Erosion Hazard Summary Report

Port Phillip Bay Coastal Erosion Hazards

Department of Energy, Environment and Climate Action

30 April 2023

Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
01	Draft	EAL	TJD	01/05/2023
02	Report	EAL	TJD	29/05/2023

Project Details

Project Name	Port Phillip Bay Coastal Erosion Hazards
Client	Department of Energy, Environment and Climate Action
Client Project Manager	Polly Matthews
Water Technology Project Manager	Toby Devlin
Water Technology Project Director	Elise Lawry
Authors	Toby Devlin
Document Number	22010534_R03_V02a_FinalReport.docx

15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800
Fax (03) 9558 9365
ACN 093 377 283
ABN 60 093 377 283

Quality ISO 9001 SAI GLOBAL
Environment ISO 14001 SAI GLOBAL
OHS ISO 45001 SAI GLOBAL

CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

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.
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 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.
Miocene	The geological epoch from 23M to 5M years ago. During this time, global climate warmed, and there was an expansion of grasslands and kelp forests.
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.
Pliocene	The geological epoch from ~5M to 2.6M years before present. Noted for a global cooling and drying, and the formation of large polar ice caps.
Pleistocene	The geological epoch 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 tide 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.
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 (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 several 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 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 instability 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 is working closely with the Association of Bayside Municipalities (ABM) which includes the 10 local governments surrounding Port Phillip Bay, Parks Victoria, Melbourne Water, Corangamite Catchment Management Authority and Traditional Owners to understand the impacts of coastal change within PPB.

The inundation and groundwater hazard components (McInnes et al., 2022) have been independently completed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and DEECA. Water Technology has 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 PPBCEHA has been completed based on the following principles:

- It is based on the current scientific understanding and available data
- It applies industry best-practice approaches
- It uses conservative (risk averse) assumptions where assumptions are required, following the precautionary principle.
- As it is understood that updates will be required in future, it adopts a modular approach, that can incorporate additional understanding, data, or methodologies as these become available.

The PPBCEHA considers regional influences over the entirety of PPB, from Point Lonsdale on the Bellarine Peninsula clockwise to Point Nepean on the Mornington Peninsula as shown in Figure 1-1. Given the regional-scale, in many instances, the outputs may be used to inform detailed local-scale assessments.

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

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 completed by CSIRO and DEECA as noted above. 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.

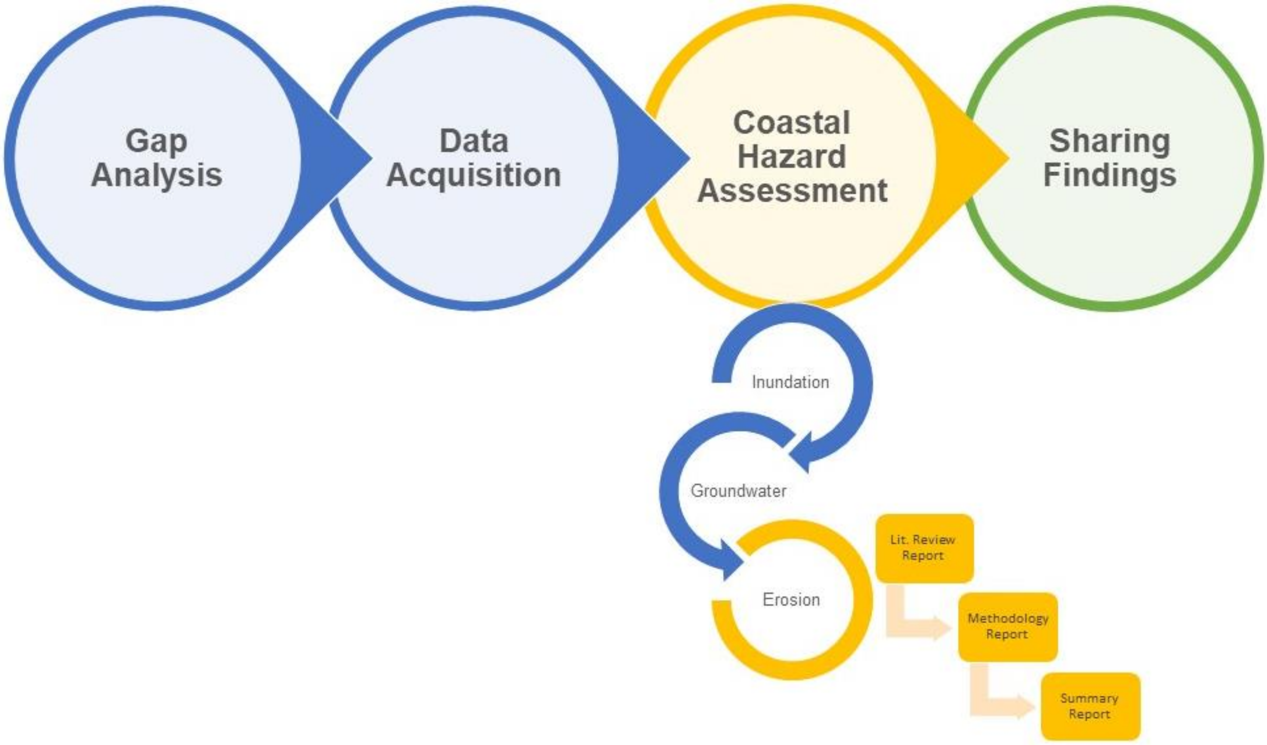

Figure 1-2 PPBCHA Stages and Components

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 PORT PHILLIP BAY DESCRIPTION

2.1 Overview

As shown in Figure 1-1, Port Phillip Bay is a large tidal bay with 300km of coastline. It ~50km wide at its widest point, but with a narrow entrance only ~2.5km across.

The Port Phillip region has undergone significant geological changes throughout history. During the late Miocene and early Pliocene periods (~5 Ma), the embayment was much larger and bounded by elevated ranges visible from the existing shoreline: The Dandenong, You Yang, and Mornington Peninsula ranges. River sediments from the eastern ranges created the Beaumaris and Sandringham sandstone outcrops (Bird, 2011).

The Pleistocene epoch (1.8Ma to 11,700 years BP) saw global climatic fluctuation, including several glacial and interglacial phases. During interglacial phases, water levels were higher, and the bay was inundated. During these periods sands were deposited in the Bay and were blown by north-westerly winds across the dry coastal plain to form sand ridges. The south-eastern area's coastal dune, running from Aspendale to Frankston, is evidence of this Aeolian formation. Such periods also included the formation of the sand shoals of the Great Sands, and the growth of the sand spit along the Nepean Peninsula. Both processes have served to constrict the flow into and out of the Bay. During the last glacial period, sea levels fell, and the rivers of the region formed a large river cutting through dune ridges, creating the existing "Rip" at the entrance to Port Phillip Bay (Bird, 2011).

In the Holocene epoch (11,700 years ago to present), sea levels rose and flooded the region again, creating a shoreline close to the current configuration of Port Phillip Bay. About 4,000 years ago, during the mid-Holocene, temperatures increased, and sea levels rose 1-2 meters above the existing levels, creating shore platforms before falling back to current levels (Bird, 2011). It has been claimed that a Holocene closure of the Bay caused it to dry out as recently as 1000 years ago, before a breakthrough of the barrier reflooded it (Holdgate, et al., 2011). Therefore, it is possible that the present shoreline is relatively young in geological terms, with sections likely still responding to these changes.

2.2 Tides and Water Levels

2.2.1 Tides

Tides on the open coast of Victoria within Bass Strait are semi-diurnal (two high, and two low tides per day). Tides enter PPB through Port Phillip Heads (the Heads) and move up the bay, with a tidal range of 1.9 m at the Heads reduced to 1.1 m and 1.2 m at Williamstown and Geelong respectively. Tidal currents generally have little effect on beaches directly. However, tidal currents can indirectly influence erosion processes in several ways:

- Migration of tidal channels shoreward creates deeper water nearer to shore, allowing for greater wave penetration.
- Tidal currents may also deposit sand on the shoreface, reducing nearshore depths and therefore the ability of larger waves to reach the shore, while also providing a surplus of sand to a given sediment compartment.
- Waves at the entrance are refracted by the changes in depth associated with tidal and shipping channels. Migration, deepening or changes in the alignment of these may change the wave refraction processes, and drastically alter the wave exposure of certain beaches.

Table 2-1 presents tidal planes for key locations in PPB.

Table 2-1 Tidal Planes in PPB (from VIC Tides 2023, Ports Victoria)

Tidal Plane	Port Phillip Heads (Point Lonsdale) (mAHD)	Williamstown (mAHD)	Geelong (mAHD)
HAT	0.95	0.59	0.66
MHHW	0.62	0.54	0.56
MLLW	-0.53	-0.26	-0.33
LAT	-0.95	-0.48	-0.52

2.2.2 Extreme Water Levels

Extreme water levels are an increase in water levels above the normal (astronomical) tide, largely driven by storm action including low air pressure (the inverse barometer effect), wind setup and Coriolis deflection of east to west currents, referred to as storm tide.

McInnes et al. (2022) conducted extreme water level modelling of Port Phillip Bay as part of the PPBCHA, including incorporation of these effects. Figure 2-3 shows the resulting 95th Percentile 1% AEP storm tide levels without the inclusion of recent sea level rise (approximately 2010 conditions).

The 1% AEP represents conditions that have an expected 1% chance of being exceeded in any given year. Given that the PPBCHA has adopted a probabilistic approach, the 95th percentile of these results represents a 95% confidence that the 1% AEP level is at or below this level.

The results demonstrate the limited variation of extreme water levels within the bay, beyond the area immediately near the heads.

2.3 Waves

In PPB, waves are produced by both ocean swell and local wind action. Ocean swell is generated by storms in the Southern Ocean and enter Port Phillip Bay from the south-west with wave periods of 12-16 seconds. These ocean swells do not penetrate very far due to the narrow entrance and the sand shoals of the Great Sands though some refract on change in depth of the maintained shipping channel. The area immediately impacted by ocean swell waves is Point Lonsdale to Queenscliff on the western side, and Point Nepean to Portsea on the eastern side.

The remainder of PPB is sheltered from such conditions, and only experiences locally-generated wind-waves that form across the bay. The pattern of wind is typified by westerlies year-round, with northerlies in winter, and southerlies in summer. Easterly winds represent ~5% of the conditions experienced and are usually mild. Wind roses at Fawkner Beacon are presented in Figure 2-1 and Figure 2-2 for summer and winter respectively. Fawkner Beacon is a wind station over water in the northern part of PPB.

Along with the wind directions, the alignment of the coast, and relative fetches (the distance over which winds can blow and generate waves) contribute to the wave influence on the shoreline. The stretch of coast from Frankston to Mordialloc is the most similar to an open coast beach, with a 50km fetch for westerly winds generating waves with periods of 3-6 seconds. This coastline has approximately equal fetches to the north-west and south-west (~35km). North of this area, the coast is more exposed to southerly conditions, driving a northward net sediment transport. To the south, the impact of northerly conditions should be greater, however the wide shallow sand flats limit the ability of waves to reach the shore.

Overall, much of PPB's sandy shorelines experience seasonal rotations, with a net transport rate dependant on the relative exposure to northerlies, southerlies, and westerlies (Bird, 2011). Due to the relative scarcity of easterly winds, shorelines that would otherwise be mostly exposed to large fetches from the east, or south-east (such as Point Wilson to the Werribee River, and some beaches on the Bellarine Peninsula) are generally low energy. However, inter-annual variation in the wind climate can result in years with a larger proportion of easterly events (for example 2021 and 2022), which can cause more notable changes to these normally settled beaches.

McInnes et al. (2022) also provided extreme wave analysis from modelled wave conditions in PPB for the PPBCHA. As discussed in the Literature Review R01 (Water Technology, 2023a), based on wave buoy observations since 2020, these results may underpredict the extreme waves. However, the results are likely to accurately represent the relative distribution of extreme waves around the bay.

Figure 2-4 presents the 95th percentile 1% AEP wave conditions around PPB at the 8m water depth contour without sea level rise (approximately 2010 conditions) after McInnes et al. (2022).

The 1% AEP represents conditions that have an expected 1% chance of being exceeded in any given year. Given that the PPBCHA has adopted a probabilistic approach, the 95th percentile of these results represents that the model predicts a 95% likelihood that the 1% AEP wave height is equal to or less than this value.

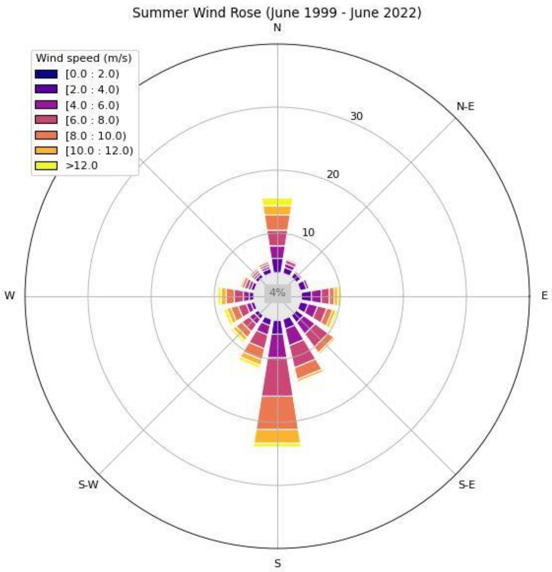

Figure 2-1 PPB Summer Wind Rose (Fawkner Beacon)

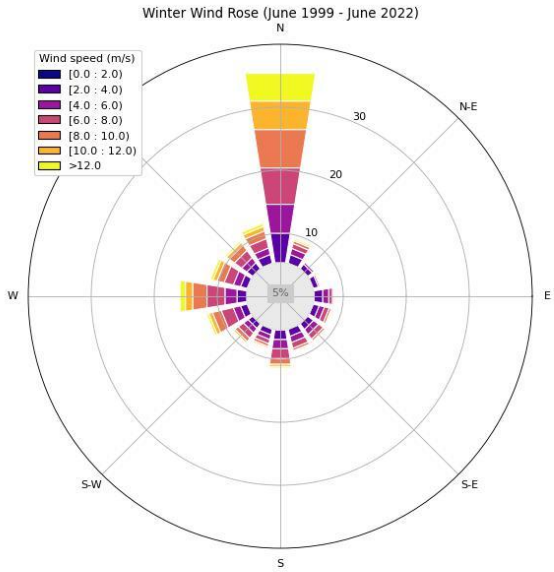

Figure 2-2 PPB Winter Wind Rose (Fawkner Beacon)

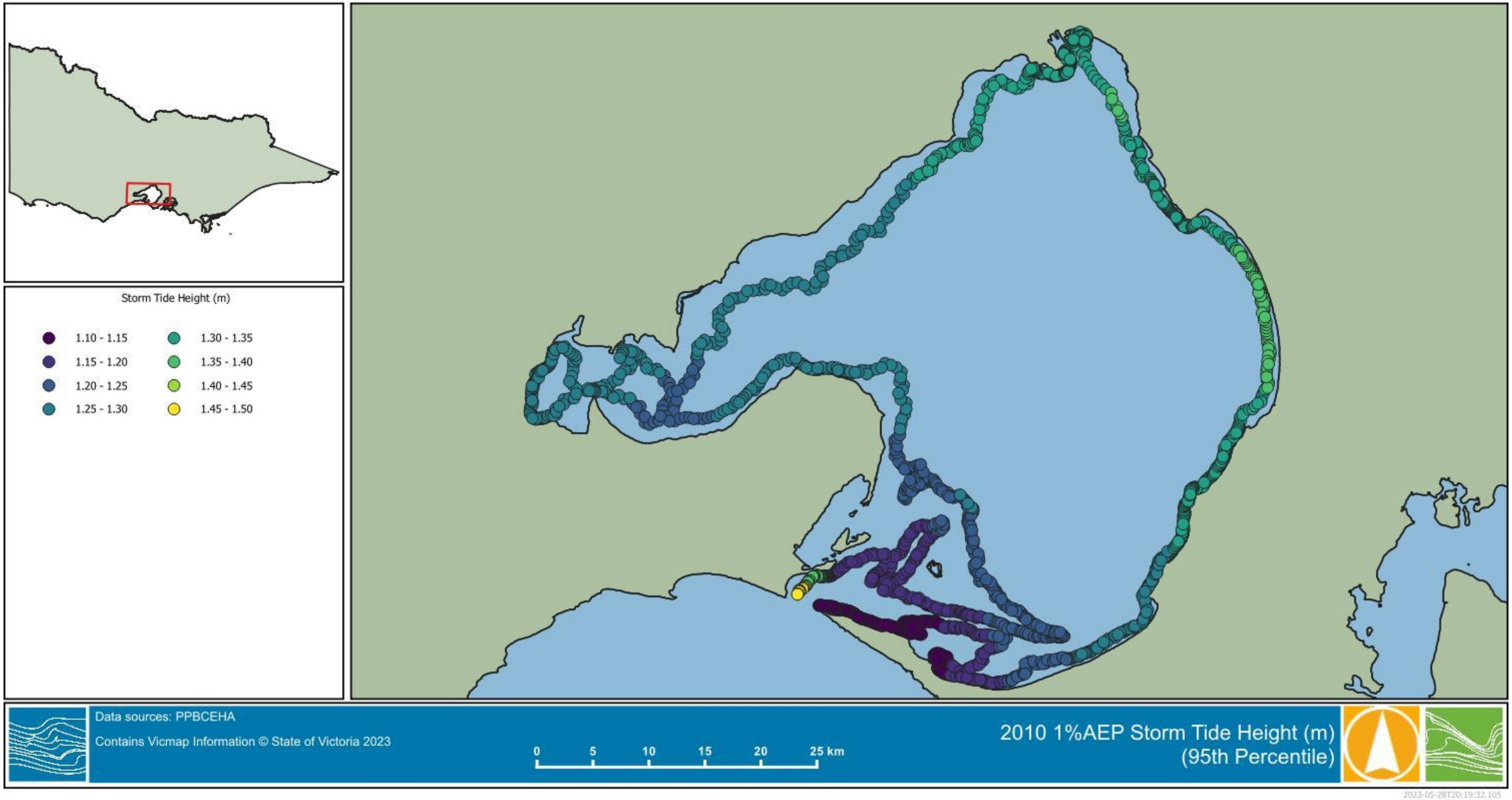

Figure 2-3 PPBCHA 1% AEP Storm Tide Levels

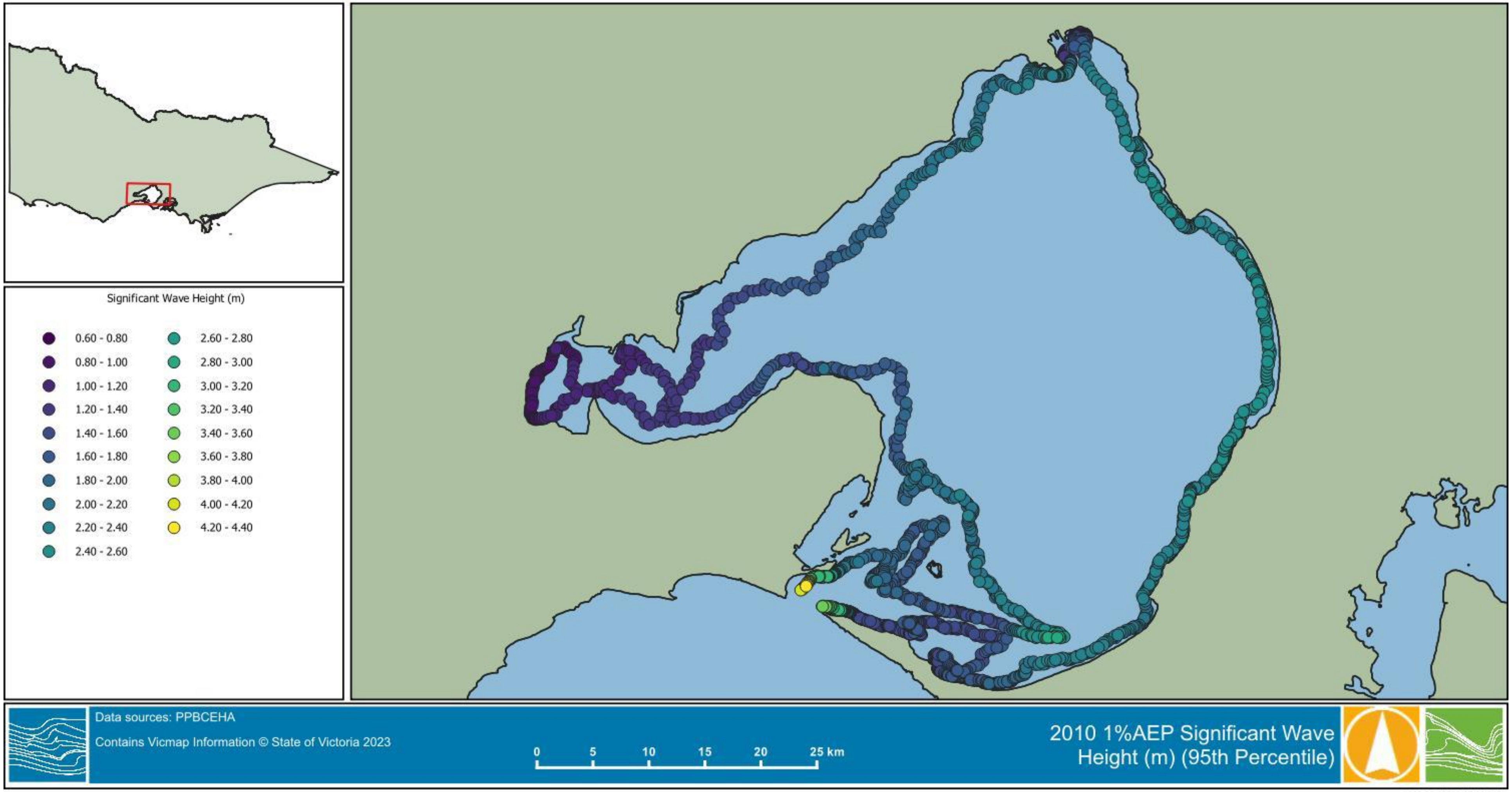

Figure 2-4 PPBCHA 1% AEP Wave Heights

2.4 Shoreline Types

2.4.1 Overview

Port Phillip Bay is highly varied in topography, geology, exposure, and the corresponding erosion processes. The shoreline of Port Phillip Bay has been generalised into a limited number of shoreline types that are representative of the different responses to erosion drivers.

These shoreline types have been informed by the following data sources:

- The national Smartline mapping (Sharples et al., 2009) provides an analysis of the geomorphology of the entire Australian coastline. The inter-tidal and backshore geomorphology fields have been used as the starting point for the shoreline analysis.
- The Coastal Asset Management System (CAMS) database provides the location of engineered shorelines within PPB.
- The available aerial imagery from the Coordinated Imagery Program (CIP) was used to correct the specific start/end points of structures and other shoreline types where clear changes could be observed. Details of the available imagery is included in the Data and Literature Review Report R01 (Water Technology, 2023a).

Based on the above, the shoreline has been divided into five simplified categories that represent the different erosion hazard processes that are likely to occur.

Figure 2-5 presents the different shoreline types spatially, with a percentage breakdown provided in Table 2-2.

Further discussion of each of these types is presented below.

Table 2-2 Breakdown of Shoreline Types in PPB

Shoreline Type	Percentage
Hard Rock	6%
Sandy	47%
Sandy with Rock Behind	5%
Soft Rock	11%
Soft Sediment	2%
Structures (engineered shoreline)	26%

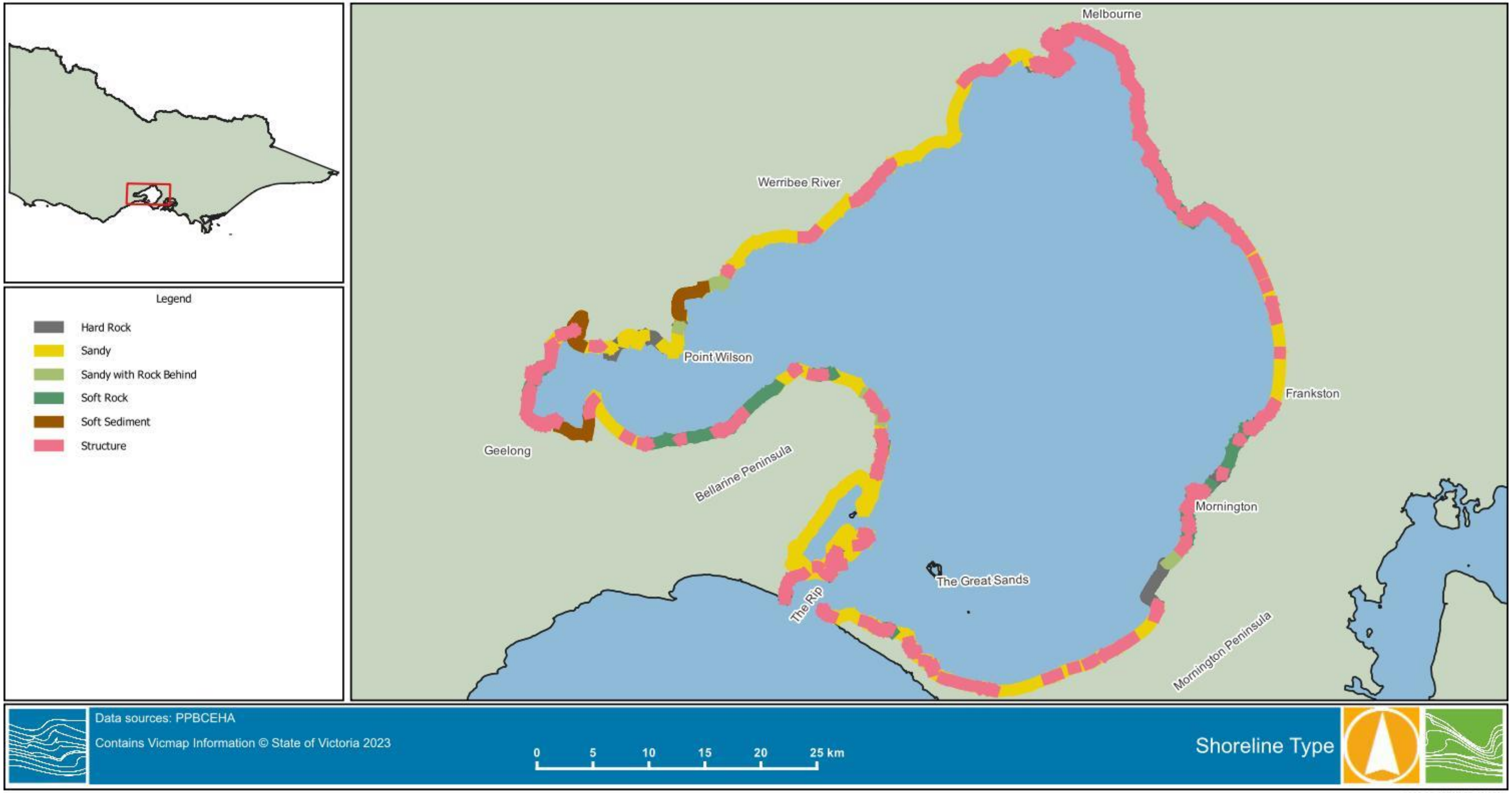

Figure 2-5 Map of Shoreline Types in PPB

2.4.2 Sandy

Sandy shorelines are formed from either the weathering and erosion of terrestrial sediments, or the onshore transport and deposition of marine-derived sediment. Due to the relative coarseness of the sediments, sandy shorelines can be present even where waves and currents are relatively strong.

Sandy beaches vary between net-eroding and net-accreting sections depending on the balance of longshore sediment transport and sand sources/sinks. Additionally, intense short waves breaking on the beach (e.g., during storms) can erode the sand, and draw it offshore. Longer period waves (between storms) can push sand towards the shore, building the beach wider.

In PPB, marine sand entering through the heads is a major additional source of sand, and the origin of most of the beach sand. This marine sand forms the large sand shoals of the Great Sands. The westerly winds, waves and currents have historically redistributed much of this to the eastern side of the Bay, with summer (southerly) and winter (northerly) waves driving sediment transport north and south respectively on a seasonal basis.

The western side of the bay is more varied, with some sandy deposits, particularly on the end of Bellarine Peninsula where the southern sand shoals can spread onto the nearby beaches. Many of the sandy areas on the western shoreline are relatively low energy and have wide sand banks and offshore shoals.

Figure 2-6 shows an example of a relatively exposed sandy shoreline at Seaford. As discussed in Section 2.3, the coast in this area is the closest to an open coast beach that can be found in Port Phillip Bay. The larger westerly fetch, and moderately large north-west and south-west fetches result in larger waves reaching the shore. Shore-parallel sandbars are evident, as is a vegetated primary dune. In nearby areas, the dune system has been heavily developed.

Figure 2-7 presents an example of a sandy beach at Rosebud. This area has a large sub-tidal series of sand bars that provide some sheltering of the shoreline from incoming waves (waves are likely to break in shallow water, dissipating energy). The sandbars are not strictly aligned to the coastline and have many tidal channels between them. Seagrass meadows are also evident in the troughs between the sandbars, suggesting that the sandbars are stable over the time-scale of seagrass growth (weeks to months).

