REPORT

Tonkin+Taylor

Victoria Coastal Cliff Assessment

Overarching Report

Prepared for
Department of Environment, Energy and Climate Action (DEECA)
Prepared by
Tonkin & Taylor Pty Ltd
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Executive summary

This report sets out assessment of coastal cliff instability and/or erosion and subsequent risk assessment for the coastal cliffs along the state of Victoria. The assessment has been split into two stages:

- Stage 1: Assessment of Areas Susceptible to Coastal Cliff Instability and/or Erosion (ASCCIE)
- Stage 2: Coastal Cliff Risk Assessment

Assessment of areas susceptible to coastal cliff instability and/or erosion

This study provides a state-wide/regional scale (also referred to as second-pass) assessment of Areas Susceptible to Coastal Cliff Instability and/or Erosion (ASCCIE) associated with areas at the cliff top and Areas Susceptible to Talus Runout (ASTaR) associated with areas at the bottom the cliff for the Victorian coastline. The purpose of this second-pass assessment is to identify ASCCIE and ASTaR at a regional/state-wide scale for present-day and future timeframes. The resulting ASCCIE and ASTaR are then used to inform the second part of the assessment, the cliff instability risk assessment. That assessment identifies assets at high risk to coastal cliff instability, erosion and slumping including consideration of public safety (see Stage 2 report).

ASCCIE and ASTaR have been assessed for the hard and soft rock coastal cliffs within the State of Victoria (i.e., 672 km), as defined by Water Technology (2022). Due to the adopted scale and level of detail to undertake this assessment, the areas outside of the identified ASCCIE and ASTaR may be considered unlikely to be susceptible. This 'second-pass' assessment has been undertaken at a high level (regional/state-wide scale) based on available data, tools and understanding of coastal processes. Uncertainty may have been introduced to this assessment by parameter uncertainty, assessment scale, dataset scales, data availability, site-specific features, other hazards and assessment and mapping methodology. These limitations should be considered and understood prior to using this report.

As this study has assessed ASCCIE and ASTaR at a state-wide/regional scale, it may be superseded by a more detailed, local scale or site-specific assessment (i.e. order of 1 m - 1 km shoreline length) undertaken by a suitably qualified and experienced practitioner using improved data and/or undertaken at a higher resolution from that presented in this report. This could include better site-specific geotechnical information to confirm subsurface soil conditions including site-specific terrestrial processes, more detailed topographic data as well as site-specific analysis and modelling of erosion. Note that due to the scale of this state-wide/regional assessment the change in geology may not be considered in detail (e.g., use of 1:250,000 geological maps may not include site-specific details), which could affect the potential ASCCIE and ASTaR. This should be assessed for a more detailed scale assessment. Furthermore, a probabilistic approach may be adopted for local-scale and site-specific assessments giving likelihood of erosion and instability based on parameter ranges rather than single values.

ASCCIE and ASTaR have been derived based on the geological unit type and cliff height. The ASCCIE are comprised of a cliff instability component and a cliff toe regression component. The combined effect identifies the area susceptible to cliff instability and/or erosion at the top of the cliffs. The cliff instability component has been assessed based a dataset of cliff profiles for which a stable angle has been derived. The cliff toe regression component is comprised a historical long-term cliff toe regression rate, derived from historical aerial images, and a factor for sea level rise effects.

The methodology used in this study are standard and well-tested approaches for defining ASCCIE for cliffed shorelines by the addition of component parameters. The methodology for defining ASTaR is a new method undertaken at a high level and based on the existing cliff height and a defined slope to identify the possible seaward extent of talus runout. For this state-wide/regional scale assessment, single values were derived for each component. This ‘building-block’ approach (i.e., combination of individual parameters) is expected to produce ‘upper bound’, conservative results, which identifies areas potentially exposed to coastal erosion, cliff instability and cliff slumping/talus runout.

The ASCCIE have been assessed for the present-day (applicable to 2025), 2040 (i.e. approx. 15 years), 2080 (i.e. approx. 55 years) and 2100 (i.e. approx. 75 years) planning timeframe scenarios. Sea level rise has been allowed for, for each scenario aligned with DEECA (2023). Resulting ASCCIE areas have been mapped for the following scenarios:

- Present-day (0 m sea level rise)
- 2040 +0.2 m sea level rise
- 2080 +0.5 m sea level rise
- 2100 +0.8 m sea level rise
- 2100 +1.1 m sea level rise
- 2100 +1.4 m sea level rise

The resulting ASCCIE distances are a combination of the cliff instability components, which have been derived using the cliff projection method, and long-term cliff toe regression. The present-day ASCCIE exclude the long-term cliff toe regression component and is comprised of the cliff instability component only.

The largest ASCCIE distances within the Wilsons Promontory (East and Southwest) and Great Ocean Road coastal compartments. The ASCCIE distances for the 2100 scenarios exceed 300 m. As it is expected that the granite geological units (i.e., within the Wilsons Promontory coastal compartments) are relatively hard rock and would unlikely result in large susceptible areas, this is mainly due to the very high cliff heights and stable angle that are slightly flatter than the actual cliff slopes. This means the ASCCIE are typically slightly landward of the present-day crest, which already sit a relatively large distance from the cliff toe due to the high cliff height.The toe erosion rate is low for cliffs within this coastal compartment. For the cliffs within the Great Ocean Road, the relatively large ASCCIE distances are a due to the combination of the high cliffs and relatively large toe erosion rates (i.e., up to 74 m for the 2100-3 scenario).

Other secondary coastal compartments within which ASCCIE distances are in the order of 200 m or more for the 2100-3 scenario are Corner Inlet, Mornington Peninsula and Port Campbell. This is typically due to the adopted stable angle and the cliff height being 50-100 m high.

The smallest ASCCIE distances (i.e., mean values <50 m) are found within the Snowy River, Phillip Island (South) and Western Port coastal compartments. This is a result of the relatively low cliff heights within these coastal compartments. The resulting ASCCIE distances for the majority of the coastal compartments are typically in the order of 100-150 m based on the typical upper bound (i.e. 10% exceedance) value.

The ASTaR have been derived for the present-day only as it is expected that future ASTaR will migrated landward as cliffs retreat, and therefore resulting in narrow zones from the current cliff toe. The areas susceptible to coastal cliff erosion and/or instability landward of the existing cliff toe are captured within the ASCCIE. The largest ASTaR distances are found within the Wilsons Promontory and Great Ocean Road coastal compartments. This is a result of the high cliff heights. The smallest ASTaR distances (i.e., <50 m) can be found within the Snowy River, Gippsland Lakes, Western Port and Port Phillip Bay (East and West) coastal compartments.

This study has provided new information at a state-wide level on cliff types and areas that may be susceptible to coastal cliff instability, erosion and slumping for the present-day and in the longer term. This will be useful to inform regional and local adaptation planning, strategic decision making and masterplans, identifying areas where more detailed local or site-specific studies are required.

Coastal cliff risk assessment

A second-pass risk assessment was undertaken which assigned an aggregated risk rating to each coastal compartment. The risk assessment framework for this study was based on AS 5334:2013, which defines risk as the "effect of uncertainty on objectives and utilises likelihood and consequence to determine risk. Where likelihood is the probability of a coastal hazard occurring, and consequence is the impact of the coastal hazard on coastal values and uses, e.g. social, cultural, economic, and environmental. The risk relied on consequence categories and themes adapted from DEECA (2022)[1] and AS 5334-2013. Coastal values were represented by spatial datasets which intersected with ASCCIE and ASTaR layers, asset and land data was used as a proxy for each coastal value.

23 coastal compartments were evaluated in the risk assessment, one coastal compartment was excluded from the analysis as no cliffs intersected the available asset or land data. For the remaining 22 coastal compartments the numerical risk ratings assigned to the compartment were translated into one of five risk categories (low, medium, significant, high, extreme). In the short-term 18% of the coastal compartments were assigned a medium risk rating and 77% were assigned a significant risk rating, a single compartment (5%) was assigned a high risk rating. In the medium-term 23% of the coastal compartments were assigned a significant risk rating and 77% were assigned a high risk rating. In the long-term 27% of the coastal compartments were assigned a high risk rating and 73% were assigned an extreme risk rating. The aggregated risk ratings developed suggest that risks to coastal values due to coastal instability and erosion hazards within assessed coastal compartments exist in all but one assessed coastal compartment in the present day and become increasingly severe over longer timeframes. The results of the risk assessment also suggest that there are coastal cliff sections within all but one coastal compartment which will require further assessment and planning by local land managers within the 50 year timeframe considered.

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[1] Victoria's Resilience Coast – Adapting for 2100+. Framework and Guidelines: A strategic approach to coastal hazard risk management and adaptation.

Recommendations to support coastal land managers with risk management in coastal cliff environments

The following guidance is provided to support coastal land managers with risk management in coastal cliff environments and with the development of adaptation plans in coastal cliff environments susceptible to instability and erosion.

Adaptation definition:

“In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.” (IPCC working group II, 2022, p 2898)

Victoria State Government’s coastal adaptation framework and guidelines require that strategic adaptation options for managing coastal hazard risk are considered in a certain order as follows:

1 Non-intervention
2 Avoid
3 Nature-based
4 Accommodate
5 Retreat
6 Protect

The six groupings included in the hierarchy are defined below. Case studies and examples demonstrating where different adaptation options have been implemented to address coastal erosion hazards are provided in Table 1. In many cases a combination of adaptation options from multiple layers of the hierarchy may be necessary and the chosen strategies may need to change over time.

Non-intervention

A non-intervention or “do nothing” option allows natural coastal processes to proceed without interference. In situations where the risks posed by coastal hazards are acceptably low or there are few assets or little development on land which is exposed to a hazard, non-intervention can be considered a suitable adaptive response. When evaluating the costs and benefits of other options, non-intervention should be a baseline option against which all other strategic adaptation actions should be compared.

Avoid

Avoiding coastal erosion hazards primarily involves planning measures which prevent people and assets from being exposed to coastal hazards. Policies and planning rules controlling the types of activities which can be undertaken within areas exposed to coastal hazards limit further intensification of existing development sites or the development of new sites in exposed locations. Setbacks from coastal cliff edges are an example of avoiding coastal erosion hazards.

Nature-based

Nature-based adaptation options employ ‘soft’ protections such as beach nourishment, dune planting and shellfish reefs to reduce the impact of natural hazards and create/restore the ecological processes and functions of coastal habitats. Nature-based solutions reduce coastal hazards through wave attenuation, sediment accumulation and stabilisation. Nature-based solutions are generally lower cost than traditional ‘hard’ engineered coastal protections and have the potential to enhance social and ecological values in coastal environments and provide other co-benefits such as carbon sequestration and improved water quality.

Accommodate

Accommodating coastal hazards enables the ongoing use of coastal land by modifying existing assets/developments or designing new developments to accommodate coastal hazards. Examples of options which accommodate hazards include the design/retrofitting of structures in areas susceptible to slope instability or erosion with foundations which will maintain structural integrity despite recession of coastal cliffs, designing structures to be relocatable once the hazard reaches a certain threshold or warnings and signage to keep people away from hazardous environments. It should be noted that with progressively rising sea levels and ongoing recession of coastal cliffs, some accommodate options may become unviable over the long term, while maintenance and servicing of exposed assets can become increasingly costly over time.

Retreat

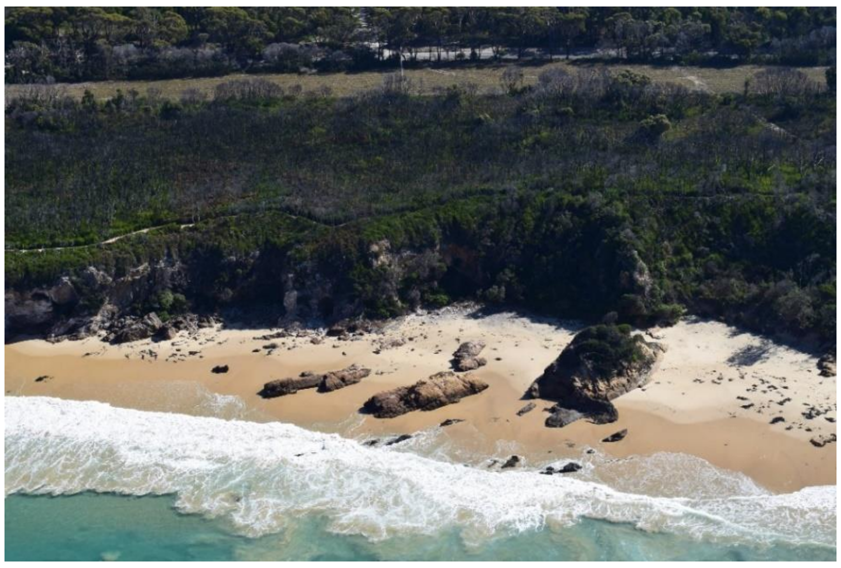
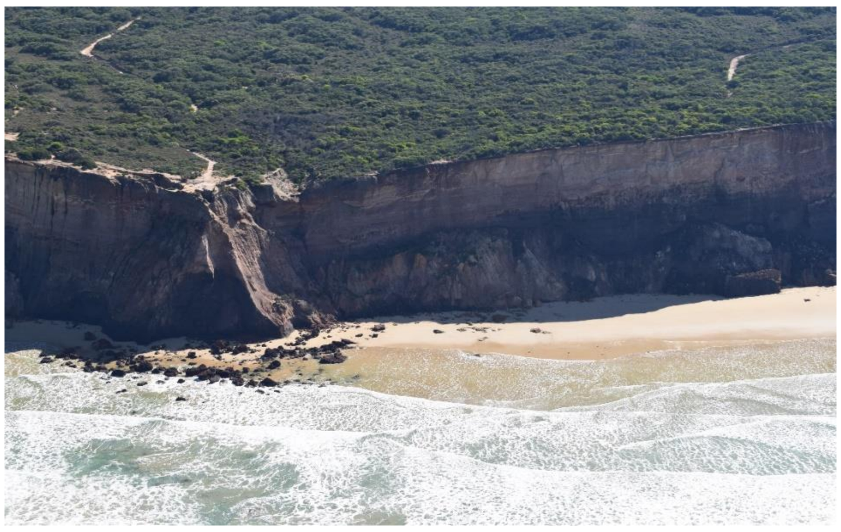
Managed retreat applies to existing development and involves moving assets, infrastructure or people and activities away from areas which are susceptible to coastal hazards. Retreat can be applied to individual assets or structures such as the relocation of a section of coastal road away from an area which is susceptible to coastal erosion, or it can be a process facilitating the relocation of entire communities or the migration of coastal species in hazard exposed locations.

Protect

Coastal protections are implemented when a decision is made to invest in defending coastal land or coastal assets over the short to medium term. It is important to acknowledge that coastal protections generally will not function indefinitely and that in future alternative protection measures or a pivot towards retreat or another adaptation strategy may be necessary. Coastal protection measures to limit cliffs erosion and instability hazards include measures to limit erosion of the cliff toe such as seawalls, revetments, sediment control structures and measures to limit erosion and instability of the cliff face including palisade walls.

Engineered protection measures modify coastal processes to prevent or delay coastal erosion, however, their use can result in unintended impacts such as increased erosion along adjacent coast if sediment supply is being reduced, or increased wave reflection and turbulence induced. Additionally, the presence of coastal protections can also promote further development in exposed locations, thereby increasing risk in the long term. Due to these limitations coastal protection options should only be considered once all other options have been assessed and deemed to be not viable.

Table 1: Case studies/examples of adaptation options for coastal erosion hazards

Non-intervention		
	Large sections of the Victorian coast are undeveloped and largely inaccessible to the public. In these circumstances non-intervention is an appropriate adaptive response as the continuation of natural coastal processes poses a minimal threat to coastal values.	 Source: Aerial photography completed for this project, near Mallacoota Airport. There is no public access to the base of the cliffs.
Avoid		
Land management planning	Planning measures implemented at Aireys Inlet restrict residential development along the coastal cliff edge. The land along the cliff edge is maintained as a park and recreation zone. Other land management measures which can facilitate the avoidance of areas exposed to coastal hazards include development setbacks, planning overlays, zone changes, land acquisitions and land swaps.	 Source: https://mapshare.vic.gov.au/vicplan/
Controlled access	Controlled access at Anglesea restricts public access to unstable and eroding cliff faces. Access restrictions are intended to isolate people from areas which are affected by coastal hazards, they can be either temporary or permanent and can be used in parallel with other adaptation options.	 Source: Aerial photography completed for this project, section of Queenscliff Coastal Reserve

Nature-based

Kelp forest restoration	Kelp forests are widespread along the Victorian coastline, however, in recent years there has been widespread loss of kelp forests due to over-grazing by sea-urchins. Kelp forests help to create lower wave energy environments on their landward side. The restoration of kelp forests has the potential to reduce susceptibility to coastal erosion.[2]	 Source: Port Phillip Bay kelp forest restoration. Port Phillip Bay kelp restoration project to fight ravages of sea urchins (theage.com.au)
Shellfish reefs	Shellfish reef structures can reduce the rate of coastal erosion and the loss of foreshore land by reducing wave energy and run-up. Shellfish reefs can also promote the accretion of sand on beaches helping to further reduce coastal erosion. Shellfish reefs also provide co-benefits due to the habitat value they provide.	 Source: Ramblers Road Foreshore, Portarlington. Living Shorelines - Ramblers Road Foreshore (marineandcoastalcouncil.vic.gov.au)
Supported littoral revegetation	Vegetation at the toe of unstable cliffs/slopes can reduce coastal erosion hazards by dissipating wave energy and stabilising slopes. Where wave climate is too high or seabed levels are too low to enable establishment of vegetation, low-profile structures such as rock sills or geotextile bag structures can be used to reduce wave climate and/or raise seabed levels until they provide an environment where vegetation can be supported. Supported littoral vegetation can also provide co-benefits in the form of enhanced habitat and biodiversity, carbon sequestration and improved amenity value.	 Source: St Annes foreshore reserve, Auckland (Tonkin + Taylor)

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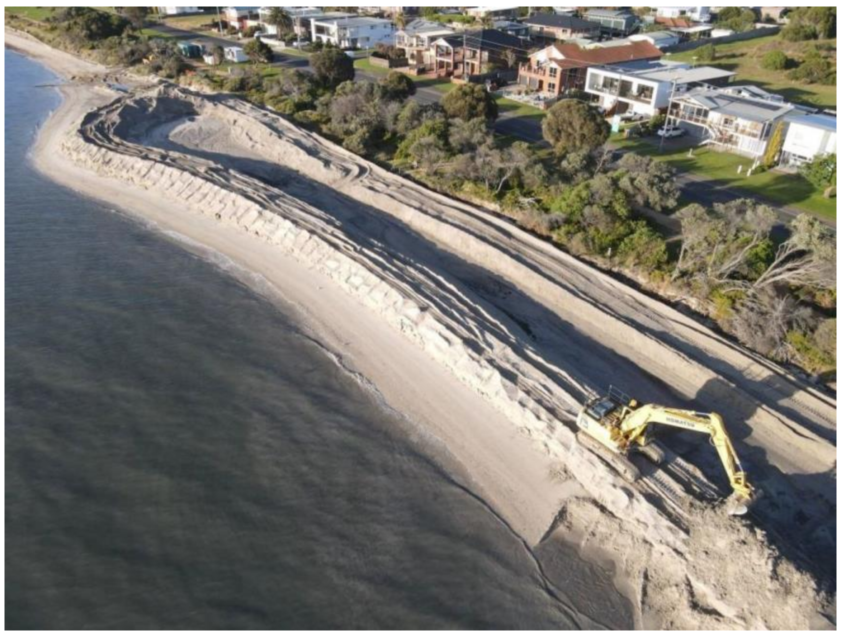
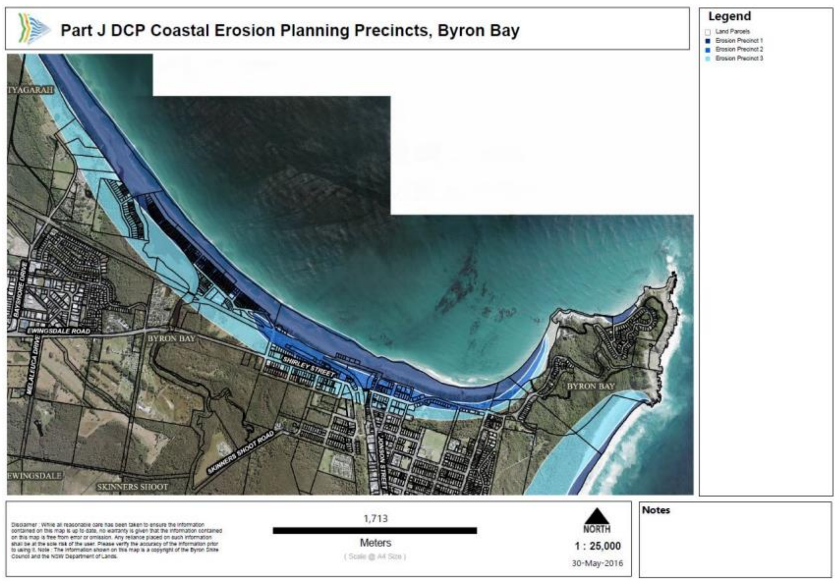
[2] The Australian guide to nature-based methods for reducing risk from coastal hazards, Earth Systems and Climate Change Hub Report No. 26 - 2021

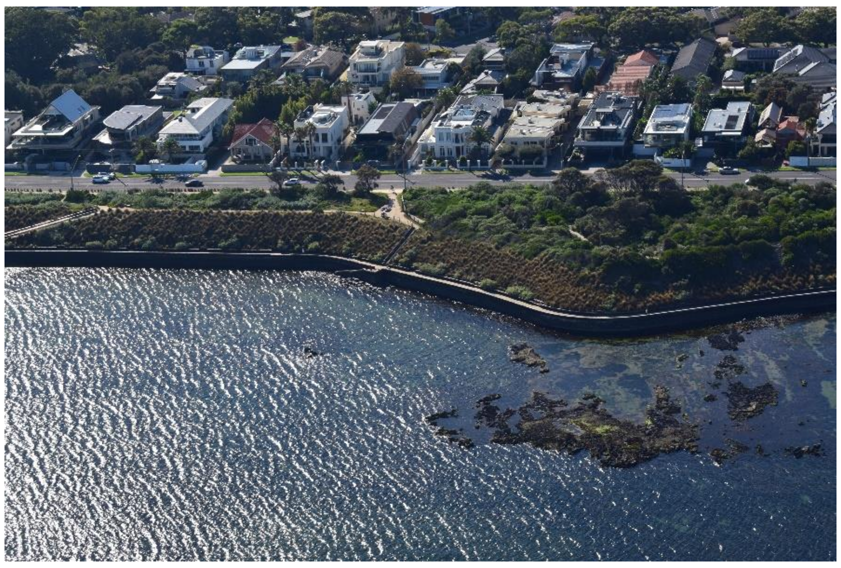
Beach nourishment	Beach nourishment creates a buffer against coastal erosion processes by adding sand volume to beaches/dunes creating a net gain of sand within a coastal compartment to offset losses from coastal erosion processes. An ongoing program of beach nourishment can provide buffer against storm erosion and slow the rate of long-term coastal recession.	 Source: St Leonards North Beach Nourishment [Barwon South West projects (marineandcoasts.vic.gov.au)]
Accommodate		
Use of resilient materials and design	Modular or relocatable structures which can be moved away from cliffs as erosion progresses are a way of accommodating coastal hazards through design to facilitate the ongoing use of coastal land and assets. The surf lifesaving tower at Smiths Beach was designed to be relocatable and was prefabricated offsite to minimise disturbances to the sensitive coastal environment.	 Source: Smiths Beach relocatable prefabricated surf lifesaving tower. MRTN Architects, Photography Jesse Marlow [Smiths Beach SLSC Tower | Builtworks]
Warning signage/Education and awareness raising	Signage warning the public of hazards associated with cliff instability and rock falls encourage members of the public to take appropriate precautions and avoid hazard prone areas. While not as effective as controlled access restrictions at isolating people from hazard prone areas, warning signage is also less likely to trigger strong challenges from the public concerned about a loss of social and cultural value due to access restrictions.	 Source: Warning signage examples. Coastline - Developing a management strategy for coastal cliff erosion hazards in South Australia (R. Raymond, 2013)
Mesh to protect from rock fall	The risk to people and assets at the base of unstable cliffs can be reduced using mesh rock netting or catch fences which prevent loose rock from falling onto roads, tracks, or structures at the base of cliffs.	

		 Source: Great Ocean Road rockfall protection. [CaseStudy_Steelgrid_GreatOceanRoad2009.pdf (rockfall.co)](CaseStudy_Steelgrid_GreatOceanRoad2009.pdf)
Slope drainage	Where rills and gullies are identified as a factor contributing to the instability of cliffs, effective management of stormwater to redirect surface water away from cliff tops can help to reduce the impact of soil saturation and scour from surface water on cliff stability.	

Retreat

Removal/relocation of infrastructure	Since 1988 Byron Shire Council has applied coastal hazard planning provisions to development in coastal hazard zones. Local planning regulations stipulate that development must be demolished or relocated when the coastal erosion escarpment encroaches to within a certain distance from the development.	 Source: Belongil Beach coastal hazard planning precincts, Byron Shire Council.

Protect

Vertical seawalls	Vertical seawalls protect the land behind them from coastal erosion, including the undercutting of cliffs and bluffs. Sea walls are hard engineered structures, which can provide a high degree of protection to a cliff toe against erosion. However, seawalls can have a wide range of other implications which must be taken into consideration such as the impact that seawalls can have on social, environmental, and cultural values as well as potentially adverse impacts of scour which can be generated by the wave energy reflected back off the face of vertical seawalls.	 Vertical seawall protecting cliff toe in Port Phillip Bay, Melbourne (Photo taken by T+T)

Rock revetments	Rock revetments are engineered structures formed by placing interlocking rock on a slope and are used at the toe of coastal cliffs and bluffs to prevent toe erosion. Rock revetments are more porous than vertical seawalls and dissipate wave energy, reducing potential reflection and overtopping. However, they have can have similar adverse effects to vertical seawalls and take up additional space.	 Rock revetment protecting cliff toe in Auckland, New Zealand (Photo taken by T+T)
Geosynthetic container revetments	Geosynthetic containers (or GSC) revetments are engineered structures consisting of large geotextile containers filled with sand or other material and stacked at the base of a cliff or dune to halt or delay toe erosion. While they can provide improved public access over the structure compared to vertical seawalls or rock revetments, they are still impermeable structures and can have similar adverse effects	 Source: Geotextile bag revetment at Portsea https://www.mornpen.vic.gov.au
Control structures	Groynes or offshore breakwaters can be utilised in isolation or in combination with beach nourishment to trap and hold sediment, reduce wave energy reacting a cliff toe and reduce cliff toe erosion.	 Source: Groyne structure, Sandringham Beach [Port Phillip projects (marineandcoasts.vic.gov.au)](marineandcoasts.vic.gov.au)  Control structures in combination with beach nourishment fronting gently sloping cliff in Auckland, New Zealand (photo taken by T+T)

Soil nailing/rock bolting	Soil/rock nails and rock bolts are a construction technique used to stabilise unstable cliffs or slopes. Soil nails can offer advantages over other protection measures due their ease of installation, cost effectiveness and their ability to be installed in areas with restricted access.	 Example of rock bolting employed along a section of Great Ocean Road (photo taken by T+T)

REPORT

Tonkin+Taylor

Victoria Coastal Cliffs Assessment

Stage 1 - Areas Susceptible to Coastal Cliff Instability and/or Erosion

Prepared for
Department of Environment, Energy and Climate Action (DEECA)
Prepared by
Tonkin & Taylor Pty Ltd
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September 2023
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Aug 2023	1	Draft report for client review	P.Knook H.Blakely W.Greatbatch	T.Shand B.Westgate D.Glover	
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Glossary of terms

Term	Description
AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ASCCIE	Area Susceptible to Coastal Cliff Instability and/or Erosion
ASTaR	Area Susceptible to Talus Runout
CD	Chart Datum
Cliff instability distance	Horizontal distance between the cliff toe and cliff crest
Cliff toe regression	Landward movement of coastal cliff toe as a result of coastal processes
Coastal accretion	A long-term trend of shoreline advance and/or gain of beach sediment volume
Coastal erosion	Landward movement of the shoreline which may include both long-term retreat over several years or decades and short-term loss of sediment due to storms
Coastal hazard	Where coastal processes adversely impact on something of value resulting in a hazard
DEECA	Department of Environment, Energy and Climate Action
DEM	Digital Elevation Model
GIS	Geospatial Information Service
LiDAR	Light Detection and Ranging – a method of remotely deriving land elevation, generally from an aeroplane
LT	Long-term erosion component
LT_H	Historical long-term erosion component
LT_F	Future long-term erosion component
m	Sea level rise response factor for cliffs
MHWS	Mean high water springs – a measure of high tide based on a statistical exceedance of high tides in a month
MHWS-10	Water level exceeded by 10% of the MHWSs
MLWS	Mean low water spring – a measure of low tide based on a statistical exceedance of low tides in a month
MSL	Mean sea level. Sea level averaged over a long (multi-year) period
RL	Reduced Level (Auckland Vertical Datum 1946)
SLR	Sea level rise. Trend of annual mean sea level over timescales of at least three or more decades. Must be tied to one of the following two types: global – overall rise in absolute sea level in the world's oceans; or relative – net rise relative to the local landmass (that may be subsiding or being uplifted)
SL	SLR component
SSP	Shared Socio-economic Pathways (SSPs) are scenarios used to derive greenhouse gas concentration trajectories adopted by the IPCC for its sixth Assessment Report (AR6) in 2021
T+T	Tonkin + Taylor (Tonkin & Taylor Ltd.)
VLM	Vertical land movements
VCMP	Victoria Coastal Monitoring Program

1 Introduction

1.1 Engagement

Tonkin & Taylor Pty Ltd (T+T) has been engaged by the Victorian Department of Energy Environment and Climate Action (DEECA) to assess the hazards associated with cliffs along the Victorian Coastline. The work has been delivered under the Coastal Professional Advisory and Services Panel (CMS102426) and signed Purchase Order CMS105959 dated 1 February 2023.

DEECA is interested in enhancing the understanding of cliff types across the State, active processes such as erosion, instabilities or slumping, and associated risks for public land, assets and safety. Therefore, DEECA engaged T+T to undertake a two-stage assessment, including:

1. Identification of areas susceptible to coastal cliff related erosion and instabilities (this report, Stage 1)
2. Coastal cliff risk assessment (Stage 2 report)

This document sets out the assessment of “Areas Susceptible to Coastal Cliff Instability and/or Erosion” (ASCCIE) associated with potential areas at the top of the cliff, and “Areas Susceptible to Cliff Talus Runout” (ASTaR) associated with potential areas at the bottom of the cliff for the approximately 672 km of hard or soft rock coastal cliffs along the Victoria shoreline, as defined by Water Technology (2022). The purpose, scope, level of detail and scale, and intended use of the assessment are set out below, including limitations on using information derived in this assessment.

1.2 Purpose and scope

The purpose of this second-pass assessment is to identify areas susceptible to coastal cliff erosion, instability and slumping (i.e. ASCCIE and ASTaR) at a regional/state-wide scale for present-day and future timeframes. The intent of this assessment is that resulting ASCCIE and ASTaR are then used to inform the second part of the assessment, the cliff instability risk assessment. That assessment identifies assets at high risk to coastal cliff instability, erosion and slumping including consideration of public safety.

The ASCCIEs have been assessed to identify extents of land that have a high likelihood of coastal cliff instability and erosion for the considered timeframes. The ASTaRs have been identified to assess the extent of areas at high likelihood of talus runout/cliff slumping. An example of a failed cliff including talus runout at the toe is an area north of Point Addis beach is shown in Figure 1.1.

ASCCIE and ASTaR have been assessed for the hard and soft rock coastal cliffs within the State of Victoria (i.e. 672 km), as defined by Water Technology (2022). Water Technology (2022) completed an assessment of mapping initial shoreline classes for the Victoria shoreline based on the national Smartline dataset, with some adjustments specifically for Victoria. The analysis in this report is focussed on the cliff extents mapped by Water Technology (2022). Any cliff outside of the hard and soft rock cliff extents defined by the Water Technology (2022), such as cliffs behind hard engineered structures or cliffs not identified by Water Technology (2022), is outside the scope of this study (refer to limitations in Section 1.4). Refer to the Smartline dataset for the locations of engineered shorelines and other types of shorelines. The assessment is based on the following scope of works:

- Review key processes that contribute to coastal cliff erosion, instability and slumping
- Review background information (data and reports) on coastal cliff toe erosion and cliff instability within the state of Victoria
- Assess values of the component contributing to coastal erosion, associated cliff instability and slumping

- Calculate and map ASCCIE and ASTaR distances using the methods set out in this report
- Apply the coastal erosion methodology for current and future sea level scenarios aligned with DEECA guidelines
- Produce a technical report describing the models and methodology utilised and a discussion of the results
- Produce maps of ASCCIE and ASTaR polygons for selected timeframes, sea level rise scenarios and likelihoods separately in GIS format.

Figure 1.1: Example of cliff failure including talus runout north of Point Addis Beach (taken 24 April 2023)

Based on the purpose of this assessment set out above, the timeframes and scenarios as set out in Table 1.1 are proposed. These have been aligned with timeframes included in DEECA (2023). This considers a wide range of timeframes, including the present-day ASCCIE that may need to be considered for public safety purposes, and up to ASCCIE-2100 for long-term coastal adaptation purposes considering at least 75 years. The ASCCIE-2040 has been included for public safety purposes for land possibly susceptible within the next 15-20 years, and the ASCCIE-2070 considering approximately 50 years. ASTaR have been assessed for the present-day conditions only.

Table 1.1: Timeframes and sea level rise scenarios

Scenario	Timeframe	Sea level rise
Present-day ASCCIE	Present day	0 m
ASCCIE-2040	2040	0.2 m
ASCCIE-2070	2070	0.5 m
ASCCIE-2100-1	2100	0.8 m
ASCCIE-2100-2	2100	1.1 m
ASCCIE-2100-3	2100	1.4 m
ASTaR	Present day	N/A

1.3 Adopted scale and level of detail

The Marine and Coastal Policy (DELWP, 2020) and Victoria's Resilient Coast – Adapting for 2100+ (DEECA, 202) provides direction on the use of coastal compartments for considering and assessing coastal hazard risks. Table 1.2 sets out the three coastal compartment categories, geographic scale and suitability for use as set out by DEECA (2023). The Victorian coast is comprised of 23 secondary compartments as per DEECA (2023), with tertiary compartments (i.e. more local/site-specific scale) currently not identified.

Table 1.2: Levels of detail for coastal hazard risk assessments (DEECA, 2023)

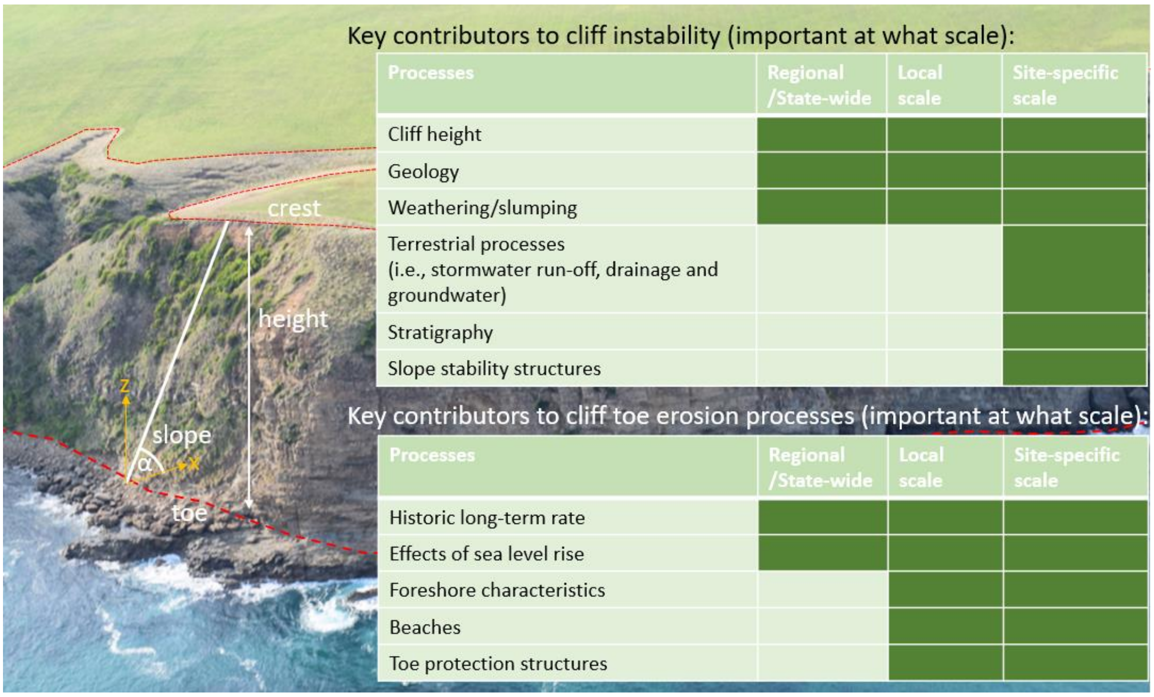
Coastal compartment category	Geographic scale	Suitability for use
Primary	Large landforms (headlands, rivers)	Large scale engineering works and long-term strategic plans
Secondary	Sediment movement on the shoreface within and between beaches	Regional planning and engineering decisions
Tertiary	Sediment movement in the nearshore areas (often individual beaches	Detailed impact studies and local management plans for vulnerable areas

As per Sharples et al. (2008), first-pass assessments are typically undertaken at a national scale, second-pass assessments on a regional scale and third-pass assessments on a more site-specific scale (i.e. local scale: 10 m to 1 km shoreline sections or site-specific scale: <10 m shoreline sections). This assessment has been undertaken as a second-pass assessment at a regional/state-wide scale, and roughly aligns with the suitability for use for secondary coastal compartments.

The prevalence of a section of coastline to be 'cliff forming' is driven by a wide array of physical and chemical processes. These include things like the geologic unit which forms the cliff, frequency and intensity of wave action, exposure to and changes in weather, development of coastal (proximal) land, drainage and many others.

