PORIRUA CITY COASTAL HAZARDS

DRAFT

August 2019

Porirua City Coastal Hazard Assessment - Draft

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PREPARED FOR PORIRUA CITY COUNCIL
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EXECUTIVE SUMMARY

Background

The Porirua City Council ("the Council") is currently reviewing and updating the Porirua District Plan ("the Plan"). The Plan contains objectives, policies and rules that relate to the management of land vulnerable to coastal hazards.

This study was commissioned by the Council to identify areas vulnerable to coastal erosion and coastal storm inundation around the coast of the district over the next 100 years and to provide broad management recommendations to assist with developing provisions for the present District Plan review.

The coastal hazard study was conducted in two stages. A "first pass" assessment considered the entire coast of the District, to provide a high-level assessment of existing and potential future risk (including the effects of sea level rise) for a planning period of 100 years. A more detailed assessment was undertaken at priority areas (identified by the first pass).

The coastal hazard assessment included a review of available published and unpublished data and three rounds of community consultation, involving well-attended workshops at key sites around the City. Further opportunity for community and stakeholder feedback will occur over coming months; with this draft report and maps provided on Council's website for feedback. In addition, PCC propose to provide the proposed District Plan and maps for community feedback prior to formal notification.

Coastal Hazard Zones Identified

In identifying coastal hazards, national and regional policy requires Council to consider a planning period of at least 100 years and to consider changes that may occur over that period including sea-level rise. National guidelines prepared by central government provide various sea level rise scenarios and associated recommendations and we have followed these.

In areas of existing subdivision and development, two coastal erosion and coastal flood hazard zones have been identified:

- **Current coastal erosion/flood hazard**, identifying the areas potentially vulnerable to coastal erosion /flooding with existing sea level and coastal processes (for erosion events with a return period of at least 100 years and for coastal inundation events with a 1% annual exceedance probability)

- **Future coastal erosion/flood hazard 1.0 m sea level rise**, identifying the additional areas potentially vulnerable to coastal erosion/flooding over the period to 2120, assuming sea level rise of 1.0 m

The existing risk to property and assets is limited to the current hazard areas, but as sea level rises over time, that risk will gradually move into the future coastal hazard areas.

In undeveloped (i.e. Greenfields) areas, national guidelines recommend consideration of a higher sea level rise scenario (1.4 m) and so in these areas the coastal erosion and coastal flood hazard zones identify the additional areas that could be impacted with such a future sea level rise over a planning period of at least 100 years.

The coastal erosion hazard zones have been mapped relative to the existing shoreline, typically the toe of bank or cliff. The coastal flood hazard zones have mapped all areas below the flood elevation using existing LiDAR data on land elevations, a simple approach known as the “bathtub” approach. Some low-lying potential flood risk areas have no obvious hydraulic links to the coast and these are mapped separately to highlight the additional uncertainty.

A reasonable but precautionary approach has been adopted towards uncertainties in the hazard assessment and mapping. It is therefore recommended that the proposed District Plan allow for site-specific refinement of the defined hazard zones based on investigation by appropriately qualified and experienced experts (a coastal scientist or a coastal engineer).

Coastal Hazard Management Recommendations

This report recommends a range of measures for sustainable management of coastal erosion and flood risk in Porirua City. These recommendations are founded on a broad “hierarchy” of management approaches, implicit in national and regional coastal policy and developed to reflect the nature of the coastal environment, the likely responses of that environment to future climate change and the implications of different coastal hazard responses.

This hierarchy is used to provide a basis for coastal management in Porirua, with emphasis on risk avoidance and reduction, through to the use of soft and hard engineering works to protect development in known hazard areas where necessary and appropriate.

Risk avoidance is recommended as the preferred approach for Greenfields subdivision and development and for major upgrades or establishment of infrastructure.

In areas of existing development, it is recommended that Council develop appropriate policies and rules to both avoid increasing and, where reasonably practicable to reduce the risk of adverse effects from coastal hazards within the identified current and future coastal hazard areas. Relevant risk reduction approaches (e.g. development controls such as setbacks, relocatability requirements and minimum floor levels) are identified and discussed.

It is recommended that any intensification of existing development be avoided in current flood and erosion hazard areas unless a site specific coastal hazard study demonstrates that there will be no increase in coastal hazard risk, and/or effective and sustainable management of the hazards is provided for in an agreed adaptive management strategy (that considers the full range of future sea level rise scenarios identified in national guidelines).

There are also many areas of Porirua where environmentally soft approaches can usefully contribute to effective coastal hazard management. We recommend that the Plan include measures to actively encourage such approaches and that Council adopt a leadership role by using such approaches rather than hard protection to protect its reserves and infrastructure where-ever practicable.

Where hard engineering is the only practicable option, it should be designed and located to avoid or minimise adverse effects on the coastline.

Coastal Compartments

We have identified a number of broad "coastal compartments", based primarily on geomorphology, coastal processes, present land uses and management considerations and provided broad and recommendations for management of coastal hazards in each of these coastal compartment types. The management recommendations reflect the hierarchy of preferred options outlined in the report.

Nearshore Roads, Rail and other significant Infrastructure

There are extensive lengths of the Porirua City coastline where significant roads, rail and/or infrastructure are located immediately adjacent to the coastal margin; often wholly or partially on reclaimed land and vulnerable to coastal hazards with existing sea level, which risk will increase significantly with projected sea level rise over the next 100 years.

While this infrastructure remains in its current location, Council and other relevant infrastructure managers (e.g. NZTA and Kiwi Rail) will have no alternative but to protect from coastal hazards and protection of such infrastructure is provided for in national coastal policy. In the absence of appropriate management, this has the potential to further significantly degrade the natural and amenity values of the adjacent shorelines.

Where protection of infrastructure is required, emphasis should be given to recreate or enhance natural coastal features and buffers to preserve, restore and/or enhance the natural and amenity values of the shoreline over time. Where hard engineering is the only practicable option, it should be designed and located to avoid or minimise adverse effects on the coastline.

Long term planning should provide for progressive raising or relocation of road and rail infrastructure away from the coast where it is practicable. Any future widening of existing roads and rail corridors should be to landward where-ever practicable.

Beaches

A wide range of beaches occur on the Porirua City coastline, including sand and mixed sand-gravel beaches on the open coast and various beaches and chenier ridges within Porirua Harbour and Pauatahanui Inlet. Beaches are important community assets valued for a wide range of recreational uses and for natural and amenity values. Some Porirua beaches (e.g. Plimmerton and Titahi) are regionally significant for recreation and amenity.

In view of the importance of beaches as an asset for the wider community, the sensitivity of these environments to engineering works and future changes in sea level, and the directions in national policy, we recommend that hard structures be avoided in the management of coastal erosion on beaches; with an emphasis instead on:

- managing development in identified hazard areas to avoid and reduce risk over time
- accepting and living with erosion where this is reasonably practicable

- restoring and enhancing natural coastal buffers such as beaches and dunes
- use of soft engineering (e.g. beach nourishment) where practicable.

Cliffs and Banks

Cliffs and banks occur along both the open and estuarine coasts of Porirua City. Cliff erosion is a one-way process, driven by slow toe erosion leading to subsequent slope instability and periodic failure. The average long-term rate of toe erosion of cliffs is generally very slow on the Porirua coast, in the order of just a few metres per century. Severe slope failure also appears to be very infrequent.

It is recommended that coastal erosion hazard on cliffs be managed by avoiding and reducing risk using development controls. These controls would require a property- or site-specific study undertaken by a suitably experienced geotechnical engineer or engineering geologist if within defined hazard areas. These interim provisions are necessarily precautionary given the uncertainties around slope failure. In some cases, such site-specific investigations may also recommend additional action to reduce risk (e.g. improved management of stormwater, slope retaining structures, foundation requirements, etc.).

Hard coastal erosion protection is generally unlikely to be required or appropriate at most sites due to the slow erosion rates and the potential for such works to be severely damaged by slope failure. These works should only be adopted where they are part of an agreed adaptive management plan and are consented as appropriate solutions.

Low-lying coastal land

In some areas of the district, there are significant areas of low-lying land adjacent to the coast and/or streams draining to the coast; including existing and former estuarine and freshwater wetlands and low-lying flood plains. Many of these areas are vulnerable to existing or projected future coastal inundation over the next 100 years. Other work indicates that many of these areas are also vulnerable to stream flooding and/or tsunami.

A further consideration relevant in many cases is provision for restoration of coastal and estuarine wetlands and their riparian vegetation and for long term landward migration and retreat of these ecosystems in response to sea level rise.

It is recommended that future subdivision and development in these areas be strictly managed using land use controls to avoid any increase in hazard risk and to provide for restoration and landward migration of coastal wetlands, with infilling of former wetland areas avoided. It is also recommended that Council consider developing generous development incentive provisions to encourage the setting aside of areas required for restoration and landward migration of wetlands.

Adaptive Management

There are also a number of developed sites with complex existing and/or potential future coastal hazard issues where we believe site specific adaptive management plans will ultimately be required, particularly (north to south):

- Pukerua Bay
- Hongoeka

- Karehana
- Plimmerton
- Golden Gate Peninsula beaches (including Ivey Bay and Brown's Bay)
- Pauatahanui
- Titahi Bay
- Central business district and vicinity

For the most part, these particular sites are either beaches and/or low-lying coastal margins; some also have nearshore roads and infrastructure.

The broader management directions are relevant to these areas, but the complexity of the issues at each of these sites means that site specific adaptive management strategies, including extensive stakeholder consultation and participation will likely be required to adequately address the issues.

The coastal hazard issues and broad management options and directions for these sites are discussed in Section 6-14.

CONTENTS

1 INTRODUCTION

1.1 Background

The Porirua City Council ("the Council") is currently reviewing and updating the Porirua District Plan ("the Plan"). The Plan contains objectives, policies and rules that relate to the management of land vulnerable to coastal hazards.

In regard to coastal hazards, the New Zealand Coastal Policy Statement (2010) (NZCPS 2010) requires identification of areas in the coastal environment that are potentially affected by coastal hazards, giving priority to the identification of areas at high risk of being affected. The NZCPS requires consideration of a planning period of "at least" 100 years including the potential effects of climate change including sea level rise.

In areas potentially affected by coastal hazards over the next 100 years, the NZCPS (Policy 26) requires Council to:

(a) *avoid increasing the risk of social, environmental and economic harm from coastal hazards;*

(b) *avoid redevelopment, or change in land use, that would increase the risk of adverse effects from coastal hazards;*

(c) *encourage redevelopment, or change in land use, where that would reduce the risk of adverse effects from coastal hazards, including managed retreat by relocation or removal of existing structures or their abandonment in extreme circumstances, and designing for relocatability or recoverability from hazard events;*

(d) *encourage the location of infrastructure away from areas of hazard risk where practicable;*

(e) *discourage hard protection structures and promote the use of alternatives to them, including natural defences; and*

(f) *consider the potential effects of tsunami and how to avoid or mitigate them.*

1.2 Purpose and scope of the study

This study was commissioned by the Council to identify areas vulnerable to coastal erosion and coastal storm inundation around the coast of the district over the next 100 years and to provide the basis for a risk based planning approach.

The coastal hazard study was conducted in two stages:

- **A "first pass" assessment** considering the entire coast of the District (Figure 1), to provide a high level assessment of existing and potential future risk (including the effects of sea level rise) for a planning period of 100 years.

- **A more detailed second pass assessment** of priority areas identified by the first pass and agreed with the Council.

The work undertaken in these stages is outlined in Chapter 2.

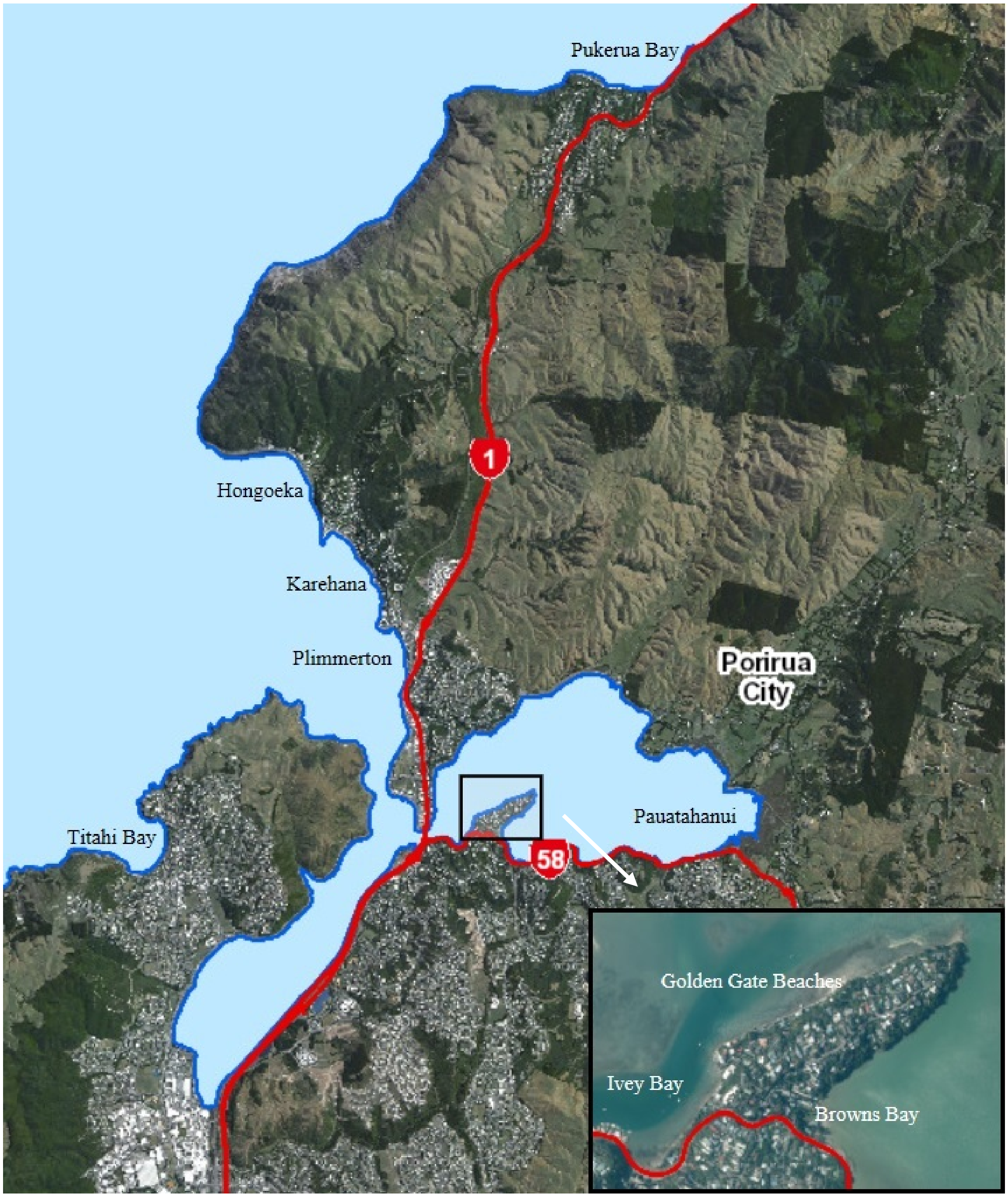

Figure 1: Extent of Porirua City Coastline with key locations.

1.3 Report Layout

This report provides an overview of a two-stage coastal hazard assessment for Porirua City. The broad project approach is outlined in Section 2.

Section 3 provides a more detailed description of the methodology used to determine coastal erosion and inundation hazard, including the approach to calculating hazards with future projected sea level rise. This section describes the various geomorphic shoreline types that exist in Porirua and the geomorphic models used to understand likely future change and associated hazards.

Section 4 summarises the national and regional policy setting, and recently completed national guidance on best practice and planning for climate change in New Zealand (MfE, 2017). The best practice guidance provides direction for the identification of hazard areas, planning for sea level rise and development controls and planning mechanisms for hazard prone land in the coastal environment. The review of policy and best practice guidance is then translated into a broad hierarchy of preferred coastal hazard management actions in Section 4.4.

Section 5 divides the coast into a number of "compartments", providing recommendations on broad approaches for the management of coastal inundation and coastal erosion to guide the Porirua City Council in the preparation of the revised District Plan. These approaches address matters such as coastal inundation and erosion risk, the management of new subdivision or major infrastructure and the general policy approach to managing new and existing development within identified coastal hazard areas. These recommendations reflect regional and national policy as reviewed in Section 4. This section also introduces the concept of adaptive management, an approach likely to be required to address coastal hazard issues at some of the more difficult sites.

Site specific hazard assessments and recommended management approaches are presented for key areas in Section 6-12.

1.4 Datum used in report

The elevations within this report are presented in terms of the Wellington Vertical Datum (WVD-53) unless otherwise noted. The relationship of this datum to other datum levels used in the area and to mean sea level for the periods 1985-2006 (MfE, 2017) and 2006-2011 (Lane et al. 2013) is summarised in Table 1. The offset from WVD-53 to NZVD-2016 varies slightly, from +0.335 m near and within Pauatahanui Inlet to +0.354 m at Pukerua Bay. Site specific corrections have been applied where necessary in our calculations.

Table 1: Relationship of WVD-53 to other datums and to mean sea level (source: Lane et al. 2013, MfE, 2017)

Datum	Offset (m)
New Zealand Vertical Datum (NZVD)	+0.335 - +0.354
2006-2011 Mean Sea Level	+0.196
1985-2006 Mean Sea Level (MSL) Baseline	+0.164
Wellington Vertical Datum (WVD-53)	0
Chart Datum	-0.8

2 PROJECT APPROACH

The study was conducted in two stages:

- Stage 1: A first pass assessment considering the entire coast of the District, with focus on developed areas.
- Stage 2: A more detailed hazard assessment focusing on priority areas as agreed with Council and identified by the first pass.

2.1 First Pass Assessment

The first pass assessment involved a high-level assessment of coastal hazards over the coast of the entire district using expert judgement and a wide range data and information including:

- Aerial photography dating from the 1940s to the present
- Historic photographs and surveys (at some sites dating from the late 1800s and early 1900s) available via Pataka, the National Library and historic survey databases
- Early descriptions and maps of the area
- Available topographic (LiDAR) data from PCC and bathymetric information
- Existing reports on coastal erosion and other relevant published resources (e.g. local history books and a range of technical reports and studies)
- Storm surge modelling and sea level reports as well as tide gauge and coastal flooding data (e.g. reports from historic events)
- Physical and geomorphic characteristics and relevant mechanisms and processes associated with coastal erosion and coastal storm inundation
- Variety of field observations around the entire developed coast of the District
- Appropriate geomorphic models to assess the potential future impact of projected sea level rise (see Sections 3.4.2 and 3.4.3 for more detail)
- Existing coastal hazard protection works

This information was analysed and synthesized to assess coastal hazards and associated management issues and options for various coastal compartments (see Section 5); the compartments based largely on geomorphic attributes and existing land uses.

2.2 Second pass hazard assessment at priority areas

This first pass assessment provided adequate information on coastal hazard identification for most areas of the District. From this broad assessment, a number of sites were also identified where more detailed work was required. These were typically areas of high existing or potential future coastal hazard risk, where complex management issues either exist or are likely to arise in the future. They are also sites where management of land use on private property will be necessary to avoid or reduce hazard risk. In most cases, these are areas where adaptive management strategies are eventually likely to be required. In such areas, good definition of the areas of risk is required to support the controls and avoid unnecessary restrictions on land use.

The sites selected for the more detailed second pass assessments included (from north to south):

- Pukerua Bay
- Hongoeka
- Karehana
- Plimmerton
- Golden Gate Peninsula beaches (including Ivey Bay, the chenier plain on the northern side of the Peninsula and Browns Bay)
- Pauatahanui
- Mana and the CBD
- Titahi Bay

More detailed work was conducted in these areas, including:

- **First round of consultation with affected landowners and communities at each of the sites**. This work involved community meetings held in August 2018 at Plimmerton (also covered Karehana), Titahi Bay, Pauatahanui, Golden Gate/Browns Bay, Pukerua Bay and Hongoeka. The primary objective of this first round of meetings was to advise local residents of the work and to seek community information (e.g. observations of past coastal erosion and flooding events; any historic information or photographs) that may be of use to the study. The community meetings provided valuable information in terms of local knowledge and historical observations, and also provided insight into community values and expectations.

- **Further field inspections,** including collection of shore profile data, observations of local geomorphology and coastal processes and an evaluation of human impacts.

- **More detailed review of historic and potential future shoreline change**, particularly the beach sites.

- **Limited sub-surface investigations** (drilling using a vehicle mounted augur) at two sites (Plimmerton and Titahi Bay) to assess any constraints on future shoreline change imposed by erosion-resistant sub-surface geology.

The available information from the above sources was then synthesized to better assess areas of existing and potential future coastal hazard risk.

In addition, the various management issues likely to arise over time were broadly assessed together with relevant management options; to provide some indication of the complexities at each of the sites that will need to be addressed by site-specific adaptive management strategies and relevant triggers.

The various hazard issues and potential management options were then discussed and refined with Council staff. A second round of community meetings was subsequently held in November 2018 at each of the six sites to discuss the findings and associated hazard management issues and options and seek community feedback.

On the basis of these discussions and feedback and further discussions with Council staff, broad recommendations were developed for the management of coastal hazard risk in each area until detailed site-specific adaptive management strategies can be agreed with the relevant stakeholders. The site specific hazard assessments and management recommendations for each of the six priority areas are given in Section 6-13).

These interim management recommendations and associated hazard maps were presented in a third series of public meetings in July 2019, with the PowerPoint presentations also made available online. This draft report and some details of coastal hazard mapping were then refined in response to feedback received during these meetings. Council also proposes to release a draft Plan including hazard maps and provisions to provide an opportunity for further public feedback before formal notification.

3 METHODOLOGY USED TO IDENTIFY COASTAL HAZARD AREAS

3.1 Coastal Hazard Areas

We have identified three coastal erosion and coastal flood hazard zones:

- **Current coastal erosion/flood hazard**, identifying the areas potentially vulnerable to coastal erosion /flooding over the next 100 years with existing sea level and coastal processes. This hazard identification assesses erosion events with a return period of at least 100 years and coastal inundation events with a 1% annual exceedance probability)

- **Future coastal erosion/flood hazard 1.0 m sea level rise**, identifying the areas potentially vulnerable to coastal erosion/flooding over the period to 2120, assuming sea level rise of 1.0 m

- **Future coastal erosion/flood hazard 1.4 m sea level rise[1],** identifying the areas potentially vulnerable to coastal erosion/flooding, assuming sea level rise of based on RCP8.5 H+ (1.36 m to 2120).

The hazard areas are defined without regard to existing structures or other intervention that may mitigate hazard. Accordingly, they show the areas at risk or potential risk in the absence of intervention. The only exception relates to roads and infrastructure, where it is assumed the assets will be protected from erosion as provided for in national policy (see further discussion in Section 5.1 and 5.2). If agreed adaptive management strategies are developed and implemented at some future date that include works that mitigate erosion or flooding in other areas, then the hazard areas may need to be revised to reflect this. It also important to appreciate that the approach we have adopted does not mean that existing sea walls (or other intervention) do not presently provide robust protection; they may, or may not. Rather, it simply means that the current measures presently do not form part of an agreed long term adaptive management strategy and/or may not be appropriate as longer term solutions (see discussion of various sites in Sections 5 and 6).

The first two hazard zones are recommended for the management of land use in areas of existing subdivision. The third hazard area is recommended for use in managing land use and development in Greenfields areas. These recommendations following the guidance provided in MfE (2017).

These coastal hazard zones identify areas that are exposed to a varying level of hazard.

The current hazard areas generally define existing (i.e. present day) risk to property and assets in the absence of intervention; the only exception being the current coastal erosion hazard areas in those locations where there are existing long-term trends for retreat (e.g. parts of Pukerua Bay). In the latter areas, erosion risk will in the more landward parts of the identified hazard area are currently low but will increase over planning timeframes.

[1] The erosion and flooding calculations reflect a sea level rise of 1.36 m to 2120, relative to the 1986-2005 baselines as directed by MfE (2017). For the purposes of reporting, we have referred to these areas as Future coastal erosion/flood hazard “1.4 m sea level rise” and referred to 1.4 m of sea level rise in the text for simplicity.

The future hazard areas are not presently at risk from erosion or flood events with a return period up to 100 years. Rather, they show the additional areas that may become at risk with future sea level rise of 1.0 m or 1.4 m.

There are considerable uncertainties in the definition of hazard risk areas, particularly in regard to both coastal erosion and the potential impact of future sea level rise. We have endeavored to make these uncertainties transparent where relevant. Given the uncertainties, we have adopted a reasonable but precautionary (i.e. err on the side of caution) approach to the definition of hazard areas. Accordingly, given the uncertainties and ongoing improvement of knowledge over time, it is recommended that District Plan provisions provide for revision of the hazard areas if justified by appropriate investigations conducted by an appropriately experienced and qualified coastal scientist or coastal engineer.

The following sections outline the methodology used to identify these areas.

3.2 Coastal Erosion

The Porirua coastline is highly varied, with many geomorphic shoreline types, including banks, cliffs, wetlands and beaches built from sand, gravel or mixed sand and gravel. These shorelines occur in both exposed open coast settings and sheltered harbour locations. In each shoreline type, there are also areas of that have been armoured against coastal erosion.

As part of this study we have identified the areas of land likely to be at risk from coastal erosion with current sea level, and with future projected sea level rise. We have used all available information and considered sea level rise values as directed by national guidance (see Section 3.4.1). The most appropriate approaches for erosion hazard assessment vary with shoreline type (i.e. beaches, cliffs, etc.) and the approach adopted in each type is briefly outlined in the following sections.

We outline our proposed approach to identifying and mapping these areas here, and in Sections 6-14 we provide more detailed background on hazard zone assessments at each relevant location.

