Coastal climate change vulnerability and adaptation

Final report: May 17, 2012

Great Ocean Road Coast Committee

Executive Summary

Climate change vulnerability and adaptation project

The *Climate change vulnerability and adaptation* project was initiated by the Great Ocean Road Coast Committee (GORCC) to enable it and other land, natural resource and infrastructure managers in Victoria's Surf Coast region to understand and respond to the challenges posed by climate change to its community, economy and natural assets. The project's objectives were to:

- Provide the first detailed climate change vulnerability assessment for the Surf Coast region;
- Recommend potential adaptive strategies to respond to climate change vulnerabilities;
- Provide a focal point for engaging the community in coastal climate change issues;
- Integrate with work at State and National levels;
- Provide a basis for future priority actions.

The project's scope was confined to *coastal* climate change challenges resulting from projected sea level rise and associated coastal erosion and recession.

A variety of stakeholders contributed to the project, including representatives of GORCC, the Department of Sustainability and Environment, Parks Victoria, Corangamite Catchment Management Authority, Surf Coast Shire and VicRoads. It was undertaken by Sinclair Knight Merz (SKM) in conjunction with Griffith University and CSIRO Marine and Atmospheric Research. In parallel with this work, CSIRO Marine and Atmospheric Research prepared an analysis of the implications of climate change for the regional wave climate and extreme sea level conditions.

This stage of the project will be followed by more detailed adaptation planning work that focuses on the key built and natural assets at risk from climate change.

Climate change projections

Historical and future emissions of greenhouse gases are projected to contribute to increases in global mean temperatures of about 2-4°C (relative to 1980-1999) by the end of the century. This In turn is projected to affect coastal and marine environments through elevated sea levels, changes in coastal wave climate and the associated patterns of erosion and sediment transport.

The extent of sea level rise over the course of this century is quite uncertain. Under most scenarios, projected sea level rise by 2030 is about 0.2 m. Sea level rise scenarios diverge significantly in the latter half of the century and range between 0.8 m and 1.4 m by 2100. This would increase the height of 1 in 100 year storm tide events for the Surf Coast region from 1.7 m to between 2.5 and 3.1 m above mean sea level. By 2100, the then 1 in 10 year storm tide event may be higher than the current 1 in 100 year event.

Sea level rise may contribute to the recession of erodible coasts, with the extent varying with coastal geomorphology, wave climate and sediment supply. A rule of thumb (the Bruun rule) adopted for this project suggests that erodible coasts may recede by 50 to 100 m for each metre of sea level rise. Based on this rule (which is the subject of much scientific debate) sandy and other unconsolidated coasts could eventually retreat by up to 20 m as a result of projected 2030 sea level rise and by 80-140 m in response to projected 2100 sea level rise.

Four sea level scenarios were adopted for the project, the current mean sea level and 0.2 m, 0.8 m and 1.4 m of sea level rise. While they correspond with current conditions and projections for 2030 and 2100, respectively, the timeframe over which these changes and any associated coastal recession occur is not considered. The 0.8 m sea level rise scenario is consistent with the requirements for climate change adaptation planning specified in the *Victorian Coastal Strategy.*

Exposure of coastal assets to inundation and recession

An analysis was undertaken of the extent to which built and natural assets may be exposed to the effects of projected sea level rise. The assessment considered temporary and permanent inundation (resulting from 1 in 100 year storm tide events and changes in mean sea level, respectively), as well as coastal recession. This stage of the assessment did not consider the extent to which exposure to these coastal hazards might damage the assets.

Exposure to coastal inundation

Exposure of built infrastructure and natural and heritage assets to temporary inundation from 1 in 100 year storm tides was assessed for each of the four sea level rise scenarios. Over 50 assets[1], with an estimated value of $16.6 million were assessed to be exposed to storm tide inundation under current conditions, including several buildings, car parks and caravan parks. This number would more than double with 0.8 m of sea level rise. The total value of (non-road) built assets on GORCC-managed land that was assessed to be exposed to temporary inundation with 0.8 m of sea level rise is $21.7 million.

Approximately 1.7 km of road is currently exposed to 1 in 100 year storm tide events. This is projected to increase to 13.4 km with 0.8 m of sea level rise. This includes short lengths of the Great Ocean Road (~0.5 km in total).

The general steepness of coastal landforms means that only relatively small areas of land would be exposed to inundation resulting from the 1 in 100 year storm tide, even allowing for the most extreme sea level rise scenario. Almost 240 ha of native vegetation was assessed to be exposed under current conditions. This was projected to increase to about 380 ha with up to 0.8m of sea level rise. Eight of 33 registered indigenous heritage sites located on GORCC-managed land would be exposed to temporary inundation with 0.8 m of sea level rise (compared with two sites currently).

Assets that are exposed to a 1 in 100 year storm tide may not necessary be damaged by them. Some types of built asset (e.g. boat ramps, some car parks or roads) could be exposed to temporary inundation with little more impact than a temporary loss of service. Some native vegetation communities located at low elevations are likely to be adapted to periodic, short-term inundation.

Exposure to coastal recession

While parts of the coastline are highly resistant to erosion (i.e. the hardened rocky coasts to the north and south of Lorne), the beaches and erodible sediments found in other locations are susceptible to coastal recession if sea levels rise as projected. Significantly more assets are located in areas that could be affected by coastal recession than is the case for temporary or permanent inundation.

Over 120 built assets located on GORCC-managed land were assessed to be exposed to coastal recession resulting from 0.2 m of sea level rise (assuming 100 m of coastal retreat for each 1 m of sea level rise). These assets are valued at over $30 million and include several buildings, car parks and caravan parks. This would almost double with projected recession resulting from 0.8 m of sea level rise. The value of assets exposed would increase to an estimated $137 million.

About 130 ha of native vegetation land was assessed to be exposed to coastal recession resulting from 0.2 m of sea level rise. This is projected to increase to over 700 ha with recession resulting from 0.8 m of sea level rise. This would include large areas of vulnerable and depleted ecological vegetation classes (EVCs), as well as small areas of EVCs whose conservation status is classified as rare and endangered and whose distribution is quite restricted. Two thirds

[1] Owned by GORCC or located on GORCC-managed land

of the identified indigenous heritage assets located on GORCC-managed land would be exposed to coastal recession with 0.8 m of sea level rise (up from 8 assets currently).

Climate change risk assessment

An assessment of climate change risk was undertaken that considered the exposure of assets to coastal hazards resulting from sea level rise as well as the consequence of that exposure. It drew on the GIS-based exposure analysis and a stakeholder workshop. It considered a broader set of assets than the exposure analysis. Risks were assessed under each of the four sea level/sea level rise scenarios adopted for the project and that erodible sections of the coast will retreat by 100 m for each metre of sea level rise.

To capture variation in the distribution of uses, as well as of built and natural assets, the climate change risk assessment was undertaken for each of six sections of the Surf Coast region’s coastline:

- Point Impossible to Bells Beach
- Bells Beach to Point Addis
- Point Addis to Urquhart’s Bluff
- Urquhart’s Bluff to Spout Creek
- Spout Creek to North Lorne
- North Lorne to Cumberland River

The six sections of the Surf Coast region differed markedly in their assessed risk from coastal inundation and recession. The differences reflect the relative concentrations of natural and (particularly) built assets, as well as coastal landform and geology. The sparsely developed Bells Beach-Point Addis and Spout Creek-North Lorne sections of the coast had significantly fewer assets exposed to the main coastal hazards than the other four sections of coastline and so recorded fewer risks.

There was typically a large increase in risk exposure between 0.2 m and 0.8 m of sea level rise. Adding a further 0.6 m of sea level rise (to 1.4 m) only marginally increased the number of assets assessed to be at “high” or “extreme” risk, although it may have added to the length or area of asset assessed to face those higher risk categories. Coastal recession rather than inundation was the major source of risk for all scenarios and sections of the coast.

Maps have been prepared for each section of the coast to highlight the types of asset exposed to risk from inundation, storm erosion and coastal recession and the sea level rise scenario that first gives rise to “high” or “extreme” risk ratings.

Material risks resulting from sea level rise were identified through the risk assessment to affect five broad asset classes, the characteristics of which are outlined in the table below. These risks should become the focus of the adaptation planning by GORCC and the wide range of other coastal asset and land managers who “own” the risks.

Characteristics of Surf Coast region priority asset-risk classes

Asset class & description	Key location(s)	Key risk owners
Beaches and associated recreational and tourism infrastructure: including beaches and the infrastructure (access tracks or pathways, car parks, playgrounds, amenity blocks, Surf Life Saving Clubs, boat ramps etc.) that add to the safety and amenity of beach use. **Assets are mostly at risk from damage due to coastal erosion and recession. Beaches are also threatened by changes in the extent and frequency of tidal inundation.**	Torquay, Anglesea, Aireys Inlet-Fairhaven, Lorne	GORCC, Parks Victoria, DSE, Surf Coast Shire, Surf Life Saving Victoria

Asset class & description	Key location(s)	Key risk owners
Environment and heritage features: intertidal and dune habitats and dependent species. Sites and places of indigenous cultural heritage. **Assets are at risk from changed inundation patterns and coastal erosion and recession.**	All six sections of coast	Aboriginal Affairs Victoria, Traditional Owners, DSE, Parks Victoria, Corangamite CMA, GORCC
Residential and commercial properties: private residential and commercial properties located in areas at risk from coastal recession. **Assets are mostly at risk of damage from coastal recession. Such damage and regional impacts on beaches and beach amenity may affect property values.**	Locations at Torquay, Anglesea, Aireys Inlet-Fairhaven, Lorne	Surf Coast Shire, Department of Planning and Community Development, private residents, business owners, GORCC, DSE, Parks Victoria.
Roads: including local roads, foot paths, sections of the Great Ocean Road and road bridges. **Material risks are mostly associated with coastal recession, despite significant lengths of road being potentially exposed in future to 100 year storm tides.**	Torquay, Anglesea, Aireys Inlet-Fairhaven. Great Ocean Road from Anglesea-Spout Creek	Surf Coast Shire, VicRoads, GORCC, Parks Victoria, DSE
Surf breaks: including reef and beach breaks. **Operation of reef and beach surfing breaks may be affected by changes in water levels.**	All six sections of coast	DSE, Parks Victoria, Surf Coast Shire, GORCC

Adaptation framework

Climate change adaptations are the 'adjustments made in natural or human systems in response to experienced or projected climate conditions or their beneficial or adverse effects or impacts'. They may be planned measures, such as the construction of groynes to hold sand on a beach, or may occur autonomously or without planned action, such as might occur as beaches backed by sand dune systems retreat inland in response to increasing sea levels.

In the context of risk management, adaptations are the controls introduced to manage priority risks. They may range from modest, incremental changes to current management practices (e.g. extending the elevation of a boat ramp so that it remains serviceable as sea levels rise) to major, transformational changes (e.g. planned retreat of residential developments from land at risk from coastal recession).

Adaptation principles

For consistency of approach, adaptation planning should be undertaken in the context of a set of underpinning principles. These principles should reflect community and stakeholder organisations' values, government policy and legislation. Seven underpinning adaptation principles have been proposed, as follows:

#1 The coastal hazard area is defined by land and assets potentially affected by at least 0.8 m of sea level rise and any associated coastal recession.

#2 Planning and decision making will be informed by the best available science and risk management approaches.

#3 Communication of climate change hazards and risk, community consultation and participation are critical ingredients in adapting to climate change.

#4 In undeveloped coastal areas, plan to avoid new development in coastal hazard areas.

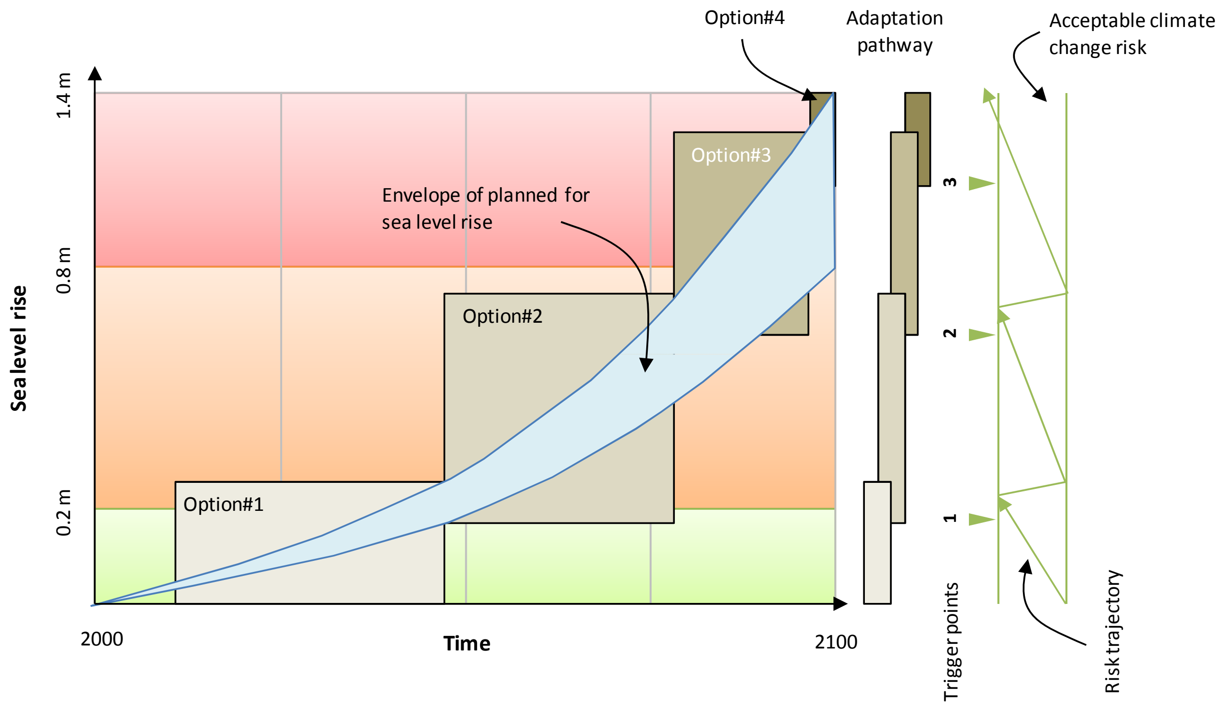
#5 In partly-developed and developed coastal areas, plan to sustainably reduce coastal hazard risk.

#6 Infrastructure developed on Crown land in partly-developed and developed coastal areas is coastal-dependent.

#7 Plan for emergency responses to extreme sea level and coastal erosion hazards in partly developed and developed coastal areas.

Flexible adaptation pathways

The adaptation framework provides for the development of flexible adaptation pathways that are responsive to experienced changes in sea levels, coastal recession and risk perception (see figure below). It provides for the sequential deployment of adaptation options or tactics, each of which suits particular 'windows' of sea level rise or coastal recession. The deployment of new adaptation options or tactics is triggered by an approaching risk threshold. The deployment process begins before the risk threshold is reached to ensure there is sufficient time for planning, finance raising and community or stakeholder engagement. Trigger points are risk-based and draw on experienced coastal hazard conditions (change in sea level, coastal recession). They are not time-based and so provide flexibility to adapt to more or less rapid sea level rise while remaining within acceptable risk levels.



Adapted from NZ Ministry for Environment 2008

Illustration of the proposed framework for flexible adaptation pathways. The chart shows the planned-for envelope of potential sea level rise during the 21st century (based on 0.8-1.4 m rise by 2100). In this illustration, four adaptation tactics are planned for deployment over the course of the century (or longer if sea level rise is less than the projected upper range). Option #1 is designed to mitigate risk to about 0.25 m of sea level rise. At about 0.2 m of sea level rise, the process for deploying Option #2 is triggered. This option mitigates risk until sea level rise reaches about 0.75 m. Deployment of Option #3 is triggered at about 0.7 m. Option #3 treats risk effectively to about 1.3 m. Above this level of rise, there are no affordable and effective options to mitigate impacts exist and option 4 – accepting sea level rise and managing its impact or retreating from it is adopted. Risk falls outside the typically accepted range from this point.

Adaptation priorities

The resources available to the current stage of the *Climate change vulnerability and adaptation* project are not sufficient to fully apply the adaptation framework above. However, adaptation priorities that flow from the risk assessment process have been defined, in terms of the types of asset, sections of coastline and potential focus areas for adaptation. The next stage of the project will see detailed adaptation planning undertaken to address the identified priority risks.

Monitoring and review

Monitoring and review are critical components of any risk management process. They are particularly important for climate change risk assessments, in which: the hazards will emerge over long time scales; understanding of risks is changing rapidly; and flexible planning responses are required. A framework for monitoring and review has been developed for adaptation to coastal climate change hazards. It includes five main elements:

- Monitoring of sea level rise and coastal recession scenarios to ensure the risk assessment and adaptation strategy are based on best available climate change science.
- Monitoring of coastal hazards and condition of key assets to detect evidence of change and trigger points for adaptation.
- Asset maintenance and renewal expenditures that relate to coastal hazards to help establish or confirm the business case for adaptation.
- Periodic review of the climate change risk register to ensure that it continues to reflect the risk priorities for coastal assets.
- Adaptation strategy to ensure that adaptation tactics and plans are consistent with risks, latest practice and government planning and policy.

Further work is required to refine the monitoring and review framework into a plan for implementation once the adaptation framework is developed into a formal adaptation strategy.

Next steps

This stage of the *Climate change vulnerability and adaptation* project has identified the key risks for GORCC and other coastal land and asset managers that are projected to result from sea level rise and associated coastal recession. A framework for adaptation has been developed that provides the basis for more detailed planning. A further stage of the project is required to undertake this more detailed adaptation planning. Some key steps that may be involved include:

- Stakeholder engagement – to engage key 'risk owners' in the details of adaptation planning.
- Literature review and method development – to identify current best practice in managing risks from sea level rise and associated change in the coastline and assessing adaptation options.
- Adaptation option development – develop long-term and flexible adaptation pathways for each class and type of asset in their unique risk contexts up to at least 0.8 m of sea level rise. Develop trigger points adaptation sequences.
- Apply economic and other assessment tools to evaluate alternative adaptation pathways and establish the case for investment.
- Develop detailed adaptation action plans for each asset class and synthesise into an overall adaptation strategy for the Surf Coast region.

Funding for this project was provided by the Australian Government.

Contents

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Version 1	27.05.2011		C.Clifton	27.05.2011	Draft
Version 2	22.07.2011	G.Race, S.Coverdale (GORCC)	A.Brinkley	22.07.2011	Revision
Version 3	12.12.2011		A.Brinkley	12.12.2011	Final
Version 4	17.05.2012	GORCC, DSE, CCMA	A.Brinkley	17.05.2012	Final

Distribution of copies

Printed:	17 May 2012
Last saved:	17 May 2012 08:12 AM
File name:	D:\skm\vwes\projects\vw05093\report\final\SKM VW05093 Project Report final 160511-v4b.docx
Authors:	Craig Clifton, Dan Ware, Stephen Impey and Chloe Hanson-Boyd
Project manager:	Craig Clifton
Name of organisation:	Great Ocean Road Coast Committee
Name of project:	Climate change vulnerability and adaptation project
Name of document:	Final report
Document version:	Version 4
Project number:	VW05093

Glossary

Adaptation	Adjustment in natural or human systems that are taken in response to actual or expected climatic [and other] stimuli or their effects, which moderates harm or exploits beneficial opportunities [2]. Adaptation is concerned with managing the unavoidable impacts of climate change (and variability) and considers what needs to be done differently – both more and better – to cope with the change
Bruun rule	The Bruun Rule of coastal erosion is a rule of thumb that applies an understanding of the dynamics of the coastal zone where substrate moves according to offshore/on shore patterns. It is particularly applied is estimating the recession of erodible coastlines in response to climate change.
Capacity building	A process of building capabilities in individuals, groups, institutions, organizations and societies to more effectively prepare for and respond to risks.
Climate change	Refers to a change in the state of the climate that can be identified by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may occur because of internal changes within the climate system or in interaction between its components, or because of changes in external forcings either for natural reasons or because of human activities. It is generally not possible to clearly make attribution between these causes. Projections of future climate change generally consider only the influence of climate on anthropogenic increases in greenhouse gases and other human-related factors (IPCC, 2007).
Coastal dependent infrastructure	Infrastructure whose use relates to its proximity to the coast. Examples include boat ramps, sailing club houses, Surf Life Saving facilities, amenities blocks.
Coastal hazard	In this report, consideration of coastal hazards is largely confined to temporary or permanent inundation (or coastal flooding) and coastal erosion and recession. Estuary closure and related flooding may be linked to these hazards.
Consequence	Outcome of an event. Risk is assessed on the basis the expected consequence of a hazard for a particular receptor (e.g. road, area of native vegetation) and the likelihood of that consequence.
Event	Occurrence of a particular set of circumstances. The event can be certain or uncertain. It can be a single occurrence or a series of occurrences.
Exposure assessment	In this report, this refers to an assessment as to whether an asset or feature may experience a permanent or temporary inundation hazard under a given climate change or sea level rise scenario. The assessment differs to a risk assessment in that the consequence of exposure is not considered.
Impact	An effect or influence.
Likelihood	The likelihood of an occurrence, an outcome or a result, where this can be estimated probabilistically. In risk assessment, it refers to the likelihood that the assessed consequence of an impact would occur.
Material risk	In this report a material risk is a "high" or "extreme" rated risk (Table 12) that management attention and action.

Mitigation	Measures taken to reduce adverse affects on the environment and/or manage associated risks. In the context of climate change it refers to human interventions that reduce the sources or enhance the sinks of greenhouse gases.
Permanent inundation	The daily or sub-daily inundation of low-lying land by typical astronomical tides.
Receptor	An asset, feature or group that potentially experiences the influence of a hazard.
Recession	The retreat of a coastline under the influence of wind and wave action and potentially resulting from sea level rise. Movement of sediment may also result in some sections of coasts advancing.
Response	In the context of this report, response generally refers to actions and decisions that are made in response to climate change (and variability), and associated risks.
Risk	The potential for realisation of unwanted, adverse consequences; usually based on the likelihood of an event occurring multiplied by the consequence of the event, given that it has occurred.
Risk assessment	The assessment of the implications of a hazard event for a receptor. It considers the potential consequence of the hazard and the likelihood of that consequence. Risk is assessed using AS/NZS ISO 31000:2009 [9].
Risk treatment	A new control or response implemented to reduce the consequence or likelihood of a risk. In a climate change context, risk treatments equated to adaptations.
Scenario	A coherent, plausible but often simplified description of a possible future state. Scenarios capture a range of future possibilities and allow decision makers to consider changes that might otherwise be ignored.
Temporary inundation	Or episodic inundation, which occurs as a result of storm surges, catchment flood events, estuary closure and/or seasonal high tides that increase water levels and inundate land outside the typical diurnal tidal range

1 Introduction

The Intergovernmental Panel on Climate Change (IPCC), in their *Fourth Assessment Report* [1] concluded that there was unequivocal evidence of warming of the global climate system. They projected that under plausible scenarios for global change and emissions of greenhouse gases, temperatures would increase by between about 2 and 4°C (relative to 1980-1999) by the end of the century. They found that after accounting for thermal expansion of ocean waters and ice cap retreat, this could lead to global mean sea levels rising by up to about 0.79 m by 2100 [2]. These estimates remain uncertain and end of century sea level rises of more than 1.0 m and even as high as 1.5 m are considered to be plausible [3].

In areas with sandy or other erodible shorelines, rising sea levels may lead to coasts retreating landwards [3]. While the rate of recession is highly uncertain, a rule of thumb (the Bruun rule [4]), suggests that some sandy coasts may retreat by 50-100 m for each metre of sea level rise.

As a manger of coastal land, environments and infrastructure, the Great Ocean Road Coast Committee (GORCC) is obliged to follow the *Victorian Coastal Strategy* [5], which states that end of century sea level rise of at least 0.8 m must be planned for. This project, the *Climate change vulnerability and adaptation* project, was initiated by GORCC to enable it and other land, natural resource and infrastructure managers in the Surf Coast region (Figure 1) to commence such planning. The project was developed to:

- Provide the first detailed climate change vulnerability assessment for the Surf Coast region;
- Recommend potential adaptive strategies to respond to climate change vulnerabilities;
- Provide a focal point for engaging the community in coastal climate change issues;
- Integrate with work at State and National levels;
- Provide a basis for future priority actions.

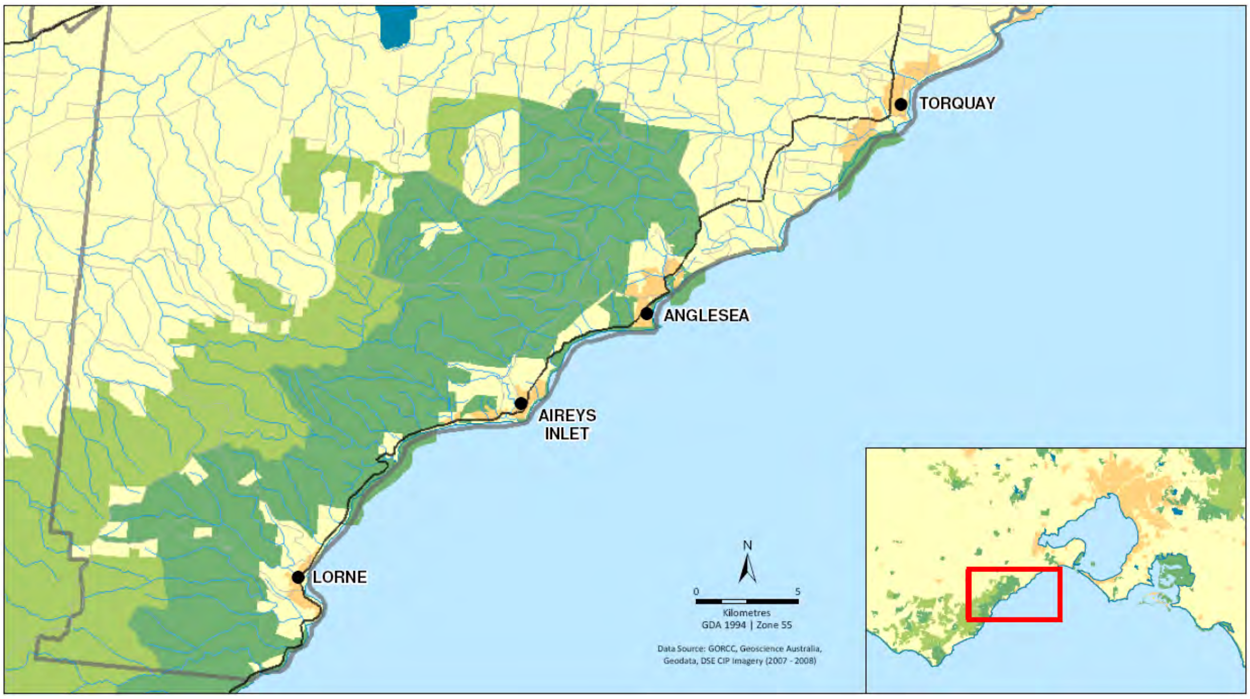


Figure 1 Victoria's Surf Coast region, which extends between Torquay and Lorne

Sinclair Knight Merz (SKM), in conjunction with CSIRO Marine and Atmospheric Research and Griffith University, were commissioned by GORCC to undertake this project. The project took a risk-based approach to assessing the potential implications of climate change for key natural and built assets and the broader community and economy of the Surf Coast region and developing appropriate responses. This document reports on its main outputs.

2 Climate change vulnerability and adaptation project approach

2.1 Overview

The *Climate change vulnerability and adaptation* project was undertaken in three main stages. Its *first stage* included several activities to establish the context for the project and develop the method to be implemented in its second stage. The initial step involved gathering data on the geomorphic conditions and built and natural assets and compiling this in a project geographic information system (GIS). A workshop was subsequently run with key technical people from the consulting team and representatives from GORCC and stakeholder organisations. Based on stakeholder input, the workshop helped to identify the key natural and built assets located in each major segment of the coastline. Presentations on the science of coastal climate change were given to develop participants' understanding and enable a scope of work to be developed for the remainder of the project that was consistent with the project objectives, budget and available science. An agreed method was then documented for the project's implementation stage.

A *climate risk and adaptation planning framework* (Chapter 2.2) was developed and applied by SKM in the project's *second stage*. Preparatory work included an assessment of historical changes in coastal landforms to detect 'background' patterns of coastline retreat and/or advance. Proximity to the coast and elevation above sea level of identified built and natural assets was also assessed to identify what may be exposed to the effects of coastal flooding, erosion and recession under current conditions and plausible levels of sea level rise.

In the project's *third stage*, *wave climate modelling* was reviewed by CSIRO Marine and Atmospheric Research [6] to assess how wave climate and extreme sea levels might change in response to sea level rise, changed ocean currents and wind conditions. This work drew on finer resolution modelling than was previously used by CSIRO in their analysis of extreme sea levels for the full extent of Victoria's open coasts [7].

2.2 Risk framework

The *Climate change vulnerability and adaptation* project adopted a risk-based approach to its consideration of the potential implications of and responses to climate change. This is consistent with the broad approach to climate change adaptation promoted by the Australian Government [8]. The risk framework is based on the Australian Standard for risk assessment and management (AS/NZS ISO31000:2009 [9]; Figure 2) and comprises five core steps:

- Establish the context – determine the objectives for the risk assessment, its scope, stakeholders who need to participate or be aware of it and the climate and climate change scenarios being considered.
- Identify risk – describe how climate change affects key elements of the system which is the subject of the risk assessment.
- Analyse risk – consequences and likelihood of each specific impact is assessed and from this the overall level of risk determined.
- Evaluate risk – the severity of risk is ranked and minor risks screened. High risk impacts that require more detailed assessment and response are identified.
- Treat risk – options for treating priority risks are identified and evaluated. More effective and practically implementable measures are incorporated into action plans that form the basis of climate change adaptation.

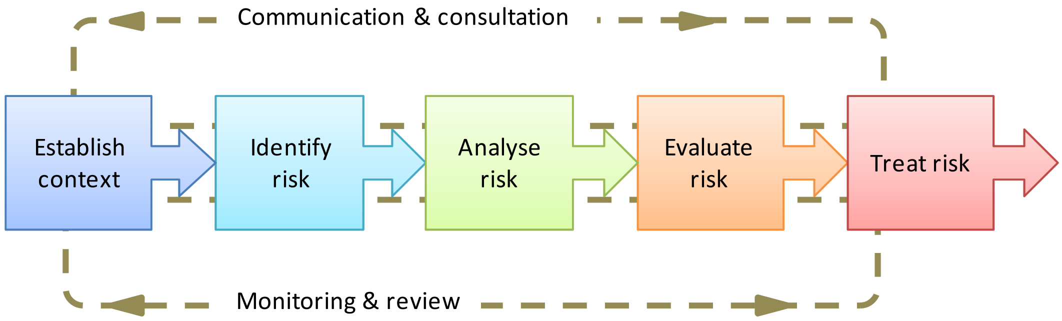


Figure 2 ISO 31000:2009 Risk assessment and management framework (redrawn from [9])

Risk assessment and adaption planning is best undertaken as a participative exercise that engages key stakeholders and draws on their knowledge of the 'system' under consideration. For this second stage of the project, key stakeholder organisations include: GORCC, Surf Coast Shire, Corangamite Catchment Management Authority (CMA), Department of Sustainability and Environment (DSE), Parks Victoria and VicRoads. Representatives of most of these organisations actively participated in various parts of the project.

