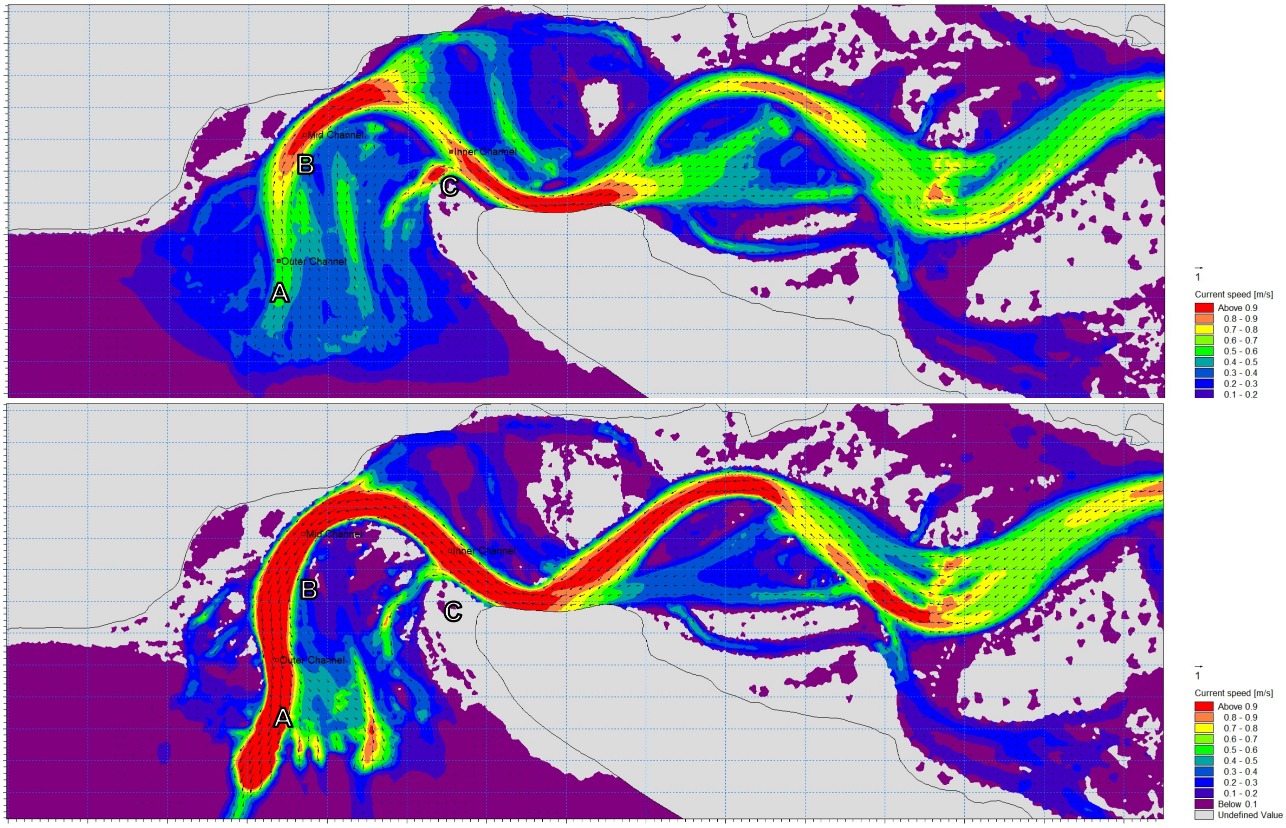

Figure 2-62 Modelled Entrance Flood (top) and Ebb (bottom) Spring Tide Current Speeds

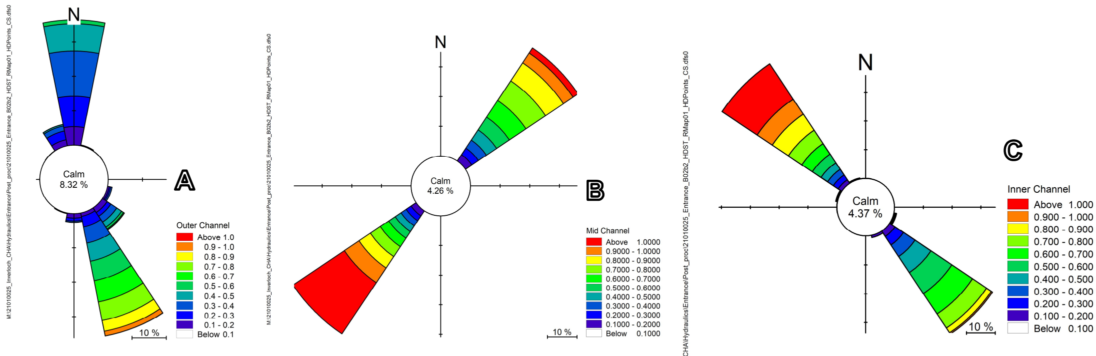

Figure 2-63 Modelled Entrance Current Roses for locations A, B and C

2.3.4.3 Anderson Inlet

Currents within Anderson Inlet are dominated by tidal flows through the tidal channels, supplemented by the additional forces across the intertidal banks during a catchment flood event. Wind and wave driven currents are low given the limited fetch in most directions, and the limited duration of deep water for the long northwest-southeast fetch provided during high tides.

The peak flood and peak ebb tidal current speeds are presented in Figure 2-64. Note these represent the highest current speed over the duration of the flood (incoming) and ebb (outgoing) tides. The peak current speed occurs at different times with the passage of the tide into and out of the Inlet.

Higher current speeds are constrained to the channels and will continue to place pressure on the outer bends of the channel, increasing sinuosity where possible. Sediments mobilised within the channels due to the strong currents are likely to be re-deposited on the beds of the channels as tidal currents drop. Unlike the entrance, current speeds are higher on the flood tide within the Inlet as the incoming water is faster to fill the Inlet. The outgoing tide is slightly longer in duration as the Inlet drains and as such the current speeds are slightly lower at the maximum. The higher ebb current speeds in the entrance noted above can be seen in the figure below along with the activation of some additional flood tide channels such as the Pound Creek approach and towards the Venus Bay jetty.

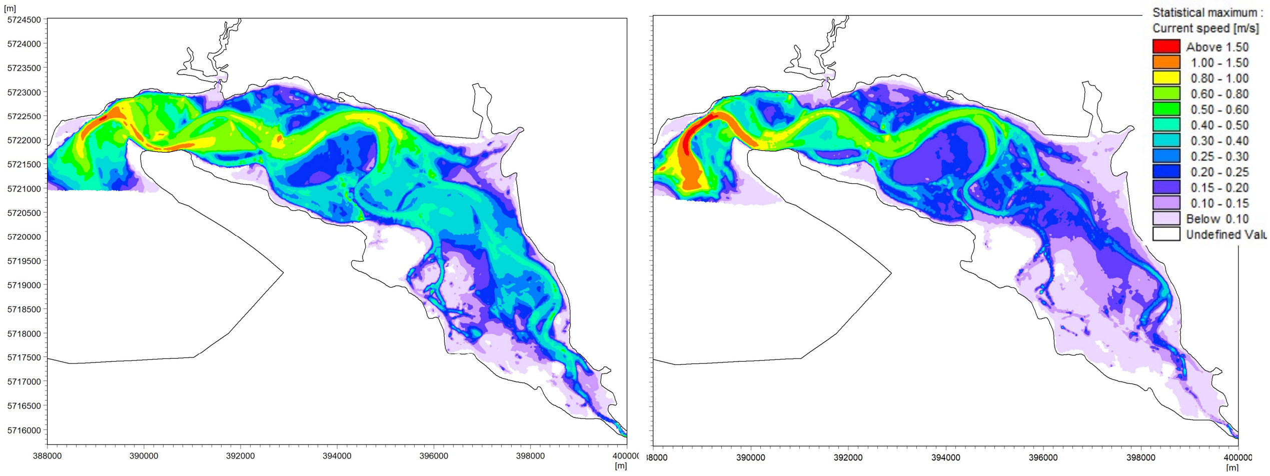

Figure 2-64 Peak flood (left), and ebb (right) tidal currents, Anderson Inlet

2.3.5 Fluvial

As described in Section 2.1, Anderson Inlet was formed by the Venus Bay coastal barrier which over time shifted northwards and restricted the outlet of the Tarwin River. The geologic and geomorphic analysis presented in Section 2.1.1 shows locations of previous outlets of the Tarwin River (labelled as Tarwin River diversions in Figure 2-3) which would have been active at different times as the barrier developed.

The catchment of the Tarwin River is extensive, extending some 50km north to the southern slopes of the Strzelecki Ranges, west to Korumburra and East to Mirboo.

Fluvial process and flows are discussed in detail in Report 5 Coastal Inundation (Water Technology, 2022).

Measurement of the impact of floods through the Tarwin River, and through smaller local catchments of Pound Creek and Screw Creek into Anderson Inlet is limited. The review of aerial imagery and historical charts described in Section 2.1.4 notes the change which has occurred to the main flow path in Anderson Inlet (upstream of Townsend Bluff) over the past 150 years. However, bed levels within the Inlet are less well captured and available survey data across the Inlet intertidal banks is limited to the single LiDAR dataset. The impacts of flood events on the elevation of the Inlet intertidal banks is unknown.

The main potential impacts of floods on coastal processes are to potentially increase the movement of sediment out of the inlet and to the coast during large events. This is discussed further in Section 2.4.

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2.3.6 Climate Variables

There are five main global climate processes that influence Victoria's climate:

- El Niño-Southern Oscillation (ENSO)
- Indian Ocean Dipole (IOD)
- East Coast (cut-off) Lows (ECL)
- Southern Annular Mode (SAM)
- Sub-tropical ridge

These climate drivers are shown schematically in Figure 2-65. They vary over the months and years to influence seasonal and inter-annual rainfall, air temperature and wind, and correspondingly oceanographic conditions and coastal processes.

The influence of each driver on the Victorian coastline is described in more detail in Table 2-17. Useful animations have been developed by Agriculture Victoria; 'Climate Dogs' explaining the features can be found at the following link: http://agriculture.vic.gov.au/agriculture/weather-and-climate/understanding-weather-and-climate/climatedogs

The different climate drivers can occur in any different combination to increase or decrease the action of other drivers. Whilst the table below provides an indication of the likely response to a single climate driver in the study area, the interaction between the climate drivers means that there is considerable noise around the direct cause and influence of climate drivers. The state of a climate driver (e.g. El Niño or La Liña) is thus considered a guide to conditions which may occur, but cannot be used to predict specific events or process drivers.

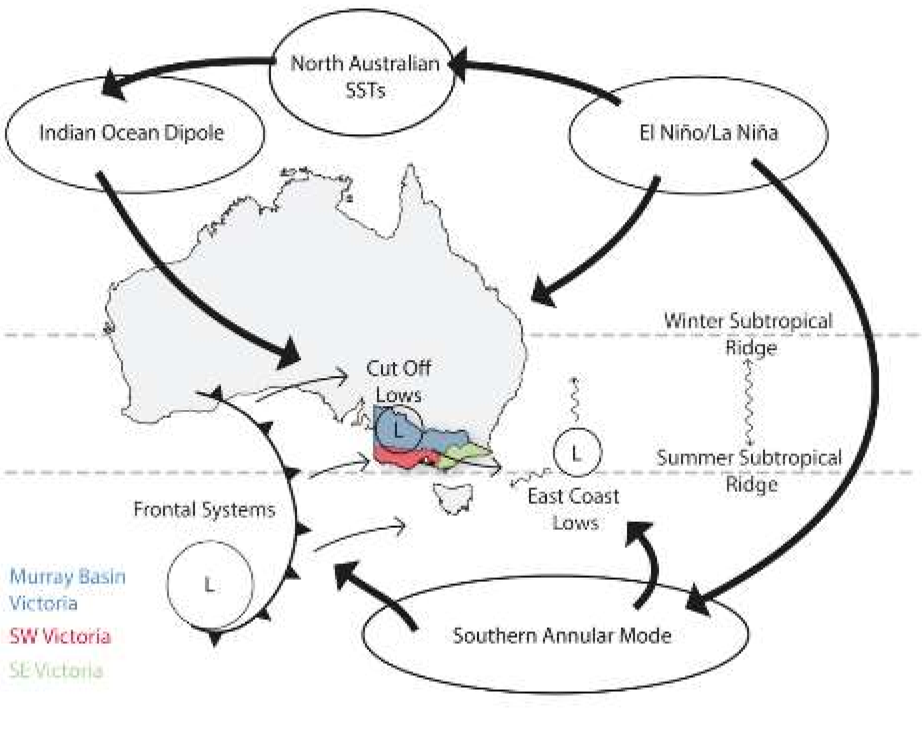

Figure 2.1: Large-scale climate features of relevance to local climate in Victoria. Thick arrows show the influence each climate mode has upon either synoptic weather types affecting Victoria or another climate mode. Thin arrows indicate wind directions associated with certain synoptic weather types. Other features are discussed in this report.

Figure 2-65 Climate drivers relevant to local climate in Victoria (Hope et al, 2017)

Table 2-17 Climate Processes influencing Victoria's Climate (BoM, 2010)

Climate Process	Influence	Influence on Study Area	Duration / timing
El Niño - Southern Oscillation (ENSO)	Warming of the central and eastern tropical Pacific Ocean, leading to changing patterns of winds, atmospheric pressure and rainfall. Three phases of ENSO are: El Niño, La Niña & Neutral.	La Niña brings strong trade winds leading to higher rainfall. One of the strongest La Niña on record occurred 2010-2011 followed by a moderate La Niña 2011-2012. Four significant flood events in the Tarwin River were recorded in this period. El Niño brings drier winter and spring periods	Months to years / Generally forms in spring, can continue to the following year
Indian Ocean Dipole (IOD)	Difference in sea temperature between western and eastern Indian Ocean leads to changes in wind, air temperature and rainfall patterns. Changes between positive, negative and neutral phases. Can be related to ENSO events with positive IOD often occurring in tandem with El Niño (positive SOI) and negative IOD with La Niña (negative SOI). When in phase the influence of the ENSO and IOD are more extreme.	When a negative IOD connects with cold fronts there can be higher rainfall and greater flow in Tarwin River. However, both positive and negative IOD events are linked with drought in Australia. Winter and spring are more heavily influenced by the IOD.	Months / Typically occurs in Victoria during the winter and spring months

Climate Process	Influence	Influence on Study Area	Duration / timing
East Coast Low (ECL)	Can occur several times a year on the east coast of Victoria. ECLs can form rapidly overnight and are formed as a sub-tropical depression that intensifies as it propagates rapidly down the east coast of Australia.	Can cause heavy and widespread rainfall in the eastern Gippsland region, and the Tarwin River catchment. Strong winds and waves approaching coastline from the south east driving sediment and elevated water level into Anderson Inlet. The wind and wave effects can be intensified by the presence of a blocking high in Bass Strait causing conditions to continue for a number of days. Significant erosion on open beaches is a common influence of ECLs.	Days / Can occur year round but stronger in Victorian winter months
Southern Annular Mode (SAM)	The north-south movement of westerly winds (low pressure system) that circulate around Antarctica in the Southern Ocean. Position of SAM influences strength and position of frontal activity. A strong SAM can affect the influence of the ENSO and IOD	SAM has the greatest influence on the coastline of southern Victoria during winter. **Negative SAM** = stronger westerly winds, higher waves and more storm energy on the Study Area coastline. Potential for increased rainfall and flow through Anderson Inlet. **Positive SAM** = weaker westerly winds, less energy on the shoreline from the west	Weeks to Months / Non seasonal
Sub-tropical Ridge	A belt of high pressure that encircles the southern hemisphere in the middle latitudes.	During winter the sub-tropical ridge moves northwards towards the equator resulting in the higher rainfall and southern frontal systems at the Study Area.	Ongoing system / Continues to move between northern and southern positions over the year / seasons.

Tabulated values are available of the Southern Oscillation Index (fluctuation between El Niño and La Niña) and the Indian Ocean Diploe are presented below in Figure 2-66.

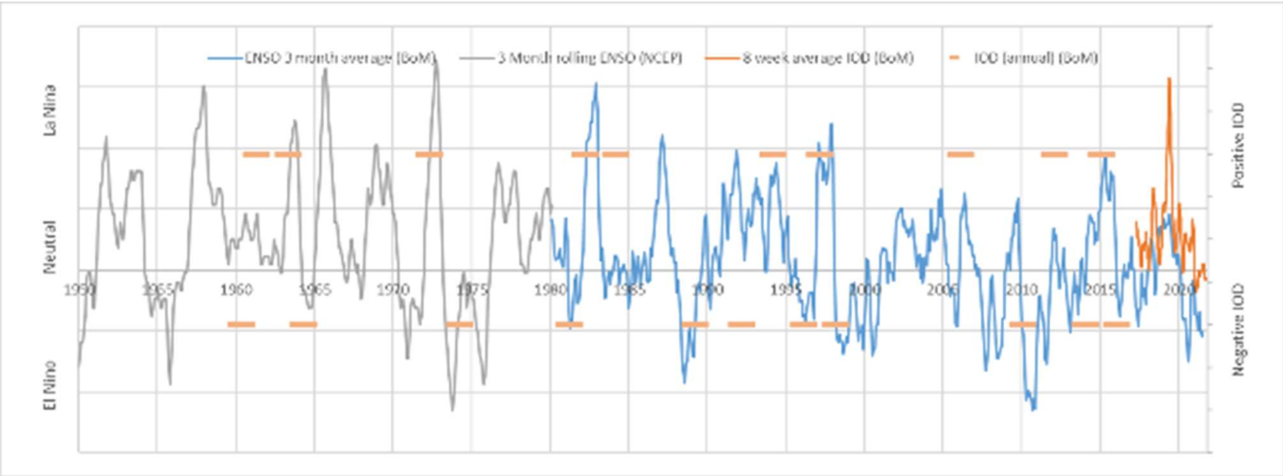

Figure 2-66 Variation of ENSO and IOD over time

2.4 Coastal Processes

2.4.1 Sediment Cells

A hierarchy of sediment cells is used to assist coastal planning, management, engineering, science, and governance along the coast. Sediment cells are spatially discrete areas of the coast within which marine and terrestrial landforms are likely to be connected through processes of sediment exchange, often described using sediment budgets. They include areas of sediment supply (sources), sediment loss (sinks), and the sediment transport processes linking them (pathways).

Sediment transport pathways include both alongshore and cross-shore processes, and therefore cells are best represented in two-dimensions. They are natural management units with a physical basis and commonly cross local government boundaries. Figure 2-67 depicts the primary and secondary sediment compartments for the study area coastline. The Study Area is contained within the primary *VIC04 Port Phillip* compartment and comprises almost all of the secondary *VIC04.03 Venus Bay* compartment. Cape Paterson and Cape Liptrap bound the western and eastern end of the secondary compartment respectively.

Detailed investigation of the supply and loss of sediment into the Venus Bay cell has not been completed for this Study, or in any prior works, and as such cannot be quantified.

It is expected that the weak tidal currents in the wider region (Figure 2-39) mean sediments within Bass Strait are currently moved primarily by wave action, from west to east in line with the regional wave climate (Figure 2-53).

Rosengren (2021) suggests there is low influx of sediment into the cell and notes "*beach sediments across the study area were principally derived from onshore transport of sands submerged by rising Pleistocene and Holocene sea-levels across the continental shelf and Bass Strait. These sands have two primary provenances (Bird, 1979, Davis 1989, Short 2020):*

- *bioclastic carbonates (comminuted biogenic sands) of ancient and contemporary origin*
- *relict terrigenous deposits sourced from rivers and alluvial fan deposits of the Haunted Hills Formation and lower sea-level siliceous dunes such as the stranded deposits on the Cape Paterson Plains.*"

Rosengren (2021) describes the northern Venus Bay area offshore of Anderson Inlet as a sediment sink with the persistent ebb-tide delta covering a ledge of submerged rock, itself which extends eastward from Cape

Paterson. The extent of the hard rock reef and the soft sedimentary strata across Venus Bay is presented in Figure 2-68.

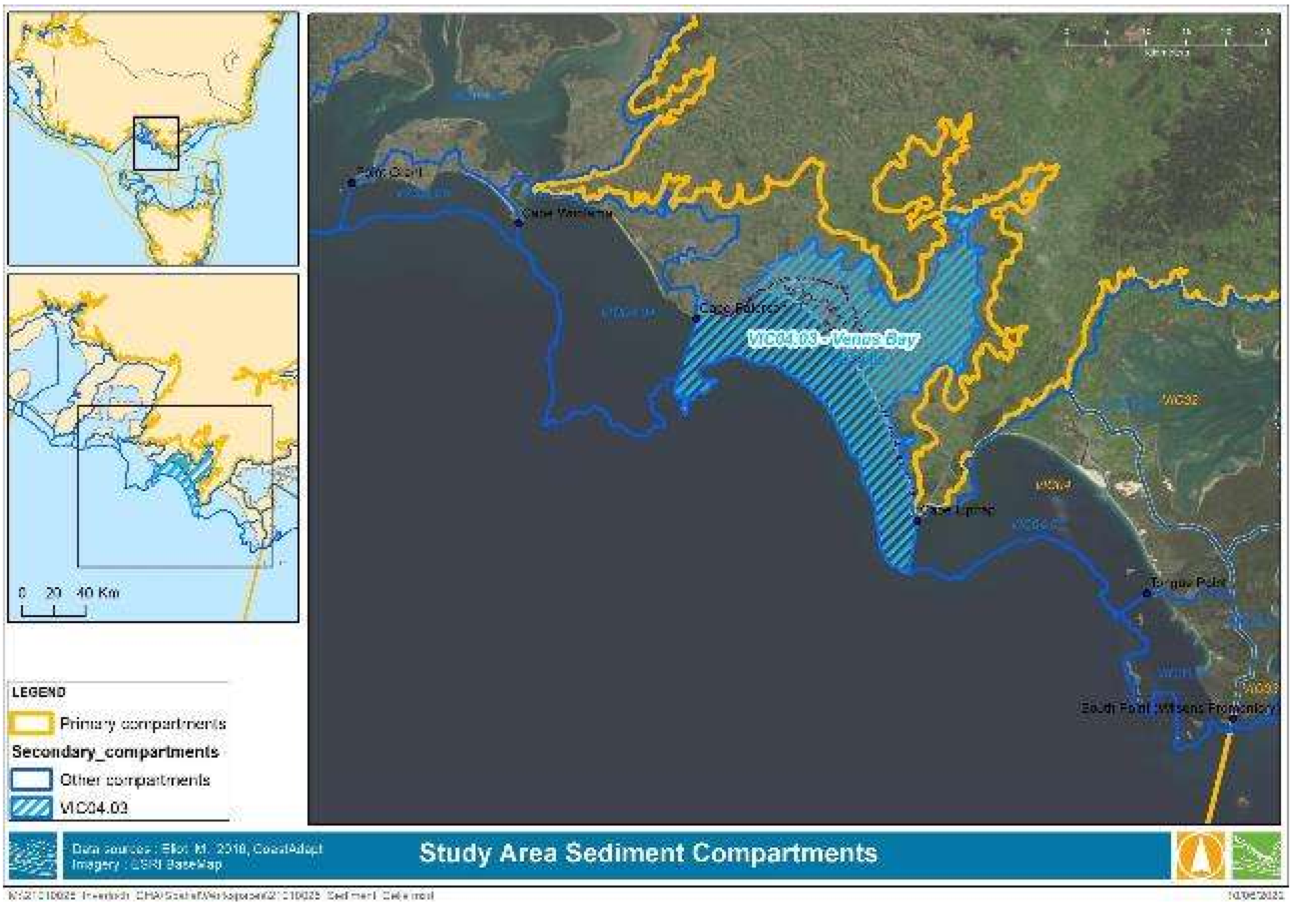

Figure 2-67 Sediment Compartments of the Cape to Cape region

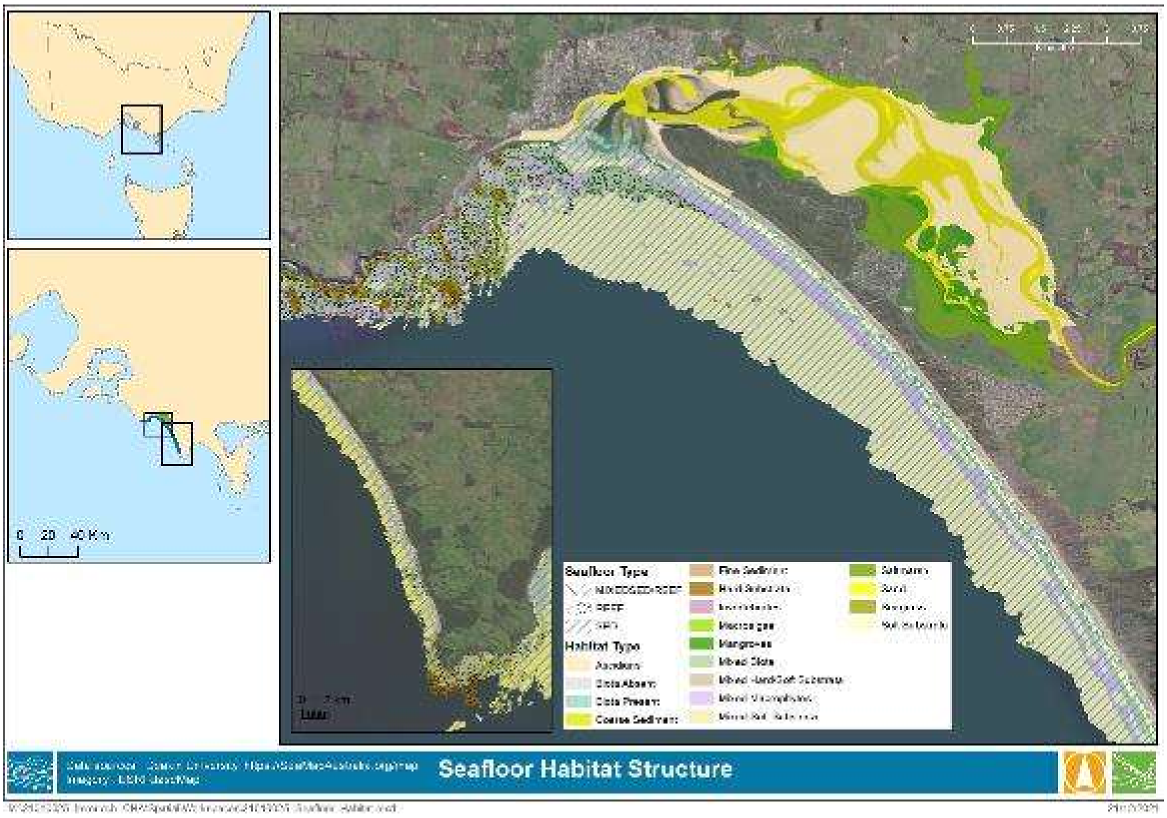

Figure 2-68 Seafloor type and habitat

2.4.2 Sediment Grain Size

Sediment sampling has been undertaken as part of the Study and through prior work assessing sediment movement in the area (SGCS, 2019, Doumtsis, 2019). Particle size analysis of samples are presented in Figure 2-69. Some key observations can be made from the sample analyses which have been undertaken over the past few years.

- 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 seize < 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.

Figure 2-69 Median Grain Size

2.4.3 Current Driven Sediment Transport

Open Coast

Along the open coast tidally driven currents are low as discussed in Section 2.3.4.1. Flood tide currents along the coast flow eastward and a small net eastward current is noted in the model. However, of importance to the Inverloch area, the ebb tide currents are westward across the entrance.

Thus, any material which is transported through the entrance on the ebb tide will have a bias to be deposited under tidal currents alone to the west of the entrance, supplying Surf Beach and Flat Rocks with sediment. However, these ebb tidal currents are low and wave energy will dominate transport, which is discussed further below.

Entrance

As presented in Figure 2-52, wave energy rapidly diminishes with distance inside the entrance. From the seaward edge of the bar to the line from Point Smythe to Ayr Creek (around 1.5km), the 1% AEP offshore wave height reduces by an order of magnitude (approx. 4-5m to 0.4-0.5m Hs). A further 500m within the entrance to the line between Point Smythe and the Inverloch boat ramp and the wave height drops further to 0.3m.

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Within this area of the entrance, current speeds, as presented in Figure 2-62, can be in excess of 1.5m/s within the channels and 0.3-0.4m/s across the sand banks.

The movement of the channels over time is presented in Section 2.1.4 and shows a pattern of increasing meander within the entrance of the channel increasingly shifting north and east with the inward migration of the main entrance bar.

The pattern of this sand bar movement and mass channel change is loosely correlated with the occurrence of significant flood events in the Tarwin River, as presented in Figure 2-71.

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

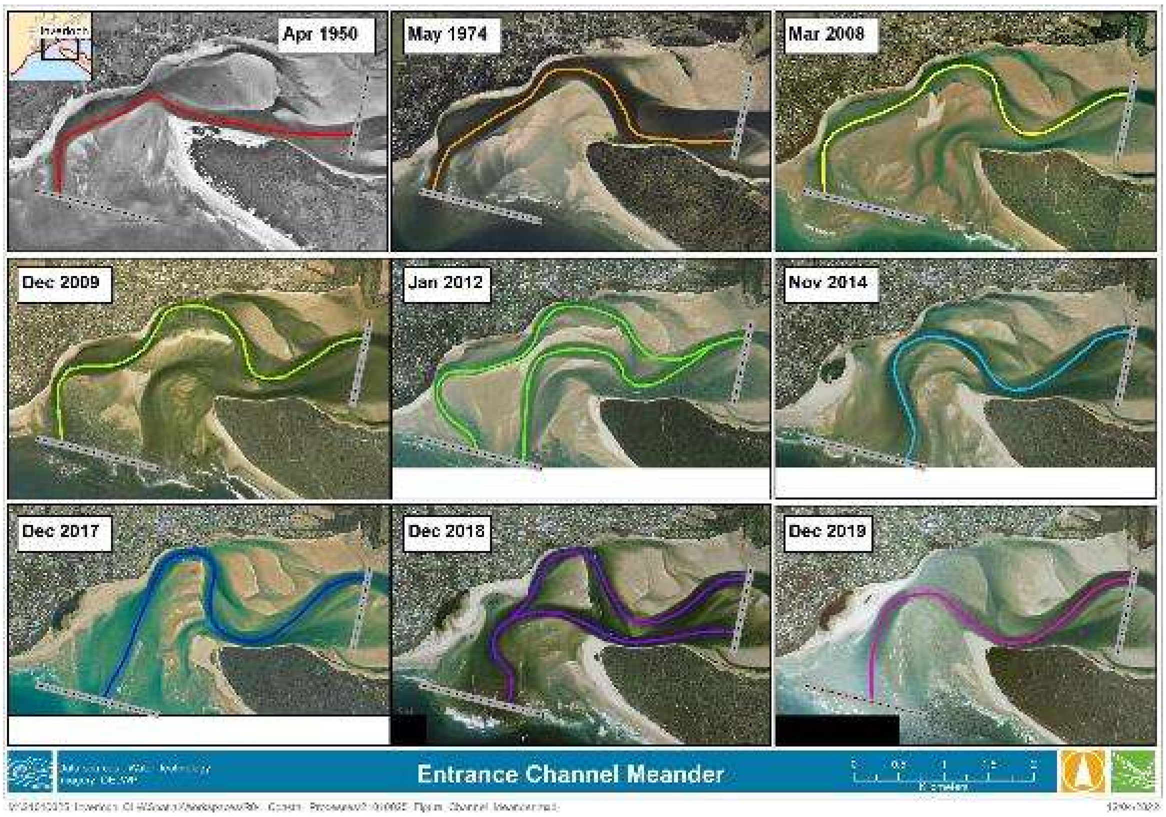
Channel Meander

Channel length (between two constant but arbitrary lines across the outer bar and inner entrance), and channel patterns for selected years are presented in Figure 2-70.

