Technical Methodology Report

Port Phillip Bay Coastal Erosion Hazards

Department of Energy, Environment and Climate Action

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GLOSSARY

Aeolian	The erosion, transport, and deposition of material by wind.
AHD	Australian Height Datum. A national datum for elevations based on mean sea level (MSL) at 30 tide gauges across Australia between 1966 and 1968.
AEP	Annual Exceedance Probability. The measure of an event's likelihood (expressed as a probability) equalling or exceeding a given magnitude in any given year.
Alluvial	Catchment water-driven sediment transport process (non-marine).
Astronomical Tide	Water level variations due to the combined effects of the Earth's rotation, and the gravitational pull of other orbiting bodies.
Backshore	The area of shore lying between the average high-tide mark and the vegetation affected by waves during severe storms.
Backshore Profile	The averaged topographic gradient of the backshore zone to 500 meters inland of the high-water mark (HWM), ignoring high foredunes, and categorised into only a few broad classes representing significant differences in backshore landform histories and processes. (e.g., low-lying plains, gently sloping terrain, moderately to steeply sloping terrain, high coastal cliff terrain).
Calibration	The process by which the results of a model are brought to agreement with observed data.
CAMS	Coastal Asset Management System. A database of over 1,500 coastal protection assets in Victoria overseen by either DEECA directly, or by delegated coastal managers.
Chart Datum (CD)	The common datum for navigational charts, typically relative to the Lowest Astronomical Tide (LAT) of a nearby standard port.
Chenier	Discrete, elongated, vegetation marine beach ridge, sandy hummock and/or shell bodies stranded on a coastal mudflat or marsh and roughly parallel to a prograding shoreline.
Colluvium	Loose, unconsolidated sediments that have been deposited at the base of a slope or cliff.
DEECA	Department of Energy, Environment and Climate Action. The Victorian Government Department responsible for protecting and enhancing the marine and coastal environment, formerly known as the Department of Environment, Land, Water and Planning (DELWP).
Delta	A complex association of geomorphic settings, sediment types and ecological habitats, at a point where a freshwater source enters an estuarine water body.

Depth-of-Closure (DOC)	The theoretical depth of water along a beach profile at which sediment movement will not occur under a given set of wave, tide, and sediment characteristics.
Diurnal	Daily. Often used to refer to a daily variation, for example in a tide.
DTM	Digital Terrain Model. A three-dimensional representation of the ground surface levels.
Ebb Tide	The outgoing tidal movement of water culminating in a low tide.
Embayment	A coastal indentation that has been submerged by rising sea level and has not been significantly infilled by sediment.
EVC	Ecological Vegetation Class. A basic mapping unit used for biodiversity planning and conservation in Victoria. Each EVC represents one or more plant communities that occur in similar types of environments.
Estuary	The tidal extent of a river or drowned valley, which receives sediment from both river and marine sources. Contains geomorphic and sedimentary conditions influenced by tide, wave and river processes.
Flood Tide	The incoming tidal movement of water, culminating in a high tide.
Foreshore	The area of shore between low and high tide marks and the land adjacent thereto.
Geomorphology	The study of the origin, characteristics, and development of landforms.
GIS	Geographical Information System. Software systems and databases for analysing spatial information.
Holocene	The period beginning approximately 12,000 years ago. It is characterised by the warming of the climate following the last glacial period and the rapid increase in global sea levels to approximately present-day levels.
Hydrodynamic Model	A numerical model that simulates the movement of water within a defined model area.
Hydro-isostasy	Deformation (depression/uplift) of the earth’s crust in response to loading/unloading of water into oceanic basins.
HAT	Highest Astronomical Tide: the highest water level that can occur due to the effects of the astronomical tide in isolation from meteorological effects.

H_s (Significant Wave Height)	H_s may be defined as the average of the highest 1/3 of wave heights in a wave record ($H_{1/3}$), or from the zeroth spectral moment (H_{m0}). Approximately the wave height that would be estimated by a trained observer from the shore.
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, e.g., intertidal habitat.
Intertidal Flats	Intertidal flats are un-vegetated, generally low gradient and low energy environments that are subject to regular tidal inundation and consist of sandy mud or muddy sand.
Levee	Raised embankment along the edge of a coastal or riverine environment.
LiDAR	Light Detection and Ranging – also known as airborne laser scanning, is a remote sensing tool that is used to generate highly accurate 3D maps of the Earth’s surface.
Lithology	A description of the physical character if a rock or rock formation.
Littoral Zone	An area of the coastline in which sediment movement by wave, current and wind action is prevalent.
Littoral Drift Processes	Wave, current and wind processes that facilitate the transport of water and sediments along a shoreline.
MACA	*The Marine and Coastal Act 2018 (VIC)*. The Victorian Government legislation describing the process of managing the marine and coastal environment.
Meander	A description given to a bend or sinuous watercourse.
MHHW	Mean Higher High Water: the mean of the higher of the two daily high waters over a long period of time. When only one high water occurs on a day this is taken as the higher high water.
MHW	Mean High Water, i.e., the mean of high water over a long period of time.
MHWS	Mean High Water Springs, i.e., the mean of spring tide water levels over a long period of time.
MLW	Mean Low Water, i.e., the mean of low water over a long period of time.
MSL	Mean Sea Level. The average water level over a long period of time.

Neap Tides	Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean).
Nearshore	The region of land extending from the backshore to the beginning of the offshore zone.
Paleochannel	A remanent of an inactive river or stream channel that has been either filled or buried by younger sediment.
Paludal	Sediments that have accumulated in a marshy or swampy environment.
PPBCHA	Port Phillip Bay Coastal Hazard Assessment: The wider project assessing coastal hazards around Port Phillip Bay, including inundation, groundwater and erosion hazards.
PPBCEHA	Port Phillip Bay Coastal Erosion Hazard Assessment: Part of the wider PPBCHA focussing on coastal erosion hazards.
Physiography	The study of the physical patterns and processes of the environment to understand the forces that produce and change rocks, oceans, weather, and flora and fauna patterns.
Planform	Planform refers to the form of a channel viewed from above. E.g., Meandering channels are sinuous single channels.
Pleistocene	The period from 2.5M to 12,000 years before present that spans the earth's recent period of repeated glaciations and large fluctuations in global sea levels.
PPB	Port Phillip Bay
Prograding shoreline	A shoreline that is advancing towards the sea due to ongoing deposition of additional sediments.
Semi-diurnal	Half daily. Used to refer to a twice-daily variation, e.g., two high tides per day.
Shoal	A shallow area within a water body; a sandbank or sandbar.
Sea Level Rise (SLR)	A permanent increase in the mean sea level.
Sediment Compartment	A segment of the coast, defined by similar coastal processes at a range of scales ranging from Primary compartments (large scale), Secondary compartments (regional scale), and Tertiary compartments (local scale, see TCSC).

Seral Succession	Seral succession is the notion that vegetation communities change in time according to a process whereby pioneer communities modify the physical environment such that they can no longer grow there and make way for later stages that are better adapted to the new conditions.
Spring Tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean).
Storm Surge	The increase in coastal water levels caused by the barometric and wind set-up effects of storms. Barometric set-up refers to the increase in coastal water levels associated with the lower atmospheric pressure characteristic of storms. Wind set-up refers to the increase in coastal water levels caused by an onshore wind driving water shoreward and piling it up against the coast.
Storm tide	Coastal water level produced by the combination of astronomical and meteorological (storm surge) ocean water level forcing.
Sub-aerial	Processes that take place on the land or at the earth’s surface as opposed to underwater or underground.
Susceptibility	The sensitivity of coastal landforms to the impacts of coastal hazards such as sea-level rise and storm waves. This may include physical instability and/or inundation.
Taxa	A taxonomic category or group, such as an order, family, genus, or species.
TCSC	Tertiary Coastal Sediment Compartment. A segment of coast defined by similar sediment transport processes at a local scale, including within the nearshore.
Tidal Planes	A series of water levels that define standard tides, e.g., 'Mean High Water Spring' (MHWS) refers to the average high-water level of Spring Tides.
Tidal Prism	The volume of water moving into and out of an estuary or coastal waterway during the tidal cycle.
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides.
Tides	The regular rise and fall in sea level in response to the gravitational attraction of the Sun, Moon, and Earth.
Total Water Level	The coastal water elevation. A combination of the tide level, storm surge, and wave setup/runup effects, on top of the local mean sea level.
VCMP	Victorian Coastal Monitoring Program. A field monitoring and knowledge management program to inform coastal management.

Vulnerability	Vulnerability is a function of exposure to climatic factors, sensitivity to change and the capacity to adapt to that change. In this report is means the degree to which a natural system is or is not capable of adapting or responding to the impacts of coastal hazards to which they are physically susceptible and exposed.[1]
Wave Setup	The increase in water level near the shore that balances the momentum of breaking waves.
Wind Shear	The stress exerted on the water's surface by wind blowing over the water. Wind shear causes the water to pile up against downwind shores and generates secondary currents.

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[1] Definition taken from the Smartline Glossary http://www.ozcoasts.gov.au/coastal/smartline_terms.jsp

[2] Definition taken from the Smartline Introduction http://www.ozcoasts.gov.au/coastal/introduction.jsp

1 INTRODUCTION

1.1 Project Overview

Port Phillip Bay (PPB) is the largest bay and most densely populated coastal area in Victoria. Key coastal communities include large parts of Greater Melbourne, Geelong, Frankston, and Mornington, as well as a number of smaller settlements. As such, this coastline provides many important functions for these communities, including as popular water-side residential land, recreational space such as coastal parklands, beaches and trails, and tourism locations for day visitors and coastal holidays. PPB also includes key areas for industry, such as shipping, commercial fishing and wastewater treatment. Finally, there are parts of PPB and its coastline with significant environmental value, including for marine life, sensitive coastal vegetation, and RAMSAR listed wetlands.

As with any other coastal area, Port Phillip Bay is naturally dynamic and prone to both slow and sudden change in response to the wind, waves and tides. Ongoing changes to the global climate may add further pressures and shift these changes beyond the bounds of present expectations.

The Department of Energy, Environment and Climate Action (DEECA) have therefore instigated the Port Phillip Bay Coastal Hazard Assessment (PPBCHA) to be able to understand the likely impacts of climate change in coastal areas. The PPBCHA considers the following hazards that are a result of coastal processes and climate-change-induced changes to them:

- Coastal Inundation Hazards – flooding due to the action of tides, storm-tides and waves.
- Coastal Groundwater Hazards – changes in the balance of fresh and salt water within coastal soils, that influence the biology, chemistry, and geology of the soils.
- Coastal Erosion Hazards – loss or slumping of coastal land due to coastal processes.

Chiefly, the PPBCHA aims to determine the extent of land that is exposed to coastal hazards at different timeframes. These outputs can then be used by stakeholders to prepare:

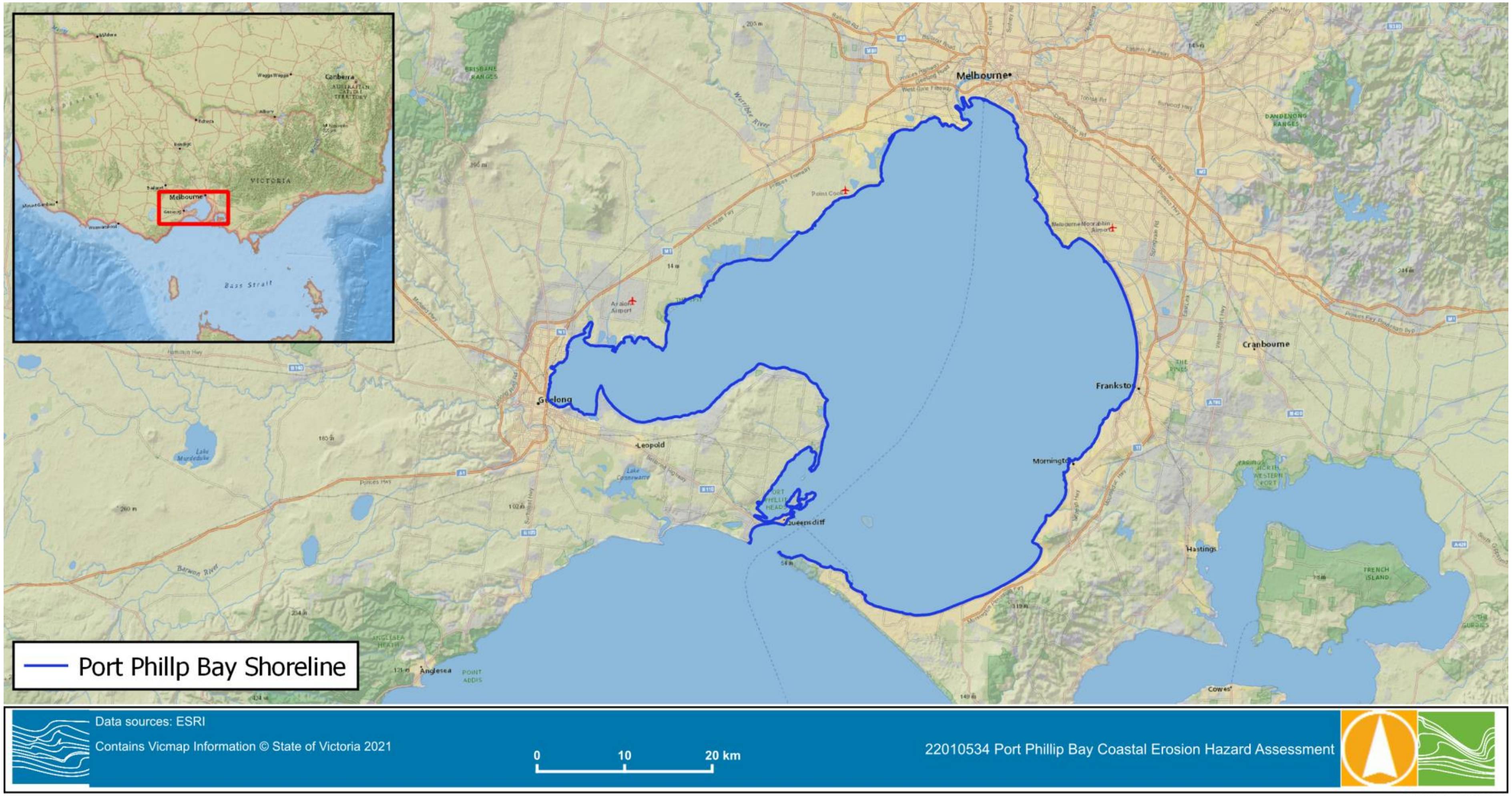
- Options to mitigate risks
- Planning for response and adaptation
- Repair and rebuild priorities for coastal assets
- Protection and Enhancement of key values
- Emergency response planning and preparedness
- Community education and understanding

DEECA are working closely with the Association of Bayside Municipalities (ABM), the 10 local governments surrounding Port Phillip Bay, Parks Victoria, Melbourne Water, Corangamite Catchment Management Authority and Traditional Owners.

The inundation and groundwater hazard components have been independently completed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and DEECA. Water Technology have been commissioned to undertake the erosion hazard component (of which this report is part), hereafter referred to as the Port Phillip Bay Coastal Erosion Hazard Assessment (PPBCEHA).

The study area coastline extends from Point Lonsdale on the Bellarine Peninsula clockwise to Point Nepean on the Mornington Peninsula. Port Phillip Bay as shown in Figure 1-1.

> *Port Phillip Bay includes key social, cultural and economic values along its coastline.*



Data sources: ESRI

Contains Vicmap Information © State of Victoria 2021

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Figure 1-1 Study Area Extent

1.2 Coastal Hazard Assessment

The PPBCHA project includes a gap analysis stage and an associated data acquisition stage (that closes many of the identified gaps). Assessments of coastal inundation hazard and changes to groundwater have been conducted. This study incorporates the erosion hazard assessment component. Relevant outputs of the previous project stages are inputs to this erosion study.

Following completion of all hazard assessment stages, DEECA will communicate the findings with the relevant stakeholders and make the datasets publicly available.

Figure 1-2 PPBCHA Stages and Components

1.3 Reporting

This document is part of a series of reports produced as part of the Port Phillip Bay Coastal Erosion Hazard Assessment (PPBCEHA). It should be read in conjunction with the following:

- Report 1: Literature Review Report (R01)
- **Report 2: Methodology Summary Report (R02)**
- Report 3: Erosion Hazard Summary Report (R03)

Accompanying this reporting is a series of supplementary datasets and mapping including:

- GIS layers representing modelled erosion hazard extents.
- Databases and GIS layers of data analysis used to prepare the erosion hazard modelling.
- Individual components of erosion hazard modelling in database formats.

2 EROSION HAZARD ASSESSMENT METHODOLOGY

2.1 Overview

The approach to defining the coastal erosion hazard zone in this study is based on the response of the shoreline position to several erosive processes occurring over varying timescales. These timescales include the **short-term erosion** (ST), consisting of the storm demand (that may recover or stabilise in the medium-term), and the long-term erosion which comprises the **Long-Term shoreline trend** (LT) caused by ongoing sediment movement, and the beach **future response to Sea Level Rise** (FR).

$$\text{Total Erosion Setback} = ST + LT + FR$$

Each of these processes is shown conceptually in Figure 2-2 to Figure 2-5. Further descriptions, along with their calculation methods are described below in Section 2.4 to Section 2.6. It is noted that these processes do not act independently and are all driven by the same physical processes. Therefore, the categorisation into three components represents the different abilities of models and data to isolate processes that occur over different timeframes.

