Takutai Kāpiti – Coastal Science and Engineering Services

Kāpiti Coast Coastal Hazards Susceptibility and Vulnerability Assessment Volume 2: Results

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Takutai Kāpiti Coastal Science and Engineering Services

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Executive Summary

As part of Phase One (hazard identification) of their "*Takutai Kāpiti: Our community led coastal adaptation project*", Kāpiti Coast District Council (KCDC) have initiated a Coastal Hazard Susceptibility and Vulnerability Assessment for the entire 38 km of Kāpiti Coast District coastline from Ōtaki in the north to Paekākāriki in the south. The purpose of this assessment is to update previous coastal hazard assessments undertaken along the KCDC coastline involving the spatial extent of areas potentially susceptible to current and future coastal erosion and inundation hazards. Differences in the methodologies used for this assessment compared to previous assessments are discussed in detail in the Volume One report

The outputs of the assessment have been developed for use by KCDC to:

- inform the *Takutai Kāpiti* project in raising community awareness of the nature and extent of the hazards, and as input into decision making to identify the triggers and potential actions under dynamic adaptive planning pathways;
- development of future management strategies for council infrastructure and property located in areas susceptible to future coastal hazards; and
- to provide base hazard data for future District Plan change processes.

However, in any application of this assessment, it should be recognised that there remains a wide range of uncertainty and sensitivity in the results, particularly over longer timeframes, and for some uses, further analysis on risks from the hazard are required (e.g. for the review of coastal hazard planning provisions in the District Plan). It is also recognised that regular updates of the results should continue to be undertaken as the understanding of climate change science and coastal process effects evolves, and further data collection and trigger monitoring is undertaken.

The purpose of this Volume 2 report is to present the results of the coastal hazard susceptibility and vulnerability assessment for the range of relative sea level rises (RSLR) projected to occur over the future timeframes of 30, 50 and 100 years. The range of RSLR presented cover the lower and upper scenarios from the Ministry for the Environment (2017) *Coastal hazards guidance to local government* adjusted for the projected range of local vertical land movement (VLM), being:

- 0.2 – 0.4 m rise over the next 30 years (e.g. by 2050);
- 0.3 - 0.7 m rise over the next 50 years (e.g. by 2070); and
- 0.6 – 1.65 m over the next 100 years (e.g. by 2120).

Due to the wide range of the 100-year RSLR projections, two intermediate projections of 0.85 m and 1.25 m rise were also included, which correspond to RCP 4.5 and RCP 8.5 climate change scenarios respectively combined with mid-range VLM projections.

This report details these results for coastal erosion (8 assessment cells – Paekākāriki, Queen Elizabeth Park, Raumati, Paraparaumu, Waikanae, Peka Peka, Te Horo and Ōtaki) and inundation (4 assessment cells – Ōtaki and Te Horo; Peka Peka and Waimeha; Waikanae and Raumati; and Paekākāriki and Whareroa) using the methods detailed in the Volume 1 Methodology report.

The vulnerability assessment includes identifying the number land parcels and assets located within the area susceptible to the hazards for each timeframe, including:

- private and public land parcels;
- key council infrastructure (three waters, roads); and
- community services (schools, medical centres).

Appended to this report are the mapped outputs of the coastal erosion and inundation assessments.

Coastal Erosion Susceptibility and Vulnerability Assessment

A series of Projected Future Shoreline Positions (PFSP) have been developed to identify where the position of the shoreline could be in the future under various Relative Sea Level Rise (RSLR) scenarios and timeframes. The results in this report focus on the landward position of the 'most likely' PFSP, defined as being the position that has a 33% chance (P33) of being exceeded with the specified magnitude of RSLR within the specified timeframe. The mapping outputs also present a landward limit of the 'likely' PFSP, this being the position that has only a 10% likelihood of being exceeded for the specified RSLR and timeframe.

The coastal erosion mapping outputs show the areas susceptible to future hazard. Areas where the shoreline is projected to advance in the future (e.g. where historical shoreline accretion rates are projected to be greater than the erosional effects of RSLR and dynamic short-term storm effects) are therefore not mapped as future hazard areas, and only the 'present-day' hazard is shown. This occurs along most of the Kāpiti Coast shoreline north of the Waikanae River, where based on historical accretion rates (assuming no future changes in the sediment budget) we can be confident that under lower RSLR projections, some areas of shoreline will experience little to no erosion. Based on past erosion responses to significant storm events (e.g. September 1976), these present-day dynamic short-term storm effects are projected to 'most likely' (P33) be in the order of 8-14 m over the majority of the district, and potentially up to 24 m at Raumati with the failure of seawall structures.

The results of the coastal erosion assessment highlighted that the coastal processes acting on the northern and southern sections of the Kāpiti Coast shoreline are very different, and will therefore result in very different magnitudes of erosion distances over the next 30, 50 and 100 years within each of these sections (Figure 1).

Northern District (Paraparaumu to Ōtaki)

Under the assumption that the sediment budget does not change in the future, the northern section of the Kāpiti Coast (Paraparaumu to Ōtaki) could continue to be well supplied with sediment from longshore sources, which would allow for the beaches to continue to accrete into the future, with the shoreline generally only projected to erode beyond the present-day hazard under higher SLR scenarios within each of the 30-, 50- and 100-year timeframes.

The projected coastal erosion distances in the northern section of the Kāpiti Coast (Paraparaumu to Ōtaki) can be summarised as being:

- For the 30-year period (2050) highest RSLR scenario (0.4 m); projected shoreline erosion in the order of -10 to -30 m.
- For the 50-year period (2070) highest RSLR scenario (0.7 m); projected shoreline erosion in the order of -10 to -45 m.
- For the 100-year period (2120) highest RSLR scenario (1.65 m); the range of projected erosion distances increases from -35 m at Ōtaki to -105 m at Paraparaumu.

It is noted that even under these high SLR scenarios, areas within the Paraparaumu cell and Te Horo cell are projected to still continue to accrete, despite the erosional effects of SLR.

Southern District (Paekākāriki to Raumati)

In contrast, the southern part of the district (Paekākāriki to Raumati) has a sediment deficit due to the cuspate foreland at Paraparaumu acting as a natural groyne and deflecting bypassing sand offshore to form a broad flat offshore sand bank and restricting beach sediment supply.

The coastal environment of the Raumati and Paekākāriki Cells within this southern area are characterised by large lengths of ad hoc shoreline protection structures that have been built, replaced and maintained since the mid 1950's. Consideration of the presence and lifetime of these structures is included in the future shorelines projections assessment through using the residual life of a structure to determine when that structure could fail or need replacing. This ranges from 10-50 years.

In this assessment, it was assumed that following the maximum residual life of the structure it would not be replaced. Due to the sediment deficit along this section of the districts' shoreline, it is projected that following this time coastal erosion will recommence for the remaining timeframes under consideration. However, it is noted that the reality of this would depend on community recommendations and council decisions which could be formed through the outcomes of the *Takutai Kāpiti* project.

As a result of the long-term erosional trend, the range of projected future erosion distances are considerably different in the southern section of the Kāpiti District compared to the north. The projected erosion distances for the southern section can be summarised as being:

- For the 30-year period (2050) highest RSLR scenario (0.4 m); projected shoreline erosion distances range from -10 to -40 in Paekākāriki, -30 to -55 m at Raumati, and -60 to -70 across Queen Elizabeth Park.
- For the 50-year period (2070) highest RSLR scenario (0.7 m); projected shoreline erosion distances increase to being in the order of -30 to -50 m in Paekākāriki, -35 to -95 m at Raumati, and -100 to -115 m in Queen Elizabeth Park; and
- For the 100-year period (2120) highest RSLR scenario (1.65 m); projected shoreline erosion distances range from -70 to -120 m at Paekākāriki, -50 to -215 m at Raumati, and up to -215 to -245 m in Queen Elizabeth Park.

There are a number of public and private land parcels that are vulnerable to the future coastal erosion hazards. The total number of land parcels that intersect with the 'most likely' PFSP throughout the district are summarised in Figure 2.

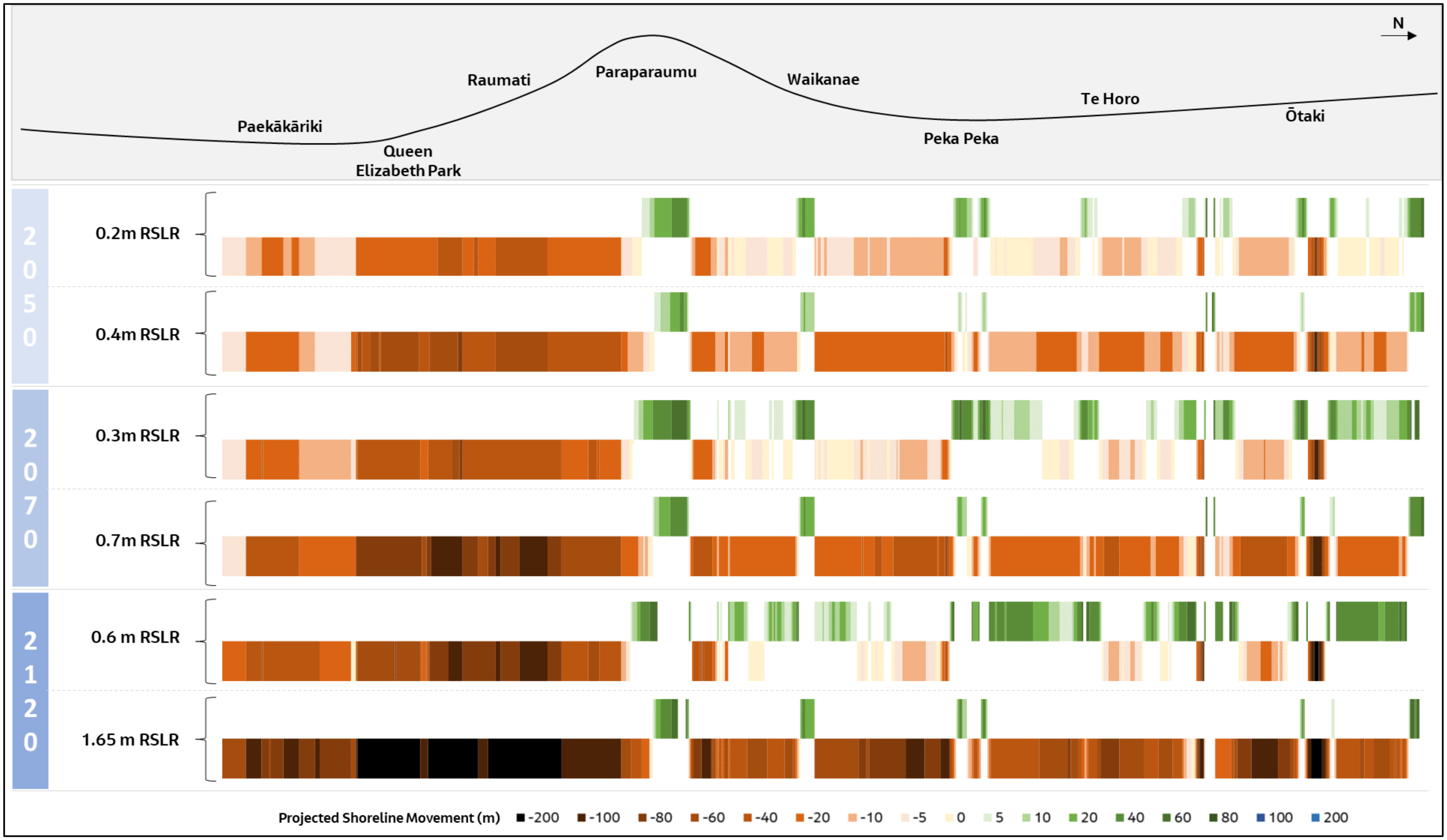


Figure 1: Summary of calculated erosion distances along the Kāpiti Coast shoreline for 30, 50 and 100 years.

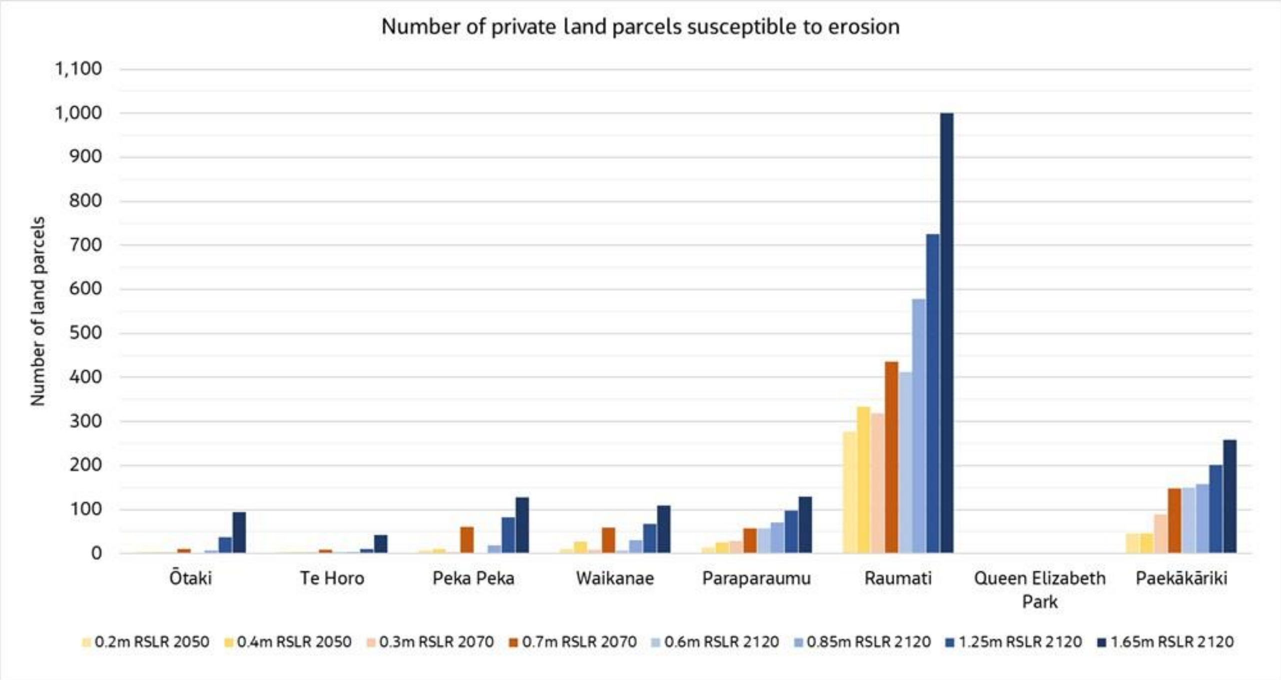


Figure 2: Summary of the total private land parcels (up to P90) that intersect with Projected Future Shoreline Positions (PFSP) across the entire Kāpiti Coast District.

Under the highest RSLR scenario, the number of private land parcels that intersect with the 'most likely' PFSP can be summarised as follows:

- For the 30-year period (2050 – 0.4 m RSLR), 449 private land parcels, of which 84% are located in the southern area of the district (Paekākāriki and Raumati).
- For the 50-year period (2070 - 0.7 m RSLR), 779 private land parcels, of which 75% are located in the southern area of the district.
- For the 100-year period (2120 - 1.65 m RSLR) 1762 private land parcels, of which 71% are located in the southern area of the district, with 56% of the total being located within the Raumati cell alone.

These results clearly indicate that the southern section of the Kāpiti Coast district is projected to be more vulnerable to coastal erosion. Based on the private property results for the highest RSLR scenario for a 100-year period (2120 – 1.65 m), Raumati is ranked the as having the highest vulnerability to coastal erosion (56% of total affected private land parcels), followed by Paekākāriki (15%), and Paraparaumu (8%). Based on this criteria, Ōtaki and Te Horo were ranked as being the least vulnerable coastal cells.

For council critical infrastructure and community services, the major potential impact of the projected coastal erosion is to coastal stormwater outfalls and roads running parallel to the coast. No schools, medical centres or hospitals were identified as being within PFSP's. The total length of assessed road that intersects with the most likely PFSP (P33) under the highest RSLR scenarios for:

- 30-year period (2050 - 0.4 m RSLR) is 2.3 km;
- 50-year period (2070 – 0.7 m RSLR) is 4.8 km; and
- 100-year period (2120 – 1.65 m RSLR) is 9.9 km.

Under the highest RSLR scenario for the 100-year period (1.65 m) the greatest total length of road potentially affected is in the Raumati cell (3.7 km), followed by Paekākāriki (3.6 km) and Ōtaki (1.8 km).

Coastal Inundation Susceptibility and Vulnerability Assessment

The coastal inundation assessment has identified areas which are potentially susceptible to inundation by the sea during a storm tide event with a 1% Annual Exceedance Probability (AEP) or 1% chance of occurring in any year. This inundation assessment uses a 'bathtub' approach to identify areas susceptible to coastal inundation at various magnitudes of RSLR in an extreme storm event.

The approach does not allow for the additional effects of heavy rain or high flow in the rivers along the coastline, which could occur at the same time as a storm tide. However, at the time of writing, updated flood hazard maps are currently being prepared by KCDC and Greater Wellington Regional Council (GWRC) using new hydrodynamic models, which will take account of the combined effects of rainfall, river flow and storm tide. The models will allow a more detailed investigation of combined sources of flooding if needed. These new dataset results are expected to be available at a later stage of the *Takutai Kāpiti* project.

The inundation maps appended to this report show all land susceptible to this probability of inundation at the present-day mean sea level, for RSLR values of:

- 0.4 m, 0.65 m, and 1.65 m (relating to the approximate upper bound projections of RSLR over the next 30, 50 and 100 years respectively); and
- 0.85 m and 1.25 m (relating to intermediate projections of RSLR in 100 years).

The inundation maps show areas which are susceptible to inundation both by overland flow directly from the sea and by flow paths from the sea along streams and rivers and the stormwater drainage network, including drainage pipes below the ground. For some of the areas identified in the maps, pathways to the sea may not currently exist in some of the RSLR scenarios considered. These areas could however be susceptible to coastal flooding if developed, for example, through the outfalls of drainage systems. Some of the susceptible areas shown on the maps are protected from coastal inundation by stopbanks, tidal flap gates or flapped stormwater outfalls but there is a residual susceptibility to inundation in the event of the failure of such measures. The mapping is based on the 'present-day' position of the shoreline and does not allow for any effect of future erosion or accretion of the shoreline on susceptibility to inundation.

As for the coastal erosion assessment, the results of the inundation assessment also show a difference in susceptibility between the northern and southern sections of the Kāpiti Coast:

- South of Paraparaumu Beach, ground levels inland of the shoreline are generally higher than the storm tide levels with RSLR to 100 years. Land susceptible to coastal inundation is limited to lower lying areas along the Wainui, Whareroa and Wharemauku Streams, Tikotu Creek and to low points along the coastline which drain to the sea through stormwater outfalls.

- From Paraparaumu Beach north to Ōtaki Beach, the area of land below storm tide level and susceptible to inundation becomes more extensive and increases with RSLR. While the ridges of dunes along the coastline prevent inundation by overland flow from the sea along most of this section of coastline, there are pathways for inundation of the low-lying inland areas where the numerous rivers and streams (the Waikanae River, Waimeha Stream, Te Kowhai Stream, Mangaone Stream, Ōtaki River and Waitohu Stream) bisect the dune ridge, and the drains and stormwater network that outfall to them.

The total numbers of public and private land parcels that intersect with the area mapped for a 1% AEP susceptibility to inundation are presented in Figure 3 together with the rate of increase in number of parcels between each value of RSLR considered.

Based on the number of land parcels which are partially or wholly susceptible to coastal inundation, the central section of the coastline, within the Waikanae - Raumati inundation cell, is the most vulnerable to inundation due to the extent of lower lying land and the number and density of individual land parcels in the coastal area. The southern section of the coastline, within the Paekākāriki - Whareroa inundation cell is the least vulnerable due to the higher ground levels and small number of land parcels in this section of the coastline. The results can be further summarised as follows:

- Under present-day sea level, the assessment indicates 857 land parcels are potentially susceptible to coastal inundation, of which 38% lie within each of the Waikanae - Raumati cell and the Ōtaki - Te Horo cell; 19% lie within the Peka Peka - Waimeha cell; and 5% lie within the Paekākāriki - Whareroa cell.

- For a RSLR of 0.4 m (30 to 50 years) the total number of potentially susceptible land parcels almost doubles to 1696; the proportion of parcels lying in the Waikanae - Raumati cell and the Peka Peka - Waimeha cell increases to 44% and 21% respectively; and the proportion of parcels lying in the Ōtaki - Te Horo cell and Paekākāriki - Whareroa cell reduces to 32% and 3% respectively.

- For a RSLR of 0.65 m (50 to 100 years) the relative proportions of susceptible parcels in each cell remains approximately the same but the total number of susceptible parcels increases to 2414, almost three times the number at present-day sea level.
- For a RSLR of 0.85 m and 1.25 m – intermediate estimates for 100 years – the total number of parcels potentially susceptible to inundation increases by 545 and 1668 respectively from the lower bound estimate of RSLR for 100 years. The largest increase is in the Waikanae - Raumati cell.

- For the highest RSLR considered – 1.65 m, an upper bound estimate for 100 years – the total number of susceptible parcels increases to 5130, six times the number at present-day. The greatest increase is in the Waikanae - Raumati cell where the number of parcels increases to 3000, over the half the total for all the cells.

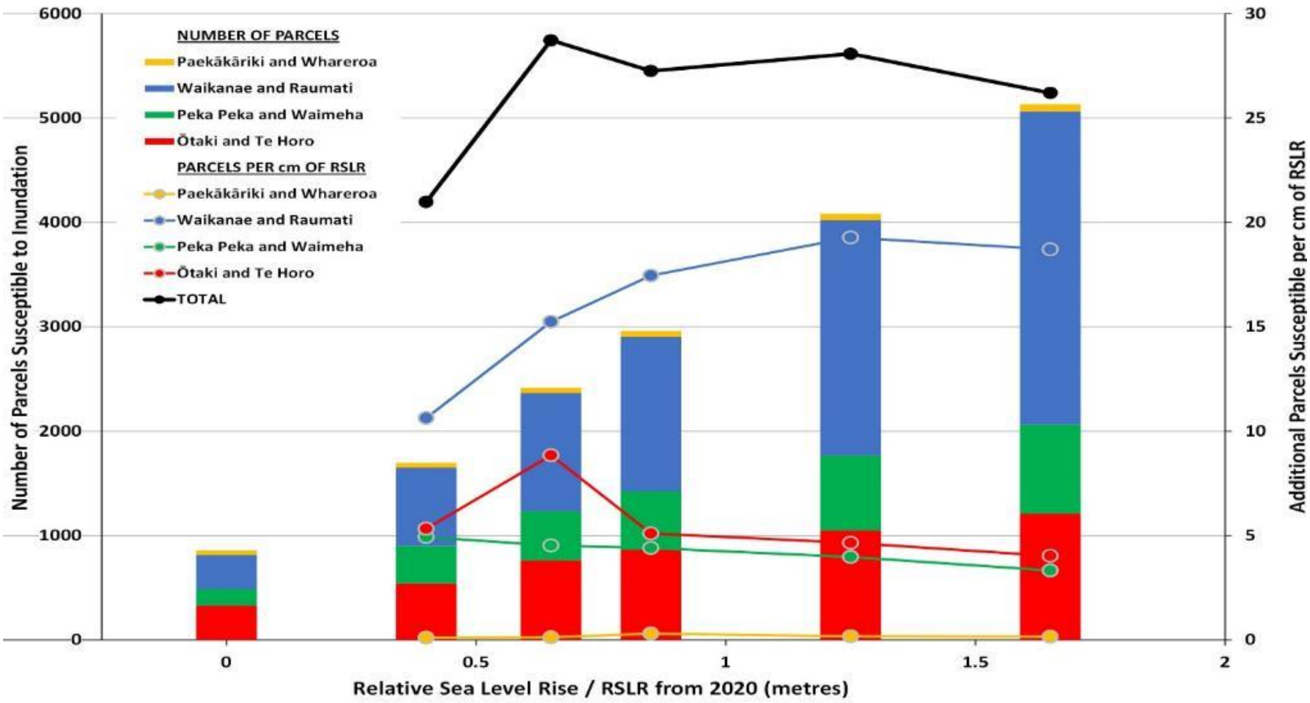


Figure 3: Chart showing the number of land parcels susceptible to inundation in each cell as bars (values on the left axis) and the change in number of parcels between each RSLR scenario considered, expressed as the number of additional parcels becoming susceptible per centimetre of RSLR, as lines (values on the right axis).

For RSLR values above 0.65 m, the total number of susceptible parcels increases at a relatively uniform rate of between approximately 26 to 29 additional parcels per centimetre of RSLR. The rate of increase in number of parcels in individual cells is largest for the Waikanae - Raumati coastal inundation cell.

The vulnerability assessment identified that the main infrastructure and services susceptible to potential inundation are stormwater pump stations, water supply bores and the principal roads which would provide routes for access to and evacuation of the coastal communities in a storm event. For most of the main access roads to the coast, extensive susceptibility to coastal inundation occurs only for the highest RSLR considered (1.65 m). Limited sections of these routes are susceptible for lower RSLR values. Minor routes and residential roads in the coastal communities are generally susceptible to inundation at lower RSLR values.

Contributions to coastal inundation from heavy rainfall and high river flows occurring in combination with a coastal event are not included in the assessment. Storm tides and RSLR will increase the extent of inundation from these types of storm event in coastal areas when they coincide. New flood models are being developed by KCDC and GWRC which will enable an assessment of the combined susceptibility to inundation. The models can also be used to provide a more detailed assessment of the extent of inundation by taking account of the capacity of the inundation pathways and connectivity with the sea.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to undertake a coastal hazard and risk assessment of the Kāpiti Coast District coastline in accordance with the scope of services set out in the contract between Jacobs and the Kāpiti Coast District Council ('the Client'). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate, or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Kāpiti Coast District Council and/or available in the public domain at the time or times outlined in this report. A site visit to key sites on the Kāpiti Coast was undertaken with key members of the Kāpiti Coast District Council staff, where anecdotal information on shoreline change and coastal structures was exchanged. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations, and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures, and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full, and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of, the Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

Glossary

Term	Definition
AEP	Annual Exceedance Probability. The probability expressed as a percentage that an event larger than the magnitude specified will occur in any one year.
ARI	Average Recurrence Interval. The average or expected time interval (e.g., years) between exceedances of a given event.
CED	Coastal Erosion Distance
Cell Boundary	The boundary between coastal erosion assessment cells used in this study.
CEPD	Coastal Erosion Prediction Distance. From Coastal Systems Limited (2008, 2012), being the distance that the open coast is predicted to erode in specified future timeframes.
Closure Slope	The slope of the beach profile from the dune height to the closure depth in the nearshore.
Composite Beach	A composite beach contains both sand and gravel, but is generally hydraulically sorted into two parts, with a gravelly backshore and a sand beach face and nearshore.
DS	Dune Stability
Dynamic equilibrium	Long-term fluctuations in the reference shoreline position about a static position
EPR	End Point Rate. Average rate of change in shoreline position calculated by dividing the difference in shoreline position (distance) from the first observation/measurement (usually aerial photograph or survey) to the last by the observation/measurement by the time period between the first and last observations/measurements.
Fluvial	Rivers and streams. Fluvial processes are those found or driven by rivers and streams.
GWRC	Greater Wellington Regional Council
Hs	Significant Wave Height. It is the height of the highest third of waves within a time series.
Hydrosystem	Includes river/stream mouths and estuaries where there is a coastal influence on the location and morphology of these environments.
IPCC	Intergovernmental Panel on Climate Change
KCDC	Kāpiti Coast District Council
LiDAR	Light Detection and Ranging. A remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth from measuring device, usually mounted on an aircraft or drone.
Likely	>66% probability of occurrence
LINZ	Land Information New Zealand

Term	Definition
Long-term accretion	Long-term beach growth which results in the reference shoreline moving in a seaward direction
Long-term retreat	Long-term erosion of the beach causing the reference shoreline to move landward
LRR	Linear Regression Rate. Average rate of change in shoreline position calculated by linear regression of all the observation/measurements of positions within the time period between the first and last observations/measurements.
MfE	Ministry for the Environment
MHWPS	Mean High Water Perigean Springs. The high tides that occur 6-8 times a year when the moon is either new or full and closest to the Earth, hence a stronger gravitational pull and higher tides than normal spring tides.
Monte Carlo Simulation	A mathematical technique used to estimate the possible outcomes of an uncertain event. It uses repeated sampling of a probability distribution to solve problems that might be deterministic in principle to create probabilistic outcomes.
Most Likely Shoreline Position	The most likely position that the shoreline will be over the proposed timeframe, calculated between the P33 and P66 probability of occurrence.
NZCPS	New Zealand Coastal Policy Statement released by the Department of Conservation in 2010. This a mandatory national policy statement under the Resource Management Act 1991.
PFSP	Projected Future Shoreline Position. General term used for the calculated shoreline position over the assessed time period.
Pluvial	Rainfall. Pluvial flooding is caused by increased rainfall.
Potential run-up overtopping areas	Areas where the beach dune or crest ridge is below the elevation of the estimated wave run-up in a 1% AEP coastal storm event. Beach overtopping could occur resulting in an increase in coastal inundation depth and/or extent.
Potential Shoreline Zone	Area between the P0 (present-day shoreline) and the very unlikely shoreline position (10% chance PFSP is landward of this position). It is considered that erosion beyond the landward limit of this zone is 'very unlikely' to occur.
'Present-day' erosion susceptibility	The magnitude of erosion that could occur should a 1% AEP storm occur. Is calculated from the addition of the short-term and dune stability components of the CED formula to determine the PFSP.
Reference shoreline position	The position on the shoreline taken as the reference point for all CED calculations. For unprotected shorelines, it is taken as the beach vegetation line on sand beaches, and the back of the gravel beach from the Ōtaki River to Te Horo. For shorelines protected by seawalls, is taken to be the position of these structures. This is taken from 2017 aerial imagery.
RCP	Representative Concentration Pathway. A greenhouse gas concentration trajectory adopted by the IPCC to describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases emitted in the years to come.
RMA	Resource Management Act 1991
RSLR	Relative Sea Level Rise. The total sea level rise from climate change and local vertical land movements relative to the level of the land.

Term	Definition
SLR	Sea Level Rise
SROCC	Special Report on the Ocean and Cryosphere in a Change Climate (IPCC, 2019).
Unlikely	< 33% probability of occurrence
Very Unlikely	< 10% probability of occurrence
VLM	Vertical Land Movement
WVD53	Wellington Vertical Datum 1953 (WVD53). This is the local Vertical Datum for land surveys established in 1953, in which zero elevation was set at MSL at the time. However, with sea level rise (SLR) since that time, the elevation of MSL for the 2005 -2011 period was established to be 0.196 m WVD53 and increased to 0.25 m WVD53 for the 2012-2018 period (Bosserelle and Lane, 2019).

1. Introduction

1.1 Purpose

As part of Phase one (hazard identification) of their "*Takutai Kāpiti: Our community led coastal adaptation project*", the Kāpiti Coast District Council (KCDC) have initiated a Coastal Hazard Susceptibility and Vulnerability Assessment for the whole 38 km of the Kāpiti Coast District coastline from Ōtaki in the north to Paekākāriki in the south (Figure 1.1). The purpose of this assessment is to update previous coastal hazard assessments undertaken along the KCDC shoreline involving the spatial extent of areas potentially susceptible to current and future coastal erosion and inundation hazards. Differences in the methodologies used for this assessment compared to previous assessments are discussed in detail in the Volume One report.

The outputs of the assessment have been developed for use by KCDC to:

- inform the *Takutai Kāpiti* project in raising community awareness of the nature and extent of the hazards, and as input into decision making to identify the triggers and potential actions under dynamic adaptive planning pathways;
- development of future management strategies for council infrastructure and property located in areas susceptible to future coastal hazards; and
- to provide base hazard data for future District Plan change processes.

However, in any application of this assessment, it should be recognised that there remains a wide range of uncertainty and sensitivity in the results, particularly over longer timeframes, and for some uses, further analysis on risks from the hazard are required (e.g. for the review of coastal hazard planning provisions in the District Plan). It is also recognised that regular updates of the results should continue to be undertaken as the understanding of climate change science and coastal process effects evolves, and further data collection and trigger monitoring is undertaken.

This assessment is reported in two volumes:

- Volume 1: Methodology; and
- Volume 2: Results (this report)

The purpose of the Volume 1 report was to summarize the coastal process environment operating along the Kāpiti Coast District and to present a detailed description of the methodology to be used in the assessment to quantify the spatial extent of the susceptibility and vulnerability to coastal erosion over timeframes of 30, 50 and 100 years in the future and to coastal inundation over 50 and 100-year timeframes. Since the release of the Volume 1 report of the methodology has been updated and altered sightly to deal with issues that have arisen in undertaking the assessment. These changes are included as an addendum to the Volume 1 report and are included in the methodology summary presented in this Volume 2 report.

The purpose of this Volume 2 report is to present the results of the coastal hazard susceptibility and vulnerability assessment for the various magnitudes of relative sea level rise (RSLR) projected to occur over the given future timeframes. The report details these results for coastal erosion and inundation for each of the assessment cells established in the methodology, drawing on all of the relevant available data on coastal processes and shoreline characteristics presented in the Volume 1 report to quantify the extent of the hazard susceptibility within each timeframe. The vulnerability assessment includes identifying the number of private and public land parcels, key council infrastructure (three waters, roads) and community services (schools, medical centres) located within the area susceptible to the hazards for each timeframe.

Appended to this results report are the map overlays of the spatial extent of the areas susceptible to each of the coastal hazards within the three timeframes. The areas susceptible to coastal erosion are defined by the Projected Future Shoreline Position (PFSP) for each timeframe. Also included on these hazard maps are the location of key council infrastructure and community services vulnerable to these hazards.

Figure 1.1: Overview of KCDC coastline covered in this coastal hazard susceptibility and vulnerability assessment.

These mapping outputs will be used by KCDC in the *Takutai Kāpiti*: *Coastal Adaptation Project* as baseline information for community awareness of hazard risk, and as input into decision making of triggers and actions under dynamic adaptive planning pathways. In addition, the mapping outputs form vital background information for the development of future coastal asset planning and management strategies, and for the review of coastal hazard planning provisions under the Kāpiti Coast District Plan.

This results report has been externally peer reviewed by Beca and Greater Wellington Regional Council, and statements of review are attached at the end of this report.

1.2 Definitions

Coastal Hazard:
In the context of this assessment, coastal hazards include current and future erosion and inundation due to actions of the sea, being the combination of sea level and waves. Therefore, projected future sea level rise (SLR) relative to the level of the land is a major consideration in the assessment of future coastal hazards. It is recognised that future SLR will also influence coastal groundwater levels and interact with downstream fluvial and coastal hinterland pluvial flooding, which may include the flood hazards from these sources. However, the bathtub inundation modelling approach adopted in this assessment do not include consideration of these interactions, as they are being addressed by a separate flood assessment currently being undertaken for KCDC.

Coastal Hazard Susceptibility:
Susceptibility is the likelihood of the hazard event occurring, covering both frequency of occurrence (incorporating consideration of duration and intensity of the event) and uncertainty of occurrence, and the spatial extent of the area affected by the erosion or inundation within specified timeframes. Therefore, SLR is a major driver of increasing susceptibility to hazard by increasing both the frequency of occurrence and/or the spatial extent affected.

Coastal Hazard Vulnerability:
Ministry for the Environment (MfE) (2017) defines vulnerability as the predisposition to be adversely affected and encompasses a variety of concept and elements including exposure, sensitivity or susceptibility to harm or damage from natural hazards, and degree of adaptive capacity of the natural and human system to accommodate change in the hazard exposure with minimum disruption or additional cost.

In this assessment we quantitatively assess the *vulnerability* of key council infrastructure (e.g., critical roads and three waters), and community services (e.g., schools, hospitals, medical centres) to the current and future exposure to coastal hazards. The evaluation of *adaptive capacity,* being consideration of the ability to accommodate and/or adapt to the hazards form part of the community engagement on adaptive planning pathways, which is Phase Two of the *Takutai Kāpiti* project.

It is noted that the original Scope of Works for the coastal hazard assessment referred to a ***Risk*** assessment. Risk is commonly defined to be *likelihood x consequence,* with the consequence component of the equation including the consideration of the full range of economic, social, cultural, and environmental consequences. Risk assessments also commonly include consideration of the above consequences on strategies and actions for dealing with the impacts of the hazards. However, consideration of this full range of these consequences and possible remediation/adaptation actions is both outside the scope of this assessment, and best considered in the Phase Two (community engagement) part of the *Takutai Kāpiti* project. Therefore, we have re-defined the assessment to be coastal hazard vulnerability rather than coastal hazard risk.

1.3 Statutory Framework

There is a strong statutory requirement for KCDC to assess the susceptibility and vulnerability of the district to coastal hazards, and to make decisions on how to manage these hazards in both current and future timeframes.

Under Section 31 of the RMA (1991) the functions of district councils include: *(b) "the control of any actual or potential effects of the use, development, or protection of land, including for the purpose of avoidance or* *mitigation of natural hazards"*. The management of significant risks from natural hazards is a *Matter of National Importance* under Section 6(h) and particular regard is to be paid to the effects of climate change under section 7(i).

The mandatory *New Zealand Coastal Policy Statement (NZCPS)* (2010), prepared under the RMA includes Objective 5 and Policies 24-27 in regard to coastal hazards. More detail around these objectives and policies are provided in Volume 1. However, it is noted that under Policy 24 of the NZCPS, the Identification of coastal hazards needs to take into account national guidance and the best available information on the likely effects of climate change on the region or district. This national guidance on the methodologies used in coastal hazard assessments is provided in the Ministry for the Environment (MfE, 2017) *Coastal Hazard and Climate Change Guidance for Local Government.*

Local authorities are required to give effect to the provisions of the NZCPS through their regional plans and policy statements and district plans. In relation to natural hazards, the *Greater Wellington Regional Policy Statement* (GWRPS 2013) includes objectives (19-21) and policies (29, 51-52) that KCDC must give effect to in their District Plan and other planning documents. The current coastal hazard provisions in the Kāpiti Coast District Plan involve the use of arbitrary fixed distance coastal building line restrictions in both residential and rural zones. These provisions are from the 1999 Operative District Plan and are considered by KCDC to be non-compliant with the requirements of the NZCPS and the GWRPS, hence the need for a Coastal Hazards Plan Change.

While the proposed RMA reform may change the over-arching legislation governing the operation of the NZCPS, it is assumed key NZCPS policies or similar will continue to shape the direction of coastal hazard identification and management under one or more of the proposed three replacement Acts[1].

1.4 Relationship with Ministry for the Environment (2017) Coastal Hazard Guidance

This national guidance provides a step-by-step approach to local government for assessing, planning, and managing the increasing hazard risks facing coastal communities. The guidance is structured around an iterative 10-step approach to secure and implement a long-term strategic planning and decision-making framework for the management of coastal areas already, or potentially in the future, affected by coastal hazards with climate change and SLR. This 10-step approach is shown in Figure 1.2, with the preparation of hazard assessments featuring in step 2, and vulnerability and risk assessments at step 4, and the development of adaptive planning strategies in steps 5-7.

The hazard identification methodologies employed in this assessment are consistent with those outlined in the *Coastal Hazard Guidance.*

As can be seen in Figure 1.2, at the core of the adaptive management approach is community engagement, to be involved at each step of the decision-making cycle, which is the essence of the *Takutai Kāpiti* project.

[1] From Press release from Minister of Environment, Hon David Parker, 10 February 2021: RMA to be repealed and replaced by Natural and Built Environment Act (NBA), Strategic Planning Act (SPA) and Climate change Adaptation Act (CAA).

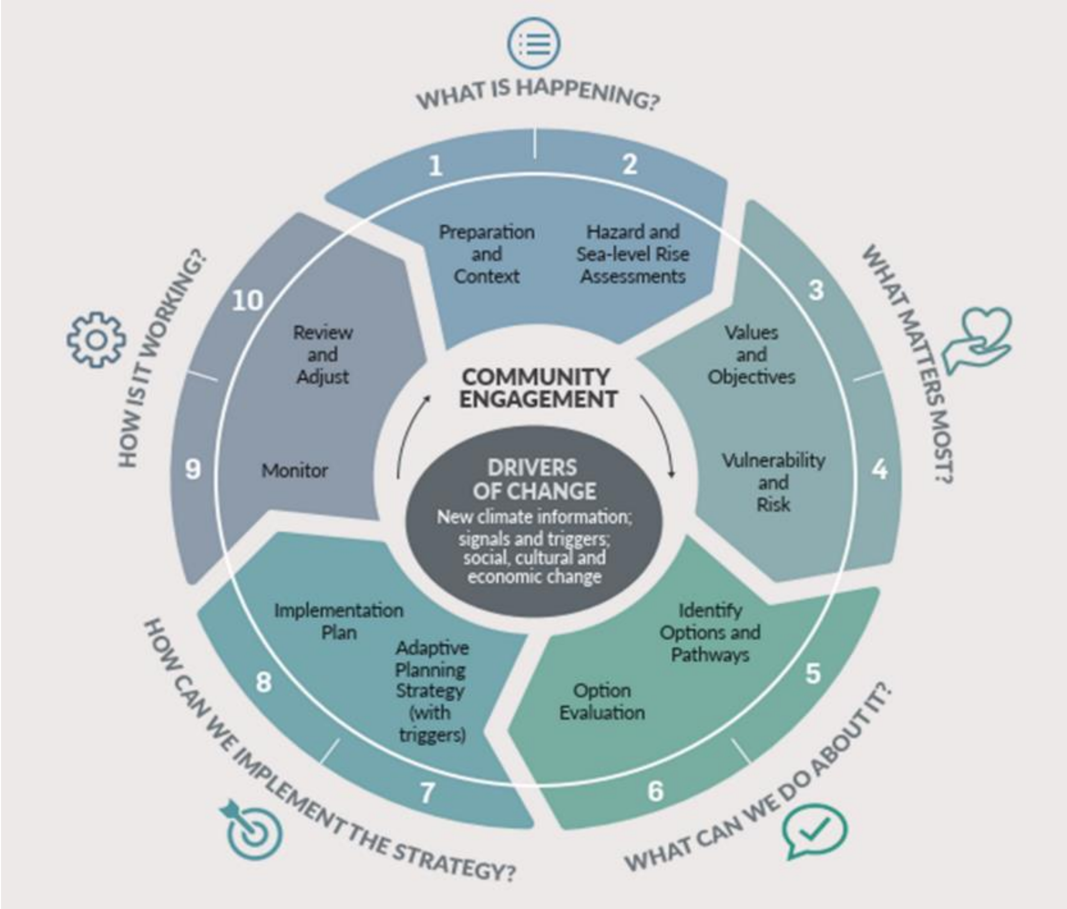


Figure 1.2: 10-step decision cycle for assessing, planning, and managing increasing hazard risks facing coastal communities. Source: MfE (2017).

1.5 Reporting Structure

The structure of this susceptibility and vulnerability results report is as follows:

- Section 2 provides an overview of the methods and approaches used in the assessment. This includes updates and alterations to the more detailed methodology provided in Volume 1.

Part One: Coastal Erosion Susceptibility and Vulnerability Results

This part of the report is written so that community members and groups interested in a specific coastal location only need to refer to the relevant section for that area, rather than the whole report.

- Sections 3-10 detail the coastal erosion assessment results for each of eight coastal cells from north (Ōtaki) to south (Paekākāriki) in turn. The location of these cells is shown in Figure 1.3.

- As set out in Volume 1, the division of the shoreline into these cells is in line with the GWRC Coastal Vulnerability Study (Mitchell Daysh, 2019), chosen to represent areas of similar coastal morphology, process, and presence of seawall structures. As shown in Figure 1.3, there are also 10 coastal hydrosystems (i.e., river/stream mouth areas) located along the Kāpiti Coast District shoreline, where the erosion susceptibility is assessed by different methodology. The erosion susceptibility and vulnerability results for these hydrosystems are also presented in sections 3-10 as a sub-section of the appropriate coastal cell.

- Section 11 provides a summary of the coastal erosion vulnerability assessment.

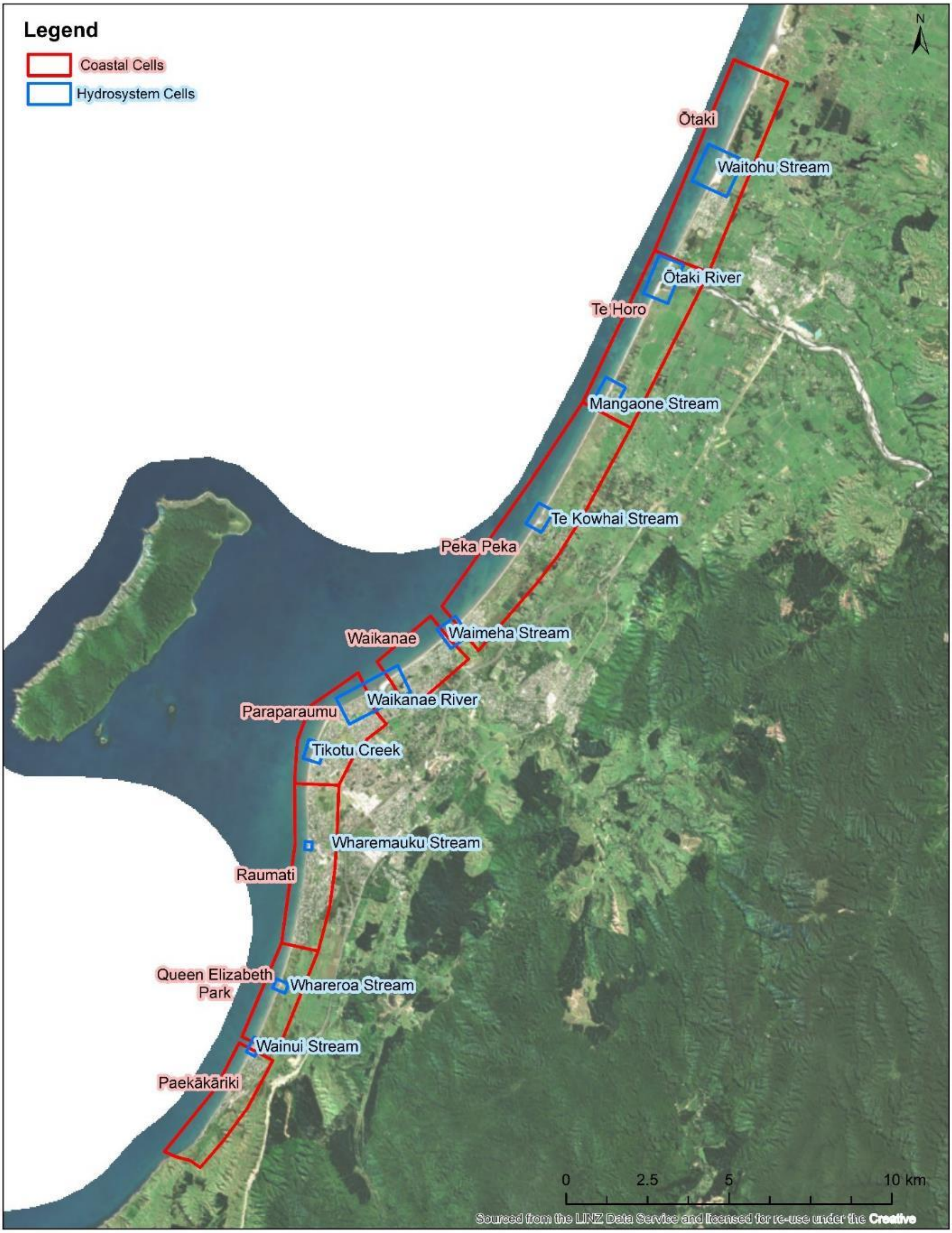


Figure 1.3: Coastal and hydrosystem cells for erosion assessment.

Part Two: Coastal Inundation Susceptibility and Vulnerability Results

- Sections 12-15 detail the coastal inundation assessment results for each of four inundation cells, being Ōtaki - Te Horo, Peka Peka - Waimeha, Waikanae - Raumati, and Paekākāriki - Whareroa. As set out in Volume 1, these cells have been defined by the following two main criteria, which allows each discrete storm tide level to be applied to a separate section of the coast without discontinuity in the mapped flood extent:
  - The locations of estimated inundation water levels by Lane et al (2012) in relation to the main inundation pathways (streams and rivers).
  - The approximate drainage catchment boundaries for the pathways.
- Section 16 provides a summary of the coastal inundation vulnerability assessment.

Part Three: Monitoring Recommendations

- Section 17 provides recommendations on the type and frequency of regular information gathering required to reduce uncertainties in future updates of the erosion and inundation modelling results and to inform the timing of action triggers under any future adaptative planning pathways.

Hazard Mapping Outputs:

- The coastal erosion hazard mapping outputs for the whole district coastline at a scale of 1:7500 are included in the following appendices:
  - Appendix A presents maps of the Projected Future Shoreline Position's (PFSP) in 2050;
  - Appendix B presents maps of the PFSP's in 2070;
  - Appendix C presents maps of the PFSP's in 2120; and
  - Appendix D presents maps of the potential hydrosystem extents for 2050, 2070 and 2120.

Within each appendix (A-C) the maps are numbered from north (Map 1) to south (Map 17).

- The coastal inundation hazard mapping outputs are presented for the whole district coastline at a scale of 1:10,000 (A3) in Appendix E (13 maps from north to south), each of which includes the potential inundation area for the six relative sea level rise scenarios applied in this assessment (0 m, 0.4 m, 0.65 m, 0.85 m, 1.25 m, and 1.65 m).

2. Methods Overview

The following sections provide a summary of the relative sea level rise (RSLR) projections, the methodology employed to quantify the areas susceptible to coastal erosion and inundation hazards under these RSLR projections, and methods to assist in assessing the vulnerability of land parcels, key council infrastructure and community services applied in this assessment. A full description of each of these methodologies can be found in Volume 1.

2.1 Relative Sea Level Rise Projections

Relative sea level rise (RSLR) is the combination of sea level rise (SLR) from global climate change (referred to as absolute rise), and local vertical land movements (VLM). Globally and within New Zealand, tidal records at major ports over the last 100-120 years indicate that sea level has been rising, with the rate of rise steadily increasing (IPCC, 2021, Hannah, 2016). Since the Wellington region is situated astride a complex network of tectonic faults associated with the subduction of the Pacific Plate under the Australian Plate, the region has a more complicated spatial and temporal pattern of long-term RSLR than other more stable parts of New Zealand.

From long-term tidal records at Wellington Harbour, Bell et al, (2018) reported that the rate of RSLR at Wellington averaged 2.28 ± 0.15 mm/yr over 119 years of record to 2017 and Denys et al (2020) reported an average of 2.18 mm/yr over a slightly shorter period to 2013. The analysis in Bell et al (2018) indicated that rates of RSLR had increased from an average of 0.72 mm/yr for the 62 years up to 1960, to an average of 2.74 ± 0.20 mm/yr for the period since 1961 to 2017, which equates to a RSLR order of 0.16 m ± 0.1 since 1961. This magnitude of rise is greater than experienced at the other main New Zealand ports with long-term records (e.g. Auckland, Lyttleton, Dunedin) (Hannah, 2016, Denys et al, 2020), and is at a higher rate than the global rise of 2.3 ± 0.7 mm/yr in the period from 1971 to 2018 (IPCC, 2021).

The future rate of RSLR will play an important role in the extent, frequency and magnitude of future coastal erosion and inundation. The SLR projections due to climate change used in this assessment are the national projections provided by MfE (2017), which are based on IPCC (2013) projections under four global greenhouse gas emissions scenarios with a local New Zealand SLR adjustment. Up to very recently these scenarios were referred to as Representative Concentration Pathways (RCP[2]). In the most recent IPCC AR6 climate change assessment released in August 2021, the make-up of these scenarios has changed to include Shared Socio-economic Pathways (SSP's[3]). Our assessment is based on the MfE (2017) guidance, and therefore refers to the RCP scenarios, with an adjustment in the SLR projections of 0.1 m by 2100 for the increases given in the IPCC (2019) report as a result of a better understanding of the contribution that the melting of the Antarctic Ice Sheet will have on SLR. This increase in SLR has been incorporated in the recent IPCC 2021 projections, however, the new SSP projections for New Zealand were not available at the time of modelling for our assessment[4]. We are confident that the range of SLR projections used in this assessment do cover the updated range of projections presented in AR6.

The recent IPCC (2021) report states that there is a high confidence that VLM will remain a major driver of RSLR in tectonically active locations; therefore, it is important that it is included in the assessment. However, it is recognised that there is considerable uncertainty in future patterns and rates of this component of RSLR. Analysis of VLM in the Wellington region by Bell et al (2018) concluded that "*It is difficult to provide a definitive long-term trend of VLM for any site in the Wellington region, largely due to the effects and ongoing influences on crustal movement of the recent earthquake events since 2013,* and *"that the deformation in this region is complex and is likely to remain so in the future*". To this can be added that the record of measured VLM rates only cover the last 10-20 years. However, there is no reason to expect that the regional long-term trend of subsidence being driven by the Australian-Pacific Plate subduction is going to stop. Based on the measured rates

[2] Representative Concentration Pathway (RCP) refers to the concentration of greenhouse gas under in the atmosphere under different emission scenarios, with the number label denoting the value of radiative forcing (W/m^2) in 2100 under each scenario

[3] Shared Scio-economic Pathways ((SSP) are scenarios of socioeconomic global change up to 2100 used to derive greenhouse gas emission scenarios under different global climate policies. As with the RCP's, the final number label denotes the value of radiative forcing (W/m^2) in 2100 under each scenario.

[4] Updated New Zealand projections from AR6 are likely to be available by mid 2022 (NZ SeaRise project).

of VLM over the last 10 - 20 years for sites in Paekākāriki, Kāpiti and Levin, an assumed range of -1 to -3 mm/yr has been applied for the projections of RSLR along the Kāpiti Coast in this assessment, with -1 mm/yr being applied to the lower SLR projection (RCP2.6), and -3 mm/yr being applied to the highest SLR projection (RCP8.5+) to cover the total range of RSLR possibilities. It is understood that the proposed updated New Zealand SLR projections due around mid-2022 (NZ SeaRise project) will include local VLM around the whole coast at around 2 km intervals.

It is important to recognise that the IPCC do not assign likelihoods to any of the climate change or SLR scenarios in any of their reports, and that projections are presented as median values within a likely range due to large number uncertainties in the processes and feedback loops. Many of the likely ranges overlay across the scenarios; for example, the median SSP5-8.5 SLR still falls within the likely range of SLR under the SSP2-4.5 scenario. Due to the uncertainty in both the timing and magnitude of future RSLR, the guidance given in MfE (2017) is that the full range of projections should be presented.

While the recent IPCC AR6 (2021 report) does indicate that the likelihood of high emission scenarios such as RCP8.5 or SSP5-8.5 that are dependent on fossil-fuelled development could be considered low due to limitations in the coal reserves required to generate the required emission levels, the falling cost of clean energy alternatives, and not including allowance for emission reduction policies in their storylines, it also states that "*the default* [greenhouse gas] *concentrations aligned with RCP 8.5 or SSP5-8.5 and resulting climate futures derived by ESMs*[5] *could be reached by lower emission trajectories than RCP 8.5 or SSP5-8.5*". New Zealand's leading scientist on SLR projections, Dr. Rob Bell *(pers com Nov 2021*), has indicated that there is no plan to drop RCP8.5 (or SSP5-8.5 equivalent) scenarios from the updated New Zealand SLR projections to be released in mid-2022 as this scenario and RCP8.5H+ represents the runaway polar ice sheet instabilities, which are now accepted as having a tipping point somewhere approaching a 2° C rise in temperature since the pre-Industrial era. It is noted that for RCP8.5 sea level rise scenario, this temperature rise is predicted by IPCC AR6 (2021) to occur around 2050 under a mid-range SSP2-4.5 scenario. Dr. Bell (*pers com*) also indicated that due to time lags in sea level response, even if we stopped emissions now resulting in air temperatures stabilising over coming decades, over 1 m of SLR is already locked in. MfE (2021) *Guide to local climate risk assessment* recommends that RCP8.5 is one of the two climate change scenarios to assess risk against (the other is RCP4.5). For these reasons, the RCP8.5 scenario is included in the assessment as one of the higher scenarios presented.

MfE (2017) also includes a more extreme RCP 8.5H+[6] scenario, which has a more rapid and higher SLR than the medium confidence IPCC (2013, 2021) projections, but is similar to the SSP5-8.5 low 50th percentile low confidence[7] scenario from IPCC AR6 (2021). MfE (2017) state that function of the RCP8.5H+ scenario is to "*stress test adaptation plans where the risk tolerance is low and/or future adaptation options are limited, and for setting an SLR for green-fields development where the foreseeable risk is to be avoided.*" Given the existing nature of the Kāpiti coast (protected and green-fields areas), it is therefore appropriate that this scenario is included in the range of scenarios presented in this assessment, as it defines the potential shortest timeframe that an any adaptation plan, policy, or action may be effective. This scenario with -3 mm of VLM forms the upper scenario considered in this assessment.

The resulting range of RSLR projections for Kāpiti coast combining both climate change and VLM are shown in Figure 2.1, which highlights the increasing uncertainty in the projections over time. The lower projections at each time frame cover the RCP2.6 scenario with VLM of -1 mm/yr, while the upper projections cover the RCP8.5H+ scenario with VLM of -3 mm/yr. As outlined above, this is to ensure that a total range of possible RSLR scenarios for adaptive planning is presented in the assessment. The projections for the three future timeframes (2050, 2070, 2120) applied in this assessment are shown by the black squares and also presented in Table 2.1, which as shown cover the upper and lower RSLR projections to be considered. Due to the large range of the 2120 RSLR projections, two intermediate projections are also included in the assessment, which broadly align with the

[5] Earth System Models, i.e. a coupled climate model that explicitly models the movement of carbon through the earth system.
[6] Is the 83rd percentile of the RCP8.5 scenario.
[7] 'Medium' and 'low' confidence scenarios is in relation to the process inputs into the SLR rise models, not the likelihood of the scenario itself. The 'low' confidence scenario confidence model represents deep uncertainty around how process associated with ice sheet melt will respond (IPCC 2021).

RCP4.5 and RCP8.5 scenarios with a -2mm/yr of VLM and are the two scenarios recommended to be considered in climate change risk assessments (MfE, 2021).

It is recognised that there is uncertainty in the time when these selected magnitudes of RSLR may occur. For example, from Figure 2.1 it can be seen that a 0.2 m RSLR projected for 2050 may occur as early as 2036 or as late as 2062, and a 0.6 m RSLR projected to occur in 2070 may occur as early as 2063 or as late as 2148. It is therefore important that the planning for coastal hazard adaptation options considers trigger levels for action based on magnitudes of RSLR rather than timeframes. It is also important to recognise that RSLR will continue beyond the longest timeframe used in this assessment (100 years until 2120), with RCP8.5H+ scenarios of greater than 2 m rise by 2150 regardless of the rate of VLM.

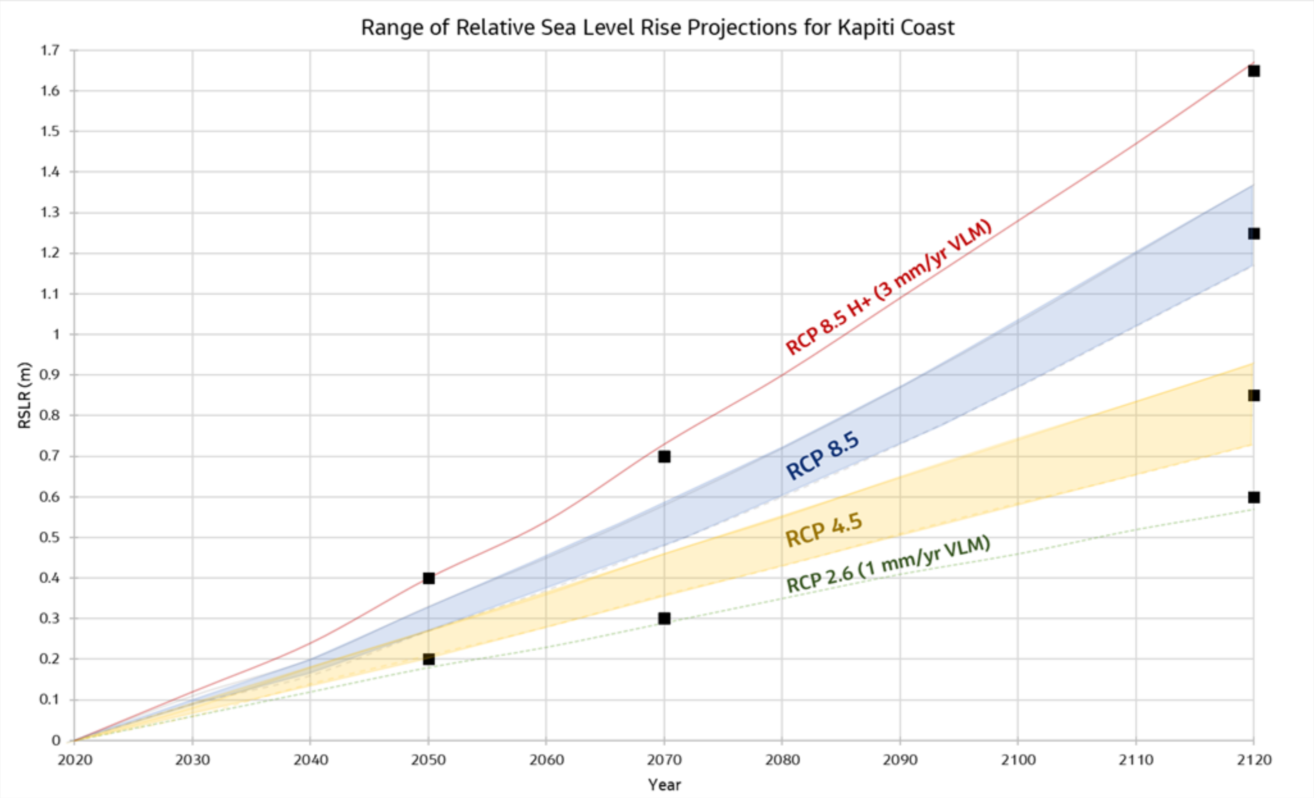


Figure 2.1: RSLR projections for the Kāpiti coast from a 2020 base level incorporating climate change scenarios and local Vertical Land Movement (VLM). The projections used in this assessment for the timeframes of 2050, 2070, and 2120 are shown by the black squares. The range of projections under the RCP4.5 and RCP8.5 scenarios cover VLM of -1 to -3 mm/yr.

Table 2.1: RSLR projections from 2020 used in this coastal hazard assessment.

Year	Lower Projection of RSLR since 2020	Intermediate Projection of RSLR since 2020	Upper Projection of RSLR since 2020
2050	0.20 m		0.40 m
2070	0.30 m (Erosion) 0.40 m (Inundation) (1)		0.70 m (Erosion) 0.65 m (Inundation)[1]
2120	0.60 m (Erosion) 0.65 m (Inundation) (1)	0.85 m, 1.25 m	1.65 m

[1]For erosion, both the value of RSLR and the time over which it occurs are important, whereas inundation depends mainly on the value of RSLR regardless of the timing. For assessing inundation, five incremental RSLR values have been selected which encompass representative projections of RSLR for the four climate change scenarios at the dates for which erosion hazards have been assessed. For example, the inundation for an RSLR value of 0.4 m is representative of hazard for an "upper bound" (RCP

8.5H+) projection of RSLR in 2050 or a "lower bound" (RCP 2.6M) projection of RSLR in 2070. 0.6m is the lower bound for 2120 RCP2.6, and 0.7m is the upper bound for 2070 RCP8.5+, so 0.65m has been taken as the mid-point to be representative of both for inundation purposes.

2.2 Coastal Erosion Methodology

2.2.1 General Approach – open coasts

The general approach used in this assessment to produce mapped open coast Projected Future Shoreline Positions (PFSP) for pre-determined increments of RSLR is a standard best practice approach involving the calculation of coastal erosion distances from the combination of four potential erosion components by the following formula:

CED = (LT x T) + SL + DS + ST

Where:

CED = coastal Erosion Distance to the PFSP;

LT = past Long-term rate of shoreline movement;

T = the time frames over which the past long-term rates are extrapolated in the future. For this assessment these are set at 30, 50, and 100 years;

SL = erosion due to future accelerated RSLR for selected range of rise over the above timeframes;

DS = dune stability factor; and

ST = short-term storm erosion.

This approach is consistent with the requirements of Policy 24 of the NZCPS: *Identification of coastal hazards* and with the best practice recommendations in MfE (2017) *Coastal Hazard and climate Change Guidance to Local Government* and Ramsay et al (2012) *Defining coastal hazard zones for setback lines: A guide to good practice.* The methodology to determine each of the components of the erosion hazard equation, which are briefly summarised below, also addressed as far as possible the limitations in the previous Coastal Systems Limited (CSL) (2008 and 2012) hazard assessments as identified by the expert peer review panel to the 2012 assessment (Carley et al, 2014). More details on previous assessments and the peer review panel findings are presented in Volume 1 (section 5).

Figure 2.2 presents a conceptual schematic of how the four components combine to determine the future coastal erosion hazard susceptibility for unprotected shorelines, which make up 80% of the Kāpiti Coast District's coastline.

