Final Report

Inverloch Region Coastal Hazard Assessment – Summary Report

Department of Environment, Land, Water and Planning

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EXECUTIVE SUMMARY

The Cape to Cape coastline between Cape Paterson and Cape Liptrap is the sixth Victorian region where a regional scale Coastal Hazard Assessment has been undertaken since 2012. Regional Coastal Hazard Assessments are designed to help Victorians understand and plan for risks along the coast by enhancing the understanding of coastal processes and generating detailed coastal mapping and information. This information will be used to assist in preparing Victorians for coastal storms, future sea level rises, floods and coastal erosion into the future.

The Inverloch Region Coastal Hazard Assessment is the key project of Stage 1 of the Inverloch Regional and Strategic Partnership (RaSP). It has included a detailed and comprehensive assessment of the coastal processes, with a focus on the processes which drive change at the entrance to Anderson Inlet. The project identified assets exposed to coastal hazards and assessed a shortlist of adaptation actions which could be used to reduce the coastal erosion hazard identified along the open coast between Flat Rocks and Point Norman to the west of Inverloch.

This Summary Report provides an overview of work detailed in a further 6 reports. These reports should be read in support of the information provided in this summary report.

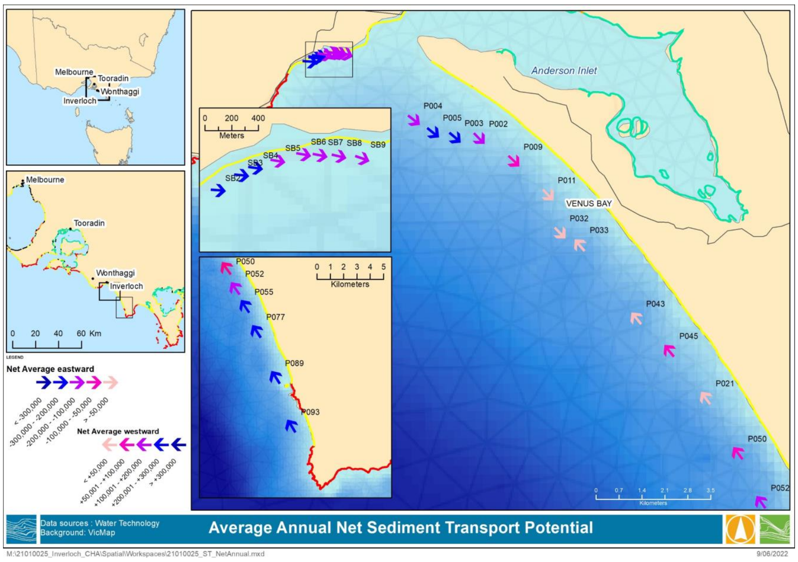
Coastal Hazard Drivers

Coastal hazards within the Study Area are driven by elevated water levels, waves and catchment flooding. Numerical modelling established design storm events for a number of probabilities and planning horizons. Existing design conditions are presented in Table 1. These design conditions were combined with projected sea level rises of +0.2m (2040), +0.5m (2070) and +0.8 m (2100). To allow for future uncertainties, two additional sea level rises of +1.1m and +1.4m were also considered for 2100.

Table 1 Existing Design Conditions

Probability	Offshore Storm Tide (m AHD)	Offshore Significant Wave Height (m)	Tarwin River Flow (m3/s)
1% AEP	2.2	6.6	305
5% AEP	2.1	6.1	-
10% AEP	2.0	5.9	237

In addition to the design storm conditions, the sediment movement and entrance morphology were assessed to establish the drivers of change within the entrance and impact of potential adaptation actions on these drivers.



Sediment transport was modelled to establish the rate and direction of the net sediment transport, as shown in the figure to the left. Sand movement within the Study Area is driven by wave energy, predominantly from the southwest resulting in a net transport along the Surf Beach and Point Smythe coastlines to the east. Net sediment transport travels northwest from Cape Liptrap towards Venus Bay.

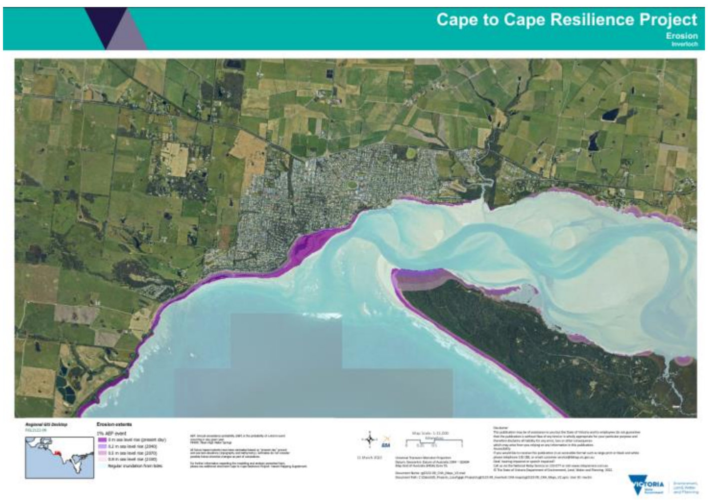
Net sediment transport at Surf Beach and across the entrance of Anderson Inlet can be influenced by the presence of an ebb tide delta, such as which was present prior to 2012. The entrance delta bar prior to 2012 helped to prevent the loss of sediment from Surf Beach into Anderson Inlet and across the entrance to Point Smythe and the Venus Bay ocean beaches.

However, the entrance channels and bar are formed and reshaped on a daily basis and the processes which drive this change are complex and unpredictable. Incoming sediment from Surf Beach, channel length, flood flows and offshore storms can all influence the position of channels and bars within the entrance from the nearshore bar to east of Townsend Bluff. Close to 2 million cubic meters of sediment has been lost from the entrance and Surf Beach area between 2009 and 2021, despite the significant growth of the dune at Ayr Creek lagoon. Surveys show the channels within the entrance are largely deeper and wider than they were prior to 2009, potentially exposing the shoreline of Inverloch to increasing coastal hazard.

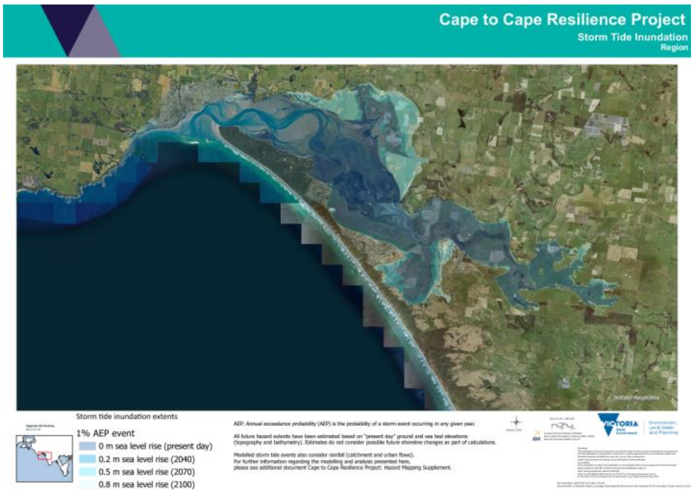
Coastal Hazards

The coastal erosion, coastal storm inundation and tidal inundation hazard zones under existing and future sea level rises and planning horizons were mapped to identify assets exposed.

The coastal erosion hazards were highest on the coastlines around Inverloch – particularly between Flat Rocks and Point Norman and to the east of the Inverloch Jetty. Coastal erosion on the open coast is driven by storm events, long shore transport and the re-profiling of the coastline as sea levels rise. Coastal erosion within the inlet is driven less by storm events and more by the passage of time over which longshore transport of sediment and reprofiling of the beach will result in a recession of the existing coastline. Along the open coastlines the erosion hazard is lower due to the wide and high dunes of Venus Bay and the cliffs of the Bunurong Road coast. Within Anderson Inlet coastal recession occurs as sea levels rise.



Erosion of the coastline may not drive recession as much as the permanent inundation of the shore due to sea level rises and the increasing elevation of the high tide level. This increasing tidal inundation may result in some changes to the vegetation along the shore as the habitable areas of mangrove and saltmarsh change with the inundation frequency of the floodplain. The tidal floodplains within Anderson Inlet are most at risk to future tidal inundation, and the levees which currently prevent seawater ingress across the floodplain will be a key driver in the future shoreline of the Inlet.



Coastal storm inundation hazard is also largely focussed within the Study Area on Anderson Inlet and Inverloch west to Flat Rocks. The high dunes and cliffs of the open coastlines prevent storm inundation from impacting assets. Within Anderson Inlet, storm inundation hazard is extensive, with inundation expected well upstream of Tarwin Lower, across the floodplain between Tarwin Lower and Venus Bay and across the northern shores of Anderson Inlet. Storm inundation through Inverloch township is limited to the low lying areas around Screw Creek – the Broadbeach Estate which is currently covered by the existing LSIO, and around Wreck Creek where the existing LSIO does not extend the full area of predicted storm inundation. Storm inundation along Surf Parade and Lohr Avenue is combined with overland catchment runoff due to the lack of stormwater infrastructure and the low lying topography. Storm inundation via Wreck Creek extends across the wetland and agricultural land on the coastal terrace below the RACV club.

Adaptation

Adaptation actions were assessed to respond to the recent coastal erosion along the Inverloch coast from Flat Rocks to Point Norman. Adaptation actions were considered as the first step on adaptation pathways for the area which will be developed in Stage 2 of the Inverloch RaSP. As such adaptation actions were limited to engineering actions which would prevent erosion of the existing coastline over a short planning horizon (i.e. until 2040).

The recommended adaptation actions are heavily dependant on the long term vision for the shoreline. Whilst construction of coastal protection structures can be completed to prevent further erosion of the coastline, once placed they are difficult to remove. A clear long term vision, through consultation with the community, is required before an action is progressed to detailed design. Monitoring of wave conditions in the waters near to the Bunurong Road and Surf Beach should be undertaken during this consultation to enable detailed design works to be confidently completed.

Summary

The Inverloch Region Coastal Hazard Assessment has provided stakeholders and community members with an enhanced understanding of the processes and drivers which define the coastal hazards impacting their shoreline.

Hazard zones identified in the CHA can now be addressed through the development of adaptation pathways, established to provide an action plan with how to respond to coastal hazards in the future so that the use and enjoyment of this beautiful part of Victoria can continue into the future.

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GLOSSARY

Term	Definition
Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be of extreme magnitude.
Astronomical tide	Water level variations due to the combined effects of the Earth's rotation, the Moon's orbit around the Earth and the Earth's orbit around the Sun.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10-year ARI flood is expected to be exceeded on average once every 10 years. A 100-year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main waterway.
Coastal Erosion Hazard	A term to collectively describe physical changes and impacts to the natural environment which are significantly driven by coastal or oceanographic processes.
Delta	A complex association of geomorphic settings, sediment types and ecological habitats, at a point where a freshwater source enters an estuarine water body
Design event	A design event is a probabilistic or statistical estimate, being generally based on some form of analysis of data. An average recurrence interval or exceedance probability is attributed to the estimate
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Embayment	A coastal indentation which has been submerged by rising sea-level in the past and has not been significantly infilled by sediment.
Erosion	The wearing away of the land through wind, wave or current forces. Often used interchangeably with recession, erosion is the loss of material rather than a landward shift of a feature. Generally considered as a short term or acute process or event.
Estuary	The seaward limit of a drowned valley which receives sediment from both river and marine sources and contains geomorphic and sedimentary conditions influenced by tide, wave and river processes
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e., flood prone land.
Geomorphology	The study of the origin, characteristics, and development of landforms

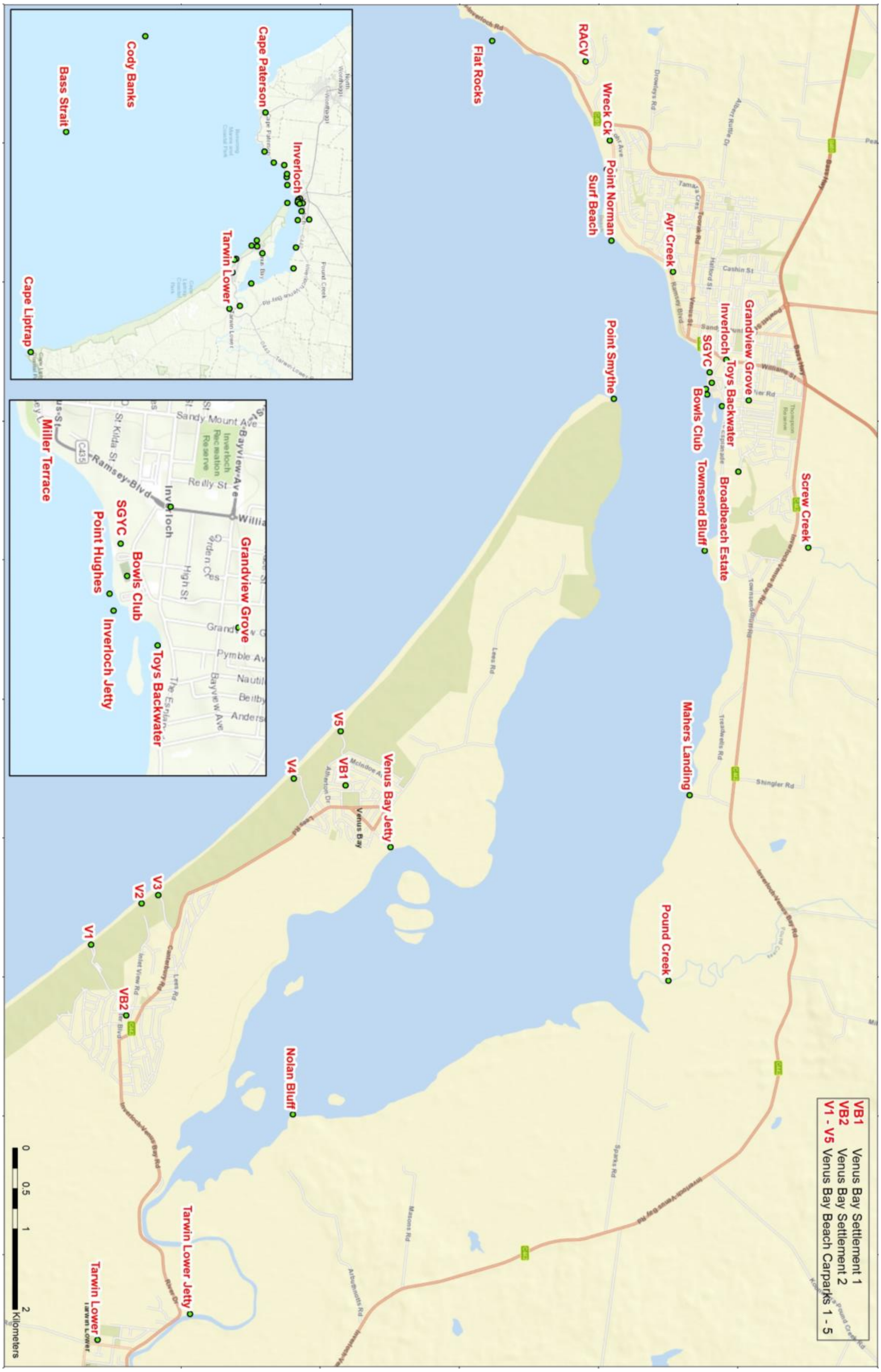
Term	Definition
HAT	Highest Astronomical Tide
ICE	Intermittently closed and open estuary
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, e.g., intertidal habitat
Inundation	Flooding because of oceanic conditions is often referred to as inundation rather than flooding although the terms are interchangeable. In this guide the term flooding is used in preference to inundation.
LiDAR	pot land surface heights collected via aerial light detection and ranging (LiDAR) survey. The spot heights are converted to a gridded digital elevation model dataset for use in modelling and mapping
MHWS	Mean High Water Springs, i.e., the mean of spring tide water levels over a long period of time.
MSL	Mean Sea Level.
Nearshore	The region of land extending from the backshore to the beginning of the offshore zone.
Ocean water level boundary	The ocean water level(s) used as the downstream boundary level for hydraulic modelling for a flood study in a coastal waterway.
Recession	The accumulation of erosion resulting in the landward shift of features such as the mean sea level or vegetation line. Recession is generally considered over a longer period.
Shoal	A shallow area within a water body; a sandbank or sandbar.
Sea Level Rise (SLR)	A permanent increase in the mean sea level.
Spring Tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean).
Storm Surge	The increase in coastal water levels caused by the barometric and wind set-up effects of storms. Barometric set-up refers to the increase in coastal water levels associated with the lower atmospheric pressures characteristic of storms. Wind set-up refers to the increase in coastal water levels caused by an onshore wind driving water shorewards and piling it up against the coast.
Swash limit (wave runup)	This is the oscillating line marking the limit to which water from a breaking wave extending landward. It defines the wet-dry beach margin and is best recorded by video photography from aerial or fixed ground cameras. Swash is driven by wave height, wavelength, and beach slope while the runup distance is determined largely by beach grain size, wave turbulence, swash-backwash interaction, and infiltration (Erikson et al., 2007)
Storm tide	Coastal water level produced by the combination of astronomical tide and meteorological (storm surge) ocean water level forcing
Tidal Planes	A series of water levels that define standard tides, e.g. 'Mean High Water Spring' (MHWS) refers to the average high water level of Spring Tides.
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides.
Tidal Waterways	The lower portions of coastal rivers, creeks, lakes, harbours, and ICEs affected by tidal fluctuations.

Term	Definition
Topography	A surface which defines the ground level of a chosen area.
Wave Setup	The increase in mean water level as waves shoal and break across the surf zone
Wave runup	See Swash limit above.
Wind Setup	The vertical rise of the water surface above the still water level caused by wind stresses on the water surface.
Wind Shear	The stress exerted on the water's surface by wind blowing over the water. Wind shear causes the water to pile up against downwind shores and generates secondary currents.

Acknowledgements

Numerous organisations and individuals have contributed both time and valuable information to the Inverloch Region Coastal Hazard Assessment. The study team acknowledges the contributions made by these groups and individuals, in particular Cass Philippou, Project Manager of the Inverloch Regional and Strategic Partnership (DELWP), Phebe Bicknell, Project Manager of the Cape to Cape Resilience Project Engagement (Alluvium), and Dr. Christine Lauchlan-Arrowsmith (Streamology) who provided guidance and direction through the project.

The study team also wishes to thank all those stakeholders and members of the public who participated in the online forums, drop-ins and/or information sessions and provided valuable inputs to the assessment of coastal inundation and erosion hazards within the Inverloch region.


VB1 Venus Bay Settlement 1
VB2 Venus Bay Settlement 2
V1 - V5 Venus Bay Beach Carparks 1 - 5
Flat Rocks
RACV
Wreck Ck
Point Norman
Surf Beach
Ayr Creek
Inverloch
Grandview Grove
SGYC
Toys Backwater
Bowls Club
Point Smythe
Broadbeach Estate
Townsend Bluff
Screw Creek
Mahers Landing
Venus Bay Jetty
VB1
V5
V4
V3
V2
V1
VB2
Pound Creek
Nolan Bluff
Tarwin Lower Jetty
Tarwin Lower
Cape Paterson
Cody Banks
Bass Strait
Cape Liptrap
Miller Terrace
Point Hughes
Inverloch Jetty
0 0.5 1 2 Kilometers

1 INTRODUCTION

1.1 Background

The Cape to Cape coastline between Cape Paterson and Cape Liptrap is the sixth Victorian region where a regional scale Coastal Hazard Assessment has been undertaken since 2012. Regional Coastal Hazard Assessments are designed to help Victorians understand and plan for risks along the coast by enhancing the understanding of coastal processes and generating detailed coastal mapping and information. This information will be used to assist in preparing Victorians for coastal storms, future sea level rises, floods and coastal erosion into the future.

