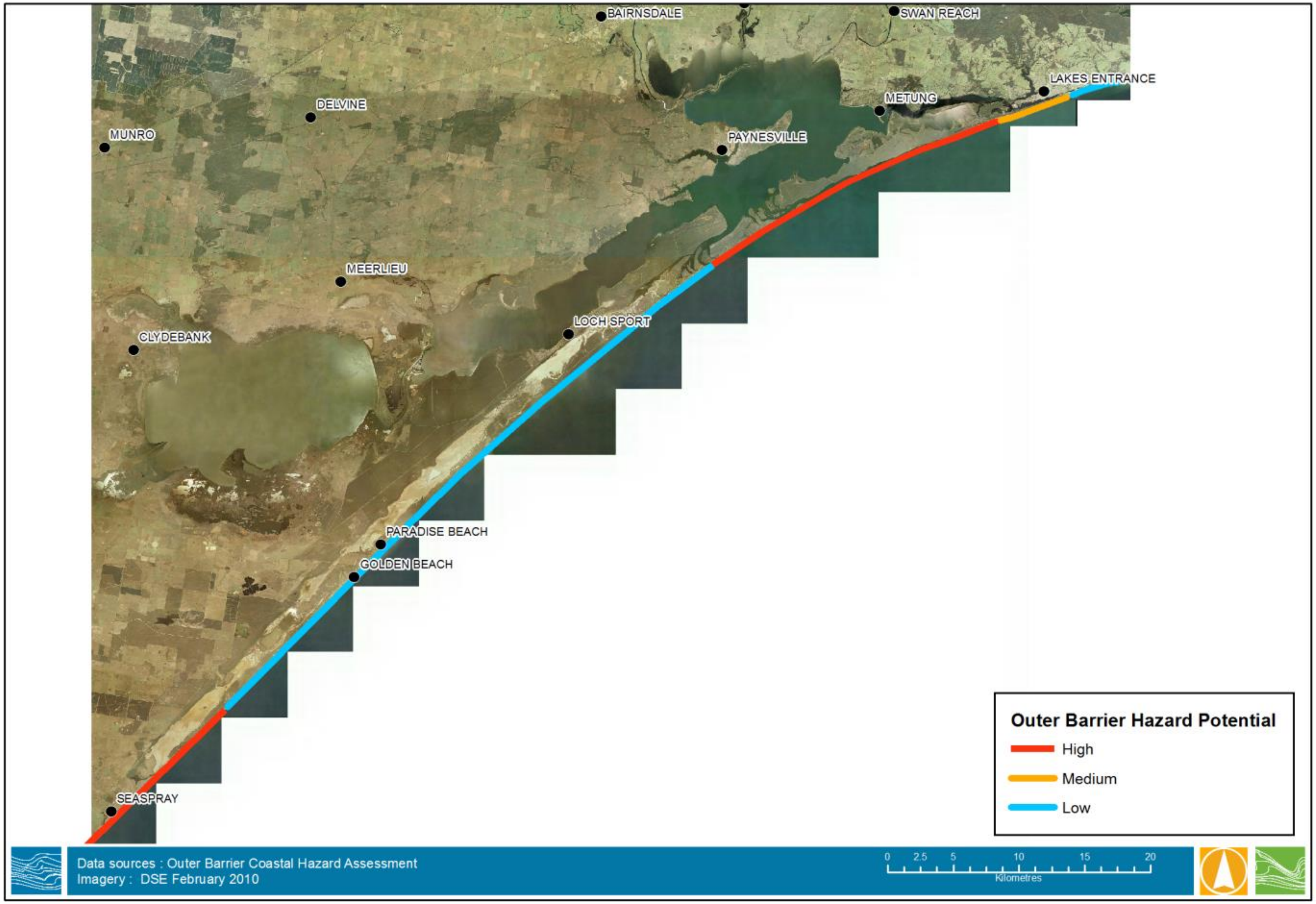


Figure 3-19 Outer Barrier Coastal Hazard Impact Susceptibility

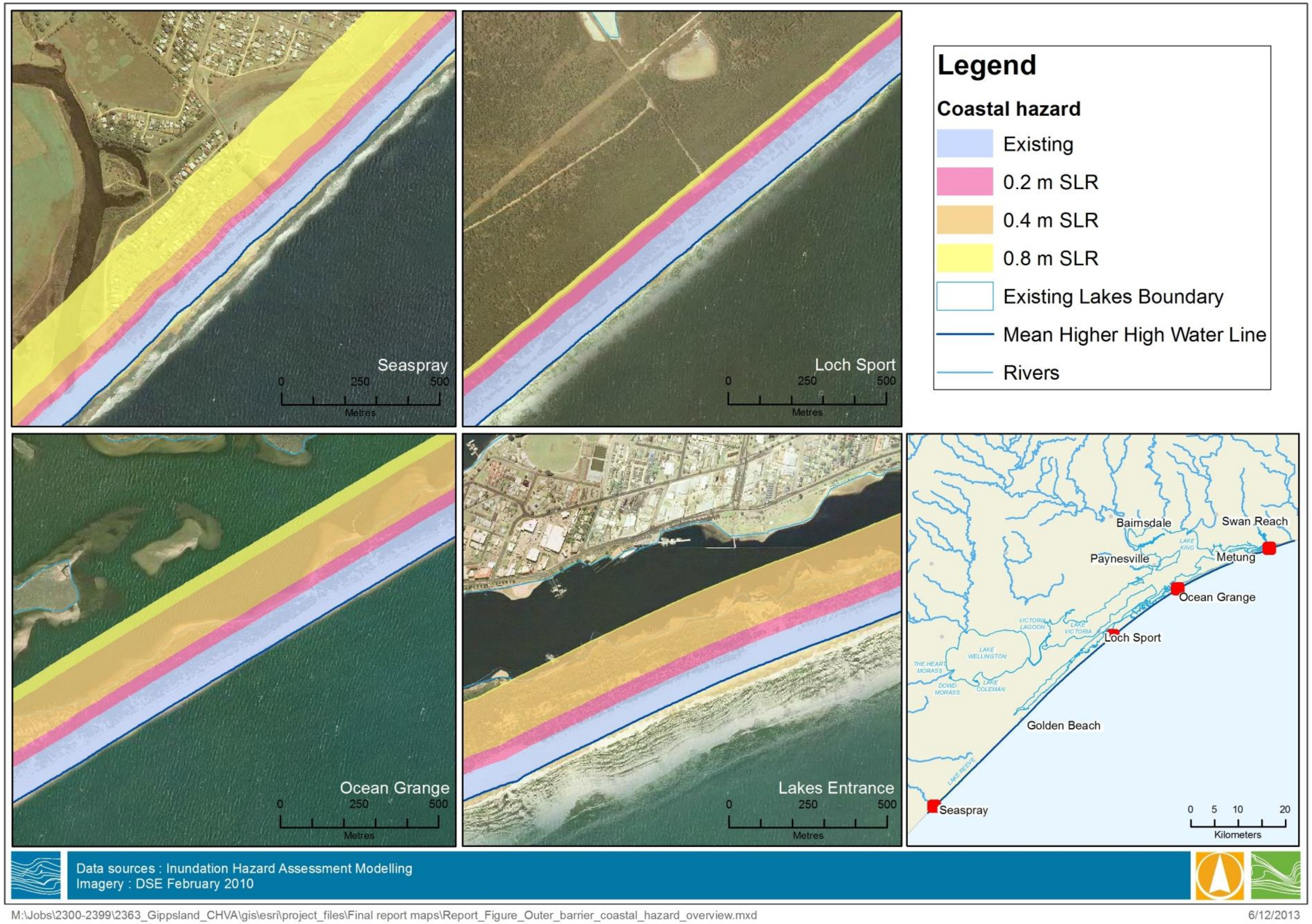


Figure 3-20 Combined Coastal Hazard Zones for the Outer Barrier

4. REPRESENTATIVE LOCATIONS

Five representative locations within the study area, as shown in Figure 1-2 and described in Section 1.8, were selected for additional detailed analysis and assessment of potential hazard impacts. The selection of the representative locations was based on their physical setting, existing susceptibility to coastal hazard impacts and through consultation with the Project Steering Group.

The representative locations selected for additional detailed analysis are:

- Lakes Entrance
- Paynesville
- Loch Sport
- Bunga Arm
- Seaspray

The following sub-sections summarise the detailed site-specific hazard impacts identified and assessed for each representative location.

4.1 Lakes Entrance

Lakes Entrance was identified as being potentially susceptible to three primary hazards:

- Coastal hazards associated with the susceptibility of the outer barrier to over wash processes;
- Inundation hazards due to a combination of river inflows and coastal water levels; and
- Lake shoreline erosion hazard.

4.1.1 Coastal Outer Barrier Hazard

The geomorphology of Outer Barrier units (Figure 3-17) in the vicinity of Lakes Entrance show some variations in origin and contemporary processes, however the physical dimensions of the barrier are relatively similar such that the potential coastal hazard impacts are considered to be broadly comparable across these units.

The Eastern Beach geomorphic unit (Unit 10), to the east of the Lakes Entrance township, is particularly narrow and low. The foredune ridge is the youngest section of barrier within the study area having only developed following the cutting of the artificial entrance in the late 19th Century, which subsequently closed the natural Reeve's River entrance that migrated along this unit. The eastern extent of the Reeve's River channel has since largely been infilled by overwash and wind-blown sand.

The Barrier Landing unit, to the west of Lakes Entrance township, is also notable for the localised narrowing of the barrier associated with the southerly projection of a tidal channel near the entrance.

Analysis of historical aerial photography and modelled sediment transport rates suggest that the shoreline position in the Eastern Beach and Lake Bunga to Red Bluff units can vary significantly. The available evidence also suggests that changes in net longshore sand transport direction (varying between NE and SW) have historically caused significant shoreline recession in these units. Narrowing of the foredune ridge occurred to such an extent that allowed overwash in the Eastern Beach unit in 1979. An image of this event is shown in Figure 4-1 below, with the golf course to the left of the picture.

Figure 4-1 Overwash at Eastern Beach, Lakes Entrance in 1979 (source Gippsland Ports)

Based on the available information and analysis, significant uncertainty exists in estimating the extent and relative timing of the potential coastal hazard impacts in this unit. This uncertainty largely stems from sensitivity of the shoreline to variations in longshore sediment transport, and dredge spoil disposal activities associated with maintenance of the artificial entrance.

Figure 4-2 displays the assessment of the potential barrier response mechanisms and subsequent extent of coastal hazard impacts under each sea level rise scenario. The coastal hazard impacts displayed in Figure 4-2 are discussed below:

- For sea level rise up to 0.2 m and timeframes of 20-30 years, the barrier response is anticipated to remain essentially stable or slightly erosional, depending on the influence of longshore sediment budget processes.
- For sea level rise of 0.4 to 0.8 m and timeframes of 50-60 years, the combination of long-term sediment budget recession or sea level rise profile adjustment could potentially reduce the integrity of the barrier to the extent that isolated and infrequent overwash events may be initiated in these units.
- For sea level rise of approximately 0.8 m or greater and timeframes of 80-100 years, major barrier translation could be expected with multiple and frequent overwash events experienced along the length of the barrier in these units. Ephemeral tidal connections across the barrier at Barrier Landing to the ocean may be initiated, however, these are not expected to form self-sustaining tidal connections to the Gippsland Lakes.

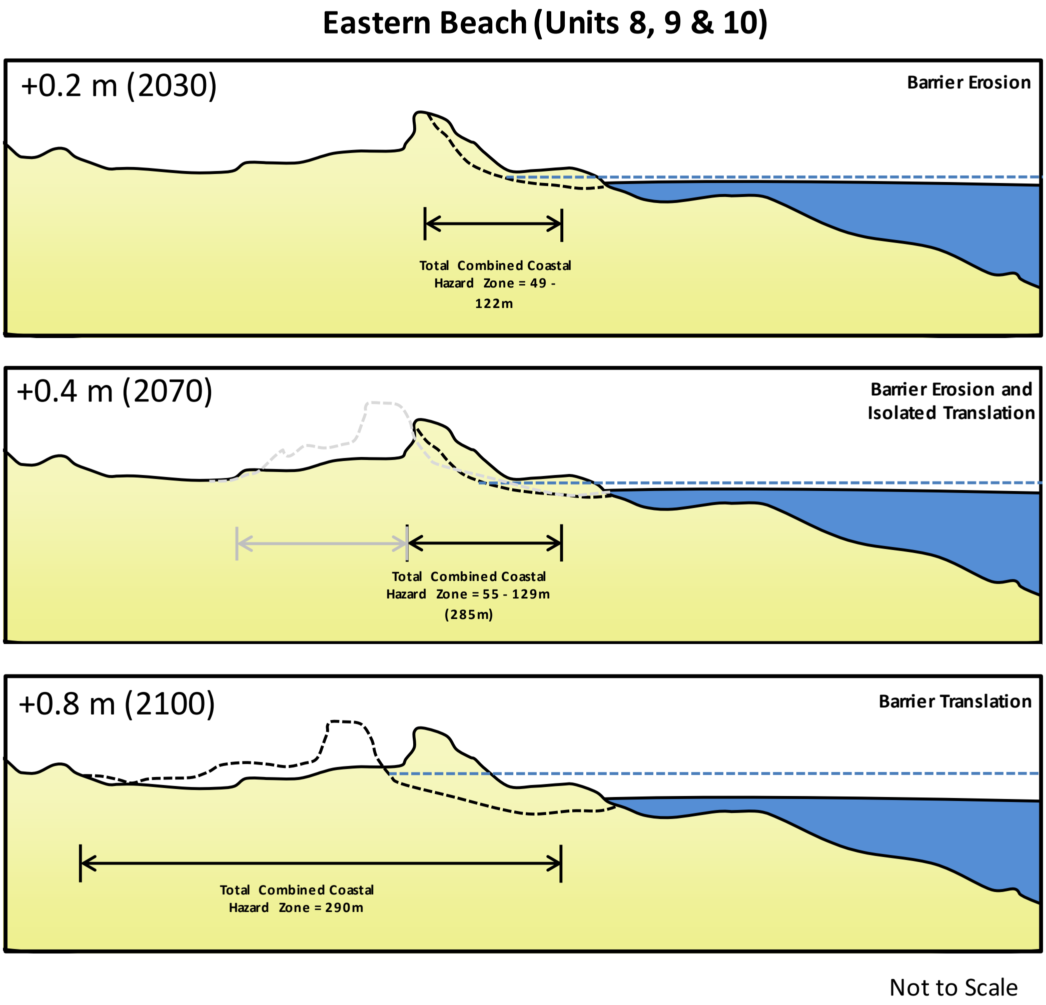


Figure 4-2 Coastal Outer Barrier Hazard Zone Distances for Lakes Entrance

4.1.2 Inundation Hazard

Table 4-1 below summarises the modelling results in terms of peak flood levels at Lakes Entrance for each event and sea level rise scenario. Table 4-1 also displays the relative SLR Response Factors.

