Final Report

Inverloch Region Coastal Hazard Assessment – Technical Methodology

Department of Environment, Land, Water and Planning

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EXECUTIVE SUMMARY

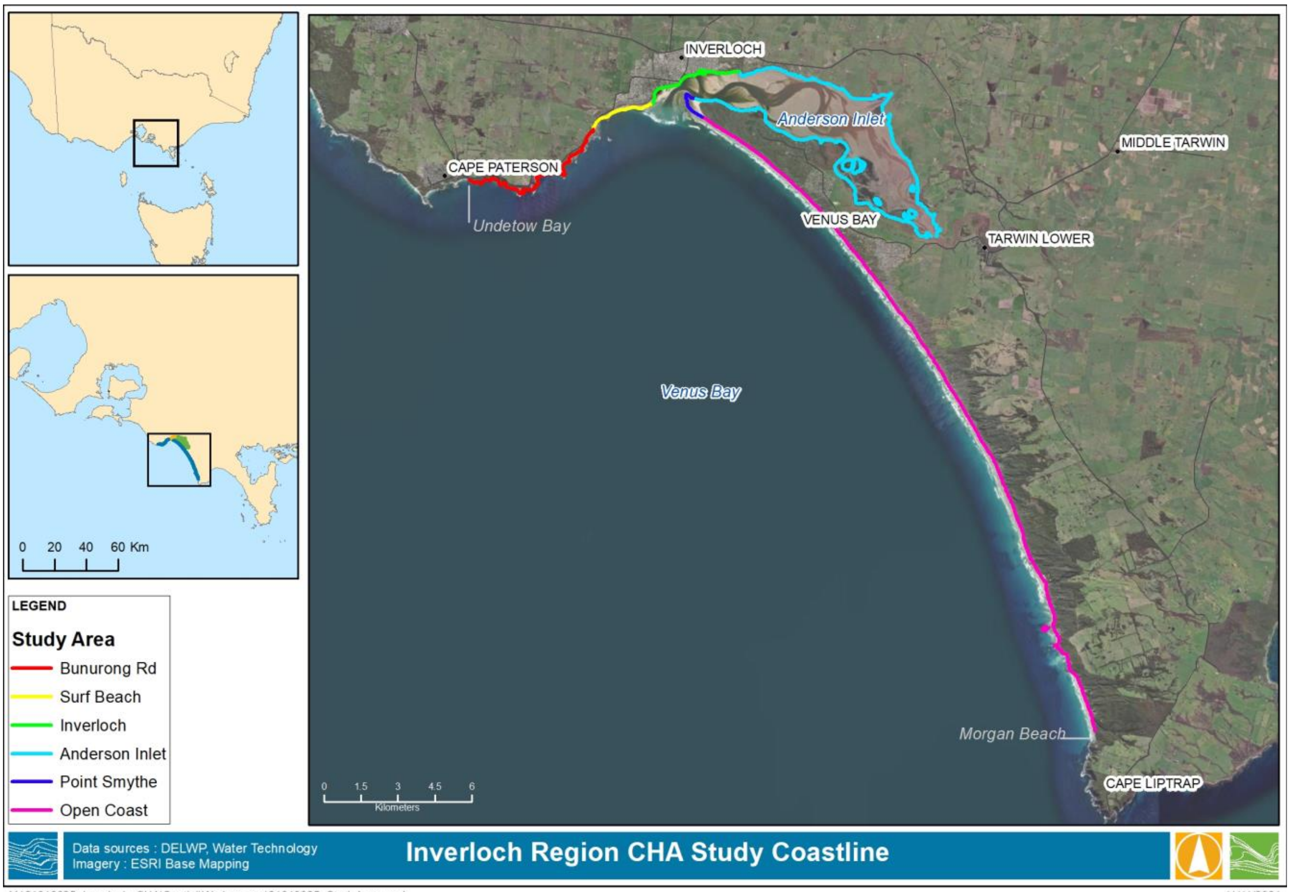
This report is the third report in a series of reports generated for the Cape to Cape Resilience project and describes the methodology undertaken to enhance the understanding of coastal hazards along the coast from Cape Paterson to Cape Litptrap, and the development of Coastal Hazard mapping layers which are to be used in asset risk assessment and adaptation planning. This report will be updated following the completion of the risk assessment and adaptation options assessment.

Details of the coastal hazards, specifically the coastal erosion and coastal inundation hazard, are provided in Report 04: Inundation Hazard and Report 05: Erosion Hazard of the reports developed for the Cape to Cape Resilience project. Coastal inundation and coastal erosion are the primary hazards assessed in this study, however hazards associated with overland flooding and groundwater changes due to sea level rise are also discussed in the inundation report.

Study Area

The Study Area comprises the coastline from the eastern end of Undertow Bay, adjacent to Cape Paterson, along the Bunurong Road to Flat Rocks, across the Inverloch Surf Beach, along the coastline of Anderson Inlet, Point Smythe and finally along the open coast beyond Venus Bay to the eastern end of Morgans Beach adjacent to Cape Liptrap.

The study area covers over 85km of coastline and a variety of exposure levels to different coastal drivers, level and density of constructed assets and cultural and historical values and geo-physical composure. The study area and the 6 (roughly) similar exposure sections are presented in the figure below.



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Methodology Overview

The purpose of the Cape to Cape Resilience project Inverloch Region Coastal Hazard Assessment is to define coastal hazards both now and for future climate scenarios; identify the assets and values at risk from the hazards, both now and into the future; and to propose, assess and review potential adaptation options to manage the risks of coastal processes on assets and values, both now and into the future.

Climate Scenarios

Future climate scenarios have been determined by the Victorian Government Department of Environment, Land, Water and Planning (DELWP), the managers of the Cape to Cape Resilience project. Climate scenarios, and the associated planning horizons are presented below.

Climate Scenarios Considered in CHA Study

Planning Horizon	Sea Level Rise Scenario
Present Climate	Present Climate
2040	0.2 m
2070	0.5 m
2100	0.8 m
2100	1.1 m
2100	1.4 m

Geomorphology

To understand how coastal drivers impact the coastline, an understanding of the coastline, the form and formation of the land is required. A coastal geomorphic investigation has been completed for this study which defined and classified the shoreline into an extensive set of coastal geomorphic sectors with unique intertidal (or shorezone) and backshore landforms and materials. The coastal geomorphic sectors were reviewed and grouped into shoreline classes which respond to coastal drivers in a similar manner. Seven shoreline classes were identified in the Study Area.

- Hard rock cliffs and platform or beach
- Soft rock cliffs and platform or beach
- Bluffs or slopes with or without a platform or beach
- Low earth cliffed shorelines
- Sandy shorelines, which includes beaches, sandy ridges, dunes, and spit morphologies
- Estuarine and tidal channels, which includes the main body of Anderson Inlet, the inflowing rivers or creek mouths, drains and drainage lines
- Coastal wetland fringed shoreline

Coastal Hazard Drivers

A wide range of input data was collected during the initial Data Assimilation and Gap Analysis stage of the Coastal Hazard Assessment (CHA). The gap analysis identified the range of available and missing data which was required to assess and define the magnitude and occurrence of coastal hazard drivers. All high importance data and knowledge gaps were filled prior to commencing the hazard assessment.

Climatological and oceanographic processes are key drivers of coastal hazards, this includes wind conditions, atmospheric pressure and storm events, tide and ocean water levels and the nearshore and regional wave climate. This data has been collated and analysed for the CHA.

Trends and patterns, as well as data extremes have been established from the available data. Where required, the available climatological and oceanographic datasets have been used to generate hindcasts or drive model simulations to define the coastal hazards. A number of numerical models have been developed to generate hindcasts, define extreme fluvial flow events, determine the extent of storm tide inundation and assess the impact of coastal hazard drivers on sediment transport and storm erosion.

Coastal Process Assessments

Numerical models have been supplemented with analysis of recent historical shoreline movement based on aerial imagery and survey to understand the change of sediment volume along the coast and through the Inlet. The entrance dynamics at Anderson Inlet are especially complex with tidal, wave and flow forces contributing to an ever-changing system of channels and bars.

Recent and rapid change has been reviewed with consideration of recent climatological and oceanographic events and trends. Numerical modelling of the entrance has been completed in an attempt to quantify the magnitude and drivers of change, although the results provide only qualitative guidance along with an enhanced understanding as to the different drivers of the entrance system.

Groundwater concepts

A conceptual groundwater model has been developed to illustrate the groundwater processes in the Study Area. The assessment has developed a conceptual model to provide an overview of the regional groundwater processes and their potential response to sea level rise and coastal change.

Risk Identification

At the time of this report, the risk identification and assessment is to be completed and the methodology will be updated upon completion.

Adaptation Assessment

At the time of this report, the adaptation assessment is to be completed and the methodology will be updated upon completion.

Inundation Hazard

The methodology used to generate inundation hazard zones at the different shorelines is presented in detail in this report. The design storm tide events and design wave conditions have been derived from the available and developed oceanographic data. The design oceanographic data is combined with significant catchment generated storm events in the Tarwin River for assessment of flooding in Anderson Inlet. The design conditions for storm tide, wave and Tarwin River inflows are presented in the table below.

Design Conditions

Design Event	Offshore Storm Tide (m AHD)	Offshore Significant Wave Height (m)	Offshore Peak Wave Period (s)	Tarwin River Peak Flow (m^3/s)
1% AEP	2.25	6.6	14.6	305
5% AEP	2.10	6.1	14.2	-
10% AEP	2.00	5.9	13.9	237

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. A total of 18 scenarios were required to cover the range of conditions required for the assessment.

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 (Lasron, 1989) considers the nearshore profile and dune to establish coastal water levels.

Within Anderson Inlet a 2-dimensional Mike21 Flexible Mesh model was used to simulate offshore storm tides, winds and flood events occurring in the Study Area. The modelling included the existing levee configuration to establish the timing and frequency of levee overtopping into the future.

The urbanised Inverloch township was assessed using a combination of SBEACH to develop nearshore water level conditions to include wave conditions on the open coast, catchment hydrology to establish upstream inflows and synthesised rainfall onto the existing pipe network, along with tailwater levels from the Anderson Inlet model to establish the impact of storm tide backflow into the urban drainage network and low-lying topography.

Sensitivity testing of a wide range of variable from inlet bathymetry, wind forcing, beach profile, wave height and rainfall critical durations have been used to establish robust coastal inundation hazard zones.

Inundation extents and paths have assumed the present day topography into the future. As identified in the development of coastal erosion hazard zones, this will lead to some over and some underestimates of inundation into the future.

Erosion Hazard

The methodology used to determine the potential extent of coastal erosion on the different shorelines is presented in detail in the report. The sea level rise scenarios and design events noted above have been used to provide erosion hazard for different planning horizons and design events.

Erosion has been considered to be in the form:

Erosion Hazard Extent = Short Term Erosion + Long Term Change + Response to SLR

Short Term Erosion

The quantification of short term erosion is limited to the exposed sandy beaches outside of Anderson Inlet exposed to ocean storm events. Within Anderson Inlet it is considered the coastline does not recover from short term erosion and the loss of land is permanent and therefore considered in the long term erosion calculation.

Along the open coast, the short term erosion has been established using the SBEACH shoreline response program. The beach profiles and design storm conditions result in typical levels of storm demand on the open Venus Bay coast (150-230m^3/m for a 1% AEP storm event) whilst smaller erosion is predicted for the more protected beaches along the Bunurong Road coast and the lower volume and flatter intertidal environment of Surf Beach at Inverloch.

Storm demand along Surf Beach is locally significant and the modelling indicates the potential for loss of the remaining primary dune during smaller storm events under existing sea level conditions.

Long Term Change

Long term recession has been quantified through review of available aerial imagery and satellite data. Rates of recession around much of the exposed coast for the envelope of imagery (1950 to 2020) is low or event negative (i.e., seaward progradation of the coast). However, this is countered with a rapid rate of recession, primarily in the most recent decade.

To acknowledge both the long term and recent rates of change, the long term change has been quantified as likely or possible, where the possible rate of change relates to the most rapid rate of sustained erosion along the coastline.

Response to SLR

The response to sea level rise, or the future recession, has been established using an equilibrium profile response model (i.e. Bruun Rule) and the existing long term rate of recession.

Whilst the Bruun Rule is often criticised as being overly simplified, the lack of long term profile or surveyed data of much of the exposed sandy coastline means that there is no additional data to add to a more complex analysis.

The sensitivity of the erosion hazard calculation to inputs such as sediment size, wave conditions, channel alignment, bed profile and water levels were assessed in the project and the most suitable parameters selected for hazard mapping.

A high degree of uncertainty regarding change at the entrance remains. The coastal process assessment has assisted in enhancing the understanding of why the entrance and surrounding coastlines have rapidly evolved over the past decade, however it is not possible to predict the future coastal drivers, and thus the future changes of the entrance in response to these drivers with any level of confidence. Trends and potential hazard zones can be identified, however the position of the shoreline at a future horizon cannot be.

Assumptions and Limitations

The Study Area is vast and located in a relatively distant and sparsely populated area of Victoria. As such there is a limited amount of frequently captured, high spatial resolution data available to quantify hazards in the Study Area.

Sensitivity testing has been undertaken to ensure the hazard zones provide a robust estimate of the range of potential areas at risk to inundation and erosion in the future. Key assumptions and limitations associated with the work carried out for the study have been listed in the report and the outcomes of the CHA should be considered with consideration of these assumptions and limitations.

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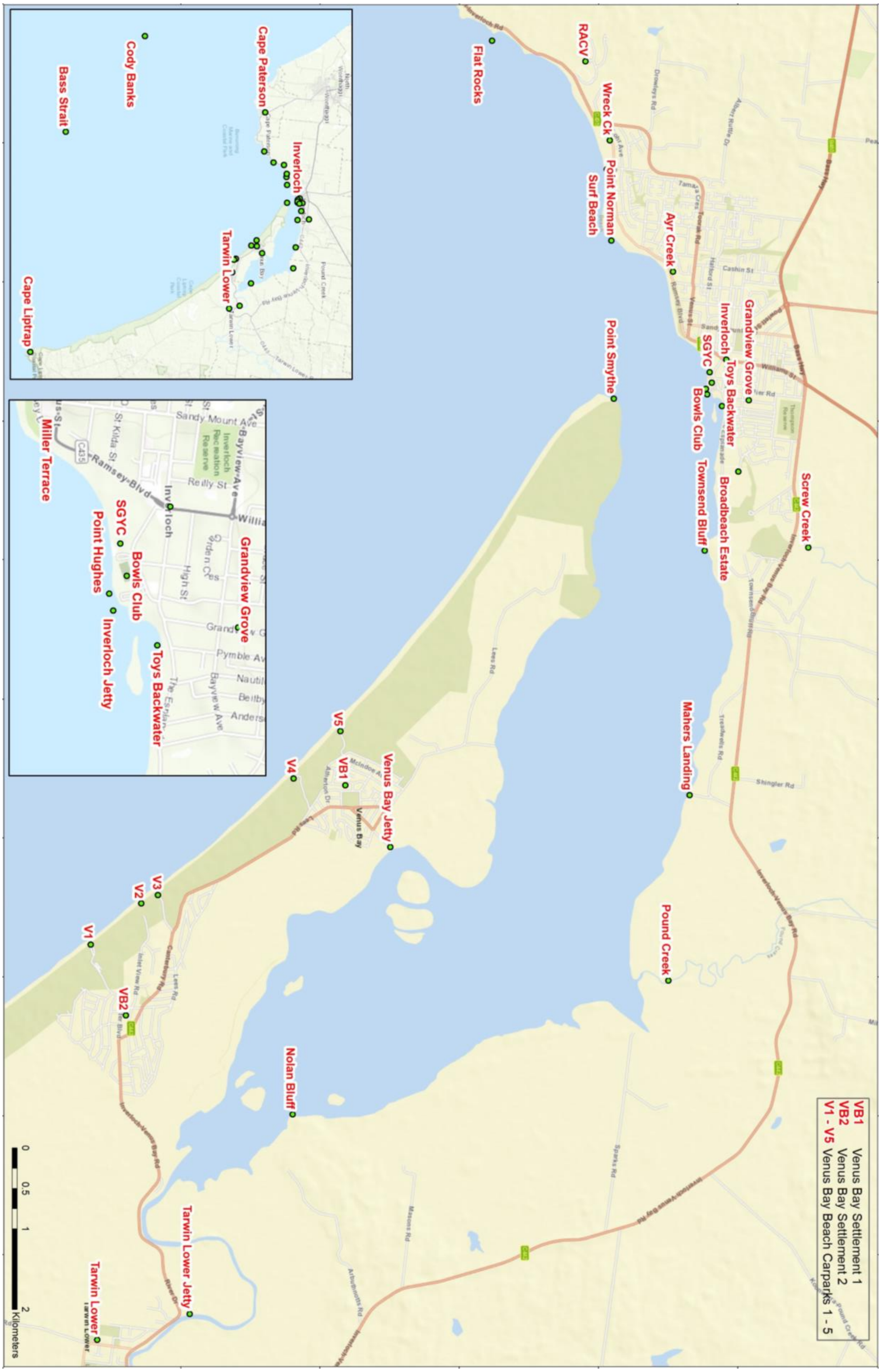
GLOSSARY

Term	Description
Aeolian	The erosion, transport and deposition of material by wind.
AEP	Annual Exceedance Probability: The measure of the likelihood (expressed as a probability) of an event equalling or exceeding a given magnitude in any given year
Alluvial	Water driven sediment transport process (non-marine)
Alongshore Transport	The movement of material along the coast parallel with the shoreline. Can also be called longshore transport.
ARI	Average Recurrence Interval
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 plane of level corresponding approximately to mean sea level
Backshore	The area of shore lying between the average high-tide mark and the vegetation, affected by waves only during severe storms
Bathymetry	Elevation of the ocean bed, the underwater version of topography
Calibration	The process by which the results of a computer model are brought to agreement with observed data
Coastal Hazard	A term to collectively describe physical changes and impacts to the natural environment which are significantly driven by coastal or oceanographic processes.
Colluvium	A term used to describe loose, unconsolidated sediments that have been deposited at the base of a slope or cliff.
Cross Shore Transport	Movement of sand on- and off-shore in a direction perpendicular to the coastline
Delta	A complex association of geomorphic settings, sediment types and ecological habitats, at a point where a freshwater sources enters an estuarine water body.
Ebb Tide	The outgoing tidal movement of water resulting in a low tide.
Embayment	A coastal indentation which has been submerged by rising sea-level and has not been significantly infilled by sediment.
Coastal Erosion	Landward retreat (temporary or permanent) of the interface between the ocean and land
Estuaries	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.
Exceedance Probability	The probability of an extreme event occurring at least once during a prescribed period of assessment is given by the exceedance probability. The probability of a 1 in 100 year event (1% AEP) occurring during the first 25 years is 22%, during the first 50 years the probability is 39% and over a 100 year asset life the probability is 63%
Flood Tide	The incoming tidal movement of water resulting in a high tide
Foreshore	The area of shore between low and high tide marks and land adjacent thereto
Geomorphology	The study of the origin, characteristics and development of land forms
GIS	Geographical Information System
HAT	Highest Astronomical Tide: the highest water level that can occur due to the effects of the astronomical tide in isolation from meteorological effects
Hindcast	A simulation of past conditions
Holocene	The period beginning approximately 12,000 years ago. It is characterised by warming of the climate following the last glacial period and rapid increase in global sea levels to approximately present day levels.

H_s (Significant Wave Height)	Hs may be defined as the average of the highest 1/3 of wave heights in a wave record (H1/3), or from the zeroth spectral moment (H_{m0}) percentiles (e.g. 2% exceedance percentile or maximum height) of the water level with inclusion of wave runup (e.g. Serafin et al., 2017)
Hydrodynamic Model	A numerical model that simulates the movement of water within a defined model area
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, eg. intertidal habitat
Intertidal Flats	Intertidal flats are un-vegetated, generally low gradient and low energy environments that are subject to regular tidal inundation and consist of sandy mud and muddy sand.
Levee	Raised embankment along the edge of a coastal or riverine environment
LiDAR	**Li**ght **D**etection **a**nd **R**anging – also known as airborne laser scanning, is a remote sensing tool that is used to generate highly accurate 3D maps of the Earth's surface
Lithology	A description of the physical character if a rock or rock formation.
Littoral Drift Processes	Wave, current and wind processes that facilitate the transport of water and sediments along a shoreline. The processes which drive longshore/alongshore transport.
Longshore Transport	The movement of material along the coast parallel with the shoreline. Can also be called alongshore transport.
Mean Total Water Level (MTWL)	The average height of the water level at the shoreline with the inclusion of wave setup compared with the Total Water Level
Meander	A description given to a bend or sinuous watercourse
MHWS	Mean Higher Water Spring: the mean peak of the spring tides
MSL	Mean Sea Level
Neap Tides	Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean).
Nearshore	The region of land extending from the backshore to the beginning of the offshore zone.
Numerical model	Computer program used to simulate real world processes. May be simple or complex.
Sea Level Rise (SLR)	A permanent increase in the mean sea level
Semi-diurnal	A twice-daily variation, eg. two high waters per day
Shoal	A shallow area within a water body; a sandbank or sandbar
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
Storm tide	Coastal water level produced by the combination of astronomical and meteorological (storm surge) ocean water level forcing
Storm Erosion	Rapid erosion of coastal backshore due to a significant storm event. There can be recovery from storm erosion as material shifted offshore is returned onshore.
Sub-aerial	Processes that take place on the land or at the earth's surface as opposed to underwater or underground.
Susceptibility	The sensitivity of coastal landforms to the impacts of coastal hazards such as sea-level rise and storm waves. This may include physical instability and/or inundation.
Taxa	A taxonomic category or group, such as an order, family, genus or species
Tidal Planes	A series of water levels that define standard tides, eg. 'Mean High Water Spring' (MHWS) refers to the average high water level of Spring Tides
Tidal Prism	The volume of water moving into and out of an estuary or coastal waterway during the tidal cycle.

Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides
Tides	The regular rise and fall in sea level in response to the gravitational attraction of the Sun, Moon and Earth
Total Water Level (TWL)	The height of the water at the shoreline height which is exceeded at higher
Validation	Confirmation that the calibration of a numerical model is suitable by testing the model parameters with a different set of data
Vulnerability	Vulnerability is a function of exposure to climatic factors, sensitivity to change and the capacity to adapt to that change. In this report is means the degree to which a natural system is or is not capable of adapting or responding to the impacts of coastal hazards to which they are physically susceptible and exposed.
Wave runup	The increased elevation of the mean water level due to the individual wave energy, dependent on the local backshore topography
Wave Setup	The increase in the mean water level across the surf zone due to waves
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


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

1 INTRODUCTION

1.1 Overview

In 2020 the Inverloch Regional and Strategic Partnership (RaSP) was established, comprising nine agencies and the Bunurong Land Council Aboriginal Corporation, working together to address the problem of erosion and inundation at Inverloch and the surrounding coast. The Department of Environment, Land, Water and Planning (DELWP) is leading the RaSP.

The RaSP's project is called the Cape to Cape Resilience Project, and a key piece of work is the Inverloch Region Coastal Hazard Assessment (CHA), which is an assessment of coastal hazards for the stretch of coast between Cape Paterson and Cape Liptrap, including Inverloch, Anderson Inlet and Venus Bay.

Water Technology has been commissioned by DELWP to undertake the Inverloch Region CHA. The Inverloch Region CHA has been a pilot program for the new *Victoria's Resilient Coast – Adapting to 2100+* program (DELWP, 2022), and Stage 2 of the program 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 H.

This report details the technical methodology to be followed to complete the coastal hazard assessment, determine the level and extent of coastal inundation and predict coastal erosion during extreme events at a number of sea level rises and climate scenarios. This report also summarises the approach for quantifying all assumptions within the proposed approaches

The results of the technical assessments, completed using this methodology, will be used to inform future stages of the CHA (FIGURE 1-1).

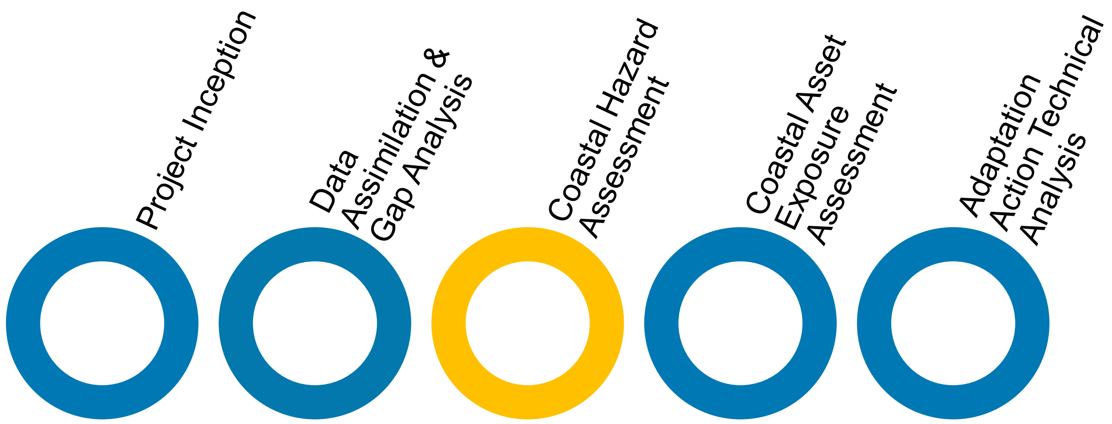


FIGURE 1-1 INVERLOCH CHA PROJECT PHASES

1.2 Study Area

The project study area extends from the eastern end of Cape Petersons most eastern beach "Undertow Bay" to the eastern end of Morgan Beach, located just west of Cape Liptrap. The project includes the shorelines of Venus Bay and Anderson Inlet, as presented in FIGURE 1-2.

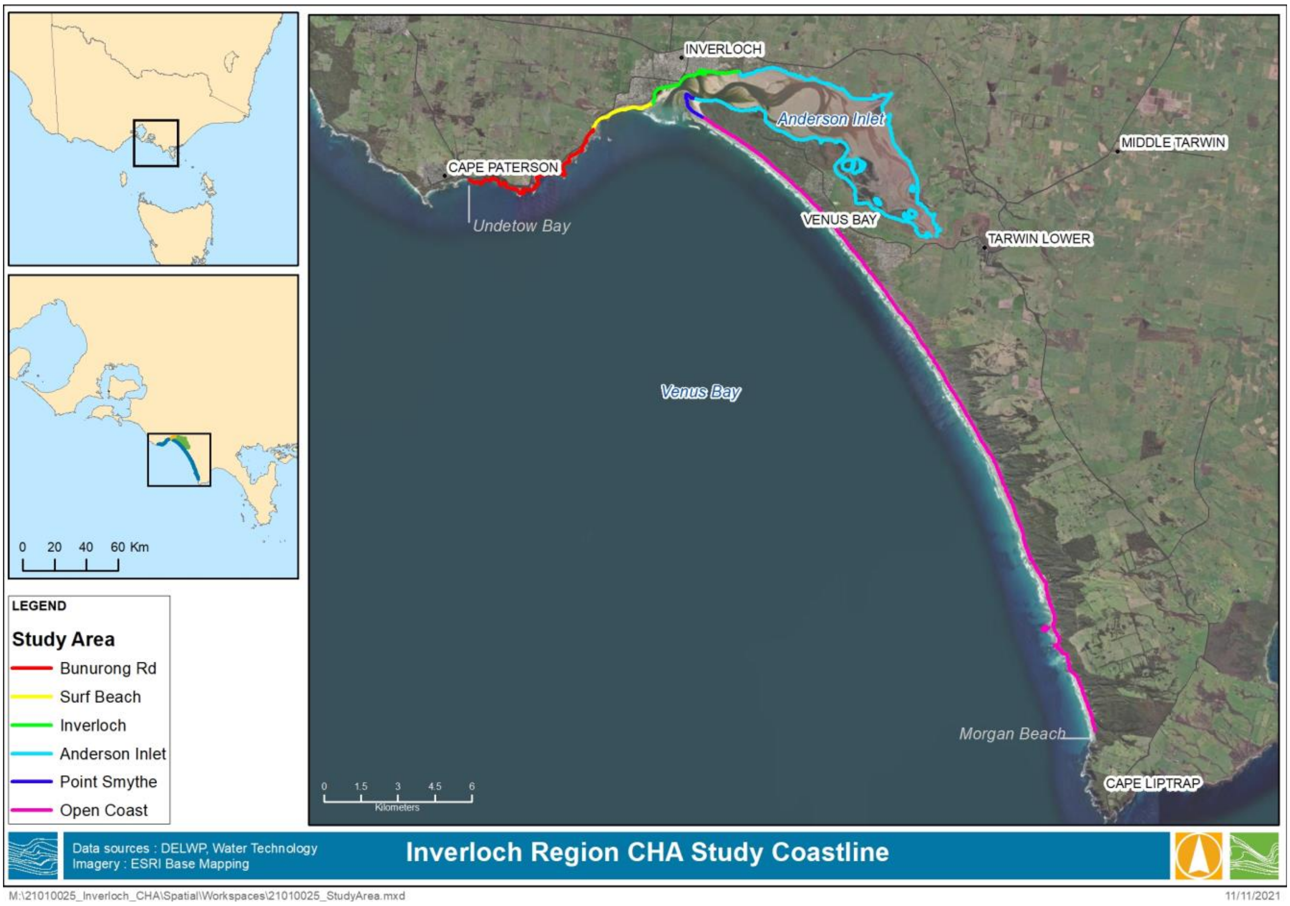


FIGURE 1-2 STUDY AREA COASTLINE

1.3 Reporting

This report describes the methodology for the different aspects of the technical works required:

- Section 1 **introduces the project** and outlines the scope of work,
- Section 2 provides a description of the approaches and scenarios to describe the **coastal hazards**.
- Section 3 details how the coastal **inundation** is to be determined.
- Section 4 details how the coastal **erosion** will be determined.
- Section 5 provides an overview of how the **values and assets** in the study area will be identified and used to develop a range of options for potential **adaptation** measures
- Section 6 details key **assumptions** that have been made to complete the technical assessments of the CHA. Section 6 also provides details of analysis techniques which were considered but not used in the final works.

The following Appendices provide further technical detail for specific aspects of the works:

- Appendix A describes the geomorphic classification of the coastline into **Geomorphic Coastline Sectors** and **Shoreline Classes** for the determination of hazard impacts
- Appendix B provides an overview of the **climatology** and how this will be used in the assessment.
- Appendix C summarises the **oceanographic** inputs and assessments to be completed.
- Appendix D details the methodology used to develop **Design Water Level** and **Design Wave** conditions for hazard assessments.

- Appendix E details the **model setup** of the 2-Dimensional hydrodynamic, wave and sediment modelling.
- Appendix G provides an example of the **Shoreline Change** analysis and Details the calculations used for determining **erosion** on each of the Shoreline Classes.

This document is Report 3 of a series of reports produced as part of the Inverloch Coastal Hazard Assessment project. 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 Coastal Erosion Hazard
- Report 5: Coastal Inundation Hazard
- Report 6: Coastal Asset Exposure Assessment
- Report 7: Adaptation Action Technical Assessment

2 STUDY METHOD OVERVIEW

2.1 Context

To set the general context for the study a thorough review of the historical, scientific, policy and planning context within which the coastal hazard assessment for the study area is undertaken has been completed. The review included the following components:

- An overview of the extent and magnitude of historical erosion and inundation along the coast and within Andersons Inlet has been undertaken.
- A review of the historical records and extent of coastal hazard impacts in the study area based on available literature and information sources. The purpose of the review has been to provide a detailed account of the type, extent, historical frequency and cause of significant coastal hazard impacts in the study area. The review has assisted in identifying the major types of coastal hazard risks to the study area and the main processes that give rise to these hazards.
- The review considered characteristics of the catchment and local flood hydrology and extent and scale of any recent flooding impacts for settlements around Andersons Inlet.
- The review considered the geomorphology of the coastline, including the broader setting along with the extent and scale of erosion impacts, focussing on the Ocean Beach, Inverloch shoreline and entrance area of Andersons Inlet.
- Current Federal and State Government policy and guidance relating to the consideration of climate change and coastal hazard impacts has been considered in the context of this study.
- The primary objectives of the study and the spatial and temporal scales over which the study assessment applies have been assessed.
- The main project stakeholders and their associated responsibilities have been reviewed including discussion with the stakeholders as to how the outputs from the study will be used to guide decision making and planning for these agencies.
- The relationship of this study to the broader Inverloch Regional and Strategic Partnership (RASP) project considering the impact of climate change and adaptation options for the study area.

2.2 Hazard Identification

The sources of hazard and their potential impacts in the study area have been identified, focusing on inundation and erosion hazards. For each of the potential hazard sources and pathways, a detailed assessment of the magnitude of these hazards and the processes/factors associated with the source of the hazards has been undertaken.

Details of the hazard identification and assessment are provided in Report 4: Inundation Hazards and Report R05: Erosion Hazards of this study. A conceptual assessment of groundwater hazard is also covered in the Inundation Hazards report. Quantification of the impact of future climate change scenarios on the sources of potential hazards has been included.

2.3 Coastal Hazard Analysis

2.3.1 Overview

The coastal hazard analysis integrates the physical processes occurring in the study area to assist in evaluation of the coastal hazard extents for a range of sea level rise scenarios. The analysis has involved the application of several numerical modelling tools to simulate a range of forcing/boundary condition scenarios to provide quantitative predictions of the coastal hazard extents within the study area. Numerical, empirical and analytical methods have been employed as part of the analysis to estimate hazard extents. The choice of method has been dependent upon the process being investigated and the current best available knowledge on sea level rise response.

2.3.2 Coastal Hazard Scenarios

The sea level rise scenarios to be assessed in the study are presented in Table 2-1. These scenarios were specified by DELWP.

Table 2-1 Sea Level Rise Scenarios

Sea Level Rise Scenario
Present Climate
0.2 m
0.5 m
0.8 m
1.1 m
1.4 m

Within the technical assessment, there are then a range of modelling and analysis scenarios which are used to understand the implications of these sea level rise conditions on coastal inundation and erosion.

The modelling and analysis scenarios have been agreed with DELWP and are summarised in Table 2-2. These specify the sea level rise scenario in combination with the wind, wave, storm tide and catchment flooding conditions.

The probability of coincidence and independence of storm tide, wave conditions and catchment runoff has been reviewed and the following points noted:

- There is some coincidence between extreme wave conditions and water levels, with close to 50% of the highest wave heights occurring in tandem with the highest residual storm surge across the 40 year hindcast
- The coincidence of storm tides and runoff has been reviewed across Australia as part of the updated Australian Rainfall and Runoff (AR&R P18/S3/011, 2014). The analysis indicated Victoria had the lowest levels of interdependence between storm tide and rainfall across Australia and the coincidence of a 1% and 1% storm tide and flooding event is not appropriate. Some dependence is present however, and as such a 1% to 10% AEP combination is typically adopted for flood studies in Victoria where storm surge is present. This was the recommended approach from the 2000 document Floodplain Management in Australia: Best Practice Principles and Guidelines (Standing Committee on Agriculture and Resource Management (SCARM), 2000).

Through consultation with DELWP the initial climate scenarios proposed have been refined to the following scenarios with corresponding planning horizons.

In recognition of the fact that urban stormwater systems are designed to carry up to a 20% AEP event, the 20% AEP event was modelled for the rural inflows to Inverloch rather than the 10% AEP as per the rural catchments. These were combined with the 1% AEP storm tide offshore and the 10% catchment flows into Anderson Inlet. This allows greater emphasis on the impact of the storm tide when the network is has reached design capacity.

Table 2-2 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%
		10%	10%	10%	1% +10% flow	1%
		5%	5%	5%	1%	1%
		1%	1%	1%	10%	20%

2.3.3 Methodology Summary

A range of technical approaches and tools have been used to assist with understanding of the erosion and inundation processes and quantify the associated hazards.

A summary of the methodology is presented in FIGURE 2-2 showing the interconnections within the input data, numerical models, coastal process assessment and flood modelling to develop the hazard zones used for risk assessment and adaptation planning.

In very simplistic terms, the flow chart presented below highlights the steps taken in this analysis.

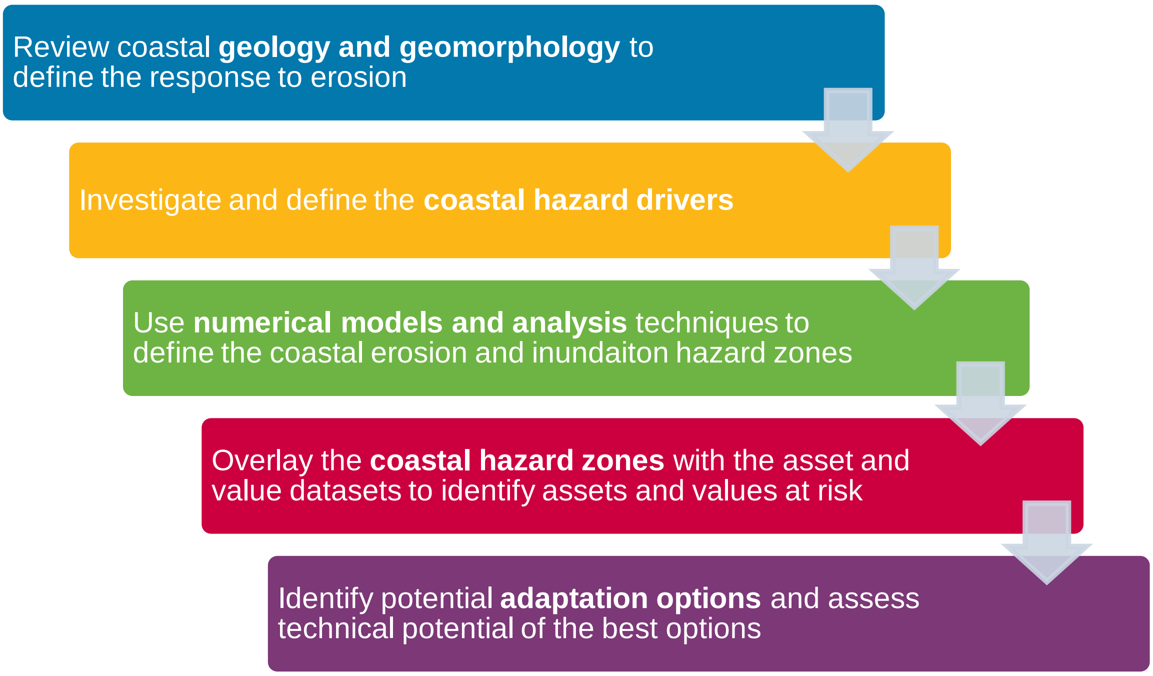


FIGURE 2-1 SIMPLIFIED METHODOLOGY STEPS

These board steps of the project methodology are described below with further details provided in the following Sections and Appendices of the report.