The risk framework (Figure 2) is used as a header in the remaining chapters of this report to flag how that particular chapter contributes to the risk assessment-adaptation planning framework.

3 The Surf Coast region

3.1 Location

Victoria's Surf Coast region corresponds with the Surf Coast Shire and extends from Point Impossible, near Torquay in the north-east, to Cumberland River, near Lorne in the south-west (Figure 1). This 55 km stretch of coastline includes nature conservation reserves and important coastal ecosystems, as well as coastal towns and villages, beaches, caravan parks and recreation reserves. The Surf Coast hinterland includes extensive areas of native forest and farming land, as well as small areas of pine and eucalypt plantation and the catchments of the small streams that drain to this section of coast.

3.2 Community and economy

The estimated population of Surf Coast Shire is approximately 26,000 [10]. The Shire and region is one of the fastest growing in Victoria and is one of the main recipients of 'sea change' migration from Melbourne and inland centres. Population is projected to grow to almost 35,000 by 2026, an increase of over 35% in 15 years [11]. Most of this growth is planned to be concentrated around Torquay.

The economy of the Surf Coast region is strongly dependent on its coastal amenity and tourism. The Great Ocean Road, which runs south-west from Torquay, attracts over 2.5 million visitors annually. During the summer peak, tourists may treble the population [12]. Over 20% of the local population work in tourism exposed employment sectors (i.e. retail trade, accommodation and food services, arts and recreation services; [13]). Sea change migration helps to drive the construction industry, which is the main industry of employment (accounting for 12% of employment [13]). Tourism adds over $258 million to the Surf Coast Shire's economy annually [14].

3.3 Climate

The Surf Coast region has a temperate climate, with mild and relatively dry summers and cooler and relatively wet winters (Figure 3). Average annual rainfall is 626 mm/y at Anglesea, but ranges between about 520 mm/y at Grovedale (the closest observation to Torquay) and 920 mm/y at Lorne.

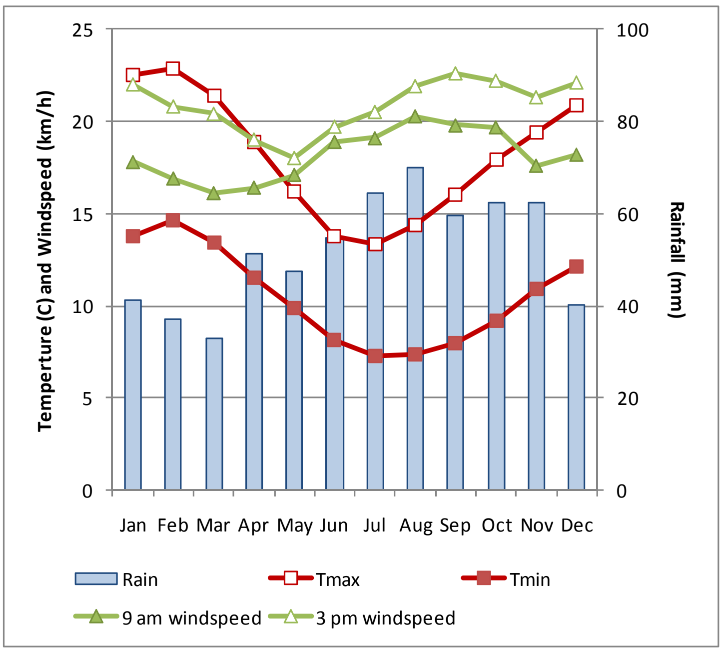


Figure 3 Average monthly rainfall, maximum and minimum temperature (Tmax/Tmin) and 9 am and 3 pm wind speed for the Aireys Inlet meteorological station [15].

Average daily maximum temperature through summer is 21-23°C and 13-14°C through winter. The proximity of Bass Strait moderates summer heat and overnight temperatures during winter relative to inland areas (Figure 3). The Surf Coast region is predominantly exposed to a southerly and westerly wind climate. Winds are strongest in spring (Figure 3) and during summer afternoons (under the influence of sea breezes).

3.4 Geology and landforms

The Surf Coast region has two major geological units [16], the Otway Group of Early Cretaceous volcanic and fluvial sedimentary bedrocks that form the coastline south from Eastern View, west of Aireys Inlet and the largely sedimentary rocks of the overlying Torquay Basin that form the coastline north-east of that point. The Torquay Basin comprises three main groups of rocks that form the surface geology or are exposed at various points along the coast [16]:

- Eastern View Group of non-marine Palaeocene to Middle Eocene sediments, comprising sequences of brown coal, clay and sand;
- Eocene to Oligocene Demons Bluff Group of sands, sandstone, conglomerate, claystone, basalt and pyroclastic rocks;
- Marine carbonate rocks of the Torquay Group.

Between Torquay and Anglesea, the coast is dominated by dissected sedimentary plains, which either form erodible cliffs or back sandy beaches. The coast to the east and west of Anglesea (to Aireys Inlet) is dominated by coastal barriers of windblown sand that form dunes or erodible cliffs that also back sandy beaches. From about Moggs Creek (west of Aireys Inlet) south-west, the coastline is dominated by the hard rocks of the Otway Ranges. These run to the coast as headlands or lie behind relatively narrow, sandy beaches.

Resistance of the coastline to erosion and recession was assessed using data on intertidal and backshore geology from the Smartline analysis [17]. Three main backshore types are identified: undifferentiated dunes, soft bedrock cliffs and hard bedrock cliffs. With the exception of a small outcrop of hard rock at Anglesea, the coast from Point Impossible to Eastern View is dominated by dunes and soft bedrock cliffs. With the exception of the coast immediately to the north and south of Lorne, the remainder of the coast south-west of Eastern View is dominated by hard bedrock cliffs (Figure 4).

There are four main intertidal landforms along the Surf Coast [17]: fine to medium sandy beaches; undifferentiated sandy beaches; soft bedrock shores; and hard bed rock shores and shore platforms. The majority of the coast has either form of sandy beach, including most areas with hard rock cliff backshores (Figure 4). Almost all of the hard rocky intertidal areas are located in areas with hard rock cliff backshores. There are only small areas classified as soft bedrock shore, all of which are located in areas with soft bedrock cliffs (Figure 4).

Smartline data have been interpreted to indicate that only the areas of hard rock cliff backshores are resistant to coastal erosion and recession in response to projected sea level rise.

3.5 Wave climate and extreme sea level conditions

The region's coastline is predominantly open and is highly exposed to the wind and wave environment generated in the Southern Ocean and western reaches of Bass Strait. Extreme sea levels in the region most commonly result from the combination of high astronomical tides and storm surges (see Chapter 4). The latter are typically associated with eastward moving cold frontal systems that bring westerly to south-westerly winds to Australia's south coast [6].

High wave events are generally associated with westerly to south-westerly winds, although shoreward wave energy transport and wave set up is smallest in westerly events and greatest in southerly events [23]. This suggests that storm surges produced under westerly wind events are unlikely to be enhanced by wave set up, whereas those generated in southerly events may be [6]. Modelling suggests that the largest waves along the Surf Coast

Figure 4 Coastal landforms of the Surf Coast region. Coastal areas that were assumed to be resistant to erosion and recession were those with hard rock cliffs, with either sandy or rocky shorelines. Coasts with sandy shorelines in front of hard rocky cliffs would be vulnerable to erosion, but are unlikely to recede. Data derived from [17].

occur under southerly wind conditions, in part due to the shelter provided by Point Hawden, near Kennett River, from larger waves from the south-west [6].

3.6 Coastal land tenure and management

Coastal land in the Surf Coast region has a variety of tenures and is managed by multiple agencies. Much of the coastline is public or Crown land and is managed by GORCC on behalf of DSE or by Parks Victoria. GORCC is typically responsible for the management of coastal Crown land reserves on which development has taken place (e.g. caravan parks, recreation areas, boat ramps) to support coastal-dependent recreation or tourism activities. Surf Coast Shire is responsible to DSE for the management of the Bells Beach Surfing Reserve.

Parks Victoria is generally responsible for the management of coastal land with lower levels of facilities and infrastructure and with greater priority to nature-based experiences. This includes the Great Otway National Park, Point Addis Marine National Park and the Eagle Rock and Point Danger marine sanctuaries, which are located off the coast. DSE manages all other marine areas and the seabed not included in the marine national park and sanctuaries.

Most of the areas inland from the GORCC managed coast are either managed by VicRoads (e.g. Great Ocean Road), Surf Coast Shire (e.g. other roads, some recreation reserves) or private land owners (e.g. residential and commercial land, golf courses).

Utility providers (i.e. Barwon Water, Powercor, Telstra) and lessees (e.g. Surf Life Saving Victoria) also have formal management responsibilities for assets and infrastructure located on GORCC-managed land.

3.7 Assets and services

Key built and natural assets and the values associated with them (Table 1) were identified through stakeholder consultation and analysis of spatial data sets from GORCC, DSE and other sources. These have been incorporated into the risk assessment and adaptation planning framework. Only assets located within about 200 m of the coast and in nearby coastal waters have been included. These were considered to be potentially exposed to the effects of sea level rise on coastal flooding, water levels and coastal erosion and recession processes.

These assets provide a wide range of valued services to the Surf Coast region and broader community. Services provided by this suite of assets have socio-economic (e.g. provision of lifestyle, recreational and aesthetic amenity, cultural heritage, generation of economic activity and employment) and environmental dimensions (especially relating to protection and maintenance of biodiversity).

Table 1 Surf Coast region key assets and services

Asset class	Description and services
Beaches	Key beaches with significant lifestyle, recreational and tourism value, particularly including those near the main settlements, Torquay-Jan Juc, Anglesea, Aireys Inlet, Fairhaven and Lorne.
Boat ramps	Developed ramps that support recreational boating and fishing, including those at the major towns (Torquay, Anglesea and Lorne).
Car parks	Coastal car parks that support recreational use of beaches, parks and recreational facilities.
Caravan parks	GORCC managed caravan parks located on coastal reserves and their associated infrastructure.
Commercial properties	Retail and other businesses located in close proximity to the coast.
Creeks and estuaries	Streams that drain to the coast, including the reaches influenced by tidal conditions (estuaries).
Cultural heritage features	Places and sites of indigenous cultural heritage, sites of non-indigenous cultural significance.

Asset class	Description and services
Drainage	Surface water drainage infrastructure running to the sea or coastal flowing streams.
Dune and cliff habitats and fauna	Near shore terrestrial habitats and their native flora and fauna.
Inter-tidal habitats and fauna	Habitats influenced by tidal inundation and wetting and drying cycles and the native fauna that rely on them.
Pathways, walks and lookouts	Defined coastal walking paths, tracks and stairs for accessing the main beaches and developed lookouts.
Parks and recreational facilities	Developed parks, playgrounds and related facilities (e.g. toilets, barbeques, swimming pools) located in foreshore reserves.
Pier	The Lorne pier, which is used for recreational fishing and boating, as well as sightseeing.
Residential property	Houses and other infrastructure associated with residential land in coastal areas.
Roads and bridges	Including the Great Ocean Road, other roads connecting commercial and residential areas located near the coast.
Sailing clubs	Clubhouse and other infrastructure associated with sailing clubs at Torquay and Anglesea.
Surf breaks	Reef and beach surf breaks.
Surf Life Saving Clubs (SLSC)	Club buildings and associated infrastructure servicing recreational use of beaches and providing emergency service support.
Water infrastructure	Potable water and waste water treatment infrastructure.

4 Coastal climate change hazards

4.1 Coastal processes

A variety of geological, atmospheric, marine and terrestrial processes continually interact to shape coastal landforms and conditions. Wind, waves, tides and storms are the primary driving forces of change in coastal landforms and conditions in Victoria.

- **Wind** - is the result of horizontal gradients in air pressure. The intensity of pressures systems, their distribution and passage across the Southern Ocean and Australian continent determine wind strength and direction. Winds generate waves and currents, which directly shape coastal landforms.
- **Waves** - are the principal source of energy for most coastal systems and develop in response to wind. Waves colliding with the coast provide the energy needed to move sediment and reshape shorelines.
- **Tides** - are the vertical movements of the water level that result from the gravitational forces of the moon and sun acting on ocean waters. This movement is responsible for the inundation of low-lying coastal land at sub-daily to seasonal timescales. Tides are another major source of marine energy that shapes coastal landforms and play an important role in the transport of coastal sediments.
- **Storms** – in Victoria, storms are generally experienced as cold fronts and intense low pressure systems pass across the Southern Ocean/Great Australian Bight. The sharp pressure gradients generate strong winds and high waves and may lead to erosion of sensitive coastal landforms [6]. Lower air pressure and wind-generated waves may also lead to elevated water levels (storm surges) and inundation of low-lying coastal land as storm systems pass. Depending on the timing of the storm, tides may exacerbate storm surge flooding. Rains generated by storms may also lead to flooding of land adjacent to coastal rivers and estuaries.

Energy from waves, tides and storms is responsible for the erosion of beaches and cliffs and the movement of sediment on and off-beaches and along the coast. Sediment moved by wave action contributes to the closure of estuaries, which occurs frequently in the Surf Coast region.

4.2 Coastal hazards

Coastal processes, such as wind, waves, tides and storms may create 'coastal hazards' that adversely affect life, property, built infrastructure and the natural environment. The primary coastal hazards that this project is concerned with are inundation and recession.

Coastal inundation

Coastal inundation is the flooding of land adjacent to coasts and estuaries by ocean waters or river catchments. Coastal inundation occurs naturally in two main forms. 'Permanent' inundation is the daily or sub-daily inundation of low-lying land by typical astronomical tides. 'Temporary' or 'episodic' inundation occurs as a result of storm surges, catchment flood events, estuary closure and/or seasonal high tides that increase water levels and inundate land outside the typical diurnal tidal range (Figure 5).

While episodic coastal inundation is rarely prolonged, it has the potential to significantly damage affected natural and built assets. The extent of damage is most influenced by the depth and velocity of water.

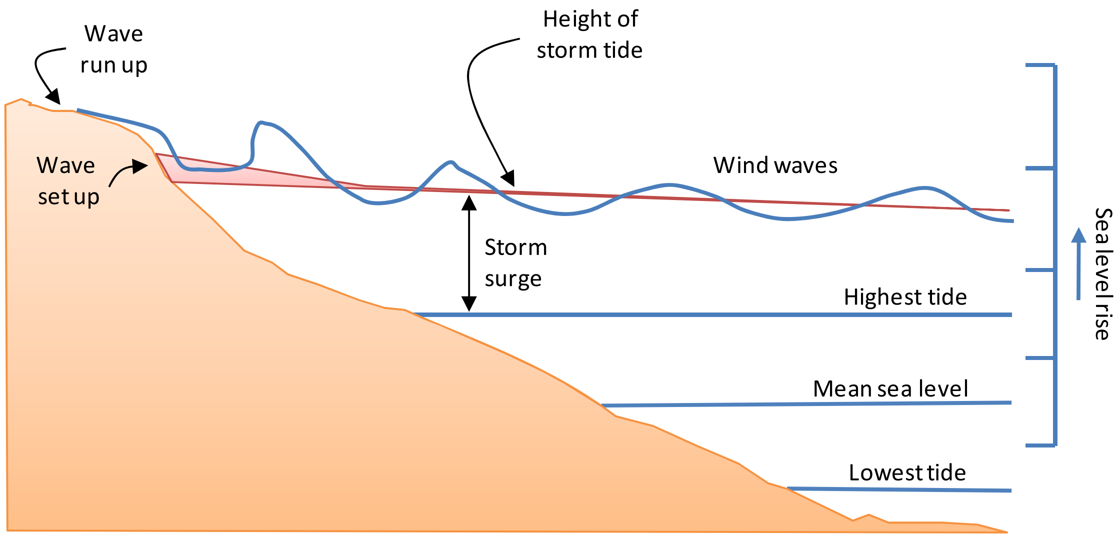


Figure 5 Illustration of how tides, storm events and sea level rise influence coastal water levels. Storm surges are temporary increases in coastal sea levels that are caused by lower atmospheric pressure and/or severe winds. Storm surges are often accompanied by a further increase in water level due to the cumulative effect of breaking waves (wave setup) and the run-up of individual waves. The height of a storm surge is influenced by its timing in relation to astronomical tides. The most extreme sea levels (storm tides) occur when storm surges combine with high astronomical tides. Warming of oceans and ice sheet melt associated with climate change are projected to contribute to rising sea levels and may exacerbate inundation under storm surge and storm tide conditions. Redrawn from [7].

The Lorne tide gauge provides a long-term record of sea level variability for the Surf Coast region. The 10 year average recurrence interval (ARI[2]) storm surge and storm tide are 0.51 and 1.32 m above mean sea level (MSL), respectively [7]. The 100 y ARI storm surge and storm tide heights, which are those typically used in coastal flood risk assessments, are 0.71 and 1.69 m above MSL, respectively [6]. Storm surge and storm tide heights are significantly lower along the Surf Coast than some other parts of the Victorian coastline. The 100 y ARI storm tide heights in Westernport Bay and parts of the western coast of Wilsons Promontory are estimated to exceed 2 m [7].

Coastal recession

The position of the coast or shoreline at any point in time is determined by the interrelation of coastal processes, landform types, sediment supply and tectonic factors such as subsidence. Coastal recession is the landward retreat of the shoreline as a result of erosion. It can occur naturally in areas with unstable landforms and erodible sediments (e.g. sandy beaches, mudflats, limestone or unconsolidated sedimentary cliffs) and may be exacerbated by rising sea levels.

Coastal recession may occur in response to the repeated removal of sediments by waves during storm events (Figure 6) or in circumstances where there is continuing unreplaced loss of sediment from the beach compartment (e.g. where an engineered structure impedes longshore sediment movement). Sandy beaches and sandy and muddy shorelines are most susceptible to the effects of storms and can erode rapidly over a very short period of time. Sandy beaches tend to commence recovery soon after storms pass as sand from the offshore bar is slowly reworked onshore (Figure 6).

---

[2] The average recurrence interval (ARI) or return period for a storm surge or storm tide of a given height is the calculated *long-term* average period between successive events of that height. However, since extreme sea levels are random events, it is possible for a storm tide with say, a 100 y ARI/return period, to recur in successive years or even weeks.

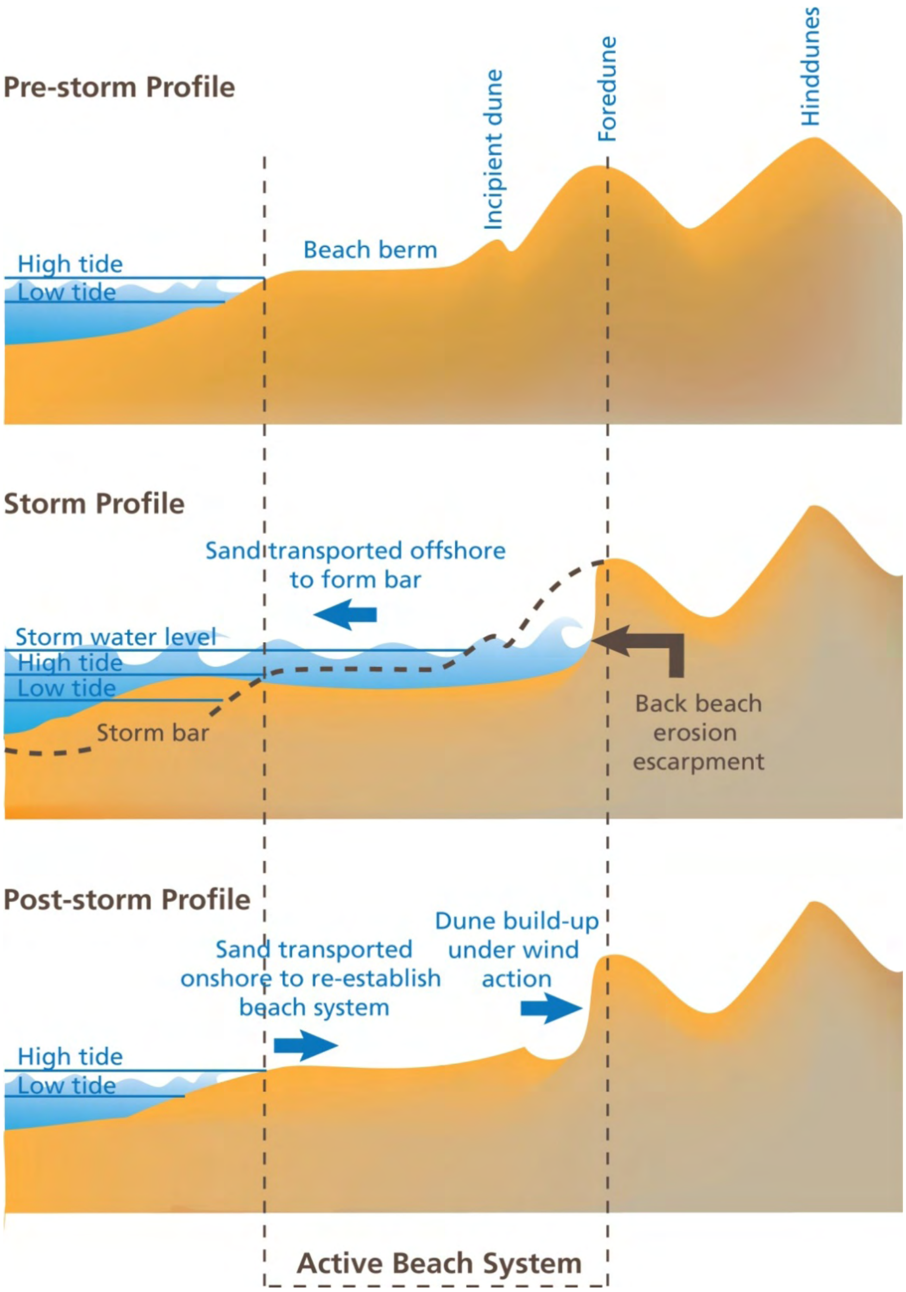


Figure 6 Beach sediment movement resulting from storms and post-storm recovery processes. The figure illustrates the pre-storm beach profile, erosion during storm events and the formation of storm bars and the progressive restoration of sand to the beach following a storm. This predominantly cross-shore transport mechanism is often found on sandy beaches bounded by rocky headlands, such as are common along the Surf Coast. Redrawn from [18].

Sandy beaches are naturally dynamic environments, with shoreline position retreating and advancing in response to individual storm events, as well as longer term climatic cycles (e.g. El Nino Southern Oscillation [ENSO]) which influence sea temperatures and levels, ocean currents and the frequency and intensity of storms.

As part of this project, an assessment was undertaken of movement in the position of the shoreline and coastal cliffs along the Surf Coast between the 1950s and the current decade (Appendix A). The assessment identified areas where the coastline had retreated by several metres over the last 60 years. Other areas were identified that did not retreat significantly over that period. This included some sandy or otherwise erodible landforms, albeit supporting dense vegetation coverage. Isolated instances were detected where the coast had advanced by several metres.

4.3 Climate change and coastal hazards

Historical and future emissions of greenhouse gases are projected to contribute to increases in global mean temperatures of about 2-4°C (relative to 1980-1999) by the end of the century [2]. Increased atmospheric greenhouse gas concentrations and elevated temperatures are, in turn, projected to significantly affect coastal and marine environments [19], including through:

- Elevated sea levels
- Changes in sea temperature
- Increased ocean water acidity
- Changes in rainfall regime and riverine sediment supply to the coast
- Changes in the intensity, frequency and/or latitude of storm systems and hence coastal wave climate.

The two key coastal hazards of concern to this project, inundation and coastal recession, may both be affected significantly by climate change, particularly sea level rise[3]. The extent of sea level rise over the course of this century is quite uncertain (Table 2), with variability relating particularly to future greenhouse gas emissions and the response of the Greenland and Antarctica ice sheets to global warming. Under most scenarios (Table 2), sea level rise by 2030 is projected to be about 0.2 m. The scenarios significantly diverge in projections for the latter half of the century. By 2100, they range between 0.82 m and as much as 1.4 m.

Table 2 Projected sea level rise (m) for 2030, 2070 and 2100 under various scenarios. These scenarios were used [6] to assess the effect of climate change on extreme sea levels for Victoria. Differences largely reflect methodological differences relating to the way in which contributions from melting ice sheets are estimated.

	Sea level rise (m)		
Future climate scenarios	2030	2070	2100
IPCC 2007 A1FI scenario[1] [2]	0.15	0.47	0.82
Netherlands Delta Committee 2008 [20]	0.20	0.70	1.10
Rahmstorf 2007 upper estimate [21]	0.23	0.74	1.40

The A1FI scenario is a high emissions scenario and roughly corresponds with recent global trends in greenhouse gas emissions.

Sea level rise will result in new areas of low lying coastal land being exposed to inundation during storm surge and storm tide events and will increase the frequency of inundation of areas that are already exposed (Figure 5). By 2030, the 10 year ARI storm tide for Lorne (~1.5 m above MSL) is projected to be equivalent to about the current 20 year event [7]. By 2100, the 10 y ARI storm tide (2.14-2.72 m above MSL) would significantly exceed the current 100 year event (1.69 m above MSL) and the current 100 year ARI storm tide height would be exceeded multiple times per year [7]. The 100 year ARI storm tide for Lorne would increase to between 2.51 and 3.09 m above MSL.

Sea level rise will also increase the depth of water over shore platforms (Figure 7) and offshore reefs. This may affect intertidal habitat availability or quality and the operation of key reef-based surf breaks (e.g. Bells Beach).

[3] The frequency and duration of estuary closures, which may contribute to coastal inundation, will also be affected by these climate change processes.

Sea level rise may contribute to the recession of erodible coasts (Figure 7). The extent of this will vary with coastal geomorphology, wave climate, bathymetry (underwater topography) and sediment supply. Bruun [4] developed a rule of thumb for unconsolidated coasts that suggests 50 to 100 m of coastal recession for each metre of sea level rise. Based on this rule of thumb[4] (which is the subject of much debate) sandy and other unconsolidated coasts could retreat by up to 20 m as a result of 2030 sea level rise and by 80-140 m in response to projected 2100 sea level rise.

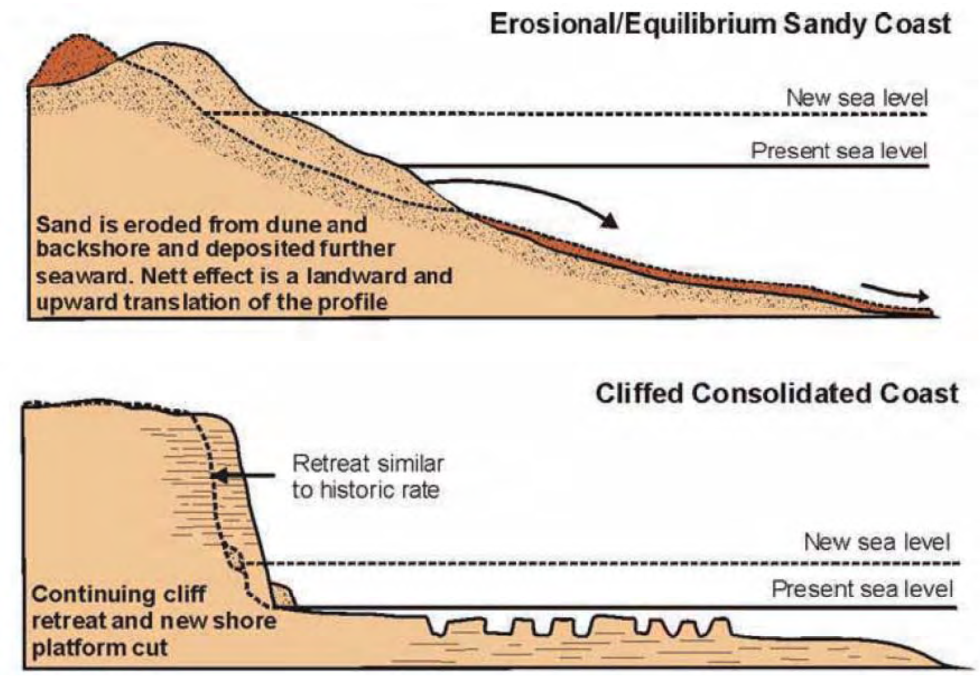


Figure 7 Influence of sea level rise on types of coastal landform relevant to the Surf Coast region. Sea level rise may contribute to the landward movement of sandy coasts. Consolidated cliffs will continue to retreat at near their current rate, but the current shore platform will be inundated to a greater depth and/or for longer periods during each tidal cycle. Erosion of unconsolidated cliffs may accelerate. Reproduced from [10].

The actual rate of retreat for parts of the Surf Coast region will be much less. Hardened, rocky coasts (Figure 4) are likely to retreat at rates similar to their historical rate (Figure 7) and most assets located in these areas will not be exposed to coastal recession. However, beaches that are backed by cliffs or rock may be eroded, but there may be little further recession of the coastline once the beach is lost.

High resolution climate and wave climate modelling by CSIRO in the project's third stage (Appendix B; [6]) identified that climate change has potential to significantly influence the region's wave climate. During summer and autumn, there is projected to be an increase in the frequency of waves generated by easterly winds, resulting in more short period waves and reduced return periods of storm wave events. Such waves drive storm erosion events and long-term coastal recession. Increased frequency of storm wave events may reduce opportunities for beach recovery times and lead to continued shoreline retreat. Change from a westerly to an easterly dominated wave regime may also alter long-shore sediment transport patterns.

---

[4] There is considerable debate in the literature about the use of the Bruun rule in coastal recession analyses. However, there is no alternative rule of thumb available that could be used in this analysis. Detailed numerical modelling would be required for more precise estimates, but may not necessarily add a great deal of value at this stage in the adaptation planning process.

In winter, the projected greater frequency of winds from the south-west and west imply greater impact from larger westerly swells. These are the long period waves favoured by surfers in this region. However increasing wavelength will lead to increased wave run up, further changes in long and cross-shore sediment budgets and rates of coastal recession [6].

CSIRO wave climate modelling [6] did not provide updated estimates of 100 year return period storm tides and so earlier work [7] will be used here. However, the projections of increased summer and autumn storm wave heights and longer period winter waves suggest that wave run up may add significantly to the height of extreme sea level events and increase the exposure of land and built and natural assets to temporary inundation. Climate change may also enhance erosion of the region’s unconsolidated coastlines (Figure 4) and contribute to coastal recession, potentially at rates estimated using the Bruun rule.

5 Exposure of assets to inundation and coastal recession

5.1 Introduction

To support the risk assessment, an analysis was conducted of exposure of natural and built assets located in proximity to the coast to inundation and/or coastal recession. This assessment differs from a risk assessment (Chapter 6) in that it only considers whether the land or assets might experience inundation or coastal erosion and not the consequence[5].

The assessment is based on several sources of data, as follows:

- **GORCC asset register** – which provided the location, name and value of a range of 267 individual built assets owned or managed by GORCC or located on GORCC-managed land[6];
- **VICMAP roads coverage** – a GIS data set showing the location of the Great Ocean Road and other roads.
- **GORCC**-managed land coverage – a GIS data set identifying public land managed by GORCC;
- **EVC coverage** – a GIS data set showing the extent, name and conservation status of ecological vegetation community (EVC) located along the coastal zone;
- **Heritage** – a GIS data set showing the location of sites of indigenous cultural significance within GORCC-managed land.

