Final Report

Inverloch Region Coastal Hazard Assessment – Inundation Hazard Assessment

Department of Environment, Land, Water and Planning

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EXECUTIVE SUMMARY

Water Technology has been commissioned by DELWP to undertake the Inverloch Region Coastal Hazard Assessment (CHA), a key piece of work of the Inverloch Regional and Strategic Partnership (RaSP). The Inverloch Region CHA covers the coastline from east of Cape Paterson to west of Cape Liptrap (the Cape to Cape region), including the coastline within Anderson Inlet.

This report details the coastal and catchment processes and coastal drivers which drive coastal inundation in the Study Area. The report also describes the potential impact of coastal inundation into the future and the influence of climate change on coastal inundation. The impact of the coastal inundation and current and future inundation hazard zones are presented and discussed within the report.

This document is Report 5 of a series of reports produced as part of the Inverloch Region Coastal Hazard Assessment project. It should be read in conjunction with the following documents prepared for the CHA:

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

The following sea level rises, planning horizons and storm events were assessed to determine coastal inundation hazard zones in the Study Area.

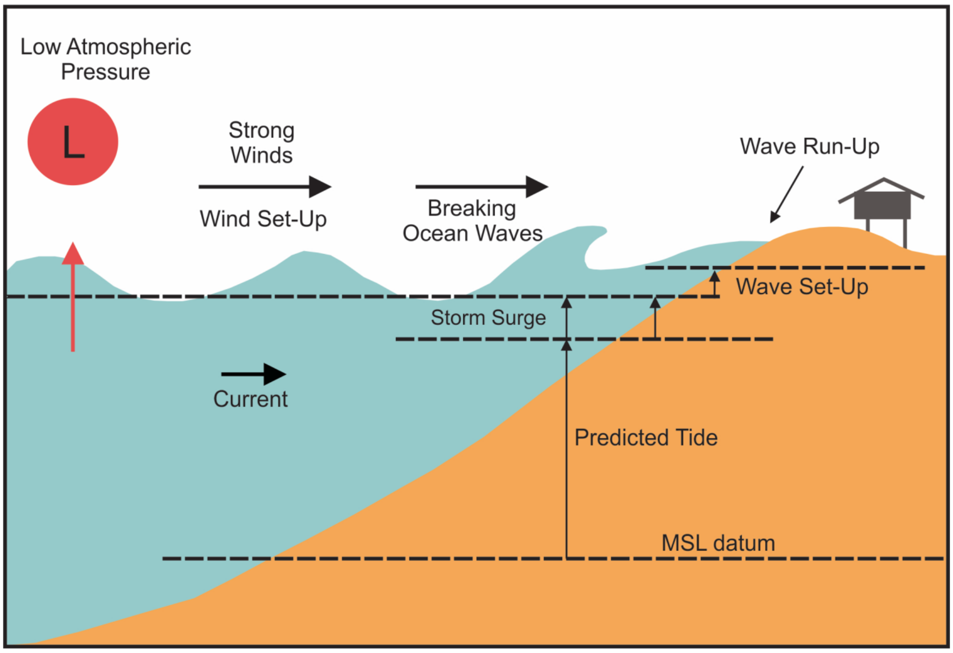
Seal Level Rise	Planning Horizon	Design Storm Events
Nil	2020	1%, 5%, 10% (20% AEP run-off was assessed for the urban catchment)
0.2 m	2040	
0.5 m	2070	
0.8 m	2100	
1.1 m	2100	
1.4 m	2100	

Inundation Processes

Flooding and inundation within the Study Area can result from increased water levels driven by coastal (ocean) processes or catchment (land) processes.

Coastal Inundation Processes

Coastal water levels are the sum of a range of different phenomena such as mean sea levels, astronomical tides, wind setup, wave setup, atmospheric pressure, and other oceanographic variations. The different water levels and components which make up the total water level are presented in the total coastal water level conceptual diagram below.



Mean Sea Level

The mean sea level within the Study Area was reviewed using available measured data. Mean sea level offshore within Bass Strait was found to be approximately 0.05 to 0.1m AHD, derived from long term measurements at Stony Point (0.07 to 0.08m AHD) and the hindcast model of the Study Area (0.04m AHD).

Mean sea level within Anderson Inlet was determined through measurements captured by the Study over a 14 month and 9 month period from May and December 2020 to mid 2021 for Inverloch Jetty and Tarwin Lower Jetty respectively. The mean sea level at Inverloch was 0.2m AHD whilst the mean sea level at Tarwin Lower jetty was 0.5m AHD, however it is noted that the mean sea level at Tarwin Lower is subject to varying baseflow in the Tarwin River which can result in higher mean sea levels during winter compared with summer months.

Astronomical Tides

The astronomical tides within the Study Area were derived from the same datasets as the mean sea level, i.e. the model hindcast for the offshore waters and the measured data within Anderson Inlet. The mean high water springs was relatively consistent throughout the study area, at 1.07m AHD offshore and 0.95m AHD within Anderson Inlet. The spring tide range was limited within the Inlet by the narrow entrance with the offshore spring tide range of 2.1m reducing to 1.5m at Inverloch Jetty and 1.0m at Tarwin Lower Jetty.

Storm Surges

Storm surges within the Study Area are driven by meteorological forcing such as the inverse barometric pressure effect, wind setup and coastal waters which generate coastally trapped waves along the southern margin of the continental Australian landmass.

Storm surges have been measured at Stony Point in Western Port and storm surges in Venus Bay are driven by the same processes. Numerical modelling of the Study Area was used to estimate storm surge magnitudes and indicate meteorological forcing and the resultant surges within Venus Bay can peak over 1.0m under extreme conditions, comparable with those measured at Stony Point, and greater than the previous 1% AEP storm surge predicted by McInnes et al (2009).

Extreme Offshore Water Levels (Storm Tide)

The extreme (or design) offshore water level driven by ocean processes has been determined by extreme value analysis of hindcast water levels. The present day and future storm tide levels are presented in the table below.

Venus Bay Offshore	Level (m AHD) (±0.05)
10% AEP	2.0
5% AEP	2.1
1% AEP	2.2

Wind Setup (Anderson Inlet)

The action of wind on the water surface creates shear stresses that can drag water in the downwind direction. In shallow depths and/or intertidal areas such as Anderson Inlet, the rate at which water is transported downwind exceeds the rate at which it can return under gravity and an increased elevation of water levels is observed at downwind locations. This is the **wind setup**.

Numerical modelling of wind setup within Anderson Inlet indicated this can increase the water level above the offshore storm tide by between 0.05m and 0.4m under strong westerly winds within the Inlet.

Wave Setup

Waves breaking on a shoreline can result in further increase in water levels shoreward of the surf zone. This is the **wave setup**. Large wave conditions and significant wave setup is limited to the open coastline in the Study Area. Wave penetration into Anderson Inlet is limited by the entrance bars and tidal flows.

Wave conditions offshore are more exposed, and the 1% AEP significant wave height derived from model hindcast is in the order of 6.6m. Wave setup across the Study Area varies with the different beach and wave types, e.g. spilling across the rock platforms along the Bunurong Road or surging up the steep beach/dune on Venus Bay. Numerical modelling of wave setup indicates wave setup can increase the coastal water level above the still water level by between 1 – 2m.

Catchment Processes

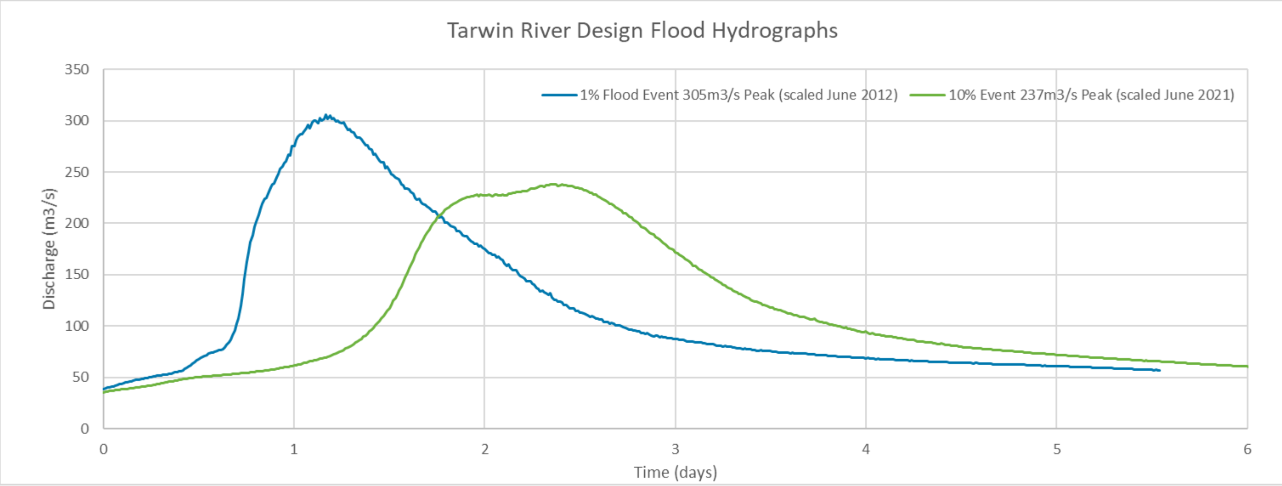
Intense and/or prolonged rainfall in the catchment produces flood flows which can affect low-lying areas adjacent to the coast. The Tarwin River is the main catchment outfall within Anderson Inlet; however, the smaller waterways of Pound Creek, Screw Creek and Ayr Creek also contribute to additional flow into the Inlet. Catchment processes contributing to coastal inundation are limited to the low lying coastal areas adjacent to Anderson Inlet and around the Inverloch township.

Catchment Description

The total catchment area of Anderson Inlet is approximately 1,200 km^2, 90% of which is the Tarwin River catchment. The Tarwin River catchment has been largely cleared for agriculture, whilst some native forests remain in the upper catchment within the Strzelecki National Park.

Tarwin River Flow

The most downstream flow gauge on the Tarwin River is at Meeniyan, approximately 40km upstream of Anderson Inlet. The gauge has been active since 1955 and provides flow and level data for a number of significant events over that period. The maximum peak flow event was recorded on June 23rd 2012 at 301 m^3/s, close to the calculated 1% AEP flood discharge of 305 m^3/s. Design flood hydrographs are shown below. The 10% AEP peak flow discharge is 237 m^3/s.



Inverloch Urban Drainage

Hydrological runoff-routing was used to inform the peak catchment flow draining through the Inverloch township from the Screw Creek and Ayr Creek catchments, in addition to the urban runoff generated within the township. Peak flow hydrographs and hyetographs were extracted from the hydrological model and used as an input to a 1D/2D hydraulic model which simulated the urban overland and channel/pipe flow (runoff-routing) in combination with the storm tide.

Coastal and Catchment Flooding Coincidence

The coincidence of a significant offshore storm tide and a catchment flood has been considered in the Study. The combination of the 1% AEP offshore storm tide and the 5% or 10% AEP catchment flood, and the 10% and 5% AEP offshore storm tide with the 1% AEP catchment flood is considered appropriate for the Study Area. This is based on the Australian Rainfall and Runoff (AR&R) guidelines (Book 6, Chapter 5, Ball et al. 2019). A review of measured at Stony Point to review coincidence of storm surge residual and peak flood flows within the Tarwin River, and an earlier analysis undertaken for the previous Tarwin River flood study (Water Technology, 2007) also supports the selection of these event combinations.

The sensitivity of resultant modelled flood levels to the assumed event combinations was reviewed and showed flood levels across the inlet are dominated by the offshore storm tide water levels, particularly under future sea level scenarios. The inundation hazard levels showed negligible change in flood extents for the different catchment AEP events.

Existing Inundation Protection Works and Structures

Extensive levees have been constructed around Anderson Inlet over the past century to convert tidal floodplains and marshlands to agriculture land. Over 50% of the coastline of Anderson Inlet is surrounded by levees, varying in crest level from 1.7m AHD to close to 3.5m AHD. The quality and condition of the levees vary across the Inlet and the majority are located on private land (Water Technology 2018).

The inundation assessment has assumed that the levee condition, specifically the crest elevation and the physical presence of the structures, remains constant over the flooding events and planning horizons. It is noted that due to the restrictions of movement during the COVID-19 pandemic, the amount of field inspection that could be completed for the study, especially across the floodplain and levees is less than planned. Survey and inspection of structures and drains through levees has not been able to be completed and thus are not included in modelling of the Inlet or floodplains.

Coastal Inundation Hazard

Further details of the approach to determining coastal inundation hazard can be found in *Inverloch Region Coastal Hazard Assessment – R03 Methodology*, Water Technology 2022.

Three methods for determining coastal inundation were used to assess the different exposure environments within the Study Area:

- Open Coast: Storm Tides + Wave Setup
- Anderson Inlet: Catchment Inflows + Offshore Storm Tides
- Inverloch township: Catchment Inflows + Rainfall + Storm Tide Tailwater

The present-day design coastal and catchment storm and flood events modelled are presented in the table below.

Design Event	Offshore Storm Tide (m AHD)	Offshore Significant Wave Height (m)	Offshore Peak Wave Period (s)	Tarwin River Peak Flow (m^3/day)
1% AEP	2.2	6.6	14.6	305
5% AEP	2.1	6.1	14.2	-
10% AEP	2.0	5.9	13.9	237

Open Coast

Coastal inundation on the open coast (Bunurong Road pocket beaches, Flat Rocks to Point Norman and the Venus Bay coastline from Point Smythe to Cape Liptrap) is caused by the elevated still water level and the wave energy running up or overtopping the coastal dune. To establish the maximum water level, the SBEACH coastal numerical model was used to simulate the design storm conditions across the local beach profile, as detailed in Report 3.

The total coastal water level varied across the Study Area with exposure to waves, and nearshore and dune topography. A summary of the total coastal water level (i.e. offshore storm tide plus wave setup) is provided for sections of the Study Area below.

Study Area Section	Total Coastal Water Level (Existing Mean Sea Level)		
	1% AEP Storm	5% AEP Storm	10% AEP Storm
Bunurong Road	3.5 – 4.3	3.3 – 4.1	3.2 – 4.0
Flat Rocks – Point Norman	3.3 – 3.6	3.0 – 3.5	3.0 – 3.3
Point Smythe – Cape Liptrap	3.4 – 4.2	3.3 – 4.1	3.2 – 3.9

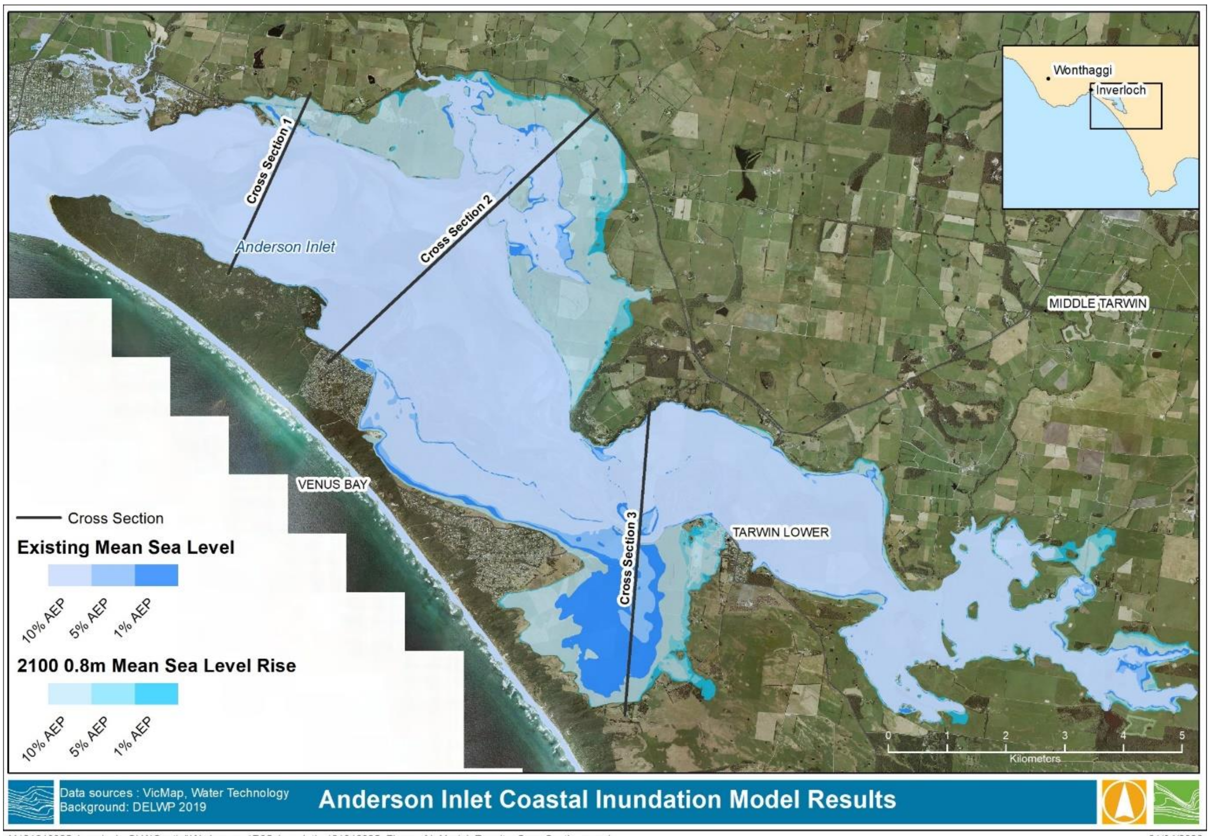
Anderson Inlet

Coastal inundation within Anderson Inlet is caused by the offshore elevated water levels propagating into the inlet at the entrance and the catchment flow from the Tarwin River (and Pound and Screw Creeks) flowing into the upstream end of the Inlet. The wide and long expanse of the Inlet also allow winds to force water against the shoreline during flood events.

A numerical model was established to simulate these processes within Anderson Inlet. Details of the numerical modelling is provided in Report 3.

The flood extents of the 1%, 5% and 10% AEP storm tide events, combined with the 10%, 1% and 1% catchment events respectively, under existing mean sea level and with 0.8m of mean sea level rise are shown below. Inundation across the Inlet floodplains increases significantly as mean sea level increases. The change in flood extent between the different combined design events is more limited with the exception of the area between Tarwin Lower and Venus Bay Settlement 1 (Cross Section 3 in the figure below) where the inundation extent under existing mean sea level significantly increases between the three simulated scenarios.

The duration of inundation is limited by the duration of the peak of the storm tide, however the flooding caused by the overtopping or backflow around levees results in water landward of a levee which may take longer to drain off the catchment.



Inverloch

Flooding within Inverloch from direct coastal inundation is limited to the low lying areas around Screw Creek and Wreck Creek where there is also limited stormwater drainage. The Ayr Creek catchment is steeper with limited low lying areas consequentially limiting areas exposed to coastal flooding.

Localised flooding can occur within the town where the elevated coastal water levels prevent the free drainage of the stormwater system. This is particularly evident around Wreck Creek where the topography is lower and stormwater network drainage is also limited in the area. Flooding as a result of elevated coastal water levels is also observed around the Inverloch Jetty and boat ramp and Screw Creek / Broadbeach Estate.

Prediction of future flooding associated with Wreck Creek is complex. Currently, the dunes protect the backshore areas from direct coastal inundation but on-going existing erosion and predicted future erosion will likely reduce or completely remove these dunes allowing direct inundation to occur.

Inundation Hazard Zones

The coastal inundation hazard zones are presented in the mapping in Appendix A.

Groundwater Hazard

A preliminary high level assessment of groundwater hazards was undertaken to assess how sea level rise is likely to influence coastal groundwater aquifers and to identify any key issues warranting further assessment beyond the scope of this project.

Groundwater Processes

Where unconfined groundwater exists near the coast a hydraulic connection with sea water exhibits an interface between the less dense freshwater sitting above, and adjacent to, a wedge of salt water. As the salt water is denser than the fresh water it moves in this form beneath the fresh water. This wedge of salt water can occur on the landward side of the coastline and can extend from metres to several kilometres beneath the freshwater system (Ivkovic et al, 2012). Mixing occurs between the freshwater and saltwater at the interface of the two, with the position and width of the interface zone depending on the particular hydrogeological and hydrological conditions.

During a tidal cycle the location of the interface can vary depending on the sea level; with the interface moving inland at the high tide and then retreating seaward on the ebb. The result is that on areas such as tidal flats, there can be a layer of saline groundwater beneath the near-shore vegetation communities during the high tide which is displaced by fresh groundwater as the tide retreats. The magnitude of these changes is strongly dependent on the level of hydraulic connection between the aquifer and the sea and the geological properties of the aquifer such as permeability.

Climate Change Impacts

Climate change has the potential to affect groundwater systems through a number of different mechanisms which influence the recharge processes for groundwater system (e.g. changes in rainfall and intensity or temperature and subsequent vegetation changes and so on).

This study has focused on the impact of seawater intrusion into the coastal groundwater system and how the current groundwater hazards may be impacted as sea levels rise. The following key potential hazards are identified:

- Landward migration of the freshwater-saltwater interface
- Permanent surface inundation of low-lying coastal regions and/or increase in the frequency and intensity of temporary inundation resulting in intrusion of salt water into freshwater reserves
- The time required for the freshwater-saltwater transition zone to reach a new equilibrium with sea level rise

Groundwater in the Study Area

The area from Tarwin Lower to the coastline and the sand spit to Point Smythe is designated as the Tarwin Groundwater Management Area. The groundwater extraction and licensing in this area is regulated by the Southern Rural Water Corporation who consider the groundwater resources in the Tarwin Groundwater

Management Area to be finite and at risk if extractions exceed permitted levels. Groundwater use and risk as a resource is considered low for the remaining land in the Study Area.

Aquifers in the Study Area comprise mainly of the Quaternary sedimentary aquifers associated with the fluvial and alluvium sediments, paludal lagoon and swamp sediments, and aeolian coastal and inland dune sand sediments deposits. The Haunted Hill and Basement aquifers become more extensively utilised further away from the coastline study area.

Drillhole information from monitoring bores at the two Venus Bay settlements indicate silty sand and shell material exists to around -40m AHD where limestone and clay deposits are encountered. Groundwater is thus likely to be unconfined along the coastal interface.

A large number of bores exists within the study area, the majority of which are for water supply, especially in the Venus Bay settlements where groundwater bores are used for non-drinking purposes. Groundwater yields within the Study Area vary between 1 and 10L/s.

The depth to the groundwater table has been estimated using this bore data and the groundwater is noted to be 5m – 6m below ground level (m bgl). The depth is less than 1m across the low lying floodplains of the Tarwin River, Screw Screek and Pound Creek areas, coinciding with areas likely to be inundated during flood events.

Groundwater flow is generally interpreted to flow towards the ocean in a south to south--west direction, supported by groundwater levels measured within bores located within the Study Area. Over the past 30 years groundwater levels within the Tarwin Groundwater Management Area have displayed relatively stable trends from year to year, with seasonal high groundwater levels at the end of winter and seasonal lows at the end of summer.

Sea Level Rise Impacts

An increase in mean sea level is generally likely to result in an increase in groundwater levels and salinity near the coastline.

Increases in groundwater salinity and quality may result in several existing bores becoming increasingly saline and therefore no longer suitable for human consumption. This would ultimately result in the need for affected users to potentially redrill, find a new suitable location, or new supply method to meet their water demands. Additionally, pumps may become damaged, need replacement or upgrading due as a direct consequence of damage caused by the increased salinity of the groundwater.

Additional groundwater hazards associated with sea level rises include:

- Increased groundwater levels; particularly in already shallow groundwater systems surrounding the Tarwin GMA.
- Increased salinisation of the Tarwin Groundwater resource and other surrounding groundwater resources.
- Increased dryland salinity due to rising groundwater levels being closer to the surface.
- Increased vegetation dieback due to rising groundwater levels closer to the surface.
- Rising sea levels may result in a geochemical shift in the Coastal Acid Sulphate Soils (CASS) from oxidising and acidifying, to reductive and neutralising. However, if groundwater extractions are shifted to another area that has not previously been extensively pumped, lowering of the local water table may occur and result in the oxidisation of CASS that have previously not been exposed to oxidising conditions.
- Increased erodibility of soils and sediments.

Summary

The coastal inundation investigation provides an enhanced understanding on the drivers of coastal inundation and the potential extent of flooding within the Study Area.

Coastal inundation is driven by elevated ocean levels above tide, combined in some locations with runoff from the catchment.

The spatial extent of inundation along the open coast is limited due to the elevated topography along Bunurong Road and the high sand dunes from Point Smythe to Cape Liptrap. Increases in mean sea level offshore will have little impact on inundation extent on the open coast (excluding Inverloch).

The catchment to Anderson Inlet is extensive and inflows from the Tarwin River can cause widespread flooding without the addition of elevated coastal waters. Tidal levees constructed over the past century within Anderson Inlet are unlikely to be sufficient to prevent flooding during combined future coastal and catchment extreme flood events and rising mean sea levels. Complete protection from elevated water levels is not provided by the levees under existing conditions and additional inundation over or around the landward extents of the levees is expected as sea levels rise across the coming century. However, the major residential areas within the Inlet at Tarwin Lower and Venus Bay are situated almost completely above the existing and predicted future coastal inundation extents for all scenarios assessed. Inundation is limited to agricultural land and some isolated properties, however the main roads connecting Tarwin Lower and Venus Bay to major services are likely to be inundated during existing and future 1% AEP inundation events.

The town of Inverloch is predominantly outside of the coastal inundation extent with the exception of areas around Wreck Creek and the residential area behind Surf Beach in the west of the town, around the Inverloch Boat ramp and jetty, and around the Screw Creek and Broadbeach Estate in the east which have previously been identified as vulnerable to inundation. The area around Wreck Creek is considered to be particularly vulnerable due to the recent erosion of the barrier dune along the coastline which currently limits direct coastal inundation of Wreck Creek and the residential area between Bunurong Road and the SLSC.

Assumptions, Limitations and Uncertainty

Prediction of future coastal inundation is complex with many forces and response mechanisms influencing the extent and likelihood of occurrence of inundation spatially and temporally. Best practice approaches have been adopted together with the latest knowledge and understanding to account for these complexities through rigorous analysis and sensitivity testing, however, there remains some limitations and uncertainty in both existing knowledge and assessment methods used to underpin the inundation hazard assessment.

Recommendations

The understanding of coastal inundation processes and impacts should be considered in any future works, development or strategic planning reviews or initiatives along the Cape to Cape region coastline. Report 6 and Report 7 of the CHA detail the coastal asset expposeure and the technical analysis of adaptation actions which build upon the work presented here.

Ongoing monitoring and additional future assessments can be used to continually update and improve model calibration and prediction of hazard zones. This includes topographic, bathymetric and sedimentary data, to feed into modelling of the estuary entrance and the dynamics of sediment transport on the Flat Rocks and Surf Beach coastline and the status of levee and drainage paths across the low lying areas around Anderson Inlet.

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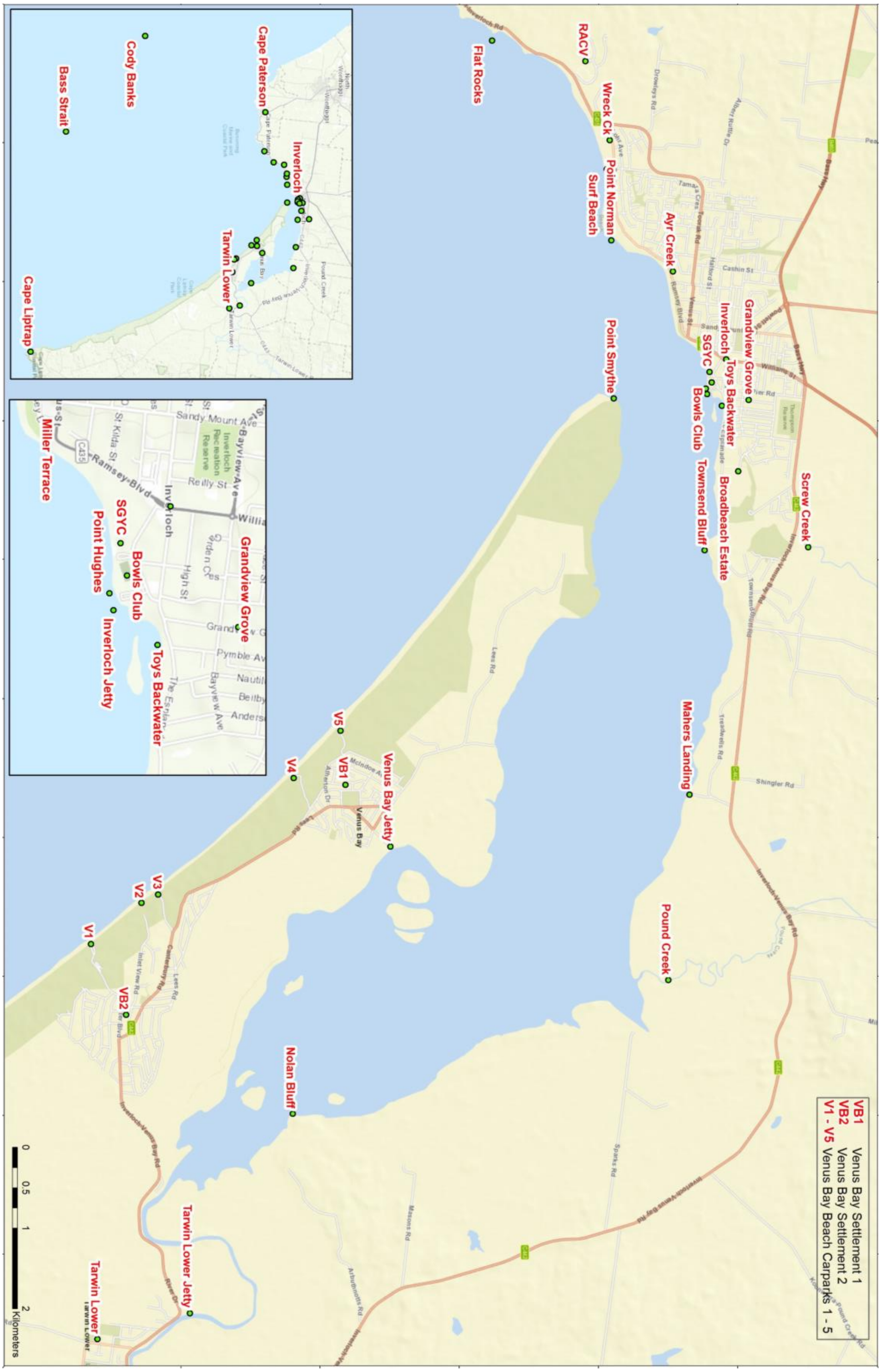
GLOSSARY

Term	Definition
Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be of extreme magnitude.
Astronomical tide	Water level variations due to the combined effects of the Earth's rotation, the Moon's orbit around the Earth and the Earth's orbit around the Sun.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10-year ARI flood is expected to be exceeded on average once every 10 years. A 100-year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main waterway.
Coastal Inundation Hazard	A term to collectively describe physical extent of flooding caused, or influenced, by coastal or oceanographic processes.
Design event	A design event is a probabilistic or statistical estimate, being generally based on some form of analysis of data. An average recurrence interval or exceedance probability is attributed to the estimate
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Erosion	The wearing away of the land through wind, wave or current forces. Often used interchangeably with recession, erosion is the loss of material rather than a landward shift of a feature. Generally considered as a short term or acute process or event.
Estuary	The seaward limit of a drowned valley which receives sediment from both river and marine sources and contains geomorphic and sedimentary conditions influenced by tide, wave and river processes
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e., flood prone land.
Geomorphology	The study of the origin, characteristics, and development of landforms
HAT	Highest Astronomical Tide
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, e.g., intertidal habitat

Term	Definition
Inundation	Flooding because of oceanic conditions is often referred to as inundation rather than flooding although the terms are interchangeable. In this guide the term flooding is used in preference to inundation.
LiDAR	Spot land surface heights collected via aerial light detection and ranging (LiDAR) survey. The spot heights are converted to a gridded digital elevation model dataset for use in modelling and mapping
MHWS	Mean High Water Springs, i.e., the mean of spring tide water levels over a long period of time.
MSL	Mean Sea Level.
Nearshore	The region of land extending from the backshore to the beginning of the offshore zone.
Ocean water level boundary	The ocean water level(s) used as the downstream boundary level for hydraulic modelling for a flood study in a coastal waterway.
Shoal	A shallow area within a water body; a sandbank or sandbar.
Sea Level Rise (SLR)	A permanent increase in the mean sea level.
Spring Tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean).
Storm Surge	The increase in 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.
Storm Tide	The combination of storm surge and astronomical tide.
Wave runup	This limit to which water from an individually breaking wave extending landward reaches. It is the combination of the wave setup and the swash uprush – the final flow of water up the beach front as the wave collapses.
Wave setup	The increase of mean water level at the beach front due to the momentum of waves breaking in the surf zone. Not the impact of an individual wave running up the beach (see wave run-up).
Wind setup	The increase in water levels caused by wind driving water towards the shore and piling it up against the coast.