2.3.3.1 Coastal Geology and Geomorphology

Coastal geomorphic sectors and shoreline classes define the specific physical form of the coastline and characterise this form based on its response to coastal processes. A brief overview of how these datasets have been derived is provided in Appendix A, with the detailed results of the analysis described in more detail in Report 4 Coastal Processes and Coastal Erosion Hazard (Water Technology, 2022).

2.3.3.2 Coastal Hazard Drivers

The range of input data required to complete the technical analysis of coastal hazards are noted in FIGURE 2-2.

Report 2 Data Assimilation and Gap Analysis (Water Technology, 2022) brought together a wide range of data and information from a variety of sources to support this project. The data was reviewed, and a detailed gap analysis completed. Following the gap analysis specific high priority gaps were addressed and further data and information captured. The catchment and urban data along with the physical data (FIGURE 2-2) detailed in Report 2 are not described further herein.

The key coastal hazard drivers of climatologic data, including wind conditions, atmospheric pressure, storm events and the climate change scenarios, along with oceanographic data includes the tide and ocean water level data as well as wave conditions are detailed in Appendix B and Appendix C respectively.

2.3.3.3 Numerical Models and Analysis

To determine how these coastal hazard drivers interact with the coastal landform, numerical modelling of catchment, oceanographic and coastal processes within the Study Area was completed. The size and complexity of this Study Area led to the requirement for a range of different numerical models as follows:

Catchment Models

A hydrologic model was developed to generate catchment inflows for the Anderson Inlet and Inverloch models (described below). Inflows were developed for the Tarwin River, Pound Creek and Screw Creek for the 1% AEP and for the 10% and 20% AEP flood events for the rural (Tarwin River, Pound Creek) and urban (Screw Creek, Inverloch) catchments respectively.

Ocean, Inlet & Inverloch Models

Hydrodynamic models have been used to simulate the transformation of coastal drivers and catchment flows to the coast and through the Inlet. The four hydrodynamic models have been used to assess conditions in the Study Area are described in further detail in Appendix E. The model domains are shown in FIGURE 2-3 and comprise:

1. A depth averaged 2-dimensional (2-D) **Open Coast** hydrodynamic model which covers eastern Bass Strait and the whole of the open coastline between Cape Paterson and Cape Liptrap, including the shore of Anderson Inlet (shown in pink);
2. A depth averaged, 2-D hydrodynamic model, including fluvial flows from the adjacent catchments, of **Anderson Inlet** (shown in purple);
3. A depth averaged 2-D hydrodynamic, wave and sediment transport morphological model of the Anderson Inlet **Entrance** (shown in yellow in Figure 2-3); and
4. A stormwater focussed model of the **Inverloch township** (shown in aqua in FIGURE 2-3). This is a 2D rain-on-grid model which includes the stormwater network and utilises the outputs from the Anderson Inlet model as boundary conditions.

The outputs from these 2-dimensional models have also been used as input into shoreline response models to predict potential beach and dune erosion under different climate scenarios.

Shoreline Response Models

The shoreline response model SBEACH (Larson, 1989) has been used to simulate the wave setup and dune erosion (horizontal setback and volume) for the range of design storm conditions required along the **Bunurong Coast**, **Surf Beach** and **Venus Bay** ocean coastlines.

Beach profiles and hindcast wave and water level data have been used in the alongshore sediment transport program LITPAK (DHI, 2017) to determine rates and variations in the sediment transport potential along the **Surf Beach** and **Venus Bay** ocean coastlines to provide context and understanding to the coastal processes.

Further details of all models and the model specifics and parameters can be found in Appendix E.

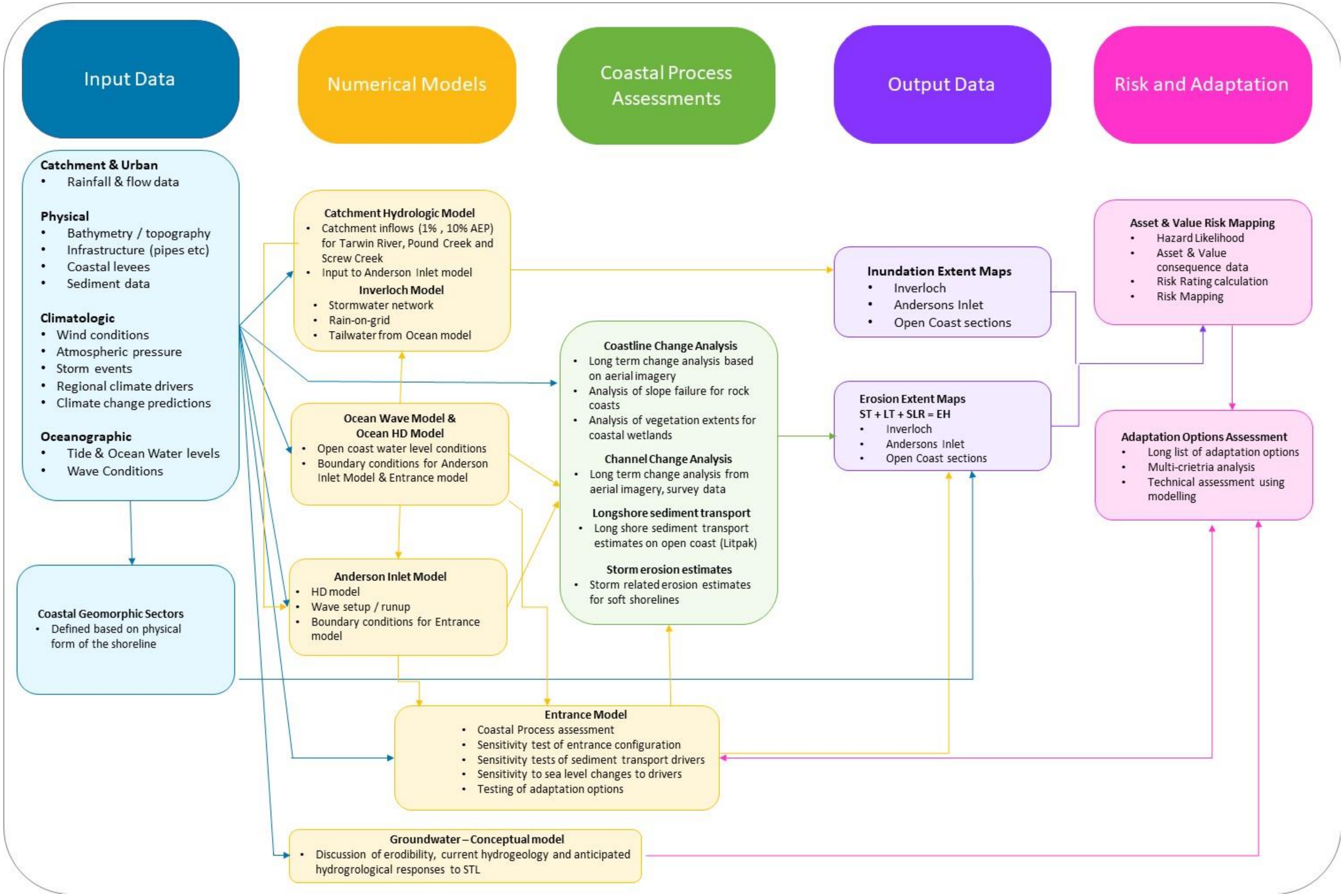


FIGURE 2-2 PROJECT METHODOLOGY FLOWCHART

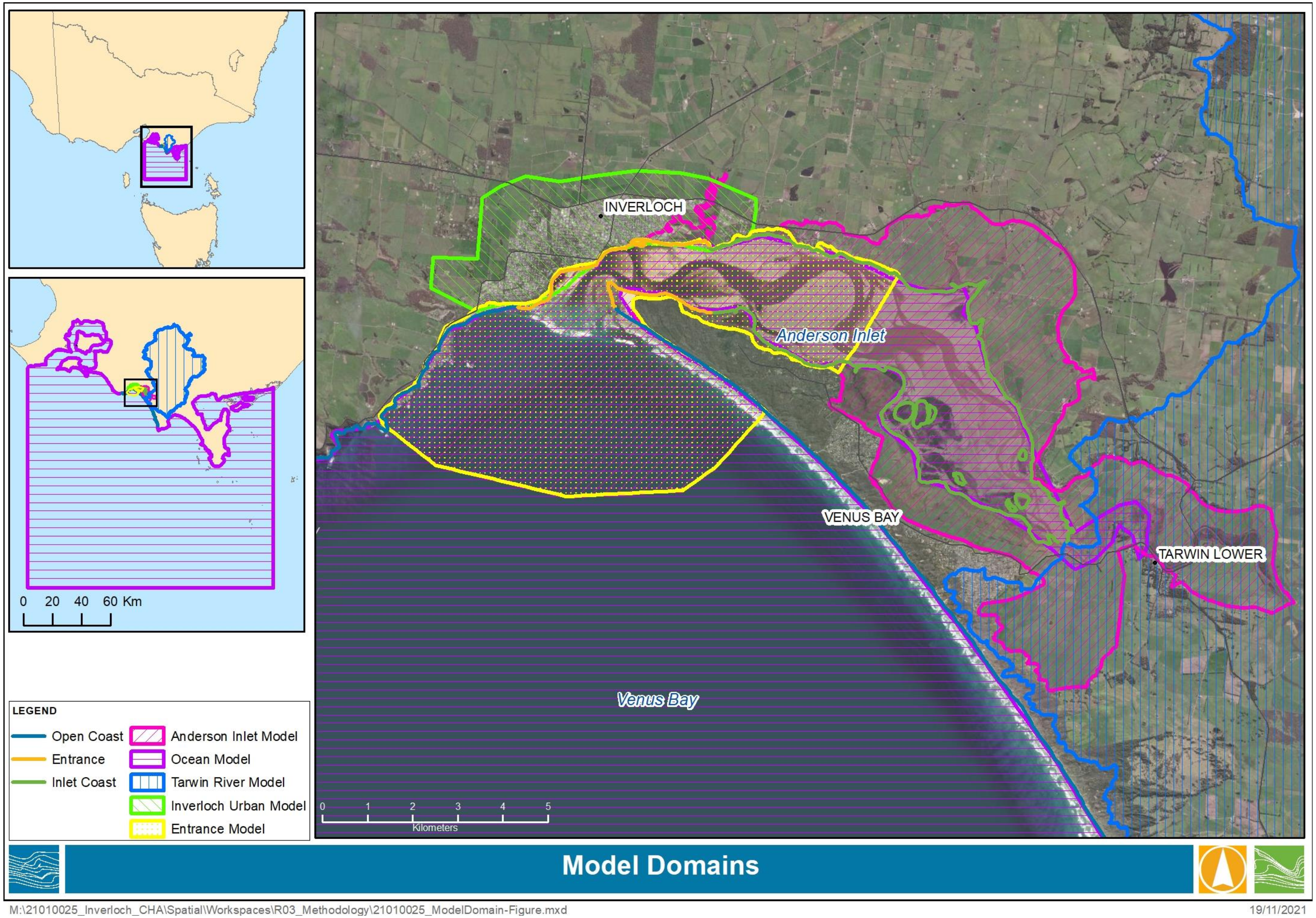


FIGURE 2-3 MODEL DOMAINS

2.3.3.4 Coastal Process Assessments

The coastal process assessments have used the coastal geomorphic sectors and shoreline classes derived for the study area, along with the outputs from the numerical modelling, to develop a detailed understanding of how the coastline along the study area changes and to attempt to quantify the rates of change.

A short overview of the approach to assessing coastal processes and erosion is provided here. Further detail is also provided in Section 4 which specifically discusses the development of the Coastal Erosion Hazard Zone.

Short-term (Storm) erosion estimates

Short-term, or storm, erosion has been determined using the program SBEACH. SBEACH was initially developed by the US Army Core of Engineers and is a numerical model which assesses the impact of wave and water level conditions on the beach profile.

The short-term erosion has been calculated for the design storm events defined in Table 2-2 using the beach profile extracted from the FutureCoast Lidar data, supplemented by LiDAR and bathymetric survey along the Inverloch shoreline collected for the project on Surf Beach. Other inputs into SBEACH such as sediment properties, presence of rock bed and angle of repose of the dunes have been generated from the available information.

Coastline change analysis

Long term change along the coastline informs the assessment of coastal erosion hazards. Long term change has been assessed in several ways for this project:

- Historic and recent aerial imagery analysis – where the sand or vegetation line along a section of coast is mapped at different times to produce a series of 'shorelines'. The beach perpendicular distance between the shorelines can be used to quantify the long-term change along the coastline.

  Significant long-term rates of change have been observed on the entrance beaches at Andersons Inlet and have been quantified by several sources (GeoScience Australia (2018), Doumtsis (2020) and Silva (2021)) which the results of this study can be compared to. The ArcGIS plugin DSAS (Digital Shoreline Analysis System), developed by the U.S. Army Core of Engineers has been used in this study along with manual assessment to establish the rate of change along the shoreline. An example of this analysis approach is presented in Appendix F-1.

- For hard and soft rock shorelines, available LiDAR has been interrogated to understand potential failure slopes where possible. An example of this analysis approach is presented in Appendix F-2.

Channel Change Analysis and Entrance Sediment Dynamics

The coastal processes, change and dynamics of the entrance have been investigated to provide an understanding of the system to assist with the development of the hazard layers but also to inform the potential adaptation options.

The evolution of the Tarwin River channel as it meanders through the entrance of Anderson Inlet was reviewed using the aerial imagery and key or trigger temporal and spatial changes established. Previous review has established that the main channel in the western part of the entrance is relatively constant in space until around 2008, after which rapid and significant change occurs.

Channel paths have been mapped from the additional aerial imagery made available for the Study in the period 1991 through 2013 and pattens or trends noted, with reference to the Doumtsis (2020) and Silva (2020) reports noted above assessing change in beach width at Points Norman and Smythe.

Bathymetric survey has been collected by Gippsland Ports within the entrance on an annual basis. In addition to this, a full survey of the entrance channels and bars and the zone offshore of Surf Beach was captured as an outcome from the Data Assimilation and Gap Analysis works in April 2021. This was complimented by LiDAR survey of the coastal dunes along Surf Beach and the Inverloch foreshore in August 2021. This data has been reviewed and volumetric change in the entrance and Surf Beach area calculated using GIS.

Sediment transport within the entrance can be significant and rapid, driven by combined tidal and wave forces. A coupled hydrodynamic, spectral wave and sediment transport (HD/SW/ST) model described in Appendix E has been used to simulate different bathymetric representations and how they respond to coastal process drivers. The Entrance Model has been used to help further understand the drivers and processes of change, and sediment dynamics within the inlet area and the processes which have combined to result in the more recent rapid erosion seen at Surf Beach since 2012. The outcomes of the analysis are described in detail in the Report 4: Erosion Hazard Report.

Longshore sediment transport

The alongshore transport rates were assessed to add to the understanding of the coastal processes operating on the Study Area and assist in the analysis of potential existing and future hazards, in particular the coincidence of any temporal change in conjunction with rapid change in the entrance configuration. The understanding of alongshore transport has been used in conjunction with the entrance dynamics to inform the planning and design of adaptation options.

The alongshore transport potential along the open coasts of Surf Beach and Venus Bay was established using the DHI LITPAK modelling tool. The LITPAK model uses the beach profile, sediment characteristics, wave, current and water level climate to simulate the volume of sediment which can potentially be transported along the coastline. Beach profiles were extracted from the FutureCoast and 2021 LiDAR/bathymetry dataset.

Longshore transport within the Inlet is limited due to the fetch length and intertidal banks. Erosion of the shoreline in the estuary will be driven by short term storm events and the increasing height of the tidal inundation due to sea level rise and as such longshore transport will not be assessed within the Inlet. The impact of flood flows on the coastline of Anderson Inlet are minimal due to the large expanse of the inlet which flood water disperse across.

2.3.3.5 Groundwater Assessment

A conceptual groundwater model has been developed to illustrate the groundwater processes in the Study Area. Limited monitoring data is available across the Study Area to quantify groundwater level, movement, or chemical properties, however information has been derived from the high number of bores across Venus Bay and used in the development of a conceptual model.

The conceptual model has been used to provide an overview of how the regional groundwater processes may respond to sea level rise or coastline change and is presented in Report 5.

2.3.3.6 Output Data

The outputs from the inundation and erosion hazard analysis will be a series of mapping layers. Coastal inundation extents have been mapped using a combination of modelled water levels and high-resolution digital elevation maps (DEMs) and modelled inundation of the coastal floodplain. Coastal erosion has been mapped using setback from the current shoreline which has been defined visually from aerial imagery as the toe of the dune on the sandy coastline, the base of the cliff for rocky coastlines, or the landward extent of the regular tidal inundation and coastal vegetation along the shore of Anderson Inlet to allow for coastal change since the collection of LiDAR in 2009. Similarly, a surveyed level has not been used as the start of any setback distance as the existing backshore/dune profile, particularly along Surf Beach, is not an equilibrium profile and use of the MHWS and MSL planes will not correctly identify areas at risk of storm erosion.

Draft hazard layers can be accessed via the ArcGIS online portal established for the project (link provided separately).

2.3.3.7 Risks Identification

At the time of this report (November 2021), this section of work is to be completed and refinement of the methodology may be required. This report will be updated to reflect the final methodology following completion of the risk and adaptation works. The intended methodology is as follows.

1. The mapping layers developed by the coastal hazard analysis will be used to identify assets and values at risk by intersecting the hazard layers and assets and values in a spatial dataset.
2. Where assets are spatially expansive (for example a road or utilities network), they will be broken into smaller segments of around 10m. This will allow examination of the proportion and spatial section of large assets which are within the hazard zones and the level/timeframe of exposure.
3. The consequence of loss or damage to assets will be developed by Alluvium as part of the Community Consultation process. This consequence information will be combined with the likelihood of asset and values exposure to determine "risk".
4. The assets and values at risk will be presented as tabulated data for each hazard scenario, with mapping completed as required. This information will be presented to stakeholders as part of discussions regarding the development of adaptation options.

2.3.3.8 Adaptation Assessment

At the time of this report (November 2021), this section of work is to be completed and refinement of the methodology may be required. This report will be updated to reflect the final methodology following completion of the risk and adaptation works. The intended methodology is as follows:

Consider the Marine and Coastal Policy (2020) to generate a wide range of adaptation options through consultation with DELWP and other key stakeholders.

Undertake a multi-criteria analysis (MCA) to determine which options will be progressed to technical assessment.

Utilise the understanding and modelling tools developed for the project to assess the five highest ranking options.

Use the technical assessment in the MCA to establish the preferred adaptation options and future planning pathways.

3 INUNDATION HAZARDS

3.1 Overview

Coastal inundation is caused by the elevation of water levels due to storm surges, wave setup and runup, catchment flows and increases in mean sea level. This section provides further detail on the assessment and identification of the extent of the coastal inundation hazard across the study area.

Three methods for determining inundation have been completed for different exposure environments in the Study Area (refer to FIGURE 1-2 for Study Area coastlines):

- Open Coast: Storm Tides + Wave Setup
  - Bunurong Road, Surf Beach, Point Smythe, Open Coast
- Anderson Inlet: Catchment Inflows + Offshore Storm Tides
  - Anderson Inlet, Point Smythe
- Inverloch: Catchment Inflows + Rainfall + Storm Tide Tailwater
  - Surf Beach, Inverloch

A description of the different methodologies is provided below.

3.2 Design Storm Events

Details of the Extreme Value Analysis and examples of the methodology are provided in Appendix D.

An extreme value analysis (EVA) of the 1981-2020 hindcast wave and water level data was undertaken to establish design storm events for a range of annual exceedance probabilities (AEPs). Design oceanographic storm conditions offshore of the Study Area at the VCMP wave buoy, encompassing peak storm surge and peak wave conditions, are presented below in Table 3-1.

Peak wave conditions are associated with strong fronts passing across the Southern Ocean from west to east. Likewise, high residual/storm surges are associated with storms passing through Bass Strait and as such, the wave and storm surges will be considered to be coincident, and the 1% AEP wave height will be combined with the 1% AEP storm tide, the 5% AEP storm tide with the 5% AEP wave and so on.

Table 3-1 Present Day Design Storm Events

Design Event	Offshore Storm Tide (m AHD)	Offshore Significant Wave Height (m)	Offshore Peak Wave Period (s)
1% AEP	2.25	6.6	14.6
5% AEP	2.10	6.1	14.2
10% AEP	2.00	5.9	13.9

3.3 Open Coast

Due to the dune height and coastal cliffs along the Bunurong Road and Open Coast sections of the study area, the landward spatial extent of coastal inundation is minimal.

Along the open coast, beach profiles have been extracted from the bathymetric datasets to provide a representation of the surrounding coastline. Profiles have been selected to coincide with the wave hindcast data offshore (Figure E-1, Appendix E). For each beach profile, the design offshore wave and storm tide events presented in Table 3-1 have been simulated in SBEACH to determine the wave extreme water level at the coastline. An example of the 1% AEP offshore storm tide and 1% AEP wave height used to simulate coastal water levels are presented in Figure 3-1. It is important to note the limited duration of the peak water levels and wave heights along the coast. Any inundation is likely to be relatively limited in duration due to the fall of the tide underlying the storm tide which can reduce the water level 1.5m during a spring tide in 6 hours. The peak of the 1% AEP offshore storm tide shown below is likely to be above 2.0m AHD offshore for just 2.5 to 3 hours. This is notably shorter duration than inundation experienced in the upper floodplain during the same likelihood (1% AEP) flood in the Tarwin River.

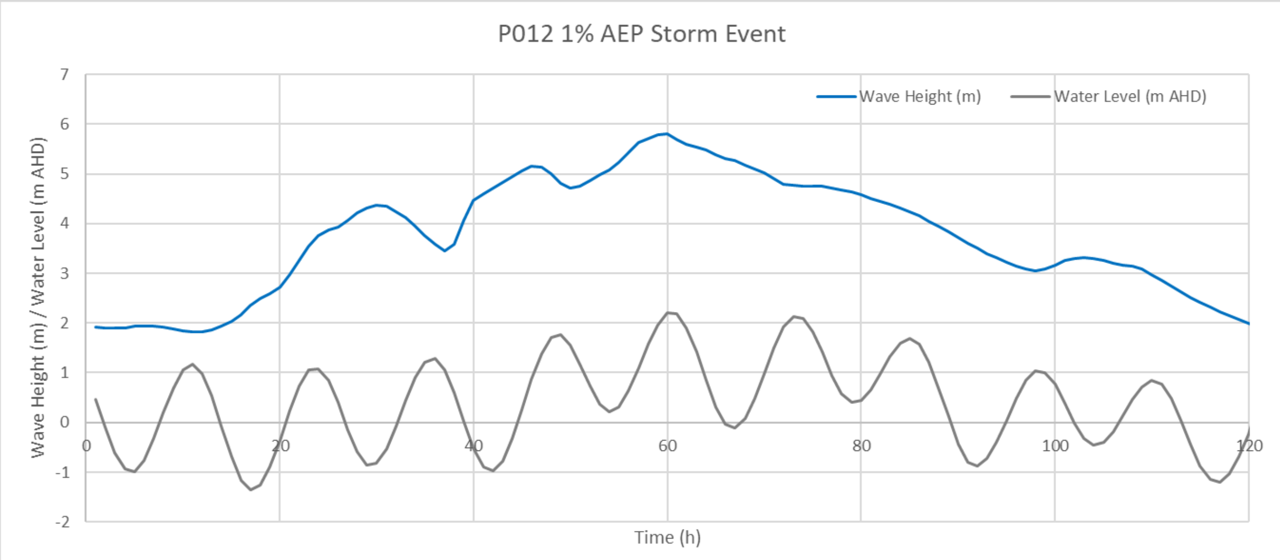


Figure 3-1 Existing 1% AEP Storm Conditions – Venus Bay Open Coast Profile 012

The extreme water level includes the wave setup but excludes the individual wave run-up as this is dependent on the hyperlocal beach dune profile and may result in misleading storm tide levels and inundation hazard when mapped across the shoreline. This is particularly the case at Surf Beach where the beach profile varies significantly along the shore. Wave run-up can be allowed for in planning freeboards.

The additional inundation due to sea level rise was added to the total water level. It is assumed that the profile will adjust with increasing sea levels and the slope of the beach and thus wave setup will remain constant.

3.3.1 Open Coast Inundation Mapping

The combination of storm tide inundation events provided in the hazard mapping is as per Table 2-2. Mapping of the inundation due to storm tides and wave setup has been completed by intersecting the storm tide with the survey digital elevation model (DEM) to create an inundation zone. This referred to as “bath-tub” mapping. Any areas which are not connected to the coastal zone, but are under the inundation water surface level, are removed from the inundation zone.

Due to the steepness of the open coastal dune, the potential landward extent of inundation is limited along the Venus Bay ocean coast and hence the use of a bath-tub mapping approach is appropriate.

Along the Surf Beach section of Inverloch, the potential inundation is greater due to the lower coastal dune and Wreck Creek openings cutting through the dune. It is also noted the coastal dune along Surf Beach is vulnerable to erosion and the potential position and protection offered by the primary dunes uncertain beyond the present climate. To provide a greater understanding of the potential coastal inundation along Surf Beach under existing conditions the storm tide + wave setup timeseries was extracted from SBEACH and used as a tailwater boundary in the local Inverloch inundation model (Section 3.5). This is described further in this section below. Simulation of inundation using the Inverloch model provides a higher level of accuracy compared with the bathtub intersection as the model considers the duration and volume of water during the storm event and how these can flow over and across the coastal dune to the low lying land behind. This has only been completed and presented in the mapping for the existing / present day 1% AEP storm scenario as the future heights and position of the dune is uncertain.

3.4 Anderson Inlet

A 2-D numerical model was established to simulate the offshore storm tides, design winds and catchment inflows into Anderson Inlet to assess flooding in the sheltered Inlet where extreme waves have limited impacts. Detail of the numerical model setup is provided in Appendix E-4.

Design storm tides presented in Table 3-1 and Appendix D were used as an offshore boundary force and wind conditions identified in the Climatology review (Appendix B), and tested as per Section 3.4.2 used as a boundary force within the Inlet. Offshore wind conditions have been considered in the hydrodynamic hindcast used to generate the offshore storm tide level.

This is a dynamic modelling approach (as opposed to the static bathtub intersection), and like the existing 1% event at the Surf Beach area, the modelled flood extents take into account the temporal variation in water levels and volumes during the storm tide. This dynamic modelling approach provides a more accurate representation of the likely flood events and depths compared to bath-tub modelling for low lying coastal areas. When using the inundation model results to identify coastal hazards, the duration of the inundation will be considered.

3.4.1 Catchment Inflows

The storm tides have been combined with the 1% and 10% AEP flooding events in the Tarwin River, Pound and Screw Creek catchments as per Table 2-1.

The dependence of storm tide and catchment flow along the coast of Victoria are, as noted in Section 2.3.2, the lowest in Australia (AR&R 2014) for short, medium and longer storm events.

Design flow events have been generated for the Tarwin River by utilising standard hydrologic and hydraulic processes. The key steps undertaken are as follows:

- A Flood Frequency Analysis (FFA) using 2019 AR&R approaches on the Tarwin River measured flow data.
- Generation of a new RORB model of the Tarwin River.
- RORB model calibration.
- Monte Carlo approach to develop design hydrology that is verified to the FFA.
- Generation of 1% and 10% AEP flood hydrographs.

The 1% and 10% AEP design flows for the Tarwin River at the Meeniyan gauge are presented in Table 3-2. To simulate a representative flood in the system, these peak flows have been used to scale actual measured flood hydrographs to use as “Design Events”, presented in Figure 3-2. The two floods selected have been experienced in recent times so provide a good representation of potential flood hydrograph based on catchment land use. It is noted that the volume of a flood is different from the peak flood discharge and can influence inundation, particularly in tidal inlets where flood storage is influenced by coincidence with peak tidal levels.

The discharge of the recent June 2021 flood event was determined to be between a 20% and 10% AEP event, based on the Flood Frequency Analysis completed on the Tarwin River data, and was chosen to be scaled up to represent a 10% AEP in the modelling. The peak of the 2021 flood is notably flatter (and thus longer in duration) than the 2012 event which was selected to be scaled up to represent the 1% AEP event. The 2012 event hydrograph was selected for the 1% AEP design flood as it is the largest flood on record in the Tarwin River and the peak flow was close to a design 1% AEP event.

On review of the flood volumes, the measured flood events had a similar volume of water during the flood event, however, when the events were scaled to the representative design flows, the “2021 10% AEP” carried a slightly higher volume of water than the “2012 1% AEP” event. This is not unusual in flooding conditions as all floods are different in shape. However, using a large volume 10% event in Anderson Inlet where offshore storm tidal levels dominate flooding, was considered acceptable and provided an additional level of conservativeness for the more frequent riverine flooding event.

Table 3-2 Tarwin River Flood Flows

Design Event	Peak Design Flow (m^3/s) (Flood Volume (ML))
1% AEP	305 (53,280 ML)
10% AEP	237 (58,330 ML)

The calibrated Tarwin River RORB model has been used to generate additional RORB models for the ungauged (and considerably smaller) Pound and Screw Creeks to determine the 1% and 10% AEP flood hydrographs for those catchments.

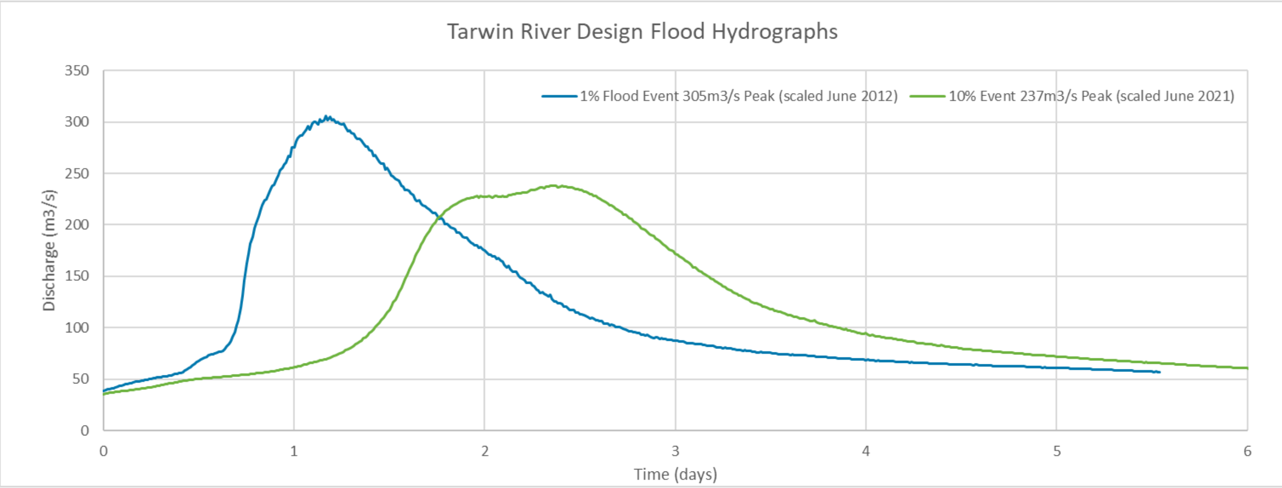


Figure 3-2 Design Flood Hydrodygraphs

3.4.2 Sensitivity Assessment

To test the sensitivity of the model to different inputs and assess the significance of some of the uncertainties in the drivers of coastal inundation, a suite of sensitivity testing was undertaken, as described in Appendix E-4.

The following key aspects were assessed and are discussed in Appendix E-4:

- Wind stress and wind direction
- Model bathymetry
- Catchment runoff
- Storm and flood timing; and
- Design event joint probability

3.4.3 Anderson Inlet Coastal Inundation Hazard Mapping

To establish the extent of coastal inundation hazard within the Inlet, the events described in Table 2-2 have been simulated using the Anderson Inlet model described above and in Appendix E-4 to generate inundation map layers for each sea level rise projection and storm tide / flood flow design event.

The extent of the inundation hazard is a representation of all areas within the model domain which are inundated during the simulation, as opposed to a snapshot in time of the inundation occurring. Thus the inundation extent shows areas which may not be inundated at the same time during a storm and flood event.

The inundation extent shows areas which are hydraulically connected and the timing and volume of water in the storm and flood event is sufficient to wet the inundated area, unlike the bath-tub presentation described for the Open Coast sections which do not consider timing or volume. Some areas within the model extent are inundated to different depths to adjacent areas, especially where water has overtopped low lying levee bunds. The duration of inundation varies across the study area from short durations of inundation to permanently inundated.

The inundation extent is linked to the resolution of the model and in areas of very little topographical change mapping may show small areas inundated which are above the flood level or may miss minor drainage paths below the model resolution.

3.5 Inverloch

Coastal inundation at Inverloch is dependent on the position and height of the beach and entrance sand bars during a storm event. The stormwater network at Inverloch includes seven coastal outflow points which may allow backflow of seawater from the Inlet into the town. For the purposes of this study it has been assumed the drainage network is free to back flow from the coast into the network and visa versa and that free drainage (apart from tail water level) is allowed from the network to the coastal waters.

The estuary openings of Wreck Creek, Ayr Creek and Screw Creek also pose a vulnerability to backflow from elevated coastal water levels.

3.5.1 Coastal Tailwater

The nearshore dynamic design water levels generated by the Anderson Inlet model have been used as the tailwater level of the stormwater network in Inverloch. The Anderson Inlet modelled water level includes the combined effects of:

- Offshore storm tide (astronomical tide, storm surge – barometric pressure, ocean wind forces)
- Local wind stress
- Catchment inflow

Given the order of magnitude difference in forcing of the storm tide from Bass Strait compared to the urban runoff in Inverloch, the ocean and Inlet tailwater has a greater impact on low lying coastal land rather than the local stormwater runoff increasing the combined storm tide and catchment flood levels within Anderson Inlet. Thus, tailwater levels from the Anderson Inlet model feed into the stormwater network modelling rather than the urban drainage feeding into the coastal water level modelling of Anderson Inlet.

3.5.2 Urban Drainage

To establish the impact of these tailwater levels on the urban drainage, the following steps were completed:

- Hydrological assessment using RORB to confirm peak flows from upstream catchments;
- The 20%, 10% and 1% AEP rainfall events were used in RORB to generate flows;
- Identification of the critical 1%, 10% and 20% AEP storm events and temporal patterns.

A 1- and 2-Dimensional hydraulic model of Inverloch used the inputs from the local RORB models and representative rainfall to test the pipe network and determine the existing overland flow paths, flood extents, and flood levels. The MHWS was used as a tailwater when considering the existing overland flow paths. The town is above the existing MHWS level (0.94m AHD) and backflow from a spring tide does not occur, or cause backflow or drainage problems in the network.

The design coastal tailwater was then added as a boundary and the areas impacted (i.e. the areas where inundation was changed with the addition of the tailwater) used in the coastal inundation hazard mapping.

3.5.3 Sensitivity Testing

Given the catchments contributing to Ayr Creek and Screw Creek are ungauged, the peak 1%, 10% and 20% AEP flows were verified against other verification methods (i.e., Rational Method and Regional Flood Frequency Estimation). A sensitivity analysis was undertaken, to assess the peak 1%, 10% and 20% AEP flow rates and find the best fit, based on the following parameters:

- Fraction Imperviousness;
- Initial losses [mm];
- Continuing losses [mm/h]; and
- Kc parameters

3.5.4 Inverloch Inundation Mapping

3.5.4.1 Flat Rocks to Inverloch SLSC

As noted in Section 3.3.1, more detailed review of existing storm tide and catchment runoff inundation risk at Surf Beach (from Flat Rocks to the Inverloch SLSC) via Wreck Creek has utilised the extreme coastal water levels, including wave setup, generated by SBEACH.

The recent rapid change, and the vulnerability to future change, of the coastal dune along Surf Beach suggests the inundation processes at Surf Beach, particularly from Flat Rocks to east of the SLSC, will be significantly different in the near future. The coastal dunes which currently provide a buffer between the ocean and the low lying land and Wreck Creek flow path are at risk of erosion by the middle of this century. Inundation which currently occurs via backflow up Wreck Creek and across the dune and under the road at Flat Rocks may be able to occur directly from the coast if the coastal dune buffer is eroded as sea levels rise. Direct inundation from the ocean will result in a larger extent of flooding as the time and volume restrictions forced by the Creek and road culverts which slow the flood and restrict the flooding will be removed.

Given this potential for additional hazard, the more precautionary approach of the bathtub inundation has been used to establish the inundation hazard extent for future sea level rise and planning horizon scenarios in this area whilst a 2D dynamic model simulating back flow up Wreck Creek and across the road at Flat Rocks has been used to assess the inundation of the existing storm tide event.

3.5.4.2 Inverloch SLSC to Screw Creek

The extent of the catchment and rainfall driven inundation within Inverloch, with and without design storm tide tailwater conditions, have been established to understand the impact of storm tides on the lower drainage network.

The events described in Table 2-2 have been simulated to generate inundation map layers for each sea level rise projection, catchment flow, rainfall, wind and storm tide design event.

The inundation extent is derived from the maximum extent of flooding across the model, not a timestep within the model simulation. As with the Anderson Inlet inundation, model cells are dynamically linked so show inundation areas which are hydraulically linked. Stormwater network details (pipes, pits etc) allow areas to be inundated which are not connected by overland flow.