Exposure for key built, natural and heritage assets is described below. Exposure to inundation is assessed on the basis of the 100 year return period storm tide. The assessment of exposure to coastal recession assumes (following the upper range for the Bruun rule) that 1 m of sea level rise leads to the retreat of erodible coasts by 100 m. Assets located in areas with hard, rocky coastlines were not considered to be exposed to coastal recession.

5.2 Built infrastructure

GORCC manages several Crown land reserves along the Surf Coast. These reserves contain much of the basic recreational and tourism infrastructure, including boat ramps, car parks, caravan parks, piers and fishing platforms, playgrounds, public amenities, shopping centres, lookouts and foreshore boardwalks. These areas are also traversed by stormwater drains and paths. The close proximity of these assets to the coast means that many are exposed to hazards associated with sea level rise.

GORCC's asset register includes 267 assets with monetary value attributed[7]. The register includes both GORCC – owned assets and other assets that have been constructed on GORCC-managed land. The total value of assets in the register is approximately $167 million. Assets worth over 10% of this total value ($16.6 million) were assessed to be exposed to the current 100 year storm tide event (Figure 8). The value of assets exposed would increase to $18.9 million with just 0.2 m of sea level rise. Some $21.7 million and $29.6 million of assets owned by GORCC or located on GORCC managed land would be exposed to extreme sea level conditions with 0.8 m and 1.4 of sea level rise, respectively.

[5] While assets may be assessed to be highly exposed to coastal inundation (for example) because they are located at low elevation, they may be well adapted to periodic inundation and not experience significant damage as a result. Thus the risk of damage resulting from inundation (the product of consequence and likelihood) would be low, while exposure is high.

[6] These assets may be referred to as GORCC assets, although they are not all owned by GORCC. The value of the assets was estimated by GORCC and is based on their depreciated value.

[7] This includes multiple segments of the footpaths and tracks that are exposed at different sea levels or coastal retreat distances. The number of assets with monetary values attributed, but not including paths and tracks, is 187.

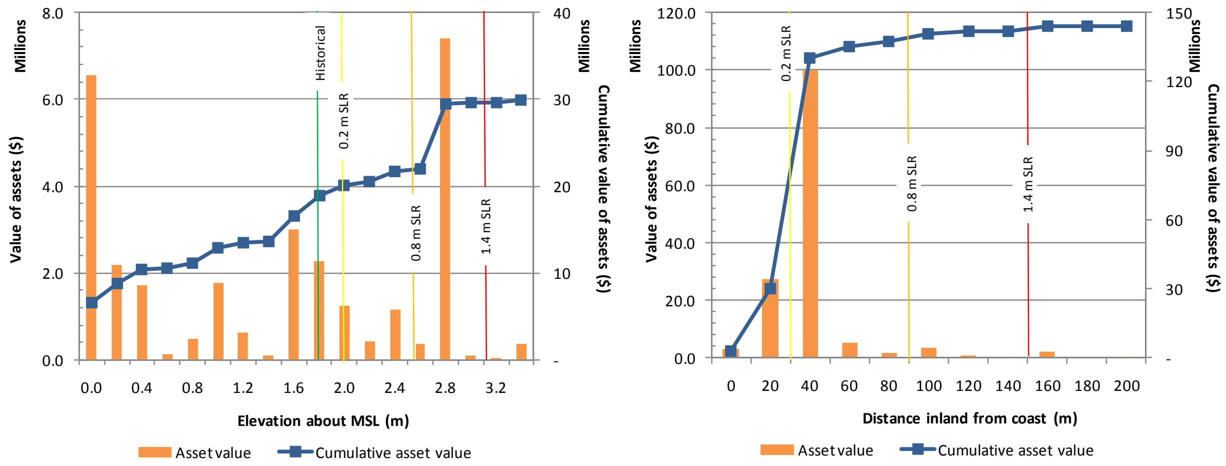


Figure 8 Exposure of assets owned by GORCC or located on GORCC-managed land to coastal inundation and recession potentially resulting from sea level rise. Exposure to inundation (left hand graph) is assessed relative to 100 y return period storm tides. Exposure to coastal recession (right hand graph) is assessed on the basis of 100 m of recession in erodible coasts ultimately resulting from each metre of sea level rise. Assets located in sections of the coast that are resistant to erosion have not been included in the analysis for coastal recession.

Coastal recession resulting from 0.2 m of sea level rise would potentially expose $3.2 million in assets. This increases to $137 million and $142 million in assets with recession resulting from 0.8 and 1.4 m of sea level rise, respectively (Figure 8).

5.3 Roads

The Surf Coast region has a well developed road network that serves local populations and passing business and tourist traffic. The road network includes the Great Ocean Road, the main road connecting coastal settlements in the region. Exposure of the road network (not including local roads in residential areas) to coastal hazards resulting from climate change is depicted in Figure 9.

Approximately 1.7 km of road is exposed to 100 year storm tide events under current conditions. This increases to 3.6 km with just 0.2 m of sea level rise and 13.4 km with 0.8 m of sea level rise. Only very short lengths of the Great Ocean Road (~0.5 km in total) are exposed to the 100 year storm tide with up to 0.8 m of sea level rise.

Over 2 km of the Great Ocean Road and over 3 km of other roads are exposed to coastal recession resulting from just 0.2 m of sea level rise. Over 13 km of Great Ocean Road and over 30 km of other road are exposed to coastal recession resulting from 0.8 m of sea level rise.

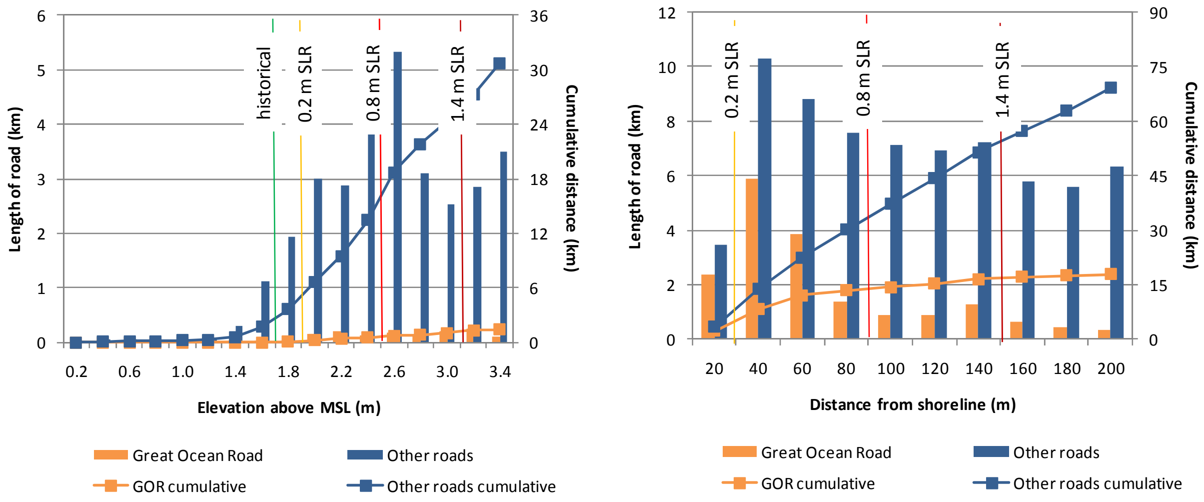


Figure 9 Exposure of roads to coastal inundation and recession potentially resulting from sea level rise. Exposure to inundation (left hand graph) is assessed relative to 100 y return period storm tides. Exposure to coastal recession (right hand graph) is assessed on the basis of 100 m of recession in erodible coasts ultimately resulting from each metre of sea level rise. Assets located in sections of the coast that are resistant to erosion have not been included in the analysis for coastal recession.

5.4 Native vegetation

Ecological vegetation class (EVC) mapping for the Surf Coast region has been used to assess the exposure of native vegetation communities to coastal hazards (Figure 10). Almost 240 ha of native vegetation are currently exposed to the 100 year storm tide event. This includes much of the area of native vegetation whose conservation status is classified as endangered, depleted or vulnerable. The area of native vegetation exposed to the 100 year storm tide is projected to increase to over 380 ha if sea levels rose by 0.8 m.

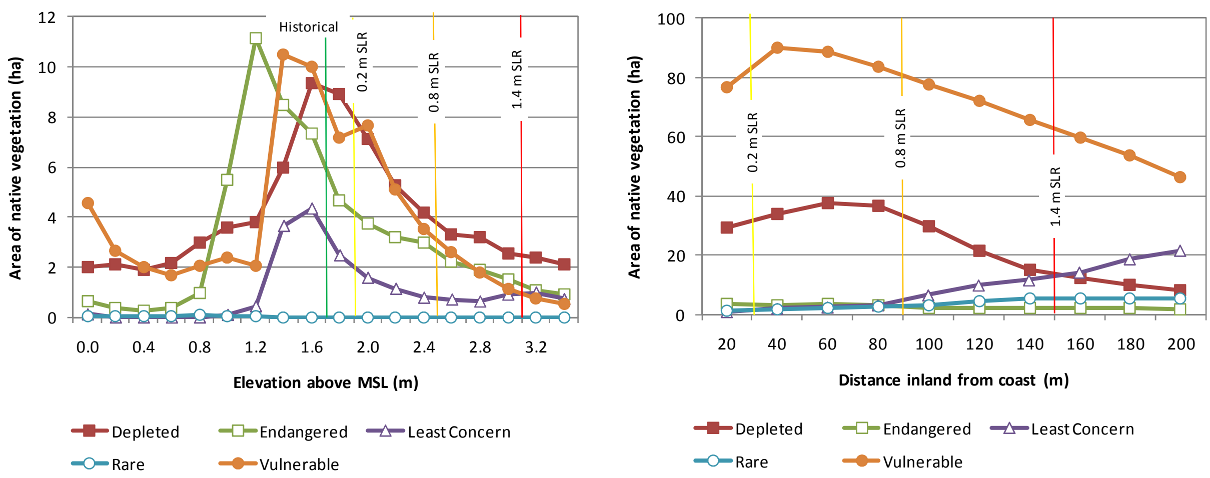


Figure 10 Exposure of native vegetation to coastal inundation and recession potentially resulting from sea level rise. Exposure to inundation (left hand graph) is assessed relative to the 100 year return period storm tide. Exposure to coastal recession hazards (right hand graph) is assessed on the basis of 100 m of recession in erodible coasts ultimately resulting from each metre of sea level rise. Land and assets in sections of the coast that are resistant to erosion have not been included in the analysis. The analysis considers the area of EVCs, grouped by conservation status.

Over 130 ha of native vegetation is exposed to coastal recession that may result from less than 0.2 m of sea level rise (Figure 10). Over 700 ha would be exposed with 0.8 m of sea level rise, including relatively large areas of vulnerable and depleted EVCs (339 and 138 ha, respectively). About half of the area of endangered EVCs is located in locations that are exposed to coastal recession resulting from 0.8 m of sea level rise.

5.5 Heritage assets

Some 33 registered (indigenous) cultural heritage assets are known to be located on land managed by GORCC. Their exposure to inundation and coastal recession hazards is illustrated in Figure 11. Two assets are located on land that is currently exposed to the 100 year storm tide. With 0.8 m of sea level rise, this would increase to eight. Eight assets are exposed to coastal recession that may result from less than 0.2 m of sea level rise. A total of 22 heritage assets are exposed to coastal recession that may result from 0.8 m of sea level rise.

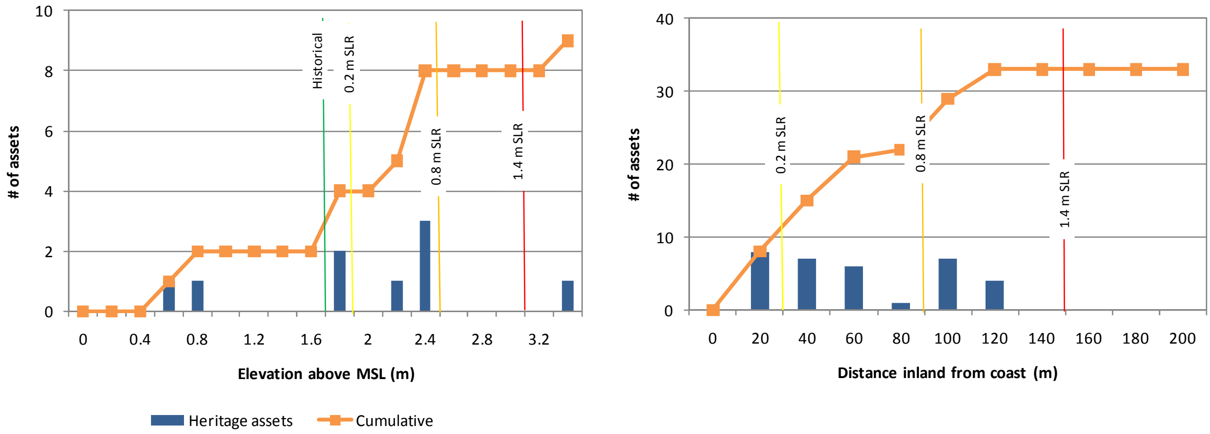


Figure 11 Exposure of cultural heritage assets located on GORCC-managed land to coastal inundation and recession potentially resulting from sea level rise. Exposure to inundation (left hand graph) is assessed relative to the 100 year return period storm tide. Exposure to coastal recession hazards (right hand graph) is assessed on the basis of 100 m of recession in erodible coasts ultimately resulting from each metre of sea level rise. Land and assets in sections of the coast that are resistant to erosion have not been included in the analysis.

6 Climate change risk assessment

6.1 Overview

The main objective of this stage of the *Climate change vulnerability and adaptation* project was to undertake an assessment of the risks associated with human-induced climate change. The assessment considered the key coastal assets identified in Table 1. It was based on the asset exposure analysis (Chapter 5) and a stakeholder workshop in which risks to assets listed in Table 1 were assessed using standard risk assessment protocols (AS/NZS ISO 31000:2009 [9]).

The Surf Coast region was divided into six sections for the risk assessment (Figure 12), with the division reflecting settlement patterns, coastal geomorphology and the distribution of assets. The sections were:

- 1. Point Impossible to Bells Beach
- 2. Bells Beach to Point Addis
- 3. Point Addis to Urquhart's Bluff
- 4. Urquhart's Bluff to Spout Creek
- 5. Spout Creek to North Lorne
- 6. North Lorne to Cumberland River

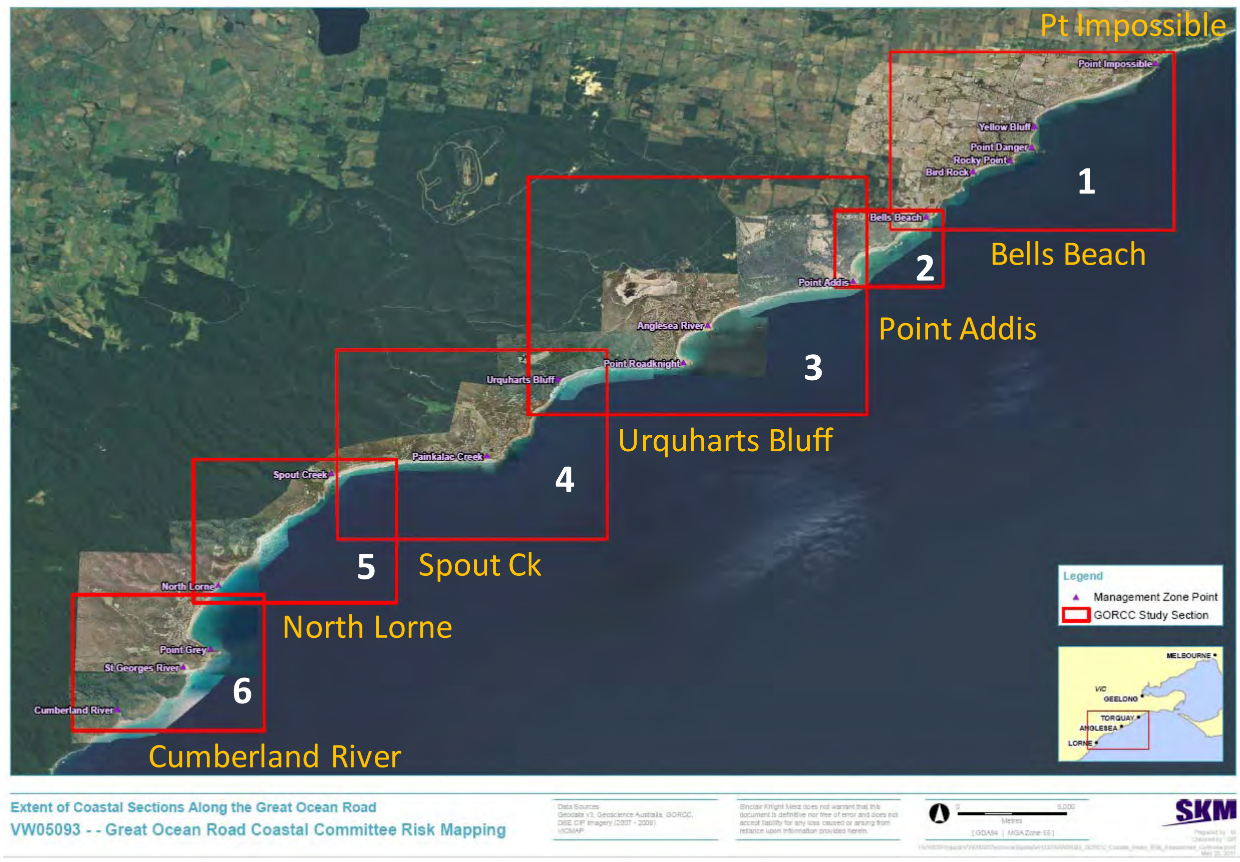


Figure 12 Subdivision of Surf Coast region for the risk assessment. This map and map-based summaries of the risk assessment for each section of coast are given in Appendix D.

The risk assessment used four sea level/sea level rise scenarios:

- Historical conditions – risk was assessed under current (late 20th century) conditions for storm surge/tide events and coastal erosion and recession.

- 0.2 m sea level rise – reflecting the amount of sea level rise projected by most sources (Table 2) by about 2030-2040.
- 0.8 m sea level rise – which reflects the minimum 2100 level of sea level rise required for planning consideration under the *Victorian Coastal Strategy* [5];
- 1.4 m sea level rise – the highest level of rise for 2100 included in assessments of extreme sea levels along the Victorian coast [6].

Scenarios are expressed in terms of sea level rise rather than time period, due to the extent of uncertainty surrounding projections of rates of sea level rise. At this point, 1.4 m is considered to be a plausible, near worst case scenario for the end of the century.

For the purposes of the risk assessment, coastal recession for sandy and erodible shorelines was projected to take place at the upper value of Bruun's rule of thumb (i.e. 100 m of recession for each metre of sea level rise, see Chapter 4.3), once the shoreline has reached equilibrium with the amount of sea level rise[8]. It was assumed that there would effectively be no exposure to coastal recession above historical rates for parts of the Surf Coast region with consolidated, hard rock coastlines (Figure 4), apart from any areas of sandy beach in front of the rocky cliffs.

6.2 Identification of risks

The potential effects of sea level rise and coastal recession on the key Surf Coast region assets were identified in preparation for the risk assessment workshop (Table 3). A generic list was developed and used as appropriate, depending on the assets that were actually located within the relevant section of the coast and that were potentially exposed to the effects of climate change (i.e. due to temporary/ permanent inundation, long-term coastal recession and storm erosion) under the most extreme scenario.

Table 3 Potential effects of sea level rise and coastal recession on key assets and the services they provide and the primary criterion against which consequence was assessed in the risk assessment.

Asset class	Description of risk(s)	Primary assessment criterion[1]
Beaches	Loss of beach width and associated recreational or tourist usage due to temporary/permanent inundation. Loss of amenity.	Community
Boat ramps	Loss or reduced use of asset due to inundation or damage from erosion. Increased maintenance or rebuild cost.	Asset
Car parks	Temporary/permanent inundation or damage from erosion results in loss of use and/or increased repair/maintenance costs. Closure of car park leads to road congestion, reduced public safety and loss of amenity.	Asset
Caravan parks	Damage to facilities from erosion/recession/inundation leads to loss of use and/or increased repair/maintenance costs. Erosion/recession/inundation lead to reduction in availability of sites, leading to reduced income and business viability.	Asset
Commercial properties	Reduced turnover and/or loss of property value for commercial businesses resulting from damage to properties from inundation/erosion/recession, loss of access, poor appearance of property and reduced attractiveness of local area.	Finance

[8] This may occur at some significant time after sea levels have risen by the projected amount.

Asset class	Description of risk(s)	Primary assessment criterion[1]
Creeks and estuaries	Loss of vegetation, destruction of fauna/flora habitat, change in water quality and ecology resulting from elevated sea levels, erosion and sedimentation.	Environment
Cultural heritage features	Damage to heritage sites from erosion/recession/inundation leading to loss of cultural values, tourism attraction and local knowledge. Increased maintenance expenditure.	Environment
Drainage	Damage or reduced drainage capacity from inundation leading to repair costs or blockage and increased storm flood damage in towns.	Finance
Dune and cliff vegetation, habitats and fauna	Loss of vegetation and destruction of habitat.	Environment
Inter-tidal habitats and fauna	Loss of habitat.	Environment
Pathways, walks and lookouts	Erosion/recession/inundation leads to loss of access or use. Amenity and tourism value reduced. Safety hazard for users.	Asset
Parks and recreational facilities	Damage and loss of use due to erosion/recession/inundation. Increased maintenance expenses. Reduced amenity.	Asset
Pier	Erosion damage leads to loss of access, reduced amenity and user safety hazard.	Asset
Residential property	Damage from erosion/recession/inundation leads to loss of access, reduced asset value and/or increased maintenance costs.	Finance
Roads and bridges	Daily/sub-daily inundation leads to loss of use of roads/bridges and increased maintenance. Damage to bridges and roads from erosion leading to temporary/permanent loss of use and increased maintenance or rebuild costs.	Asset
Sailing clubs	Access to building and its use diminished. Building and foundations damaged or destroyed. Increased maintenance costs or rebuild costs.	Asset
Surf breaks	Loss of beach or reef surf break. Reduced tourist/recreational usage. Loss of amenity.	Community
Surf Life Saving Clubs (SLSC)	Damage to SLSC results in diminished capacity to provide beach patrol services, leading to reduced user safety.	Safety
Water infrastructure	Accelerated deterioration of and increased maintenance costs due to surface inundation and/or elevated groundwater levels. Damage to pipes and loss of land in easement.	Finance

Note:
1. The primary consequence criterion is the one that was assessed to provide the highest level of consequence.

Risks were also identified to local residents and business operators (apart from on their properties), as well as to GORCC and the Surf Coast Shire. Risks were assessed for the latter as a whole as they were not solely attributable to specific sections of the coast. The potential impacts considered in these assessments were:

- **Residents and other beach users** – erosion/ inundation of beaches lead to reduced safety.
- **Residents and other road users** - erosion/ inundation of roads/bridges lead to reduced safety, seeking of alternative routes, increased travel times, congestion and loss of amenity.
- **GORCC and Surf Coast Shire** - long-term loss of use and/or reduced attractiveness of beaches, other tourist/recreational sites and activities, businesses and private dwellings leads to loss of capital base, rate revenue, caravan park or other revenue and organisational reputation.

- **Tourism operators** - long-term loss of use and/or reduced attractiveness of beaches and other tourist/recreational sites and activities leads to loss of revenue, business failure and reduced employment.

6.3 Assessment and evaluation of risks

Risk assessment approach

The risk assessment was conducted separately for each of the six sections of the Surf Coast region (Figure 12). Risk was assessed for each of the identified potential climate change impacts (Table 3) that were relevant to the assets located in that section of coastline (and identified in Stage 1 of this project). Risk under the four sea level rise or climate change scenarios (Chapter 6.1) was assessed concurrently. The assessment first considered the type of consequence criterion to be used (i.e. the one indicating the greatest consequence of the potential impact). The level of consequence under each scenario was assessed using Table 10 in Appendix C and then the likelihood of each impact's consequence was assessed (using Table 11 in Appendix C). The assessment assumed existing control measures were in place.

The overall levels of risk for the respective combinations of consequence and likelihood were defined by Table 12. The form of response required by each level of risk is given in Table 13. Material risks, those to which some form of response is required, were those assessed as either high or extreme.

A preliminary assessment, considering only the Point Impossible-Bells Beach section of the coast, was undertaken in a full-day workshop with representatives of key stakeholder groups, including GORCC, Surf Coast Shire, Corangamite CMA, VicRoads and the tourism industry. The workshop was used to 'calibrate' assessments for the remainder of the Surf Coast region by the SKM team.

Overview of risk assessment

The six sections of the Surf Coast region differed markedly in their exposure to risk from coastal inundation and recession (Figure 13). The differences reflect the relative concentration of natural and (particularly) built assets close to the coast, as well as coastal landform and geology. The sparsely developed Bells Beach-Point Addis and Spout Creek-North Lorne sections of the coast had significantly fewer assets exposed to the main coastal hazards than the other four sections of coastline and so recorded fewer risks. There was typically a large increase in risk exposure between 0.2 m and 0.8 m of sea level rise. Adding a further 0.6 m of sea level rise (to 1.4 m) only marginally increased the number of assets assessed to be at "high" or "extreme" risk, although it may have added to the length or area of asset assessed to face those higher risk categories and the number of risks in the "extreme" category.

Differences also exist across the Surf Coast region in the relative risk exposure to the different types of coastal hazard (Figure 14). For the historical sea level and 0.2 m of sea level rise scenarios, there were no material (high or extreme) risks associated with either temporary or permanent inundation. Coastal recession was the major source of material risks for all scenarios and sections of the coast (Figure 14).

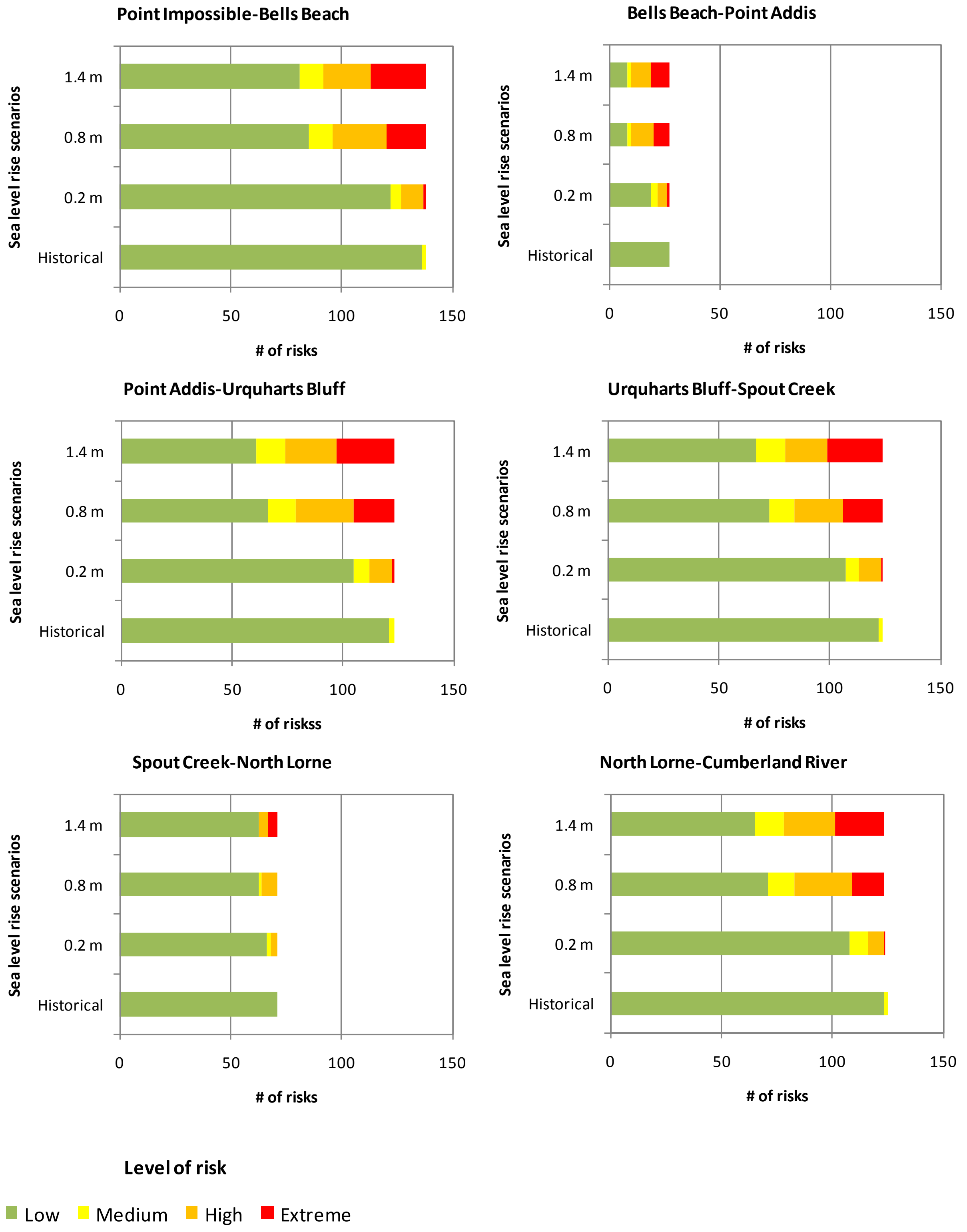


Figure 13 Summary of risk assessment for six sections of the Surf Coast region. Graphs show the total number of risks in each category (Table 12) for each of the sea level rise/climate change scenarios.

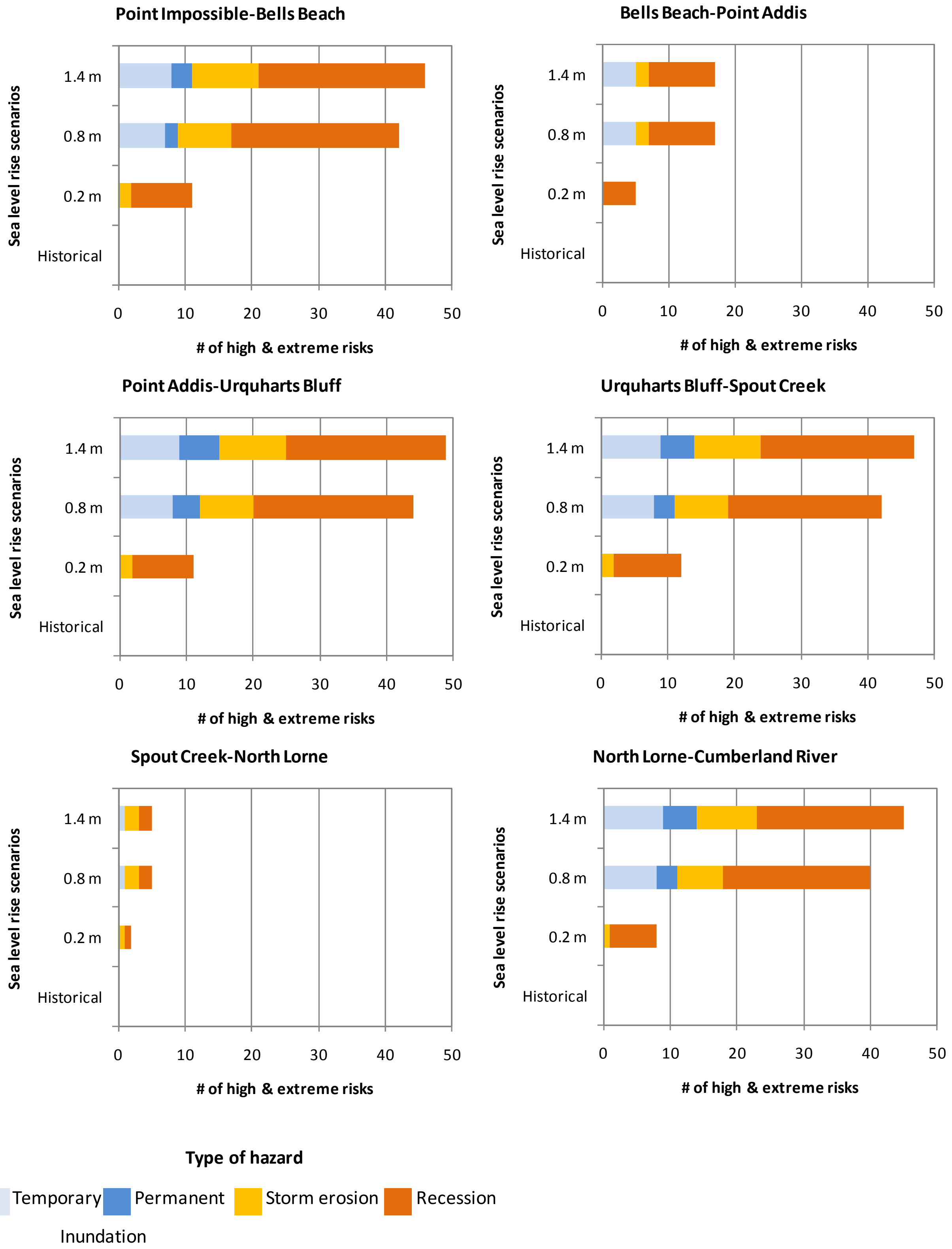


Figure 14 Summary of risk assessment for six sections of the Surf Coast region. Graphs show the total number of high and extreme risk for each type of coastal hazard for each of the sea level rise/climate change scenarios.

