Tertiary Coastal Compartments in Port Phillip Bay: Review, Definition & Methodology

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Executive Summary

Sediment compartments are a framework for managing the coastline on different temporal scales. The tertiary scale is the most applicable to management and delineates sediment movement occurring over a period of a decade.

There are no precise criteria for mapping tertiary sediment compartments. A range of criteria have been used nationally including spatial scale, bathymetry and topography, storm inundation to individual submarine and subaerial landforms. There are no nationally, or internationally, consistent criteria.

This review of the state of knowledge and mapping methodologies around Australia developed a comprehensive definition and set of criteria for mapping tertiary sediment compartments. *A tertiary compartment is defined as a section of coast within which long- and cross-shore movement of sediment can be expected to occur within a decade (< 10 years). This movement is calculated based on geomorphic features related to aeolian and hydrodynamic processes.*

A new 5-point criteria is developed for classifying compartment boundaries. This is based on a qualitative assessment of sediment exchange between compartments and ranges from open to leaky (3 subclasses) and closed.

A total of 205 tertiary compartments were mapped around the 338.1 km coast of Port Phillip Bay (PPB). The majority of the shoreline (142 compartments, 267.4 km (79%)) is composed of soft sedimentary landforms. 16.5% of compartment boundaries were open, 45.1% of the compartment edges are leaky and 33.3% boundaries are completely closed.

The extent and composition of tertiary compartments cannot be considered fixed on a > 10 year scale due to active spit migration in some areas and significant management intervention which defines many contemporary compartments.

Contents

Introduction

The coast is a scale integrated system (Phillips, 1988, 2012; Woodroffe, 2003). That is, the current morphology of landforms along the shore is the product of instantaneous processes that cause weathering and erosion acting over extended periods which can stretch to millennia. The ability of any individual landform to respond to a given event also depends on the confining boundary conditions of the system and its antecedent morphology. At a fundamental level these boundary conditions delineate soft (depositional) landforms (e.g. beaches and dunes (Loureiro et al., 2012)) from hard erosional forms (e.g. shore platforms and rocky cliffs (Kennedy et al., 2014)), but it also applies to the type of sediment which is present at a given location (Dalrymple & Thompson, 1977; Gourlay, 1968; Gourlay, 1980). For example, gravelly beaches behave differently to sandy beaches, the former being predominantly a subaerial feature while for the latter the majority of the profile is found below the water line (Jennings & Shulmeister, 2002; Short & Jackson, 2013). Even for sandy beaches, grain size is a critical boundary condition with coarse-sand beaches generally being steeper than fine-sand beaches. The result is the behaviour of a given stretch of coast to storms or sea level rise is highly variable.

The spatial and temporal scale over which landforms operate is critical to understand for coastal management. For example, the ability of a beach to recover from high waves (instantaneous scale) during a storm (event-scale) will depend on the sediment supply to the coast, which in turn is influenced by factors of geology and regional climate. For example, a sediment starved beach in an enclosed environment is less likely to recover from a storm than a higher energy beach with abundant sand being transported into and through the system (Thom et al., 2018; Thom & Hall, 1991).

Connectivity is one of the key factors to understanding coastal response (Anthony & Aagaard, 2020). While individual bar movements during a storm reflect instantaneous wave hydrodynamics, the overall trajectory of shoreline movement (recession or progradation) may reflect processes on the 100's to 1000's kilometre scale. In fact, most coastal landforms bear the imprint of processes throughout the current Holocene sea level highstand and some even back to the Last Interglacial period and older (Murray-Wallace & Woodroffe, 2014).

To account for this spatial and temporal complexity coastal managers have generally tried to view the coast in terms of the whole system, or as a catchment. To parameterize the coast into management units, fit-for-purpose of the task, a range of classifications have been used since the mid-20th century, with compartments generally being the most widely accepted nomenclature today (see Thom et al., (2018) for a review).

In Australia the compartment framework of Thom et al (2018) is now widely used for delineating coasts. Three scales are used to account for the range of landscape drivers.

(1) Primary Compartments which are bounded by major structural features such as headlands or changes in shoreline orientation. Over 100 have been identified in Australia,
(2) Secondary Compartments which are defined by smaller scale structural features of which >350 have been identified in Australia, and;
(3) Tertiary compartments which are also known as sediment cells. There is no consistent definition of a tertiary compartment both nationally and internationally. This review will explore the definitions used in Australia with the aim to develop a standard definition of compartments at this scale.

The Thom et al (2018) framework underpins the CoastAdapt tool (CoastAdapt, 2022) developed for managing future coastal change in a warming world. The compartments framework is further defined on a temporal scale of 50-100 years (Primary), 25 – 50 years (secondary) and 10 years (Tertiary) (Figure 1). While the compartments approach and terminology are now in widespread use, there are other schemes also commonly used such as coastal cells, e.g., (Stul et al., 2015) in Western Australia; or sectors, e.g., (Minar, 2019) for the Bellarine Peninsula, Victoria.