A key finding of the flood modelling analysis for Lakes Entrance was that the SLR Response Factor is approximately 0.9. This means that the increase in peak flood levels at Lakes Entrance is predicted to be 0.9 times the magnitude of the sea level rise (10% less than SLR).

The SLR response factor is larger at Lakes Entrance than other locations within the Gippsland Lakes due to the proximity to the artificial entrance and confined geometry of the lakes in this area. Flood heights are therefore more significantly driven by tidal and coastal water levels compared to other locations, where flood storage has greater influence.

Table 4-1 Relative Change in Peak Flood Levels to Sea level Rise at Lakes Entrance

Sea Level Rise Scenario	10% AEP Flood		1% AEP Flood	
	Level Change (m)	SLR Response Factor	Level Change (m)	SLR Response Factor
0.0 m	0.0	-	0.0	-
+ 0.2 m	0.17	0.86	0.17	0.86
+ 0.4 m	0.37	0.92	n/a	n/a
+ 0.8 m	0.75	0.93	n/a	n/a

Figure 4-4 shows the inundation extents around Lakes Entrance for the 10% AEP flood case under existing, 0.2, 0.4 and 0.8 m sea level rise scenarios. Significant increases in inundation extents are predicted within Lakes Entrance for sea level rise scenarios greater than approximately 0.4 m under the representative 10% AEP flood case.

To assess the sensitivity of coastal hazard impacts identified for Lakes Entrance, hydrodynamic modelling of a washover of the Outer Barrier at Eastern Beach was undertaken for a 1% storm tide scenario incorporating 0.8 m of sea level rise. This simulation demonstrated that an isolated washover of the Outer Barrier at Eastern Beach would not significantly impact peak storm tide levels or inundation extents at Lakes Entrance. Figure 4-3 shows the predicted patterns of erosion and deposition associated with the washover event. The simulated sediment transport patterns are similar to that observed during the nearby 1979 washover (Figure 4-1).

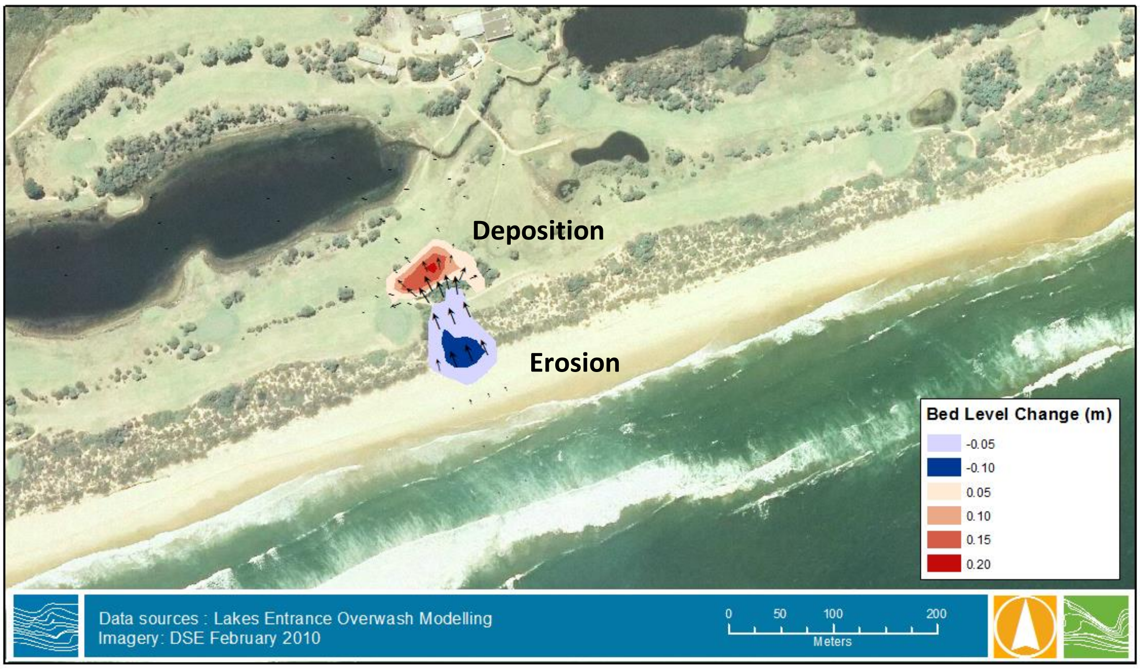


Figure 4-3 Predicted Extent of Washover Deposits at Eastern Beach, Lakes Entrance

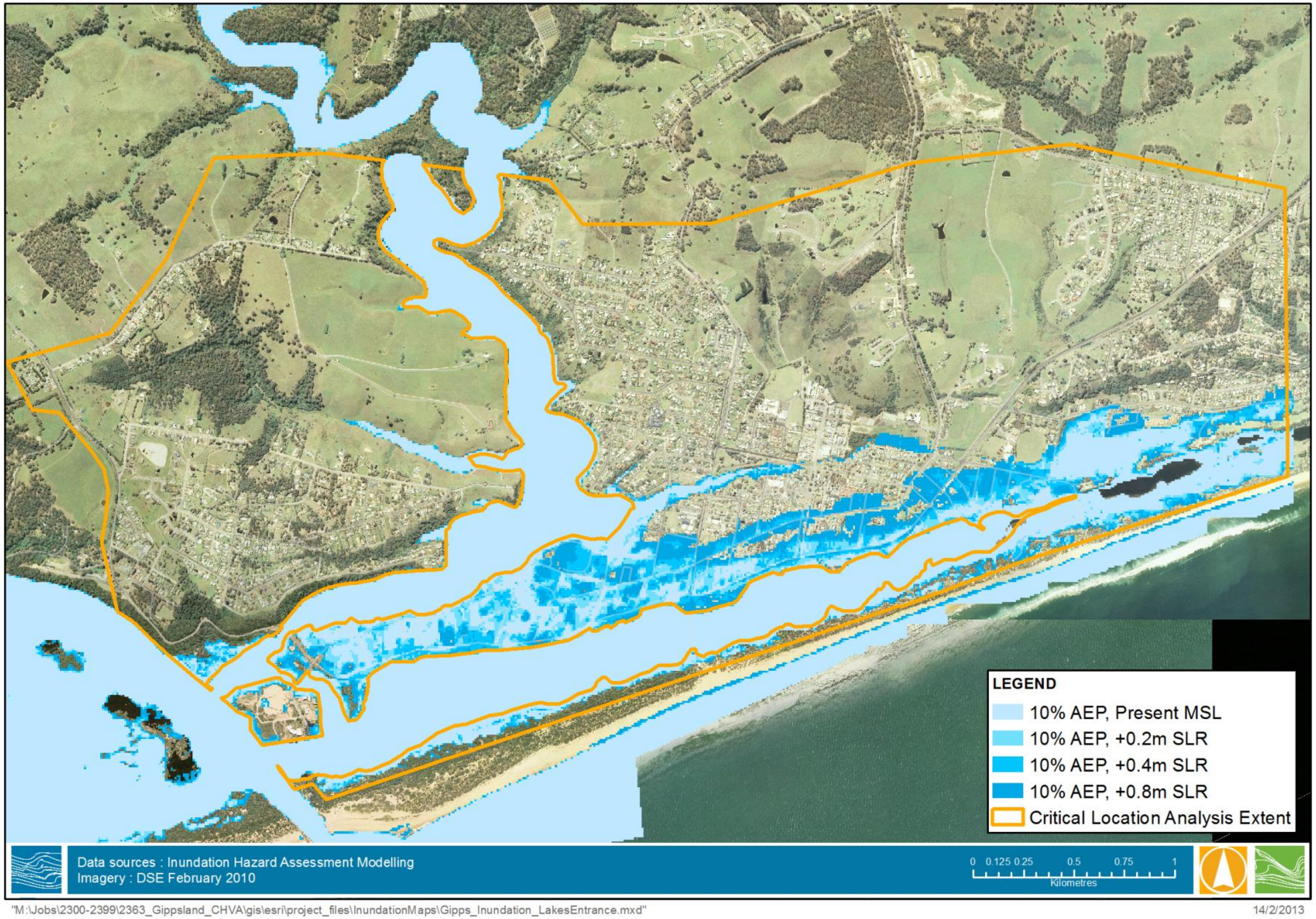


Figure 4-4 Inundation Extents for the 10% AEP Flood Event Under Existing, 0.2, 0.4 and 0.8 m Sea Level Rise Scenarios at Lakes Entrance

4.1.3 Shoreline Erosion Hazard

In general, shoreline erosion hazard is not considered a major coastal hazard in Lakes Entrance, compared to inundation and outer barrier erosion risk. Most of the shores in this area are sheltered from significant wave energy due to the limited open water area. However the shorelines along the entrance and Reeve Channel are subject to high, erosive velocities under ambient tidal conditions as well as floods. These shorelines presently require rock protection to combat erosion threat.

The shoreline erosion susceptibility and hence hazard around the township of Lakes Entrance is to a significant extent currently mitigated by the presence of artificial structures. Future maintenance and/or adaptation arrangements for the existing protection structures are unknown. It was therefore assumed that these structures would not exist under SLR conditions, providing a worst-case scenario. Should these structures not be maintained or be removed, then a large portion of the Lakes Entrance shoreline becomes susceptible to erosion as shown in Figure 4-5 below. It is anticipated that shoreline protection works are likely to be maintained and extended such that most of the area of significant susceptibility will be protected from further erosion.

The 0.9 m contour shown on Figure 4-5 is an indicator of the potential location of the future shoreline, based on existing topography data. This shows that in areas where steep beach slopes and/or revetments exist there will not be significant movement in shoreline location. However for areas where there is a lower slope near the present shoreline, set-backs of 20 to 50 m are expected, particularly around Bullock Island, the western end of the township and the lake side of the Outer Barrier.

Based on nominal erosion rates and the predicted inundation line for 0.8 m SLR, the zone of shoreline hazard is shown in Figure 4-6. This shows that the western end of Lakes Entrance is more likely to be exposed to shoreline erosion hazard as well as sections of North Arm. Shoreline erosion hazard zone depths of 20 to 40 m are common in these areas.

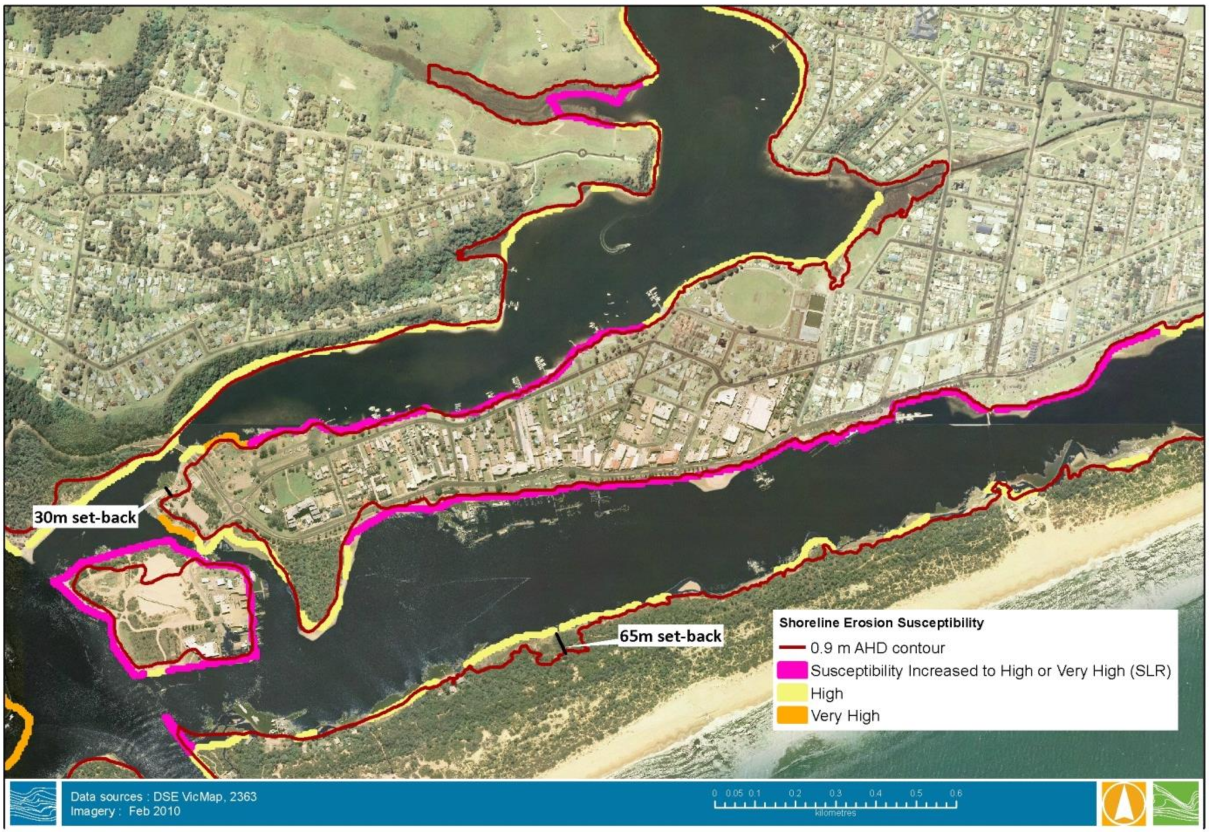
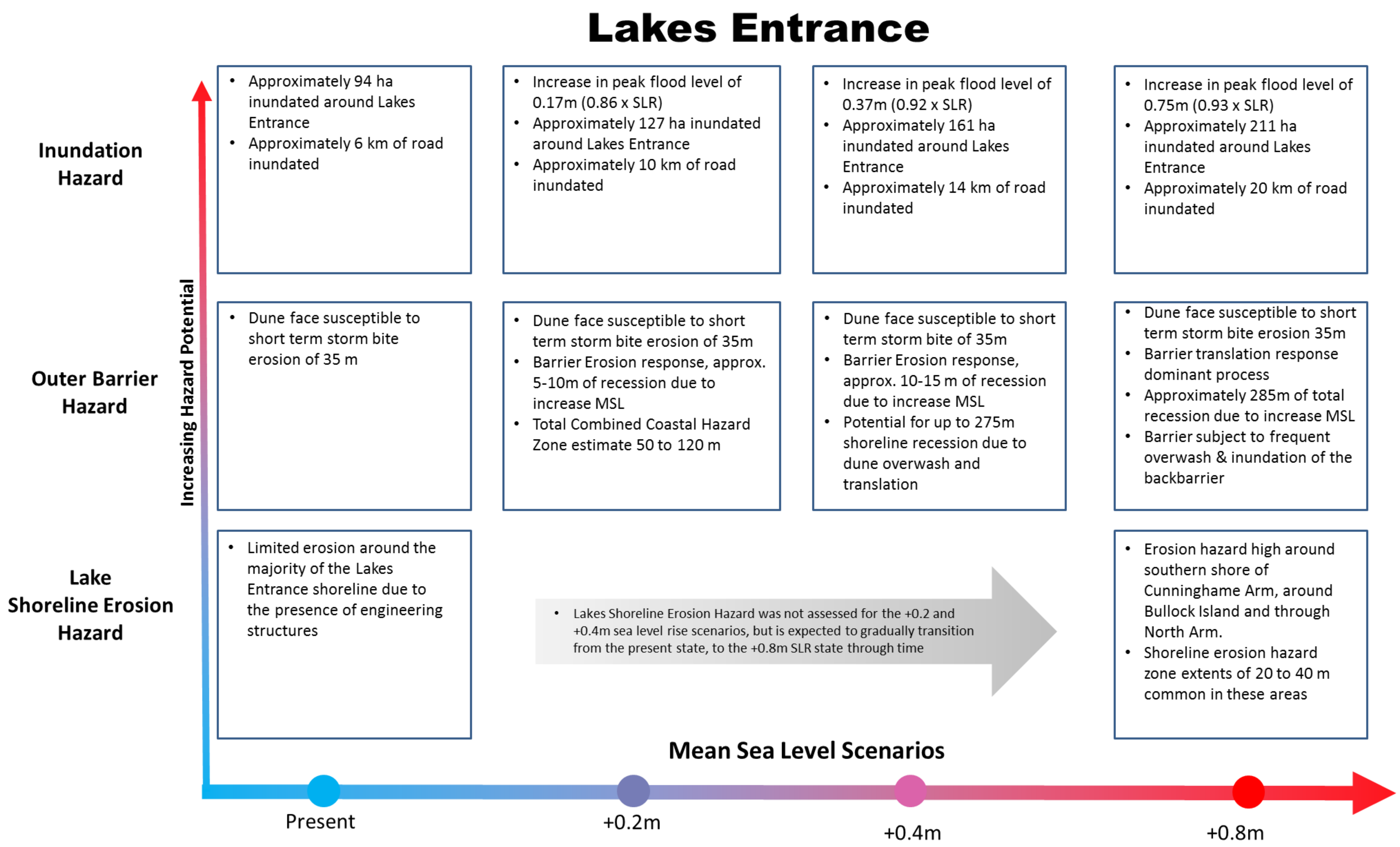


