Department of
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Environment

Victorian Coastal Hazard Guide

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Victoria

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Victorian Coastal Hazard Guide



Table of contents

1 Executive summary

Coastal hazards such as erosion and inundation are largely the result of the natural processes that occur along Victoria's dynamic coastline. The high social, economic and environmental value that we place on our coastline means that the hazards produced by these processes affect Victorians beyond those just living and working on the coast. However, the processes are highly complex and their effects are difficult to predict with any certainty.

Although coastal hazards occur naturally, we have had a considerable effect on how these hazards are manifested through our use and development of the coastal zones. It is widely recognised that a consistent approach to coastal hazards along the entire coast is now needed, taking into account the effects of climate change. This Guide is the first step towards achieving that consistency.

Population growth and urban development along the coast, along with the effects of climate change, are likely to increase the risks that coastal hazards present to Victorians. We cannot eliminate the hazards, but we can assess the risks associated with them and use that knowledge through adaptive management to minimise the risks that they pose. In this regard, the Guide outlines a five-stage coastal hazard risk management framework based on best practice.

By itself the Guide will not resolve the risks to assets and values associated with coastal hazards. Instead it provides information that can be used to inform policies and practices put in place by a wide range of organisations and individuals. It may be applied in various ways, including educating and informing stakeholders about coastal hazards and risk and providing a consistent risk-based framework for considering coastal hazards.

In the future the Guide will need to be reviewed and refined as our understanding of coastal processes and coastal hazards improves, and as new methods for managing coastal hazards become available. As it develops in this way, it will help to ensure Victoria's coast and its communities are resilient to the effects of a changing climate.

Left:
London Bridge,
Port Campbell
(Photo: Nick Wynn)

2 Introduction

2.1 What is the Victorian Coastal Hazard Guide?

The Guide has been developed to improve the understanding of coastal hazards, the effect that climate change may have on these hazards, and approaches that may be used to manage the effects of these hazards.

The Guide provides a compendium of information on coastal hazards and a consistent basis for risk-based assessments of coastal hazards. It should also enable more effective communication of the complexities and uncertainties that exist when considering coastal hazards, and both inform and focus the development of policies and practices.

The Guide is the first of its kind for Victoria and provides a step forward in developing a consistent state-wide approach for considering the effects of coastal hazards. It is envisaged that the Guide will be updated and revised as our knowledge and understanding of how our natural environment behaves increases, and as policies and practices continue to be developed.

The Guide focuses on three types of coastal hazards and their implications:

- erosion — the short-term retreat of sandy shorelines as a result of storm effects and climatic variations
- recession — the progressive and ongoing retreat of the shoreline
- coastal inundation — the temporary or permanent flooding of low-lying areas caused by high sea level events, with or without the impacts of rainfall in coastal catchments.

The Guide has not been developed for any one group of stakeholders or any particular decision-making process. Rather, it provides best-practice guidance on the factors that need to be considered when assessing risks associated with coastal hazards.

2.2 What is the purpose of the Guide?

The Guide has three major purposes:

- to provide an overview of coastal hazards in Victoria, including the physical processes that drive them and how the effects of climate change may exacerbate these hazards
- to outline a risk-based approach for considering coastal hazards in decision-making processes that is consistent with international best practice
- to promote the incorporation of adaptive management when considering appropriate ways of managing the coastal hazard risk.

The coastal hazard assessment process has been incorporated into a risk management framework to enable coastal hazard assessments to be applied consistently in a risk management context.

Left:
Thirteenth Beach, Barwon Heads (Photo: Nick Wynn)

2.3 Who will use the Guide?

It is anticipated that the Guide will be used by a wide range of users for various purposes. Although the information in the Guide is generally technical in nature, users will not need particular technical or scientific training in order to use it.

Different users will find some sections of the Guide more relevant than other sections. Those who wish to improve their understanding of coastal hazards and how climate change will influence the coastal zone will find Sections 2 to 7 of the Guide useful.

Coastal practitioners such as coastal public land managers, coastal planners, public infrastructure providers, local government planners and consultants who are seeking guidance on what to consider when assessing and responding to the risks posed by coastal hazards are likely to find Section 8 more relevant for their purposes.

2.4 How to use the Guide

The following table summarises the purpose and relevance of each section.

Section	Title and purpose	Relevance
2	**Introduction** Explains the goals, purposes and intended audience of the Guide	Need to know in order to use the Guide
3	**Context** Summarises the community's connection with the coast, including the dynamic nature of the coast and current policy	Useful for you to know
4	**Victorian coast** Summarises the different types of coastline in Victoria	Useful for you to know
5	**Coastal processes** Explains key coastal processes such as winds, waves, currents, tides, and sediment transport	Useful for you to know
6	**Effects of climate change on coastal hazards** Explains the effect of climate change on coastal hazards	Useful for you to know Helps you make decisions
7	**Implications for the Victorian coast** Focuses on the susceptibility of the Victorian coast to coastal hazards and climate change	Useful for you to know Helps you make decisions
8	**Risk assessment** Provides a risk-based approach for considering coastal hazards, including principles of adaptive management relating to risk management	Helps you make decisions
9	**Closing summary** Provides some concluding remarks	Useful for you to know

2.5 How to apply the Guide

The Guide may be applied in various ways, including:

- educating and informing about coastal hazards and risk
- encouraging the incorporation of adaptive management principles as part of a considered approach to managing coastal hazard risk
- explaining the range of different risk management options, in order of effectiveness
- encouraging people to think in terms of levels of acceptable, tolerable and intolerable risk
- providing stakeholders with a consistent risk-based framework for considering coastal hazards
- informing the design and scale of local coastal hazard assessments.

Figure 2–1 Nepean Highway crossing over the Patterson River, Carrum. (Photo: Werner Hennecke.)

3 Context

3.1 Social

Victoria's 2000 km coastline and its hinterland is one of the state's major assets. The coast is home to over one million people, forms a critical part of our natural and cultural heritage, and contributes significantly to our economy and well-being. The economic values of the coast, not including the ecosystem services it provides, generate around $4 billion annually.[1]

Victorians have a particular affinity with the coast: '[In 2007] almost 9 out of every 10 Victorians visited the coast at least once. The coast contributed significantly to the physical and mental wellbeing of Victorians by providing a place to exercise, recreate and unwind.'[1]

However, pressures associated with population growth and the expansion of coastal settlements puts the values that draw people to coastal areas at risk. One of the biggest challenges for managing the coastal area is to understand and balance the often competing human activities in a sustainable manner.

3.2 Population trends

Victoria is experiencing unprecedented population growth along the coast. The movement to coastal areas outside capital cities, known as the 'sea change' phenomenon, is occurring predominantly in areas within a 90-minute drive of major coastal cities and towns. People are moving to the coast for a variety of reasons, such as the presence of affordable housing and employment opportunities or a more liveable climate, relaxed lifestyle and less congestion. Increasing affluence, access to technology and improved transport links have enabled greater mobility and choice when considering where to live and holiday along the coast. Victorians' strong desire to be near the coast is also evident in the increasing levels of second home or holiday home ownership in many coastal settlements.[47] Table 3–1 summarises the historical and projected population trends for the Victorian coast.

Coastal settlements are characterised by large fluctuations in population between certain days of the week and also seasons. These fluctuations result in significant population spikes during weekends and summer months, creating complex management pressures. With a significant proportion of Victoria's population nearing retirement over the next decade, coastal areas are likely to experience further population pressures as retirees move to the coast and take up permanent residence.

Table 3–1 Summary of historical and projected population trends.

	Year			Actual increase 1996–2006		Projected increase 2006–2016	
Region	**1996**	**2006**	**2016**	**Net**	**%**	**Net**	**%**
All Victoria	4,560,149	5,128,300	5,574,755	568,151	12.46	446,455	8.71
Coastal Victoria	883,698	1,017,654	1,109,889	133,956	15.16	92,235	9.06
Coastal contribution	19.38%	19.84%	19.91%	–	–	–	–

Source: Victorian Coastal Council (2011).[47]

Left: Twelve Apostles, Port Campbell (Photo: Nick Wynn)

Although 'sea change' is still occurring, there is evidence that the trend is gradually slowing over the whole Victorian coast. The average annual growth rate for coastal towns for the period between 2001 and 2006 slowed by 0.3% when compared to the preceding census period (1996–2001). The growth rate for all Victorian towns slowed by 0.1% compared to the same census period.[3]

Between 2001 and 2009, the highest growth rates were seen in outer Melbourne coastal municipalities such as Wyndham and Casey, although much of this growth took place inland from the coastal zone. The Surf Coast and Phillip Island have had the highest coastal population growth in regional Victoria, while parts of the South Gippsland coast experienced a decline in population (Figure 3–1).[4]

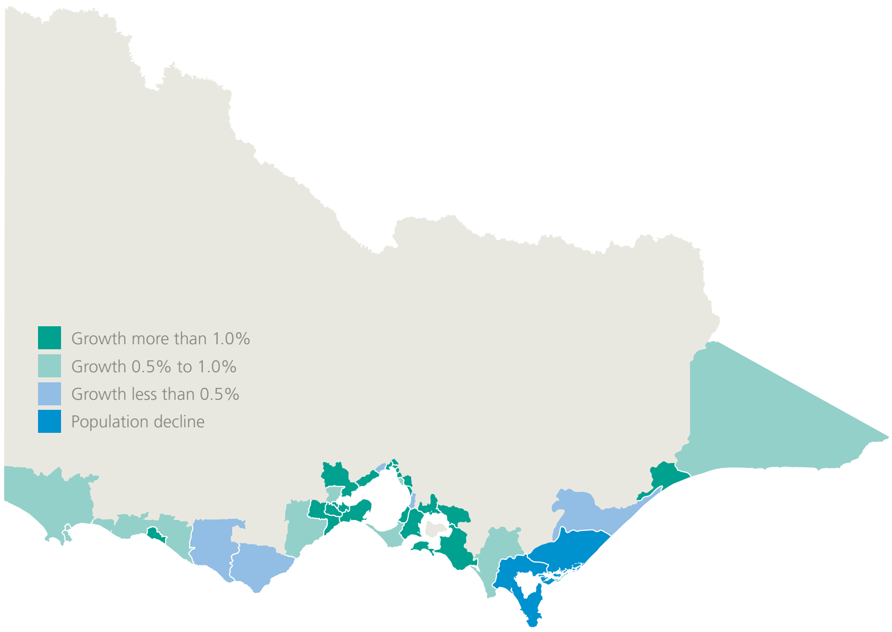


Figure 3–1 Population changes between 2001 and 2009 along the Victorian coast.[4]

3.3 Climate change

Because it is the interface between land and sea, the coastal zone is particularly sensitive to the physical impacts of climate change, especially with regard to increased sea levels and the potential for increased wave heights and storm frequency. This sensitivity is exacerbated by the socio-cultural and economic importance of the coast.

Climate change and its relationship with coastal vulnerability present numerous challenges for coastal planners and land managers, particularly in relation to risk and uncertainty. Decisions must be made even though there is a degree of uncertainty about the effects, and while the information base is continually and rapidly expanding.

Because of the life expectancy of structures such as roads and buildings and the enduring nature of the coast's natural values, the impacts of climate change on coastal hazards need to be incorporated into decision-making processes now.

3.4 Physical

Coasts and estuaries are dynamic and are influenced by processes such as tides and the effects of currents, winds, waves, rainfall and river flows. Where these coastal processes are likely to adversely affect life, property or aspects of the natural environment, they create coastal hazards.

Climate change will not produce new coastal hazards but is likely to increase the extent or frequency of existing hazards. In particular, coastal inundation and coastal erosion/recession is expected to be worsened because of a number of factors, including changes in:

- mean sea level
- storm climates (storm surges, storm tides and atmospheric changes)
- tidal ranges
- wave climates
- rainfall.

Coastal inundation and coastal erosion/recession are the most significant coastal hazards, and are therefore the focus of this guide.

3.4.1 Coastal inundation

Coastal inundation may occur during extreme weather, when higher water levels cause seawater to flood land that is normally dry. The primary causes of inundation are storm surges combining with high tides (storm tides) and extreme wave events. Flooding can be worsened in estuaries by rainfall in coastal catchments. Additionally, the effects of climate change are contributing to a progressive permanent increase in sea level that will increase the extent and duration of storm-induced coastal inundation (Figure 3–2).

Figure 3–2 Coastal inundation at a coastal tourist park, Portarlington.
(Photo: Bellarine Bayside Foreshore Committee of Management.)

3.4.2 Coastal erosion/recession

Coastal erosion is a short-term response that can occur as a result of extreme storms or as a result of seasonal variations such as the winter–summer cycle of erosion and accretion. Typically sandy shorelines may recover from these short-term episodes.

Coastal recession (Figure 3–3) is the inland movement of the coastline that results from the permanent removal of material from a part of the coast. While erosion/recession is a natural process that has formed the present coastal edge, it is a hazard if it can adversely affect human life, property or aspects of the natural environment.

Figure 3–3 Dune recession at Mounts Bay, Apollo Bay. (Photo: Chris Sharples.)

3.5 Coastal hazard management

The traditional model for coastal management decision-making viewed coasts as a static rather than dynamic boundary between land and sea, and assumed that inundation and erosion/recession were discrete or localised events. It was believed that a particular problem could be solved by actions such as the construction of engineering works to prevent further erosion or recession. Hazard management was dominated by engineering-based approaches that often led to the level of risk increasing rather than diminishing. Increased risk can also result if actions taken to protect one area lead to unintended consequences in other areas. This 'develop–defend' cycle is shown in Figure 3–4.

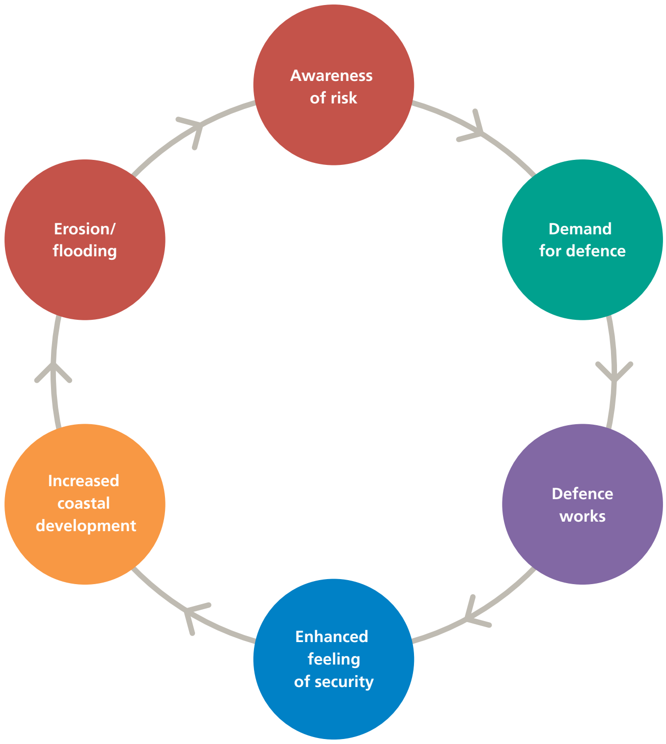


Figure 3–4 The develop–defend cycle, adapted from Carter et al. (1999).[46]

Sustainable coastal hazard management seeks to define and implement strategies and policies that integrate our understanding of natural coastal behaviour with the rational use of space and resources.

A significant advance in coastal hazard management has been the recognition of the importance of understanding processes within a ‘coastal cell’ rather than at a discrete location. Management that does not consider the bigger picture can result in poor outcomes and an unintended transfer of consequences.

A coastal cell is a stretch of coastline within which sediment movement is self-contained. These cells can vary from several hundred metres to tens of kilometres. A change or modification to one part of the cell can affect other areas in the cell; for example, engineering works at the mouth of a river to improve access up the river may result in sand accumulation on one side of the river mouth and shoreline erosion on the other side as the sediment transport pathway is interrupted (Figure 3–5).

Sustainable coastal hazard management needs to view natural processes along shorelines as a total system. Coastal management that is based on an improved understanding of coastal cells or distinct sub-cells within them, and that recognises that shorelines vary over time, is more likely to reduce the negative impacts associated with the mitigation of erosion/recession or inundation, in both time and space.[5]

Figure 3–5 Training walls at the entrance to the Moyne River, Port Fairy, with sand accumulating to the left (west) of the wall. (Photo: Chris Sharples.)

3.6 Policy

Governments throughout Australia and the rest of the world are establishing processes and benchmarks for assessing and managing the impacts of climate change on the coast.

The *Victorian Coastal Strategy 2008* (VCS) was prepared as a response to pressures on coastal and marine environments associated with population growth, tourism and the projected effects of climate change. It provides a comprehensive, integrated framework for managing coastal areas in Victoria, and establishes a hierarchy of principles for planning and decision-making for the state's coasts, estuaries and marine areas.

Action 2.1(d) of the strategy identifies the need to provide guidance to planners and managers on a consistent approach to coastal hazards, taking into account the effects of climate change. This Guide responds to that Action.

The process of considering and evaluating various adaptation responses will be complex and challenging, but it should be founded on principles that reflect community values, government policy and legislation. Six guiding principles for coastal adaptation planning and management are shown in Box 3-1. These provide a useful foundation for decision-making and planning on the coast.

In relation to coastal climate change, the VCS provides further direction as follows:

1. Plan for sea level rise of not less than 0.8 m by 2100, and allow for the combined effects of tides, storm surges, coastal processes and local conditions when assessing risks and impacts.
2. Apply the precautionary principle to planning and management decision-making when considering the risks associated with climate change.
3. Prioritise the planning and management responses and adaptation strategies to vulnerable areas, such as protect, redesign, rebuild, elevate, relocate and retreat.
4. Ensure that new development is located and designed so that it can be appropriately protected from climate change's risks and impacts and coastal hazards.
5. Avoid development within primary sand dunes and in low-lying coastal areas.
6. Encourage the revegetation of land abutting coastal Crown land using local provenance indigenous species to build the resilience of the coastal environment and to maintain biodiversity.
7. New development that may be at risk from future sea level rise and storm surge events will not be protected by the expenditure of public funds.
8. Ensure that climate change should not be a barrier to investment in minor coastal public infrastructure provided the design-life is within the timeframe of potential impact.
9. Ensure planning and management frameworks are prepared for changes in local conditions as a result of climate change and can respond quickly to the best available current and emerging science.
10. Ensure all plans prepared under the *Coastal Management Act 1995* and strategies relating to the coast, including Coastal Action Plans and management plans, consider the most recent scientific information on the impacts of climate change.

There is no doubt that risks associated with coastal hazards will increase, mainly because of a combination of consequences from past coastal management and development decisions, the continual demand for prime coastal real estate, the natural appeal of coasts to the Victorian community, and the effects of climate change. This places local authorities under considerable pressure because they are responsible for making decisions about land use that must balance the need for long-term sustainability and opportunities for wise use and development.

Box 3–1 Guiding principles

1. Informed decision-making — decisions are based on best practicably available information and potential impacts of climate change.
2. Integrated decision-making — decisions consider short and long-term environmental, social and economic considerations.
3. Risk management — decisions based on informed assessment and management of risk, applying the precautionary approach.
4. Complementarity — Victorian Government decisions should complement those of the Commonwealth Government.
5. Equity — decisions should increase the capacity of vulnerable groups, future generations and the environment to adapt to climate change.
6. Community engagement — decisions should engage communities.