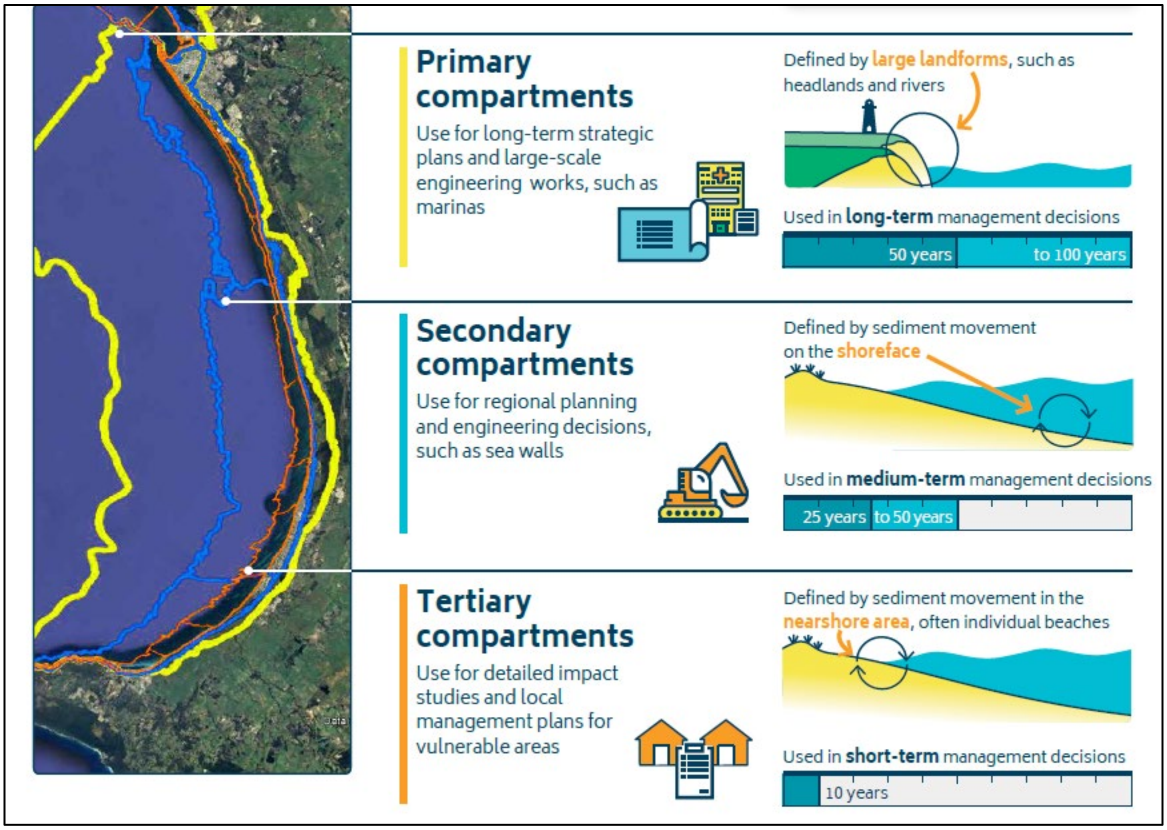


Figure 1: Spatial and temporal delineations of coastal sediment compartments used by CoastAdapt building on the framework of Thom et al. (2018).

One significant difficulty with the compartment scheme occurs in the definitions of the smallest unit, namely tertiary compartments. While CoastAdapt uses a temporal scale of a decade and nearshore area to define these compartments, there are no clear definitions of precisely what processes or physical characteristics should be used to map this scale. Thom et al (2018) left the task of defining this scale to local jurisdictions and as a result there are a variety of scales and features used nationally to map at this level. As a result, there is no agreed upon definition of a tertiary compartment

The need for a consistent definition and criteria for defining a tertiary compartment is pressing as tertiary compartments are specifically referred to in the Victorian Marine and Coastal Policy 2020 as being “suitable for detailed impact studies and local management plans for vulnerable areas” (DELWP, 2020)

Aim

The aim of this review is to assess the parameters used to delineate tertiary scale compartments around Australia and subsequently test their applicability to Port Phillip Bay (PPB). Core to this assessment is defining the spatial and temporal scale over which tertiary compartments operate. The aim is therefore to produce a working definition of a tertiary compartment and apply this to Port Phillip Bay through mapping the compartments within this large structurally-controlled estuary. The definition and methodology is also developed so that DELWP can subsequently use it for future coastal management including hazard assessments.

Methodology

To define a Tertiary Compartment a two-step methodology was undertaken.

Step 1: Literature Review. A targeted literature review was conducted to identify the principal usage of compartments in coastal assessments in Australia. This literature was then interrogated to extract the precise spatial and temporal variables used in each work to define a compartment.

Step 2: Expert Panel/Working Group. An expert panel was formed consisting of key stakeholders in coastal landform management in Victoria. Individuals were identified based on their professional expertise and experience across a diverse range of fields. Each member of the panel was required to have significant standing in their relative profession and extensive experience in understanding the Victorian coast.

Expert Panel

Prof David Kennedy. Coastal Geomorphologist, The University of Melbourne.

Dr David Provis. Senior Principal Oceanographer, Cardno (Stantec).

Dr Andrew McCowan. Senior Principal Engineer and Chair of Board, Water Technology.

Dr Jak McCarroll. Marine Data Scientist, Marine Knowledge, Biodiversity, Department of Environment, Land, Water and Planning

Dr Elisa Zavadil. Project Manager Victoria’s Resilient Coast - Adapting for 2100+, Department of Environment, Land, Water and Planning

Tertiary Compartment Definitions (Step 1)

The following section is an analysis of the variety of definitions of tertiary compartments in Australia. Due to the extensive cross referencing between studies and dominance of just a few groups in the mapping compartments the following analysis is taken from key representative publications.

Thom et al (2018) / CoastAdapt Framework

This work was the conclusion for a continental-wide assessment of coastal vulnerability to sea level rise. The work reviewed the current understanding of compartments, dating back to the 1960's. It then developed the broad compartments approach for Australia which is operationalised through the CoastAdapt portal. Primary and Secondary compartments were mapped nationally in this work, but the tertiary scale was left to the discretion of local authorities. A spatial scale and sediment movement/storage is used to provide a mechanism for defining tertiary compartments (Table 1).

Table 1: Summary of the characteristics used to define tertiary compartments within the work of Thom et al (2018) / CoastAdapt.

Location	Key Text	Scale Element/definitions
National	"Tertiary compartments (> 1000): Based on secondary compartments, which are sub-divided at obstructions (usually headlands) into tertiary compartments, some as small as an individual beach. Tertiary compartments may act as self-contained sediment compartments or be linked to adjoining compartments. These typically occur at scales less than 1: 25,000." (page 107)	• Individual Beach • Obstructions • 1:25,000 scale
	"are smaller tertiary compartments or cells with identifiable pathways of sediment movement driven by waves and currents." (page 104)	• Wave & current processes of sediment transport
	"Essentially there is a "store" of sediment within a tertiary compartment comprising landform units, such as beaches, barriers and dunes, which are capable of being mobilised under different process conditions of varying magnitude and frequency." (Page 106)	• Individual landform scale

Eliot (2013)

This report provides a summary of an extensive mapping project undertaken in Western Australia focussed on defining compartments of all scales. The author was also an author of the Thom et al (2018) framework. The work provides the most detailed criteria for delineating compartments of all scales, with specific metrics used to define tertiary units. These metrics range from set bathymetric contours and landforms to quantification of annual change landform dynamics.

Table 2: Summary of the characteristics used to define tertiary compartments within the work of Eliot (2013) for the Western Australian coast.

Location	Key Text	Scale Element/definitions
Western Australia	"tertiary (local planning) compartments based on the individual coastal landforms present" (page v)	• Individual landforms • Landward limit of <u>annual</u> change • Seasonal – interannual scale • Landward limit of erosion or HSD (term not defined in report).
	"Closer to shore, the outermost, continuous 20m isobath was chosen as the offshore boundary for the tertiary compartments (local and site planning units) to include areas of coast subject to variability in response to short-term changes in metocean processes." (page 11)	• Offshore boundary at 20 m isobath
	Tertiary cells are confined to the reworking and movement of sediment in the nearshore and potential seasonal to interannual responses. (Page 3)	• Annual change • Nearshore sediment transport
	Bathymetry and topography.	• Offshore depth limit at 15 m (open coast), 7 m (sheltered open coast, lee of structures), 5 m (toe of terrace or "large sand bars" where locally-generated wind waves are dominant) • Structures that restrict sediment movement < 5-7 m depth • Subtidal seaward margin of shore platforms • Toe of terrace or sediment bank
	Landward Limit	• Foredune • Landward limit of annual change/"apparent erosion" on beaches • Seaward limit of rocks for erosional coast • MHWM on engineered and rocky coasts • Watershed for promontories or islands

Nanson et al. (2022)

This work is conducted by Geosciences Australia and is focused on mapping shoreline change around the Australian margin using three decades of satellite data. It has a geomorphology focus and typifies the compartments approach of this national organisation which is focussed on decadal scale change for tertiary compartment definition.

