Victoria's Resilient Coast

Coastal Hazards Extended Guideline

Department of Energy, Environment and Climate Action

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FOREWORD

Victoria has over 2,500km of coastline that Traditional Owners of Country have nurtured for countless generations. Today, Victoria's coastline is of high cultural, social, environmental, and economic value, and is celebrated as a place to live and visit. At times, coastal processes including erosion, inundation, and other physical/chemical processes, may have a negative impact on coastal values and uses. When this occurs, we often refer to these processes as coastal hazards. Factoring in climate change, coastal hazards are likely to intensify, for example increased erosion from more frequent extreme weather events, and permanent inundation posed by sea level rise.

While coastal processes are well understood, it is hard to predict when these impacts will occur or the impact they may have on specific localities in the future due to the complexity of interactions. This guide provides an overview of key information to assist in coastal hazard adaptation planning and is a supporting Module to Stage 3 of Victoria's Resilient Coast guidelines (DEECA, 2023) and updates the former 2012 Victorian Coastal Hazard Guide.

Geomorphic and coastal processes are described through the broad settings and processes relevant to the Victorian coastline, including distinctive coastal compartments and landforms which make Victoria's coastline diverse. These include a range of shoreline classes, such as rocky coasts, sandy and muddy shorelines, estuarine environments, and engineered coastlines. This sets the basis to understand the different types of coastal environments vulnerable to coastal hazards.

Understanding the physical processes occurring in coastal environments is important to adequately plan for coastal hazards. This includes climate variables and patterns such as wind, air pressure and rainfall, and ocean systems such as waves, currents, water levels, sea surface temperature and salinity.

To take a consistent approach to coastal hazard adaptation planning across the State, clear definitions of the coastal hazards relevant to Victoria are provided in this guide. These are categorised as erosion and inundation hazards, changes in estuary or offshore sediment dynamics, and other hazards such as saline intrusion. The mechanisms of these hazards and the shoreline classes most vulnerable to each is detailed to provide a focus for localities, depending on the type of coastal environments present.

While understanding the mechanisms of physical processes and hazards is essential, population pressures through in-migration and the 'sea change' phenomenon occurring in coastal areas also adds pressure on infrastructure and development, as well as increasing the number of people potentially exposed to coastal hazards. Additionally, climate change is exacerbating the rate of change in coastal areas, with increased frequency and intensity of extreme weather events and sea level rise. Considering these drivers of change is important to shape adaptive planning outcomes and adequately plan for the future.

This guideline also provides a section dedicated to assist those undertaking hazard assessments with specific data requirements. A data assimilation and list of example custodians is provided by specialist subject area, these are classified under Land and Ocean Survey and Imagery, Geology and Geomorphology, Oceanographic and Coastal Processes, Environmental and Climate, Catchment and Stormwater Inundation, Groundwater, and Assets and Infrastructure.

Lastly, best practice approaches are summarised to give readers an overview of what localised and regional studies can be undertaken to assess coastal hazard risks to be fit for purpose of coastal settlements. This includes commentary on scale and complexity, identifying relevant shoreline classes, hazards and values, event likelihood, planning horizons and uncertainty. This understanding provides a consistent foundation for coastal hazard adaptation planning for our Victorian marine and coastal environments.

CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This guide is intended to improve understanding of the marine and coastal environment, coastal processes and the associated coastal hazards in Victoria and provide a consistent basis for which risk-based assessments of coastal hazards can be undertaken in accordance with *Victoria's Resilient Coast – Adapting for 2100+* guidelines (DEECA 2023, formerly DELWP), and adaptation planning progressed.

Natural processes such as erosion and inundation continually shape our diverse and dynamic coastline. When these processes may have an adverse impact on environmental, cultural, social and economic values along the coast, we refer to them as coastal hazards.

The guide focuses on the following types of defined coastal hazards throughout Victoria:

- Erosion hazards:
  - Hard rock cliffs with and without a beach;
  - Soft rock cliffs with and without a beach;
  - Low-earth scarp; and
  - Sandy shorelines.
- Inundation hazards:
  - Permanent inundation; and
  - Storm tide inundation.
- Estuary dynamics:
- Off-shore sediment dynamics; and
- Saline intrusion of freshwater aquifers.

This guide has been developed to support *Victoria's Resilient Coast – Adapting for 2100+ framework and guidelines* (DEECA 2023), which provide a strategic approach to coastal hazard risk management and adaptation. This extended guideline has been informed by the collaborative process underpinning the development of Victoria's Resilient Coast, and is a resource for all who have a role in managing and caring for the coast.

This guide includes an overview of the physical character of the Victorian coast and key coastal land forming processes as a basis for identifying the how the coastal environment behaves and interacts with identified economic, environmental, social and cultural values.

1.1 Who will use this 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 environment will find Sections 4 and 5 of the guide useful.

Coastal practitioners such as coastal public land managers, urban planners, public infrastructure providers, local governments and consultants who are seeking guidance on what to consider when identifying and assessing coastal hazards are likely to find Sections 2, 6 and 7 more relevant for their purposes.

1.2 How to use this guide

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

Table 1-1 How to use this guide

Section	Title and overview	Purpose
2	**Geomorphic Setting** Summarises the different types of coastline in Victoria including geomorphic processes, coastal compartments and shoreline classes.	Background context Informs approach and scope for place-based hazard assessments and adaptation planning
3	**Physical Coastal Processes** Describes physical process mechanisms driving change along Victoria's coastline, including climate variables, winds, waves, currents and tides.	
4	**Coastal Hazard Definitions** Clear definitions of the coastal hazards relevant to Victoria.	
5	**Key Drivers of Change** Describes other factors such as climate change, population pressures and governance frameworks that help to shape adaptive planning outcomes and adequately plan for the future. Explains the effect of climate change on coastal hazards.	
6	**Coastal Hazard Data and Information** Provides a list of specialist contemporary data sources from a variety of example custodians and organisations.	Assists you to scope technical assessments, adaptation needs, and make decisions
7	**Best Practice for Adaptation Planning** Provides guidance on best practice hazard assessment approaches and principles, including planning horizons, scenarios, and technical methods.	

2 GEOMORPHIC SETTING

This section outlines the broad coastal features, key coastal types and process characteristics of the Victorian coast. The aim is to identify distinctive coastal compartments across Victoria where different coastal processes and coastal hazards apply.

2.1 Nature of the Victorian Coast

2.1.1 Diverse Landscape Setting

The Victorian coast extends over 2600 km from Cape Howe in the east to Cape Nelson in the west consisting of a varied physical environment. The open coastline is typically a high wave energy coast but there is substantial variation determined by shoreline orientation and coastal bathymetry. The eastern and western coastlines have a narrow continental shelf and experience more extreme wave conditions than the central coast (Cape Otway to Lakes Entrance) where wave conditions are reduced somewhat by King Island, Tasmania, Flinders Island and the shallower waters of Bass Strait.

Victoria's open coast is characterised by an alternation of hard and soft rock cliffs and sandy shorelines exposed to high energy ocean swell, whereas the bays, numerous estuaries and tidal lagoons are significantly less exposed. Victoria's semi-enclosed coastal embayments, lagoons and estuaries include a variety of soft shoreline types e.g., mangroves and salt marsh not generally found on the open coast. Figure 2-1 shows the variation in Victoria's open coastline and total length of each shoreline class.

Sea level has been around its current elevation (±1.5 m) over the past 6000 years, and it is over this period that coastal processes have formed and re-shaped the sandy coastlines and some of the soft-rock cliffs of today.

2.1.2 Geology

Victoria's coastal geology comprises rocks ranging in age from the Cambrian age igneous and sedimentary complex at Waratah Bay (formed 580 million years ago) to widespread unconsolidated Pleistocene and Holocene dune systems and estuarine sediments emplaced over the last 10,000 years (Figure 2-2). Much of the Victorian coastline has been influenced by tectonic activity initiating uplift and subsidence and all the present coast has experienced short-term and long-term sea level changes.

Landscapes associated with tectonic activity include the elevated Otway Ranges, Mornington Peninsula, and Strzelecki Ranges, and the subsidence depressions of Port Phillip, Western Port and Corner Inlet.

Setting / shoreline class	Total Length (km)	%
Sandy shorelines	1002	38%
Low earth scarp shorelines	138	5%
Hard rock cliffs with platform and/or beach	528	20%
Soft rock cliffs with platform and/or beach	144	5%
Estuarine and tidal channels	671	25%
Engineered coastline	160	6%

Figure 2-1 Shoreline Classes of Victoria

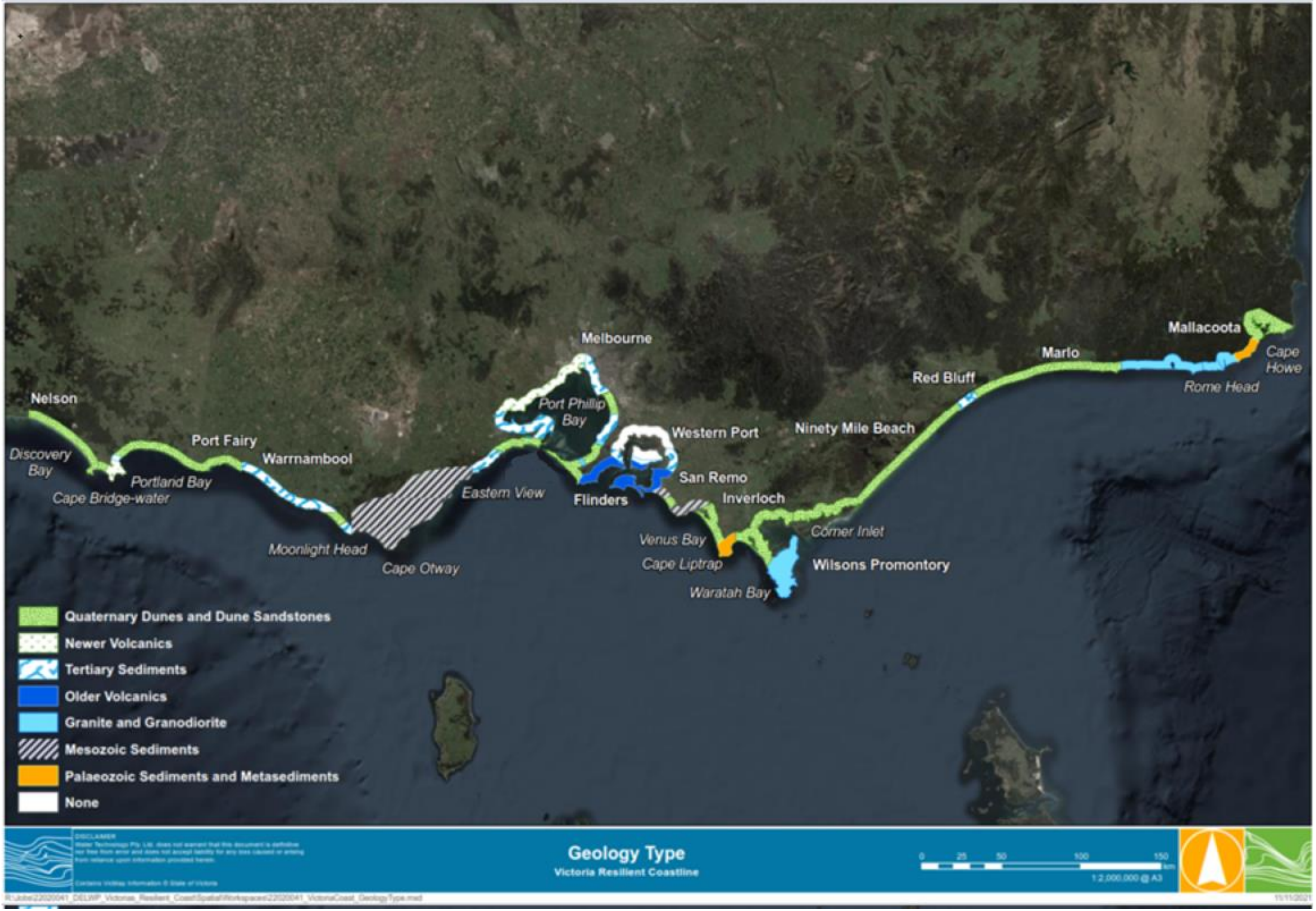


Figure 2-2 Geology of Victorian Coastline Defining the Geomorphic Setting – Coastal Delineation

2.1.3 Diversity of Shoreline Classes

Victoria's coastal landforms include a variety of geomorphological features that continue to evolve as a result of interactions between geological factors and coastal processes such as ocean swell, storm surge, currents, prevailing wind, changing sea levels and tidal movement. The coastline is in constant flux. What at present appears to be a stable beach, for example, may have changed considerably over the longer time scales as what we see is but a single point in time in the ongoing development of the physical character of the coast.

Table 2-1 Shoreline Classes

Setting / shoreline class		Total Length (km)	% of shoreline*
Sandy shorelines	Beaches are formed from a combination of terrestrial and marine-derived sediments. In Victoria, sandy shorelines cover extended sections of the open coast, as well as smaller pocket or compartmentalised beaches.	1002	38%
Low earth scarp shorelines	Low earth scarp shorelines or 'muddy' coasts are typically restricted to the low-energy environments of large bays and consist of low cliffs and scarps, intertidal flats consisting of silty sand or peat materials, often colonised by mangroves, seagrasses or saltmarsh vegetation.	138	5%
Hard rock cliffs with platform and/or beach	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 estuarine areas.	528	20%
Soft rock cliffs with platform and/or beach		144	5%
Estuarine and tidal channels	Over 100 streams enter the sea either via estuaries and tidal channels. Around 85% of Victoria's estuaries are Intermittently Closed and Open Lakes and Lagoons.	671	25%
Engineered coastline	Some sections of the coast have been significantly modified over time by with the use of infrastructure – seawalls, drains, groynes.	160	6%
Coastal floodplains	Coastal floodplains include all low-lying coastal areas which may be prone to inundation and may experience seawater incursion during an elevated water level event such as king-tide or be vulnerable to permanent inundation under different sea level rise scenarios.	N/a	N/a
Off-shore environments	The off-shore environment includes the bed beyond the intertidal zone up to three nautical miles, or 5.5 kilometres off-shore.	N/a	N/a
**Statistics based on DEECA and National Smartline tool datasets*			

2.2 Defining the Geomorphic Setting

2.2.1 Purpose and Approach

The purpose of characterising coastal geomorphology is to define the composition and origin of the nearshore, foreshore and backshore materials as the basis for assessing past and contemporary physical processes and inform technical assessments of future change.

Defining the geomorphic setting involves understanding and defining the landscape geology, shoreline classes and coastal compartments:

- **Landscape geology** – the broad landscape context within Victoria, including geology, formational processes / age of major coastal landforms.
- **Shoreline class -** is based on geologic features of the coast – and is used to understand the geomorphic setting and determine the response model (to coastal hazards) for a given length of coastline. Shoreline class may be consistent across several coastal compartments or vary significantly within coastal compartments.
- **Coastal compartments** - are based on a combination of geologic setting and sediment transport processes – and are used to delineate the study area of interest, inform the technical coastal hazard assessments, and underpin strategic adaptation planning.

2.2.2 Definitions and Concepts

A range of terms are used to identify the physical terrestrial and marine components of coastal areas and terminology varies in academic and technical research. In these guidelines, the term “coastline” refers to the seaward margin of the land - or the landward margin of the sea, while “coastal zone” refers to a wider area enclosing the coastline extending seaward and landward.

A conceptual example of the definitions and concepts discussed in this section is provided in Figure 2-3.

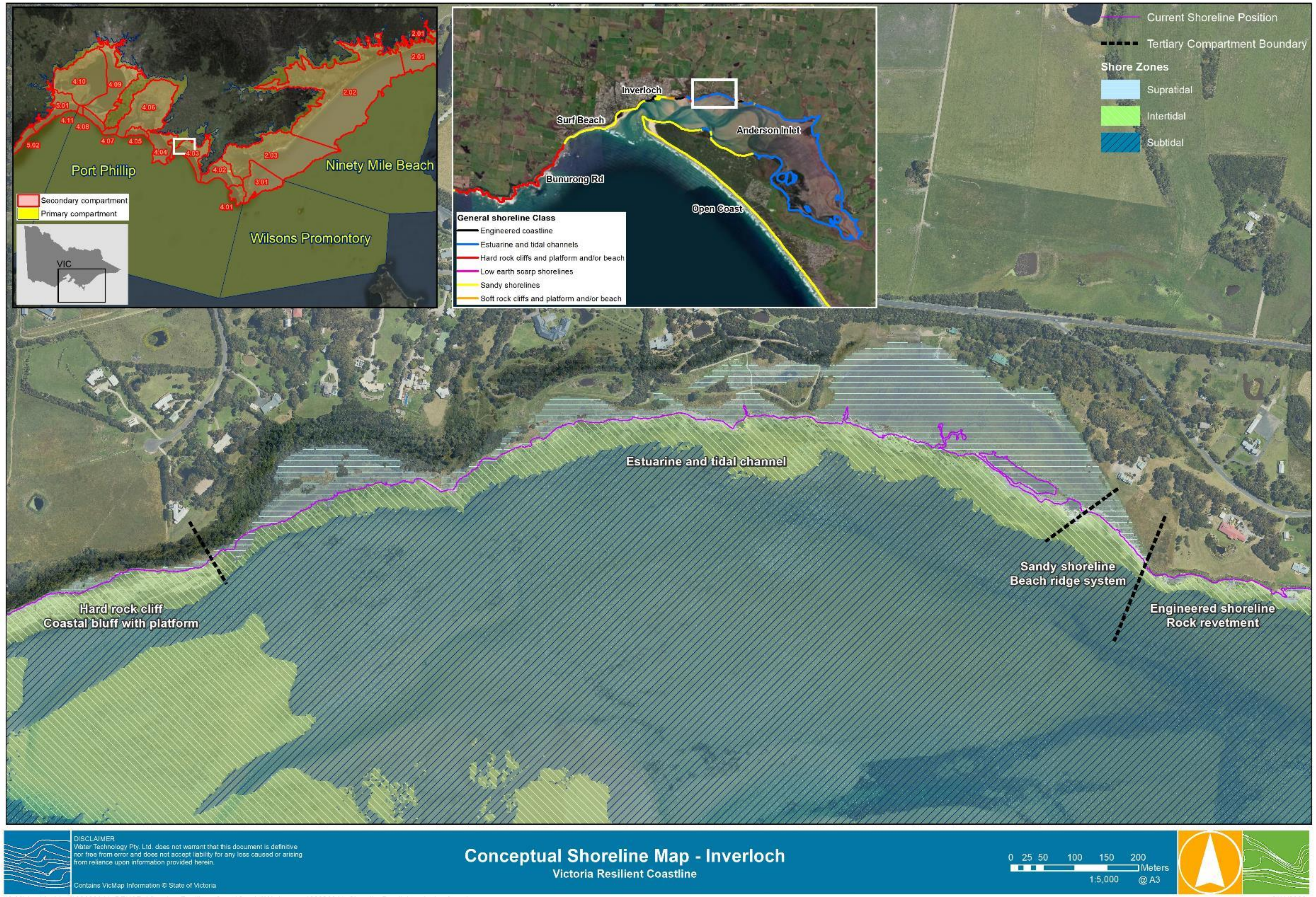


Figure 2-3 Terms and definitions example - conceptual Shoreline Map of Inverloch

The key geomorphological terms used in these guidelines are defined below.

Table 2-2 Coastal Geomorphology Definitions

	Term	Definition
Geologic / geomorphic descriptors	Landscape geology	The broad landscape context within Victoria, including geology, drainage basin/catchments, formational processes / age of major coastal landforms.
	Shoreline Class	A length of coast with a characteristic appearance in plan and profile and comprised of a limited range of geological materials. E.g., rocky coast, sandy shoreline as described in Table 2-3 to Table 2-10.
	Shoreline sub-class	A sub-type of shoreline class, with finer resolution of variations in geomorphic features, suitable for informing tertiary sediment compartments and detailed coastal modelling approaches. E.g., rocky coast with shore platform, rocky coast with beach. This is the smallest unit of study when defining coastlines and covers the area of the nearshore affected by high tide, sub-tidal and intertidal zones.
Coastal compartments	Coastal Compartment	Sections of coastline defined by landform (shoreline classes) and the sediment transportation processes that occur within the compartment. Split into primary, secondary, and tertiary.[1]
	Primary Coastal Compartment	Primary compartments are defined by large landforms (such as headlands and rivers)[2]
	Secondary Coastal Compartment	Secondary compartments are defined by sediment movement on the shoreface within and between beaches.
	Tertiary Coastal Compartment	Defined by sediment movement in the nearshore area on an **interannual and decadal timescale**. Tertiary compartments are defined by an assessment of geomorphic shoreline sub-class, combined with an understanding of local sediment transport processes.
Geomorphic elements linked to defining sediment compartments	Swash limit (wave runup)	This is the oscillating line marking the limit to which water from a breaking wave extending landward. It defines the wet-dry beach margin and is best recorded by video photography from aerial or fixed ground cameras. Swash is driven by wave height, wavelength, and beach slope while the runup distance is determined largely by beach grain size, wave turbulence, swash-backwash interaction, and infiltration.[3]

[1] State Government of Victoria (2020). Marine and Coastal Policy. Available: www.marineandcoasts.vic.gov.au
[2]Thom, B., (2015) Coastal Compartments Project: Summary for Policy Makers. Prepared for Dept of Agriculture, Water and the Environment
[3] Erikson, et al., (2007) Swash zone characteristics, California. Research Gate.

	Term	Definition
	Shoreline	The shoreline is the interface between ocean and land represented by an irregular line in planform and elevation. It is the seaward limit at which land at any moment is submerged by wave swash. It is determined by two interactive components: ▪ forcing factors—astronomical tidal wave, and swell and wind waves—that move the water column landward; and ▪ the three-dimensional form—elevation and slope—of the marine and landfall surface the water crosses. On a coherent rock shore platform, the shoreline position varies according only to the state of the tide and local wave conditions and displays limited temporal variation. On beaches (unconsolidated substrate) where wave swash can mobilise the substrate, the shoreline can vary rapidly (between waves and between tides) responding to changes in substrate morphology and elevation. The shoreline—as represented by a line on maps or imagery is referred to an elevation such as “0” Australian Height Datum (AHD). On sandy shorelines this line will be a generalisation, as the elevation of beach material changes overt time and the datum plane may be emerged or submerged according to sand accretion or depletion.
	Backshore	The backshore is the landforms extending landward from the swash limit. It is initially higher than the limit of swash but may then slope inland and become lower than sea-level.
	Shore zone (intertidal, sub tidal and supra tidal zone)	The shore zone or intertidal zone is the area between the upper subtidal zone (effectively the lowest low water level) and the landward limit of swash. On intertidal areas of unconsolidated sediment (boulders, gravel, sand, mud), the shore zone is also referred to as the beach-face. It is the zone where sediment moves cross-shore and along-shore, predominantly in response to wave-induced currents in the swash and backwash, but wind can also play a significant role, particularly during low tide exposure of the beach. A sub-unit of the shore zone is the supratidal zone - an area landward of direct swash that is impacted by wave splash and occasionally washed by a storm surge. The supratidal zone is the seaward limit of the backshore. On rocky shores the shore zone is a shore platform.

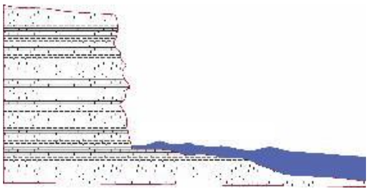
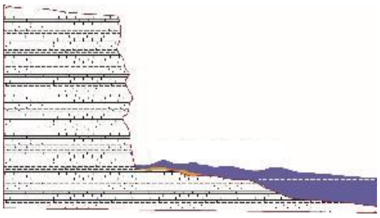
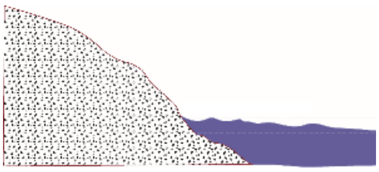
2.3 Shoreline Classes

Shoreline Classes have discrete definitions of shoreline typology and a similar response and rate of change to coastal processes including sea level rise and associated coastal hazard impacts.

This guideline identifies eight generalised Shoreline Classes occurring as discrete lengths along the Victorian coast. Different Shoreline Classes are to be used to link the shoreline typology to the physical and coastal processes and to estimate responses to different coastal hazards. Shoreline classes, and associated sub-classes are described below.

- Hard rock cliffs and platform and/or beach (including bluffs);
- Soft rock cliffs and platform and/or beach (including bluffs);
- Low earth scarp;
- Sandy shorelines;
- Estuarine environments including tidal channels, mangrove and saltmarsh;
- Engineered coastline;
- Off-shore environments; and
- Coastal floodplains.

Table 2-3 Shoreline Classes – Hard Rock Cliffs

Hard Rock Cliff	Length	Description
 1. Hard rock cliff and shore platform  2. Hard rock cliff and platform beach  3. Hard rock cliff – plunging cliff	528km 20% of the Victorian Coastline	Hard rock cliffs are consolidated rock formations shaped by marine and sub-aerial processes and are of highly varied form and profile. Hard rocks are composed of strongly cohesive crystalline igneous or well-cemented sedimentary origin and on the Victorian coast include granite, basalt, and some sandstones and limestones. Cliffs may be very steep or sloping surfaces of varied height, scale and shape. Hard rock cliffs are particularly susceptible to deep-seated mass movements that may be initiated by a combination of surface processes and/or due to marine influences at the base of the cliff. Key variants include: 1. Hard rock cliff shore and platform consists of a steep slope of exposed hard rock and/or partly vegetated surface on weathered hard rock with a shore platform of variable width and generally well-defined outer edge that is exposed at low spring tides (Figure 2-4); 2. Hard rock cliff with a sand/gravel beach that partially covers the platform – sediment derived from off-shore; 3. Plunging cliff without a shore platform;

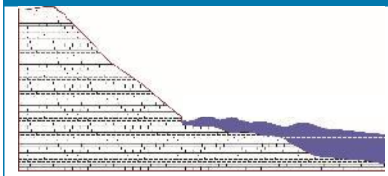
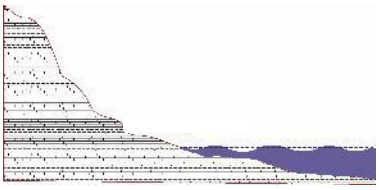
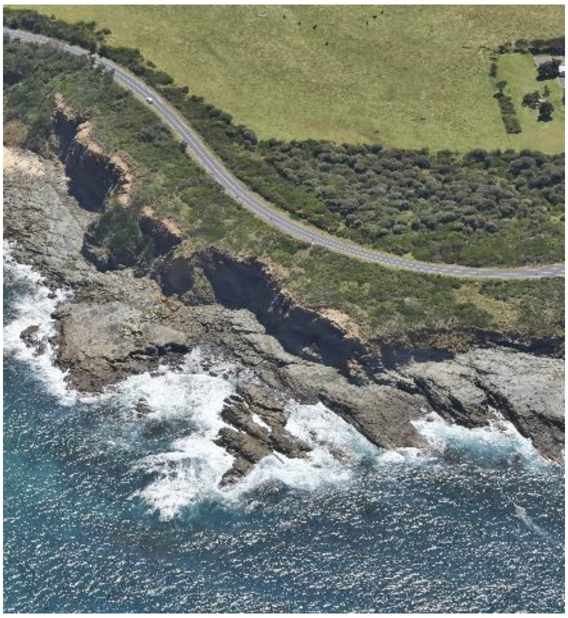
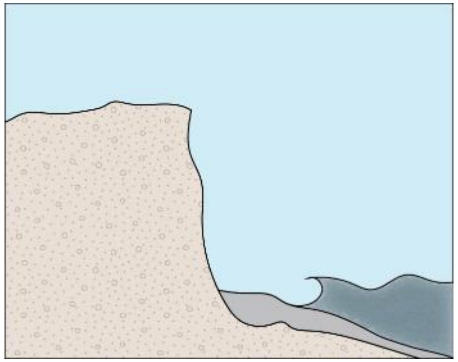
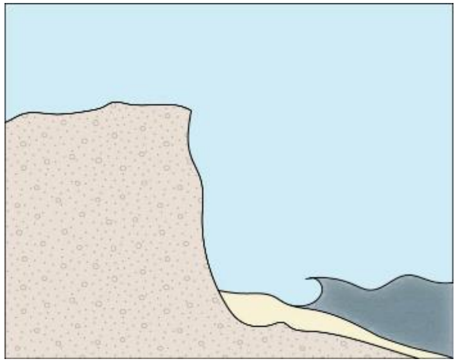
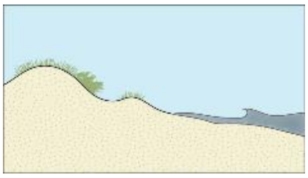
Hard Rock Cliff	Length	Description
 4. Steep coastal slope and basal cliff  5. Coastal bluff		4. Steep coastal slope and basal cliff. Basal undercutting in softer layers may occur; and 5. Coastal bluffs currently beyond present wave action but may be re-activated under higher sea levels.  **Figure 2-4 Example Hard Rock with Shore Platform – Cape Paterson to Flat Rocks**

Table 2-4 Shoreline Classes – Soft Rock Cliffs

Soft Rock Cliff	Length	Description
 Soft rock cliff with shore platform  Soft rock cliff with beach	144 km 5% of the Victorian Coastline	Soft rock coasts (e.g., limestone, clay) can occur on open coasts and within embayments. Soft rock cliffs are subject to similar sub aerial and marine processes and experience continuous to intermittent marine erosion. The key variants include: 1. Soft rock with/without a short platform; and 2. Soft rock with/without a beach. Soft rock cliffs are near-vertical slope of exposed rock. A sand beach and/or dunes may be present at the base of the cliff and sometimes bury the cliff. The presence of sand dunes or a beach in front of the cliff can slow the rate of erosion. A shore platform of more resistant material may be developed. A range of sub-aerial processes contribute to erosion of the high soft rock cliffs including groundwater pore pressure and seepage which contribute to slope failure through block or slumping type movements, furthermore surface runoff and rain impact can affect the stability of the cliff face. Wave action is also a significant process for change on these shorelines.

Soft Rock Cliff	Length	Description
		 Figure 2-5 Example Soft Rock Without Shore Platform - Anglesea  Figure 2-6 Example Soft rock Limestone Cliffs with Minimal Shore Platform – Loch Ard, Port Campbell

Table 2-5 Shoreline Classes – Sandy Shorelines

Sandy Shorelines	Length	Description
 This can include several variants: 1. Barrier/ spit systems; 2. Beach ridge systems; and 3. Pocket beach systems	1002 km 38% of the Victorian Coastline	Sandy shorelines are formed from a combination of terrestrial and marine-derived sediments. Sandy coasts occur on open coasts and in embayments. In Victoria key variants include: 1. Barrier/ spit systems formed during the Holocene marine transgression over the last 10,000 years, typically at a change in backshore coastline orientation and in the lee of nearshore islands or built structures; 2. Beach ridges systems; a series of parallel/sub-parallel dune ridge sequences which have formed successively behind a sandy shore. These ridges may fluctuate between accreting and eroding coastlines over time depending on the local coastal processes; and 3. Pocket beach systems; compartmentalised beaches of deposited sediments formed between headlands and within coves.  **Figure 2-7 Example Multiple Beach Ridges System – Entrance Point, Wilsons Promontory (Source: Rosengren, 2022[4])**

[4] Rosengren, N., (2022) Image provided for DELWP Victoria's Resilient Coast.

Sandy Shorelines	Length	Description
		 Figure 2-8 Example Barrier Spit Landform – Mallacoota Inlet (Source: Rosengren, 20225)

[5] Rosengren, N., (2022) Image provided for DELWP Victoria's Resilient Coast.

Table 2-6 Shoreline Classes – Low Earth Scarp

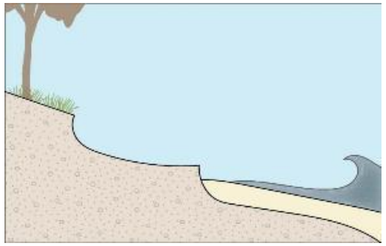
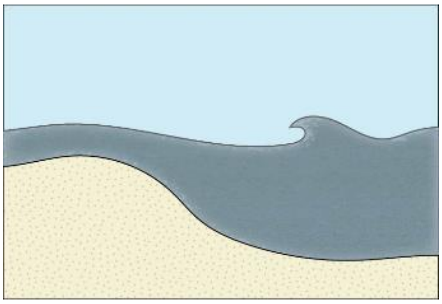
Low earth scarp	Length	Description
 This can include several variants: 1. Low earth scarp (with sand) with beach; and 2. Low earth scarp (peat/alluvium/organic) with/without beach.	138km 5% of the Victorian Coastline	Low earth scarps typically develop in lower wave energy environments and comprise of a wide intertidal flat or silty sand or peats and muds with a sparse distribution of mangroves. These landforms a have low elevation and often leveed. Key variants include: 1. Low earth scarp with an intermittent, narrow sandy beach; and 2. Low earth scarp of soft sediments of poorly consolidated and unconsolidated peat, alluvium or organic material. Historically and presently these shorelines are typically undergoing active shoreline recession.  Figure 2-9 Example Low Earth Scarp in Western Port near Gurdies Nature Conservation Area

Table 2-7 Shoreline Classes – Estuarine and Tidal Areas

<table>
<tr><th>Estuarine and Tidal Channels</th><th>Length</th><th>Description</th></tr>
<tr><td>
These can include several variants:
1. Embayments and drowned river valleys;
2. Wave or tidally dominated estuaries & deltas;
3. Coastal lagoons and creeks;
4. Tidally dominated estuaries and deltas; and
5. Tidal creeks and drain.</td><td>671km

25% of the Victorian Coastline</td><td>A partially enclosed coastal waterway that is influenced by tides and coastal processes; a zone where freshwater mixes with salt water. Estuary systems may be permanently or periodically open to the sea.
The key characteristics of this shoreline class are:
1. The presence of a tidal and/or riverine channel(s) transporting marine water into rivers and coastal lagoons and extend considerable distances landward of the main shoreline;
2. A low elevation backshore zone which is often leveed; and
3. Wide intertidal flat of silty mud and sand.

Figure 2-10 Example of an Intermittently Closed Estuary Entrance at Curdies River.

Figure 2-11 Example of Tidal Creeks at Tooradin, Western Port.</td></tr>
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Table 2-8 Shoreline Classes – Engineered Coastline

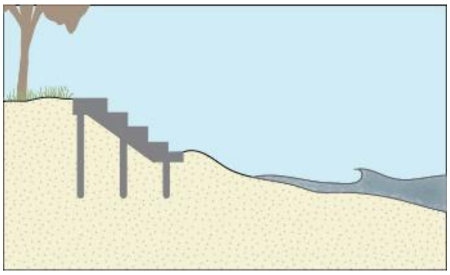
Engineered coastline	Length	Description
 Can include the following structures: 1. Harbours, marina, esplanades, jetties and boating facilities 2. Sea walls, revetments, gabions 3. Groynes, breakwaters (timber or masonry) 4. Sand and/or sediment renourished beaches; 5. Drains and constructed stormwater outlets; 6. Recreational access, car parking, roads, lookout platforms, fencing.	160km 6% of the Victorian Coastline	Engineering coastlines can be situated on open coast or embayed areas, and are typically urban environments with a range of infrastructure. The presence of coastal engineering structures can have a significant impact on natural coastal processes, including limiting / disrupting sediment transport.  **Figure 2-12 Engineered Coastline in the Port of Portland**

Table 2-9 Shoreline Classes – Coastal Floodplain

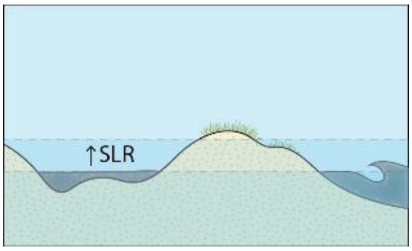
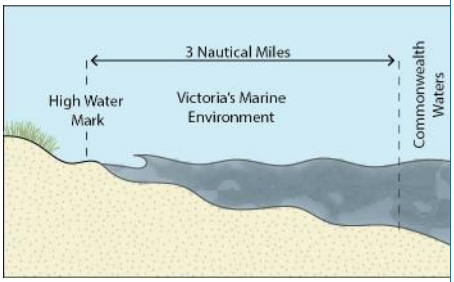
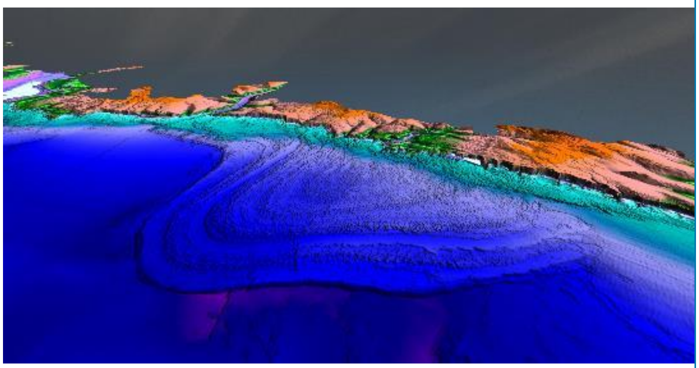
Coastal Floodplains	Setting	Description
 Coastal floodplains, low lying land prone to inundation.	Land behind the backshore below HAT	Coastal floodplains include all low-lying land behind the shoreline which may experience seawater incursion during an elevated water level event such as king-tide or be vulnerable to permanent inundation under different sea level rise scenarios. As sea-level continues to rise, coastal floodplains will increasingly experience inundation by high tides, including the frequency and depth of flooding. [10] Because of low elevation, coastal floodplain ecosystems and agricultural land use is at risk from saltwater intrusion. Many areas may become too wet and salty to grow crops. With sea level rise, salt tolerant plants and ecosystems are likely to experience landward migration.  **Figure 2-13 Low Lying Coastal Floodplain, Corner Inlet (Source: Rosengren, 2022[12])**

Table 2-10 Shoreline Classes – Off-Shore Environment

Off-shore environment	Length	Description
 The off-shore environment includes features such as: 1. Bathymetric features; 2. Tidal channels; 3. Sediment dynamics; and 4. Supported ecosystems.	N/a	The off-shore environment includes the bed beyond the intertidal zone up to three nautical miles, or 5.5 kilometres off-shore. The off-shore environment is influenced by marine and coastal processes and human intervention. Changes in the offshore environment can include alterations in currents and sediment dynamics (e.g., sediment slugs, tidal channels) that can create a hazard for associated values (e.g., seagrass, kelp forests, navigation).  **Figure 2-14 Off-Shore Environment Setting, Port Campbell – LiDAR and Bathymetric Image Showing Offshore Features (Source: Rosengren, 2022[6])**

[6] Rosengren, N., (2022). Image provided for DEECA Victoria's Resilient Coast.