3.2.1 Sand Beaches

There are a number of components to be considered when estimating the width of coastal erosion hazard zones for any planning period (“t”), including:

- Any long-term trends for permanent erosion or accretion (“LT”)
- Maximum likely dynamic shoreline fluctuations over the planning period (“ST”)
- Slope instability associated with collapse of over steepened erosion scarps (“S”)
- Potential effect of climate change over the planning period, particularly sea level rise (“X”)

Typically, these components are summed to provide a total width of hazard area (“CHEZ”):

$$CHEZ = (LT \times t) + ST + S + X$$

In areas where sea walls constrain erosion, an additional factor has to be included to allow for the effect of the sea wall; unless the sea wall (or a replacement structure) is likely to be adopted as an appropriate long-term solution. In essence, this factor involves estimating how much further the toe of bank would lie if the sea wall were not present.

We have estimated these components for each site using the available information discussed in Section 2.2, with particular emphasis on field observations and geomorphology, historic aerial photographs and surveys and community information. The following sections briefly outline the methods used to assess each component.

Long Term Trends for Shoreline Change

Long term trends for permanent shoreline advance or erosion were assessed using historic aerial and other photography, historic surveys, field observations and geomorphology and community information. Most sand beaches appear to be presently in dynamic equilibrium; the shorelines fluctuating backwards and forwards over time with little to no existing trend for permanent shoreline advance or retreat. However, long term trends do occur in parts of Pukerua Bay (see Section 6).

Dynamic Shoreline Fluctuations

Sandy beaches are naturally dynamic and respond rapidly to changes in local coastal processes. These systems are the most vulnerable to coastal erosion and the most likely to be severely affected by the impacts associated with hard coastal protection works. Natural functioning of sandy beaches relies on the presence of an intact sand dune, which is part of the natural beach system, and is critical to processes of natural erosion and recovery.

Sand dunes are formed when wind blows sand inland from the beach, where it is "caught" by sand trapping grasses and accumulates. This sand is stored in the dune until there is a storm event that erodes the beach and the face of the dune. Eroded sand is transported offshore to form offshore bars (Figure 2). In calmer conditions, sand from these nearshore bars is worked back onto the beach and over time beach levels recover (Figure 3). Natural dune recovery occurs as windblown sand from the beach is trapped by vegetation; but depends on suitable sand trapping vegetation occurring on the dune (e.g. spinifex and pingao).

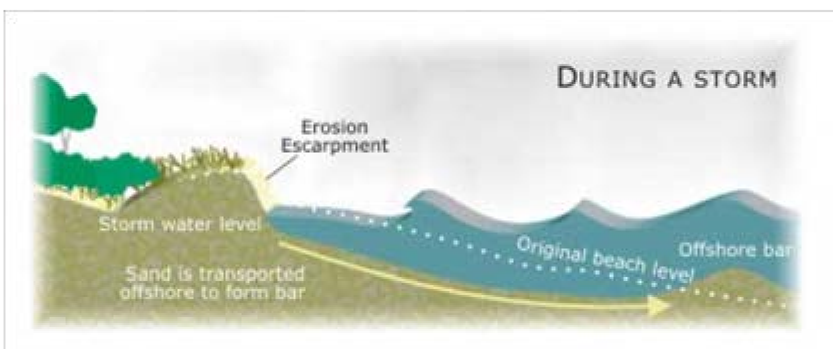

Figure 2: During storms, sand is eroded from the dune and forms bars offshore that absorb wave energy.

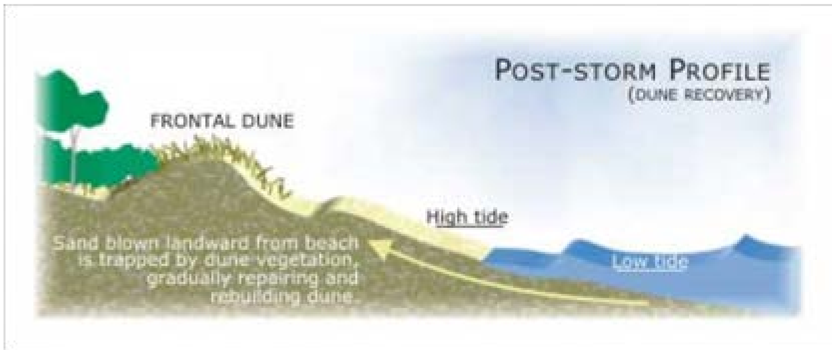

Figure 3: During calmer wave conditions, sand from the offshore bars makes its way to the beach and over time the dunes rebuild.

Sandy beaches can also experience dynamic shoreline fluctuations with extended periods of erosion and accretion due to causes such as climate cycles that alter weather patterns (e.g. affect the frequency of storms).

The maximum scale of the dynamic shoreline fluctuations (often referred to as the dynamic envelope) is typically only evident over long periods of time (generally many decades). Care and long-term records are therefore required to adequately assess the maximum likely dynamic shoreline fluctuations and to distinguish any contribution of permanent long-term trends for erosion or accretion.

Collapse of Erosion Scarps

Following severe storms, dune erosion and beach lowering typically form near vertical erosion scarps. These scarps can collapse to a more stable slope at a later date, generally in the order of 26 degrees in unconsolidated sands. In identifying erosion hazard zones, it has been assumed that the dune face will collapse to this stable slope. In practice, the value of this parameter is generally close to the height of the dune above the dune toe, as material collapsing from the top of the dune face will form a slope at the base of the scarp, stabilizing the slope.

3.2.2 Gravel Beaches

Mixed sand and gravel beaches occur along the open coast from Pukerua Bay through to Hongoeka, inclusive. Small patches of mixed sand and gravel beaches also occur perched on the landward edge of the rock reefs along the Karehana foreshore.

The morphology and dynamics of gravel and mixed sand and gravel beaches (Jennings and Shulmeister, 2002) vary markedly from the sandy beach systems and hence a different approach is required for coastal erosion hazard assessment.

Figure 4 presents an idealised profile of a mixed sand gravel beach. The cross-shore profile can be broadly subdivided into at least three distinct berms:

- a low-tide berm also known as the beach step
- a high-tide or swash berm, and
- a storm berm at the top of the beach.

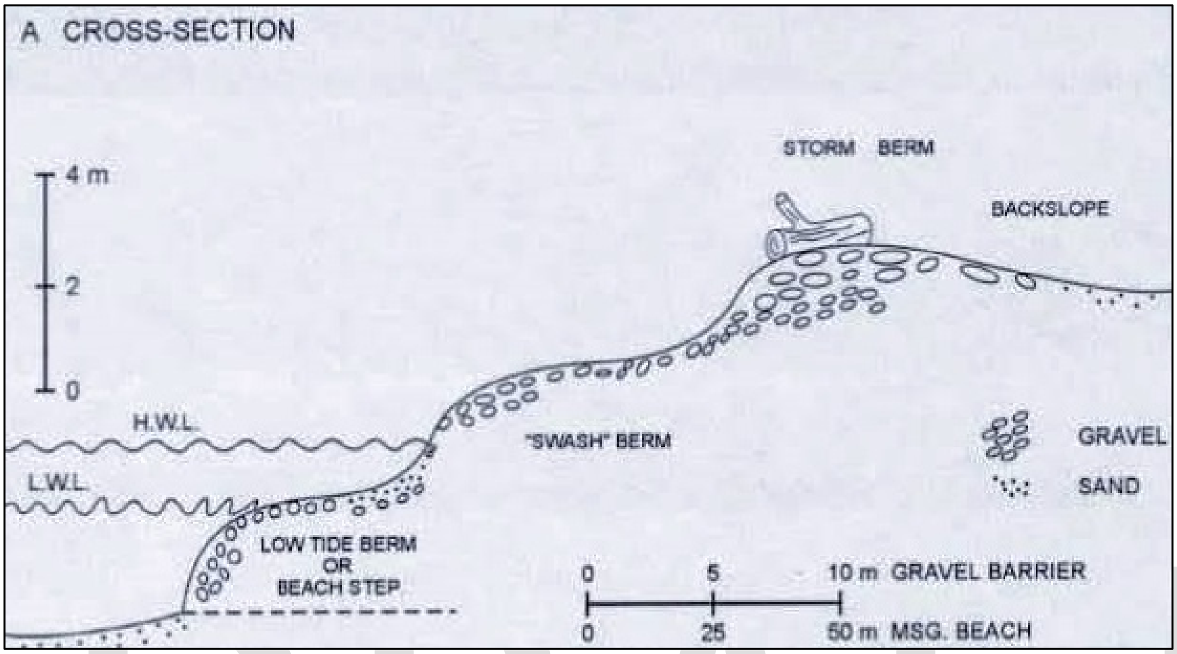

Figure 4: Idealised sketch showing typical cross-section over a mixed sand gravel beach (from Jennings & Shulmeister, 2002).

The beach step marks the seaward edge or closure point of mixed sand-gravel beaches. Seaward of the beach step, the gravels typically give way to a low gradient nearshore comprised of sand. All waves are modified and start breaking when they cross the step, which is responsible for the plunging breakers typical of gravel beaches.

The high-tide or swash berm is very dynamic and is often characterised by a number of (typically low) berms or ridges formed under differing wave and tidal conditions. In practice, this tends to be the area where most dynamic change occurs.

The highest and main storm berm (commonly also called a storm ridge) further landward (Figure 4) is formed by the more extreme storms that affect the beach. This berm is formed by sediments deposited during wave run-up and overtopping during severe storms. Sediments are also carried over the storm berm and deposited on the landward side as the overwash dissipates, typically forming a gentle backslope.

The main storm ridge still occurs on most of the mixed sand gravel beaches along the undeveloped coast between Pukerua Bay and Hongoeka and along the central and southern areas of Hongoeka itself. However, at Pukerua Bay and along the gravel sections of the Karehana coast, natural storm ridges have been buried by historic reclamation undertaken to form the beachfront roads in these areas. In the latter areas, the gravel beaches are backed either by slowly eroding reclamation fill or shoreline protection works.

On gravel barriers, the total width of the coastal erosion hazard zone has been assessed using a similar sum of components approach to that adopted for sandy beaches:

$$CEHZ = ST + (LT * t) + X + SI \tag{4}$$

Where,

- LT = Any long-term trends for permanent erosion or accretion
- ST = Maximum likely dynamic shoreline fluctuations over the planning period
- SI = Slope instability associated with collapse of eroded banks to a more stable slope
- X = Potential effect of climate change over the planning period, particularly sea level rise

The unique morphodynamics of mixed sand and gravel beaches mean that targeted approaches are required to estimate some of these erosion components. The slope instability parameter for instance is only relevant at sites such as Pukerua Bay where the beach has been truncated by historic reclamation and is backed by a slowly eroding reclamation fill. At other sites where the natural profile remains intact this component will not be relevant, and these beaches do not form vertical scarps.

The various erosion components were assessed as follows.

Long term trends

Any existing trends for long term net shoreline advance or retreat were primarily assessed using the same approach outlined earlier for sandy beaches – particularly historic photographs and surveys and community information.

Overwash[2] plays an important role in the dynamics and evolution of gravelly beaches, particularly gravel barriers. On many coasts, these features tend to migrate landward (i.e. erode or retreat) through the process of storm-wave overwash or "rollover" – in contrast to the beachface erosion that characterizes the response of sandy beaches to storms. This rollover process reflects the dominance of wave upwash over backwash, due to infiltration reducing the sediment transport capacity of the backwash.

The available data (particularly aerial photography) suggest that the main storm ridge is relatively stable and is not undergoing permanent long-term retreat at relevant sites in Porirua. Rather, beaches backed by a wide storm ridge tend to be fairly stable and resilient; typically, in dynamic equilibrium or (possibly) even experiencing very slow net accretion.

Long term erosion trends typically occur only where the main storm ridge has been eliminated by human activities and the beach is backed by reclaimed land (e.g. Pukerua Bay). In some such areas, seawalls have been placed to stop the erosion.

[2] Overwash is the flow of water and sediment over a coastal dune or beach crest during storm events (or other situations with high water)

Dynamic shoreline fluctuations

Dynamic shoreline fluctuations have generally been assessed on the basis of the available shoreline change data and field/geomorphic considerations.

In most areas, the only significant dynamic fluctuations occur seaward of the main storm ridge. Accordingly, dynamic shoreline fluctuations have generally been assessed as zero on gravel beaches.

3.2.3 Cliffs

There are many cliffed shorelines in Porirua City, including much of the open ocean coastline, and the Golden Gate Peninsula in Pauatahanui Estuary.

Coastal erosion of cliffs typically occurs slowly and unlike beaches is essentially a one-way process. Cliff erosion mechanisms relate to coastal erosion at the toe, and to slope instability processes higher up. Coastal processes work to erode the base of the slope, until over steepening causes slope failure to a stable slope as shown schematically in Figure 5.

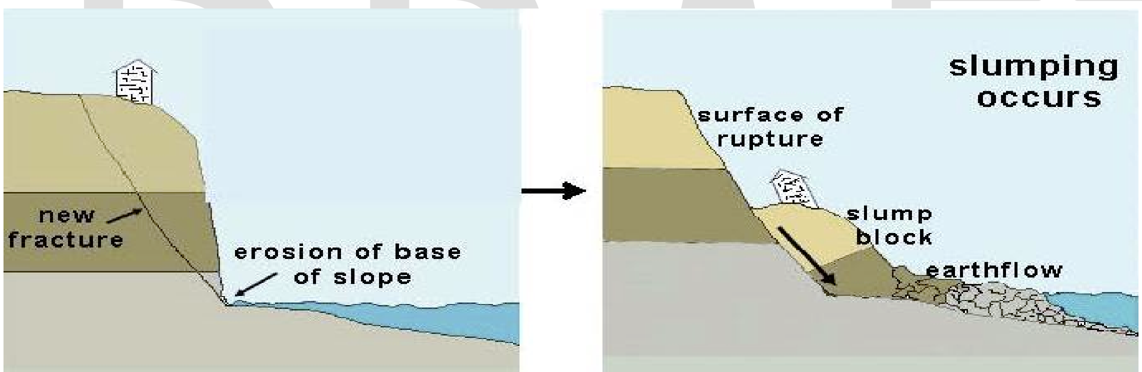

Figure 5: Processes of cliff erosion.

The key factors that need to be considered in erosion hazard assessment for cliff sites are:

- Historic long term (i.e. time-averaged) rate of toe erosion
- Slope instability arising from the toe erosion (typically assuming failure to a stable slope)
- Potential effect of sea level rise on the above factors (i.e. particularly toe erosion)

A range of data and methods have been used to estimate coastal erosion hazard zones for cliff environments along the Porirua coast including:

- Geological, geomorphic and field observations to estimate very long-term erosion rates (e.g. shore platform width) and likely stable slope.
- Historical aerial and other photography
- Historic shoreline surveys
- Empirical techniques to estimate the potential impact of projected sea level rise (discussed further in Section 3.4.2.

3.2.4 Mapping Baseline

The baseline from which coastal erosion hazard areas have been mapped varies from site to site due to geomorphic and anthropogenic (e.g. seawalls) factors. On sandy beaches, the baseline is typically adopted as the toe of the natural bank or dune, with appropriate adjustment for any seawalls. On sandy beaches subject to significant dynamic shoreline fluctuations, we have also assessed the location of the baseline relative to historic shoreline fluctuations to avoid double-counting of dynamic changes. On gravel beaches, the crest of the main storm ridge is typically adopted as the baseline. For cliffed areas, the existing toe of cliff has been adopted as the baseline or, where this feature cannot be accurately mapped, a proxy ground level (depending on the physical setting) from LiDAR data.

3.3 Coastal Storm Flooding

The key components contributing to coastal storm inundation over the next 100 years (Figure 6) comprise:

- astronomical tides
- storm surge, being elevation of sea level by barometric and wind effects
- wave effects, including wave set-up and wave run-up
- rise in relative sea level due to climatic and tectonic changes.

These various components are illustrated in Figure 6 and discussed further below.

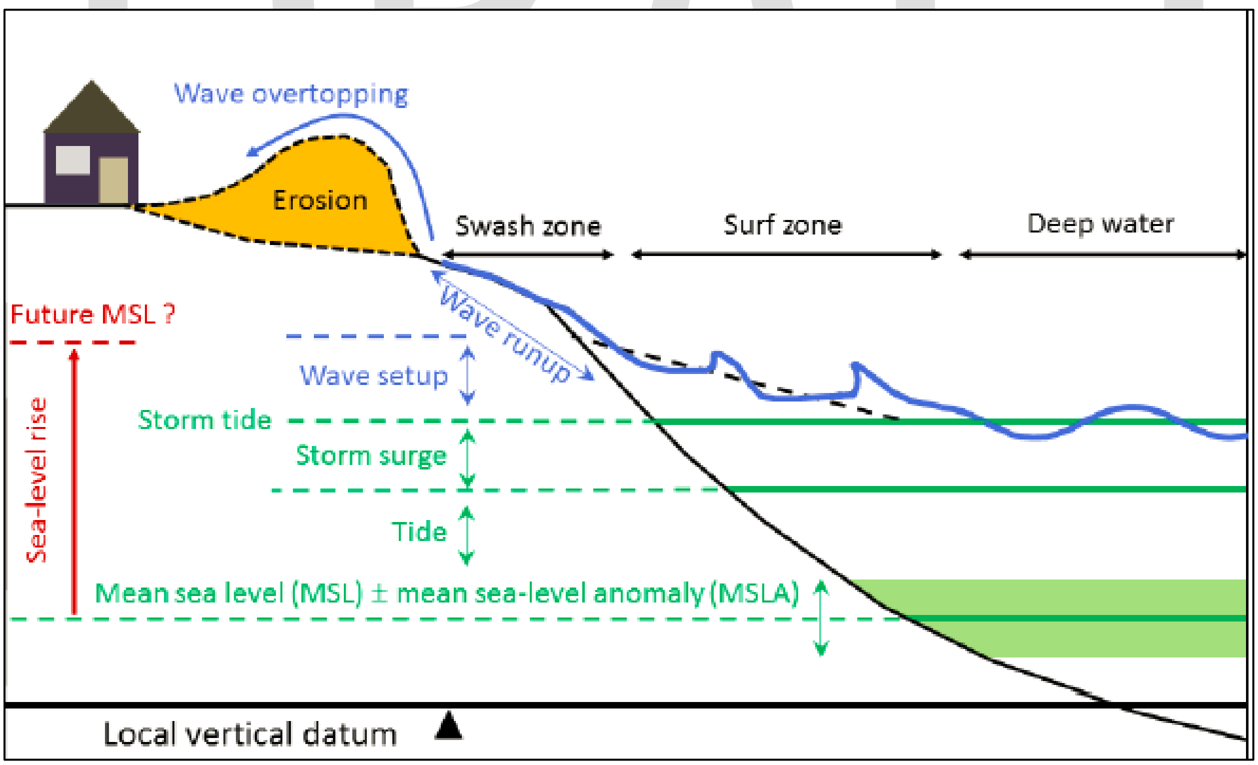

Figure 6: Summary diagram showing the various components that contribute to coastal storm inundation (source: Figure 30 from MfE, 2017)

3.3.1 Astronomical Tides

Astronomical tides are the dominant component of coastal storm inundation for the Porirua City coastline and key tidal parameters for the open coast (Karehana) and Porirua Harbour (Mana Cruising Club) are summarised in Table 3. It can be seen that the tidal parameters at both sites are very similar. A key aspect is the very limited (0.2 m) neap tide range, though the mean tide range is much greater (1.4 m) (Table 2). The highest astronomical tide (HAT) is given as 0.95 m (WVD-53) by Lane et al. (2013).

Table 2: Key tidal parameters for Karehana (open coast) and Mana Cruising Club (Porirua Harbour) (source: LINZ secondary ports table). Note: Elevations are relative to Chart Datum at Port Taranaki and not WVD-53.

Tidal Parameter		Karehana (m)	Mana (m)
MHWS	Mean High Water Spring	1.7	1.7
MHWN	Mean High Water Neap	1.1	1.2
MSL	Mean Sea Level	1	1
MLWN	Mean Low Water Neap	0.9	0.9
MLWS	Mean Low Water Spring	0.3	0.4

3.3.2 Storm Surge and Storm Tide

Storm surge results from the combination of barometric set-up and wind set-up which elevate water level above the predicted tide (Figure 6). Barometric set-up effect occurs when low atmospheric pressure over the ocean drives an increase in water level. Wind set-up is a rise in water level arising from strong onshore or alongshore winds.

Wave breaking processes generate an increase in the average elevation of sea level (wave set-up) during storm events due to the release of wave energy in the surf zone as waves break. When offshore waves are large, wave set-up can raise the water level at the beach substantially. Most weather systems approach the Wellington Region from the west of New Zealand and therefore propagate towards the Porirua coast, generating wind waves and swells that affect the study area. The wave effects are therefore generated by the same events that drive barometric and wind set-up.

NIWA (Lane et al. 2013) assessed storm surge and wave effects for the coast of the Wellington Region. The study modelled selected historic storm events with a join annual exceedance probability of 1% and simulations were also undertaken that included sea level rise increments of 0.5 m, 1.0 m and 1.5 m. This study provides the best available data to assess potential coastal storm inundation for the Porirua City coastline and has primarily been adopted for first pass assessments of coastal storm flooding in this report.

The "storm tide" is the storm-elevated sea level arising from the combination of the predicted tide and storm surge (Figure 6). Wave set-up occurs over similar timescales to that of storm surge and is included by Lane et al. (2013) in the calculations of "storm tide" extreme seas levels for the Wellington Region. The modelling study by Lane et al. (2013) indicated that wave set-up can contribute as much as 0.7-0.8 m on the open coast of Porirua but has little or no influence at the sheltered harbour shoreline.

The extreme "storm tide" elevations calculated by Lane et al. (2013) also include sea level 'anomaly' (sometimes referred to as "mean level of the sea" or "MLOS"); longer-term variation of the sea level that do not relate to tides. Such sea level variations occur at time periods over a year (seasonal changes), several years (El Niño and La Nina Climate Cycles) and over decades (Pacific Decadal Oscillation). Therefore, while tide levels can be accurately predicted, the actual sea level at any given location is likely to differ from the predicted tide. This value can be evaluated through analysis of tide gauge data, and the range of sea level anomaly measured in Wellington was typically up to +/-0.15 m (Lane et al., 2013).

Table 3 presents elevations for the 1% AEP storm tide at four locations within Porirua City.

Table 3: Storm tide elevations for Porirua Harbour (source: Lane et al. 2013).

Location	1 % AEP Storm Tide (WVD-53)
Pukerua	**2.02 m**
Porirua Harbour Entrance	**1.59 m**
Porirua City	**1.70 m**
Titahi Bay	**1.88 m**

3.3.3 Wave Run-up

"Wave run-up" is the maximum vertical extent of wave up-rush on a beach or structure above the still water level (i.e. the water level that would occur without waves) (Figure 6). The magnitude of wave run-up depends on the angle of the shore to the approaching waves, the nearshore water depth, wave height and period, beach slope and the nature of the shoreline (beach, dunes, vertical or sloping seawalls etc.). Wave run-up is therefore more significant on exposed open coasts and less so on sheltered estuarine shorelines.

Wave run-up is not included in calculations of storm tide level as it is only a short-term fluctuation in water level. Coastal inundation is generally controlled by the maximum static water level driven by tides, storm surge and wave set-up. Wave run-up can have significant effects near the coastal edge, but the flow is rapidly dissipated. Where wave run-up is sufficient to overtop coastal margins, it can also contribute to ponding in areas further landward but flooding elevations in such areas are not likely to exceed the static "storm tide" elevations.

Notwithstanding this, storm wave run-up can reach to considerably higher levels than the "storm tide" elevations (particularly in in exposed open coast areas) and aggravate inundation and cause physical damage to structures in the more nearshore areas. We have included an allowance for wave run-up close to the shore on exposed coasts. On estuarine shorelines, wave run-up and surface water irregularities have been provided for in the freeboard allowance. These allowances are discussed in Sections 6-10 as relevant.

3.4 Sea Level Rise

3.4.1 National Policy and National Guidelines

The NZCPS (2010) requires that Councils plan for the likely impact of projected sea level rise over at least the next 100 years. In the future, accelerated sea level rise is anticipated in response to global warming and so it is not appropriate to simply extrapolate past trends to predict the future. However, the rate of change over the next 100 years is subject to considerable uncertainty. National guidance (MfE, 2017) therefore recommends that Councils consider the likely impacts of a number of plausible scenarios, and from these develop adaptive management plans that can respond to sea level rise as it occurs. The recommended projections are based on future global emission scenarios developed by the Intergovernmental Panel for Climate Change (IPCC, 2013 & 2014) and are summarised in Table 4.

Table 4: Summary of sea level rise scenarios for management (MfE, 2017).

Scenario	2070	2120
Low (RCP 2.6) Lower bound "surprise"	0.32 m	0.55 m
Intermediate (RCP 4.5)	0.36 m	0.67 m
Transitional		1.00 m
High+ (RCP8.5) (85th percentile)	0.61 m	1.36 m

The MfE (2017) national guidance recommends Councils apply the following sea level rise values for coastal hazard planning where an adaptive plan is not yet in place:

- **Greenfields developments or major new infrastructure**: avoid all risk and use only RCP8.5 H+.
- **Intensification or change in land use of existing development**: no transitional value is provided, and any intensification/land use change requires a full adaptive management planning process using the four sea level rise scenarios (at the scale appropriate to the scale of the intensification).
- **Existing exposed development**: use a transitional sea level rise of 1.0 m (2120) until a full adaptive management plan is complete.
- **Low-risk non-habitable works and activities**, particularly those with a functional need to be near the coast: use transitional value of 0.65 m by 2120, which aligns with RCP4.5 (2120).

We believe that the guidelines for low-risk non-habitable uses are too broad and appropriate sea level rise values will vary considerably according to the nature of the works. Otherwise, we have adopted the recommended guidelines.