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

1 INTRODUCTION

1.1 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 B.

This report details the coastal and catchment flood related processes which are present in the Study Area. The report also describes the potential impact of coastal inundation into the future and the influence of climate change on coastal inundation. The impact of the coastal inundation and current and future inundation hazard extents (defined as 'hazard zones') are presented and discussed within the report. Groundwater within the Study Area has been reviewed and a desktop assessment of potential hazards identified.

The results of the technical assessments, including this assessment of coastal inundation and identification of the coastal inundation hazard zones, will be used to inform the adaptation options analysis of the CHA (Figure 1-1).

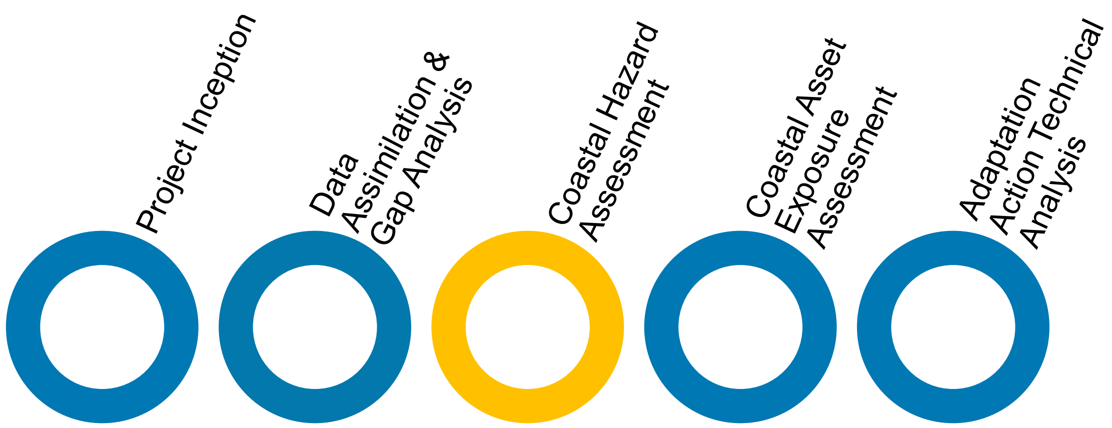


Figure 1-1 Inverloch CHA Project Phases

1.2 Study Area

The project study area extends from the eastern end of Cape Patersons 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.

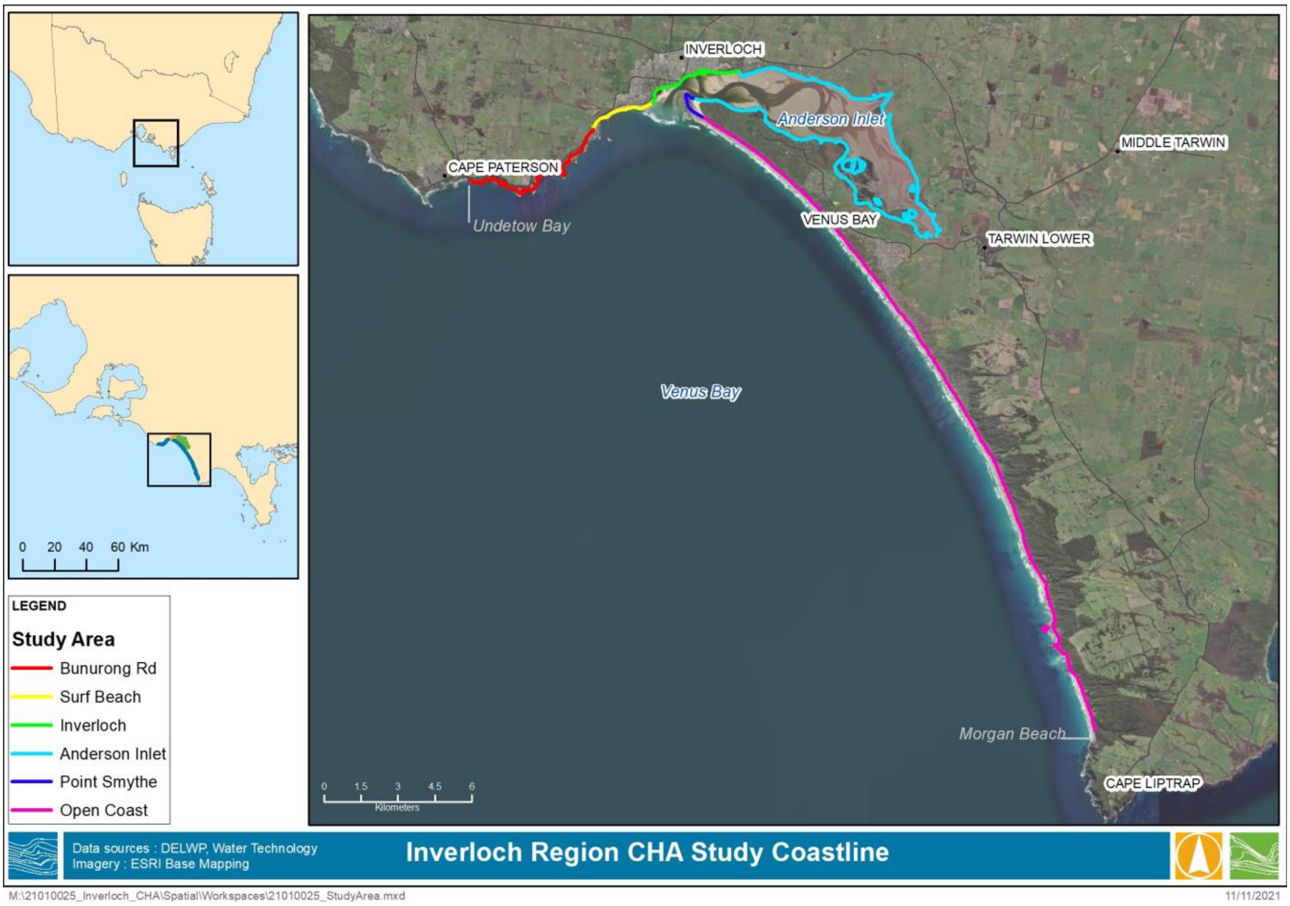


Figure 1-2 Study Area Coastline

1.3 Reporting

This report describes the coastal inundation drivers and the impact of the coastal inundation on the existing coastal area, including defining the current and future coastal inundation hazard zones. The report is structured as follows:

- Section 1 **Introduces the project** and outlines the scope of work,
- Section 2 describes the **Processes** which drive coastal inundation in the Study Area, including the meteorological, oceanographic and fluvial parameters.
- Section 3 summarises the **Approach** used to determine the existing and future coastal inundation within the Study Area and presents the **Coastal Inundation Hazard Zones** across the Study Area.
- Section 4 provides a high level assessment of **Groundwater Hazards** to identify areas where groundwater hazards are likely to occur.

- Section 5 **Summarises** the Coastal Inundation Hazard Assessment, notes the assumptions, liabilities and uncertainties inherent in the assessment and provides a guide on **How to use the Study Outputs** along with **Recommendations** for further work or assessment.

The following Appendices are attached to this report to provide additional information regarding the coastal inundation and impacts in the Study Area:

- **Appendix A** presents the **Coastal Inundation Hazard Mapping**

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

1.4 Study Parameters

Specific parameters have been adopted for the Study, as defined by DELWP. In particular, the sea level rise and the associated planning horizons used in this assessment have been selected based on the best available information and current planning policy. The sea level rise increments used in this study are presented in Table 1-1 with the associated planning horizon.

Table 1-1 Project Sea Level Rise to consider

Seal Level Rise	Planning Horizon
Nil	2020
0.2 m	2040
0.5 m	2070
0.8 m	2100
1.1 m	2100
1.4 m	2100

Along with sea level rise, the Study has been tasked with assessing the implication of different magnitude storm events on inundation extents. Storm events in the past have been described as a “1 in 10/20/50/100 etc” year event – the Average Recurrence Interval (ARI). However, this is misleading as the level of storm is determined through a probability analysis and the 1 in 100 year ARI event is actually reference to the likelihood of that event (or a larger event) occurring in any one year, with an Average Exceedance Probability (AEP) of 1%. The conversion and probability of any event occurring is presented in Table 1-2.

A likelihood of 1.00 is equivalent to there being a 100% probability this event will occur in the timeframe. Likewise, the table shows that the likelihood of having the 1% AEP extreme event in a 10 year period is 0.10 – i.e. there is a 10% chance that the 1% AEP event will occur in a 10 year period.

The 1%, 5% and 10% AEP storm events have been used to assess erosion hazard in the Study.

Table 1-2 Storm Events to consider and annual likelihood of occurring for a given exceedance probability

Annual Exceedance Probability (AEP)	*(Average Recurrence Interval, ARI)*	Likelihood of Event occurring within					
		1 year	5 years	10 years	20 years	50 years	100 years
	1	0.63	0.99	1.00	1.00	1.00	1.00
20%	*5*	0.18	0.63	0.86	0.98	1.00	1.00
10%	*10*	0.10	0.39	0.63	0.86	0.99	1.00
2%	*50*	0.02	0.10	0.18	0.33	0.63	0.86
1%	*100*	0.01	0.05	0.10	0.18	0.39	0.63
0.1%	*1000*	0.00	0.00	0.01	0.02	0.05	0.10

2 INUNDATION PROCESSES

2.1 Overview

Flooding and inundation within the Study Area can result from the interaction between a number of physical forcings and hydrodynamic processes, as shown in Figure 2-1. These processes can be described generally as coastal (from the ocean) or catchment (from the land) inundation processes. The following sections summarise the main physical forcing that can give rise to extreme water levels in the Cape to Cape region.

Additional detail on the coastal processes contributing to coastal inundation can be found in *Report 4 – Coastal Processes and Erosion Hazard* (Water Technology, 2022).

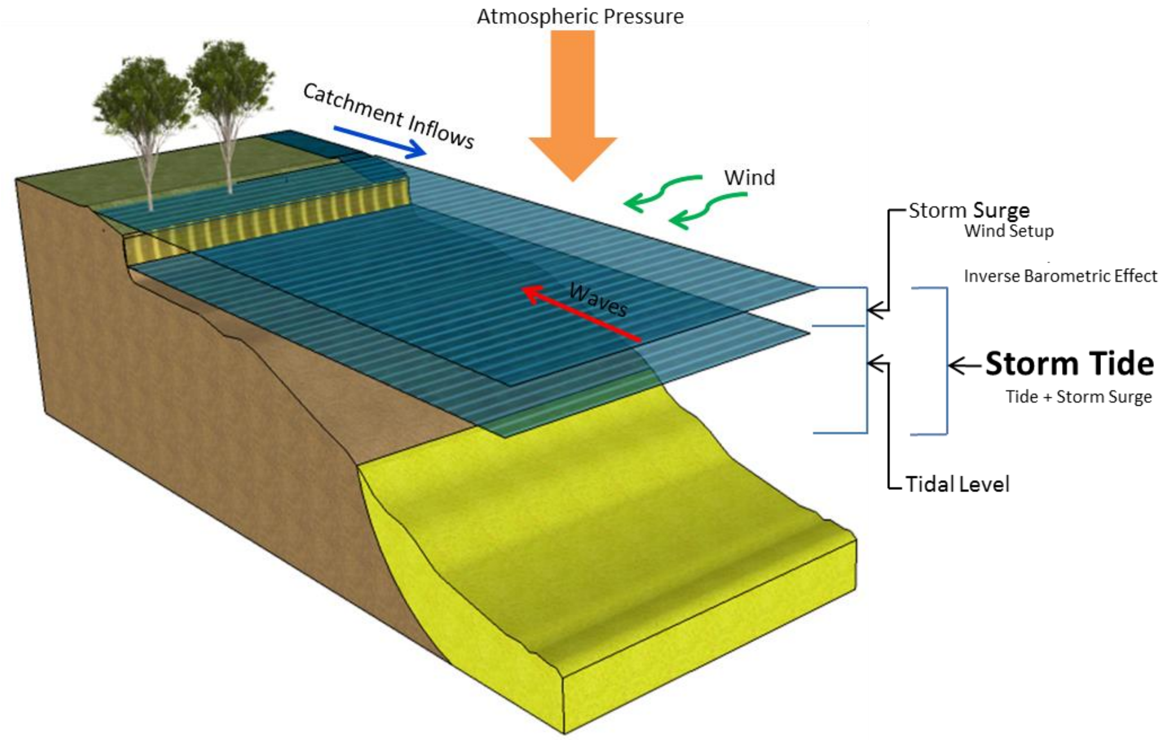


Figure 2-1 Processes Producing Elevated Coastal Water Levels

2.2 Coastal Inundation Processes

The processes driving **total coastal water level** variations relevant for assessing inundation hazards within the Cape to Cape region are described below. Variations in the coastal water level are caused not only by the astronomical tides, but also by phenomena such as wind setup, atmospheric pressure, oceanographic variations and wave setup. The different water levels and components which make up the total water level are presented in Figure 2-2.

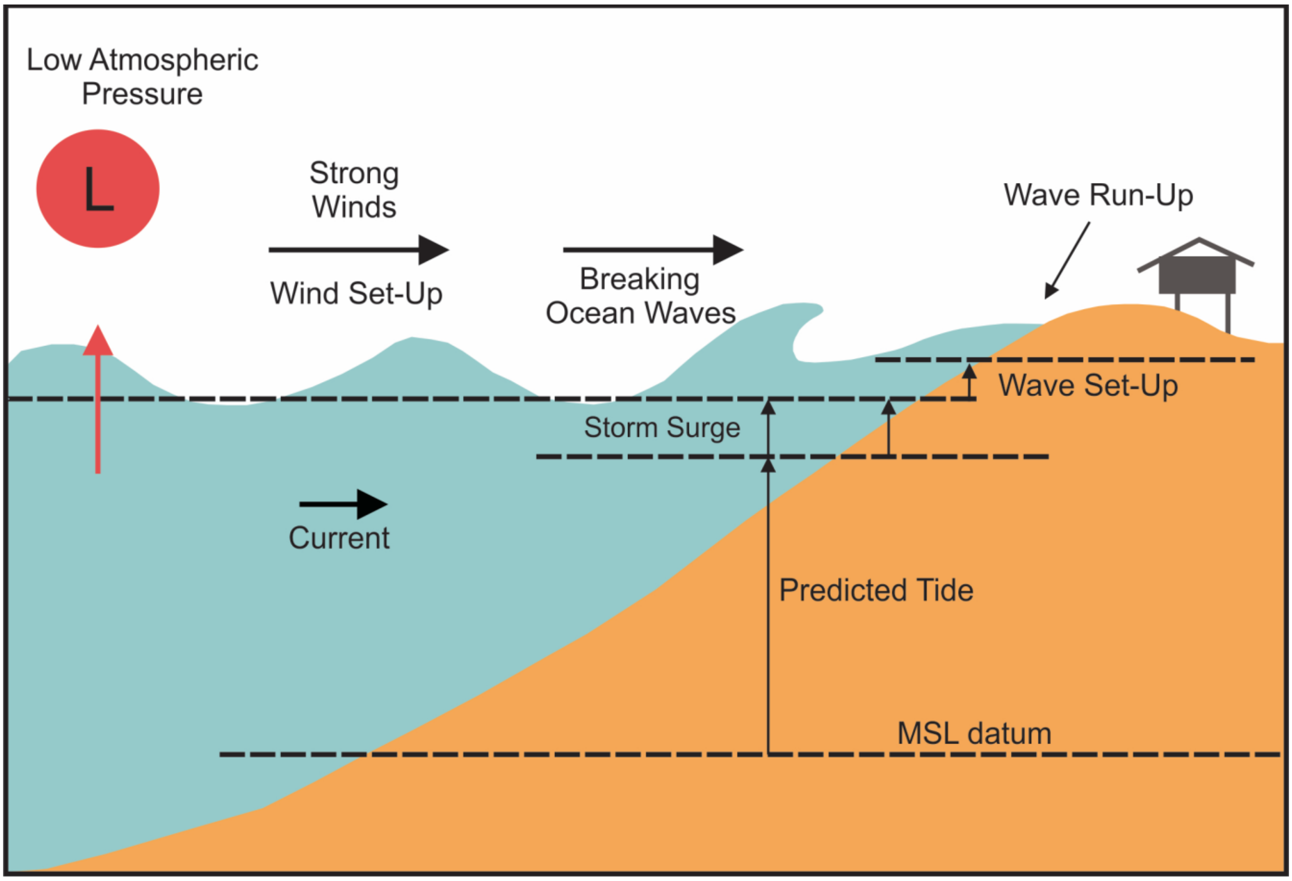


Figure 2-2 Components of the Total Water Level (Bush, 2019)

2.2.1 Mean Sea Level

The **mean sea level** within the Study Area has been assessed to understand the datum on which to apply sea level rises described in Table 1-1. The Australian Height Datum (AHD) was established in 1971 and based upon sea level observations from 1966-1968 at 30 locations around Australia. The level of 0.00m AHD was set to mean sea level at this time.

Mean sea level for key locations within the project area have been established and are presented in Table 2-1.

Mean sea level at Stony Point has been obtained from the Australian National Tide Tables which provides a mean sea level of 1.78m above LAT. The Stony Point Tidal Station metadata (BoM, 2010) notes the LAT is 1.69m below 0.00m AHD. Measured data from the Australian Baseline Sea Level Monitoring Program has also been analysed and the long term mean sea level, which varies over different timescales, is in the order of 1.77-1.78m LAT (i.e. 0.07 to 0.08m AHD).

Mean sea level for Venus Bay has been derived from an analysis of the hindcast water level simulated for the project. The model used offshore astronomical tidal boundaries with a residual from Stony Point added to incorporate the non-tidal water level component. The MSL at Venus Bay of -0.03m is relative to MSL at Stony Point and thus is also adjusted to Australian Height Datum by +0.07 to +0.08m AHD to be +0.04 to +0.05m AHD.

The mean sea level at Inverloch Jetty and Lower Tarwin Jetty are based on 14 and 9 months of measured data respectively. The tidal planes at Lower Tarwin had not reached an equilibrium during the data collection period, i.e. the harmonic analysis of the measured data continued to change as more data was collected, and changed notably with the seasonal influx of base flow from the Tarwin River. Tidal planes at Lower Tarwin may therefore be updated should additional data become available.

Table 2-1 Mean Sea Level within the Study Area

Location	Source	MSL
Stony Point	Australian Tide Tables (MSL above LAT) BoM LAT to 0 MAHD	0.07m AHD
Venus Bay (offshore)	40 year hindcast developed for project BoM tidal analysis	0.04m AHD
Inverloch Jetty	Gippsland Ports measured data (2020-2021) BoM tidal analysis	0.19m AHD
Lower Tarwin Jetty	Gippsland Ports measured data (2020-2021) BoM tidal analysis	0.46m AHD

2.2.2 Astronomical Tides

Venus Bay and Anderson Inlet experience water level variations associated with **astronomical tides** caused by the gravitational attractions between the Earth, Moon and Sun. Astronomical tides result in relatively high frequency diurnal (daily) and semi-diurnal (twice daily) water level variations that propagate across Bass Strait into Venus Bay and onwards into Anderson Inlet. The astronomical tides undergo further modifications within Anderson Inlet due to interactions with the entrance bathymetry and Inlet shape. Tidal planes within the Study Area are provided in Table 2-2 with further detail regarding astronomical tides provided in Report 4.

Table 2-2 Study Area tidal Planes

Tidal Plane	Venus Bay (Offshore)	Inverloch Jetty	Tarwin Lower Jetty
Highest recorded water level (date)	2.07 (7/11/1994)	1.86 (27/08/2020 17:32)	1.76 (28/07/2021 17:30)
Highest Astronomical Tide (HAT)	1.51	1.39	1.44
Mean High Water Spring (MHWS)	1.07	0.94	0.95
Mean Sea Level (MSL)	0.05	0.19	0.46
Mean Low Water Spring (MLWS)	-0.99	-0.57	-0.03
Lowest Astronomical Tide (LAT)	-1.59	-0.84	-0.29
Lowest recorded water level (date)	-2.07 (18/05/1991)	-1.15 (01/01/2021 20:36)	-0.56 (28/01/2021 21:54)
Source	BoM[3]	BoM[4]	BoM[5]

Notes: 3. Venus Bay tidal planes have been provided by BoM through analysis of model hindcast water levels generated for this study. These levels are intended for use in this study only.
4. Inverloch Jetty tidal planes have been generated by the BoM based on water levels measured by Gippsland Ports for this study at the Inverloch Jetty between May 2020 and July 2021.
5. Tarwin River Jetty tidal planes have been generated by the BoM based on water levels measured by Gippsland Ports for this study at the Tarwin Lower Jetty between November 2020 and July 2021.

2.2.3 Storm Surges

Additional coastal water level variations, also known as the **residual water level**, propagate into the Study Area associated with:

- meteorological forcing due to:
  - the inverse barometric pressure effects, and
  - wind stress; and
- the interaction of weather systems and coastal waters which generate coastally trapped waves along the southern margin of the continental Australian landmass.

Storm surge is the common term used to describe the residual associated with the passing of a storm event. Large storm surges in the Study Area are generally associated with the passage of strong cold fronts and associated low pressure systems along the southern margin of the Australian continental land mass. Within Anderson Inlet strong and consistent winds across the inlet can also cause localised storm surges.

The combined elevated water level due to the astronomical tide and storm surge is generally referred to as a **storm tide**.

Report 4 (Water Technology, 2022) provides further details and examples of common storm processes, and the regional climate drivers which can influence coastal water levels in the Study Area. Storm surges within Venus Bay can peak over 1.0m and the peak annual storm surge is above 0.5m. Peak storm surges measured within Anderson Inlet in 2020 – 2021 were up to 0.5m at Inverloch and Tarwin Lower jetties.

2.2.4 Extreme Offshore Water Levels

Report 4 details the generation of the offshore extreme storm tide levels from a 40 year modelled hydrodynamic hindcast. The offshore extreme storm tide levels exclude the dynamic wave setup on the coastline which can be influenced by local coastal topography as water runs up the beach.

The present day storm tide levels are presented in Table 2-3 along with the HAT and MHWS for reference. An indication of the level of uncertainty associated with the predicted storm tide levels has been provided. This uncertainty is the result of the cumulative uncertainty of the analysis and modelling process. Some of the uncertainties relate to the data inputs, whilst others are dependent on the numerical modelling processes itself. Sources of output uncertainty related to the input data for the analysis and modelling include:

- Topographic and bathymetric data
- Observed and estimated offshore water level data for model inputs (i.e., current day mean sea level)
- Observed water levels for the hindcast model calibration

Sources of uncertainty related to the modelling processes include:

- Model numerical and computation schemes
- Floating point accuracy of computing resources
- Model schematisation and set-up
- Model parameters such as computational time-steps, surface-friction and other energy-loss parameters

The model development process can only address uncertainties arising from model schematisation and set-up, and model parameters. The remaining aspects are constrained by the available data sources.

Table 2-3 Venus Bay Extreme Offshore Water Levels

Venus Bay Offshore	Level (m AHD)
Mean High Water Spring (MHWS)	1.1
Highest Astronomical Tide (HAT)	1.5
10% AEP	2.0 ±0.05
5% AEP	2.1 ±0.05
1% AEP	2.2 ±0.05

2.2.5 Wind Setup in Anderson Inlet

The action of wind on the water surface creates shear stresses that can drag water in the downwind direction. In the deeper waters offshore wind blowing over long distances across Bass Strait contributes as wind setup to the offshore storm surge. In shallow depths and/or intertidal areas especially within Anderson Inlet, the rate at which water is transported downwind exceeds the rate at which it can return under gravity and an increased local wind setup (elevation of water levels) is observed at downwind locations within Anderson Inlet.

Sensitivity testing undertaken for the modelling of coastal inundation hazards within Anderson Inlet, described in Report 03, shows wind setup within the Inlet can cause increases in water level along the Inlet shorelines of 0.05m to 0.4m under sustained 1% AEP wind conditions. The direction and duration of the wind, as well as the water level within the Inlet has a significant influence on total wind setup levels.

2.2.6 Wave Setup

The action of wind on the water surface also generates waves which propagate in the downwind direction. Along a shoreline, the dynamics of waves in shallow depths along the coastline, including the wave breaking process, can result in further increase in water levels shoreward of the surf zone. This is the **wave setup**.

Waves can contribute to peak water levels at the shoreline and thus require consideration as part of the coastal inundation hazard assessment. Two sources of waves occur within the Study Area; ocean swell waves and locally generated wind waves.

2.2.6.1 Ocean Swell Waves

The Bunurong Road and Venus Bay coastlines are exposed to ocean swell conditions. A hindcast of wave conditions has been developed by researchers at the University of Melbourne as part of the Victorian Coastal Monitoring Program (VCMP). Detail on the model and model parameters can be found in the PhD Thesis being prepared by Jin Lui (publication expected 2023) and via published papers of Liu (2022) and others in the VCMP wave modelling project (Young, Medici, etc).

The wave hindcast model by Lui, referred to herein as the “University of Melbourne wave model”, or the “UoM” model/data, has been used to establish the long term wave climate within the Study Area, with wave hindcast data from 1980 through to 2020 provided at the location of the VCMP buoy in Venus Bay, and at nearshore points in depths of around 20m along the Study Area open coast (Figure 2-3).

The hindcast has been used to establish design wave conditions along the coast which have been used in determining coastal inundation and wave setup levels. Further details regarding the extreme wave conditions and wave climate can be found in Report 4.

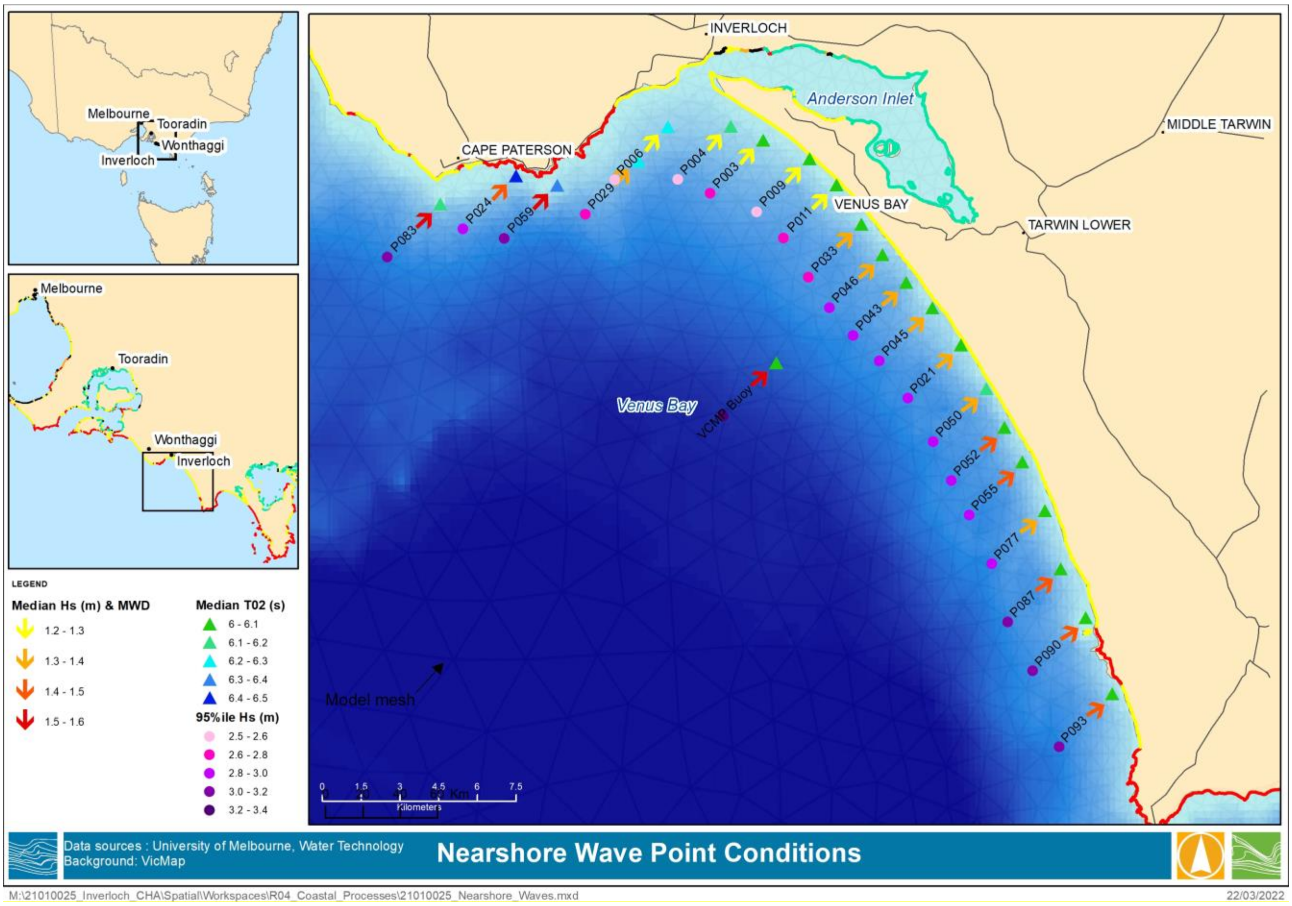


Figure 2-3 Nearshore Wave Hindcast Conditions

The entrance bars and channels, along with the strong tidal flows, actively minimise the wave energy which can enter Anderson Inlet. The penetration of the 1% AEP design wave into Anderson Inlet is provided in Figure 2-4 and shows the main wave action is limited to the open coastline.

