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EXECUTIVE SUMMARY

Introduction

Water Technology has been commissioned by DELWP to undertake the Inverloch Region Coastal Hazard Assessment (CHA), a key piece of work of the 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 past and current coastal processes and coastal drivers which have formed the existing coastline. The report also describes the potential impact of coastal processes on the coastal environment into the future and the influence of climate change on coastal drivers and processes. The impact of the coastal processes, current and future erosion zones and zones of coastal recession are presented and discussed within the report.

This document is Report 4 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 & 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 erosion 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	

Coastal Process Assessment

Coastal Evolution

The coastline of the Study Area and the Tarwin embayment has formed between the faulted landscape to the west and south through the high energy wave and wind environment of Bass Strait. Progressive movement of sand enclosed the Tarwin River and formed Anderson Inlet during periods of varying sea levels and via wind and wave transported sands. Much of the sediment within the Inlet, especially on the floodplains above the current tidal range have been delivered via catchment runoff.

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

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

A detailed review of the change in vegetation, channel and bars within the Study Area has noted areas of rapid change both more recently such as at Surf Beach and Wreck Creek, and during the mid-20th century such as Toys Backwater. Ongoing change at Point Smythe is noted and the change in the channel length and migration of the primary flood tide sand bar is presented.

Coastal Classification

To assist with the description and processes acting on the coastline, the Study Area was classified into coastal geomorphic sectors and coastal geomorphic domains, defined by the backshore and intertidal landforms and material. A large number (181) of different coastal geomorphic sectors were identified, these were filtered into five Shoreline Classes, in line with those described in *Victoria's Resilient Coast - Coastal Hazards Extended Guideline* (DELWP, 2022). The Shoreline Classes are key to preparing erosion hazard zones for risk assessment and adaptation. The length and proportion of the different shoreline classes are presented in the table below.

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

Coastal Bathymetry and Topography

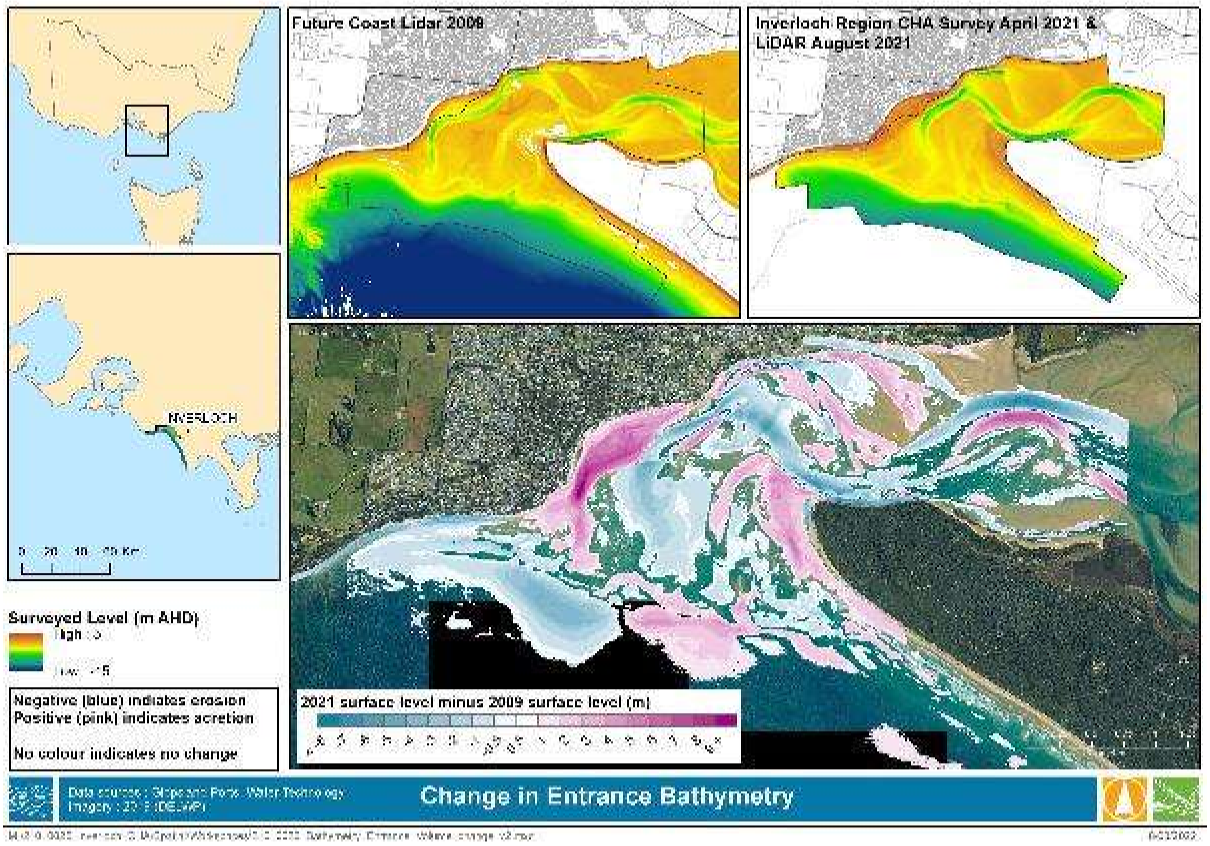
The ocean and coastal bathymetry have a key influence on the coastal processes and drivers in the Study Area.

The bathymetry of Bass Strait is relatively shallow, limited to around 70-80m in depth. Within the Study Area, the bathymetry is dominated by rocky outcrops at Cape Paterson and Cape Liptrap. The nearshore slope from the coast descends relatively smoothly 10-15km offshore to the floor of Bass Strait. Southeast of Cape Paterson a shallow (to -20m AHD) uprising named Cody Banks extends the edge of the nearshore slope, and the surrounding seafloor is notably shallower with a wide shelf at -45 - -50m AHD extending from around 6km offshore for a further 6km.

High resolution bathymetric survey is available from the Victorian Government FutureCoast program collected in 2008/09 and covers the full nearshore extent of the Study Area (to -20m depth). The data shows the Bunurong Road coast is characterised by wide rock platforms 0 to -1m AHD extending up to 1km offshore. Some sandy pocket beaches are present between rocky headlands. Towards Inverloch, between Flat Rocks and Point Norman, there is a notable change in grade between the inshore, broken wave zone (i.e. greater than -1.5m AHD) and the nearshore, breaking wave zone (i.e. to -8m AHD) where a small reef outcrops around 1km offshore after which the seafloor slopes near lineally to -20m AHD.

Along the Venus Bay open coast a typical exposed ocean coastline pattern of sand bars and rip channels is evident. The depth between channels and bars can vary up to a meter in depth between -0.5m AHD and -4m AHD. Beyond the nearshore zone the bed transitions from convex in the western end, indicating excess sand, to linear and concave in the south/east, indicating more equilibrium sediment conditions.

Significant change has occurred in the bathymetry of the entrance between the 2008/09 LiDAR capture and the present day. Survey was collected across the entrance for the CHA, providing an update of the new conditions in the entrance. A massive amount of sediment has been lost from the overlapping survey areas – a net change of -1.8M m^3 calculated from the datasets. Change is not even across the entrance – this volume would represent a change of only -0.15m across the entrance area – instead it is the balance of significant areas of volume loss such as from Surf Beach and the ebb tide delta, and significant volume gain, such as the sediment enclosing Ayr Creek lagoon. Entrance channels have, in general, become deeper and wider within the entrance, however the main channel is wider and shallower across the outer bar. Significant loss of material is noted at the upstream extent of the overlapping survey – it is unknown if this reduction in bed level continues upstream within the Inlet or is limited to the entrance area. The net change in the entrance bathymetry is shown in the figure below.



The bathymetry data collected for the CHA is supplemented by topographic data collected for the project along the Wreck Creek/Surf Beach coastline where significant coastal recession is occurring. The LiDAR captured for the project in 2021 was compared with the 2008/09 LiDAR and a net loss of 300,000m3 was calculated, including the complete loss of sand dunes more than 10m AHD in height. The majority of the beach along this coastline has also been lowered by at least 1m, with over 50% of the surveyed area reduced in elevation by more than 3m.

Within the Inlet itself, regular survey of the channel by Gippsland Ports allows comparison with the 2008/09 data where the channel overlaps. A long section thalweg (channel centreline) of the 2008/09 and 2020 surveys shows relatively consistent increase in both surveys of channel depth from the entrance to the mouth of the Lower Tarwin. Notably however, the recent channel survey indicated the channel has much deeper pockets near the entrance than the 2008/09 configuration.

Metocean Conditions

The magnitude, frequency and variability of the main oceanographic and meteorological processes that influence the Study Area were reviewed and analysed. The physical oceanographic and meteorological processes of Bass Strait have strongly influenced the recent geological evolution and contemporary coastal processes of Venus Bay and Anderson Inlet and as such an understanding of these processes provides the foundation for understanding historical coastal change. In turn, this enables the assessment of potential coastal hazards, existing and future, along the Study Area coastline through this century.

Water Levels

Astronomical tidal water levels used in the Study have been derived from a number of sources, including the Australian National Tide Tables and constituents derived by the Bureau of Meteorology from data recorded at Inverloch Jetty and Tarwin Lower Jetty by Gippsland Ports. Measured water levels within Bass Strait are not readily available, the nearest ongoing tidal monitoring stations being located at Stony Point and Port Welshpool. Offshore tidal planes within Venus Bay are derived from the model hindcast established for the Study (see Report 3 – Technical Methodology). Tidal planes are shown in the table below.

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

The Ocean Model hindcasted astronomical tides, wind forces across Bass Strait and regional storm surges into the Study Area. An extreme value analysis on the hindcast total water level has determined the extreme offshore design water level under present day conditions as shown below.

	1% AEP	5% AEP	10% AEP
Offshore Water Level (m AHD)	2.20	2.10	2.00

Wind Conditions

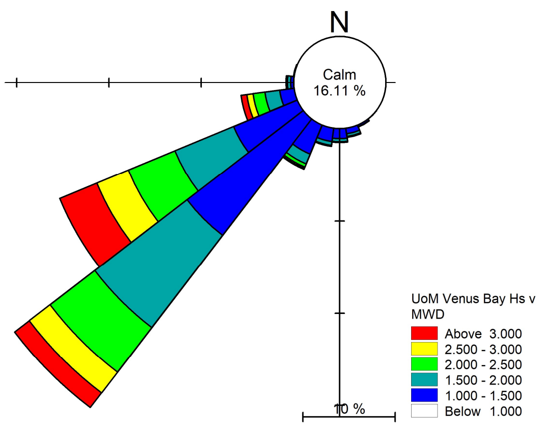
Wind data recorded and modelled within the Study Area shows a wind climate which varies daily and seasonally consistent with conditions experienced across central and western coastal Victoria. Onshore-offshore wind direction change, common to coastal locations are observed (offshore in the morning, onshore in the afternoon), and the seasonal pattern of south-westerly and easterly winds dominating in summer and north-westerly winds dominating in winter are also seen in the data analysed.

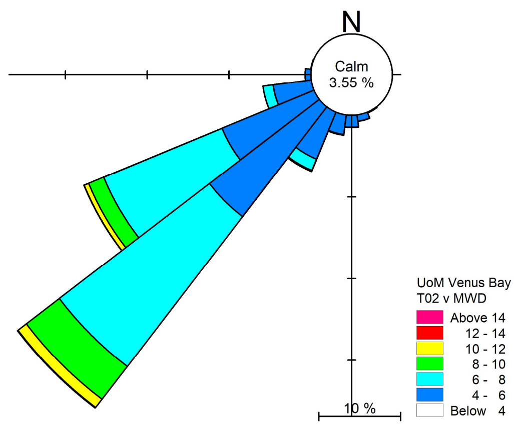
Wind speeds show interannual and inter-decadal variation with some decades characterised by stronger winds and storm events whilst other periods, including the current period, show a decrease in the average land based wind speed.

Wave Conditions

Wave conditions within the Study Area are dominated by ocean waves generated by large-scale weather systems over the Southern Ocean and Bass Strait. These waves propagate across Bass Strait and refract into Venus Bay. Rarely, some southeast wave energy can be experienced in the study area due to the presence of an East Coast Low east of Wilsons Promontory.

Wave timeseries from a hindcast wave model provided by the University of Melbourne was used to represent wave conditions within the Study Area (Lui, 2022). The hindcast wave data indicated a recent trend towards stronger waves and stormier ocean wave conditions. The hindcast wave rose and the design offshore wave conditions derived from the hindcast are shown below.





	1% AEP	5% AEP	10% AEP
Offshore Significant Wave Height (m)	6.6	6.1	5.9

Measured data offshore of Inverloch within Venus Bay has been captured by the Victorian Coastal Monitoring Program (VCMP) since 2020. A number of locally significant events which occurred during the measurement period were reviewed and the probability noted:

- 11 April 2020 (peak Hs 5.64m, Tp 10.2s, peak wave direction 239 degrees) < 20% AEP
- 2 May 2020 (peak Hs 5.82m, Tp 11.4s, peak wave direction 224 degrees) 10 - 20% AEP
- 11 April 2021 (peak Hs 5.25m, Tp 9.3s, peak wave direction 227 degrees) << 20% AEP
- 29 October 2021 (peak 5.68m, Tp 11.4s, peak wave direction 203 degrees) ~ 20% AEP

Currents

Tidal currents on the open coast are relatively weak with a small easterly flood and westerly ebb tidal current. Tidal currents reduce in strength from west to east as they approach the Bass Strait tidal divide around Waratah Bay.

Tidal currents within the entrance are more significant with flood and ebb tide currents peaking at over 1.0m/s. The ebb tide current dominates in the entrance, with high currents speeds observed over a larger extent within the channel than the flood tide as the water drains off the entrance bars and is constrained within the channels.

Tidal currents within Anderson Inlet show larger areas of higher currents on the flood tide, the peak ebb tide flows limited to much smaller pockets. Tidal currents within the Inlet are less than 1.0m/s within the channels, and typically below 0.5m/s for the majority of the Inlet.

Coastal Processes

Sediment Sources and Sinks

Sediment movement within the Study Area is driven by a combination of wave energy on the open coast and tidal currents in and around the tidal channels of Anderson Inlet and the entrance.

Detailed investigation of the supply and loss of sediment into the Venus Bay sediment cell, anchored by Cape Paterson and Cape Liptrap, has not been completed for this Study, or in any prior works, and as such cannot be quantified. However, it is expected that the weak tidal currents in the region mean sediments offshore of Venus Bay and within Bass Strait are currently moved primarily by wave action, from west to east in line with the regional wave climate.

Sediment Samples

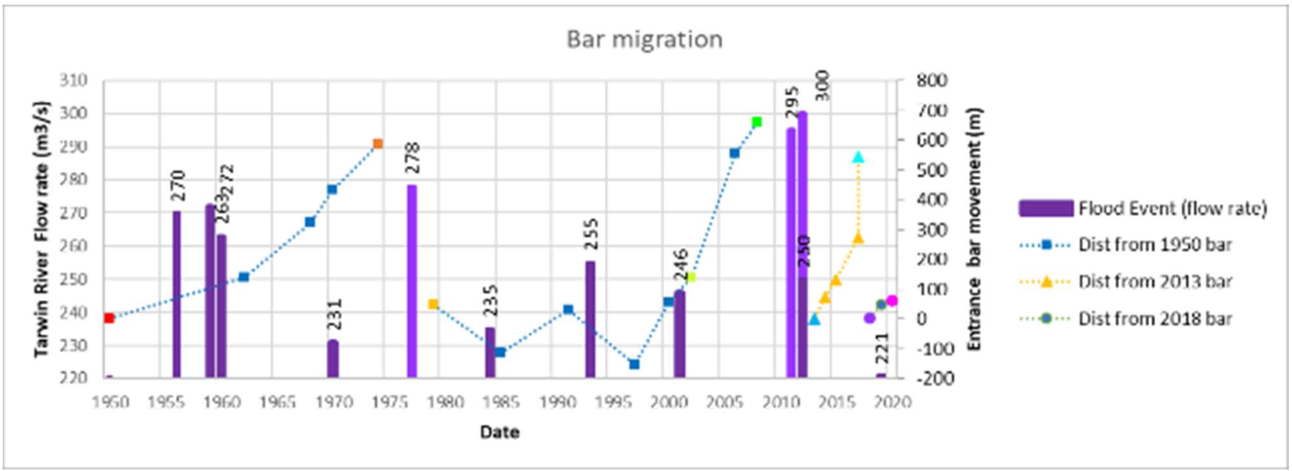
Local sediment sampling has been undertaken as part of the Study and through prior work assessing sediment movement in the area (SGCS, 2019, Doumtsis, 2019). Key observations made from the sample analyses which have been undertaken over the past few years as follows.

- Sediments along the open ocean beaches are considered fine to medium grain sand with a median grain size 0.2-0.3mm.
- Sediments along the Inverloch foreshore can be fine sands with grain size < 0.2mm, particularly on the sheltered beach, however are generally classified fine to medium with d50 0.2 – 0.3mm.
- Coarser sand is found on the tidal bars and along the outer edge of Point Smythe where the median grain size is in excess of 0.3mm.
- Coarser material has been observed at Mahers Landing, however the material within Anderson Inlet is a wider mix with very coarse gravel and shell mixed with fine silts.

Current Driven Sediment Transport

The low ocean tidal currents have minor influence on sediment transport along the open coasts. At the entrance, ebb tide currents have potential to shift a small amount of sediments from the Inlet and entrance bars to the west towards Surf Beach and Flat Rocks.

Within the entrance, tidal currents (along with wave energy) form the shape and depth of the entrance channels and bars. The timeline of aerial imagery of the entrance shows a pattern of increasing channel meander (similar to a low gradient river) as the channel increasingly shifts north and east. The channel meander length increases until a point-bar erosion cut is made and the meander length reduces. The channel meander processes are also interrupted in a loose correlation with significant flood events in the Tarwin River. The figure below shows the north-eastward progression of the channel over time through the increasing distance of the entrance bar from the 1950, 2013 and 2018 bar over time and the impact on this distance of new channels cutting through the expanded entrance bar following significant flood events such as 1977 (<5% AEP event). In these cases, the high flows erode the sandy material and temporarily generate a straight channel. Similar changes in channel position are noted after the 2011/12 floods, which included close to a 1% AEP flood event. A more significant change in channel arrangement in 2012 follows what could be the tipping point of the channel meander length, forming a new channel. A new channel arrangement is also observed in 2018, again occurring after a long channel meander had formed, indicating a potential cut-off level of the meander length.



To assess the entrance dynamics, complex coupled hydrodynamic, wave, sediment transport and morphological numerical modelling of the entrance was carried out for the project as discussed in Report 3 (Technical Methodology, Water Technology 2022c). Whilst the model was unable to replicate the full morphological dynamics of the entrance between the two available bed surveys of 2009 and 2021 due to computational limitations and lack of detailed calibration data, the modelling was able to demonstrate the processes which drive change in the inlet and entrance areas.

Key processes include:

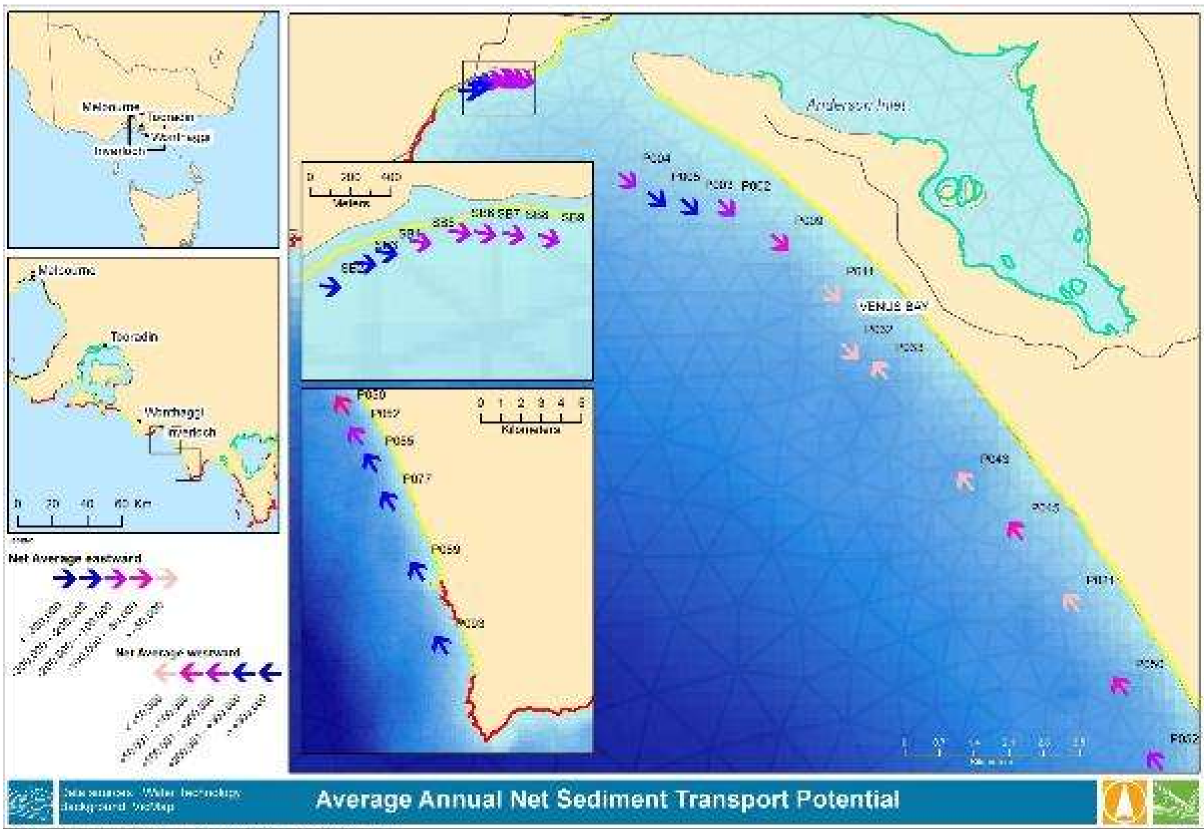
- The development of the ebb tide delta offshore is tidally dominated
    - Waves then work to close the ebb tide channel and cause a shift of the channel eastward
- During the ebb tide, flow channels form across the outer sand bar
    - Again wave energy shifts sediment to orient channels on a NW-SE plane
- The location of the leading edge of the main sandbar is driven by wave energy
    - Without wave energy the channel becomes wider and deeper without notable migration of the bar to the northeast
- Expansion of Point Smythe into the entrance is driven by wave energy
    - Tidal hydrodynamics and growth of the ebb tide channel around Point Smythe are interrupted by the incoming wave energy and sediment deposition

Wave Driven Sediment Transport

Sediment transport on the open coasts of the Study Area is driven by wave energy. Wave hindcast data from the University of Melbourne was used to drive the alongshore sediment transport model LITPAK to establish rates of sediment transport potential.

The sediment transport varies along the open coast as shown in the figure below. The sediment transport potential was highest along Surf Beach where the angle of the beach to the incoming waves is more acute and the wide flat beach enables sediment transport across a wide profile. The model establishes sediment transport potential rather than actual sediment transport. Sediment transport is limited by the available supply of sediment, especially along the Flat Rocks to Point Norman stretch of coast.

Sediment transport along Point Smythe and Venus Bay indicates a net transport away from Point Smythe, in contrast to the geological development of the Point, indicating the spit has reached its maximum position under the current wave climate, having been generated by waves from a more southerly direction driving sediment westward. Sediment transport potential reduces eastward to the Venus Bay settlement, east of which the net transport rate becomes increasingly westward. This follows the changing orientation of the beach along this coastline. Sediment transport potential between 200,000 and 300,000 m^3/ year were simulated for the south-eastern extent of the Study Area, similar in magnitude to other exposed coastal locations in Victoria.



Analysis of the sediment transport modelling results showed the seasonal and decadal changes also noted in the wind and wave climate. Greater sediment transport eastward was noted during winter months with the higher number of significant south-westerly storms across Bass Strait.

Most significantly, the modelling indicated a strong increase in net eastward transport potential since 2012 on Surf Beach, corresponding to the rapid recession of the coast since this time.

Coastal Process Synopsis

Regional coastal drivers and sediment transport processes are presented in conceptual images. More detailed change and response to drivers around the entrance to Anderson Inlet are also presented to enhance the understanding of how the coastline responds in this dynamic area.

Coastal Erosion Hazard

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

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

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

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

Short Term Erosion

Short Term Erosion is the impact on the coastline from a storm event. The shoreline response model SBEACH (Larson, 1989) has been used to calculate the volume and setback associated with a design storm event. Storm erosion has only been calculated on coastlines where storms will cause short term erosion from which there may be some recovery due to the subsequent onshore movement of sand following a storm event. These coastlines are the pocket beaches along Bunurong Road, the coast from Flat Rocks to Point Norman and the Point Smythe to Cape Liptrap sandy coast.

Storm erosion varies with local bathymetric profile and dune elevation and slope. Survey collected in 2021 has been used for the beaches to the west of the entrance, whilst the 2008/09 LiDAR has been used on the Venus Bay coastline. It is understood that some changes may have occurred to the modelled beach slope since the survey collection and subsequent analysis.

A summary of short-term storm demand is presented below. Storm demand on the open coast is similar to early, wide pass estimates made previously for the Victorian coast (Mariani, 2012). The shoreline setback, measured from the toe of the existing beach scarp, is heavily dependent on beach profile, and the slumping and reshaping of the beach profile, which in some cases, can lead to a greater set back distance for a smaller storm demand, e.g. where a dune scarp may form from a smaller storm which a larger dune collapse during a bigger event will partially infill during beach reprofiling.

Coastline	Storm Demand (m^3/m)		Shoreline Setback (m)	
	1%	10%	1%	10%
Bunurong Road Pocket Beaches	35 - 164	30 - 154	8 - 50	7 – 38
Flat Rocks – Point Norman	22 - 77	17 - 74	2 - 39	5 – 45
Point Smythe – Cape Liptrap	146 - 185	135 - 171	20 - 21	19 - 21

Long Term Recession

Long term recession considers the existing rate of coastal retreat. *Recession* is considered as the lateral movement of features such as the shoreline over time, where-as *short term erosion* is the loss of beach material such as loss of a dune in a storm. Recession is effectively the cumulative long term impact of all storms, large and small from which the beach does not fully recover.

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

Where there is accretion of the shoreline over time, the recession is considered to be 0m within the erosion hazard formula. Where long term recession shows time periods of extended high rates of recession (e.g. Wreck Ck/Surf Beach between 2012 and 2019), an additional "possible" long term recession rate has also been determined. This "possible" recession rate is not included in the calculation of hazard zones as the rapid change in coastline is not representative of recession over the long term. Coastal recession includes the impact of channel meander within Anderson Inlet, especially where it has resulted in a continued setback of the coast and loss of vegetation on the northern shore of Point Smythe.

A summary of long term recession is presented below. The "possible" recession, based on short term rapid recession, is shown in italics.

Coastline	Linear regression rate (m/y)	Long term recession (m)*		
		2040	2070	2100
Bunurong Road Pocket Beaches	0 – 0.2	0 - 4	0 - 11	0 -18
Flat Rocks to Point Norman	0 – 0.7	0 - 14	0 - 35	0 – 56
*Flat Rocks to Point Norman**	*2 – 10*	*40 - 200*	*100 - 500*	*160 - 800*
Point Norman to Screw Creek	0 – 1.5	0 - 30	0 - 75	0 – 120
*Point Norman to Screw Creek**	*0 – 16*	*0 - 320*	*0 - 800*	*0 – 1280*
Anderson Inlet	0 – 1.2	0 - 24	0 - 60	0 - 96
Point Smythe	1.2 – 2.6	24 - 52	60 - 130	96 -208
Venus Bay	0 – < 0.1	0 - 20	0 - 50	0 - 80

Future Recession

To consider the effects of rising sea levels on the coastal hazard zone, future recession is calculated. Determining the future recession of the coastline is complex as the future bathymetric profile and coastal dune slope and height is unknown. The short term erosion and long term recession presented above will change the bathymetric and beach profiles in the future and sea level rises may unlock, or capture, incoming or existing sources and sinks of sediment.

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

Whilst the Bruun Rule is often criticised for being overly simplistic, the wave dominated, sandy coastlines of the Study Area provide suitable conditions to apply this calculation. Similarly, in areas where there is higher risk of significant recession of the beach profile due to longshore sediment transport (e.g., Surf Beach) or migrating tidal channels (Inverloch foreshore), the simplicity of the Bruun Rule is also appropriate given these uncertainties. The magnitude of recession due to open coast sandy beach profile response to increasing sea levels can be considered an approximation only.

The future recession due to sea level rises within the Inlet is associated with the increased tidal inundation and landward migration of vegetation. Wide expanses of the Anderson Inlet floodplain are within the future spring tide range and recession of the coastline may occur. This area is, however, presented as a permanent inundation layer within the Inundation Hazards Report.