Figure 4-5 Shoreline Erosion Susceptibility at Lakes Entrance under 0.8 m SLR

Figure 4-6 Lakes Entrance Shoreline Hazard Extent under 0.8 m SLR

4.1.4 Summary of Coastal Hazards

A summary of the coastal hazards at Lakes Entrance is provided in Figure 4-7, which shows increasing SLR from left to right on the bottom axis and increasing potential hazard from bottom to top on the side axis. This highlights that inundation is considered to provide the most severe coastal hazard both under present and future SLR conditions.



Summary of the Key Hazards at Lakes Entrance

- Lakes Entrance is currently subjected to inundation during a 10% AEP flood event. Inundation extents have been shown to increase with increasing mean sea level, with peak water levels increase at approximately 0.9 times the amount of sea level rise.
- Recession of the outer barrier accelerates with increasing mean sea level. A critical tipping point is expected to occur between 0.4 and 0.8m SLR, when barrier overwash is likely to increase in frequency, leading to significantly larger hazard zones.

Description of Scenarios

- **Inundation Hazards:** The inundation simulation results are based on a 10% AEP flood event with the associated sea level rise
- **Outer Barrier Hazards:** Based on 0.2, 0.4 and 0.8m increase in mean sea level
- **Shoreline Erosion Susceptibility:** Based on a 0.8 m increase in mean sea level

Figure 4-7 Summary of Coastal Hazard Assessment at Lakes Entrance

4.2 Paynesville

Paynesville was identified as being potentially susceptible to two primary hazards:

- Inundation hazards due to a combination of river inflows and coastal water levels; and
- Lake shoreline erosion hazard.

Due to the distance from the ocean, Paynesville is not considered to be susceptible to outer barrier erosion hazards over the next century.

4.2.1 Inundation Hazard

Table 4-2 below summarises the modelling results in terms of peak flood levels at Paynesville for each scenario. Table 4-2 also displays the relative SLR Response Factors.

A key finding of the flood modelling analysis for Paynesville was that the SLR Response Factor is approximately 0.65. This means that the increase in peak flood levels at Paynesville is predicted to be around 0.65 times the magnitude of the sea level rise (35% less than SLR).

The SLR response factor at Paynesville closely approximates the overall relationship between storage and elevation within the Gippsland Lakes Basin as described in Report 2: Inundation Hazard.

Table 4-2 Relative Change in Peak Flood Levels to Sea level Rise at Paynesville

Sea Level Rise Scenario	10% AEP Flood		1% AEP Flood	
	Level Change (m)	SLR Response Factor	Level Change (m)	SLR Response Factor
0.0 m	0.00	-	0.0	-
+ 0.2 m	0.12	0.58	0.13	0.65
+ 0.4 m	0.26	0.65	n/a	n/a
+ 0.8 m	0.54	0.67	n/a	n/a

Figure 4-8 displays the inundation extents around Paynesville for the 10% AEP flood case under existing, 0.2, 0.4 and 0.8 m sea level rise scenarios. Minor to modest increases in inundation extents are predicted within Paynesville and Raymond Island for sea level rise scenarios greater than 0.4 m under the 10% AEP flood case. Areas along Burrabogie Island, the south-east part of Paynesville and the south-west part of Raymond Island area most effected.

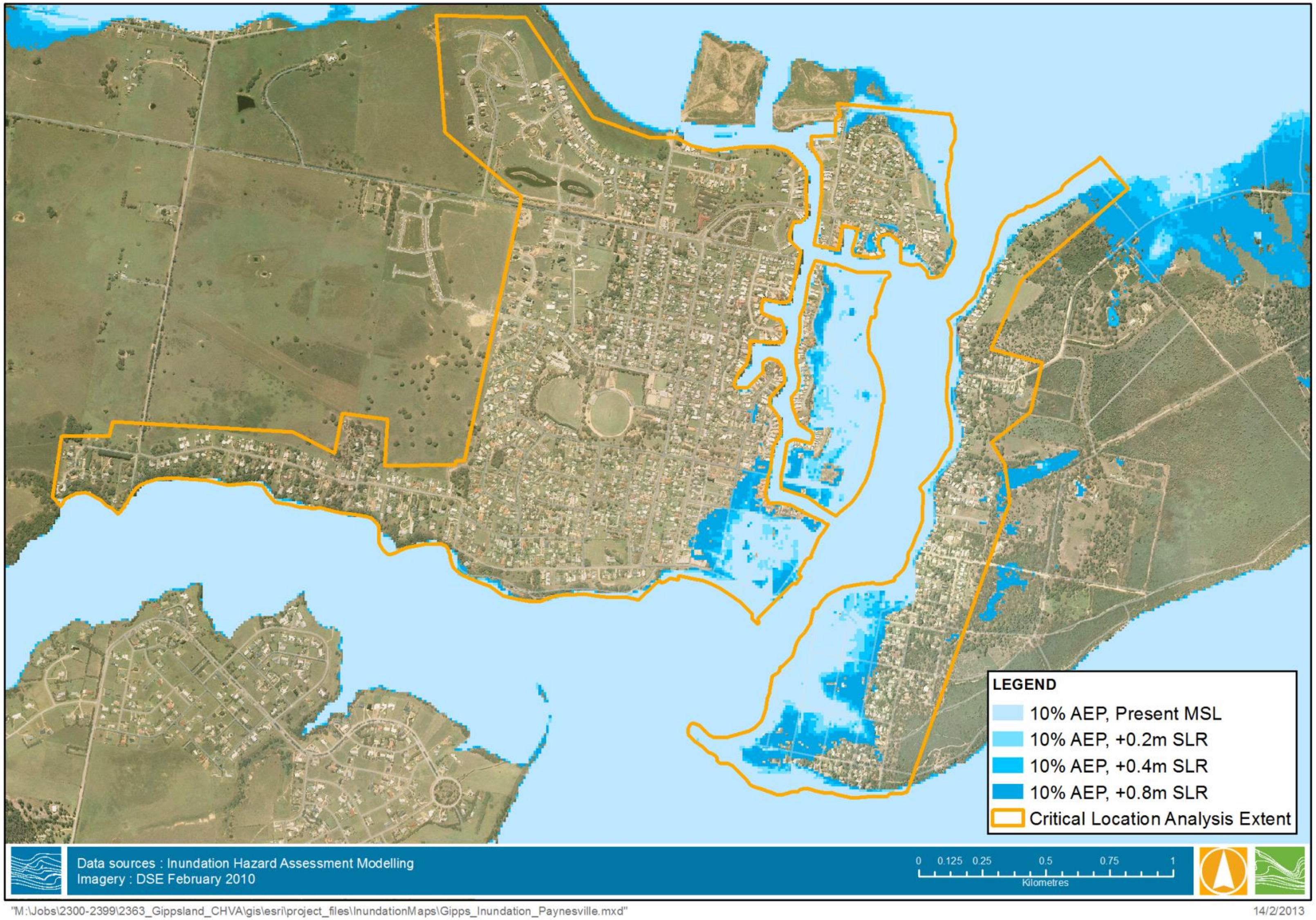


Figure 4-8 Inundation Extents for the 10% AEP Flood Event Under Existing, +0.2, 0.4 and 0.8m Sea Level Rise at Paynesville

4.2.2 Shoreline Erosion Hazard

The presence of artificial structures and rock beaching along the shoreline at Paynesville reduces susceptibility to erosion and hence erosion hazard. This is particularly evident along both sides of McMillan Strait and on the Paynesville Foreshore from the Gippsland Lakes Yacht Club to Sunset Beach. Should these structures not be maintained or removed then a large portion of the Paynesville shoreline becomes susceptible to erosion as shown in Figure 4-9 below. It is anticipated that shoreline protection works are likely to be maintained and extended such that most of the area of significant susceptibility will be protected from further erosion.

The assessment also shows that the southern and eastern shores of Raymond Island are more susceptible to erosion, with a number of other low-lying swampy sites on the northern shoreline showing increased susceptibility under sea level rise. As opposed to the southern shores which tend to be sandy and more adapted to wave impacts, the northern shores are composed of silty soils which are more susceptible to wave attack. A typical section of this shoreline is shown in Figure 4-10. These silty shorelines are typically bound with swamp vegetation, which has adapted over time from freshwater to more salt tolerant species; however most of these areas are low-lying and hence susceptible to permanent inundation from moderate increases in mean sea level.

The 0.9 m contour shown on Figure 4-9 gives an indicator of the potential location of the future shoreline, based on existing topography data. This shows that in areas where steep beach slopes and/or revetments exist there will not be significant movement in shoreline location. However for areas where there is a lower slope near the present shoreline, set-backs of up to 500 m are expected, particularly on the shore between Paynesville and Eagle Point, and the northern shore of Raymond Island.

Based on nominal erosion rates and the predicted inundation line for 0.8 m SLR, the zone of shoreline hazard is shown in Figure 4-11. This shows that the northern side or Raymond Island is more likely to experience significant shoreline erosion hazard as well as the area north of Paynesville, towards Eagle Point. Shoreline erosion hazard zone depths of 50 to 100 m or more are common in these areas, whilst most of the southern and shore of Raymond Island and Paynesville township has erosion hazard zone depths of less than 20 m.