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The Inverloch Region CHA has been a pilot project for the new *Victoria's Resilient Coast – Adapting to 2100*+ program (DELWP, 2022), and Stage 2 of the Inverloch RaSP will further develop adaptation pathways and actions to assist the community adapt to future coastal risks. The framework for the *Guidelines*, and the function of this report and the full suite of reports prepared for the Inverloch CHA, is detailed in Appendix A.

This project was commissioned by the Department of Environment, Land, Water and Planning (DELWP) through the Inverloch Regional and Strategic Partnership (RaSP) which was established in 2020 to address the problem of erosion, recession and inundation at Inverloch and the surrounding coast. The RaSP comprises nine government agencies and the Bunurong Land Council Aboriginal Corporation and is led by DELWP.

The information developed by the project will assist in better understanding, planning for, and managing coastal hazards. It will allow management agencies and other key stakeholders to identify and define triggers as the basis for short-, medium- and long-term management responses. Specifically, the information is intended to support decision-making about local infrastructure, natural asset management, emergency management planning, to inform land use planning and statutory planning decisions, and to provide information to support the development of adaptation plans.

Information from this project will also add to the suite of information available to help identify how and where State Government, local government, the community, industry and other levels of government and governance agencies can work together to respond to or address the potential impacts of climate change.

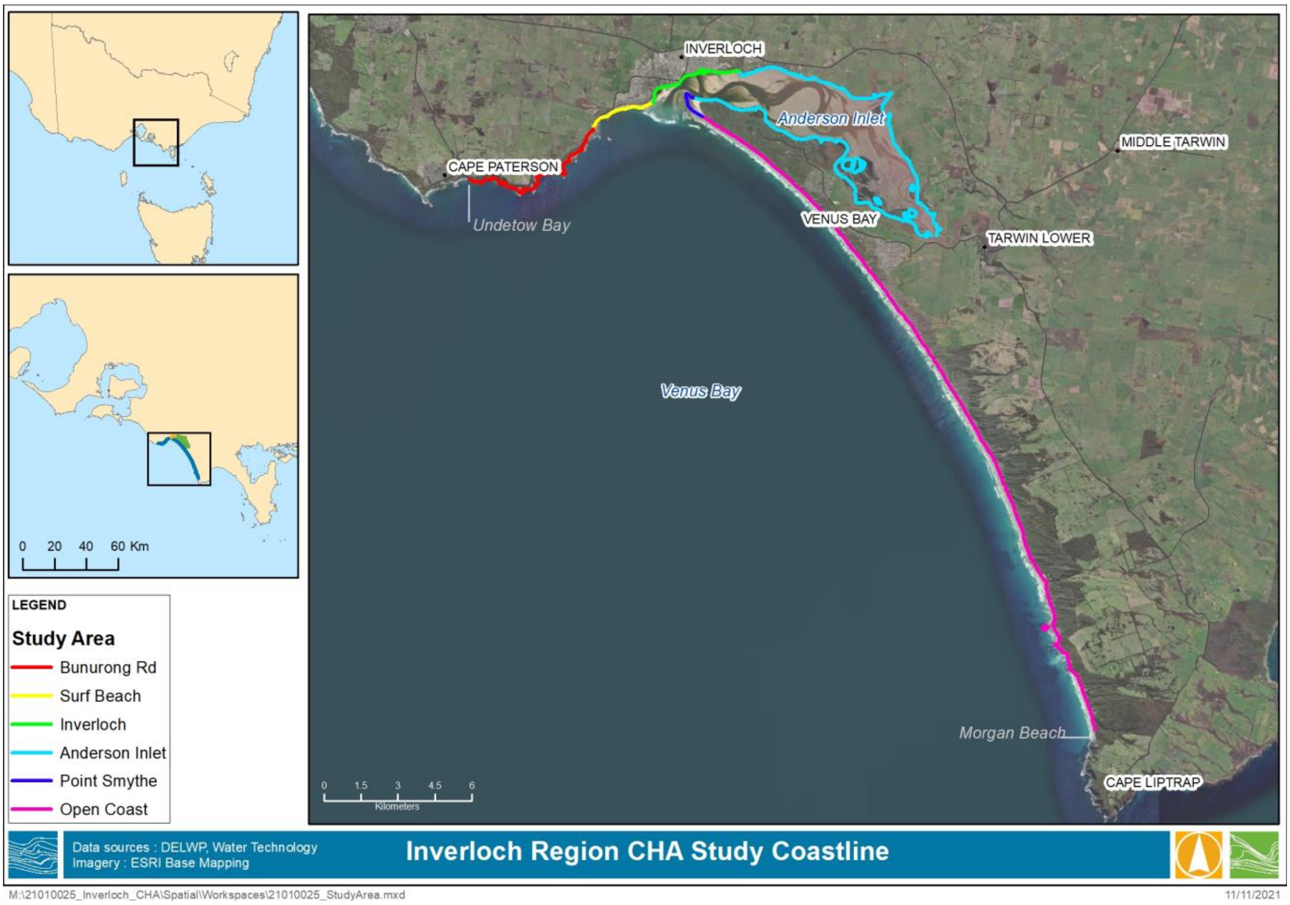


Figure 1-1 Inverloch Region CHA Study Area

1.2 Scope

The Inverloch Region CHA provides information on the extent of coastal hazards and their physical impacts for the Cape to Cape coastal environment, focusing on inundation and erosion hazards in particular.

The Victorian Marine and Coastal Strategy (DELWP, 2022) requires planning for sea level rise of not less than +0.8 m by 2100, which is reflected in the three sea level rise scenarios of +0.2m (2040), +0.5m (2070) and +0.8 m (2100) that have been considered in this study. To allow for future uncertainties, two additional sea level rises of +1.1m and +1.4m were also considered for 2100.

Along with sea level rise each scenario also considered the 10%, 5% and 1% Annual Exceedance Probability (AEP) storm tide, combined with the 1%, 1% and 10% AEP catchment generated inflows to Anderson Inlet respectively. Each scenario has been assessed in terms of the likely impacts on inundation and erosion hazards along the open coastlines and within Anderson Inlet.

In addition to coastal hazards associated with surface water, a high level review of the impact of the sea level rise scenarios on groundwater within the coastal areas of the Study Area was also undertaken.

1.3 Governance

A Project Control Board (PCB), Project Working Group (PWG) and Technical Reference Group (TRG) were established to govern the Inverloch CHA project. These were made up of members from each agency within the RaSP, and various technical experts. The project has undergone technical reviews at various stages and a final peer review by an independent technical expert (Professor Ron Cox, Water Research Laboratory/UNSW) engaged by DELWP.

1.4 Project Team

This project was undertaken as a partnership between Water Technology (Lead Consultant and project manager) and a number of independent technical experts who provided specialist input to key aspects of the assessment.

The key team members are summarised as follows:

- Dr. Andrew McCowan, Dr. Michael Miloshis, Nicholas Tan (Water Technology) – hydrodynamics, physical processes, data analysis
- Elise Lawry (Water Technology) – project management, hydrodynamics, physical processes, hazard and adaptation assessments
- Vitaly Leschen and Ben Hughes (Water Technology) – catchment modelling and hydrology
- Bjorn Bryant and Celine Marchenay (Water Technology) – urban catchment modelling
- Andrew Telfer (Water Technology) – physical processes, and groundwater
- Chris Charles (Water Technology) – spatial analysis
- Dr. Christine Lauchlan Arrowsmith (Streamology) – project direction, hydrodynamics, physical processes, assessment methodology
- Dr. Neville Rosengren (Environmental GeoSurveys) & Tony Miner (A.S. Miner Geotechnical) – coastal geomorphology and geology

1.5 Reporting

This document is Report 1 of a series of reports produced as part of the Inverloch Region CHA. It should be read in conjunction with the following:

- **Report 1: Project Summary Report**
- Report 2: Data Assimilation and Gap Analysis
- Report 3: Technical Methodology
- Report 4: Coastal Processes and Erosion Hazard Assessment
- Report 5: Inundation Hazards
- Report 6: Coastal Asset Exposure Assessment
- Report 7: Adaptation Action Technical Assessment

This report is structured as follows:

- Section 1 **Introduces the project** and outlines the scope of work and background,
- Section 2 provides an overview of the study area and **coastal hazard drivers**,
- Section 3 describes the **main findings** of the coastal hazard assessment,
- Section 4 provides an overview of the **hazard exposure**, and
- Section 5 details potential **adaptations actions** assessed by the project

2 STUDY AREA CONTEXT

The characteristics and susceptibility of the Cape to Cape coastline to coastal hazards, including sea level rise, is integrally related to the nature and variations in geology, geomorphology, and the hydrodynamic setting that exists in the Study Area. These are briefly summarised below, with more detailed information provided in Report 4 and Report 5 (see Section 1.5).

2.1 Landform

2.1.1 Geology and Geomorphology

The coastline of the Study Area and the Tarwin embayment formed between the faulted landscape to the west and south through the high energy wave and wind environment of Bass Strait. Progressive movement of sand enclosed the Tarwin River and formed Anderson Inlet during periods of varying sea levels and via wind and wave transported sands. Much of the sediment within the Inlet, especially on the floodplains above the current tidal range have been delivered via catchment runoff. The coastal evolution of the Venus Bay barrier through the development of dunes and river diversions, is presented in Figure 2-1 below.

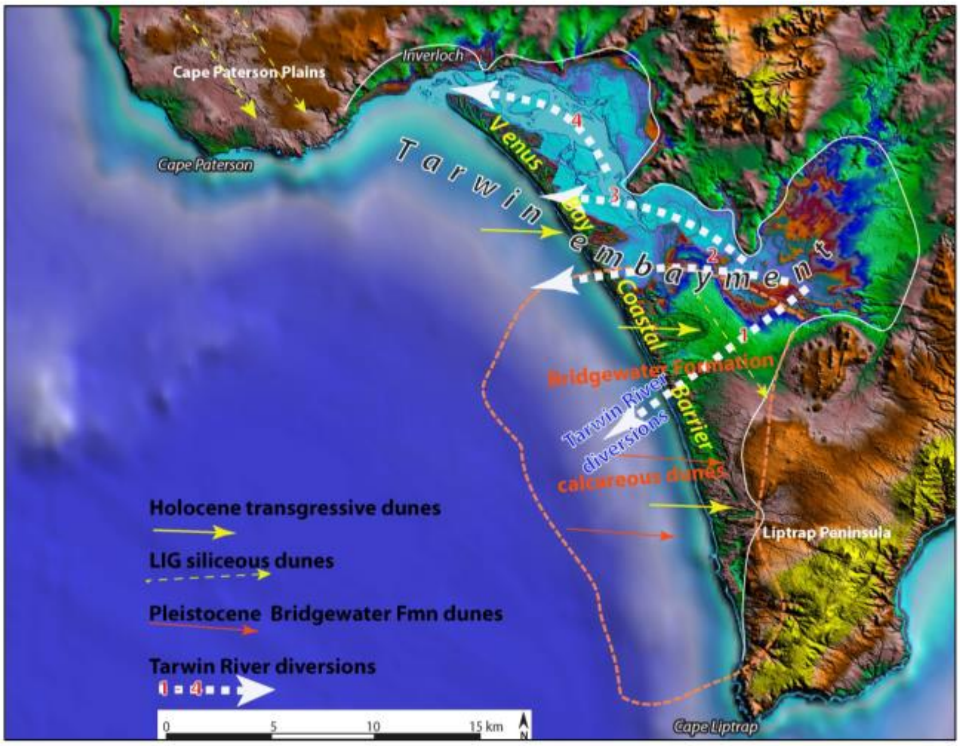


Figure 2-1 Coastal Evolution of the Venus Bay barrier (Rosengren, 2021)

2.1.2 Recent Evolution

At the time of European settlement the coastline was similar to the current day form, albeit with more dense vegetation covering the hills and salt marsh and likely mangrove spread throughout the Inlet. Land use changed significantly following colonisation and significant loss in vegetation across the catchment and within the Inlet has occurred. Revegetation of the coastal margin in the west of the Study Area, and along the Point Smythe sand spit has occurred over the past 50 years.

The coastline has also been modified through the construction of levees and drainage channels within Anderson Inlet, and the construction of various seawalls and groynes along the Inverloch township coastline.

Changes in vegetation, channel and bars within the Study Area are noted with areas of rapid change occurring both more recently such as at Surf Beach and Wreck Creek, and during the mid-20th century at Toys Backwater. Ongoing change at Point Smythe is noted and the change in the channel length and migration of the primary flood and ebb tide sand bar occurs on a short timeframe.

2.1.3 Topography and Bathymetry

The topography and bathymetry of the Study Area and surrounding areas are shown in Figure 2-2. The topography and bathymetry along the South Gippsland coastline are dominated by a series of rocky outcrops at Cape Woolamai, Cape Paterson, Cape Liptrap and Wilsons Promontory which form crenulate bays in their lee. The nearshore slope from the coast descends relatively smoothly 10-15km offshore to the -70m AHD contour and the floor of Bass Strait. Southwest of Cape Paterson Cody Banks extends the coastal shelf and provides additional protection to the northern shore of Venus Bay.

The topography around the Study Area is characterised by high cliffs to the west of Anderson Inlet between Cape Paterson and Flat Rocks. From Flat Rocks to Inverloch the coastline is developed through a series of low Holocene dunes, backed by a bluff representing the Last Inter-Glacial Maxima (LIGM) shoreline and a likely change in strata from the Holocene sand. Between Inverloch and Screw Creek the coastline drops again and the LIGM bluff is evident. The low lying tidal floodplains of the Tarwin River extend well beyond Tarwin Lower and elevation is below 5m AHD to near Middle Tarwin. The dune ridges which extend to Point Smythe are over 30m AHD in places and the Venus Bay settlements are located largely above the 5m AHD contour. South of the Inlet the coastal dune rises to 40m AHD and the now fluvial plains are around 20m AHD. Further south the coastal dune is backed by a high plain which increases in elevation with latitude south to Cape Liptrap.

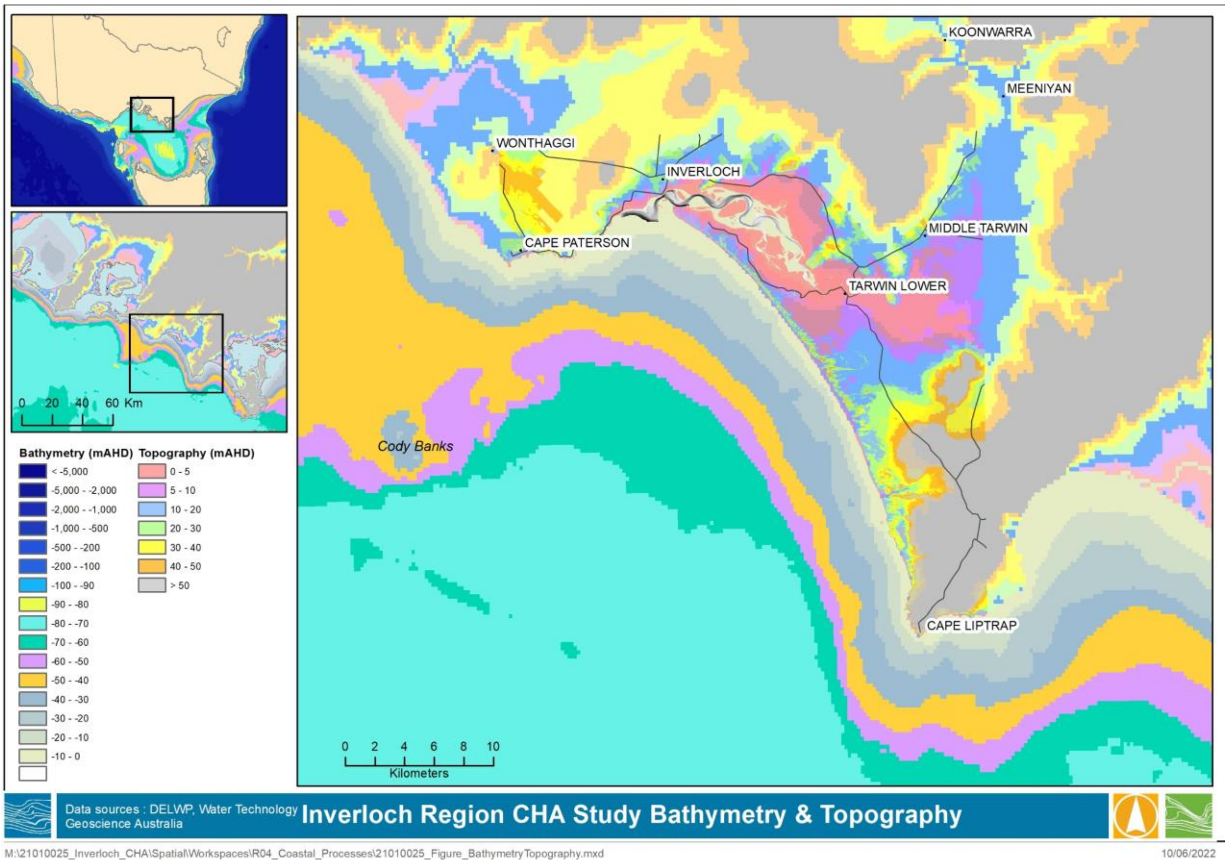


Figure 2-2 Study Area Bathymetry and Topography

2.1.4 Shoreline Classes

The Study Area was classified into five Shoreline Classes, in line with those described in *Victoria's Resilient Coast - Coastal Hazards Extended Guideline* (DELWP, 2022). The Shoreline Classes are key to preparing erosion hazard zones for risk assessment and adaptation. The length and proportion of the different shoreline classes are presented in Table 2-1 with the spatial distribution of the shoreline classes shown in Figure 2-3. The sandy shoreline in Figure 2-3 has been split to indicate the sandy shores of the open coast and those associated with the Point Smythe spit and Inlet morphology.