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

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

This change of channel alignment in response to meander length could be coincidental and driven by other features (floods, wave conditions), however there is a pattern evolving to suggest that there could be a length at which the tidal flow responds to the meander length by incising a new channel. Continued review of aerial imagery and channel length could be used to confirm and quantify any relationship.



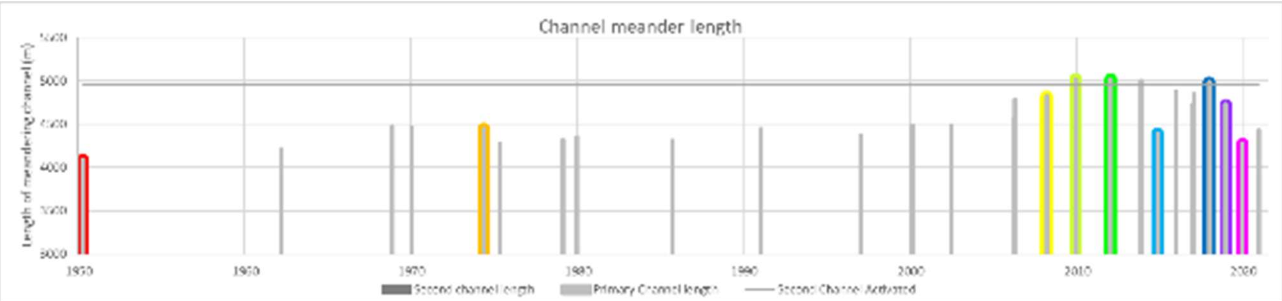


Figure 2-70 Entrance Channel Meander Length

Bar migration

As noted, in addition to the length of the channel, the cut through of bars and channels may be driven by higher flows associated with flood events. To demonstrate this, the position of the inner/inlet edge of the main channel bar is shown in Figure 2-71, highlighted for the year of image. The aerial images in the centre of the top two rows show the bar migrating into the inlet. A large flood event then occurs between the centre and right-hand side image of Figure 2-71 and the impact on the bar and leading channel is shown by the shift back towards the entrance, suggesting that large flow events cause this cut through of the bar and realignment of the channel. The flow events and distance to the leading edge of the sand bar is shown in the graph in Figure 2-71.

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

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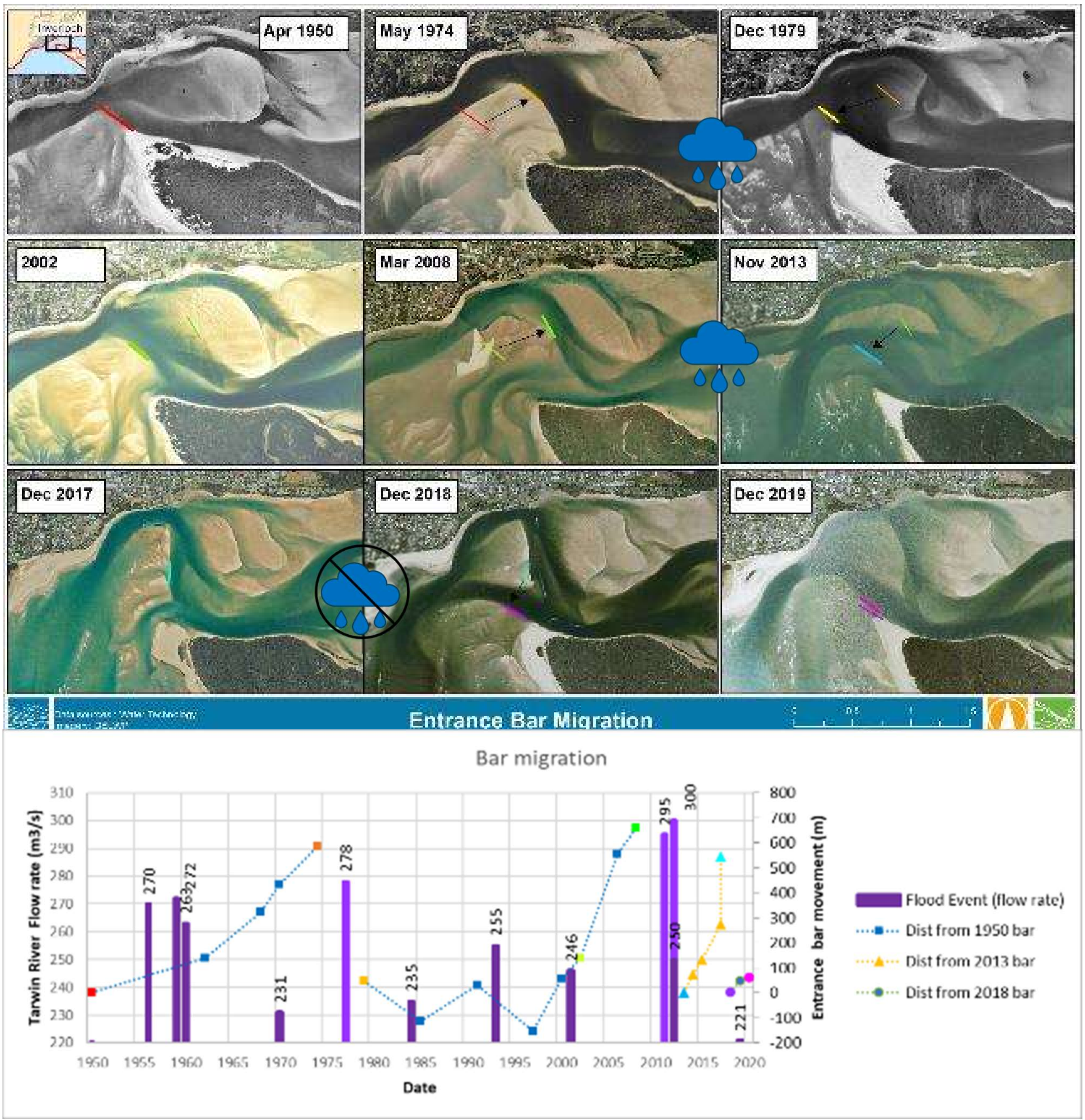

Figure 2-71 Entrance bar movement and Tarwin River flood coincidence

Complex coupled hydrodynamic, wave, sediment transport and morphological numerical modelling of the entrance was carried out for the project as discussed in Report 3, Appendix E. Whilst unable to replicate the dynamics of the entrance between the two available bed surveys of 2009 and 2021 due to computational limitations and lack of sufficiently detailed calibration data, the modelling was able to demonstrate the processes which drive change in the inlet and entrance areas.

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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

Whilst it is not possible to collect past data, further understanding of the entrance dynamics could be made by revisiting the modelling of the entrance as a specific project focus. Additional data collected for this project, and the information developed for this Study could enhance future modelling studies.

2.4.4 Wave Driven Sediment Transport

To understand the wave driven sediment transport in the Study Area the hindcast wave conditions provided by the University of Melbourne, and the hindcast water levels developed for the project were used as the basis of a longshore sediment transport model LITPAK.

The LITPAK model uses the beach profile, sediment characteristics, wave, current and water level climate to simulate the volume of sediment which can **potentially** be transported along the coastline. Beach profiles were extracted from the FutureCoast and 2021 LiDAR/bathymetry dataset. It is important to note the sediment transport model provides indicative rates of sediment transport which could be moved along the coastline considering the general beach shape, sediment size and oceanographic conditions. The variability of the beach profile over time, and the availability of sediment to be transported, is not considered in the LITPAK model.

Beach profiles were simulated along the coast from Flat Rocks to the western side of the entrance to Anderson Inlet and from the eastern side of the entrance to Cape Liptrap. As expected, the direction of the net sediment transport potential (i.e., the transport in one direction minus the transport in the opposite direction) determined by the alongshore transport modelling closely follow the average wave directions presented in Figure 2-59 in combination with the angle of the coastline.

Where the average wave direction is west of shore normal (i.e. to the left of a line at a right angle to the coastline) the transport potential is from west to east denoted as a negative number in the analysis below. Where the average wave direction is east of shore normal (left of a line at right angles to the coastline), the transport potential is from the east to the west and is denoted as a positive number in the analysis below. A simple schematic of this is presented in Figure 2-72. A beach in equilibrium has zero net transport, but may have any rate of gross transport potential, which is the sum of the transport left (west) and right (east) and is not affiliated with any direction.

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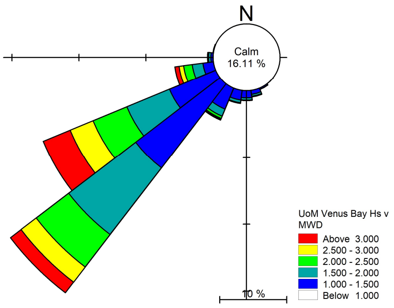
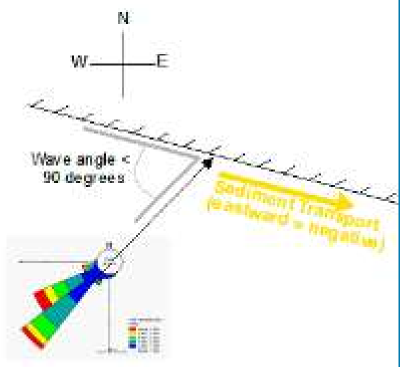
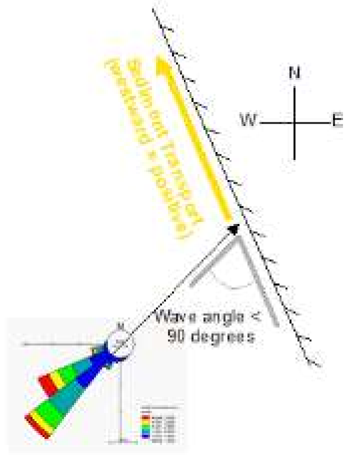
<table>
<tr><th>Wave Rose</th><th>Net Eastward Transport
(-ve m³/m)</th><th>Net Westward Transport
(+ve m³/m)</th></tr>
<tr><td>
</td><td>
</td><td>
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Figure 2-72 Simplified schematic of net sediment transport, wave direction and beach angle

The direction and average annual volume of the net sediment transport potential along the coast (based on hindcast data from 1982-2020) are presented in Figure 2-73. The naming of the profile relates to the wave data provided by the University of Melbourne. The modelling indicates that material moves from Flat Rocks across the entrance to Anderson Inlet and towards the Venus Bay settlement in diminishing volumes until there is a reversal in net sediment transport direction from Cape Liptrap west towards the Venus Bay settlement area.

This contrasts with the previous Holocene epoch development of dune ridges extending from Cape Liptrap to Point Smythe forming Anderson Inlet as visible in the LiDAR topography (Figure 2-4, Section 2.1.1).

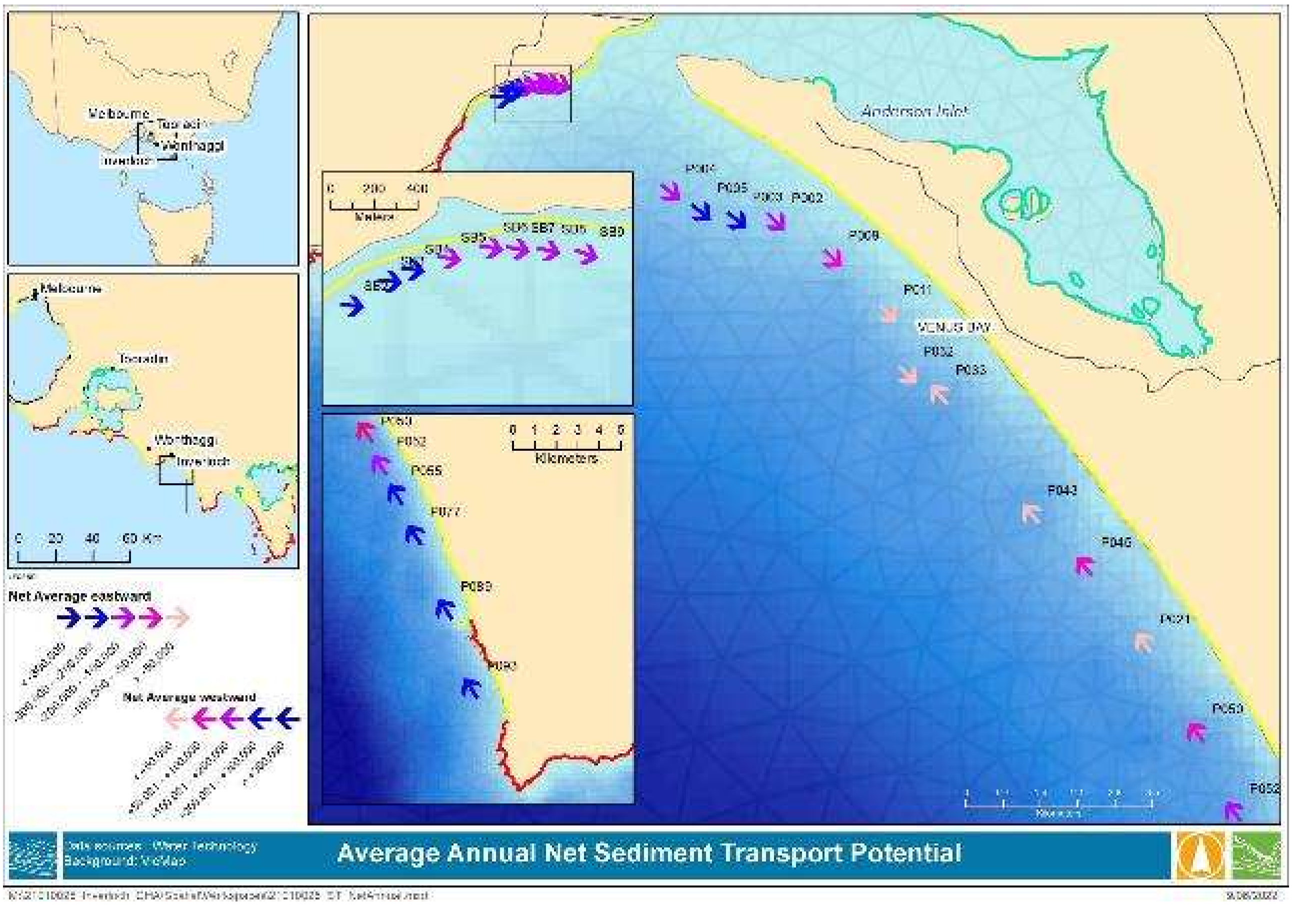

Figure 2-73 Direction and Average Annual Net Sediment Transport Potential

The sediment transport rates presented in Figure 2-73 are the average annual rate of the simulation period from 1982 through 2020. The volume of sediment transport potential can vary significantly on a number of timeframes across the study area. Additional analysis of the results is provided below. The conditions to the west of the entrance, which are more protected and influenced by diffraction and refraction are presented separately from the exposed coastline from Point Smythe to Cape Liptrap.

Point Smythe to Cape Liptrap

Net and Gross Sediment Transport Potential

The net sediment transport along the open coastline east of Point Smythe is initially from west to east away from the entrance until the angle of the beach is in a stable alignment with the incoming wave direction and there is little to no net sediment transport – between wave points P011 and P043 (Figure 2-73). Close to Point Smythe there is a notable curvature in the coastline at P005 and P003 which have a more southerly face than P004 at the western end of the beach which leads to an increase in transport potential east at these two profiles compared to P004 and P002. East of P043, net transport potential towards the entrance increases and there is a notable increase in both the net and gross transport from P055 towards Cape Liptrap as the coastline aligns to face west of the incoming wave climate.

The annual variation of the net, and gross sediment transport potential is shown in Figure 2-74, illustrating the range of the annual transport rates can vary significantly around the average, especially where there are higher rates of transport. Between P032 and P043 the annual transport direction can also vary from year to year.

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Interestingly, the section of coast between P032 and P043 aligns with the northern extent of the underlying Bridgewater Foundation calcareous dunes (see Figure 2-3), and location of a potential earlier entrance for the Tarwin River embayment.

Seasonal Sediment Transport Potential

Also presented is the variance of the sediment transport across a calendar year (Figure 2-75). As discussed in Section 2.3.3, there is notable seasonality in the wave climate, with calmer and more southwest conditions dominant in the summer compared with more energetic and more west-southwesterly conditions in the winter months. The angle of the coastline is such that these winter conditions drive stronger transport eastward at the Point Smythe end of the beach in the winter months, with less net eastward transport occurring in the summer. At the Cape Liptrap end of the beach there is less seasonal variation, with slightly higher transport observed in the transitional seasons of autumn and spring. Transport potential in the area where there is low net transport (i.e. P011 through P043) show higher net transport potential west towards the entrance in summer and east, away from the entrance in winter. This illustrates the potential for sediment to shift along the coastline throughout the year, nourishing and denuding the beach profile of material.

Sediment Transport Potential across the beach profile

The net and gross sediment transport potential represent the potential volume of sediment passing across the total extent of the cross shore beach profile. The LITPAK modelling also provides a description of where across the beach profile transport occurs, allowing an understanding of the depth and extent offshore in which the sediment moves.

Typical of an open ocean beach, the sediment transport occurs primarily within the breaker zone, from -6m AHD to +1m AHD, with peak transport generally occurring between -3m AHD and -1m AHD (Figure 2-76). This aligns with LiDAR bathymetry presented in Section 2.2.2 with bars and channels forming through breaking waves and rip channels which distribute sediment along the open beaches.

Annual Variation of Sediment Transport Potential

The variation in the sediment transport potential across the near 40 year hindcast simulation is noted by the maximum and minimum lines in the net and gross annual transport graphs (Figure 2-74). The timeline of the variation has been further assessed and a pattern of cyclical higher or lower than average transport potential on the 5-year average data is observed which is similar to the wave direction pattern noted in Section 2.3.3.3. The variance (coloured bars), annual average of the variance (grey dash line) and a 5-year rolling average of the average variance (black line) are presented in Figure 2-77. Between 1995 and 2000 there was an increase in easterly, and decrease in westerly, transport (i.e. a positive variance) which reversed the following half decade from 2000 through 2005 where greater westerly and less easterly transport potential occurred. From 2005 to 2013, more easterly and less westerly transport than the long term average then occurred along the beach before 2014 through to present experienced a strong increased in westerly, and decrease in easterly transport potential. Transport potential through to the end of 2020 appears to be still more westerly than average, although not increasingly so. Since 1995 the variance from the average has been more uniform along the beach, although the annual data does show variance from year to year which is smoothed by the 5 year averaging.

The total annual net transport potential is presented in Figure 2-78 and again highlights the significant sediment transport potential along the open coastline along with the variability from year to year. The right-hand side of the chart reaffirms the assessment in Figure 2-77 that a greater westerly (or less easterly) transport potential occurs from around 2012. Linear trends on the annual net transport also shows a slope in the data becoming more westerly (or less easterly).

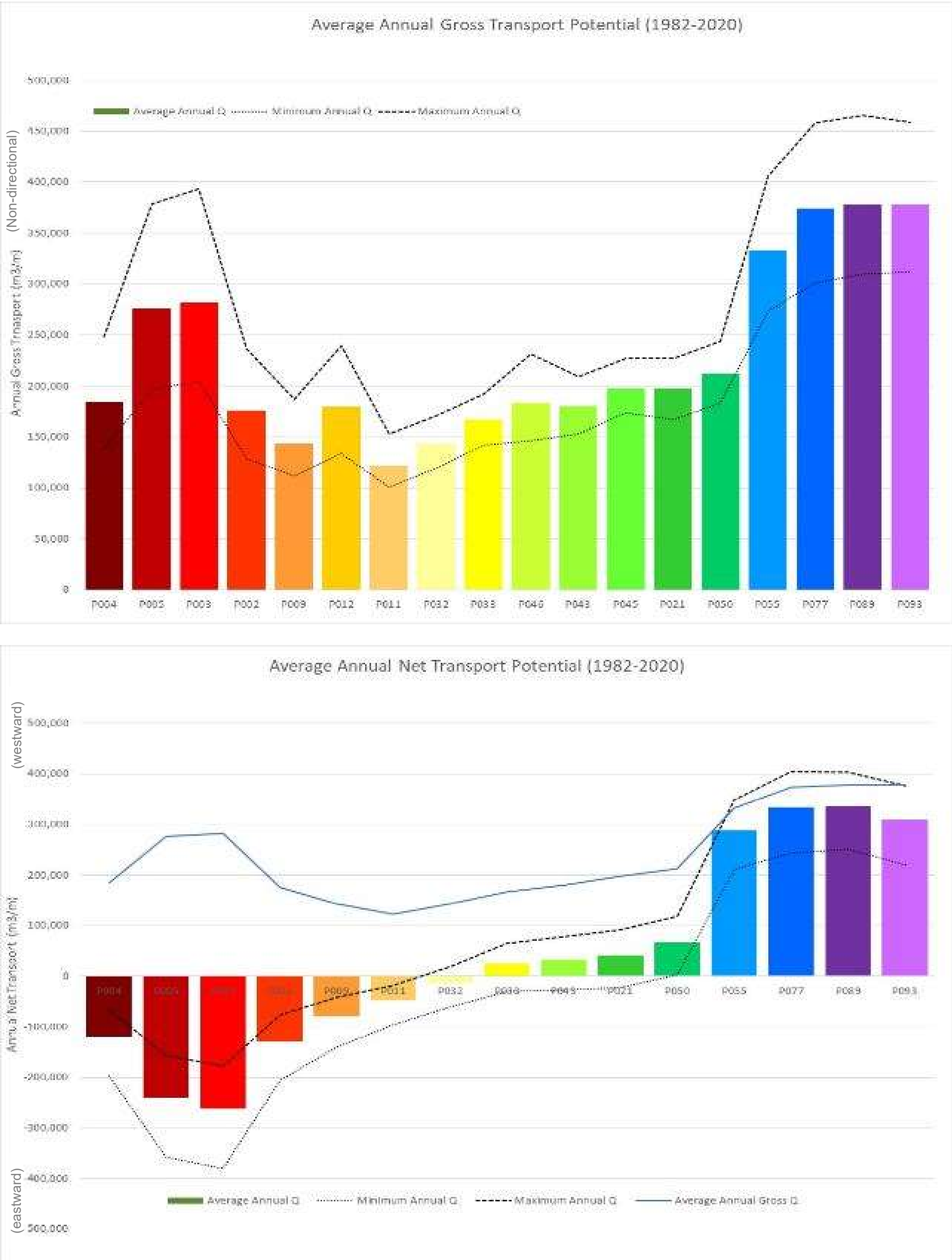

Figure 2-74 Average Annual Gross and Net Sediment Transport Potential, Point Smythe to Cape Liptrap

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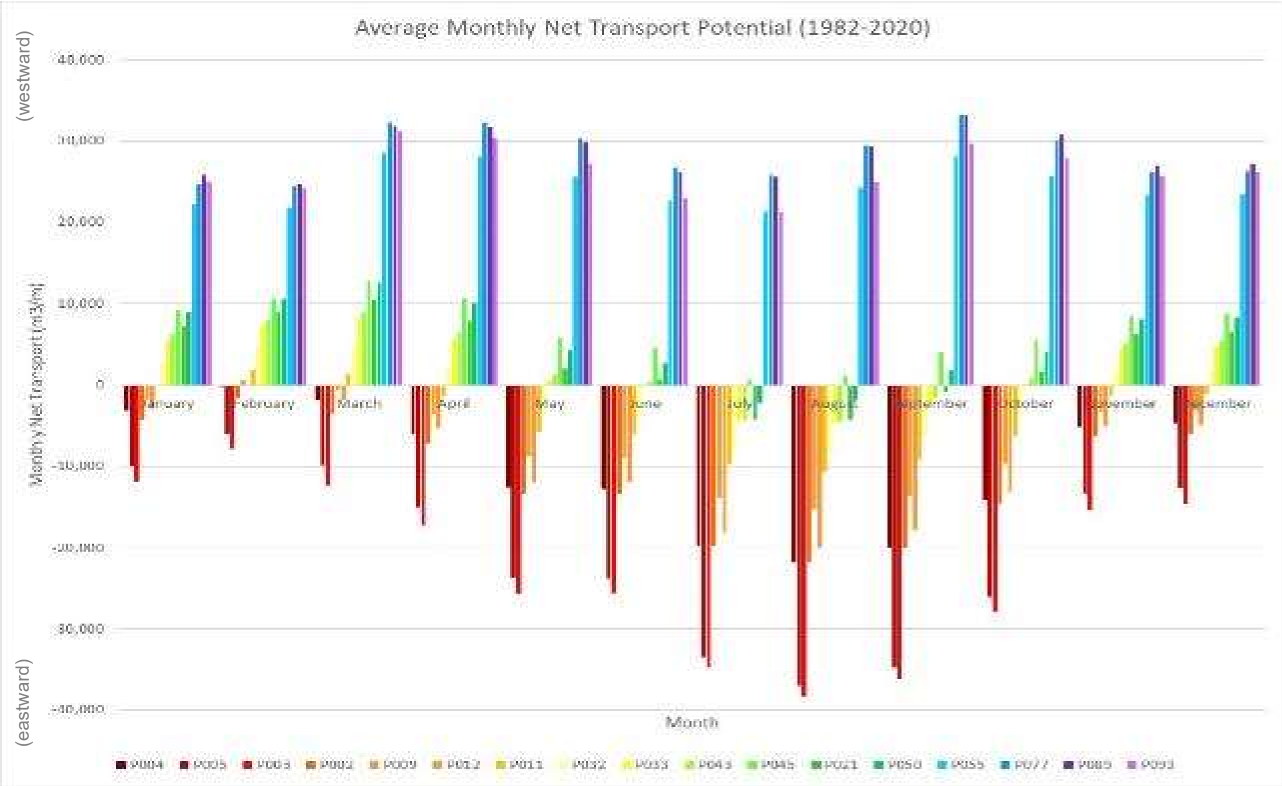

Figure 2-75 Average Monthly Net Sediment Transport Potential, Point Smythe to Cape Liptrap

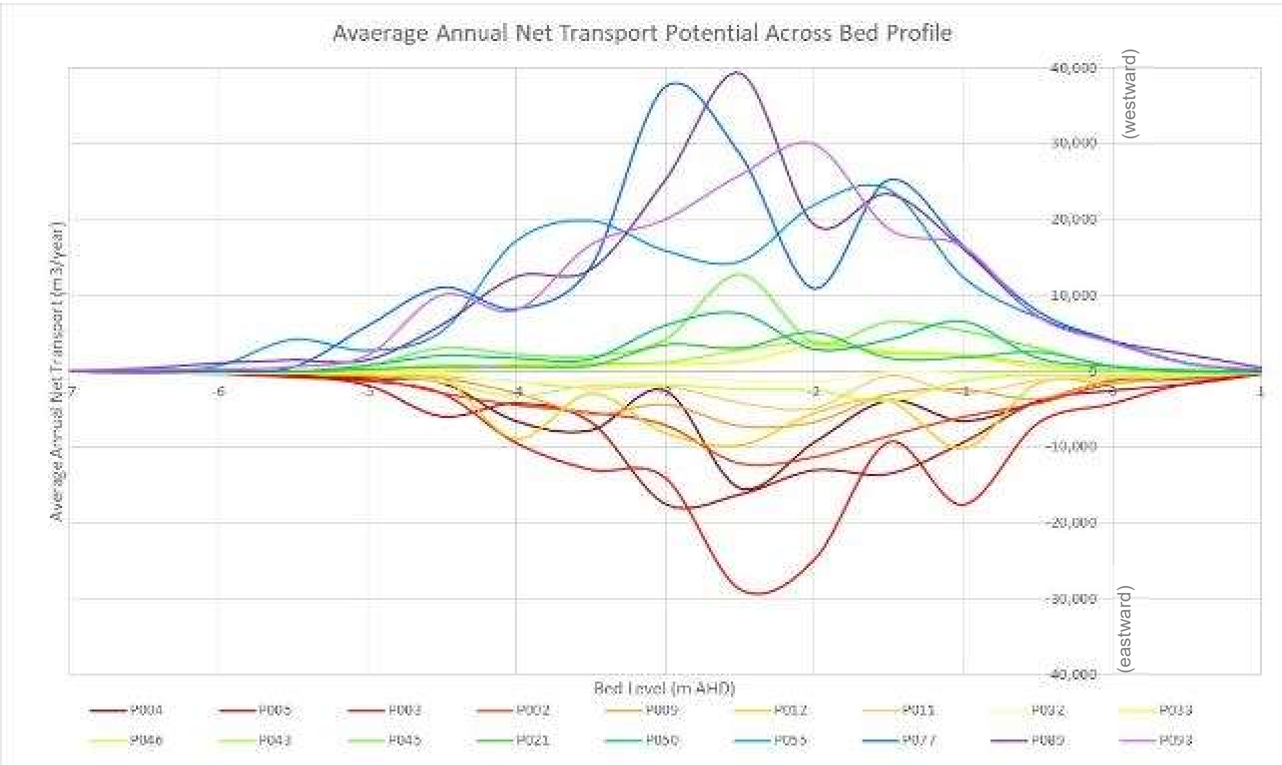

Figure 2-76 Average Annual Net Sediment Transport Potential across Bed Profile, Point Smyth to Cape Liptrap

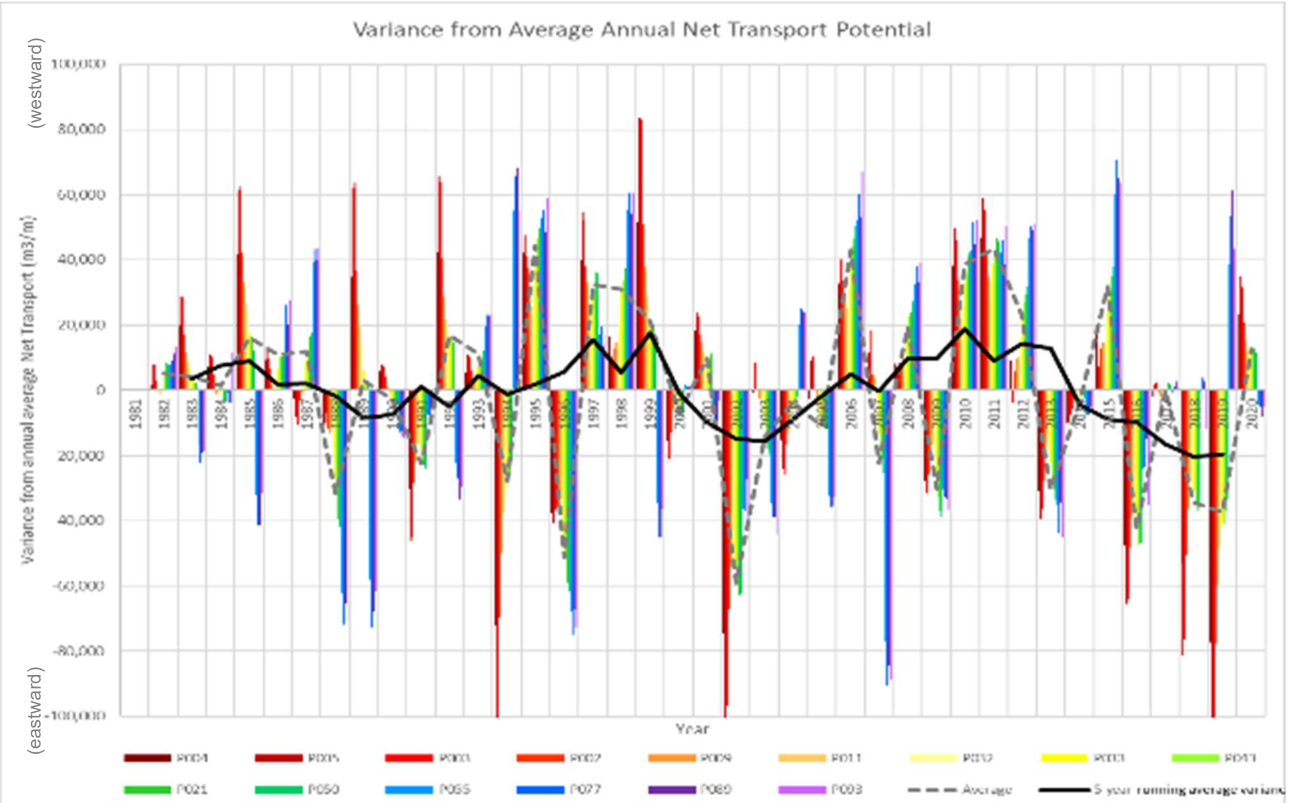

Figure 2-77 Annual Variance from Average Annual Net Sediment Transport, Point Smythe to Cape Liptrap