* Climate Change Act 2010 (Victoria).

4 Victorian coast

4.1 Nature of the coast

The Victorian coast has been formed and reformed by natural processes over millions of years, and continues to evolve and change. It is composed of two distinct geological units, the Otway Basin and the Gippsland Basin, which are characterised by a shelly and carbonate-rich embayed coastline to the west of Wilsons Promontory and a silica–quartz coastline dominated by long sandy beaches to the east. The present sea level has been around its present level (±1.5 m) over the past 6000 years[6] and it is over this period of time that coastal processes have shaped the coastlines we are familiar with today. This section provides an understanding of coastal features, key coastal types and characteristics of the Victorian coast.

Victoria has a varied coastal environment, but most of the coastline consists of open coasts exposed to high-energy oceanic waves and coastal processes. Numerous embayments, tidal lagoons and estuaries, often called 'coastal re-entrants', comprise the remainder of the coastline and are significantly less exposed to oceanic swells.

Open coasts are predominantly characterised by an alternation of rocky and sandy coasts, whereas coastal re-entrants typically include rocky and sandy shores but also include a variety of other soft shoreline types not generally found on the open coast.[7] Some sections of the coast have been significantly modified over time by human development; for example, the urbanised coastline of Port Phillip Bay. Along with the generally rocky or sandy natural coastlines, managed or altered coastlines can be considered to be a different type of coastal landform. Table 4–1 presents the key landform types for open coasts, coastal re-entrants and engineered coasts in Victoria.

Table 4–1 Key coastal types

Open coasts	Coastal re-entrants	Engineered coasts*
• Hard rock coasts • Softer (friable) rock coasts • Sandy (beach) coasts • Colluvial or weathered bedrock coasts (talus-dominated shores)	• Hard rock shores • Softer (friable) rock shores • Sandy shores • Other soft sediment (erodible) re-entrant shores (e.g. muddy mangrove shores)	• Hard rock or fabricated (concrete, steel, etc.) coasts (vertical or near-vertical) • Hard rock or fabricated coasts (sloping) • Hard rock fronted by sand (nourished) • Sand (nourished) coast • Interrupted alongshore processes (e.g. through groyne, breakwater or placement of other structure or mechanism such as submerged reef, detached breakwater or dredging)

* Engineered coasts may be on open coasts or coastal re-entrants.

Left:
Cliffs of Cape Patton, near Apollo Bay (Photo: Nick Wynn)

4.1.1 Rocky coasts

Rocky coasts are the result of the weathering of ancient rocks over millennia by marine and atmospheric processes such as waves, currents and winds. They comprise a range of landform types, including hard rock coasts (e.g. granite, basalt, sedimentary) and soft rock coasts (e.g. limestone, clay), and occur on open coasts and in coastal re-entrants. Rocky coasts may be very steep or sloping, or they may have a very low or platform form.

Cliffed hard rock shores make up approximately 22% of the Victorian coastline (Table 4–2). They do not experience significant erosion over human time-scales. Cliffed soft rock shores make up around 6% of the coastline. The actively receding limestone cliffs near Port Campbell (Figure 4–1) are a good example of a cliffed soft rock shore.

Figure 4–1 Actively receding soft rocky coastline, Bay of Islands, south-west Victoria. (Photo: Richard Reinen-Hamill.)

4.1.2 Sandy and muddy coasts

Beaches are formed from a combination of terrestrial and marine-derived sediments. Sandy coasts occur on open coasts (Figure 4–2) and in coastal re-entrants. In Victoria they may be long, sandy beaches or smaller pocket or compartmentalised beaches. Muddy coasts are restricted to the low-energy environments of coastal re-entrants (Table 4–1). In their natural state they are often colonised by mangroves, seagrasses or saltmarsh vegetation.

Around 73% of the Victorian coastline is fringed by geologically recent deposits of materials, including long stretches of sandy barriers and dune systems in Gippsland and western Victoria, which blanket older geologies.[8]

Sandy shores make up 51% of the coastline. They are likely to be significantly prone to erosion (e.g. Ninety Mile Beach), although this is less likely to cause coastal recession where beaches are backed by bedrock (approximately 21% of the coastline).

Figure 4–2 Sandy coast at McLoughlins Beach, Gippsland. (Photo: Richard Reinen-Hamill.)

Muddy shores, including mangrove, saltmarsh, clayey-gravelly and muddy shore types, make up 22% of the coastline. Good examples of this type of shoreline are the muddy or sandy tidal flats of Corner Inlet and Western Port.

Table 4–2 Major indicative coastal lengths for selected coastal landform stability classes.

	Rocky coasts		Sandy and muddy coasts		
	Hard rock cliffs	Soft rock cliffs	Sandy shores backed by soft sediment	Sandy coast/ shores backed by bedrock	Muddy sedimentary shores (e.g. tidal flats) backed by soft sediments
Indicative length (km)	510	130	690	490	500
Indicative proportion of coastline	22%	6%	30%	21%	22%

Source: Adapted from DCC (2009).[17]

4.1.3 Engineered coasts

Unnatural modifications to the Victorian coast have been made over the past 150 years, including the construction of harbours, marinas and boating access facilities, breakwaters, seawalls, groynes and training works (Figure 4–3). Engineered coasts are generally classified as either hard or soft coast, according to the type of material used — mainly rocks or concrete for hard coasts, and sand for soft coasts. They comprise about 8% of the Victorian coastline and are generally in urbanised areas.

A key feature of engineered coasts is that the coastline may respond atypically to changing coastal processes, because natural processes have been interrupted through infrastructure works of some type. Common system responses include erosion, degradation of coastal barriers, submergence of mudflats, increased recession on soft rock cliffs, and increased mangrove encroachment into saltmarsh communities as a result of tidal penetration.[8]

Figure 4–3 Engineered coastline at Frankston, Port Phillip Bay. (Photo: Chris Sharples.)

5 Coastal processes

5.1 Introduction

An improved understanding of the coastal systems and processes such as winds, waves and tides is necessary for understanding coastal hazards and the impact of climate change on them. However, there are complex interactions, relationships and feedback loops in near-shore environments (Figure 5–1). Our understanding of these interactions and relationships is generally poor and is often limited by a lack of information.

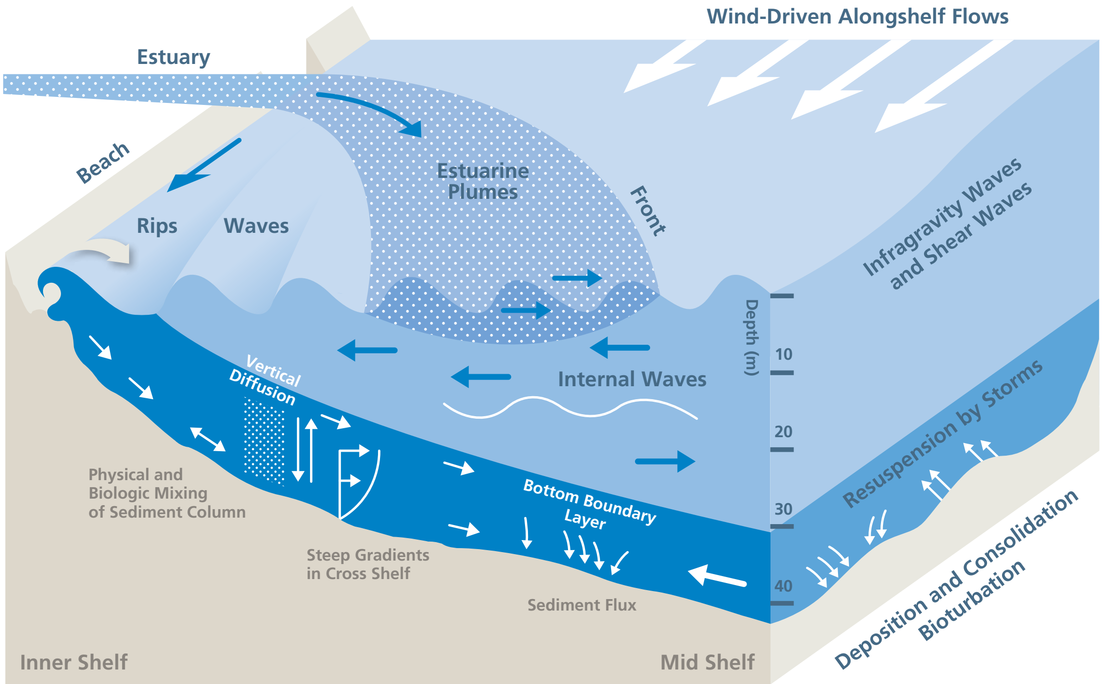


Figure 5–1 The complex and interrelated coastal responses to key physical drivers. Source: Redrawn from Nittrouer et al. (1994).[9]

This section describes coastal systems and processes in Victoria, focusing on the following key processes:

- atmospheric processes (wind, current, rainfall)
- storms
- sea level (tides, sea level fluctuations)
- extreme events (storm surges, storm tides)
- waves
- sediment supply and transport
- vertical land movement.

Left: April 2009 storm Black Rock, Port Phillip Bay (Photo: Werner Hennecke)

5.2 Atmospheric processes

5.2.1 Wind

Winds generate waves and currents, which are two of the most important physical parameters that shape coastal landforms. Winds are generated by the large-scale movement of air and are influenced by a wide range of factors, from large-scale atmospheric circulation patterns to the time of day and the nature of the surrounding terrain. The two main causes of atmospheric circulation are the differential heating between the equator and the poles and Earth's rotation (Coriolis force). Low-pressure systems (cyclones) also significantly influence wind patterns for short periods of time (see Section 5.2).

5.2.2 Ocean currents

Ocean currents are generated primarily by winds but can also be driven by differences in temperature and salinity (density currents). Global wind patterns generate persistent ocean circulation in the Pacific, Atlantic and Indian Oceans. In shallow coastal waters, current patterns become complicated because of bottom friction and the complex bathymetry of the coast. In the surf and swash zones, the effect of ocean currents is overwhelmed by currents that run parallel to the coastline (longshore currents), which are caused primarily by waves approaching the coastline obliquely.

Upwelling and downwelling are common near coasts and can be caused by winds, or by temperature or salinity differences. Upwelling plays an important role in marine ecosystems by bringing nutrient-rich water from the bottom to the surface in coastal waters (e.g. the Bonney Upwelling in western Victoria).

The waters of the western coast of Victoria are situated at the end of the east-flowing Leeuwin Current, which traverses the continental shelf of the Great Australian Bight. The east coast of Victoria is adjacent to an extension of the East Australia Current. The central Victorian coast (Bass Strait) is relatively quiescent and the currents are generally affected by localised winds and storms because Tasmania provides some shelter for this coast.

5.2.3 Rainfall

Rainfall primarily affects the coast through river discharges and estuarine flooding. Rainfall may also affect dune vegetation and mobility. Victoria's rainfall patterns are generalised by higher late winter and spring rainfalls in the west, with a less discernible pattern in the east. Annual variations can be significant, in particular in the east where low-pressure systems can cause heavy rainfall. Victoria's rainfall patterns are also affected by the climatic systems of the Pacific Ocean (e.g. El Niño and La Niña) and the Indian Ocean (e.g. Indian Ocean Dipole); see Box 5–1.

Box 5–1 El Niño and weather patterns affecting Australia's climate

El Niño is the name given to the temporary warming of the central and eastern Pacific Ocean, which leads to a shift in weather patterns across the Pacific. The shift in atmospheric conditions is known as the Southern Oscillation. This causes the east-to-west trade winds to diminish or even reverse. El Niño is generally associated with drier conditions across large areas of eastern Australia. El Niño can occur every three to eight years.

La Niña, the opposite of El Niño, is a cooling of the central and eastern Pacific Ocean, which is associated with wetter conditions in eastern Australia. La Niña conditions often occur after El Niño events.

The Walker Circulation is an east–west circulation of the atmosphere above the Pacific, with air rising above warmer ocean regions and descending over the cooler ocean areas.

The Southern Oscillation Index (SOI) measures the strength and phase of the Southern Oscillation and Walker Circulation. It is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. Sustained negative values are associated with El Niño events and a weakening of the Walker Circulation. Positive SOI values indicate La Niña events.

The **Inter-decadal Pacific Oscillation** (IPO) is similar to El Niño except that events tend to last 20–30 years, with changes being felt throughout Oceania but mainly in the northern and southern Pacific. The Inter-decadal Pacific Oscillation is thought to strongly modulate annual El Niño variability.

The **Indian Ocean Dipole** (IOC) measures changes in sea surface temperatures in the Western Indian Ocean against corresponding changes in the Eastern Indian Ocean. A positive phase of the Indian Ocean Dipole, which is associated with cooler than normal sea surface temperatures in north-western Australia, leads to a reduction in the rain-bearing weather systems that extend to Victoria during spring. Three consecutive positive Indian Ocean Dipole events occurred in the years prior to 2009 and may have contributed to the severity of the 2009 Victorian bushfires.

5.3 Storms

Mid-latitude cyclones (also called extra-tropical or frontal cyclones) propagating from west to east in the 'Roaring Forties' (about 40°S latitude) over the Southern Ocean are the dominant influence on the Victorian coastal environment. They may be up to 2000 km in diameter and rotate in a clockwise direction around centres of low atmospheric pressure. They are usually less intense than tropical cyclones and therefore their damage is generally less severe. However, because they are more frequent than tropical cyclones, the cumulative impacts of mid-latitude cyclones can often be profound.

Other intense low pressure systems called East Coast Lows can develop several times a year over eastern Australia, generally during autumn and winter with a maximum frequency in June.[10] They can cause significant damage to the New South Wales and eastern Victorian coasts, bringing gales, heavy rainfall and high waves.

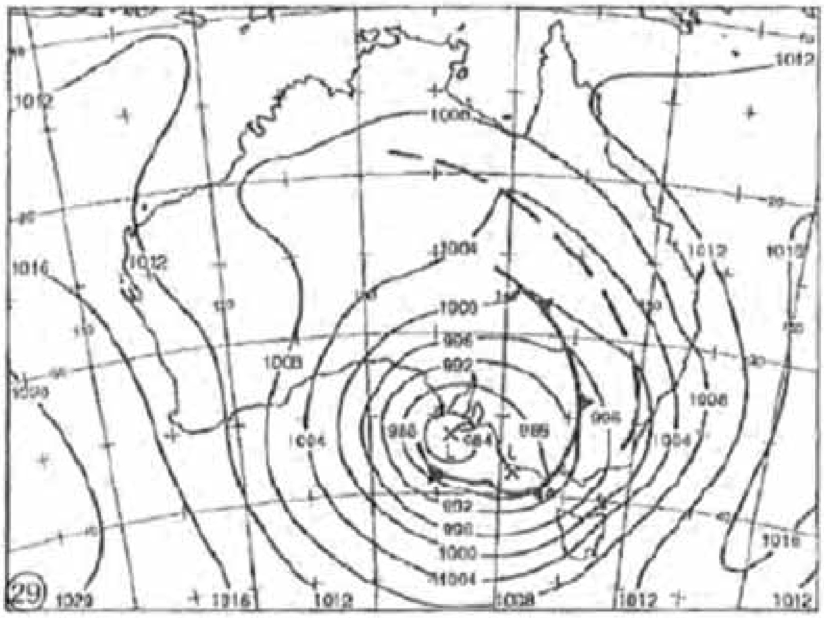


Figure 5–2 Synoptic weather chart for 28 September 1996, showing a mid-latitude cyclone that brought easterly winds exceeding 70 km/h along the Victorian coast.
Source: Hemer et al. (2008).[11]

5.4 Sea level

5.4.1 Tides

Tides are the periodic rise and fall of sea level caused by a combination of the gravitational pull of the Moon and Sun and the rotation of the Earth. Tidal heights vary as a result of the changing gravitational forces as the Moon revolves about the Earth, and the Earth revolves about the Sun.[12]

The coast to the west of Apollo Bay experiences mainly diurnal tides (one high and one low tide per day) whereas to the east the tides are mainly semi-diurnal (two high tides and two low tides per day). The Victorian coast has a spring range that varies from 0.6 m (micro-tidal) inside Port Phillip Bay to 2.3 m (meso-tidal) in neighbouring Western Port.[13] A summary of the key characteristics of the tides at tide gauge stations along the open coast and in Port Phillip Bay is shown in Table 5–1.

Table 5–1 Tidal characteristics at tide gauges on the Bass Strait coast and in Port Phillip Bay in metres relative to mean sea level. Heights are given for highest astronomical tide (HAT), mean high water springs (MHWS) and mean high water neaps (MHWN). At stations marked by an asterisk, tides are generally diurnal and so the average value of the high tides is given by the mean higher high water (MHHW) and mean lower high water (MLHW).

Location	HAT	MHWS/MHHW	MHWN/MLHW
Portland*	0.69	0.44	0.18
Port Fairy*	0.73	0.43	0.18
Apollo Bay*	1.09	0.83	0.13
Lorne	1.27	0.81	0.42
Stony Point	1.56	1.11	0.67
Waratah Bay	1.49	1.11	0.74
Port Welshpool	1.3	0.95	0.57
Lakes Entrance*	0.59	0.32	0.01
Point Hicks	0.83	0.48	0.28
Point Lonsdale*	0.88	0.57	0.31
Queenscliff	0.47	0.45	0.06
Geelong	0.55	0.44	0.1
Williamstown	0.44	0.4	0.07
St Kilda	0.52	0.41	0.07
Frankston	0.5	0.39	0.06

Sources: McInnes et al. (2009a,b).[14,15]

5.4.2 Sea level fluctuations

Long-term sea levels fluctuate above or below the long-term average and are influenced by climatic patterns such as the El Niño — Southern Oscillation (ENSO) and Inter-decadal Pacific Oscillation (IPO). Negative ENSO values are associated with El Niño events and a lack of storminess and rainfall in eastern Australia, which also coincides with slightly lower sea levels. The opposite is true for La Niña events. For example, the National Tidal Centre (NTC) reported lower than normal sea levels at tide gauges in Esperance (Western Australia) and Thevenard and Port Stanvac (South Australia) during the 1997–98 El Niño, and higher than normal sea levels in the subsequent La Niña event. A less pronounced increase in sea levels of approximately 10 cm was recorded between November 2008 and February 2009, corresponding with positive ENSO values that are indicative of La Niña conditions.[16] Similar conditions might be expected along the western Victorian coast.

Episodic or cyclic variations in sea level such as these may be superimposed on longer-term changes in mean sea level, which are discussed in Section 6.2.

5.4.3 Extreme sea levels

Extreme sea levels along the Victorian coast usually result when high tides coincide with storm surges associated with weather systems that bring westerly winds to the southern coast of Australia.[14] They are most extreme during storm tide events; for example, when a storm surge coincides with a high spring tide.

Storm surges are the temporary increases in coastal sea levels caused by falling atmospheric pressure and severe winds during storms.[14] The main synoptic weather systems responsible for storm surges along the coastline of Victoria are west-to-east travelling cold fronts, which occur all year-round but tend to be more frequent and intense in the winter months.[14] At present, storm surge heights in Victoria typically range from 0.5 to 1.0 m for a 1-in-100-year storm event.[14]

The 'storm tide level' is derived from the combination of the astronomical tide level and storm surge (Figure 5–3), and is the effective 'still water level' during an extreme event. The effects of wave set-up and run-up therefore need to be added to the storm tide level at any locality to calculate the maximum sea level at the shore. Storms are often accompanied by heavy rain caused by the same weather system, which may lead to river flooding in estuaries and temporary inundation in low-lying backshore areas and could exacerbate erosion.