Processes that may result in cliff instability and/or cliff toe erosion/regression at different scales are shown in Figure 1.2. For this regional/state-wide assessment, processes that have been considered include:

- Historic long-term cliff toe erosion (i.e. wave action and tides)
- Effects of sea level rise on historic toe erosion
- Geology
- Cliff height
- Weathering resulting in slope instability
- slumping/land sliding resulting in talus runout and slope instability



Key contributors to cliff instability (important at what scale):

Processes	Regional /State-wide	Local scale	Site-specific scale
Cliff height	🟩	🟩	🟩
Geology	🟩	🟩	🟩
Weathering/slumping	🟩	🟩	🟩
Terrestrial processes (i.e., stormwater run-off, drainage and groundwater)			🟩
Stratigraphy			🟩
Slope stability structures			🟩

Key contributors to cliff toe erosion processes (important at what scale):

Processes	Regional /State-wide	Local scale	Site-specific scale
Historic long-term rate	🟩	🟩	🟩
Effects of sea level rise	🟩	🟩	🟩
Foreshore characteristics		🟩	🟩
Beaches		🟩	🟩
Toe protection structures		🟩	🟩

Figure 1.2: Key contributors to cliff instability and cliff toe erosion and the typical scale at which they are able to be considered

This report is not intended to be a full catalogue and study of the myriad of cliff forming processes at work along the Victorian coastline as these are wide and varied. The interplay between any number of these processes, when active along any particular stretch contribute to whether an area is cliff forming, or not. The methodology adopted for the cliff instability component of these works intrinsically accounts for the combined effects of all processes currently active on the section of coastline where each particular geologic unit daylights. Amalgamating the processes and using the geology as the differentiating feature results in a suitable resolution for a regional scale study, however for the local scale studies, the importance and scale of one, or many individual processes may have a large impact and require particular consideration.

An example of an area along the coast where geology drives the shape and type of coastline formed can be observed along a section of the coastline in San Remo, from Punchbowl Reserve to BoreBeach. The geology that daylights in these cliffs is the Wonthaggi Formation which is a sedimentary rock unit deposited in a fluvial environment. This material is susceptible to cave forming along this section of coastline due to wave action preferentially eroding a locally weaker section of rock, likely driven by presence of a persistent defect set in the rock. Once these caves form, they become slowly larger to the point where the ‘bridging’ material, forming the roof of the cave becomes too thin to support its own weight and collapses. Punchbowl is an example of a remnant cave which collapsed in on itself to form the semicircular or arcuate shape that can be seen in a number of locations along this section of coast (see Figure 1.3 below).

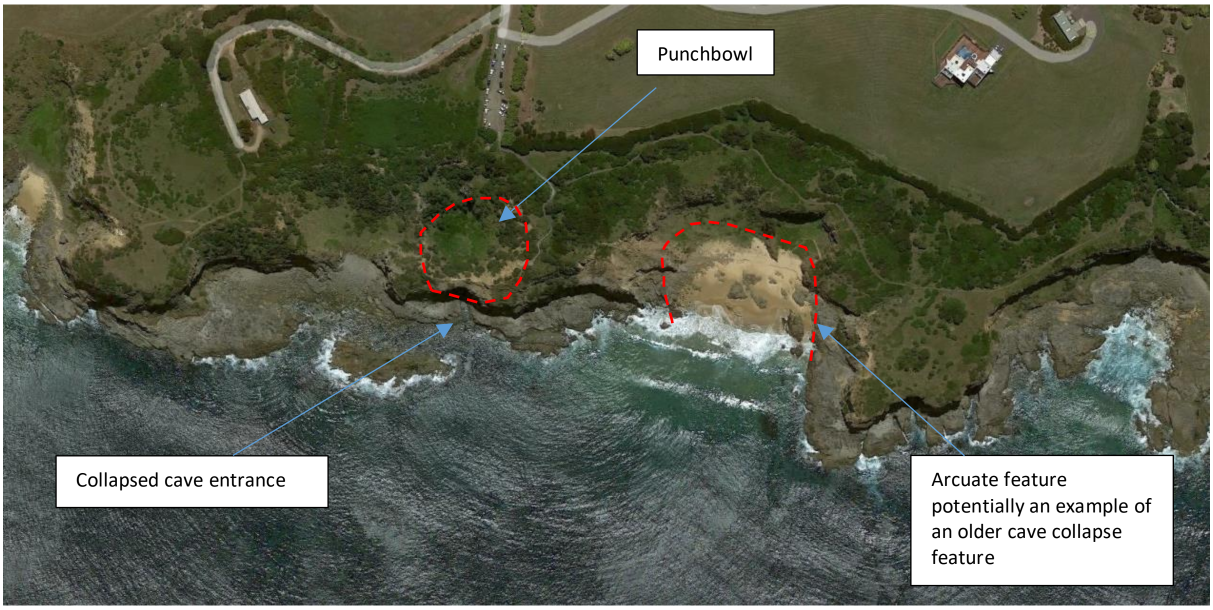


Figure 1.3: Google Earth image of 'Punchbowl' in San Remo showing cave collapse and resulting coastline shape.

1.4 Intended use and limitations

Due to the adopted scale and level of detail to undertake this assessment, the areas outside of the identified ASCCIE and ASTaR may be considered unlikely to be susceptible. It should be noted that this 'second-pass' assessment has been undertaken at a high level (regional/state-wide scale) and may be superseded by local and site-specific scale assessment by a suitably qualified and experienced practitioner.

The regional/state-wide scale assessment is based on available data, tools and understanding of coastal processes. Uncertainty may be introduced to the assessment by:

- An incomplete understanding of the parameters influencing the areas susceptible to coastal cliff instability and/or erosion
- Errors introduced in the collection and processing of data, and/or scale of data
- Scale of assessment and variance in the processes occurring alongshore
- Limited long-term toe erosion rates
- Other hazards such as land based geotechnical instability, or planning and landscape impacts, etc. that are not accounted for within the ASCCIE
- Adopted methodologies
- Deterministic vs probabilistic approach
- The scale of the mapping.

Parameter uncertainty

Uncertainty in individual parameters is incorporated into the present assessment by considering mean values (i.e. 50% exceedance likelihood) and upper bound values (i.e. 10% exceedance likelihood) for each component. Uncertainties in individual parameter components will reduce as better and longer local data is acquired, particularly around rates of long-term shoreline movement and shoreline response to sea level rise. For future updates uncertainties may be reduced based on longer and more detailed datasets available.

Assessment scale

Due to the large scale of the assessment, errors are inherently introduced due to the alongshore variance. To identify areas that could potentially be susceptible to coastal cliff instability and/or erosion upper bound values have been adopted for each component. This means that in some areas the ASCCIE may be overpredicted (i.e. shown further landward). However, this also means that ASCCIE may be underpredicted in areas where values are larger than the typical upper bound value (i.e. the largest or maximum values). Therefore, this assessment is recommended to be used as a preliminary tool. This regional/state-wide scale assessment may be superseded by local and site-specific scale assessment by a suitably qualified and experienced practitioner.

Dataset scales

In addition to the scale of the assessment, the scale of the datasets that has been used is an important limitation. For instance, the cliff shoreline as identified by Water Technology (2022) has been used for this assessment, which is understood to have been based on the Smartline dataset that was derived on a national scale. Therefore, some areas identified as cliffs may not actually be cliffs, and some cliff sections may not have been included. Another example is the geological maps that have been used show the extent of geological units on plan view, however, cliffs may be comprised of multiple geological unit layers. These limitations should be considered when undertaking a local or site-specific assessment.

Data availability

Due to the large length of cliff shoreline along the State of Victoria (i.e. 674 km as identified by Water Technology, 2022), detailed long-term rates along the entire cliff shoreline could not be derived. Georeferenced historic aerial photographs are available back to the 1940s in some areas and have been used to derive historic cliff toe positions at selected, discrete locations. This means that at locations where historic cliff toe regression rates cannot be derived, information from previous reports or rationalised rates have been used (refer to Section 5.3). This has likely resulted in under- and overestimation of historic cliff toe regression rates for these areas.

Site-specific features

In addition to the derivation of long-term rates, site-specific features such as beaches or reef platforms fronting cliff toe, seawalls protecting cliff toe or other structures stabilising cliff slope/crest have not been considered. If erosion of the cliff toe is halted through either natural (i.e. establishment of a beach) or artificial (i.e. through rock protection) processes, then the above cliff will continue to adjust until a stable profile is reached. After which time vegetation often becomes established as there is no further removal of material. These features should be considered when undertaking a local or site-specific assessment.

Other hazards

The ASCCIE values assessed for this study identify areas susceptible to processes related to coastal erosion only, including instability of the land above (refer to Section 1.3). Other hazards and requirements such as, but not limited to, small/local scale processes, planning, amenity, and landscape matters, are not accounted for within the ASCCIE. Therefore, the ASCCIE derived in this report should not be used for residential development or subdivision purposes. More refined assessments should be undertaken for the purposed of development or subdivision, with a more detailed assessment likely refining the zones generated from the regional assessment approach. The appropriate assessments should consider issues associated with visual effects, amenity, recreation, effect of non-residential buildings such as in ground or above ground utilities, fences, and paths, and other site-specific processes as shown in Figure 1.2.

Methodology

The methodologies adopted in this report are based on best practice. These methods are typically based on theoretical understanding of coastal processes and are simplified such that they are appropriate for most of the shorelines. However, there may be shorelines that behave differently and cannot be described by one of the adopted methods. For instance, if the cliff crest and cliff toe become physically disconnected (e.g. due to cliff top erosion or land sliding), the adopted method for cliffs may not be entirely appropriate. Furthermore, in this regional-scale assessment a distinction between true cliffs (actively eroding) and coastal hill slopes (formed over millenniums) could not be made, with both types considered as coastal cliffs.

The Envirolink guide to good practice (Ramsey et al., 2012) recommends moving from deterministic predictions to probabilistic projections, and that the recognition and treatment of uncertainty is a key source of variance between coastal hazard predictions by practitioners. This could be addressed by using probability distributions for a more detailed assessment. For a regional/state-wide scale assessment it is not possible to adopt a probabilistic approach due to the large scale, total length of the shoreline and lack of site-specific data to build probability distributions around each parameter. It is more appropriate to undertake a probabilistic assessment on a local-scale or site-specific scale, with the regional/state-wide assessment identifying these areas that are at high risk for more detailed assessment.

Mapping

Mapping of the ASCCIE or ASTaR inherently introduces errors due to the mapping method and resolution. For this assessment transects at 30 m alongshore intervals have been used, with straight lines interpolating between output points. This could result in jiggered lines when zooming in too close. Furthermore, the mapping tool does not always accurately identify the cliff toe and cliff crest as a result of cliff profile/geometry. This is particularly evident for non-cliffs or very gentle slopes. Some manual edits have been made interpolating between adjacent transects using engineering judgement.

1.5 Report layout

The report has been structured as follows:

a **Background information:**
  - The coastal cliff environment is described in **Section 2**
  - Data sources are outlined in **Section 3**

b **Assessment methodology and analysis:**
  - The analysis methodology for deriving ASCCIE (and areas susceptible to talus runout) is outlined in **Section 4**
  - The derivation of key coastal erosion and talus hazard components is detailed in **Section 5**

c **Assessment outcomes, conclusions, and recommendations:**
  - The results are summarised and discussed in **Section 6**
  - A framework for refining ASCCIE in **Section 7**
  - A summary of the assessment and recommendations are then provided in **Section 8**

1.6 Outputs and deliverables

A technical report supported by geospatial layers have been prepared for this assessment. The following outputs have been created:

- Victorian Coastal Cliff Assessment technical report (this report) including:
    - ASCCIE methodology description
    - Resulting ASCCIE distances
    - Description of cliff morphology
    - Cliff toe erosion rates for assessed locations
- Supporting geospatial data.
    - ASCCIE layers for 5 timeframes
    - ASTaR layer for present-day timeframe

2 Coastal cliff environment

2.1 Setting

The shoreline along the state of Victoria consists of 672km of cliffed shoreline (defined as hard or soft rock coastal cliffs by Water Technology 2022). These cliffs vary by geology (see Section 2.2), orientation, shape and wave exposure across the state (Figure 2.1). Within Victoria, coastal cliffs are primarily found on the open coast with exposure to high-energy waves from the Bass Strait. These vast sections of open coast cliffs are coupled with localised sections of cliffs within more sheltered environments (in Port Phillip Bay and Western Port).

Figure 2.1: Victoria cliffed coastline setting

The coastal cliffs along the state's shoreline vary in geometry and shape both alongshore and cross-shore. Cliffs vary from nearly vertically faced, such as along the Shipwreck Coast and Otway Coast, to very gently sloping. Alongshore cliffs may be straight for kilometres, interrupted by headlands, or undulating. Figure 2.2 shows a selection of photographs of cliffs with different shapes and geometries, taken during the aerial survey (see Section 3.3 for details).

The majority of the coastline which has been designated as cliff forming within the Water Technology (2022) study are located westward from Wilsons Promontory, with only minor areas of cliffed coastline east of this point.

Figure 2.2: Examples of cliffs with different shapes and geometries along the shoreline at Castle Cove (top left), Wilsons Prom (top right), Yambuk (bottom left) and Jan Juc (bottom right)

2.2 Geology

2.2.1 Geological map

The geology of the Victoria cliff shoreline has been reviewed using the *Geological Survey of Victoria,* 1:250,000 geological maps (Figure 2.3). These geological maps were produced in 2014 and provide full coverage of the state of Victoria. The geological maps have been reviewed to identify the cliff-forming geologic units that outcrop along the cliff type coastline.

It should be noted, that there were a number of locations along the coastline where two different geologies were observed daylighting in the slope. An example of this was observed at Aireys Inlet Lighthouse during the ground truthing exercise, where rocks belonging to the Jan Juc formation are seen exposed in the upper slope, overlying basaltic rock belonging to the Angahook Formation which form the cliff toe. Combined geologic cliff sections like this were not included in this regional scale study and the geology as shown on the geologic map of the area has been adopted.

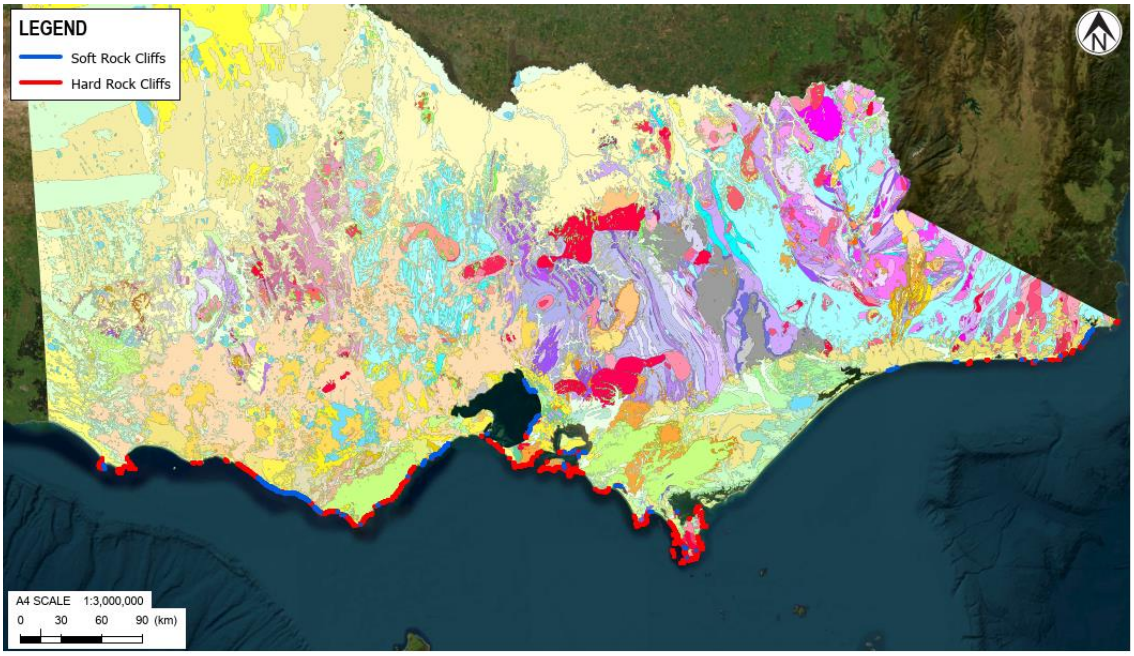


Figure 2.3: 1:250,000 Geological map for the state of Victoria (source: Geological Survey of Victoria, 2014)

2.3 Geological context

Victoria lies toward the southern end of a mobile belt that underwent major tectonic instability during the Paleozoic Era (Cambrian to Permian Periods) , with pressure applied from the east resulting in the development of deep depositional troughs through to the Carboniferous. These thick sequences of sediments were deformed along a roughly north-south orientation. This was followed by a milder tectonic regime through to the present and has resulted in a generally east-west orientation observable in the younger rocks and a number of prominent fold/fault axes across the state.

A period of volcanism occurred during the early Cambrian Period, as part of the pre-geosynclinal stage, with thick sequences of basalt lava being deposited. This volcanism ended in the mid to late Cambrian, with geosynclinal conditions firmly established by the Ordovician Period. This led to the formation of thick sequences of sediments which were deposited during a period of basin filling. Toward the end of the Ordovician, marine regression (sea level fall) initiated a period of erosion in western Victoria.

By the lower Devonian Period, the fossil record includes more land plants which indicates some contiguous land areas, however this was still interspersed with some bands of shallow neritic fauna with the previously common deeper shell fossils becoming rare. The entire sequence through to the early Devonian were subject to sporadic periods of deformation and volcanic intrusions which were more concentrated and evidenced in the east of the state. By the end of the Devonian, the whole of Victoria was largely stabilised and non-marine sedimentation was occurring into two large graben structures, one in the west near the Grampian Ranges and the other near central Victoria.

By the Lower Carboniferous Period, the tectonic instability on the overall mobile belt (concentrated in the east) had ceased, with a period of glacially and fluvio-glacially derived sedimentation to follow into the Permian and Triassic.

A new tectonic regime in the Mesozoic Era (i.e. Triassic onwards) led to initiation of depositional basins in the south of the state. These basins are thought to have subsided very rapidly, with thick sequences (2 km thick) of sedimentary deposits forming within the Jurassic to Lower Cretaceous and extending through into the Paleogene.

The onshore and offshore geology of southern Victoria comprises a series of Mesozoic and Cenozoic Era sedimentary basins separated by bedrock “highs” of Paleozoic Era igneous and metasedimentary rocks (Figure 2.4).

The Upper Cretaceous saw a marine transgression in the western part of the state which led to deposition of near shore marine sediments, of up to around 900 m thickness onto the coastal belt between Port Campbell and Nelson on the South Australian border.

The Paleogene Period was another of deposition which can be divided into three main environments: the coal measures (swampy deposits), the marine deltaic (shells and marine) and the onshore carbonaceous environment (plants and pollen). The prevalence and dominance of sediments relates to the location in relation to the basins and highlands mentioned above, and the changes in sea level which reached a maximum in the Miocene Epoch (lower Neogene Period).

The Cenozoic Era saw two periods of volcanism, one in the Eocene Epoch (Older Volcanics) and one in the Pleistocene Epoch (Newer Volcanics). Locally, the Older Volcanics were concentrated in the east of Melbourne, with the Newer Volcanics located almost entirely in the west of Melbourne.

The Victorian Coastline is made up of different materials from all of the above geological units. Typically the cliff forming units to the east of Melbourne are various granite/granodiorite units, a mixture of sedimentary rock units and Older Volcanics. To the west, the granite/granodiorite units are missing and the Older Volcanics are exchanged for the Newer Volcanics, still with a mixture of sedimentary rock units.

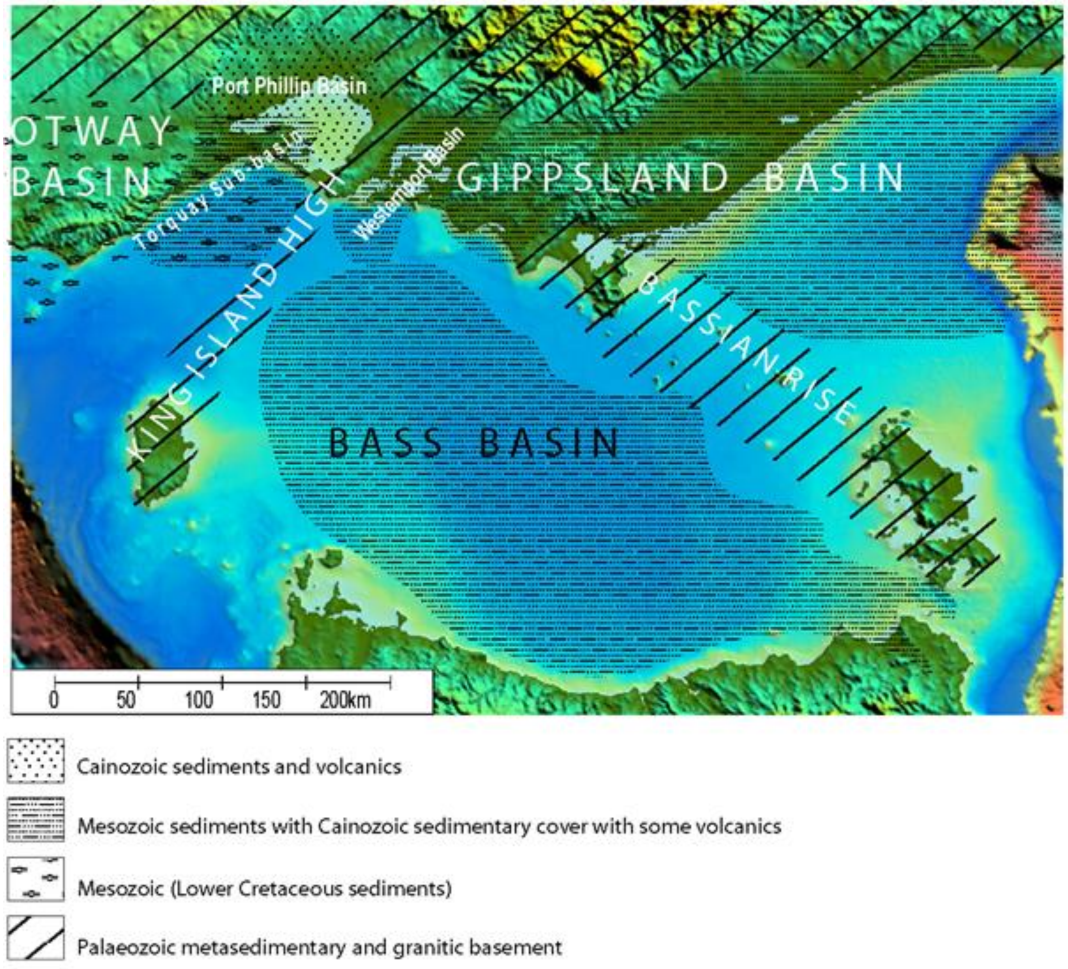


Figure 2.4: Geological basins of southern Victoria and Bass Strait, (source: Rosengren and Boyd 2008)

2.4 Topography and bathymetry

Topography has been assessed using the Digital Elevation Model (DEM) derived from the combined LiDAR (Light Detection and Ranging) datasets that together cover the entire state of Victoria (refer to Section 3.1). The DEM was used for determining the cliff crest, toe and existing slopes. An example of the DEM is shown in Figure 2.5. Offshore bathymetry data has not been used for this assessment.

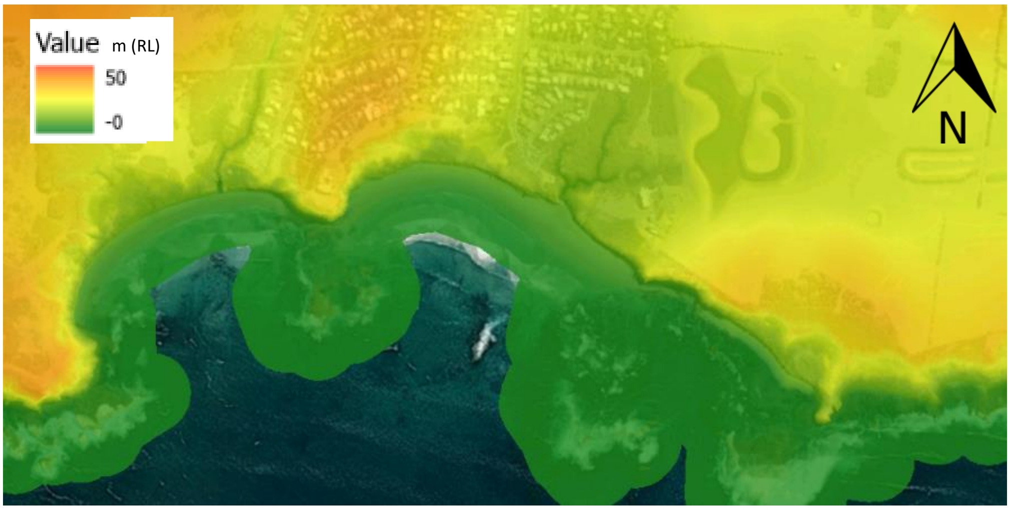


Figure 2.5: Example of the DEM at Phillip Island

2.5 Coastal water levels

2.5.1 Astronomical tide

Tidal levels across the state of Victoria have been sourced from Ports Victoria (2022) and have been set out in Table 2.1. The spring tidal levels for diurnal (once daily) and semi-diurnal (twice daily) signals have been provided for the open coast and sheltered environments across the state. Within Victoria, the east coast typically experiences diurnal tides, with the west coast experiencing semi-diurnal tides (refer to Ports Victoria, 2022).

Table 2.1: Astronomical Tides in m AHD[1] throughout the state of Victoria (Ports Victoria, 2022)

Location	Predominant tide	HAT[2] (m)	MHWS/MHHW[3] (m)	MLWS/MLLW[4] (m)
Portland	Diurnal	0.79	0.54	-0.34
Western Port (Stony Point)	Semi-diurnal	1.69	1.2	-1.02
Port Welshpool	Semi-diurnal	1.65	0.95	-0.92
Lakes Entrance	Diurnal	0.7	0.5	-0.43
Point Lonsdale	Semi-diurnal	0.95	0.62	-0.53
Geelong	Diurnal	0.66	0.56	-0.33
Melbourne (Williamstown)	Diurnal	0.59	0.54	-0.26
Port Phillip Heads (Nepean Bank)	Semi-diurnal	0.72	0.51	-0.51

[1] AHD = Australian Height Datum
[2] HAT = Highest Astronomical Tide
[3] MHWS/MHHW = Mean High Water Springs/Mean Higher High Water
[4] MLWS/MLLW = Mean Low Water Springs/Mean Lower Low Water

2.5.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind stress from winds blowing along or onshore, which elevates the water level above the predicted tide. The combined elevation of the predicted tide and storm surge is known as the storm tide. CSIRO (2009a and 2009b) derived storm tide estimates by using hydrodynamic modelling that combined storm surge elevations with astronomical tides for the open coast of Victoria as well as for Port Phillip Bay. These storm tide predictions for a 100-year ARI event are shown in Table 2.2.

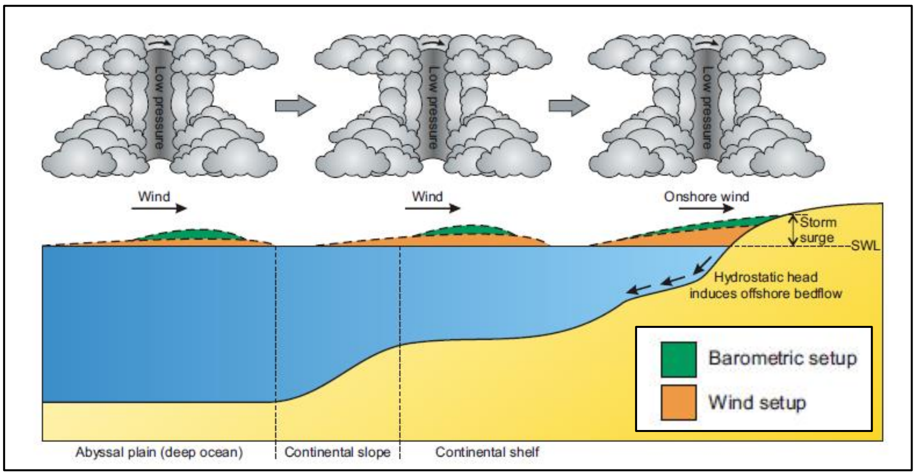


Figure 2.6: Processes causing storm surge (source: Shand et al., 2010)

Table 2.2: Storm tide levels relative to late 20th Century mean sea level across Victoria.

Open Coast (CSIRO 2009a)		Port Phillip Bay (CSIRO 2009b)	
Location	**100-year ARI Storm Tide Level (m)**	**Location**	**100-year ARI Storm Tide Level (m)**
Portland	1	Point Lonsdale	1.4
Port Fairy	1.1	Queenscliff	1.2
Warrnambool	1.1	Geelong	1.1
Apollo Bay	1.4	Werribee	1.1
Lorne	1.7	Williamstown	1.1
Stony Point	2.1	St Kilda	1.2
Kilcunda	1.9	Aspendale	1.1
Venus Bay	2	Frankston	1.2
Walkerville	2	Mornington	1.1
Port Welshpool	1.6	Rosebud	1.1
Seaspray	1.5	Rye	1
Lakes Entrance	1	Sorrento	1
Point Hicks	1.4		

2.5.3 Sea level rise

The latest information on long-term sea levels (i.e, sea level rise) is available based on the IPCC AR6 report (IPCC, 2021). Sea level rise is considered in the form of different Shared Socio-economic Pathways (SSPs), include SSP1-2.6 (sustainability scenario), SSP2-4.5 (middle of the road scenario), SSP3-7.0 (regional rivalry scenario) and SSP5-8.5 (fossil-fuelled developed scenario). Projected sea levels have been obtained using the global Sea Level Project Tool from NASA (i.e. sealevel.nasa.gov). This tool includes 3 stations across the state of Victoria, including at Stony Point, Lorne and Portland. The range of projected sea levels based on the three points, which include projected vertical land movements, is shown in Table 2.3.

Table 2.3: Projected sea level rise (m) based on IPCC AR6

Timeframe	SSP2-4.5 (p50)	SSP3-7.0 (p50)	SSP5-8.5 (p50)
2040	0.12-0.14	0.13-0.14	0.14-0.15
2070	0.29-0.32	0.32-0.34	0.35-0.38
2100	0.5-0.54	0.60-0.64	0.68-0.72

Source:sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool
Projections relative to 1995-2014 baseline

Note that for this project sea level rise values as per Table 1.1 (Section 1.2) have been adopted, which are aligned with DEECA (2023). Comparing the sea level rise values in Table 1.1 and Table 2.3 shows that the adopted values as per Table 1.1 are typically slightly higher.

2.6 Wave exposure

The majority of the coastal cliffs within the state of Victoria are situated on the open coast and are exposed to high-energy ocean waves from the Bass Strait. The highest wave energies impact the western extent of the Victorian coastline, with some sheltering of high-energy waves to the north and northwest of Tasmania (Liu et al., 2023 and Figure 2.7). For peak (100-year ARI) wave events, hindcast modelling conducted by Liu et al. (2023) found offshore wave heights reached a peak magnitude of 12.5 m.

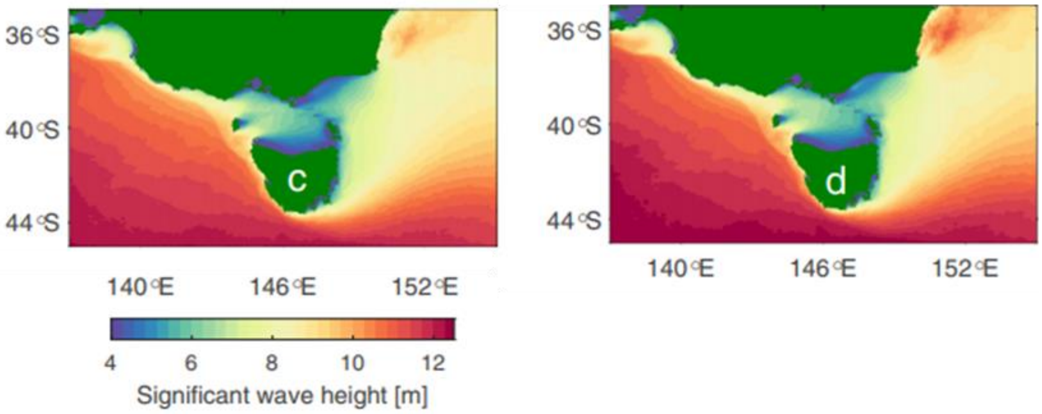


Figure 2.7: Wave climate from WW3 hindcast within the Bass Strait for: c.) 50-year ARI , d.) 100-year ARI (Source: Liu et al. 2023).

The wave climate within the more sheltered regions of the Victorian coastline (such as Port Phillip Bay and Westernport Bay) is driven by locally generated wind waves. Within Port Phillip Bay, maximum wave heights (for a 100-year ARI event) have been modelled to reach 2.2 m (Figure 2.8)

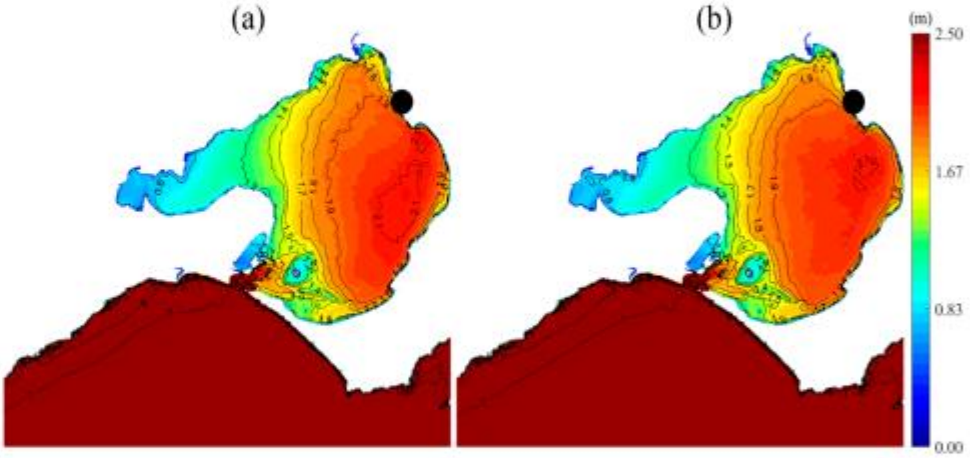


Figure 2.8: Estimates of the 100-year return period significant wave height within Port Phillip Bay for a) 90th percentile and b) 95th percentile (source: Tran et al., 2021)

3 Data sources

3.1 Spatial topographic data

3.1.1 LiDAR datasets

A LiDAR survey of the Victoria region was undertaken between 2006 and 2009 by the Department of Sustainability and Environment and provides full coverage of the entire Victorian coastline. This LiDAR was processed into a Digital Elevation Model (DEM) surface and has a grid resolution of 2.5 m x 2.5 m.

In addition to the 2006-2009 LiDAR, there is more recent higher resolution LiDAR coverage of localised areas within Victoria. These additional data sets are as follows:

- Victorian Coastal LiDAR Level 3 Classification (Port Phillip Bay & Western Port and East & West Victoria). This dataset consists of a reprocessed DEM from the original 2006-2007 LiDAR data.
- 2017-2018 Greater Melbourne LiDAR. This dataset consists of 1m DTM (Digital Terrain Model) of 12,000 km^2 of coast across the Greater Melbourne region.
- 2019-2020 Great Ocean Road Elevation and Photography. This dataset consists of a 0.5m grid resolution DEM.
- 2020-2021 Bayside Yarra LiDAR. This dataset consists of a DEM with data captured at 24 pts/m^2.

All of these LiDAR datasets were used in combination for the entire cliffed shoreline, with the highest resolution and most recent LiDAR data being used for each location. Figure 3.2 shows the LiDAR dataset extents that have been used for this study.

3.1.2 Coastal transects

In addition to the LiDAR DEMs and DTMs described above, coastal transects were provided by DEECA for the full length of the Victorian coast. These transects are 400 m long and spaced at 30 m increments along the shoreline (see example of transects in Figure 3.1). For this project some transects (e.g. at very high cliffs) have been extended to capture the entire cliff profile.