Rather than selecting a single value for each of these components, a wide range of potential values will be used according to different probability distributions. This allows the modelling to incorporate the natural variability in erosion processes (e.g., the inter-annual changes in the net sediment budget), and the inherent variability due to the limited understanding or lack of long-term data (e.g., the selection of the depth-of-closure).

A monte-carlo modelling approach will be used to sample each of these likely ranges many times (at least enough samples for the output statistics to converge) to generate a distribution of potential total erosion setbacks. The Erosion Hazard Extent can then be calculated by extracting a particular selected output from this distribution (as a distance in meters) and applying this landward from an established 'baseline' shoreline position.

The total erosion setback has been applied on a tertiary coastal sediment compartment (TCSC) basis. TCSCs represent discrete sections of shoreline that have similar sediment transport characteristics that interact in the nearshore. The extent of TCSCs within PPB has been based on recent work by Kennedy (2022), who convened an expert panel to provide input into appropriate limits. These have been modified slightly to align the start and ends with the latest aerial imagery (e.g., where a groyne defines the compartment boundary). Figure 2-1 shows the TCSCs in PPB.

In most cases, each TCSC will have a single value for the total erosion setback that can be applied to an assumed 'baseline' shoreline position over the whole compartment. However, for some TCSCs, there are short sections with key sediment transport controls that require excluding one or more of the erosion components. These cases are shown in Table 2-1.

Table 2-1 Profiles characteristics and relevant modelled processes

Case	Short-term	Long-term	SLR Response
Profiles with maintained seawalls	No	No	No
Profiles with seawalls in 'very poor' condition	Yes	Yes	Yes
Profiles with offshore breakwater/reef protection	No	Yes	Yes
Soft cliff profiles	No	Yes	Yes
Hard cliff profiles	No	Yes	No
All other profiles	Yes	Yes	Yes

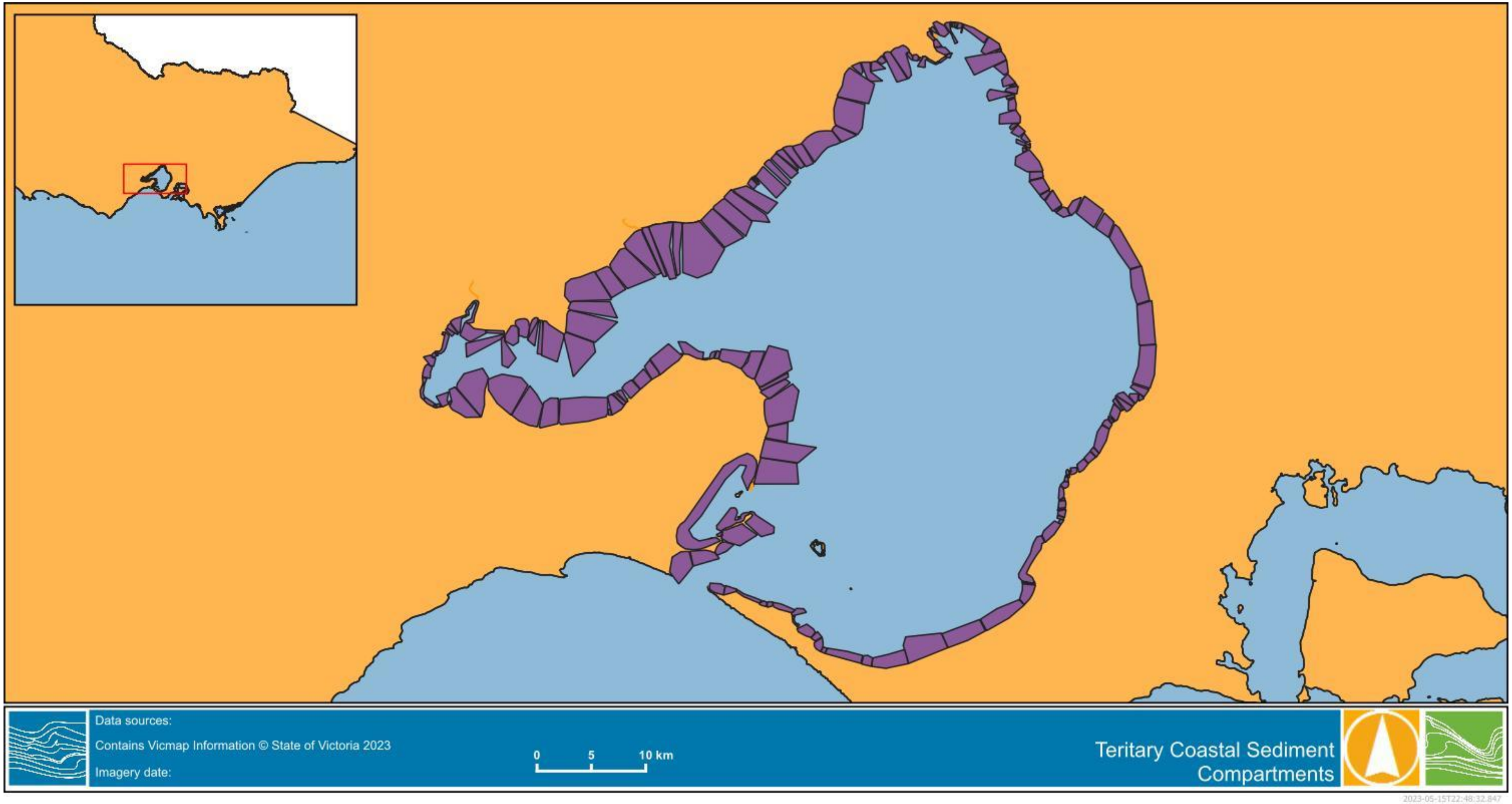


Figure 2-1 TCSC Boundaries in PPB

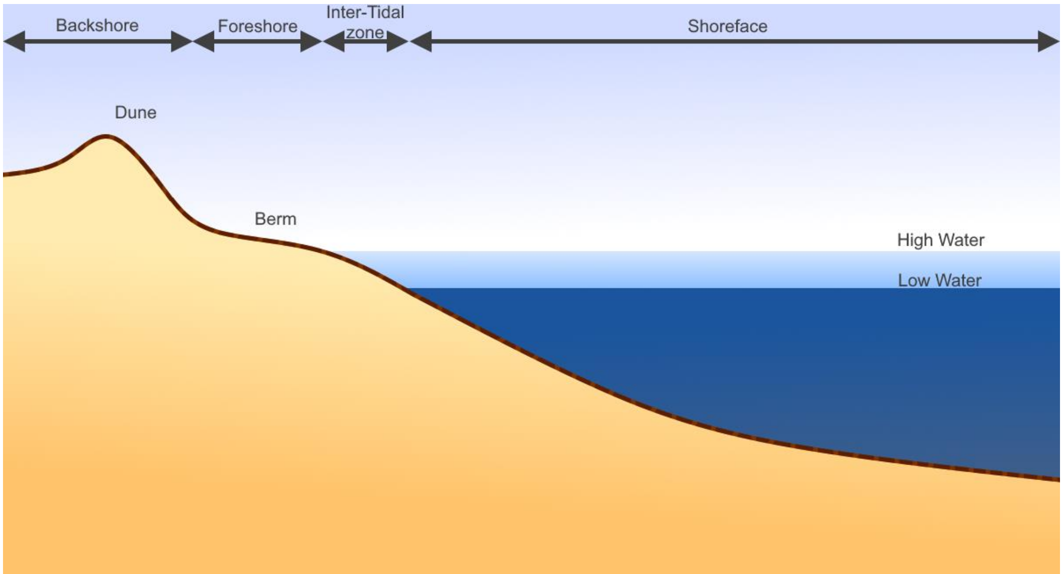


Figure 2-2 Non-eroded beach, including description of beach sections

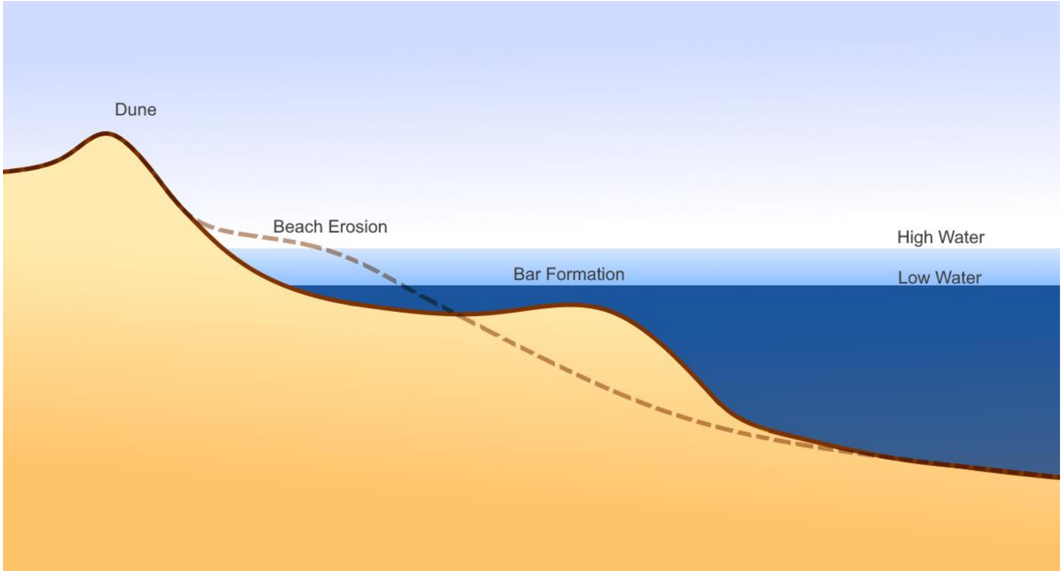


Figure 2-3 Typical Short-term erosion response

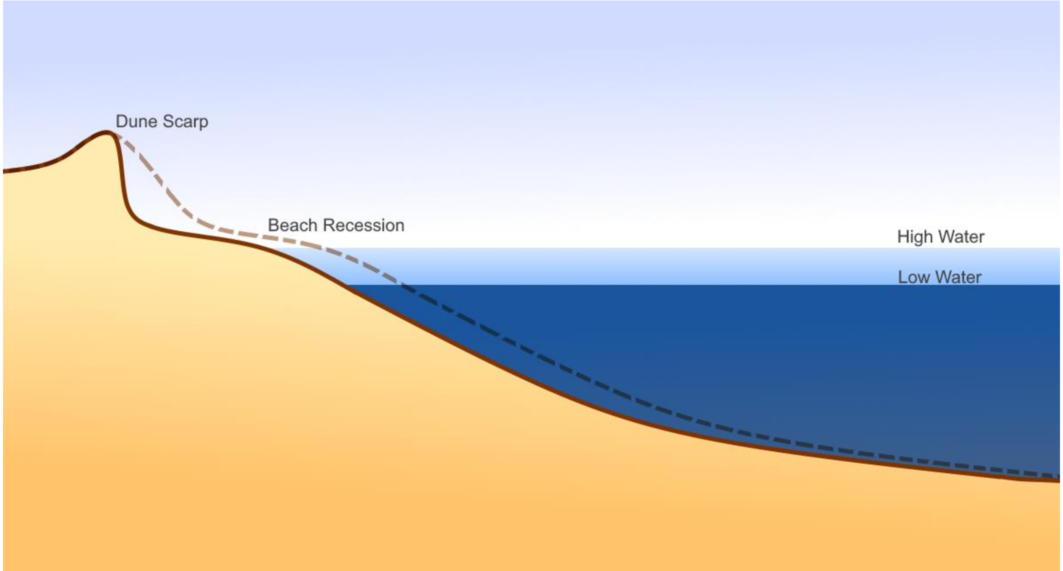


Figure 2-4 Typical Long-term trend erosion response

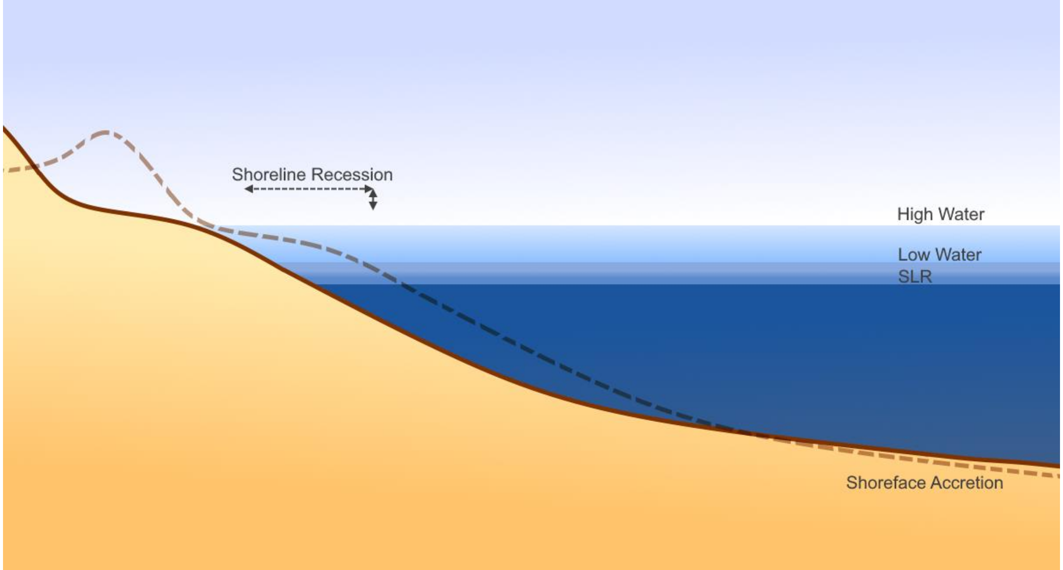


Figure 2-5 Typical SLR response of shoreline

2.2 Shorelines Mapping Approach

For an erosion hazards study, there needs to be a reference 'shoreline' from which erosion hazard is measured. This is not trivial as there may be many processes that cannot be readily captured by the erosion modelling approach (e.g., human interventions, such as beach scraping, dune/berm restoration and revegetation), and there may have been many shoreline changes since the most recent aerial imagery, or DEM data available.

For this study, the position of many shorelines based on available aerial imagery has been mapped as a line to better-understand historic shoreline position (and extrapolate to the future, see Section 2.4.6). The definition of the 'shoreline' mapped was selected as a shoreline that is stable in the short-term – and is therefore not influenced by seasonal rotation or small storm erosion/recovery processes.

For most sections of PPB this uses the line of observable vegetation. There are certain areas where short sections of vegetation have been artificially removed (i.e., for a beach access, or for coastal views), and the gap in vegetation does not indicate an erosion hotspot. Where these are less than 200m in length, the shorelines have been drawn following the beach between the vegetation either side. Where seawalls and similar 'hard' structures are present, they will be used as the representative shoreline in these areas. For rock revetments, this will follow the crest of the rock wall. Similarly, for cliffs the shoreline will be mapped to the base of the cliff.

This approach is expected to be applicable for all shoreline types and represent the relevant changes for all shoreline types. Where engineered structures are used in lieu of the vegetation line, there will be no change over the time between the aerial images.

Figure 2-6 Example of mapped shorelines at Dendy St Beach; 1960s (left) and 2010 (right)

2.3 Treatment of Coastal Structures

Existing maintained coastal structures, such as seawalls, groynes, etc. are assumed to be maintained into the future under all scenarios. Any shorelines with an existing functional seawall will be assumed to have no erosion hazard. The seawall is assumed to provide ongoing protection to the backshore and will be maintained as such. The beach seaward of the structures will be assumed to be erosion-prone and within a hazard extent. The justification for this is that seawalls are built to protect shorelines with previous erosion management issues. Existing seawalls with a very poor condition will **not** be assumed to provide this ongoing protection.

This approach has been requested by DEECA and has the following consequences:

- Any assessment of adaptation of existing structures at end-of-life will require a specific local-scale model that extends this study with the options for adaptation assessed individually.
- Any potential erosion hazard due to failure of coastal structures (i.e., undermining of seawalls, overtopping erosion, or sudden stability failure) is not captured. Local coastal managers will need to maintain existing structures for these erosion hazard extents to be valid.