Risk mapping

Maps summarising the risk assessment results are provided for all sections of the Surf Coast region in Appendix D. The maps highlight the assets located within each section of coast and the sea level rise scenario at which particular types of hazard (i.e. storm erosion, coastal recession, permanent/temporary inundation) first reach material (high or extreme) levels.

#1 Point Impossible-Bells Beach

Assets and values

The section of coast between Point Impossible and Bells Beach is the most intensively developed area within the entire Surf Coast region. It includes Torquay with the residential and commercial development and infrastructure associated with this rapidly growing community. Several stretches of beach are popular with local residents and visitors and have significant supporting infrastructure (e.g. Surf Lifesaving and Sailing Club facilities, boat ramps, public parks, playgrounds, toilet facilities etc). This stretch of coast also includes several high profile surf breaks (but not the iconic Bells Beach, which is included in section 2). Less developed areas retain habitat and indigenous heritage values.

This section of coast is characterised by sandy beaches which are backed by steep dunes or cliffs, which are generally unconsolidated and susceptible to erosion and coastal recession. Some of the beaches may not be able to retreat if sea level continues to rise and may be eroded or inundated more frequently and/or for longer through the diurnal tidal cycle.

The types and location of coastal assets in this section of coast are presented in Appendix D, as is a summary of the outputs of the risk assessment.

Temporary and permanent inundation

Several features of this stretch of coast were assessed to face high or extreme risk from permanent or temporary inundation (Map 1 in Appendix D), including parts of the beach, the estuaries of Spring and Deep Creeks, the various surf breaks, storm water drainage and inter-tidal habitat and the fauna it supports.

Beaches and inter-tidal habitats and dependent fauna were assessed to be most exposed to risk, with high or extreme risk triggered by just 0.2 m of sea level rise. Limited opportunities for the beach to retreat intact mean that with relatively small amounts of sea level rise, they would experience increased periods of inundation during diurnal tidal cycles. If sea levels continued to rise, this would reduce their amenity and habitat value.

Storm erosion and coastal recession

Examples of almost all of the asset types in this section of coast were assessed to experience material risks from coastal recession as a result of either 0.2 or 0.8 m of sea level rise (Map 1). These include the beaches and associated tourism and recreational infrastructure (e.g. car parks, boat ramps, sailing and Surf Lifesaving Clubs, playgrounds), natural environments and any remaining heritage sites and places.

Many of these assets were also assessed to be subject to material risk from storm erosion. However, the level of risk from the latter was generally assessed to be less than from recession, reflecting the possibility of unrecoverable loss of function (and hence greater risk consequence) with recession and the possibility of repair and recovery from storm impacts.

This section of coast has significant residential development located in areas that are not protected by hard rocky cliffs and that may be affected by coastal recession as a result of 0.8 m or more of sea level rise.

Summary

The concentration of highly-valued assets and their high level of risk exposure makes the Point Impossible-Bells Beach section of coast a hot spot for risk from sea level rise. The amenity of the local community and at least parts of the local economy would be significantly challenged by 0.8 m of sea level rise and possibly less.

#2 Bells Beach-Point Addis

Assets and values

This is one of the least developed sections of the Surf Coast region and has few built assets in the areas that are potentially exposed to coastal inundation or recession (Map 2 in Appendix D). The primary assets of this section of coast are surf breaks at Bells Beach and Point Addis, the beach to the north of Point Addis, natural habitats and any remaining heritage sites and places. The main built assets are the Bells Beach car park, beach access tracks and other access tracks.

This section of coast is characterised by relatively high, but erodible cliffs that fall to (mostly) sandy beaches.

Temporary and permanent inundation

The beach-related assets face material risks associated with change in the permanent inundation regime (i.e. depth, duration of inundation). It was assessed that 0.8 m or more of sea level rise may change the operation of the reef breaks in this area and could diminish their value for surfing.

Habitat and heritage values were also assessed to face material risks from climate change.

Storm erosion and coastal recession

The backing of the beaches by cliffs provides little opportunity for them to retreat intact. As a consequence beaches and their recreational use were assessed to face material risks from coastal recession and storm erosion (Map 2). Access to the beaches and the Bells Beach car park was also assessed to be at risk from coastal recession associated with 0.2 and 0.8 m of sea level rise, respectively.

Summary

There are few and relatively low value built assets at risk from sea level risk and coastal recession in this section of coast. However, any adverse impact from sea level rise on the iconic Bells Beach and its surf conditions may be quite detrimental to the economy and reputation of the entire Surf Coast region.

#3 Point Addis-Urquharts Bluff

Assets and values

The section of coast between Point Addis and Urquharts Bluff includes the town of Anglesea and its associated residential, commercial and recreational infrastructure (including a boat ramp, caravan park, car pack and Surf Lifesaving Club). Some of this is located in close proximity to the beach (Map 3 in Appendix D). Anglesea is a popular tourist destination and several of its beaches are used extensively. Urquharts Bluff also has a notable surf break.

The coastline west of Point Roadknight and adjacent inland areas form parts of marine and terrestrial conservation reserves. Anglesea River drains to the coast immediately to the east of the town. The Great Ocean Road first approaches the coast at Anglesea and from there runs parallel to the coast most of the way to Lorne.

This section of coast includes two distinct geologies. North and east of about Point Roadknight, the coast consists of sandy beaches backed by dunes and in some places cliffs of erodible rock. West and south of Point Roadknight, the coast remains sandy, but the coastal dune complex is backed by harder rocks that characterise the Otway Range.

Temporary and permanent inundation

The coast around the town of Anglesea is relatively low lying and, as a result, some assets are at risk from temporary inundation during extreme sea level events and/or changes in the tidal reach (Map 3). Assets at risk from inundation include the beaches and surf breaks, beach-side car parks, GORCC's Anglesea caravan park, Anglesea River estuary, storm water drainage infrastructure and intertidal habitats and dependent fauna. Material risk levels were assessed to be triggered by 0.8 m of sea level rise in most cases.

Storm erosion and coastal recession

The beaches, dune systems and many of the types of built asset found in this section of coast were assessed to be at risk from coastal recession, and to a lesser extent, from erosion events (Map 3). As was the case for Point Impossible-Bells Beach, this reflects that the risk consequence of erosion was generally assessed to be less significant for erosion than permanent recession.

The close proximity of some assets to the beach means that coastal recession from as little as 0.2 m of sea level rise was assessed to trigger material risks (e.g. beach, car park, boat ramp). For the majority of assets, material risks would be triggered by 0.8 m of sea level rise. This would include residential properties, particularly those in the vicinity of the Anglesea River estuary and Point Roadknight, parts of GORCC's Anglesea caravan park and some sections of local road and the Great Ocean Road.

Summary

As with Point Impossible-Bells Beach, the concentration of assets with high risk exposure in this section of coast makes it a second hot spot for risk from sea level rise. Key natural assets, the amenity of the local community, some property and business values and parts of the local economy could be significantly challenged by about 0.8 m of sea level rise and coastal recession that may result from it.

#4 Urquharts Bluff-Spout Creek

Assets and values

Much of the coast between Urquharts Bluff and Spout Creek is settled (Map 4 in Appendix D). It includes Aireys Inlet-Fairhaven and the small settlement of Moggs Creek, as well as the same types of built and natural assets as the other developed sections of the coast (e.g. boat ramps, Surf Lifesaving Club, car parks, beaches and surf breaks, etc.).

This section of coast includes the second of the region's two main estuaries. The estuary of Painkalac Creek separates Aireys Inlet from Fairhaven and has relatively large areas of land that are periodically inundated, by both river flooding and extreme sea levels.

The Great Ocean Road runs close to the coast along much of this section and provides spectacular coastal scenery for tourists. Some areas of residential development are also located at low elevation and/or in close proximity to the coast.

Most of this section of coast comprises sandy beaches, backed in some cases by dune systems and, in other cases, by erodible cliffs. The hard rocky hills retreat from the coast around Aireys Inlet, but approach it again west of Moggs Creek (Map 4).

Temporary and permanent inundation

A similar set of assets are exposed to material risks from inundation in this section of coast as in other developed sections of the Surf Coast region (Map 4). Several car parks, beaches, Painkalac Creek estuary, surf breaks, drainage and intertidal habitat and dependent fauna are at material risks from sea level rise, in most cases of at least 0.8 m.

While sections of the Great Ocean Road at the Painkalac Creek crossing are exposed to inundation during extreme sea level events – becoming more frequent with sea level rise – the consequence of such incidences was not assessed as being sufficient to lead to a material (high or extreme) risk.

Storm erosion and coastal recession

Most of the built and natural assets located in this section of coast face material risks from coastal recession with sea level rise of either 0.2 or 0.8 m (Map 4). This includes sections of the Great Ocean Road and other local roads, residential land and much of the recreational/tourism infrastructure near the beaches.

Summary

Aireys Inlet-Fairhaven is the third of the region's main sea level rise and coastal recession risk hotspots. Risk exposure is similar to the other sections of the coast and includes residential areas, key recreational and tourism infrastructure, beaches and surf breaks. Local social and economic implications are likely to be similarly significant.

Sections of the Great Ocean Road face material risks from coastal recession. This is particularly problematic as there are few alternative routes connecting to the west that could be used if the road experiences significant damage from erosion during a storm event.

#5 Spout Creek-North Lorne

Assets and values

The coast between Spout Creek and North Lorne is sparsely developed, with individual isolated houses, but no significant settlements to the south until North Lorne (Map 5 in Appendix D). Apart from at Spout Creek, beaches are small and not particularly accessible and so experience lower usage than most other areas.

The Great Ocean Road continues to roughly parallel the coast south and west of Spout Creek, however it is mostly elevated well above the beach. Scenic values of this section of road are particularly high.

The hills of the Otway Ranges run to the coast along most of this section. The rocks of this landform are hard and relatively resistant to erosion in these areas (Figure 4) and as a result the coast is unlikely to recede in response to sea level rise. The coast comprises a mix of rocky headlands, cliffs and small strips of sand backed by rocks.

Temporary and permanent inundation

The steepness of the coast and sparse development of much of this area means that only surf breaks and the boat ramp near Spout Creek face material risks from permanent inundation.

Storm erosion and coastal recession

The car park and boat ramp near Spout Creek and intertidal habitat and dependent fauna are the only assets at material risk from storm erosion and coastal recession. While there are residential properties located relatively close to the coast, the erosion resistant rocks mitigate risks from recession.

Summary

The coast between Spout Creek and North Lorne is the section of Surf Coast region that is least exposed to risks from sea level rise and associated coastal recession. It has few built assets located in close proximity to the coast and much of the coast is rocky and not exposed to coastal recession. However, several GORCC assets in the Spout Creek area (boat ramp and car park) are located on or behind a sandy beach and are susceptible to coastal erosion and recession.

#6 North Lorne-Cumberland River

Assets and values

This final section of coast includes the town of Lorne, which is a popular tourist and sea change community. The suite of built assets is similar to those found at other coastal settlements (Map 6 in Appendix D) and includes residential and commercial properties, a Surf Lifesaving Club, a caravan park and beachside recreational facilities. Lorne also has its famous pier, which is an important tourism asset. This section of coast includes the main Lorne beach and several popular surfing breaks, natural habitats and Erskine River and its estuary.

Lorne is surrounded by the forests and hills of the Otway Ranges. The hills run to the coast across much of this section, although Lorne is built down to the relatively flat, sandy main beach.

Temporary and permanent inundation

Assets that are exposed to material risks from temporary or permanent inundation are those located on the beach (Map 6), including the beach itself, surf breaks, boat ramp, stormwater drainage and habitat and dependent fauna. Most assets were assessed to face material risks with 0.8 m or more of sea level rise.

Storm erosion and coastal recession

Exposure to coastal recession and storm erosion is similar to other settled areas of the Surf Coast region. The beach and boat ramp were assessed to face material risk from recession resulting from 0.2 m of sea level rise. Other, mostly built assets (including sections of the Great Ocean Road and residential and commercial development) face material risks from coastal recession resulting from up to 0.8 m sea level rise.

The focus of risk from erosion and coastal recession is on the township of Lorne, which is the only area of this section of coast that is susceptible to erosion. The main Lorne beach is particularly vulnerable, as its retreat is limited by the Great Ocean Road and the commercial development located on its northern side.

Summary

Lorne is the fourth main regional hot spot of risk from sea level rise and coastal recession. Risk exposure at Lorne is similar to the other sections of the coast that are susceptible to coastal erosion and recession. The exposure assessment (section 5), identified that this section of coast has the greatest value of assets exposed to coastal recession of any section of coast ($95.9 million).

Local and perhaps regional social and economic implications of sea level rise of about 0.8 m would be significant. The Lorne beach and associated recreational and amenity potential would be at severe risk, which would jeopardise the tourism economy.

The coast south and west from Lorne is steep and comprises hard rocks and is not significantly threatened by sea level rise at the scale considered in the three scenarios used here.

GORCC

GORCC faces exposure to material risks from sea level rise to its operations as an owner, manager and/or operator of coastal land, infrastructure and businesses on several fronts (e.g. Figure 8 maps in Appendix D), as follows:

- **Direct damage** – few GORCC assets face material risks from damage associated with extreme sea levels. This reflects that relatively few assets are located within the reach of such events and that most of those that are (e.g. boat ramps, piers) are designed for temporary and/or permanent (partial) inundation. A greater number (and value) of assets are exposed to material risks from storm erosion. This reflects the relatively large number of assets located close to erodible coasts and their susceptibility to damage from erosion. Damage from extreme sea levels may temporarily restrict the use of the asset and will require financial expenditure for repair work.
- **Reduced or loss of usage** – resulting from temporary or permanent inundation, damage from storm erosion or the effects of the coastline receding. Permanent inundation may lead to the loss or diminished use of an asset (e.g. caravan park, car pack, boat ramp) and/or the need to relocate (e.g. a toilet block) or extend to maintain usage (e.g. a boat ramp). Storm erosion may result in reduced usage while repairs are made. Recession may lead to permanent loss of the asset or its function.
- **Loss of revenue or increased operating cost** – where assets are damaged or access to beaches is lost as a result of extreme sea levels and/or storm erosion, operations and maintenance costs for GORCC would increase. Temporary or permanent loss of access to an asset or of its operating function (e.g. as a caravan park) could also reduce revenue and profitability. Any failure to maintain assets (e.g. car parks, beach access paths, playgrounds) that leads to health or safety incidents for users could lead to litigation, legal liability and the costs associated with them.
- **Loss of reputation** – as the entity responsible for the operation and management of high usage coastal infrastructure, any persistent loss of operating capacity by those assets, even if because of 'natural' coastal hazards, could adversely affect GORCC's reputation with the community and government.

Impacts associated with each of these are expected to increase as sea levels rise and susceptible parts of the coast recede. Given the level of exposure across GORCC's business, this may lead to maintenance or renewal costs and/or losses in revenue (e.g. from caravan parks) that challenge its financial viability.

Impacts of sea level rise on other coastal assets, such as beaches and surf breaks may also reduce the attractiveness and reputation to tourists and other visitors of the Surf Coast region as a whole. This was assessed to be a material risk for GORCC as it could contribute to reduced revenue (especially from GORCC caravan parks) and further stretch the financial viability of GORCC's operations.

Surf Coast Shire

Surf Coast Shire is exposed to material risks from sea level rise in broadly similar ways to GORCC. It faces risks from direct damage to its assets, such as local roads, footpaths and stormwater drainage systems, following extreme sea level and/or coastal erosion events. This may lead to reduced or loss of usage and increased maintenance or operating costs.

The more significant risks to the Surf Coast Shire are those that may affect the amenity and attractiveness of the region as a tourist and residential location. The potential loss of beaches and beach access, as well as damage to residential and commercial properties (only at some locations) could reduce property values, business revenue, the Shire's rate base and its capacity to provide services. The Shire's reputation may also be adversely affected if they did not intervene effectively to reduce damage to roads and residential or commercial properties from inundation or coastal recession.

Other risk owners

The risk assessment did not specifically consider the overall risk faced by other agencies who are responsible for the management of assets at risk from sea level rise impacts. However organisations such as DSE, Parks Victoria and VicRoads, which are responsible for the management of public land and the natural, built or cultural heritage assets it contains, face significant risks and management challenges.

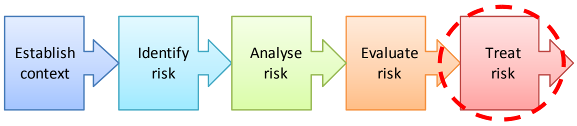
6.4 Priority risks

Material risks from climate change that were identified through the risk assessment relate to five broad asset classes, the characteristics of which are outlined in Table 4. These risks will be the focus of the adaptation framework outlined in Chapter 7. The classes that relate to built assets and infrastructure are mostly concentrated in or near the main population centres. Those relating to natural or heritage assets are more widely distributed along the coast.

The table identifies the key organisations that 'own' or have significant responsibility for the priority risks. In addition to GORCC, the key risk owners include: Surf Coast Shire, State Government agencies or statutory authorities (e.g. DSE, Parks Victoria, Corangamite CMA, Aboriginal Affairs Victoria, Department of Planning and Community Development, VicRoads) and indigenous traditional owner groups.

Table 4 Characteristics of Surf Coast region priority asset-risk classes

Asset class & description	Key location(s)	Risk owner(s)
Beaches and associated recreational and tourism infrastructure: including beaches and the infrastructure (access tracks, car parks, playgrounds, amenity blocks, Surf Lifesaving Clubs, boat ramps etc.) that add to the safety and amenity of beach use.	Torquay, Anglesea, Aireys Inlet-Fairhaven, Lorne	GORCC, Parks Victoria, DSE, Surf Coast Shire
Environment and heritage features: intertidal and dune habitats and estuaries and dependent species. Sites and places of indigenous cultural heritage.	All six sections of coast	Aboriginal Affairs Victoria, Traditional Owners, DSE, Parks Victoria, Corangamite CMA
Residential and commercial properties: private residential and commercial properties located in areas at risk from coastal recession.	Locations at Torquay, Anglesea, Aireys Inlet-Fairhaven, Lorne	Surf Coast Shire, Department of Planning and Community Development, private residents, business owners
Roads: including local roads, footpaths, sections of the Great Ocean Road and road bridges.	Torquay, Anglesea, Aireys Inlet-Fairhaven. Great Ocean Road from Anglesea-Spout Creek	Surf Coast Shire, VicRoads, GORCC, Parks Victoria.
Surf breaks: including reef and beach breaks.	All six sections of coast	DSE, Parks Victoria



7 A framework for adaptation

7.1 Adaptation

Adaptations are the 'adjustments made in natural or human systems in response to experienced or projected climate conditions or their beneficial or adverse effects or impacts' [22]. Adaptations may be planned measures, such the construction of groynes to hold sand on a beach or the reconstruction and raising of a road that is regularly cut during storm tide conditions. They may also occur autonomously or without planned action, such as might occur as beaches backed by sand dune systems retreat inland in response to increasing sea levels.

In the context of risk assessment and management, adaptations are the new controls – beyond current management practice – that are introduced to manage priority risks. Adaptations may range from modest, incremental changes to current management practices (e.g. extending the elevation of a boat ramp so that it remains serviceable as sea levels rise) to major, transformational changes (e.g. planned retreat of residential developments from land at risk from coastal recession).

The *Victorian Coastal Strategy* [5] has adopted a relatively simple typology of adaptation, as follows:

- Protect – beaches, dunes, and infrastructure, land use and development from sea level rise and coastal recession.
- Accommodate – sea level rise and coastal recession through planning and building policies and provisions, redesign and rebuild of infrastructure at risk.
- Retreat – through relocation of infrastructure, land use and development

Adaptation strategies typically also include a fourth type of adaptation, the development of adaptive capacity. As the name suggests, these types of adaptation are concerned with developing the capacity of an organisation, community or other 'system' to understand and moderate risks from climate change and realise any benefits [8].

Different types of adaptation option will be more or less suited to particular contexts. Where the value of an asset at risk from sea level rise or recession is high relative to the cost of risk treatment, protective options may be used. In situations where asset values at risk are relatively low or asset protection is relatively expensive or ineffective, sea level rise or coastal retreat may be accommodated (e.g. by ensuring infrastructure is not developed in at-risk locations or that it is not significantly damaged by storm tide inundation). Where protective options are or will ultimately be unable to successfully mitigate risks from coastal inundation or recession, it may be necessary to relocate existing infrastructure, land use or development (i.e. retreat) to locations that are not exposed to such risks.

It may also be necessary to accept that some material risks from climate change cannot be effectively mitigated within financial or other resource constraints or that there will only be a limited time or range in sea levels in which it will be possible to effectively treat risks.

7.2 Adaptation principles

For consistency of approach, adaptation planning should be undertaken in the context of a set of underpinning principles. These principles should reflect community and stakeholder organisations' values, government policy and legislation. Key sources of coastal adaptation planning principles include the Victorian *Climate Change Act* 2010 and *Victorian Coastal Strategy* [5]. A preliminary set of principles for coastal climate change adaptation in the Surf Coast region has been developed that draws on these and other sources (Figure 15).

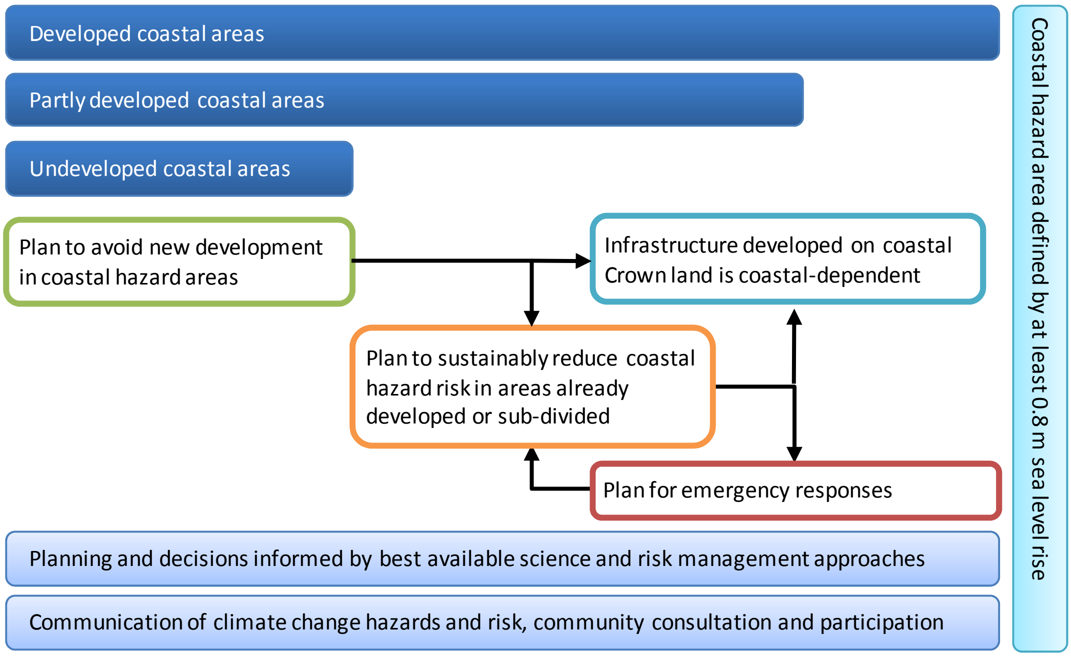


Figure 15 Preliminary principles for coastal climate change adaptation for the Surf Coast region. Adapted from [10, 5, 23]

Seven principles for coastal climate change adaptation are proposed, namely:

#1 The coastal hazard area is defined by at least 0.8 m of sea level rise and any associated coastal recession – adaptation planning must consider at least the land at risk from a 100 y storm tide with 0.8 m of sea level rise (scenario 3) and the likely extent of coastal recession resulting from this.

#2 Planning and decision making will be informed by the best available science and risk management approaches – the information base on coastal climate change hazards will continue to change rapidly and require regular updates of the risk assessment.

#3 Communication of climate change hazards and risk, community consultation and participation – communication and engagement are critical ingredients in developing the capacity of the community to adapt to climate change.

#4 In undeveloped coastal areas, plan to avoid new development in coastal hazard areas.

#5 In partly developed and developed coastal areas, plan to sustainably reduce coastal hazard risk – as appropriate, deploying appropriate options that protect coastal assets, accommodate sea level rise and coastal recession or initiate a process of retreat from high risk areas.

#6 Infrastructure developed on Crown land in partly-developed and developed coastal areas is coastal-dependent – the focus of any infrastructure that is developed on coastal Crown land should be on infrastructure that relies on proximity to the coast and/or facilitates public use of or access to it (e.g. boat ramps, Surf Life Saving Clubs, toilet blocks etc). Development that is not coastal-dependent should be located in other areas (as per principles #4 and #5).

#7 Plan for emergency responses in partly developed and developed coastal areas – understandings of exposure of people, land and other assets to extreme sea level and coastal erosion hazards should provide a basis for emergency management planning.

The adaptation framework and priorities developed in the following sections incorporate these principles.

7.3 Adaptation framework

The proposed adaptation framework provides for the development of flexible adaptation pathways that are responsive to experienced changes in sea levels, coastal recession and risk perception. The framework envisages the sequential deployment of adaptation options or tactics that are suited to particular 'windows' of sea level rise or coastal recession. The deployment of new adaptation options or tactics is triggered by an approaching risk threshold that is based on the sea level or other limit of effectiveness of the current options. The process of deploying the adaptations begins before the risk threshold is reached to ensure there is sufficient time for planning, finance raising and community or stakeholder engagement (Figure 16). Trigger points are risk-based and draw on experienced coastal hazard conditions. They are not time based and so provide flexibility to adapt to more or less rapid sea level rise while remaining within acceptable risk levels.

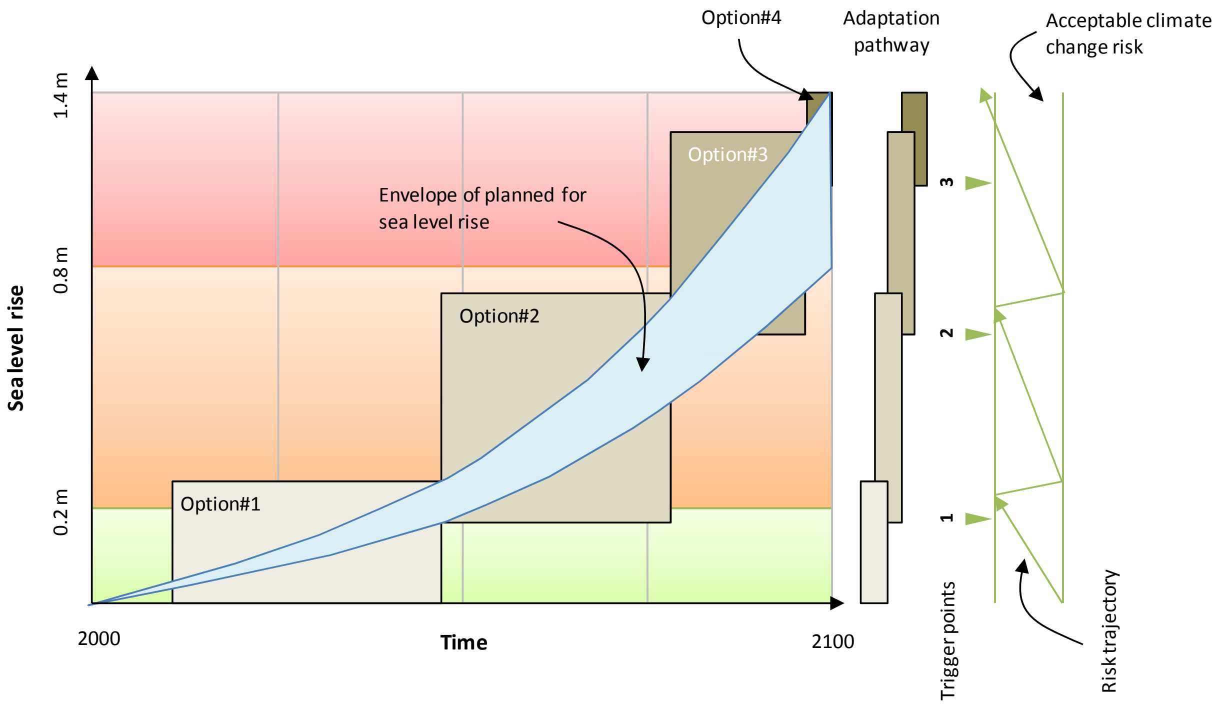


Figure 16 Illustration of the proposed framework for flexible adaptation pathways. The chart shows the planned-for envelope of potential sea level rise during the 21st century (based on 0.8-1.4 m rise by 2100). In this illustration, four adaptation tactics are planned for deployment over the course of the century (or longer if sea level rise is less than the projected upper range). Option #1 is designed to mitigate risk to about 0.25 m of sea level rise. At about 0.2 m of sea level rise, the process for deploying Option #2 is triggered. This option mitigates risk until sea level rise reaches about 0.75 m. Deployment of Option #3 is triggered at about 0.7 m. Option #3 treats risk effectively to about 1.3 m. Above this level of rise, there are no affordable and effective options to mitigate impacts exist and option 4 – accepting sea level rise and managing its impact or retreating from it is adopted.. Risk falls outside the typically accepted range from this point. Adapted from [10].

The adaptation options may be single measures or comprise an integrated suite of activities that involve planning, finance raising, community engagement and implementation. They can include not intervening: either because the level of risk does not (yet) warrant intervention, or because there are no affordable and/or effective risk treatments.