Figure 3.1: Example of DEECA transects at the 12 Apostles on Great Ocean Road

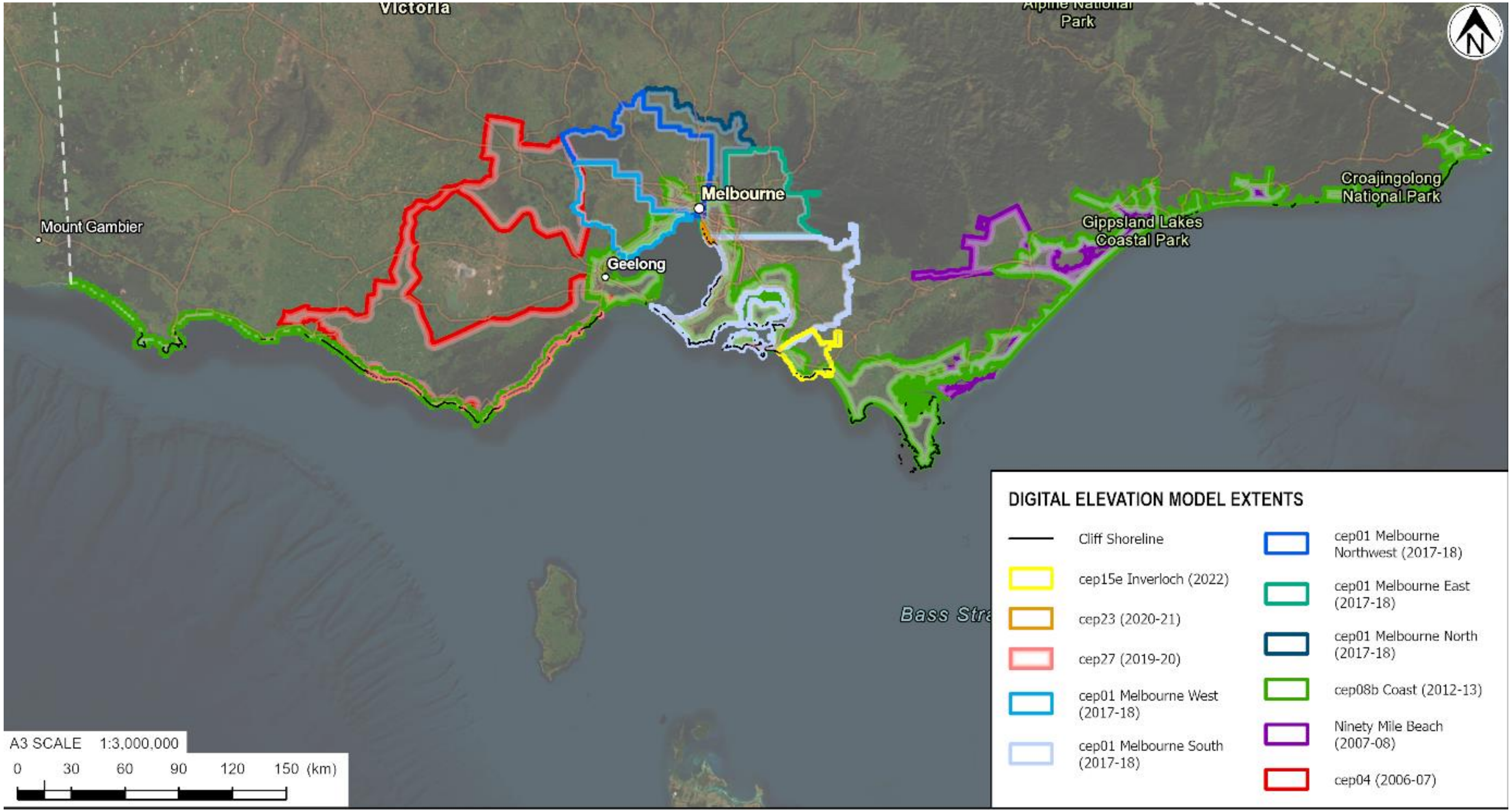


Figure 3.2: Extents of LiDAR datasets

3.2 Secondary coastal compartments

The secondary coastal compartments were provided by DEECA and were used as part of the shoreline classification process. As discussed in Section 1.3, these secondary coastal compartments describe areas where sediment moves on the shoreface within and between beaches.

Figure 3.3: DEECA secondary coastal compartments

3.3 Aerial survey

An aerial survey of the Victoria cliffed shoreline was undertaken using a fixed wing aeroplane in April 2023. The purpose of this was to obtain high resolution oblique photographs of the cliff shorelines. The aeroplane was flown at an elevation of roughly 500 ft (~150 m) and typical offshore distance of 300-500 m. The oblique aerial photographs have been processed and geo-tagged so that a clean dataset of photographs including their GPS coordinates is available.

The obliqueness of the photographs is particularly useful for interpretation of shoreline slopes, heights and relief, and validation of geological unit, lithology and susceptibility to landslides. This data is intended to be used in combination with available Victoria LiDAR datasets information and right-angle photography. Figure 3.4 shows examples of oblique aerial photographs along the Victoria shoreline captured during the aerial survey. Appendix A shows more details of the aerial survey.

Figure 3.4: Selected photographs taken during the aerial survey at Cape Bridgewater (top left), Wilsons Prom (top right), 12 Apostles (bottom left) and Peterborough (bottom right)

3.4 Georeferenced aerial photographs

Historic and present-day aerial photographs were provided by DEECA (via the DELWP image web server). Aerial photographs have been captured between 1930 and 2022, but full coverage of the Victoria cliffed shoreline is not achieved until 2010/2011. Aerial photographs provided were georeferenced (accuracy unknown), some georeferencing errors were noted for the older stitched aerial photographs, with particularly large errors noted in the 1947 Otways surfcoast aerial and the 1945 Wilsons Promontory aerial. Appendix B includes the aerial photographs that have been used for this study including location.

3.5 Existing studies

3.5.1 Coastal Hazard Management policies and frameworks

Existing coastal hazard management policies and frameworks have been reviewed to provide a basis for the assessment. The latest guidance document relevant for this study is DEECA (2023): Victoria's Resilient Coast guidelines 2100+. That document has been used to align timeframes, sea level rise scenarios and likelihoods used within this study.

3.5.2 Previous assessments of cliff coastal hazards

Previous reports and datasets assessing cliff coastal hazards within the Victoria region that were available, have been reviewed to provide background data and information. Long-term cliff regression rates from previous studies were used for comparison to and validation of the present assessment as well as to infill data where digitised rates from the Victoria Coastal Monitoring Programme (VCMP) were available on cliff transects within the CoastKit dataset[1].

The previous reports outlined in Table 3.1 were identified to have long-term cliff regression rates that were digitised for the cliff toe using present and historic aerials (the same methodology as used in the present assessment, which is discussed further in Section 5.3).

Table 3.1: Reported long term cliff toe erosion rates

Location	Geological unit[1]	DEECA secondary coastal compartment	Report	Mean Rate (m/yr)	Notes
Yallock-Bulluk	Wonthaggi Formation	Cape Woolamai-Cape Paterson and Venus Bay	Tonkin + Taylor (2020)	0.1	Limited accuracy of georeferencing with a low rates of observed shoreline change, meant that the accuracy of georeferencing (5 m) was taken to determine the rate.
12 Apostles	Heytesbury Group	Port Campbell	Bezore et al. (2016)	0.22	Mean rate taken for aerials digitised between 1947 and 1994.
Fossil Beach south, Port Phillip Bay	Sandringham Sandstone	Port Phillip Bay (east)	McInnes et al. (2020)	0.15	Classified as soft cliff with beach within this assessment. Vegetation line was digitised in historic and present day aerials.
Daveys Bay north point, Port Phillip Bay				0.13	
Manyung Rocks, Port Phillip Bay				0.04	
Half Moon Bay north, Port Phillip Bay	Brighton Group			0.01	

[1]Discussed further in Section 5.2

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[1] CoastKit Victoria (mapshare.vic.gov.au)

In addition to the reported rates, regression rates within the VCMP dataset for the Anglesea Cliffs (Figure 3.5) were extracted. These rates were then used to supplement the digitised rates determined from the present assessment (refer to Section 5.3).

Figure 3.5: Anglesea rates from aerial imagery (dated between 1962-2020) within the VCMP database, where erosion rates are provided in m/year

4 Methodology

4.1 Staged approach

The project approach has been set out in the form of a workflow shown in Figure 4.1. The methodology for each stage has been further detailed in the subsequent sections (i.e. in Sections 4.3 and 4.4), with the high-level approach summarised below:

1. The assessment of geology has been undertaken first to understand the different cliff types and classify the shoreline into manageable geological units (refer to Section 5.2). The Water Technology (2022) hard and soft cliffs classified shoreline have been used as a basis.
2. Coastal cliff toe regression rates have been assessed by deriving rates at targeted locations (i.e. spread across a representative sample of shoreline sections for each geological unit) (refer to Section 5.3). These rates have been complemented with existing data (which is outlined in Section 3.5.2). Statistical typical (i.e. 50% exceedance) and upper-bound (i.e. 10% exceedance) values have been derived.
3. In parallel, an assessment of cliff instability processes and assessment of cliff instability areas has been undertaken (refer to Section 5.4). As with the toe regression rates, this has been conducted based on the derived geological units. Deterministic typical (i.e. 50% exceedance) and upper-bound (i.e. 10% exceedance) values have been derived.
4. The cliff toe regression and cliff instability data were then combined to assess the areas susceptible to coastal cliff instability and/or erosion (ASCCIE) for selected timeframes and climate change scenarios. This includes validation of the desktop study data using observations from site inspections and review of aerial survey photographs. Section 6 sets out the resulting ASCCIE and ASTaR including individual components.
5. In addition to determining ASCCIE, this assessment includes assessment areas susceptible to talus runout (i.e. ASTaR). This includes mapping of areas that are subject to talus runout from cliff landslides (refer to Sections 4.4 and 5.5).
6. The second stage of this assessment includes the classification of coastal cliff risks for a range of timeframes and scenarios (#6), which includes recommendations on risk management options (#7) (see Stage 2 report).

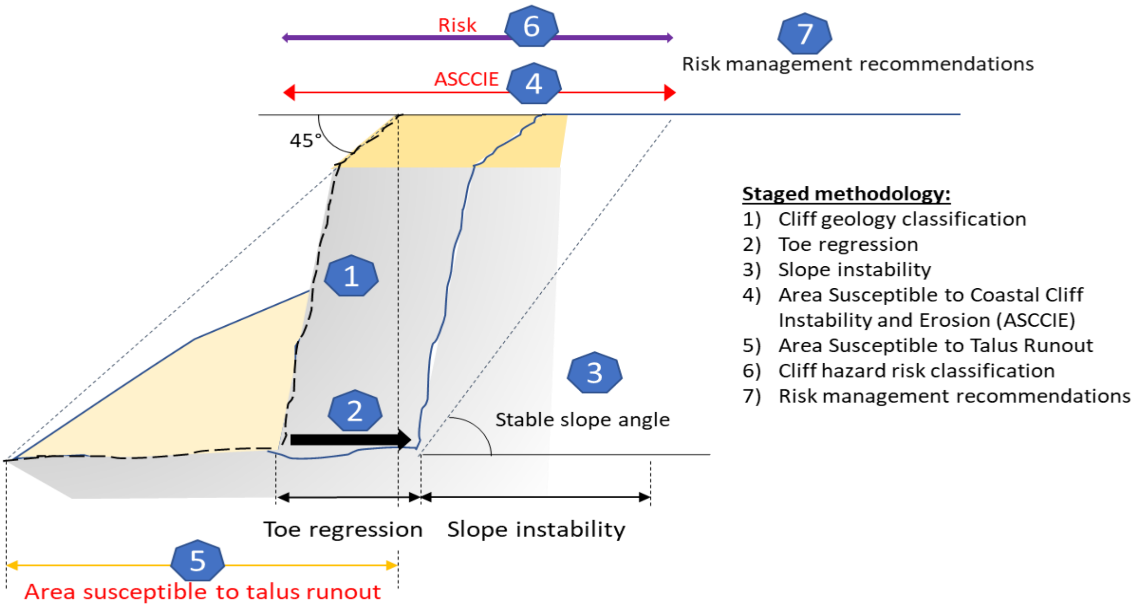


Figure 4.1: Conceptual model for the assessment outlining the derivation of areas susceptible to coastal cliff instability and erosion as well as to talus runout.

4.2 Geospatial data derivation

Cliff data such as cliff toe position/elevation, cliff crest position/elevation and cliff face slope have been derived using the Cliff Feature Delineation Tool (CFDT) developed by USGS (2020). This is a GIS based tool that can identify these features using cross-sections as input and an initial cliff toe position/elevation as a starting point. Figure 4.2 shows an example of cliff features identified along a cliff shoreline using the CFDT. Transects at 30 m interval have been provided by DEECA (see Section 3.1.2), which have been used to extract cliff profiles based on the LiDAR data (see 3.1.1). These profiles were then used to extract the cliff toe, crest and slope.

For this assessment, the Mean High Water Mark (MHWM) level has been used as an initial estimation as the cliff toe elevation/position (i.e. the baseline), which is a requirement for the CFDT tool. The MHWM from the Smartline dataset has been used for this. The CFDT tool then identifies the cliff toe at each transects, which has been used as the baseline for this assessment.

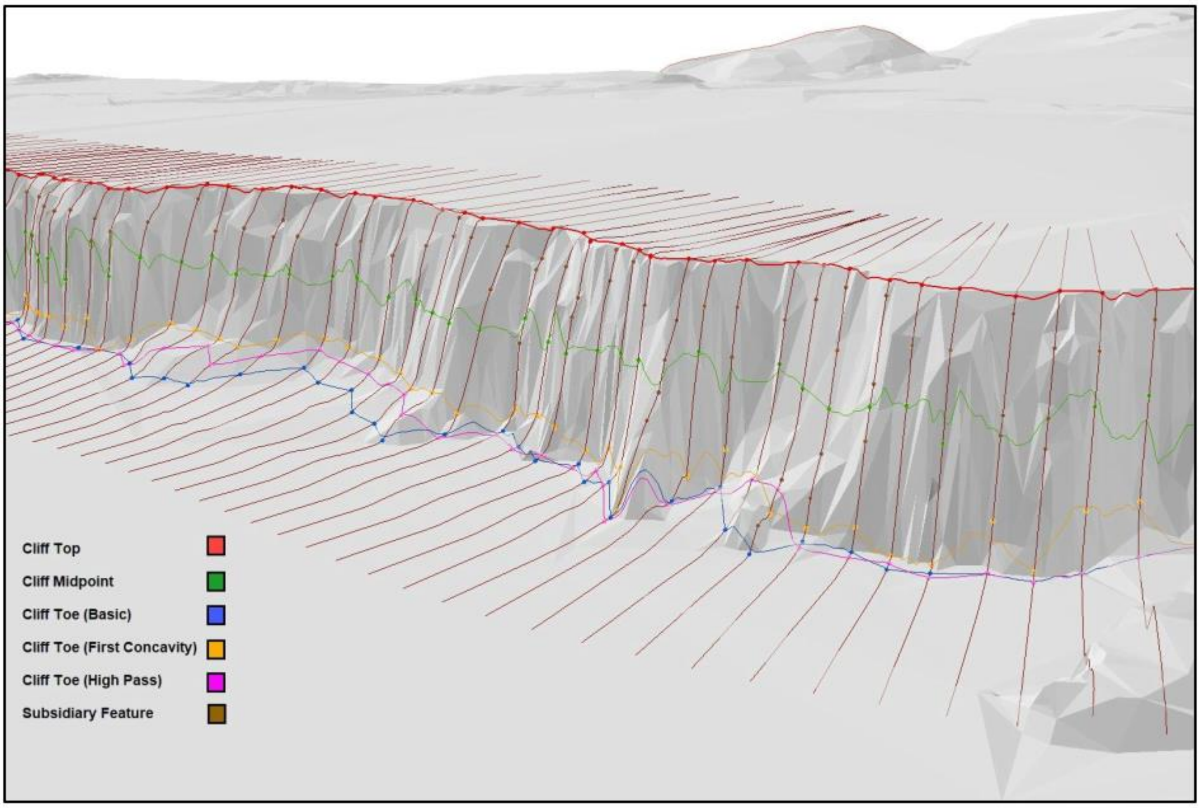


Figure 4.2: Example of cliff features identified along cliff (source: USGS, 2020)

4.3 Areas Susceptible to Coastal Cliff Instability and Erosion (ASCCIE)

4.3.1 Conceptual model for deriving ASCCIE

Consolidated shorelines, which include soil and rock cliffs, are not able to rebuild following periods of erosion but rather are subject to a one-way process of degradation. As outlined in Section 4.1 and Figure 4.1, ASCCIEs typically have two components:

- **Toe Erosion**

  A gradual retreat of the cliff toe caused by weathering, marine and bio-erosion processes. This retreat will be affected by global process such as sea level rise and potentially increased soil moisture. Future cliff toe position based on historical erosion rates with a factor applied to allow for the effect of future sea level rise.

- **Cliff Instability**

  Episodic instability events are predominately due to a change in loading or material properties of the cliff or yielding along a geological structure. In soft cliffs, instability causes the cliff slope to flatten to a slope under which it is “stable” (geo-mechanically). Soil cliff slope instabilities are influenced by processes that erode and destabilise the cliff toe, including marine processes, weathering and biological erosion or change the stress within the cliff slope. Most of the hard cliffs are stable at very steep angles. Instability events may range from small-scale instabilities (block or rock falls) or discontinuities, to cliff slope instability cause by large-scale and deep-seated mass movement. The latter mode of failure in hard cliffs is rare.

Note that these types of instability events cannot be predicted with certainty. They can only be monitored once signs of movement are observed. To generate a rate from episodic events the time period needs to be long enough to enable the cliffs to undergo a full cycle of regression; toe erosion, over steepening, instability, removal of failed material, toe erosion.

The conceptual models for the toe erosion component and cliff instability component are as follows:

$$\textit{Cliff Instability} = (h_C/\tan\alpha) \tag{Equation 4.1}$$

$$\textit{Cliff Toe Regression} = ((LT_H \times LT_F) \times T) \tag{Equation 4.2}$$

Where:

h_C = Height (m) of the cliff

α_r = The overall instability slope angle (degrees)

LT_H = Historical long-term retreat (regression rate), (m/year)

LT_F = Factor for the potential increase in future long-term retreat due to sea level rise effects.

T = Timeframe over which erosion occurs (years).

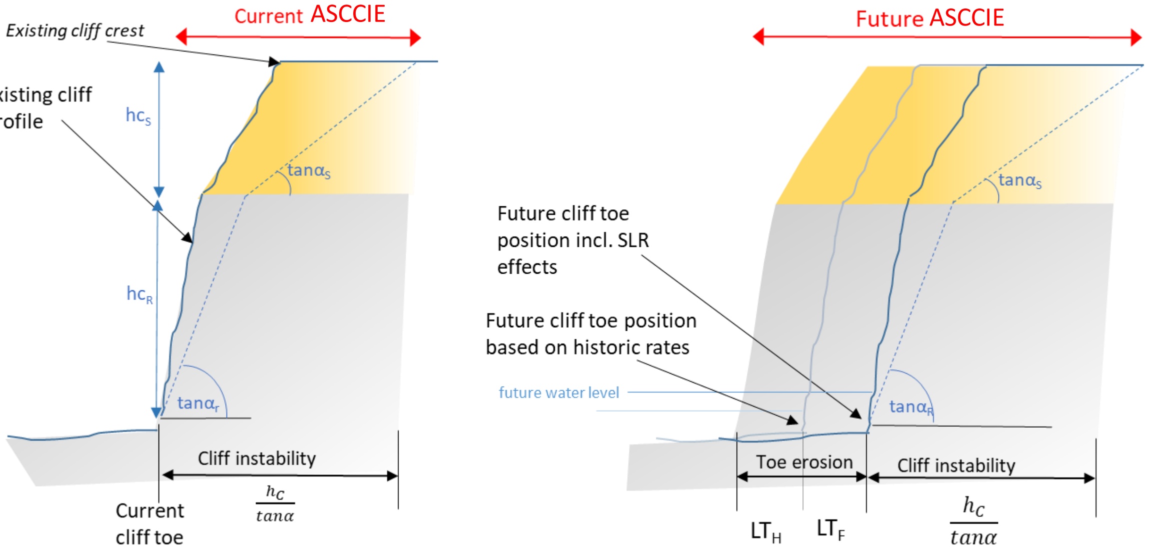


Figure 4.3: Definition sketch for areas susceptible to coastal cliff instability and erosion (ASCCIE)

These can then be combined into the models for consolidated shoreline for the present day and future ASCCIE (Equation 4.3). The present-day area is a function of the cliff instability component only as regression of the cliff toe is a long-term process (i.e. by using T = 0 in Equation 4.3).

The future area is a function of both cliff instability and cliff toe regression, with the latter likely being affected by increased sea level rise rate effects. Combining both the cliff instability and cliff toe regression for both present-day and future ASCCIE is set out in the subsequent sections. The ASCCIE have been offset from the most recent cliff toe position as described in the previous section.

$$ASCCIE = (LT_H \times LT_F \times T) + (h_C/\tan\alpha) \qquad \text{(Equation 4.3)}$$

4.3.2 Transect-based approach

To derive the ASCCIE along the entire shoreline, component values have been assigned to each transect (see Section 4.2) intersecting with the cliff shoreline as indicated by Water Technology (2022). This has been done by assigning geological unit classes to each transect (refer to Section 5.2 how that has been done). Values for each component (i.e. historic long-term regression, effects of sea level rise and the stable angle) could then be derived for each of the considered geological unit classes. An example of transects intersecting different geological unit classes is shown in Figure 4.4.

This was based on a review of the spatial distribution of geological units, which were generally consistent over sections of coastline for a certain shoreline orientation and geographic location. Furthermore, wave exposure does not vary significantly across the coastline on a regional scale, apart from the difference between wave exposure along the open coast (i.e. high) and within embayments (i.e. low). The open coast sections of cliff-type coastline having consistently high exposure to wave energy. This is additionally supported as the key areas of low wave exposure (such as Port Phillip Bay) primarily had geology that was not found on the open coast. Therefore, this was not used to differentiate between component values.

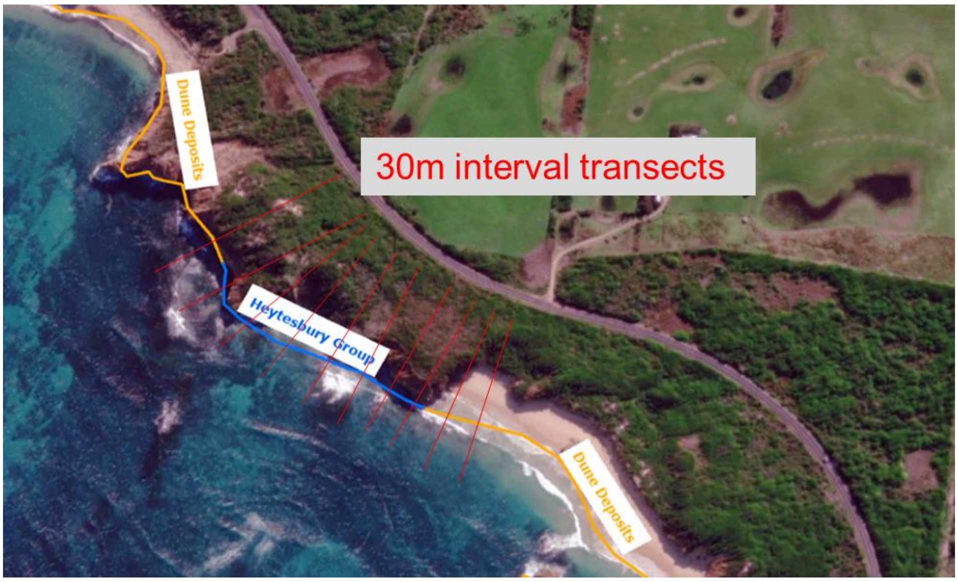


Figure 4.4: Example of the geological unit and transect-based approach sucessfully identifying localised changes in shoreline geology

4.3.3 Parameter combination

For this regional/state-wide scale assessment, a deterministic approach has been adopted using single values for each component. Statistical analyses have been carried out to derive mean values (i.e. 50% exceedance) and typical upper bound values (i.e. 10% exceedance) for both the toe erosion and slope instability components. The 10% exceedance probability (i.e. 10% likelihood of exceeding that value) has been adopted as the typical upper bound value as agreed with DEECA.

As potential limitations in available data (e.g., poor resolution and georeferenced aerials) may affect the number of data points (e.g. only 1-2 cliff toe erosion distances), a statistical approach may not be possible everywhere. For sections with limited datapoints, the largest value has been adopted as the typical upper bound value (refer to Section 5.3 for more details).

4.3.4 Mapping methodology

The toe erosion and cliff instability component have been combined and mapped using the cliff projection method. This method maps the ASCCIE at 30 m intervals along the predefined DEECA transects by projecting the derived composite slope profile into the DEM from the future toe position. The intersection point between the project slope profile and DEM/cliff profile is the resulting ASCCIE. A schematisation of this method is shown in Figure 4.5. For this regional/state-wide scale assessment, elevation data has been extracted for each of the DEECA transects using the available LiDAR data.

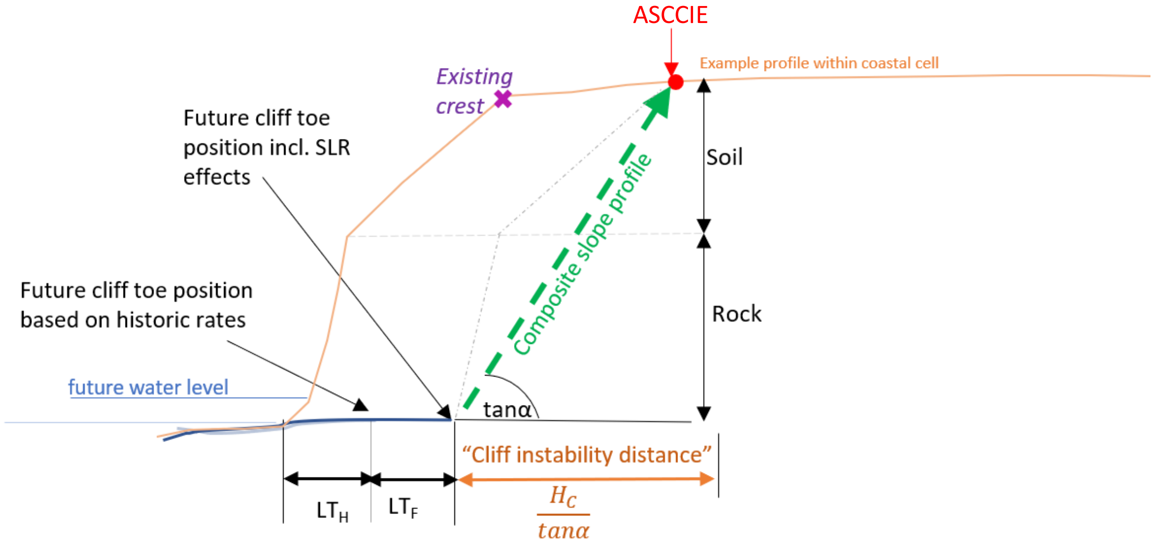


Figure 4.5: Schematisation of cliff projection mapping

ASCCIE points have been generated for each of these transects, and these ASCCIE points were then combined with the estimated toe position to form polygon areas. An example of this is shown in Figure 4.6, including transects and intersections points and final ASCCIE boundary polygon line. This shows that some intersection points are skipped to create a realistic ASCCIE polygon line. It should be noted that due to the cliff profile geometry and alongshore variation in cliff height and slopes, the ASCCIE polygon line may not always create a representative line, with expert judgement used to manually edit lines where deemed required.

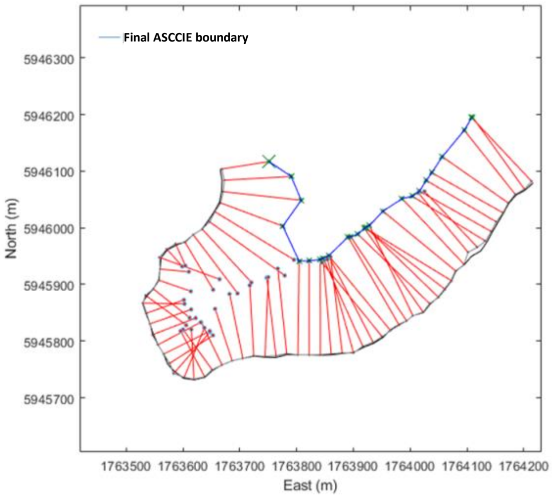


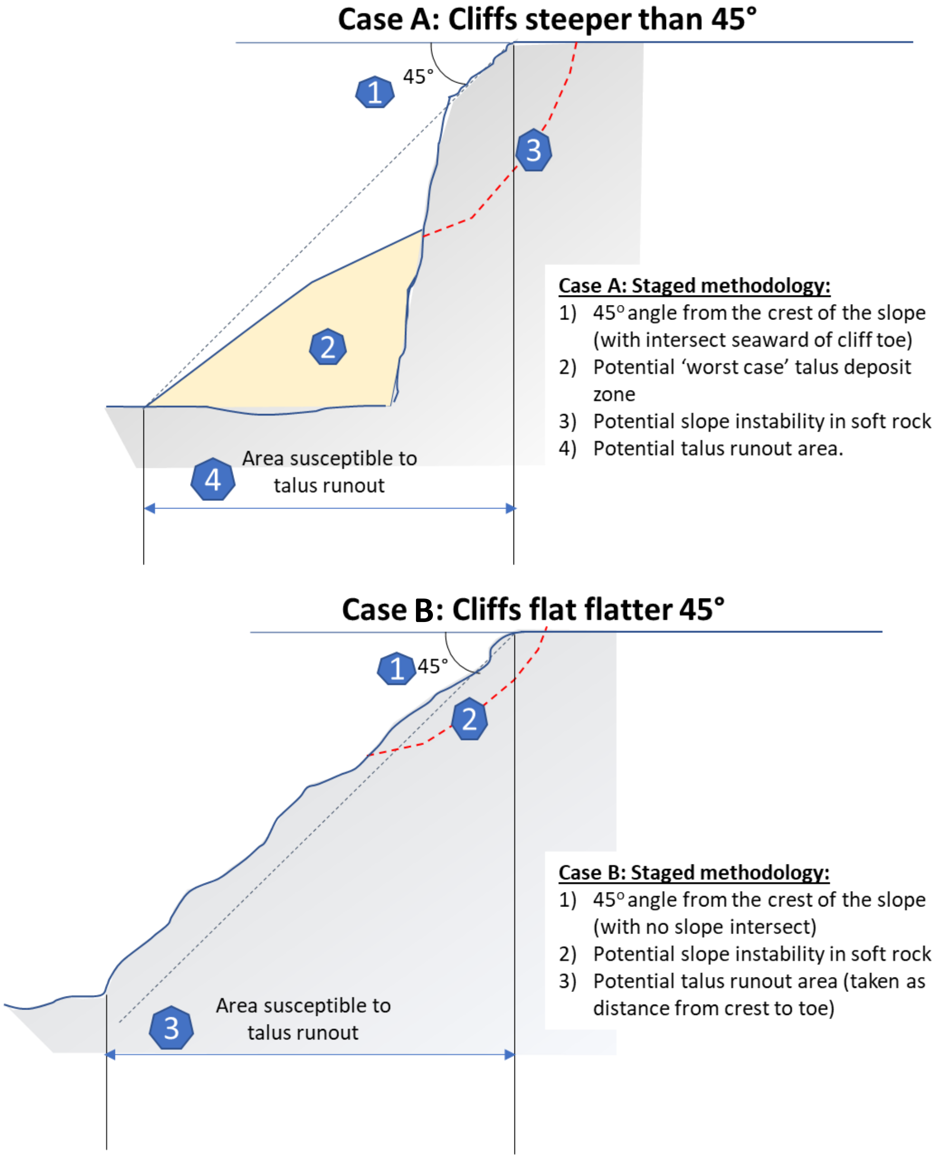
Figure 4.6: Example of combining ASCCIE points into a polygon, with the blue line representing the final ASCCIE line and red lines representing the transects

4.4 Areas Susceptible to Talus Runout (ASTaR)

In addition to considering the ASCCIE, this assessment considers areas susceptible to talus runout (ASTaR). Across the Victoria region, several large-scale landslips have been associated with the soft rock cliff materials. Further to this, there has been a recent fatality due to one of these events. Consequentially, as part of this assessment, ASTaR at the base of the cliffs have been assessed. A review of a limited number of areas was undertaken, which identified that the talus runout can extend as far out from the toe of the cliff as the height of the cliff (a relationship between talus runout and cliff height of 1:1). An example of this is shown in Figure 4.7, with the measured talus runout width found to be approximately equal to the cliff height. Based on the above, a 45° angle has been adopted to be projected from the cliff crest seaward along the profile.

Figure 4.7: Talus runout at the base of a cliff east of Anglesea (source: Google Earth, 28/1/2019)

Two cases have been considered for determining the talus runout distance (Figure 4.8). Firstly, for cliffs steeper than 45°, this projection line intersects with the slope seaward of the cliff toe (Case A in Figure 4.8). For this case, the talus runout distance is therefore defined as the distance from the crest to this intersection point. The second case occurs for cliffs flatter than 45° (Case B in Figure 4.8). For these cliffs, the talus runout line does not intersect with the cliff profile seaward of the toe, meaning that the talus runout distance is defined as the distance from the crest to the toe.



Case A: Cliffs steeper than 45°

Case A: Staged methodology:

1) 45° angle from the crest of the slope (with intersect seaward of cliff toe)
2) Potential 'worst case' talus deposit zone
3) Potential slope instability in soft rock
4) Potential talus runout area.

Case B: Cliffs flat flatter 45°

Case B: Staged methodology:

1) 45° angle from the crest of the slope (with no slope intersect)
2) Potential slope instability in soft rock
3) Potential talus runout area (taken as distance from crest to toe)

Figure 4.8: Definition sketch for areas susceptible to talus runout

5 Component derivation

5.1 Planning timeframe (T)

The adopted timeframes including sea level rise scenarios have been set out in Table 1.1. These scenarios have been aligned with DEECA (2023) and includes:

- Present-day
- 2040 (approx. 15-year timeframe)
- 2070 (approx. 45-year timeframe)
- 2100 (approx. 75-year timeframe)

For the 2100 scenario three sea level rise values have been considered as set out in Table 1.1.

5.2 Geological units

As noted above, there is a wide range of different provinces included along the Victorian coastline, including areas which are beach fronted, some stretches with tall/sheer cliffs and others with coastal rock platforms. One component which has an important part to play with the formation of the coastline is the geology that daylights in the shoreline. The strength of the geologic unit is a significant driver for whether the material would be resilient to wave action/erosion, however there are other components which could impact the ‘cliff forming’ potential of a geologic unit, including weathering, prevalence and orientation of rock defects, degree of previous alteration or deformation and many other characteristics. For the regional scale study, the rock strength has been used as the main characteristic for grouping geologies into the domains that have been used for the study. This allowed consideration and general ordering of different units susceptibility to toe erosion which was carried through to next stage of this study.

The *Geological Survey of Victoria,* 1:250,000 geological maps have been used to identify the cliff forming geologic units that outcrop along the subject coastline. The geologic units have been compiled based on the observations of outcrops and form cliffs. This were then be refined by combining geologic units or formations with similar properties, ages or behaviour into a “*domain*”.

As an example of a domain, there are numerous Devonian aged granite/granodiorite units which outcrop and form cliffs along the subject coastline, all with different names. Their material properties (strength, fracture spacing, groundwater, grain size and mineralogical composition), instability mechanisms, regression or erosion potential are very similar. This indicates that their material behaviour is similar. These units have therefore been grouped into a single bucket which we have called the Devonian aged Granite/Granodiorite domain in Table 5.1.

This exercise has been repeated for the outcropping units along the coastline, resulting in the derivation of 15 distinct domains. Each unit within the domain has been individually validated to ensure that the coastal profiles and material behaviour are characteristic of that domain. The extents of each of the 15 distinct geological unit domains is mapped in Figure 5.1, Figure 5.2, and Figure 5.3.