Table 3: Summary of the characteristics used to define tertiary compartments by Geosciences Australia with a nationwide focus.

Location	Key Text	Scale Element/definitions
National	"TCC are thus the most temporally appropriate spatial scale for investigating the last 32 years of geomorphic change at inter-to intra-decadal timescales, and we focus our examination of the insights provided by DEA Coastlines to eight example TCCs." Page 3. TCC = Tertiary Coastal Compartment.	• Inter/intra decadal

Minar (2013)

This report is the first to attempt to map the shoreline within Port Phillip Bay with a focus on the Bellarine Peninsula. This work provides the basis for subsequent mapping of the full PPB shoreline by the same team, and its inclusion reflects the importance of the work in a local (Victorian) context.

The key aspect of this study is that "*whilst some consideration was also given to the transport of sediment along the Bellarine Peninsula coast (based on a number of coastal studies with an interpretation of these process), it is important to note that this was not a significant basis for sector definition." (page 10).* As sediment transport is not used to define shoreline sectors, the results cannot be considered comparable to the compartments framework. It is a fundamentally different classification system although the intention is similar, namely to define the coastline into parts that can assist planners in their management of the shore.

McInnes et al. (2022)

This is a report examining coastal hazards in Port Phillip Bay, Victoria. It categorised shoreline sectors using similar methods to Minar (2013), focusing on coastal geomorphology over sediment transport processes. Specifically, "shoreline data and information was also compiled to aid in the interpretation of the hazards presented in this study as well as provide foundational information for future erosion hazard assessments. A geomorphic survey identified 528 coastal geomorphic sectors (CGS-also referred to as tertiary compartments) around PPB. The sectors were determined on the basis of backshore and intertidal landform characteristics. More than half of these sectors (290 CGS) totalling around 200 km of coastline, are beach fronted. However, these beaches have a variety of backshore features ranging from engineered structures to cliffs and wetlands. Hard or soft rock cliffs occur extensively on the eastern side of PPB and the Bellarine Peninsula whereas low-lying wetland areas are most prevalent in the west, south-west and central-east parts of PPB." (Page 16)

This report extensively references the Australian Sediment Compartment Framework established by Thom et al. (2018) and CoastAdapt (see above). The report does not however map compartments. They map "sectors" which are "determined on the basis of backshore and intertidal landform characteristics" (page 16, 212).

Sectors are not equivalent to compartments as the latter is focussed on sediment transport rather than solely landform character.

Complexities

The first workshop of the group reviewed the existing knowledge and definitions of tertiary compartments and then analysed them in a Victorian (Port Phillip Bay) context. It was emphasised that defining a tertiary compartment requires identification of sediment transport pathways over a temporal scale of a decade or less. That is, it is both time and geomorphic features that delineate compartments, especially in the longshore direction.

A major complexity is that the temporal and spatial scale of sand movement along an individual beach will vary and is difficult to quantify. For example, what is the distance of annual movement of sediment along a particular beach? Cross shore sediment movement will likely also be variable within a single compartment, especially in areas where there is a long continuous length of beach such as the Dromana-Rosebud-Rye shoreline. In such long compartments any section of beach is connected to the immediate area, however over a decade it is unlikely that sand will move from one end of a beach to the other. It was recognised that there is little global research on estimating the length of coast that sediment can be transported over, with established equations typically quantifying transport as a volumetric rate passing a specific point on the coast. It was also noted that there is very little research on sediment transport in Port Phillip Bay and a paucity of data on coastal geomorphic change.

Tertiary compartment boundaries are almost certainly going to be either leaky or closed like the primary sediment compartment definitions of Thom et al. (2018). Management interventions, such as dredging, will determine whether the boundary is leaky or not. For example, at the entrance to Patterson Lakes River, dredge spoil is placed on the downdrift beach next to the channel. This means a compartment boundary at this location would be leaky (or have no boundary). However, if the spoil was exported out of the compartment (e.g., for renourishment elsewhere, or as fill), then this compartment boundary becomes closed.

The management use of the compartments does require a degree of subjectivity and therefore requires the uncodified expertise of the user. The operational definition therefore needs to account for this to allow a non-expert to apply the classification scheme and adjust to future changes in management practice.

The offshore boundary of the compartment may be less important, whether it be defined in terms of wind wave length (seafloor sediment movement), closure depth, or a geomorphic parameter. It was concluded the 5 m contour, consistent with Eliot (2013) would provide a practical boundary as an initial assessment to be further refined as more detailed beach morphodynamic studies in the bay become available.

Working Definition of a Tertiary Compartment for Port Phillip Bay

In accordance with the temporal nature of this definition, and consistent with the intent of Thom et al. (2018), a tertiary compartment is assumed to encompass sediment movement over a maximum of 10 years. The identification of sediment movement is conducted through the mapping of geomorphic features such as surf zone bars, berms, and dunes to define the on and offshore limits of the compartment (Table 4).

Definition: *A tertiary compartment is a section of coast within which long and cross-shore movement of sediment can be expected to occur within a decade (< 10 years). This movement is calculated based on geomorphic features related to aeolian and hydrodynamic processes.*

Table 4: Parameters used for defining and mapping tertiary compartments within Port Phillip Bay.

Temporal Scale		
<10 years	the long and cross-shore movement of sediment that could be expected to occur within a decade. (Based on CoastAdapt Temporal Frame)	
Spatial Scale		
Seaward Features	< 5 m depth	Due to the fetch limited nature of the bay, sediment movement can be assumed to be restricted to < 5 m on the decadal scale. The depth is based on the Eliot classification, supported by Goodfellow & Stephenson (2005) where all bar movement was < 3 m depth at Seaford. While this depth can be defined based on the limited field studies undertaken in the eastern part of the bay, along the western margins where wide intertidal fine sediment flats occur, backed by chenier/swash ridges, the link between offshore and onshore sediment system is poorly known. Chenier evolution is often closely related to storm waves (Augustinus, 1989; Otvos, 2012; Schofield, 1960; Woodroffe et al., 1983) and more work is required to understand these unique enclosed chenier systems in western Port Phillip Bay.
	Swash and surf zone bars	Those which are shore parallel whose morphology is indicative of infragravity and gravity wave interaction in the nearshore. This excludes tidally-dominated bedforms further seaward of the wind-wave dominated sediment transport system.
	Seaward edge of shore platforms and artificial structures	Where wave-formed bars are unable to bypass structures or rocky outcrops the boundary is set at the seaward limit of these features.
Landward Features	Upper limit of storm wave run-up	Defined within the CSIRO PPB Hazard Study (McInnes et al., 2022).
	Crest of foredune	Delineated by vegetation change from grasses (*Spinifex*, *Ammophila*, *Thinopyrum* sp.) to bushes (e.g., salt bush) and trees.
	Landward limit of swash berms	Delineated by vegetation change from grasses (*Spinifex*, *Ammophila*, *Thinopyrum* sp.) to bushes (e.g., salt bush) and trees.
	Base of sea wall	A seawall is assumed to be a permanent structure on the decadal timescale and provides an immovable and impermeable barrier separating marine and terrestrial sedimentary processes.
Longshore Extent	Structural	Fixed natural (e.g., headlands) and artificial (e.g., groynes) that interrupt littoral zone sediment transfer.
	Geomorphic (orientation)	Changes in shoreline orientation indicative of a change in sediment transport rates due to differing wave exposure.
	Geomorphic (trends)	For long sections of continuous beach (5-10 km), the compartment boundary is defined on the basis of shoreline trends of accretion and erosion as quantified from satellite aerial mapping (DEA, 2022).
	Migrating	A compartment edge (e.g., sand spit) which is prograding in a longshore direction.