Accordingly, for both coastal erosion and coastal flooding, we have defined the coastal hazard areas for present sea level and possible future coastal hazard areas for both 1.0 m and 1.4 m sea level rise.

3.4.2 Effect of Sea Level Rise on Coastal Erosion

Beaches

The response of sandy beaches to sea level rise depends on many factors and accurately predicting future change is very difficult.

Observations of historic surveys and photographs (Section 2.1) indicate that the open coast and estuarine beaches of Porirua City are not actively accreting over human management timeframes; being either in dynamic equilibrium or slowly eroding. On such beach systems, sea level rise is expected to drive an overall trend for shoreline retreat on both sand and gravel beaches; with the beach profile adjusting landwards and upwards in response to the higher water level.

Shand et al. (2013) present a useful summary of the methods commonly used to provide indicative estimates of the erosion likely to arise from any given sea level rise. As they note, the most commonly used methods are simple geometric models which simply consider two-dimensional (cross-shore) changes – such as the standard Bruun Rule (Bruun, 1962 & 1988) used on sandy beaches and the generalized Bruun Rule used for gravel beaches.

These simple two-dimensional geometric models assume that neither the cross-shore shape of the beach profile nor the plan shape of the beach system are otherwise significantly modified; as might occur if climate change affects other key drivers additional (e.g. wave climate; sediment supply/budget). Obviously, this is an area of considerable uncertainty, one of many relating to potential climate change effects. It is our view that any such changes on the Porirua coast are more likely to aggravate than offset or mitigate erosion. We therefore believe that the use of these simple geometric models to provide indicative estimates of erosion is not likely to result in overly precautionary estimates of future erosional response. It is important to appreciate that (regardless of the assessment model used), estimates of shoreline response to sea level rise are indicative rather than being accurate predictions. Future monitoring and the use of adaptable management approaches are therefore critical to successful long-term management.

Sand Beaches

On sandy beaches, the standard Bruun Rule assumes that the equilibrium cross-shore profile of the beach (out to the seaward edge, known as the closure depth) is moved upward and landward conserving mass and original shape. This change results in the upper areas of the beach being eroded with this volume balanced by equivalent deposition offshore (see top diagram in Figure 7). With this simple model, indicative estimates of erosion can be obtained using the following basic relationship:

$$\text{Erosion} = (\text{SLR} \times L)/h_*$$

Where:

SLR	=	Sea-level rise (m) (labelled B in Figure 7)
L	=	Distance between the landward and seaward edges of the beach system
h_*	=	Elevation difference between seaward and landward edges of the active beach system

Estimates using the Bruun Rule and available bathymetric and topographic data available for Titahi Bay suggest that erosion of 40-50 m might occur for every 1.0 m of sea level rise. However, drilling conducted at the site indicated that potential future erosion is constrained by the limited width of the dune at this site; with the dunes backed by more erosion resistant materials (see further discussion in Section 11).

At the other open coast sand beaches (i.e. Ngatitoa, Plimmerton and the northern area of Karehana Bay), the Bruun Rule is unlikely to be a realistic model as the offshore topography is complicated by various factors. Many of the beaches along Karehana shoreline are essentially perched beaches sitting on a rock reef, while others have rock reefs offshore which modify wave action. Plimmerton and Ngatitoa beaches are also part of an integrated sediment system which includes the flood- and ebb-tide delta systems of Porirua Harbour. There are significant uncertainties in estimating the likely response of these beaches to sea level rise. For instance, with perched beaches, an increase in sea level rise is likely to increase depths over the rock reefs and increase wave energy reaching the shoreline. With Plimmerton and Ngatitoa, there is potential for sediment to be lost not only to cross-shore adjustment of the beach profile (as per the Bruun Rule assumptions) but also to growth of the flood- and ebb-tide delta systems with sea level rise.

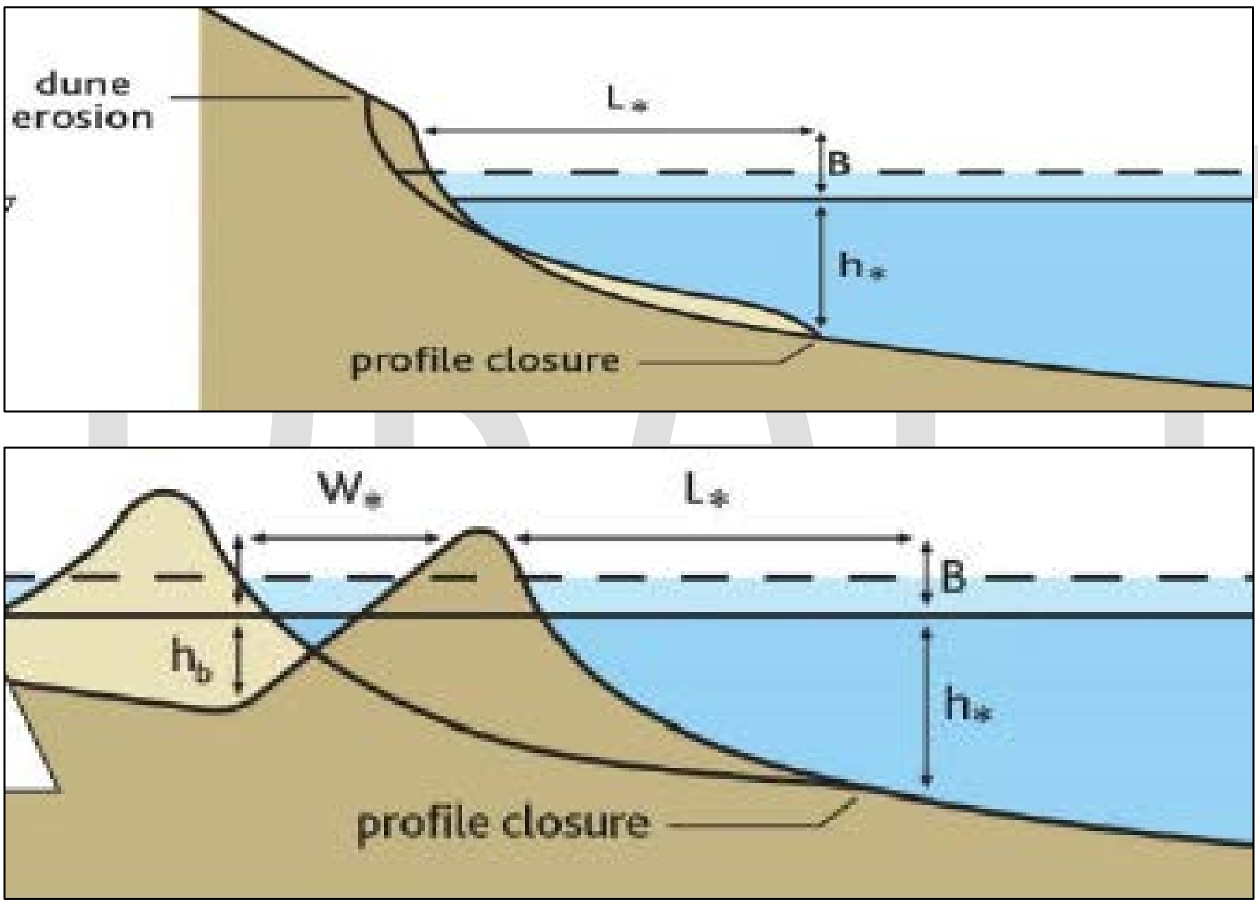

Figure 7: Schematic diagrams showing the standard Bruun Rule (top) and the generalised Bruun Rule (bottom) (Modified from Figure 1 in Shand et al. 2013).

At these sites, application of the standard Bruun Rule is unlikely to give realistic estimates of erosion. In order to provide indicative estimates of erosion, we have used a typical upper beach slope of 1:20 in erosion calculations. In our view, this method is likely to provide lower order estimates, and this will need to be taken into account in the development of adaptive management strategies for these sites. It is difficult to provide useful indicative upper limit estimates of erosion due to the complications relevant at these sites. However, in the absence of the complications related to offshore topography, the estimate of 40-50 m erosion per 1.0 m of sea level rise obtained for Titahi Bay would probably provide an indicative estimate.

For estuarine beaches, the seaward toe of the beach face has been taken as the closure depth and an average slope of 1:10 (based on field measurements) was adopted for first pass calculations of erosion due to sea level rise at most sites.

Mixed sand-gravel beaches

On mixed sand-gravel and gravel beaches, storm waves typically push material higher on the profile to build a wave-formed storm ridge. This is in contrast to the offshore sand transfer that occurs during storm erosion on sandy beaches. Sea level rise at gravel beaches therefore results in the storm ridge being more frequently overtopped by waves, causing the storm ridge to migrate landwards and upwards, a process known as rollover.

The landward retreat of the shoreline can be estimated by the generalised Bruun Rule (Figure 7):

$$\text{Erosion} = \text{SLR} \times (L + W)/(h_* - h_b)$$

Where

SLR	=	Sea-level rise (m) (labelled B in Figure 7)
L	=	Closure distance (distance from the storm ridge to the seaward toe of the gravel beach)
W	=	Back barrier width (distance from crest to landward edge of the storm ridge)
H_*	=	Closure depth (essentially the seaward toe of the gravel barrier)
h_b	=	Elevation at landward edge of the storm ridge (i.e. limit of common overwash deposits).

The sum (L + W) essentially represents the total width of the barrier system from the seaward edge (i.e. closure depth – being the base of the beach step) to the landward edge (i.e. the landward edge of the wash-over deposits). The rollover model is particularly sensitive to back-beach elevations, with estimated erosion increasing markedly with decreasing back-beach elevations (i.e. increasing values of h_b).

There is only one developed site (Hongoeka) where we used the rollover model. However, the rollover model assumes a fixed sediment volume, assuming more seaward areas of the beach are eroded to provide the sediments for upwards and landward migration of the storm ridge. We suspect however that there is a volume of longshore transport passing through this area and note that this input may enable the storm ridge to migrate landwards and upwards without much permanent erosion of the beach to seaward. Accordingly, we have complemented the rollover model estimate with a lesser estimate of erosion based on landward extrapolation of the existing beach slope. Given the present uncertainty, we believe both estimates should be considered in developing any adaptive management plan for this site.

At sites where the beach system has been truncated by historic reclamation and is now backed by an erosion scarp cut in reclamation fill (e.g. Pukerua Bay), we have used the average beach slope to estimate the increased erosion that could arise from sea level rise.

Cliffs

Projected future sea level rise is also likely to increase erosion of cliffs and banks; particularly in areas where wave action influences existing toe erosion rates. As sea level rises, the frequency and severity of wave attack increase at the toe of the banks/cliffs.

The influence of sea level rise on bank and cliff erosion rates is still an active area of research and while various methods have been proposed to estimate these effects the methods have significant challenges. Ideally, Le Cozannet et al. (2014) argue that it is necessary to rely on local observations and models applicable in the local geomorphological context.

At this point in time, there are no models developed in the local Porirua context that can be used to predict the potential influence of future sea level rise on bank/cliff erosion. However, Ashton et al. (2011) propose the following generic cliff retreat framework/equation for the response of a wide range of cliffed shores to sea level rise:

$$R_2 = R_1(S_2/S_1)^m$$

Where R_2 is the future rate of toe erosion, R_1 is the historic (and presumed present) rate, S_2 is the projected future rate of sea level rise and S_1 is the historic rate of sea level rise. The constant *m* ranges from -0.5 (inverse feedback – damped erosion), through 0 (no effect) to 1 (instant response).This model is probably the best available approach for estimating the effect of sea level rise on future cliff erosion rates where wave erosion is the principal mechanism acting on the cliff face. However, the difficulty lies in choosing an appropriate value of the power function *m.*

On open coast sites with high rates of bank or cliff recession, the SCAPE (Soft Cliff and Platform Erosion) predictive model (*m* = 0.5) has provided reasonable estimates when tested against the known record of sea level rise and cliff retreat for various open coast soft cliffs in the UK; including The Naze, Essex (Walkden and Hall, 2005), NE Norfolk (Dickson et al., 2007) and the Suffolk Coast (Brooks and Spencer, 2010). However, a value of *m*=0.5 is probably too high for Porirua coast where rates of cliff recession are slow on both open and estuarine coasts. Accordingly, a value of *m* = 0.4 has been adopted for this study.

A recent NIWA investigation indicates that Wellington Harbour has experienced an average rise in relative sea level of 2.03 ±0.15 mm/yr in the last 100 years (Bell and Hannah, 2012); a substantial increase from the rates assessed in earlier studies (1.73 mm/yr up to 1988 and 1.78 mm/yr up to 2001) by Hannah (1990, 2004). However, much of the recent increase in relative sea level is due to slow-slip tectonic processes since around 1997 rather than accelerated sea level rise (Bell and Hannah, 2012).

Given an effective sea level rise of 0.84 m for the next century and an historic rate of sea level rise of 0.17 m over the last century, this yields a multiplier of approximately 2 – suggesting that existing erosion rates could be doubled. Accordingly, when dealing with cliff erosion we have assumed existing toe erosion rates will effectively double in response to 1.0 m sea level rise. In reality, this is probably only likely to occur in areas with relatively soft and erodible banks but nonetheless ensures a reasonably precautionary approach.

In areas where the banks are composed of relatively erodible fill (e.g. Pukerua Bay), we adopted a different approach – assuming that bank toe erosion will increase markedly with increased frequency and severity of wave attack. In these situations, we have calculated the additional bank erosion by extrapolating the present beach slope landward by the sea level rise value. Again, this is may precautionary, but this is appropriate in the absence of more detailed data and analysis.

3.4.3 Effect of Sea Level Rise on Coastal Flooding

Sea level rise is expected to greatly exacerbate the frequency and severity of coastal flooding over the next 50-100 years. Severe coastal inundation events that are currently very rare will become common with even relatively small sea level rise. For instance, Table 5 indicates the change in frequency of what is presently a 1% AEP coastal inundation event with differing sea level rises. The table was produced for Wellington but is also broadly applicable to Porirua which has a similar spring tide range. The table illustrates that with only 0.3 m sea level rise, a 1% AEP event with current sea level will become an annual event (i.e. occurring once a year on average rather than once every 100 years). With sea level rise of 0.7 m or higher, a 1:100 year event with current sea level would occur every tide.

Table 5: Changes in the frequency of a 1%AEP coastal inundation event in the Wellington Region with differing sea level rises. (source: Slide produced by NIWA for roadshow promoting MfE 2017 guidelines)

1.4 m spring-tide range

SLR	Wellington
0cm	Every 100 years
10cm	Every 20 years
20cm	Every 4 years
30cm	Once a year
40cm	Every 2 months
50cm	Twice a month
60cm	3 times a week
70cm	Every tide
80cm	Every tide
90cm	Every tide
100cm	Every tide

PCE (2015); NIWA (2015)

The extent and severity of flooding during rare storm events will also be much greater in areas where coastal land is low lying; with areas not presently subject to coastal inundation likely to be affected.

In this study, information on coastal inundation including the effects of sea level rise is largely derived from Lane et al. 2013. In addition, we have included additional allowances for wave effects as follows:

i. In nearshore areas (e.g. beachfront roads and the most seaward beachfront properties within 30 m of the shore) along the open coast, where it has been assumed that breaking waves bores associated with wave run-up and overtopping will be a significant influence on coastal inundation.

ii. At sites along the open coast where offshore rock reefs are significant in wave transformation (e.g. Pukerua Bay and Karehana), we have assumed that with wave run-up increase with significant sea-level rise due to greater wave energy reaching the shoreline (due to greater depths over the rock reefs and therefore less dissipation of storm wave energy). Accordingly, in these open coast areas we have provided for an increase in wave run-up effects with sea level rise. The values adopted at each site are discussed in the site-specific chapters later in the report. As with i., it is assumed that these influences are limited to the area within 30 m of the present shoreline. Obviously, with future shoreline retreat such influences could extend further landward but that will depend on how erosion is managed at each site.

3.5 Freeboard

A “freeboard” allowance of 0.25 m has been included in the 1% AEP storm tide estimates throughout the district to allow for minor factors such as uncertainties in the estimates, local effects which may amplify flooding and vehicles driving through flooded waters. This freeboard allowance was added to the wave effects calculated for each site.

It should be noted that this “freeboard” is part of the calculation and mapping of inundations levels but is not directly applicable for minimum floor levels. In some cases, this freeboard may be adequate for minimum floor levels but at other sites it may not.

It is also important to emphasize that the estimated flood levels are for rare and severe (i.e. 1 in 100 year, or 1% AEP) storm events and therefore the estimated flooding areas will cover a larger extent than past observed events in many cases. As with erosion, the flood level estimates also ignore any mitigation provided by existing sea walls; another factor which will result in flooding areas being larger area than presently impacted. These various uncertainties are part of the reason that it is important that the proposed Plan provide for revision of the hazard areas on the basis of site-specific assessments by an appropriately qualified and experienced professional; generally a coastal scientist or a coastal engineer.

4 POLICY SETTING

District Councils have an obligation under National and Regional policy to identify and manage coastal hazards. National Policy directs Councils to manage hazard prone land and associated development in such a way that over time builds community resilience and preserves natural processes and ecosystems. The Regional Policy Statement also requires Councils to identify areas at risk from coastal hazards, with priority on high risk areas.

In addition to reducing coastal hazard risk, Council also needs to provide for other coastal values when planning development near the coast, including providing adequate setbacks for natural character, public access, biodiversity, physical processes and amenity. We have provided here a brief overview of the policies most relevant to our assessment of coastal hazards and the associated management recommendations.

4.1 National Policy

The New Zealand Coastal Policy Statement (NZCPS) 2010 directs all Councils in New Zealand to manage coastal hazards by identifying hazard areas and implementing management approaches that mitigate future coastal hazard risk. This statement contains a number of objectives and policies directed at coastal hazard management.

The overarching principles of the NZCPS prioritise <u>locating new development away from risk areas</u> and <u>protecting and restoring natural defenses to coastal hazards</u> (i.e. dunes, beaches, vegetation).

<u>Policy 24</u> requires Councils to identify the areas likely to be at risk from coastal hazards (erosion, flooding and tsunami) over at least the next 100 years. To do this, the Council must examine the physical processes and drivers, the geomorphic characteristics of the coast, the short- and long-term natural fluctuations, the human impacts, and the likely impact of climate change.

<u>Policy 25</u> addresses the management of these hazard areas and directs Councils to avoid any activities that increase the risk of coastal hazards, and to encourage management decisions that decrease risk over time (e.g. managed retreat or relocatable buildings). This policy discourages the use of hard protection structures.

<u>Policy 26</u> highlights the importance of natural defenses such as beaches, estuaries, coastal vegetation and dunes in providing protection from coastal hazards.

<u>Policy 27</u> addresses the most challenging aspect of coastal hazard management, where there is significant existing development in areas at risk from coastal hazards. This policy (for full policy see Appendix A) provides guidance for working through the range of potential management options. The focus is on long term sustainable risk reduction approaches, which may include the removal or relocation of development or structures.

This policy does recognise that in some cases, hard protection structures may be the only practical option, but that the social and environmental costs of such an approach must be acknowledged and that planning should identify transition mechanisms for moving to a more sustainable approach in the longer term. <u>Policy 27 (4)</u> states very clearly that hard protection structures designed to protect private property should not be located on public land.

Historically the approach to coastal erosion management has been dominated by the use of hard engineering structures to "hold the line" and prevent the erosion of both private and public land and assets. The adverse environmental, social and economic impacts of these approaches are now well recognised. "Hard" coastal protection structures interfere with natural coastal processes, can impact severely on the public values of shorelines and often tie communities into a perpetual cycle of ever-increasing financial investment.

National policy therefore now directs Councils to work with communities to manage coastal hazards in a way that over time decreases risk and increases the long-term resilience of coastal environments and communities. This is more important than ever as we face the likely impacts of projected sea level rise in coming decades. To achieve this, Councils are now required to prioritise risk avoidance and reduction over the use of engineering works that control natural processes. A full discussion of this hierarchy is given in Section 4.3, and this forms the basis of our management recommendations to Porirua City Council.

4.2 Regional Policy

The Wellington Regional Policy Statement (RPS) contains policies and methods that relate to the sustainable future management of the coastal environment and natural hazards. The RPS highlights the need to increase community resilience by reducing the risk from natural hazards (including coastal hazard) over time. The RPS also acknowledges the major consequences likely to occur as a result of sea level rise in the form of coastal inundation and erosion.

Objective 19 and 20 of the RPS are particularly relevant:

Objective 19: "The risks and consequences to people, communities, their businesses, property and infrastructure from natural hazards and climate change effects are reduced."

Objective 20: Hazard mitigation measures, structural works and other activities do not increase the risk and consequences of natural hazard events.

Objective 21: Communities are more resilient to natural hazards, including the impacts of climate change, and people are better prepared for the consequences of natural hazard events.

Some of the most relevant policies and methods in the RPS that implement these objectives are outlined below. There are many other relevant policies, including those relating to the identification of the coastal environment, public access and natural character in the coastal environment.

4.2.1 Policy 29: Avoiding inappropriate subdivision

Policy 29: Avoiding inappropriate subdivision and development in areas at high risk from natural hazards – district and regional plans Regional and district plans shall:

(a) identify areas at high risk from natural hazards[3]; and

[3] An area should be considered high risk if there is the potential for moderate to high levels of damage to the subdivision or development, including the buildings, infrastructure, or land on which it is situated. The assessment of areas at high risk should factor in the potential for climate change and sea level rise and any consequential effect that this may have on the frequency or magnitude of related hazard events (Greater Wellington Regional Policy Statement).

(b) include polices and rules to avoid inappropriate subdivision and development in those areas.

4.2.2 Policy 51: Minimising the risks and consequences of natural hazards

Policy 51: Minimising the risks and consequences of natural hazards – consideration. When considering an application for a resource consent, notice of requirement, or a change, variation or review to a district or regional plan, the risk and consequences of natural hazards on people, communities, their property and infrastructure shall be minimised, and/or in determining whether an activity is inappropriate, particular regard shall be given to:

(a) the frequency and magnitude of the range of natural hazards that may adversely affect the proposal or development, including residual risk[4];

(b) the potential for climate change and sea level rise to increase the frequency or magnitude of a hazard event;

(c) whether the location of the development will foreseeably require hazard mitigation works in the future;

(d) the potential for injury or loss of life, social disruption and emergency management and civil defence implications – such as access routes to and from the site;

(e) any risks and consequences beyond the development site;

(f) the impact of the proposed development on any natural features that act as a buffer, and where development should not interfere with their ability to reduce the risks of natural hazards;
(g) avoiding inappropriate subdivision and development in areas at high risk from natural hazards;

(h) the potential need for hazard adaptation and mitigation measures in moderate risk areas; and

(i) the need to locate habitable floor areas and access routes above the 1:100 year flood level, in identified flood hazard areas.

4.2.3 Policy 52: Minimising adverse effects of hazard mitigation measures

Policy 52: Minimising adverse effects of hazard mitigation measures – consideration. When considering an application for a resource consent, notice of requirement, or a change, variation or review of a district or regional plan, for hazard mitigation measures, particular regard shall be given to:

(a) the need for structural protection works or hard engineering methods;

(b) whether non-structural or soft engineering methods are a more appropriate option;

[4] Policy 51 refers to "residual risk", which is the risk that remains after protection works are put in place. Stopbanks, seawalls and revetments and other engineered protection works can create a sense of security and encourage further development. In turn, this increases the extent and value of assets that could be damaged if the protection works fail or an extreme event exceeds the structural design parameters (Greater Wellington Regional Policy Statement).

(c) avoiding structural protection works or hard engineering methods unless it is necessary to protect existing development or property from unacceptable risk and the works form part of a long-term hazard management strategy that represents the best practicable option for the future;

(d) the cumulative effects of isolated structural protection works; and

(e) residual risk remaining after mitigation works are in place,

so that they reduce and do not increase the risks of natural hazards.

The Regional Policy Statement directs District Councils (though Method 1) to amend District Plans to implement these and other policies.

4.3 Hierarchy of preferred management actions

National Policy (NZCPS, 2010) and National Guidance (MfE, 2017) direct Councils to base future coastal hazard management around a "hierarchy" of management approaches. The policies and guidance encourage risk avoidance as the most preferred approach, through to the "last resort" of hard protection works. The range of management approaches are described below with some broad guidance about how they are applicable in different settings. Our recommendations in the following sections are based on implementing this broad hierarchy as it applies to the Porirua coast.

4.3.1 Risk Avoidance

Risk avoidance is the "first" approach to managing land use in hazard areas and should be applied where practicable. Ideally all development and infrastructure are located away from potential hazard areas to ensure long term sustainability and resilience. Assets should be located away from areas at risk with current sea level as a matter of priority.

This approach is further endorsed by the MfE national guidance that requires Councils to plan conservatively and with long timeframes where Green field development or major infrastructure is proposed in the coastal area. In areas of existing development, it is occasionally possible to relocate development or infrastructure outside hazard areas, particularly where land parcels are large and/or where the existing hazard exposure is minor.

Ideally, coastal assets would be located landward of identified coastal hazard areas where they have been defined. This approach is practicable where there is space for reasonable use to occur landward of the identified setbacks, such as where residential sections are deep and erosion rates are slow. This approach is well suited where erosion is predominantly due to short-medium term dynamic fluctuations in the shoreline and there is no significant long-term trend for erosion, or as part of a long-term management plan.

4.3.2 Risk reduction

Where complete avoidance of hazards is not possible, land use and development should be managed over time to reduce existing risk exposure. This approach can be applied in areas of existing development and can include relocating houses and infrastructure to landward as they are rebuilt or renovated (particularly away from current hazard areas) or constructing buildings in a manner that makes them adaptable over time. This is achieved through coastal development controls and long-term planning.

Risk reduction is rarely a standalone management approach, but the outcome of many other actions that may be taken within the hierarchy. Risk reduction over time is also central to any long-term adaptive management plan.