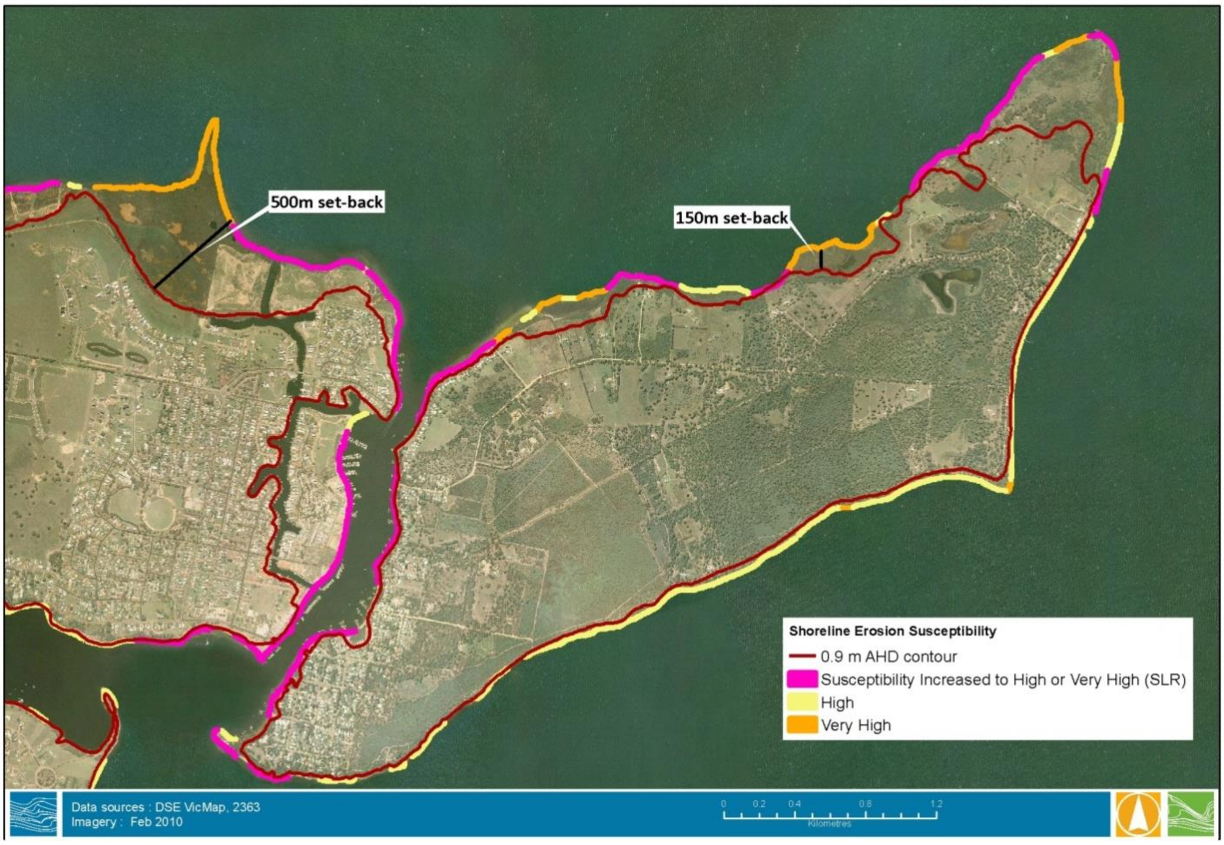


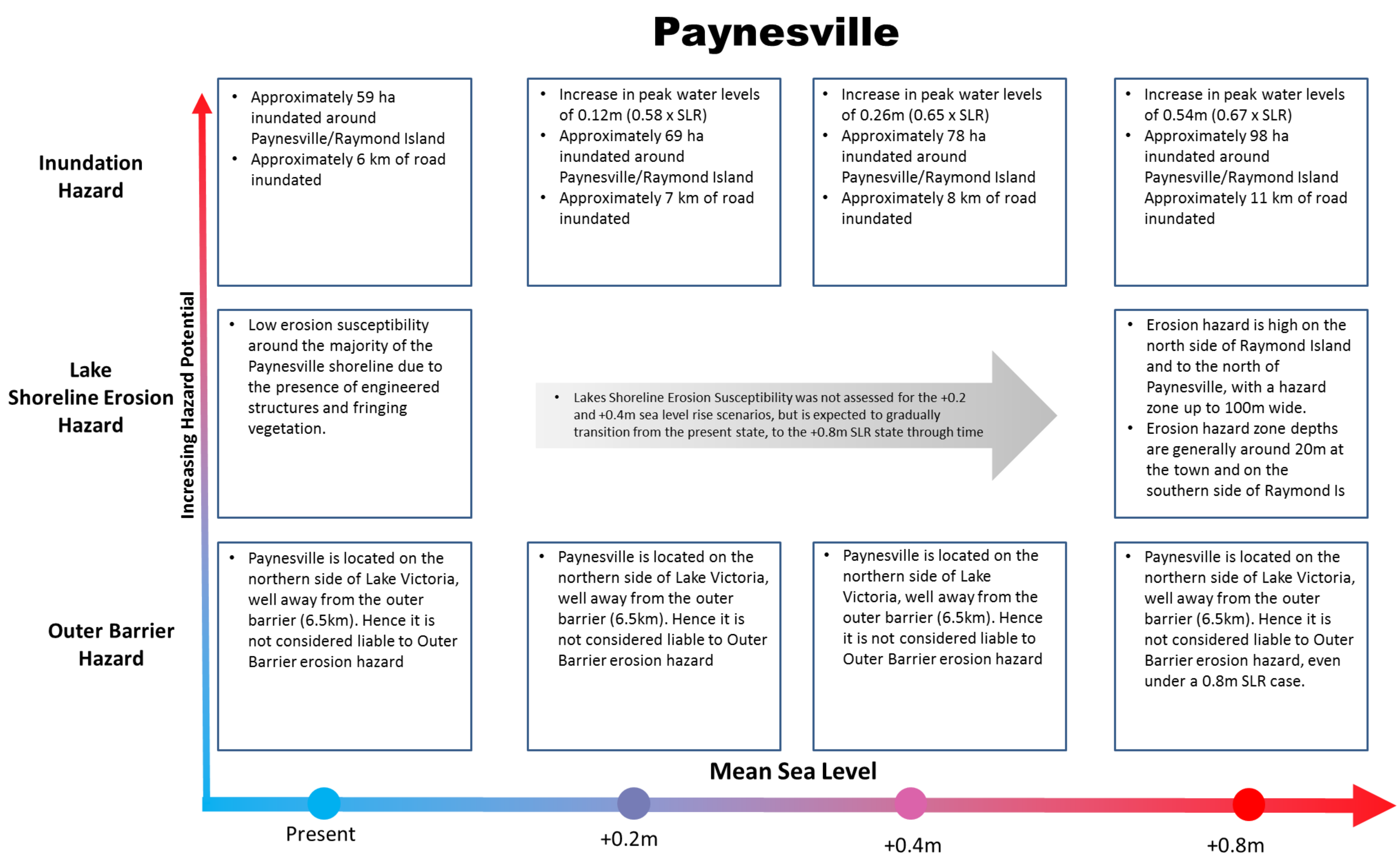
Figure 4-9 Shoreline Erosion Susceptibility at Paynesville under 0.8 m SLR

Figure 4-10 Erosive Section of Shoreline between Paynesville and Eagle Point

Figure 4-11 Paynesville – Raymond Island Shoreline Hazard Extent under 0.8 m SLR

4.2.3 Summary of Coastal Hazards

A summary of the coastal hazards at Paynesville is provided in Figure 4-12, which shows increasing SLR from left to right on the bottom axis and increasing potential hazard from bottom to top on the side axis. This highlights that inundation is considered to provide the most severe coastal hazard both under present and future SLR conditions.



Summary of the Key Hazards at Paynesville

- The key hazard at Paynesville is inundation. Peak water levels increase by approximately 0.65 time the rise in mean sea level for both the 10% and 1% AEP flood events. A large increase in the number of properties flooded is expected between the present and 0.2m of sea level rise scenarios, and increasing through higher mean sea levels, albeit at a slower increase rate.

Description of Scenarios

- **Inundation Hazards:** The inundation simulation results are based on a 10% AEP flood event with the associated sea level rise
- **Shoreline Erosion Susceptibility:** Are based on the existing and 0.8m increase in mean sea levels

Figure 4-12 Summary of Coastal Hazard Assessment at Paynesville

4.3 Loch Sport

Loch Sport was identified as being potentially susceptible to two primary hazards:

- Inundation hazards due to a combination of river inflows and coastal water levels; and
- Shoreline erosion hazard.

Due to the distance from the ocean, Loch Sport is not considered to be susceptible to outer barrier erosion hazards over the next century.

4.3.1 Inundation Hazard

Table 4-3 below summarises the modelling results in terms of peak flood levels at Loch Sport for each scenario. Table 4-3 also displays the relative SLR Response Factors.

A key finding of the flood modelling analysis for Loch Sport was that the SLR Response Factor is approximately 0.65. This means that the increase in peak flood levels at Loch Sport is predicted to be 0.65 times the magnitude of the sea level rise (35% less than SLR).

The SLR response factor at Loch Sport closely approximates the overall relationship between storage and elevation for the Gippsland Lakes.

Table 4-3 Relative Change in Peak Flood Levels to Sea level Rise at Loch Sport

Sea Level Rise Scenario	10% AEP Flood		1% AEP Flood	
	Level Change (m)	SLR Response Factor	Level Change (m)	SLR Response Factor
0.0 m	0.0	-	0.0	-
+ 0.2 m	0.12	0.58	0.13	0.65
+ 0.4 m	0.26	0.64	n/a	n/a
+ 0.8 m	0.54	0.67	n/a	n/a

Figure 4-13 displays the inundation extents around Loch Sport for the 10% AEP flood case under existing, 0.2, 0.4 and 0.8 m sea level rise scenarios. Only very minor increases in inundation extents are predicted at Loch Sport for sea level rise scenarios up to 0.8 m under the 10% AEP flood case. This reflects the fact that most of Loch Sport is situated on an elevated dune system, well above the surrounding lake. The areas of greatest extent change are along the ocean side of Loch Sport, facing Lake Reeve.

Figure 4-13 Change in Inundation Extent for a 10% AEP Event at Loch sport Under Existing, 0.2, 0.4 and 0.8m of Sea Level Rise

4.3.2 Shoreline Erosion Hazard

Figure 4-14 below shows the change in shoreline susceptibility for the 0.8 m SLR scenario. As with other sites, this analysis assumes that structures do not exist in the future case. In the present situation there are numerous groynes, every 100-200 m along the western part of the shoreline and less frequently on the eastern side. The presence of beach protection measures indicates there has been an eroding shoreline at some stage in the recent past. These structures act to mitigate the potential for erosion under present mean sea level conditions. It is anticipated that shoreline protection works are likely to be maintained and extended such that the area of significant susceptibility on the Lake Victoria shore will be protected from erosion in the future.

The assessment also shows that the greatest change in susceptibility to erosion is along the Lake Reeve shore. As opposed to the Lake Victoria shore, which is sandy and adapted to wave impacts, the Lake Reeve shore is typically composed of silty soils which are more susceptible to wave attack. Due to the minimal depth of water typically in Lake Reeve, waves are presently of little impact on this shore. However, under SLR Lake Reeve will have greater depth and more potential to generate wave energy that can result in shoreline erosion.

The 0.9 m contour shown on Figure 4-14 is an indicator of the potential location of the future shoreline, based on existing topography data. This shows that in areas where steep beach slopes exist there will not be significant movement in shoreline location. However for areas where there is a lower slope near the present shoreline, set-backs of up to 250 m are possible along the Lake Reeve shore.

Based on nominal erosion rates and the predicted inundation line for 0.8 m SLR, the zone of shoreline hazard is shown in Figure 4-15. This shows that the southern shoreline of Loch Sport is more likely to experience significant shoreline erosion hazard than the area north. Shoreline erosion hazard zone depths of 100 to 200 m or more are common along the shore of Lake Reeve, whilst most of the northern shore of Loch Sport has erosion hazard zone depths of less than 20 m.

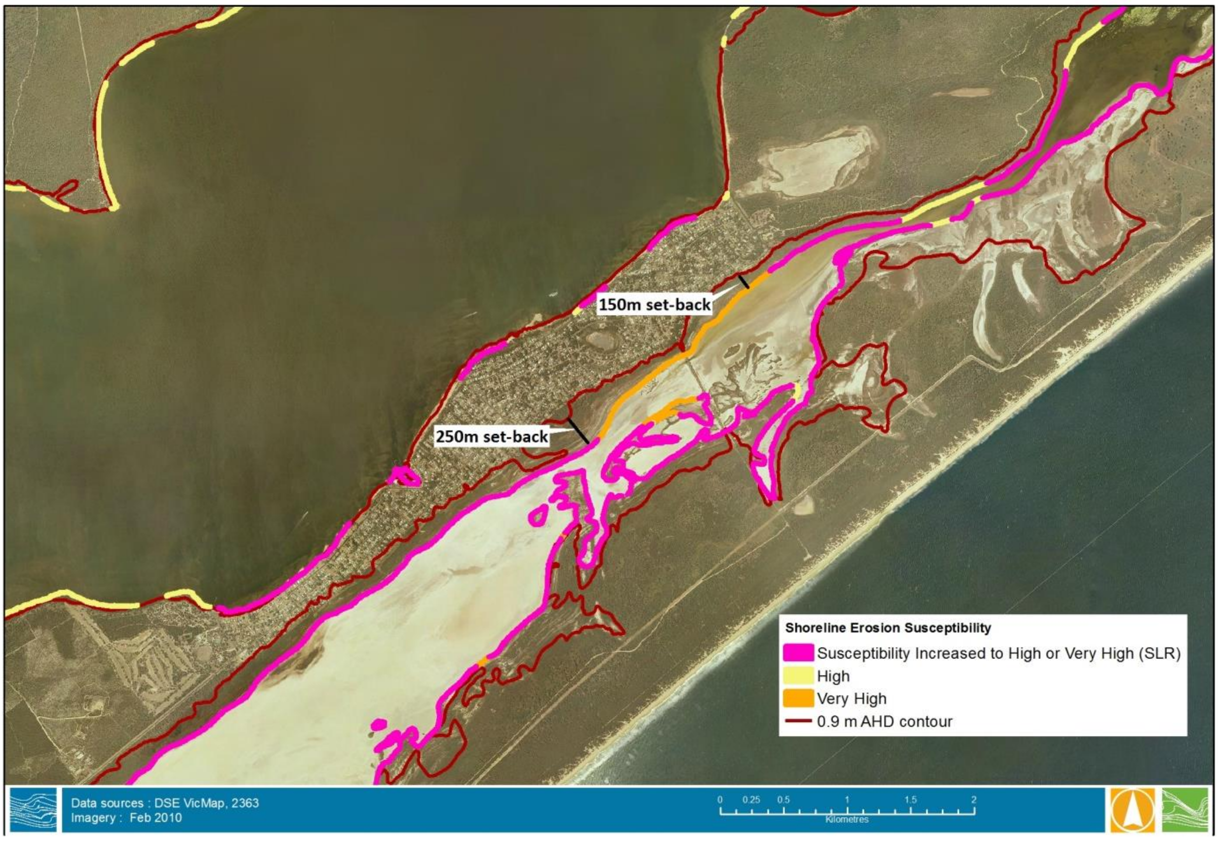


Figure 4-14 Shoreline Erosion Susceptibility at Loch Sport under 0.8 m SLR

Figure 4-15 Loch Sport Shoreline Hazard Extent under 0.8 m SLR

4.3.3 Summary of Coastal Hazards

A summary of the coastal hazards at Loch Sport is provided in Figure 4-16, which shows increasing SLR from left to right on the bottom axis and increasing potential hazard from bottom to top on the side axis. This highlights that inundation and shoreline susceptibility are considered to provide the most severe coastal hazards both under present and future SLR conditions.