Compartment Boundaries

The boundaries between compartments at the national scale are classified as either leaky or closed. This recognises that quite often sediment flows between different sections of the coast at various times. In the CoastAdapt / Thom et al. (2018) framework a closed compartment is one where there is no sediment exchange, whereas a leaky compartment has sediment exchange between landforms along the coast (Fig. 2).

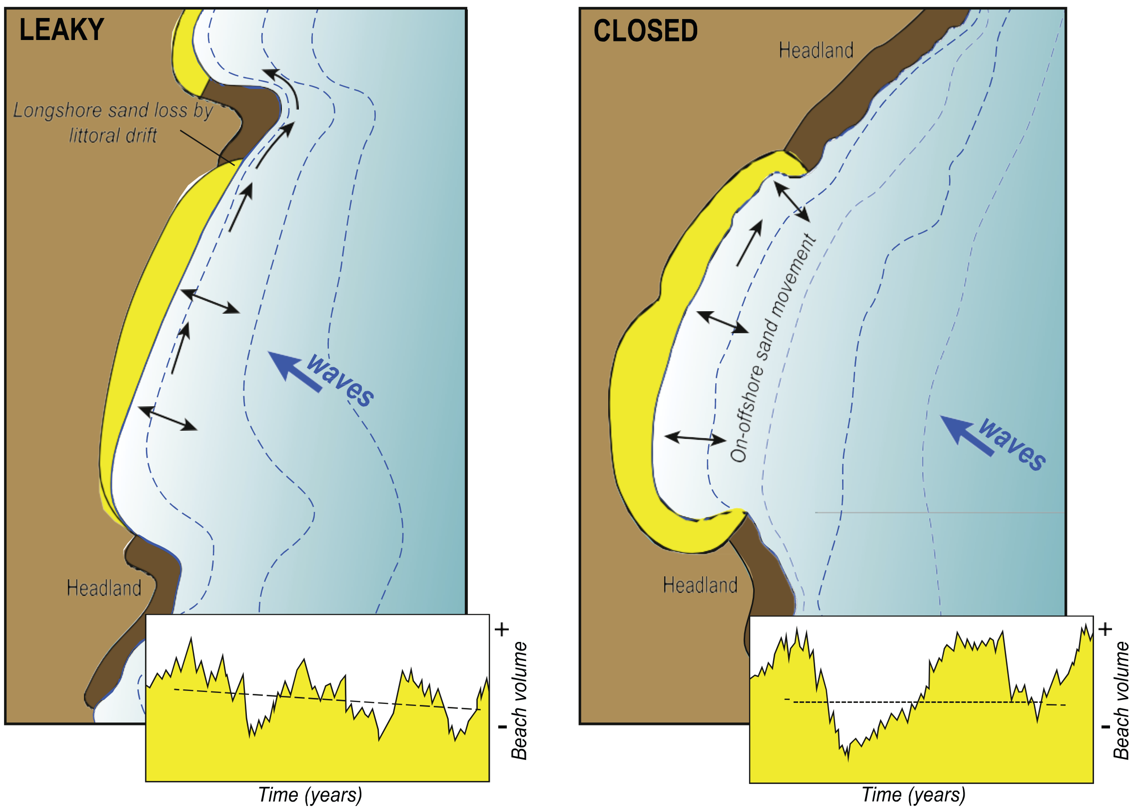


Figure 2: The two types of compartment boundaries initially developed by Thom (1989) and expanded on by Thom et al (2018) to show sediment pathways (black arrows). (Reproduced from Thom et al (2018).

The two-part classification of CoastAdapt was found to not appropriately describe the complexity of sediment transport on the tertiary scale in Port Phillip Bay. This is because the degree of leakage between compartments is highly variable, and a binary classification would mask sediment transport complexity to the likely detriment of management actions.

The boundary of a compartment will be determined on a 5-point scale, based on a refinement of the classifications of Thom et al (2018) and Thom (1989) (Fig. 3).

(1) Closed, where sediment remains confined within the littoral zone of the compartment or is not connected to neighbouring compartments.

(2) Leaky, where sediment transport occurs between compartments at the Tertiary Scale. It is noted that transport pathways and rates will be different between the upper and lower shoreface. Port Phillip Bay beaches present a range of subtidal morphologies from wave to tidally-driven bar systems as well as dune and swash determined berm features. To differentiate between these types of leaky boundaries, they are subdivided into three categories (i) sediment is transported as a veneer at the outer (deeper) edge of the compartment, (ii) sediment transport is by offshore/shore detached subtidal bars, (iii) sediment transport is inter-subtidal with restriction of the subaerial beachface transport.

(3) Open, where sediment freely moves across the beach. As sediment exchange is unimpeded across such a boundary it is important to consider adjacent compartments in any process or hazard assessment. Such boundaries are defined by either:

    i. numerical modelling of longshore transport fluxes and extents, due to wave and tidal action (usually not available, and not available in this instance).
    ii. length scales and transitions of geomorphological features (e.g., shoreline orientation, nearshore bars).
    iii. length scales of erosion/deposition regions in decadal scale imagery.

This applies for very long continuous beaches where sediment transport, while exchanged freely in a longshore/cross shore direction, is unlikely to impact distal shoreline behaviour beyond a given extent, at a decadal timescale. It is worth noting that the few studies of the distance of longshore transport over annual to decadal timescales are difficult to apply for hazard assessments and erosion monitoring. Longshore transport is generally quantified as volume per unit of time rather than a distance of transport. It is also important to note that it is the total sediment supply (budget) that is important in determining shoreline behaviour and this varies from the transport potential of individual particles.

Why is the "open" boundary definition necessary? Consider a continuous beach, 10's of km long, in a fetch-limited environment such as Port Phillip Bay. If a sand nourishment is conducted at one end of this stretch, it is highly unlikely to impact shoreline behaviour at the distal end on a decadal timescale. Therefore, by the temporal nature of the tertiary compartment definition, and from the practical perspective of coastal management, it becomes necessary to define 'open' compartment boundaries along this stretch of coast.