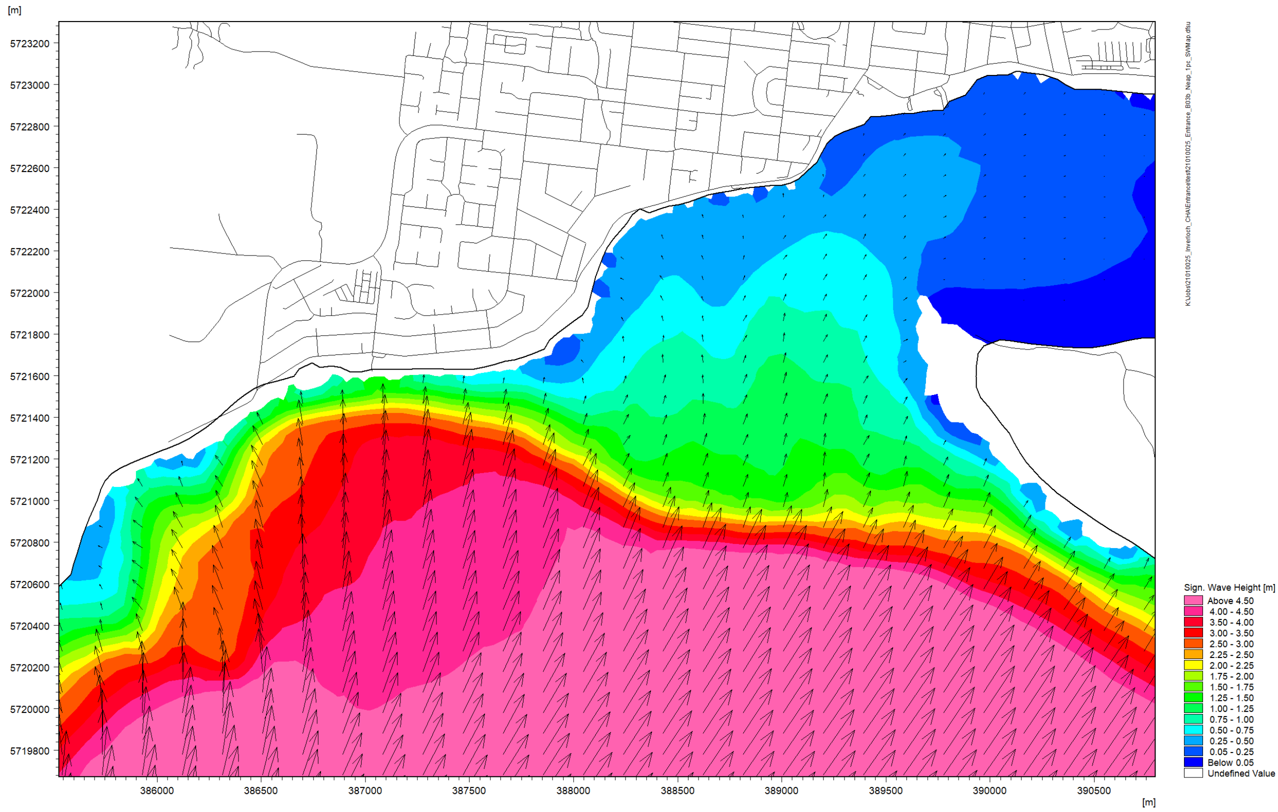


Figure 2-4 Design Wave Penetration into Anderson Inlet (1% AEP Hs + Spring Tide)

2.2.6.2 Locally Generated Wind Waves

Ocean swell waves are essentially confined to Bunurong Road, Wreck Creek/Surf Beach and Point Smythe/Venus Bay shoreline, with locally generated wind waves dominating the wave climate within Anderson Inlet. Locally generated wind waves are characterised by their generally smaller wave height, shorter wave period and highly variable directional distribution in comparison to ocean swell waves. Within Anderson Inlet wave generation is significantly limited by the fetch length across the exposed banks during low tide and waves are not considered to generate a significant additional water level component due to wave setup at the shoreline.

2.3 Catchment Inundation Processes

Intense and/or prolonged rainfall in the catchment produces flood flows which can affect low-lying areas adjacent to the coast. Many of these low-lying areas, particularly within Anderson Inlet, were intertidal or low lying swamps prior to European settlement and are thus naturally flood-prone. Levees and drains constructed in the 20th century reduce the severity and duration of flooding in these areas. However, elevated coastal water levels can exacerbate catchment generated flood events in these areas.

The Tarwin River is the main catchment outfall within Anderson Inlet; however, the smaller waterways of Pound Creek, Screw Creek and Ayr Creek also contribute additional flow into the Inlet.

Catchment processes contributing to coastal inundation are limited to the coastline within Anderson Inlet and within the Inverloch township.

2.3.1 Catchment Description

The catchments of the Study Area are presented in Figure 2-5. The total catchment area of Anderson Inlet is approximately 1,200 km^2. Smaller creeks or flow paths along the Bunurong Road and Venus Bay coastline have not been assessed in this Study as they do not contribute to coastal water levels. The Tarwin River catchment makes up almost 90% of the catchment of Anderson Inlet and is the most dominant inflow into the Study Area.

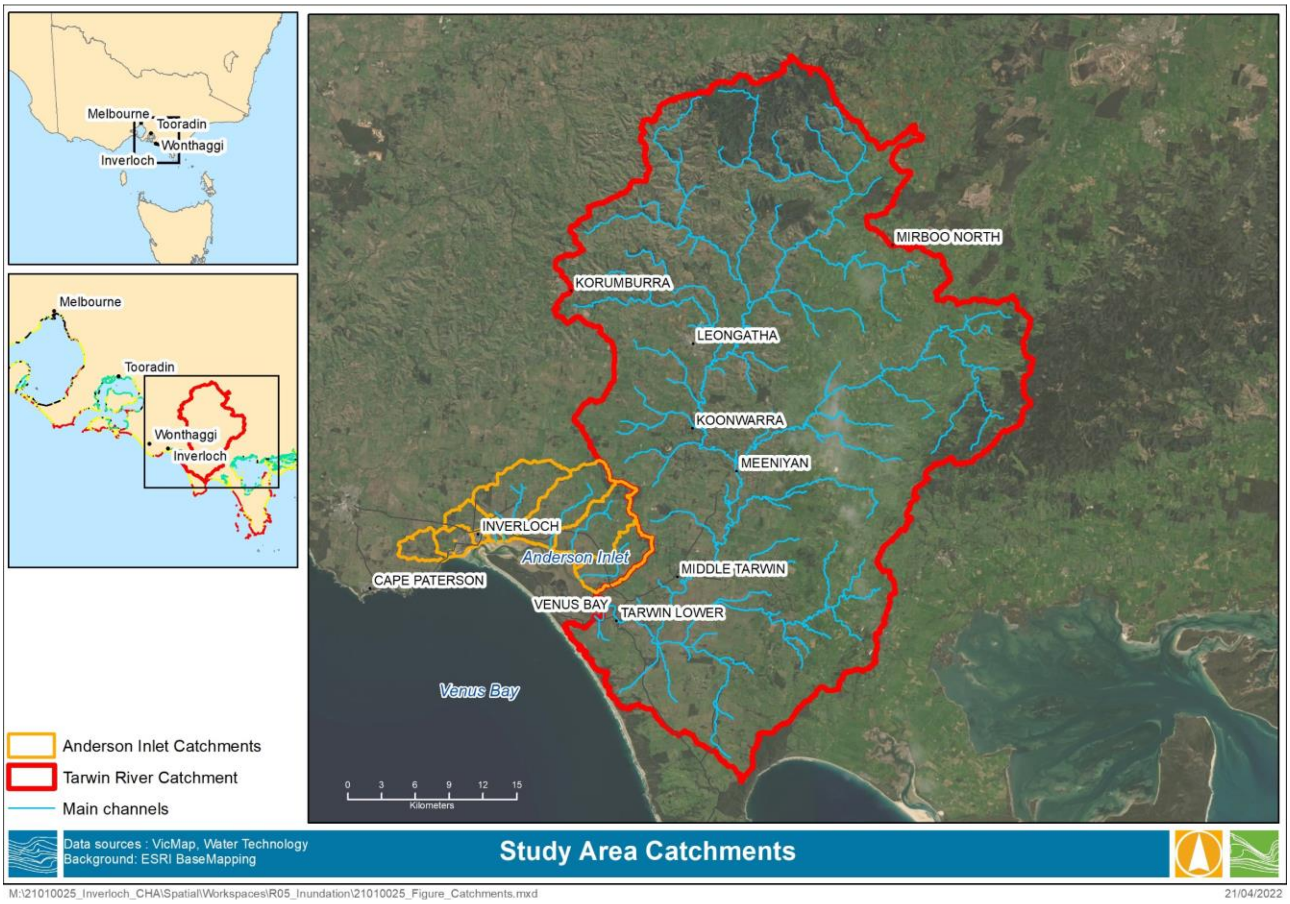


Figure 2-5 Study Area Catchments

The catchments have been largely cleared for agricultural land use, especially in the lower catchment. Clearing for mining in the early settlement days was common across the mid catchment whilst the very upper reaches of the catchment in the Strzelecki National Park remain in pre-European settlement condition.

Prior to European settlement, Screw Creek, Pound Creek and Tarwin River would feed into wide intertidal and marshlands surrounding Anderson Inlet. To enable agricultural production around the Inlet, these marshes were drained with a network of channels and protected from tides by levees which have permanently altered the catchment. Inundation in the low-lying areas has been improved, especially upstream of Tarwin Lower but outflows to Anderson Inlet will have increased, with quicker response times to catchment rainfall events.

2.3.2 Tarwin River Flows

Flooding of low-lying areas between Meeniyan and Tarwin Lower in the Tarwin River catchment are common with road closures typically occurring on at least an annual basis.

The Tarwin River has a gauge at Meeniyan, 40km upstream of Tarwin Lower. The gauge provides daily flow data from June 1955 to present. The flow data is presented in Figure 2-6 with the top 10 flow events provided in Table 2-4.

The catchment is seasonal, with 50% of the flow occurring in the winter months and less than 5% of all flow occurring in the summer months. Despite this, peak flood flows have occurred in each month from March through September, and events in September especially can experience a similar flow volume to those in June.

The peak flood event on June 23rd 2012 of 301 m^3/s occurred in addition to significant flood events earlier the same year in June (259 m^3/s on June 5th) and May (191 m^3/s on May 27th) contributing to the catchment runoff and resulting in significant flooding across the catchment. Significant rainfall in April of 2011 also resulted in large scale flooding and a peak flow rate of 296 m^3/s on the 14th . The flooding and rainfall during 2011 and 2012 were significant across much of south-eastern Australia, fed by ex-tropical cyclones combining with a strong La-Niña period. Climate drivers, and their influence on the meteorology affecting the Study Area are discussed in more detail in Report 4.

No other catchments are gauged within the Study Area.

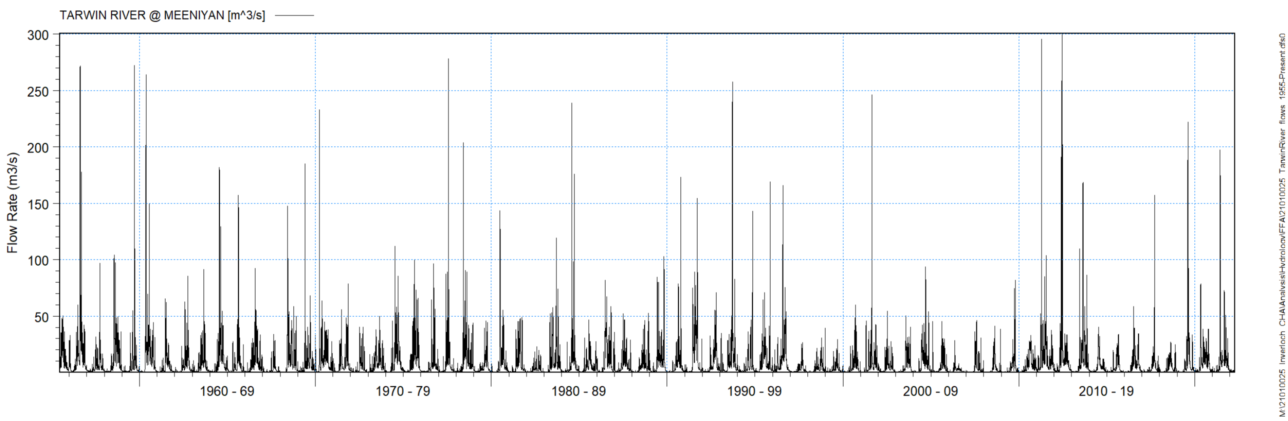


Figure 2-6 Flow Rate, Tarwin River @ Meeniyan (Gauge 227202)

Table 2-4 Highest Daily Flow, Tarwin River @ Meeniyan

Date	Flow Rate (m^3/s)
23 June 2012	301
14 April 2011	296
27 July 1977	278
21 September 1959	272
17 August 1956	272
16 May 1960	264
28 July 1977	262
05 June 2012	259
22 September 1993	258
22 August 2001	246

The design flood flows developed for the Anderson Inlet / Lower Tarwin model are shown below in Table 2-5 and have been established through numerical modelling and flood frequency analysis, as discussed in Report 3. Flood events in 2012 and 2021 have been scaled up to provide representative hydrographs for the 1% AEP and 10% AEP respectively.

These floods provide hydrographs representative of flow on the existing catchment and topography. The flood events show the variety of flood processes in the catchment can result in different flood dynamics such as time to peak, peak flow duration and the tail of the flood. The 2021 event was also selected for the modelling as this event was captured in the water level data measured for the Study at the Inverloch and Tarwin Lower Jetties and was used to validate the numerical model.

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

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

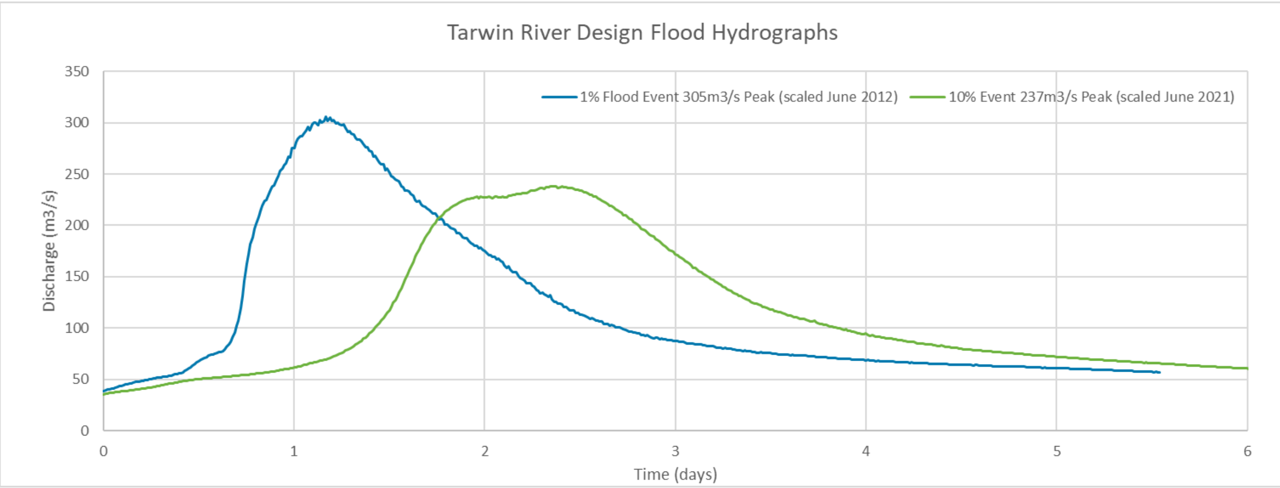


Figure 2-7 Tarwin River Design Flood Hydrographs

2.3.3 Inverloch Urban Drainage

Inundation of the Inverloch township is driven by the height of elevated coastal water levels and the volume and intensity of overland flow from the catchment around Inverloch and rainfall on Inverloch itself, as well as the combination of these drivers.

The elevated water levels along the Inverloch open coast (Surf Beach) and inlet (Point Norman to Screw Creek) shorelines were determined via the estimation of offshore and coastal water levels described in Section 2.2 and the flooding through Anderson Inlet driven by the coastal water levels and Tarwin River flows noted in Section 2.3.2 respectively.

The volume and intensity of overland flow into Inverloch, and the rainfall onto the urban catchment were determined by the hydrological runoff-routing program RORB and a 1D/2D model built in TUFLOW respectively. The TUFLOW model was used to convey the surface flow and rainfall runoff over the available topographic LiDAR, joining catchment runoff draining into the stormwater network. Approximately 85km of stormwater piping (pipes greater than or equal to 0.3m) was included in the model, as shown in Figure 2-8. The direct connection of the stormwater network with the coastal and inlet waters are also noted in Figure 2-8.

The piped drainage network at the eastern and western ends of the town are limited, with shallow surface swales directing overland flow along Lohr Avenue and Surf Parade in the west and no data available within the Broadbeach estate or caravan park.

Ayr Creek and Wreck Creek are conveyed under roads with large (i.e. up to 4m wide) culverts. Outfalls to the coastline are noted in pink. Outfalls are open drains which allow free flow to the coastal and Inlet waters. However, they can also be impacted by local coastal processes and drainage restricted through the build-up of sand at the coastal/Inlet connection. The most extreme example of this is Ayr Creek, however drainage is restricted by sand to some extent with the exception of the drain along the new seawall at the Inverloch boat ramp where the drain is elevated above the sand level.

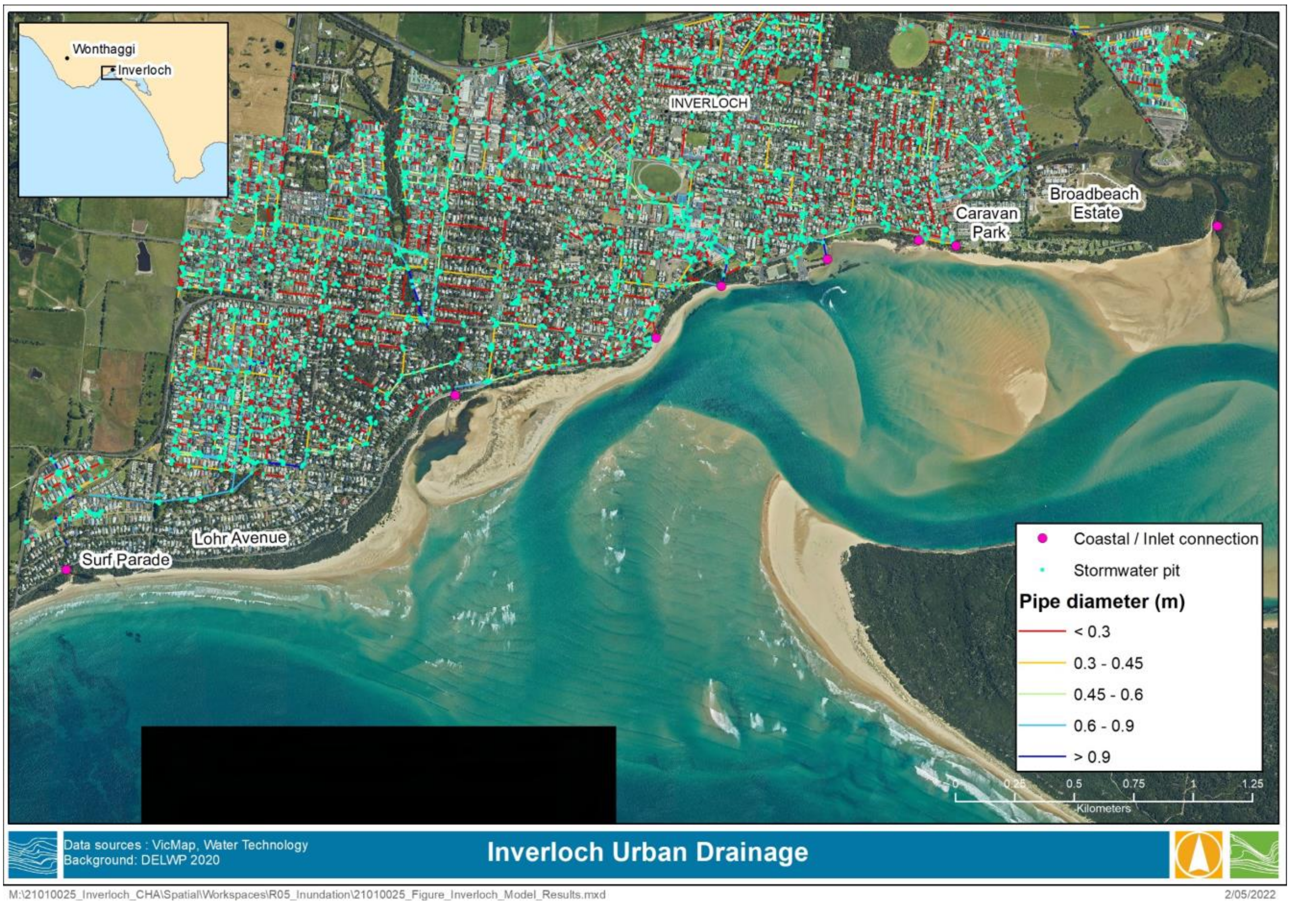


Figure 2-8 Inverloch Modelled Stormwater Drainage Network

2.4 Coastal and Catchment Flooding Coincidence

2.4.1 Overview of Joint Probability

The project brief specified a number of scenarios to be analysed in this assessment, which are detailed in Section 1.4. Each scenario incorporates a component of sea level rise along with a storm tide and catchment generated flood.

If the storm tide and the catchment generated flood are independent events from a statistical viewpoint then the chance of one occurring is not changed by the occurrence of the other event. The probability of both events occurring at the same time is therefore the product of their individual probabilities. For instance, assuming the storm tide and catchment flood are independent, the probability of a 1% AEP storm tide and a 1% AEP catchment flood occurring at the same time is then 0.01 % (1 in 10,000 chance). This represents an extremely rare event.

However, if the storm tide occurs as a result of the same meteorological processes (i.e. from the same storm) that result in a catchment generated flood then the events are termed conditional. The conditional probability of both events occurring is then different than the product of their individual probabilities and more complicated to estimate.

The impact of conditional storm tide and catchment flooding is particularly important in relation to coastal flooding such that if a particular weather event which results in high river flows also produces a significant storm tide, a greater level of flooding could occur than if the storm tide and catchment flooding are independent events.

2.4.2 Australian Rainfall and Runoff – Project 18

Due to the risk of underestimating coastal flooding with incorrect assumptions on joint probability and independence, in 2014 a significant amount of research was undertaken to understand the joint probability of coastal storm tides and catchment flooding around Australia.

The research, coined Project 18 (Zheng, 2014) for the Australian Rainfall and Runoff guide (AR&R, Ball et al, 2019) assessed gauge records and meteorological processes across Australia and established levels of coincidence between storm tides and catchment floods across Australia based on measured coastal storm tides and catchment flow data.

The analysis indicated Victoria had the lowest levels of interdependence between storm tide and rainfall across Australia and coincidence of a 1% AEP storm tide and 1% AEP catchment flood event is not probable.

To confirm this assessment for the Study Area, the relationship between catchment runoff and storm tides were reviewed. Figure 2-9 presents the peak offshore modelled storm surge coinciding with the peak flow event measured at Meeniyan since 1981 to coincide with the hindcast water level dataset. As expected, there is no strong correlation between high storm surge residual and extreme flow in the Tarwin River.

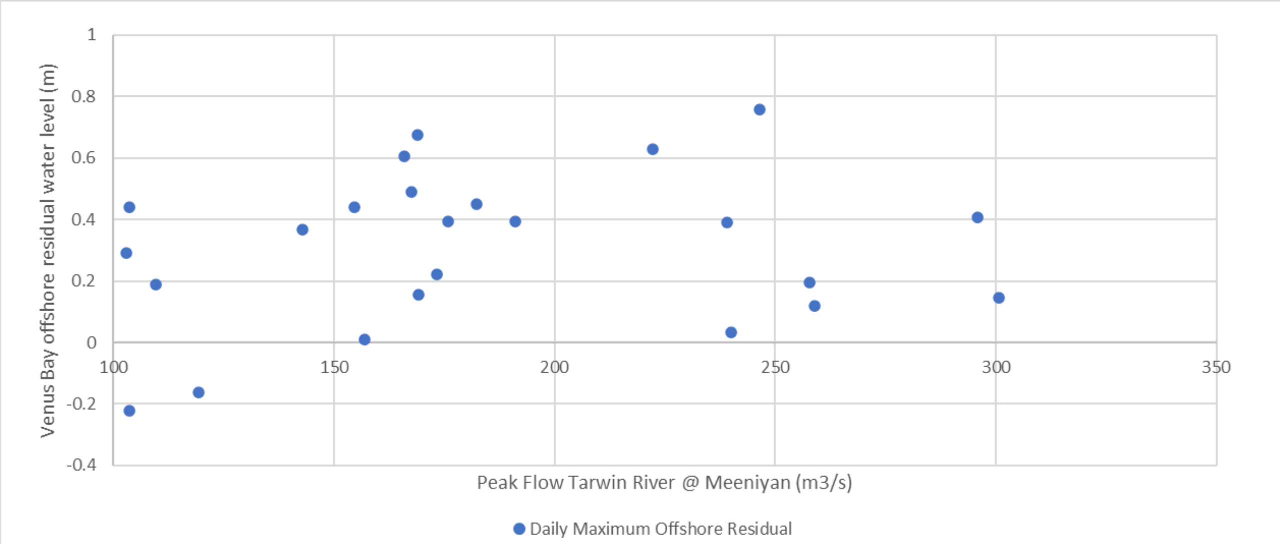


Figure 2-9 Relationship between coastal water level residual and peak flows over 100m³/s at Meeniyan on the Tarwin River

The simplistic approach for assessing inundation hazard conservatively assumes that catchment and oceanic flood events occur together. The resultant flood levels will provide the upper envelope of likely inundation for a given AEP flood event. This then sets a very conservative design flood level, which will have a joint AEP of at least 1% but likely much less than 1%. The exact AEP it represents is not defined in such an approach.

The approach taken for this project is a version of the 'pre-screening' level analysis as outlined in Australian Rainfall and Runoff (Ball et al, 2019). The aim of the 'pre-screening' analysis is to calculate the outer envelope of flood estimates in order to characterise the potential zone of flood impacts and the relative significance of the different flood drivers on the predicted flood extents. Across Victoria, and within the Study Area, the difference between a 10% and 1% AEP storm tide event is generally 0.2m or less and the resultant inundation extents are therefore often very similar (although there are exceptions). Catchment floods exhibit a greater range of flows across the same range of AEPs.

When developing the inundation hazard zones, a combination of coastal and catchment AEP events has been selected which reflects the relative significance of the different flood drivers and their dependence. A full joint probability modelling analysis was not considered warranted for this study, based on the relatively limited differences between the predicted flood events for different combinations of catchment and coastal flood AEPs, and the limited number of assets potentially susceptible to inundation in those areas that did show more variability.

Table 3-5 provides the scenarios modelled for inundation hazard mapping within Anderson Inlet (for various AEP combinations of storm tide, local wind, catchment flow, urban flow for the range of sea level rises). Report 3 provides detail on the sensitivity testing completed for the Study, including review of the modelling of the combined 1% storm tide and 1% catchment flow events. The inundation extent from the combined 1% AEP storm tide and 10% AEP catchment flow, along with the 1% AEP storm tide and 1% AEP catchment flood is presented again in Figure 2-10 and illustrates the limited difference in flood extents between the 1% and 10% AEP catchment flood when combined with the 1% storm tide. Changes in the inundation area are limited to agricultural land at the edge of the floodplain.

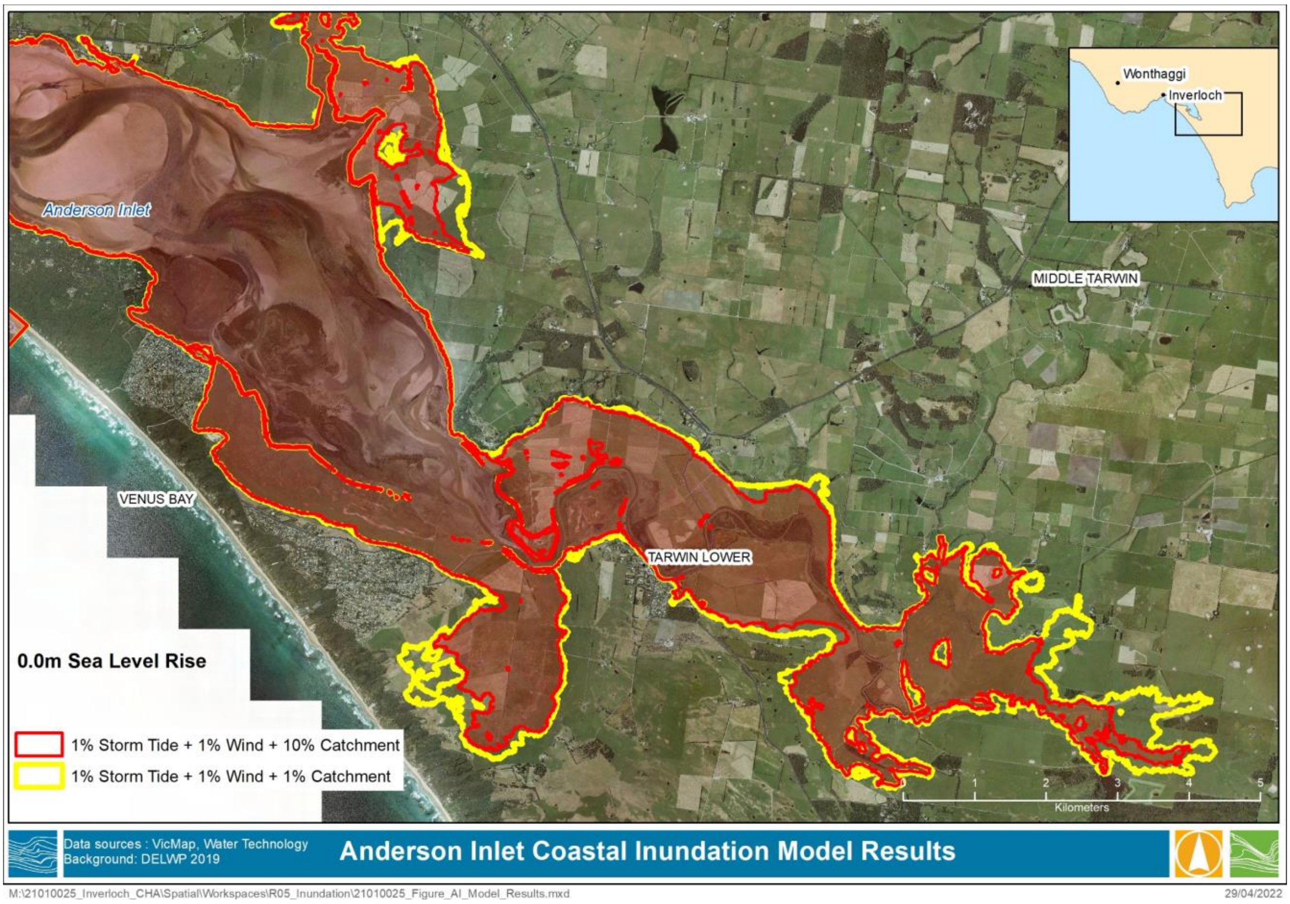


Figure 2-10 Inundation extent, 1% AEP Storm Tide and Catchment flow versus 1% AEP Storm Tide and 10% AEP Catchment Flow

2.5 Existing Inundation Protection Works and Structures

The following sections provides an overview of the extent of the existing inundation protection works and structures which limit or influence inundation extents and water levels on the low lying plains surrounding Anderson Inlet during periods of either extreme coastal water levels and/or high catchment flows.

2.5.1 Coastal Levees

Formal and informal embankments, referred to as coastal levees in this study, currently surround approximately 52% of the shoreline of Anderson Inlet. The structures predominantly exist along the eastern shorelines towards the entrance to the Tarwin River as shown in Figure 2-11. Levees on the north-eastern bank appear to have been constructed in the late 1960s, although less formal drainage paths were established prior to this, and some levees are observed around Venus Bay and the mouth of Tarwin River in the 1950 historical image. The heights of the coastal levees are generally constructed to 10-13ft (~3 – 3.5m), or what is considered in the area to be above the 1934 flood event levels. Based on the LiDAR survey, the levee crest actually varies in elevation from +1.5m near Venus Bay Settlement 1 and upstream in Pound Creek to above +4.0m AHD around Nolan Bluff. Additional levees along the Tarwin River are reported to have been constructed by European settlers in the 1850s and are generally lower in the range of +1.5m AHD to +2.5m AHD.

Preliminary assessment of the levees surrounding Anderson Inlet, based on earlier storm tide and catchment assessments was undertaken by Water Technology for the South Gippsland Shire Council in 2018 (Water Technology, 2018).