The duration of inundation is not linked to the inundation extent varies across the study area from short to long durations of inundation.

The inundation extent is linked to the resolution of the model and at the outer extents or in areas of very little topographical change may show small areas inundated which are above the flood level.

4 EROSION

4.1 Overview

The analysis of coastal erosion hazards generally considers short-term processes, associated with single extreme events or clusters of events, and longer-term processes resulting in shoreline recession (or accretion) over several years to decades (e.g. DSE, 2012; Water Research Laboratory, 2013; Water Technology, 2014e) and future potential response to sea level change.

For shorelines comprised primarily of beaches (either with backshore dunes or rock slopes), the short-term component is referred to as storm erosion or storm bite and is caused by the extreme waves and currents that accompany a coastal storm. In the aftermath of storm erosion, where sand has been moved offshore, calm-weather swells may move sand back onshore. It may also be transported along the coast by longshore currents, which may be persistent or variable. Eroded finer sediments, including sand, may be permanently lost from the system by being taken offshore into deeper water by currents and turbulence in extreme storms.

In the absence of significant swell or exposure to swell, such as in Andersons Inlet, there may be little or no recovery between short term erosion events, compared to episodic recovery that occurs on open sandy coasts.

Longer-term shoreline erosion is often due to a combination of factors, such as changes to net longshore transport and sediment supply (for beaches), and sea level rise (SLR). In the case of coastal cliffs, long term recession is often associated with cliff lithology and structural features promoting instability such as the angle of repose of the material and height of the cliff as well as wave energy at the toe.

4.1.1 Approach

The approach to defining coastal erosion hazard zones in this study is based on the response to coastal drivers from the coastal geomorphic sector and shoreline class. For each shoreline class the potential short term, long term and SLR component of the erosion hazard applicable to the specific location is identified, considering the backshore, intertidal and subtidal morphology.

The methodology for calculating erosion potential within each shoreline class is provided in Appendix G. The erosion hazard extent used in mapping will be in the form:

Erosion Hazard Extent = Short Term Erosion + Long Term Change + Response to SLR

Each of these processes and how they will be calculated are described below.

4.2 Short term erosion

4.2.1 Open Coast Sandy Shorelines

Modelling of cross-shore sediment transport, or storm erosion, has been carried out for the open coast using the shoreline response model SBEACH. SBEACH transforms the offshore wave climate inshore and calculates the change in beach profile due to the storm wave energy. This is also referred to as the “storm demand”.

4.2.1.1 Beach Profiles

The FutureCoast DEM has been used to establish beach profiles along the coastline. The FutureCoast DEM has been supplemented along the coastal dune and in some intertidal areas by topographic LiDAR collected as part of the project along the Bunurong Road and Surf Beach, and with bathymetric survey offshore of Surf Beach. The LiDAR and bathymetric survey collected for the project is not as extensive as the FutureCoast DEM (i.e. it does not extend to the offshore limit of the SBEACH model) and as such some interpolation and smoothing has been undertaken to meld the two datasets where required.

Profiles for SBEACH have been extracted from the DEMs along the Open Coast where wave hindcast points are located, at regular intervals along the Surf Beach coastline and at the centre of the beach within the pocket beaches of the Bunurong Road.

4.2.1.2 Model Inputs

The storm tide signal developed from the hindcast water levels was used in conjunction with a synthesised design wave event, based on the design wave conditions developed from the modelled wave hindcast. These are both described in Appendix D.

Two design storms were simulated concurrently as shown in Figure 4-1. This is a common practice and assumes that no recovery of the beach occurs between the design storms. The use of two design storms also allows for initial storm response (i.e. some "smoothing") of localised topographic and bathymetric features in the profile from the first storm before the second storm forces the profile further towards the equilibrium beach profile of the input design conditions.

The extreme storm tide and wave events were combined with increases in mean sea level as described in Table 2-2.

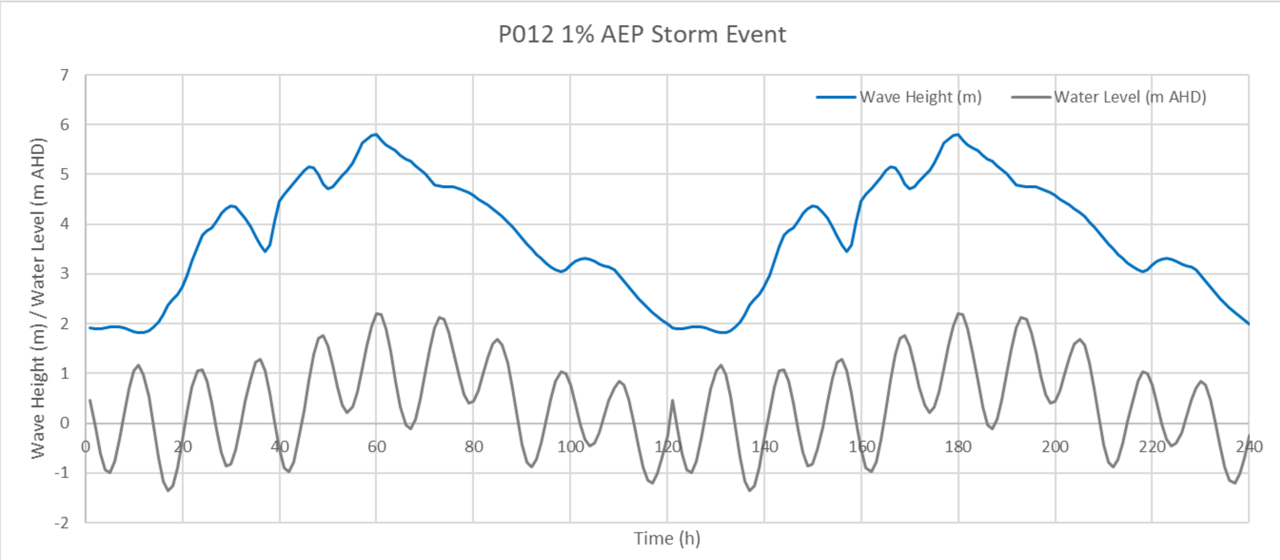


Figure 4-1 Existing 1% AEP Storm Conditions – Venus Bay Open Coast Profile 012

4.2.1.3 Model Validation

Model validation has been limited by the lack of beach survey in the study area. Beach profile surveys have been collected for the project at 5 locations along Venus Bay prior to and after a small storm at the beginning of May 2021. Small changes in the beach profiles (+/- 0.3m maximum) were captured in the surveys, primarily on one profile where a lowering of the whole beach profile was observed from -1m AHD, across the beach and up the dune to 3m AHD. More significant changes can be observed when comparing the survey to the Future coast data (~1m) however the period between the FutureCoast data capture and the recent beach profiles is too significant to make any real assumptions on storm bite.

The SBEACH model was validated to the small storm events of 2021 along the open coast. The primary mode of adjustment was an increase of the dune slope prior to collapse. In the case of the Venus Bay dunes, the dense vegetation allows a much steeper dune than the default value assumed for SBEACH.

The design storm volume of the open coast was in the order of 130-250m^3/m. This is in line with regional estimates of storm demand based on general wave climate and exposure of 200m^3/m for the South Gippsland coastline (Mummery, J.C., 2016). The setback however was significantly less – a maximum of 21m at the toe of the dune compared with the regional estimate of 75 – 114m. This is due to the very steep and high dune along the open coast, and the significant protection offered by the dense vegetation.

Beach profiles have been collected on a 2-6 week period by the South Gippsland Conservation Society (SGCS) along the Surf Beach and around Point Norman since 2019. The limited spatial extent (limited to dry beach at the time only) and resolution (~5m intervals) across the profile and the significant longshore transport contributing to erosion of the Surf Beach dunes made this data difficult to use for model calibration. Testing of the dune slope and sediment size were used to establish the sensitivity of the environment to change and variation.

Storm demand provided by SBEACH on the Surf Beach coast were significantly less than estimated in Mummery (2016), primarily due to the more sheltered nature of the beach, the wide flat beach profile and the limited volume in the dune system available for erosion. Storm demand at Surf Beach, which ranged from 20 to 80 m^3/m, typically removed or significantly reduced the size of the existing primary dune which itself is significantly lower and thinner than the dune captured in the 2009 FutureCoast LiDAR.

Validation data is not available for the Bunurong Road pocket beaches. LiDAR captured for the Department of Transport along the Bunurong Road shows change in some beach profiles between 2009 and 2021. Storm demand from the 1% AEP is again significantly less than the regional estimates with exception to the most westerly beach (Bunurong Pocket Beach #1) at which SBEACH estimated a reasonable 1% AEP storm demand of 164m^3/m. Pocket beach #1 is less sheltered by headlands and there is no rock platform to dissipate wave energy. The remaining pocket beaches are either significantly sheltered by large headlands, or protected by a wide rock platform, or both and wave conditions at these beaches are significantly attenuated and the results of SBEACH are considered reasonable for the inshore oceanographic conditions.

Storm demand was also limited along the Bunurong Road by the limited sand availability. The hard bottom feature in SBEACH was used to reduce the mobile sediment to that observed in the 2021 and 2009 aerial photographs associated with the DEM profile data. The 1% AEP storm demand along the Bunurong Road beaches (excluding Beach #1) was in the order of 20 to 120 m^3/m and the volume of sand was in the range 30 - 100 m^3/m, illustrating the vulnerability of some beaches to significant storms.

4.2.1.4 Erosion Setback

The erosion setback generated by SBEACH was assessed and the distance of the setback determined at the design water level. Initially it was intended that the setback distance be determined using the setback at the level of HAT. However due to the steep face of the coastal dune in the Study Area, reprofiling of the beach after a storm resulted in material often slumping across the HAT level which could be interpreted as “accretion” rather than erosion. Along Surf Beach the active dune was located landward of the HAT to an extent that the hazard zone would potentially include a section of the profile which was already eroded.

The setback in SBEACH was thus calculated for each beach profile and the setback of the coastline taken from the position of the toe of the dune. This is discussed further in the erosion hazard mapping methodology in Section 4.5.

4.2.2 Anderson Inlet

The shallow depth, low-energy wave climate, mangrove fringing and shoreline strata within Anderson Inlet results in limited short-term erosion potential of the Inlet coastline. Any episodic erosion caused by storm events is assumed to be captured within the long term trend analysis as there is no recovery of these shorelines as would occurs for sandy coasts.

Short term erosion setback is thus not considered for Anderson Inlet.

4.2.3 Entrance and Sandy Spits

Short term erosion of the entrance coastline which is not exposed to the ocean wave climate is driven by tidal currents and smaller wind waves. As with the Inlet, episodic erosion caused by tidal currents will be captured by the long term trend analysis of the shoreline position.

Short term erosion setback is thus not considered for the entrance coastline not exposed to direct ocean wave action.

4.3 Long term change

4.3.1 Open Coast Sandy Shorelines

The long-term rate of shoreline change includes both ongoing trends and long-term cyclical fluctuations. These may be due to changes in sea level, fluctuations in coastal sediment supply or associated with long-term climatic cycles.

The long-term rate of recession along the open ocean sandy shorelines of Venus Bay, Surf Beach and the pocket beaches along the Bunurong Road has been based on rates of change (in meters per year) determined through aerial and satellite imagery analysis. A combination of the seaward extent of the coastal vegetation and the toe of the dune has been used to define the shoreline position in the imagery. The variation in defining the shoreline position has been necessary due to the steep dunes on the open coast and the variable cover of the coastal vegetation. Where possible, the toe of the dune has been to establish the position of the shoreline.

4.3.1.1 Surf Beach Long Term Change

The position of the shoreline in the Study Area can be quite variable, as experienced along the Surf Beach in the past decade. The rate of long term recession has been determined using a linear regression rate to establish the “likely” recession along the coast. It should be emphasised that the **term long term change** in the context of this study is the **change between 1950 and 2021**. The long term change has been established by calculating the linear trendline of the position of the shoreline since the initial aerial image in 1950. This method was completed manually along the Venus Bay coast and using the USACE DSAS package for Surf Beach and Bunurong Road.

However, this linear trendline does not provide any recognition of the significant recent change in shoreline position, especially along Surf Beach. Along this section of the Study Area the coastline accreted in the years following 1950 before remaining in a relatively stable location until the early 2010s with short term rates of erosion and accretion varying between -/+ 5 to 6m per year. Since 2010 there has been significant and steady increase of erosion with over 50m of shoreline lost at an average rate above 5m per year. This significant change is noted as occurring after the change in the entrance channel configuration and loss of the ebb tide delta.

In the example beach profile presented in FIGURE 4-2, located just west of the mouth of Wreck Creek in August 2021, the linear recession rate across the 70 year period between 1950 and 2021 (0.5m per year of recession) was close to a tenth of that which has occurred since 2012 (5m per year recession).

In recognition of the variability experienced along the coast, and the (geomorphologically) short period of data available to differentiate between trends and cycles, it was considered reasonable to expect the longer term recession could be considered to be at least “likely” to occur, whilst the rapid erosion experienced in recent time was at least “possible” to continue at this accelerated rate.

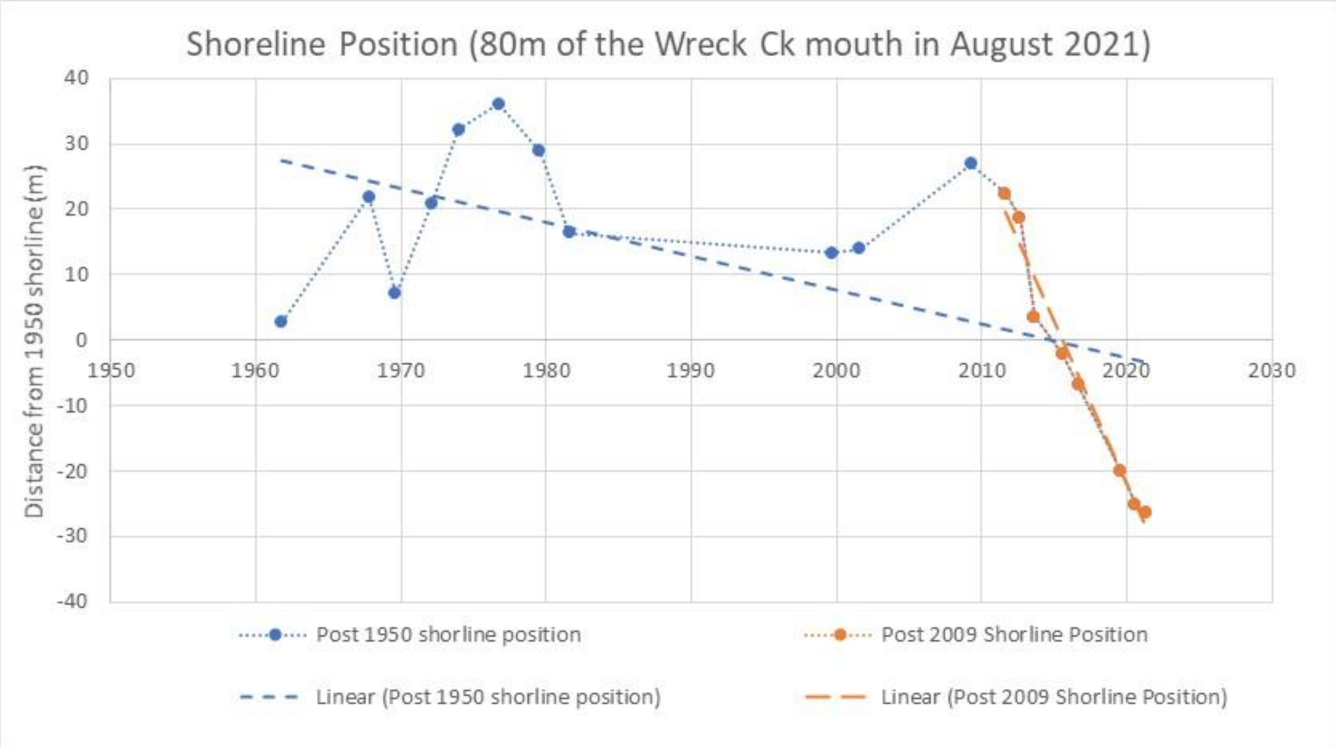


FIGURE 4-2 LIKELY AND POSSIBLE RECESSION RATES

4.3.1.2 Venus Bay Coast

In contrast to Surf Beach, the shoreline along Venus Bay has largely accreted or returned to a similar position as the shoreline in 1950, based on assessment of the coastline in aerial imagery and manually intersecting the shoreline position across the temporal dataset. This accretion is likely, in some part, to be in response to changes in land use along the open coast and the emergence of significant vegetation cover which has provided stability to the coastal dunes and reduced wind blow outs and storm erosion.

Accretion rates vary significantly along the coast, and as with Surf Beach, some sections of the coast have experienced erosion in more recent times, albeit at a considerably lower rate. However, the shoreline position along the coast is seaward of the 1950 position.

Rather than use a negative recession rate (i.e. a seaward accretion of the shoreline) reflected by the linear regression, a long term recession rate of 0m/y was adopted for the Venus Bay coastline. The long term rate of accretion along the coastline is in the order of 0.1 – 0.75m/y. More recent change observed in the east of the Study Area towards Point Smythe shows variation in erosion and accretion between -3m /year and +1.5m/year for short periods between 2009 and 2019.

4.3.1.3 Bunurong Road

Analysis of the shoreline position of the pocket beaches along the Bunurong Road was undertaken using the aerial imagery and the DSAS software as described above. The steep cliffs, which cause shadowing and distortion of some of the imagery, resulted in some uncertainty regarding the position of the shoreline.

The linear regression of the shoreline position was established and used as a rate of recession for these beaches. Where the rate of recession was negative (i.e. accretion had occurred over the imagery time period), a rate of 0m per year of recession was adopted. Recession and accretion ranged from -0.2m per year to +0.3m per year.

Where a hard rock of soft rock cliff was present the angle of the surrounding cliffs were analysed using the FutureCoast DEM and the stable angle of repose determined from the cliffs in the vicinity. The height of the cliff was derived from the DEM and the potential setback due to slumping or collapse established from the angle of repose and cliff height. This follows the method described in Shand et. al. 2015 presented in FIGURE 4-3 which shows present (left) and future (right) coastal hazard zones. The cliffs along the Bunurong Road did not show long term rates of recession (LTR) and as such the coastal hazard zone had no long term recession component here.

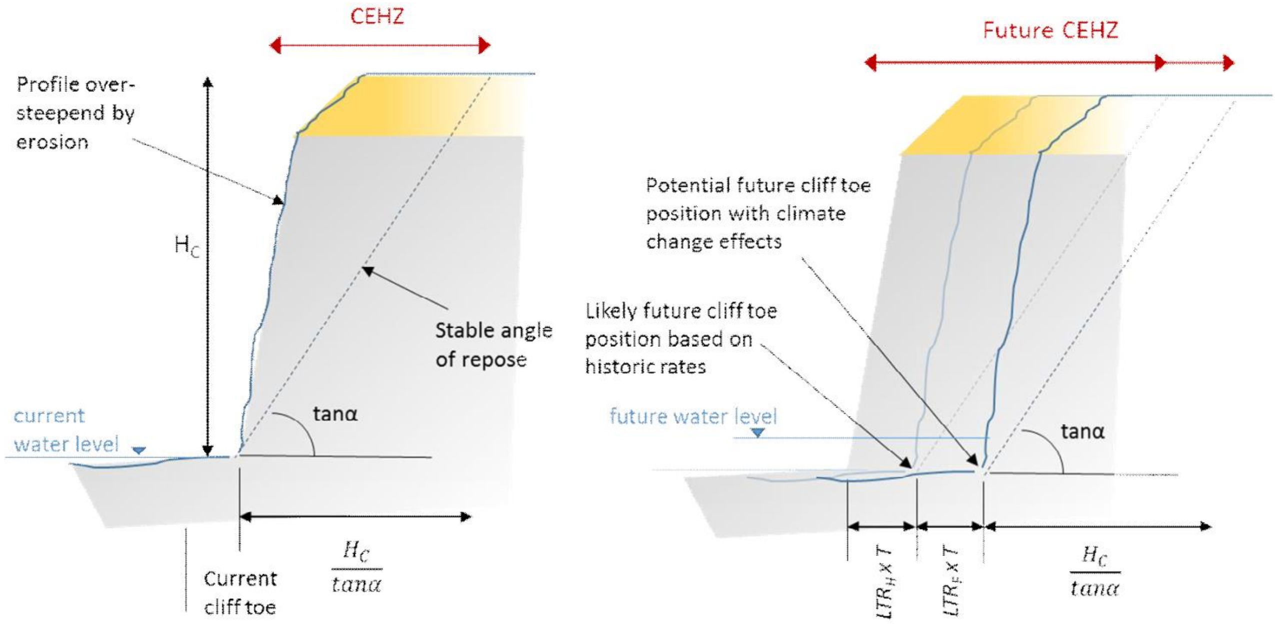


FIGURE 4-3 LONGTERM RECESSION OF CLIFFED SHORELINES (SHAND ET AL 2015)

4.3.2 Anderson Inlet Shoreline

The long term rate of change within Anderson Inlet has been determined by reviewing aerial imagery as described above for the open sandy coastline. The USACE DSAS tool was used to establish the linear regression rate along the shoreline.

The shoreline position has been taken as the position where regular inundation is not occurring, i.e. landward of the mangrove and other estuarine vegetation.

In some areas the shoreline of Anderson Inlet was observed to be prograding due to sedimentation. In these cases, the recession was considered to be 0m per year.

4.3.3 Entrance & Sandy Spits

Long term change including erosion and deposition at the entrance and adjacent spit landforms is complex and has been investigated by analysis of the geomorphology and formation of the landforms, their changes over time (aerial imagery analysis, lidar and survey analysis) and through process-based modelling (Appendix E) to help understand in more detail the drivers of change which help inform what future conditions might look like.

However, to define the **rate** of long term recession, and enable prediction of a hazard zone to future time frames, a continuation of the methodology described above using historical images was deemed most appropriate. Imagery from 1950 through to 2021 was used to establish the shoreline and the rate of linear regression determined using the DSAS program. The impact of rapid accretion of the shoreline at Ayr Creek in recent times along with the significant changes at Toys Backwater were assessed manually to ensure changes in the "shoreline" position were considerate of these different features. As with the Surf Beach coastline, the long term rate of recession was considered to be "likely" to occur, whilst the rate of rapid coastal change was deemed to be "possible" to occur again in the future.

Changes to the shoreline around Screw Creek were also reviewed manually to determine the long term rate of recession.

4.4 Response to Sea Level Rise

4.4.1 Open Coast Sandy Shorelines

The response of the coastline along the open coast to sea level rise has been calculated using the Bruun Rule (Bruun, 1962). Although the Bruun Rule is often criticised for being overly simplistic, for the open coastline, particularly between Point Smyth and Cape Liptrap, the wave dominated, sandy coastline provides suitable conditions to apply this calculation.

Initial assumptions regarding the coastal processes included the expectation that the entrance shoals were fed by the Venus Bay open coast beaches. However, analysis of the longshore sediment transport found this not to be the case and wave conditions adjacent to the shore indicate longshore sediment is instead transported away from the entrance. This is described in detail in Report 4. As such, additional sediment loss from the open coast to maintain the entrance shoals and bars was not included in future shoreline recession due to sea level rises. However, it is noted that the source of the sand to supply the entrance remain an area of uncertainty into the future.

The Bruun Rule has also been used to estimate potential future erosion at Surf Beach until the predicted (total) setback encounters the edge of the last interglacial shoreline (Appendix A), located where the sandy dune ridges intersect a high bluff above approximately 5m AHD. From this point, the angle of repose of the bluff has been used to determine an erosion zone buffer at the crest of the bluff. This section of the coastline is subject to long term erosion trends which, as noted in Section 4.3.1.1, have been significant in recent times. The uncertainty in the future dune volume and nearshore profile to even the nearest planning horizon in 2040 is high and as such the simplicity of the Bruun Rule is preferred.

The Bruun Rule has been applied on the most westerly pocket beach along the Bunurong Road. The remaining beaches are unsuitable for application of the Bruun Rule due to the wide rocky platform seaward of the beach and the hard or soft rock cliff landward of the beach.

Sensitivity of the Bruun Rule to the definition of the beach slope was completed for all sections of the Study Area. The definition of the beach slope was tested by adopting different combinations of the Hallermeier (inner or outer) or Berkemeier limits for the depth of closure and the location of the active shoreface, from the crest of the primary dune, the secondary dune berm or crest of the dune, depending on the beach and landward dune profiles.

4.4.2 Anderson Inlet

The shoreline of Andersons Inlet contains a range of coastal landforms, including soft rock and low earth cliffs, estuarine and tidal channels as well as coastal fringed wetlands. These shorelines have varied responses to sea level rise.

4.4.2.1 Soft Rock / Bluffs and Slopes / Low earth cliffs

For these shoreline classes there is likely to be an increased hazard due to increased wave energy at the cliff toe. There is considerable uncertainty as to the magnitude of this increased rate of erosion. Relevant references include Walkden and Dickson (2006), Ashton et al (2011), Trenhaile (2011). Given the uncertainty, the long term rate of recession determined using aerial imagery (Section 4.3.2) was multiplied by a factor of 2 to account for this. This is conservative and in line with the approach adopted for soft rock coasts in Tasmania (Sharples et al 2013).

4.4.2.2 Estuarine and Tidal Channels

In addition to the recession of the shoreline driven by increased wave energy on the soft shore and backshore material, there is likely to be a landward translation of the shoreline in line with the landward translation of the mean high-water line (termed permanent inundation).

This has been assessed by mapping the current and future tidal planes on the existing LiDAR topography of the study area. It is noted that there is uncertainty in the outcomes of this determination of erosion as recession of the shoreline based on the long term rate of recession will also impact the inundation area but the exact form of this erosion at any future time is unknown. As such, this permanent inundation has been presented as a stand alone coastal hazard layer, separate from coastal erosion hazard and coastal inundation hazard.

4.4.2.3 Coastal Fringed Wetlands

Coastal fringed wetlands will likely respond to sea level rise through landward migration of the vegetation communities in line with changes to the tidal regime. This migration may be constrained by the presence of levees or development or changes to the backshore material (i.e., a sandy backshore).

This process has been considered as a change in shoreline position through the rising tide levels and the future hazard captured in the permanent inundation hazard layers, as per the landward translation of the shoreline through increasing MHWS.

4.4.2.4 Anderson Inlet Erosion Hazard Zone

Thus, within the Inlet the coastal erosion hazard zone is limited to areas where existing coastal recession is observed. Low lying areas are captured in the permanent inundation hazard zone. This covers the majority of the inner entrance, where the past floodplains of the Tarwin River are very flat above the current MHWS. Closer to the entrance, or in the vicinity of the tidal channel, the long term rate of recession determined by imagery can exceed the extent of the future permanent inundation.

Within the Inlet it has been assumed (as directed by DELWP) that levees do not interrupt landward migration of the shoreline.

4.4.3 Entrance and Sandy Spits

Long term change, including erosion and deposition at the entrance and adjacent spit landforms is complex and has been investigated to help understand the drivers of change and help to inform what future conditions might look like. Analysis has included assessment of:

- the geomorphology and formation of the landforms,
- the change over time
  - aerial imagery analysis
  - lidar and survey analysis
- longshore sediment transport

- process-based modelling (Entrance Model)

There are currently no predictive techniques which will accurately forecast the exact future entrance conditions and location of the sandy spit landforms for a given sea level rise scenario.

The location of the last interglacial shoreline at 5m AHD along the Inverloch shoreline from Ayr Creek to Screw Creek is considered the limit of the Holocene sand deposits within the entrance area. This area, which ranges in width from 50-250m west of Toys Backwater and up to 600m across Broadwater nearer to Screw Creek (Figure A-3). This low lying area is thus all considered susceptible to increases in mean sea level.

To provide some indicative extent of the potential setback for different sea level horizons, the simplified Bruun Rule was used along the Inverloch shoreline. The slope of the beach profile along the Inverloch shoreline has varied considerably over time with the changing position of the tidal channels and the associated width of nearshore/intertidal beach. “Active” slope relevant to Bruun has been generally considered to decrease from Point Hughes east to Screw Creek, with the exception of the bank attached channel at the armoured rock wall adjacent to the Inverloch Jetty where a steep slope and the coastal protection limits future recession.

The use of the Bruun Rule along the Inverloch coast assumes that the tidal sand shoals will rise with rising sea levels and maintain a similar profile. The active slope angle also assumes the channel will remain in the bounds of the observed channel alignment. At the eastern end of Inverloch between Toys Backwater and Screw Creek the Bruun Rule has assumed the dune translation response to sea level will be at the coastal dune rather than the whole profile to the tidal channel. The active slope will thus be from mean sea level to the MHWS level.

It is noted that the Screw Creek area is also low lying and likely to be increasingly inundated with tidal water into Screw Creek, also increasing flow and potentially bank erosion within the Creek. As such the area will be vulnerable to change beyond shoreline-based recession from sea level.

Based on the analysis described above, the Erosion Hazard Report will provide additional details on the response of this area to sea level rise and how this may impact the erosion hazard extent.

4.5 Erosion Hazard Mapping

The erosion hazard extent has been determined for each of the different functional shorelines as described in Appendix G and the methods described above. The erosion extent is interpolated between cross sections where the erosion setback has been calculated. Interpolation of hazard zones between coastal types, e.g. sandy coastline and a cliff or coastal protection structure, does not occur and sharp changes in the hazard zones are noted. This ensures clear delineation of the different shoreline categories and risk.

Where appropriate (i.e. Surf Beach and the Inverloch foreshore) erosion hazard includes the “likely” hazard zone and the “possible” hazard zones to reflect the more rapid long term erosion rates discussed above.

The storm demand, or the short term erosion, is presented as the current erosion hazard zone and the long term and future recession setback from this zone.

The erosion hazard zone begins at the toe of the existing dune, based on the 2019 aerial image, or in the case of Surf Beach and the Inverloch shoreline, the position of the toe of the dune/shoreline in August 2021. The exception to this is Ayr Creek where the seaward extent of the coastal vegetation is considered the more appropriate base for the erosion hazard zone due to the transient nature of the sandy dunes currently present.

Along the coastline of Inverloch aerial and historical imagery showed previous coastal protection works had been constructed to prevent erosion of the shoreline. With the exception of the recent temporary rock armour works at the Bunurong Road/Wreck Creek intersection and the geotextile sand bag wall at the Inverloch SLSC, and the rock armour wall around the Inverloch Jetty all coastal protection structures are assumed to fail and not prevent future coastal recession. The temporary works along Surf Beach are considered to only prevent erosion in the current planning horizon. The more significant engineered structure at the Jetty is considered to prevent erosion through the assessment period.

Erosion hazard zones have been established for the scenarios presented in Table 2-2.

5 ASSETS, VALUES AND ADAPTATION

5.1 Asset and Value Mapping

A database of the spatial location and extent of all assets and values was established from data collected for the project. This asset and value dataset was used to identify what impact future coastal hazard could have on the coastline within the Study Area.

The asset database has been provided to DELWP. The asset database is a complication of assets and values available at the time of the Study. Both assets and values will change overtime.

5.1.1 Hazard Exposure Likelihood

To establish the likelihood of vulnerability to coastal hazards, the assets and values which fall within each hazard layers has been identified using ArcGIS. A layer for each of the different storm events and associated sea level rise and planning horizon detailed in Table 2-2 was used to identify which assets and values were within the hazard zone for each scenario.

The likelihood of exposure at each planning horizon, based on which layer first captures the asset and value, has been defined using the ratings presented in Table 5-1.

The length and proportion of exposure to the coastal hazards for assets such as roads has been 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).

Table 5-1 Coastal Hazard Likelihood Rating – Design Event

Hazard Annual Exceedance Probability (storm tide)	Likelihood
10%	Likely
5%	Likely
1%	Possible

5.1.2 Hazard Consequence

The consequence of exposure of coastal hazards to assets and values has been determined through assessment of community consultation by Alluvium (2022). The consequence rating developed by Alluvium is tailored to the community and key stakeholder feedback in the Study Area.

5.1.3 Hazard Risk

Risk Management is the term applied to a logical and systematic method of establishing the context, identifying, analysing, evaluating, treating, monitoring, and communicating the risks associated with any activity, function or process in a way that will enable organisations to minimise losses and maximise opportunities (Standards Australia, 2018). Risk is identified as the product of the likelihood and consequence of an event impacting on an asset or objective.

Risk = Likelihood x Consequence

The level of coastal hazard risk has been determined by Alluvium (2022). Risks have been classified for different geographical areas and sub areas along the coast as shown in Table 5-2 and Table 5-3. DELWP has proposed to undertake adaptation action to manage or minimise any risk rated as a medium or higher in the existing or 2040 planning horizons.

Table 5-2 Coastal Hazard Risk in Study Area

Asset / Hazard	Existing	2040	2070	2100
Bass Coast Shire (excluding Inverloch)				
Coastal Erosion	Low	Low	Low	Medium
Coastal Inundation	Low	Medium	Medium	Significant
Tidal Inundation	Low	Low	Low	Medium
Inverloch (based on town boundary)				
Coastal Erosion	Medium*	Significant*	Significant	High
Coastal Inundation	Medium	Medium	Significant	Significant
Tidal Inundation	Low	Low	Medium	Medium
South Gippsland Shire Council				
Coastal Erosion	Low	Low	Medium	Medium
Coastal Inundation	Medium	Medium	Significant	Significant
Tidal Inundation	Medium	Medium	Significant	Significant

* at some locations within the area

Table 5-3 Coastal Hazard Risk in Inverloch Sub-areas

Asset / Hazard	Existing	2040	2070	2100
Bunurong Road (Flat Rocks to Wreck Creek)				
Coastal Erosion	Medium*	Medium	Significant*	Significant
Coastal Inundation	Medium*	Medium*	Medium	Medium
Tidal Inundation	Low	Low	Low	Low
Wreck Creek dunes (Wreck Creek to Ozone St)				
Coastal Erosion	Medium*	Medium	Significant	High
Coastal Inundation	Low	Medium*	Medium	Medium
Tidal Inundation	Low	Low	Low	Low
Toys Backwater				
Coastal Erosion	Medium*	Medium*	Medium	Significant
Coastal Inundation	Low	Medium*	Medium*	Medium
Tidal Inundation	Low	Low	Low	Low
Broadbeach Estate / Screw Creek				
Coastal Erosion	Low	Low	Low	Low
Coastal Inundation	Medium*	Medium*	Medium	Medium*
Tidal Inundation	Low	Medium*	Medium*	Significant*

* at some locations within the area

5.2 Adaptation Assessment

A technical assessment has been undertaken to identify adaptation actions suitable for further assessment and consultation.

The adaptation actions were considered following the guidelines provided in the Marine and Coastal Policy 2020:

- Non-intervention
- Avoid
- Nature based methods
- Accommodate
- Retreat
- Protect

The compendium of adaptation actions presented in the *Victoria's Resilient Coast – Adapting to 2100*+ Pilot Guidelines (DELWP, 2022) was reviewed to identify adaptation actions suitable to provide a level of risk management over a short planning horizon. The short planning horizon was identified to allow for long term adaptation through avoidance and retreat actions to be developed and implemented.

A multi-criteria analysis (MCA) was undertaken to determine which adaptation actions were preferred for each coastal hazard and sub-location.

The technical modelling tools (SBEACH, LITPAK) and the data generated in the coastal hazard assessment (hindcast water levels, design wave conditions, etc) were used to assess the feasibility and develop concept plans for five adaptation options along the Inverloch coastline from Flat Rocks to Point Norman.

6 ASSUMPTIONS & LIMITATIONS

6.1 Assumptions

A number of assumptions regarding model setup, calibration and validation have been made to generate inundation and hazard mapping for the Inverloch Region CHA.

A summary list of key assumptions is provided below.

- With the exception of areas surveyed in 2021, it is assumed there has not been significant change in the topography or bathymetry since the 2009 FutureCoast LiDAR capture.
- Sediment across the study area is relatively consistent (fine-median grain). Sediments will be assumed to be consistent with other nearby sediments, and sediment characteristics are assumed to be constant through the bed and dune profile.
- Rock is known to be present within the entrance to the Inlet, however the extent is unknown. Rock is only assumed to impact the movement of sediment and coastal setback where the extent and level is clear.
- A lack of core logs through the dunes of the Inverloch township limits the understanding of their geological development. It is assumed the material seaward of the last interglacial shoreline is Holocene sand and able to erode through coastal drivers.
- Sand will continue to be supplied into the Venus Bay secondary sediment compartment (from currently unknown sources) as has occurred in the recent geomorphological timeframe.
- The hindcast wave and water level data produced for, or used by, this study is assumed to provide an accurate representation of the conditions in the Study Area over the past 40 years.
- It is assumed this 40 year period provides a good representation of the conditions likely to be experienced in the time context of this assessment. With the exception of sea level rise, the impact of climate change on other coastal drivers has been assessed through sensitivity testing to assess the potential range of impact.
- The measured water levels at Tarwin River show the tidal planes can vary through the year. It is assumed this only impacts the lower tidal planes due to the influence of catchment flows and the higher water levels (MHWS and HAT) have been accurately determined from the 8 months of measurement.
- Long term coastal change derived from aerial imagery assumes the delineation of the coastline is accurate, noting the level of accuracy varies depending on image quality, capture angle and georeferencing.
- Erosion and inundation do not dynamically influence one another. Inundation of the coastal zone for future sea level scenarios assumes erosion has not altered the existing topography. This is assumed due to the inherent uncertainty in predicting the exact form of the shoreline at any given time in the future.
- Inundation (and free drainage) via the stormwater network is not constrained by sand build-up or other debris.
- Levees are considered to remain at their current height and position when considering flood mapping for all existing and future scenarios. It is assumed that they are able to withstand changes in water level and higher permanent water levels on their seaward side as a result of sea level rise.
- However, for the erosion hazard mapping the levees are considered susceptible to erosion at the same rate as the land seaward of each levee. The land and floodplains protected by levees are also assumed to be susceptible to erosion at the rate of the adjacent shoreline.