Table 5.1: Adopted geological domains

Type	Age	Domain Name	Domain Description
Rock	Early to middle Ordovician	Pinnak Sandstone	Sandstone, siltstone, rare chert: sandstone dark to pale grey and green colours; very thick to thin-bedded, turbiditic, moderately sorted, quartz-rich with minor feldspar and detrital mica, thick beds are mostly massive graded (Bouma Ta) and in places with granulestone bases, thinner beds with well-formed laminated and cross-bedded intervals (Bouma Tb and Tc); siltstone dark grey to green; well-bedded, with smooth regular banding
Rock	Silurian to middle Devonian	Murrindindi Supergroup (including Liptrap Formation, Waratah Limestone	Siltstone, shale, sandstone, rare conglomerate and limestone; sandstone typically quartz-rich in the lower part and lithic in the upper part; siltstone commonly bioturbated; marine to fluvial.
Rock	Devonian	Devonian aged Granite/Granodiorite	Biotite granite/granodiorite: generally grey, equigranular; contains quartz, plagiolcase, orthoclase, biotite, minor hornblende and accesory sphene, allanite and ilmenite;
Rock	Late Devonian	Merrimbula Group	Sandstone, conglomerate, siltstone, quartzite, shale
Rock	Early Cretaceous	Wonthaggi Formation	Lithic volcaniclastic sandstone, arkose, siltstone, minor conglomerate and coal; fluvial
Rock	Early Cretaceous	Eumeralla Formation	Sandstone, mudstone, mud-clast conglomerate, minor coal: blue-green to grey; arkose to feldsarenite; fine to medium grained, mostly medium to thick-bedded, cross-bedded
Rock and Soil	Paleogene	Wangerrip Group (including the Pebble Point Formation and Wiridjil Gravel)	Quartz sand, minor clay: micaceous, fine-grained, friable, generally massive; minor planar cross-bedding; minor gravel, minor volcanic and metamorphic lithic cobbles and pebbles; near shore, shallow marine deposits
Rock and Soil	Eocene	Cenozoic Aged Volcanics (including the Mornington Volcanic Group)	Basanite with lesser alkali basalt, nepheline hawaiite, nepheline mugearite, hawaiite, mugearite and nephelinite; lava flows, shallow intrusives and pyroclastics; minor interbedded fluvial sediments and lignite
Rock and Soil	Eocene to Miocene	Demons Bluff Group	Marlstone, limestone, mudstone, sandstone, minor lignite, Carbonaceous pyritic silt to fine sand, clay, and clayey sand; contains occasional shelly fossils and glauconite.
Rock and Soil	Miocene	Heytesbury Group (including the Port Campbell Limestone and Gellibrand Marl)	Calcareous quartz sand, sandy limestone, limestone, marl, & calcareous clay. Occasional to abundant shelly fossils

Type	Age	Domain Name	Domain Description
Rock and Soil	Miocene to Pliocene	Sandringham Sandstone (includes Red Bluff Sandstone, Brighton Group)	Sandy silt, fine sandstone, sandy conglomerate to pebbly sandstone, clayey sand, clayey gravel, carbonaceous band including plant fossils; lag deposit including variable to highly-rounded pebbles; horizontal and swaley cross-lamination
Rock and Soil	Miocene to Pliocene	Sale Group	Clastics and carbonate sediments: includes gravel, claystone, sandstone, siltstone; nonmarine to marginal marine
Rock	Pleistocene to Late Pleistocene	Bridgewater Formation	Calcarenite: medium to coarse grained shell fragments and minor quartz; consolidated, thin interbedded red palaeosols, minor hard calcrete capping, prominent dune cross-bedding; coastal dune deposits
Rock	Miocene to Holocene	Newer Volcanic Group	Olivine tholeiite, quartz tholeiite, basanite, basaltic icelandite, hawaiite, mugearite, minor scoria and ash, fluvial sediments: tholeiitic to alkaline; includes sheet flows and valley flows and intercalated gravel, sand, clay
Soil	Quaternary	Dune Deposits	Sand, silt, clay: well sorted, poorly consolidated; coastal dune and beach deposits, some variable cementation

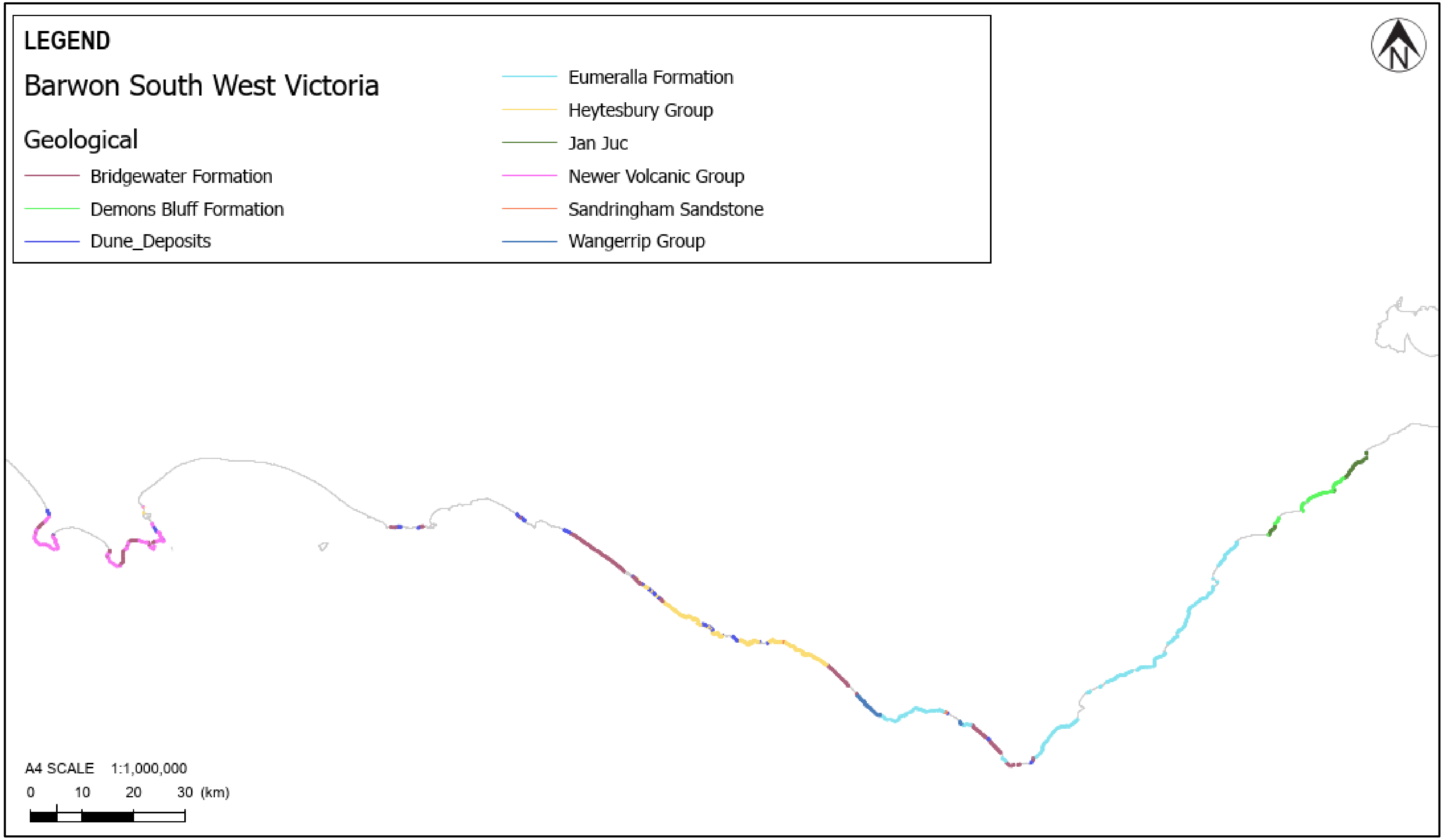


Figure 5.1: Map of geological units for Barwon South West (BSW) Victoria

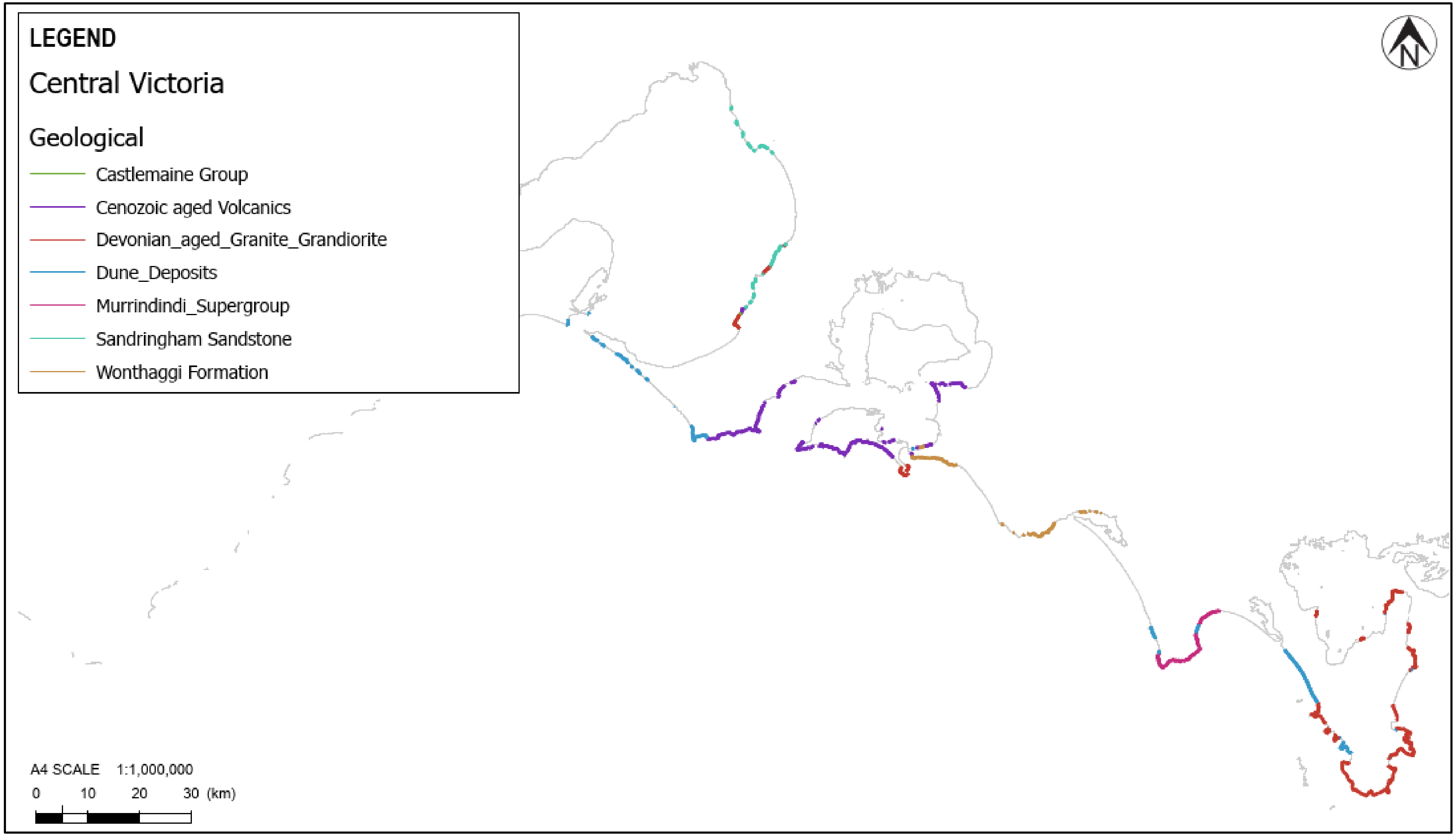


Figure 5.2: Map of geological units for Central Victoria.

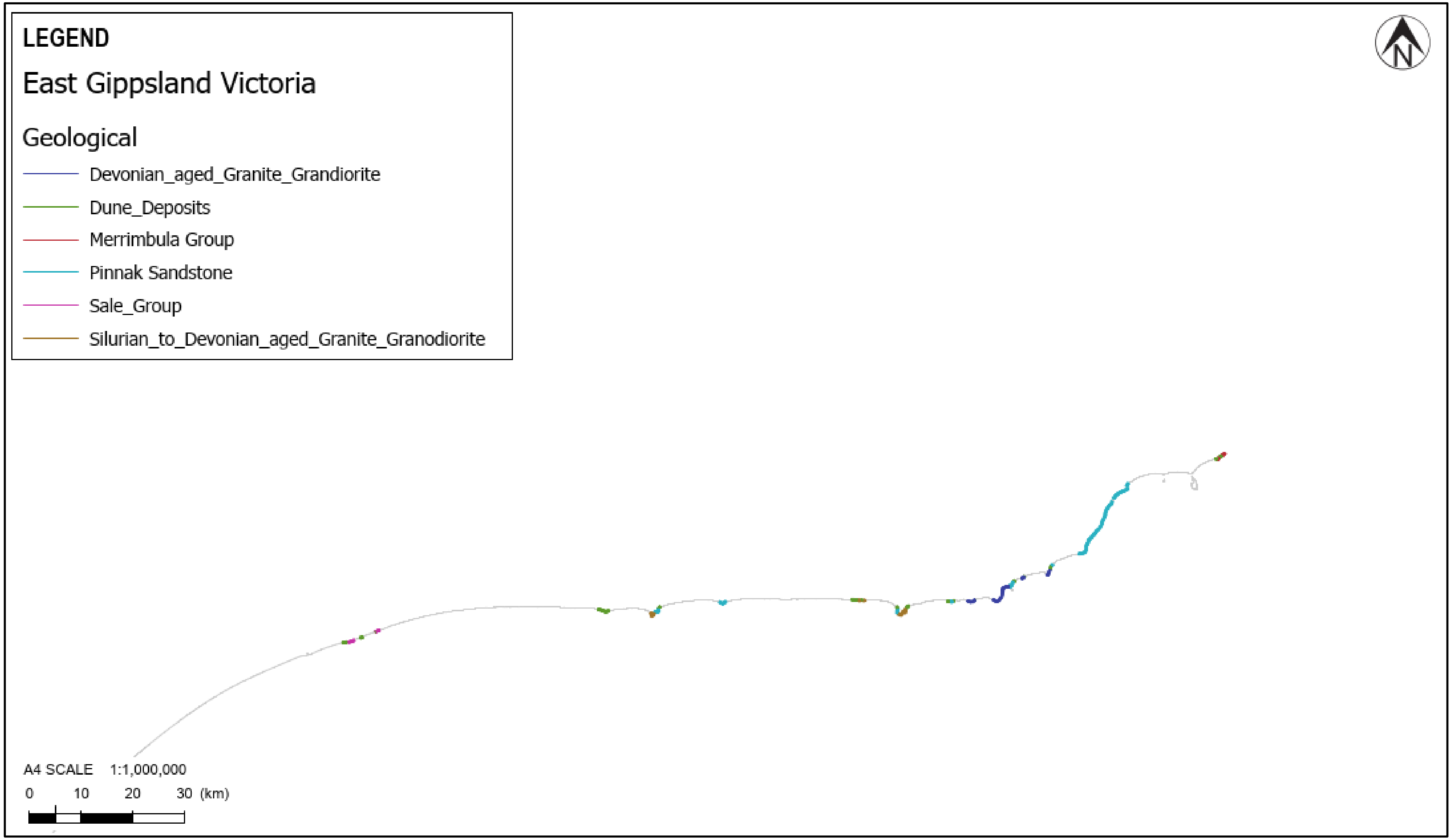
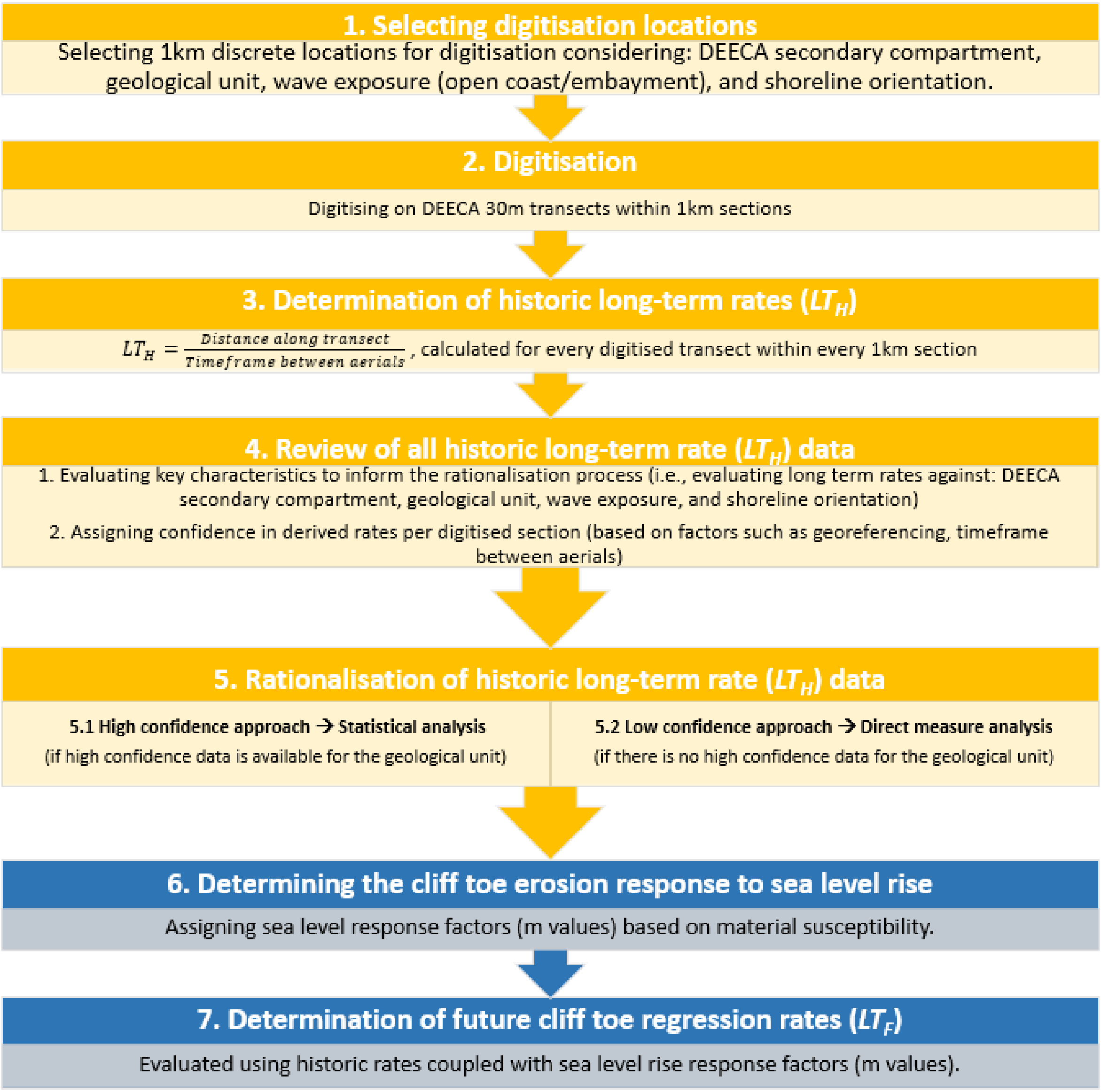


Figure 5.3: Map of geological units for East Gippsland, Victoria.

5.3 Cliff toe regression

The historic cliff toe erosion (LT_H) and future cliff toe erosion (LT_F) components have been derived using the methodology set out in Figure 5.4. The historic toe erosion rates were derived using a digitisation approach, whereby erosion rates were determined at discrete locations and then rationalised for the full cliffed Victorian shoreline (steps 1 to 5 in Figure 5.4), this process is discussed in further detail in Section 5.3.1. Future cliff toe erosion rates were then derived using a combination of the historic rates with future sea level rise response factors (steps 6 and 7 in Figure 5.4); this process is subsequently discussed further in Section 5.3.2.



1. Selecting digitisation locations

Selecting 1km discrete locations for digitisation considering: DEECA secondary compartment, geological unit, wave exposure (open coast/embayment), and shoreline orientation.

2. Digitisation

Digitising on DEECA 30m transects within 1km sections

3. Determination of historic long-term rates (LT_H)

$LT_H = \frac{Distance\ along\ transect}{Timeframe\ between\ aerials}$, calculated for every digitised transect within every 1km section

4. Review of all historic long-term rate (LT_H) data

1. Evaluating key characteristics to inform the rationalisation process (i.e., evaluating long term rates against: DEECA secondary compartment, geological unit, wave exposure, and shoreline orientation)

2. Assigning confidence in derived rates per digitised section (based on factors such as georeferencing, timeframe between aerials)

5. Rationalisation of historic long-term rate (LT_H) data

5.1 High confidence approach → Statistical analysis
(if high confidence data is available for the geological unit)

5.2 Low confidence approach → Direct measure analysis
(if there is no high confidence data for the geological unit)

6. Determining the cliff toe erosion response to sea level rise

Assigning sea level response factors (m values) based on material susceptibility.

7. Determination of future cliff toe regression rates (LT_F)

Evaluated using historic rates coupled with sea level rise response factors (m values).

Figure 5.4: Process used to derive historic (yellow) and future (blue) cliff toe regression rates

5.3.1 Historic long-term toe regression rate

The long-term trend for cliff shorelines has been assessed by considering the average shoreline retreat at the toe of the cliff. This retreat may be caused by weathering (wet-drying or biological) or mechanical (wave-induced) processes.

A typical method for evaluating long-term trends is to digitise historical shoreline positions using georeferenced aerial imagery. If two (or more) shoreline positions are digitised using temporally spaced aerials, regression rates can be determined using the distance and timeframe (i.e. number of years) between digitised shorelines. With limited reported toe regression rates (refer to Table 3.1 in Section 3.5.2), digitisation has been undertaken at discrete locations along the cliffed Victorian shoreline. Rates have been determined for these discrete locations by digitising a historic shoreline position (from 1930-2010) and a present-day or latest shoreline position (from 2017-2022).

Digitisation was undertaken for multiple 1 km sections within each DEECA secondary coastal compartment and geological unit, to provide representative rates that could later be rationalised and applied to the full shoreline. Within each coastal compartment, 1 km sections were positioned to provide broad coverage of the geology, wave exposure (i.e. open coast or embayment) and shoreline orientation. In total, digitisation was undertaken for approximately 53 x 1 km sections of cliffed shoreline (see Figure 5.5). The earliest available photographs with sufficient resolution and latest photographs have been used to digitise the cliff toe, meaning two data points have been used to calculate the long-term cliff erosion rate.

Figure 5.5: Digitisation points across the full Victoria region, DEECA secondary coastal compartments are displayed

To maximise digitisation efficiency, instead of digitising the full shoreline as is typically undertaken when determining historic toe regression rates, the shoreline was digitised using discrete points on the DEECA transects (spaced at 30 m intervals) within each 1km section (refer to Figure 5.6 and Figure 5.7 for examples of this process).

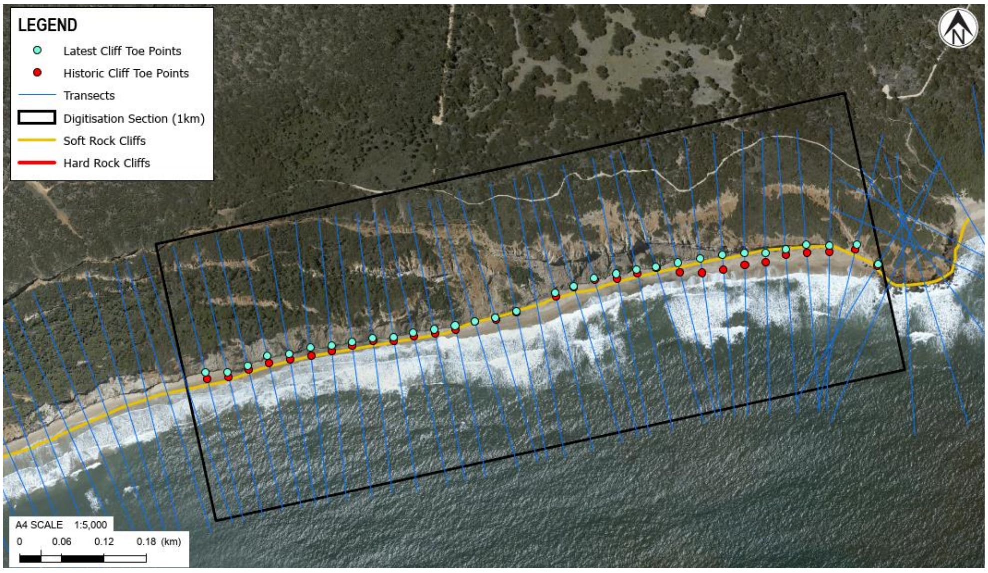


Figure 5.6: Cliff toe digitisation on a present-day (2021) aerial for a 1km section of shoreline within the Torquay DEECA secondary coastal compartment

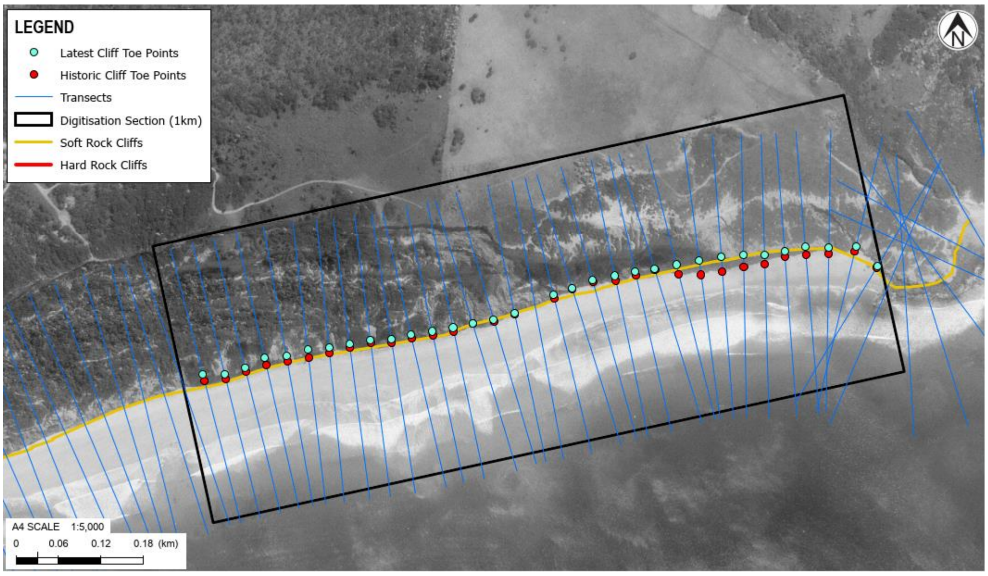


Figure 5.7: Cliff toe digitisation on a historic (1979) aerial for a 1km section of shoreline within the Torquay DEECA secondary coastal compartment

Long-term historic rates were then calculated using the timeframe and distance between the earliest historic and latest cliff toe positions on each of the digitised transects (see an example of individual rates calculated in Figure 5.8). No accretion is possible for cliff shorelines except where landslide material temporarily occupies the shoreline in front of the cliff face (before being removed by wave action). However, as this is not considered accretion of the cliffs, rates showing accretion were removed from the analysis.

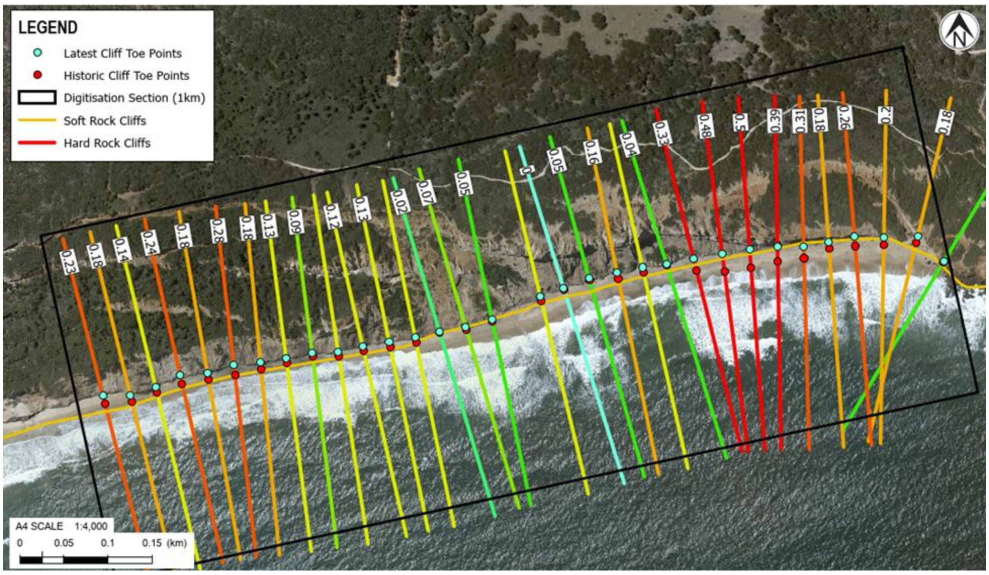


Figure 5.8: Example of cliff toe erosion rates, calculated for each transect for a 1km section of shoreline within the Torquay DEECA secondary coastal compartment

Following calculation of individual rates for every transect, the confidence in the prediction of these rates for each section was assigned. Low confidence was typically assigned for sections with moderate to significant imagery georeferencing errors (as discussed in Section 3.4) or for sections where the cliff toe was difficult to distinguish. Difficulty in distinguishing the cliff toe was particularly apparent for the granite-type cliffs where there was a lack of a consistent cliff toe feature (Figure 5.9).

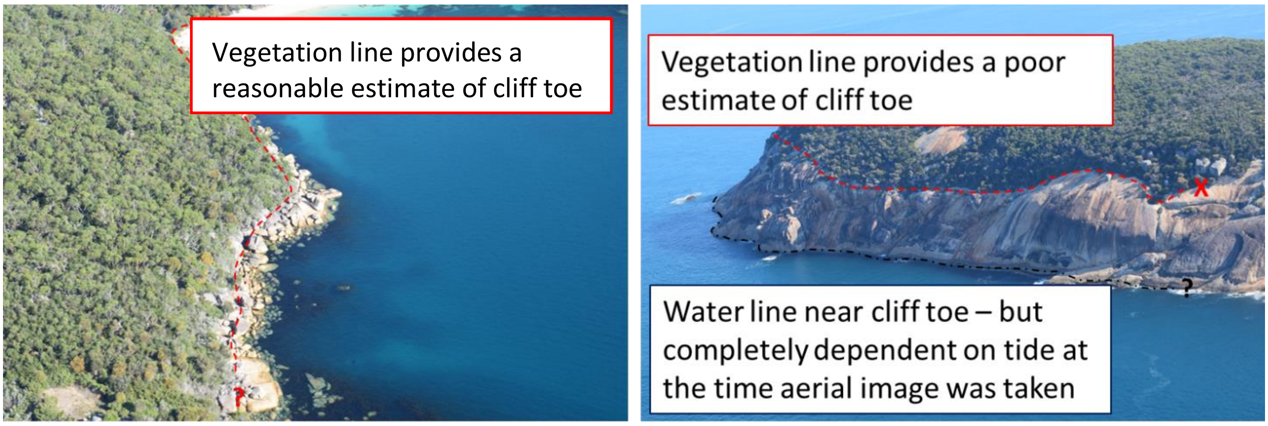


Figure 5.9: Example of differences in cliff toe features within the granite type geological groups (example provided for devonian aged granite grandiorite within Wilsons Promontory)

As discussed in Section 4.3.2, analysis was undertaken using a transect and geological unit-based approach. After assigning confidence to each section, individual transect rates were grouped into the 15 geological units. Subsequently, two methods for rationalising historic rates were used:

- Statistical approach
- Direct measure approach

The first method is a statistical analysis and has been used for geological units with high-confidence rate data available. The second method is a direct measure analysis for geological units without high-confidence data. The only two geological units without any high confidence data were the two granite type units (Devonian aged granite/granodiorite and Silurian to Devonian aged granite/granodiorite) which was associated with the difficulty in identifying the cliff toe features (see example in Figure 5.9).

The high-confidence statistical method used a statistical analysis to determine the rationalised rate that would be applied to all cliff shorelines within a given geological unit. For this analysis, low confidence data (with errors due to georeferencing or difficulty in distinguishing the cliff toe) was removed. The spread in the remaining high-confidence data for each geological unit is shown in Figure 5.10. For each geological unit with high-confidence data, the mean rate was assigned as the mean, and the upper rate was assigned as the 95th percentile (i.e. 5% exceedance) rate. A demonstration of this process within the Demons Bluff Formation geological group is provided in Figure 5.11.

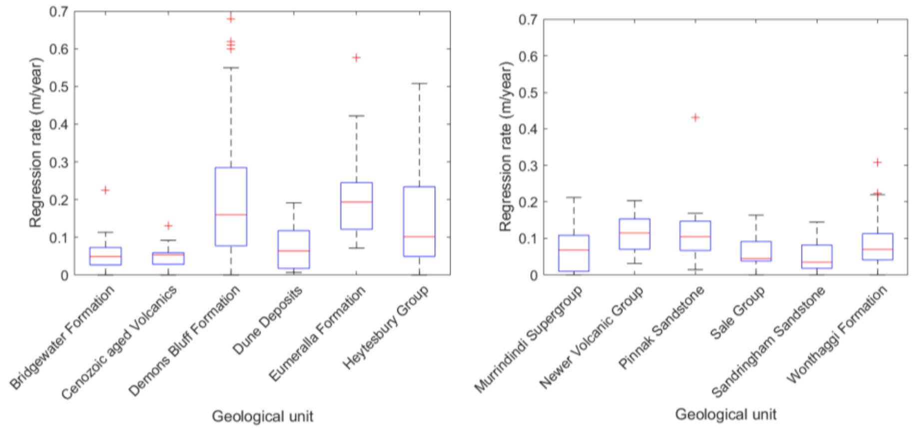


Figure 5.10: Spread in erosion rates for high confidence data grouped with geological units

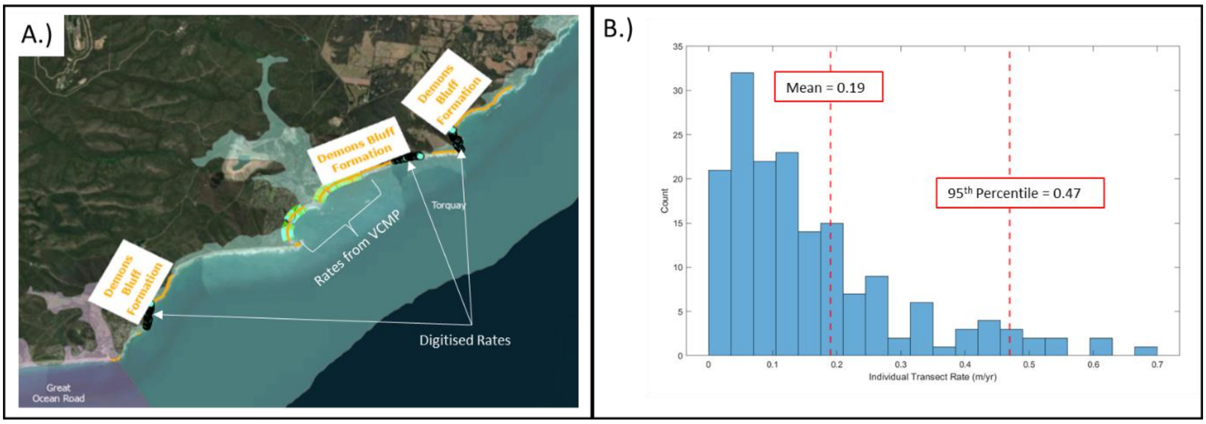


Figure 5.11: Example of statistical analysis method for high confidence data for demons bluff formation. A.) shows the digitised rates (including those from VCMP) and B.) shows the spread in rates data and the corresponding mean and 95th percentile (i.e. 5% exceedance) rates

The low-confidence direct measure method has been used to determine the representative long-term erosion rates that would be applied to the two granite-type geological units. This method tracked defined cliff toe-type features along consistent transects between historic and most recent aerial imagery at discrete locations. The rates were then defined by the retreat distance identified in the features between historic and most recent imagery (see example of this in Figure 5.12).

For the two granites, a maximum movement of 0.02 m/year with an average of 0.01 m/year was found. It is assumed that the differences obtained were primarily associated with the low resolution of historic aerials and that in reality there was minimal historic movement. However, these rates were still applied as a conservative representation of the cliff movement for these geological units.

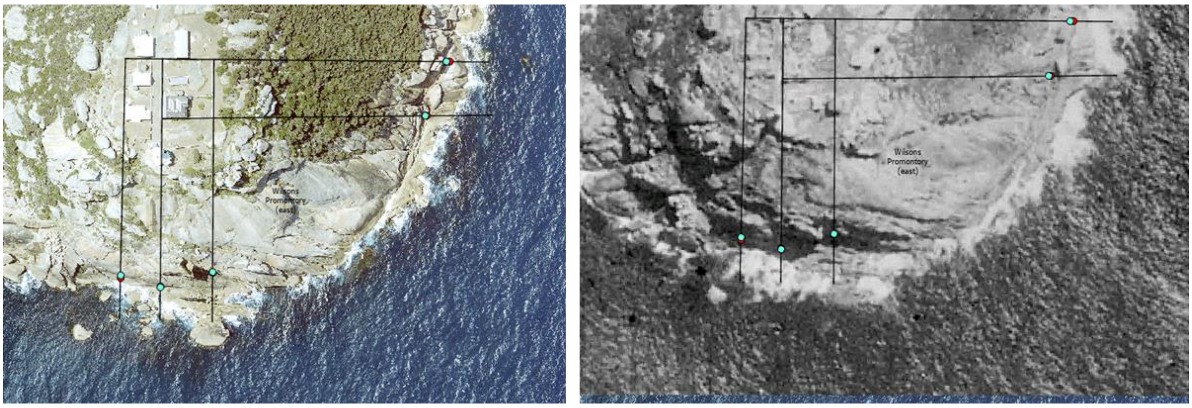


Figure 5.12: Deriving long-term rates for devonian aged granite grandiorite within Wilsons Promontory by tracking consistent features on transects cast to fence lines of the Wilsons Promontory Lighthouse (to remove georeferencing errors)

5.3.1.1 Adopted values

After the assessment of historical long-term toe erosion rates undertaken for this study, data and information from external sources (refer to Section 3.5.2) were added to complement the dataset. This was then used to derive historical long-term cliff toe erosion rates for each geological unit. Appendix B includes the derived historical long-term rates derived for this study including additional information from external data sources.

Table 5.2 shows a summary of the mean, 10% exceedance (i.e. 90th percentile) and 5% exceedance (i.e. 95th percentile) rates per geological unit derived using both the high-confidence statistical approach and low-confidence direct measure approach. Note that due to the limited length of shoreline for the Wangerrip Group, Merrimbula Group and Jan Juc Formation, the rates have been based on similar geological units. Table 5.2 shows that the smallest LT values are found for the two granite geological units (Devonian aged granite/granodiorite and Silurian to Devonian aged granite/granodiorite) and the largest LT values for the Heytesbury formation geological unit (primarily located in the area surrounding the 12 Apostles). The 10% and 5% exceedance values were then rationalised to a limited number of classes (i.e. 0.02, 0.1, 0.15, 0.2, 0.3 and 0.5 m/year) with adopted values for each geological unit shown in Table 5.1.

Table 5.2: Summary of historical LT rates (m/year) and adopted values per geological unit

Geological unit	m/year			
	Mean rate	10% exceedance rate	5% exceedance rate	Adopted values
Devonian aged Granite/Granodiorite	0.01	0.02	0.02	0.02
Silurian to Devonian aged Granite/Granodiorite	0.01	0.02	0.02	0.02
Newer Volcanic Group	0.11	0.17	0.20	0.2
Eumeralla Formation	0.15	0.26	0.32	0.3
Murrindindi Supergroup	0.07	0.14	0.17	0.15

Geological unit	m/year			
	Mean rate	10% exceedance rate	5% exceedance rate	Adopted values
Pinnak Sandstone	0.12	0.22	0.24	0.2
Wonthaggi Formation	0.08	0.18	0.21	0.2
Wangerrip Group[2]	0.08	0.18	0.21	0.2
Merrimbula Group[1]	0.07	0.16	0.16	0.15
Castlemaine Group[1]	0.07	0.16	0.16	0.15
Sale Group	0.07	0.16	0.16	0.15
Cenozoic aged Volcanics	0.05	0.08	0.10	0.1
Demons Bluff Formation	0.19	0.43	0.47	0.5
Jan Juc Formation[3]	0.19	0.43	0.47	0.5
Heytesbury Group	0.21	0.47	0.47	0.5
Bridgewater Formation	0.05	0.10	0.11	0.1
Sandringham Sandstone	0.06	0.13	0.14	0.15
Dune Deposits	0.08	0.18	0.19	0.2

[1] Adopted from Sale Group
[2] Adopted from Wonthaggi Formation
[3] Adopted from Demons Bluff Formation

5.3.2 Cliff response to sea level rise

Erosion of a consolidated shoreline is a one-way process of material removal, which typically can be divided into components. Gradual recession is caused by weathering and coastal processes along with episodic failures due to changes in loading, daylighting of geological structures or extreme events (e.g. storms, rainfall, leaking utilities).

This section describes the method for assessing gradual cliff toe regression because of rising sea levels. Marine hydraulic processes affect cliffs either by wave action causing erosion at the toe, or by removing slope debris deposited at the toe following cliff-face collapse. Sea level rise increases the amount of wave energy able to propagate over a fronting platform or beach to reach a cliff toe, removing talus more effectively and increasing the potential for hydraulic processes to affect erosion and recession. However, in some locations, the existence of a talus provides self-armouring, and may slow cliff toe regression due to waves. For sea cliffs that are not protected by reefs or beaches and are fronted by a relatively deep foreshore, sea level rise may not have any effect on wave exposure of the cliff toe.