The projected recession for future sea level rises is presented below.

Coastline	Sea Level Rise (m)				
	0.2	0.5	0.8	1.1	1.4
Bunurong Road Pocket Beaches	1 – 3m	3 – 8m	7 – 13m	8 – 17m	10 – 22m
Flat Rocks to Point Norman	11 – 17m	27 – 43m	43 – 69m	60 – 95m	76 – 121m
Point Norman – Screw Creek	0 – 4m	0 – 10m	1 – 16m	1 – 22m	1 – 28m
Anderson Inlet	n/a	n/a	n/a	n/a	n/a
Venus Bay	6 – 10m	16 – 26m	25 – 42m	34 – 57m	44 – 73m

Cliff Erosion

In some cases, there is potential for recession of a sandy coastline landward to a point where the coastal processes interact with a different strata, e.g., a rocky cliff or earthen rise. This shoreline, which may have previously been classified as a "Bluff" is converted to an active "Hard" or "Soft" Rock Cliff through this recession. Hazards posed by erosion of cliffs present around the Bunurong Road and elsewhere within the Study Area are also considered differently to the processes described above. The erosion hazard here is considered a Cliff Erosion Hazard Zone.

The Cliff Hazard Erosion Zone is calculated through analysis of the existing slope angles of the cliff section and mapped as a hazard zone. Cliff slopes are susceptible to deep-seated mass movements that may be initiated by a combination of surface processes and/or due to marine influences at the base of the cliff. Slope failures are considered a potential source of hazard along the cliff shorelines as they can result in major impacts landward of the cliff edge and can occur with little to no warning.

Erosion Hazard Zones

The total erosion hazard zones are presented in the mapping in Appendix E.

Summary

The coastal process investigation provides 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 hazard zones which in turn have been used to identify assets and values which may be vulnerable to coastal hazards. The exposure of assets and values to coastal erosion hazards are described in Report 6 (Coastal Asset Exposure Assessment) of the CHA.

There has been significant change in the entrance area between 2012 and 2021. This rapid change is the combined result of a long channel meander beginning to breakdown, the breakdown likely exacerbated by the flooding in 2011 and 2012, then combined with an increase in westerly wave energy from 2012 through 2019. These processes have combined to reduce the extent and strength of the ebb tide jet and delta which had formed alongside Point Norman. As this delta reduced the more southerly facing beach angle encouraged increasing net westward sediment transport to wash sediment from Point Norman into the entrance to Ayr Creek, and across the entrance to the Point Smythe nearshore zone.

The rapid change has not been recorded at Inverloch previously and as such there are no opportunities to assess similar drivers and responses. The entrance is a dynamic environment, capable of relatively rapid and significant change. Adaptation options to minimise risk to assets and values in the area should factor these fluctuations into any design.

Assumptions, Limitations and Uncertainty

Prediction of future coastal erosion is complex with many forces and response mechanisms influencing the extent and likelihood of occurrence of erosion 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 remain some limitations and uncertainty in both existing knowledge and assessment methods used to underpin the erosion hazard assessment.

Recommendations

The understanding of coastal erosion drivers and responses 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 exposure 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.

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GLOSSARY

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

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

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


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

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, recession 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 E.

This report details the past and existing coastal processes and coastal drivers which have formed the existing coastline. The report also describes the potential impact of coastal processes into the future and the influence of climate change on coastal drivers and processes. The influence of the coastal processes, current and future erosion zones and zones of coastal recession are presented and discussed within the report.

The results of the technical assessments, including this assessment of coastal processes and identification of the zone of coastal erosion and recession hazard, will be used to identify assets in the coastal hazard zone and inform the technical assessment of selected adaptation actions (Figure 1-1).

For ease of reading, the term erosion will be used to describe both the short term storm driven loss of beach material, and also the total potential loss of material through the combined impacts of short term erosion and long and future coastal recession. The term recession will be used to refer to long term landward shift of the shoreline through observed or predicted change.

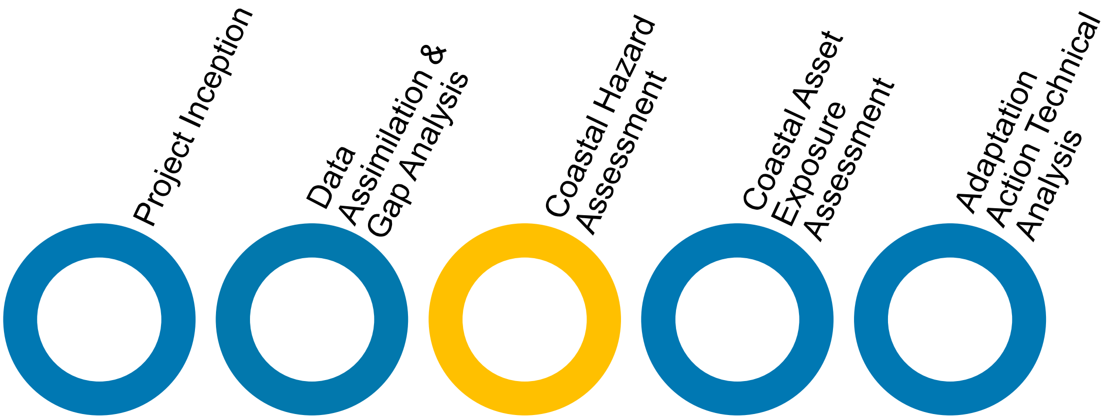


Figure 1-1 Inverloch CHA Project Phases

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.

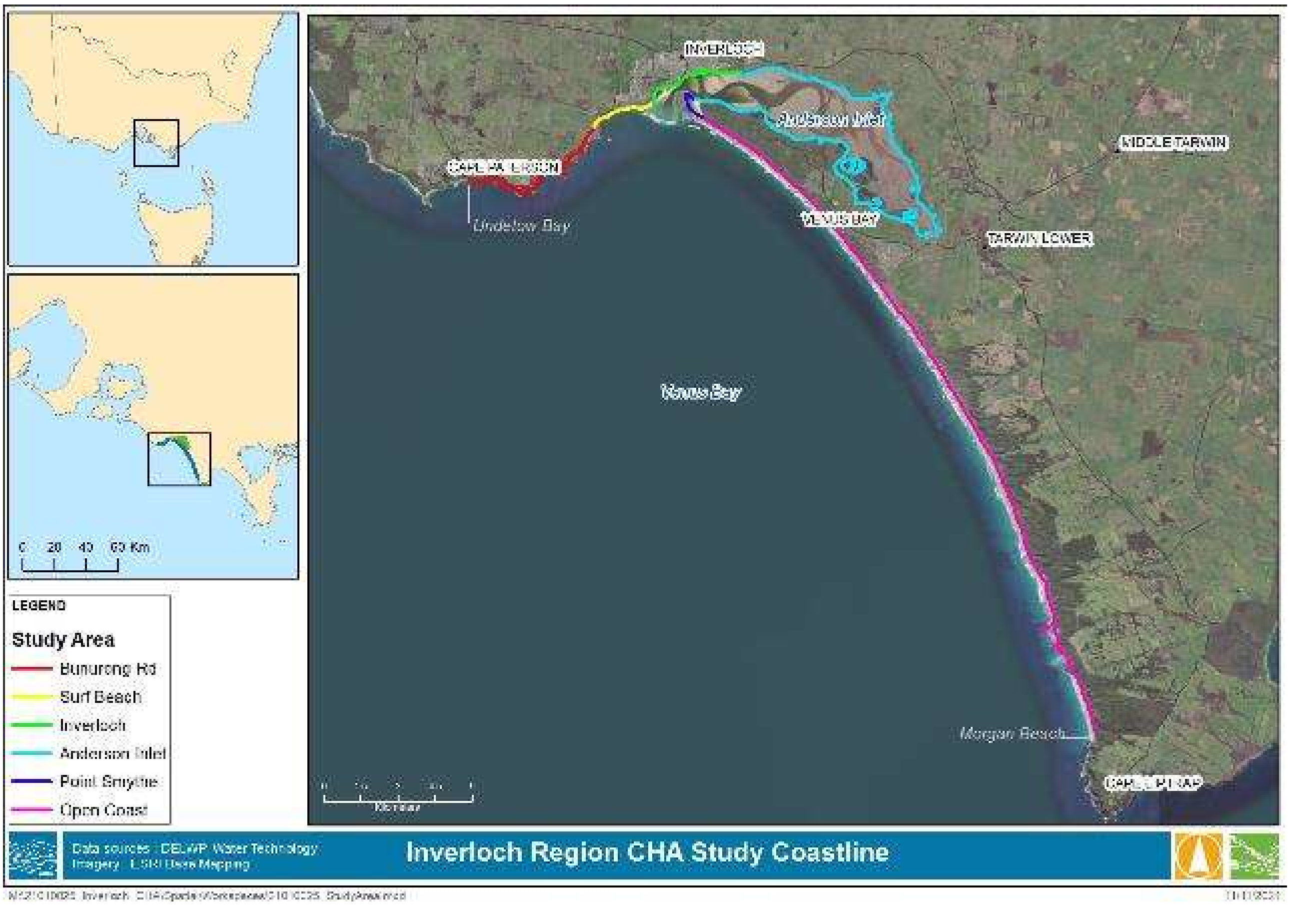


Figure 1-2 Study Area Coastline

1.3 Reporting

This report describes the coastal process drivers, the coastal processes and the influence of the coastal processes on the existing shoreline, including the current and future erosion 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 erosion in the Study Area, including the geomorphology, metocean condition and sediment transport.
- Section 3 presents a **Synopsis** of the coastal processes and conceptual drawings illustrating the coastal process pathways in the Study Area.
- Section 4 summarises the **approach** used to determine the existing and future erosion within the Study Area and presents the **Erosion Hazard Zones** across the Study Area.

- Section 5 **Summarises** the Erosion 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 processes and impacts in the Study Area:

- **Appendix A** contains ***Inverloch Coastal Hazard Assessment – Coastal Geomorphology***, a report prepared by Neville Rosengren (Environmental GeoSurveys) and Tony Miner (ASMiner Geotechnical) for Water Technology to support the coastal hazard assessment.
- **Appendix B** contains the **aerial imagery** and shoreline position through the **entrance** to Anderson Inlet for the individual years, providing further details for the shoreline change review provided in Section 2.1.4.
- **Appendix C** presents analysis of **aerial imagery** to define **long term change** of the sandy coastlines along the Study Area.
- **Appendix D** presents the **Erosion Hazard Mapping**

This document is Report 4 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: Inundation Hazards
- 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 have been selected based on the best available information and current planning policy. The sea level rises used in the 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 rises, the Study has been tasked with assessing the impact of varying potential storm events. 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, or the Average Exceedance Probability (AEP). 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 COASTAL PROCESS ASSESSMENT

The changing form and location of the shoreline has been documented along the coastline in the Study Area, in particular at Inverloch, since the settlement of the village. To understand the reasons for coastal change, identify areas at risk to erosion hazards, and to test options to help the community to adapt to or manage the coastal change, an understanding of the coastal processes is required. There are three key steps in understanding coastal processes and thus defining the coastal hazard zone:

1. Understanding the **geology** of the land and the **geomorphologic processes** which have created the current state of the coast.
2. Identifying and defining the parameters of current and future **coastal hazard drivers**.
3. Using this understanding of the geology and coastal response along with the definition of the coastal hazard drivers to predict and define the **coastal processes**.

Each of these is described in the following sections with a synopsis and conceptual model provided in Section 3. Applying the understanding of the coastal processes developed during this study, the coastal hazard drivers are then used to define the **coastal erosion hazard zones** described in Section 4.

2.1 Coastal Evolution

The evolution of the coast, including the spatial location of sandy beaches and the extent of coastal vegetation occurs over a range of time scales including:

- At the geological scale (10,000-100,000+years), coastal change is dominated by sea level movements and large-scale geological processes primarily dealing with the location and movement of rock.
- At geomorphic scales (100-10,000years), coastal evolution is determined by the sediment transport driven by regional and local metocean climate and sediment provenance and availability.
- Over planning scales (10-100years), sediment sources and sinks and pathways due to local landform changes and metocean climate and weather events.
- Over coastal management scales (days to 10years), significant changes occur due to storms – generally cross-shore erosion leading to coastal recession.

A detailed review of the physical character, namely the geology and geomorphology, and landscape evolution of the Study Area was completed for this project by Neville Rosengren (Environmental GeoSurveys) and Tony Miner (ASMiner Geotechnical). The full report is provided in Appendix A, while a brief overview is presented in Section 2.1.1.

Additional influences on the coast, such as land use change and the implementation of coastal protection works also change how the coastline develops and details of these changes are discussed.

2.1.1 Cape to Cape Geology and Geomorphology

The general geology of the study area is presented in Figure 2-1, from the oldest Palaeozoic basement rocks (540 million years BP to 250 million years before present (BP), including the Cambrian, Devonian, Ordovian, Silurian), through the Mesozoic (250 million to 66 million years BP) and then to the more recent Cenozoic period (66 million years BP to present, including the Palaeocene - Miocene, Pliocene, and Quaternary).

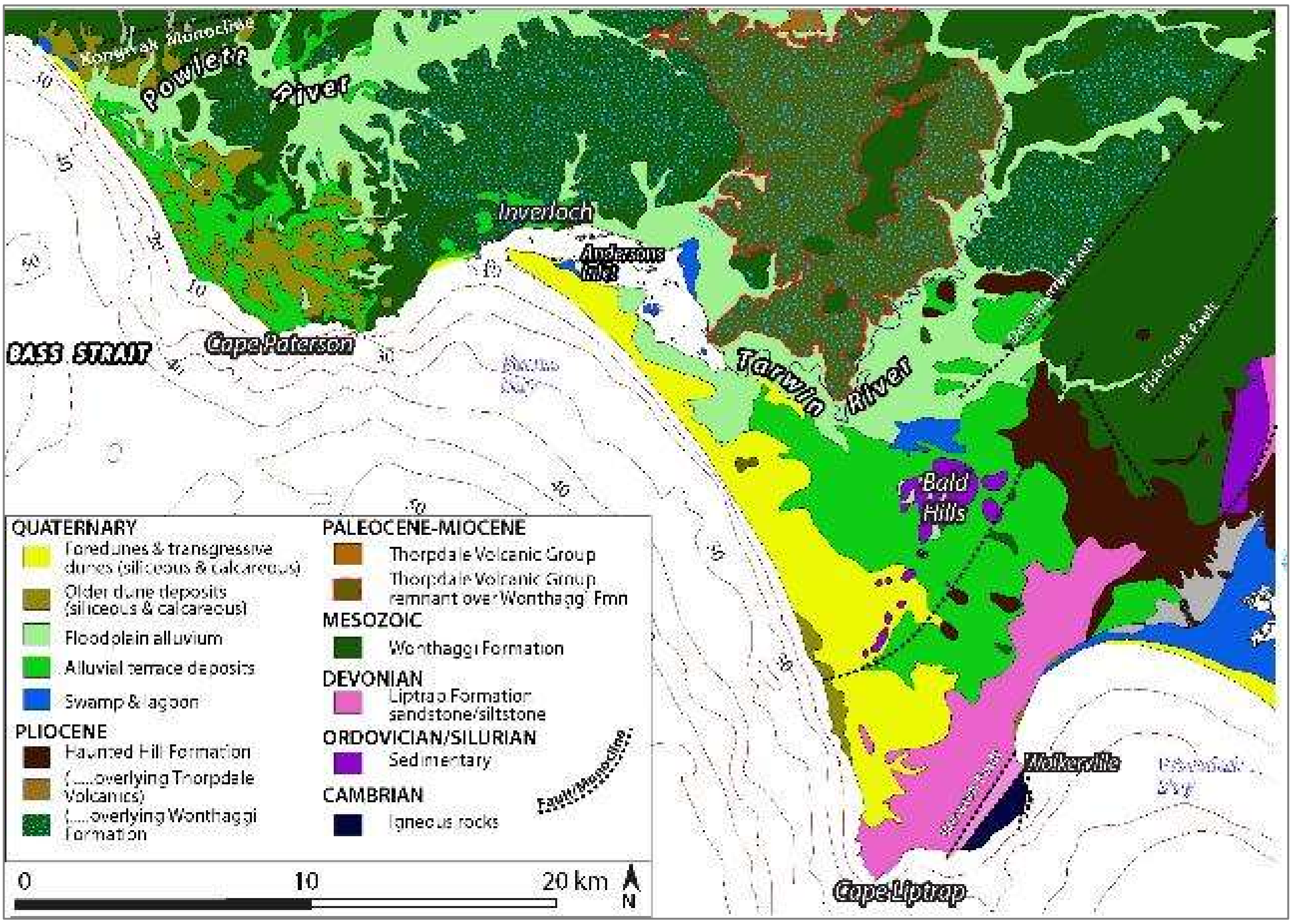


Figure 2-1 Geology of West Gippsland (Rosengren, 2021)

Along the coast, materials of the Quaternary period (2.6 million years ago to present), which includes the dunes, floodplains, swamps and lagoons cover much of the Study Area; however the older Mesozoic Wonthaggi formation materials are present along the coast from Cape Paterson to Inverloch and **influence the form on the coastline in these areas**. The Devonian Liptrap formation sandstone then bookends the area to the south at Cape Liptrap.

The general geomorphological features present across the study area are summarised in Figure 2-2 and Table 2-1.

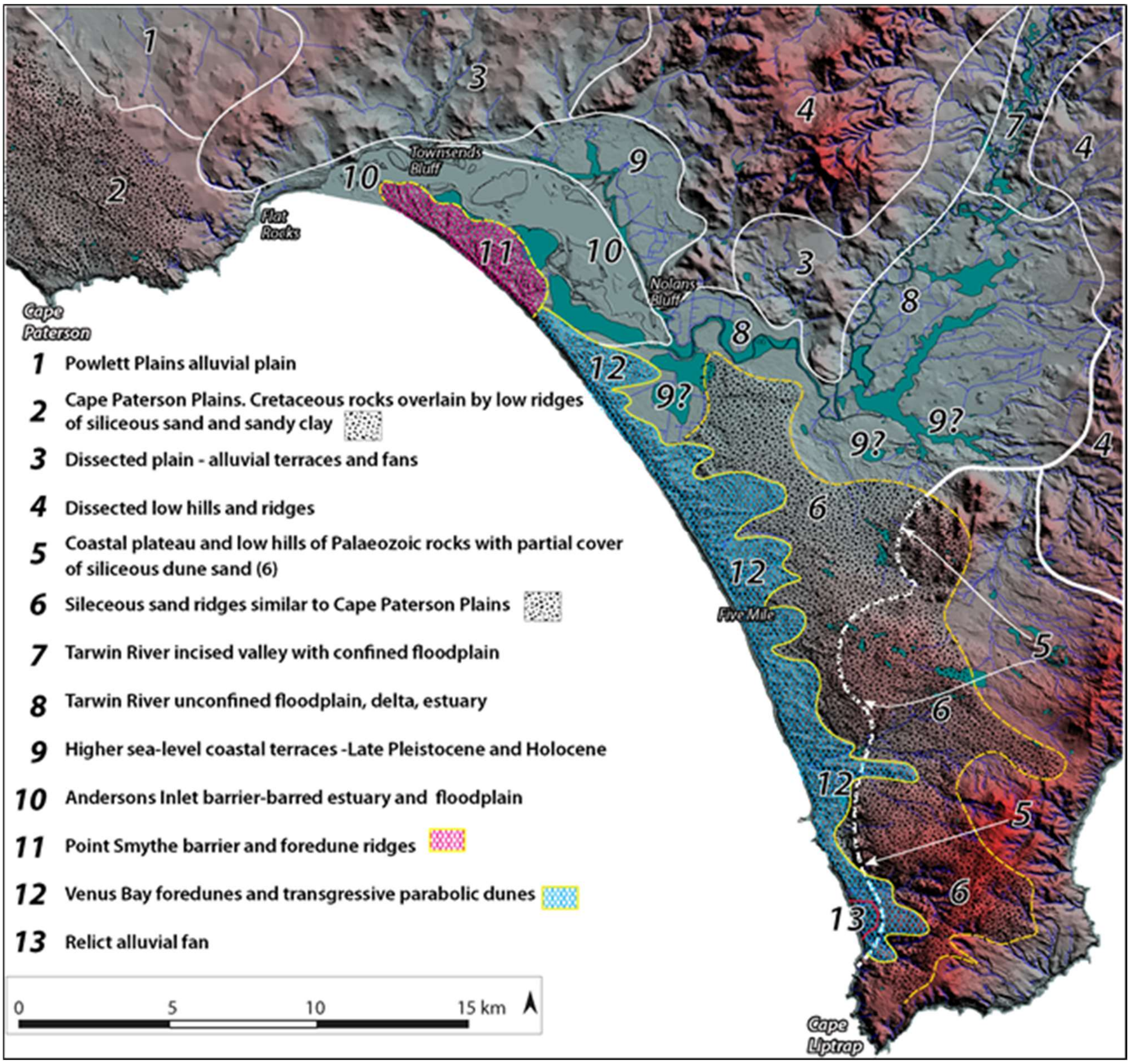


Figure 2-2 Spatial Extent of Geomorphological Landform Units in the Study Area (Rosengren, 2021)

Table 2-1 Summary of Geomorphological Landform Units in the Study Area

Unit #	Name	Description
1	Powlett Plains alluvial plain	Gently undulating alluvial plains of the Powlett River southern tributaries.
2	Cape Paterson Plains	A gently undulating surface at elevations 40 m to 50 m above sea level with relief <10 m extends south from Wonthaggi to Cape Paterson.

Unit #	Name	Description
3	Dissected Plain	North of Inverloch below the hills and ridges is a dissected planar surface of 10 m to 30 m relief. The surface finishes at the inner margin of the marine terraces bordering the northern coast of Anderson Inlet.
4	Dissected low hills and ridges	The southern margin of the Western Strzelecki Ranges are low hills and ridges of Wonthaggi Group. The ridges reach 125 m elevation and slopes are moderately steep with incised valleys.
5	Coastal plateau and low hills	The undulating to flat surface south of Tarwin Lower to Cape Liptrap and Walkerville. The plateau eastern and southern margins are dissected coastal slopes, cliffs and bluffs. The western margins lie beneath Bridgewater Formation and transgressive dunes.
6	Sileceous sand ridges	Low elongate ridges with relief around one metre. The ridges extend across the slopes of Bald Hill and extend to the backshore at Walkerville, possibly continuing down those slopes onto the exposed seafloor during the Last Glacial Maximum time
7	Tarwin River incised valley with confined floodplain	North of the Buffalo – Lower Tarwin Road the Tarwin River is a confined floodplain less than one km wide bordered by hillslopes and higher alluvial terraces.
8	Tarwin River unconfined floodplain	South of the Buffalo – Lower Tarwin Road the Tarwin River valley is three to five km wide. The present channel lies against the base of the ridge extending south as Brights Road bluff.
9	Higher sea-level coastal terraces	Flat to very gently sloping surfaces at elevations between <1 m to 6 m occur north of Anderson Inlet. The terraces extend into the lower Tarwin River valley west and south of Brights Road bluff to Tarwin Meadows.
10	Anderson Inlet	Anderson Inlet is the permanently open, tide-dominated barrier-enclosed estuary of the Tarwin River
11	Point Smythe barrier and foredune ridges	The recurving spits caped by foredunes at the end of the Holocene epoch coastal barrier (within the Quaternary period but formed beginning around 11,700 years before present).
12	Venus Bay foredunes and transgressive parabolic dunes	A Holocene epoch coastal barrier that encloses Anderson Inlet, anchored to the south by Cape Liptrap.
13	Relict alluvial fan	A relict alluvial fan deposit, dated to around 25,000 years ago, during the Last Glacial Maximum (the period around 19,000-30,000 years ago when the ice sheets reached their maximum across the world).

How Venus Bay and Anderson Inlet evolved to their current geomorphological state is described in detail in Appendix A and presented conceptually in Figure 2-3. A brief overview of this evolution is summarised below.

Figure 2-3 Coastal Evolution of the Venus Bay barrier (Rosengren, 2021)

- The Study Area is between the faulted landscape to the west and south and the high energy wave and wind environment of Bass Strait.
- Between the more resistant geology and low hills of Cape Paterson and the Liptrap peninsula, the Tarwin embayment was formed.
- This embayment has enclosed and progressively infilled with sand predominantly delivered from the coast.
- These sands gradually formed the Venus Bay coastal barrier, by way of windblown sand blown up from what is now Bass Strait during periods of lower sea level to form dunes (the Pleistocene Bridgewater formation dunes)
- Then later during the Holocene when sea levels were closer to present day conditions, wave and wind driven sand covered and extended these earlier dune formations.
- More recently again, the barrier has extended further northward to Point Smythe as a series of recurved dune ridges, driven by longshore sand movement from the south, culminating at Point Smythe at the mouth of Anderson Inlet today (Figure 2-4).
- Much of the fine-grained sediments (silts and muds) within the current inlet have been delivered from catchment sources, via the Tarwin River and local waterways. These fine sediments gradually infill the head of the embayment. Coastally derived sands also slowly infill the embayment as they enter the inlet through the entrance between Point Smythe and Point Hughes.

- However, much of the sand in the entrance is recirculated through the entrance channels, along the adjacent shoreline and beaches both to the north and south, and within the flood and ebb tide deltas.

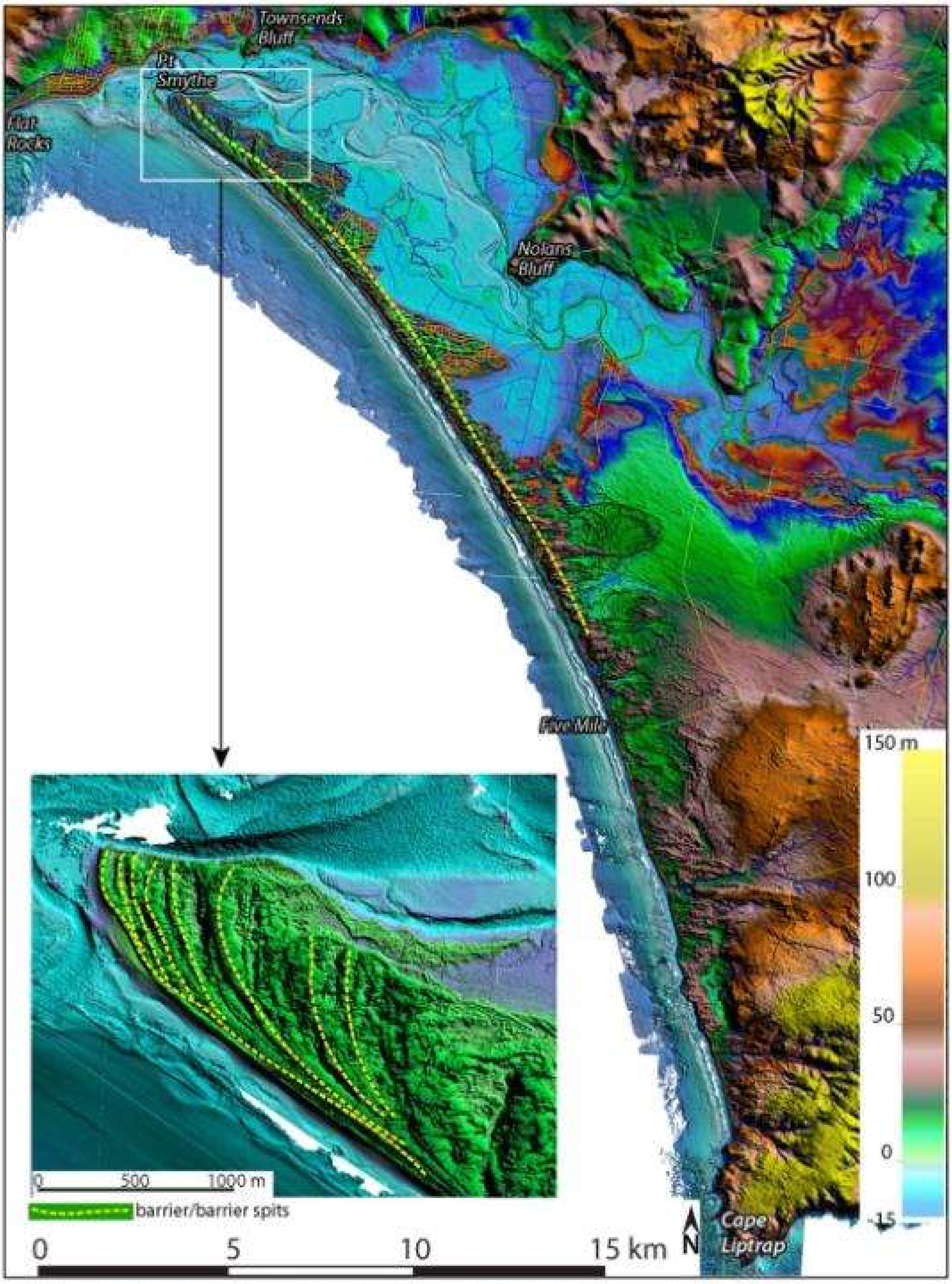


Figure 24. Coast barrier of eastern Venus Bay extending north from Five mile and enclosing Andersons Inlet (red lines are beaches. The inset shows the change in configuration of the barrier as recurving spits north of Venus Bay 2nd Estate

Figure 2-4 Development of Point Smythe sand spit (from Rosengren, 2022)

2.1.2 Post Colonisation Changes in Catchment

A summary of the more recent historical events and changes to the Study Area is provided Appendix A. Land use changes and levee control has had a significant influence on the coastline and its continued evolution.

