Timaru Coastal Erosion Assessment

Timaru Coastal Erosion Assessment

IZ133600-NM-RPT-0001 | 0

July 21 2020

Environment Canterbury and Timaru District Council

Document history and status

Revision	Date	Description	Author	Reviewed	Approved
A	04/04/2020	Draft Report	Kate MacDonald	Derek Todd	Ian Wiseman
B	3/7/2020	Final Draft report	Kate MacDonald	Derek Todd	Ian Wiseman
C	21/07/2020	Final Draft Report	Kate MacDonald	Derek Todd	Ian Wiseman
0	21/07/2020	Final Release	Kate MacDonald	Derek Todd	Ian Wiseman

Timaru Coastal Erosion Assessment

Project No:	IZ133600
Document Title:	Timaru Coastal Erosion Assessment
Document No.:	IZ133600-NM-RPT-0001
Revision:	0
Document Status:	Final
Date:	July 21 2020
Client Name:	Environment Canterbury and Timaru District Council
Project Manager:	Andy Boyd
Author:	Kate MacDonald
File Name:	IZ133600-NM-RPT-0001-0 Timaru Coastal Erosion Assessment 2020

Jacobs New Zealand Limited

Level 2, Wynn Williams Building
47 Hereford Street
Christchurch Central
PO Box 1147, Christchurch 8140
New Zealand
T +64 3 940 4900
F +64 3 940 4901
www.jacobs.com

Contents

Executive Summary

In November 2019 Environment Canterbury (ECan) and Timaru District Council (TDC) commissioned Jacobs to undertake a coastal erosion assessment to determine the potential changes in shoreline position over the next 100 years along the Timaru District coastline. This assessment has developed **Projected Future Shoreline Positions (PFSP)** for different sea-level rise (SLR) scenarios over a 50 and 100-year timeframe, for the purpose of guiding decision making for land use planning in the next District Plan for the Timaru District and for the development of future coastal asset planning and management strategies.

Methodology

This assessment looked at projected future shoreline change over a 50 and 100 year period from 2020 with varying magnitudes of sea-level rise (0.2, 0.4 and 0.6 m by 2070; 0.6, 0.8, 1.2, and 1.5 m by 2120) across various morphologies including loess and alluvial cliffs, mixed sand and gravel beaches and barriers, and sand beaches. The assessment has been split into three shoreline 'Compartments' – South of Timaru; Timaru Urban Area; and North of Timaru. Within these compartments, they are further divided into 'Coastal Cells' based on defining features, trends and morphologies, with each cell being defined by a number of assessment transects located every 50 m along the shoreline. Projected Future Shoreline Positions (PFSP) were determined using the following equation:

$$PFSP = (LT \times T) + SL + ST$$

Where T is the timeframe for the assessment (e.g. 50 and 100 years); LT is the rate of long term shoreline movement; ST is the short term storm erosion; and SL is the erosion due to accelerated sea-level rise (SLR) over the selected timeframes.

The assessment used a probabilistic approach, where each component of the PFSP equation is assigned a probability distribution and run through a 'Monte Carlo' stimulation to obtain 10,000 random realizations of the resulting shoreline change for that component, which are then combined to produce a distribution of possible outcomes of total erosion for each timeframe and SLR scenario at each assessment transect. From this distribution the 'most likely' (e.g. 50% probability of occurrence) and 'very unlikely' (5% probability of occurrence) PFSP having been mapped along the entire coastline of the Timaru District. As well as the maps of the PFSP for each SLR scenario and timeframe, the key output from the report are summary tables for each coastal cell of the erosion distances from the present day shoreline to the PFSP for each SLR scenario and timeframe.

Erosion Component Results

The extrapolation of the long-term rate for the PFSP was calculated by measuring the historical shoreline change across a series of aerial imagery captured between 1938 and 2020, with most of the district being covered by at least seven historical images. Historical rates were determined using the Digital Shoreline Analysis Systems (DSAS) tool in ArcGIS to calculate linear regression rates and 95% confidence levels for historical shoreline positions.

South of Timaru average rates of historical retreat ranged from -0.01 to-0.05 m/yr for the beach at the Pareora Meatworks and south to the Pareora River, -0.14 to -0.27 m/yr for the loess cliffs at Normanby and Scarborough, and -0.36 m/yr to -0.56 m/yr for MSG beach ridges in the southern compartment.

In the Timaru Urban Area, the loess cliffs at the Patiti Point headland have undergone rapid recent retreat since 2017 along the more exposed cliff line facing to the south east and east due to very low sediment volumes on the MSG barrier beach in front of the cliff that transitions into South Beach to the north. As a result, mean erosion rates over the last 65 years have averaged -0.24 to -0.32 m/yr along the exposed segments of the headland.

Caroline Bay and South Beach are two areas along the district coastline which has been historically accreting at significant rates, with accretion of +2.65 to 4.5 m/yr at Caroline Bay, and +1 to +2.65 m/yr at South Beach.

The highest historical erosion rates were found at Washdyke Lagoon, where on average, rates of shoreline retreat were found to be -2.3 m/yr over the last 60 years. North of Timaru, erosion rates decrease in a northward direction from Washdyke Lagoon on the Seadown Coast, reducing to -1 to -1.5 m/yr between the Opihi and Orari Rivers , and down to 0.45 m/yr of the lowland and alluvial cliff to the north of the Orari River.

