Data and Literature Review 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 the likelihood (expressed as a probability) of an event 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 metres 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.
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.
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 which 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 warming of the climate following the last glacial period and 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)	Hs may be defined as the average of the highest 1/3 of wave heights in a wave record (H1/3), or from the zeroth spectral moment (H_{m0}). Approximately the wave heights 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	**Li**ght **D**etection **a**nd **R**anging – also known as airborne laser scanning, is a remote sensing tool that is used to generate highly accurate 3D maps of the Earth's surface.
Lithology	A description of the physical character if a rock or rock formation.
Littoral 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.
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.
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.
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.
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.
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]
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.

[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 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 extends from Point Lonsdale on the Bellarine Peninsula to Point Nepean on the Mornington Peninsula. Port Phillip Bay and the study area extents are shown in Figure 1-1.

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

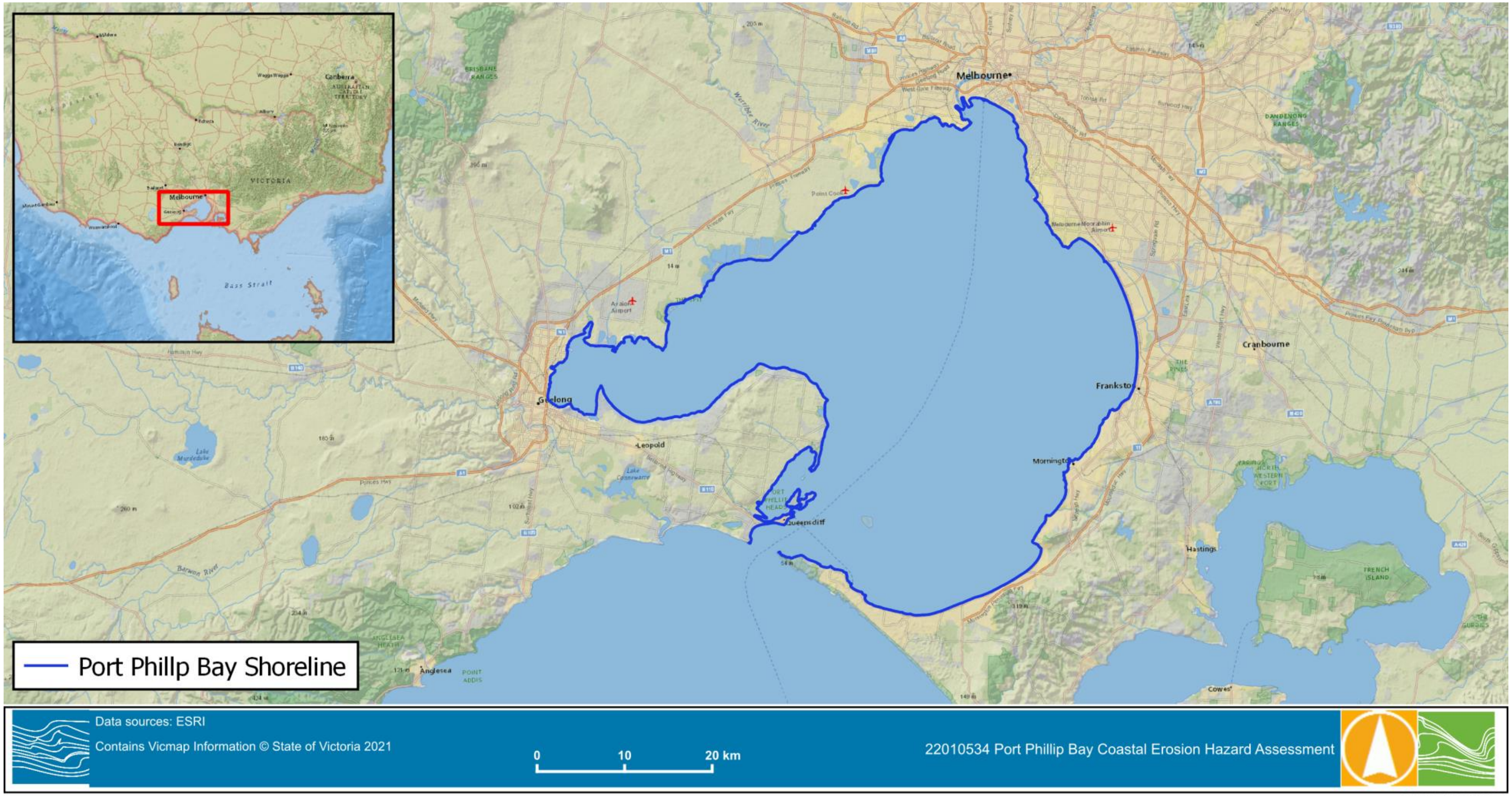


Figure 1-1 Study Area Extent

1.2 Coastal Erosional 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.

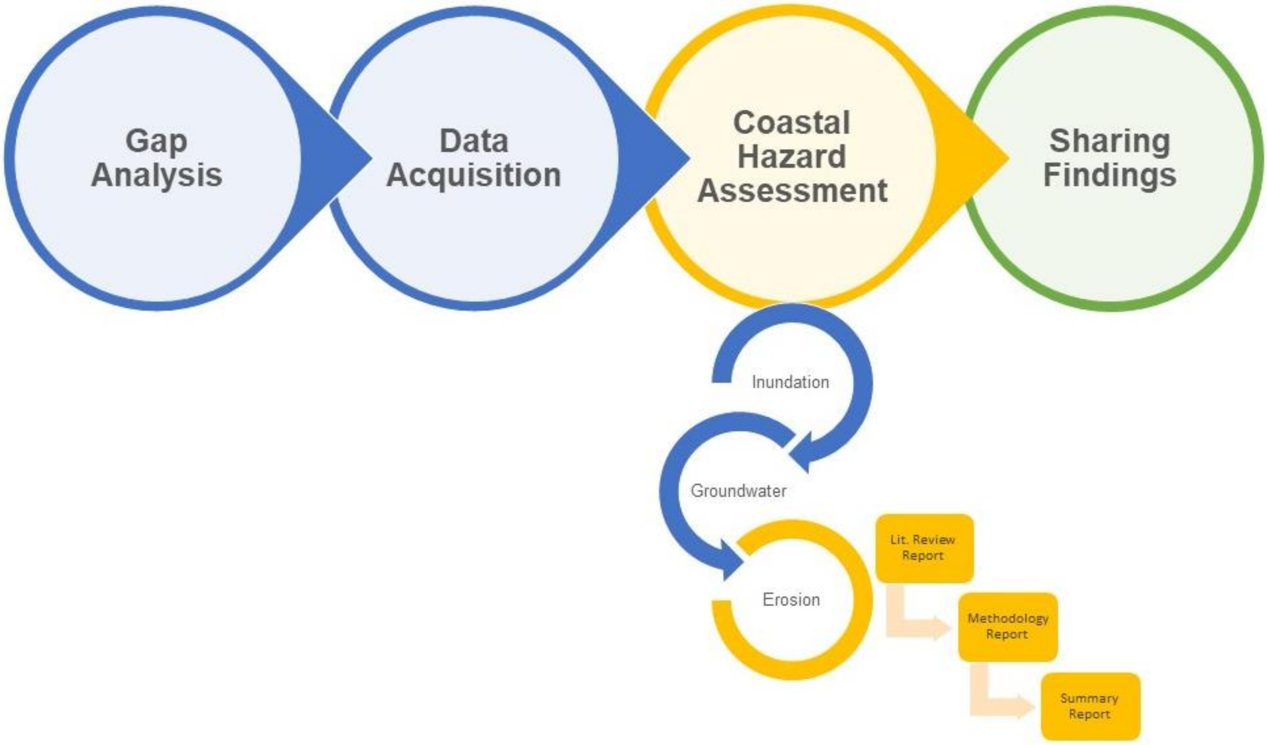


Figure 1-2 PPBCHA Stages and Components

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 EXISTING LITERATURE AND DATASETS

2.1 Legislation, Policy, and Guidelines

The Marine and Coastal Act 2018 (VIC) (MACA) is the foundational piece of legislation that enables the recent Victorian coastal management reform. It establishes the objectives and a set of guiding principles for management of marine and coastal areas.

The Victorian Marine and Coastal Council (established by the MACA) has subsequently developed the Marine and Coastal Policy (2020), which sets the guiding vision for these reforms and the Marine and Coastal Strategy (2022), which establishes a series of actions to achieve these. This process follows the directions of the MACA, with each document endorsed by the Minister.

The PPBCHA aligns with many of these documents and comes directly from Activity 3.4 in the Marine and Coastal strategy – Deliver priority coastal hazard data and maps to fill known gaps along the coast.

Finally, DELWP have prepared the *Victoria's Resilient Coast – Adapting for 2100+* project to provide a state-wide approach to coastal adaptation. This includes a framework for coastal managers and communities to plan for a sustainable adaptation of local coastal areas in response to climate change and coastal hazards. A core requirement for this process is a detailed understanding of the likely threats spatially.

2.2 Victorian Coastal Monitoring Program

The Victorian Coastal Monitoring Program (VCMP) has developed an ongoing data collection campaign for Victoria's open coast, as well as Port Phillip Bay and Western Port. It achieves this through partnerships with local governments and committees of management, as well as universities and citizen science.

A core part of the VCMP is to make these data available to a wide range of stakeholders. This is achieved by providing access to freely-accessible web portals through which datasets can be viewed, analysed and downloaded.

Of key interest to the PPBCHA, there are two key monitoring projects with coverage in Port Phillip Bay:

- Wave monitoring buoys.
- Unmanned Aerial Vehicle surveying of beaches.

2.2.1 Wave Buoy Data

A series of six wave monitoring buoys have been deployed around Port Phillip Bay to collect key wave parameters (significant wave height, period and direction) since December 2018. The location of the buoys is shown in Figure 2-2.

The spotter buoys measure the motion of the water surface using GPS positioning, and are capable of sampling at 2.5 Hz. This data is automatically processed into key wave parameters at half-hourly intervals, with wave periods able to be resolved in the range 1s to 30s. The wave data is automatically uploaded to a data dashboard (https://vicwaves.com.au).

The spotter buoy data includes noisy spikes, with spurious jumps in wave heights that are not physically achievable. The cause of these is unknown, but they can be readily removed by correlation to wind data, or by identifying wave heights in excess of 1 m with peak periods higher than can be generated for fetch-limited environments (>10s period)

While these datasets do not yet extend for a sufficient timeframe to extrapolate the wave or coastal volume change processes into the future, they can be used to validate other modelling or analysis tools against recent periods. Over the short period of deployment, the wave buoys have recorded many different extreme events, with at least 72 events exceeding a 1.0m Hs and 19 events exceeding a 2.0m Hs at the Central PPB buoy location. Figure 2-1 shows a timeseries of the Central PPB wave buoy data, with the events exceeding 2.0m Hs highlighted.

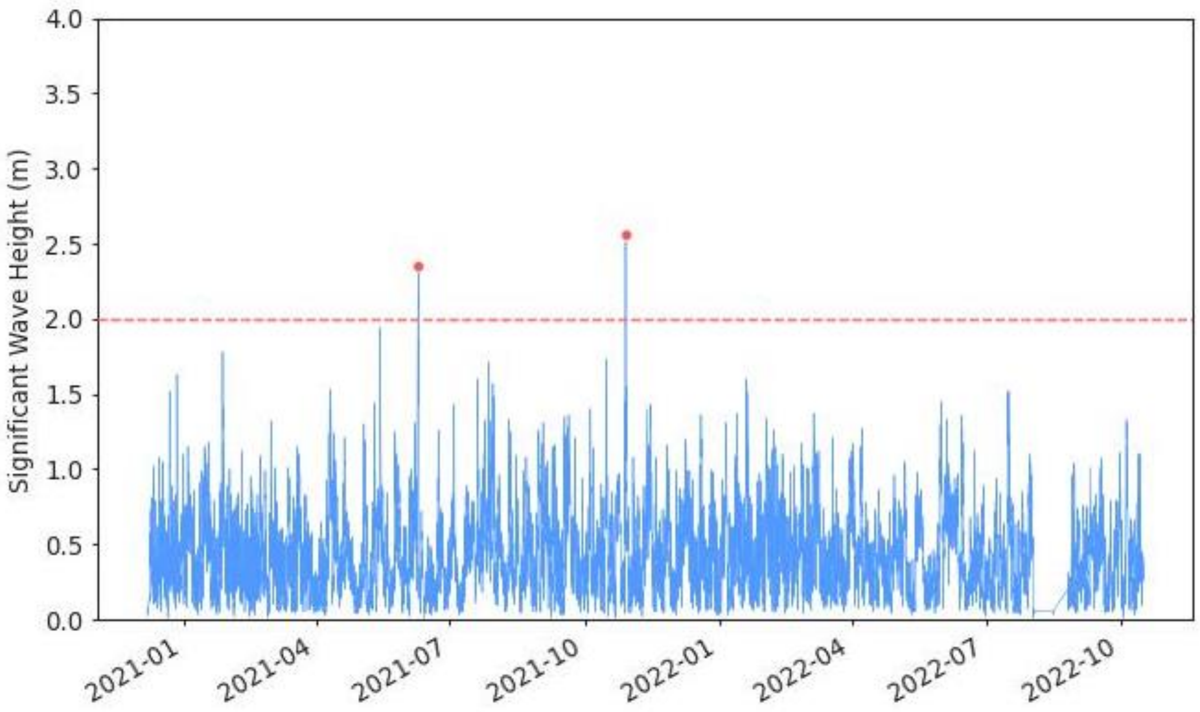


Figure 2-1 Central Port Phillip Bay Wave Buoy Data

Figure 2-2 VCMP Wave Buoy Locations

2.2.2 UAV Survey Data

Regular 3-dimensional survey scans are conducted at 14 sites around PPB using Unmanned Aerial Vehicle (UAV) or drone technology. The location of these sites is shown in Figure 2-4.