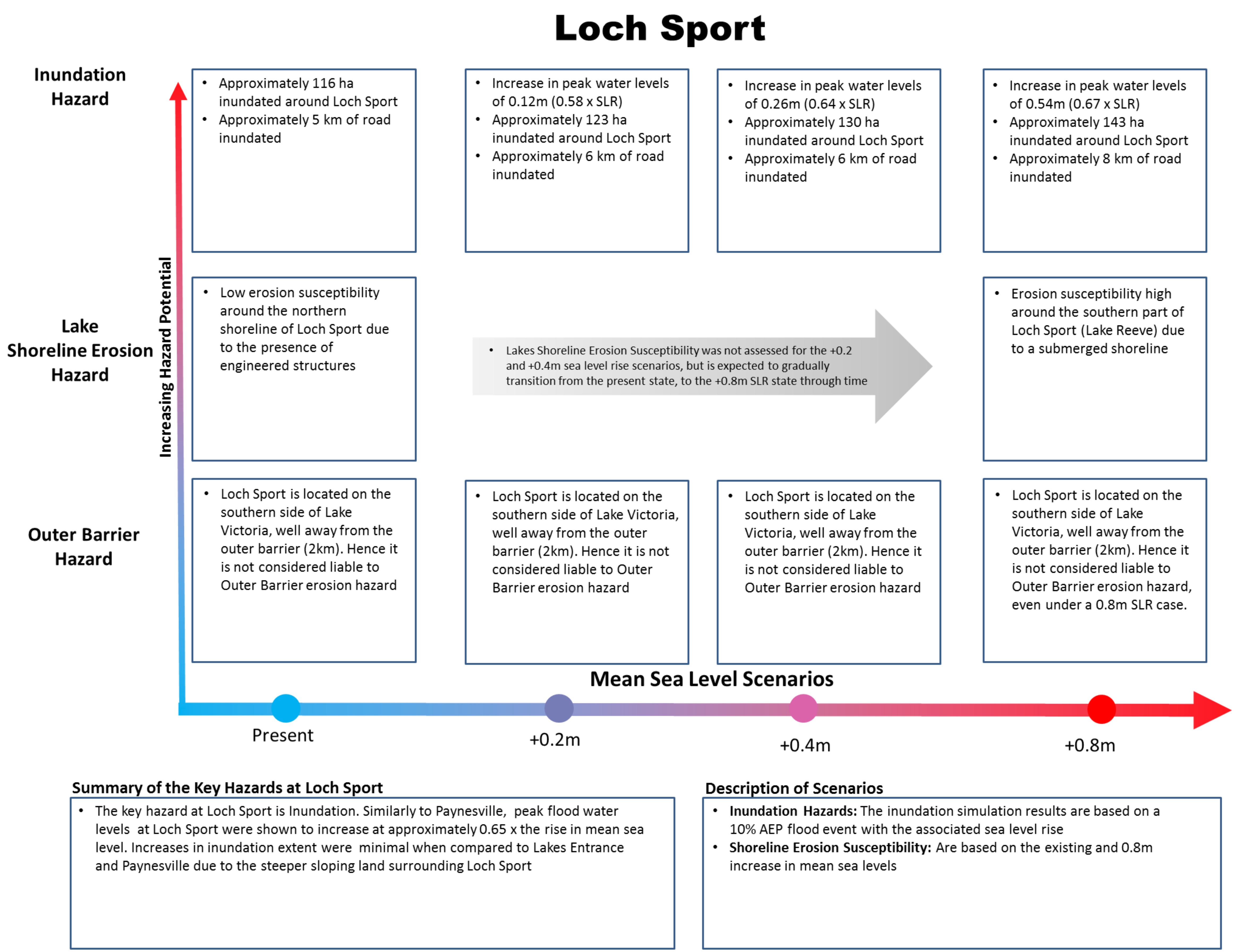


Figure 4-16 Summary of Coastal Hazard Assessment at Loch Sport

4.4 Bunga Arm

Bunga Arm was identified as being potentially susceptible to three primary hazards:

- Inundation hazards due to a combination of river inflows and coastal water levels;
- Coastal hazards associated with the susceptibility of the outer barrier to over wash processes; and
- Lake shoreline erosion hazard

4.4.1 Coastal Outer Barrier Hazards

Bunga Arm is the remainder of an easterly deflected tidal channel associated with a major, long-lived tidal entrance and associated flood tide delta that existed in this region up until approximately 4,000 years ago. The Outer Barrier narrows eastward along Bunga Arm and its volume declines significantly as shown in Figure 3-18. The dune system is narrow and discontinuous and the surface is a complex of hummocks, ridges and troughs with blowouts and former washover sites extending into Bunga. Arm.

Comparisons of coastal profiles from 2007 and 2012 in this unit show that significant shoreline recession has occurred over this period, with the dune scarp receding by approximately 10-12 m at locations surveyed. At locations with particularly low barrier volumes, the percentage decline in total barrier volume due to this recession approaches 15%. However it has not been possible to determine whether these changes are related to longer-term, longshore sediment budgets or short-term, cross-shore sediment transport processes.

Active movement of dunes in the form of wind-blown troughs and back-dune sand deposition exist with moderate frequency in this unit. Figure 4-17 shows photographs of a location near the Second Blowhole in Bunga Arm with active dune face blowout and back-dune deposition. Comparisons of coastal profiles at this location from 2007 and February 2013 are provided in Figure 4-18. These show significant landward movement of the barrier sediments and lowering of the crest over this period.

Figure 4-17 Active Dune Blowout and Apron, Bunga Arm (Feb, 2013)

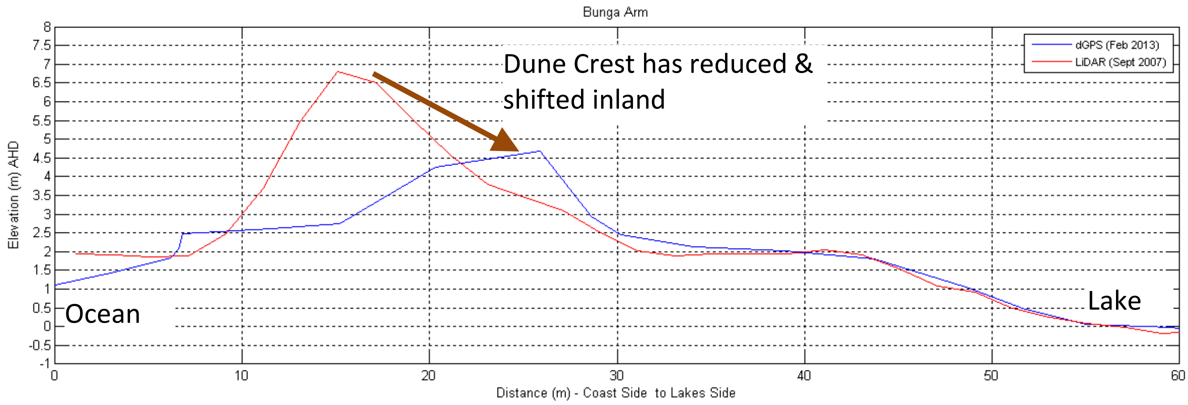


Figure 4-18 Comparison of Coastal Profiles at Active Erosion Site, Bunga Arm

Figure 4-19 displays the assessment of the potential barrier response mechanisms and subsequent extent of coastal hazard impacts under each sea level rise scenario for Bunga Arm. The coastal hazard impacts displayed in Figure 4-19 are discussed below:

- For sea level rise of up to 0.2 m and timeframes of 20-30 years, the barrier response is anticipated to remain essentially erosional, with continued decline in the barrier volume, width and height. Coastal hazard impacts are expected to remain largely limited to the shoreward face of the barrier, however isolated, active transgressive dunes could develop low points in the barrier which would become vulnerable to minor overwash events.
- For sea level rise of approximately 0.4 to 0.8 m and timeframes of 50-60 years, the likelihood of coastal hazard impacts extending into back barrier areas increases significantly. The combination of long-term sediment budget recession or sea level rise profile adjustment could be expected to reduce the integrity of the barrier to the extent that relatively infrequent and minor overwash events may be initiated at a small number of locations in this unit. Coastal hazard impacts associated with these events would extend locally into Bunga Arm lagoon. Transgressive dunes could also be expected to increase in number and extent due to sustained scarping and destabilisation of the foredune.
- For sea level rise of 0.8 m or greater and timeframes of 80-100 years, the potential for major barrier translation exists and could result in multiple and frequent overwash events experienced along the length of the barrier in this unit. Significant quantities of washover deposits would be emplaced in Bunga Arm lagoon. Ephemeral tidal connections between Bunga Arm lagoon and the ocean may be initiated, however these are not expected to be self-sustaining and their influence on water levels in the greater Gippsland Lakes are expected to initially be minor.

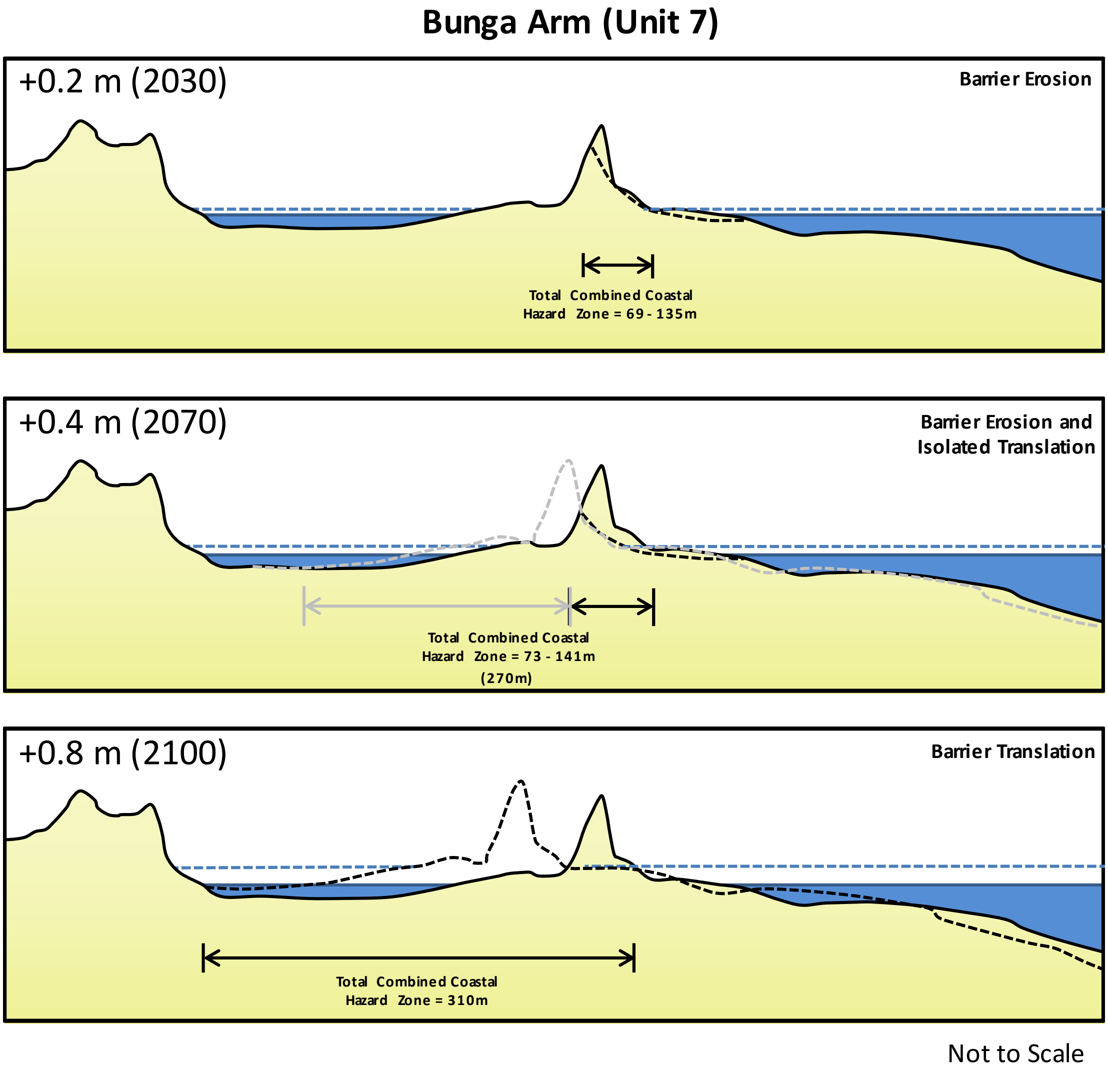


Figure 4-19 Coastal Outer Barrier Hazard Zone Distances for Bunga Arm

4.4.2 Inundation Hazard

Hydrodynamic model simulations were undertaken for the 10% AEP flood case under existing, 0.2, 0.4 and 0.8 m sea level rise scenarios. The 1% AEP flood case was also simulated under existing and 0.2 m sea level rise.

Table 4-4 below summarises the modelling results in terms of peak flood levels at Bunga Arm for each scenario. Table 4-4 also displays the relative SLR Response Factor for each sea level rise scenario. These results show that the impact at Bunga Arm is essentially the same as for Paynesville with a SLR Factor of 0.65.

The SLR response factor at Bunga Arm closely approximates the overall relationship between the change in storage and elevation for the Gippsland Lakes Basin.

Table 4-4 Peak Relative Change in Peak Flood Levels to Sea level Rise at Bunga Arm

Sea Level Rise Scenario	*10% AEP Flood*		*1% AEP Flood*	
	Level Change (m)	*SLR Response Factor*	Level Change (m)	*SLR Response Factor*
0.0 m	0.0	-	0.0	-
+ 0.2 m	0.12	0.58	0.13	0.65
+ 0.4 m	0.26	0.64	n/a	n/a
+ 0.8 m	0.53	0.66	n/a	n/a

Figure 4-20 displays the inundation extents within Bunga Arm for the 10% AEP flood case under existing, 0.2, 0.4 and 0.8 m sea level rise scenarios. Only very minor increases in inundation extents are predicted within Bunga Arm for sea level rise scenarios up to 0.8 m under the 10% AEP flood case.

In consideration of the sensitivity of coastal hazard impacts identified for Bunga Arm and the Gippsland Lakes more generally, additional hydrodynamic modelling analysis of the impact of a washover of the Outer Barrier at Bunga Arm on inundation hazards in the Gippsland Lakes was undertaken. The 10% AEP flood with 0.8 m SLR scenario was modelled, incorporating a washover-initiated tidal channel connection from Bunga Arm to Bass Strait. The flood level modelling results from this simulation showed that a minor tidal channel connection from Bass Strait in Bunga Arm would result in small decreases in peak flood levels at locations within the Gippsland Lakes compared to the existing conditions.