To determine the short-term storm erosion component, 34 ECan coastal profiles that have been surveyed at least annually over the past 30-40 years were analysed to calculate the maximum inter survey erosion distances. Identified periods of upper beach/ cliff edge contour retreat were then checked against the ECan storm database to ensure that changes were most likely driven by storm events. These maximum erosion distances were then put into a Generalised Extreme Value (GEV) Distribution to calculate the likely erosion from a 100-year Annual Recurrence Interval (ARI) erosion episode. Sand beaches, MSG ridges and barriers had variable short term erosion components which range between -3.8 m to -51 m, while the short term erosion component on cliffs was much smaller with a range from -0.5 m to -5 m.

The effect of sea level rise was calculated using a range of methods across the various morphologies along the Timaru District coast. For the sand beach of Caroline Bay, the standard Bruun rule (Bruun, 1962) approach was applied, which indicated that the effect of sea-level rise could reduce on-going accretion by up to 40 m over the next 50 years, and up to 107 m over the next 100 years. For MSG barriers backing onto lagoons and river mouths, retreat through barrier roll-over was calculated using Measures et al (2014) method, where results show on average up to -11 m of erosion over the next 50 years, and up to -32 m of erosion over the next 100 years. For MSG beach ridges backed by stopbanks and natural hinterland, the lack of a backshore barrier elevation resulted in the Measures et al (2014) method not producing appropriate retreat distances, so a modified Bruun rule approach was used applying a closure depth for offshore sediment transfer of the coarse sediment to the toe of the steep nearshore face present on the beach profiles for these types of beaches. This results in a smaller erosion effect due to accelerated SLR than on sand beaches, with the results for the MSG beach ridges in the Timaru District being an average retreat of up to -7 m over the next 50 years, and on average up to -16 m over 100 years. For Cliffs, an adapted Walkden and Dickson (2008) method was used to determine the likely effect on the loess and alluvial cliff morphologies. Results range from limited effects of SLR on protected cliffs at Waimataitai Bay, erosion of up to -14 m over 50 years and -38 m over 100 years at the alluvial cliffs south of the Rangitata River and retreat up to -22 m over 50 years and up to -52 m over 100 years at loess cliffs at Patiti Point.

Projected Future Shoreline Position Results

A summary of the 'most likely' (e.g. P50) PFSP distances from the present day shoreline is presented below in Table 1, which shows the range of averaged erosion distances to the PFSPs under the highest SLR scenario assessed for 50 and 100 year timeframes. The table shows that there is significant variability in the predicted shoreline movement along the Timaru Coast over both of these timeframes. This variability along the shoreline is a result of the different shoreline morphologies, which in turn influence the approach used to determine the effect of SLR, historical erosion rates, and short term response to storms. These results are then discussed for each coastal compartment in turn below:

Table 1: Ranges of calculated average erosion distances for the 'most likely' (P50) PFSP distances at coastal cells along the Timaru District coastline for the highest SLR scenario used in this assessment.

Coastal Compartment	Coastal Cell	Range of Average PFSP Distances 2070 (0.6 m SLR by 2070)	Range of Average PFSP Distances 2120 (1.5 m SLR by 2120)
South of Timaru	**Pareora River to Pig Hunting Creek**	-13 to -32 m	-24 to -66 m
	Normanby to Scarborough	-15 to -63 m	-33 to -100 m
	Saltwater Creek	-54 m	-81 m
Timaru Urban Area	**Patiti Point**	-14 to -35 m	-29 to -77 m
	South Beach	PFSP lines not produced due to high accretion rates	
	Caroline Bay	+92 to +131 m	+189 to +292 m
	Waimataitai Bay and Dashing Rocks	-10 to -30 m	-22 to -65 m
North of Timaru	**Washdyke Lagoon**	-126 to -141 m	-241 to -281 m
	Southern Seadown Coast	-63 to -129 m	-120 to -248 m
	Northern Seadown Coast	-50 to -66 m	-92 to -128 m
	Opihi River and Milford Huts	-109 to -135 m	-195 to -248 m
	Opihi River to Orari River	-63 to -100 m	-119 to -185 m
	Orari River to Rangitata River	-22 to -42 m	-46 to -86 m
	Rangitata Huts	-14 to -27 m	-19 to -45 m

South of Timaru

In the southern compartment of the district coastline, at the Pareora Meatworks PFSP erosion distances are projected to be -8 m to -13 m over the next 50 years, and -14 m to -24 m over the next 100 years, assuming the revetment structure is not maintained in its current position. This assumption is valid for future decision making to give an indication of what will happen to the shoreline if existing coastal protection is not maintained. The probability analysis indicated there is a 5% probability that these erosion distances could be in the order of 20 m greater by 2070, and 40 m greater by 2120.

At the loess cliffs along the southern compartment (between Pareora Meatworks and Jack's Point), the PFSP erosion distances are in the order of -10 m to -31 m over the next 50 years, and -22 m to -66 m over the next 100 years. The greatest erosion on loess cliffs is likely to occur south of Pig Hunting Creek, and the smallest erosion is predicted at Scarborough. Along the mixed sand and gravel ridges in the southern compartment, PFSP erosion distances are likely to be -20 m to -63 m over the next 50 years, and -53 m to -100 m over the next 100 years. The greatest erosion distances occur at the wetlands around the mouth of Pig Hunting Creek, and smallest being to north of the Pareora Meatworks. For both shoreline morphologies, the probability analysis indicates there is a 5% probability erosion distances could be 5-10 m higher than the 'most likely' position by 2070, and 10-20 m higher by 2120. There is greater uncertainty for the MSG ridge at Saltwater Creek, where there is a 5% probability that erosion distances are in the order of 20 m further than the 'most likely' position by 2070, and up to 40 m further by 2120.