However, for the remaining 20% (Paekākāriki, Raumati, and parts of Paraparaumu), seawalls that have been present in various forms since the 1950's have had a large influence on past and present rates of shoreline movement and will continue to do so as sea level continues to rise. Thus, the presence of seawalls has been taken into account in the erosion assessment by assuming that the structures will remain in place and functional until they reach their residual life as determined from the KCDC coastal structures database[8]. At this time the structures are assumed to fail, be removed and not replaced, with the coast transiting back to a natural shoreline with natural erosion processes recommencing. Further details of the decision making and process around how the structures are included in the assessment of future erosion are included in Volume 1 (Section 6.1.1). However, it is noted that any consideration of decisions around the cost benefit of maintaining existing structures or replacement with new structures is beyond the scope of this assessment.

A 'Present-day' erosion susceptibility is also calculated using the short-term and dune stability factor components to show the magnitude of erosion that could occur if a 1% AEP coastal storm event were to occur

[8] KCDC coastal structures database prepared by Tonkin and Taylor (2016) and updated in 2021 for Raumati structures.

with the shoreline in its current position. For coasts currently protected by seawalls, the present-day hazard (short-term + stability factor) is the erosion that could occur if the structure failed in the storm event.

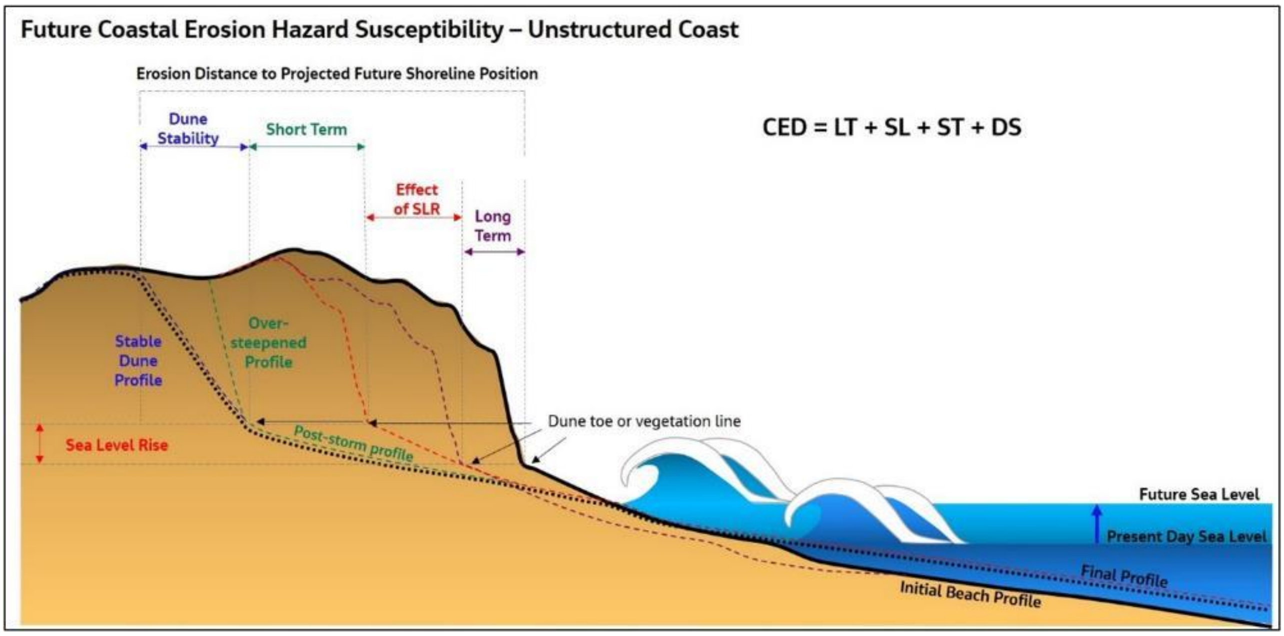


Figure 2.2: Conceptual diagram of components calculated for future coastal erosion hazard susceptibility on an unstructured coast.

2.2.2 Extrapolation of past long-term shoreline movements (LT)

The location of past open coast shorelines, being identified as the vegetation line, dune line, back of gravel beach, or seawall position, were determined from 6-8 aerial imagery dates at around 10-year intervals between 1948 and 2017 (see Volume 1, Table 6.2 for all dates). This close to 70-year record is considered sufficient to cover a range of decadal variations in erosion drivers (waves, water levels, variations in sediment supply) and the significant storm events in 1954, 1957, 1976 (2), 1980, and 1994 (2). The GIS based Digital Shoreline Analysis System (DSAS) tool was applied to the digitized reference shorelines to calculate the net shoreline change and linear regression rates of the shoreline movements since 1948 at 760 transects at 50 m intervals along the entire coast of the district (see Volume 1, Appendix C for the location of these transects).

For sensitivity checking, the DSAS results from the 1998 to 2017 period for relevant transects were checked against the movements of the 3 m contour (which due to a lack of attribute data is taken as a proxy for dune toe and hence also assumed to be the vegetation line) from beach profile surveys (Appendix F) at unprotected sites, which are limited to a similar period. Importantly, the results of this sensitivity checking showed that both the DSAS and the profile data showed the shoreline movements being in the same direction for all 14 profile sites tested (e.g. both accretion or both erosion), with the differences in the magnitudes of movement at 50% of the sites being less than 10 m. Due to the difficulty in accurately digitising shorelines, and the use of a standard proxy from the surveys, there results are considered to be acceptable. The beach profile data analysis also examined the relationship of the shoreline position changes to beach volume changes, for input into cell-by-cell sediment budget calculations presented in Appendix H.

It is recognised that these past rates of shoreline movement included the effects of contemporary sea level rise, which for accreting coasts would have reduced the rate of advance due to sediment supply, and for eroding coasts would have increased the rate of retreat. These rates of past shoreline movement, including the effect of contemporary sea level rise, were then extrapolated for 30, 50, and 100 years into the future.

For shoreline sections where a seawall structure was present and consequently had zero shoreline movement 'post-structure', there is a need for a 'non-structure' rate to extrapolate future shoreline erosion as the coastline develops a new equilibrium after the removal of structures that have reached the end of their life. The common approach of using the shoreline change from an adjacent un-modified section of coast was not practical for the Raumati and Paekākāriki shoreline cells due to the continuous length of seawall structures. Therefore, for these cells, a 'pre-structure' rate obtained from the CSL (2008 & 2012) assessment was used for the future extrapolation following the end of the residual life of the structure.

Further details of the methodology used to extrapolate past rates of shoreline movement are included in Volume 1 (Section 6.3), with the limitations of the methodology being presented in Section 6.9.3 of that report.

2.2.3 Effect of Future Accelerated Sea Level Rise (SL)

A key point in the consideration of the erosion effects of future RSLR is to only deal with the potential effects of future accelerated rise, and not 'double accounting' of the contemporary rates of rise that are already included in the extrapolation of historical long-term shoreline movements. In this assessment, this is dealt with by discounting the future rate of RSLR over the specified time frames by the known contemporary SLR, so that the potential effects are limited to only those associated with the future rate of RSLR. The alternative method of calculating the effect of the absolute future RSLR and discounting the long-term rate of shoreline for the effects of contemporary RSLR produces similar combined distances of future shoreline change.

The resulting rates of future accelerated rates of rise above contemporary rates of rise for each magnitude of absolute RSLR applied in each timeframe for unprotected sections of the shoreline are presented in Table 2.2. For protected sections of shoreline, the extrapolation of long-term historical rates is taken from shoreline movements pre-structures (e.g. pre-1948), where pre-1950 the rate of RSLR was 0.73 mm/yr (Bell et al, 2018). This rate has been used to discount the future rate of RSLR at modified sites to account for the smaller amount of RSLR captured in the historical extrapolation for the long-term. Due to this historical SLR rate being lower, the resulting discounted rate for future RSRL is higher as shown in Table 2.3. The discounted RSLR magnitudes are only for the calculation of the erosion hazard and should not be used for other purposes.

For sand beaches a standardized 'Bruun Rule' (Bruun,1962) approach was used to determine sand beach retreat for the RSLR projections presented in Table 2.1 for the 30-, 50- and 100-year timeframes. Although this method is widely used in the international literature and is recommended in MfE (2017), it is also widely recognized as having limitations. The model involves the assumptions of conservation of an equilibrium profile shape with the volume eroded seaward from the beach being that required to raise the nearshore profile out to the closure depth for cross-shore sediment transport by the same vertical increase as the increase of SLR, with the resulting horizontal shoreline retreat being dependent on the closure slope from dune crest to the closure depth. The beach profiles used to determine the range of crest heights and beach slope input parameters for the sea level rise component are presented in Appendix F. Closure depths were calculated using Hallermeiers (1981) equation with the wave input parameters from MetOcean (2007), with nearshore distance to this depth being measured from offshore profiles presented by Lumsden (2003) and re-produced in Appendix G.

Table 2.2: Discounted rates of RSLR used in the erosion calculations for unprotected sections of shoreline to avoid double accounting for contemporary rates.

Time Frame	Magnitude of Absolute RSLR	Absolute Rate of RSLR	Discounted rate of RSLR[(1)]	Discounted magnitude of RSLR
2050	0.2 m	6.67 mm/yr	3.93 mm/yr	0.12 m
	0.4 m	13.33 mm/yr	10.59 mm/yr	0.32 m
2070	0.3 m	6.00 mm/yr	3.26 mm/yr	0.16 m
	0.7 m	14.00 mm/yr	11.26 mm/yr	0.56 m
2120	0.6 m	6.00 mm/yr	3.26 mm/yr	0.33 m
	0.85 m	8.50 mm/yr	5.76 mm/yr	0.58m
	1.25 m	12.50 mm/yr	9.76 mm/yr	0.98 m
	1.65 m	16.50 mm/yr	13.76 mm/yr	1.38 m
Note (1): Discounted for contemporary rate of RSLR: 2.74 mm/yr (Bell et al, 2018)				

Table 2.3: Discounted rates of RSLR used in the erosion calculations for protected sections of shoreline to avoid double accounting for contemporary rates.

Time Frame	Magnitude of Absolute RSLR	Absolute Rate of RSLR	Discounted rate of RSLR[(1)]	Discounted magnitude of RSLR
2050	0.2 m	6.67 mm/yr	5.95 mm/yr	0.18 m
	0.4 m	13.33 mm/yr	12.61 mm/yr	0.38 m
2070	0.3 m	6.00 mm/yr	5.28 mm/yr	0.26 m
	0.7 m	14.00 mm/yr	13.28 mm/yr	0.66 m
2120	0.6 m	6.00 mm/yr	5.28 mm/yr	0.53 m
	0.85 m	8.50 mm/yr	7.78 mm/yr	0.78m
	1.25 m	12.50 mm/yr	11.78 mm/yr	1.18 m
	1.65 m	16.50 mm/yr	14.78 mm/yr	1.47 m
Note (1): Discounted for 1891 - 1960 of RSLR: 0.72mm/yr (Bell et al, 2018)				

Further details of the use of the Bruun Rule, the input parameters, and limitations are included in Volume 1 (Section 6.4.1), with further limitations of the methodology presented in Section 6.9.4 of that report. It is noted that one of the major limitations cited about the Bruun rule is that it does not include consideration of longshore transport inputs/losses or plan shape controls. Both of these limitations are overcome in this assessment by the combination of the Bruun rule results with the historical shoreline change results from the DSAS transects that include the horizontal shoreline response to sediment inputs/losses and plan shape controls at 50 m spacing.

As a sensitivity test, the theoretical volumes of beach loss due to RSLR over the 70 years of the DSAS were included in the cell-by-cell sediment budget presented in Appendix H to see if these were reasonable from a sediment budget perspective, in that the volumes moving between cells could be reasonably explained by the coastal processes operating.

A modification to the original Bruun Rule was required to assess the potential effect of RSLR on the composite beach in the Ōtaki River to Te Horo coastal cell, using an approach developed by Jacobs (2020) for similar beach types on the Canterbury coast. Further details of the modifications are included in Volume 1 (Section 6.4.2).

2.2.4 Short-term Storm Erosion (ST)

For this assessment, the spatial distribution of short-term storm erosion is based on the observations noted by Gibb and Wilshere (1976) for the September 1976 storm, which was classified by Lane et al (2012) as being close to a 0.5% AEP joint wave and storm tide event. Details of these observed erosion distances are presented in section 6.5 of Volume 1, and limitations of the methods presented in Section 6.9.5 of that report.

2.2.5 Dune Stability Factor (DS)

The dune stability (DS) factor delineates the area potentially susceptible to erosion landward of the erosion scarp. The parameter assumes that storm erosion results in an over-steepened dune scarp which must adjust to a more stable slope for the beach sediment land parcels. For this assessment, dune stability was calculated using a standard industry practice formula based on the "slope replacement theory of cohesionless sand" (Clark and Small, 1982), which is dependent on the height of the dune and the angle of repose of the loose sand. The range of dune heights input parameters are from the beach profiles presented in Appendix F, and angle of repose for loose sand was taken to be in the range 30 to 34 degrees.

The dune stability factor was not applied in the Te Horo cell due to the presence of a composite mixed sand and gravel beach, within which the low gravel crest barrier retreats by rollover rather than dune scarp formation.

Further details on the dune stability factor are included in Volume 1 (Section 6.6), with limitations of the methodology presented in Section 6.9.6 of that report.

2.2.6 Probabilistic Approach

There are three sources of uncertainty in predicting the position of future shorelines with sea level rise:

1. The uncertainty in the magnitude of RSLR within specified timeframes (or the timeframes for specified magnitudes of RSLR). Uncertainty is dealt with by adopting scenarios of RSLR that cover the current best estimates of the likely range of magnitudes of rise over the three timeframes of 30, 50 and 100 years.

2. The uncertainty from limitations in the methods used to estimate the coastal process and shoreline response to RSLR. It is not possible to quantify this uncertainty.

3. The uncertainty and limitations in the data used in the above methods to quantify the projected future shoreline movements. This uncertainty is quantified by a probabilistic approach involving applying probability distributions to each of the input parameters used to calculate each of the components of the CED calculation. Such an approach is a best practise industry standard, which is recommended in the MfE (2017) *Coastal Hazard and climate Change Guidance to Local Government*.

Under this approach, a range of values from a triangular distribution (e.g. lower bound, mean, and upper bound) for each input parameter within the erosion component calculations are applied to a 'Monte Carlo' simulation to obtain 10,000 random values (termed realisations or observations) for each erosion component. The lower, mean, and upper bounds of the resulting distribution of values for each erosion component for homogenesis transects within each coastal assessment cell are presented in Appendix I.

The combination of the corresponding random values for each of the erosion component results in a distribution of 10,000 values of the possible CED from the current shoreline position to the PFSP, from which probabilities of occurrence are calculated. Figure 2.3 shows the CED distribution for a theoretical transect, where the bars represent the number of realizations from the 10,000 trials and the red line represents the cumulative probability that the erosion distance will be exceeded along with annotations of the 'likelihood rating' associated with specific probabilities from MfE (2017). Therefore, the probabilities decrease with distance from the current shoreline position, as there is decreasing likelihood that erosion will reach or exceed this position with the specified magnitude of SLR within the specified timeframe. Hence for the same SLR magnitude and timeframe, we can be more certain that erosion will reach the positions with higher probabilities, and less certain it will reach the positions with lower probabilities.

From this distribution, the following two probability scenarios for the PFSP have been developed to help guide future discussions on dynamic adaptive planning pathways and coastal asset planning:

- A 'most likely' scenario, being the range of positions that the PFSP has between 33-66% probability of being located in for the specified magnitude of RSLR over the given timeframe. In this report this range is termed as P33-P66, with the P33 position representing the PFSP that has a 33% probability of being located further landward for the specified magnitude of RSLR over the given timeframe. PFSPs beyond this location are considered to be 'unlikely'.
- A 'very unlikely' scenario, being the position that there is a 10% probability of the future shoreline being in this position or further landward for the specified magnitude of RSLR over the given timeframe. In this report this position is termed as P10.

As shown in Figure 2.3, these scenarios are consistent with the terminology of likelihoods recommended by MfE (2017, Appendix C), with the 'very unlikely' position being the landward limit of the 'likely' range of positions.

More details on the probability approach are included in Volume 1 (Section 6.2), with limitations of the approach presented in Section 6.9.2 of that report.

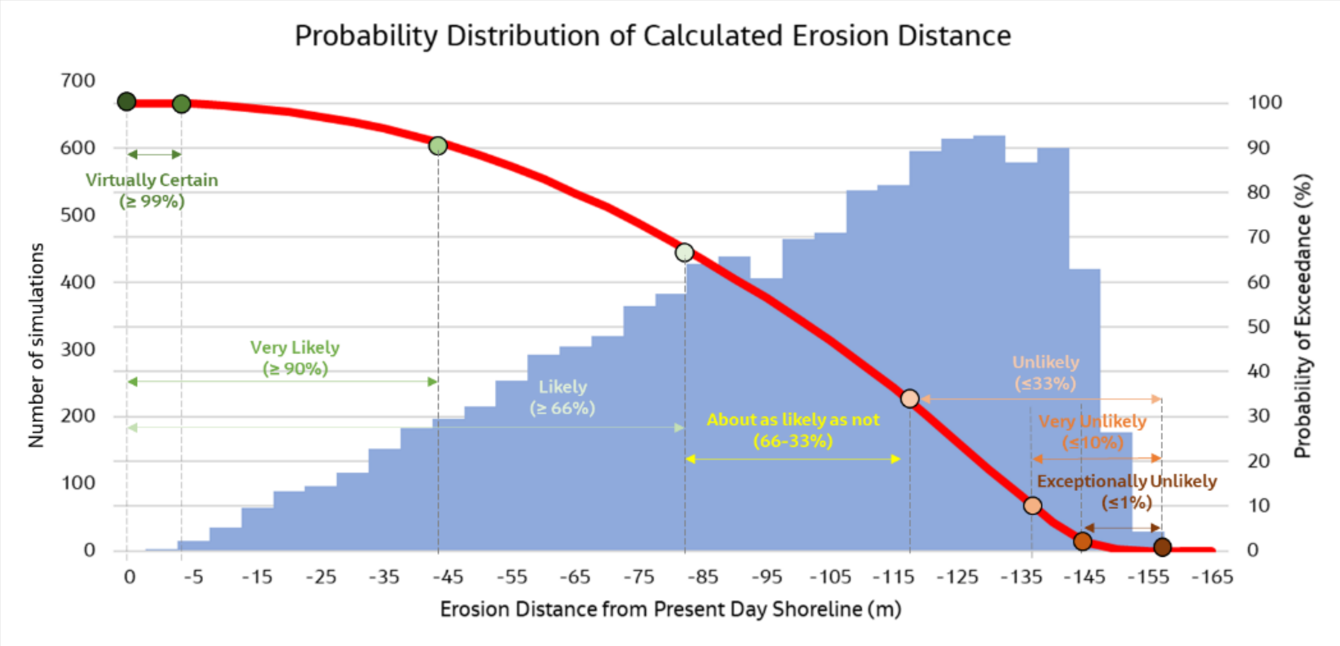


Figure 2.3: Example of Probability distribution of CED from present-day shoreline. The bars represent the number of realisations from the 10,000 trials and the red line represents the cumulative probabily that the erosion distance will be exceeded.

2.2.7 Hydrosystems (River/Stream mouths)

As shown in Figure 1.3, there are also ten coastal hydrosystems (i.e. river/stream mouth areas) located along the Kāpiti Coast District shoreline, where the erosion susceptibility is assessed by a different methodology. A different methodology was required for these environments as the open coast erosion components could not be applied in the same way with any confidence along hydrosystems due to different and complex processes occurring in these environments. For example, there was very poor long-term linear regression rates of shoreline change (i.e. very low R^2 values) due to the influence of river mouth mitigation. In line with the the 2014 expert panel review comments (Carley et al, 2014), each hydrosystem has been assessed individually with consideration of the following factors:

- The position of the mouth environment in relation to the adjacent future shoreline position;
- The topography and elevation of the land surrounding the mouth environment;
- The conservation of area and volume of the available water ponding within the mouth environment;
- The relationship of the future width and depth of the mouth throat to its current position; and
- The occurrence of structures and assumptions around their future existence.

Based on the individual responses for each hydrosystem to these considerations, we developed a decision tree approach for determining how the future position of each mouth inlet would be assessed, resulting in four assessment methods being developed to account for the different hydrosystem characteristics. An overview of the decision tree approach is presented in Figure 2.4, with details on each assessment method being presented in Volume 1 (Section 6.7).

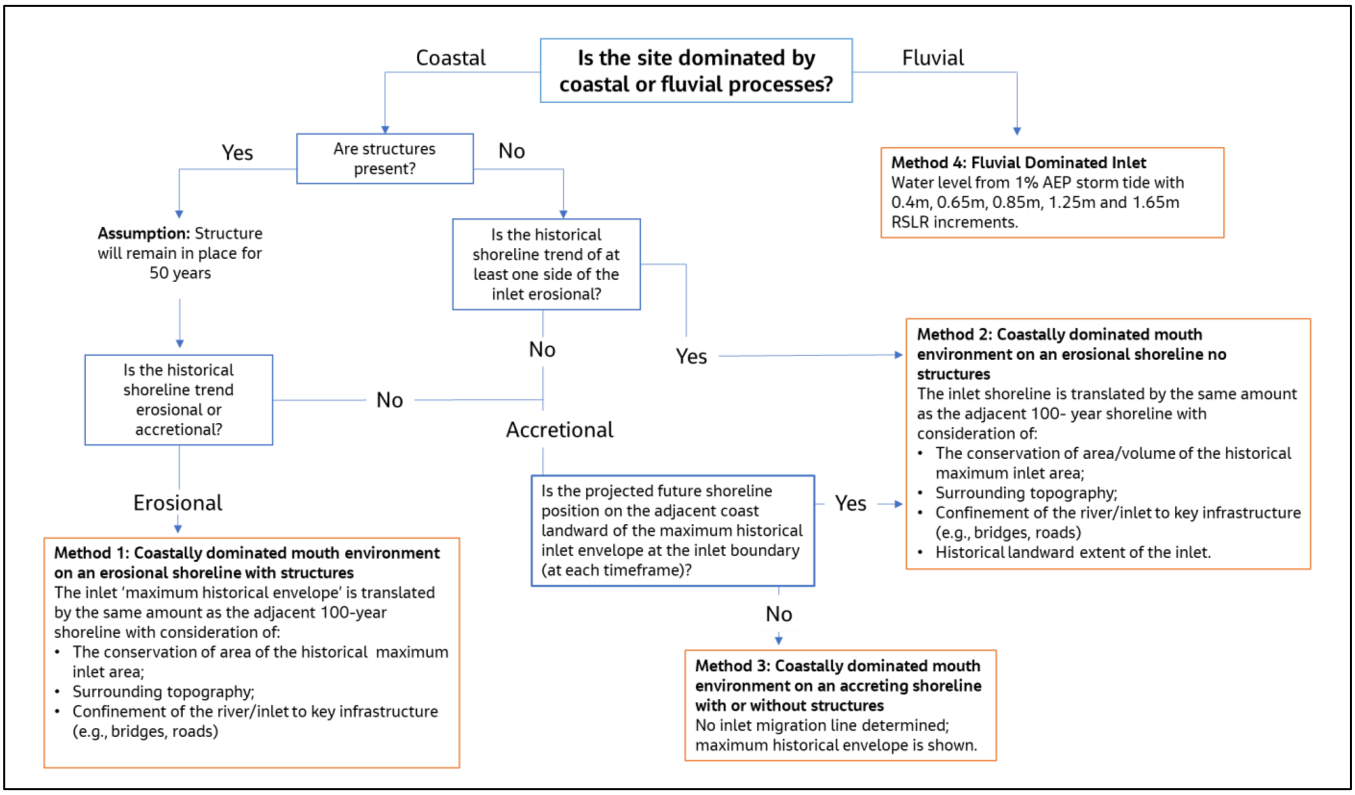


Figure 2.4: Decision tree for applying appropriate method to each Hydrosystem (e.g. river/stream mouth) environment.

Following the decision tree approach, a range of 'Hydrosystem Extents' were developed for each of the river/stream mouth locations for each timeframe and RSLR scenario. Although these zones are subjective based on the considerations above, they indicate the extent of potential longshore migration of the river/stream mouth in the future, with the landward extent of the zone being the anticipated maximum landward position of the hydrosystem environment. Due to the more subjective nature of defining these future migration areas, we are less confident with the position of these shorelines than the PFSP calculated for the open coast.

It is recognised that at hydrosystems on accreting sections of coast where Method 3 is the adopted approach, there are some discontinuities between the open coast shoreline PFSP and the hydrosystem cell PFSP. This is due to the historical envelope of the hydrosystem from the aerial photographs having been used to represent the maximum potential future landward extent based on the assumption that it has been in this position before. However, since the adjacent open coast shoreline has shown an historically accreting trend, the calculated future erosion distances are reduced, therefore resulting in a discontinuity of the PFSP between the hydrosystem cell and open coast cell. It is recognised that this is a conservative approach but is considered appropriate for use in the adaptive planning decision making, however further investigation and refinement should be undertaken for use of these extents in any district plan provisions.

2.2.8 Mapping Outputs

For the mapping outputs, a transparent layer is presented to show the range of PFSP's that could occur for the given RSLR scenario and timeframe up to the 'very unlikely' position, for which there is only a 10% probability of being reached or exceeded. In the report this is referred to as the P10, and on the mapping output this transparent layer is presented as the '10-99%' shoreline range.

A more solid band shows the range of shoreline positions that are 'most likely' to occur, being those that have a 33% to 66% likelihood of where the PFSP could be over a defined RSLR scenario and timeframe. There is a 33% probability that the PFSP will be located landward of the band (e.g. more erosion), and 33% probability that it will be seaward of the band (e.g. less erosion).

The projected shoreline position is calculated from a 'smoothed' present-day reference shoreline, which for mapping purposes has had small changes in the orientation of the shoreline smoothed out (e.g. corners of walls, sand dune blow outs). Once the probabilistic outputs were plotted, these were reviewed to determine where there were any discontinuities along the future shoreline, and further investigation was undertaken to determine why these discontinuities had occurred. These discontinuities generally occurred at the cell boundaries, in association with a change in discrete profile inputs being used for calculations. Where necessary, PFSP between known data input locations were smoothed to remove abrupt changes in PFSP orientations which were unlikely to occur in nature. For example, across the Raumati and Paraparaumu cell boundary there was a prominent change in PFSP distances due to the RSLR component inputs (as a result of the bathymetry of the nearshore profile). PFSP distances were smoothed between the two beach profile locations to represent that there was a gradual rather than abrupt longshore change between profiles which would affect the PFSP. In general, this reduced the erosion distances of PFSP when undertaken.

2.3 Coastal Inundation Methodology

Our approach in assessing susceptibility and vulnerability to coastal inundation is to make use of existing data to provide an initial assessment of the area most likely to be affected by flooding from coastal storms for a range of potential RSLR scenarios that are consistent with those used in the coastal erosion assessment. The existing flood hazard model assessments for the district all have limitations in how far they address the needs of this *Takutai Kāpiti* project. In order to provide an initial assessment of coastal flood hazard that overcomes some of these limitations, we have used a simpler "bathtub" method to produce new coastal flood maps. However, it should be noted that new flood models being developed by KCDC are expected to become available during the course of the project. These new models will allow a more detailed simulation of the combined flooding from coastal storms, pluvial and fluvial events and can be used to further support the development of adaptation pathways as required.

2.3.1 **The "Bathtub" method**

In this method, a digital elevation model (DEM) of the ground surface is used to map all areas of ground which lie below a given sea level. For our assessment we have used ground level data from the 2017 KCDC LiDAR aerial survey. The sea levels considered in the method are defined by the storm tide level, including wave setup, and allowances for future rises in the mean level of the sea.

This method maps all land which is potentially susceptible to inundation by the sea, however the method does not explicitly take account of inundation pathways. The resulting maps show all land below the sea level considered, including areas which are not currently directly connected to the sea by overland flow paths. In some cases, these areas are connected to the sea by streams and rivers which flow into the sea or by the stormwater drainage network, including drainage pipes below the ground as well as open channels, which discharge into streams and rivers or directly to the sea. In other cases, pathways may not currently exist, but these areas could become vulnerable to coastal flooding if developed, for example, due to the effect of the rising sea level on groundwater levels or on impeding drainage at stormwater outfalls.

The bathtub method does not take account of defences such as stop banks or tidal flap gates (or other backflow prevention measures) on stormwater outfalls. In this way the mapping includes areas with a residual vulnerability to inundation in the event of the failure of such defences. The method is based on the topography of the coastline at the time of the 2017 LiDAR survey and the scenarios we have mapped do not include the effect of any erosion or accretion of the coastline that may occur in the future

The effect of extreme sea level on coincident rainfall and high river flows cannot be considered explicitly in the bathtub method. Elevated water level in the sea, streams, or rivers due to coastal storms can increase pluvial and fluvial flooding if they coincide. Although the bathtub method cannot provide an assessment of the combined effect of multiple coincident sources of flood hazard, the mapping provides a complete initial assessment of the land potentially vulnerable to coastal inundation over a range of future sea level rise scenarios. The new flood models developed by KCDC will then allow further investigation of combined flooding where needed.

2.3.2 Extreme sea levels

In our assessment we have only considered the 1% AEP storm tide levels because:

(1) flood hazards are defined in the District Plan Maps by the 1% AEP event;

(2) estimates of the 1% AEP storm tide level are available from previous detailed tide and wave modelling; and

(3) the difference between the 1% AEP storm tide level and the level for other AEPs is small in comparison to the differences in projected RSLR for the scenarios we are considering.

We have adopted the 1% AEP storm tide levels at shore, including wave setup, derived from Lane et al (2012) at the locations along the Kāpiti coast indicated in Figure 2.5 and as presented in Table 24. The levels in Table 2.4 also include adjustment of the MSL to 2020 levels. The wave setup included in these estimates was derived for the open coast, whereas the primary inundation pathways along the Kāpiti coast are through river mouths where wave setup tends to be less, therefore these estimates are likely to be somewhat conservative.

Table 2.4: Current 1% AEP extreme sea levels at shore.

Location	1% AEP extreme water level at shore (storm tide + wave set-up) relative to WVD53 (2005-11) Source: Lane et al (2012, Table 3-3)	1% AEP extreme water level at shore (storm tide + wave set-up) relative to WVD53 (2020)
Ōtaki North	2.38 m	2.43 m
Waikanae Beach	2.26 m	2.31 m
Paraparaumu Beach	2.09 m	2.14 m
Raumati Beach	2.09 m	2.14 m
Paekākāriki	2.09 m	2.14 m

2.3.3 Sea level rise scenarios

In addition to present-day sea level, representative scenarios for the following five magnitudes of RSLR have been considered in this assessment, covering time frames of 2050, 2070 and 2120:

- RSLR of 0.40 m; being approximately the upper projection of rise by 2050 (RCP 8.5H+ projection +VLM) and the lower projection of rise by 2070 (RCP2.6M).
- RSLR of 0.65 m; being approximately the upper projection of rise by 2070 (RCP 8.5H+ plus VLM) and the lower projection of rise by 2120 (RCP2.6 medium projection plus VLM).
- RSLR of 0.85 m; being a lower intermediate projection of rise by 2120 (approximately RCP4.5 medium projection plus VLM).
- RSLR of 1.25 m; being a higher intermediate projection of rise by 2120 (approximately RCP8.5 medium projection plus VLM).
- RSLR of 1.65 m; being approximately the upper projection of rise by 2120 (RCP8.5+ projection plus VLM).

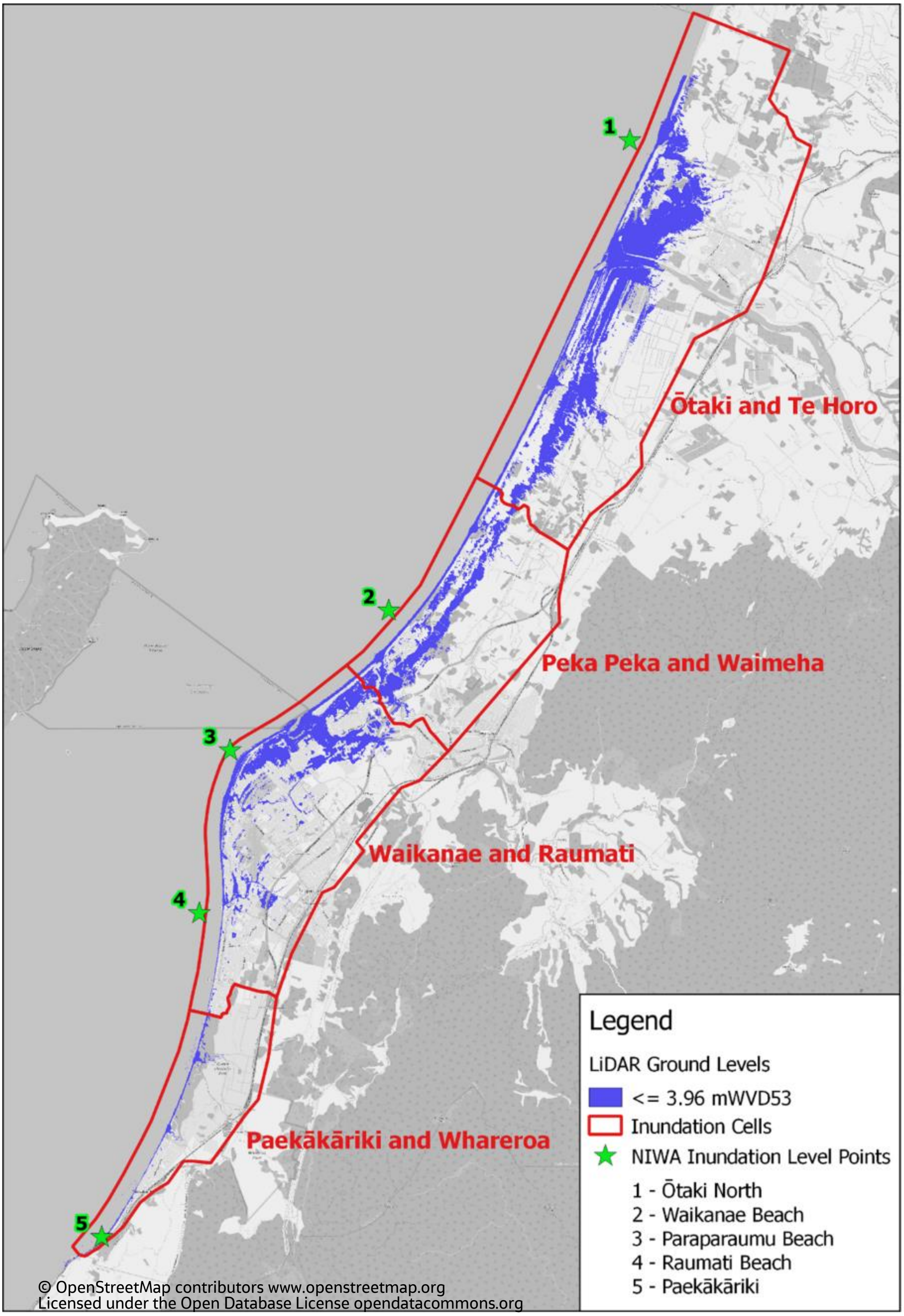


Figure 2.5: Areas of land potentially susceptible to coastal inundation hazard over a 100-year period (i.e. ground level lower than 3.96 m WVD-53). The coastal inundation cells considered in this project and the location of points at which sea levels for inundation assessment were previously derived by NIWA (Lane et al, 2012).

2.3.4 Definition of inundation cells

Figure 2.5 shows the four inundation cells considered in our assessment. The cells have been defined by two main criteria:

- The locations of estimated inundation water levels by Lane et al (2012) in relation to the main inundation pathways (streams and rivers); and
- The approximate drainage catchment boundaries for the pathways.

This allows each discrete storm tide level to be applied to a separate section of the coast without discontinuity in the mapped flood extent using the bathtub method. The "Ōtaki and Te Horo" cell covers the inundation pathways to which the Ōtaki North storm tide level applies and the "Peka Peka and Waimeha" cell covers inundation pathways to which the Waikanae Beach storm tide level applies. The storm tide levels at the three remaining points (Paraparaumu Beach, Raumati Beach and Paekākāriki) are the same and the remaining section of the district is split between the largely urban area in the "Waikanae and Raumati" cell and the largely rural area in "Paekākāriki and Whareroa" cell.

2.3.5 Wave runup and overtopping assessment

The purpose of including an element of wave run-up in the inundation assessment was to identify potential areas where run-up has the potential to overtop the dune of beach ridge and therefore result in an additional contribution to the inundation resulting from the storm tide. The assessment is limited to identification of locations where this could occur based on the calculated wave runup levels for present-day beach elevations and slopes. However, the effect of this run-up overtopping has not been quantified in terms of increased water depths or spatial extent of flooding.

The 2017 LiDAR DEM was used to determine the shoreline areas along the entire coastline where the dune/structure elevation and immediate hinterland is below the combined storm tide level and run-up height presented in Table 2.4 (from Lane et al, 2012) (except for Te Horo, where the results from Lane are rejected and the re-calculated estimated maximum run-up level of 2.77 m from the September 1976 storm is used). These areas are defined as "potential run-up overtopping" areas. Areas which had been identified in the initial bathtub assessment as being inundated, and then identified as having an additional inundation pathway via runup, are delineated on the inundation maps to show that runup and overtopping could increase the inundation depth and extent at this area beyond that resulting from the static tide level. Figure 2.6 illustrates the method graphically.

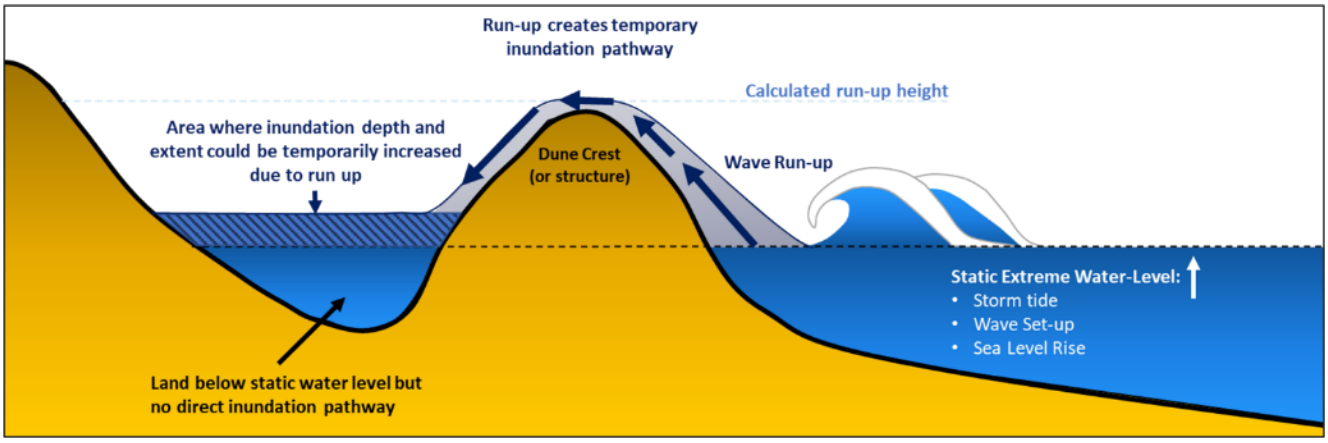


Figure 2.6: Schematic showing how run-up has been incorporated in the bathtub assessment. Areas from the bathtub mapping have been identified as being potentially affected by an increase in inundation depth and spatial extent where an inundation pathway has been created via run-up.

Table 2.5 shows the resulting run-up levels calculated for each of the inundation cells. It should be noted that the September 1976 storm run-up heights (which are generally the largest of the 13 storms considered in that study) have been combined with the representative September 1994 storm 1% AEP storm tide level (including wave setup) for which the wave height (and therefore run-up) were lower than the 1976 storm. Therefore, the estimated run-up levels are potentially conservative.

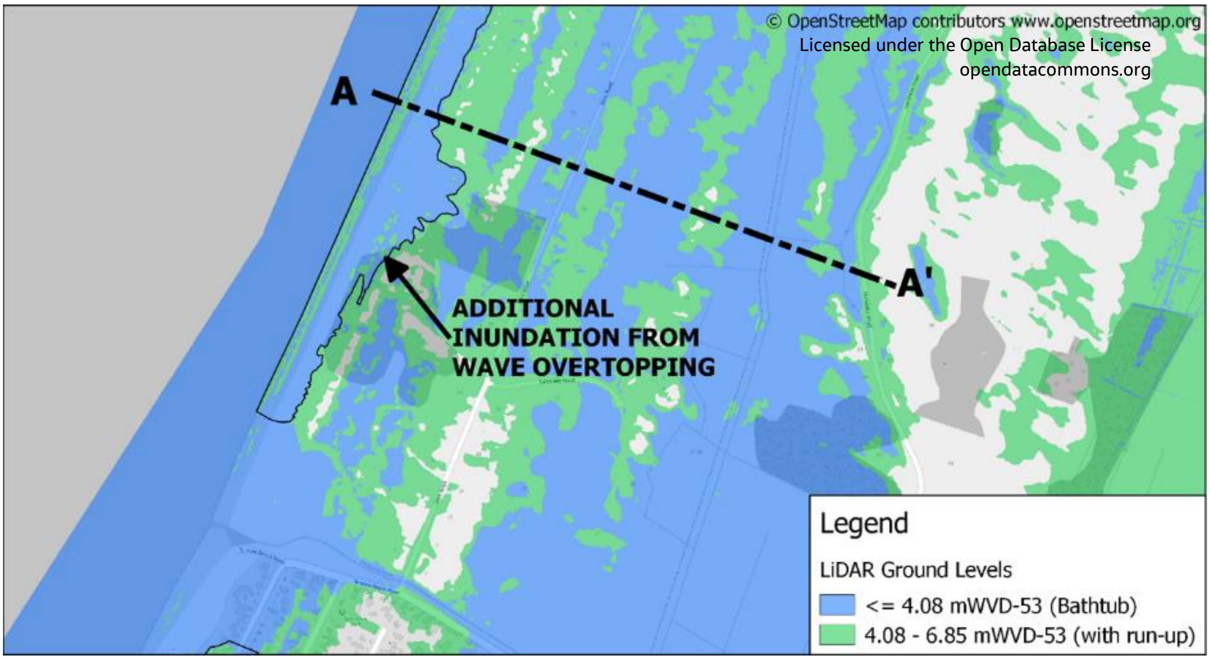
Table 2.5: Estimated wave run-up heights and levels for 1% AEP storm.

Location of run-up height calculation[1]	Run-up height[2] (m)	Applicable inundation cell (or area thereof)	Location of storm tide calculation[4]	1% AEP water level (m WVD-53)						
				Storm tide without RSLR or run-up	Storm tide with RSLR and run-up					
					RSLR 0 m	RSLR 0.4 m	RSLR 0.65 m	RSLR 0.85 m	RSLR 1.25 m	RSLR 1.65 m
Ōtaki Beach	1.09	Ōtaki and Te Horo (north of Ōtaki River)	Ōtaki North	2.43	3.52	3.92	4.17	4.37	4.77	5.17
Te Horo	2.77[3]	Ōtaki and Te Horo (south of Ōtaki River)	Ōtaki North	2.43	5.2	5.6	5.85	6.05	6.45	6.85
Waikanae	1.35	Peka Peka and Waimeha	Waikanae Beach	2.31	3.66	4.06	4.31	4.51	4.91	5.31
Paraparaumu	0.38	Waikanae and Raumati (north of Tikotu Creek)	Paraparaumu Beach	2.14	2.52	2.92	3.17	3.37	3.77	4.17
Raumati	0.65	Waikanae and Raumati (south of Tikotu Creek)	Raumati Beach	2.14	2.79	3.19	3.44	3.64	4.04	4.44
Paekākāriki	1.09	Paekākāriki and Whareroa	Paekākāriki	2.14	3.23	3.63	3.88	4.08	4.48	4.88

Notes:
[1, 2]As per Table B-2 of Lane et al, 2012 for storm of 12 September 1976
[3]Recalculated from wave data for storm of 12 September 1976
[4]As per calculations of Lane et al, 2012

This approach was only applied to areas where the immediate hinterland of the dune/structure was lower than the dune/structure, and therefore water from wave overtopping would pool and accumulate. Where the dune/structure was overtopped but the hinterland elevation continued to increase immediately behind the dune/structure, it is assumed that there will only be minimal increase to inundation depths on a highly variable temporal scale, and water will run back down the slope not adding a large volume to the additional pooling of water.

In identifying the areas of potential additional inundation from wave run-up we have only delineated the first swale area inland of the dune crest on the basis that once a wave has run-up and overtopped the first dune crest and collapsed into the swale it is unlikely to continue travelling further inland to run-up and overtop successive dunes. Figure 2.7 shows a map of an example inundation area on the coastline north of Te Horo and a representative cross-section through the dune field for the case of RSLR of 1.65m. In this scenario the combined storm tide level and wave run-up height, shown in green in the figure, is relatively high (6.85 m WVD-53) and exceeds ground levels for approximately 1 km inland. The static storm tide level is shown in blue (4.08 m WVD-53). In this situation we have only delineated the first swale area within the bathtub extent (at around a distance of 100m from the beach) as susceptible to additional inundation from wave run-up and overtopping.



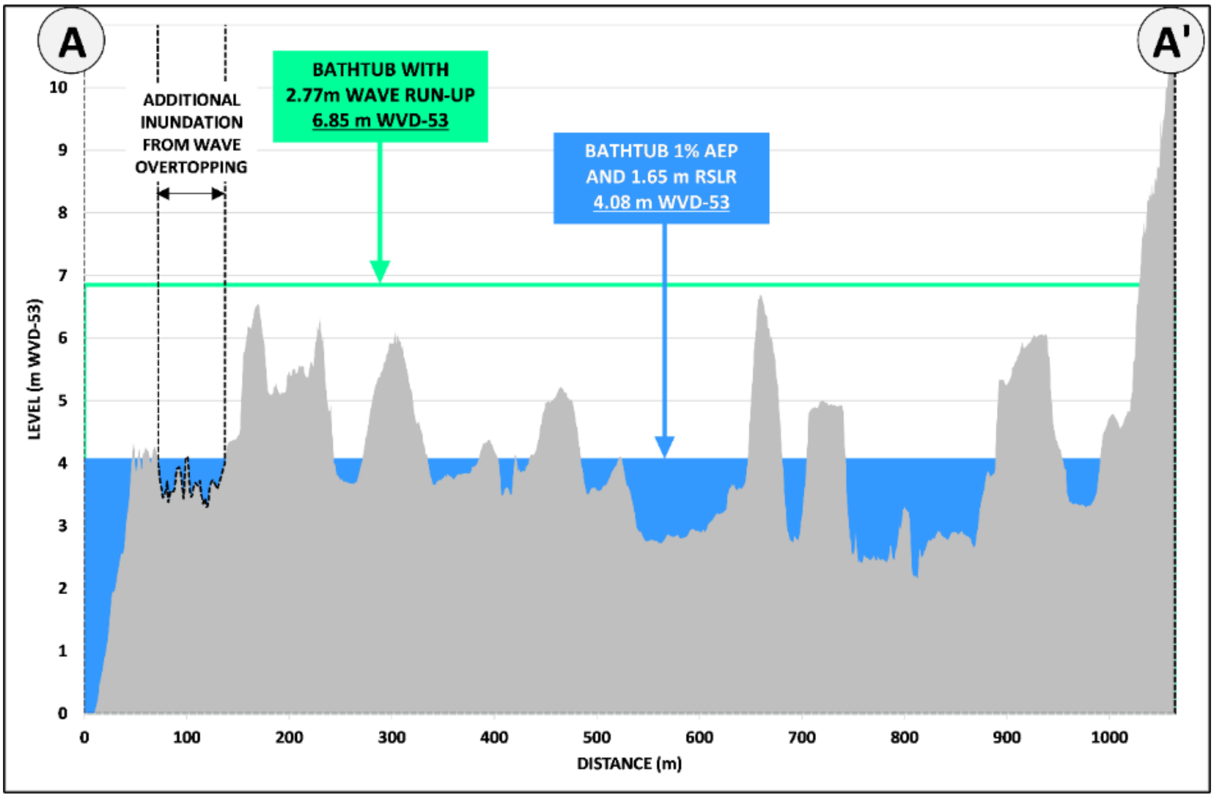


Figure 2.7 Example of how areas susceptible to additional inundation from wave run-up and overtopping have been delineated. In the map in the top diagram the bathtub inundation area, ground below the static storm tide level, is shown in blue and the additional area below the wave run-up level is shown in green. The lower diagram compares the ground profile and the two water levels along the section line A-A' shown on the plan above. The first swale area below the bathtub level is delineated as susceptible to additional inundation from wave overtopping.

2.4 Vulnerability Assessment

In this assessment we have quantitatively assessed the *sensitivity* of key council infrastructure and community services to the current and future exposure to coastal hazards. The purpose of this assessment is to determine when various assets or services may become affected by SLR. In assessing this, we are able to develop a high-level vulnerability profile for each coastal cell.

This assessment has not considered any social, ecological, or culturally significant assets, sites, or services, as this will require input from the community to understand what assets or sites the community values. It is understood this is likely to form part of the assessment in Phase Two of the project.

The vulnerability assessment considered the following community services and critical infrastructure:

- Key roads which run parallel to the shoreline
- Schools
- Medical Centres
- Public coastal stormwater outlets
- Wastewater treatment plants
- Water supply bores
- Pump stations
- Land parcels

All community service and infrastructure data was provided by KCDC.

Property data was extracted from the LINZ data service and reclassified based on land ownership data into public and private land parcels.

Public land parcels include:

- Libraries
- Police Stations
- Forestry
- Community Centres/Halls
- Cemeteries
- Carparks
- Schools
- Waterworks
- Water supply
- Road connection and designations
- State housing
- Reserves (scientific, scenic, road, recreation, esplanade)
- Public Transport

Private land parcels were classified as everything not included within the public land layer, which was therefore assumed to be privately owned.

An asset or service was assessed as being 'affected' if the location of the asset/service intersected with the hazard susceptibility at the 50-year or 100-year timeframe. For the inundation hazard, water depths are not reported as part of this vulnerability assessment.

Part 1: Coastal Erosion Susceptibility and Vulnerability Assessment

3. Ōtaki Coastal Cell

3.1 Summary

The Ōtaki Coastal Cell covers approximately 6.3 km of shoreline from the northern boundary of the district to the northern edge of the Ōtaki River. The open coast environment along this cell consists of a mostly sandy beach, with some Ōtaki River gravels, backed by a series of low dunes, except at the Waitohu Stream mouth where they have been able to grow to significant heights. The sediment supply rate into this cell is greater than the transport losses to the south, resulting in long-term shoreline accretion throughout the cell.

The shoreline north of the Waitohu Stream is projected to continue to accrete under the lower RSLR scenarios in each timeframe but would most likely erode under the higher RSLR scenario where the erosional effects of RSLR are predicted to outpace the accretion rate. In contrast, along the Ōtaki settlement the shoreline is generally projected to erode by small magnitudes under the lower RSLR scenarios (RCP2.6 plus 1mm/yr VLM) over all timeframes (e.g. average less than 10 m driven by short-term storm erosion and post-storm dune slope adjustments), and erosion under the highest RSLR scenario (RCP8.5H+ plus 3 mm/yr VLM) being projected to be in the order of -30 m over the next 30 years (2050), -43 m over the next 50 years 2070), and -94 m over the next 100 years (2120).

The 'most likely' PFSP does not intersect with Marine Parade until 2070 when the length of affected road is 708m under the highest RSLR scenario, increasing to 1755m effected by 2120. No public land parcels intersect with the 'most likely' PFSP until 2120, when up to three land parcels could be affected. The number of private properties potentially affected by the projected erosion depends on the magnitude of RSLR; 3-4 intersect with the 'most likely' PFSP within the next 30 years; 3-10 within 50 years; and 1 to 95 within 100 years. An additional 18 private and one public land parcel could be affected by potential future migration at the Waitohu Stream mouth. These results place the Ōtaki cell sixth out of eight for vulnerability of private proprieties to projected future coastal erosion.

The coastal setting, future erosion components and PFSP results for the Ōtaki cell are discussed in more detail in the sections below.

3.2 General Description

The Ōtaki Coastal Cell covers approximately 6.3km of shoreline from the northern boundary of the district to the northern edge of the Ōtaki River hydrosystem cell, as shown in Figure 3.1. This figure also presents the location of key data reference points within the cell (e.g. DSAS transects, beach and bathymetric profiles).

Key features of the cell include the Waitohu Stream Hydrosystem located near the centre of the cell and the Ōtaki Beach settlement located between the Waitohu Stream and the Ōtaki River. The settlement contains 1,100 private dwellings, is home to approximately 1800 residents (Statistics New Zealand, 2018), has a coastal frontage of approximately 1300 m and is surrounded to the east by farmland located on the coastal plains.

The open coast environment along Ōtaki Coastal cell consists of a sandy beach backed by dunes which reach elevations of 5.5 m to 6 m (WVD1953), as can be seen in Figure 3.2. The dunes provide a continuous length of protection along the frontage of the Ōtaki Beach Settlement, acting as a 30-80 m wide buffer between the beach and Marine Parade, which runs parallel to the shoreline through the settlement. Most houses located within the Ōtaki Beach settlement are located on the landward side of Marine Parade. However, the Ōtaki Surf Life Saving Club building (Figure 3.2) is located on the seaward side of Marine Parade, creating a small opening in the dune line (Transect 674). Other small breaks in the dune line include numerous access ways for pedestrians and vehicles.

The shoreline in this cell is orientated to the WNW and exposed to the full impact of dominant north-west ocean swell and storm waves generated by weather systems crossing the Tasman Sea. Beach sands are supplied to the cell via the persistent southward longshore transport of sediments supplied predominantly from the four large rivers to the north (Whanganui, Whangaehu, Rangitikei and Manawatu Rivers) at an estimated rate of 94,000 m^3/yr (Tonkin & Taylor, 2018 derived from de Lange, 2013). Based on the analysis of volume changes in the beach profile record, an estimated average 42,400 m^3/yr (6.7 m^3/m/yr) is retained within the beach system in this cell, leading to net shoreline accretion (see Appendix H).

Figure 3.1: Ōtaki Coastal Cell key features and data reference points (DSAS transects, beach and bathymetric profiles).

Figure 3.2: Ōtaki Beach sand dunes at the Ōtaki Beach Surf Life Saving Club.

3.3 Structures

There are no coastal protection structures located in the Ōtaki cell.

3.4 Erosion Components

3.4.1 Extrapolation of Long-term Rates

The historical shoreline positions within the Ōtaki coastal cell were digitised from between 6-8 aerial photographs from 1948 to 2017. Figure 3.3 overlays these shoreline positions at Ōtaki Beach settlement on the 1948 aerial imagery, demonstrating the long-term accretion that has occurred over the nearly 70-year period.

The DSAS analysis revealed that this long-term accretion has occurred throughout the open coast of the Ōtaki cell since 1948, with the resulting average rates of change from the linear regression shown in Figure 3.4. In general, the accretion rates north of the Waitohu Stream are higher (e.g. +0.5 to +1 m/yr) than the rates along the Ōtaki Beach Settlement to the south of the stream (generally < +0.5 m/yr).

The upper and lower bounds of the triangular distribution for the probability approach were taken as being ± the 90% confidence level of the average rate from the linear regression. The resulting lower bound still resulted in beach accretion at all transects.

The extrapolation of the average and 90% confidence interval rates into the future results in the beach accretion distances presented in Table 3.1.

Figure 3.3: Historical shorelines from 1948-2017 showing long-term accretion at the Ōtaki Beach settlement overlaid on 1948 aerial imagery.

Table 3.1: Projected shoreline accretion distances in the Ōtaki coastal cell from the extrapolation of average long-term rates of shoreline movement from aerial photographs 1948-2017.

Transects	Next 30 years (by 2050)	Next 50 years (by 2070)	Next 100 years (by 2120)
North of the Waitohu Stream (Transects 710-750)	+22.4 (± 8.8) m	+37.3 (± 14.7) m	+ 74.5 (± 29.6) m
Ōtaki Beach Settlement (Transects 645-680)	+9.7 (± 4.7) m	+16.2 (± 7.9) m	+32.4 (± 15.8) m
The distances in brackets are the upper and lower bounds of uncertainty, being the 90% confidence interval of the LRR from the DSAS.			

Figure 3.4: Long-term accretion rates at Ōtaki calculated from DSAS.

3.4.2 Effect of Future Accelerated Sea Level Rise

As explained in Section 2.2.3, to avoid 'double accounting' of contemporary sea level rise and to isolate the effects of RSLR to being just for the acceleration in the rate of rise, the resulting erosion distances are calculated for the 'discounted' rates of rise for each timeframe as presented in Table 2.2.

For the Ōtaki cell, the calculation of the effect of accelerated sea level rise by the Bruun Rule used the beach profile parameters of profiles 460 and 450 and offshore profiles 49 and 50 (locations shown in Figure 3.1, beach profiles are presented in Appendix F, and offshore profiles in Appendix G). Both beach profiles (Appendix F) had similar beach heights (5.6-5.9 m), with a small range of beach width[9] (106-127 m at profile 460; 86-89 m at 450), and therefore beach slopes were similar for all profile survey dates. The offshore profiles presented by Lumsden (2003) (Appendix G) showed very similar bathymetry at both locations and are therefore assumed to be consistent across the whole cell, and also displayed similar nearshore slopes to the range of closure depths calculated by Hallermeiers limits from the MetOcean (2007) wave statistics (inner closure depth of -9 m located 1050 m offshore, outer closure depth of -13 m located 1500 m offshore).

These ranges of input values formed upper and lower bounds of the triangular distribution for the calculation of the range of erosion distances due to RSLR, with the average conditions being the mid-point between the upper and lower bounds. The results of these calculations are presented in Table 3.2.

Table 3.2: Projected erosion distances in the Ōtaki coastal cell from future acceleration of rates of RSLR, where '-' indicates erosion and '+' indicates accretion.

Time Frame	Magnitude of Absolute RSLR	Average Erosion Distance	Lower Bound Erosion Distance	Upper Bound Erosion Distance
2050	0.2 m	-10.0 m	-9.3 m	-10.2 m
	0.4 m	-26.7 m	-24.9 m	-27.3 m
2070	0.3 m	-13.9 m	-13.0 m	-14.2 m
	0.7 m	-47.3 m	-44.1 m	-48.4 m
2120	0.6 m	-27.8 m	-25.9 m	-28.4 m
	0.85 m	-48.7m	-45.3 m	-50.0 m
	1.25 m	-82.1 m	-76.5 m	-84.0 m
	1.65 m	-115.5 m	-107.6 m	-118.1 m

As can be seen from these results, the uncertainty in the magnitude of RSLR within each timeframe results in large increases in the projected erosion distance; with the range of distances increasing as the uncertainty in RSLR increases. For example, there is a 17 m increase in projected average erosion between the lower and upper RSLR scenario for 2050, compared to an 88 m increase in projected average erosion between the lower and upper RSLR scenarios for 2120.

However, in contrast, the similar closure slopes for upper and lower bounds of input parameters result in a very narrow range of values for sea level rise effects within the same RSLR scenario. For example, for the 2050 timeframe the range of uncertainty due to input parameters are within ± 1-3 m across both SLR scenarios; in 2070 the range increases to 2-5 m; and in 2120 this range increases to 3 m for the lowest RSLR scenario (0.65 m RSLR) and 12 m for the highest RSLR scenario (1.65 m RSLR). While these ranges of uncertainty appear low, they are strongly influenced by the small variations in the input data, and do not take account of the limitations in the method for calculating RSLR effects. It is not possible to quantify the uncertainty from these limitations[10].

[9] Beach width is the distance between the beach crest and the 0 m contour.
[10] For limitations of method, see Section 6.9 of Jacobs (2021) Volume 1 report.

3.4.3 Short-term Storm Erosion

The short-term component for Ōtaki was based on post-storm observations from Gibbs and Wilshere (1976) following the September 1976 storm, which was later assessed to be a 0.5% AEP event (Lane et al, 2012). The observations indicated that there was an upper limit of 10 m of erosion at Peka Peka, which we have assumed to be the same at Ōtaki Beach.

For the probabilistic method, a conservative approach was taken by applying the -10 m upper limit as the mean for a quasi-distribution, with ± 50% to give an upper bound of the triangular distribution of -15 m erosion and a lower bound of -5 m erosion.

3.4.4 Dune Stability

The dune stability component for Ōtaki is calculated on height (dune toe to dune crest) at the two surveyed profiles located within the cell (profile 450 and 460, see Figure 3.1 for location) and angle of repose of dry sand (30 to 34 degrees). For the probabilistic approach, the mean erosion from dune stability for profile 450 is -3.4 m, with upper and lower bounds of -4.3 m and -2.7 m respectively. This has been applied to transects 638 to 664 (see Figure 3.1 for locations). For Profile 460, the mean dune stability erosion is -2.7 m, with upper and lower bounds of -3.5 m and -2.2 m, which has been applied to transects 665-764.

3.5 Projected Coastal Erosion Distances

The resulting CED's calculated by the probabilistic method are presented below. Maps displaying the spatial location of the present-day hazard and PFSP are presented in maps 1-3 of Appendix A (2050), Appendix B (2070), and Appendix C (2120).

3.5.1 Present-day Erosion Susceptibility

The present-day erosion hazard is representative of the potential erosion hazard which could occur if a large storm were to happen in the immediate/near future. This present-day hazard is a combination of the short-term storm erosion (Section 3.4.3) and the dune stability factor (Section 3.4.4). It represents the dynamic nature of shoreline movements where short-term erosion can occur independently of long-term trends or the effects of future RSLR.

For the Ōtaki open coast cell the present-day hazard was calculated to 'most likely' (P33 position) be -12 m to -13 m of erosion, with erosion unlikely to exceed -19 m.

3.5.2 Future Coastal Erosion Susceptibility

The raw outputs from the Monte Carlo simulation of the landward limit of 'most likely' zone (P33 position) for the three timeframes are presented below in Figure 3.5 to give an indication of the changes in shoreline position that could be expected to be over the next 100 years. It should be noted that these raw distances (Appendix J) have been smoothed in the mapping outputs to remove unrepresentative small-scale irregularities in the current day shoreline position and for consistency with coastal process plan-shape considerations, as well as consideration of future inlet migration. Therefore, the raw outputs may not directly correlate with the PFSP shorelines mapped in Appendices A, B, and C. It should also be noted that distances mentioned in the text have been rounded to the nearest 0.5 m.

The following provides a summary of the projected erosion distances to the landward limit of the most likely zone (P33) across each RSLR scenario.

A notable feature of these results is that for each timeframe the open coast to the north of the Waitohu Stream is projected to continue to accrete under the lower RSLR scenarios (RCP2.6 plus VLM 1mm/yr and RCP4.5 plus 2 mm/yr VLM), even with the inclusion of the present-day hazard, but would erode under the higher RSLR scenario (RCP8.5 plus 2mm/yr VLM and RCP8.5H+ plus 3mm/yr VLM)). This is due to accretion keeping pace with SLR induced erosion under the lower RSLR scenarios, however erosion overrides the accretion under the higher RSLR scenarios. However, to the south of the Waitohu Stream, due to the lower contemporary long-term accretion rate, even the lower RSLR scenarios result in net projected erosion.

When comparing erosion distances across the lower and upper RSLR scenarios for different timeframes, it is recognised that some results may appear counter-intuitive. This is due to the greater influence of the short-term and dune stability components over shorter time frames. As a result, erosion distances in 2050 for 0.2m RSLR can be greater than erosion distances in 0.6 m RSLR for 2120. Similarly, erosion distances for upper RSLR scenarios over shorter timeframes (e.g. 0.7m RSLR 2070) can be greater than lower SLR scenarios over a longer timeframe (e.g. 0.6 m RSLR 2120).

2050

As can be seen from Figure 3.5, for the shoreline north of the Waitohu Stream for the 0.2m RSLR scenario, the shoreline is projected to experience an average of 5 m of accretion, however the shoreline change in this area varies significantly, with accretion potentially reaching up to 48 m at the northern end of the cell. Since the mapping products in Appendix A only show areas where erosion is predicted, the resulting accreted PFSP is not presented. However, under the higher RSLR scenario (0.4 m), the area to the north of the Waitohu Stream is projected to experience on average -12 m of erosion.

To the south of the Waitohu Stream, the frontage of the Ōtaki Beach Settlement is projected to experience on average -13 m of erosion with 0.2m of RSLR, which is due totally to the inclusion of the short-term and dune stability components. This net erosion is projected to increase to -29.5 m with 0.4 m of RSLR, of which short-term and dune stability components contribute more than 50%. Similar to the shoreline to the north of the stream, there is a large variation in the position of the future shoreline, with less erosion predicted closer to the Waitohu Stream hydrosystem cell to the north of the settlement, and the Ōtaki River Coastal hydrosystem cell to the south.

2070

As shown in Figure 3.5, the area north of the Waitohu Stream is projected to continue to accrete under the lower 0.3 m RSLR scenario on average by 19.5 m, and up to a maximum of +91 m at the northern end of the cell. However, under the higher 0.7 m RSLR scenario, the average shoreline position would switch to being erosional, with average erosion along this section projected to be -13.5 m, all of which is due to the short-term and dune stability components.

Along the frontage of the Ōtaki Beach settlement, under the lower 0.3 m RSLR scenario, the shoreline is projected to experience an average of -10 m of erosion, again being driven by the short-term and dune stability components. With 0.7m of RSLR, this erosion is projected to increase on average up to -43 m, which demonstrates the additional RSLR effect under this scenario.

At the southern end of the settlement nearing the Ōtaki River hydrosystem cell, the projected future erosion is less, being an average of -4.0 m with 0.3m RSLR, increasing to an average of -37 m with 0.7 m RSLR.