6.2 Key Assumption

A significant assumption to the generation of hazard layers and assessment of adaptation options is the presumption that there is no mass geomorphic change to the entrance. Significant retreat or accretion of Point Smythe could significantly alter erosion and inundation within Anderson Inlet and along the Inverloch coastline.

6.3 Limitations

The Study Area comprises an extensive spatial area and complex shoreline with a range of shoreline types and coastal hazard drivers all at play and all interacting.

The identification of hazards has been completed to provide an understanding of the existing and potential future hazards on the coastline for adaptation planning. The results should not be over-interpreted or analysed at a micro scale (individual lot scale). The hazard layers have not been developed to predict erosion and inundation hazard on a lot-by-lot basis.

The hazard layers also present potential hazard without adaptation measures.

The assessment of coastal processes and hazards within the Study Area has been complex with many different drivers and processes acting to form the coastal environment and drive future change. Through the project a number of methodologies have been considered and/or trialled to develop the coastal hazard layers. These alternative approaches are noted in Table 6-1 with a brief description as to the reasoning for their rejection.

Table 6-1 Alternative methodologies

Assessment	Method	Rejection
Coastal Erosion – Entrance	2/3D numerical model simulating sand transport by wave and tidal forcing	The Entrance Model (Appendix E-5) was considered as a tool to quantify erosion setback within the entrance. The model provides understanding on the drivers and response of the entrance, however it was not considered suitable to predict future behaviour given the magnitude of unknowns and assumptions which would be required to simulate "future" erosion of a "future" entrance. Further detail on the limitations and opportunities of the morphological model are described in Appendix E-5.

Assessment	Method	Rejection
Coastal Erosion – Surf Beach	Alongshore transport / LITPAK transport rates	The shore at Surf Beach is subject to a number of erosion forces, specifically the short term storm bite and the longer term coastal recession. The storm bite can be reasonably assessed by SBEACH for existing conditions, however, does not capture the rapid erosion which has occurred over the past decade. This erosion is due to the changes of the entrance ebb tide delta and the increase in storm westerly storm events driving longshore sediment transport. Quantification of the longshore transport loss portion of the long term erosion (i.e. the m/year of beach volume loss) was attempted through the use of the LITPAK modelling, by assessing longshore transport on a finer scale spacing of profiles along the beach and quantifying the difference between successive profiles as the net gain or loss from a profile. i.e. if the longshore transport direction from the profile "upstream" is less than the longshore transport at the given profile, there would be a net loss of sediment across the profile equivalent to that difference. The beach recession could then be quantified from this. However, the results from the LITPAK modelling were contradictory to that observed in the aerial imagery, due to the complex diffraction and wave breaking cause by the rocky platform at Flat Rocks and offshore of Surf Beach and the method was not used.
Coastal Erosion – Open coasts	Volumetric analysis for Future Sea Level Rise	Various analysis techniques were considered to asses the potential recession of the open coast with sea level rise such as a simplified volume exchange (i.e. Bruun Rule but with the actual rather than simplified beach profile) and Vellinga. Bruun Rule was selected due to: - its common use and thus familiarity and acceptance; - the lack of extensive observed datasets to carry out more rigorous analysis; and - in the case of the open coast, the wide buffer available for an overestimation of retreat.
Coastal Inundation – Open Coast	2D coupled hydrodynamic wave model	The coupled 2D hydrodynamic wave model (Appendix E-3-6) was considered to determine storm tide levels along the open coast, however the domain of this model is not suitable for using the calculated design conditions as a boundary force. The length of the Study Area open coast and steep coastal dunes were also not compatible with generating a refined 2D model to simulate coastal inundation. The coastal dune could not be represented in a resolution fine enough to provide a high level of accuracy in inundation level up the dune.

Assessment	Method	Rejection
Coastal Inundation – Surf Beach/Wreck Creek	2D model	The Wreck Creek area landward of Surf Beach is low lying and vulnerable to inundation from the coast, particularly through wave setup. 2-dimensional modelling of Wreck Creek was considered for all climate scenarios to establish the potential extent of inundation during a storm tide event. However, the coastal dunes at Wreck Creek are also very vulnerable, as the recent erosion of the dune have indicated. It is likely the dune and swash zone will be different in the near future, at last by the next planning horizon to be considered beyond present day. 2-dimensional modelling of this area to assess coastal inundation using the present day coastal dune (and the inherent protection provided from inundation) was thus considered potentially misleading if presented at this level of “accuracy”. Whilst the inundation and erosion are considered separately in the Study, the significant risk to the dunes at Wreck Creek was the driver to limit 2D modelling of Wreck Creek inundation to present day conditions.
Coastal Drivers – Wave Conditions	Changing wave heights, periods or directions for future climate scenarios	It is expected that wave conditions, height, period and direction will change through anthropogenic climate change affects in the timeframe of this study. However, the level of change is uncertain. Waves in the Southern Ocean are expected to increase; however the latitude of the storms is also expected to change, resulting in an altered wave climate in the Study Area due to the sheltering offered by Tasmania. Given this uncertainty, sensitivity testing of wave climates has been completed when generating an understanding of the coastal response to hazard drivers, however the design conditions based on the University of Melbourne hindcast has been used in the hazard mapping.

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APPENDIX A
COASTAL GEOMORPHOLOGY

A-1 Coastal Geomorphic Sectors and Shoreline Classes

To inform the coastal hazard assessment, the study area has been classified into **coastal geomorphic sectors (CGS)**. Each CGS is defined by its backshore and shorezone (intertidal) landforms and materials.

Coastal geomorphic sectors have then been grouped into **shoreline classes** which bring together those sectors whose landforms and materials are likely to respond in a similar way to coastal processes and hence sea level rise and can therefore be assessed using the same analysis techniques.

The coastal geomorphic sectors and shoreline classes differ from the “coastal compartments”, used to group areas of connected coastal sediment movement and interrelated coastal processes, in such that they consider the long term morphology and morphological development of the shoreline and land area.

A brief overview of these classifications is provided herein, while further details and definitions are included in the Erosion Hazard Report and in works by Rosengren (2021) as part of this project.

A-1-1 Coastal Geomorphic Sectors

A coastal geomorphic sector (CHS) is a discrete length of coast that comprises a mappable unit with key differences to adjacent sectors. Lateral variation in one or more key characteristics defines the boundary between sectors. A differentiator between adjacent sectors is their response to coastal processes and how they respond to changed water levels and wave energy. Each sector comprises a description of the shoreline and backshore landforms, for example a sandy beach in front of a low coastal bluff or a shore platform at the base of hard rock cliff. A number of CGS are likely to be within one “tertiary coastal compartment” used to describe coastal sediment processes and pathways. Along the study area a total of 192 CGSs were defined. These are presented in Figure A-1.

A-1-2 Shoreline Classes

The eight major shoreline classes identified for the study area to support the assessment of coastal hazard impacts have been termed as follows:

- Hard rock cliffs and platform or beach
- Soft rock cliffs and platform or beach
- Bluffs or slopes with or without a platform or beach
- Low earth cliffed shorelines
- Open coast sandy shorelines, which includes beaches, sandy ridges, and dunes
- Estuarine sandy shoreline, including spit morphologies
- Estuarine and tidal channels, which includes the main body of Anderson Inlet, the inflowing rivers or creek mouths, drains and drainage lines
- Coastal wetland fringed shoreline

There is an additional class of shoreline class that has been applied to shorelines where there is an existing coastal structure. The structure may be formal or informal (e.g., a seawall) and are assessed individually.

Within each shoreline class, the various CGS’s represented contain some variations in lithology, evolution and physical processes operating on them but are considered likely to show similar responses and rate of change to sea level rise. The shoreline classes across the study area are shown in Figure A-2.

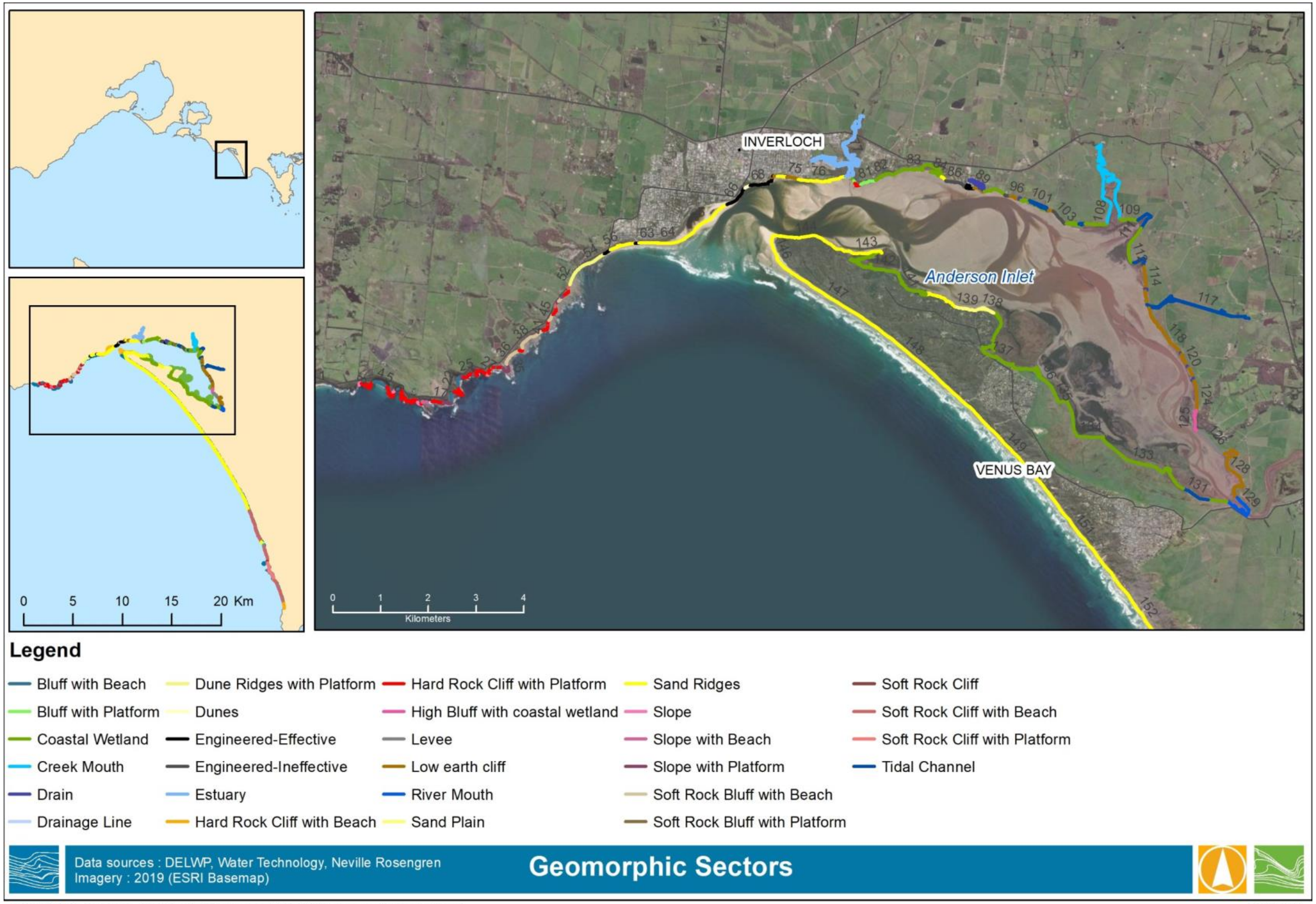

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FIGURE A-1 COASTAL GEOMORPHIC SECTORS IN THE STUDY AREA

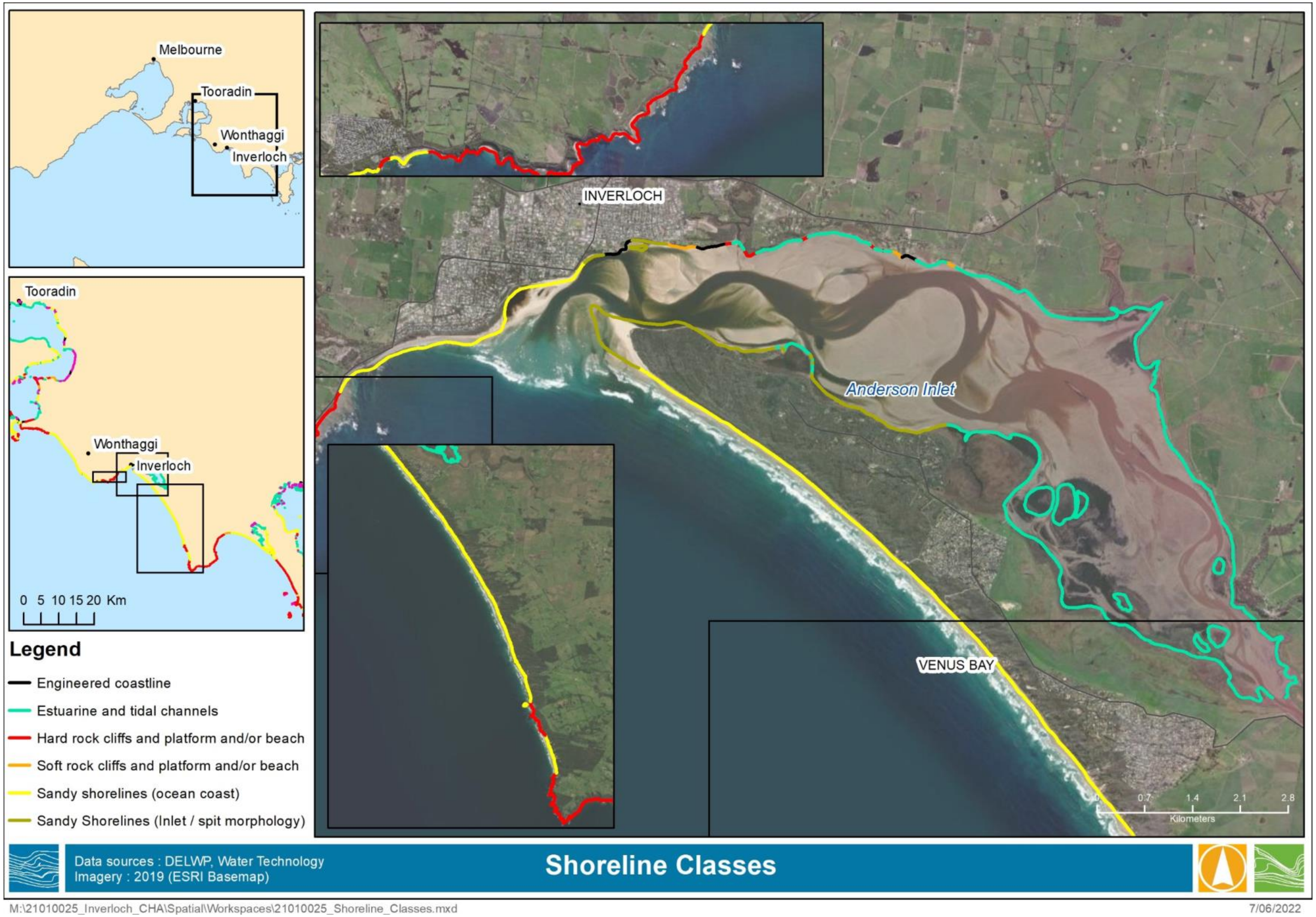


FIGURE A-2 SHORLINE CLASSES S IN THE STUDY AREA

A-2 Previous Shorelines

Rosengren (2021) identified a range of historic shorelines and probable processes which shaped Anderson Inlet and the surrounding ocean coastline. Much work has been done to classify coastal types, geomorphology and the drivers of geomorphologic processes to provide context for coastal erosion assessments.

An understanding of the development of the shoreline position and backshore landforms was presented by Rosengren, with change occurring over a range of spatial and temporal scales. The geomorphological assessment noted the dynamism of the geomorphological development of the coast which continues to present times.

This continual and varied change meant that defining a past stable coastal configuration which would assist predictions for future possible coastal forms was “challenging at best and highly uncertain” and “must be viewed within the context of the understanding and the insight gained from a historical geomorphic perspective”.

Thus, there is no firm position within the Study Area where it can be expected the coastline will migrate to over time, however the presence of a clear Last Interglacial Maximum shoreline was identified through the presence of numerous cliffs, terraces and bluffs above present sea level at a level of 5-7m AHD. Much of the material deposited below this level but above the present day sea level are Holocene and Pleistocene deposits from present and past tidal and fluvial processes.

Based on this, the position of the Last Interglacial Maximum shoreline was used in erosion calculations as the point where the current patterns and processes of erosion were likely to change. The position of the Last Interglacial Maximum shoreline as defined by Rosengren is presented in Figure A-3.

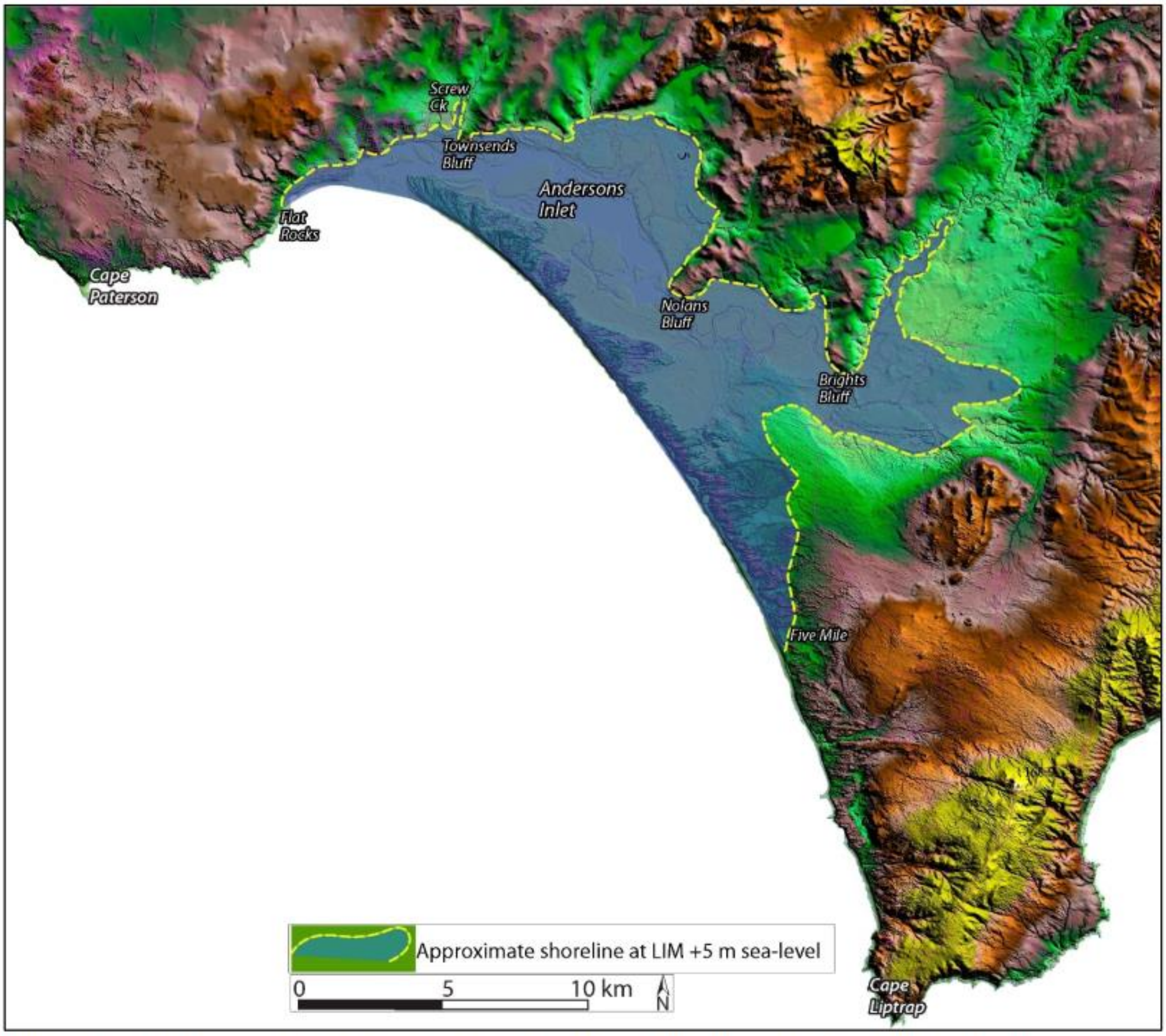


Figure 5. Generalised position of the ocean shoreline during the Last Interglacial Maximum The rapid sea-level rise post-17,000 years established open ocean conditions in west Gippsland and submerged the lower Tarwin valley. (Base image Vicmap 10 m DEM, Australian Bathymetry and Topography Grid, June 2009).

FIGURE A-3 LAST INTERGLACIAL MAXIMUM SHORELINE (ROSENGREN, 2021)

APPENDIX B
CLIMATOLOGY

B-1 Wind Conditions

A review of measured wind data from the Bureau of Meteorology (BoM) stations at Wonthaggi and Pound Creek (local stations), as well as Wilsons Promontory, Cape Schanck and Cape Otway (longer period) has been undertaken to identify the seasonal, annual and interannual change in conditions at Inverloch. The analysis includes a review of peak and average wind speeds annually, seasonally and from different directions to generate wave conditions within the entrance. Winds have been adjusted to consistent duration and heights using the Australian Standards AS 1170.

Winds from 2 global models – ERA5 and WW3 have also been extracted at a point offshore of Inverloch within Venus Bay and a similar analysis completed to assess windiness and patterns over the available hindcast period 1979 to 2020.

B-2 Atmospheric Pressure

Review of measured and modelled atmospheric pressure has been undertaken to establish the bounds and rate of change of atmospheric pressure in the Study Area. Atmospheric pressure directly influences water level through the “inverse barometer effect” such that a drop in atmospheric pressure results in a direct rise in still water level due to the reduced pressure pushing the water surface down.

B-3 Storm Events

The measured and modelled wind data has been reviewed for changes in “storminess”, i.e. the number of times wind speeds above a defined threshold that have continued for a substantial amount of time, and period where a rapid drop in atmospheric pressure indicates a significant low pressure front has occurred. The occurrence, frequency and pattern in storminess has been reviewed to identify where there are periods of more or less than average storminess and change in trends or averages.

Design wind speeds have been assessed at the different gauges and offshore sources. The limited the period of record and consistency of data of the local wind stations resulted in the Australian Standards AS1170 Design Wind Speeds being adopted for the modelling works completed for the study.

B-4 Climate Change Predictions

The predicted changes in climatology towards 2100 have been reviewed and the relevant aspects to the study, i.e. changes in wind speed and direction, wave conditions and rainfall/riverine flow used to assess sensitivity of the modelling tools. Predictions will also be used to test adaptation options.

APPENDIX C
OCEANOGRAPHY

C-1 Water Levels

C-1-1 Astronomical Tides

Measured water levels at Inverloch Jetty and Tarwin River have been used for calibration of a number of the numerical models. The measured water levels, collected by hydrographers Gippsland Ports, have been processed by the BoM Tidal Unit. The BoM has provided tidal constituents and tidal planes based on the data measured by Gippsland Ports from May 2020 (November 2020 for Tarwin River) through February 2021 and again from May 2020 through August 2021 with an update in late September 2021.

Water Technology recorded water levels at Inverloch, Lower Tarwin, Screw Creek and Venus Bay for other studies for a 4-6 week period in 2004. This data was used for validation of the Anderson Inlet model and captured a small flood event in June 2004. The tidal range and timing of the data captured in 2004 was compared with that collected more recently with close correlation observed.

Long term water levels have been measured at Stony Point in Western Port since 1993. The Stony Point water level was used in conjunction with offshore astronomical tidal boundaries for hydrodynamic boundary in the Ocean Model (Section E-2).

C-1-2 Residual Water Levels

The modelled hindcast offshore residual water level was analysed to review coincidence with wave storms and changes in storminess patterns in the Study Area. The length of storm surges was reviewed to generate a synthetic design storm tide for inundation and erosion mapping.

C-2 Wave Conditions

Waves have been measured offshore of Inverloch within Venus Bay and offshore of Wilsons Promontory by the VCMP since 2019. The data has been constantly reviewed and the updated recorded data used to inform the study and the shoreline response to storm events. However, this dataset is too short to establish long term patterns or design conditions within the Study Area.

The wave data at Inverloch during 2020 has been used to calibrate hindcast modelling by the University of Melbourne (as part of the VCMP) to develop wave conditions at high resolution along the Victorian coastline. The results of this wave model (based on the WaveWatch III modelling system) have been provided by the University of Melbourne and have been used in assessment of storm tide levels, sediment transport and storm erosion assessments. Calibration of the (University of Melbourne) wave model to the measured offshore data at both Inverloch and Wilsons Promontory are shown in Figure C-1 for the period of VCMP measurements (approximately 1 year). The results illustrate the model outputs at Inverloch and Wilsons Promontory. Wave roses illustrating the 202002021 VCMP measured wave data versus the 1981 – 2020 hindcast data are presented in Figure C-2.

Wave at the Inverloch VCMP buoy are almost completely from the southwest or west-southwest in line with the exposure to Bass Strait. Wave heights are typically less than 2.0m significant, with the larger waves above 3.0m from both the southwest and west-southwest. The VCMP buoy recorded smaller waves and a greater proportion of waves from the south-southwest through south-southeast during 2020-21 than the hindcast period. Peak wave periods are typically between 12 and 16 seconds at the buoy, with the observed period capturing significantly more lower peak periods, although the calibration data presented in Figure C-1 suggests the hindcast may over estimate the peak wave period. Model skill parameters are presented in Table C-1 and highlights this, with a RMSE for the peak wave period of 3.0 seconds and a bias of 1.5 seconds.

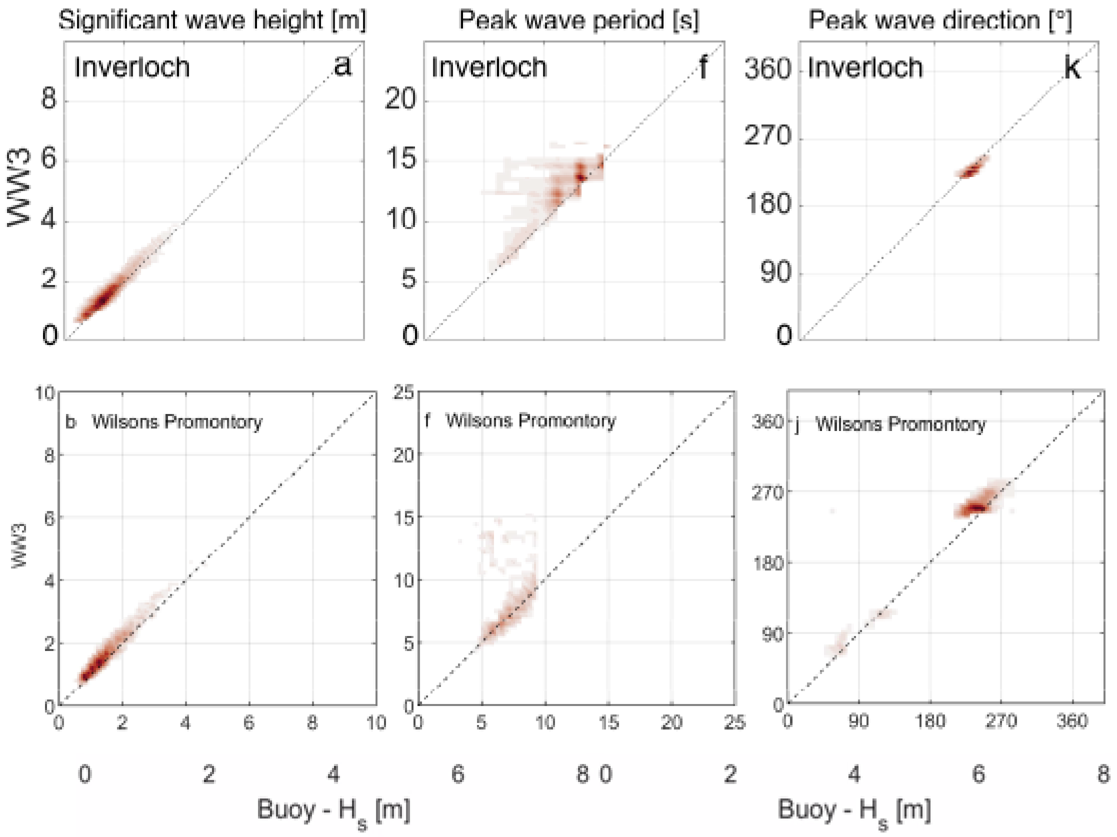


FIGURE C-1 COMPARISON OF MEASURED AND MODELLED WAVES, LIU 2021

Table C-1 Hindcast Wave Model Skill Parameters

Parameter	Correlation Co-efficient	RMSE	Bias
Inverloch			
Significant Wave Height (m)	0.95	0.26	0.14
Peak Wave Period (seconds)	0.53	3.04	1.46
Peak Wave Direction (degrees)	0.54	14.75	10.59
Wilsons Promontory			
Significant Wave Height (m)	0.96	0.29	0.1.8
Peak Wave Period (seconds)	0.60	3.13	1.23
Peak Wave Direction (degrees)	0.87	34.68	11.63

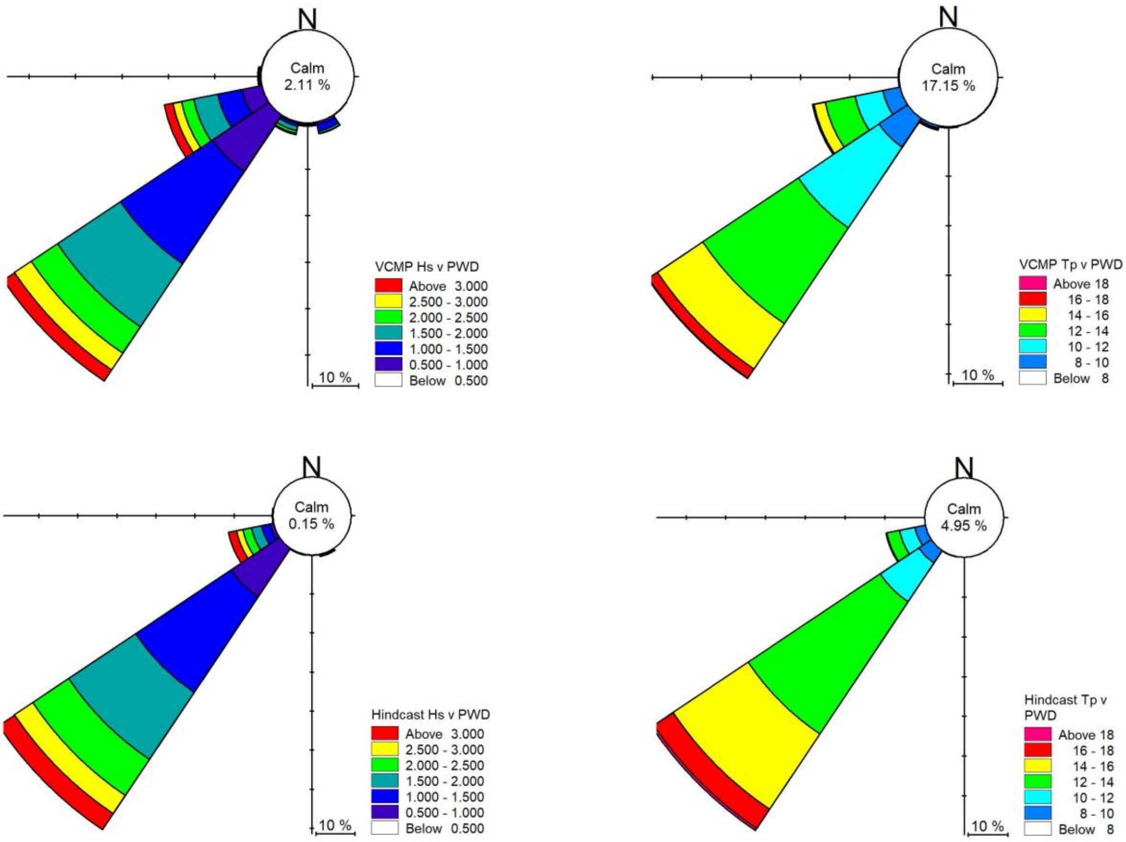


FIGURE C-2 VCMP OBSERVED (TOP) VERSUS UNIVERSITY OF MELBOURNE HINDCAST (BOTTOM) SIGNIFICANT WAVE HEIGHT (LEFT) AND PEAK WAVE PERIOD (RIGHT) IN VENUS BAY

APPENDIX D
DESIGN CONDITIONS

D-1 Design Water Levels

An extreme value analysis (EVA) of the 1981-2020 hindcast water level data was undertaken to establish design storm events. An "extreme value" approach has been used where independent storm events within the data record that peak at "extreme" values (typically defined as being 2 to 3 standard deviations above the mean) have been identified and concatenated into an "extremal" population.

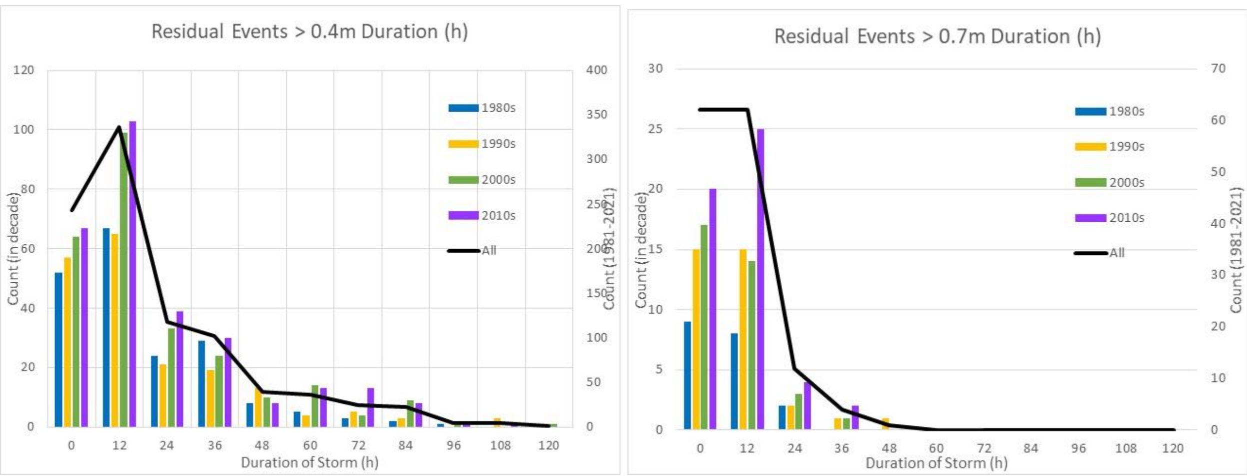
From here, an extreme value analysis was undertaken in order to determine the design conditions for a range of annual exceedance probabilities (AEPs). The peak design storm tide conditions offshore of the Study Area at the location of the VCMP wave buoy are presented below in Table D-1. The extreme water level based on the Stony Point measured water level is provided for reference.

Table D-1 Design Water Level Conditions

Design Event	Offshore Storm Tide (m AHD)	Stony Point Storm Tide (m AHD)
1% AEP	2.20	2.10
5% AEP	2.10	2.00
10% AEP	2.00	1.95

In order to develop a representative storm tide scenario that captured the critical temporal and spatial characteristics of storm tides in Venus Bay, further analysis of the water level hindcast was undertaken.

All storm surge events greater than 0.4m, 0.5m, 0.6m and 0.7m were extracted from the residual water level derived from the hindcast. The duration of each storm surge greater than each cut-off level was then calculated and a histogram of these durations is shown in Figure D-2. It can be seen that the water levels in the majority of large storm surge events in Venus Bay persist above 0.4m and 0.7m for approximately 6-18 hours. The number of storm events can also be seen to be greater in the second half of the 40 year record.