Table 2-1 Shoreline Classes

Shoreline class	Total Length (km)	% of shoreline
Sandy shorelines	41	48%
Hard rock cliffs with platform and/or beach	12	14%
Soft rock cliffs with platform and/or beach	0.8	1%
Estuarine and tidal channels	30	35%
Engineered coastline	1.2	1%

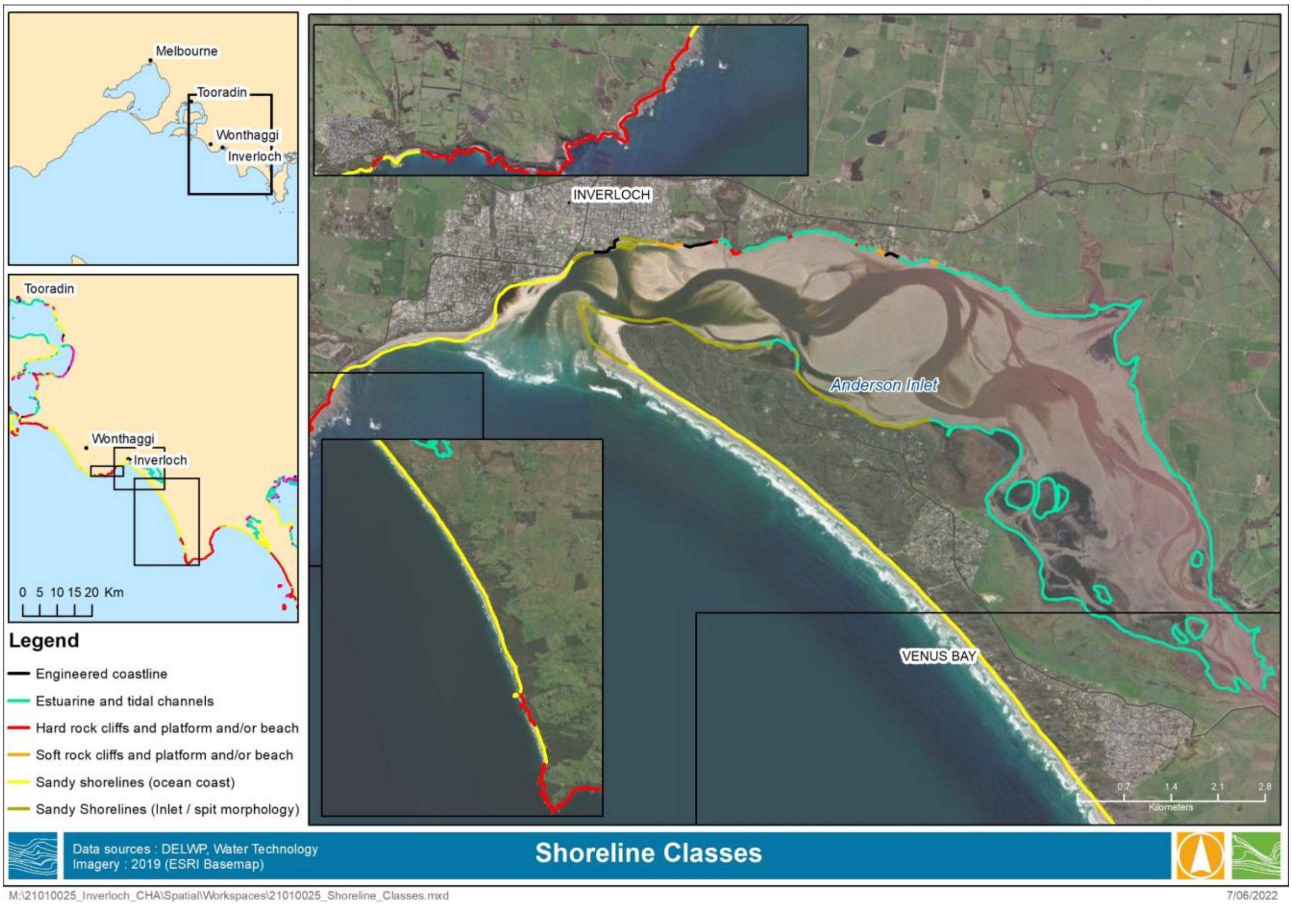


Figure 2-3 Shoreline Classes in Study Area

2.2 Hydrodynamic Setting

2.2.1 Coastal Driven Water Levels

Astronomical tides dominate water level variation in the Study Area, with a spring tide range of 2.0m offshore in Venus Bay reducing through the entrance to 1.5m at Inverloch Jetty and 1.0m at Tarwin Lower Jetty. Tidal water planes and constituents have been generated from data captured for the study, as presented in Table 2-2

Table 2-2 Study Area tidal Planes (m AHD)

Tidal Plane	Stony Point	Venus Bay (Offshore)	Inverloch Jetty	Tarwin Lower Jetty	Waratah Bay
Highest recorded water level (date)	2.00 (10/05/2016)	2.07 (7/11/1994)	1.86 (27/08/2020 17:32)	1.76 (28/07/2021 17:30)	n/a
Highest Astronomical Tide (HAT)	1.62	1.44	1.39	1.44	1.51
Mean High Water Spring (MHWS)	1.15	1.00	0.94	0.95	1.11
Mean Sea Level (MSL)	0.0	-0.03	0.19	0.46	0.0
Mean Low Water Spring (MLWS)	-1.08	-1.06	-0.57	-0.03	-1.09
Lowest Astronomical Tide (LAT)	-1.69	-1.66	-0.84	-0.29	-1.69
Lowest recorded water level (date)	-1.99 (17/05/1991)	-2.07 (18/05/1991)	-1.15 (01/01/2021 20:36)	-0.56 (28/01/2021 21:54)	
Source	ANTT[1]	BoM[3]	BoM[4]	BoM[5]	ANTT[2]

Notes: 1. Stony Point is a Standard Port in the Australian National Tide Tables (ANTT) with 40+ years of measured data used to generate tidal constituents and planes.
2. Waratah Bay tidal planes published in the ANTT are based on a very short (< 30 days) record of measured tides in 1954. Care should be taken when considering these levels.
3. Venus Bay tidal planes have been provided by BoM through analysis of model hindcast water levels generated for this study. These levels are intended for use in this study only.
4. Inverloch Jetty tidal planes have been generated by the BoM based on water levels measured by Gippsland Ports for this study at the Inverloch Jetty between May 2020 and July 2021.
5. Tarwin River Jetty tidal planes have been generated by the BoM based on water levels measured by Gippsland Ports for this study at the Tarwin Lower Jetty between November 2020 and July 2021.

Water level residuals (i.e. differences in the water level above or below the astronomical tide) are driven by winds and atmospheric pressure changes across Bass Strait, and by long period coastally trapped waves which propagate from west to east along the southern edge of the continent. Storm surges/residuals are the result of more intense storm winds and inverse pressure forces which drive the ocean water surface to higher levels.

Numerical modelling developed for the study has been used to generate a 40 year hindcast of the water levels in Venus Bay which has been used to define the extreme offshore water levels, as presented in Table 2-3. The hindcast levels have been compared with extreme values determined from measured water levels at Stony Point for comparison (also presented in Table 2-3).

The levels represent a change from the previous storm tide levels in Venus Bay developed by CSIRO (McInnes, 2009) and reflect both the refined modelling used for this study and the different approach to generate design water levels (i.e. the assessment of total water level – this study, compared with decoupled storm tide and tide as in CSIRO).

Table 2-3 Extreme Water Levels offshore of Venus Bay

	1% AEP	5% AEP	10% AEP	HAT	MHWS
Offshore Water Level (m AHD)	2.20	2.10	2.00	1.44	1.00
Stony Point Design Water Levels (m AHD)	2.10	2.00	1.95	1.62	1.15

2.2.2 Wave Climate

The wave climate in Venus Bay is dominated by ocean waves generated by large-scale weather systems over the Southern Ocean and Bass Strait. The islands of Tasmania and King Island, located within Bass Strait, limit the direction of the longest period waves which approach Venus Bay, as presented in Figure 2-4, to those from the southwest and west. Limited amounts of south-east wave energy can be experienced during the passage of an East Coast Low diffracting around Wilsons Promontory to the study area.

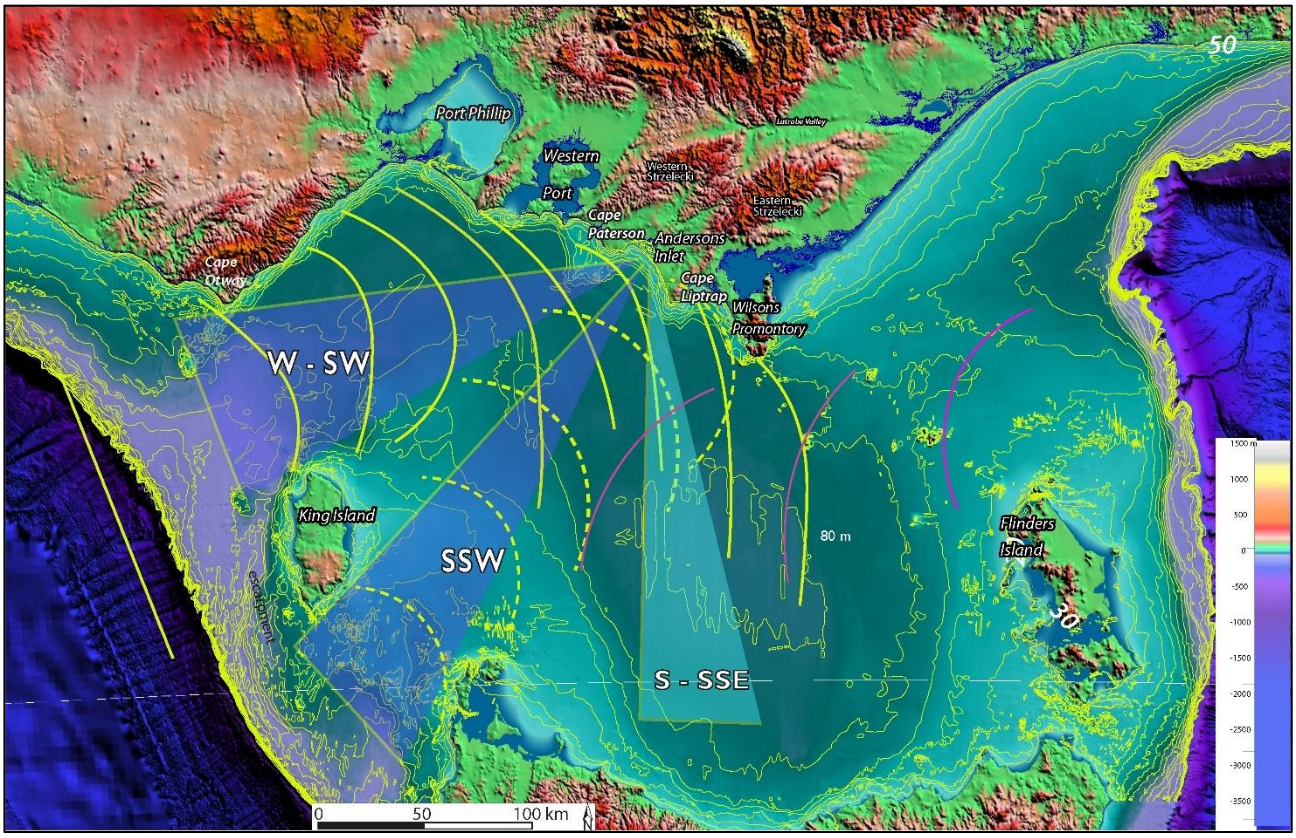


Figure 2-4 Wave generation to Venus Bay (Rosengren, 2021)

A short period of measured waves within Venus Bay from January 2020 onwards is supplemented by a 40 year hindcast of hourly significant waves, provided by the University of Melbourne in research funded by DELWP's Victorian Coastal Monitoring Program (VCMP).

The hindcast model data has been used to calculate coastal erosion and determine nearshore total coastal water levels for the Study as well as provide an enhanced understanding of the coastal processes which drive sediment movement along the shorelines.

The hindcast wave roses are shown below in Figure 2-5 and demonstrate the dominance of the southwest waves passing north of King Island and across Bass Strait from the Southern Ocean. The median significant wave height for the 40 year hindcast is 1.5m and the 95th percentile exceedance is 3.2m Hs. Mean wave periods are predominantly in the range of 4 to 8 seconds, whilst peak wave periods range from 8 to 14 seconds.

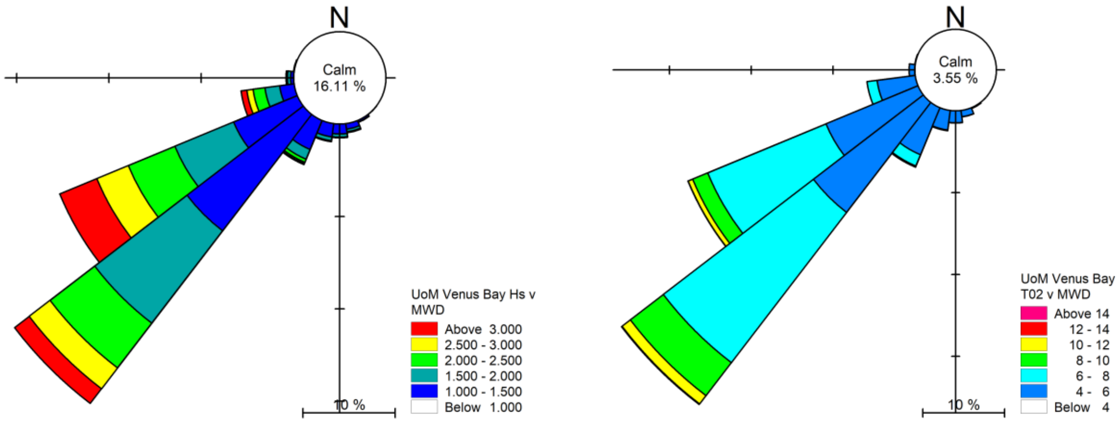


Figure 2-5 Hindcast wave roses of Hs and T02 for the full hindcast (top row), summer months (middle row) and winter month (bottom row)

Analysis of the hindcast reviewed trends and patterns within the wave data which was highlighted by a general increase in wave height and storm activity in the period from 2012 through to 2020, accompanied by a rotation of the storm wave direction to the west.

Extreme offshore and nearshore waves were derived from the hindcast, with the design nearshore wave conditions established around the 20m depth contour along the study coastline. The offshore extreme wave parameters, at the location of the VCMP buoy in Venus Bay, are shown in Table 2-4 along with the highest VCMP measured and University of Melbourne hindcast wave conditions.

Table 2-4 Extreme Offshore Wave Conditions based on Hindcast Wave Data (1981-2020) and Measured Data (2020 – 2022)

Design Event	Offshore Significant Wave Height (m)	Offshore Peak Wave Period (s)
1% AEP	6.6	14.6
5% AEP	6.1	14.2
10% AEP	5.9	13.9
20% AEP	5.7	13.7
Maximum hindcast wave height *(6/11/1994 21:00)*	6.5	11.6
Maximum hindcast wave height since entrance change *(26/04/2009 17:00)*	6.0	11.5
Maximum hindcast wave height comparable with VCMP buoy, i.e. 2020 *(2/05/2020)*	5.2	10.74
Maximum measured wave height comparable with Hindcast data *(2/05/2020)*	5.8	11.4

Design Event	Offshore Significant Wave Height (m)	Offshore Peak Wave Period (s)
Maximum measured wave height (2020 – 2022) *(2/05/2020)*	5.8	11.4

2.2.3 Catchment Inflows

Anderson Inlet was formed by the Venus Bay coastal barrier which over time shifted northwards and restricted the outlet of the Tarwin River. Figure 2-1 shows locations of previous outlets of the Tarwin River which would have been active at different times as the barrier developed.

The existing catchment of the Tarwin River is extensive, extending some 50km north to the southern slopes of the Strzelecki Ranges, west to Korumburra and East to Mirboo. The catchments of the full Study Area are presented in Figure 2-6. The total catchment area of Anderson Inlet is approximately 1,200 km^2. The Tarwin River catchment makes up almost 90% of the catchment of Anderson Inlet and is the most dominant inflow into the Study Area.

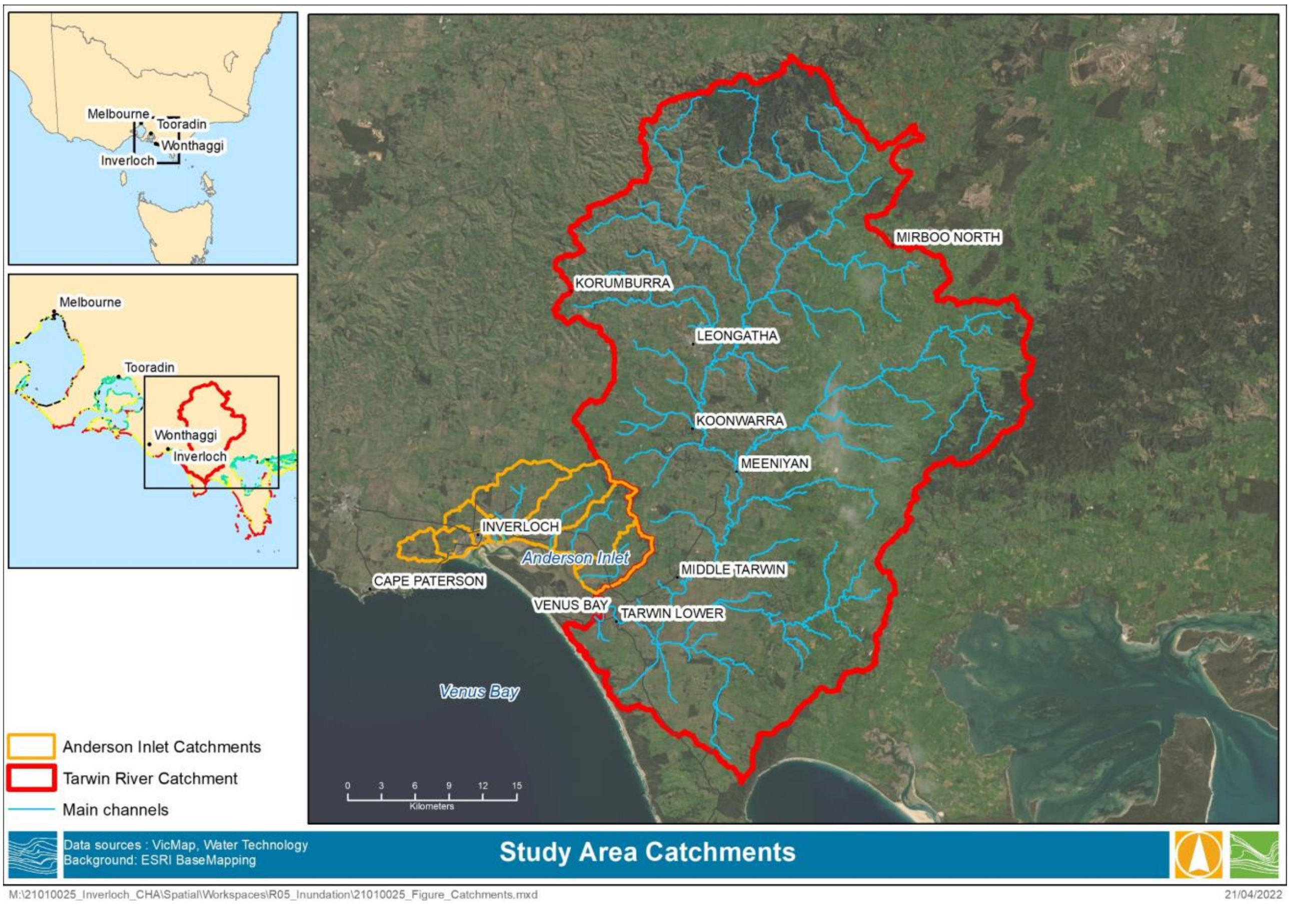


Figure 2-6 Study Area Catchments

Flooding of low-lying areas between Meeniyan and Tarwin Lower in the Tarwin River catchment are common with road closures typically occurring on at least an annual basis. The Tarwin River is ungauged within the Study Area, with the closest measure gauge at Meeniyan, 40km upstream of Tarwin Lower. The gauge provides daily flow data from June 1955 to present. The highest flow on record occurred during the wide spread flooding which occurred down the east coast of Australia in June 2012 when a flow of 302m^3/s was recorded.

Design flood flows have been developed for the study. These are presented below in Table 2-5. Design flows have been established through numerical modelling and flood frequency analysis. Flood events in 2012 and 2021 have been scaled up to provide representative hydrographs for the 1% AEP and 10% AEP respectively, presented in Figure 2-7.