2.4 Coastal Compartments

The Marine and Coastal Policy 2020 directs planners and decision makers to consider marine and coastal processes “in the context of their coastal compartment type when planning for or managing coastal hazard risks”.

Coastal compartments are spatial units, identified along the coast where there is a strong connectivity between submarine morphology, substrate, marine processes, sediment availability and transport and backshore landforms. A coastal sediment compartment is a section of coast which shares a common sediment resource with clearly defined physical boundaries. The compartment may be open, leaky or closed at either or both boundaries and the sediment budget may be positive, stable or negative[7].

Coastal compartments occur at national to local scale and can be used to describe the long-term to short-term coastal behaviour. The criteria for Primary and Secondary Compartments have been established at a national scale. The recommended approach is for delineating coastal compartments in Australia into three tiers (Primary, Secondary and Tertiary) where each scale supports different types of decision making has been defined in Figure 2-15, from a coastal compartments study[8]

The application of Tertiary compartments has been completed for the coast of Western Australian but there is currently no comprehensive representation for other states.

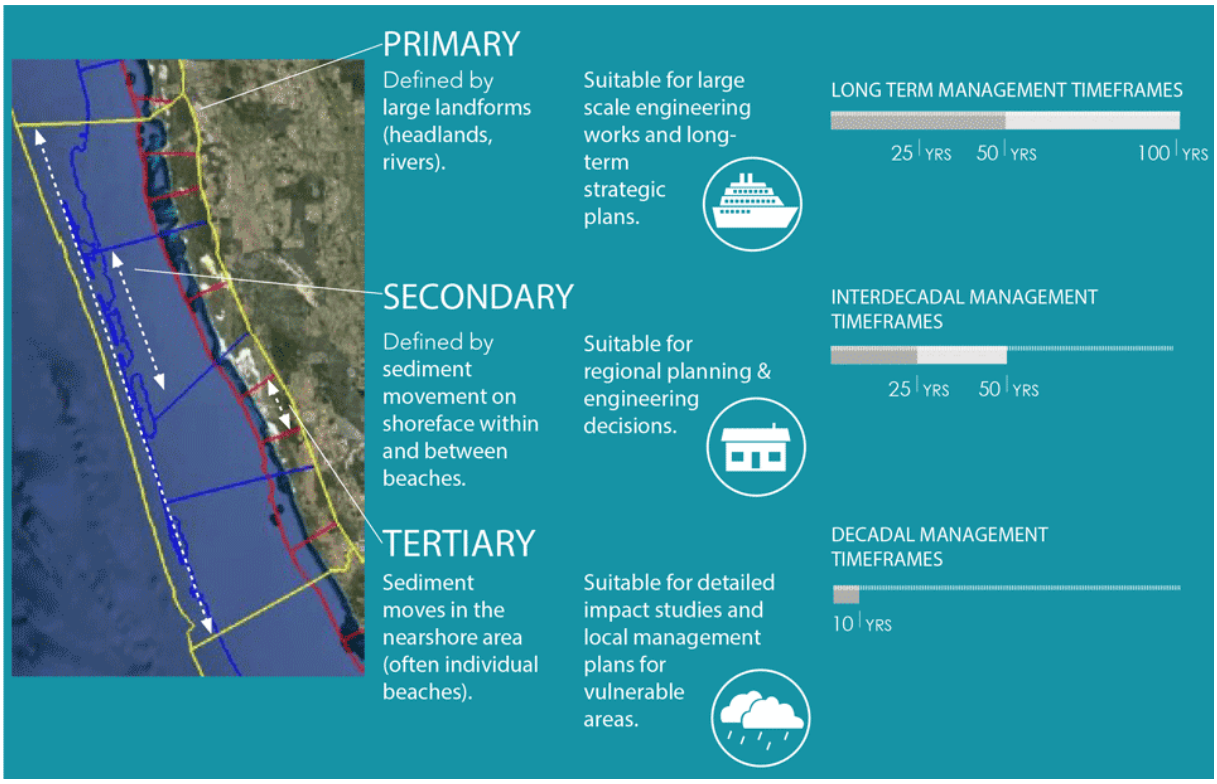


Figure 2-15 Coastal Compartment Scales, Use and Timeframes (Source: Thom. B., (2015))

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[7] Short et al., (2018). National sediment compartment framework for Australian coastal management. Prepared for Coast Adapt.

[8] Thom, B., (2015). Coastal Compartments Project: Summary for Policy Makers. Prepared for Dept of Agriculture, Water and the Environment

The purpose of coastal sedimentary compartment analysis is to determine the nature and paths of sediment transport (onshore-off-shore and alongshore) in coastal systems. Sediment movement along a coastline occurs within a spatial envelope (the store) extending from the deepest point on the seafloor from which sediment can be moved by wave and current action to the landward extent that sand is washed or blown but may still be returned to the shoreline by a reverse of these transport processes known as the sweep zone.[9]

The advent of terrestrial and bathymetric LiDAR and advances in sonar and sub-bottom profiling have reduced uncertainty of determining the limits of the onshore-off-shore sediment transport, but this still requires high levels of technical expertise and expense for consistently reliable data acquisition.

The seaward limit of the sweep zone is a response of seafloor sediment to wave and current action and does not change over a defined time. It can be determined by repeated high resolution cross-shore profile surveys. The ultimate landward limit is more difficult to establish as it is defined by a wide range of topographical and process variables and is more likely to be impeded by engineered structures.

The national coastal compartments approach to coastal classification is hierarchical, descending from the 2 coastal “provinces” (tropical and temperate) based on climate, 7 coastal “divisions” based on coastal orientation, 23 “regions” based on geology and coastal configuration, 102 “primary compartments” determined by coastal structural features such as headlands and large bays, and ~350 “secondary compartments” on geomorphology[10].

2.5 Delineation and Descriptions of Primary and Secondary Compartments in Victoria

The Victorian coast is comprised of six primary compartments and 23 secondary compartments (the westernmost extends into South Australia) (Figure 2-16).

Implicit in the adoption of the term compartments is that boundaries can be recognised and mapped. Geomorphic boundaries in the general landscape range from sharp and abrupt to diffuse and sediment movement in and out varies from one compartment to the next. In a coastal compartment context, the boundaries are defined by their role in containing sediment movement, notably the lateral alongshore boundaries. Some sedimentary compartments have boundaries clearly defined by elongate headlands and recessed embayments with minimal exchange alongshore.

For example, Kitty Miller Bay on the south coast of Phillip Island is a “closed” tertiary sedimentary compartment[11] (Figure 2-17), while Mounts Bay (Marengo) is an example of a “leaky” compartment or sub-compartment where sediment moves into and out of adjoining compartments by passing around headbands (Figure 2-18).

[9] Davies, J.L., (1974). The coastal sediment compartment. Australian Geographical Studies
[10] Short et al., (2018). National sediment compartment framework for Australian coastal management. Prepared for Coast Adapt.
[11] Nearmap (2019). Available at: www.nearmap.com.au

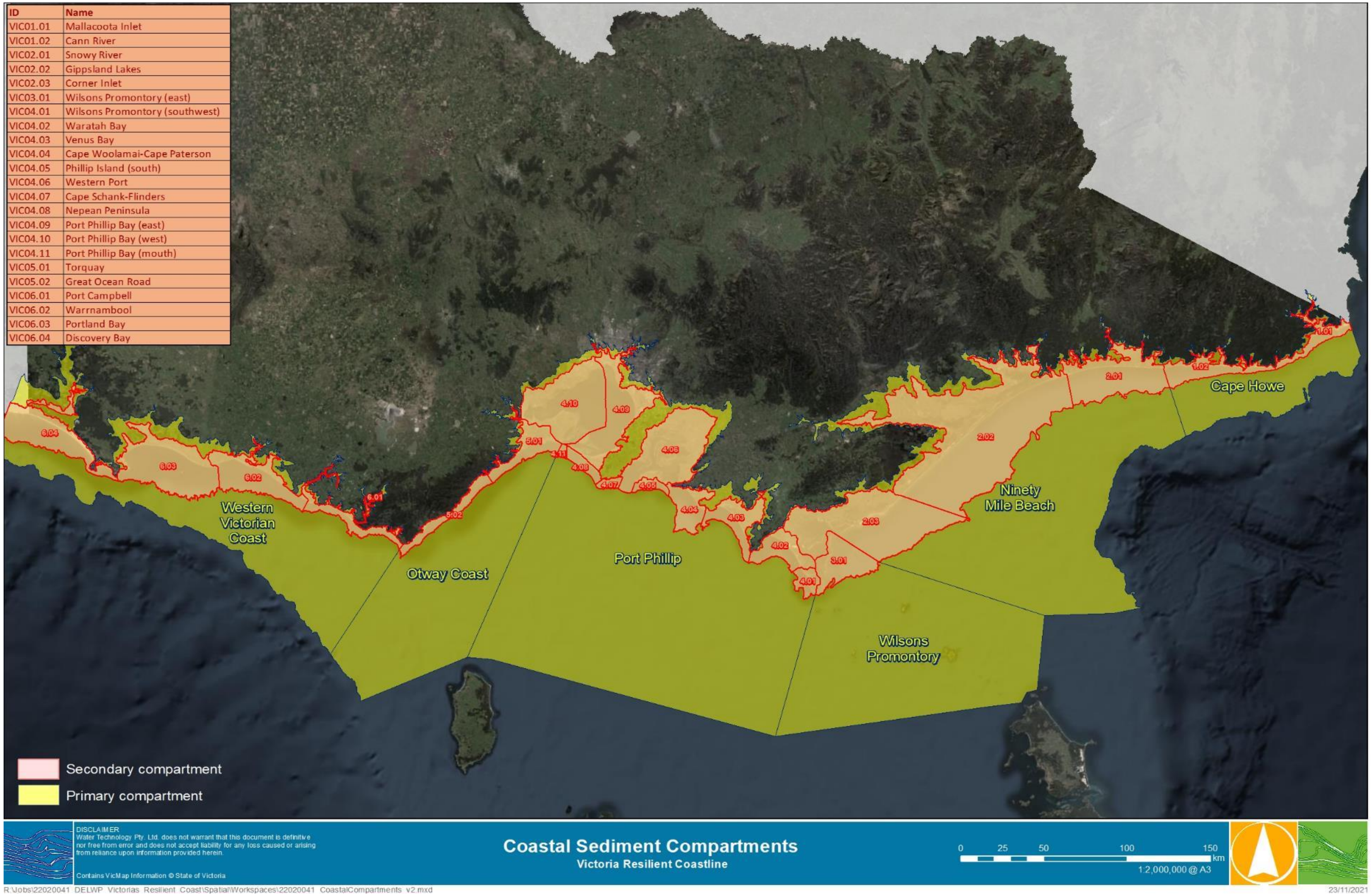

Figure 2-16 Primary and Secondary Coastal Compartments

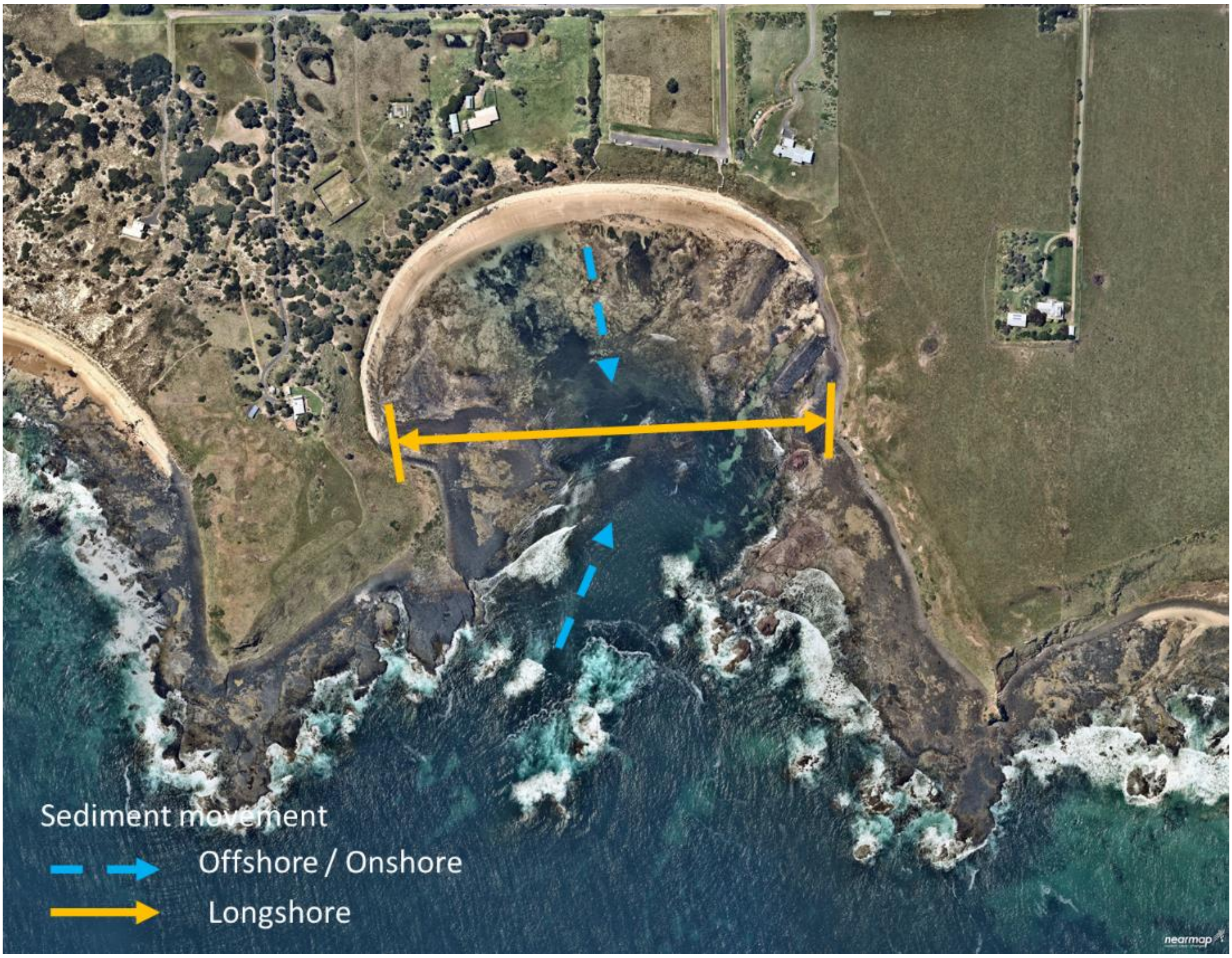

Figure 2-17 Example 'Closed' Tertiary Sediment Compartment - Kitty Miller Bay, Phillip Island (Source: Nearmap, November 2019).

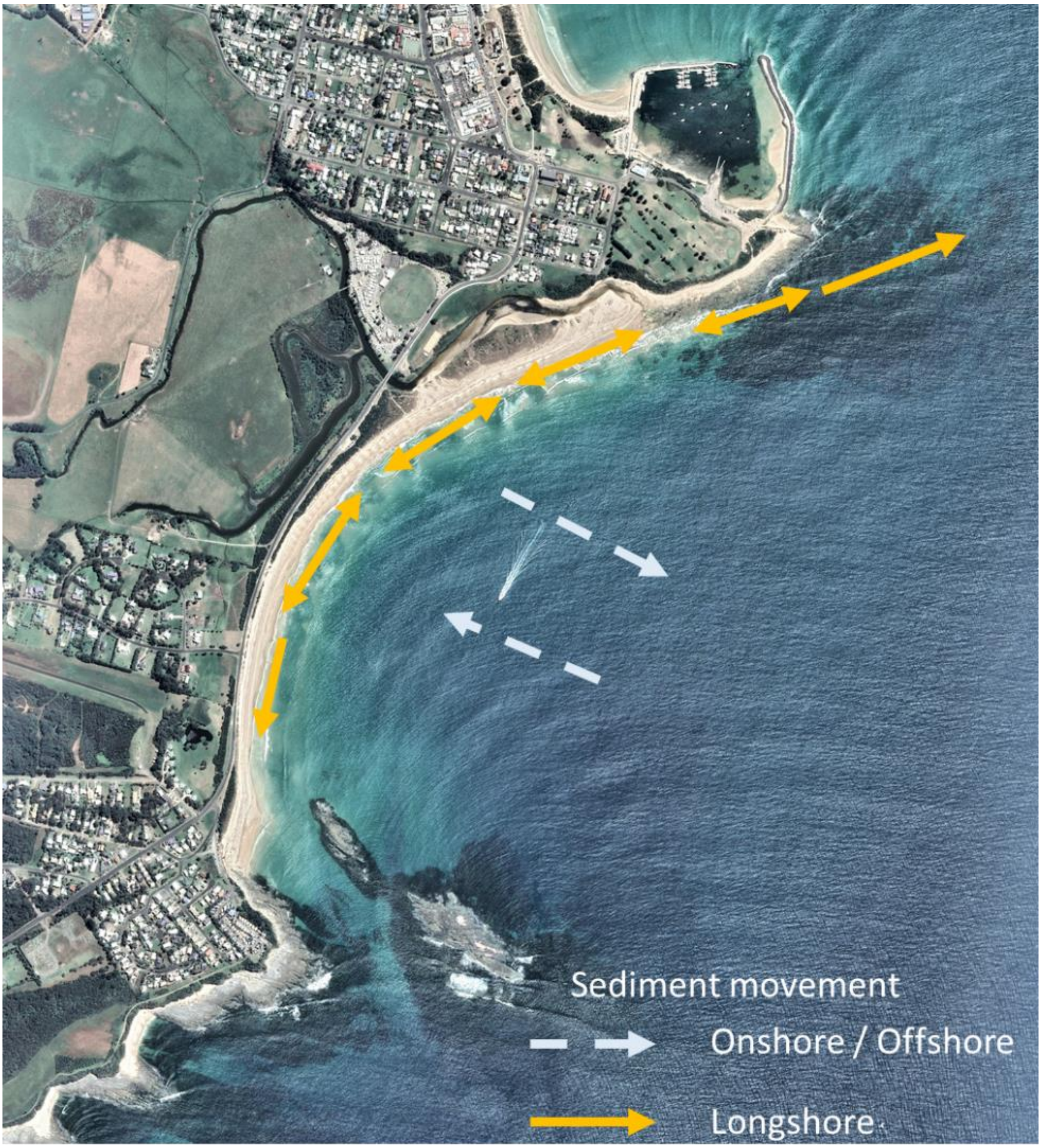

Figure 2-18 Example 'Leaky' Tertiary Sediment Compartment – Mounts Bay, Marengo (Source: Nearmap; 2019)

Table 2-11 Description of Primary and Secondary Coastal Compartments in Western Victoria (West of Cape Otway)

Geographic Zone	West (West of Cape Otway)				
Geology	In the west, unconsolidated Quaternary dunes overlay Pleistocene calcarenite from Discovery Bay to Bridgewater Promontory. The promontory itself consists of ancient volcanics namely basalt and tuff capped by calcarenite which form vertical cliffs. Much of this area is covered by limestone and karstic processes forming numerous caves. The cliffs are topped by Quaternary dune systems formed by wind and wave action.				
Primary Compartment	*Western Victorian Coast*				*Otway Coast*
Secondary Compartment	**Discovery Bay**	**Portland Bay**	**Warrnambool**	**Port Campbell**	**Great Ocean Road**
Included area	From Danger Point (Brown Bay, SA) to Cape Nelson	From Cape Nelson to Port Fairy (Griffiths Island)	From Port Fairy (Griffiths Island) to Peterborough (Wild Dog Cove)	From Peterborough (Wild Dog Cove) to Cape Otway	From Cape Otway to Split Point
Geomorphic description (Source: Coast Adapt Shoreline Explorer / Rosengren. N)	Discovery Bay is a Holocene barrier coast of intermittent foredunes and ridges overlying cemented Bridgewater Formation limestone. Includes estuary environments including the Glenelg Estuary The surf beach is interrupted by outcrops of this limestone. Behind and between barrier ridges and areas of stabilised transgressive dunes are the linear wetlands of Long Swamp draining to the tidal bay of Mud Lagoon. Active marine cliffs are the backshore along approximately 25 km of coast at Cape Bridgewater, Cape Nelson and Cape Grant. Most are hard rock at western Bridgewater Bay and the head of Nelson Bay.	Calcarenite & dune sands over hard basaltic, cliffed and sloping shores at Cape Nelson/Portland & Cape Reaumur-Port Fairy. Long sandy beaches and dune barrier backed by and overlying dune calcarenite ridges and soft marine sediments in Portland Bay. North of Portland Harbour, 2.8 km of shore is backed by active cliffs and slumping backshore bluffs	Cliffed, marine limestone, soft-rock coast from Peterborough to Childers Cove; Hard calcarenite coast to Warrnambool; Large sandy beach-dune barriers at Lady, Armstrong and Port Fairy Bays, backed by and embayed between rocky calcarenite ridges.	A rocky cliffed coast of relatively soft, Cenozoic-age sedimentary rocks, including the marine limestones of the Port Campbell region and more resistant Cretaceous Otway Group rocks to Cape Otway. Dune calcarenites cap the older rocks in many places. Minor beaches fringe the mostly rocky shores	Dominantly steep rocky coast of volcaniclastic sandstones & mudstones; Calcarenite over lithic sandstones at Cape Otway; Drift-aligned sandy beaches at Mounts Bay, Apollo Bay, Lorne and Cinema Point-Eastern View.
LGA	Glenelg Shire Council	Glenelg Shire Council / Moyne Shire Council	Warrnambool Shire Council / Moyne Shire Council	Moyne Shire Council / Corangamite Shire Council/ Colac Otway Shire Council	Colac Otway Shire Council / Surf Coast Shire Council

Table 2-12 Description of Primary and Secondary Coastal Compartments in Central Victoria (Between Cape Otway and Wilsons Promontory)

Geographic Zone	Central (Between Split Point and Wilsons Promontory)												
Geology	The Southern region comprises pre-Cenozoic rocks, in fault-bounded structural blocks expressed as the Otway Ranges and Mornington Peninsula and other elevated areas (including Wilsons Promontory). There is variable cover of limestones, basalts and unconsolidated sand dunes. Port Phillip and Western Port are sunklands: fault-bounded blocks displaying relative subsidence partially inundated by the present-day sea level.												
Primary Compartment	*Otway Coast*	*Port Phillip*											*Wilsons Promontory*
Secondary Compartment	**Torquay**	**Port Phillip Bay (west)**	**Port Phillip Bay (mouth)**	**Port Phillip Bay (east)**	**Mornington Peninsula**	**Cape Schanck-Flinders**	**Phillip Island (south)**	**Western Port**	**Kilcunda**	**Venus Bay**	**Waratah Bay**	**Wilsons Promontory (west)**	**Wilsons Promontory (east)**
Included area	From Split Point to Point Lonsdale	From Point Lonsdale to Williamstown	From Point Lonsdale to Point Nepean	From Williamstown to Point Nepean	From Point Nepean to Cape Schanck	From Cape Schanck to West Head	From Point Grant to Cape Woolamai	From West Head to Point Grant	From Cape Woolamai to Cape Paterson	From Cape Paterson to Cape Liptrap	From Cape Liptrap to Tongue Point	From Tongue Point to South Point	From South Point to Entrance Point

Geographic Zone	Central (Between Split Point and Wilsons Promontory)												
Geomorphic description (Source: Coast Adapt Shoreline Explorer / Rosengren. N)	Drift- and swash-aligned beaches from Split Point to Breamlea are backed and interspersed with Cenozoic-age sedimentary soft-rocks. Two swash-aligned beaches at Barwon Heads are backed by hard, Pleistocene, aeolian, calcarenite barriers and dune sands.	Mostly swell-sheltered shores with narrow low-energy beaches backed & interspersed by Cenozoic-age soft-rock sediments from Queenscliff to Geelong, and by interspersed hard basalt and soft sediment shores and backshores from Avalon to Williamstown.	Encompasses tidal mouth of Port Phillip Bay but does not include shoreline.	Swell-sheltered tidal embayment shore with numerous narrow sandy beaches, backed by & interspersed with generally soft-rock materials, including Cenozoic-age sediments, deeply weathered granites & volcanics, & calcarenite.	Sandy beaches with rocky calcarenite headlands and reefs backed by large, swash-aligned, Pleistocene calcarenite dune barrier complex, mantled by unconsolidated Holocene dunes and sand-sheets. Bounded by hard-rock basalt promontory of Cape Schanck.	Swell-exposed cliffs of Cenozoic-age, hard basalt bedrock, with a narrow cliff-backed sandy beach at Flinders.	Swell-exposed, hard rock, cliffed coast in the west-central area (basalt) & at Cape Woolamai (granite); Sandy pocket beaches in the west-central area; A long, sandy, swash-aligned beach barrier backed by transgressive dunes dominating the E.	Deep structural and tidal embayment with a range of coastal environments, from swell-dominated to swell-sheltered, with strong tidal currents and longshore sediment transport in parts, and with hard-rock, soft-rock, sandy and muddy-mangrove shores.	Cliffed, mainly rocky coast between Sam Remo & Kilcunda; Long stretch of swash-aligned sandy beaches between Kilcunda & Coal Point; Cliffed rocky shores from Coal Point to Cape Paterson.	Long sandy beaches and dune barrier between prominent hard rock headlands to N & S; Backed by mostly stabilised transgressive dunes; Large, permanently open tidal estuarine lagoon behind the N end of the barrier	Long sandy beach & dune barrier well-embayed between large, hard rocky headlands; Active & stabilised transgressive dunes behind the southern, more westerly-exposed part of bay; Large tidal estuarine lagoon backs the sandy barrier	Dominantly hard rocky coast with several sandy beaches deeply embayed between prominent hard rocky headlands	Sandy beaches separated by large, sloping to cliffed, hard rocky promontories; Dominantly cliffed rocky shore with well embayed beaches (southern half); Dominantly sandy beaches backed by prograded sandy barriers (northern half).
LGA	Surf Coast Shire Council / Greater Geelong City Council, Bellarine Ward / Queenscliffe Borough Council	Queenscliffe Borough Council / Geelong City Council / Wyndham City Council / Hobsons Bay City Council	Mornington Peninsula Shire Council / Queenscliffe Borough Council	Mornington Peninsula Shire Council / Frankston City Council / Kingston City Council / Bayside City Council / Port Phillip City Council / Melbourne City Council / Hobsons Bay City Council	Mornington Peninsula Shire Council	Mornington Peninsula Shire Council	Bass Coast Shire Council	Mornington Peninsula / Bass Coast Shire Council	Bass Coast Shire Council	Bass Coast Shire Council / South Gippsland Shire Council	South Gippsland Shire Council	South Gippsland Shire Council	South Gippsland Shire Council / Wellington Shire Council

Table 2-13 Description of Primary and Secondary Coastal Compartments in Eastern Victoria (East of Wilsons Promontory)

Geographic Zone	Eastern (East of Wilsons Promontory)				
Geology	The Eastern Plains are underlain by sediments and pre-Cainozoic rocks and are dominated by fluvial sedimentary deposits developed on a marine plain. The sedimentary deposits are made up of siltstone, silty shale and felspathic sandstone. Outcropping of these rocks is restricted to East Gippsland.				
Primary Compartment	Ninety Mile Beach			Cape Howe	
Secondary Compartment	**Corner Inlet**	**Gippsland Lakes**	**Snowy River**	**Croajingolong**	**Mallacoota Inlet**
Included area	From Entrance Point to McLaughlins Beach outlet	From McLaughlins Beach outlet to Red Bluff	From Red Bluff to Cape Conran	From Cape Conran to Rame Head	From Rame Head to Cape Howe
Geomorphic description (Source: Coast Adapt Shoreline Explorer / Rosengren. N)	Tide-dominated inlet; Large ebb & flood tide deltas at four entrances. Extensive intertidal sand & mud flats; Prograded sandy barrier islands (in the E); Granite peninsula of Wilsons Promontory (in the W); Inner mangrove & saltmarsh shores.	Long unbroken swell-exposed and drift-aligned sandy beach barrier (Ninety Mile Beach) of multiple parallel beach ridges in unconsolidated and semi-lithified sediments enclosing large tidal lagoons (Gippsland Lakes) engineered entrance maintained by dredging at Lakes Entrance.	Long drift-aligned beach and dune barrier backed by soft (semi-lithified) Cenozoic-age sandstone bedrock, with intermittently closed estuarine lagoons at Lake Tyers and the Snowy River estuary.	Long drift-aligned beaches and dune barriers with several hard rock promontories of granite and sandstone; backed by veneers of soft semi-lithified sandstones and transgressive dune sands over hard basement rocks. Large intermittently closed coastal lagoons of Sydenham Inlet (Berm R.) and Tamboon Inlet (Cann R.)	Long drift-aligned beaches and dune barriers with several points and cliffed sections of hard granite and sandstone; backed by soft sandstones and dune sands over the basement rocks. Several small estuaries and large intermittently closed estuarine lagoon at Mallacoota Inlet. Massive transgressive dune fields in the east.
LGA	Wellington Shire Council / East Gippsland Shire Council	East Gippsland Shire Council	East Gippsland Shire Council	East Gippsland Shire Council	East Gippsland Shire Council

2.6 Delineation and Descriptions of Tertiary Compartments in Victoria

There is no existing national dataset of tertiary sediment compartments or methodology for assessment. Given the dynamic nature of the coastline at finer spatial scales, tertiary sediment compartments are typically defined/updated at a point in time for a given region/local area.

Parts of the Victorian coastline have been mapped to a tertiary compartment level of detail and based on a consistent approach in the Coastal Hazard Assessments for Barwon Southwest, Port Phillip, Western Port, Ninety Mile Beach and Inverloch, and local studies of Mounts Bay, Apollo Bay and the Bellarine Peninsula (bay and ocean coast).

The guidance in this section provides an approach for the consistent identification of tertiary coastal compartments to inform place-based hazard assessments and adaptation planning. This approach is consistent with the approaches applied to date for tertiary mapping along the Victorian coastline.

Tertiary compartment mapping is useful to inform detailed coastal hazard assessments and modelling approaches. They may not be required for all assessments – and expert advice should inform scoping of projects to ensure the level of detail in coastal compartment mapping is fit for purpose.

2.6.1 Approach

Tertiary coastal compartments are lengths of shoreline where the geomorphic form, sediment budget and sediment cells are known with a high degree of confidence. Effectively this involves defining the geomorphic sub-classes, and then considering aggregation into tertiary compartments based on local sediment cells for discrete parts of the coast.

Determining the sediment budget to tertiary resolution requires substantial spatial and temporal data. The minimum requirements are details of the geomorphic sub-classes and expert assessment of local sediment cells, which may include consideration of 3-dimensional geometry of sediment bodies, the forcing processes of the coastal environment, and tracing volume and pathways of sediment movement.

Within the context of secondary sediment compartments, the tertiary assessment approach involves:

A) Review available data / resources

There are a range of tools and resources to support the assessment of tertiary sediment compartments for the Victorian coast (Text Box 1). This includes the national Smartline tool, CoastKit Victoria resources, available data and expert technical assessments.

B) Define shoreline sub-classes

Within secondary compartments, more detailed shoreline classes and sub-classes can be identified as per the descriptions in Table 2-3 to Table 2-10. This can be done using widely available topographical, bathymetric, geological and hydrological data sets (among others) supplemented by aerial photograph interpretation and ground-truthing.

Shoreline sub-classes (sometimes referred to as geomorphic sectors) consider the various combinations of subtidal, intertidal and backshore geomorphology within the broader shoreline class category. Shoreline sub-classes are comprised of two or more landform categories, for example a low earth scarp with a sandy beach, or hard rock cliff with a shore platform. A key differentiator between adjacent shoreline sub-classes is their response to coastal processes and how they respond to changed water levels and wave energy.

Initial assessments can be completed with desktop analysis and should be refined with on-ground inspections. This can be supplemented by high quality oblique aerial photography of the shore zone and backshore by light aircraft or UAV. Oblique imagery gives a virtual three-dimensional view. This imagery is current and can be compared to recent and historical vertical aerial photography, bathymetric and coastal LiDAR, geological and ecological resources and updated literature and unpublished information to provide detailed data to define sectors.

C) Define tertiary compartments

Shoreline sub-classes can be refined into tertiary compartments based on additional review of local data sets and monitoring of coastal processes, known shoreline response and observable sediment dynamics. This process may require an expert panel approach to ensure the technical detail in tertiary compartment mapping is fit for purpose for coastal modelling, planning and design purposes.

TOOLS AND RESOURCES TO SUPPORT TERTIARY COMPARTMENT MAPPING

Smartline Tool

The Australian Coastal Geomorphology Smartline methodology provides a tool for national coastal risk assessment. The Smartline is a representation of geomorphic features developed into a single, consistent map of coastal landforms for the entire Australian coast.

The Smartline is a polyline representation of the geomorphic features located within 500m of the high-water mark and is provided in CoastAdapt at two resolutions:

- A single map layer used to classify the coast into landform categories based on very broad differences in the composition and erodibility of coastal landforms

Separate layers that provide information on a number of the shoreline class types as described in in Table 2-3 to

- Table 2-10 for the Victorian coastline.

The tool is only applicable to the open coast and major embayments and does not consider estuaries or coastal lagoons such as Gippsland Lakes. Please refer to *Coastal Hazard Data and Information* for information about defining estuarine areas.

CoastKit

DEECA have launched a state-wide tool that provides access to multiple spatial mapping layers, marine and coastal scientific project data, imagery and resources in one centralised platform. The CoastKit database includes access to shoreline geology and the Smartline Basic polyline, the Victorian Coastal Monitoring Program (VCMP) study and survey locations and available data, information on beach facilities, coastal protection assets and infrastructure.

Local Data Sources

Local data can be analysed from:

1. High resolution 3-D terrain models (sub-aerial, sub-surface and submarine);
2. Repetitive measurements of these by bathymetric and terrestrial LiDAR, sonar and sub-bottom profiling, ground-penetrating radar;
3. Multiple profiling to define the sweep-zone;

6. Age-sequencing from radiometric measurements e.g., OSL and C14 dating;
7. Wave, current and wind data from direct observations and hindcasting;
8. Detailed geomorphic history and evolution of the coast; and
9. Details of human impacts and built structures that can influence the above.

3 PHYSICAL COASTAL PROCESSES

The key physical processes that drive change in the coastal zone are climate, oceanography and correspondingly geomorphology. It is therefore important to have a thorough understanding of the interactions and cyclical nature of these physical processes.

Much is known about these physical coastal processes in the scientific literature. However, these processes are constantly changing, so continued data collection and modelling is required to keep knowledge up to date. They are also independent of government boundaries and driven by physical boundaries across land, air and ocean.

This section presents a snapshot of the following physical coastal processes for Victoria:

- Climate variables
  - Wind, Air Pressure, Rainfall.
- Ocean Systems
  - Bathymetry, waves and currents.
  - Water levels – tide, storm tides, sea-level rise.
- This information provides relevant context for coastal hazards in Victoria, and a guide for the range of processes that should be assessed at regional and local scales to inform place-based adaptation planning.
- It is recommended that ongoing research, data collection and monitoring is aligned to continue improving our understanding of these processes, and to support long-term management and adaptation.

3.1 Climate Variables

There are five main global climate processes that influence Victoria's climate:

- El Niño-Southern Oscillation (ENSO),
- Indian Ocean Dipole (IOD),
- East Coast (cut-off) Lows (ECL),
- Southern Annular Mode (SAM), and
- Sub-tropical ridge.

These climate drivers[12] (Figure 3-1) vary over months and years to influence seasonal and inter-annual rainfall, air temperature and wind, and correspondingly oceanographic conditions and coastal processes (Table 3-1).