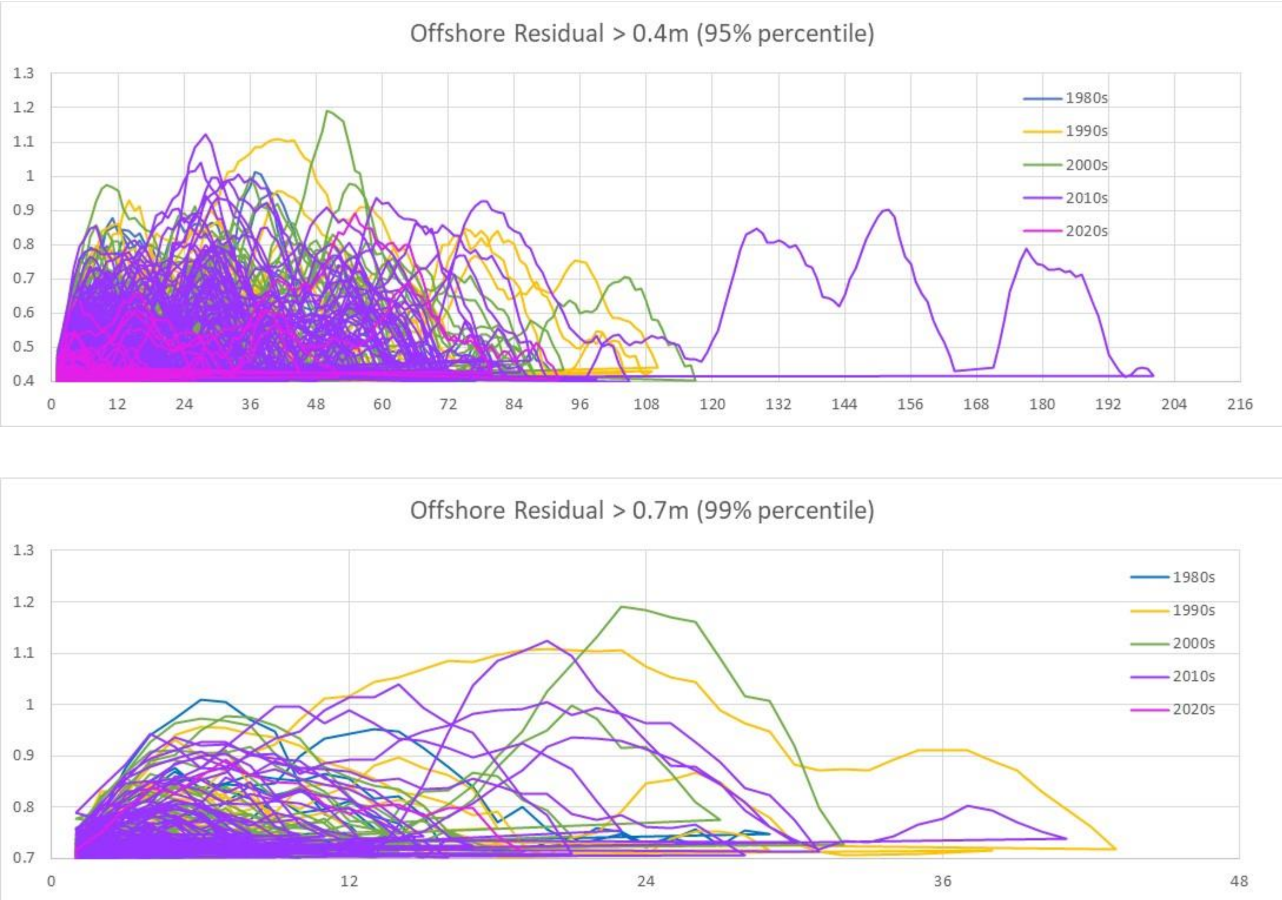


FIGURE D-1 ANALYSIS OF STORM TIDE RESIDUAL DURATIONS

To develop a design storm surge scenario with similar temporal characteristics as is observed from the hindcast, a simple cosine function was used to develop a synthetic storm surge which, when combined with the astronomical tide, produced a maximum water level height equivalent to the estimated 1%, 5% and 10% AEP storm surge height presented in Table D-1. The duration of the storm tide was developed considering the analysis above. A residual of 0.4m represents the 95th percentile of the storm tide residual and a duration of 53 hours above 0.4m is representative of the 90th percentile of storm durations. These parameters were considered reasonable for use at the Study site and similar to generation of storm tides simulated in previous CHA (Water Technology, 2014). They synthetic storm tide, including residual and tidal signal for the 1% AEP event is presented in Figure D-2.

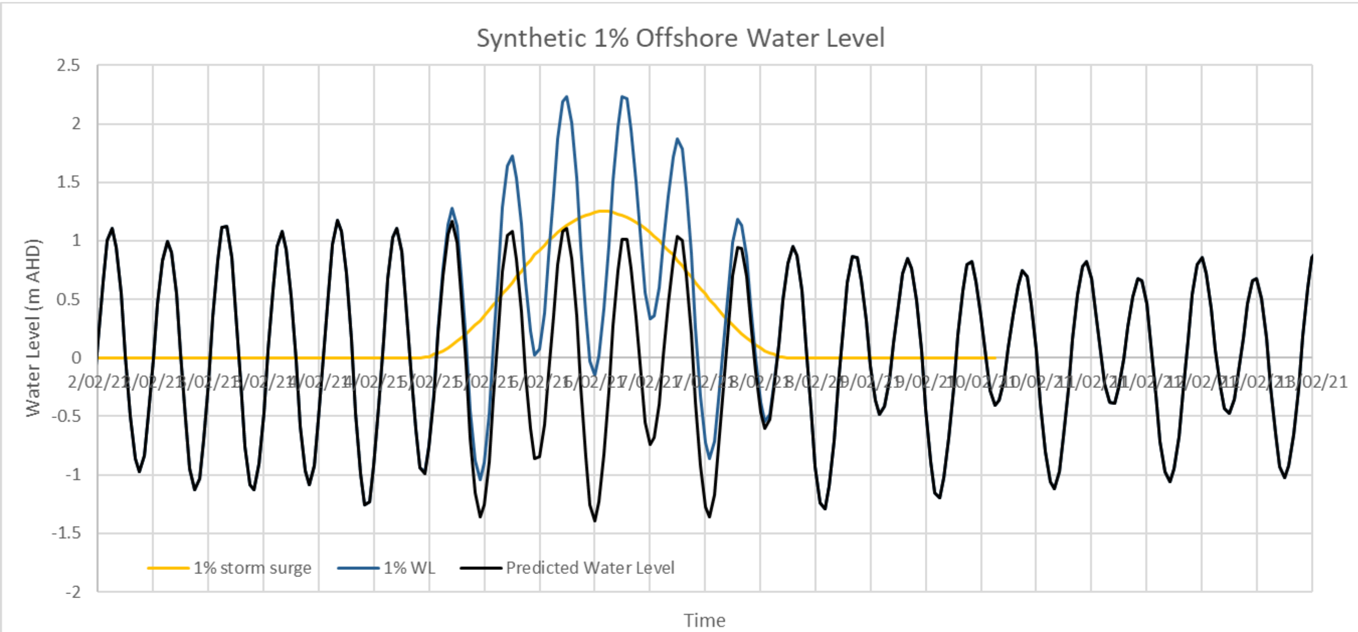


FIGURE D-2 DESIGN 1% AEP STORM SURGE AND STORM TIDE WATER LEVELS IN VENUS BAY

D-2 Design Wave Heights

An extreme value analysis (EVA) of the 1981-2020 hindcast wave data provided by the University of Melbourne was undertaken to establish design storm wave events. An "extreme value" approach has been used where independent storm events within the data record that peak at "extreme" values (typically defined as being 2 to 3 standard deviations above the mean) have been identified and concatenated into an "extremal" population.

From here, an extreme value analysis was undertaken in order to determine the design conditions for a range of annual exceedance probabilities (AEPs). Design storm waves offshore of the Study Area at the VCMP wave buoy are presented below in Table D-2. The 1% AEP significant wave height of 6.6m is similar to the 6.5 – 7.0m Hs 1% AEP provided for the waters offshore of Venus Bay by the Marine Energy Atlas, generated by the Australian Government *Australian Renewable Energy Agency* (ARENA) and CSIRO (Hemer, 2018) and accessed via the National Map data catalogue. Analysis and publication of wave conditions based on measured data along the Victorian coastline is rare. The Port of Melbourne wave buoy located near the entrance to Port Phillip Bay is the longest recording wave dataset for the nearshore Victorian waters (1993 – present, with gaps), however analysis of this data including extreme value analysis has not been published. It is noted waves of 6.5m significant have been observed in the data measured at the entrance to Port Phillip Bay (Advisian, 2016) during the period 2001 – 2013, however additional data is not available.

The highest wave measured at the VCMP Inverloch buoy is since deployment in 2020 is 5.82m, equivalent to around a 15% AEP based on the model hindcast. The highest wave predicted by the hindcast was a 6.5m Hs during the November 1994 storm, presented in Figure D-2. The 1994 storm event has been used as a template for the design wave used in modelling for this study.

Peak wave conditions are associated with strong fronts passing across the Southern Ocean from west to east. Likewise, high residual/storm surges are associated with storms passing through Bass Strait and as such, the wave and storm surges will be considered to be coincident, and the 1% AEP wave height will be combined with the 1% AEP storm tide, the 5% AEP storm tide with the 5% AEP wave and so on.

Table D-2 Design Wave Conditions

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

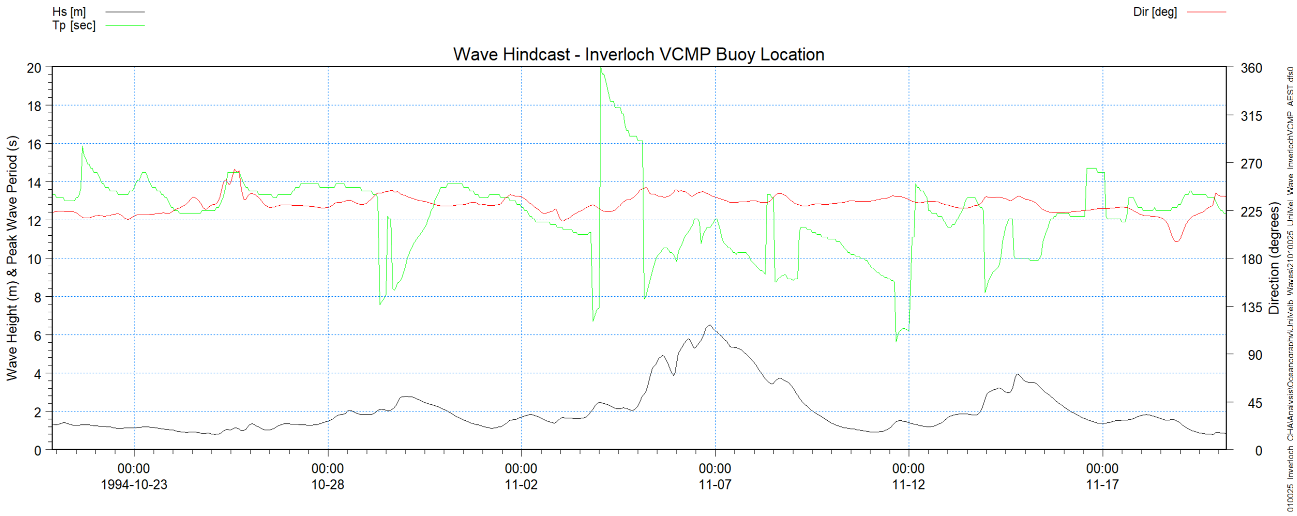


FIGURE D-3 DESIGN 1% AEP STORM SURGE AND STORM TIDE WATER LEVELS IN VENUS BAY

APPENDIX E
NUMERICAL MODEL DETAILS

Numerical modelling of the Study Area has been completed to provide knowledge and information to understand the coastal process, erosion and inundation across the Study Area coastline.

The modelling domains are presented above in FIGURE 2-3, and illustrate the five separate models developed to understand conditions within the Study Area.

E-1 Model Software

The Danish Hydraulic Institutes MIKE modelling system will be used to simulate hindcast and forecast conditions within the Study Area. Water Technology has used the MIKE modelling software extensively on similar coastal hazard studies and has existing models of the study area in the MIKE system. The modelling system is globally recognised as a robust and appropriate tool for assessing water levels, waves and sediment transport in coastal environments.

E-2 Ocean Wave Model

As identified in the Data Assimilation and Gap Analysis phase of the project, the University of Melbourne has undertaken global wave modelling with a high resolution, Victorian focussed downscale hindcast developed through the VCMP. The hindcast provided wave conditions at around 500m intervals along the coast of the study area, approximately 1km offshore. Additional details regarding the model can be found in Liu (2022).

Hourly wave parameters shown in Table E-1 have been extracted along the coast at locations presented in Figure E-1. The depth of the data points is shown in red, green, blue and pink. The points have provided the offshore wave conditions for the shoreline response models SBEACH and LitPak.

The hindcast wave record has also been used to establish design events for wave conditions as described in Appendix D to be combined with design water levels as per Table 2-2.

Table E-1 Wave Hindcast Parameters

Parameter	Unit
Significant wave height, H_s	m
Wind wave height, PH_{s0}	m
Primary swell wave height, PH_{s1}	m
Secondary swell wave height, PH_{s2}	m
Mean Period, T_{02}	s
Peak frequency, f_p	s^{-1}
Mean wave direction, Dir	degree
Peak wave direction, D_p	degree
Wind speed vectors, Wnd	m/s
Wind wave energy flux	Kw/m

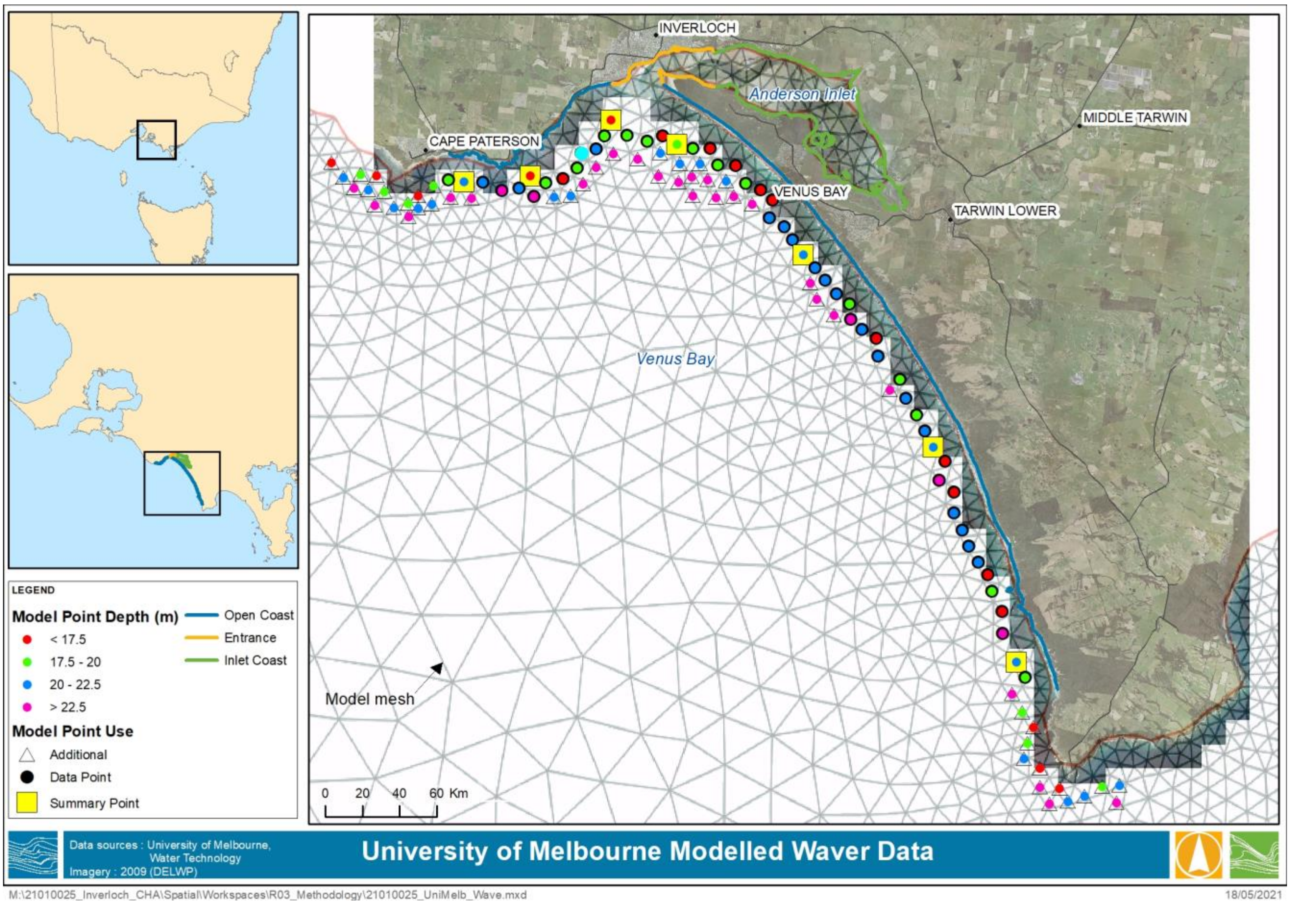


FIGURE E-1 LOCATION OF WAVE HINDCAST DATA POINTS

E-3 Ocean Hydrodynamic Model

A schematic of the Ocean Hydrodynamic Model is presented in Figure E-2.

E-3-1 Modules

The model hindcast of water levels and currents along the study area coast will use the hydrodynamic module of the Mike21 Flexible mesh modelling system.

E-3-2 Domain

The hydrodynamic ocean model domain extends across Bass Strait from west of Western Port to east of Wilsons Promontory as shown in the top left inset of Figure E-3. The model domain allows a higher resolution model mesh along the coastline to be included without compromising project timelines. The resolution of the model along the coast is presented in Figure E-3, main window. Nearshore mesh resolution is in the order of 200-300m whilst offshore is in the order of 3km.

The model bathymetry has been generated using the FutureCoast DEM, supplemented by the GeoScience 250m DEM below the extent of the FutureCoast DEM – approximately for bed levels below -20m AHD.

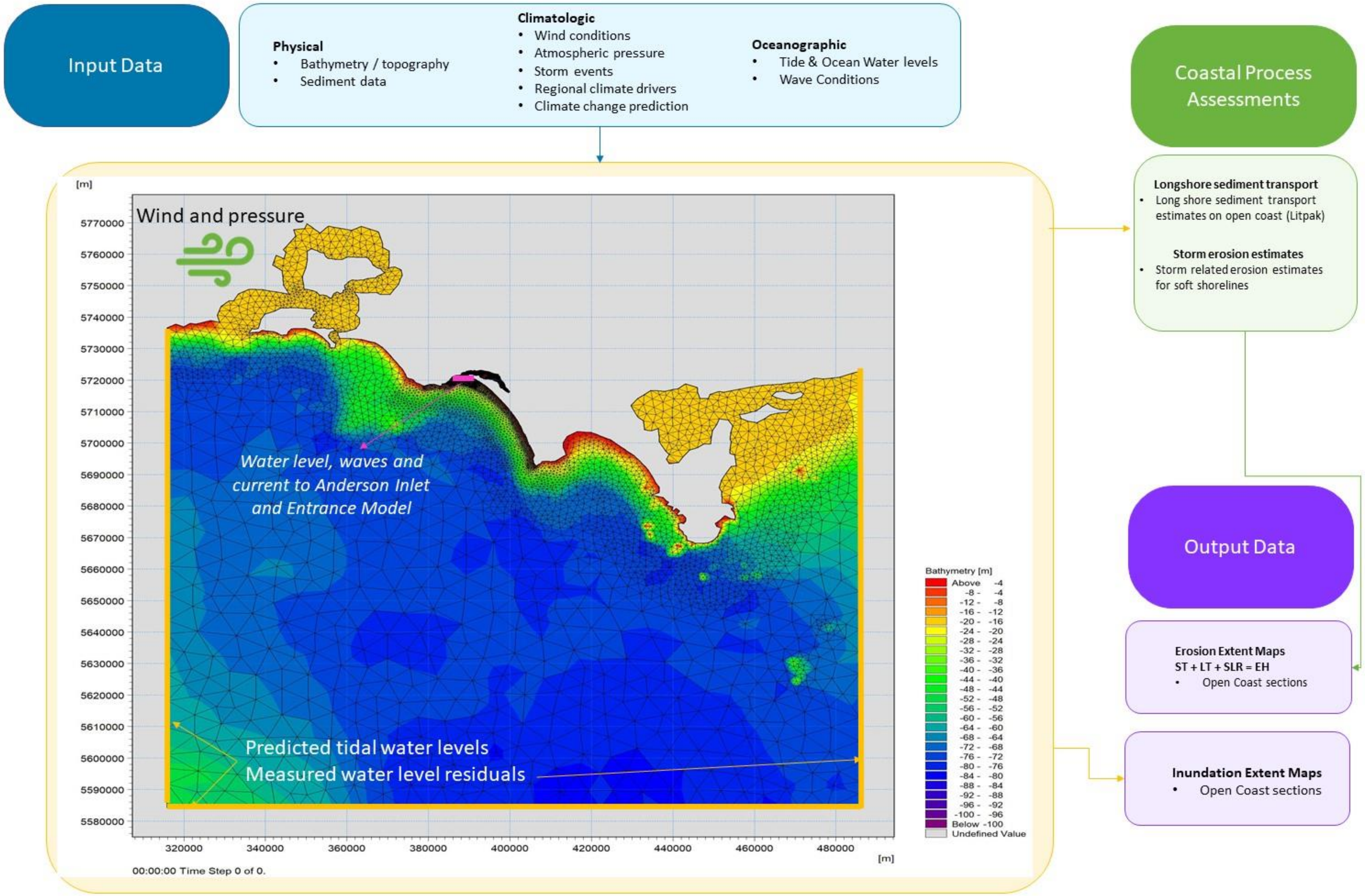


FIGURE E-2 OCEAN HYDRODYNAMIC MODEL INPUTS/OUTPUTS

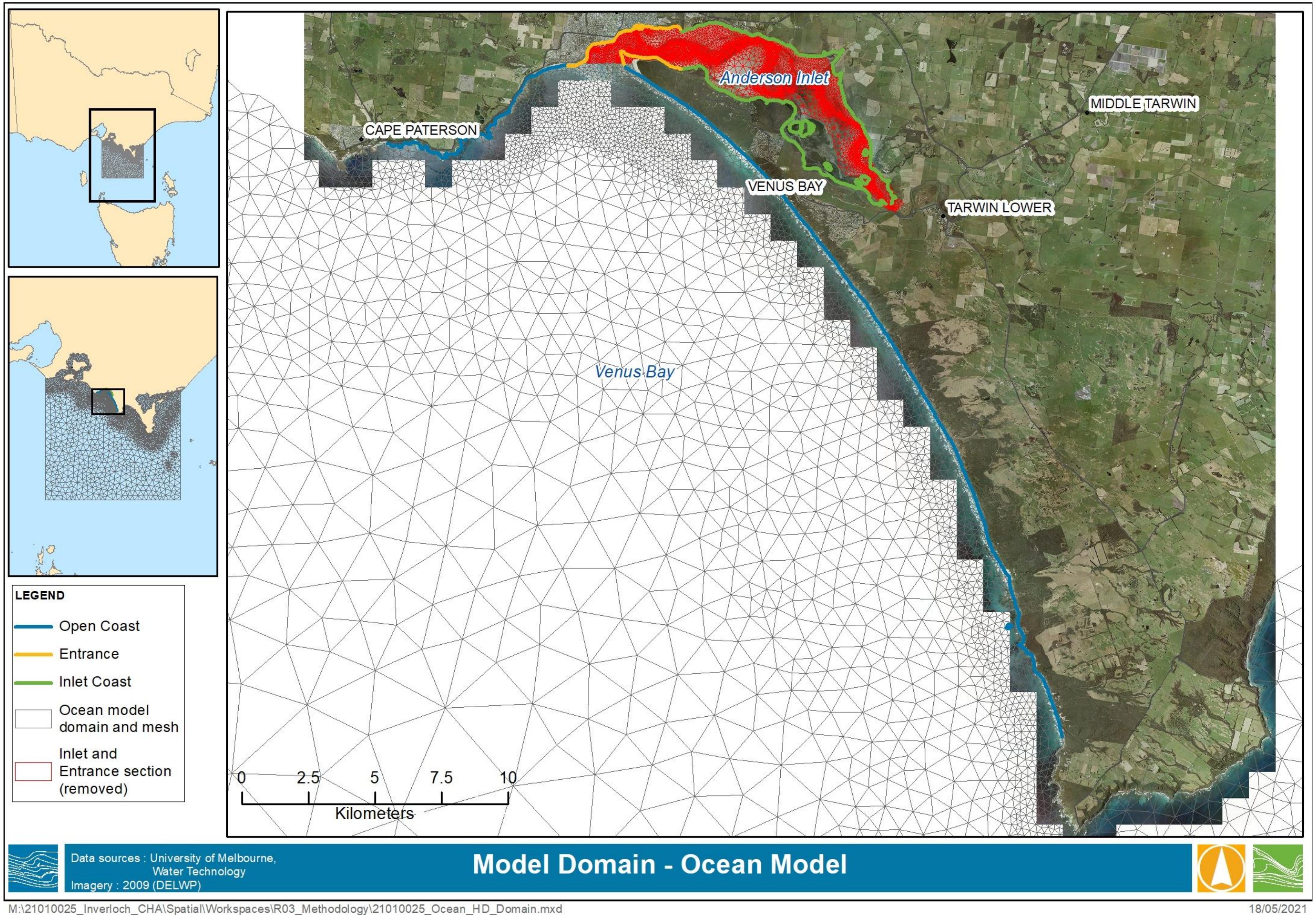


FIGURE E-3 OCEAN HYDRODYNAMIC MODEL DOMAIN

E-3-3 Model Development

The lack of available measured data in the coastal waters between Stony Point and Port Welshpool (east of Wilsons Promontory) resulted in verification of the ocean model to water levels measured within Anderson Inlet. Calibration of the model was completed to astronomical tides, predicted at Stony Point, Inverloch and in the offshore waters of East Mancour Island (15km southeast of Wilsons Promontory).

To enable the calibration of tidal hydrodynamics and verification to the measured water levels at Inverloch Jetty, the model domain extended into Anderson Inlet and the modelled and predicted or measured water levels at Inverloch Jetty compared.

The storm surge component of the total water level at the Inverloch Jetty was observed to be closely correlated to that measured at Stony Point (Figure E-3) and thus the storm tide component of the water levels within Venus Bay were also considered to be likely to be closely correlated with Stony Point and Inverloch Jetty.

The addition of Anderson Inlet to the Ocean Model significantly increased computation run time with the finer elements used to represent the entrance channels. Whilst run times were acceptable for the calibration and verification, Anderson Inlet was removed from the model domain to run the 40 year hindcast to simulate offshore water levels in Venus Bay. The hydrodynamics within Venus Bay were compared for the calibration period with and without Anderson Inlet in the domain to ensure the removal of the Inlet would not impact ocean water levels.

E-3-4 Boundary Conditions

Tides

The DHI tidal boundary tool has been used to generate predicted spatial and temporally varying tides along the model boundary within Bass Strait to simulate a 40 year hindcast from 1981 through 2021. This tool uses the DTU Global Tide Model to generate predicted tides on the model boundary. The tidal boundary was added to the model at a six minute interval whilst the model used a 10 minute timestep for calculations.

Residual water levels have been added to the model using measured data from the ABSLMP Stony Point gauge. Residual water levels measured at Stony Point are similar to those measured at Inverloch Jetty as displayed in Figure E-4 (noting the overlap of measurements is limited to the recent period from November 2020 through April 2021 which does not include any significant storm events) Good calibration can be achieved using the Stony Point residual data on all boundaries due to the relatively small model domain and dominance of residuals travelling from west to east through Bass Strait past the Study Area. The difference between the residual at Inverloch and Stony Point is, on average, around +0.02m in favour of Inverloch, although this does differ across the concurrent measurement period from May 2020 through February 2021 such that the difference in the residual is greater at Inverloch through the first half of the record (+0.05m) compared with the second half (+0.01m). This could be an annual cycle or limited to the measured period.

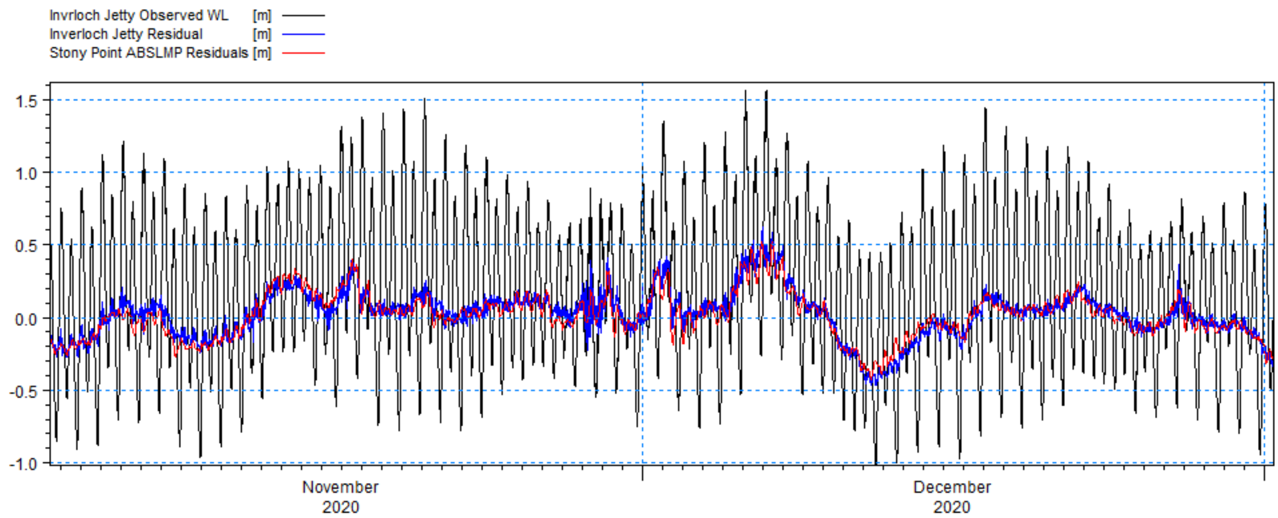


FIGURE E-4 TIDAL RESIDUALS MEASURED AT INVERLOCH JETTY AND STONY POINT

Wind

Wind and atmospheric pressure data has been extracted from the ERA5 global model and used as a spatially varying map of speed and pressure across the hydrodynamic model domain. The spatial and temporal resolution of the ERA5 model (0.25 degree ~ 27km, and 1 hour respectively) is considered sufficient to generate local wind and pressure fields within Bass Strait. The ERA5 global model provides atmospheric forcing from 1981 through 2021.

Bed Roughness

Bed roughness was set in offshore waters to a Manning's n = 0.05, in the range typical for nearshore and ocean applications. The bed resistance was decreased to n = 0.028 through the entrance channels within Anderson Inlet to the Inverloch Jetty tide gauge where measured data was used to verify the model performance.

E-3-5 Calibration and Verification

Calibration

The astronomical tidal signal at the Inverloch Jetty has been derived from measured water levels at Inverloch Jetty. Calibration of the model has been undertaken for the period of November – December 2020 when survey of the entrance channel was collected in conjunction with recording of measured water level at the Inverloch Jetty. Calibration details are provided in Figure E-4 for Inverloch Jetty with additional scatter plots showing the good correlation of astronomical water levels at Stony Point in Western Port and at East Moncoeur Island, located 15km southeast of Wilsons Promontory.

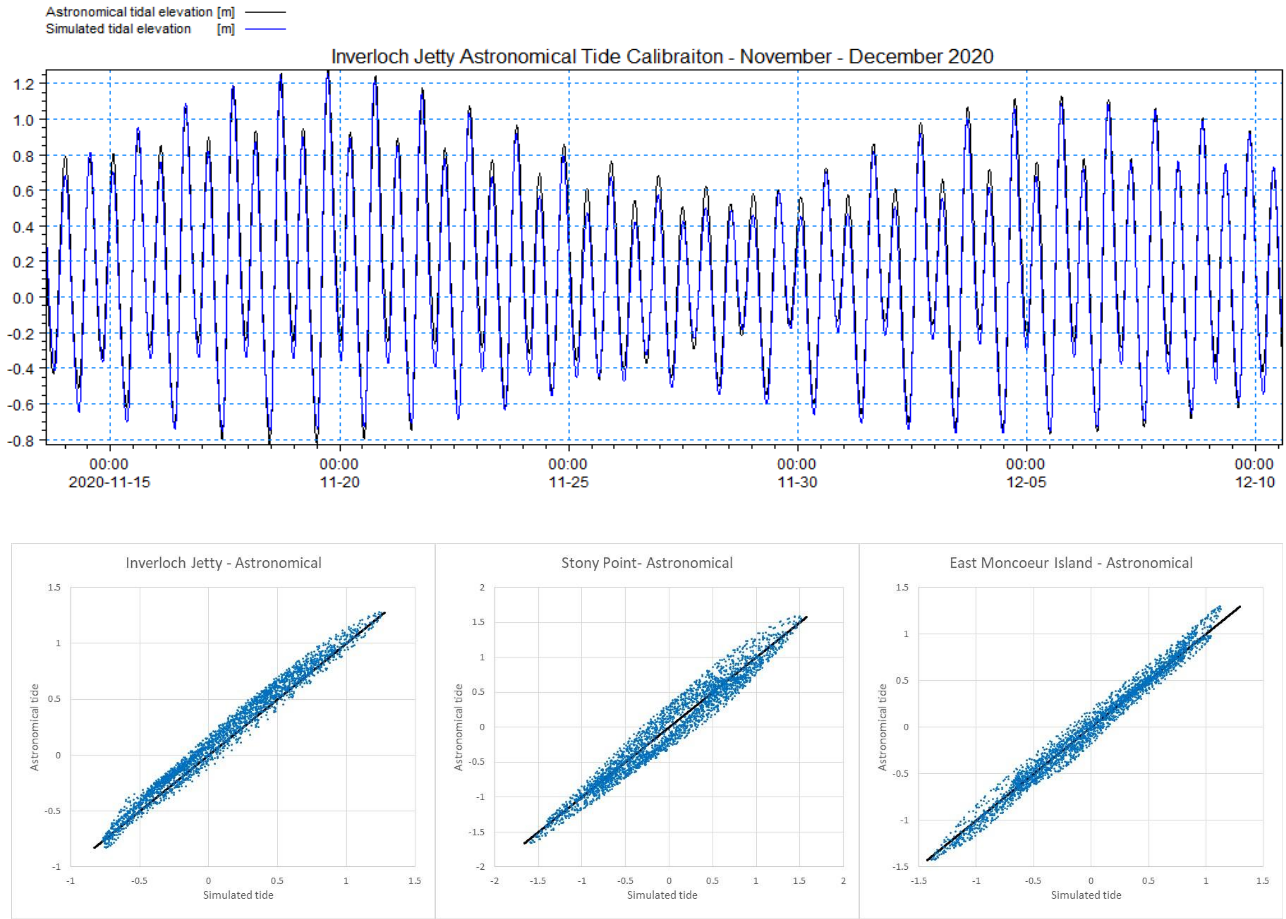


FIGURE E-5 OCEAN MODEL ASTRONOMICAL TIDE CALIBRATION

Verification

Following calibration to astronomical tidal conditions, the tidal residual measured at Stony Point as added to the water level model boundaries, along with wind forcing from the ERA5 hindcast. Modelled water levels at the Inverloch jetty have been compared to measured data for November 2020 and the residual water level input (e.g., averaging of the Stony Point residual) refined until good calibration was achieved. Other model parameters were not adjusted from the astronomical tidal model setup. Model validation details are provided in Figure E-6.

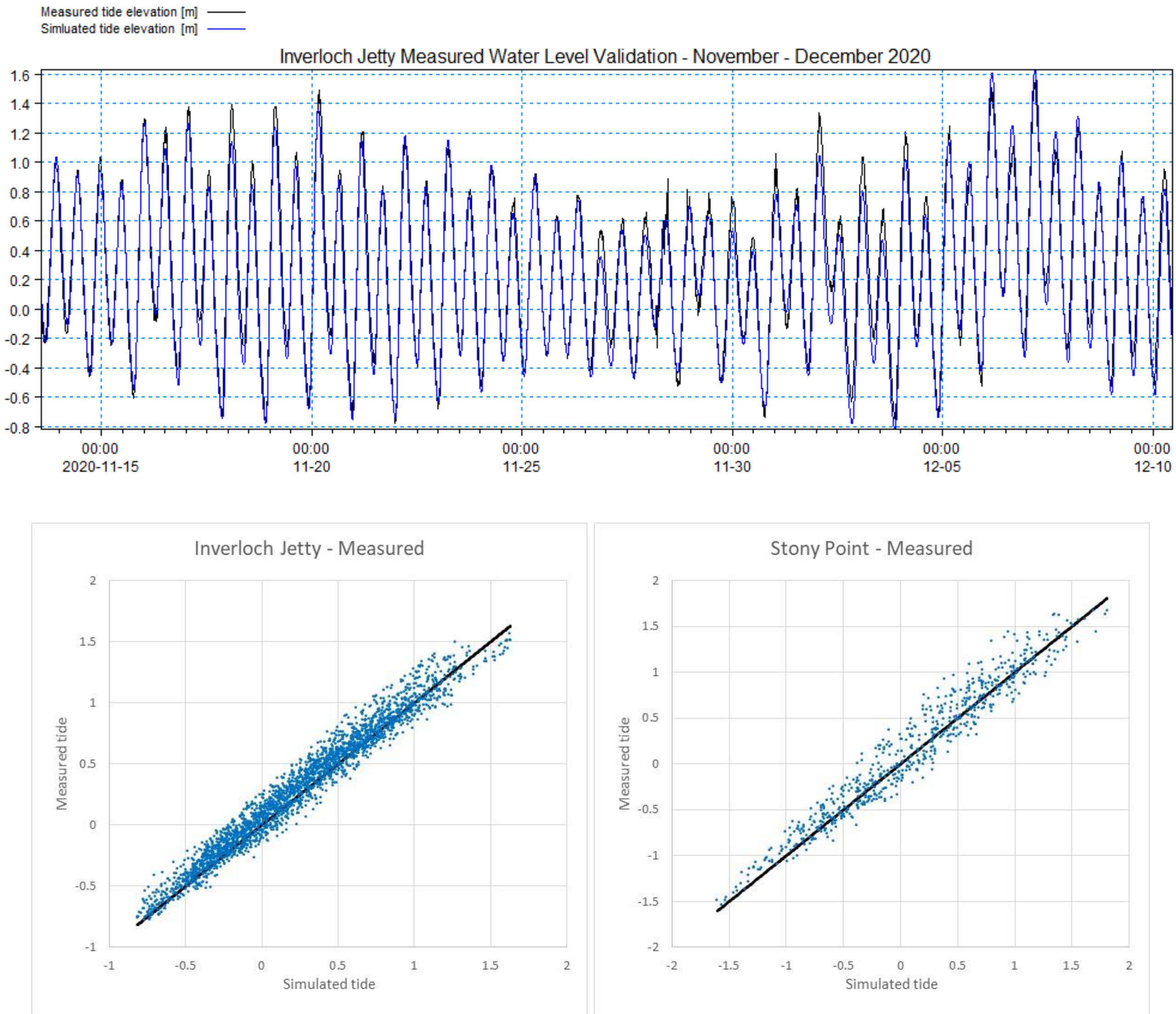


FIGURE E-6 OCEAN MODEL MEASURED WATER LEVEL VALIDATION

E-3-6 Hindcast

The calibrated hydrodynamic model has been simulated from 1981 through to 2020 to generate a hindcast of water levels within Venus Bay.

The hindcast water levels have been used to establish design events for water levels as described in Appendix D to be combined with design wave conditions as per Table 2-2.