The drones use photogrammetry to measure the elevations of the beach and backshore. The survey is accurately georeferenced using visual control points manufactured by Propeller Aero (www.propelleraero.com). Survey datasets are uploaded to a Propeller Aero site (https://vcmp.prpellr.com) that allows for processing, analysis, and downloading of these datasets.

The surveys accurately capture elevations down to the water line. This allows for analysis of the change in water line position, or change in the position of a specific elevation contour. However, large erosion/accretion events are likely to move the water line relative to other surveys, and the transport of sand in the nearshore may be significant. As such, the volumetric analysis between surveys may not accurately represent the total sediment transport volumes that influence the beach over that period.

Surveys are conducted every 1-3 months, with variations in the exact frequency over time. This interval is such that the impact of individual storm events cannot be isolated. Given that storm activity and wind directions in Port Phillip Bay are highly seasonal, it is likely that a given 1-month period will contain several events that may transport sediment and cause change in the beach alignment and volume. Large storm events are not likely to completely recover within the inter-survey period however, and the difference in the surveys either side of such an event may approximate the magnitude of storm demand in the 'dry' beach.

Figure 2-3 shows a cross-shore transect of the survey datasets available at Portarlington. The total variation in the 0mAHD contour position over this time period is <10m.

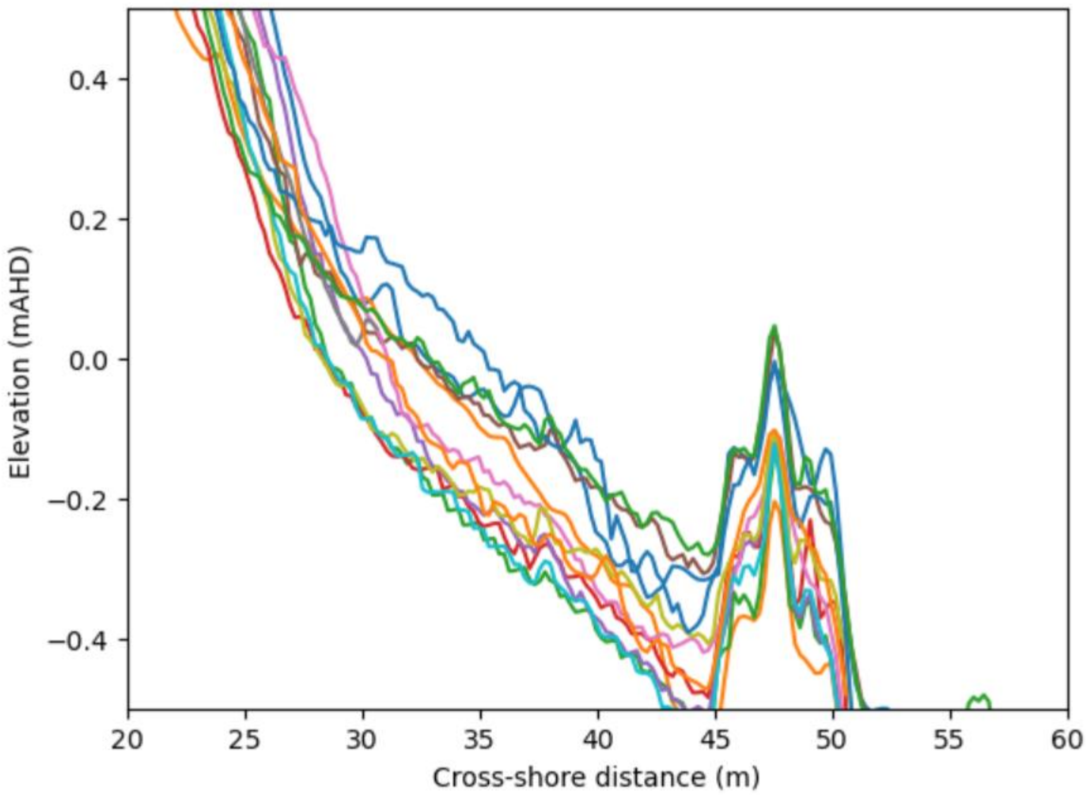


Figure 2-3 Portarlington Survey Transects

Figure 2-4 VCMP Survey Locations

2.3 CSIRO PPBCHA

CSIRO has undertaken the initial stages of the Port Phillip Bay Coastal Hazard Assessment work. The final report (McInnes et al., 2022) provides a detailed overview of the processes impacting coastal hazards in Port Phillip Bay such as:

- Context related to the geological variation, geological-scale history, and origin of coastal sediments
- Summary of engineering modifications and structures surrounding parts of the shoreline
- Meteorological forces and climate influences on waves and tides
- Wave, Hydrodynamic and tidal processes (including existing data and previous modelling studies)
- Extreme water levels and storm wave conditions (5%, 2% and 1% AEP at present-day and future planning horizons)
- Sediment transport processes
- Groundwater processes

The key factors influencing the coastal erosion hazard assessment are described further below.

2.3.1 Geological context and coastal processes

The CSIRO report (McInnes et al., 2022), referring to a range of other literature, presents the geological history that has influenced the evolution of the landforms. The major influences found are as follows:

- Periods of marine deposition, consolidating into sedimentary rocks and interspersed with igneous intrusions, notably granite batholiths (490 to 350 million years ago (Ma)).
- Tectonic events, faulting and basalt lava flows forming key features of the Bellarine and Mornington Peninsulas (100 – 23 Ma).
- Oscillating glacial extents, with corresponding shifts in sea level. Periods of lower sea level resulted in a dry bay, with the Yarra River meandering through it. Higher sea levels resulted in coastal sediment transport growth of the Nepean Peninsula, and occasional closing of the mouth of PPB (2.7Ma – 10 ka).
- Establishment of near-current sea levels, ingress of marine sediment deposits (last 11.7 thousand years), with strong evidence of a significant recent change 1000 years ago as a closed entrance was breached, flooding PPB that had largely dried out behind.
- Post European settlement, with introduction of non-endemic species, dredging, engineering of shorelines, beach nourishment, and beginnings of human-induced climate change (1788 – present).

The resulting coastal geology is shown in Figure 2-5 below. Red arrows indicate resistant rock outcrops. The variation in geology is evident around the shoreline.

This feeds into a summary of the key coastal processes as follows:

- PPB is fetch-limited, with waves and key currents driven by wind conditions interacting with the tides.
- Tides are micro-tidal, with tidal ranges further reduced inside PPB (approximately half the tidal range of Bass Strait immediately outside the PPB entrance).
- The seasonal variation of the sub-tropical ridge (STR) results in changes in the wind patterns seasonally, including eastward propagating low pressure systems and fronts that have the potential to cause storm surges and most likely to occur in Winter.
- The eastern side of PPB is more exposed to higher energy waves, resulting in sandy beach deposits and exposed cliffs.

- The southern part of PPB has a large flood-tide delta known as the Great Sands, formed of sand that has washed through the entrance in the past 11,000 years. These shallow shoals are a key hydrodynamic control within PPB.
- The western side of PPB is more sheltered and experiences large seagrass bed development, somewhat limiting sediment transport.

The outcome of this combination of events is an enclosed bay with varied geology, ranging from sandy beaches, large sandy shoals, intertidal mudflats, sedimentary cliffs, igneous outcrops, and highly engineered ongoing interventions.

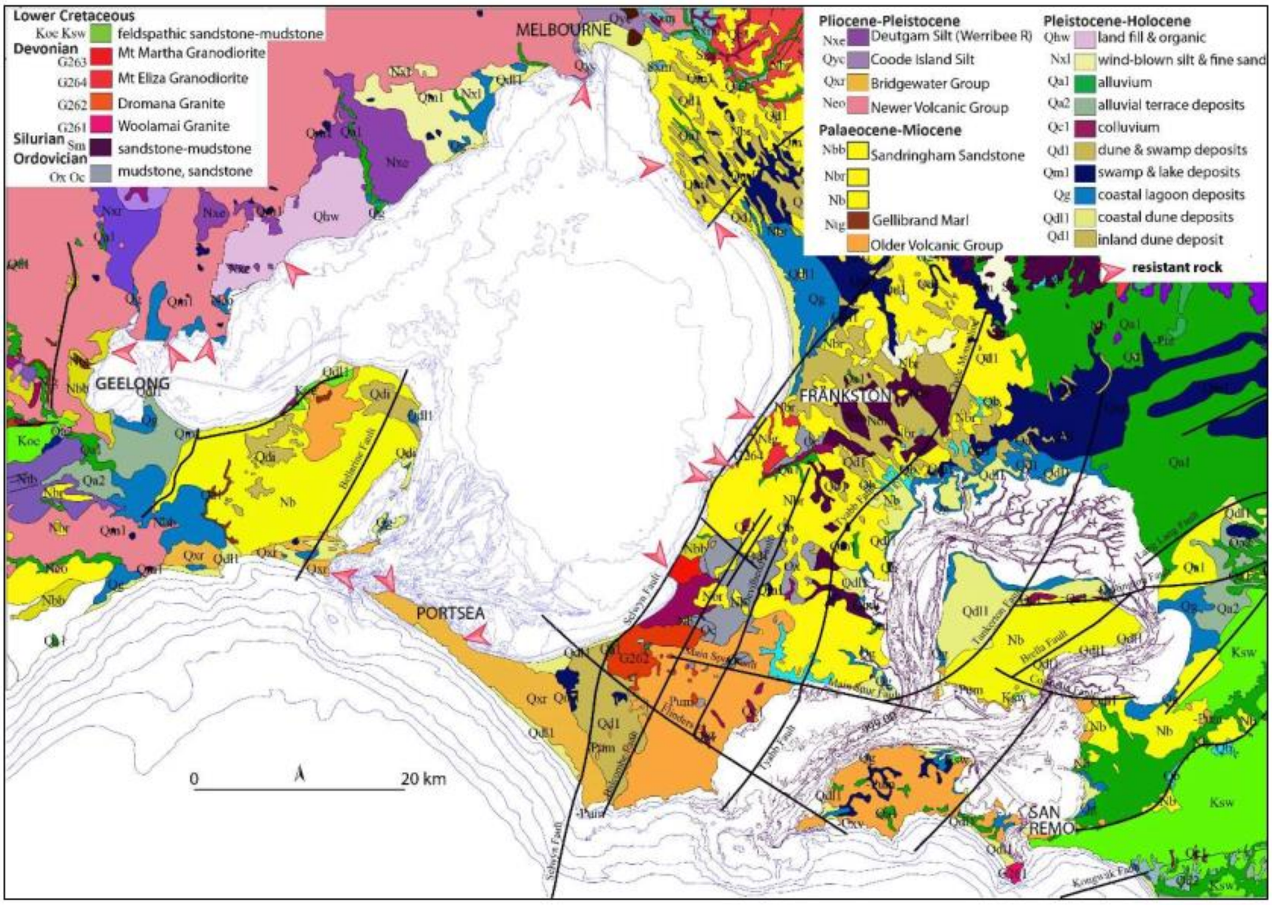


Figure 2-5 Coastal Geology map used in McInnes et al., 2022 (originally sourced from Seamless Geology, Geoscience Victoria 2011)

2.3.2 Extreme Sea Level Modelling

The CSIRO (2022) work includes modelling of still-water-level (SWL) conditions at present-day and under several sea level rise (SLR) scenarios (0.2, 0.8 and 1.4 m SLR with linear interpolation used to determine 0.5 and 1.1 m SLR conditions). This modelling utilised the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM), which was in turn forced by global-scale models of oceanic water level, waves and atmospherics (wind and mean sea level pressure). This model simulates storm-tide effects by directly modelling the physical processes that drive them – the inverse barometer effect of lower air pressure, and the setup caused by wind shear on the ocean surface. The model extends offshore to capture much of Bass Strait where such systems develop before impacting PPB.