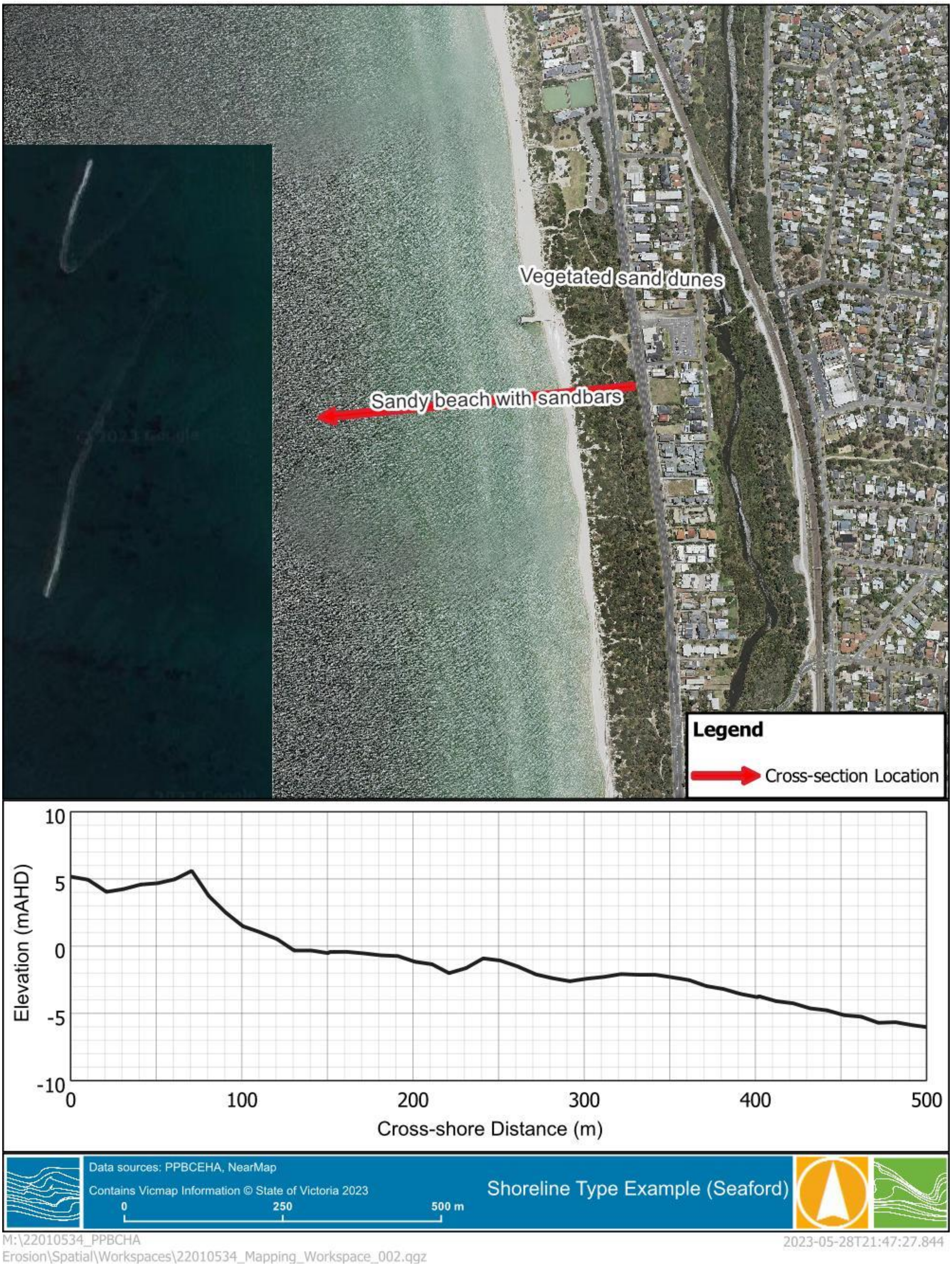

Figure 2-6 Example of Sandy Shoreline with dune (Seaford)

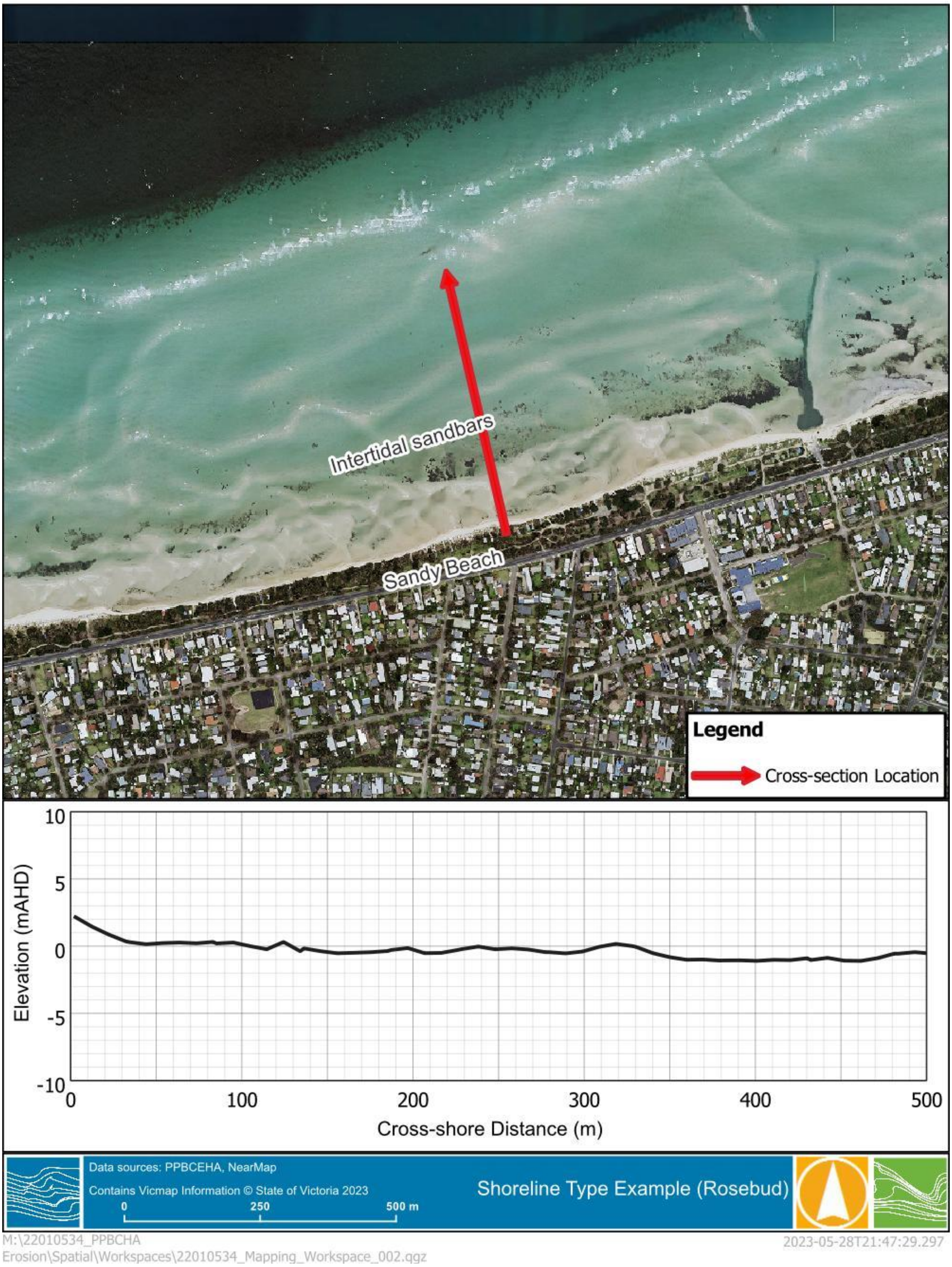

Figure 2-7 Example of sandy shoreline with wide multi-bar shoreface (Rosebud)

2.4.3 Sandy with Rock Behind

Approximately 5% of the PPB coastline consists of sandy beaches that are immediately backed by rock (soft or hard). These areas tend to lie between rocky headlands where sand can accumulate and form a narrow beach. These rocky headlands are often protruding features of the same rocky backshore.

The erosion process in such shorelines will begin as a typical sandy beach response, but transition to a cliff retreat process once the sand is depleted. Cliff retreat rates are likely to be much slower than the sandy shoreline, and as such these areas may have a lower overall erosion hazard than a purely sandy shoreline.

A key uncertainty lies in the location of the transition point. As much of the bedrock may be buried, or vegetated, the transition point cannot be easily determined from inspection of aerial imagery, or even from on-site inspection. Instead, these areas require geotechnical surveys to inform the understanding of the bedrock position.

Figure 2-8 shows an example at Mothers Beach of a sandy beach between two rocky headlands, and a steep rocky backshore behind it. Rocky outcrops are visible in the nearshore, but so too are sandbars.

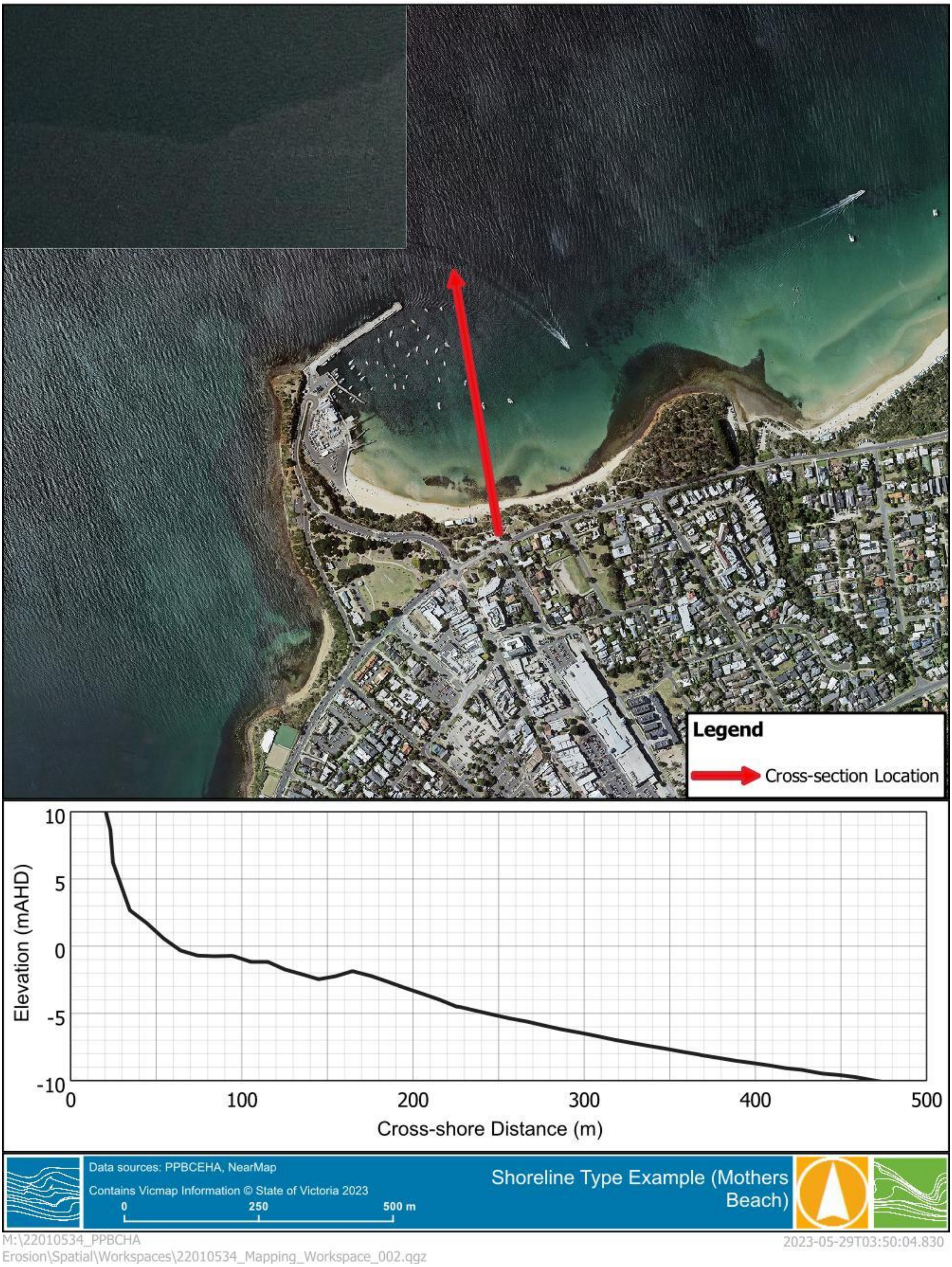

Figure 2-8 Example of Sandy Shoreline with Rocky Backshore (Mothers Beach)

2.4.4 Soft Sediment

Soft sediment shorelines tend to consist of finer materials than sandy shorelines, e.g., silty sands, clays and muds. The origin of these tends to be alluvium or organic material. They are highly vulnerable to erosion, so are usually only present where wave exposure is low.

Within PPB, soft sediment shorelines only occur at the Spit Nature Reserve (Avalon) in the lee of the sandy breached barrier spit, in Stingaree Bay, east of Geelong, and in Limeburners Bay at the mouth of Hovells Creek. However, it is likely that this shoreline type may become more prevalent if ongoing coastal erosion, combined with SLR erode the narrow sandy beaches along much of the western shoreline of PPB.

Soft sediment shorelines tend to be low-lying and relatively sheltered from large wave events. Most of these coastal areas currently include a narrow sandy beach, with some low rocky outcrops. Based on a conservative approach, these low shorelines are likely to become tidally inundated with SLR (McInnes et al, 2022), resulting in shorelines relatively far landward.

Figure 2-9 shows the Spit Nature Reserve shoreline. A sandy barrier spit has been breached in the nearshore, which shelters the shoreline. The cross-section shows that the nearshore is very shallow, but that the backshore is also.

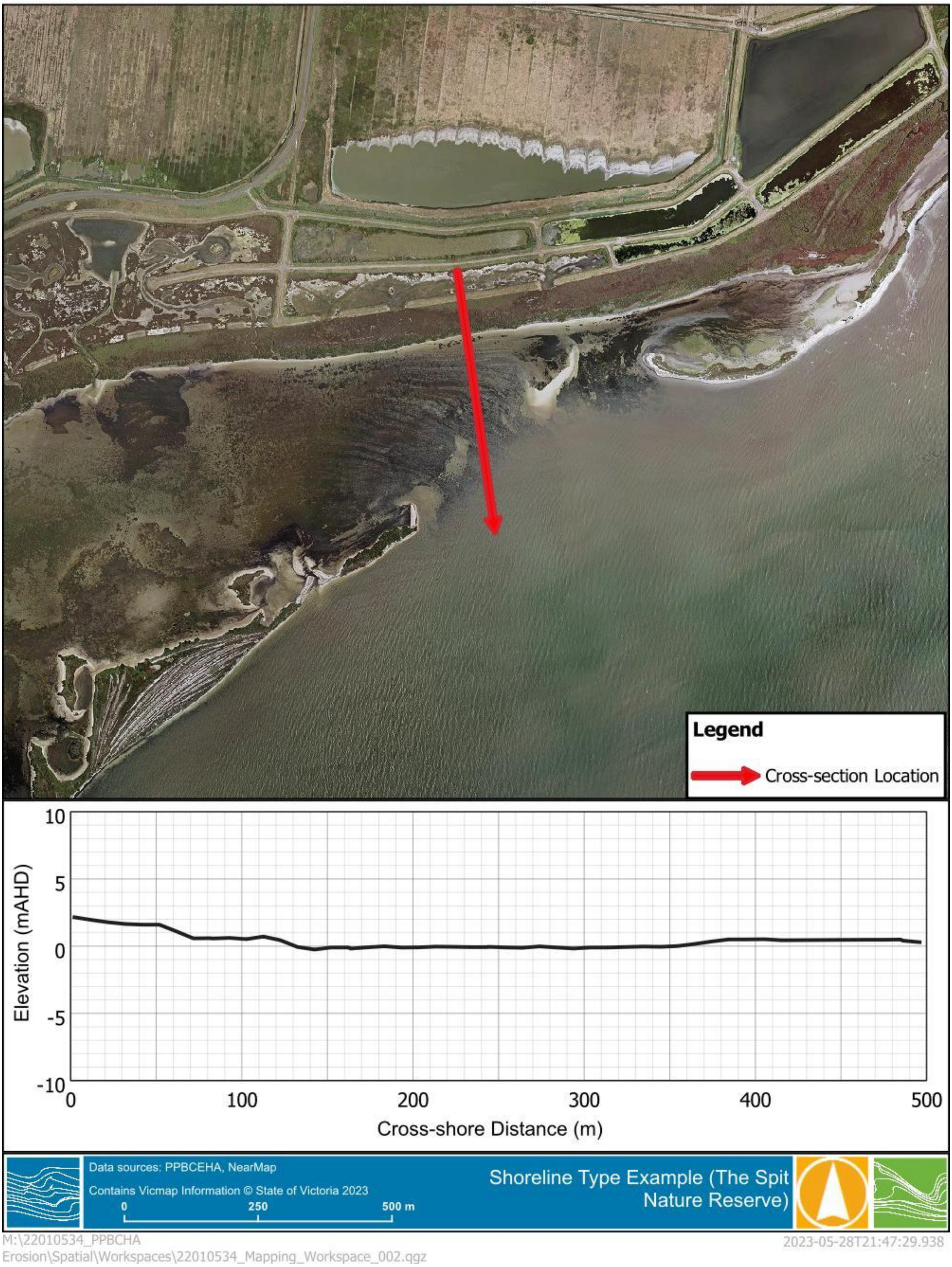

Figure 2-9 Example of Soft sediment shoreline (The Spit Nature Reserve)

2.4.5 Soft Rock Cliffs

Soft rock cliff shorelines consist of cliffs of mudstone, limestone, clay, and weakly-cemented sedimentary rocks. Soft rock cliffs can take several forms:

- 'Active' cliffs, with an exposed and active erosion face. These may experience frequent wave impacts and may include a shore platform, or low tide sandy beach.
- 'Non-active' cliffs. The rocky features are protected from direct wave attack by a narrow beach, high rock platform or outcrop.

Erosion of soft rock cliffs depends on the coastal processes, with active cliffs likely to have a higher rate of erosion than those with a sandy buffer. However, other erosion processes can also be important, such as groundwater pore pressure, vegetation roots, and surface runoff.

Once eroded, there are no short-term mechanisms whereby coastal processes can re-establish the cliff volume. However, erosion of the cliffs (particularly high cliffs) can add a significant volume of sediment to the nearshore, which may form a talus, or small beach, that reduces the further erosion of the cliff.

As such, the overall rate of erosion is relatively low, but net-accretion is unlikely. The only mechanism for accretion is a substantial long-term sediment surplus that causes growth of a beach in front of the cliff. As such, it would represent a change from a soft rock cliff shoreline to a sandy shoreline with rock backing.

In Port Phillip Bay, soft rock cliffs are present around Mount Eliza, and also from Beaumaris to Brighton. Many of these include pocket beaches in front of partially buried rock features, in between exposed cliff headlands.

Figure 2-10 presents an example of a soft rock cliff at Black Rock. A high, steep cliff drops down to the water line at the exposed cliff headland. North and south of this there is a sandy beach visible, with a steep backshore indicating buried soft rock.

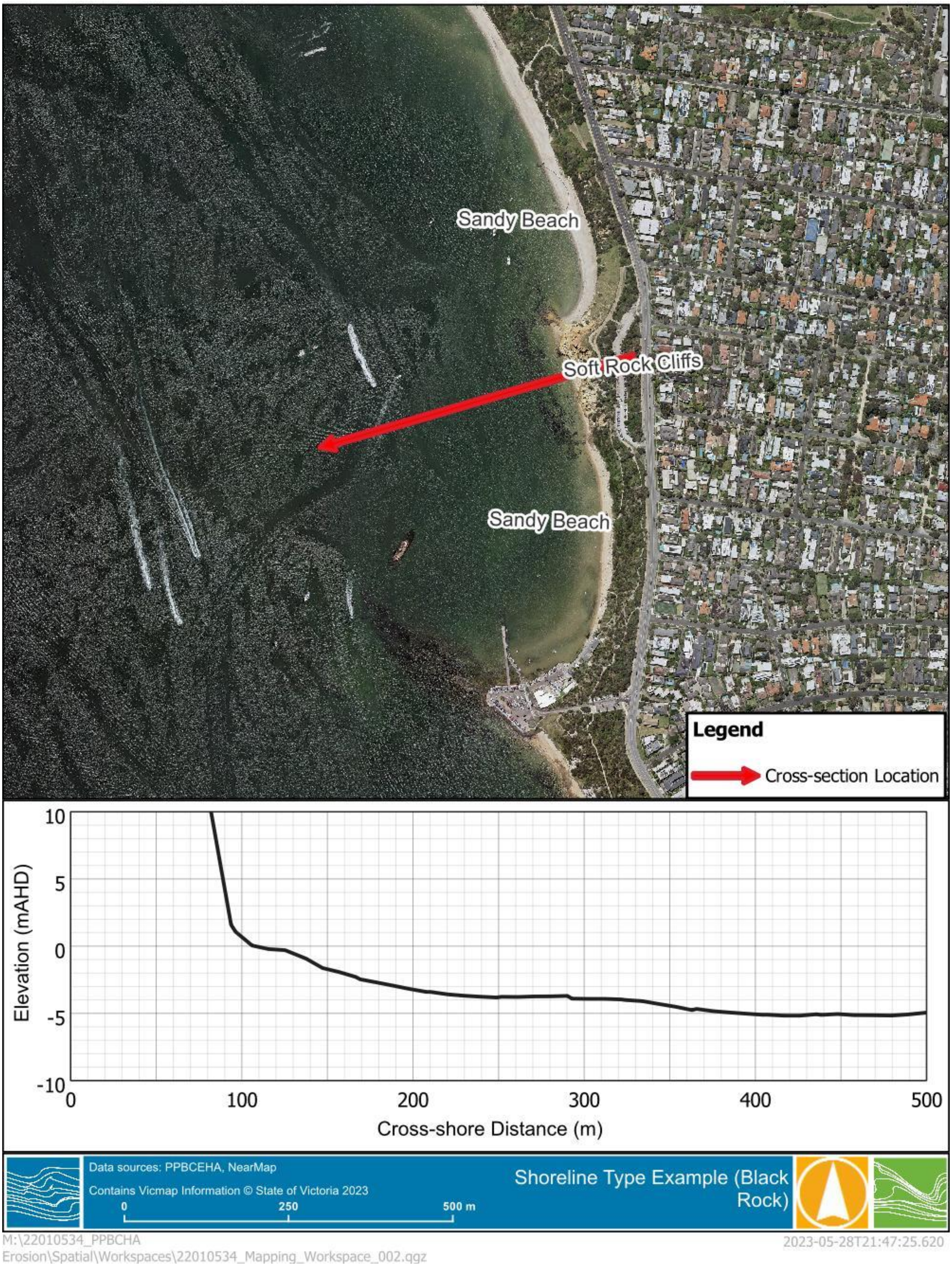

Figure 2-10 Example of Soft Rock Cliffs (Black Rock)

2.4.6 Hard Rock

Hard rock shorelines include igneous intrusions (granite, basalt, etc.) and well-cemented sedimentary rocks. They can range from steep vertical cliffs, to sloping bluffs not currently impacted by waves, or low rock intrusions that form small headland features. Rocky shorelines also often include nearshore rocky-reef features that can partially shelter adjacent shorelines, or otherwise interrupt coastal processes. Conversely, when activated (sandy beach buffer erodes to expose hard rock), the rock can function like a seawall, reflecting waves to exacerbate nearshore erosion, and causing terminal scour of the downdrift shoreline.

Erosion of hard rock shorelines is often in the form of large mass movements (particularly for cliff failure). As such, there can be little to no change in shoreline position for a long time, before a large sudden failure and readjustment of the shoreline.

Within Port Phillip Bay, hard rock is mostly present on the eastern shore around Mount Martha, parts of Mornington and Mount Eliza. There are basalt outcrops around Avalon and Cocoroc on the western shore. However, these are typically low features, and are typically submerged, or buried by sand and some fine sediments.

Figure 2-11 presents an example of a steep hard rock cliff at Mount Martha. The cliff falls to a rocky platform at the shoreline that influences the nearshore slope down to a 5 m water depth.

Figure 2-12 shows a low rocky shoreline at Point Lilias. This area has a much lower backshore (<5 mAHD) and no defined steep slopes. The rocky features are partially buried by sand and soft sediments in both the nearshore and backshore.

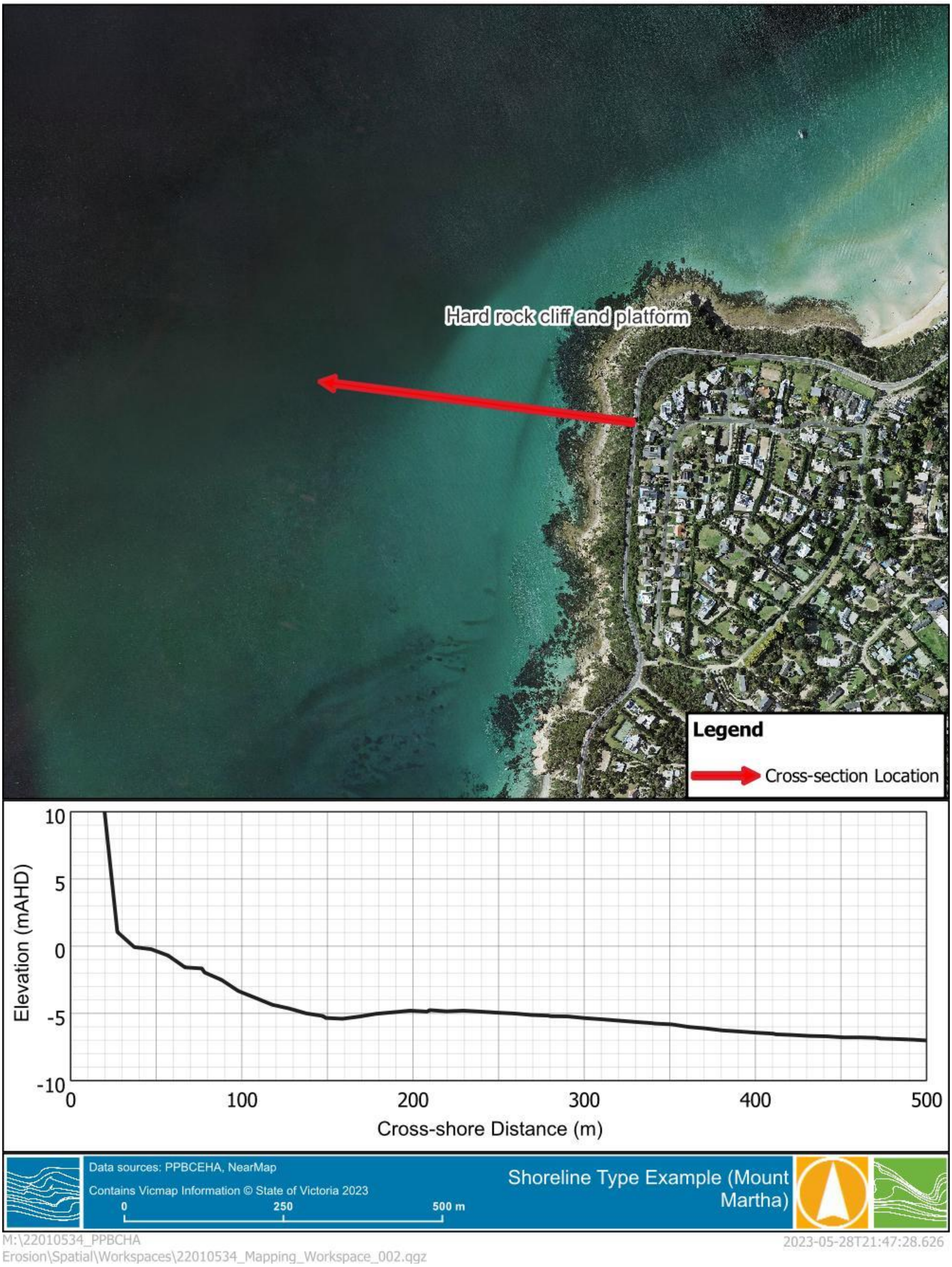

Figure 2-11 Example of Hard Rock Cliffs (Mount Martha)

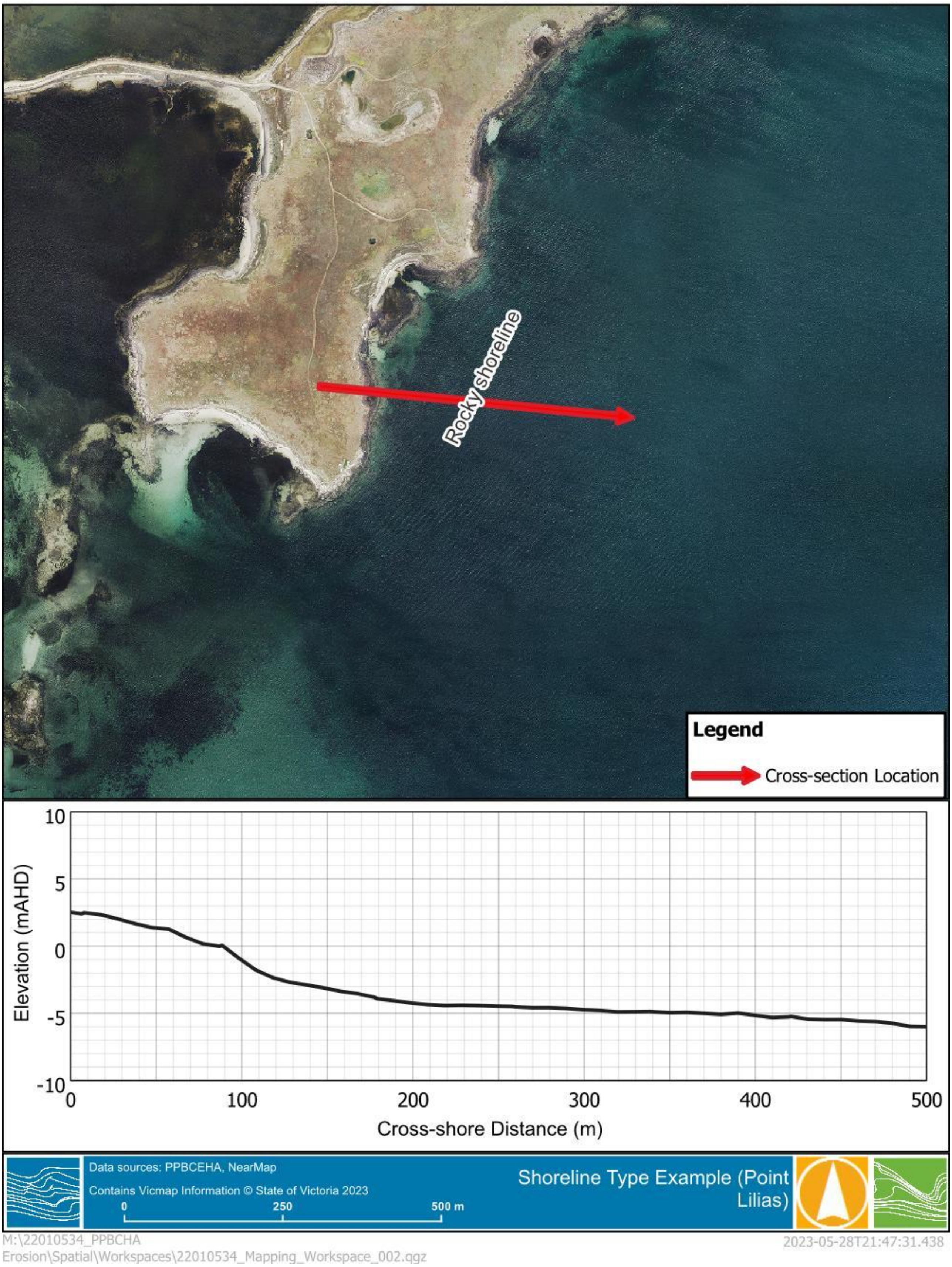

Figure 2-12 Example of rocky features (Point Lilias)

2.4.7 Structures (engineered shorelines)

Engineered shorelines are sections of the coast that have been modified by structures to maintain a particular position or alignment. This includes various types of seawalls, as well as harbours and wharves.