The earliest survey of the Study Area in 1868 (Figure 2-5) notes the coastal plains are designated as “dense dwarf scrub” (Bunurong Road), “dense gum scrub” (Flat rocks – Point Norman), “salt marsh” (Anderson Inlet), and “low range hills covered in tee tree” (Venus Bay). This contrasts with the aerial imagery of 1950 (lower figure, Figure 2-6) where open pasture dominates the land use and the view from Cape Paterson to Venus Bay (Figure 2-7). Vegetation around Cape Paterson and within the Inverloch town area visible in the 1950 image is no longer present by 1991. Coastal vegetation along Bunurong Road is visible in the 1991 image, becoming more widespread by 2019. The closure of the western end of Point Smythe to grazing results in the re-establishment of vegetation through 1991 to the dense coverage visible in the present day (2019) imagery.

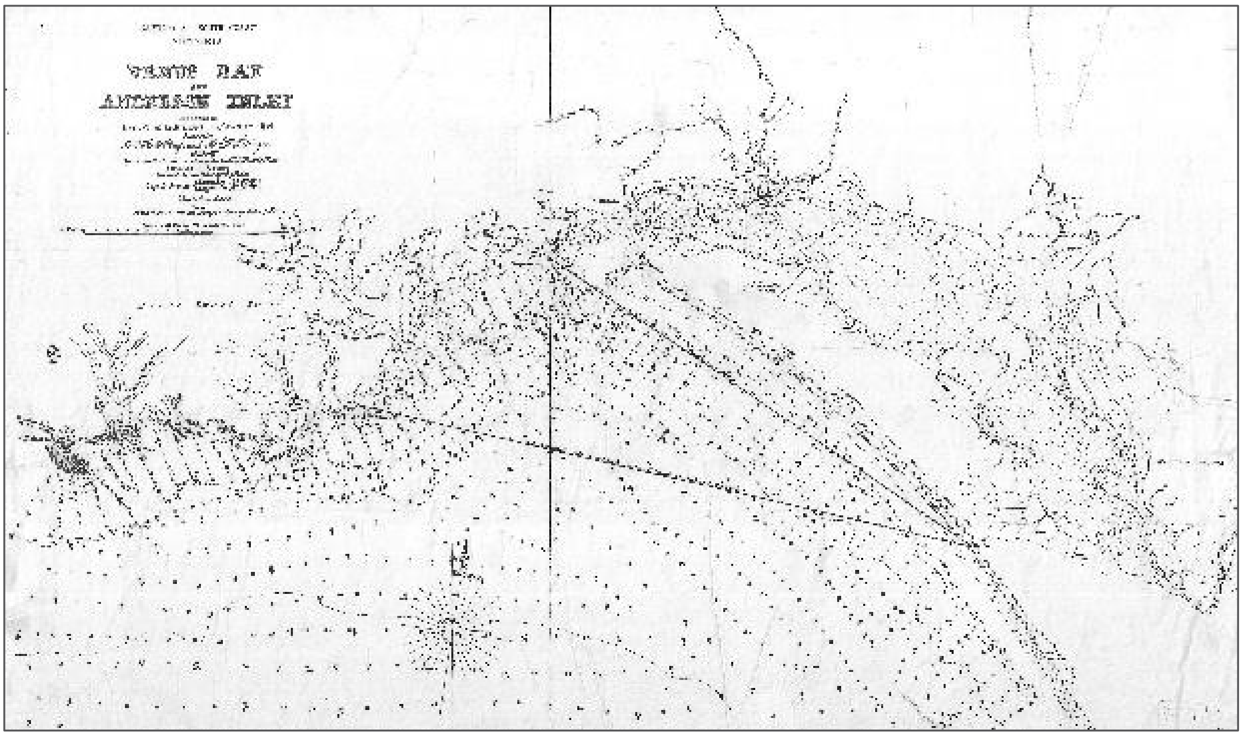


Figure 2-5 Venus Bay and Anderson Inlet Hydrographic Survey (Royal Australian Navy, 1968-9)

Figure 2-6 Land use and management change since 1950

Figure 2-7 Cape Paterson to Venus Bay (State Library Victoria, Rose Series 1920-1954)

Around Anderson Inlet the construction of the majority of the earthen levees preventing ingress of coastal waters onto the low-lying land occurred between 1962 and 1968 (based on aerial imagery analysis). The levees appear to be rudimentary structures, with the borrow pits used to construct the levees still present in places on the land- and sea-ward side of the structures (Figure 2-8). Anecdotal evidence from community consultation reports that levees were constructed to a height of "13 feet" (~4m) designed to prevent inundation to the "1938 flood" (thought to be the 1934 flood which resulted in significant inundation across much of Melbourne and southern Victoria). 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.

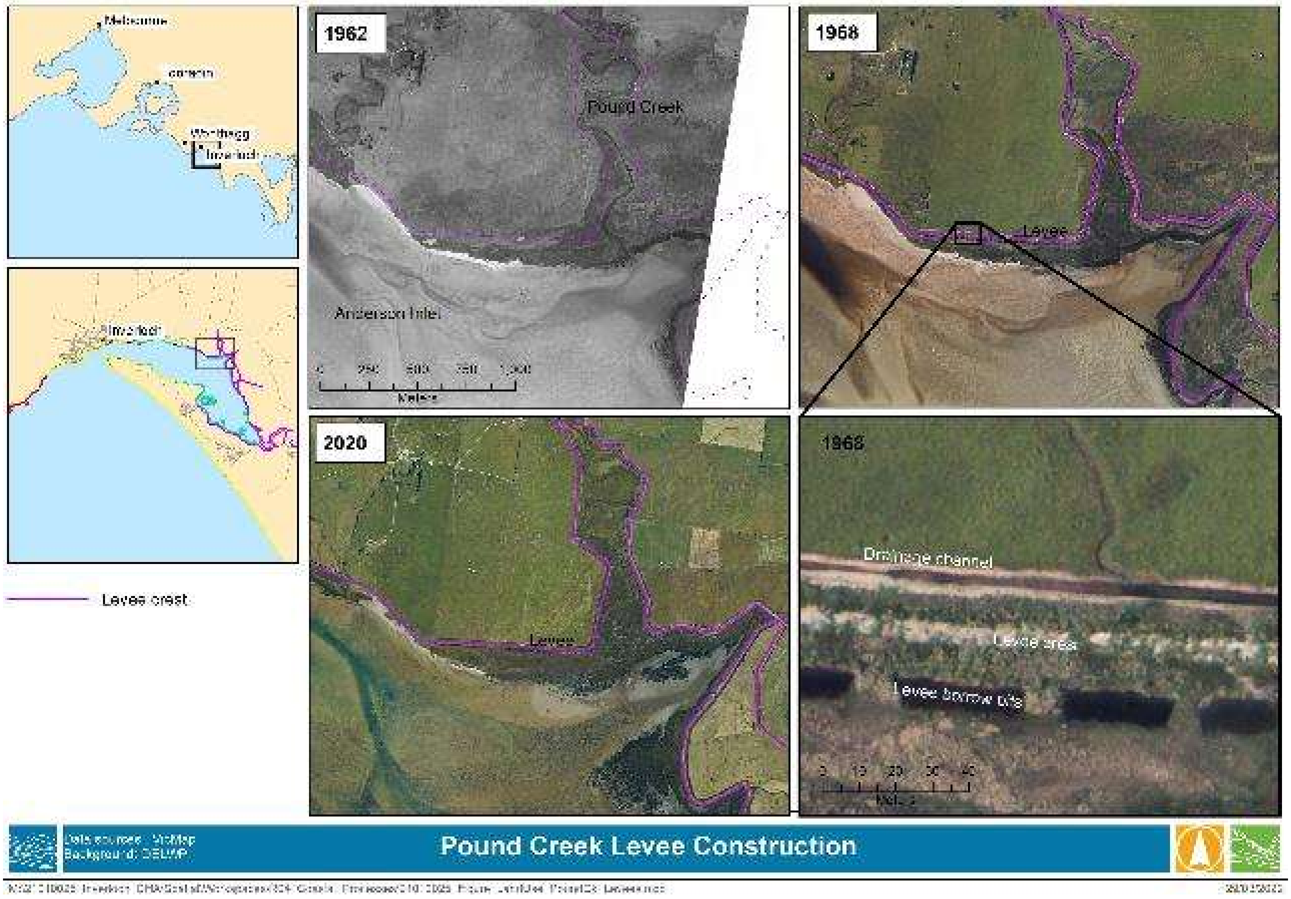


Figure 2-8 Levees and borrow pits for levee construction, Pound Creek

2.1.3 Coastal Protection Works in Inverloch

Similar to the land use change, past and present coastal protection works at Inverloch are evident in the collection of historical aerial imagery, described in the Report of the Foreshore Erosion Board of 1936 (Foreshore Erosion Board, 1936) and in South Gippsland Conservation Society's "*Shifting Sands – Inverloch – A Fascinating Place*" (Williams, 2002).

Williams (2002) notes workers through the depression of the 1920s and 30s constructed the wooden and masonry groynes and seawalls, potentially those presented in Figure 2-9 and describes the presence of jetties at Mahers Landing and Inverloch being present before the beginning of the 20th Century allowing trade and transport to the area from Melbourne.

The 1890 bathymetric survey of the Entrance to Anderson Inlet by Mason (1890) shows the rudimentary beginnings of the Inverloch town with streets and parcels and the "jetty" connecting Anderson Inlet with the wider colony via boat. The land connection of the jetty is located approximately 100m north-north- west (NNW) of the current position and the 1890 jetty extends approximately 40m seaward to allow access to waters 12 ft deep at low water.

The Foreshore Erosion Board Report describes previously constructed timber groynes designed to prevent erosion of the beach east of the jetty, now the land reclaimed along the Esplanade comprising the grassy overflow carpark, picnic area and BBQ shelter (Rotary Park / Pymble Ave Reserve). To the west the Report details previous placement of loose stone groynes to prevent erosion of the cliff at Point Hughes and the erosion of the beach further west of this, presumably towards Ayr Creek.

The Erosion Board Report recommends the spending of £4.612.00 to undertake coastal protection works encompassing:

- 2,050 feet (625m) of "*tea-tree basket walling to prevent further inroads of the sea into foreshore reserve, and the construction of groynes as an aid to beach building*", and
- 1,200 feet (365m) of "*stone walling to prevent further erosion of land around Point Hughes, and construction of stone groynes*" to protect the headland.

An example of the tea-tree walling used to the east of the jetty is shown below in Figure 2-9 and what is assumed to be the stone walling and timber (as opposed to stone) groynes recommended to the west of the jetty towards Point Hughes.

The extent and type of protection works which have been identified within the Inverloch township area either through documentation, survey or historical imagery is presented in Figure 2-10. Structures which are known to still exist are highlighted in green, with those shown in red either no longer present, or not visible (i.e. buried by sand or vegetation).

Existing coastal protection works are extensive along the coastline, and vary from new and intact, such as the rock armour seawall along Bunurong Road or the geotextile sandbag revetment at the Inverloch Surf Life Saving Club (SLSC), to old and dilapidated such as the rudimentary rock and tyre seawall adjacent to Ayr Creek. The masonry seawall shown in Figure 2-9 is thought to be partially buried under sand at the carpark at Venus Street. The timber groynes also shown in Figure 2-9 above are no longer present.

The location of present and past coastal protection works points to an area which at some stage faced erosion or inundation hazards causing risk to assets on the land. The presence and condition of coastal protection structures has been considered in the determination of coastal hazard extents described in Section 4.

Figure 2-9 Tea-tree walling (Erosion Board, 1936) and Masonry seawall (State Library Victoria)

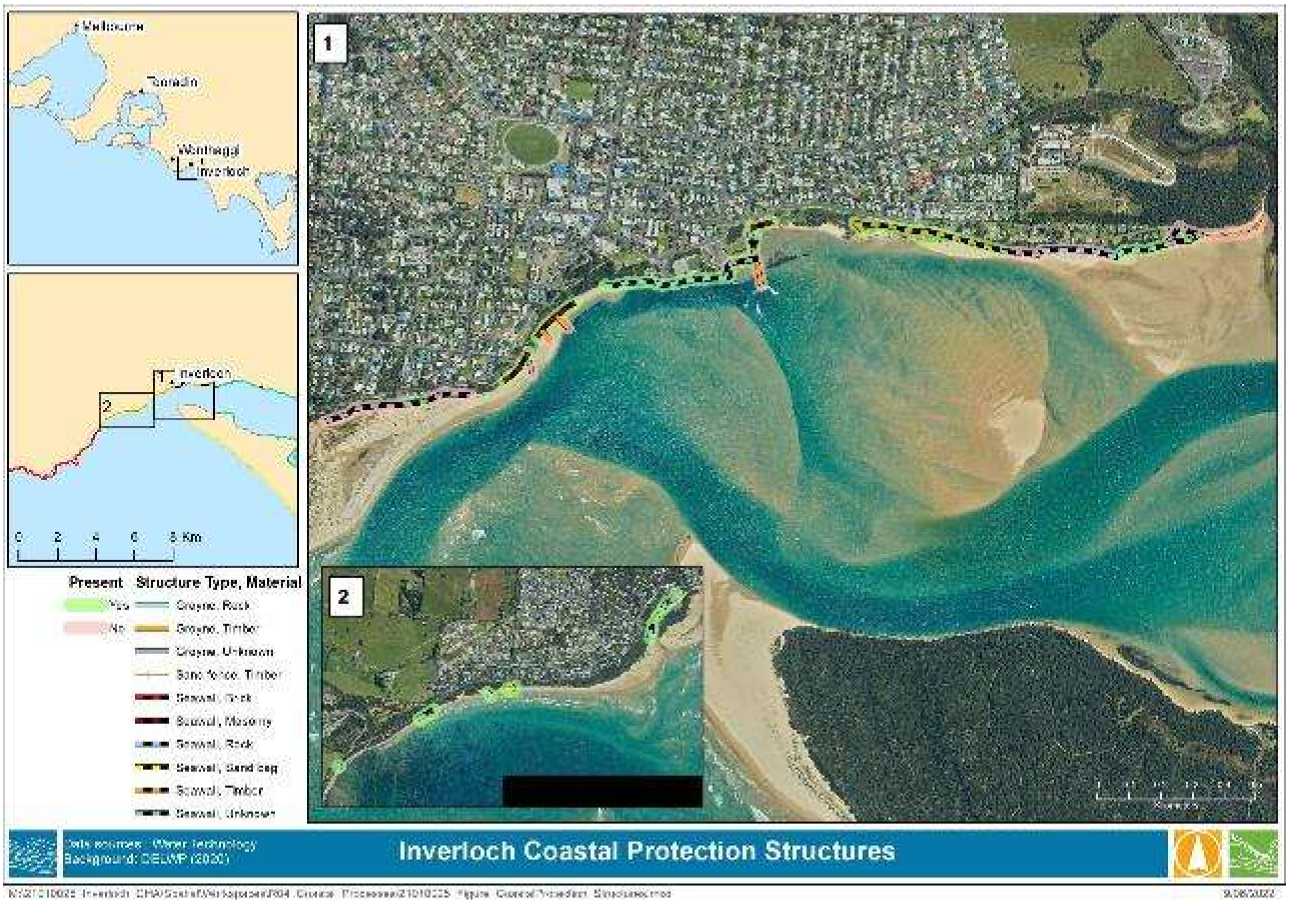


Figure 2-10 Known Coastal Protection Works within Study Area

2.1.4 Shoreline and Channel Change

Analysis of available aerial imagery has allowed comparison of the extent and limits of vegetated coastal areas. The vegetation line along the coastline is often considered a good representation of the "stable" coastline – i.e. the area not regularly impacted by tidal and wave conditions, and likely to be a reasonable delineation of the active coastal zone.

Similar analysis has been undertaken to review the migration of the main tidal channels within the entrance to Anderson Inlet. This analysis is more qualitative as the depth and clarity of the water can make interpretation of the edge of the tidal channel difficult and the stability of the channel is more difficult to define by the presence of vegetation.

A timeline of available aerial imagery covering the entrance and Anderson Inlet is presented in Figure 2-11. The coastline around the entrance is captured at least every 6 years since 1962 with increasing frequency to at least bi-annual capture since 2006. In total, 36 images cover the entrance coastlines and sandbars. To provide an overview of change on the entrance coastline, the vegetation line from 1950 and 2020 along with the aerial image is presented below in Figure 2-12. Each aerial image and the position of the shoreline in each image is presented separately in Appendix B.

The Study Area has been separated into different areas to assist in interpreting changes. Analysis for different areas are presented in Table 2-2. The change on Surf Beach is presented in Figure 2-15, at Point Smythe in Figure 2-22 and within the entrance channels in Figure 2-23.

Table 2-2 Analysis of Shoreline Change

Study Area Section	Details of Changes
Flat Rocks – Wreck Creek, Figure 2-13	At the western end of the beach there is little net change in the position of the coastline, although there is accretion of the shoreline visible around the current entrance to the RACV resort, with new vegetation establishing from 1950 through 1980. Recession had begun by 2008 and continues through to 2021. From the RACV resort to Wreck Creek the pattern of early accretion from 1950 through to the 1980-1990s is observed before the recession which continues today is noted in the imagery from 2012. The position of the Bunurong Road rock revetment is 25m landward of the 1950 shoreline.
Wreck Creek mouth, Figure 2-14	The entrance of Wreck Creek changes from an open sandy berm in 1950 with an apparently actively growing spit forcing the entrance eastward to a heavily vegetated environment with lagoons and a receding dune in 2020. A number of drainage paths from the north and east are noted to flow into Wreck Creek. The Creek entrance appears to reach its most eastern position in 1970 before remaining relatively stable until 2013 following which recession westward is observed in 2014 through 2019. The new entrance is established in 2020.
Inverloch Surf Life Saving Club to Point Norman, Figure 2-15	The existing sandbag wall at the Inverloch SLSC is approximately 10-15m landward of the toe of the dune in 1950, however, similar to the surrounding coastline, accretion and vegetation of the beach in front of the SLSC occurred through the 1950s and 60s, peaking 55m seaward of the 1950 line in 1979. The coastline receded from this maximum position by around 20m by 2012, then rapidly receded across the next decade to the current alignment. Further east towards Point Norman a coastal lagoon (likely formed in a similar manner to the Ayr Creek lagoon) is observed in the 1979 imagery (Figure 2-16). Recession of Point Norman and the offshore area is observed in the images of the early 1970s to 1975 in the lead up to the lagoon formation. It is not known how long the lagoon took to form between 1975 and 1979, nor how long it remained. The area has been infilled, but not vegetated by 1985. A rapid retreat of the dune and vegetation of around 50-60m occurred during the development of the lagoon which then recovered to a peak seaward extent in 2006 close to 100m from the 1979 coastline. The current trend is recessional since 2006 with a greater change observed in 2020 than previous years.

Study Area Section	Details of Changes
Point Norman to Ayr Creek, Figure 2-17	Around Point Norman the 1950 shoreline shows early recession through the 1960s and 70s, although there is considerable movement of the channel through the entrance. The coastline on the western bank of Ayr Creek initially showed accretion through the 1960s of 20m before 60m of recession rapidly moved the shoreline to an alignment similar to the present vegetation line, perhaps as a result of the coastal protection structures still visible. The Ayr Creek lagoon (Figure 2-18) developed rapidly following the tidal channel alignment shift in January 2012 followed by the build-up of sediment at the entrance in November 2013 and the migration of this sand into the entrance semi-enclosing the lagoon by November 2014 creating a sandy berm. The development of the lagoon is presented in Figure 2-18. The lagoon moved the shoreline over 350m from the mouth of the Ayr Creek and the imagery shows signs of vegetation stabilising the sandy material. However the lagoon broke across the berm and reconnected with the entrance channels in 2018 and the sand appears to be dissipating due to tidal flushing and channel realignment in the entrance.
Ayr Creek to Inverloch Jetty, Figure 2-19	The coastline adjacent to Ayr Creek in the east to Point Hughes showed a similar pattern to the western coastline – initial accretion through to 1970 before a 50-60m recession to the current alignment. Northeast of Point Hughes similar accretion occurred through to the mid 1970s which was followed by recession through the 80s and 90s to the present day shoreline position. The area just east of the boat ramp in 1950 appears to be newly vegetated sand, reclaimed as a bowling green by 1962 and formalised boat ramp car parking and extended jetty visible in the 1968 image. Also visible in the 1968 image is the first evidence of a rock armour seawall along the front of the bowls club and carpark. The shifting channel resulted in an extension of the 70m jetty in 1968 to 140m in 1970 and reduction to 70m again in 1974, 27m in 1975 and finally 22m in 1979 where it remained until 2000.
Toys Backwater, Figure 2-20	Significant change has occurred in Toys Backwater, the area east of the original boat ramp since 1950, and most likely in the years prior. The 1950 image, with the reclaimed land west of the ramp also shows evidence of a growing sand spit from the boat ramp enclosing waters along the Esplanade at Pier Road. By 1962 this sand spit becomes vegetated and seawalls have been constructed from between Nautilus and Anderson Ave to Cuttriss St along The Esplanade. The waters in Toys Backwater are kept connected to the Inlet waters although they appear stagnant in 1968. Gradual reclamation of the land adjacent to the boat ramp carpark is formalised by 1974 with a rock wall 100m square of the boat ramp. A groyne, or potentially storm water drain extends from the reclaimed land to the channel and likely assists to scour the sand spit resulting in a vegetated island within Toys Backwater and tidal ingress to the Esplanade again. The area slowly infilled with sand and vegetation extended the shoreline to close to level with the boat ramp (100m seaward) in 2006 after which gradual recession, accelerated by the terminal scour of the reclaimed land adjacent to the boat ramp, has occurred and the coastline in the west of Toy Backwater has returned to its 1950 position.

Study Area Section	Details of Changes
Screw Creek, Figure 2-21	East of Cuttriss Street and the extent of the Toys Backwater spit/lagoon formation, the coastline has remained stable. Minor changes can be observed in the imagery; however these are small and transient with some greater incidence of accretion and recession between small headlands along the caravan park frontage. Recession of the entrance to Screw Creek western bank has resulted in a setback of around 20m since the mid-1970s.
Point Smythe, Figure 2-22	Across the Inlet to Point Smythe (northern bank, opposite Screw Creek) the imagery shows a gradual and continuing recession of between 30 and 100m total recession from 1950 to 2020. Directly opposite Cuttriss St, this recession increases to 170m, with rapid change between 1950-1962 (50m) and 2000 to 2006 (35m). Coastal recession continues, although the rate has reduced significantly with 20m of change noted since 2006. At the north-eastern tip of Point Smythe the recession is largely constant from 1950 through to 1985 after which vegetation of the sandy spit pushes the point westward through to 1991. At some point between 1991 and 2000 the channels begin to erode the newly vegetated dunes and in 2006 the vegetation line has receded to a line similar to the 1985 extent on the western face of the Point, whilst also continuing to recede 30-40m on the northern bank of the spit Point. More recently the western face of the spit has stabilised. The ocean side of Point Norman has been accreting since 1950 with the dune vegetation increasing and potentially reducing the loss of wind blown sand. The dunes show evidence of growth and recession indicating storm bite and recovery over a longer period.
Entrance Channels, Figure 2-23	The entrance channel position along the western edge of the Inlet remains constant from 1950 through to 2008. Change in the position of the main sand bar and main channel can be observed, along with the increasing capacity of the flow path east of the boat ramp. An increase in sinuosity in the channel is observed, and especially notable around Point Smythe from 1991 and upstream towards Townsend Bluff from around 2000. The width of the intertidal platform directly south of Townsend Bluff has decreased from almost 700m to less than 250m. The entrance channel across the bar, widened with the channel change between 2013 and 2015, has slowly reduced in width, becoming more constrained through to the end of 2020.

Study Area Section	Details of Changes
Anderson Inlet Channels, Figure 2-24	A range of imagery also covered the channels within Anderson Inlet. Some channels are disconnected in Figure 2-24 as reflection or turbid water made identifying the main channel difficult. There is a notable increase in channel sinuosity since 1950, beginning as early as 1962 and continuing to progress upstream over time. Where the channel is located close to the bank of the Inlet the constriction of the channel with the increased sinuosity has resulted in a narrower, potentially more incised channel (e.g. adjacent to Mahers Landing where the channel width has reduced from 157m to just over 100m). Distances from the coastline to the channel have reduced where the channel bends are increasing sinuosity, for example the bend upstream (directly south) of Mahers Landing has shifted 100m closer to the mangrove/wetland area north of Venus Bay settlement one. Additional islands have formed on the intertidal banks offshore of the Venus Bay jetty and channels are more incised in the later images than 1950. The width of the channel closer to the mouth of the Tarwin River has increased as more flow paths meander across the main flow area.