[12] Hope, P, Timbal, B, Hendon, H, Ekström, M, Potter, N. (2017). *A synthesis of findings from the Victorian Climate Initiative (VicCI)*, Bureau of Meteorology, 56pp, Australia

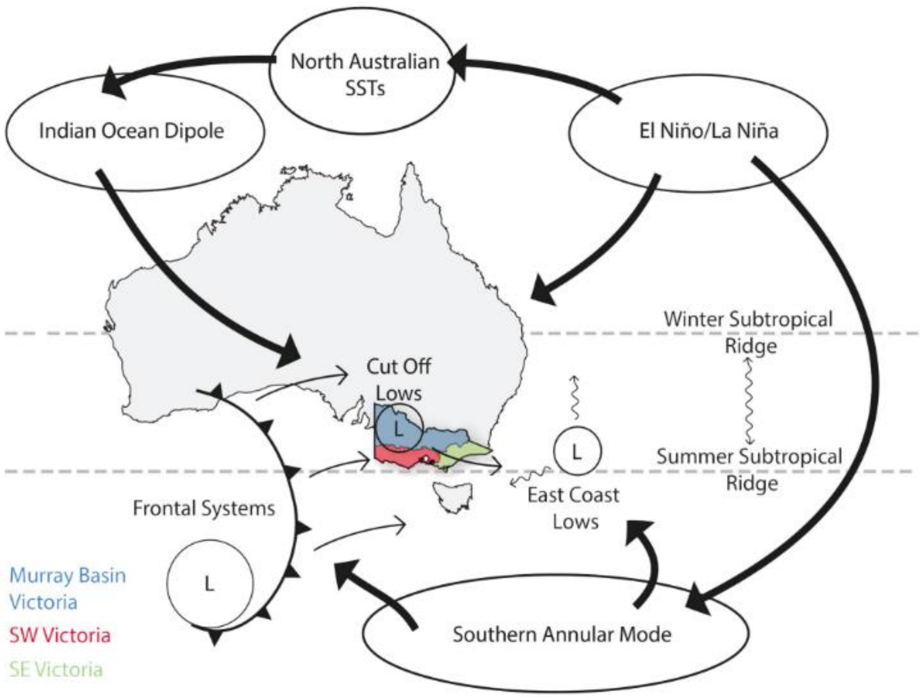

Figure 3-1 Australian Climate Drivers[13] (Source: Bureau of Meteorology, 2010)

Table 3-1 Climate Processes Influencing Victoria's Climate

	Influence Description	Impact on Victorian Coastline
El Niño - Southern Oscillation (ENSO)	Warming of the central and eastern tropical Pacific Ocean, leading to changing patterns of winds, atmospheric pressure and rainfall. Three phases of ENSO are: El Nino, La Nina & Neutral.	Important for Victoria, particularly in winter and spring La Nina brings strong trade winds leading to higher rainfall El Nino brings drier winter and spring periods
Indian Ocean Dipole (IOD)	Difference in sea temperature between western and eastern Indian Ocean leads to changes in wind, air temperature and rainfall patterns. Changes between positive, negative and neutral phases. Can be related to ENSO events	IOD connecting with cold fronts can produce higher rainfall. Positive and negative IOD events linked with drought across Australia. El Nino combined with positive IOD results in dry periods; and vice versa.
Southern Annular Mode (SAM)	The north-south movement of westerly winds (low pressure system) that circulate around Antarctica in the Southern Ocean. Position of SAM influences strength and position of frontal activity.	SAM has the greatest influence in southern Victoria during winter. Negative SAM leads to expanding fronts, increases likelihood of winter rainfall in southern Victoria.

[13] Bureau of Meteorology (2010). *Australian Climate Influences*. bom.gov.au accessed 26th October 2018.

	Influence Description	Impact on Victorian Coastline
		Positive SAM results in contracting fronts decreased winter rainfall in southern Victoria.
Sub-tropical Ridge	A belt of high pressure that encircles the southern hemisphere in the middle latitudes	During cooler months the ridge moves northwards towards the equator bringing more rain-bearing cold fronts to southern Australia and coastal Victoria.
East Coast Low (ECL)	Can occur several times a year on the east coast of Victoria. ECLs can form rapidly overnight and are formed as a sub-tropical depression that intensifies as it propagates rapidly down the east coast of Australia.	Cause heavy and widespread rainfall in the eastern Gippsland region. Strong winds and waves approaching coastline from the southeast Wind and wave effects can be intensified by the presence of a blocking high.

3.2 Wind

Wind speed and direction along the Victorian coast varies with the seasons. In general, during the winter winds tend come from a northern direction and from the south during summer. Topography can have a significant effect on local winds along the coast. For example: exposed locations such as Cape Nelson, Cape Otway, Wilsons Promontory and Gabo Island experience stronger wind speeds, and greater occurrences of extreme wind speeds than say Geelong or Melbourne.

The local prevailing wind moving across the sea can create wind waves that can result in higher sea levels as these arrive at the coast in combination with swell.

The Bureau of Meteorology[14] (BoM) presents average annual, seasonal and monthly rainfall for locations throughout Victoria, which have a wind record for at least 15 years. The wind roses are available from the BoM (Figure 3-2). It shows the frequency of occurrence of wind speed and direction. The wind roses are available for 9am and 3pm for individual months, seasonally and annually.

The wind roses are set up in a circle like a compass. When looking at it, the top represents north, the right represents east, the left represents west and the bottom south. As a "branch" extends along one of these directions, it indicates the wind was blowing from that direction, not towards it. The percentage of calm conditions is represented by the size of the centre circle, the bigger the circle, the higher the frequency of calm conditions. Speed ranges of 10km/h are used in the wind roses, and the length of the branch is proportional to the frequency of winds blowing within the corresponding range of speeds in that direction.

[14] Bureau of Meteorology (2021), *Wind roses for Australian sites*. bom.gov.au accessed 26th November 2021

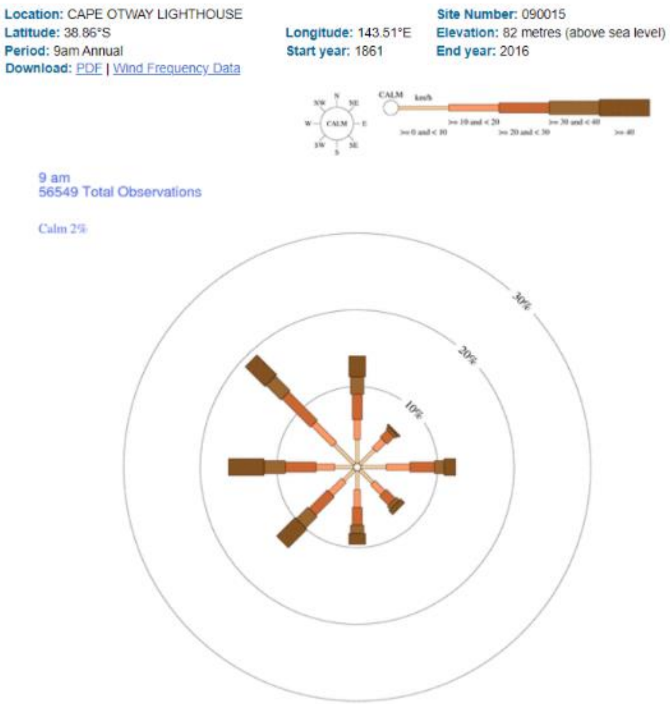

Figure 3-2 Annual Average Wind Speed and Direction at 9am Recorded at Cape Otway, Victoria

3.3 Air Temperature

Historically, the hottest month along the Victorian coast is February, with mean monthly temperatures ranging typically from 18 to 20°C, whilst the coolest is July, with mean monthly temperatures ranging from 10 to 11°C. Temperatures vary dependent upon location along the coast, which is largely attributed to the degree of protection from oncoming winds. For example, temperatures within Port Phillip and Western Port are higher than the more exposed locations such as Wilsons Promontory. Temperatures are also higher along the Gippsland coast than the remainder of the state due to the presence of the Great Dividing Range which blocks the warm, moist air resulting in a warming and drying on the downwind side. Also contributing is the East Australian Current, which brings warmer water into this area. There is a pattern of increase in mean air temperatures and an 11-year running mean of global average temperature anomalies (relative to the 1961–1990 average) (Figure 3-3)[15]. Whilst there is intra and annual variation, the overall historic trend is of increasing air temperatures.

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[15] Hope, P, Timbal, B, Hendon, H, Ekström, M, Potter, N. (2017). *A synthesis of findings from the Victorian Climate Initiative (VicCI)*, Bureau of Meteorology, 56pp, Australia

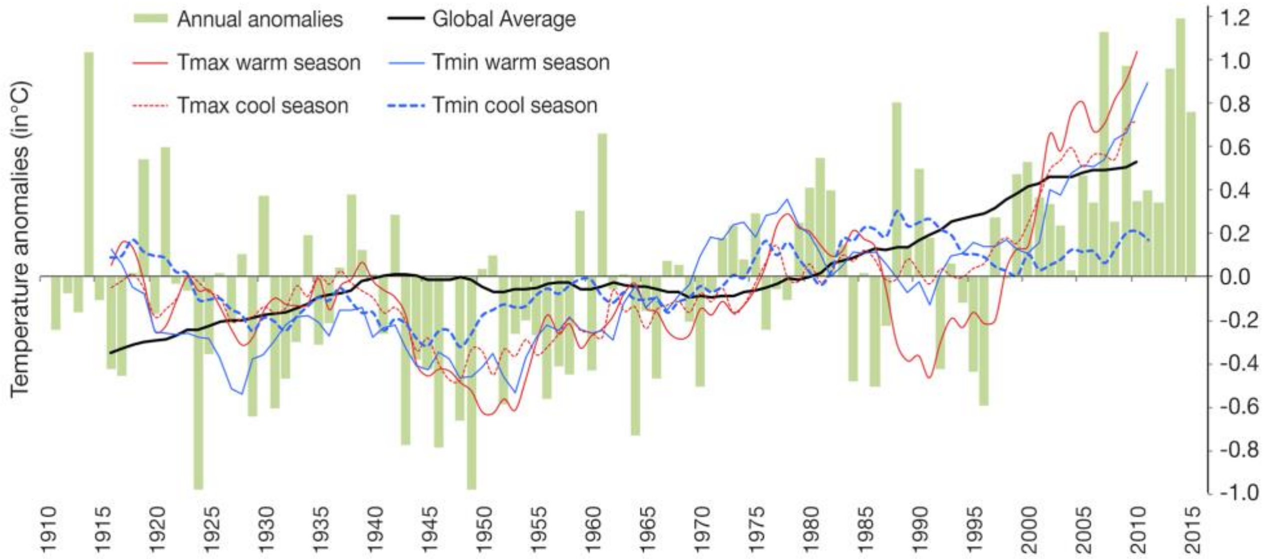

Figure 3-3 Annual Victorian Mean Air Temperature Anomalies (in °C) (relative to the 1911 to 2015 average) (Source: Hope, P., et al 2017)

3.4 Rainfall

Average annual rainfall varies widely from the east to west of Victoria. Rainfall is higher along the more mountainous Otway, South Gippsland and far-East Gippsland coasts. For example, average annual rainfall in Melbourne is about 650mm; Geelong has 520mm; Portland has 840mm and Mallacoota 940mm. In general, rainfall is higher during the winter months, and lower during the summer months. [15]

Interannual variability in rainfall is strongly linked to the climate influences and there are three key modes that affect rainfall in Victoria; the El Niño–Southern Oscillation, the Indian Ocean Dipole and Southern Annular Mode.

3.5 Ocean Systems

3.5.1 Bathymetry

The bathymetry offshore from the Victorian coastline in Figure 3-4 shows the central part of the coast forms the northern boundary of Bass Strait[16]. Here the water depths range typically from 50 to 80m. To the east and west, the continental shelf is much narrower and extends only 50 to 100km offshore. The depth here is between 100m to 200m. The Bassian Plain to the northwest of the Bass Strait sits around 75m to 100m deep. The coastal topography below 10m AHD (Australian Height Datum) is also included, showing the low-lying areas of coastal Port Phillip, Western Port, and the Gippsland region.

[16] Victorian Environment Assessment Council (VEAC) (2019). Assessment of Values of Victoria's Marine Environment Report May 2019. veac.vic.gov.au accessed November 2021.

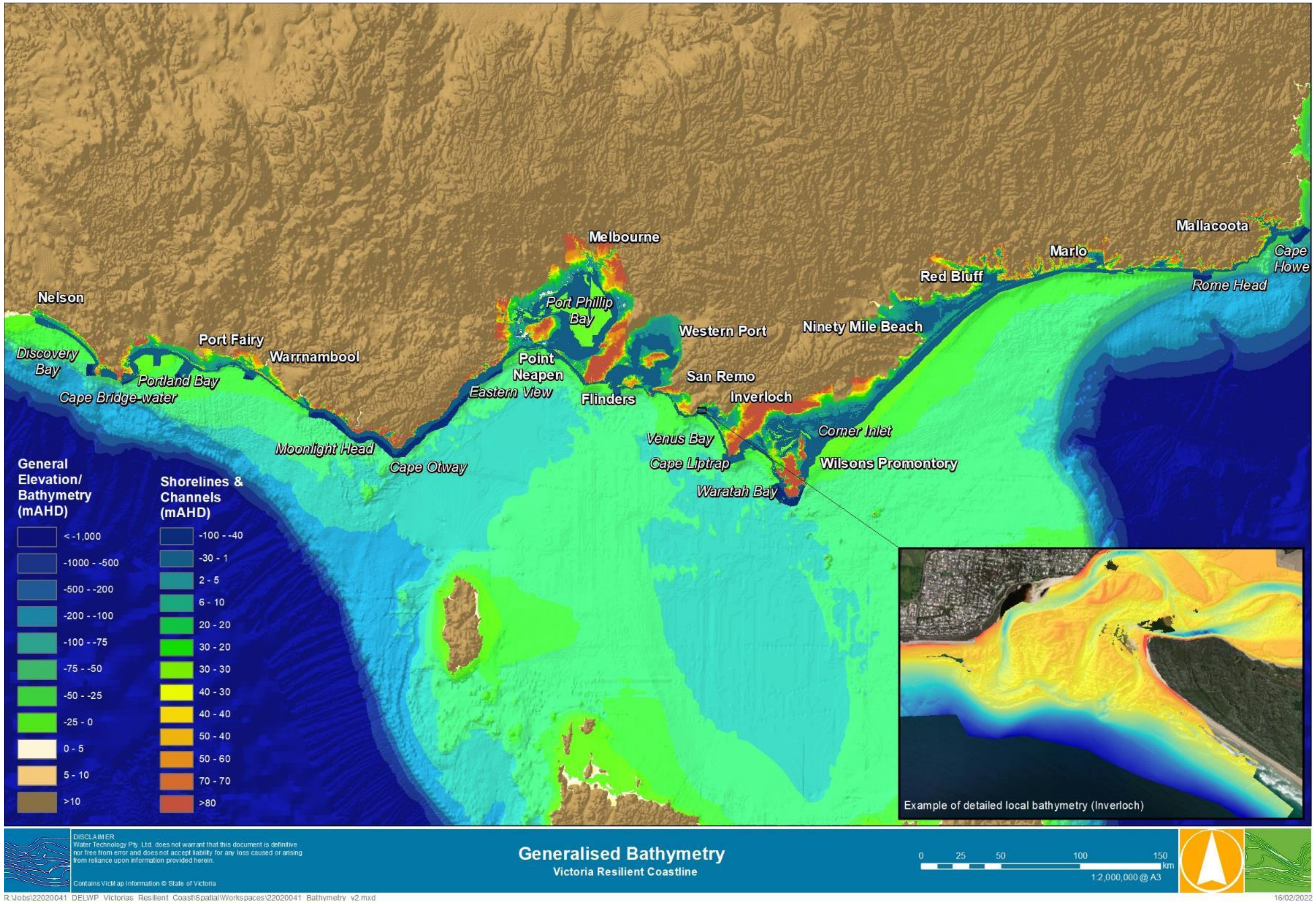

Figure 3-4 Generalised Bathymetry of Victoria Coastline (Source: VEAC 2019)

3.5.2 Waves

Wave heights and directions are strongly dependent upon the wind speed and the "fetch" (the distance over which the wind blows). Waves that are still under the influence of the wind that is generating them are generally termed wind-waves, while waves that have propagated away from their generation area are termed swell. At the latitude of Bass Strait (approximately 40º South), the west to east passage of successive low-pressure systems generate the prevailing westerly winds; the so-called "Roaring Forties". With long fetches to the west, these in turn generate high west and southwest wind-waves and swells that dominate the wave conditions along much of the Victorian coast.

So-called 'median wave conditions' drive the day-to-day environment. The median significant wave heights along the Victorian coast (where the significant wave height is the average of the highest one-third of waves) are shown in Figure 3-5.[17]

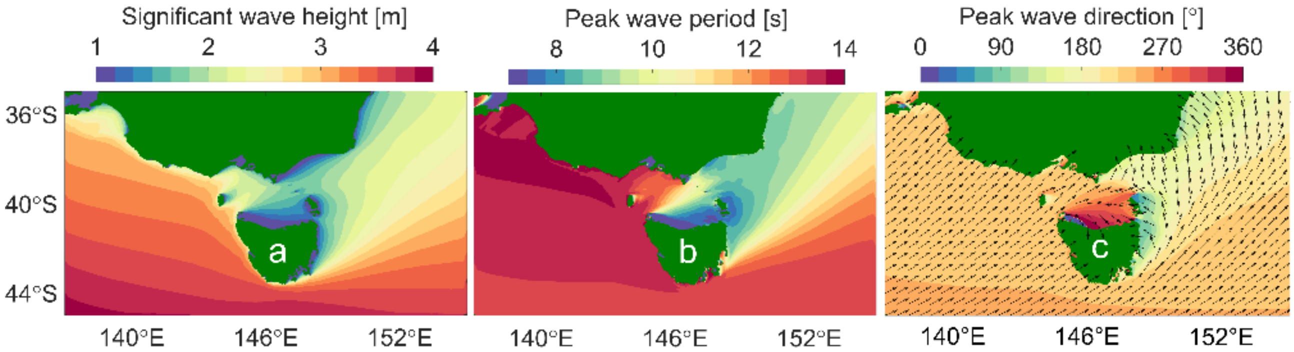

Figure 3-5 Model Predictions of Mean Wave Climate (from 1981 to 2020) a) Significant Wave Height, b) Peak Wave Period, c) Peak Wave Definition

- West: West of Cape Otway;
  - Dominated by high west to southwest wind waves and swells;
- Central: Between Cape Otway and Wilsons Promontory;
  - Cape Otway provides some protection from the prevailing westerly waves, and locally generated wind-waves contribute to the overall wave climate.
- Eastern: East of Wilsons Promontory;
  - Comprises locally generated south to southwest wind-waves, and east to southeast wind waves and swells propagating in from the Tasman Sea.
  - The highest waves are generated by extreme east to southeast winds associated with East Coast Lows.

Waves observed during storm events are key for cross-shore sediment transport (the main cause of discrete erosion events) as well for the design of coastal protection structures.

[17] DELWP (2021), Victorian Coastal Monitoring Program (VCMP). Unpublished.

3.5.3 Water Levels

3.5.3.1 Tide

The tide along the Victorian coastline is predominantly diurnal in the west (one tide per day), transitioning to semi-diurnal (two tides per day) along the central and eastern parts of the coast. Usually, one tide is bigger than the other. Representative tidal conditions[18] variability of the tidal range along the coast is provided in the table below. The tide in Port Phillip is significantly reduced by its narrow entrance to have a range of around 0.8m (Williamstown), while the tide in Western Port becomes amplified to have a range typically of 2.0 to 3.0m (Stony Point).

Table 3-2 Sea Level Across Victoria (m AHD)

Gauge Name	MHWS	HAT	Tidal Range (m)
Portland	0.44	0.69	<1
Apollo Bay	0.83	1.09	1.5 to 2.0
Lorne	0.81	1.27	1.5 to 2.0
Williamstown	0.42	0.52	1.0 to 1.5
Stony Point	1.11	1.56	1.5 to 2.0
Port Welshpool	0.95	1.65	1.1 to 1.9
Point Hicks	0.48	0.83	1.0 to 1.5

3.5.3.2 Storm Tides

Storm surges are generated by the combined effect of wind set-up and low atmospheric pressure that occurs during storms. The height of a storm surge is influenced by its timing in relation to astronomical tides. The most extreme sea levels are storm tide events, which occur when storm surges combine with high astronomical tides. Storm tide elevations for a 1% AEP (Annual Exceedance Probability) show the highest storm tide elevations are expected to occur in Western Port (in excess of 2.0m AHD), and eastern Bass Strait (up to 2.0m AHD).

[18] McInnes, K., Macadam, I. and O'Grady, J. (2009). The effect of climate change on extreme sea levels along Victoria's coast. Report for the Department of Sustainability and Environment. Marine and Atmospheric Research. CSIRO, Melbourne

Figure 3-6 Example of Storm Tide at the Entrance to Mordialloc Creek, 24th June 2014

Figure 3-7 Example of Storm Tide at the Entrance to Mordialloc Creek, 24th June 2014

3.5.3.3 Sea Level Rise

Sea level is predicted to rise with the increased temperatures associated with climate change. The increase will be due to a combination of thermal expansion of the upper layers of the ocean and an increase in ocean volume due to partial melting of glaciers and of the Greenland and Antarctic ice shelfs.

Global projections indicate sea level rise is expected to continue of approximately 0.1m every ten years in Victoria, i.e., 0.8m by 2100 based on the RCP8.5. Please refer to *Key Drivers of Change* for further climate change and sea level rise discussion.

3.5.4 Currents

Currents along the Victorian coast can be divided into three main categories:

- tidal currents;
- net through flows; and
- interactions with larger scale oceanic circulations (Figure 3-8).

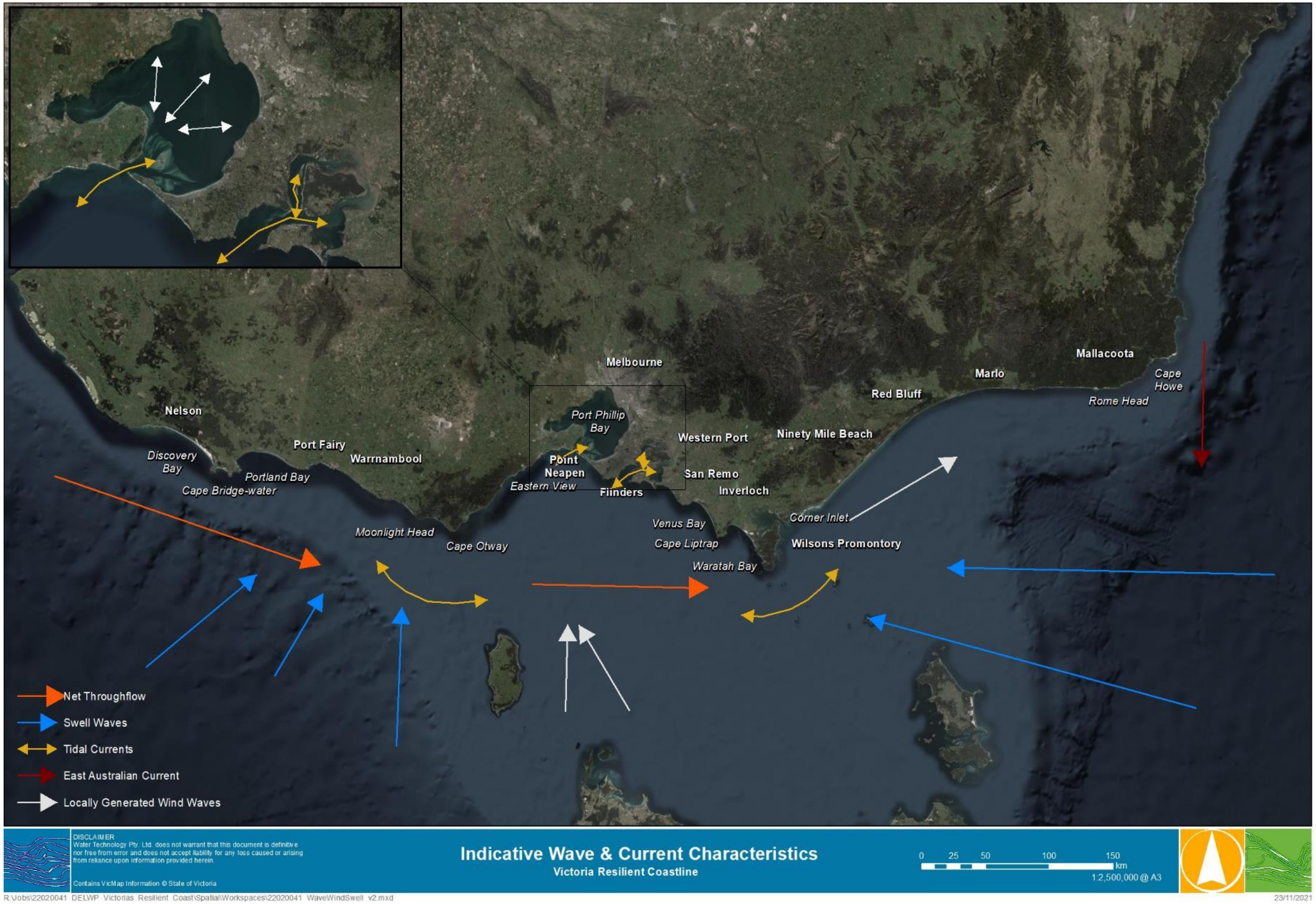

Figure 3-8 Indicative Wave and Current Characteristics

3.5.4.1 Tidal Currents

Tidal currents propagate into Bass Strait from both the west and the east. This results in the strongest tidal currents along the main coast occurring at Cape Otway and east of Wilsons Promontory.

The strongest tidal currents along the coast are, however, associated with the entrances and main channel systems of large tidal embayments, such as Port Phillip, Western Port, and Cornet Inlet. Strong tidal currents also occur at Lakes Entrance.

3.5.4.2 Net Throughflow

Net flows through Bass Strait are strongly linked with wind speed and direction. Although net flows can occur in either direction the greater proportion of westerly winds in the region result in a greater proportion of west to east net flows. Based on measurements carried out in autumn and winter, much of the west to east net flow occurs in surges lasting two to three days following the passage of a cold front through the region[19]

3.5.4.3 Swell Waves

Swell waves are ocean waves that travel beyond the area where they are generated. 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.

3.5.5 Sea Surface Temperature and Salinity

Sea surface temperature varies moving from the west to east along the coast by approximately 3 to 4°C. The seawater along the western and central sections of the Victorian coast tends to be relatively cold and more saline. Temperatures of around 13ºC in winter may increase to be around 17 to 18ºC in summer. However, temperatures can vary locally from beach to beach which is dependent upon position relative to the movement of water masses entering Bass Strait. For example, protected bays (such as Port Phillip) can have a much greater temperature range than the greater ocean surrounding the bay.

The eastern Victorian coast is affected by the East Australia Current. This is a warm relatively saline current that flows down the east coast of Australia. As it continues southwards from Gabo Island, it can flow west and south-westward to form a front of warm surface water off the Gippsland coast.

During winter, net east-going flows can form a down-welling or "cascade" of colder, and denser Bass Strait water down the eastern edge of the continental shelf[20]. During summer, upwelling of cold deep water can occur west of Portland. This is due to the presence of high-pressure systems and is known as the Bonney Upwelling[21]. The current sea surface temperature and salinity level at the time of writing is in Figure 3-9 and Figure 3-10.

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[19] Baines, P.G., Hubbert, G. and Power, S. (1991). *Fluid Transport through Bass Strait,* Continental Shelf Research, Vol. 11, No. 3.

[20] Tomczak, M. (1985). The Bass Strait Water Cascade during winter 1981, Continental Shelf Research, Vol. 4, No. 3

[21] DELWP (2012). Victorian Coastal Hazard Guide. Future Coasts Program, Melbourne

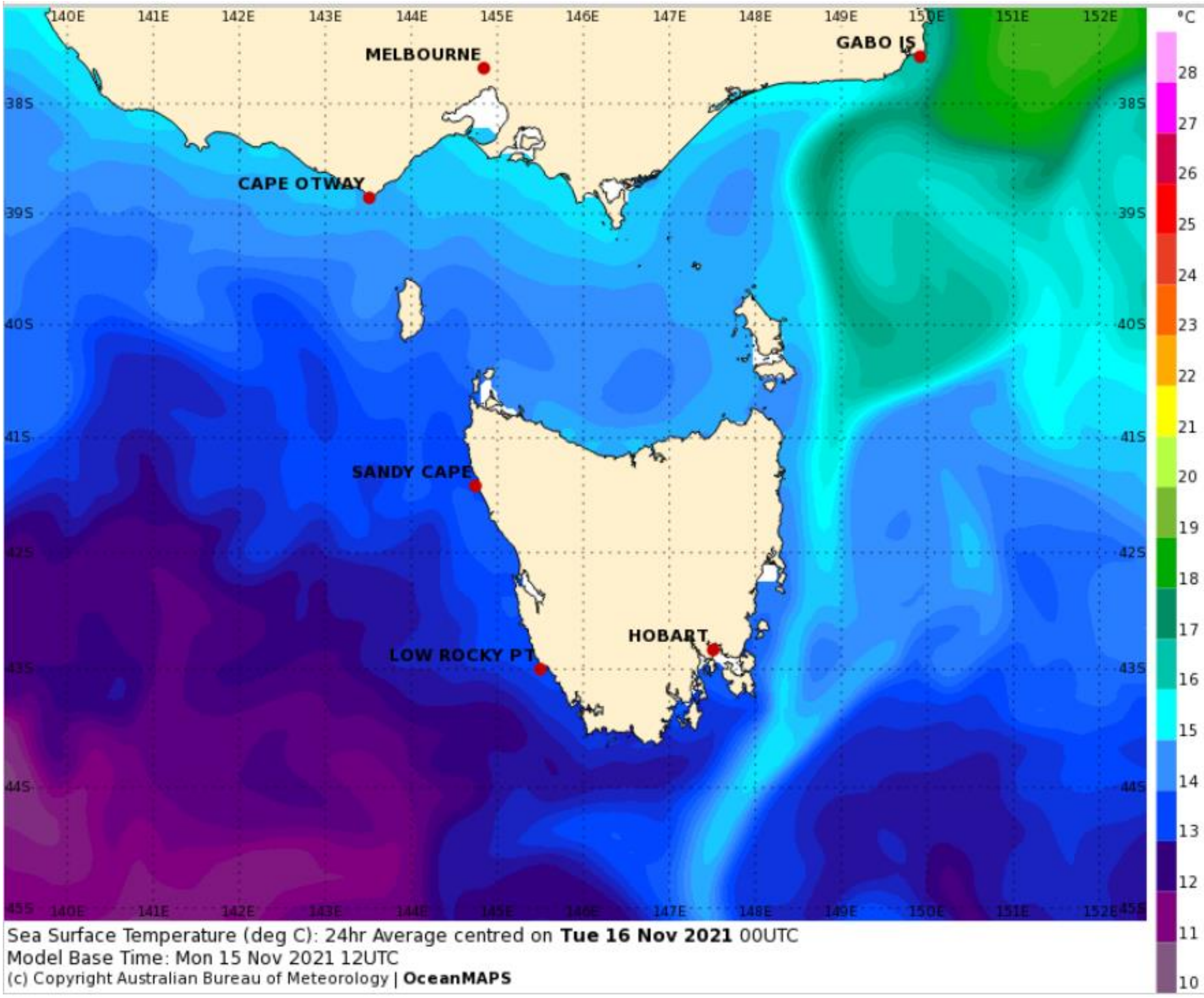

Figure 3-9 Example of Sea Surface Temperatures (deg C), taken on 16th November 2021 (Source: BoM, 2021)

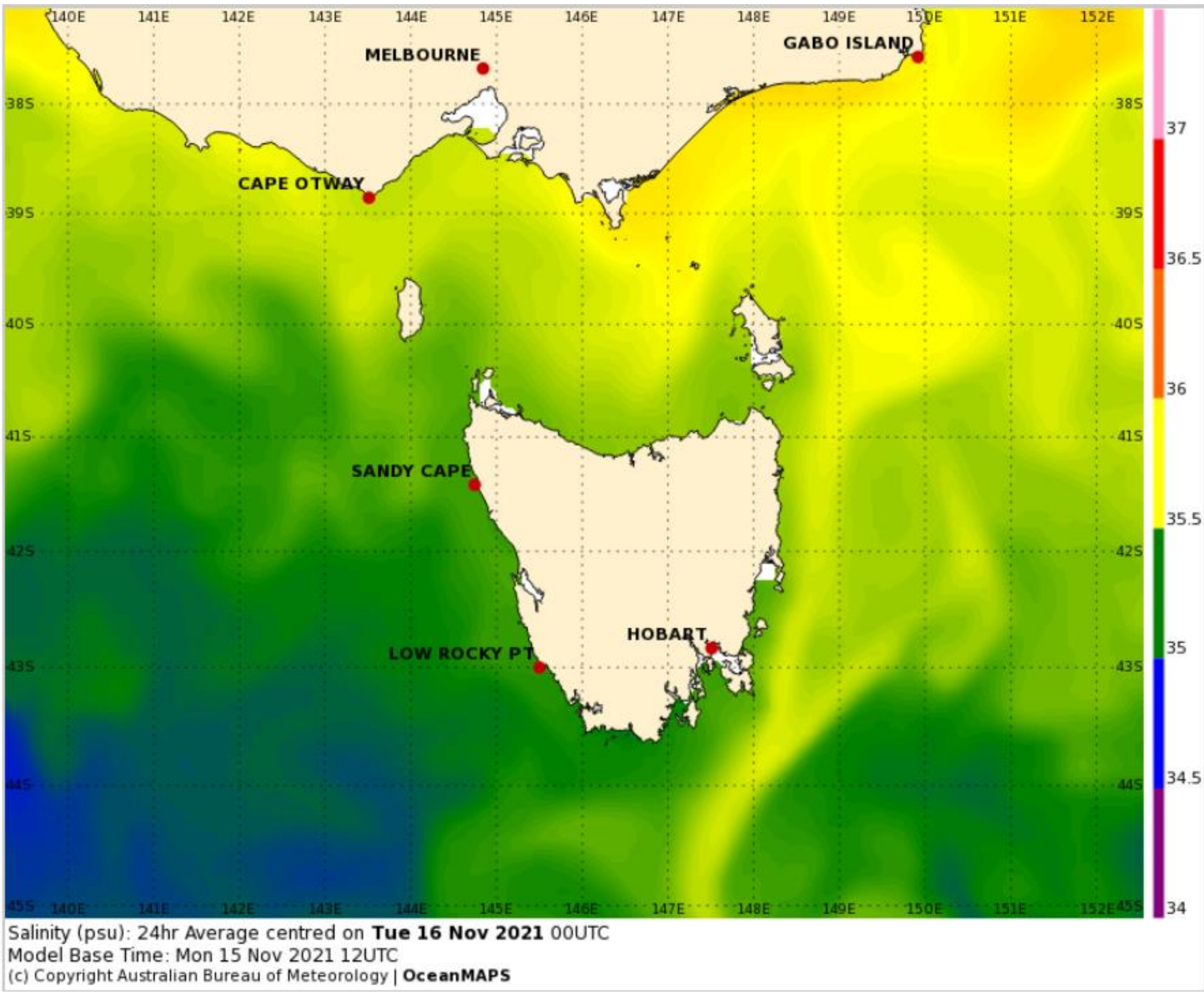

Figure 3-10 Example of Salinity Levels (psu), Taken on 16th November 2021 (Source: BoM Ocean Maps, 2021)

It is recommended that local data and investigations are undertaken for local coastal hazard and adaptation planning. Climate variability, and therefore oceanographic and geomorphological changes means that data collection and modelling is required to keep up to date via ongoing research, data collection and monitoring to ensure the long-term sustainable management of the marine and coastal zone.

3.6 Implications of Climate Change

Victoria's shoreline classes will respond differently to sea level rise, for example, some coastal shorelines will retreat landward, with others may experience accelerated erosion or block falls. Example impacts are described in Figure 3-11.