E-3-7 Coupled Wave and hydrodynamic Ocean Modelling

As noted, hindcast wave conditions have been provided by the University of Melbourne (Appendix C-2). Unfortunately, the wave hindcast data is only available until December 31, 2020, and does extend through to the end of April 2021 when the high resolution and full coverage of the entrance bathymetry was captured.

The survey of April 2021 provides the most up to date depiction of the entrance available for the study, and as such a coupled spectral wave and hydrodynamic version of the Ocean Model was generated which covered the period of November 2020 through April 2021 to provide boundary conditions for the Anderson Inlet and Entrance models where simulations are required for analysis of conditions post 2020.

The coupled Mike21 Ocean Model has the same domain and mesh resolution as the hydrodynamic hindcast model described above and is driven by ERA5 winds, DHI astronomical tides, Stony Point water level residuals and WW3 boundary conditions. It is noted these boundary conditions result in a slightly different wave climate than that provided by the University of Melbourne and thus the resultant wave conditions along the coast show minor variations for the single overlapping month of simulation in 2020. However, the coupled model provides a good representation of offshore wave conditions as presented in the comparison of measured and modelled wave data shown in Figure E-7.

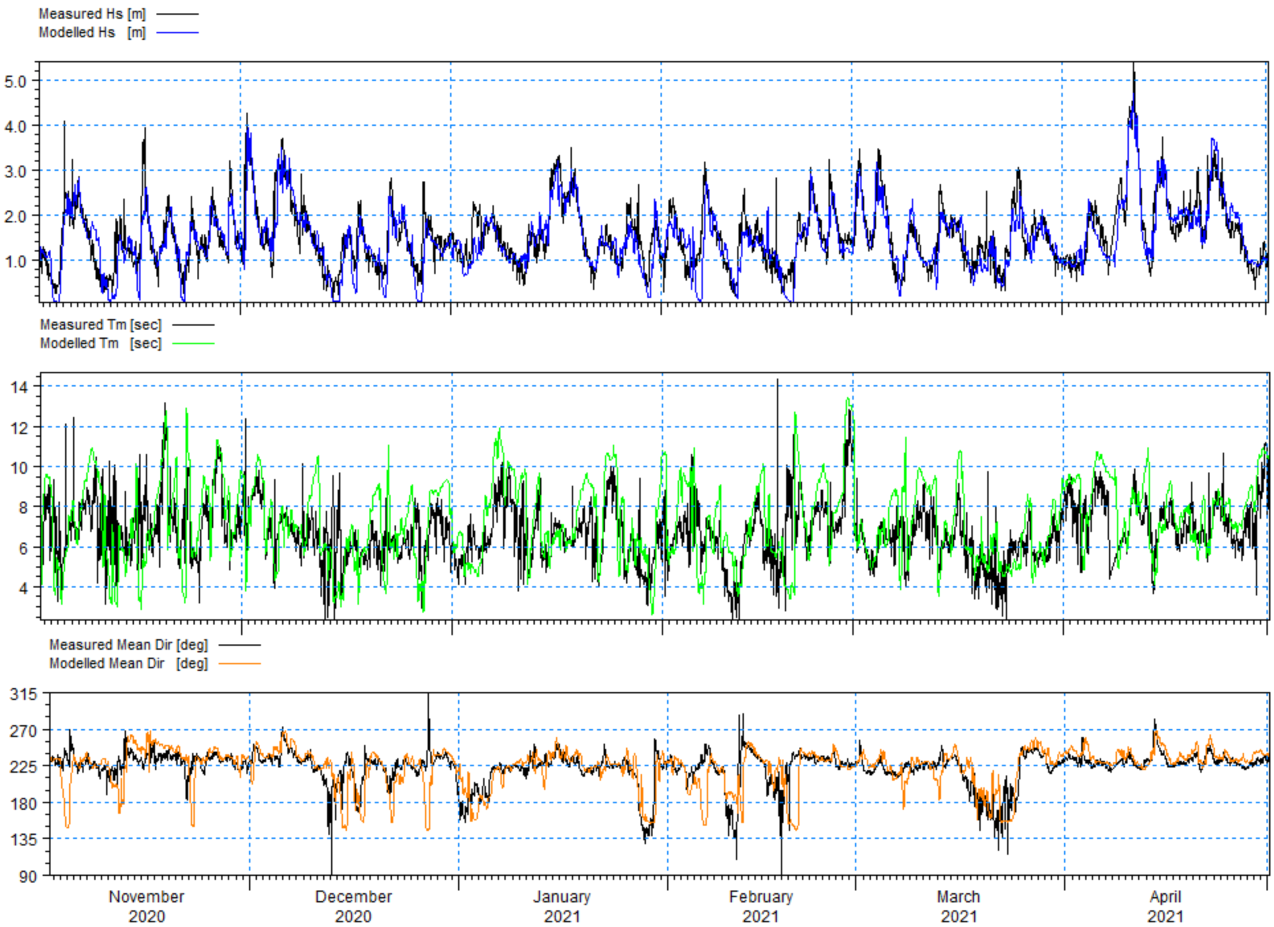


FIGURE E-7 VERIFICATION OF COUPLED WAVE AND HYDRODYNAMIC OCEAN MODEL WITH MEASURED WAVE DATA

E-4 Anderson Inlet Hydrodynamic Model

The ***Anderson Inlet Model*** has been generated to simulate the hydrodynamic movement of water within Anderson Inlet from offshore of the entrance at Inverloch in Venus Bay through the Inlet and upstream of Tarwin Lower in the Tarwin River.

The model will be used for 3 key purposes:

1. Generate storm tide inundation overlays for existing and future design storm events (including input from fluvial flows);
2. Provide hydrodynamic boundary conditions for the Inverloch Urban drainage model; and
3. Provide hydrodynamic boundary conditions for a high-resolution numerical model assessing morphology within the entrance to Anderson Inlet.

A schematic of the Anderson Inlet Model is presented in Figure E-8.

The purpose of the model is to provide input into the CHA to define **coastal risks**. The model may be supplemented in the future by an updated Flood Study of the Tarwin River or Inverloch Urban Drainage Assessment to define flood risks from rainfall.

The quality and accuracy of a numerical model is heavily dependent on the data available to build the model inputs. A *Data Assimilation and Gap Analysis* was completed as part of the CHA (R02) which details the data available for the study, identifies data gaps and the outcomes associated with these data gaps.

Some data gaps were identified which were unable to be filled and have resulted in missing, older or incomplete data to be used in the generation of the Anderson Inlet model. Missing, outdated or older data does not invalidate the outcomes of the model, however these gaps should be noted as they may need to be considered in the interpretation and use of model results.

Key data gaps, and the impact on modelling of Anderson Inlet are described in Table E-2. Where relevant, these gaps are referred to within the model setup, calibration and results sections of this Appendix.

Table E-2 Data Gaps of the Anderson Inlet model

No.	Data Gap	Details	Impacts
1	Bed survey of Anderson Inlet	New bathymetric survey of the entrance was captured for the project in April 2021. Survey of the main channel from the entrance to Anderson Inlet was captured by Gippsland Ports in November 2020. Survey of the intertidal areas and low lying floodplains of Anderson Inlet has not been completed since the FutureCoast LiDAR capture in 2009	It is assumed that the intertidal floodplain has remained at a constant level since 2009. It is clear this is an incorrect assumption in some areas due to the changes in vegetation cover, however no data is available to reliably (and consistently) update the survey data. Flooding and drying of the intertidal areas may vary from actual, however the levels are not likely to be significantly higher in the majority of the Inlet and variance are likely to be minimal and more localized to areas of higher vegetation.
2	Offshore measured water levels	Offshore measured water levels are not available within Venus Bay.	A hindcast model of eastern Bass Strait has been used to drive water levels and hydrodynamics into Anderson Inlet as described in Appendix E-2. The Ocean model was calibrated to water levels at Inverloch in 2020 and used to generate water levels offshore from 1981-2021. The hindcast water data offshore has then been used in the calibration of the Anderson Inlet model.

No.	Data Gap	Details	Impacts
3	Limited concurrent data	The entrance channels vary significantly over a short period and can impact hydrodynamics within the entrance. Change in entrance configuration is observed between survey in November 2020 and April 2021. Measured water level data at Inverloch for calibration around the April 2021 survey is limited due to data recording failure.	Some calibration of the model was completed a period prior to survey of the entrance bathymetry used in the model. Ideally calibration would occur with concurrent datasets, however this was not possible, however general hydrodynamic properties will be consistent.
4	Measured current speeds	Measured current speeds within the flow channels are not available.	Given the purpose of the model (storm tide inundation), the calibration of the model to current speeds is not critical, however, if possible, future works should include measurement of current speeds across a spring tide, concurrent with bed survey and Inlet and offshore water levels.
5	Spatially varying wind data	Wind data is measured locally at Pound Creek, north of Anderson Inlet. Wind may vary spatially around the inlet and across the high Venus Bay dunes onto the inlet.	Assessment of the wind sensitivity to direction was completed for the final results.
6	River Inflows	Measured data is not available for Pound or Screw Creeks and not in the lower part of the Tarwin River	Gauged data on the Tarwin River is available at Meeniyan, approximately 40km upstream. Flows have been scaled to the model boundary at Tarwin Lower, however cannot be verified by measured data. Flows from Pound Creek and Screw Creek will have a minor impact on coastal hazards compared with the storm tides. Pound and Screw Creek flows have been based on scaled flows at Lower Tarwin.

E-4-1 Model Domain

The model domain extends across the Inlet and upstream of Lower Tarwin. The model domain and bathymetry are presented in Figure E-9. The focus of the model is Anderson Inlet and the tidal and fluvial floodplains upstream of the entrance where the shoreline and channels are less dynamic. The model domain extends offshore to enable simulation of tides and storm surges into the entrance.

The floodplain surrounding Anderson Inlet is low, with levee banks in many areas preventing regular flooding or inundation under existing conditions.

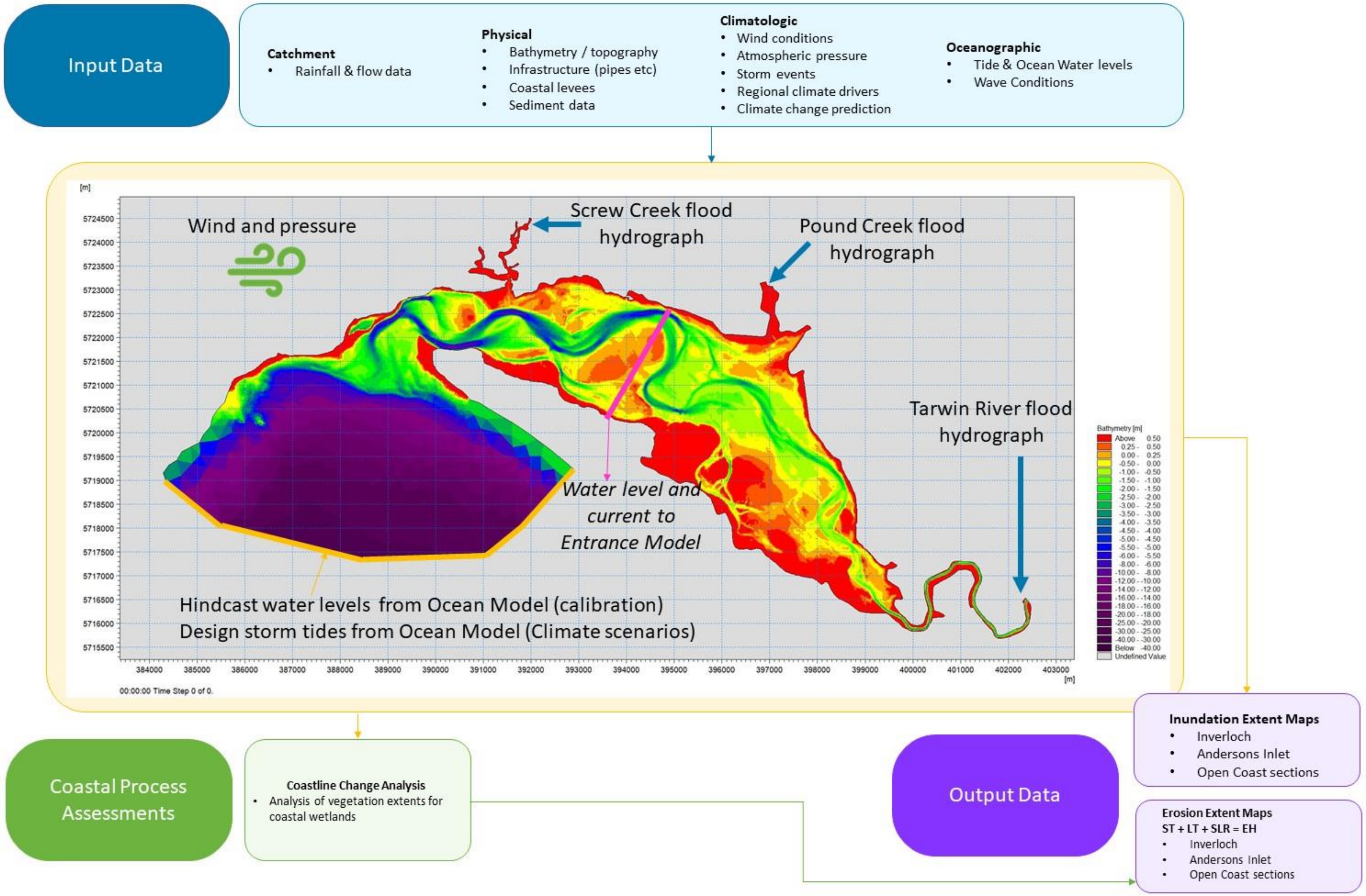


FIGURE E-8 ANDERSON INLET MODEL INPUTS/OUTPUTS

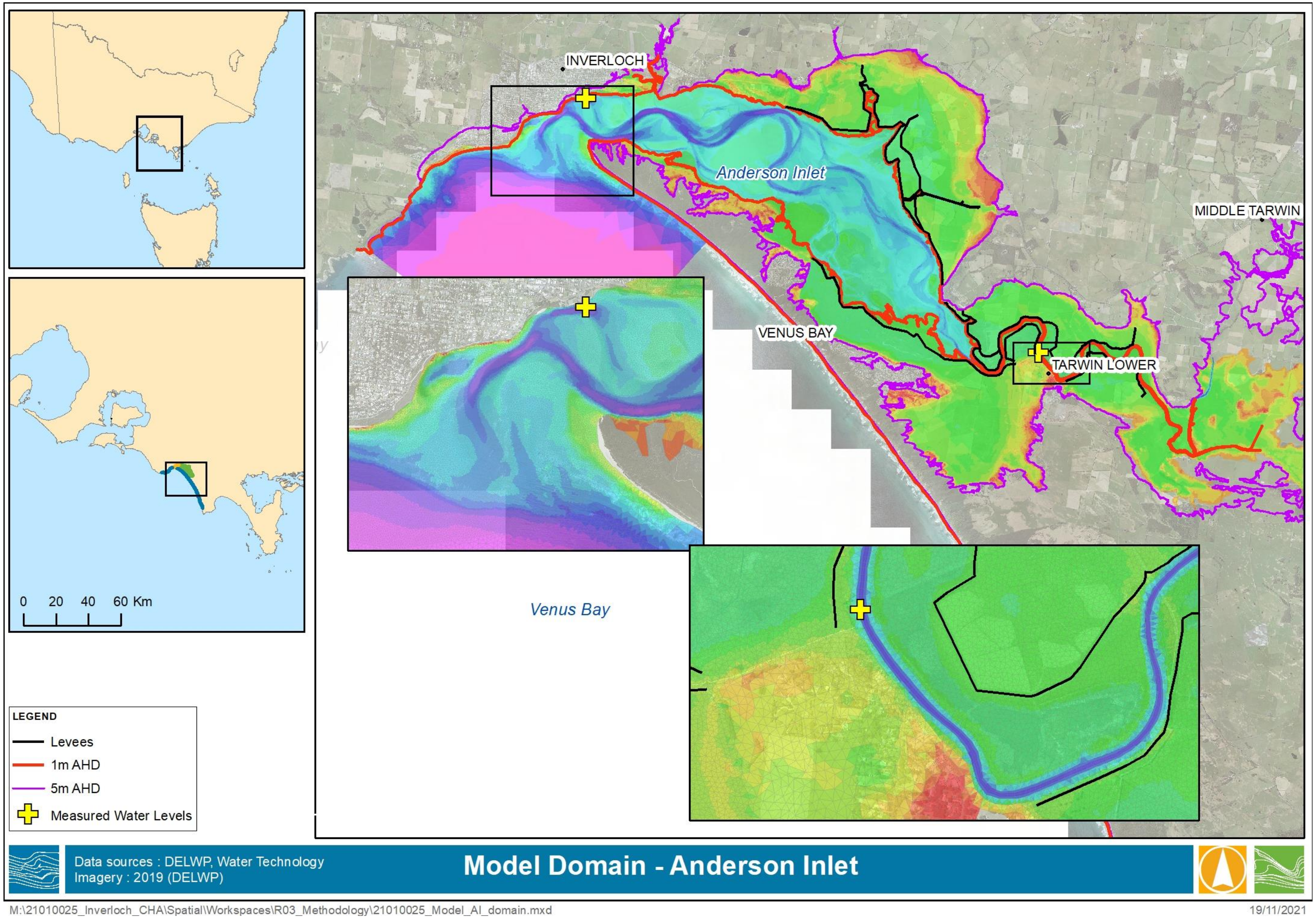


FIGURE E-9 ANDERSON INLET MODEL DOMAIN

E-4-2 Model Mesh and Bathymetry

The bathymetry of the model along the coast is presented in Figure E-9, main window, with highlight boxes showing the model at the entrance and Tarwin Lower. The mesh resolution is in the order of 10-20m side lengths across the domain and at least 4 elements (10-15m width) are maintained within the channel of the Tarwin River. Levees are added to the model using the model structure function which allows xyz points to be defined as a breakpoint across the model mesh. The resolution of the levee xyz file is 1m horizontally, extracted from the 2013 LiDAR DEM which has a vertical accuracy of +/-0.1m and a horizontal accuracy of +/-0.3m.

The model bathymetry has been generated using the FutureCoast DEM, supplemented by the hydrographic survey captured by Gippsland Ports in 2020 (Tarwin River channel) and 2021 (Anderson Inlet Entrance).

E-4-3 Boundary Conditions

Offshore Water Level

A water level boundary was extracted from the coupled wave and hydrodynamic ocean model along the offshore boundary and used to force tidal hydrodynamics into Anderson Inlet for calibration and validation.

The synthesised storm tide (Appendix D) was used for the production runs. An example showing the design 1% AEP storm tide is presented in Figure E-10.

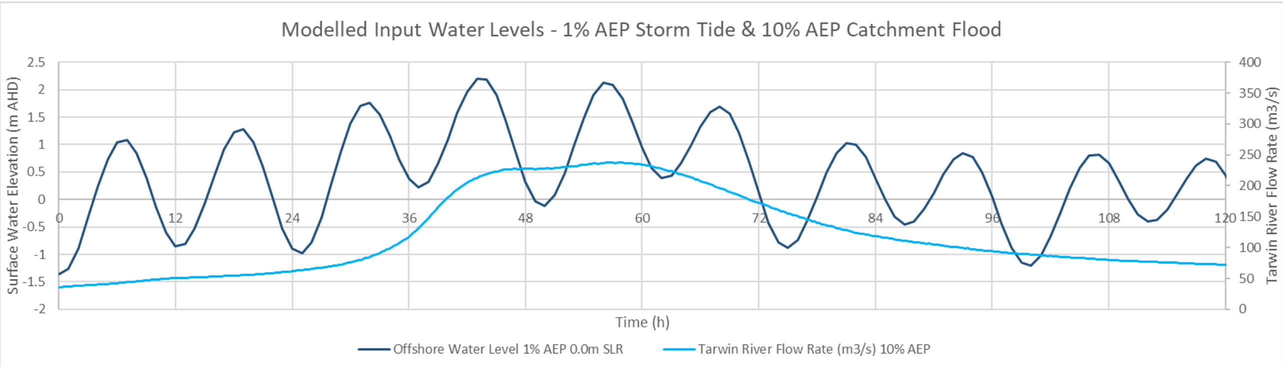


Figure E-10 Synthesised Storm Tide Boundaries and Flood Events

Tarwin River

Flow hydrographs from the Tarwin River, Pound and Screw Creeks have been generated as part of the Study (Section 3.4). The hydrological analysis has been used to scale the Tarwin River @ Meeniyan gauge which allowed generation of local hydrographs from 1955 through to 2021, including the June 2021 storm event which occurred during the modelling works.

Design flow hydrographs have been generated for the Tarwin River, Pound and Screw Creeks as described in Section 3.4.1, and presented in Figure E-10 (for the design 10% AEP flood event) Coincidence of catchment flooding and storm tides are discussed further in Section E-4-7.

Wind

The Climatology review has assessed available measured and modelled wind data within the Study Area. Design winds used within the Anderson Inlet model to simulate water level setup are generated using the Australian Standards Wind Load Codes due to the limited duration of the high quality data recorded at Pound

Creek and the different exposure recorded at Wilsons Promontory or Wonthaggi. Sensitivity of flood levels to wind speed and direction are discussed further in Section E-4-7.

Waves

There is no recorded wave data within the Inlet and it is assumed that swell wave energy does not penetrate the entrance. This was tested using the finer resolution Entrance Model which indicated that waves were highly dissipated across the entrance channels and bars and had little influence on conditions upstream of Inverloch.

Bed Roughness

Bed roughness has been used as a calibration factor and was adjusted through the calibration process. Vegetation classes have been generated using spatial analysis of satellite data across the model domain with Mannings n values ranging from 0.05 – 0.025 in the sandy estuary and offshore and up to 0.10 where heavy vegetation is observed in the aerial imagery.

E-4-4 Calibration

Calibration

The Anderson Inlet model has been calibrated to water levels measured at the Inverloch and Tarwin Lower jetties, collected by Gippsland Ports in 2020-2021. The location of model boundaries and bed roughness through the Inlet channels and across the sandy tidal banks and mangrove margins to Tarwin Lower have been refined to calibrate the hydrodynamics of the Anderson Inlet model. Calibration of measured water levels are presented in Figure E-10 and show a good level of correlation.

FIGURE E-11 MODELLED VERSUS MEASURED WATER LEVELS – CALIBRATION FEBRUARY 2021

Measured versus modelled residual (i.e., the non-astronomical portion of the water level variation) for Inverloch and Tarwin Lower are presented in Figure E-11. The model successfully captures the varying residual through the calibration period.

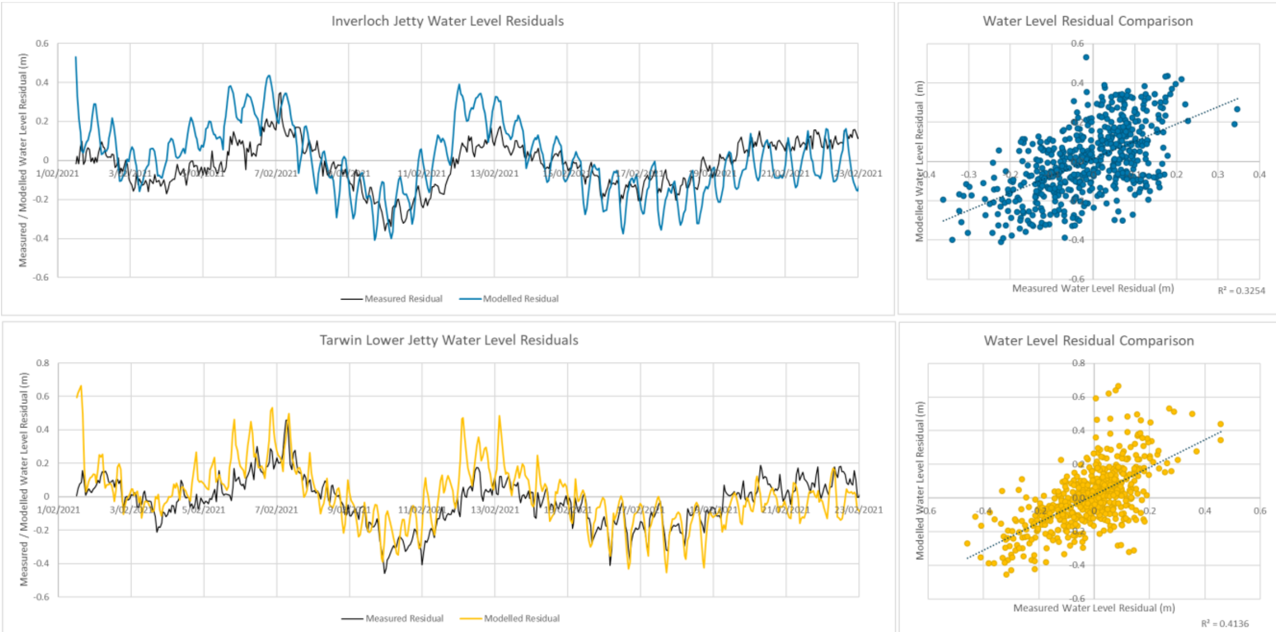


FIGURE E-12 MODELLED VERSUS MEASURED WATER LEVEL RESIDUALS – CALIBRATION FEBRUARY 2021

Calibration Tests

A range of variables were tested in model calibration, as described in Table E-3. Variables were tested in isolation and combination until the performance measures described above were achieved. The limited bathymetric data through the Inlet, especially across the intertidal bars limits the level of accuracy which can be realistically achieved in calibration. Additional changes to calibration parameters will provide only small changes to model results compared with changes associated with variations in the model in the bathymetry, and for further accuracy additional bathymetry across the entrance should be collected.

Table E-3 Model Calibration Tests

Parameter	Tests	Impacts
Bathymetry	Increases in tidal floodplain in Anderson Inlet to assess changes in bathymetry since FutureCoast bathy collection	Minimal change in water levels at Tarwin River (<0.1m)
	Changes to survey joins between different datasets	Negligible change in results
	Change to the channel representation of the Tarwin River section of the model	Better capture of water level peaks at the Tarwin Lower jetty, at the expense of cutting off low waters, however no impact on water levels within Anderson Inlet.
Roughness	A range of different roughness values within the channels, on the sand bars and offshore have been tested	Most significant impacts in calibration. Changes tidal heights and shape.
Wind	Wilsons Promontory winds were tested to assess the impact of the Venus Bay dunes on the local wind climate and water movement on Anderson Inlet	Negligible changes to water level peaks and troughs at times (<0.05m) at Inverloch. More notable at Tarwin Lower (0.1m).

Parameter	Tests	Impacts
Flow	As there is no calibration data to verify the flows from Tarwin River, an increase of 10% was tested for the discharge flow into Anderson Inlet	No observed change, however it is noted the calibration period is during a normal, low flow period.
	The smaller impact of flows from Pound Creek was tested by turning the flows on and off	No observed change, however it is noted the calibration period is during a normal, low flow period.

E-4-5 Verification

Verification of the model was completed by simulating the model for the June 2021 flood event which occurred during the Study, after much of the modelling work had been completed. Some changes to the model bathymetry were required to achieve an acceptable level of calibration, specifically the areas across the intertidal banks at the mouth of the Tarwin River where updated survey is not available. Changes here impacted the low water levels more notably than the high water as the flow from the river into Anderson Inlet was improved. Changes were not noted at Inverloch from this change in bathymetry. The concurrent measurement of a flood event (albeit relatively small) at Meeniyan and Lower Tarwin also allowed some update of the hydrologic model which generated flow inputs to the model.

The measured water levels at Inverloch Jetty and Tarwin Lower presented in Figure E-12 with the modelled water level. Whilst the water levels do not match the measured data exactly, they do provide a good representation of the change in tidal signal, particularly the drowning out of the low tide signal, during a flood event. Additional gauged data within the Tarwin River catchment capturing discharge between Meeniyan and Tarwin Lower during a flood is required to improve the model as there are significant overbank losses which are difficult to simulate with the limited data available. However, the peaks of the flood event and tide are well represented by the model.

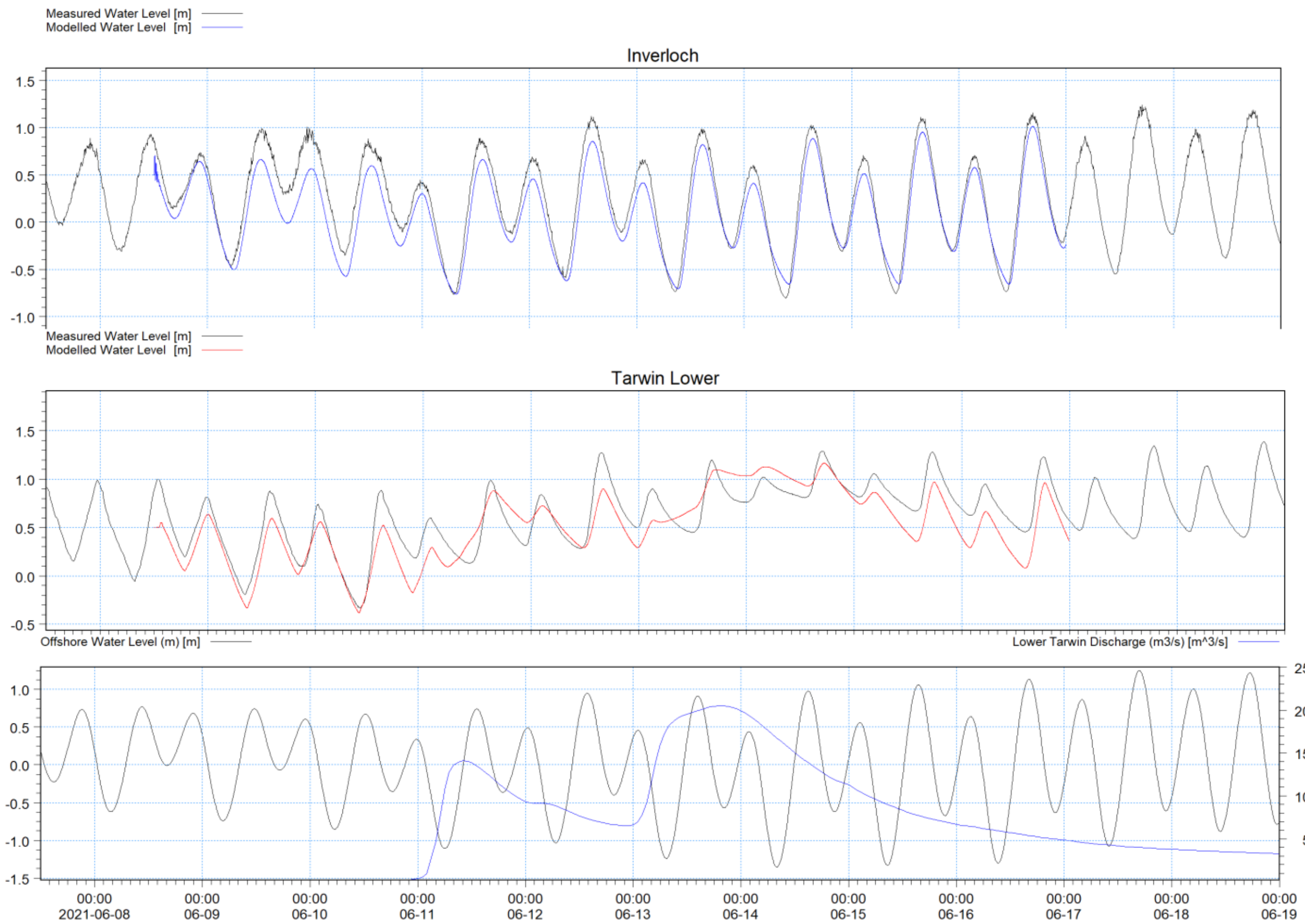


FIGURE E-13 MODELLED VERSUS MEASURED WATER LEVELS – VALIDATION JUNE 2021

E-4-6 Additional Verification

An additional verification simulation was completed to assess model performance with a modified bathymetry and a different set of measured water levels. The model bathymetry used FutureCoast DEM across the whole nearshore domain, including the entrance. The offshore area again utilized the GA250m DEM.

Water levels from the Ocean Model hindcast was used to drive offshore water levels into Anderson Inlet where water levels at Inverloch Jetty, Screw Creek intertidal bank, Venus Bay jetty and Tarwin Lower jetty were compared with measured data. Data was measured in September 2004 by Water Technology for other works in the area and captured a small flood event as observed at the Tarwin River gauge. The impact of the flood event can be seen in the drowning out of the low tide at Tarwin Lower, but cannot be seen at the gauges within the Inlet.

The measured water levels at Inverloch Jetty Screw Creek, Venus Bay Jetty and Tarwin Lower are presented in Figure E-13 with the modelled data and illustrate the model can provide a good representation of water level conditions within the Inlet despite the lack of concurrently collected bathymetric data to define tidal channels and bars present at the time of water level data collection.

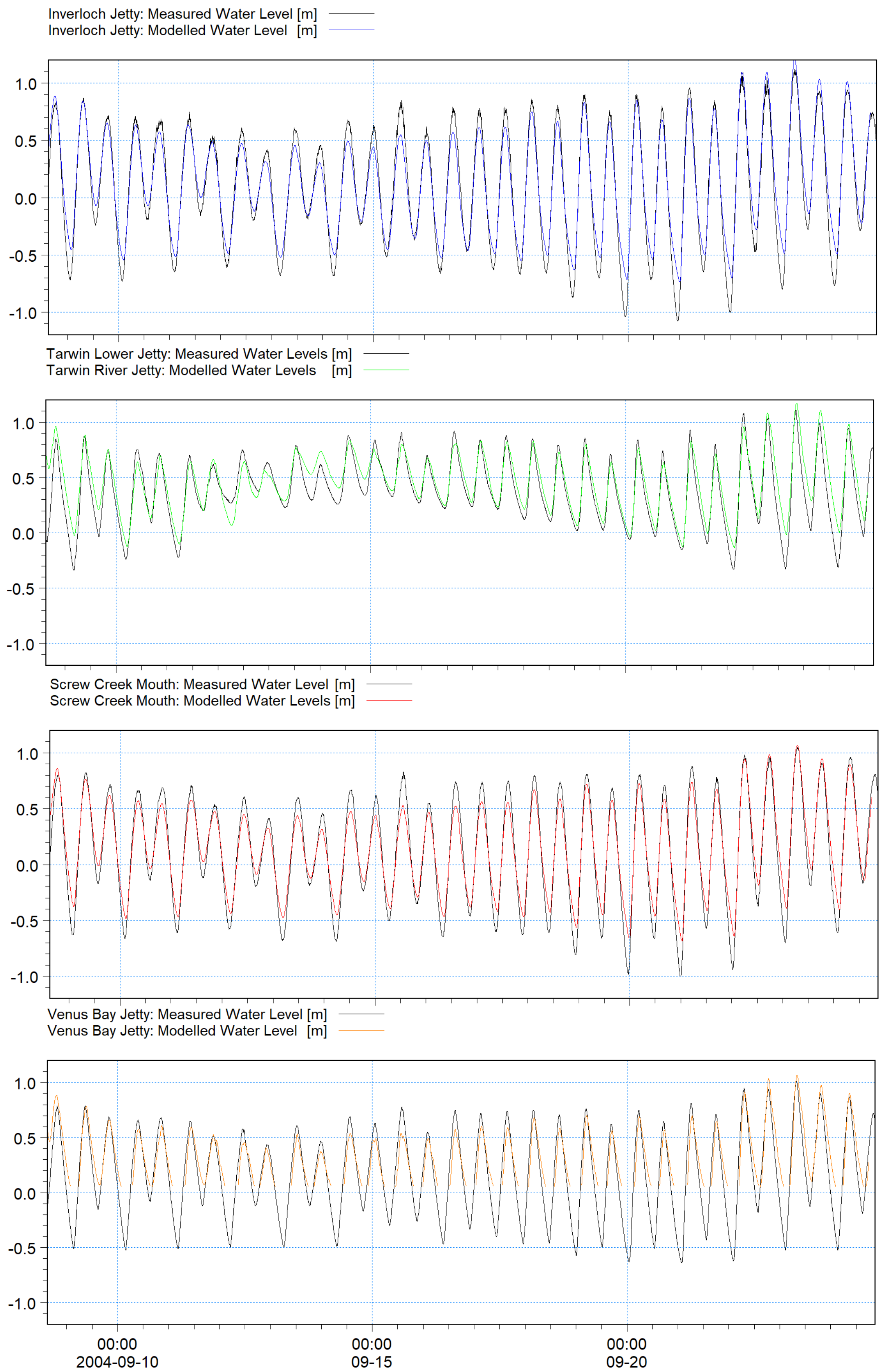


FIGURE E-14 MODELLED VERSUS MEASURED WATER LEVELS – SEPTEMBER 2004

E-4-7 Sensitivity Testing

Wind Setup

Sensitivity of the Inlet water levels to design winds has been assessed using a design wind conditions from 8 directions (cardinal and intercardinal directions). The westerly wind resulted in the most significant increase in storm tide levels for the majority of the Inlet and as such, a synthesised windstorm based on a measured westerly wind storm events, was scaled to the 1% and 10% AEP design winds and used as a boundary force in the numerical model. A westerly wind was also considered most appropriate as storm surges are associated with the passage of fronts across the Bass Strait in a west to east direction.

Simulation of the design wind condition in conjunction with the design storm tide does result in additional inundation across Anderson Inlet compared to the storm tide inundation without wind setup. An increase in the flood level between 0.05m and 0.4m is observed in the modelling of the existing mean sea level 1% AEP storm tide and 1% AEP wind scenario. Strong winds are likely to be present during a design storm event so this additional water level should be considered in inundation hazards. The use of the design wind speed based on the Australian Standards (see Report 4 for details) is conservative, however unavoidable given the lack of measured data within the Inlet. The more conservative use of the Australian Standards winds can be considered to provide for the uncertainty associated with additional setup due to wave generation within Anderson Inlet which has not been included in the modelling. Wave generation, and wave setup, within Anderson Inlet during a storm event will be limited by depth across the intertidal banks at the edge of the Inlet.