Coastal levees have been built primarily to prevent the ingress of saline coastal water onto agricultural land during large storm tide events in Anderson Inlet. Travel restrictions imposed in Victoria during the COVID-19 pandemic limited the amount of field inspection that could be undertaken during flood modelling to check drainage pathways through levee banks and the low points where levees were overtopped. This could be undertaken during future updates of this work.

The importance of the coastal levees and embankments for controlling coastal inundation in Anderson Inlet is demonstrated in Figure 2-11 and Figure 2-12 which shows the low and vulnerable nature of the surrounding coastal plains landward of the levees and shoreline.

Whilst the levees are generally built to a height considered sufficient to provide protection from an extreme storm event under existing mean sea levels, low points in levees allow limited overtopping during storm tide events. An example of one these breaks is Figure 2-11 and Figure 2-12, where the Venus Bay levee long section shows the levee dips from 2.5m AHD to below 1.7m AHD, below the current 1% AEP offshore storm tide.

Similarly, levees often do not extend landward to the extent of the predicted storm tide event, allowing backflow around the levee at the upstream extent.

For the purposes of the inundation hazard assessment, it is assumed that all coastal levees that are currently in place remain in place at their current extent and configuration into the future. Low points in levees are not repaired and the landward extents of levees have not been extended in model simulations.

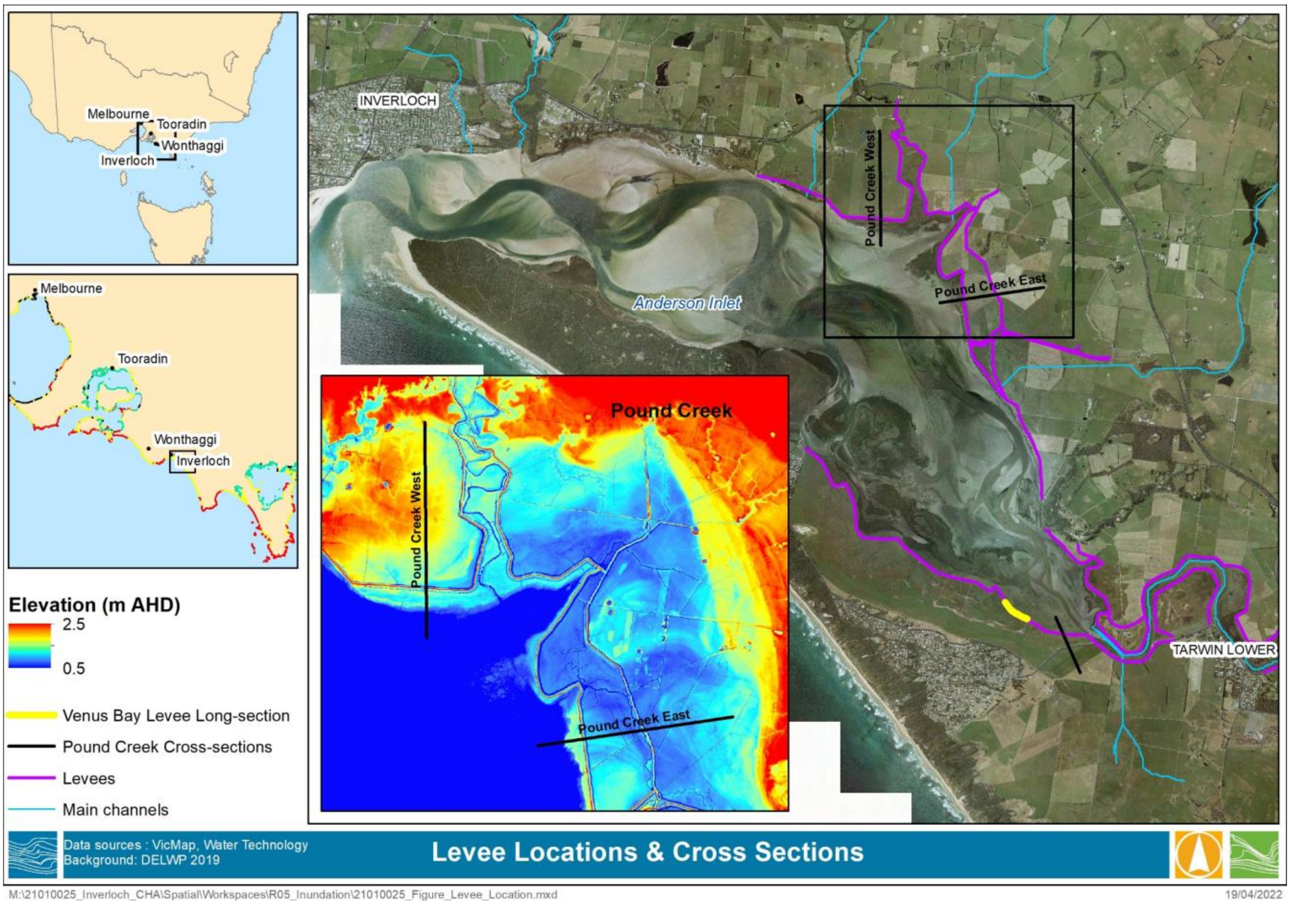


Figure 2-11 Existing Coastal Levees in Anderson Inlet

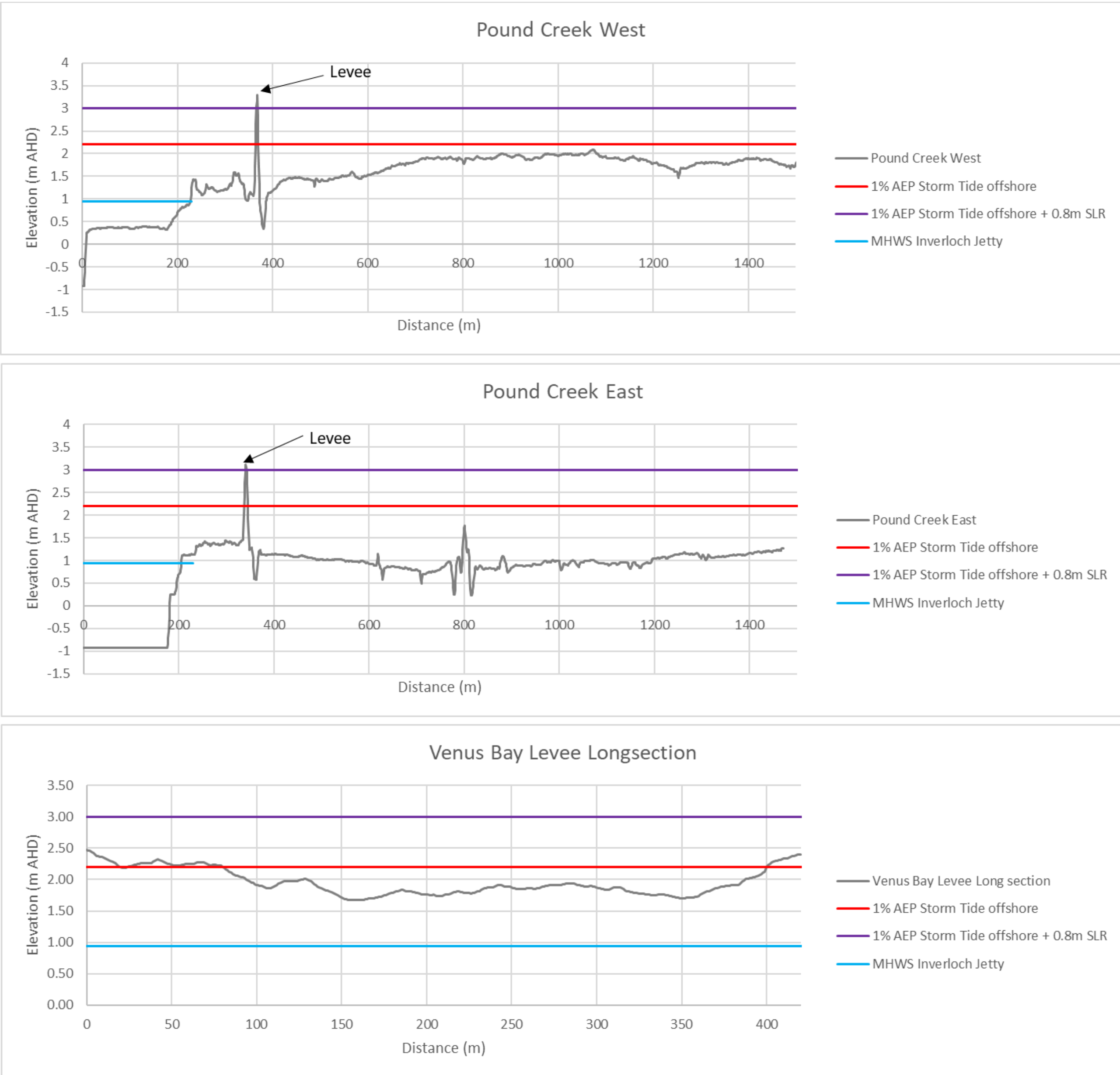
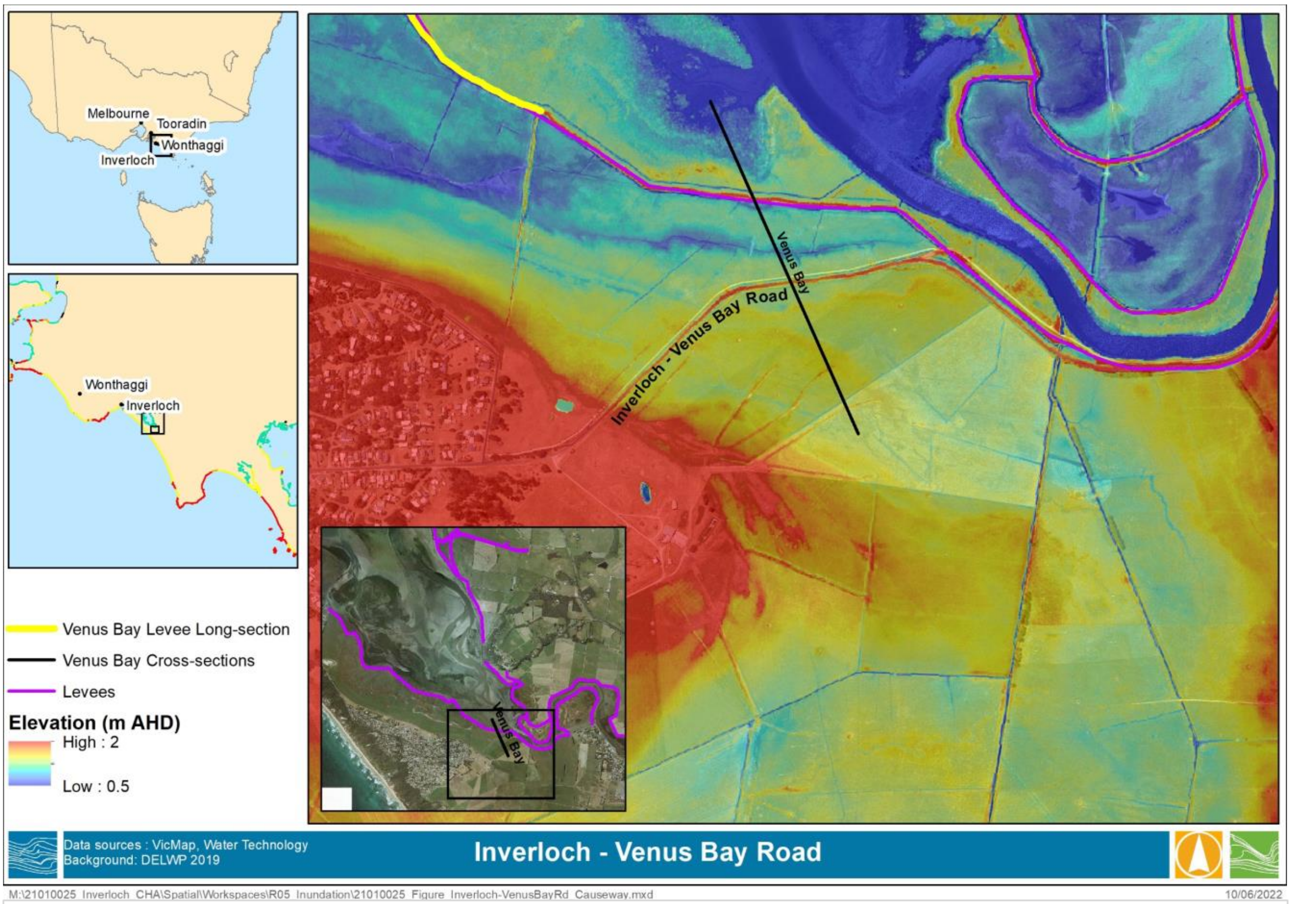


Figure 2-12 Cross Section west (top) and east (middle) of Pound Creek from Anderson Inlet inland, and long section along Venus Bay levee (bottom)

2.5.2 Road Network

The road network in the Study Area, especially around Anderson Inlet and Wreck Creek provides a degree of protection to the floodplain from inundation. At several locations along the Inverloch-Venus Bay Road which connects Venus Bay with Tarwin Lower, carriageways are comprised of elevated causeways relative to the surrounding land. The hydraulic connectivity through the causeways is limited to a small number of culverts and/or bridge structures which allow some flow.

The causeways provide significant control over coastal inundation and/or catchment flooding and the subsequent drainage of the floodplain. Figure 2-13 highlights the elevation of the Inverloch-Venus Bay Road in relation to key coastal water levels.



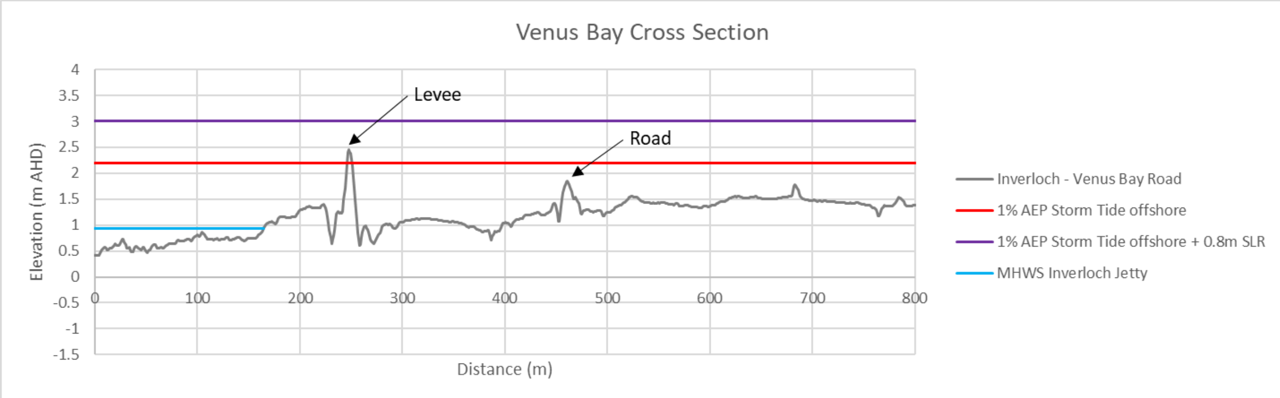


Figure 2-13 Inverloch - Venus Bay Road Topography and Cross Section

3 COASTAL INUNDATION HAZARD

To understand the existing and future risks due to sea level rises of coastal flooding on the Study Area, detailed numerical modelling of the open coast, Anderson Inlet and the Tarwin River has been undertaken.

Further details of the approach to determining coastal inundation hazard can be found in *Inverloch Region Coastal Hazard Assessment – R03 Methodology*, Water Technology 2022. The coastal inundation hazard has been determined for the range of predicted sea level rises and design events presented in Table 1-1 and Table 1-2 respectively.

The "*permanent inundation*", or the extent the future mean high water spring (MHWS) tide will inundate, is also presented in the coastal inundation hazard mapping.

3.1 Overview of Assessment Approach

Three methods for determining inundation were used to assess the 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 (plus wave setup), Inverloch

For each of the areas, design storms were generated to drive coastal water levels to use in conjunction with design wave conditions or design catchment hydrographs. The present day design coastal and catchment storm and flood events are presented in Table 3-1. The combination of offshore storm tides and catchment flow events used to determine inundation hazards in Anderson Inlet are presented in Table 3-5.

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)	Tarwin River Peak Flow (ML/day)
1% AEP	2.2	6.6	14.6	305
5% AEP	2.1	6.1	14.2	-
10% AEP	2.0	5.9	13.9	237

3.2 Open Coast

Coastal inundation on the open coast is caused by the elevated still water level and the wave energy piling water up along the coast. Individual waves can add to the water level through wave run-up of the individual swash, however this has not been included in this study.

To establish the level to which the water piles up, or "sets up", against the coast, the numerical model SBEACH, also used to establish coastal erosion, has been used to simulate the design storm conditions presented in Table 3-1 across the surf zone and beach profile.

Projected increases in mean sea levels due to sea level rise was added to the modelled nearshore coastal water level. It is assumed that the beach profile will adjust with increasing sea levels and the slope of the beach and thus wave setup will remain constant.

3.2.1 Beach Profiles

Beach profiles have been extracted along the Study Area coastline to determine the local topography. Profiles have been extracted from the 2008/09 LiDAR along the Venus Bay coastline. Updated LiDAR collected in 2021 for the Department of Transport and for the Inverloch CHA has been used along the Bunurong Road and Flat Rocks to Point Norman coastlines respectively.

Along the Bunurong Road coastline profiles have been extracted within the pocket beaches identified in the coastal geomorphology assessment (Report 4), shown in Figure 3-1. The location of beach profiles from Flat Rocks to Point Norman are identified in Figure 3-2. The nearshore location of wave hindcast data from the University of Melbourne (Section 2.2.6.1) has been used to establish beach profiles along the Venus Bay coast, as shown in Figure 2-3.

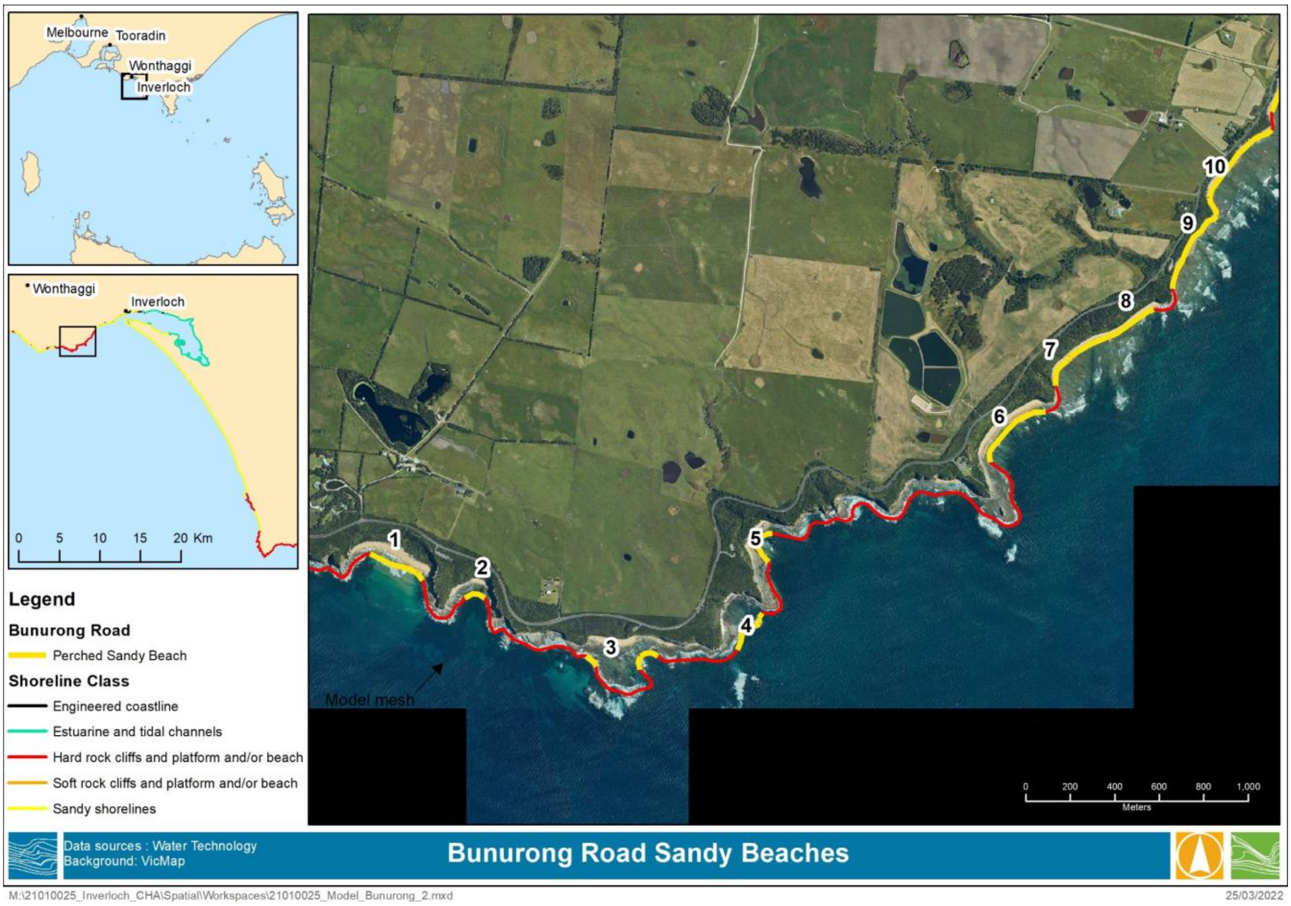


Figure 3-1 Bunurong Road pocket beaches

Figure 3-2 Beach profile locations Flat Rocks to Point Norman

3.2.2 Storm Event

The combined storm tides and wave conditions described in Table 3-1 were used to drive coastal water setup along the coast. The storm tide signal and temporal wave patterns have been established through analysis of the hindcast data, described in Appendix D, Report 3 (Water Technology, 2022).

An example of the input storm event, based on the existing 1% AEP storm tide and 1% AEP nearshore wave event is presented below in Figure 3-3. This represented the conditions predicted for Profile 012, near to the Venus Bay Beach Carpark #4 on the Venus Bay open coast shore.

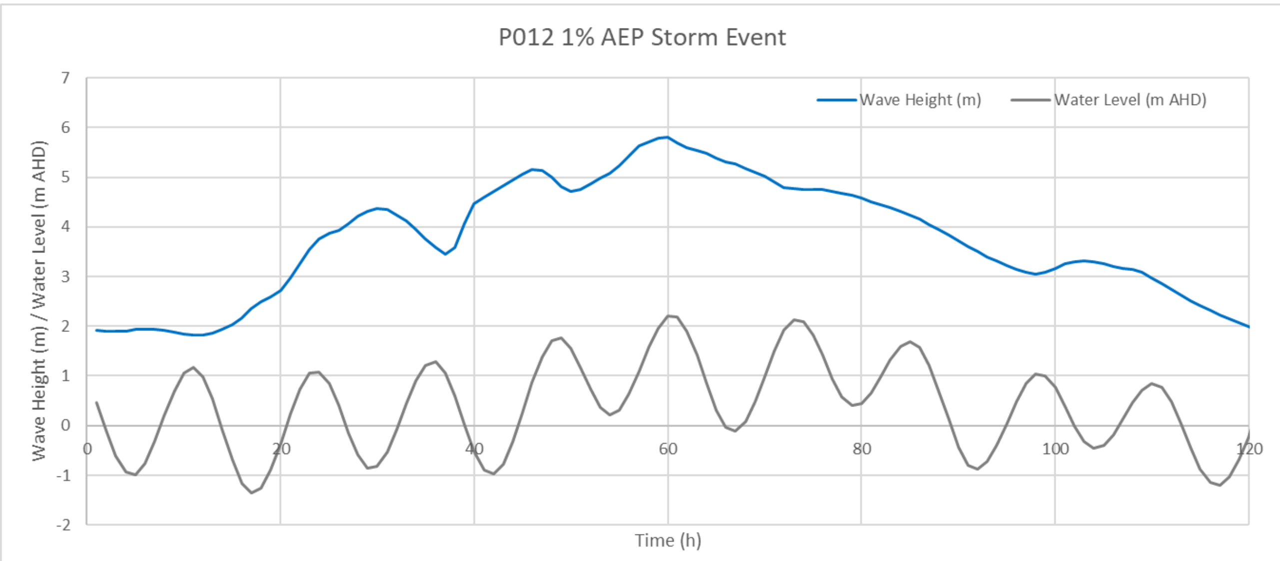


Figure 3-3 Existing 1% AEP Storm Conditions – Venus Bay Open Coast Profile 012

3.2.3 Total Coastal Water Levels

3.2.3.1 Bunurong Road

The coastal inundation processes along Bunurong Road, including the transformation of waves inshore to the sandy pocket beaches, is more complex than the inundation at the open coastline of Surf Beach and Venus

Bay. Significant wave breaking and diffraction across the rocky platforms result in lower wave energy at the coastline along the Bunurong Road coastal section.

An example of the wave transformation inshore and the total water level at Pocket Beach #4 is presented in Figure 3-4. The present-day storm event water level along Bunurong Road is provided in Table 3-2. Inundation of the Bunurong Road coastline is limited due to the high cliffs which dominate this area. Inundation landward of the road is not possible within the planning horizons or sea level rises considered in this Study.

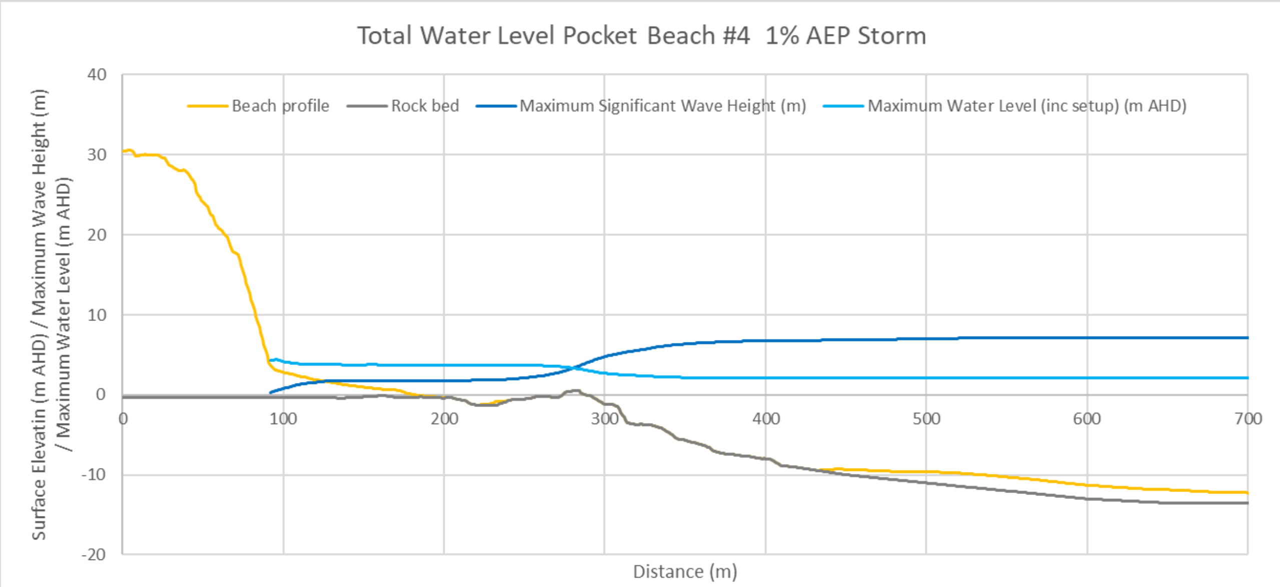


Figure 3-4 Maximum Water Level, Pocket Beach #4, Bunurong Road – 1% AEP Existing Conditions

Table 3-2 Total Coastal Water Level, Bunurong Road

Pocket Beach	Total Coastal Water Level (Existing Mean Sea Level) (tide + storm surge + wave setup) (m AHD)		
	1% AEP Storm	5% AEP Storm	10% AEP Storm
1 – 3	3.6 – 4.3	3.4 – 4.1	3.3 – 4.0
4 & 5	3.5 – 4.2	3.3 – 4.0	3.3 – 3.9
6 – 10	3.5 – 3.9	3.3 – 3.5	3.2 – 3.4

3.2.3.2 Flat Rocks – Point Norman

The Flat Rocks to Point Norman coastline is exposed to wave action which is tempered in the west of the section by the Flat Rock outcrop, increasing in exposure towards the entrance to Anderson Inlet. The coastline, in contrast to Bunurong Road and Venus Bay, is backed by a low coastal dune which separates the coastline from the Wreck Creek wetlands and Surf Beach residential estate.

The dune has suffered significant erosion in recent times with dunes of 10m in elevation eroded in the past decade. The inundation along this coastline has been determined using the most recent data available for the study, a high resolution LiDAR dataset captured in August 2021. It should be noted that the nearshore and beach profiles in this section of coast are vulnerable to further change in the future.

Because of this potential for further change of the coastal dune profile, the total water level along the coast has been determined by SBEACH and the **inundation extent** established as follows:

- Existing conditions (0.0m mean sea level) – dynamic modelling:
  - The timeseries of the total coastal water level as determined by SBEACH has been used as a tailwater boundary in a 2-dimensional hydraulic model to establish the extent of inundation. This dynamic approach simulates the flow of water through Wreck Creek into the low lying land during the peak of the storm event; and
- Future conditions (increasing mean sea levels) – static bathtub modelling:
  - The peak of the total coastal water level as determined by SBEACH, plus increases in mean sea levels have been used to establish the extent of future inundation using the existing LiDAR topography and the bathtub method. The potential reduction in inundation extent due to the relatively short duration of the elevated coastal water level and high friction across flow paths have not been considered for future inundation.

Static bathtub modelling was used to generate future inundation hazard layers given the vulnerability of the low coastal dune in the Flat Rocks – Point Norman coastline to coastal erosion. The protection offered by the dune into the future is highly uncertain. To use the existing dune which prevents direct inundation of the landward area may have resulted in an underestimation of the likely flood extent, while predicting the future height and location of the dune would require significant assumptions about the rate of erosion and subsequent form of the coastal dune which would limit the applicability of the hazard layers. The precautionary approach of intersecting the coastal water level with the topography was considered appropriate in this area. The dynamic modelling of the existing conditions results in a smaller area of inundation than the direct bathtub / topography intersection method due to the hydraulic processes resolved in the modelling including time of inundation due to the varying water level and roughness of the floodplain which can slow the spread of floodwaters.

Similarly, the inundation of the area inland of Wreck Creek includes wave setup. The vulnerability and recent significant change of the coastal dune along this coastline results in uncertainty as to the level of protection that will be provided by the dune in the future. The precautionary approach assumes that the current dune and Wreck Creek flow path does not limit inundation landward. Additional investigation with different dune configurations could be carried out in the future to further investigate the sensitivity of the flood extent to different dune heights and extents, however this is outside the scope of this Study.

It is also noted that coastal inundation extents landward of the coastal dune are based on the available terrestrial LiDAR from 2009. Some areas inland of Wreck Creek have been developed through sub-division since this time and earthworks associated with the development are likely to have changed the local topography and therefore the flood extent may differ if updated topographical data were available for the analysis.

Total water levels along the Flat Rocks – Point Norman coast under present day conditions are presented in Table 3-3. Levels along this coastline are lower than at the more xposed Bunurong Road beaches. The sheltering nature of Cape Paterson on the wave climate is evident in the total coastal water levels.

Coastal inundation zones are presented in Appendix A. Sections of the Surf Beach residential area also include the urban catchment inundation which is influenced by the storm tide tailwater.

The area is vulnerable to coastal inundation in the future, especially where the coastal dune is low and subject to coastal erosion, as discussed in Report 4.