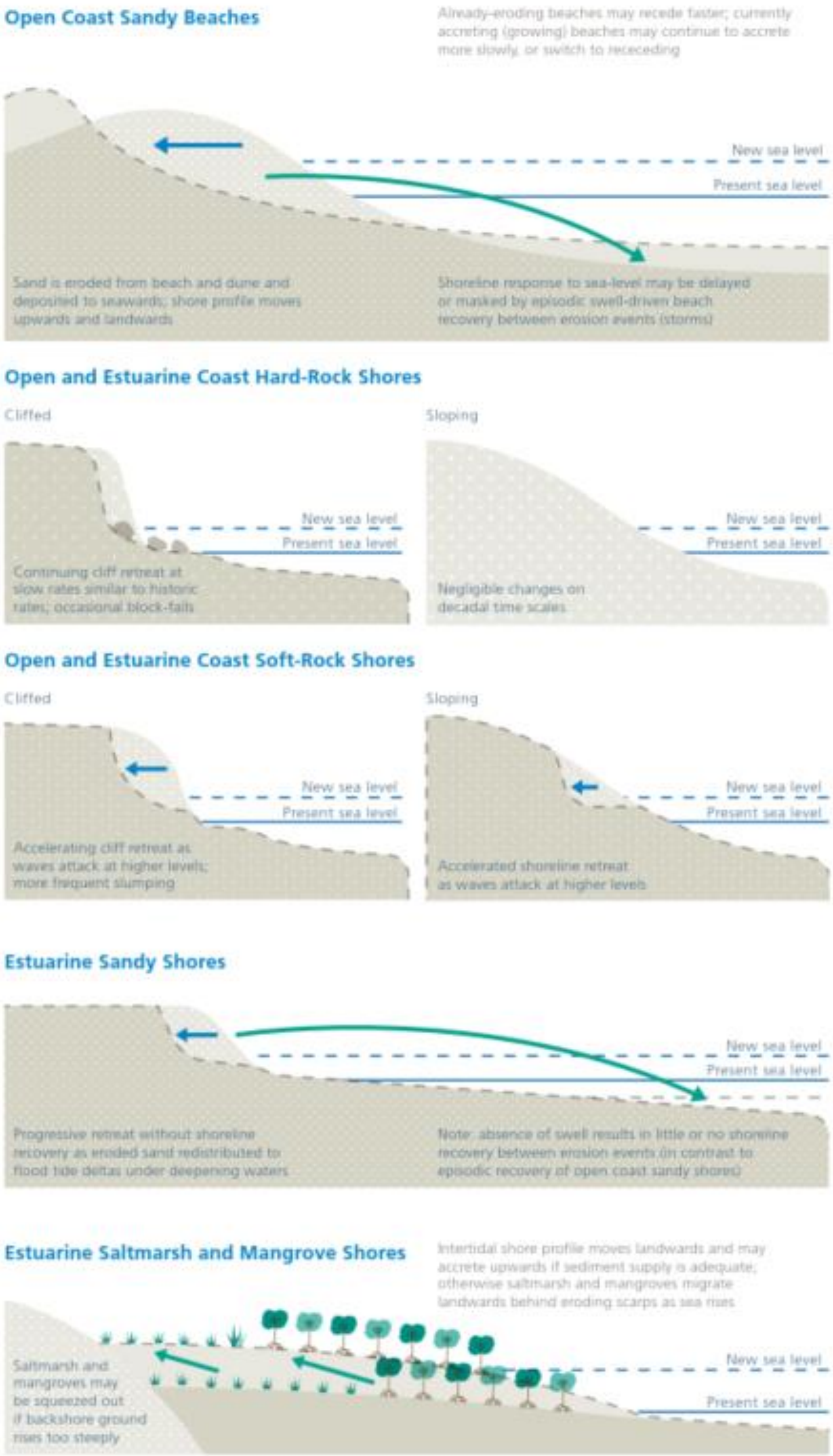

Figure 3-11 The Impact of Sea Level Rise on Various Coastal Environment Types (Source: DELWP 2012)

4 COASTAL HAZARD DEFINITIONS

4.1 Coastal Hazard Types

Natural physical and coastal processes that interact with the geomorphic setting continue to shape the marine and coastal environment.

At times, coastal processes including erosion, inundation, and other physical/chemical processes, may have an adverse impact on coastal values and uses. When this occurs, we often refer to these processes as coastal hazards.

> *When natural coastal processes have an adverse impact on coastal values and uses, we often refer to these processes as coastal hazards.*

It is important to consider the wide range of coastal hazards such as: inundation of coastal settlements, low lying areas and intertidal ecosystems, storms that erode beaches, damage infrastructure and coastal habitats, or the long-term erosion of the coastlines that threatens to erode sites and values of cultural significance.

Coastal hazard definitions typically focus on different forms of erosion and inundation and can include consideration of additional hazards such as saltwater intrusion to groundwater aquifers.

Definitions of coastal erosion, inundation and other coastal hazards vary nationally and for different Victorian locations and shoreline classes. This guide sets out ten (10) separate coastal hazards relating to both the process and physical setting or shoreline class (Table 4-1).

These hazard definitions provide a consistent basis to inform coastal hazard management and adaptation in Victoria. Exposure to these hazards, and associated consequence of exposure, is considered for a diversity of cultural, environmental, social, and economic values in adaptation planning.

The type of assessments required to identify these coastal hazards will depend on the scale of the assessment, shoreline type, specific place-based needs, and complexity of the potential risks. Some additional hazard types may also be included in specific place-based assessments.

Table 4-1 Coastal Hazard Definitions

Category	Process / hazard	Setting/classes include:		Mechanisms
Erosion	Short-term erosion: Event-based erosion of sediment (storm-bite) and recovery Long-term erosion (recession): Progressive	Hard rock	Hard rock cliffs are consolidated rock formations shaped by marine and sub-aerial processes, and are of highly varied form and profile Key variants include: ▪ Hard rock cliff and shore platform; ▪ Hard rock cliff with a sand/gravel beach;	Erosion associated with terrestrial processes and wave action causing weathering, undercutting, slope failures (landslip) and cliff-falls.

Category	Process / hazard	Setting/classes include:		Mechanisms
	retreat of shoreline position over time		■ Plunging cliff without a shore platform; ■ Steep coastal slope and basal cliff; and ■ Coastal bluffs.	
		Soft rock	Soft rock coasts (e.g., limestone, clay) can occur on open coasts and within embayments. Soft rock cliffs are subject to similar sub aerial and marine processes and experience continuous to intermittent marine erosion. The key variants include ■ Soft rock with a shore platform; and ■ Soft rock with a beach.	Erosion associated with combined terrestrial processes and wave action causing weathering, undercutting, slumping, slope failures (landslip) and cliff-falls.
		Sandy shorelines	Sandy shorelines are formed from a combination of terrestrial and marine-derived sediments. Sandy coasts occur on open coasts and in embayments. The key variants include: ■ Barrier/ spit systems; ■ Beach ridges systems; and ■ Pocket beach systems.	Erosion generally associated with storms or with elevated water levels. Can be driven by ocean or localised wind waves or tidal currents, as well as overland flow/drainage. Susceptible to short and long-term erosion.
		Low-earth scarp	Low earth scarps typically develop in lower wave energy environments and comprise of a wide intertidal flat or silty sand or peats and muds with a sparse distribution of mangroves. These landforms a have low elevation and often leveed. Key variants include: ■ Low earth scarp with an intermittent, narrow sandy beach; and ■ Low earth scarp of soft sediments of poorly consolidated and unconsolidated peat, alluvium or organic material.	Erosion primarily associated with a low active scarp cut into soft, poorly consolidated sediment. May also be influenced by overland flow and drainage. Erosion is typically long-term recession.

Category	Process / hazard	Setting/classes include:		Mechanisms
Accretion	Build of sediment in a localised area	All shoreline types	Accretion is the process of sand deposition, instead of erosion and builds up over time. Accretion typically occurs during the calmer seasons. Beach accretion is generally a more gradual process than beach erosion, and may be short term, long term, or episodic	Localised build-up of sand, typically driven by long-shore sediment transport and well as influenced by erosion processes.
Inundation	Permanent inundation Regular or persistent inundation by the regular tidal cycle	All low-lying coastal land	Permanent inundation occurs when low-lying areas become regularly inundated as part of the local tidal cycle, up to and including the Highest Astronomical Tide (HAT). Increases in mean sea level over time will influence the extent of permanently inundated areas.	Occurs when low-lying areas are regularly flooded due to tidal processes. Understanding the scale of inundation and associated impacts is required over various sea level rise scenarios.
	Storm tide inundation Temporary event-based inundation	All low-lying coastal land	Storm tide inundation is the total elevated sea height at the coast during a storm, combining storm surge and the predicted tide height. Storm surges are caused by the combination of low pressure and high winds associated with a severe storm.	Caused by a combination of predicted tides, storm-surges, and high wave action during severe storm events. Results in elevated water levels (storm surge), wave setup and wave runup causing overtopping and inundation.
Estuary dynamics	Changes in form and processes associated with estuarine and tidal areas	Estuary / tidal areas	A partially enclosed coastal waterway that is influenced by tides and coastal processes; a zone where freshwater mixes with salt water. Estuary systems may be permanently or periodically open to the sea. These can include several variants: ▪ Estuaries, Intermittently, Open and Closed Lakes or Lagoons (ICOLLs), ▪ River or creek mouths, ▪ Coastal lakes; and ▪ Natural or constructed drains.	Highly dynamic sediment environment in response to tides, sea level, storm events and catchment runoff. Resultant variations in channel alignments, sandy spits and entrance opening and closure.

Category	Process / hazard	Setting/classes include:		Mechanisms
Off-shore sediment dynamics	Changes in form and processes associated with offshore bathymetry and sediment transport	Up to 3 nautical miles offshore	Off-shore environment beyond the intertidal zone, including the bed beyond the intertidal zone up to three nautical miles, or 5.5 kilometres off-shore. The offshore environment includes: ■ Bathymetric features; ■ Tidal channels; ■ Sediment dynamics; and ■ Supported ecosystems.	Dynamic submarine sediment transport environment offshore, influenced by tides, sea level, and storm events. Resulting variations in sea-bed bathymetry and sediment dynamics.
Saline intrusion	Saline intrusion Movement of saltwater into freshwater areas / groundwater	Up to 5km inland from high water mark	Saline intrusion can occur in many ways, including vertical movement of the water table, and lateral movement of coastal waters. May occur in coastal wetlands, freshwater aquifers, springs, and systems in low-lying coastal areas	Rising sea levels may result in movement of seawater inland, including elevated groundwater and extension of salt water

4.2 Coastal Hazard Descriptions

4.2.1 Erosion

Coastal erosion is the process of winds, waves and coastal currents shifting sediment away from a localised area of the shoreline.

Short-term erosion (storm bite) is erosion that occurs on a short-term basis, often during a storm. The shoreline and beach then gradually regain sediment (rebuilds).

Long-term erosion (recession or retreat) is a continuing movement of the shoreline position in a landward direction, occurring either gradually over many years, or when the shoreline does not recover following a short-term erosion event.

The approach to defining coastal erosion hazard zones is based on the identified shoreline class. There are four types of discrete shoreline class that have been used to help define the erosion hazards that impact the Victorian coastline; **sandy shoreline, low-earth scarps, soft rock and hard rock** (Table 4-2).

Engineered structures may be present within the identified shoreline class that may impact upon sediment dynamics.

Table 4-2 Erosion Hazard Description

Category	Process / hazard	Setting/classes include:		Mechanisms
Erosion	Short-term erosion: Event-based erosion of sediment (storm-bite) and recovery	Sandy shorelines	Sandy coast/embayments, beach ridge systems, barrier systems, and sandy spits.	Erosion generally associated with storms or with elevated water levels. Can be driven by ocean or localised wind waves or tidal currents, as well as overland flow/drainage. Susceptible to short and long-term erosion.
	Long-term erosion (recession): Progressive retreat of shoreline position over time	Low-earth scarp	Wide intertidal flats, silty sand or peats and muds. Narrow sandy beach may exist.	Erosion primarily associated with a low active scarp cut into soft, poorly consolidated sediment. May also be influenced by overland flow and drainage. Erosion is typically long-term recession.
		Soft rock	Soft rock cliffs with and without a beach.	Erosion associated with combined terrestrial processes and wave action causing weathering, undercutting, slumping, slope failures (landslip) and cliff-falls.
		Hard rock	Hard rock cliffs with and without a beach.	Erosion associated with terrestrial processes and wave action causing weathering, undercutting, slope failures (landslip) and cliff-falls.

4.2.1.1 Erosion of Sandy Shorelines

Sandy shorelines are formed from a combination of terrestrial and marine-derived sediments. Sandy coasts occur on open coasts and in embayments. The location and form of sandy shorelines, which includes beaches, sandy ridges and spits and dunes on open and embayed coasts, are dependent on both ongoing trends and long-term cyclical fluctuations in sea level, coastal sediment supply or climatic cycles (Figure 4-1).

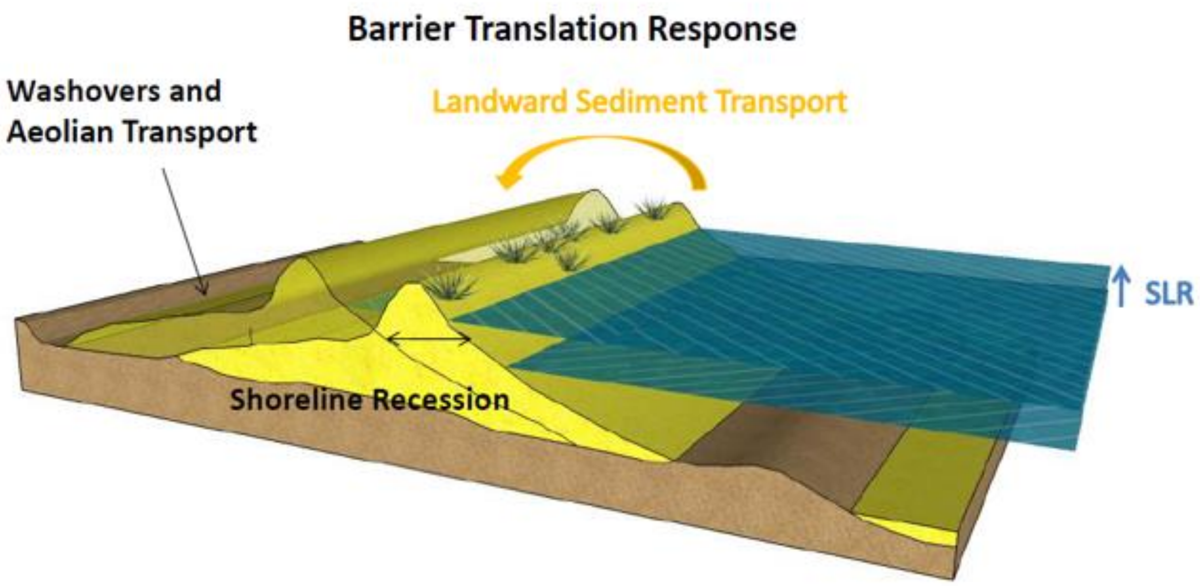

Figure 4-1 Conceptual Model of 'Sandy Shorelines' Shoreline Class

Erosion of this shoreline class is usually associated with storms or with elevated water levels and can occur on the open coast. Longshore transport of sediment along the coast relates to the currents and prevailing winds and can lead to longer term erosion if there is a net sediment supply deficit. In Victoria, longshore transport trends are variable and seasonal with beaches rotating between summer and winter profiles. There are often sand lobes that represent intermittent inputs of longshore sediment into the system. Generally, the mechanisms or frequency of some of these features are yet to be defined and require further research.

Short term erosion events are often interspersed with a recovery phase when sediment moves back onshore to rebuild as sand from offshore is slowly reworked onshore. 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.

Erosion of sandy shorelines which are not exposed to the ocean wave climate are driven by tidal currents and smaller wind waves. Sandy shorelines on the open coast are likely to respond to sea level rise via upward and landward movements which are commonly termed recession whereby material is eroded from the upper beach and deposited offshore. The increase in sea level results in landward recession of the shoreline.

4.2.1.2 Erosion of Low Earth Scarps

Low earthed scarps are common in low energy environments like Anderson Inlet and Western Port. Erosion processes are similar to soft rock coastlines, with surface processes and undercutting due to waves driving shoreline recession (moving its position further landward). The recovery (rebuilding) of a low earthed cliff is limited by the available sand in nearshore areas or being moved along the coast. These coastlines are likely to be more susceptible to rising sea levels than rocky coastlines. Being lower in elevation, sea level increases may inundate the landward edge of the cliff, leading to long-term erosion (landward recession) of the coastline (Figure 4-2 and Figure 4-3).

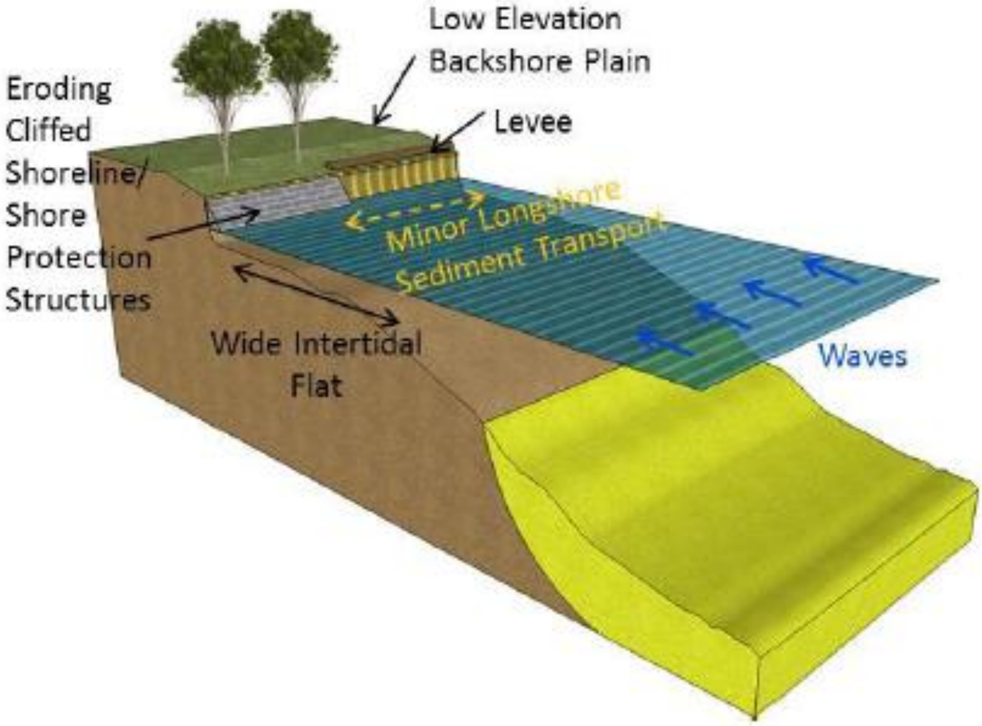

Figure 4-2 Conceptual Model of the 'Low Earth Scarp" Shoreline Class

Figure 4-3 Typical Erosion of Low Earth Scarps from Western Port, Victoria

4.2.1.3 Erosion of Hard Rock Shorelines

Hard rock cliffs are consolidated rock formations shaped by marine and sub-aerial processes and are of highly varied form and profile.

Over geological timescales (thousands of years), softer sediments are eroded away, exposing hard rocky coasts. These coasts are more common in areas of high energy (strong wave action). Hard rock cliff slopes are susceptible to deep-seated mass movements (i.e., cliff fall or landslide) that may be initiated by a combination of surface processes (rain, surface runoff) and/or due to marine influences at the base of the cliff (e.g., toe undercutting). Hard rock erosion can occur with little or no warning.

Where a sandy beach is 'perched' on a rock platform at the base of a cliff, increasing sea levels and wave energy can result in sand loss, due to limited sand volumes and increased wave reflection off the rocky coast (Figure 4-4).

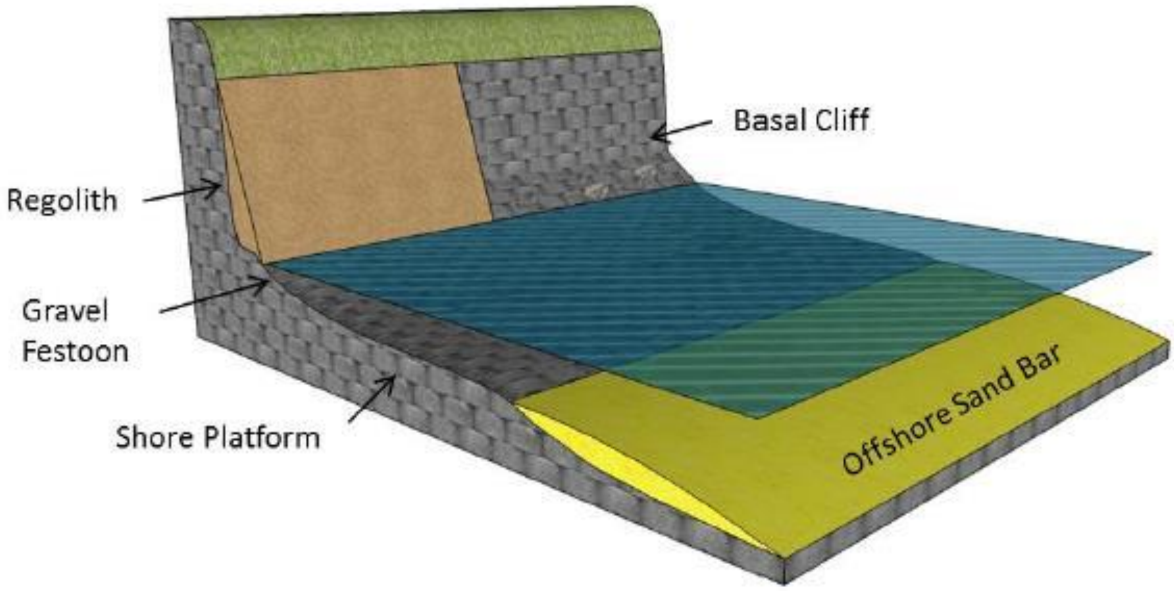

Figure 4-4 Example of Hard Rock Cliff Conceptual Shoreline Class

The rates of change on these shorelines are generally highly episodic and may be associated with extremes of wet and dry climatic conditions and phases of strong wave attack and elevated coastal water levels. The rates of change are also highly variable laterally and vertically based on the resistance and other properties of the rock formations

Mass movements, landslides or slope failures are the most significant process for assessment of the potential extent of hazards along these shorelines. These can occur due to variety of mechanisms including rotational and translation slips, soil creep, and rock slides. Detailed, site specific knowledge of the geology, geomorphology, hydrogeology and the soil and rock mechanics is required to assess the site-specific soil and rock slope stability and potential failure mechanisms on these shorelines.

Landslides are the most common after bushfires or flooding. Landslides can carry debris such as boulders and trees downhill and can cause significant damage to buildings and be dangerous to anyone in the area. The gradient of the land impacts the risk of a landslide occurring, and there is a greater risk if the burnt area is on steep land, however other factors such as the structure of the rocks below the surface need to be considered[i22].

Landslides have been a regular event in the natural evolution of landscapes in the Corangamite Region over the past several million years.

The Otway Group rocks which mostly consist of sandstones and mudstone are regarded as the most landslide-pone of the geological units that are in southwest Victoria. The occurrence of landslides as a result of climate change, are expected to increase as a result of the increased risk of bushfires and flooding occurring.

Figure 4-5 Example of Hard Rock Cliff Mass Movement Erosion on the Upper Slopes Including Rotational Sliding Develops a Concave Profile Above a Steep Lower Slope Shaped by Joint Orientation (Source: N Rosengren, 2013)

4.2.1.4 Erosion of Soft Rock Shorelines

Soft rock coasts (e.g., limestone, clay) can occur on open coasts and within embayments. Soft rock cliffs are subject to similar sub aerial and marine processes and experience continuous to intermittent marine erosion.

Soft rock shorelines comprise of steep slopes that are generally exposed with a sandy beach or platform at the base (Figure 4-6). A range of sub-aerial processes contribute to erosion of the high soft rock cliffs including groundwater pore pressure and seepage, shrink-swell detachment, and chemical interactions with the soil material which contribute to slope failure through block or slumping type movements.

[22] State Emergency Service (2021). Landslides – Take action and stay safe. Available: www.ses.vic.gov.au/

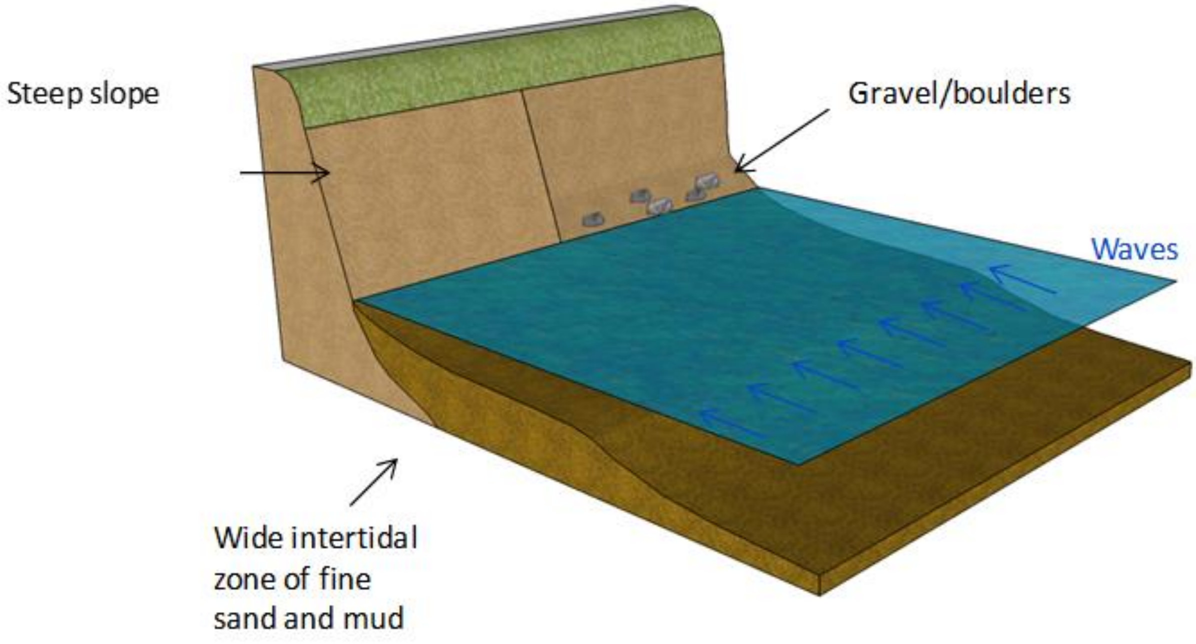

Figure 4-6 Example of Soft Rock Conceptual Shoreline Class

Surface runoff and rain impact can affect the stability of the cliff face through mechanisms such as sheet flow across the surfaces or concentrated runoff that produce rills and drainage gullies which indent the cliff surface. Mass movements and landslides can be exacerbated by the occurrence of bushfires which, due to the loss of plants and roots from bushfire damage, which leaves the ground soft and heavy, leading to a greater chance of a landslide occurring.

Wave action is also a significant process for change on these shorelines. Intermittent wave action at the toe of the cliff can create notches in the cliff face which undermine upper layers of the cliff face which subsequently topple onto the platform beach at the base of the cliff.

This shoreline class also include bluffs or slopes where the cliff is currently out of the dynamic coastal zone, but it is close enough thus that it could be activated in the future under higher sea levels. Future rates of cliff erosion could be expected to vary subject to the amount of wave energy at to the toe of the cliff, although sub-aerial processes will still significantly influence future rates of cliff erosion on these shorelines[23] (Figure 4-7).

[23] Rosengren, N., (2013). Image provided for Victoria's Resilient Coast.

Figure 4-7 Erosion of Soft Rock Cliffs at Red Bluff (Source: N Rosengren, 2013)

4.2.2 Accretion

Accretion is the process of sand deposition, instead of erosion and builds up over time. Accretion typically occurs during the calmer seasons. Beach accretion is generally a more gradual process than beach erosion, and may be short term, long term, or episodic (Table 4-3).

Changes to the elevation of the sea bed caused by accreting sediments can create a hazard for associated environmental, cultural and economic values. For example, deposition around marine and coastal infrastructure such as in harbours or upon boat ramps. Accreting sediments may smother and impacting seagrass ecosystems, cause sedimentation of estuary systems and/or navigation channels.

Table 4-3 Accretion Process Description

Category	Process / hazard	Setting/classes include:		Mechanisms
Accretion	Build of sediment in a localised area	All shoreline types	Shoreline, dunes and intertidal zone	Localised build-up of sand, typically driven by long-shore sediment transport and well as influenced by erosion processes.

4.2.3 Inundation

Generally, hazards in this category are from the temporary or permanent inundation of low-lying land. This includes coastal inundation from tidal process and overtopping or breaching of dunes, coastal barriers, beach access points or protection works; and/or via rivers, streams or stormwater outlets. Inundation of low-lying land also occurs from heavy rainfall when natural watercourses do not have capacity to carry excess water, this is known as catchment flooding. For the purposes of this guide, inundation refers to either permanent inundation by regular tidal cycles or temporary event-based inundation caused by storm tides (Table 4-4).

Table 4-4 Inundation Hazard Description

Category	Process / hazard	Setting/classes include:		Mechanisms
Inundation	Permanent inundation Regular or persistent inundation by the regular tidal cycle	All low-lying coastal land	Low-lying shoreline areas, coastal floodplains, estuary margins	Occurs when low-lying areas are regularly flooded due to tidal processes. Understanding the scale of inundation and associated impacts is required over various sea level rise scenarios.
	Storm tide inundation Temporary event-based inundation	All low-lying coastal land	Low-lying shoreline areas, coastal floodplains, estuary margins	Caused by a combination of predicted tides, storm-surges, and high wave action during severe storm events. Results in elevated water levels (storm surge), wave setup and wave runup causing overtopping and inundation.

4.2.3.1 Storm Tide Inundation

Storm tide inundation is the total elevated sea height at the coast during a storm, combining storm surge and the predicted tide height. Storm surges are caused by the combination of low pressure, high winds and wave energy associated with a severe storm.

Low-lying areas are temporarily inundated which can be worsened by being combined with catchment flooding during a rain or high flow event. Storm tide inundation results in elevated water levels (storm surge), wave setup and wave runup which may result in risks to public safety, property damage, loss of accessibility to coastal communities, groundwater contamination and accelerated coastal erosion. The components that are included in the calculation of storm tide inundation are shown conceptually in the image below[24].

[24] DEWLP (2012). Victorian Coastal Hazard Guide. Future Coasts Program, Melbourne.

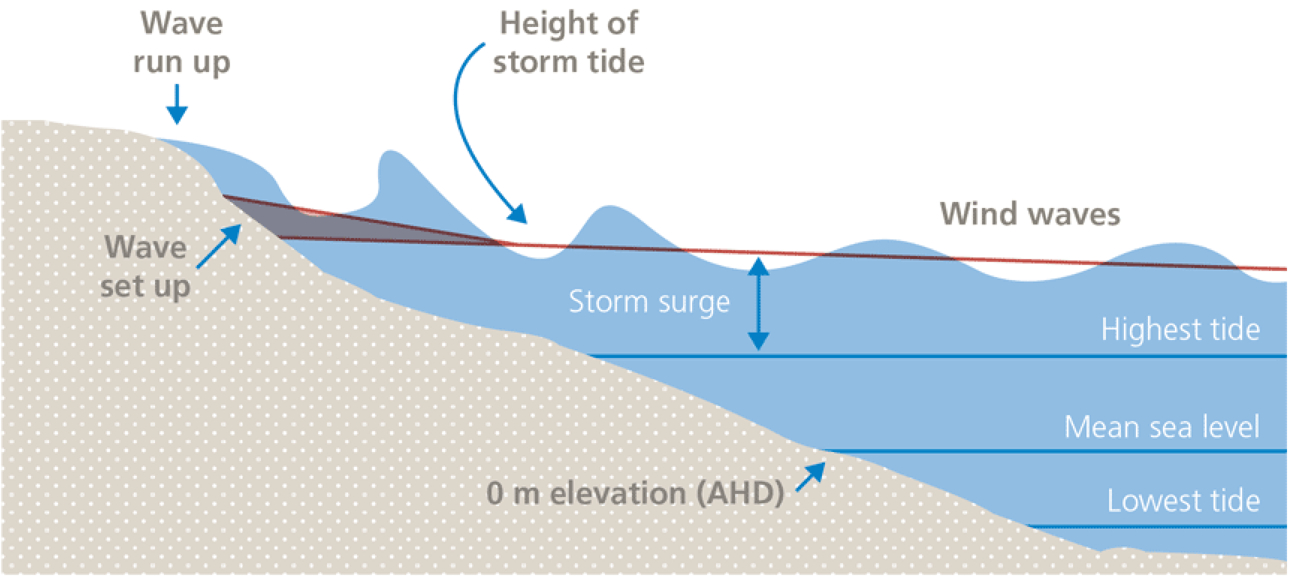

Figure 4-8 Defining a Storm Tide Event (Source: DELWP)

Storm tide events can cause overtopping and inundation along shorelines with low-earth scarps, estuaries and sandy coasts which are most susceptible due to their proximity to tidal inundation, and the frequent movement of transportable sediment from these environments. While soft rock cliffs may be topographically higher than low-lying areas, both soft rock and hard rock coasts can also be inundated, depending on the storm-tide event or sea level rise extent.

The interaction of catchment flooding and coastal processes is an important consideration in determining overall flood risk in coastal waterways. The influence of these two factors on flooding varies with ocean level, due to both tidal fluctuations and storm impacts, the condition of the entrance interface between the coastal waterway and the ocean, distance from the ocean, and the size and shape of the waterway and catchment draining to the entrance.

Catchment flooding and storm-tide inundation events operating during the same meteorological event is known as a coincident event. It is common that both extreme rainfall and extreme storm surge will be driven by these same meteorological processes, therefore these two factors are considered dependent. Statistically, in Victoria, the level of dependence of both storm surge and catchment flooding is considered low in comparison to the rest of Australia. This is discussed further in Key Drivers of Change.

Figure 4-9 Example of a Storm Surge Event at Port Fairy (Source: Moyne Shire Council[25])

4.2.3.2 Permanent Inundation

Permanent inundation occurs when low-lying areas become regularly inundated as part of the local tidal cycle, up to and including Mean High Water Springs (MHWS) or Highest Astronomical Tide (HAT). Increases in mean sea level over time will influence the extent of permanently inundated areas.

There are two types of impacts: permanent inundation forming a new shoreline and the increased risk to assets due to their increased exposure to inundation. This is increasingly important for embayments or estuaries which are permanently connected to the ocean. Understanding the impacts of permanent inundation on environmental, social, cultural or economic values is a critical issue in the to the management of impacts relating to sea level rise.

In addition to the recession of the shoreline because of increased wave energy on the soft shore and backshore material, there is likely to be a landward translation due to permanent tidal inundation of low lying land. Low-earth scarps, estuaries and sandy rock coasts are most susceptible to inundation, due to their proximity to tidal inundation, and the frequent movement of transportable sediment from these environments.

[25] DELWP (2012) Victorian Coastal Hazard Guidelines. Future Coasts Program.

While soft rock cliffs may be topographically higher than low-lying areas, both soft rock and hard rock coasts can also be inundated, depending on the extent of sea level rise.

Coastal wetlands and lakes which receive intermittent tidal fluctuations may be permanently impacted by sea level rise as will the habitats that provide a wide range of ecosystem services. In response, coastal wetlands and the fringe shorelines are likely to migrate landward to higher elevations where land is available (Figure 4-10). Inevitably as this migration of the intertidal zone reaches natural and man-made barriers there will be an element of coastal 'squeeze' with the loss of habitats.

The inundation of the tide along the estuarine and tidal channels is determined by the channel and the elevation of low-lying areas adjacent to the tidal channels. In many instances, drains and associated embankments and levees have been constructed to limit the extent of tidal inundation in low lying swampy areas adjacent to tidal and estuarine channels. Where the tidal channel is crossed by a road or highway, culverts are often present that can throttle the spread of the tide further along the channel and into low backshore swamp zones.

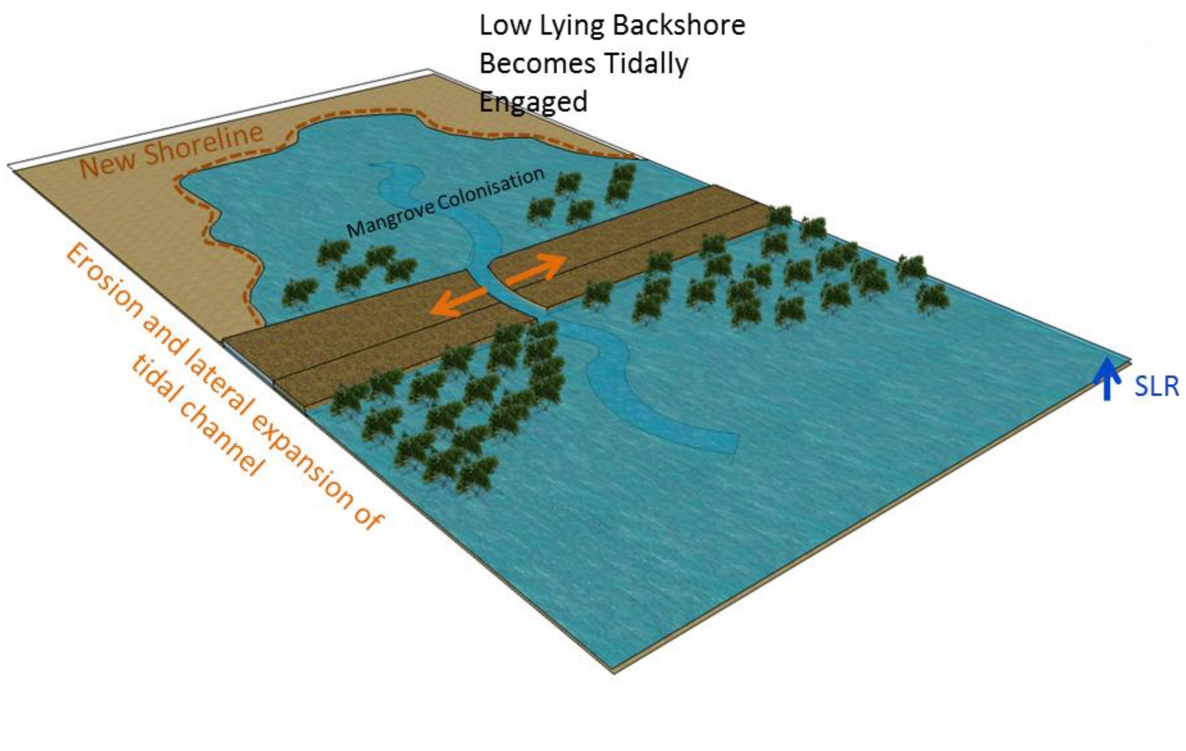

Figure 4-10 Response of Estuarine Environment and Tidal Channel to Permanent Inundation Associated with Sea Level Rise

Permanent inundation is likely to have increased impacts on environmental, cultural, social and economic values with incremental sea level rise as the landward extent of inundation increases. For example, coastal communities are likely to experience inundation of roads, property and/or infrastructure on an increasingly regular basis. Over time the regular tidal levels are likely to become similar in magnitude to present day storm tide levels (Figure 4-11)[26].