Table 2-5 Anderson Inlet / Lower Tarwin Model Boundary Flood Flows

Design Event	Peak Design Flow (m^3/s)
1% AEP	305
10% AEP	237

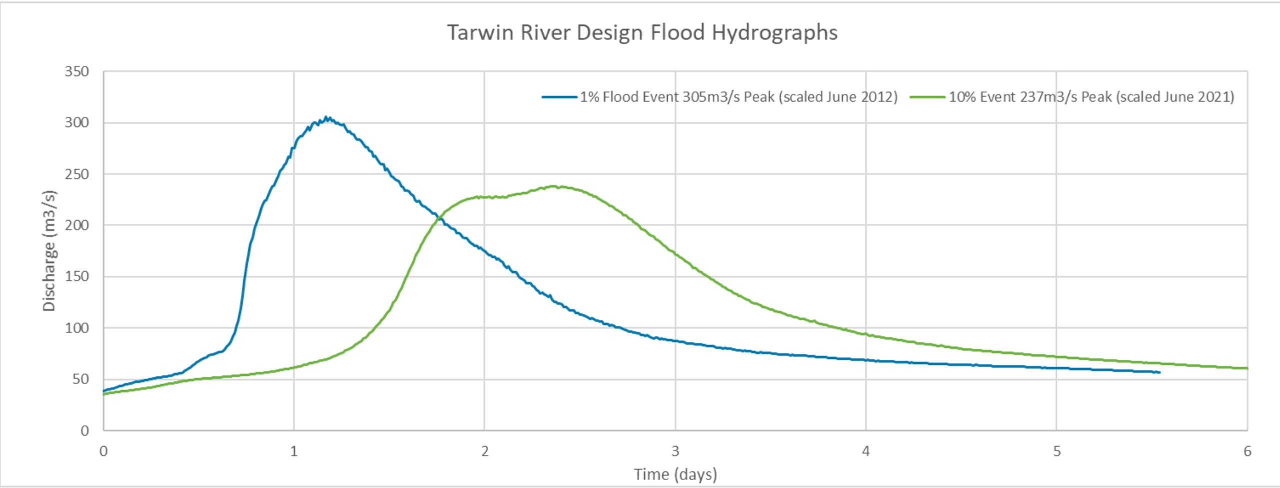


Figure 2-7 Tarwin River Design Flood Hydrographs

2.3 Sediment Movement

2.3.1 Surveyed Differences

The entrance to Anderson Inlet is highly dynamic with annual survey of the channels by Gippsland Ports showing annual movement of the 4m+ deep channel by over 100m as the alignment and meander of the channel changes. Wide survey coverage of the entrance bathymetry captured in 2008/09 and again in 2021 shows significant changes in bed levels and channel arrangements, most notably the development of the Ayr Creek dunes and lagoon, the loss of the incised tidal channel on the western side of the entrance and the shallow entrance channel delta on the offshore edge of the entrance bar.

The total change in sediment volume within the entrance and along the coast of the adjacent Surf Beach area is in excess of 1.8M m^3, a small average change over a large area, but with significant changes in localised bed depth, dune formation (Ayr Creek) and dune loss (Surf Beach) noted in the surveys.

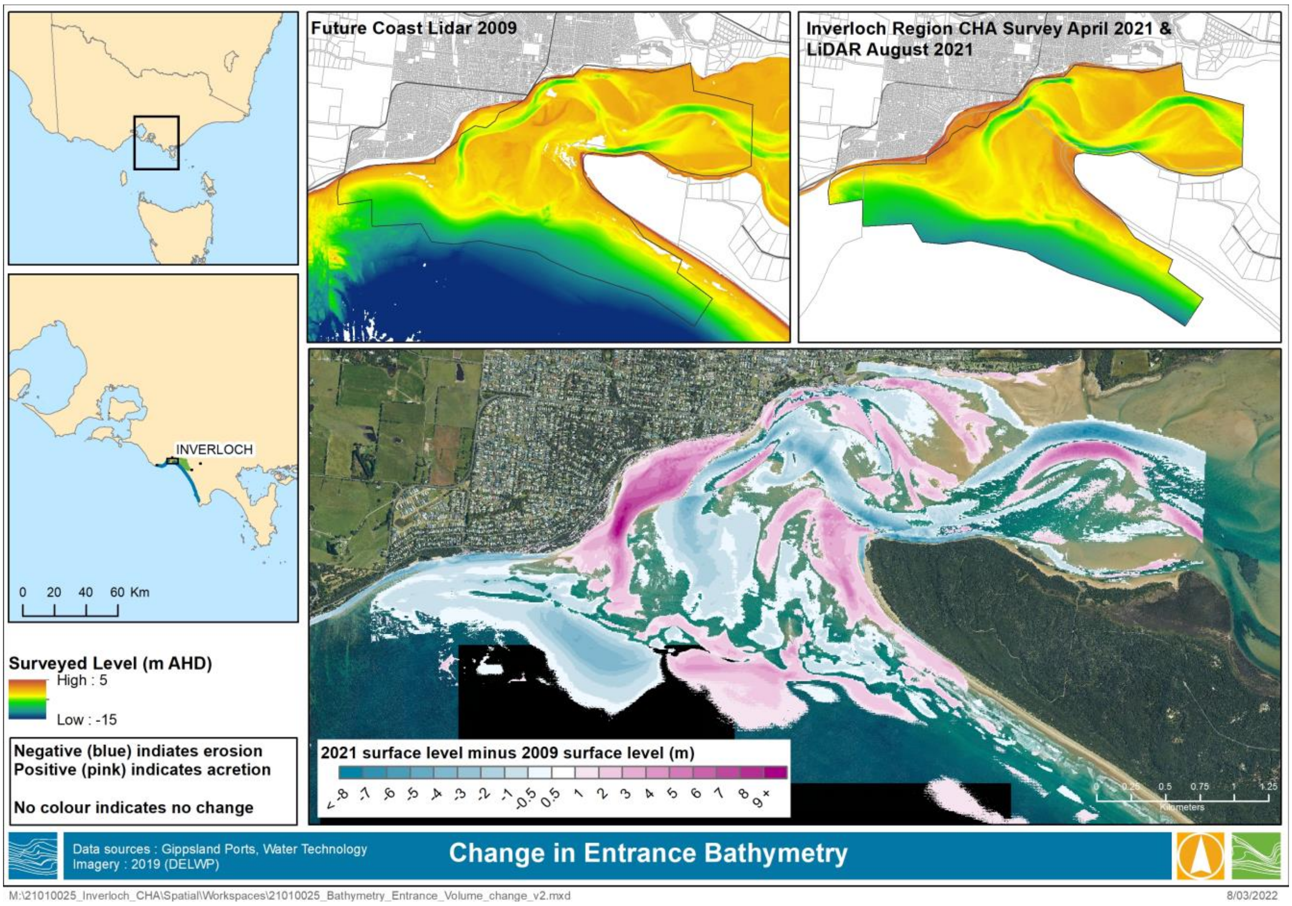


Figure 2-8 Depth Change within the entrance to Anderson Inlet

2.3.2 Sediment Transport

The sediment system within the Study Area is effectively a natural system, adjusting and adapting in form in response to the environmental drivers and forces. Human intervention in the system is minor, with most human impact associated with land use change and introduction of invasive species whose impact is beyond the scope of this assessment. Limited coastal protection works along the shoreline of Inverloch have resulted in localised changes to the coastlines and channel configuration.

The natural drivers of the sediment movement are considered to be tidal currents and wave forces.

2.3.2.1 Tidal Currents

Tidal currents within Venus Bay are minimal and show a weak eastward flood current along the coastline with a slight dominance over a weak westward ebb tide current. The westward ebb tide current may assist to return some material from the entrance channels to Surf Beach and vice versa with the eastward flood tide current pushing material from Surf Beach towards the entrance, however this is expected to be minimal. A tidal divide between Waratah Bay and Wilsons Promontory minimises current speeds in this area of Bass Strait.

Tidal currents within Anderson Inlet and through the entrance have a more significant impact on sediment movement with strong ebb and flood tide channels scouring material daily within the entrance. Tidal currents within Anderson Inlet are relatively high and have resulted in changes in the channel configuration through the

Inlet over the 70 year period of photographic record, although the change within the Inlet body is minimal compared to the entrance morphology.

Within the entrance, as noted above, deep tidal channels shift tens of meters laterally across the entrance annually representing significant actions of scour and deposition with each tidal oscillation.

2.3.2.2 Wave Forces

The hindcast wave climate has been used to understand the magnitude, patterns and changes in the wave driven sediment transport along the open coastline. The numerical model LITPAK was used to determine rates and direction of the net sediment transport potential, as presented in Figure 2-9. The dominance of the southwest wave energy results in a net eastward sediment transport potential along the coast to the west of the entrance, with the net eastward transport diminishing in volume towards the Venus Bay Settlements, around which point the angle of the coastline to the south-westerly wave results in a reversal of the net sediment transport potential westward, increasing in rate as the shoreline becomes less square with the wave energy.

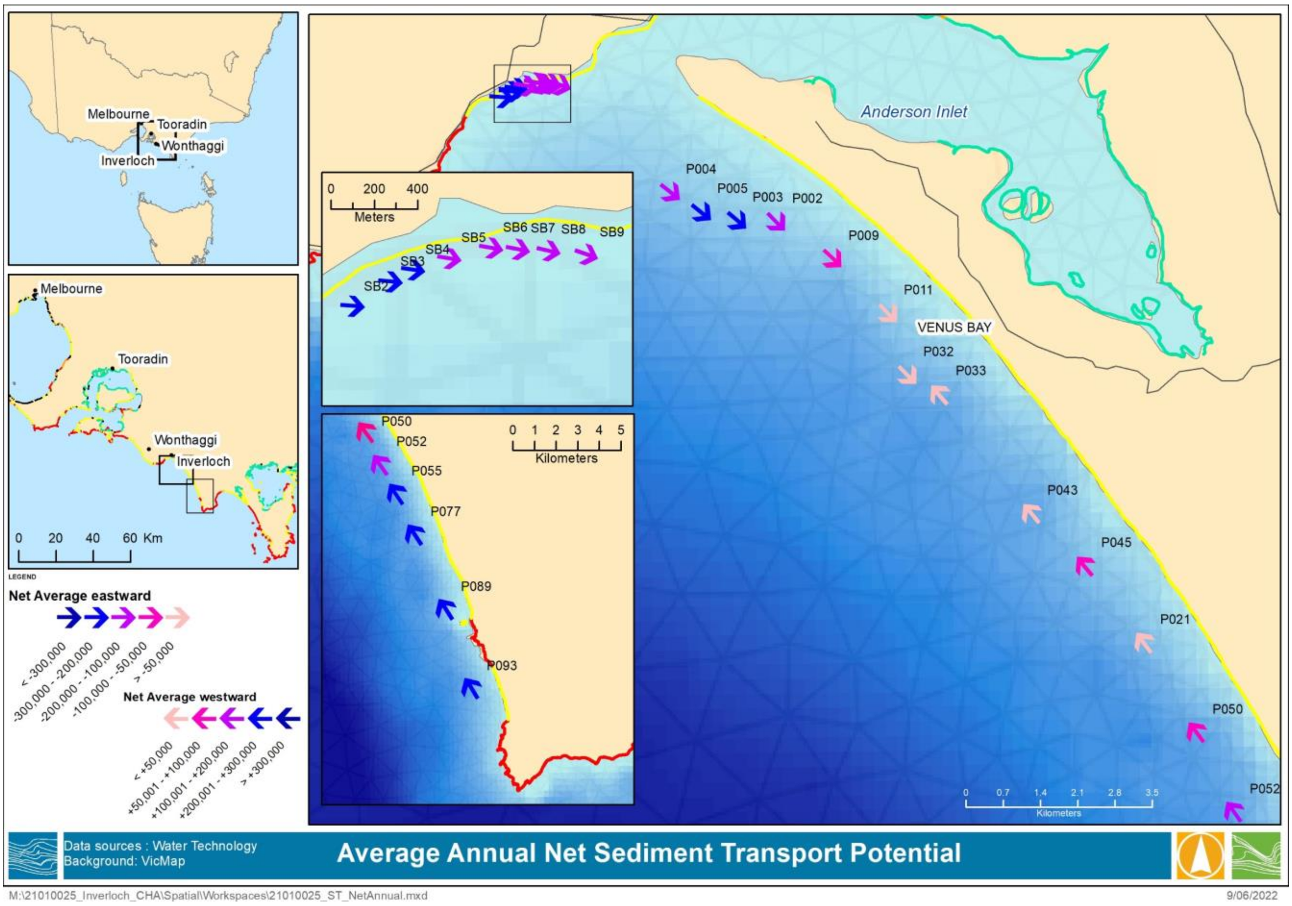


Figure 2-9 Direction and Average Annual Net Sediment Transport Potential

Analysis of the hindcast sediment transport showed fluctuation both above and below the long term average transport rate as the wave intensity and angle shifted over time. Periods of lower sediment transport along the Surf Beach coastline were simulated through the 1980s, followed by around average transport through the 1990s to 2012 after which a strong trend of increasing sediment transport east was observed in the hindcast data. This correlates to the increase in erosion along this stretch of the beach in this period.

2.3.2.3 Entrance Morphology

A number of hypothesis have been presented to assist with the understanding of the entrance channel morphology which also impacts the width and stability of the neighbouring Surf Beach and coastline between Wreck Creek and Flat Rocks. The entrance channels and bars have maintained a relatively similar flow path over the period of photographic record (1950 – present day). However changes and trends have been observed in the imagery, as detailed below, which suggest different drivers result in changes within the entrance at different times.

Channel Meander

Channel length (between two constant but arbitrary lines across the outer bar and inner entrance), and channel patterns for selected years are presented in Figure 2-10.

Between 1950 and 2002 the "channel length" is between 4,000m and 4,500m as the bars and channel slightly shift in sinuosity through the entrance but are in largely the same location. In the image captured in 2006 the channel length increases above 4,500m for the first time in the aerial image record. The channel length continues to increase through 2008 until 2009 where it exceeds 5,000m and a strong secondary tidal channel, evident in the 2012 image, is formed. The main tidal channel is in excess of 5,000m through 2012 and 2013, although imagery shows the secondary channel is becoming more prominent, until in 2014 where the initial channel is cut off from the main flow path and the "new", more direct main channel is less than 4,500m in length.

The channel length increases again towards 5,000m through 2015, 2016 and 2017 and passes this potential "trigger point" of 5,000m in 2018 and a strong secondary channel is once again observed in imagery. This secondary channel then becomes the new main channel as tidal flow follows the more direct path, notably shorter in 2019 than 2018.

This change of channel alignment in response to meander length could be coincidental and driven by other features (floods, wave conditions), however there could be a length at which the tidal flow responds to the meander length by incising a new channel and the aerial imagery could continue to be monitored to confirm any relationship.

Bar migration

As noted, in addition to the length of the channel, the cut through of bars and channels may be driven by higher flows associated with flood events. The position of the inner/inlet edge of the main channel bar is shown in Figure 2-11, highlighted for the year of image. Each image in the centre on the top two rows show the bar migrating into the inlet. A large flood event occurs between the middle and right hand side image of Figure 2-11 and the impact on the bar and leading channel is shown by the shift back towards the entrance, suggesting that large flow events cause this cut through of the bar and realignment of the channel.

However, as shown in the bottom row, between 2017 and 2018 there is no large flow event but a large channel realignment occurs and the leading bar shifts towards the entrance. In this instance, the channel meander length discussed above is likely to be the driving force, demonstrating the different processes driving channel morphological change in the entrance.

Channel Infill

In addition to these more fluvial morphological drivers, the change in wave conditions from 2012 through 2019 resulted in a net increase of sediment from Surf Beach passing into the entrance. The numerical modelling used in the Study established that the wave energy has a role in pushing the entrance channel towards Point Smythe at the edge of the bar. Evidence of this is observed in the bed survey across the bar and the shallow secondary channel running parallel to the outer entrance bar as sediment and channel are pushed eastward.

An increase in this energy, and an influx of sediment from Point Norman may have assisted to infill the channel and disperse tidal flows across the bar, as observed in the arial imagery from 2012 onwards.