4.3.3 Living with erosion

In some cases, it may be acceptable to live with coastal erosion. This approach can be appropriate where:

- coastal hazards only affect the area periodically and do not prevent ongoing use of the area (e.g. land may be affected but not dwellings or infrastructure, coastal erosion associated with dynamic fluctuations rather than permanent retreat)
- where the environmental/social/economic impacts of protection measures are unacceptable due to the sensitivity or values of the natural coastline (i.e. high value beach, ecologically significant wetland) and these values outweigh the impacts of the hazard
- the affected area is not developed, or development is of low intensity and/or is resilient to the hazard.

Living with coastal hazards can often form part of a longer term dynamic adaptive plan, with associated triggers to move to an alternative approach when the extent or frequency of the hazard impact is considered no longer acceptable.

While this approach refers to erosion, very occasional and shallow flooding of property may also be acceptable depending on the property's use. Living with erosion can also form part of a longer term dynamic adaptive plan, with associated triggers to move to an alternative approach when erosion reaches a given point, or the effects of erosion are considered no longer acceptable.

A "living with erosion" response is difficult to implement where high value public or private assets are at risk in the short term. In these circumstances, a detailed plan is required, based on community and stakeholder input, to determine the course of action. This plan may contain actions from across the full coastal hazard management hierarchy of actions.

4.3.4 Enhancing natural buffers

Natural coastal systems such as beaches, dunes and wetlands can provide effective protection against coastal hazards. National Policy acknowledges this and promotes the preservation and enhancement of these buffers to aid in the management of long-term coastal hazards. Enhancing natural buffers such as beaches, dunes and wetlands can be viable and bring significant benefits where:

- natural buffers are already present and/or have been previously degraded (i.e. they used to exist),
- coastal erosion is dynamic and therefore natural dunes are required for shoreline recovery,
- wetlands can provide protection from wave action and flooding on estuarine shorelines.

It is important to recognize that natural buffers are natural coastal systems and are only sustainable in an environment that is geomorphologically suited.   While naturally functioning dunes provide a buffer for erosion and are critical to dune recovery between periods of erosion, they will not prevent erosion from occurring.

4.3.5 Soft engineering

Soft engineering approaches work with nature and aim to provide protection from coastal hazards while avoiding the adverse effects associated with hard engineering works that interfere with natural processes. In many cases, soft engineering approaches will provide amenity and/or ecological benefits as well as hazard protection. Soft engineering approaches are most likely to be a viable approach where:

- the local wave environment is low to moderate (i.e. estuarine or sheltered coastal setting)
- the coastal setting is part of a relatively discrete, enclosed sediment transport system (for beach nourishment)
- there are important land-based assets that require protection (that cannot be relocated), but the shoreline is also highly valued for recreation/amenity/ecology

Soft engineering approaches in high energy open coast environments can be applicable if the value of assets to be protected are sufficiently high but are often prohibitively expensive and performance can be uncertain. Approaches such as beach scraping and beach nourishment require ongoing maintenance.

Soft engineering approaches in sheltered environments can be cost effective and generate very positive outcomes. It is critical that soft engineering approaches are designed and implemented based on principles of coastal geomorphology and hydrodynamics and a clear understanding of the local coastal system.

4.3.6 Hard engineering

"Hard" engineering refers to structures act as barriers to natural processes in order to prevent erosion or flooding of the land and historically have been the first line of action against coastal erosion. These approaches include sea walls, rock revetments, breakwaters, groynes and offshore reefs. While providing some certainty of protection, these approaches can have significant adverse effects on wider coastal values and in some cases lead to a long-term increase in vulnerability to future coastal hazards.

Under current national and regional policy "hard" engineering works such as seawalls are now generally only used where there is no alternative, and where regionally or nationally significant public infrastructure is at risk. This emphasis has changed globally, due to the ongoing expense of engineering works and maintenance, residual risk and the severe adverse effects on the quality of beach fronting an erosion protection structure. The presence of coastal protections works also encourages ongoing (often increasing) investment in public and private assets in the at-risk area, exacerbating the long-term risk rather than reducing it.

The most commonly applied hard engineering structure is the seawall, either in the form of a vertical wall or a sloping rock revetment. Unfortunately, these structures can however have severe adverse effects on beaches (Pilkey & Wright, 1988; Wright & Pilkey, 1989). By way of example, Figure 8 illustrates the impact of a seawall placed on an eroding beach. On a natural beach, the shoreline adjusts response to a phase of erosion. The dune and high tide beach re-establish to landward and the recreational and ecological value of the beach and dunes is unchanged. Where the erosion is part of a natural cycle, over time the dune and beach will build slowly seaward and the erosion will be reversed.

If a seawall is constructed to protect the land from erosion, this prevents landward movement of the beach and dune. The seawall does not change the natural coastal processes driving the trend for erosion. The erosion of the beach will therefore continue, and with the profile unable to move landward, useable beach is lost. This impacts on natural character, recreational value and ecological value of the beach. A seawall separates the beach from the dune and interrupts the natural processes of beach recovery. Without a functioning dune, it is more difficult for the shoreline to recover from short term erosion.

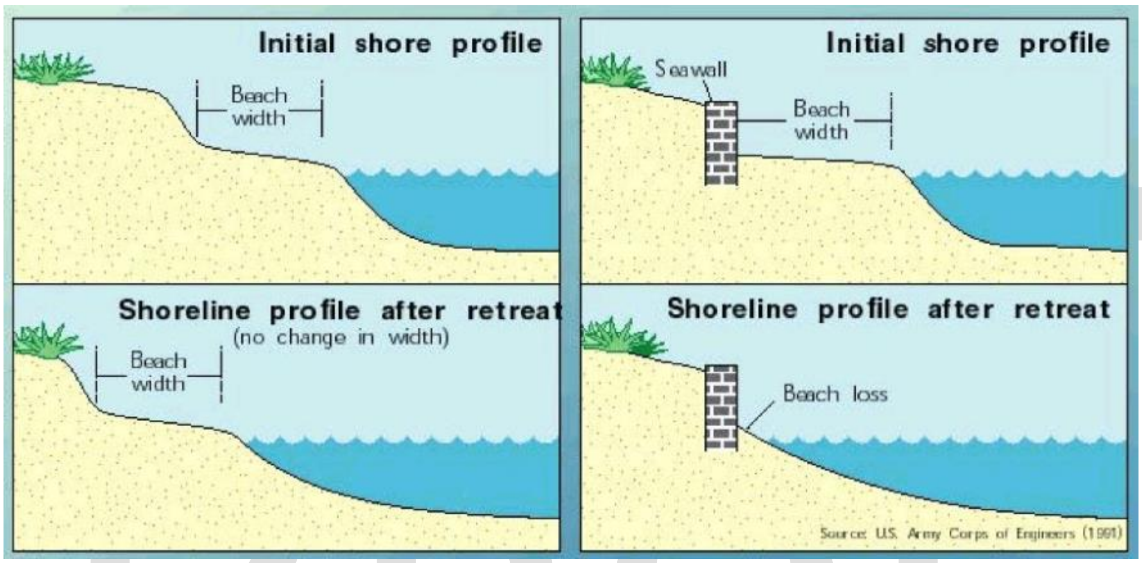

Figure 8: Impact of a seawall on an eroding beach.

Beach lowering is not only an impact on recreational and ecological values. As the beach level drops in front of the seawall, wave and tidal impacts on the seawall increase. Deeper water close to the shore allows larger waves to impact on the structure, requiring more robust engineering to avoid wall failure. Beach lowering can also expose seawall foundations, or cause slumping of sloping rock structures. Seawalls often also cause increased "end effect" erosion of unprotected shorelines nearby.

Sea level rise will continue to exacerbate these effects in the medium to long term. Over time, any "hard" engineering works that protect assets from coastal erosion and/or flooding will become increasingly difficult and expensive to maintain and will have more severe impacts on public and ecological values. Notwithstanding this, in some cases, hard engineering structures can be necessary to protect high value infrastructure, or to protect development or coastal reserves where balance of values and impacts are weighed in favour of protection of the land.

In terms of the application of seawalls or other hard engineering approaches for coastal management in the context of Porirua City, these structures may be appropriate as either temporary or permanent part of the chosen coastal management approach where they are part of adaptive management plan that has been developed by the community that ensures a necessary balance between private and public values and long term sustainability.

5 COASTAL HAZARD MANAGEMENT RECOMMENDATIONS

On the basis of the coastal hazard assessment and relevant management considerations, we have broadly subdivided the Porirua City coastline into the following coastal compartments based primarily on geomorphology, coastal processes, present land uses and management considerations:

1. Nearshore Roads and Rail
2. Infrastructure and Services
3. Beaches
4. Cliffs and Banks
5. Low-lying coastal land

This chapter provides a broad recommendations and directions for management of coastal hazards in each of these broad coastal compartment types covering a range of coastal management approaches that can be incorporated into the District Plan as policies, rules or other methods. We also provide recommendations for managing development in coastal hazard areas that apply throughout the District. These approaches are structured in a way that reflects the hierarchy of options described above and are designed to reduce risk and adverse effects from coastal hazards over time.

There are also a number of developed sites with complex existing and/or potential future coastal hazard issues where we believe site specific adaptive management plans will ultimately be required, being (north to south):

- Pukerua Bay
- Hongoeka
- Plimmerton
- Golden Gate Peninsula beaches (including Ivey Bay and Brown's Bay)
- Pauatahanui
- Titahi Bay

For the most part, these particular sites are either beaches and/or low-lying coastal margins and some also have nearshore roads and infrastructure. Accordingly, the broad management directions for such areas as recommended in this chapter are relevant. However, the complexity of the issues at each of these sites means that site specific adaptive management strategies, including extensive stakeholder consultation and participation will likely be required to adequately address the issues. As described in Section 2.2, a more detailed assessment of coastal hazards was completed at these sites, including two rounds of community consultation. The coastal hazard issues and broad management options and directions for these sites are discussed in Section 6-13.

In our view, the issues at these sites will not be able to be successfully managed without site specific adaptive management plans developed in partnership with relevant stakeholders and the wider community. Nonetheless, where practicable, we have provided interim management recommendations to prevent complication of the issues until agreed adaptive management strategies have been developed and implemented.

5.1 Management of Nearshore Roads and Rail

There are extensive lengths of the Porirua City coastline where significant roads and/or rail infrastructure are located immediately adjacent to the coastal margin, including:

- Most of the coastline of the Onepoto arm of Porirua Harbour – including Onepoto Road, Titahi Bay Road, Wi Neera Drive and both the North Island main trunk rail line and SH 1
- Most of the coastline of the Pauatahanui Inlet arm of Porirua Harbour, including SH 58, Grays Road and Motukaraka Point
- The North Island main trunk rail line between Ngatitoa Domain and Plimmerton
- The foreshore roads between Plimmerton and Hongoeka – including part of Beach Road, Sunset Parade, Moana Road and Hongoeka Bay Road
- SH 1 north of Pukerua Bay to the boundary with Kapiti Coast District Council

This entire infrastructure is of at least district significance and some lengths are of regional (e.g. SH 58) and national significance (e.g. SH 1 and the North Island Main Trunk). Many of the roads also contain significant buried services (e.g. sewer lines, water supply, electricity, phone/internet).

The field investigations, historic research and hazard assessment indicates that most of this significant infrastructure is located wholly or partially on reclaimed land and would be vulnerable to erosion either with existing sea level or potential sea level rise over the next 100 years. For example, elevation data and storm surge analysis suggest some isolated areas of State Highway 58 are already vulnerable to occasional overtopping during storms with current sea level (e.g. Browns Bay south, Bradeys Bay, Duck Creek). Extensive stretches of Grays Road are also vulnerable to coastal flooding during a 1% AEP storm event with existing sea level. With sea level rise in the future, this inundation hazard becomes widespread along both roads (e.g. see Figure A7 in Appendix 1).

While this infrastructure remains in its current location, Council and other relevant infrastructure managers (e.g. NZTA and Kiwi Rail) will have no alternative but to protect from coastal hazards. In the absence of appropriate management, this has the potential to further significantly degrade the natural and amenity values of the adjacent shorelines. For instance, while beaches and other natural shorelines still occur seaward of the infrastructure in some locations (e.g. parts of SH 58, Grays Road and the coastal road between Plimmerton and Hongoeka), the coastal erosion likely to accompany projected sea level rise will likely largely eliminate these features over the next century and beyond. Similarly, use of some hard protection structures (e.g. sloping rock walls) has the potential to reduce or eliminate remnant natural shorelines through encroachment and burial losses.

The following directions are therefore recommended for the management of coastal hazards in these areas:

- Avoid or reduce the hazard through relocation of the assets wherever possible and raising of ground levels if/when required.

- Provide for progressive relocation of infrastructure and buried services away from the coast through long term planning. For instance, it may be practicable to relocate parts of Grays Road further from the coast over time as many adjacent areas are currently rural land. It may also prove practicable over time to remove the rail corridor and SH 1 from Porirua Harbour or to reduce the level of encroachment by landward relocation. Any future widening of existing roads and rail corridors should be to landward where-ever practicable.

- Recognise the need to lift many roads in the future to avoid the significant aggravation of coastal inundation likely to accompany projected sea level rise.

- Where protection of infrastructure is required, emphasis should be given to recreate or enhance natural coastal features and buffers to preserve, restore and/or enhance the natural and amenity values of the shoreline over time. This is particularly applicable in more sheltered environments (e.g. estuarine shorelines) where these measures are likely to be most practicable. These natural features/buffers could include:

    - Naturally vegetated riparian margins
    - Beaches or cheniers
    - Saltmarsh and other coastal wetlands
    - Combinations of the above

- Where use of natural shoreline features is not practicable, preference should be given to the use of soft engineering options which protect the shoreline by creating or enhancing natural features adjacent to the shoreline (e.g. beach nourishment with appropriate sand retention structures where required; constructed coastal wetlands with appropriate protection along the seaward margin).

- Where hard engineering is the only practicable option, it should be designed and located to avoid or minimise adverse effects on the coastline, by:

    - locating the structure as far landward as reasonably practicable
    - where appropriate using vertical structures in preference to sloping structures to minimise seaward encroachment
    - designing hard structures to resemble natural shorelines where possible
    - minimising the length of the structure required
    - prioritising environmental considerations over cost considerations in the location and design of the structure
    - planning appropriately and using other measures to reduce the need for the structure over time.

Given that existing major roads and rail infrastructure will most likely be protected for the reasons noted earlier in this section, we have not extended coastal erosion hazard zones landward of these areas. This has particular implications for sites such as Karehana where much of the private development on the immediate landward side of the road would otherwise be very likely to be subject to severe erosion with projected sea level rise over the next 100 years. We have identified coastal flood hazard areas landward of such infrastructure but recognise that this risk might also be, to at least some extent, mitigated; depending on how increased coastal flooding risk to the road or rail infrastructure is managed. This matter can be addressed in site-specific adaptive management strategies at a later date where relevant; at which time the hazard areas can be modified if appropriate (e.g. if coastal inundation hazard is likely to effectively precluded or mitigated). In the interim, a precautionary approach is required until site-specific adaptive management strategies are developed and agreed with relevant stakeholders.

5.2 Management of Infrastructure and Services

Council owned reserve land often occupies a narrow strip along the coastline and historically has been a conveniently accessible location for the placement of major infrastructure. Unfortunately, these coastal reserves can be threatened by coastal erosion and flooding, and this risk will increase over time with projected sea level rise.

We recommend that the Council does not place new significant infrastructure within the identified coastal erosion and flooding hazard areas unless there is a long-term plan in place that provides for adaptation or sustainable protection of the infrastructure. Where infrastructure in these hazard areas becomes due for renewal, we recommend that the Council considers alternative locations away from hazard areas where possible and develops triggers to undertake works to raise roads where they are exposed to unacceptably frequent or severe flooding.

Stormwater outlets discharging to the coast can exacerbate erosion, particularly on sandy beaches. Wherever possible, stormwater should be redirected to soakage or other storage and not discharged directly to the shoreline. Where discharge to the coast is unavoidable, Council should work toward naturalisation of outlets to more closely resemble natural streams.

5.3 Management of Beaches

Porirua beaches exist in many different forms and physical settings. On the open coast there are gravel beaches at Pukerua and Hongoeka, and sandy beaches at Plimmerton and Titahi. Cheniers and estuarine beaches are found in more sheltered locations within Porirua Harbour and Pauatahanui Inlet. Beaches are made from mobile sediments so are vulnerable to existing and future coastal erosion.

Beaches are often critical community assets valued for a wide range of recreational uses and some Porirua beaches are regionally significant for recreation and amenity. Particular examples include Plimmerton and Titahi Bay beaches. Beaches are also highly valued areas for living and have been extensively subdivided. Historically, much of this subdivision was undertaken with little to no regard for or understanding of natural coastal processes and associated shoreline movements and much development has been placed in areas vulnerable to coastal erosion. At such sites, seawalls often proliferate over time in an effort to protect high value private property. However, as discussed in Section 4.3.6, these structures can have significant adverse effects on the beach and associated values, including recreational values and public access along the beach at higher stages of the tide. These effects may become very severe with the aggravation of erosion expected to accompany projected sea level rise.

In view of the importance of beaches as an asset for the wider community (and in some cases probably to the local economy), the sensitivity of these environments to engineering works and future changes in sea level, and the directions in national policy, we recommend that hard structures be avoided in the management of coastal erosion on beaches; with an emphasis instead on:

- managing development in identified hazard areas to avoid and reduce risk over time
- accepting and living with erosion where this is reasonably practicable
- restoring and enhancing natural coastal buffers such as beaches and dunes
- use of soft engineering (e.g. beach nourishment) where practicable.

Soft engineering approaches can be a way to protect both the beach and nearshore public and private assets, though these approaches can be very expensive and complex on open coasts.

At some developed beaches (e.g. Pukerua Bay, Plimmerton, Karehana Bay, Golden Gate Peninsula beaches and Titahi Bay), the existing and potential future erosion hazard issues are very complex and difficult because of extensive development (including private property and public infrastructure) very close to the shore. In these areas, adaptive management strategies developed in partnership with landowners and the wider community will be required (see Section 5.7 for further discussion).

We recommend that Council communicate the risk posed by coastal hazards to the beaches themselves and to adjacent public and private assets and work with landowners and the wider community to develop long term adaptive management plans for such sites. These various sites are discussed further in following sections, including the existing and potential future issues and possible management options. Interim recommendations are also recommended for management of coastal hazards at each of these sites until an agreed adaptive management strategy can be developed. These interim recommendations will require more community consultation and discussion.

5.4 Management of Cliffs

Unlike dynamic coastal changes seen at beaches, cliff erosion is a one-way process often driven by slow toe erosion leading to subsequent slope instability and periodic failure.

The first pass assessment indicates that the average long-term rate of toe erosion of cliffs is generally very slow on the Porirua coast; shore platform widths and historic photos suggesting the time-averaged toe erosion rates are likely less than 0.025 m/yr at all sites and in estuarine areas probably <0.01 m/yr. As discussed in section 3.4.2, preliminary estimates of the effect of sea level rise suggest that rates of toe erosion on natural cliffs (as opposed to reclaimed land or fill materials) might be doubled by a sea level rise of 1.0-1.5 m; but would still remain low.

Similarly, severe slope failure/adjustment also appears to be very infrequent at most sites. In the first pass assessment, no evidence was found of any large slips (e.g. extending to cliff tops) in the photographs and data examined for developed cliff areas of the Porirua coast. To date, community consultation has also not highlighted any major historic events, though some slope failure events were reported to have occurred in the lower areas of some cliffs (e.g. parts of eastern Titahi Bay landward of the beach and some limited areas around the Golden Gate Peninsula).

Nonetheless, it is clear from geomorphic evidence that periodic slope failure extending to cliff tops does occur. The existing cliff faces are typically very steep suggesting relatively steep stable slopes. However, slope instability is a very complex matter and a precautionary approach is appropriate for a first pass assessment. On the basis of existing cliff slopes, we recommend a stable slope of 1V:1.5H is adopted for development on existing developed cliffs.

Given the very slow rates of toe erosion (when averaged over time), there is no point in sea wall structures at most sites. The major hazard risk relates rather to rare but severe slip events – which events would also destroy or bury any seawalls. It is therefore recommended that coastal erosion hazard on cliffs be managed by avoiding and reducing risk using development controls. On the basis of the first pass assessment, the following recommendations are provided for managing developed cliff areas:

- Cliffed shorelines on estuarine margins (e.g. Golden Gate Peninsula) – a building exclusion setback based on average toe erosion rates of 0.02 m/yr and a stable slope of 1V:1.5H
- Cliffed shorelines on the open ocean coast - a building exclusion setback based on average toe erosion rates of 0.05 m/yr and a stable slope of 1V:1.5H

The setbacks should be measured from the existing toe of cliff at the time of the application. The toe erosion rates include an allowance for aggravation of erosion by projected sea level rise.

These interim provisions are necessarily precautionary given the uncertainties around slope failure. We recommend that Council also provide for the recommendations to be reduced if supported by a property- or site-specific study undertaken by a suitably experienced geotechnical engineer or engineering geologist. In some cases, such site-specific investigations may also recommend additional action to reduce risk (e.g. improved management of stormwater, slope retaining structures, foundation requirements, etc).

Hard engineering works designed to protect cliffed environments from coastal erosion should be restricted to areas where they are part of a community based adaptive management plan and are consented as appropriate long-term solutions. Such measures are very unlikely to be either required or appropriate at most sites.

5.5 Management of Low-Lying Coastal Land

In some areas of the district, there are significant areas of low-lying land adjacent to the coast and/or streams draining to the coast, including existing and former estuarine and freshwater wetlands and low-lying flood plains. Many of these areas are vulnerable to existing or projected future coastal inundation over the next 100 years.

A further consideration relevant in many cases is provision for restoration of coastal and estuarine wetlands and their riparian vegetation and for long term landward migration and retreat of these ecosystems in response to sea level rise. This is a particularly relevant consideration for Greenfields development. There has been significant historic loss of wetlands around the margin of Porirua Harbour due to reclamation, particularly around the Onepoto Arm (Focus, 2017), and to drainage and bunding. There is an opportunity to preserve and potentially recover many of these areas with Greenfields development. In addition, coastal wetlands are likely to migrate landwards in response to sea level rise. Any constraints on this landward migration (such as development, infrastructure or protection works) will result in further loss of coastal wetlands due to “coastal squeeze” effects.

5.6 Management of Development in Coastal Hazard Areas

The impact of future sea level rise means that even with no changes to existing development, coastal hazard vulnerability and risk will continue to increase over time. Any Greenfields development or further intensification within the defined hazard areas will also further exacerbate vulnerability and risk.

Management of existing and future development in identified hazard areas is therefore required to avoid significant exacerbation of existing vulnerability and risk over time. This section outlines broad recommendations for the management of development within areas identified as being vulnerable to existing or potential future coastal hazards.

5.6.1 Greenfields Development

In line with the recommendations in national guidance (MfE, 2017), we recommend that development controls ensure any Greenfields development avoid all identified areas of potential coastal erosion or coastal flooding hazard up to and including the 8.5 H+ sea level rise scenario.

It is also recommended that any Greenfields development in low-lying coastal areas provide for restoration of coastal wetlands where these features have been lost historically and where relevant for landward expansion and migration in response to sea level rise of at least 1.4 m. Accordingly, it is recommended that infilling and reclamation be strictly controlled within the RCP8.5+ hazard areas where it may interfere with this objective. However, it is also important that controls do not impact on existing farming activities, which are often very reliant of existing measures such as drains, bunding and flap-gated culverts. The adverse effects of these measures can be relatively readily reversed when and if opportunity for wetland restoration occurs. A co-operative approach is strongly recommended in working with farmers to avoid future wetland loss and, where practical, encourage wetland restoration. It is also recommended that policy development examine potential incentive mechanisms to encourage appropriate wetland restoration within these areas.

5.6.2 Intensification of Existing Development

In line with the recommendations in national guidance (MfE, 2017), we recommend appropriate development controls to ensure that intensification of existing development is avoided in all identified areas of potential coastal erosion or coastal flooding hazard (up to and including the 8.5 H+ sea level rise scenario) unless effective and sustainable management of the hazards is provided for in an agreed adaptive management strategy. In simple terms, we recommend that no further intensification of existing use be permitted in any coastal hazard area unless an adaptive management strategy is in place to ensure future vulnerability is appropriately mitigated.

5.6.3 Existing Development

In areas of existing development, it is recommended that Council develop appropriate policies and rules to reduce existing and future vulnerability over time within the identified current and 1.0 m sea level rise coastal hazard areas, including:

- Avoid development in areas of current erosion hazard to the extent practicable. Where it is not practicable to avoid risk, reduce risk by landward location to the extent practicable and provide for practicable future relocation of buildings

- Manage development to reduce risk in areas of future erosion hazard by locating buildings as far landward as possible and providing for future adaptability or relocation of buildings.

- Minimum floor levels be required in coastal flood hazard areas for habitable and commercial development, so that new and upgraded buildings are elevated above the area at risk from coastal flooding now and in the future.

Minimum floor levels of habitable dwellings that cannot be practicably lifted should provide for protection from up to 1.0 m sea level rise over the next 100 years. Where design provides for the house to be readily and practicably lifted at some future date, a lesser standard can be adopted – though ideally minimum floor levels should be adequate for at least 50 years, including sea level rise of 0.4 m. Triggers tied to future sea level rise should be included in consent conditions and appropriately recorded (e.g. on LIM/PIM data for the property) to ensure the dwelling will be further lifted if required in the future.

Management of commercial buildings is more complex and will depend on design life, proposed use and other considerations. These measures are best developed as part of an adaptive management strategy for any given area. However, by way of interim measures, it is recommended that similar policies and rules be applied as for habitable dwellings unless a report from a suitably trained and experienced coastal hazard specialist (scientist or engineer) indicates that the risk can be otherwise appropriately managed.