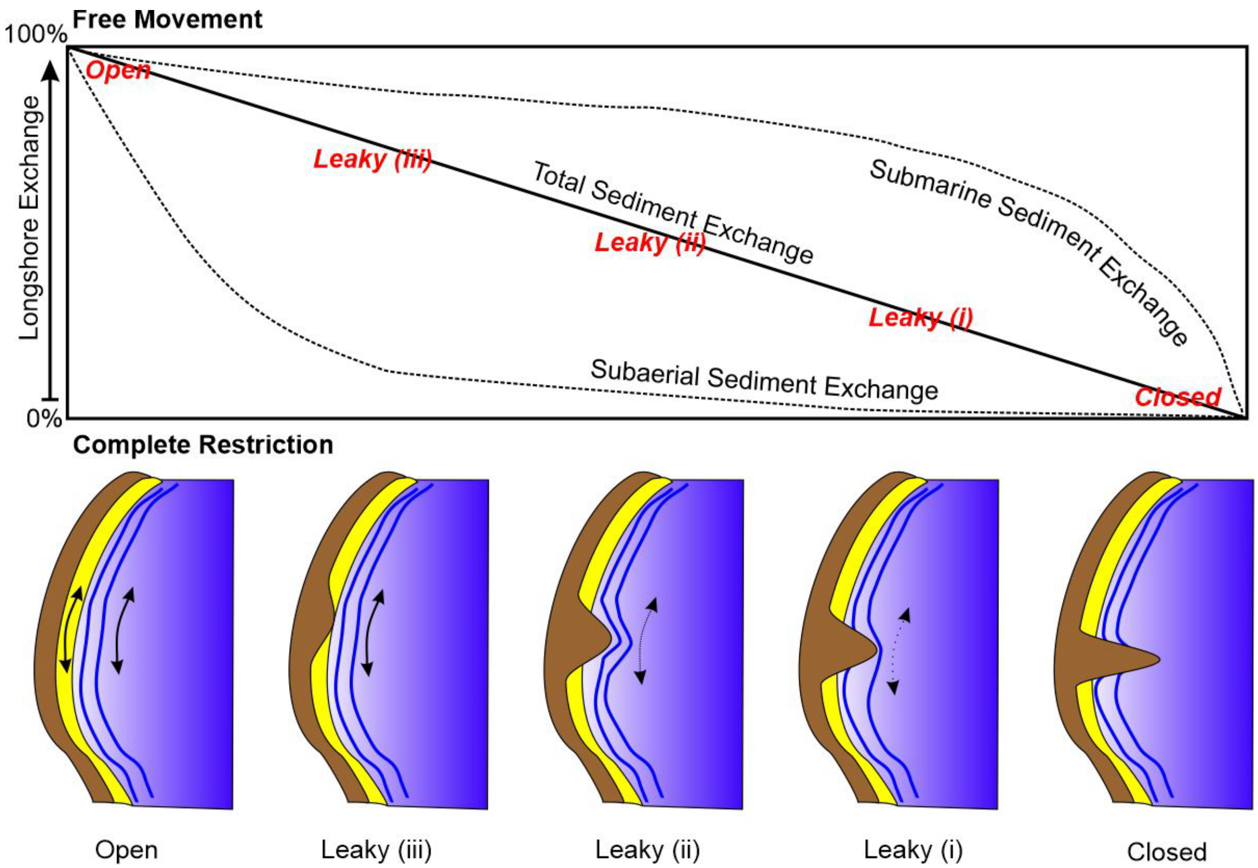
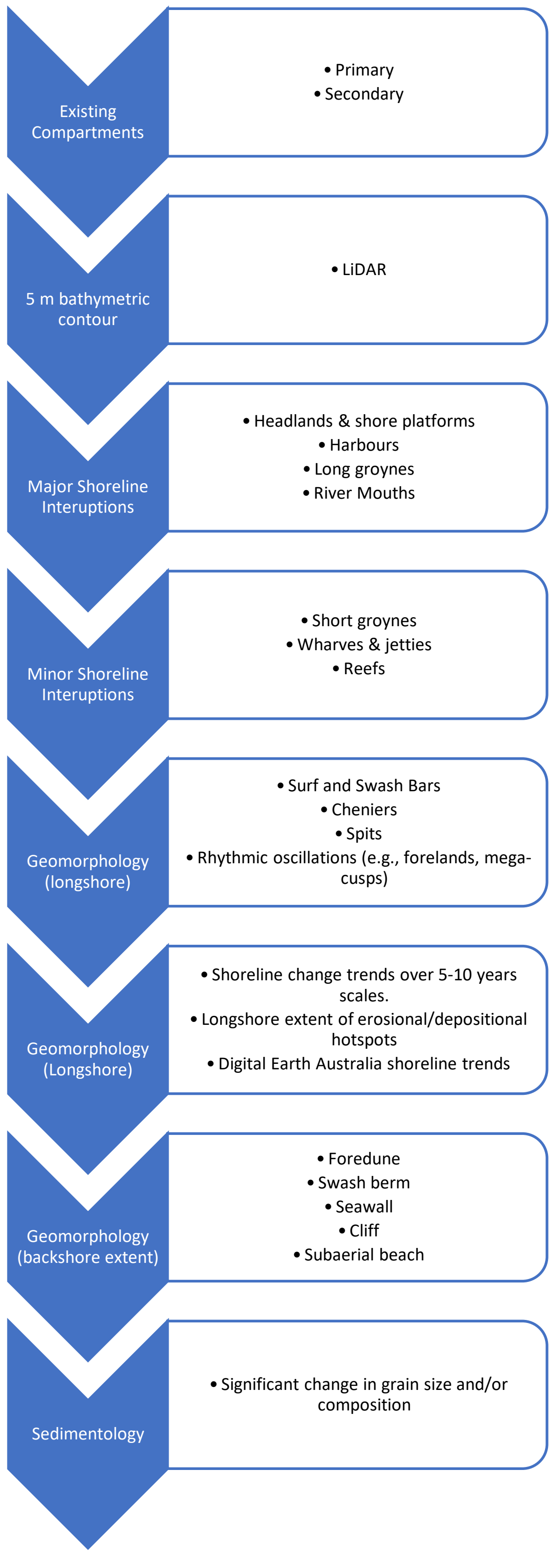


Figure 3: The 5-point scale of compartment boundaries based on the degree of sediment sharing between adjacent areas developed in this analysis.

The compartment boundaries are qualitative assessments of sediment transport potential between sections of beach. There is an increase in the rates and volumes of sediment transport from Closed → Leaky (i) → Leaky(ii) → Leaky (iii) →Open, however at present a quantitative assessment cannot be made due to a lack of detailed compartment specific sediment transport measurements.