2120

From Figure 3.5, the shoreline north of the Waitohu Stream with 0.6 m of RSLR (RCP2.6 plus 1 mm/yr VLM) over the next 100 years is projected to accrete by an average of 52 m, which decreases to 30 m accretion with 0.85 m of RSLR (RCP4.5 plus 2mm/yr VLM). Under scenarios with higher rates of RSLR, the long-term future is projected to switch to being erosional; 1.25 m of RSLR (RCP8.5 plus 2 mm/yr VLM) resulting in an average erosion distance of -2 m, and 1.65 m of RSLR (RCP8.5H+ plus 3mm/yr VLM) projected to result in up to -35 m of erosion.

Conversely, along the frontage of the Ōtaki beach settlement, 0.6 m SLR is projected to result in average erosion of -7 m, increasing to an average of -28 m erosion with 0.85 m RSLR; and -61 m of erosion with 1.25 m of RSLR. At the highest scenario of 1.65 m RSLR, the projected net erosion distances are an average of -94 m.

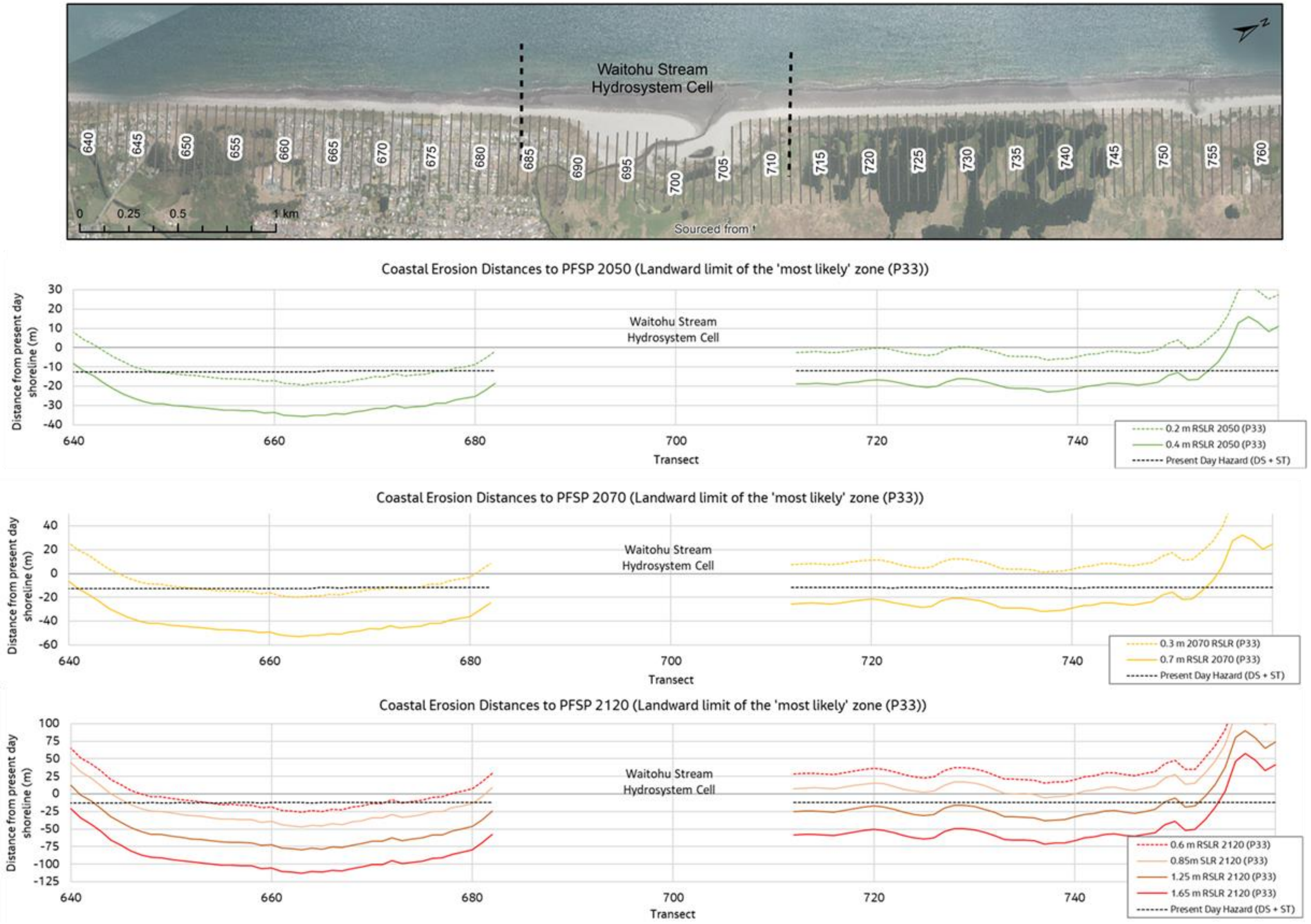


Figure 3.5: Erosion/Accretion distances to projected future shoreline positions in the Ōtaki cell under future RSLR scenarios.

3.5.3 Comparison of results to previous coastal hazard assessments

The results of the PFSP presented in Section 3.5.2 are calculated to be less than previous coastal erosion assessments for this cell.

The Lumsden (2003) coastal management strategy proposed a -75 m 'Secondary Development Setback' across the Ōtaki Cell, which was a deterministic approach for assessing long-term trends at the site and the effect of a 0.45 m RSLR over the next 100 years. Comparatively, our lowest RSLR projection over a 100-year period was 0.6 m, which in front of the Ōtaki beach settlement produced an average 'most likely' (P33) erosion of -7m, an upper bound of maximum 'most likely' erosion of -26m and is predicted to be 'very unlikely' to exceed -31 m of erosion.

Compared to the CSL (2008 & 2012) coastal hazard assessment, the results produced in this study are also less. For a 0.3 m RSLR over 50 years scenario, CSL calculated an average erosion distance of -36 m along the Ōtaki Beach Settlement, and an average of -42 m of erosion north of the Waitohu Stream. These results did not include extrapolation of accretion rates in the CED calculations, instead assuming a static shoreline with future sediment supply, such that all future shoreline change will be due to the effects of RSLR, short-term storms, and dune stability factors following a storm event. However, in this current assessment with the same magnitude of RSLR (0.3 m), due to the inclusion of extrapolation of historical accretion rates in the PFSP, the area north of the Waitohu Stream is projected to continue to accrete under the lower 0.3 m RSLR scenario by an average of 19.4 m. At the Ōtaki Beach settlement, the shoreline is projected to erode by an average of -10 m over the same period. Over this 50-year timeframe, erosion distances are projected to be between -10 m and -40 m under the higher 0.7 m RSLR scenario.

3.6 Waitohu Stream

The Waitohu Stream is the only hydrosystem cell located within the Ōtaki coastal cell, for which the historical shoreline positions are presented in Figure 3.6. The mouth has historically shown to migrate to the northern extent of the hydrosystem cell. The adjacent shoreline on both sides of the stream have historically shown accretion, as also shown in Figure 3.4.

There are no river training structures located within the hydrosystem cell, however, there has been significant dune restoration on the left back near the coastline by local community groups, which has played a role in training the very dynamic river mouth (Figure 3.7).

Due to the accretional nature of the adjacent shoreline, and the net positive movement of the inlet itself, Method 3 from the coastal hydrosystem decision tree, being the maximum historical hydrosystem shoreline position (see Section 2.2.7) was used to indicate the possible future migration of the hydrosystem. This is recognised to be a conservative approach, because the accretional nature of the adjacent shoreline means there is no coastal process reason to expect that the hydrosystem shoreline would erode back to this 1948 position in the future whilst the open coast continues to accrete. However, to give an indication of the spatial limits of where the hydrosystem has been in the past, this historical maximum envelope of the river mouth environment has been used, as marked by the black dotted line in Figure 3.6, are shown in Map 5 of Appendix A, B, and C, and in more detail in Appendix D (hydrosystems).

While the adjacent shoreline does begin to erode under higher RSLR scenarios in each timeframe, the extent of erosion is not projected to be landward of the historical hydrosystem envelope until 2120 under the highest RSLR scenario on the northern edge. Therefore, it is projected that the edge of the hydrosystem cell would merge into the open coast PFSP, as is mapped in Map 2 of the 2120 maps presented in Appendix C.

Figure 3.6: Historical shoreline position and maximum shoreline envelope at Waitohu Stream.

Figure 3.7: Waitohu Stream viewed from the Moana Street Entrance with the large dune that helps direct the stream mouth northward on the left. This is part of an older dune remnant that built up due to Marram planting.

3.7 Vulnerability

3.7.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified affected council critical infrastructure and community services that intersected with mapped PFSP up to the landward limit of the 'most likely' PFSP (P33). The results of this assessment are presented in Table 3.3.

Table 3.3: Council critical infrastructure and community services in the Ōtaki cell that intersects with the 'most likely' PFSP under various sea level rise scenarios.

	RSLR Scenarios							
	2050		2070		2120			
Asset	**0.2 m**	**0.4 m**	**0.3 m**	**0.7 m**	**0.6 m**	**0.85 m**	**1.25 m**	**1.65 m**
Marine Parade (Total Length = 2400m)[(1)]	0m	0m	0m	708m	0m	130m	1283m	1755m
Coastal Stormwater Outlet[(2)]	7	9	8	9	9	9	9	10

(1) Length of road intersecting landward limit of 'most likely' PFSP
(2) Number of outlets intersecting landward limit of 'most likely' PFSP

The results of this assessment show that over the next 30 years the total length of Marine Parade does not intersect with the PFSP (P33) for both RSLR scenarios. However, under the higher RSLR scenarios over the 50 year and 100-year timeframes, Marine Parade could be affected by coastal erosion. Under the highest RSLR projection (0.7 m 2070), 30% of Marine Parade could be affected, which increases to 73% affected under the highest RSLR scenario (1.65 m) over the 100-year timeframe.

Coastal stormwater outlets were the only piece of critical infrastructure and community services identified to be affected in the Ōtaki cell, with only a small increase in the number affected between the lowest RSLR scenario and timeframe (0.2 m 2050, seven effected) and the highest RSLR scenario and timeframe (1.65 m 2120, 10 effected). Therefore, seven open coast stormwater outlets located in south Ōtaki or towards the Ōtaki River are considered to be highly vulnerable to SLR.

3.7.2 Land parcels

The number of land parcels (public and private) which intersect with the PFSP up to the landward limit of the 'most likely' position (e.g. P33) and the landward limit of the 'unlikely' position (e.g. P10) were calculated to give an indication of vulnerability of land parcels within a coastal cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels (see Section 2.4). The results of this assessment for the Ōtaki cell are presented below in Figure 3.8, and in Appendix L.

The results indicate that only three parcels of public property intersect with the 'most likely' and 'unlikely' PFSPs under the highest RSLR scenario over a 100-year timeframe. For private land parcels, the results indicate that over a 30-year timeframe (2050) there is little difference in the number of parcels that intersect with the PFSP under the lower and upper scenarios and the 'most likely' and 'unlikely' projections, with a maximum of four parcels being affected. Over a 50-year timeframe, three properties intersect with the 'unlikely' PFSP under the lowest RSLR scenario, which increases to seven land parcels under the higher 0.7 m RSLR scenario. Under the highest RSLR scenario over a 100-year timeframe (1.65 m RSLR), 92 land parcels intersect with the landward limit of 'most likely' PFSP, and up to 95 land parcels at the landward limit of the 'unlikely' PFSP.

Within the mapped future hydrosystem position for the Waitohu Stream (described in Section 3.6), over all RSLR scenarios and timeframes 18 private land parcels intersect with the mapped future inlet position; as well as one public property.

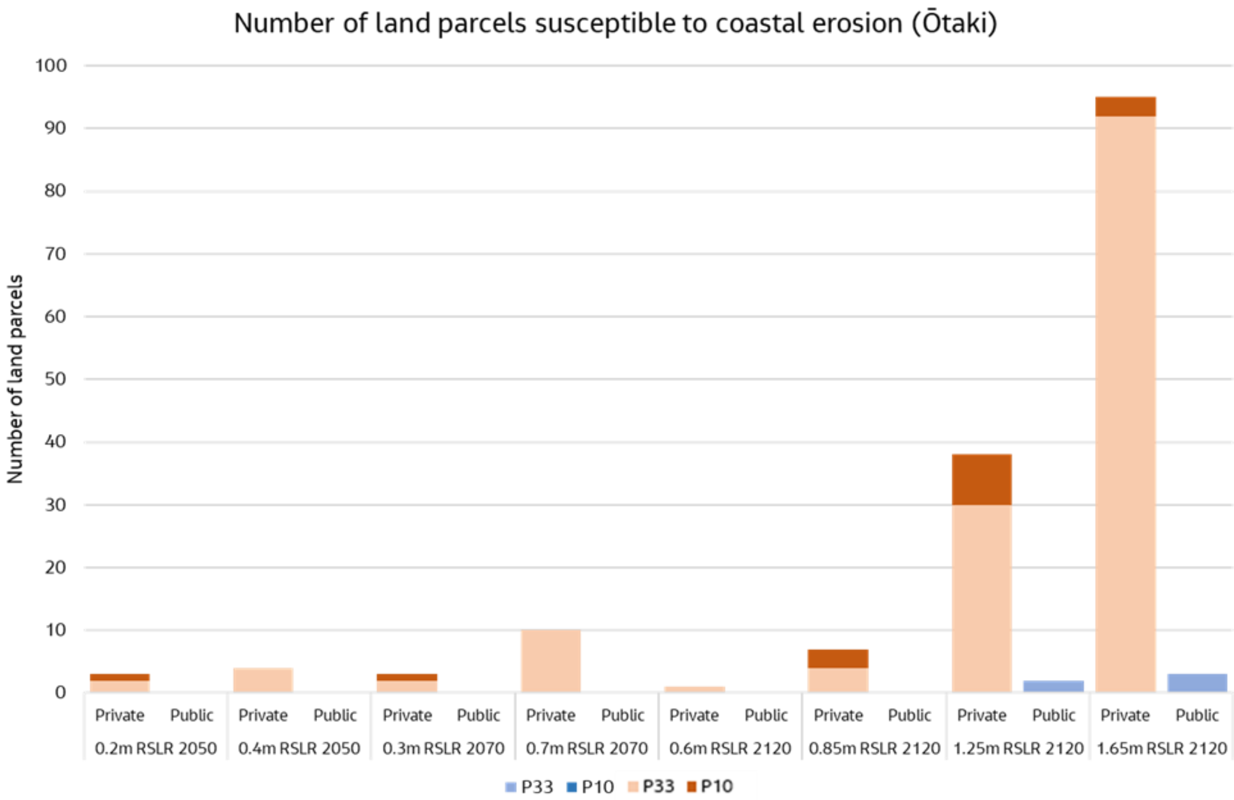


Figure 3.8: Number of public and private land parcels in Ōtaki potentially susceptible to coastal erosion. Lighter orange/blue show the number of properties susceptible to erosion up to the P33 (landward limit of the most likely), with the darker blue/orange showing additional parcels potentially affected between the P33 and P10 shoreline position.

4. Te Horo Coastal Cell

4.1 Summary

The Te Horo Coastal Cell covers approximately 5.1 km of shoreline from the northern edge of the Ōtaki River, to the southern end of the Te Horo Beach settlement. The beach environment along this cell is a composite/mixed sand and gravel beach type due to the gravel influence supplied from the Ōtaki River. The combined supply rate from longshore transport and the Ōtaki River is greater than the transport losses to the south, resulting in a long-term shoreline accretion throughout the cell.

The shoreline in the Te Horo cell is generally projected to continue to accrete under the lower RSLR scenarios in each timeframe with erosion limited to the short-term storm effects (-10 m) but would most likely erode under the higher RSLR scenario where the erosional effects of RSLR are predicted to outpace the accretion rate from sediment supply. At the Te Horo settlement, erosion under the highest RSLR scenario (RCP8.5H+ plus 3 mm/yr VLM) is projected to be in the order of -21 m over the next 30 years (0.4 m RSLR by 2050); -30 m over the next 50 years (0.7 m RSLR by 2070); and -70 m over the next 100 years (1.65 m RSLR by 2120). The results along the remaining shoreline in the Te Horo cell indicate that there are areas of greater erosion (up to -100 m) and continued accretion (up to +40 m) over the highest RSLR scenario for the 100-year period.

There was no identified critical infrastructure or community services within the Te Horo cell in the vulnerability assessment which are projected to intersect with the PFSP over any of the future RSLR scenarios up to 100 years. The 'most likely' PFSP across the highest RSLR scenario at all timeframes also does not intersect with any public land parcels. For private proprieties, over the range of RSLR scenarios up to four intersect with the 'most likely' PFSP within the next 30 years; three to eight within 50 years; and three to 42 within 100 years. An additional 16 private land parcels could be affected by potential future migration at the Mangaone Stream, and up to three public and one private land parcel intersects with potential future migration of the Ōtaki River. These results place the Te Horo cell seven out of eight for vulnerability of private proprieties to projected future coastal erosion.

This coastal cell and the results are discussed in more detail in the sections below.

4.2 General Description

The Te Horo Coastal Cell covers approximately 5.1 km of shoreline from the northern edge of the Ōtaki River, to the southern end of the Te Horo Beach settlement, as shown in Figure 4.1. This figure also presents the location of key data reference points within this cell (e.g. DSAS transects, beach profiles and bathymetric profiles).

The cell includes the Ōtaki River Hydrosystem Cell (transects 615-636) at the northern end of the cell, as well as the Mangaone Stream Hydrosystem Cell (transects 547-556) at the southern end near the Te Horo settlement. The projected shoreline positions within these hydrosystems are detailed in sections 4.6 and 4.7 respectively.

The wider Te Horo area has approximately 1,400 residents with 750 dwellings (Statistics New Zealand, 2018), of which there is a concentration of these at the small beach side settlement. Residential properties in the Te Horo settlement have a 70 to 100 m wide buffer between the current shoreline and dwellings. Except for the small settlement, the land within this cell is mostly farmland located upon the old coastal plains.

The beach environment along this cell is a composite/mixed sand and gravel beach type (Figure 4.2) due to the gravel influence supplied from the Ōtaki River, which is transported predominantly to the south, and is recognised as a micro-morphology in relation to the rest of the Kāpiti coast shoreline. The presence of gravel within the beach decreases in a southward direction from the Ōtaki River as this larger sediment is reduced to sand sized sediment by abrasion processes with sliding movements up and down the foreshore by swash action. The beach returns to being comprised totally of sand sized material just south of the Te Horo settlement, around the southern boundary of this cell.

Figure 4.1: Te Horo coastal cell key features and data reference points (DSAS transects, beach and bathymetric profiles).

Figure 4.2: Composite beach environment at Te Horo Beach settlement near Mangaone Stream. Note the elevation of houses in the settlement relative to the beach elevation.

The shoreline in this cell is orientated to the WNW and exposed to the full impact of dominant north-west ocean swell and storm waves generated by weather systems crossing the Tasman Sea. Beach sands are therefore also supplied to the cell from the residue of the river supply from the large rivers to the north (Whanganui, Whangaehu, Rangitikei and Manawatu Rivers) transported via the Ōtaki cell (estimated 43,9000 m^3/yr – Appendix H) with a further 11,000 m^3/yr estimated to be supplied by the Ōtaki River (Tonkin & Taylor, 2018). Based on the analysis of volume changes in the beach profile record, an estimated average of 20,500 m^3/yr (4.0 m^3/m/yr) is retained within the beach system, leading to shoreline accretion (see Appendix H).

As shown in Figure 4.2, the presence of gravel in the beach profile creates steeper foreshore slopes than the sand beaches found in other cells located along the rest of Kāpiti Coast District. Based on the beach profile data, the beach crest elevation throughout the cell is generally around 3.6 m WVD-53. It is normal for mixed sand and gravel beaches to have lower crest elevations than sand beaches due to the reduced ability for wind to form dunes (e.g. due to greater grain sizes), and the influence of wave run-up overtopping the crest.

4.3 Structures

There are no coastal protection structures identified in the Te Horo coastal cell. However, there are stopbanks located within the Ōtaki River hydrosystem cell along the left and right bank of the Ōtaki River.

4.4 Erosion Components

4.4.1 Extrapolation of Long-term Rates

The historical shoreline changes within the Te Horo coastal cell were digitised from 7-8 aerial photographs from between 1948 and 2017. A section of the DSAS analysis at the front of the Te Horo Beach settlement, overlaying the 1948 aerial imagery, is presented in Figure 4.3, demonstrating the long-term accretion that has occurred over the nearly 70-year period. Note that this photograph pre-dates the development of the settlement. The raw rates of shoreline change over this period calculated from the DSAS analysis are presented in Figure 4.4.

In undertaking the DSAS analysis, the results showed that for the transects between the Ōtaki River and Mangaone Stream there was a poor long-term linear trend to the shoreline movements, with R^2 values less than 0.5. As a result, for this area (transects 552-607), the End Point Rate (EPR) of shoreline movement was used rather than the linear regression rate, with ± 50% of the EPR being applied as the upper and lower bounds of the triangular distribution used in the probability analysis, which reflects the larger uncertainty in the results. A reasonable coastal processes explanation could not be confirmed for this poor linear relationship, although it is considered that it may relate to sediment input pluses associated with flood events in the Ōtaki River that are episodic and non-linear. These storm events can also reshape the foreshore forming steep storm berms and cuspate topography, and therefore the beach crest will vary quite differently from one aerial photo to the next.

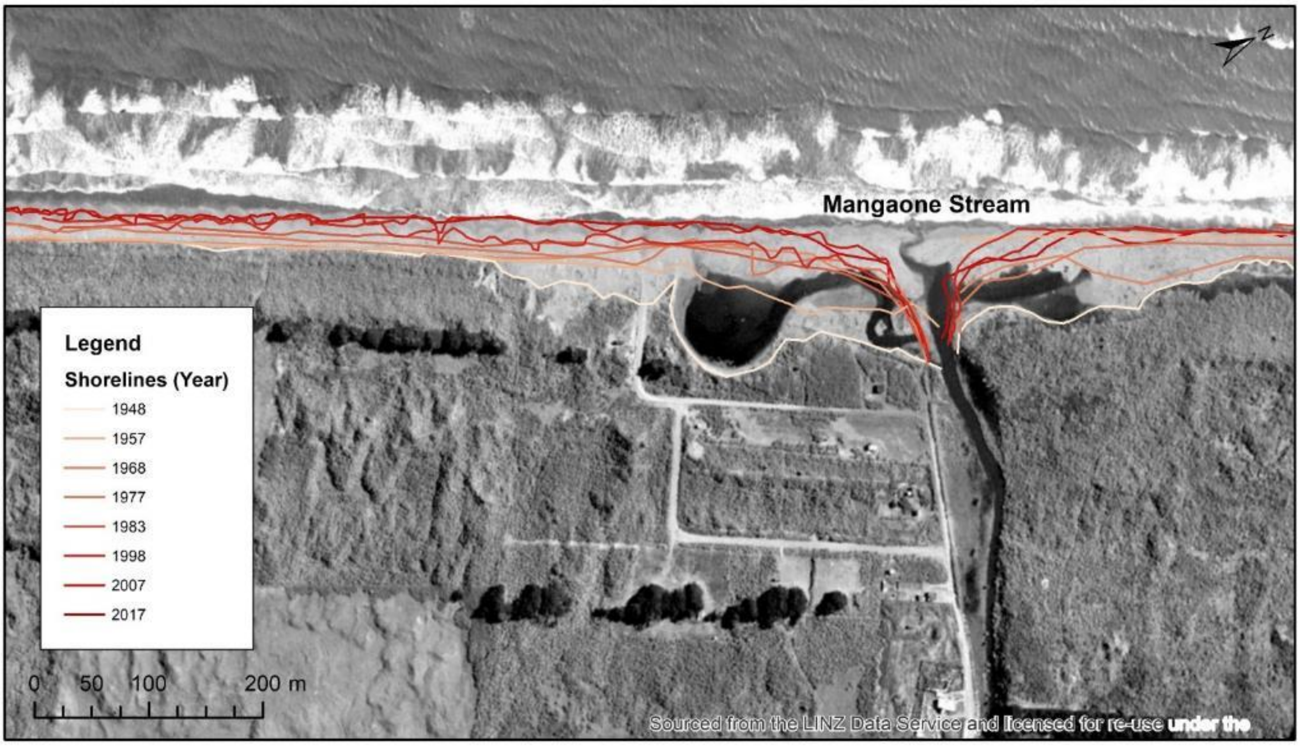


Figure 4.3: Historical shorelines from 1948 - 2017 showing long-term accretion at the Te Horo Beach settlement, overlaid on 1948 aerial imagery.

As demonstrated in both Figure 4.3 and Figure 4.4, the shoreline along the Te Horo coastal cell has a long-term accretional trend, with locally isolated areas of slightly higher accretional trends around the hydrosystem environments. Between the Mangaone Stream and the Ōtaki River, the average accretion rate is +0.4 m/yr, being slightly less at the southern end (+0.3 m/yr Transects 557-585) and increasing in the north where there is a small, isolated area of increased accretion rates (+0.5 m/yr Transects 585-595). Along the frontage of the Te Horo settlement (transects 537-546) the average accretion rate is also higher; being +0.52 m/yr from the linear regression analysis.

The extrapolation of the average and upper/lower bounds rates of shoreline movement into the future results in the beach accretion distances are presented in Table 4.1.

Table 4.1: Projected shoreline accretion distances in the Te Horo coastal cell from the extrapolation of average long-term rates of shoreline movement from aerial photographs 1948-2017.

Transects	Next 30 years (by 2050)	Next 50 years (by 2070)	Next 100 years (by 2120)
Between Mangaone Stream and Ōtaki River (Transects 557-616)	+12.0 (± 6.3) m	+20.0 (± 10.6) m	+ 40.0 (± 21.1) m
Te Horo Beach Settlement (Transects 537-546)	+16.3 (± 4.4) m	+27.1 (± 7.3) m	+54.2 (± 12.6) m
The distances in brackets are the upper and lower bounds of uncertainty. For between Mangaone Stream and the Ōtaki river are ± 50% of the EPR, and for Te Horo Beach settlement are the 90% confidence interval of the LRR from the DSAS.			

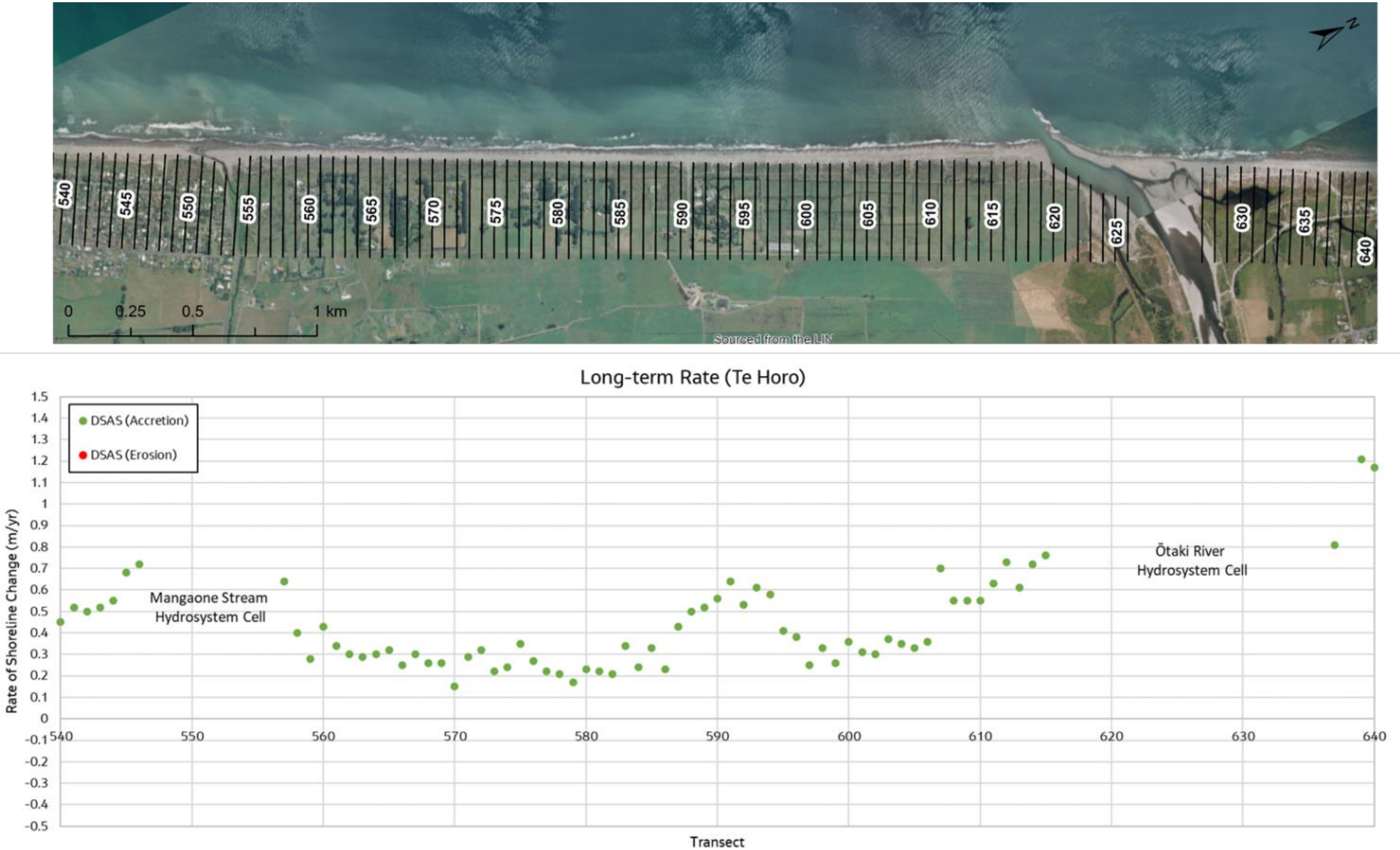


Figure 4.4: Long-term rates calculated from DSAS in the Te Horo coastal cell.

4.4.2 Effect of Future Accelerated Sea Level Rise

As explained in Section 2.2.3, to avoid 'double accounting' of contemporary sea level rise and to isolate the effects of RSLR to being just for the acceleration in the rate of rise, the resulting erosion distances are calculated for the 'discounted' rates of rise for each timeframe as presented in Table 2.2.

For the Te Horo cell, the effect of accelerated sea level rise was calculated by the modified Bruun Rule for composite sand/gravel beaches as detailed in Section 6.4.2 in the Volume 1 methodology report, using the beach profile parameters of profiles 420, 430 and 440, and offshore profiles 46, 47, and 48 (locations shown in Figure 4.1, beach profiles are presented in Appendix F, and offshore profiles in Appendix G). For this assessment, profile 440 is assumed to have a 50% gravel component due to its close proximity to the gravel source at the Ōtaki river mouth, and Profile 420 is assumed to have a reduced 15% gravel component, as it is located 1.5 km north of the known transition to sand beach south of Te Horo Beach settlement.

The beach profiles (Appendix F) in this cell indicate that there is small variance in the beach height across the cell, with beach height generally being around 3.6 m WVD-53. Average beach width decreases in a northward direction, with profile 420 having a mean beach width of 55 m, decreasing to 42 m at profile 440 in the north. This is considered to likely be as a result of the increased presence of gravel at the northern 440 profile, steepening the beach profile. The bathymetry profiles from Lumsden (2003) (Appendix G), at the same location as the beach surveys, also showed little variation between the sites in terms of closure slope to the range of closures depths calculated by Hallermeiers limits from the MetOcean (2007) wave statistics (inner closure depth of -8.8 m located 1075 m offshore, outer closure depth of -12.8 m located 1500 m offshore). Therefore, the main difference in effect of RSLR longshore within the cell is due to the presence of gravel at the profile sites, and the reduced effect of RSLR this has, where profiles that have a greater gravel component have a smaller erosion distance from RSLR.

These ranges of input values formed upper and lower bounds of the triangular distribution for the calculation of the range of erosion distances due to RSLR, with the average conditions being the mid-point between the upper and lower bounds. The results of these calculations are presented in Table 4.2.

Table 4.2: Projected erosion distances in the Te Horo coastal cell from future acceleration of rates of RSLR where '-' indicates erosion and '+' indicates accretion.

Timeframe	Magnitude of Absolute RSLR	Profile 420 (south)	Profile 430	Profile 440 (north)
2050 (30 years)	0.2 m	-9.6 ±2.4 m	-7.3 ± 2.4 m	-5.6 ± 2.4 m
	0.4 m	-25.7 ±3.7 m	-19.4 ± 6.3 m	-14.9 ± 9.1 m
2070 (50 years)	0.3 m	-13.4 ± 2.4 m	-10.1 ± 3.3 m	-7.7 ± 4.7 m
	0.7 m	-45.5 ± 6.5 m	-34.4 m ± 4.8	-26.3 ± 14.1 m
2120 (100 years)	0.6 m	-26.7 ± 3.8 m	-20.2 ± 6.6 m	-15.5 ± 9.5 m
	0.85 m	-46.8 ± 6.7 m	-35.4 ± 11.5 m	-27.1 ± 16.6 m
	1.25 m	-78.9 ± 11.3 m	-59.7 ± 19.3 m	-45.7 ± 27.9 m
	1.65 m	-111.0 ± 15.4 m	-84.0 ± 27.2 m	-64.3 ± 39.3 m

As can be seen from these results, the uncertainty in the magnitude of RSRL within each timeframe results in large increases in the projected erosion distance; with the range of distances increasing as the uncertainty in RSLR increases. For example, there is a 10-14 m increase in projected average erosion between the lower and upper RSLR scenario for 2050, compared to a 49-84 m increase in projected average erosion between the lower and upper RSLR scenarios for 2120.

In contrast, the longshore differences in the projected erosion distances between the profiles are smaller (4 m for 0.2 m RSLR by 2050, 47 m for 1.65 m RSLR by 2120). Likewise, the similar closure slopes for upper and lower bounds of input parameters result in a very narrow range of values for sea level rise effects within the same RSLR scenario. While these ranges of uncertainty appear low, they are strongly influenced by the small variations in the input data, and do not take account of the limitations in the method for calculating SLR effects[11].

4.4.3 Short-term Storm Erosion

The short-term component for Te Horo was based on post-storm observations from Gibbs and Wilshere (1976) following the September 1976 storm, which was later assessed to be a 0.5% AEP event (Lane et al, 2012). The observations indicated that there was an upper limit of 10 m of erosion at Peka Peka, which we have assumed to be the same at Te Horo Beach.

For the probabilistic method, a conservative approach was taken by applying the -10 m upper limit as the mean for a quasi-distribution, with ± 50% to give an upper bound of the triangular distribution of -15 m erosion and a lower bound of -5 m erosion.

4.4.4 Dune Stability

The dune stability factor was not applied in the Te Horo cell as the low gravel crest barrier retreats by rollover rather than dune scarp formation.

4.5 Projected Coastal Erosion Distances

The resulting CED's calculated by the probabilistic method are presented below. Maps presenting the spatial location of the present-day hazard and PFSP are presented in are presented in maps 3-5 of Appendix A (2050), Appendix B (2070), and Appendix C (2120).

4.5.1 Present-day Erosion Susceptibility

The present-day erosion hazard is representative of the potential erosion hazard which could occur if a large storm were to happen in the immediate/near future. This present-day hazard is the short-term storm erosion component in this cell (Section 4.4.3). It represents the dynamic nature of shoreline movements where short-term erosion can occur independently of long-term trends or RSLR. For the Te Horo open coast cell, the present-day hazard was calculated to 'most likely' (P33 position) be -9 m to -11 m of erosion, with erosion unlikely to exceed -13 m.

4.5.2 Future Coastal Erosion Susceptibility

The raw outputs from the Monte Carlo simulation of the landward limit of 'most likely' zone (P33 position) for the three timeframes are presented below in Figure 4.5 to give an indication of the changes in shoreline position that could be expected to be over the next 100 years. It should be noted that these raw distances (Appendix J) have been smoothed in the mapping outputs to remove unrepresentative small-scale irregularities in the current day shoreline position and for consistency with coastal process plan-shape considerations, as well as consideration of future inlet migration. Therefore, the raw outputs may not directly correlate with the PFSP shorelines mapped in Appendices A, B, and C. It should also be noted that distances mentioned in the text have been rounded to the nearest 0.5 m.

[11] For limitations of method, see Section 6.9 of Jacobs (2021) Volume 1 report.

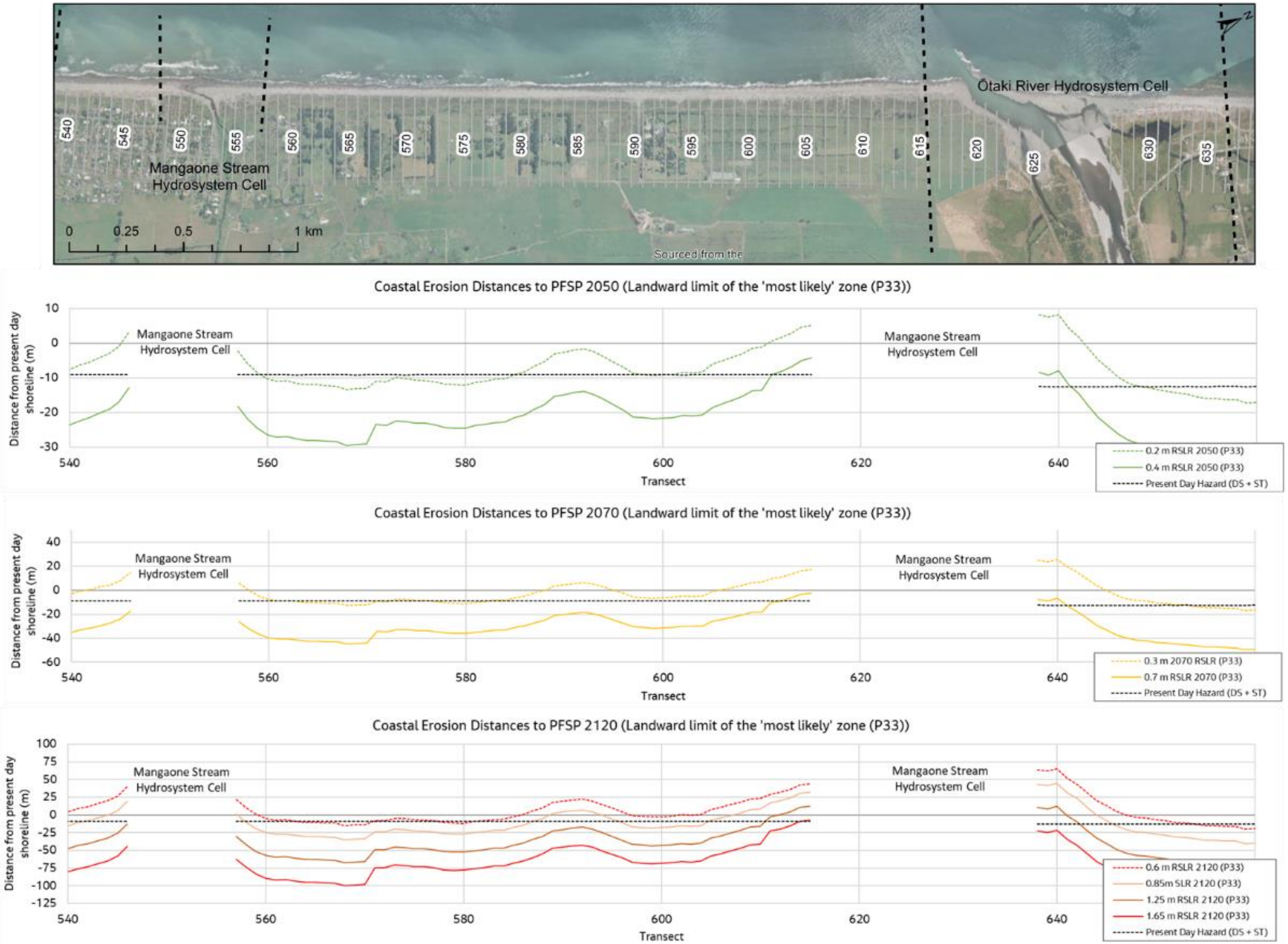


Figure 4.5: Erosion distances to projected future shoreline positions under future RSLR scenarios.

The following provides a summary of the projected erosion distances to the landward limit of the most likely zone (P33) across each RSLR scenario.

In general, under the lower RSLR scenarios (0.2m 2050; 0.3m 2070; and 0.6m 2120 under RCP2.6 plus 1mm/yr VLM scenario) the extrapolation of the historical accretion rates over the last 70 years is similar to the projected erosion due to RSLR, therefore the net total retreat along the Te Horo coastal cell for each of these scenarios is not projected to be any more than the present-day hazard (-9 to -11m). But under higher RSLR projections (RCP8.5 plus 2mm/yr VLM and RCP8.5H+ plus 3mm/yr VLM), in each timeframe the erosion increases to be beyond the present-day hazard due to the accretion caused by surplus sediment supply not being able to keep pace with the erosional effects of RSLR. However, there are also some small, isolated areas along the shoreline where long-term accretion is expected to continue due to higher historical accretion rates (e.g. around transect 590).

Another overall trend is that due to the assumed effect of gravel on the RSLR erosion component, erosion is generally greater at the southern end of the cell, and less at the northern end of the cell where the percentage of gravel in the beach profile is higher (see Section 4.4.2).

When comparing erosion distances across the lower and upper RSLR scenarios for different timeframes, it is recognised that some results may appear counter-intuitive. This is due to the greater influence of the short-term storm component over shorter time frames. As a result, erosion distances in 2050 for 0.2m RSLR can be greater than erosion distances in 0.6 m RSLR for 2120. Similarly, erosion distances for upper RSLR scenarios over shorter timeframes (e.g. 0.7m RSLR 2070) can be greater than lower SLR scenarios over a longer timeframe (e.g. 0.6 m RSLR 2120).

2050

As shown in Figure 4.5, for the shoreline frontage of the Te Horo Beach settlement (538-546), under 0.2 m of RSLR the shoreline is projected to experience an average of -5 m of erosion. These erosion distances decrease in a northward direction; being projected to be up to -9 m at the southern end of the settlement and reducing to < -4 m at the Mangaone stream. Under the 0.4 m RSLR scenario, the average erosion distance is projected to increase to -21 m with higher erosion distances of -25 m at the southern end of the cell and lower erosion distances of -17 m at the Mangaone River.

For the area of shoreline between the Mangaone Stream and the Ōtaki River (transects 557-615) for the 0.2 m RSLR scenario, the shoreline is projected to experience an average of -8 m of erosion, with longshore variations between– 13 m to +4 m (e.g. accretion). Under the 0.4 m RSLR scenario, the average projected erosion distance increases to -21 m, with the range of distances varying between -30 m to -5 m.

As noted above, along both segments of shoreline, the projected erosion in the 0.2 m RSLR scenario is completely made up of the present-day hazard component (short-term), whereas under the higher 0.4 m RSLR scenario, the present-day hazard makes up only 50% of the average erosion distance due to the greater erosion impact of the higher sea level.

2070

As can be seen in Figure 4.5, under the 0.3 m RSLR scenario the shoreline frontage of the Te Horo Beach settlement is projected to have a small average beach accretion (+2 m), however, the southern end of the cell could erode by up to -5 m. Under the higher 0.7 m RSLR scenario, the average erosion distance is projected to be -30 m, with -33 m projected at the southern end of the cell decreasing to -10 m of erosion near the Mangaone Stream.

For the area of shoreline between the Mangaone Stream and the Ōtaki River, the average erosion distance is projected to be – 4 m, ranging from up to -12 m of erosion to +16 m of accretion (at the northern end near Ōtaki River).

2120

Figure 4.5 shows that with 0.6 m of RSLR (RCP2.6 plus 1 mm/yr VLM), the shoreline along the frontage of the Te Horo Beach settlement is projected to experience an average accretion of +15 m with results ranging from stability at the southern end of the cell (0 m of shoreline movement) and up to +40 m of accretion at the Mangaone Stream. However, with a 0.85 m of projected RSLR (RCP4.5 plus 2mm/yr VLM), the projected shoreline movement changes to erosion with an average retreat of -5 m, increasing to -38 m with 1.25 m of RSLR (RCP8.5 plus 2 mm/yr VLM) and up to an average of -70 m under the 1.65 m RSLR scenario (RCP8.5H+ plus 3mm/yr VLM), with projected retreat ranging from -84 m at the southern end of the cell to -44 m near the Mangaone Stream.

For the area of shoreline between the Mangaone Stream and the Ōtaki River, with 0.6 m of RSLR the shoreline is projected to accrete by an average of +3 m; however across this area the shoreline projections range from -14 m erosion to accretion of up to +40 m (near the Ōtaki River). With 0.85 m of RSLR, this average shoreline accretion switches to erosion at an average of -12 m and increasing to -40 m retreat with 1.25 m RSLR. Under the highest RSLR scenario, the average 'most likely' total erosion distance is projected to be -66 m, however with a large range from -100 m of erosion near the Mangaone Stream to -10 m erosion near the Ōtaki River.

4.5.3 Comparison of results to previous coastal hazard assessments

The results of the PFSP presented in Section 4.5.2 are calculated to be less than previous coastal erosion assessments for this cell.

The Lumsden (2003) coastal management strategy proposed a -75 m 'Secondary Development Setback' from Peka Peka to Ōtaki, which was a deterministic approach for assessing long-term trend at the site and the effect of a 0.45 m RSLR over the next 100 years. Comparatively, our lowest RSLR projection over a 100-year period was 0.6 m, which across the Te Horo cell produced an average 'most likely' (P33) accretion of +6 m, an upper bound of maximum 'most likely' erosion of -15 m and is predicted to be "very unlikely' to exceed -70m of erosion at any location.

Compared to the more recent CSL (2008 & 2012) coastal hazard assessment, the results produced in this study are also less. For a 0.3 m RSLR over 50 years scenario, CSL (2008 & 2012) calculated an average erosion distance of -27.5 m across the Te Horo cell. These results did not include extrapolation of accretion rates in the CED calculations, instead assuming a static shoreline such that all future shoreline change will be due to the effects of RSLR, short-term storms, and dune stability factors following a storm event. However, as detailed above, in this current assessment, for the same magnitude of RSLR (0.3 m), the inclusion of extrapolated historical accretion rates over the last 70 years due to sediment supply in the projection results in average retreat of -2 m across the cell with the same magnitude of RSLR and a maximum most likely' erosion of -15 m. However, it is also noted that within this 50-year timeframe, erosion distances are projected to be up to -30 m under a 0.7 m RSLR scenario. It is also noted that our calculated effect of RSLR alone was greater than CSL (2008). CSL (2008) calculated an average of -8 m of erosion due to RSLR across the cell, while our assessment calculated an average of -13.5 m of erosion at the southern end of the cell, and up to a maximum erosion effect of -15 m.

4.6 Ōtaki River

The Ōtaki River is one of two hydrosystems located within the Te Horo coastal cell. The Ōtaki River is located near the northern boundary of the coastal cell, south of the Ōtaki Beach settlement as shown in Figure 4.1. The historical shoreline positions of the Ōtaki River mouth are presented in Figure 4.6, showing the historical landward extent of the river mouth environment. Stopbanks along both banks of the Ōtaki River were constructed in the 1940's, which confined the movement of the river within these banks and prevented flooding into low lying farmland on either side of the river. The Ōtaki River hydrosystem is classified as a barrier beach enclosed tidal river mouth (Hume et al., 2016) as shown in Figure 4.6. The river mouth migration is based on periodic break throughs of the gravel barrier at the mouth, which fronts a small hapua lagoon on the right bank.

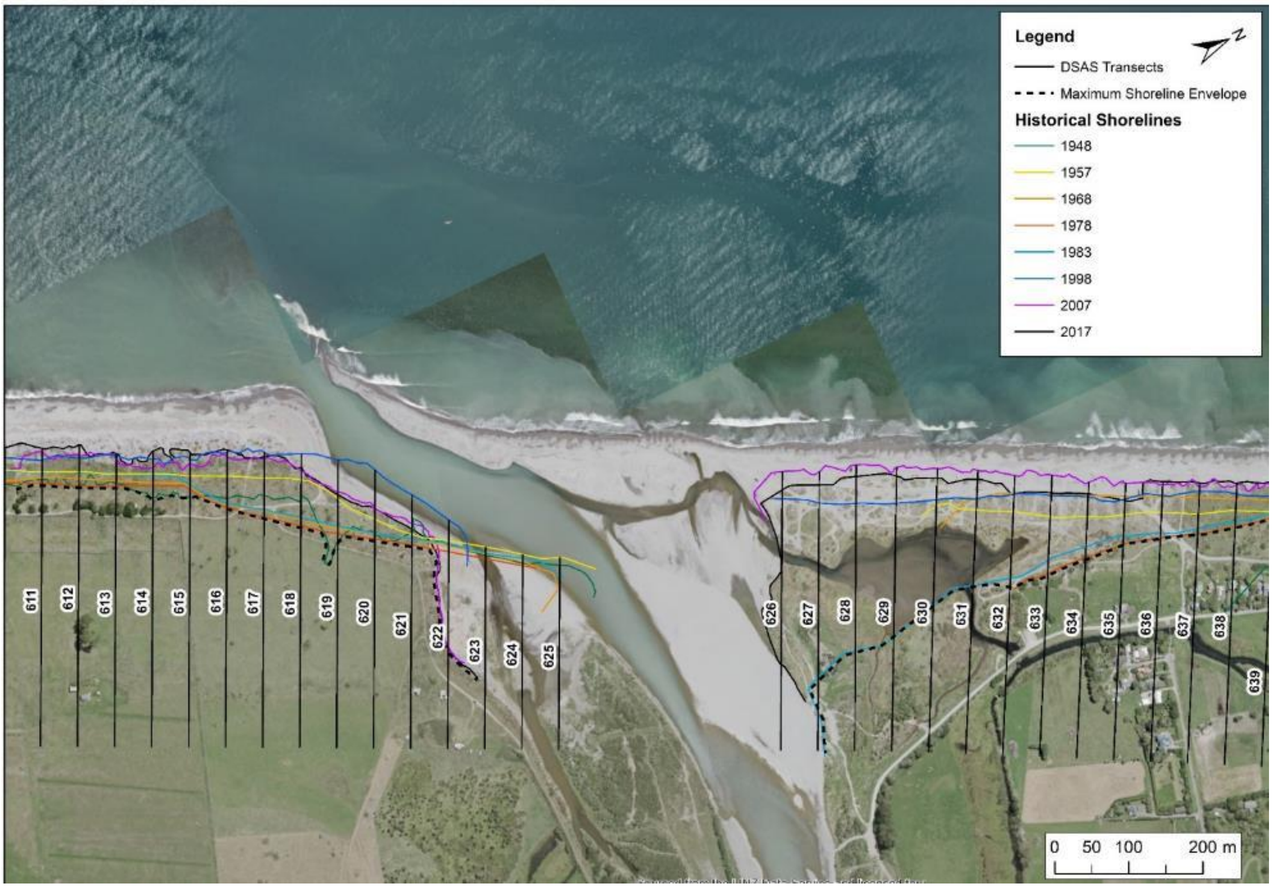


Figure 4.6: Historical shorelines and maximum shoreline envelope at Ōtaki River.

Figure 4.7: Ōtaki River mouth facing south, showing the gravel component in beach profiles.

In our classification of hydrosystems (Volume 1, Section 6.7) the Ōtaki River was determined to be a 'fluvial' dominated site, as opposed to 'coastal' dominated site (e.g. Mangaone Stream). As a result of this classification, the potential future extent of the hydrosystem is determined using the RSLR flood modelling scenarios produced in Part 2 of this report (0.4 m, 0.65 m, 0.85 m, 1.25 m and 1.65 m). This approach is based on the principle that for these large river mouth environments, the morphology is shaped by both fluvial and extreme coastal events. It is assumed inundation from this combination of events would produce salt intolerant vegetation die back around the edges of the mouth/hapua, which could promote scouring and allow for changes in the morphology of the mouth environment.

It is important to note that this assessment is used as an indicator for where the mouth/hapua environment could move to under the assumption of vegetation die back causing scour. The approach does not take into account the velocity of water or the transport of sediment in these events which would also result in scour of the inlet edges. This approach also does not take into account more frequent events than may inundate vegetation (e.g. 10-year ARI events), between which there is less time for the vegetation to recover between events. However, the currently underway hydrodynamic modelling of smaller more frequent events should give a better understanding of how the interaction of coastal/fluvial processes shape the morphology of the hydrosystem and how these may change in the future.

In this assessment, the current day shoreline was mapped against the 1% AEP storm tide level to give an indicative proxy of where the hydrosystem shoreline was placed in relation to water depth. This assessment showed that in this sized event, the area inundated with consistent 0.25-0.5 m water depths aligns with the hydrosystem present-day shoreline. Therefore, the position of these water depths in 1% AEP storm tide events with RSLR has been taken as a proxy shoreline for where the hydrosystem shoreline could erode to in the future, based on the above assumptions around processes.

The results of this assessment are mapped in Map 4 of Appendix A, B and C (PFSP maps for 2030, 2070, 2120 representatively). These maps show that under the 0.4 m and 0.65 m RSLR scenarios, there is likely to only be a small amount of erosion (<10 m) along the edge of the current hapua area. However, with 1.65 m of SLR, a 1% AEP storm tide event could cause a large breach on the gravel barrier fronting the hapua lagoon with subsequent large volumes of saltwater moving into the hapua during high tide phases, and resulting in potential hapua migration back to the stopbank on both banks of the lower river channel as shown in Map 3 of Appendix C. This could increase the width of the hydrosystem by up to 200 m. With adjacent shoreline movement, the seaward extent of the hydrosystem will erode to align with the adjacent shoreline as also shown in Map 3 of Appendix C.

4.7 Mangaone Stream

The Mangaone Stream is a small hydrosystem at the southern end of the Te Horo cell, on the northern border of the Te Horo Beach Settlement. The stream is coastally dominated and tends to migrate from north to south. The hydrosystem has had a long-term accretionary trend, in line with the adjacent shorelines (see Figure 4.4 and Figure 4.8). There are no shoreline structures confining the migration of this stream.

Due to the accretional nature of the adjacent shoreline, and the net positive movement of the inlet itself, Method 3 from the coastal hydrosystem decision tree (see Section 2.2.7) was used to determine the possible future migration of the hydrosystem. This is recognised to be a conservative approach, because the accretional nature of the adjacent shoreline means there is no coastal process reason to expect that the hydrosystem shoreline would erode back to this 1948 position in the future whilst the open coast continues to accrete. However, to give an indication of the spatial limits of where the hydrosystem has been in the past, this historical maximum envelope of the river mouth environment has been used, as marked by the black dotted line in Figure 4.8 , are shown in Map 2 of Appendix A, B, and C, and in more detail in Appendix D (hydrosystems).

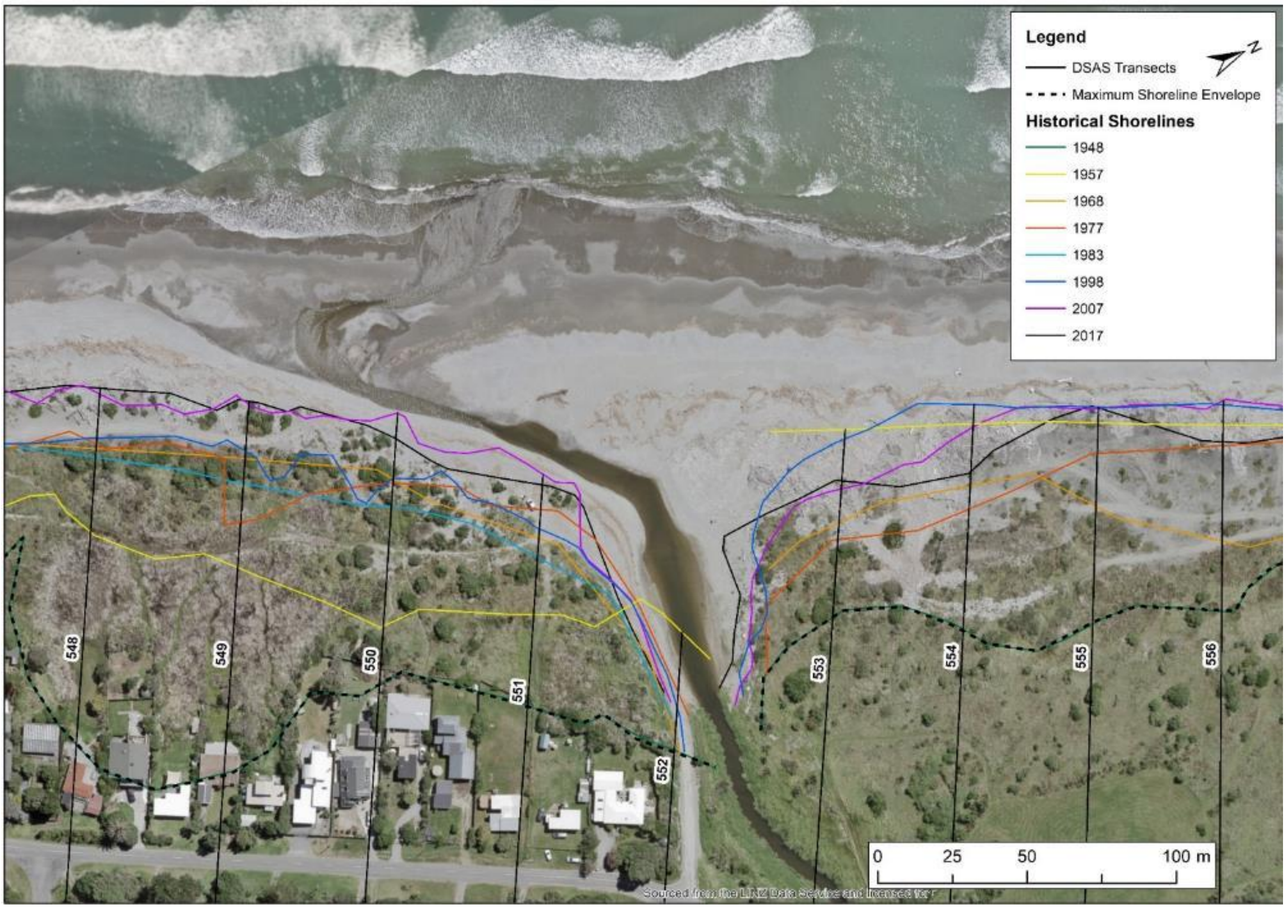


Figure 4.8: Historical shorelines and maximum shoreline envelope at Mangaone Stream.

While the adjacent shoreline begins to erode under higher RSLR scenarios in each timeframe, the extent of erosion is not projected to be landward of the historical hydrosystem envelope until 2120 under the highest RSLR scenario on the northern edge. Therefore, it is projected that the edge of the hydrosystem cell would merge into the open coast PFSP, as is mapped in Map 5 of the 2120 maps (Appendix C).

4.8 Vulnerability

4.8.1 Council Critical Infrastructure and Community Services

No council critical infrastructure or community services assessed in the Te Horo coastal cell were identified as intersecting with the mapped PFSP up to the landward limit of the most likely (P33).

4.8.2 Land parcels

The number of land parcels (public and private) which intersect with the PFSP up to the landward limit of the 'most likely' position (e.g. P33) and the landward limit of the 'unlikely' position (e.g. P10) were calculated to give an indication of vulnerability of land parcels within a coastal cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels (see Section 2.4). The results of this assessment for the Te Horo cell are presented below in Figure 4.9 and in Appendix L.

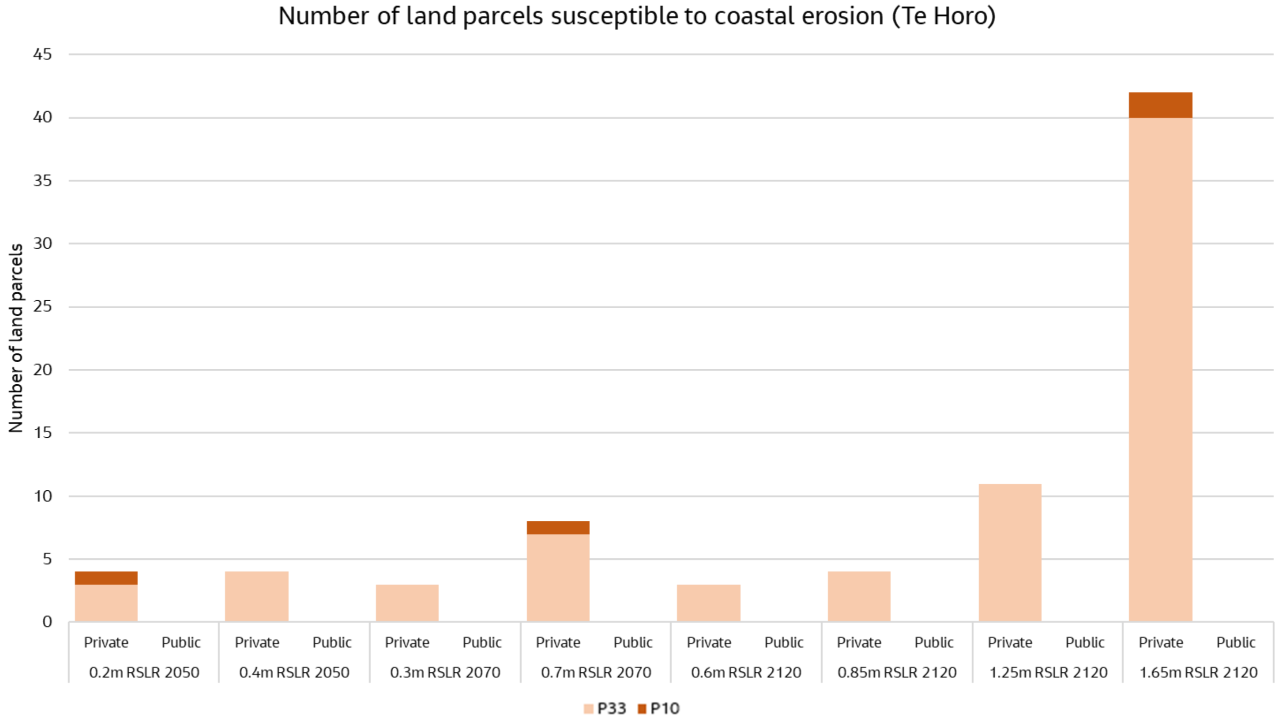


Figure 4.9: Number of public and private land parcels in Te Horo potentially susceptible to coastal erosion. Lighter orange shows the number of properties susceptible to erosion up to the P33 (landward limit of the most likely), with the darker orange showing additional parcels potentially affected between the P33 and P10 shoreline position.

From the results presented in Figure 4.9 it is shown that over all timeframes, there are no parcels of public property that intersect with the 'most likely' and 'unlikely' PFSPs.

Under the lower SLR scenarios in each timeframe, three to four private land parcels intersect with the 'most likely' PFSP. For the 2070 highest RSLR scenario (0.7 m) the number of intersecting land parcels increases to eight, and under the highest RSLR scenario over the 100-year period (1.65 m 2120) the number of intersecting land parcels increases to 42.

Inside the Ōtaki River hydrosystem cell (Section 4.6), one public land parcel and one private land parcel intersects with the potential future hydrosystem migration up until the 1.65 m RSLR scenario, where three public land parcels intersect with the future hydrosystem position.

At the Mangaone Stream hydrosystem cell (Section 4.7), across all timeframes and RSLR scenarios, no public land parcels intersect with the mapped potential future hydrosystem position; however, 16 private land parcels do.

5. Peka Peka Coastal Cell

5.1 Summary

The Peka Peka coastal cell covers approximately 8 km of sand beach shoreline from the Te Horo Beach settlement to the Waimeha Stream in the south. Beach sands are supplied to the cell from southward longshore transport, which has contributed a good supply of sediment creating a long-term accretionary trend throughout the cell.

The shoreline in the Peka Peka cell is generally projected to continue accreting, or experience a small amount of erosion (less than the present-day hazard) under the lower RSLR scenarios in each timeframe. However, under the higher RSLR scenario it is projected to erode as the effects of RSLR are forecast to outpace the accretion rate resulting in net long-term erosion. For the shoreline fronting the northern Waikanae Beach settlement and the Peka Peka settlement, erosion under the highest RSLR scenarios is projected to be in the order of -25 m over the next 30 years (0.4 m - 2050); -30 to -40 m over the next 50 years (0.7 m - 2070); and -70 to -90 m over the next 100 years (1.65 m - 2120). The area of shoreline between the two settlements is projected to erode at a similar distance over the higher100 year RSLR scenario.

Coastal stormwater outfalls are the only council critical infrastructure identified as intersecting with PFSP. Depending on the magnitude of RSLR, between seven to 10 private proprieties intersect with the 'most likely' PFSP within the next 30 years; three to 61 within 50 years; and up to 127 within 100 years. An additional one to six private and two to three public land parcels could be affected by potential future migration at the Te Kowhai Stream, as well as 30-35 private land parcels at the Waimeha Stream. This places the Peka Peka cell fourth out of eight for vulnerability of private proprieties to projected future coastal erosion.

This coastal cell and the results are discussed in more detail in the sections below.

5.2 General Description

The Peka Peka coastal cell covers approximately 8 km of shoreline from the southern boundary of the Te Horo Beach settlement to the Waimeha Stream hydrosystem cell in the south, as shown in Figure 5.1. This figure also presents the location of key data reference points within this cell (e.g. DSAS transects beach and bathymetric profiles).

The total cell covers transects 380-537, and includes the northern end of the Waikanae Beach settlement (transects 380-396), the Peka Peka settlement (transects 413-455), and the Te Kowhai Stream hydrosystem cell (transects 456-468). At the southern end of the cell is the Waimeha Stream hydrosystem cell, which covers transects 364-379. The shoreline within this cell consists of sandy beaches, which have dune heights of 5.4 - 6.3 m WVD-53, as shown in Figure 5.2. The dunes provide a continuous length of protection along the frontage of both the Peka Peka settlement and northern end of the Waikanae beach settlement.