The list of known structures and their condition will be based on the existing Coastal Asset Management System (CAMS) database, provided by DEECA. Where there are limitations in the CAMS dataset, they will be treated as follows:

- Structures observed **in recent aerials but not in CAMS** will be included based on their extent shown in the latest aerial imagery. Figure 2-7 demonstrates an example where the CAMS database terminates the extent of a seawall, but it is clear from 1970s aerial images that this structure extends further but has been buried within the dune in more recent times. A faint outline is observable in the 2021 imagery that suggests that this seawall is still present.
- Structures **in CAMS but not in recent aerials** (i.e. cannot be located in aerials) will be assumed to be spurious or failed, and these sections of shoreline will be assessed as though no structure is present Figure 2-8 shows an example of a seawall noted in CAMS that does not align with the recent shorelines, and is likely spurious.
- Structures **in old aerials but not in CAMS or recent aerials** will be assumed to have been removed and these sections of shoreline will be assessed as though no structure is present. This approach is readily understood, but may limit the analysis of shoreline positions in the past (i.e., if a seawall was previously present then the shoreline will have been artificially stabilised).
- Structures in CAMS **assessed as very poor** as part of the 2021 condition audit (DELWP, 2021) will be assessed as not providing ongoing protection. In these areas, the seawall stabilises the shoreline in the aerial imagery, removing the ability to determine any long-term ongoing erosion trend. Therefore, the only erosion processes that can be applied to these sections will be short-term (storm) erosion and response to SLR.

Figure 2-7 Example of area with no structure in the CAMS database but clearly a seawall visible

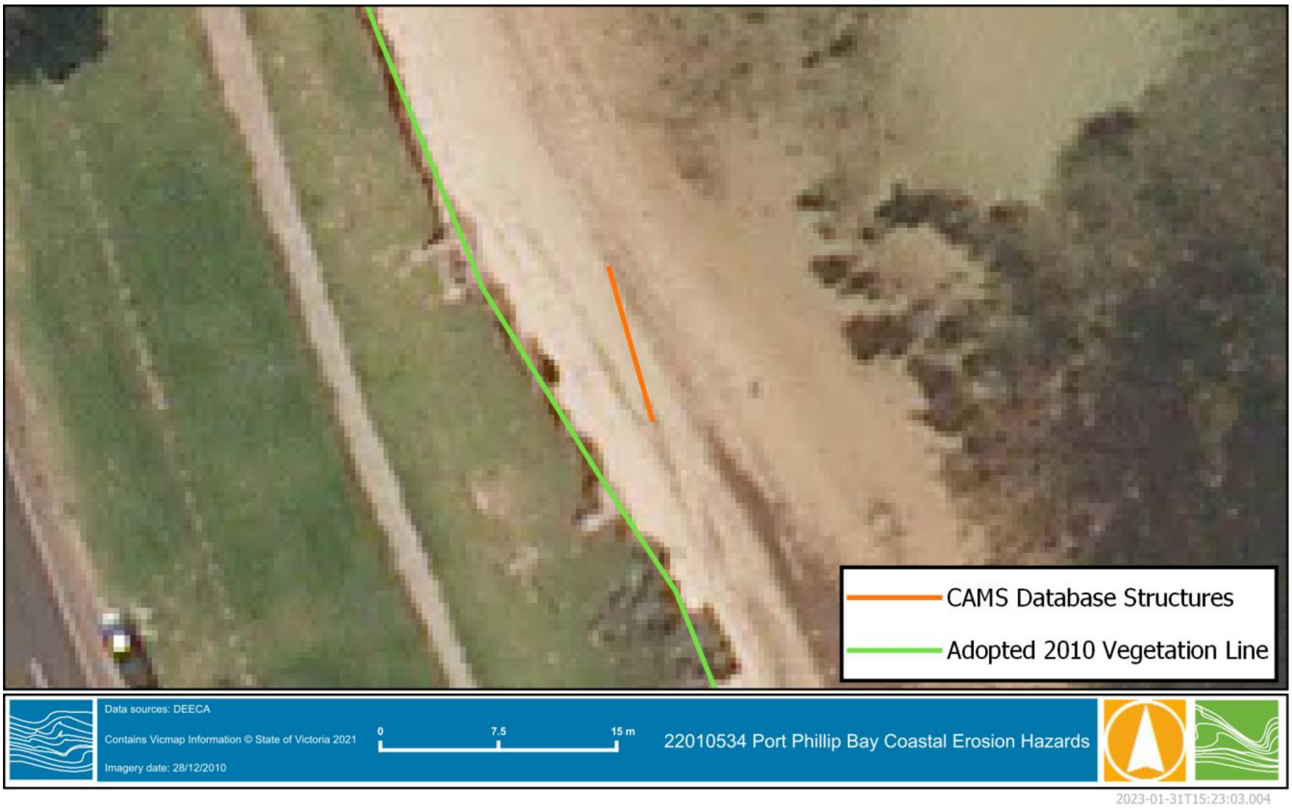


Figure 2-8 Example of structure in CAMS database but not present in the latest aerial imagery

2.4 Short-term Erosion

2.4.1 Description

In Port Phillip Bay, short-term erosion trends are primarily driven by two processes:

- Seasonal variations in wind and wave directions that cause beach rotation. Winter consists of predominantly northerly winds, that drive sediments to the southern end of sediment compartments. Conversely, summer includes more southerly winds, driving sediments north (Bird, 2011). The ends of each beach that sand moves away from become temporarily much narrower, as a form of fluctuating erosion.
- Storm waves that erode the beach over the course of a single storm, or series of 'clustered' storms. Such events erode the foreshore and draw sand offshore into sandbars (as shown in Figure 2-9). These sandbars are reworked onto the beach during calmer conditions in a process called 'beach recovery'.

For the purposes of considering erosion *hazard*, this study has only assessed the second (storm erosion). This is for the following reasons:

- Beach rotation occurs over the scale of seasons, any net loss during these processes (imbalance in the rotational processes) will be captured as part of the long-term erosion trend (see section 2.4.6).
- Storm erosion occurs quickly and cannot be prepared for as readily. Net losses can still be captured in long-term erosion trends, but gross inter-storm changes also represent a potential hazard.

It is noted that the above rationale for excluding beach rotation is based on the understanding of existing processes. If future wave conditions resulted in a higher magnitude of beach rotation oscillations, then there would be a resulting increase in the fluctuating beach width, likely at the expense of some additional erosion of the backshore. While this process is plausible (Liu et al., 2023), there is limited data available to inform hazard modelling in PPB. Future updates to PPB erosion modelling should reconsider this assumption as further information becomes available.

Finally, beach rotation can occur at an event scale (storm-driven). Within PPB, this effect is known to occur, and can be significant. However, this is not included in the storm component as it requires advanced local modelling of beach morphology. Moreover, as this process depends on the incident wave direction, it requires an in-depth analysis of the probability of different wave-height and direction combinations. This is a limitation of the scale of this study, and further refinements of this modelling should consider including this process for greater detail at local scales.

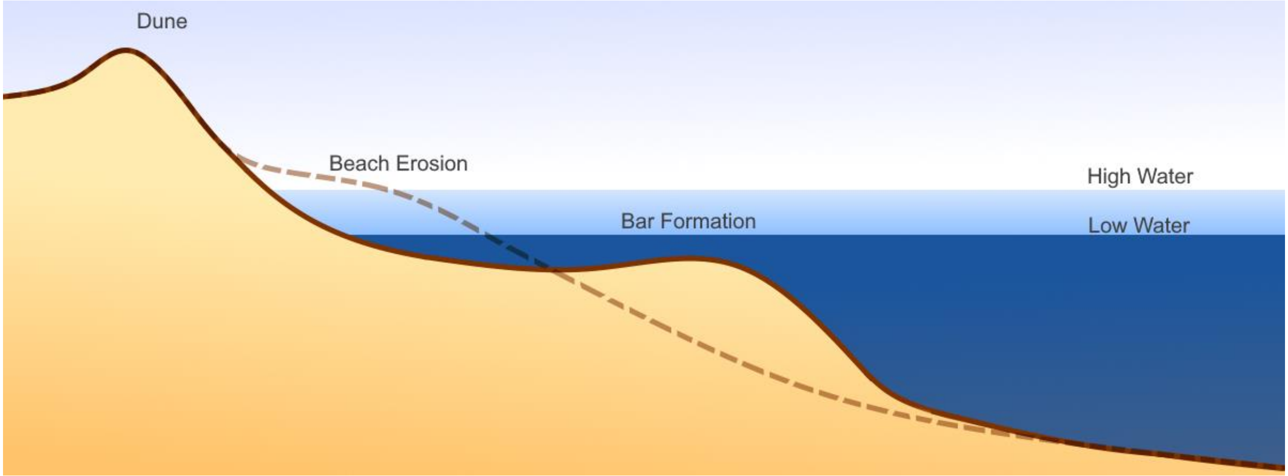


Figure 2-9 Typical Storm Erosion Pattern

2.4.2 Approach

Short-term erosion has been assessed using the SBEACH (Storm induced BEAch CHange) model, developed by the US Army Corps of Engineers (Larson and Kraus, 1989). SBEACH is a cross-shore transport equilibrium profile model that simulates profile updates in response to offshore wave forcing based on an initial profile, and basic sediment parameters such as grain size. SBEACH is solely a cross-shore model with no simulation of any longshore processes, which may also occur during storm events. As such, the SBEACH erosion results represent the average storm erosion occurring along a beach.

2.4.2.1 Model Geometry

The SBEACH model has been specified using a single representative cross-shore profile for each TCSC. This representative profile has been developed based on taking an average (mean) of the applicable profiles along the beach at the spacing of the beach transects (~100m) as extracted from the VIC FutureCoasts 2.5m marine LiDAR and 10m VCDEM 2017 data offshore and the FutureCoasts 1m Terrestrial LiDAR data onshore. These profiles were aligned relative to 0 mAHD and interpolated onto a consistent spacing (1m) prior to averaging. Certain transects within each sediment compartment were excluded from the average as they are not representative of profiles that may experience storm erosion, such as:

- Transects through seawalls and similar coastal protection structures.
- Transects through cliff features.
- Transects intersecting offshore protective structures such as breakwaters, constructed reefs, etc.
- Transects in low-energy areas with shallow water and limited wave fetch, such as small, enclosed bays, or protected areas behind headlands.

Figure 2-10 shows an example average profile (in red), with the full set of applicable profiles in that TCSC shown behind it (in grey).

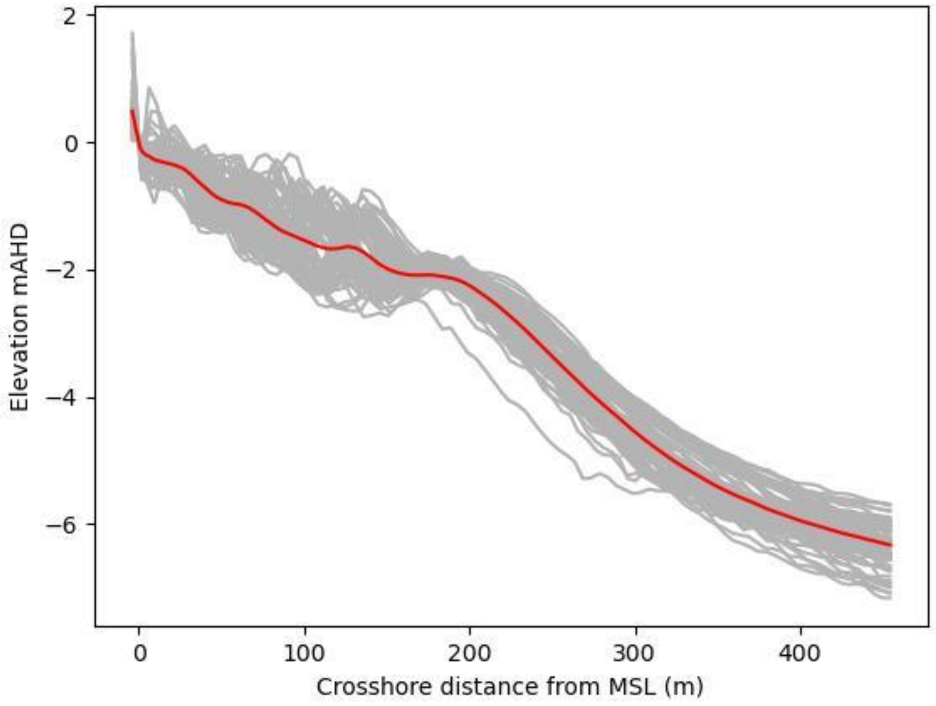


Figure 2-10 Example Average Profile

This process is a scalable way of determining a representative profile for each TCSC, although it contains several limitations:

- It may 'smooth out' sandbar features that are naturally semi-permanent and reduce wave impact on the beach.
- It relies on the existing DEM, which may not be representative of future conditions.
- For TCSCs with few transects, it is sensitive to the placement of the transects along the shore.

Table 2-2 presents several alternative approaches that were considered and ultimately rejected, with the reason for rejection noted. These different options were sensitivity tested for a 1% AEP storm at Mount Martha, with the storm bit volume, and storm recession distance for these also noted. In spite of the reasons for rejection, the overall variance in recession distance between different profile selection options was small (e.g., 0.42 m for a mean of all transects and 0.47 m for an arbitrary central profile).

The only exception was the Dean profile, which (for the small subset of TCSCs tested) showed setbacks an order of magnitude greater than the other tests. The Dean profile is based on constant dissipation of waves in an exposed open-coast environment. This description does not apply to PPB, which is typified by large convex nearshore profiles and multiple sand bars, or sheltered beaches with refracted, locally generated waves.

Table 2-2 Alternative SBEACH profile selections considered

Profile Type	Reason for Rejection	Sensitivity test results (1%AEP Mt Martha)
Using mean of subset of suitable samples	Not Rejected.	Storm bite volume: -0.66m^3/m Recession distance: -0.42m
Single profile from centre of TCSC	Does not necessarily represent the whole sediment compartment. Central profile not necessarily appropriate if through a rocky reef or breakwater.	Storm bite volume: -0.78m^3/m Recession distance: -0.47m
Median profile from TCSC transect spacing	Resulted in 'noisy' profiles, skewed by different offshore distances to sandbars or reef features.	Not tested, too noisy to be useful.
Using mean of all transects in TCSC	Incorporates inappropriate transects (tend to be flatter, less-exposed profiles). Sensitivity testing suggests potential to be less-conservative.	Storm bite volume: -0.66m^3/m Recession distance: -0.42m
Taking central profile and artificially removing sandbars or reef features	Overly subjective for each TCSC.	Storm bite volume: -0.78m^3/m Recession distance: -0.47m
Fitting a 'Dean' (1991) equilibrium profile to data	Port Phillip Bay is more sheltered than typical for profiles as described by Dean. The observed profiles tend to have a far greater sand volume in the nearshore, and lower energy. Fitting of the lines was poor, and results tended towards over-conservative.	Storm bite volume: -8.83m^3/m Recession distance: -4.00m

2.4.2.2 Model Forcing

The SBEACH model is forced with the CSIRO SCHISM-WWMIII extreme water level and wave conditions extracted offshore of each sediment compartment (McInnes et al., 2022). The modelled storms used are the 1%, 2% and 5% AEP events.

The CSIRO work produced three different outputs for each storm frequency: the median 'standard return level' result, and an upper/lower confidence interval range representing the 95th percentile and 5th percentile respectively. This dataset has been supplied by CSIRO at the 8m depth contour. The average (mean) of all such output points offshore of each TCSC has been collated to determine the input for the SBEACH modelling. Table 2-3 shows an example of this for the Sandringham Beach sediment compartment (TCSC 027). The full set of averaged wave/water-level conditions have been supplied in a separate database.

It is believed that the SCHISM-WWMIII storm waves may be underpredicted based on the limited model calibration data and the more recent evidence of the VCMP wave buoy data (not available for the SCHISM-WWMIII modelling). Further discussion on the details of the underprediction can be found in the Literature and Data Review Report R01 (Water Technology, 2023a). Due to this likely underprediction however, the upper confidence interval has been selected from the available results. The SCHISM-WWMIII model is in the process of being updated (DEECA, pers. Comm) and future erosion modelling in PPB should incorporate this revision.

This results in three different storm simulations per sediment compartment.

Table 2-3 Example of Averaged SCHISM-WWMIII results near Sandringham

Event	Wave Height			Storm Tide		
Confidence Interval	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
5% AEP	1.98	1.99	2.12	1.03	1.07	1.17
2% AEP	2.07	2.13	2.28	1.07	1.15	1.27
1% AEP	2.12	2.24	2.41	1.17	1.21	1.35

Each storm was constructed as a simple triangle of wave heights from 0.5 m up to the applied peak wave conditions and back to 0.5 m over a 48-hour period as shown in Figure 2-11. Water levels were applied by using the same approach for storm-surge and adding this to a predicted spring tide, with the peak occurring in the middle of the time period, aligned to the target total extreme water level. The 48-hour storm has been informed by the analysis by CSIRO for the PPBCHA Inundation study (McInnes et al. (2022) (Appendix C)). CSIRO demonstrated that the majority of storms are captured within a 48-hour period. The CSIRO work adopted a 6-hour offset between the wave height peak and the total water level peak (water level lagging wave heights) for input into the coastal inundation modelling. However, the PPBCEHA has adopted a coincident peak for the following reasons:

- As input wave heights are likely to be underpredicted, aligning the peak with higher water levels increases the impact that they may have on the beach (a conservative selection to mitigate wave underprediction).
- A misalignment of timing of peaks within the coupled SCHISM-WWMIII may be a potential reason for the wave underprediction (waves and wave fetch limited by depth in some cases). This is unconfirmed, but it is a possibility that the wave/storm-tide timing is not perfectly resolved.
- It is simple to adopt, and not likely to be less correct for design storm modelling.