Sediment Compartments within Port Phillip Bay (Step 2)

The following methodological hierarchy was used to classify compartments within Port Phillip Bay.



A total of 205 tertiary compartments were mapped around the 338.1 km coast of PPB (Fig. 4). Compartment type was qualitatively assessed through observation of aerial imagery (NearMap). Where a compartment contained multiple elements (e.g. small beach and seawalls) its classification was determined on what was qualitatively assessed as being the dominant mode. It is recognised that there is a degree of subjectivity in this assessment. The majority of the shoreline (142 compartments, 267.4 km (79%)) is composed of soft sedimentary landforms. In the northern, eastern and southern shore from the mouth of the Yarra River to Point Nepean this shoreline was composed of single to multibar sandy beaches. Where the lateral accommodation space is available, dune systems are present being most well developed in the Frankston and Dromana/McRae embayments. The ability of dunes to develop is highly restricted in the northern part of the bay where seawalls have extensively been constructed. The exception is at Port Melbourne Beach where a wide (55 m) foredune complex has formed in the past 15 years. This site is at the northern limit of littoral drift in the bay and therefore has a positive sediment budget allowing for dune development. In the south western side of the bay from Point Lonsdale to Geelong, along the Bellarine Peninsula, the sandy beaches are narrower, with aeolian deposition being limited and swash berms dominating (Jiang, 2019). On the western side of the bay sandy beaches are narrow (10 m) and form behind wide (400+ m) sediment flats.

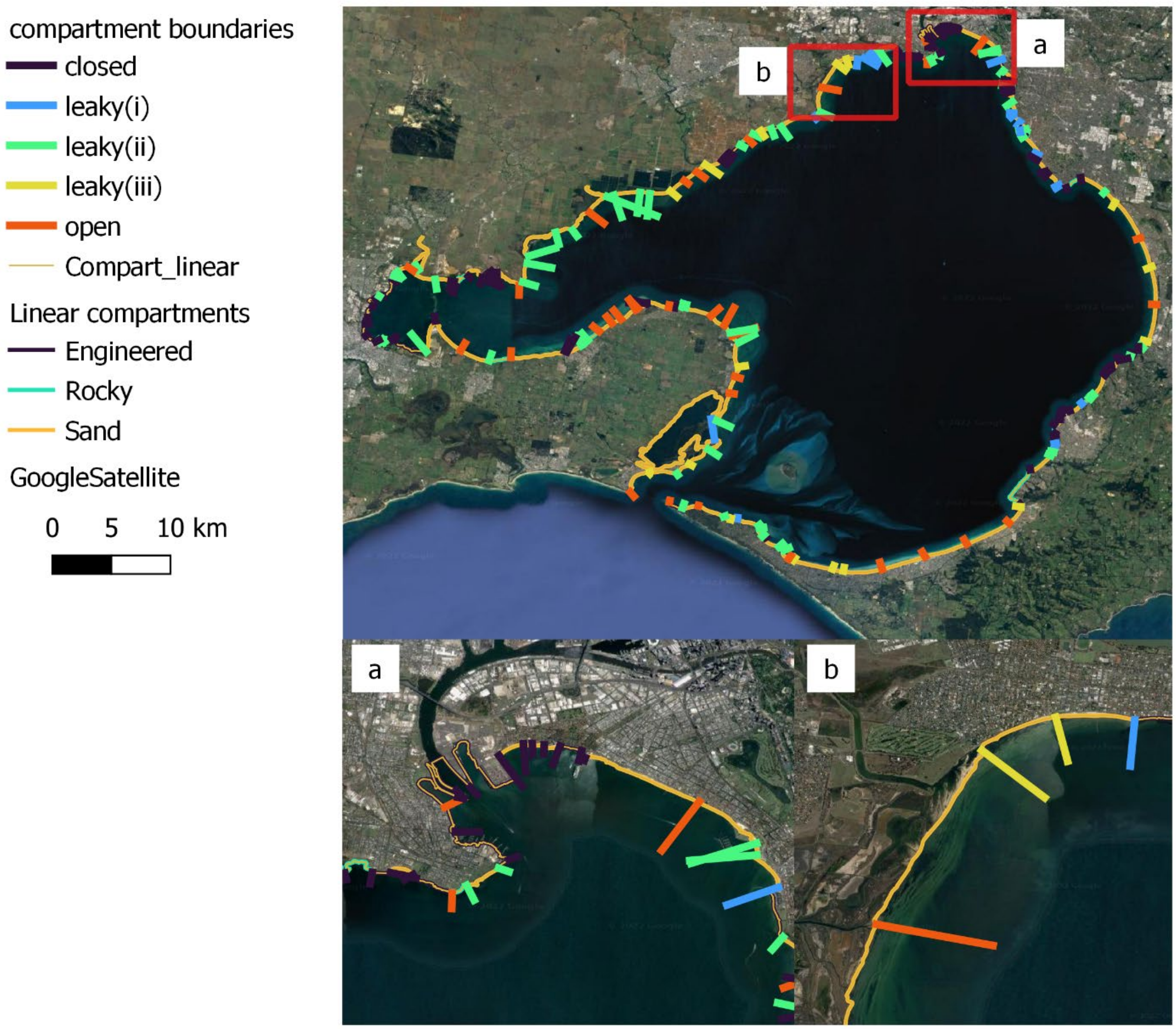


Figure 4: 205 compartments are mapped within Port Phillip Bay, with the 5 boundary types found round the bay. The length of the boundaries extends to the 5 m bathymetric contour. (a) Engineered compartments dominate around the mouth of the Yarra River, while (b) a range of compartment type occur along the Altona shoreline.

Engineered shorelines (43 compartments, 45.7 km (13.5%)) are the next most common type and are defined in this analysis as engineered walls. They are most common in the port area of Geelong and around the mouth of the Yarra River where Victorian transport infrastructure is concentrated. Seawalls and hard engineering are much more widespread within the bay, with almost the entire shoreline from Port of Melbourne to Black Rock being armoured by seawalls, however at the tertiary scale, these seawalls are fronted by beaches maintained by renourishment programs. If the beaches maintained by these such renourishment programs were classified as engineered structures, then almost the entire bay would be classified as engineered. Critically, at the tertiary scale the coast is sandy as there are dynamic beaches present even though at the secondary to primary scales the coast would likely be classified as entirely engineered.

Rocky compartments are the final type mapped within the bay and comprise 7.4% of the shoreline for a total length of 25.1 km (20 compartments). These areas are composed of a mix of shore platforms, boulder beaches and vertical cliffs. They include highly eroded granitic shorelines of Mt Martha, clays cliffs in the Geelong Arm as well as sandstones in the north of the Bay. Much of the rocky shore has been armoured and those areas still able to supply sediment to the littoral zone tend to occur in remote places or areas of higher relief.