In the Peka Peka settlement, coastal properties line the shoreline, however there is a minimum 55 m buffer between coastal dwellings and the present-day shoreline (e.g. dune vegetation line), with most dwellings being setback in the order of 80 m. Coastal properties also line the shoreline in the northern Waikanae settlement, where dwellings are generally setback 30-40 m from the present-day shoreline. Between the two settlements, and to the north of the Peka Peka settlement, the land use comprises of farmland located upon the old coastal plains.

Figure 5.1: Peka Peka Coastal Cell key features and data reference points (DSAS transects, beach and bathymetric profiles).

Figure 5.2: Peka Peka Beach showing high elevation of sand dunes and access way for vehicles.

The shoreline in this cell is orientated to the WNW but has a slightly reduced exposure to the impact of dominant north-west ocean swell and storm waves generated by weather systems crossing the Tasman Sea. Beach sands are supplied to the cell from the persistent southward longshore transport (see section 2.1 of Vol 1 Methodology report), and this reliable supply of sediment has created a long-term low accretionary trend for the cell. Based on the analysis of volume changes in the beach profile record, an estimated average 3,900 m^3/yr (0.48 m3/m/yr) is retained within the beach system in this cell, leading to net shoreline accretion (see Appendix H).

5.3 Structures

There are no coastal protection structures located in the Peka Peka coastal cell.

5.4 Erosion Components

5.4.1 Extrapolation of Long-term Rates

The historical shoreline changes within the Peka Peka coastal cell were digitised from 7 - 8 aerial photographs from between 1948 and 2017. A section of the DSAS analysis at the front of the Peka Peka settlement to the south of Te Kowhai Stream, overlain over 1948 aerial imagery, is presented in Figure 5.3, demonstrating the long-term accretion that has occurred over the nearly 70-year period. Note that this photograph pre-dates the development of the settlement. The raw rates of shoreline change over this period calculated from the DSAS analysis are presented in Figure 5.4.

The results of the analysis show that the entire length of the open coast cell has experienced accretion since 1948. North of the Waimeha Stream, fronting the northern end of the Waikanae Settlement (transects 380-396) accretion rates are an average of +0.48 m/yr, which reduce slightly to an average of +0.41 m/yr for the coastline between the Waikanae settlement and Peka Peka Settlement (transects 397-412). Along the frontage of the Peka Peka settlement (transects 413-455), the average accretion rate decreases further to +0.35 m/yr, and then increases North of the Te Kowhai Stream hydrosystem cell (Transects 469-537) to an average accretion rate of +0.76 m/yr. This high average rate is influenced by isolated areas of very high accretion between 1948 and 1956 associated with the treatment and planting of sand blow-outs with marram as can be seen in the 1948 aerial imagery of Figure 5.3

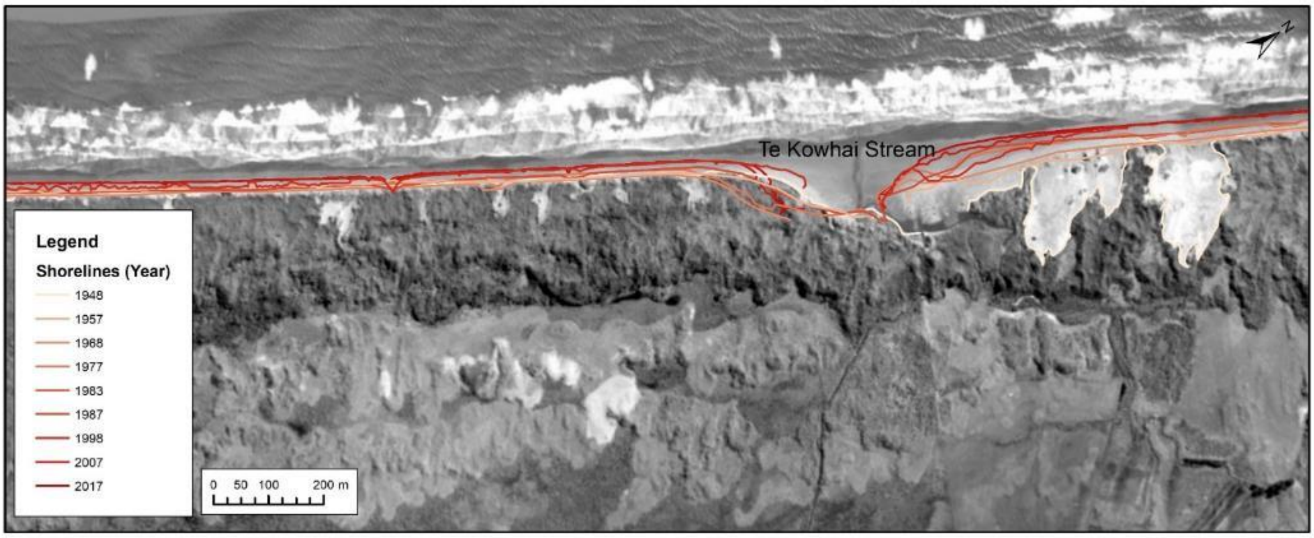


Figure 5.3: Historical shorelines from 1948-2017 overlay on 1948 aerial imagery at the Peka Peka beach settlement near the Te Kowhai Stream. Note the sand blow-outs at multiple locations along the seaward face of the dune line.

The upper and lower bounds of the triangular distribution for the probability approach were taken as being ± the 90% confidence level of the average rate from the linear regression. The resulting lower bound still resulted in beach accretion at all transects.

The extrapolation of the average and 90% confidence interval rates into the future results in the beach accretion distances are presented in Table 5.1.

Table 5.1: Projected shoreline accretion distances in the Peka Peka coastal cell from the extrapolation of average long-term rates of shoreline movement from aerial photographs 1948-2017.

Transects	Next 30 years (by 2050)	Next 50 years (by 2070)	Next 100 years (by 2120)
North end of Waikanae Settlement (north of Waimeha Stream) (Transects 380-396)	+14.3 (± 4.2) m	+23.8 (± 7.1) m	+ 47.6 (± 14.2) m
Between Waikanae and Peka Peka settlements (Transects 397-412)	+12.3 (± 4.4) m	+20.4 (± 7.3) m	+40.9 (± 14.7) m
Peka Peka Settlement (Transects 413-455)	+10.6 (± 4.5) m	+17.7 (± 7.5) m	+35.4 (± 15.0) m
North of Te Kowhai Stream (Transects 469-537)	+22.5 (± 9.9) m	+37.5 (± 16.5) m	+75.0 (± 33.0) m
The distances in brackets are the upper and lower bounds of uncertainty, being the 90% confidence interval of the LRR from the DSAS.			

Figure 5.4: Long-term rate across the Peka Peka coastal cell calculated from DSAS.

5.4.2 Effect of Future Accelerated Sea Level Rise

As explained in Section 2.2.3, to avoid 'double accounting' of contemporary sea level rise and to isolate the effects of RSLR to being just for the acceleration in the rate of rise, the resulting erosion distances are calculated for the 'discounted' rates of rise for each timeframe as presented in Table 2.2.

For the Peka Peka cell the effect of RSLR was calculated by the Bruun Rule using the beach profile parameters of profiles 390, 400 and 410 and offshore profiles 44 and 45 (locations shown in Figure 5.1, beach profiles are presented in Appendix F, offshore profiles in Appendix G).

The beach parameter characteristics varied only slightly between the three beach profile sites, with dune elevations being between 5.4 m and 6.3 m, and beach width varying from 96 m up to 180 m. The offshore profiles within the cell presented by Lumsden (2003) (Appendix G) were generally steeper than those in the more northern cells and showed slight variation between the profiles with the southern profile (44) having a steeper closure slope (beach crest to the inner closure depth (1:104 to -8.7 m depth) compared 1:118 for profile 45).

These ranges of input values formed upper and lower bounds of the triangular distribution for the calculation of the range of erosion distances due to RSLR, with the average conditions being the mid-point between the upper and lower bounds. The results of these calculations are presented in Table 5.2.

Table 5.2: Projected erosion distances in the Peka Peka coastal cell from future acceleration of rates of RSLR where '-' indicates erosion and '+' indicates accretion.

Timeframe	Magnitude of Absolute RSLR	Profile 390 (Waikanae Beach settlement)	Profile 400 (Peka Peka Settlement)	Profile 410 (north Te Kowhai Stream)
2050 (30 years)	0.2 m	-8.8 ± 0.2 m	-9.8 ± 0.5 m	-8.7 ± 0.2m
	0.4 m	-23.4 ± 0.5 m	-26 ± 1.3 m	-23.1 ± 0.6 m
2070 (50 years)	0.3 m	-12.2 ± 0.3 m	-13.6 ± 0.7 m	-12.0 ± 0.3 m
	0.7 m	-41.1 ± 0.9 m	-46.1 ± 2.2 m	-40.9 ± 1.1 m
2120 (100 years)	0.6 m	-24.3 ± 0.5 m	-27.1 ± 1.3 m	-24.1 ± 0.7 m
	0.85 m	-42.6 ± 0.94 m	-47.5 ± 2.3 m	-42.1 ± 1.1 m
	1.25 m	-71.9 ± 1.6 m	-80.0 ± 3.9 m	-71.0 ± 1.9 m
	1.65 m	-101.1 ± 2.2 m	-112.6 ± 5.4 m	-99.9 ± 2.7 m

As can be seen from these results, the uncertainty in the magnitude of RSLR within each timeframe results in large increases in the projected erosion distance; with the range of distances increasing as the uncertainty in RSLR increases. For example, there is a 14 m increase in projected average erosion between the lower and upper RSLR scenario for 2050, compared to a 100 m increase in projected average erosion between the lower and upper RSLR scenarios for 2120.

In contrast, the longshore differences in the projected erosion distances between the profiles are an order of magnitude smaller (1 m for 0.2 m RSLR by 2050, 12 m for 1.65 m RSLR by 2120). Likewise, the small variations in closure slopes for upper and lower bounds of input parameters result in only a very narrow range of values for sea level rise effects within the same RSLR scenario. While these ranges of uncertainty appear low, they are strongly influenced by the small variations in the input data, and do not take account of the limitations in the method for calculating SLR effects.

5.4.3 Short-term Storm Erosion

The short-term component for Ōtaki was based on post-storm observations from Gibbs and Wilshere (1976) following the September 1976 storm, which was later assessed to be a 0.5% AEP event (Lane et al, 2012). The observations indicated that there was an upper limit of 10 m of erosion at Peka Peka.

For the probabilistic method, a conservative approach was taken by applying the -10 m upper limit as the mean for a quasi-distribution, with ± 50% to give an upper bound of the triangular distribution of -15 m erosion and a lower bound of -5 m erosion.

5.4.4 Dune Stability

The dune stability component for Peka Peka is based on an analysis of three surveyed profiles located within the cell (profile 390, 400, and 410, see Figure 5.1 for locations) and angle of repose of dry sand (30 to 34 degrees). For the probabilistic method, the following distributions were formed based on beach profile survey data:

- At profile 390, the mean erosion from dune stability is -3.1 m, with upper and lower bounds of -4.0 m and -2.3 m respectively.
- At profile 400, the mean erosion from dune stability is -2.5 m, with upper and lower bounds of -3.5 m and -2.1 m respectively.
- At profile 410, the mean erosion from dune stability is -3.2 m, with upper and lower bounds of -3.8 m and -2.7 m respectively.

5.5 Projected Coastal Erosion Distances

The resulting CED's calculated by the probabilistic method are presented below. Maps displaying the spatial location of the present-day hazard and PFSP are presented in maps 6-9 of Appendix A (2050), Appendix B (2070), and Appendix C (2120).

5.5.1 Present-day Erosion Susceptibility

The present-day erosion hazard is representative of the potential erosion hazard which could occur if a large storm were to happen in the immediate/near future. This present-day hazard is a combination of the short-term storm erosion (Section 5.4.3) and the dune stability factor (Section 5.4.4). It represents the dynamic nature of shoreline movements where short-term erosion can occur independently of long-term trends or RSLR. For the Peka Peka open coast cell, the present-day hazard was calculated to 'most likely' be -12 m to -14 m of erosion, with erosion unlikely to exceed -16 m.

5.5.2 Future Coastal Erosion Susceptibility

The raw outputs from the Monte Carlo simulation of the landward limit of 'most likely' zone (P33 position) for the three timeframes are presented below in Figure 5.5 to give an indication of the changes in shoreline position that could be expected to be over the next 100 years. It should be noted that these raw distances (Appendix J) have been smoothed in the mapping outputs for coastal process plan-shape considerations, as well as consideration of future inlet migration, and therefore the raw outputs may not be able to be directly correlated with the PFSP shorelines mapped in Appendices A, B, and C. It should also be noted that distances mentioned in the text have been rounded to the nearest 0.5 m.

The following provides a summary of the projected erosion distances to the landward limit of the most likely zone (P33) across each RSLR scenario.

When comparing erosion distances across the lower and upper RSLR scenarios for different timeframes, it is recognised that some results may appear counter-intuitive. This is due to the greater influence of the short-term and dune stability components over shorter time frames. As a result, erosion distances in 2050 for 0.2m RSLR can be greater than erosion distances in 0.6 m RSLR for 2120. Similarly, erosion distances for upper RSLR scenarios over shorter timeframes (e.g. 0.7m RSLR 2070) can be greater than lower SLR scenarios over a longer timeframe (e.g. 0.6 m RSLR 2120).

2050

As shown in Figure 5.5, the Waikanae Beach shoreline north of the Waimeha stream hydrosystem cell (transects 380-396) is projected to erode an average of -9 m with 0.2 m of RSLR, and an average of -23 m under a RSLR of 0.4 m. The shoreline between Waikanae Beach and Peka Peka (transects 397-412) is projected to erode an additional -2 m on average under both RSLR scenarios.

The Peka Peka coast (transects 413-455) is projected to erode an average of -13 m with 0.2 m of RSLR, which increases to -26 m of erosion with 0.4 m of RSLR. North of the Te Kowhai Stream hydrosystem cell, the erosion distances are projected to decrease due to the slightly higher historical accretion rates in this area, and is projected to erode an average of -2 m with 0.2m RSLR, increasing to -16 m of erosion with 0.4 m of RSLR.

The results indicate the projected erosion within this cell under the lower 0.2 m RSLR scenario are predominantly in response to the short-term and dune stability erosion components. However, under the higher 0.4 m RSLR scenario there is a small net erosion as the increase in sea level rise starts to override the contemporary accretion rate.

2070

The 2070 Waikanae Beach shoreline north of the Waimeha Stream is projected to erode an average of -3 m, increasing to -32 m with 0.7 m of RSLR. Similar to the 2050 scenarios, the shoreline north of the settlement (transects 397-412) is only projected to erode by an additional -2 m to that at Waikanae.

For Peka Peka settlement shoreline, erosion distances averaging 10 m are projected with 0.3 m of RSLR over this period, increasing to -43 m with 0.7 m RSLR.

Projected erosion distances decrease in a northward direction north of the Te Kowhai Stream, where the shoreline is projected to accrete by an average of +9 m with 0.3 m RSLR., However, this switches to erosion at 0.7 m RSLR with a projected average erosion distance of -20 m along this stretch coast.

As with the projections to 2050, the results indicate the projected erosion distances over the next 50 years, under the lower RSLR scenario of 0.3 m, are predominantly in response to the short-term and dune stability erosion factors. However, under the higher 0.7 m RSLR scenario there is net erosion due to sea level rise overriding the contemporary rate of accretion.

2120

Under the lowest RSLR scenario of 0.6 m (RCP2.6 plus 1 mm/yr VLM) over the 100-year timeframe, on average, the shoreline south of Peka Peka is projected to accrete, however, this switches to becoming erosional if RSLR increases to 0.85 m (RCP4.5 plus 2mm/yr VLM) or higher. Along the Waikanae Beach coast, north of the Waimeha Stream, the projected accretion under the lowest RSLR scenario (0.6 m) is an average of +7.5 m, switching to average erosion of -11 m when RSLR reaches 0.85 m, -40 m with RSLR of 1.25 m (RCP8.5 plus 2 mm/yr VLM), and -70 m of erosion under the highest RSLR scenario of 1.65 m (RCP8.5H+ plus 3mm/yr VLM).

The shoreline position between Waikanae Beach and Peka Peka is projected to remain stable under the lowest scenario of 0.6 m RSLR (average accretion of +0.4 m) and retreat slightly more than the southern section under higher rates of RSLR; averaging -18 m with 0.85 m RSLR, -47 m with 1.25 m RSLR, and -77 m under the highest 1.65 m RSLR scenario.

For the Peka Peka settlement coast, erosion is predicted under all RSLR scenarios. Under the lowest scenario of 0.6 m RSLR over the 100-year period, the shoreline is projected to erode by -8 m, made up entirely of the present-day hazard components. The erosion distance is projected to increase under the 0.85 m RSLR scenario to average of -28 m, increasing -60 m with a 1.25 m RSLR, and -93 m with 1.65 m RSLR.

North of Te Kowhai Stream projected future shorelines are calculated to be accretional under the two lowest RSLR scenarios over the 100-year period. With 0.6 m of RSLR, this shoreline is projected to accrete by an average of +31 m, decreasing to an average of +15 m with 0.85 m of RSLR. This changes to be erosional with an average retreat distance of -14 m at 1.25 m of RSLR, increasing to an average of -45 m of erosion with 1.65 m of RSLR. For all but the highest RSLR scenario, these average erosion distances are completely due to the present-day hazard components.

5.5.3 Comparison of results to previous coastal hazard assessments

The results of the PFSP presented in Section 5.5.2 are calculated to be, on average, less than previous coastal erosion assessments undertaken in the area.

The Lumsden (2003) coastal management strategy proposed a -75 m 'Secondary Development Setback' from Waikanae to Peka Peka, which was a deterministic approach for assessing the long-term trend at the site and the effect of a 0.45 m RSLR over the next 100 years. Comparatively, our lowest RSLR projection over a 100-year period was 0.6 m, which across the Peka Peka cell, produced an upper bound of maximum 'most likely' positions (P33) of -18 m, and an average of +14 m of shoreline accretion. The accretion distances north of the Te Kowhai Stream were projected to be up to 100 m.

Compared to the more recent CSL (2008 & 2012) coastal hazard assessment, the results produced in this study are also less. For a 0.3 m RSLR over the 50-year scenario (e.g. 2070), CSL (2008 & 2012) calculated an average erosion distance of -27.5 m across the Peka Peka cell. These results did not include extrapolation of accretion rates in the CED calculations, instead assuming a static shoreline with future sediment supply, such that all future shoreline change will be due to the effects of RSLR, short-term storms, and dune stability factors following a storm event. However, as detailed above, in this assessment for the same magnitude of RSLR (0.3 m), the inclusion of extrapolated accretion rates from the last 70 years in the projection results in a stable shoreline throughout the Peka Peka cell, with a maximum 'most likely' erosion of -15 m at the Peka Peka settlement. However, it is also noted that within this 50-year time frame, average erosion distances are projected to be 30-40 m under a 0.7 m RSLR scenario.

It is noted that for the other erosion components, the erosion distances from CSL (2008) were similar to those obtained in the current assessment. For example, CSL (2008) calculated -13 m to -19 m of erosion across the cell due to 0.3 m of RSLR, compared to our assessment which calculated -12 m to -14 m of erosion. CSL (2008) calculated a combined dune stability and short-term erosion component of -13 m to -16 m, compared to our assessment that calculated a present-day hazard (see Section 5.5.1) that was 'most likely' to be -12 m to -14 m, and unlikely to exceed -16 m.

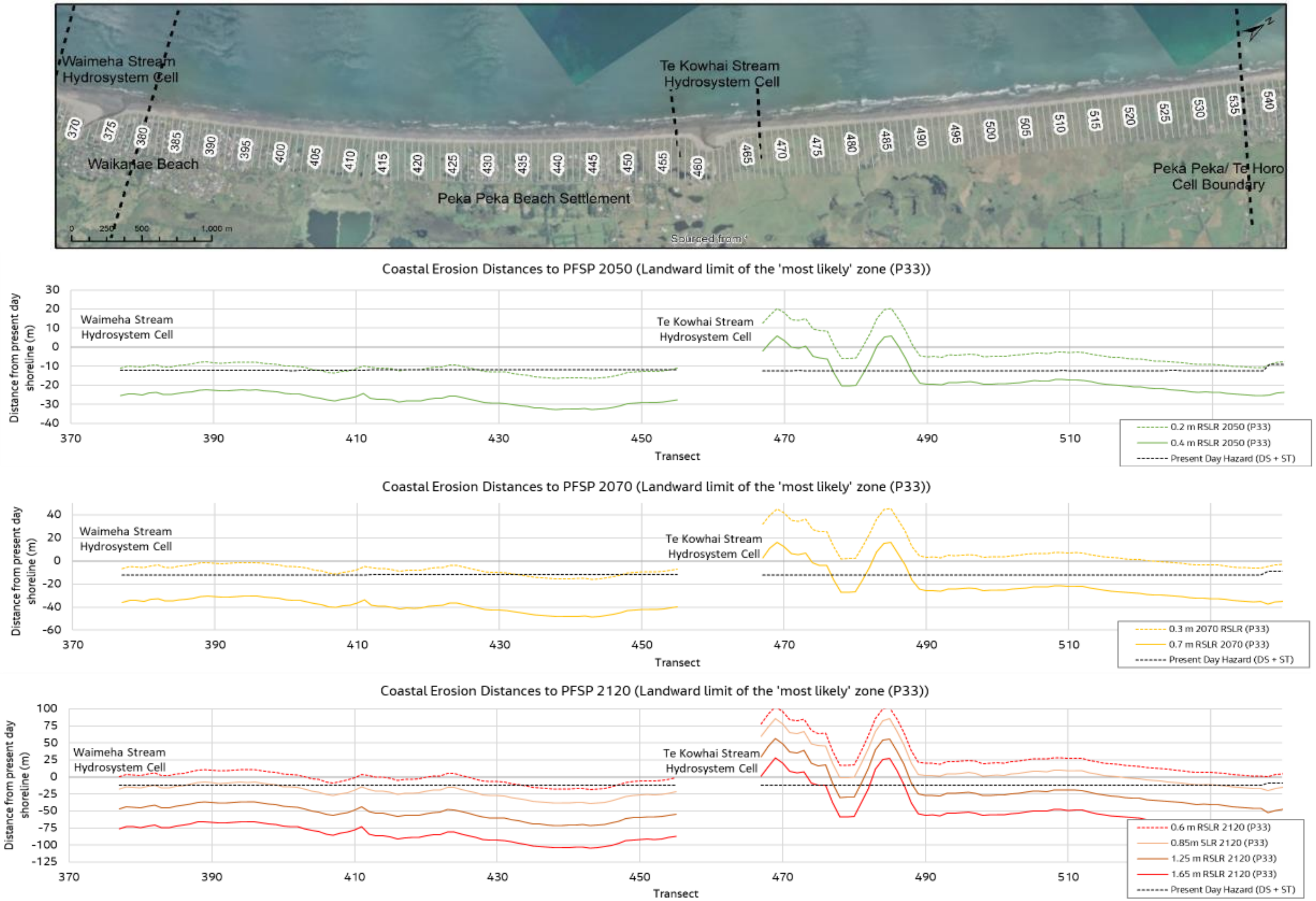


Figure 5.5: Erosion distances to projected future shoreline positions under future RSLR scenarios.

5.6 Te Kowhai Stream

The Te Kowhai Stream hydrosystem cell is located at the northern end of the Peka Peka settlement, within the Peka Peka coastal cell. Te Kowhai Stream has a generally low volume flow and a small meander envelope at the coast with no structures having been built to constrain the river mouth position. The hydrosystem generally has an accretionary trend, as the inlet migrates seaward in line with the adjacent shoreline trends as shown in Figure 5.6.

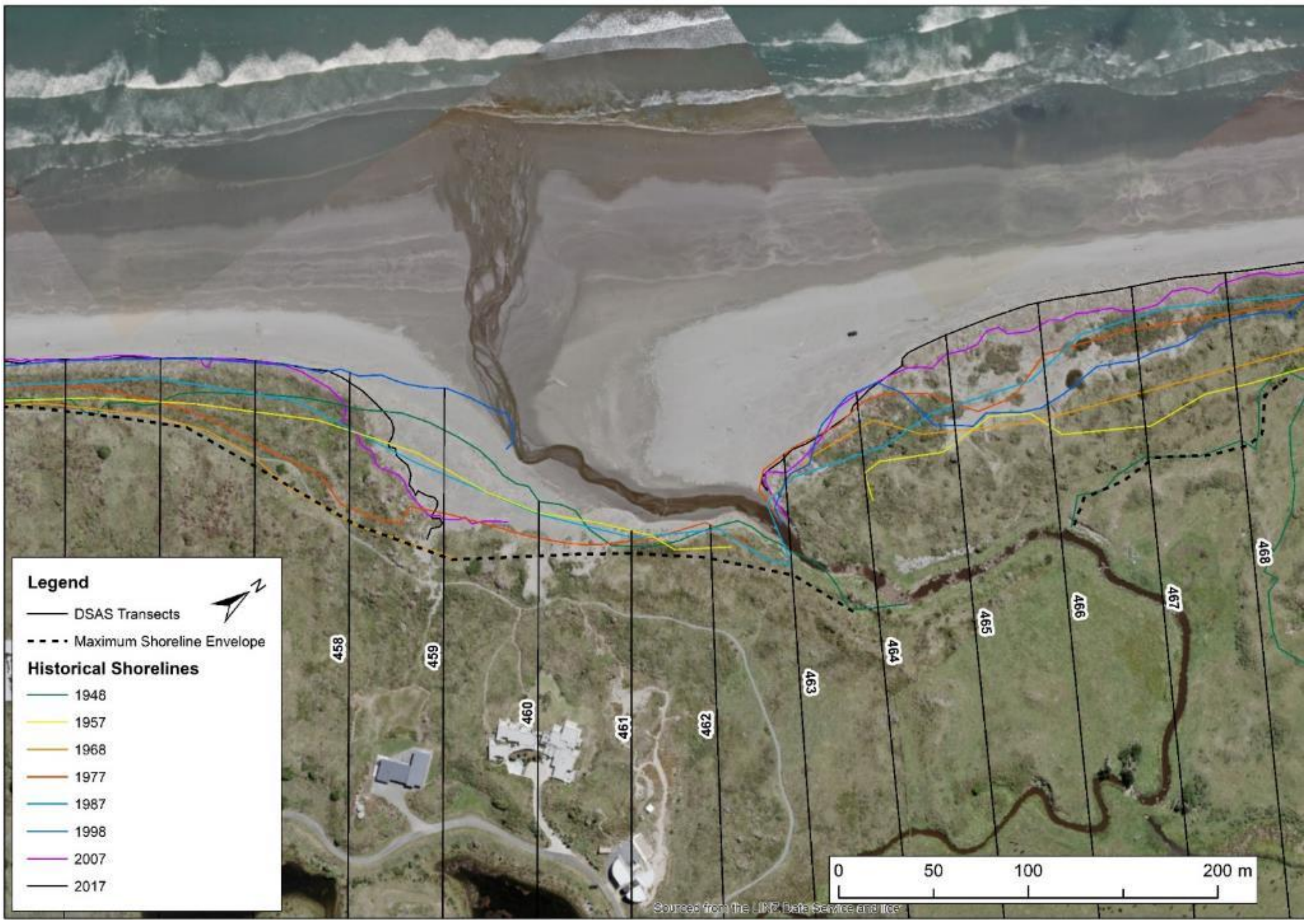


Figure 5.6: Historical shorelines and maximum shoreline envelope at Te Kowhai Stream.

Due to the accretional nature of the adjacent shoreline, and the net positive movement of the inlet itself, Method 3 from the coastal hydrosystem decision tree, being the maximum historical hydrosystem shoreline position (see Section 2.2.7) was used to indicate the possible future migration of the hydrosystem. This is recognised as conservative, due to the accretional nature of the adjacent shoreline, as there is no coastal process reason to expect that the hydrosystem shoreline would erode back to the 1948 position in the future whilst the open coast continues to accrete. However, to give an indication of the spatial limits of where the hydrosystem has been in the past, this historical maximum envelope of the river mouth environment has been used, as marked by the black dotted line in Figure 5.6, are shown in Map 7 of Appendix A, B, and C, and in more detail in Appendix D (hydrosystems).

Under the higher RSLR scenarios in the 50- and 100-year timeframes (0.7 m RSLR 2070 and 1.65 m RSLR 2120), the southern shoreline adjacent to the hydrosystem cell is projected to erode further landward than the extent of the historical envelope. In these two scenarios, a Method 2 approach is adopted, where the shape of the current shoreline is translated landward to meet the landward extent of the projected future shoreline position. This approach is only adopted on the southern side of the inlet under both RSLR scenarios, as the shoreline north of the inlet is projected to only erode a small amount, not beyond the historical envelope, under the same RSLR scenarios.

5.7 Waimeha Stream

The Waimeha Stream hydrosystem is located at the southern end of the cell between the Peka Peka coastal cell boundary and the Waikanae coastal cell boundary, for which the historical shoreline positions are presented in Figure 5.7. There are no river training structures located within the hydrosystem cell, however, the edges of the historical envelope (see black dotted line in Figure 5.7) align with coastal properties and therefore may be controlled by structures. The shorelines adjacent to the hydrosystem have shown to be historically accretional, with the mouth of the stream migrating from north to south over the observed period. The inlet itself has been in a generally accretional state since 1948.

Figure 5.7: Historical shorelines and maximum shoreline envelope at Waimeha Stream.

Due to the accretional nature of the adjacent shoreline, and the net positive movement of the inlet itself, Method 3 from the coastal hydrosystem decision tree, being the maximum historical hydrosystem shoreline position (see Section 2.2.7), was used to indicate the possible future migration of the hydrosystem. This is recognised to be a conservative approach, as due to the accretional nature of the adjacent shoreline, there is no coastal process reason to expect that the hydrosystem shoreline would erode back to this 1948 position in the future whilst the open coast continues to accrete. However, to give an indication of the spatial limits of where the hydrosystem has been in the past, this historical maximum envelope of the river mouth environment has been used, as marked by the black dotted line in Figure 5.7, are shown in Map 9 of Appendix A, B, and C, and in more detail in Appendix D (hydrosystems).

By the higher RSLR scenario in 2120 (1.65 m RSLR), the adjacent shorelines to the hydrosystem cell are projected to erode beyond the historical envelope extent. Therefore, it is projected that the edge of the hydrosystem cell would merge into the open coast PFSP, as illustrated in Map 9 of the 2120 projections (Appendix C), however, the migration of the inlet closer to the stream mouth is not projected to be landward of the historical maximum extent.

5.8 Vulnerability

5.8.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified affected council critical infrastructure and community services that intersected with mapped PFSP up to the landward limit of the most likely PFSP (P33). The results of this assessment are presented in Table 5.3

Table 5.3: Council critical infrastructure and community services affected in Peka Peka cell under various sea level rise scenarios.

	RSLR Scenarios							
	2050		2070		2120			
Asset	**0.2m**	**0.4m**	**0.3m**	**0.7m**	**0.6m**	**0.85m**	**1.25m**	**1.65m**
Coastal Stormwater Outlet (1)	2	3	2	3	0	**3**	3	3
(1) Number of outlets intersecting with landward limit of PFSP							(2)	(3)

Coastal stormwater outlets were the only critical infrastructure or community services identified to be affected in the Peka Peka cell. For the lower RSLR scenarios in the 2050 and 2070, two stormwater outlets could become affected by coastal erosion, which increases to three outlets under the higher RSLR scenarios (0.4 m 2050 and 0.7 m 2070). There are no stormwater outlets projected to be affected under 0.6 m 2120 scenario due to the extrapolation of the higher accretion rate over this 100-year period, however, under the three other RSLR scenario over this timeframe, three stormwater outlets are projected to be affected.

5.8.2 Land parcels

The number of land parcels (public and private) which intersect with the PFSP up to the landward limit of the 'most likely' position (e.g. P33) and the landward limit of the 'unlikely' position (e.g. P10) were calculated to give an indication of vulnerability of land parcels within a coastal cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels (see Section 2.4). The results of this assessment for the Peka Peka cell are presented below in Figure 5.8 and Appendix L.

From the results presented in Figure 5.8 it is shown that under the lowest RSLR scenarios across all timeframes, two public land parcels intersect with the 'most likely' and 'unlikely' PFSPs. This increases to be four, eight, and 10 land parcels under the higher RSLR scenarios for 2050, 2070 and 2120 respectively.

For private land parcels, the results indicate that over a 30-year timeframe (2050) there are seven to 10 land parcels that intersect with both PFSPs under both the lower and upper RSLR scenarios. Over the 50- and 100-year timeframes, there is a large difference in the number of private land parcels potential affected by coastal erosion between the lower and upper RSLR scenarios. Over a 50-year timeframe (2070) there are two properties intersecting with the 'most likely' PFSP for a 0.3 m RSLR, which increases to 57 land parcels with 0.7 m of RSLR. By 2120, under the lower RSLR scenario (0.6 m) only one private land parcel intersects with the 'most likely' PFSP, increasing to 17 parcels with a RSLR of 0.85 m, 73 parcels with a RSLR of 1.25 m and 127 parcels with a RSLR of 1.65 m . It is counter-intuitive that considerably less land parcels are affected over 2120 timeframe with 0.6 m RSLR than for 0.7m RSLR in 2070. This is due to the relatively higher influence of the extrapolated historical accretion rate to the erosion effect of accelerated sea level rise in each of the lower RSLR scenarios compared to the upper RSLR scenarios, where the effects of accelerated sea level rise are dominant.

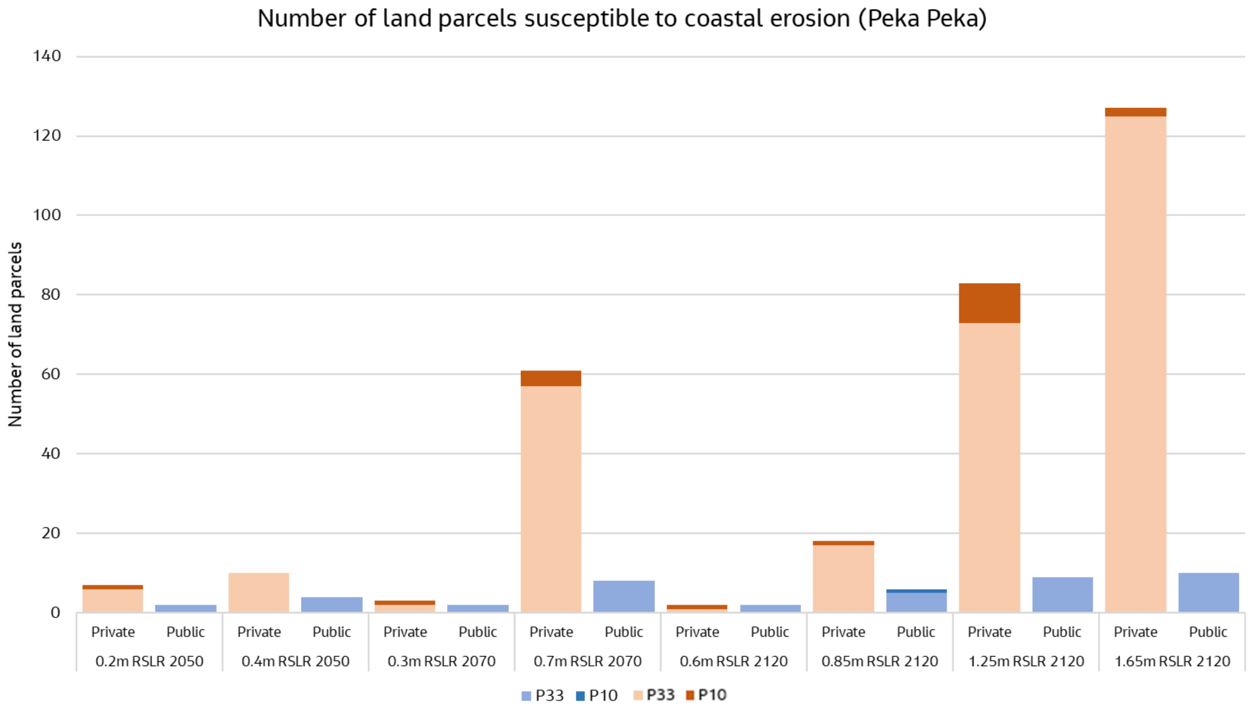


Figure 5.8: Number of public and private land parcels in Peka Peka potentially susceptible to coastal erosion. Lighter orange/blue show the number of properties susceptible to erosion up to the P33 (landward limit of the most likely), with the darker blue/orange showing additional parcels potentially affected between the P33 and P10 shoreline position.

In terms of private property potentially affected by coastal erosion, Peka Peka is the third most vulnerable cell, behind the Raumati and Paekākāriki coastal cells.

At the Te Kowhai Stream hydrosystem cell (Section 5.6), over a 30-year timeframe only one private and two public land parcels intersect with the potential future hydrosystem position with a 0.4 m RSLR. This increases to three private and three public land parcels with 0.7 m RSLR by 2070, and to six private and three public land parcels with 1.65 m RSLR by 2120.

For the Waimeha Stream hydrosystem cell (Section 5.7), no public land parcels intersect with the potential future hydrosystem position over all timeframes and RSLR scenarios. For both RSLR scenarios in 2050 and 2070, 30 private land parcels intersect with the potential future hydrosystem position. This increases under the highest RSLR scenario in 2120 (1.65 m) to be 35 land parcels.

6. Waikanae Coastal Cell

6.1 Summary

The Waikanae Coastal Cell covers approximately 2 km of shoreline from the Waimeha Stream to the Waikanae River. The cell is located at the northern end of the wave shadow created by Kāpiti Island; therefore, wave energy is reduced relative to cells further north. Sediment is supplied to this area predominantly from the north via longshore transport and to a lesser degree, from the Waikanae River. There is a good supply of sediment creating a long-term accretionary trend throughout the cell.

The shoreline in the Waikanae cell is generally projected to continue to accrete, or experience a small amount of erosion (less than the present-day hazard) under the lower RSLR scenarios in each timeframe, but is projected to erode under the higher RSLR scenarios due to the effects of greater rates of SLR outpacing the rate of accretion from longshore transport. At Waikanae Beach, erosion under the highest RSLR scenarios is projected to be in the order of -18 m over the next 30 years (0.4 m - 2050), and -26 m over the next 50 years (0.7 m - 2070). For the 100-year scenarios, long-term erosion is projected to occur for RSLR greater than 0.85 m, increasing to -35 m for RSLR of 1.25 m, and up to -60 m for RSLR of 1.65 m.

Coastal stormwater outlets are the only council critical infrastructure identified as intersecting with PFSP, with up to 6 outfalls potentially affected by coastal erosion. Depending on the magnitude of RSLR, between 6 to 28 private proprieties intersect the 'most likely' PFSP within the next 30 years; 3 to 59 within 50 years; and over 100 within 100 years. An additional three to four public land parcels could be affected by potential future migration at the Waikanae River over all timeframes and RSLR scenarios. Three to four additional private land parcels could be affected by inlet migration around the Waikanae River across all RSLR scenarios up to 2070, increasing up to 30 private land parcels for the maximum 2120 scenario (RSLR 1.65 m). This places the Waikanae cell fifth out of eight for vulnerability of private proprieties to projected future coastal erosion.

This coastal cell and the results are discussed in more detail in the sections below.

6.2 General Description

The Waikanae coastal cell covers approximately 2 km of shoreline from the southern boundary of the Waimeha Stream hydrosystem cell to the northern boundary of the Waikanae River hydrosystem cell, as shown in Figure 6.1. This figure also presents the location of key data reference points within this cell (e.g. DSAS transects, beach and bathymetric profiles). While no hydrosystem cells are included within the coastal cell, the Waikanae River hydrosystem cell will be discussed in Section 6.6. The Waimeha Stream hydrosystem was discussed in Section 5.7 as part of the Peka Peka coastal cell.

The Waikanae coastal cell is a short section of shoreline which makes up the frontage of the Waikanae Beach settlement south of the Waimeha Stream. The larger Waikanae Beach settlement (including north of the Waimeha Stream) has approximately 3,250 residents and 2,100 private dwellings (Statistics New Zealand, 2018). The land within the Waikanae cell is mostly residential properties, with some small reserves and parks.

The coastal environment within the Waikanae coastal consists of a sandy beach backed by dunes that reach elevations of up to 7.0 m WVD-53, which provide a contiguous natural buffer to coastal hazards along the Waikanae Beach shoreline. Many dwellings sit on or slightly behind this high dune, as shown in Figure 6.2

The dunes provide good natural protection from the effects of coastal erosion and inundation for the residential properties in the settlement. The dune varies in width along the shore but is generally in the order of 25 to 30 m wide.

The cell is located at the northern end of the wave shadow created by Kāpiti Island, and therefore wave energy is reduced from the cells further north, which influences the closure depths for the calculation of erosion effects from RSLR (see section 6.3.2). Sediment is supplied predominantly from the north via longshore transport (see section 2.1 of Volume 1 Methodology report) and contributes enough material for a long-term accretionary trend along the length of the cell. The Waikanae River also contributes an estimated 4,000 m^3/yr of sand to local coastal sediment budget (Tonkin & Taylor, 2018). The combination of the wave shadow effect and local sediment supply results in a transition of shoreline orientation to being more to the northwest compared to the shoreline to the north, and this marks the being of the cuspate foreland that has formed in the lee of Kāpiti island. Based on the analysis of volume changes in the beach profile record, average accretion volumes are estimated to be in the order of 9,600 m^3/yr (4.8 m^3/m/yr) across the cell (see Appendix H).

Figure 6.1: Waikanae Coastal Cell key features and data reference points (DSAS transects, beach and bathymetric profiles).

Figure 6.2: Alongshore view facing north of Waikanae Beach, showing proximity and elevation of residential houses in the backshore.

6.3 Structures

There are no coastal protection structures located in the Waikanae Coastal Cell. Within the Waikanae River hydrosystem cell, there is a small causeway across the end of the Waimanu Lagoon on the north bank.

6.4 Erosion Components

6.4.1 Extrapolation of Long-term Rates

The historical shoreline changes within the Waikanae coastal cell were digitised from 7 - 8 aerial photographs across a 70-year period from 1948 to 2017. A section of the DSAS analysis at the front of the Waikanae settlement overlain on the 1948 aerial imagery is presented in Figure 6.3: Historical shorelines from 1948-2017 overlaid on 1948 aerial imagery showing rapid accretion from 1948 to 1957, then slower rates of long-term accretion through to 2017. Figure 6.3 demonstrates that rapid accretion occurred in the 1948 to 1957 period, followed by slower rates of accretion over the following 60 years to 2017. Note that this photograph pre-dates the development of the settlement. The raw rates of shoreline change over this period calculated from the DSAS analysis are presented in Figure 6.4.

The results of this analysis show that the entire length of the Waikanae open coast cell has experienced accretion. Accretion rates are slightly higher closer to the Waikanae River mouth relative to rates seen at the northern end of the cell near the Waimeha Stream. Along the Waikanae Beach shoreline (transects 324-364), the average historical accretion rate is +0.41 m/yr, with a range of +0.61 m/yr (transects 328) to +0.14 m/yr (transect 360). In the southern half of the cell (transect 324-345), the R^2 values are lower (generally 0.4-0.5) compared to the northern half of the cell (>0.8), due to the rapid accretion that occurred between 1948-1957, as shown in Figure 6.3.

The upper and lower bounds of the triangular distribution for the probability approach were taken as being ± the 90% confidence level of the average rate from the linear regression. The resulting lower bound still resulted in beach accretion at all transects.

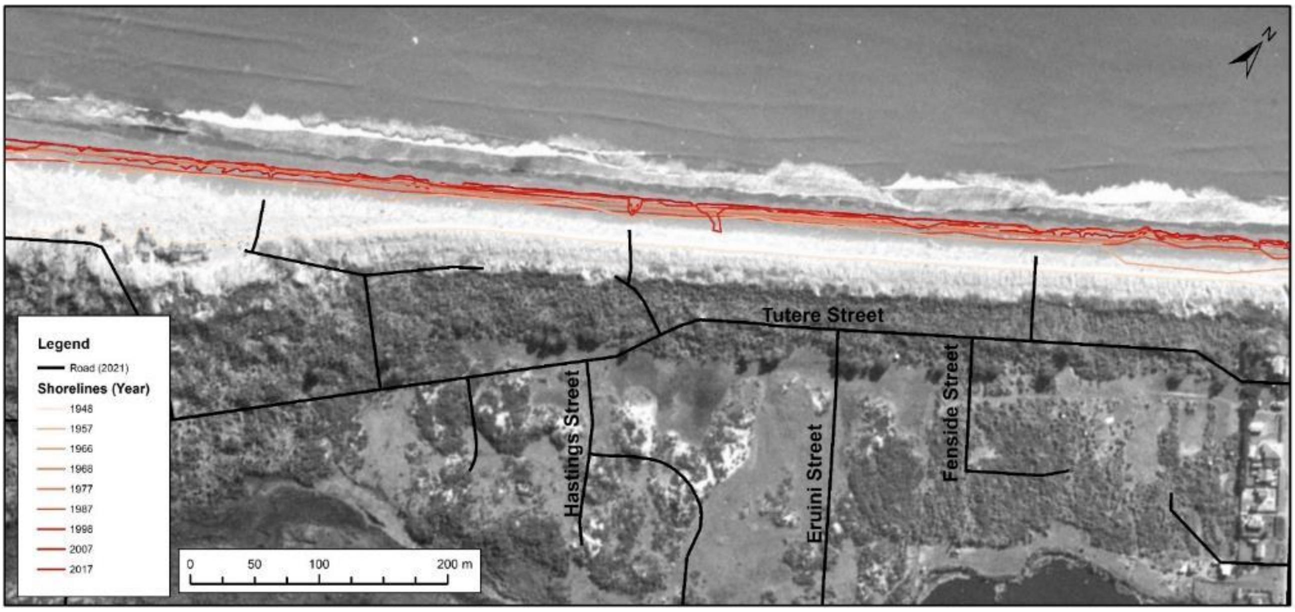


Figure 6.3: Historical shorelines from 1948-2017 overlaid on 1948 aerial imagery showing rapid accretion from 1948 to 1957, then slower rates of long-term accretion through to 2017.

The extrapolation of the average and 90% confidence interval rates into the future results in the beach accretion distances presented in Table 6.1.

Table 6.1: Projected shoreline accretion distances in the Waikanae coastal cell from the extrapolation of average long-term rates of shoreline movement from aerial photographs 1948-2017.

Transects	Next 30 years (by 2050)	Next 50 years (by 2070)	Next 100 years (by 2120)
Waikanae Settlement (Transects 324-364)	+12.2 (±8.1) m	+20.3 (±13.5) m	+40.6 (± 27.0) m
The distances in brackets are the upper and lower bounds of uncertainty, being the 90% confidence interval of the LRR from the DSAS.			

6.4.2 Effect of Future Accelerated Sea Level Rise

As explained in Section 2.2.3, to avoid 'double accounting' of contemporary sea level rise and to isolate the effects of RSLR to being just for the acceleration in the rate of rise, the resulting erosion distances are calculated for the 'discounted' rates of rise for each timeframe as presented in Table 2.2.

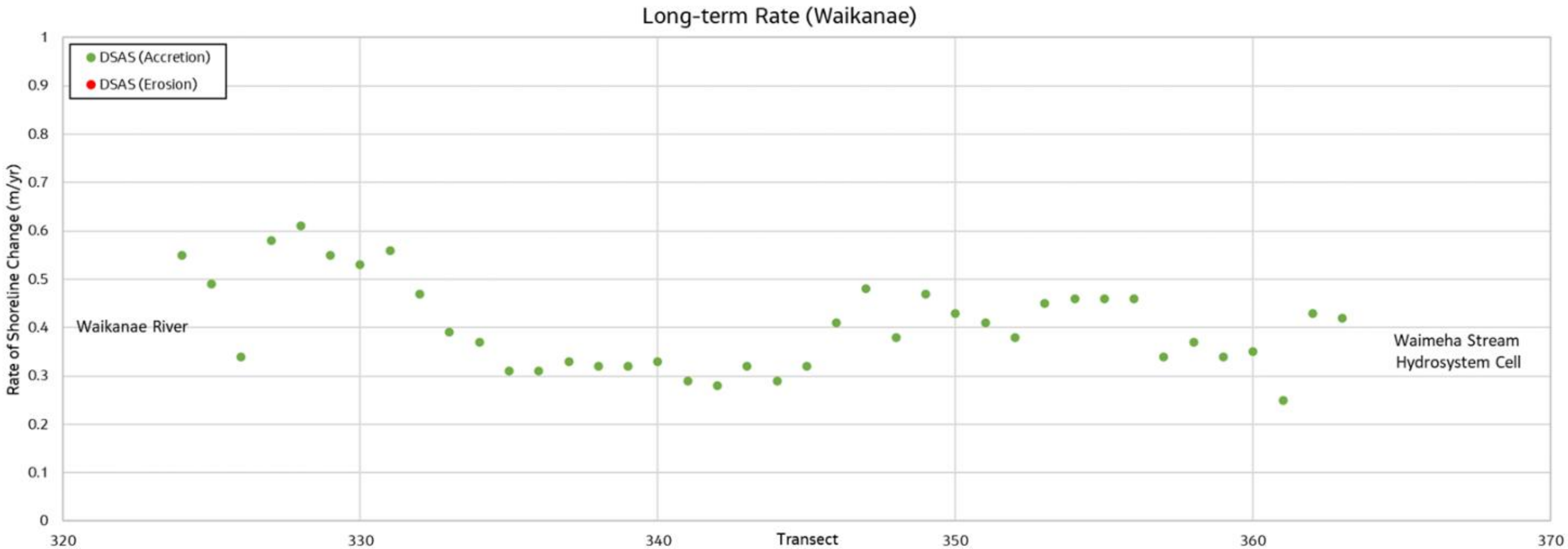


Figure 6.4: Long-term rates for the Waikanae coastal cell calculated from DSAS.

For the Waikanae coastal cell, the effect of RSLR was calculated by the Bruun Rule using the beach profile parameters of profile 370 and 380 and offshore profile 43 (locations shown in Figure 6.1) beach profiles are presented in Appendix F, offshore profiles in Appendix G).

Both beach profiles had similar beach heights (6.3 to 7 m), with a small range of beach width[12] (85-115 m at both profiles). Offshore profile 43 presented by Lumsden (2003) positioned at the same location as at profile 380 was used for both profiles, so there is no variation in the offshore profile characteristics applied within this cell. As a result, this analysis there is little variation in the input values for the upper and lower bounds of the triangular distribution for the calculation of the range of erosion distances due to RSLR, so the uncertainty in the projected erosion distances due to uncertainty in the input parameter is also correspondingly small. The results of these calculations are presented in Table 6.2.

As can be seen from these results, the uncertainty in the magnitude of RSLR within each timeframe results in large increases in the projected erosion distance; with the range of distances increasing as the uncertainty in RSLR increases. For example, there is a 12-13 m increase in projected average erosion between the lower and upper RSLR scenario for 2050, compared to a 65-67 m increase in projected average erosion between the lower and upper RSLR scenarios for 2120.

In contrast, the longshore differences in the projected erosion distances between the profiles are significantly smaller (< 1m for 0.2 m RSLR by 2050, 3 m for 1.65 m RSLR by 2120). Likewise, as noted above the small variations in upper and lower bounds of the input parameters result in only a very narrow range of values for SLR effects within the same RSLR scenario. While these ranges of uncertainty appear low, they are strongly influenced by the small variations in the input data, and do not take account of the limitations in the method for calculating SLR effects.

Table 6.2: Projected erosion distances in the Waikanae coastal cell from future acceleration of rates of RSLR where '-' indicates erosion and '+' indicates accretion.

Timeframe	Magnitude of Absolute RSLR	Profile 370	Profile 380
2050 (30 years)	0.2 m	-7.4 (± 0.2) m	-7.7 (± 0.2) m
	0.4 m	-19.7 (± 0.6) m	-20.5 (± 0.4) m
2070 (50 years)	0.3 m	-10.3 (± 0.3) m	-10.7 (± 0.2) m
	0.7 m	-34.9 (± 1.0) m	-36.3 (± 0.7) m
2120 (100 years)	0.6 m	-20.5 (± 0.6) m	-21.4 (± 0.4) m
	0.85 m	-35.9 (± 1.0) m	-37.4 (± 0.77) m
	1.25 m	-60.5 (± 1.7) m	-63.0 (± 1.3) m
	1.65 m	-85.2 (± 2.4) m	-88.7 (± 1.8) m

6.4.3 Short-term Storm Erosion

The short-term component for Waikanae was based on post-storm observations from Gibbs and Wilshere (1976) following the September 1976 storm, which was later assessed to be a 0.5% AEP event (Lane et al, 2012). The observations indicated that there was an upper limit of 5 m of erosion at Waikanae.

For the probabilistic method, a conservative approach was taken by applying the -5 m upper limit as the mean for a quasi-distribution, with ± 50% to give an upper bound of the triangular distribution of -7.5 m erosion and a lower bound of -2.5 m erosion.

[12] Beach width is the distance between the beach crest and the 0 m contour.

6.4.4 Dune Stability

The dune stability component for Waikanae is based on an analysis of the two surveyed profiles located within the cell (profile 370 and 380, see Figure 6.1 for location). For the probabilistic method, the mean erosion from dune stability for profile 370 is -3.8 m, with upper and lower bounds of -4.6 m and -3.1 m respectively. This has been applied to transects 323 to 342 (see Figure 6.1 for locations). For Profile 380, the mean dune stability erosion is -3.4 m, with upper and lower bounds of -4 m and -2.9 m, which has been applied to transects 343 to 364.

6.5 Projected Coastal Erosion Distances

The resulting CED's calculated by the probabilistic method are presented below. Maps displaying the spatial location of the present-day hazard and PFSP are presented in maps 9 and 10 of Appendix A (2050), Appendix B (2070), and Appendix C (2120).

6.5.1 Present-day Erosion Susceptibility

The present-day erosion hazard is representative of the potential erosion hazard which could occur if a large storm were to happen in the immediate/near future. This present-day hazard is a combination of the short-term storm erosion (Section 6.4.3) and the dune stability factor (Section 6.4.4). It represents the dynamic nature of shoreline movements where short-term erosion can occur independently of long-term trends or RSLR. For the Waikanae open coast cell, the present-day hazard was calculated to 'most likely' be -8 to -9 m of erosion, with erosion unlikely to exceed -10 m.

6.5.2 Future Coastal Erosion Susceptibility

The raw outputs from the Monte Carlo simulation of the landward limit of 'most likely' zone (P33 position) for the three timeframes are presented in Figure 6.5 to give an indication of the changes in shoreline position that could be expected to be over the next 100 years. It should be noted that these raw distances (Appendix J) have been smoothed in the mapping outputs for coastal process plan-shape considerations, as well as consideration of future inlet migration, and therefore the raw outputs may not be able to be directly correlated with the PFSP shorelines mapped in Appendices A, B, and C. It should also be noted that erosion distances mentioned in the text have been rounded to the nearest 0.5 m.

The following provides a summary of the projected erosion distances to the landward limit of the most likely zone (P33) across each RSLR scenario.

In general, the CED's are relatively similar along the cell's shoreline length, with accretion or lower erosion distances occurring near the northern and southern end of the cell in close proximity to the hydrosystem cells where there are potentially small, localised sediment supplies. Under the lower RSLR scenarios in each timeframe, the PFSP are generally either accretional, or slightly erosional. The erosion projected under these RSLR scenarios is less than the combined short-term and dune stability components (e.g. the present-day hazard) implying that at these magnitudes of RSLR accretion from the ongoing supply of sediment will be greater than the erosion from accelerated SLR. However, under the higher RSLR scenarios in each timeframe, the projected erosion distances are greater than the present-day hazard, implying that the projected effects of accelerated sea level rise dominate over sediment supply.

When comparing erosion distances across the lower and upper RSLR scenarios for different timeframes, it is recognised that some results may appear counter-intuitive. This is due to the greater influence of the short-term and dune stability components over shorter time frames. As a result, erosion distances in 2050 for 0.2 m RSLR can be greater than erosion distances in 0.6 m RSLR for 2120. Similarly, erosion distances for upper RSLR scenarios over shorter timeframes (e.g. 0.7 m RSLR 2070) can be greater than lower SLR scenarios over a longer timeframe (e.g. 0.6 m RSLR 2120).

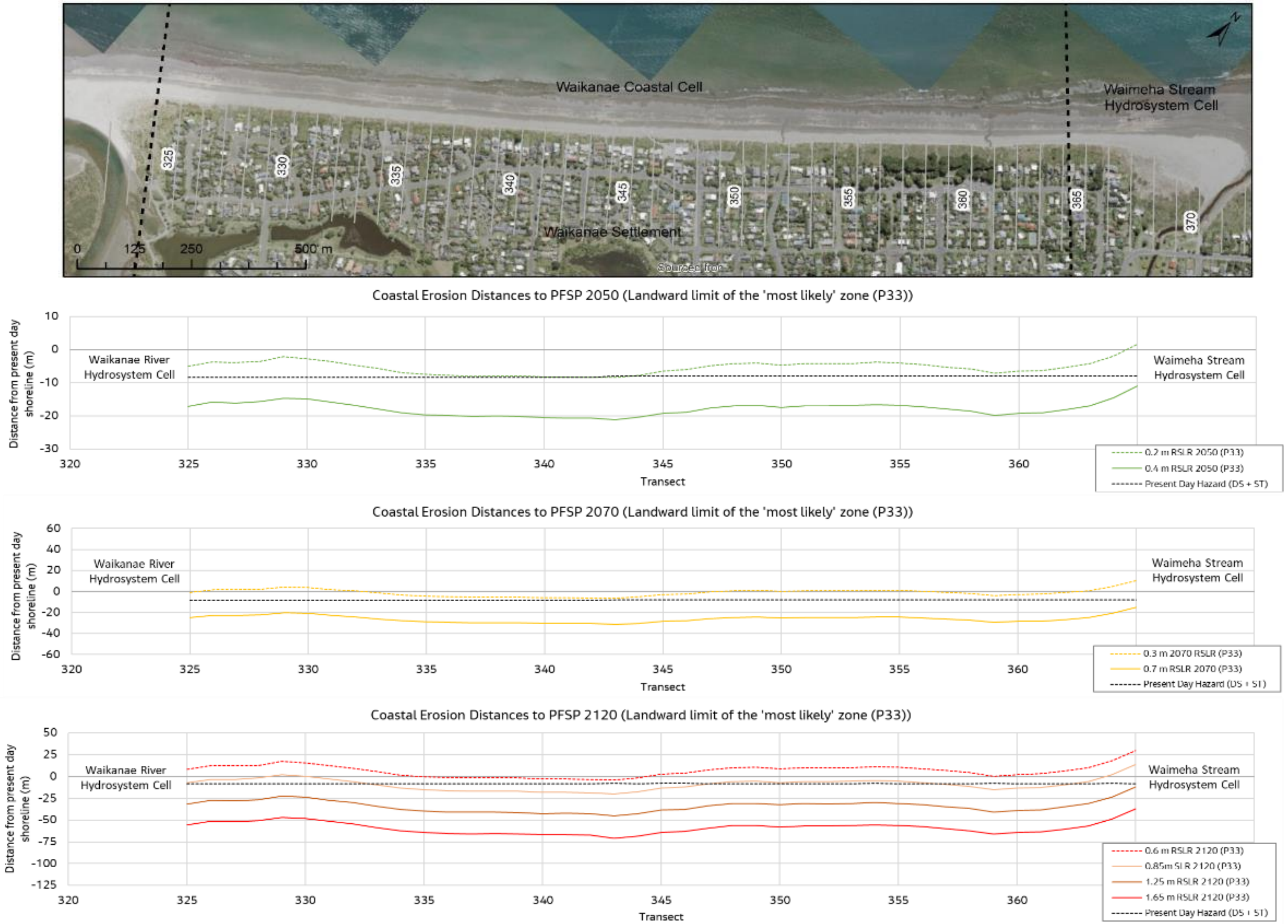


Figure 6.5: Erosion distances to projected future shoreline positions under future RSLR scenarios.

2050

As shown in Figure 6.5 , under RSLR of 0.2 m, the shoreline is projected to experience an average of -5.6 m of erosion, varying from -2 m to -8 m of erosion alongshore. These net erosion distances are driven by the inclusion of the short-term and dune stability components.

Under the 0.4 m RSLR scenario, this average erosion distance increases to be an average of -18 m, with a maximum of – 21 m projected at transect 343. Short-term and dune stability components contribute 50% of the erosion distance under this RSLR scenario.

2070

With 0.3 m of RSLR over the next 50 years, the shoreline within the Waikanae Cell is projected to experience an average shoreline erosion of -1 m, with a calculated maximum of -6 m of erosion around the centre of the cell, and some projected accretion at the northern and southern ends of the cell. The average projected erosion across the cell is again being driven by the short-term and dune stability components.

However, with 0.7 m of RSLR over the next 50 years, the Waikanae Beach shoreline is projected to experience an average of -26 m of erosion, indicating the additional RSLR effect under this scenario. Maximum erosion alongshore is projected to be – 31 m (transect 343).

2120

Under the lowest RSLR scenario of 0.6 m (RCP2.6 plus 1 mm/yr VLM), the shoreline fronting the Waikanae Beach settlement is projected to accrete by an average of +6 m, with a maximum of +17 m (transect 329) and a small amount of erosion projected (less than -4 m) across transects 335-344. With 0.85 m of RSLR (RCP4.5 plus 2mm/yr VLM), this average shoreline movement changes to being erosional, with an average projected retreat of -10 m, increasing to around -35 m with 1.25 m RSLR (RCP8.5 plus 2 mm/yr VLM), and an average of around -60 m under the highest RSLR scenario of 1.65 m (RCP8.5H+ plus 3mm/yr VLM).

6.5.3 Comparison of results to previous coastal hazard assessments

The results of the PFSP presented in Section 6.5.2 are calculated to be less than previous coastal erosion assessments undertaken in the area.

The Lumsden (2003) coastal management strategy proposed a -75 m 'Secondary Development Setback' from Waikanae to Peka Peka, which used a deterministic approach for assessing long-term trend at the site and the effect of a 0.45 m RSLR over the next 100 years. Comparatively, our lowest RSLR projection over a 100-year period was 0.6 m, which across the Waikanae cell produced an average 'most likely' position (P33) of accretion by +6 m. This difference in assessments is primarily a result of our inclusion and of the extrapolation of long-term accretion rate in this assessment, reducing the impact of RSLR in this area under lower RSLR scenarios.

Compared to the more recent CSL (2008 & 2012) coastal hazard assessment, the results produced in this study are also less. For a 0.3 m RSLR over 50 years scenario, CSL (2008 & 2012) calculated an average erosion distance of -38 m along the front of the Waikanae Beach settlement. These results did not include extrapolation of accretion rates in the CED calculations, instead assuming a static shoreline with future sediment supply, such that all future shoreline change will be due to the effects of RSLR, short-term storms, and dune stability factors following a storm event. However, as detailed above, in this current assessment for the same magnitude of RSLR (0.3 m), the inclusion of extrapolation of historical accretion rates over the last 70 years due to sediment supply in the projection results an average projected erosion of -1 m across the Waikanae cell, with a maximum 'most likely' erosion of -6 m. However, it is also noted that within this 50-year timeframe an average of around 30 m of erosion is projected to occur under a 0.7 m RSLR scenario.

Overall, individual components used in this assessment for the Waikanae Cell were generally calculated to be slightly less than the CSL assessment, however the inclusion of accretion in the extrapolation of long-term rates as part of the PFSP calculations meant that under lower RSLR scenarios the Waikanae coastal cell is expected to experience low to no erosion. While the dune stability factor used in the CSL (2008) study was similar to what was used in this assessment, the short-term erosion component was over double the erosion distance used in this assessment. A RSLR effect of -15 m of erosion was used in the CSL assessment, compared to the slightly less -11 m of erosion projected in this assessment.

6.6 Waikanae River

The Waikanae River is located between the Waikanae and Paraparaumu coastal cell. The river mouth environment of the Waikanae River is an estuary (Figure 6.6) and is defined in Hume et al (2016) as a spit enclosed tidal river mouth. The mouth undergoes a general cycle of southward migration as a result of the longshore sediment transport regime that builds the spit from the north across the mouth. Periodically, the spit is breached in large storm events and the cycle starts again. On rare occasions, the spit is cut mechanically by Greater Wellington Regional Council if the river threatens to flood properties, with the last instance occurring in 2001.

The digitised historical shorelines either side of the river mouth and extent of the estuary in the earliest 1948 image are shown in Figure 6.7. As can be seen in this figure, the southern limit of the 1948 mouth estuary extended around 500 m further south and further landward that the current southern boundary, but rapidly infilled by the time of the January 1957 image, presumably by natural causes, and has continued to progressively migrate further north at slower rates since this time. From the images, residential development of this area appears to have started some time before 1966, such that by 2017 this area was completed developed with residential housing.

Figure 6.6: Waikanae River/Estuary.

In our classification of hydrosystems (Volume 1, Section 6.7) the Waikanae River was determined to be a 'fluvial' dominated site, as opposed to 'coastal' dominated site (e.g. Waimeha Stream). As a result of this classification, the potential future extent of the hydrosystem is determined using the RSLR flood modelling scenarios produced in Part 2 of this report (0.4 m, 0.65 m, 0.85 m, 1.25 m, and 1.65 m). This approach is based on the principle that for these large river mouth environments, the morphology is shaped by both fluvial and extreme coastal events. It is assumed inundation from this combination of events would cause vegetation die back, and shape the morphology of the mouth environment.