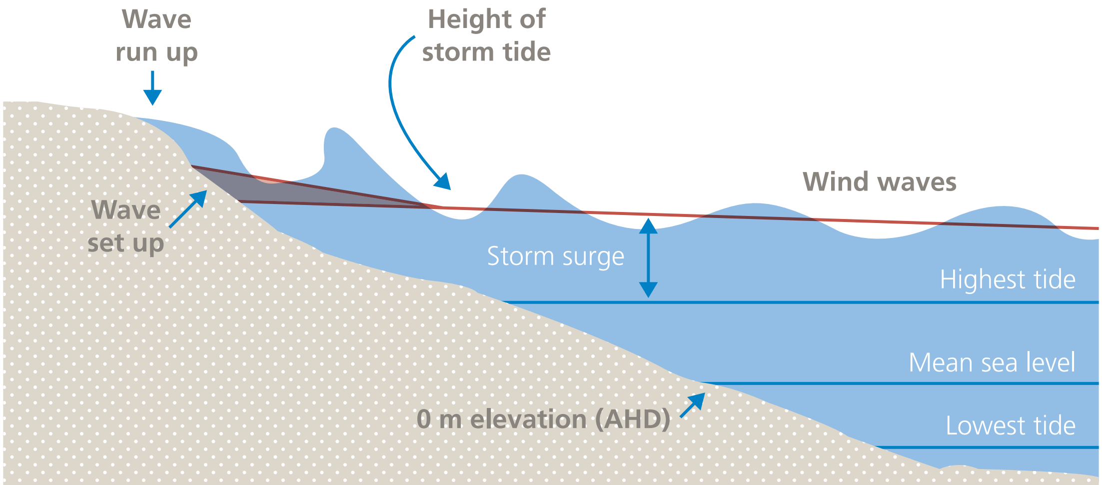


Figure 5–3 Components of storm tide and breaking wave processes.

5.5 Waves

Waves provide most of the energy that shape shorelines and drive sediment transport. The size of a wave is determined by:

- wind speed (energy)
- wind duration (the period of time that wind blows over water)
- fetch (the distance of open water over which the wind has blown)
- water depth.

Waves are called wind waves when they are formed from winds in the local area. When waves travel outside their area of generation they are called swells. Both wind waves and swells occur along the Victorian coast.

The wave climate of Victoria's open coast is mostly characterised by westerly and south-westerly swells and winds generated by mid-latitude cyclones and associated frontal systems that propagate from west to east over the Southern Ocean. The outer extents of Port Phillip Bay and Western Port as well as the coast to the east are exposed to swell and wind waves from Bass Strait and the Southern Ocean as well as being influenced by high-intensity low-pressure systems (see Section 5.2).[17] Within Port Philip Bay, Western Port and Gippsland Lakes, wind waves dominate.

5.6 Sediment sources and transport

Beaches and shorelines change in response to climatic conditions as they seek an equilibrium state. This change can in turn be affected by changes in sediment supply and transport (see Figure 5–4). Sediment is brought into the coastal system at a particular location by a range of mechanisms, including:

- longshore transport (from another part of the coast)
- shoreline erosion
- onshore transport (from deeper water)
- river and estuary supply (minimal in Victoria)
- biogenic production (shells/coral)
- artificial nourishment.

Sediment can be removed from a particular location by:

- longshore transport (to another part of the coast)
- losses to estuary and harbour areas
- losses to the offshore system/shelf
- wind erosion
- extraction for commercial or public purposes.

Sediment transport can be onshore/offshore and/or longshore, depending on prevailing conditions, and can occur in short, medium and long-term cycles. Sediment can be transported in a suspended form in the water body or as bed load (that is, rolled along the seabed).

Longshore sediment transport generally occurs in the surf zone. The strength and direction of transport depends on a number of interrelated factors, including wave height and direction, sediment size, local bathymetry, and coastal features such as islands and reefs.

Offshore transport is caused by large, steep waves that erode sand from the upper beach and move it to the deeper offshore area. The seaward extent of wave-driven offshore transport is a function of the wave height and period. Typically the limit of offshore transport is around 10 m to 20 m.

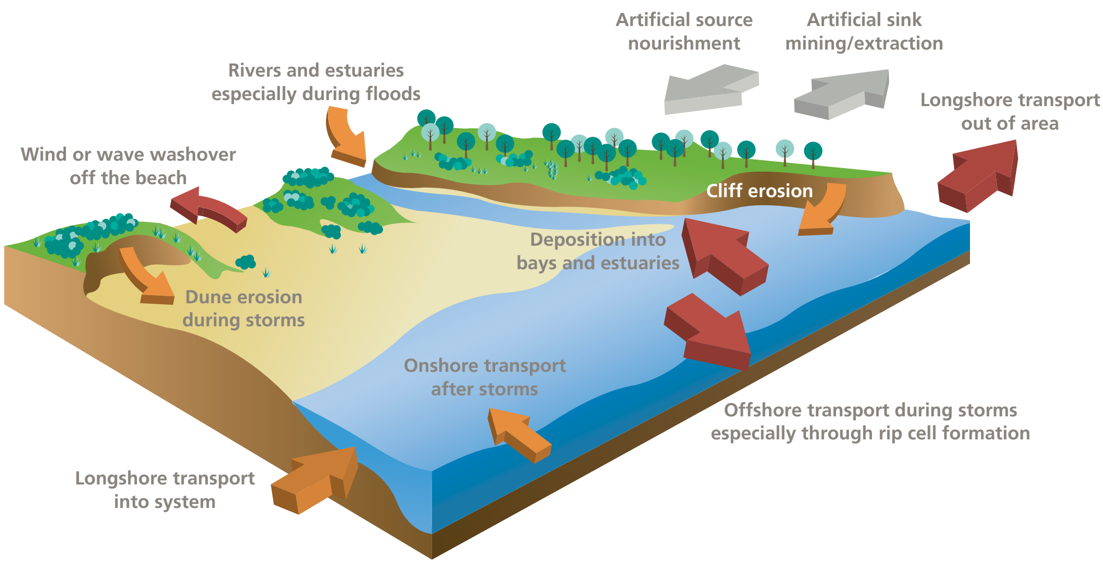


Figure 5–4 Typical sediment budget sources and sinks in Victoria. Source: modified from Government of New South Wales (1990).[18]

Artificial structures such as groynes, jetties and seawalls can have a significant impact on natural transport rates, potentially affecting shorelines many kilometres away. Groynes directly interrupt longshore sediment transport, whereas seawalls can interrupt natural onshore–offshore transport and lead to more rapid beach erosion and an increase in the velocity of longshore currents. Development along rivers and estuaries and artificial management of estuary openings can also affect sediment transport rates, leading to altered rates of accretion or erosion (Figure 5-5).

Figure 5–5 Groyne at Point Lonsdale, Bellarine Peninsula (left) and timber beach wall at Lang Lang, Western Port (right). (Photos: Richard Reinen-Hamill.)

Windborne sediment transport can play an important role in beach and dune formation. Sand deposited on beaches during accretion periods dries and is then transported by wind towards the back of the beach to form dunes (Figure 5–6). Wind can transport sand large distances on land, creating large, transgressive sand dune systems such as the one at Cape Howe, on the border between Victoria and New South Wales. Beach wrack, vegetation and trees can help to trap, settle and bind sand, creating dunes. Storms may erode the dunes and transport the sand offshore or along the shore.

5.7 Vertical land movement

Coastal subsidence is the sinking of land in the coastal zone and can lead to the coast being more susceptible to sea level rise and storm surge. Land (including coastal) subsidence can be caused by a number of possible factors including falling groundwater tables.

In Gippsland, the water levels in the Latrobe Aquifer have fallen by approximately 20 to 40 metres over the last 30 years. Recent studies have concluded that there is currently no evidence that the coastline in this area has begun to subside in a measurable way.[51]

Figure 5–6 Example of a wind-blown sand dune, The Honeysuckles, 90-Mile Beach. (Photo: Nick Wynn.)

6 Effects of climate change on coastal hazards

6.1 Introduction

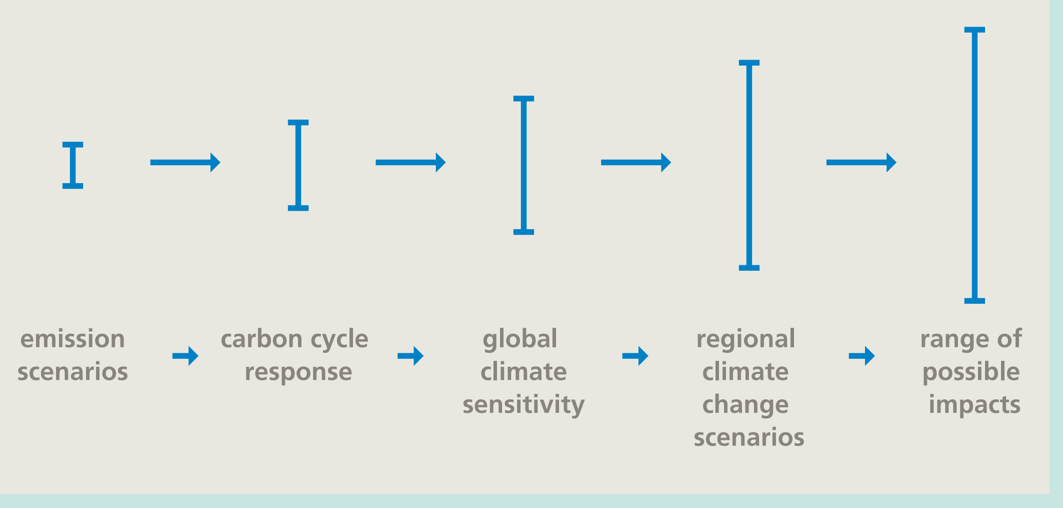
It is not expected that climate change will create any new coastal hazards, but at many locations it has the potential to make existing coastal hazards worse. Climate change may affect:

- the rate of change and the mean level of the sea
- the frequency and elevation of extreme sea levels
- the height of waves
- the frequency and intensity of rainfall, and thus catchment flooding.

Different aspects of climate change have different levels of uncertainty associated with them. So although there is high confidence about some projections, there is less confidence in others. The way uncertainty accumulates through the various stages from predictions to impact assessments can create a cascading level of uncertainty (see Box 6–1).

Box 6–1 Cascade of uncertainty

Uncertainty can accumulate through the process of climate change prediction and impact assessments. This 'cascade of uncertainty' occurs as a result of coupling the separate probability distributions for factors such as emission and biogeochemical cycle calculations needed to calculate radiative forcing, climate sensitivity, climate impacts and valuation of impacts. If this approach is continued through to economic and social outcomes, even larger ranges of uncertainty would be accumulated.



Source: Scheider et al. (2002).[19]

6.2 Global perspective

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. It was established to provide a clear scientific view on the current state of knowledge on climate change and its potential environmental and socio-economic impacts. The IPCC reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide that is relevant to understanding climate change, and provides summaries of these assessments about every six years.

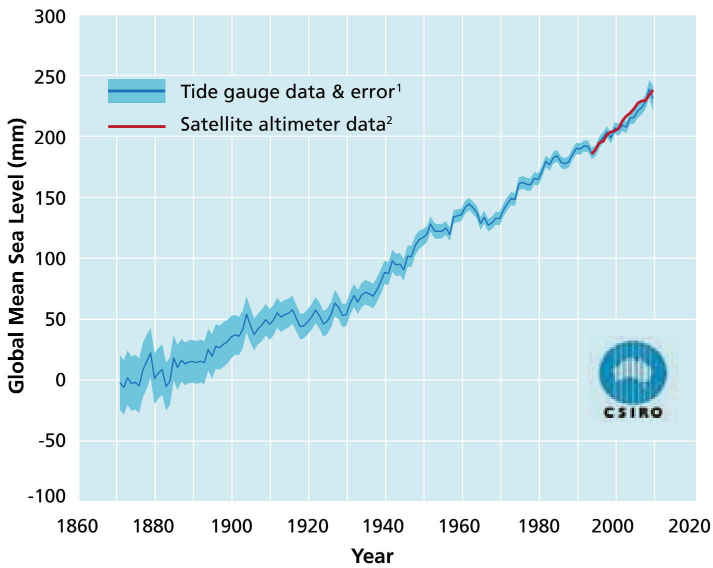
The Fourth Assessment Report (AR4) of the IPCC, released in 2007, concluded that 'warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level'.[20]

Left:
Barwon Bluff, Barwon Heads
(Photo: Nick Wynn)

The science of climate change is also continually evolving. More recent research has indicated that some measures of climate change are tracking at or above the worst-case scenarios considered possible in AR4.[21] The IPCC's Fifth Assessment Report (AR5) is expected to be completed in 2013–2014. This report will provide an update of knowledge on the scientific, technical and socio-economic aspects of climate change.

6.3 Effects of climate change on the mean level of the sea

Global average temperatures have increased by some 0.76°C from the late 1800s to 2005,[22] resulting in both warming of the oceans and melting of ice on land. Over this period there has also been a global increase in the mean level of the sea, with an average rise of 0.17 m over the course of the 20th century (Figure 6–1). Since 1990 sea levels have risen faster than expected, at a rate close to the upper limits of projections. Sea levels are not rising evenly everywhere since certain regional oceanographic processes cause different rates of rise. In Victoria tide gauges have recorded rises of between 1.7 mm/year and 2.5 mm/year since 1991,[16] equalling or exceeding the longer-term average rate.



Yearly average data; Latest data: 2009; Figure updated 25-Jun-2010
1 Updated from Church and White (GRL, 2006)
2 Combined TOPEX/Poseidon, Jason–1 & Jason–2 (CSIRO)

Figure 6–1 Historic changes in global mean sea level based on tide gauge and satellite altimeter data. Source: CSIRO (2011).[22]

Computer modelling has been used to provide projections of the future climate over time scales of centuries. A range of six plausible scenarios has been used by the IPCC to describe the way in which emissions may change in the future. These are known as A1FI, A1T, A1B, A2, B1 and B2. Taking the full range of six scenarios, the AR4 projected a sea level rise of between approximately 0.25 and 0.85 m by 2095 relative to levels in 1990. Figure 6-2a plots sea level rise using the A1FI (high emissions) scenario as adjusted, from 1990 to 2100.[14]

It has been acknowledged that even greater increases are possible than those included in AR4. Figure 6-2b show a range of published rates of new sea level rise estimates for the 21st century from different models in comparison to the AR4 projections. The AR4 A1FI projection at 2100 in Figure 6-2b matches the 2100 range in Figure 6-2a, while the more recent projections suggest higher sea level ranges.[23]

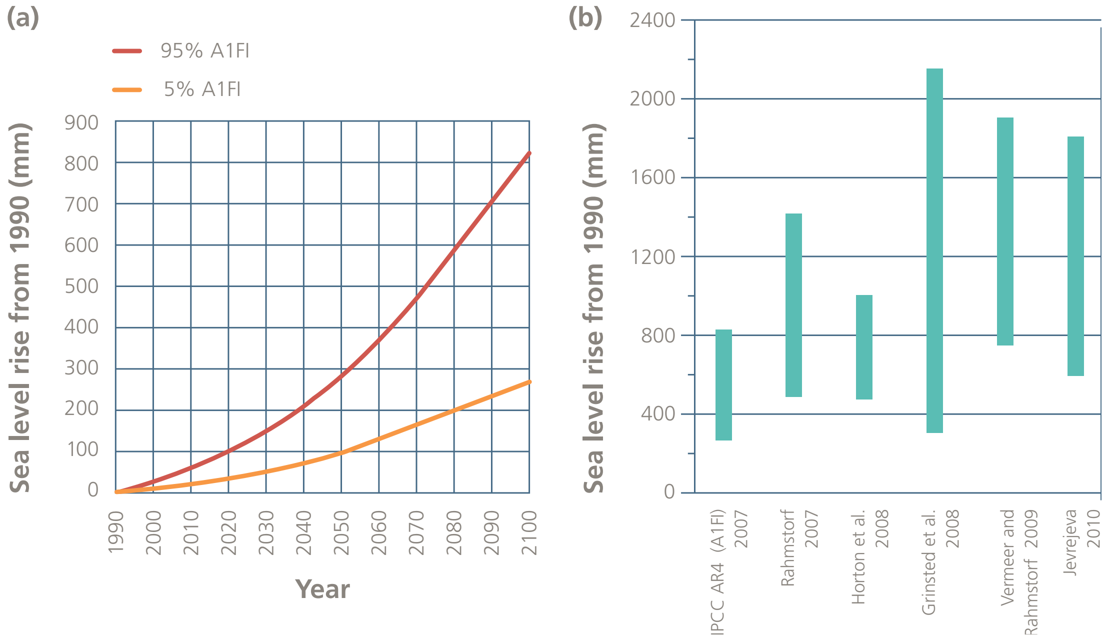


Figure 6–2 (a) Sea level rise predictions based on the A1FI high emission scenario in AR4, and (b) projections of sea level rise at 2100 completed since AR4. Sources: (a) Adapted from Hunter (2010).[49] (b) Redrawn from Rahmstorf (2010).[50]

While projections of sea level rise are now focused on 2100, it is important to realise that surface warming and hence sea level rise will continue past 2100 even if warming of the atmosphere stopped today, because there is a lag of many decades for the sea to adjust to the higher temperature of the atmosphere.

6.4 Extreme sea levels

A detailed analysis of extreme sea levels for Victoria has been undertaken. CSIRO[14,15] used hydrodynamic models to estimate the combined tide and storm surge heights to provide storm tide levels for the entire Victorian coast. Return periods were estimated using extreme value statistical analysis to provide storm tide levels for a range of return periods at selected locations around the Victorian coast, and for predicted sea level increases at 2030, 2070 and 2100 based on the A1FI (high emission) scenario.[14] The approach used by CSIRO is illustrated in Figure 6–3.

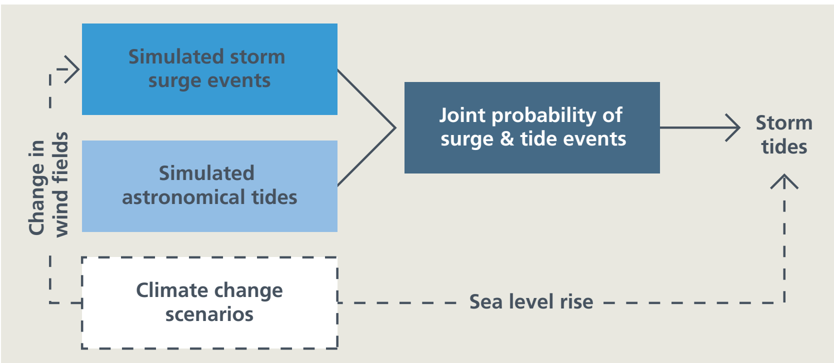


Figure 6–3 The approach used by CSIRO to assess potential climate change effects on extreme sea level.