The tidal model was extensively calibrated to several tide recordings around PPB and shows good agreement to them. There is a noted slight underprediction of higher water levels at most calibration locations, but overall, the correlation and root mean squared error (RMSE) indicate a good comparison. There is a high level of confidence that this hydrodynamic model is accurately reproducing the processes controlling tidal water level variations in PPB.

Extreme water level analysis is presented using a 35-year hindcast of this model. The results of this extreme value analysis (EVA) have been compared with other similar studies (Water Technology, 2017 and McInnes et al., 2009), as well as direct comparison to the Williamstown and Geelong tide gauge EVAs for an equivalent 35-year period. This comparison shows modelled peak water levels that are lower than seen in the Williamstown data (consistent with the calibration understanding), but that the overall modelled extreme storm tides are within a 95th-percentile confidence interval of the gauge data. When comparing the model to the full dataset of Williamstown tide gauge data (not just the equivalent 35-years), the SCHISM model results sit below the 95th-percentile confidence interval. The comparison at Geelong for the 35-year period shows an almost exact match. These comparisons are shown below.

Table 2-1 Williamstown Tide Gauge Comparison (after McInnes et al., 2022) (WT17 refers to the Water Technology 2017 analysis)

Williamstown	5%	2%	1%
Tide Gauge 1934-2014	1.17[1.11, 1.23]	1.27[1.19, 1.35]	1.34[1.25, 1.43]
Tide Gauge 35 yrs	1.14 [1.05, 1.23]	1.23 [1.12, 1.34]	1.3 [1.17, 1.43]
SCHISM 35 yrs	1.07 [0.99, 1.15]	1.15 [1.05, 1.25]	1.21 [1.09, 1.33]
SCHISM 20 yrs	1.03 [0.94, 1.12]	1.09 [0.98, 1.2]	1.14 [1.01, 1.27]
WT17 (BoM only)	1.12	1.15	1.18
WT17 (BoM + Adams)	1.16	1.23	1.27
McInnes et al., (2009)	1.03 [0.94,1.12]	1.09 [1.00, 1.18]	1.12 [1.02, 1.22]

Table 2-2 Geelong Tide gauge Comparison (after McInnes et al., 2022)

Geelong	5%	2%	1%
Tide Gauge 35 yrs	0.94 [0.87, 1.01]	1.00 [0.91, 1.09]	1.06 [0.96, 1.16]
SCHISM 35 yrs	0.95 [0.89, 1.01]	1.00 [0.92, 1.08]	1.05 [0.96, 1.14]
SCHISM 20 yrs	0.91 [0.85, 0.97]	0.95 [0.87, 1.03]	0.98 [0.89, 1.07]
McInnes et al., (2009)	0.98 [0.89, 1.07]	1.03 [0.94, 1.12]	1.09 [0.99, 1.19]

SCHISM hydrodynamic modelling was also conducted for a series of 20-year periods with the addition of SLR offsets on the offshore boundary to assess the non-linear influence of higher mean sea levels on total storm tide. Water level EVA for these has been compared to an equivalent 20-year analysis from the baseline period (noting that a 20-year EVA provides less-accurate predictions than using the full 35-years of baseline modelling). The results show that increases in sea level of up to 1.4m provide an additional overall increase in 1% AEP storm-tide impact of 70mm. This additional effect was then added to the more-accurate predictions from the 35-year analysis to provide future extreme water levels.

Overall, there may be a slight underprediction of extreme water level conditions as compared to the longest available dataset (Williamstown Tide Gauge), but one that is small in overall magnitude (90 to 130 mm), and similar to the uncertainty in EVA estimates for the 35-year period (+/- 120 mm). The model provides value overall (as opposed to adopting gauge analysis only) as it can be used to show spatial variation in storm surge effects, and comparison under SLR scenarios. The SLR comparisons show a small additional increase in extreme water levels (up to 70mm) associated with the highest SLR projections. This additional amount is notable, but small in the overall context of the total water level (i.e., compared to the 1.4m of SLR and ~600 mm of storm surge above HAT) and is a smaller variation than the confidence range of the EVA (+/- 120 mm).

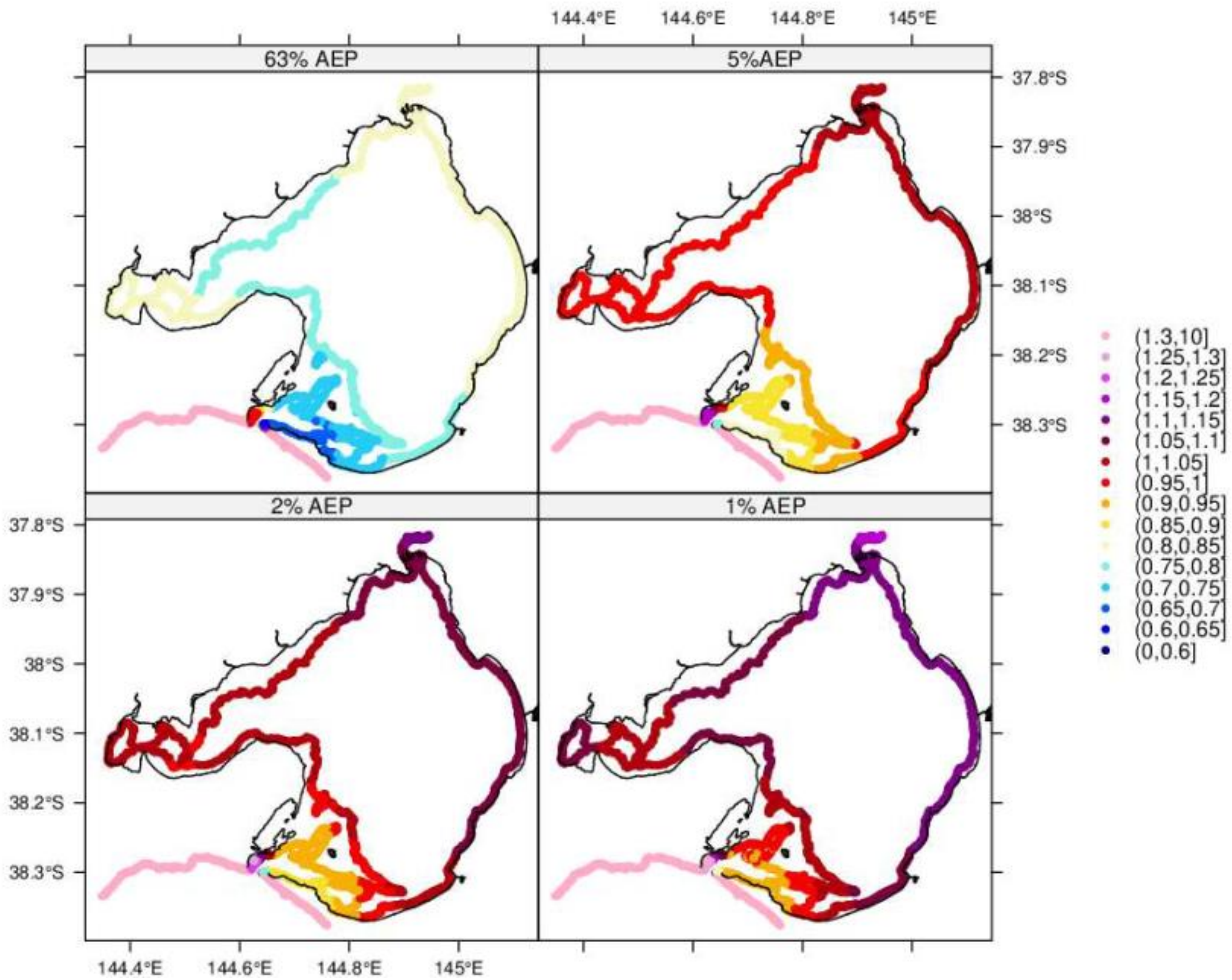


Figure 2-6 Extreme Water Level AEPs (m) (after McInnes et al., 2022)

2.3.3 Extreme Wave Modelling

Coupled with the SCHISM model is an internal wave modelling module called the Wind Wave Model III (WWMIII). This model is forced by the same atmospheric model as the wider SCHISM results, and includes an offshore boundary generated by a larger wave model in Bass Strait (that uses the industry-standard SWAN wave model). The wave model was used to run a 35-year hindcast as part of the coupled SCHISM-WWMIII hindcast. This hindcast was then used to estimate the extreme wave AEPs that could be used to inform coastal hazards (specifically wave setup, wave runup and overtopping in the CSIRO inundation work, and storm erosion hazard within the PPBCEHA).

The WWMIII model included calibration to wave data that was available at the time of modelling. These wave data observations are highly limited, and do not provide a long-term continuous period over which to assess variation, and do not provide spatial coverage of the range of different wave exposures within PPB. The most recent datasets used for calibration are from three wave buoys that were deployed offshore from the PPB entrance in 2011.

The WWMIII results show a good correlation to the recent offshore data. However, given that offshore wave penetration into PPB is limited and almost all waves are locally generated, this does not provide much indication of model skill within the enclosed PPB area. The limited datasets within PPB show a poorer correlation to data, with RMSE up to 300 mm at Rosebud (in the context of modelled peak wave heights below 2.5 m). The report commentary finds that given the limited data available, the model performs adequately. This conclusion of the authors is not supported by the evidence presented (timeseries comparison as shown in Figure 2-7), which shows that the WWMIII simulations tend to underpredict the wave heights and periods for most peaks.

With the limited data, it is difficult to determine the cause of the discrepancy. However, given the sheltered environment of PPB, it is likely a combination of:

- Potential underprediction, or poorly resolved spatial variation of input wind conditions (WWMIII uses global modelled wind, and not observations).
- Parameterisation of key wind-wave processes, such as white-capping, wind-wave growth functions, and bed friction.
- Temporal variability in the presence of sand shoals. The WWMIII uses bathymetric data that has mostly been collected since 2006. However, within PPB wave fetch may be controlled by the heights of sand shoals relative to overall storm-tide water levels. This makes comparison to historic datasets, particularly in shallower areas influenced by such shoals, difficult.

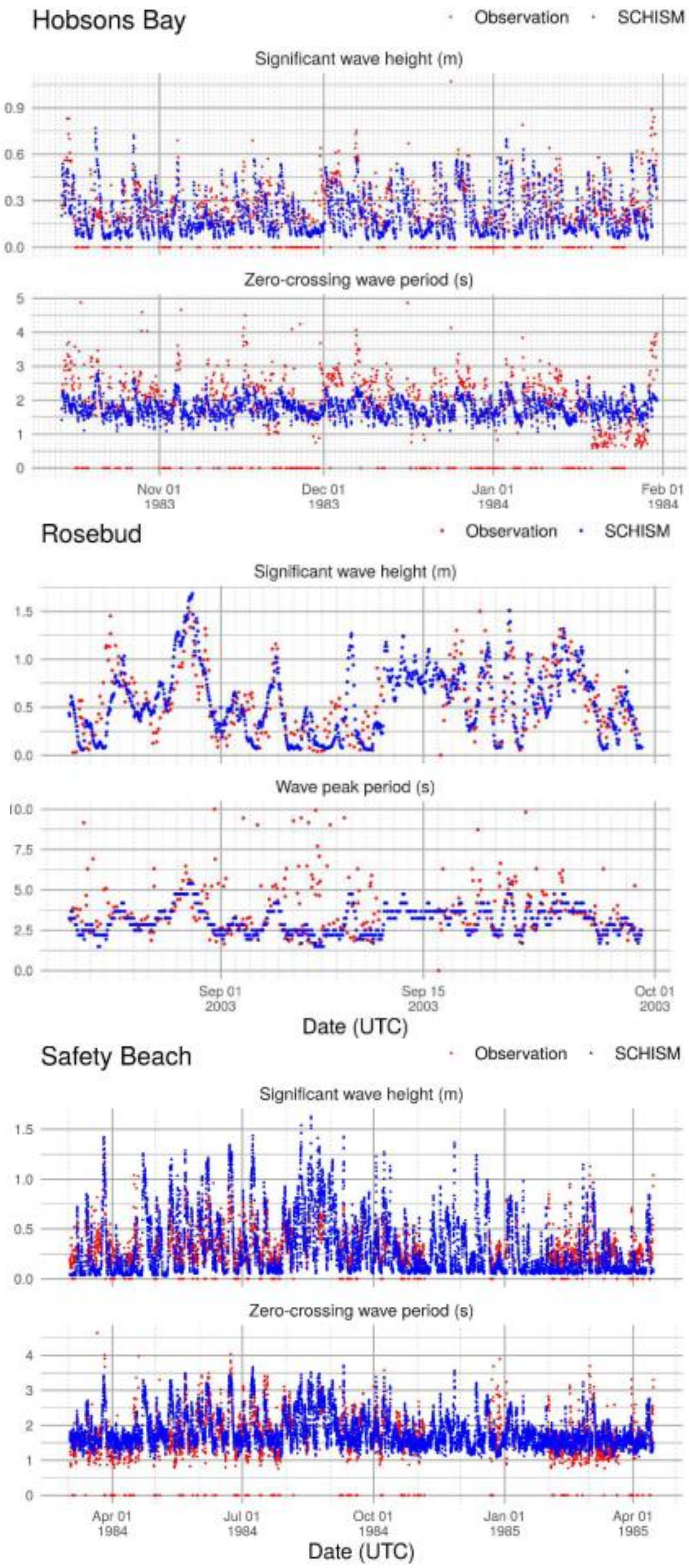


Figure 2-7 SCHISM-WWMIII comparisons to three wave observation datasets in PPB (after McInnes et al., 2022)

The report notes that DELWP (now DEECA) are implementing a wave monitoring program within PPB (now part of the VCMP, see section 2.2.1), that could be used to further validate the model at a later date. This data was not available at the time of model development, and the SCHISM-WWMIII hindcast does not cover this period for direct validation.