This approach does not take into account the movement of the water through the inlet during these events. For example, the velocity of water or the transport of sediment that could also result in scour of the inlet edges. Furthermore, this approach does not take into account more frequent events (i.e., 1:10 yr ARI) that can cause inundation and die-back of vegetation for which, there is less time for it to recover between events. It is important to note that this assessment is used as an indicator for where the mouth/estuary environment could migrate to under the assumption of vegetation die back causing scour. However, hydrodynamic modelling of smaller more frequent events (e.g. 1 in 10-year annual return interval) would give a better understanding of how the interaction of coastal/fluvial processes in these events shape the morphology of the hydrosystem and how these may change in the future.

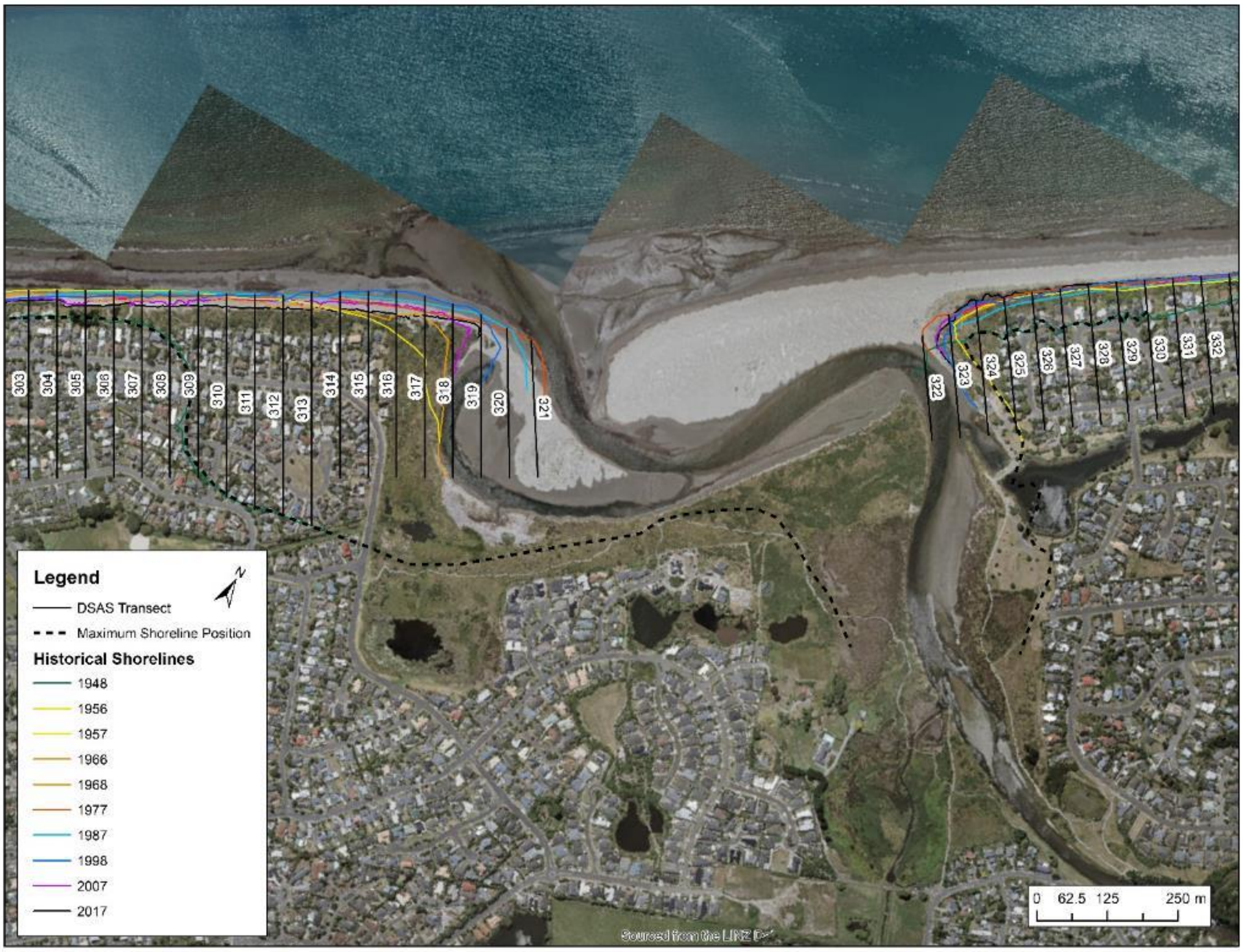


Figure 6.7: Historical shorelines and maximum shoreline envelope at Waikanae River.

In this assessment, the current day shoreline was mapped against the 1% AEP storm tide event to give a proxy indication of where the shoreline was placed in relation to water depth during the storm-tide event. This assessment showed that the area inundated with 0.25-0.5 m water during the event aligns with the hydrosystem present-day shoreline. Therefore, the position of these water depths in 1% AEP storm tide events with RSLR has been taken as a proxy shoreline for where the hydrosystem shoreline could retreat to in the future, based on the process assumptions discussed above.

The results of this assessment are that under 0.4 m and 0.65 m of RSLR, there is only likely to be a small amount of erosion, largely occurring around the seaward edges where the adjacent shoreline is projected to erode. For 1.65 m of RSLR the results indicate that the erosion of the southern estuary bank could extend out to Manly Street, however, this would depend on how well the small wetland area east of the current estuary in this area responds to complete inundation with salt water under this RSLR scenario. There is also likely to be some erosion along the northern edge of the hydrosystem cell as well, as the hydrosystem merges into the PFSP.

6.7 Vulnerability

6.7.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified affected council critical infrastructure and community services that intersected with mapped PFSP up to the landward limit of the most likely PFSP (P33). The results of this assessment are presented in Table 6.3.

Table 6.3: Council critical infrastructure and community services effected in Waikanae cell under various sea level rise scenarios.

	RSLR Scenarios							
	2050		2070		2120			
Asset	**0.2m**	**0.4m**	**0.3m**	**0.7m**	**0.6m**	**0.85m**	**1.25m**	**1.65m**
Coastal Stormwater Outlet (1)	6	6	3	6	1	**6**	6	6

(1) Number of outlets intersecting landward limit of 'most likely' PFSP

Coastal stormwater outlets were the only piece of critical infrastructure and community services identified to be affected in Waikanae. As can be seen from the results in Table 6.3, under both RSLR scenarios in 2050, six coastal stormwater outlets could be affected by coastal erosion in large storm events. However, by 2070 due to the extrapolation of the long-term accretion rates, which keep pace with the effect of RSLR under the lower scenarios, only three outlets are projected to be affected, compared to six outlets projected to be affected under all timeframes for the higher RSLR scenario.

6.7.2 Land parcels

The number of land parcels (public and private) which intersect with the PFSP up to the landward limit of the 'most likely' position (e.g. P33) and the landward limit of the 'unlikely' position (e.g. P10) were calculated to give an indication of vulnerability of land parcels within a coastal cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels (see Section 2.4). The results of this assessment for the Waikanae coastal cell are presented below in Figure 6.8 and in Appendix L.

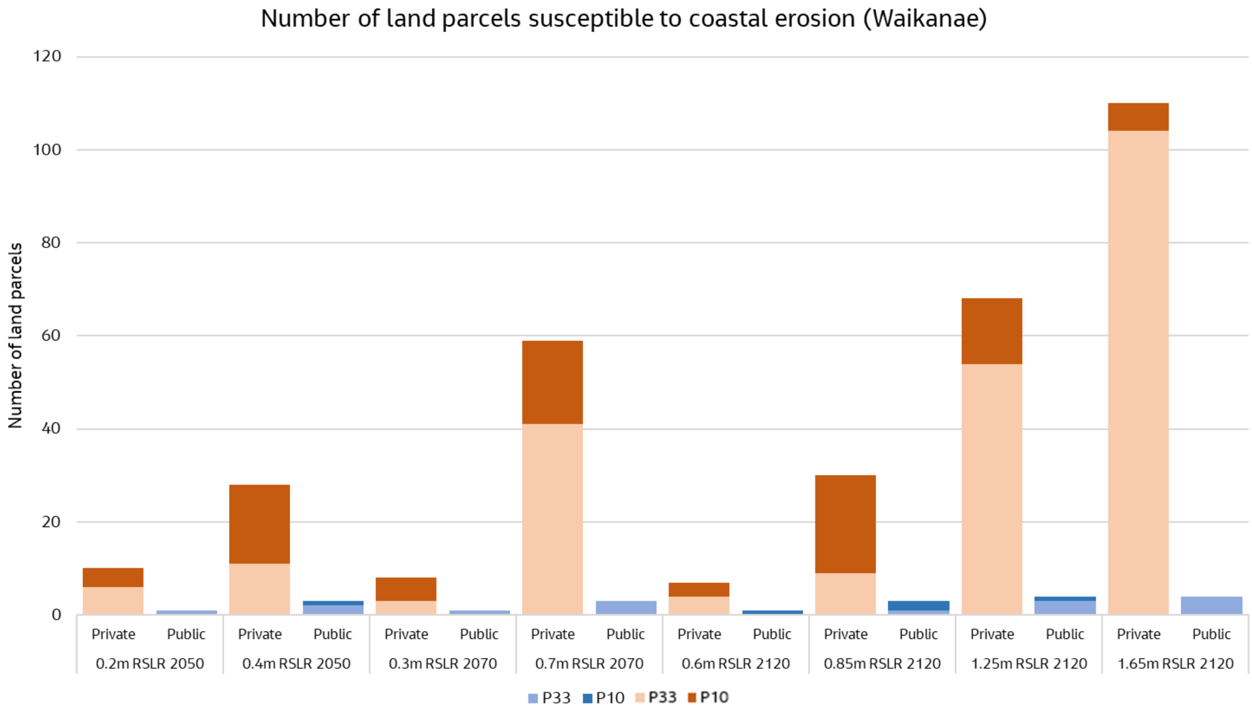


Figure 6.8: Number of public and private land parcels in Waikanae potentially susceptible to coastal erosion. Lighter orange/blue show the number of properties susceptible to erosion up to the P33 (landward limit of the most likely), with the darker blue/orange showing additional parcels potentially affected between the P33 and P10 shoreline position.

From the results presented in Figure 5.8 it is shown that up to four parcels of public property intersect with the 'most likely' and 'unlikely' PFSPs over the 100-year highest RSLR scenario. For private land parcels within the Waikanae coastal cell, there is a large difference in the number of land parcels which intersect with the 'most likely' PFSP between the higher and lower RSLR scenarios within each timeframe, especially for the 50- and 100-year timeframes.

Over a 30-year timeframe (2050), 6 to 11 land parcels intersect with the 'most likely' PFSPs for both RSLR scenarios. Over a 50-year timeframe (2070) three land parcel intersect the 'most likely' PFSP for a 0.3 m RSLR, increasing to 41 land parcels with 0.7 m of RSLR. Under the lowest RSLR scenario for 2120 (0.6 m), four private land parcels intersect with the 'most likely' PFSP, increasing to nine parcels for RSLR of 0.85 m, 54 parcels for RSLR of 1.25 m, and 104 parcels for the highest RSLR scenario of 1.65 m. Based on potential number of land parcels affected, Waikanae is ranked as the fourth most vulnerable coastal cell, behind Raumati, Paekākāriki and Peka Peka.

At the Waikanae River, two to three public land parcels and three to four private land parcels could be affected by potential hydrosystem migration over the RSLR scenarios for 30 years (2050) and 50 years (2070). However, under the highest RSLR scenario for 100 years (1.65 m), the number of private land parcels affected could increase to 30 due to the projected potential erosion of the southern bank of the estuary.

7. Paraparaumu Coastal Cell

7.1 Summary

The Paraparaumu coastal cell covers approximately 3.4 km of shoreline from the south bank of the Waikanae River to Rua Road, being the northward limit of the near continuous coastal protection structures located along the Raumati coastal cell to the south. Since this cell is located around the apex of the cuspate foreland formed in the leeward wave shadow of Kāpiti Island, the shoreline has historically been accreting over the majority of its length as the foreland continues to grow and migrate to the south. For the central part of the cell, at the apex of foreland, this accretion is projected to keep pace of the erosional effects of RSLR for all scenarios over all timeframes up to 100 years. However, south of Tikotu Stream, where the long-term accretion rate has been less, the erosional effects of SLR are projected to outpace the accretion, resulting in net long-term erosion under the higher RSLR scenarios. For the northern end of the cell, the extrapolation of historical erosion combined with the effects of RSLR could result in 20 – 30 m of shoreline erosion over the next 30 years, increasing to 30 -50 m by 2070, and 50 -100 m by 2120.

Coastal roads running parallel to the shoreline within the cell are potentially vulnerable to coastal erosion with SLR. Around 50 m of Marine Parade is potentially vulnerable under the higher RSLR scenario for the next 30 years, increasing to between 200 m and 300m with the higher RSLR scenarios in 50 and 100 years respectively. However, Manly Street is only likely to be affected under the highest RSLR scenario over 100 years (1.65 m). In addition, six to nine coastal stormwater outfalls are projected to be potentially affected by coastal erosion within the next 30 to 50 years, increasing to 12 over within 100 years. Depending on the magnitude of RSLR, between 13-20 private properties intersect with the 'most likely' PFSP within the next 30 years, increasing to 21- 54 within 50 years, and 49 -119 within 100 years. This places the Paraparaumu cell third out of eight for vulnerability of private proprieties to projected future coastal erosion.

This coastal cell and the results are discussed in more detail in the sections below.

7.2 General Description

The Paraparaumu Coastal Cell covers approximately 3.4 km of shoreline from the Waikanae River hydrosystem cell to Rua Road, Paraparaumu Beach, as shown in Figure 7.1. This figure also presents the location of key data reference points within this cell (e.g. DSAS transects, beach and bathymetric profiles). The southern boundary of the cell corresponds to the northward limit of the near continuous coastal protection structures located along the Raumati coastal cell.

This coastal cell covers the Paraparaumu Beach township, and includes the Tikotu Stream hydrosystem cell (transects 270-274), located on the southern side of the cuspate foreland. The assessment of future shorelines in this hydrosystem are covered in Section 7.6. The majority of the cell has been developed for residential and commercial use, with the Paraparaumu township[13] containing approximately 2,700 dwellings, and is home to approximately 6,420 residents (Statistics New Zealand, 2018). The Paraparaumu Beach area also contains other key services for the district, including the airport, golf club, and a small shopping and food and beverage precinct in the area around MacLean Street and Marine Parade. Along Marine Parade, which runs parallel to the shore, residential and commercial land parcels are located on the landward side of the road such that at the southern end of the cell there is a 20 m buffer between these land parcels and the shoreline, which increases northward towards Tikotu Stream. From Manly Road, on the north side of Tikotu Stream, subdivision has occurred on the seaward side of the road and residential land parcels front the open coast north to the Waikanae River. Dwellings located along this section of shoreline are setback from the present-day shoreline in the order of 75 m near the Tikotu Stream, with the buffer reducing in a northward direction to be in the order of 40 m closer to the Waikanae River.

[13] Paraparaumu Beach West and Paraparaumu Beach North from Statistics New Zealand (2018) census data.

Figure 7.1: Paraparaumu coastal cell key features and data reference points (DSAS transects, beach and bathymetric profiles).

Figure 7.2: Paraparaumu Beach near Ngapotiki Street access (south side of cuspate foreland apex) showing vegetated dune elevations in the order of 6 – 6.5 m. Note the seaward location of the houses at 175-177B Manly Street and the small block seawall feature at the toe of the dune in front of these houses.

As shown in Figure 7.1, the cell includes the apex of the cuspate foreland (around transects 285 to 295) where the wave shadow effect in the lee of Kāpiti Island from the prevailing northwest swell and storm waves is at its greatest, and it is here where the greatest shoreline advance over the Holocene has occurred. Historically sediment supplied from the north via longshore transport (see section 2.1 of Volume 1 Methodology report) and from the Waikanae River has been deposited right around the apex of the cuspate foreland, which based on the analysis of volume changes in the beach profile record is estimated to be in the order of 6,500 m^3/yr (1.9 m^3/m/yr) across the cell (see Appendix H).

The cuspate foreland now acts as a natural groyne, restricting the supply of sediment to the beaches further south. As a result of the cuspate foreland, the orientation of the shoreline within the cell changes from a NNW direction on the north side of the apex to WNW on the southern side, so is differentially exposed to wind and wave swell from NW or SW storm events. This change in orientation affects the capacity of the longshore sediment transport currents as it alters the breaking angle of the waves around the feature, which in turn modifies the current regime leading to greater deposition on the north side of the foreland. Together, these processes interrupt the southward movement of sediment leading to a sand supply deficit for the beaches further south from Raumati to Paekākāriki. There is a small component of northward transport under southerly swells, but this is a minor component to the dominant southward movement from NW swells. The growth of the cuspate foreland has also steepened the nearshore slopes in the area, and is considered to have constricted the tidal flow in the Rauoterangi channel between Paraparaumu and Kāpiti Island.

The coastal environment along this cell consists of a sandy beach backed by dunes which reach elevations in the order of 4.5 to 5 m WVD-53 around the southern side of the cuspate foreland as shown in Figure 7.2 and increases to around 6 to 6.5 m nearer the Waikanae River hydrosystem cell (profiles 340 and 350, see locations in Figure 7.1). There are a number of foot access tracks through the dune system within the cell, and vehicle access to the foreshore is available at the Kāpiti Boating club located on the north side of Tikotu stream mouth), as shown in Figure 7.1.

7.3 Structures

There is only one structure located in the Paraparaumu cell, which is a concrete block wall at 175-177B Manly Street which can be seen in Figure 7.2. This structure has a residual life of 10 years[14]. There are also small river mouth training structures located on the banks of the Tikotu Stream.

7.4 Erosion Components

7.4.1 Extrapolation of Long-term Rates

The historical shoreline changes within the Paraparaumu coastal cell were digitised from 7 - 8 aerial photographs across a 70-year period from 1948 to 2017. A section of the DSAS analysis for the apex of cuspate foreland overlay on the 1948 aerial imagery is presented in Figure 7.3.

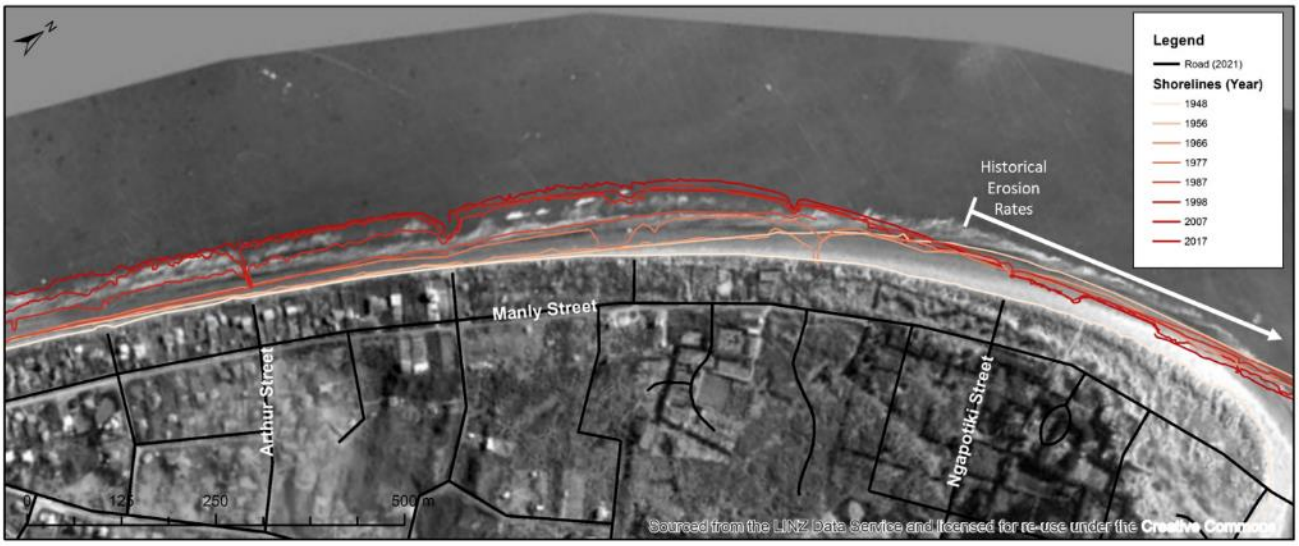


Figure 7.3: Historical shorelines from 1948-2017 showing the long-term erosion around the apex of the cuspate foreland, overlaid on 1948 aerial imagery. Note the presence of erosion since 1956 on the north side of the apex.

As can be identified from Figure 7.3, the majority of the shoreline has experienced continuous accretion since 1948, except for the section to the north of the apex, which has experienced erosion since 1956. The accretion in the 1948 – 1956 period in this area is associated with the infilling of the southern part of the Waikanae estuary during this period, with corresponding minimum accretion of the shoreline to the south most likely due to sediment supply from the north being used in the estuary infill. The mapping of the shorelines supports the observation of Gibb (2002) that the apex of the cuspate foreland has been migrating southward over the last 65 years.

The raw rates of shoreline change over this period calculated from the DSAS analysis are presented in Figure 7.4. Due to the shoreline advancement around the Waikanae River mouth between 1948-1956, as a result of estuary infilling, followed by erosion since this time, transects 298 to 314 returned low R^2 values (< 0.3) from the linear regression analysis. The 1948 shoreline was removed from the analysis across these transects on the grounds that the large shoreline advancement (in the order of 50 -90 m for transects 298 – 308 and over 300 m for transects 309 -313 where the mouth estuary was located in 1948) was not representative of contemporary trends of shoreline movement since 1956. As a result, R^2 values generally improved to greater than 0.5 and as shown on Figure 7.4 the general long-term trend has been erosion at rates of between -0.08 m/yr to -0.36 m/yr, with an average rate of -0.23 m/yr.

[14] From T&T 2016 coastal structures database

Immediately south of the apex of the cuspate foreland, the shoreline has experienced high rates of accretion which decrease in a southward direction to Tikotu Stream. The average historical accretion rate over this area (transects 275-298) is +1.1 m/yr, with a maximum of +1.56 m/yr (transect 293), and a minimum of +0.86 m/yr north of the Tikotu Stream hydrosystem cell (transect 275).

South of Tikotu Stream to the southern boundary of the cell (transects 254-269), the shoreline has also shown continued accretion over the 1948-2017 period, but at a slower average rate of +0.39 m/yr. The rate of accretion also reduces in a southward direction, with +0.68 m/yr of accretion measured at transect 269, reducing to +0.23 m/yr at the southern end of the cell (transect 254).

The extrapolation of the average and 90% confidence interval rates into the future results in the shoreline movement distances presented in Table 7.1.

Table 7.1: Projected future shoreline movement distances in the Paraparaumu coastal cell from the extrapolation of average long-term rates of movement from aerial photographs 1948-2017.

Transects	Next 30 years (by 2050)	Next 50 years (by 2070)	Next 100 years (by 2120)
South of Waikanae River (North of cuspate foreland apex) (Transects 299-312)	-6.0 (± 8.2) m	-10.1 (± 13.7) m	-20.1 (± 27.4) m
Apex of cuspate foreland (transects 275-298)	+32.8 (± 9.4) m	+54.6 (± 15.7) m	+109.3 (± 31.5) m
South of Tikotu Stream (south of cuspate foreland apex) (Transects 254-269)	+11.8 (± 7.9) m	+19.6 (± 13.1) m	+39.2 (± 26.2) m
The distances in brackets are the upper and lower bounds of uncertainty, being the 90% confidence interval of the LRR from the DSAS.			

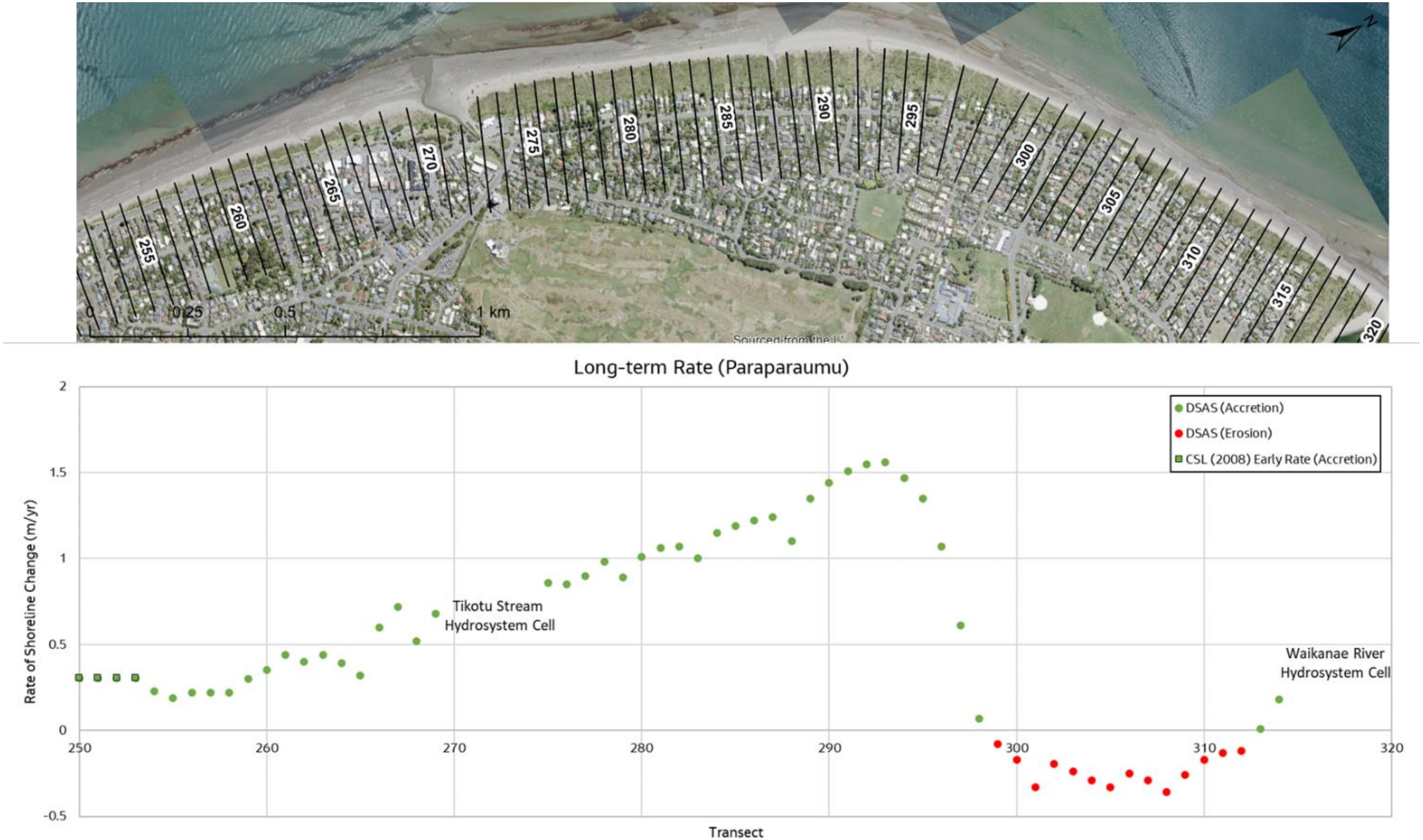


Figure 7.4: Long-term rates at Paraparaumu calculated from DSAS.

7.4.2 Effect of Future Accelerated Sea Level Rise

As explained in Section 2.2.3, to avoid 'double accounting' of contemporary sea level rise and to isolate the effects of RSLR to being just for the acceleration in the rate of rise, the resulting erosion distances are calculated for the 'discounted' rates of rise for each timeframe as presented in Table 2.2.

For the Paraparaumu coastal cell, the effect of RSLR was calculated by the Bruun Rule using the beach profile parameters of profiles 300, 310, 320, 330, 340, and 350 and offshore profiles 15-17 (locations shown in Figure 7.1). From the beach profiles, the beaches closest to the Waikanae River (profile 340 and 350) have steeper beach profiles with higher dune elevations (6.2 -6.5 m) and narrower beach width[15] (mean of 72 m and 79 m respectively) than the profiles at the apex of the cuspate foreland and further south towards Tikotu Stream (dune elevations generally less than 5 m, and mean widths 110-165 m). Due to the Kāpiti Island wave shadow effect, closure depths are less in this cell that those further north. Also, the nearshore profiles around the cuspate foreland presented in Lumsden (2003) (Appendix F), are considerably steeper than those in the northern cells. As expected, the steepest nearshore slope is located at the apex of the foreland (profile 16 – slope 1: 50 to outer closure depth of -7 m), becoming increasing flatter for profiles both north and south of this location.

These ranges of input values formed upper and lower bounds of the triangular distribution for the calculation of the range of erosion distances due to RSLR, with the average conditions being the mid-point between the upper and lower bounds. The results of these calculations are presented in Table 7.2. As can be seen from the Table, the uncertainty in the magnitude of RSRL within each timeframe results in increases in the projected erosion distance; with the range of distances increasing as the uncertainty in RSLR increases. For example, there is an 8-11 m increase in projected average erosion between the lower and upper RSLR scenario for 2050, compared to a 40-50 m increase in projected average erosion between the lower and upper RSLR scenarios for 2120.

Table 7.2: Projected erosion distances in the Paraparaumu coastal cell from future acceleration of rates of RSLR.

Timeframe	Magnitude of Absolute RSLR	Discounted magnitude of RSLR(1)	Profile 300 (south of foreland apex)	Profile 310 (on foreland apex)	Profile 320 (on foreland apex)	Profile 330 (north of foreland apex)	Profile 340 (north of foreland apex)	Profile 350 (north of foreland apex)
2050 (30 years)	0.2m	0.12 m	-6.9 (±0.1) m	-5.4 (±0.1) m	-5.5 (±0.7) m	-5.7 (±0.2) m	-4.6 (±0.1) m	-4.6 (±0.2) m
	0.4m	0.32 m	-18.3 (± 0.3) m	-14.3 (±0.2) m	-14.6 (±1.7) m	-15.3 (±0.4) m	-12.3 (±0.3) m	-12.2 (±0.4) m
2070 (50 years)	0.3m	0.16 m	-9.5 (± 0.2) m	-7.4 (±0.1) m	-7.6 (±0.9) m	-7.9 (±0.2) m	-6.4 (±0.1) m	-4.5 (±1.1) m
	0.7m	0.56 m	-32.4 (±0.5) m	-25.3 (±0.3) m	-25.9 (±3.1) m	-27.0 (±0.7) m	-21.7 (±0.5) m	-23.6 (±0.8) m
2120 (100 years)	0.6m	0.33 m	-19.1 (±0.3) m	-14.9 (±0.2) m	-15.2 (±1.8) m	-15.9 (±0.4) m	-12.8 (±0.3) m	-12.7 (±0.4) m
	0.85m	0.73 m	-33.4 (±0.5) m	-26.0 (±0.35) m	-26.6 (±3.2) m	-27.8 (±0.75) m	-22.4 (±0.5) m	-22.3 (±0.76) m
	1.25m	0.98 m	-56.2 (±0.9) m	-43.9 (±0.6) m	-44.9 (±5.3) m	-46.9 (±1.3) m	-37.7 (±0.9) m	-37.6 (±1.3) m
	1.65m	1.38 m	-79.1 (±1.3) m	-61.8 (±0.8) m	-63.2 (±7.5) m	-66.0 (±1.8) m	-53.1 (±1.2) m	-52.9 (±1.8) m

(1) Discounted for contemporary rate of RSLR: 2.74 mm/yr (Bell et al, 2018)
The distances in brackets are the upper and lower bounds for the input parameters

[15] Beach width is the distance between the beach crest and the 0 m contour.

As a result of the combined beach and nearshore steepness, the closure slopes are correspondingly steeper in the Paraparaumu cell than in the northern cells, so consequently the erosion effects due to future accelerated RSLR will also be less compared to the northern cells. For example, erosion due to SLR could be up to 8 m less in the Paraparaumu cell than in the Waikanae cell by the highest magnitude of RSLR by 2050 (e.g. 0.4 m), and up to 35 m less for 1.65 m of RSLR by 2120. Alongshore, within the cell, the smallest effects of RSLR are projected to be experienced north of the foreland apex, and the greatest effect is projected to be to south of the apex where beach and nearshore slope are relatively flatter. However, these differences are relatively small (< 3 m for 0.2 m RSLR by 2050, and up to 25 m for 1.65 m RSLR by 2120). Likewise, the small variations in closure slopes for upper and lower bounds of the input parameters for each transect result in a very narrow range of values for sea level rise effects within the same RSLR scenario. While these ranges of uncertainty appear low, they are strongly influenced by the small variations in the input data, and do not take account of the limitations in the method for calculating SLR effects.

7.4.3 Short-term Storm Erosion

The short-term component for Paraparaumu was based on post-storm observations from Gibbs and Wilshere (1976) following the September 1976 storm, which was later assessed to be a 0.5% AEP event (Lane et al, 2012). The observations indicated that there was an upper limit of 5 m of erosion at Paraparaumu.

For the probabilistic method, a conservative approach was taken by applying the -5 m upper limit as the mean for a quasi-distribution, with ± 50% to give an upper bound of the triangular distribution of -7.5 m erosion and a lower bound of -2.5 m erosion.

7.4.4 Dune Stability

The dune stability component for Paraparaumu is based on an analysis of the six surveyed profiles located within the cell (profile 300, 310, 320, 330, 340 and 350, see Figure 7.1 for locations). For the probabilistic method, the distributions detailed in Table 7.3 were formed based on beach profile survey data. Dune stability factor increases in a northward direction through the cell due to the increasing dune elevations in this direction.

Table 7.3: Dune stability distributions for Paraparaumu Coastal Cell.

Profile	Lower Bound	Mean	Upper Bound
300	-2 m	-2.3 m	-2.7 m
310	-1.9 m	-2.4 m	-3.3 m
320	-2 m	-2.5 m	-3 m
330	-1.8 m	-2.3 m	-2.9 m
340	-3 m	-3.5 m	-4 m
350	-3.1 m	-3.6 m	-4.4 m

7.5 Projected Coastal Erosion Distances

The resulting CED's calculated by the probabilistic method are presented below. Maps displaying the spatial location of the present-day hazard and PFSP are presented in maps 11 and 12 of Appendix A (2050), Appendix B (2070), and Appendix C (2120).

7.5.1 Present-day Erosion Susceptibility

The present-day hazard represents the dynamic nature of shoreline movements where storm erosion can occur independently of long-term trends or the effects of future RSLR. As such, this hazard distance is a combination of the short-term storm erosion (Section 7.4.3) and the dune stability factor (Section 7.4.4), which represents the potential erosion distance that could occur if a large storm (e.g. 1% AEP) were to happen at any time in the future, including the immediate/near future.

For the Paraparaumu coastal cell, the present-day hazard was calculated to 'most likely' be an average of -7 m to -8 m of erosion, with erosion unlikely to exceed -10 m. The present-day hazard is slightly higher at the northern end of the cell where higher dune heights contribute to higher dune stability factors.

7.5.2 Future Coastal Erosion Susceptibility

The raw outputs from the Monte Carlo simulation of the landward limit of 'most likely' zone (P33 position) for the three timeframes are presented below in Figure 7.5 to give an indication of the changes in shoreline position that could be expected over the next 100 years. It should be noted that these raw distances (also presented in Appendix J for P66, P33, and P10) have been smoothed in the mapping outputs for coastal process plan-shape considerations, as well as consideration of future inlet migration, and therefore the raw outputs may not be able to be directly correlated with the PFSP shorelines mapped in Appendix A, B and C. It should also be noted that erosion distances mentioned in the text have been rounded to the nearest 0.5 m.

The following provides a summary of the projected erosion distances to the landward limit of the most likely zone (P33) across each RSLR scenario.

2050

As shown in Figure 7.5, assuming that the erosional trend continues for the short stretch of historically erosional shoreline to the north of the cuspate foreland apex (transects 299-314), with 0.2m of RSLR the shoreline is projected to experience an average erosion distance of -20 m, which increases with 0.4 m of RSLR to be an average of -28 m. Under the lower RSLR scenario, short-term and dune stability components contribute 50% of the erosion distance, which reduces to 33% under the higher 0.4 m RSLR scenario due to the larger erosion contribution from RSLR.

Across the apex of the cuspate foreland to Tikotu Stream (transects 275-298) accretion is projected to continue under both RSLR scenarios, being an average of +18 m for RSLR of 0.2 m and reducing to +9 m for the higher 0.4 m RSLR scenario. Since the mapping products in Appendix A only show erosion, the resulting accreted PFSP's are not presented on the maps.

For the southern section of the cell south of Tikotu Stream (transects 254-269) under the 0.2 m RSLR scenario, projected shoreline movements average erosion of – 4 m, but range from + 4 m immediately south of Tikotu Stream to -10 m at the southern boundary of the cell. Under the 0.4 m RSLR scenario, the average erosion distance is projected to increase to -15.6 m of erosion, of which short-term and dune stability components contribute more than 50%. Again, the projected erosion distance is less at the Tikotu stream (-8 m) than at the cell southern boundary (-21 m).

2070

With 0.3m of RSLR, the currently eroding shoreline north of the foreland apex (transects 299-314) is projected to erode on average a future -27 m, which increases with 0.7 m of RSLR to an average of -44 m.

In contrast, across the apex of the cuspate foreland to Tikotu Stream (transects 275-298), the shoreline is projected to continue to accrete, at an average distance of +36 m, with projected maximum accretion distances being up to +57 m. This average projected accretion decreases with 0.7 m of RSLR to be +18 m as the erosional effects of RSLR become more influential.

South of the Tikotu Stream, under the lower 0.3 m RSLR scenario, the range of projected shoreline movements varies from to -9 m erosion at the southern boundary to +13 m accretion at Tikotu Stream. With 0.7 m of RSLR, erosion is projected to occur along all of this section, ranging from -10 m to -32 m of erosion with an average of -23 m.

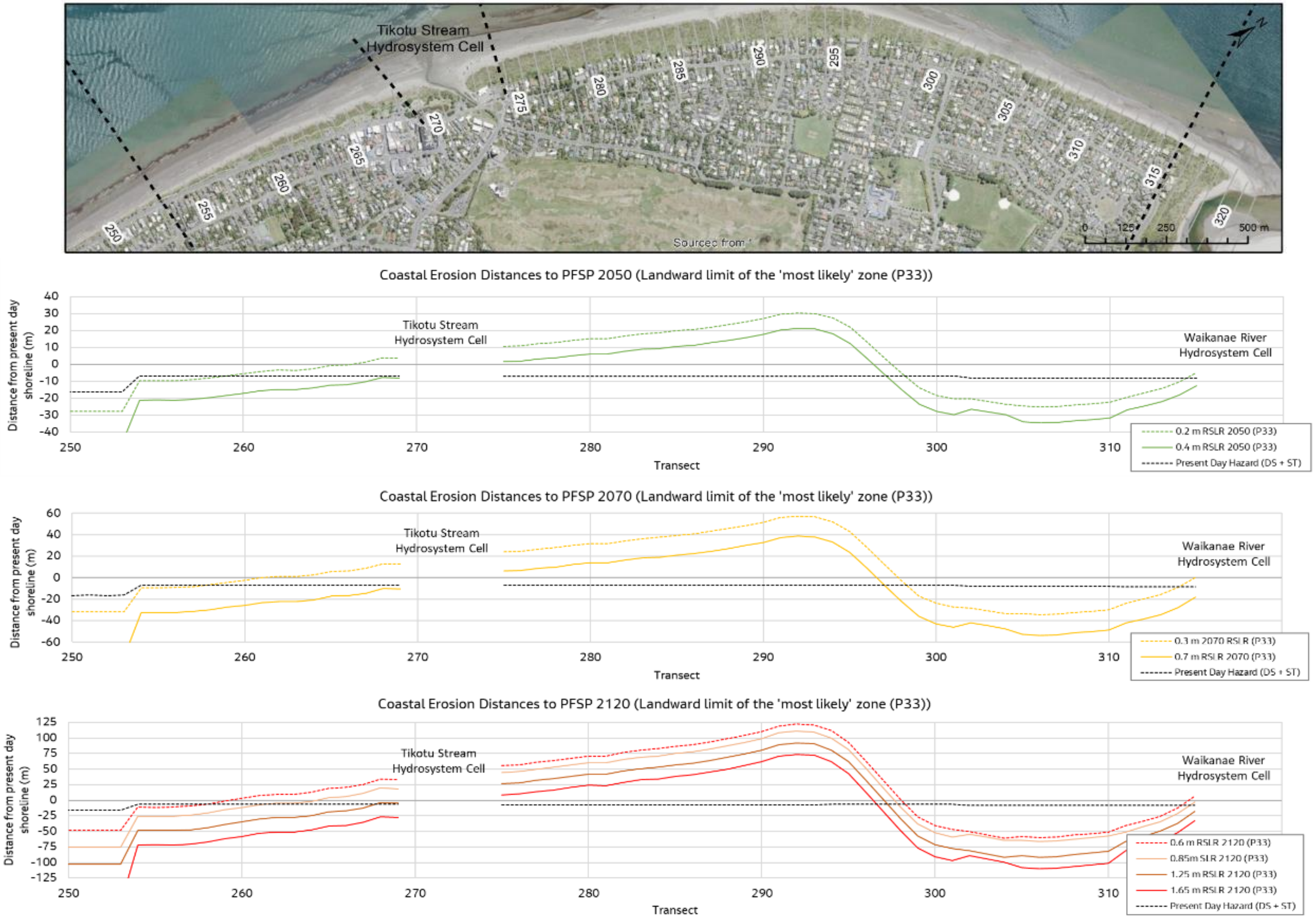


Figure 7.5: Erosion distances to projected future shoreline positions under future RSLR scenarios.

2120

As shown on Figure 7.5, under the lowest RSLR scenario of 0.6 m RSLR (RCP2.6 plus 1 mm/yr VLM), the currently eroding northern part of the cell is projected to experience further erosion by an average of -46 m, which increases to an average of -53 m with 0.85 m of RSLR (RCP4.5 plus 2mm/yr VLM). With higher rates of RSLR, the projected erosion distances are further increased to be an average of -75 m with 1.25 m RSLR (RCP8.5 plus 2 mm/yr VLM), and to -91 m erosion with 1.65 m of RSLR scenario (RCP8.5H+ plus 3mm/yr VLM).

Again, in contrast the apex of the cuspate foreland is projected to continue accrete under all RSLR scenarios, however the greatest advance of +80 m is projected under the lowest scenario (0.6 m) and reducing with higher scenarios as the effect of SLR becomes more prominent. Under the highest RSLR scenario (1.65 m RSLR), the apex of the cuspate foreland is still projected to accrete by an average of +44 m.

South of the Tikotu Stream, under the 0.6 m RSLR scenario, the shoreline is projected to accrete by an average of +8 m. However, this varies from +34 m of accretion near the Tikotu Stream to -11 m of erosion at the southern end of the cell. A tipping point to erosion along the total length of this section of shoreline is projected with 0.85 m of RSLR, with an average distance of -7 m, which is projected to increase to -30 m with 1.25 m of RSLR. Under the highest RSLR scenario of 1.65 m, the projected net erosion distances are an average of -53 m.

7.5.3 Comparison of results to previous coastal hazard assessments

The results of the PFSP presented in Section 7.5.2 are calculated to be less than previous coastal erosion assessments undertaken in the area.

The Lumsden (2003) coastal management strategy proposed a -75m 'Secondary Development Setback' across the Paraparaumu Cell, which was a deterministic approach of assessment long-term trend at the site and the effect of a 0.45m RSLR over the next 100 years. Comparatively, our lowest RSLR projection over a 100-year period was 0.6m, which for the historical eroding area on the north side of the foreland apex produced an average erosion distance of -46 m. However, our assessment also determined that around the apex of the cuspate foreland, the shoreline is projected to accrete by an average of +80 m, which reduces to an average of +8 m south of Tikotu Stream.

Compared to the more recent CSL (2008 & 2012) coastal hazard assessment, the results produced in this study are also less. For a 0.3 m RSLR over 50 years scenario, CSL (2008 & 2012) calculated an average erosion distance of -59 m along the northern section of the cell. Comparatively, along this section of shoreline our assessment has calculated an average projected erosion distance to be -27 m, with a range of -9 to -34 m of erosion. The CSL erosion distances are higher for this section of shoreline due to a greater contribution from short-term erosion (10 m greater), and the RSLR effect (15 m greater).

Across the accretional apex of cuspate foreland to Tikotu Stream, the CSL (2008) assessment calculated an average of -53 m of erosion with 0.3 m of RSLR over the next 50 years. In our current assessment, this area of shoreline is projected to accrete by an average of +36 m, with projected accretion distances being up to +57 m. This difference is due to the current assessment including the extrapolation of shoreline advance around the apex, whereas CSL assumed a static shoreline with future sediment supply, such that all future shoreline change will be due to the effects of RSLR, short-term storms, and dune stability factors.

Along the area to the south of the Tikotu Stream, the CSL (2008 & 2012) assessment calculated an erosion distance of -36 m. Comparatively, this current assessment calculated that on average the shoreline would remain relatively stable, ranging from -9 m of erosion (south end of cell) to +13 m of accretion (Tikotu Stream). The difference in these assessment distances is due to both the short-term and RSLR components being larger in the CSL (2008 & 2012) assessment, but is mostly due to the extrapolation of contemporary shoreline accretion rates in the PFSP calculations across this area.

7.6 Tikotu Stream

The Tikotu Stream is the only hydrosystem cell (Figure 7.6) located within the Paraparaumu coastal cell. The historical shoreline positions in the hydrosystem and the adjacent shoreline are presented in Figure 7.7. As shown in the figure, the shoreline on both sides of the stream mouth has historically shown large accretion by up to 50 m. There are two river training structures at the throat of the stream which restrict movement of the stream, however the channel mouth can migrate over a wider area.

Due to the accretional nature of the adjacent shoreline, and the net positive movement of the inlet itself, Method 3 from the coastal hydrosystem decision tree, i.e., the maximum historical hydrosystem shoreline position (see Section 2.2.7) was used to indicate the possible future migration of the mouth envelope. This is recognised to be a conservative approach, because the accretional nature of the adjacent shoreline means there is no coastal process reason to expect that the hydrosystem shoreline would erode back to this 1948 position in the future whilst the open coast continues to accrete. However, to give an indication of the spatial limits of where the hydrosystem has been in the past, the historical maximum envelope of the river mouth environment (e.g. 1948) has been used to show identify this area, as marked by the black dotted line in Figure 7.7.

Figure 7.6: Tikotu Stream, Paraparaumu.

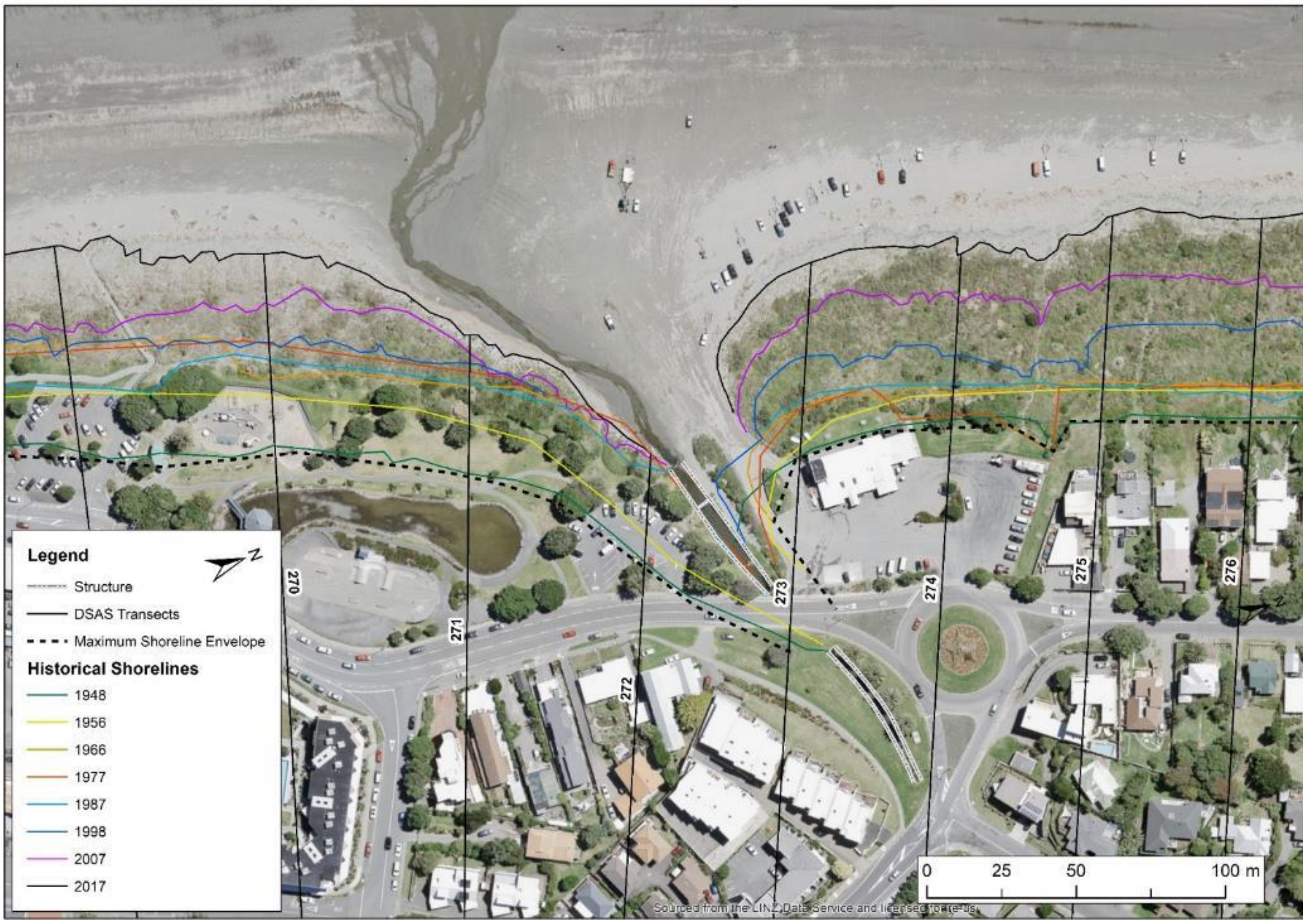


Figure 7.7: Historical shorelines and maximum shoreline envelope at Tikotu Stream.

7.7 Vulnerability

7.7.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified affected council critical infrastructure and community services that intersected with mapped PFSP up to the landward limit of the most likely PFSP (P33). The results of this assessment are presented in Table 7.4.

Table 7.4: Council critical infrastructure and community services affected in Paraparaumu cell under various sea level rise scenarios.

	RSLR Scenarios							
	2050		2070		2120			
Asset	**0.2 m**	**0.4 m**	**0.3 m**	**0.7 m**	**0.6 m**	**0.85 m**	**1.25 m**	**1.65 m**
Marine Parade (Total length = 1100m) (1)	0 m	55 m	0 m	225 m	15 m	54m	256m	393 m
Manly Street (Total length = 3175m) (1)	0 m	0 m	0 m	0 m	0 m	0m	0m	290 m
Coastal Stormwater Outlet (2)	6	9	6	8	5	6	11	12

(1) Length of road intersecting landward limit of 'most likely' PFSP
(2) Number of outlets intersecting landward limit of 'most likely' PFSP

The results show that for Marine Parade, under the lower RSLR scenarios for 2050, 2070 and 2120, coastal erosion is projected to have minimal (maximum 15m at 2120) to no effect. However, under the higher RSLR scenarios, 55 m (5% of total length), 225 m (20%) and 393 m (35%) of this road could be affected by 2050, 2070 and 2120 respectively. However, Manly Street is only likely to be vulnerable under the highest level of RSLR (1.65 m) for 100 years, when around 10% of the road length intersects with the 'most likely' PFSP.

Apart from the above roads, coastal stormwater outlets were the only council critical infrastructure and community services identified to be affected in Paraparaumu, with six to nine stormwater outfalls potentially being affected by erosion by 2050 and 2070, and as many as 12 outlets could be affected with 1.65 m of RSLR by 2120.

7.7.2 Land parcels

The number of land parcels (public and private) which intersect with the PFSP up to the landward limit of the 'most likely' position (e.g. P33) and the landward limit of the 'unlikely' position (e.g. P10) were calculated to give an indication of vulnerability of land parcels within a coastal cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels (see Section 2.4). The results of this assessment for the Paraparaumu coastal cell are presented below in Figure 7.8 and Appendix L.

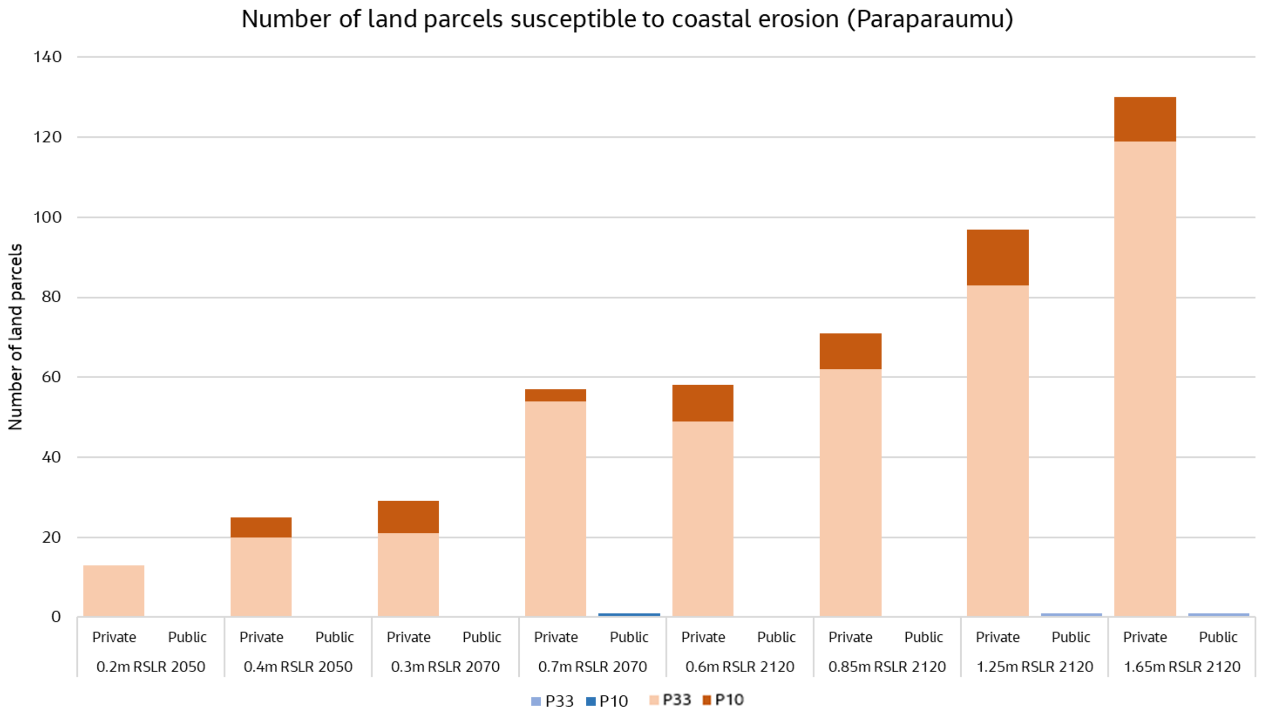


Figure 7.8: Number of public and private land parcels in Paraparaumu potentially susceptible to coastal erosion. Lighter orange/blue show the number of properties susceptible to erosion up to the P33 (landward limit of the most likely), with the darker blue/orange showing additional parcels potentially affected between the P33 and P10 shoreline position.

These results show that over all timeframes and RSLR projections no public parcels intersect with the 'most likely' PFSP. For private land parcels, the results indicate that over a 30-year timeframe (2050), under the lowest RSLR scenario (0.2 m) 13 private land parcels intersect with the 'most likely' PFSP, which increases to 20 land parcels with 0.4 m RSLR. By 2070 the number of private parcels intersecting with the 'most likely PFSP ranges from 21 (RSLR 0.3 m to 54 (RSLR 0.7m). By 2120 these number of vulnerable private land parcels increase from 49 (RSLR 0.6 m), to 62 (RSLR 0.85 m), to 83 (RSLR 1.25 m), and to 119 for RSLR of 1.65 m.

Across all timeframes and RSLR scenarios within the Tikotu Stream hydrosystem cell, no private land parcels intersect with the potential hydrosystem extent, but two public land parcels could be affected.

In terms of the amount of potential land parcels effected, Paraparaumu ranks third out of the eight coastal cells.

8. Raumati Coastal Cell

8.1 Summary

Coastal processes within the Raumati cell are strongly influenced by the presence of Kāpiti Island (wave shadow effect), and the cuspate foreland immediately to the north acting like a natural groyne deflecting bypassing sand offshore to form a broad flat offshore sand bank and restricting beach sediment supply. As a result the beach has suffered periodic large-scale erosion in response to significant storm events, which have resulted in a near continuous line of ad hoc public and private coastal protection structures (seawalls) being constructed since at least the 1950's.

Projected future erosion of the shoreline under RSLR scenarios takes into account the presence of these protection structures for a period of time up to their estimated residual life of 10-30 years, after which it is assumed that the structures are not replaced, and the beach reverts to a natural system. The whole cell is projected to erode across all timeframes over all RSLR scenarios, with predicted retreat being the greatest in Raumati South (40-55 m by 2050, 55-95 m by 2070, 95-215 m by 2120). Projected erosion distances for Raumati Beach are 10 m, 20 m, and 40-70 m less for the three timeframes respectively.

In terms of council critical infrastructure, a water supply bore and 24 coastal stormwater outlets within the cell are vulnerable to the coastal erosion hazard at all timeframes. A considerable length of council roads also intersects with the "most likely' shoreline projections under all RSLR scenarios; 850-900 m by 2050, 850- 1375 m by 2070, and 1500 – 3000 m by 2120.

There are also a large number of private land parcels that intersect with the 'most likely' PFSP within each timeframe depending on the RSLR scenario; 269-329 in the next 30 years, 308-429 within 50 years; and 406-939 within 100 years. This makes the Raumati cell the most vulnerable to projected future coastal erosion for private proprieties. An additional seven to eight public land parcels could be affected by the projected coastal erosion in all timeframes and RSLR scenarios up to 2070 and the lower scenarios for 2120, with an increase to 18 public parcels under the highest RSLR scenario over the 100-year timeframe.

This coastal cell and the results are discussed in more detail in the sections below.

8.2 General Description

The Raumati Coastal Cell covers approximately 5km of shoreline located between the Paraparaumu and Queen Elizabeth coastal cells, on the south side of the cuspate foreland as shown in Figure 8.1. This figure also presents the location of key data reference points within this cell (e.g. DSAS transects, beach and bathymetric profiles).

The Raumati cell includes the Raumati Beach and Raumati South communities, as well as the Wharemauku Stream Hydrosystem Cell (see section 8.7) located in the centre of the Raumati Beach West community (transects 214-219). The cell consists of approximately 3,900 private dwellings, and 9000 residents[16].

Coastal processes within the cell are strongly influenced by the presence of Kāpiti Island, which produces a leeward wave shadow, and by the cuspate foreland in the adjoining Paraparaumu cell to the north. This foreland acts like a natural groyne, which in combination with the wave shadow effect, reduces the long shore sediment supply to the Raumati coastal cell and cells further south. The bathymetry map presented as Figure 2.1 of the Vol. 1 Methodology Report indicates that some of the sand that does pass around the foreland is deposited on the nearshore to form a wide flat sand bank from Raumati to Paekākāriki in water depths of 7 m to 12 m, which is closest to shore at Raumati. Some of the bypassing sand is also likely to be deflected offshore by the constricted tidal currents across foreland to be deposited into the Rauoterangi channel. These processes are likely to further reduce the supply of sand to the beaches at Raumati and further south.

[16] Raumati South, Raumati Beach East and Raumati Beach West private dwellings and resident counts from 2018 Census data (Statistics New Zealand, 2018).

Figure 8.1: Raumati Coastal Cell key features and data reference points (DSAS transects, beach and bathymetric profiles).

As result of these processes, the beach has experienced periodic large-scale erosion in response to significant storm events, which have resulted in a near continuous line of ad hoc public and private coastal protection structures being constructed since at least 1955. Since their original construction, many structures have failed in storm events, as shown in Figure 8.2, and been subsequently rebuilt. These ad hoc structures vary in length, type, and age, however the majority within the Raumati cell are a mix of rock revetments and timber sea walls. Residential property has been developed right up to the seawalls, leaving only a small buffer zone between most coastal protection structures and private residential dwellings.

Figure 8.2: Coastal erosion behind failed coastal structures which fronted homes on Rosetta Road following the September 1976 storm (Image provided by KCDC).

8.3 Structures

Table 8.1 outlines the general types of coastal protection structures present along the 5 km length of shoreline, and their 'grouped' maximum residual life based on Tonkin and Taylor (2021) coastal protection database assessment. Along Raumati cell the structures are predominantly timber sea walls and rock revetment structures with an assessed maximum residual life of 10-20 years.

Structures in the database are described as 'primary' or 'secondary' structures, where the primary defence is the structure located most seaward, and the secondary structure is located landward of the primary structure. An example of this is shown in Figure 8.3 and Figure 8.4, where there is a primary rock revetment structure, and a secondary timber seawall structure. Secondary structures providing a second level of protection along Raumati cell occur along approximately 50% of the coastal cell.

Table 8.1: Generalised groupings of structures based on maximum residual life (from Tonkin and Taylor (2021)) and high-level description of structure type/material.

Transect	Assumed residual life (years)	General type of structure present
153-162	10	Rock revetment structure with secondary timber wall structure located behind the revetment.
163-173	20	Timber sea wall.
174-192	10	Rock revetment structure with secondary timber wall structure located behind the revetment.
193-215	10	Timber seawall with a secondary timber seawall generally present on landward side.
216-217	30	Timber river mouth training structure at Wharemauku Stream.
218-253	10	Timber seawalls.
218-253	10	Timber seawalls.
218-253	10	Timber seawalls.

Figure 8.3: Old Coach Road in Raumati South, showing the toe rock riprap and the secondary timber wall behind it.

Figure 8.4: Private timber sea wall with primary and secondary structure (Image supplied by KCDC).

Of the 5 km of shoreline, approximately 3540 m consists of structures that are maintained privately, and 3320 m are maintained by KCDC, GWRC or NZTA. The overlap in this maintenance is generally where the secondary structure is maintained privately, and the primary structure is maintained by KCDC, GWRC or NZTA.

The Wharemauku Stream has a timber river mouth training wall structure located on its left bank which was constructed in the 1960's then extended at some time in the early 1970s (i.e., it is visible in the 1977 aerial imagery) to its current extent to prevent migration of the river mouth into the carparking infrastructure to the south. Since the construction of the training wall, the stream has largely hugged the left bank alongside the wall. In line with the methodology detailed in the Volume 1 report, for this assessment it is assumed that the river mouth training wall has a residual life of 30 years.

In assessing the effects of sea level rise into the future, consideration has been had for the presence of these structures in the coastal erosion susceptibility assessment, and their future presence along the shoreline. The methods used to take account for these structures within the assessment are detailed in the Volume 1 report.

8.4 Erosion Components

8.4.1 Extrapolation of Long-term Rates

Following construction of the various seawalls along this coastal cell, the historical shorelines have been fixed in place at various points in time depending on the construction date and subsequent maintenance. Shoreline movements recorded in aerial imagery are more a reflection of the development and rebuilding of these structures, rather than the natural shoreline movement as observed in the northern part of the district, or the short-term fluctuation of sand volume in the profiles. The presence of these structures has masked the natural trend of the shoreline. Therefore, extrapolating a long-term future rate based on historic shoreline movements from aerial imagery that post-date seawall construction and development of the area is not appropriate for the Raumati cell.

In the CSL (2008 & 2012) coastal hazard assessment, 'early rates' of shoreline change based differences in shoreline position on cadastral surveys from the 1880's to positions on aerial imagery from the mid 1950's (pre structure) were calculated to determine what the historical shoreline trend was pre-structures. These rates were used in this assessment and were attributed to same transect groupings based on location and shoreline features for extrapolation into the future. The location of where these 'early rates' were calculated is presented in Figure 8.5. The upper and lower bounds for the probability distribution are based on ± 50% of the early rate.

These 'early rates' of shoreline change obtained from CSL (2008 & 2012) which are extrapolated into the future once sea walls have failed/ been removed and their relevant transects are presented in Figure 8.5. As shown in the figure, these are generally erosional at the southern end of the cell (-0.24 m/yr to -0.11 m/yr), and switch to accretional north of Wharemauku Stream (up to +0.3 m/yr). This indicates that the construction of coastal protection along the shoreline north of the Wharemauku Stream are most likely to have been reactive to dynamic short-term erosion during large storm events (e.g. July 1954, Oct 1957), rather than in response to a long-term erosion issue.

If coastal protection structures were removed in 2021 along the shoreline South of Wharemauku Stream, the extrapolation of these rates into the future results in an average beach erosion over the next 30 years of -5 m. This increases to an average of -8 m over the next 50 years, and -17 m over the next 100 years. However, it is recognised that the protection structures along this section of shoreline have a residual life of 10-20 years, and therefore for inclusion in the CED calculations, these rates are only extrapolated for the period of time after the structure is assumed to have failed. Along this section of shoreline, consideration of the presence of structures reduces this amount of erosion by an average of 2 m by 2050. These assumptions around structure failure and removal have been made for the purposes of this assessment in order to have consideration of the current protection structures, and how long they may be functional for into the future. However, it is recognised that the assumptions around the future of these structures (e.g. replacement or maintenance) may be different depending future decisions made by the community and the council under the *Takutai Kāpiti project*.