The CSIRO study calculated extreme sea level rise for four climate change scenarios. Two of which are summarised below; the other two 'higher' scenarios can be found in the CSIRO reports. [14] [15]

1. **Scenario One** considered the AR4 A1FI scenario for mean sea level rise over the 21st century (i.e. 0.15 m, 0.47 m and 0.82 m for 2030, 2070 and 2100 respectively).[22]
2. **Scenario Two** combined the AR4 A1FI scenario with the equivalent high annual averaged wind speed change averaged over Bass Strait calculated by CSIRO and the Australian Bureau of Meteorology.[24]

Tables 6–2 and 6–3 present summaries of 1-in-100-year storm tide levels at selected locations on the Victorian open coastline and for Port Phillip Bay respectively for current climate conditions and the two scenarios sumarised above. It is important to note that the levels shown in these tables do not include wave and wind set-up, as the CSIRO modelling did not include estimates of these factors. Higher-resolution studies of sections of the coastline utilising different methodologies and data sets may yield different return levels.[14]

Table 6–2 Rounded 1-in-100-year storm tide height return levels for selected locations along the Victorian open coast under current climate conditions and the AR4 A1FI (Scenario One) and with the AR4 A1FI scenario and wind speed change (Scenario Two) for 2030, 2070 and 2100.

Location	Storm tide levels (m)						
	Current climate	2030		2070		2100	
		1	2	1	2	1	2
Portland	1.0	1.2	1.2	1.5	1.6	1.8	2.1
Port Fairy	1.1	1.2	1.3	1.5	1.7	1.9	2.1
Warrnambool	1.1	1.2	1.3	1.5	1.7	1.9	2.1
Apollo Bay	1.4	1.6	1.6	1.9	2.0	2.2	2.5
Lorne	1.7	1.8	1.9	2.2	2.3	2.5	2.7
Stony Point	2.1	2.2	2.3	2.6	2.7	2.9	3.1
Kilcunda	1.9	2.1	2.2	2.4	2.6	2.8	3.0
Venus Bay	2.0	2.1	2.2	2.4	2.6	2.8	3.1
Walkerville	2.0	2.1	2.2	2.5	2.6	2.8	3.1
Port Welshpool	1.6	1.8	1.8	2.1	2.3	2.5	2.7
Seaspray	1.5	1.7	1.7	2.0	2.2	2.3	2.6
Lakes Entrance	1.0	1.2	1.2	1.5	1.7	1.9	2.1
Point Hicks	1.4	1.5	1.6	1.8	2.0	2.2	2.5

Note: All values are in metres relative to late 20th century mean sea level.
Source: McInnes et al. (2009a).[14]

Table 6–3 Rounded 1-in-100-year storm tide height return levels for selected locations around Port Phillip Bay under current climate conditions and the AR4 A1FI scenario (Scenario One) and with the AR4 A1FI scenario and wind speed change (Scenario Two) for 2030, 2070 and 2100.

Location	Storm tide levels (m)						
	Current climate	2030		2070		2100	
		1	2	1	2	1	2
Point Lonsdale	1.4	1.6	1.6	1.9	2.1	2.2	2.5
Queenscliff	1.2	1.4	1.5	1.7	1.9	2.1	2.3
Geelong	1.1	1.2	1.3	1.5	1.7	1.9	2.2
Werribee	1.1	1.2	1.3	1.6	1.8	1.9	2.2
Williamstown	1.1	1.3	1.4	1.6	1.8	1.9	2.3
St Kilda	1.2	1.3	1.4	1.6	1.8	2.0	2.3
Aspendale	1.1	1.3	1.4	1.6	1.8	2.0	2.3
Frankston	1.2	1.3	1.4	1.6	1.8	2.0	2.3
Mornington	1.1	1.3	1.4	1.6	1.8	2.0	2.3
Rosebud	1.1	1.2	1.3	1.6	1.8	1.9	2.2
Rye	1.0	1.2	1.3	1.5	1.7	1.9	2.2
Sorrento	1.0	1.2	1.3	1.5	1.7	1.8	2.1

Note: All values are in metres relative to late 20th century mean sea level.
Source: McInnes et al. (2009b).[15]

Figure 6–4 shows the variation in storm tide height around Victoria for the 1-in-100-year storm surge for the current climate. Figure 6–5 shows the storm tide heights for the sea level rise situation at 2100 with wind speed increases (Scenario Two).

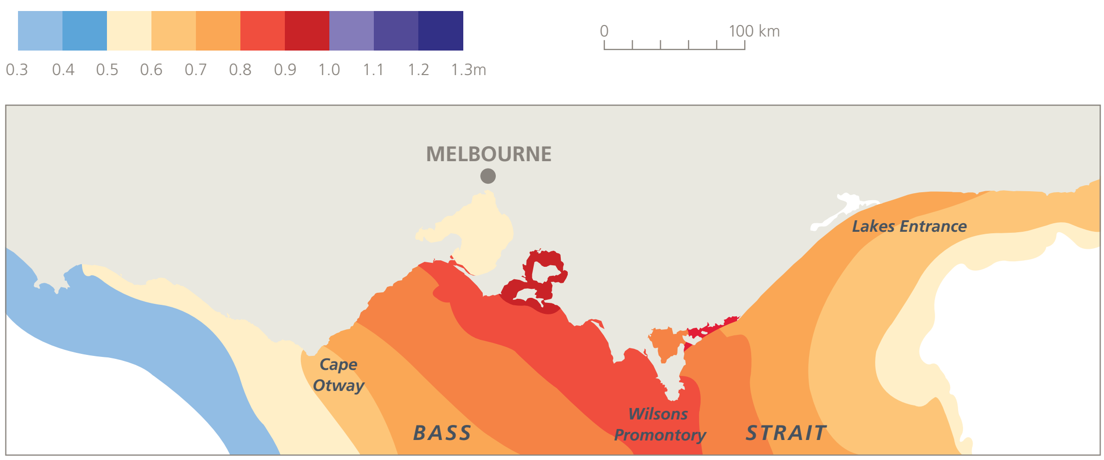


Figure 6–4 Current 1-in-100-year storm tide heights along the Victorian coast.
Source: McInnes et al. (2009a).[14]

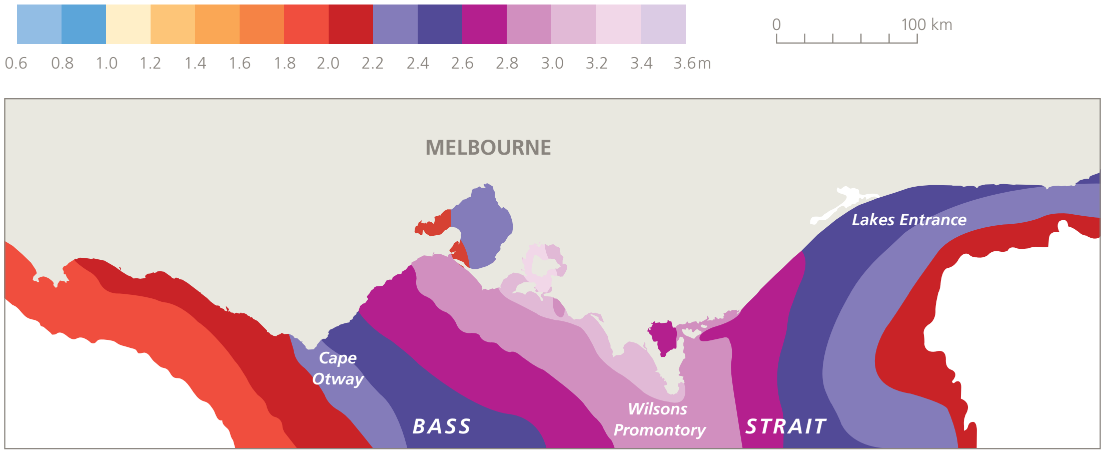


Figure 6–5 Future 1-in-100-year storm tide heights along the Victorian coasts, using AR4 A1FI scenario and wind speed change (Scenario Two) at 2100. Source: McInnes et al. (2009a).[14]

Even without storm tides, the predicted increase in sea levels will result in higher water levels and an increase in the frequency and duration of inundation of low-lying land. Because of the higher water levels resulting from sea-level rise, inundation that was previously caused only by larger, less frequent storms will be caused by more frequent storms.

6.5 Waves

Waves on the Victoria coast have four sources. Two are cyclonic, resulting from mid-latitude and east coast cyclones (or low-pressure systems, often referred to as East Coast Lows), and two are associated with high-pressure systems, including local sea breezes.[13]

Mid-latitude cyclones move continuously across the Southern Ocean and generate most of the swell waves arriving on the western coasts of Victoria. Each month between five and nine cyclones cross south of Victoria, generating waves on about 300 days of the year. In summer, when the cyclones are situated well south, near-shore waves are characterised by long, moderate to high swells. In winter, when cyclones are closer to the coast, they can generate higher seas (locally generated wind waves) and swells. Typically these waves are 2 to 3 m high with periods of 12 to 14 seconds, and arrive from the south-west.

East Coast Lows can occur throughout the year, but are more frequent from May to July. On average three or four East Coast Lows form each year and last approximately five days, impacting on the Gippsland coast where they arrive from the east to north-east. Typical wave heights during these East Coast Lows range from 2 to 3 m with periods of between 10 and 12 seconds. One extreme wave of 14.1 m was recorded on the Newcastle Waverider buoy during the 9 June 2007 East Coast Low — the highest recorded since records began in 1992.[25]

High-pressure systems that form to the west of Tasmania and weave eastwards can bring strong winds from the east to south-east and generate local waves and swells. Significant wave heights in the Southern Ocean correlate closely with a regional atmospheric climate feature known as the Southern Annular Mode as well as the Southern Oscillation Index.[26] Wave direction along the southern and western coasts of Australia shifts from a westerly to southerly direction with the intensification of the Southern Ocean storm belt associated with the Southern Annular Mode. Along Australia's eastern coast, a similar rotation of wave direction occurs during El-Niño events, from easterly to southerly (see Box 5–1).

Table 6–4 Typical wave characteristics on the Victorian coast.

Characteristic	Western Victoria	Central Victoria	Port Phillip Bay	Eastern Victoria
Typical significant wave heights, H_s (m)	2.5–5	2–4	0.5–2.0	1.0–2.5
Maximum deep water wave heights, H_{maxo} (m)	12–15	8–10	2.5–3.5	4–6
Peak periods, T_p (secs)	12–14	12–14	2–4	6–12
Typical mean wave directions	SW	SW	SW–W–NW	SW–SE

Source: Tim Womersley (Water Technology), pers. comm.

An analysis of the variability in extreme wave events in the last 50 years showed a slight positive trend in the frequency of large wave events over this period.[21] An earlier investigation reported that climate change forcing produces an upper trend of the Southern Annular Mode, with an intensification and southward shift of the Southern Ocean storms.[27] Because of the strong correlation of significant wave heights with the Southern Annular Mode, climate change is likely to increase the height of deep-water waves off the coast of Victoria.[26] Therefore there is expected to be an increased frequency of large waves as a result of future climate change.

6.6 Rainfall

Annual average rainfall is expected to decrease by around 4% by 2030, but the full range of model uncertainty ranges from –9% to +1% depending on the emissions scenario modelled.[28]

The greatest decreases in rainfall are likely to occur in winter and spring, while heavy rainfalls are most likely to increase in summer and autumn. By 2070, annual average rainfall is likely to decrease by 6% (–14% to +2%) under a lower emissions growth scenario or by 11% (–25% to +3%) under a higher emissions growth scenario.[28] Figure 6–6 shows annual average and seasonal rainfall projections for 2070 under the low and high emissions scenarios.

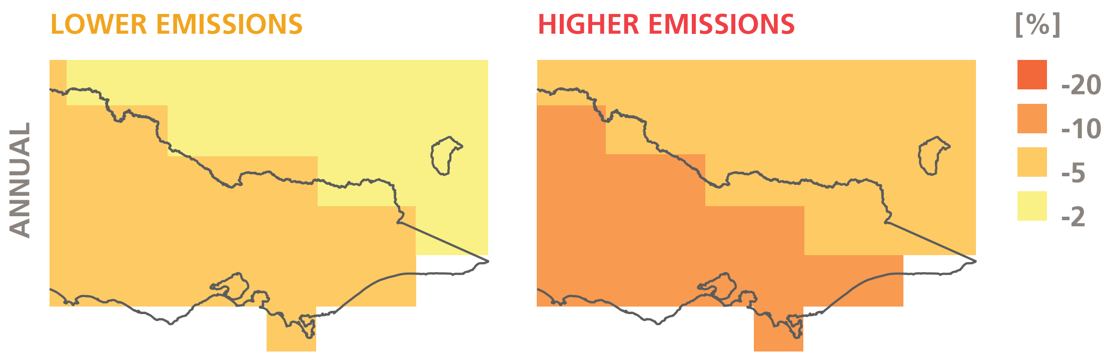


Figure 6–6 Annual average rainfall projections for 2070 under the lower and higher emissions growth scenarios. Source: Department of Sustainability and Environment (2009).[28]

7 Implications for the Victorian coast

7.1 Introduction

Climate change is unlikely to create any new coastal hazards, but at many locations it will make existing hazards worse. This could result in increased rates of coastal erosion, more extensive and frequent coastal flooding, increasing intrusion of seawater into estuaries and coastal aquifers, changing water quality, groundwater characteristics and sedimentation, and increasing seawater temperature that may affect ecosystems.

The effect of coastal hazards and the consequential exacerbating influence of climate change will affect the coastal margins around the Victorian coastline. However, the impact will depend upon both the coastal hazard and the shoreline type or landform.

Table 7–1 shows the relative sensitivity of coastal landforms to changes in different climate drivers for open and re-entrant coastal areas. Open coasts are characterised as being exposed to swells. They are mainly rocky and sandy coasts and are subject to high-energy erosion. Sandy beaches may fully or partly recover after storms as the swell returns sand to beaches.

Re-entrant locations include estuaries, tidal lagoons and other largely or wholly tidal environments that are sheltered from swells. These areas may be exposed to locally generated erosive seas (wind waves), as well as currents from tidal flows and river discharges. Softer rock shorelines and muddy shores are common within re-entrant locations, but are rare on open coasts. Erosion rates may be as significant or even greater than those on open coasts, because of the weaker geologies and landforms (Figure 7–1). These shores are also less capable of recovery after erosion because of the absence of onshore swells. However, there may be significant local and regional variability that can result in variations in the sensitivity and hence the response of a coastal landform at a specific location.

Figure 7–1 Low-energy eroding shoreline, Jamjerrup, Lang Lang, Western Port. (Photo: Werner Hennecke.)

Left:
Ocean Grove Beach
(Photo: Nick Wynn)

Table 7–1 Relative sensitivity of coastal landforms to change under different climate change factors in Victoria.

	Driver	Location	Landform: Hard rock coasts	Soft rock coasts	Sandy shores	Sandy shores (generally tide-dominated)	Other soft sediment shores	Engineered coasts
Climate change driver	Sea level	Open	L	M	L–H	–	–	L–M
		Re-entrant	L	M	–	H	H	L–M
	Storm surge	Open	L	M	H	–	–	L–M
		Re-entrant	L	M	–	H	H	L
	Wave height	Open	L–H	M	H	–	–	L–M
		Re-entrant	L–H	M–H	–	L–M	H	L–M
	Wave direction	Open	L	M	L–H	–	–	L–M
		Re-entrant	L	M	–	M	H	L
	Rainfall	Open	L	L	L–M	–	–	L
		Re-entrant	L	L	–	L	L–M	L

L = Low, M = Medium, H = High
Sea level = sensitivity to accelerations in sea level rise
Storm surge = sensitivity to changes in the frequency or/and intensity of storm surge
Wave height = sensitivity to changes in wave height generated by storms
Wave direction = sensitivity to changes in wave direction (e.g. changes in sediment transport patterns)
Rainfall = sensitivity to changes in the pattern and/or intensity of rainfall

7.2 Coastal inundation

The primary cause of coastal inundation is storm surge that combines with a high tide level and perhaps heavy rainfall over the catchment (Figure 7-2). While severe coastal inundation is infrequent at present, it has the potential to cause significant damage to both private and public assets. The main areas at risk from coastal inundation are the foreshore areas of estuaries, lagoons and waterways, and low-lying areas that are protected only by narrow natural or artificial barriers along the open coast.

The combination of a high tide and a storm surge (storm tide) can worsen flooding caused by heavy rainfall in the catchment by preventing low-lying inundated areas from draining.

Areas most vulnerable to inundation are generally beach fronts and low-lying wetland and coastal reserve areas, including Portland, Port Fairy and Barwon Heads in the west, Tooradin and Seaspray in the east and Queenscliff, Point Wilson, Point Cook to St Kilda, and Mordialloc to Seaford around Port Phillip Bay.

Figure 7–2 A storm surge at high tide, Port Fairy, western Victoria.
(Photo: Moyne Shire Council.)

7.3 Coastal erosion and recession

Coastal erosion (storm-induced) and recession (progressive erosion) is caused mainly by high waves, high tides and storm surges (Figure 7–3). This can result in temporary, long-term or permanent coastline retreat, depending on the shoreline type (see Table 7–2). The frequency and magnitude of coastal erosion and recession are expected to increase with rising sea levels because more storms will be able to drive erosive waves high on the shoreline — something that only larger, infrequent storms can do at present.

The position of the coastline or shoreline at any time is determined by coastal processes, coastal landform types and attributes, the sediment supply and geological factors such as subsidence.

Table 7–2 Typical ranges of coastal erosion/recession for different shoreline types.

Morphology	Erosion (storm events)	Recession
Sandy coasts (open)	• Highly variable, depending on local conditions and coastline features • Dune toe retreat can be in the order of tens of metres in an extreme storm • Subsequent beach and dune rebuilding possible, provided sediment is available and there is sufficient time between storm events	• Highly variable, depending on local conditions and coastline features, but generally up to 3 m/year • Eroded sand or sediment permanently lost to compartment sediment budget as sea-level rise increases subtidal accommodation space • Under future climate change scenarios, most Victorian beaches will eventually recede when erosion events become too frequent to allow full recovery between storms
Sandy shores, soft sediment shores (re-entrant)	• Highly variable, depending on tide and storm-wind wave erosion • High tide changes can be in the order of tens of metres during extreme events • Can be highly localised (e.g. through dredging or cutting of channels) • Eroded sand or sediment may be temporary or permanently lost to compartment sediment budget	• Limited rebuilding capacity • Variable over short distances
Rocky coasts (open and re-entrant)	• Hard rock coasts generally stable over human time-frames • Soft rock coasts can be prone to relatively rapid erosion, slumping and rock fall • No capacity to rebuild in human time-frames	• Soft rock coasts highly variable depending on local conditions and coastline features (e.g. slope, fracturing, hydraulic processes) • Erosion rates can average 1–5 m over 100 years • Hard rock coasts generally stable over human time-frames
Engineered coasts	• Can be variable, depending on integrity of structure • Loss of sand/sediment shoreward of seawall or barriers in storm events • Wave run-up and overtopping may undercut, out-flank or weaken structural integrity over time • Potential impact on coastline updrift of coastal protection structures such as groynes if sediment budget is altered	• Will be variable depending on integrity of structure (most, if not all, structures have a finite life and will need to be upgraded, replaced or removed)

Source: adapted from Sharples (2009)[7] and Ministry for the Environment (2008).[29]

Figure 7–3 Coastal erosion at Port Fairy, western Victoria.
(Photo: Moyne Shire Council.)

7.3.1 Soft sediment coasts

The rate of coastal recession will depend on shoreline type and local processes. Fluctuations in the overall trend can occur because of the variable frequency of storm events and the influence of cyclical process that can occur over a period of seasons (e.g. El Niño).