The CSIRO report compares the WWMIII extreme wave estimates to another recent study that included wave modelling (Cardno, 2018). There are several variations between these two datasets, with the Cardno data values higher than WWMIII for the western side of PPB, and vice-versa for the eastern side. There are many methodological differences between the two modelling approaches that may introduce these differences. Both studies were limited in the available wave observation data for calibration/validation.

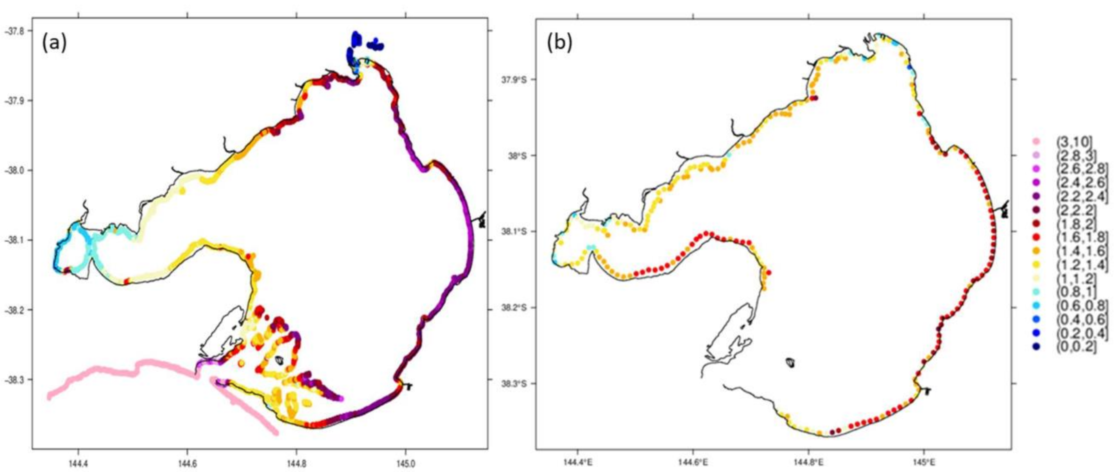


Figure 2-8 Comparison of 1% AEP modelled wave heights from CSIRO WWMIII modelling (left) and Cardno (2018) modelling (right) (after McInnes et al., 2022)

The WWMIII extreme value analysis predicts peak 1% AEP Hs values of up to 2.5 m at more exposed locations within PPB (Frankston, Seaford, Sandringham) and <1 m at more sheltered locations (Corio Bay). Maps of the maximum-likelihood estimate AEP wave heights from the WWMIII model are shown in Figure 2-9.

As the VCMP wave observation program data was not available at the time of the WWMIII modelling, a comparison of these is not provided in the CSIRO reporting. However, the predicted WWMIII extreme values have been compared to observed events, to understand if the data are plausibly consistent.

The WWMIII extreme value outputs taken near to the location of the Sandringham wave buoy finds that the 1% AEP extreme wave estimate (significant wave height) is 2.24 m. The observed dataset at Sandringham (December 2020 to present, with some data gaps) shows three (3) wave events exceeding this value (data presented in Figure 2-10). The largest observed wave height was 3.39 m in January 2022. While the observed wave dataset does not extend for long enough to conduct an EVA on its own, two events exceeding the 5% AEP, one of which exceeds the 1% AEP by a significant margin is statistically improbable within a 2-year period. This suggests a high likelihood that the WWMIII data underpredicts the extreme wave climate in PPB.

In conclusion, the WWMIII data are likely to be underestimating wave heights (particularly extreme waves) in PPB. This will influence coastal erosion modelling as driven by extreme wave (storm) conditions, with the overall sediment transport likely to be underpredicted. However, for consistency with the remainder of the PPBCHA it would be highly advantageous for the PPBCEHA to utilise the same model inputs. It may also be likely that the storm erosion is a minor component of the total erosion hazard at longer timeframes, and an underprediction of the extreme wave heights will not unduly change the total hazard extent. Therefore, the WWMIII model should be favoured, pending sensitivity testing of the storm erosion modelling under different wave heights. Any bias or uncertainty introduced thereby should be acknowledged as a limitation within the overall erosion hazard methodology. If the sensitivity testing proves that this uncertainty is unacceptable, alternative methodologies for understanding the storm-driven erosion hazard should be considered.

Finally, it is noted that DEECA have commissioned an improved calibration of the WWMIII model that incorporates the latest data from the VCMP wave buoy network. These model outputs will not be available in time for the PPBCEHA, but may be available for future studies, or updates to the erosion modelling estimates.

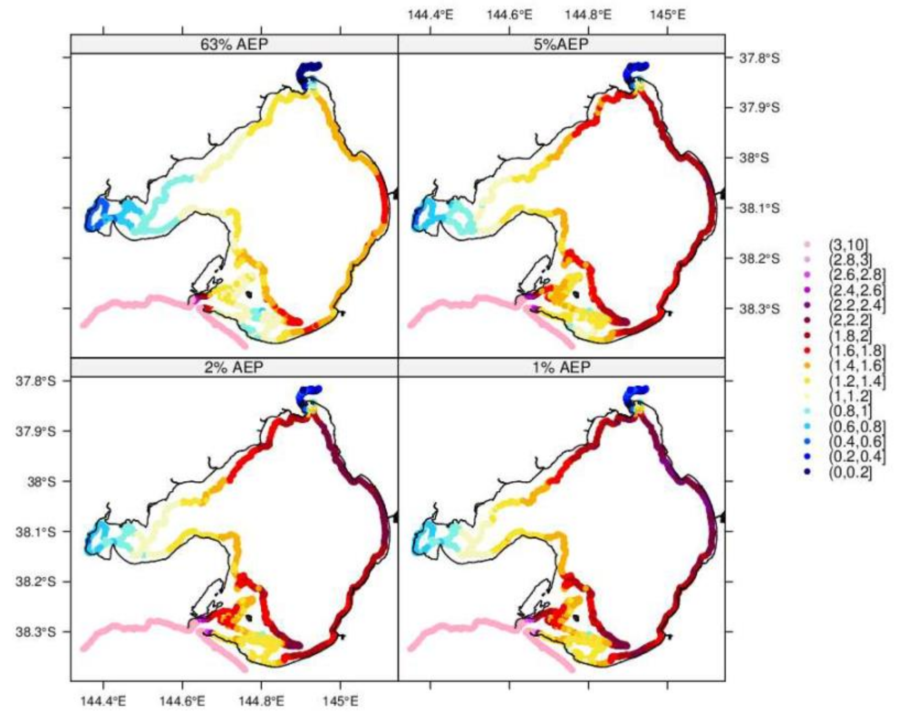


Figure 2-9 Extreme Significant wave height estimates (m) (after McInnes et al., 2022)

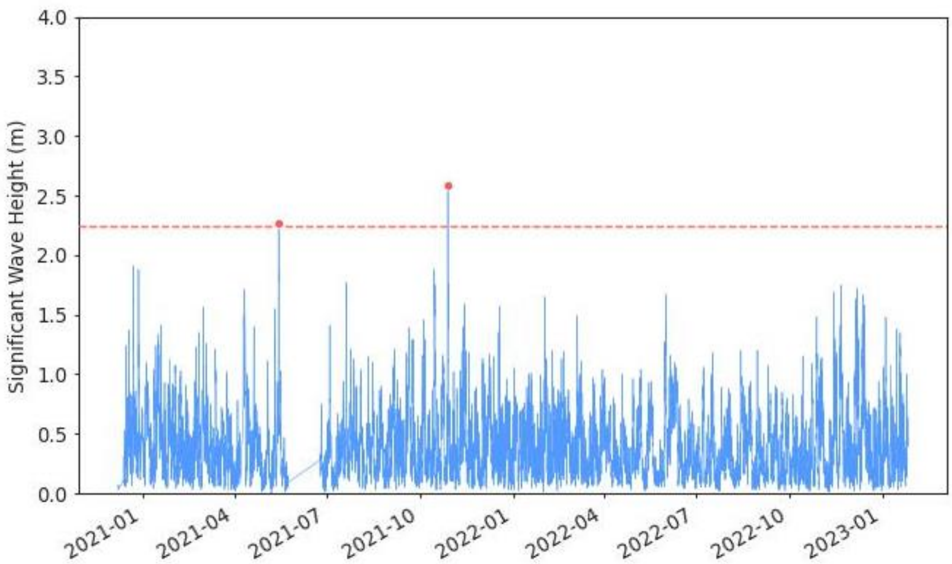


Figure 2-10 Sandringham Wave Buoy, with line representing a 2.24m wave height (1% AEP from the WWMIII analysis) and the event peaks exceeding it

2.4 Aerial Imagery

Aerial imagery is available for the entirety of Port Phillip Bay in a series of stitched (merged together seamlessly) and georeferenced datasets that represent decadal intervals from 1930 to 1990 (noting some spatial gaps). Additionally, there are several datasets of images since 1990 from the DELWP Coordinated Imagery Program (CIP), Landata and other commercial aerial imagery suppliers.

The decadal datasets vary in resolution and quality (older images being greyscale and less clear) and consist of images that do not necessarily correspond to the exact starting year of each decade. However, they represent a continuous dataset that allows changes to be tracked in a consistent manner.

For the PPBCEHA, the decadal imagery datasets have been proposed to analysis coastal vegetation line movements over time as an analogue for ongoing coastal recession processes. A total of 10 grouped datasets has been sought from the range of available images. These include

- The ‘decadal’ images from 1930s to 1990s (7 decadal datasets)
- The PPB-wide 2005 aerial image
- The PPB-wide 2010 aerial image
- The most recent available aerial images around PPB (typically 2019-2022)

The full set of considered images are provided in Table 2-3 below. Within the decadal images, there are several overlaps where certain images can be excluded entirely. The selection of these favoured higher-quality images where suitable, or the larger images (images that could be used consistently over a wider area) where quality differences were minimal.

For the purpose of identifying a coastal vegetation line, the images offer different challenges. Recent images provide the clearest and highest resolution, where vegetation can be readily identified, but may encourage ‘over-fitting’ vegetation lines at the scale of individual shrubs and trees. Older images, particularly the grayscale images, make determining vegetation lines difficult as dark shadows may indicate a transition from a lighter sandy beach to a strip of vegetation, but may also indicate rocky reef, seagrass, or other features in these areas. Examples of these are shown in Figure 2-12 and Figure 2-13.

There are also minor indicators of errors in the stitching of the aerial images as shown below near Blackrock in the 1950s where the road is misaligned. These errors are rare and only impact small areas in older images. They are likely within the uncertainty range of digitisation of aerial imagery.

Due to the above challenges, and the quality of older images, it is expected that manual digitisation of aerial images will have an error margin of ~20 m for images from the 1950s and older, and ~10 m for more recent images. These errors are not likely to be biased in any one direction or another, and can be incorporated into the trend analysis of shoreline positions (the errors should average out somewhat between successive images for trend analysis). The uncertainty should be considered in the context of the final hazard products but overall is thought to be acceptable, and the images suitable for this process.