Timaru Urban Area

In the Timaru Urban Area, there is significant variability in the PFSP distances across different morphologies. At the loess cliffs at the Patiti Point 'most likely' erosion to the PFSP over the next 50 years is in the order of -22 m to -35 m for the SE facing part of the headland and in the order of -17 m to -28 m for the east-facing segment. Over a 100-year timeframe, these erosion distances increase to -50 m to -80 m for the SE facing cliff segment and -40 m to -60 m for the east-facing segment. For the less exposed NE face of the headland that transitions into South Beach the 'most likely" erosion to the PFSP being -8 to –14 m over the next 50 years, and -18 m to -42 m over 100 years. The probability analysis indicates that due to uncertainties in the data there is a 5% chance that these erosion distances could be around 8 m greater than the 'most likely' PFSP within 50 years, and up to 18 m greater over 100 years.

Along the shorelines adjacent to the Port, there are very high historic accretion rates. PFSP's at South Beach for 50 and 100 years were not produced due to the extrapolation of the high historical accretion rates that would result in the beach toe at the northern end extending beyond the Eastern Spur Groyne in around 20 years, therefore limiting further accretion. The effect of SLR or short-term erosion is not large enough along this section of coast to offset the high accretion rates. A similar situation is projected to occur at Caroline Bay, where as shown in Table 1, the continued advancement of the shoreline is expected to be on average up to +130 m over the next 50 years, and in the order of +290 m over the next 100 years despite the effects of SLR. However, it is noted that the 100-year PFSP is likely to be an overestimate because the wave energy arriving at the shore is likely to increase as the shoreline advances into less sheltered water. The higher wave energy at shore will also make it more difficult to accumulate sediment, therefore slowing down the accretion rate at this section of shoreline.

The shoreline at Waimataitai Bay is protected by armoured rock and has been generally stable since the revetment construction in the 1930s. Assuming the continued maintenance and upkeep of the revetment structure, the PFSP would be expected to be similar to the current shoreline position. Under a "non-maintenance" scenario, the 'most likely' erosion in this area could be up to -10 m within 50 years and up to -20 m within 100 years. The probability analysis indicates that due to uncertainties in the data there is a 5% chance that these erosion distances could be up to 7 m greater within 50 years, and up to 17 m greater over 100 years. North of Waimataitai Bay at the exposed segments of Dashing Rocks, projected 'most likely' future erosion distances in the range of -17 m to -30 m within 50 years, and -40 to -65 m within 100 years depending on the magnitude of SLR.

North of Timaru

The coastal cell likely to be affected by the greatest amount of erosion over the next 50 years is the mixed sand and gravel barriers and ridges at Washdyke Lagoon, which are predicted to retreat -126 to -141 m over the next 50 years and -241 to -281 m over the next 100 years under the highest SLR scenario. The probability analysis indicates that there is a 5% chance that over a 50-year time frame these erosion distances could be up to 40 m greater than the 'most likely' at the south end of the lagoon and up to 15 m greater at the north end. Over a 100-year time frame this uncertainty increases, with a 5% chance that the erosion distances could be up to 75 m greater at the southern end and up to 35 m greater at the northern end. The PFSP distances along the Seadown coast generally decrease in a northward direction to the Opihi River mouth, where erosion distances are projected to reduce to -50 to -66 m over the next 50 years, and -92 to -128 m over the next 100 years under the highest SLR scenarios. The probability analysis indicates that there is a 5% chance that over a 50-year time frame these erosion distances could be in the order of 20-25 m greater, and in the order of 45-55 m greater over a 100-year period.

PFSP erosion distances increase at the Opihi River mouth, where the 'most likely' erosion of the gravel barrier is in the range of -103 to -135 m by 2070, and -183 m to -248 m by 2120, with slightly larger projected retreat along the northern arm of the lagoon due to higher extrapolation of historical erosion rates. However, uncertainty is higher along this coastal cell with the probability analysis indicating there is a 5% chance that erosion distances would be more than an additional 40 m greater over 50 years or more than 75 m greater over 100 years. Between the Opihi River and the Orari River, PFSP erosion distances over the majority of the cell are projected to be up to -100 m over the next 50 years, and around -185 m over the next 100 years, however these distances do decrease at the northern end of the cell by up to 60 m. The probability analysis indicates that there is a 5% chance that erosion distances would an additional 30 m greater over 50 years or more than 60 m greater over 100 years.

From the Orari River to the Rangitata River, the average PFSP erosion distance within a 50-year timeframe is projected to be up to -33 m for MSG ridges and up -42 m for alluvial cliffs under the highest SLR scenarios tested. Over a 100-year period, these erosion distances increase to -65 m for MSG beach ridges and up to -86 m for the alluvial cliffs. There are similar levels of uncertainties across both morphologies, with the difference between the 'most likely' and the 'very unlikely' (P5) PFSP being 8-12 m over 50 years and 16-23 m over 100 years. At the Rangitata Huts, the effects of short-term storms and SLR is most likely going to override any trend of long-term accretion due to sediment supply, resulting in projected erosion distances in the range of -10 m to -14 m over the next 50 years, and between -9 m and -18.5 m over the next 100 years. There is a 5% probability that erosion distances could be 10-15 m higher than the 'most likely' position by 2070, and 25-30 m higher by 2120.

Relative Contribution of PFSP Erosion Components

For MSG barrier and gravel ridge beaches, the extrapolation of the long term historical rate accounts for on average 75-85% of the PFSP line over both 50 and 100 year time-frames. The short term component on average contributes 10-20% of the PFSP line, with SLR only contributing around 5%. This indicates that these beach types are likely to be subjected to significant erosion hazards under any magnitude of sea-level rise if the site has been highly erosional in the past.