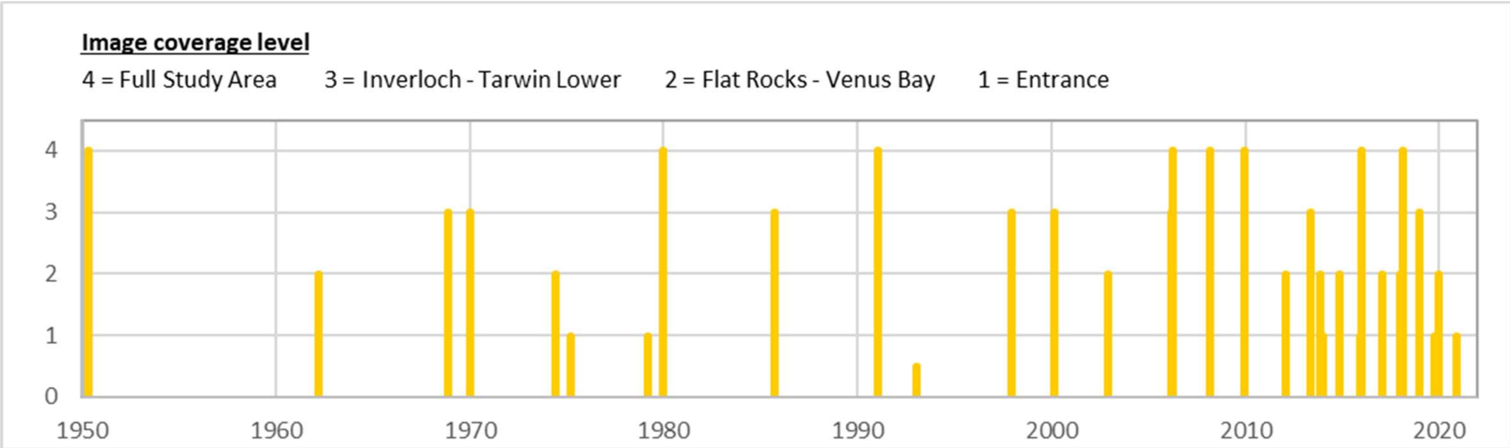


Figure 2-11 Aerial imagery availability

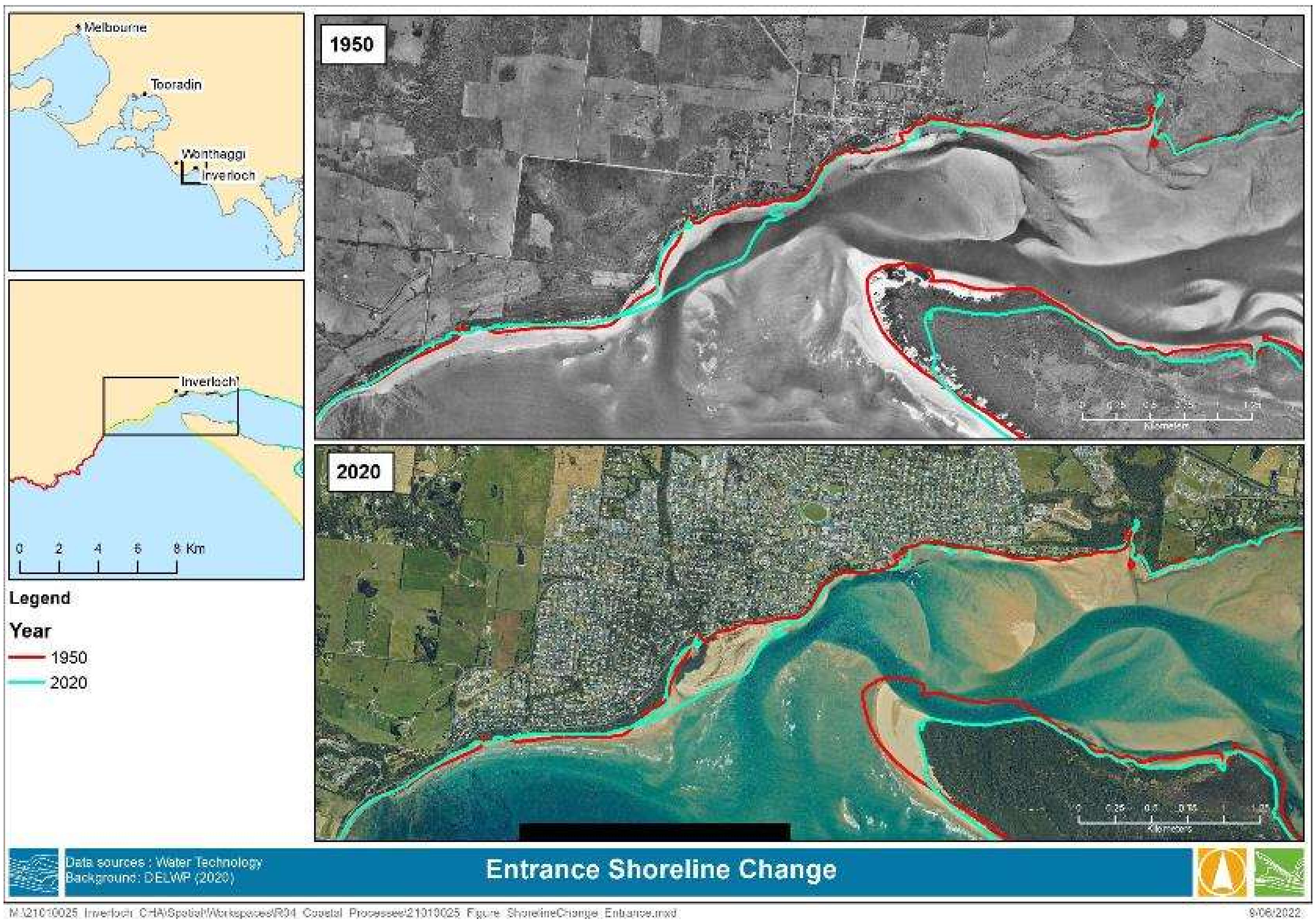


Figure 2-12 Shoreline Change, entrance 1950 - 2020

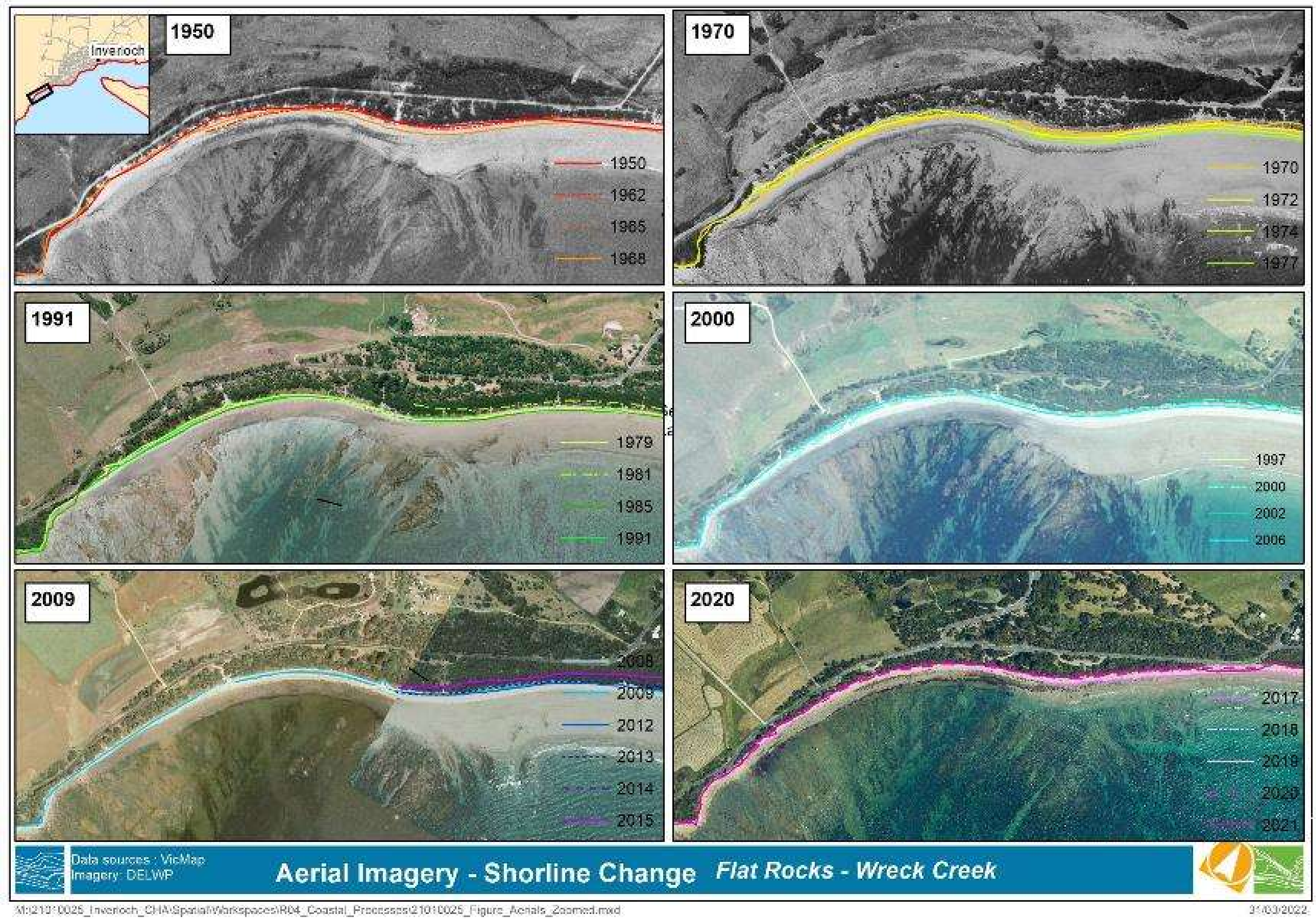


Figure 2-13 Shoreline Change – Flat Rocks to Wreck Creek

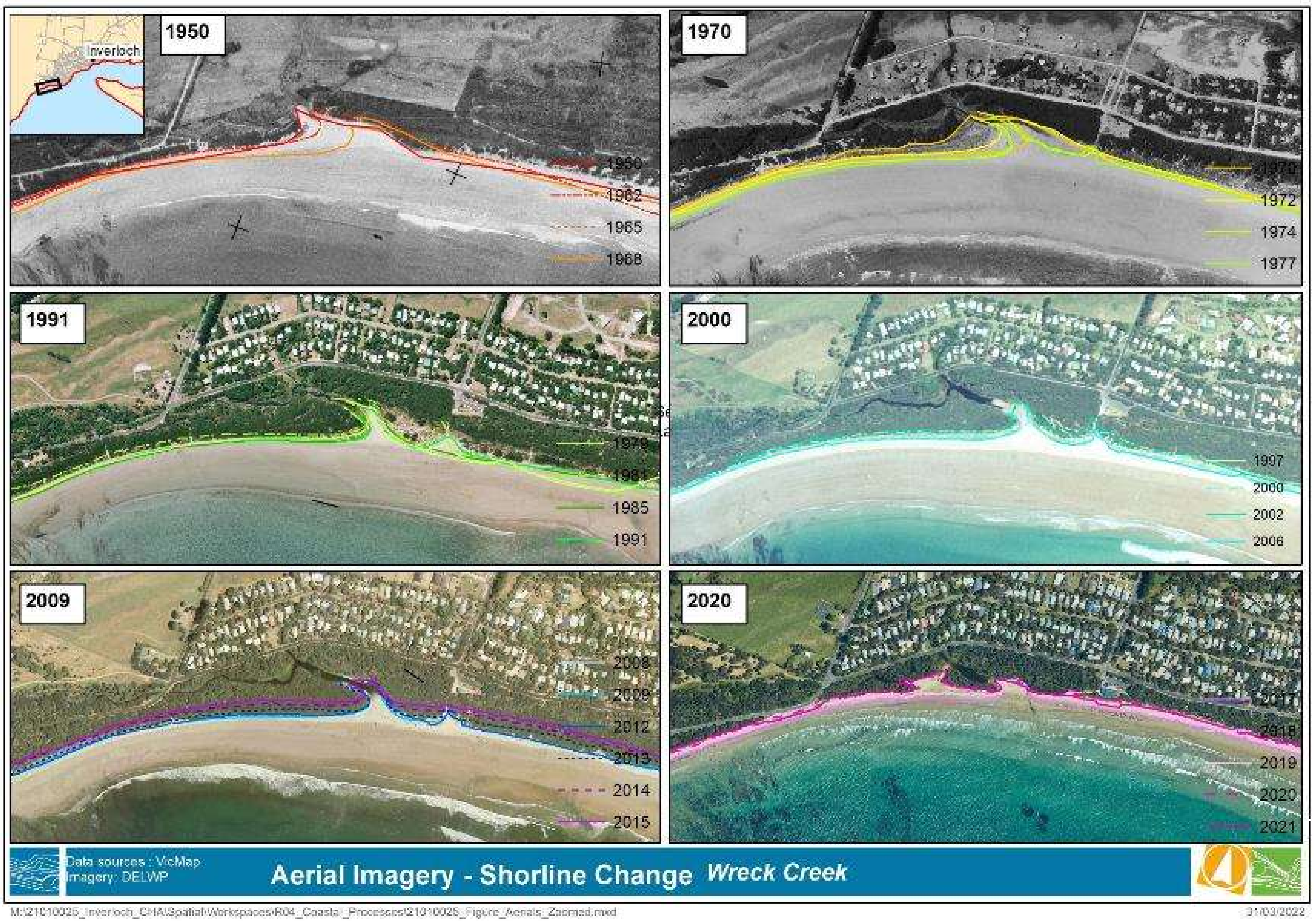


Figure 2-14 Shoreline Change – Wreck Creek

Figure 2-15 Shoreline Change, Surf Beach and Inverloch

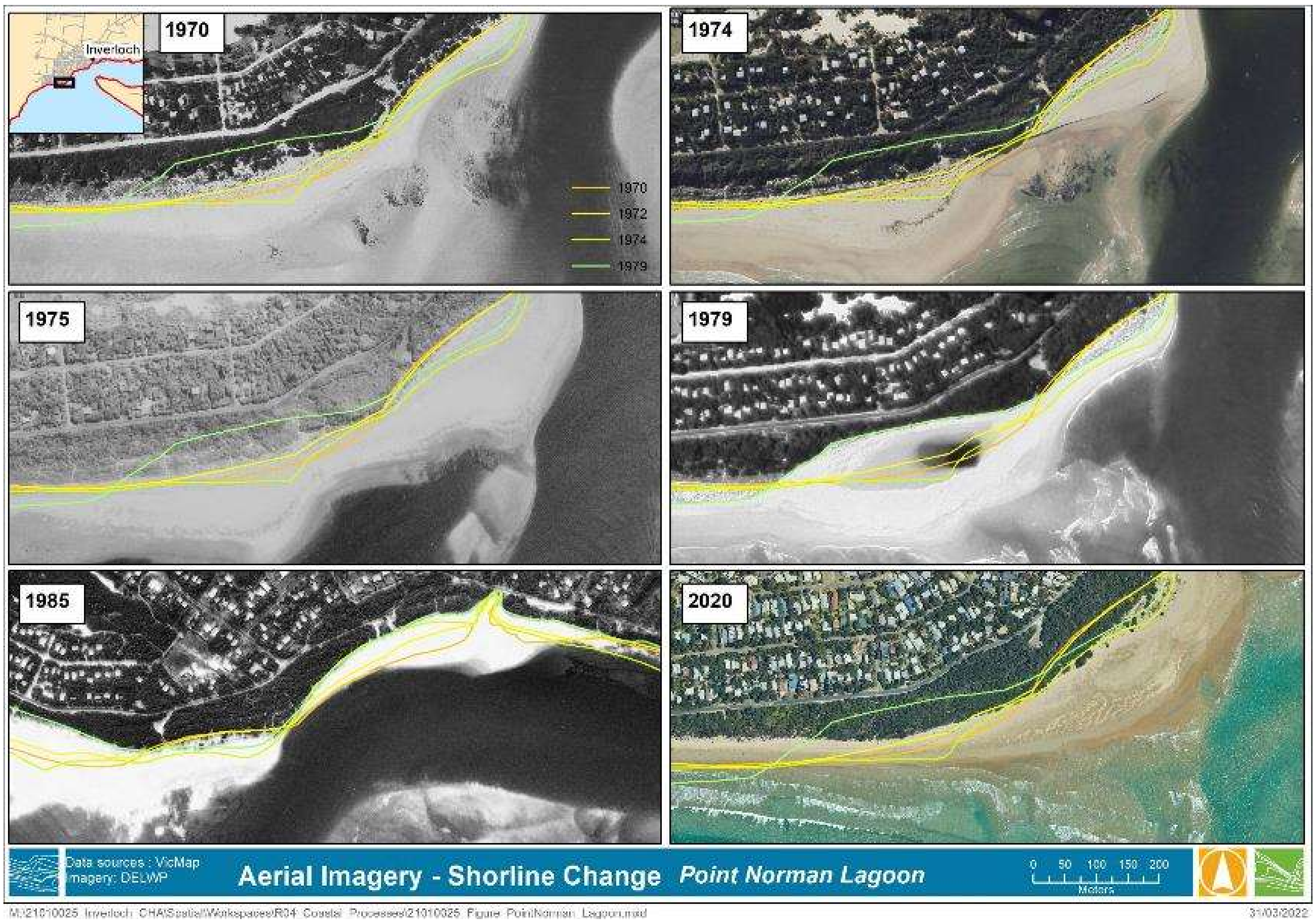


Figure 2-16 Shoreline Change – Point Norman Lagoon

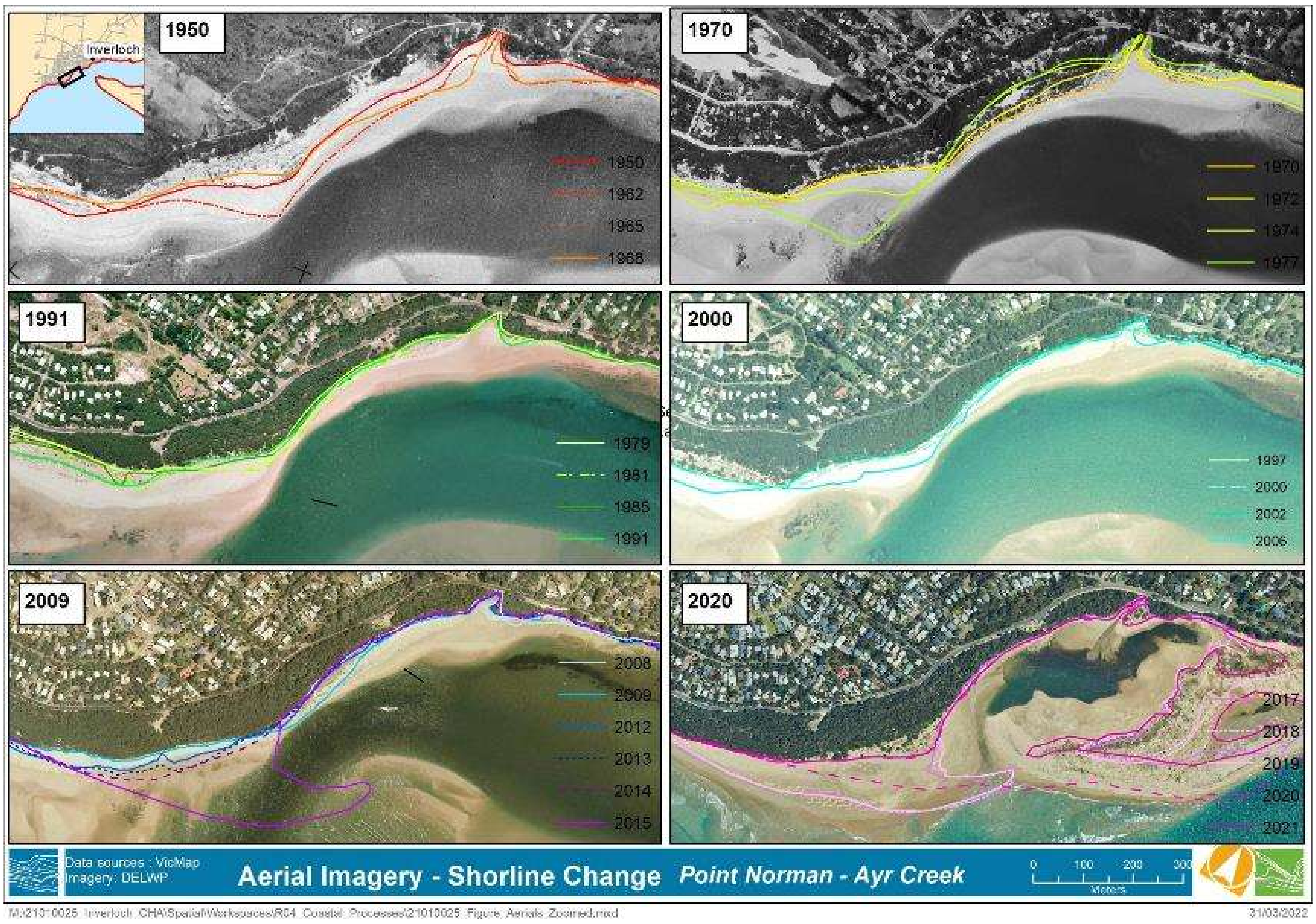


Figure 2-17 Shoreline Change, Point Norman – Ayr Creek

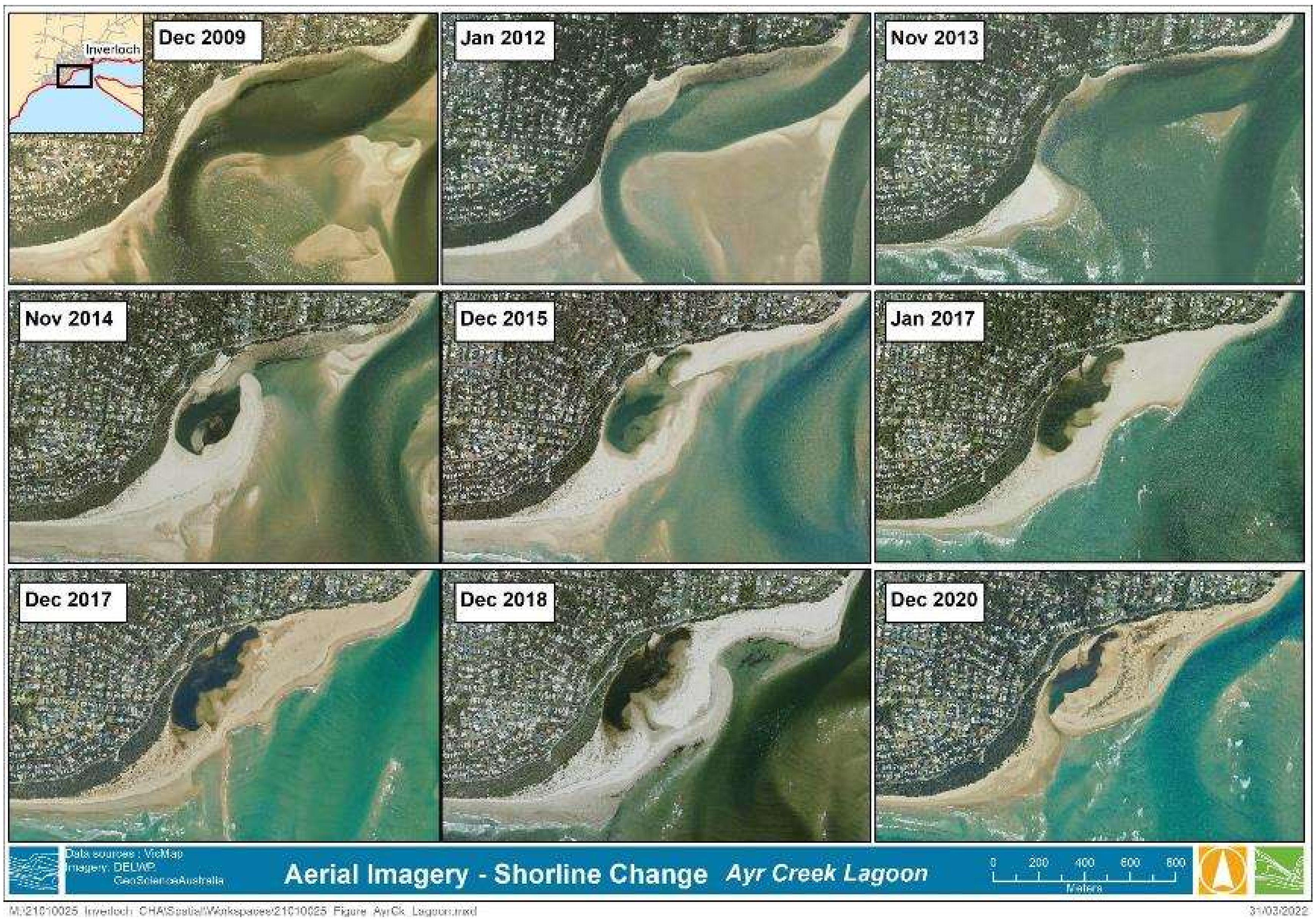


Figure 2-18 Formation of Ayr Creek Lagoon

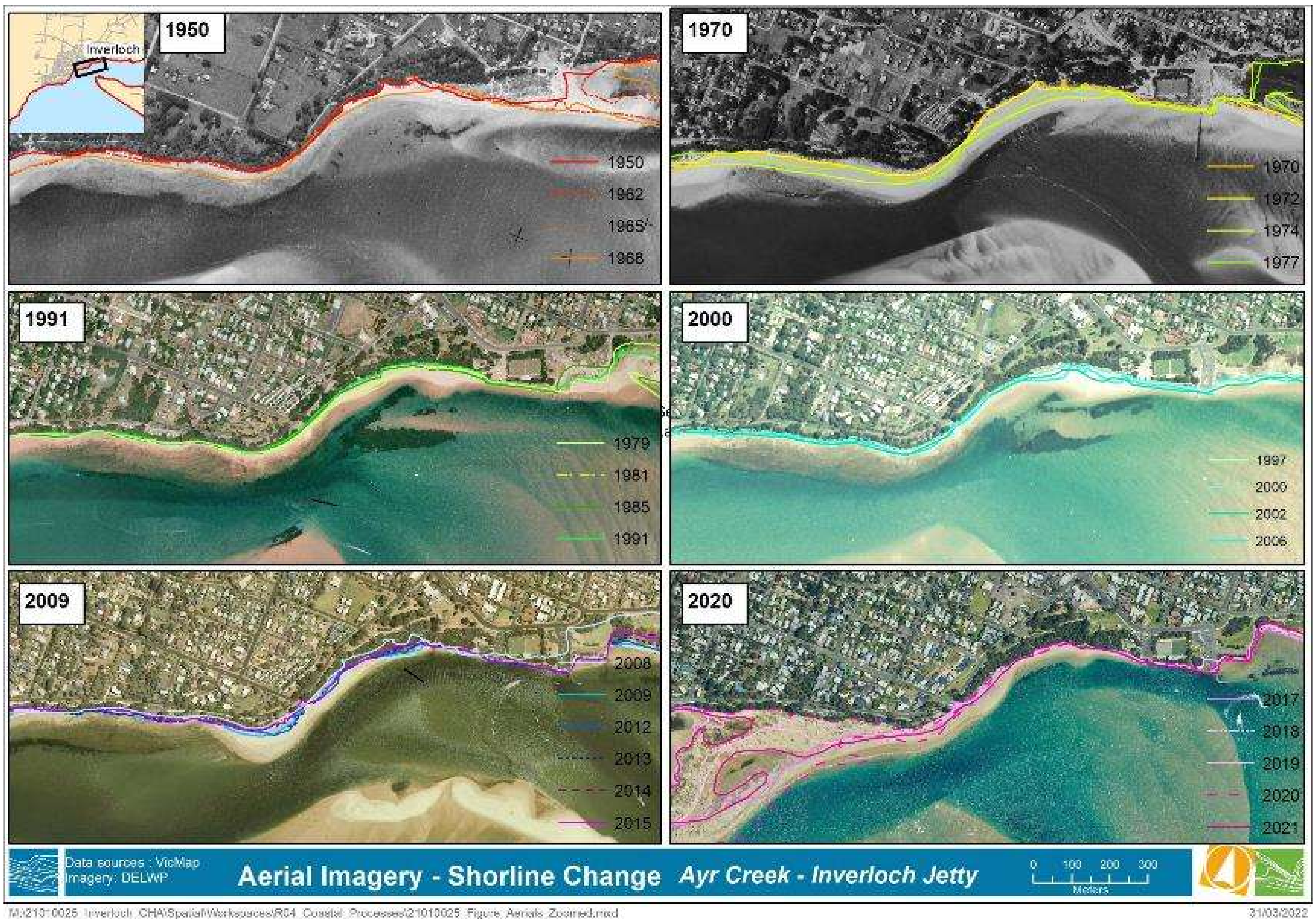


Figure 2-19 Shoreline Change, Ayr Creek – Inverloch Jetty

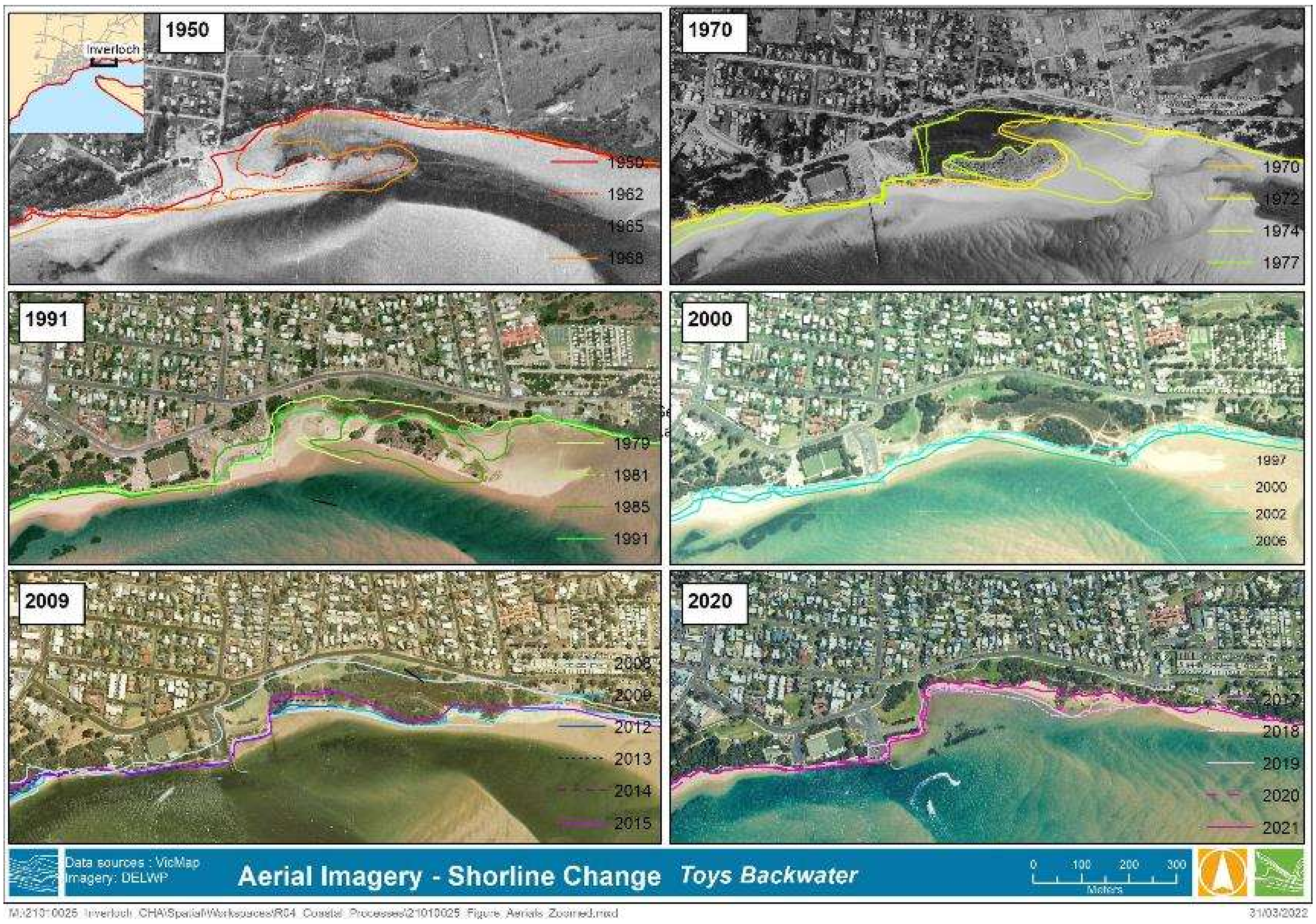


Figure 2-20 Shoreline Change, Toys Backwater

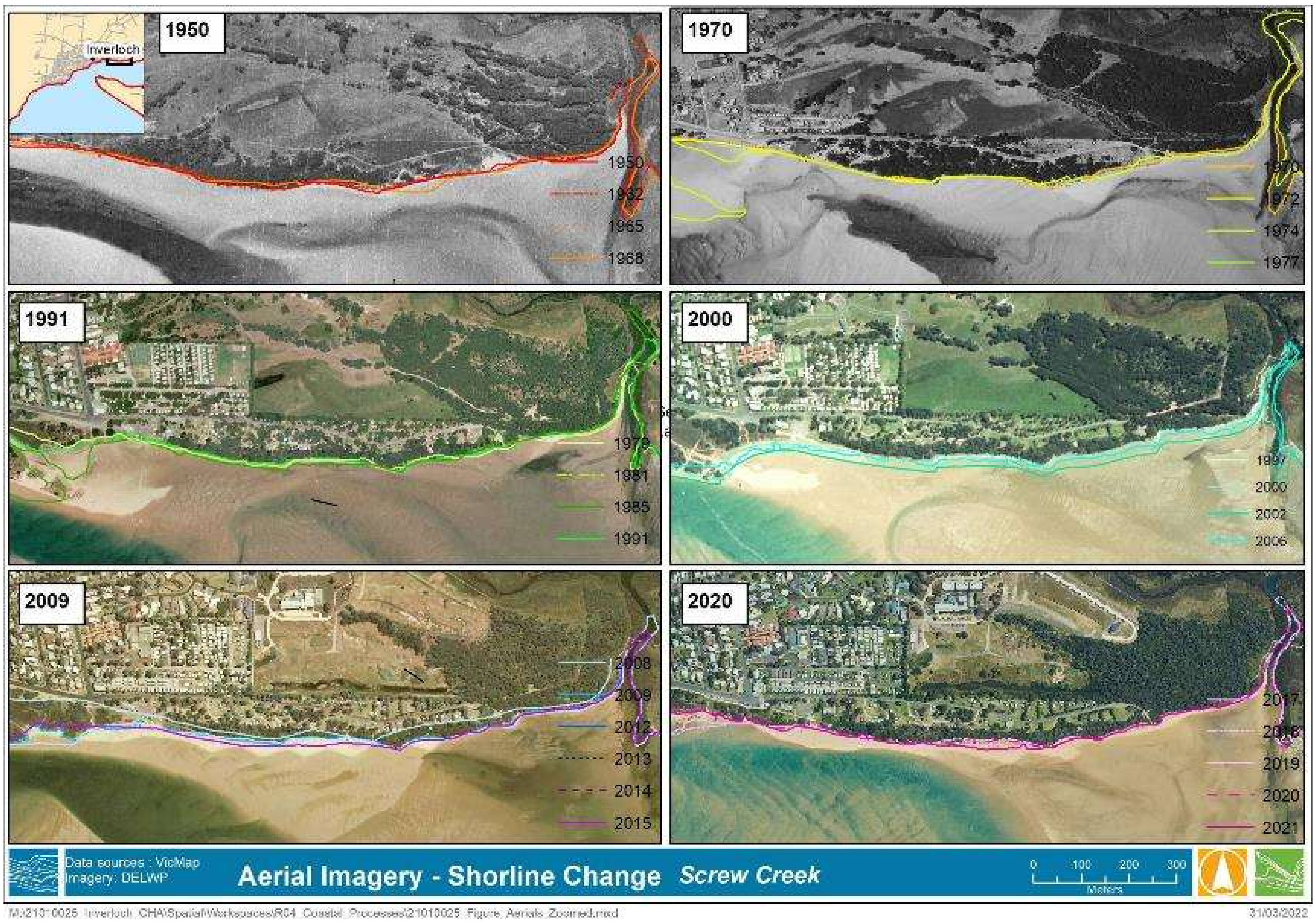


Figure 2-21 Shoreline Change, Screw Creek

Figure 2-22 Shoreline Change, Point Smythe

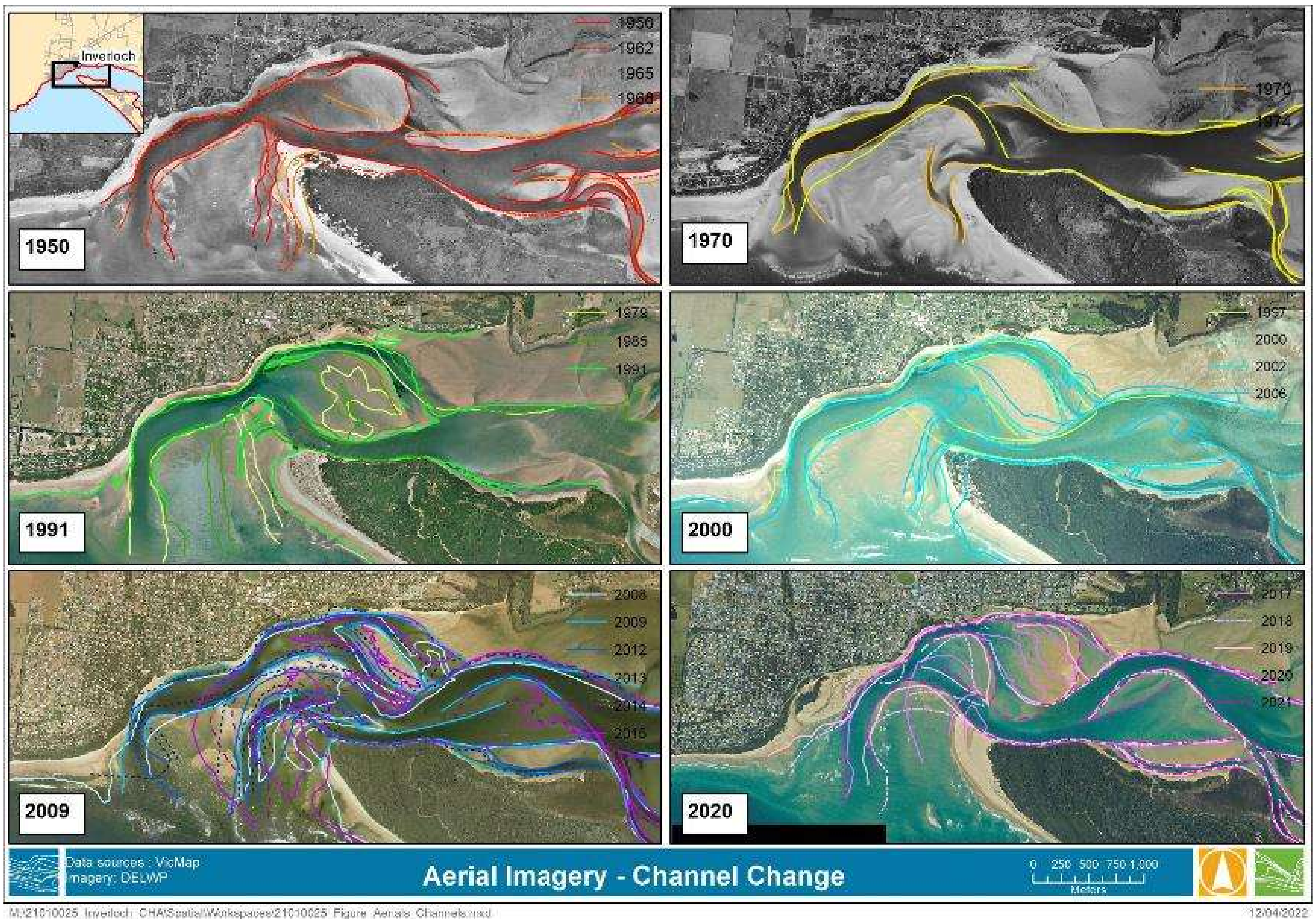


Figure 2-23 Channel Change, Entrance

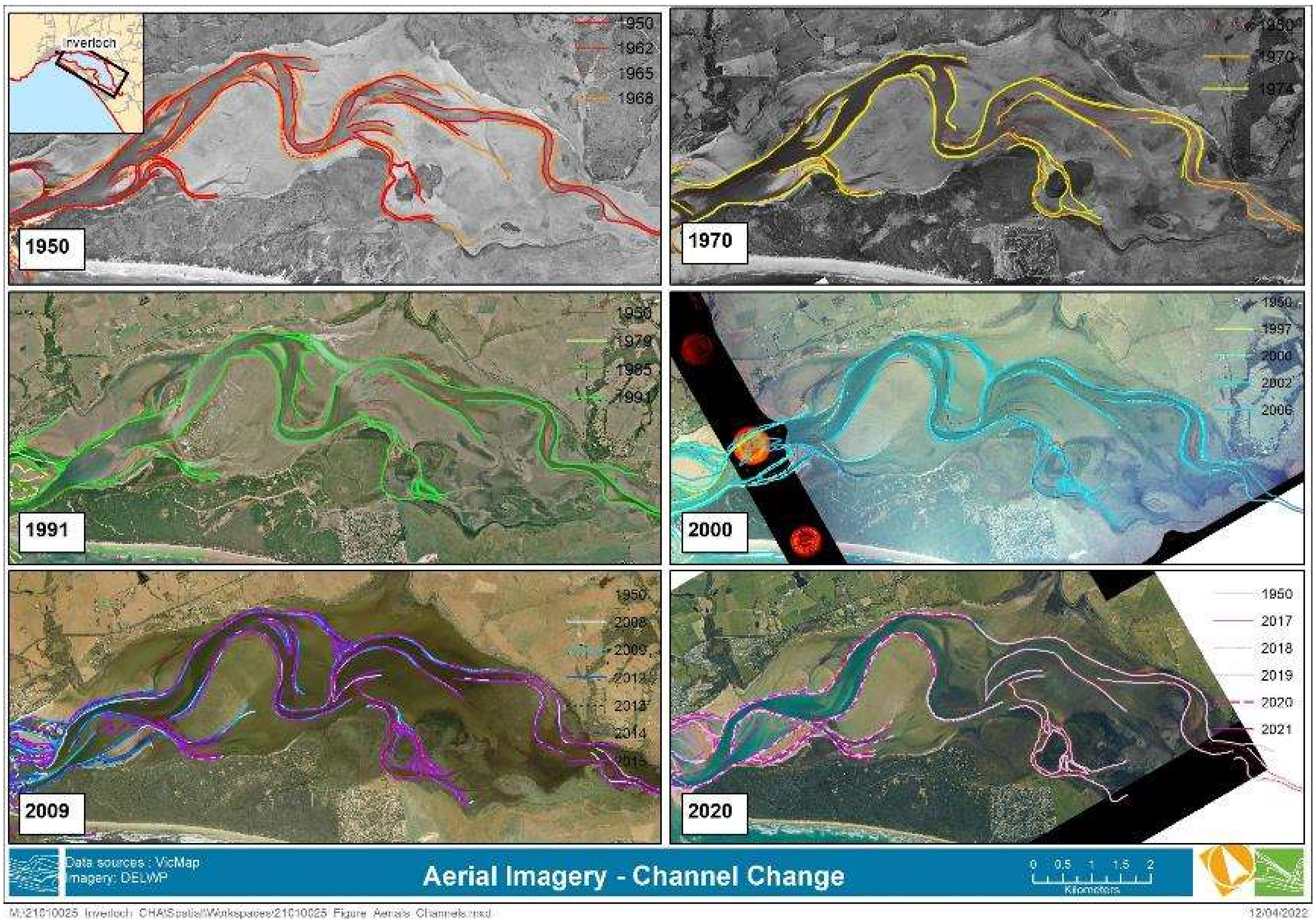


Figure 2-24 Channel Change, Anderson Inlet

2.1.5 Coastal Geomorphic Classification

Bringing together the understanding of geology and geomorphology together with more recent changes to inform the coastal hazard assessment the study area has been classified into coastal geomorphic sectors (CGS) and coastal geomorphic domains (CGD) by Environmental GeoSurveys as part of this project (Rosengren, 2021). Each CGS is defined by its backshore and shorezone (intertidal) landforms and materials, while the CGDs represent a reach of coastline with a limited and specific array of landforms and geomorphic processes. A brief overview of these classifications is provided herein, while further details and definitions are included in Appendix A with the full report from Environmental GeoSurveys.

2.1.5.1 Shoreline Sub-Classes (Coastal Geomorphic Sectors)

A coastal geomorphic sector (CGS) is a discrete length of coast that comprises a mappable unit with key differences to adjacent sectors. Within the recently released *Victoria's Resilient Coast - Coastal Hazards Extended Guideline* (DELWP, 2022), the coastal geomorphic section is referred to as the Shoreline Sub-Class, in recognition that the CGSs are grouped together to form Shoreline Classes. Lateral variation in one or more key characteristics of a shoreline sub-class / CGS defines the boundary between sectors. A differentiator between adjacent sectors is their response to coastal processes and how they respond to changed water levels and wave energy. Each sector comprises a description of the shoreline and backshore landforms, for example a sandy beach in front of a low coastal bluff or a shore platform at the base of hard rock cliff. Along the study area a total of 181 CGSs were defined.

Figure 2-25 Coastal Geomorphic Sectors of the Study Area

The approach to estimating coastal erosion hazards is based around the definitions of the CGSs. Estimates of erosion depend on the shoreline and backshore materials combined with the local oceanographic and/or catchment processes. Materials are classified as "hard" or "soft" as a qualitative measure of their resistance to these processes.

2.1.5.2 Shoreline Classes

As described in Appendix A, Rosengren (2021) combines several CGSs into more generalised units of "coastal geomorphic domain" (CGD) along the coastline. These groupings reflect locations where the oceanographic and/or catchment processes interacting with the landforms are the same along a section of the shoreline. However, the local response of the shoreline to these processes within each domain will vary depending on their CGS characteristics.

The CGS and CGD have been reviewed and five (5) Shoreline Classes have been derived to support the methodology for determining coastal erosion hazard (see Report 3). These five Shoreline Classes are consistent with those used in the *Victoria's Resilient Coast - Coastal Hazards Extended Guideline* (DELWP, 2022). The spatial extent of the shoreline classes is presented in Figure 2-26 and the proportion of the extent of each class within the Study Area shown in Table 2-3. The sandy shoreline class has been split to show the sandy shorelines exposed to the open ocean and the sandy shorelines where spit morphology and inlet processes dominate.

Figure 2-26 Shoreline Classes in Study Area

Table 2-3 Shoreline Classes in the Study Area

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

2.2 Coastal Bathymetry & Topography

The ocean and coastal bathymetry have a key influence on the coastal processes and drivers in the Study Area. The bathymetry, captured via a range of data sources is described in detail below.

2.2.1 Bass Strait / Open Coast

The bathymetry of Bass Strait is relatively shallow for an open coast, with the sunken plateau connecting Victoria and Tasmania limited to around 70-80m in depth. To the east and west of the plateau the edge of the continental seafloor drops to 5000m in depth.

Closer to the Study Area, the bathymetry along the South Gippsland coastline is dominated by a series of rocky outcrops at Cape Woolamai, Cape Paterson, Cape Liptrap and Wilsons Promontory which form crenulate bays in their lee. The nearshore slope from the coast descends relatively smoothly 10-15km offshore to the -70m AHD contour and floor of Bass Strait. Profiles of the Study Area open coast are presented with the bathymetry in Figure 2-27.

Southeast of Cape Paterson a shallow (to -20m AHD) uprising named Cody Banks extends the edge of the nearshore slope, and the surrounding seafloor is notably shallower with a wide shelf at -45 - -50m AHD extending from around 6km offshore for a further 6km.

The bathymetry profiles within Venus Bay show a variation in bathymetric profiles from convex at Cape Paterson in the west, flat offshore of the entrance to Anderson Inlet and concave in the east along the open sandy coastline to Cape Liptrap. Data from the GeoScience Australia 250m DEM has been used to understand the offshore bathymetry.