Engineered shorelines are usually constructed in response to ongoing erosion to protect assets behind them. As such, they are typically present on actively (or previously active) erosive shorelines.

Alternatively, they can be constructed to reclaim or realign the shoreline. Engineered shorelines can create additional land area near the coast for development. Such features may also force the shoreline into a new alignment that would not otherwise be stable without engineered protection.

Finally, engineered shorelines can be used for operational reasons not directly related to sediment transport processes, such as needing a vertical wall for shipping wharves, or breakwater sheltering for a marina or harbour.

Regardless of the intended purpose, engineered shorelines often disrupt the ‘natural’ coastal processes of the coast either side. This can cause accretion or erosion, or both depending on the form of the structure and the underlying sediment transport.

Current coastal management thinking and government policies (e.g. the Marine and Coastal Policy 2020), discourages the creation of engineered shorelines unless no other options are viable in the context of protecting and managing nearby coastal values. However, legacy engineered shorelines are often relied upon by significant areas of developed land. Adaptation of these areas therefore needs to carefully consider the neighbouring effects, as well as the historical and current usage.

In PPB, engineered shorelines expanded rapidly following European colonisation. Early development around the bay favoured engineered shorelines as a response to stabilise the shoreline position, or to construct new marina and port facilities. Engineered shorelines now represent the second most common shoreline type around PPB (behind sandy shorelines). Many of these areas are contiguous (much of Corio Bay, and the City of Port Phillip), as construction of one protection structure can exacerbate erosion downdrift (terminal scour), leading to additional protection structures. Some of these areas have artificially created beach systems in front of the engineered shorelines using groynes and sand nourishment (e.g., St. Kilda to Port Melbourne). As such, the beaches may respond to coastal processes as normal, but with a seawall providing a last line of defence for extreme erosion.

Figure 2-13 shows an example at Middle Park Beach. This is a heavily engineered shoreline, with a nourished beach in front controlled along the shore by groynes. Landward of the seawall, the topography is flat and highly developed. The nearshore beach slope extends only ~100 m offshore, before becoming very flat.

Figure 2-14 shows a contrasting engineered shoreline at the Port of Geelong. The seawall assists in controlling a very steep slope. This is important as relatively deep water is required near to the shoreline to allow for safe navigation for shipping.

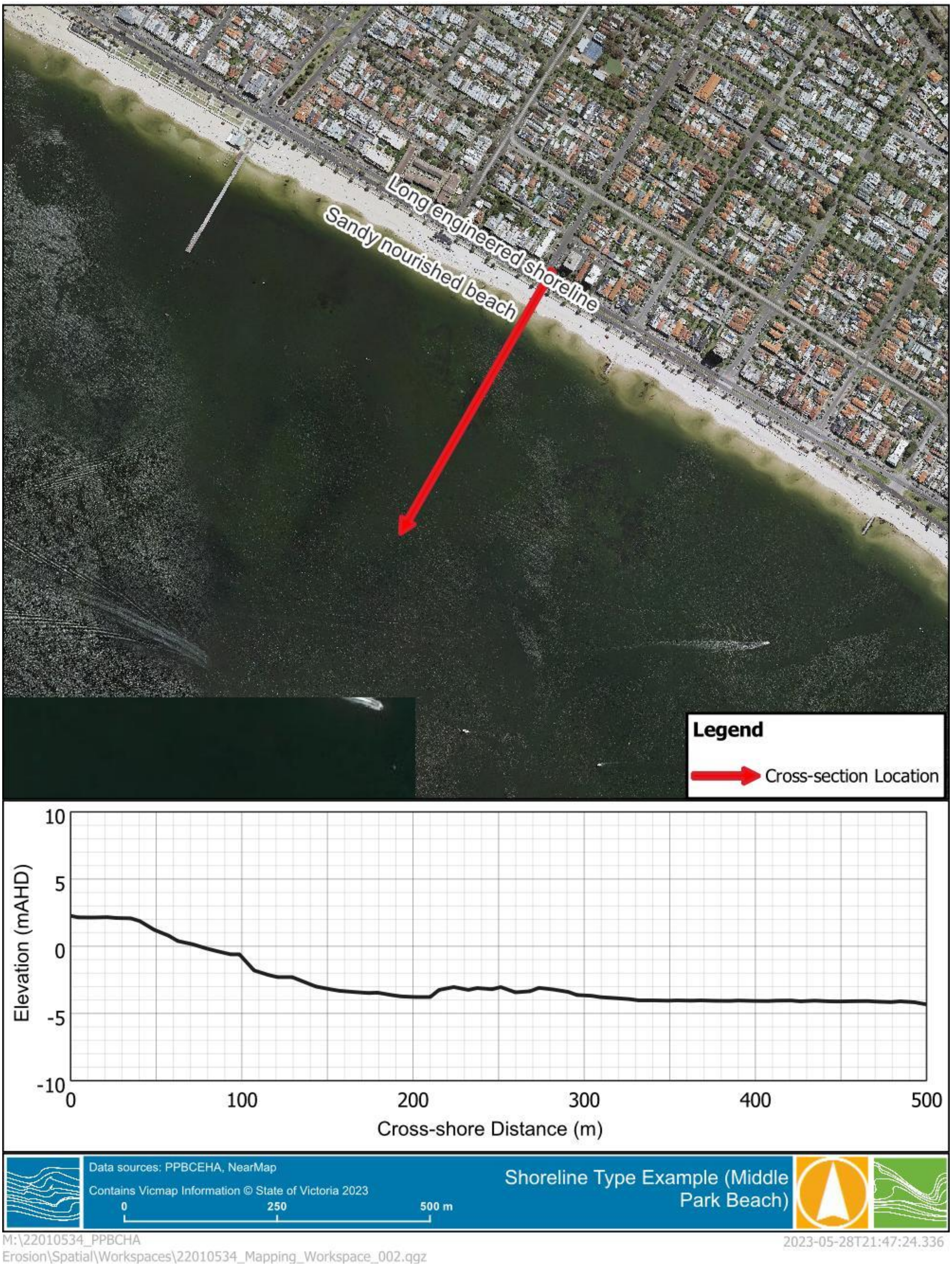

Figure 2-13 Example of Engineered Shoreline (Middle Park Beach)

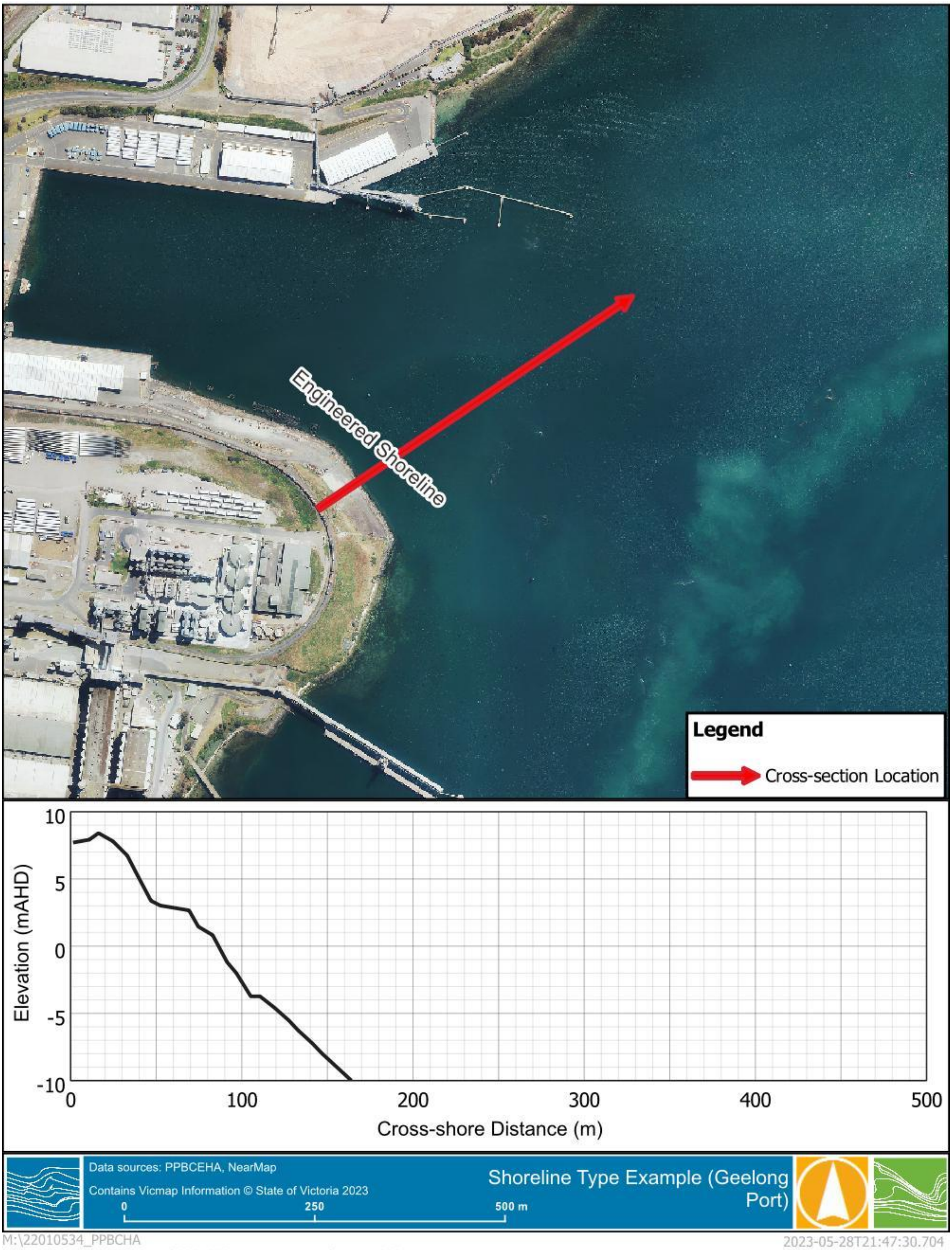

Figure 2-14 Example of Engineered Shoreline (Geelong Port, Corio Bay)

2.5 Backshore Influences

2.5.1 Overview

The shoreline types are for the most part representative of the currently 'active' shoreline types (the system currently eroding or interacting with coastal processes). However, as future erosion progresses, or as sea level rises, the response of the shoreline may change under certain backshore conditions.

Within Port Phillip Bay, there are four different backshore situations that can occur:

- Backshore is similar in response to the current active shoreline.
- Backshore consists of low-lying wetlands that are inundated under SLR conditions (described further below).
- Backshore consists of buried cliffs that are likely to slow the erosion rate once exposed (described further below).
- Backshore includes functional coastal protection structures (e.g., seawalls) that limit further shoreline recession (as described in Section 2.4.7).

2.5.2 Low-lying wetlands

Low-lying wetlands occur in several locations around PPB, usually with a fringing shoreline of a narrow sandy beach, saltmarsh and/or embankment levees. These areas are typified by their low elevation, usually below 2.5mAHD. Future sea levels are likely to inundate the backshore, with the new high tide line significantly different to present-day. Similarly, relatively small erosion effects, such as of an embankment levee, can result in a breakthrough and a large shift in shoreline position.

In these areas, the shoreline may be highly sensitive to erosion once it exceeds a certain limit, and the link between coastal erosion hazard and coastal inundation hazard cannot be easily disregarded.

As such, the erosion hazard extent is more uncertain in these areas. Modelling and the use of outputs should consider the range in results (rather than any single output), to understand the dynamic nature. These areas are more likely to require frequent updated hazard modelling as new data on SLR projections becomes available, and as the response of the shoreline (in particular the chance of a breakthrough) is observed.

2.5.3 Backshore Bluffs

There are several cases where the backshore is very steep and is likely to consist of high bedrock features, that are currently buried and covered in vegetation. However, the active shoreline consists of narrow beaches, often bound by headlands where the bedrock is exposed, and offshore rocky reef outcrops.

Key examples include Half Moon Bay at Black Rock (shown as a 'soft rock cliff' example in Figure 2-10). In this setting, the steep topography is indicative of the underlying rock.

Erosion in such areas will progress until the rock is exposed, whereupon it will transition to a much slower rate based on erosion of the cliff. For the PPBCEHA, this has been modelled and captured using a simplified approach to estimate the maximum onshore limit of erosion hazard as a function of cliff height and an angle of repose. This approach (detailed in the Methodology Report R02, Water Technology, 2023b) allows the cliff limits to be updated in future as further information on cliff stability and erosion processes becomes available.

3 EROSION HAZARD COMPONENTS

3.1 Hazard Overview

The Methodology Report R02 (Water Technology, 2023b) provides a more-detailed description of the modelling methodology.

Modelling of erosion hazard processes has been split into three separate components that can be assumed to operate independently, and with different results:

- Long-term erosion (LT), representing ongoing net-changes in shoreline position due to imbalances in sediment supply and loss within a sediment compartment. This is assumed to continue over the period of the modelled planning horizons.
- Short-term erosion (ST), representing the short-term component of shoreline change. ST erosion can occur from the scale of individual storms to multi-annual responses to extreme events. The focus of the ST component is on rare extreme events that may not have occurred within the observed period of the LT trends. As erosion hazard is applied from the vegetation line, the study implicitly assumes a depleted beach prior to ST erosion.
- SLR response (Future Response, FR), representing the additional changes in sediment transport processes, and their effects on shoreline position, with higher mean sea levels.

The total erosion is the sum of these three components.

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

Each of these three components have been applied as probability distributions that have been sampled many times (Monte Carlo modelling) before combining as the total erosion. The result is many possible Total Erosion Setback outputs, upon which key statistics can be extracted based on levels of certainty or risk appetite.

3.2 Study Scale

The spatial and temporal scale of a Coastal Hazard Assessment influences the ways that the outputs are interpreted. The PPBCEHA considers regional influences over the entirety of PPB, from Point Lonsdale on the Bellarine Peninsula clockwise to Point Nepean on the Mornington Peninsula as shown in Figure 1-1.

The industry best-practice is to use a sediment compartments approach to considering spatial and temporal scales (Thom, 2018). The PPBCEHA divides the coast on the basis of Tertiary Coastal Sediment Compartments (TCSC), with each TCSC assumed to be exposed to uniform hazard potential. The outputs cannot therefore predict any variations of coastal erosion hazard within each TCSC.

Consequently, the modelled hazard extents do not represent a future shoreline position for each TCSC. Instead, they represent regions that a future shoreline position is expected to fall within, with an associated level of confidence.

In many instances this is appropriate for the decision-making requirements, as the medium- to long-term shoreline response is expected to be similar (in a probabilistic sense) at the TCSC scale. However, there are also instances where the outputs of the PPBCEHA may not provide sufficient detail on their own and should be used to inform further local-scale studies. In particular this is the case for:

- Areas with significant coastal risk that may benefit from a finer discretisation of hazard.
- Decision-making of interventions that may influence local-scale sediment transport (e.g., removal of, or construction of coastal protection structures).

- Areas with noted geological variation in the backshore that will alter how the shoreline responds at a sub-compartment scale.

3.3 Erosion Baseline

Erosion hazard has been mapped from a specified baseline taken from the vegetation line (based on aerial imagery from 2010), or equivalent stable shoreline (due to a seawall or similar structure). Therefore, the beach seaward of this line is considered to be inherently part of the erosion hazard extent. This area is likely vulnerable to erosion that occurs on a sub-yearly scale, such as:

- Seasonal beach rotation in response to the shift in winter to summer wind waves.
- Smaller fluctuations caused by prevailing wave and tide conditions (small storms, or large tides with average waves). These can result in minor beach rotations, net fluctuations, or sandbar movements.

3.4 Short Term Erosion (ST)

3.4.1 Overview

Shorelines undergo erosion in response to increased wave attack during storms. Some shorelines (in particular sandy shores) go through a subsequent period of 'recovery' where the beach is able to rebuild following a storm. Where this cyclical pattern occurs, the area prone to this fluctuation must be considered as part of the erosion hazard zone.

It is noted that for shorelines that have no mechanism for recovery following a storm (e.g., cliffs, soft sediments), the associated retreat of the shoreline will be captured in the LT trend. As such, no additional ST component is applied.

Where the storm response is uncertain (low earth scarp shorelines in particular), it is possible that the shoreline may or may not recover. A conservative assumption is to provide an additional storm erosion allowance, noting that the nature of such shorelines is low energy, and storm impacts are likely to be small anyway.

For this study, SBEACH (USACE, 1991) has been used to model a single storm erosion setback for each sediment compartment to which it may apply. The Methodology Report (R02) (Water Technology, 2023b) provides further detail on the development of the storm erosion model.

3.4.2 Application of short-term erosion

There are several cases where storm erosion has been excluded from the erosion hazard modelling. These are as follows:

- Functional engineered shorelines, where erosion is controlled by shoreline protection.
- Cliffs (hard and soft), where no recovery processes apply, and storm erosion is captured in the long-term erosion analysis.
- Areas protected by offshore breakwaters and storm waves cannot reach the shoreline (Figure 3-1 presents an example from Portarlington).
- Small embayments with a fetch less than 5km. Such areas are not likely to experience cyclical storm erosion and recovery effects, and any storm-driven erosion component will be captured in the long-term erosion analysis.

Figure 3-2 presents a map demonstrating all the areas of PPB that have and have not had storm erosion applied to them within the erosion hazard assessment.

Figure 3-1 Example of shoreline without ST applied

Figure 3-2 Map of short-term erosion applicability

3.4.3 Short-Term Erosion Output Results

The ST modelling (SBEACH) results provide an insight into the vulnerability of much of PPB to storm erosion. Figure 3-3 presents a map of the modelled present-day 1% AEP storm erosion setbacks around PPB (that are to be applied to the vegetation line). For the most part storm erosion is small, with the largest erosion setbacks (5-10m) experienced in areas exposed to larger waves that penetrate Port Phillip Heads such as Point Lonsdale, Queenscliff and parts of Point Nepean and Portsea. The highest storm erosion further from the entrance was ~6m at Mordialloc Beach. It is noted that much of this beach is protected by seawalls, with only smaller sections exposed to wave energy.

The majority of sediment compartments within PPB had storm erosion setbacks less than 3m. Many Tertiary Coastal Sediment Compartments (TCSCs) experienced some movement of sediments in the nearshore within the model, but no change in the inter-tidal or upper-beach areas i.e., no change beyond the vegetation baseline. As such the short-term erosion setback for these TCSCs is zero.

Therefore, while the wave height is one factor of the total erosion setback, the sediment size and nearshore profile are also key. Larger waves will tend to break on offshore sandbanks, reef outcrops, shoals and similar features.

3.4.4 Uncertainty

The uncertainty of short-term erosion is relatively small in overall magnitude, particularly as the overall erosion rates associated with such conditions are small in PPB.

The wave conditions modelled as part of the PPBCHA are likely underpredicted, which will have a result on the potential ST erosion. Sensitivity testing and analysis of this uncertainty is provided in the Methodology Report R02 (Water Technology, 2023b). This showed that at small ranges, it is likely to be linearly proportionate to the wave height underprediction, i.e., an increase in the wave height by 10% is likely to result in a 10% increase in the setback.

The major source of uncertainty for short-term erosion is the likelihood of a given storm occurring. Erosion hazard has been assessed for given particular wave exceedance probabilities (AEPs). Depending on the weather and climate, different levels of exposure may occur. For example, easterly storm events are rare within PPB, and therefore such conditions may cause a rarely seen beach response, outside of the typical range. This may be a rotation of smaller beaches, a longshore loss of sand around headlands, or direct storm bite on normally sheltered areas.

Storm erosion has been calculated within the SBEACH model at the present-day inter-tidal beach. However, the results have been included in the total erosion hazard applied from the vegetation line. For many beaches this implicitly assumes a depleted beach prior to the ST effect and discounts any existing sandy buffer that may otherwise reduce the erosion effects. This choice is conservative, but accounts for the uncertainty in seasonal rotation (not assessed), which may effectively deplete one end of the beach. Furthermore, it factors in the potential for storm clusters that may result in a depleted beach prior to a final storm.

Figure 3-3 Map of modelled 1% AEP storm erosion setbacks (present day)

3.5 Long Term Shoreline Change (LT)

3.5.1 Overview

Long term change in shoreline position is caused by ongoing erosion processes that are not offset by recovery or accretionary processes within a given TCSC or vice-versa. A major mechanism for this is the differential in the longshore sediment transport rate between beach compartments, i.e., where the volume of sediment leaving a TCSC from one end is greater than the incoming volume at the other. If the opposite is true, then a shoreline may be accreting over the long-term, offsetting other erosion processes (short-term fluctuations and SLR response). Where longshore gradients are causing erosion of one TCSC, it is likely that there is either a TCSC updrift that is intercepting sediment and accreting, or one downdrift that is being flooded with high rates of sediment and accreting.

Cross-shore losses or supplies can also occur. Losses occur where sediment is drawn offshore and lost from the active beach system. In PPB this could occur if sediments were eroded by storms, and then lost into nearby tidal channels or deeper areas, or where cliff and low-earth scarp erosion causes loss of sediments from the shore, but there are no processes to transport these back into a beach or similar system. Cross-shore supplies occur where prevailing wave and tidal conditions push sediment landward, widening the beach.

In either case, the result is a potential for a shoreline to erode at a sustained rate. It is possible that eventually such processes will stabilise, with a new shoreline alignment limiting further long-term trends. However, for the purpose of hazard modelling, it is conservative to assume that such equilibrium conditions will not occur over the timeframe of interest. If data of long-term trends have been assessed over a long-enough period, then it is reasonable to assume it will continue for at least as long again. However, if the observational record is sufficient to determine that a new equilibrium has been reached, then the anomalous period can be removed from the record. This approach has been conducted for the PPBCEHA as discussed in the Methodology Report R02 (Water Technology, 2023b).

Modelling of LT trends depends on the available data and the underlying processes. The longshore transport processes on straight sandy beaches can be modelled relatively easily using numerical models, or empirical formulae. However, these approaches become more difficult for complex headlands and/or engineered features where the transport may spill around in pulses. Furthermore, such modelling relies on suitable wave conditions as the primary forcing. Any bias or uncertainty in the waves will apply to the transport rates. As the sediment leaving one beach corresponds to the sediment entering another, any error in the longshore rates will multiply over time and space. There are no widely used models of long-term cross-shore sediment supply or loss, beyond mass-balance rules for Future Response to SLR (see Section 3.6).

Long term trends have been assessed by mapping shoreline positions from aerial imagery around PPB since the 1930s (dataset availability and quality vary with time and space). A linear regression trend has been applied to these shoreline positions using the Digital Shoreline Analysis System (DSAS) (USGS, 2018). A more detailed description of the modelling methodology can be found in the Methodology Report (R02) (Water Technology, 2023b).

3.5.2 Long Term Shoreline Change Results

The LT (DSAS) analysis of the shoreline positions resulted in a rate of shoreline change for transects at ~50m spacing (exact spacing varies slightly as lines move around complex headlands, etc.). The results were aggregated within each TCSC, with a triangular probability distribution constructed using the 2.5th, 50th, and 97.5th percentiles as the lower limit, modal centre, and upper limit respectively.

An example from Frankston Pier (TCSC 41, with 12 transects) is shown in Figure 3-4, with shoreline change centred around accretion of 0.05 m/year, but ranging from almost stable, to higher accretion of nearly 0.1 m/year. The raw results are shown along with the Monte Carlo (MC) results sampled from the triangular distribution.

A more extreme example is presented in Figure 3-5 for Queenscliff Lookout (TCSC 93, with 41 transects), where the shoreline is typically stable within the bounds of uncertainty, but ranges from high rates of erosion to moderate rates of accretion. In these settings, it is often the case that the wider TCSC is undergoing a rotation, or shoreline realignment over the long term. In the case of Queenscliff Lookout, there is a localised section of erosion associated with terminal scour of the adjacent seawall. As such, one end of the TCSC may be experiencing erosion, with the other accreting, or localised pockets of shoreline change may be occurring on a sub-compartment scale due to other processes.

The result is that understanding the erosion hazard relies on an accurate selection of the output statistics. Selecting from the conservative end of the TCSC may be reasonable for many use-cases but will be unrealistic (over-conservative) in erosion hazard extent parts of the TCSC that may be accreting, or relatively stable. However, selecting from an ‘average’ or central value for the TCSC may underpredict the erosion hazard at the most extreme locations. In the case of the Queenscliff Lookout example described above and shown in Figure 3-5, selecting a conservative output (e.g., the 95th percentile), will result in a large erosion applied to the TCSC (>0.5 m/year erosion). However, the shoreline trends indicate that parts of the beach are accreting.

Sub-compartment scale analysis is required in such cases to determine whether the differential in LT trends within the TCSC is likely to continue. In this case, the erosion hazard can be reduced in the accretionary areas. Alternatively, it is possible that such processes may stabilise or reverse in the long term, and the conservative estimates may better-represent the potential shoreline variation.

The need for sub-compartment scale analysis can be determined based on the following two criteria:

- Erosion hazard extents encompass significant values that may require adaptation.
- The variability of long-term rates is high (see Figure 3-7 or PPBCEHA analysis databases).

> *Local scale (Sub-compartment scale) analysis may be required where the LT variability.*

Figure 3-6 presents the modal (central) value of the LT rate distribution for every TCSC. The highest erosion trends occur at Point Nepean and near the Western Treatment Plant (~0.7 m/year erosion). Accretionary trends occur in places, most notably near Queenscliff (0.7 m/year accretion), and at the tombolo behind the Royal Brighton Yacht Club (~1 m/year accretion).

Figure 3-7 presents the associated variability in the LT rate (the range of the triangular distribution) for every TCSC. Many of the areas with the more extreme modal rates also show the highest variability. This indicates that these areas are highly mobile, but with large differences within the TCSC. The exception to this is Point Nepean, which has low variability in its steady erosion trend.