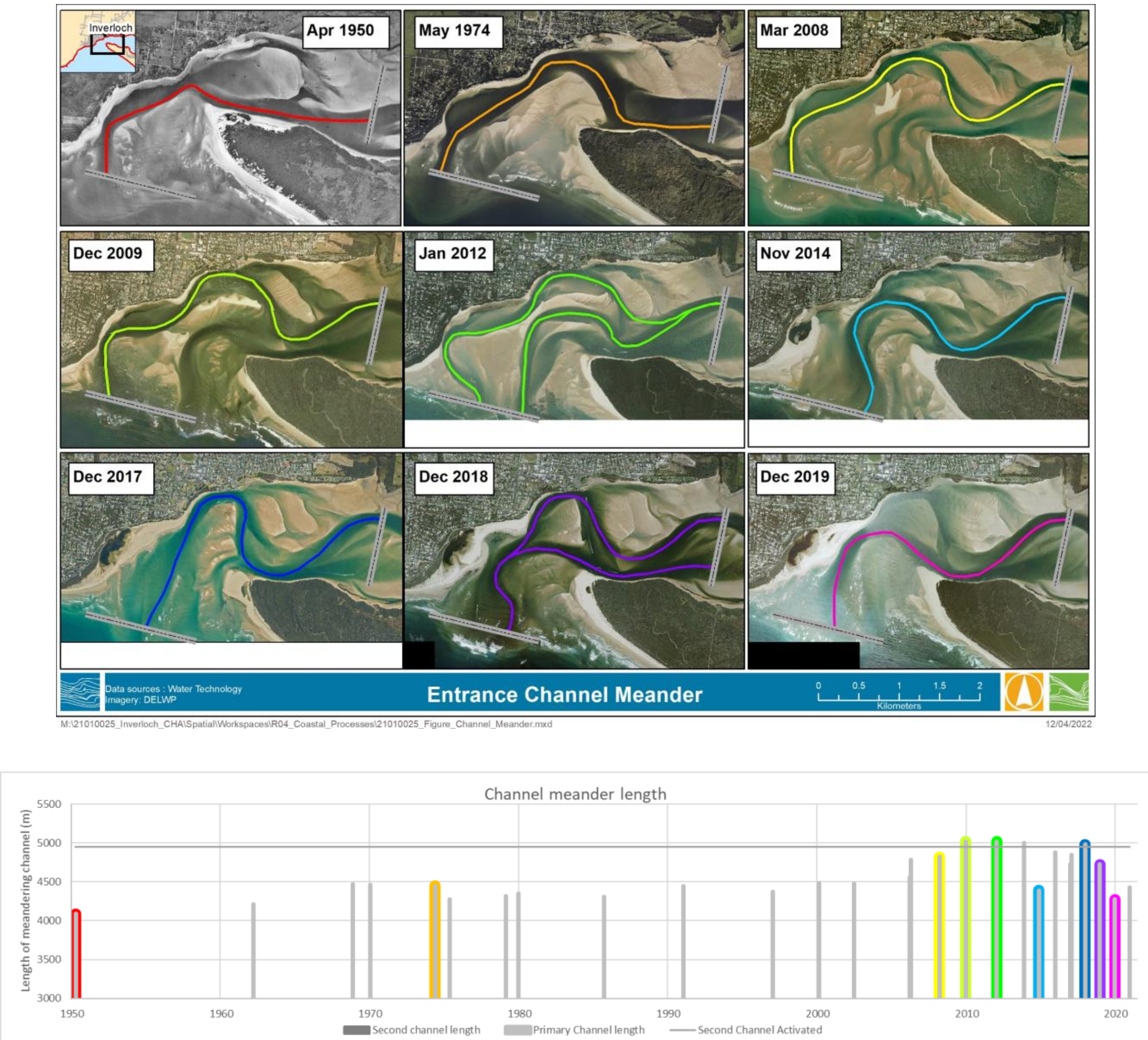


Figure 2-10 Entrance Channel Meander Length

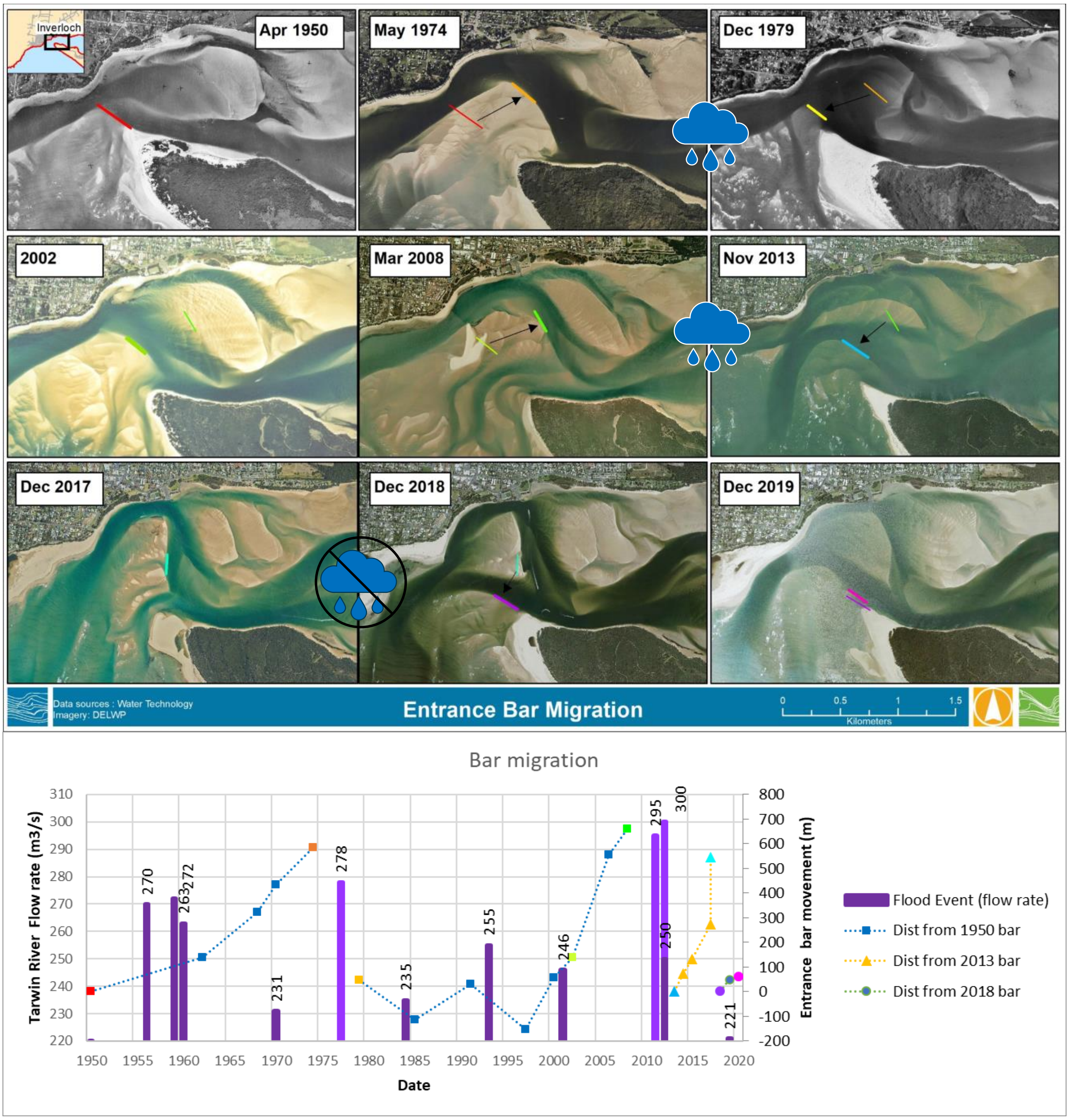


Figure 2-11 Entrance Channel and Bar migration

2.3.2.4 Surf Beach Erosion

The rapid erosion on Surf Beach, between Flat Rocks and Point Norman, has been caused by a combination of the change in channel alignment in 2009 to 2012 and the increase in westerly wave conditions.

The ebb tide delta prior to 2009 was extensive and resulted in a realignment of the bed contours to a more southwest facing direction, in line with the incoming wave (left, Figure 2-12). As the nearshore contours rotated to this angle along Surf Beach, the net sediment transport eastward reduced and the Surf Beach was formed as a (leaky) pocket beach.

Following the loss of the ebb tide delta, and the "flattening" of the edge of the entrance bar, contours along Surf Beach realigned to be closer to the angle of the shoreline, i.e. more southerly facing. This rotation in the nearshore contours results in a greater level of net sediment transport eastward.

Combined with – or a result of – the increase in wave energy and more westerly storm events from 2012, the increase in net sediment transport resulted in the rapid loss of material in the nearshore zone of Surf Beach. This would allow greater wave energy to approach the shoreline, and, again combined with the higher storm events, would allow greater erosion of the dune at the rear of the beach. This material taken offshore during a storm event, would be entrained in the net eastward sediment transport regime and lost from the beach system, unavailable to reform the beach and nearshore zone in calmer weather.

This feedback system appears to be reducing through late 2021 and early 2022 with a recovery in beach levels measured along Surf Beach. This is likely due to the reduction in westerly storm events over summer and a higher incidence of easterly storms as the imagery from 2021 (Figure 2-12) does not indicate the reforming of the ebb tide delta.

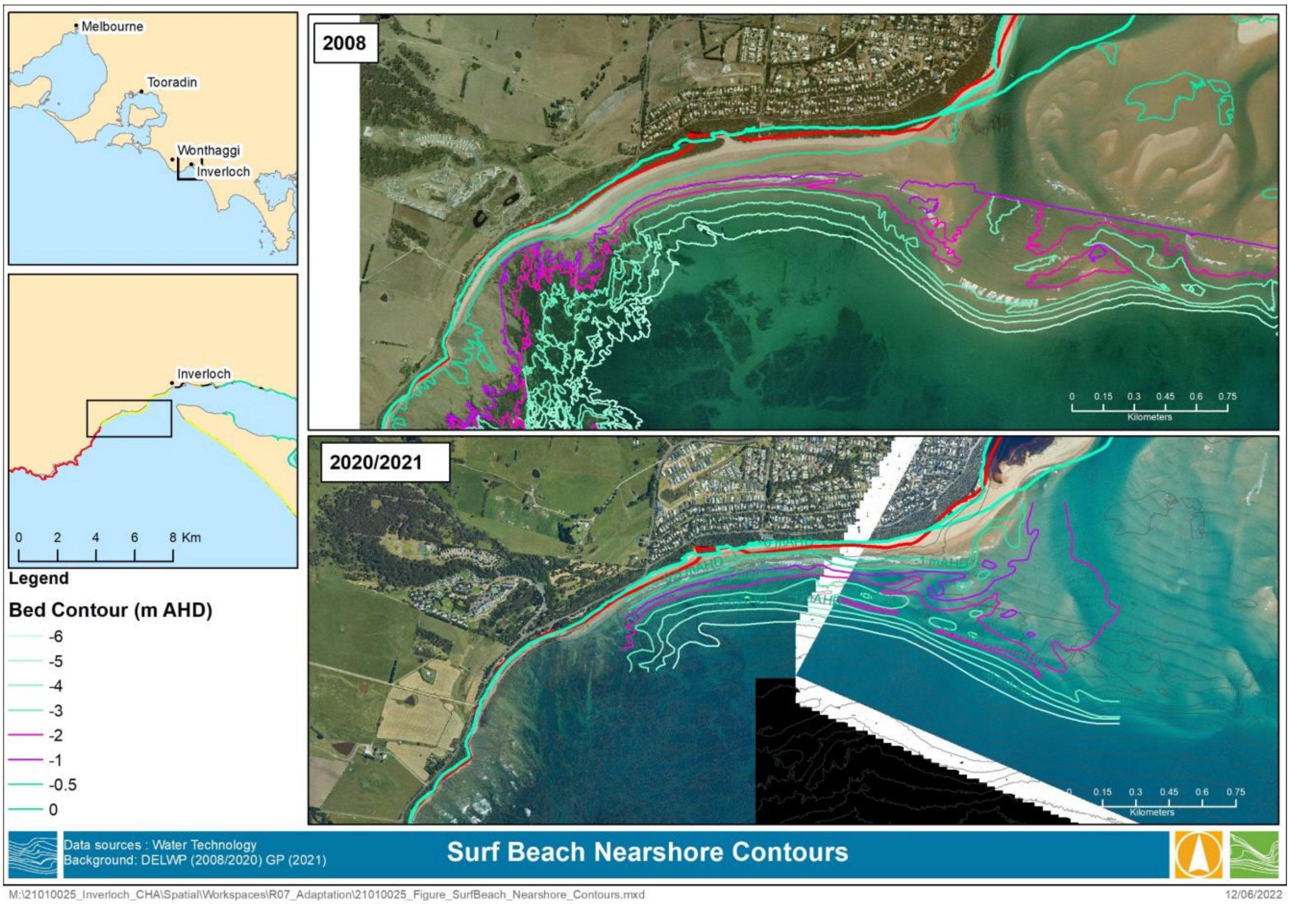


Figure 2-12 Surf Beach Contours, 2008 v 2021

2.3.2.5 Sediment Transport Summary

The processes which drive entrance change and erosion of the Surf Beach discussed above are not processes which can be easily "predicted":

- The increase in wave energy and slight rotation to the west is a global weather force, variable and is not predictable or "manageable" (i.e. cannot be controlled to do as we would like).
- Flood flows through the catchment and into Anderson Inlet are not predictable or manageable as there are no flow controls to change flood behaviour (i.e. dams).
- The channel meander length can be observed, however the forces which drive channel meander are variable (flow, wave energy, unknown) and not predictable. Management of channels within the entrance is possible, but not advisable due to the impact on the surrounding environment.

This lack of predictable (or manageable) drivers means that it is not possible to predict (or manage) with certainty, the future position of the entrance channel, or the re-establishment of the ebb tide delta and reduction in net loss of sand from Surf Beach. The erosion hazard zones generated for the Study acknowledge this uncertainty through the use of "likely" and "possible" erosion hazard zones, especially for the Surf Beach coastline.

2.3.3 Sediment Sources

A loss of close to 2 million cubic meters of sand has been measured in the area around Surf Beach and the entrance delta between 2008/09 and 2021. Some of this material can be seen to have shifted inshore to Ayr Creek and across the channel entrance to Point Smythe, however a net loss of material in the entrance area is recorded.

The location of this volume of sediment is unknown and the sources and sinks of sediment within the Study Area have not previously (nor in the CHA) been investigated.

3 COASTAL HAZARDS

3.1 Overview

Coastal erosion and inundation hazards vary significantly across the Study Area. Given the large spatial extent and range of different environments, a range of techniques were developed and applied to understand the key drivers and processes associated with these hazards in order to develop estimates of the likely extent of each hazard under projected increases in mean sea level of +0.2 m, +0.5 m and +0.8 m.

A combination of events has been assessed, as shown in Table 3-1 which allows a detailed assessment of exposure probability and assessment of risk now and into the future.

Report 4 and Report 5 of the CHA detail the assessment of these coastal erosion and inundation hazards with a summary of the hazards are presented in the following sections.

Table 3-1 Coastal Hazard Scenarios to be assessed

Planning Horizon	Sea Level Rise	Design Wind Event	Design Wave Event	Storm Tide Event	Catchment Flow Event	Urban Flow Event
2021	0	10%	10%	10%	1%	1%
		5%	5%	5%	1%	1%
		1%	1%	1%	10%	20%
2040	0.2	10%	10%	10%	1%	1%
		5%	5%	5%	1%	1%
		1%	1%	1%	10%	20%
2070	0.5	10%	10%	10%	1%	1%
		5%	5%	5%	1%	1%
		1%	1%	1%	10%	20%
2100	0.8	10%	10%	10%	1%	1%
		5%	5%	5%	1%	1%
		1%	1%	1%	10%	20%
2100	1.1	10%	10%	10%	1%	1%
		5%	5%	5%	1%	1%
		1%	1%	1%	10%	20%
2100	1.4	10%	10%	10%	1%	1%
		5%	5%	5%	1%	1%
		1%	1%	1%	10%	20%

3.2 Erosion Hazards

3.2.1 Methodology

The coastal processes and their drivers described above have been used to define the extent of the coastal erosion hazard in the Study Area between Cape Paterson and Cape Liptrap. The different shoreline classes developed through geomorphological analysis have been used to determine which method is suitable to calculate existing and future erosion hazard.

The coastal erosion hazard presented in the mapping for this Study is a hazard zone, not a predicted future shoreline position. As the coastline around the entrance is highly dynamic, fluctuation in erosion as sand moves along the coastline and across the entrance may result in more or less erosion, and potentially accretion, at different times. The coastal erosion hazard zone represents an area where coastal erosion is likely to impact the coast at some point within the defined planning horizon.

The coastal hazard erosion zone presented in the mapping is derived as follows:

Erosion Hazard Zone = Short Term Erosion + Long Term Recession + Response to SLR

3.2.1.1 Short Term Erosion

Short Term Erosion is the impact on the coastline from a storm event. The SBEACH model has been used in the Study to calculate the volume and setback associated with a design storm event. Storm erosion has only been calculated on coastlines where storms will cause short term erosion from which there may be some recovery due to the subsequent onshore movement of sand following a storm event. These coastlines are the pocket beaches along Bunurong Road, the coast from Flat Rocks to Point Norman and the Point Smythe to Cape Liptrap sandy coast.

Storm erosion varies with local bathymetric profile and dune elevation and slope. Survey collected in 2021 has been used for the beaches to the west of the entrance, whilst the 2008/09 LiDAR has been used on the Venus Bay coastline.

3.2.1.2 Long Term Recession

Long term recession considers the existing rate of coastal retreat. Recession is effectively the cumulative long term impact of all storms, large and small from which the beach does not fully recover.

The long term recession within the Study Area has been based on the 70 years of available aerial photography which cover the area in detail. The position of each shoreline relative to the shorelines in 1950 has been mapped and a linear regression rate determined. The total long term recession is calculated by using the linear regression of the long term recession as a rate (m/y) and the time to the next planning horizon, i.e. 20 years until 2040, 50 years to 2070 and 80 years to 2100.

Where long term recession shows time periods of extended high rates of recession (e.g. Wreck Ck/Surf Beach between 2012 and 2019), an additional “possible” long term recession rate has also been determined. Coastal recession includes the impact of channel meander within Anderson Inlet, especially where it has resulted in a continued setback of the coast and loss of vegetation on the northern shore of Point Smythe.

3.2.1.3 Future Recession

To consider the effects of rising sea levels on the coastal hazard zone, future recession is calculated.

Given the uncertainties as to what the future profile and alongshore sediment transport regime will present, the response of the coastline to sea level rise has been determined using the equilibrium beach profile “Bruun Rule”. The profile model has considered the existing beach and bathymetric profile, existing design wave conditions and existing beach sediments, calculating the change associated with the rising mean sea level.

The future recession due to sea level rises within the Inlet is associated with the increased tidal inundation and landward migration of vegetation. Wide expanses of the Anderson Inlet floodplain are within the future spring tide range and recession of the coastline may occur. This is noted in Section 3.4 and the impacts of this permanent rise in tidal height is presented as a permanent inundation hazard layer.

3.2.1.4 Cliff Erosion

Where there is potential for recession of a sandy coastline landward to a point where the coastal processes interact with a different strata, i.e. a rocky cliff or earthen rise, the calculation of erosion extent will revert to a Cliff Erosion Hazard Zone. The Cliff Erosion Hazard Zone is calculated through analysis of the existing slope angles of the cliff section and mapped as a constant hazard zone, considered on a different time scale to the 2100 planning horizon used in the CHA.

3.2.2 Key Findings

A summary of short term storm demand, long term recession and future recession is presented in Table 3-2. The erosion at each section of the coast is dependent on the processes operating and the beach profile which can result in significant change in a short section.

Long term recession noted in italics is associated with the *potential* long term recession associated with the rapid rates of erosion experienced recently at Surf Beach and in the past at Toys Backwater. These erosion rates are not reflective of the long term change which has been used to generate the erosion hazard zones, however are important to note, and are captured in the risk assessments completed for the CHA by Alluvium (Alluvium, 2022b).

Erosion hazards increase with the rising sea level, and over time. The coastline along Inverloch from Wreck Creek to Townsend Bluff shows evidence of retreat over the longer term which is likely to continue over time, pushing the coastline landward. The increasing sea levels will encourage the wave and tidal forces active on the coast to reshape the dune and nearshore zone to accommodate the increased water levels and where possible, retreat will occur with the increasing sea levels.

Erosion hazards are significant along the Flat Rocks to Point Norman coastline, around Toys Backwater and Screw Creek and in limited pockets around Anderson Inlet. The pressure of the tidal channel on Point Smythe is notable and the Inlet edge of the Point has seen significant setback over the photographic record. The response to this section of the coastline to sea level rise and the continuing morphology of the entrance channels is difficult to predict and could alter the coastal erosion hazards along the Inlet coast into the future.

Where cliffs are present on the coastal zone (predominantly along Bunurong Road) the cliff erosion hazard zone has provided a buffer to allow for deep-seated mass movements that may be initiated by a combination of surface processes and/or due to marine influences at the base of the cliff. Slope failures are considered a potential source of hazard along the cliff shorelines as they can result in major impacts landward of the cliff edge and can occur with little to no warning.

Table 3-2 Coastal Erosion Extents (m)

Coastline	Shore Term Erosion Setback (m)		Long term recession (m)*			Sea Level Rise (m)				
	1%	10%	2040	2070	2100	0.2m	0.5m	0.8m	1.1m	1.4m
Bunurong Road Pocket Beaches	8 - 50	7 - 38	0 - 4	0 - 11	0 -18	1 - 3	3 - 8	7 - 13	8 - 17	10 - 22
Flat Rocks – Point Norman	2 - 39	5 - 45	0 - 14	0 - 35	0 - 56	11 - 17	27 - 43	43 - 69	60 - 95	76 - 121
*Flat Rocks to Point Norman**			*40 - 200*	*100 - 500*	*160 - 800*					
Point Norman to Screw Creek			0 - 30	0 - 75	0 - 120	0 - 4	0 - 10	1 - 16	1 - 22	1 - 28
*Point Norman to Screw Creek**			*0 - 320*	*0 - 800*	*0 - 1280*					
Anderson Inlet			0 - 24	0 - 60	0 - 96					
Point Smythe (Inlet side)			24 - 52	60 - 130	96 -208					
Point Smythe (ocean side) – Cape Liptrap	20 - 21	19 - 21	0 - 20	0 - 50	0 - 80	6 - 10	16 - 26	25 - 42	34 - 57	44 - 73

3.3 Storm Inundation Hazards

3.3.1 Methodology

Extreme elevated water levels within the Study Area are a function of a number of different physical pressures and processes including offshore storm surge, wind and wave set-up, and catchment generated inflows, as schematised in Figure 3-1.