7.4 Adaptation priorities

The current stage of the *Climate change vulnerability and adaptation* project did not fully apply the adaptation framework (Figure 16). This section provides the foundation for subsequent work to do so by scoping out the adaptation priorities that flow from the risk assessment process (Chapter 5). Adaptation priorities are documented below for each of the five main classes of at-risk asset in terms of:

- **Issues contributing to the risk faced by the asset class** – what is the nature of the risks faced by this asset class, where are the at-risk assets located and under what sea level rise scenarios are material risks likely to emerge?
- **Existing risk controls** – what, if any, measures are currently in place to manage this risk?
- **Reasons why there remain material risks allowing for existing risk controls** – if there currently are risk controls in place, why does there remain a material risk to the asset?
- **Potential adaptation options** – specified in terms of the four main types of adaptation defined in Chapter 7.1, protect, accommodate, retreat and develop adaptive capacity.

The following sections provide preliminary (and non-exhaustive) documentation of existing risk controls and potential adaptation options.

Beaches and associated recreation and tourism infrastructure

This asset class includes Surf Coast region beaches that are intensively used by residents and visitors, as well as the nearby infrastructure that supports various beach-related uses. Almost all of GORCC's assets are included in this asset class. Most assets are located on or near beaches at the region's four main towns, Torquay, Anglesea, Aireys Inlet-Fairhaven and Lorne. Adaptation priorities are documented in Table 5.

Table 5 Adaptation priorities for beaches and associated recreation and tourism infrastructure.

Risk issues							
Each of the coastal hazards pose risk to Surf Coast beaches and associated recreation and tourism infrastructure. Coastal recession and storm erosion were assessed to be the main sources of risk. Material risks were reported against most types of asset, although not all of them. Assets for which no material risk was assessed from the four coastal hazards include: lighthouses and pools. Material risks were most commonly assessed to emerge with 0.8 m of sea level rise, although risks to beaches, boat ramps and some car parks were assessed to emerge with coastal erosion and recession resulting from up to 0.2 m of sea level rise.							
		Surf Coast section and sea level rise scenario at which material risks first assessed (blank if no material risks)					
Climate change hazard	Asset	1	2	3	4	5	6
Temporary inundation Reduced use of asset or operational capacity due to inundation during periodic extreme sea level events	Beach	0.8 m		0.8 m	0.8 m		0.8 m
	Car park			0.8 m	0.8 m		0.8 m
	Caravan park			0.8 m			
Permanent inundation Permanent or partial loss of use due to sub-daily inundation by tides with sea level rise	Beach	0.8 m	0.8 m	0.8 m	0.8 m		0.8 m
	Boat ramp			0.8 m		0.8 m	0.8 m
Storm erosion Episodic damage to beaches and built assets during storm events.	Beach	0.8 m	0.8 m	0.8 m	0.8 m		0.8 m
	Boat ramp	1.4 m		1.4 m	1.4 m		1.4 m
	Car park	0.8 m		0.8 m	0.8 m		0.8 m

	Lookout/walkway		0.8 m				
	Beach	0.8 m	0.8 m	0.8 m	0.8 m		0.8 m
		Surf Coast section and sea level rise scenario at which material risks first assessed (blank if no material risks)					
Climate change hazard	Asset	1	2	3	4	5	6
Coastal recession Loss of access and/or permanent damage to assets resulting from coastline retreat. Original location of asset taken up by retreating coastline.	Beach	0.2 m	0.2 m	0.2 m	0.2 m		0.2 m
	Boat ramp	0.2 m		0.2 m		0.2 m	0.2 m
	Car park	0.8 m	0.2 m	0.8 m	0.2 m		0.8 m
	Caravan park	0.8 m		0.8 m	0.8 m		0.8 m
	Lookout/walkway	0.8 m	0.2 m	0.8 m	0.8 m		0.8 m
	Playground	0.8 m		0.8 m	0.8 m		0.8 m
	Sailing club	0.8 m					
	Surf Lifesaving Club	0.8 m		0.8 m	0.8 m		0.8 m
	Toilet block	0.8 m		0.8 m	0.8 m		0.8 m

Existing risk controls

- Sand dune stabilisation and constructed beach access paths
- Location of infrastructure at elevations and distances from shore that ensure access during most sea level conditions
- Buildings and infrastructure design and construction are adapted to coastal environments

Why do material risks remain?

Location and design of buildings and other infrastructure and management of beach have all been on the basis of historical extreme sea level conditions and cycles of shoreline accretion and recession. Sea level rise is projected to extend temporary and permanent inundation beyond the historical range and lead to significant landward migration of erodible shorelines.

Potential adaptation options

- Protect – construct artificial reefs and/or other structures to retain sand on beach, beach nourishment to replace sand lost to storm erosion. Construct sea walls or levees to protect key coastal-dependent infrastructure (e.g. Surf Life Saving Club).
- Accommodate – extend boat ramps to higher elevation to maintain useability as sea levels rise. Close beaches and/or beach side parks, as required, during extreme sea level conditions. Repair boat ramps and car parks following storm damage.
- Retreat – Relocate beachside amenities to less exposed locations at the end of their lifecycle. Relocate non-coastal dependent infrastructure from coastal public land.
- Develop adaptive capacity – incorporate retreat planning into GORCC asset management/renewal planning, detailed coastal erosion modelling to refine risk assessment and evaluate adaptation options.

Environment and heritage features

This asset class incorporates dune and intertidal habitats and dependent fauna, as well as any sites and places of indigenous cultural significances. At-risk environmental features are located along the entire length of the region's coast. Heritage features that are at risk from sea level rise are located in dunes and erodible cliffs. Adaptation priorities are documented in Table 6.

Table 6 Adaptation priorities for environment and heritage features.

Risk issues							
Temporary inundation was assessed to only pose material risk to creeks. Other hazards posed material risks to a wider range of assets. Permanent inundation posed risks to all environment and heritage features except dune habitats. Storm erosion and coastal recession pose material risks to creeks and features located on the beach and in adjacent dunes. Many of the risks were assessed to be material with just 0.2 m of sea level rise.							
		Surf Coast section and sea level rise scenario at which material risks first assessed (blank if no material risks)					
Climate change hazard	Asset	1	2	3	4	5	6
Temporary inundation Periodic saline intrusion into creeks beyond current extent. Impact on water quality and aquatic communities.	Creeks & estuaries	0.8 m		0.8 m	0.8 m		0.8 m
Permanent inundation Permanent change to tidal exposure of intertidal habitat and fauna. Permanent shift in saline intrusion into streams and operation of estuary. Inundation of heritage sites.	Creeks & estuaries	0.8 m		0.8 m	0.8 m		0.8 m
	Fauna	0.2 m	0.2 m	0.2 m	0.2 m		0.2m
	Heritage sites		0.8 m				
	Intertidal habitat	0.2 m	0.2 m	0.2 m	0.2 m	0.8 m	0.2 m
Storm erosion Episodic damage to habitats, heritage sites and creeks and estuaries.	Creeks & estuaries	0.8 m		0.8 m	0.8 m		0.8 m
	Dune vegetation	1.4 m		1.4 m	1.4 m		1.4 m
	Heritage sites	0.2 m		0.2 m	0.2 m		
Coastal recession Permanent loss of habitat or heritage features. Permanent change to operation of estuaries and drainage from creeks.	Coastal environments	0.8 m	0.8 m	0.8m	0.8 m		0.8 m
	Dune vegetation	0.8 m		0.8 m	0.8 m		0.8 m
	Creeks and estuaries	0.8 m		0.8 m	0.8 m		0.8 m
	Heritage sites	0.2 m		0.2 m	0.2 m		
Existing risk controls							
- Sand dune stabilisation and constructed beach access paths. - Legal protection to avoid disturbance of heritage sites.							

- Establishment of coastal and marine protected areas.

Why do material risks remain?

Existing risk controls were not designed to deal with sea level rise and coastal recession, beyond assisting with autonomous adaptation (e.g. as coastal dunes retreat).

Potential adaptation options

- Protect – construct artificial reefs and/or other structures to retain sand on beach or new intertidal habitat.
- Accommodate – avoid development of new non-coastal dependent infrastructure behind coastal dunes to allow retreat as sea levels rise.
- Retreat – Relocate development areas behind coastal dune systems to allow natural recession processes.
- Develop adaptive capacity – assess indigenous cultural heritage in areas exposed to coastal recession to understand assets and values.

Residential and commercial properties

This asset class incorporates residential and commercial properties and related infrastructure, including stormwater drainage systems. Risk is expressed in relation to the physical assets and property values. Most material risks are concentrated in the major settlements (in sections 1, 3, 4 and 5). Adaptation priorities are documented in Table 7.

Table 7 Adaptation priorities for residential and commercial properties.

Risk issues

All four of the coastal hazards were assessed to pose material risks to residential and commercial properties (mostly around the four main towns). Risks to the operation of storm water drainage systems were assessed to be material with 1.4 m of sea level rise. Other risks were assessed to be material with 0.8 m of sea level rise and in some instances with 0.2 m. Apart from the operations of storm water drainage systems, material risks were assessed to be posed to properties and property values.

		Surf Coast section and sea level rise scenario at which material risks first assessed (blank if no material risks)					
Climate change hazard	Asset/ risk receptor	1	2	3	4	5	6
Temporary inundation Extreme sea level conditions do not allow storm water drainage system to operate effectively, resulting in flooding of notionally protected areas	Storm water drainage	1.4 m		1.4 m	1.4 m		1.4 m
Permanent inundation Permanent change to sea levels results in storm water drainage system failing to operate as planned, leading to unintended flowing. Property values affected by diminished value of beaches resulting from elevated sea levels	Property value	0.8 m	0.8 m	0.8 m	0.8 m		0.8 m
	Storm water drainage	1.4 m		1.4 m	1.4 m		1.4 m
Storm erosion Loss of access and/or property damage as a result of storm erosion events.	Property	0.8 m		0.8 m	0.8 m		0.8 m

		Surf Coast section and sea level rise scenario at which material risks first assessed (blank if no material risks)					
Climate change hazard	Asset/ risk receptor	1	2	3	4	5	6
Coastal recession Loss of access and/or property damage as a result of coastal recession. Loss of property values due to property damage and reduced beach amenity. Damage to storm water drainage infrastructure as coast recedes.	Property value	0.2 m	0.8 m	0.2m	0.2 m		0.2 m
	Residential property	0.8 m		0.8 m	0.8 m		0.8 m
	Storm water drainage	0.8 m		0.8 m	0.8 m		0.8 m

Existing risk controls

- Flood level assessments.
- Planning regulations and building codes that ensure new properties are not located in flood prone areas or located close to dunes.
- Planning and design of stormwater drainage systems.

Why do material risks remain?

Location and design of buildings and storm water drainage systems have all been on the basis of historical extreme sea level conditions and cycles of accretion and recession in shoreline location. Sea level rise projected to extend temporary and permanent inundation beyond the historical range and lead to landward migration of erodible shorelines. Property values are strongly influenced by amenity provided by beaches and beach access.

Potential adaptation options

- Protect – construct artificial reefs, sea walls and/or levees to provide protection against storm erosion, coastal recession and/or coastal flooding.
- Accommodate – rebuild stormwater drainage system to accommodate projected sea level rise. Implement planning controls to avoid new residential or commercial development in at-risk areas. Require adapted design/construction during property redevelopment. Alternative economic development to reduce reliance of property values and business incomes on tourism. Emergency planning to address public safety risks posed by storm erosion events.
- Retreat – Buy and lease back residential and commercial developments in at-risk areas while they are safe to occupy and decommission to create an easement for coastal retreat when risks approach critical threshold. Relocated non-coastal dependent infrastructure from coastal Crown land.
- Develop adaptive capacity – update Surf Coast planning scheme to account for projected sea level rise and coastal retreat.

Roads

This asset class incorporates local road, road bridges and the Great Ocean Road. Risk is expressed in relation to two main types of asset. Material risks are confined to the four main towns and erodible sections of the coast, where the Great Ocean Road runs close to the beach. Adaptation priorities are documented in Table 8.

Table 8 Adaptation priorities for roads. Circles indicate sea level rise scenario at which risks were first assessed to be high or extreme.

Risk issues

While some sections of road are periodically inundated during extreme sea level events and are projected to be inundated more frequently with sea level rise, risks associated with inundation were not assessed to be material due to the relative effectiveness of risk controls. Material risks were confined to those associated with damage and loss from storm erosion and coastal recession. Risks were mostly assessed to become material with 0.8 m of sea level rise, with the exception of those faced by some roads in the Urquharts Bluff-Spout Creek section of the coast.

		Surf Coast section and sea level rise scenario at which material risks first assessed (blank if no material risks)					
Climate change hazard	Asset	1	2	3	4	5	6
Storm erosion Repairable damage to roads and bridges during storm events.	Bridge	0.8 m		0.8 m	0.8 m		0.8 m
	Roads	0.8 m		0.8 m	0.2m		0.8 m
Coastal recession Temporary or permanent damage to roads and bridges as erodible coasts recede	Bridge	0.8 m		0.8 m	0.8 m		0.8 m
	Roads	0.8 m		0.8 m	0.2 m		0.8 m

Existing risk controls

- Location of roads and bridge approaches above extreme sea levels and in historically stable areas removed from coast.
- Design and construction with appropriate materials.
- Road closures and traffic diversions during extreme sea level events.

Why do material risks remain?

Sea level rise and coastal recession make historically safe route selection and road elevation decisions obsolete.

Potential adaptation options

- Protect – construct artificial reefs, sea walls and/or levees to provide protection against storm erosion and coastal recession and/or coastal flooding.
- Accommodate – rebuild roads and bridges at higher elevation to accommodate greater flood risk. Strengthen bridges to withstand storm erosion impacts. Avoid new residential/commercial developments in at-risk areas. Make financial provision for increased maintenance/rebuild expenditure.
- Retreat – plan for rerouting of key roads away from coastal hazard areas.
- Develop adaptive capacity – incorporate climate change risks into asset management and transport planning processes.

Surf breaks

This asset class incorporates the key beach and reef surfing breaks along the Surf Coast. Material risks were assessed to occur across the entire coastline and with 0.8 m of sea level rise. Adaptation priorities are documented in Table 9.

Table 9 Adaptation priorities for surf breaks.

Risk issues							
Increased sea levels may change the way in which beach and reef breaks operate and diminish the value of the surfing experience offered. Risks to surf breaks were only assessed to be material for permanent inundation, with 0.8 m of sea level rise.							
		Surf Coast section and sea level rise scenario at which material risks first assessed (blank if no material risks)					
Climate change hazard	Asset	1	2	3	4	5	6
Permanent inundation Permanently elevated sea levels may have a strongly detrimental effect on the operation of key reef and beach surfing breaks.	Surf break	0.8 m	0.8 m	0.8 m	0.8 m	0.8 m	0.8 m
Existing risk controls							
▪ None.							
Why do material risks remain?							
There are no existing controls to address risks for existing breaks.							
Potential adaptation options							
▪ Accommodate – use artificial reefs to maintain function of key reefs breaks (or develop breaks in new areas). ▪ Retreat – relocate surfing competitions to locations retaining or developing suitable waves. ▪ Develop adaptive capacity – wave modelling to more rigorously assess implications of sea level rise for surf conditions.							

8 Monitoring and review

Monitoring and review are critical components of any risk management process (Figure 2) and are particularly important for any such process related to climate change, in which the hazards will emerge over long time scales, understanding of risks is changing rapidly and adaptive planning responses (e.g. Figure 16) are required. A framework for monitoring and review has been developed for adaptation to coastal climate change hazards (Figure 17). It has three main components, as described below.

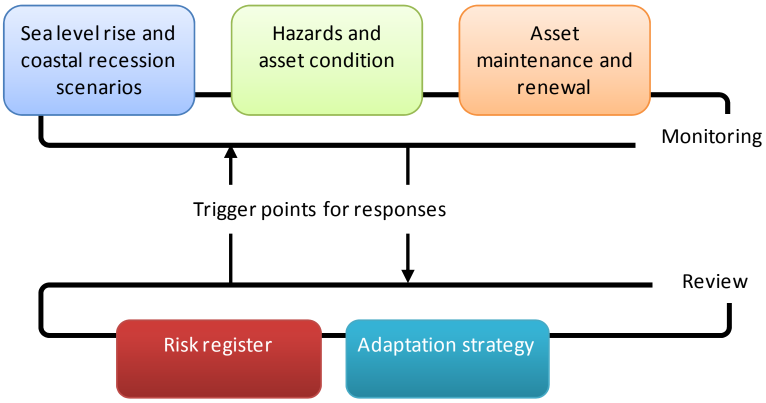


Figure 17 Monitoring and review framework for coastal climate change adaptation

Further work is required to refine the monitoring and review framework into a plan for implementation. However, this should follow the development of the adaptation framework into a formal adaptation strategy for the Surf Coast region with adaptation action plans for particular asset classes (see Chapter 9).

8.1 Monitoring

Despite considerable research effort, sea level responses to global warming remain quite uncertain. Risks to the Surf Coast region are determined by how global-scale influences translate into regional sea levels, wind patterns, ocean currents and wave climates. Monitoring of scientific literature on sea level rise and of public policy responses, as well as studies of regional influences on coastal hazards, is required to ensure that the scenarios used in the risk assessment remain plausible and apply best available science.

Monitoring in support of climate change adaptation should include collection and analysis of information on the key coastal hazards and coastal asset condition. Data from the Lorne tide gauge should be periodically interrogated to track local changes in mean and extreme sea levels and compare them with changes in the global mean and modelling of extreme sea levels. This will enable actual sea level rise and the associated risk to be tracked against the scenarios and any trigger points flagged in adaptation planning (Chapter 8.2). Shoreline movement should be assessed periodically in areas with concentrations of vulnerable assets to track erosion and coastal recession processes and detect events or change that pass relevant trigger points or thresholds. The condition of selected coastal assets should also be monitored to detect any changes that relate to experience of coastal hazards and, over time, any change due to sea level rise or coastal recession.

As part of GORCC and other stakeholders' asset management processes, information should be gathered on maintenance or repair expenses that relate specifically to coastal hazards (i.e. storm tide flooding, erosion events) and the events they were associated with. Over time this will allow changes in patterns of asset damage and maintenance expenditure to be detected and help to support business cases for investment in adaptation measures. Recorded asset maintenance expenditure might also be used as a trigger for investment in adaptation measures (Chapter 8.2).

8.2 Trigger points for responses

The flexible adaptation framework proposed here (Chapter 7.3; Figure 16) is underpinned by the identification and use of risk-based 'trigger points' to flag the need to initiate or modify adaptive responses. The trigger points used must be capable of being detected unambiguously, preferably through proposed monitoring processes. They must also express a meaningful change in the level of risk or impact from coastal climate change hazards.

It is not possible at this stage of the adaptation planning process to establish specific trigger points or monitoring protocols. More specific detail on the exposure of priority assets to the respective coastal climate change hazards and the adaptation tactics and opportunities is required. However it is possible to specify the types of triggers that may be considered, for example:

- **Triggers based on changes in sea level** – risks to built and natural assets arising from coastal inundation relate back to changes in mean and extreme sea levels. Triggers might be based on both, as they may change somewhat independently, based on the influence of changes in wind and wave climate and different assets have differing sensitivities to permanent and temporary inundation. Sea level triggers would be used for adaptive measures for assets (e.g. beaches, roads, car, caravan parks, buildings) whose use or value is sensitive to inundation.

  For erodible sections of the coast, triggers based on sea level change might also be used to flag emerging risks for coastal erosion and recession and the need for adaptive responses.

- **Triggers based on coastal recession** – coastal recession and the exposure of new land and assets to erosion are the major (coastal) drivers of coastal climate change risk. Triggers based on recession of the coast from a given (e.g. 2011) baseline could be used to guide the timing of planned retreat of assets from exposed coastal areas. Given that coastal recession typically occurs in steps, rather than incrementally, trigger points would need to be set well in front of sensitive assets.
- **Triggers based on asset condition or damage** – the condition of built or natural assets or the accumulated cost of repairing damage sustained as a result of inundation or erosion could be used as a trigger for some adaptive measures. Where adaptation is expensive (relative to the asset value) or otherwise difficult to implement, it may be prudent to accept damage from coastal hazards and then either invest in repairs or accept a decline in condition or value. A trigger point would be specified that defined the point at which repair costs were no longer small relative to asset value or at which asset condition was no longer acceptable and more direct intervention was required.
- **Triggers based on asset exposure** – the concept for this type of trigger is similar to that based on asset condition or damage, however it is anticipatory rather than reactive. Such triggers would be used where there is or is anticipated to be a growing concentration of assets (e.g. residential or commercial buildings) or uses in areas that may become exposed to coastal hazards. Investment in adaptive planning or responses might only be required where development (for example) is set or proposed to exceed a defined level of intensity in an area exposed to future coastal hazards.

Periodic review processes (below) would provide the opportunity to compare results from monitoring with trigger levels and potentially lead to new phases in adaptation plans.

8.3 Review

Data and information from monitoring would be used to review and potentially revise the coastal climate change risk register, the adaptation strategy and supporting planning.

The risk register developed for this project should be reviewed periodically to ensure that it continues to reflect the risk priorities for coastal assets in the Surf Coast region. The review should revise sea level rise scenarios as (or if) suggested by the best available science on coastal climate change hazards and evidence from local monitoring. It would be updated to reflect any new risk treatments and the development of any new infrastructure or assets in areas exposed to coastal hazards. A brief review of the register should be undertaken annually, with a thorough revision at about five yearly intervals. The revision of the risk register should involve the full set of risk owners and precede the revision of adaptation plans or strategies.

Consistent with the plan-do-check-review approach to adaptive planning, the overarching adaptation strategy developed for the Surf Coast region and supporting action plans (see Chapter 9) should include periodic review processes. The periodic revision of the risk register would be a key input, as would data from monitoring of the science and information base and local coastal and asset conditions. The reviews would provide the opportunity to detect any of the trigger points that may be used to mark the transition to a new phase in the adaptation pathway for a particular asset or asset class. Adaptation options and tactics would be revised in the light of new science, adaptation practice, local experience and any changes in relevant policy, planning or regulations. Action and investment plans would also be updated.

9 Next steps

This stage of the *Climate change vulnerability and adaptation* project has identified the key risks for GORCC and other key stakeholders arising from sea level rise and associated coastal recession. It has also developed frameworks for adaptation, as well as monitoring and review. This work provides the basis for more detailed adaptation planning that reflects the spatial and temporal distribution of risk, the unique nature of each type of asset and the aspiration and capacity of 'risk owners' and the broader community to tackle the risks they face.

A further stage of the *Climate change vulnerability and adaptation* project is required to undertake this more detailed adaptation planning. Some key steps in that work are outlined below.

- Stakeholder engagement – to engage key 'risk owners' (Table 4) in this next stage of the project, particularly in the details of adaptation planning. Refine and agree on adaptation principles.
- Literature review and method development – review relevant literature on coastal planning and management to identify current best practice in managing risks from sea level rise and associated coastal recession. Use this and other relevant literature to develop methods for evaluation of alternative adaptation pathways and investments in coastal adaptation.
- Adaptation option development – develop long-term adaptation pathways, following the framework in Figure 16, for each asset in their unique spatial and temporal risk contexts. The adaptation pathway would include the suite and/or sequence of options to mitigate risk of at least 0.8 m of sea level rise. Develop the implementation process for each suite or sequence of options, including any planning, community and stakeholder engagement, raising finance, works or activities required. Develop sea level rise or coastal recession trigger points that will be used to flag the commencement of transition from one adaptation option to the next in the sequence (if relevant).
- Option and implementation process evaluation – apply economic and TBL[9] assessment tools to evaluate alternative adaptation pathways and establish the case for investment.
- Adaptation strategy development – develop detailed adaptation action plans for each asset class based on the preceding work. Synthesise these in an overall adaptation strategy for the Surf Coast region. Develop a monitoring and review plan (based on the framework in Chapter 8) for inclusion in the strategy.

[9] TBL – triple bottom line assessment, incorporating social, economic and environmental criteria.

10 Limitations

The exposure and risk assessments undertaken for this project are limited by the methods used and assumptions made about sea level rise and coastal recession. Key limitations and assumptions include:

- The assessment of exposure to coastal inundation was based spatial data layers on asset location and a high resolution digital elevation model. Uncertainties in both information sources may contribute to errors in the elevation above mean sea level attributed to assets. The assessment also did not consider the potential pathway by which assets may be inundated by sea levels of a particular height. Natural or constructed features may prevent some assets from being inundated by sea levels that are higher than their elevation about mean sea level.
- The assessment of exposure to coastal recession is based on the assumption, following the Bruun rule, that erodible coastlines may retreat by up to 100 m for each 1 m of sea level rise. Use of the Bruun rule is common in “high level” coastal hazard assessments, but its validity is the subject of considerable debate. More robust modelling methodologies are available for detailed investigations.
- The risk assessment considered sea level rise scenarios and associated distances of coastal recession. They assess the consequence and likelihood (i.e. risk) of coastal hazards if those scenarios are realised. No assessment has been made of the likelihood that any of those scenarios will occur.
- The maps produced for this project (Appendices A and D) are for information purposes only and should not be used for detailed planning. Maps in Appendix D list the assets identified in stakeholder workshops in stage 1 of this project and are not meant to be exhaustive representations of the assets exposed to or at risk from coastal inundation, erosion or recession.

11 References

1. Intergovernmental Panel on Climate Change [IPCC] 2007a. Climate change 2007: Synthesis report. Summary for policymakers. IPCC.
2. IPCC 2007b. IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (eds.)]. Cambridge University Press.
3. Department of Climate Change 2009. Climate change risks to Australia's coast. A first pass national assessment. Department of Climate Change.
4. Bruun P 1962. Sea-level rise as a cause of shore erosion. American Society of Civil Engineering Proceedings, Journal of Waterways and Harbors Division 88: 117–130.
5. Victorian Coastal Council 2008. Victorian Coastal Strategy 2008. Victorian Coastal Council.
6. McInnes, K, J. O'Grady and M. Hemer 2011. Waves and extreme sea levels on the Great Ocean Road Coast: implications of future climate change. A report for Sinclair Knight Merz and Great Ocean Road Coast Committee. CSIRO Marine and Atmospheric Research, 2011.
7. McInnes, K., I. Macadam, and J. O'Grady. 2009. The Effect of Climate Change on Extreme Sea Levels along Victoria's Coast. A Project Undertaken for the Department of Sustainability and Environment, Victoria as part of the 'Future Coasts' Program. Melbourne : CSIRO Marine and Atmospheric Research, 2009.
8. Australian Greenhouse Office 2006 Climate change impacts & risk management. A guide for business and government. Australian Greenhouse Office.
9. Standards Australia 2009. AS/NZSISO 31000:2009 Risk management: principles and guidelines. Standards Australia.
10. Ministry for the Environment 2008. Coastal Hazards and Climate Change. A Guidance Manual for Local Government in New Zealand. 2nd edition. Revised by Ramsay, D, and Bell, R. (NIWA). Prepared for Ministry for the Environment.
11. Department of Sustainability and Environment 2008. Victoria in Future population projections. www.dse.vic.gov.au/victoriainfuture
12. Surf Coast Shire undated. Welcome to the Surf Coast Shire. http://www.surfcoast.vic.gov.au/about_you_council.htm
13. Australian Bureau of Statistics 2007. Community profile series: Surf Coast Shire. Cat. No. 2001.0-2006.
14. Ainsaar M. and Riusseene M. 2006. Tourism strategic plan for the Surf Coast region. Consultancy report to Surf Coast Shire. Urban Enterprises Pty Ltd.
15. Bureau of Meteorology Aireys Inlet weather station data, station 090180.
16. McLaren S, Wallace MW, Gallagher SJ, Dickinson JA and McAllister A. 2009. Age constraints on Oligocene sedimentation in the Torquay Basin, south-eastern Australia. *Australian Journal of Earth Sciences* 56, 595-604.
17. Geoscience Australia 2010. OzCoasts: Australian Online Coastal Information. Smartline data sets. www.ozcoasts.org.au
18. NSW Government 1990. NSW coastline management manual. NSW Government. http://www.environment.gov.au/coasts/publications/nswmanual/index.html
19. CSIRO and Bureau of Meteorology 2007 Climate change in Australia. Technical report 2007. CSIRO.

20. Vellinga, P., 2008: Exploring high end climate change scenarios for flood protection of the Netherlands. International Scientific Assessment, 136pp

21. Rahmstorf, S., 2007: A semi-empirical approach to projecting future sea-level rise. Science 315(5810), 368–370.

22. Smit, B. Pilifosova O. Burton I. Challenger B. Huq S. Klein R.J.T. Yohe G. 2001. Chapter 18 Adapting to climate change in the context of sustainable development and equity. IPCC Third Assessment Report, Intergovernmental Panel on Climate Change.

23. Parliament of Victoria 2010. *Climate Change Act.* Parliament of Victoria.

24. Coastal Engineering Solutions Pty Ltd 2012. Coastal processes study. Report to Great Ocean Road Coast Committee. Draft.

Appendix A Historical changes in coastline location

An analysis of historical changes in coastline position was conducted for the entire length of the Surf Coast. Aerial photography from 1951 and 1975 was sourced and the coastline position digitised. Coastline positions in 1951 and 1975 were then overlaid with current imagery for the coast to enable change to be assessed. The following maps show examples of how the coastline has or has not changed over the last almost 60 years[10].

Coastline location was marked either by the upper edge of cliffs or the edge of vegetated dunes. Differences in coastline location may be due to coastal recession, loss of vegetation cover from the lower extent of dunes and, in some instances, uncertainties in defining coastline position (e.g. due to the quality of the image shading etc.). Registration errors (i.e. inaccuracies in the digitisation process) also contribute to some instances of apparent movement of the coast.

A summary of the maps is given below. A key diagram and the six maps are given on the following pages.

- Map 1 Bells Beach-Point Addis - the map suggests that the cliffs have receded by several metres in some locations, particularly near the section of cliff that was already collapsed and vegetated in 1951 (right hand side of red box).
- Map 2 Anglesea River - vegetation on the dunes and rocks to the west of the river mouth have generally receded, although sand has accumulated and vegetation become established on the western side of the river mouth. Low cliffs to the east of the river mouth have also retreated in some locations (e.g. top right hand corner of map, outside red box).
- Map 3 Southern outskirts of Anglesea - the erodible rocky shoreline has retreated by several metres in most of the section of coast contained in the red box. No change can be detected in come stretches of coast outside the box.
- Map 4 Point Roadknight-Urquharts Bluff - the coastline has retreated marginally along much of this section of coast.
- Map 5 South of Urquharts Bluff - some small sections of the coast (e.g. centre of red box) have retreated a significant distance over the past 60 years. The rocky headland at the bottom of the box also appears to have retreated, although other rocky headlands (towards top of box) have resisted erosion.
- Map 6 Lorne - the margin of vegetated dune has receded significantly in the last 60 years, particularly near the mouth of Erskine Creek. The beach appears to have been more stable to the north of the mouth of the creek.

GORCC has recently commissioned a more detailed investigation of coastal erosion processes (by Coastal Engineering Solutions Pty Ltd). That study [24] used aerial photography from separate 9 years between 1947 and 2007, including the three sets used here. Its conclusions were similar to those here, that the position of the coastline position has changed only to a limited extent between 1947-2007, at most in the order of metres rather than tens metres.

[10] Further sites could have been included in the presentation. However, the six selected sites were considered to provide the illustration of coastal change required. Coastline position in 1975 is not shown due to the limited difference over the longer period.