Soft coasts such as sandy beaches and sandy and muddy shorelines are highly susceptible to changes in the storm climate and could erode rapidly over a very short time. Sandy beaches on dynamically stable, open (swell-exposed) coasts tend to commence recovery soon after the storm period passes, as sand from the offshore bar is slowly reworked onshore (Figure 7–4). Large storms may redistribute beach sediments alongshore or deep into the offshore system, slowing the recovery. Soft sediment shorelines on re-entrant coasts may recover more slowly, if at all, because there are limited mechanisms for moving sediment onshore.

Long-term trends in beach or shoreline position may depend on the influence of a range of factors, such as antecedent natural conditions (sea levels, storm frequency, ENSO) and human-induced activity (coastal structures, land use change, vegetation removal, etc.). Care must be taken when interpreting changes in the shoreline position from historical data because of these complex relationships.

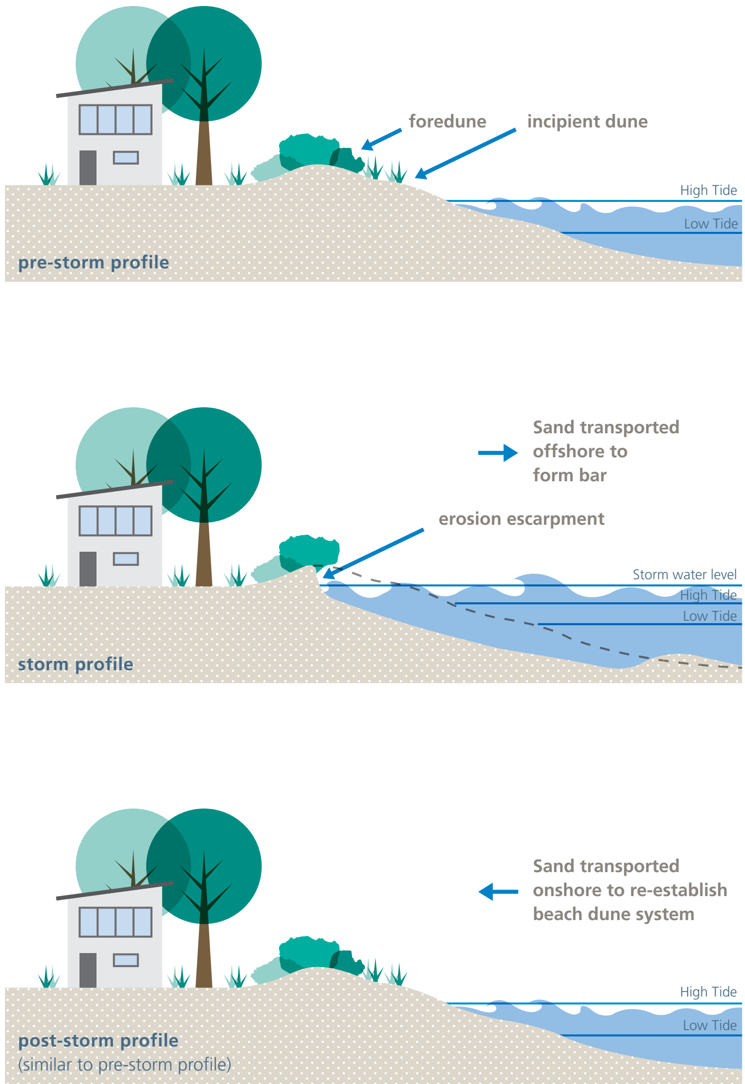


Figure 7–4 Example of a stable, open (swell-exposed) sandy coastline's response to a storm event. Source: adapted from NSW DLWC (2001).[30]

7.3.2 Rocky coasts

Rocky coasts and shorelines are generally less susceptible to erosion than other coasts. Hard rock shoreline types may show very little erosion on human time scales. However, softer rock shores may recede at significant rates on both open and re-entrant shores and are not capable of recovery. Wave and tidal forces associated with large storms can undercut rocky shores and trigger landslides on fractured, weathered or weakly consolidated cliffs. Waves and tidal action may remove the resulting talus from the base of cliffs, maintaining exposure of the eroding face to the physical agents of erosion.

Hard rock coasts are generally less prone to climate change effects than other shore types. In coastal re-entrants, particularly where there is a softer rock or clayey-gravel shoreline, the shorelines are generally not exposed to large-scale erosion because of the lower energy of waves and tidal forces compared to the open coast. However, their weaker geology can result in ongoing recession, and inundation effects may be more influential. These areas do not generally have any way of rebuilding as there is an absence of swells that can assist with the onshore movement of sediment. Therefore changes in sea level may cause erodible re-entrant shores to recede more rapidly than open coasts.

7.3.3 Artificially modified and engineered coasts

Modifications to the coast can have a significant impact on sediment budgets and sediment transport, exacerbating coastal erosion and recession. For example, many of the beaches of Port Phillip Bay (Figure 7–5) have been isolated from their original sediment source, so that today some beaches are maintained artificially by dredging and beach fill. Typical intervention activities include:

- coastal protection works such as groynes and seawalls, which can affect the movement of beach and near-shore sediment
- beach fill or nourishment, which artificially redistributes beach and near-shore sediments and can affect the sediment budget
- infrastructure development, including harbours and marinas, jetties, boat ramps, and canal or waterway modification, which can affect the sediment budget and flow
- construction on active beach systems and dunes, which reduces the ability of coasts to adapt naturally to change
- modification or removal of mangrove and saltmarsh vegetation, which reduces the buffering effect of these systems on shoreline erosion and affects environmental values
- changes to catchment activities such as deforestation and urbanisation, resulting in modifications to environmental flows, which can reduce or increase the volume and timing of the sediment supply to the coast
- artificial maintenance of entrances by dredging or deepening, which can affect tidal flow and sediment transport
- sediment extraction for commercial purposes, which may reduce sand volumes in coastal compartments.

Figure 7–5 Engineered coast at St Kilda, Melbourne. (Photo: City of Port Phillip.)

7.3.4 Climate change effects

Predicting the impacts of climate change is even more uncertain than predicting climate change itself (see Box 6–1). The additional uncertainty of impacts arises because of our limited knowledge about long-term biophysical responses to climate and about the role of non-climate factors and because there is seldom enough data to fully characterise site-specific conditions.[31]

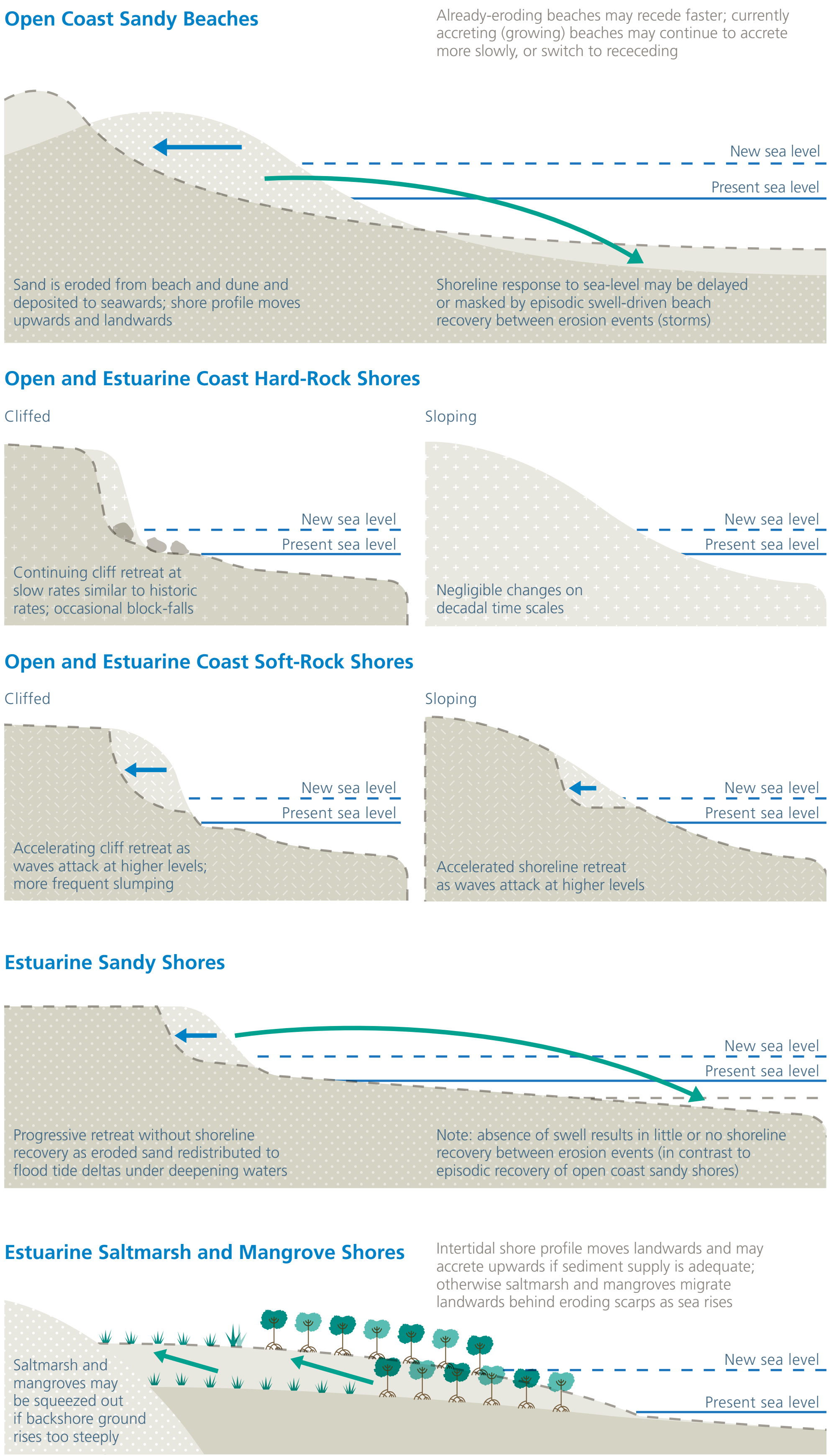
Figure 7–6 shows the generalised impacts of sea-level rise on different kinds of Victorian coastlines for both open and estuarine coastal landforms.

Sandy shores, especially those on the open coast, are highly mobile and variable. Over the long term, the rate of coastal advance or retreat is determined by the balance between any changes in sediment supply and the space that is available for sediment deposition.[31] However, sandy shores also rapidly change as a result of short to medium-term processes, many of which are not well understood nor able to be assessed because of the relatively short-term data sets available.

Because of this variability, accurate assessments of the potential effect of climate change are not possible on sandy shores. Conceptual equilibrium models are often used. These models are based on the assumptions that the existing dynamically stable shorelines are in equilibrium with the hydrodynamic environment, that an increase in sea level would bring increased wave energy to the shoreline, and that the shoreline would adjust to this increased energy, establishing a new equilibrium.

The most commonly applied model for sand coasts is the Bruun Rule (Box 7–1). More sophisticated numerical modelling techniques can also be used to provide guidance on the likely effects of climate change on sediment budgets and shoreline movement.

Because of the existing natural variability, the effects of sea-level rise are not yet readily evident in all areas, and there are very few areas where sea-level rise is the only process operating on a coastal cell.[31] The wider influence of coastal morphology, sediment supply and transport needs to be considered in combination with sea-level rise in order to better understand the potential effects of climate change on sandy coastal systems.



NOTE 1: In all cases the timing, scale and nature of shoreline responses to sea-level rise may vary depending on locally variable conditions including wave exposure and sediment availability.

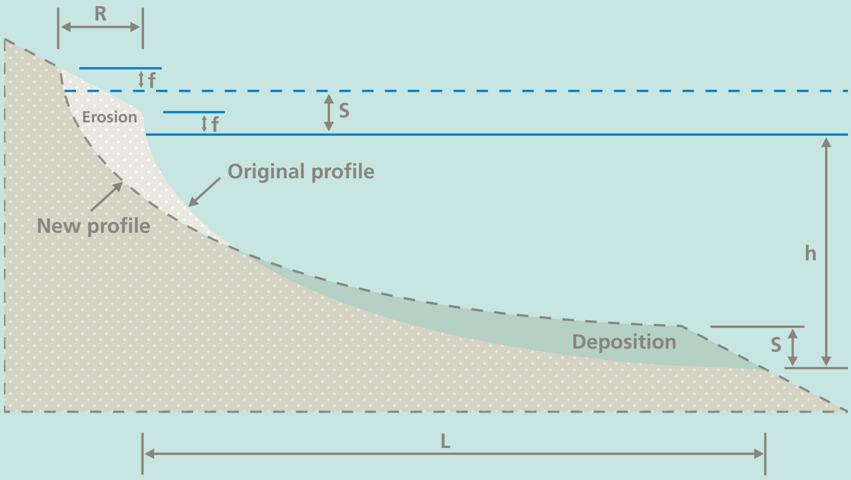
NOTE 2: Open Coast = swell-exposed; Estuarine coast = Swell-sheltered (includes tidal lagoons and other re-entrants).

Figure 7–6 Generalised impacts of sea-level rise on different types of Victorian coasts. Source: C. Sharples (University of Tasmania), modified from Rahmstorf (2009).[23]

Box 7–1 The Bruun Rule

There is limited understanding of coastal responses to climate change and sea-level rise because of the time scales involved and uncertainties about future erosion trends under changing climates. The most widely cited method of quantifying the response of a shore to rising sea-levels is known as the Bruun Rule. It is based on the assumption of an equilibrium shoreline that will adjust to a new equilibrium. The increase in sea level *S* that results in a shoreline retreat *R* is defined as:

$$R = SL/h$$



where *L* is the cross-shore width of the active profile (i.e. cross-shore distance from closure depth to furthest landward point of sediment transport), *h* is the height of the active profile to closure depth (maximum depth of sediment transport). The rate of shoreline retreat is directly proportional to the rate of sea level rise.

The Bruun Rule does not depend on a particular coastal profile, but does assume that no sediment is lost from the coastal system and makes no allowances for gradients in the longshore or cross-shore transport of sand. It also assumes that the coast consists of unconsolidated sands with a coastal dune.

The Bruun Rule has been the subject of much debate and criticism, but is still generally supported [32] and a recent observational study[33] has given it weight. Modifications to the Bruun Rule have been made to account for losses of sediment and for different shoreline types, such as reef coasts.

Alternative equilibrium beach models have been used to quantify the effects of climate change, and some more sophisticated coastal sediment budget models are based on the concept of 'coastal cells'. [19]

8 Risk assessment

8.1 Introduction

The purpose of risk assessment is to:

- identify and characterise the nature of the risk
- identify qualitative or quantitative estimates of risk
- compare the sources of risk
- assess the impacts of uncertainty
- assess and compare options to manage the risk.

A widely used approach to risk analysis in relation to coastal hazards is based on the source–pathway–receptor concept (Figure 8–1). For coastal hazards the sources of risk are the coastal processes of extreme water levels and wave energy, and the influence that climate change can have on these sources. The pathway is the processes of inundation and erosion, which takes into account the topography and composition of the land. The receptors are the assets valued by the community.

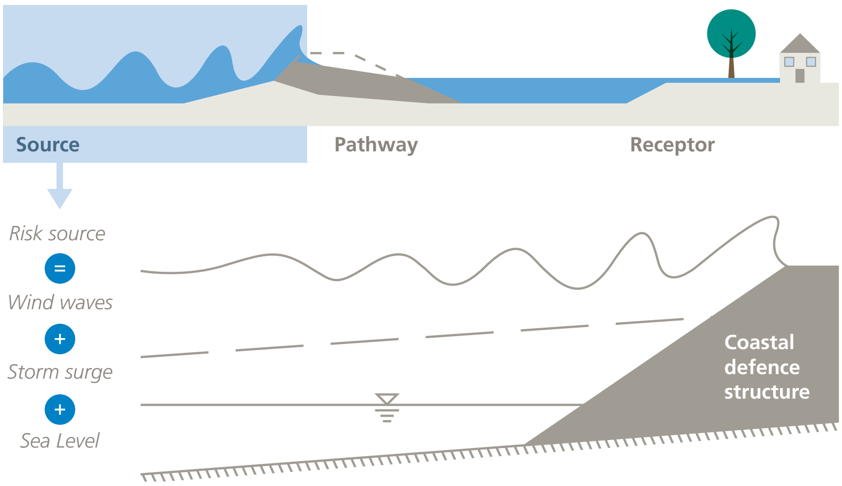


Figure 8–1 The source–pathway–receptor concept for coastal hazard risk assessments. Source: Wahl and Jensen (2011).[34]

The risk is the combination of the probability of the coastal hazard (involving both the source and the pathway) and the consequence to the receptor:

$$R = P \times C$$

where R = risk
P = probability of the coastal hazard
C = consequence (heath and safety, social, economic or environmental loss).

Left:
Painkalac Creek, Aireys Inlet
(Photo: Candace Jordan)

Risk assessment is advantageous because it:

- documents hazards, risks and assumptions, so they can be communicated to stakeholders
- provides a basis for risk to be explicitly recognised and reduced, shared, transferred or accepted
- reduces the chance of unidentified risk
- creates more opportunities to mitigate risk
- encourages creative thinking and input of engineering experience and expertise into the decision-making process
- widens the range of decisions and mitigation strategies available.[(35)]

8.2 Fundamental concepts in risk assessment

Various fundamental concepts should be considered as part of a risk assessment, including that:

- there is a degree of risk that is acceptable or tolerable
- risk varies over time
- risk varies spatially
- risks assessments need to match the scale of risk and the data or information available
- uncertainty needs to be considered.

8.2.1 Acceptable or tolerable risk

The definition of what is an acceptable or tolerable risk can vary significantly from one stakeholder group to another and needs to be assessed and agreed early on in the risk assessment process.

8.2.2 Risk and time

Time is a fundamental consideration in any risk assessment of coastal hazards, particularly when the effects of climate change are being considered. Risks not present now may develop in the future as a result of shoreline erosion/recession or increased inundation, and existing risks may be worsened. This can be recognised in the risk assessment process by including a range of time periods that are used to quantify the coastal hazard.

8.2.3 Spatial change to risk

There can be significant variation in a coastal hazard even over relatively short distances because of a range of factors, such as a changing shoreline composition and hydrodynamic environments, topography and geology that modify either the source or the pathway. Coastal hazard risk can also be affected by land use and cultural and environmental assets (i.e. different receptors).

8.2.4 Comprehensiveness of risk assessment

The level of detail that must be considered in a risk assessment will depend on the quality of information used to derive an understanding of the coastal hazard, as well as the scale and value of the receptors potentially affected by that hazard.

The order of complexity and costs of risk assessment, in ascending order, is:

1. qualitative
2. semi-quantitative
3. quantitative.

A qualitative assessment is often done first to get a broad indication of the level of risk and to reveal the major risk issues and areas where additional information is required for more detailed assessments. It can be used to screen overall hazard risks and prioritise those that need further evaluation. A qualitative assessment may be all that is required to identify the broad scale risks. However, it may be necessary to undertake a more specific semi-quantitative or quantitative analysis on the major risk issues.