For cliffs morphologies, SLR has a greater contribution to the PFSP line given that the method used is an acceleration of the historical erosion rate, with consideration of feedback of eroded material back into the beach, as well as the volume of material in front of the cliff. At loess cliff sites, on average the long term extrapolation component and the SLR component are equal contributors to the PFSP line (45-55%) while the short term erosion component is generally around 2-5%. At alluvial cliffs, over the 50 year timeframe the extrapolation of the historical erosion rate is the greatest component (65%), while the SLR component (20%) and the short-term component (15%) are almost equal contributors. Over the 100 year timeframe, the long term component remains relatively similar (60%) while the SLR component increases to 35% while short term erosion reduces to 5%.

Recommendations

It is recognised that there are limitations in the future erosion projections and PFSPs due to deficiencies with the data availability, assumptions on how this data is used to develop the assumptions and uncertainties with the methods. To reduce these limitations and uncertainties, and to validate the results of this assessment, we recommend that the following investigations be continued or initiated:

- Monitoring of Patiti Point be continued by both profile surveying and collection of LiDAR and aerial imagery to allow the continued surveillance of the temporal component and magnitude of the recent rapid increase in erosion rates at this location and undertake further investigation into understanding the physical processes around the recent acceleration of erosion rates to determine the likelihood and frequency of these occurring again.

- Address the uncertainty around the long term position of accreting beaches at Caroline Bay and South Beach from the two-dimensional nature of the erosion assessment carried out in this assessment, by undertaking 3-Dimensional modelling of longshore transport processes to better define the potential future shoreline positions at these locations which would better account for the changing interaction between wave regime and sediment transport potential with shoreline advance.

- At Washdyke Lagoon, undertake a more detailed volumetric assessment of the barrier to determine the likely change in barrier volume as it continues to roll back into the lagoon and the loss of elevation as the remaining volume is stretched over a greater shoreline length. This assessment would provide a better indication of whether there is enough volume available for the barrier to retreat inland as far as what has been assessed in this report, or whether the barrier is likely to breach and disintegrate earlier before reaching that point due to lack of volume.

- Along the Seadown coast, a more in-depth investigation of the magnitude and temporal/spatial patterns of accelerated erosion rates associated with stopbanks being breached of over-run by coastal erosion should be undertaken as these could greatly influence the time and location of the PFSP's.

- A more detailed assessment should also be carried out on the revetment structures along the shoreline (e.g. Pareroa, Waimataitai, Dashing Rocks) to determine in more detail the erosion consequences of not maintaining these structures, or to better determine to how much maintenance will be required to maintain these structures under various SLR scenarios in the future.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to undertake a coastal and erosion hazard assessment of the Timaru District coastline in accordance with the scope of services set out in the contract between Jacobs and Environment Canterbury ('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 Client and/or available in the public domain at the time or times outlined in this report. 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.

1. Introduction

1.1 Project Background

In November 2019 Environment Canterbury (ECan) and Timaru District Council (TDC) commissioned Jacobs to undertake a coastal erosion assessment to determine the potential changes in shoreline position over the next 100 years along the Timaru District coastline. This assessment has developed **Projected Future Shoreline Positions (PFSP)** for different sea-level rise (SLR) scenarios over a 50 and 100-year timeframe, for the purpose of guiding decision making for land use and asset planning and future coastal management.

The assessment uses a probabilistic approach[1], with 'most likely' (50% probability of occurrence) and 'very unlikely' (5% probability of being exceeded) future shoreline positions having been determined along the entire coastline of the Timaru District. The assessment takes into account the extrapolation of historical shoreline movements, the magnitudes of past short-term storm erosion, the impacts of various magnitudes of SLR on future erosion. Coastal processes and how the varying coastal morphology and geology of the coastline controls the plan shape of the shoreline were also considered.

This report sets out the methodology used in the assessment and findings at key areas of interest along the Timaru District coast. The report is accompanied by a series of maps and digital shapefiles which provide greater detail on the PFSP along the Timaru District coastline within 50 and 100-year timeframes.

While this report has only assessed the erosion hazard, it is written in parallel with the NIWA Timaru District Coastline Coastal Inundation Assessment[2], which models potential inundation areas and depths under the same SLR scenarios over the next 100 years. NIWA's assessment does not take into account the potential future loss of existing stopbanks as determined by this erosion assessment that would affect their inundation protection function.

1.2 Project Scope

The required scope of this project included:

- Using a methodology consistent with the relevant requirements of the New Zealand Coastal Policy Statement (NZCPS) (DoC 2010), the MfE (2017) Coastal Hazard Guidance and any other best practice guidelines;
- Applying a methodology that takes into account the different geologies and morphologies of the Timaru District shoreline and that incorporates an understanding of the coastal processes operating along this coastline;
- Using a probabilistic approach to create a series of projected future shoreline positions along the Timaru District coastline over 50-year and 100-year timeframes with varying levels of sea-level rise;
- Reporting on the outcomes of the erosion assessment (this report) and present these findings in a workshop with Environment Canterbury and Timaru District Council (TDC); and
- Providing ECan and TDC with shapefiles of PFSP to guide decision.

[1] A probabilistic approach involves defining a probability distribution for each variable then running thru a 'Monte Carlo Simulation' to produce a distribution of 10,000 random possible outcomes which probabilities can then be assigned to (e.g. 50% chance the shoreline will be landward of this point).

[2] Bosserelle, C (2020). Timaru District Coastal Hazards Assessment Coastal Inundation. Prepared for Environment Canterbury.