Adaptability (e.g. buildings that can be practicably relocated and/or lifted if required) is a key consideration in reducing existing and future coastal hazard vulnerability. As such, we recommend that Council work with appropriate local professionals (e.g. architects, civil or structural engineers) to help develop and promote guidelines to encourage increased use of more adaptable design.

Ground levels will very likely need to be raised in coastal inundation hazard areas over time; to avoid both significantly increased frequency and severity of flooding as sea level rises and complications from potential groundwater level changes (which are often strongly influenced by sea level in coastal settings). However, this a very complex consideration as ad hoc raising of ground levels can also aggravate existing and future flood hazard for adjacent areas. Appropriate guidelines can therefore only be devised as detailed adaptive management strategies are developed and will need to consider coastal flooding, stream/river flooding (including overland flow paths) and stormwater flooding.

5.7 Adaptive Management Plans

There are a number of sites in Porirua City where existing development and infrastructure lies within identified coastal hazard areas and reducing or eliminating risk will conflict with private use of the affected properties.

Historically the approach to coastal erosion management in these situations has centred around the use of hard engineering structures to "hold the line" and prevent the erosion of both private and public land and assets. The adverse environmental, social and economic impacts of these approaches are now well recognised. "Hard" coastal protection structures interfere with natural coastal processes, can impact severely on the public values of shorelines and often tie communities into a perpetual cycle of ever-increasing financial investment.

There is also much uncertainty in making predictions about the way that the world's climate and in turn coastal systems behave. In the past there has been a tendency to be precautionary and plan for the "worst-case" or "most likely" scenario. While this approach is intuitively sensible, the huge uncertainties and long timeframes involved mean it can place unduly severe restrictions on current use of coastal properties and assets.

The issues are very complex and difficult, and it is not possible to simply avoid all coastal hazard risk in the short to medium term. Reducing this risk over time requires difficult decisions to be made about the long-term sustainability of development and structures in the risk zones and to establish a balance between public and private benefits and costs.

In this context, coastal hazards in developed areas are best managed using an adaptive management approach. Adaptive management is a flexible approach to managing development, which is able to adjust in response to changing circumstances over time. Adaptive management works to make changes over time (i.e. not just "business as usual"), but without making expensive and impractical "overnight" changes. The intention is to avoid taking unnecessarily drastic actions based on the worst-case scenario but instead being ready to adjust the planned course of action as events unfold. An effective adaptive management plan also ensures that actions taken in the short term do not compromise future flexibility and choice of options for longer term action. The aim is to transition over time to a more sustainable management approach.

Adaptive management aims to be sensitive to the community and its aspirations, and local variations in aspirations and sensitivities to increasing risk. It also helps to cope with uncertainty by establishing trigger or decision points with the community and making a plan to implement these in both the short and long term.

There are five key stages to adaptive management:

1. Building a shared understanding (processes, hazards, community resilience)
2. Exploring the future and how communities are affected and identifying objectives
3. Building adaptive pathways
4. Implementing the strategy in practice
5. Monitoring the strategy using early signals and triggers (decision points) for adjusting between pathways.

Adaptive management plans need to be developed within input from affected landowners and the wider community. The development of such a plan requires the community and stakeholders to agree on long term outcomes and to identify appropriate signals and triggers to initiate the staged integration of the plan. Where existing development is located in areas at risk from coastal hazards, there is often a conflict between the preservation of private and public assets. Dynamic adaptive pathway planning for coastal settlements in Porirua will need to include:

- agreement on preferred management responses and long-term outcomes that balance private and public values.
- identification of key effects and drivers
- thresholds and triggers (e.g. beach state, sea level rise value) for each phase of the adaptation plan (e.g. relocation of assets as required)
- provisions for ongoing use of the area (e.g. to provide for reasonable use of the properties while practicable), without incurring liability for the wider community
- cost sharing and whether there is compensation and/or alternatives for affected landowners.

An adaptive management strategy will be essential at some settlements in Porirua, given the complex issues and competing values. The establishment of these plans will be challenging and will take time and requires patience and open dialogue. The provisions of the District Plan will represent only a part of the wider actions required.

6 PUKERUA BAY

6.1 Description

Pukerua Bay is located near the northern extent of the PCC coastline on the northern side and towards the eastern end of a large headland (Wairaka Point), with the shoreline oriented semi-perpendicular to the general trend of the coast (Figure 1). The orientation of the coast means that it is exposed to waves from the north and northwest and relatively sheltered from other wave directions.

The coastal margin of Pukerua Bay consists of a steep vegetated escarpment fronted by a narrow coastal plain and mixed sand and gravel beach (Figure 9). The coastal plain is probably composed of both colluvium from periodic slips and, further seaward, coastal sands and gravels transported alongshore into the area. The steep slopes east of the adjacent Wairaka Point headland provide an active supply of gravel and rocks to the shoreline from slips/scree and coastal erosion. A stream also delivers gravels and sands to the coast towards the western end of the settlement. It appears that sands and gravels transported alongshore into the area tend to be trapped due to the prevailing net eastwards transport between Wairaka Point and Pukerua Bay and the net southwards longshore transport along the rocky coastal bordering SH1 further north towards Paekakariki. However, the narrow nature of the coastal plain which has accumulated since present sea level was attained (about 7000-7500 years ago) indicates that net sediment input is relatively slow (Focus, 2016). The escarpment landward of the coastal plain was once subject to active wave erosion associated slope stability but is now protected by the beach and coastal plain and is densely vegetated.

Figure 9: General view of Pukerua Bay (Brendan beach in the foreground) looking westwards.

In central and western areas of the foreshore, the beach is backed by the foreshore access road, Ocean Parade; with private properties further landward (Figure 9). In more eastern areas (known as Brendan Beach), residential properties have no vehicle access and the foreshore is backed by a narrow reserve and walkway fronting private properties (Figure 10). The walkway is located along the immediate landward edge of the beach in an area that was part of the active beach in its natural condition. Consequently, the path is regularly covered with debris by wind and wave action and periodically damaged by storm waves. Storm wave run-up also extends into the seaward edge of properties and many have constructed vertical (often concrete) walls over the years to manage erosion and/or wave flooding. The existing houses are primarily located on the coastal plain, though some houses also appear to extend landward into the toe of the steep escarpment.

Figure 10: View of Brendan Beach

Field inspection indicates that the original natural coastal plain at Pukerua Bay has been raised and extended seaward (reclaimed) to provide for the beachfront access road (Ocean Parade); the current bank backing the beach consisting largely of various fill materials, though the original beach and back-beach sediments are evident at lower levels (Focus, 2016). Prior to development the original natural backshore was much lower and probably consisted of gravel storm ridges formed by wave run-up and overtopping during storm wave events. These natural landforms typically occur along the back of mixed sand and gravel beaches such as Pukerua Bay and are also common along the natural shoreline between Pukerua Bay and Hongoeka. At Brendan Beach, the beach is sandier and the narrow coastal plain on which the houses (and, in places, a narrow public reserve) are located may originally have been either a gravel storm ridge or a dune. The mixed sand and gravel beach is fronted by a wide shallow rocky reef further seaward, which acts to reduce wave energy.

6.2 Coastal Erosion Hazard

Erosion currently occurs primarily along the back of the more western of the three beaches comprising the Pukerua Bay foreshore, where the shoreline has been reclaimed seaward in the past. The erosion occurs during rare and severe episodic storm wave events during which the reclaimed bank can be eroded by an average of up 0.5 m along extensive lengths and by up to 1.0-1.5 m in localised areas. The frequency of severe erosive events is not known with certainty, but available information and community advice suggests such events probably have an annual exceedance probability of around 8-10%.

Examination of historical photography and survey data indicates that historically bank erosion rates have been very slow (Eco Nomos, 2003; Focus, 2016), with average long-term rates backing the beach at the western end of the in the order of 0.05-0.10 m/yr; probably towards the lower end of this range in most areas.

The central beach area is less vulnerable to erosion, with the shoreline having not been reclaimed seaward over the active beach. In this area, the road is located on a raised bank at the toe of the escarpment with no private development landward. Erosion is largely restricted to the low narrow shelf seaward of the raised bank; though there is some evidence the road may have been threatened in isolated areas (particularly towards the eastern end) in the past. At Brendan Beach, the properties and limited reserve extend seaward of the original natural shoreline and onto the active beach and would likely erode landward some distance in the absence of existing structures; estimated as in the order of 5-10 m, varying alongshore.

While observed rates vary, we have assumed a long-term erosion rate of 0.1 m/yr along the full length of Pukerua Bay (including Brendan Beach). Erosion appears to be slower in the central area of the Bay but there is limited data to determine this with certainty. The toe erosion of the reclaimed shoreline fronting the more northern end of the bay is progressive and occurs only slowly as noted above (up to about 0.1 m/yr when averaged over long periods of time). A 1.0 m allowance for bank instability has also been included to define the current erosion hazard zone.

Projected future sea level rise is likely to increase the rate of bank erosion due to more frequent and severe wave attack. Calculations based on nearshore beach profile slopes suggest that erosion of approximately 15 m may occur for every metre of sea level rise. A summary of erosion calculations and erosion hazard areas is presented in Table 6 and the plotted areas are shown in Figure A1.

Table 6: Erosion hazard estimates for Pukerua Bay

Sea Level Scenario	Existing 100 year	Future erosion	Slope stability	Total Erosion
Current	10 m	0 m	1 m	11 m
1.0 m	10 m	13.5 m	1 m	24.5 m
1.4 m	10 m	17 m	1 m	28 m

6.3 Coastal Flooding Hazard

Coastal inundation hazard was estimated as discussed in Section 3.3 and results are summarised in Table 7.

We have adopted an allowance for wave effects of 0.75 m combined with the 1%AEP storm tide elevation with current sea level; which suggests coastal inundation could affect elevations to RL 2.77 m (WVD). Plotting of this elevation suggests that coastal inundation is presently limited to areas seaward of the current road edge, consistent with advice from residents. It is also broadly consistent with information from locals that waves wash over and deposit sediment on the foreshore pathway at Brendan Beach, which has elevations of 2.7-3.0 m. As discussed in Section 3.3, some wave effects are likely to occur above the mapped flood level as seen at Brendan Beach, but these effects are expected to be temporary and relatively minor.

In the longer term, storm tide elevations will increase, at least commensurably, with sea level rise. Wave set-up and wave run-up may also be increased with sea level rise due to increased water depths over the offshore reefs allowing higher waves to penetrate closer to shore. Accordingly, in estimating the area that could be impacted by sea level rise of 1.0 m or more, we have adopted a greater allowance for wave effects (Table 7). These figures are indicative only and detailed modelling would be required to confirm or improve them.

Table 7: Coastal Inundation Levels at Pukerua Bay.

Sea Level Scenario	1% AEP Surge	Wave Effects	Inundation Level
Current	2.02 m	0.75 m	2.77 m
1.0 m	2.97 m	1.00 m	3.97 m
1.4 m	3.33 m	1.00 m	4.33 m

6.4 Management Options and Recommendations

Coastal erosion and inundation hazard areas are identified in Appendix 1 (Figure A1(i) and A1(ii)).

The erosion hazard calculations indicate that in the absence of appropriate action, parts of the road and in some places the buried services (sewer and water mains) on the seaward side would likely be threatened by erosion even with current sea level; probably within timeframes of 30-50 years. In the longer term, with projected sea level rise the road could be entirely lost and the seaward edges of adjacent properties affected.

The current erosion rates are very slow and recent work suggests these can be effectively managed by periodic placement of suitable sacrificial fill materials, similar to historic practice (Focus, 2016). However, future significant sea level rise may cause more severe erosion and additional action is eventually likely to be required.

Sea walls are unlikely to be an appropriate response to such severe erosion at this site due to the significant beach loss that would occur due to passive erosion effects and encroachment losses (as would occur with sloping structures). Even with existing sea level, past rock placement has had significant adverse effects on beach width and amenity. Pukerua Bay is a popular visitor destination and popular for walking, boat launching and general beach recreation. Snorkelling, swimming and kaimoana gathering are also popular. Beach loss and degradations is therefore unlikely to be acceptable to beach users, though some local beachfront owners expressed at the public meetings that these effects may be acceptable at the northern end because the beach in this area is not well used.

As noted by earlier work (Focus, 2016) there is some evidence that beach sediments tend to be partly trapped or retained in this area. It may therefore be possible to use beach nourishment with appropriate sands and gravels to provide an appropriate long-term solution to erosion that would protect the values of the beach as well as the road, associated services and adjacent private properties. If it were practicable in the longer term to undertake sufficient beach nourishment to enable a wide beach and storm ridge to form, this would also help mitigate coastal inundation.

Detailed investigation would be required to confirm the practicality and costs of this option, including details such as maintenance requirements and costs, whether or not a sediment retention structure (e.g. groyne) would be required, and appropriate cost-sharing.

Other longer-term options could include landward relocation of the road, including (if required) purchase of seaward areas of adjacent private properties to create sufficient space. This option is not likely to be favoured by property owners unless other options were not practicable (i.e. last resort). Lesser landward relocation of the road could however potentially be combined with beach nourishment if required to reduce the cost and improve the practicality of this option.

The longer-term management of coastal erosion will require a site-specific adaptive management plan (see Section 5.7) to find a suitable solution (or combination of measures) that balances the interests of adjacent property owners with the wider community and beach user community. The development of this strategy will require extensive community and stakeholder consultation and detailed further investigations to investigate the feasibility of beach nourishment, and to develop preferred options and triggers for their implementation.

Given the current absence of an agreed long-term strategy, appropriate management of infrastructure and private development will be required within the identified coastal hazard areas as discussed in Section 5.

Public and private assets at Pukerua Bay are generally elevated sufficiently to be at little risk from coastal inundation with current sea level, though the foreshore path at Brendan Bay is frequently inundated and it is likely that local properties would also be affected in the absence of existing structures. Detailed engineering investigations would be required to assess the potential for alternative lower maintenance options to the present path. However, as the path is typically low and located on the back of the active beach, it is subject to significant wave run-up during storms. Accordingly, options such as raised structures are likely to be expensive and maintenance costs after storms may also be high.

In the longer term with future sea level rise, several properties and short stretches of the road at Pukerua Bay may become vulnerable, assuming current land elevation. As sea level rise will increase water depths over the rock reefs to seaward, increasing wave energy along the shoreline, it is also possible given the exposed location that extreme wave run-up may increase over the value of 1.0 m assumed in these calculations. Future management options may include raising land levels where necessary.

7 HONGOEKA

Hongoeka is a mixed sand and gravel beach backed by a high gravel storm ridge (Figure 11). Beach sediments are supplied by net southwards longshore drift from the cliffed shorelines and mixed sand-gravel beaches to the north.

Figure 11: Hongoeka Beach, looking north towards the Hongoeka Village and marae.

The settlement to landward is very low lying and backed by a steep bush catchment. Some properties and dwellings experience flooding during storm events. Most flooding is due to run-off from the catchment rather than coastal inundation, though the gravel beach can accrete over the stream/culvert entrance and exacerbate flooding.

7.1 Coastal Erosion Hazard

Historical records and community information indicates that the gravel beach fronting Hongoeka settlement has not eroded significantly in living memory. Community advice, survey information and historic photography suggest that the shoreline here may have accreted in recent decades, at least in some areas. However, our analysis suggests there is some uncertainty about long term trends and the data is ambiguous. We have therefore assumed that the beach is presently dynamically stable for the purposes of coastal erosion hazard identification. As gravel and debris is carried over the storm ridge and deposited on the landward side in rare and severe events, the width of the storm ridge provides a useful indication of the minimum width of significant morphologic change with existing sea level.

On this basis, the landward edge of the storm barrier has been adopted as the current coastal erosion hazard area. In the area of the marae, the shoreline is held approximately 5 m seaward of its natural position by a rock structure (Figure 12), and therefore we have provided for this effect within the current erosion hazard area.

Hongoeka is the only developed site in Porirua with a full storm ridge remaining landward of the beach. Estimation of future erosion in response to sea level rise using the rollover model (see Section 3.4.2) suggests the crest of the storm ridge may migrate landward by 12-14 m for every 1.0 m of sea level rise.

However, as noted in Section 3.4.2, this simple geometric model only considers the beach system in two dimensions (i.e. cross-shore) and assumes that the volume of sediment in the barrier system remains unchanged. On the Porirua coast, gravel sediments appear to be supplied by periodic slope failure along the steep bluffs between Pukerua Bay and Hongoeka, and by occasional small streams that discharge along the coast; with a net southwards transport of sands and gravel along the coast. Accordingly, this ongoing longshore sediment supply may offset any erosion; i.e. longshore drift may supply the sediment required for landward and upward adjustment of the storm ridge. In this case, the best estimate of the potential erosion would be provided by the average slope between to the seaward toe of the beach and the crest of the storm ridge.

This latter approach has been adopted for the mapped erosion hazard lines at Hongoeka (i.e. in calculating the potential effects of projected future sea level rise on erosion) but it is important to acknowledge that the extent landward erosion might also be slightly higher (as estimated by the rollover model). We believe the lesser value is adequate and the most appropriate for management of erosion hazard in the interim. However, the uncertainty will need to be taken into account in the development of adaptive management strategies for this site, and erosion estimates using the rollover method should also be considered.

Figure 12: The seawall fronting the marae at Hongoeka holds the shoreline seaward of its natural position. As a result, the natural gravel ridge has been lost.

A summary of erosion calculations and hazard areas is presented in Table 8 and the plotted areas are shown in Appendix 1 (Figure A2). Future erosion hazard is limited largely to the coastal reserve landward of the village. The only exception is the marae at the northern end of the bay, which is located on low-lying land very close to the shore. Historical evidence and information from local residents suggest that the land where the marae is located accreted over the last 50-100 years, and the associated property boundaries were adjusted to reflect this accretion in the 1990s. The subsequent need to armour the site suggests, however that this land is still vulnerable to dynamic shoreline changes; so the earlier accretion may simply have been a dynamic change rather than permanent long term shoreline advance. There is no evidence of ongoing accretion in recent years.

Table 8: Calculations of likely coastal erosion at Hongoeka.

Sea Level Scenario	Existing 100 year	Future erosion	Slope stability	Total Erosion
Current	15-20 m	0 m	0 m	15-20 m
1.0 m	15-20 m	6.0 m	0 m	21-26 m
1.4 m	15-20 m	8.4 m	0 m	23.4-28.4 m

7.2 Coastal Flooding Hazard

Results for existing sea level indicate little coastal flooding risk to the settlement apart from the area of the marae building. Existing flooding risk is primarily associated with stream flooding. In the longer term with projected sea level rise, coastal flooding is likely to impact seaward areas of the settlement. This presumes however that existing land elevations will be maintained.

Where it is intact, the gravel storm ridge fronting Hongoeka Village dissipates wave energy provides protection from wave overtopping during storm events. This is consistent with advice from local Maori landowners, who suggest that only minor wave overtopping of the storm ridge occurs during major storms, with significant debris and gravel transport over the ridge only likely during very rare and severe storm wave events. If the storm ridge is able to migrate naturally upwards and landwards in response to future sea level rise (as described in Section 3.4.2)3.4.2, this protection should be retained. In calculating likely storm surge impacts we have therefore assumed this protection from wave run-up will remain, and we have adopted the minimum freeboard allowance of 0.25 m.

In some areas (e.g. fronting the marae buildings), the ridge has been lowered by anthropogenic activity. Where the storm ridge no longer exists, the coastal inundation calculations include an allowance for an additional 0.5 m for wave impacts (within a 30 m coastal margin), as with other exposed beachfront locations (Table 9).

Table 9: Coastal Inundation Levels at Hongoeka.

Sea Level Scenario	**1% AEP Surge**	**Freeboard**	**Wave Effects (Nth End <30 m)**	**Inundation Level**	
				Village	**Marae (<30 m)**

Current	2.02 m	0.25 m	0.5 m	2.27 m	2.77 m
1.0 m	2.97 m	0.25 m	0.75 m	3.24 m	3.99 m
1.4 m	3.33 m	0.25 m	0.75 m	3.60 m	4.35 m

7.3 Management Options and Recommendations

Coastal erosion and inundation hazard areas are identified in Appendix 1 (Figure A2).

Coastal erosion hazard is primarily limited to the northern end of the settlement in the vicinity of the marae, where development has encroached well seaward. The existing rock protection fronting the marae provide some short-term protection from erosion but will not provide an appropriate long-term solution against erosion, due not only to engineering limitations, but to adverse environmental effects. Use of softer approaches to hold the shoreline (e.g. beach nourishment) are not likely to be cost effective at this site.

In the medium to longer term, the most appropriate option is likely to be relocation of the marae building and road landward of the erosion hazard areas. This would also enable a natural gravel beach and storm berm to be reestablished along the entire frontage, providing protection from coastal wave overtopping. However, implementation of this will need to be integrated with other aspirations and is complicated by land ownership issues and will require significant negotiation within the local community.

The existing natural storm ridge is a significant factor in protection from coastal inundation and risk would increase if this feature is modified (e.g. levelled). If allowed to develop and adjust naturally, it is very likely that the gravel storm ridge will adjust in response to sea level in the future and continue to provide protection. Maintenance of this feature is therefore important in the longer term to minimise coastal inundation risk. However, hydraulic links (e.g. streams) will still result in some aggravation of coastal inundation as sea level rises.

Given the current absence of an agreed long-term strategy, appropriate management of infrastructure and private development will be required within the identified coastal hazard areas as discussed in Section 5. In particular, management of stream and coastal flooding will require a comprehensive and integrated management plan prepared in partnership with local iwi and the relevant landowners.

8 KAREHANA

The Karehana shoreline as defined in this report extends from the southern side of Hongoeka to the Plimmerton Boating Club. In its original natural state, the coast was composed of sand and gravel beaches perched on and fronted by rock reefs, backed by gravel ridges or sand dunes (Figure 13) and in some areas by low-lying wetlands or floodplains.

Figure 13: View of Karehana area from 1894 showing beach and dunes perched on rock reefs which also extend to seaward in many areas.

Development of the area formed beachfront roads (e.g. Moana Road and Sunset Parade) along the full length of the shoreline with residential development to landward (Figure 14 and Figure 15). In many areas the rocky shore platform is still backed by narrow gravel beaches (Figure 16). In some areas, these beaches are providing relatively effective protection to the road and there is little active erosion evident. However, most of the natural gravel storm ridge and/or dunes backing the beach have been levelled during formation of the road. Over time, the beachfront roads (often located on fill) have been armoured in most places with vertical or steeply sloping seawalls.

Figure 14: Photograph of Karehana taken in 1947.

8.1 Coastal Erosion Hazard

Historical data indicates that the existing sand beaches at Karehana fluctuate over time, but there is no evidence in the historic data of long-term erosion. Rather, the coastal roads (e.g. Moana Road) and footpaths/reserve to seaward have encroached over the active beach, leading to a loss of beach width (coastal squeeze effects). If there were no protection structures, erosion would impact on the road and other infrastructure that has been placed within what was originally part of the active coastal margin.

These impacts will become much more severe with projected sea level rise, due directly to increase in water level and also to increased wave energy at the shore (the latter relating to increased water depths over the offshore reefs with sea level rise). These effects are likely to lead to permanent beach loss as well as potential damage to the existing wall and erosion of unprotected stretches of shoreline.

In line with our approach outlined in Section 5.1, the erosion hazard areas (Figure A2 and A3) have not been extended landward of the Moana Road or Sunset Parade as it is assumed these significant roads will need to be protected in the foreseeable future.

Figure 15: Sand and gravel beach at Karehana Bay.

Figure 16: Narrow gravel beaches topping rock reefs at Karehana. The road has been constructed seaward over the original natural coastal margin.

8.2 Coastal Flooding Hazard

Coastal inundation has been calculated as discussed in Section 3.3, and estimated extreme sea levels for Karehana are summarised in Table 10. Figure A3 in Appendix 1 provides an overview of the areas potentially affected by coastal inundation with current sea level and with future sea level rise.

We have adopted an allowance for wave effects of 0.50 m within 30 m of the coast, combined with the 1%AEP storm tide elevation with current sea level and a small freeboard allowance; which indicates likely coastal inundation elevations of RL 2.77 m (WVD). Further landward, wave effects are expected to become insignificant and coastal inundation levels reflect this (Table 10).

In the longer term, storm tide elevations will increase commensurably with sea level rise. Storm wave effects (wave setup and wave run-up) are also likely to increase with sea level rise due to increased water depths over the offshore reefs. In estimating the area that could be impacted by sea level rise of 1.0 m or more, we have therefore adopted a greater allowance for wave effects (Table 10).

Table 10: Coastal Inundation Levels at Karehana.

Sea Level Scenario	1% AEP Surge	Freeboard	Wave Effects (<30 m)	Inundation Level	
				Inland >30 m	Beachfront <30 m
Current	2.02 m	0.25 m	0.5 m	2.27 m	2.77 m
1.0 m	2.97 m	0.25 m	0.75 m	3.24 m	3.99 m
1.4 m	3.33 m	0.25 m	0.75 m	3.60 m	4.35 m

8.3 Management Implications and Recommendations

There are two residential properties (6a and 7a Moana Road) as well as some public infrastructure (e.g. Plimmerton Fire Station, buried services) located on the seaward side of the roads. These assets are typically located on a thin veneer of sediment (sand and gravels) over the underlying rock reef/shore platform. In the absence of protection, these assets are vulnerable to coastal erosion even with current sea level. The reclamation at the Plimmerton Boating Club is also low lying and currently vulnerable to coastal flooding with current sea level.

The beachfront road is very low lying (RL 2.5-3.0 m) with only minor and sometimes no reserve buffer to seaward and is therefore vulnerable to coastal erosion and inundation with existing sea level (Figure A3). This has been confirmed by feedback from local residents, who reported relatively regular overtopping of parts of Moana Road during storm events.