The compartment boundaries were classified on two levels, (i) the structure, if present, that defines the limitation to sediment movement and (ii) the ability of sand to move into the adjacent compartment. Of the 206 compartments boundaries, 55.8% (115 boundaries) are defined based on an engineering intervention which was most commonly a seawall or groyne, but also in two cases is related to an offshore breakwater. The higher percentage of boundaries being engineered, as opposed to entire compartments with this classification is a direct function of the high degree of management intervention conducted along the shoreline of PPB. Geomorphology, such as a change in shoreline direction or a natural headland, defined 42.7% (88) of the boundaries. At three locations the boundaries were classified as migrating, where cross shore shoreline progradation exceeded >2.5 m /year (DEA, 2022) resulting from the longshore extension of the sediment compartment (Fig. 5). This occurred at the Queenscliff Foreshore Reserve as a shore attached spit progrades north due to the dumping of dredge spoil and transport of sand into the bay from through the heads, at the tip of the sand spit at Swann Bay Bluff as well as the mouth of Laverton Creek. In the case of Laverton an eastern migrating spit has formed a barrier across the entrance to the creek likely due to a source of sand from the subtidal sediment flats fronting the creek and updrift in a southerly direction.

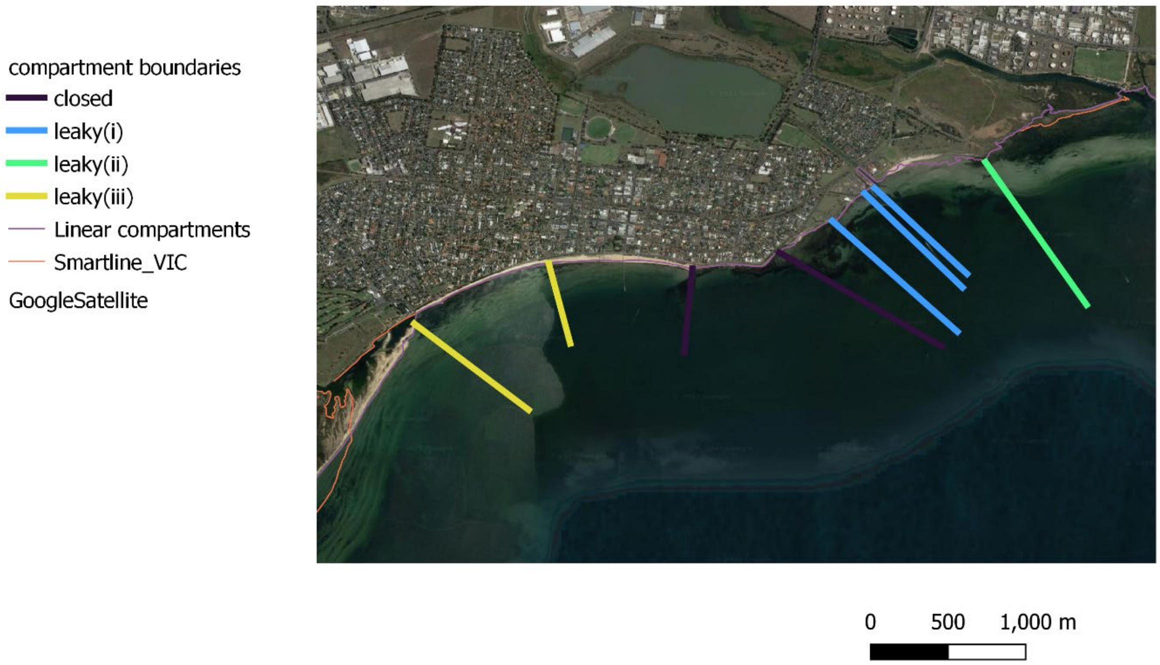


Figure 5: The beach compartments at Altona Beach. A leaky(iii) compartment occurs at the end of the spit which forms across the entrance to Laverton Creek. Sand from this spit likely contributes to the nearby beaches, although there is no subaerial sediment conn

Sediment movement, assessed qualitatively, was highly variable in the bay. 16.5% (34 boundaries) were open with free sediment exchange occurring between compartments. Of these, 70.5% were classified on the basis of geomorphology such as a change in coastal orientation or shoreline erosional trends (Fig. 6). The engineered boundaries were commonly very small groynes. In two cases the engineered open boundary is related to an offshore breakwater which had interrupted sediment transport on the annual, but not decadal scale (Fig. 7). Leaky compartments boundaries form 45.1% of the compartment edges, with 28.6% of all boundaries being leaky (ii) (64.4% of leaky boundaries). Leaky (iii) and (i) boundaries constitute 7.8 and 8.7% of all boundaries respectively. 79 (33.3%) boundaries were completely closed, with 64.5% of these boundaries being engineered. Management actions such as channel dredging are very important at the tertiary scale for determining a compartment boundary. For example, many small estuaries and river entrances are likely to have been naturally intermittently closed (Kennedy et al., 2020), but are now kept open through dredging. Examples include Mordialloc Creek and Patterson River, Frankston. The marina-residential development of Martha Cove is an example of the same morphology of an open channel but one which is entirely artificial as a result of dredging for a canal-style residential and marina estate. In these instances, the dredged channel entrances are classed as a compartment boundary as sediment transport is inhibited by dredging between the retaining walls that define the entrance. On the annual scale there is restriction of sediment movement especially evident by the absence of a subaerial beach. On the tertiary scale however, there is sediment transfer as channel degrade spoil is deposited on the neighbouring beaches maintaining a sediment connection. The important aspect is the management strategy both creates the compartment in the first instance by interrupting longshore sediment movement, but then maintains a sediment connection over a longer time through dredging. Such boundaries can be highly sensitive to change. If dredging was to cease then the littoral drift system would be reconnected within years, but if the dredge spoil was to be exported from the system to be utilised for other purposes, the boundary would become closed resulting in a negative sediment budget.