The topography around the Study Area is characterised by high cliffs to the west of Anderson Inlet, where the coastline reaches over 40m AHD within 300m of the shoreline. Through the entrance, the wide expanse of intertidal levels through the entrance gives way to higher ridges and the Screw Creek catchment. Across the upper Inlet the coastal dune peaks at 20m AHD in elevation before the wide Inlet and low tidal flats rise up to 40m AHD. South of the Inlet the coastal dune rises to 40m and the fluvial plains are around 20m AHD and further south the coastal dune is backed by a high plain which increases in elevation with latitude south.

2.2.2 Nearshore

The Victorian Government FutureCoast program collected high resolution bathymetry in 2008/09 which extends from the shoreline to around the -20m AHD contour. This data has been reviewed to provide context and information for the analysis of coastal hazards. The FutureCoast bathymetry in the Study Area is presented in Figure 2-28 along with cross shore profiles of the FutureCoast dataset.

Along the Bunurong Road coast the bathymetry is characterised by wide rock platforms 0 to -1m AHD extending up to 1km offshore and rock reef creating an irregular surface beyond the extent of the FutureCoast bathy. Some smooth sandy pocket beaches are present with sand perched on the rock reefs (Profile 1 & 2, Figure 2-28).

Between Flat Rocks and Point Norman the 2008/09 bathymetry (Profile 3) shows a step in the bathymetry between the inshore, broken wave zone, (>-1.5m AHD) and the nearshore, breaking wave zone, to -8m AHD where a small reef outcrops around 1km offshore and the seafloor slopes near lineally to -20m AHD.

The pattern of sand bars and rip channels is evident from Profile 4 east to Profile 7 along the Venus Bay open coast, typical of exposed ocean beaches. The depth between channels and bars can vary up to a meter and are visible in the bathymetry in depths between -0.5m AHD and -4m AHD. Beyond the nearshore zone the bed slope at Profile 4 is close to concave and extends close to 2.5km before reaching depths of -20m AHD. In contrast, the bed slope further from the entrance is much steeper with the -20m contour closer to 1km from the shoreline.

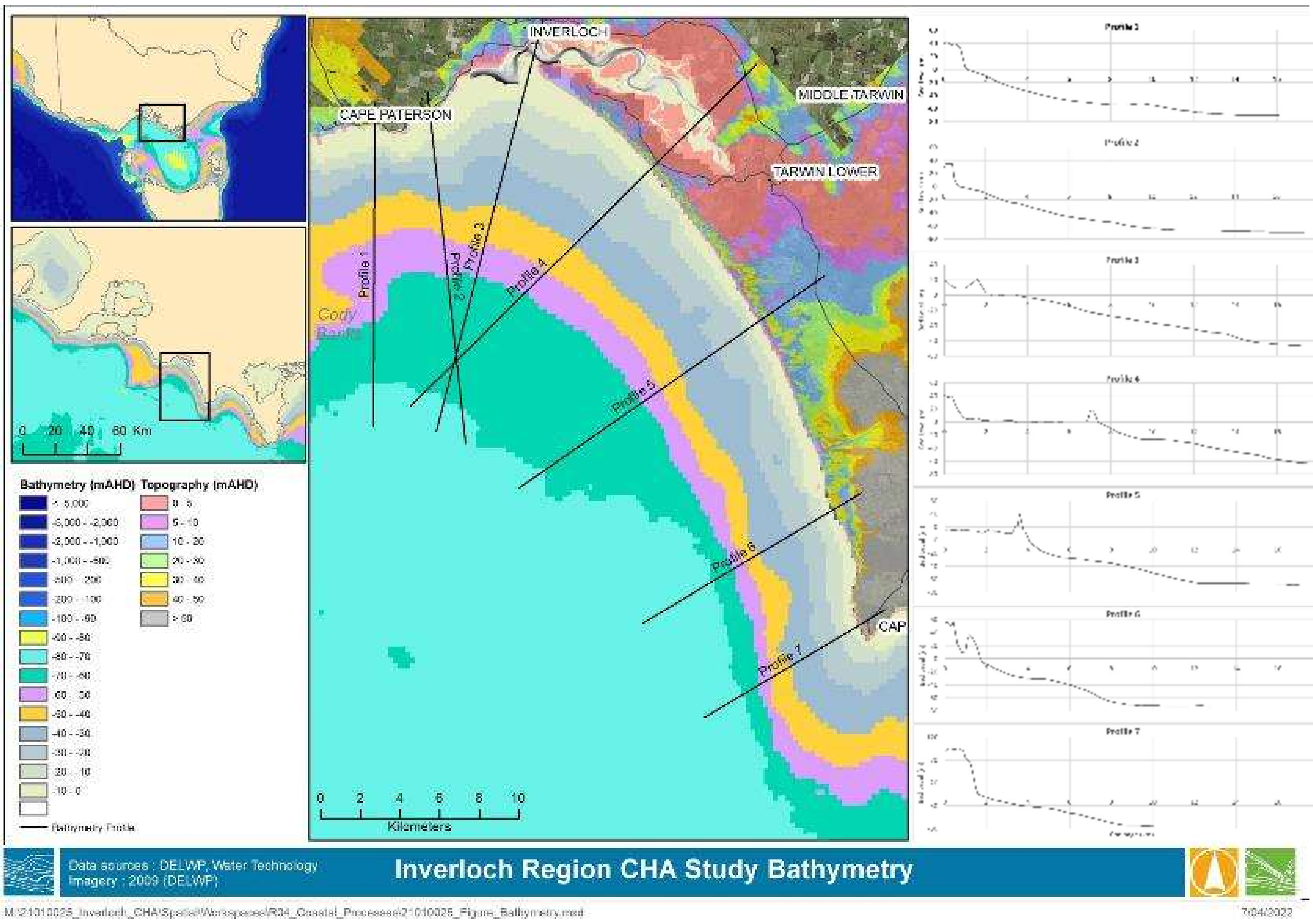


Figure 2-27 Bass Strait / Open Coast Bathymetry & Topography

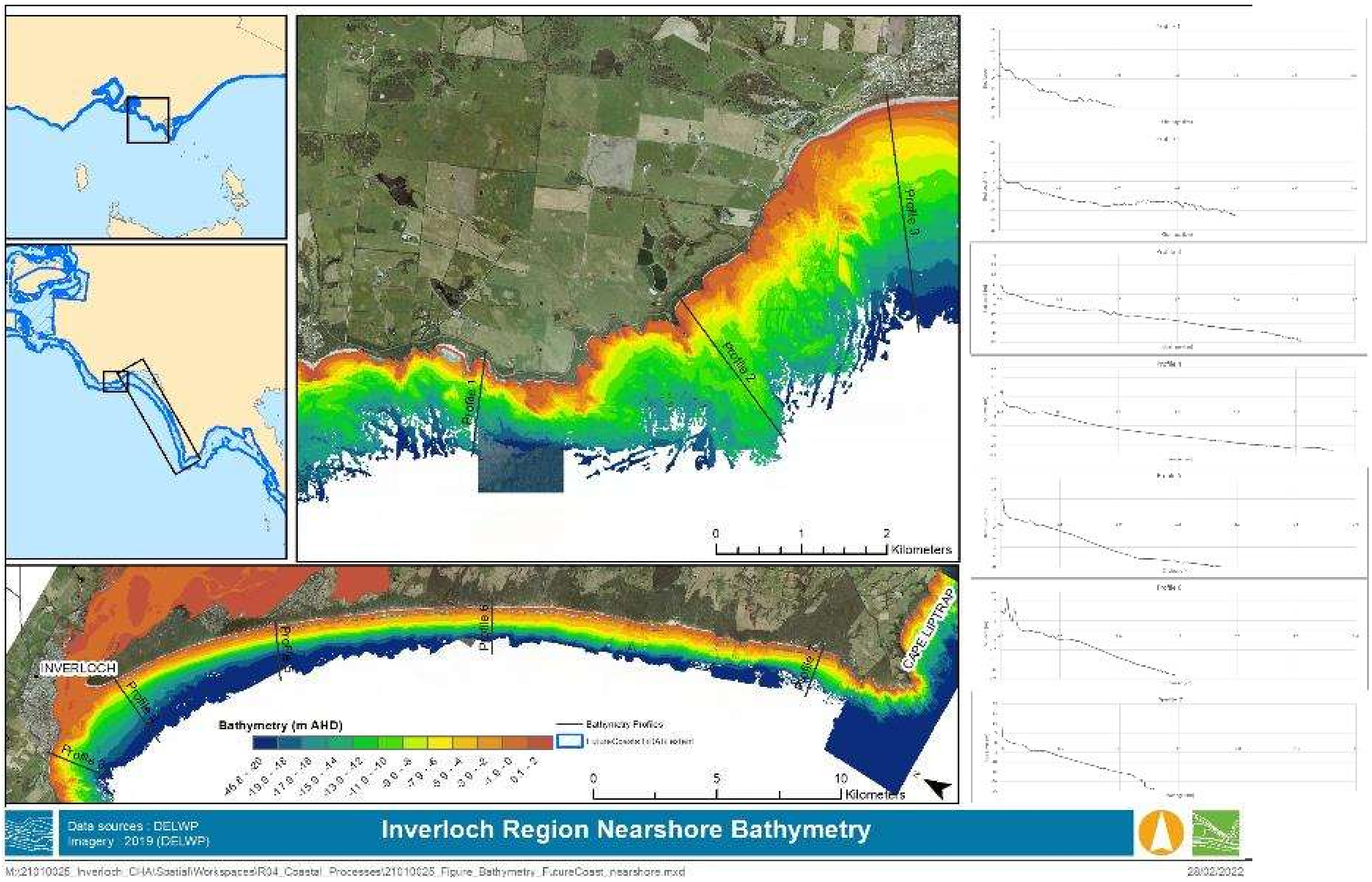


Figure 2-28 Study Area Nearshore Bathymetry

2.2.3 Entrance

The changes in the shoreline position and the position of sandbars within the entrance and main body of Anderson Inlet, observed over time through analysis of aerial imagery, were presented in Section 2.1.4. This section describes the changes below the water line, based on bathymetric survey of the entrance channels and sand bars. Data for this analysis was sourced from the FutureCoast dataset, survey from Gippsland Ports of the channels only, and via survey of the entrance for the current project, completed by Gippsland Ports in 2021.

The bathymetric surveys, and the bed level change between each survey from 2008/09 through 2021, are presented below in Figure 2-30 and Figure 2-31 respectively. The channel position varies widely between the two surveys. The minimum depth is between -2.0 and -2.5m AHD whilst the maximum depth is consistently deeper than -6.0m AHD. Some deep sections of the channel remain consistent, with tidal currents maintaining depths adjacent to the Inverloch boat ramp and along the northern side of Point Smythe.

The survey data collected in 2004 is of lower density and the surface generated is not as consistent with the later surveys (and thus not presented in Figure 2-30), however similar depths and location of these deep points are observed. Of note, the area of the deepest section of the channel adjacent to the Inverloch Jetty has remained constant since 2004, however the depth has increased notably (from -4m AHD in 2004 to -10m AHD in 2020) and the width of the channel has increased allowing deeper water nearer to the boat ramp. At the toe of the boat ramp in 2004 the depth was in the order of -1m AHD compared with -4.5m AHD in 2020.

The evolution of the main flow channel can be observed in the aerial imagery presented above in Figure 2-23, and the surveyed bathymetry shown in Figure 2-30. The main channel is noted to be south of the boat ramp bar in 2004, shifting to adjacent to the boat ramp in the FutureCoast 2008/09 survey, cutting through the western edge of the boat ramp bar in 2013, migrating north towards the ramp in 2016 and 2017 and increasing in depth through 2019 and 2020.

Along with the spatial shift across the entrance, the change in channel depth and width through the entrance varies as shown in Figure 2-29. Cross sections have been extracted at 3 locations through the entrance from the 2008/09 and the 2021 surveys to establish the cross-sectional flow area for the spring and neap tides as presented in Table 2-4.

The centre of the channel, between Miller Terrace in Inverloch and Point Smythe, notably restricts the volume of water able to flow through the entrance during the change in tide. Change in the central cross-sectional area are presented in Table 2-4; the increase in volume at the outer and inner entrance commensurate with the loss of material shown in Table 2-5, and the decrease of flow area in the central entrance area also reflective of the gain of material in this zone (again noted in Table 2-5).

The maximum bed level of the channel between Point Norman and Point Smythe of -2.0 – -2.5m AHD indicates the entrance always maintains a flowing channel, and at least 1.0 – 1.5m water depth could be expected on all tides given the lowest astronomical tide (LAT) at Inverloch Jetty is -0.84m AHD (Table 2-6). The actual depth of water may be lower however, as it is noted that the LAT derived from the model hindcast is -1.66m AHD and the lowest modelled water level within Venus Bay was -2.07m AHD. In these rare events flow may be limited more significantly within the channel, albeit for a short period of time.