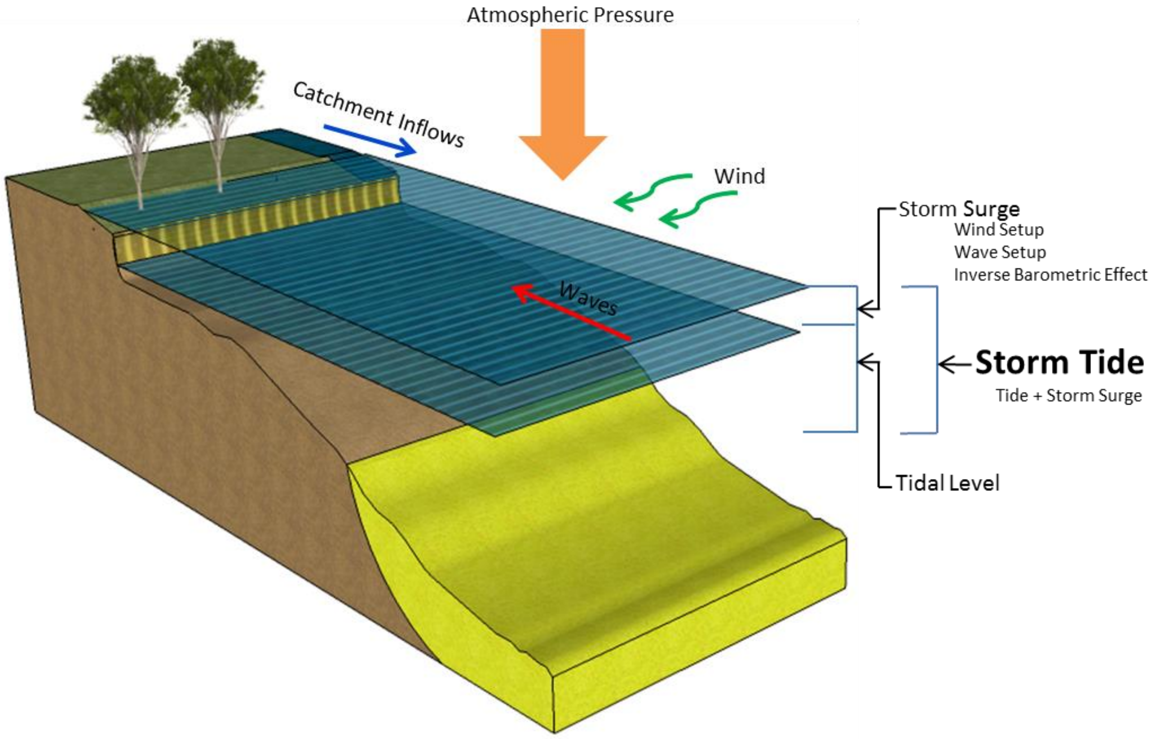


Figure 3-1 Processes Producing Elevated Coastal Water Levels

To assess inundation hazards two major inundation processes were analysed; a representative extreme storm tide event and an extreme catchment generated flood event, occurring in the Tarwin River catchment as well as the smaller Pound, Screw, Ayr and Wreck Creek catchments feeding into Anderson inlet. Urban flow considered the 1% or 20% AEP in acknowledgement of the design capacity of the urban stormwater network. Coincidence of extreme events for the different drivers were reviewed and the combinations of storm tide, wave, flooding and sea level rise established for the project.

Inundation of the open coast used the coastal shoreline response model SBEACH to determine the total onshore water level from the maximum wave setup and storm tide levels offshore. SBEACH considers the nearshore profile and dune to establish coastal water levels and includes the wave setup on the coastline. The level of the setup was then mapped using the bathtub method along the exposed coast.

Within Anderson Inlet a 2-dimensional MIKE21 Flexible Mesh model was used to simulate offshore storm tides, Inlet winds and catchment flood flows, generated using the RORB hydrologic model. The modelling included the existing levee configuration to establish the timing and frequency of levee overtopping into the future. Inundation extent was established as the maximum extent from the model.

The urbanised Inverloch township was assessed using a combination of either SBEACH to develop coastal water levels including wave conditions on the open coast, catchment hydrology to establish upstream inflows, Inlet tailwater levels from the MIKE21 model and a TUFLOW model to add synthesised rainfall onto the existing pipe network drainage in Inverloch. The TUFLOW model was used to establish the impact of storm tide backflow into the urban drainage network and low-lying topography. The inundation extent was generated through the combination of maximum extent from the TUFLOW model and via a bathtub method for future sea level rise scenarios in the Surf Beach residential area and Wreck Creek catchment based on the SBEACH coastal water levels.

3.3.2 Key Findings

Coastal inundation hazard varied widely across the Study Area. Along the open coastlines of Bunurong Road and Venus Bay ocean coast inundation is minimal, the extent of the elevated sea levels limited by the Bunurong Road cliffs and Venus Bay dune systems.

Along Wreck Creek and within the Surf Beach residential area inundation is greater, with the extent of inundation hazard increasing with rising sea levels. The inundation extent across Wreck Creek and the Surf Beach residential area also has a higher level of uncertainty into the future given the risk of erosion of the primary coastal dune which currently prevents direct inundation from wave setup. The lack of stormwater drainage along Surf Parade and Lohr Avenue also contribute to the volume of overland flow and inundation presented in the hazard zones.

The main township of Inverloch is located on the elevated ridge above Anderson Inlet and is not impacted by existing or future storm tides. The area around the boat ramp and jetty, and east towards Screw Creek is noted to become increasingly vulnerable with sea level rise and the boat ramp car park is known to be inundated under existing conditions. The inundation hazard extent within the Broadbeach Estate remains expansive, covering a similar area to that already identified in the Bass Coast LSIO.

Inundation across the low lying land of Anderson Inlet is predicted to be extensive under existing and future extreme water levels. Levees which prevent inundation from higher probability events begin to be less effective as water levels exceed 2.0m AHD offshore. Inundation begins through elevated waters flowing beyond the landward extent of the levee, before being increasingly likely to overtop levees as sea levels rise. Tarwin Lower and the Venus Bay settlements are above the existing and future inundation levels, although road access to the commercial and residential areas is likely to be restricted during the storm tide event. Drainage of the waters behind the levees will be driven by the location and condition of any drains through the levees.

3.4 Tidal Inundation

Along with significant inundation due to the elevated coastal water levels during a storm event, the coastline in the Study Area will be subject to a higher level and more frequent inundation due to rising tidal water levels. The existing mean low water spring level of -0.6m AHD within Inverloch will be expected to increase to +0.2m AHD by 2100 and as such land which was previously intermittently inundated will become permanently wet.

Likewise the existing mean highwater spring level of 0.9m AHD will increase to 1.7m AHD, significantly changing the elevation and extent of land which will be subject to tidal currents, wave energy and saline water on a regular basis.

This increase in the tidal plane and expansion of the tidal inundation area is not considered an erosion process in itself, and as such some of the impacts of the increasing tide are not considered in the erosion hazard extents. Instead, this change in shoreline position through the increase in mean high water springs is captured through the generation of “permanent inundation” hazard maps.

These hazard maps show large expanses of the Anderson Inlet floodplain are within the hazard zone and a change in vegetation and use (especially agriculture) is likely to occur.

3.5 Assumptions, Limitations & Uncertainty

Prediction of future coastal hazard within the Study Area is complicated by the array of drivers and response mechanisms. Best practice approaches have been adopted together with the latest knowledge and understanding to account for these complexities through rigorous analysis and sensitivity testing, however, there remains some limitations and uncertainty in both existing knowledge and assessment methods used to underpin the coastal hazard assessment.

3.5.1 Assumptions

The key assumptions associated with the coastal hazard assessment are as follows:

- It is assumed that the 40y hindcasts of water levels and wave conditions are sufficient to estimate the 1% AEP events
- It is assumed that modelled hindcast and measured tidal waters are generally representative of conditions, at Tarwin Lower especially where the measured data does show some seasonal variation.
- It is assumed that the models adopted produce reasonably reliable conditions where data does not exist for model calibration / validation (*this is a common assumption and why numerical models which are well established and tested are used*)
- Erosion zones assume coastal recession will occur at a consistent rate landward. This is a conservative assumption as there is no allowance for impediments to erosion such as vegetation, infrastructure, buildings/foundations or changes in strata. It is assumed the soft material along the shore is uniform landward to the location of the backshore cliff or bluff.
- With the exception of the rock seawall along the Inverloch foreshore from the South Gippsland Yacht Club, past the bowls club and Inverloch Jetty to the northern return to the Esplanade, coastal structures are assumed to not prevent landward recession and erosion. The rock seawall adjacent to Bunurong Road and the geotextile sandbag wall seaward of the Inverloch Surf Life Saving Club are assumed to be temporary structures and considered only in the present day storm erosion estimates.
- Inundation zones assume the existing, or in most cases the FutureCoast LiDAR topography from 2008/09, remains unchanged into the future. Inundation does not presume any change in the topography within the coastal erosion hazard zones. This is especially relevant for areas of low topography or vulnerable dunes such as Wreck Creek. There are also some sections of the catchment which are known to have been altered since the LiDAR capture (e.g. Paperbark Place, Broadbeach Estate) where inundation hazard zones will differ with further investigation/update of topographic survey.
- It is assumed that the drainage network in Inverloch and especially the coastal outfalls are allowed to backflow and drain freely and are not obstructed by mechanical (e.g. tidal gates) or natural features (e.g. sand bar).
- It is assumed that earthen levees within Anderson Inlet will remain in their current state and dimensions into the future for *inundation hazard*. For *erosion hazard*, the opposite is assumed – that the earthen levees within Anderson Inlet will *not* prevent or limit further erosion.
- The study assumes the current bathymetry/topography remains constant as sea levels rise.
- There is an assumption that long term historic changes will occur in a similar manner and rate into the future (separate from the impact of sea level rise).
- It is assumed there is no mass change of entrance and tidal bar dynamics (e.g. extreme case of the last interglacial maximum (Rosengren, 2022).

3.5.2 Limitations

The assumptions made and the complexity of coastal process in the Study Area mean that there are some limitations on the results which cannot be overcome. In particular, it is noted:

- The coastal hazard zones are to provide an understanding of exposure and support for adaptation planning. Coastal hazard is not a prediction of a specific flood event or future shoreline.
- Results should not be over-interpreted at the micro (lot/property) scale.
- The coastline in the Study Area can be very dynamic. The coastal hazard presented is based on the conditions observed and data available at the time of analysis. Conditions may differ to the time of reading. This is important to consider for the Wreck Creek area where significant change of the coastal topography since data collection and numerical modelling could change the extent of coastal inundation and erosion.

3.5.3 Uncertainty

Following assessment of the coastal hazard drivers in the Study Area, the assessment of coastal hazards is considered potentially sensitive to the following future sources of uncertainty:

- The composition of the strata through the Bunurong Road cliffs is not well known and core logs and sediment analysis would be needed to provide greater detail on the potential failure mechanisms.
- The processes which influence the entrance morphology and erosion at Surf Beach have been investigated and their effect on the coastline assessed individually and in combination. However, the dynamic nature of these processes, the process which drive them, and the interaction which occurs between the influencing forces means prediction of the morphological processes and responses at the entrance has a high level of uncertainty. Hazard maps have been designed to show zones of hazard which encompass these processes, but they do not predict a future shoreline position.
- The magnitude and contribution to the extent of inundation from wave setup and overtopping/breaching due to lack of inshore wave calibration data. This is especially noted in areas where significant wave transformation and shoaling occurs, i.e. along Bunurong Road across rock platforms and along the Wreck Creek to Point Norman shoreline.
- Likewise there is a high level of uncertainty in the migration of Point Smythe and the future response of the sand spit to the changing channel morphology.
- The magnitude and contribution to the extent of inundation from elevated coastal water along the Wreck Creek to Point Norman shoreline due to the rapidly changing coastal dune and topography.

Ongoing monitoring and additional future assessments can be used to continually update and improve model calibration and prediction of hazard zones. This includes topographic, bathymetric and sedimentary data, in particular to feed into modelling of the estuary entrance and the dynamics of sediment transport on the Flat Rocks and Surf Beach coastline.

4 HAZARD EXPOSURE

4.1 Hazard Exposure

The key output of the Inverloch Region CHA are erosion and inundation hazard extents in the form of GIS layers along the full length of the Cape to Cape coastline. A set of GIS layers have been produced to quantify the extent of the erosion and inundation hazard for each sea level rise scenario investigated.

The erosion hazard extents have been determined based on the geomorphic makeup of the coastal sector, as described in Report 4. The inundation hazard extents were mapped based on the outputs from the hydrodynamic modelling which has been smoothed to provide an appropriate interface.

Assets within the Study Area have been identified through analysis with project stakeholders and review of available data. A number of broad asset classes such as buildings, features or interest, infrastructure etc were established from the asset review.

These asset classes were compiled into a suite of point, line or polygon GIS layers depending on data availability and/or the most suitable spatial representation of each asset type. Asset classes were then broken-down further by subtype (e.g. telecommunications lines, sewerage network, electricity network etc.), and identified as being located in either the Inverloch township, the remaining areas of Bass Coast Shire, or South Gippsland Shire.

The length and proportion of exposure to the coastal hazards for assets such as roads and property was determined to quantify the level of exposure (i.e. if just 1m of a 100m road is within a hazard layer this 1m is identified, but the small proportion of the exposure is also noted).

A summary of the exposure of key assets within the Study Area is presented in Table 4-1.

Table 4-1 Key Asset Exposure

Scenario		Exposure			
Planning Horizon / Sea Level Rise	Storm tide Design Event	Buildings (count)	Roads (length / proportion)	General Residential Land GRZ1 (area)	Farming Zone FZ (area)
Coastal Erosion					
2021 + 0m SLR	10% AEP	0	0.9 km (0.1%)	0 km^2 (0%)	0.08 km^2 (<0.1%)
2100 + 0.8m SLR	10% AEP	84	6.7 km (1.0%)	0.07 km^2 (1.0%)	0.38 km^2 (0.1%)
2021 + 0m SLR	1% AEP	0	1.0 km (0.2%)	0 km^2 (0%)	0.08 km^2 (<0.1%)
2100 + 0.8m SLR	1% AEP	95	6.7 km (1.1%)	0.07 km^2 (1.1%)	0.38 km^2 (0.1%)
Coastal Inundation					
2021 + 0m SLR	10% AEP	40	17.1 km (2.7%)	0.54 km^2 (8.3%)	20.0 km^2 (5.2%)
2100 + 0.8m SLR	10% AEP	65	31.3 km (5.0%)	0.66 km^2 (10.2%)	37.7 km^2 (9.8%)
2021 + 0m SLR	1% AEP	17	14.2 km (2.2%)	0.31 km^2 (4.8%)	25.6 km^2 (6.7%)
2100 + 0.8m SLR	1% AEP	116	33.5km (5.3%)	0.56 km^2 (8.6%)	40.2 km^2(10.5%)
Permanent Inundation					
2021 + 0m SLR		2	0.3 km (0.05%)	0.02 km^2 (0.2%)	5.96 km^2 (1.6%)
2100 + 0.8m SLR		20	5.5km (0.9%)	0.11 km^2 (1.7%)	24.0 km^2 (6.3%)

4.2 Assets at Risk

Alluvium Consulting developed likelihood and consequence ratings based on consultation with the community and stakeholders in the Study Area. For full details, see the *Cape to Cape Resilience Project Risk and Vulnerability Assessment* (Alluvium, 2022).

The likelihood and consequence ratings were used to determine the risk posed by the coastal hazards to coastal assets and values over the range of planning horizons detailed in Table 3-1.

A summary of the risks posed to the different areas developed by Alluvium is presented in Table 4-2. The highest risks are associated with coastal erosion in Inverloch by the end of this century, and through storm tide and permanent inundation within South Gippsland Shire from present day and increasing to the end of this century.

The Bass Coast Shire area outside of Inverloch is relatively unexposed to coastal hazards, although small sections of Bunurong Road should be monitored due to the close proximity to the cliff hazard zone.

The extent of the coastal hazard zones can be seen in reports 4 and 5 of the coastal hazard assessment, whilst mapping of the subsequent ***risk*** can be found in Alluvium (2022).

Table 4-2 Regional Risk Summary (Alluvium, 2022)

Area	Coastal Erosion				Storm Tide Inundation				Permanent Inundation			
Sea Level	0.0m	0.2m	0.5m	0.8m	0.0m	0.2m	0.5m	0.8m	0.0m	0.2m	0.5m	0.8m
Planning Horizon	2020	2040	2070	2100	2020	2040	2070	2100	2020	2040	2070	2100
Inverloch	Med	Sig	Sig	High	Med	Med	Sig	Sig	Low	Low	Med	Med
Bass Coast	Low	Low	Low	Med	Low	Med	Med	Sig	Low	Low	Low	Med
South Gippsland Shire	Low	Low	Med	Med	Med	Sig	Sig	Sig	Med	Med	Sig	Sig

4.3 How to Use the Study Outputs

The information generated by the Inverloch Region CHA along with the coastal hazard GIS datasets can be used to provide a better understanding of coastal hazards in an area of interest, particularly the key processes and drivers of change and how these may be impacted by sea level rise.

Examples of the use of both the understanding of the coastal hazard processes and the hazard layers has been captured in Report 7 Adaptation Action Technical Assessment.

The recommendations provided in the various study reports, with regard to future data collection and monitoring, knowledge gaps, and assessments, aim to further improve certainty and confidence in the outputs of this study. The change experienced on the Surf Beach coastline at Inverloch since 2012 provides an important example that coastlines are dynamic and rapid and potentially damaging coastal change can occur on previously “stable” coastlines. A coastline should always be considered a dynamic environment and our understanding will evolve and enhance over time as more observation and change is documented.

5 ADAPTATION ACTIONS

Technical assessment of potential engineering adaptation actions to address coastal erosion hazard at Inverloch between Flat Rocks and Point Norman were assessed as part of the CHA.

Whilst coastal hazard risks are present now and into the future for a number of locations within the Study Area, the community desire to address the rapid erosion of the coastline at Surf Beach led to the focus of adaptation actions on this section of the coast. Further work in Stage 2 of the RaSP will work to develop adaptation pathways and a Coastal Resilience Plan to address coastal hazard risk for the Study Area.

5.1 Multicriteria Analysis

Multicriteria analysis was used to assess the most appropriate actions for the coastline, with the section between Flat Rocks and Wreck Creek considered as one action area and between Wreck Creek and Point Norman as the second area.

The objective of the multicriteria analysis is to apply a semi-qualitative and quantitative approach to compare alternative actions. The multicriteria analysis was used to shortlist engineering actions for detailed technical assessment. The multicriteria analysis provides a decision-making tool for complex situations where there may be conflicting objectives. The weightings used for the different objectives are presented in Figure 5-1.

The assets vulnerable to coastal erosion within the Flat Rocks to Wreck Creek section are Bunurong Road and services within the road reserve. Community engagement during the project highlighted that for a high proportion of the community, the assets within the Wreck Creek to Point Norman section are more associated with the natural environment and use of Surf Beach, and the maintenance of values which they enjoy by accessing and using the beach for recreation.