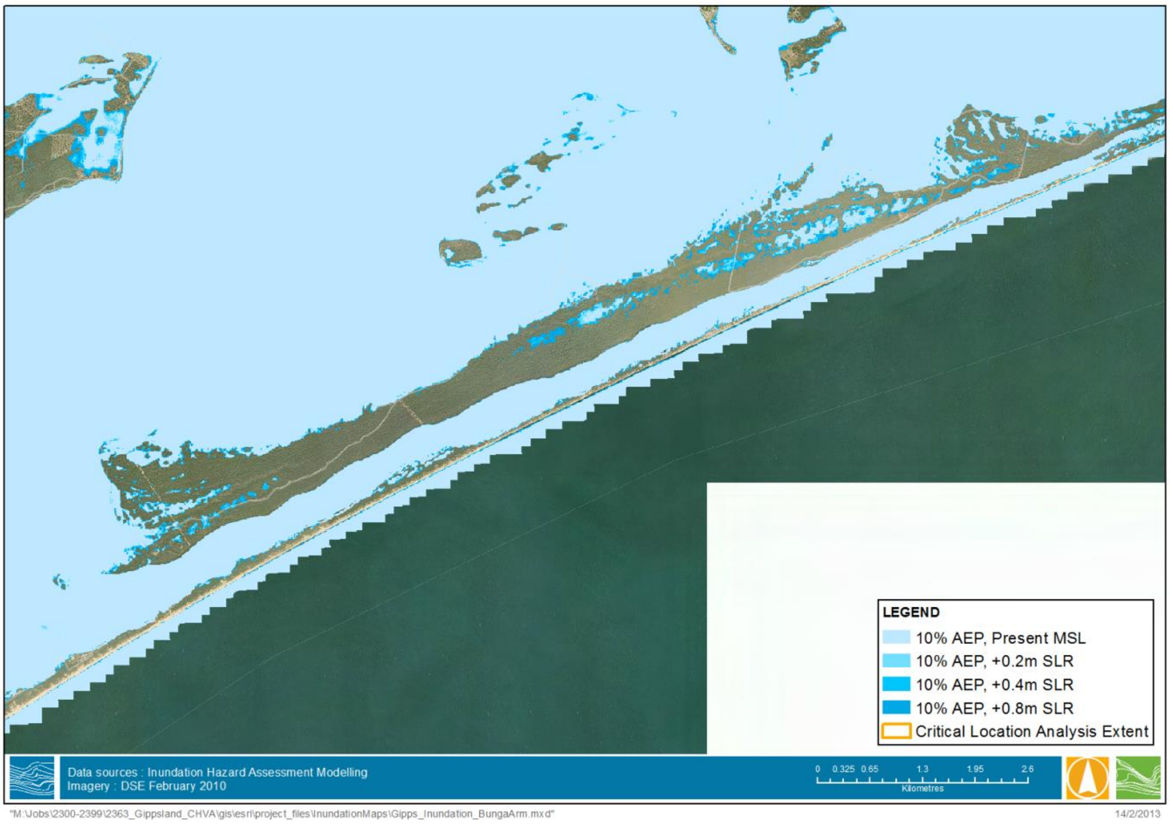


Figure 4-20 Change in Inundation Extent for a 10% AEP Event in Bunga Arm Under Existing, 0.2, 0.4 and 0.8 m of Sea Level Rise

4.4.3 Shoreline Erosion Hazard

The erosion susceptibility for Bunga Arm is predominantly a function of the physical components, dominantly sandy areas in particular, along with biological factors. The environmental components of wave and current exposure have less impact in this area. This is due to the narrow width of Bunga Arm, providing limited potential for wave development. Further, as the Entrance to Bunga Arm is more than 20 km from the artificial opening of Lakes Entrance, tidal currents are negligible. Therefore, erosion potential for the lakeside shoreline (due to lakeside processes) is limited. The Coastal Outer Barrier Hazard assessment highlighted the potential for significant barrier movement landwards, much greater than likely lakeside shoreline erosion.

Figure 4-21 below shows the change in shoreline susceptibility for the 0.8 m SLR scenario. Under the sea level rise scenario there is some increase in the spatial extent of shoreline erosion susceptibility (predominantly to the south of Sperm Whale Head) but as the majority of the area is currently erosion susceptible there is effectively little change. A major impact of SLR will be the inundation of the low islands near the entrance to Bunga Arm. These islands provide important breeding habitat for marine birds and typically have elevations below 1 m AHD. Progressive inundation of these features is expected up to 0.8 m SLR with some expected to completely disappear. This impact is highlighted in Figure 4-22, which shows the shoreline erosion hazard zone for the 0.8 m SLR case. The area of greatest impact is around the islands at the entrance to Bunga Arm.

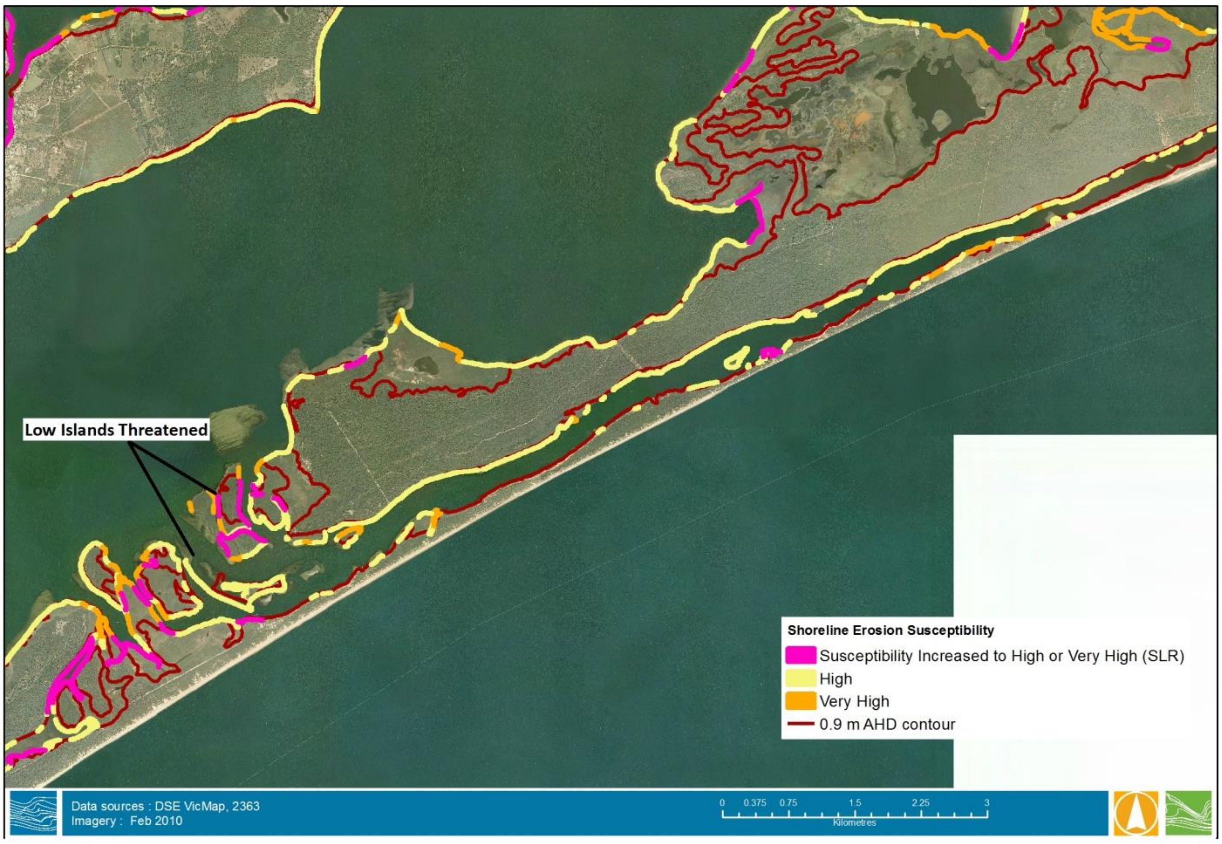


Figure 4-21 Shoreline Erosion Susceptibility at Bunga Arm under 0.8 m SLR

Figure 4-22 Bunga Arm Shoreline Hazard Extent under 0.8 m SLR

4.4.4 Summary of Coastal Hazards

A summary of the coastal hazards at Bunga Arm is provided in Figure 4-23, which shows increasing SLR from left to right on the bottom axis and increasing potential hazard from bottom to top on the side axis. This highlights that Outer barrier hazards are considered to provide the most severe coastal hazards both under present and future SLR conditions.

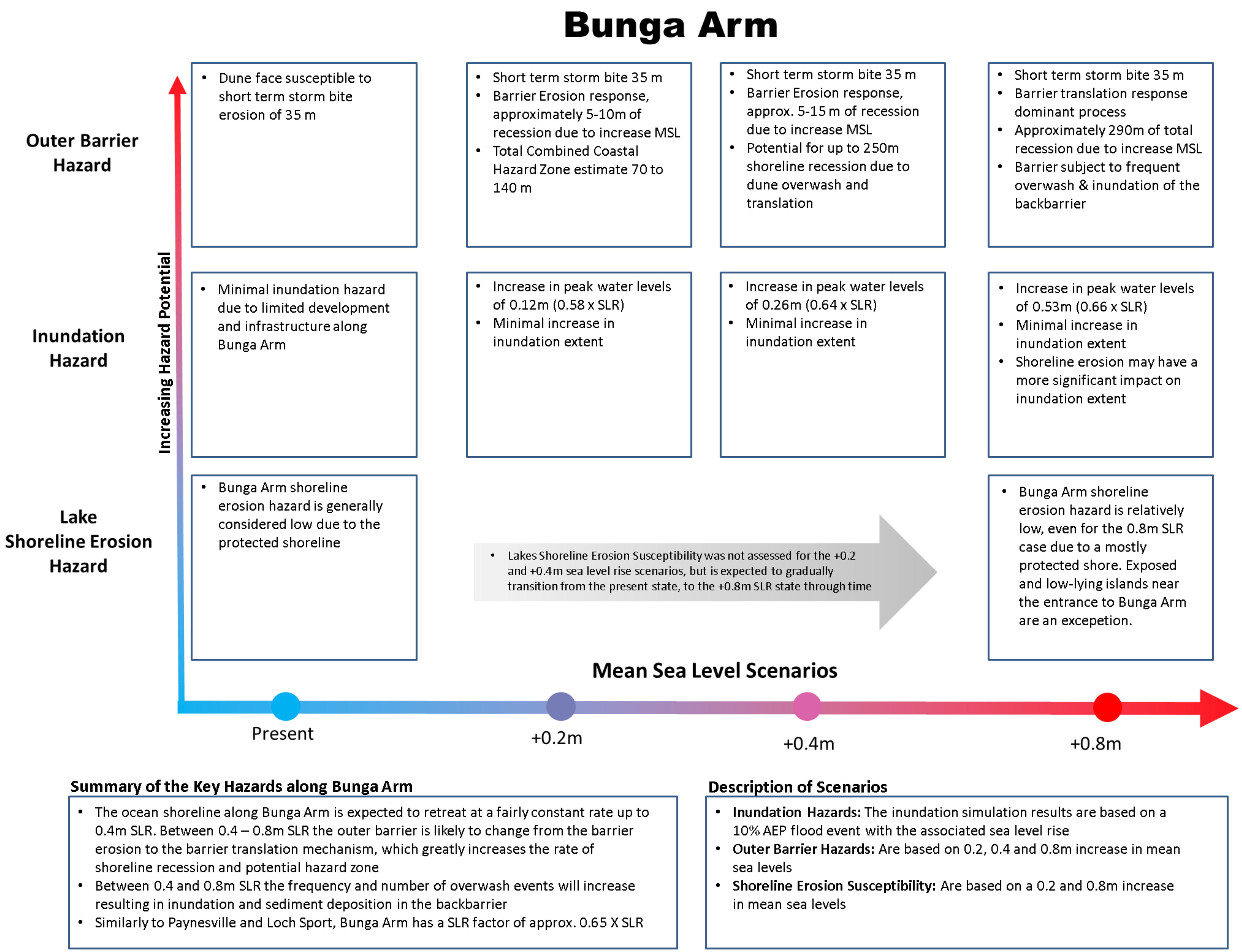


Figure 4-23 Summary of coastal hazard assessment at Bunga Arm

4.5 Seaspray

Seaspray was identified as being potentially susceptible to two primary hazards:

- Coastal hazards associated with the susceptibility of the outer barrier to over wash processes; and
- Inundation hazards due to a combination of major flood events in Gippsland Lakes and Outer Barrier overwash.

At present Seaspray is not susceptible to shoreline erosion hazards as water does not permanently occupy Lake Reeve in this area. The lake bed varies from around 0.5 m to 1.5 m AHD elevation in the nearby area and as sea level progressively rises, only small areas of permanent open-water are expected to develop, even for the 0.8 m SLR case. Hence shoreline erosion processes will tend to be restricted to periods of significant flooding over the next century.

4.5.1 Coastal Outer Barrier Hazards

The geomorphology of the Outer Barrier in the vicinity of Seaspray and The Honeysuckles exhibits receding characteristics. The barrier comprises a single, narrow ridge with a low volume of sand. The back barrier morphology shows limited development of dune ridges compared to the wide washover and lagoon deposits which are rich in estuarine and even marine species indicating a long period of back barrier lagoon development and frequent marine incursions as recently as the last 3,000 years.

Longshore transport modelling suggests there is an underlying sediment deficit of the order 70,000 m^3/yr on average, due to the gradual north-east longshore drift of sediment. The analysis of the geomorphology, historical photography and longshore sediment transport do, however, suggest the underlying sediment deficit is most pronounced in the south-western geomorphic unit of the study area and may be contributing to current shoreline recession in the vicinity of Seaspray. Rates of shoreline recession at Seaspray have approached 1 m/year on average over the last 20 years but shoreline position was relatively stable over the preceding 30 years. Approximately 5% of the total barrier volume has been lost from sections of the barrier between Seaspray and The Honeysuckles based on coastal profile comparisons from 2007 to 2012.

Based on the available information and analysis, significant uncertainty exists in estimating the extent and relative timing of the potential coastal hazard impacts in the vicinity of Seaspray due to the apparent sensitivity of the shorelines to variations in longshore sediment transport.