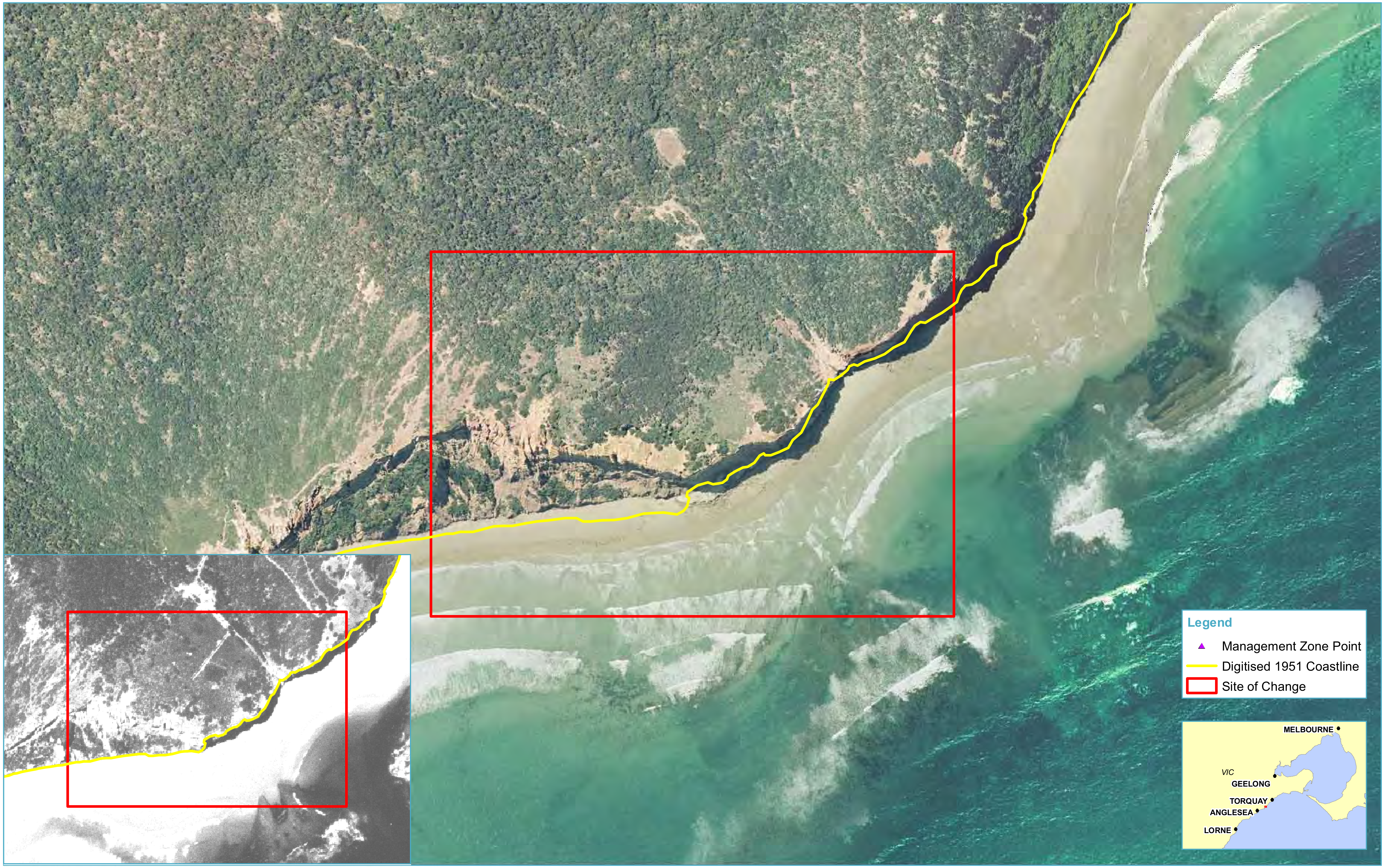
Sites Displaying Change Along the Great Ocean Road - Overview

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 3,000
Metres
[GDA94 | MGA Zone 55]

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Coastal_Areas_at_Risk.mxd
May 19, 2011



Sites Displaying Change Along the Great Ocean Road

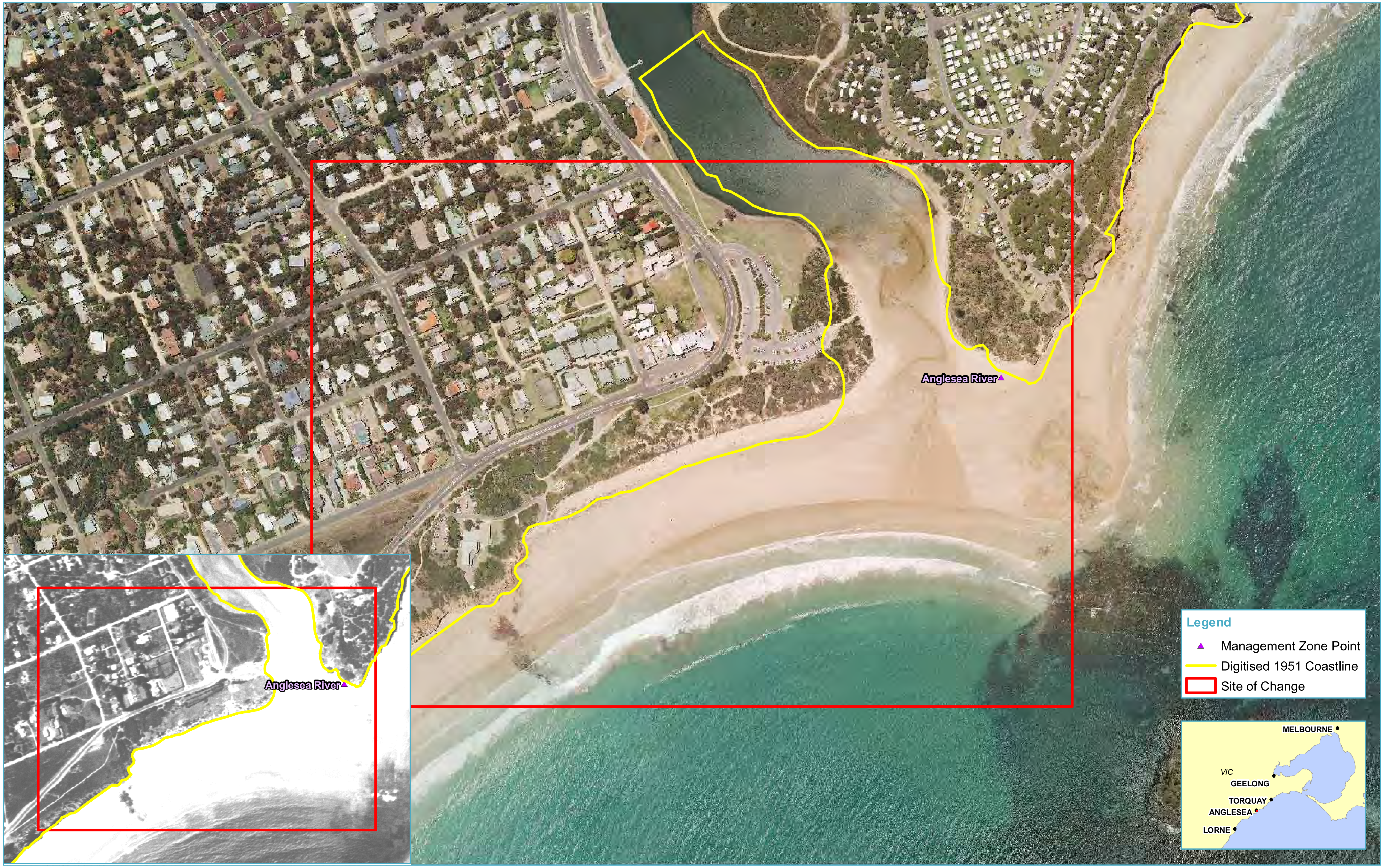
Map: 1

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 140
Metres
[GDA94 | MGA Zone 55]

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Coastal_Areas_at_Risk.mxd
May 19, 2011



Sites Displaying Change Along the Great Ocean Road **Map: 2**

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 120
Metres
[GDA94 | MGA Zone 55]

SKM

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Coastal_Areas_at_Risk.mxd
May 19, 2011

Sites Displaying Change Along the Great Ocean Road **Map: 3**

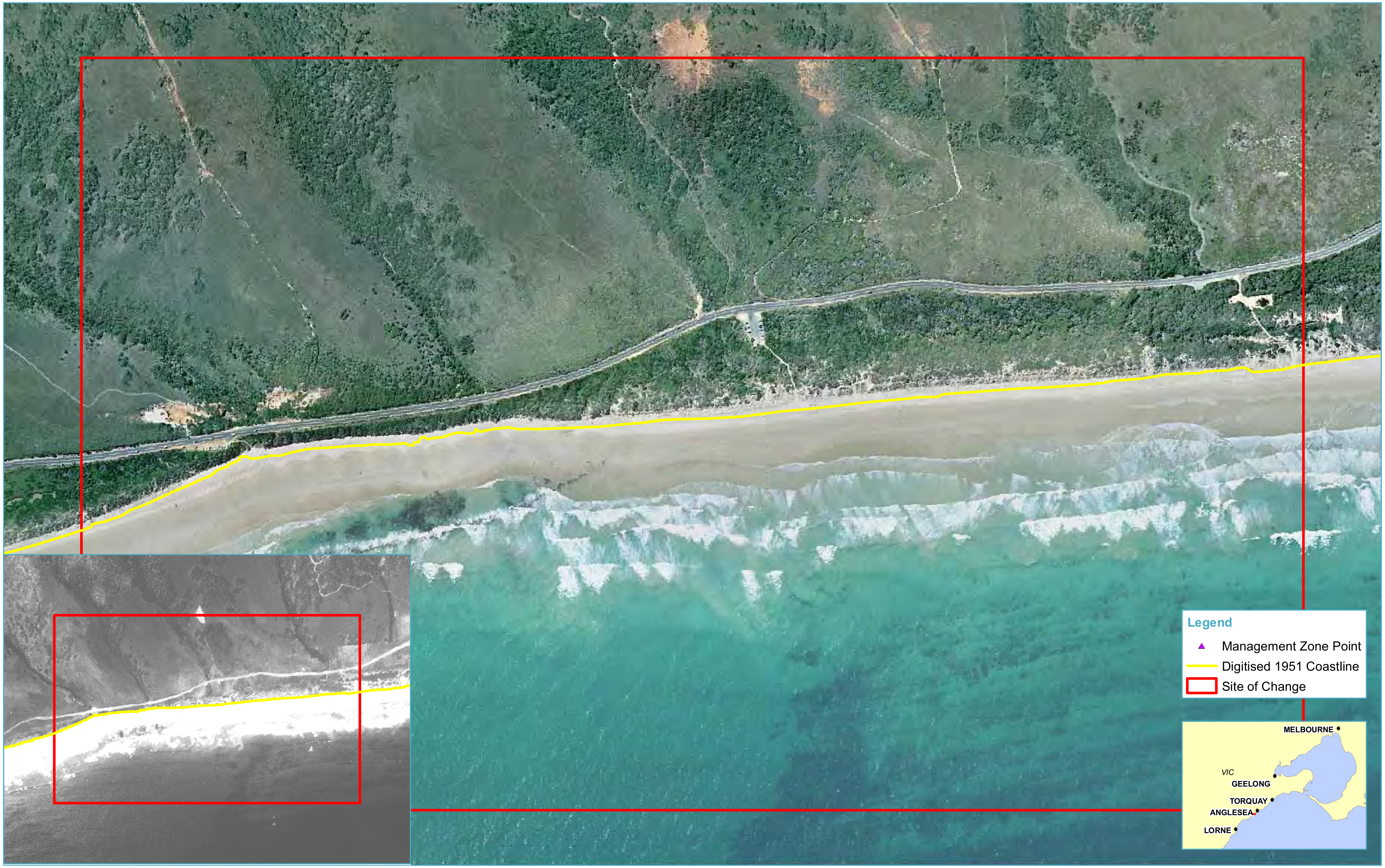
VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 120
Metres
[GDA94 | MGA Zone 55]

SKM

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Coastal_Areas_at_Risk.mxd
May 19, 2011



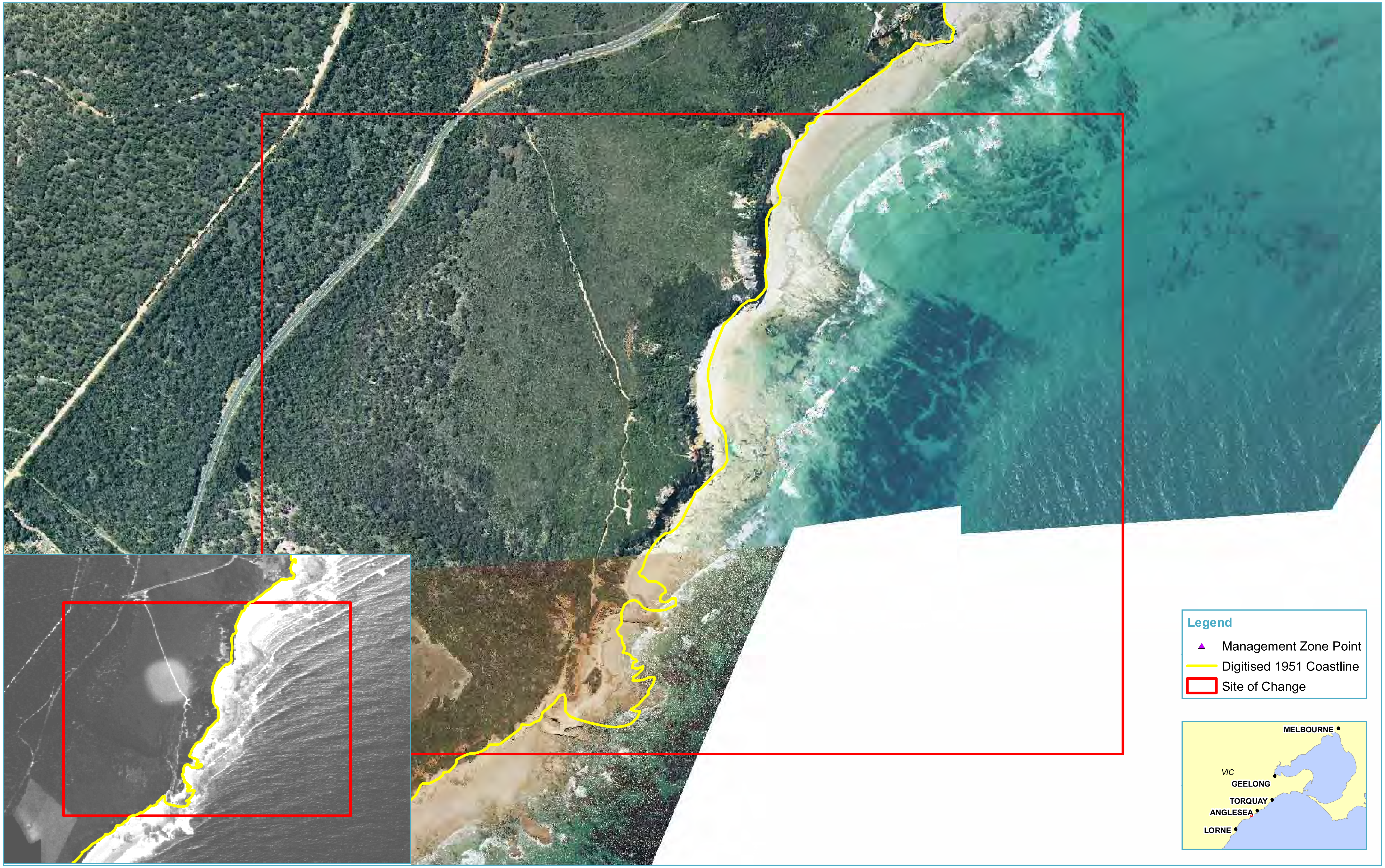
Sites Displaying Change Along the Great Ocean Road **Map: 4**

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 160
Metres
[GDA94 | MGA Zone 55]

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Coastal_Areas_at_Risk.mxd
May 19, 2011



Sites Displaying Change Along the Great Ocean Road

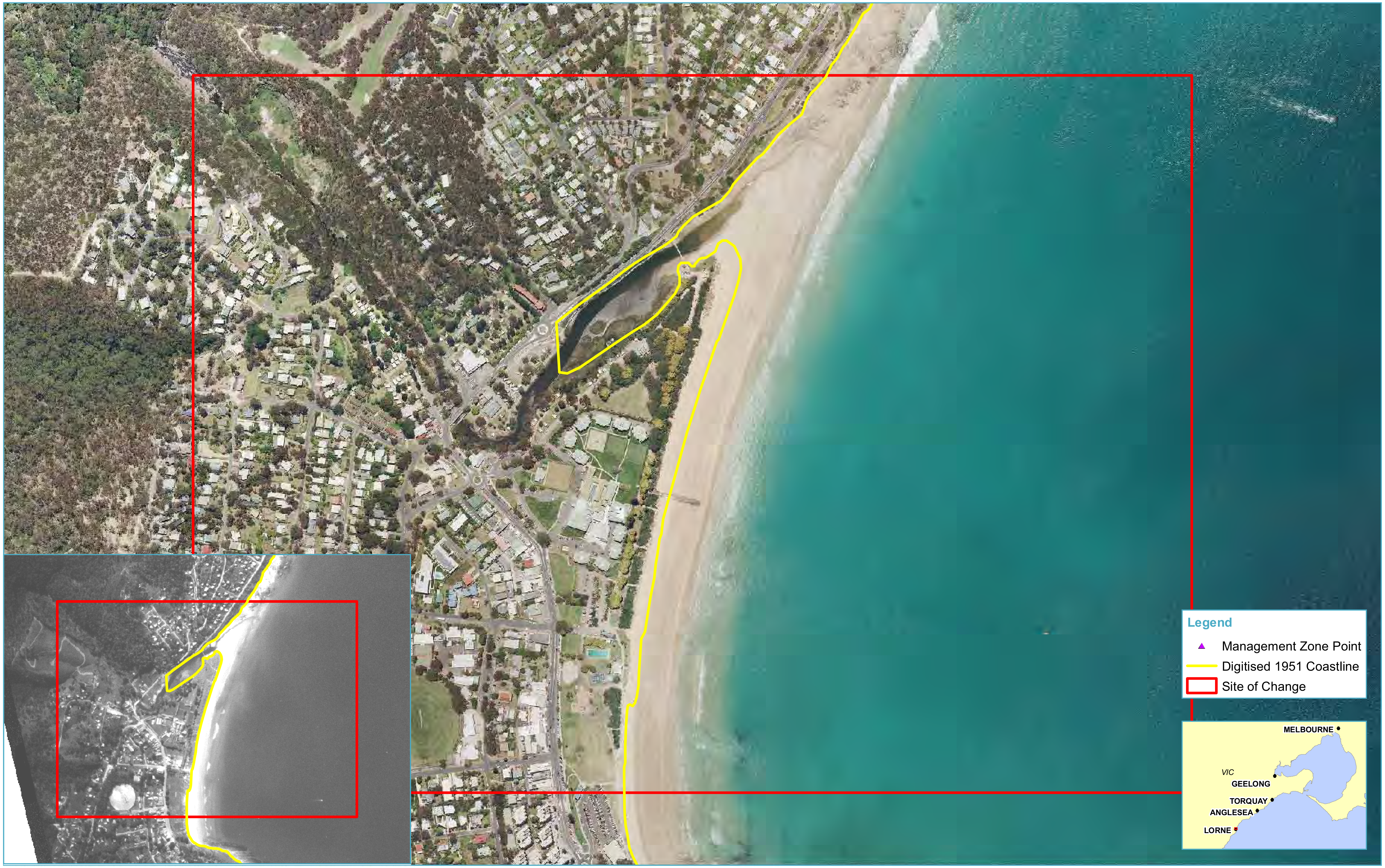
Map: 5

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 160
Metres
[GDA94 | MGA Zone 55]

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Coastal_Areas_at_Risk.mxd
May 19, 2011



Sites Displaying Change Along the Great Ocean Road **Map: 6**

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

Sinclair Knight Merz does not warrant that this document is definitive nor free of error and does not accept liability for any loss caused or arising from reliance upon information provided herein.

0 200
Metres
[GDA94 | MGA Zone 55]

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Coastal_Areas_at_Risk.mxd
May 19, 2011

Appendix B CSIRO report on future wave climate for the Great Ocean Road coast

Waves and extreme sea levels on the Great Ocean Road Coast: Implications of future climate change

Kathleen McInnes, Julian O'Grady, Mark Hemer
28 September 2011

Report for Great Ocean Road Coast Committee

Enquiries should be addressed to:
Dr Kathleen L. McInnes
CSIRO Marine and Atmospheric Research
PMB #1
Aspendale, 3195
P +61 3 92394569
e-mail: kathleen.mcinnes@csiro.au

Distribution list

Daniel Ware Sinclair Knight Merz	1

Contents

1. INTRODUCTION

Climate change is a significant issue for Australia's coastal communities. Regardless of international efforts to reduce greenhouse gas emissions, the global climate is projected to undergo significant change in the 21st century in response to greenhouse gas emissions since the beginning of the industrial era. The changes that are particularly relevant to the coast include rising sea levels and possible changes in circulation patterns that may impact on sea level extremes, waves and coastal currents. The impacts of these changes, will depend not only on the physical environment but also socio-economic factors. Therefore, both must be considered when addressing coastal management responses to deal with future climate change. This report, which focuses on the physical attributes of the coast, therefore forms part of a larger study conducted by Sinclair Knight Merz on behalf of the Great Ocean Road Coast Committee (GORCC) to address appropriate management responses for the future management of the Great Ocean Road coastline.

Two classes of coastal hazard related to oceanic extremes that are particularly significant in the context of coastal management are coastal inundation and shoreline stability. The susceptibility of coastal regions to erosion and inundation is primarily related to various intrinsic physical (e.g. shoreline slope) and geomorphological characteristics.

Episodes of extreme sea levels brought about by storm surges, high waves or high tides or a combination of these are a major cause of inundation and erosion events. However, shoreline change may also be affected by more gradual changes in mean sea level and wave climate (including the height, direction and period of waves). Changes in mean sea level alter the wave period and hence refraction of waves. Changes in atmospheric circulation patterns may alter wave direction with consequent changes to other wave characteristics. Other changes such as in sediment supply to the coast due to changing rainfall or river flow characteristics (Nicholls et al., 2007) may also affect coastal erosion. Subsidence of coastal terrain due to isostatic rebound (Mitrovika et al., 2010; Blewitt et al., 2010), or sediment compaction from anthropogenic activities such as oil, gas and water extraction (Syvitski et al, 2009) may also affect coastal inundation.

Anthropogenic climate change poses a threat to coastal regions through a number of potential pathways. These include;

- Rising mean sea levels, which cause landward recession of coastlines that are made up of erodible materials.
- Changes in the frequency or severity of transient storm erosion events.
- Changes wave speed due to sea level rise that alters wave refraction,

- Changes in atmospheric circulation patterns that alter wave direction, which may lead to the realignment of shorelines and alter the frequency or severity of severe storm wave and surge events which may affect the occurrence of episodic inundation and erosion events.

The present report reviews recent studies on extreme sea levels due to storm surge. The role of waves, and in particular wave direction, on extreme sea levels along the GOR shoreline is investigated briefly through a set of wave model simulations to better understand the additional contribution of waves to extreme sea level events along this coastline. A review of recent relevant climate change studies that provide guidance on how future climate change may influence extreme sea level and wave climate in this region is also given.

2. EXTREME SEA LEVELS

Extreme sea levels along the Victorian coast were investigated in McInnes et al, (2009a, b). Extreme sea levels most commonly occurred due to the combination of tides with storm surges. The most common cause of storm surges was found to be the eastward-moving cold frontal systems that bring westerly to southwesterly winds to the south coast of Australia. The 1 in 100 year return level was evaluated to be 1.2±0.12 m above mean sea level (approximately AHD) on the open coastline near Cape Otway, increasing to about 1.8±0.13 m above mean sea level at Torquay.

Scenarios of future mean sea level rise and wind speed were also applied to these values to yield future climate values. Four scenarios were investigated (Table 1). Scenario 1 is derived from the high-end value of the projected range of sea level rise for 2090-2099 reported by the IPCC (2007). These values relate to the A1FI emissions scenario for future greenhouse gas emissions (Nakićenović and Swart, 2000). The values used here were obtained from Hunter (2009) who scaled the IPCC (2007) values to yield values throughout the 20th century relative to 1990.

The impact of future wind speed change on storm surges were also explored. To be consistent with the high-end A1FI scenario for sea level rise, the high (90th percentile) estimates for changes in annual average wind speed for the A1FI emissions scenario from climate change projections for Australia were used (CSIRO and BoM, 2007) (see http://www.climatechangeinaustralia.gov.au/) and are summarised in Table 1. It was noted that, because of the large uncertainties in wind speed change in this region as represented by the set of Fourth Assessment Report climate models, the Australian projections did not preclude the possibility of future decreases in annual average wind speed in Bass Strait.

Since the release of the IPCC (2007) report, other sea level rise and coastal impact assessments have been undertaken that put forward alternative sea level rise scenarios for 2100. For example, based on a simple statistical model, Rahmstorf (2007) suggests a likely range of values for sea-level rise over the 1990-2100 period of 0.5 to 1.4 m. A report prepared for the Dutch Delta Committee, which assesses post- Fourth Assessment Report publications on the impacts of recent warming trends on ice sheet dynamics, derives an upper bound of sea level rise of 1.1 m by 2100 (Vellinga, 2008). These additional scenarios were also been considered in McInnes et al, (2009a, b) and form scenarios 3 and 4 in Table 1. The total sea levels evaluated for these scenarios are presented in Table 1 and indicate that even by 2030, a 1 in 100 year event could become a 1 in 20 year event.

Table 1: Storm tide height return levels for Apollo Bay and Lorne under current climate conditions and scenarios of sea level rise and wind change as indicated. All values are in metres relative to late 20th Century mean sea level.

				2030			2070			2100			
	Return Period (yrs)	**Future Scenario**		**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**4**
		Sea Level Rise (m)		0.15	0.15	0.20	0.47	0.47	0.70	0.82	0.82	1.10	1.40
		Wind Speed Change (%)		-	4	-	-	13	-	-	19	-	-
		Current Climate											
Apollo Bay	10	1.10	±0.11	1.25	1.30	1.30	1.57	1.71	1.80	1.92	2.13	2.20	2.50
	20	1.23	±0.11	1.38	1.43	1.43	1.70	1.82	1.93	2.05	2.25	2.33	2.63
	50	1.34	±0.12	1.49	1.55	1.54	1.81	1.95	2.04	2.16	2.36	2.44	2.74
	100	1.42	±0.13	1.57	1.63	1.62	1.89	2.04	2.12	2.24	2.46	2.52	2.82
Lorne	10	1.32	±0.11	1.47	1.52	1.52	1.79	1.94	2.02	2.14	2.35	2.42	2.72
	20	1.46	±0.12	1.61	1.67	1.66	1.93	2.06	2.16	2.28	2.50	2.56	2.86
	50	1.59	±0.13	1.74	1.81	1.79	2.06	2.22	2.29	2.41	2.63	2.69	2.99
	100	1.69	±0.13	1.84	1.91	1.89	2.16	2.33	2.39	2.51	2.74	2.79	3.09

3. WAVES

The GORCC region from Torquay to Cumberland River (see Figure 1) is comprised mainly of beaches backed by rock or dune systems which may become vulnerable to erosion if wave attack is to increase as a result of climate change (Port of Melbourne Authority, 1992). Wave breaking at the coast can contribute to sea level extremes through wave set up and run up, both of which occur as a result of wave breaking in the coastal zone. Wave setup is an increase in the mean water level shoreward of the region in which breakers form at the seashore, caused by the onshore momentum flux against the beach, while wave runup is the maximum vertical uprush of water on a beach or structure above the still water level following wave breaking (see Figure 2).

Figure 1. The region over which the 0.011°x0.011° (~1 km) resolution wave model simulations are performed. The inset shows the larger 0.11°x0.11° resolution domain from which wave spectra boundary conditions are obtained.

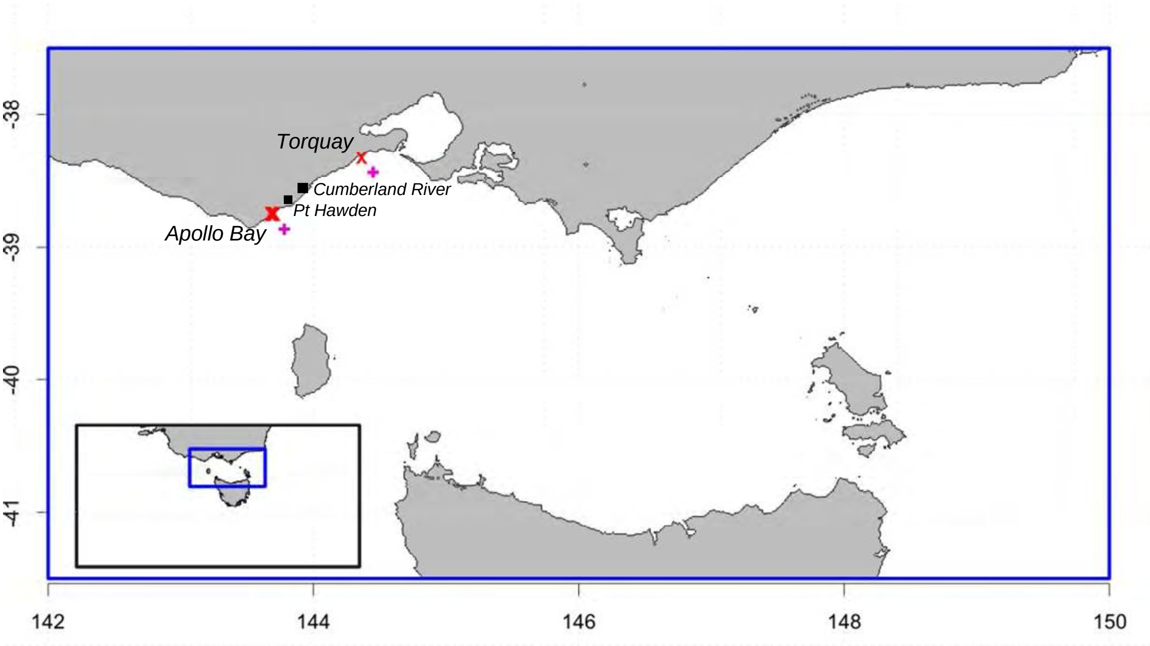
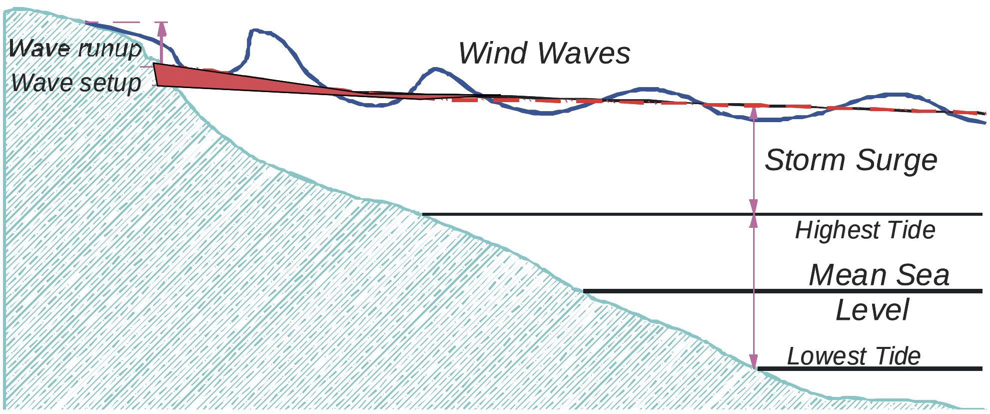


Figure 2. Schematic diagram showing the relative contributions from various coastal and oceanic processes that lead to coastal inundation.