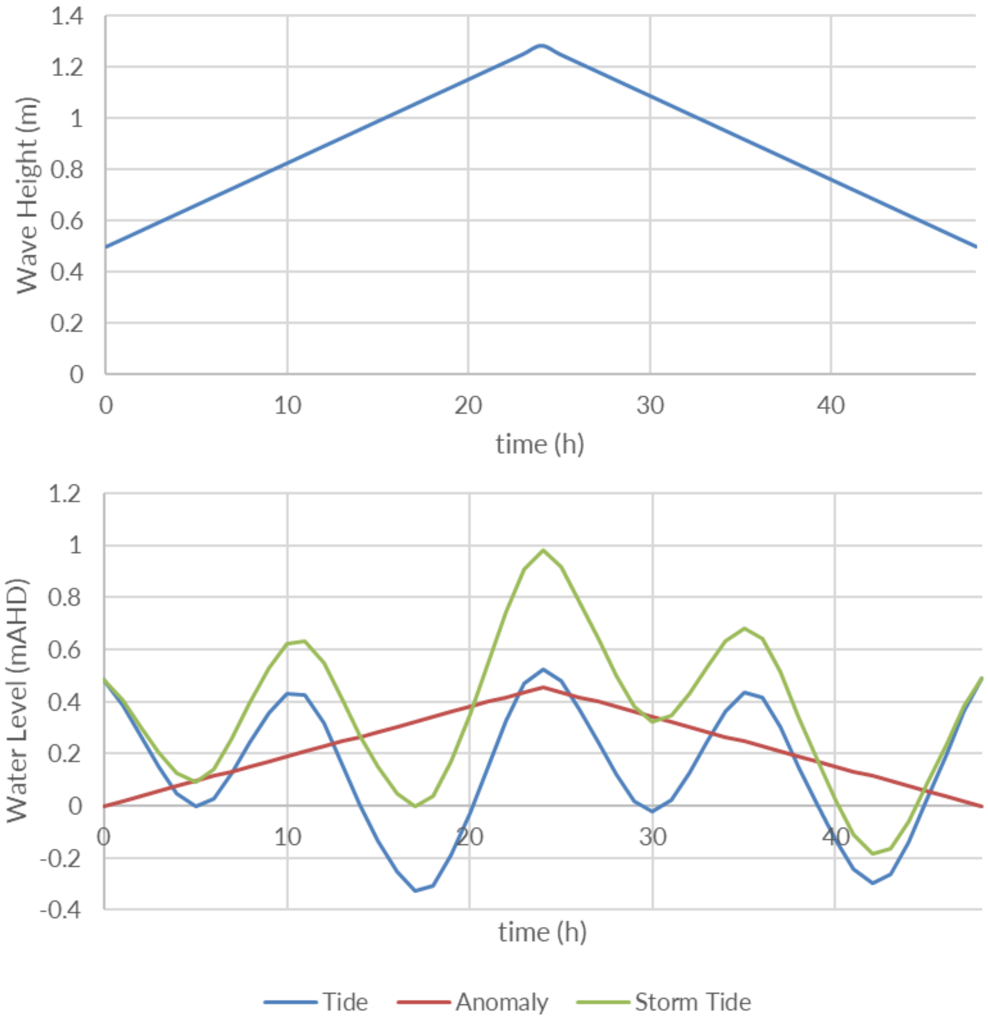


Figure 2-11 SBEACH Storm Input Timeseries

2.4.3 Calibration/Verification

The SBEACH modelling was calibrated/verified by simulating historical storm events with available data (waves and water levels) and comparing these to the VCMP datasets around PPB. SBEACH model calibration involves adjusting three parameters, the first of which is a scale factor that adjusts the overall rate of sediment transport and is the main factor to adjust. The other two parameters control the shape of the bar and surfzone (narrow peaked bar, flat surfzone, etc.).

2.4.3.1 Storm Event Calibration

While the VCMP data records are only short, there are several large events that provide reasonable results, with which to calibrate the SBEACH model.

The largest event observed in the VCMP wave buoy data is the 28th of October 2021 wave event that peaked at just over 2.5m (Hs) at the Sandringham wave buoy. This buoy is offshore and representative of waves conveniently heading towards the nearby Sandringham Beach VCMP UAV survey area. Therefore, this event has been analysed to calibrate the SBEACH model.

The VCMP UAV surveys captured data either side of the event: the first on the 8th of October (20 days prior to the peak) and the second on the 5th of November (8 days after the peak). The central part of the exposed Sandringham beach includes a section bound by two groynes. Figure 2-12 shows that significant beach rotation is observed in the VCMP data for this period. As such, a profile was extracted from the centre of this area to attempt to isolate the component of cross-shore sediment transport only (SBEACH does not resolve longshore transport).

Figure 2-13 presents the results comparing the final SBEACH profiles with the observed VCMP profiles in the centre of the groyne-bound sub-compartment. The model has been calibrated to show the correct order of magnitude of sub-aerial beach erosion and an approximate fit to the profile. The fit is good above the inter-tidal range, which is less-likely to be impacted by conditions outside of the storm event. The erosion volume (and average setback over the eroded profile height) are comparable. The comparison begins to trend poorly below high tide (~0.45 mAHD), where it is expected that the observed data may be skewed by sediment transport throughout the longer ~month period.

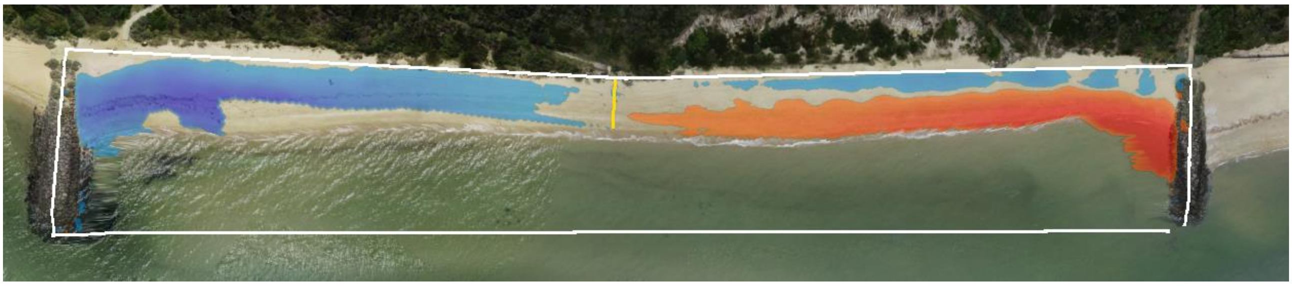


Figure 2-12 Sandringham Beach groyne sub-compartment beach rotation (yellow line indicates cross-section adopted, red indicates erosion, blue indicates accretion) (October 2021)

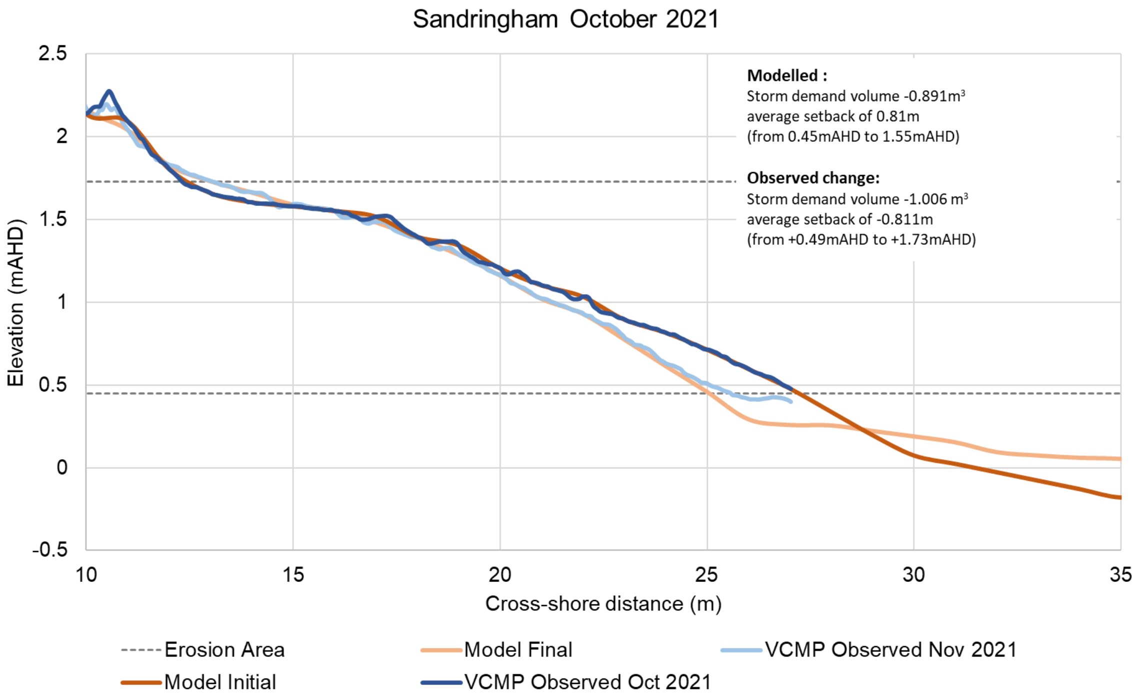


Figure 2-13 Sandringham October 2021 Event Calibration

Similar testing was done for a number of other events as summarised in Table 2-4 (results not shown). The outcomes were varied but tended to be within the same order of magnitude, and varying reproduction of the exact profile. This was assumed to be due to the following limitations:

- Substantial beach rotation is observed at some beaches and cannot be simulated by SBEACH. Other models can simulate these processes but are beyond the scope of the large-scale PPB assessment (too time consuming). These should be considered for local-scale subsequent studies.
- The inter-survey period is sometimes large (~2 months) relative to the short-duration of the storms (~48-hours). Therefore, the ambient sediment transport processes may be significant and therefore the storm effects cannot be isolated. This is of particular concern when there is a large period following the storm event, within which the beach may 'recover'.
- The nearest wave buoy may not always be representative of the waves incident on a given beach.

Table 2-4 Modelled SBEACH Calibration events

Location	Largest Event Date	Prior Survey	Following Survey	Nearest Wave Buoy
Altona	23/10/2022	26/09/2022	07/11/2022	Werribee
Mount Eliza	30/10/2022	21/10/2022	02/12/2022	Mount Eliza
Patterson River	28/10/2021	15/09/2021	05/11/2021	Mount Eliza (up wind)
Dromana/McCrae	28/10/2021	25/10/2021	14/12/2021	Rosebud
Sandringham	28/10/2021	8/10/2021	5/11/2021	Sandringham

2.4.3.2 Long-term Verification

In order to verify the calibrated SBEACH model, a longer period was simulated. Two surveys at St Leonards were observed to show a clear erosion setback as shown in Figure 2-14 for the period 29th September 2022 to 18th November 2022. This period included a late-October storm event with a peak wave height of 1.86m at the nearby Indented Head wave buoy but did not show any clear signs of beach rotation as observed in the VCMP UAV data.

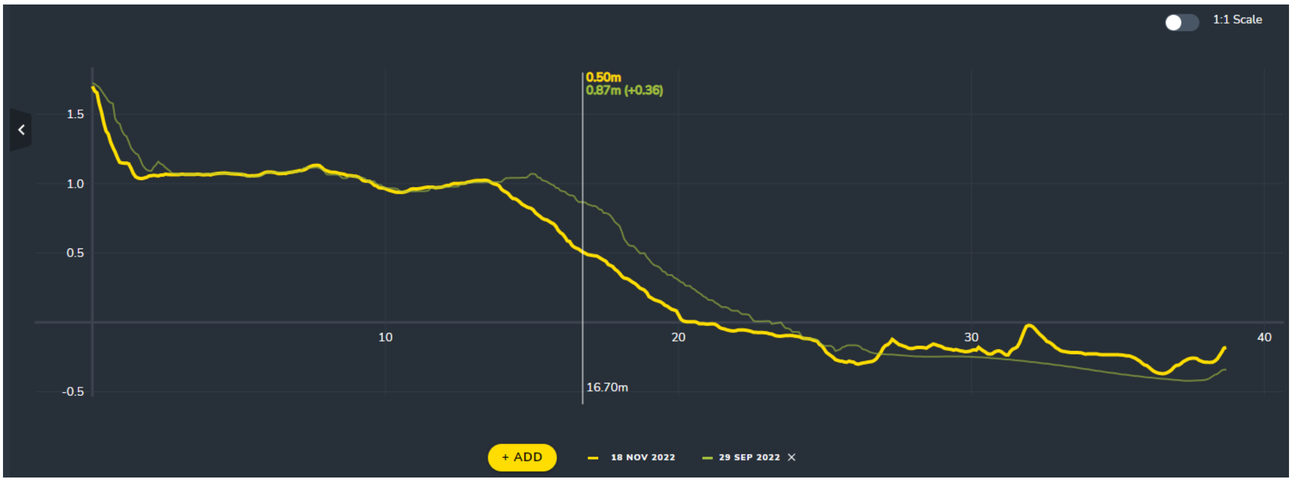
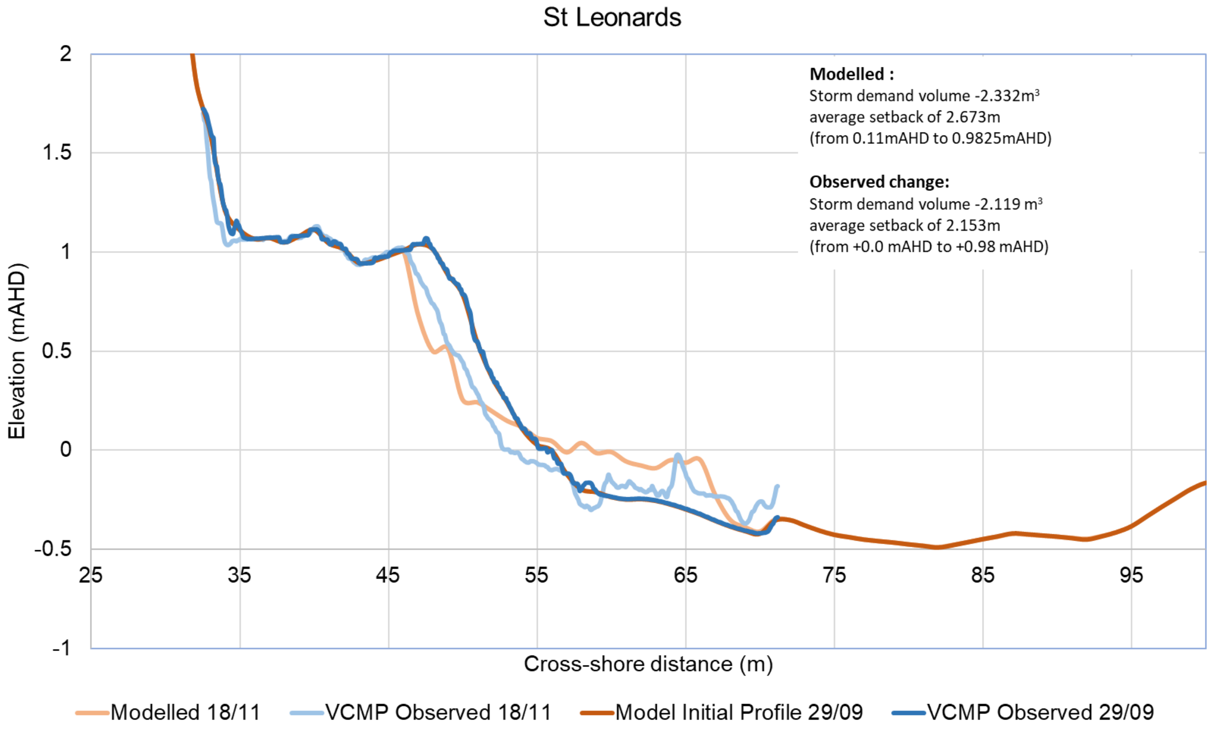


Figure 2-14 VCMP UAV data St Leonards October 2022

This entire period was modelled in SBEACH, using the initial profile from the VCMP UAV data, the wave record from Indented Head, and tides taken from the Williamstown Tide Gauge. The results are shown in Figure 2-15 and demonstrate that the SBEACH model does an acceptable job of reproducing the erosion processes over this period. The SBEACH results show a higher accretionary effect in the nearshore, which is not observed in the VCMP data. However, the erosion of the swash zone and beach berm are similar in magnitude, with a slight overprediction in the model.



Modelled :
Storm demand volume -2.332m^3
average setback of 2.673m
(from 0.11mAHD to 0.9825mAHD)

Observed change:
Storm demand volume -2.119 m^3
average setback of 2.153m
(from +0.0 mAHD to +0.98 mAHD)

Figure 2-15 St Leonards SBEACH Verification 29/09/22 to 18/11/22

2.4.4 Output Processing

The outputs of SBEACH are the final beach profiles following the applied storm event, not a specific erosion setback distance. The final profile tends to show a flattening of the shoreface as the sub-aerial beach is lowered, and the nearshore sandbars grow.