Sea level rise will increase wave energy reaching the shoreline and severely aggravate existing coastal inundation and erosion hazard, including much more frequent and severe wave overtopping. This vulnerability will continue to increase over time.

Sunset Parade and Moana Road provide the main route through Karehana and on to Hongoeka. In the foreseeable future therefore, it seems likely that preservation of this road is likely to be the practicable option. Given the current vulnerability and likely future sea level rise effects, additional works may be necessary to raise the road over time. However, given the severity of future effects, landward relocation and/or narrowing of the road cannot be ruled out, depending on the scale and rate of sea level rise.

Severe beach loss is inevitable, which will impact on local recreational values and further exacerbate wave impacts on the sea walls and adjacent roads. Management approaches such as beach nourishment may be viable in Karehana Bay, but without further investigation this cannot be confirmed.

Given the complexity and severity of future coastal hazards in this area, a community based adaptive management plan (as outlined in Section 5.7) will be required to determine the best course of action. Until such a plan is in place, development controls should be implemented to avoid exacerbation of risk and, where practicable, to reduce risk within identified hazard areas; as recommended in Section 5. These controls are likely to include minimum floor levels, and controls on building and renovations in identified hazard areas.

9 PLIMMERTON

Plimmerton Beach as defined in this report extends from the small headland at the northern end (Fire Station Point) to Tawhitikuri/Goat Point at the southern end. Taupo Stream discharges towards the southern end of the beach. The beach is a fine-grained sandy beach, approximately 650 m long and is a very popular and significant recreational beach. It is the first safe bathing and recreational beach readily accessible by public transport north of Wellington (Cawthron, 2005) and is well used throughout the year. It is also a significant site for windsurfing, being the most popular wave spot in the Wellington area (WWA, undated) and rated as a windsurfing site of national significance (Cawthron, 2005).

Early historic photographs indicate that a usable high tide dry beach originally extended along the full length of Plimmerton beach; with the beach backed by low dunes (Figure 17). Subdivision commenced in the area north of Taupo Stream in 1888 (DP 407), with the survey placing property boundaries on the active beach seaward of the dunes. Over subsequent decades, seawalls were progressively extended along the beach as owners sought to retain their boundaries and further develop properties. Interaction of coastal processes with these structures has resulted in lowering of the beach, with a usable high tide dry beach now rarely evident anywhere north of Taupo Stream (Focus, 2018).

Figure 17: View of Plimmerton Beach in 1895 showing original natural beach and dunes.

The area south of Taupo Stream is Crown land that was taken for road and railway purposes in 1939, with a reserve along the frontage. Various private houses now occur on this large lot. The development is set further landward than the area north of Taupo Stream and so a high tide beach and a narrow width of dune still exist in most areas (Figure 18). Immediately south of the stream, there is a small grassed public reserve fronted by a low timber seawall (Figure 19) This reserve presently provides the only grassed reserve along the back of Plimmerton Beach and is highly valued for public use.

Figure 18: Plimmerton Beach south of the Taupo Stream. Housing in this area is located slightly further landward in relation to the natural shoreline, which has left space for a natural beach and narrow dune.

Figure 19: Taupo Reserve, immediately south of Taupo Stream. The reserve is low lying, and currently experiencing slow erosion.

9.1 Coastal Erosion Hazard

Analysis of historic photos from the late 1800s and aerial photographs from the 1940s indicates that there has been some loss of high tide beach north of Taupo Stream. This appears to be mostly due to the placement of property boundaries and subsequently seawalls on the active beach, rather than due to any significant erosional trend (Focus, 2018). In particular, it appears that the seaward location of the sea walls results in regular wave reflection and scouring which lower bed levels in front of the seawalls.

While permanent shoreline retreat may also have contributed to the beach loss, the historic photos suggest no permanent erosion (simply shoreline fluctuations), with a similar level of beach loss to the present in the 1940s and 1950s. This is also consistent with observations of long-term local residents, who report significant changes in beach levels but note that these changes are dynamic (i.e. beach level fluctuates up and down) rather than progressively worsening as would be expected if there were an underlying erosional trend. Similarly, records show dynamic fluctuations of approximately 10 m between the most seaward and the most landward shorelines south of Taupo Stream, but no clear evidence for either permanent erosion or accretion over the historical record.

Coastal erosion hazard areas have been identified based on all available historic data, community information and field observations and measurements. From this information we have identified the area of coastal margin most likely to be impacted by coastal erosion with current sea level and climate conditions, and with future sea level rise (Table 11, Figure A4(i) and A4(ii)). These areas include an allowance for natural dynamic fluctuations, slope stability and (in some areas) the current impact of coastal structures.

Drilling at Plimmerton indicates that erodible Holocene sands extend back to at least Steyne Avenue north of the Taupo Stream and back to at least South Beach Road to the south of the stream. Accordingly, there are no natural constraints on erosion back to at least these roads. At present, erosion along Plimmerton Beach is constrained by sea walls. The influence and relevance of these sea walls to the management of future erosion is discussed in Section 9.

In calculating erosion hazard areas at Plimmerton, we have assumed dynamic dune toe fluctuations of 5 m and 10 m to the north and south of Taupo Stream, respectively; with the baseline adjusted to allow for sea wall effects. We have also allowed 5 m for dune face collapse and uncertainty. Sea level rise effects were estimated using methods described in Section 3.4.2.

The current coastal erosion hazard zone identified north of the Taupo Stream highlights the area of coastal margin at high risk from coastal erosion with current sea level. The hazard area reflects the likely immediate shoreline adjustment if the seawall were removed or damaged, and a small allowance for formation of a narrow beach. This area does not provide for all possible shoreline fluctuations with current sea level and assumes that whatever long term management approach is taken, there will be some form of management that limits the landward adjustment of the shoreline. South of Taupo Stream, the current coastal erosion hazard zone provides for a full range of expected natural coastal fluctuations with current sea level.

Table 11: Coastal erosion calculations for Plimmerton Beach.

Sea Level Scenario	Dynamic Fluctuations		Sea Level Rise Erosion	Slope/dune factor	Total Erosion	
	North	South			North	South
Current	5 m	10 m	0 m	5 m	10 m	15 m
1.0 m	5 m	10 m	17 m	5 m	27 m	32 m
1.4 m	5 m	10 m	24 m	5 m	34 m	39 m

9.2 Coastal Flooding Hazard

Coastal inundation has been estimated as discussed in Section 3.3, and the estimated extreme sea levels for Plimmerton are summarised in Table 12. Figure A4(i) and A4(ii) in Appendix 1 provide an overview of the areas potentially affected by coastal inundation with current sea level and with future sea level rise.

We have adopted an allowance for wave effects of 0.75 m within 30 m of the coast, combined with the 1% AEP storm tide elevation with current sea level; which indicates likely coastal inundation elevations of RL 2.77 m (WVD). At the northern and more sheltered end of the beach we have reduced the allowance for wave effects to 0.5 m based on independent observations from several long-term locals. Further landward, wave effects are expected to become insignificant and coastal inundation levels reflect this.

Table 12: Coastal Inundation Levels at Plimmerton.

Sea Level Scenario	**1% AEP Surge**	**Freeboard**	**Wave Effects (<30 m)**	**Inundation Level**	
				Inland >30 m	**Beachfront <30 m**
Current	2.02 m	0.25 m	0.5 m*	2.27 m	2.77 m
1.0 m	2.97 m	0.25 m	0.75 m	3.24 m	3.99 m
1.4 m	3.33 m	0.25 m	0.75 m	3.60 m	4.35 m

*0.25 m at northern Plimmerton as discussed.

9.3 Management Implications and Recommendations

In terms of coastal erosion, the hazard analysis indicates that in the absence of the current sea walls the shoreline north of Taupo Stream would likely experience short term erosion up to 10 m into the properties on some occasions with existing sea level. As indicated in Table 11 and illustrated in Figure A4(i) and A4(ii), projected future sea level rise could erode a further 17-24 m landward. These are probably lower order estimates as discussed in Section 3.4.2).

To date, the erosion hazard has been managed using sea walls, which have largely eliminated high tide dry beach north of Taupo Stream due to passive erosion effects described in Section 4.3.6. In the longer term, continued reliance on sea walls would cause severe beach loss and associated impacts on public access and beach amenity.

Sea walls in their current location are therefore unlikely to be an appropriate long-term solution at Plimmerton, for the many reasons described in Section 4.3.6, though they are likely to continue to play a role in coastal management in the short to medium term. Accordingly, an adaptive management strategy will be required to appropriately manage coastal erosion while balancing conflicting public and private interests.

Environmentally "soft" approaches such as beach nourishment might be a viable alternative or complementary option to protect properties while also enhancing the beach and associated public values. Detailed investigations and modelling would however be required to assess the practicality and cost of such an approach, together with detailed landowner and community consultation. If it were not practicable to hold the present shoreline using beach nourishment and any associated sand retention structures (e.g. groynes) then some retreat of the current seawall alignment would be required.

South of Taupo Stream, existing coastal erosion hazard has less impact on existing development but could potentially threaten some properties and dwellings (Figure A4(ii)). Erosion will however become much more severe with projected sea level rise and could potentially erode back to the road landward of the properties in some areas. Given the importance of the beach in this area, sea walls are unlikely to be an appropriate response to this erosion because of the impact on the beach. Accordingly, any adaptive management strategy for Plimmerton Beach will also need to address coastal erosion hazard in this area.

The coastal inundation mapping indicates that beachfront properties north of Taupo Stream are potentially vulnerable to wave overtopping during extreme events with existing sea level. These wave impacts have been observed in recent extreme events though advice from most property owners at the meetings is that flooding over the last 50-70 years has been less extensive shown on the maps and primarily limited to the front end of the properties. This suggests that the flood levels used may be slightly conservative, though the mapping is for a rare and extreme (1%AEP) event. It probably also reflects some mitigation of inundation by the sea walls. While the sea walls result in severe wave reflection, clapotis[5] effects and significant sea spray, they are commonly higher than the properties and undoubtedly have an overall beneficial effect on reducing inundation.

[5] Refers to a non-breaking "standing wave" pattern, caused by the reflection of waves from a near vertical shoreline like a breakwater, seawall or steep cliff.

While the assessed potential coastal inundation of these properties is relatively minor with current sea level, future sea level rise will greatly increase both the frequency and severity of inundation.

South of Taupo Stream, the land elevations and the significant beach and dune buffer mean that the residential dwellings are sufficiently elevated to be at low risk from coastal inundation with current sea level. However, future sea level rise of 1.0 m or more will result in significant coastal inundation hazard to these properties; compounded by loss of the beach and dune buffer to erosion.

The Plimmerton Fire Station is very low lying and is located in a very exposed location (Figure 20). The land and building are both impacted by occasional coastal flooding and wave run-up effects even with current sea level. Over time these impacts will become more frequent and very severe with projected sea level rise. It is likely that an alternative location will need to be found for this critical community asset.

Figure 20: Plimmerton Fire Station. This site is already vulnerable to coastal erosion and coastal inundation effects with current sea level. Any future sea level rise will threaten the sustainability of this critical community asset.

In the absence of an agreed adaptive management strategy, interim measures are required to prevent aggravation of the risk posed by coastal erosion and coastal inundation hazard. We recommend that the development controls discussed in Section 5 are applied in the identified hazard areas.

We also recommend that the Porirua City Council provides some leadership on use of soft approaches at Plimmerton, including:

- Dune restoration: there is considerable scope south of Taupo Stream for soft approaches, including living with erosion, beach push-ups and dune restoration at Taupo Reserve and fronting the properties to the south.

- Adapting to erosion: a small-scale trial could be undertaken on public land with landward adjustment of seawalls at Queens Ave, while ensuring protection of adjacent private property.

11 TITAHI BAY

Titahi Bay is an embayed beach located on the southwestern side of Whitireia Peninsula (Figure 1). The beach is valued for swimming and surfing and is regarded as a prime recreational asset and a significant natural feature in the Wellington Region. There is a very active local Surf Club with a rich history.

Titahi Bay is a moderate wave energy environment, sheltered to swell from all directions except the northwest. The central and southern portions of the beach are most exposed to wave energy from larger waves, but often the Bay experiences only small, low energy locally generated waves. The beach is composed of medium to fine sands, and some gravels, the latter probably from local streams and usually concentrated at the top of the beach. The beach has only a relatively limited volume of sands and gravels and only very minor ongoing supply of sediment from either marine or stream sources. The limited beach sediments overlie an historic shore platform formed by cliff retreat.

In the northeastern section of the embayment, the beach is backed by a steeply sloping vegetated sea cliff (Figure 21); while a narrow strip of dunes occurs southwest of the central Surf Club (Figure 22), backed by an old sea cliff composed of sandstone and Pleistocene sand dunes. The Surf Club is located on a low-lying narrow strip between the sea cliff and the beach. The dunes immediately southwest of the Surf Club are fronted by a concrete block seawall. The beach is backed residential development along most of its length with property boundaries close to the top of the cliff and the back of the dunes.

11.1 Coastal Erosion Hazard

Coastal erosion hazard areas have been identified at Titahi Bay to provide for likely dynamic fluctuations, gradual erosion of the cliffed shorelines, and to provide for potential slope instability (Figure A5).

In the dune area southwest of the surf club, historic photographs dating from the 1920s show fluctuations in the width of coastal dune but no trend for permanent erosion or accretion. There is no evidence that the dunes have eroded back to the ancient sea cliff in the last 100 years. Using geomorphic evidence from the southern end of the beach (south of the seawall), we estimate a maximum likely dynamic fluctuation of 8.0 m with current sea level.

Drilling was undertaken on the beach and landward of the seawall to determine the width of the Holocene sands (i.e. area most vulnerable to erosion). These bores confirmed that the dunes are relatively narrow (typically <20-25 m) and backed by more erosion resistant materials. This reduces the vulnerability of the landward properties to coastal erosion.

In the longer term, projected sea level rise is likely to drive a slow trend for erosion of the dunes, with estimates suggesting potential for up to 40-50 m erosion per 1.0 m of sea level rise (3.4.2). However, as the drilling indicates that the dunes are backed by more erosion resistant materials, we have limited the erosion hazard zones to the width of the dunes plus a narrow margin (5-7 m) to allow for uncertainty and some cliff erosion.

Figure 21: View looking eastwards from Titahi Bay surf club showing the steep vegetated banks which characterise the eastern end of the beach. Historic photographs indicate that at times, narrow dunes also develop in limited areas seaward of these cliffs, though not at present.

Figure 22: Titahi Bay dunes south of the Surf Club. Much of this shoreline is also fronted by a vertical seawall built in the early 1980s to prevent wind erosion.

There is uncertainty, however about the boundary of this erosion resistant material immediately south of the Surf Club, where the presence of the stream and the topography suggest the underlying geology may differ. Further site-specific drilling is required to determine if erosion resistant material exists in this area, and the hazard zone reflects this uncertainty (i.e. we have assumed that sands may extend further landward).

The current coastal erosion hazard in the cliffed area north of the Titahi Bay Surf Club was assessed based on a long-term cliff toe recession rate of 2.5 m per century and a stable slope angle of 1V: 1.5H. With future projected sea level rise, it is likely that the rate of cliff erosion will increase as discussed in Section 3.4.2. Coastal erosion hazard calculations for the cliff area north of the Surf Club are summarized in Table 13.

Table 13: Coastal erosion calculations for Titahi Bay north of the Surf Club. Methods for determining setbacks south of the Surf Club are described above.

Sea Level Scenario	Erosion Existing SL	Future erosion due to SLR	Slope factor	Total Erosion
Current	2.5 m	0 m	12-23 m	14.5-25.5 m
1.0 m	2.5 m	2.5 m	12-23 m	17-28 m
1.4 m	2.5 m	4.5 m	12-23 m	19-30 m

11.2 Coastal Flooding Hazard

Coastal inundation has been estimated as discussed in Section 3.3, and the estimated extreme sea levels for Titahi Bay are summarised in Table 14. Figure A5 in Appendix 1 provides an overview of the areas potentially affected by coastal inundation with current sea level and with future sea level rise.

Table 14: Coastal Inundation Levels at Titahi Bay.

Sea Level Scenario	1% AEP Surge	Wave Effects	Inundation Level
Current	1.88 m	0.75 m	2.63 m
1.0 m	2.85 m	1.00 m	3.85 m
1.4 m	3.21 m	1.00 m	4.21 m

11.3 Management Implications and Recommendations

Private residential development is generally located landward of the areas of existing coastal hazard risk, though the surf club and boat sheds are within the current coastal hazard areas. With projected sea level rise, there is however potential for some private properties and nearshore infrastructure (e.g. roads and services) to be affected by erosion (Figure A5).

The boat sheds at either end of the beach are presently the most vulnerable to coastal hazards; being low lying and periodically affected and occasionally damaged during storm surge and high wave events. Future sea level rise will greatly increase the frequency and severity of flooding and is likely to make the ongoing use of these boat sheds increasingly unsustainable.

Figure 23: Titahi Bay boat sheds are low lying and vulnerable to flooding and wave damage during extreme events. These impacts will become much more frequent even with a small amount of sea level rise.

The Titahi Bay Surf Club is located on a narrow, low-lying coastal plain in the centre of the beach. This area is very susceptible to coastal erosion and also potentially vulnerable to wave overtopping during extreme events. The building has been protected from coastal erosion for many decades by a seawall that has recently been replaced. The club site is likely to remain viable for a further 20-30 years with maintenance or replacement of the sea wall but in the longer term an alternative location will be required. This is a critical community facility for beach users and it is recommended that PCC work with the surf club to identify an alternative more sustainable long term location.

The longer-term risk to some private properties and nearshore public infrastructure can be effectively managed using development controls as discussed in Section 5.

The existing seawall constrains erosion of the dunes southwest of the surf club. However, this interferes with natural sand exchange between the beach and the dunes discussed in Section 3.2.1. Sand continues to blow from the beach to the dune, but the natural beach and dune processes can no longer recycle sand to the beach, and the volume of sand trapped behind the seawall has increased (Figure 24 and Figure 25). Without any return of sediment from the dune, the beach has become increasingly lowered, and gravel dominates on the upper beach. This process will continue, and the beach will continue to degrade if there is no change in management regime. This sea wall will become increasingly inappropriate as erosion is aggravated by projected future sea level rise.

The current seawall is however valued by some beachfront residents because of historic issues with windblown sand and perceptions that they could be vulnerable to coastal erosion longer term if the structure was not present. This study indicates that longer term vulnerability to coastal erosion is however limited.

Figure 24: Titahi Bay seawall immediately following construction (photo GWRC).

Figure 25: Titahi Bay seawall present day. Note large amount of sand accumulation in marram grass landward of the seawall. This sand is unable to recycle to the beach through natural processes. The Titahi Bay Surf Club can be seen in the background.

Further discussion is required with local residents and wider beach user community to develop adaptive management strategy and balance amenity and public access with environmental effects and coastal hazard implications. The strategy will determine the long-term future of the seawall, public access, management of the boatsheds and details of the proposed walkway.

12 IVEY BAY AND GOLDEN GATE PENINSULA BEACHES

This section of shoreline includes the beaches occurring from Ivey Bay to Browns Bay, including the northern shoreline of the Golden Gate Peninsula.

12.1 Coastal Erosion Hazard

12.1.1 Ivey Bay

The beach at Ivey Bay is contained in a small embayment on the eastern side of the Golden Gate Peninsula. The beach shoreline is backed by a low lying coastal plain up to approximately 30 m wide. The land seaward of the road is publicly owned but currently utilised by a kindergarten.

The nature of the original natural shoreline is unknown, but field examination and topography suggest it was probably a low beach chenier fronting a narrow coastal plain composed of chenier ridges and/or estuarine wetlands. Various rock and other ad hoc protection structures occur along the shoreline and in places hold the present coast up to 5 m seaward of what would otherwise be its natural position (Figure 26).

Figure 26: Ivey Bay shoreline.

In calculating the current erosion hazard area we have allowed for erosion of up to 5 m associated with dynamic shoreline fluctuations based on geomorphic considerations and historic photography but no permanent long term trend for erosion or accretion. The narrow coastal plain and the embayed setting suggests the shoreline is probably accretionary over centuries but any trend for net shoreline advance is likely to be less than 1.0 m per century. The potential response of the shoreline to sea level rise was estimated as outlined in Section 3.4.2 adopting a typical beach slope of 1:10. Erosion hazard calculations are summarised in Table 15 and mapped in Figure A6 (i).

Table 15: Coastal erosion calculations for Ivey Bay.

Sea Level Scenario	Existing 100 year	Future erosion	Slope/dune factor	Total Erosion
Current	10 m	0 m	0 m	10 m
1.0 m	10 m	8.5 m	0 m	18.5 m
1.4 m	10 m	12.0 m	0 m	22 m

12.1.2 Golden Gate Beaches

The beaches along the northern shoreline of the Golden Gate Peninsula front a narrow Holocene coastal plain comprised of former chenier ridges and wetlands. Naturally the shoreline would have been fronted by a sand and shell chenier ridge with relict chenier ridges and wetlands further landward, similar to the small remnant natural shoreline towards the eastern end of the (Figure 27).

Figure 27: View of natural remnant chenier backed by estuarine wetland towards the northern end of the Golden Gate chenier beach shoreline.

The coastal plain has been extensively subdivided, and the existing beach is backed by a narrow coastal reserve of varying width and private properties. Beachfront dwellings are often located very close to the shore and sometimes even over the public reserve; with a variety of ad hoc sea wall structures placed to protect this development and the narrow public walkway (Figure 28). In many places the seawalls extend well seaward of the natural shoreline and have significantly narrowed and degraded the beach, though small areas of remnant beach remain in areas without sea walls (see bottom photo in Figure 28).

Figure 28: Views of northern shore of the Golden Gate Peninsula showing close proximity of many dwellings to the sea and various sea wall structures. The near view in the bottom photo shows a remnant area of natural beach in an area without sea walls.

In its natural state, the shoreline is likely to have been very dynamic as cheniers migrate landward due to storm wave overtopping. In addition, new chenier ridges would periodically move onshore from the adjacent harbour. There would also be longshore gains and losses associated with wave-generated longshore drift. Where the beach is backed by sea walls, landward migration is no longer possible; but shoreline and/or beach level fluctuations would still be observed over decades due to periodic gain and loss of sand associated with longshore drift and onshore movements from the adjacent harbour.

In estimating coastal erosion hazard, we have allowed for the realignment of the present shoreline that would occur if sea walls were removed and for likely dynamic shoreline fluctuations that would also occur over time; providing a total estimated erosion hazard width of up to 10 m (Table 16). Estimates of likely additional coastal recession in response to sea level rise have been calculated as described in Section 3.4.2 and are based on a typical (surveyed) beach slope of 1:10. The widths of the different erosion hazard zones are summarised in Table 16 and mapped in Figure A6(ii). In mapping the area potentially vulnerable to erosion we have taken into account the fact that the coastal plain is relatively narrow in some areas and backed by erosion resistant materials; though this mapping should be further improved when a detailed site-specific adaptive strategy is developed for this area.

Table 16: Coastal erosion calculations for Golden Gate beaches.

Sea Level Scenario	Existing 100 year	Future erosion	Slope/dune factor	Total Erosion
Current	10 m	0 m	0 m	10 m
1.0 m	10 m	8.5 m	0 m	18.5 m
1.4 m	10 m	12.0 m	0 m	22 m

12.1.3 Browns Bay Beach

Browns Bay is a sheltered embayment backed by a small sandy beach and low lying coastal plain. Field observations and existing topography suggest that the original natural coastline was probably a beach and chenier ridge backed by low-lying and probably wetland areas. The area is now extensively developed.

The beach is backed by a reserve of varying width, though this has been privatized in most areas. There are also various ad hoc sea wall structures along the shoreline (Figure 29), most located on public reserve but some on private boundaries. For the most part, these appear to have been constructed as private benefit structures. As with Ivey Bay and the chenier beaches along the northern shoreline of Golden Gate Peninsula, encroachment onto the active shoreline has a long history and is evident even in the earliest aerial photos (dating from 1941/42).

Historical information provides no evidence of significant long-term erosion and the lack of beach width in some areas (particularly central and northern areas) appears to be largely a consequence of historic reclamation.

The current erosion hazard zone was estimated based on shoreline adjustment in the absence of the sea walls with a small allowance for dynamic coastal fluctuations. The width of this zone (10 m) is very similar to the width of the original chenier feature as estimated on the basis of existing topography. In the absence of the sea walls, erosion is however only likely to be this severe in central and northern areas where seawalls encroach well seaward of the natural shoreline.

Figure 29: Various views of Browns bay shoreline – showing northern and central areas (top 2 photos) and the southern end (bottom photo)

At this site, calculations of the erosion that could accompany projected sea level rise adopted a 1:20 slope based on the limited available topographic information – a lower gradient than the 1:10 slope typically used for most estuarine shorelines. Calculations are shown in Table 17 and illustrated in Figure A6(iii).

Table 17: Coastal erosion calculations for Browns Bay.

Sea Level Scenario	Existing 100 year	Future erosion	Slope/dune factor	Total Erosion
Current	10 m	0 m	0 m	10 m
1.0 m	10 m	17 m	0 m	27 m
1.4 m	10 m	24 m	0 m	34 m

12.2 Coastal Flooding Hazard

Coastal inundation has been estimated based on the data of Lane et al. (2013) as discussed in Section 3.3 and 3.3 with estimated extreme sea levels summarised in Table 18. Figure A6(i), A6(ii) and A6 (iii) in Appendix 1 provides an overview of the areas that could potentially be affected by coastal inundation with current sea level and with future sea level rise.

The various shorelines are located within the Pauatahanui Inlet and are therefore relatively sheltered. A minimal allowance of 0.25 m freeboard was therefore included for wave effects; except for the north-facing Golden Gate beaches, where an additional 0.25 m was included to allow for wave run-up effects during major storms. The latter allowance was based on field observations and residents reports of storm wave run-up in early 2018.