Table 3-3 Total Coastal Water Level, Flat Rocks – Point Norman

Beach Profile	Total Coastal Water Level (Existing Mean Sea Level) (tide + storm surge + wave setup) (m AHD)		
	1% AEP Storm	5% AEP Storm	10% AEP Storm
Flat Rocks – RACV	3.3 – 3.5	3.1 – 3.3	3.0 – 3.1
RACV – Bunurong Road/Wreck Creek	3.3 – 3.5	3.0 – 3.4	3.0 – 3.3
Bunurong Road/Wreck Ck – Point Norman	3.4 – 3.6	3.3 – 3.5	3.2 – 3.3

3.2.3.3 Venus Bay

Coastal inundation levels for the different storm events along the Venus Bay open coast are presented in Table 3-4. Variation in the local profile can result in minor changes in the total water level, and the increased exposure of the coastline towards Point Smythe, which results in higher waves as shown in Figure 2-3, also results in an increasing total water level along the coast eastward.

The steep and high coastal dune along the open coast between Point Smythe and Cape Liptrap limits coastal inundation to a narrow band along the coastline. No overtopping or inundation of other features along the coast is likely to occur in the planning horizons and sea levels assessed in this Study.

An example output of the SBEACH modelling, including the maximum water level across the profile and the transformation of the wave inshore at the P012 profile is presented in Figure 3-5. The offshore storm tide water level of 2.2m AHD increases to 4.2m AHD as the wave energy and winds drive the water level across the nearshore slope and up the coastal dune.

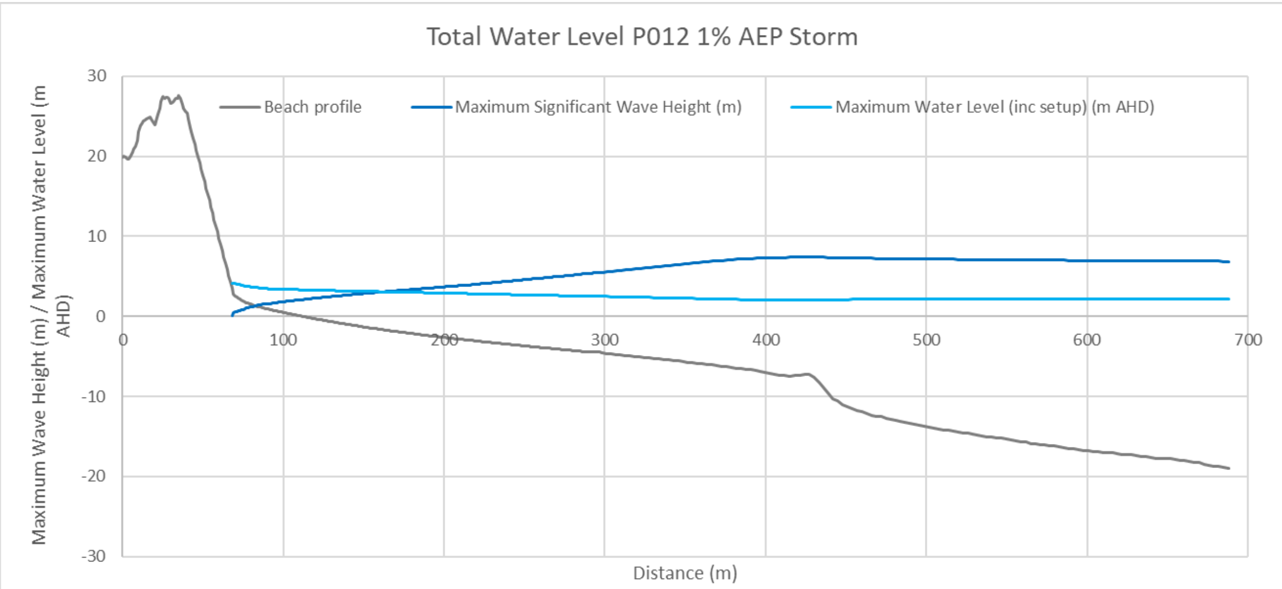


Figure 3-5 Maximum Water Level, P012, Venus Bay – 1% AEP Existing Conditions

Table 3-4 Total Coastal Water Level, Venus Bay

Beach Section	Total Coastal Water Level (Existing Mean Sea Level) (tide + storm surge + wave setup) (m AHD)		
	1% AEP Storm	5% AEP Storm	10% AEP Storm
Point Smythe (P004-012)	3.4 – 3.9	3.3 – 3.6	3.2 – 3.5
Central (P011-050)	3.7 – 4.2	3.5 – 4.1	3.4 – 3.8
South-Cape Liptrap (P055-P093)	3.5 – 4.0	3.4 – 3.9	3.3 – 3.9

3.3 Anderson Inlet

Coastal inundation within Anderson Inlet is caused by the offshore elevated water levels flooding the inlet and the catchment flow from the Tarwin River, and to a much lesser significant extent, Pound and Screw Creeks, elevating the upstream water levels. The wide and long expanse of the Inlet also allow winds to force water against the shoreline during flood events.

A 2-D numerical model was established to simulate these processes within Anderson Inlet. Details of the numerical model setup, calibration and sensitivity testing is provided in Report 3.

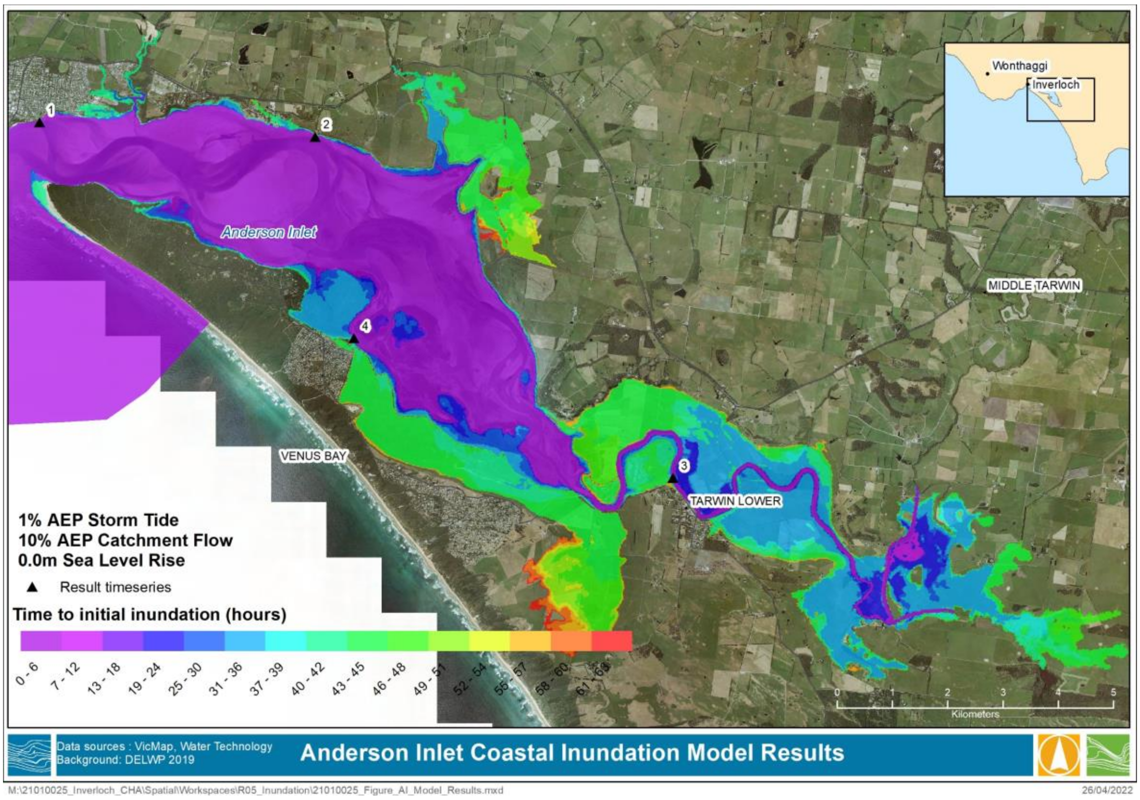
3.3.1 Flooding Processes

To provide some additional context to the flooding processes within Anderson Inlet, the time to begin flooding, time to peak of flood and total duration of “flooding” in the model for the 1% AEP offshore storm tide under current MSL combined with a 10% AEP catchment flood and a sustained 1% AEP wind from the west across Anderson Inlet is shown in Figure 3-6 and Figure 3-7. The total simulation period for the production runs is 120 hours (5 days, as shown in Figure 3-8). Timeseries of water surface elevation within the floodplain positions noted in Figure 3-6 are also shown in Figure 3-8.

The inundation processes and timing are common across all model results – flooding of the Inlet and tidal floodplains is driven by coastal water levels rather than catchment flows, with the exception of the area to the east of Pound Creek which can be inundated initially by catchment runoff overtopping the creek banks in the north of the model area. Elsewhere the increasingly elevated storm tide propagating into the inlet causes inundation initially across the intertidal flats then via backflow around the landward end of levees, followed by overflow over low points in levees, and then via total submergence of the levee bank as storm tide levels within the Inlet increase. Following inundation via levee overtopping, floodwater is typically not able to fully drain quickly, and the floodplain can remain inundated to the end of the model simulation period. It is noted that any tidal valves or other drains which currently have capacity to drain water from the floodplain is not included in the model as this data was unavailable for the Study and restrictions on movement during the Study due to the COVID-19 pandemic limited the ability for field inspections during modelling works.

Coastal inundation levels and depths across Anderson Inlet at the cross sections noted in Figure 3-9, are presented in Figure 3-10 and show the peak inundation level for the 1%, 5% and 10% offshore storm tide and local wind events combined with the 10%, 10% and 1% AEP event catchment flows respectively under existing and 2100 0.8m sea level rise scenarios. The influence of coastal levees on inundation levels can be seen where inundation levels on the Inlet side of the levee is often higher than those on the floodplain. This difference is due to the limited duration of the elevated water level within the Inlet and the subsequent time available to inundate the area landward of the levee to the same level.

The use of a hydrodynamic model instead of intersecting the peak surface water elevation across the topography (i.e. bathtub modelling) allows a greater level of this detail to be included, however the future accuracy of the predicted flood extent and depth is reliant on the height and position of levees remaining constant.



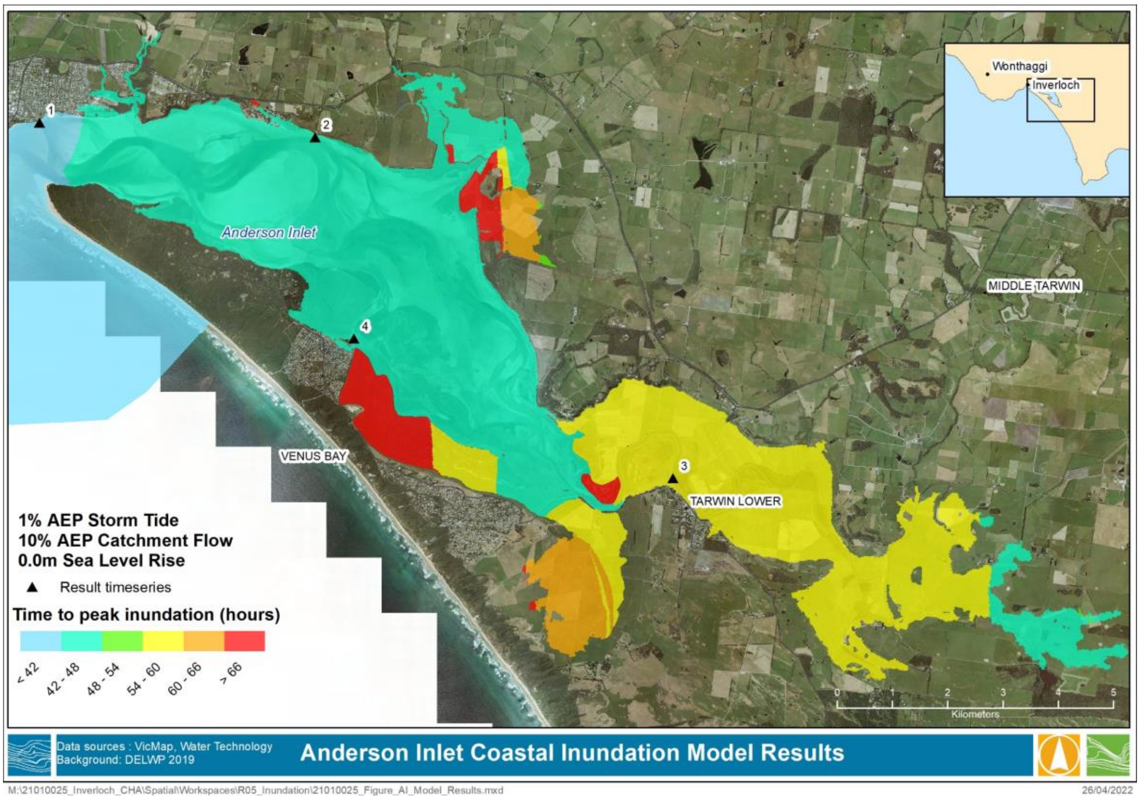


Figure 3-6 Time to start (top), time to peak (bottom) of inundation level, Anderson Inlet, Existing 1% AEP Storm Tide + 10% catchment flood

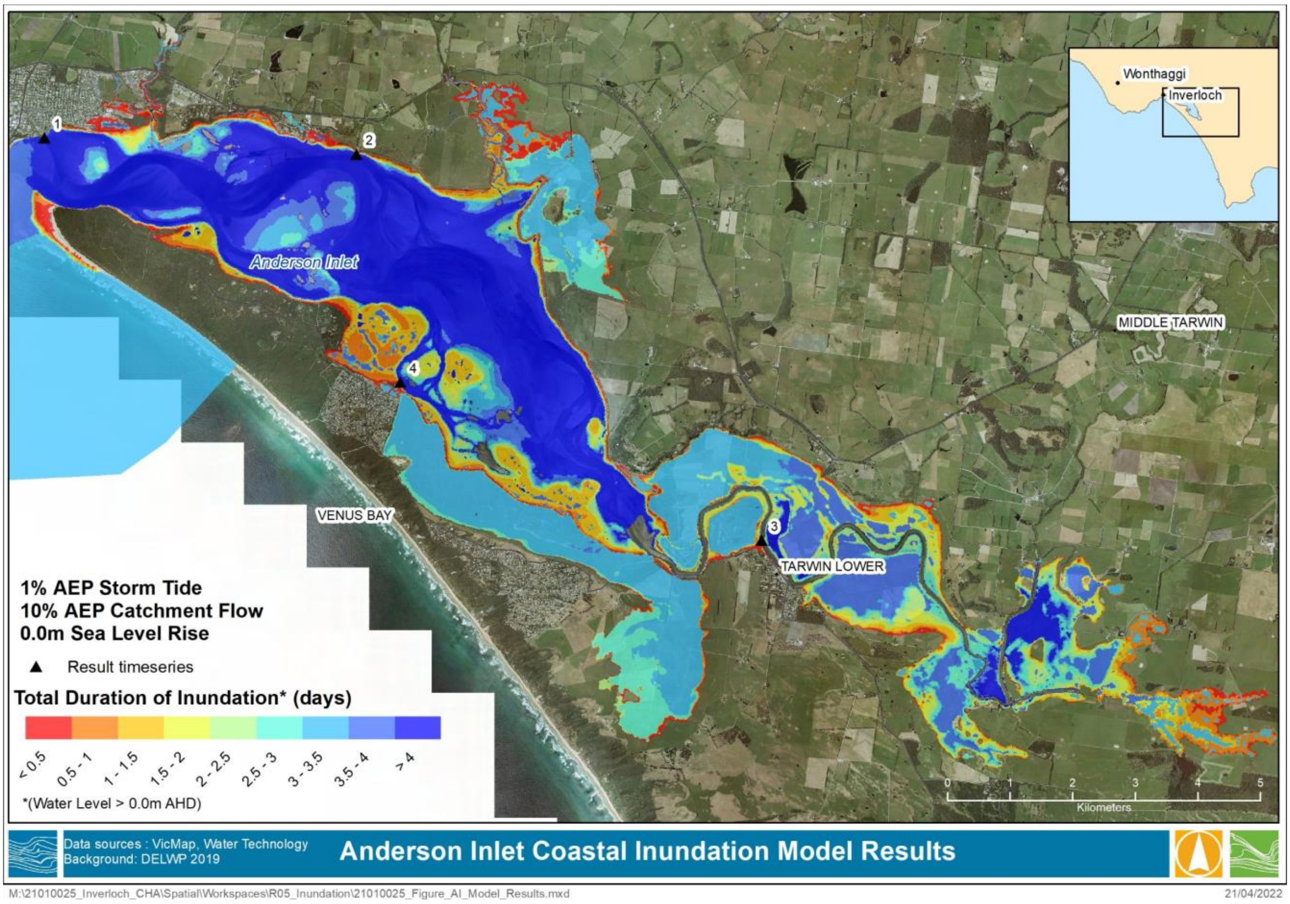


Figure 3-7 Duration of inundation, Anderson Inlet, Existing 1% AEP Storm Tide, 1% Wind + 10% catchment flood

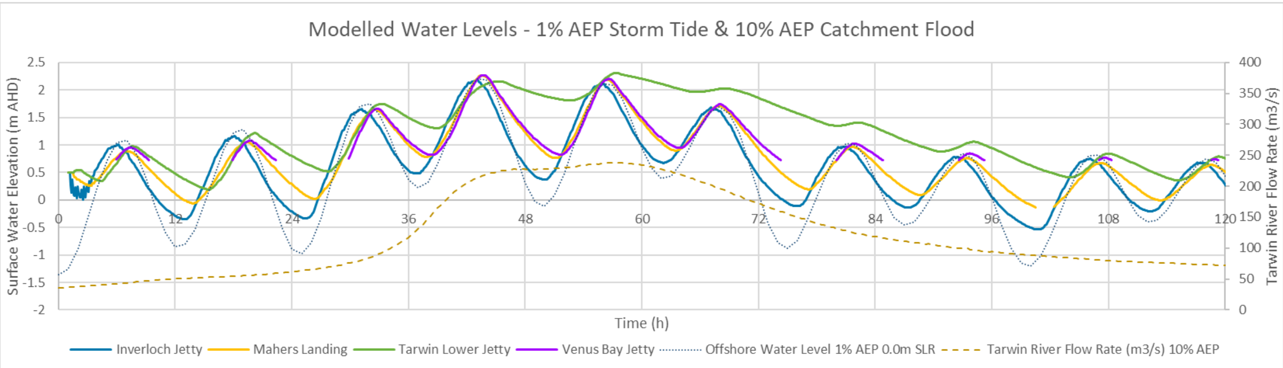


Figure 3-8 Timeseries of water surface elevation, Anderson Inlet, Existing 1% AEP Storm Tide, 1% Wind + 10% catchment flood

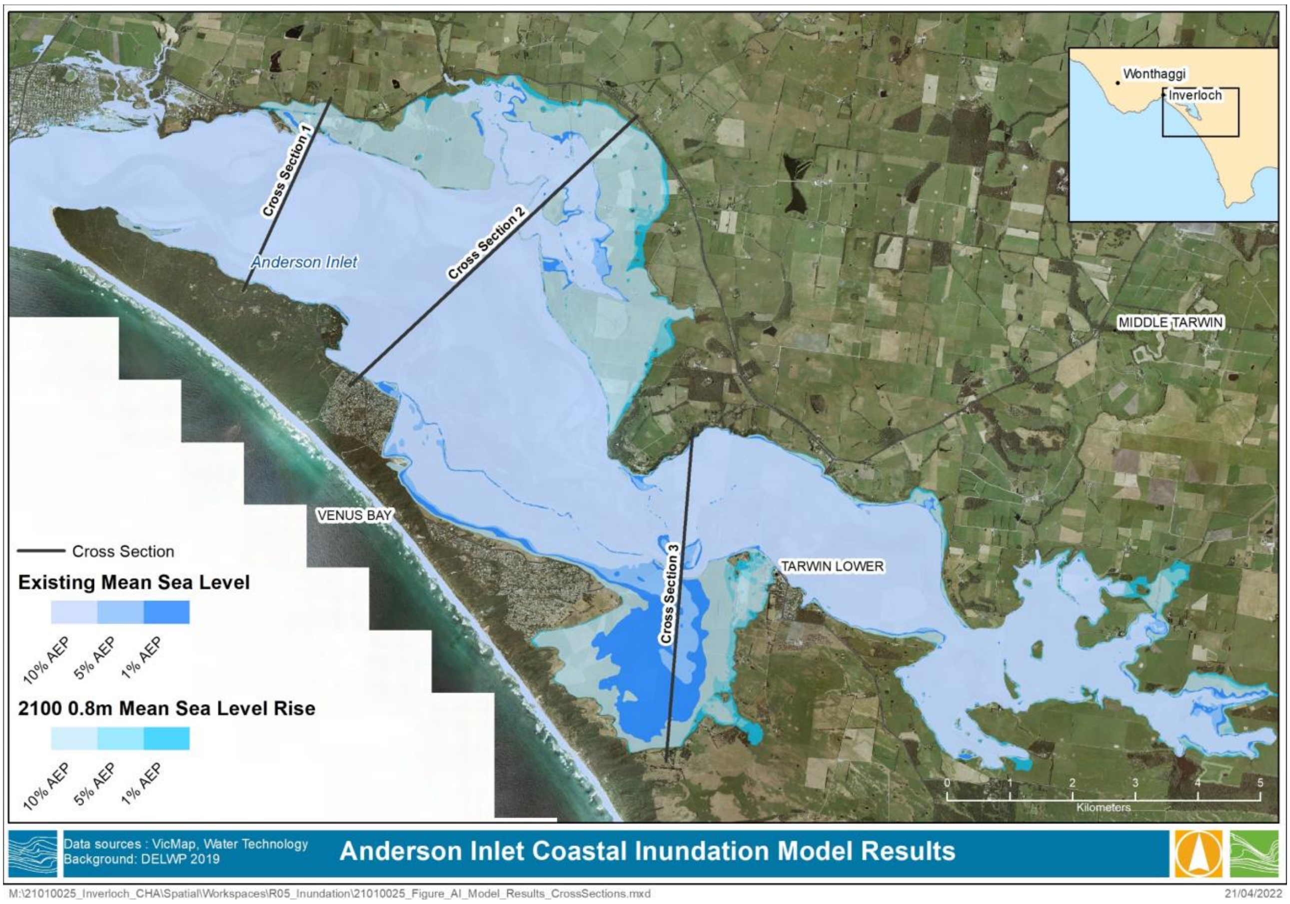


Figure 3-9 Anderson Inlet Inundation and Cross Section Locations, Existing and 2100 0.8m SLR scenarios

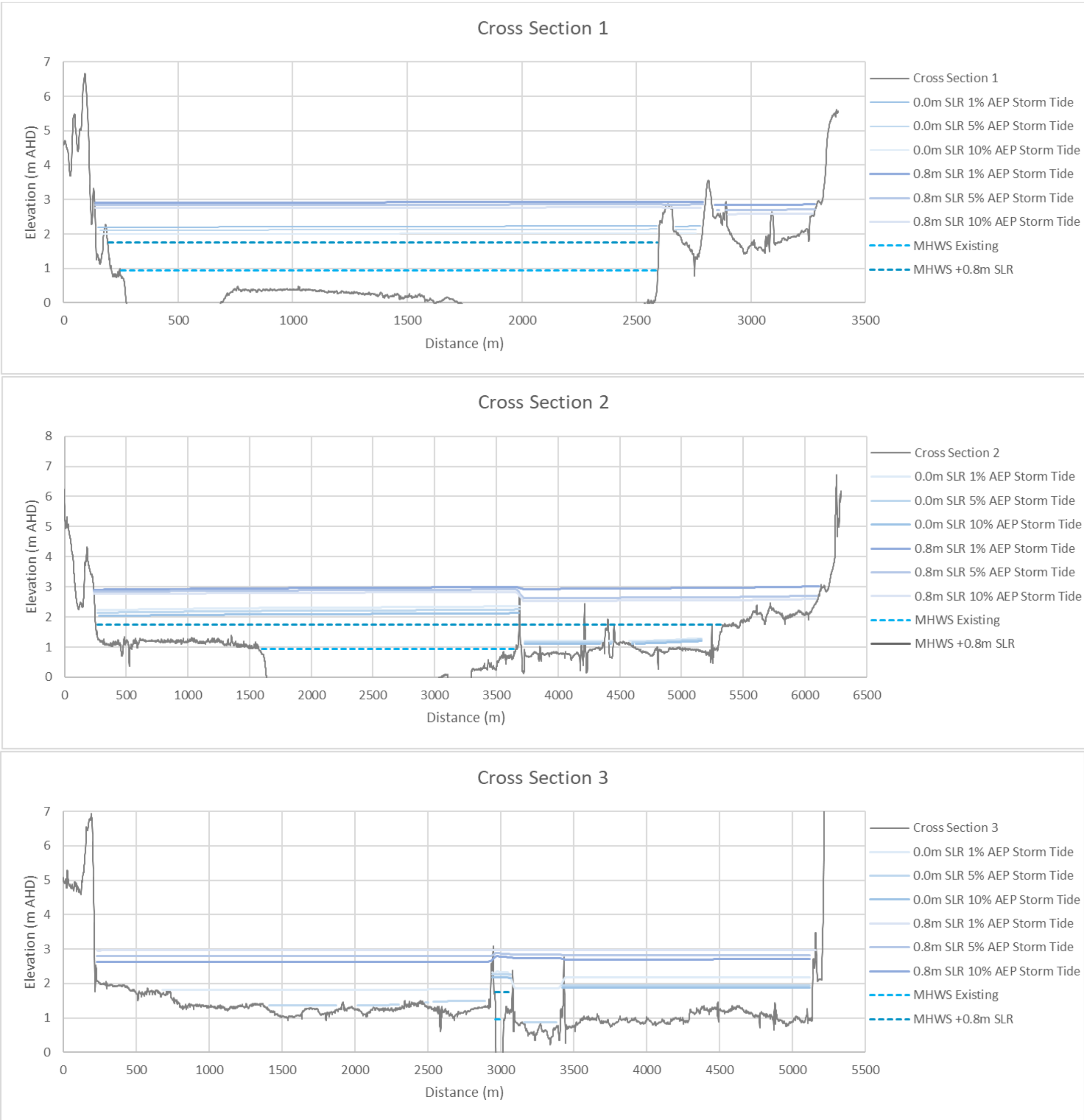


Figure 3-10 Anderson Inlet Inundation Cross Sections

3.3.2 Hazard Mapping

The hazard maps presented in Appendix A present the maximum water level resulting from the combined offshore storm tide, catchment flood and wind conditions described in Table 3-5. The water level is the maximum shown at any time during the simulation, regardless of the duration of the flooding.

Coastal inundation hazard mapping using the Anderson Inlet hydrodynamic model terminates at Screw Creek after which the Inverloch urban catchment model presents flooding.

Table 3-5 Coastal Inundation Scenarios Modelled in Anderson Inlet

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

3.4 Inverloch

3.4.1 Inundation Drivers

Coastal inundation hazard at Inverloch is driven by water levels contributing via the following pathways:

- Open ocean storm tide levels
  - Water levels along the open coast can cause flooding via Wreck Creek and Ayr Creek during elevated storm tides
- Nearshore wave setup
  - The open beach and small dune system along the beach from Wreck Creek to Point Norman is subject to storm tides **and** wave setup, resulting in additional water levels flowing into Wreck Creek and across any low coastal barriers in the future
- Flood levels within Anderson Inlet
  - Flood levels determined through the Anderson Inlet model are used as a tailwater boundary for the urban drainage system, and can backflow up Screw Creek into Broadwater Estate
- Urban runoff

- The drainage network for Inverloch is extensive and assists to move water around the hilly urban area
- The urban drainage network also routes flows from the rural catchments outside of the town through to the coastline

- Urban drainage system over/backflow
  - There are 7 coastal outfalls along the Inverloch foreshore

3.4.2 Flooding Processes

Like an extreme event in the rural catchment, extreme events occurring in the urban catchment are considered to be independent of, and driven by, different processes compared to the generation of an extreme storm tide event. As such, the 1% AEP storm tide is combined with a 20% AEP catchment flood event, along with the other combinations detailed in Table 3-1. The 20% AEP catchment flood is generally the level urban stormwater systems are designed to carry before they reach capacity.

However, unlike the rural catchment and flow within the Tarwin River, the flow within the Inverloch urban catchment which results in flooding is driven by local rainfall and runoff and flow peaks for a short duration. The 1% AEP storm tide boundary, the Anderson Inlet water level generated from the 1% AEP storm tide + 10% AEP catchment flood model at Ayr Creek, Point Hughes, adjacent to the Inverloch Jetty and at the mouth of Screw Creek are presented in Figure 3-11. The 20% urban catchment hydrographs used as boundaries on the upstream side of the town within the Inverloch urban model are also shown in Figure 3-11.

Sensitivity testing of the flood peaks indicated that when the peak of the storm tide is not timed to coincide directly with the peak of the urban flood, there is no combined flood effect, i.e. the inundation due to storm tide does not change, nor does the inundation caused by runoff from the catchment, unless the peaks are coincident, then there is a change in the inundation extent. As the Study is an assessment of the *coastal inundation*, urban catchment inundation which does not interact with the coastal water is not presented in the coastal inundation hazard layers.

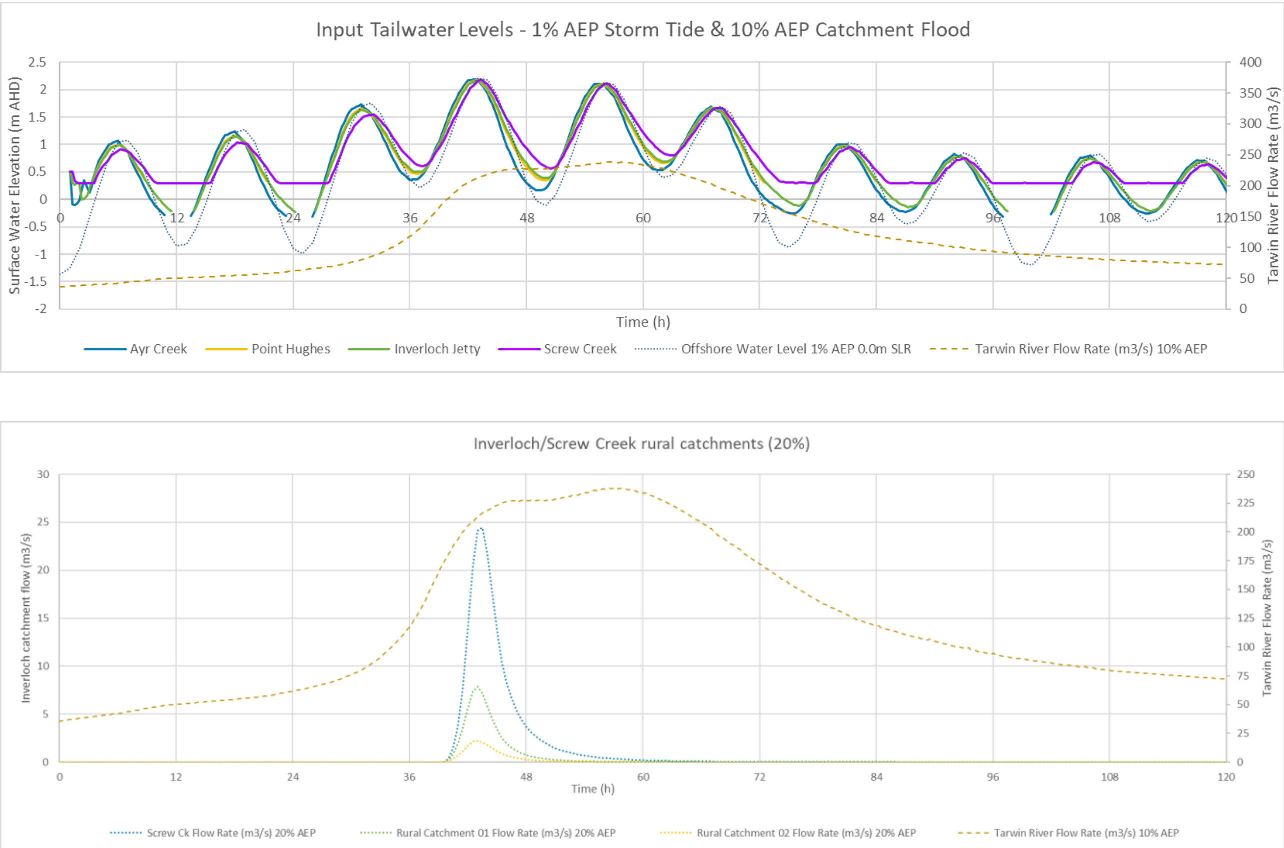


Figure 3-11 1% AEP Storm Tide Model Boundaries, Inverloch Urban Model

3.4.3 Hazard Mapping

The complex processes and different flood drivers have resulted in some overlapping of the inundation hazard layers generated by different processes.