There are several ways to extract a single erosion distance from the SBEACH results. Two alternatives that were considered and ultimately rejected are as follows:

1. Measure the most landward extent of any profile change. This is overly conservative, the distance of profile change for relatively flat profiles is very large, and relatively short for steeper profiles. This conflicts with the understanding of coastal processes, where low and flat profiles are more likely in low-energy environments, with limited storm erosion potential (e.g., wide inter- and supra-tidal mudflats).
2. Select a given contour (e.g., based on HAT, or the wave runup distance) and measure the shoreline retreat at this elevation. This methodology is not appropriate for all shoreline types, as for some types, the erosion will be larger or smaller at different contours, depending on the backshore, sediment grain size, and incident wave energy.

These are shown below in Figure 2-16.

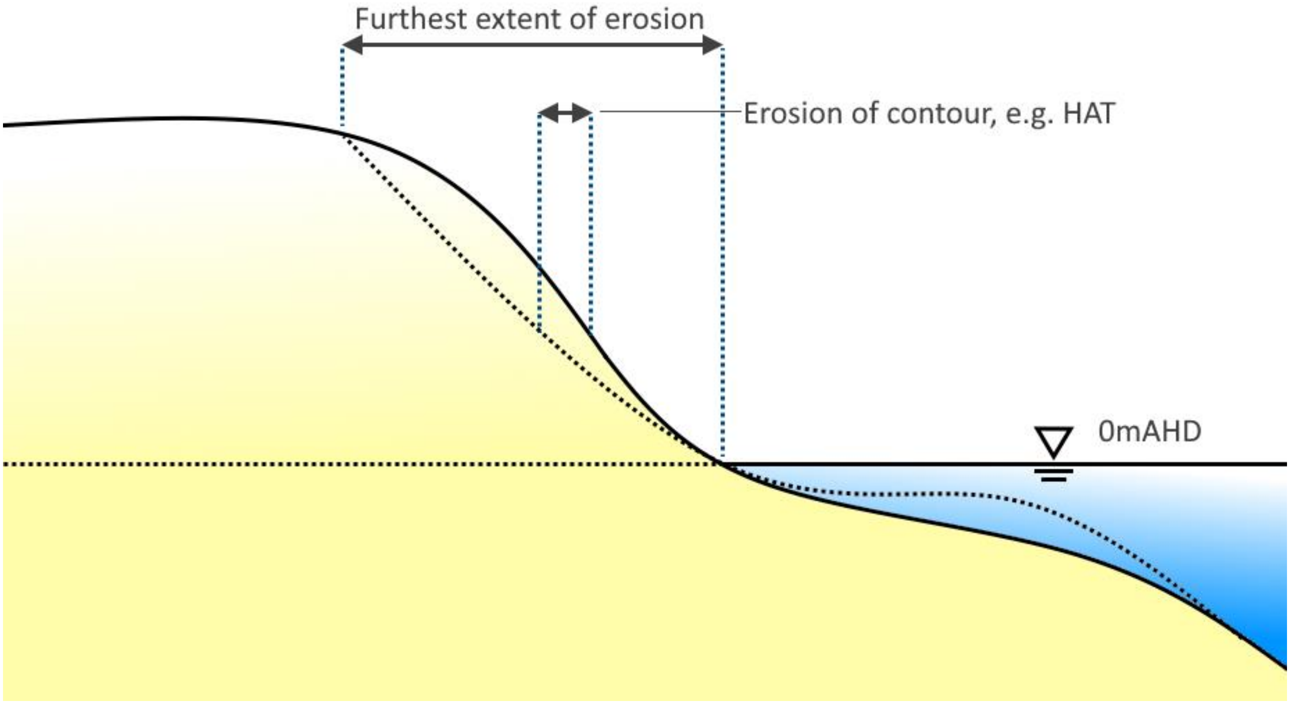


Figure 2-16 Erosion setback alternatives

Therefore, a methodology has been selected to convert the profile change to an 'average' setback experienced by the subaerial and inter-tidal beach. This is calculated by distributing the erosion volume above 0 mAHD over the height of the profile that has experienced erosion. This methodology has been used previously for SBEACH model outputs for a number of locations around Australia (Mariani et al., 2012).

Figure 2-17 shows an example of this, where the dotted line represents the post-storm erosion profile. The total volume of erosion is 8m^3/m, and it occurs over a vertical distance of 2m. Therefore, the average setback is 4m.

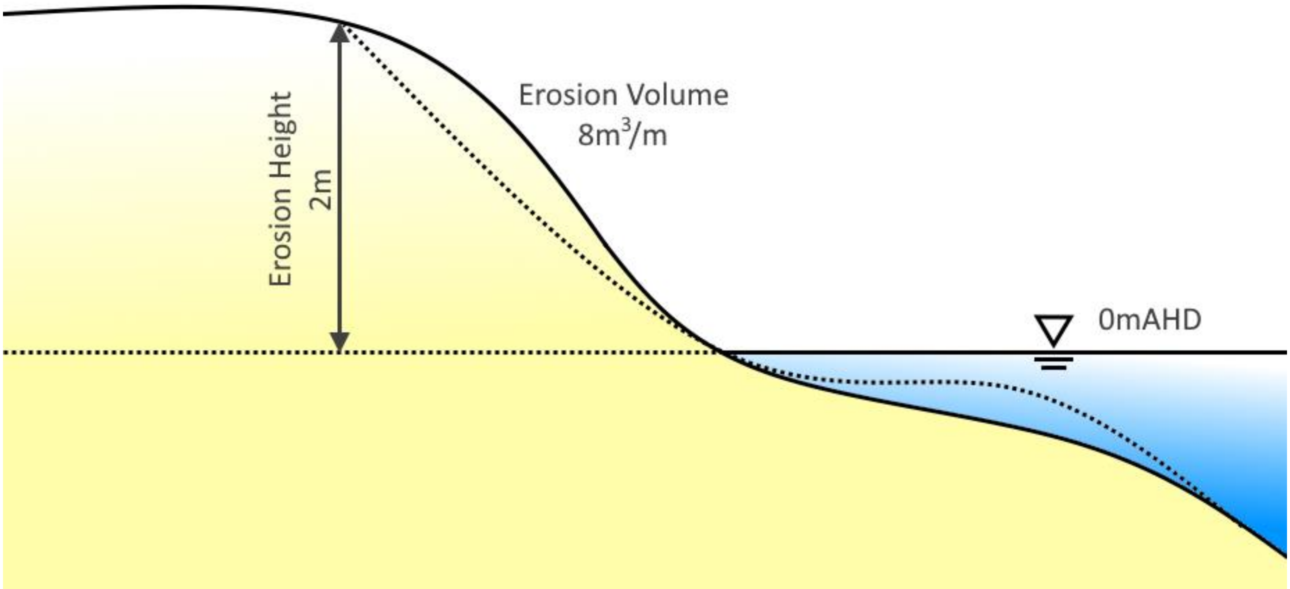


Figure 2-17 Erosion setback calculation methodology

There are several limitations with this methodology:

- It does not represent the distance of the beach landward that experiences some profile change in response to storms, but only a mean setback of the shoreline position. This may be an important consideration for structures placed on the beach, where change in beach elevation may undermine their footings. This difference is a key limitation of the overall CEHA approach, but one that has been considered acceptable (see Section 4).
- There may be storms that result in a marginally higher storm demand volume, but a much larger erosion height. This will result in a lower average setback for a higher storm demand. This difference is typically small, and the process is more likely to occur for profiles with steeper backshores, where wave can result in a thin erosion volume over a large height. Conceptually, this is a reasonable result as erosion of steep shorelines may provide additional sediment volume that reduces the average shoreline retreat position.

These limitations are conceptual only and relate to the difference between modelling an actual change in beach morphology, as opposed to quantifying erosion hazard extents behind a baseline shoreline. Over the timescales of interest (out to 2100), the specific beach profile response is uncertain. For example, beaches may tend to steepen, or flatten, depending on other changes in coastal processes, interactions with different backshore geologies, and the response to SLR. Modelling of such processes is beyond the scope of this scale of coastal hazard modelling and requires additional data and information. The inclusion of short-term storm hazard as an average setback from the stable vegetation line should provide a suitable allowance that encompasses the uncertainty of different future beach morphologies (i.e., it applies the average setback directly to the ‘dune’ rather than the inter-tidal water line).

2.4.5 Probabilistic Outputs

Three storm events have been modelled in SBEACH for the three AEP scenarios respectively (described in Section 2.4.2). This only provides a single output result per AEP scenario, which is inconsistent with the remainder of the probabilistic approach used in the CEHA. Therefore, a methodology has been developed to apply a probabilistic uncertainty range either side of the SBEACH outputs in the form of a triangular distribution as shown in Figure 2-18.

The range for the triangular distribution has been developed based on the relative range from the CSIRO SCHISM-WWMIII probabilistic outputs (but using the 95th percentile as the central 'modal' point). SBEACH modelling was conducted on a subset of exposed sediment compartments using the full set of probabilistic SCHISM-WWMIII outputs. Table 2-5 presents an example of these results for the 1% AEP conditions at Sandringham Beach (TCSC 027). Overall, the testing finds that a +/-30% factor on the SBEACH results would provide a suitable triangular distribution range, centred on the conservative 95th percentile results from SCHISM-WWMIII.

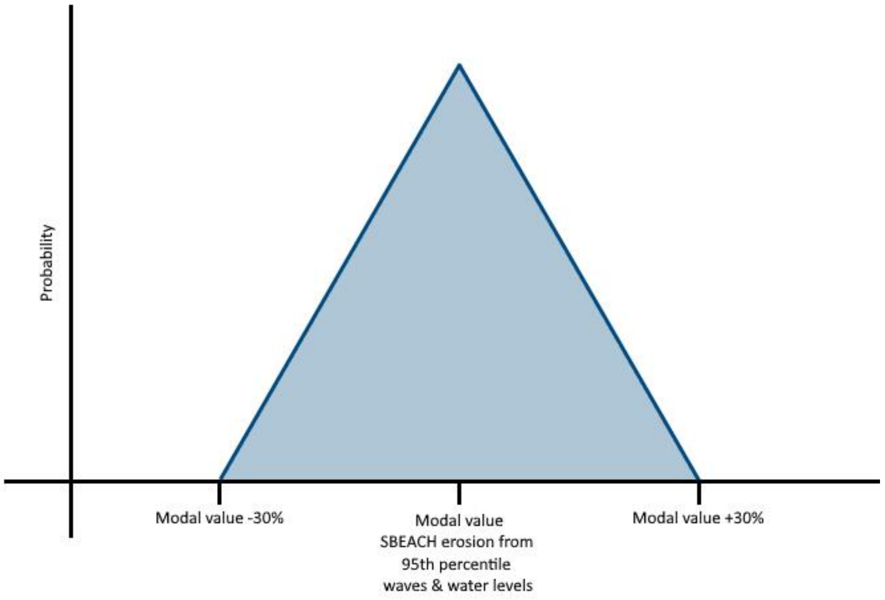


Figure 2-18 Adopted Storm Erosion Probabilistic Distribution Approach

Table 2-5 Sensitivity testing of storm confidence interval on SBEACH modelled erosion – Sandringham

Hs (m)	Comment	Storm Demand (m^3/m above AHD)	Setback (m)	Ratio (relative to median)
2.12	Lower bound of 1% AEP confidence interval (5th percentile)	1.10	0.66	-28%
2.24	Median of 1% AEP	1.51	0.91	-
2.41	Upper bound of 1% AEP confidence interval (95th percentile)	1.96	1.18	+30%

2.4.6 Sensitivity Testing

It is noted that the SBEACH model utilises SCHISM-WWMIII input data that may be underpredicting the extreme wave conditions. As such a range of increasing wave conditions has been modelled to analyse the overall sensitivity and provide an understanding of the likely impact on the erosion outputs. A peak Hs of 4m has been set for this modelling based on deep-water wave growth nomograms (CERC, 1984) for a 50km fetch.

Three different beaches were assessed with this approach: Frankston, St Leonards and Sandringham (based on existing calibration profiles and availability of data). Figure 2-19 shows that for St Leonards and Sandringham, the setback response is approximately linear within the range of modelled wave heights. The results at Frankston show only minor erosion response until the wave heights exceed 2.2m. The setback response appears to be more exponential over this range of wave heights.

A key observation is that regardless of the likely distribution, storm erosion is likely to be <5m for even 1%AEP events within PPB. This is small in the context of trends extrapolated to 2100, and likely to be a minor component of overall erosion hazard. Therefore, any underprediction of wave heights is not anticipated to limit the usefulness of the model outputs.

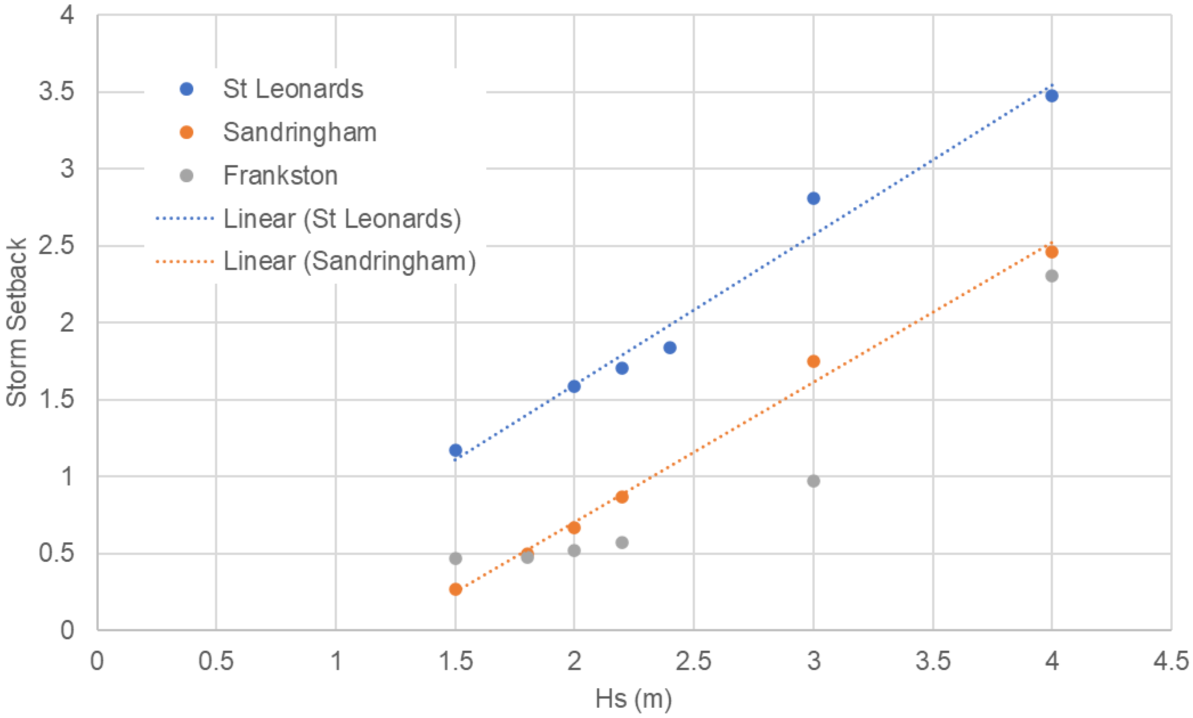


Figure 2-19 Wave Height Sensitivity Testing

2.5 Long-term Shoreline Trend

2.5.1 Description

In the medium to long term, changes in the rate of longshore sediment transport along the coast results in either a surplus of sediment accumulating in a sediment compartment, or a deficit. These effects result in a corresponding change in the shoreline position, with surpluses typically causing prograding shorelines (widening beaches) and deficits causing ongoing erosion. There can be multiple drivers of these changes in longshore transport rates, ranging from long-term coastal responses to shifts in dominant wind and wave directions, or more immediate responses to changes in the shoreline topography, such as the construction of groynes.

In addition to longshore sediment transport changes, other sources and sinks of sediment can result in similar effects. Within PPB, there are several other processes that may apply to different areas in different magnitudes such as:

- Dredging, sand scraping or beach renourishment either removing or supplying sand within a coastal sediment compartment
- Cross-shore sediment losses (e.g., from storms) that do not recover (such as erosion of soft cliffs, or where sediment is drawn into tidal channels and transported elsewhere by currents)
- Cross-shore sediment supplies, from large nearshore sand shoals
- Supplies of catchment sediments from rivers and creeks

Notably, these effects are highly coupled, as the sediment transport within one TCSC influences the rate of transport to those TCSCs either side. This is easy to observe when groynes or similar structures block the flow of sediment and cause an accumulation of sediment ‘updrift’ and a deficit ‘downdrift’.

Within Port Phillip Bay, this is a major influence of the coastal erosion hazard over the medium to long term. Different shoreline types have differing drivers of this recession. There are also areas of Port Phillip Bay that have accreted over the longer term, which can be observed within the long-term trends.

2.5.2 Approach

The trend in ongoing shoreline change has been assessed by analysing the historical changes in vegetation lines at the back of the beaches as observed in aerial imagery. Specifically, vegetation line changes (as representative of shoreline change) have been mapped from 7 decadal near whole-of-bay aerial images from the 1930s to the 1990s, and three subsequent snapshots of aerial imagery from the Coordinated Imagery Program (CIP), ~2005, ~2010 and ~2021. The full list of images included in this analysis is shown in Table 2-6.