Reinen-Hamill et al. (2006) used the method by DEFRA (2002), who proposed a simple method to evaluate cliff toe regression in soft-cliff environments by assuming that future regression (LT_F) is proportional to historical rates (LT_H) multiplied by the ratio of future (S_F) to historical sea-level rise (S_H). The model shown in Equation 5.1 below assumes, however, that the profile will respond instantaneously and that all cliff toe regression that has occurred historically was a function of historical sea-level rise (i.e. marine processes).

$$LT_F = LT_H \times \frac{S_F}{S_H} \qquad \text{(Equation 5.1)}$$

Walkden and Dickson (2006) use process-based mathematical models to simulate the sensitivity of shore profile response to SLR over timescales of decades to centuries incorporating factors for rock strength, cliff height, wave and tide characteristics, beach volume at the cliff toe, the distribution of erosion under a breaking wave field, profile slope and variation of tidal elevation. They found that regression rates become independent of beach volume below approximately 20 m^3/m (i.e. below this volume the beach does not influence cliff toe regression rates but above it the beach offers some protection).

In the absence of beach protection, they find that for the soft cliffs tested (historical rates of toe regression of 0.8 to 1 m/year), an equilibrium toe regression rate could be described by the following equation.

$$LT_F = LT_H \sqrt{\frac{S_F}{S_H}} \qquad \textit{(Equation 5.2)}$$

It was noted, however, that equilibrium conditions take some time to develop, with the case tested taking nearly 1000 years to adjust from a past sea level rise rate of 2 mm/year to a future rate of 6 mm/year, although the majority of the increase occurred in the first century.

Ashton et al. (2011) proposed a generalised expression for future cliff toe regression rates of cliff shorelines (shown in Equation 5.3 and Figure 5.13), where *m* is the coefficient, determined by the response system (sea level rise response factor). The future rate of sea level rise *(S_F)* is based on the adjusted sea level rise values as set out in Table 1.1 divided by the relevant timeframes. The historical rate of sea level rise (*S_H*), 2.1 mm/year, is based on DEECA (2023).

$$LT_F = LT_H \left(\frac{S_F}{S_H}\right)^m \qquad \textit{(Equation 5.3)}$$

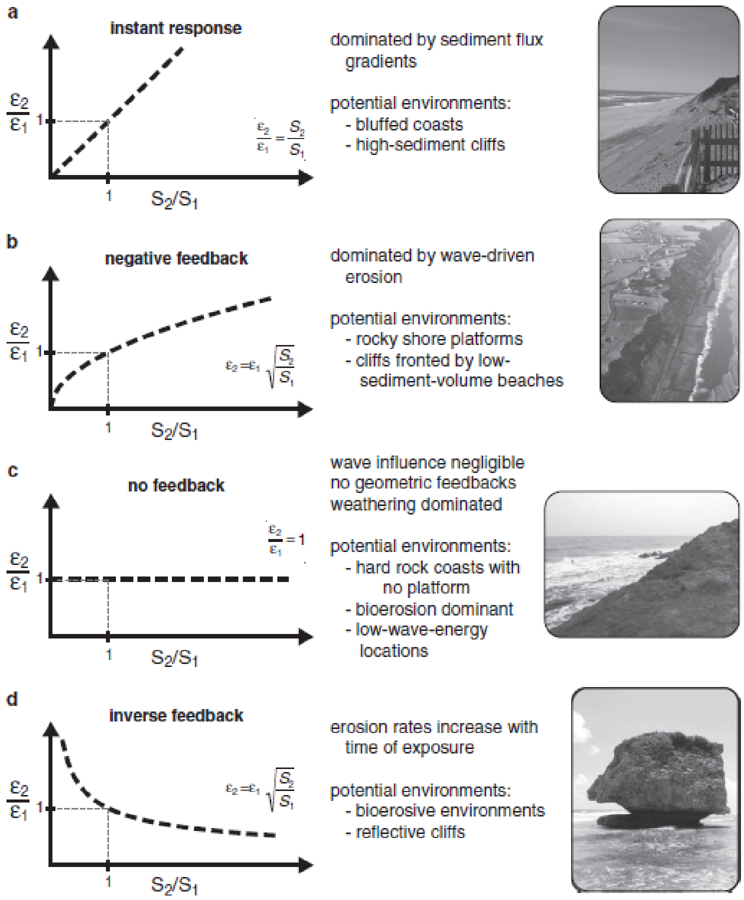


Figure 5.13 Possible modes of cliff response to SLR (adapted from Ashton et al., 2011), with E_1 = historical long-term rate, E_2 = future long-term rate, S_1 = historical SLR and S_2 = future SLR

An instantaneous response (*m* = 1) is where the rate of future toe regression is directly proportional to the increase in SLR. An instant response is typical of unconsolidated or weakly consolidated shorelines. No feedback (*m* = 0) indicates that wave influence is negligible, and weathering dominates.

The most likely response of consolidated soft-rock shorelines is a negative/damped feedback system (*m* = 0.5), where rates of cliff toe regression are slowed by development of a shore platform (see Figure 5.13). Ashton et al. (2011) also suggested an additional case of inverse feedback when *m* < 0 indicating a reduction in cliff toe regression with increasing sea levels. They suggest this could occur when erosion is influenced by factors such as bio-erosion is controlled by bio-erosion or the wave-impact regime, which could be modified by additional submergence. The approach suggested by Ashton et al. (2011) is conceptually plausible and has the potential to predict cliff toe regression rates on a wide variety of rock types with further analysis. The Ashton et al. (2011) formula has therefore been adopted for this study.

5.3.2.1 Adopted values

Given the uncertainties in deriving response type without detailed site-specific modelling, analysis and calibration data, a range of response types have been considered. Material erosion susceptibility (i.e. hardness) and change in wave energy/exposure are the two main factors which contribute to cliff shoreline response and have therefore been used to derive the sea level rise response factor. The geological units have been ranked from low to high susceptibility with judgement used by experienced geologists to assign relative material susceptibility to each geological unit. The change in wave energy has been assessed by reviewing the current shoreline setting for each geological unit type. For geological unit types that typically have beaches or reefs fronting the cliff toe, the change in wave energy is expected to be high as sea level rise likely increases exposure to waves. For geological unit types that are typically exposed to relatively deep waters, the change in wave energy is expected to be low as sea level rise would likely have limited influence on wave exposure. For shorelines that had a mix of beaches/reefs and no beaches/reefs, a medium change in wave energy was assigned. Table 5.3 outlines the range of response factors (*m*) for the adopted main geological types, including the relative material susceptibility.

The negative/damped feedback system (*m* = 0.5) has been used as an upper bound value as higher *m* values would realistically not be expected to occur in the Victoria coastal cliffs. For the hard geological units, such as the granites, a lower bound of *m* = 0 has been assigned as no change with sea level rise is expected. The *m* values were then assigned based on relative differences in susceptibility in geological units. The adopted *m* values for each geological unit have been based on the change in wave energy/exposure.

Table 5.3: Adopted response factors to sea level rise for the Victoria cliff geological units (*m*)

Geological unit	Material susceptibility	Change in wave energy	Low	Medium	High	Adopted Value
Devonian aged Granite/Granodiorite	Low	Low	0	0.05	0.1	0
Silurian to Devonian aged Granite/Granodiorite	Low	Low				0
Newer Volcanic Group	Low	High				0.1
Eumeralla Formation	Low-Med	High	0.05	0.1	0.2	0.2
Murrindindi Supergroup	Low-Med	High				0.2
Pinnak Sandstone	Low-Med	Medium				0.1
Wonthaggi Formation	Med	High	0.1	0.2	0.3	0.3
Wangerrip Group	Med	High				0.3
Merrimbula Group	Med	Medium				0.2
Castlemaine Group	Med	Medium				0.2
Sale Group	Med	Medium				0.2
Cenozoic aged Volcanics	Med	High				0.3
Demons Bluff Formation	Med-High	Medium	0.2	0.3	0.4	0.3
Jan Juc Formation	Med-High	Medium				0.3
Heytesbury Group	Med-High	Low				0.2
Bridgewater Formation	High	Medium	0.3	0.4	0.5	0.4
Sandringham Sandstone	High	High				0.5
Dune Deposits	High	High				0.5

5.4 Cliff instability

5.4.1 Analysis of cliff slopes

Cliff data such as cliff toe position/elevation, cliff crest position/elevation and cliff face slope have been derived using the Cliff Feature Delineation Tool (CFDT) developed by USGS (2020) in combination with an in-house processing tool for sections where the CFDT did not provide realistic output.

Transect lines at every 30 m along the entire coastline were supplied by DEECA. These transects were extracted and plotted on a graph of cliff height vs cross shore distance for each of the different geologic domains that we had determined in Section 5.2 above. These were then plotted on a histogram which counted total number of transects within a slope gradient range to determine the 50% exceedance, 10% exceedance and 5% exceedance for each domain. These angles were then plotted back onto the scatter plots as shown below, using the Bridgewater Formation outputs as an example.

This method was adopted, as it would intrinsically include the impacts from the multitude of different processes which are currently occurring within each unit, such as terrestrial processes (e.g. stormwater runoff, groundwater, drainage), weathering etc. As these processes are acting on the current slopes, they are therefore implicitly included and represented in the dataset for each geologic domain.

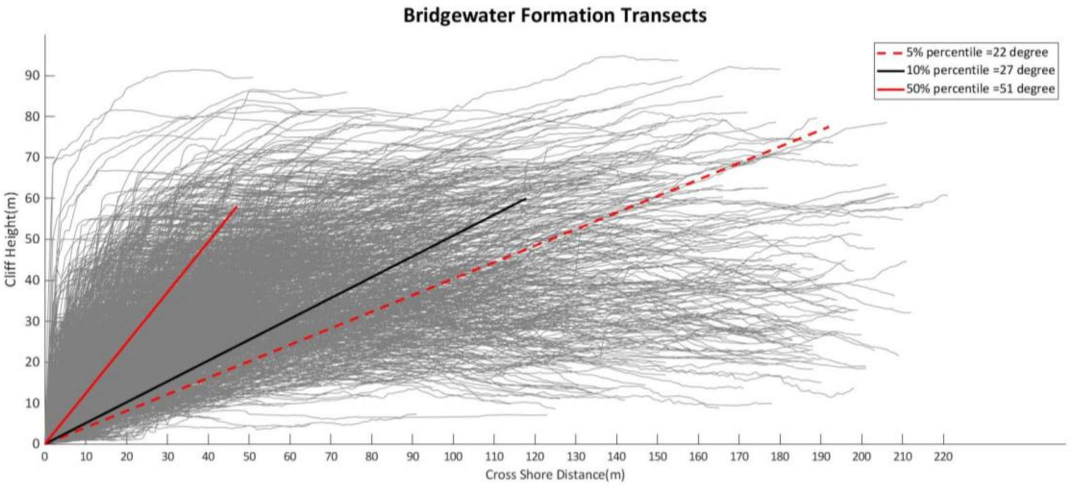


Figure 5.14: Example of all transect profiles for one geologic domain (Wonthaggi Group) showing the likely, unlikely and very unlikely stable slope angles

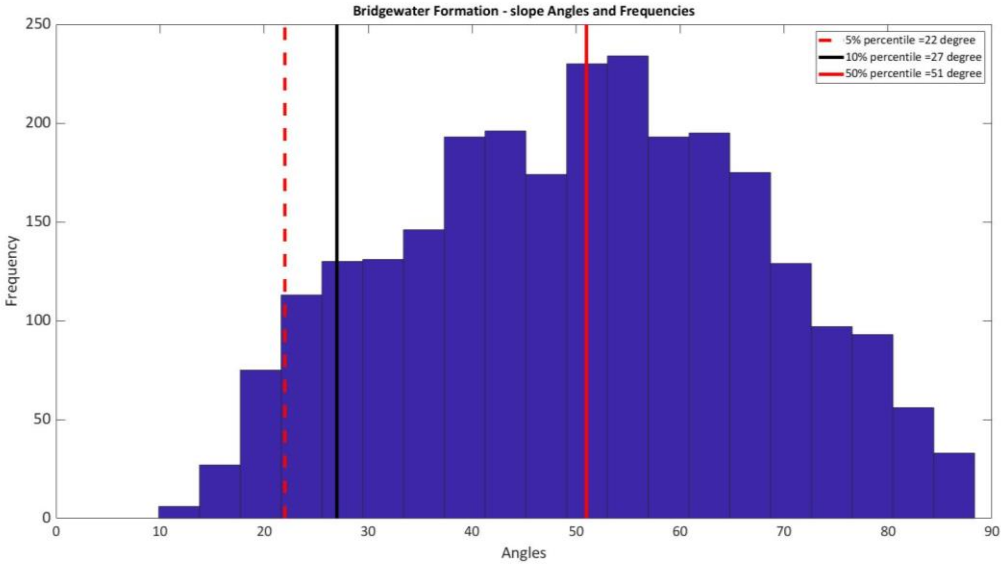


Figure 5.15: Example of histogram for above transects showing the number of how many of the above transects fit into each range of slope gradients within this geologic domain

Once all of the geologic domains had been graphed and analysed, slope profile values for 'Likely', 'Unlikely' and 'Very Unlikely' conditions were rationalised, as set out in Table 5.4. The 'Unlikely' cliff slope has been adopted for the regional assessment, after some discussion with DEECA, with the 'Very Unlikely' cliff slopes representing the slope angle including the greatest uncertainty.

It should be noted that this study has adopted slope angles based on statistical analysis of a large sample of existing cliff slopes for each geologic domain. This also includes existing very flat slopes, which dominate the lower probability slope angles (i.e. 'Unlikely' and 'Very Unlikely' slope angles). The 'Very Unlikely' slope angles therefore tend to be close to the flattest slope angle derived from existing cliff profiles and are unlikely to be applicable across the wider region, hence the 'Unlikely' value has been adopted.

Table 5.4: Adopted ASCIE cliff slope angles

Geological Unit	Composite slope profile (°)		
	Likely	Unlikely (adopted values)	Very Unlikely
	50% exceedance	10% exceedance	5% exceedance
Devonian aged Granite/Granodiorite	30	20	18
Newer Volcanic Group	50	29	27
Silurian to Devonian aged Granite/Granodiorite	26	17	13
Murrindindi Supergroup	31	23	16
Merrimbula Group[1]	37	29	26
Eumeralla Formation	31	20	18
Pinnak Sandstone	31	18	16
Sale Group	37	29	26
Cenozoic aged Volcanics	38	28	25
Jan Juc Formation	47	27	23
Wonthaggi Formation	44	26	20
Demons Bluff Formation	44	28	23
Heytesbury Group	73	37	31
Sandringham Sandstone - Beach in front	29	22	19
Sandringham Sandstone - No beach in front	32	21	19
Bridgewater Formation	51	27	22
Wangerrip Group	32	25	23
Dune Deposits	34	18	16

[1] Adopted from Sale Group

5.5 Areas Susceptible to Talus Runout (ASTaR)

As per the methodology set in Section 4.4, the ASTaR distance is dependent on the cliff height at each transect. This is a geospatial exercise, with cliff height and cliff crest extracted for each transect as set out in Section 4.2, which have been used to map the ASTaRs. Section 6.2 sets out the resulting ASTaR distances.

6 Results

For each transect, the ASCCIEs have been mapped using the method set out in Section 4.3.4 and parameter values set out in Sections 5.3.1.1, 5.3.2.1 and 5.4.1. The ASTaR have been mapped using the method set out in Section 4.4.

6.1 Resulting ASCCIE distances

The resulting ASCCIE distance is a combination of the cliff instability component, which has been derived using the cliff projection method, and long-term cliff toe regression. The present-day ASCCIE exclude the long-term cliff toe regression component and is composed of the cliff instability component only.

6.1.1 Results per geological unit

Table 6.1 shows the resulting mean and typical upper bound (taken as 10% exceedance value) ASCCIE distances for the considered scenarios, including toe regression distances summarised per geological unit.

Table 6.1 shows that the largest ASCCIE distances are found within the Devonian aged Granite/Grandiorite and Eumeralla Formation. The distances exceed 300 m for both geological units for the 2100 scenarios, which is a result of the high cliff heights. As it is expected that the granite geological units are relatively hard rock and would unlikely result in large susceptible areas, this is mainly due to the very high cliff heights and stable angle that are slightly flatter than the actual cliff slopes as the 10% exceedance cliff slope has been adopted to map. An example at Wilsons Prom is shown in Figure 6.1. This means the ASCCIE are typically slightly landward of the present-day crest, which already sit a relatively large distance from the cliff toe due to the high cliff height.

Where the toe regression for Devonian aged Granite Grandiorite unit is limited (i.e., in the order of several metres), the toe regression for the Eumeralla Formation is significant for the ASCCIE 2100-3 scenario (i.e. in the order of several decametres). Other geological units for which ASCCIE distances are in the order of 200 m or more are Demons Bluff, Dune Deposits, Murrindindi Supergroup and Wangerrip Group. This is typically due to the adopted stable angle and the cliff height being 50-100 m high.

The smallest ASCCIE distances are found within the Merrimbula Group and this is a result of the relatively low cliff heights. Other geological units for which ASCCIE distances are typically less than 100 m are the Sale Group, Cenozoic aged Volcanics and Castlemaine Group. This is typically due to the relatively low cliff heights (i.e. typically <50 m) compared to the other geological units.

The resulting ASCCIE distances for the majority of the geological units are typically in the order of 100-150 m based on the typical upper bound (i.e. 10% exceedance) value. This includes Pinnak Sandstones, Wonthaggi Formation, Sandringham Sandstone, Newer Volcanic Group, Bridgewater Formation, Silurian to Devonian aged Granite Granodiorite, Jan Juc Formation and Demons Bluff Formation.

6.1.2 Results per coastal compartment

Table **6**.2 shows the resulting mean and typical upper bound (taken as 10% exceedance value) ASCCIE distances for the considered scenarios, including median and maximum toe regression distances summarised per secondary coastal compartment. These distance are measured from the present-day cliff toe.

Table **6**.2 shows that the largest ASCCIE distances within the Wilsons Promontory (East and Southwest) and Great Ocean Road coastal compartments. The ASCCIE distances for the 2100 scenarios exceed 300 m. For cliffs within the Wilsons Promontory coastal compartments, the relatively large ASCCIE distances are mainly due to the very high cliff heights of the granite cliffs and stable angle that are slightly flatter than the actual cliff slopes (refer to explanation in Section 6.1.1). The toe erosion rate is low for cliffs within this coastal compartment. For the cliffs within the Great Ocean Road, the relatively large ASCCIE distances are a due to the combination of the high cliffs and relatively large toe erosion rates (i.e., up to 74 m for the 2100-3 scenario).

Other secondary coastal compartments within which ASCCIE distances are in the order of 200 m or more for the 2100-3 scenario are Corner Inlet, Mornington Peninsula and Port Campbell. This is typically due to the adopted stable angle and the cliff height being 50-100 m high.

The smallest ASCCIE distances (i.e., mean values <50 m) are found within the Snowy River, Phillip Island (South) and Western Port coastal compartments. This is a result of the relatively low cliff heights within these coastal compartments. The resulting ASCCIE distances for the majority of the coastal compartments are typically in the order of 100-150 m based on the typical upper bound (i.e. 10% exceedance) value.

Figure 6.2, Figure 6.3 and Figure 6.4**Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.** show summary maps of the resulting cliff toe regression, cliff instability and total ASCCIE distances across the state of Victoria for the ASCCIE 2100-1 scenario. This also shows that the largest ASCCIE distance are typically situated along the Great Ocean Road and Wilsons Promontory.

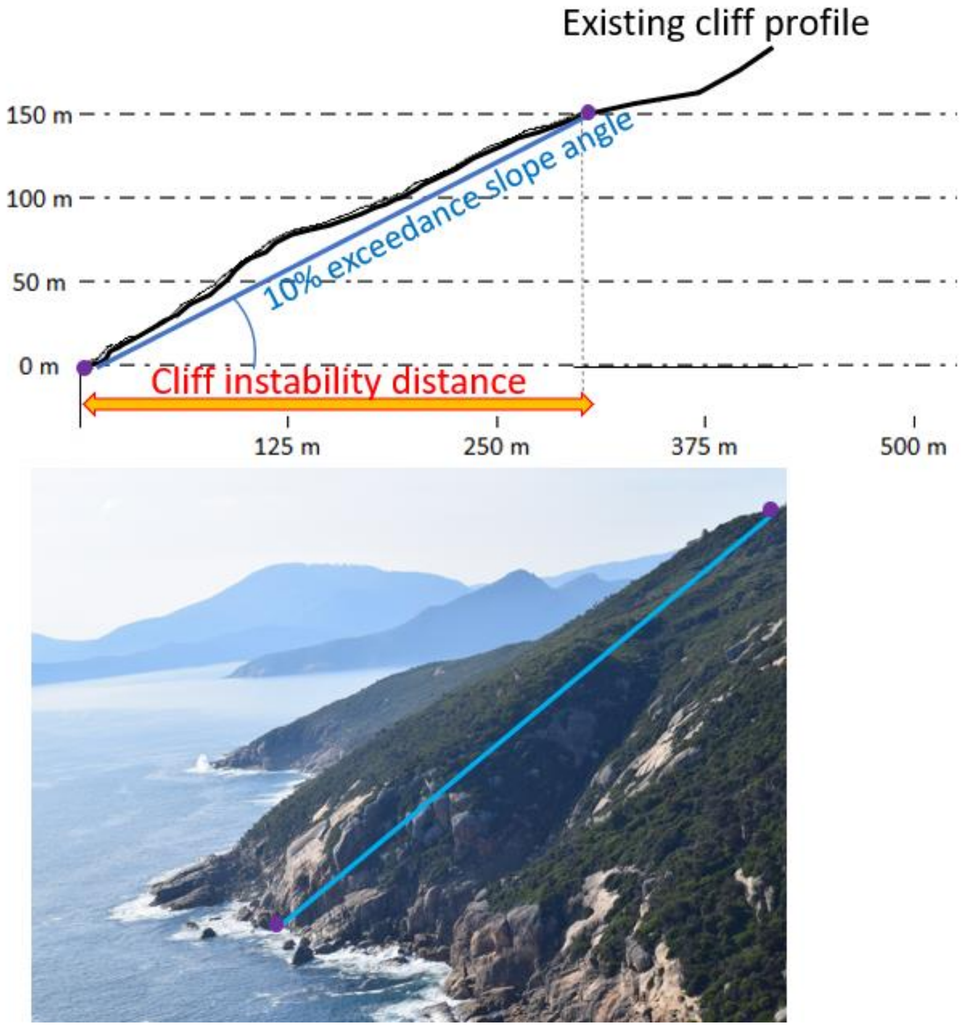


Figure 6.1: Example of large instability distance due to very hight cliff heights and slightly flatter stable angle at Wilsons Promontory

Table 6.1: Summary of mean (and typical upper bound[1]) resulting ASCCIE distances (m) measured from present-day cliff toe for considered scenarios including toe distances summaries per geological unit

Geological Unit	Component	Scenario					
		2025	2040	2070	2100-1	2100-2	2100-3
Merrimbula Group	Toe	0	-3.6	-9.8	-15.9	-16.9	-17.8
	ASCCIE	-7 (-28)	-11 (-34)	-19 (-41)	-26 (-42)	-26 (-42)	-26 (-42)
Dune Deposits	Toe	0	-8.0	-21.2	-34.3	-40.2	-45.3
	ASCCIE	-57 (-167)	-63 (-173)	-72 (-169)	-89 (-195)	-94 (-200)	-100 (-207)
Pinnak Sandstone	Toe	0	-4.0	-11.1	-18.1	-18.7	-19.1
	ASCCIE	-42 (-83)	-46 (-87)	-54 (-94)	-60 (-102)	-60 (-101)	-60 (-101)
Devonian aged Granite Grandiorite	Toe	0	-0.3	-0.9	-1.5	-1.5	-1.5
	ASCCIE	-108 (-307)	-110 (-314)	-108 (-321)	-114 (-324)	-114 (-324)	-114 (-325)
Silurian to Devonian aged Granite Granodiorite	Toe	0	-0.3	-0.9	-1.5	-1.5	-1.5
	ASCCIE	-50 (-138)	-50 (-138)	-50 (-138)	-50 (-138)	-50 (-137)	-50 (-137)
Sale Group	Toe	0	-3.6	-9.8	-15.9	-16.9	-17.8
	ASCCIE	-12 (-45)	-18 (-48)	-27 (-54)	-34 (-60)	-35 (-61)	-35 (-61)
Murrindindi Supergroup	Toe	0	-3.6	-9.8	-15.9	-16.9	-17.8
	ASCCIE	-71 (-179)	-77 (-184)	-85 (-192)	-93 (-200)	-93 (-200)	-94 (-201)
Wonthaggi Formation	Toe	0	-5.7	-15.3	-24.9	-27.4	-29.4
	ASCCIE	-43 (-83)	-50 (-88)	-61 (-98)	-71 (-108)	-73 (-110)	-74 (-112)
Cenozoic aged Volcanics	Toe	0	-2.9	-7.6	-12.4	-13.7	-14.7
	ASCCIE	-26 (-65)	-27 (-66)	-33 (-69)	-38 (-75)	-39 (-76)	-40 (-76)
Castlemaine Group	Toe	0	-3.6	-9.8	-15.9	-16.9	-17.8
	ASCCIE	-38 (-52)	-46 (-57)	-54 (-65)	-61 (-71)	-62 (-72)	-63 (-73)
Sandringham Sandstone	Toe	0	-6.0	-15.9	-25.7	-30.1	-34.0

Geological Unit	Component	Scenario					
		2025	2040	2070	2100-1	2100-2	2100-3
	ASCCIE	-37 (-69)	-45 (-78)	-56 (-91)	-66 (-104)	-70 (-108)	-74 (-112)
Jan Juc	Toe	0	-14.3	-38.2	-62.2	-68.4	-73.6
	ASCCIE	-46 (-81)	-62 (-95)	-86 (-120)	-110 (-147)	-115 (-153)	-120 (-157)
Demons Bluff Formation	Toe	0	-14.3	-38.2	-62.2	-68.4	-73.6
	ASCCIE	-51 (-95)	-70 (-111)	-97 (-147)	-122 (-178)	-128 (-184)	-132 (-188)
Eumeralla Formation	Toe	0	-7.2	-19.5	-31.8	-33.9	-35.6
	ASCCIE	-143 (-326)	-152 (-327)	-168 (-341)	-181 (-357)	-182 (-358)	-205 (-398)
Bridgewater Formation	Toe	0	-3.4	-9.0	-14.6	-16.6	-18.3
	ASCCIE	-61 (-109)	-66 (-112)	-72 (-119)	-78 (-124)	-80 (-126)	-81 (-127)
Wangerrip Group	Toe	0	-5.7	-15.3	-24.9	-27.4	-29.4
	ASCCIE	-110 (-200)	-119 (-211)	-134 (-232)	-148 (-247)	-151 (-252)	-154 (-257)
Heytesbury Group	Toe	0	-12.0	-32.5	-53.0	-56.5	-59.3
	ASCCIE	-37 (-78)	-49 (-90)	-69 (-110)	-89 (-130)	-91 (-133)	-95 (-135)
Newer Volcanic Group	Toe	0	-4.0	-11.1	-18.1	-18.7	-19.1
	ASCCIE	-46 (-116)	-53 (-120)	-62 (-129)	-71 (-135)	-71 (-135)	-71 (-135)

[1] 10% exceedance value

Table 6.2: Summary of typical[1] (and typical upper bound[2]) resulting ASCCIE distances (m) measured from present-day cliff toe for considered scenarios including toe distances summarised per secondary coastal compartment

Secondary Compartment	Component	Scenario					
		2025	2040	2070	2100-1	2100-2	2100-3
Mallacoota Inlet	Toe	0	-4 (-8)	-11 (-21)	-18 (-34)	-19 (-40)	-19 (-45)
	ASCCIE	-38 (-84)	-42 (-87)	-48 (-92)	-54 (-99)	-55 (-99)	-55 (-99)
Croajingolong	Toe	0	-4 (-8)	-11 (-21)	-18 (-34)	-19 (-40)	-19 (-45)
	ASCCIE	-51 (-147)	-56 (-152)	-64 (-162)	-72 (-174)	-74 (-180)	-76 (-181)
Snowy River	Toe	0	-8 (-8)	-21 (-21)	-34 (-34)	-40 (-40)	-45 (-45)
	ASCCIE	-5 (-8)	-11 (-35)	-22 (-43)	-33 (-61)	-37 (-64)	-43 (-74)
Gippsland Lakes	Toe	0	-4 (-8)	-10 (-21)	-16 (-34)	-17 (-40)	-18 (-45)
	ASCCIE	-8 (-41)	-16 (-43)	-33 (-52)	-48 (-60)	-53 (-126)	-61 (-161)
Corner Inlet	Toe	0	0 (-8)	-1 (-21)	-2 (-34)	-2 (-40)	-2 (-45)
	ASCCIE	-81 (-228)	-81 (-228)	-81 (-226)	-81 (-226)	-81 (-225)	-81 (-223)
Wilsons Promontory (east)	Toe	0	0 (-8)	-1 (-21)	-2 (-34)	-2 (-40)	-2 (-45)
	ASCCIE	-116 (-355)	-118 (-357)	-114 (-333)	-130 (-368)	-129 (-361)	-130 (-364)
Wilsons Promontory (southwest)	Toe	0	0 (-8)	-1 (-21)	-2 (-34)	-2 (-40)	-2 (-45)
	ASCCIE	-172 (-462)	-177 (-458)	-173 (-447)	-177 (-449)	-176 (-448)	-180 (-444)
Waratah Bay	Toe	0	-4 (-8)	-10 (-21)	-16 (-34)	-17 (-40)	-18 (-45)
	ASCCIE	-52 (-172)	-58 (-175)	-68 (-182)	-78 (-191)	-82 (-192)	-85 (-192)
Venus Bay	Toe	0	-6 (-8)	-15 (-21)	-25 (-34)	-27 (-40)	-29 (-45)
	ASCCIE	-61 (-166)	-68 (-171)	-80 (-180)	-89 (-188)	-92 (-190)	-94 (-191)
Kilcunda	Toe	0	-6 (-6)	-15 (-15)	-25 (-25)	-27 (-27)	-29 (-29)
	ASCCIE	-65 (-130)	-70 (-132)	-79 (-136)	-87 (-144)	-88 (-146)	-89 (-147)
Phillip Island (south)	Toe	0	-3 (-3)	-8 (-8)	-12 (-12)	-14 (-14)	-15 (-15)
	ASCCIE	-33 (-70)	-32 (-67)	-36 (-71)	-43 (-77)	-43 (-79)	-44 (-80)
Secondary Compartment	**Component**	**Scenario**					

Secondary Compartment	Component	Scenario					
		2025	2040	2070	2100-1	2100-2	2100-3
		2025	2040	2070	2100-1	2100-2	2100-3
Western Port	Toe	0	-3 (-8)	-8 (-21)	-12 (-34)	-14 (-40)	-15 (-45)
	ASCCIE	-14 (-42)	-18 (-47)	-24 (-54)	-29 (-61)	-31 (-62)	-31 (-63)
Cape Schanck-Flinders	Toe	0	-3 (-8)	-8 (-21)	-12 (-34)	-14 (-40)	-15 (-45)
	ASCCIE	-66 (-128)	-66 (-134)	-66 (-129)	-71 (-132)	-72 (-131)	-74 (-138)
Mornington Peninsula	Toe	0	-8 (-8)	-21 (-21)	-34 (-34)	-40 (-40)	-45 (-45)
	ASCCIE	-92 (-212)	-87 (-216)	-89 (-188)	-109 (-227)	-111 (-230)	-115 (-227)
Port Phillip Bay (east)	Toe	0	-6 (-6)	-16 (-16)	-26 (-26)	-30 (-30)	-34 (-34)
	ASCCIE	-44 (-86)	-50 (-91)	-58 (-98)	-65 (-103)	-68 (-106)	-70 (-108)
Port Phillip Bay (west)	Toe	0	-8 (-8)	-21 (-21)	-34 (-34)	-40 (-40)	-45 (-45)
	ASCCIE	-13 (-25)	-22 (-30)	-33 (-40)	-44 (-50)	-49 (-55)	-53 (-58)
Torquay	Toe	0	-14 (-14)	-38 (-38)	-62 (-62)	-68 (-68)	-74 (-74)
	ASCCIE	-49 (-87)	-66 (-102)	-92 (-131)	-117 (-160)	-122 (-166)	-127 (-172)
Great Ocean Road	Toe	0	-7 (-14)	-20 (-38)	-32 (-62)	-34 (-68)	-36 (-74)
	ASCCIE	-130 (-349)	-142 (-356)	-161 (-369)	-179 (-384)	-181 (-384)	-182 (-386)
Port Campbell	Toe	0	-7 (-12)	-20 (-33)	-32 (-53)	-34 (-56)	-36 (-59)
	ASCCIE	-81 (-196)	-89 (-203)	-102 (-217)	-114 (-223)	-116 (-225)	-134 (-271)
Warrnambool	Toe	0	-8 (-12)	-21 (-33)	-34 (-53)	-40 (-56)	-45 (-59)
	ASCCIE	-44 (-88)	-53 (-94)	-67 (-109)	-79 (-124)	-81 (-126)	-84 (-130)
Portland Bay	Toe	0	-4 (-12)	-11 (-33)	-18 (-53)	-19 (-56)	-19 (-59)
	ASCCIE	-37 (-94)	-44 (-101)	-53 (-108)	-61 (-115)	-63 (-116)	-64 (-117)
Discovery Bay	Toe	0	-4 (-8)	-11 (-21)	-18 (-34)	-19 (-40)	-19 (-45)
	ASCCIE	-58 (-132)	-64 (-137)	-74 (-145)	-82 (-153)	-83 (-154)	-84 (-155)

[1] Average value for ASCCIE and median value for toe retreat (to reflect one of the actual geological unit derived toe retreat values)

[2] 10% exceedance value for ASCCIE and max value for toe retreat.

Figure 6.2: Long-term toe erosion distance for the ASCCIE 2100-1 scenario

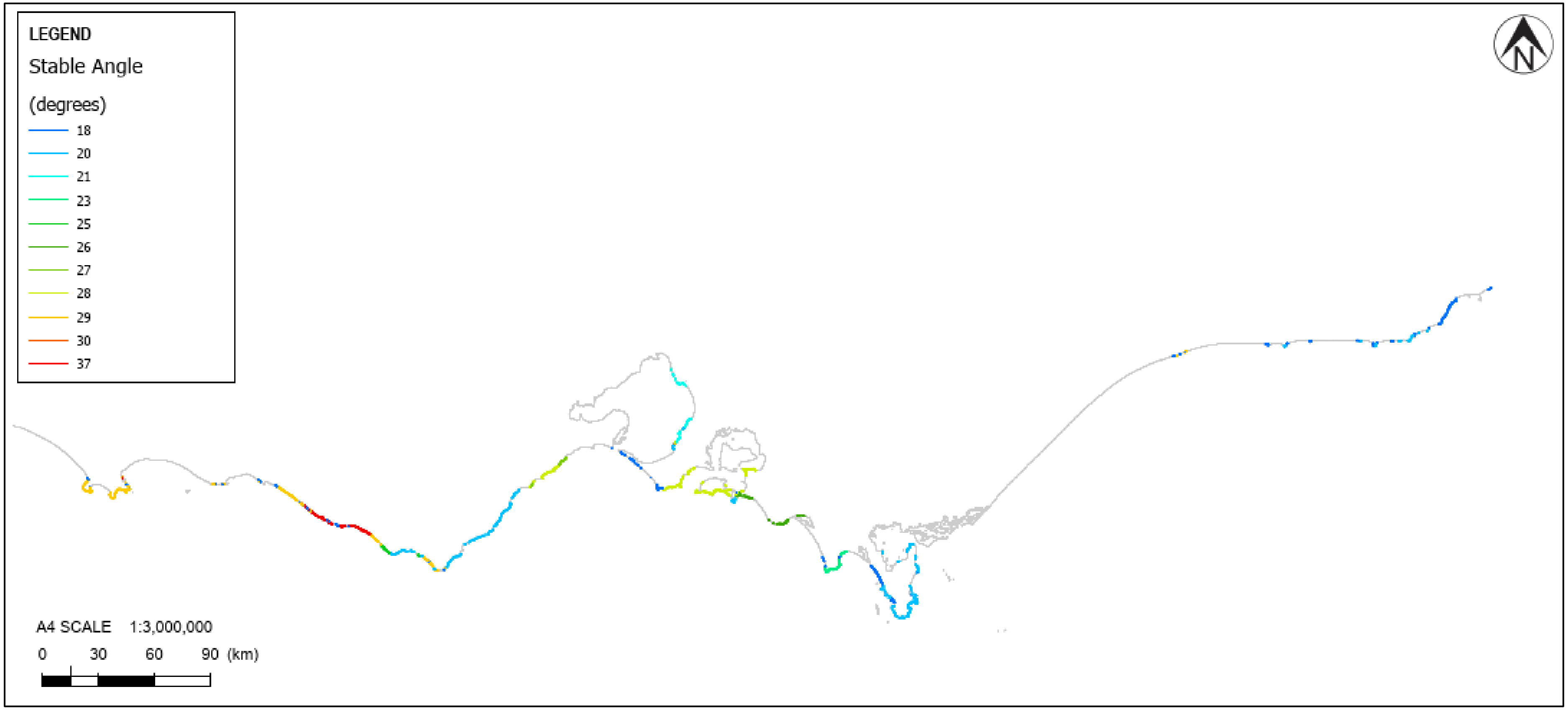


Figure 6.3: Stable angle along the cliff shoreline of Victoria

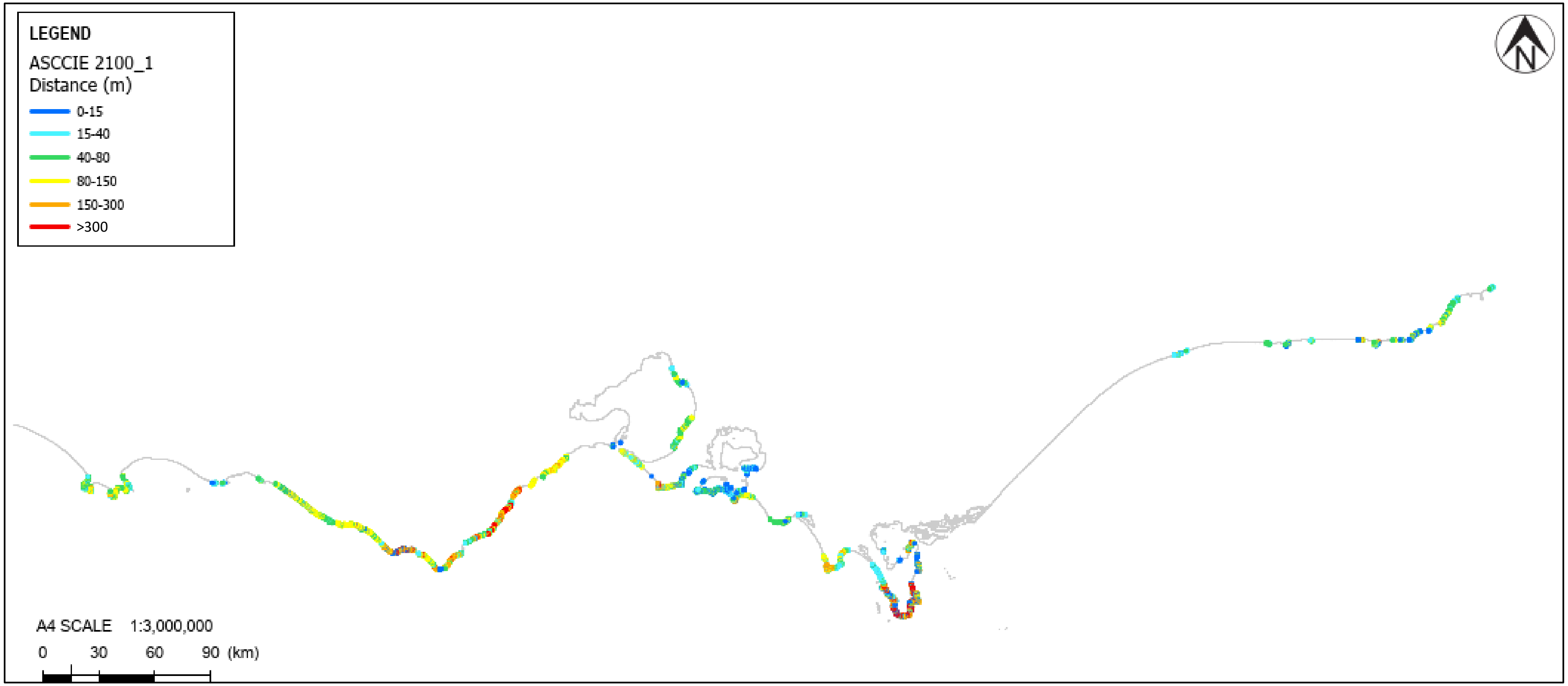


Figure 6.4: ASCCIE distances for the ASCCIE 2100-1 scenario

6.2 Resulting ASTaR distances

6.2.1 Results per geological unit

Table 6.3 shows the resulting mean and typical upper bound (i.e. 10% exceedance) ASTaR distances for each geological unit. This shows that the largest distances are found within the Devonian aged Granite/Grandiorite and Eumeralla Formation. This is a result of the high cliff heights. The smallest distances are found within the Merrimbula Group, Castlemaine Group, Jan Juc Formation and Dune Deposits, and are typically less than 50 m based on the 10% exceedance values.