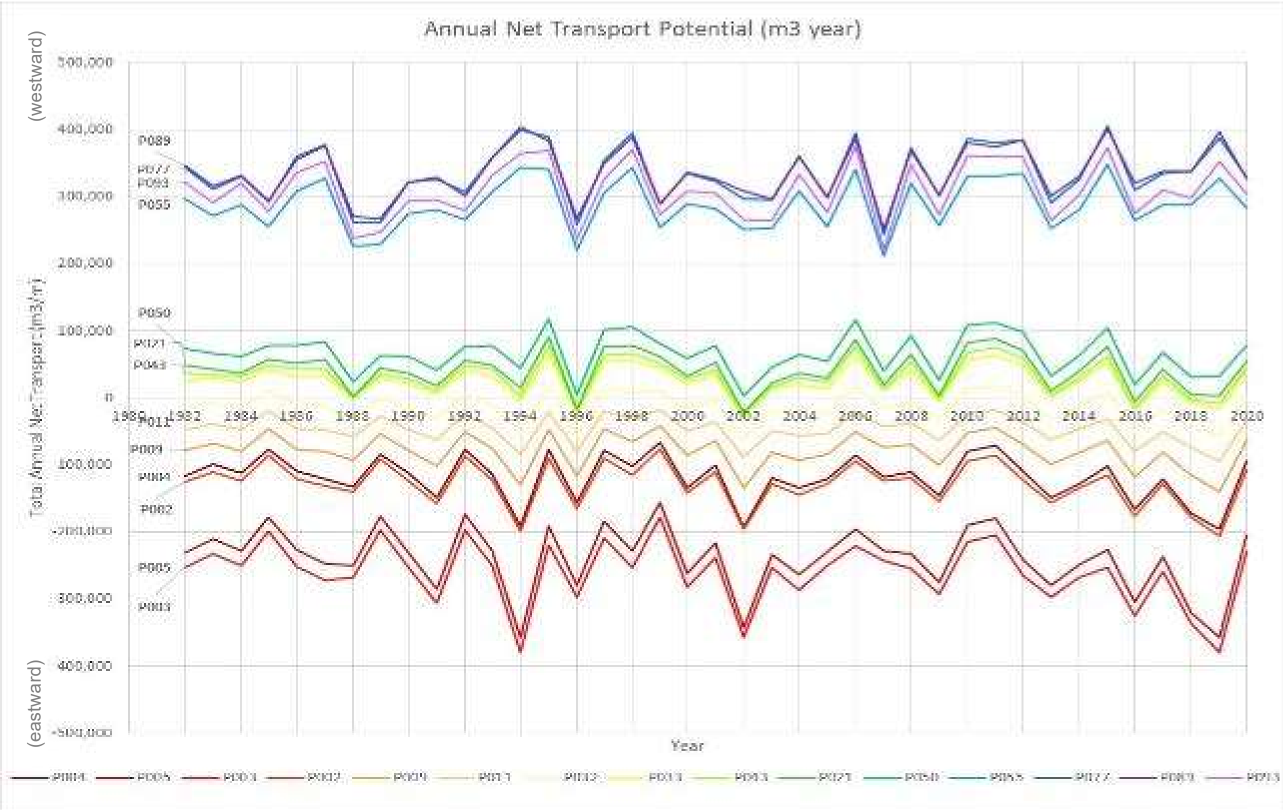

Figure 2-78 Annual Net Sediment Transport Potential, Point Smythe to Cape Liptrap, 1982-2020

Flat Rocks to Point Norman

It is important to note in preface to this analysis that the beach conditions between Flat Rocks and Point Norman, i.e., Surf Beach, have been changing rapidly in the past 10 years. This analysis has been completed using bed profile data which is likely to be different to the current beach condition and different to that which has been present for the whole duration of the wave hindcast and simulation. Wave modelling has been completed to transform offshore wave conditions inshore to better represent the locally reduced wave heights due to shallow depths and refraction around Flat Rocks, however there is no calibration data available to confirm the wave conditions inshore.

These factors should be considered when reviewing these results and the general patterns and relative conditions along the beach should considered with more weight than the numerical values of the sediment transport rates.

Whilst modelling was completed for additional profiles west and east of those presented, the results are not considered robust enough to include in the discussion due to additional uncertainty on wave transformation across the rocks in the west and refraction of wave direction into the Point Norman sand shoal.

Net and Gross Sediment Transport Potential

The net sediment transport along the Surf Beach foreshore is from west to east towards Point Norman and the entrance, as presented in Figure 2-79. The transport potential is highest in both net and gross transport potential at Point 003 just east of the Bunurong Road rock revetment. Transport potential reduces from the 2018 entrance to Wreck Creek past the SLSC towards Point Norman. The rate of transport along this coast approaching the entrance to Anderson Inlet will vary considerably with the bathymetry between Wave Street and Point Norman. When there is a considerable amount of sand offshore of Point Norman and the beach alignment faces more south-west than south, the net sediment transport will reduce. When there is less sand at Point Norman and the offshore contours are relatively parallel with the coastline the net sediment transport will increase.

The range of net and gross sediment transports across the hindcast are shown in Figure 2-79, indicating the annual transport can vary by 20-30% of the average level.

Seasonal Sediment Transport Potential

The variance of the sediment transport across a calendar year is presented in Figure 2-80. As discussed in Section 2.3.3 and above, there is notable seasonality in the wave climate, with calmer and more southwest conditions dominant in the summer compared with more energetic and more west-southwesterly conditions in the winter months.

The average net monthly transport potential along the beach is eastward year round. The angle of the coastline along Surf Beach is such that waves from east of south are required to drive any transport to the west (i.e. a net positive transport potential). Whilst these waves do occur, they are of limited energy and duration and the average net monthly transport for all months is still eastward, albeit with less intensity during the summer months compared to the winter and early spring conditions.

Sediment Transport Potential across the Beach Profile

As with the Venus Bay open coast, the transport potential across the beach profile transport has been assessed to provide an understanding of the depth and extent offshore which the sediment moves at Surf Beach. It is noted again at this beach there has been significant change in the beach profile in the past decade and the location of the peak transport on the beach may vary over time.

Noting this, the majority of the sediment transport potential along the Surf Beach occurs in water shallower than 4m and predominantly on the bed between -2m AHD and -1m AHD. The distance offshore of these levels varies along the coast but is located approximately 50 to 150m offshore. Review of the bathymetric survey from 2009 and 2020 (Section 2.2.2) indicates the distance from the 0m AHD to the -2m AHD contour has remained relatively consistent, albeit shifting landward as the coastline has eroded.

Annual Variation of Sediment Transport Potential

As with the Venus Bay open coast, the timeline of the annual variation has been further assessed by comparing the average transport in each year with the long term annual average. The pattern of higher or lower than average transport potential (equating to less or more than average eastward transport respectively at Surf Beach) is presented in Figure 2-82. The cyclical pattern relating to wave conditions noted at the open coast is again evident at Surf Beach. The long term average shows lower levels of eastward transport potential occurring in the 1980s before becoming greater than average for a short period in the mid-1990s, driven by a year of very strong easterly transport potential in 1994. Through the late 1990s and 2000s conditions oscillate around the long term average on an annual basis, with a slight bias to less than average transport over the longer term. From 2012 the long term average transport potential trend becomes notably stronger east than average, driven by increasing net transport east through 2015-16 and 2018-19. As with the open coast, 2020 conditions are less eastward than the long term average.

The running 5-year average variance along the Venus Bay open beach and the average of profiles along Point Smythe (P004-P011) are also shown in Figure 2-82 to illustrate the change along the Study Area coastline. Notable differences in the beaches are the more balanced conditions when considering the whole Venus Bay coastline – which includes the more dominant west transport potential towards Cape Liptrap. Conditions at the profiles along Point Smythe are more similar to Surf Beach, however with smaller variation in the 1980s and 1990s and greater variation in the 2000s. The change from relatively neutral average transport to strong eastward transport along Point Smythe and the Venus Bay coast occurs 1-2 years after the conditions are observed at Surf Beach.

The total annual net transport potential on Surf Beach is presented in Figure 2-83 and highlights variability from year to year, including the spike in eastward transport in 1994 and the trend for stronger westerly transport potential from 2010 to 2019.

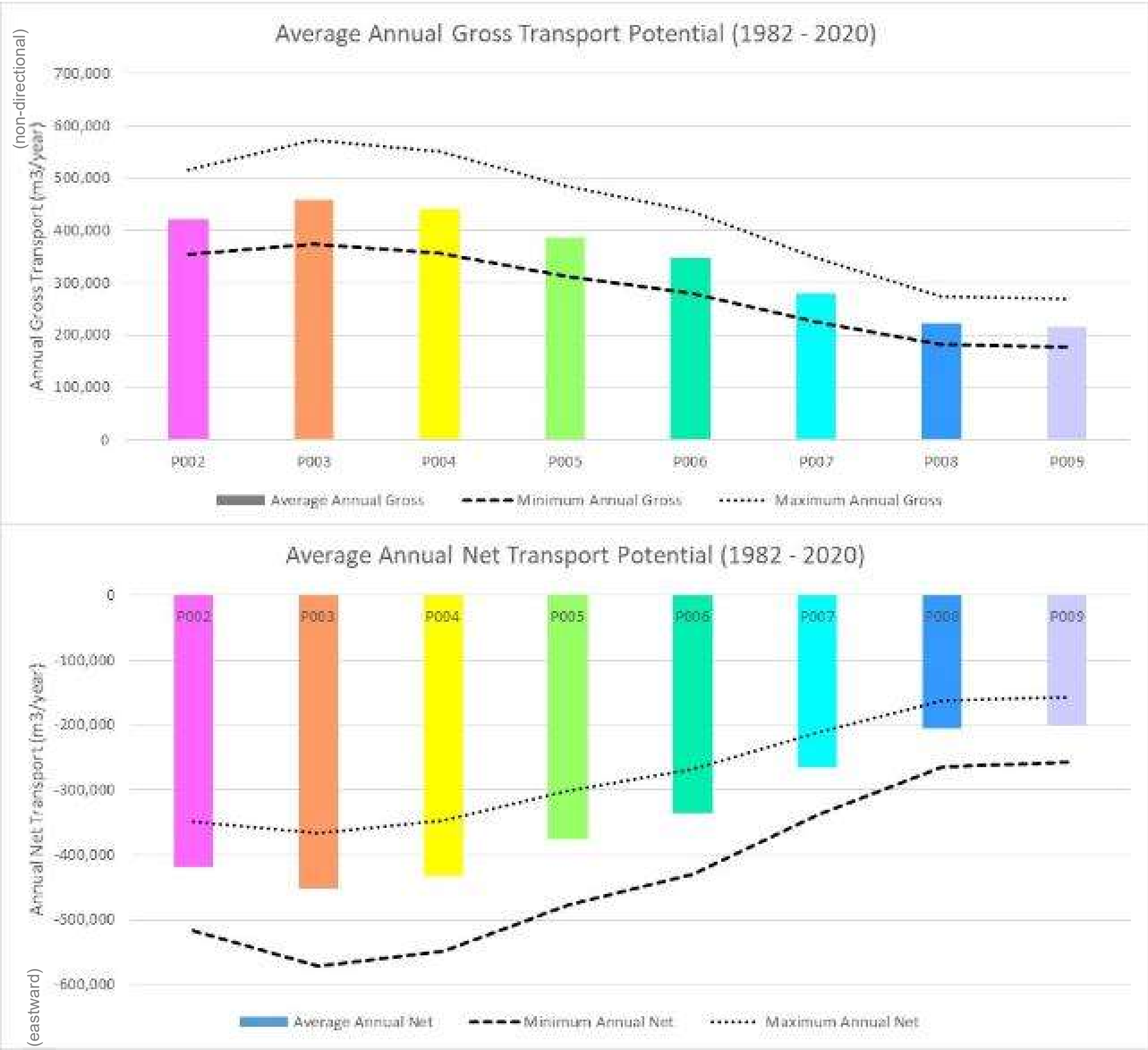

Figure 2-79 Average Annual Gross and Net Sediment Transport Potential, Surf Beach

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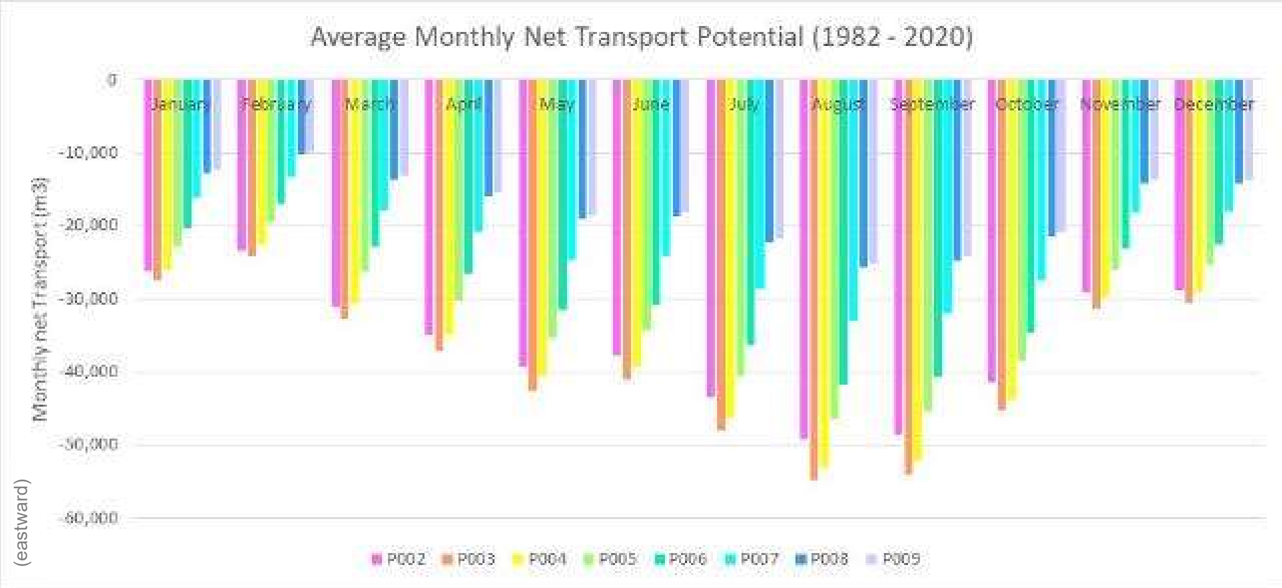

Figure 2-80 Average Monthly Net Sediment Transport Potential, Surf Beach

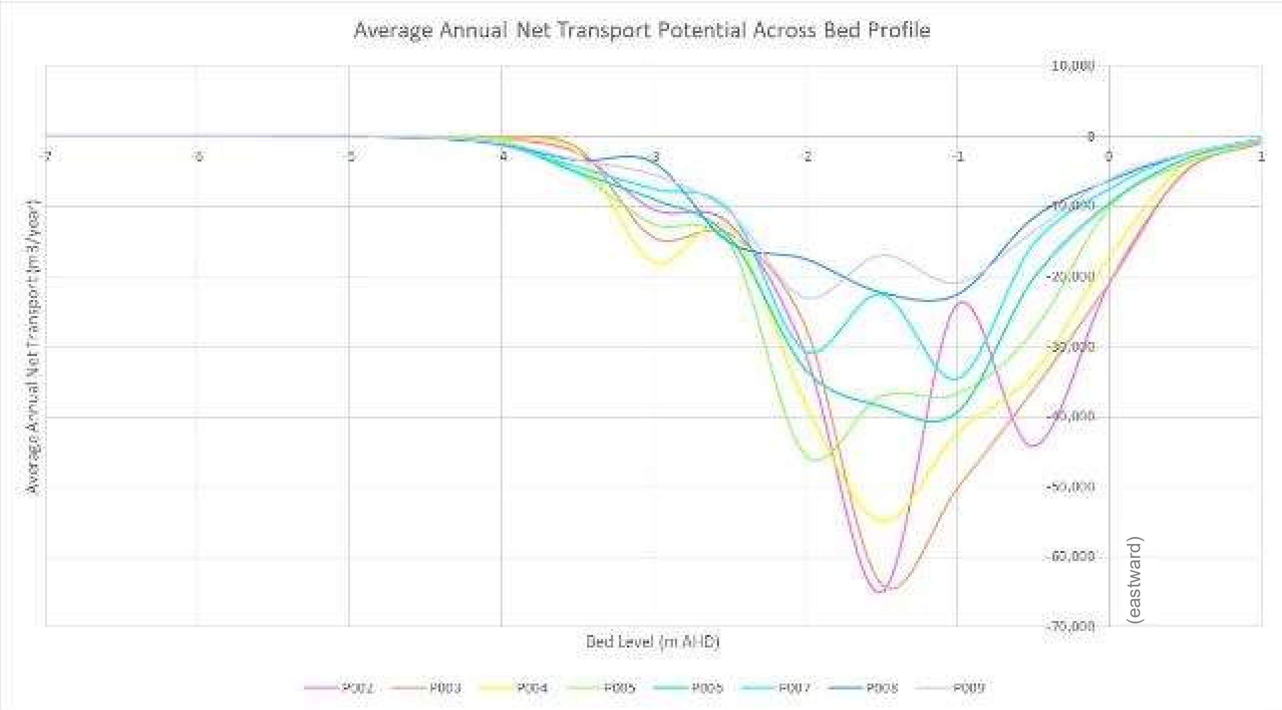

Figure 2-81 Average Annual Net Sediment Transport Potential across Bed Profile, Surf Beach

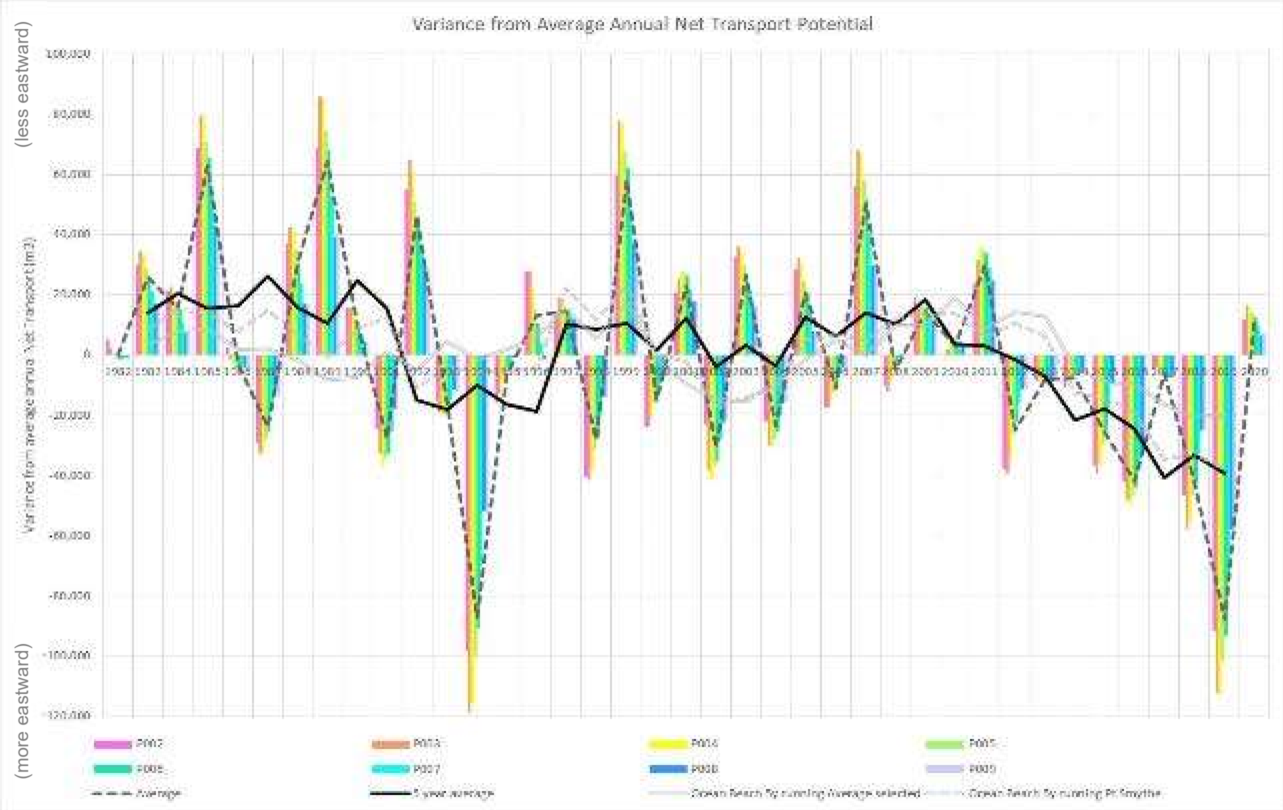

Figure 2-82 Annual Variance from Average Annual Net Sediment Transport, Surf Beach

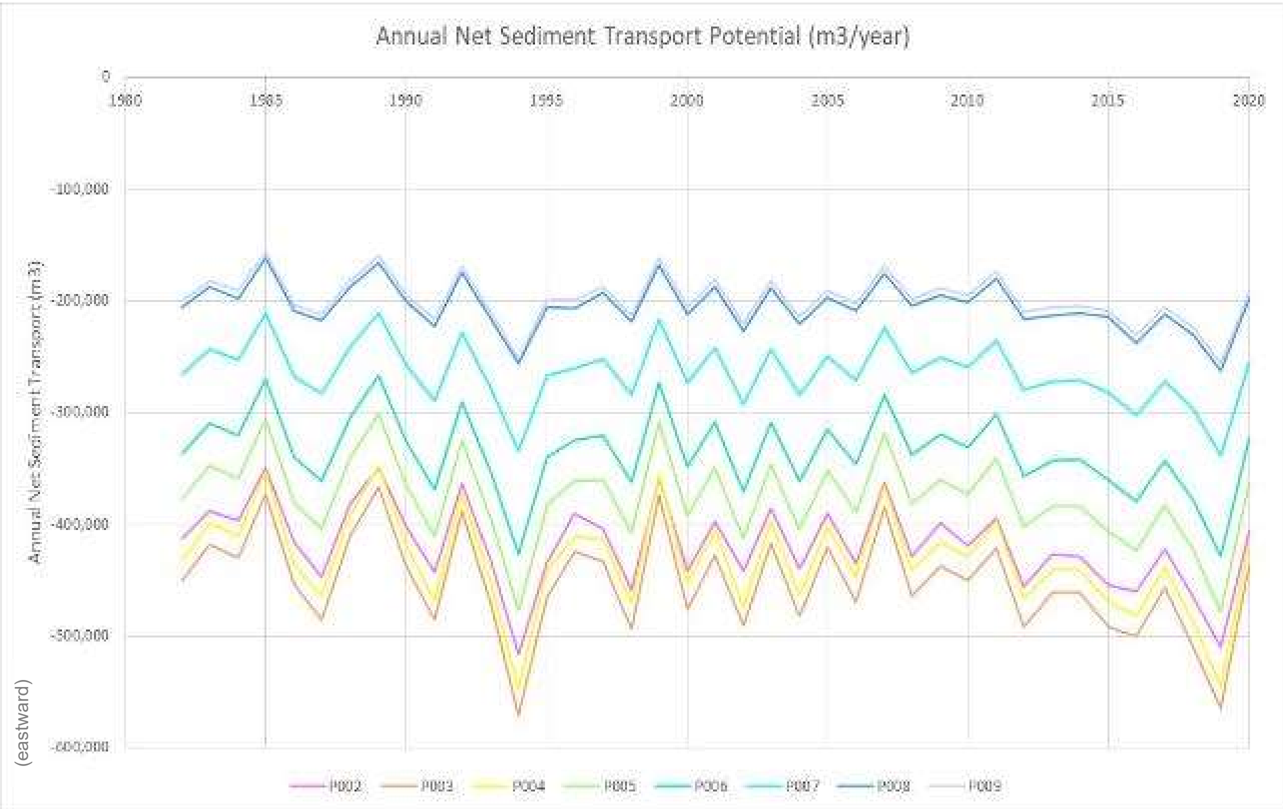

Figure 2-83 Annual Net Sediment Transport Potential, Surf Beach, 1982-2020

2.4.5 Sediment Sources and Sinks

A key area of uncertainty in the understanding of the coastal processes is the source of sand to the Study Area. The following observations are noted:

- The cross shore bathymetry captured in the 2008/09 LiDAR shows convex beach profiles at Surf Beach and concave beach profiles along the open Venus Bay coastline (Figure 2-28). A convex beach profile illustrates a beach profile with greater volumes of sand than the equilibrium profile. A concave beach profile can represent both the cross shore profile in equilibrium, or a profile with a deficit of sand.
- Sediment grain size is relatively constant across the Study Area, with sediments sampled in the range of 0.2-0.3mm median grain size. Coarser grain sediment is common on the bars where higher currents mobilise the finer sediment.
- Offshore multibeam survey and underwater video has identified the offshore area as comprising sedimentary bedforms devoid of visible biota.
- Astronomical tidal currents in the Study Area are low, the area being the meeting point of the tidal waves from the west and east of Bass Strait. This could result in only small volumes of sedimentary material being supplied by the adjacent secondary sediment cells either side of the Venus Bay cell (and not passed on).
- The constant eastward sediment transport along Surf Beach with a prograding (1950s-1970s), relatively stable (1980s-2000s) and rapidly eroding (2012 – present) shoreline suggests that sediment is supplied to the coastline from an offshore source.
- Accretion of the open coast shoreline at the extent of Point Smythe is noted in aerial imagery since 2015 despite the local increase in net sedimentation east towards the Venus Bay settlments. However, the same increase in eastward transport at Point Smythe also occurs on Surf Beach. The accretion at Point Smythe is likely material lost from Surf Beach and the nearshore bar being pushed towards the Venus Bay coastline.
- The opposing alongshore sediment transport rates towards the centre of the Venus Bay open coastline but lack of prograding shoreline at the confluence of the opposing transport suggests that sediment is lost offshore along this coastline. Likewise the lack of significant rates of coastal recession at Point Smythe and Cape Liptrap indicate sediment is supplied to these beaches in a rough equilibrium with that lost to the alongshore transport rate.

3 COASTAL PROCESS SYNOPSIS

The coastal process drivers and resulting coastal processes described in Section 2 have been used to generate the following synopsis and conceptual diagrams.

The initial two conceptual diagrams show the coastal processes acting in the whole Study Area. The following diagrams present the area from Flat Rocks across the entrance to Point Smythe where there is the most dynamic change of the shoreline. The synopses aim to show the dominant coastal process drivers identified from the analysis in Section 2. The summary of diagrams is provided in Table 3-1.

For each of the different drivers there is considerable noise around the relationship between the driver and the response of the coastline, as well as the interplay between different combinations of coastal process drivers. The strength of any one driver can be a guide to the potential response of the coastline, but not a predetermination. The coastal process drivers and the variability of the individual forces will continue to influence the coastline in the Study Area into the future, and climate change may further affect the interaction and response of the coastline in varying ways.