The characteristics of the winds that are associated with high wave events and storm surges at Kingfish B platform in eastern Bass Strait have been investigated by O'Grady and McInnes (2011). They found that high wave events occur under both easterly and westerly wind events, but the majority, 71% of all events occur in conjunction with winds with a westerly component (mainly SW and W), while only 23% have winds with an easterly wind component (i.e. NE, E, SE). Using tide gauge data at Lakes Entrance, they found that an even greater proportion of storm surges were associated with westerly component winds (93% of events) and the remaining 7% were associated with southerly winds (S). High wave events occurring in conjunction with westerly component winds tended to be associated with positive sea level residuals at the coast whereas high waves under easterly component winds usually were associated with small positive or negative sea level residuals at the coast.

However, they also found that the shoreward wave energy transport and wave setup on the coastline to the south of Lakes Entrance was smallest in the westerly event and largest in the southerly event. This result suggested that for this coastline storm surges produced under westerly wind events were not likely to be further enhanced by wave setup while those generated by southerly wind events could be further enhanced along the open coast due to wave setup. More generally this result indicates that shoreline orientation with respect to the prevailing wind direction is an important factor in determining whether wave setup will contribute to extreme sea levels on the open coast.

The orientation of the Great Ocean Road coastline is similar with respect to the prevailing wind and wave conditions as the coastline studied in O'Grady and McInnes (2011). Here we briefly investigate the effect of wind direction on waves affecting the Great Ocean Road coastline. A series of eight SWAN wave model experiments were conducted with constant wind forcing of 21.1 m/s from eight directions. The simulations were performed until a steady state solution was achieved to represent wave heights under a fully arisen sea. The simulations were performed over two regions. The first region (inset in figure 1) comprised a wave model grid at a 0.11º x 0.11º (approximately 10 km) resolution. The broader region of this grid, which extends from 35 to 50°S and spans longitudes from 130 to 150°W means that longer period swell that may affect the Great Ocean Road coastline was captured. The directional wave energy spectra from this simulation, was applied to the lateral boundaries of a second set of simulations carried out at 0.011º x 0.011º (approximately 1km) resolution over the region shown in Figure 1.

The decreasing water depth adjacent to the coast causes waves to undergo refraction so that the wave crests become more aligned with the coastline direction as they propagate towards the shore. The degree to which this occurs as they approach the coast is investigated by comparing wave energy spectral diagrams at a nearshore and offshore coastal location (2 km and 15 km offshore respectively) at two points along the GOR coast; Apollo Bay in the south and Torquay in the north. Figure 3 shows the wave energy density spectra (EDS) for Apollo Bay in the south while Figure 4 shows the point at Torquay. At both the N15km and S15km locations, longer period waves are generally associated with westerly and southwesterly winds while shorter period waves occur under easterly and southeasterly wind forcing owing to the greater fetch in the west and southwest directions compared to the east and southeast. At the S15km location winds from the southwest produce the most energetic waves followed by westerly and southerly winds. In the westerly wind case, refraction of the wave field has occurred so that the waves are propagating towards the northeast. Closer into shore at S2km, considerable wave refraction has occurred so that the most energetic waves propagating towards the northwest quadrant (i.e. onshore) result from wind conditions varying clockwise from northeasterly to westerly.

Figure 3. The 2-dimensional variance/energy density spectrum (EDS) in polar coordinates at a point 15 km (top) and 2 km (bottom) offshore from Apollo Bay The eight figures surrounding the legend clockwise from top centre represent constant wind forcing from the N, NE, E, SE, S, SW, W and NW directions respectively. The location in polar space describes the direction of the wave energy propagation in m^2/Hz in Cartesian coordinates relative to the source, the distance from the centre of the plot indicates the period of the waves in seconds and the shading indicates the magnitude of the energy.

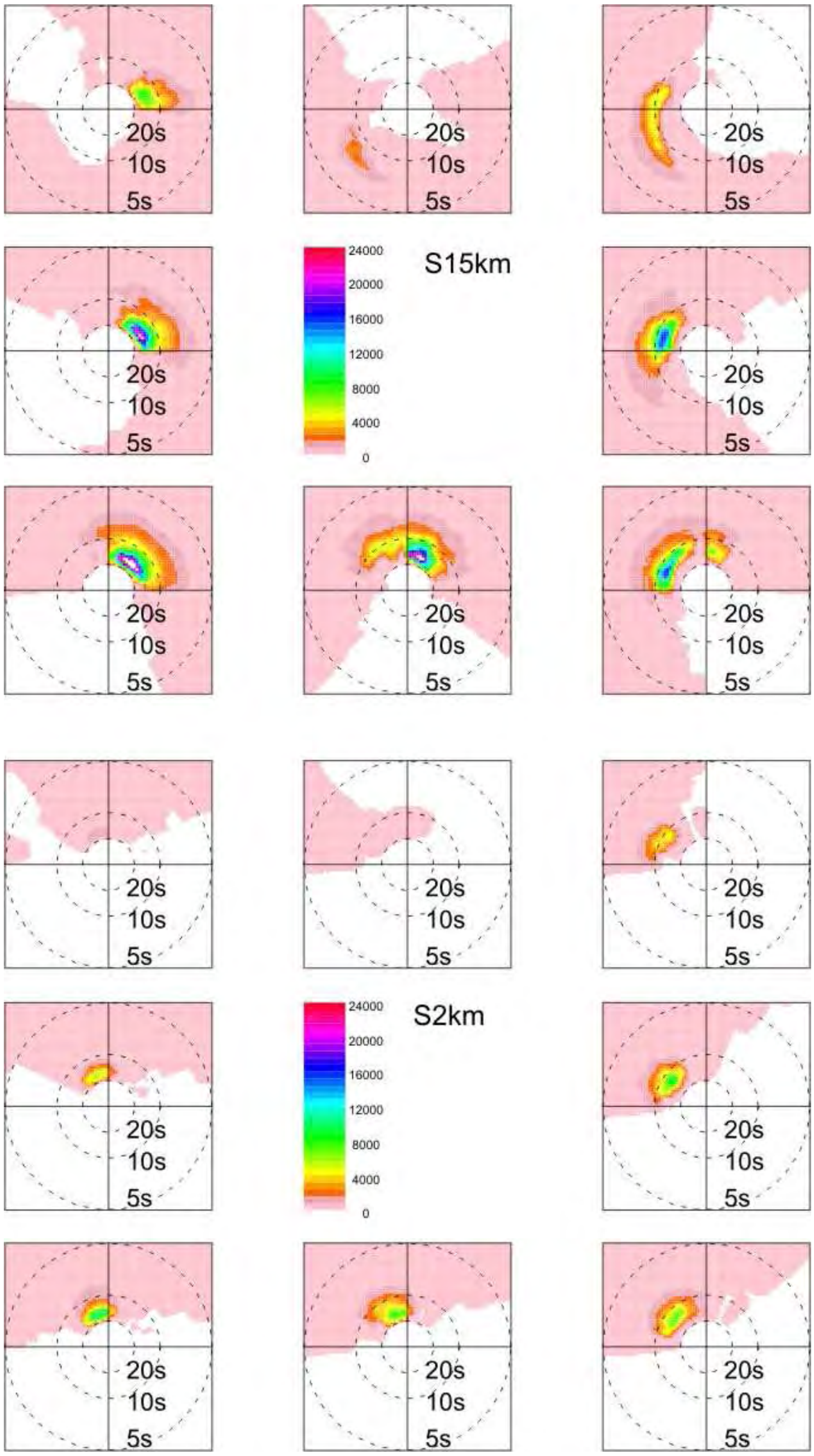
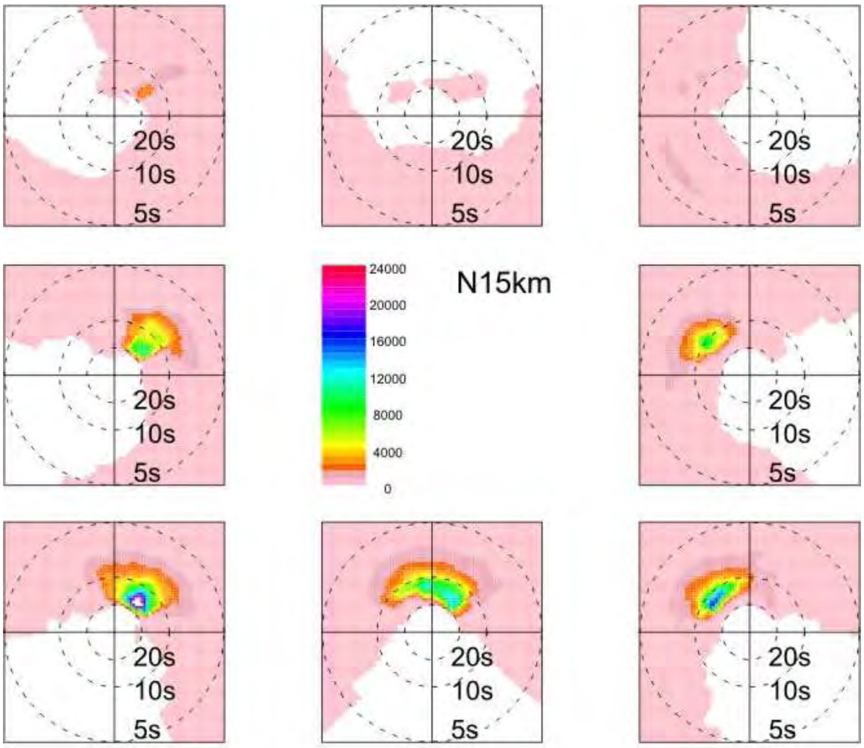
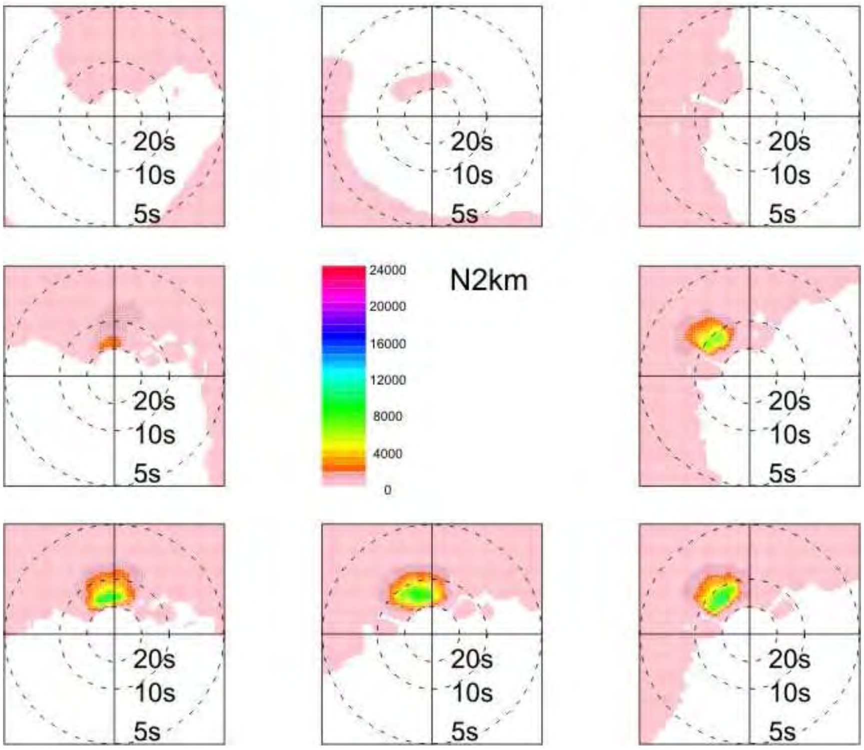


Figure 4. The 2-dimensional variance/energy density spectrum (EDS) in polar coordinates at a point 15 km (top) and 2 km (bottom) offshore from Torquay. The eight figures surrounding the legend clockwise from top centre represent constant wind forcing from the N, NE, E, SE, S, SW, W and NW directions respectively. The location in polar space describes the direction of the wave energy propagation in m^2/Hz in Cartesian coordinates relative to the source, the distance from the centre of the plot indicates the period of the waves in seconds and the shading indicates the magnitude of the energy.

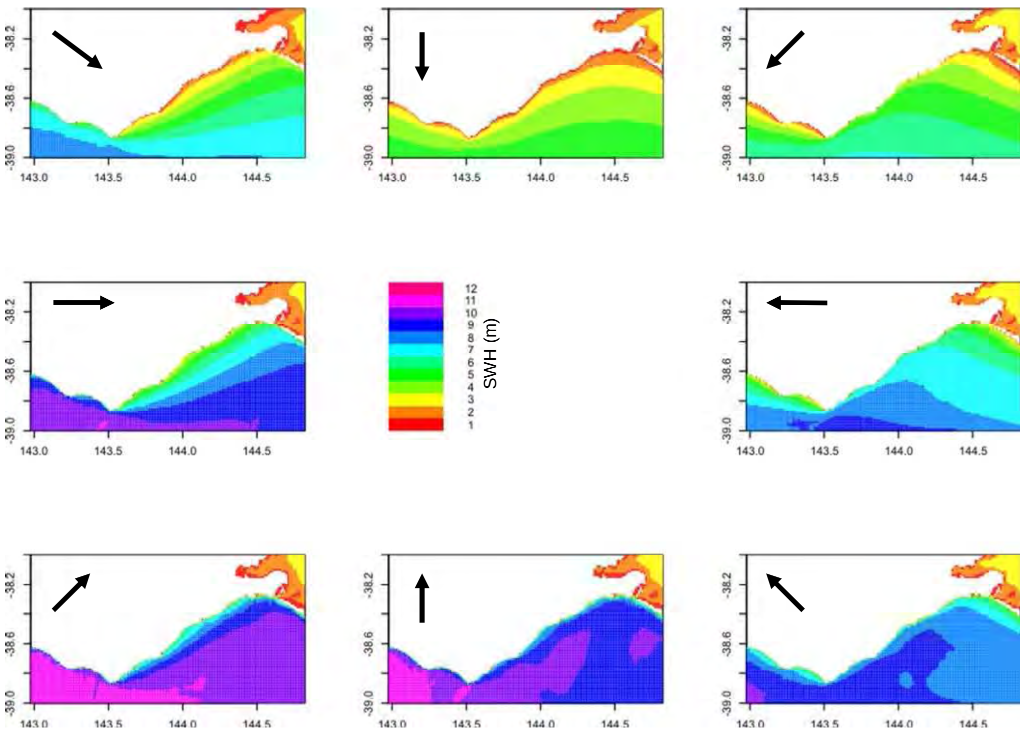




The smallest waves occur under northerly winds. At the N15km location, the most energetic waves result from winds varying clockwise from easterly to westerly. At N2km location, the most energetic waves propagating towards the coast occur for wind conditions ranging from the east to southwest.

The resulting field of significant wave height (SWH - the highest one third of waves) from each simulation on the 1km grid is shown in Figure 5. The largest waves in central Bass Strait of up to 11 m occur with sustained winds from the southwest while the lowest waves from 2 to 5 m arise when winds are from the north. However, the largest waves along the Great Ocean Road coast occur when winds are southerly since Point Hawden near Kennett River shelters the stretch of coastline further to the northeast when the wind is from the southwest.

Figure 5. The significant wave height (SWH) arising from the application of a constant wind from the direction indicated by the arrow in each figure.



4. THE EFFECT OF CLIMATE CHANGE ON WINDS AND WAVES

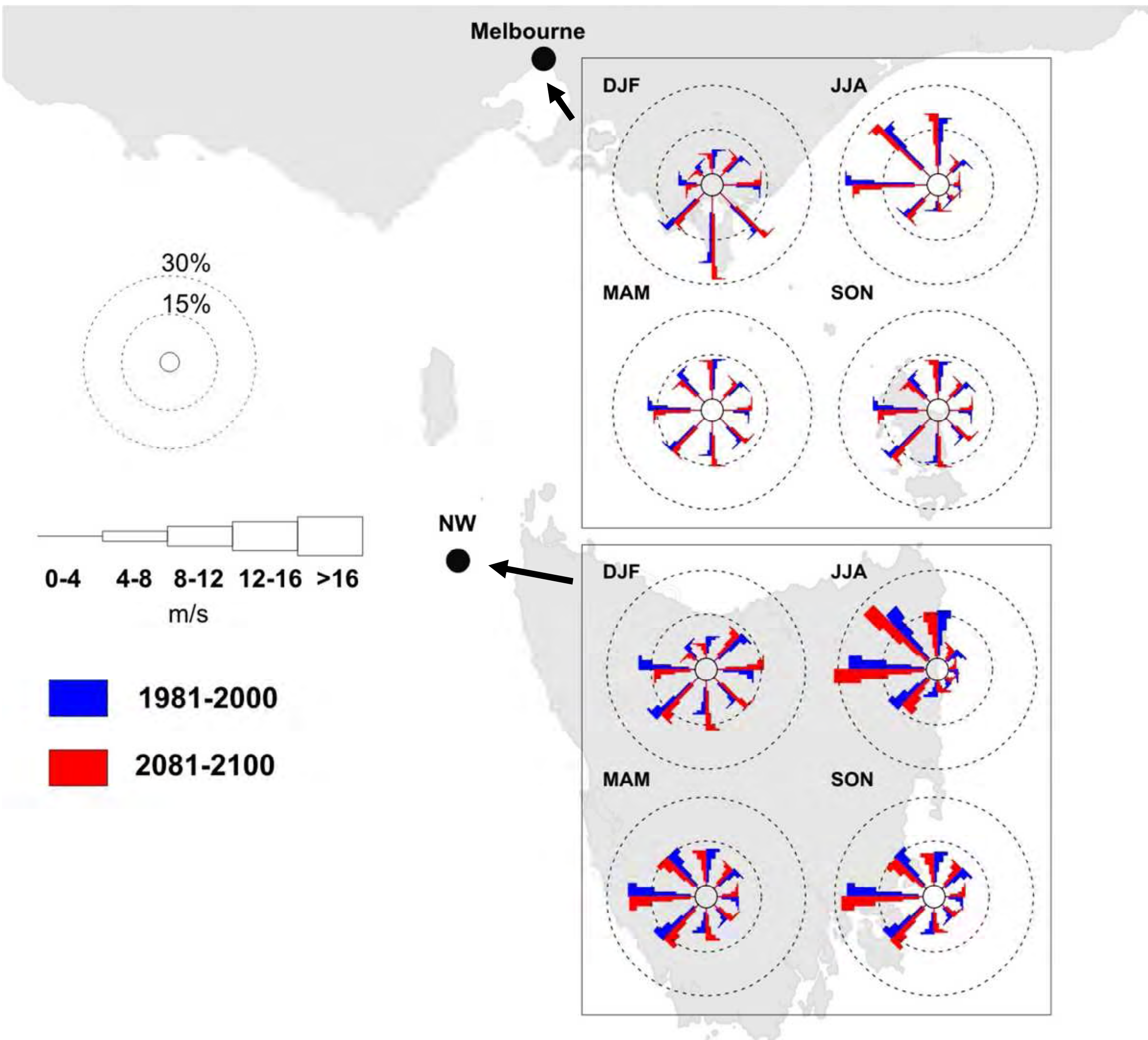
As part of the recent Climate Futures for Tasmania project, future climate simulations with a high resolution climate model have been carried out over Australia (Gross, 2010). These simulations were performed with CSIRO's Cubic Conformal Atmospheric Model (CCAM) over the Australian region at approximately 50km resolution with boundary forcing obtained from six different global GCMs under two different scenarios of future greenhouse gas emissions. Projections of future wave climate change were developed for the eastern Australian seaboard using three of these model simulations by Hemer et al, (2010). This study found that the future changes to the mean wind field between the time intervals 2081-2100 relative to 1981-2000 consisted of a southward shift of approximately 3° in the position of the subtropical ridge (STR - the separation between the easterly trade winds in the north and the westerly mid-latitude winds in the south and located at around 30ºS on the east coast of Australia). The southward shift in the STR was associated with a strengthening of the easterly trade winds, a strengthening of westerlies south of 45º S and a weakening of westerlies between the STR and 45º S.

The wind changes projected by one of the CCAM simulations between the 2081-2100 and 1981-2000 are illustrated seasonally in Figure 6 at points to the north and south of the Great Ocean coastline. This particular CCAM simulation obtains forcing conditions from the GFDL 2.0 GCM and was chosen because the change in winds was strongest in this model, although it is generally representative of the changes seen in the other simulations. This shows that at both the Melbourne and NW locations there is an increase in the frequency of winds from the east to the south in DJF and MAM and to a lesser extent in SON including an increase in the frequency of the stronger wind classes. In DJF there is an increase in frequency in northwesterly and northerly winds at Melbourne and a marked increase in frequency of northwesterly and westerly winds at the NW location.

Hemer et al, (2010) employed wave models to project possible future changes to the east coast wave climate based on the winds simulated in three different CCAM simulations. Several methods for applying wind forcing to wave models to develop projected changes were applied. In all methods used a robust decrease in mean significant wave height, Hs, along the east Australian coast relative to present climate conditions was found. The magnitude of the projected change was relatively small (less than 0.2 m), but significant, and increased northwards along the NSW coast. A relatively small (~5°) anticlockwise rotation in mean wave direction is projected to occur over the same period

Both Wang and Swail (2006) and Mori et al (2009) investigated projected changes in global wave climate. While quantitative comparisons between studies is not possible, qualitatively these studies project similar wave conditions for different future climate scenarios (SRES A2 and SRES A1B respectively). The projected southwards shift of the southern ocean storm belt associated with the projected increase in positive polarity of the southern annular mode leads to a decrease in locally generated wave activity (wind-sea) along the Southern Australian coast throughout the year (including local to the GORCC region). Wave activity in the Southern Ocean is however projected to increase in energy, particularly during Autumn and Winter months, and this projected change will also likely influence the Southern coasts with greater swell wave energy and a potential more southerly orientation to the swell direction.

Figure 6. Seasonal wind rose diagrams developed from 20 years of once-daily climate model data and representing the average breakdown of wind speed and direction from 1981-2000 (blue) and 2081-2100 (red). The figures show the percentage of time the wind is from each of the eight compass directions (e.g. the blue or red bars directly above each circle indicate winds from the north, those to the right indicate easterly winds and so on). Wind speed is indicated by the width of each bar segment and the total length of the bar segments from all eight directions adds to 100% of the time in each season.



5. CONCLUDING DISCUSSION

With regards to extreme sea level events which occur due to frontal troughs that are associated with westerly/southwesterly winds, wave model simulations performed here indicated that considerable refraction of waves occurs such that extreme sea levels arising from storm surges may be further amplified by wave setup.

Climate change simulations imply a greater frequency of waves generated from easterly winds and a reduced frequency waves generated by westerly and southwesterly winds during DJF and MAM. This will mean a greater frequency of shorter period waves impacting the GOR coast. Section 3 of this report indicates that nearshore wave heights under easterly wind conditions are greater than during westerly events, although of shorter wave period. The implications of these changes will vary along the coast depending on local defences, but an increasing frequency of these events will effectively reduce the return period of storm wave events in the region. Storm wave events drive both ephemeral and chronic coastal erosion, leading respectively to short and long-term coastal recession. The increasing frequency of these events may lead to shorter beach recovery times after ephemeral erosion events, and consequent continued retreat of the shoreline position. The shift from a westerly to an easterly dominated wave regime will also lead to change in wave direction, and consequent long-shore transport of sediment. Such changes have potential to influence position and intensity of coastal sediment budgets. Such changes may lead to either an advance or retreat in the position of the shoreline depending on the local geography.

In JJA, greater frequency of winds from the southwest and west, imply greater impact from larger westerly swells in winter. These swell waves are the long period waves favoured for recreational surfing along the Great Ocean Road coast, and an increase in frequency of these events may favour these activities. However, longshore transport in the swash zone scales with wave period (due to the wave period dependence on wave breaker type, Kamphuis, 1991). Similarly wave run-up increases with increasing wavelength. Consequently, changes in swell conditions will have greater influence on coastal long-shore and cross-shore sediment budgets than the locally generated wave changes.

In addition to the projected changes in wind conditions influencing the wave climate, the effects of sea-level rise will alter the nearshore geography and morphology such that waves propagating to the coast will be effected. Chini et al. (2010) investigated the impact of SLR on the inshore wave climate along the UK coast, and found that SLR leads to an increase of inshore wave height in shallow waters, despite minimal projected change in offshore wave statistics. However, over the time-span of decades, it could be anticipated that the seabed and beach profiles will evolve accordingly. These sediment transport processes are not taken into account here, but their influence could also be significant.

REFERENCES

Blewitt, G, Altamimi, Z, Davis, J, Ross, R., Kuo, C-Y, Lemoine, F.G., Morre, A.W., Neilan, R.E., Plag, H-P, Rothacher, M., Shum, C.K., Sideris, M.G., Schöne, T., Tregoning, P., and Zerbini, S. 2010: Geodetic observations and global reference frame contributions to understanding sea-level rise and variability. In Understanding Sea-Level Rise and Variability Eds. Church, JA Woodworth, PL Aarup, T & Wilson WS. Blackwell Publishing Ltd. P326-372.

Chini N, Stansby P K, Leake J, Wolf J, Roberts-Jones J, Lowe J. 2010. "The impact of sea level rise and climate change on extreme inshore wave climate: a case study for East Anglia (UK)". Coastal Engineering. Vol. 57. pp 973-984. DOI: 10.1016/j.coastaleng.2010.05.009

Hemer M, McInnes, K.L. and Ranasinghe, 2010: Investigation of climate change driven variations in offshore wave climate along the NSW coast Final Report for Department of Climate Change and Energy Efficiency, October 2010, 64pp.

Hunter, J., 2009: Estimating Sea-Level Extremes Under Conditions of Uncertain Sea-Level Rise. Climatic Change. DOI 10.1007/s10584-009-9671-6.

IPCC, 2007: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers. 18pp http://www.ipcc.ch/SPM2feb07.pdf

Kamphuis J. W. (1991b). Alongshore sediment transport rate. J. Waterway, Port, Coastal and OceanEngineering, American Society of Civil Engineers, 117; 624-640.

McInnes, K.L., I. Macadam, and J.G. O'Grady, 2009a: *The Effect of Climate Change on Extreme Sea Levels along Victoria's Coast. A Project Undertaken for the Department of Sustainability and Environment, Victoria as part of the 'Future Coasts' Program*. CSIRO, Victoria, Australia. 58 pp. www.climatechange.vic.gov.au

McInnes, K.L., O'Grady, *and Macadam, I. 2009b: The* Effect of Climate Change on Extreme Sea Levels in Port Phillip Bay. *A Project Undertaken for the Department of Sustainability and Environment, Victoria as part of the 'Future Coasts' Program*. CSIRO, Victoria, Australia www.climatechange.vic.gov.au

Mitrovica JX, Tamisiea ME, Ivins ER, Vermeersen LLA, Milne GA, and Lambeck K, 2010: Surface Mass Loading on a Dynamic Earth: Complexity and Contamination in the Geodetic Analysis of Global Sea-Level Trends (2010) Ocean Temperature and Salinity Contributions to Global and Regional Sea-Level Change. In: Church JA, Woodworth

PL, Aarup T and Wilson WS (eds) Understanding Sea-Level Rise and Variability. 2010 Blackwell Publishing Ltd. ISBN: 978-1-444-33451-7.

Mori, N., T. Yasuda, H. Mase, T. Tom and Y. Oku (2010) Projection of extreme wave climate change under the global warming, Hydrological Research Letters, Vol.4, pp.15-19. (doi:10.3178/hrl.4.15)

Nakićenović, N., and Swart, R., (eds.), 2000: Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599pp.

O'Grady, J.G. and McInnes, K.L. 2010: Extreme wind waves and their relationship to storm surges in northeastern Bass Strait. *Australian Meteorology and Oceanography Journal*, (in press).

Port of Melbourne Authority (1992), Victorian Coastal Vulnerability Study. Coastal Investigations Unit, Port of Melbourne Authority, Port Melbourne, VIC. 60pp.

Ranasinghe, R., R. McLoughlin, A. Short, and G. Symonds, 2004: The Southern Oscillation Index, wave climate, and beach rotation. *Marine Geology*, **204(3-4)**, 273-287

Syvitski, J.P.M., A.J. Kettner, I. Overeem, E.W.H. Hutton, M.T. Hannon, G.R. Brakenridge, J. Day, C. Vörösmarty, Y. Saito, and L. Giosan, 2009: Sinking deltas due to human activities. Nature Geoscience, 2, 681-686.

Wang, X.L., and V.R. Swail, 2006: Climate change signal and uncertainty in projections of ocean wave heights. Clim. Dyn., 26, 109–126.

Contact Us
Phone: 1300 363 400
+61 3 9545 2176
Email: enquiries@csiro.au
Web: www.csiro.au

Your CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.

Appendix C Risk assessment framework

Risk is the product of assessments of the consequence and likelihood of an impact for a given climate change scenario. Inputs to the assessment include:

- Consequence and likelihood tables (Table 10 and Table 11, respectively)
- A risk matrix that defines the level of risk associated with each combination of consequence and likelihood (Table 12);
- Definitions of how to respond to each level of risk (Table 13).

Details of each of these are given below. Risk tables drew from several sources, including GORCC and [7].

Table 10 Consequence criteria and descriptors

	Asset Damage	Community & lifestyle	Environment & heritage	Local economy & growth
Very serious **Long term, extensive, irreversible with high level impacts, potentially at state wide levels**	Significant damage to most assets resulting in loss of capability.	The region would be seen as very unattractive, moribund and unable to support its community	Major long-term environmental damage. Major damage to significant heritage assets. Regional extinction of species.	Regional decline leading to widespread business failure, loss of employment and hardship
Serious **Extensive, long term, but reversible event with high impacts on a regional level**	Significant damage to many assets resulting in very limited capability	Severe and widespread decline in services and quality of life within the community	Damage to environment &/or heritage assets causes concern to community. Local extinctions.	Regional stagnation such that businesses are unable to thrive and employment does not keep pace with population growth
Moderate **Localised long term but reversible event with moderate impacts on a local level**	Damage to assets resulting in isolated loss of capability	General appreciable decline in services	Community concerns regarding impacts on environmental & heritage assets. Serious medium term environmental effects.	Significant general reduction in economic performance relative to current forecasts
Minor **Localised, reversible short term reversible event with minor effects which are contained to an onsite level**	Damage to assets resulting in restrictions in capability	Isolated but noticeable examples of decline in services	Minimal impact on environment or heritage features.	Individually significant but isolated areas of reduction in economic performance relative to current forecasts
Insignificant **Minimal, if any, impact which have an overall negligible net effect**	Minor damage requiring increased maintenance	There would be minor areas in which the region was unable to maintain its current services	No impact on environment or heritage features.	Minor shortfall relative to current forecasts

	Public administration	Public safety and health	Reputation	Financial
Very serious Long term, extensive, irreversible with high level impacts, potentially at state wide levels	Public administration would fall into decay and cease to be effective.	Large numbers of serious injury or loss of lives	n/a	>$100M
Serious Extensive, long term, but reversible event with high impacts on a regional level	Public administration would struggle to remain effective and would be seen to be in danger of failing completely.	Isolated instances of serious injuries or loss of life	Serious public or media outcry. (International or national coverage)	$10-$100M
Moderate Localised long term but reversible event with moderate impacts on a local level	Public administration would be under severe pressure on several fronts.	Small number of injuries	Significant adverse attention by media, public or NGOs. (State based)	$1M - $10M
Minor Localised, reversible short term reversible event with minor effects which are contained to an onsite level	Isolated instances of public administration being under severe pressure.	Serious near misses or minor injuries	Media attention of local concern	$10-S1M
Insignificant Minimal, if any, impact which have an overall negligible net effect	There would be minor instances of public administration being under more than usual stress but it could be managed.	Appearance of threat or no actual harm	Minor, adverse local public or media attention or complaints	<$10k

Table 11 Likelihood descriptors

Likelihood	Descriptors
Almost certain	Recurrent events - expect this event several times per year. Single event - highly likely (>90% probability).
Likely	Recurrent events - expect this event several times each decade. Single event - more likely to occur than not (50-90% probability).
Possible	Recurrent events - expect this event to occur every decade or so. Single event - less likely than not, but still appreciable chance of occurring (10-50%).
Unlikely	Recurrent events - event expected to occur only 1-2 times per century. Single event - unlikely but not negligible (1-10%).