The Digital Shoreline Analysis System (DSAS) developed as part of the U.S. Geological Survey (USGS, 2018) Coastal Change Hazards project provides an analysis of shoreline change based on spatial analysis of shorelines in a GIS format and has been used to analyse these mapped shorelines. While DSAS was developed for assessing rates of instantaneous shoreline trends from historic imagery, it uses a simple geometric analysis of shoreline position, that is equally applicable to vegetation lines. DSAS casts equally spaced perpendicular transects across the mapped shorelines, along which the vegetation/shoreline position can be tracked. The spacing was adjusted to ensure good spatial representation of shoreline changes, with a maximum nominal spacing of 100m.

The result is a linear trend in shoreline position for each of the cross-shore transects.

Table 2-6 Aerial Imagery Used

"Decade" group	Available Imagery Name	To Be Used	Date
1930	melbourne_1930oct17_air_vis_100cm_mga55	Yes	October 1930
	altona-bay_1939jan01_air_bw_10cm_mga55	Yes	January 1939
	mornington_1938oct28_air_vis_24cm_mga55	Yes	October 1938
1940	altona-bay_1942may01_air_bw_15cm_mga55	Yes	May 1942
	mornington_1949feb15_air_bw_40cm_mga55	Yes	February 1949
	geelong_1946oct10_air_vis_50cm_mga55	Yes	October 1946
1950	east-coast_1951jan01_air_vis_15cm_mga55	Yes	January 1951
	point-nepean_1951oct15_air_bw_16cm_mga55	Yes	October 1951
	point-cook_1951jan01_air_vis_15cm_mga55	Yes	January 1951
	mentone-beach_1951jan01_air_vis_15cm_mga55	No	January 1951
	seaford-pier_1951jan01_air_vis_15cm_mga55	No	January 1951
	altona-pier_1951jan01_air_vis_15cm_mga55	No	January 1951
1960	point-cook_1964mar08_air_vis_15cm_mga55	Yes	March 1964
	fishermans-bend_1960_air_bw_23cm_mga55	Yes	January 1960
	corio-bay_1966apr02_air_vis_15cm_mga55	Yes	April 1966
	bellarine_1968nov18_air_vis_15cm_mga55	Yes	November 1968
	bellarine_1966jun09_air_vis_15cm_mga55	Yes	June 1966
	werribee-south_1966jun09_air_bw_15cm_mga55	Yes	June 1966
	sandringham-dromana_1966feb28_air_vis_15cm_mga55	Yes	February 1966
	rye-point-nepean_1966feb28_air_vis_15cm_mga55	Yes	February 1966
1970	fishermans-bend_1977jan01_air_bw_23cm_mga55	Yes	January 1977
	domana-bay_1974jan26_air_vis_16cm_mga55	Yes	January 1974
	curlewis_1977Sep25_air_vis_15cm_mga55	Yes	September 1977
	corio-bay_1970dec19_air_vis_40cm_mga55	Yes	December 1970
	carrum_1974jan26_air_vis_15cm_mga55	Yes	January 1974
	bellarine_1970apr14_air_vis_15cm_mga55	Yes	April 1970
	werribee-south_1972nov14_air_bw_15cm_mga55	Yes	November 1972
	sunnyside-beach_1975feb14_air_vis_10cm_mga55	Yes	February 1975
	beaumaris_1974jan26_air_vis_16cm_mga55	Yes	January 1974
	mount_eliza_1974jan26_air_vis_16cm_mga55	Yes	January 1974
	mornington_1974jan26_air_vis_16cm_mga55	Yes	January 1974
	rye-point-nepean_1974jan24_air_vis_12cm_mga55	Yes	January 1974
	frankston_1974jan26_air_vis_16cm_mga55	Yes	January 1974

"Decade" group	Available Imagery Name	To Be Used	Date
1980	fishermans-bend_1989jan28_air_vis_21cm_mga55	Yes	January 1989
	corio-bay_1985mar09_air_vis_15cm_mga55	Yes	March 1985
	bellarine_1985mar09_air_vis_15cm_mga55	Yes	March 1985
	altona-bay_1985mar09_air_vis_15cm_mga55	Yes	March 1985
	werribee-south_1989nov26_air_vis_18cm_mga55	Yes	November 1989
	port-phillip-east_1980dec08_air_vis_20cm_mga55	Yes	December 1980
	werribee-south_1985nov23_air_vis_75cm_mga55	No	November 1985
	fishermans-bend_1986jan24_air_vis_15cm_mga55	No	January 1986
1990	bellarine_1990nov23_air_vis_38cm_mga55	Yes	November 1990
	altona_bay_1991may27_air_vis_22cm_mga55	Yes	May 1991
	werribee-south_1992apr30_air_vis_75cm_mga55	Yes	April 1992
	port-phillip-east_1989nov27_air_vis_24cm_mga55	Yes	November 1989
	corio-bay_1990nov23_air_vis_38cm_mga55	Yes	November 1990
2005	melbourne_2005dec11_air_vis_35cm_mga55	Yes	December 2005
2010	portphillip_2010dec28_air_vis_35cm_mga55	Yes	December 2010
2021	frankston_2021jan20_air_vis_10cm_mga55	Yes	January 2021
	red-hill_2021jan20_air_vis_10cm_mga55	Yes	January 2021
	lara_2021dec13_air_vis_10cm_epsg7855	Yes	December 2021
	melbourne_2021oct27_air_vis_10cm_epsg7855	Yes	October 2021
	mordialloc_2021nov01_air_vis_10cm_epsg7855	Yes	November 2021
	williamstown_2021nov02_air_vis_10cm_epsg7855	Yes	November 2021
	point-cook_2021nov02_air_vis_10cm_epsg7855	Yes	November 2021
	werribee-south_2021dec13_air_vis_10cm_epsg7855	Yes	December 2021
	point-nepean_2020apr15_air_vis_10cm_mga55	Yes	April 2020
	rye_2020apr15_air_vis_10cm_mga55	Yes	April 2020
	geeong_2019oct01_air_vis_10cm_mga55	Yes	October 2019

2.5.3 Trimming of aerial images

There are cases where the mapped shorelines are not representative of underlying shoreline trends. This tends to occur when construction or intervention in coastal processes causes a realignment of the shoreline. Conceptually, this process will eventually stabilise, with any underlying trends being observable afterwards. In practice however, it can be difficult to establish that a shoreline has stabilised.

The methodology to address this constraint is to trim the vegetation lines that are likely to be impacted by temporary trends that should not be included in the long-term analysis. There is a subjective component to this in determining the length over which a given interruption (e.g., end scour effects of a seawall) is likely to apply. The scale of the CEHA is such that detailed coastal processes analysis of each such feature for the available historical period (1930s – present) is not practical. As such, selections have been made based on where mapped shorelines begin to converge to alignments further from the source of the interruption.

A case study is presented for the Avalon Beach Boat Ramp (Corio Bay). Figure 2-20 shows the complete mapped vegetation lines on top of a range of the historical aerial images. It is clear that the construction of the boat ramp and salt farms in the 1960s-1970s caused a rapid change in shoreline alignment but has stabilised since then.

Moreover, the extent of the impact along the beach is apparent as the difference between the pre- and post-boat ramp shorelines reduces further to the west, until the lines converge to a similar spacing.

Figure 2-21 shows that the adopted approach at Avalon Beach was to remove the mapped shorelines prior to the 1980s from the point of diversion in the west.

This methodology has been continued around PPB in numerous locations. The complete set of DSAS transects organised in TCSCs, with the corresponding list of included/excluded shoreline years can be found in the attached database.

Several alternatives to this approach were considered and rejected as follows:

- Including all mapped vegetation/shorelines in all areas would skew the trends where sudden changes have occurred.
- Removing the problematic years from the whole TCSC (rather than a subjective segment selection) was also considered. However, this approach is likely to remove useful data, particularly in areas with large TCSCs and only small areas impacted by a historic interruption.

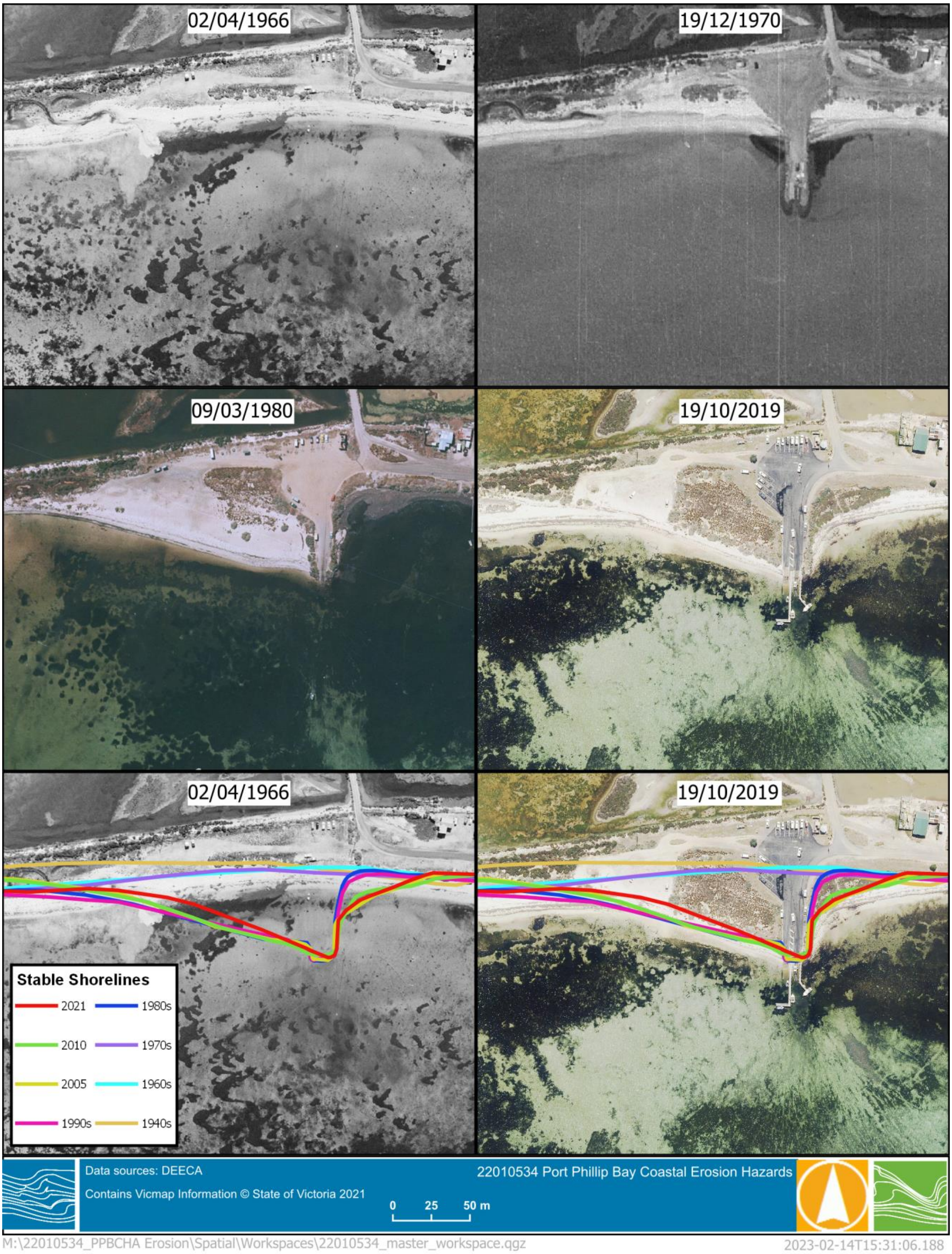


Figure 2-20 Mapped complete shorelines at Avalon Beach

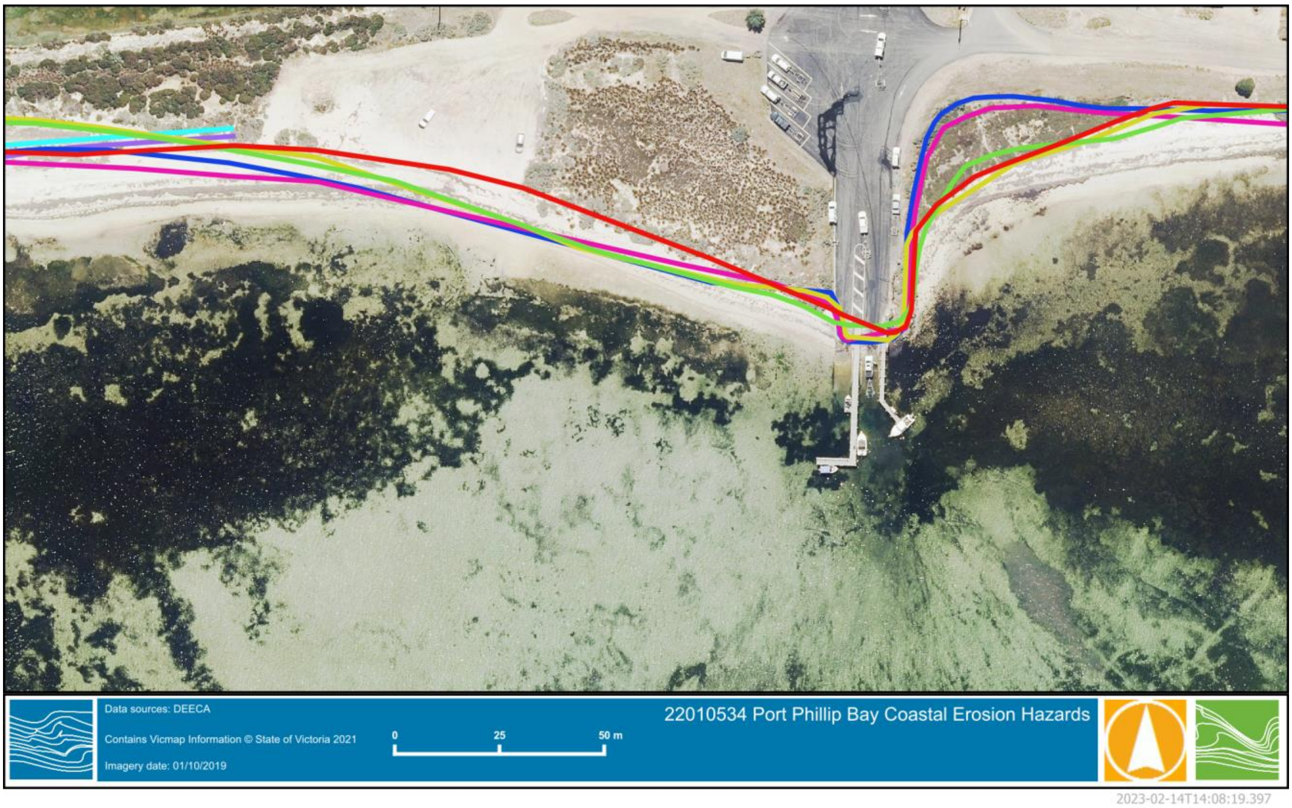


Figure 2-21 Adopted trimmed shorelines at Avalon Beach

2.5.4 Probabilistic Outputs

In order to derive a probabilistic long-term erosion component for each TCSC, the linear regression rates for all of the transects in a TCSC have been grouped and analysed. A triangular distribution has been developed that uses the median shoreline regression rate as the modal value, and the 97.5th percentile and 2.5th percentile as the upper and lower bounds respectively. The 97.5th and 2.5th percentiles were selected based on the range in which 95% of the data sit. For a normal distribution, this would represent two standard deviations. It is noted that the shoreline trend rates are unlikely to exactly fit a normal distribution, so an actual calculation of standard deviation would be inappropriate.

Figure 2-22 presents an example of the histogram of linear shoreline rates overlayed with the resulting triangular distribution as extracted from the DSAS transects at Frankston Beach.

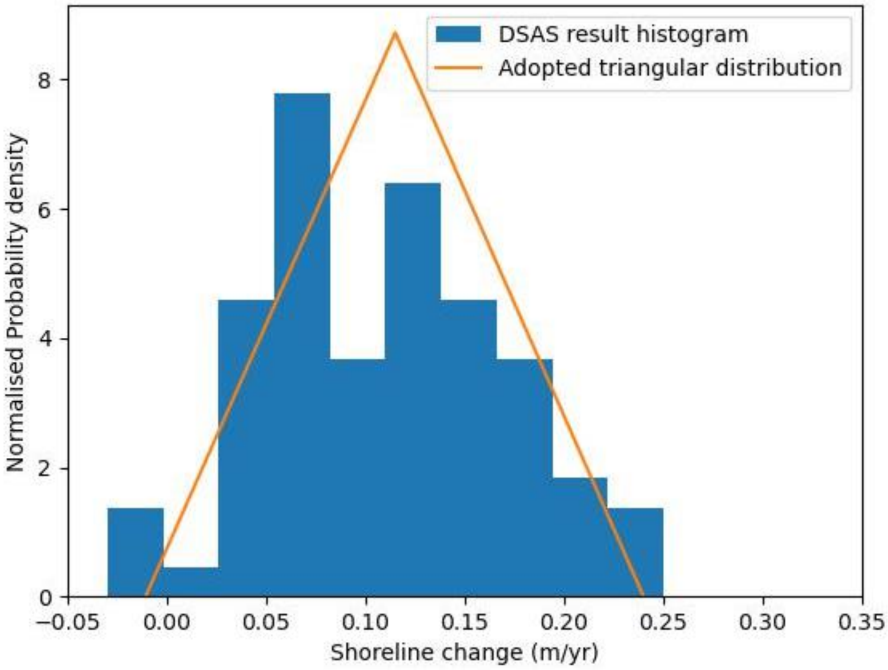


Figure 2-22 Triangular distribution based on results at Frankston Beach

2.5.5 Verification

There are no equivalent long-term datasets that can be used to verify the entirety of the analysed aerial imagery dataset. In fact, such lines are often a preferred verification tool for modelling of long-term sediment budgets.