Table 3-1 Coastal Process Concept Diagrams

	Concept	Extent
1	Hydrodynamic / Oceanographic and Sediment Transport Processes within the Study Area	Full Study Area
2	Stable entrance, strong relatively constant channel path	Entrance
3	Long entrance channel breakdown and additional channel flow path forming	Entrance
4	Entrance channel breakdown following flooding	Entrance
5	Ebb tide delta breakdown, sediment movement	Entrance
6	Surf Beach recession, channel stabilising	Entrance

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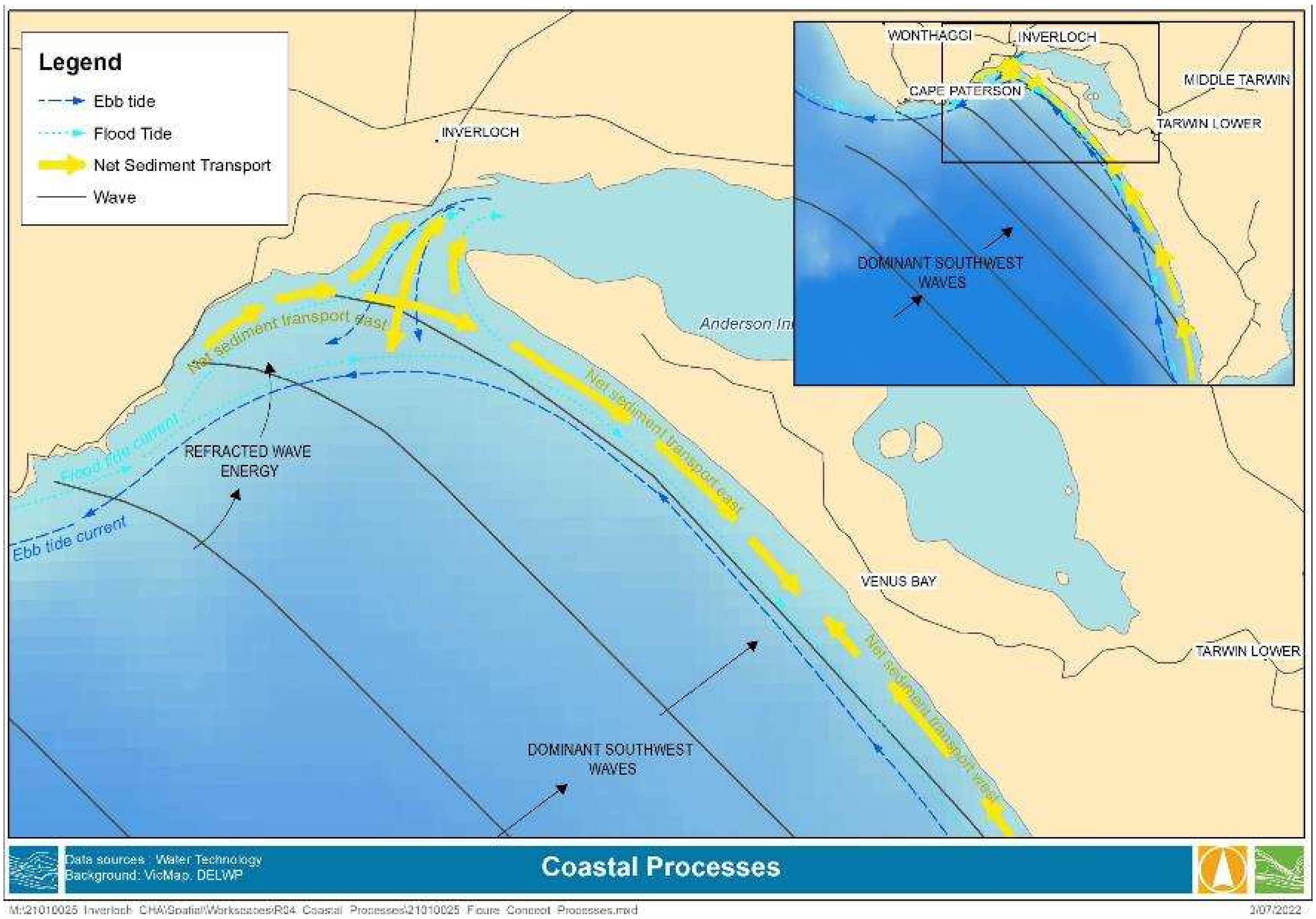
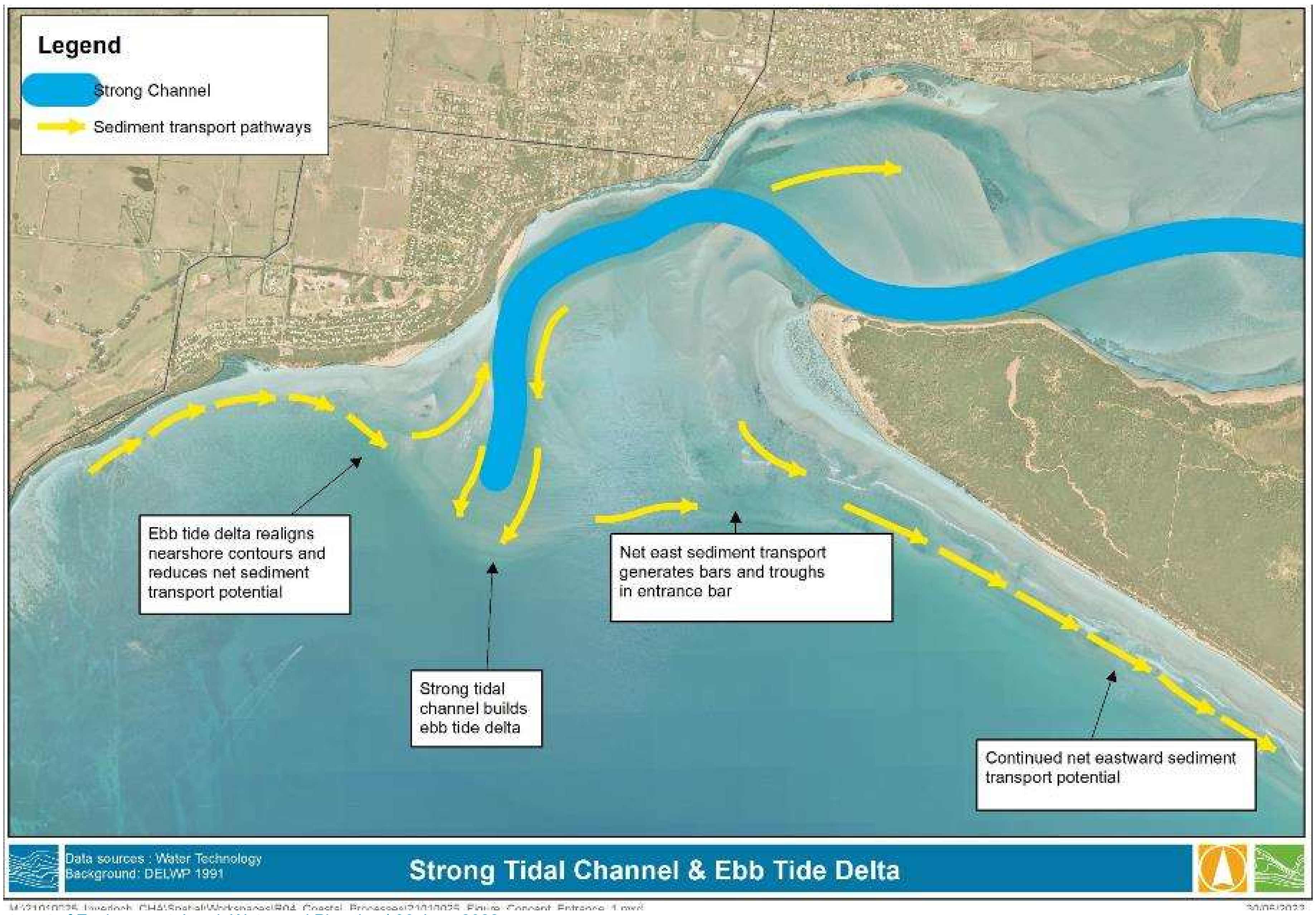
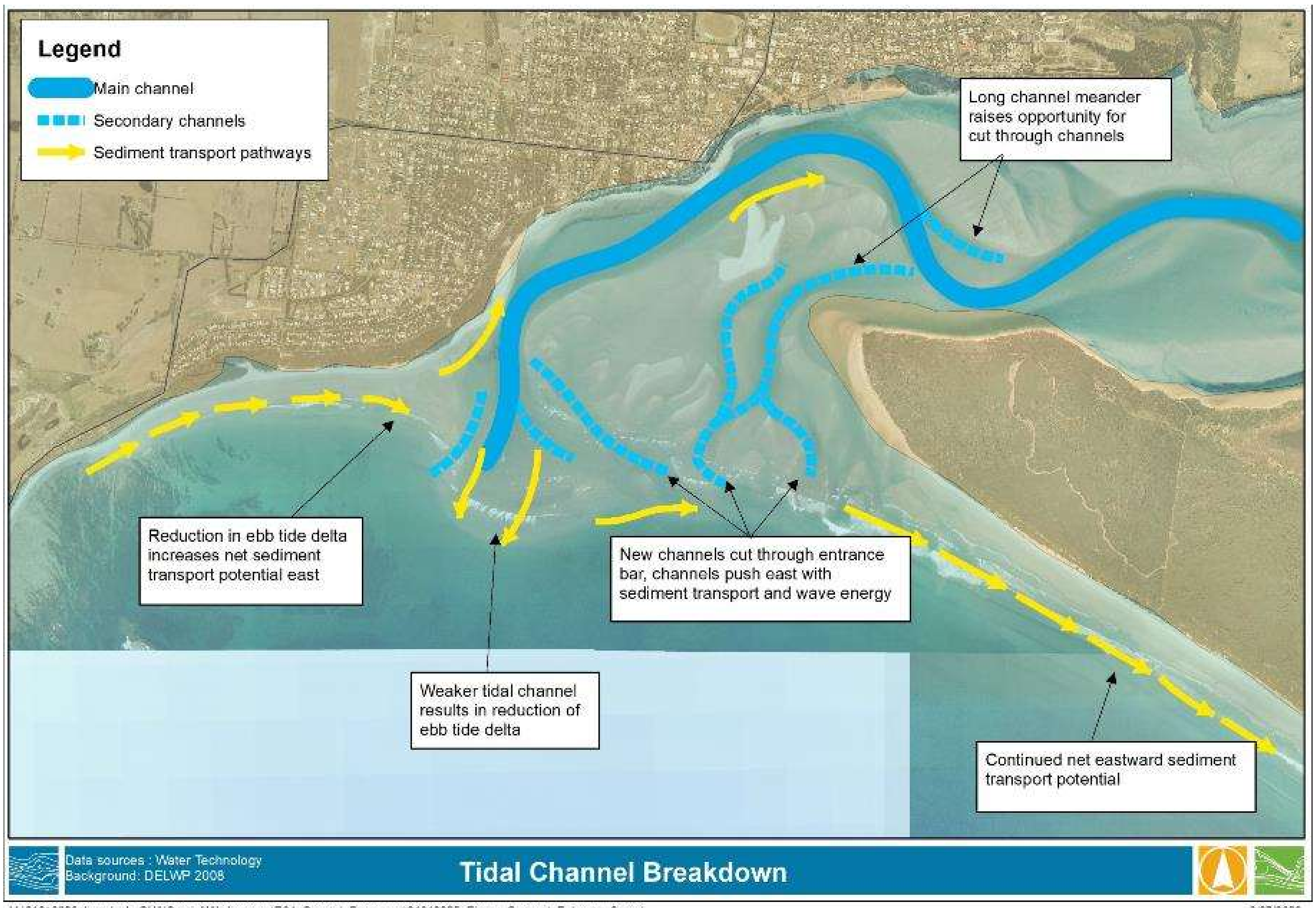
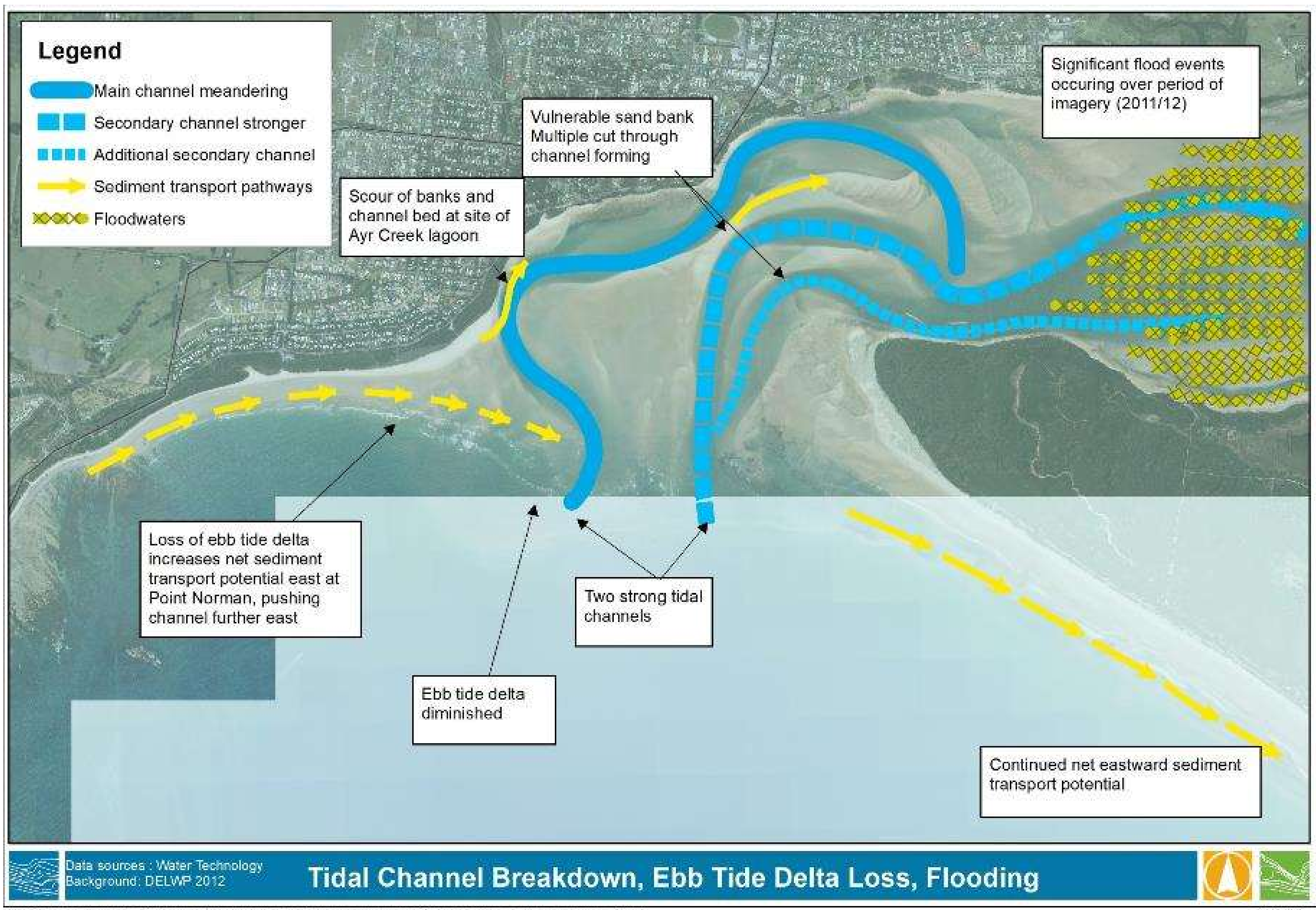
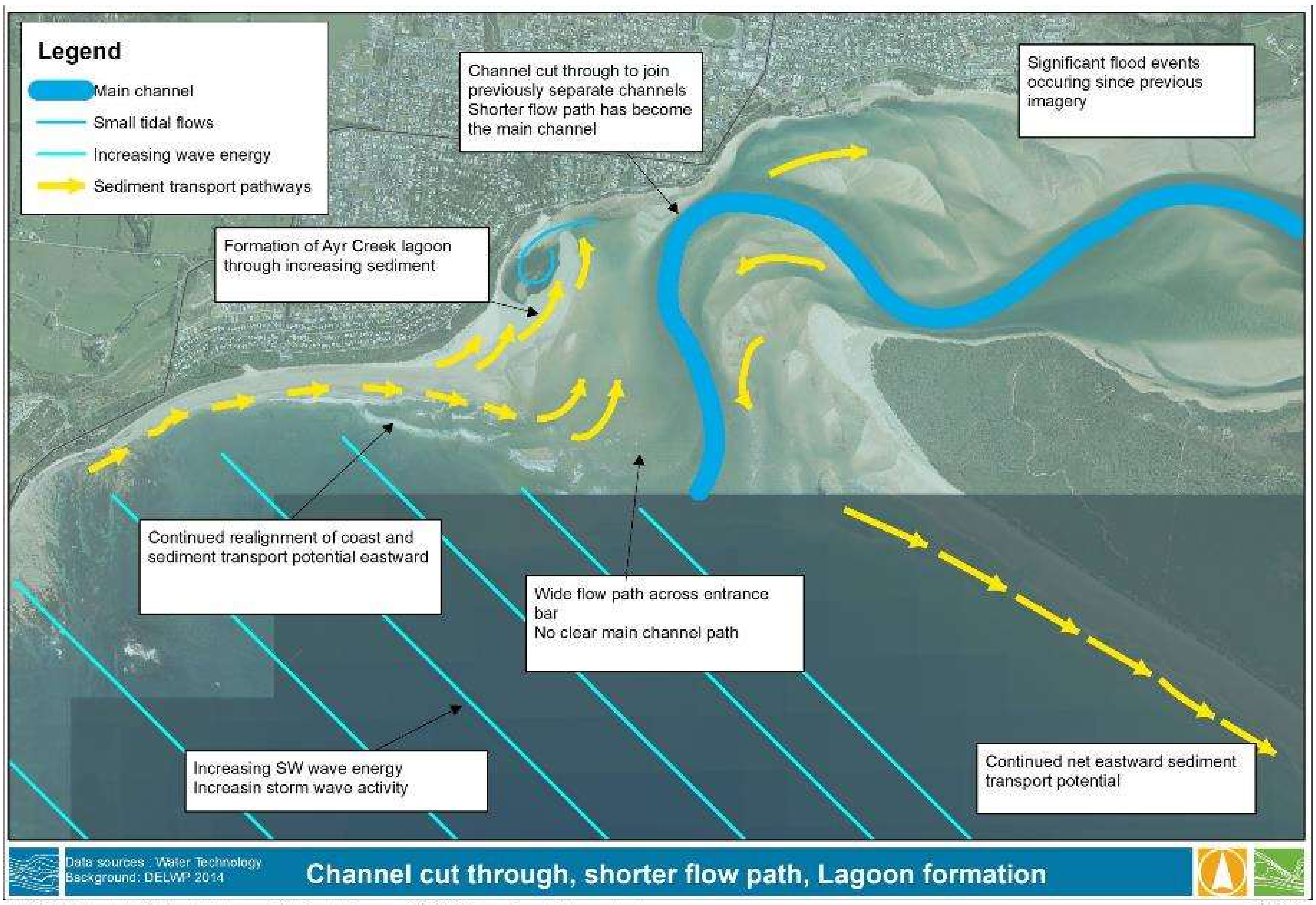
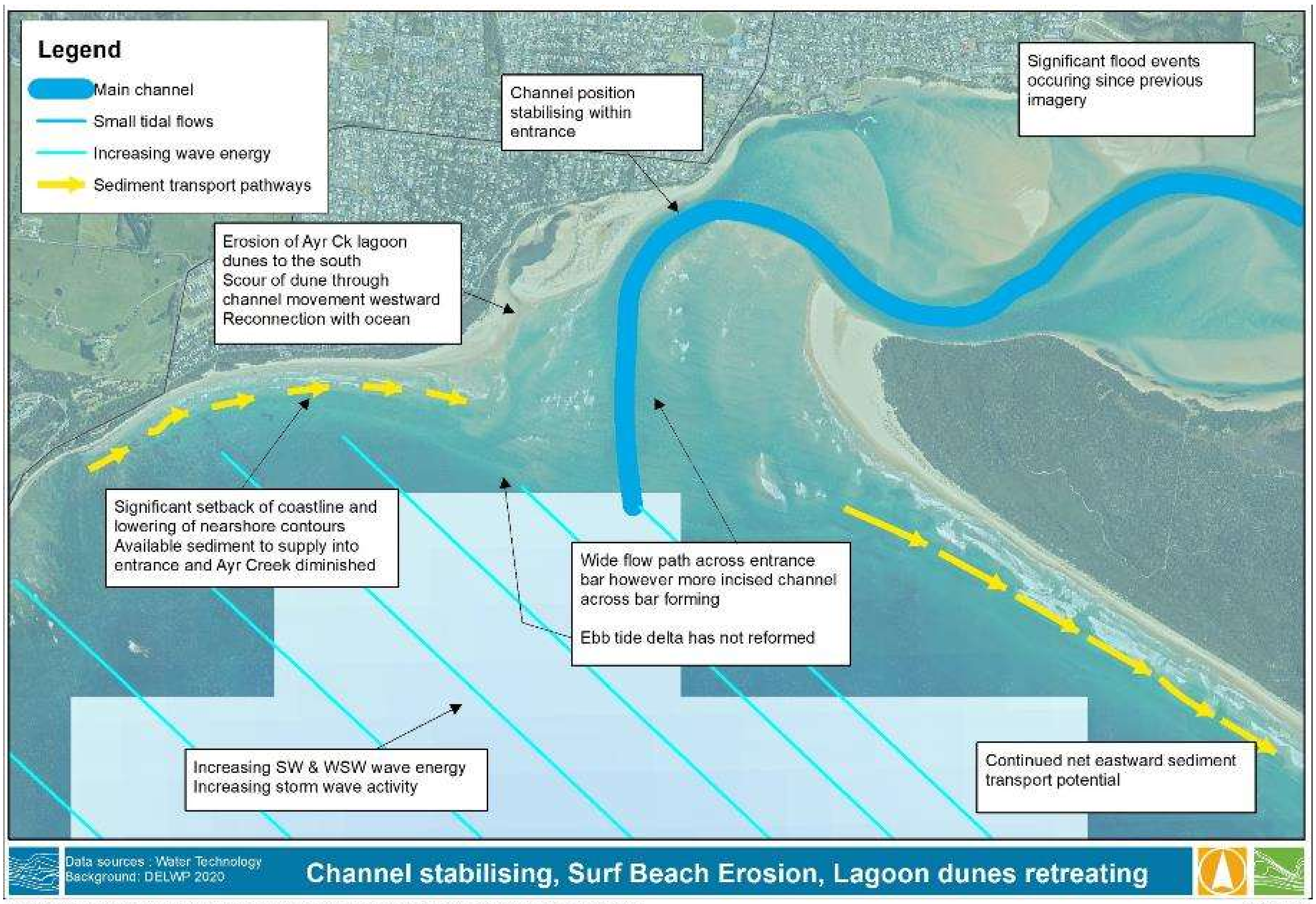

Legend
Ebb tide
Flood Tide
Net Sediment Transport
Wave
INVERLOCH
Anderson Inlet
Net sediment transport east
Flood tide current
Ebb tide current
REFRACTED WAVE ENERGY
Net sediment transport east
VENUS BAY
TARWIN LOWER
Net sediment transport west
DOMINANT SOUTHWEST WAVES
WONTHAGGI
INVERLOCH
CAPE PATERSON
MIDDLE TARWIN
TARWIN LOWER
DOMINANT SOUTHWEST WAVES
Data sources : Water Technology
Background: VicMap, DELWP
Coastal Processes
M:\21010025 Inverloch CHA\Spatial\Workspaces\R04 Coastal Processes\21010025 Figure Concept Processes.mxd
3/07/2022


Legend
Strong Channel
Sediment transport pathways
Ebb tide delta realigns nearshore contours and reduces net sediment transport potential
Strong tidal channel builds ebb tide delta
Net east sediment transport generates bars and troughs in entrance bar
Continued net eastward sediment transport potential
Data sources : Water Technology
Background: DELWP 1991
Strong Tidal Channel & Ebb Tide Delta


Legend
Main channel
Secondary channels
Sediment transport pathways
Long channel meander raises opportunity for cut through channels
Reduction in ebb tide delta increases net sediment transport potential east
New channels cut through entrance bar, channels push east with sediment transport and wave energy
Weaker tidal channel results in reduction of ebb tide delta
Continued net eastward sediment transport potential
Data sources : Water Technology
Background: DELWP 2008
Tidal Channel Breakdown
3/07/2022


Legend
Main channel meandering
Secondary channel stronger
Additional secondary channel
Sediment transport pathways
Floodwaters
Significant flood events occuring over period of imagery (2011/12)
Vulnerable sand bank Multiple cut through channel forming
Scour of banks and channel bed at site of Ayr Creek lagoon
Loss of ebb tide delta increases net sediment transport potential east at Point Norman, pushing channel further east
Two strong tidal channels
Ebb tide delta diminished
Continued net eastward sediment transport potential
Data sources : Water Technology
Background: DELWP 2012
Tidal Channel Breakdown, Ebb Tide Delta Loss, Flooding
3/07/2022


Legend
Main channel
Small tidal flows
Increasing wave energy
Sediment transport pathways
Channel cut through to join previously separate channels Shorter flow path has become the main channel
Significant flood events occuring since previous imagery
Formation of Ayr Creek lagoon through increasing sediment
Continued realignment of coast and sediment transport potential eastward
Wide flow path across entrance bar
No clear main channel path
Increasing SW wave energy
Increasin storm wave activity
Continued net eastward sediment transport potential
Data sources : Water Technology
Background: DELWP 2014
Channel cut through, shorter flow path, Lagoon formation
3/07/2022


Legend
Main channel
Small tidal flows
Increasing wave energy
Sediment transport pathways
Channel position stabilising within entrance
Significant flood events occuring since previous imagery
Erosion of Ayr Ck lagoon dunes to the south
Scour of dune through channel movement westward
Reconnection with ocean
Significant setback of coastline and lowering of nearshore contours
Available sediment to supply into entrance and Ayr Creek diminished
Wide flow path across entrance bar however more incised channel across bar forming
Ebb tide delta has not reformed
Increasing SW & WSW wave energy
Increasing storm wave activity
Continued net eastward sediment transport potential
Data sources : Water Technology
Background: DELWP 2020
Channel stabilising, Surf Beach Erosion, Lagoon dunes retreating

4 COASTAL EROSION HAZARD

The coastal processes and their drivers described previously have been used to define the extent of the coastal erosion hazard. The following section defines the assessment approach and extent of the different erosion hazard zones for each section of the Study Area coastline.

4.1 Overview of Assessment Approach

Further details of the approach to determining erosion hazard can be found in *Inverloch Region Coastal Hazard Assessment – Report 3 Technical Methodology*, Water Technology 2022. The erosion hazard has been determined based on the coastal type and the magnitude of potential erosion from short term erosion to long term and future recession.

4.1.1 Shoreline Segmentation

The study area has been classified into shoreline sub-classes (referred to by Rosengren as coastal geomorphic sectors (CGS)), defined by its backshore and shore zone (intertidal) landforms and materials. The shoreline sub-classes have then been grouped into five shoreline classes which bring together those sectors whose landforms and materials are likely to respond in a similar way to coastal processes and sea level rise and can therefore be assessed using the same analysis techniques.

Section 2.1.5.2 provides a description and mapping of the shoreline classes in the Study Area.

4.1.2 Total Erosion Calculation

The extent of the coastal erosion hazard zone is based on the response of the coastal geomorphic sector and shoreline class to coastal process drivers. For each shoreline class the potential short term, long term and sea level rise (SLR) component of the erosion hazard applicable to the specific location is identified, considering the backshore, intertidal and subtidal morphology.

The methodology for calculating erosion hazard within each shoreline class is provided in Report 3. The erosion hazard zone used in mapping will be in the form:

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

The erosion hazard zone is setback from the toe of the current dune position, based on imagery or survey. The setback has been set from the current dune toe to ensure that erosion hazard zones mapped on the current aerial imagery do not exclude eroded areas from the existing hazard zone (as would be the case if HAT or MHWS was used)

4.2 Storm Erosion

The shoreline response model SBEACH (Larson, 1989) has been used to determine the impact of design storm events on the sandy beaches across the study area. 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. For locations such as the rocky cliffs of the Bunurong Road coast, and the low earth shoreline of Anderson Inlet short term storm erosion has not been calculated.

The storm events used in the SBEACH analysis have been derived from the oceanographic data described in Section 2.3 and are further detailed in Appendix D, Report 3. An example of the input storm event, based on the existing 1% AEP storm tide and 1% AEP wave event occurring twice in series (i.e. two 120 hour storm events occurring with no recovery of the beach profile between storms), is presented below in Figure 4-1. This

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represented the conditions predicted for Profile 012, near to the Venus Bay Beach Carpark #4 on the Venus Bay open coast shore.

The beach profiles for SBEACH have been extracted from the 2008/09 LiDAR, or the more recently captured bathymetric survey (April 2021) and LiDAR (August 2021) for the coastline between Cape Paterson and Screw Creek. Sedimentary parameters in the model are based on data collected, discussed in Section 2.4.2.

Storm demand and coastal setback for each section of the Study Area coastline are presented in the following sections.

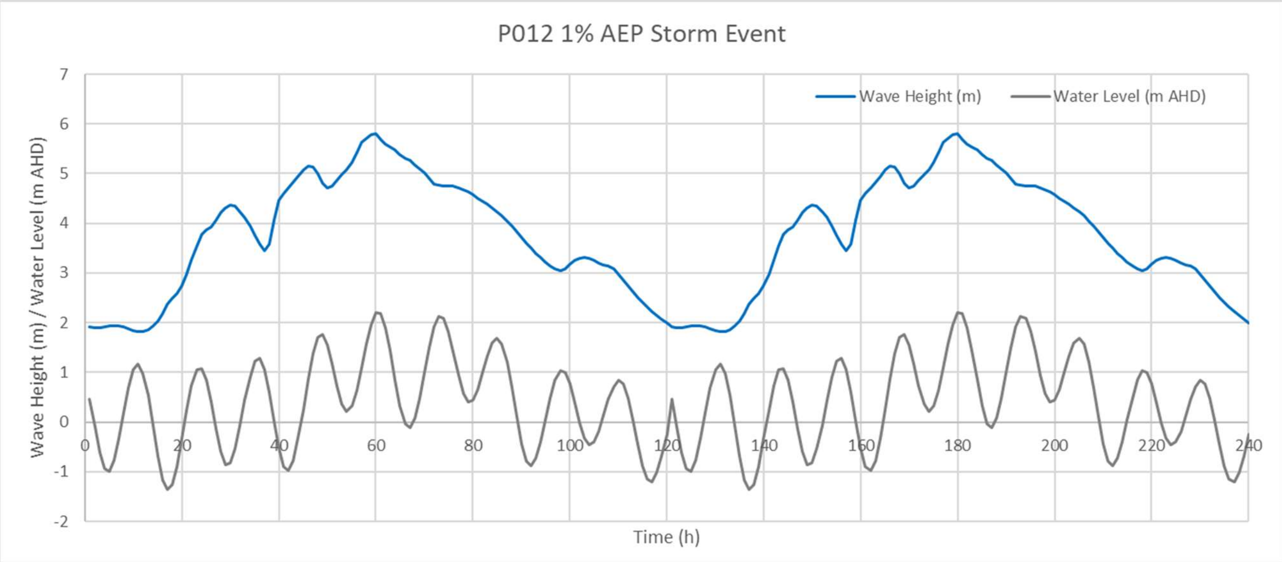

Figure 4-1 SBEACH Existing 1% AEP Input Storm Conditions

4.2.1 Bunurong Road

The Bunurong Road section of the Study Area comprises a number of perched beaches either fully constrained within two headlands (western end) or along an exposed rock ledge (eastern end). The extent of this section of the coast, and the pocket and perched beaches are presented in Figure 4-2.

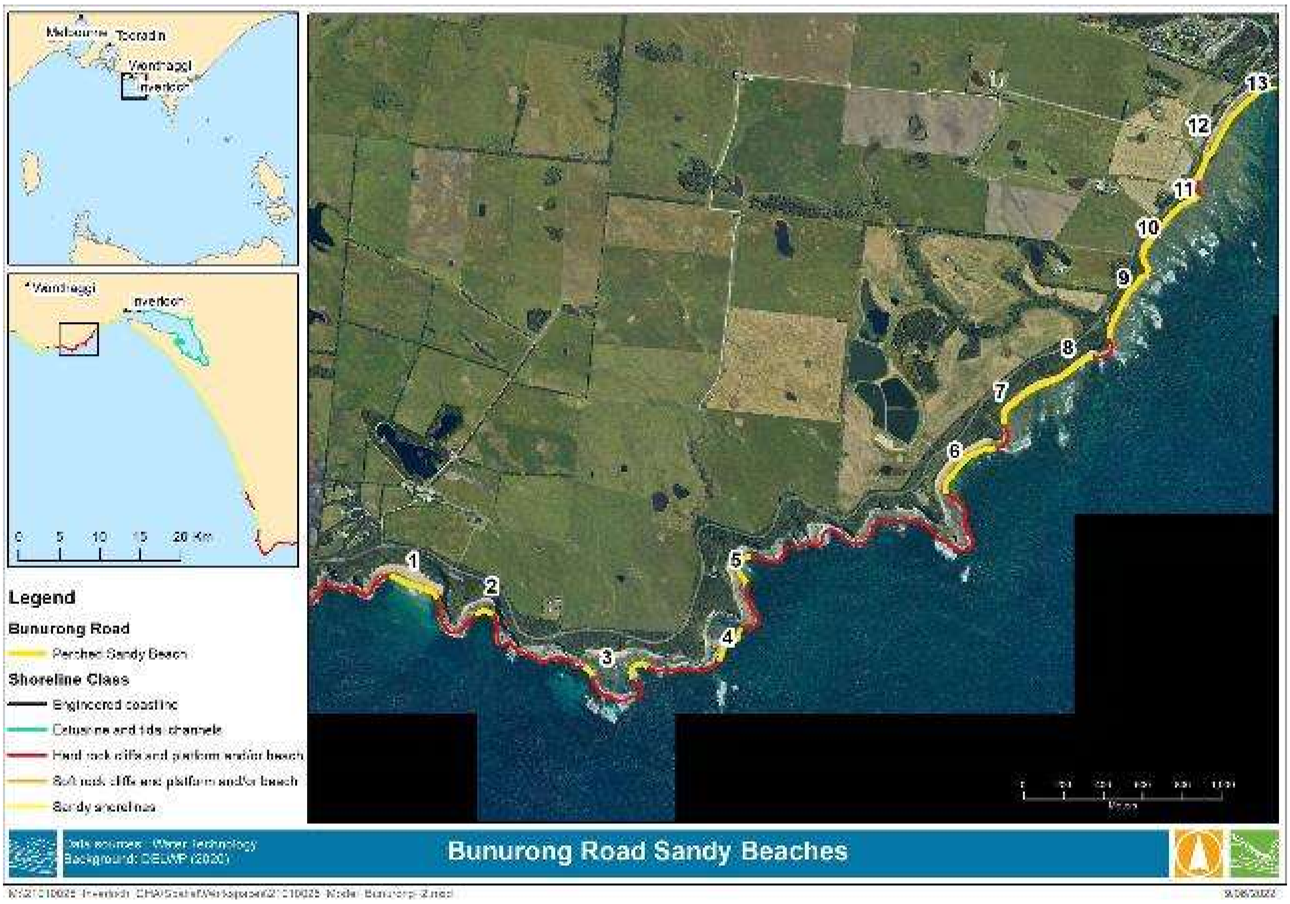

Figure 4-2 Bunurong Road beaches

The available volume of sand has been estimated from analysis of the 2021 LiDAR and high resolution imagery collected by the Department of Transport and shared with DELWP for the project. For simplicity, it is assumed the sand on the beach is perched on top of the rock platform which continues at the nearshore level to the cliff. The volume of sand, and the storm demand predicted by SBEACH for the different design storm events is presented in Table 4-1. The maximum recession, based on the toe of the post storm dune, is also shown in the table. Where the storm demand exceeds the available sediment in the perched or pocket beach, or the recession exceeds the beach width and begins to “erode” the cliff in the SBEACH model (e.g. Profile 04 and Profile 09, shown in Figure 4-3),, the beach is assumed lost, and a zone of cliff erosion hazard is then considered (see Section 4.3). These are denoted in red in Table 4-1.