1.3 Coastal Overview

The coastline of the Timaru District is approximately 50 km from the Pareora River in the south to the Rangitata River in the north. Along this length is a wide range of coastal geologies and morphologies including loess cliffs, low mixed sand and gravel ridges and barriers, basalt reefs and cliffs, sand beaches, alluvial cliffs, river mouths, and coastal lagoons. The coastal hinterland also includes the Port of Timaru (PrimePort), the Timaru urban and industrial areas, farmland, road and rail networks, the district landfill, the urban wastewater treatment plant, and a number of shoreline protection works (stopbanks and rock revetments).

The spatial arrangement of the geomorphic cells along the district's coastline is presented in Figure 1.1, with examples of the different morphologies presented in Table 1.1.

The coast of the Timaru District is exposed to a mixed wave climate of southerly and south-east swell and local northerly short period wind waves, with high energy storm events generally being from east to south directions. Wave conditions are generally greater in the southern part of the district, with the 1% AEP[3] significant wave height (maximum likelihood) ranging from 5.07 m at Rangitata River mouth to 5.57 m to the south of the Timaru urban area (Stephens et al. 2015).

The predominance of southerly wave direction and SW-NE shoreline orientation results in a net northerly sediment transport along the shoreline in a dual transport system in which coarse gravel is transported along the beach and finer sands are transported in the nearshore. Sediment arriving across the district's southern boundary is sourced from the Waitaki River approximately 50 km south of Pareora, and from erosion of approximately 16 km of high alluvial cliffs forming the northern section of the Waitaki River coastal fan. Very little gravel and coarse sand input is assumed to be sourced from the small creeks and rivers north of Waitaki, including from the Pareora River (estimates 4,000- 17,000 m^3/yr as reported in Todd, 1989). Following abrasion[4] of the gravel in transport along the beach, the volume of beach gravel and coarse sand arriving at the Timaru urban shoreline at South Beach has been estimated by a number of studies to be in the range of 51,000 – 60,000 m^3/yr (Hicks 2006). The majority of this material has been trapped by the Timaru Harbour Eastern Extension Breakwater to form around 80 hectares of accreted land at South Beach since the harbour development started in 1878.

In contrast, the fine sands transported by wave action in the nearshore can bypass the harbour breakwaters, with some being deposited in the entrance channel. Current practice is that this material in the entrance channel is dredged by the port and deposited approximately 1 km off Washdyke beach. Some of the fine sands that bypass the harbor breakwaters are being deposited in Caroline Bay due to the low wave energy conditions in the lee of the Harbour North Mole. As a result, Caroline Bay has been transformed from a narrow shingle beach pre-harbour construction to a wide flat sand beach with the shoreline having advanced in the order of 640 m and the accumulated sand area covering over 35 hectares, since the 1880s. North of Caroline Bay, a former shingle beach extending from Benvenue Cliffs and around Dashing Rocks was completely eroded away after gravel supply from the south ceased, resulting in the loss of Waimataitai Lagoon from between these two headlands.

North of Dashing Rocks is the southern limit of the wide sweep of the Canterbury Bight, with shoreline orientation again being SW-NE and beach gravels subject to high rates of net northward longshore transport and abrasion. Hicks (1994) estimated sediment losses along the 12 km of the Washdyke – Seadown coast south of the Opihi River at 20,000 m^3/yr to northward transport and 10,000 m^3/yr to abrasion. With limited gravel input from the south, the low gravel ridge along this section of coastline has experienced on-going rapid erosion over the last 150 years; retreat distances in the order of 440 m at Washdyke Lagoon reducing to around 160 m at the Opihi River (Todd 1989, Gabites 2008a). This erosion and beach rollover have dramatically reduced the areas of

[3] A 1% AEP (Annual Exceedance Probaility) Storm has a 1% probability of occurring in a given year. Maximum likelihood is the 50th percentile value within a distribution of values.

[4] Abrasion occurs when gravel and other material is picked up by high wave energy and thrown against the coastline, causing more material to be broken off and carried away by the sea.

Washdyke Lagoon and Milford Lagoon (at the Opihi river mouth), and overpowered coastal stopbanks first constructed in the 1930s to protect the low-lying coastal farmland from sea inundation, resulting in the structures having to be relocated landward at least twice.

At the Opihi River, the mouth is often blocked by the northward drifting beach gravels, however, the river does supply sand and gravel sediment to the coastal sediment budget with average bedload supply volumes estimated to be in the order of 16,800 to 37,200 m^3/yr (Thompson & Adams 1979, Gibb & Adams 1982, Griffiths & Glasby 1985). Further north the Orari River, which was diverted in the 1950s to its current position from its former meandering northern position, also supplies sand and gravel to the coastal budget at estimated rates of 6,200 to 15,100 m^3/yr (Thompson & Adams 1979, Gibb & Adams 1982, Griffiths & Glasby 1985). The Rangitata River is a larger supplier for coastal sand and gravel (bedload estimates 38,800 to 156,000 m^3/yr), however, the majority of this supply is transported north out of the study area. This northern section of the Timaru District coastline has also experienced long-term erosion, with rates over 120 years since 1866 being in the order of 1.7 to 1.2 m/yr between the Opihi and Orari Rivers, reducing to down to 0.5 m/yr at the alluvial cliffs south of the Rangitata River.