Existing information such as that provided by Smartline[37] and the Australian Government's first pass assessment may provide enough information about coastal hazards for a qualitative assessment (see Box 8–1).[17]

Box 8–1 Australian Government first pass assessment

A first pass assessment was undertaken by the Australian Government to assess the extent and magnitude of climate change risks for Australia's coastal zone.[17] It focused on risks to settlements and infrastructure, ecosystems and industries in the coastal zone. For Victoria the inundation risks for a 1-in-100 year storm tide event (on top of sea level rise) were assessed, using modelled storm tide data based on a 1.1 m sea level rise from CSIRO. Some key findings that came out of this assessment for Victoria were:

- 27600 to 44000 residential buildings could be exposed to inundation from a sea-level rise of 1.1 metres. The replacement value would be in the order of $6.5–$10.3 billion.
- 70% of the residential buildings at risk are in the local government areas of Kingston, Hobsons Bay, Greater Geelong, Wellington and Port Phillip.
- Approximately 4700 residential buildings are within 110 m of 'soft' erodible coasts.

The assessment noted that the areas currently most vulnerable to inundation are generally beach frontage and low-lying wetlands and coastal reserves, including Portland, Port Fairy and Barwon Heads in the west of the state, Tooradin and Seaspray in the east, and Queenscliff, Point Wilson, Point Cook to St Kilda and Mordialloc to Seaford in Port Phillip Bay.

As with any broad-scale assessments carried out at this scale, such as the First Pass Assessment, a range of factors must be assumed. It is important that the assumptions and caveats that underpin this assessment are understood in the consideration of the findings.

8.2.5 Uncertainty

Although the risk assessment process provides a systematic approach to considering coastal hazards and the resulting consequences, there will always be uncertainty. Uncertainty may relate to both the likelihood and the consequences of a hazard (Figure 8–2).

It is important to understand and define where uncertainty exists, to consider which uncertainties have the greatest potential to affect decisions, and to consider steps that could be taken to reduce the uncertainty.

Uncertainty may be clarified by expert judgement (qualitative risk assessment) or further investigations and specialist assessment (semi-quantitative or quantitative risk assessment). In both qualitative and quantitative risk assessments, the stated risk must be clearly expressed and understood by all stakeholders, and any assumptions and their impact on the level of uncertainty must be clearly understood and communicated.

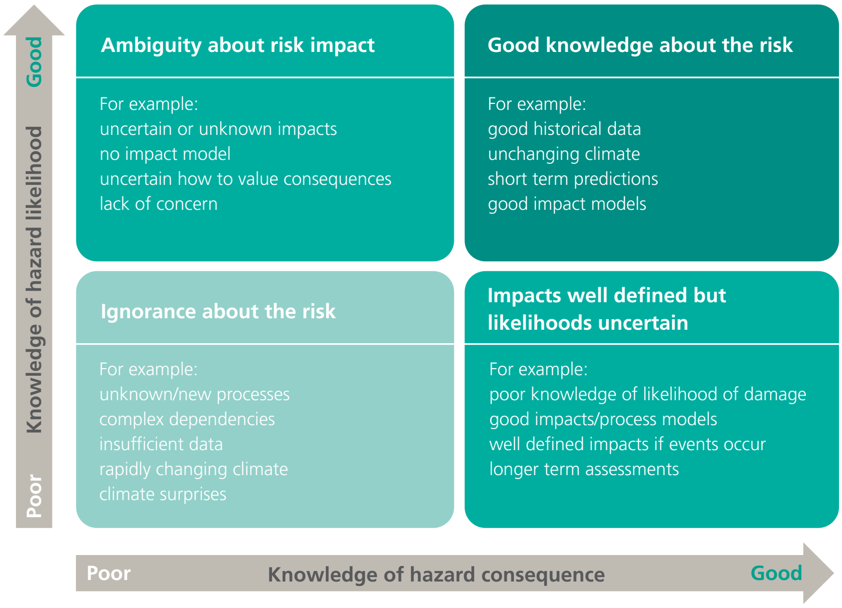


Figure 8–2 Sources and ranges of uncertainty for coastal hazard risk in relation to climate change. Source: Willows and Connell (2003).[38]

8.3 Coastal hazard assessment and the risk management framework

Coastal hazard assessments are an essential component of identifying and understanding coastal hazard risk in the context of overall risk management. In keeping with best practice, this process follows a well-established risk assessment and management framework that is based on the relevant Australian and New Zealand Standard.[39] There are five major stages in the decision-making process (Figure 8–3). Continual communication and consultation with stakeholders, and continual monitoring and reviewing, are integrated into the process.

This risk management framework can be used to ensure that coastal hazards, and the effects of climate change on them, are systematically and appropriately taken into account by individuals, developers, coastal land managers and planners in relation to proposed developments and in the management of land in coastal locations. The risk management process can also be used to develop a consistent approach when considering other hazards and their consequences.

The physical processes (sources) and the extent of inundation and erosion/recession (pathways) are considered in the ‘Risk Identification’ and ‘Risk Analysis’ stages of the process (Figure 8–3).

The process of risk assessment is valuable when there are uncertainties about the outcomes. In risk assessment involving climate variability that affects existing coastal hazards as well as future climate change this is particularly true, because there are inherent uncertainties with respect to probabilities and consequences for both climate variability and climate change.

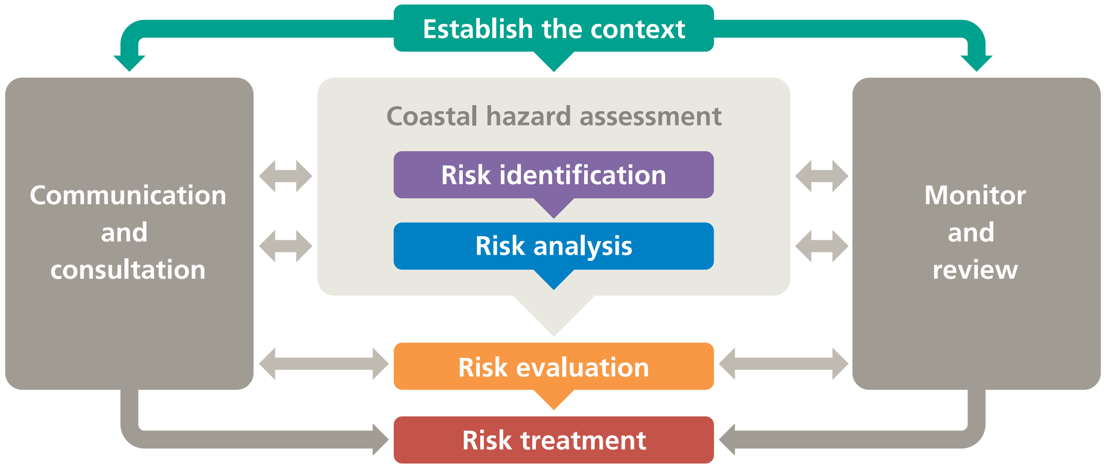


Figure 8–3 The risk management process. Source: Standards Australia (2008).[39]

8.3.1 Communication and consultation

Communication and consultation is an integral part of the coastal hazard risk management framework and continues throughout the process. Consultation means informing stakeholders on the process being undertaken, the expected outcomes and the implications, and evaluating and considering feedback from stakeholders.

Communication and consultation should involve a dialogue that focuses on mutual education rather than a one-way flow of information from the decision-maker to stakeholders.[40]

The benefits of effective communication and consultation include:

- quality input that leads to quality decision-making
- greater stakeholder satisfaction with the final planning product, because of their involvement in shaping it
- a greater chance of successful implementation because more stakeholders feel committed to the plan or project's goals and take ownership of the plan's design
- good governance, transparency and open communication.

Stakeholders most likely to be affected by coastal hazards are usually in the best position to feed local knowledge into the process and to manage and respond to the risks.

Consultation is most effective when it is initiated as early as possible (Figure 8–3) and is often formalised in a communication and consultation plan. Generally, this plan should include:

- the objectives of the specific communication or consultation
- who will be involved and how the communication channels work
- what is to be communicated and what is to be consulted
- how information will be communicated.

Stakeholder involvement is particularly useful in establishing the context and analysing and evaluating risks. Stakeholder participation through the assessment processes will greatly increase willingness of stakeholders to engage and take ownership, particularly in the risk treatment stage.

8.3.2 Stage 1: Establish the context

Establishing the context involves defining the basic parameters within which coastal hazard risk must be managed, and sets the scope for the rest of the risk management process. This stage includes establishing:

- the objective and scale of the coastal hazard risk assessment
- the spatial extent of the study area and the key coastal processes that occur
- the planning period to which the assessment will apply
- risk criteria
- stakeholders and others who may have an interest in the particular area.

8.3.2 a Defining the objective and scale of the coastal hazard risk assessment

The first step is to articulate the coastal hazard problem. Defining the problem can also assist in the selection of the appropriate level of risk assessment required. The level and complexity of coastal hazard risk assessments will include consideration of:

- the scale and extent of the existing or proposed assets area or values potentially at risk
- the planning period required to be considered
- the quality of available information.

The definition of the objective and scale of the assessment needs to be understood and agreed by the relevant stakeholders.

8.3.2 b Scale and extent of the study area and key coastal processes

The key objectives of this step are to:

- define the area to which the risk assessment will apply
- identify the key coastal processes affecting this area
- collect and assess data to identify and fill knowledge gaps.

Spatial extent of study area

Defining the spatial extent of the study area to which the risk assessment will apply begins with identifying the specific area of concern. This may be an area of development or future development, or an area of particular value for social or environmental reasons. The full extent of the study area can then be selected to ensure that it encompasses all key coastal processes operating in the area. The resulting spatial extent may be significantly larger than the specific area that is to be assessed.

An understanding of coastal processes and their location and scale are essential parameters for defining the study area.

Coastal processes

The study area must fit within a defined coastal compartment that includes definable onshore, offshore and alongshore boundaries. The boundaries should be selected to simplify the identification and quantification of sediment movements (e.g. back beach erosion escarpment, offshore limit of onshore–offshore sand transport, and shoreline controls such as prominent rock headlands). The aim is to be able to define and understand the physical processes acting on the compartment and the sediment movement across the boundaries, and hence any net gain or loss of sediment to the compartment.

Depending upon the aim and scale of the risk assessment, the coastal compartment could encompass sub-cells or regions in which different processes occur.

Data collection and assessment

Data collection and assessment is crucial to the overall understanding of coastal processes, the methodology adopted (qualitative, semi-qualitative and quantitative) and the reliability of the subsequent hazard definition.

Data collected at this stage may include:

- historical data (e.g. earlier shorelines shown in aerial photographs, surveys or charts, records of significant extreme events and human-induced changes)
- geomorphological and geological data
- surface elevations (topographic mapping such as LIDAR)
- spatial/mapped data
- process data (winds, waves, currents)
- sediment properties
- storm water levels
- hydrological data
- groundwater intrusion.

This task should not be undervalued, and appropriate resources should be allocated for it to be undertaken and evaluated thoroughly. Inevitably, appropriate data will not be available on all these factors. An assessment of the adequacy of the data should be made and, if appropriate, strategies should be put in place for addressing any deficiencies.

As part of this stage, best estimates of storm erosion, inundation levels and long-term recession are needed. These may come from information about known events and extrapolations of historical trends. Empirical techniques and numerical modelling are also essential tools for extending this data or assessing the likely impacts, if local measurements do not exist. Proven models that are calibrated for similar conditions and locations are generally acceptable.

8.3.2 c Defining the planning period

This step follows on from the broader definition of the objective and scale of the coastal hazard risk assessment discussed in Section 8.3.2 a. A planning period must be established and is critical to determining how extreme events and the potential effects of climate change are taken into account.

The Victorian Coastal Strategy (see Section 3.6) requires that a sea-level rise of no less than 0.8 m by 2100 is taken into account. In certain circumstances it may be appropriate to consider shorter or longer planning periods while maintaining consistency with this policy. The consistency can be maintained by using the applicable sea-level rise projection for the chosen planning period, providing that the projection is drawn from the same A1FI scenario from which the policy statement is drawn (see Figure 6–2a).

Because of the inherent uncertainty in sea-level rise projections, it can be advantageous to model a series of sea-level rise projections for a given planning period (see Section 8.3.4 b). This provides a greater level of sophistication in outputs because each projection can be translated into a likelihood of the event occurring, as demonstrated in Table 8–3. However, the cost of a coastal hazard risk assessment will be greater if extra planning periods and sea-level rise projections are modelled.

If the planning period is too short, an intensification of coastal land use may hasten the need for intervention and increase the associated costs, thus not providing adequate mitigation of risks from coastal hazards. If the planning period is too long, opportunities to use coastal land might be constrained unnecessarily.

The nature of the asset or value potentially at risk should also be considered when determining a planning period. For example, issues such as adaptive capacity, exposure and intensification of land use should be taken into account.

When undertaking a coastal hazard risk assessment for strategic purposes that may encompass large stretches of coastline with diverse land uses, it would be advantageous to choose a series of planning periods such as 2040, 2070 and 2100, and beyond if necessary.

8.3.2 d Identifying the coastal hazard risk criteria

The criteria by which coastal hazard risk is to be evaluated should be developed at a preliminary level at this stage. Matters to consider include:

- the nature of the coastal hazards to consider (e.g. storm effects, inundation, erosion, recession), including combined probabilities
- how likelihood will be defined
- how the level of risk will be determined (e.g. hazard maps for different events)
- the views of stakeholders
- the level at which risk becomes acceptable or tolerable.

The risk criteria should be reviewed and further developed and refined throughout the risk identification and analysis process.

8.3.3 Stage 2: Risk identification

This stage identifies the sources of risks and their areas of impact. For each of the potential hazard sources and pathways, an assessment is made of the magnitude of these hazards and how likely they are to occur. The risk identification process may also identify new pathways for consideration. At this stage a check on data requirements is also useful to ensure there is sufficient information collected in the coastal process stage (Section 8.3.2 b) to progress with a risk assessment.

Coastal hazards and their consequences often have multiple sources, pathways and receptors. These hazards may be related and interactive, or may occur over differing time scales. Table 8–1 shows sources and pathways for a range of coastal hazards.

Table 8–1 Coastal hazard sources and pathways.

Hazard	Source	Pathways
Coastal inundation	• sea level rise (tides, storm surges, climate change) • waves • river flow • rainfall • climate cycles (ENSO, IPO) • wind	• direct inundation of low-lying land • overtopping or breaching of dunes, coastal barriers or protection works • inundation via beach access points and boat ramps • inundation via rivers, streams or stormwater outlets
Saline intrusion	• sea level rise (tides, storm surges, climate change) • waves • river flow • rainfall • climate cycles (IPO, ENSO) • wind	• hydraulic connection to aquifer beds • flow along buried stream channels • flow through crushed rock in fault zones
Coastal erosion or recession: soft shores	• sea level rise (tides, storm surges, climate change) • waves • interrupted sediment supply • catchment discharges • climate cycles (ENSO, IPO) • wind	• long-term continuous (structural) retreat • long-term fluctuating retreat • short-term fluctuations/cycles • river/coastal dynamics • human-induced changes
Coastal erosion: rock coasts	• geological defects/controls • sea level rise (tides, storm surges, climate change) • waves • climate cycles (ENSO, IPO) • wind	• slumping • undermining • removal of talus toe protection • lowering of shore platform • lowering of fronting beach • internal factors (defects) • groundwater/surface water • weathering
Damage to engineered coasts	• sea level rise (tides, storm surges, climate change) • waves • interrupted sediment supply • catchment discharges • climate cycles (ENSO, IPO) • wind	• undermining • overtopping • increased wave forces

Source: adapted from Ministry for the Environment (2008).[29]

8.3.4 Stage 3: Risk analysis

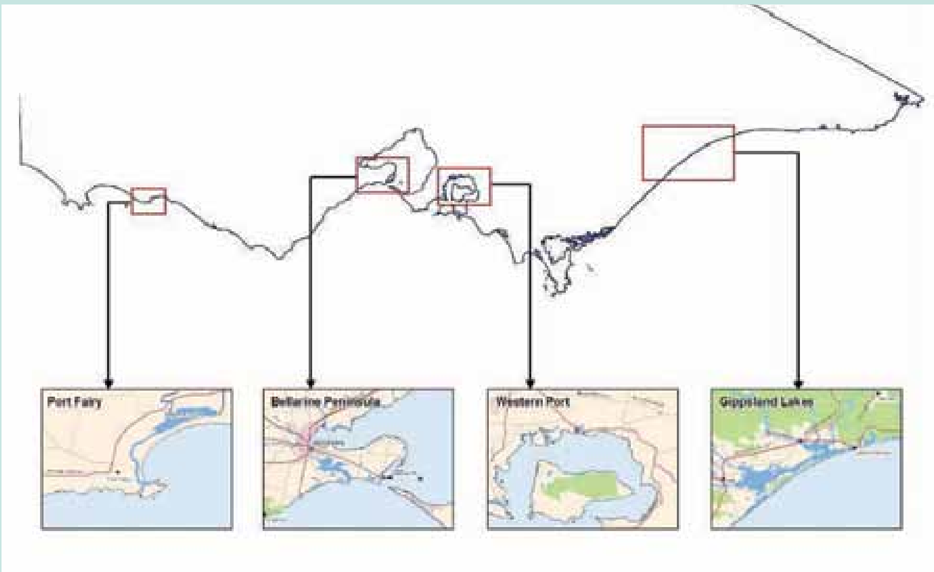
Risk analysis provides guidance on whether a coastal hazard risk needs to be treated, and about the most appropriate risk treatment strategies. It considers the source of the coastal hazard risk, the consequences, and the likelihood that those consequences may occur.

The analysis of risk can be qualitative, quantitative or a combination of both (semi-quantitative), depending upon the context, level of information and the requirements for the specific assessment.

A scoping-level assessment using basic information and qualitative assessments can often help to focus on more detailed assessments in areas where consequences are likely to be more significant. If there is still a high level of uncertainty following the risk analysis, it may be appropriate to undertake additional work to reduce the uncertainty, and then repeat the risk assessment with the improved information.

Box 8–2 Local Coastal Hazard Assessments

In 2009, the Victorian Government committed funds, through the Future Coasts program, to support the preparation of four Local Coastal Hazard Assessments, in partnership with local organisations.



In general, the aims are to:

- generate comprehensive coastal hazard assessments at selected locations, to support on-ground decision-making and risk assessments
- improve the capacity of local government to identify and plan for coastal hazard risks
- test and document appropriate methodologies for assessing coastal hazards
- establish local collaborative partnerships
- share information.

The outputs of the local assessments will be hazard maps for selected future planning periods that will delineate levels of coastal hazard risk. Sea-level rise projections will be incorporated into the methodology.

The local assessments will consider site-specific conditions such as the local sediment transport regime, coastal geology and geomorphology, wave dynamics, existing structures, catchment inundation, hydrology and hydrodynamics, groundwater and bathymetry.

The local assessments should provide data at an adequate level of detail and resolution in order to develop planning responses and to model and evaluate adaptation options.

8.3.4 a Developing risk criteria

This stage follows on from the preliminary evaluation carried out in the initial development (see Section 8.3.2 d) where the risk criteria was identified. Criteria should be developed to enable the significance of the risk to be evaluated. Important factors that should be considered in developing risk criteria include:

- the kinds of consequences that will be considered
- how likelihood will be defined
- what risks are broadly acceptable, tolerable and intolerable.