Figure 2-11 Aerial imagery misalignment

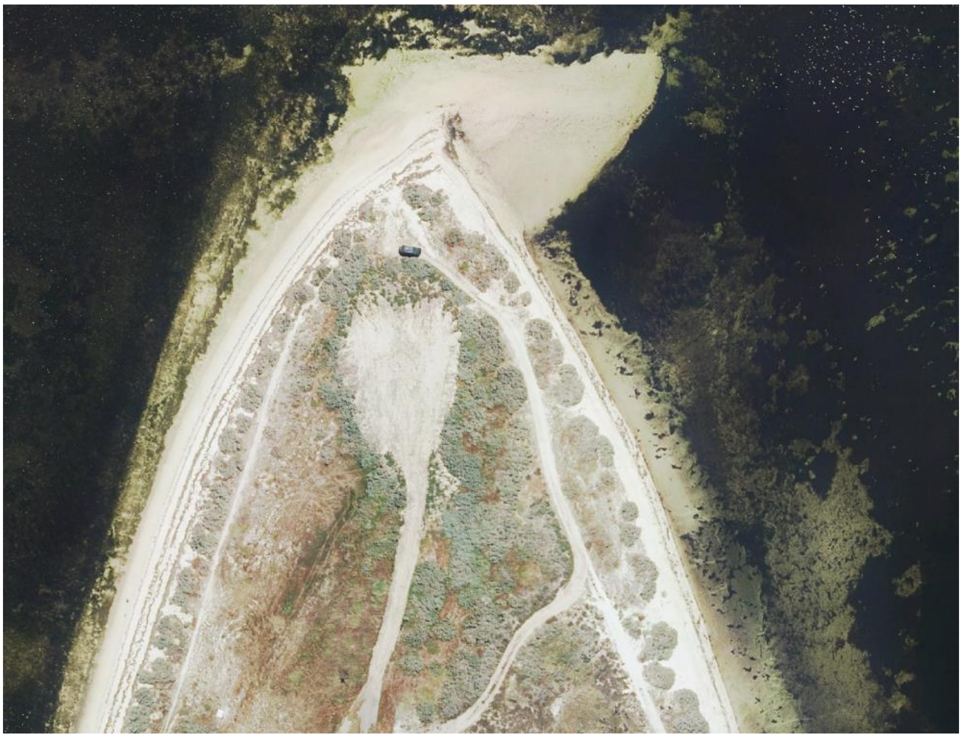


Figure 2-12 Most recent image at Point Henry (geeong_2019oct01_air_vis_10cm_mga55)

Figure 2-13 Kororoit Ck, Altona 1930s (altona-bay_1939jan01_air_bw_10cm_mga55)

Table 2-3 Available Imagery considered of Port Phillip Bay

"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 Tertiary Coastal Sediment Compartments

The boundary and extent of Tertiary Coastal Sediment Compartments (TCSCs) within PPB has been recently determined through an Expert Panel lead by the University of Melbourne. Details of the expert panel and associated workshops can be found in the summary report (Kennedy, 2022).

This data has been made available for this erosion study and will form the basis of a discretisation scale for changes in the sediment transport and erosion characteristics along the coast.

The approach for defining TCSC boundaries has been adapted from the methodology developed by Thom et al. (2018) and further expanded by others. The Thom et al. methodology described TCSCs as either leaky or closed. Leaky compartments allow for some exchange between landforms, whereas closed compartments do not. However, this methodology has been refined to account for very long open beaches in fetch-limited domains (such as Dromana to Rye), where although notionally unconstrained, interruptions in sediment transport or budget at one end of the system will not influence the other end at the scale of a decade at least. Furthermore, the concept of a leaky compartment was refined into three sub-categories depending on whether sediment transport between landforms occurs in (1) offshore deeper areas, (2) subtidal bars, or (3) inter-subtidal.

The result is a set of 205 TCSC defined by their boundaries around PPB as shown below. These compartment definitions are a useful starting point for the discretisation of the erosion hazard modelling. However, they need some refining of their positioning (to align with the centre of a headland, or along a groyne, etc.).

Finally, some adjustments to the number of compartments (merging/splitting) may be required. The methodology used sediment transport characteristics as the differentiator for sediment compartments. However erosion hazard depends not only on the sediment transport, but the vulnerability of the backshore, which varies at a sub-compartment scale (i.e. where a seawall sits within a TCSC, or across the boundary between multiple TCSCs).

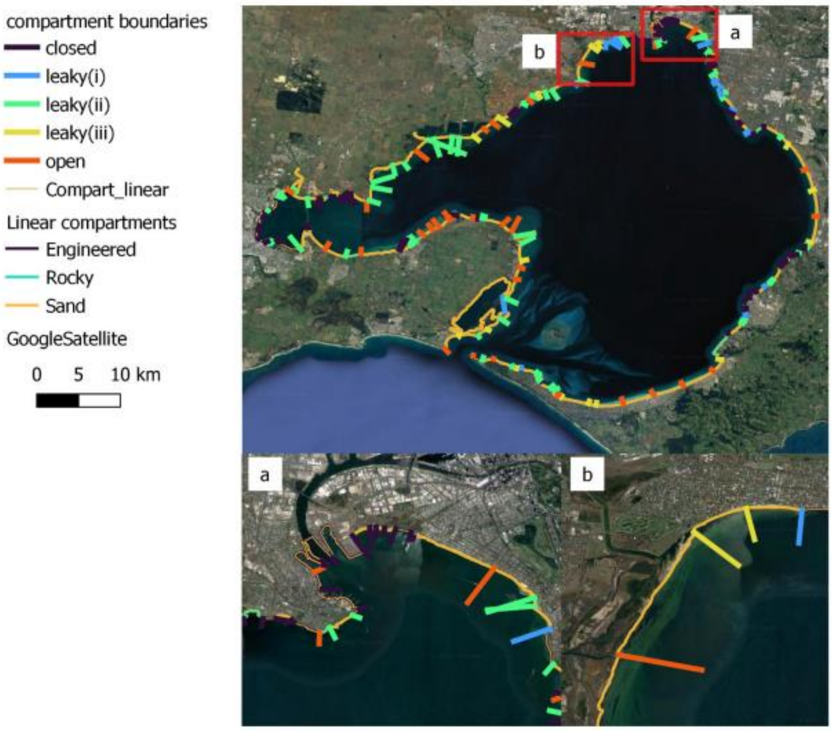


Figure 2-14 TSCS compartment boundaries (after Kennedy, 2022)

2.6 Shoreline Type

There are several different shoreline classifications within PPB that provide insight into the vulnerability of the shoreline to erosion:

- Kennedy (2022), who divided the coast into Engineered, Rocky and Sand shorelines as part of the TCSC division (see section 2.5).
- McInnes et al. (2022), who provided the concept of 'geomorphic sectors' based on a large number of backshore types.
- The National Smartline dataset (Sharples et a., 2009), which has been widely used around Australia to understand coastal vulnerability.

The shoreline types for PPB based on the National Smartline dataset are shown in Figure 2-15 with associated descriptions from the Victoria's Resilient Coast guidelines (Water Technology, 2022) presented in Table 2-4. The most common shoreline types are sandy coastlines (32%) and engineered coastline (32%), followed by estuarine and tidal channels (18%, with over 50% located within Swan Bay), Low Earth Scarp Shoreline (10%, located predominantly in Corio Bay) and a small proportion of soft (5%, 17km) and hard (3%, 9km) completing the 330km of PPB shorelines.

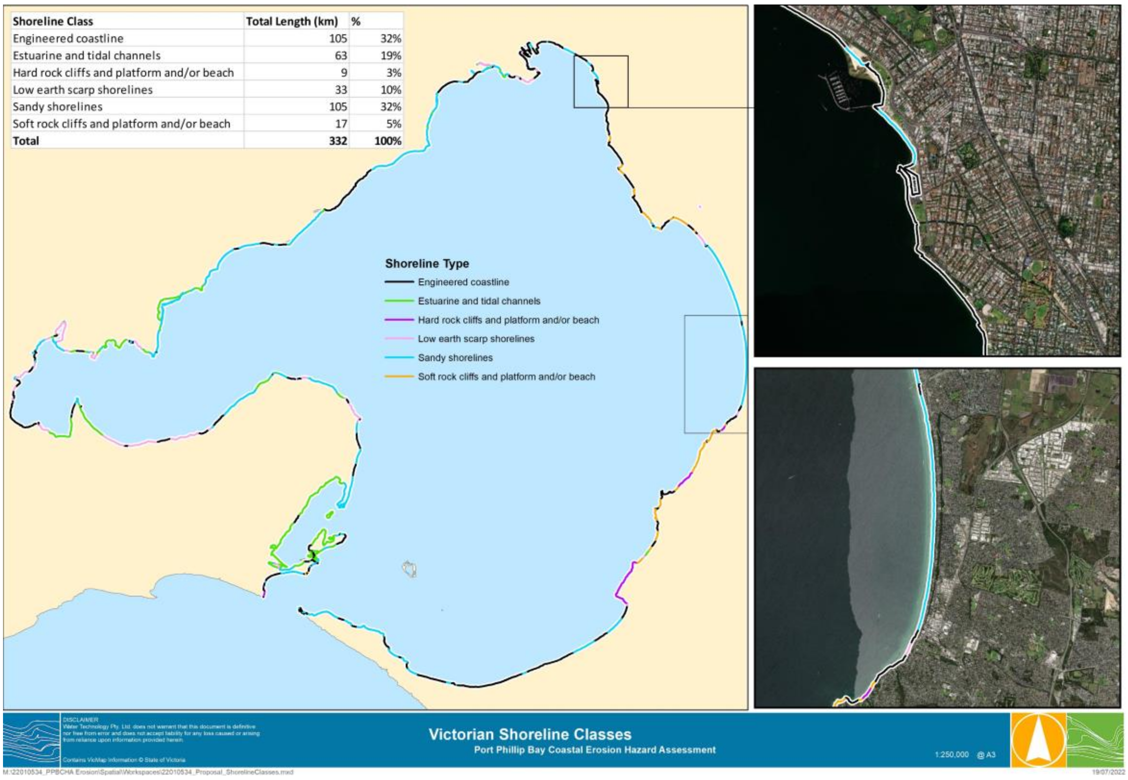
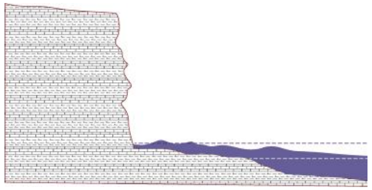
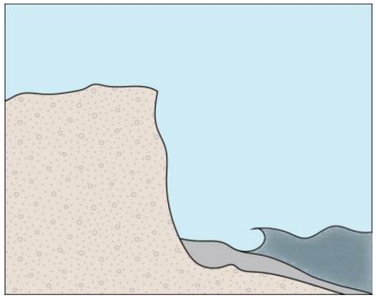
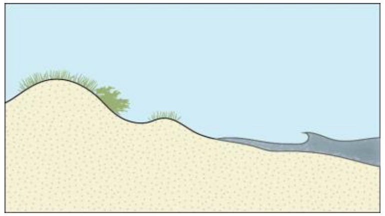
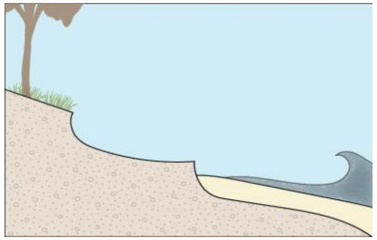
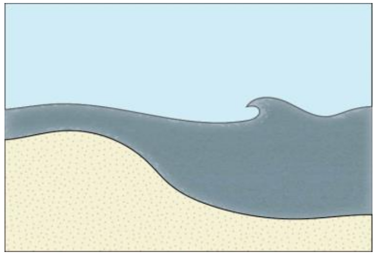
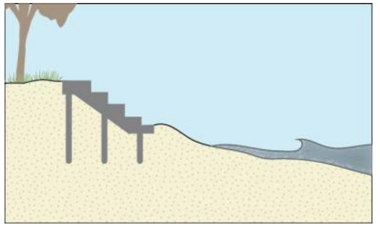


Figure 2-15 Shoreline types of Port Phillip Bay

Table 2-4 Shoreline Types

Type	Conceptual Model	Description
Hard Rock Cliff 3% of Port Phillip Bay shoreline		Hard rock cliffs are consolidated rock formations shaped by marine and sub-aerial processes and are of highly varied form and profile. Hard rocks are composed of strongly cohesive crystalline igneous or well-cemented sedimentary origin and on the Victorian coast include granite, basalt, and some sandstones and limestones. Cliffs may be very steep or sloping surfaces of varied height, scale and shape. Hard rock cliffs are particularly susceptible to deep-seated mass movements that may be initiated by a combination of surface processes and/or due to marine influences at the base of the cliff. Key variants include: 1. Hard rock cliff shore and platform consists of a steep slope of exposed hard rock and/or partly vegetated surface on weathered hard rock with a shore platform of variable width and generally well-defined outer edge that is exposed at low spring tides; 2. Hard rock cliff with a sand/gravel beach that partially covers the platform – sediment derived from off-shore; 3. Plunging cliff without a shore platform. 4. Steep coastal slope and basal cliff. Basal undercutting in softer layers may occur; and 5. Coastal bluffs currently beyond present wave action but may be re-activated under higher sea levels.
Soft Rock Cliff 5% of Port Phillip Bay shoreline		Soft rock coasts (e.g., limestone, clay) can occur on open coasts and within embayments. Soft rock cliffs are subject to similar sub aerial and marine processes and experience continuous to intermittent marine erosion. The key variants include: 1. Soft rock with/without a shore platform; and 2. Soft rock with/without a beach. Soft rock cliffs are near-vertical slope of exposed rock. A sand beach and/or dunes may be present at the base of the cliff and sometimes bury the cliff. The presence of sand dunes or a beach in front of the cliff can slow the rate of erosion. A shore platform of more resistant material may be developed. A range of sub-aerial processes contribute to erosion of the high soft rock cliffs including groundwater pore pressure and seepage which contribute to slope failure through block or slumping type movements, furthermore surface runoff and rain impact can affect the stability of the cliff face. Wave action is also a significant process for change on these shorelines.