The VCMP survey data will ultimately provide a useful dataset to compare rates of retreat within TCSCs but does not yet extend over a sufficient time period to allow any seasonal or medium-term processes to be removed.

2.6 Future Shoreline Response (to SLR)

2.6.1 Description

The concept of an equilibrium beach profile assumes that the shoreface dissipates wave energy proportionately as waves approach the shore. If the seabed were shallower than this hypothetical equilibrium, then excess wave energy would act at this point, mobilising the sand, and scouring the bed. Conversely, where the bed is deeper than equilibrium, any sediment mobilised elsewhere is prone to falling into this area, and becoming trapped (i.e., there is no mechanism to keep it mobilised at these depths).

Bruun (1962) investigated this concept in relation to increases in mean water levels. This work noted that as seas rise, the relative depth of each area of the seabed is increased, created a large ‘accommodation space’ in which sediment can become trapped and no longer able to mobilise. Once this accommodation space is filled, the profile is once again at an equilibrium. In the absence of any other sources of sediment supply, the material ultimately filling the accommodation space will come from the dune system. The mechanism for this is likely to be storm erosion that draws sand offshore into the accommodation space.

Bruun developed a simple geometric model (the ‘Bruun Rule’) that is widely used (though often criticised) to provide a future shoreline erosion hazard allowance. The Bruun Rule establishes that the ratio of sea level rise to shoreline retreat is equal to the shoreface slope from the dune to an offshore ‘depth of closure’ (DOC), representing the point at which cross-shore sediment transport is negligible. This shoreface slope (Horizontal distance divided by vertical distance) is often referred to as the Bruun Factor. The geometric model is given by:

$$R = S.L/(H_d+H_f)$$

Where, R is the setback distance, S is the rise in mean sea level, L is the width of the active profile H_d is the depth of closure, and Hf is the foredune height.

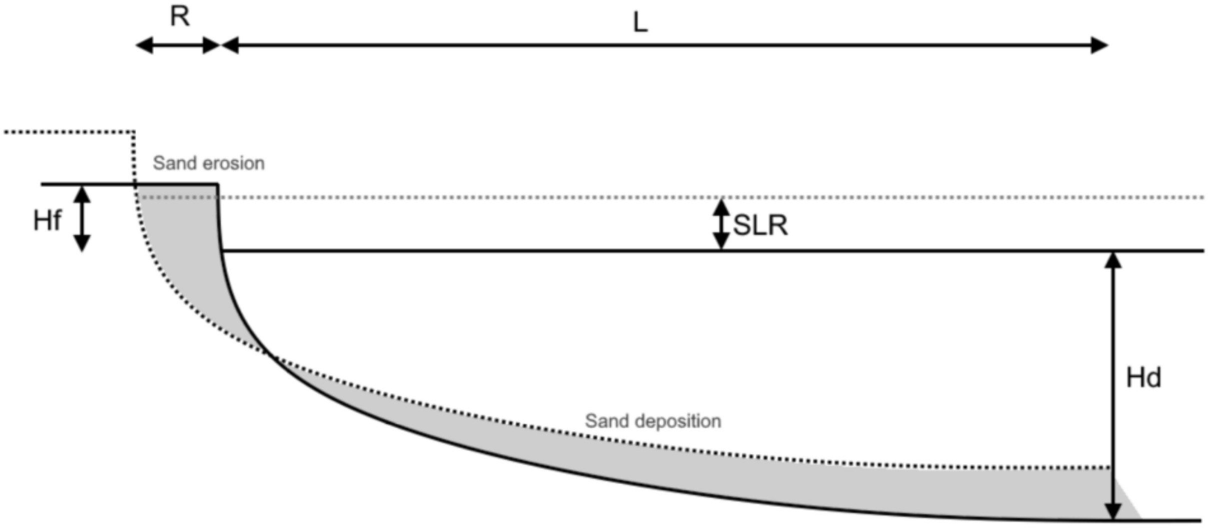


Figure 2-23 Bruun Rule conceptual figure

2.6.2 Approach

This study primarily utilises the Bruun Rule to assess the potential future recession due to SLR.

The critical input to this approach is the selection of the active profile. The use of an active profile (as defined by a selected DOC and to a less-extent a foredune height) inherently assumes a given timescale, as even small sediment transport processes over large timeframes can result in a meaningful contribution of shoreline position. While several different methodologies are widely used, this study proposed to use two distinct methods:

- For relatively exposed beaches experiencing storm cut and recovery, the Hallermeier (1981) Inner-Shoal depth will be used to define the depth of closure. The wave runup extent (based on Stockdon et al. 2012) will define the foredune height. If a coastal dune/barrier is exceeded by the runup extent (overwash), then the peak of this barrier will be used.
- For more sheltered beaches and shorelines, the beach slope of the foreshore between mean sea level and the wave runup extent will define the 'active' profile.

This second methodology reduces the problem whereby low-energy shorelines (with flat slopes) predict very large SLR responses in shoreline position. The beach slope methodology has been used successfully in several other studies of enclosed embayments, estuaries and other low-energy coastal environments (Tonkin & Taylor, 2017, Water Technology, 2022, as well as 'eshorance': Stevens, 2010).

The approach for deciding on which of the above to use will be as follows:

- Any shorelines protected by enclosed embayments (fetch <10km) use the second method
- Any shorelines with a calculated active beach slope (from the first method) that is greater than 100m use the second method
- All remaining shorelines use the first method.

This approach will be conducted on all of the transects (which are at an average of 50m spacing) within each TCSC to produce a large number of Bruun factors around PPB.

2.6.2.1 Cliff Retreat

Where the shoreline consists of cliffs, that are directly interacting with coastal processes, the Bruun Rule in either of the aforementioned forms is inappropriate. Fundamentally, an increase in the nearshore shoreface accommodation space will not drive further erosion of the cliff, and as the slope is steep, the beach-face approach will show limited setback.

Ashton et al. (2011), assessed different methodologies of analysing cliff response to SLR and found that the rate of retreat depends on the rate of SLR (and not the total SLR level). A simple formula was proposed as follows:

$$R_2 = R_1\sqrt{\frac{S_2}{S_1}}$$

Where R_1 and R_2 are the rates of cliff retreat at two different time periods and S_1 is the initial rate of SLR and S_2 is the future rate of SLR.

This approach has been adopted for cliffed coasts in the modelling. The cliff retreat rates (as observed in the LT trend) will be scaled relative to the mean rate of SLR over the timeframe of interest.

The background rate of SLR has been assumed to be 2.1 mm/year (White et al., 2014), and the mean rate has been taken as the projected SLR divided by the timeframe. Table 2-7 demonstrates the resulting scale factor for the future scenarios assessed.

Table 2-7 Cliff Retreat Future Response Factors

Year	SLR (m)	Mean Rate (mm/y)	$\sqrt{\frac{S_2}{S_1}}$
2010	0.0	2.1	1
2040	0.2	6.67	1.74
2070	0.5	8.33	1.95
2100	0.8	8.89	2.01
2100	1.1	12.22	2.36
2100	1.4	15.56	2.66

2.6.3 Probabilistic Outputs

In order to reduce the total range of Bruun factors around PPB into a useful probabilistic distribution, a similar methodology to that adopted for the long-term trend has been used (see Section 2.5.4). The Bruun factors for each transect within each TCSC have been analysed, with a triangular distribution constructed from the 2.5th percentile, median and 97.5th percentile.

Figure 2-24 and Figure 2-25 show examples of the slopes calculated from the range of transect profiles, along with the resulting triangular distributions for Frankston Beach (method 1) and Blairgowrie (method 2) respectively.

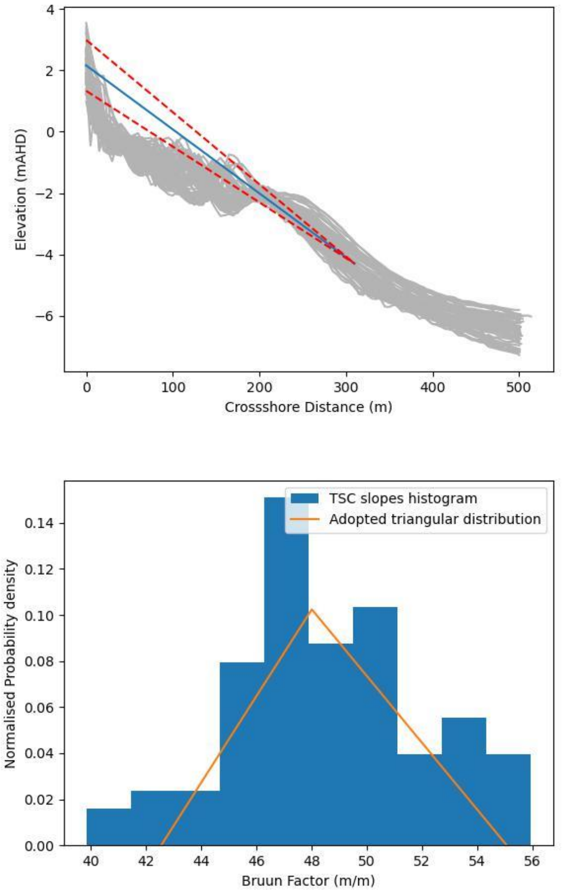


Figure 2-24 Example of Method 1 results (Frankston Beach)

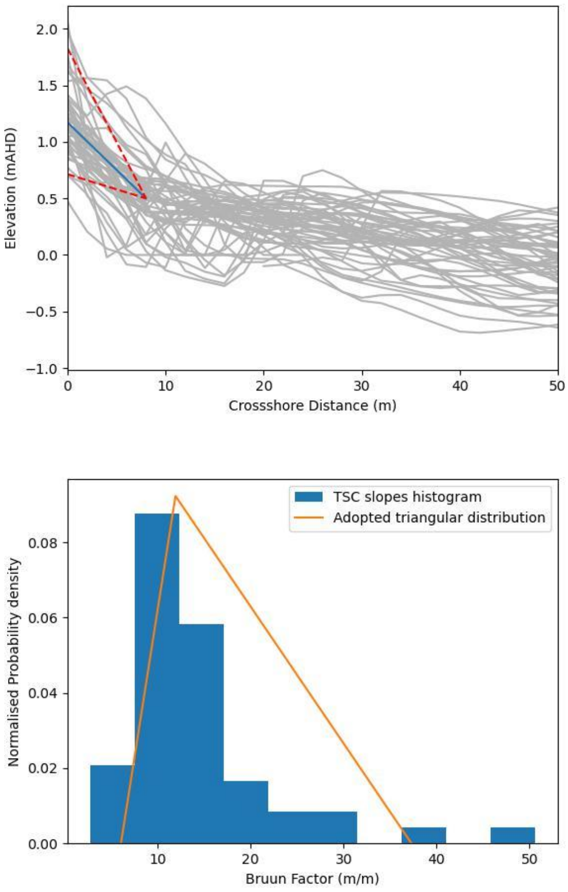


Figure 2-25 Example of Method 2 results (Blairgowrie)

2.6.4 Verification

No verification of the SLR response is possible as any existing SLR response in shorelines cannot be reasonably separated from other shoreline changes in the recent past. This is because the inter-annual variation in shoreline positions is high, and the existing total SLR is relatively low, with a limited expected coastal retreat. Additionally, the retreat as projected by the Bruun Rule may not be reached instantaneously with the rising sea level but requires additional coastal processes to rework those sediments.

2.7 Baseline Shoreline Selection

The baseline shoreline is the current assumption of the ‘present-day’ shoreline position. It is the point from which erosion hazard setback distances will apply.

This study will adopt the 2010 shoreline position (as mapped from the bay-wide 2010 aerial image using the process described in Section 2.2). This shoreline is most representative of the coastal LiDAR data that underpins the short-term erosion modelling, the Bruun Rule DOC analysis, and the wave/hydrodynamic SCHISM modelling previously undertaken.

This approach ignores any subtlety of erosion impact within the unvegetated sandy beach. As such, a change in the width of the sandy beach that does not influence the vegetation line is not quantified.

The main justification of this approach is that it selects a present-day shoreline position that is likely to be stable in the short-term and not include any recent storm erosion, seasonal beach rotation or beach renourishment that should not be propagated to future planning horizons. Therefore, at this timescale, the sandy beach is considered to be inherently prone to erosion hazard. This is appropriate for most coastal planning requirements, but is limited in the following situations:

- Assessment of temporal changes in beach amenity (i.e., beach width) will require consideration of shorter timescales and cannot be assessed with the outputs of this study (but also does not need the longer timescales of this study).
- Any risk to assets seaward of the vegetation line cannot be assessed, and these are considered to be at high risk of erosion by default. This may be appropriate for permanent structures, but lacks nuance for temporary structures, which may be adaptable at the timescale of individual storms, or seasonal variations.

Ultimately, any site-specific assessments over shorter timescales are likely to require dedicated local coastal processes studies that include additional short-term erosion influences such as beach rotation, high-frequency storm events, and protective works such as nourishment and beach scraping.

3 EROSION HAZARD MAPPING METHODOLOGY

3.1 Planning Horizons

The relevant planning horizons relate to sea level rise benchmarks required by DEECA. This is consistent with the CSIRO (McInnes et al. 2022) methodology for Inundation in the PPBCHA. The relevant sea level rise projections are 0.2, 0.5, 0.8, 1.1 and 1.4m above current mean sea level (MSL). Additionally, a present-day baseline scenario without SLR will be included. The future years associated with each SLR scenario are shown in Table 3-1.

Table 3-1 Planning Horizons

SLR (m)	Year	No. Years
0.0	2010 (present day)	0
0.2	2040	30
0.5	2070	60
0.8	2100	90
1.1	2100 (sensitivity 1)	90
1.4	2100 (sensitivity 2)	90

3.2 Modelling AEP Scenarios

The use of an event frequency only applies to the short-term erosion hazard. The 1%, 2% and 5% Annual Exceedance Probability (AEP) events have been assessed in combination with all the modelled planning horizon timeframes. These adopted AEP events are consistent with the PPBCHA inundation assessment and utilise the same wave and hydrodynamic modelling inputs.

3.3 Erosion Hazard Probability

The result of the monte-carlo modelling is a probability distribution erosion hazard setback distance. While of scientific interest, these probability ranges may not necessarily assist coastal managers in assessing erosion prone areas. As such, mapping will be undertaken using the 95th percentile model result (representing the condition at which there is a 5% likelihood of greater erosion hazard, and 95% likelihood of lesser erosion hazard). The complete set of calculated percentiles is available in a separate database.

3.4 Hazard Mapping of Structures

Where coastal protection structures are present, the modelled hazard extents are limited to the alignment of these features. A 10m landward buffer has been applied to the hazard extents in these areas to ensure that the coastal protection asset is included within the hazard extent. This approach will allow any GIS analysis of assets prone to coastal hazards to capture these structures, and make sure that they are part of any adaptation planning.

3.5 Mapping of backshores with cliffs

3.5.1 Description

There are several locations around Port Phillip Bay where steep bluffs and cliffs are present in the backshore, however the current ‘active’ shoreline is not a cliff (e.g., may be a sandy beach). Projecting the erosion processes of the current active shoreline into the cliff is likely to overestimate the erosion hazard extent as it is anticipated that cliffs will erode slower on average than loose sediments.

The key challenges for modelling this sudden change in erosion processes for these areas are as follows:

- The ‘starting point’ of the cliff is unknown as it may be partially buried at the toe.
- The condition of the bedrock, including its height, shape, structure and erodibility, is unknown, and will influence the corresponding erosion hazard.
- There are no observed rates of change for these cliffs under the direct action of coastal processes.
- With a monte-carlo simulation, there will be many (in this case 1 million) different projected timeframes at which the transition in processes may occur. This is computationally inefficient to simulate.

It is noted that DEECA has commenced a state-wide cliff hazard assessment project. It is expected that this work will provide an assessment of these constraints, along with further data collection, to derive a robust methodology for cliff hazard modelling. Unfortunately, the outcomes of that work will not be available in time for this study. Future updates, or interpretation of the resulting hazard outputs should consider the cliff hazard assessment once it is available.