Consequences

Consequences are typically defined using a consequence scale. Consequence scales define a range of consequence levels (e.g. insignificant to catastrophic) associated with a particular hazard, and what is meant by each level for a range of exposure/receptor categories. Consequences are not only focused on damage to property or assets. There may also be consequences for exposure/receptor categories such as environment, society and health and safety. These are typically presented as a 'consequence matrix' consisting of three parts; scale of impact, tolerability (severity) of impact and consequences. Table 8–2 shows an example of a consequence matrix identifying a range of impacts and their tolerability. Quantifying impacts in terms of number of people injured, or costs in dollar or percentage values, helps to compare the consequences and impacts of proposed treatment strategies.

Table 8–2 Example of a consequence matrix.

Scale of impact	Description of consequences			
	Health & safety	**Social**	**Economic**	**Environmental**
Major	Multiple fatalities, or significant irreversible effects to > 50 persons	Ongoing serious social issues. Significant damage to structures and items of cultural significance	Severe, i.e. over $10 million or more than 50% of assets	Severe long-term environmental impairment of ecosystem functions
Severe	Single fatalities and/or severe permanent disability (>30%) to one or more persons	Ongoing serious social issues. Significant damage to structures and items of cultural significance	Major, i.e. between $1M and $10M or 10 to 50% of assets	Very serious long-term environmental impairment of ecosystem functions
Moderate	Moderate irreversible disability or impairment (< 30%) to one or more persons	Ongoing social issues, permanent damage to buildings and items of cultural significance	Moderate, i.e. between $100,000 and $1M or 10% of assets	Moderate short term effects but not affecting ecosystem functions
Minor	Reversible injury possibly requiring hospitalisation	Ongoing social issues, temporary damage to buildings and items of cultural significance Medium- term social issues, minor damage to dwellings	Minor, i.e. between $10,000 and $100,000 or 1% of assets	Minor effects on physical environment
Negligible	Minor first aid or no medical treatment required	Negligible short-term social impacts on local population, mostly repairable	Small, i.e. less than $10,000 or 0.1% of assets	Insignificant effects on physical environment

The identification of exposure/receptor categories and the descriptions of consequences should be completed in consultation with key stakeholders, to reflect the local hazard context as well as the social, economic and environmental consequences. The consequences shown in Table 8–2 could be modified to allow for particular requirements and issues in the study area and the level of detail required. For example, separate categories could be added for the built environment, separating out residential and commercial properties. Many organisations have existing and accepted consequence scales that could be used to assist in the development of a coastal hazard consequence scale.

Likelihood

Likelihood scales are used to define the likelihood that a coastal hazard will occur. Likelihoods must be carefully developed for each particular study area, and a clear description of what is meant by each likelihood level must be provided.

Interpretations of the likelihoods on which to base coastal hazard risk assessments are complex because a number of sources could combine to create a particular hazard,[(41)] including sea-level extremes, tides, high winds and waves, and climate change effects. Typical likelihood scales include a range of probabilities, from virtually certain to very unlikely. These scales can be based on expert opinion and qualitative assessment for broad-scale, high-level risk assessments. More sophisticated assessments of likelihood may be warranted if the consequences are expected to be significant.

Box 8–3 Difference between ARI and AEP

The average recurrence interval (ARI) and annual exceedance probability (AEP) are measures of the rarity of an event and are often used interchangeably. ARI is the average number of years between events which exceed a certain magnitude (i.e., a level or elevation). AEP on the other hand is defined as the probability that a particular level will be exceeded in a single year.

Relationship between ARI and AEP

The table below shows the relationship between ARI and AEP for return intervals between 1 and 100 years. ARIs greater than 10 years are closely approximated by the reciprocal of the AEP. The 1% AEP and the 100 year ARI events are effectively the same magnitude and can be used interchangeably. However, for ARIs below 10 years the AEP and ARI are less comparable.

ARI (years)	AEP (%)
1	63.2%
2	39.3%
5	18.1%
10	9.5%
20	4.9%
50	2.0%
100	1.0%

The use of the ARIs can lead to confusion because they are often misinterpreted as implying that the associated magnitude of an event is only exceeded at regular intervals, and that if one such event has occurred recently then another will not occur for a certain number of years. For example, 'if a 1-in-100 year event has just occurred, it cannot happen again for another 100 years', which is not the case.

The likelihood of inundation may be also defined using either annual exceedance probability (AEP) or average recurrence interval (ARI) for events with a return interval of greater than 10 years. The AEP is the probability of a threshold being equalled or surpassed in a single year. For example, an AEP of 0.01 means that there is a 1% chance that an event equal to or greater than a certain level will occur in any given year. The ARI for an event is a different method of expressing the same thing. For example, an event with an AEP of 0.01 or 1% would have an ARI of 100 years; that is, an expectation that, as a long-term average, it would recur once in 100 years (see Box 8–3). Different likelihoods can be chosen for different land uses and also for different types of hazards.[42]

Table 8–3 shows an example of possible combination of coastal hazards, taking into account a range of possible sea-level rise effects combined with tides, wave and storm surges and elevated catchment flows, with the defined likelihood for the present and for 2040, 2070 and 2100. This table suggests that the combination of events characterised by a 1% AEP storm surge and wave event combining with a mean high water spring tide and a 10% AEP catchment event can be classed as likely to occur currently, but will become virtually certain in 2040 as increased sea levels increase the frequency of the impacts of this type of event occurring.

Table 8–3 Examples of likelihood scales assigned to qualitative assessments using a combination of storm tide, wave height and catchment flow from current perspective.

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

Levels of risk

The relationship between risk and its components (i.e. consequences and likelihoods) can be represented by a matrix. The number of steps or divisions along each side of the matrix is determined by the level of detail required and the nature of the measurements, as well as the context, scope, resources and use. The risk matrix defines the level of risk for a particular combination of consequence and likelihood (see Table 8–4).

Table 8–4 Example of a risk matrix.

		Consequence				
		Insignificant	**Minor**	**Moderate**	**Major**	**Extreme**
Likelihood	Virtually certain	Medium	High	High	Extreme	Extreme
	Likely	Medium	Medium	High	High	Extreme
	About as likely as not	Low	Medium	Medium	High	High
	Unlikely	Low	Low	Medium	Medium	High
	Very unlikely	Low	Low	Low	Medium	Medium

8.3.4 b Coastal hazard identification

Hazard identification is the consideration of the influence of the sources of coastal hazard. This includes a process to identify and quantify the current coastal processes and hazards affecting the shoreline and the potential impacts that are of interest in the study area. This should include (where relevant):

- a quantified sediment budget
- coastal and catchment inundation
- shoreline erosion/recession
- instability
- coastal groundwater changes
- sea-level rise
- catchment flooding.

The coastal hazard assessment needs to take into account site-specific factors such as sand movement, groundwater impacts, infrastructure, access and evacuation routes, and foundation constraints. This is required to clearly identify assets that could be affected by coastal hazards, taking into account short-term influences, observed or inferred long-term trends, and the potential effects of climate change.

Sediment budget A sediment budget for the compartment, including the quantification of sediment sources and sediment sinks, is a key element in the definition of present-day processes. It should be considered in a regional context and should be consistent with the understanding of coastal process and sediment budget assessments for adjacent compartments, if this information is available. The sediment budget provides a basis for assessing the sensitivity of the shoreline to changes in coastal processes, and identifies whether there is an existing sediment imbalance that is controlling or contributing to the shoreline response. Importantly, the impact of any proposed development or response/management strategy needs to be tested against the sediment budget over time.

Coastal hazard assessment

Developing an understanding of existing coastal processes and hazards is a complicated process because of the range of different physical and temporal scales and the interaction of positive and negative feedbacks in the coastal system. Quantifying how the retreat and advance of coastlines will be influenced by climate change is even more challenging.[29]

The level of assessment required will depend upon the available level of information and developed knowledge for the study area, as well as the value of assets at risk and the available budget. For example, when looking at coastal inundation, broad assessments can be made using existing information, which may be available from a regional or state-wide assessment,[43] and relatively simple assessment techniques such as 'bath-tub' inundation modelling, in which a constant rather than time-varying water level is used. This may provide an overall first impression of the possible effects at a broad scale. Alternatively, a more sophisticated approach using a combination of field investigations and modelling could be used to quantify the existing coastal hazards. This would be the recommended approach in areas where the consequences are more significant and a greater understanding of the hazard is required.

As extreme events are caused by a number of variables (storm surge, tide, wave height and rainfall) a consideration of the contribution of these factors needs to be taken into account. Conventional practice for coastal hazard assessments is to consider the effects of a 1% AEP event. This is typically applied to storm tide and wave events. However, some allowance for a large catchment flow from heavy rainfall may also be useful. For example, Table 8–3 combines the 1% AEP storm surge and wave height with 10% AEP catchment flows.

While the Victorian Coastal Strategy specifies 0.8 m of sea level rise by 2100 as the minimum to be considered, a range of possible future sea levels could be usefully considered to understand how they would affect the coastal hazard risk. Consistency with the Strategy is maintained by using the applicable sea-level rise projection, providing that the projection (for a given planning period) drawn from the same A1FI scenario from which the policy is drawn (see Figure 6–2a).

These sea levels can be assigned to a planning period based on the best available predictions, to enable a time-based assessment of hazards. For example, from the IPCC's A1FI scenario the following levels could be used to assess the effect of climate change on coastal hazards and the sensitivity of the system to changes: 0.2 m, 0.5 m, 0.8 m, 1.1 m and 1.4 m (see Figure 6–2). As an absolute minimum, the existing coastal hazard (i.e. with no sea-level rise included) and the effects of an 0.8 m sea level rise should be assessed.

While there have been significant advances in modelling techniques and our understanding of coastal processes, there is often insufficient data or knowledge for a particular system or cell to quantify the potential long-term effects. Often predictions of the potential effects of climate change on erosion have relied upon simple equilibrium models that produce a landward translation of the coastal profile based on an increase in water level. The most commonly applied method is the Bruun Rule and its variants (see Box 7–1).

Any assessment of the effects of climate change can provide only broad estimates of the hazard potential in a particular area, so an acknowledgement of the assumptions and uncertainty must be clearly stated. The degree of uncertainty in hazard assessment can be reduced by improving the understanding of the coastal cell and the existing causes of coastal change.

8.3.4 c Coastal hazard mapping

The output of a coastal hazard assessment should be a set of coastal hazard maps for the planning period. The coastal hazards should be mapped for the sediment compartment and show at least the following information:

- the landward extent of foreshore erosion for a present-day designated storm event (see Table 8–3), including the landward extent of any zone of reduced foundation capacity associated with this designated event at present
- the extent of oceanic inundation at present, including storm surge computation, wave set-up, wave run-up and dune overtopping and, where relevant, flood extent from an adjacent estuary or catchment
- the impacts of future climate change, based on the time period for the study and the intervals for assessment, as set out in Table 8–3
- consideration of uncertainty or safety factors based on the adequacy of available data and the existing knowledge of processes and effects.

The need for expertise on the part of the person undertaking this assessment cannot be over-emphasised. While the numerical models are a useful and powerful tool for testing the outcomes, they do not provide a definitive and automated methodology. Of particular concern is the lack of field data for the calibration and verification of the models at the location, and the implications of impacts as the processes change over time.

8.3.5 Stage 4: Risk evaluation

Because risk is the product of a hazard and a consequence, coastal hazard maps are used to identify the likelihood of a hazard during the planning period and to assist in the quantification of the consequences on the attributes of concern (e.g. health and safety, social, economic, environmental).

The purpose of risk evaluation is to make decisions about what risks need treatment, and the treatment priorities, based on the outcomes of the risk analysis. Risk evaluation involves comparing the level of risk found during the analysis with the risk criteria. Decisions that need to be evaluated include:

- whether a risk needs treatment (see Section 8.3.6)
- whether an activity should be undertaken
- priorities for treatment.

Decisions should take into account the wider context of the risk and include the tolerable risk, or the level of risk that individuals or the community are prepared to 'tolerate' under certain circumstances in return for a specific benefit.

A common approach is to divide risk into three bands:

- **upper band** — adverse risks are intolerable and risk reduction measures are essential
- **middle band** — costs and benefits are taken into account and opportunities balanced against potential adverse consequences
- **lower band** — positive or negative risks are negligible, or so small that no risk treatments are needed.

These bands can be then used in an approach to risk called 'As Low As Reasonably Practical' (ALARP), as shown in Figure 8–4. Stakeholders often have different perceptions of tolerable and intolerable levels of risk, depending on their familiarity with the risk, their trust in the effectiveness of the existing risk management, and their perceptions of the risk and benefits.

The same risk may seem negligible to one stakeholder but very high to another. The definition of what risks are tolerable must therefore involve effective consultation and communication with all stakeholders.

For example, in terms of the risk matrix in Table 8–4 the lower band may be characterised by low risk and the upper band by extreme risk, while medium and high risk items are classified in the middle band.

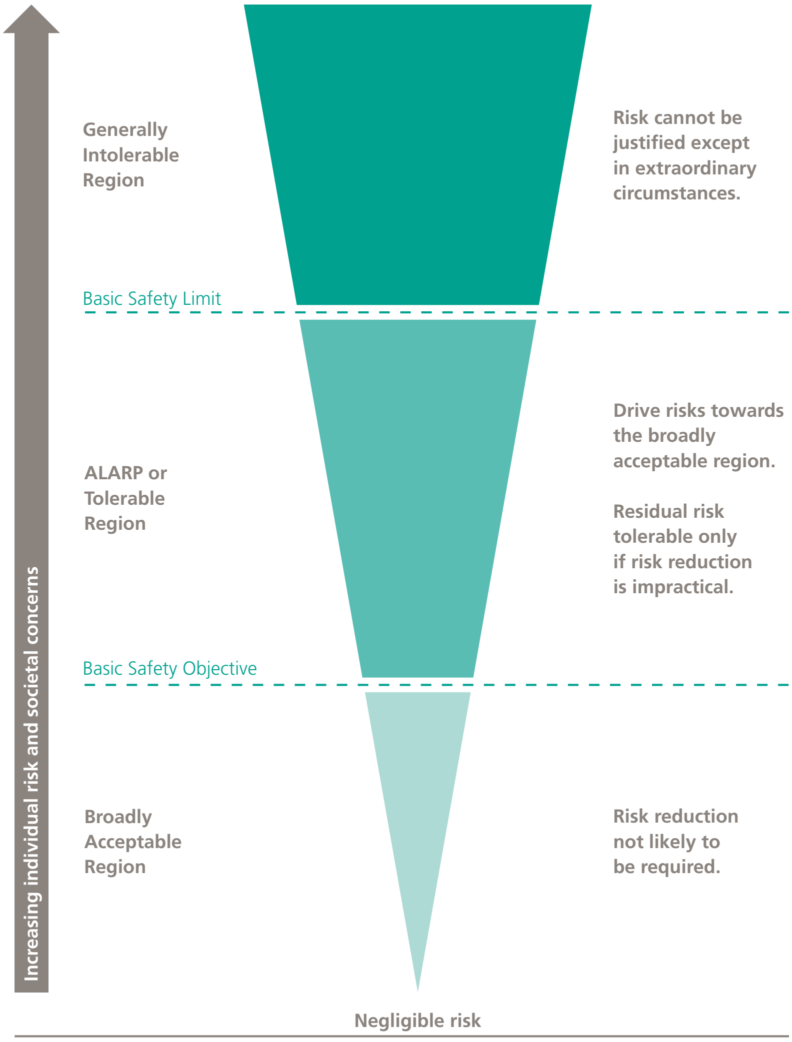


Figure 8–4 The ALARP principle.[48]

8.3.6 Stage 5: Risk treatment

The final stage in the coastal hazard risk assessment and management assessment relates to how to respond to the coastal hazard risk. This section provides guidance on how both existing and future coastal hazards may be addressed to assist in decision-making once the cause of the risk is understood. Risk treatment, like risk assessment generally, is context-specific — actions that are appropriate and effective for reducing risks in one situation may not be appropriate in other circumstances.

The key advantages of risk management is that it:

- encourages the explicit recognition of uncertainty in the decision-making process
- provides a common approach to comparing different responses to uncertainty
- facilitates the assessment and positive management of unwanted outcomes. [34]

8.3.6 a Principles of adaptive management

Adaptation is about enhancing the capacity to adapt to coastal hazards and the future effects of climate change by minimising, adjusting to, or taking advantage of the consequences. This approach supports the guiding principles of the Victorian Coastal Strategy (see Section 3.6).

A key part of this process is to ensure that flexibility is incorporated into the process to help deal with changing risks and uncertainties. This adaptive management approach is illustrated in Figure 8–5. This figure shows that without some form of action the level of risk from coastal hazards and climate change is likely to increase. Conversely, the level of risk can be significantly reduced if the precautionary approach is applied now to take into account the potential for climate change effects that may occur at some time in the future. However, this may provide an unnecessarily conservative approach to the management of the risks associated with the hazard. The adaptive management approach is based on understanding the tolerance to risk and having some treatments or actions that would be implemented if the decision or trigger point was reached. These treatments or actions would be carried out over time to maintain the level of risk within the tolerable bounds.

This form of adaptive management should be part of a considered response to coastal hazards, climate change and risk. It requires a clear understanding of the tolerable level of risk, and the interventions or actions to be implemented to address risks once the risk exceeds that level. In this way cost-effective and timely management of coastal hazards can be achieved.

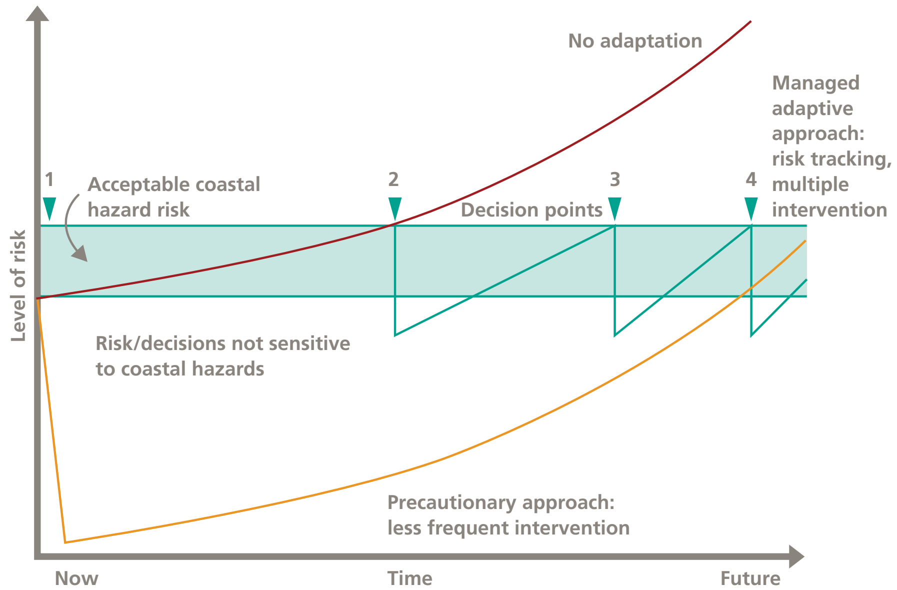


Figure 8–5 Approaches to adaptation and their effect on the level of risk over time. Source: adapted from Donovan et al. (2004).[44]

The key principles for adaptation include:

- understanding existing risks and vulnerability to coastal hazards and climate change, and their critical thresholds
- identifying the most adverse hazard or combination of hazards, and focus on actions to manage the most vulnerable areas
- recognising the value of no-regrets, low-regrets and win–win adaptation options
- iterative decision making by evaluating the results and adjusting actions on the basis of what has been learned
- avoiding actions that will make it more difficult to cope with coastal hazards and climate risk in the future.[29]

8.3.6 b Principles for managing coastal hazard risk

Coastal hazards and climate change adaptation require the evaluation of options against social, economic and environmental criteria relating to their implementation costs, the benefits of mitigating the risk, and the effects on local and off-site natural or built assets.