Type	Conceptual Model	Description
Sandy Shorelines 32% of Port Phillip Bay shoreline		Sandy shorelines are formed from a combination of terrestrial and marine-derived sediments. Sandy coasts occur on open coasts and in embayments. Key variants include: 1. Barrier/ spit systems formed during the Holocene marine transgression over the last 10,000 years, typically at a change in backshore coastline orientation and in the lee of nearshore islands or built structures; 2. Beach ridges systems; a series of parallel/sub-parallel dune ridge sequences which have formed successively behind a sandy shore. These ridges may fluctuate between accreting and eroding coastlines over time depending on the local coastal processes; and 3. Pocket beach systems; compartmentalised beaches of deposited sediments formed between headlands and within coves.
Low earth scarp 10% of Port Phillip Bay shoreline		Low earth scarps typically develop in lower wave energy environments and comprise of a wide intertidal flat or silty sand or peats and muds with a sparse distribution of mangroves. These landforms a have low elevation and often leveed. Key variants include: 1. Low earth scarp with an intermittent, narrow sandy beach; and 2. Low earth scarp of soft sediments of poorly consolidated and unconsolidated peat, alluvium or organic material. Historically and presently these shorelines are typically undergoing active shoreline recession.
Estuarine and tidal channels 19% of Port Phillip Bay shoreline		A partially enclosed coastal waterway that is influenced by tides and coastal processes; a zone where freshwater mixes with salt water. Estuary systems may be permanently or periodically open to the sea. The key characteristics of this shoreline class are: 1. The presence of a tidal and/or riverine channel(s) transporting marine water into rivers and coastal lagoons and extend considerable distances landward of the main shoreline; 2. A low elevation backshore zone which is often leveed; and 3. Wide intertidal flat of silty mud and sand.

Type	Conceptual Model	Description
Engineered coastlines 32% of Port Phillip Bay shoreline		Engineering coastlines can be situated on open coast or embayed areas, and are typically urban environments with a range of infrastructure. The presence of coastal engineering structures can have a significant impact on natural coastal processes, including limiting / disrupting sediment transport. Can include the following structures: 1. Harbours, marina, esplanades, jetties, and boating facilities 2. Sea walls, revetments, gabions 3. Groynes, breakwaters (timber or masonry) 4. Sand and/or sediment renourished beaches. 5. Drains and constructed stormwater outlets. 6. Recreational access, car parking, roads, lookout platforms, fencing.

2.7 CAMS Dataset

The Victorian Coastal Asset Management System (CAMS) dataset contains information on many coastal assets throughout Victoria, including seawalls, groynes, breakwaters, and training walls. This dataset has been made available as part of the erosion hazards study to identify areas with existing maintained structures that will prevent erosion exposure if maintained. The provided version of this dataset is a spatial dataset (GIS Shapefile) containing information on the asset name/ID, type, materials, and basic dimensions. Where available, it also includes information of the most recent condition score as assessed by various condition assessments. 865 different assets are provided around PPB of which 333 have either not been assessed or are rated as being in 'Poor' or 'Very Poor' condition as shown in Figure 2-16.

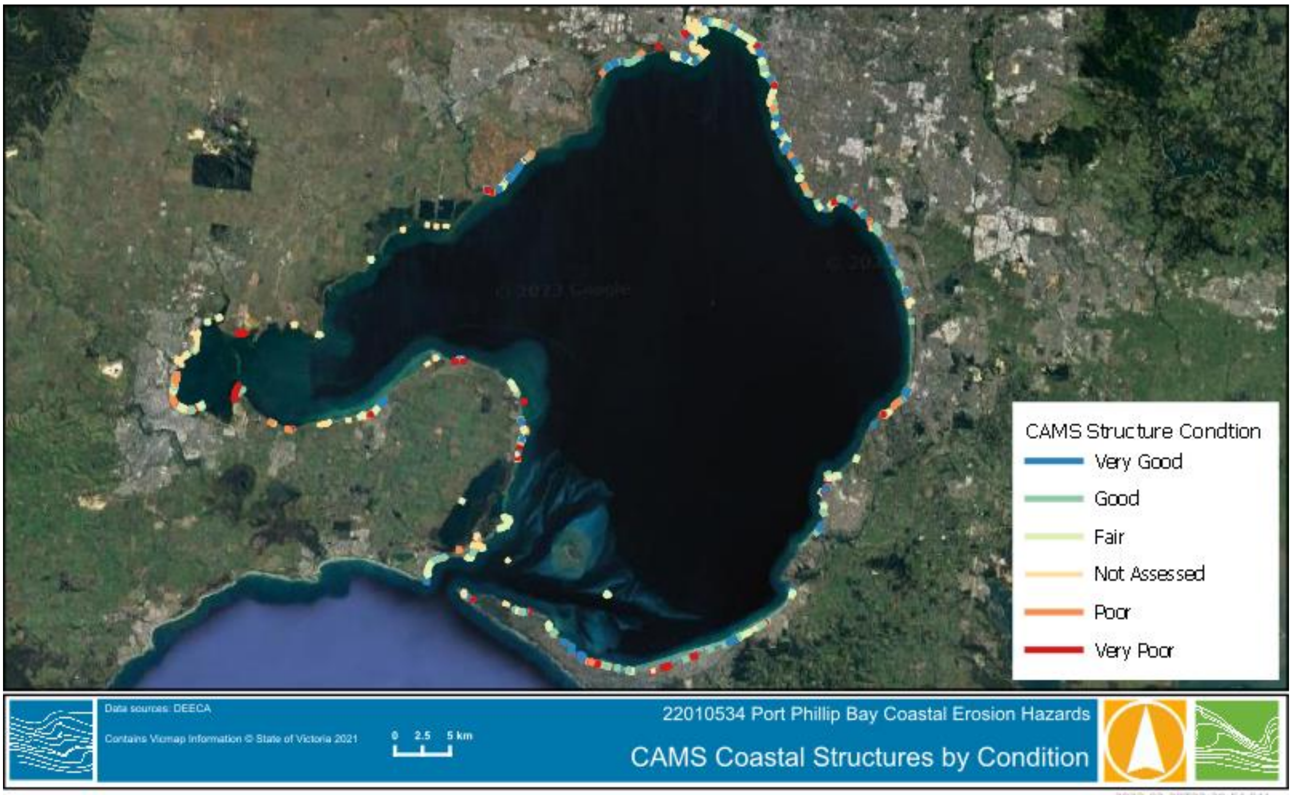


Figure 2-16 CAMS Coastal Structures by Condition Score

This dataset is mostly complete and fit-for-purpose but will require some modification to align spatial positions of seawalls more accurately along the visible structure as seen in aerial imagery.

Additionally, the dataset has the following limitations to consider:

- Assets noted in CAMS that are not identifiable in aerial imagery (may be destroyed/removed) (see Figure 2-17);
- Potential assets visible in aerial imagery but not noted in CAMS, suggesting either:
  - New assets not yet incorporated into the database.
  - Private/illegal assets not known to relevant agencies.
  - Assets that appear in older aerial images, but which may have been buried.
  - Assets simply missed during inspections and walkovers.

- Assets that may extend beyond their noted position in CAMS, but may be partially buried, or in unknown condition (see Figure 2-18).
- Assets in clear state of disrepair (and potentially noted as poor condition) that are not functional.

Each of these limitations will need an appropriate response that manages how they are to be considered within the hazard modelling.

It is likely that the CAMS database will be continuously updated with additional information as assets are identified, constructed, extended or removed. Additional continued condition assessments are also likely that may identify deterioration or restoration of different assets. These updates could be incorporated into future revisions of erosion hazard modelling.

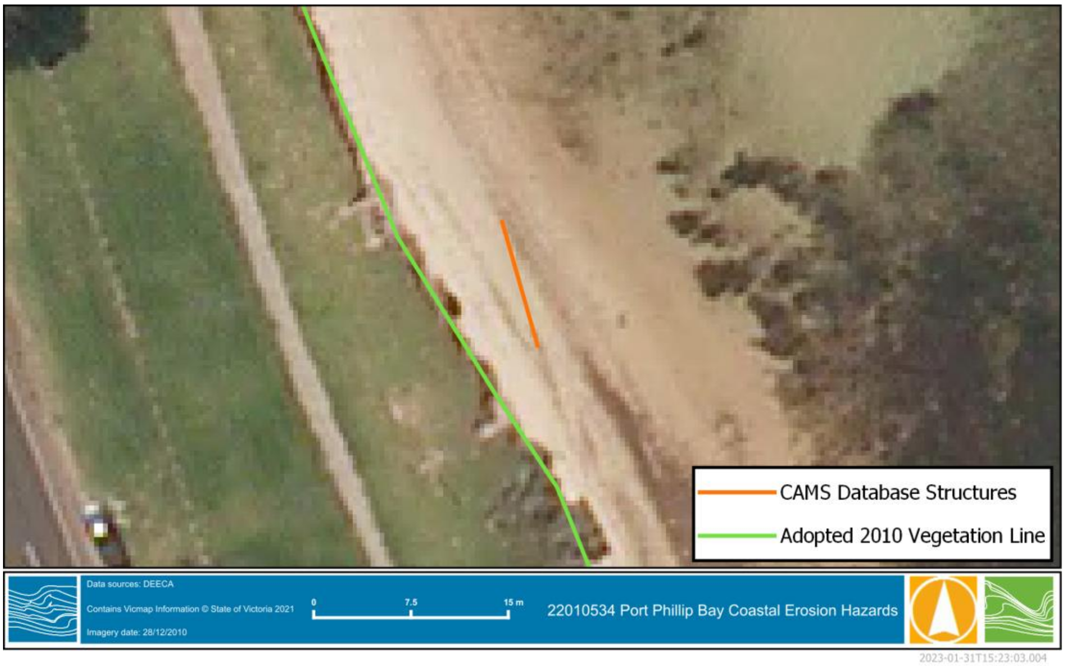


Figure 2-17 CAMS structure that cannot be identified in aerial imagery

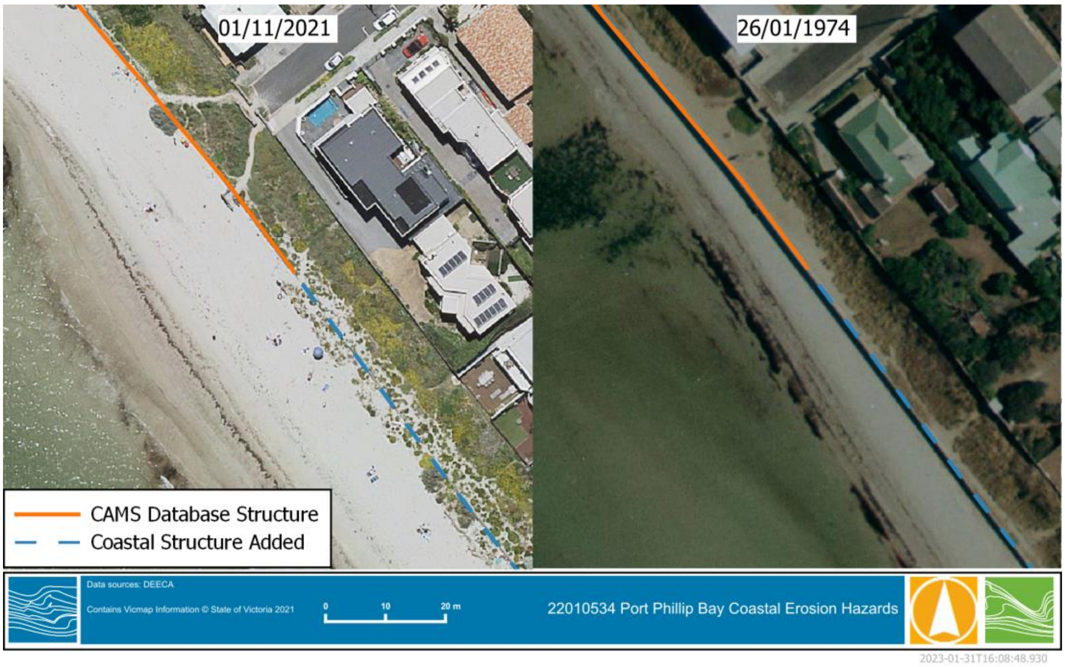


Figure 2-18 Structure that may be buried and is not completely mapped by CAMS database (two years shown to observe historical exposed seawall extent)

2.8 Elevation Data

Quality topographic and bathymetric elevation data is fundamental to modelling of coastal erosion. The height of the primary dune or equivalent coastal scarp, as well as the beach slope are all indicative of the total sediment 'buffer' to erosive effects. Analysis of the nearshore beach profile from reliable bathymetric datasets can also provide an indication of the cross-shore sediment transport patterns

The primary source of coastal elevation data is from the FutureCoasts coastal LiDAR DEM dataset captured between 2007 and 2009 (referred to as the 2010 VCDEM). This dataset consists of topographic data at 1m resolution (vertical accuracy ±100mm, horizontal accuracy ±350mm) and bathymetric data at 2.5m resolution (vertical accuracy ±500mm, horizontal accuracy ±3170mm). The LiDAR data is limited in some locations by the presence of suspended sediment plumes in the nearshore areas, that do not allow the seabed elevation to be captured.