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[26] Lauchlan Arrowsmith, C (2022). Guidelines for Modelling the Interaction of Catchment Flooding and Oceanic Inundation, Report prepared for the Glenelg Hopkins Catchment Management Authority.

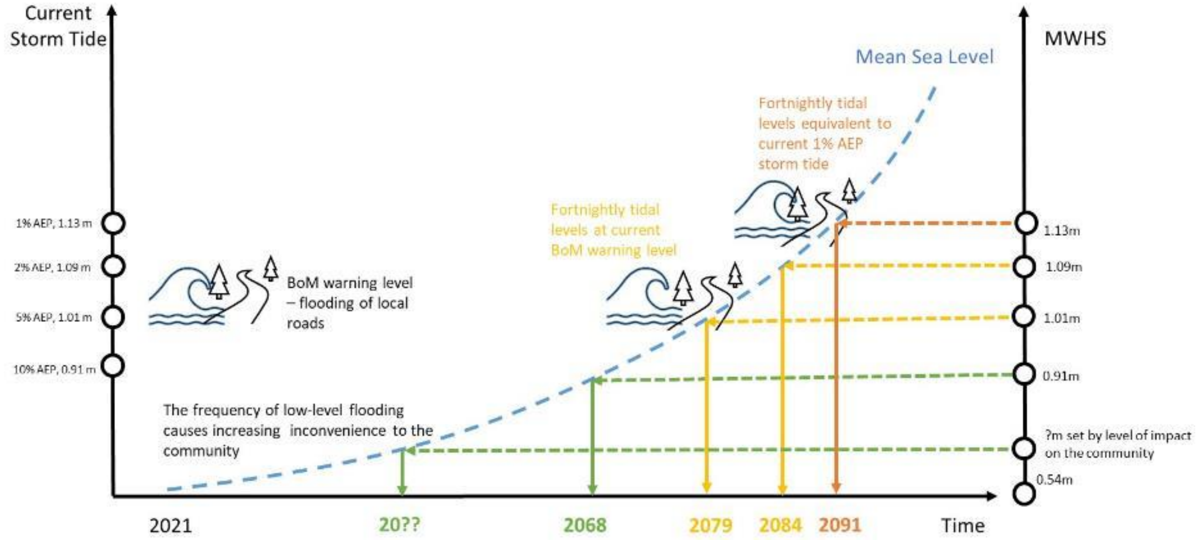

Figure 4-11 Comparison of MHWS Levels to Current Storm Tide Level in Port Fairy (Source: Glenelg Hopkins CMA).

4.2.4 Estuary Dynamics

Estuaries and tidal channels are dynamic and occur across a range of landscape settings such as embayments and drowned river valleys, wave or tidally dominated estuaries & deltas, coastal lagoons and creeks, tidally dominated estuaries and deltas; and tidal creeks and drain. Estuaries can be permanently open or intermittently open and closed, they are dynamic and sensitive to localised catchment and coastal processes.

Changes in dynamic estuary processes may have an adverse impact on associated estuary values and uses, creating a hazard. Highly mobile sediments can impact upon water quality, ecosystem health and fluvial flood hazards within the estuary or coastal lake and are constantly changing shape in response to sediment transports, tidal flows and storm events.

In Victoria, intermittently open closed estuaries (ICEs) are the dominant type of estuary and constitute 93% of all estuaries along the 1700 km long open coastline[27]. ICEs are highly sensitive to catchment runoff and the frequency of entrance opening and closure (Figure 4-12)[28]. Entrance conditions affect a range of factors such as berm height, water levels, flushing, water quality, salinity and sediment dynamics in coastal lakes and lagoons.

[27] McSweeney, S.L., Kennedy, D. M. & Rutherfurd, I. D. (2017)., A geomorphic classification of intermittently open /closed estuaries (ICE) derived from estuaries in Victoria. Progress in Physical Geography.
[28] CSIRO (2021). Australian Online Coastal Information OzCoasts.org.au accessed November 2021

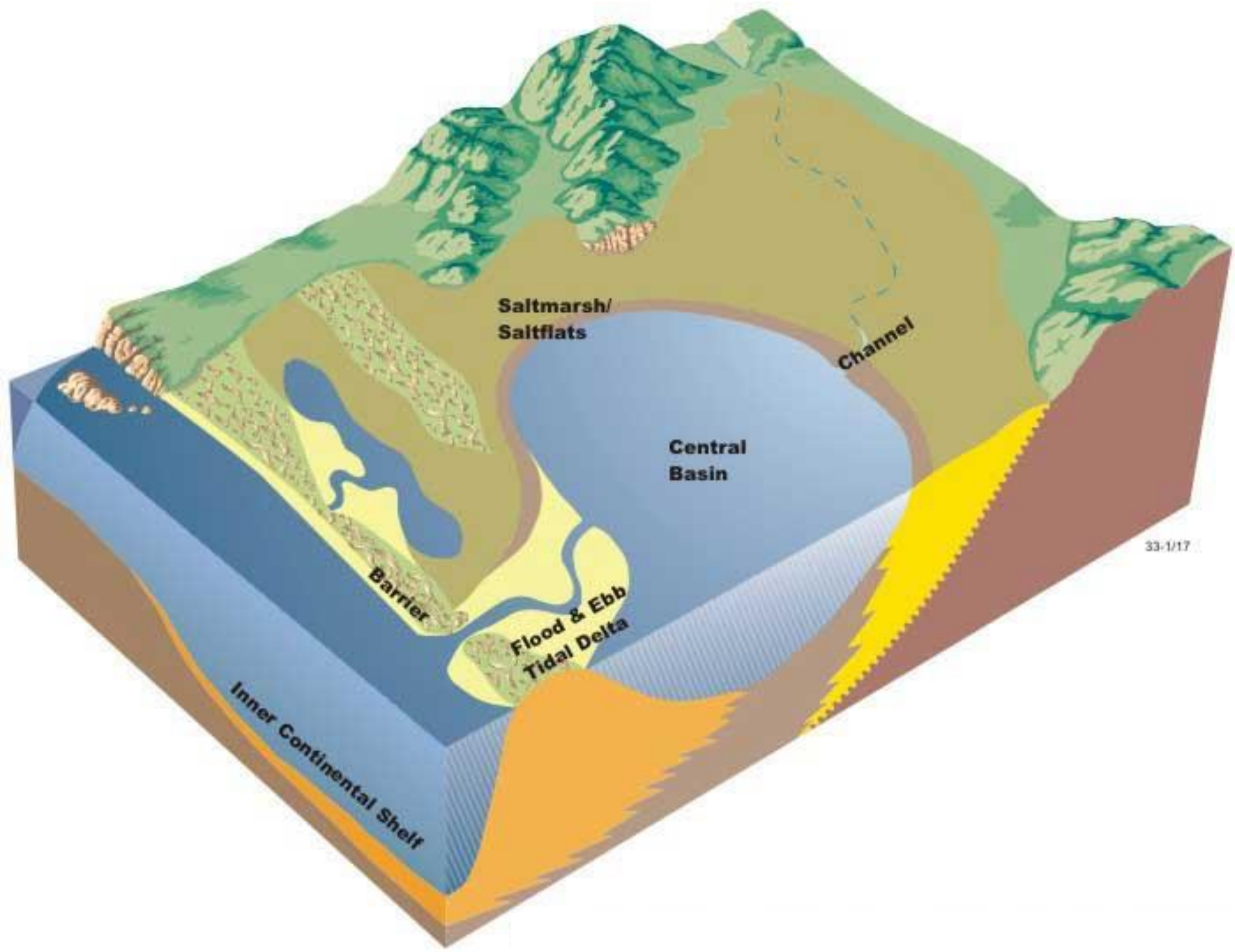

Figure 4-12 Conceptual Model of an ICE Type Estuarine Environment (Source: CSIRO)

In estuarine environments, sea level rise may cause an increase in the area of backshore that becomes tidally inundated and, in areas where the topography of the backshore is sufficiently flat, may result in large tidal variations through the estuary. With increasing frequency of inundation due to sea level rise, new shorelines could be expected to develop at the advancing tidal limit.

It is also likely that stream gradients along the lower reaches of rivers, creeks, drains and estuaries will decrease due to sea level rise which may result in variations in the channel alignment due to the development of meanders.

4.2.5 Off-Shore Sediment Dynamics

The off-shore environment includes the bed beyond the intertidal zone up to three nautical miles, or 5.5 kilometres off-shore. The offshore environment includes features such as bathymetric features, tidal channels, sediment dynamics; and supported ecosystems.

Changes in the offshore environment can include alterations in currents and sediment dynamics (e.g., sediment slugs, tidal channels) that can create a hazard for associated environmental, cultural and economic values such navigational channels, kelp forest or seagrass ecosystems (Figure 4-13)[29][30].

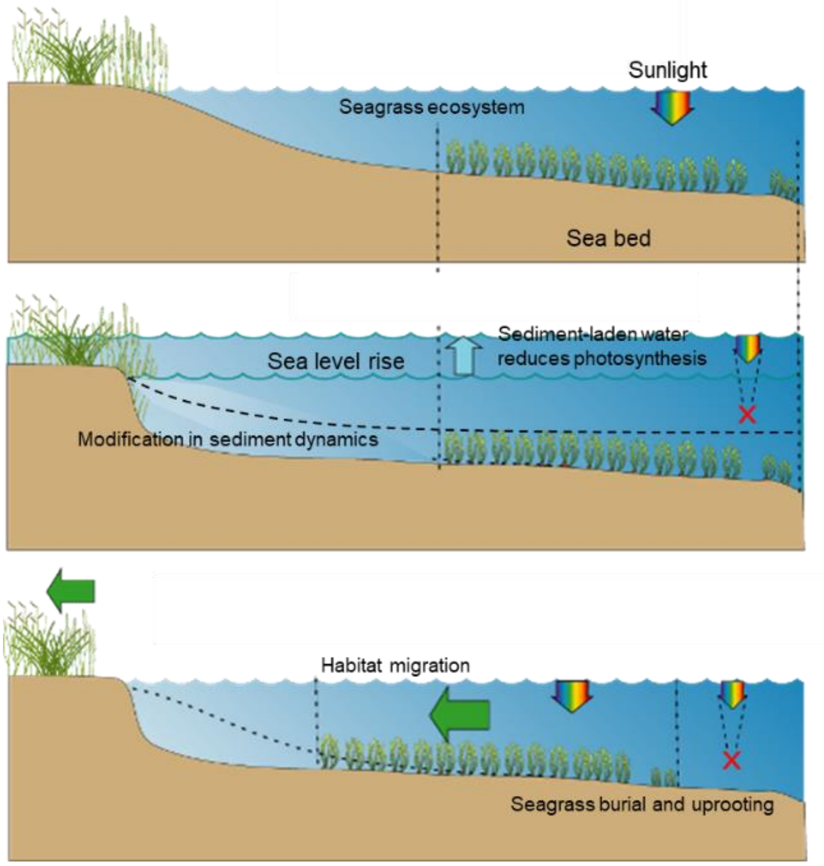

Figure 4-13 Conceptual Model of Off-Shore Seagrass Ecosystem Response to Sea Level Rise (Source: Adapted from Wicks, E.C 2006)

4.2.6 Saline Intrusion of Groundwater

Saline groundwater intrusion is the movement of saline groundwater into freshwater aquifers over time. Increased salinity can affect water quality, including for drinking water and irrigation. Saline intrusion can occur in many ways, including vertical movement of the water table, and lateral movement of coastal waters.

Changes in land use, coastal processes, and mean sea level over time can influence the extent of saline groundwater intrusion.

Understanding whether coastal groundwater systems will be impacted negatively by sea level rise requires investigation of local geology and determining what type of aquifer is present.

An initial conceptual model of groundwater systems may include a review of physical geology to inform the assessment of erosion potential, and a hydrogeological assessment (physical, aquifer properties, water levels)

[29] Wicks, E.C., (2006), Coastal plant communities and sea level rise. University of Maryland.
[30] Duarte. C.M., (2002), The future of seagrass meadows. Journal of Environmental Conservation.

to inform predictions of changes in groundwater level and hence moisture content and erosion potential of the near-surface materials.

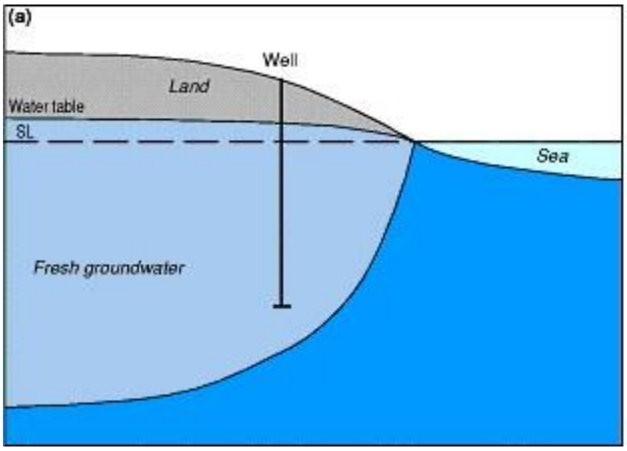

Figure 4-14 Conceptual Model of Saltwater Intrusion into Groundwater Aquifers (Source: OzCoasts Australian Online Coastal Information)

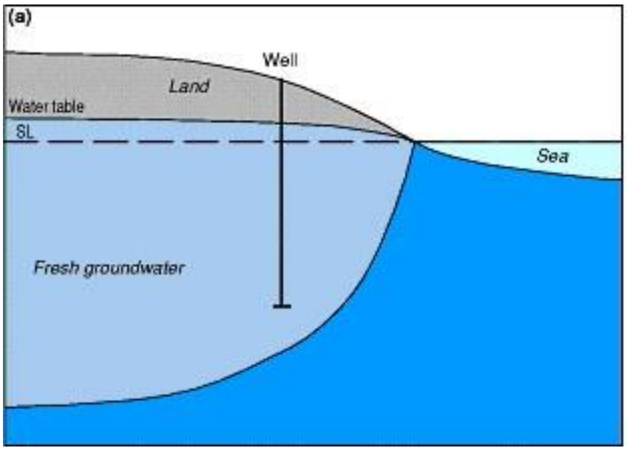

Figure 4-15 Conceptual Model of Saltwater Intrusion into Groundwater Aquifers (Source: OzCoasts Australian Online Coastal Information)

5 KEY DRIVERS OF CHANGE

5.1 Overview

This section outlines a range of factors that potentially influence the ongoing coastal processes that shape the Victorian coastline.

Climate change exacerbates existing coastal hazard threats to the Victorian coastline such as increased frequency and intensity of extreme weather events, changes to ocean temperatures and mean sea levels.

It is important to consider climate change projections and scenarios published in the latest IPCC 6th Report when identifying coastal hazards, as well as the regional contextualisation of this data. Additionally, demographic considerations such as growth of coastal settlements, vulnerability of communities, and associated infrastructure demands, may increase to coastal hazard risk. This section also considers the latest population projections from the Australian Bureau of Statistics to provide an overview of population pressures.

Planning reforms are also a driver of change in enabling sustainable development across all coastal regions. The planning framework of Victoria has changed considerably over the last decade in recognition of sustainable development practices, economic shifts and technological advancements which have improved the balance between social, cultural, economic, and environmental values.

5.2 Climate Change

Understanding how the climate is changing and the likely impact on a regional scale is critical to effectively plan for resilience and adaptive communities and continued sustainable use of coastal areas. To understand regional impacts, global projections and earth system interactions are modelled, from which results can be contextualised to local scales. The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change, and enables models, scenarios, and projections to be developed and peer reviewed by the climate experts from 195 countries around the world.[31]

IPCC climate change projections are based on sophisticated global and national climate models that simulate the climate using some of the world's most powerful supercomputers to successfully represent important elements of historic and present climate (such as global average temperature). These models allow for future scenarios to be simulated based on differing future levels of greenhouse gas emissions.[32] These climate models are used to generate global averages and can be adapted to complete additional modelling to understand regional implications. This section provides a global and national context, before identifying regional impacts.

5.2.1 Global Context – IPCC 6th Assessment Findings

The IPCC 6th Assessment Report[33] released in 2021 presents the most recent scientific research on climate change projections and 'our possible climate futures'. Continued release of emissions contributes to an accelerated greenhouse effect, causing significant and accelerating anthropogenic warming. This report states:

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[31] Intergovernmental Panel on Climate Change (2021). The Intergovernmental Panel on Climate Change. Available: https://www.ipcc.ch
[32] State Government of Victoria (2018). Victoria's Coast and Marine Environments under Projected Climate Change: impacts, research and priorities.
[33] Intergovernmental Panel on Climate Change (2021). 6th Assessment Report Climate Change 2021: The physical science basis - summary for policymakers. Available: https://www.ipcc.ch

"It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean cryosphere and biosphere have occurred."

Additionally, human activity such as widespread deforestation and urbanisation contribute to unprecedented change to global climate systems. Key impacts of climate change include:

- Increased frequency and intensity of extreme weather events;
- Increased global average air and ocean temperature; and
- Increased global average sea levels.

The regional impacts of these global trends have a variety of expressions based on local contexts, summarised in the categories of *heat & cold, wet & dry, wind, snow & ice, other, coastal* and *open ocean* (Figure 5-3).

Updated scenarios

The four Representative Concentration Pathways (RCP) referenced in previous IPCC assessment reports have been replaced with five 'Shared Socio-economic Pathway' (SSP) scenarios. These SSP scenarios are used to present ranges of impact for various climatic changes, depending on the timeframe we reach net zero emissions. These Shared Socio-economic Pathways include:

- SSP 1 – global emissions reach net zero by 2050, followed by substantial net negative emissions;
- SSP 2 – global emissions reach net zero by 2050, then moderate net negative emissions;
- SSP 3 – global emissions continue at the current rate;
- SSP 4 – global emissions are double current rate by 2100; or
- SSP 5 – global emissions are double current rate by 2050.

This enables a linear relationship between cumulative greenhouse gas emissions and global warming, as shown in Figure 5-1.

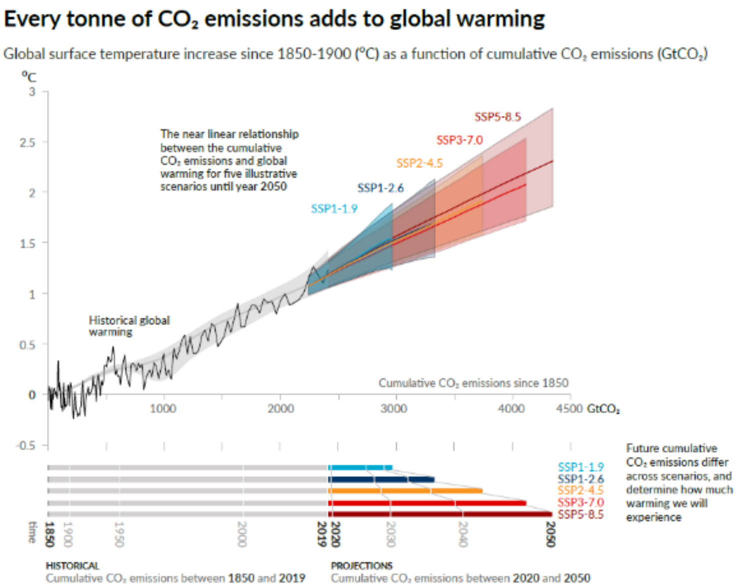

Figure 5-1 The Linear Relationship Between Carbon Emissions and Global Warming Trends (Source: IPCC, AR6).

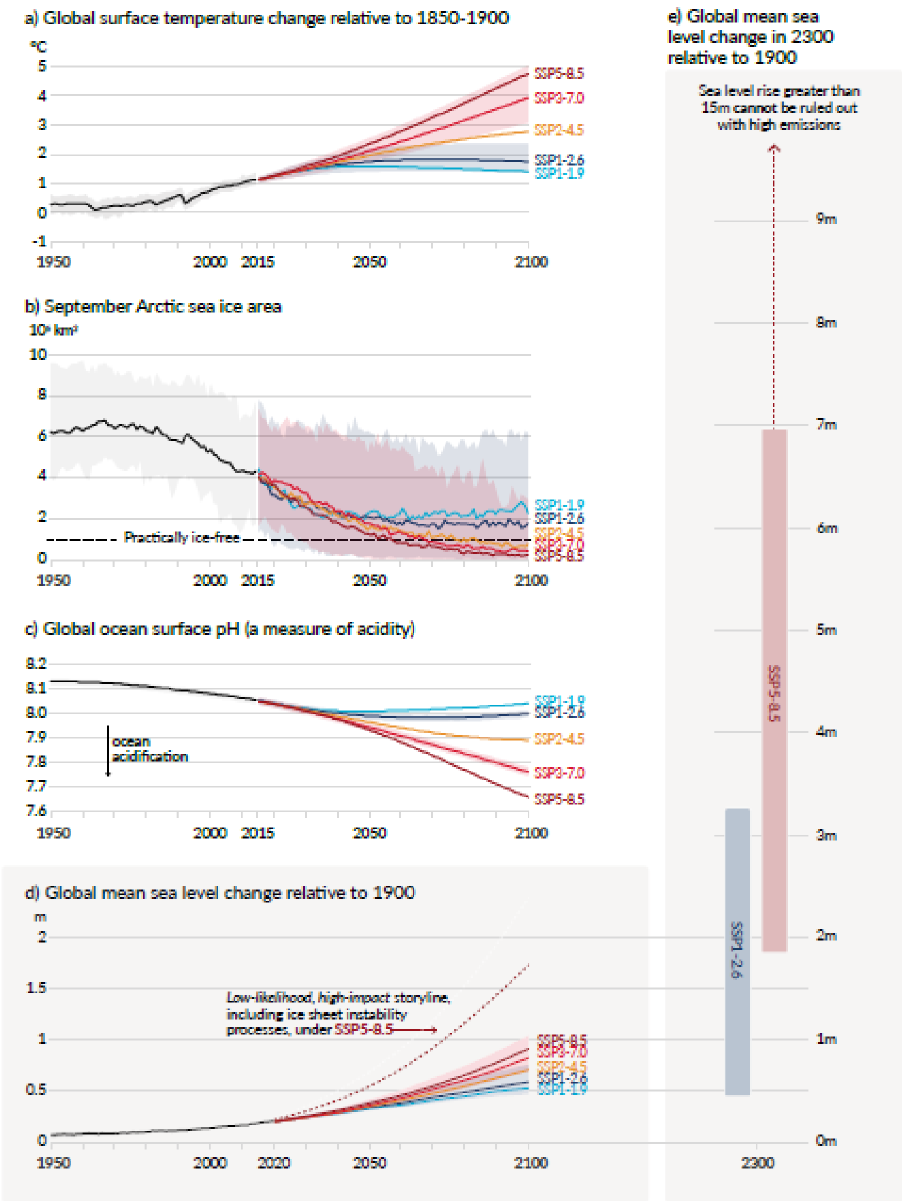

Figure 5-2 Change to Major Climate Systems (Source: IPCC, AR6).

GRAPH EXPLAINER –projected changes to major components of the global climate system

- Each graph depicts a major component of the global climate system that is changing. These include surface temperature, extent of arctic sea ice, ocean surface temperature, and sea level;
- All SSP scenarios are shown in each graph to give an indication of possible climate futures and the magnitude of impact on key components of the climate system;
- The timescale combines historic climate data from the 1950's with modelled scenarios towards 2100; and
- Human activities affect all major climate system components with some responding over decades and others over centuries.

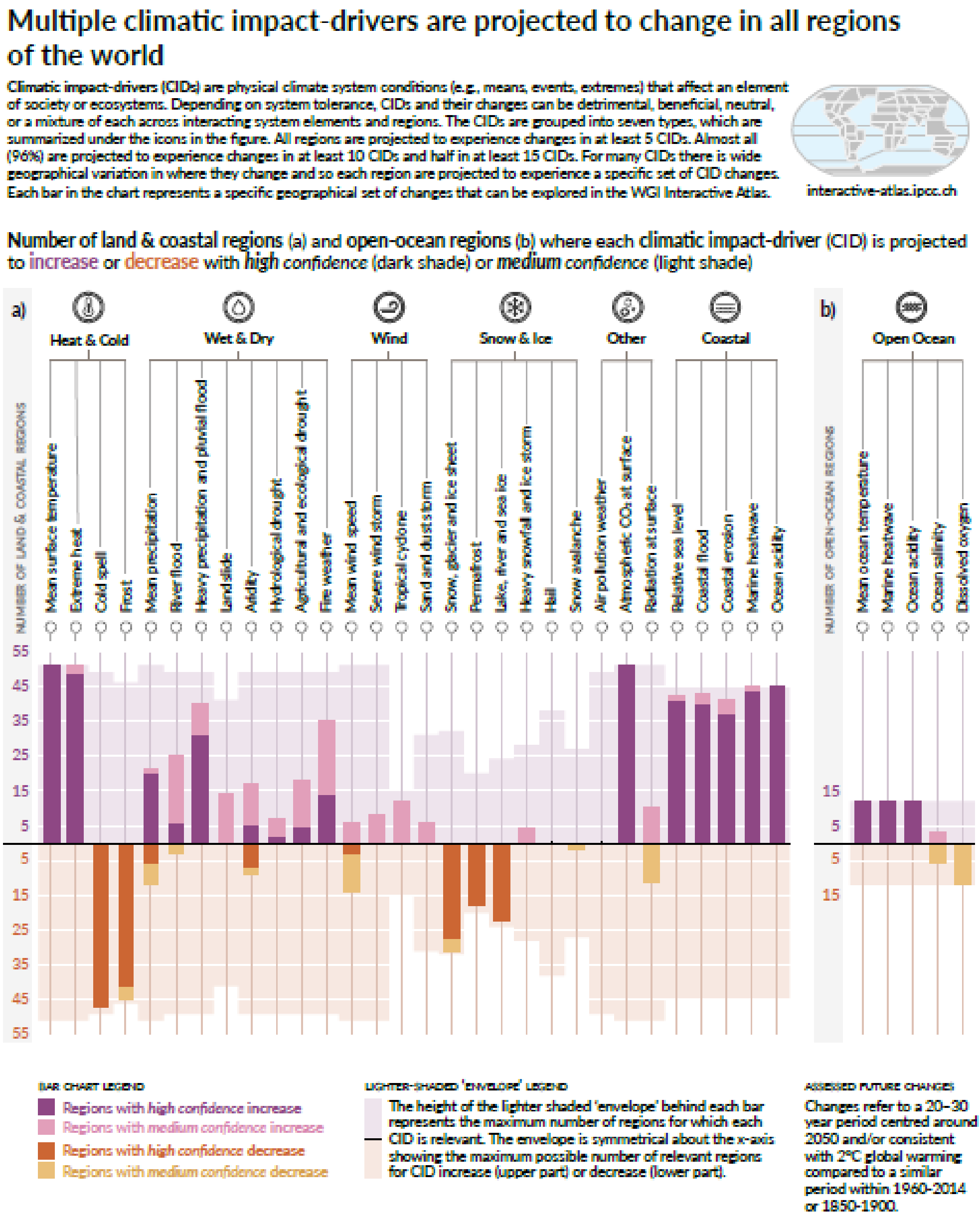

Figure 5-3 Climate Impact Drivers, Noting Coastal Impacts (Source: IPCC, AR6).

GRAPH EXPLAINER –number of regions where change to each aspect of the climate is occurring

- Each graph depicts the series of 'climatic impact drivers' including heat & cold, wet & dry, wind, snow & ice, other, coastal and open ocean aspects. The number of regions where increases or decreases (from the region's average) are projected;
- This graph highlights how widespread the number of impacts are across the world's regions, as well as that impacts are cumulative (multiple changes occurring within each region); and
- The IPCC state that multiple 'climatic impact drivers' are projected to change in all regions of the world, with at least 10 different aspects of the climate (e.g., average rainfall) changing in each region.

5.2.2 Understanding the Technical Definition of 'Uncertainty'

The IPCC's 6th Assessment Report has included a range of data of varying certainty, referring to the *range of possible outcomes*, rather than the reliability of the data projections. Data projections listed as 'medium or high uncertainty' for example, refer to the many different outcomes possible based on the interaction of many different factors, which could eventuate in a variety of ways.

The IPCC 6th Assessment Report refers to 'Our possible climate futures', based on the possible SSP pathways, and the level of certainty associated with different impacts based on global climate modelling, and the likelihood of occurrence (probability). All projections are useful to consider, and SSP scenarios should be contextualised to regional scales to understand possible local impacts.

5.2.3 Impacts of Climate Change on the Oceans

A high-level summary of assessment findings in relation to oceans includes:

- Past GHG emissions (since 1750) have committed the global ocean to future warming, as well as upper ocean stratification, ocean acidification, ocean deoxygenation to continue at rates dependant on future emissions;
- Mountain and polar glaciers are committed to continue melting for decades or centuries, as well as loss of permafrost, and Arctic and Antarctic ice loss;
- While mean sea level rise for each SSP is listed in Table 5-1 based on medium confidence modelling, due to the 'deep uncertainty' in ice sheet processes, mean sea level rise under a very high GHG emissions scenario resulting in 2m by 2100 and 5m by 2150 'cannot be ruled out';
- A decrease in the proportion of carbon taken up by land and ocean carbon sinks, resulting in a larger proportion of carbon being stored in the atmosphere. Historically, around 70% of carbon was stored in land and ocean sinks; and
- Multiple climatic impact-drivers resulting in increased coastal flooding, coastal erosion, marine heatwaves, and ocean acidity, with possible increase or decrease depending on localities of sea surface temperature.

Table 5-1 IPCC 6th Assessment Report – Sea Level Rise Projections Based on 'Possible Climate Futures'

GHG emission scenarios	Shared Socio-economic Pathway (warming)	Global mean sea level rise by 2100 (relative to 1995-2014)
Very low (net zero by 2050, then net negative emissions)	SSP 1 – 1.9 °C	0.28 – 0.55m
Low (net zero by 2050, then net negative emissions)	SSP 1 - 2.6 °C	0.32 – 0.62m
Intermediate (current rate)	SSP 2 - 4.5 °C	0.44 – 0.75m
High (double current rate by 2100)	SSP 3 – 7.0 °C	0.63 – 1.01m
Very high (double current rate by 2050)	SPP 5 - 8.5 °C	0.98 – 1.88m

While these impacts are broader than the context of Victoria, changes in global averages and climate systems have an impact on regional and local changes.

5.2.4 National Context – State of the Climate 2020 Findings

The State of the Climate 2020[34] report authored by CSIRO and the Australian Bureau of Meteorology present a national context to climate change science. The major categories influencing climate changes in ocean environments include sea surface temperature, ocean heat content, sea level and ocean acidification, driven by increased average temperatures. This trend in average annual temperature increase can be observed in Australia since the 1920's, as shown in Figure 5-4.

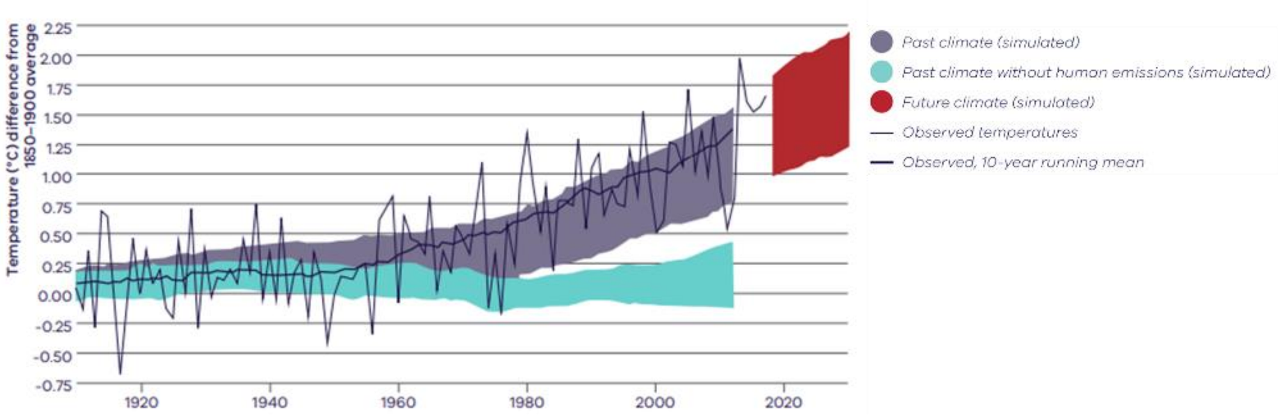

Figure 5-4 Australia's Average Annual Temperature Relative to 1850 (Source: DELWP 2019)

Further to the findings of the ICPP, regional impacts in Australia have been identified by the State of the Climate 2020 report as significant ocean warming occurring in south-eastern Australia (including Victoria and Tasmania), as shown in Figure 5-5. In this region, sea warming is occurring at twice the global average rate, resulting in more frequent marine heatwaves. It has been found that oceans are 'taking up' about 90% of the additional heat in the atmosphere caused by increased emissions, acting as a buffer to atmospheric temperature rise. This impacts many aspects of marine ecosystem health.

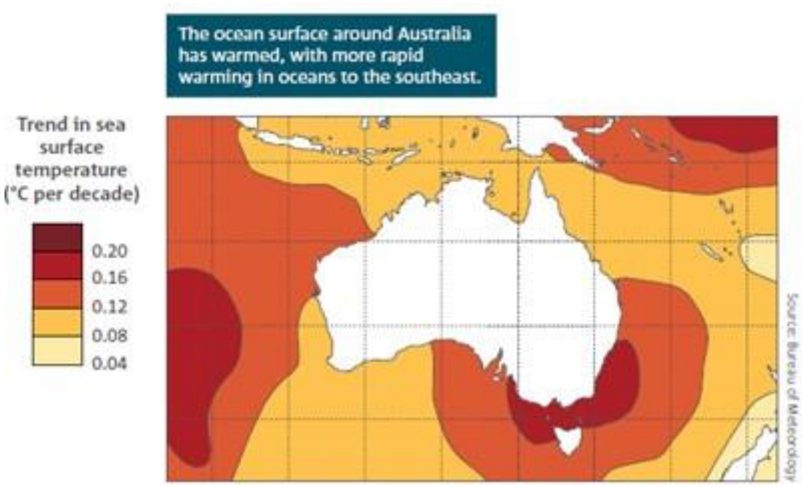

Figure 5-5 Sea Surface Temperatures in the Australian Region from 1950 – 2019 (Source: BoM)

[34] CSIRO and Bureau of Meteorology (2020). *State of the Climate Report 2020.* Available: https://www.csiro.au/en/research/

Ocean warming is contributing to sea level rise due to thermal expansion. Ocean warming is responsible for approximately a third of observed global sea level rise. Other factors include ice loss in polar regions, and changes in stored water on land. The most notable cause of global sea level rise is ice loss from Greenland, Antarctica, and glaciers since 1993, and continue to occur at an accelerating rate.

As per IPCC assessment findings, global sea levels are increasing. This is also observable in Australia, with sea level rise rates varying across the region. The largest increases are observed in North and Southeast Australia (including Victoria), with annual variability due to climate systems such as El Nino and La Nina.

Between the years 1966 and 2009, recorded sea levels around the Australian coastline rose at a rate of 2.1mm/year. Increased rates are already observable, with sea level rise between 1993 and 2009 occurring at rate of 3.1mm/year. This trend is expected to continue, with sea level rise along the Victorian coastline projected to occur at the rate of 4mm/year, equating to an increase of 24 cm since the 1900s.[35]

This is summarised in Figure 5-6 and this quotation from the State of the Climate report (2020):

Rising sea levels pose a significant threat to coastal communities by amplifying the risks of coastal inundation, storm surge and erosion. Coastal communities in Australia are already experiencing some of these changes.

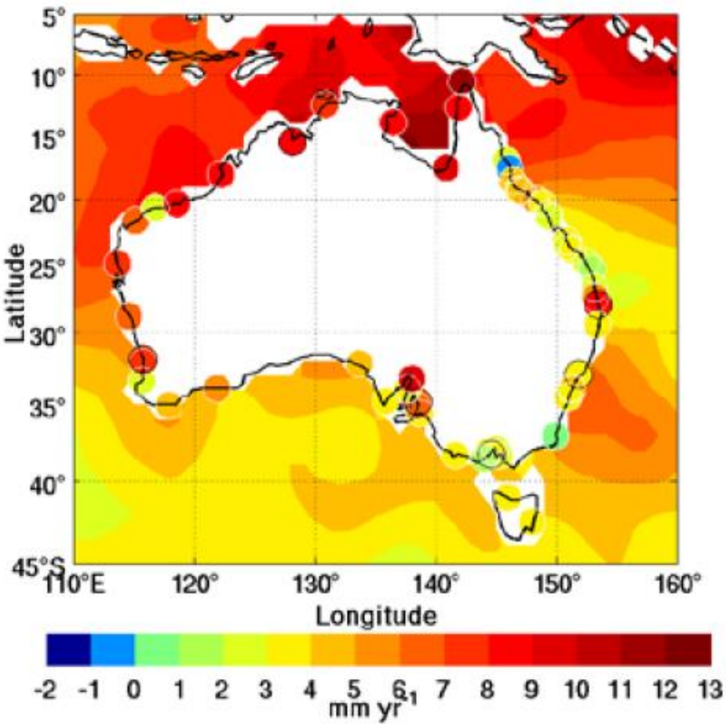

Figure 5-6 Global Sea Trends from Satellite Altimeters and Tide Gauges for 1993 – 2010 After Correction for Glacial Isostatic Adjustment (Source: CSIRO; BoM 2015)

A number of interrelated mechanisms occur that impact sea level rise, such as additional sedimentation on the sea floor, ice melt, and the weight of ice supressing land. Since the last ice age over 20,000 years ago, the weight of the ice has been relieved causing land masses to gradually rise overtime, known as the glacial

[35] CSIRO and State Government of Victoria (2019). Great South Coast Climate Projections. Available: www.climatechange.vic.gov.au

isostatic adjustment. This is considered when modelling sea level rise as it causes the level of land to increase relative to the level of the sea.