Table 3-1 presents the results of the long-term shoreline change by shoreline type (considering all transects in each shoreline category). The rocky shorelines show variation around a modal value of zero. This highlights the variation and uncertainty in such features. Although, the 'rocky' shorelines may also include some areas that are dominated by rock but may have short sections within where rocks are buried and exposed by coastal processes and appear in the long-term trends.

Sandy shorelines show the highest variation, ranging from large accretionary sections to large erosive sections. This is as expected and represents variations in alongshore sediment transport between TCSCs. Sandy shorelines experience longshore sediment transport variation. As such, there are sections that have net losses or net supplies of sand, resulting in associated erosion or accretion trends. Care has been taken to attempt to remove the influence of short- to medium-term disruptions that may appear in the trend analysis (e.g., groyne construction). This process has been described in the Methodology Report R01 (Water Technology, 2023b). However, where the data record is not long enough to confirm that a trend has stabilised, it has been assumed to continue for the projected planning horizons. Updated modelling may be required where further observations confirm that such effects are temporary.

> *Updated modelling may be required where further observations confirm that larger LT trends are temporary and are not likely to continue over the planning horizons.*

Soft rock shorelines tend towards erosion, though with some small sections including potential for small accretion. The few soft sediment shorelines (The Spit Nature Reserve) tend towards accretion, as the sheltered embayment appears to be experiencing deposition of material within it, by both runoff of additional fines to the nearshore, and the landward movement of sediment from the breached barrier spit. Engineered shorelines are stable by nature and show no variation.

Table 3-1 Analysis of Shoreline Change (erosion is positive)

Shoreline Type	2.5th%ile (m/year)	50th%ile (m/year)	97.5th%ile (m/year)
Hard Rock	-0.20	0.00	0.18
Sandy	-0.75	-0.03	0.93
Soft Rock	-0.16	0.01	0.25
Soft Sediment	-0.47	-0.03	0.11
Engineered	0	0	0

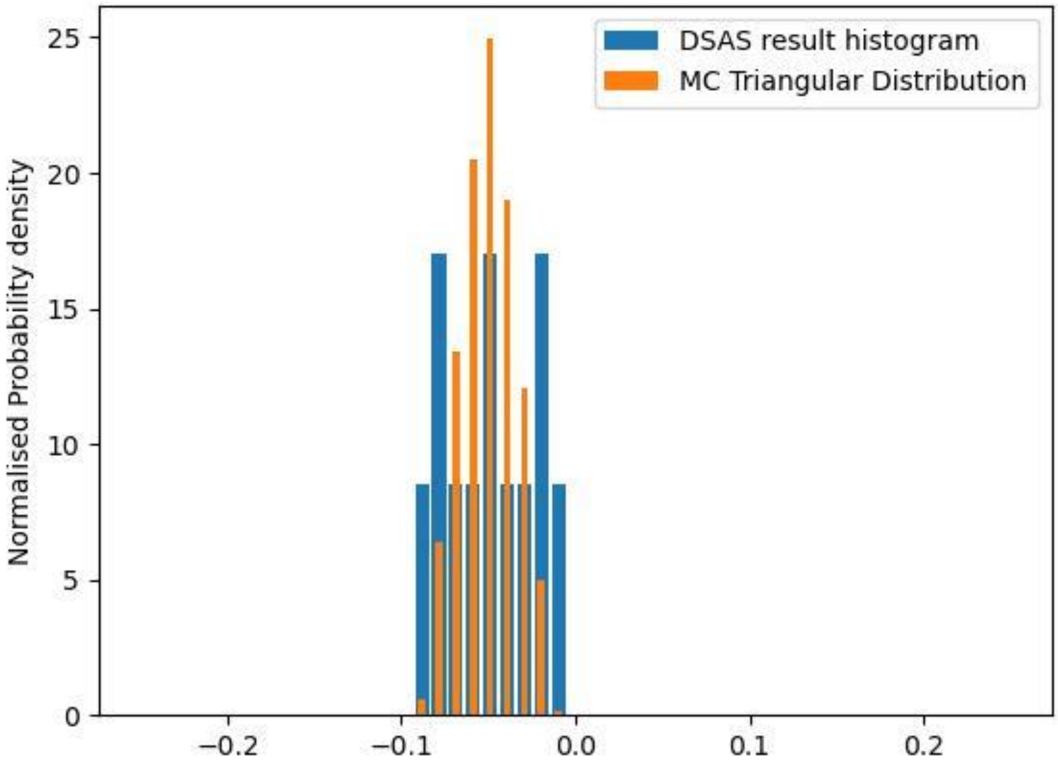

Figure 3-4 Shoreline Change Results for TCSC 41 (Frankston Pier) (positive is erosion)

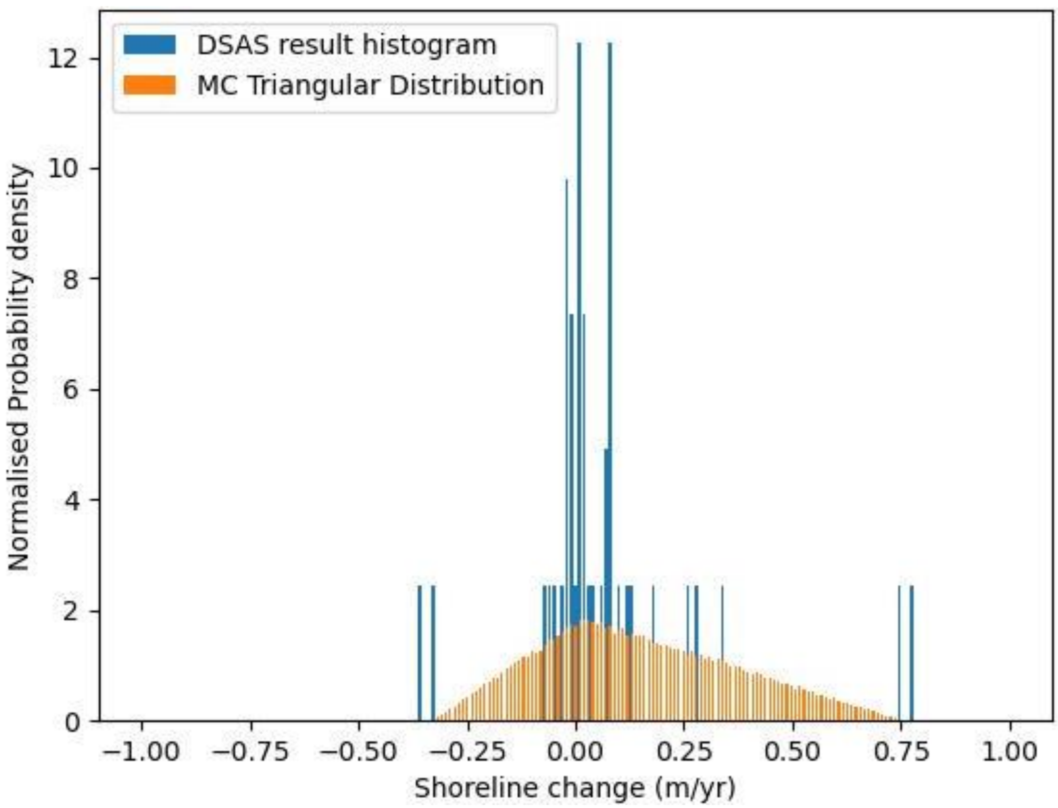

Figure 3-5 Shoreline Change Results for TCSC 93 (Queenscliff Lookout) (positive is erosion)

Figure 3-6 Map of Modal Long-Term change

Figure 3-7 Map of Variability (range of the triangular distribution) in Long Term change

3.5.3 Cliff Retreat Results

Cliffs have been separately analysed to apply their anticipated rates of change to backshore potential cliff features (discussed in the Methodology Report R02, Water Technology 2023b). Table 3-2 presents the rates of change as observed for the hard rock cliffs, and soft rock cliffs (subsets of the hard rock and soft rock shoreline types that have been analysed only where active cliffs are currently present – i.e., excluding low rocky shorelines).

An example of the results for a hard rock cliff compartment (TCSC 70, Mount Martha Cliff, The Pillars, with 106 transects) is shown in Figure 3-8. The results demonstrate that the hard rock cliff transects overwhelmingly demonstrate a zero change, with a small number of transects showing some variation from this. The transects showing variation appear to be in small areas of erosion loss, with occasional stable talus features forming that may allow for effective accretion of the shoreline. There is also likely to be some variation based on the inherent uncertainty of the aerial imagery shoreline analysis, as described in the Data and Literature Review Report R01, and Methodology Report R02 (Water Technology, 2023a, and 2023b).

The soft cliff results show a similar modal stable value, with a slight potential for accretion. These cliff features are known to erode through a number of features, including stormwater runoff and aeolian erosion. Erosion of these cliffs can provide (and historically has provided) an additional source of sediment to the nearshore that do not erode further if the coastal erosion drivers are mild (i.e., erosion due to runoff, but largely sheltered from incident waves). In this case, the shoreline has the potential to accrete as the cliff erodes.

In terms of hazard however, the more erosive limits have been used as input for the cliff clipping layer (as described in the Methodology Report R02 Section 3.5 (Water Technology, 2023b)).

Table 3-2 Cliffed Shoreline Rates of Change (positive is erosion)

Cliff Type	Lower limit (2.5th%ile)	Modal (50th%ile)	Upper Limit (97.5th%ile)
Hard Rock	-0.11	0	0.17
Soft Rock	-0.14	0	0.13

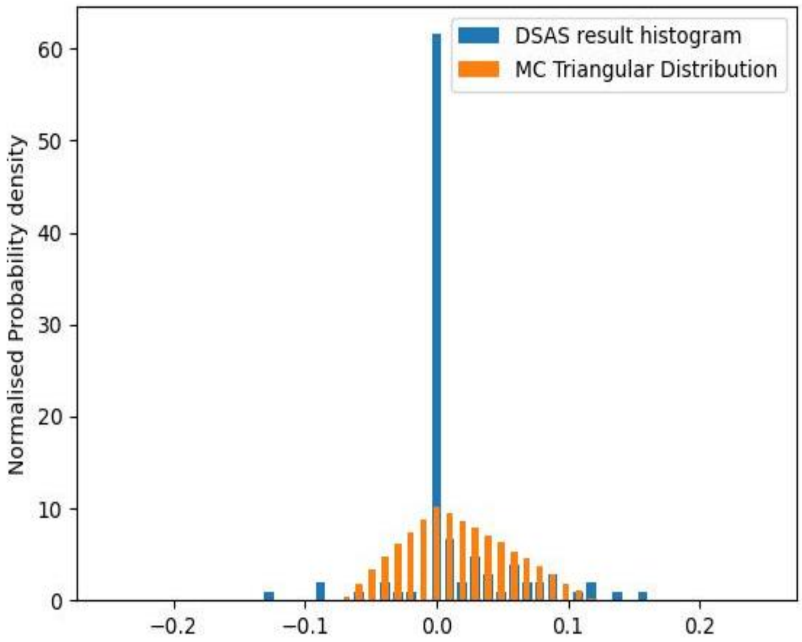

Figure 3-8 Shoreline Change Results for Mount Martha Cliff (positive is erosion)

3.5.4 Mobile Spits

A transect based approach to quantifying LT coastal change (such as the DSAS methodology in this study) is only applicable to coasts where the shoreline orientation is approximately stable with gains and losses quantifiable as onshore / offshore shoreline movements. This approach is not suitable for where major realignments in coastal orientation or form occur, such as inlet mouths and mobile spits.

Mobile spits and sand lobes may progress through a sediment compartment over the order of years to decades, with a large variation in shoreline position and changes in coastal vegetation growth (as mapped in this study). If a large sand feature moves through a TCSC within the observed period of shoreline change, then it will skew the shoreline position results in several ways:

- Sections of shoreline that have had a large sand lobe in front of them at the beginning of the record will show very high erosion as the shoreline moves landward.
- Sections of shoreline had the sand lobe moving into them over the course of the observed record, will show very high accretion as the shoreline moves seaward.
- Sections of shoreline in between the initial and final position of the sand lobe may either show as being stable, or highly accretive and then highly erosive, depending on the speed of the sand transport relative to the frequency of available aerial images.

The problem for extrapolation is that the ‘noise’ associated with the large pulse of sand moving along the shore may make it impossible to distinguish any other underlying net trend (‘signal’) of the shoreline behind it. However, it equally cannot be assumed that such a feature is a one-off and given that it has occurred once in an area, it may do so again.

In PPB, there are two locations that appear to be heavily influenced by the movement of sand spits:

- The eastern side of Swan Island, where sand bypassing from Queenscliff Harbour has resulted in major changes in shoreline position (100m+) propagating northward through the TCSC. (See Figure 3-9).
- The Altona Cheetham Wetlands from Skeleton Creek to Laverton Creek, where the Laverton spit has developed and separated from the coast over the period of available aerial images. (See Figure 3-10).

In both of these situations, the whole area of change should be considered a ‘coastal hazard zone’, given that any values within may be impacted by the coastal changes.

There is a low confidence in extrapolating the observed results for these two areas. Therefore, these areas have been modelled separately, with a conservative area of geomorphological uncertainty applied based on the observed total envelope of shoreline position for each of the cross-shore transects (i.e., the difference between the most seaward, and most landward shoreline positions). A triangular distribution has been constructed using the 2.5th, 50th, and 95th percentile outputs of the transect shoreline envelope within each of the three TCSCs that are impacted by mobile spits. This is not applied as a rate, but as a single erosion hazard extent. This means that even the near-term results (e.g., 2010, 2040), show large erosion hazard extents. However, given the substantial variation that has been observed in these areas over the scale of 1-2 decades, this is considered to be appropriate.

Figure 3-11 shows the modal shoreline change that has been applied in the triangular distribution. This is equivalent to the median shoreline change envelope for these TCSCs. Figure 3-12 presents the range of these results (the limits of the triangular distribution).

Figure 3-9 Swan Island Sand Lobe Progression

Figure 3-10 Laverton Spit formation

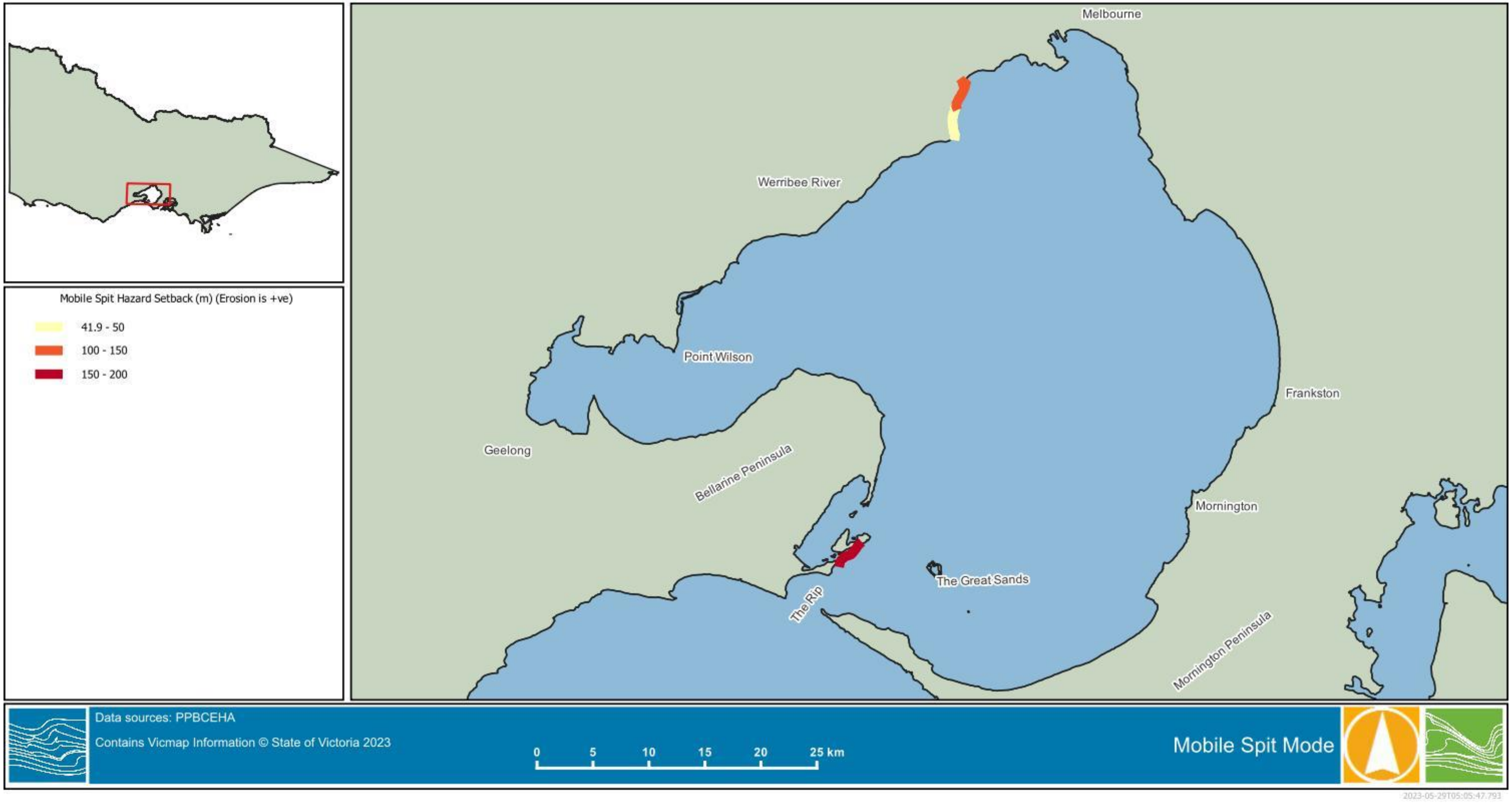

Figure 3-11 Mobile Spit Modal Hazard Allowance

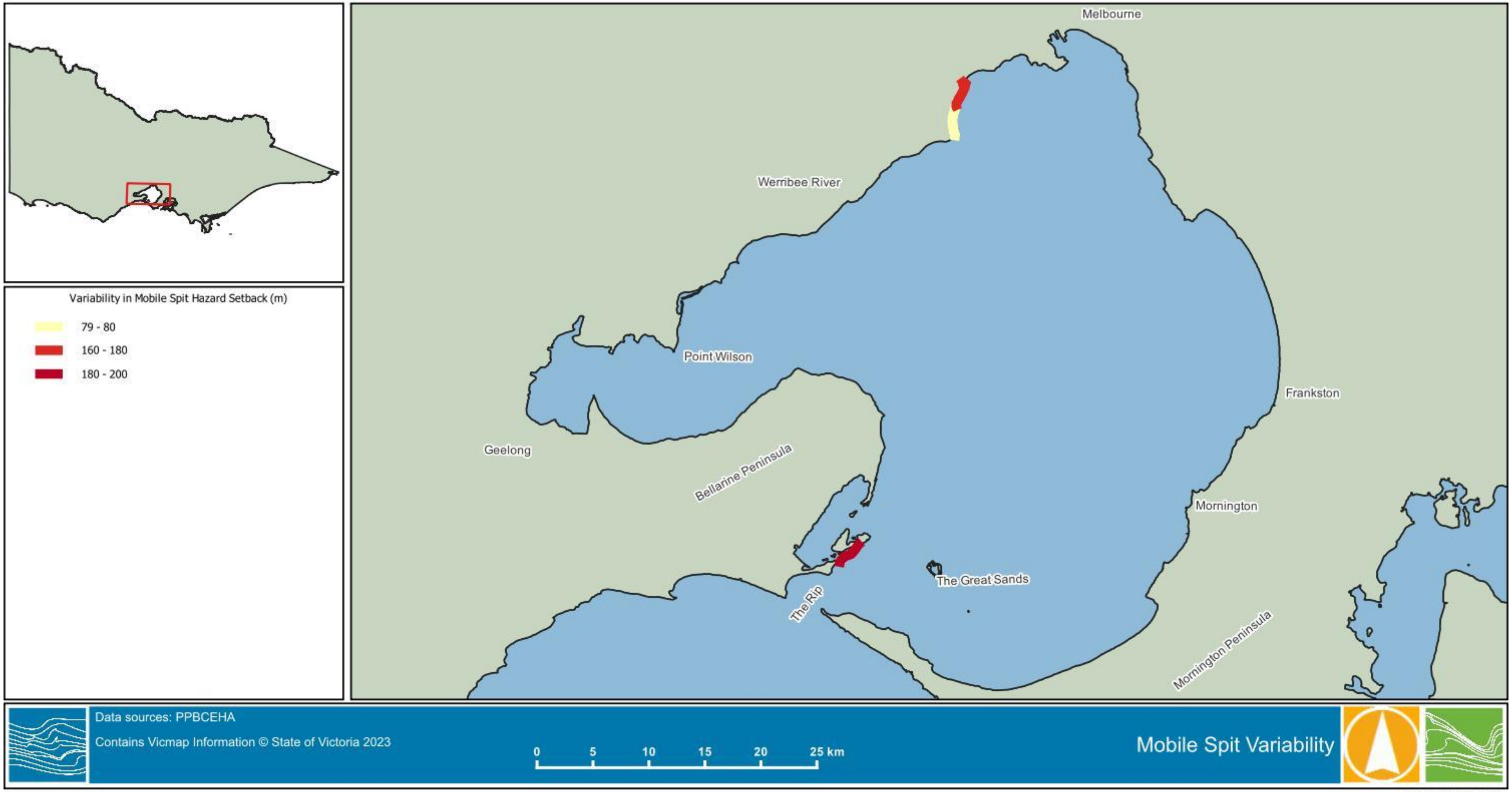

Figure 3-12 Mobile Spit Hazard Range Variability

3.5.5 Temporary LT Disruptions

There are several processes that can influence the shoreline trends temporarily but are not appropriate to apply as an ongoing process.

Beach renourishment occurs widely around PPB and has the potential to alter shoreline positions over the short- to medium-term. However, this is not expected to be a major source of uncertainty or error due to the following:

- Major nourishment campaigns tend to occur in front of engineered shorelines (to maintain a beach for amenity/recreation). Given that the modelling approach excludes hazard in these areas, nourishment works will not influence the outcomes.
- The vegetation line approach only observes changes that occur on a temporal scale greater than the vegetation growth. Therefore small nourishment campaigns that respond to seasonal or storm event conditions are not likely to result in vegetation line trend.
- Additionally, as the aerial images analysed are ~decadal, nourishment works would need to be ongoing over the scale of multiple decades to significantly influence the results (a single anomalous shoreline change would be evident and easy to exclude from the data.

The uncertain factor of renourishment is where repeated nourishment campaigns is masking an underlying erosion trend. The model will not be able to predict this, and therefore there is an implicit assumption in the modelling that the nourishment works will continue at the same rate as in the observed data.

The construction of groynes, seawalls, boat ramps and other coastal structures, or dredging of channels can also influence the sediment transport processes for nearby areas. Where possible, these factors have been removed from the LT analysis. This has been conducted by observing sudden anomalous changes in shoreline position, and removing the shorelines the are influences by this. For example, shorelines before and immediately after a new groyne installation could be removed, and the analysis only conducted for the period after the shoreline has stabilised.

The key issue with the above is that there may not be sufficient data to confirm whether a trend has stabilised, is about to stabilise, or is imminently about to respond dynamically to a recent disruption. There is no reasonable way to quantify these issues and they reiterate the need for further hazard modelling at regular frequencies to incorporate new data, and verify ongoing processes.

3.5.6 Uncertainty

There are several elements that introduce uncertainty to the long-term erosion component. Key sources of this uncertainty are:

- The resolution and quality of the analysed aerial imagery
- The suitability of a constant extrapolation of historical trends
- The spatial variation – i.e., the fact that the results have been grouped by TCSC, even though there may be processes that occur at a finer scale (e.g., terminal scour, or spit migration). Note that for longer time periods, averaging over these spatial extents may be appropriate.

The resolution and quality of the aerial imagery is assumed to be +/-20m for the oldest imagery (1930s and 1940s, black and white imagery with low resolution) and +/-10m for more recent imagery (based on the ability to accurately determine vegetation lines. These errors should average out between images given a sufficient number of them (i.e., there is no bias in the inaccuracies). However, a conservative estimate of approximate uncertainty in this approach assumes a maximum error of +20 in 1930 and -10 in 2020, for a total of 30 m variance over a 90-year analysed period. The expected average variability in shoreline rate is therefore +/- 0.33 m/year.

For the most part however, the uncertainty of the long-term trend is well-captured within the range of analysed results. The Monte Carlo model captures this range of outcomes in-turn by incorporating them into the final erosion outputs (using the methodology described in Section 3.1 and further in the Methodology Report R02 (Water Technology, 2023b)). However, as discussed in Section 3.5.2, care needs to be taken to assess the outputs according to an appropriate need.

3.6 Future Response (FR) to Sea Level Rise

3.6.1 Overview

For a given 'average' wave climate, the beach will converge towards a slope that balances the incoming wave energy with the depth due to the following:

- Shallow areas with higher wave action on the seabed will erode until they are deep enough to limit the wave effects, and;
- Deeper areas are less-influenced by waves and will tend to in-fill with sand.

The outcome of this theory is an 'equilibrium profile' whereby no further net sediment transport occurs in the cross-shore direction. It is unlikely that any systems ever truly reach such a state given that wave conditions are highly varied, seabeds are not made of homogenous sediments and other processes can impact the sediment transport. However, this theory is useful to examine the potential for a shoreline to respond to sea level rise.

Bruun (1962) originally explored this theory and hypothesised that as sea levels rise (SLR), the nearshore seabed is effectively deeper, and therefore any sediment that deposits there is less likely to be mobilised in future. Given that storms and other erosive processes are known to draw sediment off the beach and into the nearshore, there is a likely mechanism whereby such erosion processes occur, and the sediment is 'trapped' in the deeper nearshore area, resulting in an unbalanced setback of the shoreline. This process will continue until the nearshore seabed has been effectively raised to match the same relative depth as the 'pre-SLR' equilibrium profile. Bruun formulated this mass balance using simple geometry known as the 'Bruun Rule', which is discussed further in Section 3.6.2.

In environments where the shoreface is not dominantly shaped by cross-shore wave action and/or sandy sediment is not abundant it is not clear that the Bruun Rule is applicable. Key cases include:

- Low-energy environments with wide and shallow intertidal, or sub-tidal flats. Without larger long-period waves, there is limited mechanism for such sand/mud flats to be pushed towards the shore, and as such there is a surplus of sand in the nearshore area.
- Offshore features (rock reefs, etc.) that do not readily respond to changes in waves and water levels, and may trap cross-shore sediment transport flows
- Systems where nearshore sediment transport patterns (transverse bars, sand shoals, current-driven transport) are large relative to the sediment exchange with the shore.

In these scenarios, an increase in mean water levels does not cause a change to the sediment exchange between the beach and the shoreface. However, at a minimum the effective shoreline position will rise along the upper beach face in proportion to the new mean sea level. For the PPBCEHA, the baseline minimum erosion hazard area is based on the stable shoreline (notionally the vegetation line or similar, as described in the Methodology Report R02). Therefore, under a future SLR condition this minimum hazard extent should adjust such that it is an equal distance from the future mean-sea-level position, as it is from mean-sea-level at present day. Therefore, the slope of the upper beach face can be used to account for a minimum expected shift in future baseline erosion hazard conditions, with all other erosion components (short-term and long-term), being relative to this.

Finally, cliff retreat does not align with either of the two previous descriptions. However, evidence suggests that the rate of cliff retreat is increased when the rate of SLR increases (not with a stable SLR rate). The Methodology Report R02 describes the methodology of Ashton (2011), which has been used to provide an additional increase in the observed cliff retreat rates, according to the projected rates of SLR.

3.6.2 Bruun Factor Analysis – Depth of Closure

As described in the Methodology Report (R02) (Water Technology, 2023b), the Bruun Rule can be simplified to present recession for a given SLR as a ratio known as the 'Bruun Factor'. The Bruun Factor is typically formulated as the shoreface slope between a dune crest height and an offshore depth-of-closure, below which cross-shore transport is minimal over the time-frame of interest.

The depth of closure for this modelling has been assessed using the Hallermeier (1982) inner shoal depth formulation, but with a conservative 1% AEP significant wave height (noting that the extreme waves may be underpredicted). This results in depths of closure for most areas of PPB of 2.5m to 4.5m (skewed towards ~4m). Beaches exposed to incoming ocean swell (e.g., Queenscliff) had the largest depths of closure to a maximum of 8.9m.

The resulting Bruun Factors (average slope out to the depth of closure) were calculated on all the transects within each TCSC. The 2.5th, 50th and 97.5th percentiles (median and 95% confidence interval) from these transects were used to form the bounds of a triangular probability distribution.

Figure 3-13 presents this the modal value of the triangular distribution for each TCSC in PPB to which they are applied. Figure 3-14 presents the variability based on the range of the triangular distribution (the 95% confidence interval of the analysed dataset).

The eastern shoreline of PPB has (modal) shoreface inverse slope (Bruun Factor) values typically <50. This correlates to a 50m setback for every 1m of SLR. The variation in these Bruun Factors is of a similar order to the modal Bruun Factor, is often <10. The highest variability is observed at Queenscliff. It is debatable whether such a shoreline is applicable for the Bruun approach given the flat nearshore shoreface. However, there is noted cross-shore exchange in this area (supply and potential storm demand), so a conservative assessment has been made to adopt the Bruun Factor.