North of the Wharemauku stream, extrapolation of these rates into the future result in an average beach accretion over the next 30 years of +7 m. By 2070, this increases to an average of +11 m of accretion; and by 2120 this increases again to an average of +22 m. Consideration of the residual life of the protection structures along this section of coast again reduces the amount of extrapolated accretion by 2 m in 2050. However, it is recognised that whilst the early rates suggest a natural accretional trend north of the Wharemauku Stream, the lack of any natural vegetated dunes and lowering of the contemporary foreshore as result of the seawalls means that it is unlikely that the removal/failure of shoreline structures would result in immediate growth of the shoreline.

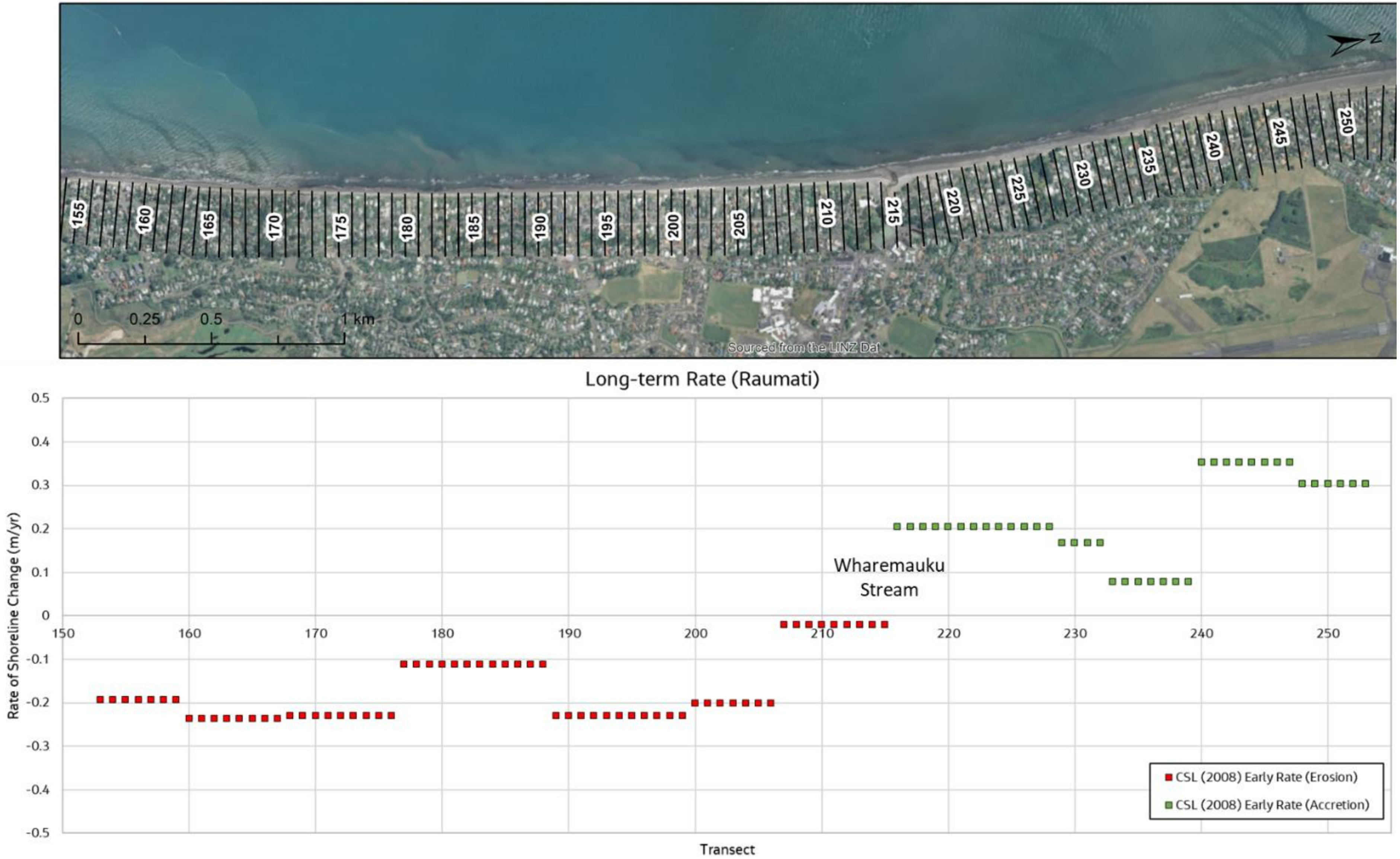


Figure 8.5: Long-term rates applied to the Raumati cell shoreline

8.4.2 Effect of Future Accelerated Sea Level Rise

As explained in Section 2.2.3, to avoid 'double accounting' of contemporary sea level rise and to isolate the effects of RSLR to being just for the acceleration in the rate of rise, the resulting erosion distances are calculated for the 'discounted' rates of rise for each timeframe as presented in Table 2.3.

For the Raumati coastal cell, the effect of RSLR along this coastal cell was calculated using the Bruun Rule with measured parameters from beach profiles 250 to 290 and offshore profiles 5a, 6, 7 and 7d (see locations in Figure 8.1, beach profiles presented in Appendix F, and offshore profiles in Appendix G) and 2017 LiDAR data from around the same locations as the profiles. This effect was calculated with consideration for the assumed residual life of the current protection structures along the Raumati shoreline, with the erosion distances being projections of what could occur following failure of the seawalls driven by the effect of RSLR only. Further details on the methods used to calculate these distances can be found in the Volume 1 report (Section 6.4.1).

From the beach profiles and LiDAR, the former natural dunes located behind the existing seawalls were interpolated to have variable elevations range from 3.5 m (From LiDAR around profile 270) to 12.5 m (from LiDAR around profile 260). Beach widths[17] were generally less than 100 m, and less than 50 m for the central and southern profiles (profiles 250-270). The offshore profiles presented by Lumsden (2003) (Appendix G) show the presence of the offshore sand bank south of the cuspate foreland, with nearshore slopes generally being flatter than 1:200 across both inner and outer closure depths (inner depths range -4.7 to -5.6 m, outer depth range -8.5 to -10.3 m), except for a steeper slope (1:107) for the inner nearshore at the southernmost profile (offshore profile 5a).

These ranges of input values formed upper and lower bounds of the triangular distribution for the calculation of the range of erosion distances due to RSLR, with the average conditions being the mid-point between the upper and lower bounds. The resulting calculated mean erosion distances due to the effect of RSLR at transect groups (based on structure residual life and relevant beach profile) is presented in Table 8.2.

The results can be summarised for the structure residual life and uncertainty in magnitude of RSLR in each time frame by the following:

- By 2050, the effect of 0.2 m RSLR at structures with a 10-year residual life is calculated to be in the order of -15 m, and increases to be in the order of -35 m with 0.4 m RSLR. The effect of RSLR at sections of shorelines where structures have a 20-year residual life (transects 163-173) are calculated to experience -7 to -9 m of erosion with 0.2m RSLR, and increases to -17 to -21 m of erosion with 0.4m of RSLR.
- By 2070, the effect of 0.3 m RSLR at structures with a 10-year residual life is calculated to be in the order of -25 m, and increases to be in the order of -65 m with 0.7m RSLR. The effect of RSLR at sections of shorelines where structures have a 20-year residual life (transects 163-173) are calculated to experience -18 to -20 m of shoreline erosion with 0.3m RSLR, which increases to -51 to -57 m of erosion with 0.7m of RSLR.
- By 2120, the effect of 0.6 m RSLR at structures with a 10-year residual life is calculated to be in the order of -56 to -59 m. This effect is in the order of -49 to -52 m where shoreline structures had a residual life of 20 years. With 1.65m of RSLR, the erosion effect increases to be -160 m to-183 m of erosion. The results indicate that the effect of the extra 10 years of protection in reducing future erosion is minimal over a 100-year timeframe.

[17] Beach width is the distance between the beach crest and the 0 m contour.

Table 8.2: Mean calculated effect of RSLR at transect segments in the Raumati cell with consideration for residual structure life, where '-' indicates erosion and '+' indicates accretion.

			Calculated Mean Erosion Effect of RSLR (m)					
Transects	Profile	Structure Residual Life	0.2 m (1) RSLR (2050)	0.4 m (1) RSLR (2050)	0.3 m (1) RSLR (2070)	0.7 m (1) RSLR (2070)	0.6 m (1) RSLR (2120)	1.65 m (1) RSLR (2120)
153-162	250	10	-14.9 (±5.9) m	-33.9 (±13.5) m	-25 (±10.0) m	-67.7 (±27.0) m	-56.3 (±22.4) m	-159.2 (±63.4) m
163-168	250	20	-7.4 (±3.0) m	-16.9 (±6.7) m	-17.6 (±7.0) m	-50.8 (±20.2) m	-48.9 (±19.5) m	-159.2 (± 63.4) m
169-173	260	20	-9.0 (±1.8) m	-21.3 (±4.2) m	-19.5 (±3.9) m	-56.5 (±11.2) m	-52.0 (±10.3) m	-169.0 (± 33.5) m
174-192	260	10	-15.5 (±3.1) m	-35.2 (±7.0) m	-26.0 (±5.2) m	-70.4 (±13.9) m	-58.5 (±11.6) m	-182.9 (±36.2) m
193-215	270	10	-15.3 (±3.2) m	-34.9 (±7.4) m	-25.8 (±5.5) m	-69.7 (±14.8) m	-58.0 (±12.3) m	-181.3 (± 38.4) m
216-240	280	10	-14.2 (±2.6) m	-32.4 (±6.0) m	-23.9 (±4.4) m	-64.7 (±12.0) m	-53.9 (±9.9) m	-168.3 (± 31.1) m
241-253	290	10	-14.8 (±0.2) m	-33.7 (±0.5) m	-24.9 (±0.4) m	-67.3 (±1.1) m	-56.0 (±0.9) m	-175.0 (±2.8) m

(1) Absolute RSLR values, they have been discounted for historical rate of RSLR: 0.72 mm/yr (1891-1960) (Hannah & Bell, 2012). The distances in brackets are the upper and lower bounds for the input parameters

The range in the uncertainty of the resulting erosion distances from the upper and lower bounds of the input parameters is variable across the profiles. The lowest range is at profile 290, where the uncertainty is generally less than 1 m except for the 1.65 m RSLR scenario in 2120. This low range of uncertainty is strongly influenced by the small variations in the input data, and do not take account of the limitations in the method for calculating RSLR effects. The greatest uncertainty occurs at profile 250 due to a greater range of lower to upper bounds of the input parameters resulting in uncertainty of 6-13 m for 2050 RSLR scenarios increasing to 22-70 m uncertainty for the 2120 scenarios.

8.4.3 Short-term Storm Erosion

The short-term component for the Raumati cell was based on post-storm observations from Gibbs and Wiltshere (1976) of the September 1976 storm, which was later assessed to be a 0.5% AEP event (Lane et al, 2012). The observations indicated that there was an upper limit of 15 m of erosion along this stretch of coast after structures had failed.

For the probabilistic method, a conservative approach was taken by applying the -15 m upper limit as the mean for a quasi-distribution, with ± 50% to give an upper bound of the triangular distribution of -22.5 m erosion and a lower bound of -7.5 m erosion

8.4.4 Dune Stability

The dune stability component for Raumati is based on an analysis of five surveyed profiles located within the cell and the 2017 LiDAR data from around the profiles, and applied a 'walls down' approach, where the LiDAR data was used to determine what a 'natural' dune height would be behind the present seawalls.

The resulting dune stability factors used for the probabilistic method at each profile are as follows:

- At profile 250, the mean dune stability factor is -5.5 m, with upper and lower bounds of -8.9 m and -4.1 m respectively.

- At profile 260, the mean dune stability factor is -7.2 m, with upper and lower bounds of -11.3 m and -3.6 m respectively.
- At profile 270, the mean dune stability factor is -4.5 m, with upper and lower bounds of -6.8 m and -1.5 m respectively.
- At profile 280, the mean dune stability factor is -3.0 m, with upper and lower bounds of -8.1 m and -1.5 m respectively.
- At profile 290, the mean dune stability factor is -2.5 m, with upper and lower bounds of -3.3 m and -2.1 m respectively.

8.5 Projected Coastal Erosion Distances

The resulting CED's calculated by the probabilistic method are presented below. Maps displaying the spatial location of the present-day hazard and PFSP are presented in maps 12-14 of Appendix A (2050), Appendix B (2070), and Appendix C (2120).

8.5.1 Present-day Erosion Susceptibility

The present-day erosion hazard is representative of the potential erosion hazard which could occur if a large storm were to happen in the immediate/near future. This present-day hazard is a combination of the short-term storm erosion (Section 8.4.3) and the dune stability factor (Section 8.4.4). It represents the dynamic nature of shoreline movements where short-term erosion can occur independently of long-term trends or RSLR.

For the Raumati coastal cell, the mapped present-day hazard is based on erosion following structure failure in a significant storm event. If structures did not fail in the event, there would be no erosion hazard, however there would likely be scouring in front of the structure, and potential back scour behind the structure if it was overtopped by waves.

For the southern section of the Raumati Cell, the present-day hazard is calculated to 'most likely' be -20 to -23 m of erosion at the southern end of the cell (transects 153-168), increasing to -21 to -24 across transects 169-192. This present-day hazard decreases again around the Wharemauku Stream to 'most likely' be -18 to -21 m, and decreases further to -16 to -19 m of erosion across transects 241-253.

8.5.2 Future Coastal Erosion Susceptibility

The raw outputs from the Monte Carlo simulation of the landward limit of 'most likely' zone (P33 position) for the three timeframes are presented below in Figure 8.6 to give an indication of the changes in shoreline position that could be expected to be over the next 100 years. It should be noted that these raw distances (also presented in Appendix J for P66, P33, and P10) have been smoothed in the mapping outputs for coastal process plan-shape considerations, as well as consideration of future inlet migration, and therefore the raw outputs may not be able to be directly correlated with the PFSP shorelines mapped in Appendix A, B and C. It should also be noted that erosion distances mentioned in the text have been rounded to the nearest 0.5 m.

The following provides a summary of the projected erosion distances to the landward limit of the most likely zone (P33) across each RSLR scenario.

2050

For the shoreline to the south of the Wharemauku Stream, under the 0.2 m RSLR scenario the shoreline is projected to experience an average of -38 m of erosion, of which the present-day storm components contribute more than 50%. The projected average erosion increases to -54 m with 0.4 m of RSLR. Segments of shoreline with structures that had residual lives of 20 years are projected to experienced up to 8 m less of erosion in the 0.2 m RSLR scenario, and up to 15 m less erosion with 0.4 m RSLR over the 30-year timeframe than structures which only have a 10-year residual life.

Figure 8.6: Erosion distances to projected future shoreline positions under future RSLR scenarios

For the shoreline north of the Wharemauku Stream, for the 0.2m RSLR scenario, the shoreline is projected to experience less erosion, with an average retreat of -29 m, with the present-day storm components again contributing more than 50%. This projected erosion increases to an average of -47 m under the 0.4 m RSLR scenario. The reduced future erosion is due to the extrapolation of the historical low 'pre-structure accretion rates (see Figure 8.5) for this section of shoreline. However, since the accretion rate is lower than the predicted erosion from RSLR, net erosion occurs following wall failure. It is important to note that prior to wall failure, the beach is likely to continue to lower in front of the wall due to scour, which is discussed further in Section 8.6.

2070

By 2070, it is assumed that all walls have failed and not been replaced, and the beach is returning to a natural dynamic shoreline.

For the 0.3 m RSLR scenario, south of Wharemauku Stream the shoreline is projected to erode -53 m. These erosion distances are projected to increase with 0.7 m of RSLR to be an average of -94 m. To the north of Wharemauku Stream, under the lower 0.3 m RSLR scenario, the shoreline is projected to experience an average of -34 m of erosion, and with 0.7 m of RSLR, this increases to be an average of -75 m of erosion.

2120

Again for this timeframe it assumed that the current seawalls have not been replaced following failure before 2050.

South of Wharemauku Stream, with 0.6 m of RSLR (RCP2.6 plus 1 mm/yr VLM) over the next 100 years, the shoreline is projected to erode by an average of -95 m. This increases to an average of -122 m with 0.85 m of RSLR (RCP4.5 plus 2mm/yr VLM) and increases further to -153 m with 1.25 m of RSLR (RCP8.5 plus 2 mm/yr VLM). Under the highest RSLR scenario of 1.65 m RSLR (RCP8.5H+ plus 3mm/yr VLM), the shoreline is projected to erode an average of -219 m. The projected erosion generally increases in a northward direction from the southern cell boundary to the Wharemauku Stream.

Less erosion is projected in the northern section of the cell relative to the southern section of the cell. With 0.6 m of RSLR, the shoreline north of the Wharemauku Stream is projected to erode by an average of -53 m. This increases to be an average of -79 m with 0.85 m of RSLR; and increases further to be an average of -105 m of erosion with 1.25 m of RSLR. With 1.65 m of RSLR, the shoreline is projected to erode an average of -167 m.

8.5.3 Comparison of results to previous coastal hazard assessment

The results of the PFSP presented in Section 8.5.2 are calculated to be very similar to previous coastal erosion assessments undertaken along the Raumati coastal cell, as is presented in Table 8.3.

Table 8.3: Comparison of averaged results from this assessment, CSL (2008 & 2012), and Lumsden (2003) for two RSLR scenarios.

	This Assessment (Jacobs, 2021) Average of P33 PFSP Values		CSL (2008 & 2012) 'Repair' CEHD		Lumsden (2003) Secondary Development Setback	
Timeframe (RSLR Scenario)	South of Wharemauku Stream	North of Wharemauku Stream	South of Wharemauku Stream	North of Wharemauku Stream	South Raumati	North Raumati
50 years (0.3m RSLR)	-53 m	-34 m	-42 m	-34 m	NA	NA
100 years (0.45m RSLR)	-95 m	-52 m	NA	NA	-90 m	-75 m

The Lumsden (2003) coastal management strategy proposed that for a RSLR of 0.45 m over the next 100 years a -90 m 'Secondary Development Setback' should be applied at south Raumati, and a -75 m 'Secondary Development Setback' should be applied to Raumati Beach. Comparatively, our lowest 100-year RSLR scenario

(0.6m) calculated an average of -95 m of erosion in Raumati South and -52 m of erosion in Raumati Beach over the same 100-year timeframe.

Compared to the more recent CSL (2008) coastal hazard assessment, the results produced in this study were also very similar. CSL (2008) calculated that with 0.3m of RSLR over the next 50 years, if walls were to occasionally fail and no be repaired, south of the Wharemauku Stream was likely to experience an average of -42 m of erosion, and north of the Wharemauku stream an average of -35 m of erosion. Comparatively, under the same 50-year 0.3 m RSLR scenario, the results for PFSP in this current assessment were an average erosion of -53 m south of the Wharemauku Stream, and an average of -34 m to the north of the stream. For the scenario calculated by CSL (2008) where walls were removed from the present-day, erosion was calculated to be an additional -22 m south of the Wharemauku Stream, and an additional -15 m to the north of the Wharemauku Stream.

8.6 Profile Lowering

An assessment was undertaken to determine the potential beach foreshore lowering in front of the seawall structures at the beach profile locations shown in figure 8.1 under the future RSLR scenarios for 2050 (0.2 m and 0.4 m RSLR). This assessment used the erosion distances due to RSLR as calculated in Section 8.4.2 to translate the profile landward and provide an estimate of what the effect of RSLR could be on foreshore lowering in front of the seawalls if these structures was to remain in place for the next 30 years.

The results of this analysis are presented in Table 8.4 and graphs showing the translated profiles and resulting beach lowering is presented in Appendix K. This assessment assumes that the toe depths of the sea walls present are sufficient to withstand the resulting scour depths, however, confirmation of this assumption is beyond the scope of this assessment.

Table 8.4: Projected beach lowering and 1% AEP storm event water depth at sea wall toe at beach profiles located within the Raumati coastal cell, across the range of 2050 RSLR projections.

Profile	RSLR projection	Beach Elevation at toe of sea wall (m WVD53)	Scour depth from current average profile (m)	Water level at seawall in 2050 1% AEP sea level event [(1)] (m)	Water Depth at seawall in 2050 1% AEP sea level event (m)
250	Current day average profile	0.6			
	0.2 m RSLR	0.3	-0.3	2.34	2.04
	0.4 m RSLR	-0.15	-0.75	2.49	2.64
260	Current day average profile	0.65			
	0.2 m RSLR	0.3	-0.35	2.34	2.04
	0.4 m RSLR	-0.45	-1.1	2.49	2.94
270	Current day average profile	1.2			
	0.2 m RSLR	0.6	-0.6	2.34	1.74
	0.4 m RSLR	0	-1.2	2.49	2.49
280	Current day average profile	1			
	0.2 m RSLR	0.4	-0.6	2.34	1.94
	0.4 m RSLR	-0.25	-1.25	2.49	2.74
290	Current day average profile	1.4			

Profile	RSLR projection	Beach Elevation at toe of sea wall (m WVD53)	Scour depth from current average profile (m)	Water level at seawall in 2050 1% AEP sea level event [(1)] (m)	Water Depth at seawall in 2050 1% AEP sea level event (m)
	0.2 m RSLR	0.8	-0.6	2.34	1.54
	0.4 m RSLR	0.2	-1.2	2.49	2.29
[1]Storm tide + wave set up from Table 4.2 of Volume 1 Methodology Report. 1% AEP at lower SLR projection is 2.34 m WVD53 (2020).					

The results of this assessment indicate that beach lowering due to RSLR will be less at the southern end of the cell (e.g., profiles 250 and 260) than at the northern end (e.g., profiles 270, 280 and 290). For the southern profiles, the lowering under a 0.2 m RSLR scenario over the next 50 years is projected to be in the order of -0.3 to -0.35 m, increasing to -0.75 m to -1.1 m with 0.4 m of RSLR. At the northern end of the cell, under 0.2 m of RSLR, the projected beach lowering could be in the order of -0.6 m and with 0.4 m of RSLR this could double and be up to -1.25 m. However, it is noted that beach elevations at the sea wall toe are generally higher at the northern end of the cell, so that the resulting toe elevations after the 50-year period will be similar, if not still higher, than at the southern end of the cell.

These results suggest that if the seawalls do not fail over the next 30 years as assumed (e.g., out-live their residual life), they are likely to experience significant foreshore lowering due to SLR at the toe of the structure, which could, depending on the toe foundation depth, also result in failure. However, the identification of any such sites would require information on toe foundation depths and is beyond the scope of this assessment. Due to increased water depth against walls, wave runup on the structures will also be higher, increasing the risk of back scour by overtopping.

8.7 Wharemauku Stream

The Wharemauku Stream (Figure 8.7) is the only hydrosystem cell located within the Raumati coastal cell. Historical shoreline positions for this hydrosystem are presented in Figure 8.8. The stream has timber river mouth training structures on both the left and right bank, with the left bank timber training wall extending out to approximately the mean high-water mark as shown in Figure 8.8. The river mouth environment is constrained by the training wall that limits migration of the stream mouth into the car park fronting the Waterfront Bar & Kitchen, where historically the mouth had migrated to (see Figure 8.8) prior to the training wall being extended in the 1970's.

Figure 8.7: Wharemauku Stream facing upstream showing the timber training wall on the left bank of the stream.

Figure 8.8: Historical shorelines and maximum shoreline envelope at the Wharemauku Stream.

The adjacent shoreline on either side of the hydrosystem cell is controlled by seawall structures, however 'early rates' used in Section 8.4.1 suggest that south of the stream the shoreline was eroding, and north of the stream the shoreline was accreting pre-1950's when the walls began to be constructed.

Due to the structurally controlled nature of this hydrosystem cell, and the erosional nature of the shoreline to the south, Method 1 from the coastal hydrosystem decision tree (see Section 2.2.7) was used to determine the possible future migration of the hydrosystem. This method assumes that the mouth training structure will stay in place for the next 30 years, after which it is assumed that the structure is removed, and the inlet area will likely migrate landward in line with the adjacent shoreline over a 50- and 100-year period. It is expected that the inlet would generally maintain its shape as it migrates landward but will be constricted by the surrounding topography and infrastructure such as the Matatua Road bridge.

The results of this analysis highlight that if river mouth training structures were to be maintained to hold the river mouth in place, there would be increased pressure on these structures from adjacent shoreline erosion if open coast structures failed, causing the training walls structures to extend below the MHWS and, potentially interrupting longshore sediment transport process and consequently becoming more costly to maintain. It is noted that the seawall fronting the carpark which the training wall is anchored to has recently been upgraded, and therefore these processes would depend on the maintenance of the sea wall, and whether it fails and is removed in the next 30 years. Due to the complexities of predicting future management decisions in regard to coastal protection structures, there are uncertainties around the resulting hydrosystem extents for future RSLR.

8.8 Vulnerability

8.8.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified affected council critical infrastructure and community services that intersected with mapped PFSP up to the landward limit of the most likely PFSP (P33). The results of this assessment are presented in Table 8.5.

Table 8.5: Council critical infrastructure and community services affected in Raumati cell under various sea level rise scenarios.

	RSLR Scenarios							
	2050		2070		2120			
Asset	**0.2 m**	**0.4 m**	**0.3 m**	**0.7 m**	**0.6 m**	**0.85 m**	**1.25 m**	**1.65 m**
Marine Parade (1) (Total length = 350m)	350m	350m	320m	350m	350m	350m	350m	350m
Wharemauku Road (1) (Total length =650m)	6m	42m	17m	75m	80m	93m	148m	275m
Rosetta Road (1) (Total length = 2250m)	0	0	0	0	135m	1748m	1849m	2000m
Hoby's Way (1) (Total length = 125m)	0	0	0	0	0	51m	125m	125m
The Esplanade (1) (Total length = 950m)	495m	520m	515m	950m	950m	950m	950m	950m
Water Supply Bore (2)	1	1	1	1	1	1	1	1
Coastal Stormwater Outlet (2)	24	24	24	24	24	24	24	24

(1) Length of road intersecting landward limit of 'most likely' PFSP
(2) Number of outlets intersecting landward limit of 'most likely' PFSP

The vulnerability assessment identifies a number of roads and critical infrastructure which could be affected by coastal erosion over a 30-, 50- and 100-year timeframe. Over all timeframes and RSLR projections, 90-100% of Marine Parade is projected to be affected by coastal erosion. Sections of Wharemauku Road could also be compromised by coastal erosion in the future, with up to 42 m potentially affected under the higher RSLR for 2050; 75 m under highest RSLR scenario for 2070; and increasing to 275 m under the highest RSLR scenario for 2120. Rosetta Road and Hoby's Way do not intersect with the 'most likely' PFSP until 2120, with almost 90% of Rosetta Road intersecting with the PFSP under all RSLR scenarios and the total length of Hoby's Way intersecting with the PFSP under a 1.25 m RSLR scenario. For the Esplanade, over 50% of the road length intersects with the 2050 PFSP's under both RSLR scenarios, increasing to the total length intersecting for 0.7 m RSLR by 2070 and all 100-year RSLR scenarios.

A water supply bore, and all 24 coastal stormwater outlets located within the Raumati cell intersect with the 'most likely' PFSP at each timeframe and RSLR scenarios.

8.8.2 Land parcels

The number of land parcels (public and private) which intersect with the PFSP up to the landward limit of the 'most likely' position (e.g. P33) and the landward limit of the 'unlikely' position (e.g. P10) were calculated to give an indication of vulnerability of land parcels within a coastal cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels (see Section 2.4). The results of this assessment for the Paekākāriki cell are presented in Figure 8.9 and Appendix L.

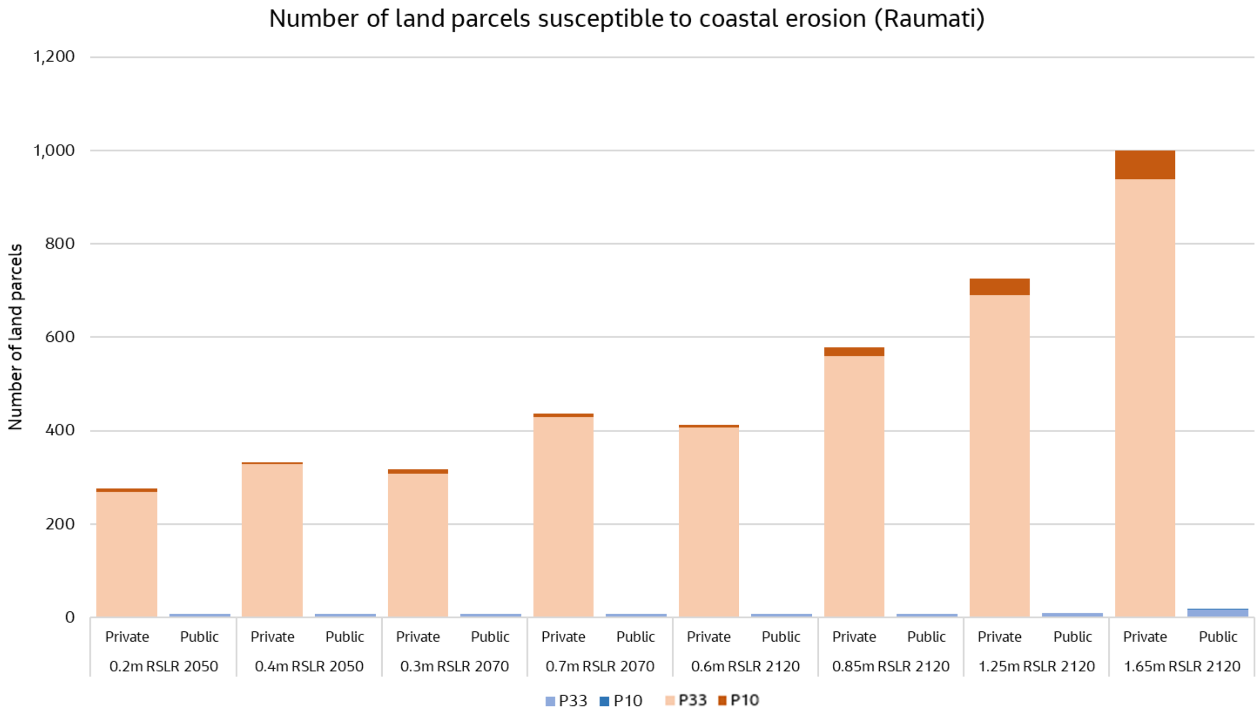


Figure 8.9: Number of public and private land parcels in Raumati potentially susceptible to coastal erosion. Lighter orange/blue show the number of properties susceptible to erosion up to the P33 (landward limit of the most likely), with the darker blue/orange showing additional parcels potentially affected between the P33 and P10 shoreline position.

These results indicate that seven to nine public land parcels intersect with the 'most likely' PFSPs across all RSLR scenarios and timeframes up to the 1.25 m RSLR (2120) scenario, with an increase to 18 public land parcels vulnerable under the most extreme 1.65m RSLR scenario in this 100-year timeframe.

For private land parcels, the results indicate that over a 30-year period with 0.2 m of RSLR there are 269 land parcels that intersect with the 'most likely' PFSP position, which increases to 329 under the 0.4 m RSLR scenario. By 2070, 308 private land parcels would intersect with the 0.3 m RSLR scenario, increasing to 429 parcels with 0.7 m of RSLR. For the 2120 projections, the number of private land parcels intersecting with the 'most likely' PFSP range increases from 406 for a 0.6 m RSLR, to 559 for a 0.85 m RSLR, to 691 for a 1.25 m rise, to 939 parcels for a 1.65 m rise.

Within the Wharemauku Stream hydrosystem cell, one public property intersects the potential future hydrosystem extent under all RSLR scenarios and timeframe up to 1.65 m RSLR by 2120, when the number affected increases to two. For private land parcels, over a 30-year period (2050) eight to nine private land parcels intersect with the potential future hydrosystem extent. Over a 50-year period (2070) eight land parcels intersect under the lower RSLR scenario (0.3 m), increasing to 16 land parcels with 0.7 m of RSLR. For the 2120 projections, the number of private parcels intersecting with the hydrosystem increases from 13 under the lowest RSLR scenario (0.6 m RSLR) to 29 under the highest RSLR scenario (1.65 m).

From this vulnerability assessment, it is shown that in terms of private property potentially effected by coastal erosion, Raumati is the most vulnerable cell in the Kāpiti District, accounting for 56% of the total vulnerable private land parcels by 2120.

9. Queen Elizabeth Park Coastal Cell

9.1 Summary

The Queen Elizabeth Park Coastal Cell covers approximately 3.2 km of sand beach shoreline from Raumati to Wainui Stream. Due to the cell's location south of the cuspate foreland and the entire Raumati cell locking up the shoreline behind a continuous seawall, this cell has a sediment budget deficit, resulting in long-term erosion along the whole length of the cell.

Under all RSLR scenarios across all timeframes the shoreline is projected to erode in the future, with slightly larger erosion distances at the northern end of the cell compared to the southern end. Erosion under the upper RSLR scenarios is projected to be in the order of -60 to -70 m over the next 30 years (0.4 m RSLR - 2050); -100 to -115 m over the next 50 years (0.7 m RSLR - 2070); and -200 to -250 m over the next 100 years (1.65 m RSLR - 2120).

Over the next 50 years with 0.7 m of RSLR, 43 m of Whareroa Road is projected to intersect with the 'most likely' PFSP. Over the 100-year timeframe, with 1.65 m of RSLR this increases to 170 m. For public property, four land parcels intersect with the 'most likely' PFSP for all RSLR scenarios over the next 30 years (2050) and 50 years (2070). This increases to five public land parcels under the highest RSLR scenario in 2120 (1.65 m). An additional one to two public land parcels could be affected by future migration of the Whareroa Stream. Due to the park status of the Queen Elizabeth Park coastal cell, no private land parcels are projected to intersect with 'most likely' PFSP over any timeframe.

This coastal cell and the results are discussed in more detail in the sections below.

9.2 General Description

The Queen Elizabeth Park Coastal Cell covers approximately 3.2 km of shoreline from the Raumati Coastal Cell in the north, to the northern boundary of the Wainui Stream Hydrosystem Cell, as shown in Figure 9.1. This figure also presents the location of key data reference points within this cell (e.g. DSAS transects, beach and bathymetric profiles).

Queen Elizabeth Park is a regional park primarily used for recreational purposes (e.g. hiking, mountain biking). There are no dwellings or coastal properties located within this cell. The cell also includes the Whareroa Stream hydrosystem cell (transects 123-131), which is located in the centre of the park. Within the cell are many sites of historical significance for mana whenua, some of which are threatened by coastal erosion such as midden sites that are being exposed in the eroding dune faces.

As with the Raumati cell, the coastal process environment along Queen Elizabeth Park is strongly influenced by the wave shadow in the lee of Kāpiti Island and by the cuspate foreland in the Paraparaumu cell to the north, which acts like a natural groyne, reducing the long shore sediment supply to the southern shoreline. The bathymetry map presented as Figure 2.1 of the Vol 1 Methodology Report indicates that some of the sand that does pass around the foreland is deposited on the nearshore to form a wide flat sand bank from Raumati to Paekākāriki in water depths of 7 m to 12 m. Some of the bypassing sand is also likely to be is deflected offshore by the constricted tidal currents across foreland to be deposited into the Rauoterangi channel. These processes are likely to further reduce the supply of sand to the beaches at Raumati and further south.

As shown in Figure 9.2, the coastal environment along this cell consists of a sandy beach foreshore backed by sand dunes which have foredune elevations of up to 6 m and extensive higher back dunes of over 14 m elevation. As a result of the reduced sediment supply, the beach foreshore width within this cell is relatively narrow (40-65 m) compared to the accretionary sand beaches found in the northern end of the district.

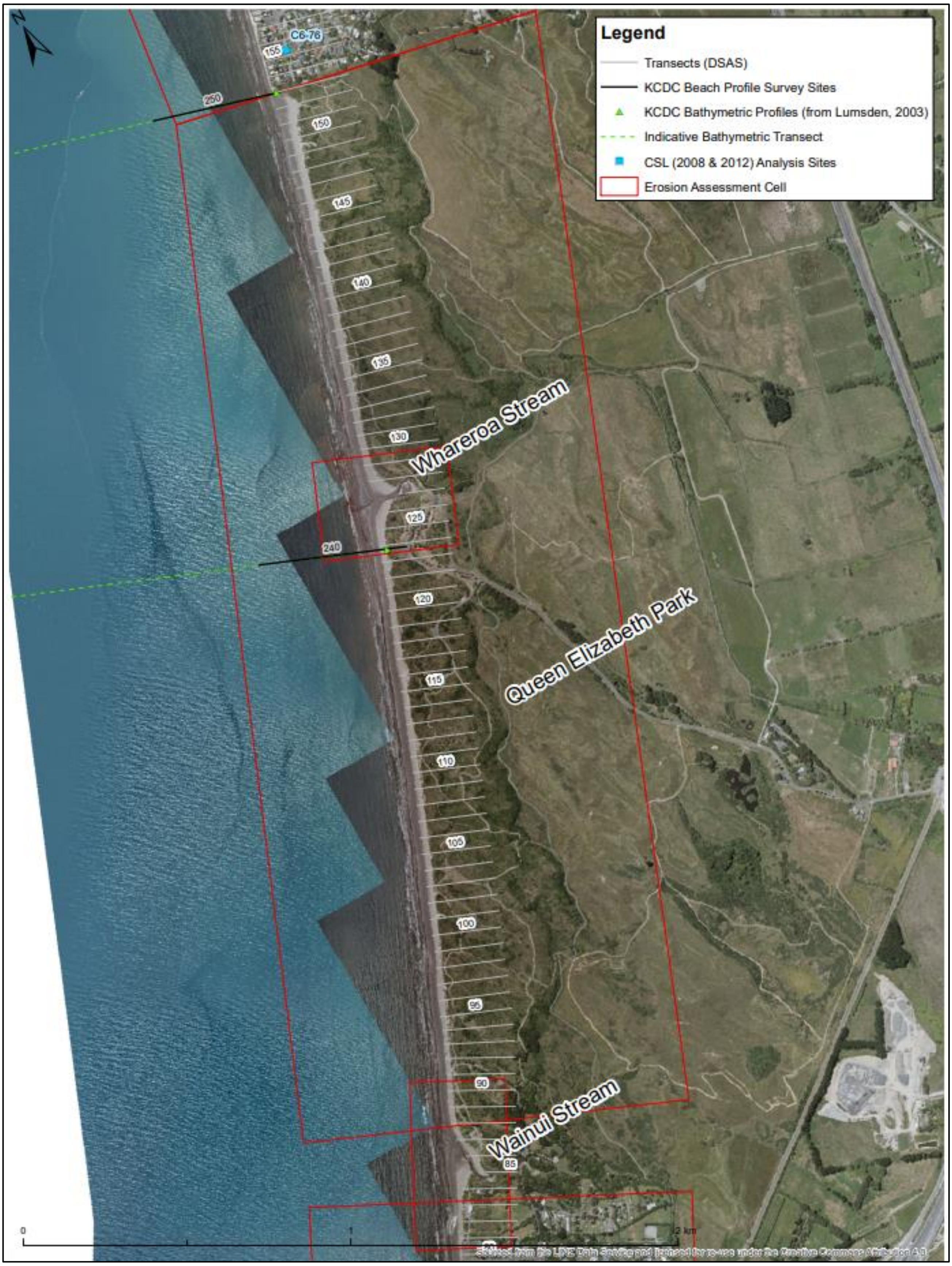


Figure 9.1: Queen Elizabeth Park Cell key features and data reference points (DSAS transects, beach and bathymetric profiles).

Figure 9.2: View facing south from the northern cell boundary, showing sandy beach and high dune coastline of Queen Elizabeth Park.

9.3 Structures

There are no coastal protection structures located inside the Queen Elizabeth Park cell.

9.4 Erosion Components

9.4.1 Extrapolation of Long-term Rates

The historical shoreline positions within the Queen Elizabeth Park coastal cell were digitised from between 6-7 aerial photographs from 1948 to 2017. Figure 9.3 overlays these shoreline positions at the northern end of the cell on the 1948 aerial imagery, demonstrating the long-term erosion that has occurred over the nearly 70-year period.

The DSAS analysis revealed that this long-term erosion has occurred throughout the open coast of the cell since 1948, with the results being presented in Figure 9.4. For the transects north of the Whareroa Stream (Transects 132-152), the R^2 values from the linear regression were acceptable (> 0.6), so the linear regression rates are used, being in the order of -0.3 m/yr near the Whareroa Stream and increasing to -1.35 m/yr at the northern cell boundary (Transect 152) where end effects erosion from the adjacent Raumati seawalls are evident. For Transects 89-122 to the south of the Whareroa Stream, the linear regression returned poor R^2 values (< 0.3) due to fluctuations between erosion and accretion occurring against different time periods. As a result, the End Point Rate was used to extrapolate the long-term rate at these transects rather than the Linear Regression Rate. Generally, erosion rates in this area have been between -0.1 m/yr and -0.3 m/yr, with an average erosion rate along this stretch of shoreline of -0.19 m/yr.

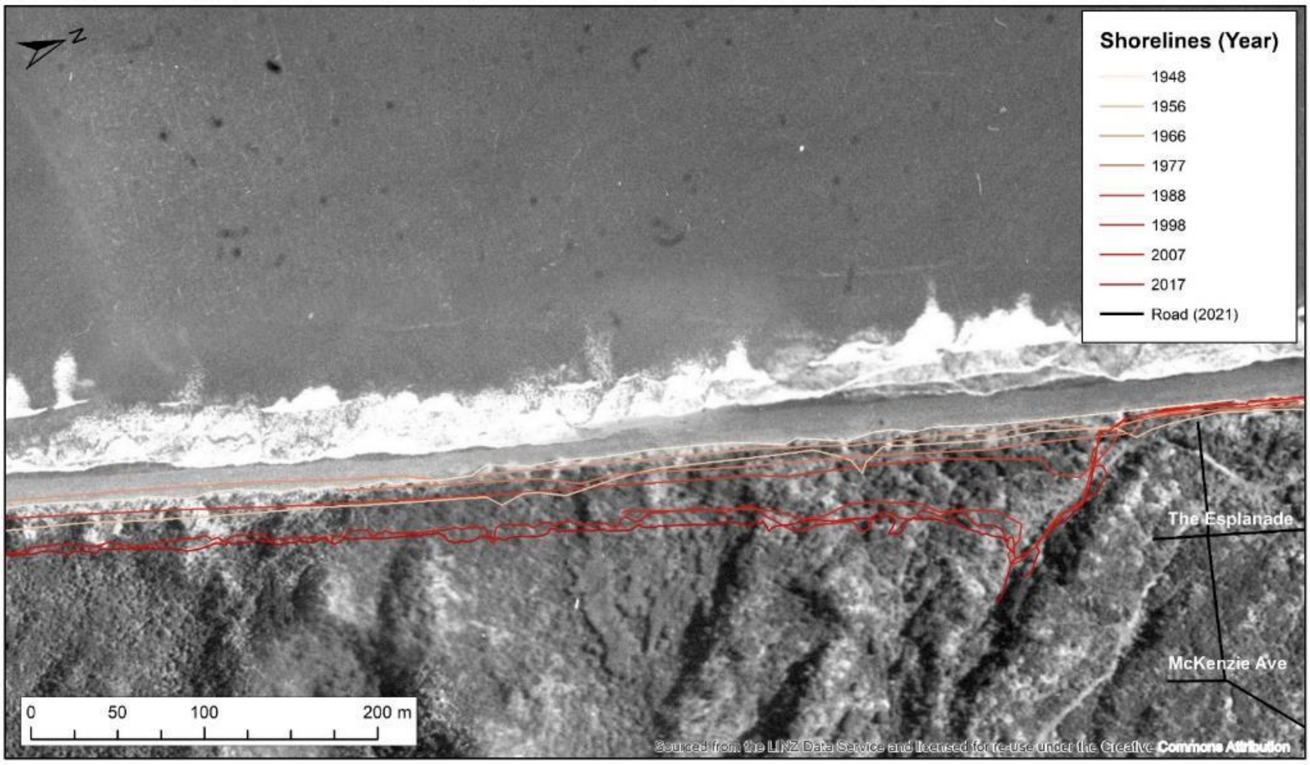


Figure 9.3: Historical shorelines from 1948-2017 showing long-term erosion in Queen Elizabeth Park overlaid on 1948 aerial imagery. This image covers the northern cell boundary, showing the long-term end effects of the South Raumati coastal protection structures.

The upper and lower bounds of the triangular distribution for the probability approach were taken as being ± the 90% confidence level of the average rate from the linear regression where the LRR was applied, and ±50% the mean EPR when the EPR was applied (Transects 89-122). The resulting upper bound still resulted in beach erosion at all transects.

The extrapolation of the average and confidence interval rates into the future results in the beach erosion distances presented in Table 9.1.

Table 9.1: Projected shoreline erosion distances in the Queen Elizabeth Park coastal cell from the extrapolation of average long-term rates of shoreline movement from aerial photographs 1948-2017.

Transects	Next 30 years (by 2050)	Next 50 years (by 2070)	Next 100 years (by 2120)
South of Whareroa Stream (Transects 89-122)	-5.8 (±2.9) m	-9.6 (±4.8) m	-19.2 (± 9.6) m
North of Whareroa Stream (Transects 132-152)	-15.1 (±8.0) m	-25.1 (±13.3) m	-50.3 (± 26.6) m
The distances in brackets are the upper and lower bounds of uncertainty, being the 90% confidence interval of the LRR from the DSAS applied to transects 132-152; and 50% of the mean EPR used for transects 89-122.			

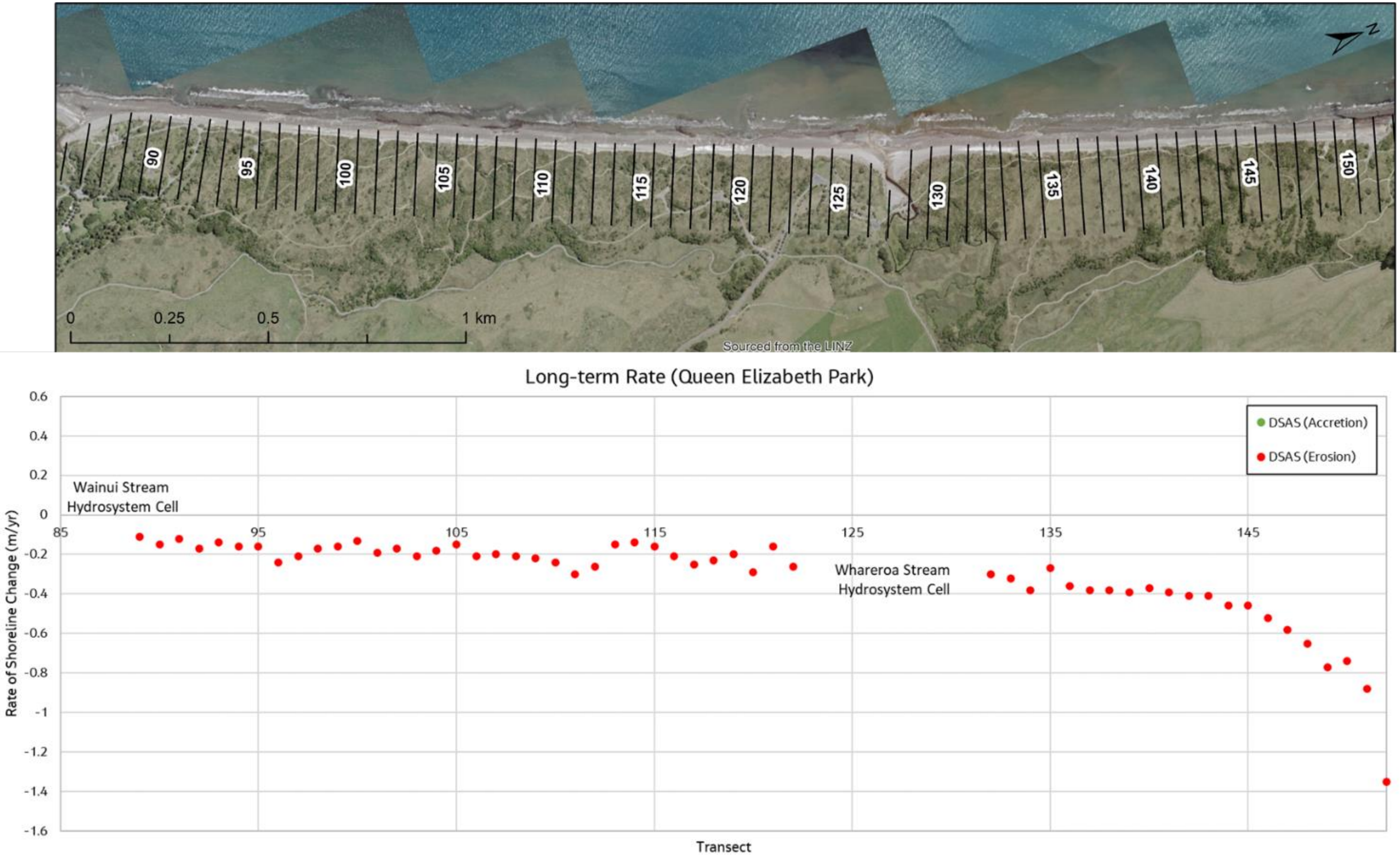


Figure 9.4: Long-term rate calculated from DSAS in Queen Elizabeth Park

9.4.2 Effect of Future Accelerated Sea Level Rise

As explained in Section 2.2.3, to avoid 'double accounting' of contemporary sea level rise and to isolate the effects of RSLR to being just for the acceleration in the rate of rise, the resulting erosion distances are calculated for the 'discounted' rates of rise for each timeframe as presented in Table 2.2.

For the Queen Elizabeth Park coastal cell, the effect of RSLR was calculated by the Bruun Rule using the beach and bathymetry profile parameters from profile 240 (locations shown in Figure 9.1, Beach profiles are presented in Appendix F, and offshore bathymetric profiles from Lumsden (2003) are presented in Appendix G). The parameters from these profiles were applied to all transects within the cell. Since there is only one input profile, there is little variation in the input values for the upper and lower bounds of the triangular distribution for the calculation of the range of erosion distances due to RSLR, so the uncertainty in the projected erosion distances due to uncertainty in the input parameter is also corresponding small. The results of these calculations are presented in Table 9.2.

Table 9.2: Projected erosion distances in the Queen Elizabeth Park coastal cell from future acceleration of rates of RSLR, where '-' indicates erosion and '+' indicates accretion.

Timeframe	Magnitude of Absolute RSLR	Average Erosion Distance	Lower Bound Erosion Distance	Upper Bound Erosion Distance
2050 (30 years)	**0.2m**	-17.3 m	-7.2 m	-17.7 m
	0.4m	-46.6 m	-19.4 m	-47.7 m
2070 (50 years)	**0.3m**	-24.0 m	-9.0 m	-24.6 m
	0.7m	-82.6 m	-29.2 m	-84.5 m
2120 (100 years)	**0.6m**	-48.0 m	-15.6 m	-49.1 m
	0.85m	-84.6 m	-26.6 m	-86.6 m
	1.25m	-126.2 m	-36.9 m	-129.1 m
	1.65m	-201.8 m	-61.6 m	-206.4 m

However, due to the nature of the beach and bathymetric profiles in this cell, there is some additional uncertainty around the appropriateness of some of the input parameter used in the Bruun Rule calculations. For the bathymetric profiles the presence of the offshore sand bank results in a convex profile shape between the inner and outer closure depth (7.6 m and 11 m water depth respectively) which is considerably different from the typical equilibrium profile assumed under the Bruun Rule (e.g. progressively greater depths with offshore distance). As a result the nearshore slope to the mid-point between the two closure depths is very similar to the outer depth, resulting in a heavily skewed triangular distribution where the upper limit and mean are very similar, and the lower limit is much less.

The dune elevation for all calculations was taken from the present-day foredune of beach profile 240 located in the centre of the cell, which elevations in the order of 5.8 m across all surveys. While this is the most appropriate dune elevation to use in calculations of RSLR effect over the next 30-year period, it may not be the most appropriate as the shoreline retreats into the higher back dunes (elevations in the order of 14 m) over the 50- and 100-year timeframe. The probabilistic distribution accounts for this potential increase in dune elevation over a 50- and 100-year period by setting a lower bound profile of -14 m dune height and 80 m dune width, which results in a skewed triangular distribution as the higher dune elevation results in a smaller erosion distance.

These calculations assume that future erosion truncates the beach profile rather than migrates it landward, such that the present high back dunes hold their elevation as they become the future foredunes. However, further investigations and research is required to confirm these profile adjustments.

9.4.3 Short-term Storm Erosion

The short-term component for Queen Elizabeth Park was based on post-storm observations from Gibbs and Wilshere (1976) following the September 1976 storm, which was later assessed to be a 0.5% AEP event (Lane et al, 2012). The observations indicated that there was an upper limit of 10 m of erosion at Queen Elizabeth Park.

For the probabilistic method, a conservative approach was taken by applying the -10 m upper limit as the mean for a quasi-distribution, with ± 50% to give an upper bound of the triangular distribution of -15 m erosion and a lower bound of -5 m erosion.

9.4.4 Dune Stability

The dune stability component for Queen Elizabeth Park cell is based on an analysis of one surveyed profile located within the cell (profile 240, see Figure 9.1 for location). For the probabilistic method, the mean erosion from dune stability for profile 240 is -2.9 m, with upper and lower bounds of -4.2 m and -2.2 m respectively. This has been applied to all transects within this cell. It is noted that these calculated have been taken from the surveyed foredune, however the dune stability factor is likely to increase overtime as the shoreline erodes back into higher dunes in the back dune environment.

9.5 Projected Coastal Erosion Distances

The resulting CED's calculated by the probabilistic method are presented below. Maps displaying the spatial location of the present-day hazard and PFSP are presented in maps 15 and 16 of Appendix A (2050), Appendix B (2070), and Appendix C (2120).

9.5.1 Present-day Erosion Susceptibility

The present-day erosion hazard is representative of the potential erosion hazard which could occur if a large storm were to happen in the immediate/near future. This present-day hazard is a combination of the short-term storm erosion (Section 9.4.3) and the dune stability factor (Section 9.4.4). It represents the dynamic nature of shoreline movements where short-term erosion can occur independently of long-term trends or RSLR. For the Queen Elizabeth Park coastal cell, the present-day hazard was calculated to 'most likely' be -12 m to -14 m of erosion, with erosion unlikely to exceed -16 m.

9.5.2 Future Coastal Erosion Susceptibility

The raw outputs from the Monte Carlo simulation of the landward limit of 'most likely' zone (P33 position) for the three timeframes are presented in Figure 9.5 to give an indication of the changes in shoreline position that could be expected over the next 100 years. It should be noted that these raw distances (Appendix J) have been smoothed in the mapping outputs for coastal process plan-shape considerations, as well as consideration of future inlet migration, and therefore the raw outputs may not be able to be directly correlated with the PFSP shorelines mapped in Appendix A, B and C. It should also be noted that erosion distances mentioned in the text have been rounded to the nearest 0.5 m.

The following provides a summary of the projected erosion distances to the landward limit of the most likely zone (P33) across each RSLR scenario.

In general, under all RSLR scenarios, the shoreline within the Queen Elizabeth Park cell is projected to erode under all RSLR scenarios. South of the Whareroa stream (transects 89-122), PFSP's have little variability alongshore, and North of Whareroa Stream, PFSP distances increase in a northward direction due to the increase in historical erosion rates towards the Raumati Cell boundary. The variability of PFSP distances alongshore within the Queen Elizabeth Park cell is small, where longshore changes are predominantly driven by the historical shoreline trends at each transect. Only one beach profile is available for assessment within this cell, however due to the uniformity of the shoreline within this cell it is noted that there are limited longshore differences in the beach profile characteristics used to calculate the effect of RSLR.

2050

For the shoreline to the south of Whareroa Stream for the 0.2m RSLR scenario, the shoreline is projected to experience an average of -35 m of erosion. Under the higher RSLR scenario (0.4 m RSLR), erosion is projected to increase to an average of -61 m.

For the shoreline to the north of Whareroa Stream, under the lower 0.2 m RSLR scenario, the shoreline is expected to experience an average of -44 m of erosion, with higher erosion distances of up to -54 m at the northern end of the cell. With 0.4 m of RSLR, this erosion is expected to increase on average up to -70 m, with maximum erosion distances projected to be up to -85 m near the Raumati cell boundary due to end effects from the Raumati seawalls. Although these seawalls have a residual life of 10-30 years, the end-effects are included over the whole 30-year period due to extrapolation of the past long-term erosion rates, which includes the end-effects.

2070

Under the lower 0.3 m RSLR scenario for 50 years (2070), the shoreline to the south of the Whareroa Stream, the shoreline is expected to erode by an average of -44 m, which increases with 0.7 m of RSLR to an average of -96 m.

The shoreline to the north of Whareroa Stream with 0.3 m of RSLR is projected to erode by an average of -60 m over the next 50 years. This increases to an average of -112 m of erosion with 0.7 m of RSLR over the same timeframe, which reaches a maximum of -136 m at the northern end of the cell (Transect 152). This localised maximum erosion distances include the end effects from Raumati seawalls over the total 50-year period. However, should the walls not be maintained/replaced beyond their residual life, the influence of these end effects on future erosion distances would diminish, resulting in lower erosion distances to the PFSP. Although it is difficult to quantify, this reduction in end effects is reflected in the mapping of the 2070 PFSP positions in Appendix B, with the raw erosion distances at Transect 152 being reduced by in the order of 40 m in the mapping product, diminishing to no reduction within 200 m to the south (e.g. by Transect 148).

2120

For the area of shoreline to the south of Whareroa Stream, with 0.6 m of RSLR (RCP2.6 plus 1 mm/yr VLM) over the 100-year timeframe the shoreline is projected to erode by an average of -75 m. This is projected to increase with 0.85 m of RSLR (RCP4.5 plus 2mm/yr VLM) to be an average of -103 m, and with 1.25 m RSLR (RCP8.5 plus 2 mm/yr VLM) to be an average of -139 m of erosion. Under the highest RSLR scenario of 1.65m RSLR (RCP8.5H+ plus 3mm/yr VLM) the projected average erosion increases to -206 m.

For the area of shoreline north of Whareroa Stream, under the lowest RSLR scenario (0.6 m RSLR) the shoreline is projected to erode by an average of -107 m, being up to a maximum of -156 m erosion at the northern end of the cell (Transect 152). With 0.85 m of RSLR, this average increases to -138 m, and with 1.25m of RSLR to -173 m of erosion. Under the highest RSLR scenario (1.65 m RSLR) the shoreline north of the Whareroa Stream is projected to experience an average of -241 m of erosion. As is noted above for the 2070 results, should the Raumati seawalls not be maintained/replaced beyond their residual life, the above erosion distances at the northern end will be conservative due to a much-reduced influence of end effects erosion over this time frame than calculated by the extrapolation of the cotemporary long-term rates. As above, although it is difficult to quantify, this reduction in end effects is reflected in the mapping of the 2120 PFSP positions in Appendix B, with the raw erosion distances at Transect 152 being reduced by in the order of 75 m in the mapping product, diminishing to no reduction with 200 m to the south (e.g. by Transect 148).

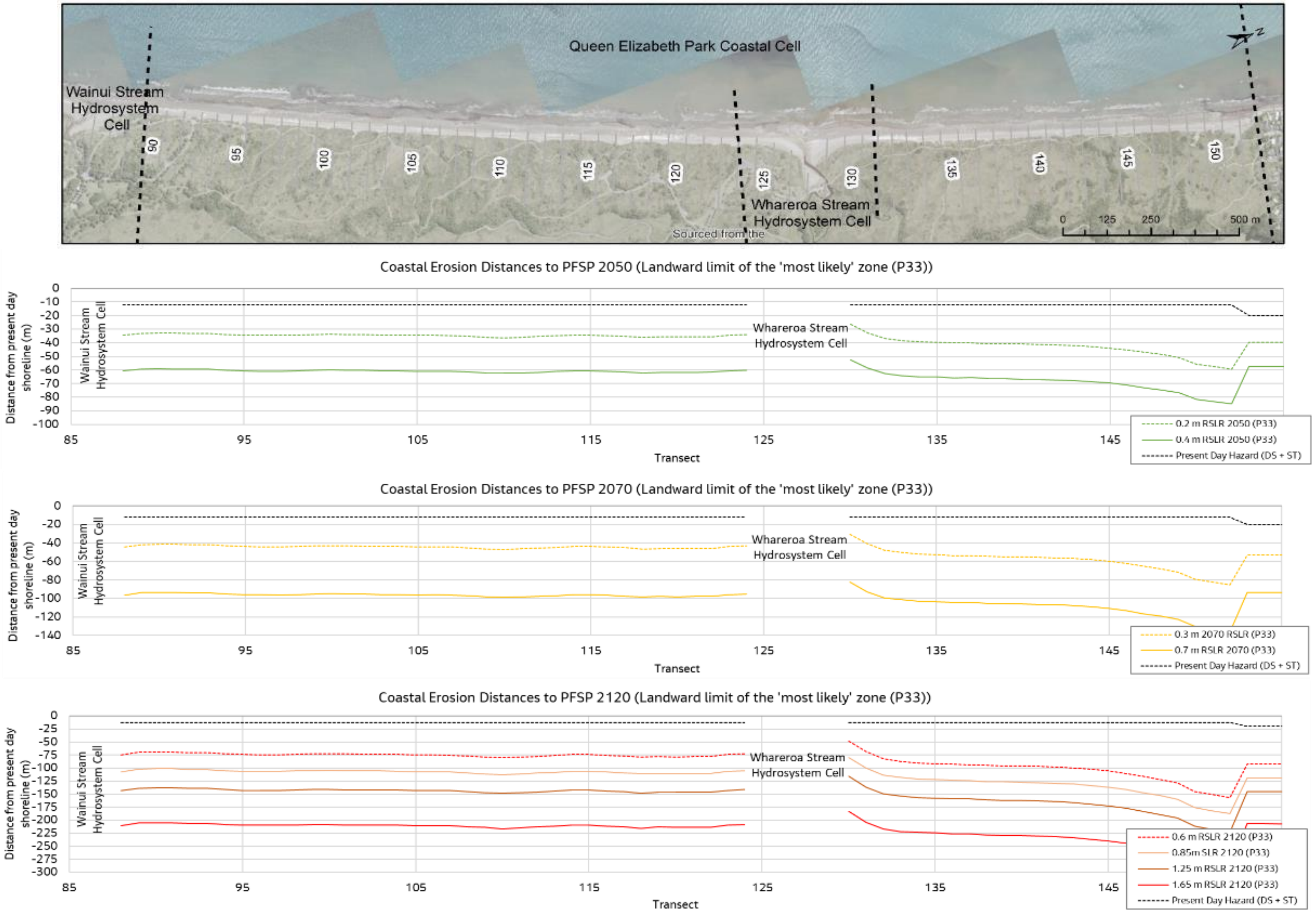


Figure 9.5: Erosion distances to projected future shoreline positions under future RSLR scenarios

9.5.3 Comparison of results to previous coastal hazard assessments

The results of the PFSP presented in Section 9.4.2 are calculated to be less than previous coastal erosion assessments undertaken in the area. The Lumsden (2003) coastal management strategy proposed a proposed a -200 m 'Secondary Development Setback' across the Queen Elizabeth Park Cell, which was a deterministic approach of assessment long-term trend at the site and the effect of a 0.45 m RSLR over the next 100 years. Comparatively, our lowest RSLR projection over a 100-year period was 0.6 m, which projected an average erosion distance of -75 m of erosion south of Whareroa Stream, and an average of -107 m of erosion along the shoreline to the north of Whareroa Stream.

Compared to the more recent CSL (2008 & 2012) coastal hazard assessment, the results produced in this study are also less. For a 0.3 m RSLR over 50 years scenario, CSL (2008 & 2012) calculated erosion distances for two scenarios regarding whether the walls were removed or "repaired" or "held" in the Raumati coastal cell. The difference between these two scenarios is that the extrapolation of the long-term rate was reduced to account for the change in erosion rates following the removal of the Raumati sea walls. The erosion projections produced in this assessment align closely with the "walls removed" scenario from the CSL (2008 & 2012) assessment. The wall "held" and "repaired" scenarios produced erosion distances which were 5 to 25 m greater than our average along the southern section of shoreline within this cell, and 15 to 60 m greater along the northern section of shoreline within this cell.

The key differences between the CSL (2008 & 2012) assessment and this assessment are driven from the long-term component and dune stability components. The long-term component in the "walls removed" approach for the CSL (2008 & 2012) assessment were on average twice as high as those used in this assessment. Dune stability factor was also considered to be -10 to -14 m in the CSL (2008 & 2012) assessment, whereas it was considered to be in the order of -3 m in this assessment, due to the use of the present-day foredune for beach height. Both calculations of the effect of RSLR and short-term were very similar across both assessments

9.6 Whareroa Stream

The Whareroa Stream is the only hydrosystem cell located within the Queen Elizabeth Park coastal cell, for which the historical shoreline positions are presented in Figure 9.6. From aerial imagery, it can be seen that in the 1950's the stream began to meander to the south into the left bank, causing this bank to erode. By 1966 a training wall on the left bank had been constructed, which restricted stream movement to the present-day, and since then the stream has maintained its position along the left bank against the training wall. The shoreline on the adjacent sides of the inlet has historically been eroding, however it is noted that since the construction of the river mouth training structure there has been a small amount of accretion at the mouth of the right bank due to deposition of material in the inlet.