3.5.2 Approach

A ‘cliff clipping’ approach has been developed that limits the overall erosion hazard extent. This approach defines a maximum setback extent that can be achieved by the cliff, and ‘clips’ the underlying hazard extent to this limit. Therefore, this approach is applied as a GIS correction to the hazard layers, rather than as an explicit modelling input.

The maximum cliff setback extents have been prepared based on the following:

- Mapping the top of suitable cliff lines based on the change in topography (steep slope begins to flatten) in the VCDEM2017 dataset. Locations of cliffs are determined by inspecting the Smartline (Sharples et al., 2009) ‘backshore proximate’ and ‘backshore distant’ fields for indications of steep rocky features.
- Applying the 95th percentile cliff retreat rate (0.1 m/y) from active cliffs from the LT trend analysis (using shorelines and DSAS as described in Section 2.5) and increasing this based on the methodology described in Section 2.6.2.1.
- An additional allowance beyond the current cliff to allow for short-term failure and readjustment as the cliff becomes active.

3.5.2.1 Slump/Failure Plane Area

The slump/failure plane component represents the understanding that the cliffs may respond rapidly once exposed to coastal processes, or cliff face may be weathered and not stable once impacted by coastal processes. It is similar in nature to the angle-of-repose of loose sediments, in that there is likely to be some angle backwards the defines the extent most prone to this failure.

A 45-degree (1H:1V) slope has been assumed in this modelling. This angle has been adopted based on the angle of repose of crushed gravel, shear failure planes in elastic materials and comparison to currently exposed and weathering cliffs in PPB (Tassels Cove and Black Rock in particular). It is likely to be conservative as these observed cliffs are known to weather in response to rainfall runoff (i.e., not coastal erosion), flattening the effective slope at the top and many other ‘hard rock’ cliffs in PPB are typically steeper than this.

The centre of the slump setback has been assumed to be in line with the top of the cliff. Therefore, the effective slumping setback is equal to half the height of the cliff projected landward from the top of the cliff (example in Figure 3-1). The result is that taller cliffs have a higher overall erosion hazard extent than lower ones.

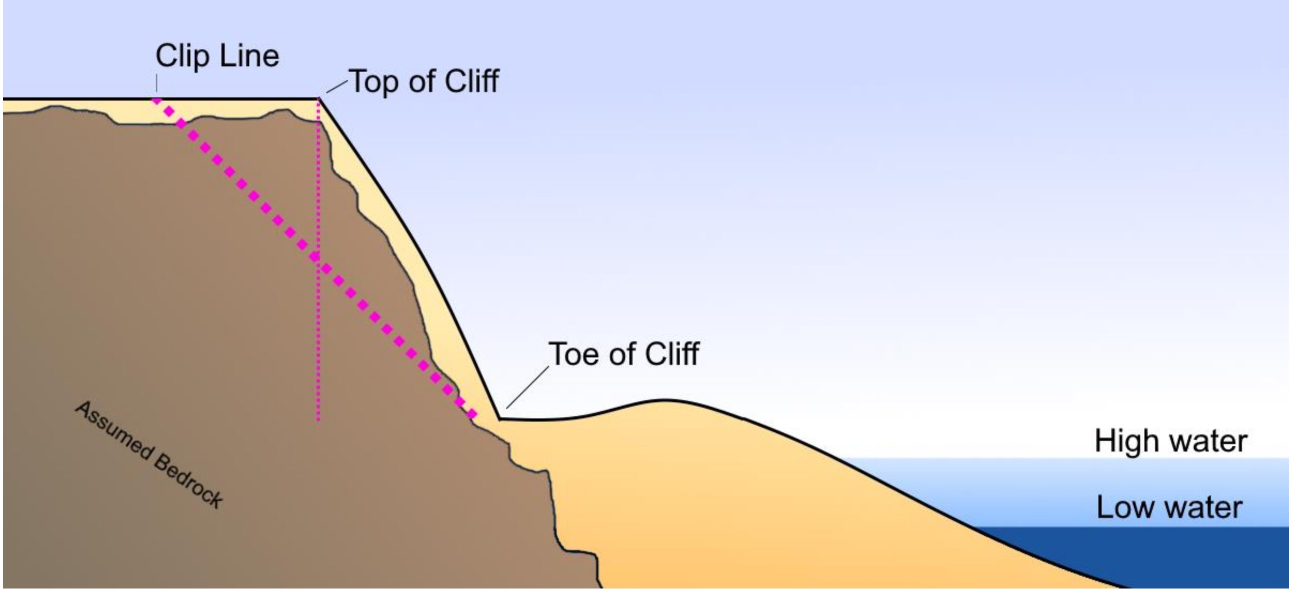


Figure 3-1 Cliff clip slumping approach

3.5.3 Clipping Lines

Figure 3-2 presents an example of the adopted clipping lines at Mentone, along with the line representing the top of the cliff. The different future scenarios demonstrate that at more distant planning horizons and with greater SLR, the limiting effect of the cliff is reduced.

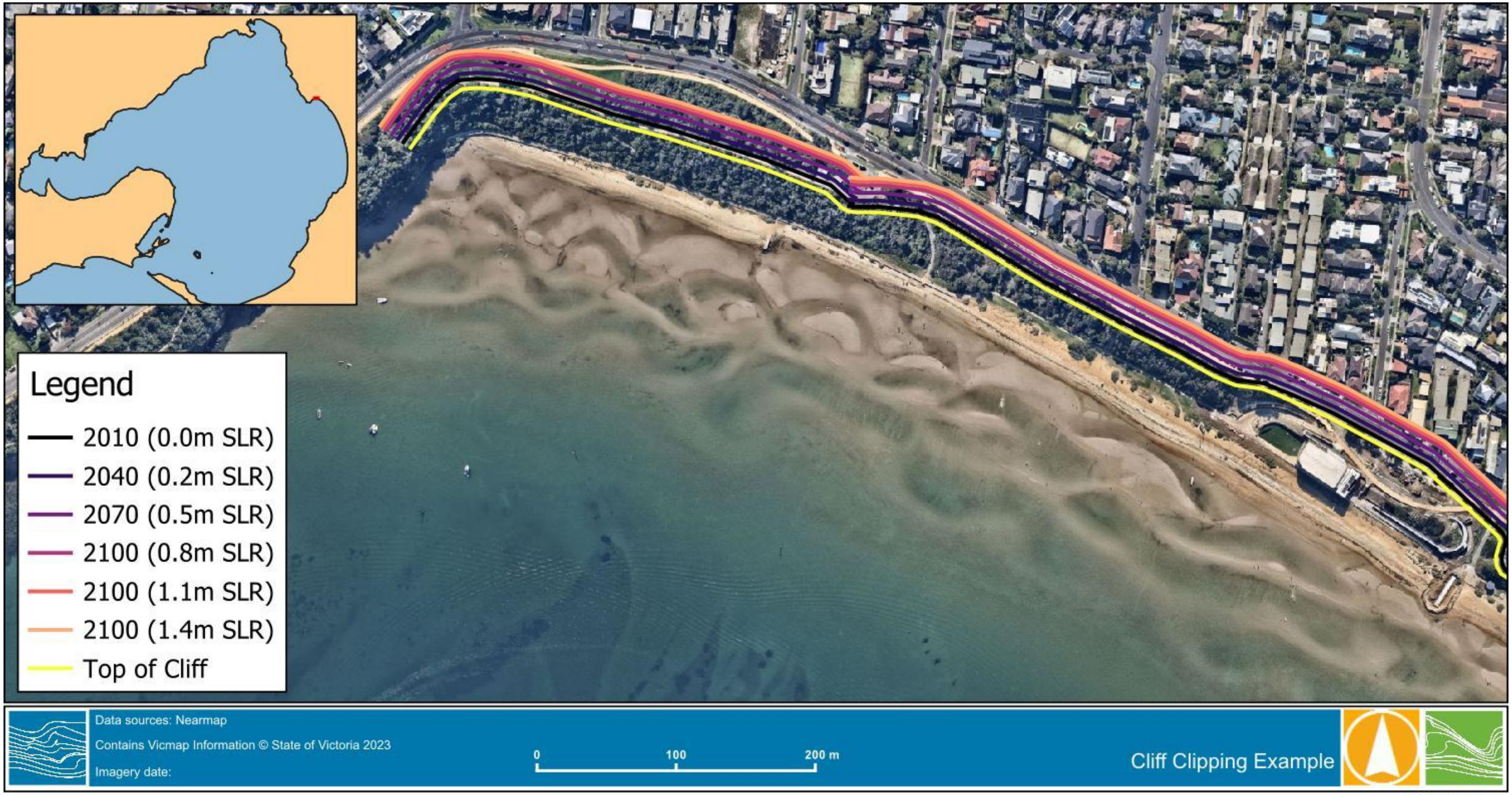


Figure 3-2 Cliff Clipping Lines

3.5.4 Limitations

The adopted cliff clipping approach is simplistic, but provides a rationale for reducing the overprediction of coastal erosion hazard in these areas. It still errs on the side of conservativism, and further work may consider addressing the following limitations to reduce the coastal erosion hazard extent further:

- The underlying bedrock extent is unknown, and may sit closer to the toe, or immediately under the back of the beach. In this case, the erosion will transition to a cliff retreat process earlier than assumed, with a further-reduced overall hazard extent.
- The adopted 45-degree angle may be flatter than a cliff failure plane, or weathered cliff slope. Steeper assumed slump or failure angles will reduce the hazard extent further.
- The cliff slope may already be on a 45-degree angle (or some other non-vertical slope), and applying this effect from the top of the cliff ignores this. Further slumping or failure along such angle planes is reduced where there is already a gradual slope, and as such the erosion hazard extent could be reduced further.
- Cliff retreat rates may differ from the 95th percentile rate included (0.1 m/y). As this is a conservative choice, lower rates of retreat will result in a decreased hazard extent.

4 ASSUMPTIONS AND LIMITATIONS

4.1 Maintenance of Coastal Protection Structures

A core assumption within the adopted methodology is that coastal protection structures will be maintained in the future. This has been interpreted as meaning that existing seawalls and similar engineered shorelines will be maintained and upgraded in future to ensure that they are able to continue to provide the same level of protection as at present. As noted in Section 2.3, structures that are currently in a ‘very poor’ condition will be assumed to be not functional at present day and will be assessed as though they are not providing any protection.

These assumptions are valid for many areas of the PPB coastline where legacy development behind coastal protection structures is likely to lead to a default management action of continued maintenance and upgrade of these. Any adaptation planning may reasonably consider this as the ‘base case’ and hence it is suitable for this initial coastal hazard assessment. Any alternative adaptation pathways would need to be investigated as separate modelling exercises.

The key limitation of this assumption is that it reinforces the continued maintenance of engineered shorelines, even in locations where this may not be the preferred management action. PPB is highly varied, and many of the engineered shorelines may have been constructed for legacy reasons that no longer apply, and alternative adaptation actions may achieve better outcomes. Additionally, it provides no understanding of the risk if these assets are not continued to be maintained (i.e., the ‘do nothing’ approach), which may occur if appropriate planning and funding allocations are not undertaken.

Coastal managers of these areas will require separate dedicated studies to understand the coastal hazard risk in the event of planned removal or failure of these structures.

4.2 Beach Nourishment

The LT trend approach inherently captures influences of beach nourishment on the historical shoreline position analysis. This limitation is also noted in the Data and Literature Review Report R01 (Water Technology, 2023a). The major beach nourishment works appear to be in front of engineered shorelines, which will not influence the analysis of erosion hazard with the adopted methodology. However, there are smaller nourishment campaigns that are known to have occurred in non-engineered beaches.

For the most part, nourishment campaigns are small in the wider context of multi-decadal trends and are not expected to influence the position of vegetation lines. However, given the paucity of data around historical nourishments, it is possible that erosion trends are masked by repeated beach widening. If this is the case, then the outcome of this modelling is that it effectively assumes that nourishment of a similar order of magnitude will continue to occur for such locations.

4.3 Modelling Tool Limitations

The outputs of the erosion hazard modelling are limited by the range of processes that can be captured by the methodologies adopted. Key limitations noted are:

- SBEACH is not able to capture longshore sediment transport that occurs during storm events (event-scale beach rotation) as discussed in Section 2.4.
- The short-term erosion is modelled at the shoreline but is effectively applied to the dune as an average shoreline shift as discussed in Section 2.4.
- The wave climate (in particular the incident wave direction) may change over time. This will influence the ST processes and LT trends. Limited information is available to quantify these, and the vegetation

mapping methodology is unsuitable to capture these. Once suitable data is available, alternative methods can be prepared to amend the projection of LT trends, and to refine the ST modelling in response.

4.4 Extrapolation of historical trends

The modelling methodology relies on understanding the historical trends of wave climate/storm activity and of ongoing shoreline changes. This has the following limitations:

- Trends may not continue indefinitely; due to
  - The recent past may be anomalous in the long-term or be part of a multi-decadal cycle that is not captured with the available data.
  - Beach changes may not continue indefinitely (as simple extrapolation will project), as processes will respond to new beach alignments, etc.
- Historical data may include errors/noise that will be propagated
- Historical interventions are implicit in the historical data, with an extrapolation effectively assuming that a similar rate of intervention will continue. Historical interventions may include:
  - Beach renourishment
  - Dredging
  - Creation of seawalls/groynes in response to significant erosion

Most of these limitations can be incorporated into the probabilistic modelling. Ultimately, such limitations represent the limits of future projections. Updated hazard modelling will be required in future to capture any improved datasets and understanding or to capture any changes in trends with time.

4.5 Input Data

There are likely to be inherent limitations to the input data that add uncertainty to the modelled hazard extents. This is true of all inputs such as:

- Water Level and Wave inputs (from SCHISM model) – these have only limited calibration/validation due to the lack of available data. However, as this only influences the modelled storm erosion extent, this is likely to be a smaller error in the long term, as storm erosion does not dominate compared to LT trends and SLR responses.
- DEM data – this fundamentally underpins the short-term erosion calculation (in the form of initial profile) and the Future Shoreline Response (in the form of shoreface slope and Bruun factor).
- SLR projections – these are based on assumed social emissions pathways, that may increase/decrease as global society responds to the risks of climate change.
- Shoreline mapping from aerial imagery – shoreline mapping may introduce some variation in shoreline position from the digitisation of low-resolution images, or where the position of the stable shoreline is uncertain. This error is expected to be in the order of ±10m for most images, and ±20m for the older (1930s, 1940s and 1950s) images. This error is mitigated by the clear patterns of trend between subsequent images and is incorporated within the triangular distribution developed for each TCSC. There is not likely to be a constant bias in this error, so the statistical combination of multiple transects mitigates this as best as possible.

These limitations and uncertainties can be either captured within the range of probabilistic modelling or can be selected to be conservative (to support planning). Ultimately, coastal hazard modelling will need to be updated when updated data becomes available (e.g., updated SLR projections, DEM data).

4.6 Shoreline definition

This methodology has selected the shoreline based on a vegetation line, equivalent stable contour or the most seaward coastal protection structure (seawall, etc.).

As noted in Section 2.7, this approach mitigates many uncertainties associated with seasonal variations and fluctuations of the exposed sandy beach. However, this comes at the cost of not providing any assessment of erosion into the sandy beach. Therefore, any exposed beach seaward of the adopted stable shoreline (indicated by the vegetation line) is considered to be within the erosion hazard extent by default.

There may be beaches within PPB that rely on the presence of a wide beach as a primary source of coastal protection, or that are nourished to maintain this protection and any amenity. Assessments of this ‘buffer zone’ or of beach width and amenity are not available from the outputs of this model. It is noted that such analysis will require separate studies, but that these studies do not represent a traditional ‘hazards study’ but are more focussed on the nuances of adaptation planning, and the management of beaches for social, environmental and cultural reasons.

Finally, the outcomes of this study do not therefore assume that any exposed beach will be entirely eroded before any other hazard occurs. Rather, the hazard extent simply represents the area prone to change in elevation due to coastal processes. This is implicit in exposed sandy beaches but does not mean that they are necessarily underwater. Instead, there may be a future vegetation line somewhere within the mapped erosion hazard extent, which for many beach systems will still have an equivalent sandy beach seaward of it.

5 CONCLUSION

This report presents a methodology that has been developed to assess the erosion hazard extent around Port Phillip Bay for future timeframes out to 2100 (with different sea-level-rise projections).

The methodology has been developed considering the following:

- Available data and confidence in application of datasets (as described in the Data and Literature Review Report R01 (Water Technology, 2023a)).
- Consistency with best-practice hazard modelling approaches, and the remainder of the PPBCHA.
- Efficient modelling tools over a large-scale (PPB-wide) study.
- Modularity and reusability, such that future updated datasets can be readily incorporated.

The result is a set of modelling tools that can be combined to calculate a zone of potential future setback (i.e., erosion hazard) for each TCSC in PPB.

Limitations of the adopted methodology have been explored and should be considered in any use of the outputs, or refinement of erosion hazard modelling at local-scales. However, the limitations are considered to be acceptable in the context of the target usage of the erosion hazard extents, and the uncertainties associated with the datasets.

The final erosion hazard results and further discussion of the outputs can be found in the PPBCEHA Final Hazard Report R03 (Water Technology, 2023b).

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