6.2.2 Results per coastal compartment

Table 6.4 shows the resulting mean and typical upper bound ASTaR distances summarised per secondary coastal compartment. This shows that the largestest distances are found within the Wilsons Promontory (East and Southwest) and Great Ocean Road coastal compartments, as a result of the relatively high cliff heights. The smallest ASTaR distances (i.e., <50 m) can be found within the Snowy River, Gippsland Lakes, Western Port and Port Phillip Bay (East and West) coastal compartments.

Figure 6.5 shows a spatial plot of the resulting ASTaR along the cliff shoreline of Victoria. This also shows that the largest ASTaR distances are typically situated along the Great Ocean Road and Wilsons Promontory.

Table 6.3: Summary of mean and typical upper bound (i.e., 10% exceedance) ASTaR distances measured from present-day cliff crest per geological unit (m)

Geological unit	Mean	Typical upper bound (i.e., 10% exceedance)
Merrimbula Group	-25	-39
Dune Deposits	-26	-47
Pinnak Sandstone	-33	-65
Devonian aged Granite/Grandiorite	-56	-116
Silurian to Devonian aged Granite/Granodiorite	-53	-102
Sale Group	-26	-55
Murrindindi Supergroup	-51	-98
Wonthaggi Formation	-36	-59
Cenozoic aged Volcanics	-29	-50
Castlemaine Group	-27	-44
Sandringham Sandstone	-29	-55
Jan Juc	-29	-41
Demons Bluff Formation	-42	-78
Eumeralla Formation	-67	-128
Bridgewater Formation	-41	-74
Wangerrip Group	-38	-72
Heytesbury Group	-28	-58
Newer Volcanic Group	-31	-53

Table 6.4: Summary of mean and typical upper bound (i.e., 10% exceedance) ASTaR distances measured from present-day cliff crest per secondary coastal compartment (m)

Secondary Compartment	Mean	Typical upper bound (i.e., 10% exceedance)
Mallacoota Inlet	-32	-67
Croajingolong	-43	-91
Snowy River	-25	-45
Gippsland Lakes	-25	-47
Corner Inlet	-46	-99
Wilsons Promontory (east)	-63	-122
Wilsons Promontory (southwest)	-57	-115
Waratah Bay	-36	-90
Venus Bay	-39	-87
Kilcunda	-39	-76
Phillip Island (south)	-30	-56
Western Port	-26	-41
Cape Schanck-Flinders	-33	-54
Mornington Peninsula	-39	-99
Port Phillip Bay (east)	-28	-49
Port Phillip Bay (west)	-19	-25
Torquay	-36	-61
Great Ocean Road	-66	-127
Port Campbell	-47	-94
Warrnambool	-25	-50
Portland Bay	-30	-50
Discovery Bay	-34	-62

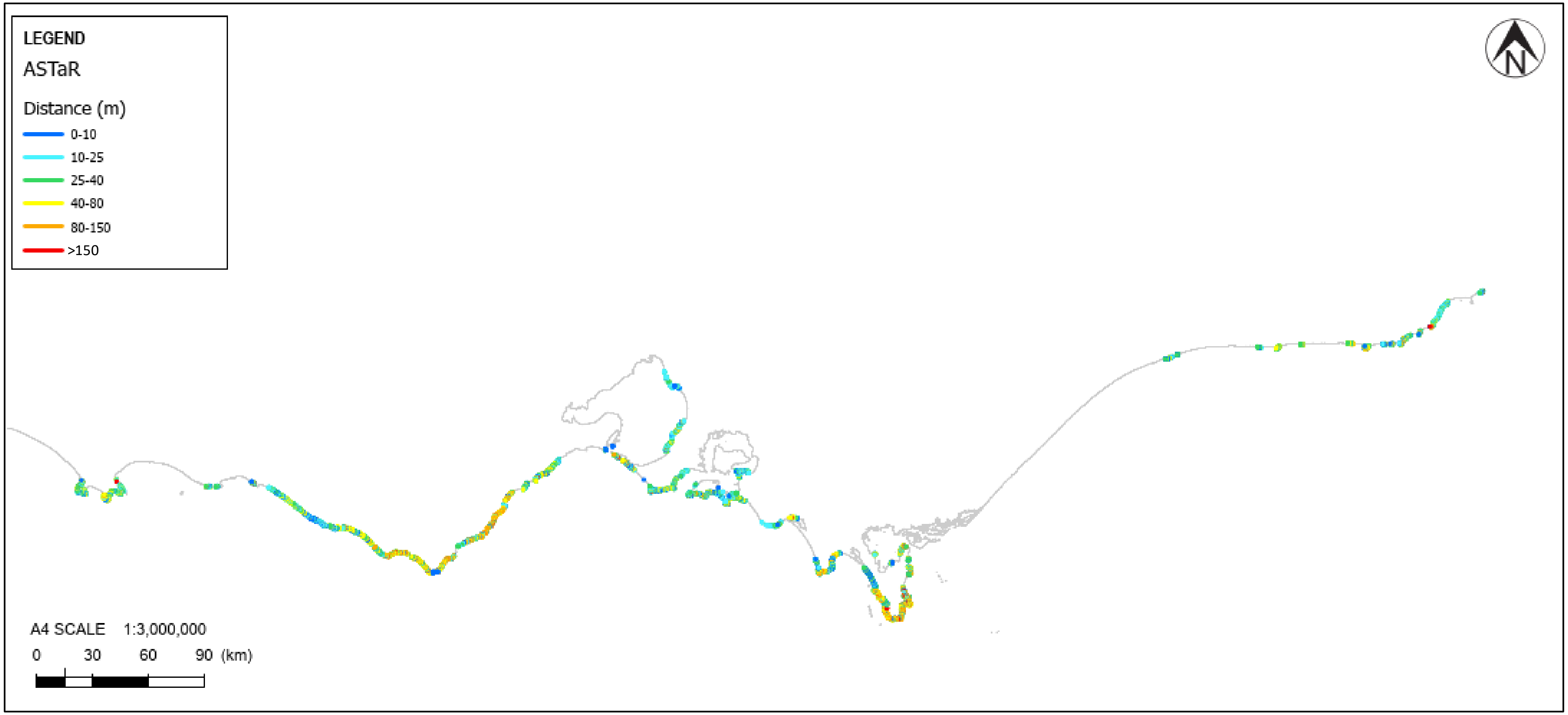


Figure 6.5: Resulting ASTaR across the cliff shoreline of Victoria

6.3 Mapping

ASCCIE and ASTaR have been mapped using the methodology set out in Section 4.3.4 and Section 4.4, respectively. The scenarios that have been mapped are set out in Table 1.1. An example of the projection method used for mapping is illustrated in Figure 6.6 with the final mapped outputs displayed in Figure 6.7 for this area. The ASCCIE and ASTaR have been provided in digital format, with more details provided in Appendix C.

Figure 6.6 shows a cross-section (black solid line) of a cliff within Demons Bluff, including the future toe erosion distance for the 2100 +0.8 m sea level rise scenario (yellow dashed line). This shows the toe erosion distance from the present-day cliff toe is 62 m for this example. The stable angle is then projected from the future toe position until it intersects with the cliff profile. The cliff instability zone is 50 m, with the total ASCCIE 112 m from the present-day cliff toe position.

Figure 6.6 also shows the ASTaR projected seaward from the present-day cliff crest (green dashed line) to its intersection with the foreshore. The calculated ASTaR distance from the present-day cliff crest is 38 m for this example.

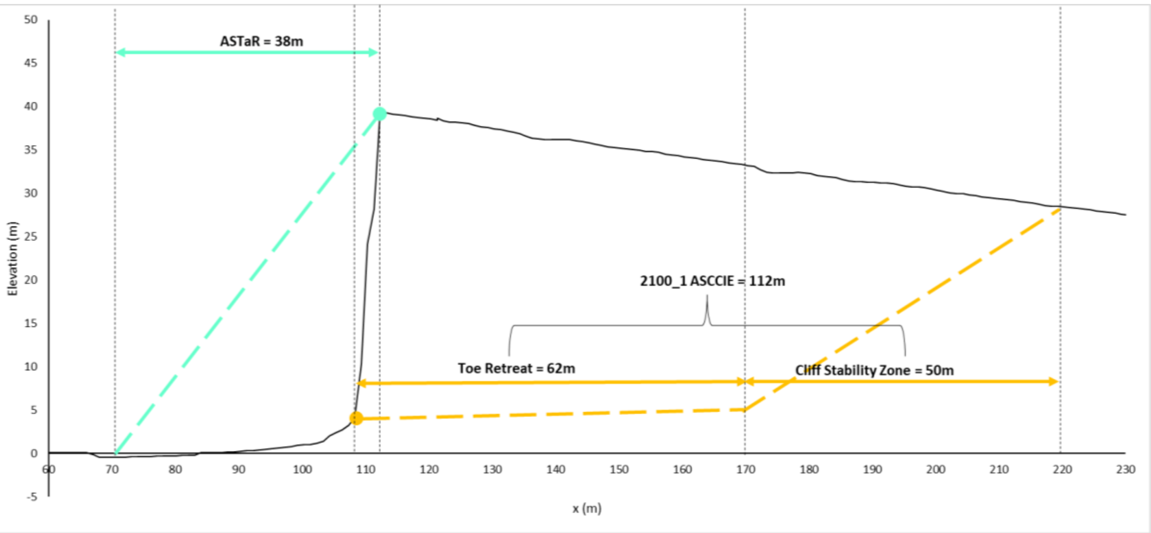


Figure 6.6: Example of ASTaR and ASCCIE 2100_1 cliff projection mapping for a transect at Demons Bluff, Anglesea (refer to Figure 6.7 for polygons for this area with this transect highlighted in yellow)

Figure 6.7 shows a plan view of both the ASCCIE and ASTaR at the same location as the cross-section shown in Figure 6.6. The figure includes the present-day cliff toe (seaward boundary of ASCCIE polygons) and the ASCCIE zones for the considered scenarios (landward boundary indicating future cliff crest position). The ASTaR are mapped as well, extending from the present-day cliff crest (landward boundary of the ASTaR polygon) to the seaward talus runout extent (seaward boundary of the ASTaR polygon). The transects at 30 m alongshore interval that have been used for the mapping have been included as well.

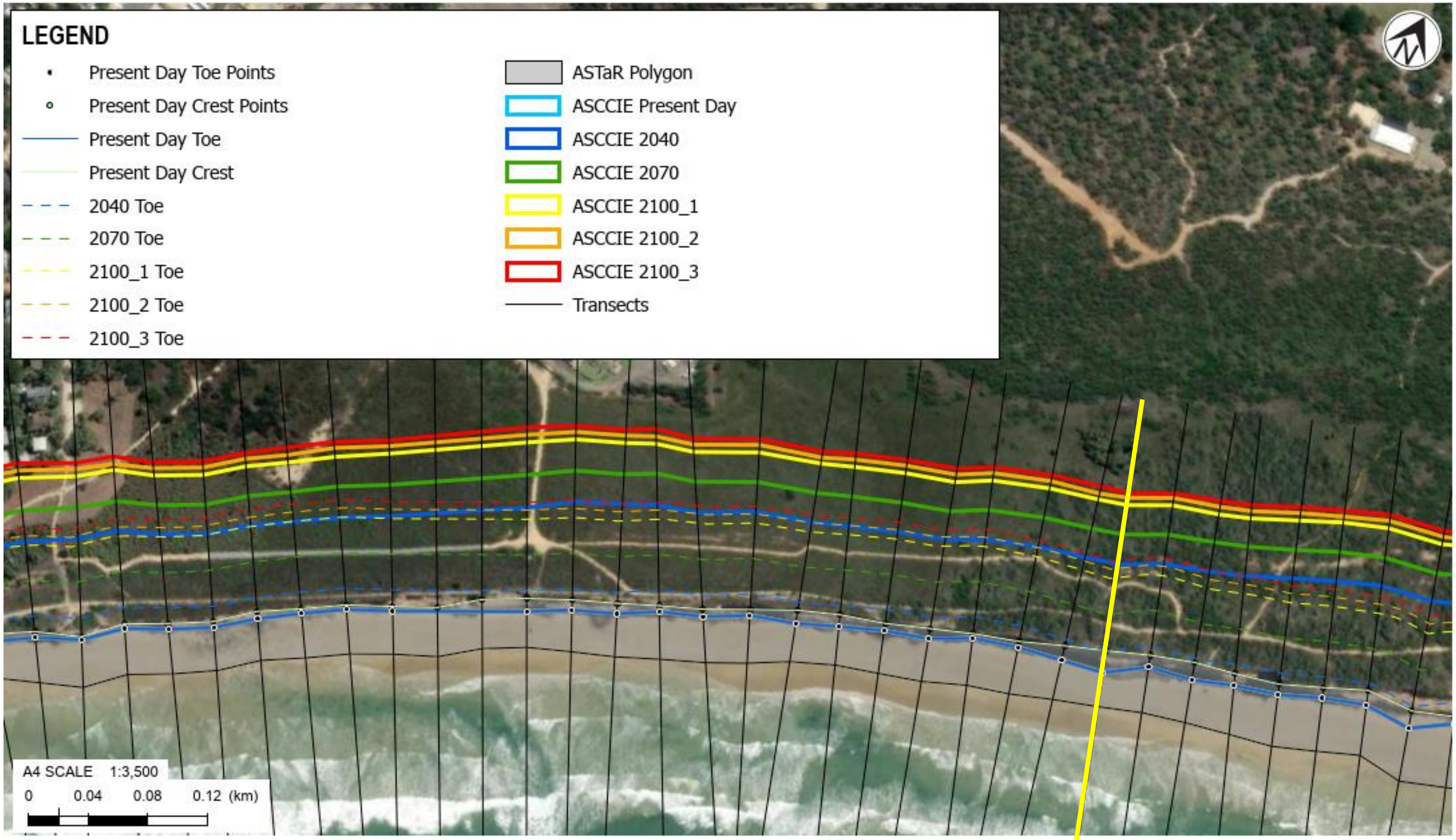


Figure 6.7: Example of mapped ASCCIE and ASTaR at Lorne-Queenscliff Coastal Reserve

6.3.1 Mapping limitations

As a result of the mapping approach for cliffs (e.g. cliff projection at 30 m intervals), the resulting ASCCIE and ASTaR lines may appear slightly angular. The shoreline is highly variable along some sections with rapid changes in elevation and orientation. As a result, the mapped lines/polygons have been modified along these sections using engineering judgement where required to make the lines/polygons more realistic. However, it is noted that this has been undertaken taking a high-level state-wide view, as the ASCCIE/ASTaR lines/polygons are not intended to be used on a site-specific level. Therefore, some site-specific inaccuracies may still be observed.

As set out in the project limitations Section 1.4, the ASCCIE and ASTaR have been derived based on cliffs identified by Water Technology (2022), and therefore some sections of shoreline that are actually cliffs have not been included in this study, as seen during the ground truthing site visit at the Beaumaris Sea Scout Boat Shed location. See Figure 6.8 showing location and Water Technology (2022) cliff line and Figure 6.9 showing cliff in this same location below. However, sections of shoreline that have been identified as cliffs but are actually unconsolidated shorelines have been included in this study. Due to the flatter slopes and shallow heights, ASCCIE and ASTaR along these sections may be less applicable and may seem very narrow.

Figure 6.8: Example of a section of cliff at Beaumaris which is not included in the Water Technology Smart Line data.

Figure 6.9: Example of a section of cliff at Beaumaris which is not included in the Water Technology Smart Line data.

In addition to the mapping limitations, the following may occur along some sections of the cliff shoreline:

- Toe is landward of visual toe
- Crest is landward of ASCCIE
- All ASCCIE the same

An example of where the cliff toe is landward of the visual toe/vegetation line is shown in Figure 6.10. This is a result of a narrow beach including/excluding dune vegetation fronting the actual cliffs. The USGS tool identifies the actual cliff toe, with the ASCCIE and ASTaR based on the identified cliff toe and crest. This may mean that the long-term toe erosion is overestimated along these sections as a result of beach material protecting the cliff toe. This is a limitation of this state-wide assessment and should be refined on a more detailed level assessment.

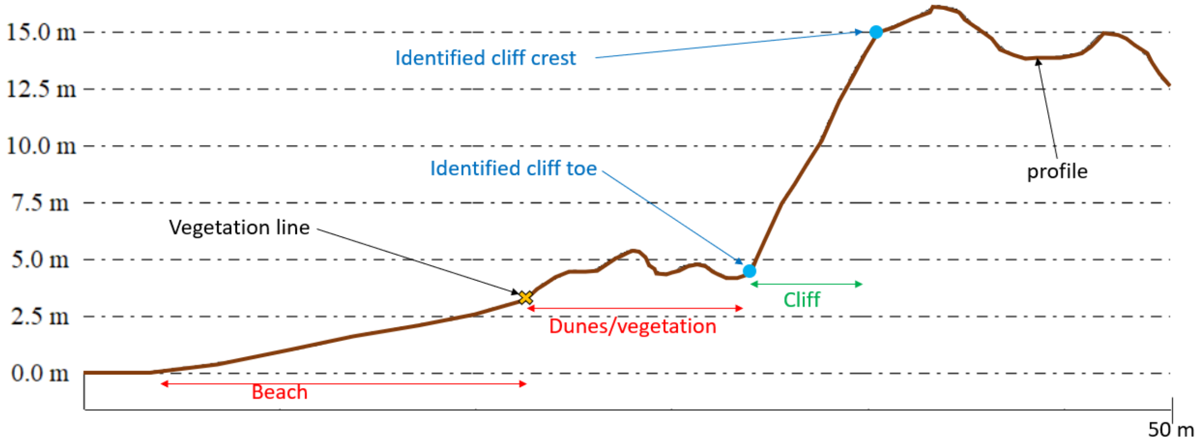


Figure 6.10: Example of cliff toe landward of vegetation/beach

Along some section of the shoreline, the identified cliff crest is landward of the ASCCIE line/polygon. This is a result of the derived stable angle being steeper than the existing slope along that particular section, which may intersect landward of the existing crest. This is a limitation of this state-wide assessment as set out in Section 1.4.

In some cases, the ASCCIE polygons for all six scenarios are the same. This is the case where the long-term erosion rates are similar for each scenario (e.g., LT = 0 m/year for granites).

Because the method used to generate ASCCIE distances is at a scale appropriate for a state-wide/regional assessment, the resulting spatial layers should not be used on a local-scale or site-specific bases (refer to limitations in Section 1.4). However, the techniques used to develop these distances can be refined to provide more detailed mapping showing areas susceptible to coastal cliff instability, erosion and talus runout at a sub-regional level.

These maps showing the more detailed lines are not intended for site-specific use; for example, when making decisions about building design. Rather, they present the areas within which more detailed studies such as site-specific hazard assessments should be considered to define the risk. The mapping will enable land managers along the Victorian cliff shoreline to review and engage with our current understanding of long-term coastal change and climate change impacts and will inform future sustainable hazard management approaches for the state/region.

7 Framework for refining ASCCIE and ASTaR

ASSCIEs have been assessed on a state-wide/regional scale for this study. This may introduce errors and uncertainties due to the scale of the study (i.e. as a result of simplifications applied, and classifications made). The limitations of the state-wide/regional scale ASCCIE and ASTaR (refer to Section 1.4) should therefore be considered and the intent of these ASCCIE/ASTaR should be understood before using the state-wide/regional-scale ASCCIE/ASTaR. The ASCCIE/ASTaR have been assessed as a second-pass assessment and identify the areas *potentially* susceptible to erosion, instability and/or talus runout.

Site specific hazard assessments may be needed for risk assessment or potential development in the ASCCIE/ASTaR zone(s). Such assessment should be undertaken by a suitably qualified and experienced practitioner.

In undertaking a more detailed scale assessment for cliffs, the following approach to derive ASCCIEs is recommended:

1. Use the model described by Equation 4.3 (Section 4.3.1) to derive current or future ASCCIE for cliffs.
2. Use site specific data to derive component values or distributions:
   a. Historical long-term regression: assess historical toe regression rate.
   b. Future long-term regression: determine appropriate *m* value, and relevant SLR value to determine future LT_F using Equation 5.3 and multiply with LT_H.
   c. Cliff instability:
      i. determine lower rock height and appropriate slope based on specific geological conditions.
      ii. determine upper residual soil depth and appropriate slope considering any site-specific structures or drainage (if applicable).
3. Combine the future toe erosion with the cliff instability zone to derive ASCCIE as shown within Section 4.3.4.
4. Determine appropriate baseline along the cliff toe and map ASCCIE distance(s).

For a more detailed scale assessment of ASTaR, the following approach is recommended:

1. Use the model described in Section 4.4 to derive ASTaR.
2. Use site specific data to derive component values or distributions:
   - Cliff height along shoreline of interest
   - Review of potential talus runout distance based on site-specific evidence or modelling
3. Derive site-specific relationship of cliff height versus landward distance of talus runout, to be applied along shoreline of interest.
4. Determine appropriate baseline along the cliff crest and map ASTaR distance(s).

8 Summary and recommendations

8.1 Summary

This study provides a state-wide/regional scale assessment of Areas Susceptible to Coastal Cliff Instability and/or Erosion (ASCIE) associated with areas at the cliff top and Areas Susceptible to Talus Runout (ASTaR) associated with areas at the bottom of the cliff for the Victorian coastline. The purpose of this second-pass assessment is to identify ASCCIE and ASTaR at a regional/state-wide scale for present-day and future timeframes. The intent of this assessment is that resulting ASCCIE and ASTaR are then used to inform the second part of the assessment, the cliff instability risk assessment. That assessment identifies assets at high risk to coastal cliff instability, erosion and slumping including consideration of public safety (see Stage 2 report).

ASCCIE and ASTaR have been assessed for the hard and soft rock coastal cliffs within the State of Victoria (i.e. 672 km), as defined by Water Technology (2022). Water Technology (2022) completed an assessment of mapping initial shoreline classes for the Victoria shoreline based on the national Smartline dataset, with some adjustments specifically for Victoria. The analysis in this report is focussed on the cliff extents mapped by Water Technology (2022). Any cliff outside of the hard and soft rock cliff extents defined by the Water Technology (2022), such as cliffs behind hard engineered structures or cliffs not identified by Water Technology (2022), is outside the scope of this study. The intended use and limitations of this study (see Section 1.4) should be considered and understood before the results of this study are used.

ASCCIE and ASTaR have been derived based on the geological unit type. Shore normal transects at 30 m have been provided by DEECA, which have been used to assign a geological type. For each of the geological types, component values have been derived for the historical long-term erosion rate, effect of sea level rise on historical toe erosion and stable angle components. The USGS tool has been used to extract the cliff toe, cliff crest and cliff slope based on the cliff profiles derived from a combined LiDAR dataset for the state of Victoria.

The methodology used in this study are standard and well-tested approaches for defining ASCCIE for consolidated shorelines by the addition of component parameters. The methodology for defining ASTaR is a new method undertaken at a high level and based on the existing cliff height and a defined slope. For this state-wide/regional scale assessment, single values were derived for each component. This ‘building-block’ approach (i.e. combination of individual parameters) is expected to produce ‘upper bound’, conservative results, which identifies areas potentially exposed to coastal erosion, cliff instability and cliff slumping/talus runout.

The ASCCIE have been assessed for the present-day (applicable to 2025), 2040 (i.e. approx. 15 years), 2080 (i.e. approx. 55 years) and 2100 (i.e. approx. 75 years) planning timeframe scenarios. Sea level rise has been allowed for, for each scenario aligned with DEECA (2023). Resulting ASCCIE areas have been mapped for the following scenarios:

- Present-day (0 m sea level rise)
- 2040 +0.2 m sea level rise
- 2080 +0.5 m sea level rise
- 2100 +0.8 m sea level rise
- 2100 +1.1 m sea level rise
- 2100 +1.4 m sea level rise

The ASTaR have been derived for the present-day only as it is expected that future ASTaR will migrate landward as cliffs retreat, and therefore resulting in narrow zones from the current cliff toe.

The areas susceptible to coastal cliff erosion and/or instability landward of the existing cliff toe are captured within the ASCCIE.

The largest ASCCIE distances within the Wilsons Promontory (East and Southwest) and Great Ocean Road coastal compartments. The ASCCIE distances for the 2100 scenarios exceed 300 m. As it is expected that the granite geological units (i.e., within the Wilsons Promontory coastal compartments) are relatively hard rock and would unlikely result in large susceptible areas, this is mainly due to the very high cliff heights and stable angle that are slightly flatter than the actual cliff slopes. This means the ASCCIE are typically slightly landward of the present-day crest, which already sit a relatively large distance from the cliff toe due to the high cliff height.The toe erosion rate is low for cliffs within this coastal compartment. For the cliffs within the Great Ocean Road, the relatively large ASCCIE distances are a due to the combination of the high cliffs and relatively large toe erosion rates (i.e., up to 74 m for the 2100-3 scenario).

Other secondary coastal compartments within which ASCCIE distances are in the order of 200 m or more for the 2100-3 scenario are Corner Inlet, Mornington Peninsula and Port Campbell. This is typically due to the adopted stable angle and the cliff height being 50-100 m high.

The smallest ASCCIE distances (i.e., mean values <50 m) are found within the Snowy River, Phillip Island (South) and Western Port coastal compartments. This is a result of the relatively low cliff heights within these coastal compartments. The resulting ASCCIE distances for the majority of the coastal compartments are typically in the order of 100-150 m based on the typical upper bound (i.e. 10% exceedance) value.

The largest ASTaR distances are found within the Wilsons Promontory and Great Ocean Road coastal compartments. This is a result of the high cliff heights. The smallest ASTaR distances (i.e., <50 m) can be found within the Snowy River, Gippsland Lakes, Western Port and Port Phillip Bay (East and West) coastal compartments.

This study has assessed ASCCIE and ASTaR at a state-wide/regional scale and may be superseded by a more detailed, local scale or site-specific assessment (i.e. order of 1 m - 1 km shoreline length) undertaken by a suitably qualified and experienced practitioner using improved data and/or undertaken at a higher resolution from that presented in this report. This could include better site-specific geotechnical information to confirm subsurface soil conditions including site-specific terrestrial processes, more detailed topographic data as well as site-specific analysis and modelling of erosion. Note that due to the scale of this state-wide/regional assessment the change in geology may not be considered in detail (e.g. use of 1:250,000 geological maps may not include site-specific details), which could affect the potential ASCCIE and ASTaR. This should be assessed for a more detailed scale assessment. Furthermore, a probabilistic approach may be adopted for local-scale and site-specific assessments giving likelihood of erosion and instability based on parameter ranges rather than single values.

This study has provided new information at a state-wide level on cliff types and areas that may be susceptible to coastal cliff instability, erosion and slumping for the present-day and in the longer term. This will be useful to inform regional and local adaptation planning, strategic decision making and masterplans, identifying areas where more detailed local or site-specific studies are required.

8.2 Recommendations

This assessment has used the best available tools and available data to derive state-wide/regional scale ASCCIE and ASTaR, which may be refined using more detailed data and may be improved when better tools and methods become available. The following recommendations are provided that could improve the quality of the data and tools/methods that may become available for future assessments:

- **Update to the shoreline classification**

  The shoreline classification derived by Water Technology (2022) has been used to assess and map ASCCIE and ASTaR. This includes shoreline extents classified as hard and soft cliffs, based on the national Smartline dataset. However, this dataset has likely excluded some sections of the Victorian shoreline that are actual cliffs. It is recommended to review and refine the cliff shoreline extents as mapped by Water Technology (2022) to ensure cliff shorelines that have not been included in that dataset will be included, and should be considered in addition to this assessment.
- **Ongoing monitoring of cliffs (i.e. continuing VCMP)**

  Capturing cliff topography or profiles (1D/2D/3D) provide valuable information on coastal change including long-term changes. Data can be used to derive component values for hazard assessment with longer datasets providing more accurate results. This includes cliff toe erosion, stable cliff slope and talus runout components. It is therefore recommended to continue to survey the existing cliff sites.
- **Establish cliff monitoring sites**

  In addition to continuing monitoring existing cliff profiles/sites, benchmarks for cliff profiles should be established and profiles should be surveyed using laser scanners or similar at a bi-annual or more frequent basis. This would provide better information on short- and long-term cliff toe and crest erosion rates, and slope angles. Long-term erosion rates are typically derived from analysing historical aerials; however, these are typically obscured by vegetation along the cliff crest and large uncertainty in shoreline or cliff toe position.

  It is recommended to start these surveys as soon as practicable so that in 10 years this data can be used to verify the long-term erosion rates and slope angles. Laser cliff profiles are recommended at cliff shorelines where development is situated close to the existing cliff crest and other representative sites.
- **Review and incorporate new technologies for monitoring coastal change**

  Traditional methods of monitoring coastal change include profile surveys and digitisation of the cliff toe within historic aerial photographs. New technologies are emerging such as using UAVs to capture full terrain models, low cost ‘citizen-science’ techniques such as CoastSnap (refer to Splinter et al., 2018) to monitor cliff toe or talus runout position, or use of satellite imagery or InSAR data to examine shoreline change and mass movement. These technologies may provide improved and/or lower cost data to be used in future updates or subsequent local scale assessment but their accuracy, cost and the usefulness of output data requires review and potentially trial.
- **Location and extent of coastal structures**

  This present assessment has excluded cliff shorelines protected by coastal structures. It is recommended to incorporate the location, extent and condition of coastal structures in more detailed-scale assessments. By assessing the precise extent and condition of each structure, the risk of failure can be estimated and incorporated into assessments.
- **Refined scale assessment for high-risk areas**

  It is recommended to undertake refined scale and more detailed assessments for high-risk areas to better understand susceptibility to erosion. This assessment has identified areas potentially exposed to coastal hazards on a state-wide/regional scale, the ASCCIE and ASTaR distances may be refined using more detailed and site-specific data and/or a probabilistic assessment method. This would provide the likelihood of occurrence of the ASCCIE/ASTaR and enable better decisions may be made based on a more complete understanding of likelihood. Based on the results of this assessment, it would be recommended to review areas at high-risk in particular along the Great Ocean Road, with select local-scale assessments to be undertaken based on the risk assessment outcomes (see Stage 2 Report).

9 Applicability

This report has been prepared for the exclusive use of our client Department of Environment, Energy and Climate Action (DEECA), with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

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Appendix A Aerial survey information

An aerial survey of the Victoria coastline was undertaken in April 2023. The purpose of this survey was to obtain high resolution oblique photographs of the cliff coastline. This type of survey has proved to be much more useful and efficient for a state/region-wide assessment than a ground-based inspection and photographs. The obliqueness of the photographs is particularly useful for interpretation of coastline slopes, heights and relief, and validation of geological type, lithology and susceptibility to landsliding. This data is intended to be used in combination with available LiDAR information and right-angle photographs.

A1 Flight route

The aerial survey was undertaken on 24 and 25 April 2023. The flight dates and routes are shown in Appendix A Table 1 and Figure 1.1, with departures were from the Mornington Peninsula airport in Tyabb.

On 24 April the flight included the western part of the Victoria shoreline, flying around Port Phillip Bay and then westward to the border with South Australia. On 25 April the flight included the eastern part of the Victorian shoreline, flying from the border with New South Wales back to Port Phillip Bay.

The airplane was flown at an elevation of roughly 500 ft (~150 m) and typical offshore distance of 300-500 m. The offshore distance varies alongshore due to the irregular shoreline. As the two flights took an entire workday specific flight times to reduce effects of shadows could not be allowed for. Therefore, shadows may cover the cliffs in the photographs along some sections.

Appendix A Table 1: Flight dates and area

Date	Fly area
24-4-2023	Port Phillip Bay to SA border (East to West)
25-4-2023	NSW border to Point Nepean National Park (East to West)

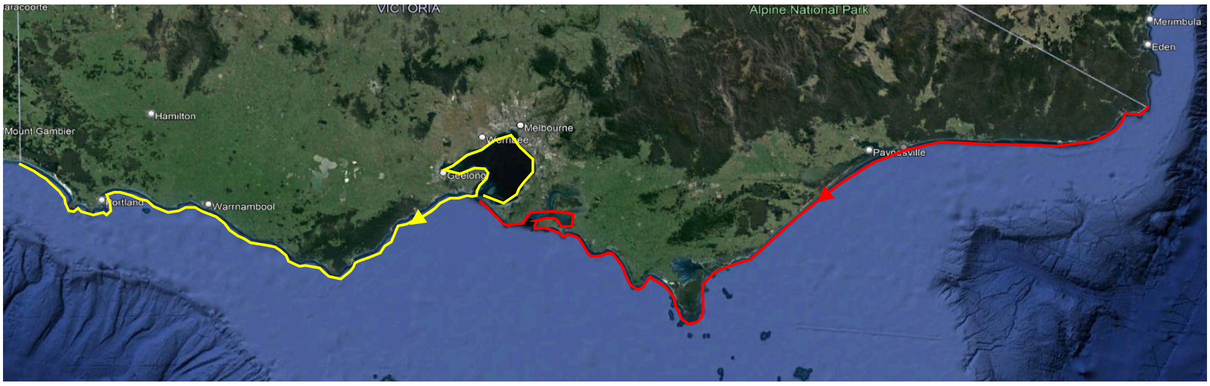

Figure Appendix A.1: Flight scheme (yellow = 24-4-2023, red = 8-4-2023)

A2 Equipment

The aerial survey was undertaken using a Cessna 172 airplane (see Figure Appendix A.2) chartered from Peninsula Aero Club. The airplane can carry up to four people, including a pilot, has a single engine and can fly up to 175 km/hr.

A Nikon D5300 camera with a focal length of 35 mm was used to take photographs. Photographs were taken at 3 to 5 second intervals to achieve a reasonable overlap. The interval of taking photographs varies depending on the irregularity of the shoreline (e.g. straight coastline versus shoreline transitioning from headlands to embayments). The location of the airplane was recorded at 10 second intervals using a Garmin GPSmap 64s.

Figure Appendix A.2: Similar Cessna 172 airplane

A3 Processed photographs

The photographs were sorted, cleaned up and further processed using the program GeoSetter. The photographs were geo-tagged using this program which links the recorded GPS coordinates to the photographs based on synchronised time of both the GPS device and camera. The program was then used to create GoogleEarth files (i.e. *.kmz), which allows you to see thumbnails and locations of the photographs in GoogleEarth or other GIS programs (see example in Figure Appendix A.3).