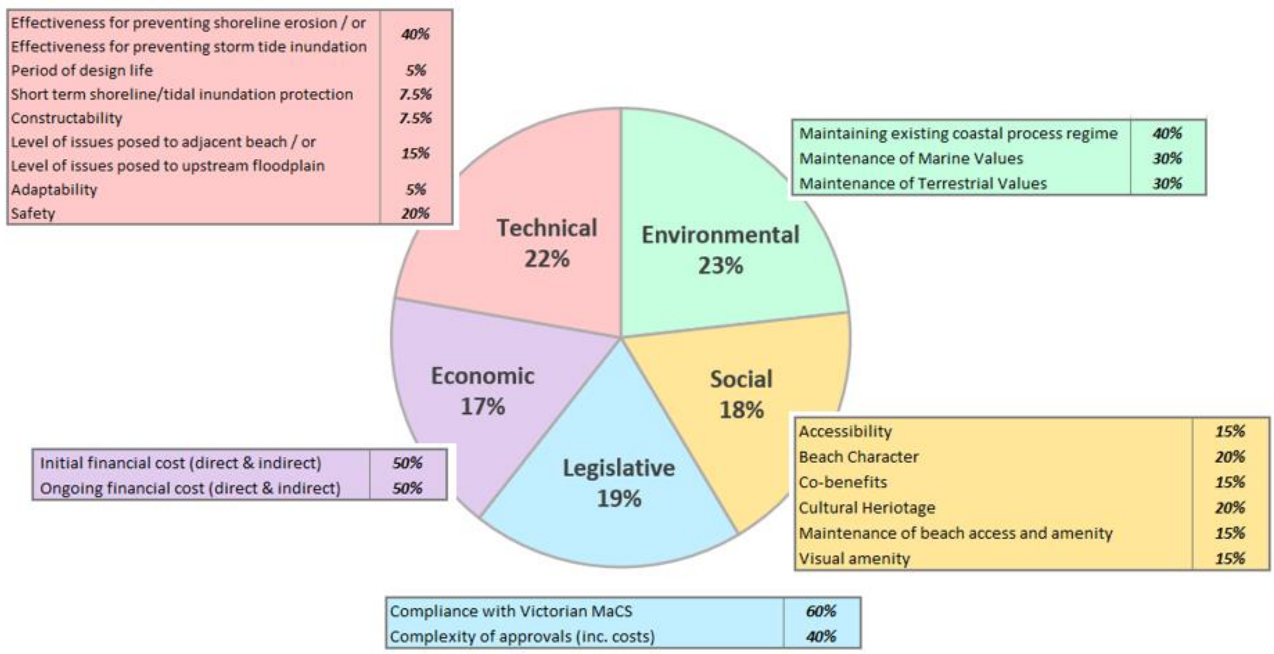


Figure 5-1 Multicriteria Analysis Weighting

5.1.1 Ranked Adaptation Actions: Bunurong Road - Flat Rocks to Wreck Creek

Beach nourishment – one off and ongoing – were identified as the highest ranked actions (rated 1 and 2) for reducing the coastal erosion hazard along Bunurong Road. However, the risks associated with relying on a single nourishment to protect the coastline until the 2040 planning horizon are considerable and ongoing beach nourishment, assisted by dune protection and revegetation is considered a more technically feasible solution, albeit potentially with higher ongoing costs.

Engineering actions such as construction of a seawall (constructed of either geotextile bags or rock) were rated next highest ranked (3 and 4), with a higher technical effectiveness score than nourishment but with greater impact on the existing coastal processes, marine and terrestrial values than nourishment.

Based on the multicriteria analysis, a technical feasibility assessment of beach nourishment and a seawall were completed for the Bunurong Road – Wreck Creek section of the coastline.

5.1.2 Ranked Adaptation Actions: Surf Beach - Wreck Creek to Point Norman

Consistent with the Bunurong Road section of this coastline, the highest ranked adaptation option is beach nourishment. Despite the high overall rank, it is unlikely that a single beach nourishment project alone will be sufficient to prevent coastal erosion for a planning horizon of 2040 and the action scored a low technical score. Ongoing beach nourishment and management are the second highest ranked action to provide coastal erosion protection, however, again it is noted that there will be a significant ongoing cost and potential impacts to the environmental values of the location where the sand is sourced from and also from the constant movement of sand across the beach.

A groyne field assessed in the multicriteria analysis was considered to occur in combination with beach nourishment, and provided a notably lower, but still acceptable score in the multicriteria analysis. Seawalls score well technically at preventing erosion of the dune system, but do not match community expectations for maintaining a natural beach.

A single long groyne at Point Norman and nearshore breakwaters both scored low on the multicriteria analysis, however these are actions which have been discussed in the community both prior to and during the CHA project.

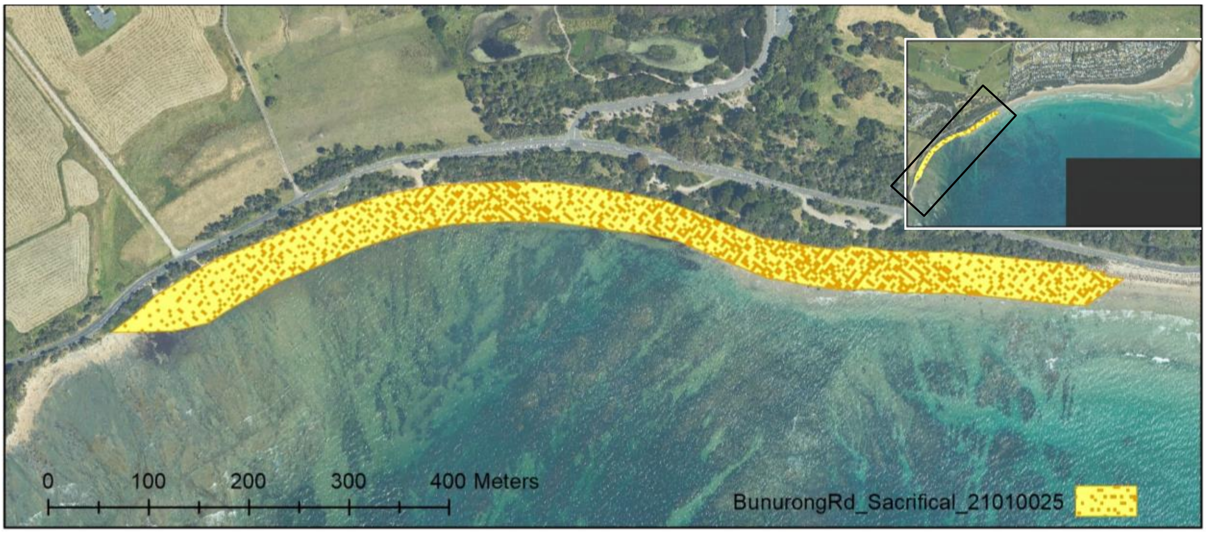
Based on these analyses, technical feasibility of a series of groynes, a single long groyne at Point Smythe, and a series of nearshore breakwaters were completed for the Wreck Creek to Flat Rocks section of the coastline.

5.2 Technical Assessment

5.2.1 Bunurong Road Beach Nourishment

To reduce the risk of erosion of the coastline along Bunurong Road and damage to the road and services, beach nourishment was designed for the 2% AEP existing storm event. This beach nourishment is sacrificial and would require replacement after a storm and maintenance of levels across the design life.

The volume of sand required for the sacrificial beach is in the order of 75,000 to 100,000m^3, placed to a level of 2.5m AHD and a width of around 40m. A conceptual scale of this is presented in Figure 5-2 (note horizontal and vertical scales are not equal).



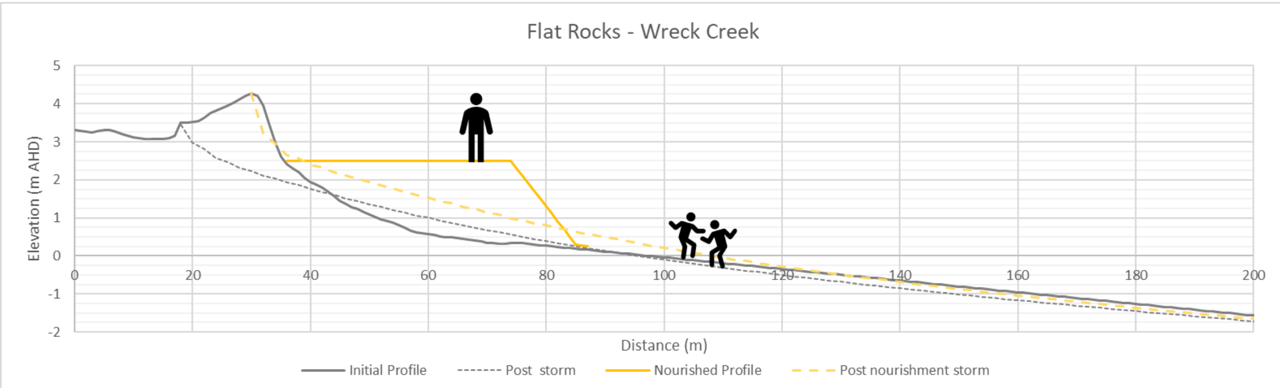


Figure 5-2 Sacrificial Beach Nourishment, Bunurong Road

Risks associated with sacrificial nourishment for coastal protection are as follows:

- Construction works
  - Some loss of dune vegetation could be expected along the beach during nourishment as machinery accesses the beach.
  - Significant truck movements, or pipe and dredge pumps would be required to place the material, posing a safety risk to beach users.
  - Ongoing management would result in more truck movement across the beach, impacting beach users and posing a safety hazard.
  - A suitable source of sand is required for ongoing nourishment and beach management. A sand supply of this magnitude may be difficult to find, and multiple sources may be required for land based supply. A large dredge, capable of delivering sand inshore would be required for offshore sand supply. A suitable sand supply would need to be identified and the risks associated with removing the sand from the borrow site fully assessed.
- Inundation
  - Nourishment is required for protection from storm tide inundation from the sea, however the high dune will also prevent free drainage of the catchment and would result in extended (both in duration and extent) flooding of the low lying area landward of the road.

- Amenity
  - Construction of a 40m wide beach at 2.5m AHD elevation would change the amenity of the beach, especially the interface between the beach and the rock platform. The wide flat beach would initially be replaced by a high beach and steep face, then a wider flatter beach as the profile adjusts to the environment.

5.2.2 Bunurong Road Seawall

A seawall along would be effective at preventing erosion of the coast impacting the road or services. The seawall would need to be in the order of 1,000m in length. Construction of the wall could be done in stages or as a single project.

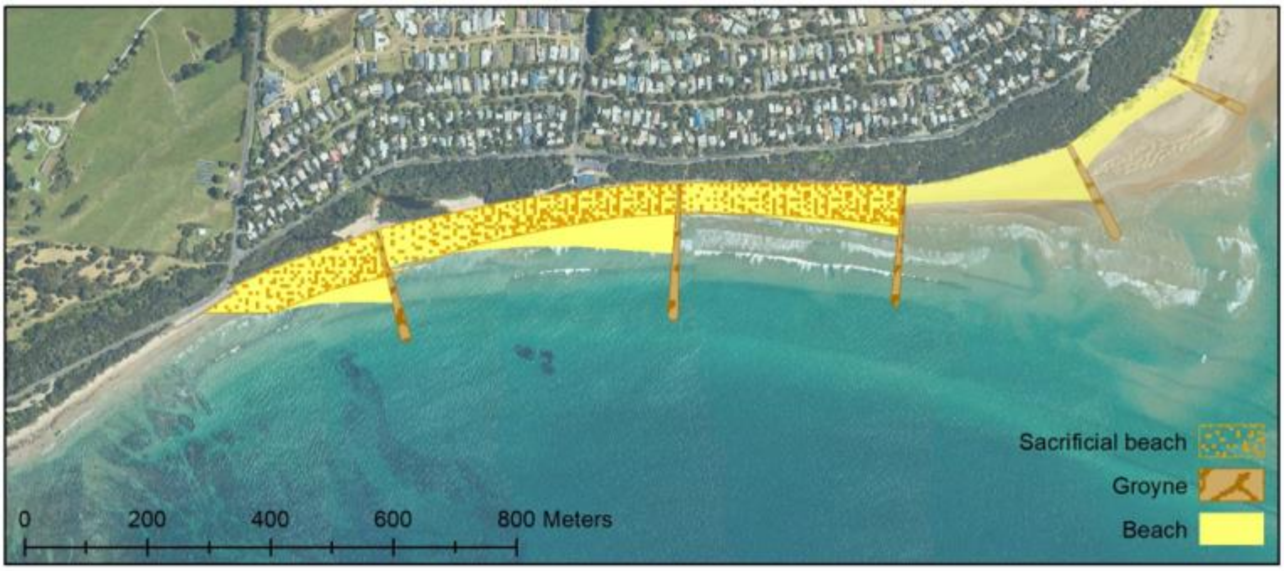
Some risks associated with construction of a seawall along Bunurong Road are as follows:

- Construction works
  - A loss of dune, dune vegetation and beach could be expected along the seawall path during construction. Parts of the remaining dune are narrow and it is likely that in some parts dune could be lost completely with construction of the wall.
- Access
  - Access points may be limited due to the narrow zone available for construction of the wall.
- Inundation
  - Overtopping, backflow through Wreck Creek of catchment flows could lead to inundation of the low lying land behind the seawall. Drainage would be required through the wall.
- Terminal Scour
  - Erosion of the dune at the Bunurong Rd/Wreck Creek bridge (culvert) would result in the formation of a new mouth of Wreck Creek at the end of the seawall. This could impact the bridge foundations. Exposure of the bridge to direct wave energy during a storm event could also occur if terminal scour and the changing of the creek alignment widened the creek mouth at this point.
  - Erosion of the dune and vegetation adjacent to the wall would be expected.
- Amenity
  - Construction of a seawall would have a significant impact on the visual aesthetics of the beach from Flat Rocks to Wreck Creek
  - The lowering of the beach would have an impact on the availability of the beach and access to the beach area will be reduced as the lowered beach is increasingly inundated in high tide conditions.

5.2.3 Surf Beach Groynes

A series of short groynes and beach nourishment along the Surf Beach from the Wreck Creek seawall east beyond the Inverloch SLSC would **reduce the rate of coastal recession** to the dunes which currently provide a buffer between the road, services (water, power, communications etc), residential areas and the ocean wave and tidal forces.

The length, spacing, height and beach nourishment required for the groynes to successfully prevent erosion of the existing dune over the next planning horizon (i.e. to 2040) were determined through the technical analysis. A conceptual image of the groyne and beach layout and size of the groyne across the beach is presented in Figure 5-3.



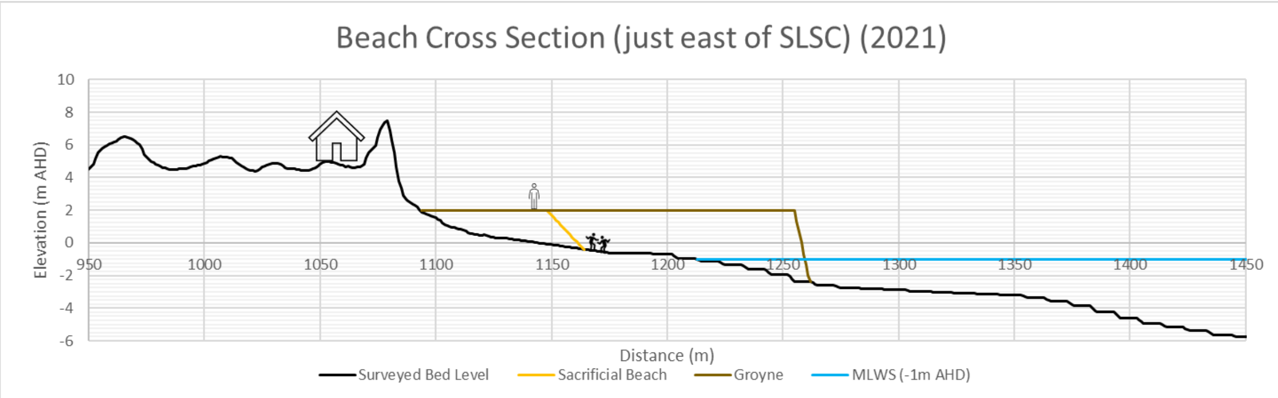


Figure 5-3 Conceptual groyne layout and size

Construction of a series of groynes, combined with beach nourishment, is a technically feasible option for protecting the shoreline at Surf Beach, however the following provides a summary of an initial pass of potential risks to Surf Beach and the adjacent shoreline:

- Construction works
  - A loss of dune, dune vegetation and beach could be expected along the beach during construction with the movement of plant, and the excavation required to construct secure footings.
- Inundation
  - The nourished beaches would prevent the drainage of Wreck Creek across the beach surface.
  - The low dunes at the western most beach (Bunurong Road / Wreck Creek) are likely to be overtopped during a 2% AEP storm event and sand would block creek drainage further.
- Beach nourishment
  - Nourishment has been designed to be sacrificial and it is assumed that the protection offered by beach nourishment would be lost or largely diminished following a 2% AEP storm event. Following a large storm renourishment would be required.

- The volume of nourishment assumes the beach would realign to the long term wave angle and remain largely within the groyne cell. Loss of beach material without renourishment following storm events would, over time, result in a narrowing of the protective beach along the coastline.
- A suitable source of sand is required for ongoing nourishment and beach management.

- Amenity
  - Construction of a series of groynes would have a significant impact on the visual aesthetics of the coast along Surf Beach.
  - The equilibrium alignment of the coastline is notably different to the current alignment. If the beach extended out to the stable alignment, the beach width would be significant in parts (i.e. 100m+).
  - The nourishment (depending on nourished material) would likely result in a high dry beach followed by a steep slope at the water face to meet the existing flat beach, notably different to the existing wide flat beach.
- Adjacent Coastline
  - Erosion of the coastline eastward of the most eastern groyne as sediment would be blocked by the groyne field.
  - Construction of the groynes around Point Norman to prevent this groyne-driven terminal scour may result in scour of the bed at the groynes as current shears off the channel alongside the groyne. This could cause feedback and draw the main channel closer to the groyne as scour increases.
  - Undercutting of groynes by the migrating channel could cause the structure to fail and collapse. This could lead to erosion of the adjacent shoreline.
  - A change in sediment supply within the entrance and a migration of the entrance channel towards groyne-driven terminal scour could lead to scour of the dunes north of Point Norman and recession of the coastline towards Surf Parade and Veronica Street. Review of early aerial photography indicates the dune here was once much narrower (30m) and the channel closer to the residential area.
  - The beach alignments are based on the long term wave climate. An extended deviation from the long term climate has been observed in more recent times contributing to the rapid recession of the Surf Beach coastline. A similar deviation from the long term wave climate could change the beach angle or distance offshore at which sediment transport occurs, resulting in a different response or equilibrium beach.

5.2.4 Surf Beach Long Groyne

A single long groyne at Point Norman was assessed to respond to community interest in the concept, which has been considered as early as 1890 as a means for opening Anderson Inlet to permanent navigation.

The technical ability of a long groyne to anchor sufficient sediment to protect the existing shoreline at Wreck Creek and the SLSC is uncertain. A significant volume of sand is required to assist the beach and nearshore contours to realign such that the net sediment transport eastward is reduced and the beach can balance with the net transport eastward. This is presented conceptually in Figure 5-4.