Inland of the coast between Flat Rocks and Point Norman the combination of the 1% AEP storm tide and 20% AEP urban flow event, and the 5% and 10% AEP storm tide with the 1% AEP urban flow event also results in contrasting dominance of inundation hazard extents. Closer to the coast, the larger inundation hazard extent is associated with the 1% AEP storm tide (and 5% or 10% AEP catchment flood), whilst on the inland side of the inundation hazard zone the larger hazard extent is associated with the 5% and 10% AEP storm tide as it is combined with the 1% AEP catchment flood.

As noted in Section 3.2.3.2, flooding of Wreck Creek and Surf Beach residential area under existing sea levels has been completed with a dynamic tailwater, including wave setup, whilst future inundation hazard layers use bathtub modelling to intersect the elevated total coastal water level with the topography.

Inundation hazard extents generated for the area east of Wreck Creek combine the dynamic urban catchment flooding and the bathtub intersection of the storm tide and wave setup for future sea level rises. The impact on flood extent of the offshore storm tide and wave setup diminishes towards Point Norman as direct exposure to the open coast lessens and the urban catchment processes begin to dominate.

Timeseries of flood levels for the 1% and 10% AEP storm tides, combined with the 10%/20% and 1% catchment AEP design flows respectively, are shown in Figure 3-13 and Figure 3-14. The timeseries are provided for key locations across Inverloch, noted in the inundation hazard extents for the same scenarios in Figure 3-12. The total coastal water level at Point 1 includes the impact of wave setup.

The timeseries demonstrate the different flooding processes within the hazard zones. Within the Surf Beach residential area, Point 01 and Point 02 show water level within the overland flow path and at the tailwater end of Wreck Creek. Figure 3-13 illustrates where the intense 1% AEP rainfall in the catchment results in a rapid response of the water surface elevation causing flooding at Point 01 whilst at Point 02, which is directly exposed to the coastal bound, flooding is delayed until the peak of the storm tide occurs and the runoff from the catchment combine. As noted previously, the Inverloch catchment model flooding has been optimised to coincide the critical duration of the urban runoff in key areas with the peak of the storm tide. At Ayr Creek (Point 03), flooding is less responsive to the storm tide boundary, with the runoff within the steeper catchment driving the water level peak prior to the peak of the storm tide (centre chart, Figure 3-13). The elevated storm tide level delays the drainage of urban areas after the 1% AEP catchment event within Ayr Creek and at the Inverloch Jetty and Screw Creek (lower chart, Figure 3-13).

During a 1% AEP storm tide levels and lower catchment flood conditions flooding is less responsive to rapid rainfall runoff and the water surface elevation at Point 01 and Point 02 rises more in sync with the nearshore storm tide (top, Figure 3-14). The water surface elevation rises further as the catchment drains into Wreck Creek due to the coincidence of the critical duration and the storm tide. This delayed catchment response from the smaller catchment event is also seen at Ayr Creek as catchment flow drainage is reduced by the inundation caused by the elevated storm tide whilst flooding levels increase with the restricted drainage from the storm tide boundary at Inverloch Jetty and Screw Creek.

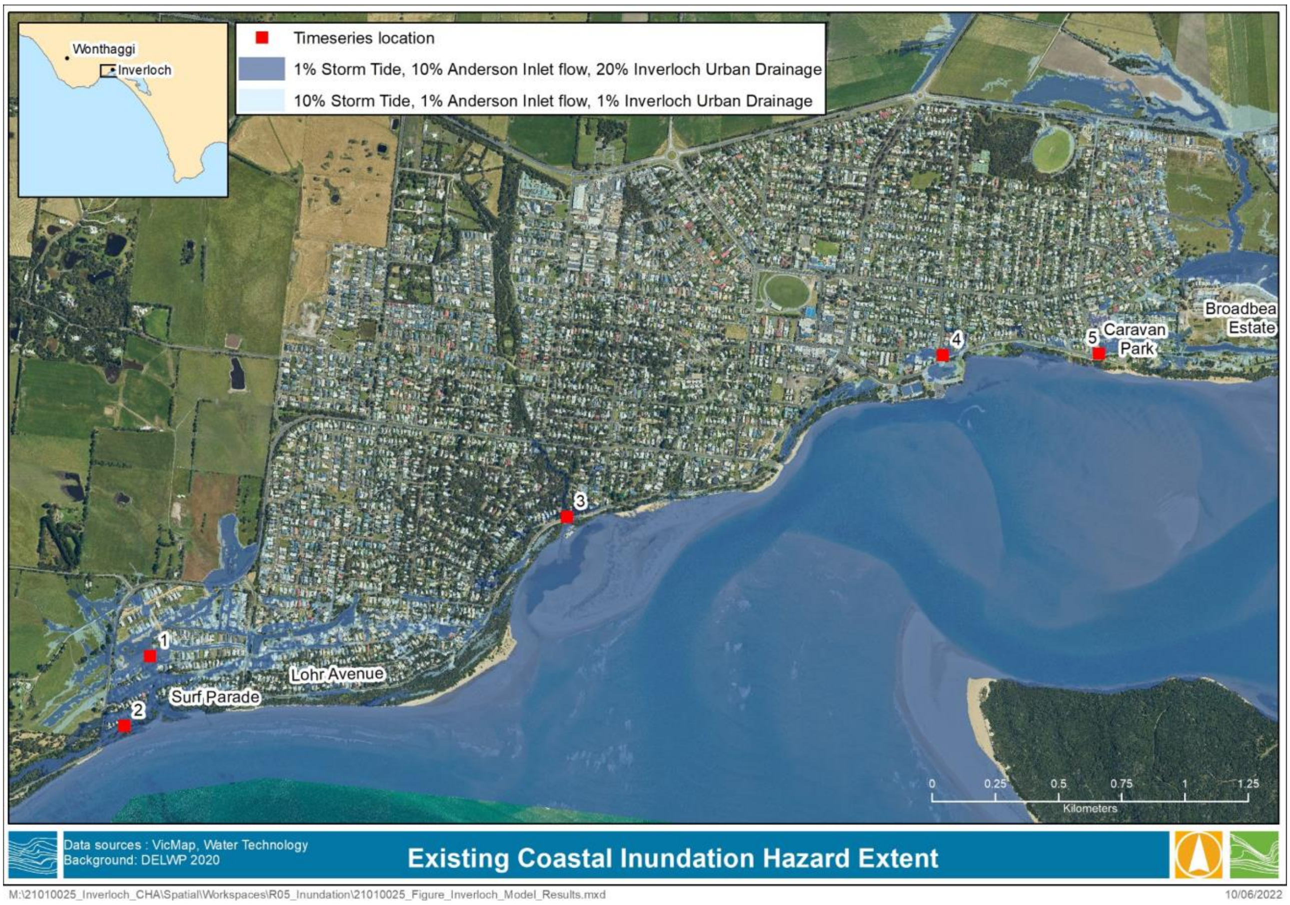


Figure 3-12 Existing Coastal Inundation Hazard Extent, Inverloch

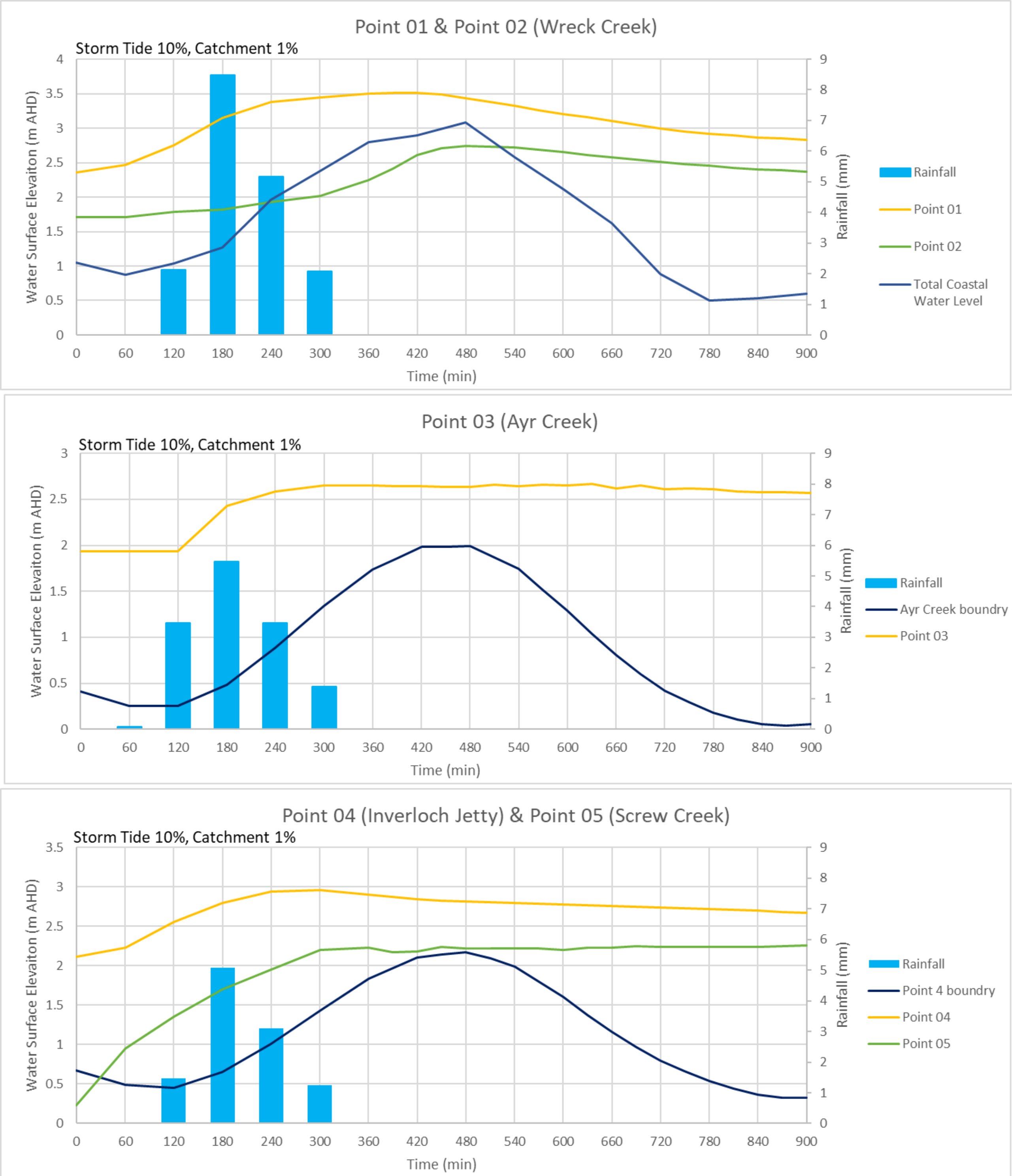


Figure 3-13 Time varying water levels, Existing 10% AEP Storm Tide + 1% Inverloch Catchment

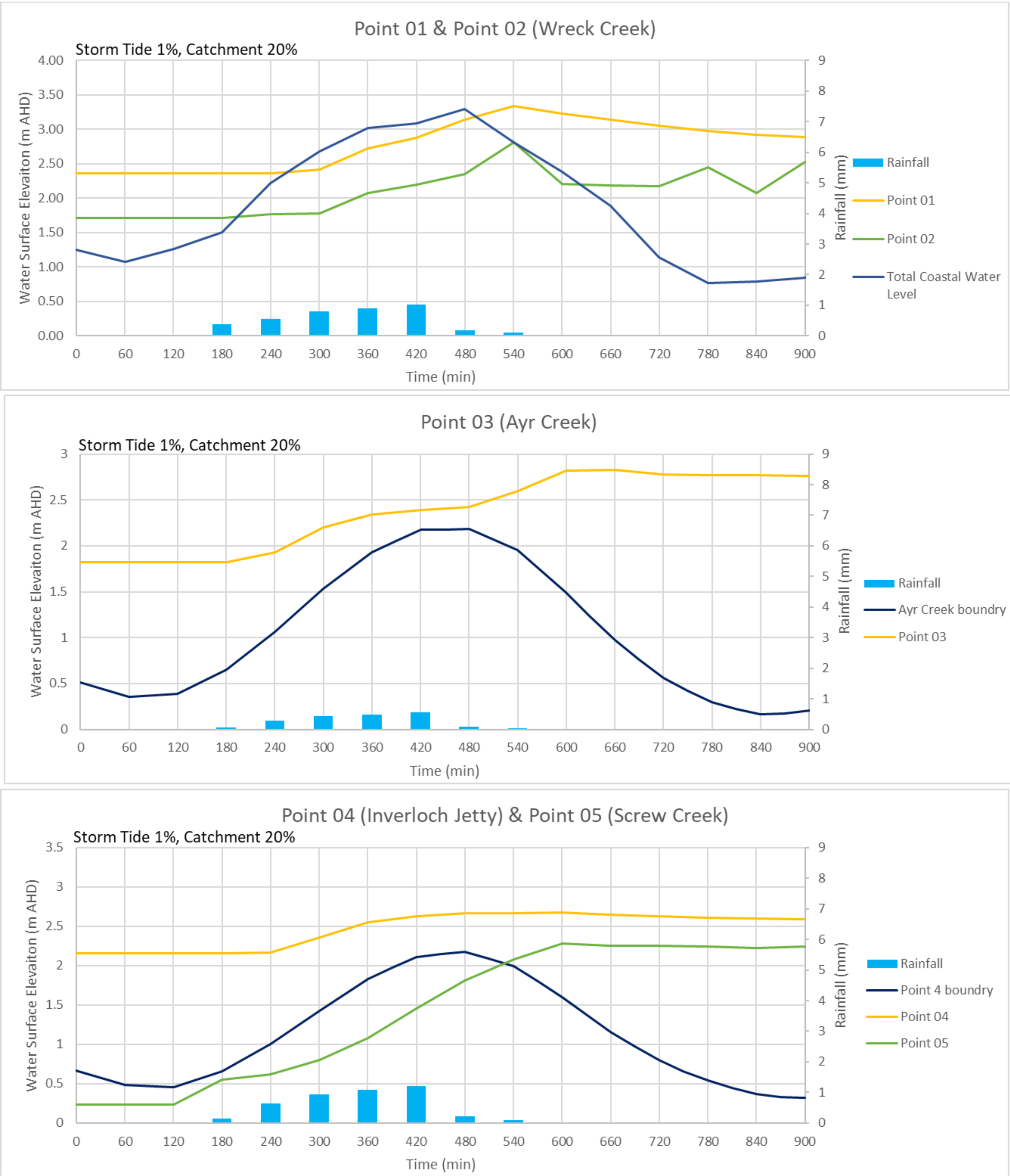


Figure 3-14 Time varying water levels, Existing 1% AEP Storm Tide + 20% Inverloch Catchment

3.5 Inundation Hazard Zones

The processes which contribute to the extent of coastal inundation hazard have been presented above for each section of the coastline.

It is important to note here that, like the erosion hazard, the coastal inundation hazard zone is an area which the coastal and fluvial processes in the Study Area could cause an inundation hazard to be realised. The coastal inundation hazard zones should not be considered a distinct and final area within the Study Area to which a flood will definitely not exceed during certain events or at future planning horizons. The coastal environment, and the urban and rural catchments are complex environments with many variables and are subject to changes over time. The hazard zones have been generated to capture assets and values within the zone which could suffer be impacted by coastal inundation and are therefore considered at risk. In many areas along the Study Area, there may be no identified asset or value and thus no risk from the coastal inundation hazard.

The resulting hazard zones for the different sections of the coastline are presented in Appendix A.

3.6 Comparison to Previous Storm Tide Mapping

Previous storm tide and sea level rise mapping has been undertaken and incorporated into the *Land Subject to Inundation Overlay* (LSIO) in the Bass Coast Shire Planning Scheme (2016).

The previous coastal inundation extent adopted the storm tide levels developed by CSIRO (McInnes, et al, 2009) which determined storm tide levels from a combination of measured data and hydrodynamic modelling. Those storm tides for Inverloch and the open coast of Venus Bay are provided in Table 3-6. Those storm tide levels have been used in bathtub modelling to intersect the coastline with the storm tide to define the Land Subject to Inundation. The LSIO in the Bass Coast Planning Scheme is the 1% AEP storm tide, the extent of which is presented in Figure 3-15. The 1% AEP storm tide inundation hazard zone developed for this Study, which includes the 20% AEP urban catchment flow, for the same area is also shown in Figure 3-15. The extent of the new coastal inundation hazard zone is notably larger than the previous extent, primarily due to the following:

- The nearshore 1% AEP storm tide calculated for this Study is higher than the 2009 storm tide (2.2m AHD versus 1.96m AHD)
- The additional water level due to wave setup on the coastal dune is considered in the current Study
- Urban runoff and flooding combined with a storm tide is now included in the coastal inundation hazard zone
- Inundation is included for Wreck Creek

Other changes compared to the LSIO are likely to be the use of a dynamic model to define the existing inundation hazard zone. This considers the timing and duration of the various components and could be expected to result in smaller inundation zone, if not for the magnitude of the storm tide and additional water level of the wave setup which is excluded from the current LSIO.

Table 3-6 CSIRO Storm Tide Levels (McInnes, 2009)

Storm Tide at "Venus Bay"	Storm Surge (m AHD)	Storm Tide (m AHD)
10%	0.77 (±0.05)	1.54 (±0.10)
5%	0.80 (±0.05)	1.70 (±0.10)
1%	0.85 (±0.07)	1.96 (±0.12)

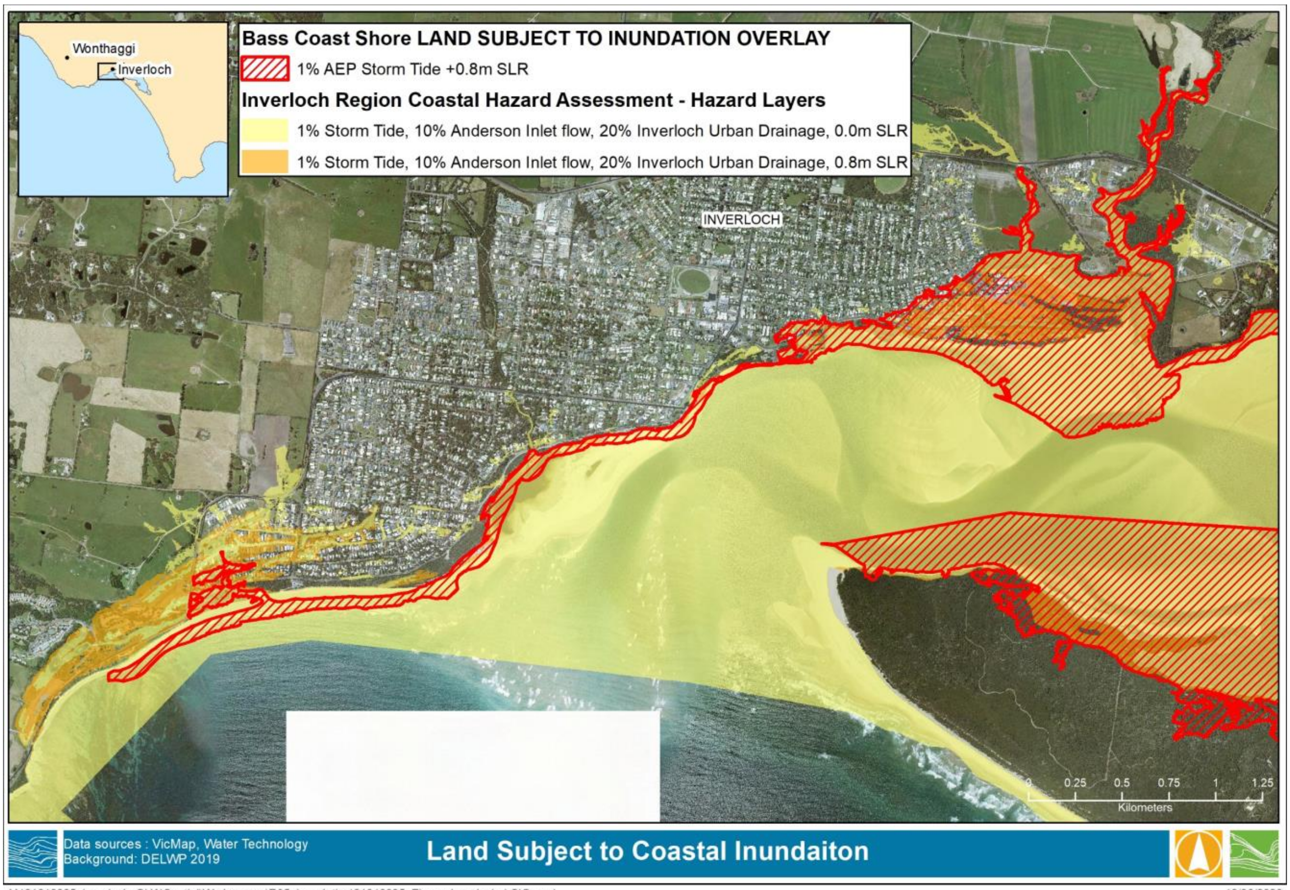


Figure 3-15 Bass Coast LSIO at Inverloch compared with Coastal Inundation Hazard Zones

3.7 Permanent Inundation

The increase in mean sea level will result in an increase in the elevation of tidal planes across the Study Area. The offshore levels presented in Table 2-2 will increase directly with the increase in mean sea level. The tidal planes within Anderson Inlet are likely to increase by at least as much, however the changing hydraulics of the entrance with increasing sea levels will influence the magnitude of increase, particularly of the low water tidal planes.

The extent to which the low lying land within the Study Area will be impacted by sea level rise has been assessed by intersecting the future MHWS level with the topography. The future MHWS levels considered are presented in Table 3-7.

Table 3-7 Future MHWS Levels

Planning Horizon	Sea Level Rise	MHWS (m AHD)		
		Offshore	Inverloch Jetty	Tarwin Lower Jetty
Present Day	0.0 m	1.1	0.94	0.95
2040	0.2 m	1.3	1.14	1.15
2070	0.5 m	1.6	1.44	1.45

Planning Horizon	Sea Level Rise	MHWS (m AHD)		
		Offshore	Inverloch Jetty	Tarwin Lower Jetty
2100	0.8m	1.9	1.74	1.75
2100	1.1 m	2.2	2.04	2.05
2100	1.4 m	2.5	2.34	2.35

The extent of this inundation is presented in the Inundation Hazard Maps in Appendix A. Figure 3-10 also shows the extent of potential tidal inundation across the Anderson Inlet at selected cross sections.

Whilst the future tidal inundation will be short lived, it will be regular, the mean high water spring level within Anderson Inlet currently exceeded roughly 5% of the year, equivalent to 450 hours, or 37.5 hours per month. This regular inundation will likely result in a migration landward of vegetation (assuming the rate of sea level rise is greater than the rate of sedimentation), and the possible undermining of earthen levees around the floodplain. As a precautionary approach, it has been assumed that the existing levees around Anderson Inlet will not interrupt the areas vulnerable to future inundation from the elevated MHWS tide.

4 GROUNDWATER

4.1 Overview

A preliminary high level assessment of climate change and groundwater hazards was undertaken to assess how sea level rise is likely to impact coastal groundwater aquifers and to identify any key issues warranting further assessment beyond the scope of this project. The review has involved the following components:

- Literature review of sea level rise impacts on coastal aquifer systems
- A general review of the Cape to Cape Region groundwater systems – extent and conditions
- Identification of key potential groundwater hazards under present and future sea level conditions

4.1.1 Key Drivers and Processes of Coastal Groundwater

Coastal aquifer systems where there is a hydraulic connection with sea water exhibit an interface between the less dense freshwater sitting above, and adjacent to, a wedge of salt water. As the salt water is denser than the fresh water it moves in this form beneath the fresh water. This wedge of salt water can occur on the landward side of the coastline and can extend from metres to several kilometres beneath the freshwater system (Ivkovic et al, 2012). Mixing occurs between the freshwater and saltwater at the interface of the two, with the position and width of the interface zone depending on the particular hydrogeological and hydrological conditions. The key components and processes are displayed conceptually in Figure 4-1.

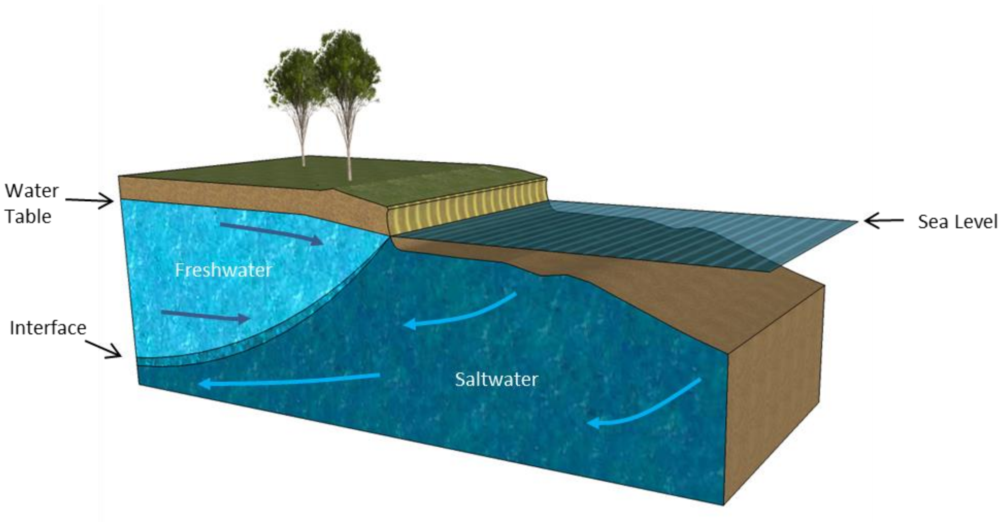


Figure 4-1 Conceptual freshwater-saltwater interface in an unconfined coastal aquifer

During a tidal cycle the location of the interface can vary depending on the sea level; with the interface moving inland at the high tide and then retreating seaward on the ebb. The result is that on areas such as tidal flats, there can be a layer of saline groundwater beneath the near-shore vegetation communities during the high tide which is displaced by fresh groundwater as the tide retreats. The magnitude of these changes is strongly dependent on the level of hydraulic connection between the aquifer and the sea and the geological properties of the aquifer such as permeability. This effect can be significantly magnified during elevated storm tides and extreme coastal storm wave events.

Rivers, stream and drainage channels can provide freshwater inputs known as “recharge” to the coastal groundwater systems, but they can also act as conduits for the more dense salt water to move inland with the tidal movements.

Another key process by which saline water migrates landward is as a result of groundwater extraction. The extraction of the freshwater through pumping lowers the groundwater table and can reverse the natural movement of fresh groundwater towards the coastline. This change in hydraulic gradient allows salt water to move more easily into the freshwater areas.

The movement of saline water from sea water sources into freshwater aquifer systems is known as sea water intrusion.

4.1.2 Sea Level Rise Impacts

Sea level rise is predicted to have a number of potential impacts upon coastal aquifer systems. The following key potential hazards have identified:

- Landward migration of the freshwater-saltwater interface. The scale of the intrusion of sea water is likely to be dependent on the capacity of the groundwater table to rise at the same rate as sea level change. Surface controls such as drains, wetlands, streams/rivers, groundwater evapotranspiration, and groundwater abstraction may limit the water table rise that could occur (Werner and Simons, 2009). This is displayed conceptually in Figure 4-2.
- As well as sub-surface impacts, sea level rise may also result in the permanent surface inundation of low-lying coastal regions and/or increase the frequency and intensity of temporary inundation. This could result in the intrusion of salt water into freshwater reserves by movement of the interface or by downward seepage. It may also limit existing recharge zones (Ivkovic et al, 2012). This is shown conceptually in Figure 4-3.
- The time taken for the freshwater-saltwater transition zone to reach equilibrium can vary significantly. Highly permeable aquifers can have a quick response time from a geological point of view. Nevertheless, even in these rapid systems, the time scale will still be in the order of years to decades for a new dynamic state of equilibrium to be reached. Barlow (2003) found that sea water intrusion from past sea-level rise fluctuations have not yet reached equilibrium even after periods as long as 100,000 years (Ivkovic et al, 2012), noting that the extreme change in sea levels over this period, including a rise in mean sea level of over 120m in the past 18,000 years is significantly greater than the 0.8m increase projected to 2100

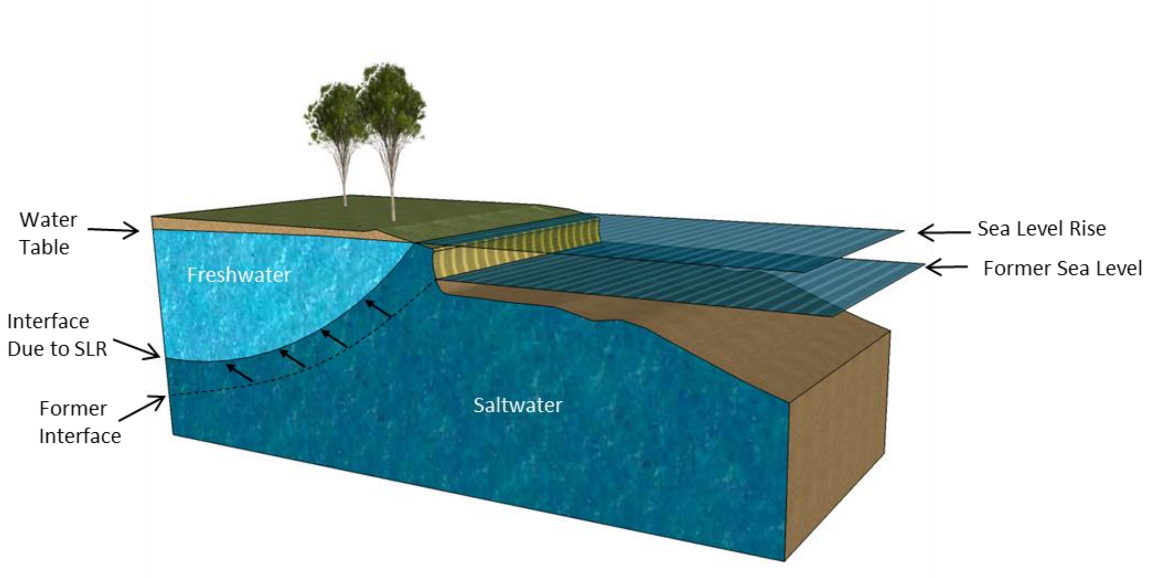


Figure 4-2 Upward and Landward shift in the Freshwater-Saltwater Interface as a result of SLR

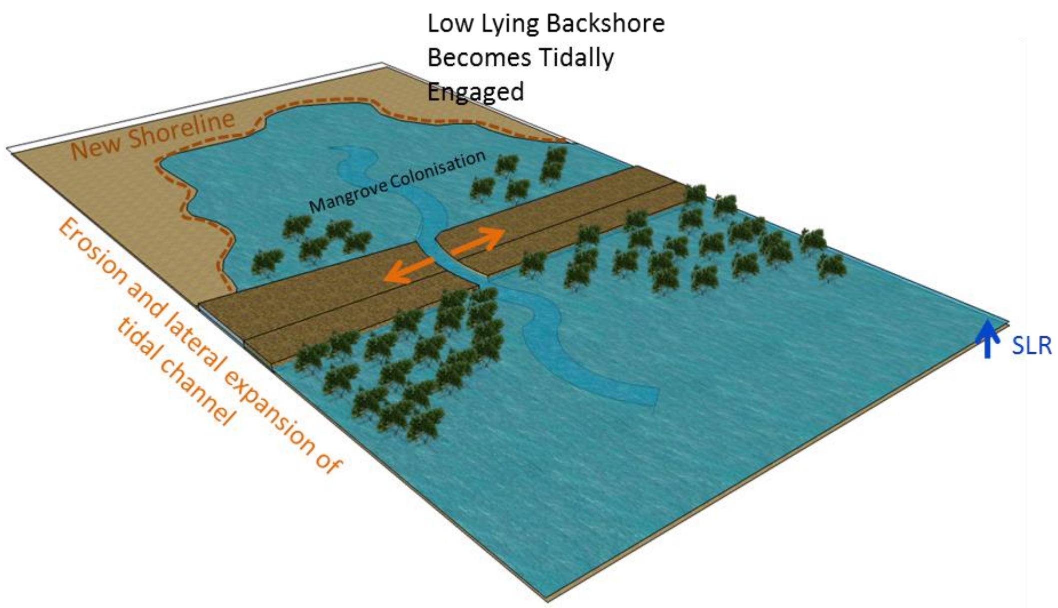


Figure 4-3 Increased Inundation of Backshore Areas with Sea Level Rise

4.1.3 Other Climate Change Influences

Climate change has the potential to influence groundwater systems through a number of other mechanisms, including the following (based on Barron et al, 2011):

- Changes in rainfall amounts and intensity,
- The effect of vegetation from changes in temperature and carbon dioxide,
- Alteration of groundwater-surface water interactions, such as sea water intrusion in coastal settings.