Due to the structure on the left bank being present within this hydrosystem cell, and the natural erosional nature of the adjacent shorelines, Method 1 from the coastal hydrosystem decision tree (see Section 2.2.7) was used to determine the possible future migration of the hydrosystem. This method has taken into account that the structure will stay in place for the next 30 years, and assumes that it will be removed following that time resulting in the inlet area most likely migrating landward in line with the adjacent shoreline over 50- and 100-year timeframes. It is expected that the inlet would maintain its shape and migrate landwards with the adjacent shoreline, whilst having some consideration for surrounding topography and some infrastructure.

The results of this analysis however highlight that if river mouth training structures were to be maintained to hold the river mouth in place, there would be increased pressure on these structures from adjacent shoreline erosion, causing these structures to extend out from the natural shoreline, and would become more costly to maintain. This is likely to be an issue within the next 30 years.

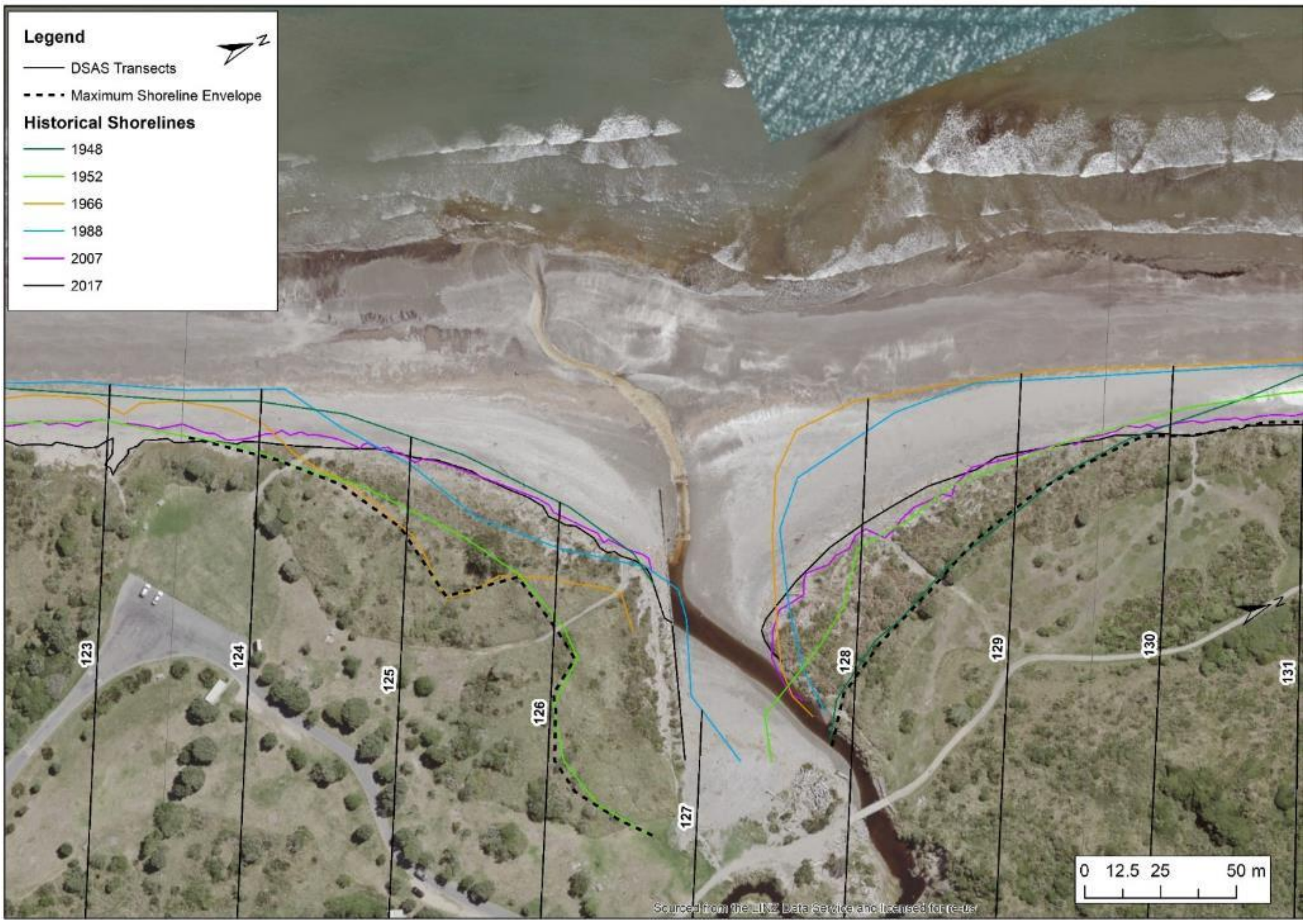


Figure 9.6: Historical shorelines and the maximum shoreline envelope for the Whareroa Stream

9.7 Vulnerability

9.7.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified affected council critical infrastructure and community services that intersected with mapped PFSP up to the landward limit of the most likely PFSP (P33). The results of this assessment are presented in Table 9.3.

Table 9.3: Council critical infrastructure and community services affected in Queen Elizabeth Park cell under various sea level rise scenarios.

	RSLR Scenarios							
	2050		2070		2120			
Asset	0.2m	0.4m	0.3m	0.7m	0.6m	0.85m	1.25m	1.65m
Whareroa Road (Total length = 1950m)	0	0	0	43m	18m	71m	118m	170m

The results of this assessment identified that Whareroa Road was the only identified key piece of council critical infrastructure vulnerable to coastal erosion within the Queen Elizabeth Park coastal cell. As shown in Table 9.3, the road begins to intersect with 'most likely' PFSP under the 0.7 m of RSLR in 2070, with 43 m of the road intersects with the PFSP. By 2120, this increases to up to 70 m affected under the 0.85 m RSLR scenario, up to 118 m with RSLR of 1.25 m and up to 170 m with the 'most likely' PFSP under the highest RSLR projection of 1.65 m over this 100-year timeframe.

9.7.2 Land parcels

The number of land parcels (public and private) which intersect with the PFSP up to the landward limit of the 'most likely' position (e.g. P33) and the landward limit of the 'unlikely' position (e.g. P10) were calculated to give an indication of vulnerability of land parcels within a coastal cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels (see Section 2.4). The results of this assessment for the Queen Elizabeth Park cell are presented below in Figure 9.7 and in Appendix L.

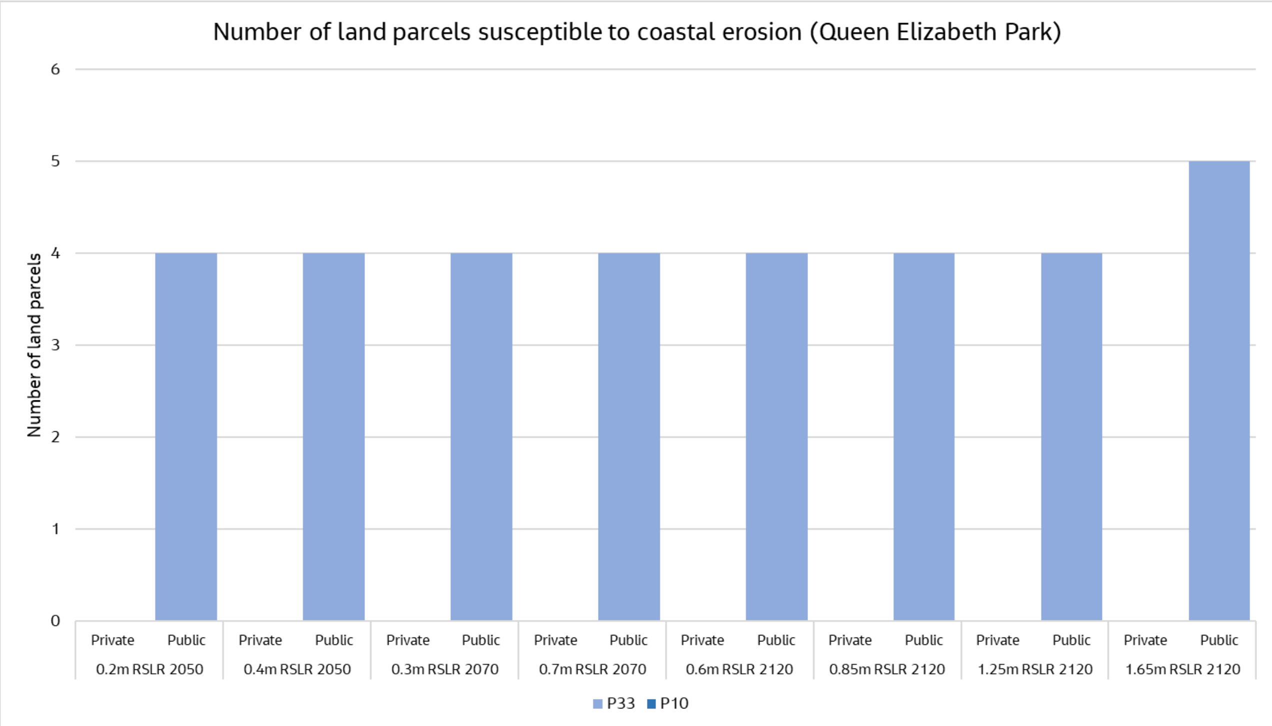


Figure 9.7: Number of public and private land parcels in Queen Elizabeth Park potentially susceptible to coastal erosion. Lighter orange/blue show the number of properties susceptible to erosion up to the P33 (landward limit of the most likely), with the darker blue/orange showing additional parcels potentially affected between the P33 and P10 shoreline position.

As expected, due to the park status of Queen Elizabeth Park, no private property intersects with 'most likely' PFSP within this coastal cell over the next 100 years, under all RSLR scenarios. For public property, four land parcels intersect with the 'most likely' PFSP for all RSLR scenarios over the next 30 years (2050) and 50 years (2070). Under the highest RSLR scenario in 2120 (1.65 m), five public land parcels intersect with the 'most likely' PFSP.

For the Whareroa Stream hydrosystem cell, no private land parcels intersect with the potential future hydrosystem. One public property intersects the potential future hydrosystem extent under all RSLR scenarios and timeframe, until 2120 (1.65 m RSLR) where this increases to two public land parcels. It is noted that the Whareroa Stream area marks the traditional boundary between Ngati Toa Rangatira and Te Ati Awa ki Whakarongotai and is a significant site for mana whenua.

From this vulnerability assessment, in terms of private property potentially affected by coastal erosion, the Queen Elizabeth Park cell is the least vulnerable in the Kāpiti Coast District, but it is recognised that it is a significant area for mana whenua and has high recreational and ecosystem values.

10. Paekākāriki Coastal Cell

10.1 Summary

The Paekākāriki Coastal cell covers approximately 4 km stretch of shoreline located between Wainui Stream, and the southern district boundary. Coastal processes within the Paekākāriki cell are strongly influenced by the presence of Kāpiti Island (wave shadow effect), and the cuspate foreland to the north acting like natural groyne deflecting bypassing sand offshore to form a broad flat offshore sand bank and restricting beach sediment supply. As a result the beach has suffered periodic large-scale erosion in response to significant storm events, which have resulted in a near continuous line of ad hoc public and private coastal protection structures (seawalls) being constructed since at least the 1950's.

Projected future erosion of the shoreline under RSLR scenarios takes into account the presence of these protection structures for a period of time up to their estimated residual life of 10-50 year, after which it is assumed that the structures are not replaced, and the beach reverts to a natural system. Structures at the northern and southern ends of the cell have assumed residual life of 30-50 years, and therefore over a 30- and 50-year periods the greatest erosion distances may occur through the centre of the cell where structures are assumed to have failed within these timeframes. Across this central area of the Paekākāriki Cell, projected erosion distances for the highest RSLR scenarios are in the order of -30 m by 2050; -50 m by 2070; and -100 m by 2120.

In terms of council critical infrastructure, 15 coastal stormwater outlets within the cell are vulnerable to the coastal erosion hazard at all timeframes. The Parade is projected to completely intercept with the 'most likely' PFSP line within 50 years. Ames Street is only projected to intersect with the PFSP in 100 years, with 60 m affected under the lowest RSLR scenario (0.6 m) increasing to 690 m at the highest RSLR scenario (1.65 m). State Highway 1 is projected to become affected following the assumed failure of the coastal protection structure there after 50 years.

There are a large number of private land parcels that intersect with the 'most likely' PFSP within each timeframe; 45 in the next 30 years, 83-148 within 50 years; and 149-245 within 100 years. An additional three public land parcels could be affected by the projected coastal erosion in all timeframes and RSLR scenario, and a further one private and one public land parcel are projected to be affected by coastal erosion around the Wainui Stream. This places the Paekākāriki cell as the second most vulnerable to projected future coastal erosion for private land parcels.

This coastal cell and the results are discussed in more detail in the sections below.

10.2 General Description

The Paekākāriki Coastal cell covers approximately 4 km of shoreline located between the southern boundary of the Wainui Stream hydrosystem cell in the north, to the southern district boundary in the south, as shown in Figure 10.1. While the Wainui Stream is not located within the Paekākāriki coastal cell, it is discussed in this section. Figure 10.1 also presents the location of key data reference points within this cell (e.g. DSAS transects, beach and bathymetric profiles).

This cell includes the Paekākāriki settlement which spans the length of the cell. The settlement contains 801 private dwellings and is home to approximately 1,750 residents (Statistics New Zealand, 2018). This settlement is located at the southern end of the coastal plain, which narrows down to less than 200 m at the base of the coastal escarpment and Paekākāriki Hill.

The coastal environment along this cell contains an ad hoc mix of public and private coastal protection structures which have been constructed since 1955 onwards in response to large storm events, two of which can be seen in their current form in Figure 10.2 and Figure 10.3. Since their original construction, many structures have failed in storm events and subsequently been rebuilt. The structures vary in length, type, and age, however

Figure 10.1: Paekākāriki Coastal Cell key features and data reference points (DSAS transects, beach and bathymetric profiles).

the majority of them are rock revetments and timber sea walls, with a few railway iron and tyre structures. South of The Parade, property has been developed right up to the shoreline with only a small buffer between properties and the present-day shoreline (Figure 10.3). Along the Parade there are a series of timber walls and rock revetments along its seaward edge. Despite being located landward of The Parade, coastal properties are only set back in the order of 20 m from the present-day shoreline (see Figure 10.2). The Paekākāriki Surf Life Saving Club is located on the coast at the northern end of the cell near the Wainui Stream hydrosystem cell. There are plans to remove this structure and built a clubhouse further inland.

Due to the natural groyne effect of the cuspate foreland, the sediment supply to this cell is restricted to supply of erosion material from Queen Elizabeth Park being transported south. Erosion is further enhanced by some of the sand that does pass southwards of the cuspate foreland being deflected offshore to form an offshore sand bank from Raumati to Paekākāriki. Coastal erosion in the cell during storm events has most likely been amplified due to long-term beach lowering in front of the coastal protection structures. There is some thought that erosion along the southern Kāpiti coast has been caused by the construction of SH1 in the late 1930's cutting off the supply of material from the escarpment behind the highway. However, we consider that this would have only supplied a small volume of gravel to the local shoreline at the southern limit of the district.

Figure 10.2: Rock revetment structure along The Parade, Paekākāriki.

Figure 10.3: Rock revetment at southern end of Paekākāriki showing elevation of backshore.

10.3 Structures

The Paekākāriki coastal environment consists of a 3.7 km mix of public and private ad hoc coastal protection structures, with approximately 300 m of more natural shoreline remaining. Table 10.1 outlines the general types of structures present along the shoreline, and their 'grouped' maximum residual life based on Tonkin and Taylor (2016) coastal protection database assessment. Along the Paekākāriki coastal environment, structures are predominantly timber sea walls and rock revetment structures with an assessed maximum residual life of 10-30 years. Examples of these rock revetment structures are presented in Figure 10.2 and Figure 10.3.

A seawall at the southern end of the district provides hard protection for State Highway 1 and is currently owned and maintained by Waka Kotahi. For this assessment it is assumed that this structure will be maintained for at least the next 50 years, but recognises that ownership of the structure may change once Transmission Gully has been completed.

Of the 3.7 km of structured shoreline, approximately 1 km is privately maintained, with 2.7 km being maintained by KCDC and Waka Kotahi. Only 150 m of shoreline has 'secondary' structures (e.g. a second structure located landward of the primary seawall). There are no structures in the Wainui Stream hydrosystem cell.

When assessing the effects of future sea level rise in the coastal erosion susceptibility assessment, consideration was given to both the contemporary and future existence of these structures in the shoreline. The methods used to take account for these structures within the assessment are detailed in the Volume 1 report.

Table 10.1: Generalised groupings of structures based on maximum residual life (from Tonkin and Taylor (2016)) and a general description of the structure type/material.

Transect	Assumed maximum residual life (years)	Type of structure present
1-14	50	Waka Kotahi rock revetment sea wall
15-24	10	Rock revetment
30-38	10	Mix of sea walls made up of concrete, rubber tyres, timber, and rail irons.
39-43	20	Mix of timber sea walls and concrete sea walls.
44-48	10	Mix of timber sea wall, rock revetment, or a seawall consisting of rubber tyres and rail irons. Some timber structures (secondary structures) behind rock revetment structure.
49-58	30	Rock revetment
59-76	30	Timber sea walls and rock revetment.
77-81	30	Rock revetment

10.4 Erosion Components

10.4.1 Extrapolation of Long-term Rate

The presence of protection structures along over 90% of the Paekākāriki coastline means that many parts of the shoreline became fixed post-construction and have remained fixed for a long period of time with small non-linear changes occurring as they have been variously repaired and rebuilt. Therefore, shoreline movements recorded in aerial imagery are more of a reflection of the development and rebuilding of these structures, rather than the natural shoreline movement as observed in the northern part of the district. Effectively, the seawalls have masked the natural fluctuations of the Paekākāriki shoreline, therefore, extrapolating a long-term future rate based on historical shoreline movements derived from the aerial imagery is only suitable for the small section of non-engineered shoreline in this cell (transects 25-31).

In the CSL (2008 & 2012) coastal hazard assessment, 'early rates' of shoreline change based on aerial imagery from the mid 1950's (pre structure) and cadastral surveys from the 1880's were calculated to determine what the historical shoreline trend was pre-structures. These rates were used in this assessment and were attributed to small transect groupings based on location and shoreline features for extrapolation into the future. The location of where these 'early rates' were calculated is presented in Figure 10.1.

The rates extrapolated into the future and their relevant transects are presented below in Figure 10.4. The rates produced by CSL (2008 & 2012) are generally very low across the length of the cell, being less than -0.2 m/yr, with an average erosion rate across the structured areas of the cell of -0.11 m/yr. Extrapolation of this average erosion rate over the next 30 years results in -3 m of erosion, -6 m of erosion over the next 50 years, and -11 m of erosion over the next 100 years.

The calculated rate of shoreline change at the southern, centennial highway end of the cell is very low (-0.08 m/yr). This is likely due to both natural and human causes including the SH1 seawall that was constructed in the late 1930's being included in the observation period and the more stable rocky and gravelly coastline. The extrapolation of this rate over the 50 years following assumed structure failure would equate to -4 m of erosion.

Along the unstructured section of shoreline (transects 25-31), the R^2 values for the linear regression rates were low (<0.4), which is likely a result of end effects occurring from adjacent shoreline structures influencing the rate of shoreline change. The End Point Rate was used across this section of shoreline for extrapolation into the future, which is an average erosion rate of -0.17 m/yr, with the greatest rate at the southern end of the non-engineered section (-0.37 m/yr at transect 25).

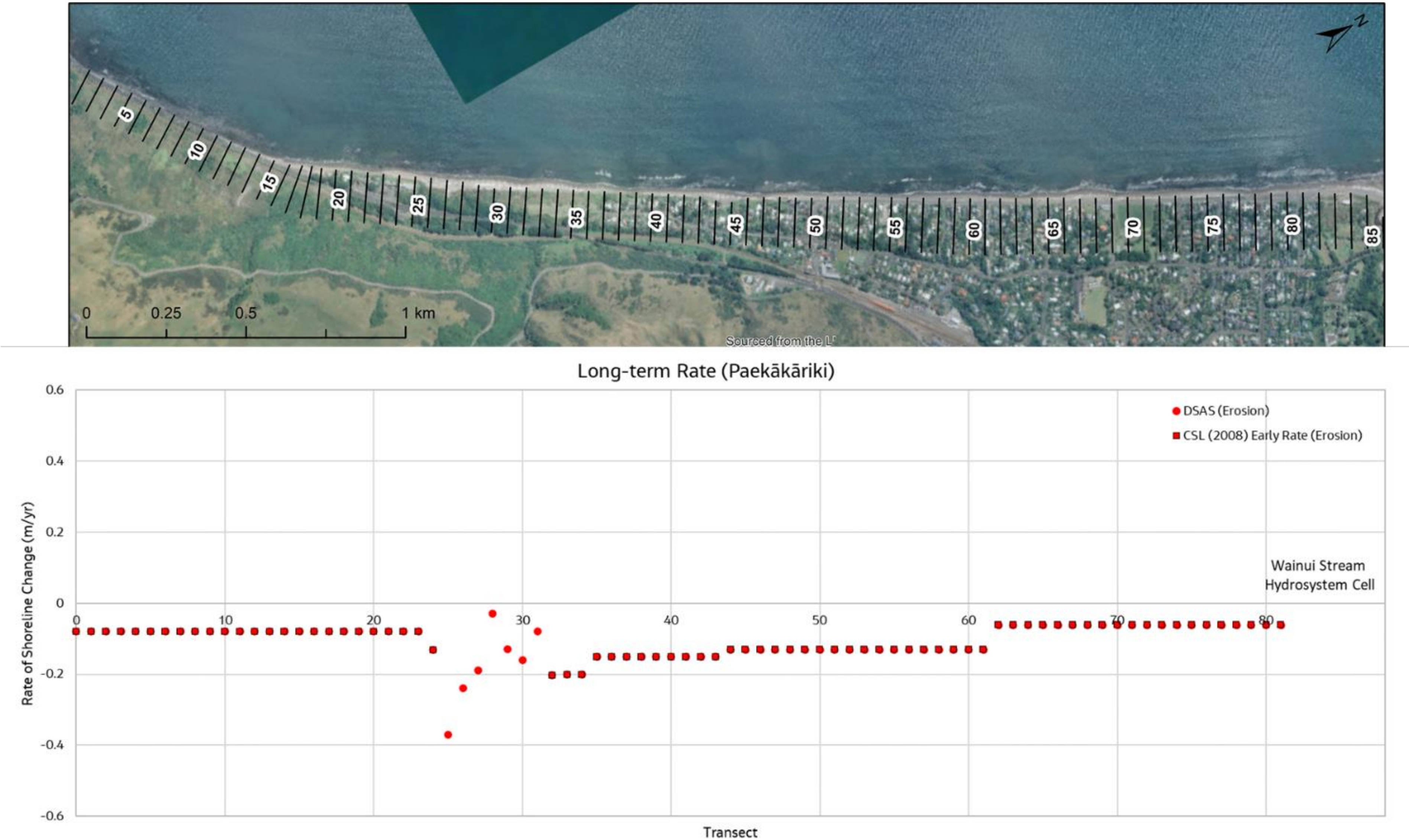


Figure 10.4: Long-term rates calculated and applied at Paekākāriki.

The extrapolation of this average erosion rate over the next 30 years results in -5 m of erosion, -9 m over the next 50 years, and -17 m over the next 100 years. Using the maximum erosion rate, up to -11 m of erosion could occur over the next 30 years; -19 m over the next 50 years; and -37 m of erosion over the next 100 years.

It is noted that historical erosion rates are only extrapolated for the period of time after the assumed wall removal.

10.4.2 Effect of Future Accelerated Sea Level Rise

As explained in Section 2.2.3, to avoid 'double accounting' of contemporary sea level rise and to isolate the effects of RSLR to being just for the acceleration in the rate of rise, the resulting erosion distances are calculated for the 'discounted' rates of rise for each timeframe as presented in Table 2.3.

The effect of RSLR along this coastal cell was calculated using measured parameters from beach profiles 200 to 230 (see locations in Figure 10.1) and LiDAR data at the same locations to determine a 'natural' dune height, as opposed to structure height. The beaches in the Paekākāriki cell tend to be narrow in width (generally less than 50 m), with a variable beach height from 5 to 21 m. Offshore profiles presented by Lumsden (2003) at two of the four beach profile locations showed very similar bathymetry across the whole cell.

This effect was calculated with consideration for the presence of existing structures along the Paekākāriki shoreline and their assumed residual life. These distances are representative of the erosion which could occur following failure of the structure driven by the effect of RSLR only. Further details on the methods used to calculate these distances can be found in the Volume 1 report.

The calculated effects of RSLR used in the PFSP calculations are presented Table 10.2, which are based on the beach profile applied at that transect, as well as the residual life of the structure at that location. This table highlights the reduced erosion effect by having the structure in place over the first 30 years and how this effect lessens over 50 years, eventually having little to no effect on erosion distances over the 100-year period relative to non-engineered sites.

The effects of RSLR for input into the PFSP calculations are summarised as follows:

- By 2050, the effect of 0.2 m RSLR is calculated to be -4 to -8 m of erosion at sites which have a structure removed, with this range increasing to – 9 m to -21 m of erosion with 0.4 m RSLR.
- By 2070, the effect of 0.3 m RSLR is calculated to be -6 m to -14 m of erosion, increasing with 0.7 m of RSLR to be a range of -15 m to – 38 m of erosion.
- By 2120, the effect of 0.6 m RSLR is calculated to be -11 m to -31 m of erosion; -20 m to -46 m of erosion with 0.85 m RSLR; -33 to 83 m of erosion with 1.25 m RSLR; and -47 m to -96 m of erosion with 1.65 m of RSLR.

Table 10.2: Mean calculated effect of RSLR at transect segments in the Paekākāriki cell with consideration for residual structure life, where '-' indicates erosion and '+' indicates accretion.

			Calculated Erosion Effect of RSLR (m)					
Transects	**Profile**	**Structure Residual Life**	**0.2m(1) RSLR (2050)**	**0.4m(1) RSLR (2050)**	**0.3m(1) RSLR (2070)**	**0.7m(1) RSLR (2070)**	**0.6m(1) RSLR (2120)**	**1.65m(1) RSLR (2120)**
0 - 14	200	Assumed 50 years	Structured	Structured	Structured	Structured	-17.3 (±0.9) m	-60 (±3.0) m
15 - 24	200	10	-8.2 (±0.4) m	-18.7 (±0.9) m	-13.9 (±0.7) m	-36.2 (±2.5) m	-31.2 (±1.6) m	-96.1 (±5.5) m
25 - 31	210	Unstructured	-4.1 (±0.8) m	-10.9 (±2.1) m	-5.7 (±1.1) m	-19.3 (±3.8) m	-11.3 (±2.2) m	-47 (±9.2) m

			Calculated Erosion Effect of RSLR (m)					
Transects	Profile	Structure Residual Life	0.2m[(1)] RSLR (2050)	0.4m[(1)] RSLR (2050)	0.3m[(1)] RSLR (2070)	0.7m[(1)] RSLR (2070)	0.6m[(1)] RSLR (2120)	1.65m[(1)] RSLR (2120)
32-38	210	10	-4.3 (±0.8) m	-9.7 (±1.9) m	-7.2 (±1.4) m	-19.4 (±3.8) m	-16.1 (±3.2) m	-50.5 (±9.9) m
39-43	220	20	-3.7 (±0.5) m	-8.9 (±1.3) m	-8.1 (±1.2) m	-23.5 (±3.3) m	-21.7 (±3.1) m	-70.5 (±10.0) m
44-48	220	10	-6.5 (±0.9) m	-14.7 (±2.1) m	-10.8 (±1.5) m	-29.3 (±4.2) m	-24.4 (±3.5) m	-76.3 (±10.8) m
49-58	220	30	Structured	Structured	-4.4 (±0.6) m	-14.7 (±2.1) m	-18 (±2.5) m	-61.6 (±8.7) m
59-81	230	30	Structured	Structured	-5.7 (±0.7) m	-18.9 (±2.2) m	-23.2 (±2.7) m	-79.5 (±9.3) m
82-83	230	Unstructured	-7.9 (±0.9) m	-21.2 (±2.5) m	-11 (±1.3) m	-37.6 (±4.4) m	-22.1 (±2.6) m	-91.7 (±10.7) m
(1) Absolute RSLR values, they have been discounted for historical rate of RSLR (0.72 mm/yr (1891-1960) (Hannah & Bell, 2012)) where structures are in place, and discounted for the contemporary rate of RSLR (2.74 mm/yr (Bell et al, 2018)) for unstructured sections of shoreline.								

10.4.3 Short-term Storm Erosion

The short-term component for Paekākāriki was based on post-storm observations from Gibbs and Wiltshere (1976) of the September 1976 storm, which was later assessed to be a 0.5% AEP event (Lane et al, 2012). The observations indicated that there was an upper limit of 5 m of erosion along this stretch of coast.

For the probabilistic method, a conservative approach was taken by applying the -5 m upper limit as the mean for a quasi-distribution, with ± 50% to give an upper bound of the triangular distribution of -7.5 m erosion and a lower bound of -2.5 m erosion.

10.4.4 Dune Stability

The dune stability component for Paekākāriki is based on an analysis of four surveyed profiles located within the cell (profile 200, 210, 220 and 230, see Figure 10.1 for locations). Dune stability in Paekākāriki was calculated using a 'walls down' approach, where LiDAR was used to determine what a 'natural' dune height would be behind the present wall. The dune stability factors used for the probabilistic method at each profile are as follows:

- At profile 200, the mean dune stability factor is -2.8 m, with upper and lower bounds of -3.5 m and -2.1 m respectively.
- At profile 210, the mean dune stability factor is -14.3 m, with upper and lower bounds of -19 m and -10 m respectively.
- At profile 220, the mean dune stability factor is -6.7 m, with upper and lower bounds of -7.8 m and -5.8 m respectively.
- At profile 230, the mean dune stability factor is -3.1 m, with upper and lower bounds of -3.8 m and -2.1 m respectively.

It is noted that profile 210 has a much larger dune stability factor than found elsewhere in the district. This profile is of the natural beach, however the LiDAR profiles within 100 m each side of the profile showed that the land continues to increase in elevation in the backshore, without the usual interdune swale, such as that which commonly occurs in Queen Elizabeth Park. Elevations around the profile site reach up to 24 m in elevation within 50-70 m of the 0 m contour, and these elevations have been used to calculate the dune stability factor for this profile site.

10.5 Projected Coastal Erosion Distances

The resulting CED's calculated by the probabilistic method are presented below. Maps displaying the spatial location of the present-day hazard and PFSP are presented in maps 17 and 18 of Appendix A (2050), Appendix B (2070), and Appendix C (2120).

10.5.1 Present-day Erosion Susceptibility

The present-day erosion hazard is representative of the potential erosion hazard which could occur if a large storm were to happen in the immediate/near future. This present-day hazard is a combination of the short-term storm erosion (Section 10.4.3) and the dune stability factor (Section 10.4.4). It represents the dynamic nature of shoreline movements where short-term erosion can occur independently of long-term trends or RSLR. Due to the longshore variation in beach elevations which influence the dune stability factor, there is long shore variability in the calculated present-day hazard. The present-day hazard can be summarised in the following transect groupings:

- Along transects 1-24, the present-day hazard was calculated as 'most likely' to be -7 to -8 m of erosion, with erosion unlikely to exceed -9 m.
- Along transects 25-38, the present-day hazard was calculated as 'most likely' to be -18 to -20 m of erosion, with erosion unlikely to exceed -22 m.
- Along transects 39-, the present-day hazard was calculated as 'most likely' to be -11 to -12 m of erosion, with erosion unlikely to exceed -13 m.
- Along transects 59-83, the present-day hazard was calculated as 'most likely' to be -8 m of erosion, with erosion unlikely to exceed -9 m.

In some areas of the PFSP mapping, only the present-day erosion susceptibility is mapped, due to the residual life of the structures being 30-50 years, and therefore they are assumed to provide full protection (e.g. no erosion) over that period. The present-day erosion susceptibility is presented to show the potential amount of erosion that could occur following wall failure along these sections.

10.5.2 Future Coastal Erosion Susceptibility

The raw outputs from the Monte Carlo simulation of the landward limit of 'most likely' zone (P33 position) for the three timeframes are presented below in 10.5 to give an indication of the changes in shoreline position that could be expected to be over the next 100 years. It should be noted that these raw distances (Appendix J) have been smoothed in the mapping outputs for coastal process plan-shape considerations, as well as consideration of future inlet migration, and therefore the raw outputs may not be able to be directly correlated with the PFSP shorelines mapped in Appendix A, B and C.

The following provides a summary of the projected erosion distances to the landward limit of the most likely zone (P33) across each RSLR scenario.

2050

Over the next 30 years the shoreline at the southern end (transects 1-14) and northern end of the cell (transects 49-83) along the Paekākāriki seawall, the PFSP is entirely a reflection of the short-term erosion and dune stability components, representing the present-day hazard due to the assumed residual life of these structures being 30 years or more. At the southern end of the cell the forecast erosion distance averages -8 m over both RSLR scenarios, while at the northern end of the cell the forecast erosion distance is between -8 to -12 m.

Between transects 15-48, the residual life of the structures ranges from 10-20 years, and therefore PFSP's over this period under both RSLR scenarios are landward the position of the present-day erosion hazard. Due to multiple factors, including the structure's residual life and variability within erosion components alongshore, over the two timeframes there is a degree of longshore variability in the PFSP. With 0.2m of RSLR, the shoreline is projected to experience an average erosion distance of -23 m, which increases with 0.4 m of RSLR to an average of -31 m of erosion.

2070

Over a 50-year period, the highway seawall at the southern end of the district is assumed to still be in place., Therefore, the PFSP is entirely a result of the short-term erosion and dune stability components, resulting in a possible -8 m of erosion.

Between transects 15-48, all structures over the 50-year timeframe are assumed to have failed with the coast returning to a natural shoreline. There is some longshore variability across these transects due to the erosion components and previous presence of structures. However, under a 0.3 m RSLR scenario, the shoreline is projected to experience an average of -30 m of erosion and under the higher 0.7 m RSLR scenario this increases an average of -47 m.

Along the shoreline at the northern end of the cell (transects 49-83), it is assumed that after 30 years the seawalls have failed, and the shoreline returns to a natural form. Over the 20-year period following wall failure, under 0.3 m RSLR the shoreline is projected to experience an average of -17 m of erosion, increasing with 0.7 m of RSLR to -30 m of erosion.

2120

In this assessment it is assumed that the seawall from transects 0-14 has failed by 2070. Under this scenario, with 0.6 m of RSLR (RCP2.6 plus 1 mm/yr VLM) over the following 50 years to 2120, it is projected that this section of shoreline would 'most likely' experience -30 m of erosion. With 0.85 m of RSLR (RCP4.5 plus 2mm/yr VLM), this increases to an average of -38 m; and -60m with 1.25 m of RSLR (RCP8.5 plus 2 mm/yr VLM). Under the highest RSLR scenario of 1.65 m RSLR (RCP8.5H+ plus 3mm/yr VLM), 'most likely' erosion is projected to average -72 m across these transects.

For the shoreline across transects 14-48 where structures are assumed to have failed by 2050, under the lowest 0.6 m RSLR scenario, the shoreline is projected to erode by an average of -50 m. With 0.85 m of RSLR, this average erosion distance increases to -61 m, and with 1.25 m of RSLR this increases further to average -75 m of erosion. With the highest RSLR scenario (1.65 m RSLR), erosion distances are projected to be an average of -100 m.

Along the northern end of the cell (transects 49-83) where the structure is assumed to fail around 2050, erosion distances with 0.6 m of RSLR are projected to average of -38 m. With 0.85 m of RSLR, the average increases to be -50 m and with 1.25 m of RSLR increases further to average -71 m. With 1.65 m of RSLR the average erosion distance increases to -96 m.

Figure 10.5: Erosion distances to projected future shoreline positions under future RSLR scenarios.

10.5.3 Comparison of results to previous coastal hazard assessments

The results of the PFSP presented in Section 10.5.2 are calculated to be less than previous coastal erosion assessments undertaken in the area. The Lumsden (2003) coastal management strategy proposed a -85 m 'Secondary Development Setback' across the Paekākāriki Cell, which was a deterministic approach of the assessed long-term trend at the site with the effect of a 0.45 m RSLR over the next 100 years. Comparatively, our lowest RSLR projection over a 100-year period was 0.6 m, which produced an average of -50 m of erosion along the southern end of the cell, and -40 m at the northern end of the cell, with a maximum 'most likely' within the cell of – 60.3 m of erosion.

Compared to the more recent CSL (2008) coastal hazard assessment, the results produced in this study project slightly less erosion than the previous assessment, however the results are similar. CSL (2008) calculated that with 0.3 m of RSLR over the next 50 years, if walls were to occasionally fail but then be repaired, across the southern to middle section of the Paekākāriki cell (transects 14-47) the shoreline was likely to experience -31 m to -50 m of erosion and at the northern end of the cell (around transect 70), the shoreline was calculated to experience -29m of erosion. For the scenario calculated by CSL (2008) where walls were removed from the present-day, erosion was calculated to be an additional -5 to -18 m across the southern to middle section of the Paekākāriki cell, with an additional -18 m at the northern end of the cell (around transect 70). Comparatively, under the same 50 year 0.3m RSLR scenario, the results for the PFSP's produced in this report showed there could be an average of -30 m of erosion across the southern to middle section of the cell, with a maximum 'most likely' of -43 m. Across the northern section of the cell, this assessment calculated an average erosion of -17 m.

The difference between the individual components used in the CSL (2008 & 2012) assessment and this assessment are summarised as follows:

- The long-term rates used for extrapolation into the future is the same for both assessments, as the early rates calculated in the CSL (2008 & 2012) assessment were adopted for this assessment.
- Dune stability factors in the CSL (2008 & 2012) assessment are higher by an average of -3 m than the dune stability factor calculated in this assessment.
- The short-term storm erosion component in the CSL (2008 & 2012) assessment is 10 m greater than the -5 m erosion used in this assessment.
- The RSLR components are very similar, ranging from -5 to -11 m in the CSL (2008 & 2012) assessment; compared to -4 m to -14 m used in this assessment.

10.6 Beach lowering

An assessment was undertaken to determine the potential beach lowering in front of protection structures with future RSLR. The assessment used erosion distances calculated in Section 10.4.2 to translate the most recent (October 2018) profile landward and provide an estimate of what the effect of RSLR could be on beach lowering if the structure was to remain in place for the next 30 years. The location of these profiles is shown in Figure 10.1. The results of this analysis are presented below in Table 10.3, and graphs showing the translated profiles and resulting beach lowering are presented in Appendix K. The assessment assumes that the toe depths of the existing seawalls are sufficient to withstand this magnitude of scour, however, confirmation of this assumption is beyond the scope of this assessment.

Table 10.3: Projected beach lowering and 1% AEP storm event water depth at sea wall toe at beach profiles located within the Paekākāriki coastal cell with sea walls present, across the range of 2050 RSLR projections.

Profile	RSLR projection	Beach Elevation at toe of sea wall (m WVD53)	Scour depth from current average profile (m)	Water level at seawall in 2050 1% AEP sea level event [1] (m)	Water Depth at seawall in 2050 1% AEP sea level event (m)
200	Current day average profile	2.6			
	0.2 m RSLR	1.2	-1.4	2.34	1.14
	0.4 m RSLR	0	-2.6	2.49	2.49
220	Current day average profile	1.3			
	0.2 m RSLR	0.5	-0.8	2.34	1.84
	0.4 m RSLR	0.2	-1.1	2.49	2.29
230	Current day average profile	1.8			
	0.2 m RSLR	0.9	-0.9	2.34	1.44
	0.4 m RSLR	0.45	-1.35	2.49	2.04

(1) Storm tide + wave set up from Table 4.2 in Jacobs (2021) Volume 1 report.

The results show that greatest scour is calculated to occur at the southern end of the cell (profile 200) relative to profiles located at the centre and northern end of the cell (profile 220 and 230). Profiles 200 indicates that with 0.2 m of RSLR, -1.4 m of beach lowering could occur at the toe of the current seawall, which could increase with 0.4 m of RSLR to -2.6 m of lowering, with water depth at the wall in a 1% AEP event being 2.49 m. In this scenario, beach levels at the toe of the structure would be at 0 m WVD-53 with wave run-up likely to reach the wall in all tides.

At the middle to northern end of the cell (profiles 220 and 230), with a 0.2 m RSLR, the projected beach lowering could be in the order of -0.8 m to -0.9 m; and with 0.4 m of RSLR this could increase to up to -1.1 to -1.35 m of beach lowering. Wave run-up is likely to reach the wall in all but the lowest tides.

The analysis indicates that if structures do not fail over the next 30 years as assumed, the structures could experience significant undermining due to scour in front of the structures, which could lead to their structural failure. The effect of RSLR could result in the reduction of residual life of some structures that are not footed sufficiently deep to cope with this level of scour. However, the identification of any such sites would require information on toe foundation depths and is beyond the scope of this assessment. Due to increased water depth against walls, wave runup on the structures will also be higher, increasing the risk of back scour by overtopping.

10.7 Wainui Stream

The Wainui Stream hydrosystem cell is located at the northern boundary of the Paekākāriki coastal cell, between the Paekākāriki and Queen Elizabeth Park coastal cells. The historic shoreline positions within this hydrosystem are presented in Figure 10.6. Historically, the inlet has shown to erode at the mouth of the right bank, but to accrete at the mouth of the left bank. More recently, this accretion rate has slowed, and the shoreline has been relatively stable since 1988. The stream mouth has been dynamic over the observed period, migrating from north to south across the beach over different periods.

Due to the hydrosystem having no structures, and the eroding bank on the northern edge of the stream mouth, Method 2 from the coastal hydrosystem decision tree (see Section 2.2.7) was used to determine the possible future migration of the hydrosystem. This method assumes that the inlet will migrate landward in line with the adjacent shoreline under various RSLR scenarios, with consideration for maintaining the inlet shape, surrounding topography, and some infrastructure.

Under this assessment, Wainui Stream maintains its shape until the highest RSLR scenario over 100 years (1.65m) where the greater erosion distances in the Queen Elizabeth Park coastal cell to the north indicate that the landward extent of the inlet could migrate landward back to Queen Elizabeth Road.

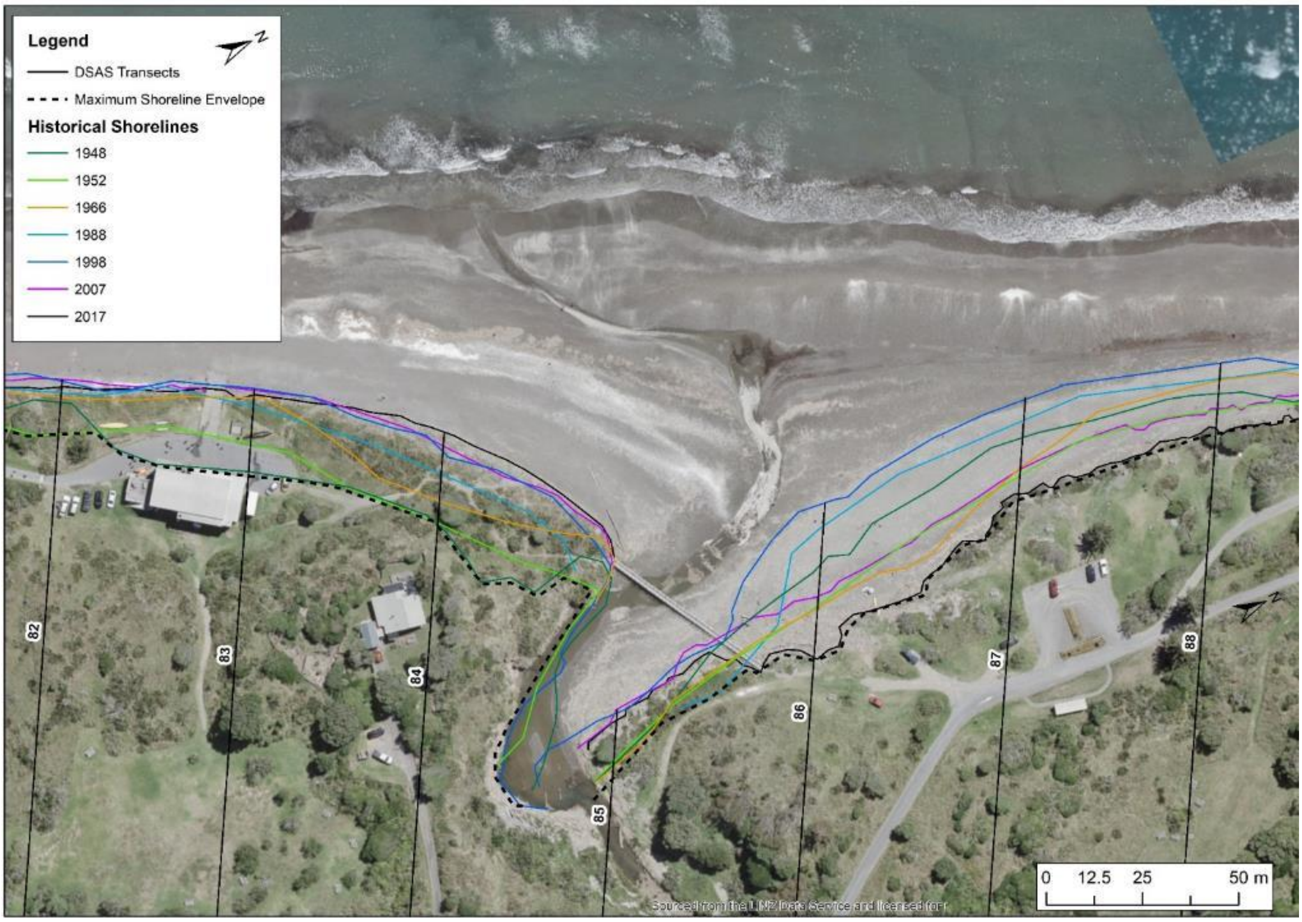


Figure 10.6: Historical shorelines at Wainui Stream mouth, and maximum shoreline envelope position.

10.8 Vulnerability

10.8.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified affected council critical infrastructure and community services that intersected with mapped PFSP up to the landward limit of the most likely PFSP (P33). The results of this assessment are presented in Table 10.4.

Table 10.4: Council critical infrastructure and community services affected in Paekākāriki cell under various sea level rise scenarios.

	RSLR Scenarios							
	2050		2070		2120			
Asset	**0.2m**	**0.4m**	**0.3m**	**0.7m**	**0.6m**	**0.85m**	**1.25m**	**1.65m**
The Parade (1) (Total length = 1580m)	550m	570m	1580m	1580m	1580m	1580m	1580m	1580m
Ames Street (1) (Total length = 950m)	0	0	0	0	60m	365m	414m	690m

	RSLR Scenarios							
	2050		2070		2120			
Asset	**0.2m**	**0.4m**	**0.3m**	**0.7m**	**0.6m**	**0.85m**	**1.25m**	**1.65m**
SH1 (1) (Total length = 3600m)	760m	800m	775m	850m	850m	969m	1152m	1290m
Coastal Stormwater Outlet (2)	15	15	15	15	15	15	15	15

(1) Length of road intersecting landward limit of 'most likely' PFSP

(2) Number of outlets intersecting landward limit of 'most likely' PFSP

The results of this assessment show that by 2070, the total length of The Parade could be affected by coastal erosion under both RSLR scenarios. Ames Street is projected to become affected in the 100-year RSLR, with 60 m of the road being affected under the lowest RSLR scenario, increasing to being 73% affected under the highest RSLR projection of 1.65 m. State Highway 1 (SH1) is projected to affected in both the 30- and 50-year scenarios, which is due to the inclusion of the present-day hazard following an assumed wall failure.

Coastal stormwater outfalls are the only critical infrastructure and community services identified to be vulnerable to erosion in Paekākāriki, with all outlets likely to effected under all RSLR scenarios from 30 years on.

10.8.2 **Land parcels**

The number of land parcels (public and private) which intersect the PFSP's up to the landward limit of the 'most likely' position (e.g. P33) and the landward limit of the 'unlikely' position (e.g. P10) were calculated to give an indication of vulnerability of land parcels within a coastal cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels (see Section 2.4). The results of this assessment for the Paekākāriki cell are presented below in Figure 10.7 and Appendix L.

From the results presented in Figure 10.7 it is shown that over all timeframes, three parcels of public property intersect with the 'most likely' and 'unlikely' PFSPs under all RSLR scenarios. For private land parcels, the results indicate that over a 30-year timeframe (2050) there are 45 land parcels that intersect with PFSP's for both RSLR scenarios. Over a 50-year timeframe (2070) this increases to 83 land parcels intersecting the 'most likely' PFSP for a 0.3 m RSLR, and 148 land parcels with 0.7 m of RSLR. By 2120, the number of private land parcels intersecting with the 'most likely' PFSP ranges from 149 under the lowest RSLR scenario (0.6 m), to 258 land parcels under the highest RSLR scenario (1.65 m). Across all timeframes, one public and one private land parcel are also likely to be affected in the Wainui Stream hydrosystem cell.

From this vulnerability assessment, it is shown that in terms of private property potentially affected by coastal erosion, Paekākāriki is the second most vulnerable cell, behind the Raumati coastal cell.

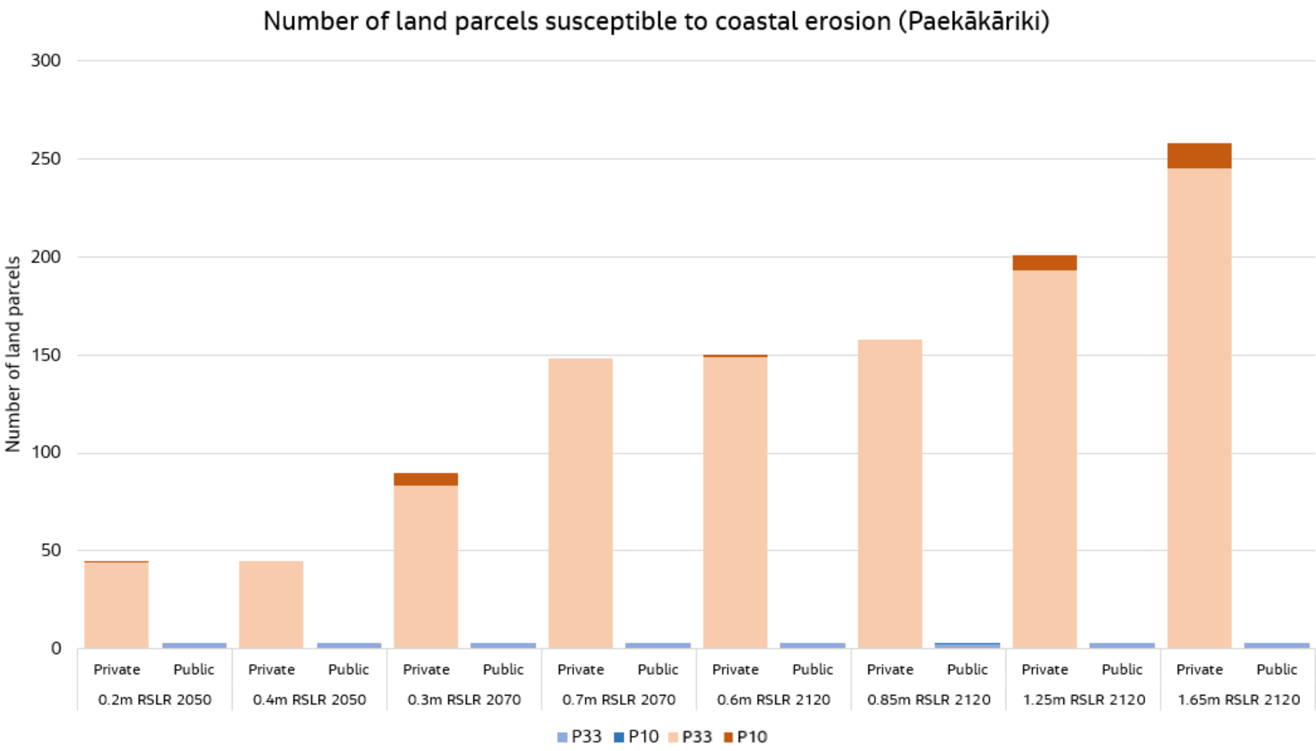


Figure 10.7: Number of public and private land parcels in Paekākāriki potentially susceptible to coastal erosion. Lighter orange/blue show the number of properties susceptible to erosion up to the P33 (landward limit of the most likely), with the darker blue/orange showing additional parcels potentially affected between the P33 and P10 shoreline position.

11. Summary of Erosion Vulnerability Assessment

A summary of the number of private land parcels intersecting the landward limit of the 'most likely' PFSP is presented below in Figure 11.1. Details about the number of land parcels that intersect the landward position of the 'unlikely' shoreline are presented within each cell section of this report and in Appendix L, as well as the individual critical infrastructure and community services potentially affected by PFSP's.

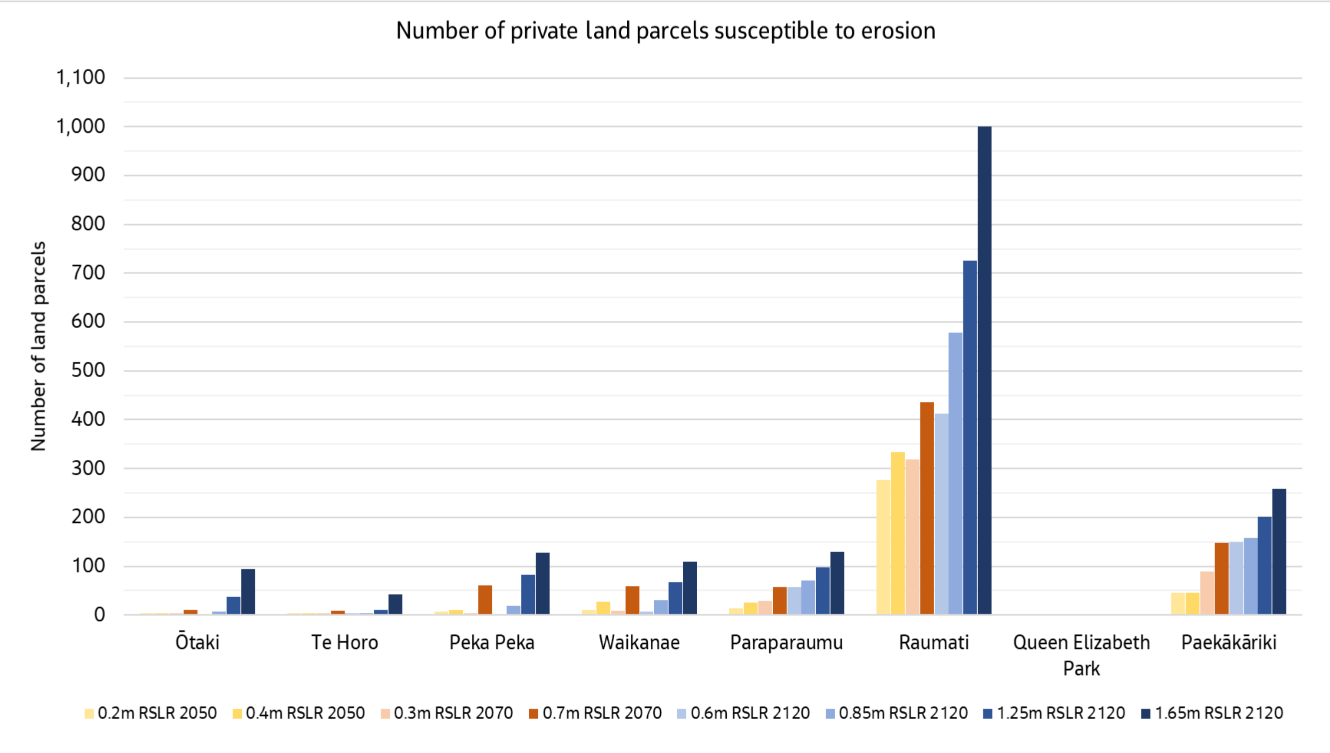


Figure 11.1: Summary of private land parcels potentially susceptible to coastal erosion in each assessment cell for RSLR increments.

Figure 11.1 clearly demonstrates that vulnerability of land parcels increases with the higher RSLR within each time frame, and increase significantly by 2120 for the higher RSLR scenarios.

From the results presented in Figure 11.1 it is also clear that land parcels in the southern area of the Kāpiti Coast District are more vulnerable to coastal erosion that in the northern area of the district. The ranking of vulnerability of coastal cells (from most to least) based on number of private land parcels affected in the highest RSLR scenario for 2120 is as follows:

1. Raumati (56% of total effected private land parcels)
2. Paekākāriki (14% of total effected private land parcels)
3. Paraparaumu (8% of total effected private land parcels)
4. Peka Peka (7% of total effected private land parcels)
5. Waikanae (6% of total effected private land parcels)
6. Ōtaki (5% of total effected private land parcels)
7. Te Horo (2% of total effected private land parcels)

8. Queen Elizabeth Park (0% of total effected private land parcels)

Under the highest RSLR scenario, the number of private land parcels that intersect the 'most likely' PFSP can be summarised as follows:

- For the 30-year period (2050 – 0.4 m RSLR), 449 private land parcels, of which 84% are located in the southern area of the district (Paekākāriki and Raumati).
- For the 50-year period (2070 - 0.7 m RSLR), 779 private land parcels, of which 75% are located in the southern area of the district.
- For the 100-year period (2120 - 1.65 m RSLR) 1762 private land parcels, of which 71% are located in the southern area of the district, and 56% of the total land parcels being located with the Raumati cell alone.

Raumati also has the greatest number of public land parcels affected, followed by Peka Peka, and Queen Elizabeth Park. However, the number of public land parcels affected is generally low across all RSLR scenarios, until the 1.65 m RSLR scenario in 2120.

For council critical infrastructure and community services, a major potential impact from the projected coastal erosion is to coastal stormwater outfalls and roads running parallel to the coast. A total of 66 coastal stormwater outfalls are vulnerable under the highest SLR scenario by 2050 (0.4 m RSLR. The cell with the greatest number of vulnerable stormwater outlets is Raumati, with 24 outlets intersecting PFSP's in all RSLR scenarios in each timeframe.

The total length of roading intersecting with the PFSP's under the highest RSLR scenarios over the 30-year period to 2050 (0.4 m RSLR) is 2330m, increasing to 4771m for the highest scenario under a 50-year period to 2070 (0.7 m RSLR) and increasing further 9868 m for the highest scenario over a 100-year period to 2120 (1.65 m RSLR). Under the highest SLR scenario for the 100-year period (1.65 m) the greatest length of roading potentially affected is in Raumati (3700 m), followed by Paekākāriki (3560 m) and Ōtaki (1755 m).

No schools, medical centres or hospitals were identified as being within projected future shoreline positions (PFSP).

Part 2:
Coastal Inundation Susceptibility and Vulnerability Assessment

12. Ōtaki and Te Horo Inundation Cell

12.1 General Description

The Ōtaki and Te Horo inundation cell covers approximately 14 km of coastline, extending from the district boundary in the north to Te Hapua Road in the south, and along which coastal inundation is determined by the Ōtaki North storm tide level as estimated by Lane et al (2012).

The cell includes the settlements of Ōtaki Beach, north of the Ōtaki River mouth and Te Horo Beach, south of the Ōtaki River mouth. The dune ridge along this section of coastline, together with the stopbanks on both sides of the Ōtaki River mouth provide an almost continuous barrier to overtopping from the sea for the range of scenarios considered in this assessment. North of the Ōtaki River, low points in the beach ridge are at the very southern end of Marine Parade leading to the intersection with Atkinson Avenue and Kāpiti Lane and at the Rangiuru Stream mouth. South of the Ōtaki River, the seaward beach ridge runs continuously to around 150 m north of Te Horo, at which point the elevation lowers toward the Mangaone Stream mouth. A low-lying area here reflects older stream mouths where the Mangaone has previously meandered, and the shoreline has slowly prograded seaward.

12.2 Inundation Pathways

The main pathways for coastal inundation are the stream and river mouths that cut through the foredunes and beach ridges. Figure 12.2 shows the main watercourses and the stormwater drainage network of the Ōtaki and Te Horo coast. Whilst the Ōtaki River provides an overland flow path for coastal flooding, the Greater Wellington Regional Council flood protection stopbanks on either side of the river are well above present-day storm tide levels. Coastal inundation via the channel of the river is only likely to occur through a combination of storm tides and high river flows during a storm event under higher future sea level rise scenarios.

On the north side of the Ōtaki River, the main inundation pathways are the Rangiuru and Waitohu Streams and a low point in the beach ridge at the southern end of Marine Parade. The Rangiuru Stream flows into a lagoon adjoining the Ōtaki River mouth / hapua through a culverted outfall in the true right stopbank. The culverts are fitted with floodgates to reduce the potential for backflow from the sea into the Stream (Figure 12.1). The stormwater network in Ōtaki Beach drains directly to the sea along Marine Parade and into the Waitohu Stream from the Moana Street catchment. Large storm tide events are understood to overtop the beach crest at the low point on the southern end of Marine Parade and cause flooding.

Figure 12.1: Floodgates on the outlet of the Rangiuru Stream through the stopbank on the true right bank of the Ōtaki River mouth. The structure is viewed from the coastal side of the stopbank and shows the flap gates on the culverts which are pushed closed when the sea level rises above the water level in the stream on other side of the stopbank by the difference in water pressure.

On the south side of the Ōtaki River, the main pathways are the Katihuku Drain and the Mangaone Stream. The Katihuku Drain flows into the Ōtaki River mouth through culverts in the true left stopbank that are fitted with floodgates to reduce the potential for backflow from the sea into the Drain. The Mangaone Stream is open to the sea and connected to the Pukemanu Drain and other smaller drainage channels in the catchment.

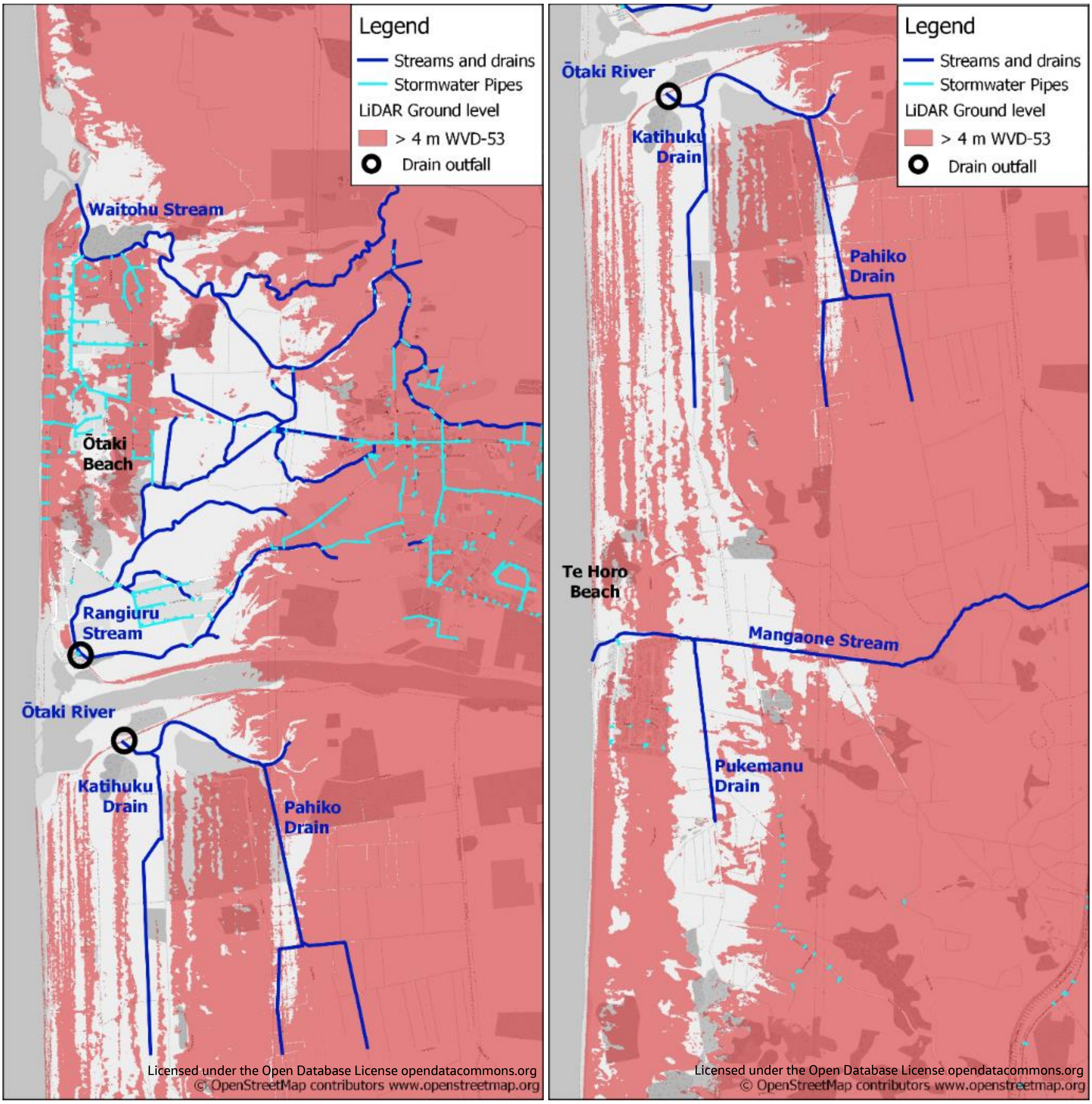


Figure 12.2: Map of the Ōtaki and Te Horo inundation cell showing the main inundation pathways - streams and drains (in dark blue) and stormwater pipe network (in pale blue). Higher ground (above 4 m WVD-53) is shaded in red.

12.3 Projected inundation

The storm tide levels for Ōtaki North and RSLR for each of the four scenarios considered are summarised in Table 12.1. Maps showing areas susceptible to coastal inundation in each scenario are provided in Appendix E. A summary of key features of the mapping in each scenario is provided below.