The pre- and post- beach profiles at Bunurong Road Beach Pocket #1, #4 and #9, illustrating the full (#1) and perched beach (#4 & #9) and the loss of material after a design storm event are presented in Figure 4-3. As noted above, the storm demand in Profiles 04 and 09 are above the available amount of sand and the cliff begins to erode in the SBEACH model. In these instances the erosion setback is truncated at the cliff and the zone of cliff erosion hazard is used in hazard mapping.

Table 4-1 Bunurong Road beach volume and storm demand

Beach #	Beach Name	Available sand (2021) (m^3/m)	Storm Demand (m^3/m)		Shoreline Setback (m)	
			1%	10%	1%	10%
Pocket 1	The Oaks	293	164	154	27	26

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Beach #	Beach Name	Available sand (2021) (m^3/m)	Storm Demand (m^3/m)		Shoreline Setback (m)	
			1%	10%	1%	10%
Pocket 2	*unnamed*	27	122	106	8	7
Pocket 3	Twin Reefs	101	21	30	18	15
Pocket 4	*unnamed*	30	68	60	9	8
Pocket 5	Shack Bay	98	54	50	29	25
Pocket 6	Eagles Nest	63	57	50	13	13
Pocket 7	The Caves	33	35	31	8	9
Pocket 8	The Caves	84	35	56	8	20
Pocket 9	Flat Rocks	65	69	65	14	12
Pocket 10	Flat Rocks	44	56	50	10	8
Pocket 11	Flat Rocks	43	50	45	31	31
Pocket 12	Flat Rocks	39	40	35	35	35
Pocket 13	Flat Rocks	66	72	69	50	38

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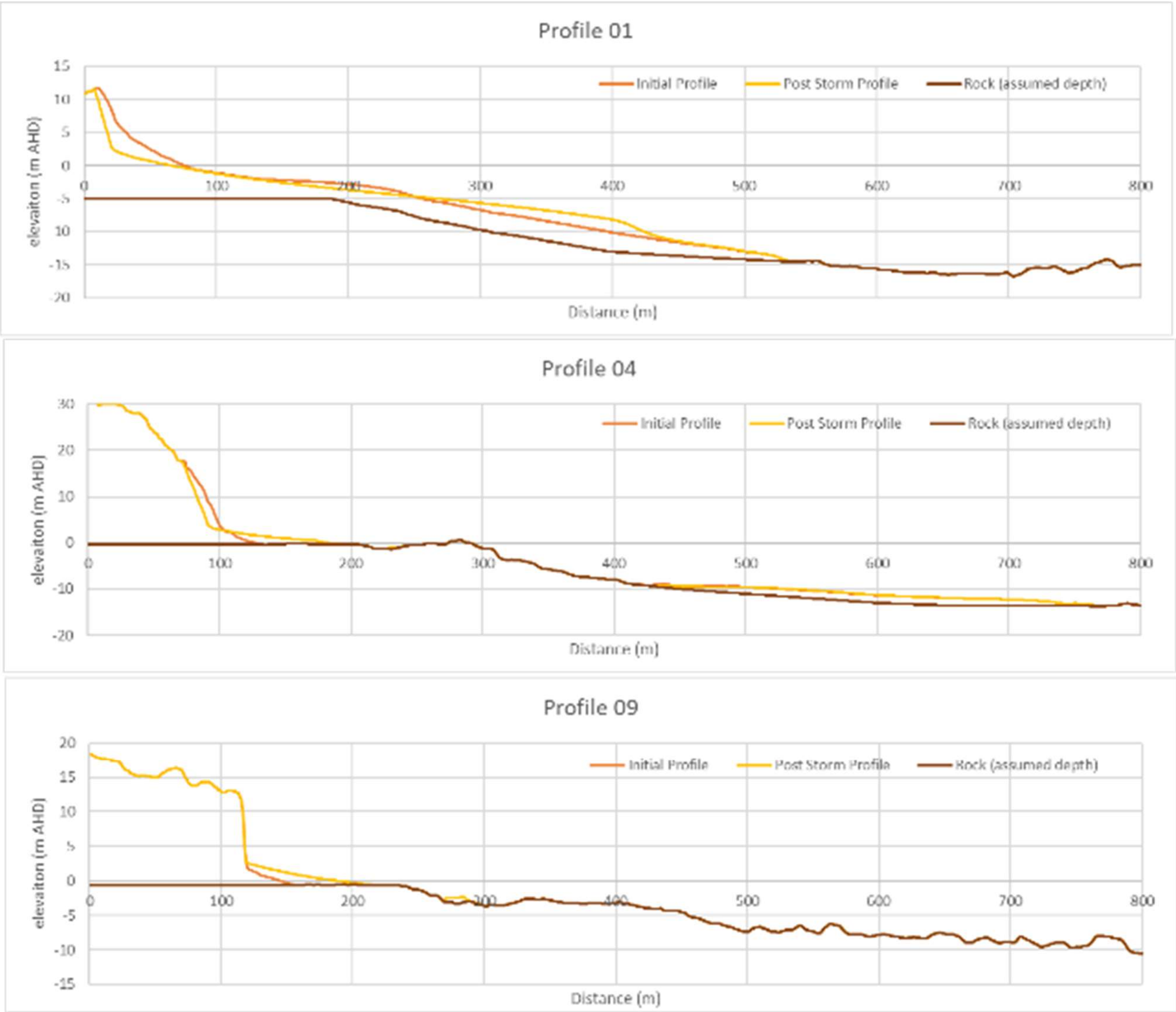

Figure 4-3 Pre- and Post-storm beach profiles, Beach #1, #4 and #9, Bunurong Road Section

4.2.2 Surf Beach

A significant loss of the existing sandy dune ridge has occurred along Surf Beach since the beginning of 2009, as shown in the beach profiles in Figure 2-34. The largest wave hindcast in this period was a 5%-10% AEP offshore significant wave, occurring in April 2009 as a 6.0m wave from the south-southwest (Table 2-15). During the period of 2009 through 2020, two other 20% AEP or greater events have occurred in Venus Bay.

One such event, the July 19th 2019 storm event (Hs max 5.7m ~ 20% AEP), was captured in the VCMP photogrammetry surveys with beach profiling on the 7th June and 30th July showing a clear change in the dune scarp. The erosion volume determined from the two surveys is in the order of 15-30m^3/m width of beach at different locations, on the lower end of the 20% AEP average storm demand of 30-50m^3/m predicted by SBEACH for the same area of beach (noting the design storm events are run twice with no recovery between in SBEACH).

Review of the subsequent VCMP beach surveys through to November 2019 indicate further slumping and erosion of the beach following a relatively large (Hs ~ 5.0m) storm in August and a series of additional smaller storms in the months following the July 2019 storm. A net loss of 50-85 m^3/m of dune was determined from

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the surveys, exceeding the predicted 20% AEP storm demand over a longer period (see Figure 4-4). This review of the wave climate and beach profiles illustrate the variability associated with storm erosion, dependant on the volume of available sand (both in the dune and nearshore), the recovery between storms and the storm intensity.

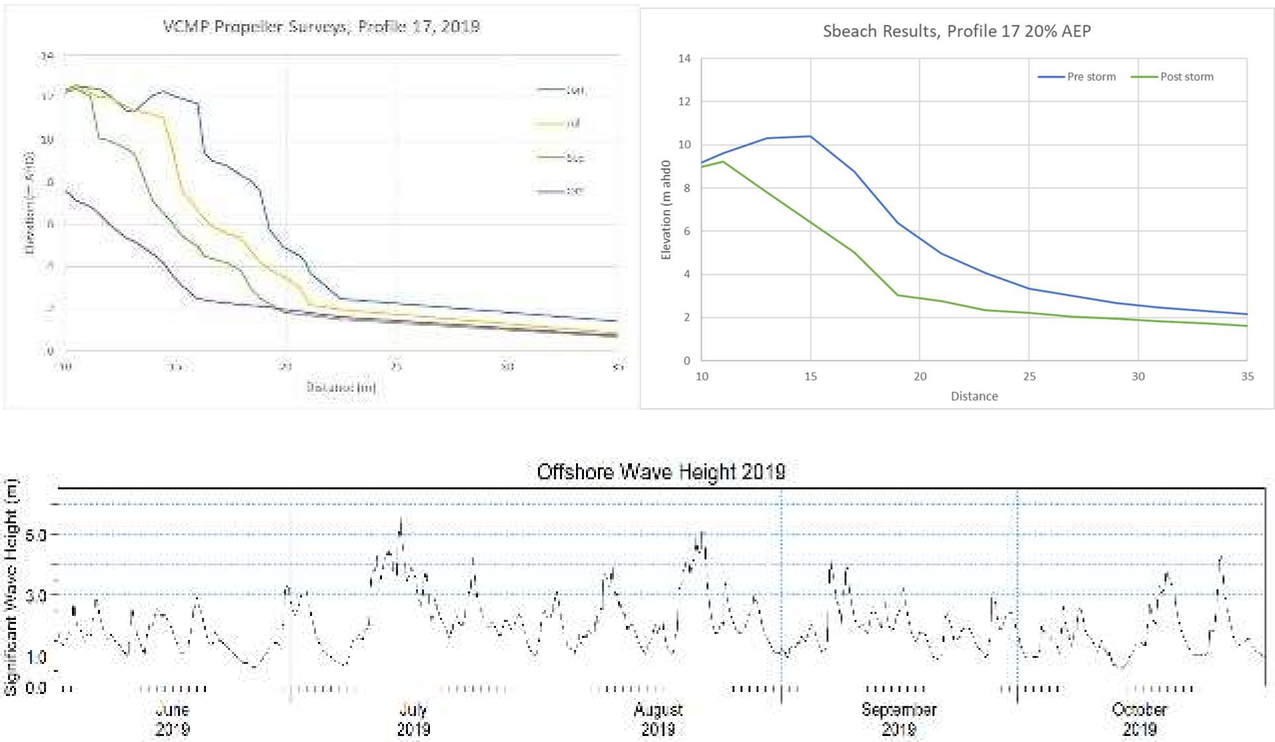

Figure 4-4 Surf Beach Dune Erosion – Measured v Modelled 20% AEP

Volumetric storm demand, and the erosion predicted by the SBEACH modelling for the beach profiles along Surf Beach is presented in Figure 4-5. Again, the volume of available sand is assumed to be perched above the rock platform based on the elevation of rock observed in the high resolution LiDAR and imagery. The SBEACH storm volume is the total volume eroded from the profile above MSL. Values at the individual profiles along the shoreline vary notably due to the nearshore bar and dune profile. The weighted average line for the 1% AEP events is shown which provide an indication of how storm conditions and their impacts change across Surf Beach. Changes to incoming wave direction and period may influence the volumetric and cross-shore extent of the storm erosion.

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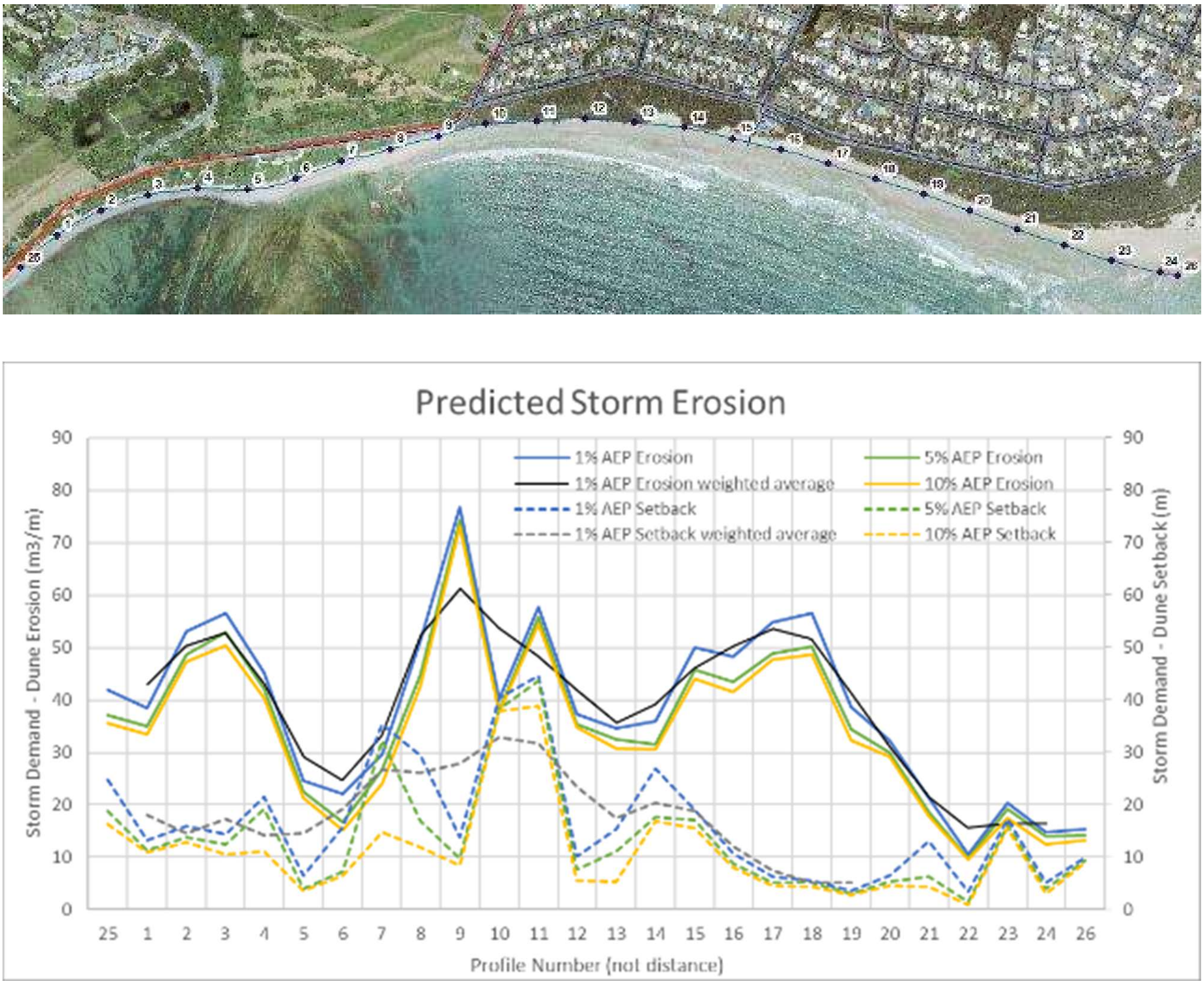

Figure 4-5 Modelled Storm Erosion Volume and Setback

4.2.3 Open Coast

The sandy dunes along the open coast of Venus Bay, east of the entrance to Anderson Inlet, are high and well vegetated, as shown in Figure 4-6. The data indicates dune elevations ranging from a peak of 15m AHD at Point Smythe, above 20m AHD near the Venus Bay settlements to upwards of 40m AHD further eastward. The seaward face of the dune changes between accreting with active vegetation growth and actively eroding with a collapsed face both temporally and spatially as presented in Figure 4-7.

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Figure 4-6 Open Coast Dunes (February 2021)

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Figure 4-7 Different phases of dune growth and decay (Rosengren, 2021)

Survey of the Venus Bay dune between Venus Bay beach carparks No 1. and No. 5 in May and June of 2021 was captured to assess the impact of a number of storm events on the dune. The offshore wave height during the period is shown in Figure 4-8 along with the offshore extreme wave heights determined through the University of Melbourne hindcast (*Report 3, Appendix D*).

A small storm was captured in the first set of survey between the 3rd and 7th of May, followed by two larger storms on the 26th May and the 10th June. These latter events were less than a 20% AEP (Hs = 5.7m), with the smaller May 26th storm peak of 4.6m roughly equivalent to the 98th percentile exceedance of annual wave maxima (i.e. the maximum annual wave height is higher than this 98% of the time).

Beach profiles captured through May and June of 2021 at the beach carpark No. 4 are shown in Figure 4-9. Small changes are observed following the first storm of May (blue to orange) and more notably by mid-June (yellow). The change in beach level is shown and occurs between +3m AHD and to the seaward extent of the survey (-1.0m AHD). The peak change is just over 0.5m erosion at around -0.3m AHD. The total change in the profile volume is minimal, with less than 6m^3/m eroded from the profile.

The 2008/09 LiDAR topography is also shown in Figure 4-9 as the green line. The surveyed beach at the beginning of May 2021 is close to 1.0m higher than the 2008/09 LiDAR profile and the toe of the primary dune is approximately 6.5m seaward of the 2009 position. The volume change between the 2008/09 LiDAR surface and 1st survey is an accretion of approximately 80m^3/m, indicating a net influx of sediment into the area of the profile.

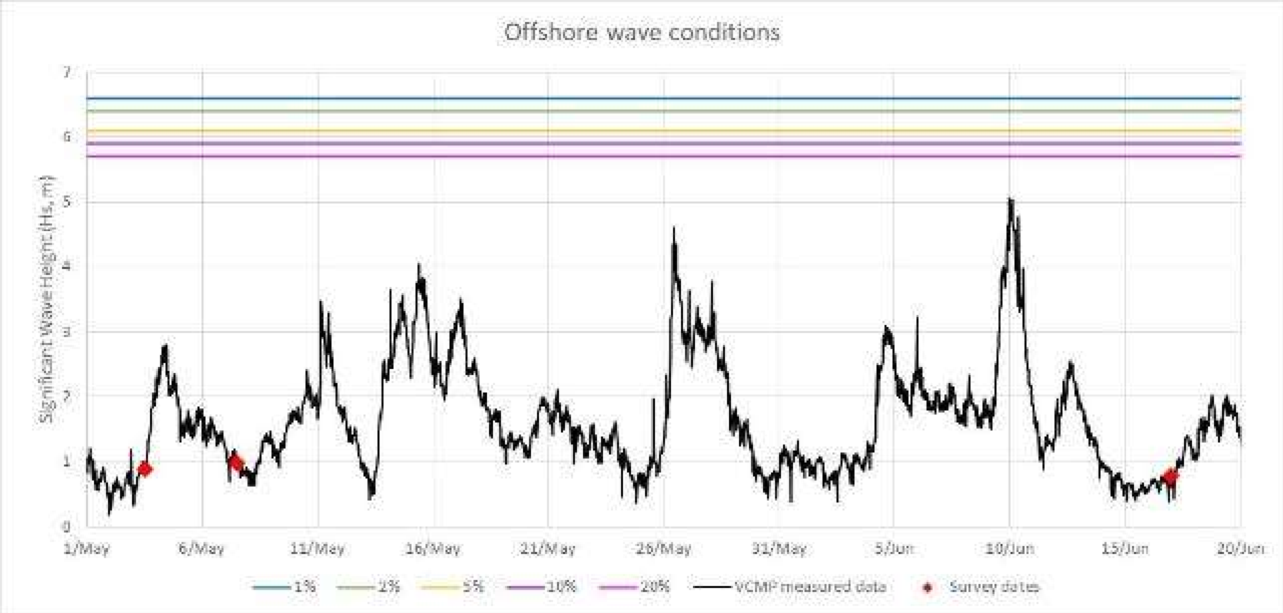

Figure 4-8 Offshore measured wave height, Venus Bay, May-June 2021 (VCMP)

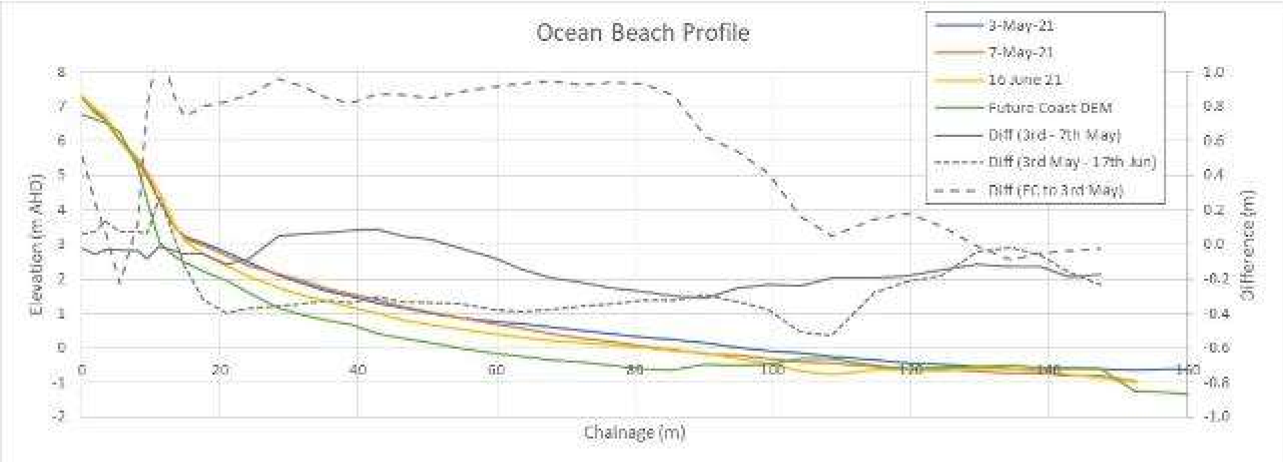

Figure 4-9 Venus Bay beach profile, Carpark No.4

SBEACH was again utilised to determine the design storm conditions, with the concurrent design storm events coinciding with a design storm tide. A summary of the storm demand is presented in Table 4-2 for different sections of the beach, with reference to the beach profiles presented in Figure 2-73. Individual storm demand varies along the coast with the site specific bathymetry and dune profile. The small horizontal setback is due to the height of the dune as the large height of dune supplies a high volume of material per meter of recession.

Results of the SBEACH modelling for P012, close to the beach carpark No. 4, are shown in Figure 4-10. Horizontal change in the post storm beach profiles are minimal despite the change in volume. The dune at this profile is over 25m in height, and SBEACH indicates the reprofiling of the dune could occur up much of the dune face through the initial storm cut at the toe and re-profiling of the dune face to achieve a similar slope to the pre-storm profile. SBEACH is an equilibrium model, and as such the post storm profile (where the beach has "reached equilibrium") shows a flattening of the nearshore bar and channel system which is formed through wave action.

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The values shown in Table 4-2 are within the range of those determined by Mariani et al (2012) (i.e. between 92 and 211m^3/m) which is used as a reference as a reasonable range for storm demand for 1% AEP storms along the Victorian coastline in the national CoastAdapt dataset (Mummery, 2016).

The steep dune results in little variation in setback, measured from the toe of the post storm dune to the pre-storm profile, which is generally around the level of the design water level offshore.

Table 4-2 Venus Bay Open Coast beach volume and storm demand

Beach Section	Storm Demand (m^3/m)			Dune Setback (m)		
	1%	5%	10%	1%	5%	10%
Point Smythe (P004-012)	146	138	135	21	21	21
Central (P011-050)	185	175	171	20	19	19
South (P055-P093)	154	146	142	20	20	20

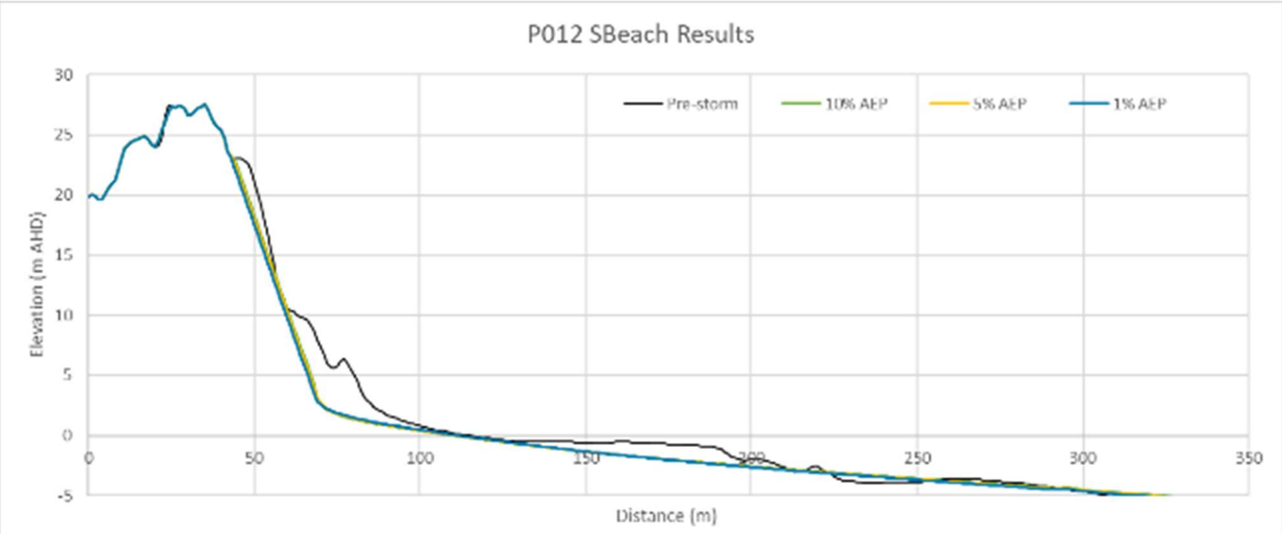

Figure 4-10 SBEACH results, P012

4.3 Cliff Erosion Hazard Zone

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, i.e. 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 recession of the buffer to the different strata. There is also potential in the Study Area that perched beaches may be lost through storm erosion or sea level rise, and the action of waves and inundation will be directly upon the backshore cliff. The erosion hazard is then considered as the Cliff Erosion Hazard Zone.

As detailed in Report 3, 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.

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The high-resolution LiDAR topography captured by DoT for its Bunurong Road planning project has been sampled to provide the natural slope angle for the cliffs along the Bunurong Road coastline. The stable slope angle, i.e. the least steep in each local sector (50 – 100m), has been used to define the width of the cliff erosion hazard zone. Increased duration of exposure to wave energy plus larger waves from accelerated SLR is likely to increase rates of hydraulic weathering and abrasion processes but for hard rock materials such as Bunurong Road, this is not expected to be significant over the time frames considered in this project. Small sectors of cliff erosion hazard buffers are also present at Townsend Bluff, and along the Venus Bay coastline to the south.

The same methodology of slope stability has been used to generate the cliff hazard zone at the rear of the Wreck Creek/Surf Beach Holocene dune area, and through the Inverloch township.

The cliff erosion hazard zone should not be confused with the Zone of Reduced Foundation (Figure 4-12), which extends further landward than the cliff erosion hazard zone and is a zone associated with what type of development can occur on the land.

An example of the Cliff Erosion Hazard Zone on Bunurong Road, with cliff slopes and sectors, is presented in Figure 4-11.

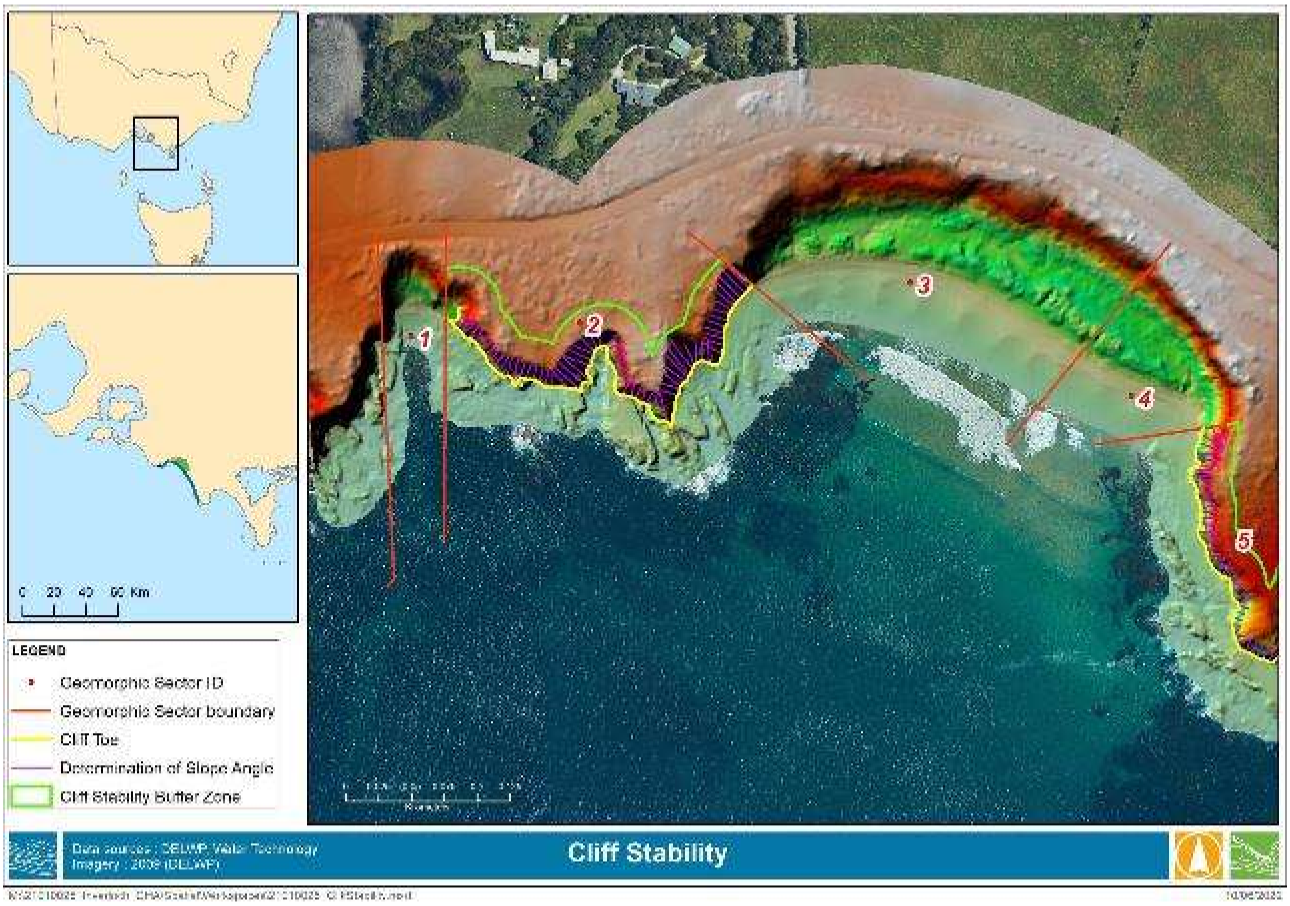

Figure 4-11 Cliff Erosion Hazard Zone, Bunurong Road

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Figure 4-12 Zone of Reduced Foundation Capacity (Nielsen, et al, 1992)

4.4 Long Term Recession

Long term coastal change has been based on analysis of aerial imagery of the Study Area. Whilst historical survey and bathymetric charts are available, they are not considered sufficiently accurate to assess change in the magnitude observed within the Study Area.