Figure 3-13 Modal Bruun Factors (using DOC approach)

Figure 3-14 Bruun Factor variability (using DOC approach)

3.6.3 Upper Beach Slope Analysis

For nearshore beach profiles with a surplus of sand, sheltering features or dominant sediment transport processes that do not interact with the shore (e.g., convex profiles, and sheltered embayment), the basic theory of the Bruun Rule will not apply. Moreover, the application of the Bruun Rule to these areas will result in very large Bruun Factors as the depth of closure is a greater distance from the shore than for steeper reflective high-energy systems.

Perversely, this means that areas that are less vulnerable to beach erosion due to SLR will incorrectly predict higher setbacks using the Bruun Rule. Figure 3-15 demonstrates this issue, where the second profile has an increased volume of sand in the nearshore, but with a shallower effective shoreface slope out to the same depth of closure (DOC), resulting in a higher Bruun Factor.

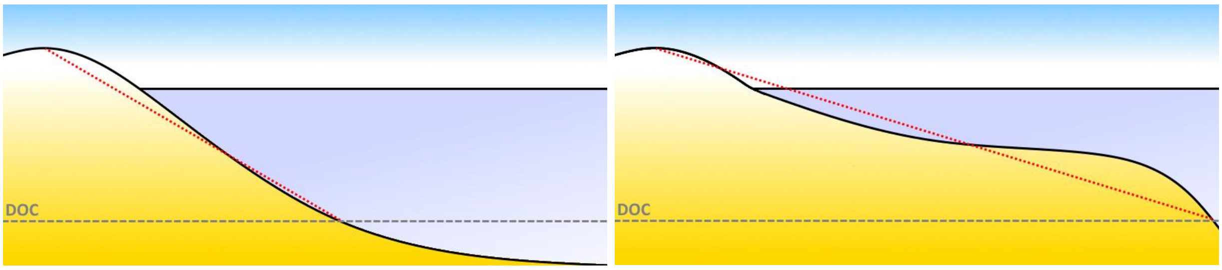

Figure 3-15 Depiction of Bruun Slopes for a classic concave up profile (Left); and a convex profile (Right)

Instead, the expected response of the shoreline to SLR will be the effective shift proportional to the water rising along the beach face. Therefore, the modelling has assumed that the upper beach face (from mean higher high water to 0.5 m above it) will be an effective slope on which to allow a minimum setback due to SLR. This has been applied in the same way as the Bruun Factor, with the median and 95% confidence interval values within each TCSC representing the triangular distribution.

Figure 3-18 presents the median beach face factor for each TCSC around PPB, and Figure 3-19 shows their variability (the range applied to the triangular probability distributions). The median values trend between 5 and 20. The variability (range) in results is highly sensitive to the backshore elevations. The highest beach face factors and effective setbacks occur where the backshore is low-lying and prone to inundation (is inter-tidal with SLR).

An example of this is at the Western Treatment Plant, where much of the coast consists of treatment ponds bounded by low earthen embankments. These embankments are lower than the future highest astronomical tide (HAT), and as such the landward shift in shoreline position is large. Figure 3-16 shows a plan view and cross-section for a TCSC near the Western Treatment Plant (TCSC 163). The peak elevation of the embankment/s is relatively low, and likely to become inundated with future sea levels. Figure 3-19 shows the triangular distribution of upper beach face factor for this TCSC (based on 12 transects). The distribution is highly skewed as a single transect passes through a lower area, resulting in a large effective beach face factor.

Once future sea levels inundate the low-lying backshore, the erosion hazard is highly uncertain. In these instances, the adopted beach face approach (with high variability) will show large FR setbacks. However, it is still likely in these areas that the inundation hazard will dominate. Therefore it is considered acceptable that the FR components in such areas are highly variable.

In general, the future response (FR) of such shorelines and environments is highly uncertain. However, it is clear that there is no justification to applying the Bruun Rule.

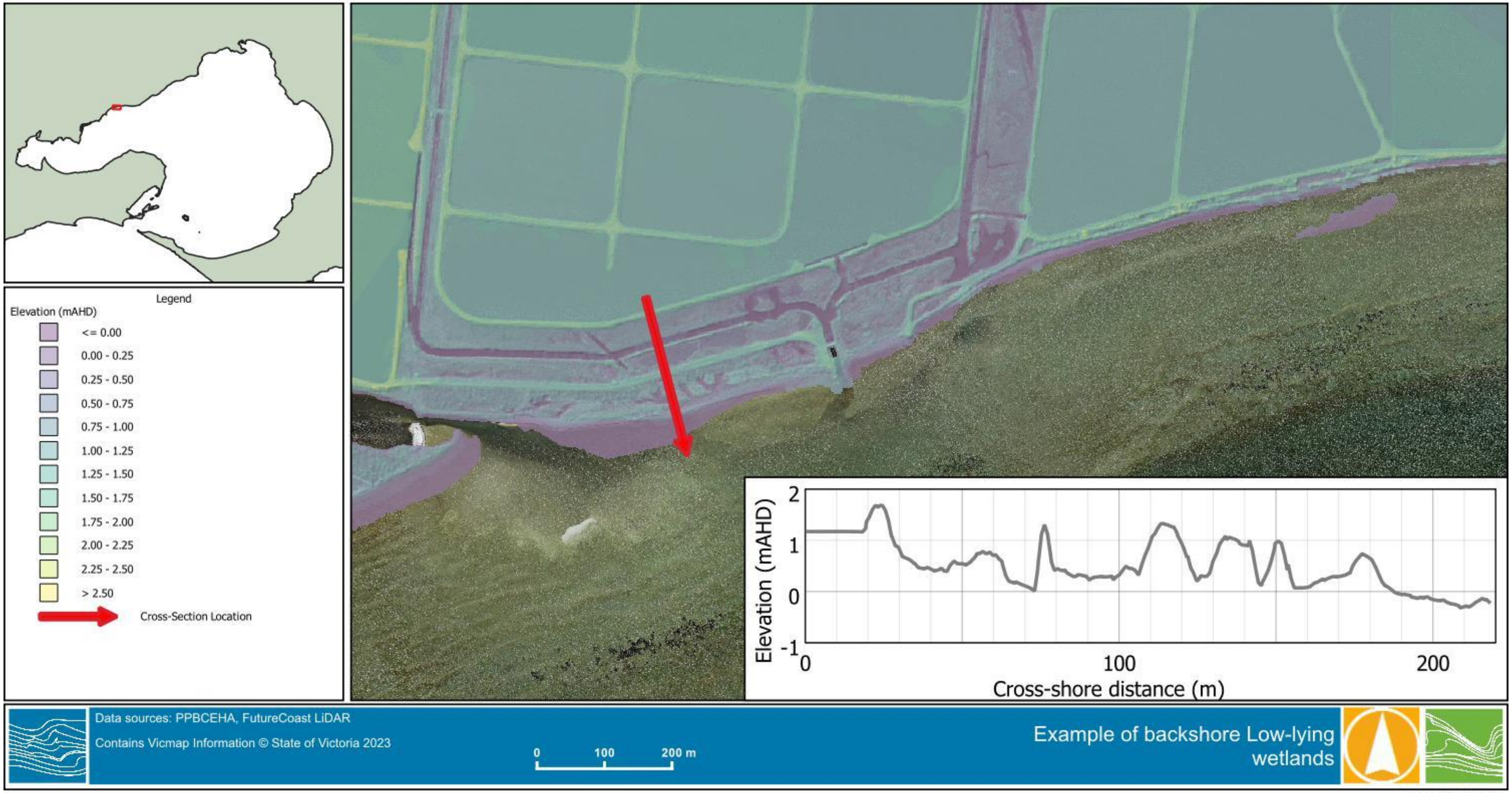

Figure 3-16 Plan view example of low-lying backshore wetlands

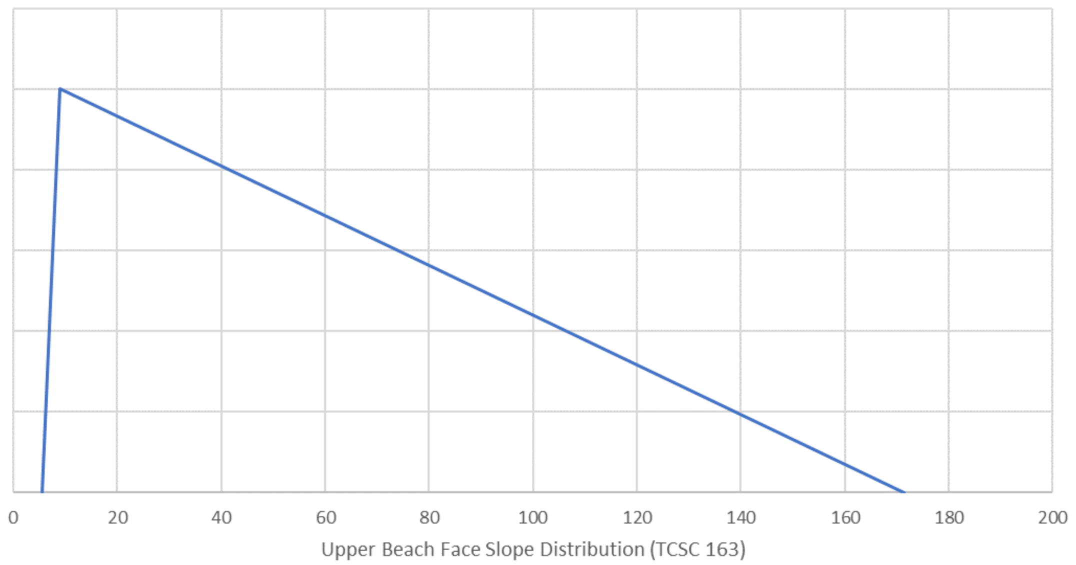

Figure 3-17 Triangular Distribution of upper beach face slope (TCSC 163)

Figure 3-18 Modal Upper Beach Face Slope

Figure 3-19 Upper Beach Face Slope variability

3.6.4 Cliff Retreat Acceleration

The acceleration of cliff retreat has been applied using the method of Ashton (2011) as described in the Methodology Report R02 (Water Technology, 2023b). This increase is uniform with the additional factors for each SLR scenario shown in Table 3-3. The methodology bases the increase in recession rates on the square root of the ratio of SLR rates:

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

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.

Table 3-3 Cliff Retreat SLR Factors

Future Year	Sea Level Rise (m)	Average Rate of SLR (mm/y)	Cliff Retreat Factor
2010	0.0	3.0	1.00
2040	0.2	6.7	1.49
2070	0.5	8.3	1.67
2100	0.8	8.9	1.72
2100	1.1	12.2	2.02
2100	1.4	15.6	2.28

3.6.5 Methodology Selection

The three different methodologies of Sections 3.6.2, 3.6.3, and 3.6.4 were applied according to the following criteria:

- For active cliffs the cliff retreat acceleration approach was applied
- For exposed sandy beaches, with concave profiles, the Bruun Rule was applied
- Where the modal slope calculated using the depth of closure exceeded 50, the profiles and exposure were inspected with the upper beach face method applied in the following instances:
  - Low-energy (fetch <5km)
  - Convex shoreface profiles
  - Low-earth scarp or estuarine shoreline types
  - Offshore reefs or sand shoals
- Where a determination was unclear, the more-conservative Bruun Rule DOC approach was applied.

This methodology is replicable, and future revisions can easily adjust the regions over which the Bruun Rule is applied.

Figure 3-20 presents the selected SLR response type for the whole of PPB. The Bruun Rule approach was applied mostly on the eastern shore, where sandy beaches with higher wave exposure dominate. The majority of PPB (that does not have a functional seawall in place) has been assessed using the upper beach face slope. This is representative of the overall low-energy nature of PPB.

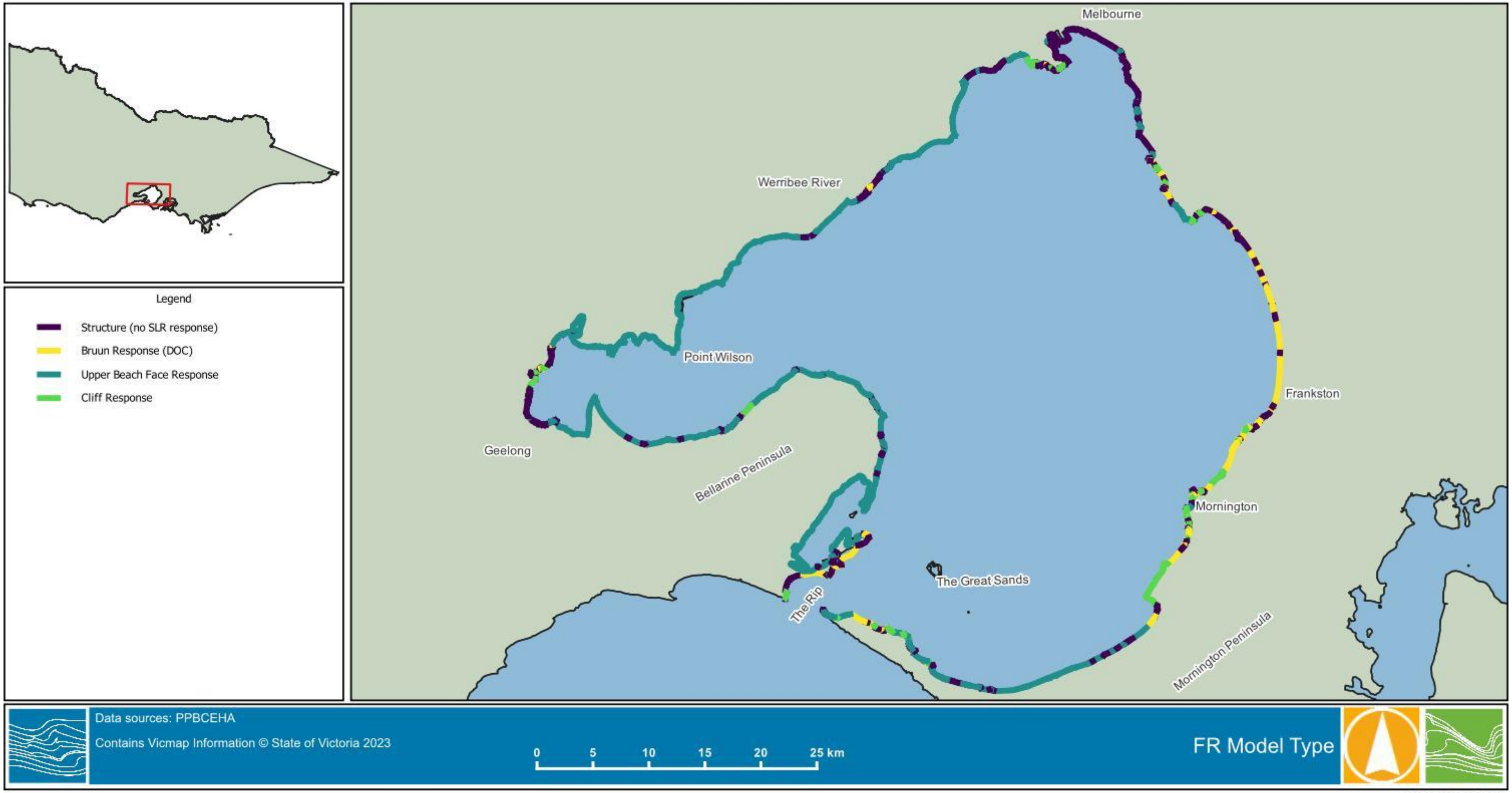

Figure 3-20 Map of modelled SLR response 'type'

3.6.6 Uncertainty

For many shoreline sections within PPB, the Future Response (FR) to SLR may dominate the total erosion hazard extent for future sea level rise scenarios. The uncertainty of the response is high, and the applied triangular distributions incorporate this. The ratio of setback to SLR (for non-cliff shorelines) can range from ~10 m/m to >100 m/m erosion.

For understanding the future erosion hazard, it will be useful to consider the whole distribution of outputs, rather than a single extracted percentile, to understand the sudden change in erosion hazard with different likelihoods.

4 TOTAL EROSION HAZARD OUTPUTS

4.1 Overview

The total erosion hazard has been calculated by adding together each of the three erosion components (ST, LT and FR) on a per-TCSC basis. This was done many times (1 million simulations), with a new random value for each of the three components selected for each one. This produced 1 million different total erosion hazard setback distances, from which key statistics can be extracted.

For general mapping purposes, the 95^{th} percentile from this output distribution has been used. This was selected to be conservative, and useful as a guide of areas potentially prone to erosion hazard. It is also consistent with the outputs developed from the inundation component of the PPBCHA.

Figure 4-1 presents an example of the total erosion setback taken from the 95^{th} percentile of the 2100 (0.8m SLR) scenario with a 1% AEP storm event. In this scenario, most of the PPB coastline has a coastal erosion hazard extent within 50m of the baseline shoreline. There are also several locations that show a net accretion (no additional coastal erosion hazard extent). This indicates that for these areas, the positive long-term change offsets the SLR response and storm demands.

The greatest setbacks are the areas with low-lying backshore areas. These are described in detail in Section 2.5.2. These areas tend to be dominated by the SLR response component and are largely inundated by future tidal levels.

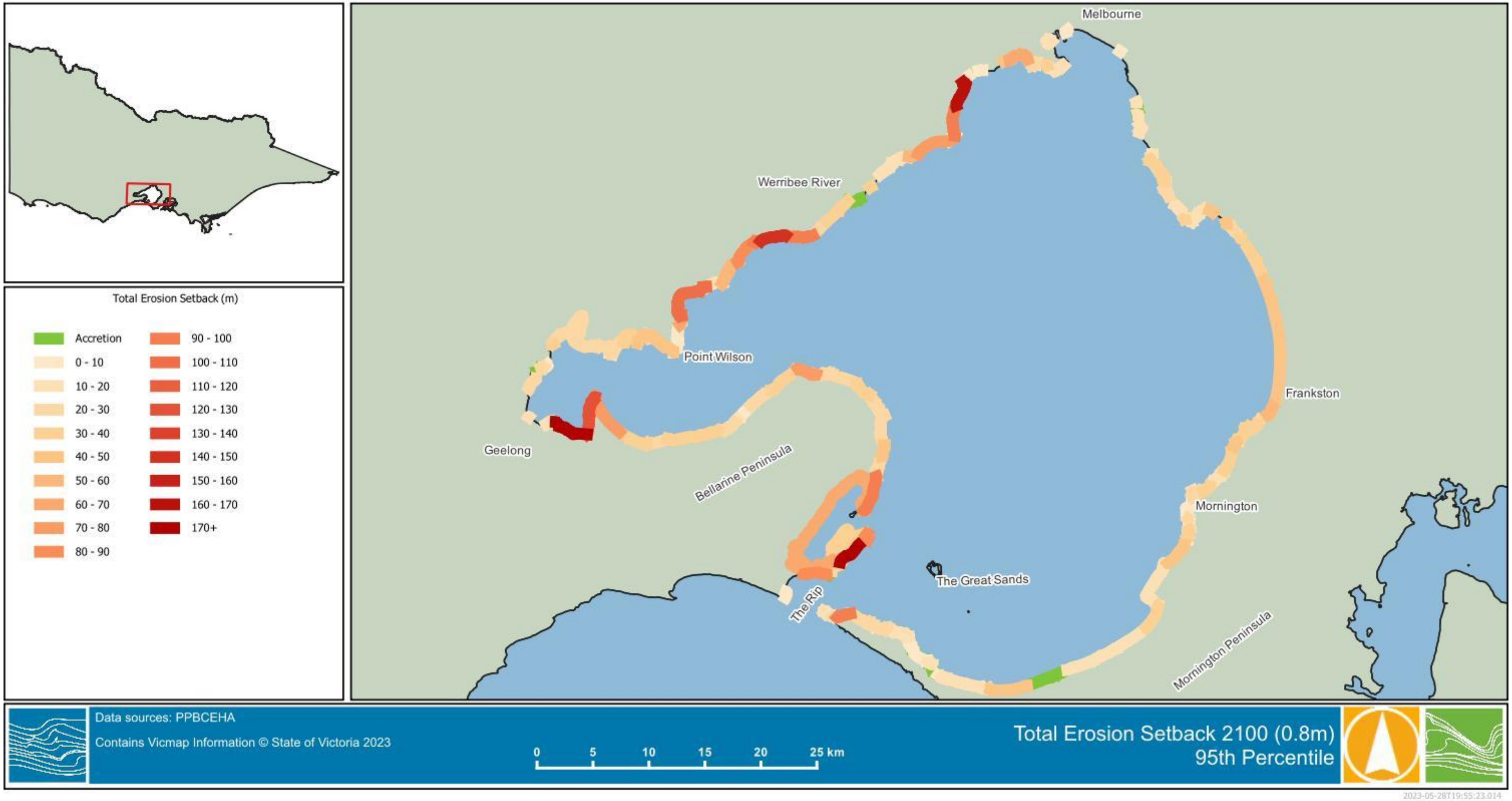

Figure 4-1 Total Erosion Setback Example (2100 0.8m SLR, 95th Percentile)

4.2 Relative Contribution of Erosion Components

For any given simulation (e.g., the 95th percentile), the total erosion may be built from different relative combinations of the three inputs. For example, a moderate future total setback (50th to 75th percentile) may be derived from an extreme SLR response with a low Long-Term component; an extreme LT with a mild SLR; or a moderate of both (ST storms erosion is noted as being a minor component compared with the LT and FR erosion components). This is even more complicated where the long-term component has the potential to be accretive.

The exact combination of these components for a given percentile is not able to be determined with certainty. Potential combinations could be offered that provide a similar total erosion setback but rerunning the Monte Carlo model would produce different results again.

Furthermore, due to the increase in variance as probability distributions are added, the 95th percentile of the total erosion hazard distribution is not equivalent to the sum of the 95th percentiles from each of the three components (ST, LT and FR). However, the 95th percentile results from the input distributions do provide an indication of the relative magnitudes of the inputs (as described in the preceding sections), that may assist in coastal management planning in response to the overall hazard.

Figure 4-2 shows an example at Queenscliff (TCSC 93) with the 95th percentiles of the three input components shown. In this TCSC and for this SLR scenario, the LT trend dominates. The FR is almost as large, and the ST component is minimal.

This is typical of the pattern around the whole of PPB. The LT trend tends to dominate (although is notably sometimes accretionary), with the FR component generally larger than the ST component.

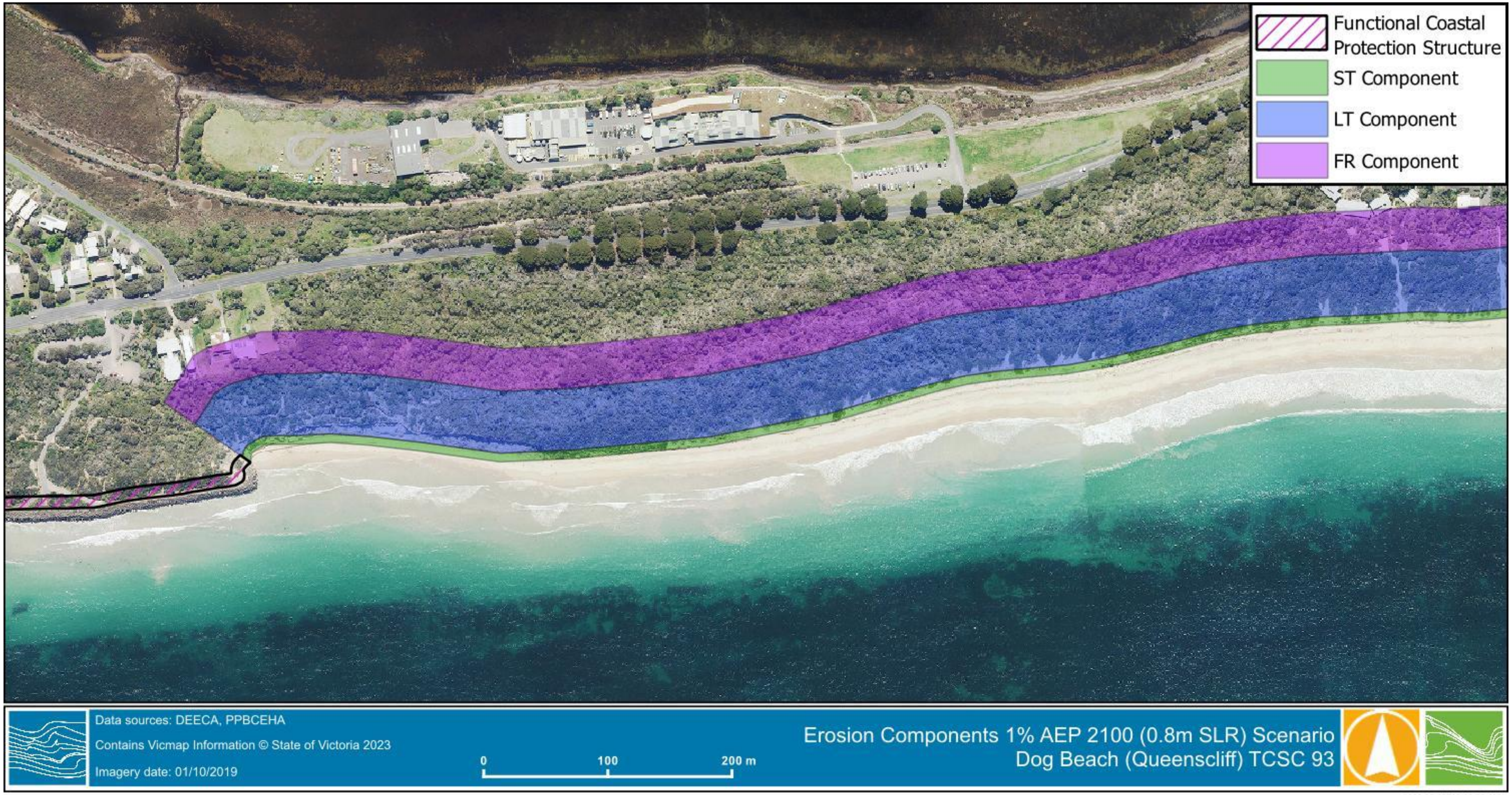

Figure 4-2 Example of Approximate Erosion Components of 95th Percentile 1% AEP 2100 *0.8m SLR)

4.3 Uncertainty

The uncertainty and variation in total erosion hazard results varies according to TCSC. The Monte Carlo modelling approach incorporates the uncertainty, and therefore the results demonstrate this. The full available datasets of modelling outputs are separately available and should be interrogated for a detailed understanding of the uncertainty for an area of interest.

Figure 4-3 presents some selected outputs of the total erosion setback results for several TCSCs around PPB for the 2100 (0.8m SLR) 1% AEP scenario. These demonstrate that the variability ranges widely depending on the dominant processes and the selected output percentile.

Some TCSCs, such as at Altona, may vary from erosion to accretion (accretion not considered a hazard). Others are dominated by one or the other. Overall, the uncertainty tends to scale with the overall magnitude of the sediment transport rates. TCSCs with higher median erosion setbacks, tend to have a higher variability also. This is indicative of more energetic shorelines that may respond dynamically in future.

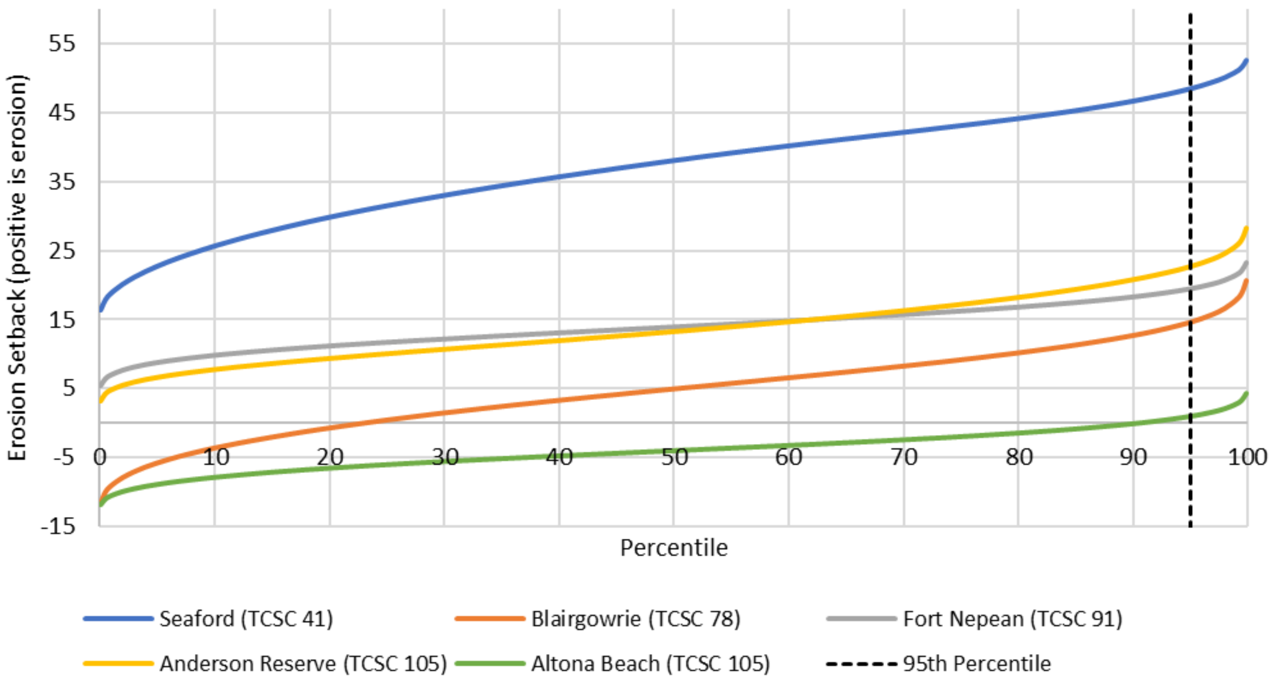

Figure 4-3 Select examples of TCSC total erosion uncertainty (2100 (0.8m SLR) 1% AEP)

5 EROSION HAZARD MAPPING

5.1 Overview

Erosion hazard outputs have been prepared based on the erosion hazard modelling presented. These outputs project a polygon landward from the shoreline that represents the area that may be prone to coastal erosion hazard under each scenario (timeframe, SLR and storm recurrence).