On the seaward side of the entrance sand bar the bathymetry rises rapidly from -15m AHD to around -3m AHD. All surveys show an outer bar offshore at -3m AHD to -4m AHD which is followed on the Inlet side parallel with the entrance by a trough 0.5-1.0m deeper (i.e. -3.5 to -5m AHD). The bed of the main combined ebb and flood tidal channel then slopes upwards into the entrance to a maximum elevation of less than -2.0m AHD at the crest of the entrance bar then slopes away as it meanders through the entrance.

The ebb tide delta which forms at the entrance can be quite prominent. In the FutureCoast 2008/09 survey, it extends some 200m seaward of the nearby toe of the sand bar; or can be distributed more widely such as shown in the 2013 and 2021 survey where the toe of the delta is less than half the distance from the adjacent toe of the bar.

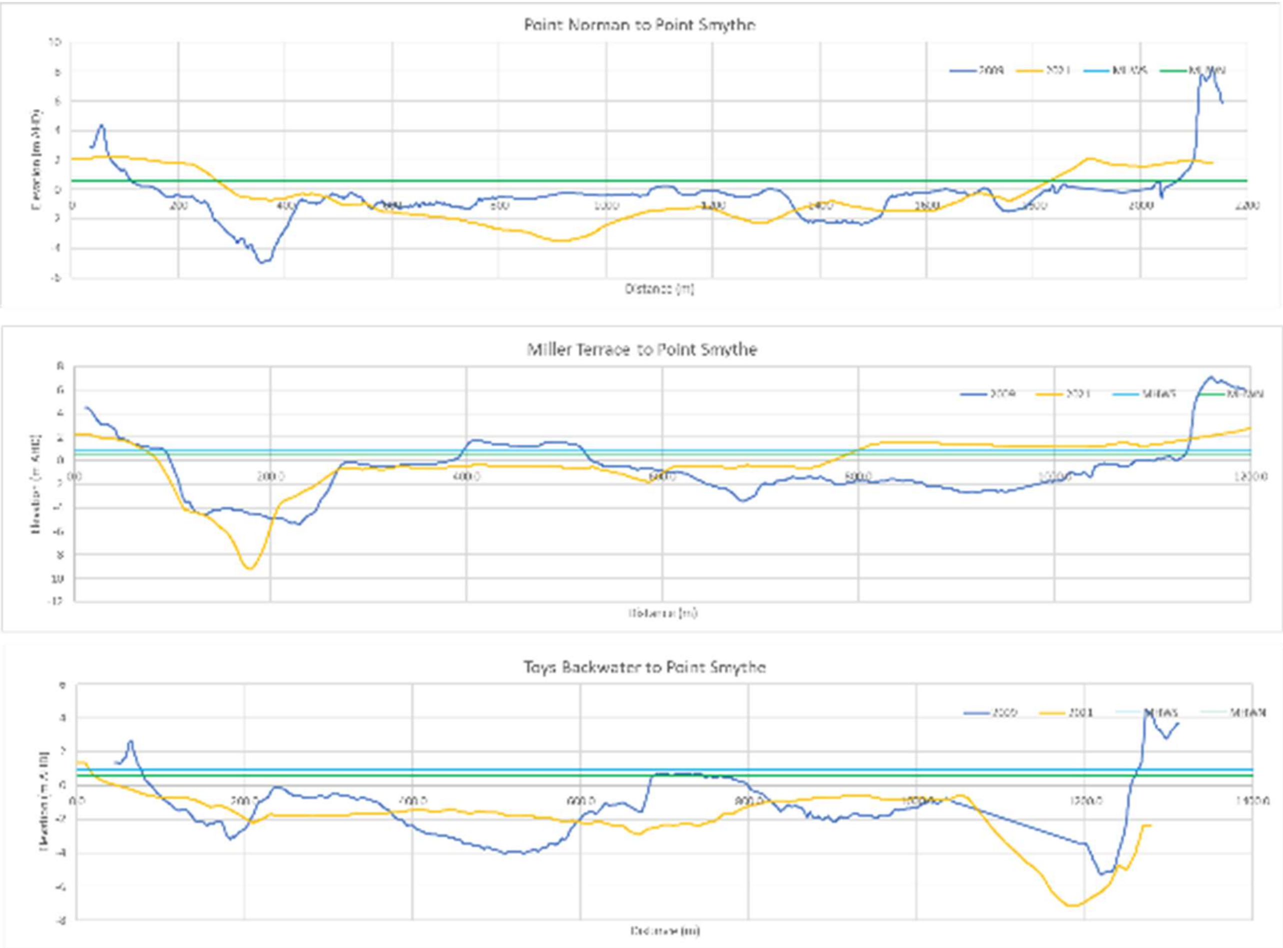


Figure 2-29 Entrance Cross Sections (looking upstream), 2009 v 2021

Table 2-4 Cross Sectional Flow Area – Entrance (m^2)

Profile	2008/09 Bathymetry	2021 Bathymetry
Spring Tide (below MHWS)		
1 – Point Norman to Point Smythe	3,300 m^2	3,700 m^2
2 – Miller Terrace to Point Smythe	2,400 m^2	1,800 m^2
3 – Inverloch Boat Ramp to Point Smythe	2,700 m^2	3,700 m^2
Neap Tide (below MHWN)		
1 – Point Norman to Point Smythe	2,600 m^2	3,100 m^2
2 – Miller Terrace to Point Smythe	2,000 m^2	1,500 m^2
3 – Inverloch Boat Ramp to Point Smythe	2,300 m^2	3,200 m^2

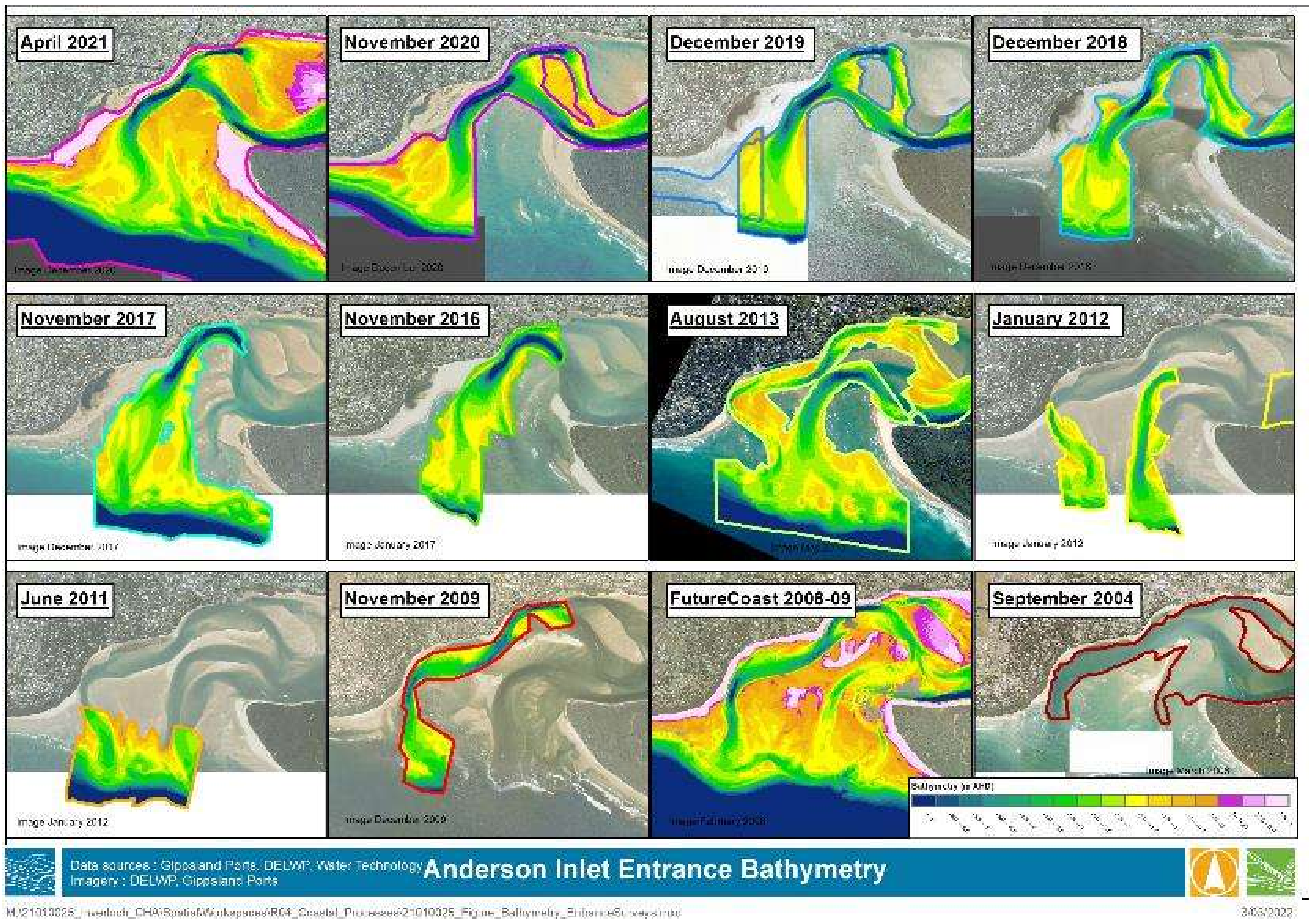


Figure 2-30 Bathymetric Survey of the entrance to Anderson Inlet

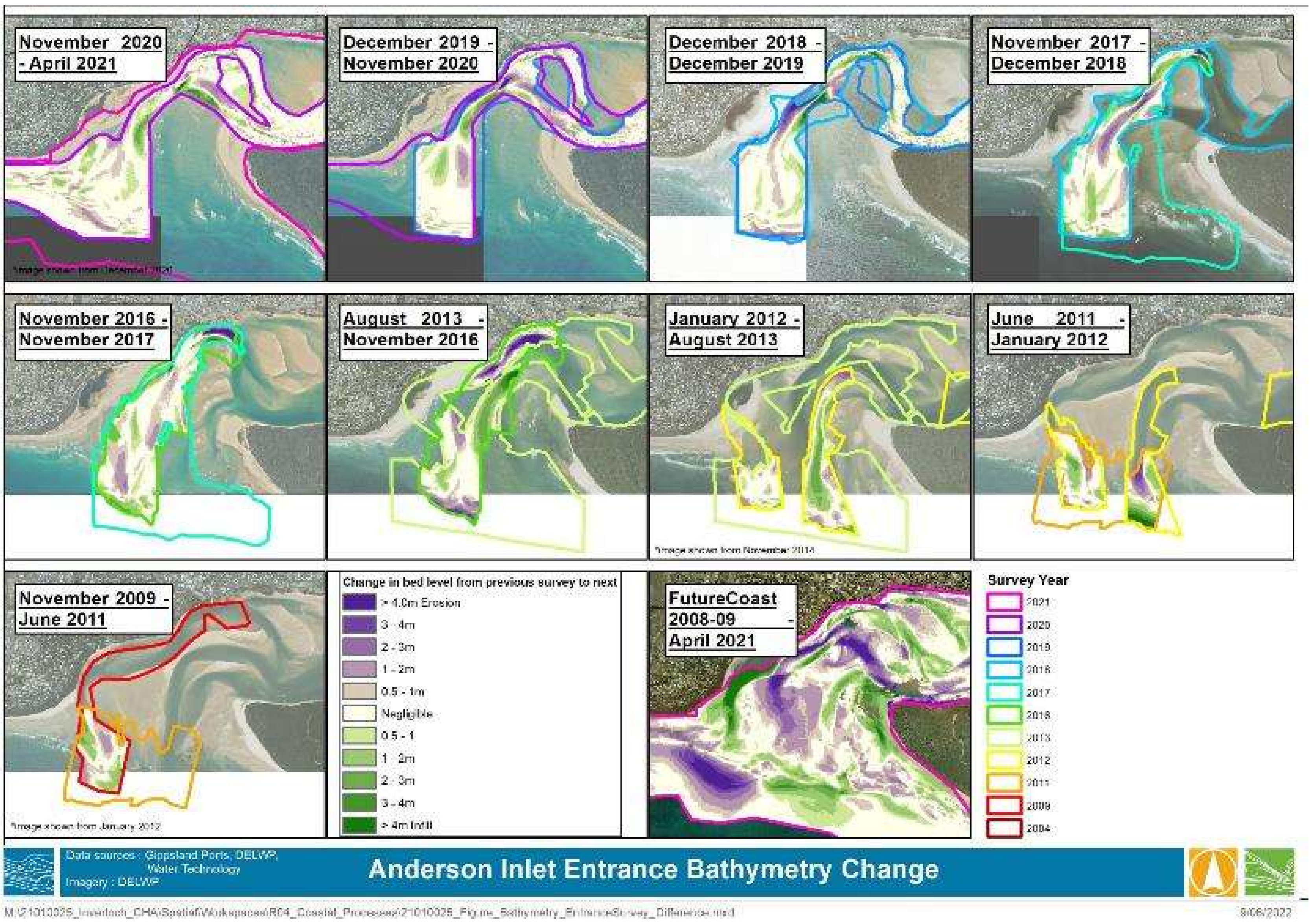


Figure 2-31 Bed level change between survey of the entrance to Anderson Inlet

2.2.3.1 Entrance Volume Change

As shown in Figure 2-30, the most expansive coverage of the entrance bathymetry has been captured in the FutureCoast data of 2009 and the bathymetry and topography collected for this project in 2021. As detailed in the preceding sections, there are many drivers of coastal processes within the entrance, and with only two (almost) complete datasets available over the 12 years it is not possible to define the influence of an individual driver. However, the change through the entrance over this period is significant and an assessment of the different volumes of sand through the entrance over time is informative and assists our understanding of the drivers and consequences of change.

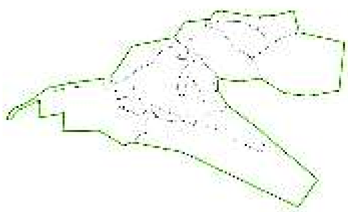
The total volume of change in the entrance and adjacent coastline from 2009 to 2021 (12 years) is a **net loss of 1,755,000 m^3**. Whilst this is a significant volume of sand, across the 11,820,000 m^2 of surveyed entrance and adjacent coastline it equates to an average change of only 0.15m decrease per square meter across the entrance area. The localised depth change varies considerably, and ranges from -10m (erosion) to +10m (deposition) as the entrance channel moves position within the broader entrance area as presented in Figure 2-32.

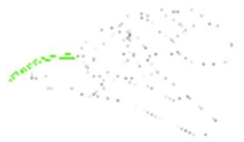
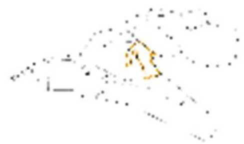
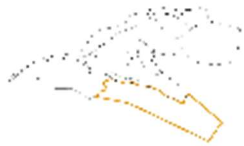
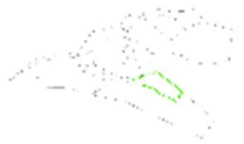
The change in sand volumes across different areas of the entrance and nearshore have been further broken down into the sectors shown in Figure 2-32 and are presented in Table 2-5.

Key points to note include:

- The entrance is not in balance:
  - There is significant net loss of 1.755M m^3 of material from 2009 to 2021 in the overlapping survey area.
  - Losses offshore at Surf Beach, old delta channel and the entrance exceed the gain at the Ayr Creek lagoon by close to 400,000 m^3.
- There is a shift in material offshore from west of the entrance to the east of the entrance.
- Th volume of sand mid-entrance has increased, however the sand appears to have moved to either side of the channel whilst the centre/main flow path has lost sediment.
- The volume of sand inside the entrance has reduced, most notably in the regular flow channels with small increases on the shore at Screw Creek.
- Loss of material from Toys Backwater is in balance with gains in the offshore bar and at Screw Creek, however not with the main channel path upstream and downstream of these bars.

Table 2-5 Volumetric Change in Entrance (2009 to 2021)

Area of Entrance	Volume Change (m^3)		Area of Entrance	Volume Change (m^3)	
Full	-1,755,000				

Area of Entrance	Volume Change (m^3)		Area of Entrance	Volume Change (m^3)	
Offshore west (Surf Beach)	-2,150,000		Outer Entrance Bar & Channels	+840,000	
Offshore east (Point Smythe)	+715,000		Inner Entrance Bar & Channels	-1,135,000	
Surf Beach	-315,000		Point Smythe bar	+590,000	
Surf Beach offshore & 2009 delta	-1,835,000		Point Smythe 2009 vegetation	-45,000	
Point Smythe offshore	+775,000		Entrance u/s Miller Terrace/Point Smythe	-645,000	
Point Smythe onshore	-60,000		Toys Backwater	-85,000	
Entrance delta bar	+450,000		Boat ramp / Toys Backwater bar	+75,000	
Ayr Ck Lagoon	+1,100,000		Screw Ck intertidal bank	+10,000	
Entrance d/s Miller Terrace/Poin t Smythe	-1,205,000		Upstream Screw Creek	-490,000	

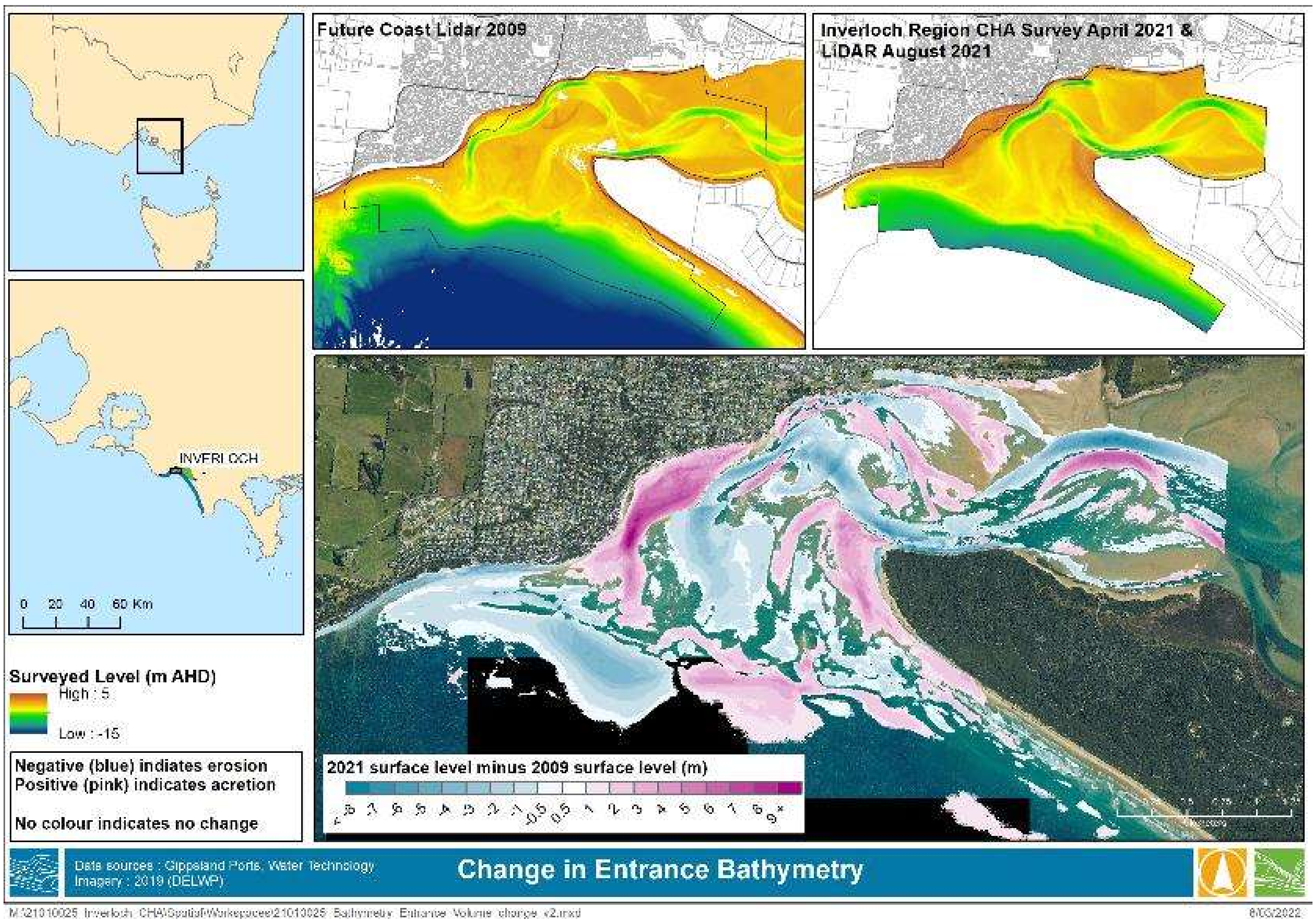


Figure 2-32 Depth of change in entrance (2009 to 2021)

2.2.4 Surf Beach

Survey data of the "Surf Beach", between Flat Rocks and Point Norman, has been captured in recent times to measure the rapid coastal recession observed since 2012. Topographic LiDAR provides the most accurate datasets and has been captured in late 2008 to early 2009 (herein referred to as the 2008/09 survey) and August 2021. The 2021 LiDAR capture is limited in width across the beach profile, however field survey (collected using a combination of amphibious vehicle and jet ski mounted single beam survey equipment) captured by Gippsland Ports for the project in April 2021 has been combined with the August 2021 LiDAR to generate a beach surface for comparison, as shown in Figure 2-33 and in profiles presented in Figure 2-34.

In addition to these survey datasets, photogrammetry has been captured as part of the VCMP Citizen Science project. Profiles data from the VCMP project at Profile 7, across the Surf Life Saving Club building is presented in Figure 2-35. The South Gippsland Conservation Society (SGCS) has also been collecting laser survey of the beach at set cross-shore profile locations.

Volumetric analysis of the difference between 2021 and 2008/09 surveys indicate a loss of beach and dune material in the order of 300,000 m^3 over a length of 2,300m (Table 2-5). The depth change, which illustrates the magnitude of sand loss, is presented in Figure 2-33.

The height of dune loss can exceed 8m where the crest of the dune has been eroded, for example just east of the SLSC where dunes more than +10m AHD in height in 2008/09 are no longer present. The majority of the beach has been lowered at least 1m with approximately 80% of the beach lowering more than 1m, 70% more than 2m, 50% more than 3m and 30% eroding more than 4m in depth. This is a notable loss in sediment on the beach face and has resulted in a large displacement of the shoreline as described in Section 2.1.4.

The ongoing photogrammetry captured on Surf Beach through the VCMP during 2021 and into 2022 has shown some recovery of beach levels following the significant lowering of the beach level and recession of the coastal dune through 2019. The seasonal pattern of beach construction during the calmer summer months and erosion during the stormier winter months (Section 2.3.3.3) is also observed in the more frequent VCMP dataset.

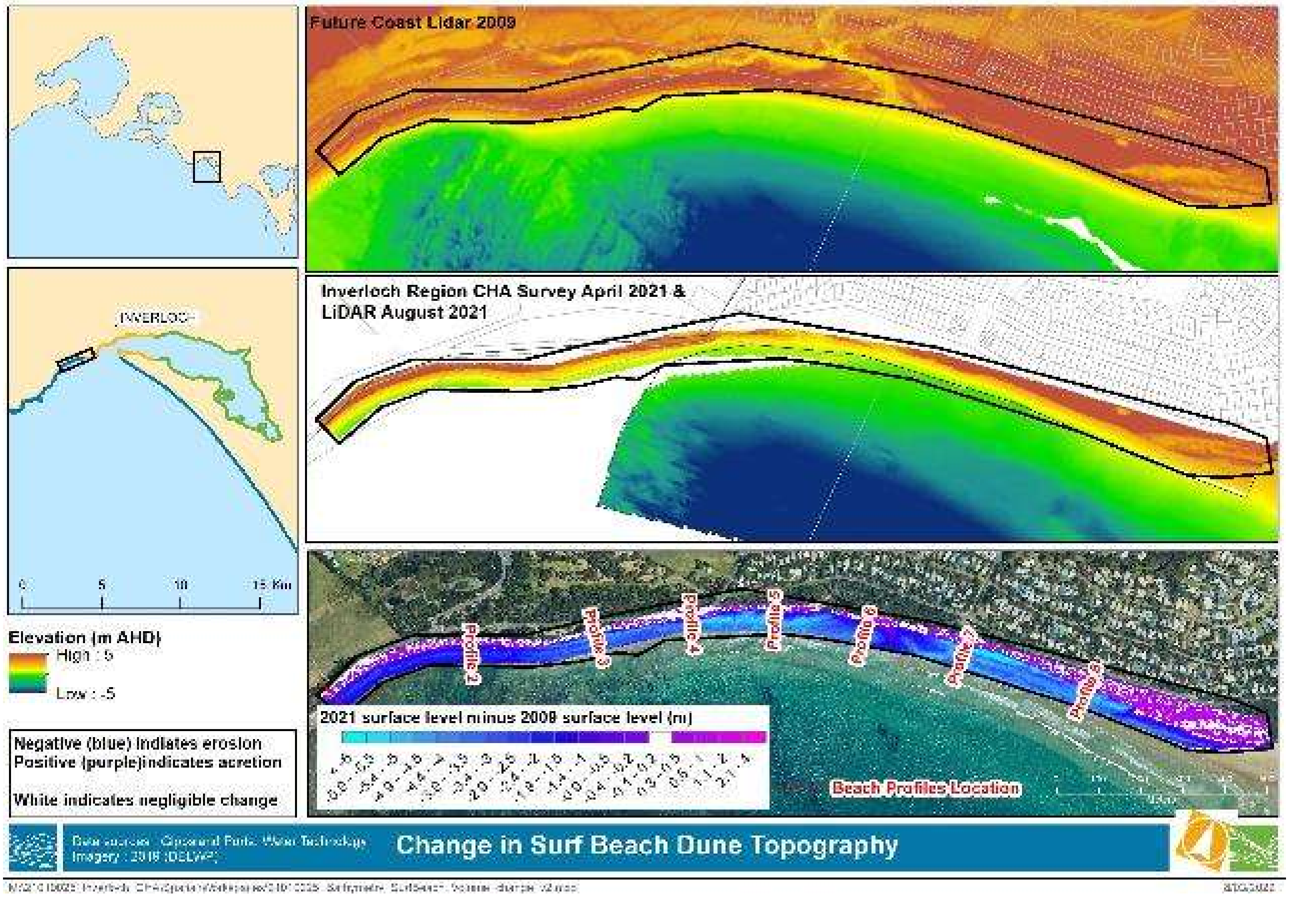


Figure 2-33 Surf Beach Topographic Survey

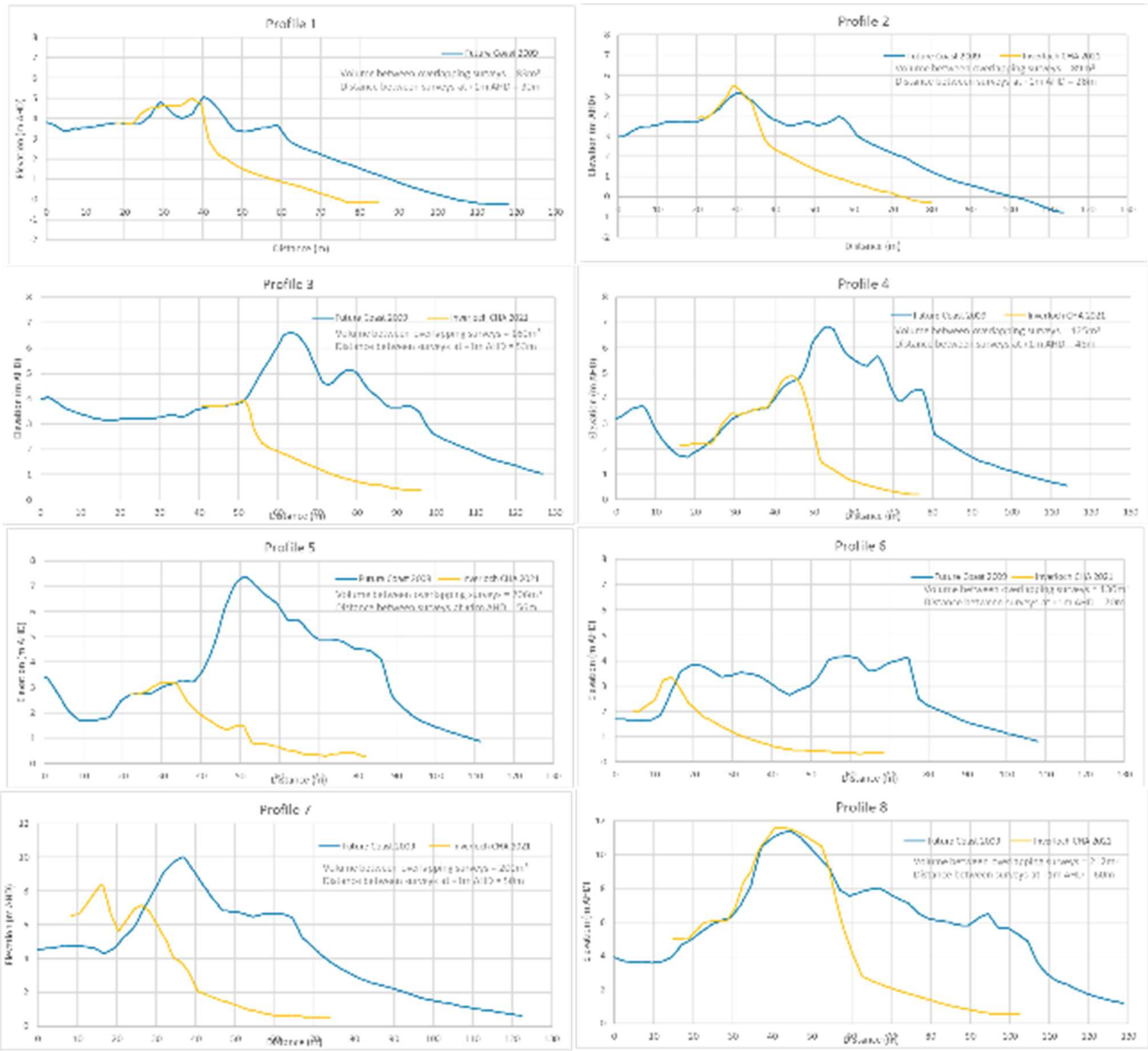


Figure 2-34 Surf Beach LiDAR Cross-sections

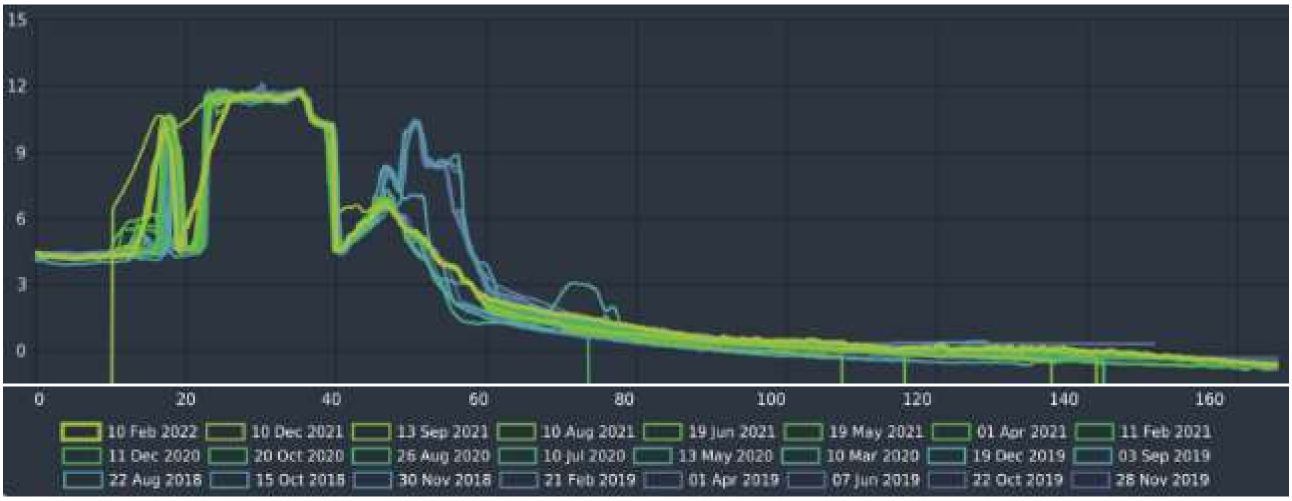


Figure 2-35 Surf Beach Photogrammetry Beach Profiles (Propeller portal extraction, 2022)

2.2.5 Anderson Inlet

As described in Section 2.1.2, Anderson Inlet has been the focus of agriculture and transport since the late 1800s. First survey of the channels through Anderson Inlet was completed in 1868 showing fathoms below spring low tides. Depths in the surveyed channel range from generally 1/4 to 2 fathoms (0.45 to 3.6m). Survey continued through the late 1800s and the early 1900s with the last historical survey captured in 1910 covering the entrance area only. Survey from 1898 show similar levels to those recorded 30 years prior.