Shoreline change in key locations has been discussed in Section 2.1.4 and the extent and frequency of aerial imagery noted in *Report 2 – Data Assimilation and Gap Analysis*.

Unlike the short term erosion, long term recession is determined on a temporal basis rather than as a result of a design event. The long term recession has been calculated for 20, 50 and 80 years into the future, assuming the planning horizons in Table 2-9 (rounded to the year 2020).

The long-term recession estimates described in the following sections are defined as “coastal recession”.

4.4.1 Bunurong Road

Aerial imagery was assessed to establish any change in the position of vegetation within the pocket beaches along Bunurong Road, as presented in Table 4-3. The toe of the cliff along the road was identified in images and a comparison made to establish any significant change, however the accuracy of change based on aerial images varies due to camera angle, shading and resolution in places where a steep cliff exists. An example of the analysis is provided for Pocket Beach No. 6 in Figure 4-13 with further detail of the changing position of the shoreline over time for each profile provided in Appendix C.

Table 4-3 Long Term Recession, Bunurong Road

Beach #	Linear regression rate (m/y)	Long term recession (m)*		
		2040	2070	2100
Pocket 1	0.1	0	0	0
Pocket 2	0.0	-1	-1	-2
Pocket 3	0.1	0	0	0
Pocket 4	0.0	0	-1	-1
Pocket 5	0.3	0	0	0
Pocket 6	0.0	0	0	0
Pocket 7	0.1	0	0	0
Pocket 8	0.0	0	0	0
Pocket 9	-0.1	-1	-4	-6
Pocket 10	0.0	-1	-2	-3
Pocket 11	-0.1	-1	-4	-6
Pocket 12	-0.2	-4	-11	-18
Pocket 13	-0.2	-4	-11	-18

* Where recession is positive (i.e. the beach is accreting) the future long term recession is set to 0m

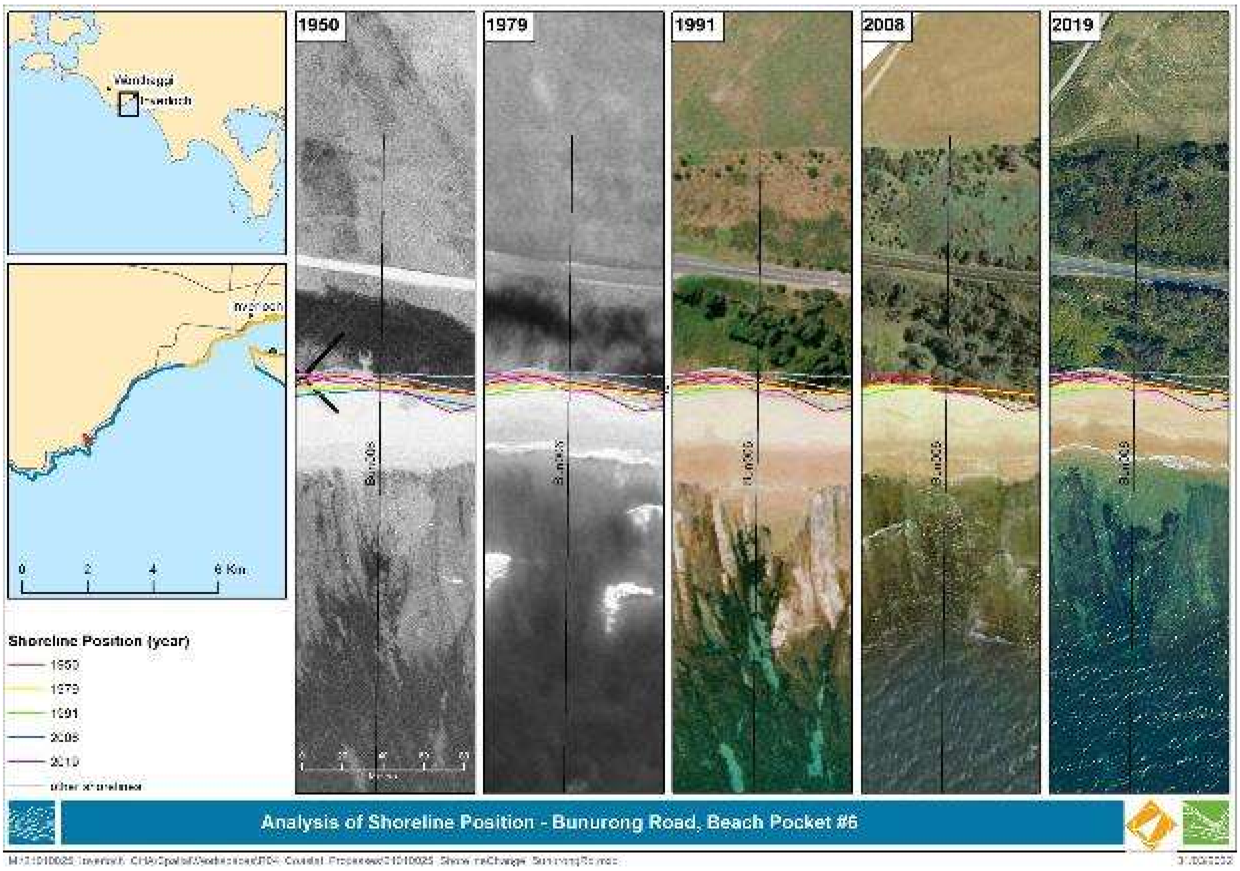

Figure 4-13 Shoreline Change Analysis, Bunurong Road Pocket Beach No. 6

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4.4.2 Surf Beach

Shoreline change based on aerial imagery has been shown in detail at the entrance to Anderson Inlet in Section 2.1.4. The position of the “shoreline”, based on the seaward extent of the coastal vegetation, at Surf Beach has also been reviewed through analysis of aerial imagery from 1950 through to 2020.

As noted in *Report 3 – Technical Methodology* and Appendix D, the long term (1950 – 2020) linear trendline of shoreline position over time does not provide any recognition of the significant recent change in shoreline position, especially along Surf Beach. Along this section of the Study Area the coastline accreted in the years following 1950 before remaining relatively stable until the early 2010s, after which significant rapid recession of the coastline occurred. The position of the shoreline over time is presented in Figure 2-15. Variation of the general trend can be seen at the mouth of Wreck Creek and around the lagoon which formed in 1979 at Point Norman, similar to the Ayr Creek lagoon (Figure 2-14 and Figure 2-16 respectively).

Analysis of historical shoreline position has also previously been completed by Doumtsis (2020) who used the End Point Rate (EPR), the rate of change based on the oldest and youngest shoreline positions and capture dates to assess shoreline change over time. The EPR considers only the net change in shoreline position and can underestimate the potential rate of recession along the beach as any accretion which occurs and is subsequently eroded (as along Surf Beach), is not accounted for.

To account for the variation observed in image analysis, and the (geomorphologically) short period of data available to differentiate between trends and cycles, the long and short term rates of change were included in the calculation of recession along Surf Beach. As noted in Report 3 it was considered reasonable to expect the longer term recession could be considered to be at least “likely” to occur, whilst the rapid rate of recession experienced in recent time was at least “possible” to continue at this accelerated rate. They dynamics of the entrance and the strong influence of the offshore wave climate make it difficult to define a probability of the “possible” erosion rate, however it is noted that the rate of recession along the Surf Beach coast appears (as of mid-2022) to be reducing.

The Linear Regression Rate (LRR) generates a linear equation from the data points and associated dates and has been used to generate recession rates for different periods along the Surf Beach coastline as presented in Figure 4-14. Analysis for selected individual cross-shore profiles is presented in Appendix C. The long term change, from 1950 through 2021 is shown in black where the average over the whole shoreline is 0.15m/year of recession. The minimum and the weighted average of the minimum rate of change along the shoreline is shown in light and dark grey shading respectively. This weighted average rate of change has been used to represent the “possible” rate of recession experienced and is notably higher in magnitude than the long term recession rate, peaking close to 9m/year of recession along the new and old entrance locations of Wreck Creek. Along the shoreline there has been periods of rapid recession throughout the period of record, although the majority of the shoreline has been impacted in the period after the entrance change from 2013 – 2021.

The extent of long term recession, based on the “likely” and “possible” recession rates for the different planning horizons are shown in Figure 4-15.

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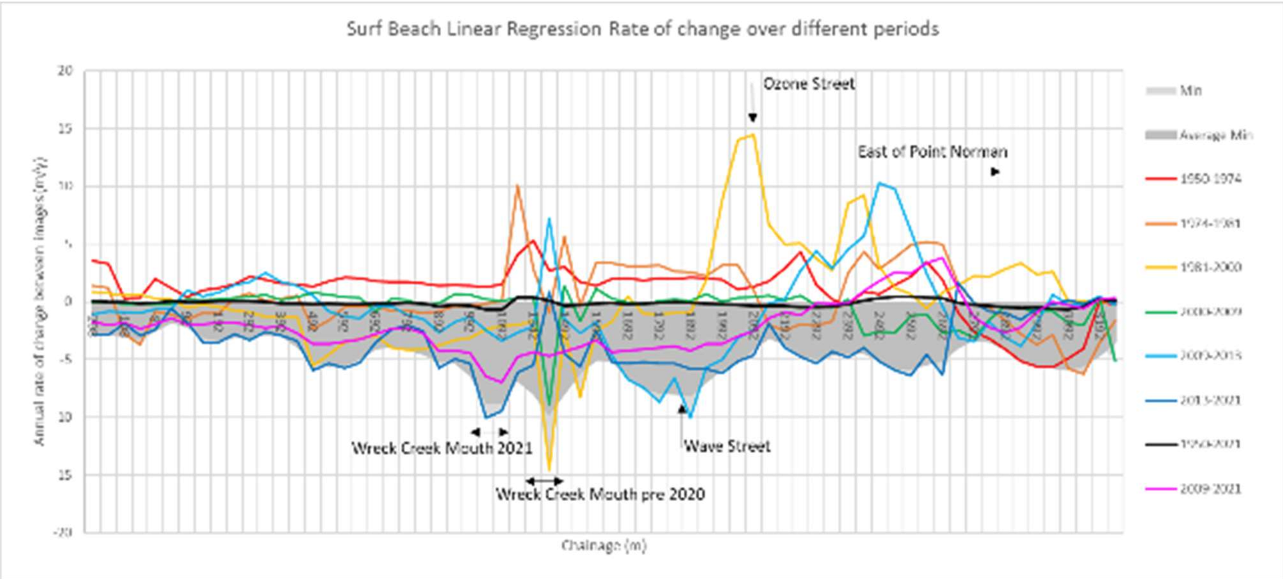

Figure 4-14 Long term rate of change, Surf Beach

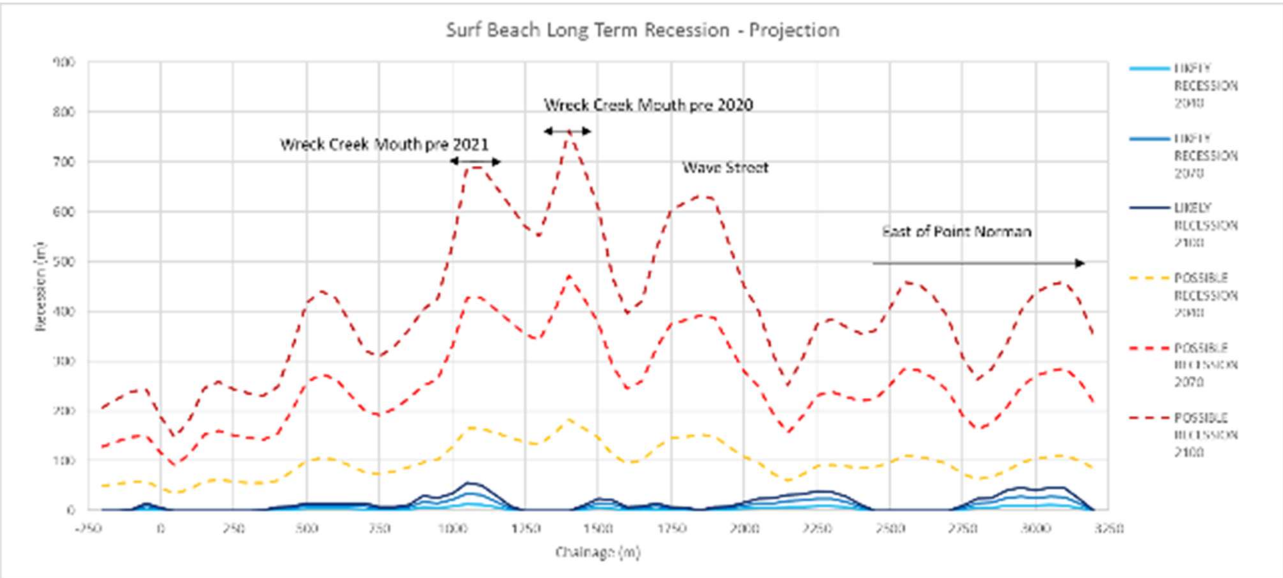

Figure 4-15 Likely and possible long term recession, Surf Beach

4.4.3 Inverloch Foreshore

The Inverloch Foreshore coastline from Point Norman to Screw Creek has experienced varying rates of accretion and recession, most notably in recent times through considerable accretion at Ayr Creek and recession at Toys Backwater. Long term recession and accretion in the entrance is driven by the shifting tidal channels and bars, as shown in Section 2.1.4.

The coastline has also been protected by various coastal engineering works as described in Section 2.1.3, some of which have been buried by accumulated sediment, or destroyed by ongoing coastal recession. The coastal protection works between the South Gippsland Yacht Club and Grandview Grove are considered to be structures with a design life which will extend into and potentially beyond the planning horizons considered in this study and as such long future term recession is considered to be 0m along this section of the Inverloch foreshore.

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The linear change in shoreline position over different timeframes is presented in Figure 4-16. Shoreline change at individual profiles along the Inverloch Foreshore are presented in Appendix C. Extreme rates of accretion are noted at the Ayr Creek outfall following the development of the lagoon and seaward migration of the shoreline. As with Surf Beach, the net shoreline rate of change over the period of photographic record (1950 – 2021) is small, with a net accretion of 0.2m/year over the total foreshore.

Other localised rapid accretion is noted at the South Gippsland Yacht Club and along the Bowls Club, and at the mouth of Screw Creek as the creek mouth shifted over time. Likewise, rapid recession at the Screw Creek mouth is captured in the aerial imagery, as well as recession along Toys Backwater since 2009 and prior to this in the 1970s and 1960s.

The extent of the "likely" and "possible" recession along the coast is presented in Figure 4-17, noting that where the long-term rate of change is positive (i.e., accretion), the recession has been set to 0m/year.

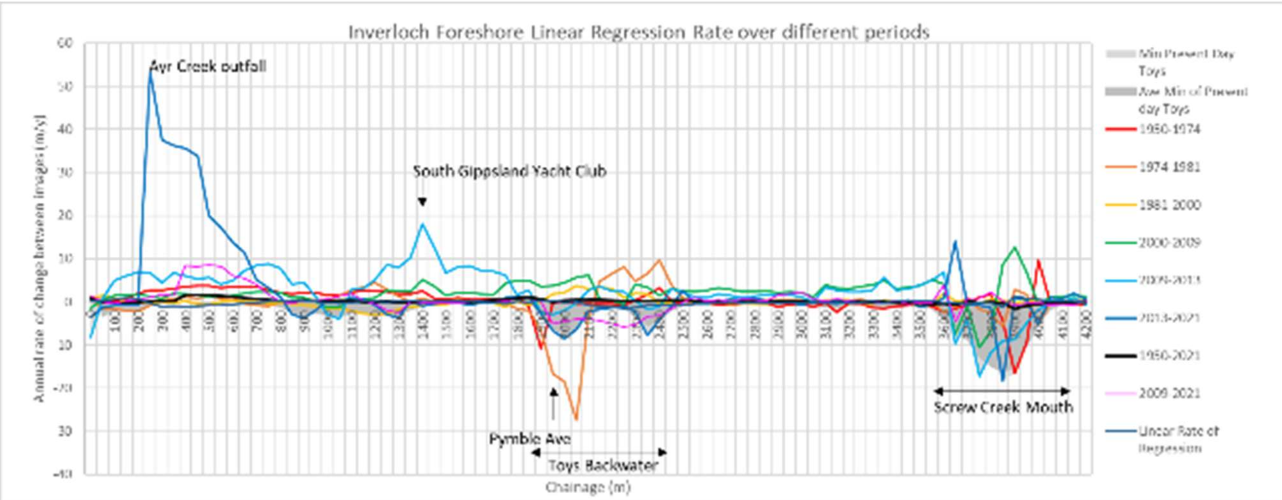

Figure 4-16 Long term rate of change, Inverloch Foreshore

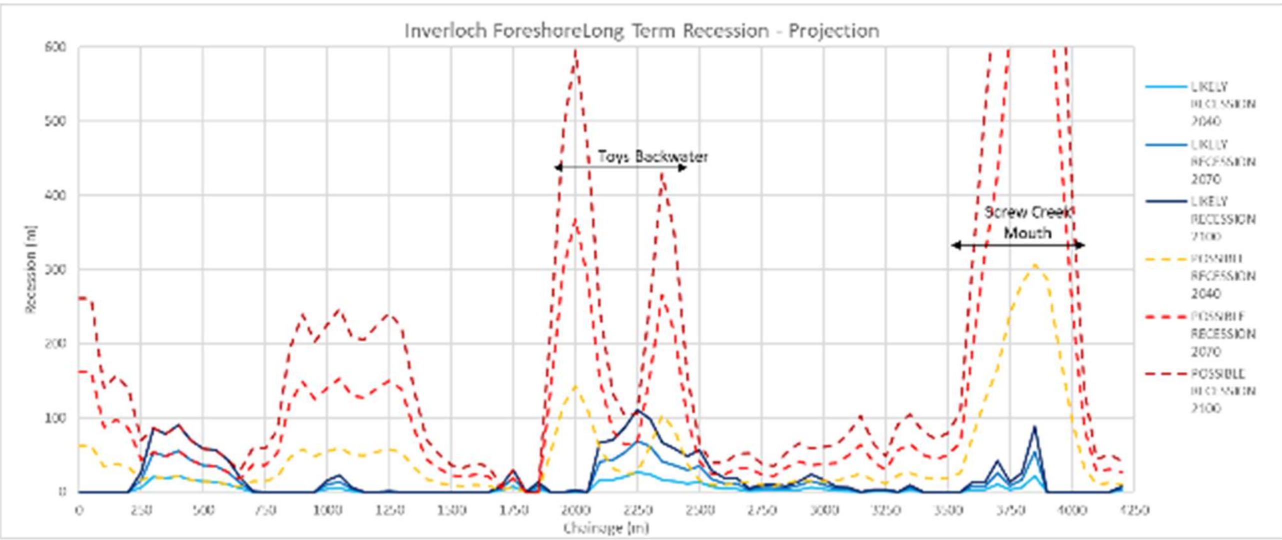

Figure 4-17 Likely and possible long term recession extents, Inverloch Foreshore

4.4.4 Anderson Inlet

Long term coastal recession within Anderson Inlet is limited by the low wave energy environment, vegetation growth, the presence of constructed levees, and other coastal protection works. The mechanisms for erosion are different from those on the exposed and sandy coastlines and coastal recession is “slow and steady” with less opportunity for recovery through supply of sediment, although recovery and accretion through sedimentation and vegetation migration is observed in sections on the coastline.

The recession along the Anderson Inlet coast can vary over a short distance, as shown below in Figure 4-18 where the top two images show recession caused by terminal scour adjacent to an engineered coastline followed by accretion through vegetation colonisation (possibly on the material eroded to the west) and recession of the coastline adjacent to the Mahers Landing boat ramp. The lower two images show the recession due to loss of mangrove fringing, potentially linked to catchment runoff of freshwater or agricultural products.

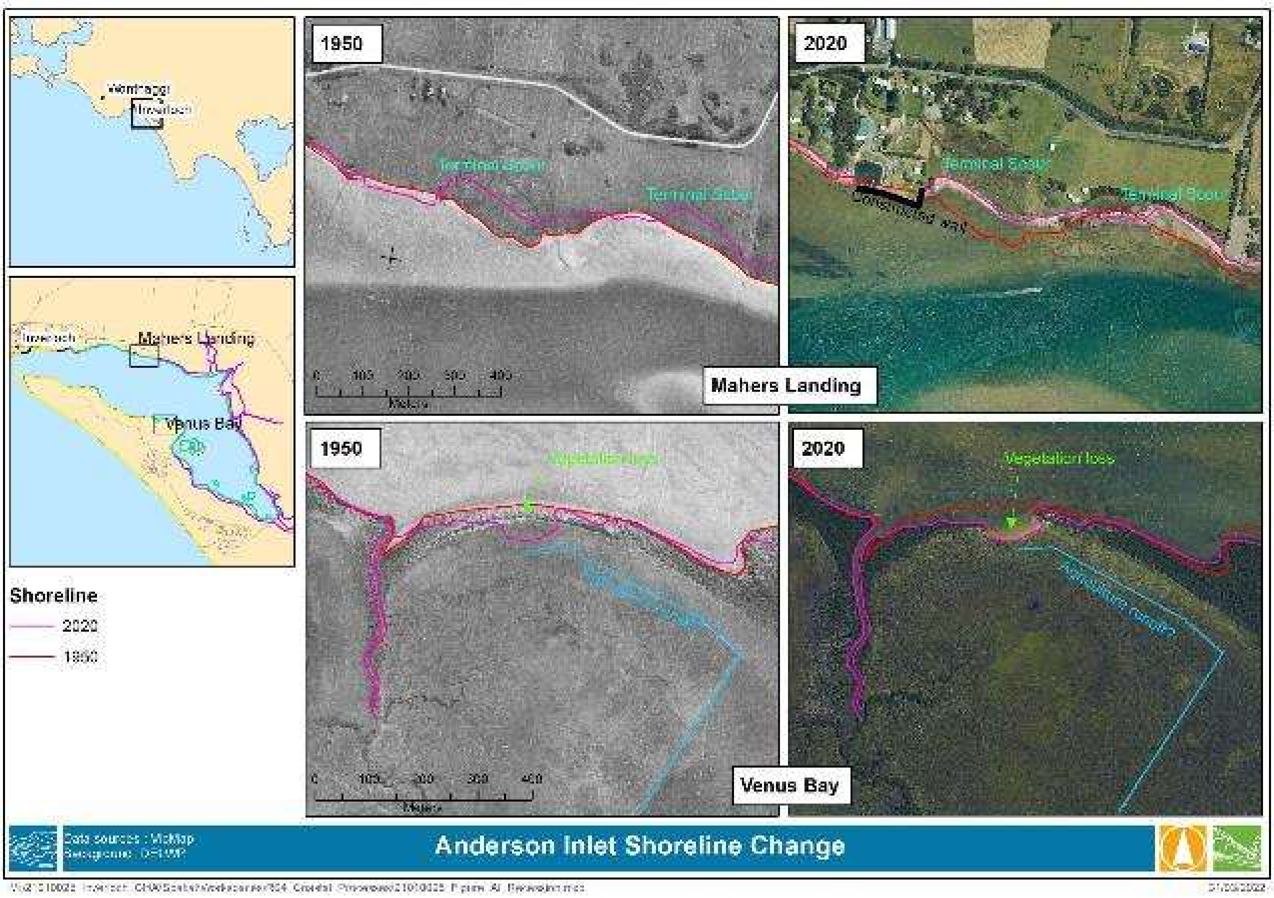

Figure 4-18 Examples of Shoreline Change, Anderson Inlet

The aerial imagery collection has been used to establish the linear regression rate around the Inlet. Regression within the Inlet is constant than the dynamic shore near the entrance and as such the “likely” recession rate at each profile has been determined only. Analysis of individual profiles along the coastline showing shoreline change over time is presented in Appendix C.

In line with previous assessments (e.g., Water Technology, 2014), the long term recession within the inlet is based on twice the linear rate of likely recession to allow for increased recession with increasing rates of sea level rise. The extent of the long-term recession for different planning horizons are presented in Figure 4-19. The levees were not considered to be barriers to potential long term recession (as per direction by DELWP).

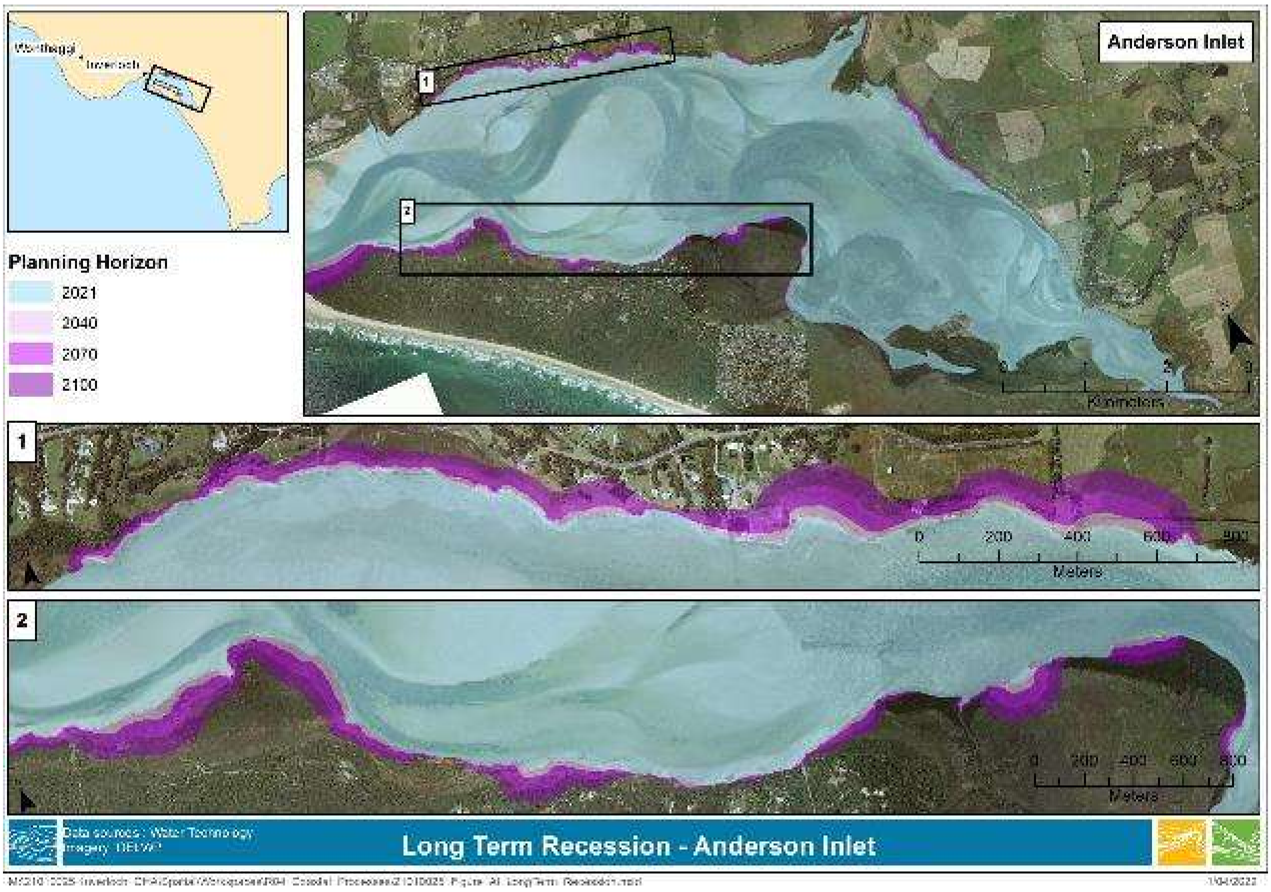

Figure 4-19 Long term recession, Anderson Inlet

4.4.5 Point Smythe

The shoreline analysis based on aerial imagery from 1950 through to present shows considerable change on the estuary side of Point Smythe. In 1950 the northwest point of the vegetated sand spit extended over 450m further northwest into the Anderson Inlet (Figure 2-22).

In contrast to the entrance conditions in 2020, in 1950 the main channel had a fairly low degree of sinuosity through the entrance and east to Mahers Landing and the estuary side of the spit had a convex shaped sand lobe extending into the main tidal channel (Figure 2-23 and Figure 2-24).

Migration of the channel towards the sand spit was greatest in the early photographic record, with the recession of the estuary side of the spit nearest the entrance averaging 5+meter of recession per year from the earliest image in 1950 through to 1974 (red line in Figure 4-20).

The rate of annual change tapers off as distance from the entrance increases, and the rate of change varies over time, with some small events of accretion (positive rate of annual change) noted in Figure 4-20, although these appear to be transient (dark blue, 2015-2019), or associated with poor aerial image georectifying rather than actual growth of the spit landward as occurred in (orange, 1974-1979). Recession rates have been as rapid as 8m/y between 1979 and 1985 near the entrance compared to 3m/y inside the Inlet between 2008 and 2015, however the long term recession along the lee of Point Smythe is between 3m/y and 1m/y. The linear rate of recession follows the long term rate of change. Change at individual profiles can be seen in Appendix C.

Projection of the annual rate of recession, as adopted for Anderson Inlet, at twice the historical rate has been applied to this shoreline given the potential for greater rates of change into the future as sea levels rise and increased change occurs in the entrance.