In addition to increased sea level and ocean temperature, ocean acidification is occurring with significant detrimental impacts to the health of marine ecosystems, to the rate of more than 30% greater acidity than pre-1880 levels. Like ocean warming and sea level rise, the rate of acidification is accelerating, and is also occurring faster in the oceans south of Australia, including Victoria.

5.2.5 Regional Impacts – Climate Change and the Victorian Coastline

The oceans around the Victorian coastline are experiencing the global and national projections described, including increased sea surface temperatures, marine heatwaves, ocean acidification, and sea level rise.

While global trends occur, regional impacts vary based on the interaction of many physical and chemical processes specific to the area. Understanding localised impacts across the Victorian coastline is a key focus of coastal hazard adaptation planning, to enable greater adaptive planning in preparation of these changes. The Victorian Coastal Council Science Panel[36] have summarised the impacts of climate change in Victoria as:

- **Temperature:** increased average temperature (between 0.6 and 1.3^{0}C by 2030, and between 1.1 and 3.2^{0}C by 2070 relative to the climate of 1986 to 2005); increased heatwaves and fewer frosts;
- **Rainfall:** less (total) rainfall in winter and spring; more frequent and more intense downpours**;**
- **Fire danger:** Harsher fire weather and longer fire seasons;
- **Sea level:** rising sea level (between 8 and 20 cm by 2030 and between 20 and 59 cm by 2070 relative to the 1986 – 2005 level), Increased frequency and height of extreme sea-level events; and
- **Oceans:** increased wave height in winter, increased frequency of easterly winds, warmer and more acidic oceans, with sea-surface temperatures rising by between 1.1 and 2.5^{0}C by 2070.

The impacts specific to coastal regions are summarised in Figure 5-7, including impacts on marine ecosystems. It is also important to consider variability in all systems as a likely impact of climate change, causing a shift in expected weather patterns on a local scale.

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[36] Victorian Coastal Council (2007). Emerging Scientific Issues on Victoria's Coast http://www.vcc.vic.gov.au/assets/media/files/SciencePanelReportAug06Published.pdf

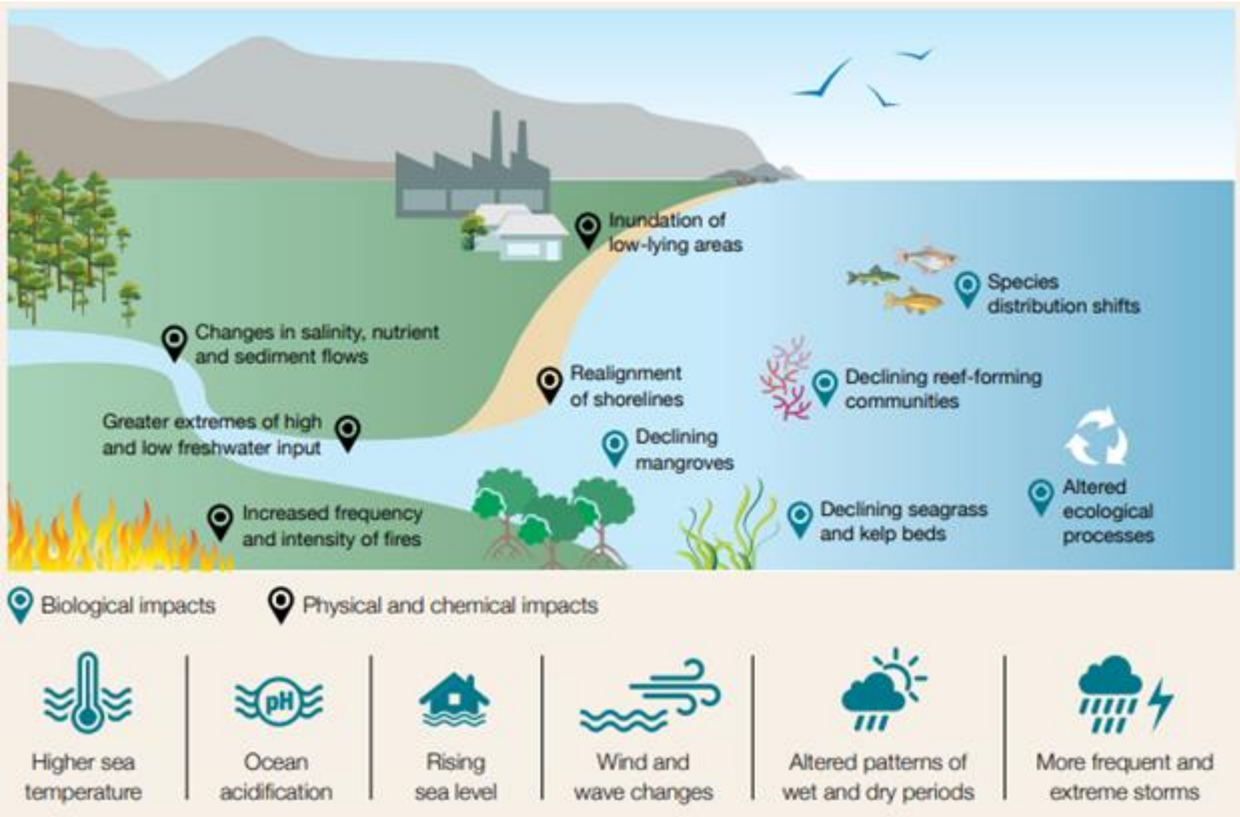

Figure 5-7 Likely Changes to Victoria's Coast caused by Climate Change (Source: VCC, 2018)

The full range of global climate change impacts are expected to be experienced on Victoria's coastline.[37] While global average sea level rise is projected according to a series of scenarios, understanding regional and local impacts is important for adaptation planning.

Insight into the impacts of sea level rise to Victoria has been enabled by a CSIRO project to digitise and quality-control the data gathered through a citizen science project. This project has recorded tide gauge records from Williamstown since 1872. While there is regional variation to sea level rise rates, the trend for Victoria is similar to the Australian average (3.1mm/year between 1993 and 2009).

Sea level projection data can be sourced from Coast Adapt.[38] Current data available provides projections across a range of planning horizons for Victoria's coastline and show similarities across each locality. This resource can be used to better understand projections; however, it is important to undertake localised assessments as a part of coastal hazard adaptation planning specific to each council area. With increased frequency and intensity of extreme weather events as a result of climate change, storm-time inundation and erosion impacts are worsening. As natural hazards intensify, coastal processes can also be intensified through increased wave action and wind speeds, driving accelerated coastal erosion and inundation rates.

Additionally, while storm tide events and riverine flooding events typically don't coincide in Victoria, the effect of coincident events compounding their impact on coastal areas could also be considered as a 'worse case' scenario (e.g., rainfall, riverine flooding and storm surge occurring during one event). Changes at the boundary

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[37] State Government of Victoria (2018). Victoria's Coast and Marine Environments under Projected Climate Change: impacts, research and priorities. Available: www.marineandcoastalcouncil.vic.gov.au
[38] Coast Adapt (2021). CoastAdapt Datasets – Sea-level rise and you: information about the future. Available: www.coastadapt.com.au/

of atmospheric circulation patterns are leading to shifts in erosion and accretion patterns, rotation of beaches and an overall less stable coastline[6]. With these considerations, projections could be conservative, with more severe impacts possible from compounding effects leading to ecological thresholds and tipping points being reached having additional impacts on other systems (feedback loops).

A summary of the impacts associated with each projection is presented in Table 5-2. This information is sourced from the Victorian Coastal Council (2018).

Table 5-2 Impacts of Climate Change on Victoria's Coast

Measures	Impacts
Sea-level rise	More frequent and extensive inundation of low-lying areas
	Loss of coastal habitat, such as roosting and nesting sites for shorebirds/seabirds (e.g., direct impacts to the Hooded Plover from nest flooding)
	Cliff, beach and foreshore erosion
	Altered intertidal areas (e.g., saltmarshes, coastal wetlands and mangrove habitats)
	Declines in seagrass abundance and extent
	Increased tidal ranges in locations with constricted opening (e.g., Port Phillip Bay)
	Loss/damage to private property, public property, and infrastructure; changes to land use
	Loss of significant heritage sites
	Loss of coastal Crown land for tourism and recreation
Wave & wind changes	Realignment of shorelines
	Changes beach profile and orientation
Ocean & current changes	Impacts on the diversity, distribution and abundance of species
Rainfall changes / wet & dry periods	Changed estuaries, greater extremes of high and low freshwater input
	Changed salinity, nutrient, and sediment flows
	Greater extremes of high and low freshwater input
	Reduced water clarity
	Changes in water quality, in particular due to changes in stormwater runoff
	Increased frequency and intensity of fires, with impacts beyond the coast
	More people visiting the coast in hot, dry periods
More frequent & extreme storm events	Intense and destructive flooding of land and buildings on the coast in areas where drainage systems lose their functionality
	Inundation of low-lying coastal environments
	Beach, foreshore, and cliff erosion
	Loss/damage to private property, public property, and infrastructure; changes to land use
	Pollution from sewer overflows

Measures	Impacts
Higher sea temperatures	Changes to species distribution
	Spread of invasive species and diseases
	Changes in recruitment patterns, flowering, breeding and migration (e.g., phytoplankton)
	Altered ocean currents
Ocean acidification	Impacts on early life stages of species, particularly larvae and plankton
	Loss of plankton base for food webs
	Changes to ecological cycles
	Damage to reef-building communities and calcium-carboned based invertebrates
	Damage to infrastructure

As demonstrated by the indicative summary, the physical and chemical impacts, as well as biological impacts likely from climate change have cultural, social, economic and environmental ramifications, and require coordinated adaption planning.

5.2.6 Other Natural Hazards

The concept of risk involves the interplay of hazard exposure and consequence, which can vary between place to place, over time, and across different hazards. There are many other natural hazards that are influenced by climate drivers that can directly or indirectly impact coastal areas, and influence coastal hazard risk, in Victoria. These broader natural hazards should be considered where relevant for each place-based coastal hazard adaptation planning context.

5.2.6.1 Bushfire

A bushfire is a fire involving grass, scrub, or forest. Bushfire events can cause injury, loss of life and/or damage property or the natural environment. The level of bushfire risk varies from region to region and from year to year and are driven primarily by fuel, topography and weather. Fires burn more intensely with abundant and drier fuel, extended periods of hot and dry periods and/or droughts. As the population grows, so does the urban footprint resulting in more people residing in the urban/rural interface zone which can have an influence on bushfire risk. The Great Ocean Road region is one of the highest risk locations for bushfire because of the proximity to the towns of Lorne and Anglesea and to the Otway Ranges. The high numbers of visitors to the region, particularly in summer months when fire risk is at its highest is a particular concern as the road configuration makes evacuation of the areas difficult.[39]

Climate change does not directly cause bushfires but exacerbate conditions that lead to greater bushfire risk. Climate change is expected to result in more severe fire weather days. Higher temperatures and longer dry seasons will increase bushfire risk in some regions, particularly for communities where houses and businesses neighbour natural ecosystems. In addition, the projected increase in the frequency of compounding extremes such as severe weather events (rainfall events, storms and cyclones and destructive winds) can add to background bushfire risk, especially in areas with increased fuel loads.[40] Forested areas that are impacted by severe winds, including cyclonic and non-cyclonic winds, can result in significant increases in surface fuels

[39] DELWP (2020). Coastal demographics in Victoria.
[40] Queensland Fire and Emergency Services, (2020). Queensland Bushfire Plan. Available: www.disaster.qld.gov.au

from leaf and branch fall. This also means that fires in these areas are more likely to burn for longer and more intensely.

The impacts that may be currently expected, will likely intensify in light of climate change as a result of the projected increase in frequency, intensity and duration of bushfires.

5.2.6.2 Heatwave

A heatwave is defined as *"three days or more of high maximum and minimum temperatures that are unusual for that location"*[41]. They are measured relative to the usual weather in the area, and relative to normal temperatures for the season in that area. The combination of the "significance index" and the acclimatisation index" takes into account people's ability to adapt to heat and if a specific heatwave is more likely to have greater human health impacts.

Heatwaves are caused by a high-pressure system that sits next to the region experiencing the heatwave, pushing hot air from the centre of Australia towards that region, but can be influenced from farther afield. For example, heatwave occurrence in Melbourne is coupled with tropical cyclones to the north-west of Australia. There are other long-term variables that impact heatwaves and their patterns off occurrence, timing and severity; this includes the climate variables of El Nino and La Nina.

While heatwaves are generally not considered as significant contributors to the nations mortality rate, research shows that extreme temperatures currently contribute to the deaths of more than 1000 people aged over 65 years across Australia and have been termed "silent killers"[41]. For example, during the 2009 Victorian bushfires, 173 people perished as a direct result of the fires, however 374 people died in the heatwave that preceded them. Most heatwaves that occur in Australia are of low intensity with most people having the capacity to cope with the level of heat. However less frequent and higher intensity heatwaves that are classified as severe are more challenging for vulnerable people such as those aged over 65, pregnant women, babies, and young children.

5.2.6.3 Severe Wind

Severe wind is associated with low pressure systems along with associated cold fronts which generate strong winds and heavy rain over large areas, causing localised flash flooding and riverine flooding[42]. The main wind damage from these low-pressure systems is often in coastal areas adjacent to mountain ranges. They also cause coastal erosion through the combined effect of large waves and an increase in sea level, which creates a storm surge. If a storm surge occurs at the same time as a high astronomical tide, the area inundated can be extensive, particularly along low-lying coastlines.

5.2.6.4 Drought

Victoria's climate is highly variable; however, the trend in recent decades is towards warmer and drier conditions. A drought is defined as *"acute water shortage*" and can be classed as serious or severe rainfall deficiency, depending on if the rainfall lies above the lowest 5% of recorded rainfall but below the lowest 10% for the period in question, or if the rainfall is among the lowest 5% for the period in question.[43] This includes the dry conditions experienced in Victoria during 1996-2010, which is widely known as The Millennium Drought

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[41] Heatwave Risk Assessment, Queensland Fire and Emergency Services (2020). Available: www.disaster.qld.gov.au

[42] Geoscience Australia (2022). Severe Wind. Available: www.ga.gov.au

[43] Bureau of Meteorology (2021). Climate Glossary. Available: www.bom.gov.au/climate/glossary

that saw more than half of the Victorian catchments (that were analysed) experience an extra 20-40% decline in their annual streamflow due to the shift in rainfall-runoff relationships.[44]

The major impact of a drought is the direct impact it has on creating water shortages to meet human needs, and whilst demand for water is growing, supply is decreasing. Recent years have seen significant reductions in the amount of water flowing into Victoria's water storages due to changing rainfall-runoff patterns, the global circulation and large-scale climate drivers such as El Nino and the Indian Ocean Dipole, which are subject to climate change.

5.2.6.5 Water Quality

Maintaining good water quality is essential to human health, the environment, cultural, economic and social values of coastal waters. There are several natural hazards that can cause water quality issues as a result of climate related natural hazards.

Blackwater events can occur when a build-up of leaf litter and debris on floodplains is washed into waterways during a flood event.[45] This causes an increased level of organic material in the water that is consumed by bacteria and results in depleted dissolved oxygen levels in the water. This can impact localised fish stocks but can also help to redistribute essential organic matter and nutrients through the landscape.

Bushfires can also affect the water quality, particularly when a heavy rain event occurs immediately after a fire. The altered soil structure and loss of vegetation cover from bushfires can increase the risk of sediments and pollutants entering the waterways and reaching the coastal waters and can impact local aquatic ecosystems.

5.2.6.6 Catchment Flooding

Flood events occur naturally and while they can be problematic for urban settlements, they also perform important environmental processes such as flushing of waterways, soil enrichment of floodplains through nutrient-rich sediment transport, and possible groundwater recharge. However, floods pose many challenges for both urban and natural environments too.

Adapting developed areas to withstand flood impacts and minimise risk of infrastructure damage is important in building resilience. This is particularly important as many townships within Australia are built on floodplains, which are prone to flooding. It's important to consider the wider context of other natural hazards when conducting coastal hazard planning, including the possibility of coincidental flooding. This is explained further in Best Practice for Adaptation Planning.

5.3 Population Pressures

The demographics of coastal communities and population growth projections are critical considerations when planning for coastal hazard adaptation. Nationally, the 'sea-change' phenomenon is seeing a migration trend away from rural and urban areas to coastal communities. With an increasing population, more people are potentially exposed to coastal hazards.

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[44] DELWP (2020). Victoria's water in a changing climate, Insights from the Victorian Water and Climate Initiative, Available: www.water.vic.gov.au

[45] Water Quality Australia, Australian Government Institute, (2021). Available: www.waterquality.gov.au

Additionally, the impact of COVID-19 lockdowns to population demographics and sea-change migration in Victoria is yet to be documented and may be a significant change to current migration trends with a rapid influx of residents from urban areas moving to coastal communities.

This section provides an overview of national and state population growth trends, as well as specific demographic considerations and population patterns in Victoria's coastal settlements. Data has been sourced from the Australian Bureau of Statistics[46], and the DELWP publication *Coastal Demographics in Victoria*[47] is a key reference.

5.3.1 Population Projections – General Trends

Victoria is home to 6.3 million people, making up close to 24% of Australia's population. Victoria's projected growth rate (1.0% - 1.7%) estimates the population will be between 10.1 and 14.5 million by 2066 (Figure 5-8), which is slightly higher than the national growth rate.

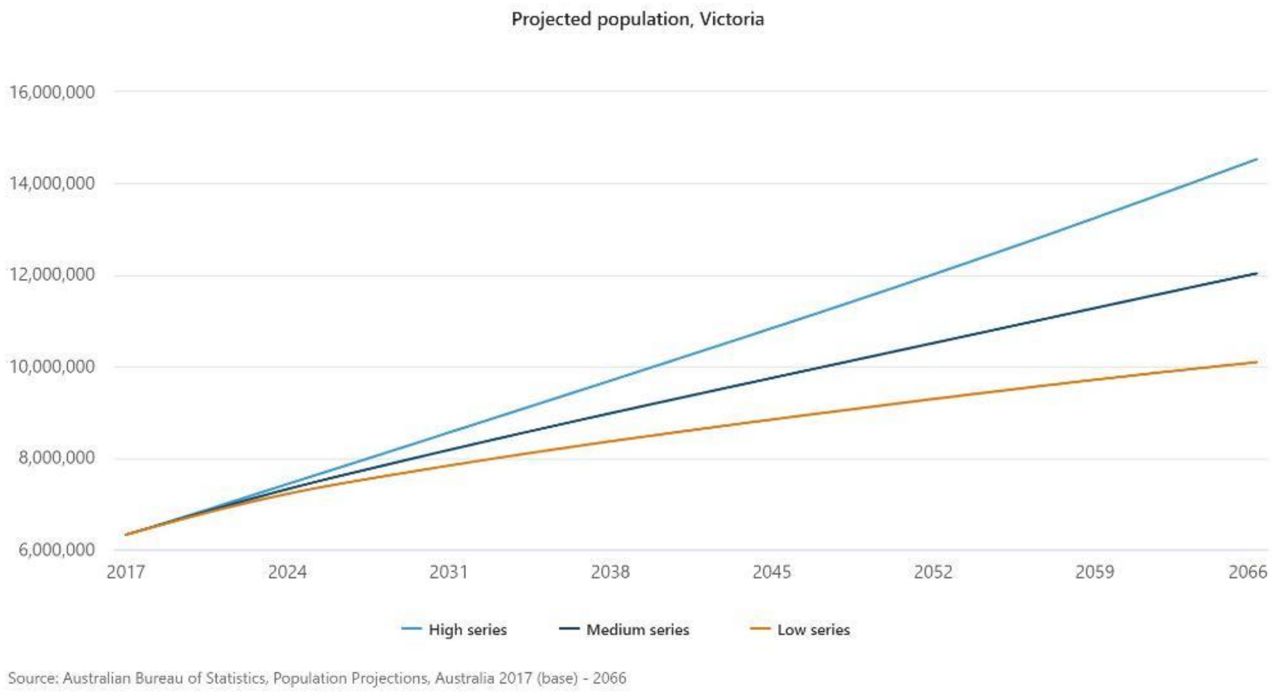

Figure 5-8 Projected Population of Victoria (Source: ABS, 2018)

Urbanisation is a significant population trend, with 77% of Victorians currently living in Melbourne. This is projected to continue, with Melbourne becoming the most populous city in the country by 2066[48].

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[46] Australian Bureau of Statistics (2018). Population projections, Australia 2017 - 2066 (latest release). Available: www.abs.gov.au

[47] McSweeney, S.L., Kennedy, D. M. & Rutherfurd, I. D. (2017). A geomorphic classification of intermittently open /closed estuaries (ICE) derived from estuaries in Victoria. Progress in Physical Geography

[48] Australian Bureau of Statistics (2018). Population projections, Australia 2017 - 2066 (latest release). Available: www.abs.gov.au

Table 5-3 Overview of Projected Population Growth in Victoria Compared to the National Growth Rate

Location	Current population 2017	Projected growth rate to 2066	Projected population 2027	Projected population 2066
Australia	24.6 million	0.9 – 1.4 %	28.3 – 29.3 million	37.4 – 49.2 million
Victoria	6.3 million	1.0 – 1.7 %	7.4 – 7.7 million	10.1 – 14.5 million

5.3.2 Considerations Specific to Victoria's Coastal Populations

While Melbourne is home to the majority of Victorians and has the state's highest projected growth rate, there is also significant population growth in the coastal areas within a 2-hour proximity of the state capital. This includes the settlements of Geelong, Bellarine Peninsula, Surf Coast and Bass Coast, which project population and density increase.

While these areas are growing, population growth in other coastal areas is less prominent, and in some localities, population is declining. The relocation of retirees to coastal settlements is a significant trend, as well as the highly variable population of coastal settlements due to part-time residency and tourism. The impacts of pandemic lockdowns are seeing migration away from urban centres towards the coast, however it is unknown whether this will be a short-term fluctuation or sustained post-pandemic, and the potential impact on attractiveness of coastal settlements for further in-migration with improved infrastructure enabled through pandemic-related population increases. The shift of work modality from office-based to flexible and work from home arrangements may see additional in-migration of working-aged population towards coastal communities.

Additionally, a combination of the majority of Victoria's coastline is public land (e.g., national parks), and land use planning measures are successfully limiting sprawl along coastal stretches, confining growth of the urban fabric inland from coastal settlements.[47]

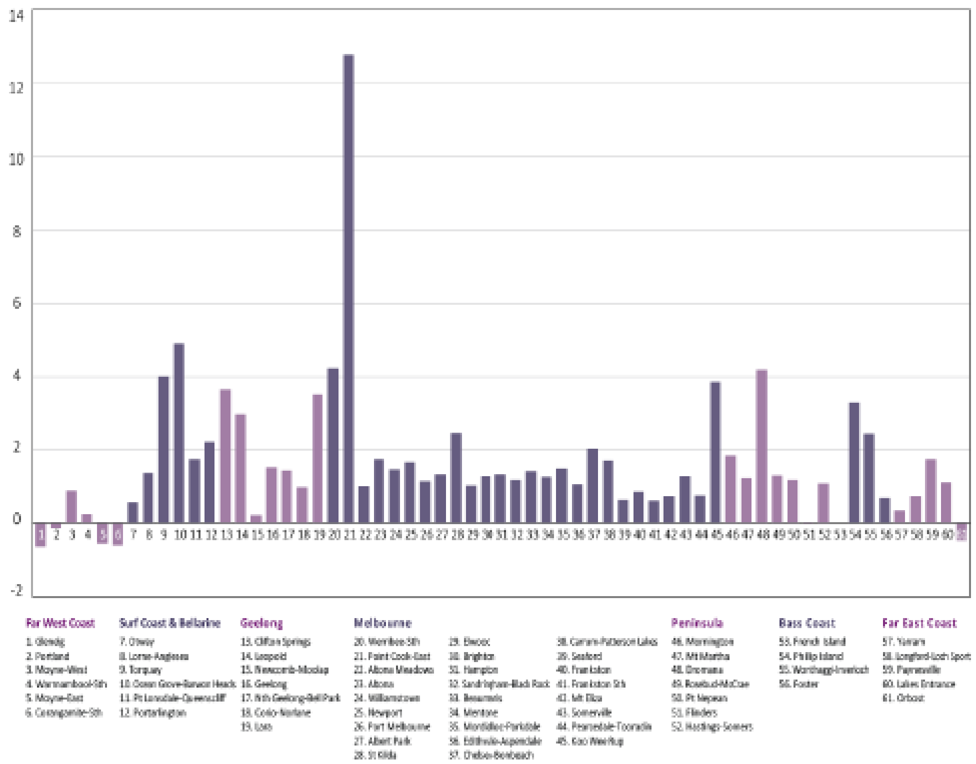

Figure 5-9 Average Annual Population Change, Victorian Coastal Regions (SA2) (Source: DELWP, 2020)

5.3.3 Aging Populations

In-migration of retirees to coastal settlements is notable, with different age structures apparent. Bass Coast and Far East Gippsland have a significantly high proportion of 'younger retirees', between the age of 60-69. Bairnsdale and other regional centres attract a higher proportion of older retirees (over the age of 70), due to their provision of health care services. These regional centres are also important in providing services for broad catchment of smaller coastal towns.

Larger coastal settlements within Port Philip Bay and surrounding Geelong have an even distribution of age groups, including young adults and families. However, the general age structure in regional coastal settlements is skewed towards older residents.

The number of Victorians over 65 years is increasing from 15% in 2017, to between 20 - 23% of Victorian residents over 65 years by 2066. This demonstrates an aging population. Current trends see a large number of retirees relocating to coastal settlements.

This may cause population growth in the short term in coastal settlements; however, the age structure of these areas is changing. Natural population growth is limited due to lower proportion of residents within the child-bearing age group. Therefore, population growth in these areas is caused by a constant influx of new retirees, which can have implications for the resilience of coastal populations to natural hazards, increasing the proportion of the population categorised as 'vulnerable' during a hazard which has the potential to amplify the pressure on emergency response services.

This is due to the fact that persons over the age of 65 are considered at a greater risk during a natural hazard event of having less evacuation capacity (e.g., may requiring assistance with mobility), and/or are at a greater risk of mortality from the hazard event itself (e.g., medications elderly persons are commonly prescribed can interfere with body temperature regulation which poses greater risk of mortality during a heat wave event).[47]

Figure 5-10 Age Structure, Victorian Coastal Regions (SA2) (Source: DELWP, 2020)

5.3.4 Mobile Populations

In addition to coastal settlements having aging populations, coastal settlements typically have a significant number of dwellings that are vacant for the majority of the year (e.g., holiday homes). Tourism is predominately domestic, being daytrips. It is important to consider the part-time population of a coastal area as well as resident populations. These can place pressure on infrastructure, services, and the environment.

These areas attract many types of part-time populations, including weekend populations, holiday makers, day-trippers, event attendees, seasonal workers, and working populations. Given the diversity of these groups, there is limited data available to understand peak populations of coastal settlements.

Part-time populations fluctuate based on different seasons, public holidays, weekends, and individual days. These fluctuations pose a challenge for service provision and disaster management planning, as well as longer-term coastal resilience planning activities[49].

While fluctuation is difficult to quantify, as excepted peak populations generally occur during summer months and on public holidays. The difference between peak periods and permanent populations can be as large as 4 to 5 times the permeant population size. This is significant, as large proportions of the population may be unfamiliar with local environments, which can decrease capacity to respond in the event of a natural hazard event.

Similarly, if a hazard event occurs during a time when the locality has an increased population due to a large number of temporary visitors/residents, evacuation capacities of infrastructure and disaster management services can be strained. Therefore, the coastal risks each settlement is exposed to may be variable based on settlement concentration, visitation patterns and road configuration (e.g., Great Ocean Road).

5.3.5 Vulnerable Populations

There are a range of demographic indicators that can be used to understand the potential vulnerability of communities. These features relate to a populations' capability and capacity for natural hazard awareness, preparedness, response, and recovery.

There are four categories of vulnerability: awareness, physical, mobility and socio-economic[ii]. Indicators include young and elderly persons, one parent families, those living in public housing, those with low income, those with limited education, those new to the region, those with limited English, those who require assistance, and those who don't have access to a private vehicle. Unoccupied dwellings are also an indicator of part-time populations and indicate potentially lower preparedness or response capacity.

While individuals and communities may have high tolerance and resilience to natural hazards, these indicators identify likely barriers to awareness, preparedness, response and/or recovery. Heatmapping demographic vulnerability can be a useful tool to investigate coastal resilience.

The DELWP research paper referenced (titled *Coastal Demographics in Victoria*) provides an overview of these vulnerability indicators and has assessed vulnerability across the different coastal regions of Victoria for a number of indicators. While this is an important resource and is based on the latest ABS data, it is suggested more localised assessments are

Recommendation: For localities identified as having high and very high demographic vulnerability, complete an updated assessment using ABS data at the SA1 scale.

[49] DELWP (2020). Coastal demographics in Victoria.

completed as a part of coastal hazard planning using 2021 census data at an SA1 level for more detailed understanding of vulnerability.

Additionally, the impact of COVID-19 lockdowns in Victoria on coastal migration should be captured during vulnerability assessments, as an influx of new residents could indicate a factor of vulnerability in being unfamiliar with region-specific risks or responses.

Given coastal settlements have a high proportion of retiree in-migration, vulnerability of this demographic is two-fold. Firstly, elderly residents typically have more health issues than younger age groups, and are likely to require assistance to prepare, respond or recover from a natural hazard, such as flooding caused by storm-tide inundation. Secondly, the relocation to coastal communities during retirement means these elderly residents are new to the area, indicating a potential lack of familiarity with the local environment and possibly lower capacity for preparing and responding to an emergency.

Additionally, having a highly mobile population also indicates the risk of lower familiarity with the region, and increases the risk of evacuation congestion if a natural hazard occurs during a time of peak visitation. All vulnerability indicators discussed in this section and in the referenced resources are recommended to be considered during coastal resilience planning activities, as efforts can be focused towards vulnerable audiences. Examples include to education about coastal hazards, engagement in emergency preparation activities, awareness raising about property-specific actions that can be taken and building of social-cohesion.

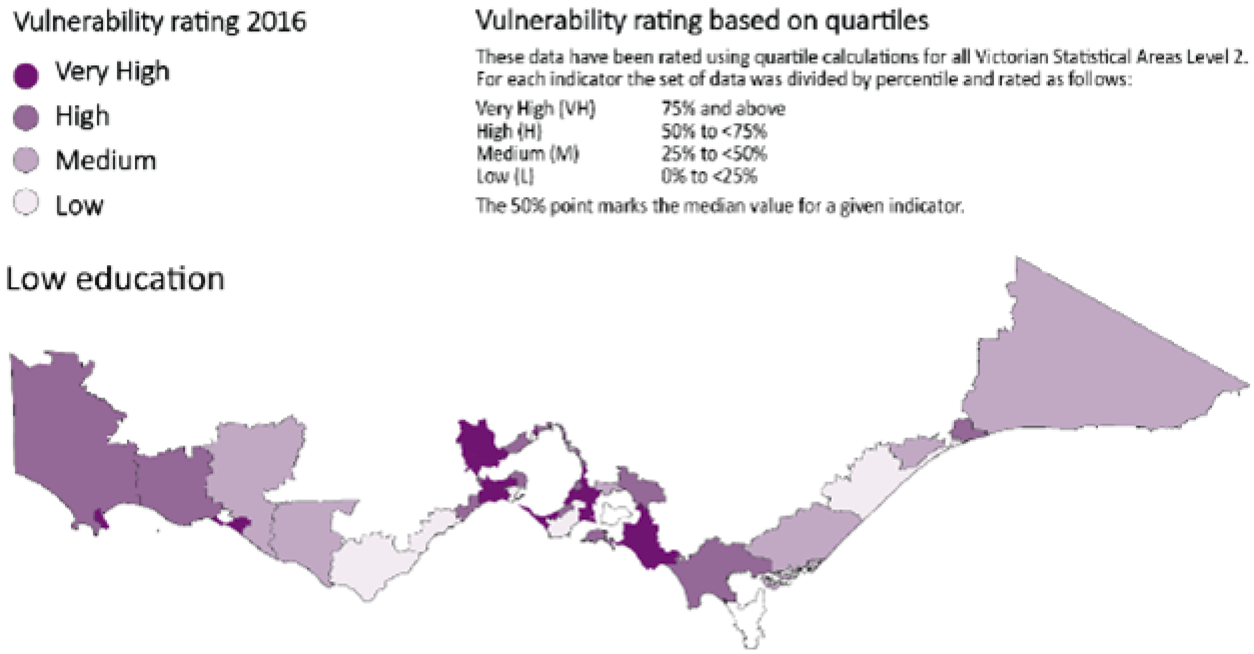

Figure 5-11 Vulnerability Assessment Results for Victoria's Coastal Regions (Source: DELWP, 2020)

5.4 Governance Considerations

All activities in the marine and coastal environment are implemented under the *Marine and Coastal Act 2018*[50] and the associated Marine and Coastal Policy 2020[51], guided by the Victorian Coastal Strategy 2022[52], and in accordance with state-wide initiatives for coastal hazards and marine spatial planning.

Marine and coastal areas present a complex interaction of social, cultural, economic, and environmental, values, with a variety of rightsholder and stakeholder interests.

5.4.1 Marine and Coastal Act 2018

The *Marine and Coastal Act 2018* (the Act) regulates management of marine and coastal environments across Victoria. The Act seeks to facilitate an integrated and coordinated approach to planning and managing marine and coastal environments.

This includes coastline protection from long-term climate change, population growth and aging infrastructure challenges. One of the guiding principles of the Act is to: *To respect natural processes in planning for and managing current and future risks to people and assets from coastal hazards and climate change.* The Act is the primary policy document governing these environments and outlines the principles and objectives for planning and management to ensure that these environments are adequately cared for so that future generations may also experience and enjoy their multiple benefits.

5.4.2 Marine and Coastal Policy 2020

Under the Act, the state-wide Marine and Coastal Policy (the Policy) facilitates effective planning, management, and sustainable use of these areas. As a part of this, the Marine Spatial Framework establishes a process for achieving integrated and coordinated planning in Victoria.

The Policy sets a 15-year vision for *"A healthy, dynamic and biodiverse marine and coastal environment that is valued in its own right, and that benefits the Victorian community, now and in the future",* providing guidance for marine and coastal environmental management, including all public and private land.

Managing coastal hazard risk is specifically addressed in Chapter 6 of this policy. This section directs planners and decision-makers to take a pathways approach to coastal hazard management.

5.4.3 Victorian Marine and Coastal Strategy 2022

The Marine and Coastal Strategy 2022 (the Strategy) identifies how the vision outlined in the Act and Policy will be achieved. It is the first of three strategies that will outline priority actions to achieve the intended outcomes of the Policy. As the first strategy, it lays the foundations for the subsequent strategies.

Several actions of the Strategy relate to the management of coastal hazards, with a focus action on adapting to the impacts of climate change. The development of the Victoria's Resilient Coasts program has been

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[50] State Government of Victoria (2018). Marine and Coastal Act 2018 (Authorised version No.003 as of 6 April 2020)

[51] State Government of Victoria (2020). Marine and Coastal Policy. Available: www.marineandcoasts.vic.gov.au

[52] State Government of Victoria (2022). Marine and Coastal Strategy. Available: www.marineandcoasts.vic.gov.au

initiated as a part of this strategy to create and adopt a state-wide approach to improve long term resilience and adaptation to coastal hazards, including state-wide hazard mapping, adaptation framework and guidelines.

5.4.4 Victoria's Resilient Coast

Victoria's Resilient Coast – Adapting for 2100+ provides a state-wide approach for coastal hazard resilience and adaptation. This includes a framework, guidelines, and support for Local Government, land managers and their communities to:

- Enable place-based, leading practice and long-term coastal hazard adaptation.
- Build on the directions in the Marine and Coastal Policy 2020.

The state-wide approach was developed through a collaborative process, including a project partnership with Traditional Owners, and a Working Group including representatives from coastal Councils, Committees of Management, Catchment Management Authorities, government agencies, water authorities and peak body groups. This Coastal Hazards Extended Guideline was developed as a part of the collaborative development of Victoria's Resilient Coast, and has been reviewed by these parties.[53]

5.4.5 Marine Spatial Planning Framework

The Marine Spatial Planning Framework[54] provides guidance to enable consistent and coordinated marine environment management across the areas of environmental health, sustainable growth, marine related and dependent economies, and climate adaptation planning. This Framework is important to enable social and economic benefits, while ensuring environmental protection of marine environments.

This Framework was developed through an evidence-based approach using best-practice principles. The function of the Framework for integration and enhanced collaboration between multiple sectors and users of the marine environment and to provide a methodology for strategic and integrated planning. While the Framework doesn't create marine plans, it outlines the process, components, and methodology for marine spatial planning to help guide planning and decision making through considering the marine system as a whole.

The output of the Marine Spatial Planning process is a Marine Plan, which is a strategic document that helps to structure and guide management decisions in the area to which the plan applies.

Implementation of the Marine Spatial Framework is being led by the Department of Environment, Land, Water and Planning, including engagement with Traditional Owners and Aboriginal communities, industry, government agencies, and the wider community.