These influences and the associated changes are predominantly recharge processes for the groundwater systems. Due to the coastal setting of the Study Area and the scope of this coastal inundation hazard assessment, the focus of this groundwater hazard review is on sea water intrusion into coastal groundwater systems and how the current groundwater hazards may be impacted by sea level rise.

The effect of changes to rainfall, catchment derived surface water, and vegetation on coastal groundwater recharge and water quality is beyond the scope of this study and could be considered along with the changes to mean sea levels as part of a groundwater focussed hazard assessment.

4.2 Groundwater Hazards in the Inverloch Region

4.2.1 Groundwater Management

The Victorian Groundwater Management Framework consists of groundwater catchments, groundwater management areas (GMAs) and water supply protection areas (WSPAs), as seen in Figure 4-4. Collectively these are known as groundwater management units.

The Study Area coastline is classified by two zones in the framework; the first being the Tarwin Groundwater Basin, the area surrounding Anderson Inlet; and the second being the remaining area outside of the Tarwin Groundwater Basin area which is classified as an “Unincorporated Area”.

Southern Rural Water Corporation considers the groundwater resources within the Tarwin Groundwater Management Area to be finite and subsequently that there is a risk to the groundwater if extractions exceed the limits/ Permission Consumptive Volumes (PCV’s) specified in the Tarwin Groundwater Catchment Statement (Management Plan).

The “Unincorporated Area”, i.e. groundwater in any area located outside of the Tarwin Groundwater Management Area, is considered to have low utilisation and subsequently the risk to the groundwater resource in the area is minimal. The Leongatha GMA is to the north, the Corinella GMA to the north west and the Yarram WSPA to the east are the nearest regulated groundwater resources.

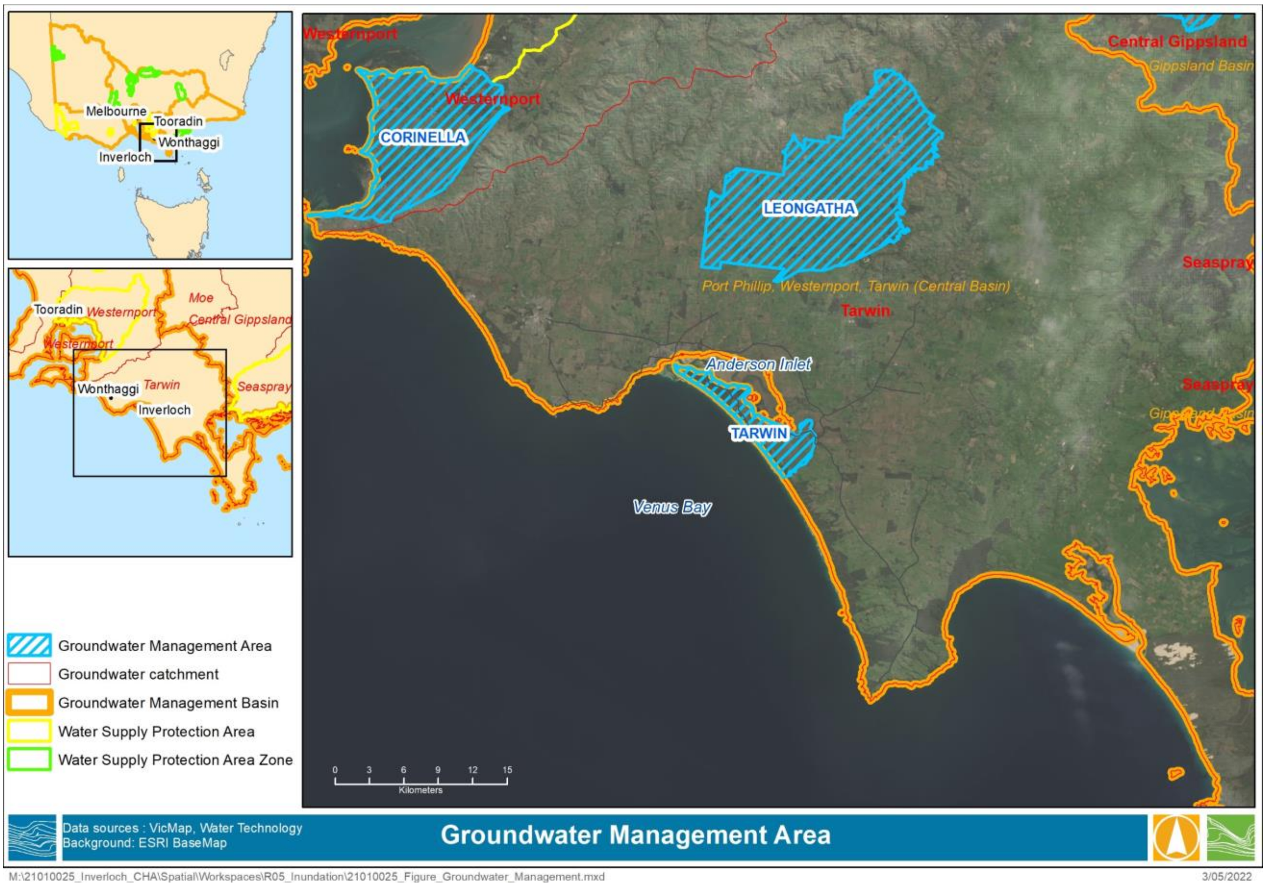


Figure 4-4 Groundwater Management Areas in Study Area

4.2.2 Groundwater & Geology

The geology and geomorphology of the Study Area has been extensively reviewed by Rosengren (2021) as part of this Study and full details of the geology which forms this region can be found in Report 4, Appendix A. The summary of the geology within the Study Area below is focussed on the role of the geology in developing groundwater basins, aquifers and flows.

The geological units in the study area predominantly consist of the Quaternary sediments, the Haunted Hill Formation, the Wonthaggi Formation, the Liptrap Formation, Undifferentiated Marine Sediments, the Mount Easton Shale, and the Cambrian Basalts, as presented in Figure 4-5.

The Quaternary sediments are characterised by fluvial and alluvium sediments (dominated by gravels, sands and silts), paludal lagoon and swamp sediments (dominated by silts and clays), and aeolian coastal and inland dune sand sediments. The Haunted Hill Formation (Tph) is dominated by fluvial crossed-bedded and lenticular gravels with occasional sands, ferruginous sand, and kaolinitic clays. The Basement units are dominated by interbedded quartz-rich marine sandstone, siltstone, shales and mudstone units with the occasional conglomerate layer, as well as a section of Cambrian basalts located on the eastern side of Cape Liptrap.

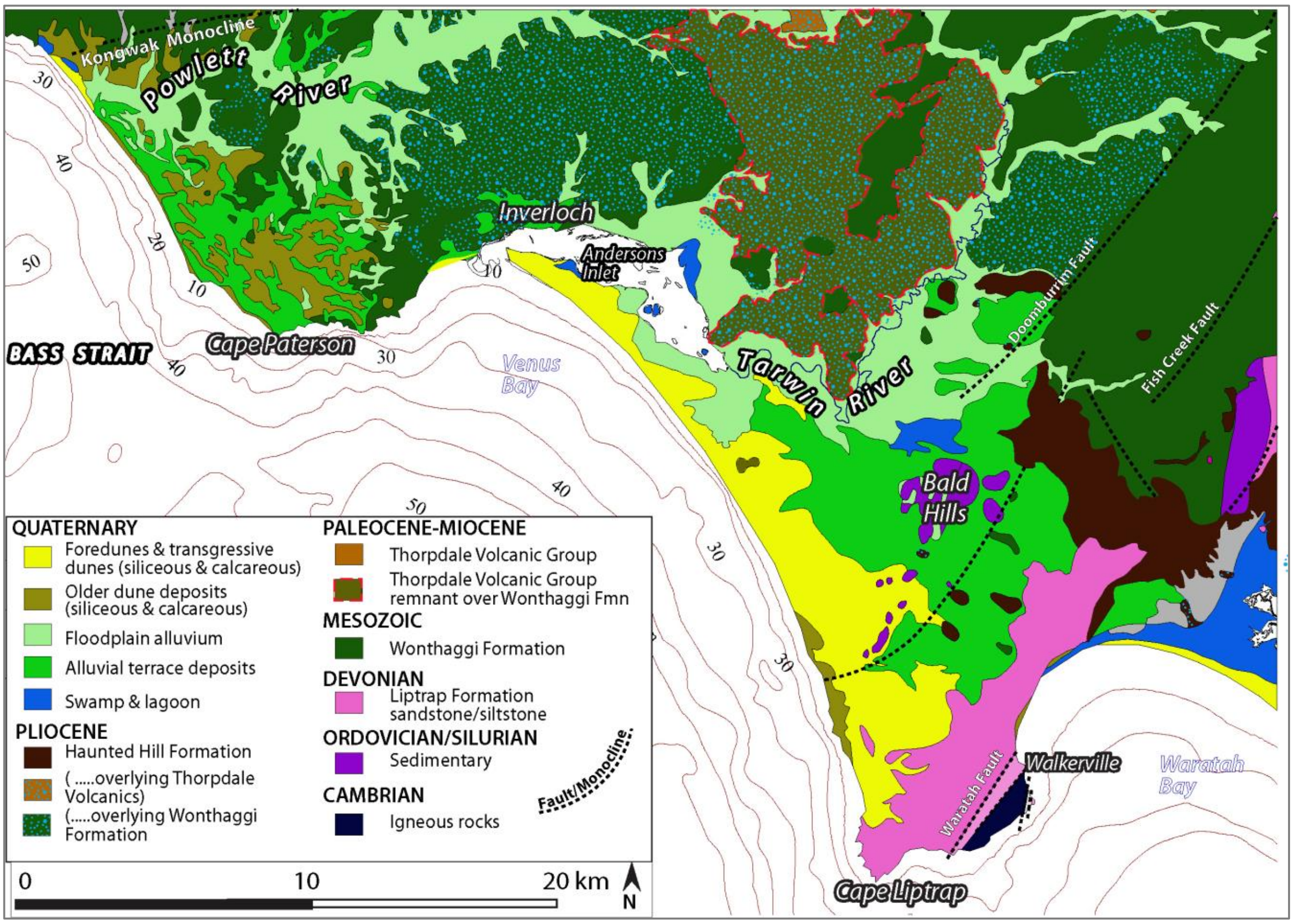


Figure 4-5 Surface Geology of Study Area (Rosengren, 2021)

4.2.3 Present Conditions

4.2.3.1 Aquifers and Aquitards

Aquifers in the Study Area comprise mainly of the Quaternary sedimentary aquifers associated with the fluvial and alluvium sediments (dominated by gravels, sands and silts), paludal lagoon and swamp sediments (dominated by silts and clays), and aeolian coastal and inland dune sand sediments deposits (as seen in Table 4-1). The Tarwin groundwater management area is considered an upper aquifer. Detailed water balance studies have not been completed for the Tarwin aquifer system.

The idealised hydrogeological cross section developed by Southern Rural Water (Figure 4-6) of for upper aquifers in the Gippsland area show recharge is highest into areas of porous alluvial surfaces, and most likely also sandy dunes such as the Point Smythe / Venus Bay terrain. Discharge from the upper aquifers occurs through baseflow to streams, evapotranspiration discharge to lakes and offshore and leakage to deeper aquifers or extraction.

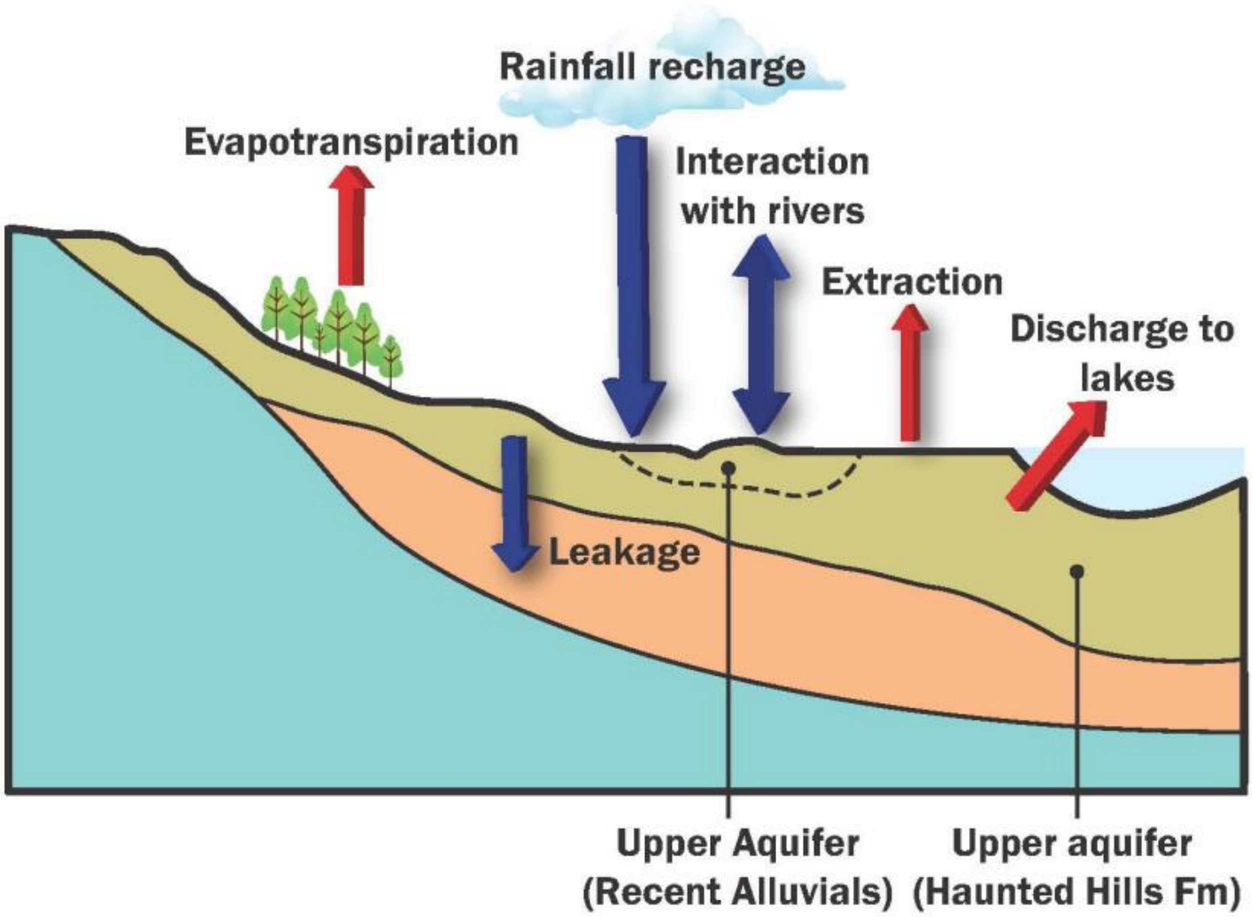


Figure 4-6 Idealised Hydrogeological Cross Section (Southern Rural Water, 2012)

Drillhole information (obtained from the Visualising Victoria's Groundwater (VVG) platform) within the study area is limited outside of the Tarwin Groundwater Management Area, and there are few sites within close proximity to the coastline. Two groundwater monitoring bores are located in the Venus Bay settlements as shown in the inset in Figure 4-7.

Table 4-1 Summary of Stratigraphic Units in the Study Area and approximate depth from Bore 114156 (Venus Bay settlement 2)

Geological Unit	From (mbgl)	To (mbgl)	From (mAHD)	To (mAHD
Fine Dry Sand	0.00	11.00	5.64	-5.36
Fine Sand Shell and Sandstone	11.00	14.30	-5.36	-8.66
Limestone and Fine Sand	14.30	23.00	-8.66	-17.36
Silty Green Marl Shell	23.00	24.00	-17.36	-18.36
Silty Green Sand Shell	24.00	33.00	-18.36	-27.36
Silty Green Sand Shell	33.00	45.00	-27.36	-39.36
Limestone and Grey Clay	45.00	50.00	-39.36	-44.36

It should be noted that the bore logs for the area are limited to bore 114156 in Venus Bay settlement 2 (north) and bore 113124 in Venus Bay settlement 1 (south). Lithology data from neither bore identify the presence of the Haunted Hill Formation (within close proximity to the coast). This appears to be consistent throughout the Study Area and the review of coastal geology and geomorphology.

The depth to basement layer (relatively impermeable rock) from VVG suggests that the basement is located approximately 39.7mbgl (metres below ground level). Based on the bore logs from 114156, the basement in this location appears to be made of a limestone unit. Importantly, this data has been generated by extrapolation between limited data points and this depth below ground level is used as a guide in the absence of any site specific data.

The zones of interest in this Study Area are the Quaternary Sedimentary units as any rise in sea levels will result in the shallow aquifer systems being the most likely formations to be affected. As such, zones 5.64 m AHD to -39.36 m AHD in Table 4-1 are the focus of this report.

Groundwater yields (a measure of how quickly groundwater can be extracted from an aquifer) within the study area can vary dramatically depending on location and the presence of high clay content clay aquitards through the region, with yields typically <1 L/s outside of the Tarwin GMA and between 1-10L/s inside the Tarwin GMA.

A significant number of groundwater bores are present within the Study Area, as noted in Figure 4-7. Data on depth to groundwater within the study area is thus very comprehensive with depth to groundwater levels being below 5.0-6.0m bgl throughout much of the study area (based on projected depth to groundwater datasets, as seen in Figure 4-8). Depth to groundwater within the study area can vary dramatically (ranging from approximately 20.0mbgl to 75.0mbgl) in a few areas due to changes in topography (e.g. foredune systems) and changes in geology (eg. Cape Paterson and Cape Liptrap) as seen in Figure 4-8.

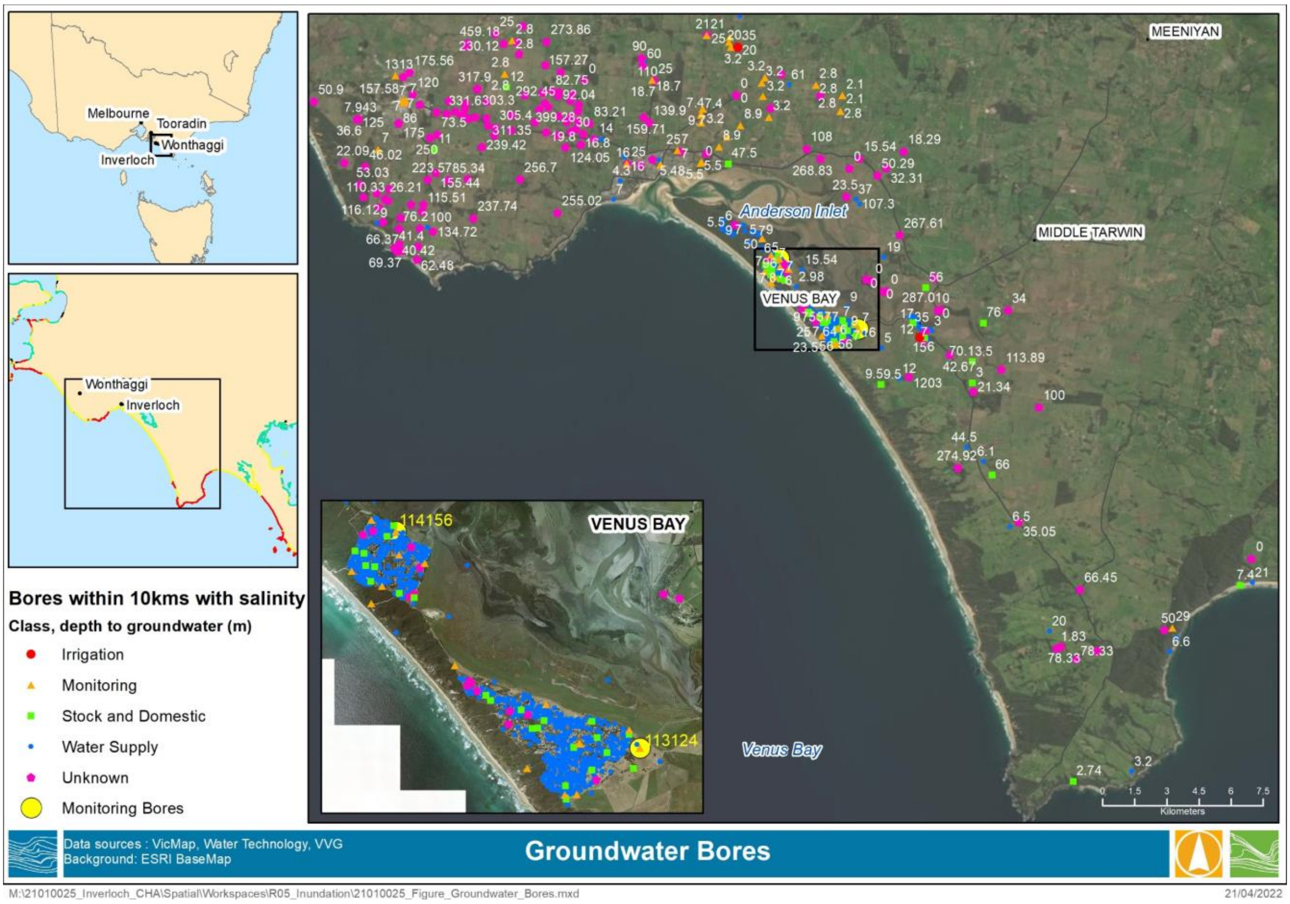


Figure 4-7 Location of Groundwater Bores

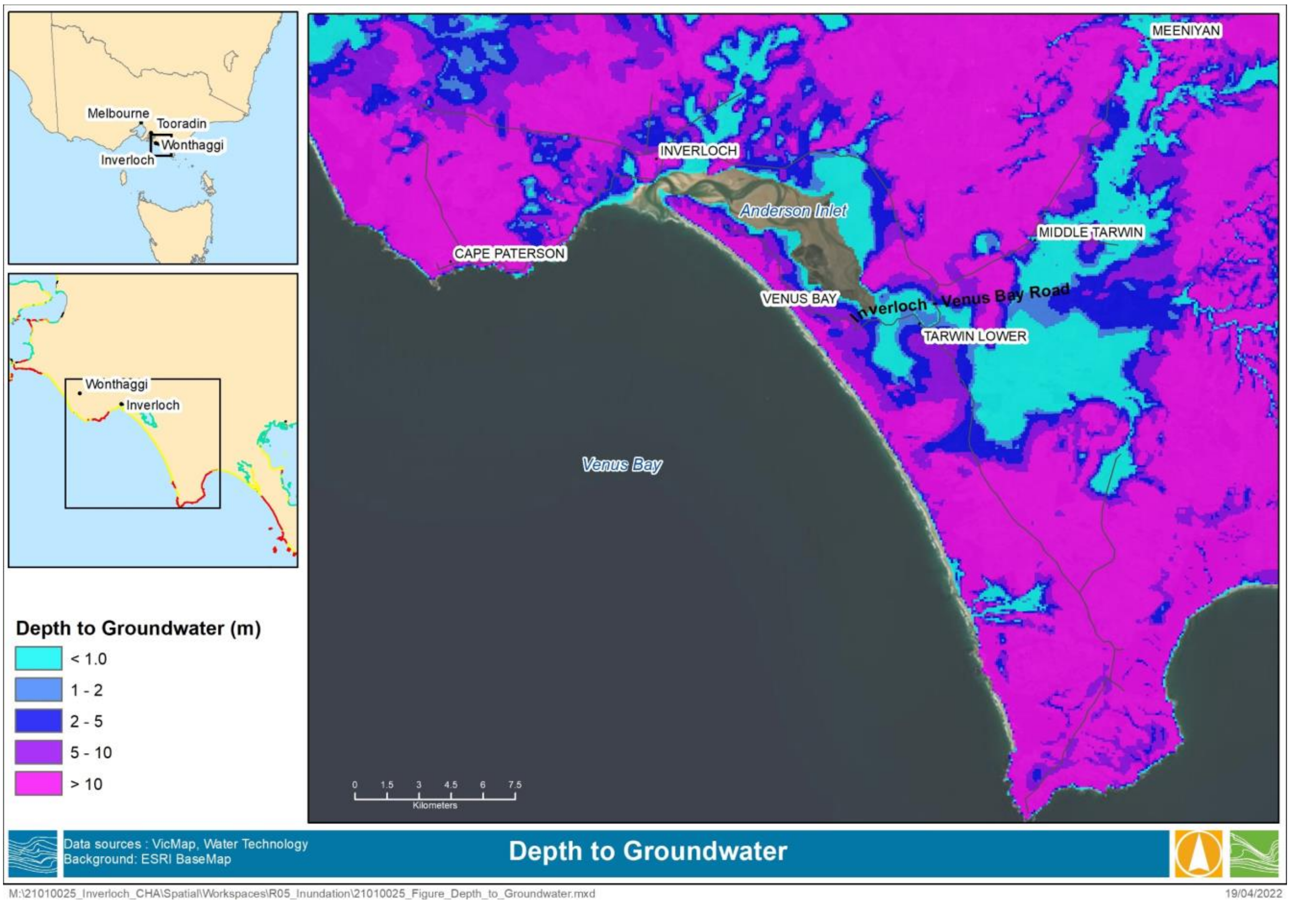


Figure 4-8 Depth to Groundwater

4.2.3.2 Groundwater Level and Flow

Regional groundwater flow in the Quaternary aquifer is generally interpreted to flow towards the ocean in a south to south--west direction, this is also supported by groundwater levels measured within bores located within the Study Area (as seen in Figure 4-7).

The surface elevation of the groundwater table is presented in Figure 4-9 along with the flow direction interpreted from the elevation. The surface of the groundwater table is reflective of the discharge into Anderson Inlet with the elevation less than 0m AHD through the Inlet and less than 2m AHD upstream of Tarwin Lower. A rise in elevation of the groundwater table can be seen along the dunes of the Point Smythe spit, suggesting flow to both the estuary and ocean side of the landform. A steep grade in the groundwater table can be seen along Bunurong Road coastline and towards Cape Liptrap.). Depth to groundwater can vary dramatically throughout the study area depending on the topography with the depth to groundwater ranging between 1.2 to 5.6 m below surface (as seen in Figure 4-8).

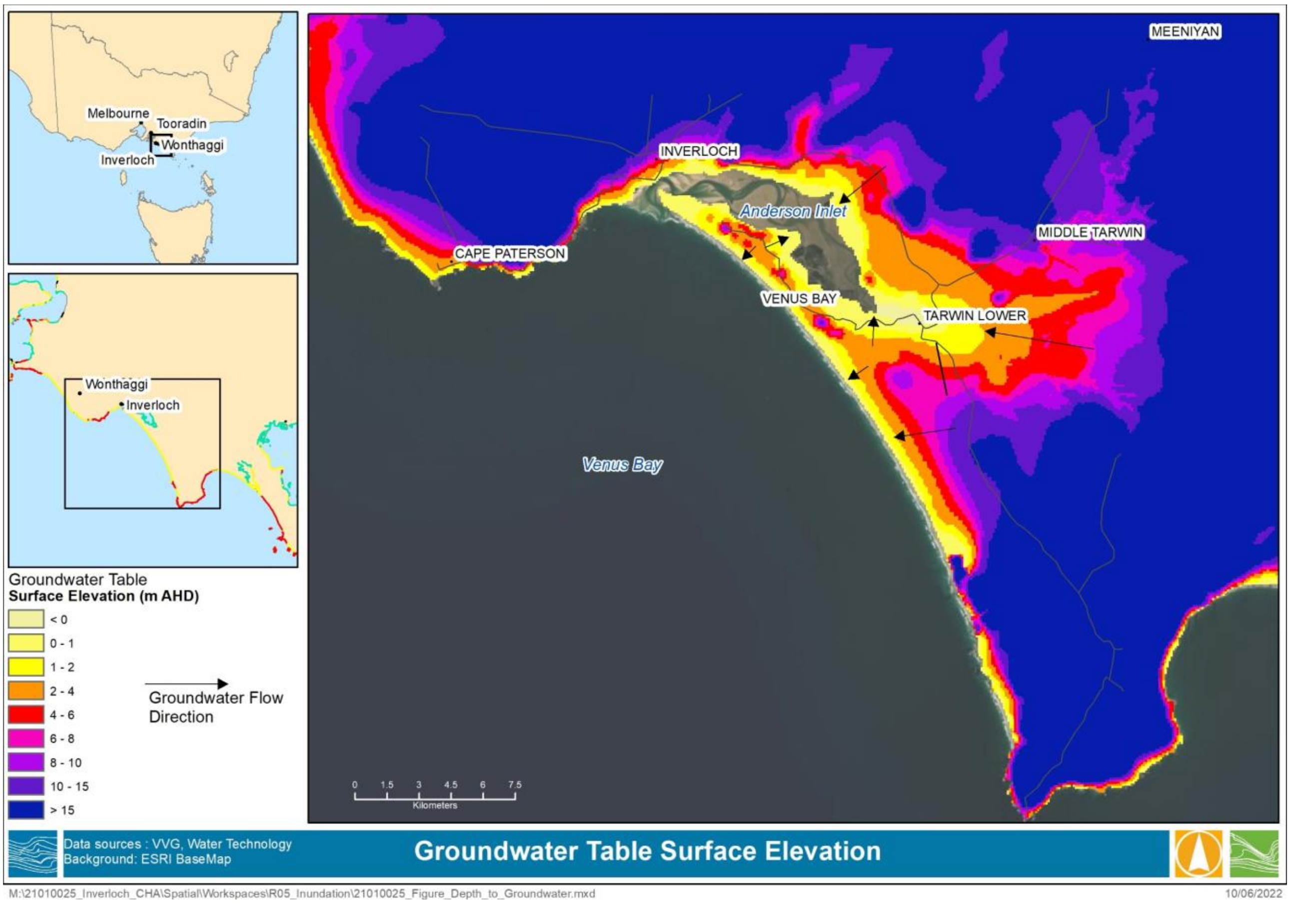
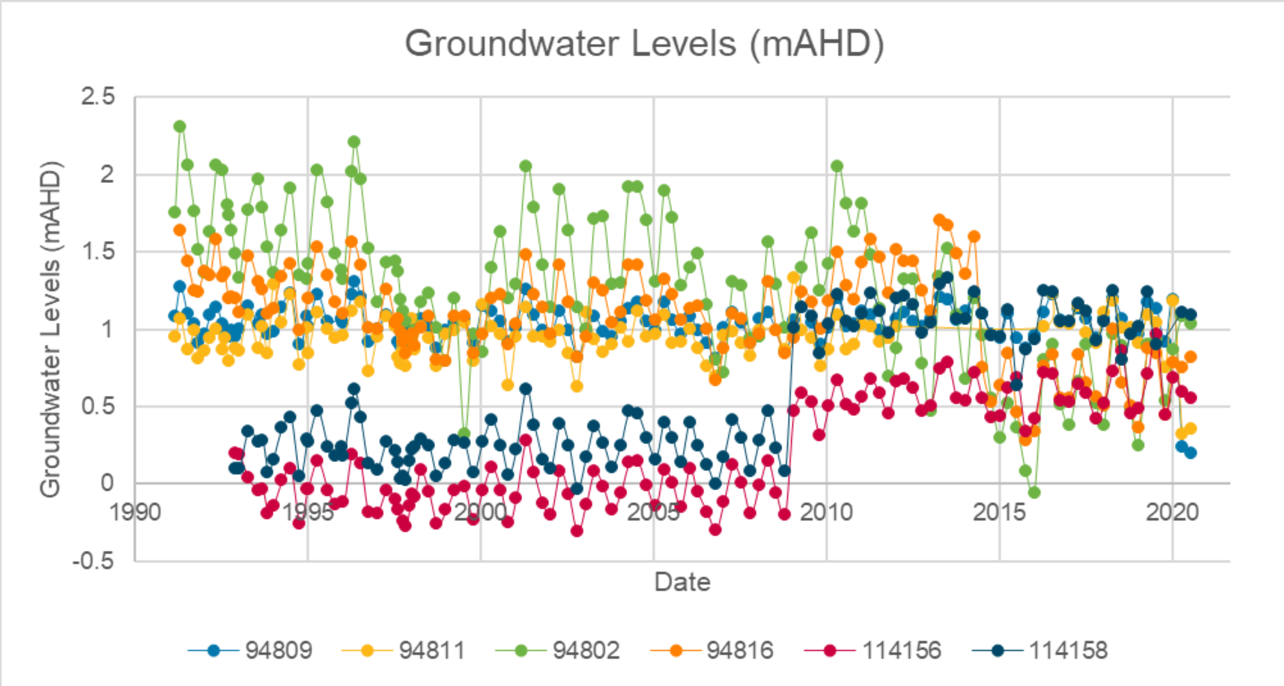


Figure 4-9 Groundwater Table Surface Elevation and Flow Direction

Over the past 30 years groundwater levels within the Tarwin Groundwater Management Area have displayed relatively stable trends from year to year, with seasonal high groundwater levels at the end of winter and seasonal lows at the end of summer (as seen in Figure 4-10).