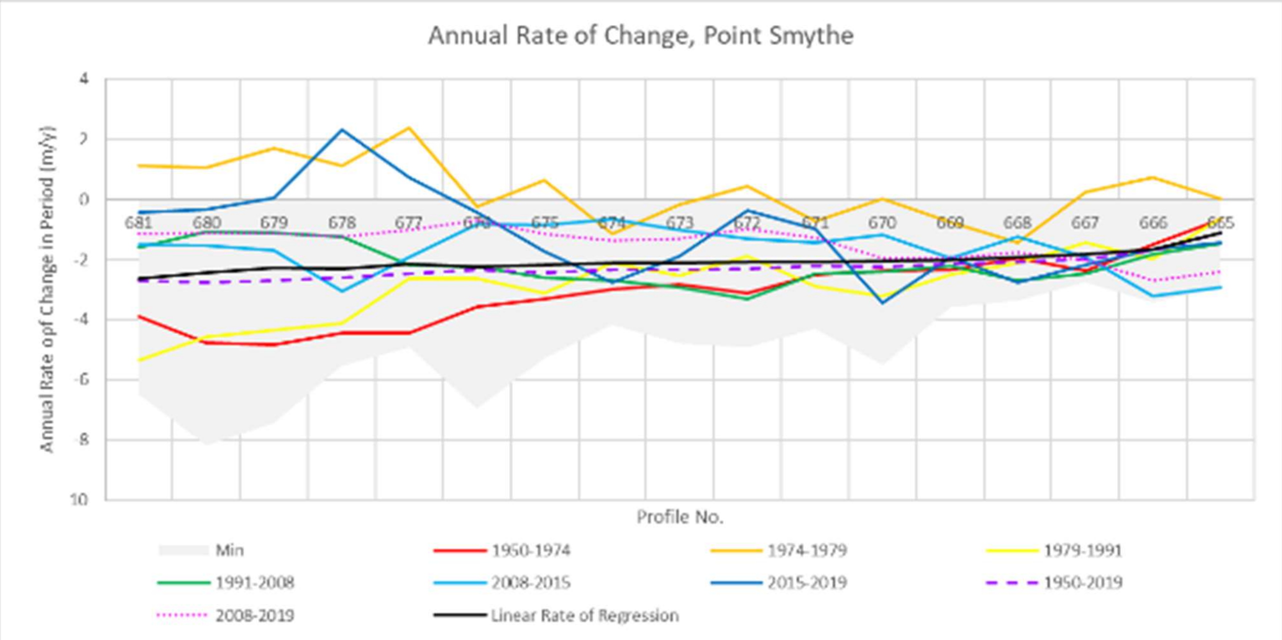

Figure 4-20 Point Smythe Annual Rate of Shoreline Change (Profile locations noted in Figure 4-21)

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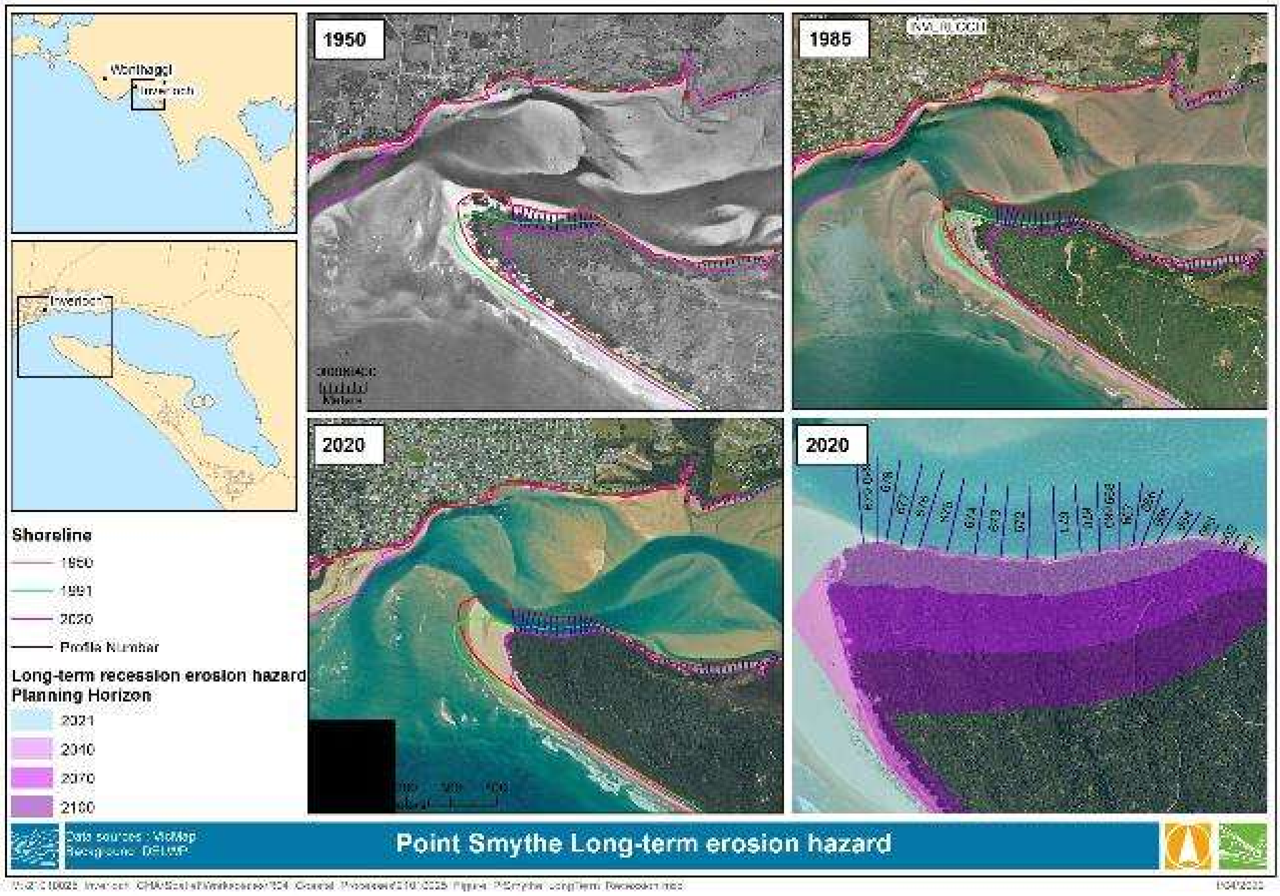

Figure 4-21 Long term recession extents, Point Smythe

4.4.6 Open Coast

As with the exposed coast at Surf Beach, there are variable *rates* of change and variable *direction* of long term change along the Venus Bay coastline. Aerial imagery has been assessed and the annual rate of change in the shoreline position over different time periods is shown below in Figure 4-22. Over the longer term, i.e. 1950 through to 2019, there has been a net accretion of the open coast of between 0.1 and 0.8m per year. More recently recession was observed at a number of profiles between 2009 and 2015 towards Cape Liptrap. Accretion of the shoreline at the profiles closest to the entrance is noted in imagery since 2015, particularly at Profile 004 and 005 closest to the entrance. Additional detail for selected profiles is presented in Appendix C where aerial imagery and shoreline position is presented.

Given the positive rate of accretion along the beach, a 0m/year recession rate was used for the different sections of the open coast when determining the total erosion.

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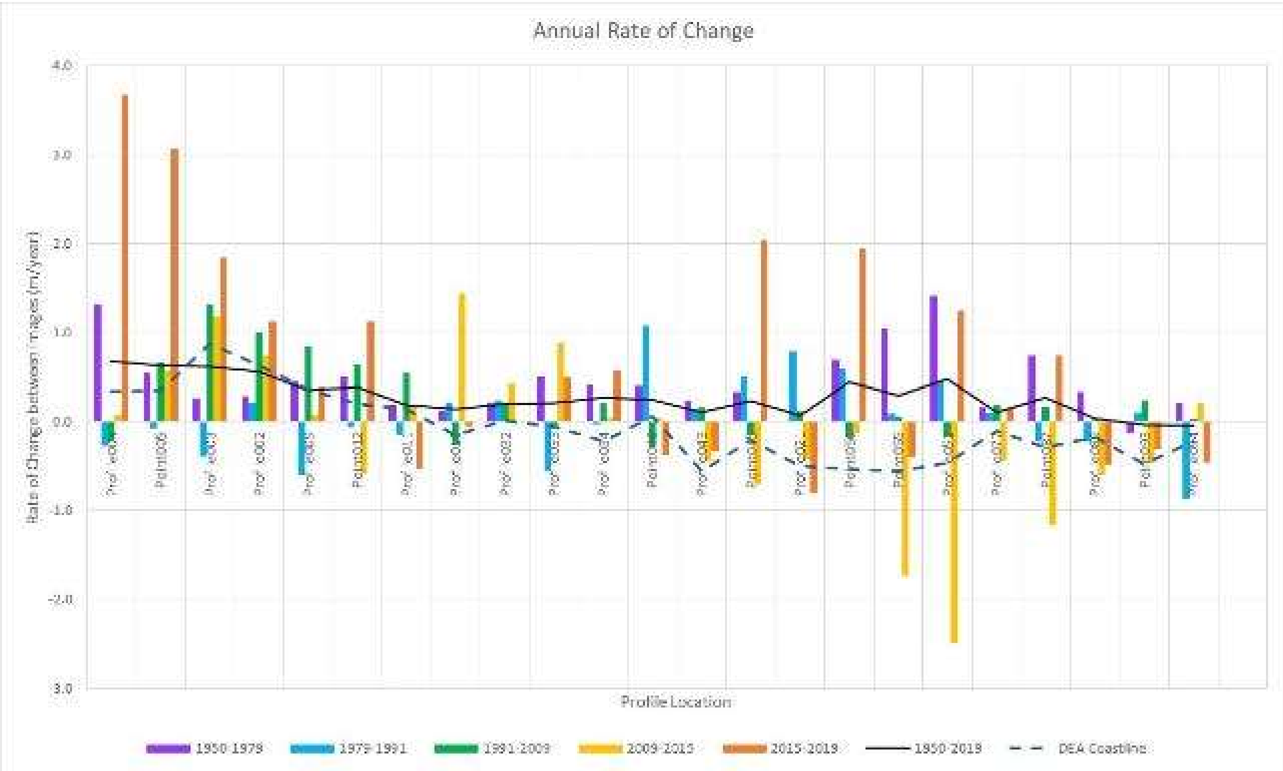


Figure 4-22 Venus Bay Open Coast Long term coastal recession

4.5 Future Recession / Response to Sea Level Rise

Determination of the future recession of the coastline within the Study Area has been calculated to estimate the impact and response of the coastline to increases in mean sea levels and tidal planes. The future recession is based on the mean sea level rise increments noted in Table 2-9.

A common methodology for considering the magnitude of response of a coastline to sea level rises is the equilibrium profile approach that reflects the understanding that the beach profile will adjust to accommodate the increased mean sea level by migrating landward and upward. This is presented pictorially in Figure 4-23, and calculated by using the “Bruun Rule” (Bruun, 1962), Vellinga (1983), or other similar equilibrium transformation formula. For this project, the Bruun Rule has been used to provide consistency with other coastal hazard assessments carried out within Victoria and around Australia.

Although 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 (i.e. Surf Beach) or migrating tidal channels (Inverloch foreshore), the simplicity of the Bruun Rule is also appropriate as the future beach profile is uncertain and such that the magnitude of recession due to profile accommodation can be considered an approximation only. The formula and parameters of the Bruun Rule are presented in Figure 4-24. Sensitivity testing of the parameters used in the formula are discussed in Report 3.

The future recession and the response of the coastline to sea level rise is described for each section of the coast below.

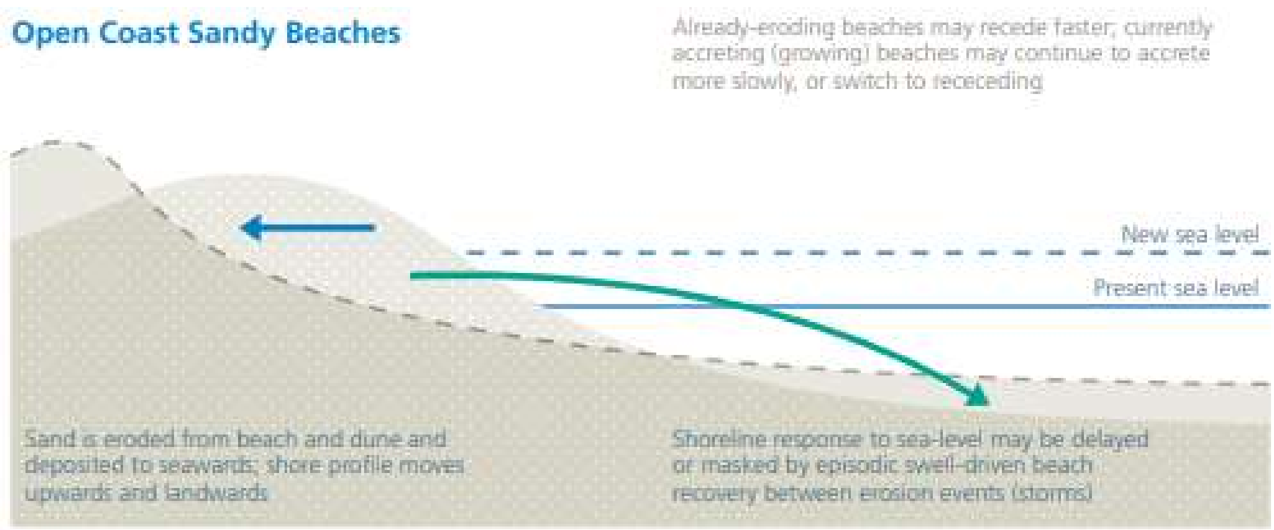
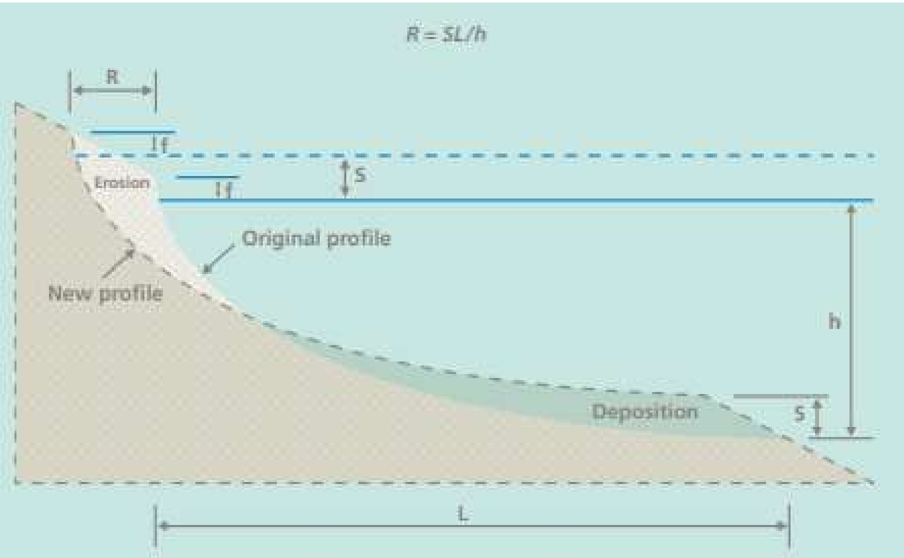


Figure 4-23 Beach Profile Response to Sea Level Rise (DSE, 2012)



R = Recession (m)

S = Sea level rise (m)

L = Length of beach profile to adapt to SLR (m)

h = depth of water at the extent of profile change. Also referred to as the *depth of closure*.

F = freeboard – additional allowance above water level

Figure 4-24 Bruun Rule parameters and formula (DSE, 2012)

4.5.1 Bunurong Road

4.5.1.1 Cliff Coastline

The cliff sections of the coastline along the Bunurong Road will be exposed to higher energy waves more frequently and for longer durations as sea levels rise and encroach on the toe of the cliffs. There is the potential for the greater exposure to increase the rates of hydraulic weathering and abrasion processes but for hard rock materials which dominate the Bunurong Road cliffs, this is not expected to be significant over the time frames considered in this project and future recession along the cliff coast is set to 0m.

4.5.1.2 Pocket Beaches

The pocket beaches along the Bunurong Road will be impacted by increasing sea levels and wave energy due to the deeper water across the nearshore rock platforms. The long term recession or accretion experienced at the pocket beaches is provided in Table 4-3 and indicates a number of beaches are already receding at a rate likely to result in little sand in the pocket at future planning horizons.

However, to prevent overly conservative estimates of recession by considering an already diminished beach profile, the profile adjustment due to sea level rise has considered the response of the existing profile. The future recession determined by the Bruun Rule for the specified sea level rises are presented in Table 4-4. These values are additional to the long term recessions indicated for the planning horizons at 2040, 2070 and 2100 in Table 4-3.

Table 4-4 Future Recession, Bunurong Road – Bruun Rule applied to Sea Level Rise

Beach #	Sea Level Rise (m)				
	0.2	0.5	0.8	1.1	1.4
Pocket 1	2	5	7	10	13
Pocket 2	1	3	6	8	10
Pocket 3	2	5	9	12	15
Pocket 4	2	6	9	12	16
Pocket 5	2	5	8	11	14
Pocket 6	2	5	9	12	15
Pocket 7	2	6	10	14	17
Pocket 8	2	4	6	8	11
Pocket 9	3	8	13	17	22
Pocket 10	3	6	10	14	18
Pocket 11	3	7	11	15	19
Pocket 12	3	8	13	17	22
Pocket 13	2	4	6	8	11

4.5.2 Surf Beach

The area from Flat Rocks to Point Norman is formed through the build-up of marine sediments as a series of dune ridges during the Holocene epoch as discussed in Section2.1. As such, it has been assumed that the material in this zone is unconsolidated and will be free to adjust to sea level rise through landward migration of the dune as per Figure 4-23.

Similar to some pocket beaches along the Bunurong Road, the coastline is already subject to recession and there is likely to be a change in the beach profile and shoreline position as sea levels rise. Whilst rates of long-term recession and storm demand have been determined for the shoreline, the re-profiling of the coastal dune and intertidal area cannot be accurately predicted into the future. As such, the existing beach and dune profile have been used to calculate the potential recession (i.e. landward movement of the shoreline) due to sea level rise along this stretch of coast.

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The extent of the future recession determined by the Bruun Rule for the specified sea level rises is presented in Figure 4-25 for the profiles presented in Section 2.4.4.

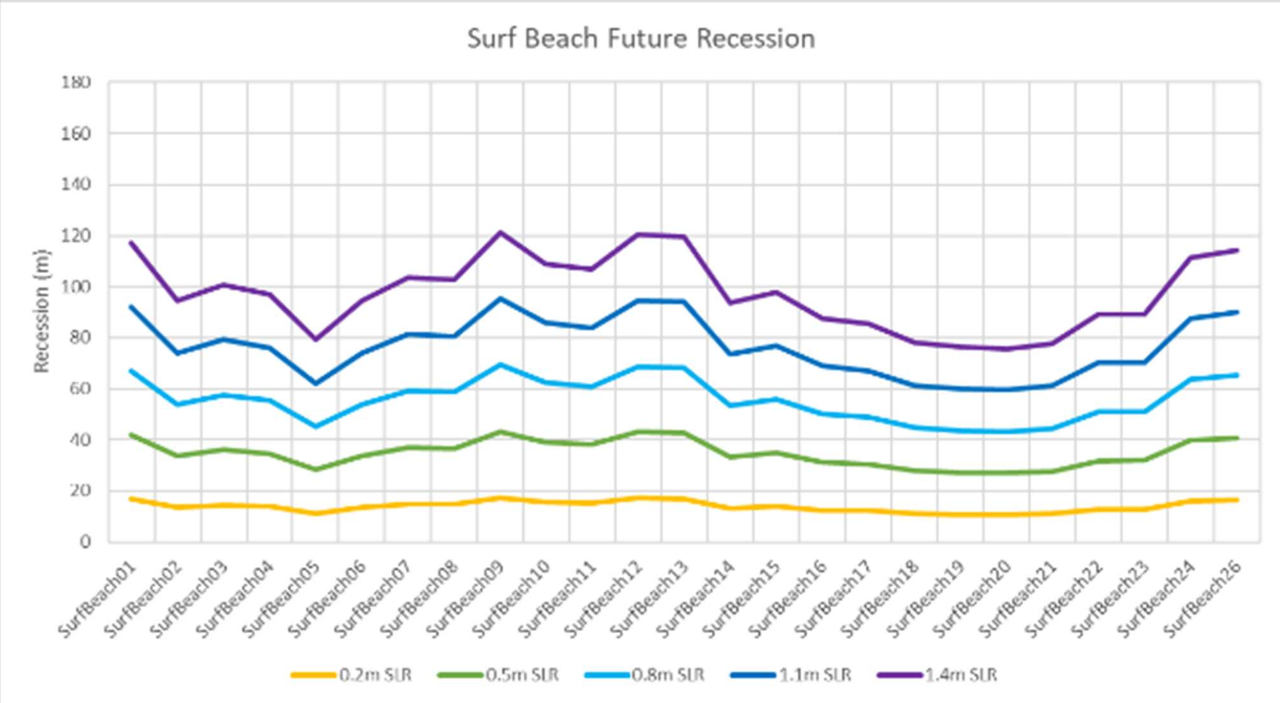

Figure 4-25 Future Recession, Surf Beach – Bruun Rule applied for sea level rise

4.5.3 Inverloch Foreshore

The conditions which drive future recession of the shoreline along the Inverloch Foreshore varies between Point Norman and Screw Creek. Between Point Norman and Venus Street the exposure to the incoming wave energy will vary considerably with the migration of the Ayr Creek sand spit and lagoon. Without the recent sand spit, the older sand deposit is considerably narrower along the backshore bluff and the main tidal channel has been observed close to the toe of the bluff.

Where recession (combined with the storm bite and long term recession) abuts the coastal bluff the hazard reverts to that of a coastal cliff where the slope of the coastal bluff is used to determine the extent of the hazard zone (as discussed in Section 4.3). This is the cases along the stretch of coastline between Point Norman to Venus Street, landward of the Ayr Creek spit.

Eastward of Venus Street determination of the future recession is complicated by the mobility of the tidal channels and the impact of this movement on the nearshore beach and profile slope. As shown in Figure 4-24 the Bruun Rule uses an equilibrium basis to translate the beach profile landward, however extension of the slope across the potentially narrow or wide intertidal beach slope can result in an under or over-estimation of future recession.

To accommodate this, and in recognition that recession processes will be less wave driven here than an open coast, the slope of the beach considered is the primary dune between the MHWS and the crest of the dune. This methodology has been adopted in similar estuarine environments where recession is limited to beach/shore re-profiling through inundation rather than wave action (Knook, 2017).

Resulting predictions of future recession along the coastline is provided in Figure 4-26. Future recession is not considered possible along the foreshore adjacent to the Yacht Club east to Toys Backwater where considerable coastal protection infrastructure has armoured and effectively constrained movement of the coastline.

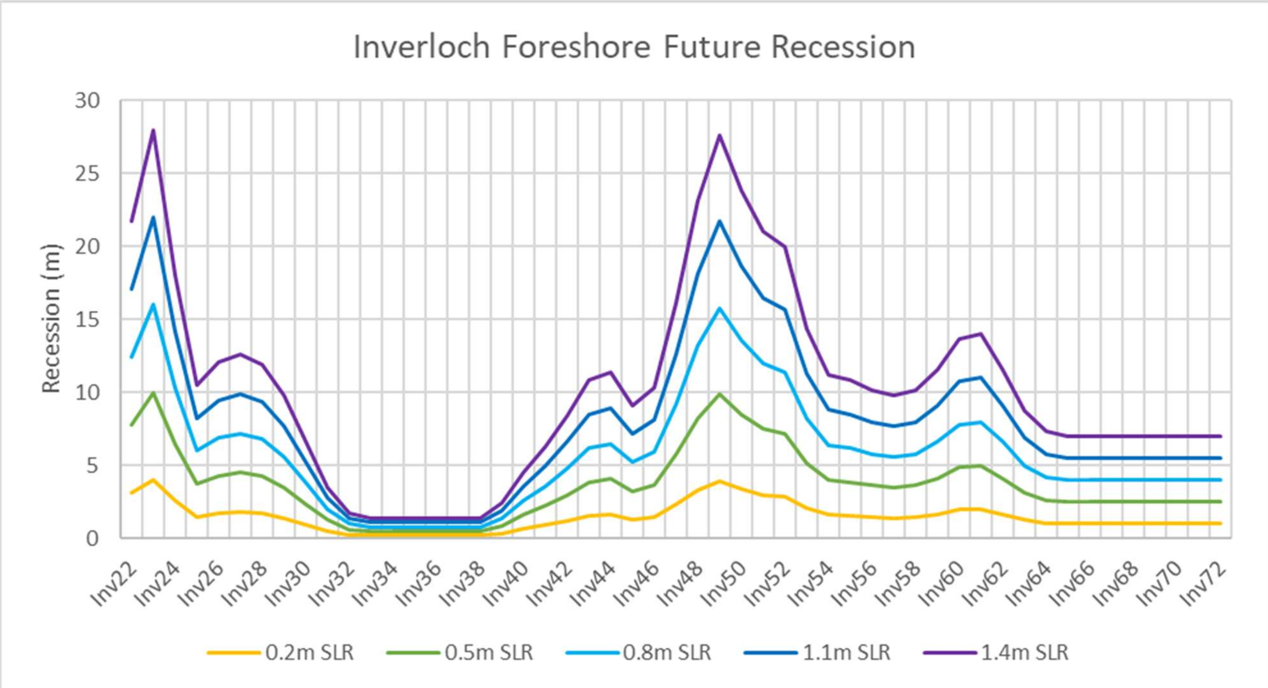

Figure 4-26 Future Recession, Inverloch Foreshore

4.5.4 Anderson Inlet

The two main shoreline classes in Anderson Inlet are either (i) soft rock/bluffs and slopes/low earth cliffs or (ii) coastal fringed wetlands. The response of these two shorelines to sea level rise varies considerably as shown in Figure 4-27.

The soft cliff and sloping shorelines could be expected to retreat at an accelerating rate through the increased nearshore water level enabling larger and more frequent wave action to erode the more frequently inundated coastline.

The primary influence of sea level rise on coastal wetlands (salt marsh and mangroves) is expected to be associated with changes in inundation frequency and depths. There is potential for an increase in coastal elevation along the saltmarsh and mangrove shores in response to sea level rises if fine sediment mobilised in the Tarwin River or within the estuary is deposited in the vegetation footprint resulting in an increase in bed levels. However, there is considerable uncertainty in the ability of coastal wetlands to adjust to sea level rise through increased rates of sedimentation. If the rate of deposition matches the rate required for the vegetation species to adjust along with the sea levels, there will be no change in the position of the coastline. If the deposition rate outpaces the sea level rise, a seaward shift of the coastline may occur, as is observed in some places along the Anderson Inlet coastline. In these cases, the future coastal recession attributed to the total coastal erosion hazard zone would be zero. In cases where there is insufficient sediment the coastline could be expected to recede at least to land levels currently at the MHWS, reflective of the existing coastline delineation. This process is considered an inundation process rather than an erosion process, and as such is not captured as an erosion hazard, however it is shown for reference in Figure 4-28 to demonstrate the future

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position of the shoreline (where sedimentation is insufficient) with respect to where the interface between land and coastal waters are.

Landward migration of the shoreline due to increased tidal inundation is presented and discussed in Report 5 – Coastal Inundation Hazards.

The areas vulnerable to future coastal recession (based on existing long term recession) are presented in Figure 4-28. Levees are not considered to prevent recession from occurring due to the nature of their construction - typically earthen levees, without toe armour or scour protection.

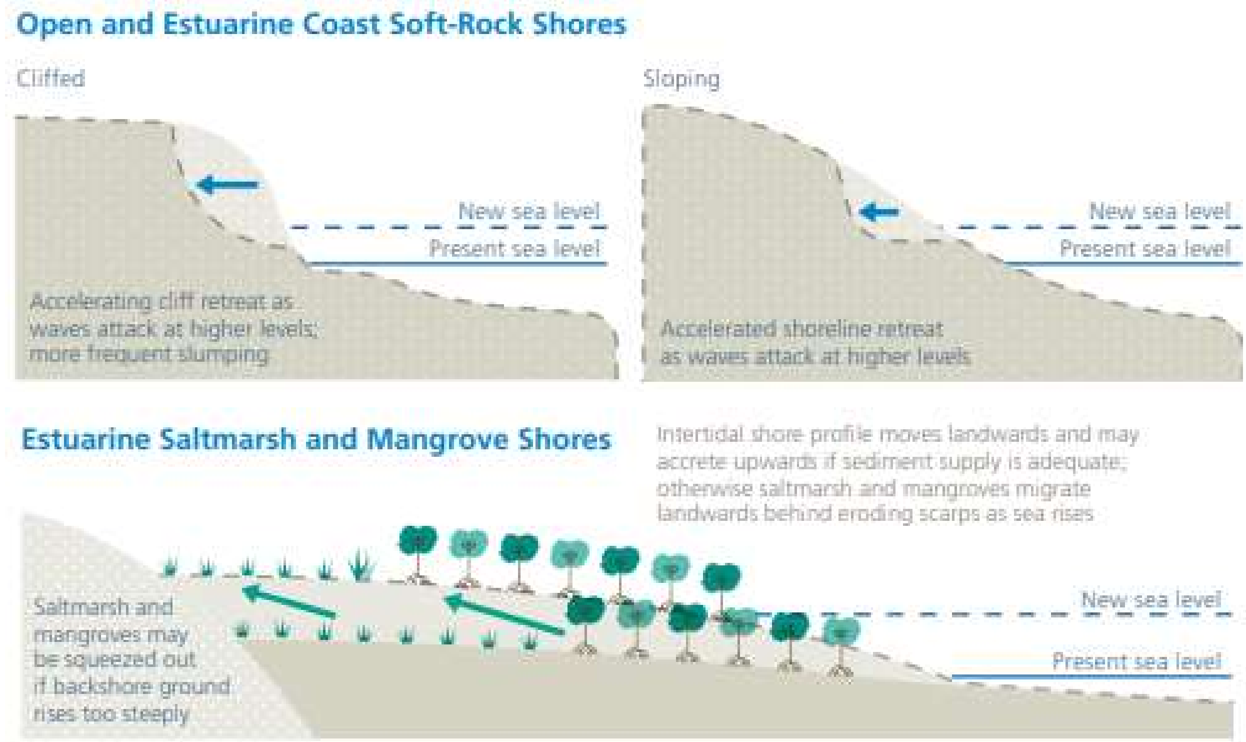

Figure 4-27 Estuarine and Mangrove Shore Response to Sea Level Rise (DSE, 2012)

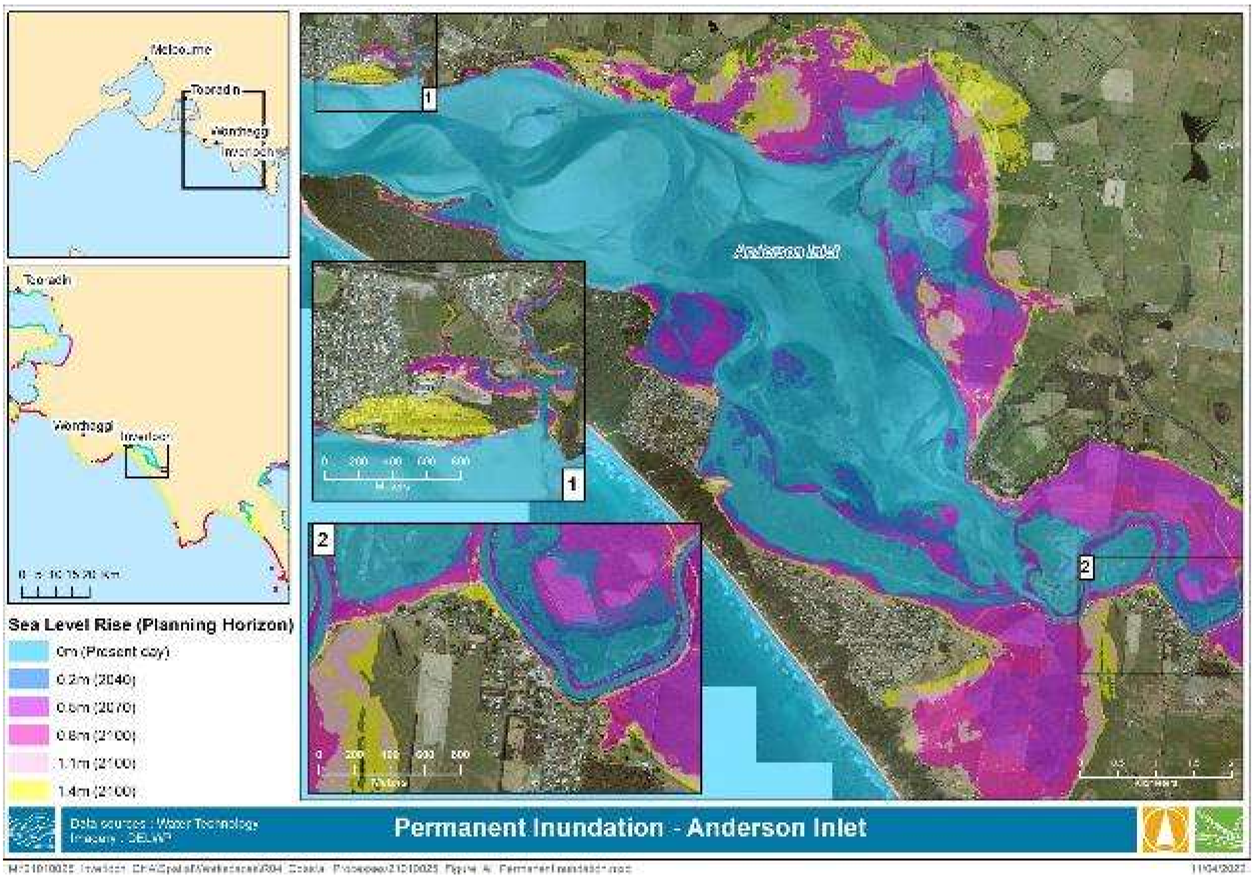

Figure 4-28 Future Tidal Inundation, Anderson Inlet

4.5.5 Point Smythe

Future recession of Point Smythe has been considered to be a process driven by re-profiling to reach an equilibrium on the ocean side and inundation and long term sediment transport changes on the Anderson Inlet side. The processes acting on the apex of the sand spit are complex, as presented in the conceptual models in Section 3 and many variations of future conditions are possible.