This section presents a discussion of the key choices in presenting the outputs and their implications. It also highlights key areas of interest from the modelling and mapping outputs.

5.2 Percentile Selection

This mapping has been primarily based on the 95th percentile of the total erosion setback results simulated in the Monte Carlo model. This is the erosion setback that is only exceeded (greater erosion) in 5% of the modelled simulations (50,000 out of 1,000,000 simulations). It can be interpreted as the extent that has a 95% likelihood of encompassing the future shoreline position, based on the assumptions of the modelling.

This percentile value was agreed with DEECA on the basis that it takes a conservative (risk-averse) approach. For any given TCSC this will tend to draw from the ‘worst’ (more erosive) part of each triangular distribution. Therefore, it is based on:

- The more erosion-prone sections of the TCSC as observed in the LT analysis (noting for sub-compartment variation this may not be representative as discussed in Section 3.5.2.
- A higher storm demand as modelled in the ST components.
- A flatter FR slope (higher FR factor).

Selection of the median output is more likely to represent the most likely average expected setback for a TCSC, but not the greatest setback within it.

Figure 5-1 presents 5th, 50th and 95th percentile outputs from the 1% AEP 2100 (0.8m SLR) results at White Beach in Rye (TCSC 76). In this area, the 95th percentile results show relatively substantial hazard into the dune, encompassing walking trails coastal vegetation and a camping ground. The 50th percentile results, however, show only minor erosion (effectively stable), even considering the Future Response (FR) component with 0.8m of SLR. The 5th percentile results show a potential for net accretion of the shoreline. The erosion hazard outputs do not map any accretion as it does not represent a hazard. It is only shown in Figure 5-1 for illustrative purposes. The conclusion in this area is that the LT component dominates the overall erosion response in this region (the other two components, ST and FR, cannot have an accretionary contribution).

End-users of the modelling outputs should consider the most appropriate percentile output for their use-case. Different results can be used to examine the variability in the erosion hazard setback and understand areas that may benefit from further local-scale modelling.

> *End-users of the modelling outputs should consider the most appropriate percentile output for their use-case*

Figure 5-1 Different Percentile Outputs Comparison. 1% AEP 2100 (0.8m SLR) for TCSC 76

5.3 Backshore Cliff Limits

Where large cliff features are present in the backshore, but the current active shoreline is not cliffed, there is the potential for a change in erosion processes in future. This is most likely to slow the rate of erosion as cliffs are not likely to erode as readily as other shoreline types. This has been resolved in the mapping by providing a 'clipping' layer based on the limit of backshore cliff erosion under future scenarios. The methodology for deriving these backshore cliff extents is described in the Methodology Report R02 (Water Technology, 2023b).

Figure 5-2 demonstrates an example at Sandringham (TCSC 27), where the erosion hazard extent is limited to the maximum cliff erosion extent. Note: only the cliff limit for the 2100 (1.4m SLR) scenario is shown, but each future scenario has been clipped to a different limit, representing the maximum expected cliff retreat point for that scenario.

In this case (Sandringham), the extent by which the hazard is reduced by the cliff varies along the shore. In some sections, the cliff limit moves landward, following the topography, and the erosion hazard area is not impacted. In others, the cliff limit comes much closer to the beach and is a major constraint on the setback distance.

These cliff limits have been designed to be conservative. A cliff is only shown where there is a high certainty that there is underlying rock that is likely to limit erosion. In many cases, there may be bedrock much closer to the shore that will limit erosion further. However, determining the exact starting point of this is impossible without a geotechnical assessment.

Local-scale studies may benefit from geotechnical data collection that can inform updated cliff limits to further reduce the erosion hazard extent.

> *Local-scale studies may benefit from geotechnical data collection that can inform updated cliff limits to further reduce the erosion hazard extent.*

Figure 5-2 Cliff Limit Example for 95th Percentile 1% AEP Results

5.4 Structure Influence

Functional Structures

Where functional structures are present, a default erosion hazard extent of 10m has been mapped. This captures these structures within the erosion hazard area. This is advantageous in the instance that hazard areas are used to analyse asset vulnerability within GIS tools, and such coastal protection assets should be flagged as potentially vulnerable. Any analysis of the actual erosion response of a given structure will require a detailed site-specific assessment. This methodology assumes that such structures will control the shoreline position under all of the modelled future erosion conditions, which may not be the case for existing structures unless they are upgraded and maintained.

Non-Functional Structures

Where non-functional structures ('Very Poor' condition in the CAMS database) are present, it has been assumed that they will not necessarily provide any protection from coastal erosion hazard. Where these are present in TCSC with available nearby information, an erosion hazard extent has been projected behind these using the relevant TCSC processes (i.e., the LT, the ST and the FR components).

However, there are some non-functional structures within TCSCs that consist entirely of engineered shorelines. As such, there is no available information on long-term shoreline position changes (as the engineered shoreline limit this), or suitable shoreface slopes, or upper beach-face slopes (as the presence of seawalls interferes with these). In these scenarios, values of erosion setback have been selected from the nearest suitable shoreline and applied.

This approach to non-functional structures increases the uncertainty in these areas. However, the intention is to represent the increase in hazard area associated with the existing lack of asset functionality. Any specific modelling of the response of erosion and asset failure in these areas will require a specific detailed model of the site-specific interactions.

Figure 5-3 shows a non-functional structure at Olivers Hill, Frankston (TCSC 42) (along with some adjacent functional structures). The erosion processes have been taken from the adjacent TCSC, which is a wide sandy shoreline. Given that this structure is relatively short, the erosion hazard extent appears as a narrow area of potential setback. This is unrealistic if the adjacent seawalls are maintained as it is unlikely that erosion would penetrate to such a degree, but it is a consequence of the regional-scale modelling that does not account for local-scale shoreline responses.

However, this approach is considered to be acceptable in that it demonstrates the higher hazard associated with seawalls in 'Very Poor' condition. If any key assets and/or values are exposed to hazard in such areas, then it warrants a detailed local-scale coastal processes assessment of the structure to inform actions.

Assessments of structure adaptation and functional needs should use these results as a starting point but will require detailed local-scale studies that consider the interactions between structures as they fail/are decommissioned/are repaired.

> *"Assessments of structure adaptation and functional needs should use these results as a starting point but will require detailed local-scale studies."*

Figure 5-3 Non-Functional Structure Example for 95th Percentile 1% AEP Results

5.5 Mobile Spits

As discussed in Section 3.5.4, mobile spits represent a high degree of uncertainty in shoreline position, even at relatively short timeframes (years to decades). Modelling of such processes is highly complex and unsuitable for a project of the scale of the PPBCEHA. Furthermore, a transect-based approach of assessing the long-term trends (such as DSAS), fails to capture the processes with any degree of accuracy.

As such, a conservative erosion hazard extent has been developed for these mobile spit areas that assumes (as a starting point) the total variation in the shoreline position in the observed record is a suitable allowance for potential shoreline movement. This is applied equally at all time periods, Short Term (ST) effects are also applied, but are consistent throughout the future timeframes. Finally, a Future Response (FR) process is included that *does* differ under different SLR projections.

Figure 5-4 presents an example of the erosion hazard extents at a mobile spit using the 95th Percentile 1% AEP results near the Laverton Spit in the Altona Foreshore Reserve (TCSC 183). As the 'baseline' considered is 2010, the underlying aerial image makes evident that the spit has continued to move northwards, and this is not captured in the erosion extent. The area to the south shows a large potential erosion hazard area that is almost equal for all future scenarios, albeit with the contribution of a FR component (in this case an upper beach face slope).

Mobile spits represent a high degree of shoreline uncertainty, and therefore coastal hazard. Any works or planning within their vicinity (within the mapped erosion hazard area as a starting point) would require a detailed study of their morphology considering the spit migration drivers, longshore transport patterns and whether it is likely to stabilise or continue to grow.

> *"Mobile spits represent a high degree of shoreline uncertainty, and therefore coastal hazard. Any works or planning within their vicinity would require a detailed local-scale study of their morphology."*

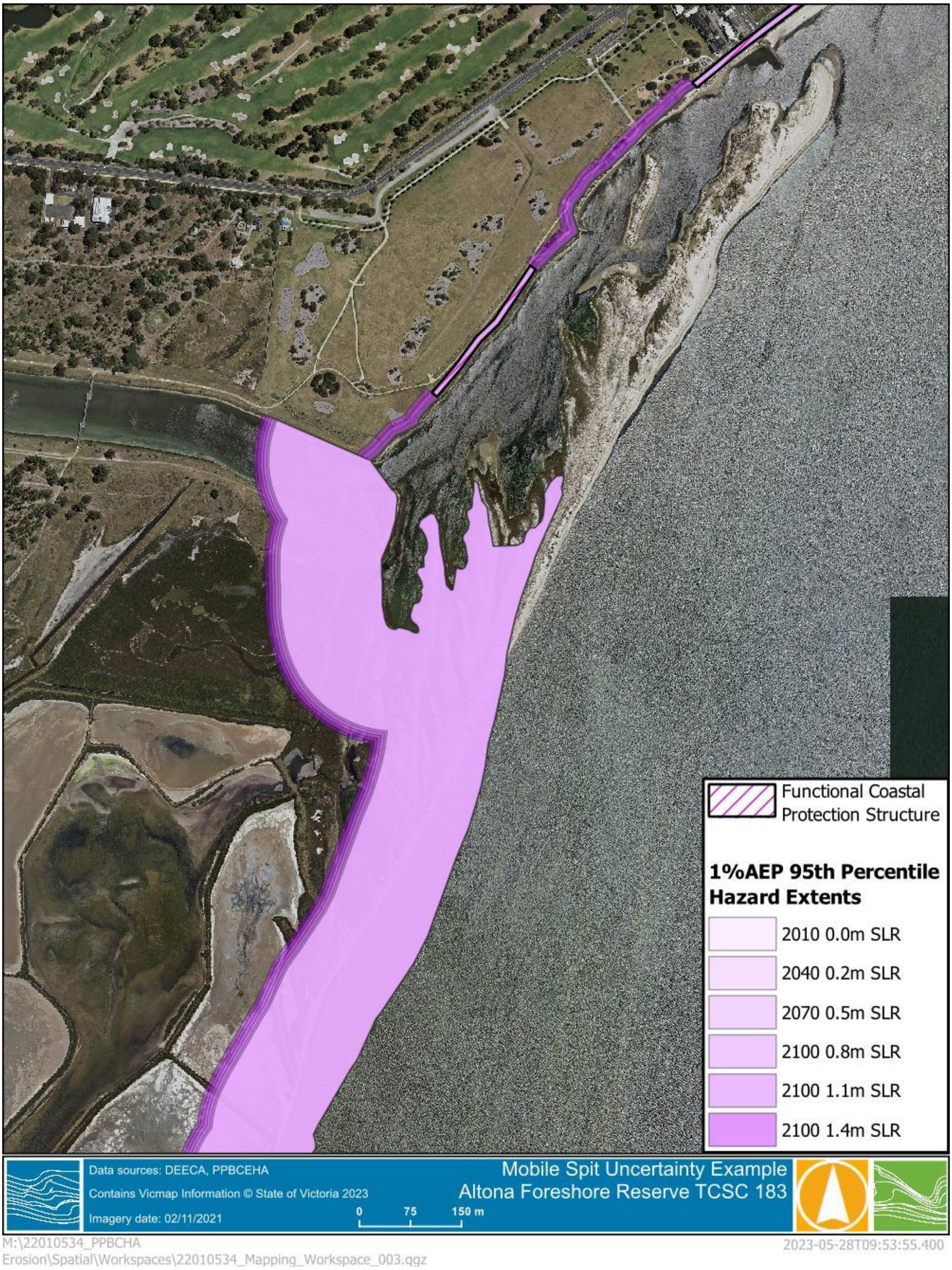

Figure 5-4 Mobile Spit Example for 95th Percentile 1% AEP Results

5.6 Future Response Methodologies

Section 3.6 presents three different methodologies for assessing the Future Response (FR) of a shoreline:

- Using the Bruun Rule, based on the shoreface slope down to the depth of closure (DOC).
- Using the upper beach face slope
- Applying a cliff retreat acceleration based on literature empirical methods (Ashton et al., 2011).

The cliff retreat approach is only applied where cliffs are currently actively exposed to coastal processes. However, the decision-making process for selecting between the other two methodologies is based on a decision-tree that incorporates the understanding of likely responses.

This approach is considered acceptable, but there will inevitably be a discontinuity where the two processes transfer.

Figure 5-5 presents an example of this switching point for the coastline between Dromana (TCSC 73) and Safety Beach (TCSC 72). These two beaches represent 'leaky' sediment compartments, and have been divided based on longshore transport processes over a decadal timescale. However, the discrete point of the change is somewhat subjective. Dromana (to the south) has a wide series of sub-tidal sandbars, that limit direct wave action and represent a surplus of sand in the shoreface. As such it is highly inappropriate to apply the Bruun Rule for such an area. Safety Beach by contrast has a narrow nearshore area and is exposed to westerly waves. There is a gradual transfer along the shore between these two systems, but the discretisation on a TCSC basis requires a sudden change in approach.

The results (Figure 5-5) demonstrate that the erosion hazard extents in Dromana (beach face) are significantly smaller than the hazard extents at Safety Beach (Bruun Rule). It is likely however that at the 95th percentile, a conservative approach has been taken. Therefore, while the erosion extent encompasses a larger setback, the southern end of Safety Beach might not respond as dramatically as the northern end.

Any consideration of detailed risk or adaptation planning in this area should consider a local-scale study that varies the discretisation approach according to the area of interest.

> *"Any consideration of detailed risk or adaptation planning in this area should consider a local-scale study that varies the discretisation approach according to the area of interest."*

Figure 5-5 Future Response Modelling Approach Change Example for the 95th Percentile 1% AEP

5.7 Sandy Shorelines

Sandy shoreline are the most common shoreline type within PPB as discussed in Section 2.4. In many ways they are the simplest to model given the predictable patterns of behaviour and robust available modelling tools.

Figure 5-6 demonstrates outputs from the 95th percentile 1% AEP at Aspendale Beach (TCSC 37). The results show relatively large erosion hazard extents that encompass several buildings and roads. The future timeframes indicate a consistent increase in hazard with time (and increasing SLR).

A sandy beach is still visible seaward of the erosion hazard extents. This is a consequence of the vegetation shoreline mapping approach, and the used of the vegetation line as the baseline as discussed in Section 3.3. This area can be considered inherently part of the erosion hazard area as it is prone to ongoing fluctuations.

Therefore, any studies that require an understanding of changing beach amenity over time will require a detailed local-scale study based on different assumptions.

> *"Any studies that require an understanding of changing beach amenity over time will require a detailed local-scale study based on different assumptions."*

Figure 5-6 Sandy Shoreline Example from 95th Percentile 1% AEP

5.8 Hard Rock Shorelines

Hard rock shorelines are the least erosive shoreline types in PPB as noted in Section 4. An example of the typical results is shown in Figure 5-7 for Martha Cliffs (TCSC 70). In this area the differences between the different future timeframes are imperceptible at the scale shown. The erosion hazard extents represent a narrow band landward of the cliff top only.

It is possible that cliff hazard may be exacerbated by processes not considered within the scope of this study. Any consideration of cliff hazard should be separately informed by appropriate geotechnical information, relative to the area in question.

> *"Any consideration of cliff hazard should be separately informed by appropriate geotechnical information, relative to the area in question."*

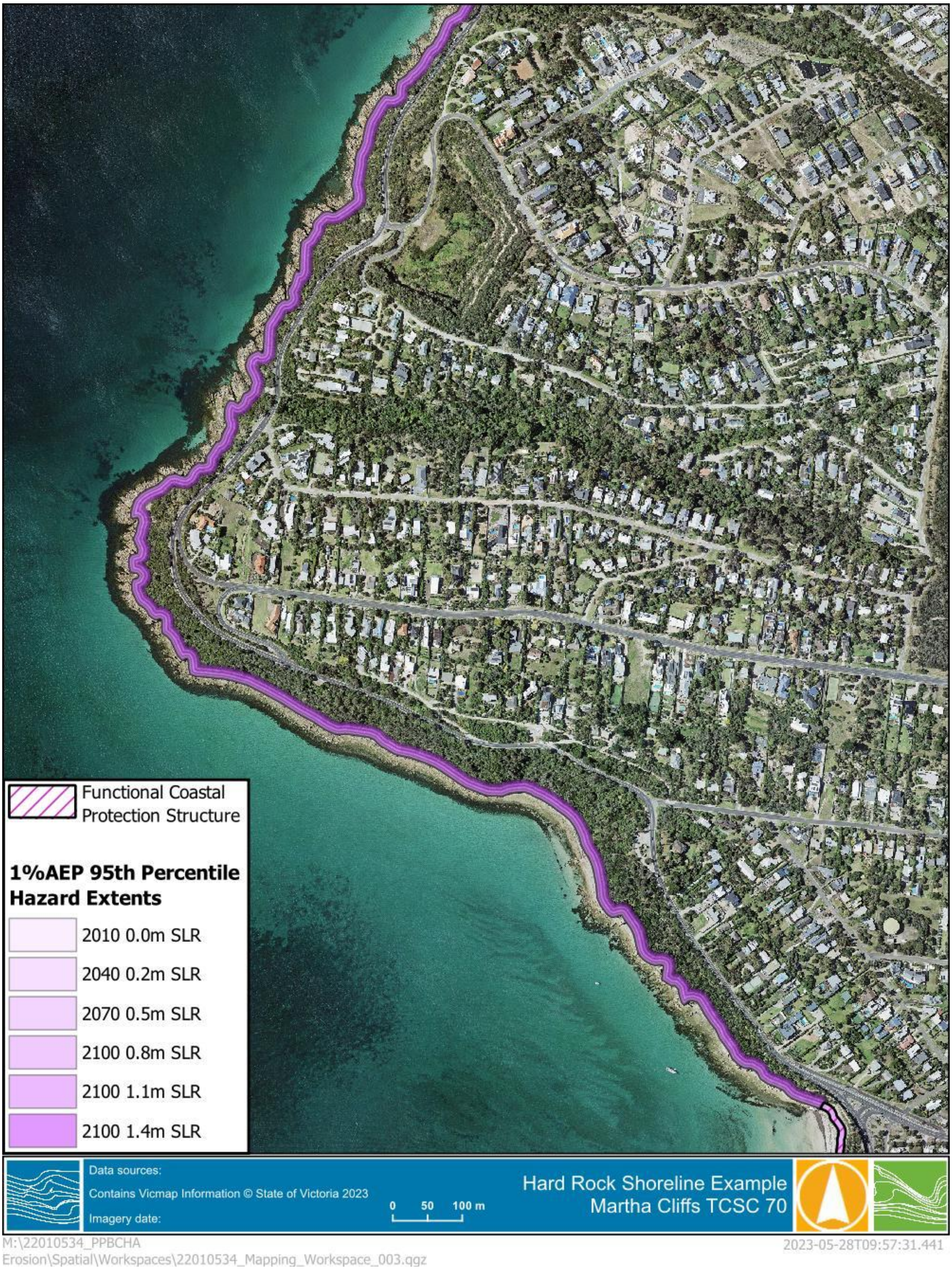

Figure 5-7 Hard Rock Shoreline Example from 95th Percentile 1% AEP

5.9 Soft Sediment Shorelines

Soft sediment shorelines are highly vulnerable to erosion processes, but often naturally not exposed to them. An example of the erosion hazard extents in The Spit Nature Reserve (TCSC 159) is shown in Figure 5-8. This area is relatively sheltered from coastal processes given its alignment towards the east (from which waves and wind is rare) and due to the presence of a partially breached barrier spit in the nearshore. As such, storm (ST) processes have limited effect, and the LT trend is small. The Erosion hazard is therefore dominated by the FR upper beach face approach. This area is more likely to be prone to coastal inundation hazard however .The response of the shoreline if submerged by future sea levels is uncertain.

Therefore, any risk assessments or planning in such areas should consult the inundation hazard extents as the likely key driver of coastal hazard.

> *“Any risk assessments or planning around soft sediment shorelines should consult the inundation hazard extents as the likely key driver of coastal hazard.”*

Figure 5-8 Soft Sediment Shoreline Example from 95th Percentile 1% AEP

5.10 Backshore Wetlands

As discussed in Section 2.5.2, low lying wetlands in the backshore can result in a high degree of uncertainty of future shoreline change. Once the primary coastal embankment, or buffer is breached, the backshore is likely to flood (inundate), with the new effective shoreline many meters landward. Depending on the usage and sensitivity of the wetlands, this may or may not represent a substantial hazard. Furthermore, the processes are compounded by the parallel coastal inundation hazards.

It is an industry standard that coastal erosion and inundation hazards are decoupled for the purposes of modelling. This is as there are no effective tools available that can assess the combined processes with any degree of accuracy over long-term (or even medium-term) timeframes.

Figure 5-9 shows an example of the erosion hazard extents at Moolap (TCSC 126), which has a backshore low-lying wetland that forms part of the former Cheetham Salt Works. The adjacent Point Henry (TCSC 125) shows a contrast where it is low-lying but not a wetland.

The results indicate that the wetlands have a similar erosion hazard extent for the nearer-term (2010 and 2040). However, with greater future sea levels, the Future Response (FR) component begins to dominate and with TCSC 126 showing nearly twice as wide a hazard extent for the 2100 1.4m SLR scenario. This is based on the uncertainty associated with the beach face slope approach in such areas.

Like the soft-sediment shorelines though (Section 5.9), these areas are likely dominated by coastal inundation processes and any further risk assessments or planning should consult these in parallel.

> *"These areas are likely dominated by coastal inundation processes and any further risk assessments or planning should consult these in parallel."*

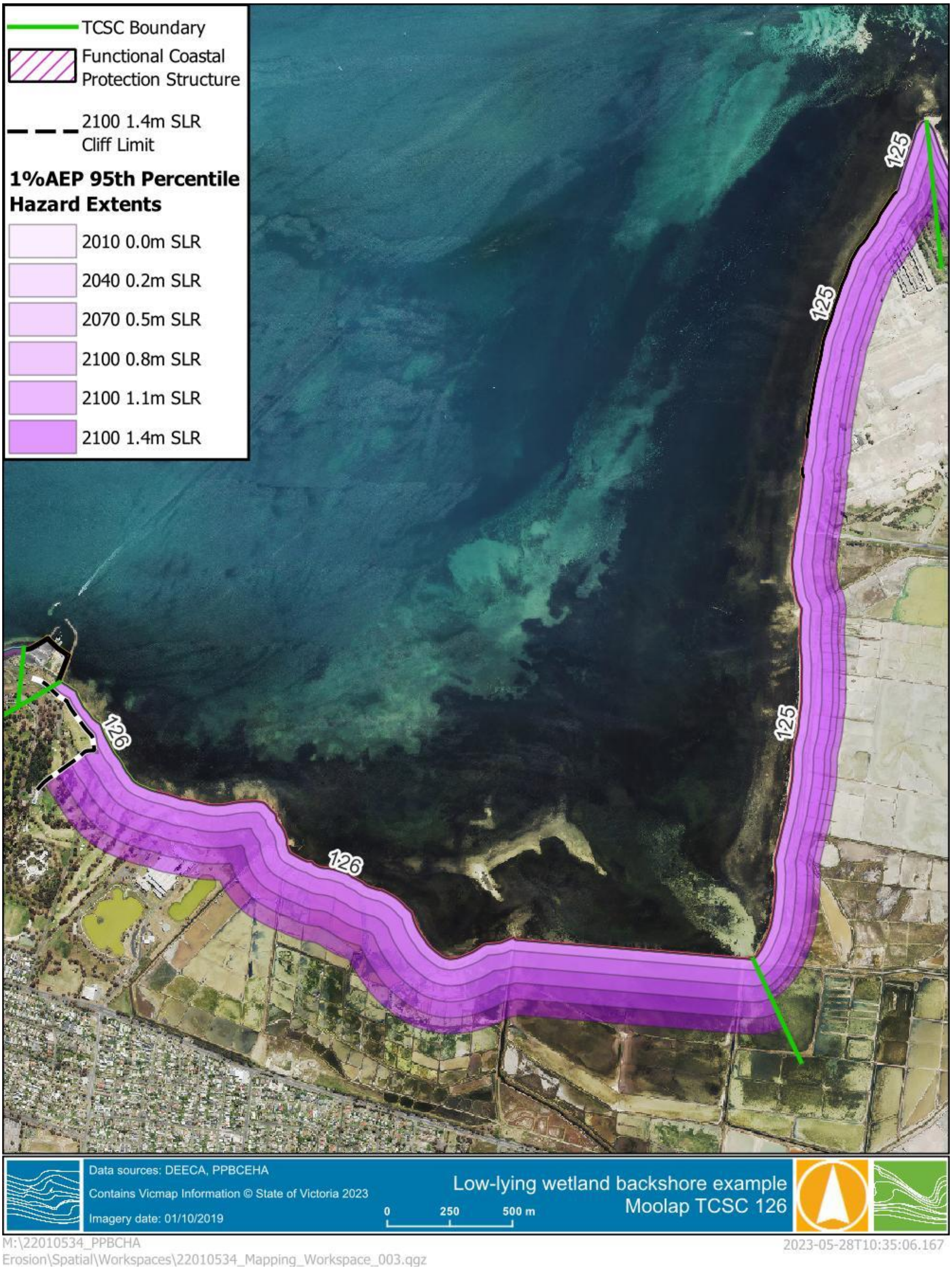

Figure 5-9 Backshore Wetlands Example from 95th Percentile 1% AEP

5.11 Erosion Hazard Mapping

Erosion Hazard mapping results have been prepared as an attachment to this report and supplied to DEECA. These include:

- 95th and 50th Percentile outputs from the Monte Carlo modelling
- 1%, 2% and 5% AEPs
- 2010 (0.0m SLR), 2040 (0.2m SLR), 2070 (0.5m SLR), 2100 (0.8m SLR), 2100 (1.1m SLR) and 2100 (1.4m SLR) results.

These outputs are in GIS formats and can be most-easily explored in a GIS software package.

For the purpose of example, erosion hazard maps are presented below for the 95th Percentile 1% AEP scenario at selected locations within each Local Government Area (LGA) around PPB.