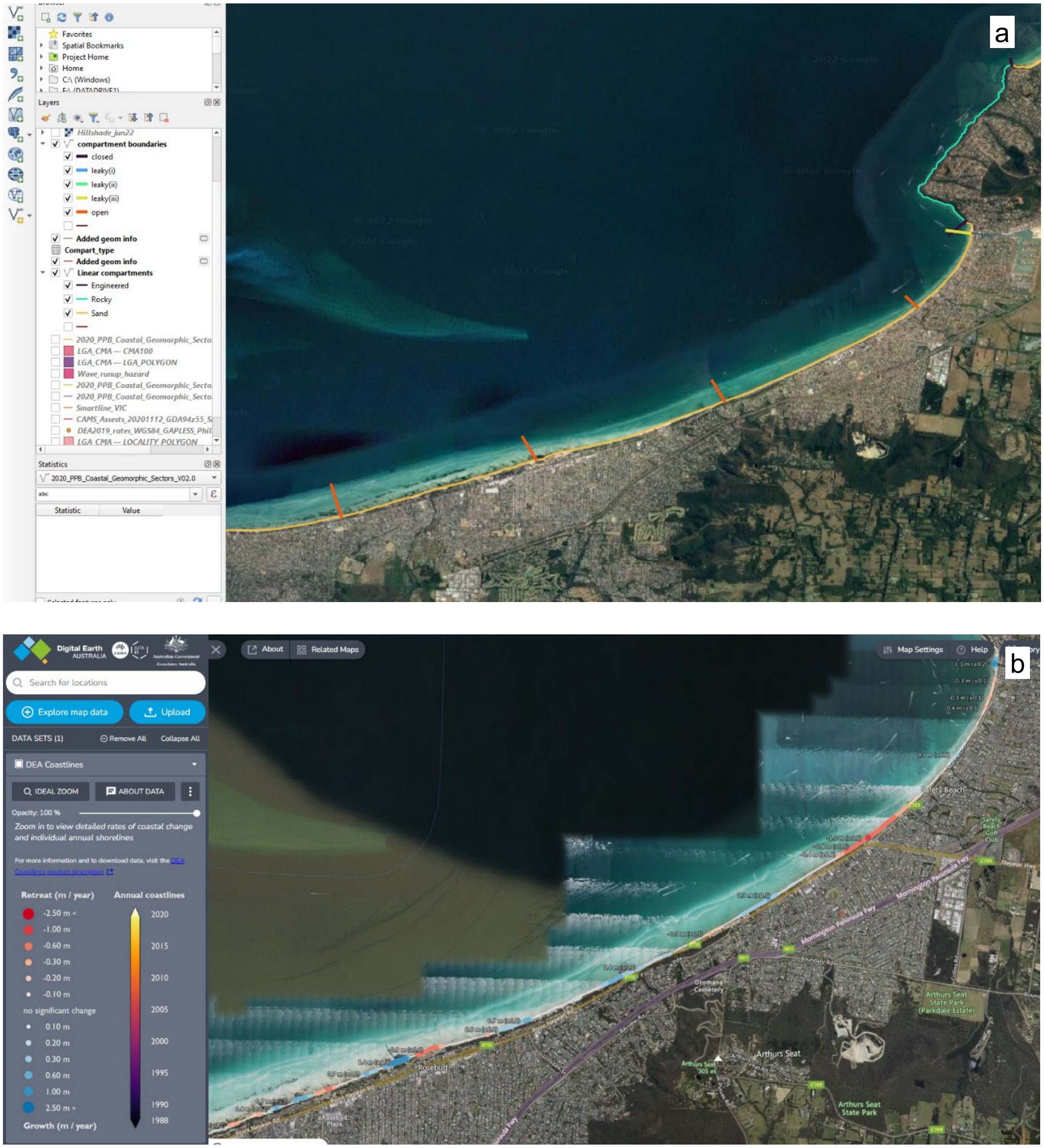


Figure 6: The open boundaries along the Dromana-Macrae shoreline (a) are delineated by changes in the decadal-scale shoreline erosional/depositional trend (b) and offshore bar morphology.

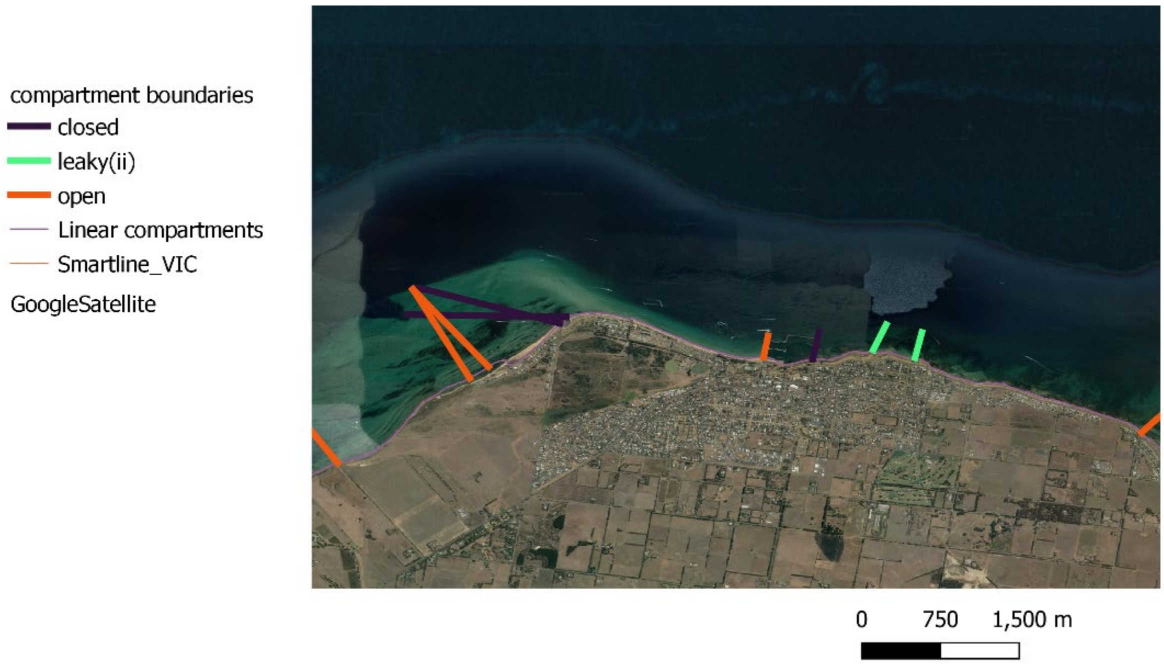


Figure 7: Portarlington contains three different compartment boundaries. The open boundary at Ramblers Rd represents the impact of the offshore reef constructed by Geelong Council which has caused a change in the sediment dynamics in its immediate vicinity in the past 4 years. It is not possible to determine whether this structure will affect decadal-scale sediment transport, hence the boundaries being open.

A significant limiting factor in defining compartments is sediment supply. By their nature, compartments are defined by the sediment they contain. Rocky coasts, while often being important sediment sources can in some instances can be considered depositional landforms in their own right (Kennedy & Milkins, 2015; Trenhaile, 2016), but generally they define the edge of a sediment compartment. In Port Phillip Bay the limited length of rocky coast is generally characterised by reworked talus at mean sea level elevations (e.g. Mt Martha shoreline) and small shore platforms (e.g. Black Rock/Sandringham) (Bird, 1993; Jutson, 1940). These are not necessarily considered to be a sediment compartment. Where there is a local sediment source such as subtidal mollusc communities small pocket beaches may occur (e.g. Point Lillias), but such pocket beaches can also be artificial. The engineered shorelines of Geelong and Melbourne Ports provide a typical example. In these areas, seawalls, wharves, groynes and other hard infrastructure dominate the shoreline. Small artificial pocket beaches can be found in these locations, such as North Shore Beach in Geelong, where the need for recreational infrastructure has meant beaches are constructed through placement of sand. The result is, although sediment would not naturally accumulate in these locations due to the infrastructure development, supply through management creates a compartment which is defined by the hard shore protection structures.

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