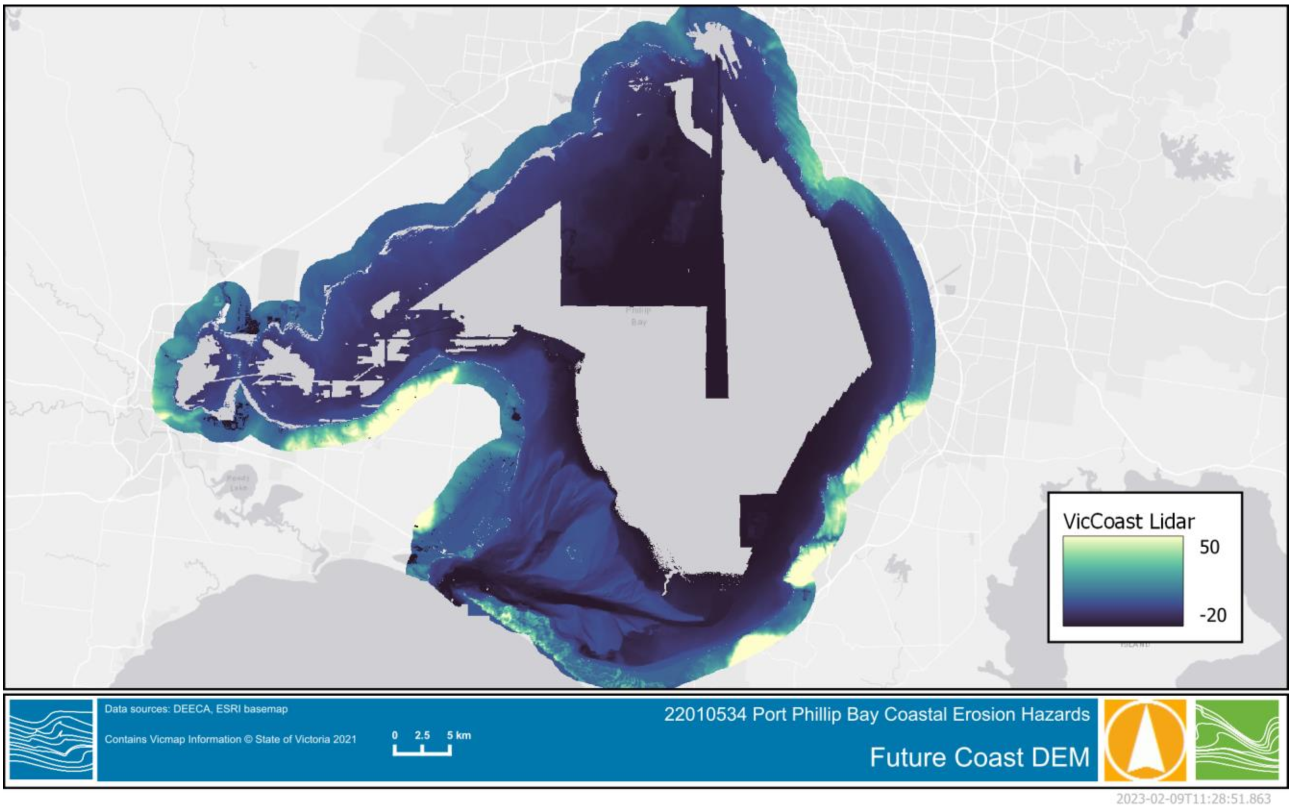


Figure 2-19 FutureCoasts DEM (2010 VCDEM) in PPB

Subsequent datasets have been merged into this primary dataset, including multibeam bathymetry, single-beam bathymetry, shuttle radar topography (SRTM) and other LiDAR sources to create a constant gridded 10m coastal DEM with no gaps and a gridded 2.5m DEM (2017 VCDEM) with some gaps in nearshore areas as described above.

The VCDEM 2017 is the most complete dataset available for usage in the PPBCEHA, given the availability of a complete continuous dataset with no gaps. The majority of the nearshore coastal information dates from pre-2010 however, and it therefore does not include any major coastal changes since this time. The more-recent data incorporated into this DEM largely occur in the centre of PPB in deeper waters, or where gaps occurred in the 2010 VCDEM.

2.9 Coastal sediment particle size

Sediment grain size data is a key parameter for modelling shoreline response to coastal processes. Additionally, sediment size is indicative of the material types in different areas (sand, silt, clay, gravel, etc.).

CSIRO (McInnes et al., 2022) provides a summary of existing sediment D50 (median grain size) around Port Phillip Bay. Additional sediment size data was collected for the PPBCHA in 2019 at a number of locations around PPB. This dataset includes summary of the D50, as well as the D10 and D90 grain size quantiles. The spatial distribution of this data is shown in Figure 2-20. The majority of data has been collected on the eastern shoreline of PPB. A wide grade of sand sizes is observed throughout the study area (D50 0.1mm to 1.8mm). The pattern loosely follows a trend towards finer sediments in shorelines with lower exposure to waves and currents. However, beach renourishment activities may have modified this in certain locations. Areas with recent beach nourishment may typically show courser sediment fractions placed than would naturally be mobilised onto that beach, given that finer fractions in such areas are prone to further erosion and dispersal.

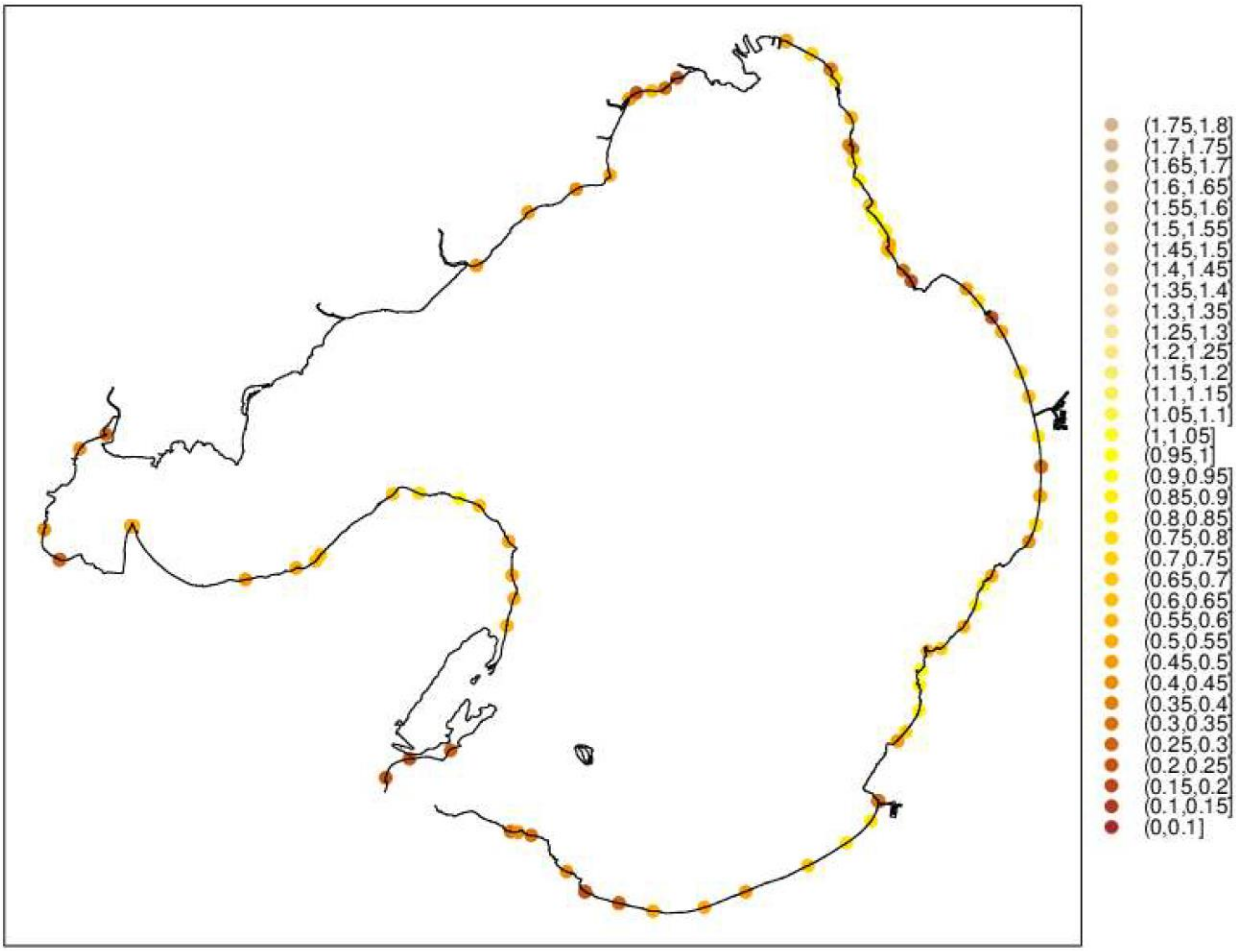


Figure 2-20 2019 PPBCHA D50 sediment size data (after McInnes et al., 2022)

Additionally, the University of Melbourne (Jiang, 2017) have a collection of grainsize information from around PPB that has been made available for the PPBCEHA. These data include various samples within the same beach in the swash zone, at the high tide mark and in the foredune. It shows a similar pattern to the CSIRO dataset. Both datasets have no data between Point Wilson and the Werribee River (most of the coast comprised of the Western Treatment Plant). It is understood that Melbourne Water are conducting an additional sediment sampling program for this coastline. This data will not be available for the PPBCEHA, but will be available for updated erosion studies, including studies specific to the Western Treatment Plant.

There is also a limited set of data in more sheltered regions of PPB such as Corio Bay and Swan Bay. This is not expected to limit the PPBCEHA, as the main need for sediment grainsize data is for storm erosion modelling. In these sheltered bays the storm component of erosion modelling is more likely to be limited by the low-energy wave climate than any changes in sediment size.