Entrance and Inlet Bathymetry

To assess the sensitivity of the storm tide to the entrance and Inlet bathymetry, the 1% AEP storm tide under present day sea level was simulated with the 2021 entrance and 2020 Inlet channel bathymetry and compared with bathymetry derived from the FutureCoast 2009 dataset to determine if the configuration of the entrance and tidal channel, and associated tidal current flows impact the storm tide levels within the Inlet.

The results indicated there was negligible change (<0.01m) in water levels within the body of the Inlet due to changes to the entrance channel and bar configuration. This is due to the entrance being largely drowned out in a storm tide event and the channels and bars having little impact on the tidal flow during high water.

More notable changes were observed at Tarwin River during the low water periods, this was associated with the need for manual interpolation the tidal channel in the FutureCoast model bathymetry where survey data was unavailable (i.e. a constant low water level was defined as the bed in the FutureCoast dataset rather than the actual channel bed). This manual interpolation of the channel resulted in differences in low water levels within the Tarwin River however there were no differences in the high water levels between the models.

Increased Runoff

Sensitivity testing of the catchment flood events was used to review any potential impact of climate change on flood flows into the Inlet. Review of the initial modelling results indicated the storm tides were the main driver of flooding in the inlet (as opposed to flooding without storm tides). To test the sensitivity of this to increased flood flows, the 1% AEP flood flow was increased by 10% and simulated with the 10% AEP storm tide and 1.4m sea level rise to test the sensitivity of extreme conditions towards the year 2100. The 10% increase in flood flow had negligible difference on flood levels within the Inlet.

Storm Peak Coincidence

The coincidence of the peak of the storm tide meeting the peak of the catchment flood was discussed during the project investigation and the impact of matching or not matching the storm peaks assessed through sensitivity testing. Flooding in Anderson Inlet is driven by the storm tide and shifting the occurrence of the peak riverine inflow has minimal impact on water levels within the body of the Inlet. Upstream of Tarwin Lower jetty there is more notable connection between the timing of the peak riverine flow and the peak water level within the river, however the maximum water level of the different scenarios was similar as the water surface elevation was closely connected to the storm tide height.

Joint Probability

The coincidence of the design storm tide and catchment flood events has been discussed in Section 2.3.2. In accordance with guidance from AR&R (Ball, 2019), the 1% AEP storm tide and 10% AEP catchment flood, and other combinations noted in Table 2-2 have been used in hazard mapping.

However, to provide context to this combination of events, the unlikely combined 1% AEP storm tide, 1% AEP design wind and the 1% AEP catchment flow events were combined using the Anderson Inlet model. The results of the modelling showed the combination of these events resulted in only minor increases in the flood extent, and primarily in agricultural areas at the edge of the inundation hazard zone with limited assets impacted by combining the 1% AEP events (Figure 7-1).

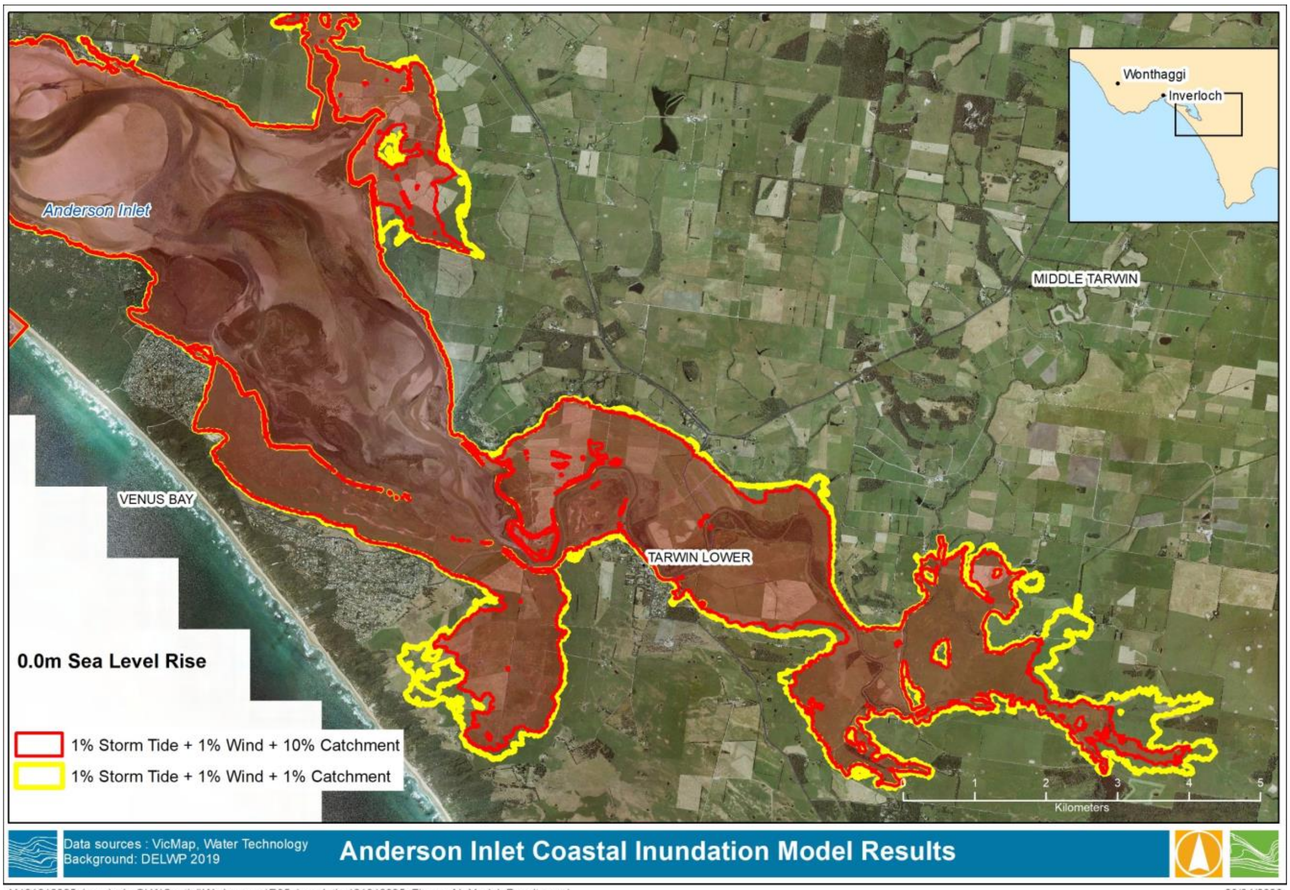


Figure 7-1 Comparison of dependent and independent storm events

E-5 Entrance Model

The ***Entrance Model*** has been used to further our understanding of the hydrodynamic, wave and sediment transport interactions through the entrance. The model outputs will be used to assist in the development of adaptation options through analysis of the physical drivers of change at the entrance and the sensitivity of these drivers to change. The outcomes of the Entrance Model have also been used to assist in defining the conceptual model of coastal processes in the Study Area. The results of the entrance model are conceptual only, assisting in the description of processes at the entrance rather than prescribing actual change.

The initial hope was that the entrance could provide predictive assessment for the project, however the development of a model capable of this is outside the realm of the study boundaries, and also lacks sufficient input data (specifically current and wave data within the entrance for detailed calibration) to justify the significant effort required to develop and run such a detailed model.

E-5-1 Modules

To assess sediment dynamics through the entrance a Mike21 Flexible Mesh coupled hydrodynamic, wave and sediment transport model was developed. The model allows the water level and wave forces across the entrance to drive bed change which then feeds back into the hydrodynamic system and simulates the change in channel and bar system over time.

Spectral wave modelling is computationally intense and results in a significant increase in model run time. Initial testing of the model using a fully coupled high resolution hydrodynamic-wave-sediment transport model resulted in unacceptably slow run times (i.e. significantly slower than real time).

As such, the wave modelling was un-coupled from the morphologically dynamic hydrodynamic-sediment transport model and the simulation period run at a higher resolution on a morphologically static bathymetry. This means that the wave modelling does not consider the changing bed levels as the simulation advances. However, the majority of wave energy is dissipated at the entrance bar and within the channels sediment transport is dominated by tidal currents. The uncoupled approach, whilst therefore not ideal, was considered to still provide understanding and insight into the waves and hydrodynamics interaction and influence of bed morphology at the entrance.

E-5-2 Domain

The model domain and bathymetry are presented in Figure E-14. The model extends offshore beyond the edge of the ebb tide delta and into Anderson Inlet to Mahers Landing where hydrographic surveys indicate the tidal channels have remained fairly stable for the period 1991 through 2021.

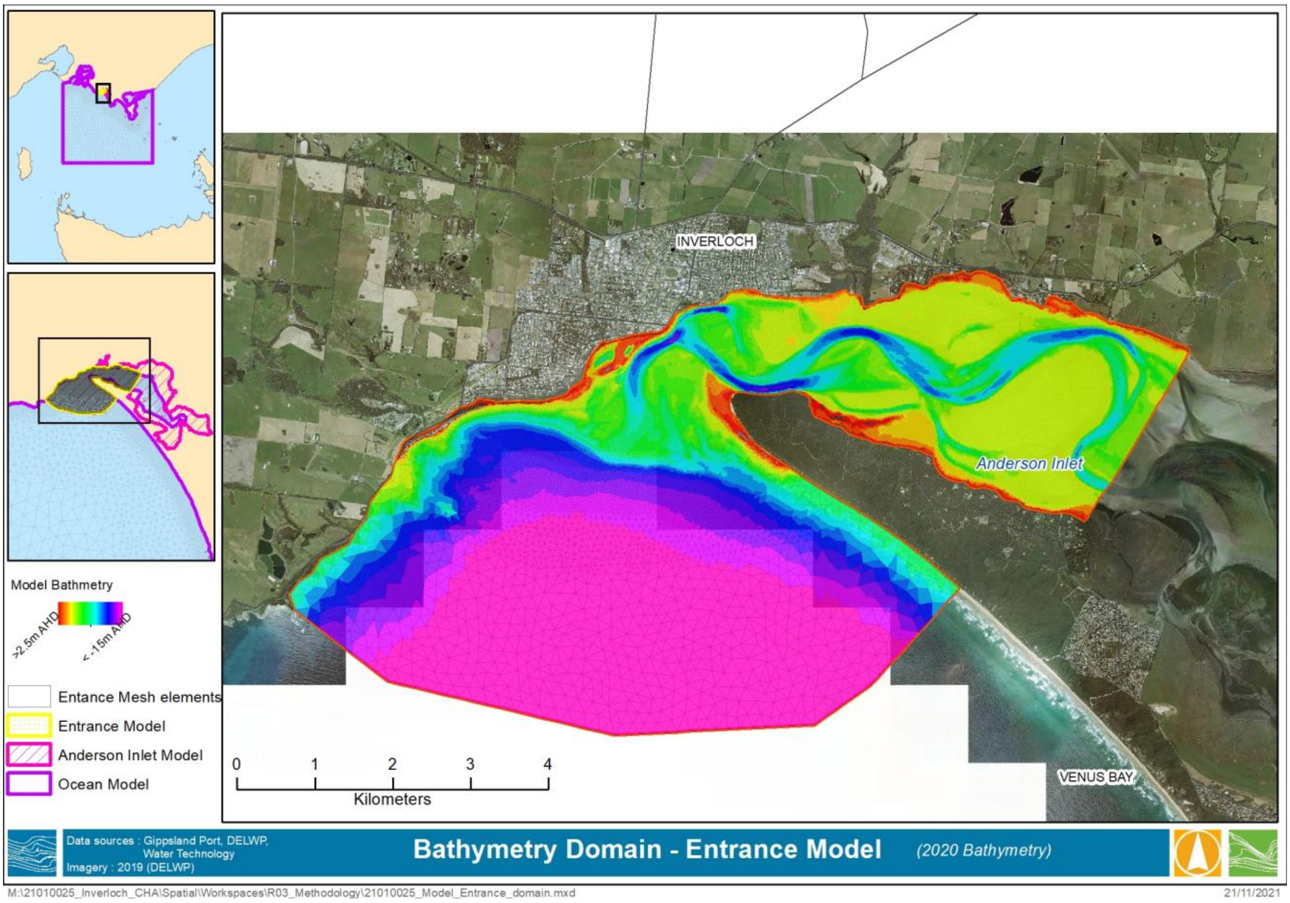


FIGURE E-15 ENTRANCE MODEL DOMAIN & BATHYMETRY

E-5-3 Model Mesh and Bathymetry

The resolution of the model mesh is in the order of 10-20m, increasing in the offshore direction to 300m as per the ocean model boundary. Initial modelling trialling a significantly finer mesh again resulted in unfeasible model run times for the project and as such a (relatively) coarser mesh resolution was used than hoped. The model mesh structure is constant across the entrance (i.e. the mesh of the channel is not different to the mesh of the sandbars etc).

The model has been run with two different initial bathymetries representing the different entrance conditions at the point in time of the FutureCoast survey (2009) and survey data collected for the project (November 2020). It is noted the November 2020 bathymetry is not a complete survey of the entrance, and as such data from the 2021 full survey, and an aerial image captured at the same time as the November 2020 survey has been used to infill the entrance bathymetry on the eastern side.

E-5-4 Boundary

Offshore

The offshore water level boundary has been extracted from the Ocean model described above in Appendix E-3. The wave conditions were generated using the University of Melbourne wave hindcast datapoints. The recent modelling period (i.e. November 2020-April 2021), utilised the wave and hydrodynamic conditions generated with the coupled waves and hydrodynamic model discussed in Appendix E-3-7. Hourly wave inputs are used whilst the hydrodynamics is added to the offshore boundary on a 15 minute timestep of varying water levels.

Mahers Landing

Currents and water levels at the upstream extent of the entrance model near Mahers Landing have been extracted from the Anderson Inlet model which was run for the 2009 and 2020 simulation periods for this purpose. Currents (u- and v-velocity) and water level was added to the model as a 5 minute interval.

Offshore

The boundary has been extended beyond the entrance on the open coast to ensure hydrodynamics from the model can drive sediment transport along the coasts adjacent to the entrance. Whilst not accurate of the reality, the model assumes no net gain or loss at the boundary, however these are distant enough from the entrance such this assumption does not impact the morphological change driven by the entrance hydrodynamics.

Whilst a rock outcrop is known to be present offshore of Point Norman the surface depth and extent are unknown. The model is sensitive to hard, non-erodible features, and as such the outcrop was not included in the model sediment classification as there was concern an over estimation of the outcrop would influence the results more than not including the outcrop given the relative rarity of its exposure.

There is scope to extend this modelling in the future and this could be an area which could be further investigated.

Sediments across the entrance were considered to be very well mixed due to the significant movement of material in the model domain. The model grain size was determined as an average of available sediment samples (0.2mm, fine to medium sand). It has been assumed that sediments do not change through bed depth.

E-5-5 Calibration

Hydrodynamic Calibration

The entrance model hydrodynamics have been calibrated to measured water levels at the Inverloch Jetty in April 2021 to coincide with the 2021 bed survey. The model calibration is presented below in Figure E-15. The model provides a good representation of the water levels measured at Inverloch. Bed roughness varied across the model domain inline with the Anderson Inlet model, with bed friction decreasing across the sandbars and ripples with depth of water through the tidal cycle and (where required) roughness to represent the vegetated shorelines in the model.

The careful positioning of the upstream boundary across the Inlet near Mahers Landing allowed the main tidal channel to be perpendicular with the model boundary, reducing the incidence of boundary errors and instability. The good calibration is reflective of the use of the modelled water levels (and currents for the upstream boundary) from the already well calibrated Ocean and Anderson Inlet models.

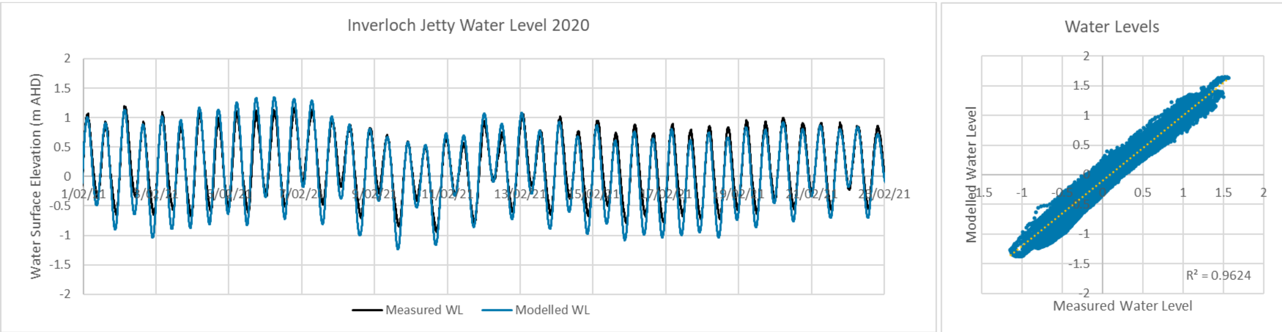


FIGURE E-16 MODELLED WATER LEVELS – INVERLOCH JETTY 2020-21

Sediment Transport Validation

The validation data available to review the response of the model bathymetry to wave and hydrodynamic conditions is limited to the survey between November 2020 and April 2021. The results of the modelling are presented below in Figure E-16 with the measured data presented in the top row, the results of the sediment transport and hydrodynamics only in the middle row, and the results of the sediment transport and hydrodynamic plus wave forces presented in the bottom row.

The computational limitations outlined above mean that the model does not provide the level of accuracy required for a quantitative assessment of processes or changes but can inform a more qualitative understanding of the key drivers and processes. The model overestimates the sediment movement within the entrance, as indicated by the greater level of scour through the channel, potentially driven in part to the larger than preferred mesh resolution required to keep model times reasonable. The steep channel banks within the high velocity channels are also difficult to replicate in numerical modelling where the same material forms flat banks such as across the ebb tide bar.

The decoupling of the wave and hydrodynamics to allow wave modelling to be completed on a coarser mesh will result in a reduction in the blocking effects of the ebb tide on wave conditions, and vice versa the impact of strong waves on the ebb currents, which will be under-represented in the modelling. Likewise the cumulative impact of waves and incoming flood tides on current forces and thus sediment transport through the entrance may be under represented.

Whilst there is potential that more detailed numerical modelling of the entrance could provide greater accuracy in future works, the size and complexity of the geographic area and processes, combined with the current limited physical data available within the entrance for model calibration, means that use of the model is limited to providing further conceptual understanding of the entrance processes at this time.

E-5-6 Sediment Transport Results

As noted, the model use has been limited to providing a more qualitative understanding of the entrance processes rather than provide predictive quantitative analysis as was hoped. To this end, the model was run for hydrodynamics (i.e. wind and tidal current forces) alone, and with these hydrodynamic and wave forces combined.

Whilst both simulations overestimate the total amount of sediment moved within the entrance, they do provide an understanding of how these different drivers modify the sediment transport within the entrance and flood/ebb delta.

The following trends can be observed in the model results which are annotated in Figure E-16:

- Tidal driven movement:
  - A – Generation of secondary channel across the centre of the outer bar
  - B – Generation of an ebb tide delta
- Wave (and tidal) movement:
  - C – Forcing of the main channel and ebb tide delta to the east
  - D – Migration of a sandbar north into the entrance
  - E – Increased sinuosity of tidal channel
  - F – Potential scour of the entrance bar in the east (initial survey is not available to confirm change)

The tidal currents act to shift the main channel to allow the most direct flow route possible (B), in conflict with the efforts of the wave energy from the southwest which forces the channel to redirect to the southeast (C). The tidal currents then again cut through the outer bank in an effort to establish a shorter flow path (C). Features in the measured data across the bar at C and F potentially support this model prediction.

However, the modelling of the entrance and the sediment transport processes are complex. Additional understanding of the unique drivers could likely be achieved through more morphological modelling, however significantly more data would be required to enhance the ability of the model to replicate the complex processes within the entrance. This would include full survey of the entrance, offshore and Inlet bathymetry regularly for a period of 1 to 2 years, regular current measurements within the entrance channels, ongoing water level and wave measurement, complimented by inshore and inner entrance wave modelling, sediment sampling and potentially ground penetrating radar or testing to establish the location and extent of rock outcrops within the entrance.

In addition to the volume of extra data required to generate a high quality, calibrated morphological model, the intense computation power required to simulate these processes is a limitation of the modelling. Model grid size in the order of 1m or less would be desirable across the entrance where the channel shifts significantly, complimented by a finer vertical scale to resolve 3D effects of the shifting currents. Super computers could assist in increasing the simulation time, however long run times would still be expected, particularly if consideration of longer term morphological modelling, e.g. 10 to 20 year periods are considered to test the model against observed changes from 2012 through 2020.

In summary, whilst the morphological model could be beneficial in further enhancing understanding of the entrance for the Inverloch Region CHA, especially when considering the impact of adaptation actions on the entrance, achieving the data collection and model simulation times described above are not realistic either in project time frames, budgets or level of additional understanding. A good understanding of the processes which drive the entrance change has been developed via the morphological modelling completed and through other modelling and study of coastal processes and hydrodynamics and the project should not be delayed to carry out further morphological modelling.

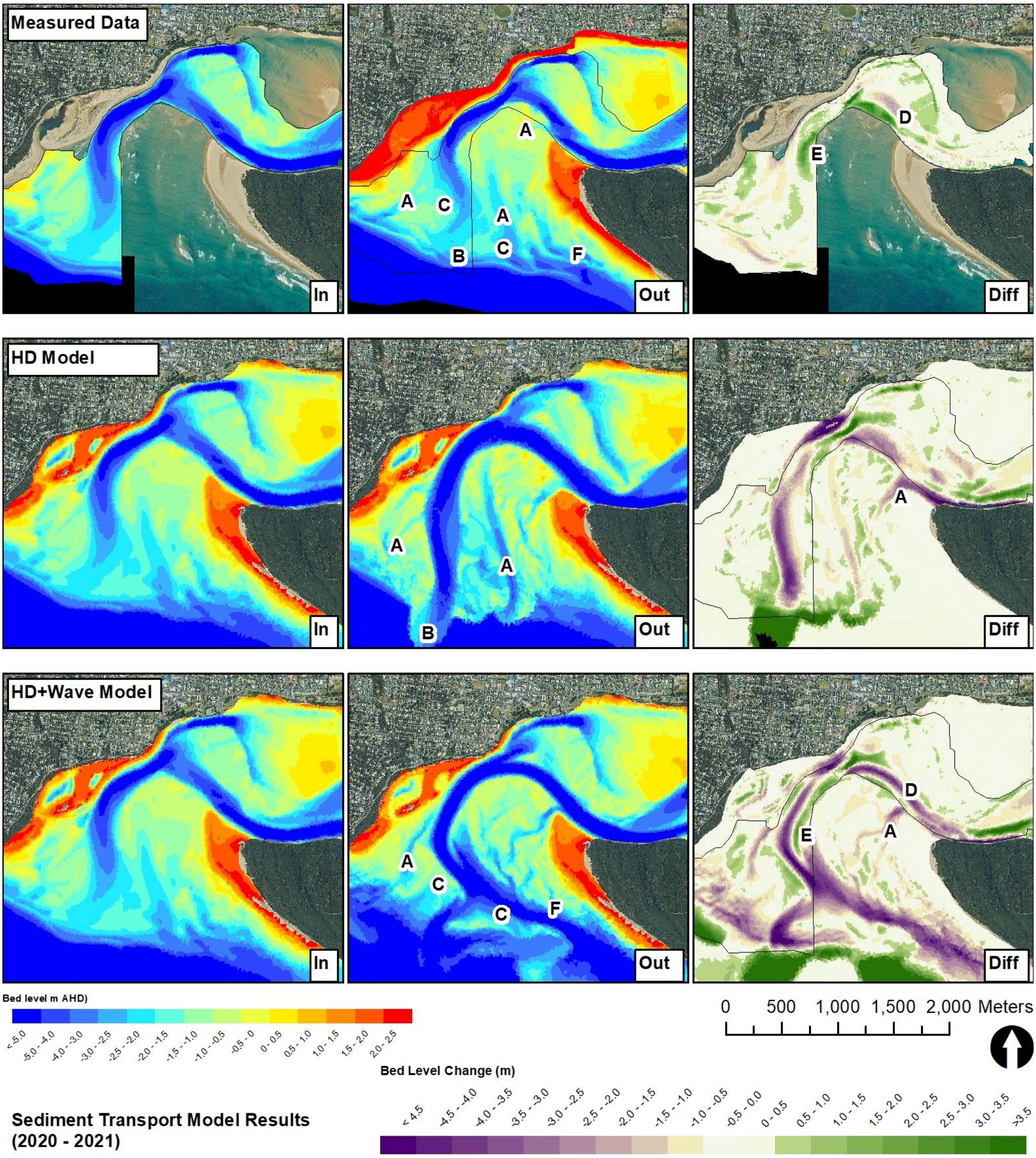


FIGURE E-17 SEDIMENT TRANSPORT MODEL RESULTS

APPENDIX F
COASTLINE CHANGE ANALYSIS

F-1 Aerial Image Analysis

Analysis of the long term rate of recession of the shoreline was undertaken using manual interrogation of the shoreline position or by using the US Army Core of Engineers Digitised Shoreline Analysis System (USACE DSAS).

The manual interpolation was used on the open Venus Bay coast where less change was observed along the coastline and the location of profiles were selected to coincide with the available wave hindcast data for storm and seedtime transport analysis.

An example of the manual assessment is shown in Figure F-1 with a sample of the aerial images, shoreline positions and analysis of data for the profile presented. The chart in Figure F-1 shows the distance of the shoreline from the 1950 position (blue) which is minimal until the year 2000 when there is a jump in the shoreline to 20m from 1950, increasing to 43m in the year 2019. The rate of annual change between each of the blue dots is shown in green with the connecting green line. The rate of annual change fluctuates between -2m per year to +3m per year between 2015 and 2018. The linear regression line for the shoreline distance from 1950 indicates the shoreline has advanced over the available time period at a rate of 0.4m per year. The linear regression of rates of change (orange) indicates this long term shoreline advancement is increasing by a small amount (0.01m per year) over the time period.

Analysis of the full length of the beach, illustrating different rates of change over the period of record, is shown in Figure F-2. For interest, the recession as calculated by the Geoscience Australia Digital Earth Australia Coastlines project is presented as the dashed line. The GA dataset only uses satellite imagery captured since 1988 and thus misses the seaward migration of the shoreline between 1950 and 1979 which occurred along much of the coastline. This in turn provides a useful reminder that the "long term" analysis is limited to the past 70 years only, and rates of "long term" trends are relative to this data.

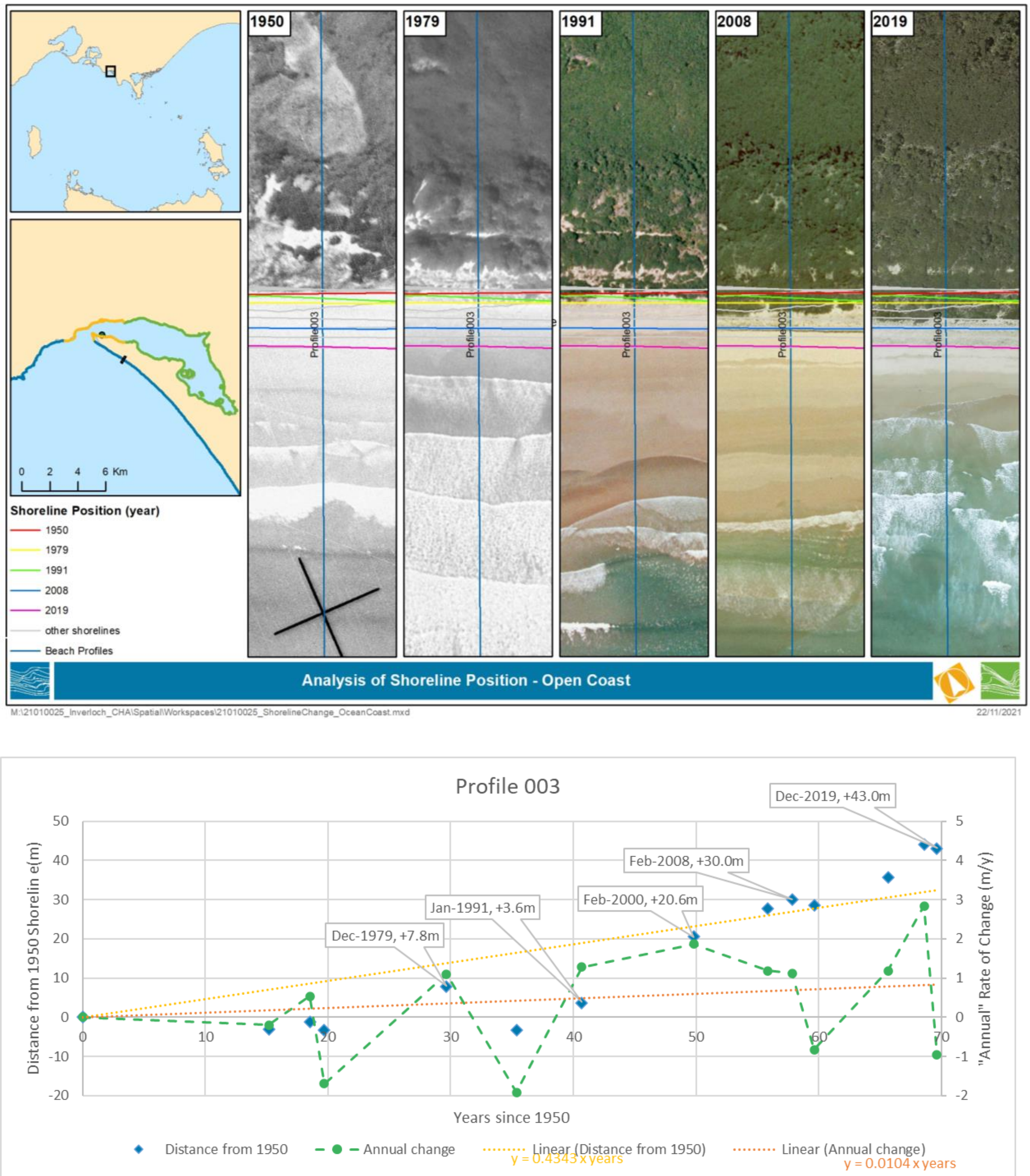


FIGURE F-1 MANUAL SHORELINE CHANGE ANALYSIS

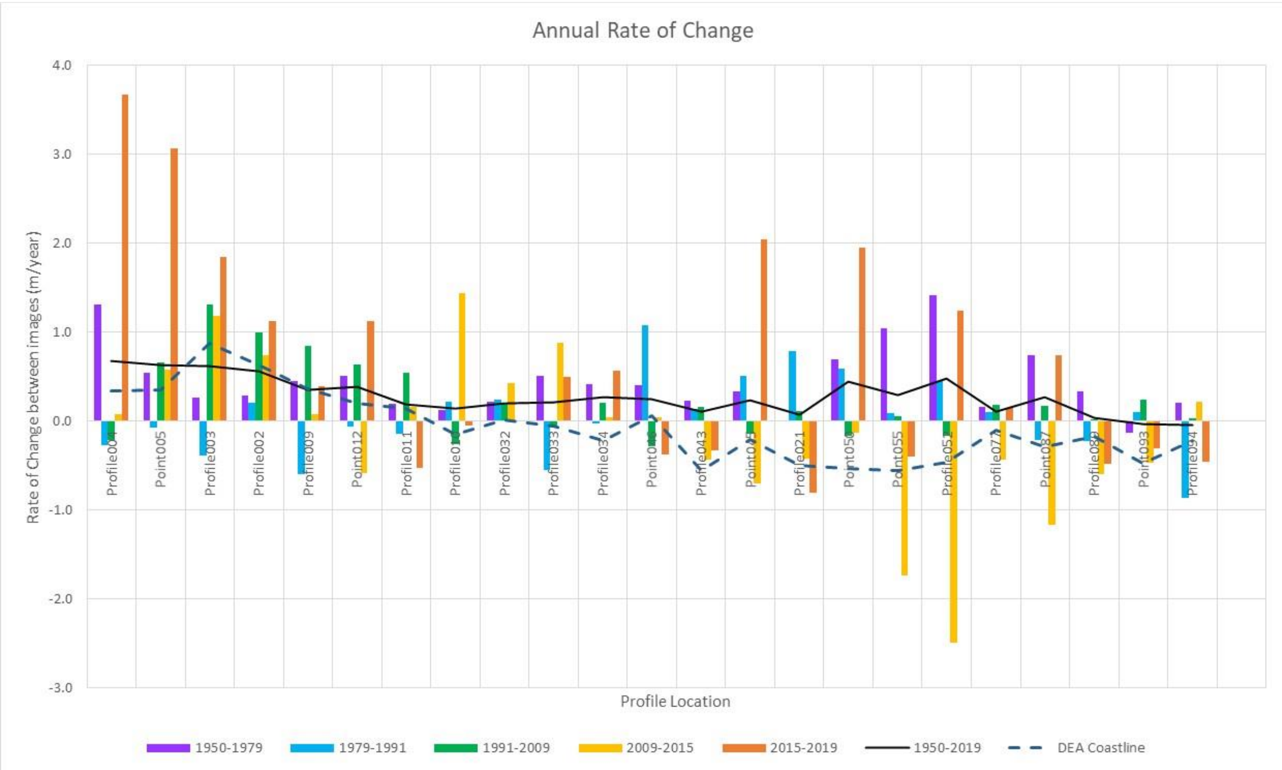


FIGURE F-2 VENUS BAY OCEAN BEACH LONGTERM SHORELINE POSITION AND CHANGE

The USACE DSAS was used to assess long-term shoreline change for the Surf Beach, Inverloch and Anderson Inlet coastline. The DSAS for Anderson Inlet is presented below in Figure F-3. Shore perpendicular profiles are automated to transect the coastline and the position and date of each shoreline is captured in the analysis. Statistics such as the linear regression rate of change (used in our analysis) is provided by DSAS, along with the total width of change (shoreline change envelope), and net change (most recent compared to first). As with the manual analysis, it is important to note the limitation of the “long term” rate being based upon the available window of data.

The length of the transects as shown in Figure F-3 indicate the shoreline change envelope, which for most of the shore is less than 30m, and the linear regression rate is likewise +/-0.5m per year. Large accretion is noted in blue where there has been mangrove or other vegetation growth along the shoreline, adjacent to Pound Creek and on the southern bank towards the mouth of the Tarwin River. The mangrove has pushed the “shoreline” over 800m into the Inlet along this bank with a linear regression rate of 13m/year. Erosion is noted in red, primarily at the entrance to Anderson Inlet where the banks of Point Smythe has receded with the meandering of the entrance channel. The banks have receded here 150 to 200m at a linear regression rate in the order of 2 to 2.5m per year.

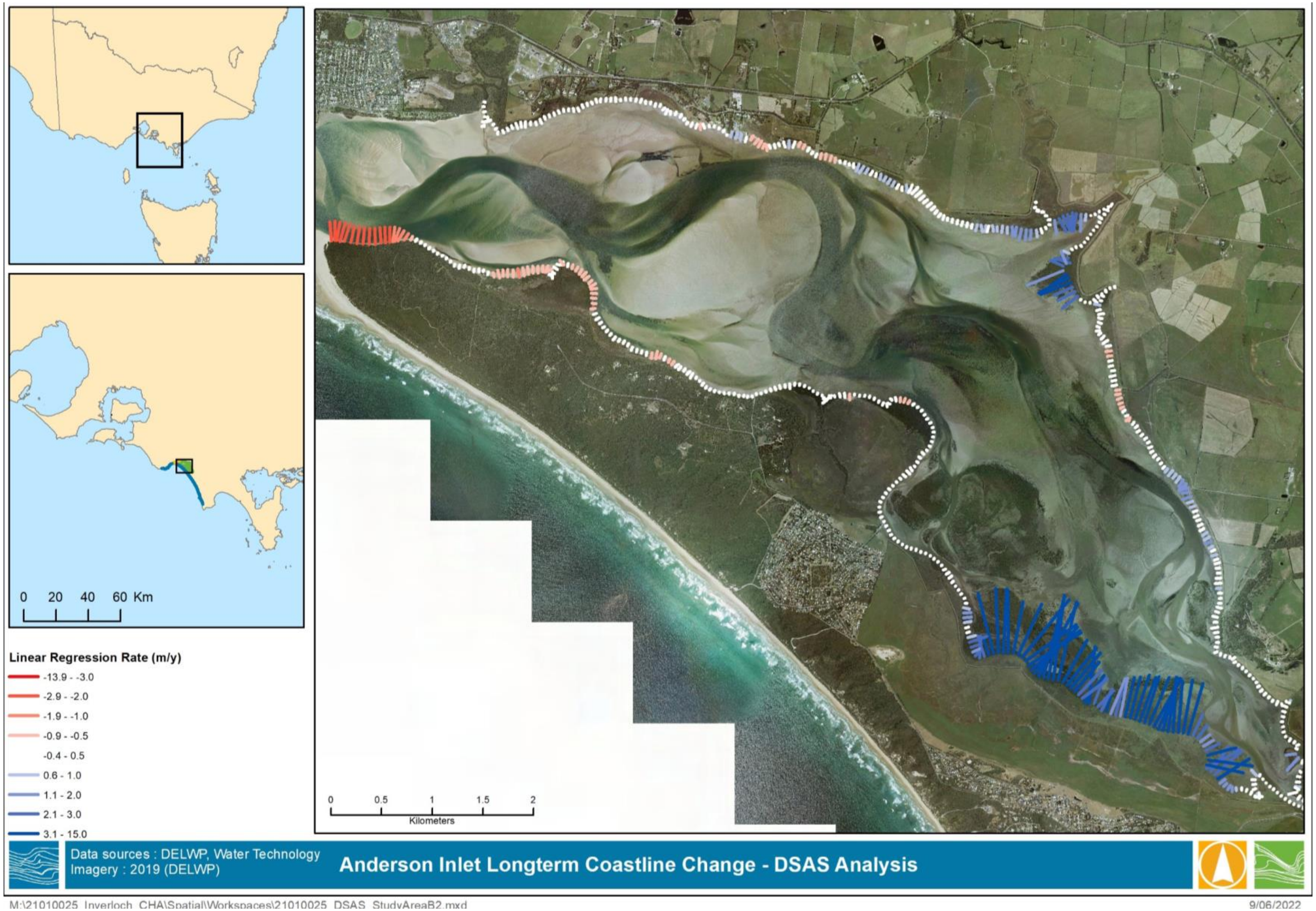


FIGURE F-3 ANDERSON INLET LONGTERM SHORELINE DSAS ANALYSIS

F-2 Slope Failure Analysis

The following steps were undertaken to understand cliff stability in the Study Area, particularly along the Bunurong Road coastline.