However, during the summer of 2009 groundwater levels in bores 114156, 114157, 114158 and 94809 display a significant increase in groundwater levels. Conversely groundwater levels in bores 94802 and 94816 display a significant decrease in water levels after the 2014 winter period. After the significant changes during the 2009 and 2014 season all bores have displayed a stable trend with similar trends seasonally. The driver of the stepped changes in the measured levels is not clear and could be investigated further in a focussed groundwater study.



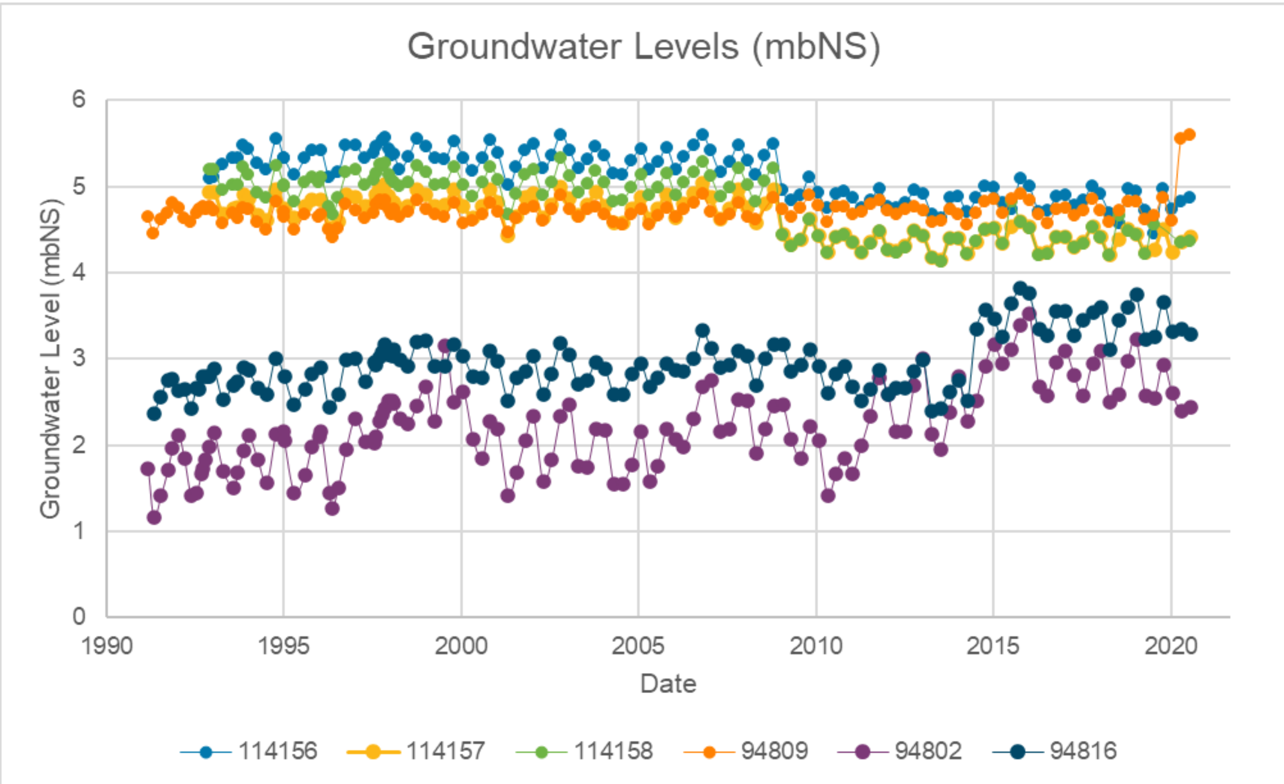


Figure 4-10 Groundwater Levels for Several Bores within the Tarwin GMA

4.2.3.3 Groundwater Wells and Licenced Use

Groundwater well data was retrieved from the Bureau of Meteorology's Australian Groundwater Explorer. The spatial search was conducted to include wells within 10 kms of the study area coastline as illustrated in Figure 4-7. Available well depths are also shown and indicate that the majority of wells are greater than 10 m in depth.

The majority of wells within the study area are used for water supply purposes including town supply and stock and domestic bores. The purpose description for each of the 1263 existing groundwater wells located within 10 kms of the study area coastline is provided in Table 4-2.

A large proportion (913 of 1263) of the groundwater bores within the study area are located within the Tarwin Groundwater Management area, with 890 of these being used for water supply purposes. A Local Management Plan has been established for the Tarwin Groundwater Management Area with a Permissible Consumptive Volume (PCV) of 1,300ML/yr, of which and only 38.0ML/year has been allocated.

Table 4-2 Groundwater Wells by Purpose within 10km of the Study Area Coastline

Purpose Description	Number of wells with 10 km
Irrigation	3
Groundwater Investigation	78
Stock and Domestic	38
Unknown	213
Water Supply	913
Total	**1263**

4.2.3.4 Groundwater Quality

There are several groundwater wells in the area from which to characterise groundwater quality, however there are no salinity focussed monitoring bores in the GMU. Generally, the groundwater quality in the Quaternary aquifer is fresher (<800 uS/cm) towards the coast, with the groundwater becoming brackish (<800-8,000uS/cm) the further that the bores are located away from the coastline, suggesting that the main source of recharge into the Quaternary aquifer occurs directly from rainfall. Bores 114159 and 94811 recorded a salinity of 17,000uS/cm in 1995 and 3,300uS/cm in 1991 respectively. These higher values are most likely due to saltwater intrusion into Quaternary and Tertiary sequences closer to the coast. Monitoring of salinity in groundwater bores is recommended for future assessment and investigation of the groundwater system.

4.2.4 Groundwater Dependent Ecosystems

Some ecosystems rely on groundwater to meet their water requirements, and as such may be sensitive to changes in the natural groundwater regime. These ecosystems are defined as Groundwater Dependent Ecosystems (GDEs). The Australian GDE Atlas published by the National Water Commission (2012) provides locations of potential GDEs based on broad scale analysis, regional studies, existing data sets and remote sensing. GDEs are broadly categorised into the following types.

- Aquatic ecosystems that rely on the surface expression of groundwater; this includes surface water ecosystems which may have a groundwater component, such as rivers, wetlands and springs.

- Terrestrial ecosystems that rely on the subsurface presence of groundwater; this includes all vegetation ecosystems.
- Subterranean ecosystems; this includes cave and aquifer ecosystems. These are not currently mapped in the atlas.

Terrestrial and aquatic GDEs as defined in the Australian GDE Atlas are illustrated in Figure 4-11. The data suggests that there is one Aquatic GDE of high potential within 5kms of the coast. Furthermore, the data suggests that there are several Terrestrial GDEs within 5 kms of the coast ranging from low to high potential, with a significant proportion of high potential GDEs surrounding the Venus Bay area. This information is based solely on that provided in the Australian GDE Atlas.

In this area, the Atlas' assessment is based on broad scale analysis of existing data sets and remote sensing. Site specific analysis is required to further ascertain the level of reliance these ecosystems may have on groundwater and their ecological value.

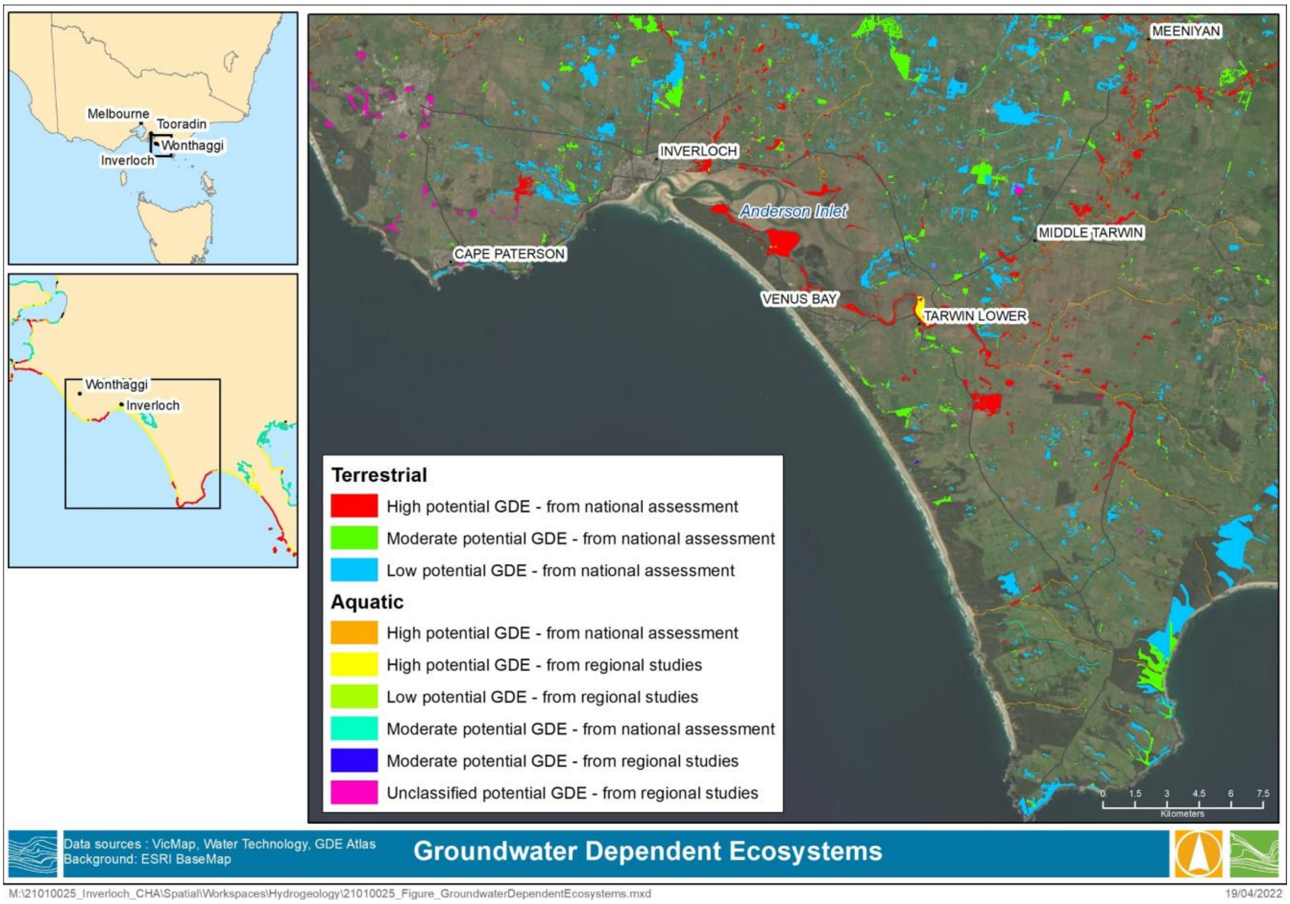


Figure 4-11 Groundwater Dependent Ecosystems (Australian GDE Atlas)

4.2.5 Coastal Acid Sulphate Soils

Coastal Acid Sulphate Soils (CASS) are naturally occurring soils that contain metal sulphide minerals and are found throughout low lying coastal and inland environments in Australia. These soils are controlled by a series of redox reactions that can be altered when they are dewatered / drained, excavated, or exposed to oxygen.

Importantly rising sea levels may result in a geochemical shift in the Coastal Acid Sulphate Soils (CASS) from oxidising and acidifying, to reductive and neutralising as sediments that were previously exposed to oxygen may become anaerobic due to rises in the groundwater table. However, if groundwater extractions are shifted to another area that has not previously been extensively pumped, lowering of the local water table may occur and result in the oxidisation of CASS that have previously not been exposed to oxidising conditions. Figure 4-12 illustrates the areas of potential Coastal Acid Sulphate Soils within the Study Area.

Potential Coastal Acid Sulphate Soils (CASS) are most likely to occur in the low lying area surrounding Anderson Inlet and Venus Bay with much of the area having a greater than 70% chance of having the presence of CASS within the soils (as seen in Figure 4-12).

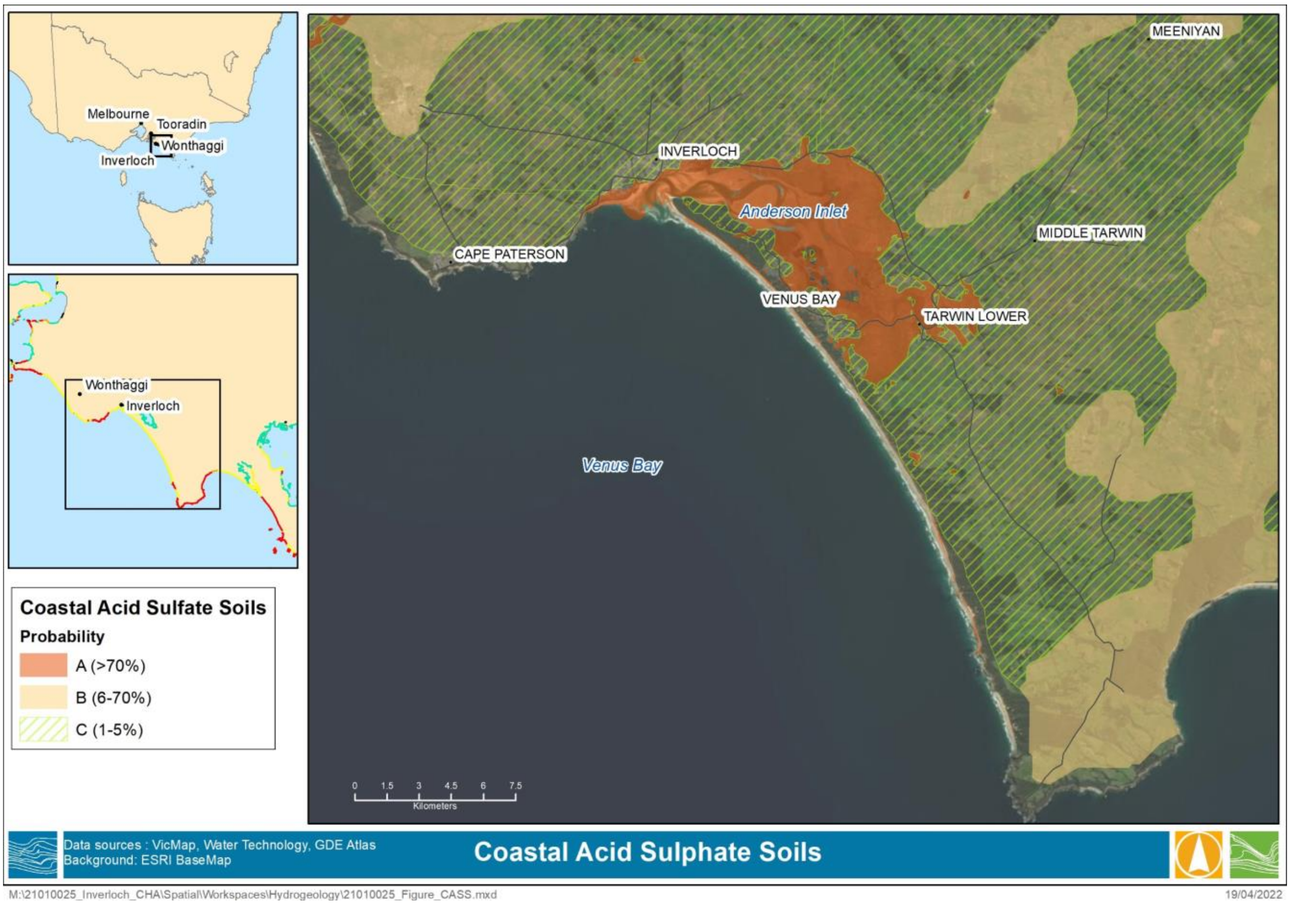


Figure 4-12 Areas of Potential Coastal Acid Sulphate Soil

4.2.6 Sea Level Rise Impacts

The range of climate and sea level rise scenarios includes increments between +0.2m to +1.4m above current levels (as seen in Table 1-1). As shown in Figure 4-2, an increase in mean sea level is likely to result in an increase in groundwater salinity near the coastline.

Increases in groundwater salinity and quality may result in several existing bores becoming too saline and therefore no longer being classified as suitable for human use. This would ultimately result in the need for affected users to potentially redrill, find a new suitable location, or new supply method to meet their water demands. Additionally, pumps may become damaged, need replacement or upgrading as a direct consequence of damage caused by the increased salinity of the groundwater. The increase to the saltwater wedge has not been considered in this report.

The beneficial uses for groundwater under SEPP (Waters) 2018 are shown in Figure 4-13. The beneficial use categories are defined by the salinity as total dissolved solids (TDS) of the water. For example, if TDS exceeds Segment A2, >1,200 mg/L, the water is no longer considered beneficial as a potable water source. The water quality of most groundwater accessed by receptors/users in the Tarwin GMA is currently below 1,200mg/L.

Under the sea level rise scenarios presented in Table 1-1 most groundwater users and receptors would most likely be impacted with a sea level rise of 0.5m or greater (4 of the 6 scenarios) due to the depth to groundwater below ground level for much of the Tarwin GMA.

Victoria Government Gazette *S 499* *23 October 2018* *51*

TABLE 2: BENEFICIAL USES FOR GROUNDWATER

BENEFICIAL USE	SEGMENT (TDS mg/L)						
	A1 (0-600)	A2 (601-1,200)	B (1,201-3,100)	C (3,101-5,400)	D (5,401-7,100)	E (7,101-10,000)	F (>10,001)
Water dependent ecosystems and species	✓	✓	✓	✓	✓	✓	✓
Potable water supply (desirable)	✓						
Potable water supply (acceptable)		✓					
Potable mineral water supply	✓	✓	✓	✓			
Agriculture and irrigation (irrigation)	✓	✓	✓				
Agriculture and irrigation (stock watering)	✓	✓	✓	✓	✓	✓	
Industrial and commercial	✓	✓	✓	✓	✓		
Water-based recreation (primary contact recreation)	✓	✓	✓	✓	✓	✓	✓
Traditional Owner cultural values	✓	✓	✓	✓	✓	✓	✓
Cultural and spiritual values	✓	✓	✓	✓	✓	✓	✓
Buildings and structures	✓	✓	✓	✓	✓	✓	✓
Geothermal properties	✓	✓	✓	✓	✓	✓	✓

Figure 4-13 SEPP (Waters) Protected Values

The potential groundwater related impacts that may be influenced due to the sea level rise include:

- Increased groundwater levels; particularly in already shallow groundwater systems surrounding the Tarwin GMA.
- Increased salinisation of the Tarwin Groundwater resource and other surrounding groundwater resources.
- Increased dryland salinity due to rising groundwater levels being closer to the surface.
- Increased vegetation dieback due to rising groundwater levels closer to the surface.
- Rising sea levels may result in a geochemical shift in the Coastal Acid Sulphate Soils (CASS) from oxidising and acidifying, to reductive and neutralising. However, if groundwater extractions are shifted to another area that has not previously been extensively pumped, lowering of the local water table may occur and result in the oxidisation of CASS that have previously not been exposed to oxidising conditions.
- Increased erodibility of soils and sediments.

4.3 Summary

Based on the sea level rise scenarios presented in Table 1-1 and the available data it is likely that the majority of groundwater users within the Tarwin GMA may be affected by small rises in sea level due to the shallow depth to groundwater within the study area and the large proportion of groundwater users relying on groundwater (958 of 1263, 918 for water supply).

Increased monitoring of salinity across the GMA is required to facilitate additional research to understand the extent of the impacts of sea level rise.

5 SUMMARY

The coastal inundation investigation undertaken for the Inverloch Region Coastal Hazard Assessment and detailed above provides the Inverloch RaSP with an enhanced understanding on the physical environment, drivers and responses of the coastline within the Study Area. This understanding has been used to develop coastal inundation hazard zones which in turn have been used to identify assets and values which may be vulnerable to coastal inundation hazards. The exposure of these assets and values to coastal inundation hazards are described in Report 6 of the Coastal Hazard Assessment.

Coastal inundation is driven by elevated tidal levels from the ocean, combined in some locations with runoff from the catchment and setup from strong winds. The catchment to Anderson Inlet is extensive and flows in the Tarwin River are known to regularly cause flooding in the areas upstream of Tarwin Lower without the addition of elevated coastal waters at the downstream end of the river. Within Anderson Inlet tidal levees constructed over the past century are unlikely to be sufficient to prevent flooding of the low lying land they shelter during extreme combined coastal, catchment and weather events. Further inundation over or around the landward end of the levees is expected as sea levels rise across the coming century. However, the major residential areas within the Inlet at Tarwin Lower and Venus Bay are almost completely above the coastal inundation zones for all scenarios assessed. Inundation is limited to agricultural land and some isolated properties, however the main roads connecting Tarwin Lower and Venus Bay to major services have potential to be inundated during significant storm events both now and under future sea level rise scenarios.

The town of Inverloch is predominantly outside of the coastal inundation hazard risk with the exception of areas around Wreck Creek and Surf Beach residential area in the west of the town, around the Inverloch Boat ramp and jetty, and around the Screw Creek and Broadbeach Estate which have previously been identified as at risk from inundation. The area around Wreck Creek is considered to be particularly vulnerable due to the recent erosion of the barrier dune along the coastline which currently prevents direct inundation of Wreck Creek and the residential area between Bunurong Road and the SLSC.

Inundation along the open coast is limited due to the elevated topography along Bunurong Road and the extensive sand dunes from Point Smythe to Cape Liptrap.

5.1 Assumptions, Limitations & Uncertainty

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

5.1.1 Assumptions

A range of assumptions are required when assessing the potential magnitude of future coastal inundation as it is not practical or possible to collect and analyse all information about every process or driver, both in the past and when predicting the future. The key assumptions which are relevant to the outcomes of the study are as follows:

- The historical bathymetric and oceanographic & catchment data in study area is limited (*as discussed in Report 2*). The study assumes the available data is largely representative of bathymetric and topographic levels across the study area in the past and into the future.
- This excludes the entrance area where it is known changes do occur. Sensitivity testing has been used to assess the range of entrance channels and configurations observed changes over the past 70 years, however it is assumed these are the limits of the change to entrance channel arrangement and capacity.

- It is assumed that the 40y hindcast of water levels and wave conditions are sufficient to estimate the 1% AEP event
- It is assumed that modelled hindcast and measured tidal waters are generally representative of conditions, at Tarwin Lower especially where the measured data does show some seasonal variation.
- It is assumed that the models adopted produce reasonably reliable conditions where data does not exist for model calibration / validation (*this is a common assumption and why numerical models which are well established and tested are used*)
- Inundation zones assume the existing, or in most cases the FutureCoast LiDAR topography from 2008/09, remains unchanged into the future. Inundation does not presume any change in the topography within the coastal erosion hazard zones identified in Report 4. This is especially relevant for areas of low topography or vulnerable dunes such as Wreck Creek. There are also some sections of the catchment which are known to have been altered since the LiDAR capture (e.g. Paperbark Place) where inundation hazard zones will differ with further investigation/update of topographic survey.
- It is assumed that the drainage network in Inverloch and especially the coastal outfalls are allowed to backflow and drain freely and are not obstructed by mechanical (e.g. tidal gates) or natural features (e.g. sand bar).
- It is assumed that earthen levees within Anderson Inlet will remain in their current state and dimensions into the future.
- The study assumes the current bathymetry/topography remains constant as sea levels rise.
- It is assumed there is no mass change of entrance and tidal bar dynamics (e.g. extreme case of the last interglacial maximum (Rosengren, 2022

5.1.2 Limitations

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

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

5.1.3 Uncertainty

Following assessment of the coastal inundation drivers and the parallel assessment of shoreline erosion hazards in the Study Area, the assessment of coastal inundation hazards is considered potentially sensitive to the following future sources of uncertainty:

- The magnitude and contribution to the extent of inundation from wave setup and overtopping/breaching due to lack of inshore wave calibration data. This is especially noted in areas where significant wave transformation and shoaling occurs, i.e. along Bunurong Road across rock platforms and along the Wreck Creek to Point Norman shoreline.
- The magnitude and contribution to the extent of inundation from elevated coastal water along the Wreck Creek to Point Norman shoreline due to the rapidly changing coastal dune and topography.

5.2 How to use the Study Outputs

The information contained in this report along with the coastal inundation hazard mapping and GIS datasets can be used to provide a better understanding of coastal inundation hazards in an area of interest, particularly the key processes and drivers of change and how these may be influenced by sea level rise. Figure 5-1 outlines the typical process for applying the coastal inundation hazard assessment outputs to assess potential risks for a particular section of the Study Area shoreline. Further use of these hazard layers has been captured in Report 6 Coastal Asset Exposure Assessment and Report 7 Adaptation Actions Technical Assessment of the Inverloch Region Coastal Hazard Assessment.

The outputs of the coastal inundation hazard assessment should also be considered in conjunction with the coastal erosion hazard assessment detailed in Report 4. An overview of both the coastal processes, erosion and inundation hazard assessments is provided in the project Summary Report (Report 1).

Develop an Understanding of the Inundation Process

- Use the information in **Section 2** to understand the processes driving inundaiton at the area of interest

Consider Future Inundation Hazard Zones

- Refer to the inundation hazard **GIS layers and mapping described in Section 3**
- **Visualise** the potential coastal inundation hazard extent for the area of interest for each event probability / planning horizon or sea level rise
- Consider the **assets vulnerable** and the consequence of the coastal inundation hazard on the asset

Understand the Assumptions, Limitations and Uncertainties

- Review other issues / considerations for the area of interest, e.g. **existing coastal protection works, timescales, groundwater** etc
- Consider the assumptions, limitaiton and uncertainties in the existing knowledge (**Section 5.1**)

Figure 5-1 How to use the Coastal Inundation Hazard Assessment Outputs

5.3 Recommendations

5.3.1 Identifying Risks and Planning Adaptation

Further detailed risk analysis can be found in the "Risk and Vulnerability Assessment Report" produced for the Inverloch CHA by Alluvium Consulting. Report 6, Report 7 and the Risk and Vulnerability Assessment Report build upon the work described in this report and provides a detailed analysis of assets exposed to coastal hazards and potential adaptation actions to assist with adaption planning for the Inverloch shoreline. Recommendations relating to adaptation to reduce the impact of coastal hazards are provided in Report 7.

5.3.2 Future Works to reduce Uncertainty

The scope of the technical work completed to date is robust and follows best practice, with the best available information and fit for purpose adaptation planning. The following recommendations are related to reducing the uncertainty and limitations discussed above in Section 5.1 and can be used to inform future iterations of adaptation planning and options assessments.

Table 5-1 Additional Works

Type	Summary	Purpose
Oceanographic Data	Measured Current Data in Entrance	To enable better understanding of entrance dynamics and enhance model calibration – velocities and flow flux over a full ebb and flood tide cycle for both spring and neap tides should be measured. A limited change in the inundation hazard zone would be expected.
Oceanographic Data	Offshore current measurement	Enable better understanding of coastal dynamics and enhance model calibration. A limited change in the inundation hazard zones would be expected.
Oceanographic Data	Inshore wave transformation	Concurrent measurement of wave conditions offshore and inshore along Bunurong Road and near Surf Beach would provide additional data and confidence to modelling of hazards and options by resolving refraction and diffraction around Cape Paterson and Flat Rocks. A change in the nearshore wave height could result in more notable changes to inundation hazard zone due to the significance of wave setup on the total coastal water level.
Topographic Data	Survey of areas of significant change since 2009 LiDAR	Updated survey of vulnerable areas such as Wreck Creek, Surf Beach residential area, Broadbeach Estate, and Point Smythe would enhance the confidence that the extent of the inundation hazard zones represents present day conditions (especially where change has occurred since 2009 survey).
	Levee survey and inspection	Inundation of the low lying tidal floodplain around Anderson Inlet is controlled by the condition and height of levees and the drainage controls within the levees and drains. Updated survey and inspection of levees, especially in vulnerable low points could be used to further refine inundation hazard extents.

Type	Summary	Purpose
Bathymetric Data	Expand entrance and Surf Beach nearshore Survey	Updated survey of the nearshore bathymetry can provide both additional confidence of existing wave transformation across the nearshore area, and information regarding the magnitude of change of the nearshore beach profile over time and hence variability of the nearshore wave height and following on, the level of wave setup driving inundation.
Groundwater Monitoring	Measure and map the saline / freshwater interface of the Tarwin GMA	Provide a more detailed understanding of the extent and depth of the groundwater through targeted monitoring
Groundwater modelling	Modelling of sea level rises on saline / freshwater interface	Provide a timeframe for adaptation where changes to the saline / freshwater infer face may begin to impact users

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APPENDIX A
COASTAL INUNDATION HAZARD ZONES

APPENDIX B
VICTORIA'S RESILIENT COAST FRAMEWORK

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

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