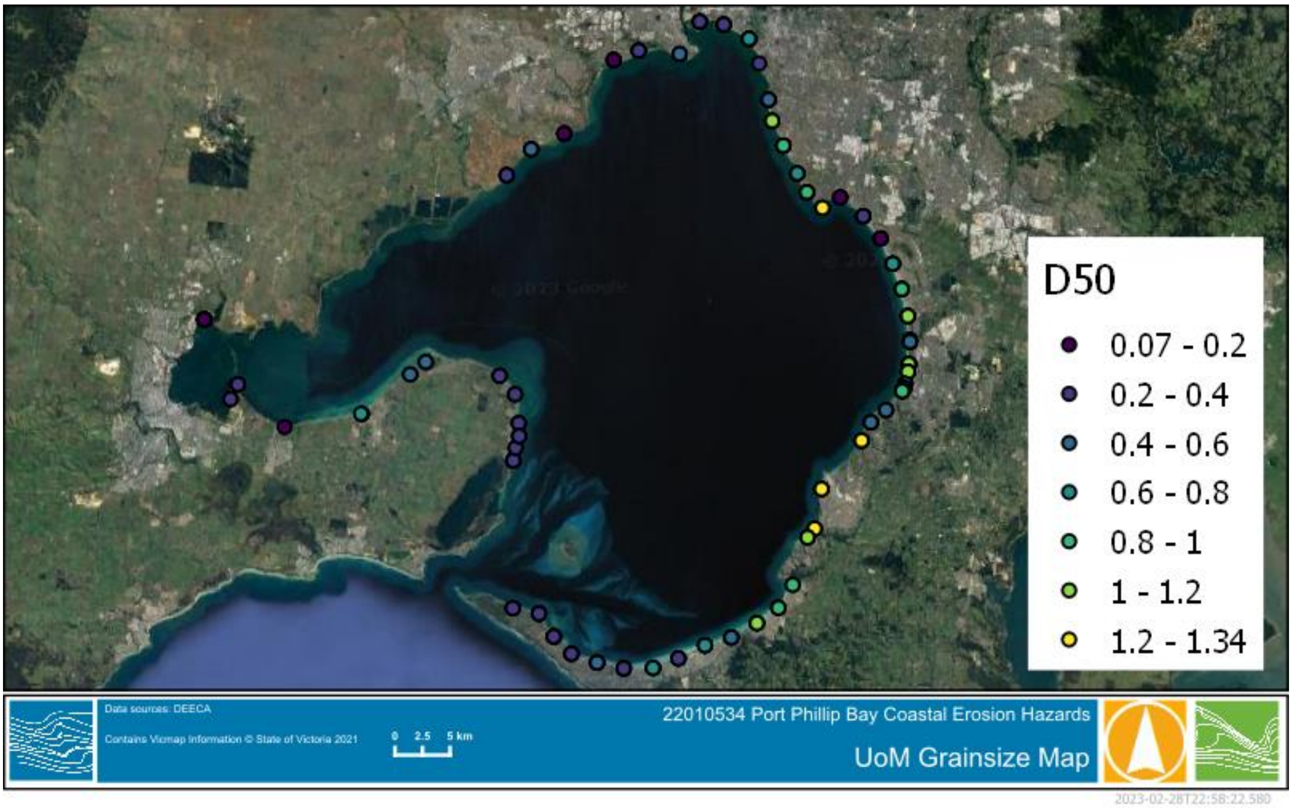


Figure 2-21 UoM Sediment Grainsize Data

2.10 Beach Renourishment Activity

Numerous beach renourishment campaigns have occurred around PPB both historically and recently. Cardno (2017) provided a summary of several known nourishment campaigns, with approximate volumes, sources and sediment sizes. This dataset has been updated and corrected by DELWP as summarised by CSIRO (McInnes et al. 2022), with the most recent recorded nourishment campaign being Rosebud East in February 2020 (flagged as potentially erroneous). The oldest recorded nourishment campaign was at Rye in June 1975.

Table 2-5 Summary of historical beach nourishment works (after McInnes et al., 2022)

Location	Completion Date	Length (km)	Volume in tonnes or (m3)*	Source	Nourishment Sand Size (mm)
Altona	Jun-82	0.3	(11,4000)	-	1.3-1.95
Altona	1989	-	(16,000)	-	1.3-1.95
Altona South	1990	-	(4,500)	-	1.3-1.95
Altona	2010	1	41,000	Gippsland Premium Quarries	Coarse
Altona	**2018**	**0.94**	**17,300**	**Quarried sand**	**Coarse**
Aspendale	Aug-79	2.8	(150,000)	-	1.01
Aspendale North	**2009**	**0.35**	**16,000**	**Gippsland Quarries**	**Coarse**
Blairgowrie	Jun-84	0.9	(33,000)	-	0.42
Blairgowrie	**2013**	**0.35**	**5,000**	**Relocated from spit near harbour**	**Fine/medium**
Brighton	**2014**	**0.35**	**25,000**	**Sandbars off foreshore**	**Medium**
Brighton - New St	Aug-87	1.1	(115,000)	-	0.7-0.94
Brighton - Park St	Jun-84	0.5	(40,000)	-	0.8
Carrum	**2017**	**0.3**	**5,000**	**Mouth of Patterson River**	**Fine**
Clifton Springs	2010	0.3	15,000	Burdetts, Langwarrin	Coarse
Clifton Springs	2014	0.3	12,8000	Quarry	Coarse
Dromana	**Nov 2014**	**0.28km east of Anthony's Nose, 0.38km west of pier**	**15,000**	**Quarry**	**coarse**
Elwood	Aug-83	0.8	(34,000)	-	0.2-0.7
Elwood	2011	0.8	36,000	Gippsland Premium Quarries	Coarse
Frankston	2014	0.7	15,000	Burdetts, Langwarrin	Coarse

Geelong (Rippleside)	Jun-84	0.5	(4,000)	-	0.23
Geelong (St Helens)	Jun-84	-	(3,000)	-	0.23
Geelong (Eastern Beach)	1984	0.4	(3,000)	-	0.23-1.1
Geelong (Eastern Beach)	1990	0.4	(15,000)	-	0.23-1.1
Hampton	1997	0.9	(156,000)	-	0.8
Hampton	**2018**	**0.8**	**22,000**	**Birdons near Sandringham Harbour**	**Fine/medium**
Mentone	Aug-78	1.8	(127,000)	-	-
Mentone	2007	0.8	15,000	Relocated from Mordialloc	medium
Mentone	**Aug 2012**		**15,000**	**Relocated from Mordialloc**	**coarse**
Middle Park	Aug-76	0.9	(120,000+)	-	0.25-0.33
Middle Park	2009	0.7	80,000	Offshore, dredged	mixture
North Aspendale	2009	0.35	16,000	Gippsland Quarries	coarse
North Aspendale	Aug-2012	0.4	10,000	Quarry	coarse
Mount Martha North	**2010**	**0.5**			
Parkdale	Aug-81	1.1	(65,000)	-	1.4
Parkdale / Mentone	2012	-	(15,000)	Relocated	-
Parkdale	**June 2019**	**0.2**	**8,000**	**Trucking sand from Mordialloc Beach**	**Coarse**
Portarlington	Nov-86	1.4	(35,300)	-	0.7
Portarlington	2010	0.4	15,000	Burdetts, Langwarrin	Coarse
Portarlington	**2012**	**0.4**	**16,000**	**Quarried**	**coarse**
Rosebud (west)	Aug-82	1	(27,000)		-
Rosebud	Jun-85	1.5	-	-	-
Rosebud	2010	0.16	3,000	Gippsland Premium Quarries	Coarse
Rosebud†	2014	-	2,064	Relocated from Rosebud foreshore	Medium
Rosebud West	**Dec 2019**	**0.3**	**9,400**	**Sandbars off foreshore**	**Medium**
Rosebud East†	**Feb 2020**	**0.35**	**13,300**	**Sandbars off foreshore**	**Medium**
Rye	Jun-75	1.8	(15,000)	-	0.73
Rye	1999	0.3	(10,000)	-	0.3
Rye	2010	0.14	3,000	Gippsland Premium Quarries	Coarse
Rye	2014	0.2	3,000	Relocated from Rye foreshore	Medium
Sandridge	1999	0.545	(76,000)		0.88

Sandringham	Aug-86	0.4	-	-	
Sandringham (Edward St)	1993	0.6	(16,000)	-	1.0+
Sandringham	2009	0.5	-	-	-
Sandringham	**2018**	**0.2**	**1,000**	**Birdons near Sandringham Harbour**	**Fine/ medium**
Sorrento	Jun-80	0.8	(40,000)	-	0.2
Sorrento East	**2014**	**0.4**	**9,000**	**Sandbars off foreshore**	**Fine/ Medium**
Sorrento West	2016	0.22	7,000	Sandbars off foreshore	Fine/medium
St Kilda	Jun-82	0.7	(70,000)	-	0.16-1.6
St Kilda	1984	0.7	(2800)	-	0.16-1.6
St Leonards	**2014**	**0.3**	**4,250**	**Burdetts, Langwarrin**	**Coarse**
Watkins Bay	1986				
West Rosebud	Aug-82	1.4	-	-	-
Williamstown	Jun-82	0.6	(29,000)	-	1.25

* Volumes in m^3 from Cardno (2017b)

† May be erroneous

Several subsequent major nourishment campaigns are known to have occurred since this dataset was compiled, notably Middle Park Beach, Sandringham, St Leonards, Mount Martha, Dromana and McCrae. This is not an exhaustive list as there are likely to have been numerous minor nourishment activities in locations to either mitigate short-term erosion effects, or as opportunistic 'beneficial reuse' of dredged sediments (such as placement of dredged material from the Altona Harbour on the adjacent beach). These campaigns range from small volumes (order 1,000 m^3) to larger nourishment campaigns (order 40,000+ m^3).

Furthermore, it is likely that nourishment occurred prior to the earliest recorded campaign in the dataset. Similarly, there are major nourishment-like campaigns that are known to occur regularly but have not been recorded in terms of their dates and sediment volumes. These are likely to include:

- Altona Harbour (as mentioned above)
- Queenscliff Harbour/Marina (significant for sand transport to Swan Island)
- Kananook Creek dredging
- A number of marinas and boat harbours that regularly dredge for navigational purposes

It is noted that while the above uses are all generally dredging for other reasons, best-practice dredging works considers that if the dredge material is clean marine sand, then beneficial reuse and placement on the beach is the preferred disposal option.

As all of the above works have the potential to alter the sediment transport processes around PPB, they are important factors to consider. Notably, any other records of beach movements (such as survey, profiles or aerial imagery analysis) may be skewed by beach nourishment works. There are two scenarios that may occur and bias any analysis:

1. Analysis shows an accreting beach; however a large nourishment campaign may have influenced this.
2. Analysis shows a stable beach, however ongoing nourishment may be balancing an otherwise eroding beach.

The second of these is harder to detect without a complete understanding of the historical nourishment/dredge placement record.

Given that complete inclusion of beach nourishment data is not available, and can therefore not be excluded from any shoreline trend, the erosion hazard methodology must account for the potential uncertainty introduced by these works.

3 DATA GAPS AND LIMITATIONS

3.1 Data Gaps

No significant data gaps have been identified that preclude a useful coastal erosion hazards study from being undertaken. There are several data gaps that would add value and increase the accuracy of future studies, such as:

- A complete dataset of nourishment and dredging volumes
- A long-term set of wave observations
- Regular beach surveys (elevation) at key locations for a long-term record including:
  - Combined terrestrial and nearshore bathymetric profile surveys at repeated locations
  - Shoreline monitoring cameras
- Updated coastal bathymetry, including any recent changes

It is noted that several of these data gaps are being rectified through the VCMP program and will become available for future updated coastal hazards studies.

These data gaps influence the methodologies available for reliable coastal erosion hazard modelling and may add some limitations to the analysis of the outputs. However, the data gaps do not undermine the overall usefulness of a Bay-scale erosion hazards study. The PPBCEHA methodology has been structured as a modular approach, whereby individual components can be updated as additional datasets become available to inform them, without repeating the entirety of the modelling exercise.

3.2 Limitations

As discussed above, data gaps and the quality of the existing datasets provide some minor limitations to the understanding of the coastal erosion hazards.

A key limitation is that where current coastal interventions have occurred (groyne/seawall construction, beach renourishment), it may be impossible to differentiate the impact of these from natural processes at certain locations due to the limited available data (such as nourishment timing and volume, date of groyne construction, etc.). As such, the study will either need to infer the underlying natural trends, or assume continued ongoing intervention.

Another key limitation is the availability of historical wave climate data to inform deterministic modelling of waves and erosion processes. Recent VCMP data suggests that the existing PPBCHA wave data may be underpredicting the extreme wave conditions. Therefore, modelling of storm erosion, or longshore sediment transport using numerical or parametric models that utilise the wave inputs can also be considered uncertain. For the sake of consistency with the wider PPBCHA, the erosion hazard modelling should favour using this wave dataset. However, sensitivity analysis should be conducted to note the likely uncertainty or bias introduced. Further discussion and evaluation of this dataset in the context of the erosion modelling can be found in the PPBCEHA methodology report.

It is likely that local-scale studies, focussing on adaptation of specific beaches and assets may need to address some of the data limitations. An example may be an adaptation plan for a beach that has been historically nourished, where there may be uncertainty around the timing and volumes of this nourishment. The understanding of the underlying natural trend will be fundamental. Overall, such limitations are not considered to be prohibitive over the wider-scale PPBCHA. The adopted methodology will be influenced by the availability of data, and any associated limitations will need to be identified and communicated as part of the final delivery.

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