1.4 Structure of the Report

This report is structured as follows:

- Section 2 presents a summary of methods used in this assessment to determine the location of the PFSP, covering the data used in the analysis and the methods for assessing long-term historic shoreline change, short-term storm erosion, and the impacts of accelerated sea-level rise. A more detailed discussion of the methodology is provided in Appendix A.
- Discussion of the coastal processes and results of the assessment are divided into the following three coastal compartments:
  - Section 3: Coast South of Timaru, covering coastal cells of:
    - Pareora River to Pig Hunting Creek
    - Normanby - Scarborough
    - Saltwater Creek
  - Section 4: Timaru urban area coast, covering coastal cells of:
    - Patiti Point
    - South Beach
    - Caroline Bay
    - Waimataitai Lagoon and Dashing Rocks
  - Section 5: Coast north of Timaru, covering coastal cells of:
    - Washdyke Lagoon
    - Seadown (Aorangi Rd to Opihi River)
    - Opihi River and Milford Huts
    - Milford coast (Milford Huts to Orari River)
    - Orari River to Rangitata River
    - Rangitata Huts
- Section 6 contains a summary and conclusions.

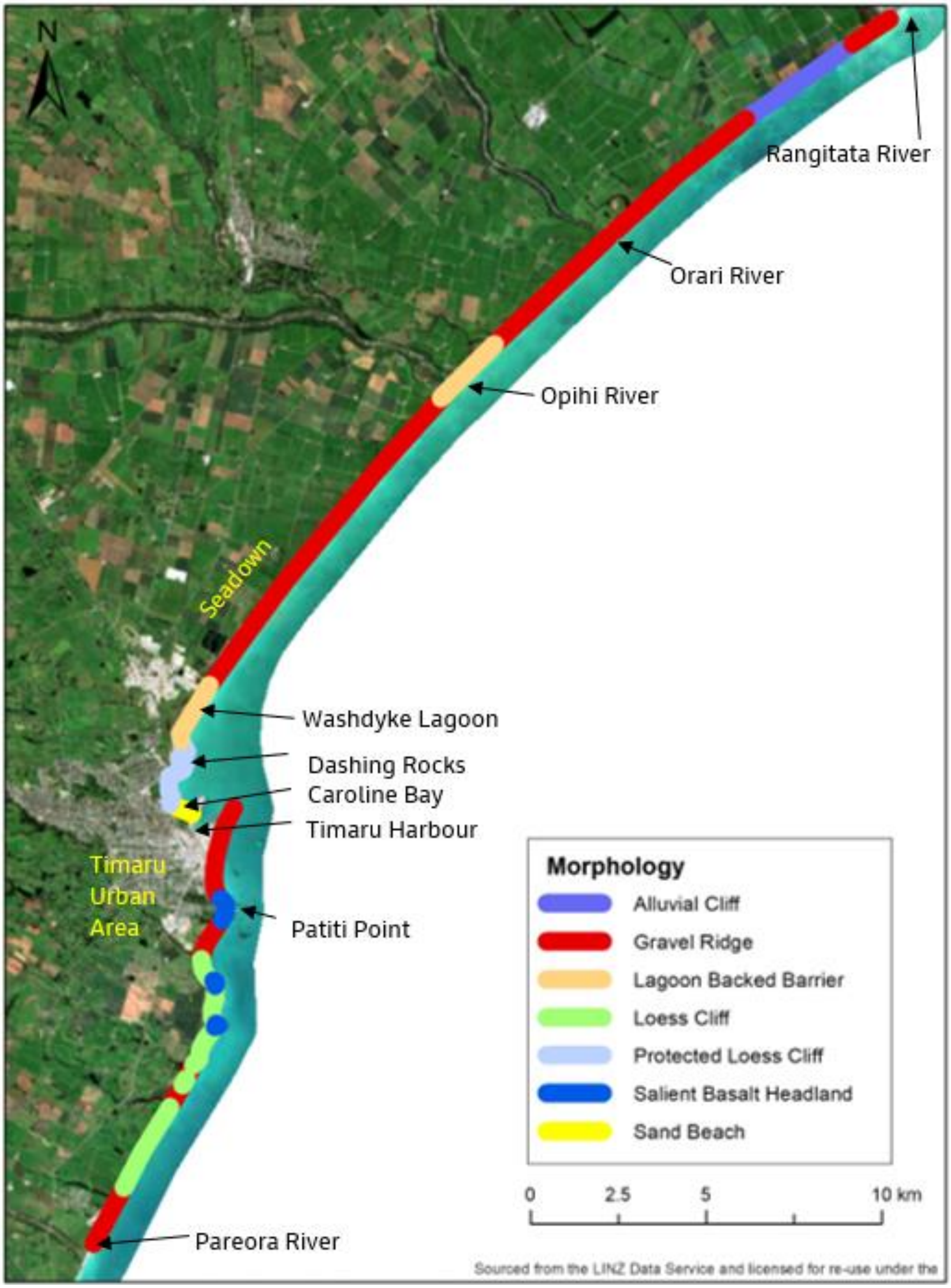
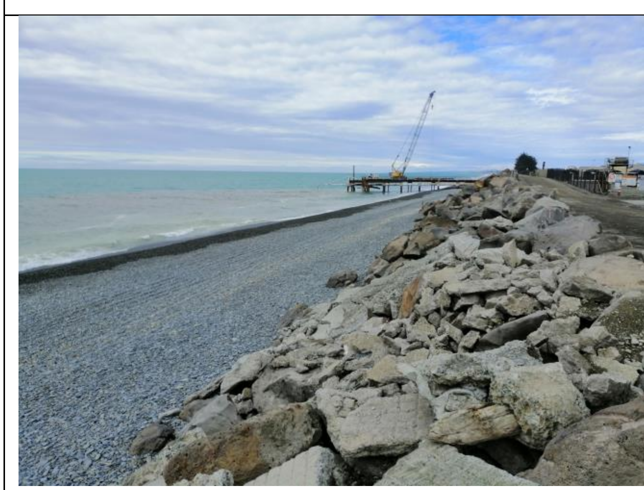


Figure 1.1: Overview of the locations of different coastal morphologies identified on the Timaru District Coastline and used for this assessment.