Table 12.1: Storm tide levels for each RSLR scenario considered in the inundation assessment for the Ōtaki and Te Horo inundation cell.

	RSLR Scenarios							
	Present-day	2050	2070		2120			
		upper 0.4 m	lower 0.4 m	upper 0.65 m	lower 0.65 m	intermediate		upper 1.65 m
RSLR	0 m	0.4 m		0.65 m		0.85 m	1.25 m	1.65 m
Storm tide level (WVD-53)	2.43 m	2.83 m		3.08 m		3.28 m	3.68 m	4.08 m

12.3.1 **Present-day inundation**

The present-day inundation hazard shows the areas which are currently susceptible to coastal flooding from large coastal storm events, and which will continue to be susceptible in the near future. The present-day hazard results when the storm-tide water levels (including wave setup but excluding wave runup and overtopping) exceed the ground elevations in the inundation cell. This area is mapped as the "1% AEP Storm Tide, 0 m RSLR" layer in the maps in Appendix E.

North of the Ōtaki River, the area's most susceptible to flooding are around the lower courses of the Waitohu and Rangiuru Streams. The Rangiuru has a measure of flood protection from the sea afforded by the stopbanks and Rangiuru culvert floodgates and also the higher ground elevations along Atkinson Avenue, but there is a residual risk from flooding in the event of a flood gate failure or a breach or piping failure of the stopbank. The present-day storm tide level is around 0.35 m below the lowest ground level around the intersection of Marine Parade, Kāpiti Lane, and Atkinson Avenue and the seaward most beach ridge here is susceptible to wave runup and overtopping. A small area of low-lying land in Caughley Place, Ōtaki Beach, also lies below the storm-tide level. The stormwater network from this catchment is pumped to the sea outfall west of the intersection of Karaka Street and Marine Parade but, this area would be susceptible to rainfall induced pluvial or surface flooding in the event of a pump failure.

South of the Ōtaki River, the area's most susceptible to flooding is the land around the Katihuku Drain outlet on the landward side of the Ōtaki River stopbank and around the mouth of the Mangaone Stream at Te Horo Beach (Figure 12.3). The land around the Katihuku Drain is protected from the sea by the Ōtaki River stopbank and the flood gates on the Katihuku Drain outfall but there is a residual risk from flooding in the event of a flood gate failure or a breach or piping failure of the stopbank. The low-lying area at Te Horo Beach is susceptible to additional inundation from wave runup and overtopping.

Figure 12.3: The mouth of the Mangaone Stream at Te Horo Beach. The Mangaone Stream provides a pathway for inundation from the sea through the high dune ridge in front of the settlement.

12.3.2 Future inundation

0.40 m RSLR and 0.65 m RSLR

North of the Ōtaki River, for both the 0.4 m RSLR and 0.65 m RSLR scenarios, the mapping shows an increase in the area susceptible to inundation around the Waitohu Stream and Rangiuru Stream. Overland flow occurs from the sea into the Rangiuru Stream catchment at the intersection of Marine Parade and Atkinson Avenue in both scenarios. Low lying parts of the Moana Street stormwater drainage catchment in Ōtaki Beach also become susceptible to flooding from backflow through the gravity outfall to the Waitohu Stream.

South of the Ōtaki River the mapping for these two scenarios shows an increase in the inundation area around the Katihuku and Pukemanu Drains and in the area around the mouth of the Mangaone Stream in Te Horo Beach.

Along this cell, some dune swales become susceptible to inundation in these scenarios. There is a measure of protection from flooding afforded to these areas by the dune or beach ridge crest.

0.85 m RSLR

In Ōtaki Beach, further low-lying areas in the Moana Street stormwater catchment – Maunka Street and Toi Street – become susceptible to backflow flooding from the Waitohu Stream. Land susceptible to inundation also increases around the Waitohu Stream, Rangiuru Stream, and the smaller drains to the north and south of the Mangaone Stream.

1.25 m RSLR

The area of land susceptible to inundation increases generally and the area around Moana Street starts to become susceptible to direct inundation by overland flow from the Waitohu Stream. Dune swales to the south of the Ōtaki River become susceptible to inundation through overland flow over the true left bank of the Ōtaki River.

1.65 m RSLR

In this scenario, large areas of the low-lying dune swales north of Ōtaki Beach are mapped as susceptible to inundation but are protected by the dune crest and are not susceptible to wave runup and overtopping. Lake Waiorongomai and the swale to the north of the lake outlet stream also become susceptible to inundation.

At Ōtaki Beach, the areas susceptible to inundation around the Waitohu Stream and Rangiuru Streams both increase in size. The area around Moana Street susceptible to direct inundation from the Waitohu Stream increases and the Rangiuru Stream catchment is susceptible to flooding from the sea over low points in the Ōtaki River stopbank at the outfall to the stream over Kāpiti Lane.

Between the Ōtaki River and the Mangaone Stream the mapping shows extensive areas susceptible to inundation within the Katihuku and Pahiko Drain catchments. The storm tide level is generally below the crest-level of the Ōtaki River stopbank and the crest levels of the highest dune ridges but, the area is also susceptible to direct inundation through the Mangaone Stream, failure of the Katihuku flood gates and breaches in the stopbank. The dune swale parallel to the coastline is susceptible to additional inundation through overtopping from wave runup which is particularly high along this section of the coast (the runup height above the storm tide water level is estimated to be almost 3 m).

At Te Horo Beach, the area susceptible to direct inundation from the sea is increased. Flooding that occurs along Rodney Avenue is has the potential to worsen with additional inundation from wave runup and overtopping. South of the Mangaone Stream, the mapping shows extensive areas susceptible to inundation within the Pukemanu Drain catchment up to the southern boundary of the cell at Te Hapua Road. The areas susceptible to inundation in the dune swales along this section of coast increases in this scenario.

12.4 Vulnerability

12.4.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified council critical infrastructure and community services that intersect the areas susceptible to coastal inundation. The results of this assessment are presented in Table 12.2. Asset location data were provided by KCDC. For inundation vulnerability, critical roads are defined as the main evacuation routes from the coast inland, perpendicular to the coastline. Apart from pump stations, stormwater assets are not considered vulnerable to inundation and have not been included in the assessment.

Table 12.2: Council critical infrastructure and community services affected in the Ōtaki and Te Horo inundation cell for each RSLR scenario considered.

<table>
<tr><th></th><th colspan="8">RSLR Scenarios</th></tr>
<tr><th rowspan="3">Asset</th><th rowspan="2">Present-day</th><th>2050</th><th colspan="2">2070</th><th colspan="4">2120</th></tr>
<tr><th>upper</th><th>lower</th><th>upper</th><th>lower</th><th colspan="2">intermediate</th><th>upper</th></tr>
<tr><th>0 m</th><th colspan="2">0.4 m</th><th colspan="2">0.65 m</th><th>0.85 m</th><th>1.25 m</th><th>1.65 m</th></tr>
<tr><td colspan="9">Critical Road for Evacuation (length susceptible to inundation)</td></tr>
<tr><td>Tasman Road</td><td>0 m</td><td colspan="2">0 m</td><td colspan="2">0 m</td><td>60 m</td><td>670 m</td><td>1250 m</td></tr>
<tr><td>Rangiuru Road</td><td>550 m</td><td colspan="2">830 m</td><td colspan="2">950 m</td><td>1010 m</td><td>1090 m</td><td>1410 m</td></tr>
<tr><td>Te Horo Beach Road</td><td>0 m</td><td colspan="2">130 m</td><td colspan="2">150 m</td><td>250 m</td><td>750 m</td><td>1160 m</td></tr>
<tr><td colspan="9">Three Waters Assets (number susceptible to inundation)</td></tr>
<tr><td>Stormwater pump station</td><td>0</td><td colspan="2">0</td><td colspan="2">3</td><td>3</td><td>3</td><td>3</td></tr>
</table>

The results of this assessment show that for the two main evacuation routes for Ōtaki Beach, Rangiuru Road is already susceptible to inundation in the present-day but, with this increasing in length from around 0.6 km presently to around 1.4 km under the highest RSLR scenario (1.65 m). Tasman Road starts to become susceptible in the 0.85 m RSLR scenario (over 50 years' time) with the length susceptible increasing to around 1.3 km in the highest RSLR scenario considered (1.65 m). The main route for Te Horo Beach, i.e., Te Horo Beach Road, starts to become susceptible at 0.4m RSLR (30 to 50 years' time).

Coastal stormwater pump stations were the only other critical infrastructure and community service identified to be affected in the Ōtaki and Te Horo inundation cell, with three assets shown to be affected for RSLR scenarios of 0.65 m and higher (50 to 100 years' time).

12.4.2 Land parcels

The land parcels (public and private) that intersect the area mapped as susceptible to coastal inundation have been calculated to give an indication of the number of land parcels potentially affected within the inundation cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels. The results for the Ōtaki and Te Horo inundation cell are presented in Table 12.3. It should be noted that the count for land parcels includes land parcels along the shoreline where the seaward boundary extends into the coastal marine area (CMA) beyond the current MHWS.

Table 12.3: Number of public and private land parcels affected in the Ōtaki and Te Horo inundation cell for each RSLR scenario considered.

	RSLR Scenarios							
	Present-day	2050	2070		2120			
		upper	lower	upper	lower	intermediate		upper
Land parcels	**0 m**	**0.4 m**		**0.65 m**		**0.85 m**	**1.25 m**	**1.65 m**
Public	10	15		18		18	20	25
Private	316	524		742		844	1,028	1,184

13. Peka Peka and Waimeha Inundation Cell

13.1 General Description

The Peka Peka and Waimeha inundation cell covers approximately 6 km of coastline, extending from Te Hapua Road in the north to the western side of the State Highway 1 intersection with Te Moana Road in the south. Coastal inundation is determined by the Waikanae Beach storm tide level as estimated by Lane et al (2012).

The cell includes the settlements at Peka Peka and the northern part of Waikanae Beach. The dune ridge along this entire section of coastline (Figure 13.1) is several metres higher than the combined storm tide level and RSLR for the range of scenarios considered in this assessment and provides a barrier to inundation by overland flow from the sea.

Figure 13.1: The dune ridge along the shoreline at Peka Peka prevents overland flow from the sea.

13.2 Inundation Pathways

The pathways for coastal inundation in this cell are Te Kowhai stream, Waimeha Stream, their tributaries, and the stormwater drainage network which discharges into the streams (Figure 13.2).

In Peka Peka and the area north of Waikanae Beach the stormwater pipe network is limited and discharges mainly to soak pits and ponds. At Waikanae Beach, north of the Waimeha Stream, the stormwater network drains mainly to sea and to soak pits, but part of the network also drains to the Ngārara Stream, a tributary of the Waimeha Stream. At Waikanae Beach south of the Waimeha Stream, the stormwater network discharges to the stream and directly to the sea.

13.3 Projected inundation

The storm tide levels for Waikanae Beach and RSLR for each of the four scenarios are summarised in Table 13.1. Maps showing the areas of land potentially susceptible to coastal inundation in each scenario are provided in Appendix E.

Table 13.1: Storm tide levels for each RSLR scenario considered in the inundation assessment for the Peka Peka and Waimeha inundation cell.

<table>
<tr><th></th><th colspan="8">RSLR Scenarios</th></tr>
<tr><th></th><th rowspan="2">Present-day</th><th>2050</th><th colspan="2">2070</th><th colspan="4">2120</th></tr>
<tr><th></th><th>upper
0.4 m</th><th>lower
0.4 m</th><th>upper
0.65 m</th><th>lower
0.65 m</th><th colspan="2">intermediate</th><th>upper
1.65 m</th></tr>
<tr><td>RSLR</td><td>0 m</td><td colspan="2">0.4 m</td><td colspan="2">0.65 m</td><td>0.85 m</td><td>1.25 m</td><td>1.65 m</td></tr>
<tr><td>Storm tide level (WVD-53)</td><td>2.31 m</td><td colspan="2">2.71 m</td><td colspan="2">2.96 m</td><td>3.16 m</td><td>3.56 m</td><td>3.96 m</td></tr>
</table>

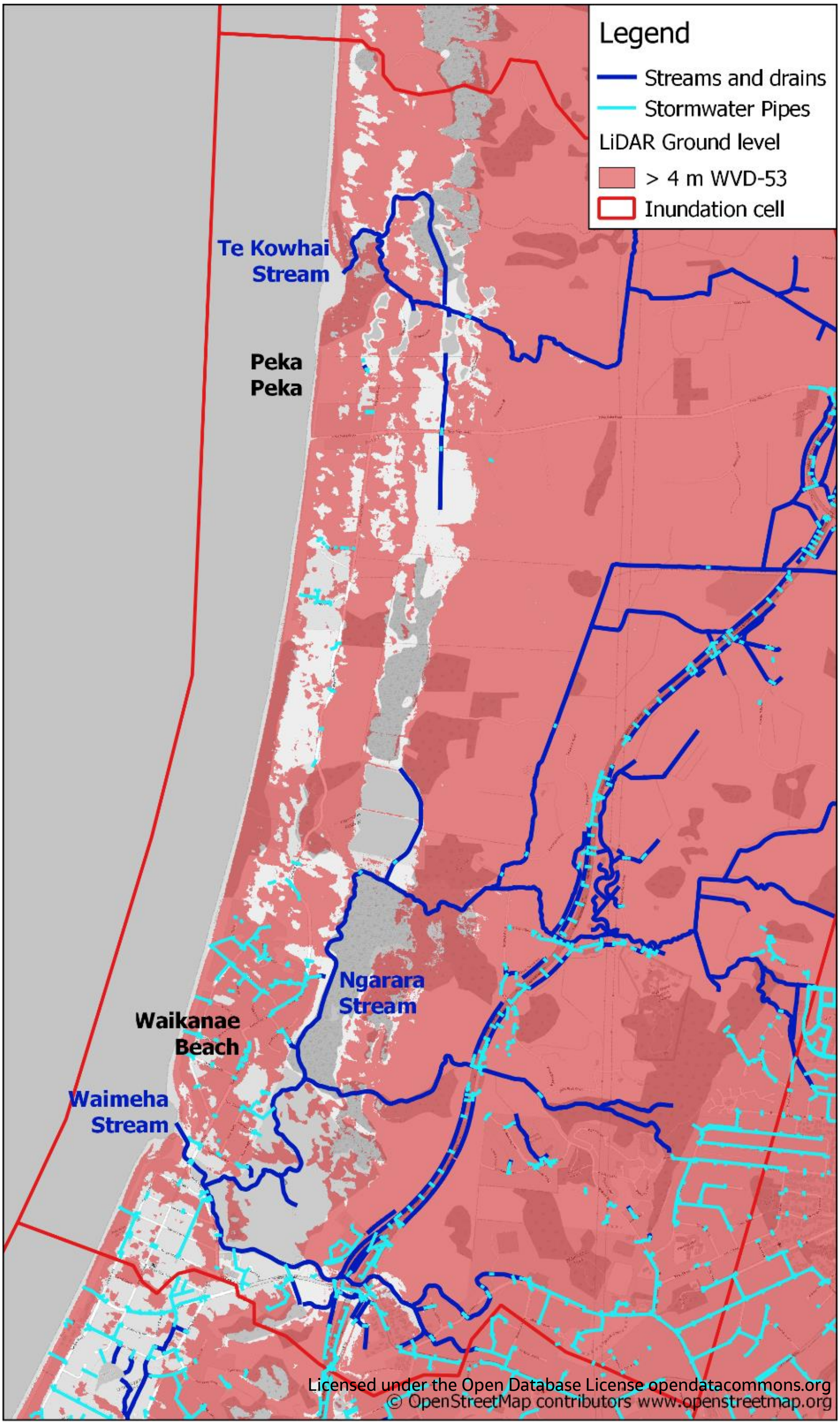


Figure 13.2: Map of the Peka Peka and Waimeha inundation cell showing the main inundation pathways - streams and drains (in dark blue) and stormwater pipe network (in pale blue). Higher ground (above 4 m WVD-53) is shaded in red.

13.3.1 Present-day inundation

The present-day inundation hazard shows the areas which are currently susceptible to coastal flooding from large coastal storm events and which will continue to be susceptible in the near future. The present-day hazard results when the storm-tide water levels (including wave setup but excluding wave runup and overtopping) exceed the ground elevations in the inundation cell. This area is mapped as the "1% AEP Storm Tide, 0 m RSLR" layer in the maps in Appendix E.

North of Waikanae Beach the only mapped areas susceptible to flooding are the ponds on the true left bank of Te Kowhai Stream and a few low-lying areas in the seaward most dune swales. The dune ridge affords a measure of protection along this stretch of coast that reduces the coastal flood hazard. At Waikanae Beach, the areas susceptible to inundation are alongside the Waimeha and Ngārara Streams. Additional inundation from wave runup and overtopping was not modelled to occur in the cell for this scenario.

13.3.2 Future inundation

0.40 m RSLR and 0.65 m RSLR

The increase in areas susceptible to inundation is similar in both these scenarios.

At the north end of Waikanae Beach, the mapping shows an increase in the susceptibility to flooding in the dune swale that runs parallel to the coastline, e.g. along Paetawa Road. These areas are currently protected from inundation by the dune ridge crest. The susceptible area around Te Kowhai Stream increases in size and land around the open drain south of Peka Peka Road, which flows into Te Kowhai Stream through ponds at Raukawa Road, starts to become susceptible in these scenarios.

In Waikanae Beach, the susceptible area around the Waimeha Stream and Ngārara Stream increases. The mapping shows the area around the northern end of Titoki Road as susceptible. The stormwater network in this area drains to ponds in the catchment rather than the Ngārara Stream and may be protected from inundation by the Ngārara Stream in these scenarios depending on the levels of the inlets to the drainage network. To the south of the Waimeha Stream, the mapping shows the areas around Tutere Street, Hona Street and Hemara Street becoming susceptible in these scenarios. The stormwater network in Tutere Street is pumped to the sea but is vulnerable to inundation from rainfall in the event of pump failure. The network in Hona and Hemara Street drains by gravity to the Waimeha Stream and is susceptible to inundation by backflow from the stream. Field Way is susceptible to direct inundation from the Waimeha Stream at the junction with Heperi Street and Huiawa Street.

Additional inundation due to overtopping from wave runup is not modelled to occur in the cell for this scenario.

0.85 m RSLR

In Waikanae Beach, the area around Rauparaha Street starts to become susceptible to inundation by backflow from the Waimeha Stream through the stormwater system. Elsewhere there is generally a small increase in the area susceptible to inundation at 0.65m RSLR. Te Moana Road starts to become susceptible to inundation from the Waimeha Stream through the stormwater drainage network. Field Way, Hughes Street and Frances Street starts to become susceptible to inundation from the stormwater outfalls to the sea – some of these are fitted with backflow prevention valves but there is a residual risk of inundation in the event of valve failure.

1.25 m RSLR

A large area of land in the dune swale around the Pharazyn ponds becomes susceptible to inundation from Te Kowhai Stream and Ngārara Stream. Te Moana Road is susceptible to direct inundation from the Waimeha Stream at the junction with Rauparaha Street. Elsewhere there is generally a small increase in the area susceptible to inundation at 0.85m RSLR.

Figure 13.3: A "scruffy dome" inlet to the stormwater drainage pipe at the low point in Hemara Street. The pipe drains to the Waimeha Stream and water can flow back up the drain from the stream and out through inlets like this one when the stream water level is raised by storm tides. The ground level here is approximately 0.3 m above the present-day 1% AEP storm tide level.

Figure 13.4: The Waimeha Stream next to the junction of Field Way and Heperi Street. The road level at the junction is approximately 0.1 m above the present-day 1% AEP storm tide level.

1.65 m RSLR

In this scenario, the susceptible areas in the dune swale north of Waikanae Beach increase and start to become connected with inundation from the Ngārara Stream to the south of the ponds at Pharazyn Reserve. Inundation extends from the Ngārara Stream northwards to Te Kowhai Stream along the entire drainage corridor.

At Waikanae Beach, north of the Waimeha Stream, the area around the north end of Titoki Road becomes susceptible to direct inundation from the Ngārara Stream and the area of inundation around the Waimeha Stream itself is increased. To the south of the Waimeha Stream, much of the remaining area up to the southern boundary of the cell is susceptible to direct inundation from the Waimeha Stream through a pathway along Te Moana Road and Rangihiroa Street in addition to backflow through the stormwater network.

Additional potential inundation due to overtopping from wave runup is modelled to occur in one location in the cell in this scenario, on the north side of the mouth of Te Kowhai Stream.

13.4 Vulnerability

13.4.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified council critical infrastructure and community services that intersected the area mapped as susceptible to coastal inundation. The results of this assessment are presented in Table 13.2. Asset location data were provided by KCDC. For vulnerability to inundation, critical roads are defined as the main evacuation routes from the coast inland, perpendicular to the coastline. Apart from pump stations, stormwater assets are not considered vulnerable to inundation and have not been included in the assessment.

Table 13.2: Council critical infrastructure and community services affected in the Peka Peka and Waimeha inundation cell for each RSLR scenario considered.

	RSLR Scenarios							
	Present-day	2050	2070		2120			
		upper	lower	upper	lower	intermediate		upper
Asset	**0 m**	**0.4 m**		**0.65 m**		**0.85 m**	**1.25 m**	**1.65 m**
Critical Road for Evacuation (length susceptible to inundation)								
Te Moana Road	0 m	0 m		0 m		30 m	155 m	500 m
Three Waters Assets (number susceptible to inundation)								
Stormwater pump station	0	1		1		1	1	1
Water Supply Bore	0	0		1		1	4	6

The results show that the main evacuation route for Waikanae Beach in this inundation cell – Te Moana Road – starts to become susceptible in the 0.85 m RSLR scenario (over 50 years' time) with the length susceptible increasing to around 0.5 km in the highest RSLR scenario considered (1.65 m). The main route for Peka Peka, i.e., Peka Peka Road, is not susceptible to inundation in any of the RSLR scenarios considered.

Coastal stormwater pump stations and water supply bores were the other critical infrastructure and community service identified to be affected in the Peka Peka and Waimeha inundation cell, with one pump station affected in 30 to 50 years' time and one bore affected in 50 to 100 years' time, increasing to six in the highest RLSR scenario (1.65 m).

13.4.2 Land parcels

The land parcels (public and private) that intersect the area mapped as susceptible to coastal inundation have been calculated to give an indication of the number of land parcels potentially affected within the inundation cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels. The results of this assessment for the Peka Peka and Waimeha inundation cell are presented in Table 13.3. It should be noted that the count for land parcels includes land parcels along the shoreline where the seaward boundary extends into the CMA beyond the current MHWS.

Table 13.3: Number of public and private land parcels affected in the Peka Peka and Waimeha inundation cell for each RSLR scenario considered.

<table>
<tr><th></th><th colspan="8">RSLR Scenarios</th></tr>
<tr><th rowspan="3">Land parcels</th><th rowspan="2">Present-day</th><th>2050</th><th colspan="2">2070</th><th colspan="4">2120</th></tr>
<tr><th>upper</th><th>lower</th><th>upper</th><th>lower</th><th colspan="2">intermediate</th><th>upper</th></tr>
<tr><th>0 m</th><th colspan="2">0.4 m</th><th colspan="2">0.65 m</th><th>0.85 m</th><th>1.25 m</th><th>1.65 m</th></tr>
<tr><td>Public</td><td>17</td><td colspan="2">23</td><td colspan="2">27</td><td>29</td><td>38</td><td>45</td></tr>
<tr><td>Private</td><td>145</td><td colspan="2">336</td><td colspan="2">445</td><td>531</td><td>681</td><td>807</td></tr>
</table>

14. Waikanae and Raumati Inundation Cell

14.1 General Description

The Waikanae and Raumati inundation cell covers approximately 11 km of coastline, extending from Te Moana Road, Waikanae in the north to the southern end of The Esplanade, Raumati South, in the south. Coastal inundation is determined by the Paraparaumu and Raumati Beach storm tide level as estimated by Lane et al (2012).

The cell includes the southern part of Waikanae Beach and takes in Paraparaumu Beach, Raumati Beach and Raumati South. This cell is the most densely developed of the four inundation cells and has an extensive stormwater network draining runoff to local streams and the sea.

Ground levels in the southern part of the cell, south of Tikotu Creek, are generally relatively high and above the highest combined storm tide and RSLR level considered in this assessment. Exceptions are the Wharemauku Stream and Tikotu Creek corridors and occasional depressions in the dune ridge along the coastline.

To the north of Tikotu Creek, more extensive areas of lower lying land occur around the Waikanae River and Estuary and its tributary streams and drains.

14.2 Inundation Pathways

The pathways for coastal inundation in the north of this cell are the Waikanae River and its tributaries, the Mazengarb Stream and Kenakena Drain, the Waimanu Lagoon and the stormwater drainage network which discharges into the streams and the lagoon. The outlets of the Kenakena Drain and Mazengarb Stream to the Waikanae Estuary are uncontrolled and provide direct pathways for coastal inundation. The Waimanu Lagoon is protected from inundation by a low causeway and an automated control weir in the lagoon outlet culvert (Figure 14.1) which reduces the potential for backflow from the estuary into the lagoon.

At the south end of the cell, the inundation pathways are the Tikotu Creek and Wharemauku Stream and the smaller drains and stormwater network which drain into them. Stormwater outfalls to the sea also provide potential pathways for inundation of some of the small depressions in the dune ridge along the coastline.

Figure 14.2 shows the location of the main pathways and features of this inundation cell.

Figure 14.1: Causeway and outlet of the Waimanu Lagoon to the Waikanae Estuary. The road level on the causeway is approximately 0.1 m above the present-day 1% AEP storm tide level.

14.3 Projected inundation

The storm tide levels for Paraparaumu and Raumati Beach and RSLR for each of the four scenarios are summarised in Table 14.1. Maps showing the areas of land susceptible to coastal inundation in each scenario are provided in Appendix E. A summary of key features of the mapping in each scenario is provided below.

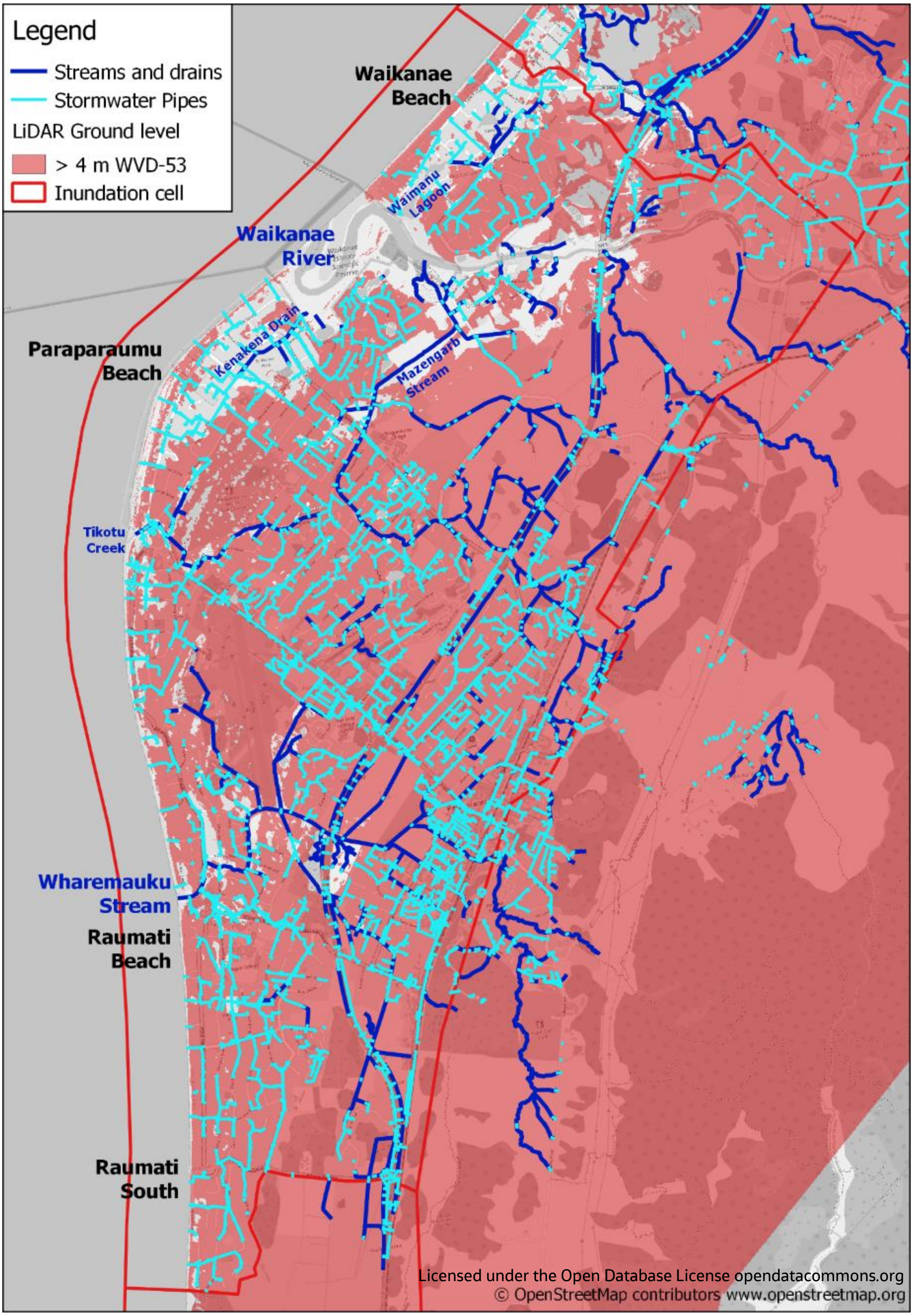


Figure 14.2: Map of the Waikanae and Raumati inundation cell showing the main inundation pathways - streams and drains (in dark blue) and stormwater pipe network (in pale blue). Higher ground (above 4 m WVD-53) is shaded in red.

Table 14.1: Storm tide levels for each RSLR scenario considered in the inundation assessment for the Waikanae and Raumati inundation cell.

	RSLR Scenarios							
	Present-day	**2050**	**2070**		**2120**			
		upper 0.4 m	**lower 0.4 m**	**upper 0.65 m**	**lower 0.65 m**	**intermediate**		**upper 1.65 m**
RSLR	0 m	0.4 m		0.65 m		0.85 m	1.25 m	1.65 m
Storm tide level (WVD-53)	2.14 m	2.54 m		2.79 m		2.99 m	3.39 m	3.79 m

14.3.1 Present-day inundation

The present-day inundation hazard shows the areas which are currently susceptible to coastal flooding from large coastal storm events, and which will continue to be susceptible in the near future. The present-day hazard results when the storm-tide water levels (including wave setup but excluding wave runup and overtopping) exceed the ground elevations in the inundation cell. This area is mapped as the "1% AEP Storm Tide, 0 m RSLR" layer in the maps in Appendix E.

In the north part of the cell the mapped susceptible areas are the Waimanu Lagoon, Waimeha Lagoon and the drainage channel connecting these ponds, the estuarine margins of the Waikanae River and ponds in the Mazengarb stormwater network. The causeway and outlet structure at the Waimanu Lagoon protects the lagoon and drainage network inland of the lagoon from inundation in this scenario but there is a residual susceptibility to flooding in the event of failures of the control structure or a breach in the causeway, which is around 0.1m above the 1% AEP storm tide level. Properties along Makora Road in Otaihanga are protected from the Waikanae River by higher ground along the river but are susceptible to inundation from the mouth of the Mazengarb Stream through a drainage culvert and low ground levels along the Otaihanga Boating Club access track (Figure 14.3).

Figure 14.3: Otaihanga Boating Club access track off Makora Road. A culvert underneath the track provides an inundation pathway from the mouth of the Mazengarb Stream (to the right) to a stormwater drainage channel (to the left). The lowest levels on the access track are approximately 0.2 m below the present-day 1% AEP storm tide level.

In the south part of the cell the only susceptible area mapped is at the northern end of Kāpiti Road, adjacent to Tikotu Creek.

Although additional inundation due to overtopping from wave runup is not modelled to occur in the cell for this scenario using the adopted methodology, some locations are locally susceptible to surface flooding from wave runup. For example, wave runup causes surface flooding of the carpark on the south side of the mouth of the Wharemauku during storm events. However, ground levels are above the storm tide level so that swash from waves does not add to any tidal inundation and the water is able to drain back to the sea and over the true left bank of the Wharemauku Stream.

14.3.2 Future inundation

0.40 m RSLR and 0.65 m RSLR

The increase in areas susceptible to inundation is similar in both these scenarios.

The area around the Waimanu and Waimeha lagoons becomes susceptible to direct inundation from the Waikanae Estuary through overtopping of the Waimanu causeway and to backflow through the stormwater network which drains into the lagoons. The area susceptible to inundation along the Waikanae River margins increases and the area around Kahu Road becomes susceptible to inundation from backflow through the stormwater network. The area susceptible to inundation along the Mazengarb Stream increases and areas connected to the stream by the stormwater network along Otaihanga Road and Ruru Road also becomes susceptible.

In the Kenakena Drain catchment, the area around Te Kupe Road and Olive Terrace becomes susceptible to inundation from backflow through the stormwater network and direct inundation from the Kenakena Drain. (Figure 14.4). In the 0.65 m RSLR scenario, the storm tide level in the Waikanae estuary exceeds the road level of Manly Street.

Figure 14.4: The Kenakena Drain is connected to the Waikanae estuary by a culvert under Manly Street and provides a pathway for coastal inundation both directly through the culvert and over Manly Street.

Along the coastline between Paraparaumu Beach and Raumati South, some of the smaller stormwater catchments which drain by gravity directly to sea start to become susceptible to inundation by backflow – e.g. Nathan Road in Paraparaumu Beach. Some of the outfalls are fitted with non-return devices and in these cases, there is a residual susceptibility to inundation in the event these fail to operate. The area around the mouth of the Wharemauku Stream becomes susceptible to inundation in these two scenarios.

Additional inundation due to overtopping from wave runup is not modelled to occur in the cell for these two scenarios. However, as in the present-day, local surface flooding from wave runup can occur, such as in the carpark at the mouth of the Wharemauku Stream.

0.85 m RSLR

In this scenario there is generally a small increase in the area susceptible to inundation at 0.65 m RSLR.

1.25 m RSLR

The area susceptible to inundation around the Kenakena Drain is much greater than in the 0.85 m RSLR scenario. The stormwater attenuation ponds alongside the Wharemauku Stream, to the west and east of the Kāpiti Expressway start to become susceptible to coastal inundation and the area along Matatua Road susceptible to backflow from the Wharemauku Stream through the stormwater drains increases. Elsewhere there is generally a small increase in the area susceptible to inundation at 0.85m RSLR.

1.65 m RSLR

In this scenario the area susceptible to inundation around the Waikanae River and Estuary – around the Waimanu and Waimeha lagoons, the Mazengarb Stream and the Kenakena Drain – becomes more extensive and much of the area becomes susceptible to direct inundation from the sea in addition to backflow from stormwater outfalls to the sea. Along Tikotu Creek the increase in area susceptible to inundation is smaller because ground levels are generally higher.

Along the coastline south of Tikotu Creek, the area susceptible to inundation from stormwater outfalls to the sea increases and some of these areas are also modelled to be susceptible to additional inundation due to overtopping from wave runup. Along the Wharemauku Stream the mapping shows increased areas susceptible to both direct inundation from the stream and through the stormwater network.

14.4 Vulnerability

14.4.1 Council Critical Infrastructure and Community Services

The vulnerability assessment identified council critical infrastructure and community services that intersect the area mapped as susceptible to coastal inundation. The results of this assessment are presented in Table 14.2. Asset location data were provided by KCDC. For inundation vulnerability, critical roads are defined as the main evacuation routes from the coast inland, perpendicular to the coastline. Apart from pump stations, stormwater assets are not considered vulnerable to inundation and have not been included in the assessment.

Table 14.2: Council critical infrastructure and community services affected in the Waikanae and Raumati inundation cell for each RSLR scenario considered.

	RSLR Scenarios					
	Present-day	2050 upper / 2070 lower	2070 upper / 2120 lower	2120 intermediate	2120 intermediate	2120 upper
Asset	**0 m**	**0.4 m**	**0.65 m**	**0.85 m**	**1.25 m**	**1.65 m**
Critical Road for Evacuation (length susceptible to inundation)						
Te Moana Road	0 m	40 m	130 m	300 m	620 m	750 m
Otaihanga Road	0 m	0 m	0 m	0 m	220 m	430 m
Mazengarb Road	0 m	0 m	40 m	150 m	330 m	380 m
Kāpiti Road	0 m	130 m	170 m	220 m	250 m	270 m
Raumati Road	0 m	0 m	0 m	0 m	0 m	90 m
Services						
School	0	0	0	0	1	2
Three Waters Assets (number susceptible to inundation)						

	RSLR Scenarios								
	Present-day	2050	2070		2120				
		upper	lower	upper	lower	intermediate		upper	
Asset	0 m	0.4 m		0.65 m		0.85 m	1.25 m	1.65 m	
Critical Road for Evacuation (length susceptible to inundation)									
Stormwater pump station	0	0		0		1	1	1	
Water Supply Bore	0	1		2		4	4	6	

The results show that two of the main evacuation routes in this inundation cell – Te Moana Road and Kāpiti Road – start to become susceptible to inundation in 30 to 50 years' time. All routes are susceptible under the highest RSLR scenario (1.65 m).

Coastal stormwater pump stations and water supply bores were the three waters assets identified to be affected in the Waikanae and Raumati inundation cell, with one bore affected in 30 to 50 years' time, increasing to six in the highest RLSR scenario (1.65 m) together with one pump station.

Kenakena School is mapped as susceptible to inundation in the two highest RSLR scenarios considered (1.25 m and 1.65 m) but the inundation is limited to the playing field adjacent to Donovan Road. Raumati Beach School is also mapped as susceptible in the 1.65 m RSLR scenario, but the potential inundation is limited to the playground and carpark adjacent to Raumati Road.

14.4.2 Land parcels

The of land parcels (public and private) that intersect the area mapped as susceptible to coastal inundation have been calculated to give an indication of the number of land parcels potentially affected within the inundation cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels. The results of this assessment for the Waikanae and Raumati inundation cell are presented in Table 14.3. It should be noted that the count for land parcels includes land parcels along the shoreline where the seaward boundary extends into the CMA beyond the current MHWS.

Table 14.3: Number of public and private land parcels affected in the Waikanae and Raumati inundation cell for each RSLR scenario considered.

	RSLR Scenarios							
	Present-day	2050	2070		2120			
		upper	lower	upper	lower	intermediate		upper
Land parcels	0 m	0.4 m		0.65 m		0.85 m	1.25 m	1.65 m
Public	35	58		68		83	127	155
Private	291	693		1,064		1,398	2,125	2,845

15. Paekākāriki and Whareroa Inundation Cell

15.1 General Description

The Paekākāriki and Whareroa inundation cell covers approximately 7 km of coastline, extending from the end of The Esplanade, Raumati South, in the north to the district boundary in the south. Coastal inundation is determined by the Paekākāriki storm tide level as estimated by Lane et al (2012).

The cell includes the Paekākāriki village and is the least densely developed of the four cells in this assessment. Ground levels over almost the entire cell are well above the highest combined storm tide and RSLR level and the coastal dune ridge rises to 20 m to 30 m above sea level. Exceptions are around the three small river mouths and occasional depressions in the dune swales.

15.2 Inundation Pathways

The pathways for coastal inundation in this cell are the Whareroa Stream, the Wainui Stream and the Waikakariki Stream as shown in Figure 15.1 and Figure 15.2. The gravity stormwater drainage network in Paekākāriki, which discharges into the Wainui Stream and to sea are generally raised well above the highest sea level considered in this assessment.

Figure 15.1: The mouth of the Whareroa Stream viewed from the true left bank of the stream looking inland. The stream cuts through the high dune ridge, providing an inundation pathway inland for the sea.

15.3 Projected inundation

The storm tide levels for Paekākāriki and Whareroa and RSLR for each of the four scenarios are summarised in Table 15.1. Maps showing the areas of land potentially susceptible to coastal inundation in each scenario are provided in Appendix E. A summary of key features of the mapping in each scenario is provided below.

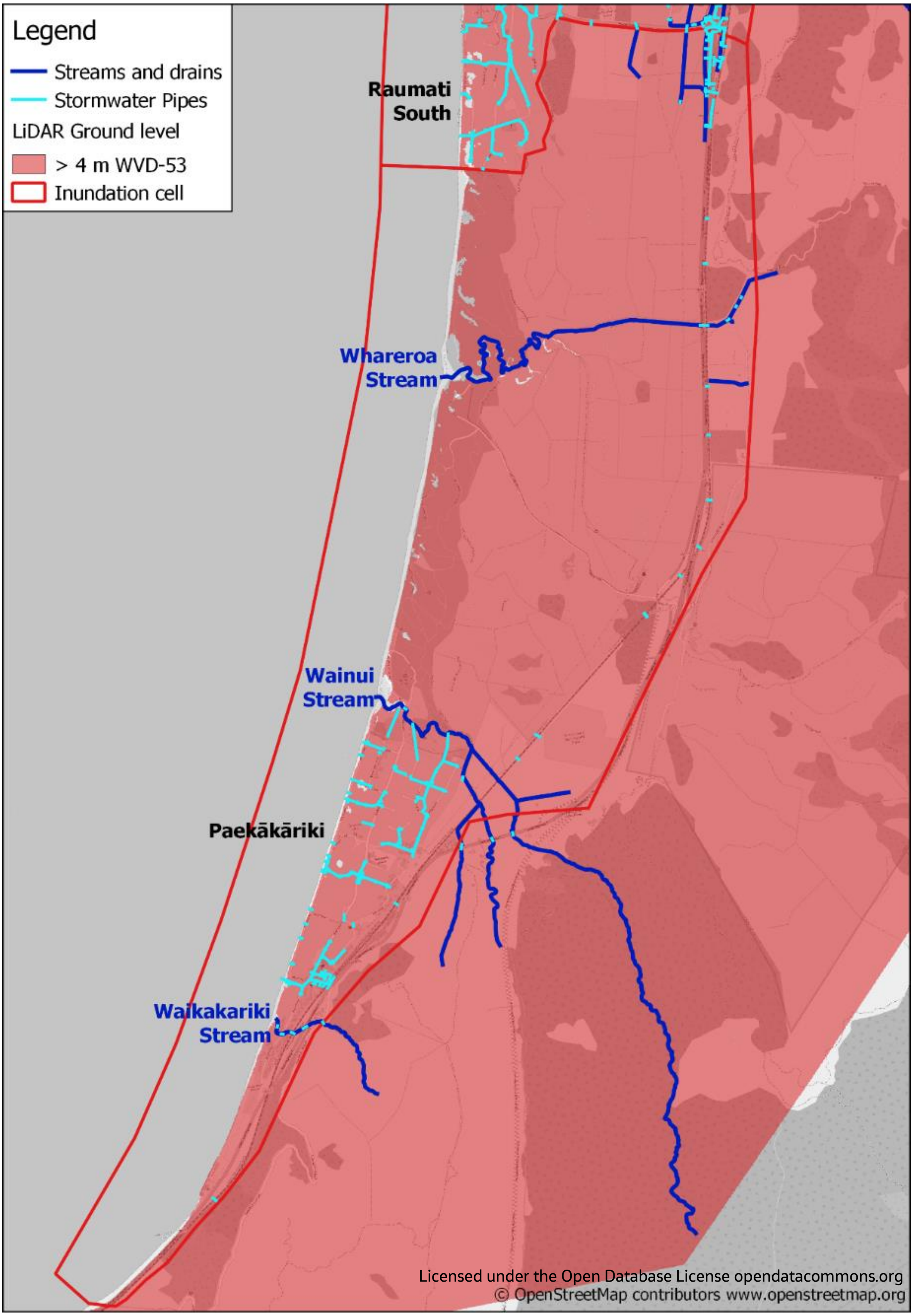


Figure 15.2: Map of the Paekākāriki and Whareroa inundation cell showing the main inundation pathways - streams and drains (in dark blue) and stormwater pipe network (in pale blue). Higher ground (above 4 m WVD-53) is shaded in red.

Table 15.1: Storm tide levels for each RSLR scenario considered in the inundation assessment for the Paekākāriki and Whareroa inundation cell.

	RSLR Scenarios							
	Present-day	2050	2070		2120			
		upper 0.4 m	lower 0.4 m	upper 0.65 m	lower 0.65 m	intermediate		upper 1.65 m
RSLR	0 m	0.4 m		0.65 m		0.85 m	1.25 m	1.65 m
Storm tide level (WVD-53)	2.14 m	2.54 m		2.79 m		2.99 m	3.39 m	3.79 m

15.3.1 Present-day inundation

The present-day inundation hazard shows the areas which are currently susceptible to coastal flooding from large coastal storm events, and which will continue to be susceptible in the near future. The present-day hazard results when the storm-tide water levels (including wave setup but excluding wave runup and overtopping) exceed the ground elevations in the inundation cell. This area is mapped as the "1% AEP Storm Tide, 0 m RSLR" layer in the maps in Appendix E.

In this cell, the mapping shows the only area susceptible to inundation is around the mouth of the Whareroa Stream. Additional inundation due to overtopping from wave runup is not modelled to occur in the cell for this scenario.

15.3.2 Future inundation

0.40 m RSLR and 0.65 m RSLR

The increase in areas susceptible to inundation is similar in both scenarios.

The mapping shows additional areas susceptible to inundation around the mouths of the Whareroa and Wainui Streams and occasional depressions in the dune swale, some of which are also susceptible to additional inundation from wave runup and overtopping.

0.85 m RSLR and 1.25 m RSLR

The main increase in areas susceptible to inundation are around the mouth of the Wainui Stream. These areas are also susceptible to additional inundation from wave runup and overtopping. Within Paekākāriki the mapping shows several localised depressions start to become susceptible to inundation from the stormwater outfalls, but which are protected to a degree by higher surrounding ground levels.

1.65 m RSLR

In this scenario the areas susceptible to inundation around the mouth of the Whareroa Stream, Wainui Stream and in the dune swales are increased and are vulnerable to additional inundation from wave runup and overtopping. A small area of inundation is mapped in the mouth of the Waikakariki Stream which is susceptible to additional inundation from wave runup.

15.4 Vulnerability

15.4.1 Council Critical Infrastructure and Community Services

The vulnerability assessment for the Paekākāriki and Whareroa inundation cell identified no council critical infrastructure and community services that intersected the area mapped as susceptible to coastal inundation for all RSLR scenarios considered.

15.4.2 Land parcels

The land parcels (public and private) that intersect the area mapped as susceptible to coastal inundation have been calculated to give an indication of the number of land parcels potentially affected within the inundation cell. Public land parcels are defined as being owned by central and local government, with private land parcels being all other remaining land parcels. The results of this assessment for the Paekākāriki and Whareroa inundation cell are presented in Table 15.2. It should be noted that the count for land parcels includes land parcels along the shoreline where the seaward boundary extends into the CMA beyond the current MHWS.

Table 15.2: Number of public and private land parcels affected in the Paekākāriki and Whareroa inundation cell for each RSLR scenario considered.

	RSLR Scenarios							
	Present-day	**2050**	**2070**		**2120**			
		upper	**lower**	**upper**	**lower**	**intermediate**		**upper**
Land parcels	**0 m**	**0.4 m**		**0.65 m**		**0.85 m**	**1.25 m**	**1.65 m**
Public	2	3		3		3	3	3
Private	41	44		47		53	60	66

16. Summary of Inundation Vulnerability Assessment

A summary of the number of public and private land parcels intersecting with the area mapped for a 1% AEP susceptibility to inundation is presented below in Table 16.1. Further details, including individual critical infrastructure and community services potentially affected, are presented within each cell section of this report.

Table 16.1: Summary of the number of land parcels that intersect with the area mapped as susceptible to coastal inundation.

<table>
<tr><th></th><th></th><th colspan="8">RSLR Scenarios</th></tr>
<tr><th rowspan="3">Inundation Cell</th><th rowspan="3">Land Parcel Type</th><th rowspan="2">Present-day</th><th>2050</th><th colspan="2">2070</th><th colspan="4">2120</th></tr>
<tr><th>upper</th><th>lower</th><th>upper</th><th>lower</th><th colspan="2">intermediate</th><th>upper</th></tr>
<tr><th>0 m</th><th colspan="2">0.4 m</th><th colspan="2">0.65 m</th><th>0.85 m</th><th>1.25 m</th><th>1.65 m</th></tr>
<tr><td rowspan="2">Ōtaki and Te Horo</td><td>Private</td><td>316</td><td colspan="2">524</td><td colspan="2">742</td><td>844</td><td>1,028</td><td>1,184</td></tr>
<tr><td>Public</td><td>10</td><td colspan="2">15</td><td colspan="2">18</td><td>18</td><td>20</td><td>25</td></tr>
<tr><td rowspan="2">Peka Peka and Waimeha</td><td>Private</td><td>145</td><td colspan="2">336</td><td colspan="2">445</td><td>531</td><td>681</td><td>807</td></tr>
<tr><td>Public</td><td>17</td><td colspan="2">23</td><td colspan="2">27</td><td>29</td><td>38</td><td>45</td></tr>
<tr><td rowspan="2">Waikanae and Raumati</td><td>Private</td><td>291</td><td colspan="2">693</td><td colspan="2">1,064</td><td>1,398</td><td>2,125</td><td>2,845</td></tr>
<tr><td>Public</td><td>35</td><td colspan="2">58</td><td colspan="2">68</td><td>83</td><td>127</td><td>155</td></tr>
<tr><td rowspan="2">Paekākāriki and Whareroa</td><td>Private</td><td>41</td><td colspan="2">44</td><td colspan="2">47</td><td>53</td><td>60</td><td>66</td></tr>
<tr><td>Public</td><td>2</td><td colspan="2">3</td><td colspan="2">3</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td rowspan="3">Totals</td><td>Private</td><td>793</td><td colspan="2">1,597</td><td colspan="2">2,298</td><td>2,826</td><td>3,894</td><td>4,902</td></tr>
<tr><td>Public</td><td>64</td><td colspan="2">99</td><td colspan="2">116</td><td>133</td><td>188</td><td>228</td></tr>
<tr><td>Public and Private</td><td>857</td><td colspan="2">1,696</td><td colspan="2">2,414</td><td>2,959</td><td>4,082</td><td>5,130</td></tr>
</table>

Based on the number of land parcels which are partially or wholly susceptible to coastal inundation, the central section of the coastline, within the Waikanae and Raumati inundation cell, is the most vulnerable to inundation due to the extent of lower lying land and the number and density of individual land parcels in the coastal area. The southern section of the coastline, within the Paekākāriki and Whareroa inundation cell is the least vulnerable due to the higher ground levels and small number of land parcels in this section of the coastline.

- Under present-day sea level, the assessment indicates 857 land parcels potentially susceptible to coastal inundation, of which 38% lie within each of the Waikanae and Raumati cell and the Ōtaki and Te Horo cell; 19% lie within the Peka Peka and Waimeha cell; and 5% lie within the Paekākāriki and Whareroa cell.
- For a RSLR of 0.4 m (30 to 50 years) the total number of potentially susceptible land parcels almost doubles to 1696; the proportion of parcels lying in the Waikanae and Raumati cell and the Peka Peka and Waimeha cell increases to 44% and 21% respectively; and the proportion of parcels lying in the Ōtaki and Te Horo cell and Paekākāriki and Whareroa cell reduces to 32% and 3% respectively.
- For a RSLR of 0.65 m (50 to 100 years) the relative proportions of susceptible parcels in each cell remains approximately the same but the total number of susceptible parcels increases to 2414, almost three times the number at present-day sea level.
- For RSLR of 0.85 m and 1.25 m – intermediate estimates for 100 years – the total number of parcels potentially susceptible to inundation increases by 545 and 1668 respectively from the lower bound estimate of RSLR for 100 years. The largest increase is in the Waikanae and Raumati cell.
- For the highest RSLR considered – 1.65 m, an upper bound estimate for 100 years – the total number of susceptible parcels increases to 5130, six times the number at present-day. The greatest increase is in the Waikanae and Raumati cell where the number of parcels increases to 3000, over half the total for all the cells.

Figure 16.1 shows the combined number of public and private land parcels intersecting with the area mapped for a 1% AEP susceptibility to inundation in each of the four inundation cells, together with the rate of increase in number of parcels between each value of RSLR considered. For RSLR values above 0.65 m, the total number of susceptible parcels increases at a relatively uniform rate of between approximately 26 to 29 additional parcels per centimetre of RSLR. The rate of increase in number of parcels in individual cells is largest for the Waikanae and Raumati coastal inundation cell.

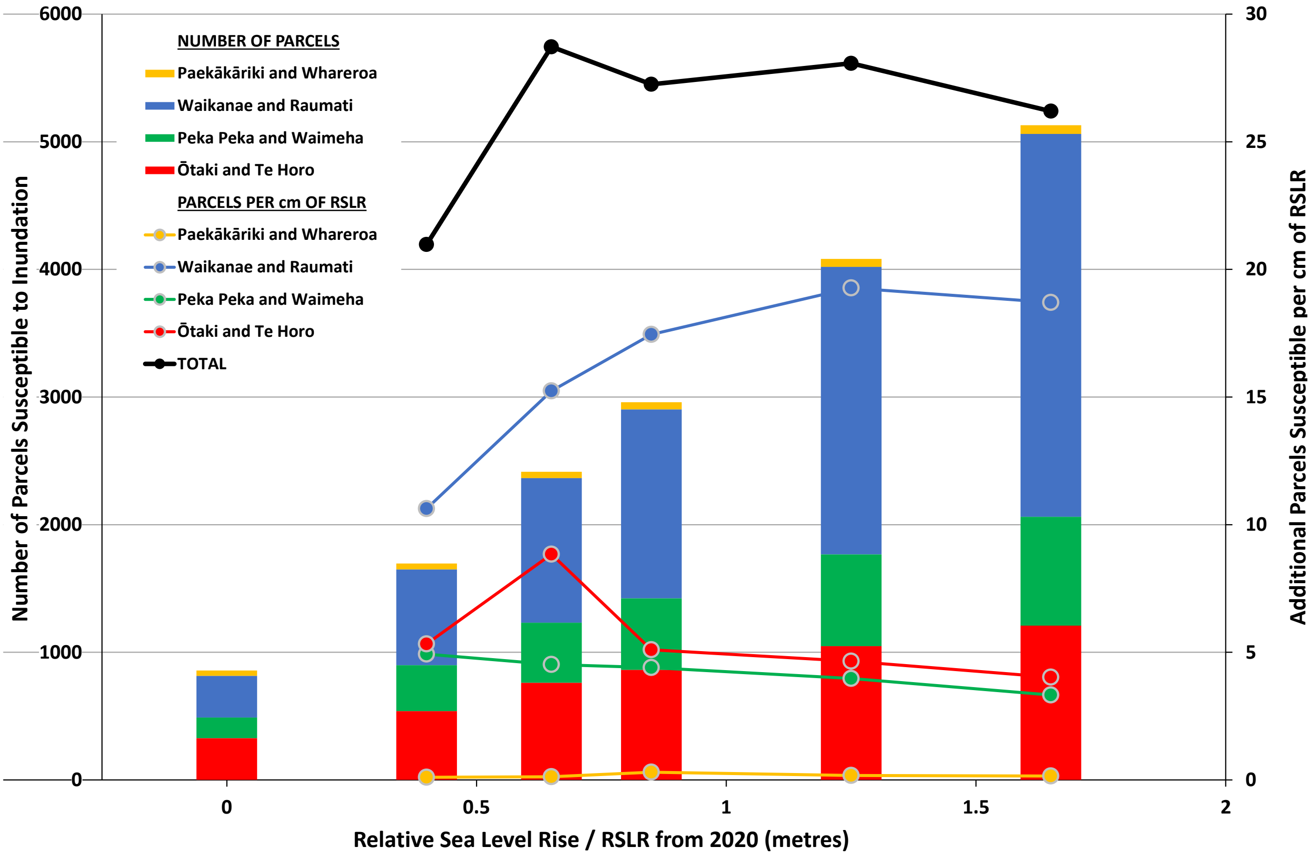


Figure 16.1: Chart showing the number of land parcels susceptible to inundation in each cell as bars (values on the left axis) and the change in number of parcels between each RSLR scenario considered, expressed as the number of additional parcels becoming susceptible per centimetre of RSLR (values on the right axis)

The vulnerability assessment identified that the main infrastructure and services susceptible to potential inundation are stormwater pump stations and water supply bores and the principal roads which would provide routes for access to and evacuation of the coastal communities in a storm event. For most of the main access roads to the coast, extensive susceptibility to coastal inundation occurs only for the highest RSLR considered (1.65 m). Limited sections of these routes are susceptible for lower RSLR values. Minor routes and residential roads in the coastal communities are generally susceptible to inundation at lower RSLR values.

Part 3: Monitoring Recommendations

17. Monitoring Recommendations

Throughout this report, and the Volume 1 Methodology report, several limitations around data availability, methods and future management decisions are noted. These limitations result in uncertainty around the PFSP results produced in this report, which have been addressed as best as possible in the probabilistic approach with the current understand of coastal environments, and current data availability. However, these uncertainties could be reduced in future assessments if more regular information is collected on the Kāpiti coast to inform both inundation and erosion modelling. Current data availability for coastal environments on the Kāpiti Coast is very limited.

The following monitoring techniques could be adopted on the Kāpiti Coast to better inform susceptibility assessments:

- Beach profile monitoring
  - Available beach profile monitoring data used in this assessment dates back to 2000, with surveys being taken every 1-3 years. While this provides some useful information about the beach, profiles taken at more frequent intervals (e.g. Annually) in the same month/season would give more comparable data to monitor beach changes and identify trends. A monitoring network has already been set up on the Kāpiti Coast with historic profiles, and future monitoring should have improved spatial and temporal resolution to add to this data set. Alternatively, other techniques such as topographic surveys using drones could be used to gather a higher volume of data that profiles at key locations including existing profile locations could be extracted from.
  - Profile monitoring pre-post storm events would be very valuable to understand beach changes following these events. The current assessment has used observations from the September 1976 storm event for the short-term component, however collecting data following these events could help verify these observations and reduce uncertainty in the assessment.
  - Monitoring beach profiles with accelerated RSLR will also allow for more information to be gathered around the response of natural and protected beach profiles to RSLR. This on-going monitoring will help address uncertainties about sediment budget responses and whether dune form migration can keep up with SLR, or whether they will become truncated over time, which will have a significant effect on ability to naturally protect against coastal inundation.
- Structure Condition
  - The condition of structures in the Paekākāriki and Raumati cell should continue to be monitored to inform future assessments, particularly for structures that fail, and whether these are replaced, as this will impact the residual life used in the assessment.
- Wave Buoy
  - There is currently no wave buoy located around the Kāpiti Coast. This time series information would help verify the wave climate modelling and provide a better understanding of the wave shadow effect of Kāpiti Island in developing a relationship between offshore wave conditions and storm effects on the beach. Going forward, these wave records could be used to verify projected changes (or assumed nil change) in wave directions and magnitudes due to climate change.
- Bathymetry Data
  - The Bathymetric data used in this assessment was collected in 2003, and therefore the assessment cannot account for any bathymetric changes which have occurred between 2003 to 2021. A new bathymetric survey could be undertaken to reduce the uncertainties around these changes, and whether there have been general nearshore elevation responses to RSLR as required under the Bruun Rule.

- Sediment Budget
  - A limitation of the sediment budget (Appendix H) is the lack of knowledge around the bulk density of the sediment in the Kāpiti District. Collecting and analysing sediment samples from various locations along the Kāpiti Coast would help inform a better understanding of the bulk densities and therefore volume of sediment that is transported into and along the district's coastline, which would help inform the next iteration of a more complex sediment budget.
  - A future limitation of the sediment budget is a lack of sediment transport modelling that links spatial variations sediment transport volumes to the spatial variations in wave climate. This would be beneficial for confirming the direction and magnitudes of sediment transport pathways across assessment cells required to verify a sediment budget, and be helpful in the interpretation of climate change and SLR effects.
- Sea Level Rise
  - One of the largest uncertainties in the modelling is the amount of RSLR that could occur by 2030, 2050 and 2120. Latest information from the NZ SeaRise program should be used once it is available to help inform the RSLR changes on the Kāpiti coast and what approximate trajectory this places the district in for the RSLR scenarios.

While collecting this further information will help inform future coastal hazard susceptibility assessments, it will also form a key role in monitoring for triggers that form the adaptive pathway responses. Triggers will be set for the adaptive pathway process which will alert the community for when action needs to be taken. These triggers can be monetary (e.g. maintenance spending of seawall exceeds $100,000 per year) or can be based on environmental triggers (e.g. shoreline is within XXm of property boundary). Having monitoring programmes in place will allow for environmental triggers to be recorded, and for the community to respond to SLR on a trigger basis, rather than within an allocated timeframe., which is a key component of the Dynamic Adaptation Planning Pathway approach.

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11 February 2022

Kapiti Coast District Council
175 Rimu Rd
Paraparaumu

Attention: Lyndsey Craig

Dear Lyndsey

Takutai Kāpiti Coastal Hazard Susceptibility and Vulnerability Methodology Review

Kapiti Coast District Council (Council) commissioned Beca on the 13 November 2020 to provide ongoing peer review services for the Takutai Kāpiti Coastal Hazard Susceptibility and Vulnerability Assessment that is being completed by Jacobs New Zealand Limited (Jacobs) for Council.

I confirm that I am a Technical Director in Coastal Science for Beca Ltd with over 20 years' experience in the field of coastal science, coastal hazards, climate change and metocean engineering. I frequently provide coastal hazard peer review services for New Zealand Councils. Review services for the Takutai Kāpiti Coastal Hazard Susceptibility and Vulnerability Assessment have been completed on the following:

- Jacobs assessment, methodology and data gap memorandum.
- Jacobs draft report: Kāpiti Coast Coastal Hazard Susceptibility and Vulnerability Assessment Volume 1: Methodology (dated 12 May 2021).
- Jacobs draft report: Kāpiti Coast Coastal Hazard Susceptibility and Vulnerability Assessment Volume 2: Results (dated 10 June 2021 and January 2022) that presents a summarised methodology and assessment results.

I can confirm that during the project I have provided intermittent review and feedback which has been integrated into the project approach and methodology with the last comments provided 11 February 2022 (Review #5).

Based on my review, I can confirm that the coastal erosion hazard methodology as outlined in the aforementioned reports:

- Is consistent with the assessment guideline intent outlined in MfE, 2017:*Coastal Hazards and Climate Change – Guidance for Local Government*.
- Adopts current assessment techniques that have been used to define coastal hazards for similar environs in New Zealand;
- Considers uncertainty of the individual parameters contributing to coastal erosion from future sea level rise; and
- Is considered appropriate considering the level of information and data available and is suitable to inform the development of potential adaptation options.

It is noted that the inundation hazard methodology has adopted a simplified inundation technique to inform the assessment with the intent of being superseded by more detailed assessments that are being completed by others. Nevertheless, the inundation assessment is considered suitable for informing adaptation options.

Yours sincerely

Connon Andrews
Technical Director – Coastal Science
on behalf of
Beca Limited
Email: Connon.Andrews@beca.com

Greater Wellington
Te Pane Matua Taiao

16 February 2022

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Tēnā Koe Lyndsey,

Kāpiti Coastal Hazard Susceptibility and Vulnerability Assessment

Kāpiti Coast District Council requested technical support from Greater Wellington Regional Council in October 2020 to provide peer review and feedback into the Takutai Kāpiti coastal hazard exposure and vulnerability assessment being undertaken by Jacobs New Zealand Limited.

To date this has involved reviewing the methodology for the assessment contained in the first volume report, a review of the results contained in the second volume and finally, a re-review of both reports following further feedback and edits.

I am the Senior Regional Hazards Analyst and policy advisor for the Wellington Regional Council. I have been employed at the Council since 2006. I hold a PhD specialising in coastal processes and geomorphology and have been involved in coastal research for over 25 years, at university level, within consultancy and currently in local government.

As the natural hazards for analyst Wellington Regional Council I provide scientific analysis, commentary and research into natural and coastal hazards that affect the Greater Wellington region and to write and/or provide expert advice and evidence for hearings, the Environment Court and policy that deals with managing the risks from natural hazards. I provide advice to policy analysts, resource managers, consents officers, engineers and elected councillors in the region, and to business's and the wider public.

Through the review of this work I provided feedback from the inception of the project and into the development of the methodology through to a peer review of the final written documents.

It is based on a reanalysis of existing data and information, of which a significant body of knowledge has accumulated for the Kapiti Coast over the past 30-40 years, and updated with the latest understandings of climate change and sea level rise published by the Intergovernmental Panel on Climate Change (IPCC). It is consistent with New Zealand guidance for coastal hazard assessments and acknowledges the uncertainty in the data and future projections focussing objectively on the numerical statistics without introducing additional subjective levels of uncertainty.

The second volume of this work applied the methodology from the first volume to calculate credible future changes in shoreline position and geomorphic coastal response as it adjusts to an ongoing rise in sea level.

A review and edit of both volumes has been undertaken in response to feedback, resulting in a number of refinements, principally, the inclusion of two additional future sea level rise scenarios. The changes add a further refinement to the report that will support adaptive coastal planning and decision making. Whilst these changes provide clarity and further useful information, they have not materially altered the original methodology or findings and the first reviews of this work remain valid.

I am satisfied that the methodology to undertake the coastal vulnerability assessment and the results from this work are appropriate for the purposes of informing and guiding community based decision making for coastal adaptation in the short, medium and long term planning horizons and to provide direction for District Plan coastal hazard management approaches.

Nāku noa, nā

Dr Iain Dawe
Senior Hazards Analyst
Environmental Policy

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