Introduction of Marram Grass appears to have significantly influenced the position and form of the Seaspray - The Honeysuckles dune. The introduction of Marram Grass has allowed the dune ridge to build vertically much higher than would occur with native species and has been apparently successful in reducing sand drift and storm overwash based on available historical accounts. However, active dune movement in the form of sand aprons are evident and wind is actively transporting sand distances of approximately 40 m landward of the dune at locations between Seaspray and The Honeysuckles.

Figure 4-24 displays the assessment of the likely barrier response mechanisms and subsequent potential extent of coastal hazard impacts under each sea level rise scenario for Seaspray. The coastal hazard impacts displayed in Figure 4-24 are discussed below:

- For sea level rise up to 0.2 m and timeframes of 20-30 years, the barrier response is anticipated to remain essentially erosional, with continued decline in the barrier volume, width and height. Coastal hazard impacts are expected to remain largely limited to the shoreward face of the barrier, except for relatively isolated active transgressive dune impacts. However, potential future scenarios including ongoing, high rates of underlying sediment budget related shoreline recession, land subsidence or a localised increase in short-term erosion associated with rip cell embayment's, could result in localised overwash of the barrier and an increased landward coastal hazard impact zone locally.

- For sea level rise of 0.4 to 0.8 m and timeframes of 50-60 years, the likelihood of coastal hazard impacts extending into back barrier areas increases significantly. The combination of long-term sediment budget recession and sea level rise profile adjustment could be expected to reduce the integrity of the barrier to the extent that overwash events may be initiated at multiple, though discrete, locations. Coastal hazard impacts associated with these events could extend over 150 m landward of the foredune. Transgressive dunes could also be expected to increase in number and extent, due to sustained scarping and destabilisation of the foredune. Potential land subsidence could be expected to dramatically increase the frequency and extent of washovers in this unit and time frame.
- Under sea level rise of 0.8 m or greater and timeframes of 80-100 years, major barrier translation could be expected with multiple and frequent overwash events experienced along the length of the barrier, impacting large areas both laterally and landward of the foredune in this unit. Intermittent connection with back barrier lagoons may be initiated across the barrier. Washover deposits associated with the overwash events may evolve into broad transgressive dunes.

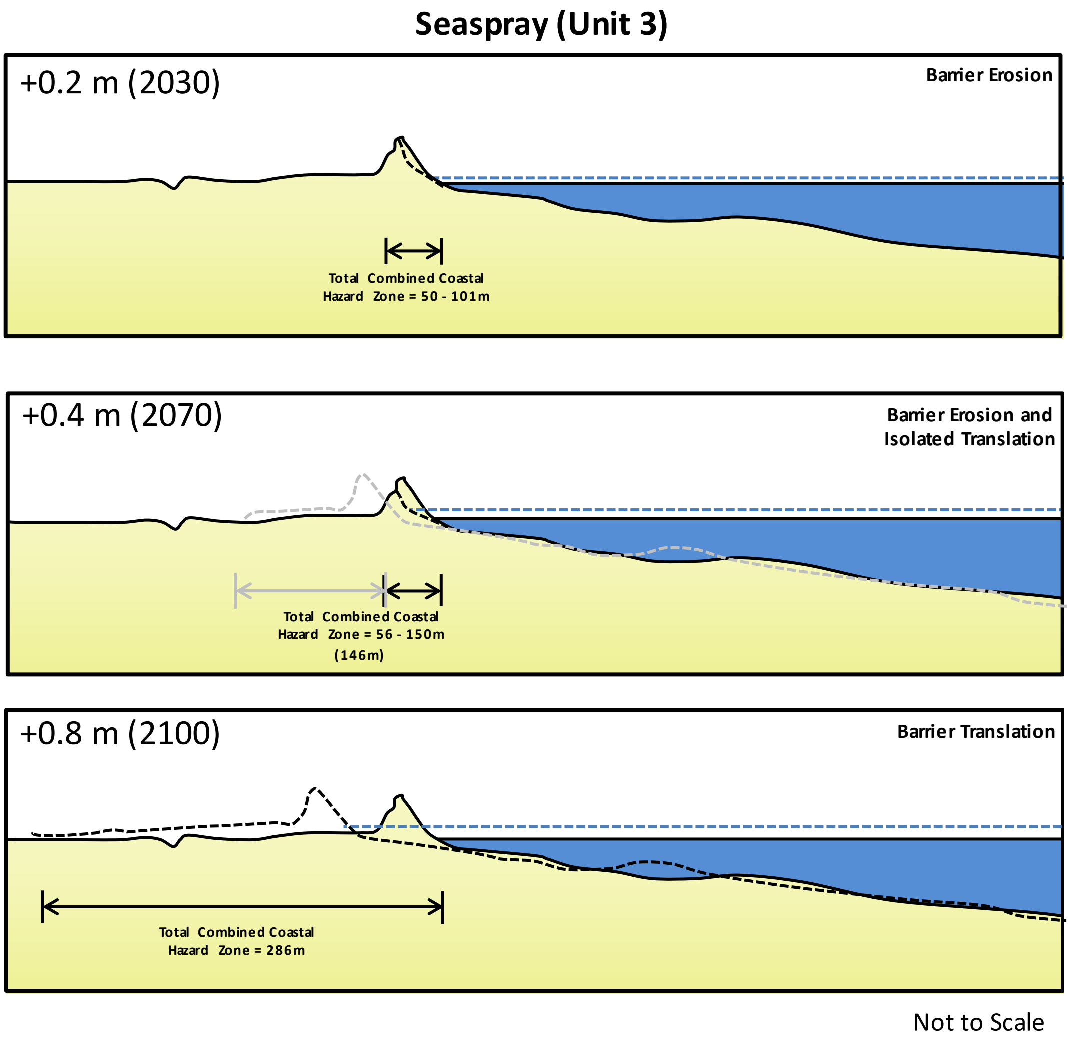


Figure 4-24 Coastal Outer Barrier Hazard Zone Distances for Seaspray

As part of the evaluation of the impact of uncertainty on the potential extent of the coastal hazard impacts identified for Seaspray, additional modelling analysis of the potential impact of washovers of the Outer Barrier in the vicinity of Seaspray was undertaken.

This modelling demonstrated that overwash could potentially result in very dynamic morphologic changes landward of the barrier in this region, as shown in Figure 4-25. Sand deposits originating from the overwash location were modelled as radiating out approximately 150 m landward of the overwash site and over a width of around 250 m. These results appear to be consistent with anecdotal and broader geomorphic records of coastal behaviour in this area. The spatial extent and general morphology of the overwash deposits predicted from this modelling analysis are similar to the contemporary washover deposits identified within this geomorphic unit at McGaurans Beach and other locations to the south-west of Seaspray.

Figure 4-25 Predicted Extent of Washover Deposits due to an Overwash Scenario at Seaspray

4.5.2 Inundation Hazards

Hydrodynamic model simulations were undertaken for the 10% AEP flood case under existing, 0.2, 0.4 and 0.8 m sea level rise scenarios. The 1% AEP flood case was also simulated under existing and 0.2 m sea level rise scenarios.

Figure 4-26 shows the predicted change in inundation for the SLR scenarios. A key result of this analysis is that the floodplain around Seaspray is only predicted to become susceptible to inundation from Gippsland Lakes floods during the 10% AEP flood case and the 0.8 m SLR scenario. Flooding under this scenario is, however, not predicted to result in peak levels of sufficient height to overtop the levees surrounding Seaspray.

The flooding analysis undertaken for Seaspray only considered potential inundation from the Gippsland Lakes and did not consider flooding impacts from Merriman Creek. Coincident flooding of the Gippsland Lakes and Merriman Creek is considered to be an extremely low probability event. The impacts of flooding in Merriman Creek at Seaspray have previously been assessed in detail (Cardno Lawson Treloar, 2010).

Two significant sources of uncertainty relating to the potential extent of inundation hazards that could develop at Seaspray were identified during the study:

- The potential extents of inundation associated with overwash of the Outer Barrier in the vicinity of Seaspray; and
- The potential impact of land subsidence associated with aquifer deflation at Seaspray.

These two cases were investigated in order to test the sensitivity of the hazard results to these potential circumstances.

Overwash

The dynamic morphologic changes predicted due to potential overwash of the Outer Barrier in the vicinity of Seaspray, discussed previously, are expected to be accompanied by coastal inundation hazards. The modelling analysis demonstrated that significant inundation of the back barrier regions (Lake Reeve) around Seaspray could be expected in an overwash scenario. The precise extent and depth of flooding in this region will depend on the number, extent and persistence of the washovers that occur due to sea level rise. At present, this cannot be predicted with any significant level of certainty. It can be reasonably concluded, however, that the potential inundation from washover events would generally be significantly less than a moderate flood under the same degree of sea level rise.

Land Subsidence

Reduction of pore water pressure within the Latrobe Aquifer due to extraction of oil and gas and dewatering of open pit coal mines has the potential to result in consolidation/compression of the aquifer sediments causing a lowering of the land surface above the aquifer. On the coastline and within the Gippsland Lakes, any relative fall in the land surface would effectively result in additional sea level rise.

Additional modelling analysis of the impact of potential subsidence, in addition to sea level rise has been undertaken to determine the sensitivity of the hazard results to this source of uncertainty.

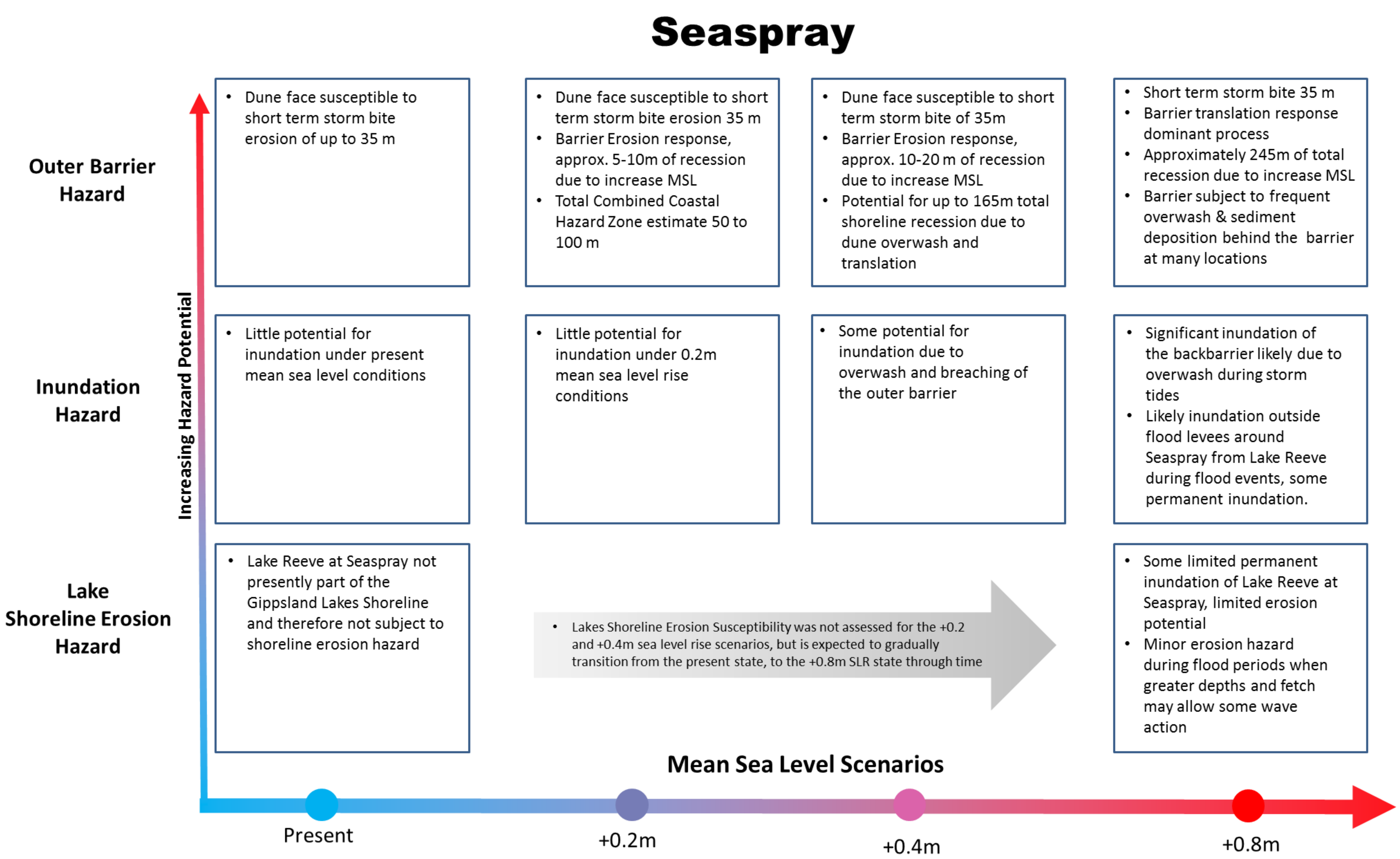
The modelling analysis demonstrated that the extent of inundation resulting from Gippsland Lakes floods would increase significantly around Seaspray with the incorporation of predicted land subsidence in this region.

In addition, land subsidence would result in an effective lowering of the elevations of the Outer Barrier and would significantly increase the likely number, extent and persistence of washover events along the Outer Barrier and the associated inundation hazards from this flooding mechanism in the back barrier regions around Seaspray.

Figure 4-26 10% AEP Flood Scenario Maximum Inundation Extent under Present MSL and SLR Scenarios at Seaspray

4.5.3 Summary of Coastal Hazards

A summary of the coastal hazards at Seaspray is provided in Figure 4-27, which shows increasing SLR from left to right on the bottom axis and increasing potential hazard from bottom to top on the side axis. This highlights that outer barrier hazards are considered to provide the most severe coastal hazards both under present and future SLR conditions.



Summary of the Key Hazards at Seaspray

- The shoreline at Seaspray is expected to retreat at a fairly constant rate up to 0.4m SLR.
- Between 0.4 – 0.8m of SLR the outer barrier is likely to respond to increased mean sea levels through the barrier translation mechanism, greatly increasing shoreline recession
- Between 0.4 and 0.8m of SLR the frequency and number of barrier breach and overwash events will increase resulting in inundation of the back barrier
- For 0.8m SLR, inundation from Lake Reeve occurs during a 10% AEP flood event in the Gippsland Lakes.