Table 18: Coastal Inundation Levels at Ivey Bay, Golden Gate and Brown's Bay.

Sea Level Scenario	**1% AEP Surge**	**Freeboard**	**Wave Effects (Golden Gate Beaches)**	**Inundation Level**	
				Ivey/Brown's	**Golden Gate**
Current	1.70 m	0.25 m	0.25 m	1.95 m	2.20 m
1.0 m	2.67 m	0.25 m	0.25 m	2.92 m	3.17 m
1.4 m	3.03 m	0.25 m	0.25 m	3.28 m	3.53 m

12.3 Management Implications and Recommendations

12.3.1 Ivey Bay

The hazard mapping (Figure A6(i)) indicates that the low-lying reserve backing Ivey Bay is at risk from both coastal erosion and inundation with existing sea level and will become increasingly vulnerable to these hazards with projected sea level rise.

Various ad hoc structures have been placed along Ivey Bay in an attempt to manage erosion (e.g. Figure 26); though these measures or other hard structures are not likely to provide an appropriate long term solution at this site.

However, we believe it is very likely that coastal erosion hazard at this site can be adequately managed by beach nourishment and/or other soft engineering techniques; these options typically being relatively practicable in sheltered harbour environments of this nature. The existing and potential longer term risk from coastal inundation might also be able to be adequately managed by appropriate soft engineering (such as beach nourishment) combined with minimum floor levels. Raising land levels is also likely to be required over time.

The details of these various measures will require the development of a site-specific adaptive management plan in association with key stakeholders and the wider community.

12.3.2 Golden Gate Beaches

The hazard analysis and mapping indicate that coastal development on the low coastal plain backing the Golden Gate beach shoreline is already extremely vulnerable to coastal erosion and inundation and these hazards will be significantly aggravated by projected future sea level rise.

The various ad hoc structures along the shoreline appear to provide a reasonable level of erosion protection at present (with appropriate ongoing maintenance). However, sea wall structures alone are not likely to provide an adequate long-term solution to erosion. These structures already significantly degrade the beach in many areas and the adverse effects will be considerably aggravated by the erosion likely to accompany projected sea level rise.

Given the significant hazard issues and the conflict between public and private interests, a site-specific adaptive plan will be required for this site to manage coastal hazard and hazard risk effectively. The site is more complex than many other parts of the harbour margin because of the higher combined wave and tidal energy and active sediment dynamics, the narrow public reserve and the close proximity of development to the sea. It is likely that implementation will also have to be phased in lowly over decades.

An appropriate adaptive management strategy is likely to require a combination of some or all of the following measures:

- beach nourishment, possibly requiring suitable sand retention structures
- appropriate setbacks and development controls to provide for landward retreat of existing development as dwellings are replaced
- minimum floor levels
- raised ground levels
- removal and/or landward replacement of existing seawalls.

Backstop sea walls (i.e. structures located sufficiently far landward to enable a high tide beach to form seaward on most normal occasions) might well be a useful component of a long-term adaptive management strategy at this site.

The complexities of the site mean that development of an appropriate strategy will require detailed investigations and active consultation with all relevant stakeholders, including adjacent private landowners and the wider community.

12.3.3 Browns Bay

The various low-lying coastal properties around this bay are vulnerable to coastal erosion and coastal inundation with existing sea level and this vulnerability will increase significantly with projected sea level rise. The existing sea walls generally provide protection from coastal erosion at present, but these are unlikely to provide appropriate long-term solutions; particularly not structures located seaward of private property boundaries.

It is probable that beach nourishment can provide an effective long-term solution to coastal erosion at this site; given the limited volume of sediments likely to be required, the relatively sheltered nature of the bay and the fact that placed sediments are likely to be retained for lengthy periods. These factors should limit maintenance requirements and associated costs. This would need to be confirmed by more detailed investigations.

The management of coastal inundation will require minimum flood levels and the raising of ground levels in many areas over time. Landward retreat of some existing dwellings will also be required over time.

Council should also investigate issues of ownership, encroachment and consenting/safety of the current private structures on Council reserve as discussed in Section 5.

13 PAUATAHANUI

Pauatahanui is a village located at the head of the Pauatahanui Inlet, the eastern arm of Porirua Harbour (Figure 1). The settlement and surrounding rural and is generally very low-lying and located on former wetlands or alluvial floodplains. The settlement is fronted by a wide expanse of intertidal flats and coastal wetland (Figure 30). The inlet itself is of very high ecological value and is recognized as a regionally significant habitat.

The Pauatahanui Stream discharges into the inlet immediately south of the village. This stream is the largest of the six catchments discharging into the Porirua Harbour and generates significant river flood hazard during extreme rainfall events.

13.1 Coastal Erosion Hazard

The shoreline of Pauatahanui village has maximum wave fetches of 3.2-3.8 km to the west and northwest, respectively; sufficient to generate moderate wave activity (waves of height 0.5-0.6 m and periods of 2-3 s) during periods of strong winds. However, wave energy is extensively dissipated by the wide (often 350-500 m) saltmarsh and coastal wetlands to seaward, so that erosion rates along the shoreline are negligible. Field inspection indicates that the seaward edge of the wetlands is slowly eroding and retreating in places, but the rate is very slow.

It is possible that the village shoreline will suffer from increased erosion with projected sea level rise, but this depends to a large extent on whether the wide wetlands to seaward can be maintained; dependent on rates of sedimentation keeping pace with sea level rise. If sedimentation does not keep pace with sea level rise, then the width of wetlands seaward of the village will diminish and erosion may increase. Overall, coastal erosion is not expected to be a major hazard issue over the next 100 years and the shoreline fronting the village is unlikely to retreat by more than five metres.

13.2 Coastal Flooding Hazard

Coastal inundation has been estimated as described in Section 3.3, and extreme water levels at Pauatahanui are summarised in Table 19. Figure A7(i) and A7(ii) in Appendix 1 provides an overview of the areas potentially affected by coastal inundation with current sea level and with future sea level rise.

Table 19: Coastal Inundation Levels in Pauatahanui Inlet.

Sea Level Scenario	1% AEP Surge	Wave Effects	Inundation Level
Current	1.70 m	0.25 m	1.95 m
1.0 m	2.67 m	0.25 m	2.92 m
1.4 m	3.03 m	0.25 m	3.28 m

Much of Pauatahanui Village is located on very low-lying land, directly adjacent to the upper reaches of the estuary. A number of properties are vulnerable to inundation with existing sea level and almost all properties in the Village seaward of Paremata Road and Paekakariki Hill Road will be subject to inundation with 1.0 m of sea level rise, together with surrounding areas of low-lying rural land and local roads.

Figure 30: Aerial view of Pauatahanui Village and surrounding areas.

The coastal inundation hazard is further complicated by flooding from the Pauatahanui Stream. Wellington Water has recently undertaken a modelling study to investigate flood hazard from the Pauatahanui Stream. Modelling results highlight river flood risk to many of the same areas that are susceptible to coastal storm inundation.

It is likely that ground water levels will also rise substantially with projected sea level rise and this will further complicate hazard vulnerability.

13.3 Management Options and Recommendations

The coastal inundation analysis indicates that Pauatahanui Village, extensive lengths of roading and adjacent low-lying rural areas will become extremely susceptible to coastal inundation with projected sea level rise; complicated also by river flooding and ground water levels, both of which hazards will also be severely aggravated by projected sea level rise. Even a small amount of future sea level rise will greatly increase the severity and (most significantly) the frequency of flooding.

These hazards (and tsunami) collectively raise significant issues. Accordingly, it is recommended that no further expansion or intensification of development be considered on low-lying flood risk areas unless a detailed adaptive management plan is developed which indicates that these hazards can be sustainably managed.

Effective long-term management of flooding hazard at Pauatahanui requires an integrated approach with both coastal and stream sources. Redevelopment of existing residential properties will need to consider the resilience of buildings and infrastructure. While the risk to existing properties and dwellings might be mitigated by appropriate minimum floor levels and, over time, raising of ground levels, significant complications will nonetheless arise with increased vulnerability of local roads and services. Accordingly, it is recommended that a site-specific adaptive management strategy be developed for the area to sustainably manage coastal and river flood hazards.

The extensive estuarine wetland and chenier banks seaward of the Pauatahanui Village are a further potential complication with sea level rise. These wetland areas have significant ecological value but, as noted above, could be significantly narrowed by sea level rise if sedimentation rates do not keep pace and maintain the high bed levels required by these plant communities. This potential loss can be at least partly offset by allowing the wetland systems to migrate landward with sea level rise; but obviously this objective poses another major obstacle to any further expansion of development on low-lying land. We recommend that PCC consider opportunities to develop suitable incentive schemes to reward landowners for protection of these areas and to offset opportunity losses with restrictions on further intensification or expansion of development. For instance, schemes which provide increased development rights outside of the hazard areas in return for restoration of wetlands and setting aside low-lying for future expansion of wetlands. Given the very high ecological value of the inlet, allowance for long term wetland migration in response to sea level rise (as discussed in Section 5.5) is of particular importance here.

As discussed in Section 5.1, the Council will need to consider the vulnerability of Grays Road to coastal flooding in the medium to longer term and plan for either (ideally) landward adjustment of the road or significant works to raise the level of the road in its current location. This planning will also need to consider the vulnerability of various lengths of the road to coastal erosion.

14 PORIRUA CITY AREA AND MANA

Coastal inundation hazard maps indicate potential coastal inundation issues in the general vicinity of the central business district and Mana; particularly longer term with sea level rise. This section briefly discusses these areas and issues.

14.1 Coastal Flooding Hazard

The coastal flood elevations used around the harbour margins in these areas are the same as those used in other estuarine margins (except parts of the Golden Gate foreshore) and are summarised in Table 20.

Table 20: Coastal Inundation Levels used for Porirua Harbour (Onepoto arm and Pauatahanui Inlet) margins

Sea Level Scenario	1% AEP Surge	Wave Effects	Inundation Level
Current	1.70 m	0.25 m	1.95 m
1.0 m	2.67 m	0.25 m	2.92 m
1.4 m	3.03 m	0.25 m	3.28 m

14.1.1 Porirua City Area

Figures A8 and A9 in Appendix 1 provide an overview of the areas potentially affected by coastal inundation with current sea level and with future sea level rise.

These figures indicate that coastal inundation with existing sea level is largely limited to coastal margins. However, the mapping suggests that a 1%AEP coastal inundation event could potentially impact some low-lying areas on the landward side of Titahi Bay Road dependent on hydraulic connections. These areas include residential properties immediately north of Mana College, around the seaward end of Te Hiko Street and on the landward side of Tangare Drive. Stormwater network maps suggest hydraulic connections may exist but numerical modeling would be required to confirm whether or not these areas could be flooded. The "bathtub" approach used in this study assumes all areas below the flood level could potentially be impacted. However, in reality, sometimes there are complications (e.g. the tide does not stay up long enough or hydraulic connections are weak) that prevent flooding and these can only be reliably assessed using numerical modelling.

While coastal flooding is likely to be limited with existing sea level, there is potential for widespread flooding with 1.0 m of sea level rise (see Figures A8 and A9 in Appendix 1), including:

- Extensive areas along the western side of Titahi Bay Road from Awarua Street to Titahi Bay Intermediate School, including (from south to north):
  - eastern areas of the Mana College grounds
  - residential subdivision extending from north of Mana College through to the landward margin of Tangare Drive
  - extensive areas of reserve land on the landward side of Titahi Bay Road north of Te Hiko Street
  - various roads including Titahi Bay Road, the seaward ends of Te Hiko Street and Te Pene Avenue, and parts of the southern end of Tangare Drive
  - parts of Titahi Bay Intermediate School at the northern end of Titahi Bay Road

- Southern end of Wi Neera Drive and adjacent reserve areas
- Extensive areas of the rail corridor

In addition, there are various low-lying areas within the CBD that could potentially be impacted depending on hydraulic links (e.g. stormwater network), including:

- Eastern end of Parumoana Street and some adjacent property (particularly 16 Parumoana Street)
- Significant areas of Semple Street and minor areas of adjacent property
- Part of Wi Neera Drive

14.1.2 Mana

Figure A10 in Appendix 1 provides an overview of the areas potentially affected by coastal inundation with current sea level and with future sea level rise.

The areas vulnerable to coastal inundation with a 1%AEP event and existing sea level are relatively minor, largely limited to the harbour margin. There are however some low-lying areas within Ngatitoa Domain that could potentially be impacted by coastal flooding with existing sea level depending on hydraulic linkages.

However, with 1.0 m of sea level rise, the area potentially affected by a 1%AEP event increases considerably and includes:

- Large areas of the central and southern regions of Ngatitoa Domain
- Low lying residential and industrial areas on the western side of SH 1 from Marine View through to Pascoe Avenue
- Various beachfront properties adjacent to low-lying areas of the Dolly Varden Reserve

14.2 Management Options and Recommendations

The coastal inundation analysis indicates that there are fairly significant areas that could be affected by coastal inundation in the vicinity of the city centre and Mana. Many of these areas are low-lying regions once occupied by former wetlands and stream channels, and (in some areas near Porirua City and adjacent to Titahi Bay Road) reclaimed from the harbour.

The areas around the central business district and Titahi Bay Road that could be affected by coastal inundation with 1.0 m sea level rise (see a Figures A8 and A9 in Appendix 1) are also affected by stream and stormwater flooding; and with 1.0 m sea level rise this hazard will increase significantly (Figure 31). The management of these hazard areas is extremely complex and will require the development of a detailed adaptive management strategy that addresses both stream and coastal flooding in an integrated manner.

The areas potentially affected by coastal inundation around Mana should ideally be tested using numerical modelling (including stormwater networks) to test the “bathtub” assumptions in this area. Numerical modelling models the movement of seawater through hydraulic links with the coast (e.g. low-lying areas, stormwater networks, any waterways) whereas the “bathtub” approach used in this study assumes the peak of the tide remains high long enough to completely flood any areas with elevations below the peak water level. Numerical modelling will also identify in more detail the nature of the hydraulic links between the coast and the low-lying areas which will help identify possible options to mitigate flooding and ensure such options do not worsen any issues with stormwater or similar flooding. For instance, most of the coastal flooding in Mana occurs through either the stormwater network or over low-lying coastal margins. Accordingly, such flooding might be able to be significantly mitigated through relatively simple actions (e.g. raising coastal margins, putting flapgates on culverts). However, the implications of such actions on release of stormwater flooding require careful consideration; particularly any raising of low-lying coastal margins.

In the absence of a detailed adaptive management strategy for either the central business district or Mana, it is important to manage land use in these areas with appropriate development controls to avoid aggravating existing risk and to reduce risk where reasonably practicable, including through implementation of appropriate minimum floor levels.

Figure 31: View of Porirua City areas potentially impacted by a 1% AEP stream flood with 1 m rise in sea level as modelled by Wellington Water. (From

http://wellingtonwater.maps.arcgis.com/apps/MapSeries/index.html?appid=3eb5709da22e4be7b017ddd32191e1b3)

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APPENDIX 1: COASTAL HAZARD MAPS

The following pages illustrate the extent of identified coastal erosion and coastal hazard areas.

We have identified a number of coastal erosion and coastal flood hazard zones:

- **Current coastal erosion zone (solid black line):** the area potentially vulnerable to coastal erosion hazard over the next 100 years with existing sea level and coastal processes. This hazard identification assesses erosion events with a return period of at least 100 years.
- **Future coastal erosion hazard 1.0 m sea level rise (dashed black line):** identifying the area potentially vulnerable to coastal erosion over the period to 2120, assuming sea level rise of 1.0 m
- **Current coastal flood hazard (dark blue):** the area potentially vulnerable to coastal flooding with existing sea level and coastal processes. This hazard identification assesses coastal inundation events with a 1% annual exceedance probability)
- **Future coastal flood hazard 1.0 m sea level rise (pale blue):** the area potentially vulnerable to coastal flooding over the period to 2120, assuming sea level rise of 1.0 m
- **Future coastal flood hazard 1.4 m sea level rise[6] (blue line):** the areas potentially vulnerable to coastal flooding, assuming sea level rise of based on RCP8.5 H+ (1.36 m to 2120).

There are some low-lying areas near the coast where the level of the land is below the predicted extreme storm surge, but on the basis of the available information, the hydraulic connection to the sea is not certain. These are expressed with back patterned areas and can be seen in the legend with an "H" added to hazard area name. More detailed modelling would be required to determine conclusively if there is a genuine coastal storm inundation hazard.

[6] The erosion and flooding calculations reflect a sea level rise of 1.36 m to 2120, relative to the 1986-2005 baselines as directed by MfE (2017). For the purposes of reporting, we have referred to these areas as Future coastal erosion/flood hazard "1.4 m sea level rise" and referred to 1.4 m of sea level rise in the text for simplicity.

Figure A1(j): Coastal flood and erosion hazard areas at Pukerua.
Porirua 0.075m Urban Aerial Photos (2016) Porirua City Council
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Figure A1(ii): Coastal flood and erosion hazard areas at Pukerua.
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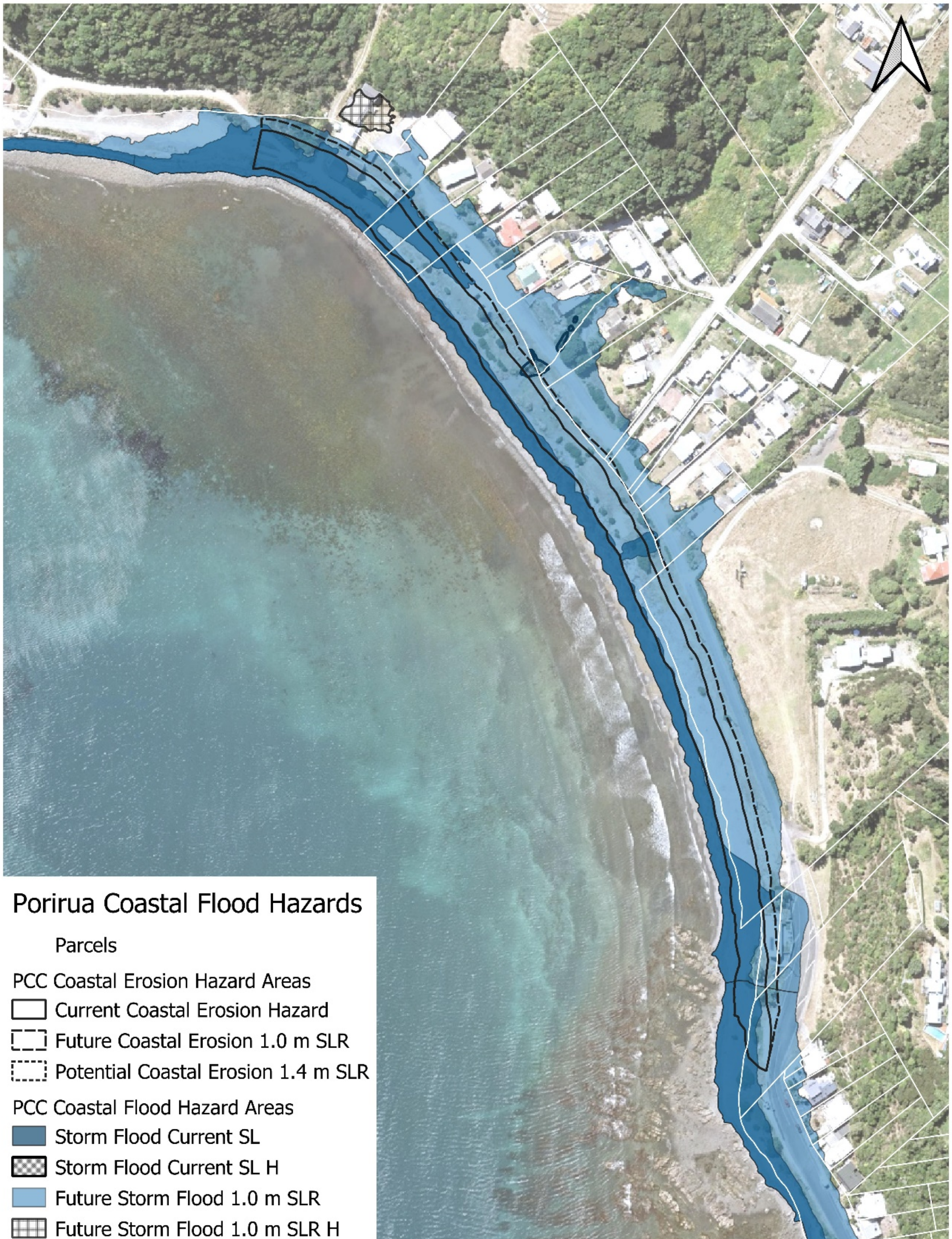

Figure A2: Coastal flood hazard areas at Hongoeka.
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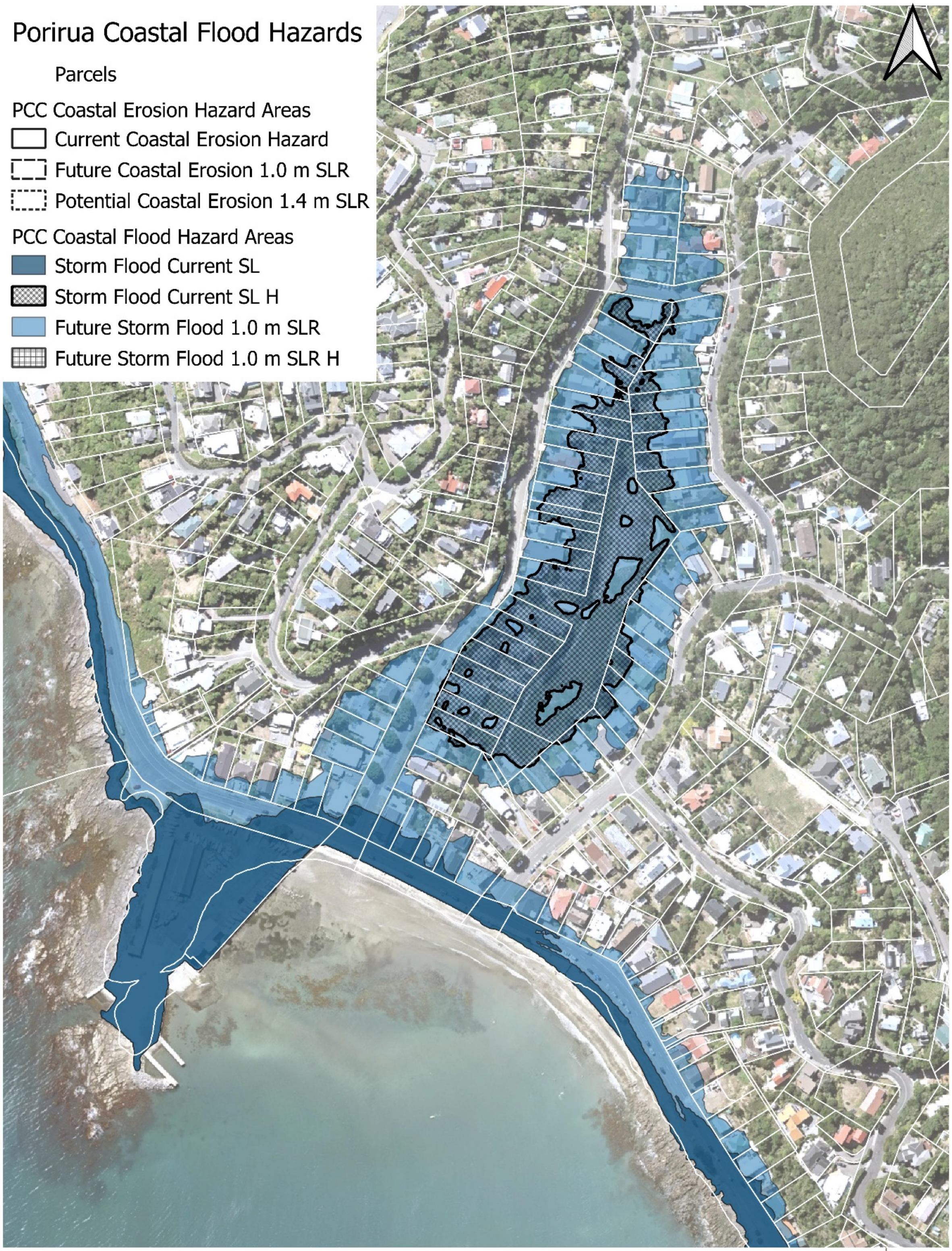