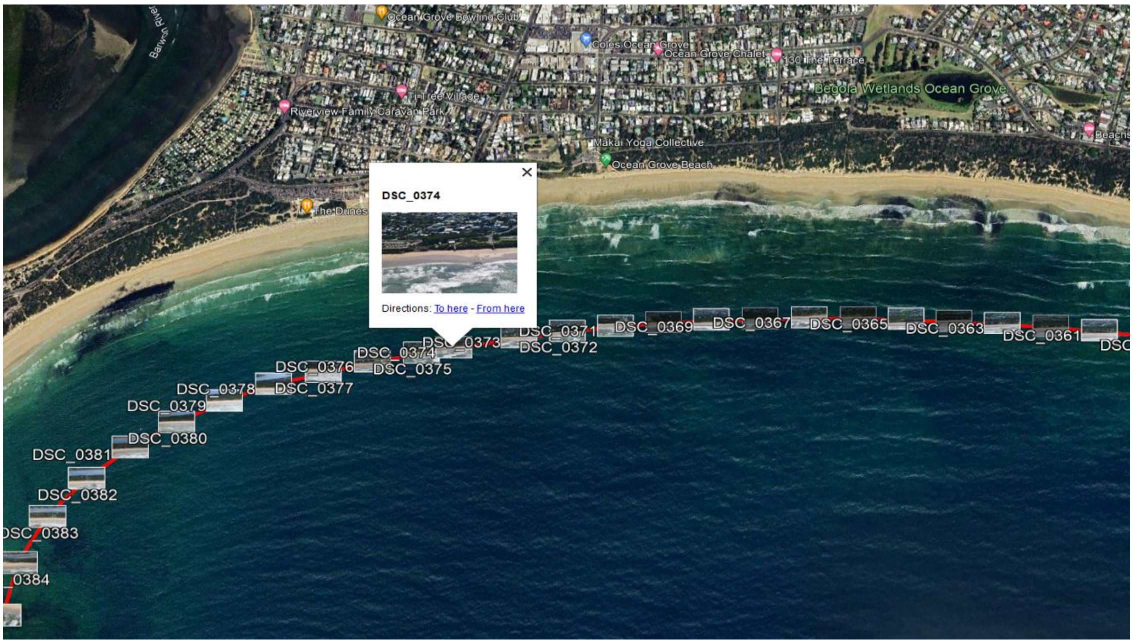

*Figure Appendix A.3: Example of *.kmz file showing locations and thumbnails of photographs in vicinity of Ocean Grove*

Some examples of aerial survey photographs are shown in Figure Appendix A.4.

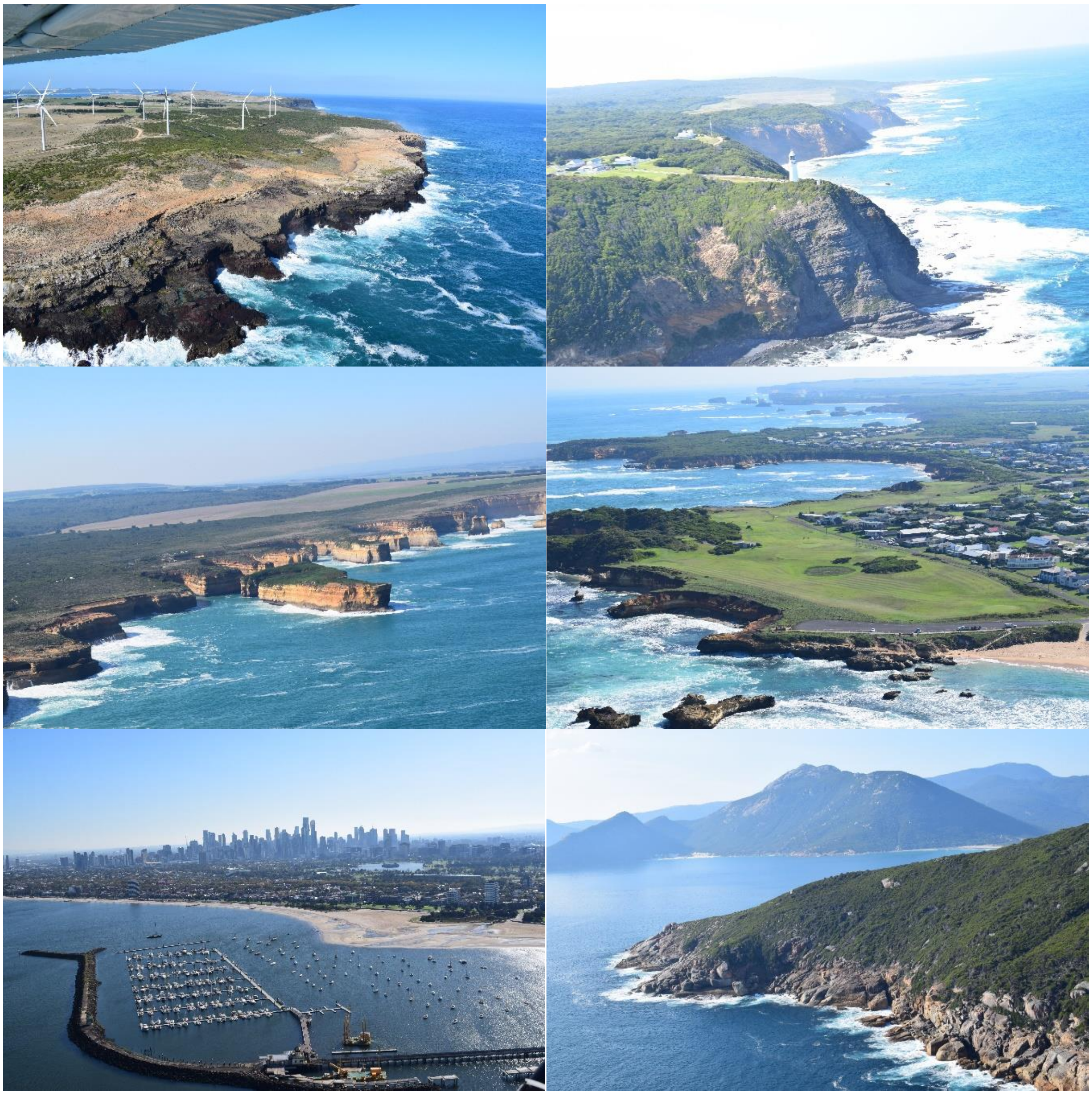

Figure Appendix A.4: Example photographs of aerial survey taken at Cape Bridgewater (top left), Cape Otway (top right), 12 Apostles (middle left), Peterborough (middle right), Melbourne (bottom left) and Wilsons Prom (bottom right)

Appendix B Summary of long-term cliff toe erosion rates

Appendix B Table: Summary of long-term cliff toe erosion rates

Compartment	Sub Section ID	Orientation	Exposure	Start Year	End Year	Mean Section Rate (m/year)	Upper Section Rate (m/year)	Confidence	Confidence rank	Source	Geological Unit Type	Material Susceptibility
Mallacoota Inlet	1	E	High	2010	2020	0.18	0.41	Medium	2	T+T (2023)	Devonian aged Granite/Granodiorite	Low
Mallacoota Inlet	3	SE	High	2010	2020	0.12	0.34	High	3	T+T (2023)	Pinnak Sandstone	Low-Med
Mallacoota Inlet	4	ESE	High	2010	2020	0.26	0.61	Medium	2	T+T (2023)	Pinnak Sandstone	Low-Med
Cann River	2	S	High	2010	2020	0.31	0.63	Low	1	T+T (2023)	Pinnak Sandstone	Low-Med
Cann River	3	SE	High	2010	2020	0.19	0.53	Low	1	T+T (2023)	Silurian to Devonian aged Granite/Granodiorite	Low
Snowy River	2	W	High	2010	2020	0.34	1.19	Medium	2	T+T (2023)	Silurian to Devonian aged Granite/Granodiorite	Low
Gippsland Lakes	1	SSE	High	1975	2021	0.04	0.06	High	3	T+T (2023)	Sale Group	Med
Corner Inlet	1	W	Moderate	1945	2019	0.05	0.16	Low	1	T+T (2023)	Devonian aged Granite/Granodiorite	Low
Corner Inlet	2	NW	Moderate	1945	2019	0.35	0.35	Low	1	T+T (2023)	Devonian aged Granite/Granodiorite	Low
Corner Inlet	3	ESE	Moderate	1945	2019	0.49	0.52	Low	1	T+T (2023)	Devonian aged Granite/Granodiorite	Low
Wilsons Promontory (east)	4	NNE	Moderate	1945	2019	0.21	0.29	Medium	2	T+T (2023)	Devonian aged Granite/Granodiorite	Low
Wilsons Promontory (southwest)	6	WSW	High	1945	2019	0.21	0.43	Low	1	T+T (2023)	Devonian aged Granite/Granodiorite	Low
Waratah Bay	1	SSE	High	2000	2018	0.25	0.49	Medium	2	T+T (2023)	Murrindindi Supergroup	Low-Med
Venus Bay	2	SSE	High	1950	2020	0.08	0.15	High	3	T+T (2023)	Wonthaggi Formation	Med
Venus Bay	3	WSW	High	1950	2018	0.07	0.17	High	3	T+T (2023)	Murrindindi Supergroup	Low-Med
Venus Bay	N/A	N/A	High	1950	2020	0.07	0.10		0	T+T (2019)	Wonthaggi Formation	Med
Cape Woolamai-Cape Paterson	1	WSW	Low	1977	2019	0.05	0.10	High	3	T+T (2023)	Wonthaggi Formation	Med
Cape Woolamai-Cape Paterson	3	SSW	High	1977	2019	0.11	0.24	High	3	T+T (2023)	Wonthaggi Formation	Med
Cape Woolamai-Cape Paterson	N/A	N/A	High	1950	2020	0.07	0.10		0	T+T (2019)	Wonthaggi Formation	Med
Cape Woolamai-Cape Paterson	2	S	High	1977	2020	0.10	0.20	High	3	T+T (2023)	Wonthaggi Formation	Med
Phillip Island (south)	1	SSE	High	1977	2020	0.05	0.17	Medium	2	T+T (2023)	Cenozoic aged Volcanics	Med
Phillip Island (south)	3	WSW	High	1977	2020	0.15	0.42	Medium	2	T+T (2023)	Devonian aged Granite/Granodiorite	Low
Western Port	4	WSW	Low	1969	2020	0.05	0.12	High	3	T+T (2023)	Cenozoic aged Volcanics	Med
Western Port	7	NW	Moderate	2000	2020	0.10	0.30	Low	1	T+T (2023)	Cenozoic aged Volcanics	Med
Cape Schank-Flinders	1	SE	High	2001	2021	0.20	0.40	Medium	2	T+T (2023)	Dune Deposits	High
Cape Schank-Flinders	2	SSE	High	2001	2021	0.26	0.63	Low	1	T+T (2023)	Cenozoic aged Volcanics	Med
Nepean Peninsula	1	SW	High	2001	2021	0.16	0.50	Medium	2	T+T (2023)	Dune Deposits	High
Port Phillip Bay (east)	1	SW	Moderate	1930	2021	0.04	0.06	High	3	T+T (2023)	Sandringham Sandstone	High
Port Phillip Bay (east)	2	SE	Low	1930	2021	0.07	0.14	High	3	T+T (2023)	Sandringham Sandstone	High
Port Phillip Bay (east)	3	NW	Moderate	1949	2021	0.02	0.06	High	3	T+T (2023)	Sandringham Sandstone	High
Port Phillip Bay (east)	4	W	Moderate	1949	2021	0.05	0.13	High	3	T+T (2023)	Sandringham Sandstone	High
Port Phillip Bay (east)	6	SW	Low	1951	2021	0.05	0.15	Low	1	T+T (2023)	Devonian aged Granite/Granodiorite	Low
Port Phillip Bay (east)	5	NW	Low	1951	2021	0.06	0.13	Low	1	T+T (2023)	Devonian aged Granite/Granodiorite	Low
Port Phillip Bay (west)	1	ESE	Moderate	1939	2021	0.07	0.19	High	3	T+T (2023)	Dune Deposits	High
Torquay	1	ESE	High	1979	2021	0.13	0.35	High	3	T+T (2023)	Demons Bluff Formation	Med-High
Torquay	2	SSE	High	1979	2021	0.18	0.48	High	3	T+T (2023)	Demons Bluff Formation	Med-High

Compartment	Sub Section ID	Orientation	Exposure	Start Year	End Year	Mean Section Rate (m/year)	Upper Section Rate (m/year)	Confidence	Confidence rank	Source	Geological Unit Type	Material Susceptibility
Torquay	5	E	Moderate	1962	2019	0.08	0.16	High	3	VCMP (2023)	Demons Bluff Formation	Med-High
Torquay	6	SE	Moderate	1962	2019	0.08	0.31	High	3	VCMP (2023)	Demons Bluff Formation	Med-High
Torquay	7	SSE	High	2007	2019	0.29	0.62	High	3	VCMP (2023)	Demons Bluff Formation	Med-High
Great Ocean Road	2	SE	High	1947	2019	0.22	0.56	Low	1	T+T (2023)	Eumeralla Formation	Low-Med
Great Ocean Road	3	S	High	1947	2019	0.20	0.62	Low	1	T+T (2023)	Eumeralla Formation	Low-Med
Great Ocean Road	5	E	High	1947	2019	0.15	0.29	High	3	T+T (2023)	Eumeralla Formation	Low-Med
Great Ocean Road	6	ESE	High	1947	2019	0.07	0.13	High	3	T+T (2023)	Eumeralla Formation	Low-Med
Great Ocean Road	7	SE	High	1979	2021	0.14	0.35	High	3	T+T (2023)	Eumeralla Formation	Low-Med
Great Ocean Road	1	S	High	1947	2019	0.19	0.44	Medium	2	T+T (2023)	Bridgewater Formation	High
Port Campbell	2	SW	High	1947	2014	0.22	0.70	High	3	Bezore et al. (2016)	Heytesbury Group	Med-High
Port Campbell	1	SW	High	1947	2019	0.13	0.42	High	3	T+T (2023)	Heytesbury Group	Med-High
Port Campbell	3	SW	High	1947	2019	0.33	0.58	Low	1	T+T (2023)	Bridgewater Formation	High
Port Campbell	4	S	High	1947	2019	0.45	0.72	Low	1	T+T (2023)	Eumeralla Formation	Low-Med
Warrnambool	1	SW	High	1947	2021	0.05	0.13	High	3	T+T (2023)	Bridgewater Formation	High
Warrnambool	2	SW	High	1947	2020	0.14	0.29	High	3	T+T (2023)	Heytesbury Group	Med-High
Portland Bay	2	S	High	1972	2019	0.09	0.17	Low	1	T+T (2023)	Newer Volcanic Group	Low
Portland Bay	3	NE	Moderate		2019	0.10	0.20	High	3	T+T (2023)	Dune Deposits	High
Portland Bay	4	S	High	1948	2020	0.05	0.16	Medium	2	T+T (2023)	Bridgewater Formation	High

Appendix C Digital data

The following digital datasets are provided as part of this report and have been provided in the form of Esri shapefiles,Google Earth kmz files, as well as text (txt) files:

- **ASCCIE polygons for the following scenarios:**
    - Present-day (naming convention VIC0101_ASCCIE_Present)
    - 2040 allowing for 0.2 m sea level rise (naming convention VIC0101_ASCCIE_2040)
    - 2070 allowing for 0.5 m sea level rise (naming convention VIC0101_ASCCIE_2070)
    - 2100 allowing for 0.8 m sea level rise (naming convention VIC0101_ASCCIE_2100_1)
    - 2100 allowing for 1.1 m sea level rise (naming convention VIC0101_ASCCIE_2100_2)
    - 2100 allowing for 1.4 m sea level rise (naming convention VIC0101_ASCCIE_2100_3)

  Note that ASCCIE polygons extend from the present-day toe (i.e. seaward boundary of the polygon) to the future crest position (i.e. landward boundary of the polygon).

- **ASTaR polygons for the present day**

  Note that ASTaR polygons extend from the present-day crest (i.e. landward boundary of the polygon) to the seaward runout or present-day toe position (i.e. seaward boundary of the polygon). The naming convention for this is VIC0101_ASTaR.

- **Transects (named InputData_Transects_) which includes the analysis inputs as metadata, namely:**
    - DEECA transect ID (field: id)
    - Secondary compartment number (field: SecondaryC)
    - Geology type (field: Geological)
    - Assessed stable angle (field: StableAngle)
    - Adopted *m* value (field: mvalue)
    - Historic long-term regression rate (field: LRR)
    - Future toe regression distances for the six scenarios (fields: Toe_2025, Toe_2040 etc.)

In addition to the digital ASCCIE and ASTaR data, the aerial survey data (refer to Appendix A) have been provided in digital format including the following:

- **Google earth kmz files of photograph thumbnails**
- **Processes photographs**

REPORT

Tonkin+Taylor

Victoria Coastal Cliffs Assessment

Stage 2 - Risk assessment

Prepared for
Department of Environment, Energy and Climate Action (DEECA)
Prepared by
Tonkin & Taylor Pty Ltd
Date
September 2023
Job Number
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Document control

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Sept 2023	1	Draft report for client review	E. Singh J. Curtis	R. Reinen-Hamill D. Glover	D. Glover
Sept 2023	2	Final report	E. Singh J. Curtis	R. Reinen-Hamill D. Glover	D. Glover

Distribution:

Department of Environment, Energy and Climate Action (DEECA)	1 copy
Tonkin & Taylor Pty Ltd (FILE)	1 copy

Table of contents

Glossary of terms

Term	Description
AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ASCCIE	Area Susceptible to Coastal Cliff Instability and/or Erosion
ASTaR	Area Susceptible to Talus Runout
CD	Chart Datum
Cliff instability distance	Horizontal distance between the cliff toe and cliff crest
Cliff toe regression	Landward movement of coastal cliff toe as a result of coastal processes
Coastal accretion	A long-term trend of shoreline advance and/or gain of beach sediment volume
Coastal erosion	Landward movement of the shoreline which may include both long-term retreat over several years or decades and short-term loss of sediment due to storms
Coastal hazard	Where coastal processes adversely impact on something of value resulting in a hazard
DEECA	Department of Environment, Energy and Climate Action
DEM	Digital Elevation Model
GIS	Geospatial Information Service
LiDAR	Light Detection and Ranging – a method of remotely deriving land elevation, generally from an aeroplane
LT	Long-term erosion component
LT_H	Historical long-term erosion component
LT_F	Future long-term erosion component
m	Sea level rise response factor for cliffs
MHWS	Mean high water springs – a measure of high tide based on a statistical exceedance of high tides in a month
MHWS-10	Water level exceeded by 10% of the MHWSs
MLWS	Mean low water spring – a measure of low tide based on a statistical exceedance of low tides in a month
MSL	Mean sea level. Sea level averaged over a long (multi-year) period
RL	Reduced Level (Auckland Vertical Datum 1946)
SLR	Sea level rise. Trend of annual mean sea level over timescales of at least three or more decades. Must be tied to one of the following two types: global – overall rise in absolute sea level in the world's oceans; or relative – net rise relative to the local landmass (that may be subsiding or being uplifted)
SL	SLR component
SSP	Shared Socio-economic Pathways (SSPs) are scenarios used to derive greenhouse gas concentration trajectories adopted by the IPCC for its sixth Assessment Report (AR6) in 2021
T+T	Tonkin + Taylor (Tonkin & Taylor Ltd.)
VLM	Vertical land movements
VCMP	Victoria Coastal Monitoring Program
Risk	Risk is defined as the "effect of uncertainty on objectives" and is the product of likelihood and consequence. Where likelihood is the probability of a coastal hazard occurring, and consequence is the impact of the coastal hazard on coastal values and uses.

1 Introduction

1.1 Engagement

Tonkin & Taylor Pty Ltd (T+T) has been engaged by the Victorian Department of Energy Environment and Climate Action (DEECA) to assess the hazards associated with cliffs along the Victorian Coastline. The work has been delivered under the Coastal Professional Advisory and Services Panel (CMS102426) and signed Purchase Order CMS105959 dated 1 February 2023.

DEECA is interested in enhancing the understanding of cliff types across the State, active processes such as erosion, instabilities or slumping, and associated risks for public land, assets and safety. Therefore, DEECA engaged T+T to undertake a two-stage assessment, including:

1. Identification of areas susceptible to coastal cliff related erosion and instabilities (Stage 1)
2. Coastal cliff risk assessment (this report, Stage 2)

This document sets out the risk assessment methodology used and the results of the risk assessment, which includes the classification of risk across several timeframes (i.e. short-term, and long-term) and climate change scenarios to identify areas currently at risk, or in the near future or long-term (e.g. 100 years).

The assessment is a second-pass, regional assessment, which will feed into more detailed assessments by coastal land managers. The approach taken is top-down and provides a coastal compartment[1] view of risk. Results provide a single risk classification (for each timeframe) with transparency on how this classification was derived (e.g. multi-criteria analysis). The approach and the purpose of the assessment is set out below, the risk assessment methodology used is set out in Section 2 and the results of the assessment are provided in Section 3.

2 Approach

2.1 Technical Inputs to risk assessment

The coastal cliff risk assessment draws on hazard data derived in the first stage of the assessment. Stage 1 of the assessment identified areas susceptible to coastal cliff related erosion and instabilities and areas susceptible to talus runout (ASCCIE and ASTaR), these results were utilised as inputs for the determination of risk ratings for each coastal compartment as detailed in this report. The methodology used to derive ASCCIE and ASTaR inputs is detailed in the Stage 1: Assessment of Areas Susceptible to Coastal Cliff Instability and/or Erosion (ASCCIE) report.

2.2 Risk management process

T+T followed the well-established risk assessment and management framework outlined in the Victoria's Resilient Coast Framework and Guidelines[2], based on ISO 31000:2018[3], refer to Figure 2.1. The treatment of risks was beyond the scope of this assessment.

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[1] Coastal compartments are spatial units, based on landforms and sediment transport processes, and provide a foundation for coastal process/hazard assessments. This assessment uses the 23 secondary compartments that make up the Victorian coastline, as per DEECA (2022).

[2] DEECA (2023). Victoria's Resilience Coast – Adapting for 2100+. Framework and Guidelines: A strategic approach to coastal hazard risk management and adaptation.

[3] International Organization for Standardization, 2018, Australian Standard AS ISO 31000:2018 Risk Management – Guidelines.

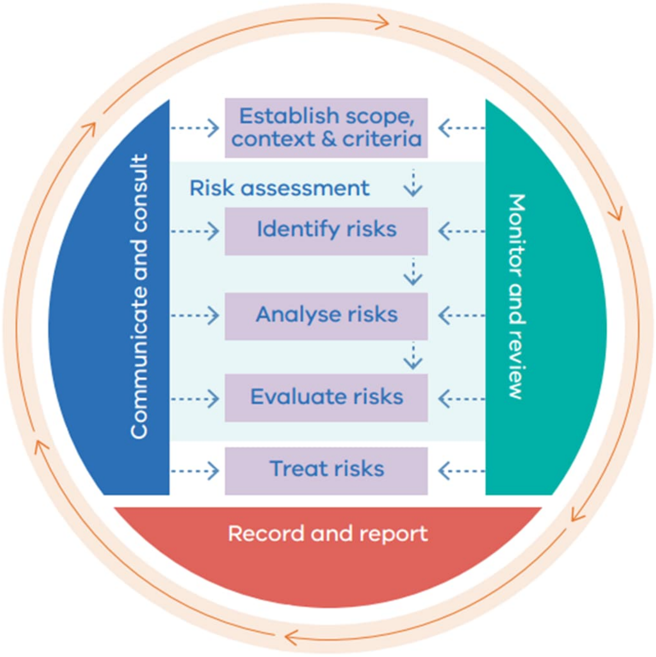

Figure 2.1: Risk Management Process (ISO 31000:2018) (source: DEECA (2023))

2.3 Communicate and consult

2.3.1 Clarification of the purpose and proposed approach to the risk assessment

Prior to commencing the risk assessment, a review and confirmation of the risk assessment purpose and approach was undertaken. This included a discussion with DEECA on what they want the risk assessment to focus on (e.g. risk to public safety and/or risk to assets on Crown land) and determining the availability of data to undertake the assessment (e.g. built assets, park services/land use, visitor numbers or culturally significant areas).

Following the review and endorsement of the methodology a desktop-based risk assessment was undertaken. The assessment involved a GIS exercise using developed Areas Susceptible to Coastal Cliff Instability and/or Erosion (ASCCIE) and Area Susceptible to Talus Runout (ASTaR) data, and digital asset and land information, to classify risks using the endorsed approach.

2.3.2 Workshop with DEECA team to test and refine risk assessment

Upon completion of the risk assessment, an online workshop was organised to present preliminary results and gather feedback from DEECA. The workshop was facilitated by our risk hazard specialists and geospatial analysts.

2.3.3 Refine risk assessment outputs and recommendations

Following the workshop, the risk assessment process was refined, and outputs finalised. Recommendations to support coastal land managers with risk management in coastal cliff environments were developed. These recommendations are framed in the Victorian Policy context and complement/align to the range of actions already underway as business as usual by land managers.

2.4 Establish scope, context and criteria

An essential first stage of any risk management process is establishing the context. T+T consulted with DEECA to confirm the parameters within which coastal erosion risk must be managed, including:

1. Objective of the risk assessment: To evaluate the likelihood and consequence of cliff instability to support risk management in areas with coastal cliffs. This includes the classification of risk across the determined timeframes and climate change scenarios.
2. Scale of the risk assessment: Second-pass, regional assessment providing a top-down coastal compartment view of risk which. The outputs of second-pass risk assessments can be used to support discussion among stakeholders regarding coastal erosion and instability risks, broader climate change risks and the development of adaptation pathways within Victoria's coastal compartments. However, it should be noted that this assessment has been undertaken at a high level (regional/state-wide scale) and is not appropriate for local scale planning. The data from this assessment may be superseded by local scale and site-specific assessments undertaken by a suitably qualified and experienced practitioner. The assessment is based on available data, tools and understanding of coastal processes.

   Uncertainty may be introduced to the assessment by:

   - an incomplete understanding of the parameters influencing the areas susceptible to coastal cliff instability and/or erosion
   - errors introduced in the collection and processing of data, and/or scale of data
   - scale of assessment and variance in the processes occurring alongshore
   - limited long-term toe erosion rates
   - other hazards such as land based geotechnical instability, or planning and landscape impacts, etc. that are not accounted for within the ASCCIE
   - adopted methodologies
   - deterministic vs probabilistic approach
   - the scale of the mapping.
3. Timeframes and scenarios: The timeframes and scenarios have been aligned with timeframes included in DEECA (2022) and are shown in Table 2.1. While time periods are used, it is recognised that there are a range of climate change trajectories and uncertainties regarding the impact of climate change on hazards.

Table 2.1: Timeframes and sea level rise scenarios

Scenario	Timeframe	Sea level rise	Relevance of scenario
Present-day ASCCIE	Present day	0 m	Considered for public safety purposes
ASCCIE-2040	2040	0.2 m	Public safety purposes for land possibly susceptible within the next 15-20 years
ASCCIE-2080	2070	0.5 m	Public safety purposes for land possibly susceptible within the next 50- years
ASCCIE-2100-1	2100	0.8 m	Long-term coastal adaptation purposes considering at least 75 years
ASCCIE-2100-2	2100	1.1 m	Long-term coastal adaptation purposes considering at least 75 years
ASCCIE-2100-3	2100	1.4 m	Long-term coastal adaptation purposes considering at least 75 years
Cliff runout susceptibility	Present day	N/A	Considered for public safety purposes

4 Coastal values at risk: Public safety is the number one priority for this risk assessment. Secondly, risk to social, environmental, cultural and economic values were also assessed, using a short-list of land and assets to represent these values. This assessment was limited to Crown land and assets/infrastructure on Crown land.

2.5 Risk assessment

2.5.1 Identify risks

T+T has been engaged by DEECA to assess the hazards associated with cliffs along the Victorian Coastline. The purpose of the second-pass assessment is firstly to identify ASCCIE and ASTaR, and secondly to assess the cliff instability risk to provide advice on managing these risks. It is understood that DEECA intends to use this information to support risk management in areas with coastal cliffs, strategic adaptation planning, third-pass local coastal hazard assessments, and other local risk mitigation actions.

2.5.2 Analyse risk

Risk analysis can be undertaken with varying degrees of detail and complexity, depending on the purpose of the analysis, the availability and reliability of information, and the resources available[4]. The scope of this study is a second-pass, regional assessment providing a view of risk at secondary compartment scale . The following sections outline the risk analysis method.

2.5.3 Evaluate risks

The evaluation of risks supports decision making. The risk analysis results are compared against risk criteria/tolerance to determine actions required.

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[4] ISO 31000:2018

2.6 Coastal compartments

As defined in DEECA (2023), coastal compartments are spatial units, based on landforms and sediment transport processes, and provide a foundation for coastal process/hazard assessments. The Victorian coast is comprised of six primary compartments and 23 secondary compartments (

This study has been undertaken as a second-pass assessment at a regional scale. This is in line with the suitability for use for secondary coastal compartments, which are at an appropriate scale for regional planning and engineering decisions.

2.7 Coastal values and assets

Table 2.3 lists the various coastal values and associated land/assets that were used as a proxy to represent each value. The land and assets considered in this study are limited to Crown land and the critical/key infrastructure/assets present on this land. Coastal values have been adapted from the example consequence themes provided in DEECA (2023)[5]. It should be noted that this second-pass assessment is based only on statewide data available at the time of the assessment. It is anticipated that Subsequent third-pass assessments will include further consideration of site-specific values sourced from local management plans and engagement with local communities and Traditional Owners.

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[5] Sourced from DEECA (2023). Victoria's Resilience Coast – Adapting for 2100+. Framework and Guidelines: A strategic approach to coastal hazard risk management and adaptation.

Table 2.2: Victorian primary and secondary coastal compartments[6]

Primary compartment	Secondary compartment	ID	Included area
Western Victorian Coast	Discovery Bay	VIC06.04	From Cape Nelson to Danger Point (Brown Bay, SA).
	Portland Bay	VIC06.03	From Port Fairy (Griffiths Island) to Cape Nelson.
	Warrnambool	VIC06.02	From Peterborough (Wild Dog Cove) to Port Fairy (Griffiths Island).
	Port Campbell	VIC06.01	From Cape Otway to Peterborough (Wild Dog Cove).
Otway Coast	Great Ocean Road	VIC05.02	Road From Split Point to Cape Otway.
	Torquay	VIC05.01	From Point Lonsdale to Split Point.
Port Phillip	Port Phillip Bay (mouth)	VIC04.11	From Point Lonsdale to Point Nepean .
	Port Phillip Bay (west)	VIC04.10	From Williamstown to Point Lonsdale.
	Port Phillip Bay (east)	VIC04.09	From Point Nepean to Williamstown.
	Mornington Peninsula	VIC04.08	From Cape Schanck to Point Nepean.
	Cape Schanck-Flinders	VIC04.07	From West Head to Cape Schanck.
	Western Port	VIC04.06	From Point Grant to West Head.
	Phillip Island (south)	VIC04.05	From Cape Woolamai to Point Grant.
	Kilcunda	VIC04.04	From Cape Paterson to Cape Woolamai.
	Venus Bay	VIC04.03	From Cape Liptrap to Cape Paterson.
	Waratah Bay	VIC04.02	From Tongue Point to Cape Liptrap.
	Wilsons Promontory (southwest)	VIC04.01	From South Point to Tongue Point.
Wilsons Promontory	Wilsons Promontory (east)	VIC03.01	From Entrance Point to South Point.
Ninety Mile Beach	Corner Inlet	VIC02.03	From McLaughlins Beach Outlet to Entrance Point.
	Gippsland Lakes	VIC02.02	From Red Bluff to McLaughlins Beach outlet.
	Snowy River	VIC02.01	From Cape Conran to Red Bluff.
Cape Howe	Croajingolong	VIC01.02	From Rame Head to Cape Conran.
	Mallacoota Inlet	VIC01.01	From Cape Howe to Rame Head.

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[6] Sourced from DEECA (2023). Victoria's Resilience Coast – Adapting for 2100+. Framework and Guidelines: A strategic approach to coastal hazard risk management and adaptation.

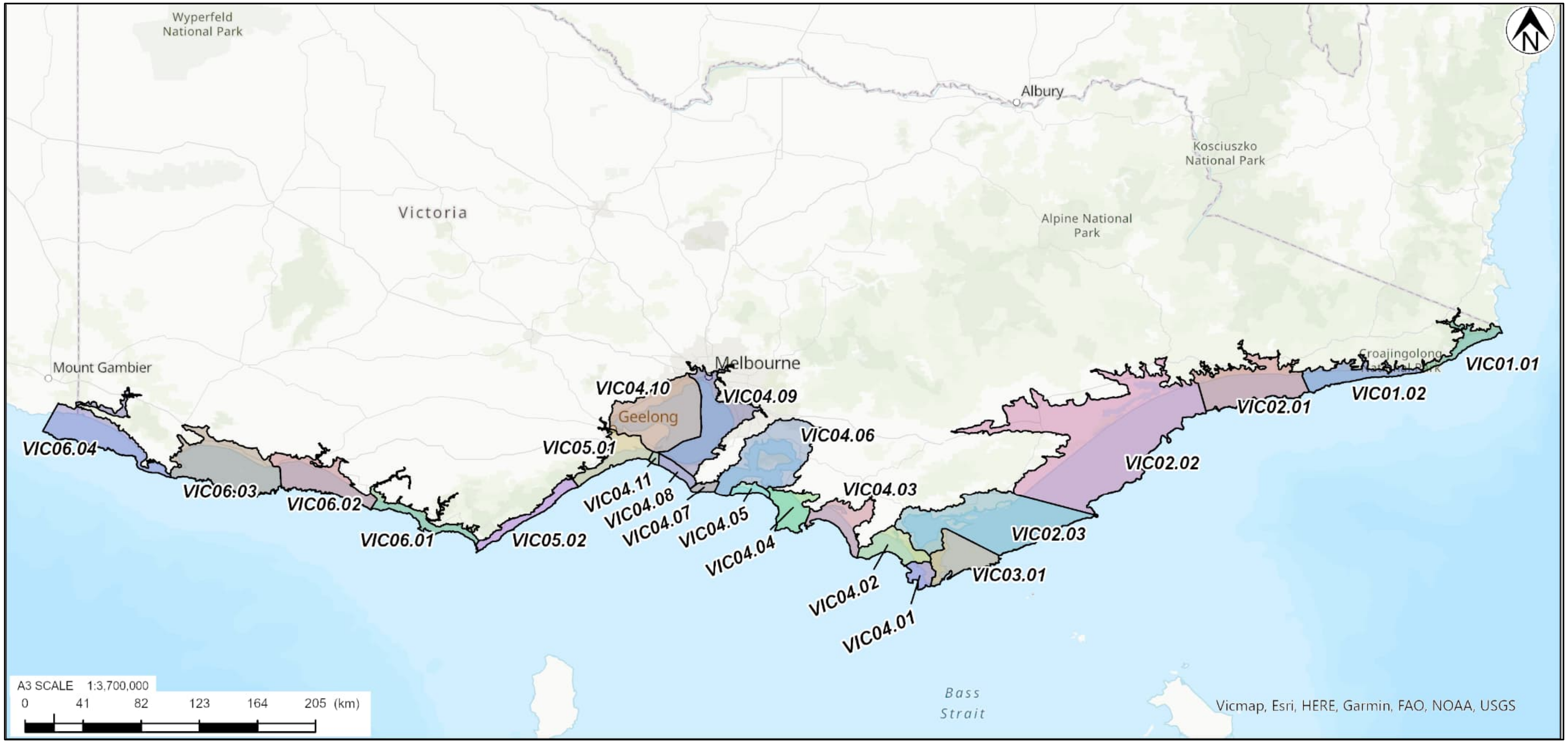

Figure 2.2: Victorian secondary coastal compartments.

Table 2.3: Coastal values and list of associated land and assets

Value	Social		Environmental	Cultural	Economic		
	Human health and safety	Access/ lifestyle			Public property and facilities	Infrastructure	Economy and growth
Asset type / proxy to represent value	Assume people have access to all coastal cliff areas.	Park and reserve facilities.	Park and ecological land.	Significant sites[7].	Crown property values.	Infrastructure.	Tourism Private property.
Specific assets from data available	Beach facilities, community spaces, recreational resource, sport facility, landmark, trails.	Beach facilities, community spaces, recreational resource, sport facility, landmark.	Park and reserve land Forested areas.	Monument, historic site, place of worship.	Crown property parcels and values.	Pipelines (water and other), powerlines, roads, rail line and stations, runways.	Community spaces, landmarks, private property parcels.
Layers from VCCRAP.gdb	BEACH_FACILITIES_SAFETY COASTAL_POI FOI_POINT FOI_POLYGON TR_ROAD	BEACH_FACILITIES_SAFETY COASTAL_POI FOI_POINT FOI_POLYGON	PARKRES TREE_DENSITY	COASTAL_POI FOI_POINT FOI_POLYGON	V_PROPERTY_MP	POWER_LINE TR_ROAD TR_RAIL TR_RAIL_INFRASTRUCTURE TR_AIR_INFRA_AREA_POLYGON HY_WATER_STRUCT_LINE FOI_LINE	COASTAL_POI FOI_POINT FOI_POLYGON V_PROPERTY_MP

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[7] Available information about significant sites was limited to the attribute data included in COASTAL_POI, FOI_POINT and FOI_POLYGON layers. From this data, monuments, historic sites, and places of worship were identified as sites of cultural significance. A lack of information pertaining to sites of cultural significance for Traditional Owners is acknowledged as a limitation of the assessment. Consultation with Traditional Owners should be prioritised as part of future third-pass assessments.

3 Risk assessment methodology

3.1 Risk framework

The risk assessment framework for this study is based on AS 5334:2013[8] (see Figure 3.1), which defines risk as the "effect of uncertainty on objectives" and utilises likelihood and consequence to determine risk. Where likelihood is the probability of a coastal hazard occurring, and consequence is the impact of the coastal hazard on coastal values and uses, e.g. social, cultural, economic, and environmental (DEECA, 2022).

Figure 3.1: Risk assessment framework adopted from AS 5334:2013.

3.2 Likelihood

The first step of the risk assessment was the development of hazard extents and likelihoods based on the mapped ASCCIE and ASTaR. Likelihood (see Table 3.1) defines the potential frequency of occurrence of a hazard occurring, and these were mapped to identify areas potentially at risk to cliff instability and/or erosion related to a likelihood. In this assessment a qualitative measure of likelihood was used, based on the guidance in AS 5334:2013.

Table 3.1: Qualitative measures of likelihood[9]

Rating	Event recurrence*
Almost certain	Has happened several times in the past year and in each of the previous 5 years *OR* Could occur several times per year.
Likely	Has happened at least once in the past year and in each of the previous 5 years *OR* May arise about once per year.
Possible	Has happened during the past 5 years but not every year *OR* May arise once in 25 years.
Unlikely	May have occurred once in the last 5 years *OR* May arise once in 25 to 50 years.
Rare	Has not occurred in the past 5 years *OR* Unlikely during the next 50 years.

*In this context, the event is cliff instability and/or erosion.