Rare	Recurrent events - event unlikely to occur more than once in a century. Single event - not expected to occur, but possible (<1%).

Table 12 Risk matrix: the level of risk associated with each combination of likelihood and consequence

	Consequence				
Likelihood	**Very Serious**	**Serious**	**Moderate**	**Minor**	**Insignificant**
Almost certain	extreme	extreme	extreme	high	medium
Likely	extreme	extreme	high	high	medium
Possible	extreme	extreme	high	medium	low
Unlikely	extreme	high	medium	low	low
Rare	high	high	medium	low	low

Table 13 Responses to assessed risk

Risk category	Response by GORCC
Extreme	Immediate action required
High	Senior management attention required
Medium	Management responsibility must be specified
Low	Managed by routine procedure

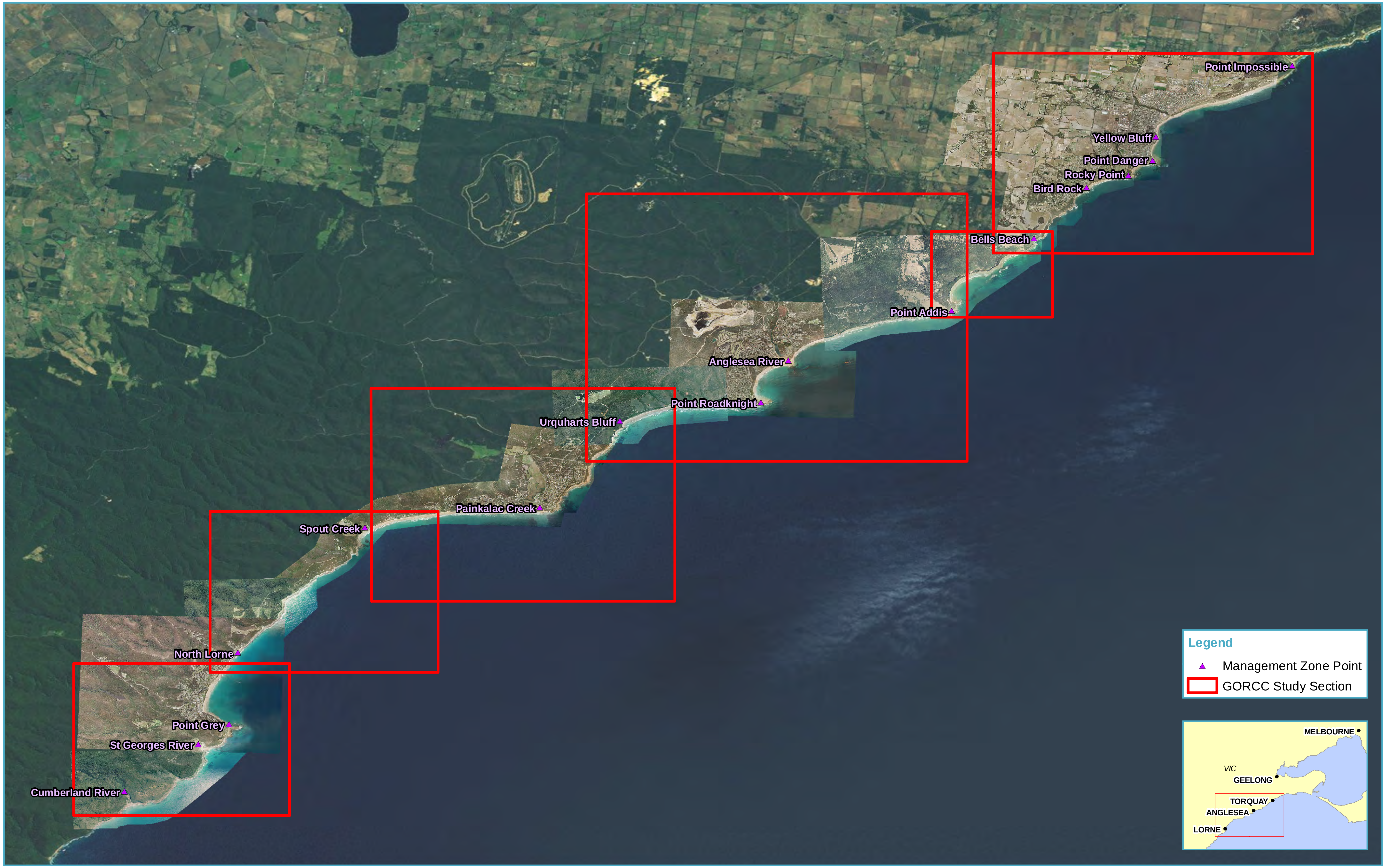
Appendix D Climate change risk assessment summaries

Overview

This appendix includes maps that summarise the risk assessment undertaken for the Surf Coast region. The maps highlight the locations of key assets, identified in stakeholder workshops, located in the coastal hazard area (defined as being within 200 m of the coast and/or 2 m in elevation over the current 100 year storm tide height). The maps also show the type of hazard for which material risks (i.e. risks that were assessed as either high or extreme) exist and the sea level rise scenario first leading to that material level of risk (0.2/0.8/1.4 m).

The first map in the sequence is the key map, which shows the extent of each of the six sections of coast.

Readers should refer to Chapter 10, which provides an overview of the limitations on the information presented in these maps. It should be noted that they are not intended to provide an exhaustive listing of assets that may face risks from climate change and should not be used for detailed planning or climate change impact analysis.



Extent of Coastal Sections Along the Great Ocean Road

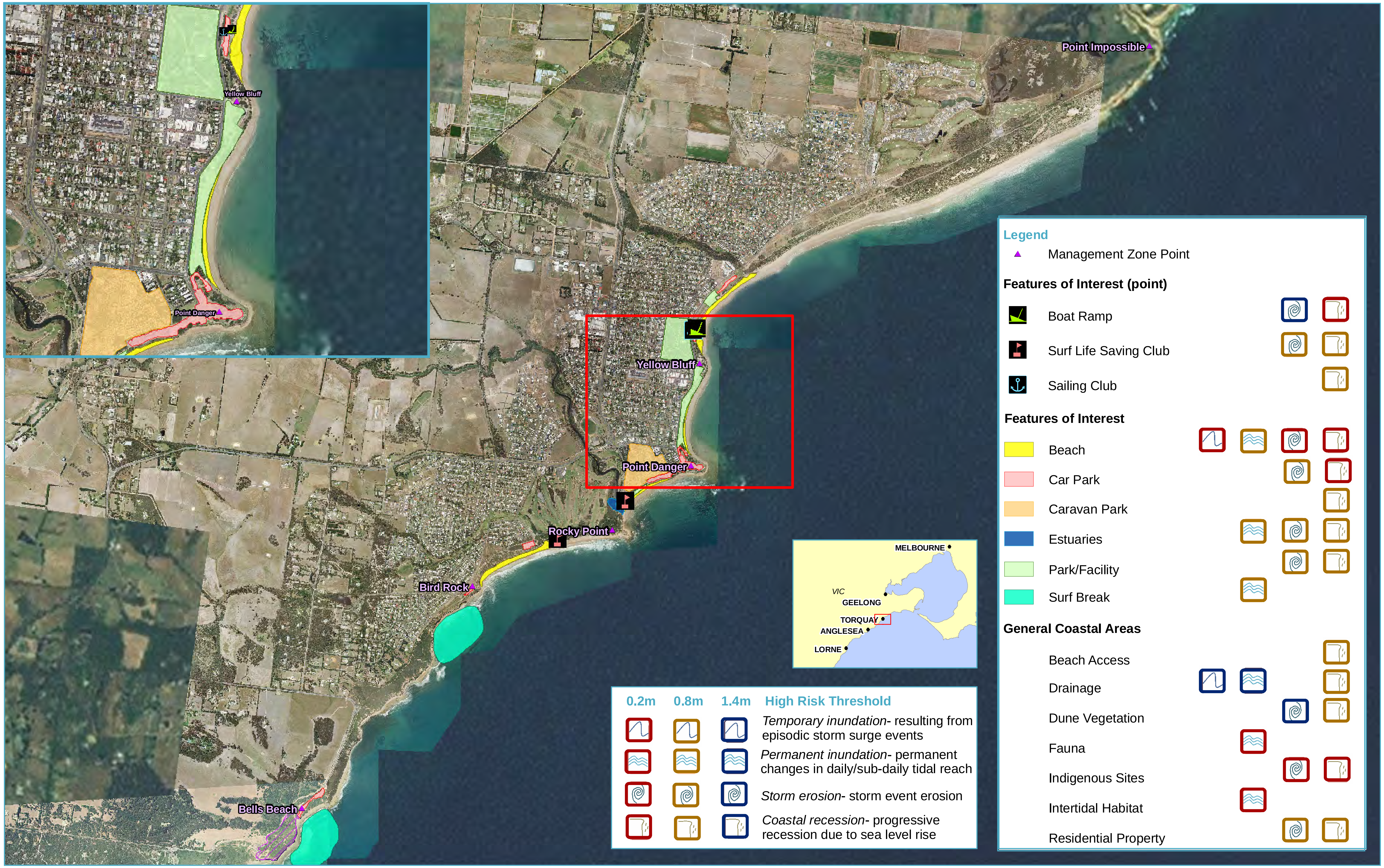
VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 5,000
Metres
[GDA94 | MGA Zone 55]

SKM

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Coastal_Areas_Risk_Assessment_Overview.mxd
May 23, 2011



Refer to main report for limitations

Map: 1

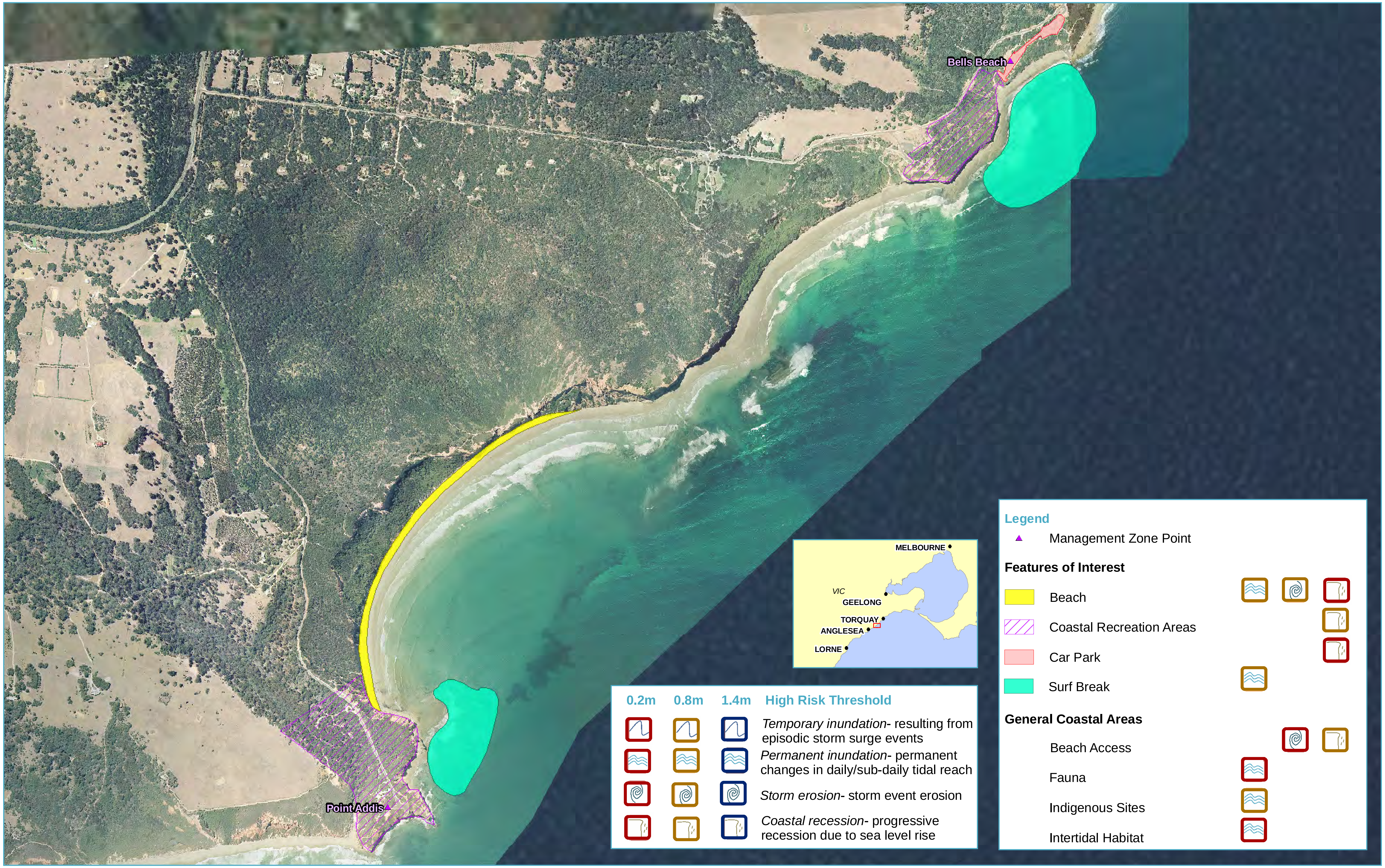
VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 500
Metres
[GDA94 | MGA Zone 55]

SKM

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Risk_Mapping_alt_temp.mxd
February 23, 2011



Refer to main report for limitations

Map: 2

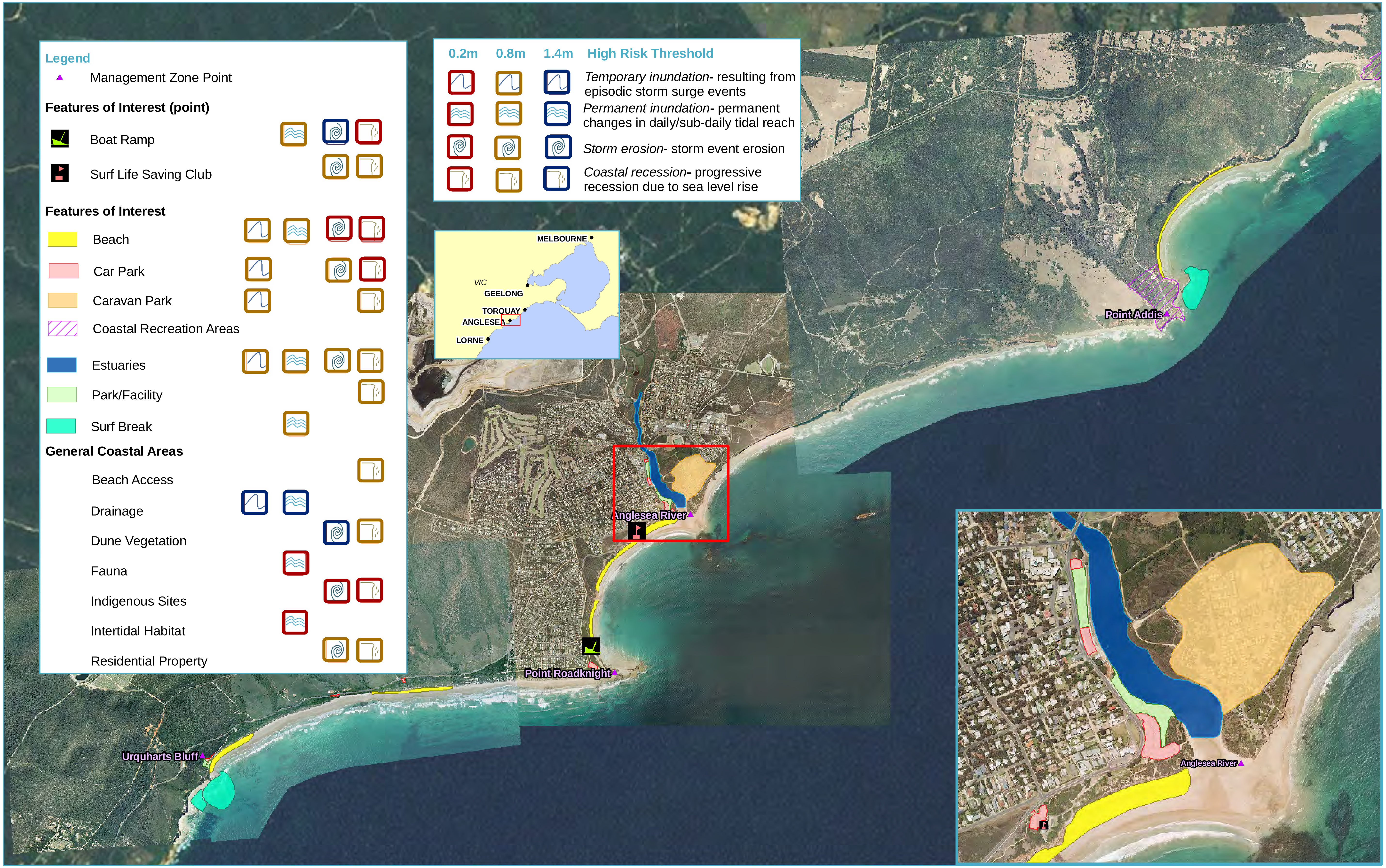
VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 220
Metres
[GDA94 | MGA Zone 55]

SKM

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Risk_Mapping_alt_temp.mxd
February 23, 2011



Refer to main report for limitations

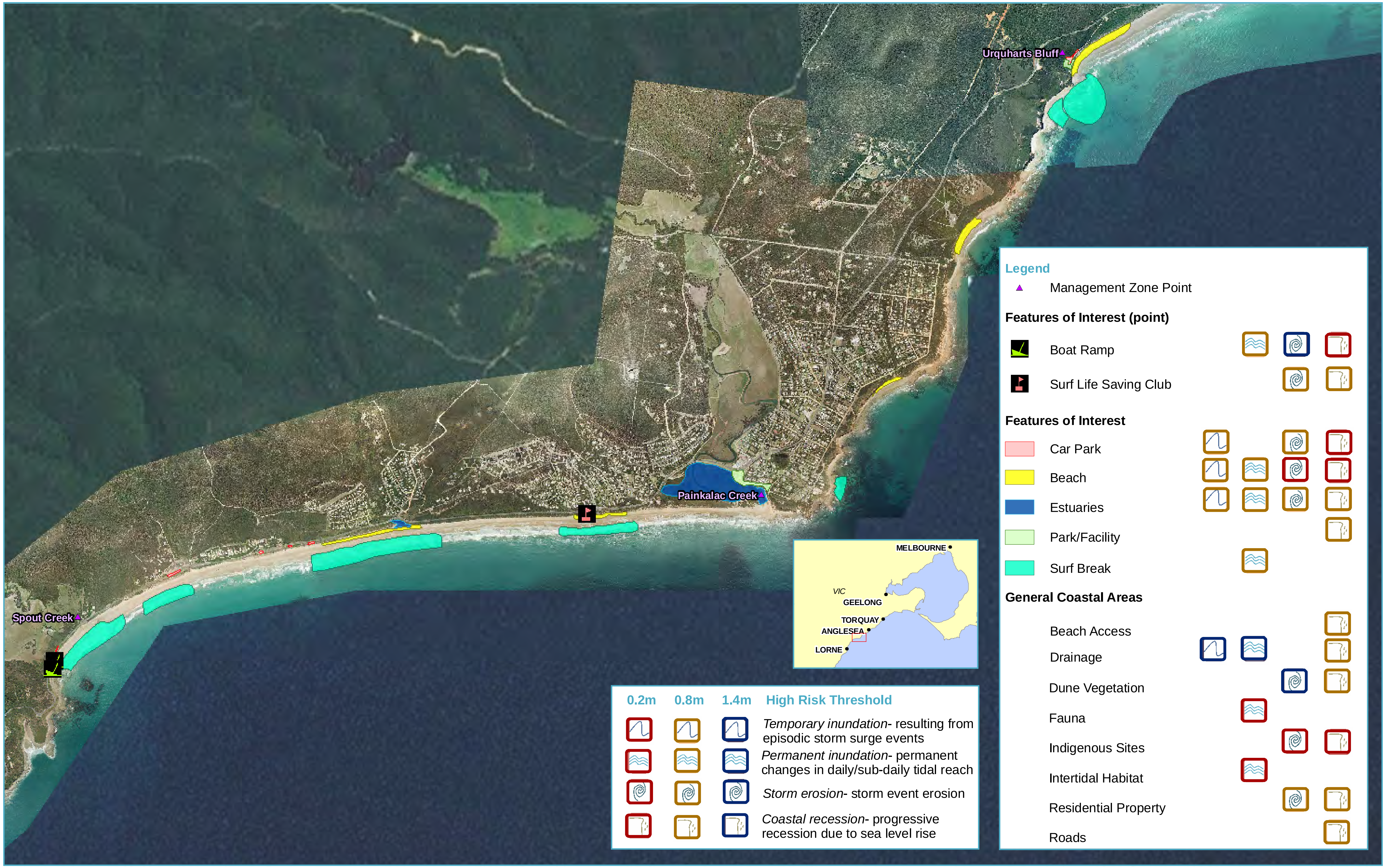
Map: 3

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC, DSE CIP Imagery (2007 - 2008)
VICMAP

0 540
Metres
[GDA94 | MGA Zone 55]

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Risk_Mapping_alt_temp.mxd
February 23, 2011



Refer to main report for limitations

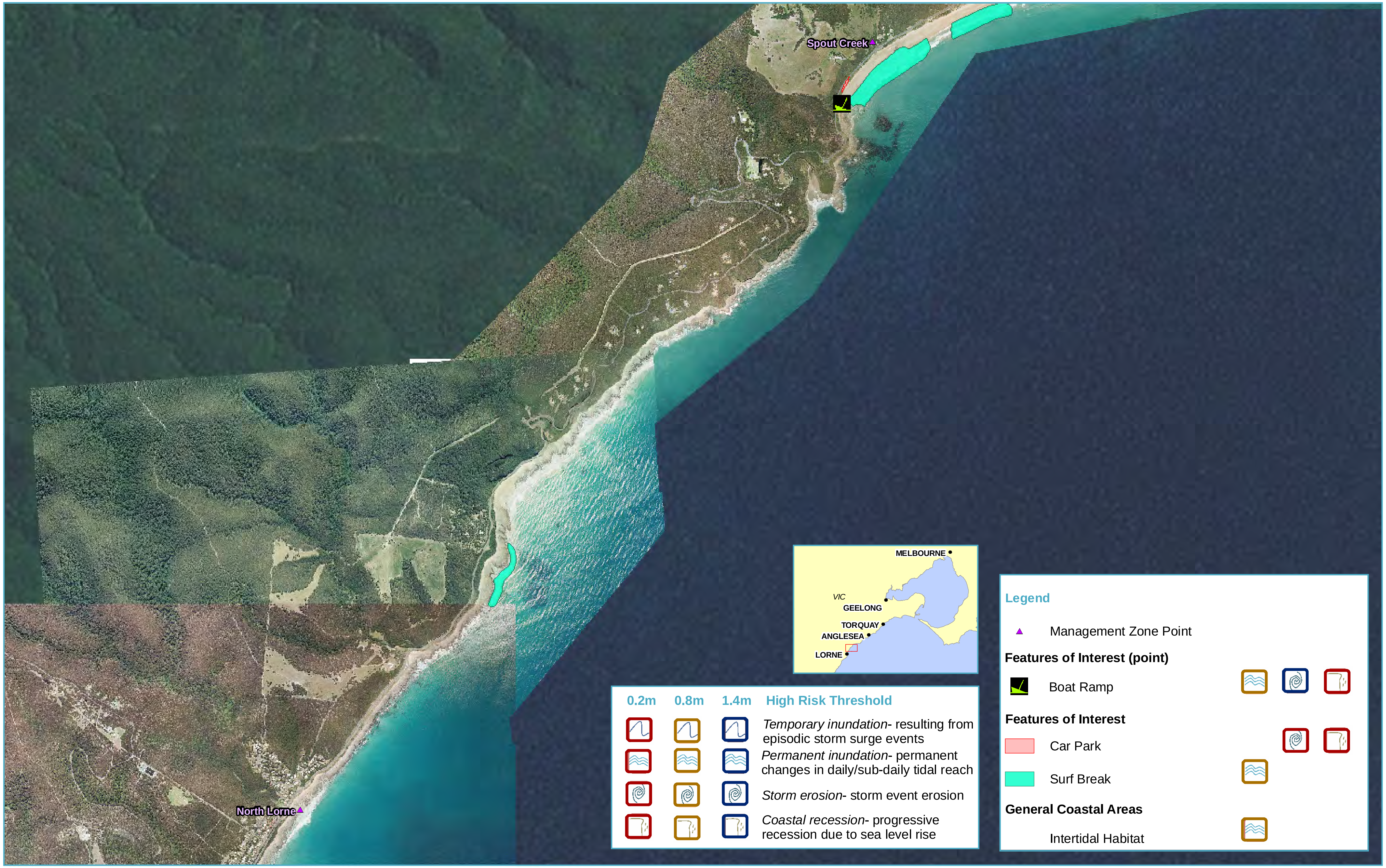
Map: 4

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

0 420
Metres
[GDA94 | MGA Zone 55]

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Risk_Mapping_alt_temp.mxd
February 23, 2011



Refer to main report for limitations

Map: 5

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

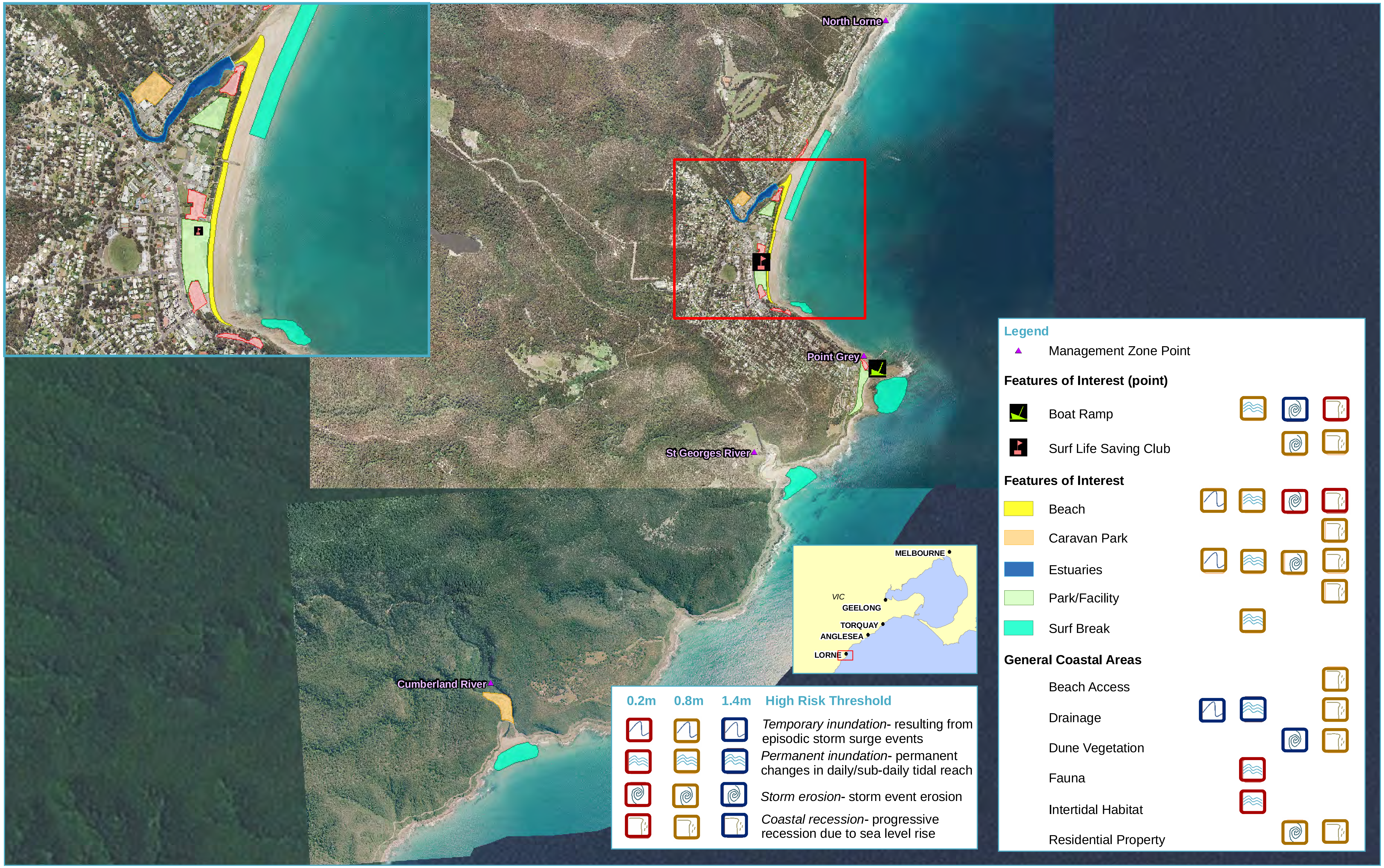
Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

Sinclair Knight Merz does not warrant that this document is definitive nor free of error and does not accept liability for any loss caused or arising from reliance upon information provided herein.

360
Metres
[GDA94 | MGA Zone 55]

SKM

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Risk_Mapping_alt_temp.mxd
February 23, 2011



Refer to main report for limitations

Map: 6

VW05093 - - Great Ocean Road Coast Committee Risk Mapping

Data Sources
Geodata v3, Geoscience Australia, GORCC,
DSE CIP Imagery (2007 - 2008)
VICMAP

Sinclair Knight Merz does not warrant that this document is definitive nor free of error and does not accept liability for any loss caused or arising from reliance upon information provided herein.

0 460
Metres
[GDA94 | MGA Zone 55]

SKM

Prepared by : SI
Checked by : GR
I:\VWES\Projects\VW05093\Technical\Spatial\ArcGIS\VW05093_GORCC_Risk_Mapping_alt_temp.mxd
February 23, 2011