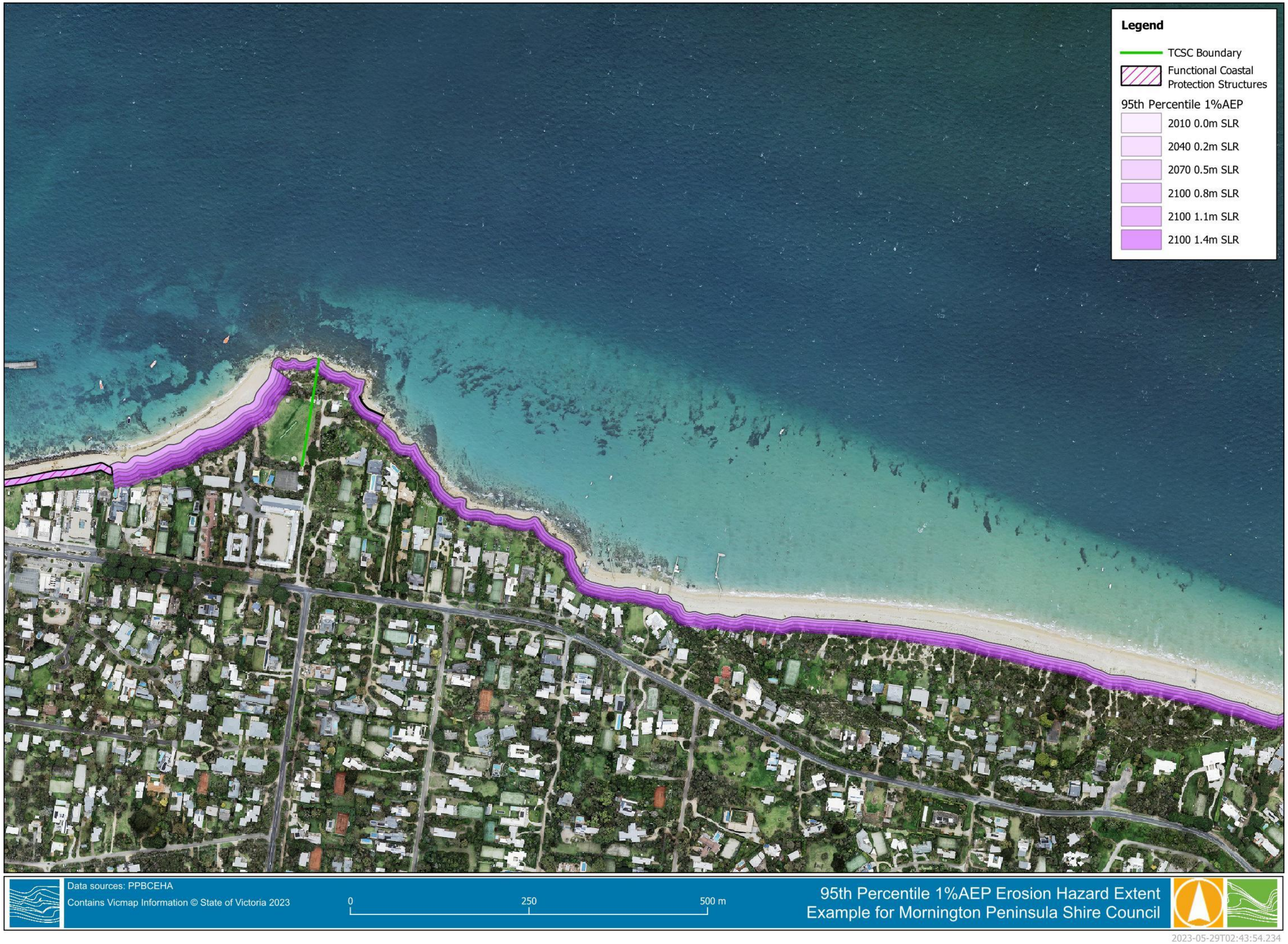

Figure 5-10 95th Percentile 1% AEP Erosion Hazard Extent Example for Mornington Peninsula Shire Council

Figure 5-11 95th Percentile 1% AEP Erosion Hazard Extent Example for Borough of Queenscliffe

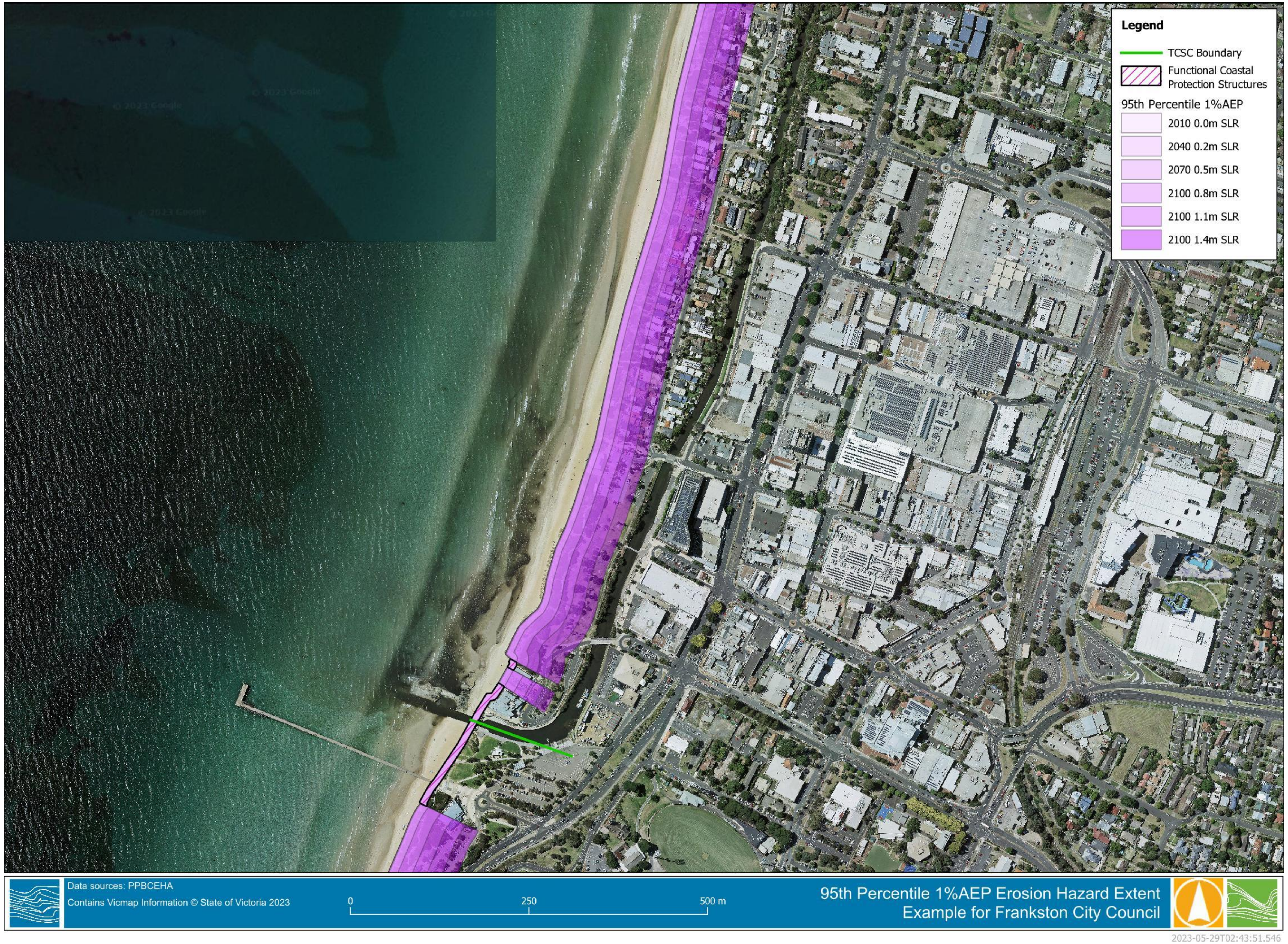

Figure 5-12 95th Percentile 1% AEP Erosion Hazard Extent Example for Frankston City Council

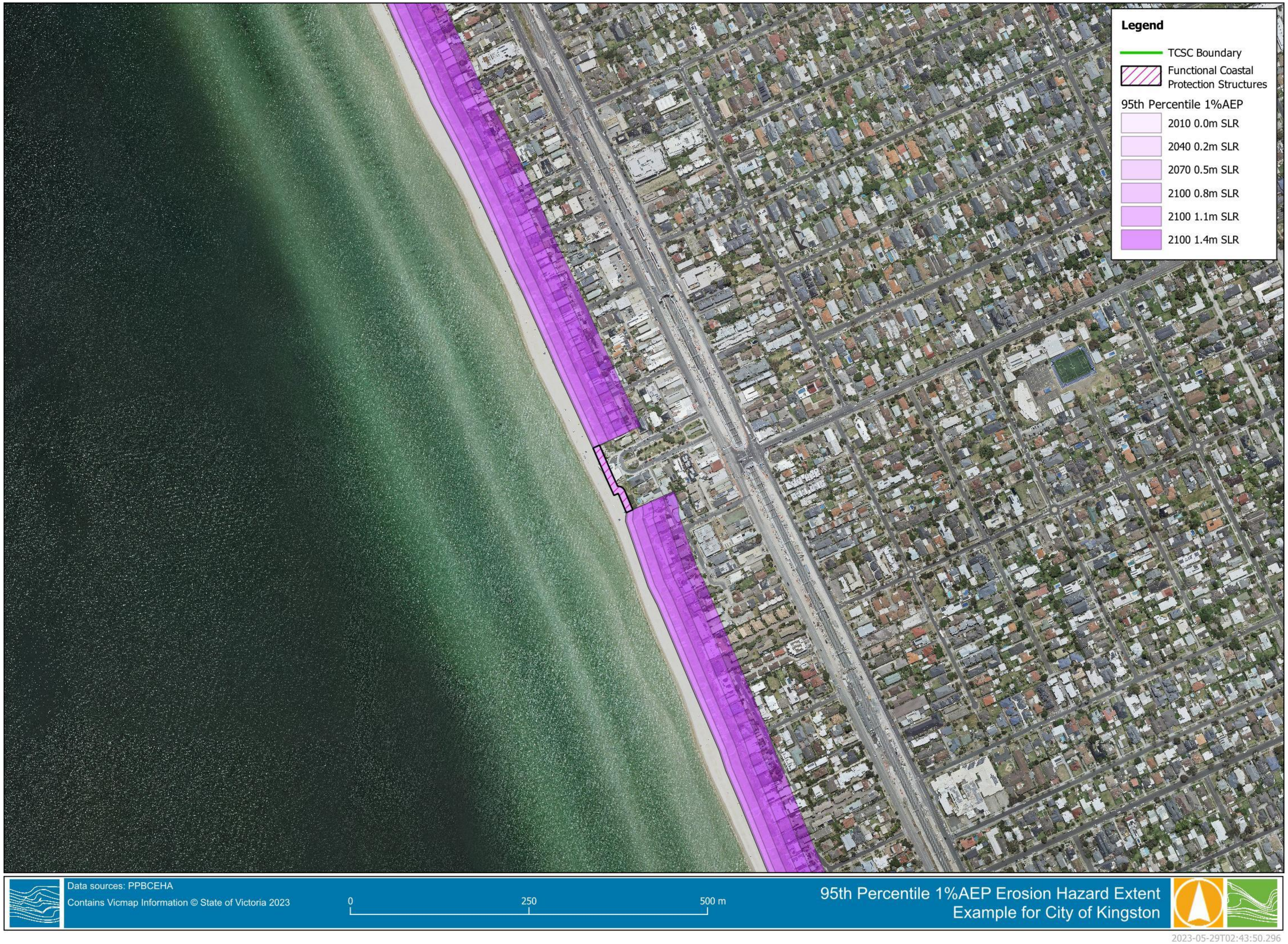

Figure 5-13 95th Percentile 1% AEP Erosion Hazard Extent Example for City of Kingston

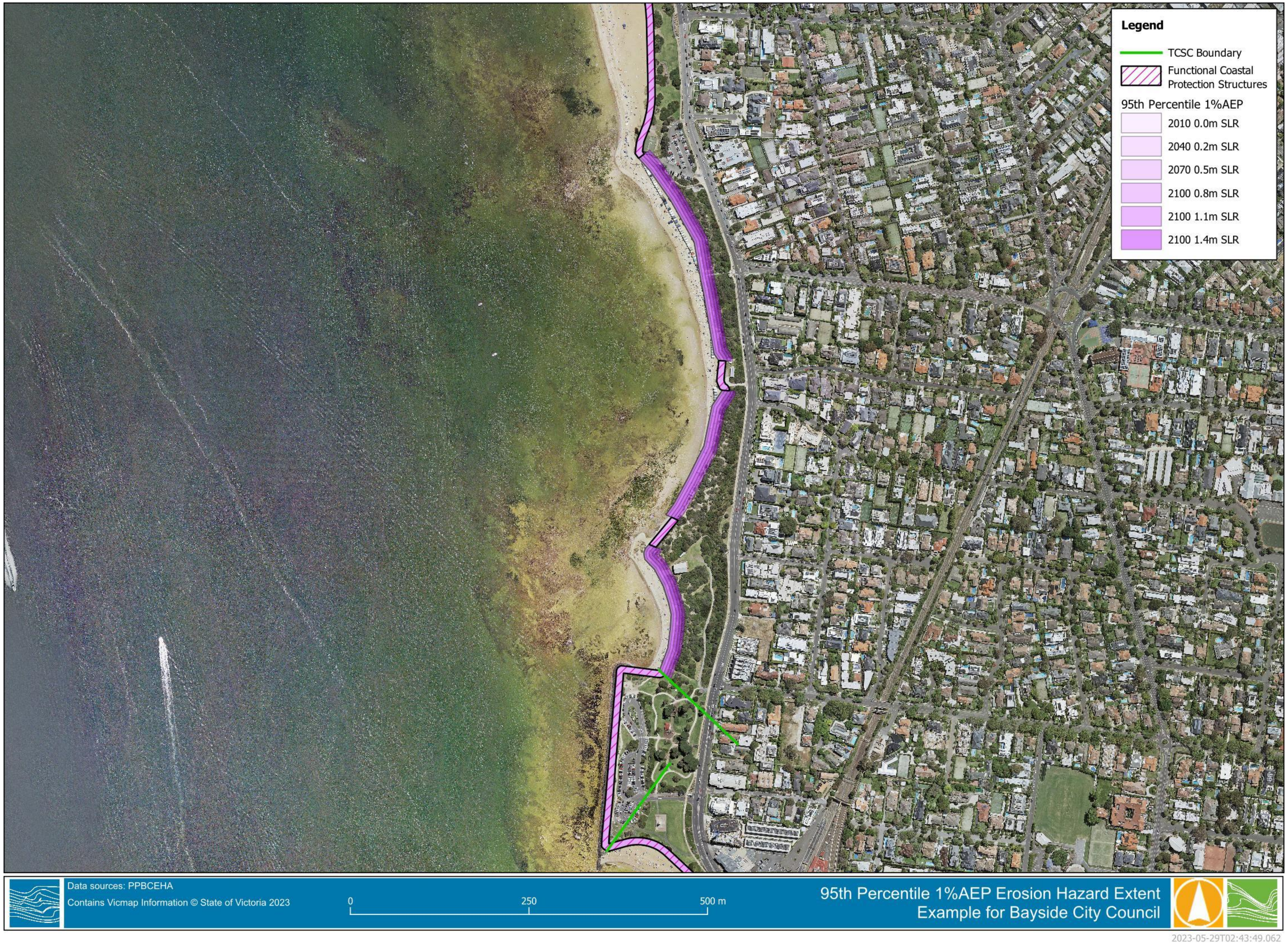

Figure 5-14 95th Percentile 1% AEP Erosion Hazard Extent Example for Bayside City Council

Figure 5-15 95th Percentile 1% AEP Erosion Hazard Extent Example for City of Port Phillip

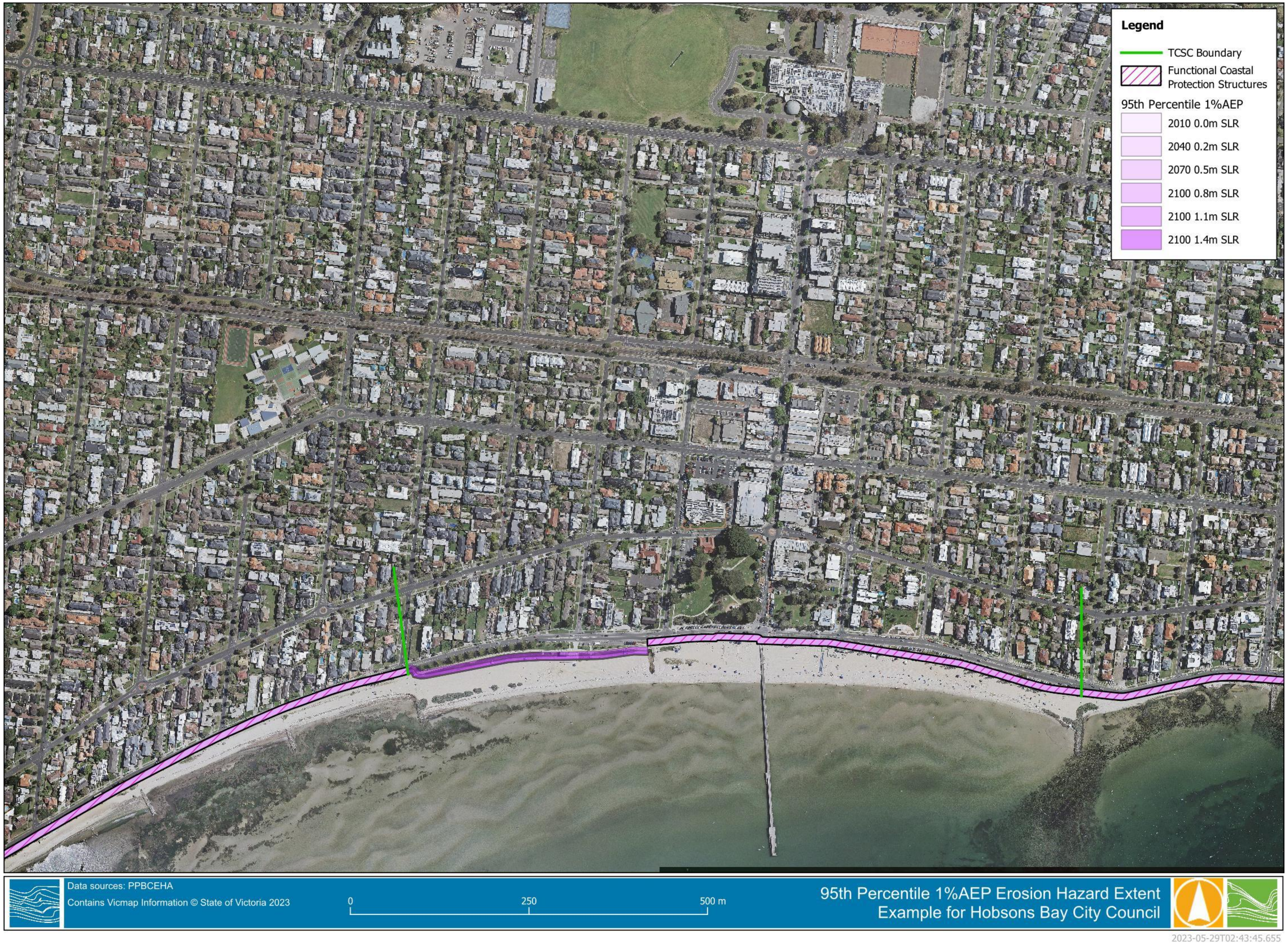

Figure 5-16 95th Percentile 1% AEP Erosion Hazard Extent Example for Hobsons Bay City Council

Figure 5-17 95th Percentile 1% AEP Erosion Hazard Extent Example for City of Wyndham

Figure 5-18 95th Percentile 1% AEP Erosion Hazard Extent Example for City of Greater Geelong

6 SUMMARY AND RECOMMENDATIONS

6.1 Overview

A coastal erosion hazard model has been prepared for Port Phillip Bay incorporating different processes and drivers of potential future erosion. A probabilistic modular approach has been adopted that acknowledges the limitations in input data, available modelling tools, and the potential for change in SLR projections that depend on a global societal decision.

As such, the model can be readily updated as additional relevant information becomes available.

6.2 Recommendations

The PPBCEHA has been developed based on the best-available datasets and information. The assumptions and data availability should be regularly reassessed

The following further works should be considered to reduce the uncertainty associated with the erosion hazard assessment:

- **Updated hydrodynamic and wave modelling**: the SCHISM modelling results are likely to underpredict wave heights in PPB. It is understood that this is currently being updated to calibrate to the now-available VCMP wave buoy data. Updated results can inform further updates to the ST erosion components.
- **Continued data collection**: The VCMP (waves and beach survey) datasets should continue to be collected to provide further input for subsequent revisions and improvements on the erosion hazard assessment.
- **Updated Bathymetric Data**: The VCMP beach survey data do not include the nearshore profile. The PPBCEHA has demonstrated that the nearshore area is an important feature of coastal processes within PPB. Additional datasets of bathymetric changes (or stability) would help to improve future studies.

In the meantime, the PPBCEHA data should be used to analyse the key risk areas (based on environmental, societal, cultural and economic values at risk) around PPB and to inform local-scale studies. Adaptation plans can then be used to prepare for the best response to future coastal hazards and avoid status-quo or maladaptive responses.

6.3 How to use Model Outputs

The key modelling outputs are the hazard maps, representing the 95th percentile of the total erosion setback, as calculated within the Monte Carlo model. It is important to recognise the following:

- Erosion hazard extents do not represent the alignment of a future shoreline but are an area within which a future shoreline may occur. The alignment, or variation within a given TCSC is likely to be contained within it but may not reach these limits at all points.
- The 95th Percentile is a conservative assessment of the hazard extent. However, 5% of the modelled scenarios exceed this. Therefore, there is a potential for different areas within the Bay to erode beyond this. The range of modelled outputs (included as a separate data table) for each TCSC should be considered to understand how variable the erosion may be for a section of coast. These may indicate areas that warrant further site-specific studies of erosion hazard to attempt to refine the understanding of the variations.
- The modelling is representative of the available data and the assumptions. Before using these outputs in future, stakeholders should assess whether the fundamental assumptions still apply (e.g., coastal protection structures are maintained), or whether updated datasets are available that may change the analysis.

Following this, the hazard outputs may be used to assess the potential area prone to erosion under different future scenarios (combinations of timeframes and SLR projections). As the hazard assessment has been conducted on a TCSC scale, any use of these outputs should also be done on a whole-of-compartment scale. Any use of the datasets for analysing sub-compartment processes (i.e., adaptation options of a particular structure) should first consider the suitability of these results, the variability in the total erosion output for this area (indicative of uncertainty) and whether there is any available site-specific data that can be used to update the erosion hazard assessment at a local-scale.

Model input summary files are attached that provide the analysed datasets and inputs required to rerun the erosion hazard model. These files may be modularly updated to produce new hazard extents as additional data become available. The list of datasets provided is summarised in Appendix B. In general, it includes data tables (in CSV formats) of the inputs for each TCSC, and GIS datasets showing the analysis areas. The Monte-Carlo model (in python code) has also been provided.

The outputs of the erosion hazard assessment should be considered in conjunction with the inundation hazard assessment (McInnes et al. 2022). This includes further background information on the storm-tide and wave inputs to the erosion hazard assessment (also described in the Data and Literature Review Report R01, Water Technology, 2023a).

7 REFERENCES

Allemand, J., Keysers, J., Quadros, N., Deen, R. (2017). *2017 Victorian Coastal DEM Report*. CRC for spatial information.

Ashton, A.D., Walkde, M.J.A., Dickson, E. (2011). *Equilibrium responses of cliffed coasts to changes in the rate of sea level rise*. Marine Geology, 284, 217-229.

Bruun, P. (1962). *Sea-level rise as a cause of shore erosion*. J. Waterways Harbors Div 88:117-130.

Bruun, P. (1988). *The Bruun Rule of erosion by sea level rise: a discussion on large-scale two- and three-dimensional usages*. JCR, 4, 627-648.

Cardno (2018). *Managing Better Now*. Report series for Association of Bayside Municipalities.

Cardno (2019). *Beach Nourishment Priorities in Port Phillip, 2018/19 to 2022/23*. Prepared for DELWP

Coastal Asset Management System (CAMS) database. Data provided by DEECA, November 2023.

Hallermeier, R.J. (1978). *Uses for a calculated limit depth to beach erosion*. Proceedings, 16th Coastal Engineering Conference, ASCE, pp. 1493 – 1512.

Hallermeier, R.J. (1981). *A profile zonation for seasonal sand beaches from wave climate*. Coastal Engineering, 4: 253-277

Holdgate, G.R., Wagstaff, B., and Gallagher, S.J. (2011) *Did Port Phillip Bay nearly dry up between ~2800 and 1000 cal. yr BP? Bay floor channelling evidence, seismic and core dating*. Australian Journal of Earth Sciences, 58: 157-175

Jiang, Z. (2019). *Foredune Dynamics on the Coast of Port Phillip Bay (PPB)*, Master of Geography Thesis, The University of Melbourne, 127pp.

Kennedy, D. M. (2022). *Tertiary Coastal Compartments in Port Phillip Bay: Review, Definition & Methodology*. Report prepared for DELWP.

Larson, M. and Kraus, N.C. (1989). *SBEACH: Numerical model for simulating storm-induced beach change, Report 01: Theory and Model Foundation*. US Army Engineer Waterways Experiment Station, Vicksburg USA.

Mariani, A., Shand, T. D., Carley, J. T., Goodwin, I. D., Splinter, K., Davey, E. K., Flocard, F., Turner, I. L. (2012), *Generic Design Coastal Erosion Volumes and Setbacks for Australia*, Antarctic Climate & Ecosystems Cooperative Research Centre, Hobart, Tasmania.

McCarroll, J. (2021). *Port Phillip Bay Beach Nourishment Program Preliminary Assessment – Incorporating Victorian Coastal Monitoring Program (VCMP) Data: Draft v4.1*. DELWP internal Report.

McInnes, K. L., O'Grady, J., Prakash, M., Dahlhaus, P., Rosengren, N., Hoeke, R., Arrowsmith, C. L., Hernaman, V., Cohen, R., Seers, B., Chen, Y., Walters, D., Couto, P., Trenham, C., Forbes-Smith, N., Gregory, R., Hemer, M., Power, R. (2022). *Port Phillip Bay Coastal Hazard Assessment: Draft Final Report*. CSIRO

Pucino, N., Kennedy, D. M., Carvalho, R. C., Allan, B., Ierodiaconou, D. (2011). *Citizen science for monitoring seasonal-scale beach erosion and behaviour with aerial drones*. Scientific Reports. 2021; 11:3935

Sharples C, Mount R, Pedersen T (2009) *The Australian coastal Smartline geomorphic and stability map version 1: manual and data dictionary*. School of Geography & Environmental Studies, University of Tasmania.

Stevens, H., (2010). *Eshorance: an online methodology for estimating the response of estuarine shores from sea level rise*, NSW Coastal Conference, 2010

Thom, B. G., Eliot, I., Eliot, M., Harvey, N., Rissik, D., Sharples, C., Short, A. D., Woodroffe, C. D. (2018). *National sediment compartment framework for Australian coastal management.* Ocean & Coastal Management, 154, 103-120.

Tonkin & Taylor. (2017). *Coastal Hazard Assessment for Christchurch and Banks Peninsula.* Prepared for Christchurch City Council.

US Geological Survey (USGS) (2018). *Digital Shoreline Analysis System (DSAS) Version 5.0 User Guide*. Report 2018-1179. Reston USA.

VCMP survey data. Available at https://vcmp.prpellr.com, credentials available upon request to vcmp@delwp.vic.gov.au, accessed January 2023.

VCMP wave data. Available at https://vicwaves.com.au, accessed January 2023.

Water Technology (2022). *Victoria's Resilient Coast Coastal Hazards Extended Guideline*. Report prepared for DELWP as part of the Victoria's Resilient Coast (VRC) program.

Water Technology (2023a). *Data and Literature Review Report R01 – Port Phillip Bay Coastal Erosion Hazards*. Report prepared for DEECA as part of the Port Phillip Bay Coastal Hazard Assessment.

Water Technology (2023b). *Technical Methodology Report R02 – Port Phillip Bay Coastal Erosion Hazards*. Report prepared for DEECA as part of the Port Phillip Bay Coastal Hazard Assessment.