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[8] Australian Standard AS 5334:2013 Climate change adaptation for settlements and infrastructure – A risk based approach.

[9] Adapted from AS 5334:2013.

The likelihood of each of the proposed hazard scenarios for the timeframes applied in this assessment are given in Table 3.2 and Table 3.3.

Likelihood is divided into five categories: rare, unlikely, possible, likely, almost certain. Each hazard scenario is assigned a particular likelihood and rated on this five-point scale. Three of the hazard scenarios introduced in Table 2.1 appear more than once in Table 3.2 as their likelihood increases from the present day because of sea level rise and/or climate change. The same is true for the cliff runout susceptibility scenario in Table 3.3.

which is considered increasingly likely over the long-term (2070-2100). Professional judgement was used to best define the likelihood of the hazard scenario for each timeframe. It is recognised that there are a range climate change trajectories and uncertainties regarding the impact of climate change on hazards. Note that the GIS exercise undertaken utilised only a single ASCCIE polygon (the most likely) for each timeframe in the analysis.

The calculation of risk ratings assumes the same likelihood for each assessed timeframe across all coastal compartments, irrespective of differences in the underlying geology of coastal cliffs across coastal compartments. This limitation of the assessment is tied to the regional scale and deterministic approach adopted in the development of hazard inputs. For a regional/state-wide scale assessment it is not possible to adopt a probabilistic approach due to the large scale, total length of the shoreline and lack of site-specific data to build probability distributions around each parameter. The purpose of this regional/state-wide assessment is to identify high risk areas, where it would be prudent to undertake more detailed, probabilistic assessment on a local-scale or site-specific scale.

Table 3.2: Coastal cliff top erosion susceptibility scenario likelihoods

Likelihood	Rating	Coastal cliff top erosion susceptibility		
		Short-term (Now - 2040)	Medium-term (2040 - 2070)	Long-term (2070 – 2100)
Almost certain	5			ASCCIE-2070 0.5m
Likely	4		ASCCIE-2040 0.2m	
Possible	3	Present-day ASCCIE	ASCCIE-2070 0.5m	ASCCIE-2100-1 0.8m*
Unlikely	2	ASCCIE-2040 0.2m		ASCCIE-2100-2 1.1m
Rare	1	ASCCIE-2070 0.5m	ASCCIE-2100-1 0.8m	ASCCIE-2100-3 1.4m

*This scenario aligns with the Marine and Coastal Policy 2020[10].

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[10] Department of Environment, Land, Water and Planning, 2020, *Marine and Coastal Policy*, Marine and Coastal Policy 2020 (marineandcoasts.vic.gov.au).

Table 3.3: Coastal cliff runout susceptibility scenario likelihoods

Likelihood	Rating	Coastal cliff runout susceptibility		
		Short-term (Now - 2040)	Medium-term (2040 - 2070)	Long-term (2070 – 2100)
Almost certain	5			Cliff runout susceptibility.
Likely	4		Cliff runout susceptibility.	
Possible	3	Cliff runout susceptibility.		
Unlikely	2			
Rare	1			

3.3 Consequence

Consequence is defined as the effect, results, or outcome of something occurring. Consequences can be both positive and negative, however, for this assessment the use of the term focuses on the negative. This assessment utilised the consequence categories and descriptions from DEECA (2022) and AS 5334-2013 as shown in Table 3.4.

Table 3.4: Qualitative measures of consequence - general coastal value-level descriptors[11]

Consequence of coastal hazard exposure	Social		Environmental	Cultural	Economic		
	Human health and safety	Access/ lifestyle			Property	Infrastructure	Economy and growth
Extreme	Loss of life and/or permanent disabilities.	Widespread, permanent impact with no viable alternatives.	Widespread, permanent impact.	Widespread, permanent impact.	Significant permanent damage and/or complete loss of property.	Significant permanent damage and/or complete loss of the infrastructure. Early renewal of infrastructure by >90%.	Widespread, permanent impact.
Major	Widespread serious injuries / illness.	Widespread, temporary disruption, with limited alternatives available. Full recovery expected to take several years.	Widespread, temporary impact Full recovery expected to take several years.	Widespread, temporary impact Full recovery expected to take several years.	Extensive property damage requiring major repair.	Extensive infrastructure damage requiring major repair.	Widespread, temporary impact Full recovery expected to take several years.
Moderate	Isolated serious injuries / illnesses Or Widespread minor injuries / illnesses.	Localised, temporary disruption, with limited alternatives available. Full recovery expected in < 1 year.	Localised, temporary impact Full recovery may take <1 year.	Localised, temporary impact Full recovery may take <1 year.	Limited property damage. Damage recoverable by maintenance and minor repair.	Limited infrastructure damage. Damage recoverable by maintenance and minor repair. Early renewal of infrastructure by 20–50%.	Localised, temporary impact Full recovery may take <1 year.

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[11] Adapted from DEECA (2022) and AS 5334-2013.

Consequence of coastal hazard exposure	Social		Environmental	Cultural	Economic		
	Human health and safety	Access/ lifestyle			Property	Infrastructure	Economy and growth
Minor	Isolated minor injuries and illnesses.	Isolated and temporary short-term disruption, with some alternatives available. Full recovery expected in < 1 month.	Isolated and temporary short-term impact. Full recovery expected in < 1 month.	Isolated and temporary short-term impact. Full recovery expected in < 1 month.	No permanent damage. Some minor restoration work required.	No permanent damage. Some minor restoration work required. Early renewal of infrastructure by 10–20%. Need for new/modified ancillary equipment.	Isolated and temporary short-term impact . Full recovery expected in < 1 month.
Negligible	Negligible injuries or illnesses.	Negligible disruption.	No expected impact.	No expected impact.	No property damage.	No infrastructure damage.	Negligible disruption.

Consequence was based on qualitative descriptors providing a narrative of the expected impacts. Each consequence descriptor is rated using a five-point scale (negligible, minor, moderate, major, and extreme) and are shown in Table 3.5.

Table 3.5: Consequence ratings

Consequence	Rating
Extreme	5
Major	4
Moderate	3
Minor	2
Negligible	1

When considering impact from coastal cliff erosion this study assumes total and permanent loss of land. Therefore, consequence ratings were assumed to be high and were simply determined by whether assets and/or land are within the hazard scenario footprints. Consequence ratings for key values are set out in Table 3.6 to Table 3.12.

Table 3.6: Consequence ratings for public health and safety

Consequence	Rating	Statement
Extreme	5	Assets or facilities that support public access and use exposed to hazard.
Major	4	No assets or facilities that support public access and use exposed to hazard - assumption that people could access all coastal cliff areas even without these facilities.

When considering public health and safety consequences resulting from coastal cliff instability and erosion this study assumes that the presence of assets or facilities within ASCCIE could lead to a loss of life, therefore the consequence rating in these situations is considered extreme. It is further assumed that even where no assets or facilities are present within coastal cliff hazard zones, the public will still have access, and the potential for loss of life cannot be excluded. These areas have been assigned a "major" consequence rating.

As a result of these assumptions, every section of coastal cliffs included in the study has been assigned a public health and safety consequence rating of "Major" or “extreme”.

Table 3.7: Consequence ratings for social values – access/lifestyle

Consequence	Rating	Statement
Major	4	Park and reserve land AND facilities exposed to hazard.
Moderate	3	Park and reserve land OR facilities exposed to hazard.
Negligible	1	No park and reserve or facilities exposed to hazard.

Table 3.8: Consequence ratings for environmental values

Consequence	Rating	Statement
Major	4	Park and reserve and/or forested land exposed to hazard.
Negligible	1	No park and reserve and/or forested land exposed to hazard.

Table 3.9: Consequence ratings for cultural values

Consequence	Rating	Statement
Extreme	5	Known sites of cultural significance exposed to hazard.
Moderate	3	No known sites of cultural significance exposed to hazard, however, area is part of the cultural landscape.

Table 3.10: Consequence ratings for economic values - public property and facilities

Consequence	Rating	Statement
Extreme	5	Exposure of property with total value >$25million.
Major	4	Exposure of property with total value >$10million.
Moderate	3	Exposure of property with total value >$1million.
Minor	2	Exposure of property with total value >$100,000.
Negligible	1	Exposure of property with total value <$100,000.

Table 3.11: Consequence ratings for economic values – infrastructure*

Consequence	Rating	Statement
Extreme	5	Road class code 0-2 exposed to hazard.
Major	4	Road class code 3-5 OR High voltage power line OR oil/gas pipeline exposed to hazard.
Moderate	3	Road class code 6-8 OR Low voltage power line OR water pipeline exposed to hazard.
Minor	2	Road class code >8 exposed to hazard.
Negligible	1	No infrastructure exposed to hazard.

*Including roads, water/oil/gas pipes and power lines.

Table 3.12: Consequence ratings for economic values – tourism and private property

Consequence	Rating	Statement
Extreme	5	Tourist sites OR Private property exposed to hazard.
Negligible	1	No tourist sites OR Private property exposed to hazard.

3.4 Risk

Risk, in the context of this assessment, is generated by combining the likelihood rating and the consequence rating for each of the coastal values. This was done for each coastal compartment and for each timeframe.

Table 3.13 outlines an example matrix used to achieve coastal value level risk scores and an example of risk tolerance scores is shown in Table 3.14. This risk matrix is aligned with AS 5334 2013 and is weighted towards higher consequence ratings. However, there is no one size fits all. Ultimately risk tolerance needs to be determined by DEECA and other key stakeholders. Completing the process for all the coastal values yielded a risk rating on a 25-point scale for each coastal value.

Table 3.13: Example risk matrix demonstrating the relationship between likelihood and consequence

Risk			Consequence				
			Negligible	Minor	Moderate	Major	Extreme
			1	2	3	4	5
Likelihood	Rare	1	Low (1)	Low (2)	Medium (3)	Medium (4)	Significant* (5)
	Unlikely	2	Low (2)	Medium (4)	Medium (6)	Significant (8)	High (10)
	Possible	3	Medium (3)	Medium (6)	Significant (9)	High (12)	Extreme (15)
	Likely	4	Medium (4)	Significant (8)	High (12)	Extreme (16)	Extreme (20)
	Almost certain	5	Medium (5)	High (10)	Extreme (15)	Extreme (20)	Extreme (25)

*Rare likelihood (1) x extreme consequence (5) has been modified from medium to significant due to low risk tolerance for extreme consequences, even for rare likelihoods.

Table 3.14: Example risk tolerance

Risk score	Risk tolerance
Low	Low risk, no action required.
Medium	Medium risk, routine management.
Significant	Significant risk, requiring further assessment, planning and actions to manage risk to a level that is as low as reasonably practicable within 5 years.
High	High risk, requiring further assessment, planning and actions to manage risk to a level that is as low as reasonably practicable within 2 years.
Extreme	Extreme risk, requiring further assessment, planning and actions to manage risk to a level that is as low as reasonably practicable within 1 year.

Table 3.15: Example of the resulting risk scores for a coastal value within a particular coastal compartment

Coastal compartment 1 - risk to social values		
Short-term	Medium-term	Long-term
Significant	Significant	High

3.5 Coastal compartment risk aggregation

To provide a single view of risk for each coastal compartment a multi-criteria analysis (MCA) was carried out using the risk scores from each coastal value, summing the risk scores to get an aggregated risk score (see Table 3.16). Table 3.17 shows an example of aggregated risk rating thresholds.

Table 3.16: Example aggregated risk matrix for a single timeframe

Coastal compartment	Risk to life	Risk to social values	Risk to environmental values	Risk to economic values	Risk to cultural values	Aggregated risk score
1	High (12)	Extreme (20)	Extreme (25)	High (12)	High (12)	81
2	Medium (6)	Medium (6)	High 10)	Medium (4)	High (12)	38
3	Extreme (25)	Significant (9)	Significant (9)	Medium (4)	High (12)	59
4	High (12)	Medium (4)	Medium (4)	Significant (9)	Medium (4)	33

Table 3.17: Example aggregated risk rating tolerance thresholds

Aggregated risk rating	Aggregated risk score
Low	<37
Medium	37-66
Significant	67-97
High	98-132
Extreme	>132

3.6 Example short-term risk rating for sample coastal compartment

Figure 3.2 depicts ASCCIE and ASTaR layers overlaid with intersecting asset data which has been utilised in the calculation of consequence ratings within the Great Ocean Road coastal compartment. Short term risk ratings for each coastal value for the Great Ocean Road coastal compartment are provided in Table 3.18 with an explanation of the underlying consequence scores. Note that likelihood scores are consistent across all coastal values within each timeframe (Table 3.2 and Table 3.3).

Figure 3.2: Risk rating example for Great Ocean Road coastal compartment.

Table 3.18: Short-term risk rating calculations for VIC5.02 Great Ocean Road

Coastal value	Consequence rating	Likelihood rating	Risk rating
Human health and safety	5 *Assets or facilities that support public access and use exposed to hazard. (Lookout facilities)*	3	15
Access/ lifestyle	4 *Park and reserve land AND facilities exposed to hazard. (Great Otway National Park and lookouts)*	3	12
Environmental	4 *Park and reserve and/or forested land exposed to hazard. (Great Otway National Park)*	3	12
Cultural	5 *Known sites of cultural significance exposed to hazard. (Monument within reserve area)*	3	15
Property	3 *Exposure of property with total value >$1million*	3	9
Infrastructure	5 *Road class code 0-2 exposed to hazard. (Great Ocean Rd, Class 2)*	3	15
Economy and growth	5 *Tourist sites exposed to hazard. (Landmarks/community spaces)*	3	15
Aggregated risk rating (sum)	93		

4 Discussion

4.1 Results

Risk ratings for each of the 22 of the 23 coastal compartments were determined in accordance with the methodology described in Section 3. No risk ratings were assigned for Port Phillip Bay (mouth) as there were no coastal cliff sections within the coastal compartment. The results of the assessment are presented in Table 4.2, an overview map of long-term aggregated risk ratings is provided in Figure 4.1. Table 4.3 gives the short-term risk ratings for the 17 coastal compartments with an aggregated risk rating of significant or higher. The tables and figures presented use the risk rating tolerance thresholds indicated in Table 3.17.

Aggregated risk ratings across the 22 coastal compartments over the three timeframes assessed range from 63 to 165. In the short-term the average aggregated risk rating for assessed coastal compartments was 82, in the medium-term the average risk rating increased to 110, in the long-term the average risk rating increased to 140. Applying the aggregated risk tolerance thresholds in Table 3.17 to the calculated coastal compartment risk ratings results in the breakdown of coastal compartments within each risk category shown in Table 4.1.

Outputs

- The complete table of aggregated risk ratings for each coastal compartment, which includes risk ratings for individual coastal value used in the aggregation is provided in Appendix A.
- A coastal compartment shapefile which includes risk ratings and the underlying consequence and likelihood ratings for each timeframe stored in the attribute table has been provided alongside this report (Appendix B Digital data).

Table 4.1: Number of coastal compartments within each risk category for each timeframe

	Risk rating category				
Timeframe	Low	Medium	Significant	High	Extreme
Short-term (Now - 2040)	0	4	17	1	0
Medium-term (2040 - 2070)	0	0	5	17	0
Long-term (2070 – 2100)	0	0	0	6	16

Table 4.2: Coastal compartment aggregated risk ratings

Coastal Compartment Code	Location	Timeframe	Aggregated Risk Rating
VIC01.01	Mallacoota Inlet	Short-term (Now - 2040)	69
		Medium-term (2040 - 2070)	92
		Long-term (2070 – 2100)	115
VIC01.02	Croajingolong	Short-term (Now - 2040)	63
		Medium-term (2040 - 2070)	84
		Long-term (2070 – 2100)	105
VIC02.01	Snowy River	Short-term (Now - 2040)	66
		Medium-term (2040 - 2070)	92
		Long-term (2070 – 2100)	115
VIC02.02	Gippsland Lakes	Short-term (Now - 2040)	60
		Medium-term (2040 - 2070)	80
		Long-term (2070 – 2100)	100
VIC02.03	Corner Inlet	Short-term (Now - 2040)	78
		Medium-term (2040 - 2070)	104
		Long-term (2070 – 2100)	130
VIC03.01	Wilsons Promontory (east)	Short-term (Now - 2040)	84
		Medium-term (2040 - 2070)	112
		Long-term (2070 – 2100)	140
VIC04.01	Wilsons Promontory (southwest)	Short-term (Now - 2040)	81
		Medium-term (2040 - 2070)	108
		Long-term (2070 – 2100)	135
VIC04.02	Waratah Bay	Short-term (Now - 2040)	87
		Medium-term (2040 - 2070)	116
		Long-term (2070 – 2100)	145
VIC04.03	Venus Bay	Short-term (Now - 2040)	87
		Medium-term (2040 - 2070)	116
		Long-term (2070 – 2100)	150

Coastal Compartment Code	Location	Timeframe	Aggregated Risk Rating
VIC04.04	Kilcunda	Short-term (Now - 2040)	87
		Medium-term (2040 - 2070)	116
		Long-term (2070 – 2100)	145
VIC04.05	Phillip Island (south)	Short-term (Now - 2040)	93
		Medium-term (2040 - 2070)	124
		Long-term (2070 – 2100)	155
VIC04.06	Western Port	Short-term (Now - 2040)	90
		Medium-term (2040 - 2070)	120
		Long-term (2070 – 2100)	150
VIC04.07	Cape Schanck-Flinders	Short-term (Now - 2040)	96
		Medium-term (2040 - 2070)	128
		Long-term (2070 – 2100)	160
VIC04.08	Mornington Peninsula	Short-term (Now - 2040)	87
		Medium-term (2040 - 2070)	120
		Long-term (2070 – 2100)	150
VIC04.09	Port Phillip Bay (east)	Short-term (Now - 2040)	99
		Medium-term (2040 - 2070)	132
		Long-term (2070 – 2100)	165
VIC04.10	Port Phillip Bay (west)	Short-term (Now - 2040)	69
		Medium-term (2040 - 2070)	92
		Long-term (2070 – 2100)	115
VIC04.11	Port Phillip Bay (mouth)	Short-term (Now - 2040)	*Port Phillip Bay (mouth) does not contain any coastal cliff sections*
		Medium-term (2040 - 2070)	
		Long-term (2070 – 2100)	
VIC05.01	Torquay	Short-term (Now - 2040)	93
		Medium-term (2040 - 2070)	124
		Long-term (2070 – 2100)	155
VIC05.02	Great Ocean Road	Short-term (Now - 2040)	93
		Medium-term (2040 - 2070)	124
		Long-term (2070 – 2100)	155
VIC06.01	Port Campbell	Short-term (Now - 2040)	93
		Medium-term (2040 - 2070)	124
		Long-term (2070 – 2100)	155
VIC06.02	Warrnambool	Short-term (Now - 2040)	90
		Medium-term (2040 - 2070)	120
		Long-term (2070 – 2100)	150
VIC06.03	Portland Bay	Short-term (Now - 2040)	87
		Medium-term (2040 - 2070)	116
		Long-term (2070 – 2100)	145
VIC06.04	Discovery Bay	Short-term (Now - 2040)	60
		Medium-term (2040 - 2070)	100
		Long-term (2070 – 2100)	140

Table 4.3: Short-term risk ratings for all coastal compartments exceeding significant risk

Coastal Compartment Code	Location	Social		Environmental	Cultural	Economic			Aggregated Risk Rating
		Human health and safety	Access/ lifestyle			Property	Infrastructure	Economy and growth	
VIC01.01	Mallacoota Inlet	15	12	12	9	6	12	3	69
VIC02.03	Corner Inlet	15	9	12	9	9	9	15	78
VIC03.01	Wilsons Promontory (east)	15	12	12	15	6	9	15	84
VIC04.01	Wilsons Promontory (southwest)	15	12	12	15	6	6	15	81
VIC04.02	Waratah Bay	15	9	12	15	9	12	15	87
VIC04.03	Venus Bay	15	9	12	15	9	12	15	87
VIC04.04	Kilcunda	15	9	12	15	9	12	15	87
VIC04.05	Phillip Island (south)	15	12	12	15	12	12	15	93
VIC04.06	Western Port	15	9	12	15	12	12	15	90
VIC04.07	Cape Schanck-Flinders	15	12	12	15	15	12	15	96
VIC04.08	Mornington Peninsula	15	9	12	15	9	12	15	87
VIC04.09	Port Phillip Bay (east)	15	12	12	15	15	15	15	99
VIC04.10	Port Phillip Bay (west)	15	9	12	9	12	9	3	69
VIC05.01	Torquay	15	12	12	15	9	15	15	93
VIC05.02	Great Ocean Road	15	12	12	15	9	15	15	93
VIC06.01	Port Campbell	15	12	12	15	9	15	15	93
VIC06.02	Warrnambool	15	12	12	15	9	12	15	90
VIC06.03	Portland Bay	15	9	12	15	6	15	15	87

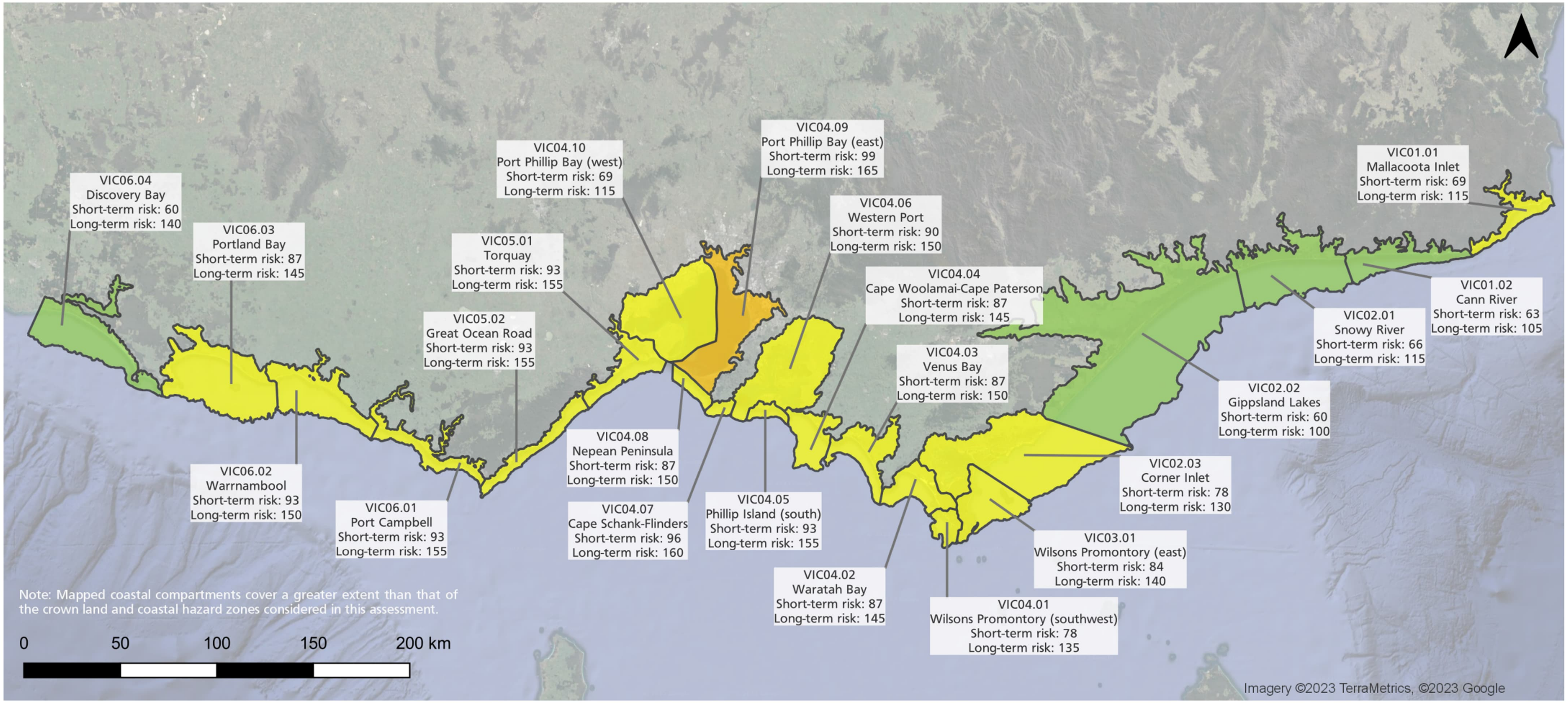

Figure 4.1: Coastal compartments aggregated long-term risk ratings.

4.2 Interpretation of results and next steps

This second-pass risk assessment provides a state-wide overview of the risks to public safety and other coastal values associated with coastal instability, erosion, and cliff runout hazards, considering short-term, medium-term, and long-term timeframes. This new information will be useful to inform regional and local adaptation planning, strategic decision making and masterplans, and identifying areas where more detailed local or site specific studies are required.

The aggregated risk ratings presented in Table 4.1, Table 4.2 and Appendix A suggest that risks to coastal values due to coastal instability and erosion hazards within assessed coastal compartments exist in all but one assessed coastal compartment in the present day, become increasingly severe over longer-time frames.

The high and extreme aggregate risk ratings in all coastal compartments over the long-term reflect the assumptions adopted in this assessment that coastal erosion results in a total and permanent loss of land, and that the concomitant consequences to assets, systems, and communities within areas susceptible to coastal instability and erosion hazards will be extreme. Furthermore, the likelihood of consequences to coastal values within areas susceptible to coastal instability and erosion hazards increases over longer timeframes, trending towards 'almost certain' in the long-term (2070-2100).

The approach taken is conservative in nature, however this is appropriate given the regional scale of the assessment undertaken which relied only on readily available land and asset data as proxies for the calculation of risk ratings for each coastal value considered. The results provided are based on DEECA's risk appetite statement which indicates that DEECA has a low tolerance for wellbeing and safety risks, environment and cultural heritage risks and economic/financial risks. Results of the risk assessment can be utilised to facilitate discussion among stakeholders regarding coastal erosion and instability risks and broader climate change risks within Victoria's coastal compartments and can serve as the foundation for more detailed third-pass risk assessments and can inform the prioritisation of adaptation actions and development of adaptation pathways for specific coastal compartments.

The consistently 'extreme' health and safety risk ratings across all timeframes reflects DEECA's very low risk tolerance for wellbeing and safety risks. A response to extreme health and safety risks could include an annual monitoring programme of coastal cliff sections, with involvement from local stakeholders in all coastal compartments, to evaluate public health and safety risks associated with coastal cliff hazards in detail. Detailed (third pass) health and safety risk assessments can then inform/trigger appropriate actions/controls to reduce residual risk to a level that is as low as reasonably practicable.

The results of the risk assessment suggest that in all assessed coastal compartments there are coastal cliff sections which will require further assessment and planning by local land managers within the next 50 years.

The spatial data utilised as inputs for the calculation of coastal compartment risk ratings, including ASCCIE and ASTaR polygons, and the assets and land areas which intersect them, are useful inputs for the identification and prioritisation of specific sections of coastline which require third-pass risk assessments. Figure 4.2 provides an example from Torquay where assets, including roads, walking tracks and tourist facilities, are exposed to coastal instability and erosion hazards and will require more detailed third-pass risk assessments. Third-pass risk assessments are not purely quantitative and incorporate qualitative judgements from stakeholders, regarding the relative importance of the impact of coastal hazards on different coastal values. The outputs of detailed, third-pass risk assessments will provide the basis for adaptation planning decisions for specific locations, communities, and systems.

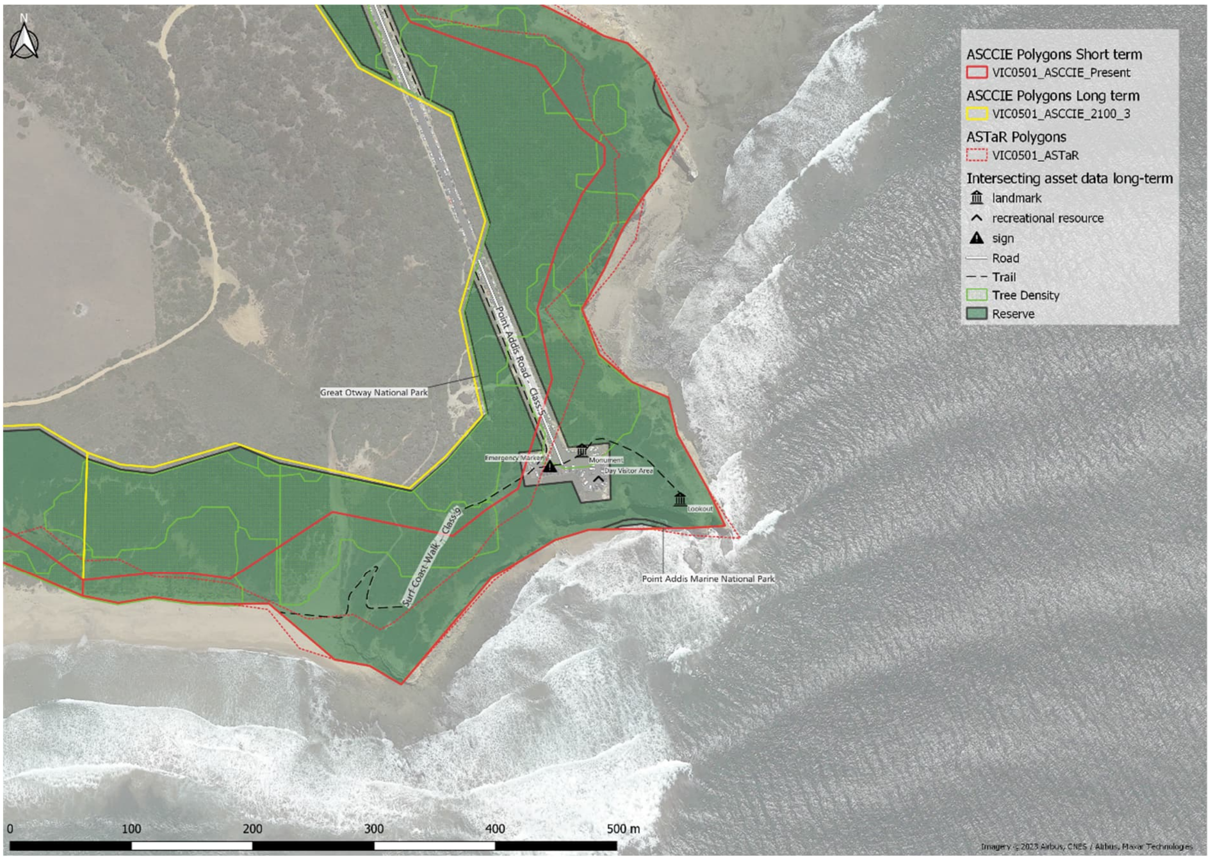

Figure 4.2: Example of asset data intersecting short-term and long-term ASCCIE and ASTaR polygons.

General recommendations to support coastal land managers with risk management in coastal cliff environments, including examples and case studies of adaptation options for coastal erosion hazards aligned with Victoria State Government's coastal adaptation framework and guidelines are provided in the Victoria Coastal Cliff Assessment report prepared by T+T August 2023.

The method utilised to produce the risk ratings presented in this report has delivered an effective overview of risks associated with coastal cliffs at the coastal compartment level. There is potential to further leverage the data underlying the assessment and to refine the outputs of the process for the benefit of end users. The following recommendations should be considered for future further development of risk assessments focused on areas susceptible to coastal instability and erosion hazards within Victoria.

- Future third-pass risk assessments building on the second-pass risk assessment framework presented in this report should include a review of risk tolerability thresholds, and the likelihood and consequence criteria used in the calculation of risk ratings. Engagement with local stakeholders should be prioritised to ensure the perspectives and risk tolerance of Traditional Owners and key stakeholders are reflected in risk ratings derived from tertiary risk assessments. Future third-pass risk assessments should also consider additional localised features such as the specific geology of coastal cliffs.
- Develop a web viewer tool which would enable end users to view underlying hazard layers overlaid with intersecting asset data, as well as coastal compartment risk data produced during this assessment.

5 Applicability

This report has been prepared for the exclusive use of our client Department of Environment, Energy and Climate Action (DEECA), with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Pty Ltd
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Appendix A Aggregated Risk Rating Table

Coastal Compartment Code	Location	Timeframe	Social		Environmental	Cultural	Economic			Aggregated Risk Rating
			Human health and safety	Access/ lifestyle			Property	Infrastructure	Economy and growth	
VIC01.01	Mallacoota Inlet	Short-term (Now - 2040)	15	12	12	9	6	12	3	69
		Medium-term (2040 - 2070)	20	16	16	12	8	16	4	92
		Long-term (2070 – 2100)	25	20	20	15	10	20	5	115
VIC01.02	Croajingolong	Short-term (Now - 2040)	15	9	12	9	6	9	3	63
		Medium-term (2040 - 2070)	20	12	16	12	8	12	4	84
		Long-term (2070 – 2100)	25	15	20	15	10	15	5	105
VIC02.01	Snowy River	Short-term (Now - 2040)	15	9	12	9	3	15	3	66
		Medium-term (2040 - 2070)	20	12	16	12	8	20	4	92
		Long-term (2070 – 2100)	25	15	20	15	10	25	5	115
VIC02.02	Gippsland Lakes	Short-term (Now - 2040)	15	9	12	9	6	6	3	60
		Medium-term (2040 - 2070)	20	12	16	12	8	8	4	80
		Long-term (2070 – 2100)	25	15	20	15	10	10	5	100
VIC02.03	Corner Inlet	Short-term (Now - 2040)	15	9	12	9	9	9	15	78
		Medium-term (2040 - 2070)	20	12	16	12	12	12	20	104
		Long-term (2070 – 2100)	25	15	20	15	15	15	25	130
VIC03.01	Wilsons Promontory (east)	Short-term (Now - 2040)	15	12	12	15	6	9	15	84
		Medium-term (2040 - 2070)	20	16	16	20	8	12	20	112
		Long-term (2070 – 2100)	25	20	20	25	10	15	25	140
VIC04.01	Wilsons Promontory (southwest)	Short-term (Now - 2040)	15	12	12	15	6	6	15	81
		Medium-term (2040 - 2070)	20	16	16	20	8	8	20	108
		Long-term (2070 – 2100)	25	20	20	25	10	10	25	135
VIC04.02	Waratah Bay	Short-term (Now - 2040)	15	9	12	15	9	12	15	87
		Medium-term (2040 - 2070)	20	12	16	20	12	16	20	116
		Long-term (2070 – 2100)	25	15	20	25	15	20	25	145
VIC04.03	Venus Bay	Short-term (Now - 2040)	15	9	12	15	9	12	15	87
		Medium-term (2040 - 2070)	20	12	16	20	12	16	20	116
		Long-term (2070 – 2100)	25	15	20	25	20	20	25	150
VIC04.04	Kilcunda	Short-term (Now - 2040)	15	9	12	15	9	12	15	87
		Medium-term (2040 - 2070)	20	12	16	20	12	16	20	116
		Long-term (2070 – 2100)	25	15	20	25	15	20	25	145
VIC04.05	Phillip Island (south)	Short-term (Now - 2040)	15	12	12	15	12	12	15	93
		Medium-term (2040 - 2070)	20	16	16	20	16	16	20	124
		Long-term (2070 – 2100)	25	20	20	25	20	20	25	155
VIC04.06	Western Port	Short-term (Now - 2040)	15	9	12	15	12	12	15	90

		Medium-term (2040 - 2070)	20	12	16	20	16	16	20	120
		Long-term (2070 – 2100)	25	15	20	25	20	20	25	150
VIC04.07	Cape Schanck-Flinders	Short-term (Now - 2040)	15	12	12	15	15	12	15	96
		Medium-term (2040 - 2070)	20	16	16	20	20	16	20	128
		Long-term (2070 – 2100)	25	20	20	25	25	20	25	160
VIC04.08	Mornington Peninsula	Short-term (Now - 2040)	15	9	12	15	9	12	15	87
		Medium-term (2040 - 2070)	20	16	16	20	12	16	20	120
		Long-term (2070 – 2100)	25	20	20	25	15	20	25	150
VIC04.09	Port Phillip Bay (east)	Short-term (Now - 2040)	15	12	12	15	15	15	15	99
		Medium-term (2040 - 2070)	20	16	16	20	20	20	20	132
		Long-term (2070 – 2100)	25	20	20	25	25	25	25	165
VIC04.10	Port Phillip Bay (west)	Short-term (Now - 2040)	15	9	12	9	12	9	3	69
		Medium-term (2040 - 2070)	20	12	16	12	16	12	4	92
		Long-term (2070 – 2100)	25	15	20	15	20	15	5	115
VIC04.11	Port Phillip Bay (mouth)		*Port Phillip Bay (mouth) does not contain any coastal cliff sections*							
VIC05.01	Torquay	Short-term (Now - 2040)	15	12	12	15	9	15	15	93
		Medium-term (2040 - 2070)	20	16	16	20	12	20	20	124
		Long-term (2070 – 2100)	25	20	20	25	15	25	25	155
VIC05.02	Great Ocean Road	Short-term (Now - 2040)	15	12	12	15	9	15	15	93
		Medium-term (2040 - 2070)	20	16	16	20	12	20	20	124
		Long-term (2070 – 2100)	25	20	20	25	15	25	25	155
VIC06.01	Port Campbell	Short-term (Now - 2040)	15	12	12	15	9	15	15	93
		Medium-term (2040 - 2070)	20	16	16	20	12	20	20	124
		Long-term (2070 – 2100)	25	20	20	25	15	25	25	155
VIC06.02	Warrnambool	Short-term (Now - 2040)	15	12	12	15	9	12	15	90
		Medium-term (2040 - 2070)	20	16	16	20	12	16	20	120
		Long-term (2070 – 2100)	25	20	20	25	15	20	25	150
VIC06.03	Portland Bay	Short-term (Now - 2040)	15	9	12	15	6	15	15	87
		Medium-term (2040 - 2070)	20	12	16	20	8	20	20	116
		Long-term (2070 – 2100)	25	15	20	25	10	25	25	145
VIC06.04	Discovery Bay	Short-term (Now - 2040)	12	9	12	15	3	6	3	60
		Medium-term (2040 - 2070)	20	12	16	20	4	8	20	100
		Long-term (2070 – 2100)	25	15	20	25	15	15	25	140

Appendix B Digital data

The follow digital datasets are provided as part of this report and have been provided in the form of Esri shapefiles:

- Coastal compartment polygons with aggregated risk ratings and underlying coastal value risk rating data supplied as polygon features within a geodatabase.

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