The next known survey was captured in 1979 and 1981 respectively by the Victorian Regional Channels Authority. The bathymetric surveys include the entrance (1979) and the channels of Anderson Inlet (1981), the later showing depths comparable with the earlier survey from the mouth of the Tarwin River to the mid-entrance point between Miller Terrace and Point Smythe. The entrance survey captures the land above MHWL in Toys Backwater, a "sand plug" at Ayr Creek and extends offshore to depths of close to -10m AHD. The depths captured by the Victorian Regional Channels Authority survey are similar to depths within the channel in preceding and subsequent surveys, noting channel alignment has changed from the 1910 survey.

The first known, and potentially only, complete and high resolution capture of Anderson Inlet channel and the tidal plains is the Future Coast dataset of 2008/09. This dataset contains some gaps where turbidity or reflection have prevented data from being recorded, especially in the channel in the upper reaches of the Inlet, however the majority of the Inlet and small islands within the Inlet, are captured. This bathymetry, and a long section along the channel centreline (or thalweg) is presented in Figure 2-36.

The gradual incline in the base of the channel can be seen in the long section along with the sharp change in bed level due to bars and troughs formed through tidal pumping. The channel shows evidence of flood and ebb tide forces, as presented in Figure 2-36, which extend into the inlet as far as Venus Bay Settlement 1. Sections of the bathymetry are missing towards the mouth of the Tarwin River.

The survey captured by Gippsland Ports in November of 2020 is presented, along with the thalweg bathymetry, in Figure 2-37. The channel thalwegs are difficult to compare directly as the distance along the channel varies with the length of the meander. Black and red dots on the bathymetries from 2008/09 and 2020 respectively indicate 2km distances along the channel. The change in the entrance channel configuration noted in Section 2.1.4 can be seen in the location of the black and red dots in the breakout box of the 2008/09 survey. This breakout box also highlights the different channel processes at play – the flood tide channels flowing into the entrance and losing some momentum, resulting in settling of sediment, and the ebb tide channel similarly reaching a point where low flow results in sediment settling to the bottom. A similar point of tidal flow direction and channel change is shown in the 2020 bathymetry adjacent to the Mahers Landing boat ramp.

The thalweg long section shows these features as the steep changes in the bathymetry, prominent in the entrance in both surveys as the channel changes from flood to ebb tide dominant. Upstream of Townsend Bluff (around 5km) the channels show less change between the surveys (noting the gaps present in the 2008/09 data, starting at around 8km) and the location of the troughs and bars is similar. Bed levels within the channel upstream of Pound Creek (14km) are limited to greater than -3m AHD, increasing to no less than -2m AHD at 17km at the mouth of the Tarwin River. Survey from the 2008/09 LiDAR is incomplete here due to high turbidity within the river, however the recent bathymetric survey, collected with single-beam echosounder provides better data through the fresh and brackish water and shows the shallow water at the river mouth extents for around 3km before depths increase notably in the Tarwin River upstream of the connection to Anderson Inlet.

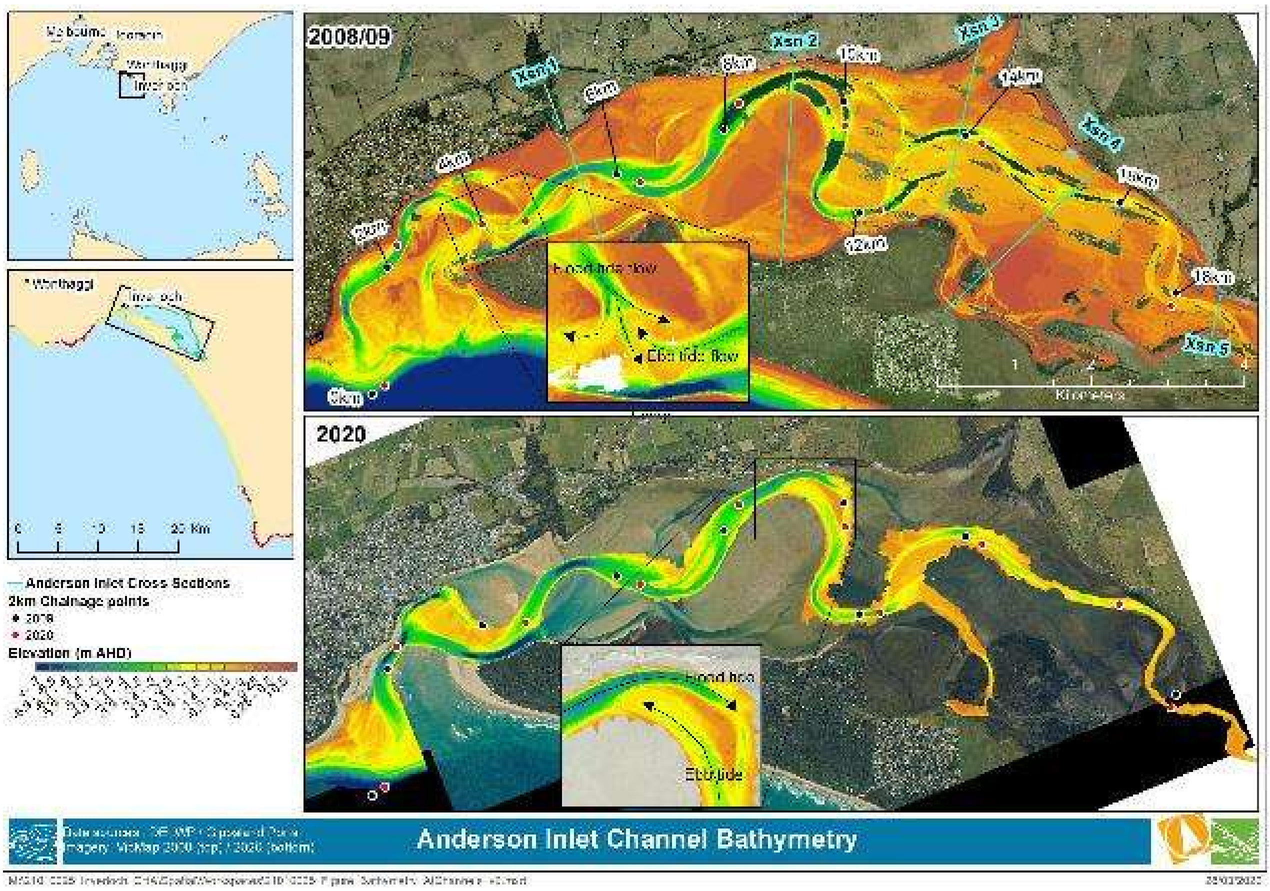


Figure 2-36 Anderson Inlet Bathymetry – 2008/09 v 2020

Figure 2-37 Anderson Inlet Channel Thalweg Bathymetry – 2008/09 v 2020

Accurate information regarding the level of the sand bars and intertidal areas within Anderson Inlet is unfortunately limited to the 2008/09 data upstream of Townsend Bluff. Comparison between the 2008/09 and 2021 survey of the entrance shows the higher sandbars at Screw Creek and on the opposite bank adjacent to Point Smythe have shown little (between -0.5m and +0.5m) change across the 12 year period. The channels shifted significantly and the area upstream of Screw Creek with overlapping bathymetries indicated a net loss of close to 500,000m^3, primarily through movement and deepening of the tidal channel.

Cross sections showing bathymetry variation across the width of the Inlet are presented in Figure 2-38 for the locations noted in Figure 2-36. As noted, the data is only available for the earlier 2008/09 survey. The cross sections show the elevation of sand bars and intertidal areas remains low within the estuary, only increasing above +0.5m AHD in the upper extent of the estuary around Venus Bay Settlement 1 and at the mouth of the Tarwin River. The single channel is a major feature in the cross section, with minor secondary channels evident along the southern side of the Inlet (right hand side of the chart). The width of the channel remains relatively constant at ~170m, narrowing only slightly to 150m at the mouth of the Tarwin River. Consistent with the profile in Figure 2-37 depths of the channel decrease from -6m AHD at Cross Section 1 to -1.5m AHD at the mouth of the Tarwin (Cross Section 5), noting the patchiness of the data in this area described above.

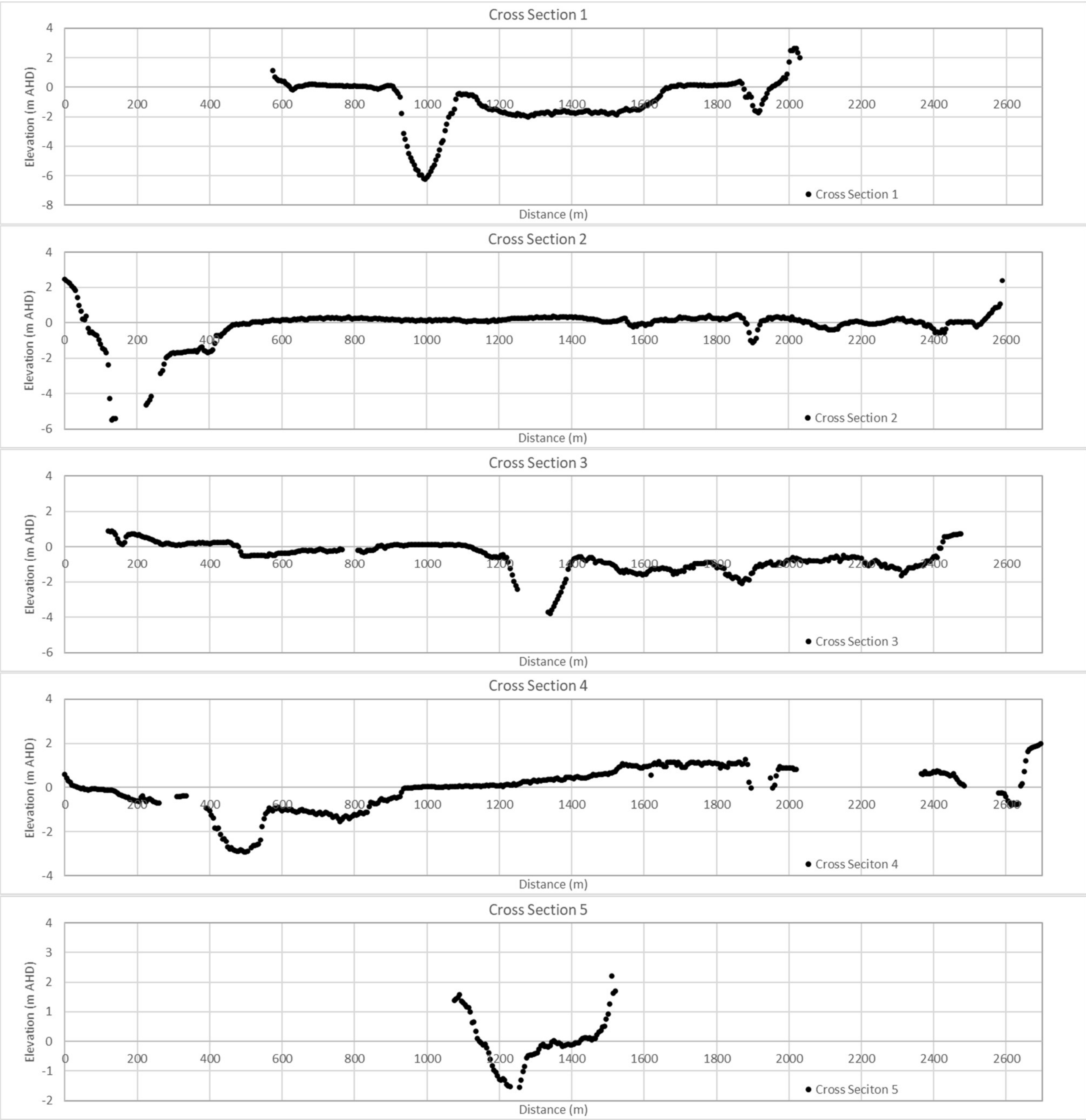


Figure 2-38 Anderson Inlet Bathymetry Cross Sections

2.3 Metocean Conditions

The magnitude, frequency and variability of the main oceanographic and meteorological processes that influence the Cape to Cape region have been analysed and reviewed. The physical oceanographic and meteorological processes of Bass Strait have strongly influenced the late evolution and contemporary coastal processes of Venus Bay and Anderson Inlet. Review and analysis of these processes provides the foundation for understanding historical coastal change. This in turn enables the assessment of potential coastal hazards, existing and future, along the Study Area coastline through this century.

2.3.1 Water Levels

The water level experienced along the coast is the sum of a number of factors in the Study Area, with water level variation driven by Astronomical Tides, atmospheric pressure, wind and wave setup, coastally trapped waves and catchment runoff. Each of these have been reviewed for the Study Area and are described below. Measured coastal water levels within the Study Area or nearby is available for analysis as described in Table 2-6, also noted in Report 2 – Gap Analysis.

Table 2-6 Measured Water Level Data

Location	Source	Data Period, frequency
Stony Point (Western Port)	BoM	December 1992 – ongoing, hourly
Inverloch Jetty	Gippsland Ports Water Technology	14/05/2020 – ongoing, 6 minutes 19/08/2004 – 10/10/2004, 6 minutes
Tarwin River	Gippsland Ports Water Technology	16/12/2020 – ongoing, 6 minutes 19/08/2004 – 10/10/2004, 6 minutes
Venus Bay Jetty	Water Technology	19/08/2004 – 10/10/2004, 6 minutes
Screw Creek	Water Technology	03/09/2004 – 10/10/2004, 6 minutes
Waratah Bay	BoM	1954, less than 30 days (used to generate tidal constituent in ANTT)

2.3.1.1 Astronomical Tides

The regular and predictable rising and lowering of ocean and coastal water levels is referred to as *tidal water level variations* (or tides). Astronomical tides are driven by the gravitational forces of the moon and sun couled with the centrifugal forces associated with the rotation of the earth around the sun and the moon around the earth. These forces cause water to move around the earth in a “wave” where the crest of the wave is the high tide.

Tidal water level variations within Bass Strait, and thus Venus Bay, are driven by the wave of tidal water movement flowing around the Southern Ocean to the west and south, and the Tasman Sea to the east. These two separate tidal waves flow across the shallow bridge of Bass Strait between Victoria and Tasmania, meeting in the area south of Waratah Bay in the centre of Bass Strait. Tidal amplitudes within Bass Strait where the waves meet are notably higher than those experienced along the western and eastern coasts of Victoria, with the spring tidal amplitude increasing to over 3.0m along the northern coast of Tasmania and within the study area between Cape Paterson and Wilsons Promontory (top and bottom left, Figure 2-39). The tidal range outside of Bass Strait is limited to less than 1.5m.

The meeting of the Southern Ocean and Tasman Sea tidal waves, and the high tidal amplitude within the study area, also coincides with an area of low tidal currents as the opposing waves come together. Tidal currents within Bass Strait peak through the narrower passes to the north and south of the King and Flinders Island groups (top and bottom right, Figure 2-39). The data shown has been sourced from Australia’s Integrated Marine Observing System (IMOS) *Ocean Current Portal* (IMOS, 2022). The low tidal currents in the area are an important factor in the coastal processes and sediment transport on the open coastline (discussed further in Section 2.4).

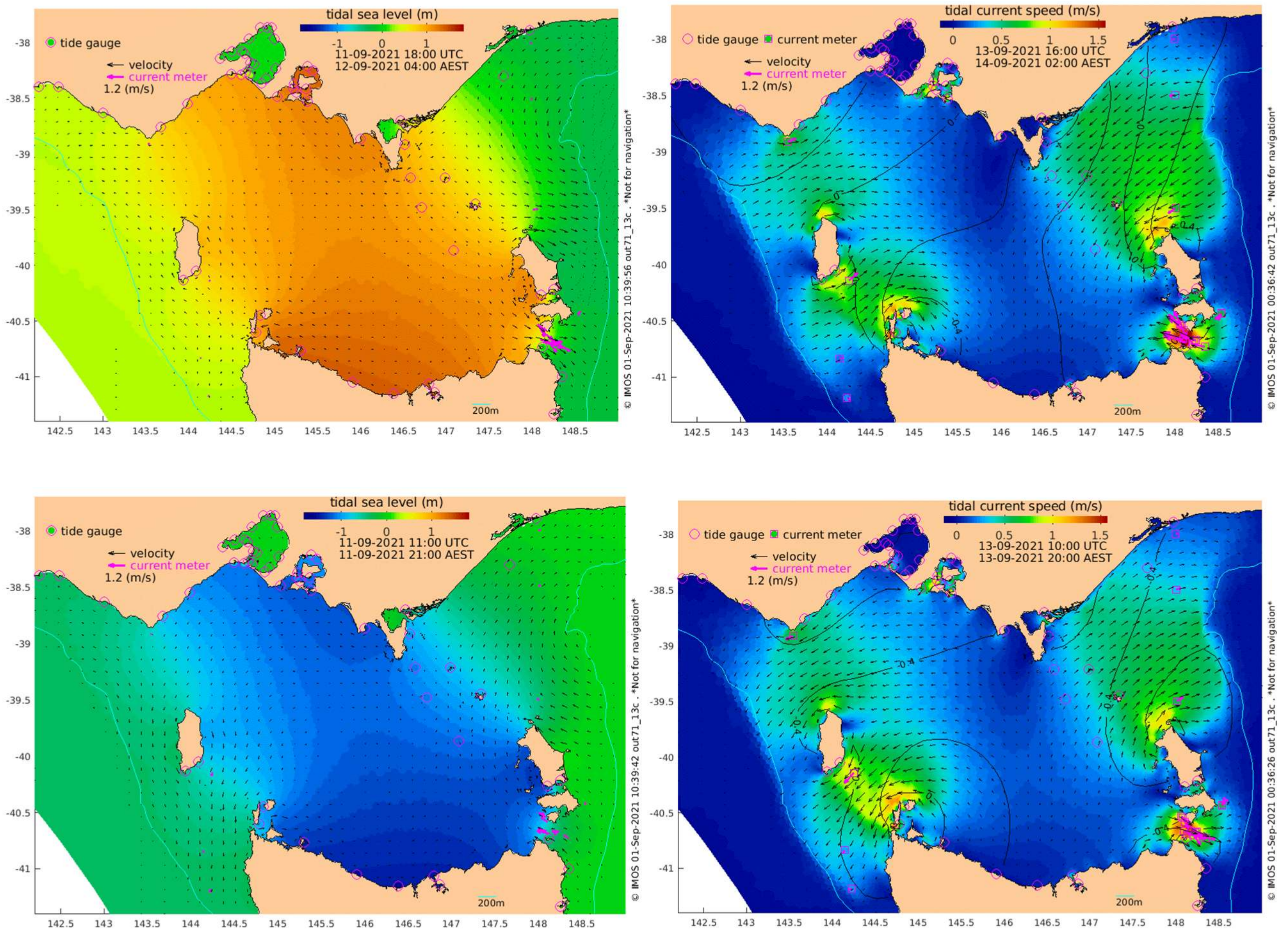


Figure 2-39 Peak spring high and low water levels (left) and peak tidal flood and ebb currents (right) within Bass Strait (IMOS 2021)

Long term measurement of water levels allows analysis to generate tidal constituents which can then be used to predict the astronomical portion of the tide at any point in the future.

Tidal constituents are also used to define the tidal planes commonly used to describe different water levels at a location – i.e. the mean high water or low water springs etc. The Highest Astronomical Tide (HAT) and the Lowest Astronomical Tide (LAT) are the highest and lowest astronomical water level which can occur in a full tidal epoch – an 18.6 year period which then repeats, with the same astronomical forces and resulting astronomical tidal water levels.

Tidal planes for the study area are presented in Table 2-7. These tidal planes have been generated from a range of sources as noted. The tides in the Study Area are semi-diurnal tides with a diurnal inequity. This means there are two high and two low tides each day (semi-diurnal) with one high tide higher and one high tide lower each day (diurnal inequity). The tides have a strong spring-neap tide cycle with spring tides (which coincide with a full or no moon) 2.5 - 3 times the neap (half-moon) tides. Peak high and low water levels recorded at the measurement stations are also noted.

Table 2-7 Study Area tidal Planes (m AHD)

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

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

Venus Bay

The tidal signal for the study area is presented for a neap-spring tidal cycle in Figure 2-40, with the spring and neap tides shown in the lower boxes. The tidal ranges within Venus Bay are similar to those observed at Stony Point, with the spring tide range up to 3m and the neap tides largely between -1.0m AHD and 0.75m AHD. The tidal phase is slightly different, with high and low tides at Stony Point occurring approximately 1.5h after Venus Bay. The tidal ranges at Stony Point and Venus Bay are similar to those predicted for Waratah Bay, however the short duration and time of the Waratah Bay measurement (< 30 days in 1950s) means it is likely the Stony Point tidal ranges, derived from long term measured water levels are more accurate as the longer period of recording allows for better analysis and prediction of astronomical forces.

Inverloch

As the tidal waters pass through the entrance the tidal range reduces and the astronomical low tide is limited to above -0.8m AHD at Inverloch Jetty compared with -1.5m offshore. The high and low tide at Inverloch Jetty is approximately 30 minute to 1 hour after the offshore slack tide, whilst the turn of the tide at Tarwin Lower Jetty is a further 2 hours later on the high tide and up to 3 hours delayed on the turn of the low tide. This extended delay in the low tide is common in estuarine environments where the ebb tide is longer than the flood tide.

Tarwin Lower

The tidal range at Tarwin Lower Jetty is smaller than that at Inverloch, ranging from -0.3m to 1.4m AHD. It is also noted there is significant variation in the low tide with increased rainfall in the Lower Tarwin catchment. Measured data through the 2021 winter show an increase in the minimum water level through Autumn and

Winter which could result in a variation of the tidal planes noted in Table 2-7 with the recording and analysis of further data. The measured data at Tarwin River is further discussed in Section 2.3.5.

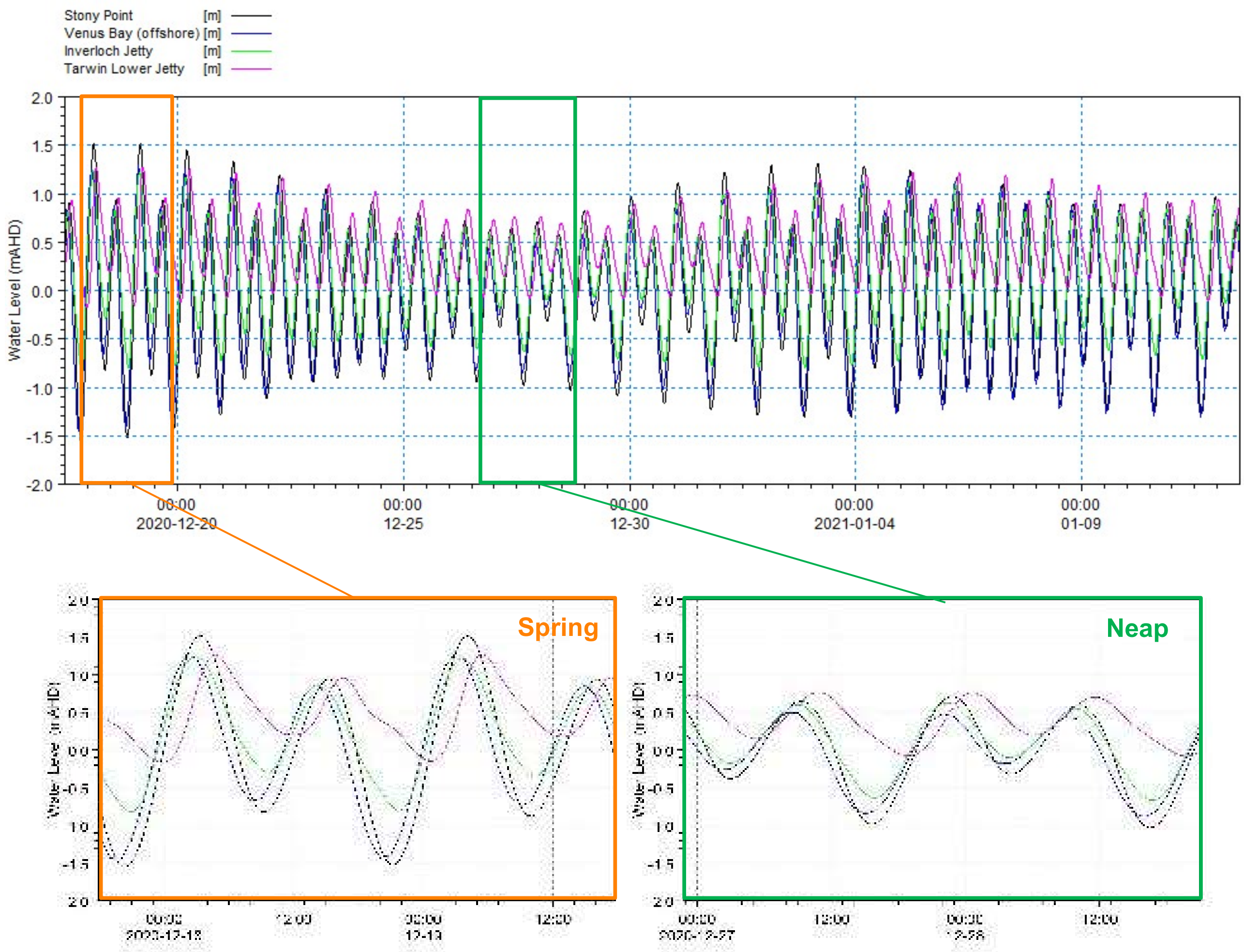


Figure 2-40 Astronomical Tidal Signal within the Study Area

An exceedance curve for the astronomical tides which illustrates the frequency of exceedance of different water levels across a tidal epoch (a 19-year period) within the Study Area is presented in Figure 2-41. Tidal planes are noted for reference at the Inverloch Jetty and in the offshore waters.