The future recession within the inlet is based on the long term historic change (Anderson Inlet side) and the Bruun Rule (ocean side). Whilst the apex of the spit has receded over 500m since 1950, as shown in Figure 2-22, this level of change is not represented in the future recession, with recession setback determined from the shift in more dense vegetation rather than ephemeral grasses. The Bruun Rule has been used to establish the potential recession on the ocean side, and, as with the greater extent of this coastline (Section 4.5.6), the recession is limited due to the steep and high coastal dune limiting the horizontal setback to volume change.

For additional context, a set of cross sections through the spit, extracted from the 2008/09 data, are presented with the MHWS and the Inlet and offshore 1% storm tide levels in Figure 4-29. These profiles show the level of future tidal and extreme water levels and illustrate the significant volume of material within the dune which will provide a buffer to future erosion.

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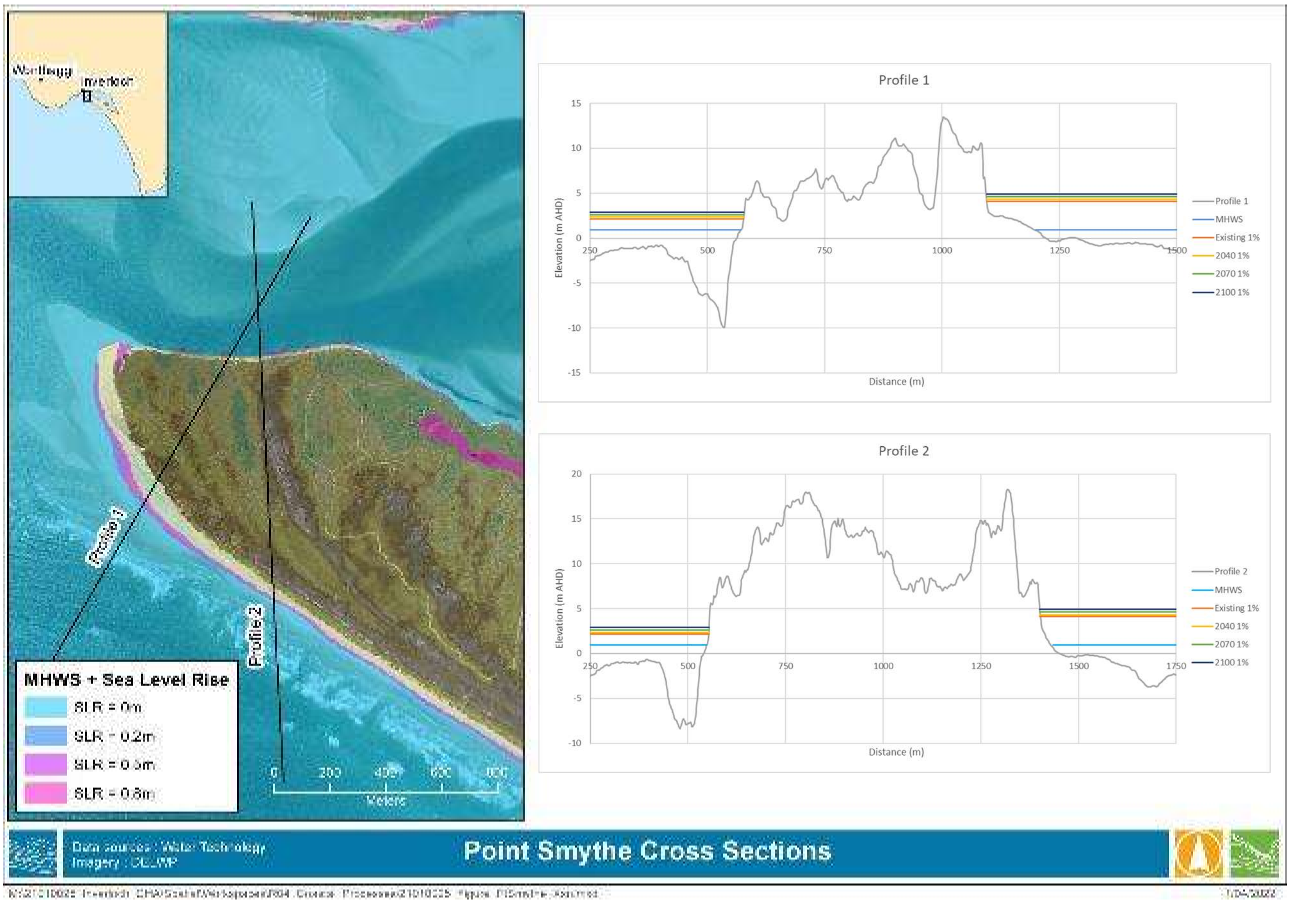

Figure 4-29 Extreme Water levels around Point Smythe

4.5.6 Open Coast

To determine the future recession along the exposed coast of Venus Bay, the Bruun Rule has been used in conjunction with the offshore wave climate and the 2009 FutureCoast LiDAR.

The open coast developed over the Quaternary period, with extensive growth during the Holocene epoch from the deposition of marine sediment and subsequent aeolian processes. As such, it has been assumed that the material in this zone is sandy sediment and will be free to adjust to sea level rise through landward migration of the dune as per Figure 4-23, albeit with more dense vegetation in places. On this aspect, it is important to note significant changes to the vegetation along the coastal dune – through changes in climate (water / wind / etc), landuse or other such as bushfire can occur but are outside the scope of this assessment.

The extent of the future recession determined by the Bruun Rule is presented in Figure 4-30 for the profiles presented in Section 2.4.4.

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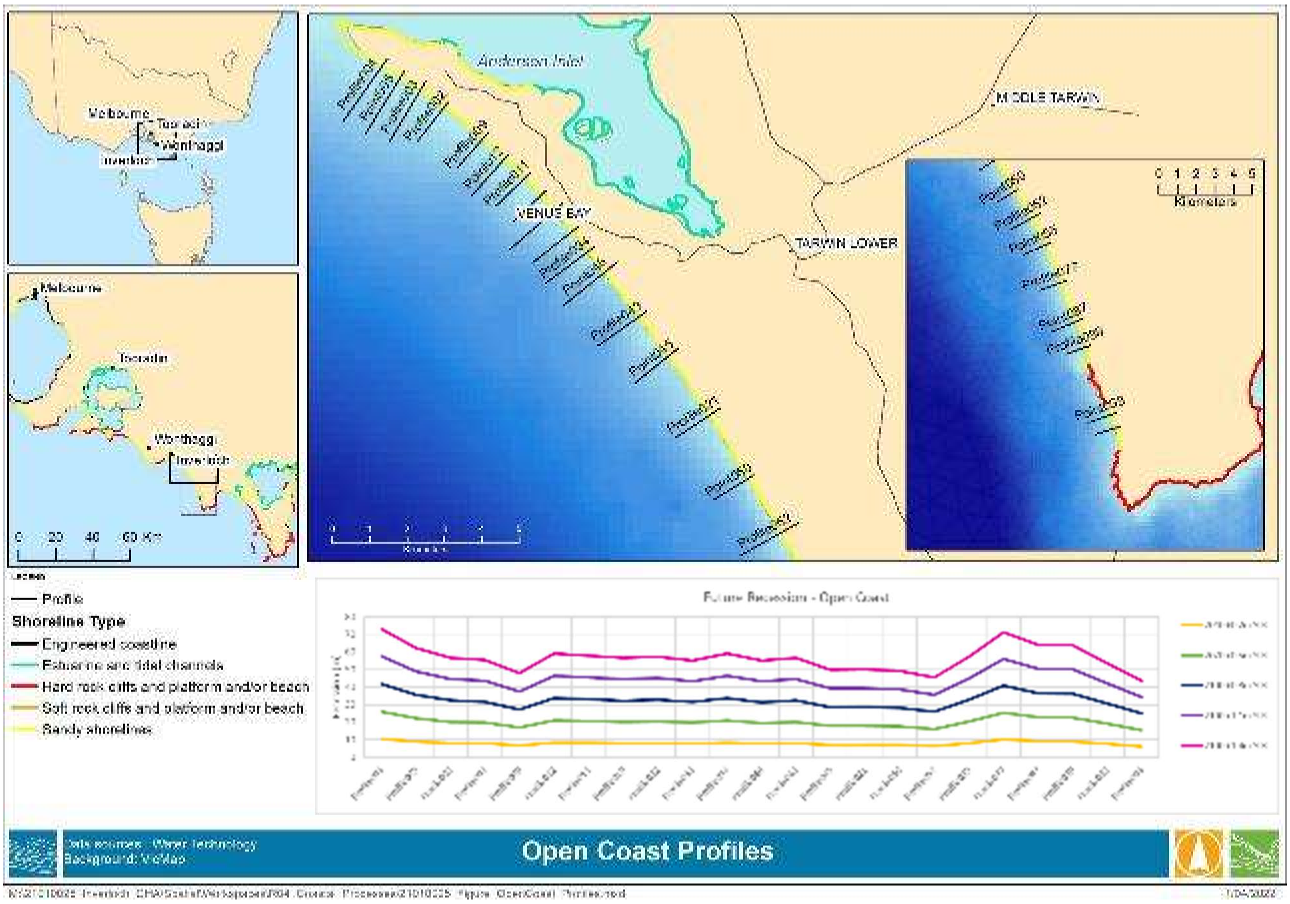

Figure 4-30 Future Recession, Venus Bay Open Coast

4.6 Erosion Hazard Zones

The parameters which contribute to the total erosion hazard zone have been presented above for each section of the coastline. It is important to note here that the erosion hazard zone is an area which the coastal processes acting on the coastline could cause an erosion hazard. The erosion hazard zones should not be considered a distinct line along the coast where the shoreline will be at each future planning horizon. The erosion hazard zones have been generated to identify assets and values within the zone which could be impacted as a consequence of erosion so that adaption of the coastal use and assets in this area can be planned for. The erosion hazard zones represent areas that may be prone to erosion processes in the future under different storm events and sea level rises.

The erosion hazard zone used in mapping is in the form:

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

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

5 SUMMARY

The coastal process investigation undertaken for the Inverloch Region Coastal Hazard Assessment and detailed above provides the RaSP with an enhanced understanding on the physical environment, drivers and responses of the coastline within the Study Area. This understanding has been used to develop coastal hazard zones which in turn have been used to identify assets and values which may be exposed to coastal erosion hazards. This report details the coastal erosion hazard zone, and inundation hazard zone is detailed in Report 5. The assets and values exposed to coastal hazards are described in Report 6 of the CHA and the risk and vulnerability of these in the Risk and Vulnerability Report (Alluvium, 2022).

Anderson Inlet has developed by marine transgression and development of the Point Smythe coastal spit. The Inlet is considered to have a wave dominated inlet entrance and a tide dominated basin within the body of Anderson Inlet. The tidal range falls from 2.1m offshore, 1.6m at Inverloch and 1.0m at Lower Tarwin. Tidal currents along the coastline are low and characterised by an eastward flood tide and westward ebb tide. Flood tide currents within Anderson Inlet are stronger than the ebb tide within the main body of the Inlet but ebb tides dominate through the entrance and a strong ebb jet tide can extend offshore. Waves are predominantly from the west-southwest to southwest with a median wave height of 1.5m and a 95th percentile exceedance of 3.2m offshore.

The tidal and wave conditions result in diminishing net eastward sediment transport along the coast from Flat Rocks to Venus Bay Settlement 1 at which point the net sediment transport becomes increasingly westward towards Cape Liptrap, in agreement with the crenulate shape of the coastline and the narrow wave band.

Sediment transport around the entrance is driven by waves on the ocean side and tidal currents within the entrance and Inlet. Within a transition zone from Point Norman to Toys Backwater waves can act to drive sediments into the Inlet, working to increase the sinuosity of the entrance channel north-eastward, spilling sediment over the bar into the channel. Concurrently ebb tides deposit sand in a delta which can form an extensive spit during periods of lower wave energy and provide additional material to Surf Beach. A strong ebb tide delta can reduce the net sediment transport potential by decreasing the angle of the coast to the incoming wave.

A significant net loss of sand has been measured in the entrance area between 2012 and 2021. The rapid change at the entrance and the erosion at Surf Beach is the result of different drivers acting on the coastal environment. The coastal drivers and associated dynamic responses which are proposed as leading to the mass entrance change are provided in Table 5-1.

Table 5-1 Coastal Process Driver and Response

Driver	Response
Channel meander length reaching maximum	Point bar cut through, Weakening of main channel dominance, Development of second, shorter channel Distribution of flow across entrance bar, reduction in ebb tide delta
Significant catchment flood flow (top 2 recorded flood events occurring in 12 months)	Flow incision across entrance sand bars, Weakening of main channel dominance Distribution of flow across entrance bar, reduction in ebb tide delta

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Driver	Response
Increase in westerly wave climate	Increase in net sediment transport east across Surf Beach Infilling of main ebb tide channel Distribution of flow across bar (further reducing ebb tide delta) Reduction of ebb tide channel due to infilling from additional wave energy and sediment transport Increase net sediment transport potential at Point Norman Reduction in periods of low wave conditions which allow ebb tide sediment transport westward to Surf Beach
Loss of ebb tide delta and jet stream *(not a coastal driver itself but results in a response)*	Change of beach angle results in increase of net eastward sediment transport across Point Norman Reduction of sediment supplied beyond wave breaker zone to return to Surf Beach

It is not possible to identify a single cause, or predominant driver of the change, given the coincidence/short time frame between the different drivers and the limited recorded evidence of similar such rapid and significant change. However, it is noted that the drivers of extreme flooding and swell wave conditions are natural processes, and it is not possible to accurately predict timing or severity of either beyond probable annual exceedances. The entrance, and to that effect the beach volume and shoreline position at Surf Beach, should thus be considered 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.

5.1 Assumptions, Limitations & 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 remains some limitations and uncertainty in both existing knowledge and assessment methods used to underpin the erosion hazard assessment. These are outlined below.

5.1.1 Assumptions

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

- Limited historical bathymetric and oceanographic & catchment data in study area (*as discussed in Gap Analysis*). The study assumes this is largely representative of bathymetric and topographic levels across the study area in the past and into the future. This excludes the entrance area where it is known large changes do occur.
- Erosion and recession are based on the observed position of the shoreline captured in 2020 or 2021 in the most recent available aerial imagery along the sandy coastlines. These positions may have shifted in the time since data collection, although this is likely to be minor.
- It is assumed recession will occur at a consistent rate landward. This is a conservative assumption as there is no allowance for impediments to erosion such as vegetation, infrastructure, buildings/foundations

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or changes in strata. It is assumed the soft material along the shore is uniform landward to the location of the backshore cliff or bluff.

- It is assumed that the models produce accurate conditions where data does not exist for model calibration / validation (*this is a common assumption and why numerical models which are well established and tested are used*). For example, there is no measured water level data available within Venus Bay with which to calibrate numerical models. The hydrodynamic model has been calibrated to water levels at Inverloch Jetty for a short period, however long term data capturing more extreme events is unavailable either within the Inlet or offshore.
- It is assumed that the 40year hindcast of water levels and wave conditions are accurate and sufficient to predict up to the 1% AEP (~100y ARI) events.
- It is assumed that measured tidal waters are representative of long term conditions – Tarwin Lower especially where the measured data does show some seasonal variation.
- With the exception of the rock seawall along the Inverloch foreshore from the South Gippsland Yacht Club, past the bowls club and Inverloch Jetty to the northern return to the Esplanade, coastal structures are assumed to not prevent landward recession and erosion. The rock seawall adjacent to Bunurong Road and the geotextile sandbag wall seaward of the Inverloch Lifesaving Club are assumed to be temporary structures and considered only in the present day storm erosion estimates.
- It is conservatively assumed that earthen levees within Anderson Inlet will not prevent or limit future recession.
- It is noted that the accuracy of the shoreline rate of change from aerial imagery is relative to georeferencing, image quality and delineation of dune/vegetation/cliff features.
- The study assumes the current bathymetry/topography remains constant as sea levels rise.
- There is an assumption that long term historic changes will occur in a similar manner and rate into the future (separate from the impact of sea level rise).
- It is assumed there is no mass morphological change of entrance and tidal bar dynamics during the horizons considered in this study.

5.1.2 Limitations

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

- The hazard zones are to provide an understanding of exposure and support for adaptation planning. Erosion hazard is not a prediction of future shoreline position.
- Results should not be over-interpreted at the micro (lot/property) scale.
- The Study Area has a complex shoreline with various types of coastal geomorphic sectors and hazard processes. Coastal geomorphic sectors have been generalised to a smaller number of shoreline types to allow the assessment of the large Study Area.
- The coastline in the Study Area can be very dynamic. The erosion drivers and response described here are based on conditions observed and data available at the time of analysis. Conditions may differ to the time of reading.

5.1.3 Uncertainty

To provide a guide on the level of uncertainty related to each coastal erosion hazard zones , a summary of uncertainty for each type of shoreline is provided below.

Table 5-2 Summary of Key Erosion Hazard Uncertainties

Shoreline Type	Key Uncertainty
Bunurong Road – Hard Rock Cliffs	Highly detailed site-specific knowledge of the geology, geomorphology, hydrogeology and the soil and rock mechanics is necessary to assess the local soil and rock slope stability and potential failure mechanisms along these shorelines. A moderate level of uncertainty exists in understanding the key processes influencing erosion of these shorelines due to the site-specific nature of the local underlying geology. Site specific data (i.e. core logs, sediment analysis) and specialist geotechnical assessments are required to improve confidence at the lot/parcel scale.
Bunurong Road – Platform Beaches	Erosion hazards along the pocket beaches adjacent to Bunurong Road are generally due to two main mechanisms; storm erosion, and equilibrium profile recession. Estimating equilibrium profile recession, both for storm erosion and sea level rise, is considered to have a moderate level of uncertainty due to limitations of available assessment methods.
Flat Rocks to Townsend Bluff – Platform Beach and Bluff/LIGM rise	Erosion hazards at the last interglacial maxima shoreline, or coastal bluff, will occur as a possible consequence of the loss of the sandy beach platforms currently situated along Surf Beach and within the entrance along the Inverloch foreshore. This bluff may be vulnerable to mass movements once the base of the bluff is destabilised by wave action. A moderate level of uncertainty exists in understanding this process due to limited information or understanding of the underlying geology and potential hazard processes. Site specific data (core logs) and specialist geotechnical assessments are required to improve confidence at the lot/parcel scale.
Flat Rocks to Point Norman (Surf Beach) – Sandy Shoreline	Coastal recession at this beach is a combination of all erosion processes, along with a significant longshore sediment transport component. Given the recent rapid recession at Surf Beach and the influence of the dynamic entrance on beach stability, there is a moderate level of uncertainty in the prediction of long term recession. The sediment transport processes are highly dynamic, can be intermittent, and vary both spatially and in time. For this reason, decision making in response to this hazard is only considered appropriate at the landform/settlement scale.
Anderson Inlet - Coastal Wetland Fringed Shoreline	The level of uncertainty is low to moderate; the adaptive capabilities of vegetation communities may limit the impact of modest amounts of sea level rise but relatively major loss of coastal wetlands could be expected by the end of the century. An upper limit on the possible extent of erosion hazards can be reasonably defined through consideration of the future extent of the MHWS.
Anderson Inlet - Low Earth Cliffed Shorelines	Ongoing rates of low earth cliff recession are virtually certain with increasing sea levels. The uncertainty relating to the trajectory and probable rates of change is considered low.

Shoreline Type	Key Uncertainty
Point Smythe	There is a high level of uncertainty in the migration of the tidal channels through the entrance to Anderson Inlet. A significant number of coastal process drivers contribute to the position and stability of the entrance and the occurrence, severity and combination of these cannot be reliably predicted into the future. Assets on Point Smythe are currently limited and thus there is limited exposure to the hazard zone.
Point Smythe – Cape Liptrap – Sandy Shoreline	Erosion hazard along the open coast is associated with storm erosion and future coastal recession. The long term position of the shoreline has been stable in the past 70 years. Uncertainty related to setback from profile equilibrium is low due to the high volume of dune in the system. A significant change in profile alignment would be required to result in significant dune reshaping and notably larger setback.

5.2 How to use the Study Outputs

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

The outputs of the erosion hazard assessment should also be considered in conjunction with the inundation hazard assessment detailed in Report 5. An overview of the coastal processes, erosion and inundation hazard assessments is provided in the project Summary Report (Report 1).

Locate Shoreline Area of Interest	• Use **Figure 2-26** to identify what **Shoreline Class** the area of interest is located in.
Develop an Understanding of the Shoreline Class	• Review the relevant shoreline type in **Section 2.1.5** • Understand the **key coastal processes and drivers, historical change and future response** available to act on the area of interest
Consider Future Erosion Hazard Zones	• Refer to the erosion hazard **GIS layers and mapping in Appendix D** • **Visualise** the potential erosion hazard extent for the area of interest for each event probability/planning horizon or sea level rise • Consider the **assets vulnerable** and the consequence of the erosion hazardon the asset
Understand the Assumptions, Limitations and Uncertainties	• Review other issues / considerations for the shlirne type, e.g. **existing coastal protection works, timescales** etc • Consider the assumptions, limitaiton and uncertainties in the existing knowledge (**Section 5.1**)

Figure 5-1 How to use the Coastal Process and Erosion Hazard Assessment Outputs

5.3 Recommendations

5.3.1 Identifying Risks and Planning Adaptation

Report 6, Report 7 and the Risk Assessment completed by Alluvium (2022) build upon the work described in this report and provide a detailed analysis of assets exposed to coastal hazards and potential adaptation action to assist with adaptation planning for the Inverloch shoreline. Further detailed risk analysis can be found in the Risk and Vulnerability Assessment Report (Alluvium, 2022). Recommendations relating to adaptation to reduce the impact of coastal hazards are provided in Report 7.

5.3.2 Future Works to reduce Uncertainty

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

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Table 5-3 Additional Works

Type	Summary	Purpose
Oceanographic Data	Measured Current Data in the Entrance	Enable better understanding of entrance dynamics Model calibration data.
Oceanographic Data	Offshore current measurement	Enable better understanding of coastal dynamics, especially storm events Model calibration data.
Oceanographic Data	Inshore wave transformation	Concurrent measurement of wave conditions inshore along Surf Beach would provide additional data and confidence to modelling of hazards and options by resolving refraction and diffraction around Flat Rocks and Cape Paterson.
Numerical modelling	Further development of a complex morphological model of the entrance	Enhance understanding of entrance dynamics. Predict a greater range of scenarios and influences of morphological change.
Numerical modelling	Improved coastal sediment transport modelling along Surf Beach	Additional numerical modelling of sediment transport along Surf Beach could be carried out with new data (inshore wave, updated survey) to enhance any design options. Potentially an academic research project given expense and duration.
Sedimentary Data	Core-logs through strata	Better predict erosion potential of vulnerable coastal areas: Surf Beach Wreck Creek Toys Backwater Point Smythe
Topographic Data	Survey of areas of significant change since 2009 LiDAR	Enhance mapping of vulnerable areas such as: Wreck Creek Surf Beach estate dunes and residential area Broadbeach Estate Point Smythe
Bathymetric Data	Expand Gippsland Ports entrance and Surf Beach nearshore survey	Expand the extent of the annual Gippsland Ports survey to cover Surf Beach and the nearshore zone and the eastern entrance around Point Smythe.
Bathymetric Data	Capture nearshore bathymetry (to -20m AHD) along coast	Understanding available sediment source and sinks of sediment.
Imagery data	Expand VCMP drone survey area	Expand the VCMP drone capture area to Flat Rocks and Miller Terrace to enable a more complete assessment of rapid coastal change

Type	Summary	Purpose
Sediment study	Enhance understanding of sediment sources and sinks	A large scale understanding of the sources and sinks along the Victorian coast will assist in the understanding of supply and loss of sediments from the coastline, and potentially identify valuable sources of sand currently under utilised
Oceanographic data	Improve design storm modelling	The wave model used for the project is calibrated to a short period of measured data with limited large storm events. Capture of additional data, especially storm events can be used to provide greater performance and confidence of the wave model during storm events.

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APPENDIX A
COASTAL GEOLOGY & GEOMORPHOLOGY REVIEW

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APPENDIX B
HISTORICAL AERIAL IMAGERY AND SHORELINE CHANGE

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APPENDIX C
LONG TERM SHORELINE CHANGE

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APPENDIX D
EROSION HAZARD ZONES

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APPENDIX E
VICTORIA'S RESILIENT COAST FRAMEWORK

	Key questions	Cape to Cape Resilience Project key deliverables	Completion timeline	Document citation	Additiona
	• Do we need action? • Who is involved? • Where's the study area? • What is our study scope?	Project plan	Mar-21	DELWP 2021, Inverloch Regional and Strategic Partnership Project Plan, Victoria, March 2021.	Website e Alluvium.
		Engagement plan	Mar - July 2021	Alluvium 2021, Cape to Cape Resilience Project Engagement Plan, Victoria, March 2021.	Project Up Resilience Fact Sheet RaSP. DEL Project Up engageme July 2021. Fact Sheet technical t 2021.
	• What do we value? • As a region and as a State? • What do we want the future to look like?	Community values study	Oct-21	Alluvium 2021, Cape to Cape Resilience Project Community Values Study - Engagement Report - Values and Experiences, Victoria, October 2021.	Engage Vi sessions -
		Cultural values assessment	Dec-21	Bunurong Land Council Aboriginal Corporation 2021, BLCAC Cultural Values Assessment: Cape to Cape Project, Victoria, December 2021.	
	• What processes are occurring and how might these change?	Inverloch region coastal hazard assessment	June 21 - Mar 22	Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 1 - Project Summary Report, Victoria, June 2022.	Fact Sheet context, p Alluvium.
				Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 2 - Data Assimilation and Gap Analysis, Victoria, June 2022.	Fact Sheet modelling
				Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 3 - Technical Methodology , Victoria, June 2022.	Project Up Assessmen Alluvium.
				Rosengren, N. & Miner, T., 2021, Inverloch Region Coastal Hazard Assessment – Coastal Geomorphology, Appendix A in Water Technology 2022c, Inverloch Region Coastal Hazard Assessment Report 3: Technical Methodology, Victoria, 2021.	
				Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 4 - Coastal Processes and Erosion Hazards , Victoria, June 2022.	
				Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 5 - Inundation Hazards, Victoria, June 2022.	
c	• How might these processes impact what we value?	Coastal hazard asset exposure assessment	April - May 22	Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 6 - Coastal Hazard Asset Exposure Assessment, Victoria, June 2022.	Project Up mapping, DELWP &

	Key questions	Cape to Cape Resilience Project key deliverables	Completion timeline	Document citation	Additiona
		Coastal hazard risk and vulnerability assessment		Alluvium 2022, Cape to Cape Resilience Project - Asset and Values Risk and Vulnerability Assessment, May 2022.	
		Economic base case		Natural Capital Economics & Alluvium, 2022, Cape to Cape Resilience Project – Economics Assessment, June 2022.	
	• How can we manage and adapt to these impacts?	Adaptation options and preferences	May - June 22	Alluvium 2022, Cape to Cape Resilience Project Adaptation Options - Engagement Report - Adaptation Engagement Outcomes, Victoria, October 2021.	TBC
		Adaptation framework summary paper		Alluvium 2022, Cape to Cape Resilience Project – Adaptation Framework Summary Paper, Victoria, June 2022.	
		Adaptation feasibility modelling		Water Technology 2022, Inverloch Region Coastal Hazard Assessment - Report 7 - Adaptation Assessment, Victoria June 2022	
		Economic assessment & cost benefit analysis		Natural Capital Economics & Alluvium, 2022, Cape to Cape Resilience Project – Economics Assessment, June 2022.	
	• Which options are feasible and suitable, both now and in the future? • How can we plan our response strategically?	Cape to Cape Resilience Plan		Inverloch RaSP Stage 2- TBC 2023	
		Cape to Cape Implementation plan/s		Inverloch RaSP Stage 2-& Partner Agencies TBC 2023 onwards	
t	• How can our response be adaptive to changing conditions? • How are we tracking in implementing our plan?	Cape to Cape Resilience Plan including implementation, monitoring and evaluation		Inverloch RaSP TBC 2023 onwards	

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Melbourne
15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800

Sydney
Suite 3, Level 1, 20 Wentworth Street
Parramatta NSW 2150
Telephone (02) 9354 0300

Brisbane
Level 5, 43 Peel Street
South Brisbane QLD 4101
Telephone (07) 3105 1460

Adelaide
1/198 Greenhill Road
Eastwood SA 5063
Telephone (08) 8378 8000

Perth
Ground Floor, 430 Roberts Road
Subiaco WA 6008
Telephone (08) 6555 0105

New Zealand
7/3 Empire Street
Cambridge New Zealand 3434
Telephone +64 27 777 0989

Wangaratta
First Floor, 40 Rowan Street
Wangaratta VIC 3677
Telephone (03) 5721 2650

Geelong
51 Little Fyans Street
Geelong VIC 3220
Telephone (03) 8526 0800

Wimmera
597 Joel South Road
Stawell VIC 3380
Telephone 0438 510 240

Gold Coast
Suite 37, Level 4, 194 Varsity Parade
Varsity Lakes QLD 4227
Telephone (07) 5676 7602

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