5.4.6 Victoria Planning Provisions

Under the *Planning and Environment Act 198*7, development is regulated under local and state-wide decision-making processes. Local councils are the responsible authority for local planning matters, assessing permit applications against the planning scheme.

The Victoria Planning Provisions are a part of the Planning Policy Framework to improve policy alignment, based on a three-tier structure that integrates state, regional and local policy. The VPP is a document

[53] State Government of Victoria (2022). Victoria's Resilient Coast – Adapting for *2100+ program*. Available: https://www.marineandcoasts.vic.gov.au
[54] State Government of Victoria (2022). Marine Spatial Planning. Available: https://www.marineandcoasts.vic.gov.au

containing a set of planning provisions for state-wide reference to enable consistency and coordination how state and regional policy can be applied in a local context with a planning scheme.[55]

VPP 12 is of particularly relevance to consider, as it discusses coastal inundation and erosion and 12.01.2S provides an overlay for land that is subject to inundation. In the context of managing climate change impacts, VPP 13 Environmental Risks and Amenity provides provisions specific to natural hazard, climate change and coastal hazards including requirements listed below:

- Natural hazards and climate change;
  - Development minimises the impacts of natural hazards and adapt to climate change; and
  - Risk areas are identified using best available climate change science.
- Coastal inundation and erosion;
  - Plans include sea level rise of not less than 0.8 metres by 2100; and
  - Developable land subject to hazards is identified and managed to ensure future development is not at risk.

[55] State Government of Victoria (2022). Planning Policy Framework translation. Available: www.planning.vic.gov.au

6 COASTAL HAZARD DATA AND INFORMATION

6.1 Overview

This section provides a high-level guide for the types of data required to undertake a coastal hazard assessment and example sources, organisations, databases and libraries that hold the relevant data. The types of information can be broadly classified under Land and Ocean Survey and Imagery, Geology and Geomorphology, Oceanographic and Coastal Processes, Environmental and Climate, Catchment and Stormwater Inundation, Groundwater, and Assets and Infrastructure.

Relevant organisations, including those examples in Figure 6-1 should be contacted to assess what information may be available in the study area. The organisations noted are example only and consultation with the lead project agency should be undertaken to ensure all potential data holders are included in consultation. Consultation should extend to current and future planned projects of other agencies to assess where complimentary data requirements could provide an opportunity to collaborate.

The data examples provided herein are an example dataset only. They should not be considered as an exhaustive list or thorough description of data available. Examples are provided to demonstrate what datasets are potentially available and relevant to the study area. A thorough **Data Assimilation and Gap Assessment** should be undertaken in preparation and in advance of the development of a detailed Coastal Hazard Assessment to identify available data and opportunities for additional data collection or collation.

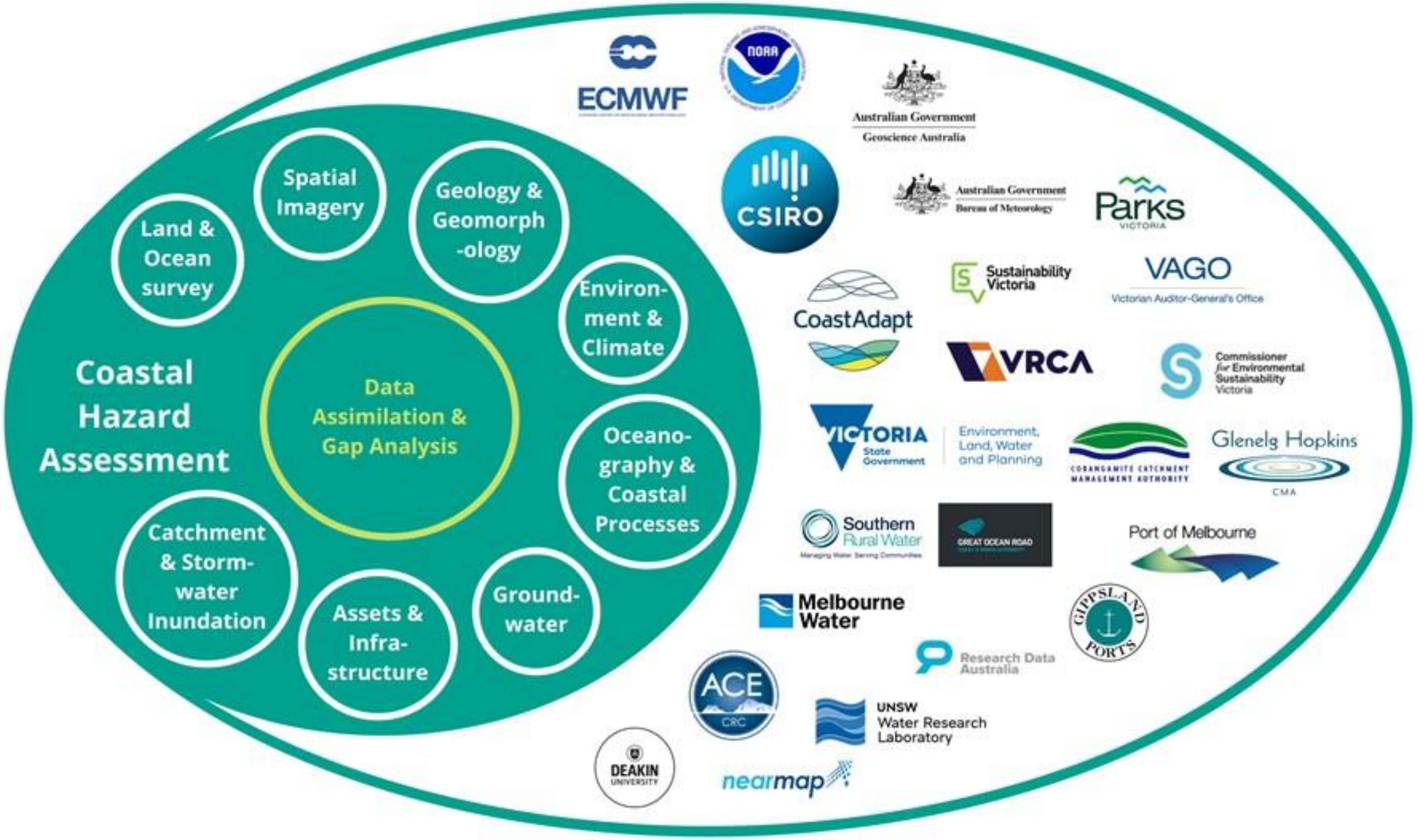

Figure 6-1 Summary of Data and Information Source

6.2 Land and Ocean Survey and Imagery

This category of data is split into the following subsets:

- Topography;
- Bathymetry; and
- Photogrammetry.

6.2.1 Topography

Topographic survey data is required to support the development of floodplain, urban and sediment transport models of the study area. Comparison of historical topographic survey data sets across a study area may assist with interpretation of coastal processes and quantification of coastal sediment movements.

State-wide high resolution topographic (and bathymetric) data for the study area is available from DEECA, collected regularly as part of the Co-ordinated Imagery Program.

Localised and more recent topographic survey data may be available from the Victorian Coastal Monitoring Program (VCMP) Citizen Science Drone Program. It should be noted the VCMP program captures drone-based **photogrammetry** (not LiDAR) of beaches across Victoria and the accuracy and quality should be checked for each project.

Victorian Coastal Monitoring Program (VCMP)

The VCMP was initiated in 2017 and is being led by DEECA's Environment and Climate Change group. It involves monitoring of wave climate, sediment movement and sediment budgets in priority coastal compartments of Victoria's open coastline, Western Port Bay and Port Phillip Bay.

Knowledge of sediment budgets help us to identify which areas of Victoria's are likely to lose or gain sediment under sea level rise and changes to wave directions. This assessment is crucial for understanding current processes and predicting future effects to undertake informed coastal adaptation planning and investment

The creation of partnerships with community groups (citizen science) and institutions to co-invest in coastal monitoring projects at both regional and local scales has been central to the success of the VCMP.

Detailed local survey may also be available from local government or coastal management groups where previous projects have been completed. Coastal managers should consider capturing regular beach survey (be it feature, profile, LiDAR or photogrammetry) in advance of procuring a Coastal Hazard Assessment.

Table 6-1 Available Topographic Data Sources and Local Examples

Custodian	Date	Scale	Detail
DEECA	2021	State-wide	The Victorian Coordinated Imagery Program (CIP) coordinates aerial imagery and elevation products.
DEECA	2008 to 2011	State-wide	Future Coasts Program collected bathymetric and topographic digital elevation modelling (DEM) using LiDAR.
Catchment Management Authority	Various	Study area specific	Floodplains LiDAR capture for CMA.
Local Council	Various	Study area specific	Localised LiDAR improvement projects.
Local Council	2011	Study area specific	Survey captured of local coastal protections structures for local coastal hazard assessment.

6.2.2 Bathymetric Data

Bathymetric data is required to support the development of hydrodynamic, wave and sediment transport analysis. Comparison of historical bathymetric survey data sets also assist in interpretation of coastal processes and quantification of coastal sediment movements.

State-wide high resolution bathymetric data is available from the Future Coast Program in the format of LiDAR DEM.. The coverage is close to complete with small sections of bathymetry missing in turbid waters where wave breaking or suspended sediments prevent accurate data collection. The Future Coast DEM is available as a 1.0m grid resolution with 0.1m accuracy (horizontal and vertical), providing an exceptional representation of the Victorian coastal zone between 2008 and 2009. The bathymetry extends to a depth of around 20m below mean sea level along the open coast, providing excellent capture of most outcrops along the Victorian coastline.

Geoscience Australia have complied a bathymetric grid of Australia from digitised hydrographic charts, multibeam and satellite remote sensing surveys at a spatial resolution of 250m.

Localised bathymetric survey may be available, from research agencies (for example Deakin University have also undertaken extensive multi beam surveys along the coast to depths of approximately 70m) and Port Authorities.

Table 6-2 Available Bathymetric Data Sources and Local Examples

Custodian	Date	Scale	Detail
DEECA	2008 to 2011	State-wide	Future Coasts Program collected bathymetric and topographic digital elevation modelling (DEM) using LiDAR.
Geoscience Australia	2009	State-wide	Australia 9 arc second Bathymetry and Topography Grid
Frontier SI	2017	State-wide	Airborne LiDAR bathymetry and elevation of Victoria. Low resolution data was used to fill large existing gaps.
Port Authorities	Various	Study area specific	Hydrographic survey of navigable channels within the port management area. Used to assess post-channel deepening topography.
University and academia	Various	Study area specific	Local multibeam Bathymetry Surveys for site specific studies may be available on request.

6.2.3 Photogrammetry

Photogrammetry is the practice of obtaining information about physical attributes through the analysis of photograph interpretation. Detailed photogrammetric analysis from the available historical aerial photographs has been undertaken across the state through projects supported by the VCMP and the SGCS.

Table 6-3 Available Photogrammetry Data Sources and Local Examples

Custodian	Date	Scale	Detail
VCMP	Various	Study area specific	Topographic survey - Drone based photogrammetry of beaches across Victoria
DEECA (formerly known as DELWP)	1947; 1969; 1977; 2002 and 2007	Study area specific	Photogrammetry for East Beach, Port Fairy

6.3 Geology and Geomorphology

Geology and geomorphology interpretation data may be required to identify variations in material and physical settings within a study area and classify discrete coastal compartments. Data is also required to identify variations in the stratigraphy and composition of cliff, shore platform and dune formations in the study area.

6.3.1 Geological Setting

A significant volume of available data is available for the Victorian coastline including geologic survey and interpretation data along with slope stability analyses. Localised geological or geotechnical assessments may be available on request.

Table 6-4 Examples of Available Geological Studies

Custodian / Author	Date	Scale	Detail
Geological Survey of Victoria	Various	State-wide	Geological map series of Victoria provided by Geological Survey of Victoria includes a variety of tools including 3D geological modelling, drill core library, geochemistry and geophysics of the state
Rosengren, N.	2019	Study area specific	Inverloch Coastal Resilience Project
Bird, E.C.F	1993	State-wide	The Coast of Victoria – the shaping of scenery, Melbourne University Press
Dept of Mines	1909	Study area specific	Memoirs of the Geological Survey of Victoria (E.J. Dunn, F.G.S., Director): Report on the Lower Powlett, Cape Paterson, and Inverloch Quarter Sheets with maps and plates by W.H. Ferguson. No. 8. Issued by W. Dickson, Secretary for Mines, under the authority of the Hon. Peter McBride, M.P., Minister for Mines.
Pritchard and Hall	1910 and 1911	Across Melbourne locations	Geological observations in Melbourne locations

6.3.2 Geomorphology

Interpretation of the geomorphology is required to establish the broad geomorphic processes that have shaped and reshaped any given coastline, interpret the response to past changes in sea levels and identify sources and characteristics of littoral and fluvial sediments.

There is limited understanding of the sources and sinks of nearshore and beach sediment across Victoria. State-wide coastal geomorphology information is provided on the CoastAdapt Smartline Explorer platform.

Geological studies are also a relevant source material for helping to define shoreline class and coastal compartments.

Availability of vertical profiles (bore logs) of subsurface geology across the state is also limited which restricts the understanding of the shoreline and backshore resilience and sensitivity to change.

Table 6-5 Example of Available Geomorphological Data Sources

Custodian	Date	Scale	Detail
CoastAdapt	2009	National	A useful source of generalised coastal geomorphology information is available from the Smartline Explorer dataset available on the CoastAdapt platform
DEECA - Index of Estuary Condition	Various	State-wide	Areas of estuarine waters derived and updated by the Index of Estuary Condition is a spatial representation of estuarine water areas. It builds upon the work by Deakin University's assessment of catchment-based threats to estuary health.

Table 6-6 Example of Available Geological and Geomorphological Studies

Author / Custodian	Date	Scale	Detail
Libraries	Various	State-wide	Historical charts from Public Records Office Victoria, available to assess geomorphological change over time.
Port Authorities	Various	Study area specific	Port history publications include navigation charts and mapping available to assess geomorphological change over time.
Bird, E.C.F	1993	State-wide	The Coast of Victoria – the shaping of scenery, Melbourne University Press
Rosengren, N.	2019	Study area specific	Inverloch Coastal Resilience Project
Rosengren, N.	2009 and 2010	Study area specific	Geology and geomorphology of the Bellarine Peninsula.

6.3.3 Sediments

Characterisation and analysis of sediment samples may be required to compliment the understanding of the movement of sediment along the coastline and is used in numerical modelling of sediment transport and erosion potential.

Geoscience Australia operates the Marine Sediments (MARS) database which contains sample data collection from various sources, both government and research agencies. Sediment sampling has been undertaken as part of several University research programs across Victoria which is available on the MARS database.

Generally, however, data pertaining to sediment size, age and characterisation is limited and may require study area specific collection and analysis of sediment.

Analysis of sediment should include as a median grain size. Other information which may be relevant can include carbonate dating and material classification to assist with understanding the origin of beach material. Sampling across the study site and beach profile should be considered.

Table 6-7 Examples of Available Sedimentology Data

Custodian	Date	Scale	Detail
Geoscience Australia	Historic database – present	National scale	Marine Sediments (MARS) database containing specific sediment information from various sample sources and survey types
Parks Victoria	Various	Study area specific	Sediment transport studies along open coast, estuarine environments and embayments for dredging and beach nourishment purposes.
Port Authorities	Various	Study area specific	Studies of the rate of change in beach profiles and analysis of beach sediment around port and embayments

6.4 Imagery

Imagery is required to support analysis of coastal changes including the comparison of vegetation extent and type, interpretation of coastal processes, quantification of coastal sediment movements and long-term change of the shoreline through beach and vegetation analysis. There are a number of different types of imagery considered relevant for the assessment of coastal hazards:

- Satellite imagery;
- Aerial Photography;
- Historical imagery; and
- Coastal obliques.

6.4.1 Satellite Imagery

Broad scale coastal change can be established via review of satellite imagery. Increasing analysis and interpretation of satellite imagery, including for elevation data or coastline position, is becoming more available and affordable. New and developing technology for analysis and interpretation using satellite imagery should be reviewed in preparation for a Coastal Hazard Assessments. There are many sources of satellite imagery some of which are subscription based.

Table 6-8 Examples of Available Satellite Imagery

Custodian	Date	Scale	Detail
DEECA	Various	State-wide	The Victorian Coordinated Imagery Program (CIP) coordinates aerial, satellite imagery and elevation.
Geoscience Australia Digital Earth Australia (DEA)	Various	State-wide	The DEA is a digital platform that catalogues earth observation data used to derive products such as the Intertidal Extents Model.

6.4.2 Aerial Photography

Photos captured by light airplanes, referred to as “aerial imagery”, are available across the Victorian coastline and provide an ongoing record of coastal change since the late 1930’s. The temporal and spatial resolution of the imagery dataset varies, with higher resolution and more frequent capture around population centres. Aerial imagery can be “georeferenced” to allow overlay of imagery for direct analysis of features and coastal change. Georeferencing requires static and ongoing features on land to be capture din the imager to anchor an image in the correct position. Georeferencing may therefore be difficult to accurately achieve in remote areas, particularly in the early part of the 20th century. Capture of imagery along high coastal cliffs may also provide difficulties for analysis where shadows, low resolution or airplane angle impact depiction of the coastline. Imagery, and the outputs from imagery should be carefully assessed.This historic aerial imagery record is available via the State Government Land Data Service (land.data.vic.gov.au).

DEECA and local governments have generally captured aerial images on an annual or biannual cycle since 2015. This data is available from the CIP. DEECA is also developing a set of georeferenced historical images and shoreline position as part of the VCMP, as well as funding collection of photogrammetry (elevation data derived from imagery) at a number of coastal locations through the Citizen Science program. Other agencies (e.g., Port Authorities) may also collect regular aerial imagery of their assets and management areas.

There are many subscription service providers that collect aerial imagery of Victoria which may be available for analysis on a shorter temporal timescale, allowing seasonal interpretation of coastal change or event-based assessment of coastal change to be completed. Universities may also have private collections of historical aerial imagery in their libraries, as with local government and local organisations.

Table 6-9 Examples of Available Aerial Photography Sources

Custodian	Date	Scale	Detail
Private aerial imagery and data companies	Various	National scale	Subscription service with access to historical high resolution aerial photographs. Updated frequently.
DEECA	1948 to present day	State-wide	Aerial imagery, including black and white and colour scanned photography and single frame photos.
VCMP	2018	Study area specific	VCMP Citizen Science Drone Program
DEECA	2016	Study area specific	Colac-Otway & Surf Coast Towns Photography & LiDAR Project

6.4.3 Historical Imagery

Review of historical imagery should not be limited to aerial images as important information on coastal use and treatment can be gained through review of ground level imagery.

The National Library of Australia and the Victorian Library both hold considerable volumes of historical images which potentially predates the capture of aerial and satellite imagery, can highlight environmental, cultural and social values of the past and present as well as changes to landform useful for the analysis of geomorphology of a given study area.

Table 6-10 Examples of Historical Photography Sources

Custodian	Date	Scale	Detail
State Library Victoria	Various	State-wide	The State Library hosts a copyright free image search online.

6.4.4 Oblique Photographs

Collections of oblique imagery, either from unmanned drones, aeroplanes, traditional camera setups or smart phones is an important dataset for assessing coastal change.

CoastSnap is delivered by the UNSW Water Research Laboratory and the NSW Department of Planning, Industry and Environment. CoastSnap is a global citizen science project to capture imagery in a fixed location that allows the tracking of shoreline change over time.

Table 6-11 Summary of CoastSnap Imagery Source

Custodian	Date	Scale	Detail
UNSW - CoastSnap	2021 onwards	Study area specific	CoastSnap fixed station and 'DIY' stationery points capture multiple images of the shoreline at: Inverloch, Cape Woolamai, Phillip Island, several locations in Port Phillip Bay, Torquay, Lorne, Great Otway National Park, Port Fairy and Discovery Bay

6.5 Oceanographic and Coastal Process

Oceanographic data is required to understand the drivers of coastal processes which generate coastal hazards. Oceanographic data includes water levels and current forces, waves and physio-chemical properties such as water temperature and salinity. The core components required to investigate coastal processes are water levels and wave conditions.

6.5.1 Wave Data

Long term wave climate data is required to support sediment transport modelling of longshore and cross shore sediment dynamics and to estimate wave setup and run-up components of coastal inundation hazards and extreme event analysis.

6.5.1.1 Measured Data

Historically, measured wave data has not been readily available in Victoria outside data captured by the Port of Melbourne at Point Nepean. Project-based measurement has been completed by various private and public bodies, such as for the Wonthaggi desalination plant, however data records cover a limited timeframe and spatial period.

Wave data has now been captured by the VCMP along the Victorian coastline since December 2019 and is currently ongoing.

Further site specific wave data may be needed to define the coastal hazards and it is important to identify this early to allow a reasonable period of data collection to capture the range of seasonal and temporal variation at the site.

Table 6-12 Available Measured Data Sources and Examples

Custodian	Date	Scale	Detail
DEECA / Universities / CSIRO / BoM	2012 onwards	Study area specific	Vicwaves.com.au – location for all wave buoy data. Study area specific wave data deployment and collation from previous projects. Live data is hosted on vicwaves.com.au
Victorian Coastal Monitoring Program (VCMP)	Various	State-wide	Deployment of wave buoys for development and refinement of wave models in study locations for previous projects
CSIRO / BoM	1994 onwards	Study area specific	Wave buoy data capture wave height and direction and available from the BoM website. Updated regularly.
Port Authorities	1993 – onwards	Study area specific	Port Authorities maintain and operate wave buoys collating data from locations in relatively deep water. For example, there are for 8 locations within Port Philip Bay. 4-hourly wave data files for non-directional Datawell Waverider buoys.
IMOS (Integrated Marine Observing System)	2019 onwards	Study area specific	Study area specific wave buoy deployment.

6.5.1.2 Modelled Data

Offshore wave climate information can also be sourced from a number of global and regional wave reanalysis models. These models are operated by a variety of national and international research organisations, including the Bureau of Meteorology and CSIRO. DEECA has recently funded development of a high-resolution wave hindcast for the Victorian coast through the University of Melbourne. Updated and refined model data is regularly available and a review of the most up to date and relevant hindcast data should be considered to assist in assessing coastal processes.

When reviewing modelled wave data to assess local coastal processes, the spatial and temporal resolution and extent, boundary inputs, outputs and ongoing production should be considered.

Global and national level wave models are also available which provide predictions for future wave conditions under a range of climate scenarios. As with hindcast wave data, the input variables and original purpose of the wave model should be considered when utilising data for coastal process assessments.

Table 6-13 Available Modelled Wave Data Sources and Examples

Custodian	Date	Scale	Detail
US National Oceanic and Atmospheric Administration (NOAA) Wave GFS data set	2021	Global	Long-term global directional wave modelling outputs: Wave forecasts out to 16 days and prediction of ocean waves forced by the atmosphere
European Centre for Medium Range Weather Forecasting (ECMWF) ERA 40 Wave model	1957 - 2002	Global	ERA-40 Model - Long-term global directional wave modelling outputs
Victorian Coastal Monitoring Program (VCMP)	Various	State-wide	Development and refinement of wave models undertaken for various study locations for previous projects
CSIRO / BoM	1979 - present	State-wide	CAWCR Wave Hindcast data provides reliable offshore wave climate information

6.5.2 Water Levels

Coastal water levels are a product of the astronomical tides, wind and atmospheric residual and wave driven setup and runup.

6.5.2.1 Astronomical Tidal Data

Astronomical tide data is available for the Victorian coastline from the Australian National Tide Tables and the Victorian Tide Tables in the form of predicted tidal height, astronomical tidal constituents and tidal planes. Astronomical tides are derived from measured water levels. Data regarding the period and length of measurement is available from both the RAN and the BoM and should be reviewed before determining the quality and potential use of astronomical tidal predictions. Port Authorities may also maintain their own gauges and provide tidal constituents for generation of astronomical tide.

Astronomical tides are driven by gravitational forces associated with the moon sun and other gravitational forces. Astronomical tides can be predicted at a chosen location for any point in time if the tidal constituents are available for that location.

Astronomical tidal planes such as mean high water springs, MHWS, or the Highest Astronomical Tide, HAT, are levels derived from the astronomical tides to describe different water levels. However, the astronomical tides do not include any changes to the water level from wind or atmospheric or wave conditions.

6.5.2.2 Measured Water Levels

Measured coastal water level can include the residual water level caused by meteorological forces, wave setup and catchment contributions. The residual is the difference between the predicted astronomical tide and the measured water level. Measured water levels can be analysed using harmonic analysis to derive astronomical tides.

Long term measured coastal water levels are available along the Victorian coastline via the BoM's Australian Baseline Sea Level Monitoring Program (ABSLMP) which has been collecting high quality measured water levels at Portland, Lorne and Stony Point in Victoria since 1991.

Water level data is also collected by Melbourne Water and the local Port Authorities around the coast. Catchment Management Authorities may also collect tidal water levels within the estuarine and the Victorian Water Measurement Information System should be reviewed for available data.

As with the wave data, coastal water levels may also be collected for private projects along the coast such as the Wonthaggi desalination plant, oil and gas or other marine applications.

Site specific data may be needed to understand the local coastal processes in detail, and it is important to identify this early to allow a reasonable period of data collection to capture the range of seasonal and event variations present at the site.

6.5.2.3 Modelled Water Levels

Reliable sea surface information can be sourced from a number of global and regional climate reanalysis models to provide a hindcast of historical data for hazard assessment. These models are operated by a variety of national and international research organisations, including the Bureau of Meteorology and CSIRO.

As with the wave modelling, the initial purpose of the model, the boundary and bathymetric inputs, temporal and spatial resolution and output parameters should be assessed to determine the most appropriate model to assist in defining local coastal processes.

Table 6-14 Available Water Level Data Sources

Custodian	Date	Scale	Detail
Royal Australian Navy Hydrographic Office	Updated Annually	National	Tidal heights, constituents and planes for Standard and Secondary Ports
BoM National Tidal Facility	Updated Annually	National	Tidal heights, constituents and planes for locations around Australia
Victoria Regional Channels Authority (VRCA)	Updated Annually	State-wide	Tidal heights, constituents and planes for locations around Victoria
BoM Australian Baseline Sea Level Monitoring Program	1991 onwards	State-wide	Portland, Lorne and Stony Point
Melbourne Water	Various	Port Phillip Bay / Western Port	Measured coastal water levels
Port Authorities	Various	Typically, in navigable waterways and ports	Measured coastal water levels

6.5.3 Current Data

Tidal and wave driven currents can have significant impact on coastal processes. A network of measured current data is not available along the Victorian coast and available measured data is limited to site specific projects.

Port Authorities, local government, research agencies and private industry hold a variety of datasets across Victorian coastal waters.

6.5.4 Historical Coastal Processes

Background historical data and information relating to coastal processes, sediment transport/dredging and shoreline responses to artificial structures may be required to guide and support coastal process assessments.

National, first pass level assessments have been completed by Federal Government Agencies which assess coastal sediments, beach change, coastal compartments and so on.

Local scale coastal hazard assessments have been completed for the Bellarine Peninsula, Port Phillip Bay, Western Port, Ninety Mile Beach/ Gippsland lakes and the Inverloch Region (completion 2022). These local scale hazard assessments provide detailed coastal process assessments for an extensive stretch of the Victorian coastline.

In addition to these wide scale projects, local coastal process assessments have been undertaken by research organisations, government agencies, councils, authorities and private interests. A thorough literature review will identify previously undertaken studies to generate background information and identify other data sources available.

Table 6-15 Examples of Coastal Processes Data and Information Sources and Local Studies

Custodian / Author	Date	Scale	Detail
Coast Adapt	2016	National scale	Coastal sediments, beaches and other soft shores
Thom, B	2018	National scale	The approach for delineating coastal compartments in Australia
Geoscience Australia	2020	National scale	Satellite imagery analysis of coastal change from 1984 – 2020
DEECA	2014 onwards	Study area specific	Analysis of the coastal processes for the purposes of the five complete Local Coastal Hazard Assessments in Bellarine Peninsula, Port Phillip Bay, Western Port, Ninety Mile Beach/Gippsland Lakes and Inverloch Region.

6.6 Environment and Climate

6.6.1 Meteorological Data

Long term hydrologic data (i.e., rainfall and stream flow) is required to support riverine and urban modelling projects which may feed into a coastal hazard assessment and is used to generate extreme terrestrial flood levels and flows.

Long term meteorologic data (i.e., wind and pressure) is required to supplement coastal wave and hydrodynamic modelling, providing a validation of global model data.

Rainfall, wind and air pressure data is available from the BoM gauging stations across Victoria.

Whilst there may be a lack of long-term wind and pressure data available uniformly across the state, wind simulated by the CSIRO global wave model captures offshore meteorological conditions which may be used for coastal modelling.

Table 6-16 Available Meteorological Data Sources

Custodian	Date	Scale	Detail
CSIRO-BoM	2014	State-wide	CSIRO-BoM product CAWCR provides wave and wind climate data on a 4-minute (approx. 7.5km) grid scale and a one-hour timestep
BoM	Various	National scale	Meteorological data
Australian Rainfall & Runoff (Ball et al. 2016) (Book 6, chapter 5)	2016	National scale	Discussion on the procedure for calculating the probability of a particular flood height in the coastal zone that considers the combination of rainfall and storm tide under different levels of dependence between the two.

6.6.2 Climate Change Predictions

IPCC climate change projections are based on sophisticated global and national climate models that simulate the climate using some of the world's most powerful supercomputers to successfully represent important elements of historic and present climate (such as global average temperature).

The major categories influencing climate changes in ocean environments include sea surface temperature, ocean heat content, sea level and ocean acidification, driven by increased average temperatures.

Nationally, sea level projection data can be sourced from Coast Adapt.[33] Current data available provides projections across a range of planning horizons for Victoria's coastline and show similarities across each locality. With the release of IPCC's 6th Assessment Report, this resource will be updated to include SPP scenarios (replacing RCP scenarios) and contextualised information from the latest assessment report for Australian regions.

The BoM and CSIRO produce a biennial "State of the Climate" summary, with the most recent summary released in 2020. The State of the Climate notes that sea levels are continuing to rise around Australia.

The Victorian Government partnered with CSIRO in 2019 to undertake high resolution climate modelling to provide an updated set of climate projections for Victoria. Furthermore, the University of Melbourne is currently undertaking a detailed numerical modelling study as part of the VCMP to assess the implications of climate change scenarios on wave conditions along the Victorian coastline.

Table 6-17 Examples of Available Climate Change Projection Data Sources

Custodian	Date	Scale	Detail
Coast Adapt	2021	National	CoastAdapt Datasets – Sea-level rise and you: information about the future
CSIRO-BoM	2020	National	State of the Climate report. Details the observed changes in Australia's climate and surrounding oceans
CSIRO - DEECA	2019	State-wide	High resolution climate modelling to provide an updated set of climate projections for Victoria. Includes projected wind speed changes.

6.7 Catchment and Stormwater Data

Urban and rural runoff into estuarine environments and the open coast poses potential hazards to the local coastline and may impact the options and impacts of adaptation measures. Outfalls of the urban catchment network at the shoreline can introduce a hazard into seemingly protected areas with SLR and extreme water levels causing back flow into the catchment. Flood modelling may be required to assess these potential impacts.

Detailed flood studies are available throughout Victoria and updated flow data for catchments are available from gauges maintained by government agencies. Gauge flow information is generally not available for smaller drainage catchments.

Stormwater network details may be sourced from local government asset databases including pipe network data such as size, pit levels and inverts along with coastal outfall details.

Where catchment flows are thought to pose a significant influence, or be at risk to future climate changes, localised flow gauging should be considered in advance of any coastal hazard assessment.

Table 6-18 Example Available Catchment and Stormwater Inundation Data Sources

Custodian	Date	Scale	Detail
DEECA	Various	State-wide	River and tributary flows from fluvial gauges can be downloaded from DEECA online database
BoM	Various	State-wide	Water Quality sampling station
Council	n/a	Municipal	Drainage network details, flood extents and impacts, upgraded works areas etc
Catchment Management Authority	n/a	Catchment	Flood extents and impacts, levee data, drainage networks etc

6.8 Groundwater

The distribution and hydraulic properties of the stratigraphy may be required to prepare a hydrogeological conceptual model and predict changes and impacts of future sea level rise to significant groundwater receptors. Seasonal information on groundwater movement (including saline intrusion), rainfall recharge and maps of potential coastal acid sulphate soils (CASS) is required.

State-wide data includes published geological map sheets (e.g., Warragul 1:250,000 geology), the SRW Groundwater Atlases, the Southern Rural Water Groundwater Hub website, Visualising Victoria's Groundwater, the Bureau of Meteorology (including Explorer and GDE Atlas), Water Measurement Information System, maps of CASS and existing local groundwater studies available from local and state government agencies.

Table 6-19 Examples Available Groundwater Data and Information Sources

Custodian	Date	Scale	Detail
BoM - Groundwater Information	2021	National dataset	Groundwater data including Explorer and GDE (Groundwater Dependent Ecosystems) Atlas.
Water Measurement Information System	2021	State-wide	WMIS is the primary access point for water level, flow and water quality and groundwater monitoring data. WMIS now contains real time data (less than 1 hour old) data for all telemetered groundwater bores.
DEECA Victorian Aquifer Framework	Various	State-wide	Geometry of aquifers and confining beds and parameters including transmissivity, hydraulic conductivity, specific yield and hydraulic gradients
Australia Research Data Commons	Various	National	Metadata and data managed by Australian Research Data Commons. Information on actual or potential groundwater dependent ecosystems and other groundwater services.
Southern Rural Water Groundwater Hub website	2014	Study area specific	Groundwater atlases provide specific detail for Gippsland, Port Philip & Western Port, Southwest Victoria.
Port of Melbourne	Various	Study area specific	Groundwater data
Pritchard (1910) and Hall (1911)	1910 and 1911	Across Melbourne locations	Geological observations in Melbourne locations
Catchment Management Authority	No specified date	State-wide	Groundwater flow systems (regional, intermediate, local), groundwater quality (chemistry).

6.9 Cultural and Heritage

The state-wide Victorian Aboriginal Heritage Register is accessible via the Aboriginal cultural heritage places and objects, known as the Aboriginal Cultural Heritage Register and Information System (ACHRIS). The Register is not publicly accessible and requires access from the Department of Premier and Cabinet.

Working in partnership with Traditional Owners on specific place-based cultural and heritage studies is important to provide a foundation to support assessments of bio-cultural values, coastal hazard risk, and enable the protection and restoration of bio-cultural values through adaptation planning.

Table 6-20 Examples of Available Cultural and Heritage Data Sources

Custodian	Date	Scale	Detail
Victorian Government – First People Relations	Various	State-wide	The Victorian Aboriginal Heritage Register holds information about known Aboriginal cultural heritage places and objects within Victoria.
Victorian Government – Victorian Heritage Database	Various	State-wide	The Victorian Heritage Database is home to the Victorian Heritage Register which lists the state's most significant heritage places, objects and historic shipwrecks protected under the Heritage Act 2017.
Victorian Government – Victorian Heritage Database	Various	State-wide	The Victorian Heritage Database is home to the Victorian Heritage Inventory which lists all known archaeological sites in Victoria.
Commonwealth Dept of Agriculture, Water and the Environment	Various	National	Australia protects its shipwrecks, sunken aircraft and other types of underwater heritage and their associated artefacts through the Underwater Cultural Heritage Act 2018, which is administered in collaboration between the Commonwealth, States and Territories.

6.10 Infrastructure

The location, dimensions and condition of infrastructure within the study area will be required to inform coastal hazard risk assessments and adaptation planning.

DEECA holds a database of all coastal protection structures around Victoria on Crown Land including location and condition following a comprehensive coastal asset condition assessment in 2021. Government agencies will hold datasets on public assets whilst utility providers are the custodian of energy, water and telecommunication assets.

The Digital Twin program is bringing a new way for effective collaboration across government, industry, education and the community. This could provide a potential hub for asset and infrastructure data in the future. The Digital Twin program:

- Enables government, industry and the community to collaborate through a shared open data platform.
- This program organises and visualises masses of data in one virtual place to create a 3D, digital version of the world, using spatial data, artificial intelligence and sensor data from across the State;
- Anticipated uses of this platform is the ability for places to be visualised and modelled before investments hit the ground, increasing transparency between planning and communities;
- This platform/program will be the first-place leaders go to plan our liveable, sustainable and resilient future and the first place people go to plan how they engage with their communities.

Collation of a timeline of construction of coastal protection structures will enhance the review of coastal geomorphology. Assets and infrastructure that may be considered include:

- Coastal levees;
- Civil Infrastructure such as roads, utilities, telecommunications and buildings;
- Stormwater pipe network;
- Jetties, piers and boat ramps; and
- Coastal access stairs.

Along with government agencies, the National and Victorian State Library hold historical records and images illustrating the previous condition and activities including infrastructure and assets on the coastline.