There is no single area of risk management that will provide a comprehensive solution to managing coastal hazard risk. Coastal hazard risk management will require a comprehensive approach with a range of management approaches that may include acceptance, avoidance, reduction, sharing and transfer. Plans that include adaptation principles are likely to be the most effective in providing long-term sustainable management. Adaptation has been, and continues to be, an integral part of how nature and humans develop and evolve in response to change.

The accepted order of effectiveness in managing risk is: avoidance, reduction, sharing, transfer (Figure 8–6). The following sections describe each of these options, but in coastal hazard management a combination of all four is usually required. A key consideration in finding the most effective solution is the time-scale; that is, when implementation is required.

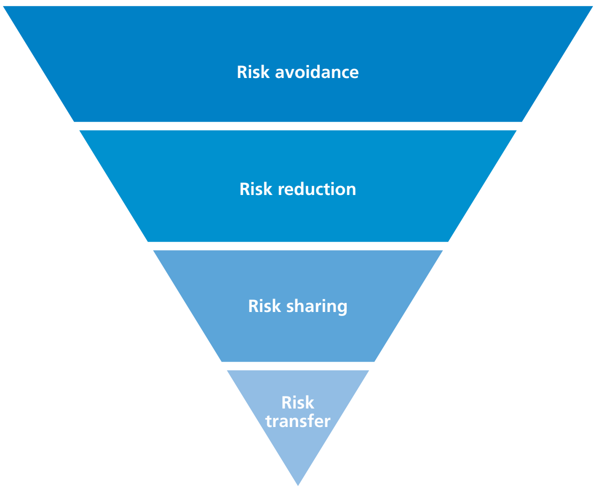


Figure 8–6 Relative contribution of risk management activities.

8.3.6 c Risk avoidance

Risk avoidance means deciding not to start or continue an activity that is at risk from a coastal hazard. This can include taking a precautionary approach to planning new development, infrastructure or services to avoid coastal hazards. It is the most effective and sustainable long-term approach to managing risk.

A coastal hazard assessment for risk avoidance delineates the area of risk; that is, the spatial and temporal extent with regard to erosion/recession, and levels and extent in terms of inundation.

While most easily undertaken in undeveloped coastal areas because of the fewer numbers of stakeholders and conflicting issues, risk avoidance can be undertaken in partially or fully developed areas. It may be possible, for example, to relocate key infrastructure assets at the end of their natural design life. However, in many areas it may be impractical to rely solely on risk avoidance, and a mix of risk avoidance, risk reduction, risk sharing and risk transfer may need to be considered.

8.3.6 d Risk reduction

Risk reduction can be achieved by either reducing the impact of hazards or the consequences of the hazard. In the past the most common method of risk reduction was to build coastal protection structures such as seawalls or coastal flood barriers to mitigate or prevent the effects of coastal hazards on the assets at risk.

Coastal protection works

Coastal protection works are typically used to maintain the shoreline at a certain position. Many of the historical erosion and inundation works have provided discrete protection for a short time, but in Europe it has been found that their longer-term effectiveness has mostly been unsatisfactory and has often resulted in a 'domino effect' of progressive hard protection works.[43] Coastal protection works tend to:

- be reactive
- be rarely the most effective or sustainable long-term option
- lead to a false sense of future security that can often result in increased coastal hazard risks, with intensification of development in the landward area (i.e. increased consequences)
- lead to other environmental damage, and impacts on other coastal values, such as downdrift erosion as a result of a structure that reduces the movement of sediment along the coast
- lead to an expectation that defence will be maintained in perpetuity.[29]

However, coastal protection works can provide time for other forms of coastal management to be implemented.

Soft engineering approaches

Soft engineering, such as dune and beach nourishment and the restoration of mangroves and seagrass beds as wave breaks, can be an alternative to coastal protection works in managing the effects of erosion/recession and inundation. This approach requires a good understanding of the coastal cell and the processes operating within it, and may not be successful or cost-effective at all locations.

Planning and regulatory controls

Alternative methods, such as planning and regulatory controls that limit the consequence of the hazard, are another way of reducing risk. These controls can include:

- planning and building regulations
- financial mechanisms
- long-term infrastructure planning.

Planning and building regulations can control and limit both future development and the redevelopment of existing uses in identified hazard areas by changing zoning and rules in planning documents. Planning can be used to implement the strategy of planned retreat in vulnerable areas over periods of decades.

Planned retreat is the strategic decision to withdraw, relocate or abandon private or public assets. This could occur at a number of scales, including:

- individual property changes, such as raising a building above a particular flood level or relocating a dwelling on an existing property
- partial or complete relocation of settlements or infrastructure.

Planned retreat requires careful consideration and the involvement of stakeholders, and should be seen as a long-term rather than short-term process. Effective planned retreat is likely to require:

- careful consideration of existing use rights
- planning regulations
- key infrastructure relocation
- property title covenants
- financial instruments
- insurance incentives or disincentives.

8.3.6 e Risk sharing

Risk avoidance and risk reduction measures will not remove all coastal hazard risk. The remaining risk may be managed by risk sharing, which involves stakeholders bearing or sharing some or all of the risk. In coastal hazard management this is likely to include information and education about the risks.

8.3.6 f Risk transfer

The last form of risk management involves transferring the risk. This could mean accepting and living with the residual risk, transferring the risk to other areas where the consequences are lower — for example, by allowing land to flood but containing the floodwater to prevent flooding elsewhere — or dealing with any associated consequences through emergency management or insurance.

8.3.7 Monitoring and review

Ongoing monitoring and review is essential to ensure that the selected risk treatment option remains relevant and appropriate. Factors such as new knowledge about climate change, improved understanding of physical systems and processes, or changes in land use may affect the likelihood and consequences of a selected treatment.

Monitoring and review also enables lessons learnt from the risk management process to inform revisions to the risk management assessment.

Monitoring should be carried out:

- to improve the knowledge of physical systems and processes
- to monitor the rate and effect of climate change
- in areas of high risk
- to document extreme events
- to assess the performance of the risk treatment approach.

In Victoria there is a general lack of reliable historical data on shoreline movement and coastal processes. The methodical collection of high-quality information (including wave data) to better inform and verify subsequent coastal hazard assessments would be useful. Similarly, measurements of erosion and flood levels should be carried out after extreme events to enable ground-truthing of values used in the coastal hazard assessment.

Physical system and process monitoring may include physical measurements and site-specific studies. The rate and effect of climate change is typically monitored and reported by organisations such as IPCC and CSIRO. Keeping up-to-date with predictions about climate change and its effects will be required to keep the risk assessment current.

9 Closing summary

Coastal processes are highly variable and complex, and their impact on the coastal zone has been very difficult to predict with any certainty. The effect that a changing climate may have on these processes further compounds the complexity and reduces certainty when projecting what shape and form our coastline will take in the future.

The risk management process provides a framework that can be used to examine the likelihood and ramifications of a specified coastal hazard event occurring and the possible response options, while accounting for local factors, stakeholder input, complexity and uncertainties.

The risk management process results in a methodical and transparent best-practice process for identifying and validating a particular course of action or decision.

The information in this Guide intentionally sets out 'what to consider' rather than 'how to consider'. This approach recognises the diversity of the needs of users, the situational nature of the problems being addressed and the essential role of qualified coastal experts (e.g. coastal engineers, coastal geormorphologists and hydrologists).

Depending on the level of knowledge of the person using the Guide, it may be advantageous to engage the services of a qualified coastal expert at any or all stages of the coastal hazard risk assessment.

Coastal hazard risk assessments can theoretically be undertaken to consider risks down to the scale of one residential block or equivalent. However, assessments undertaken for larger geographical areas are usually more cost-effective and useful because of the greater ability to strategically consider the various risk-treatment options and incorporate adaptive management principles.

The Victorian Coastal Council, in its report *Emerging Scientific Issues on Victoria's Coast: 2011 Update*, has highlighted the need to further increase the capability of coastal managers to understand how the coastline responds to climate variability, including extreme events, by enhancing their scientific understanding and providing tools (including monitoring).[45] The Guide forms a valuable first step in responding to this identified need and a foundation from which further work can progress.

Left:
Rye Foreshore and Pier, Port Phillip Bay (Photo: Werner Hennecke)

10 Useful links

The following is a limited selection of links for further reading, generally aligned with the sections of the Guide.

Section 3	
Department of Planning and Community Development Urban and Regional Research	www.dpcd.vic.gov.au/home/publications-and-research/urban-and-regional-research/Regional-Victoria
Department of Planning and Community Development Coastal Planning	www.dpcd.vic.gov.au/planning/plansandpolicies/coastal-planning-in-victoria
Department of Climate Change and Energy Efficiency: Australia's coasts and climate change	www.climatechange.gov.au/climate-change/australias-coasts-and-climate-change.aspx
National Sea Change Taskforce	www.seachangetaskforce.org.au/Home.html
Victorian Coastal Council	www.vcc.vic.gov.au/
Western Coastal Board	www.wcb.vic.gov.au/
Gippsland Coastal Board	www.gcb.vic.gov.au/
Central Coastal Board	www.ccb.vic.gov.au/
Coastlinks Victoria	www.coastlinks.vic.gov.au

Sections 4 and 5	
OzCoasts (includes Smartline)	www.ozcoasts.gov.au/
Oz estuaries Online GIS	www.ga.gov.au/meta/ANZCW0703005721.html
US National Oceanic and Atmospheric Administration: Ocean and Coastal Resource Management	coastalmanagement.noaa.gov/welcome.html
Woods Hole Oceanographic Institution	www.whoi.edu/
European Commission: Integrated Coastal Zone Management	ec.europa.eu/environment/iczm/home.htm
US Army Corps of Engineers: Coastal Engineering Manual	www.usace.army.mil/Home.aspx
US Army Corps of Engineers, Coastal & Hydraulics Laboratory: Glossary	chl.erdc.usace.army.mil/glossary
CSIRO Coastal Research Web Portal	coastalresearch.csiro.au/

Section 6	
IPCC	www.ipcc.ch
Bureau of Meteorology: Australian Baseline Sea Level Monitoring Project	www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml
Australian Academy of Science	www.science.org.au/policy/climatechange.html
Antarctic Climate and Ecosystems Cooperative Research Centre	www.acecrc.org.au/
Centre for Australian Weather and Climate Research (partnership between CSIRO and BoM)	www.cawcr.gov.au/
CSIRO Sea Level Home	www.cmar.csiro.au/sealevel

Section 7	
Future Coasts (including CSIRO Extreme Sea Level Studies)	www.climatechange.vic.gov.au/adapting-to-climate-change/future-coasts
DSE Coasts and Marine	www.dse.vic.gov.au/coasts-and-marine/coasts

Section 8	
Victorian Managed Insurance Authority	www.vmia.vic.gov.au/
Risk Frontiers Natural Hazards Research Centre	www.riskfrontiers.com/index.htm
NOAA Coastal Services Centre: Roadmap for Adapting to Coastal Risk	www.csc.noaa.gov/digitalcoast/training/roadmap/index.html
Engineers Australia: Coastal and Ocean Engineering	www.engineersaustralia.org.au/coastal-ocean-engineering
Standards Australia	www.standards.org.au/

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12 Glossary

adaptation — Adjustment in natural or human systems in response to actual or expected climate change or its effect, which moderates harm or exploits beneficial opportunities.

adaptation, low-regrets — Adaptation options in which moderate levels of investment increase the capacity to cope with future climate risks.

adaptation, no-regrets — Adaptation options (or measures) that would be justified under all plausible future scenarios, including the absence of human-induced climate change.

adaptive capacity — Ability of a human or natural system to adapt, i.e., to adjust to climate change, including to climate variability and extremes, prevent or moderate potential damages, take advantage of opportunities, or cope with the consequences.

astronomical tide — The periodic rise and fall of the water of oceans, seas and bays caused by the gravitational interactions between the Earth, Moon and Sun.

Australian Height Datum (AHD) — The level (adopted by the National Mapping Council of Australia) to which all heights for topographic mapping are to be referred.

average return interval (ARI) — A measure of risk used by engineers and insurers to describe the average time between events of a given magnitude. For example, a 1-in-100 year event has a 1 per cent probability of occurring in any given year.

bathymetric data — Measurements of the depth of a body of water.

Bruun Rule — A commonly used method for estimating the response of a sandy coast to rising sea levels.

climate change — A change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

coast — A strip of land that extends from the coastline inland to the first major change in landforms that are no longer influenced by coastal processes.

coastal accretion — The accumulation of beach sediments. Continued accumulation of sediments allows the coastline to prograde (advance seawards).

coastal erosion — Short-term retreat of sandy shorelines as a result of storm effects and seasonal climatic variations.

coastal flooding — Flooding of low-lying areas by ocean waters, caused by a higher than normal sea level.

coastal hazards — The collective term for inundation, coastal erosion and coastal recession.

coastal processes — Marine, physical, meteorological and biological activities that interact with the geology and sediments to produce a particular coastal system.

coastal protection works — Engineering works to prevent erosion or recession; includes hard protection works that armour the beach such as concrete and rock seawalls, groynes and artificial reefs that encourage the accumulation of sand on the coast, and sand nourishment to artificially replenish sand lost from the shore.

coastal recession — Progressive and ongoing retreat of the shoreline caused by an imbalance in the sediment budget.

coastal zone — The coastal waters and land within five kilometres of the coast or below the Australian Height Datum of 10 metres, whichever is farther inland.

coastline — Generally, the line forming the boundary between the land and the water.

consequence — The outcome of an event, expressed qualitatively in terms of the level of impact.

CSIRO — Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency.

diurnal tide — A tide with a period of approximately 24 hours; that is, with one high water and one low water in 24 hours.

East Coast Lows — Intense low-pressure systems that occur off the eastern coast of Australia, bringing storms and heavy rains to southern Queensland, New South Wales and eastern Victoria.

El Niño Southern Oscillation (ENSO) — A year-to-year fluctuation in atmospheric pressure, ocean temperatures and rainfall associated with El Niño (the warming of the oceans in the equatorial eastern and central Pacific). El Niño tends to bring below-average rainfall.

geomorphology — The scientific study of landforms, including their origin and evolution.

HAT — Highest astronomical tide. The highest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. HAT will not be reached every year, and it is not the most extreme sea level that can be reached because storm surges can add an additional component to sea level.

Inter-decadal Pacific Oscillation (IPO) — An irregular inter-decadal sea-surface temperature in the Pacific Ocean that modulates the strength and frequency of the El Niño Southern Oscillation (ENSO); also known as the Pacific Decadal Oscillation (PDO).

inundation — The incursion of ocean water onto low-lying land that is not normally inundated, during a high sea level event such as a storm tide or king tide.

king tide — Any high water level well above average, commonly applied to the two spring tides that are the highest for the year—one during summer and one in winter.

La Niña — The opposite state to El Niño, occurring when the SOI is positive. La Niña tends to bring above-average rain over much of Australia.

likelihood — A qualitative or quantitative measure of the probability or chance of something happening.

longshore — Parallel to the coast; used particularly in relation to the movement of sand and currents along the coast, or sand bars aligned parallel to the coastline.

lowest astronomical tide (LAT) — The lowest tide level predicted to occur under any combination of astronomical conditions.

macro-tidal coast — A coast with a maximum spring tidal range of over 4 metres.

mean water level — A tidal level reflecting the average surface level of a body of water; used mainly in the areas with little or no tidal range.

mean sea level — The arithmetic mean of hourly heights of the sea at a tidal station observed over a long period of time.

meso-tidal coast — A coast with a maximum spring tidal range of 2–4 metres.

micro-tidal coast — A coast with a maximum spring tidal range of less than 2 metres.

MHHW — Mean higher high waters. For locations that experience semi-diurnal tides, MHHW is the mean (over a long period of time) of the higher of the two daily high tides.

MHWN — Mean high water neaps. The height of mean high water neaps is the average throughout the year of two successive high waters during those periods of 24 hour when the range of the tide is at its least.

MHWS — Mean high water springs. The height of mean high water springs is the average throughout the year of two successive high waters during those periods of 24 hours when the range of the tide is at its greatest.

MLHW — Mean lower high waters — For locations that experience semi-diurnal tides, MLHW is the mean (over a long period of time) of the lower of the two daily tides.

neap tide — A tide of unusually small range occurring semi-monthly around the times of the first and last quarters of the Moon.

near-shore — The area of ocean close to the coast that is affected by waves, tides and longshore currents.

overtopping — Waves or water going over the top of coastal structures or landforms.

precautionary principle — The principle, as defined in Principle 15 of the Rio Declaration (1992) by the United Nations Conference on Environment and Development, that 'Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.'

risk — The effect of uncertainty on objectives. An effect is a deviation from the expected, positive and/or negative. An objective can have different aspects such as financial, health and safety and environmental. Risk is often characterised by reference to events and consequences. Risk is often expressed in terms of a combination of the consequences of an event and the likelihood of occurrence.

sand nourishment — The artificial placement or pumping of sand within a coastal system to encourage the build-up of the coast and protection against coastal erosion.

sea-level rise — An increase in the mean level of the oceans. Relative sea-level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be caused by the ocean rising, the land subsiding, or both. In areas subject to rapid land-level uplift (e.g. in seismically active areas), relative sea level can fall.

semi-diurnal tide — A tide with a period of approximately 12 hours; that is, two high waters and two low waters in 24 hours.

significant wave height — The average of the highest one-third of the waves in a given wave group.

south-east trade winds — The prevailing winds that blow persistently from the south-east towards the equator in the southern hemisphere.

Southern Oscillation Index (SOI) — The normalised mean atmospheric pressure difference between Tahiti and Darwin, measured at sea level. The SOI is negative during El Niño and positive during La Niña.

spring tides — Tides of increased range occurring semi-monthly near the times of full moon and new moon.

still water level — The level that the sea-surface would assume in the absence of wind waves (not to be confused with mean sea level or mean tide level).

storm surge — A temporary increase in the height of the sea at a particular location because of extreme meteorological conditions (low atmospheric pressure, strong winds, or both). The storm surge is the excess height of water above the level expected from tidal variation alone at that time and place.

storm tide — An abnormally high water level that occurs when a storm surge combines with a high astronomical tide. The storm tide level must be accurately predicted to determine the extent of coastal inundation.

swash zone — The zone of wave action on the beach, which moves as water levels vary, extending from the limit of run-down to the limit of run-up.

swell waves — Ocean waves that travel beyond the area where they are generated.

tropical cyclone — Intense low-pressure system in which winds of at least 63 kilometres per hour whirl in a clockwise direction (in the southern hemisphere) around a region of calm air (eye).

uncertainty — The state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood.

vulnerability — The degree to which a system is susceptible to adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

wave set-up — The rise in the water level above the still water level when a wave reaches the coast. It can be very important during storm events as it results in a further increase in water level above the tide and surge levels.

wave run-up — The vertical distance (above the mean water level) reached by a wave after it breaks on a shore.

wind waves — Ocean waves resulting from the action of the wind on the surface of water.