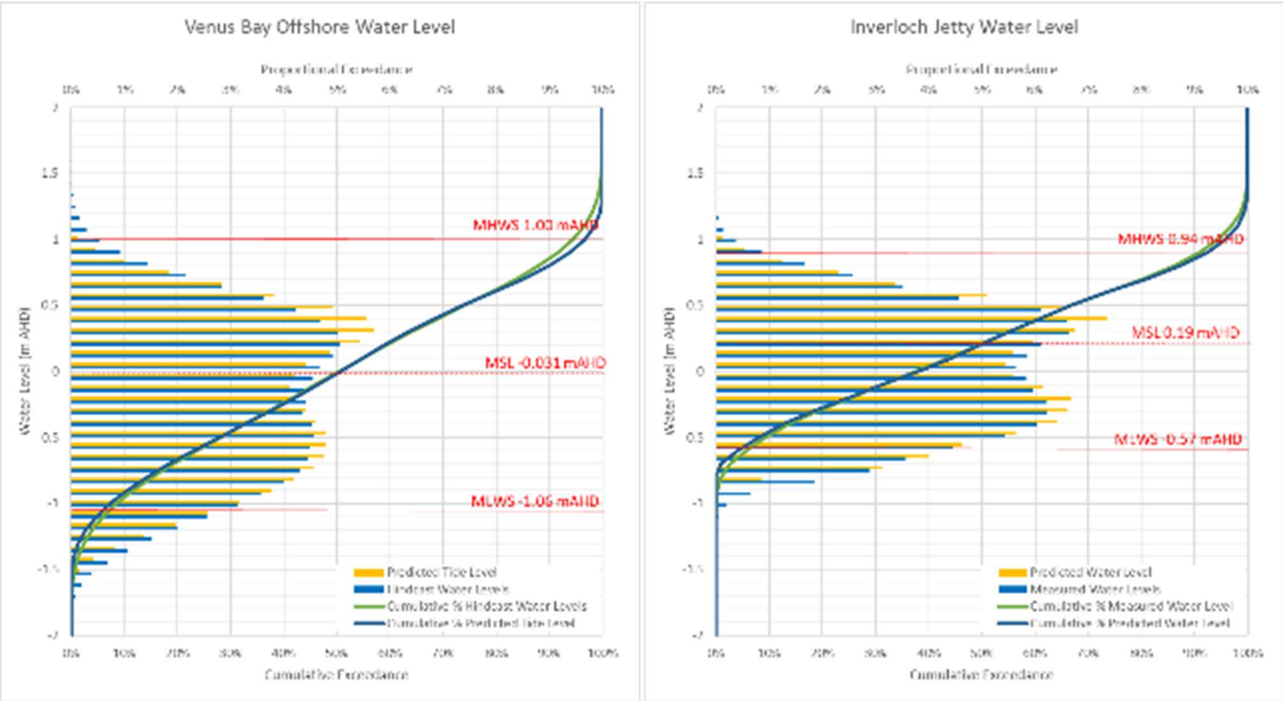


Figure 2-41 Astronomical Tide Exceedance Curve, Venus Bay (left) and Inverloch Jetty (right)

2.3.1.2 Non-Tidal Coastal Water Level Variations

Variations in the coastal water level are caused not only by the astronomical tides, but also by phenomena such as atmospheric pressure, wind setup, wave setup, and oceanographic variations. Catchment run-off and the influence on coastal water levels are discussed in Section 2.3.5, and more widespread climate drivers which can result in changes to water levels are discussed in Section 2.3.6. The different water levels and components which make up the total coastal water level are presented in Figure 2-42.

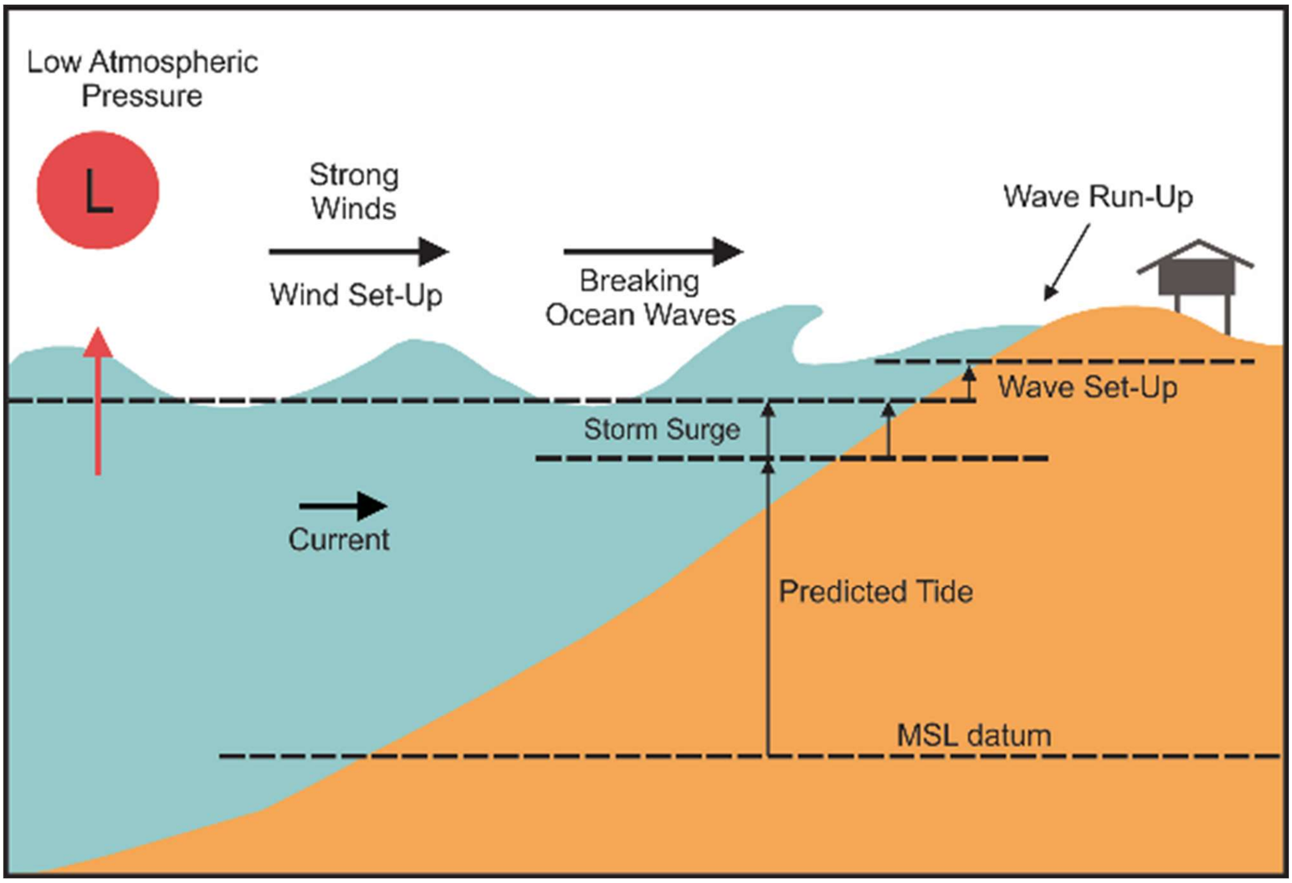


Figure 2-42 Components of the Total Water Level (Bush, 2019)

The processes shown in Figure 2-42 include **wind setup**, generated by wind blowing over the surface of the water causes water to "pile up" against the coast towards which the wind is blowing. Wave dissipation and breaking also causes water to "pile up" against the coast in a processes termed **wave setup**. Atmospheric pressure leads to local changes in sea level, with high pressure lowering the sea level and low pressure increasing the sea level, a process referred to as the **inverse barometric effect**. Along the southern Australian coastline a **coastally trapped wave** also exists, where elevated water levels generated on the west coast of Australia, or setup driven by Southern Ocean storm winds, result in higher water levels along the coast which also pass across the Study Area.

There are numerous other minor oceanic processes that can cause local variations in sea level at the coast. All these mechanisms combine, resulting in observed water level deviations from astronomical tides. They are often grouped under the term "**storm surge**" since their combined effects are greatest during a storm event. The storm surge here is the still water level, excluding the effects of waves near the coastline, as depicted in Figure 2-42.

Along the central Victorian coast, storm surges arise in relation to strong winter storms moving out of the Southern Ocean or, less regularly, from East Coast Lows (Table 2-17). The higher water levels associated with these events are significant because they allow high-energy waves from the same storms to propagate into the coastline and can result in coastal erosion.

The water level monitoring stations established by Gippsland Ports for the project captured a number of storm events where elevated water levels were observed within Anderson Inlet. Two different storm events have been selected for review here, illustrating the common processes associated with storm surges and wave conditions in Venus Bay.

Storm 1: 27/08/2020; Storm surge ~0.5m

As shown in Figure 2-43, a high pressure system is located over southeastern Australia on the 26th August 2020 before a low pressure trough and cold front pass through Bass Strait from the west late on the 27th displacing the high offshore of the east coast. Air pressure drops from around 1020 to 1016 hPA during the passage of the trough and front. The front speed is in the order of 45-50kts.

The storm surge and total water level at Inverloch and Stony Point are presented along with wave height, peak period and peak wave direction. The impact of the storm is visible in both the water levels and the wave height and period. A storm surge of close to 0.5m is observed and hindcast at Stony Point and Venus Bay respectively on the 27th August, with water levels over 0.5m above the predicted astronomical tide at the Inverloch Jetty gauge. Significant noise in the signal at the Jetty also indicates waves were acting on the jetty gauge. The wave heights measured at the VCMP buoy offshore in Venus Bay indicate wave heights close to 5.0m during the passing of the storm, with a direction between southwest and west-southwest. Prior to the storm, peak wave periods increased, although there is significant variability in the peak period record. As waves increased, the mean period also increased to close to 10 seconds.

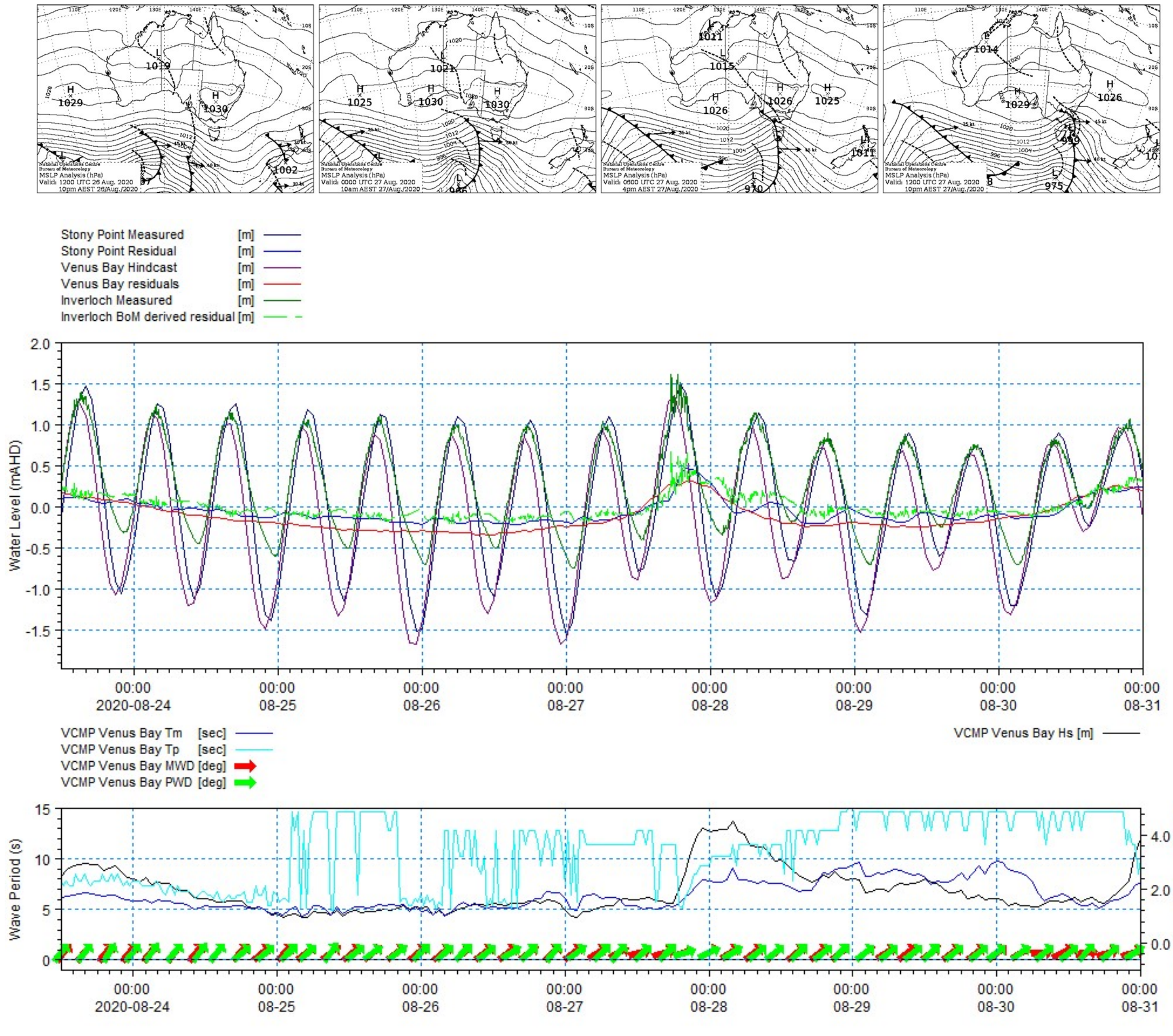
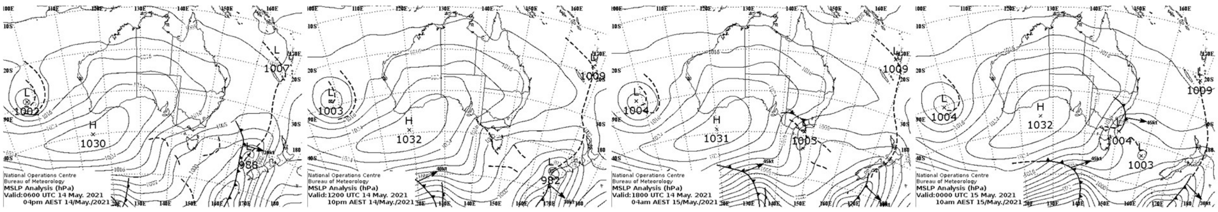


Figure 2-43 Metocean Conditions – Storm 1: 27/08/2020

Storm 2: 15/05/2021; Storm surge ~0.5m

As shown in Figure 2-44, a large high pressure system moved into the Great Australian Bight on the 14th May 2021, forcing a low pressure trough eastward towards Tasmania before shifting direction to the north towards Bass Strait. The trough is followed by a cold front which passes over Tasmania. Air pressure drops from around 1012 hPa to 1010 hPa as the trough passes before increasing to close to 1020 hPa as the front passes over Tasmania.

Residual water levels of close to 0.5m are again observed at Stony Point, Inverloch and Tarwin Lower (where data is not available in 2020). The residual water level signal is not as smooth during this May 2021 storm and the water levels are elevated, and slightly out of phase for a longer period than the 2020 event. The peak residual at Tarwin Lower occurred prior to the peak at Inverloch, potentially reflecting the increased flows in the Tarwin River due to the high amount of rainfall over the 14th and 15th May. Wave heights are also higher for a longer period (greater than 2.5m for 3 days), peaking just after the peak residual on the 15th May. The wave direction is from the southwest, with some peak waves from the west-southwest. Mean wave period change closely matches the change in wave heights.



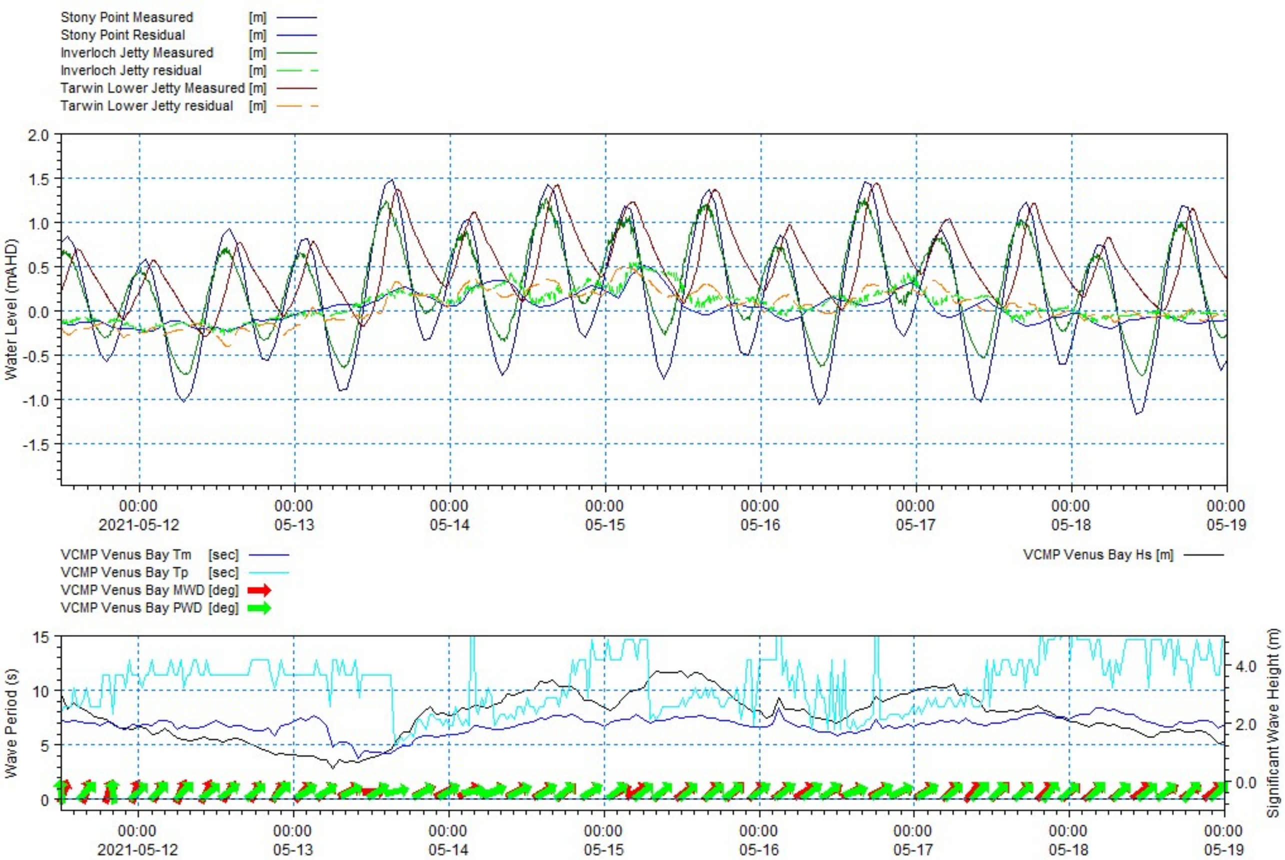


Figure 2-44 Metocean Conditions – Storm 2: 15/05/2021

Long Term Water Level Variations

Measured water levels within Venus Bay are not available and are generated for the Study by a hindcast numerical model as discussed in Report 3. The hindcast storm surge, or residual water level, being the difference between the measured water level and predicted astronomical tide, measured at Inverloch Jetty during 2020 and 2021 was similar in magnitude and timing to those measured at Stony Point (as shown in Report 3, Appendix D) and it has been assumed storm surges within Venus Bay are therefore similar to those measured at Stony Point.

The storm surge / residual water level at Stony Point has been analysed for the period 1993 – 2020 from data available from the Australian Baseline Sea Level Monitoring Project (ABSLMP) (BoM, 2021). Residual water levels at Stony Point can peak over 1.0m, with the maximum recorded hourly average residual 1.3m during the significant event which occurred on the 24th June 2014. The maximum 6 hour rolling average residual is just over 1.0m for the 27 year period (24th June 2014) (Figure 2-45).

Storm surge residuals within Venus Bay are driven by the same processes at Stony Point and are expected to be similar in magnitude. Whilst locally notable events, the coincident water level measured at Stony Point during the storm surge events described in Figure 2-43 and Figure 2-44 are below the long term average annual maximum recorded at Stony Point, and more significant storm surges into Anderson Inlet would be expected at several times per year.

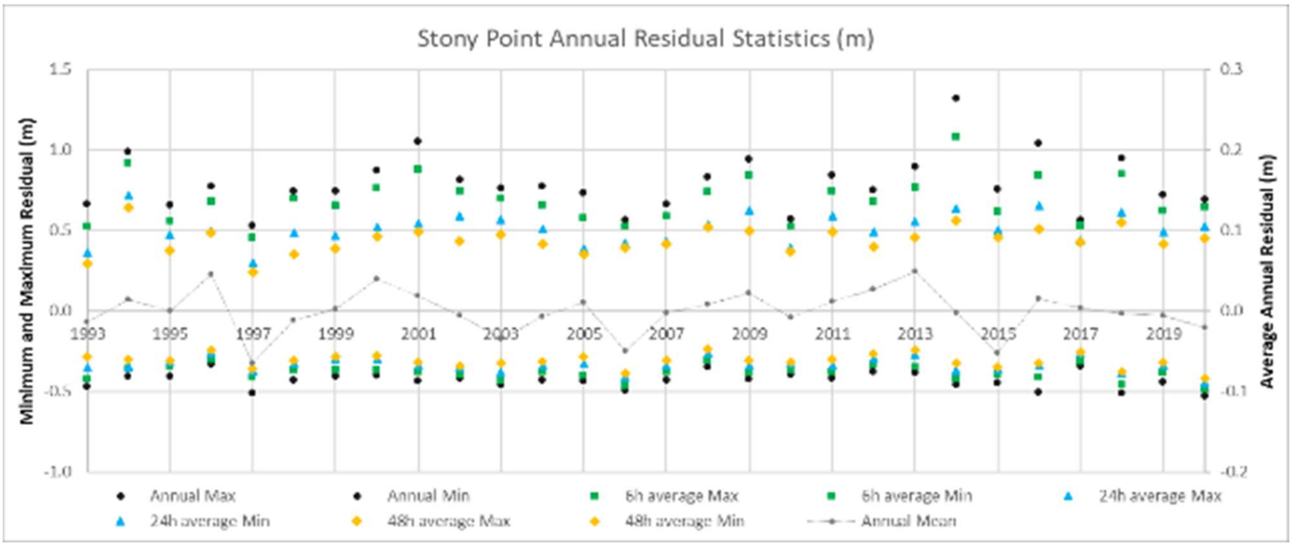


Figure 2-45 Stony Point Measured Storm Surge

2.3.1.3 Extreme Water Levels

Extreme Water Levels are those which occur under "extreme" storm conditions, and are defined as having an *annual exceedance probability (AEP)* – i.e. the chance a water level will be exceeded once in any year. This is similar to the previously used *average return interval (ARI)* which used the same statistics to estimate how often a storm would occur, e.g. a 1 in 100 year ARI event could be expected to occur with a probability of 1 in 100 in any given year. AEP is now used to emphasise that an extreme event can occur (for example) more than once in 100 years, however the chance of them occurring in any single year is 1%.

This study has been tasked with identifying the 1%, 5% and 10% AEP conditions in the Study Area.

A numerical model, described in detail in *Inverloch Region Coastal Hazard Assessment Report 3: Technical Methodology* (Water Technology, 2021), has been used to generate a 40 year reconstruction of water levels within Venus Bay, called a model hindcast. The model uses astronomical tides, measured water level residual and global model wind and air pressure data to simulate the hydrodynamic movement of water through Bass Strait and the resulting surface water levels and current speeds within the Study Area. The numerical model was calibrated to astronomical tides at Inverloch Jetty and verified using wind and residual water levels to measured water levels at the Inverloch Jetty. Details of the calibration and verification can be found in Report 3.

Analysis of the 40 year hindcast has been used to generate extreme water levels within the Study Area and along the open coast. The present day and predicted future storm tide levels are presented in Table 2-8 along with the HAT and MHWS for reference. These are offshore still water levels only and do not include the wave forces which generate wave setup near the coastline. Details on the calculation of extreme water levels can be found in Report 3. Estimated AEP water levels, based on the measured Australian Baseline Sea Level Monitoring Program (BoM, 2021) data, along with earlier data provided by the BoM which extends the measurement period at Stony Point to 1981 have also been provided for reference. Extreme water levels within Venus Bay, based on the hindcast model, are higher compared to those at Stony Point. Discussion around sensitivity of storm tide heights is discussed in Report 3.

Table 2-8 Extreme Water Levels offshore of Venus Bay

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

2.3.1.4 Sea Level Rise

The impact of climate change on sea level rise is under constant review with the IPCC 6th Assessment Report (IPCC, 2021) recently released presenting the most recent scientific research on climate change projections and 'our possible climate futures'. Works completed prior to the latest IPCC assessment by CSIRO and DELWP have summarised the impacts of climate change in Victoria and Gippsland and increments of mean sea level rise were established in late 2020 to assess changing hazards in the Study Area.

Sea level rise influences the assessment of likelihood (or exposure) of coastal hazards over different planning periods. In this study, the current year, and projections for 20, 50 and 80 years from 2020 (rounded from 2021) have been used along with two "high" sea level rises, projected for the year 2100. These are presented in Table 2-9.

Table 2-9 Study Area Sea Level Rise

Planning Timeframe (years)	2020	2040	2070	2100	2100	2100
Sea Level Rise (m)	0	0.2	0.5	0.8	1.1	1.4
1% AEP	2.20	2.40	2.70	3.00	3.30	3.60
5% AEP	2.10	2.30	2.60	2.90	3.20	3.50
10% AEP	2.00	2.20	2.50	2.80	3.10	3.40
HAT	1.44	1.64	1.94	2.24	2.54	2.84
MHWS	1.00	1.20	1.50	1.80	2.10	2.40

2.3.2 Wind Conditions

2.3.2.1 Wind Data Sources

Available measured and modelled wind data around the Study Area has been reviewed and the locations, sources, and time periods of wind data reviewed are presented in Table 2-10, and are shown spatially in Figure 2-46. It is useful to note that wind is “from” the indicated direction, i.e. a southwest wind, from 225 degrees, blows from the south west *to* the northeast.

The wind data measured at Pound Creek is considered most relevant to conditions experienced within Anderson Inlet, whilst offshore and more distant winds data which represent conditions that drive swell waves are more relevant to assessing conditions along the open coast and at the entrance. Global climate model winds and winds at exposed locations such as Wilsons Promontory and Cape Schanck are more relevant than Pound Creek in this instance. The data recorded at Wonthaggi, which is located reasonably close to the study area and extends for some time historically, is unfortunately not a consistent record suitable for analysis.

Table 2-10 Study Area Wind Data

Location	Source	Data Period, frequency, resolution (if gridded)
Pound Creek	Australian Bureau of Meteorology (BoM)	1997 – 2021, 0.5 hour
Wonthaggi	Australian Bureau of Meteorology (BoM)	1986 – 2021, 3 hour or less
Wilsons Promontory	Australian Bureau of Meteorology (BoM)	1957 – 2000, 3 hour 2000 – 2021, 0.5 hour
Cape Schanck	Australian Bureau of Meteorology (BoM)	1962 – 1992, 3 hour or less
Cape Otway	Australian Bureau of Meteorology (BoM)	1864 – 1994, 3 hour or less 1994 – 2021, 0.5 hour
ERA5	European Centre for Medium-Range Weather Forescasts (ECMRWF)	1979 – 2021, 1 hour, 27-28km
WW3	U.S.A National Oceanographic and Atmospheric Association (NOAA)	1979 – 2009, 3 hour, 7km
CAWCR	CSIRO / BoM	1979 – 2021, 1 hour, 7km
Region A1	Australian/New Zealand Standard	AS/NZS 1170.2:2011