Table 6-21 Example of Available Asset and Infrastructure Data and Information Sources

Custodian	Date	Scale	Detail
DEECA Coastal Assets Condition Assessment	2021	State-wide	Assessed the condition, location and AHD of all coastal protection structures around Victoria.
Victorian Auditor-Generals Office (VAGO), Protecting Victoria's Coastal Assets	2018	State-wide	Detailed review of the management of coastal assets across Victoria.
DEPI (Future Coasts Program)	2008 and 2011	State-wide	Coastal (protection) structures (seawalls, groynes, revetments, breakwaters, wharves). The information utilised high-resolution aerial photography. It has been found that some structures were not captured in 2011 and are therefore missing in the dataset. This is most likely because a) they were not present at the time of capture or b) could not be identified on the aerial image available.
Vic Spatial Data	2021	State-wide	Road network and cadastral dataset
Local Councils	Various	State-wide	Stormwater network data – Drainage Pits, Pipes and Outlets (including Invert Levels)
GORCAPA	Various	Study area specific	Coastline, Southwest Coast Walk, Beach User Risk, Cliff Top Property Risk.
South Gippsland Shire Council - Coastal Levees	2019	Study area specific	A detailed assessment of the coastal levees within the South Gippsland Shire Council around Anderson Inlet has been completed in 2019 by Water Technology. This comprehensive study provides a full asset database of the levee location, height and condition
Digital Twin Victoria (DTV)	2022	State-wide	Digital hub for the collation of buildings, assets and infrastructure in Victoria.
DEECA – Land registration	Various	State-wide	Land Register Services maintains a register of land, which provides information on proprietorship and interests in land.
Dial before you dig	Various	State-wide	Utility and service providers such as Multinet Gas Networks, Telstra and NBN provide information about networks to Dial Before You Dig.

7 BEST PRACTICE FOR ADAPTATION PLANNING

7.1 Overview

The purpose of this section is to provide guidance on the coastal hazard information needed for best practice adaptation planning. This includes planning horizons, scenarios, and consideration of the complexity of information needed and that is available.

Undertaking a coastal hazard assessment requires the identification of the coastal setting and shoreline class; coastal hazards relevant to the study area; and the local and regional economic, social, environmental, and cultural values. The type of coastal hazard assessments undertaken depends on the scale and purpose of the study which informs the complexity of the assessment methodology.

Identifying coastal setting and shoreline class determines the nature of the coastal hazards to consider such as erosion, inundation, changing sediment dynamics or saline intrusion. Furthermore, identifying the exposure of local values will inform a fit for purpose method of how the level of risk will be determined. Areas where high value has been identified may require more complex studies to better understand the full extent of coastal hazard risk, and the adaptive planning trigger points required to protect the values identified.

The criteria by which coastal hazard risk is to be evaluated should be developed at this stage, including the number and selected event likelihoods, as well as the planning horizons it is necessary to assess. Guidance on what coastal hazard information to consider is outlined in the following sections.

7.2 Planning Horizons

There are a range of possibilities that requires due consideration to prepare for multiple outcomes and planning horizons to understand how they would affect the coastal hazard risk.

Coastal areas are exposed to hazards and risks that occur somewhat unpredictably which is why adaptive planning is a robust response. Selecting these horizons/trigger points is not prescriptive, to enable responses to be fit for purpose to the local government area, and consistent with other local or regional strategy timeframes.

7.2.1 Principles for Selecting Planning Horizons

To select planning horizons, it is important to consider factors relevant to local jurisdictions and a number of principles. Adaptive planning is flexible and should be contextualised to suit local government requirements and existing strategy planning horizons, while maintaining consistency in approach where possible. Planning horizons selected should employ the principles of ***alignment, consistency,*** and ***relevance***. This includes:

- Alignment
  - Consider planning horizons of key strategies at the local scale.
  - Consider planning horizons of corporate planning cycles at the local and regional scale.
  - Consider the timeframe of the local land use planning scheme in place and amendment cycles.
  - Consider integration opportunities with other planning activities at the local and regional scale.
- Consistency
  - Consider the time steps that global or regional projected data is modelled in.
  - Consider national or state-wide climate change policy or planning instruments.
  - Consider advancement in best practice.

- Relevance
  - Consider IPCC assessment reporting time periods (approximately every 6-7 years).
  - Select a number of trigger points (year or sea level increments) to enable appropriate adaptation to be implemented as necessary.

Planning horizons should include adaptative pathways with trigger points. While any of these planning horizons could be used, taking a common approach enables comparability and consistency across Victoria.

Example planning horizon consideration for the principal *consistency*

- Climate data is typically modelled to the years 2050 and 2100 (e.g., IPCC 6th Assessment Report).
- Coast Adapt sea level rise data is modelled to the years 2030, 2050, 2070, and 2090.

7.2.2 Spectrum of Planning Horizons

There are a variety of different planning horizons used in coastal hazard planning. It is best practice to adopt a spectrum of planning horizons between present day and 2100, as well as to a number of trigger points.

Planning horizons can either be set time steps based on specific year intervals (e.g., 2050), be a period of time (e.g., medium-term) or be a number of years from plan creation (within 50 years). Trigger points may be time bound or based on incremental sea level rise points. An example of this is demonstrated in Table 7-1.

Table 7-1 Example of Possible Planning Horizons to Select

Period	Time step	Horizon	Sea level rise*
Base line	Baseline of historic and current data	Present day	Mean Sea Level (MSL)
Short term	10 – 25 years	2040	MSL + 0.2m
Medium term	25 to 50 years	2070	MSL + 0.5 m
Long term	50 to 100 years	2100	No less than MSL + 0.8 m by 2100
Sensitivity scenarios (examples)		2100	1.1
			1.4

Subject to future updates in sea level rise benchmarking

7.2.3 Considering Sea Level Rise

Policy 6.1 of the Marine and Coastal Policy 2020[56] states: "Plan for sea level rise of not less than 0.8 metres by 2100, and allow for the combined effects of tides, storm surges, flooding, coastal processes and local

[56] State Government of Victoria (2020). Marine and Coastal Policy. Available: www.marineandcoasts.vic.gov.au

conditions such as topography and geology, when assessing risks and coastal impacts associated with climate change."

Global sea levels are expected to rise between 0.61 and 1.10 m by 2100 above 1986-2005 levels under a high-emissions scenario, with a global average 0.84 m[57].

Alignment of sea level rise increments to time horizons should be based on the Marine and Coastal Policy 2020 and future updates to sea level rise benchmarks.

Sea level rise increments can form the trigger points for coastal hazard adaptation planning.

To do this, it is important to understand the global sea level projections, and the regional expression of these. These sea levels can be assigned to a planning period based on the best available predictions, to enable a time-based assessment of hazards. It is generally accepted that the rate of sea level rise on the Victorian coastline is approximately 10mm/year, which equates to 0.1m/10 years[58].

Example planning horizon consideration for the principle _consistency_

- Climate data is typically modelled to the years 2050 and 2100 (e.g., IPCC 6th Assessment Report).
- Coast Adapt sea level rise data is modelled to the years 2030, 2050, 2070, and 2090.

7.3 Scenarios

There are a range of hazard scenarios to consider in coastal hazard assessment. Scenario planning considers a range of likelihood events which enable varying levels of impact to be better understood.

Likelihood scales are used to define the probability of a coastal hazard occurring, based on annual exceedance probability (AEP). Likelihoods must be carefully developed for each particular study area, and a clear description of what is meant by each likelihood level should be provided.

It is best practice to use a scale of likelihood occurrences from 'likely' to 'rare'. These can be based on expert opinion and qualitative assessment for broad-scale, high-level risk assessments. More complex assessments may be warranted if the consequences are expected to be significant.

7.3.1 Principals for Scenarios

The same principles apply to select coastal hazard scenarios as planning horizons, being ***alignment, consistency,*** and ***relevance***. Specific considerations for selecting fit for purpose scenarios may include:

- Alignment;
  - Align with place-based contexts, such as modelling of drainage network design events (20% AEP) and other strategic planning considerations; and
  - Align with ISO31000 risk assessment (used in stage 4) and that using a spectrum of event likelihoods is considered best practice.

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[57] Oppenheimer et al 2018.

[58] Coast Adapt (2021). CoastAdapt Datasets – Sea-level rise and you: information about the future. Available: www.coastadapt.com.au

- Consistency;
  - Consider other hazard scenarios modelled for different hazard types in the study area (e.g., riverine flooding) and possible interaction (potential for multi-hazard assessment); and
  - Consider what scenarios may have been previously assessed in the study area and what is required to add value or further understand risk.
- Relevance;
  - Consider values identified in the study area and what level of modelling should be conducted to understand risk and how to protect identified values (social, cultural, environmental and/or economic).

7.3.2 Spectrum of Scenarios

As mentioned, it is considered best practice to include a range of likelihoods. For coastal adaption planning, a minimum of three event likelihoods for the relevant technical assessments should be included, such as 1% AEP, a smaller event (e.g., 10% AEP), and a larger event (e.g., 0.2% AEP).

In a probabilistic context, AEP event likelihoods are often assigned a descriptor such as ‘likely, possible or rare events’ as presented in Table 7-2. These descriptors can be assigned based on what is most appropriate language for different place-based contexts.

Table 7-2 Likelihood of Occurrence and Relationship to Hazard Annual Exceedance Probability (AEP)

Hazard Annual Exceedance Probability	Example descriptors
MHWS or HAT	Almost Certain
10%	Likely
1%	Possible
0.2%	Rare

Additionally, different coastal hazards have specific considerations which are discussed in the following sections, organised by hazard type.

7.4 Coastal Hazard Assessment Approaches/Considerations

This guideline is not intended to provide comprehensive detail on how to undertake a coastal hazard assessment. Best practice coastal hazard assessments are informed by national and industry best practice, which is continually advancing, and expert guidance should inform the scope of place-based hazard assessments. However initial guidance and considerations are provided below.

7.4.1 Erosion Likelihood

For erosion hazards, assessments consider the combination of short term, long term and response to sea level rise. Short term erosion is the immediate effects of ‘storm bite’ which is the horizontal recession of a beach associated with a given ‘design storm’ event. A design storm event for estimating storm bite is often based on what the community considers an acceptable risk for assets under threat from coastal hazards, i.e., the 1% AEP or 1 in 100 ARI.

The assumption of storm bite is that a characteristic beach profile is developed during storm wave attack, and that this characteristic profile provides a volume balance between the material eroded from the dune and upper beach with the material deposited further down the new profile in the nearshore zone.

Conventional practice for coastal hazard assessments is, at a minimum, consider the effects of a 1% AEP event, whereas for more complex assessments it is appropriate to consider multiple likelihoods such as both a more frequent and rarer event such as the 10% and 0.2% AEP. This is typically applied to storm tide and wave events.

7.4.2 Inundation Likelihood

7.4.2.1 Storm Tide

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. They are most extreme during storm tide events; for example, when a storm surge coincides with a high spring tide. As with assessment of erosion, conventional practice for coastal hazard assessments is to consider the effects of a 1% AEP event for simple assessments and more frequent and rarer events (10% and 0.2% AEP) for more complex assessment. The assessment of the combination of storm tide and wave events is also required for a more complex assessment.

7.4.2.2 Catchment Flooding – Joint Probability

For a complex study that requires analysis of the effects of both catchment flooding and storm tide inundation, a joint probability analysis is recommended. The interaction between fluvial flood and coastal inundation is known as the coincident flooding and a method for determining when joint probability analysis is provided in the Australian Rainfall and Runoff guide.[59]

7.4.2.3 Urban Flooding

Coastal flooding in urbanised areas will likely interact with the existing drainage network. The extent of the drainage network, and the details regarding backflow and network capacity should be understood. The drainage network could be overwhelmed in future climate scenarios if the capacity is based on a free draining tailwater below future sea level projections.

7.4.3 Coastal Hazard Mapping

The output of a coastal hazard assessment should be a set of coastal hazard maps or GIS spatial layers for the multiple planning horizons considered. The coastal hazards should be mapped for the study area and show at least the following information:

- Landward extent of foreshore erosion for a present-day designated storm event, including the landward extent of any zone of reduced foundation capacity associated with this designated event;
- Extent of oceanic inundation at present, including storm surge computation, wave set-up, and dune overtopping. Where relevant the inclusion of flood extent from an adjacent estuary or catchment;
- The impacts of future climate change, based on the planning horizon for the study and the intervals for assessment;
- Likelihood and probability mapping, including the likely location of an eroding shoreline. Hazard mapping such as depth of inundation, erosion hazard lines and/or extent of groundwater intrusion; and
- Consideration of uncertainty or safety factors based on the adequacy of available data and the existing knowledge of processes and effects.

[59] Geoscience Australia (2019). Australian Rainfall and Runoff Guidelines

7.5 Complexity of Information

When undertaking coastal hazard assessments and technical studies to better understand and quantify the exposure of an area to erosion, inundation, saltwater intrusion, offshore sediment dynamics, there is a range of possible studies that could be undertaken.

Developing an understanding of existing coastal processes and hazards considers 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.[60]

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[61], and relatively simple assessment techniques such as 'bath-tub' inundation modelling of high tide plus sea level rise, in which a constant, available information is used rather than determining and simulating time-varying site-specific design water levels. This may provide an overall first impression of the possible effects at a broad scale.

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.

Additionally, whether an area is urbanised, used for agriculture or industry, or is in a natural state should be considered in determining studies.

While many possible studies of varying geographical and complexity scales could be completed, what is commissioned needs to represent the purpose of the assessment and fit within the budget allocations. Therefore, a summary of key considerations for determining the level of complexity a study requires is provided in Appendix A and Appendix B.

7.6 Identifying Shoreline Class, Hazards and Values

There is a range of possible hazard types, likelihoods and planning horizons that could be included in studies. For assessments across multiple jurisdictional boundaries, it is important to identify and engage key stakeholders who have interest or influence in the outcomes of the study. To help the identification of coastal hazard types, a conceptual table of the hazard type and shoreline class is provided to assist with scoping and identifying knowledge gaps and uncertainties (Table 7-3).

[60] New Zealand Ministry for the Environment (2008). Coastal Hazards and Climate Change. A Guidance Manual for Local Government in New Zealand. 2nd Edition. Ministry for the Environment, Wellington

[61] DELWP (2012). Victorian Coastal Hazard Guidelines. Future Coasts Program

Table 7-3 Hazards that Affect Different Shoreline Class

#	Shoreline Class	Erosion		Permanent Inundation due to SLR	Storm Tide Inundation	Saltwater Intrusion	Offshore sediment dynamics
		Short Term Erosion	Long Term Erosion				
1	Hard Rock Cliffs with platform / beach (including bluffs)	✓	✓	✓	✓	✗	✗
2	Soft Rock Cliffs with platform / beach (including bluffs)	✓	✓	✓	✓	✗	✗
3	Low earth scarp	✓	✓	✓	✓	✓	✗
4	Sandy shorelines	✓	✓	✓	✓	✓	✓
5	Estuarine environments including tidal channels, mangrove and saltmarsh	✓	✓	✓	✓	✓	✓
6	Offshore environments	✗	✓	✗	✗	✗	✓
7	Coastal floodplains	✗	✗	✓	✓	✓	✗
8	Engineered coastlines	✓	✓	✓	✓	✗	✗

7.6.1 Identifying Erosion Hazards

For each section of coast, the potential short term, long term, and sea level rise (SLR) component of the erosion hazard applicable to the specific location should be identified, considering the backshore, intertidal and subtidal morphology along with the coastal processes specific to that location. The erosion hazard is then defined in the form:

Erosion Hazard Extent = Short Term Erosion (ST) + Long Term Change (LT) + Response to SLR (SLR).

While there have been significant advances in modelling techniques and understanding of coastal processes, there is often insufficient data or knowledge for a particular system or cell to quantify erosion on a high-resolution scale. There are a range of example methods for calculating short- and long-term erosion and recession due to sea level rise (Table 7-1).

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.

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.

EROSION STUDY CONSIDERATIONS

Erosion hazard lines for **sandy shorelines** should be determined using methodologies that combine short term, long term, and sea level rise (SLR) component of the erosion hazard applicable to the specific location.

Short term erosion

- Erosion setback lines can be measured using probabilistic modelling approaches however use of models will depend highly upon the availability of calibration data.
- Alternatively, multiple concurrent design storm simulations can be used to enable simple and consistent use across a wide area. This method, for example, simulates two or three consecutive design storms with no recovery in between and provides hazard lines for set design events.

Long term erosion

- Aerial imagery is commonly used to determine historic rates of change. Vegetation lines are typically used to define the shoreline position; however care should be taken where significant land use changes have occurred leading to vegetation changes, or where high dunes and cliffs influence vegetation and shoreline position.
- Longer term erosion occurs as the result of an imbalance in the sediment budget for the beach/dune system.
- Knowledge of sediment budgets can be understood from defining the tertiary coastal compartment and/or sub-compartment which is based on the classification of shoreline characteristics. Long term sediment transport along open coasts can also be predicted using wave climate data to calculate transport rates from a hindcast dataset.

Response to Sea Level Rise

- There are a number of approaches to estimating response to sea level rise based on basic geometric principles to more complex process-based assessments. The modified Bruun Rule (1988) is commonly used to predict a landward displacement of a beach profile to a given SLR, however it may not be the appropriate method for all sandy shoreline typologies such as sandy spits.
- Recession can be easily quantified from the landward displacement of the actual shoreline location by assuming the profile shape remains unchanged.

Erosion hazard lines for **low-earth scarp shorelines** should be determined using methodologies that combine short term, long term, and sea level rise (SLR) component of the erosion hazard applicable to the specific location. In particular:

- Significant increases in the rates of future shoreline recession are projected for these shorelines.
- Where sea level rise results in frequent, tidal backshore inundation, the persistent flood and ebb tide flows through failed levees and/or natural depressions in the backshore landscape could be expected to result in relatively rapid dissection of the shoreline.

EROSION STUDY CONSIDERATIONS (CONTINUED)

Erosion hazard lines for soft rock cliffs are likely to be determined using methodologies that consider short term, long term and sea level rise components of the erosion hazard. There is a need to determine whether the soft rock cliff has a beach and/or platform. The following key points are noted with respect to erosion of soft cliffs:

- The change in elevation of the water surface with respect to sea level is the key factor and the resultant response of platform beaches is likely to be rapid
- The volume of any sandy fronting material is likely to be impacted by sea level rise. Landward retreat of this material towards the cliff face and/or loss from the shore can be measured by methodologies discussed under the sandy shoreline class
- Increased wave energy is likely to both increase the rates of hydraulic weathering and erosion rates at which slumped material can be removed. Sub-aerial processes will still significantly influence future rates of cliff erosion on these shorelines
- Reactivation of erosion processes on 'bluff' type cliffs is likely due to sea level rise narrowing the width of platform beaches to such an extent that marine influences may begin to impact the base.
- Reactivation of bluffs where there is no fronting beach is likely in the more immediate term due to the lower slope of the platforms
- Longer term erosion can be determined by mapping historical shoreline change however care is needed when using historical imagery due to camera angle and shadowing next to high cliffs.

Erosion hazard lines for **hard rock cliffs** are likely to be determined using methodologies that consider sea level rise component of the erosion hazard. It is important to consider if there is a beach present in front which will require an assessment of short and term erosion rates. Other important notes include:

- Exposure to wave action which causes hydraulic weathering of hard rock coastlines is likely to increase with sea level rise. Understanding the rate of erosion of cliffs also depends upon the existence of beaches in front of hard rock cliffs.
- In the short term, erosion hazard to rocky platforms is not expected to be significant over the planning horizons scenarios usually considered. Long term mapping of shoreline movements over time are also unlikely to show much change in most locations.
- Increases in mean sea level will increase the duration over which the cliff base is exposed to wave action as well enable larger waves to impact these cliff bases due to the greater depths available across the shore platforms.
- Sea level rise over the timeframes considered (to 2100) are not considered to significantly influence the extent of potential hazards associated with slope failures/mass movements on these shorelines; however, sea level rise may possibly increase the likelihood and/or frequency of these hazards along these shorelines.

If there is a beach present in front, then the beach volume relative to the short- and long-term erosion volume needs to be compared.

7.6.2 Identifying Inundation Hazards

To identify inundation hazards, multiple techniques are available from simple zero-dimensional bathtub modelling to complex 3D hydrodynamic modelling. Best practice guidance for the mapping of storm tide inundation includes the modelling of storm surge water levels, wave setup and wave runup, whereas permanent inundation can be mapped using basic contour mapping to produce a horizontal extent. During the scoping stage, it is important to understand the complexity of the study required as more detailed inundation scenarios over multiple likelihoods and planning horizons may be required.

INUNDATION STUDY CONSIDERATIONS

Identifying **storm tide inundation** extents via mapping and modelling requires the analysis of long-term storm surge, coupled with wind and wave conditions. The following may be considered when conducting a storm tide inundation analysis:

- Detailed studies of storm surge and extreme wave processes.
  - Consider the type of storm tide prediction to use. In the absence of recorded data, storm surge estimation can be estimated using hindcast approaches, simulation techniques such as monte-carlo methods, joint probability methods or empirical simulation techniques
- Detailed studies of wave setup, run-up and overtopping processes.
- Consider scale of assessment and mapping technique to be employed, i.e., simple bathtub inundation using nearshore levels compared with dynamic modelling of an extreme storm tide, depending on the available data and the potential hazards to economic, environmental, cultural and social values.
- Studies that consider interaction between catchment flooding (fluvial) and a storm tide inundation event.
  - Fluvial flooding and storm-tide inundation events operating independently during the same meteorological event is known as coincident event. This is an important consideration to determining the impacts and potential risk around estuarine environments and river entrances.
  - The coincidence of storm tides and runoff has been reviewed across Australia as part of the updated Australian Rainfall and Runoff[5]. The analysis indicated Victoria had the lowest levels of interdependence between storm tide and rainfall across Australia and the coincidence of a 1% and 1% storm tide and flooding event is not appropriate. Some dependence is present however, and as such a 1% AEP to 10% AEP is typically adopted for flood studies in Victoria where storm surge is present.

Permanent inundation usually has two elements for consideration, the increased frequency of inundation on low lying areas and associated impacts; and the permanent change in tidal planes which generates a response in the shoreline through erosion and on fringing vegetation. The following may be considered when understanding permanent inundation:

- Conceptual bathtub inundation approach may be used to provide a representation of the inundation of different sea level scenarios
- Studies of the resilience and adaptive capacity of coastal ecosystems to increasing water levels and inundation of low-lying areas e.g., rock platforms, dunes, coastal vegetation and coastal floodplains.

7.6.3 Identifying Other Coastal Hazards

During the scoping stage, there may be a need to identify 'other coastal hazards' such as saline intrusion of groundwater or offshore sediment dynamics. Saline intrusion of groundwater may be considered conceptually across multiple sea level scenarios. If groundwater quality is deemed a community value, there may be a need for further detailed studies on the risk to ecosystems and drinking water supplies. Likewise, a conceptual sediment transport and sediment budget model may be appropriate to determine the likely impacts on key economic, environment, social and cultural values.

7.6.3.1 Groundwater Study Considerations

The types of studies that may be considered with regards to **groundwater** include:

- A review of the groundwater quality with different seawater inundation regimes, including the effects of climate change and relative sea level increases.
  - This may be required during an option appraisal stage such as cost-benefit analysis if important cultural and social values are affected.
- Studies of the impact on groundwater-dependent ecosystems and on ecological communities that are sensitive to waterlogging or drying.
- Studies of causes of lowering or rising groundwater which may impact coastal infrastructure functionality such as infiltration into sewerage and drainage systems).

To complete technical groundwater assessment, consider:

- Defining the typology of the coastal aquifer system and its likely vulnerability to sea water intrusion[62]. The output from this would be a conceptual model of the local or regional coastal groundwater system. For guidance, a national scale vulnerability assessment has been completed by Geoscience Australia[62].

Apply the simplified approach for rapid assessment of vulnerability to sea water intrusion. This analysis is based on an existing solution for the steady-state position of a sharp fresh water-salt water interface[63].

- The vulnerability index approach[64] can then be used to quantitatively assess the vulnerability of the coastal aquifer.
- For groundwater systems with a high vulnerability rating, further detailed numerical groundwater modelling should be undertaken. Refer the Australian Groundwater Modelling Guidelines for instruction[65].

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62 Ivkovic, K.M., Marshall, S.K., Carey, H., et. al. (2013). A national-scale vulnerability assessment of seawater intrusion: Coastal aquifer typology. Record 2013/04. Geoscience Australia, Canberra, and National Centre for Groundwater Research and Training, Adelaide.
63 Werner, A.D., Ward, J.D., Morgan, L.K., Simmons, C.T., et. al. (2012). Vulnerability Indicators of Sea Water Intrusion. Groundwater, 50: 48-58. https://doi.org/10.1111/j.1745-6584.2011.00817.x
64 Morgan, L. K., Werner, A. D., Carey, H., (2013). A national-scale vulnerability assessment of seawater intrusion: Seawater intrusion vulnerability indexing - quantitative. Record 2013/20. Geoscience Australia, Canberra, and National Centre for Groundwater Research and Training, Adelaide
65 Barnett et al, (2012). Australian groundwater modelling guidelines, Waterlines report, National Water Commission, Canberra

ADDITIONAL STUDY CONSIDERATIONS

It is important to understand the **hydrodynamics** and **sediment transport patterns** in these environments to identify the likely hazards and impacts. Impacts of erosion may include the loss of foreshore vegetation, loss of property boundaries, property damage (public and private assets) and other impacts on cultural, environmental and social values.

- Studies of the interaction of estuary flooding – from the catchment or from oceanic processes and wave processes.
- Studies of long-term changes in rates of estuary foreshore erosion and inundation, as they impact on public and private land and on recreational access, amenity and use.
- Studies to determine the nature and composition of estuary foreshores.
- Studies of the interaction of waves associated with local wind waves related to estuary or lake fetch, incursion of ocean waves
- Assessment of hazards will be dependent on the estuary typology.

The types of studies that may be considered with regards to **offshore sediment dynamics** include:

- Impacts of sea level rise, wind and waves on turbidity and increased sediment loads, changes in salinity, changes in freshwater quality, quantity and timing of flows.
- A review the sources, amount and character of sediment load and sediment redistribution in aquatic systems.
- Impacts such as sediment smothering of seagrass and other habitats.
- Studies of permanent inundation of different sea level scenarios and opportunities for aquatic ecosystems to migrate.
  - This may include the resilience and adaptive capacity of coastal ecosystems to increasing water levels for example seagrass beds, reefs or kelp forests.

7.6.4 Uncertainty

Uncertainty will be present in any coastal hazard assessment.[60] A coastal hazard assessment should relate the hazard to its likelihood and the source and significance of uncertainties should be identified.

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.

At the conceptual stage, it is useful to decide what levels of uncertainty are likely to be present in the hazard assessment and how those uncertainties might be addressed and presented. A range of planning horizons and sea level rise scenarios ensures an adaptive risk-based approach is embedded into the coastal hazard assessment mitigating uncertainty in the study.

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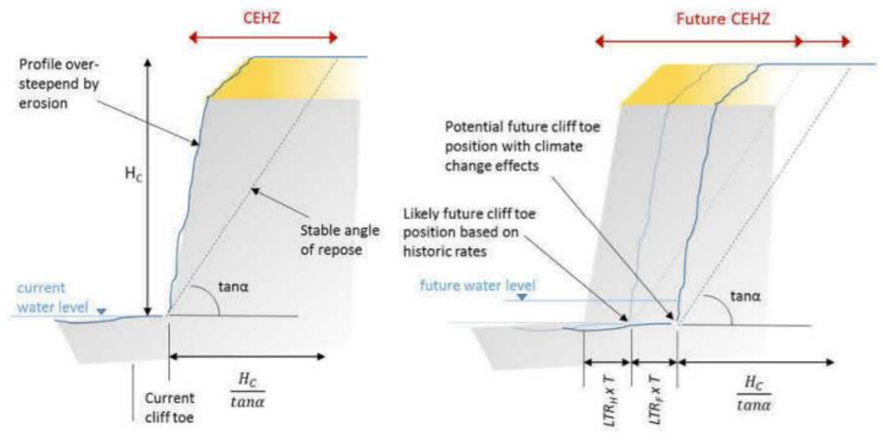
APPENDIX A
SUMMARY OF EROSION ASSESSMENT TYPES

Table 8-1 Summary of erosion hazard assessment types

Shoreline Class	Assessment of Erosion		
	Short Term Erosion	Long Term Erosion	Sea Level Rise
Hard Rock Cliff With platform	Erosion hazard to rocky platforms is not expected to be significant over the planning horizons scenarios usually considered.	Long term mapping of shoreline movements over time are also unlikely to show much change in most locations given the limited timeframes of data available. An example of determining long term coastal erosion at cliffed coasts is provided by Tonkin and Taylor.[66] Here, the erosion component associated with these shoreline classes was established based on the following equation.[67] Long term erosion hazard = $[(Hc / \tan\alpha)+(LTH \times T)] \times FoS$ Equation X Where: Hc = height (m) of the cliff. a = the stable angle of repose LTH = the historic long-term rate of recession (m/yr) based on historic aerial photo analysis (only for soft rock materials) T = timeframe (yrs) FoS = FoS Available LiDAR should be interrogated to understand potential failure slopes and define the local stable angle of repose where possible.  *Figure 4-3 Definition sketch for cliff shore CEHZ*	Sea level rise over the timeframes up to 2100 are not considered to significantly influence the extent of potential hazards associated with slope failures/mass movements on these shorelines. However, sea level rise may possibly increase the likelihood and/or frequency of these hazards.
Hard Rock Cliff With beach	Storm erosion of the beach to be calculated		Beach volume relative to the short- and long-term erosion volume needs to be compared. Methods to estimate SLR recession: include the Bruun and modified Bruun Rule model (1962)[68] (1988)[69], the Shoreface Translation Model (Cowell et al., 1992; 1995), the Komar et al., (1997)[70] Geometric Model of Foredune Erosion, the Probabilistic Coastline Recession model (Ranasinghe et al., 2011)[71], Shoreline Response Model (Huxley, 2009)[72].
Soft Rock Cliff With platform	It is recommended to check if any storm response has previously been identified for the location. If none, short term is not considered.		Increased rate of change and greater hazard to soft rock materials due to increased wave energy at toe. Refer to Hard Rock Cliff response to sea level rise.
Soft Rock Cliff With beach	Storm erosion of the beach to be calculated	With specific rega … ic rates of change.	See Hard Rock with Beach. Methods to estimate SLR recession are discussed in Mariani et al., (2012)[67]
Low earth scarp			
Sandy shorelines	Storm erosion of the beach to be calculated	Beach survey, aerial imagery and remote sensing can be used to determine historic rates of change.	Beach volume relative to the short- and long-term erosion volume needs to be compared.

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[66] Adapted from Tonkin and Taylor: Shand, T., et al. (2015). *Methods for Probabilistic Coastal Erosion Hazard Assessment.* Prepared for the Australasian Coasts & Ports Conference 2015, Auckland, New Zealand. Available: researchgate.net/publication.

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Shoreline Class	Assessment of Erosion		
	Short Term Erosion	Long Term Erosion	Sea Level Rise
		Calculation of the sediment budget using numerical modelling or empirical formula, or historical trend analysis of dredging or other sand management actions may be used in a qualitative way.	Methods to estimate SLR recession include (but are not limited to) the Bruun and modified Bruun Rule model (1962) (1988), the Shoreface Translation Model (Cowell et al., 1992; 1995), the Komar et al., (1997) Geometric Model of Foredune Erosion, the Probabilistic Coastline Recession model (Ranasinghe et al., 2011), Shoreline Response Model (Huxley, 2009).
Estuarine environments including tidal channels, mangrove and saltmarsh	Review of tidal hydrodynamics to establish patterns of channel and bar change Local wind storm erosion on sandy coastlines	Aerial imagery is used to determine historic rates of change including changing channel patterns due to vegetation or sediment pattern changes or trends	Estuaries typically have a number of complex processes which drive the shape and coastal limits of the estuary. The ability to predict future response of these shorelines to sea level rise is limited as often the interplay between the processes which deliver vastly different outcomes depending on the combination, sequence and variation over time of all of the processes. For specific estuarine forms, the likely response to sea level rise reviewed depending on their form and the appropriate response model can be selected. Khojasteh, Glamore, Heimhuber and Felder (2020)[73] provides a useful review of potential sea level rise impacts on estuaries generally. Tidal channel dimensions (excluding constructed channels such as drains) are determined by the tidal exchange that flows through them, which is a function of tidal range and hypsometry (Zhou et al 2018)[74], and the channel material and vegetation. Sea level rise increases the tidal exchange and expands the tidal prism. The projected response of the tidal channels is expansion, proportional to the change in tidal prism and the erodibility of the channel banks.
Engineered Coastlines	If a beach is present, the storm erosion of the beach material should be considered. The design life of the engineered coastline and backshore area should be reviewed to establish the potential for damage under storm conditions	The design life of the engineered coastline and backshore should be considered, along with a review of aerial imagery of coastal change prior to the construction of the engineered coastline.	The design life and proposed management plan for the engineered coastline should be considered and the methods described above for the natural shoreline type considered with respect to the design life.

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APPENDIX B
OTHER HAZARD CONSIDERATIONS

Identifying Inundation Hazards

To identify inundation hazards, multiple techniques are available from simple zero-dimensional bathtub modelling to complex 3D hydrodynamic modelling (Table B-1). The most detailed approach for the mapping of storm tide inundation includes the modelling of storm surge water levels, wave setup and wave runup, whereas permanent inundation can be mapped using basic contour mapping to produce a horizontal extent.

During the scoping stage, it is important to understand the complexity of the study required as more detailed inundation scenarios over multiple likelihoods and planning horizons may be required.

Identifying Other Coastal Hazards

During the scoping stage, there may be a need to identify 'other coastal hazards' such as saline intrusion of groundwater or offshore sediment dynamics. Saline intrusion of groundwater may be considered conceptually across multiple sea level scenarios. If groundwater quality is deemed a community value, there may be a need for further detailed studies on the risk to ecosystems and drinking water supplies. Likewise, a conceptual sediment transport and sediment budget model may be appropriate to determine the likely impacts on key economic, environment, social and cultural values (Table B-2).

Table B-1 Summary of Inundation Assessment Types

Inundation type	Assessment of inundation hazard	Strengths	Weaknesses
Storm Tide Inundation	Bath tub	Low cost and computational time. Provides horizontal extent of offshore storm tide inundation. Good for a first pass, identification of potential hazard extent. Can also be undertaken as a mapping exercise.	Provides no allowance of setup and runup due to wind or wave conditions. Appropriate for first pass only.
	1D modelling	Low computational time. Simulates depth and horizontal extent of storm tide inundation across a beach profile due to tide, storm surge, waves and winds. Can simulate dune erosion.	1d transects cannot accurately reflect backshore flow pathways as areas between cross sections are not represented. Mapping onto the shoreline may provide an over estimation of the flooding extent as temporal aspects of the storm tide and connectivity between low lying areas may not be considered.
	2D regular and irregular grid	Simulates 2D flow overland due to tide, storm surge,waves and winds Can employ irregular boundary conditions. Can model riverine flooding in concert with coastal inundation	Requires more time and a high degree of sophistication for model bathymetric and topographic generation and model setup than simpler approaches Requires (preferably) up to date high resolution DEM of coastline and offshore areas and measured data to calibrate hydrodynamics and wave modelling Significantly longer establishment, calibration and run times.

Inundation type	Assessment of inundation hazard	Strengths	Weaknesses
		Spatial and temporal water level and velocity variations represented	Higher cost than simpler methods
	3D regular and irregular grids	Simulates 3D flow overland due to storm surge, tides and waves. Replicate complex coastal bathymetries/topographies.	Over specified for some coastal inundation problems Longer run times Highest cost for computational modelling
Permanent inundation	Bath tub	Low cost and computational time. Provides horizontal extent of inundation at high tide plane	No temporal data included, may overestimate the extent of permanent inundation due to the limited duration of the high water level
	2D regular and irregular	For when there are significant assets at risk. Can incorporate flow thorough the drainage network Can consider the duration of high water and the time required for flow to reach areas further from the coast If undertaking storm tide modelling, tidal conditions would be considered as part of the same study.	Requires more time and a high degree of sophistication for model bathymetric and topographic generation and model setup than simpler approaches Requires (preferably) up to date high resolution DEM of coastline and offshore areas Significantly longer establishment, calibration and run times. Higher cost than simpler methods

Table B-2 Summary of Other Hazard Assessment Types

Hazard type	Assessment of hazard	Suggested use
Saline intrusion of groundwater	Conceptual model to simulate groundwater process A desktop review of available data to present aquifer properties, groundwater levels and likely changes as a result of changes in sea level The review of physical geology will inform the assessment of erosion potential, and the hydrogeological assessments (physical, aquifer properties, water levels) will inform predictions of changes in groundwater level and hence moisture content and erosion potential of the near-surface materials	For a high-level analysis of potential impacts on the groundwater ecosystem to determine if more detailed assessment is required. Appropriate for both regional and local coastal hazard assessment scale.

Hazard type	Assessment of hazard	Suggested use
	Groundwater model (e.g., MODLOW) Evaluates the likely pattern of changes in groundwater levels and groundwater discharge and flow patterns in response to sea level rise. Estimates of changes to the location of the seawater/freshwater interface More costly approach than conceptual model	If groundwater impacts are determined to be a critical social or environmental value. Appropriate for local coastal hazard assessment scale only. Significant input data is required to model groundwater which is typically outside the extent of that required for a CHA. Scoping studies, data gathering and an assessment of the value of any outputs should be considered at an early stage of development.
Offshore sediment dynamics	Sediment dynamic conceptual modelling	For a high-level analysis of offshore sediment dynamics and potential impacts on economic, social, environmental and cultural values to determine if more detailed assessment is required. Appropriate for both regional and local coastal hazard assessment scale.
	Regional/cross sediment cell sediment transport modelling / monitoring to establish sources and sinks of sediment to the offshore system. Requires long term coastal monitoring or modelling of longshore sediment movements and survey of offshore bathymetry over a period to establish extents and magnitude of changes in the offshore zone.	Recommended to undertake conceptual model of offshore sediment dynamics and if appropriate initiate long term monitoring of longshore and offshore sediment movements.

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