Table 1.1: Examples of morphological units defined along the Timaru District coastline.

 *(a) Low gravel ridges (mixed sand and gravel)*	 *(b) Lagoon backed gravel barriers (Washdyke Lagoon)*
 *(c) Loess Cliffs*	 *(d) Loess capped basalt cliffs (Patiti Point)*
 *(e) Shoreline protection structures (Pareora Works)*	 *(f) Stopbank backed gravel beaches*

	
(g) Alluvial Cliffs (Rangitata Huts)	*(h) Sand Beach (Caroline Beach)*[5]

[5] Photo sourced from Stuff.co.nz

2. Methodology

This section presents a summary of the methodology used to undertake the coastal erosion assessment for the Timaru District coastline. The assessment presents estimates of the **Potential Future Shoreline Positions (PFSP)** for the next 50 and 100 years, which are expressed as distances from the current shoreline position. These erosion distances are often referred to as Coastal Erosion Hazard Zone. However, this terminology is not used in this report as it is considered that it is a function of the Timaru District Council to determine a zone width (and associated rules) should they wish, that are based on the projected shoreline positions.

2.1 Data Collection and Review

2.1.1 Site Visit

A site visit along the Timaru coastline was undertaken by Jacobs, NIWA, and ECan staff on the 22nd of October 2019. The purpose of the site visit was to define morphological cells to apply the correct methodology to calculate the coastal response to sea-level rise. The main morphological cells identified are presented in Figure 1.1.

2.1.2 Literature Review

Literature was supplied by ECan to help determine the historical context of the Timaru District shoreline. A review of this literature was undertaken in the early stages of the project and was then later used to validate results (e.g. historical shoreline analysis). The key pieces of literature used to help define the morphologies of the shoreline and the historical context of structure positions (e.g. stopbanks) are listed below:

- D. Todd (1988). Annotated Coastal Bibliography of South Canterbury. South Canterbury Catchment & Regional Water Board.
- D. Todd (1989). Washdyke-Opihi Coastal Erosion Study. South Canterbury Catchment & Regional Water Board.
- B. Gabites (2008a). A summary of Environment Canterbury's coastal environment monitoring programme for the Washdyke coastline, 1994-2007. Environment Canterbury Report No. R08/98.
- B. Gabites (2008b). A summary of Environment Canterbury's coastal monitoring programme for the Timaru coastline, 1994-2007. Environment Canterbury Report No. R08/97.

2.1.3 Environment Canterbury Databases

A variety of data was obtained from ECan to inform calculations and to validate data. Relevant information from databases collated and used in this assessment includes:

- Beach profile surveying database (Annual to Bi-annual surveys since 1980) and Distance Excursion Analysis of the profile data;
- Coastal Storm Database (storm records since 2001);
- Port of Timaru water level data (1991-2019);
- Stopbank locations and elevations along the Washdyke - Seadown Coast

2.1.4 Aerial Imagery

The historical shoreline analysis was undertaken using aerial imagery photographed between 1938 and 2017 collated from Retrolens (http://retrolens.nz/) and LINZ Online data service for the entirety of the district's coastline. For Patiti Point, additional imagery from January 2020 supplied by Timaru District Council was also used. The dates of aerial imagery used and the spatial coverage along the Timaru coastline for that period is detailed below in Table 2.1.

Table 2.1: Aerial Imagery used in DSAS analysis and the corresponding area of coastline covered.

Aerial Imagery Date	Area of coastline covered	Source
22.05.1938	Timaru Township and South Timaru	Retrolens
19.09.1953	Pareora	Retrolens
09.09.1954	South Rangitata	Retrolens
08.10.1955	North Timaru (Opihi to Orari)	Retrolens
02.05.1956	North Timaru, Timaru township, South Timaru	Retrolens
18.08.1967	Pareora to Orari	Retrolens
14.02.1969	Orari to Rangitata	Retrolens
09.02.1977	Entire District	Retrolens
07.02.1985	South Timaru	Retrolens
22.07.1987	Pareora, Timaru Township north to Rangitata	Retrolens
19.01.1999	Entire District	Retrolens
11.02.2004	Entire District	LINZ Data Service
09.03.2017	Entire District	LINZ Data Service
18.01 2020	Patiti Point, Timaru	Timaru District Council

Aerial imagery sourced from Retrolens was georeferenced in ArcGIS. There is a level of error involved in georeferencing earlier imagery (1930s-1980s) due to the poor quality of the imagery and the lack of development across rural areas in Timaru, meaning that features which the images could be georeferenced to were limited.

2.2 Calculation of the Projected Future Shoreline Positions

This erosion hazard assessment applied an integrated approach using commonly accepted coastal erosion hazard formula to estimate the PFSP based on extrapolation of past shoreline movements, geometrical models, and empirical relationships to calculate the impact of sea-level rise (SLR). Specific expert knowledge and experience of the project team and Environment Canterbury coastal scientists also played an important part in understanding local coastal processes and geomorphological responses. As a result, along some sections of the coast, the shoreline projections obtained from the hazard formula have been modified due to shoreline plan–shape and process considerations, particularly the transition between two different geomorphologic cells and shoreline orientations.

The following coastal erosion hazard formula has been used to calculate the erosion distances from the current shoreline position to the PFSP. This formula meets the requirements of NZCPS Policy 24[6]:

PFSP = (LT X T) + SL + ST

[6] NZCPS Policy 24 covers the needfor the Identification of Coastal Hazards in coastal environments potentially affected by coastal hazards over at least 100 years with regard to physical drivers and processes including SLR, short term and long term dynamic fluctuations.