APPENDIX A
EROSION HAZARD MODELLING DATASETS

ID	Dataset	Folder Location	File Format	Description	Handover Date
1	SBEACH Setback Distances	.\SBEACH\SBEACH_Setback_Distances.csv	.csv	Analysed mean setback distances for every tertiary coastal sediment compartment (TCSC), and every associated storm return interval. Also includes the storm demand volumes and the height over which the erosion has been averaged.	26/05/2023
2	Raw Vegetation Line Shorelines	.\Spatial\Shorelines\Vegetation_Shorelines\{YEAR}_Vegetation_line.shp	.shp	Shapefiles containing vegetation lines for the corresponding year {YEAR}.	26/05/2023
3	Adjusted Vegetation Line Shorelines for DSAS Analysis	.\Spatial\Shorelines\Vegetation_Shorelines_Used_For_DSAS\{YEAR}_DSAS_Vegetation_line.shp	.shp	Shapefiles containing vegetation lines for the corresponding year {YEAR}. These have been editted/trimmed to remove interference from processes that are not indicative of longterm trends (e.g. groyne construction, etc.)	26/05/2023
4	Bruun and Beach Face slopes	.\MONTECARLO\Inputs\AllBruunSlopes.csv	.csv	Bruun and beach face slopes used for input into Montecarlo model. Lower (2.5th percentile), median (50th percentile) and upper (97.5th percentile) bounds for each to make triangular distribution in model. TCSC SLR value of 1 in PPB_Baseline_Shoreline.shp uses Bruun values and SLR value of 2 uses Beach Face	26/05/2023
5	Calculated DSAS LRR Results per TCSC	.\MONTECARLO\Inputs\DSAS_percentiles.csv	.csv	Analysed DSAS Longterm Recession Rate (LRR) results for the lower (2.5th), median (50th) and upper (97.5th) percentiles for every TCSC. Used for the triangular distribution in the Montecarlo for TCSC with a Longterm value of 1 in the PPB_Baseline_Shoreline.shp.	26/05/2023
6	Calculated DSAS SCE Results per TCSC	.\MONTECARLO\Inputs\DSAS_SCE_percentiles.csv	.csv	Analysed DSAS Shoreline Change Envelope (SCE) results for the 2.5th, 50th and 97.5th percentiles for every TCSC. These are used as the lower, median and upper bounds of the triangular distribution in the Montecarlo for TCSC with a value of 2 for Longterm in the PPB_Baseline_Shoreline.shp below.	26/05/2023
7	Adjusted Baseline Shoreline for Montecarlo model	.\MONTECARLO\Inputs\PPB_Baseline_Shoreline.shp	.shp	Baseline shoreline used to create erosion buffers (Not continuous). This defines the 'Type' of approach used for each erosion component using attributes for each segment. SLR values of 1 correspond to a Bruun approach, 2 to a beach face approach and 3 to a cliff retreat approach. Values of 0 indicate no SLR applied (Functional Structures only) Longterm values of 1 correspond to using the DSAS Linear regression trend and 2 to using the total change envelope (for mobile spits). Values of 0 indicate no SLR applied (Functional Structures only) Storm values of 1 correspond to applying a storm and 0 to not applying a storm.	26/05/2023
8	Sbeach Results per TCSC	.\MONTECARLO\Inputs\Sbeach_Results.csv	.csv	Analysed setback distances per storm scenario for input into Montecarlo model	26/05/2023
9	Buffer distances per shoreline segment per scenario	.\MONTECARLO\Outputs\PercentileOutputs_{STORM}_{YEAR}_{SLR}.csv	.csv	CSV files containing the buffer distance for percentiles (0.01-99.9) for each shoreline segment for the corresponding storm scenario {STORM}, year {YEAR} and sea level rise scenario {SLR}	26/05/2023
10	Script for running Montecarlo model	.\MONTECARLO\MontecarloModelRunning.ipynb	.ipynb	Script used to run the Montecarlo model. Requires Python/Jupyter Notebook software and several packages installed.	26/05/2023
11	Mean D50 grainsizes	.\SBEACH\Mean_D50_GrainSize.csv	.csv	Mean D50 grain sizes from along the beach profile extracted the from closest sample locations for each TCSC	26/05/2023
12	Mean Profile per TCSC	.\SBEACH\Profiles\Initial_Beach_Profiles\{TCSC}_MeanProfile.csv	.csv	Mean profile for each TCSC {TCSC}	26/05/2023
13	All Profiles extracted per TCSC	.\SBEACH\Profiles\Initial_Beach_Profiles\AllProfiles_Comp_{TCSC}.csv	.csv	Profiles for each transect in a given TCSC {TCSC} used to calculate the mean profile for that TCSC	26/05/2023
14	Image of plot of mean and all profiles per TCSC	.\SBEACH\Profiles\Initial_Beach_Profiles\Comp_{TCSC}.jpg	.jpg	Image of the plot of the mean profile (red line) and the profiles that were used to calculate the mean (grey lines) for each TCSC {TCSC}	26/05/2023
15	Sbeach Results per storm scenario per TCSC	.\SBEACH\Profiles\Results\{GROUP}\{TCSC}_{SUBGROUP}_{STORM}.csv	.csv	Extracted initial and final profiles per storm scenario {STORM} for each TCSC {TCSC}. They were grouped into consistent storm groupings for ease of simulation. The {GROUP} and {SUBGROUP} tags refer to these groupings and serve no other purpose.	26/05/2023
16	Storm conditions used for each TCSC	.\SBEACH\Storm_Conditions_For_SBEACH.xlsx	.xlsx	Wave Height and Storm Tide levels per storm scenario used for each TCSC	26/05/2023
17	DSAS Results	.\Spatial\DSAS\DSAS_Results.shp	.shp	Shapefile of the DSAS results for each transect	26/05/2023
18	Erosion Hazard Buffer Polygon Results	.\Spatial\Final Erosion Hazard Extents\50th Percentile\Post Cliff Clipping\{STORM}_{YEAR}_{SLR}_output_50th_percentile.shp	.shp	Shapefile of the final 50th percentile erosion hazard polygons for each storm scenario {STORM}, year {YEAR} and sea level rise scenario {SLR}. These polygons **have** been clipped by cliff clipping lines	26/05/2023
19	Erosion Hazard Buffer Polygon Results	.\Spatial\Final Erosion Hazard Extents\50th Percentile\Pre Cliff Clipping\{STORM}_{YEAR}_{SLR}_output_50th_percentile.shp	.shp	Shapefile of the final 50th percentile erosion hazard polygons for each storm scenario {STORM}, year {YEAR} and sea level rise scenario {SLR}. These polygons **have not** been clipped by cliff clipping lines	26/05/2023
20	Erosion Hazard Buffer Polygon Results	.\Spatial\Final Erosion Hazard Extents\95th Percentile\Post Cliff Clipping\{STORM}_{YEAR}_{SLR}_output_95th_percentile.shp	.shp	Shapefile of the final 95th percentile erosion hazard polygons for each storm scenario {STORM}, year {YEAR} and sea level rise scenario {SLR}. These polygons **have** been clipped by cliff clipping lines	26/05/2023
21	Erosion Hazard Buffer Polygon Results	.\Spatial\Final Erosion Hazard Extents\95th Percentile\Pre Cliff Clipping\{STORM}_{YEAR}_{SLR}_output_95th_percentile.shp	.shp	Shapefile of the final 95th percentile erosion hazard polygons for each storm scenario {STORM}, year {YEAR} and sea level rise scenario {SLR}. These polygons **have not** been clipped by cliff clipping lines	26/05/2023
22	Geodatabase of Erosion Hazard Buffers	.\Spatial\Final Erosion Hazard Extents\PPB_ErosionBuffers.gdb	.gdb	Geodatabase of the final erosion hazard polygons	26/05/2023
23	Cliff clipping lines	.\Spatial\Final Erosion Hazard Extents\Cliff_Clipping\{YEAR}_{SLR}_Cliff_Clipping.shp	.shp	Mapped cliff clipping line offset a certain distance based on year {YEAR} and sea level rise scenario {SLR}. Used to clip the erosion buffers where cliffs exist	26/05/2023
24	Traced cliff line	.\Spatial\Final Erosion Hazard Extents\Cliff_Clipping\Cliff_Clipping_Baseline.shp	.shp	Shapefile with the mapped top of cliff from which clipping layers were offset from	26/05/2023

25	Coastal Structures	.\Spatial\Shorelines\Coastal_Structures.shp	.shp	Shapefile with mapped coastal structures based on CAMs database used in analysis	26/05/2023
26	Transects used for Sbeach	.\Spatial\SBEACH_Transects.shp	.shp	Transects used to make the mean profiles for Sbeach analysis. Value of 1 in Sbeach attribute indicates a transect used	26/05/2023
27	TCSC boundaries	.\Spatial\Sediment_Compartment_Boundaries.shp	.shp	Boundaries between the TCSCs at which the buffers start/stop.	26/05/2023
28	Imagery dates per TCSC	.\Imagery_Dates	.xlsx	Table of the dates for each image used to create vegetation lines per TCSC	26/05/2023

APPENDIX B
MONTE CARLO INPUT TABLES

Table B-1 LT Triangular Distributions (from DSAS Analysis)

TCSC	Lower Bound	Mode	Upper Bound
1	-0.56675	-0.215	0.0905
18	-1.48	-1.1	-0.363
19	-0.16175	-0.055	0.058
23	0	0	0
24	-0.333	-0.23	-0.075
26	-0.15675	0.02	0.13075
27	-0.15675	0.02	0.13075
28	-0.10775	0.02	0.06775
29	-0.10625	-0.065	-0.00375
31	-0.373	-0.07	0.031
32	0.0035	0.07	0.1555
33	-0.113	-0.05	0.062
34	-0.013	0.03	0.089
35	-0.13775	-0.085	0.02775
36	-0.355	-0.165	-0.025
37	-0.2755	-0.2	-0.089
38	-0.55725	-0.15	-0.047
39	-0.349	-0.05	0.06
40	-0.2405	-0.12	-0.0295
41	-0.08725	-0.05	-0.01275
42	-0.08725	-0.05	-0.01275
44	-0.043	0.03	0.0665
45	-0.0075	0.01	0.075
46	0.03125	0.04	0.05
47	0.0215	0.04	0.11
48	-0.0245	0.02	0.096
50	-0.00475	0.02	0.04
51	-0.06	-0.03	0
52	-0.08775	0	0.0955
53	-0.00875	0.03	0.12375
54	-0.01	0.01	0.091
55	-0.0825	0	0.0375
56	-0.0375	0	0.0275
57	-0.0375	0	0.0275

TCSC	Lower Bound	Mode	Upper Bound
58	0.003	0.03	0.047
59	0.0115	0.035	0.077
60	-0.01	0.01	0.04775
61	-0.04	-0.03	0.02625
62	-0.0525	-0.01	0.05
63	-0.025	0.02	0.05
64	-0.04	-0.03	0.08125
65	0.04075	0.055	0.06925
66	-0.03	0.01	0.0895
67	-0.057	-0.01	0.065
69	-0.15225	-0.015	0.0815
70	-0.07125	0	0.12
71	-0.02	-0.02	-0.02
72	-0.122	0.01	0.042
73	-0.152	-0.06	0.068
74	-0.98	-0.36	0.08125
75	-0.6145	-0.25	-0.0855
76	-0.71475	-0.16	0.6485
77	-0.8115	-0.48	-0.0505
78	-0.24	-0.06	0.06725
79	-0.774	-0.56	-0.154
80	-0.33075	-0.12	-0.06
81	-0.29325	-0.115	0.0155
82	-0.31325	-0.12	0.04
83	-0.42925	-0.375	-0.13575
84	-0.284	-0.05	0.046
85	-0.2225	-0.045	0
86	-0.83	-0.095	0.20375
87	0	0	0.082
88	-0.009	0.02	0.03
89	-0.12575	-0.01	0.09
90	0.26775	0.725	1.02275
91	0.00975	0.07	0.15025
92	-0.0235	0.045	0.07675
93	-0.33	0.02	0.75

TCSC	Lower Bound	Mode	Upper Bound
94	-2.86325	-0.73	0.05125
95	-1.874	0	2.514
96	-0.32925	-0.03	0.28975
97	0.045	0.345	0.6675
98	-0.2685	-0.03	0.3
99	-1.57575	0.11	1.341
100	-0.08375	0.06	0.23875
101	-0.16425	-0.04	0.0895
102	-0.212	0.06	0.194
103	-0.2615	-0.09	0.07575
104	-0.02375	0.09	0.13625
105	-0.004	0.04	0.226
106	-0.0825	0.11	0.295
107	-0.14875	0.04	0.14775
108	-0.001	0.08	0.2175
109	0.05225	0.105	0.201
110	-0.261	-0.015	0.06875
111	-0.123	0.08	0.903
113	-0.856	0.01	0.473
114	-0.01175	0.085	0.15575
115	-0.01	0.02	0.121
116	-0.15425	-0.01	0.06
117	-0.166	-0.08	0.025
118	-0.073	0.02	0.13475
119	-0.21875	0.1	0.23
121	-0.20325	0.08	0.34775
122	-0.2025	0.045	0.28
123	0.001	0.16	0.3095
124	-0.34	0.04	0.18
125	-0.48025	-0.14	1.1405
126	-0.18	0.02	0.10525
128	-0.06	0.01	0.018
129	-0.06	0.01	0.018
136	-0.1925	-0.09	0.2095
137	0	0.07	0.1895

TCSC	Lower Bound	Mode	Upper Bound
138	-0.02825	-0.015	0
139	0.0205	0.03	0.087
140	-0.0365	-0.01	0.0165
141	-0.097	-0.04	0.0455
142	-0.23975	-0.05	0.05
143	-0.11825	-0.005	0.15675
144	-0.2865	0	0.1715
145	-0.08	0.085	0.2765
146	-0.35475	0.03	0.118
147	-0.1	-0.01	0.14
148	-0.13325	-0.08	-0.0045
149	-0.22	-0.06	0.126
150	-0.96	0.05	0.24
151	-0.22975	0.155	0.42275
152	-0.019	0	0.0095
153	-0.064	0.09	0.12
154	-0.212	0.09	0.12
155	-0.4235	-0.03	0.4715
156	-0.564	-0.46	0.014
157	-1.03825	-0.41	0.12475
158	-0.3305	-0.11	0.253
159	-0.62475	-0.03	0.86875
160	-0.318	-0.05	0.094
161	-0.122	0.05	0.647
162	-0.4365	0.58	0.9065
163	-0.51725	-0.185	0.044
164	-0.138	0.4	0.992
165	-0.7205	-0.13	0.716
166	-0.20225	0.765	1.093
167	-0.41	-0.165	0.1865
168	-0.163	0.04	0.34
169	-0.7155	-0.27	0.445
170	-0.8475	-0.54	-0.26825
174	-0.05925	-0.045	-0.03075
175	-0.05775	-0.005	0.05

TCSC	Lower Bound	Mode	Upper Bound
176	-0.21	-0.05	0.1
177	-0.24675	-0.2	-0.07625
178	-0.406	-0.28	0.072
179	0.02275	0.265	0.601
180	-0.2785	-0.1	0.92125
181	-0.3	-0.16	-0.07
182	-0.47675	0.12	2.0705
183	-0.22625	-0.15	-0.11125
185	-0.22625	-0.15	-0.11125
189	-0.335	0.25	0.4725
190	-0.5525	0.185	0.8475
191	-0.1705	-0.01	0.203
192	-0.0875	-0.04	0.04
194	0	0	0
195	-0.05875	0.015	0.16125
196	0.024	0.06	0.118
197	-0.104	0.02	0.168
201	-0.029	0.05	0.123

Table B-2 ST setback distances (from SBEACH)

TCSC	5% AEP	2% AEP	1% AEP
1	1.15	1.16	1.25
10	4.66	4.63	4.67
15	3.32	3.58	3.82
19	0.00	0.01	0.03
26	0.05	0.25	0.36
27	0.05	0.25	0.36
28	0.35	0.27	0.46
29	0.63	0.97	1.22
31	0.15	0.25	0.37
32	0.00	0.00	0.00
33	0.00	0.00	0.00
35	1.53	1.66	1.78
36	5.78	6.05	5.97
37	1.16	1.28	1.35
38	0.46	0.64	0.79
39	0.04	0.05	0.10
40	0.00	0.00	0.00
41	0.00	0.02	0.08
42	0.00	0.02	0.08
44	0.35	0.73	0.87
45	0.26	0.46	0.56
47	0.46	0.68	0.78
48	1.16	1.11	1.34
50	0.77	0.84	0.92
51	1.91	2.27	2.48
52	0.00	0.00	0.00
53	0.14	0.45	0.45
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.00	0.00	0.00
59	0.29	0.29	0.37
61	0.18	0.18	0.22
63	0.38	0.55	0.57
65	0.35	0.38	0.35

TCSC	5% AEP	2% AEP	1% AEP
66	0.11	0.11	0.11
69	0.00	0.00	0.00
71	0.00	0.00	0.00
72	0.01	0.05	0.15
73	0.00	0.00	0.00
74	0.64	0.79	0.90
75	1.33	1.54	1.68
76	1.58	1.81	1.98
77	1.39	1.72	1.98
78	1.26	1.40	1.56
80	1.68	1.92	1.98
81	3.06	3.29	3.49
82	1.95	2.22	2.56
83	1.15	1.43	1.63
84	0.82	1.01	1.18
85	2.24	2.57	2.76
86	1.98	2.17	2.31
87	6.93	7.26	7.51
88	0.95	1.07	1.20
89	9.44	9.74	9.51
90	7.65	6.71	5.74
91	1.31	1.38	1.43
93	6.40	5.93	5.83
94	2.65	2.69	2.78
95	5.74	6.26	6.80
97	3.35	3.84	4.25
99	2.41	2.40	2.93
100	1.45	1.73	1.94
101	0.09	0.12	0.22
102	1.46	1.74	2.02
103	0.00	0.00	0.00
104	0.24	0.16	0.17
105	0.00	0.00	0.00
106	1.23	1.49	1.70
107	1.11	1.28	1.41

TCSC	5% AEP	2% AEP	1% AEP
108	1.68	2.09	2.39
109	0.00	0.04	0.10
111	0.24	0.41	0.63
113	0.00	0.00	0.01
114	0.00	0.00	0.01
115	0.08	0.09	0.09
117	0.00	0.00	0.04
118	0.04	0.04	0.04
119	0.00	0.00	0.00
121	0.00	0.00	0.00
122	2.71	2.95	3.06
123	3.06	3.29	3.36
124	0.00	0.00	0.00
125	0.00	0.00	0.00
126	0.02	0.04	0.04
128	1.68	2.14	2.35
129	1.68	2.14	2.35
139	1.35	1.55	1.71
141	1.86	2.00	1.98
142	0.76	0.80	0.84
143	0.60	0.81	0.94
145	0.70	0.82	0.89
146	0.65	0.69	0.72
147	0.26	0.30	0.34
148	1.10	1.19	1.23
150	0.81	0.82	0.81
151	1.00	0.99	1.10
152	2.12	2.41	2.64
154	2.54	2.82	3.11
155	0.00	0.00	0.00
156	0.47	0.49	0.52
157	0.76	0.78	0.80
158	1.78	1.83	1.90
159	2.00	2.11	2.13
160	0.11	0.15	0.18

TCSC	5% AEP	2% AEP	1% AEP
161	1.09	1.09	1.03
162	3.66	3.33	3.41
163	2.27	2.27	2.35
164	0.71	0.74	0.74
165	0.60	0.68	0.73
166	2.31	2.36	2.43
167	2.42	2.58	2.43
168	1.12	1.15	1.18
169	0.85	1.21	0.98
170	2.67	2.86	2.97
174	1.31	1.41	1.47
175	0.66	0.76	0.91
176	0.38	0.53	0.61
177	0.00	0.00	0.00
178	0.01	0.02	0.03
179	0.09	0.08	0.12
180	0.64	0.81	0.87
181	2.80	2.98	3.16
182	1.01	1.10	1.19
183	0.00	0.00	0.00
185	0.00	0.00	0.00
189	0.10	0.11	0.11
190	0.92	0.96	1.06
194	0.27	0.66	1.09

Table B-3 FR Factors (from Beach Face Inverse Slope, or Bruun Factor)

Sed Comp	Beach Face Lower Bound	Beach Face Mode	Beach Face Upper Bound	Bruun Factor Lower Bound	Bruun Factor Mode	Bruun Factor Upper Bound
1	9.5	11.5	11.8	126.8	136.7	143.7
8	10.6	11.5	16.2	51.6	58.8	77.9
10	10.6	11.5	16.2	51.6	58.8	77.9
15	9.2	9.2	9.2	86.9	86.9	86.9
18	18.8	22.9	28.2	60.7	78.8	88.8
19	6.4	10.9	16.7	50.3	61.2	79.0
23	6.7	6.7	6.7	132.6	132.6	132.6
24	7.3	12.5	42.1	110.0	114.1	125.0
26	4.3	10.5	17.0	23.7	28.2	50.2
27	4.3	10.5	17.0	23.7	28.2	50.2
28	1.7	8.5	18.8	37.4	46.8	62.8
29	5.6	11.6	53.6	19.7	23.7	30.6
31	7.1	16.1	26.1	56.5	69.7	86.2
32	6.9	8.2	44.6	52.1	67.3	73.3
33	2.8	10.0	24.1	25.8	66.8	88.7
34	0.7	1.4	16.5	17.8	22.2	46.2
35	7.9	10.1	18.6	36.3	56.4	58.9
36	8.6	12.7	19.0	29.4	32.1	35.4
37	9.8	21.2	37.4	57.5	59.0	61.1
38	12.4	29.6	68.9	57.8	60.3	65.3
39	5.8	12.5	32.9	56.2	59.3	61.3
40	5.7	8.7	24.8	53.5	56.9	62.2
41	6.7	8.9	13.4	60.9	63.7	68.4
42	6.7	8.9	13.4	60.9	63.7	68.4
44	8.0	9.9	15.5	23.2	25.0	28.8
45	4.1	10.1	20.8	23.1	33.7	39.0
46	2.6	6.0	7.2	15.1	18.0	29.5
47	2.4	7.9	11.5	27.9	30.1	37.5
48	1.5	9.8	23.5	24.6	31.5	48.3
50	7.0	7.7	10.3	26.6	30.6	38.6
51	4.7	8.1	14.3	18.0	47.6	62.9
52	5.8	8.8	23.8	28.5	35.2	43.9

Sed Comp	Beach Face Lower Bound	Beach Face Mode	Beach Face Upper Bound	Bruun Factor Lower Bound	Bruun Factor Mode	Bruun Factor Upper Bound
53	4.1	7.5	11.9	25.3	30.4	39.2
54	5.6	10.0	19.0	19.8	22.9	35.5
55	5.9	8.9	16.5	22.7	33.6	57.3
56	4.0	5.9	16.0	19.1	30.3	37.0
57	4.0	5.9	16.0	19.1	30.3	37.0
58	3.0	4.2	11.1	10.6	11.2	15.6
59	5.3	8.3	11.9	18.6	21.5	26.1
60	2.2	3.4	8.7	7.8	10.4	18.0
61	3.9	8.1	10.5	21.8	32.4	38.4
62	2.6	5.1	9.7	6.1	12.6	19.5
63	3.9	4.5	6.5	12.8	22.0	31.1
64	8.0	9.4	13.7	26.9	29.5	36.0
65	3.9	11.7	19.4	23.8	25.3	26.9
66	2.8	8.3	19.4	20.6	27.9	39.8
67	6.7	8.9	9.0	28.4	32.3	37.9
69	4.6	8.1	13.6	41.0	52.6	63.7
70	0.8	4.8	17.7	5.2	13.6	45.3
71	22.9	22.9	22.9	39.0	39.0	39.0
72	5.0	9.5	12.6	31.8	36.4	44.7
73	4.8	8.8	14.8	44.9	66.5	94.3
74	5.4	10.0	53.4	75.5	81.0	103.5
75	4.4	7.0	10.6	105.5	143.5	155.7
76	5.2	9.1	20.2	84.8	151.0	167.9
77	9.4	18.2	29.5	75.4	97.0	104.4
78	6.4	10.7	20.8	58.2	89.7	103.7
79	8.5	11.0	72.0	46.2	54.4	68.9
80	4.2	7.1	10.0	67.2	70.1	72.2
81	1.2	9.5	27.3	45.9	95.2	111.6
82	1.2	9.4	13.5	33.5	55.6	73.4
83	6.0	10.3	12.6	40.0	42.8	46.3
84	1.6	2.0	4.5	23.1	30.2	40.2
85	1.0	2.1	6.6	15.7	31.6	46.1
86	1.3	7.2	14.2	12.8	40.3	73.5

Sed Comp	Beach Face Lower Bound	Beach Face Mode	Beach Face Upper Bound	Bruun Factor Lower Bound	Bruun Factor Mode	Bruun Factor Upper Bound
87	1.5	4.8	14.5	11.1	14.5	16.0
88	1.8	7.4	11.2	22.5	26.1	31.0
89	1.2	9.9	31.2	7.6	11.1	22.5
90	8.2	10.7	16.4	13.1	45.1	79.9
91	1.2	6.7	13.1	22.7	58.3	101.2
92	2.5	9.1	11.4	41.1	64.9	73.7
93	8.6	13.2	31.3	18.2	24.3	49.4
94	1.1	12.0	33.2	31.9	60.3	84.4
95	4.4	12.7	27.5	12.2	71.7	115.3
96	2.2	8.9	39.3	24.4	216.7	416.8
97	3.0	9.4	38.4	17.4	36.3	44.3
98	2.3	8.2	105.4	37.0	182.0	486.7
99	4.5	8.7	15.2	39.4	64.0	74.7
100	4.7	7.9	15.6	45.3	50.5	66.2
101	5.9	10.3	65.9	35.2	41.3	67.5
102	2.2	9.6	19.5	32.0	85.0	104.1
103	3.8	9.7	34.3	28.2	32.9	45.6
104	6.3	10.2	17.7	31.4	34.3	40.6
105	2.1	6.4	13.8	26.1	29.9	40.2
106	4.0	9.2	17.0	39.5	88.4	151.2
107	3.6	8.2	21.3	42.7	70.1	152.2
108	2.9	6.0	16.7	29.6	40.7	49.6
109	2.2	11.0	19.0	30.5	36.2	50.4
110	2.6	8.8	13.5	32.3	43.1	52.1
111	4.4	10.6	19.3	40.4	45.5	145.0
113	3.0	9.7	17.1	85.2	190.0	238.9
114	3.5	9.6	23.3	76.3	101.1	179.8
115	5.7	11.0	27.7	90.1	129.9	160.1
116	1.5	9.6	19.7	99.8	131.3	149.9
117	1.3	2.0	10.5	145.6	155.8	178.9
118	0.7	3.4	10.3	149.9	186.2	203.5
119	2.2	6.8	14.9	136.4	170.4	211.0
121	1.2	6.1	18.8	69.2	151.6	218.2

Sed Comp	Beach Face Lower Bound	Beach Face Mode	Beach Face Upper Bound	Bruun Factor Lower Bound	Bruun Factor Mode	Bruun Factor Upper Bound
122	2.4	6.0	16.0	44.9	75.8	99.0
123	2.2	5.0	11.4	94.0	111.0	121.4
124	1.8	7.2	115.4	85.5	111.3	169.2
125	6.1	11.7	130.9	127.3	290.6	491.0
126	1.4	9.8	274.4	45.3	377.0	627.6
128	1.0	7.3	17.8	12.5	20.7	35.7
129	1.0	7.3	17.8	12.5	20.7	35.7
133	1.0	7.3	17.8	12.5	20.7	35.7
136	0.6	2.8	6.6	8.2	24.1	46.3
137	0.8	2.8	12.5	0.5	8.2	15.1
138	1.1	2.0	5.2	11.5	15.2	21.0
139	1.7	1.9	2.6	19.9	25.3	27.1
140	0.4	1.5	4.7	2.2	7.8	13.0
141	2.6	6.8	8.5	38.1	43.4	43.8
142	3.3	8.0	47.4	50.7	101.4	132.5
143	1.4	6.4	32.5	20.3	36.8	186.3
144	5.7	12.6	41.2	36.3	73.6	256.0
145	3.5	8.3	20.1	105.2	161.2	189.6
146	1.8	3.5	31.7	182.2	271.8	511.1
147	7.0	10.5	23.1	221.4	263.4	383.1
148	1.7	6.1	8.0	32.3	46.2	200.7
149	2.6	10.9	30.3	11.2	18.4	54.8
150	1.3	8.0	47.9	30.0	93.0	151.5
151	1.8	5.8	43.7	113.1	137.2	221.9
152	2.8	4.4	6.0	186.0	215.9	226.7
153	3.7	9.8	15.1	109.3	154.5	190.9
154	1.0	2.6	35.9	49.3	160.1	270.0
155	3.1	10.6	36.9	71.5	160.9	225.9
156	2.8	4.6	25.8	66.9	109.9	142.7
157	4.8	10.1	25.3	101.6	136.4	168.8
158	3.2	6.8	112.3	170.1	217.1	268.9
159	2.6	11.0	120.7	99.5	343.6	715.5
160	3.2	8.9	26.4	58.4	122.3	147.7

Sed Comp	Beach Face Lower Bound	Beach Face Mode	Beach Face Upper Bound	Bruun Factor Lower Bound	Bruun Factor Mode	Bruun Factor Upper Bound
161	1.8	5.7	10.1	66.3	119.3	205.4
162	2.4	5.0	36.3	127.4	157.2	262.4
163	5.6	8.9	171.5	202.5	213.6	225.8
164	1.4	5.9	153.9	114.0	151.7	203.4
165	3.4	9.2	47.7	145.1	204.7	243.8
166	3.3	6.8	12.3	128.3	219.6	322.3
167	1.3	6.5	31.5	70.6	99.5	105.3
168	0.7	3.4	22.6	63.7	74.8	138.7
169	3.5	8.5	32.8	143.5	167.1	198.3
170	3.5	5.8	50.5	69.9	156.9	300.3
174	2.2	5.0	7.7	45.6	49.1	52.6
175	5.3	6.9	26.7	49.5	64.0	68.0
176	2.5	4.7	10.1	45.2	54.8	96.9
177	5.6	11.6	22.1	100.2	104.2	113.8
178	3.6	11.2	31.7	129.3	137.3	146.5
179	3.4	8.7	17.0	95.6	131.3	196.1
180	2.5	9.0	42.7	53.1	78.2	109.8
181	3.6	7.6	11.3	44.5	58.8	111.4
182	3.2	9.2	42.8	120.4	165.8	198.8
183	1.7	10.4	31.0	124.2	142.1	208.0
185	8.7	11.0	20.3	71.0	77.7	82.5
189	4.0	9.8	12.6	125.8	134.9	148.2
190	3.5	7.9	18.2	124.2	136.7	584.0
191	6.4	22.2	62.1	18.5	24.4	58.0
192	2.9	14.6	37.9	29.5	41.2	114.0
194	11.0	11.0	11.0	33.6	33.6	33.6
195	4.2	10.3	18.9	31.9	35.1	41.4
196	3.6	5.2	6.5	49.4	54.1	68.1
197	4.6	6.8	12.6	52.2	71.1	110.4
201	9.5	11.5	11.8	126.8	136.7	143.7

Melbourne

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

Sydney

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

Brisbane

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

Adelaide

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

Perth

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

New Zealand

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

Wangaratta

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

Geelong

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

Wimmera

597 Joel South Road
Stawell VIC 3380
Telephone 0438 510 240

Gold Coast

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

watertech.com.au