- Slope analysis of the FutureCoast LiDAR to identify cliff locations. A slope of greater than 50 degrees was identified as being the most suitable level for cliff identification.
- These sloped areas were compared with the coastal geomorphic sector data to confirm the backshore conditions.
- The LiDAR was used to determine the elevation at the top and toe of the cliff to establish the horizontal distance of the cliff slope at 5m intervals within each coastal geomorphic sector.
- The height and depth of the geomorphic sector was used to establish the maximum slope for the sector, and the setback formula (reproduced below from FIGURE 4-3) was used to provide a coastal erosion hazard zone along the rocky coast.

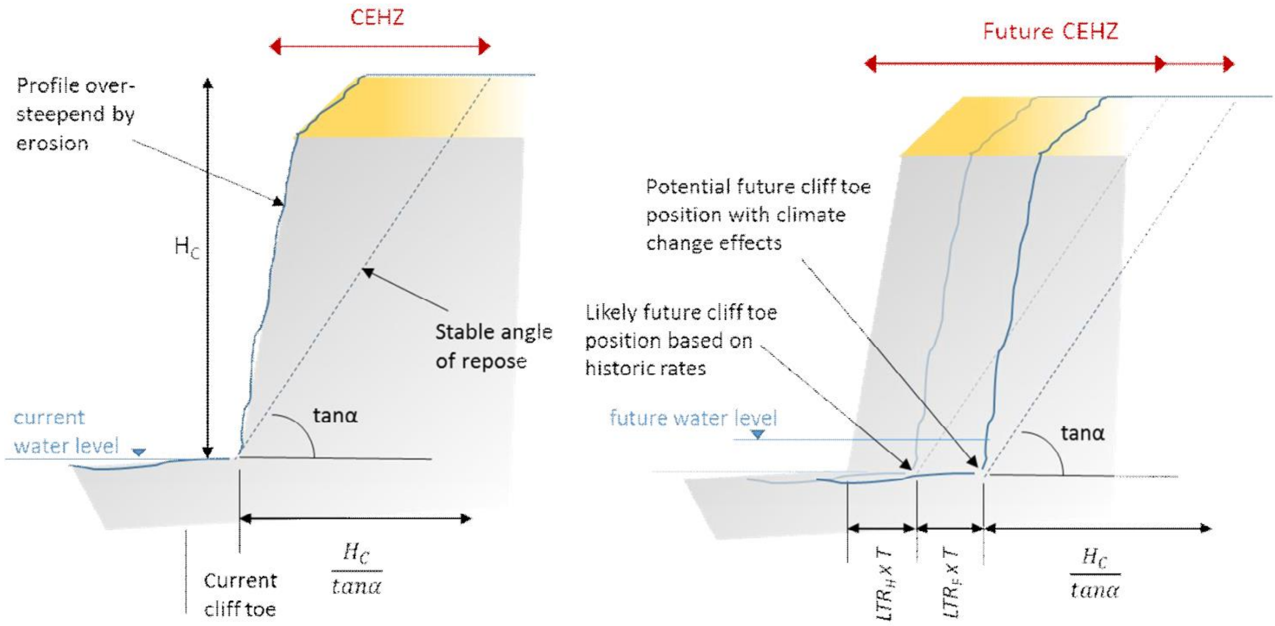


FIGURE F-3 LONGTERM RECESSION OF CLIFFED SHORLINES (SHAND ET AL, 2015)

Figure F-4 below provides an example of this process.

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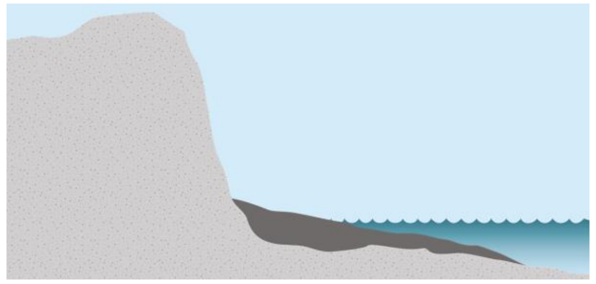
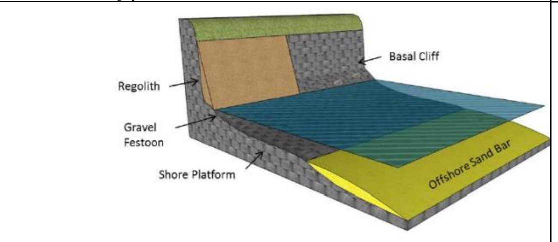
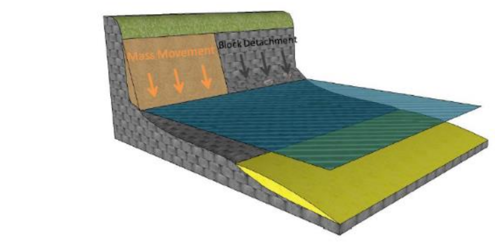
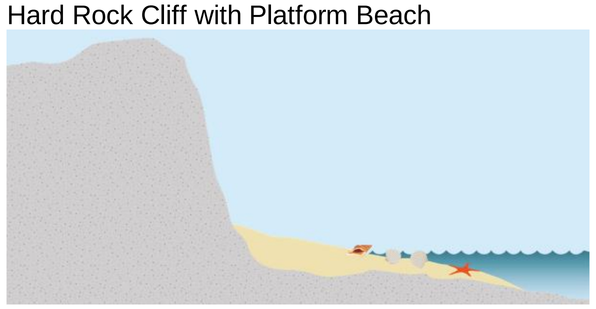
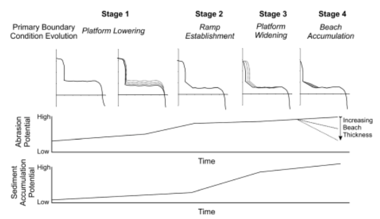
FIGURE F-4 SLOPE FAILURE ANALYSIS – IDENTIFY SLOPES > 50 DEGREES, CONFIRM IN GEOMORPHIC SECTOR, IDENTIFY TOP AND TOE OF CLIFF, MEASURE SLOPE ANGLE AND DETERINE CLIFF BUFFER

APPENDIX G
EROSION CALCULATION METHODS

Type		Description (backshore with intertidal)	Conceptual Model for Shoreline Type	Conceptual Model Sea Level Response	Method for Erosion Hazard Estimation
		The shoreline types have been grouped into "functional" shoreline types whereby the geomorphic components and processes operating are similar and as such their response to sea level rise can be assumed to be similar also.	The conceptual models (images) shown in this column were developed originally for the Western Port Local Coastal Hazard Assessment (Water Technology, 2014). Some of the morphological characteristics differ in Anderson Inlet and these models will be updated to reflect this. However, they do capture the key geomorphic components and processes operating on this conceptual shoreline type.	The conceptual sea level rise response models (images) shown in this column were developed originally for the Western Port Local Coastal Hazard Assessment (Water Technology, 2014). These will be updated with any recent advances in understanding of how the shoreline will response to sea level rise. However, no significant changes in understanding have been identified to date.	In general, for each shoreline type the erosion hazard extent will be in the form: Erosion Hazard Extent = Short term change + Long term change + Response to SLR The approach to estimating the short term, long term, and response to SLR components will be dependent on the CGS definition and are summarised in this column.
1		Hard Rock Cliff and Shore Platform 	 Figure 3-31 Hard Rock Cliff and Shore Platform Conceptual Shoreline Type The local morphology of these shorelines is related to the resistance of the material and the relative exposure to wave energy. These hard rock cliff slopes are particularly susceptible to deep-seated mass movements that may be initiated by a combination of surface processes and/or due to marine influences at the base of the cliff. This shoreline type is characteristic of the coast from Cape Paterson to Flat Rocks.	 Figure 3-34 Hard Rock, Cliff and Shore Platform Sea Level Rise Response Mechanism Sea level rise steps considered in this study are not considered to significantly influence the extent of potential hazards associated with slope failures/mass movements on these shorelines; however, sea level rise may possibly increase the likelihood and/or frequency of these hazards along these shorelines. Slope failures are considered a potential significant source of hazard along these shorelines as they can result in major impacts landward of the cliff edge and can occur with little to no warning.	Only the long-term cliff hazard is calculated to define the hazard zone: **ST:** NA. The erosion hazard to rocky platforms is not expected to be significant over the scenarios considered. **LT_{HIST}:** Mapping of shoreline movements over time but likely to show little change in most locations. It is assumed that multiple profiles sampled along the sector captures the natural stable slope angle for the cliff material. The mapped hazard zone extends from cliff toe line to the landward extent of the cliff failure width. The stable slope angle will be used to define the likely extent of future failures along these shorelines. **LT_{FUT}:** Increased duration of exposure to wave energy plus larger waves from accelerated SLR is likely to increase rates of hydraulic weathering and abrasion processes but for hard rock materials this is not expected to be significant over the time frames considered in this project.
2		Hard Rock Cliff with Platform Beach 	This shoreline type is a combination of Hard Rock Cliff and Platform shoreline with a Sandy Shoreline See Kennedy and Milkins (2015) for a conceptual model of the platform beach development, specifically for the Cape Paterson area.  **Figure 14.** A four-stage model of shore platform evolution and its relation to beach development in microtidal settings. Shore platform evolution is driven by a range of processes and in this model only the morphological element that primarily influences beach accumulation is highlighted. This model assumes an ample sediment supply. A ramp will form prior to beach development; however, whether it forms solely through platform downwearing, backwearing or a combination of both is unknown.	Kennedy and Milkins (2015) studied the platform beaches east of Cape Paterson and developed a simple evolutionary model. From the model it can be inferred that as sea level rises it will have a major impact on the beaches. This is because the increase in water depth will raise wave energy significantly in the short term but as the platforms cannot widen in the same time frame beach volumes will be lost. The change in elevation with respect to sea level is the key factor and the resultant response of beaches is likely to be rapid.	Compound sector. The sandy shoreline must be first checked to determine whether it provides some protection to erosion. Overall, we calculate the sandy shore hazard extent and truncate at the cliff toe and then calculate the cliff hazard based on Type 1. **ST:** See explanation for Sandy Shoreline (Type 8). Estimate beach volume and check beach with against estimates of LT_{FUT}. **LT_{HIST}:** See explanation for Type 1 and 8. **LT_{FUT}:** See explanation for Type 1 and 8.

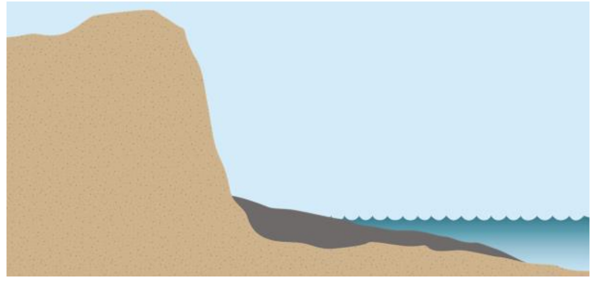
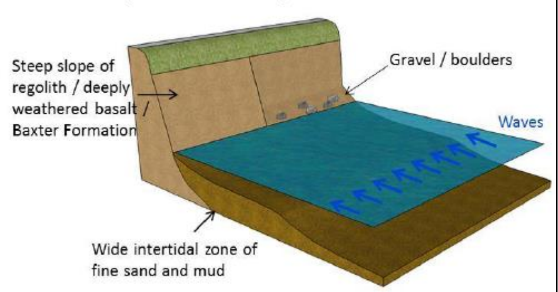
<table>
<tr><th>Type</th><th></th><th>Description (backshore with intertidal)</th><th>Conceptual Model for Shoreline Type</th><th>Conceptual Model Sea Level Response</th><th>Method for Erosion Hazard Estimation</th></tr>
<tr><td>3</td><td></td><td>Soft Rock Cliff with Shore Platform
</td><td>

Figure 3-6 Soft Rock, High Cliff Conceptual Shoreline Type

A range of surface processes contribute to erosion of these shorelines and intermittent wave action at the base of the cliff can undermine the cliff face resulting in block detachment/toppling of the cliff material onto the shore platform. Erosion under present mean sea level conditions is site specific.</td><td>Increased rates of cliff erosion could be expected on these shorelines due to the increased amount of wave energy that would be expended on the cliff face due to sea level rise; however, the processes and rates of change are likely to continue to vary linearly.</td><td>The LT_{HIST} and LT_{FUT} cliff hazard are calculated to define the hazard zone

ST: check if any storm response has been identified. If not ST = NA.

LT_{HIST}: See explanation for Type 1. However, likely to see some change in shoreline within the available historic imagery range which will provide a rate of recession for the shoreline.

LT_{FUT}: Consider increased rate of change and greater hazard to soft rock materials due to increased wave energy at toe. (Sections 4.4.2)</td></tr>
<tr><td>4</td><td></td><td>Soft Rock Cliff with Beach
</td><td>This shoreline type is a combination of Soft Rock Cliff and Platform shoreline with a Sandy Shoreline

See Kennedy and Milkins (2015) for a conceptual model of the platform beach development.</td><td>Kennedy and Milkins (2015) studied the platform beaches east of Cape Paterson and developed a simple evolutionary model. From the model it can be inferred that as sea level rises it will have a major impact on the beaches. This is because the increase in water depth will raise wave energy significantly in the short term but as the platforms cannot widen in the same time frame beach volumes will be lost.

The change in elevation with respect to sea level is the key factor and the resultant response of beaches is likely to be rapid.

The rate of retreat for a soft rock material is likely to be increased hence the need to account for this.</td><td>Compound sector. Calculate beach hazard as for Type 8 and truncate at cliff toe and then cliff hazard

ST: See explanation for Type 8. Estimate beach volume and check beach with against estimates of LT_{FUT}.

LT_{HIST}: See explanation for Type 3

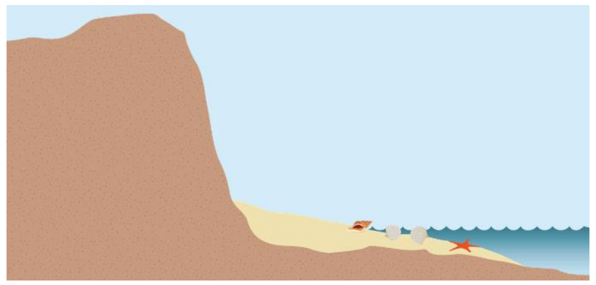
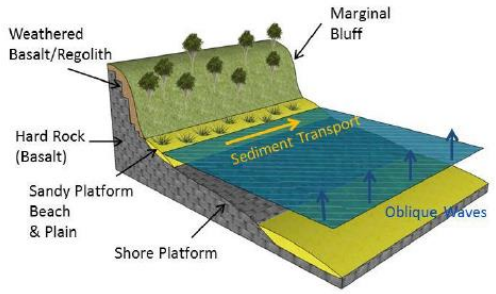
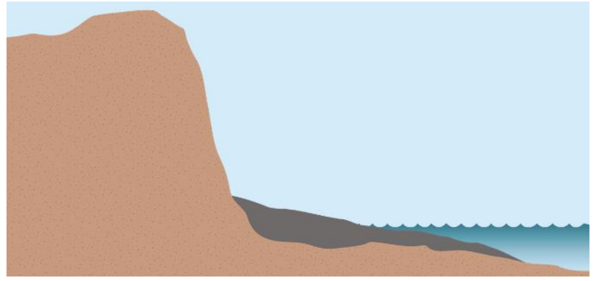
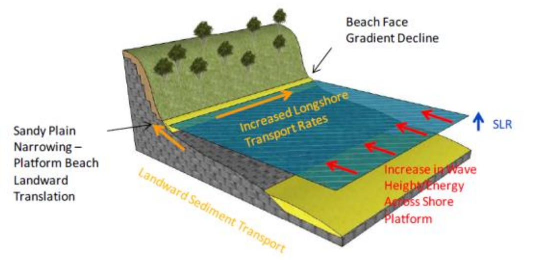
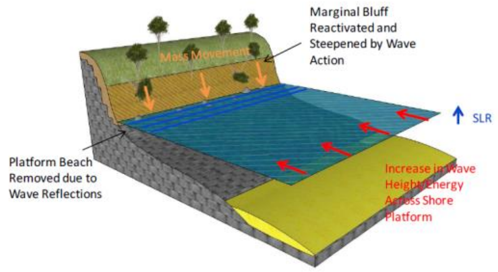
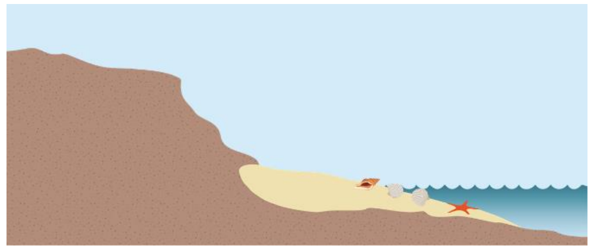
LT_{FUT}: Consider increased rate of change and greater hazard to soft rock materials due to increased wave energy at toe. (Sections 4.4.2)</td></tr>
<tr><td>5</td><td></td><td>Bluff with Platform Beach – includes several variants including:
</td><td>

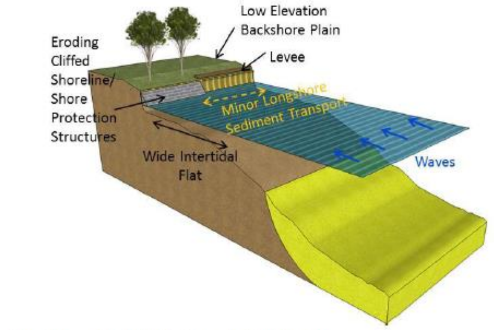
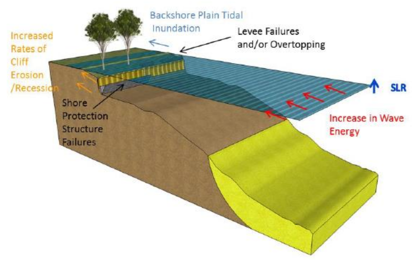
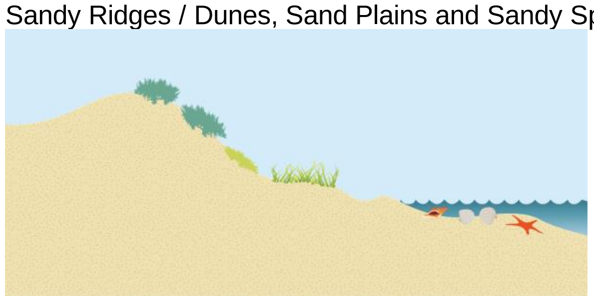
Figure 3-5 Platform-Beach and Bluff Conceptual Shoreline Type</td><td>The potential response of the platform beaches to sea level rise is likely to be complex and site specific; however, the platform beaches are expected to migrate landward at a rate that is a related to the slope of the underlying shore platform. This will essentially result in the recession of the sandy shoreline and narrowing of the sandy plain in front of the bluffs with sea level rise.

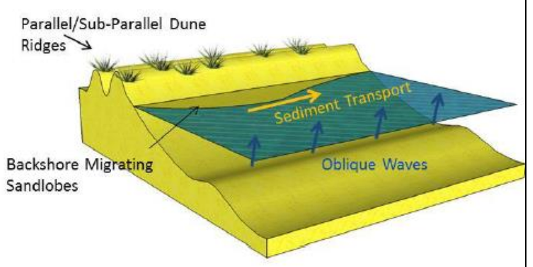
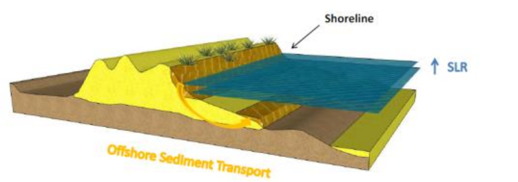
Depending on the sea level rise scenario and the initial width of the sandy plain in front of the bluffs, it is likely that platform beaches and plains will be narrowed to such an extent that marine influences may begin to impact the</td><td>Compound sector. If extreme water levels impact base of bluff or the beach hazard overlaps the cliff then treat as a cliff. Bluff could be hard or soft rock so check with the specific CGS.

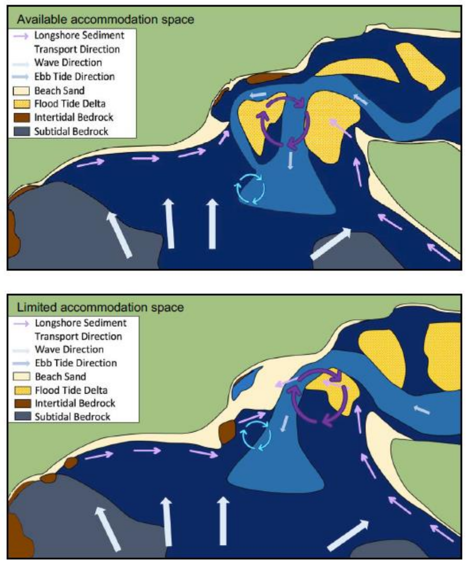
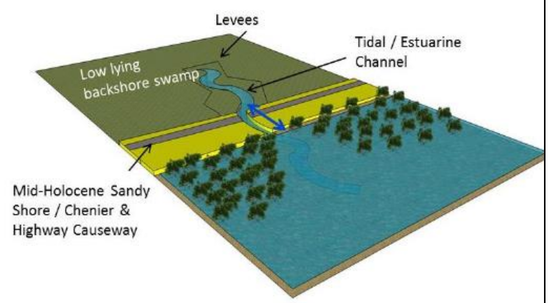
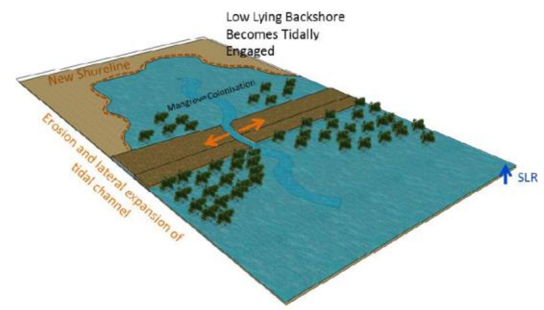
Calculate the long-term change for sandy shorelines first. If long term erosion estimate for sandy material exceeds beach with then apply LT cliff erosion approach. Assess of soft or hard rock material. If unknown apply soft rock approach.

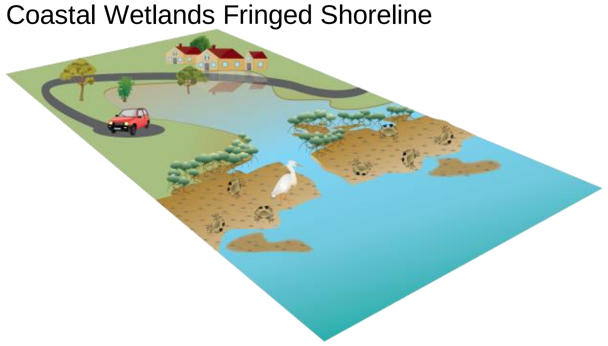
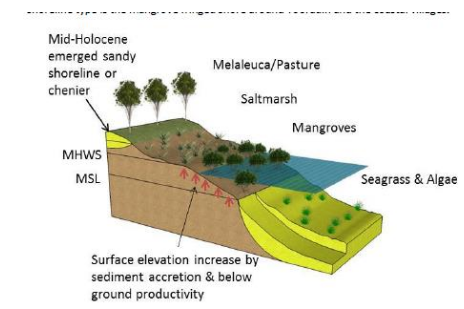
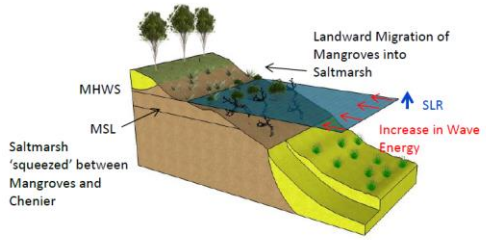
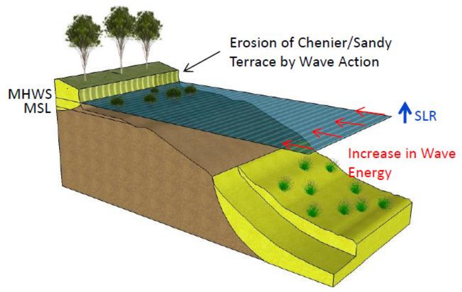
ST: See explanation for Type 8.
LT_{HIST}: See explanation for Type 1, 3 and 8.
LT_{FUT}: See explanation for relevant hard or soft rock material.</td></tr>
</table>

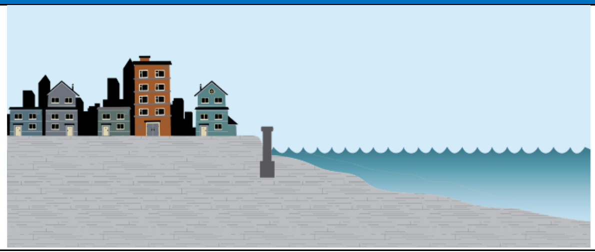
Type		Description (backshore with intertidal)	Conceptual Model for Shoreline Type	Conceptual Model Sea Level Response	Method for Erosion Hazard Estimation
		Bluff with Shore Platform  Can include hard or soft rock materials	These shorelines are comprised of bluffs of deeply weathered regolith that have been isolated from direct marine influence by the accumulation of sand and gravel beach ridges and plains. Many of the existing bluffs may have existed as active marine cliffs during the mid-Holocene higher sea level still stand. Due to their isolation from the marine influences, they are currently not experiencing active coastal erosion. These shorelines generally have a high degree of local variability and complexity associated with the underlying structure of the geologic formations and associated shore platforms as well as the width of the sandy platform beach and plain.	material comprising the base of the bluffs along sections of these shorelines. Failure of the cliffs could then be initiated. The proposed conceptual response models are currently being reviewed.  Figure 3-41 Platform Beach Shoreline Sea Level Rise Response Mechanism  Figure 3-46 Marginal Bluff Reactivation Sea Level Rise Response Mechanism	
6		Slope shorelines can include several variants:  • Slope with Beach and/or Platform • Slope (could be landslide or Valley) • Landslide slope	Similar to bluff described above but slope has failed and may or may not be actively impacted by coastal processes. The beach volume is important as a buffer to wave interaction on the slope/landslide. These sections have been grouped together due to likely similar responses to coastal processes and sea level rise.	Stability will be affected by the intersection of the tidal elevations and storm levels with the backshore.	Compound sector. If extreme water levels impact base of slope or the beach hazard overlaps the slope, then treat as a cliff. May be soft or hard rock but generally assumed soft rock unless stated explicitly otherwise within CGS description. **ST:** See explanation for Type 8. **LT_{HIST}:** See explanation for Type 1, 3 and 8. **LT_{FUT}:** See explanation for Type 3.
7		Low earth cliffed shorelines – this can include several variants including: • Low earth cliff (sand) with beach	Historically and presently undergoing active shoreline recession.	These shorelines are highly susceptible to future sea level rise impacts. Current rates of shoreline recession could be expected to increase significantly with sea level rise as the duration and depth of tidal inundation across the broad intertidal mud flats fronting these	Same approach as for Soft Rock Cliffs but rates of erosion are likely to be much higher. Use historic aerial imagery to derive trends for these areas. In some locations a levee has been built along these features which will be considered within the hazard mapping.

Type		Description (backshore with intertidal)	Conceptual Model for Shoreline Type	Conceptual Model Sea Level Response	Method for Erosion Hazard Estimation
		• Low earth cliff (peat/alluvium/organic) with/without beach	 Figure 3-3 Low Earth Cliff Conceptual Shoreline Type	shorelines will enable very significant increases in the amount of wave energy expended on these low cliffed shorelines to occur. Significant increases in the rates of future shoreline recession are projected for these shorelines. Where sea level rise results in frequent, tidal backshore inundation, the persistent flood and ebb tide flows through failed levees and/or natural depressions in the backshore landscape could be expected to result in relatively rapid dissection of the shoreline as tidal channels develop and expand in response to the extent of backshore inundation generated by tidal water level variations along these shorelines. The following conceptual response model was developed for the low earth cliffs along the Lang Lang coast of Western Port bay. This is currently being adapted to reflect the morphology in Andersons Inlet.  Figure 3-22 Low Earth Cliff Sea Level Rise Response	
8		Sandy Shoreline – includes several variants including: Sandy Ridges / Dunes, Sand Plains and Sandy Spits 	Sandy shorelines can be grouped into several categories including beach and dune ridges, as well as sand plains and spits. **Beach and dune ridges - t**hese landforms may vary from accreting to eroding over time depending on the local coastal processes. Short term erosion is associated with storm events, while swell waves return the eroded sand to the beach. Longshore transport may modify these conditions. Longer term erosion occurs as the result of an imbalance in the sediment budget for the beach/dune system. The presence of calcarenite sections within these features along the ocean shoreline south of Point Smythe will reduce the rate of	**Beach response model** The Bruun Rule predicts a landward and upward displacement of the cross-shore sea-bed profile in response to a SLR as follows: $R = L*S/(B+h)$ (1) where h is the depth closure, B is the elevation of dune or berm above mean sea level, S is the mean sea level change and L is the distance from the berm crest to the h location. This formulation is based on the assumption of a balance system between the sediment budget of the nearshore and bottom profile (Bruun, 1988). In this way, the shoreline retreat can be easily quantified from the landward displacement of the actual shoreline location but assuming the profile shape remains unchanged.	Compute and combine the **ST, LT_{HIST}** and **LT_{FUT}** for sandy shores relevant approaches depending on the form of the sandy shoreline. **ST:** storm erosion calculation **LT_{HIST}:** Aerial imagery is used to determine historic rates of change **LT_{FUT}:** Select and apply appropriate response model **Sandy Spit type landforms** (e.g. Point Hughes and Point Smythe) are a main feature of this study area and their response to sea level rise is likely to be complex and difficult to predict. A key aspect of this study is to develop an enhanced understanding of the key drivers and processes from Flat Rocks to south of Point Smythe so that we can identify likely future responses with greater certainty. It is likely we will develop a new conceptual model specific to this area.

Type		Description (backshore with intertidal)	Conceptual Model for Shoreline Type	Conceptual Model Sea Level Response	Method for Erosion Hazard Estimation
			erosion and will likely need to be considered individually for the hazard assessment. **Sand plain –** represents a low relief feature in Andersons Inlet that is the remanent of relict spit development. These areas are now located along the inner margin of the spit formed by Point Smythe and are susceptible to erosion through movement of the estuary channels. There may be some longshore sand transport and intermittent supply of sand from Point Smythe. **Sandy spit** landforms are particularly young, with the majority of these shorelines only forming following the Holocene marine transgression approximately 10,000 years ago. The combination of their young age, unconsolidated geology and sediment transport associated with waves and tides is such that these shorelines are exceptionally dynamic geomorphologic environments. The conceptual model for the sandy spit shorelines in Western Port bay is presented below. At Inverloch/Point Smythe there are also additional drivers than those presented below. The sandy spit complex at the Inlet entrance is influenced by a range of different factors.  Figure 3-7 Sandy Spit Conceptual Shoreline Type Doumtsis (2020) developed a preliminary conceptual model of the sediment transport pathways and hydrodynamic forces across the Inverloch and Point Smythe coastline which provides a starting point for this project. A major outcome of this study will be a refined conceptual model for this area.	 Figure 3-58 Conceptual Model of Equilibrium Profile Recession along a Sandy Shoreline as a Result of Sea Level Rise **Dune Ridge** Response – the response of coastal dunes to sea level rise will vary, influenced by the elevation and continuity of the dune crest (Donnelly 2007; Larson et al. 2009). For low or discontinuous dune systems, sea level rise may increase the risk of dune breaching. On larger dune systems, potential erosion of the dune toe can undercut dune vegetation, instigating wind-blown dune mobility. Dune mobilisation causes sediment to move landward, which can lead to loss from the beach and inshore system, contributing to coastal erosion. **Sand Plain** – effectively this shoreline acts as a low earth cliff formed from sandy material. It is exposed to limited wave action and increasing currents as the inlet channels migrate. The stability and response of these areas to sea level rise will be assessed further during the study and the appropriate conceptual response model developed or selected. **Sandy spit** shorelines - potential future rates of change and coastal hazard impacts along these shorelines will reflect the underlying variability associated with the key morphological drivers (yet to be defined at Inverloch/Point Smythe) and as a response to sea level rise. Therefore, the current conceptual response model is highly uncertain. It is highly likely that conventional sandy shore response models (often referred to as "equilibrium shoreline response models") will not be applicable.	

Type		Description (backshore with intertidal)	Conceptual Model for Shoreline Type	Conceptual Model Sea Level Response	Method for Erosion Hazard Estimation
			 **Figure 60** | Conceptual model of the sediment transport pathways and hydrodynamic forces across Inverloch coastline and Point Smythe coastline Note: circles identify the reworking of sand around the ebb-tide channel (blue) and around the flood-tide delta (purple).		
9		Estuarine and Tidal Channels – includes a number of variants including:  • Estuary • River or Creek mouth • Drains (constructed) • Drainage Line (natural feature)	 Figure 3-8 Estuarine and Tidal Channel Conceptual Landform This shoreline type represents a wide grouping of shoreline features principally associated with tidal creeks, drains and estuaries. For the purposes of this study they have been grouped together, due to their similar likely response mechanisms to sea level rise. The key characteristic of this shoreline type is the presence of a tidal or estuarine channel(s) that cuts perpendicular across the shoreline. These types of channel link the coastal systems to backshore areas and can extend considerable distances landward of the main shoreline. Present conditions with relation to erosion of these systems are site specific.	Where the elevation of the backshore areas is such that sea level rise may result in tidal variations through the estuarine or tidal channels this may result in large backshore areas becoming tidally inundated. With increasing frequency of inundation in these backshore areas new shorelines could be expected to develop at the advancing tidal limit. Lowering of stream gradients along the lower reaches of drains and estuaries due to sea level rise may also result in variations in the channel alignments due to the development of more frequent and larger amplitude meanders. Increased headcutting and expansion of the tidal channel network may also be a consequence of sea level rise.  Figure 3-64 Response of Estuarine and Tidal Channel Geomorphic Landform to Sea Level Rise	Our current ability to predict future response of these shorelines to sea level rise is limited. Tidal channel dimensions (excluding constructed channels such as drains) are determined by the tidal exchange that flows through them, which is a function of tidal range and hypsometry (Zhou et al 2018). Sea level rise increase the tidal exchange and expands the tidal prism. The projected response of the tidal channels is expansion, proportional to the change in tidal prism. An initial linear expansion can be assumed and the sensitivity to this tested. An indication of the possible extent of future tidal channels will be mapped as the hazard extent however there remain considerable uncertainties regarding this predicted response.

Type		Description (backshore with intertidal)	Conceptual Model for Shoreline Type	Conceptual Model Sea Level Response	Method for Erosion Hazard Estimation
				For specific estuarine forms, the likely response to sea level rise reviewed depending on their form and the appropriate response model selected. Khojasteh, Glamore, Heimhuber and Felder (2020) provides a useful review of potential sea level rise impacts on estuaries.	
10		Coastal Wetlands Fringed Shoreline  Can include tidal channels colonised by mangroves – check how frequently these shorelines occur. May have a sandy shoreline seaward of the wetland and so the sandy shore response must be considered.	 Figure 3-2 Coastal Wetland Conceptual Shoreline Type Coastal Wetland Fringed Shoreline - largely comprising coastal saltmarsh and mangroves. In Andersons Inlet these shorelines have been significantly altered by the proliferation of Spartina which has modified the wetland system.	Particularly sensitive to sea level rise as mangroves and saltmarsh can only survive in a relatively narrow range of inundation regimes and the saltmarsh-mangrove depositional terrace generally has a very low gradient, such that relatively small absolute changes in mean sea level results in large relative changes to the frequency and extent of inundation across the terrace. The response models below were developed for the Western Port LCHA and are in the process of being refined for the Anderson Inlet study area. New literature on the topic is also being reviewed.  Figure 3-16 Intermediate Mangrove Retreat into Saltmarsh SLR Response  Figure 3-17 Back Shore Erosion Ultimate SLR Response	Assessed in terms of the landward migration of vegetation and intersection of relevant tidal plane extent (MHWS) for given SLR increment. These is also likely to be seaward migration of the mangroves until the rate of sea level rise exceed their response ability. We are currently reviewing the latest understanding of mangrove response rates for Victorian sites and will use the most up to date understanding. If sandy shore seaward: Calculate beach hazard as for Type 10. Assessed in terms of the landward migration of vegetation and intersection of relevant tidal plane extent (MHWS) for given SLR increment.
11		Engineering effective & ineffective to be assessed individually based on the structure itself and the backshore/intertidal morphology			

Type		Description (backshore with intertidal)	Conceptual Model for Shoreline Type	Conceptual Model Sea Level Response	Method for Erosion Hazard Estimation
					

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.
					Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 2 - Data Assimilation and Gap Analysis, Victoria, June 2022.	
					Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 3 - Technical Methodology , Victoria, June 2022.	
					Rosengren, N. & Miner, T., 2021, Inverloch Region Coastal Hazard Assessment – Coastal Geomorphology, Appendix A in Water Technology 2022c, Inverloch Region Coastal Hazard Assessment Report 3: Technical Methodology, Victoria, 2021.	
					Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 4 - Coastal Processes and Erosion Hazards , Victoria, June 2022.	
					Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 5 - Inundation Hazards, Victoria, June 2022.	

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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