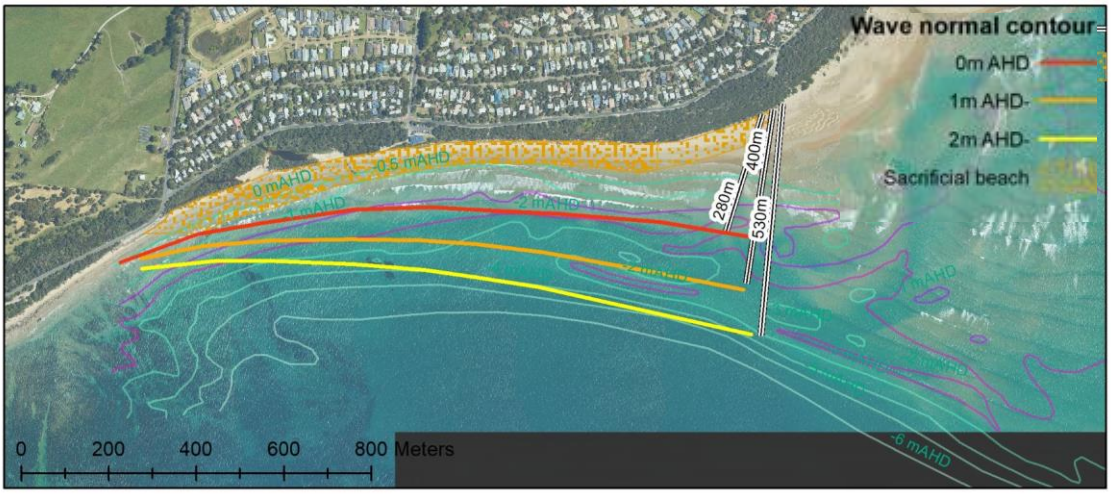


Figure 5-4 **Conceptual length and nearshore contour realignment of Long Groyne Option**

The previous ebb tide delta at Point Norman assisted in holding the beach in this shape, however construction of a groyne to replicate the delta would result in a structure beyond 500m in length and pose significant risks as detailed below:

- Construction works
  - Safety to workers and plant to construct a groyne extending 500m+ offshore
  - Availability of material and plant to construct long groyne – the size of individual armour rocks required for the groyne would be considerable and sourcing of the volume required to construct the groynes to sufficient depth would be difficult. The additional need to protect against future toe scour would complicate construction and increase costs.
- Beach nourishment
  - Beach nourishment should be carried out with the construction of a groyne to prevent erosion of the existing beach. Until the beach reaches an equilibrium alignment beach nourishment would be required to protect the existing coastline. This would need to be continued for some time.
  - A suitable source of sand is required for ongoing nourishment and beach management.
  - The sacrificial beach has been designed to offer protection in a large storm event, after which the beach would be lost or largely diminished. Renourishment would be required to maintain the erosion hazard reduction.
  - Loss of beach material without renourishment as required over time would result in a narrowing of the protective beach along the coastline.
- Inundation
  - If nourishment of the beach occurred in tandem with the groyne construction, the nourished beaches would initially prevent the drainage of Wreck Creek until the net sediment transport allowed the creek to reopen.
  - The low dunes at the western most beach (Bunurong Road / Wreck Ck) would belikely to be overtopped during a 2% AEP storm event. If this dune was overtopped dune material would be deposited into Wreck Creek and could cause the creek to have further reduced drainage capacity and result in inundation upstream.

- Amenity
  - Construction of a large groyne would have a significant impact on the visual aesthetics of the beach along Surf Beach and Point Norman.
  - The equilibrium alignment of the coastline would be notably different to the current alignment. If the beach extended out to the stable alignment, the beach width would be potentially very wide at Point Norman (300m+).
- Adjacent Coastline
  - Erosion of the coastline north of the groyne would occur as replacement sediment would be blocked by the groyne.
  - Erosion of the beach profile adjacent to the groyne may result in the main channel drawing closer to the groyne as scour increases.
  - Undercutting of the groyne by the migrating channel could cause the structure to fail and collapse.
  - The resulting change in sediment supply within the entrance and migration of the entrance channel could lead to scour of the dunes north of Point Norman and recession of the coastline towards Surf Parade and Veronica Street. Review of early aerial photography indicates the dune here was once much narrower (30m) and the channel closer to the residential area.
  - The beach alignments are based on the long term wave climate. An extended deviation from the long term climate has been observed in more recent times contributing to the rapid recession of the Surf Beach coastline. A similar deviation from the long term wave climate could change the beach angle or offshore location at which sediment transport occurs, resulting in a different response or equilibrium beach.

5.2.5 Surf Beach Nearshore Breakwaters

Nearshore breakwaters work to protect the coastline by reducing the amount of wave energy reaching the shoreline. The reduction of wave energy in the nearshore zone also reduces the alongshore sediment transport potential and sediment moving along the coastline in the lee of the breakwater may be deposited along the shoreline. Construction of nearshore breakwaters could be successful in preventing erosion of the existing coastline, however, would result in a significant change to the coastal environment, specifically the reduction of surf at “Surf Beach”.

A technical assessment was undertaken to establish the conceptual layout and dimensions of a nearshore breakwater field, as presented in Figure 5-5. The breakwaters would lead to a significant disruption in the amenity of Surf Beach.

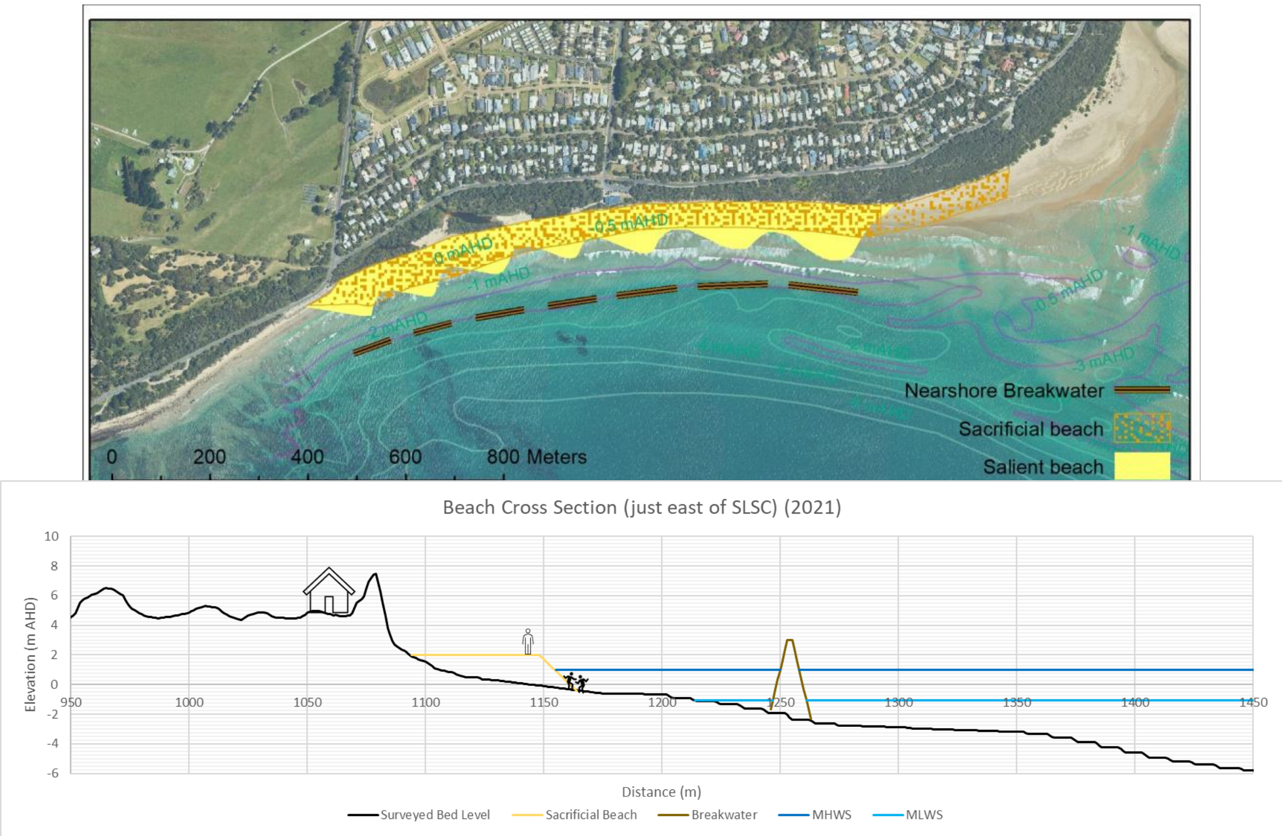


Figure 5-5 Nearshore Breakwaters at Surf Beach

Along with this disruption of beach amenity, the following risks are noted:

- Construction works
  - Safety to workers and plant to construct a series of nearshore breakwaters within the surf zone
  - Availability of material and plant to construct breakwaters. The placement of the nearshore breakwaters at the seaward side of the breaker zone means they will be exposed to the largest of waves and may experience extremely large waves breaking onto the structure. This will require very large rock or other constructed armour units which may be expensive and difficult to source, transport and place.
- Beach nourishment
  - The sacrificial beach has been developed to offer protection in a large storm event. Storm erosion would be reduced by the nearshore breakwaters and the volume of sacrificial beach could be reduced. However, the sections of the coast exposed through gaps in the breakwater would be exposed to the storm wave and would also likely suffer from some erosion of the sacrificial beach as the salient system forms. The sacrificial beach would require monitoring to ensure sufficient volume of sand is available to maintain the dune protection.
  - Nourishment may be required at the eastern end of the breakwater system to replace material trapped in the salient system.
  - A suitable source of sand is required for ongoing nourishment and beach management.

- Inundation
  - The sacrificial nourished beach would prevent the drainage of Wreck Creek.
- Amenity
  - Construction of nearshore breakwaters would have a significant impact on the visual aesthetics of the beach along Surf Beach and Point Norman.
  - The reduction of wave energy for much of the coastline may not be desirable for beach users or for surfing.
  - Growth of large salients may not be desirable for beach users.
  - Significant seaweed is known to accumulate on Surf Beach. This is likely to become trapped in the lee of the breakwaters and may cause odour and water quality issues.
- Adjacent Coastline
  - Erosion of the coastline east of the nearshore breakwaters may occur as the rate of incoming sediment is reduced by the breakwater system.
  - Erosion of the beach profile adjacent to the breakwater system may result in the main channel drawing closer to the Surf Beach, cutting through Point Norman, as observed in the late 1970s.
  - Undercutting of a breakwater by the migrating channel could cause the structure to fail and collapse.
  - The resulting change in sediment supply within the entrance and migration of the entrance channel could lead to scour of the dunes north of Point Norman and recession of the coastline towards Surf Parade and Veronica Street. Review of early aerial photography indicates the dune here was once much narrower (30m) and the channel closer to the residential area.
  - The conceptual design is based on existing depth contours and distances offshore. These have changed by 1m+ over the past decade and similar magnitude of change could impact the effectiveness of the nearshore breakwater and salient system.

5.3 Recommendations

As described in Section 2 and 3 of this report, the coastal hazard drivers along the Inverloch coastline are complex and have recently resulted in a decade of rapid change in the shoreline position from Flat Rocks to Ayr Creek.

The five engineered coastal protection actions assessed all have various advantages and disadvantages and would require significant capital works and ongoing maintenance costs. None of the options come with no risks, and many of the impacts, particularly on the entrance dynamics, cannot be predicted or modelled due to the variability of the future wind and wave climate.

5.3.1 Bunurong Road Adaptation Action Recommendation

The recommended coastal hazard mitigation action requires a decision to be made on the long term future position of Bunurong Road. For these two futures, the following actions are recommended:

- Pathway 1: Bunurong Road to remain in current position
  - Design a seawall suitable for future (2100+) conditions.
  - Include allowance for drainage of the landside catchment through the wall and tidal gates to prevent seawater backflow as sea levels rise.

  - Consider the height of the existing road and raise the road above future inundation levels to ensure access during and following extreme storm events.
- Pathway 2: Bunurong Road relocation
  - Design a seawall suitable for short term protection of the road (and services) for the full length.
  - Identify erosion trigger levels such that works should be undertaken.
  - Assess the feasibility of stockpiling rock or geotextile bags in preparation for rapid response to erosion.

5.3.2 Surf Beach Adaptation Action Recommendation

As with Bunurong Road, recommendation of coastal erosion hazard mitigation action to protect the coastal dune at Surf Beach requires a decision to be made on the future of the roads, services and residential area of Surf Beach. For alternative pathway futures, the following actions are recommended:

- Pathway 1: Maintain existing dune position and maintain a level of beach amenity for a long term horizon (i.e. 2100+)
  - Construct a series of groynes to create smaller beach pockets
  - Undertake initial beach nourishment to either generate the "sacrificial beach" suitable to prevent erosion of the dune during design storm events, or consider constructing a buried seawall as a line of last defence against dune erosion
  - Conduct beach renourishment as required or regular sand management (back passing) to maintain either the sacrificial dune at the height and width required to prevent storm erosion of the existing dune, or a beach of suitable amenity for the community.
  - Design drainage pathways from Wreck Creek through the groyne field and nourished beaches to allow catchment drainage. Consider methods to prevent backflow of seawater as sea levels rise.
- Pathway 2: Plan for retreat
  - Identify trigger levels at which time beach nourishment is to be undertaken to restore the dune to an agreed form whilst retreat is planned and enacted
  - Assess the feasibility annual beach nourishment and management (e.g. the "Sand Island"), to reduce the urgency of trigger levels and piecemeal nourishment to maintain the dune
  - Engage contractors, and gain permits for ongoing and rapid response works so delays do not occur when sand is required

5.3.3 Monitoring

Monitoring of the beach levels, bathymetric survey and aerial image collection and analysis should be continued along the open coast and into the Anderson Inlet entrance to add to the understanding of the coastal processes in the Study Area. As noted, the recent conditions have led to a slight recovery in beach levels and future works can use this information to inform detailed design considerations.

A key piece of work required for design of any constructed actions is the collection of additional wave data inshore. Inshore wave monitoring can be used to verify and refine inshore wave modelling and sediment transport assessments and optimise design solutions. Capture of wave height, period and wave direction is important for design of beach nourishment volumes and coastal protection structures.

6 REFERENCES

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APPENDIX A
VICTORIA'S RESILIENT COAST FRAMEWORK

Victoria's Resilient Coast – Adapting for 2100+ framework	Purpose	Key questions	Cape to Cape Resilience Project key deliverables	Completion timeline	Document citation	Additional products
STAGE 1 Scoping and preparation	Provide a foundation for adaptation planning aligned to best practice guidance.	• Do we need action? • Who is involved? • Where's the study area? • What is our study scope?	Project plan	Mar-21	DELWP 2021, Inverloch Regional and Strategic Partnership Project Plan, Victoria, March 2021.	Website establishment and content. DELWP & Alluvium. May 2021. Project Update 1 - Introducing the Cape to Cape Resilience Project. DELWP & Alluvium. May 2021 Fact Sheet 1 - Project scene setting, introducing the RaSP. DELWP & Alluvium. May 2021. Project Update 2 - Data gathering, gap analysis, engagement commencement. DELWP & Alluvium. July 2021. Fact Sheet 2 - Coastal adaptation and hazards technical terminology. DELWP & Alluvium. July 2021.
			Engagement plan	Mar - July 2021	Alluvium 2021, Cape to Cape Resilience Project Engagement Plan, Victoria, March 2021.	
STAGE 2 Values, vision and objectives	Ensure adaptation planning is underpinned by regional and place-based values.	• What do we value? • As a region and as a State? • What do we want the future to look like?	Community values study	Oct-21	Alluvium 2021, Cape to Cape Resilience Project Community Values Study - Engagement Report - Values and Experiences, Victoria, October 2021.	Engage Victoria online survey & on-site drop in sessions - Community values and perspectives
			Cultural values assessment	Dec-21	Bunurong Land Council Aboriginal Corporation 2021, BLCAC Cultural Values Assessment: Cape to Cape Project, Victoria, December 2021.	
STAGE 3 Coastal hazard exposure	Assess coastal hazard exposure, including scenarios that enable best practice approaches to assessing current and emerging risk.	• What processes are occurring and how might these change?	Inverloch region coastal hazard assessment	June 21 - Mar 22	Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 1 - Project Summary Report, Victoria, June 2022.	Fact Sheet 3 - Understanding coastal landscape context, processes and hazards. DELWP & Alluvium. Oct 2021. Fact Sheet 4 - Understanding coastal hazard modelling. DELWP & Alluvium. Oct 2021. Project Update 3 - Technical work (LiDAR, models, Assessment work), engagement update. DELWP & Alluvium. Nov 2021.
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Victoria's Resilient Coast – Adapting for 2100+ framework	Purpose	Key questions	Cape to Cape Resilience Project key deliverables	Completion timeline	Document citation	Additional products
STAGE 4 Vulnerability and risk	Explore place-based coastal hazard vulnerability and risk, to enable strategic consideration of adaptation needs/priorities.	• How might these processes impact what we value?	Coastal hazard asset exposure assessment	April - May 22	Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 6 - Coastal Hazard Asset Exposure Assessment, Victoria, June 2022.	Project Update 4 - Technical work update (hazard mapping, values, economics), engagement update. DELWP & Alluvium. April 2022.
			Coastal hazard risk and vulnerability assessment		Alluvium 2022, Cape to Cape Resilience Project - Asset and Values Risk and Vulnerability Assessment, May 2022.	
			Economic base case		Natural Capital Economics & Alluvium, 2022, Cape to Cape Resilience Project – Economics Assessment, June 2022.	
STAGE 5 Adaptation actions and pathways	identify, assess, consult on and decide which adaptation options and actions are the most appropriate for managing the current and future coastal hazard risks in the study area. This includes a diversity of integrated actions across land management, planning and design, nature based and engineering themes.	• How can we manage and adapt to these impacts?	Adaptation options and preferences	May - June 22	Alluvium 2022, Cape to Cape Resilience Project Adaptation Options - Engagement Report - Adaptation Engagement Outcomes, Victoria, October 2021.	TBC
			Adaptation framework summary paper		Alluvium 2022, Cape to Cape Resilience Project – Adaptation Framework Summary Paper, Victoria, June 2022.	
			Adaptation feasibility modelling		Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 7 - Adaptation Assessment, Victoria June 2022	
			Economic assessment & cost benefit analysis		Natural Capital Economics & Alluvium, 2022, Cape to Cape Resilience Project – Economics Assessment, June 2022.	
STAGE 6 Plan and implement	Confirm the plan of action for coastal hazard risk management and adaptation, and commence implementation. This includes priority actions in the adaptation pathways, shared roles and responsibilities, triggers for review and resources/requirements.	• Which options are feasible and suitable, both now and in the future? • How can we plan our response strategically?	Cape to Cape Resilience Plan		Inverloch RaSP Stage 2- TBC 2023	
			Cape to Cape Implementation plan/s		Inverloch RaSP Stage 2-& Partner Agencies TBC 2023 onwards	
STAGE 7 Ongoing monitoring and review	Ensure coastal hazard risk management and adaptation is accompanied by ongoing monitoring and evaluation process that enables effective implementation, learnings and improvement.	• How can our response be adaptive to changing conditions? • How are we tracking in implementing our plan?	Cape to Cape Resilience Plan including implementation, monitoring and evaluation		Inverloch RaSP TBC 2023 onwards	

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