Description of Scenarios

- **Inundation Hazards:** The inundation simulation results are based on a 10% AEP flood event with the associated sea level rise
- **Outer Barrier Hazards:** Are based on 0.2, 0.4 and 0.8m increase in mean sea levels

Figure 4-27 Summary of Coastal Hazard Assessment at Seaspray

5. CONCLUSIONS

The following sections provide a summary of the key conclusions drawn from the coastal and inundation hazard technical assessments.

5.1 Conclusions - Outer Barrier Coastal Hazard

- There are significant differences in the origin, evolution and contemporary morphology of the Outer Barrier landform along the length of the study area. These variations give rise to significantly different estimates of potential coastal hazard impact along the study area due to sea level rise.
- The type, variability, extent and timing of the coastal hazard impacts along the Outer Barrier have been identified as being closely related to the mechanism of barrier response that is experienced for a given magnitude of sea level rise(i.e. barrier erosion or barrier translation)
- Investigations suggest the Outer Barrier at Seaspray, Bunga Arm and Eastern Beach is likely to be susceptible to overwash and barrier translation processes for sea level rise of greater than 0.4 m.
- Overwash/barrier translation at these locations would be expected to result in coastal hazard impacts extending many hundreds of metres landward of the present shoreline.

5.2 Conclusions - Inundation Hazards

- Flood levels are primarily driven by major catchment generated flood flows into the Gippsland Lakes. Sea level rise, geomorphic changes to the Outer Barrier and changes to catchment hydrology associated with climate change will all impact flood behaviour in the Gippsland Lakes in the future.
- At a broad scale, only relatively minor, local changes in inundation extents are predicted around the majority of the Gippsland Lakes for 10% AEP design flood events combined with sea level rise up to 0.8 m. The exceptions to this being the south-western end of Lake Reeve, where large increases in inundation extents are predicted for sea level rise scenarios greater than 0.4 m and Lakes Entrance where significant additional inundation is expected.
- The SLR Response Factor provides a simple indication of the relative sensitivity of flood levels to increases in mean sea level within the Gippsland Lakes. For the majority of the Gippsland Lakes, the SLR Response Factor is predicted to be approximately 0.65, which closely approximates the relationship between storage and elevation of the Gippsland Lakes Basin.
- At Lakes Entrance the SLR Response Factor is predicted to be approximately 0.9 due to the proximity to the ocean entrance and subsequent greater influence of tidal and coastal water levels on flood behaviour. Significant increases in inundation extents are predicted within Lakes Entrance for sea level rise scenarios greater than 0.4 m in combination with a 10% AEP flood event.
- The floodplain around Seaspray is predicted to become susceptible to inundation from Gippsland Lakes floods with a 10% AEP and 0.8 m of sea level rise. Flooding under these conditions, however, is not predicted to result in flood levels of sufficient height to overtop the levees surrounding Seaspray.

5.3 Conclusions - Lake Shoreline Erosion Hazard

- The lake shoreline hazard assessment indicates a general increase level of shoreline erosion susceptibility throughout the Gippsland Lakes due to sea level rise. Those areas most affected by increases in erosion susceptibility, and hence likely to experience significant erosion hazard under sea level rise conditions, are the shoreline of Lake Wellington, Lake Reeve behind the outer coastal barrier south of Sperm Whale Head, the shoreline of Lake King from Paynesville to the Nicolson River, and the areas around Reeve Channel and Lakes Entrance.
- The shoreline erosion hazard around the townships of Lakes Entrance, Paynesville and Loch Sport are, to a significant extent, mitigated by the presence of shoreline protection structures. Should these structures not be maintained or removed then much of the shoreline around these towns become susceptible to erosion hazard.
- The lake shoreline hazard assessment shows that impacts of SLR on shoreline hazard will be dominated by the influence of inundation directly, rather than erosion processes.

5.4 Conclusions – Monitoring

- Initial coastal and shoreline profile data has been collected. This data, when compared to previous LiDAR survey, demonstrated profile change at a number of locations. The use of high-accuracy mobile GPS equipment proved efficient and flexible in allowing features to be levelled around the study area. Repeat profile surveys or broader topographic surveys of the shoreline around the Lakes would prove useful in the future understanding and management of the lakes system.
- A review of potential monitoring parameters and techniques has been undertaken. These have led to preliminary recommendations for future monitoring to inform coastal hazard assessments and adaptation.
- Ongoing consistent monitoring into the future is considered crucial to further understanding, quantifying and assessing the uncertainty surrounding this assessment. A summary of the project recommendations are provided below in Section 6, and in detail in Report 05: Coastal Monitoring.

6. STUDY RECOMMENDATIONS

6.1 General Recommendations

The following recommendations are drawn from the results and findings of the Gippsland Lakes/90 Mile Beach Coastal Hazard Assessment:

- As new monitoring data becomes available, along with improved predictions of climate change forcings (such as rainfall changes), the results of this study can be periodically updated to reflect these changes.

6.2 Inundation Hazard Recommendations

The following recommendations are drawn from the inundation hazard investigation:

- A Water Level Frequency Analysis should be undertaken for the main townships of the Gippsland Lakes to aid understanding of the full range of SLR impacts on these communities. This project has assessed the impact of SLR on flood levels due to large floods within the Gippsland Lakes. However, it has also been highlighted that there is a need to further understand the potential changes to the frequency of inundation associated with smaller flood and coastal water level events with sea level rise in the Gippsland Lakes.
- The flood modelling in this study has been undertaken to provide a reliable indication of the impact of sea level rise and climate change on flood levels within the Gippsland Lakes. It does not however constitute a full flood study. Further work in the refinement of model calibration parameters and boundary conditions could be undertaken to provide outputs that meet the requirements of a full flood study, such that the results could be applied to set levels for future land-use planning.
- Further to the above point, analysis of the impacts of 0.8 m SLR on the 1% AEP design flood scenario (or set of scenarios) within the Gippsland Lakes, along with sensitivity analysis around the uncertainties for this event could be undertaken. This would improve the information available to authorities to assess impacts at the 2100, 0.8 m SLR planning horizon.
- The impact of climate change on salinity within the Gippsland Lakes is of major ecological importance. Changes to the salinity regime could influence the biota within the lakes including fringing vegetation and related aspects such as algae and the entire food web. The existing hydrodynamic model can be utilised to investigate salinity impacts in the future.
- The sensitivity of entrance dynamics was not able to be investigated by this study. The interaction of SLR with tides, floods and dredging of the entrance and surrounds potentially has significance and could be investigated through further modelling and data collection.
- Modelling of the 1% AEP flood scenario with +0.8 m sea level rise was not undertaken due to uncertainties and potential to confuse model outputs with current declared flood levels. It is recognised that some agencies would benefit from this analysis. As noted above, further refinement of the design flood cases and additional calibration would be necessary to meet the requirements of a full flood study.

6.3 Outer Barrier Coastal Erosion Hazard Recommendations

The following recommendations are drawn from the coastal hazard investigation:

- Only approximately 5% of the Outer Barrier was covered by historical aerial photography that was available for the study. The collation and analysis of additional historical aerial photography would assist in understanding the underlying shoreline variability and trends along the Outer Barrier.
- A small number of coastal profile survey transects were undertaken for the study. Comparison of these profiles to earlier LiDAR survey revealed significant change and dynamics in the morphology of the barrier. Ongoing survey of the Outer Barrier through either repeat transect surveys or other airborne remote sensing techniques should be undertaken to develop a longer and higher resolution time-series of elevations and geomorphological change along the Outer Barrier.
- Very limited dating of the sediments of the Outer Barrier currently exists. Additional, precise dating of the Outer Barrier sediments would improve the understanding of the evolution of this landform and assist in interpreting likely future rates of change.

6.4 Shoreline Erosion Hazard Recommendations

The following recommendations are drawn from the shoreline erosion hazard investigation:

- A key knowledge gap for this study is the impact of salinity on the vegetation communities of the Gippsland Lakes shoreline and how this may impact on the current ability of these shorelines to mitigate erosion susceptibility. Coupling the impacts of changing salinity with vegetation response would require understanding of the changes to salinity regimes resulting from sea level rise as a prerequisite. This may be investigated in future through application of the hydrodynamic model, modified to resolve salinity dynamics.
- In the future the GIS data model could be used to further investigate the impacts of different assumptions regarding vegetation response to sea level rise by applying vegetation rules based on, for example, slope or rate of sea level rise. However, the underlying knowledge as to how these communities are currently responding to salinity and what their trajectory may be into the future are unknown.
- It is likely that aside from sea level rise, climate change may result in changes to rainfall frequency and intensity which would alter the river inflow regime for the inflowing rivers. However there is considerable uncertainty as to the magnitude and timescale of such changes. An additional potential impact of climate change which has even greater uncertainty surrounding it is the potential for changes in wind speeds and directions. There is currently no reliable guidance available on such changes. The hydrodynamic models used for this study could be modified to test the sensitivity of the system to a wide range of potential climate change conditions, including the impact of salinity, changes to flows, and altered wind conditions.

6.5 Recommended Monitoring

Drawing on the monitoring options outlined in the monitoring report, and based on our understanding of the system, we recommend the list of monitoring options proposed in Report 5: Coastal Monitoring and listed in Table 6-1. These measures should be considered to assist ongoing hazard assessment and management of the Lakes system. Any monitoring program should have very clear objectives and a means of closely relating the monitoring objective to the monitoring plan.

The following outlines comments in relation to monitoring:

- Annual monitoring for the baseline coastal profile transects identified in Report 5: Coastal Monitoring" will assist understanding of the long term erosion/deposition trends within the study area and would aid in reducing the uncertainty in the long term trends identified within this project.
- The monitoring of profiles as well as shoreline location should allow for the calculation and verification of erosion rates in the future. This will allow for better estimation of future shoreline hazard estimation around the lakes in particular.
- The collection of profile surveys should coincide with imagery capture if possible to maximise the value of both data sets.
- Improved mapping of shoreline EVCs that differentiates between reed beds and the scrubland would enable the impact of changes to reed bed extent to be quantified.
- Monitoring of parameters such as vegetation and salinity will allow for the links between shoreline erosion and ecological characteristics to be better understood.
- Monitoring of the extent of specific high value reed beds (such as the western shore of Lake Wellington) along with salinity measurements to assess responses to salinity and enhance understanding of responses to these systems to change
- Erosion monitoring throughout the lakes system covering a range of shoreline types, environmental conditions (exposed to waves/currents), and vegetation communities.
- Better co-ordination and sharing of monitoring responsibilities and data between agencies will result in a greatly improved overall outcome for the Gippsland Lakes. The agreed nomination of a lead agency to co-ordinate these activities would be highly beneficial.

Table 6-1 Preliminary Recommended Priority Monitoring

Monitoring Objective	Monitoring Target	Method	Range	Frequency
Assess coastal shoreline response to short and long-term coastal processes and sea level rise.	Outer Barrier Profile	GPS, possibly UAV, ortho-rectified imagery	4 sites	Seasonally and after major storms
	Outer Barrier Survey	LiDAR	Whole coast	Once every 5-10 years
Assess lake shoreline response to short and long-term coastal processes and sea level rise.	Lakes Shoreline profiles and mapping	GPS, UAV, aerial imagery	Whole shore including indicator sites	Yearly, at key sites after major storms
	Shoreline vegetation mapping	UAV, ortho-recified imagery, ground truthing	Lakes shoreline plus indicator sites	Once every 2-5 years
	Wave spectra	Bottom mounted, pressure sensing device	Temporary sensors at key locations	One-time deployment
	Wind speed and direction	Standard anemometer	At least one additional location in the central-lakes area	Continuous

7. LIMITATIONS AND UNCERTAINTY

A number of limitations and uncertainties exist that should be acknowledged when considering the finding of this project. They are described as follows:

Outer Barrier Coastal Hazards

- There is a paucity of historical aerial photography or other survey datasets in the study area to validate modelled longshore sediment transport rates and shoreline response. This makes it difficult to draw definitive and precise quantitative conclusions as to the extent to which variations in the longshore transport continuity are contributing to overall shoreline position and/or whether underlying trends in shoreline position exist.
- At present, no data exists from which detailed aeolian sediment transport rates can be inferred along the length of the Ninety Mile Beach. Therefore, there is uncertainty surrounding barrier translation rates due to onshore winds, in addition to overwash events.
- Back Barrier inundation and sediment deposition through overwash events was identified as providing a large proportion of the identified coastal hazard zone, especially and under higher mean sea levels. However, predicting the absolute timing and location of such events is not possible. Therefore, uncertainty exists as to the frequency and thus cumulative impact of such events.

Inundation Hazards

- A primary source of uncertainty stems from the unknown changes in atmospheric and oceanographic processes associated with climate change, i.e. changes in rainfall and wind patterns, exact magnitude and timing of sea level rise etc. Where deemed appropriate, sensitivity testing to changes in such processes was conducted, for example the sensitivity testing of increased catchment inflow in the inundation assessment. For the purposes of this project, where sensitivity of climatic change was not assessed, parameters such as wind speed, strength, direction, storm frequency and magnitude were assumed to remain the same as at present.
- The limited number of scenario and event combinations considered in the assessment did not enable differentiation between locations which may experience very frequent hazard impacts from other areas that would only be impacted occasionally under relatively low probability events. The study therefore provides an assessment of relative susceptibility to coastal hazard impacts generally and does not constitute a comprehensive coastal hazard vulnerability assessment at all locations within the study area.
- Two significant sources of uncertainty relating to the potential type and extent of inundation hazards that could develop at Seaspray were identified. These sources of uncertainty are associated with the potential inundation hazards from overwash of the Outer Barrier in the vicinity of Seaspray and the potential impact of land subsidence. Analysis of the potential impact of these sources of uncertainty identified that the extent and frequency of inundation hazards that could be observed at Seaspray are very sensitive to possible overwash and/or subsidence.

Lake Shoreline Susceptibility

- The accuracy of the Shoreline Erosion Susceptibility Assessment is directly related to the resolution and accuracy of the input datasets used. Further discussion on the uncertainty associated with the Shoreline Erosion Susceptibility Assessment is detailed in Report 4.
- Shoreline erosion rate estimates are provided in Table 3-1, however these are based on limited data and should not be assumed to be reliable. Refinement of erosion rate estimates can be achieved through future monitoring and analysis.

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