Figure A3(i): Coastal flood hazard areas at Karehana.
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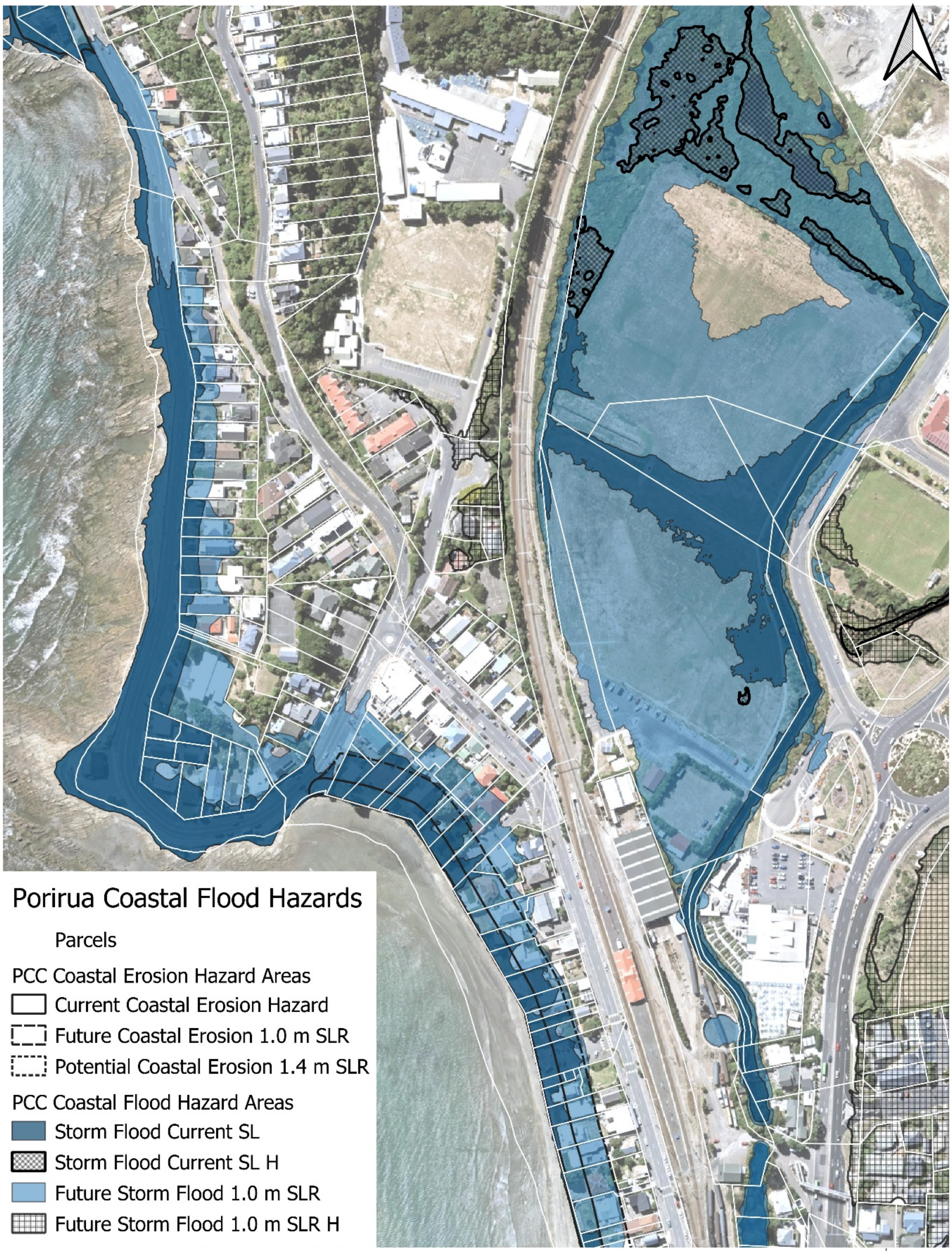

Figure A4(i): Coastal flood hazard areas at Karehana.
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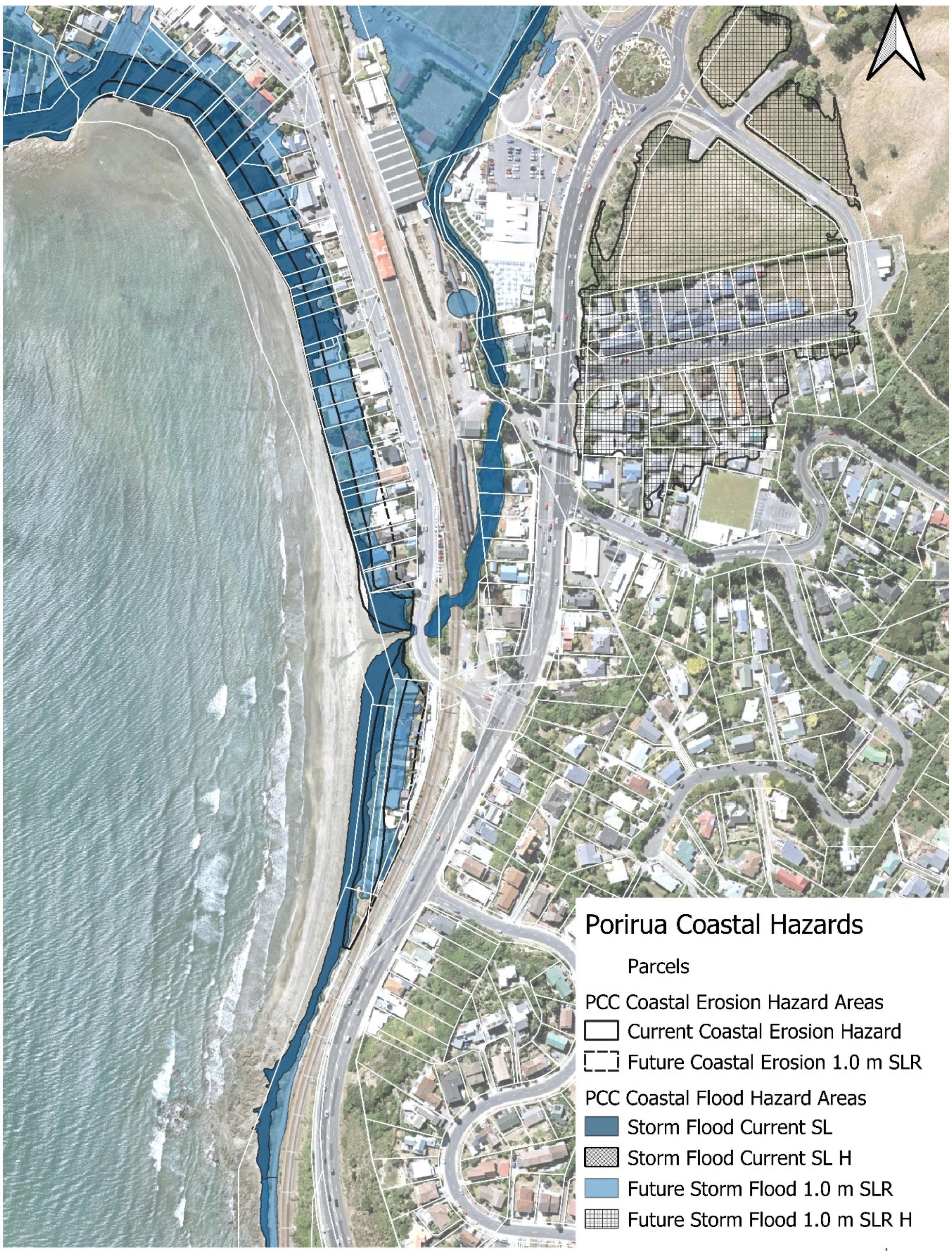

Figure A4(ii): Coastal flood and erosion hazard areas at Plimmerton.
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Figure A5: Coastal flood and erosion hazard areas at Titahi Bay.
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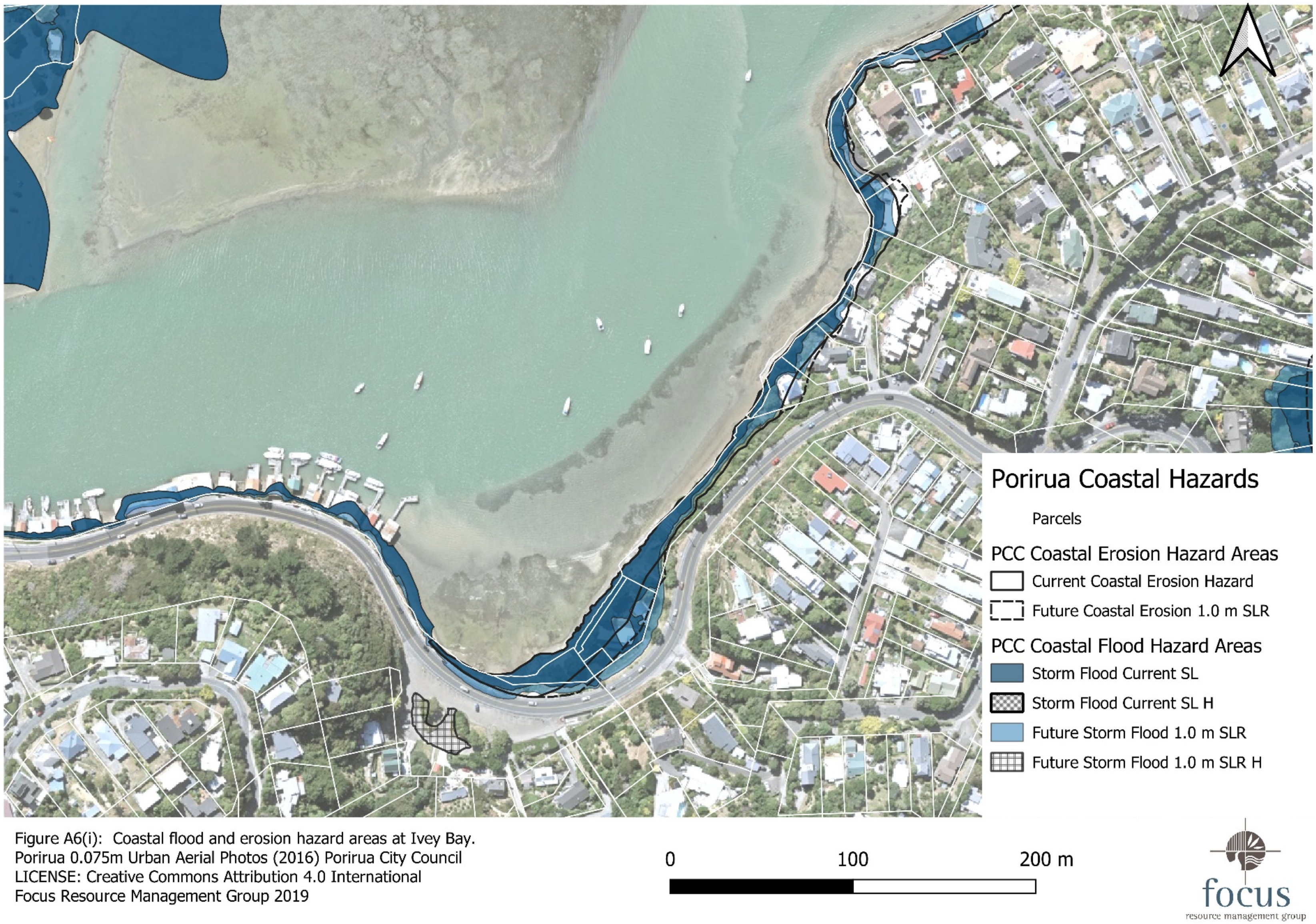

Figure A6(i): Coastal flood and erosion hazard areas at Ivey Bay.
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Figure A6(ii): Coastal flood and erosion hazard areas at Golden Gate.
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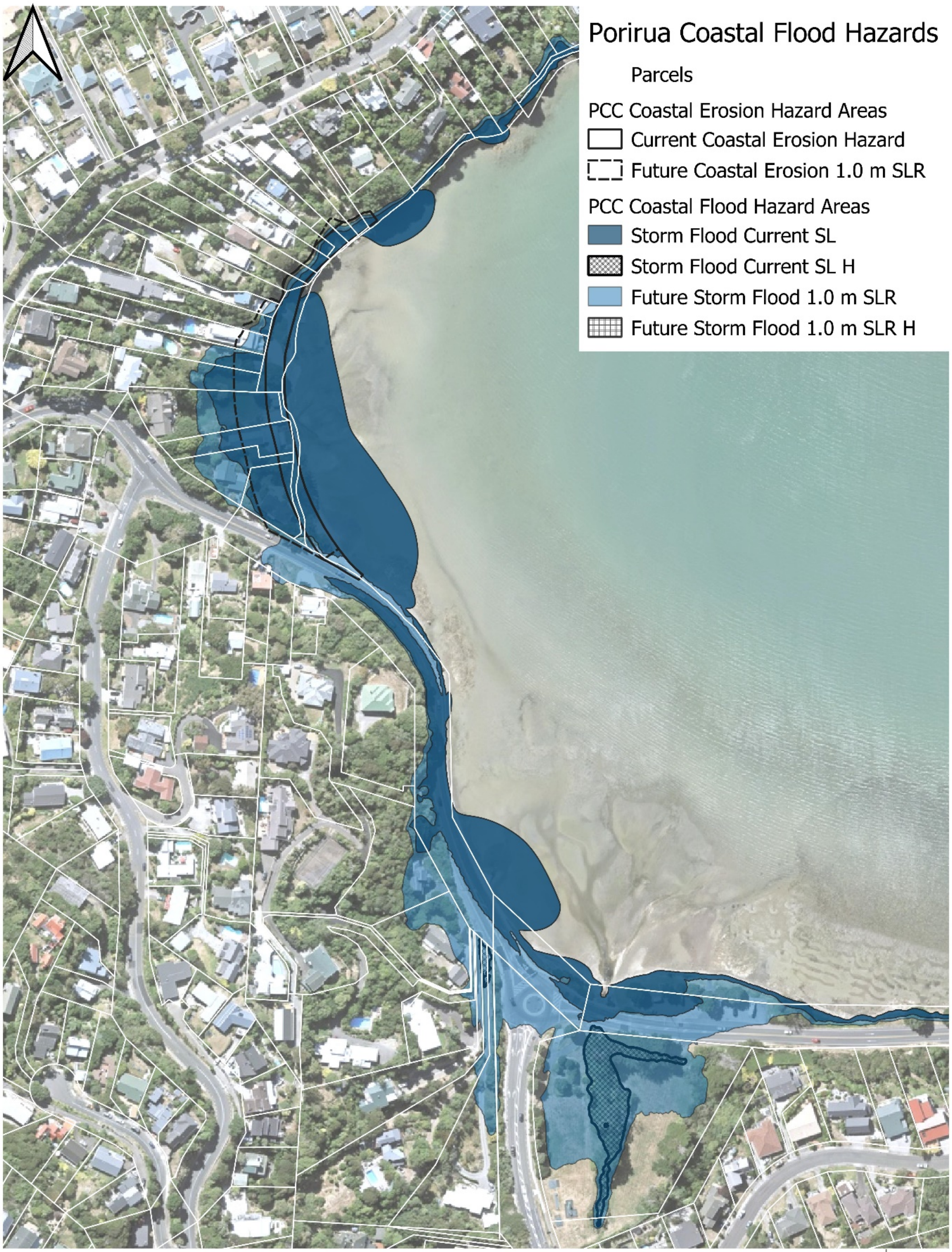

Figure A6(iii): Coastal flood hazard areas at Browns Bay.
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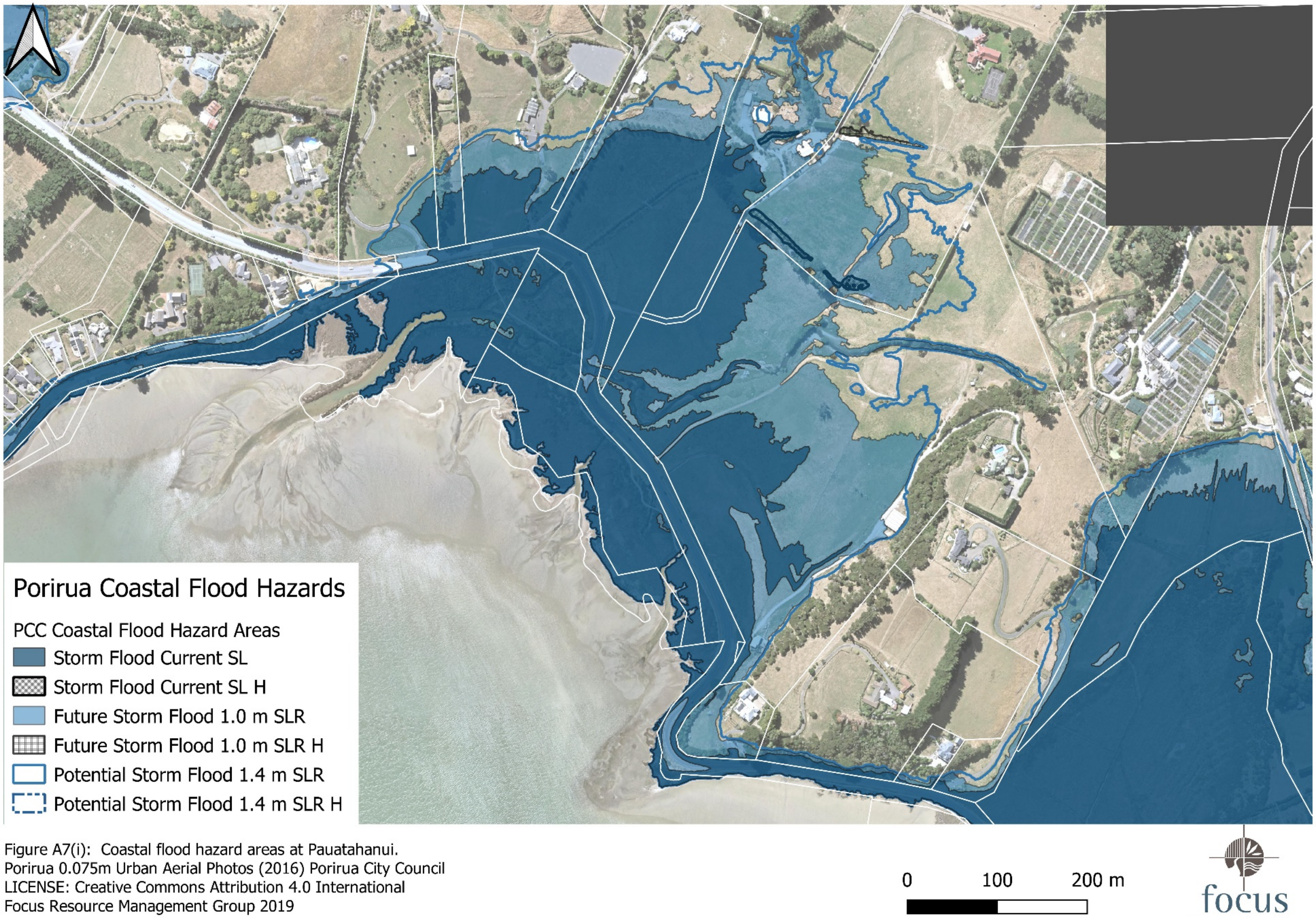

Figure A7(i): Coastal flood hazard areas at Pauatahanui.
Porirua 0.075m Urban Aerial Photos (2016) Porirua City Council

Figure A7(ii): Coastal flood hazard areas at Pauatahanui.
Porirua 0.075m Urban Aerial Photos (2016) Porirua City Council

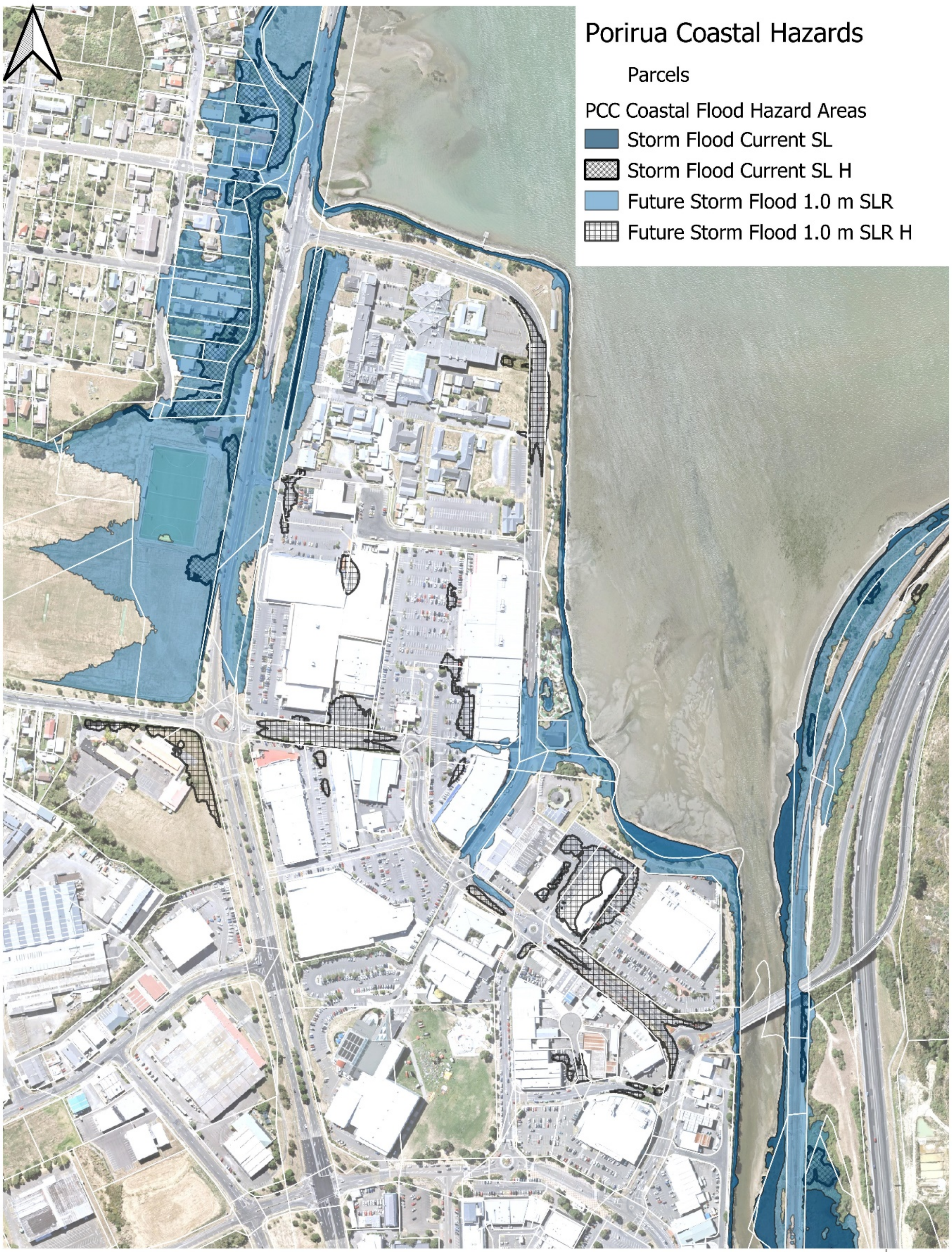

Figure A8: Coastal flood hazard areas at Mana.
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0 100 200 m

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Figure A9: Coastal flood hazard areas at Mana.
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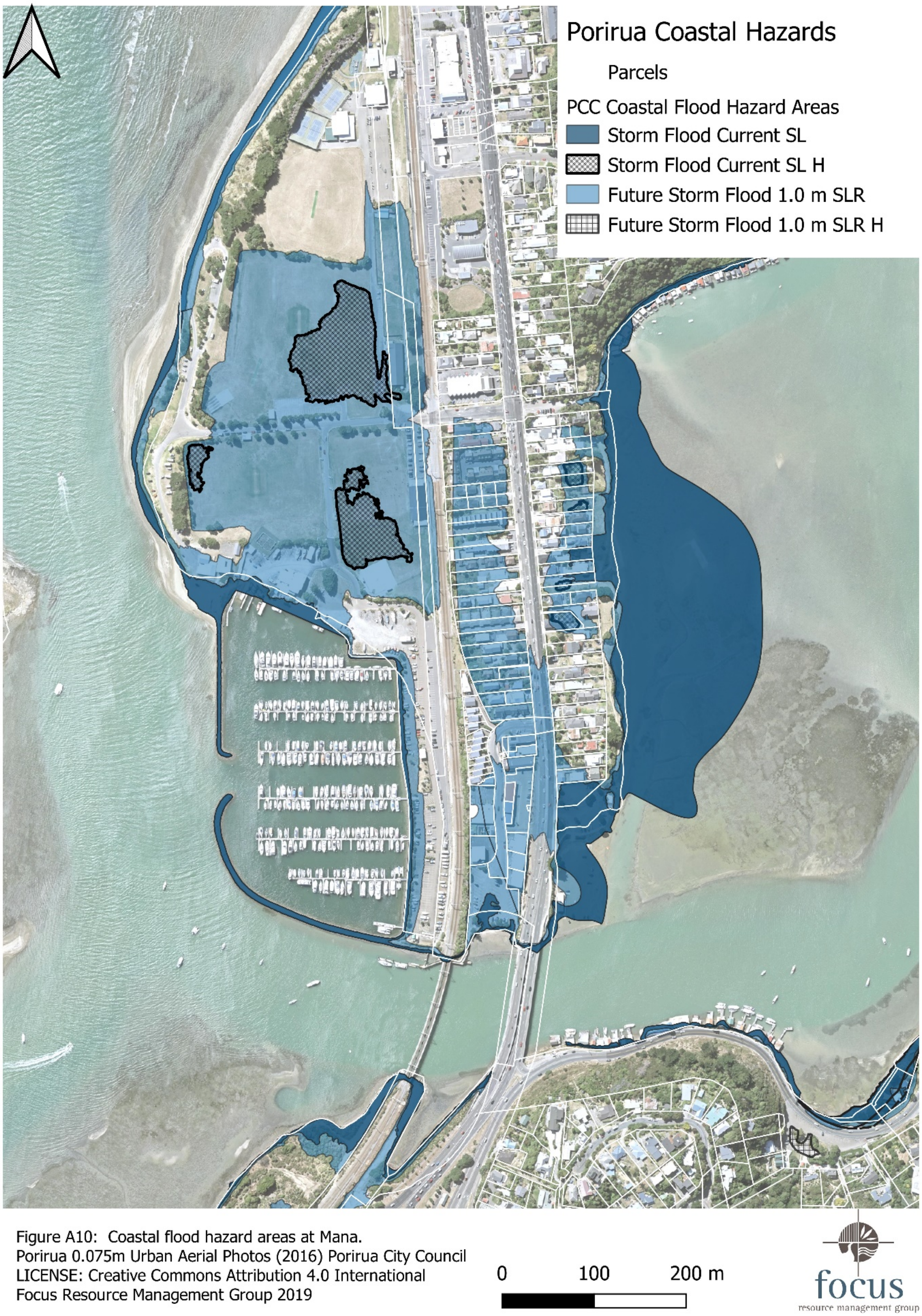

Figure A10: Coastal flood hazard areas at Mana.
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