Where:
T = Time frame (i.e. 50 and 100 years for this assessment)
LT = Rate of long-term shoreline movement
ST = Short term storm erosion
SL = Erosion due to accelerated SLR over the selected timeframes

Section 2.2.1 sets out the assumptions of the approach and Sections 2.2.2 to 2.2.4 describe the methods used to calculate each of the PFSP components.

2.2.1 Coastal Process Assumptions

The following assumptions around future coastal processes have been made in undertaking this coastal erosion assessment:

- Assumptions of no change in future wave climate (e.g. energy, direction, storminess) based on scientific projections to date for the projected period of 100 years.
- Assumptions of no change in river sediment supply and longshore transport rates based on scientific projections to date for the projected period of 100 years.
- The geology, morphology, and topography of the land behind the beach that is subject to future erosion is the same as the current conditions identified in 2020, with no modifications by human actions.
- For rock revetment coastal protection structures (e.g. Pareora Freezing works, Waimataitai), extrapolation is of the low rates of shoreline movement due to the presence of these structures, therefore the assumption is that this level of protection will continue.
- Where there are coastal stopbanks (e.g. Seadown) extrapolation includes a combination of the past variable rates from slow/stable when the beach is constrained by the stopbank to rapid once the stopbanks are breached. However, the assumption for the future is that once the current stopbanks are breached they will not be maintained or replaced.

2.2.2 Long-term Historical Shoreline Movements (LT)

The inclusion of the long-term historical shoreline movement in the PFSP formula is to ensure that appropriate previous trends driven by the relationship between wave climate, sediment supply, and sediment transport in each geomorphic cell are accounted for in future projections. As above, this assumes that in the future the same coastal processes will continue, including wave and wind climate and sediment budget.

For this assessment, historical shoreline positions are limited to those determined from aerial imagery between 1938 and 2020 as detailed in Table 2.1. These images were geo-referenced using common features and shorelines digitised in ArcGIS, with shorelines being defined by either the vegetation line, the back of the gravel beach (when backed by a lagoon e.g. Washdyke), or the clifftop edge. The GIS-based DSAS (Digital Shoreline Analysis Systems) tool was then used to calculate the net shoreline movements and long-term historical rates at transects located at 50 m intervals. The DSAS results were validated by calculating the change from the shoreline movements measured by ECan beach profile surveys over the same period as the recent aerial imagery used in the DSAS analysis.

The long-term regression rate (LRR) from the DSAS was used as the historical trend component of the PFSP equation when the R^2 value for the transect was high, indicating a strong linear trend. Where the R^2 value was low, further analysis was undertaken to determine if using the entire period of analysis was appropriate. In some instances, earlier shorelines were removed from the analysis as the rate of movement in these early periods was not representative of current day processes.

Based on the assumptions outlined in Section 2.2.1, there is a linear extrapolation of the appropriate historical long-term rate of shoreline movement. Any historical trends in erosion rates (e.g. acceleration or de-acceleration) have already been considered in determining the appropriate historical rate for the extrapolation. It is also noted that the extrapolation of historical shoreline change includes the effects of the current rate of SLR (e.g. 2 mm/yr). This is factored into the calculation of the erosion effect of future SLR as presented in section 2.2.4.

A more comprehensive description of these methods is presented in Appendix A (Section A.1.1); the historical shorelines, location of the DSAS transects and the spatial distribution of rates of shoreline movement from the analysis are presented Appendix C, and the validation of the results against shoreline movements measured by the beach profile surveys are presented in Appendix D.

Limitations

The following limitations have been identified with the methods used to calculate the long-term historical shoreline change.

- The long-term rate is dependent on the accuracy of the georeferencing of the imagery. This was difficult for earlier imagery (1930s-1980s) due to the image quality and the lack of development of land in rural areas limiting common features and structures.
- The poor image quality on earlier imagery also increased the uncertainty in the digitizing of the shoreline due to difficulty in identifying the features used to determine shoreline position. For sections of coastline where the shoreline could not be determined, a shoreline was not digitised from that image, resulting in gaps in the analysis for several transects for that period.
- At river mouths, the dynamic nature of the shoreline feature used (i.e. back of beach/barrier) means that the resulting long-term rate may not reflect the trend of the general coastline in that area. For river mouth environments, shorelines were still digitised across the back of the barrier, and it was determined in the mapping phase of the assessment if the resulting PFSP lines required adjustment to fit shoreline plan-shape considerations.
- As indicated in Section 2.2.1, the assumption that the historical rate is applicable for the future and separate from the effects of SLR. The extrapolation of the long-term rate has limitations around considerations of long-term changes in the nearshore environment, and in turn, how this will affect the future beach response.

2.2.3 Short-term Storm Erosion (ST)

The inclusion of short-term storm erosion in the PFSP equation is to account for an extreme erosion event occurring at or near the end of the planning timeframe under consideration, such that it would not be accounted for in the extrapolation of the average long-term rates. This is particularly important for dynamic beach systems which experience periods of both erosion and accretion, and for accounting for the more episodic retreat of coastal cliffs due to feedback mechanisms in cliff failure. To determine the short-term storm erosion component, 34 ECan coastal profiles along the Timaru District were analysed to calculate the distribution of inter survey erosion distances over the 30-40 year of survey record. This analysis was undertaken on retreat at a specified upper beach contour for gravel beaches or cliff edge where the retreat was a response to storm events. Identified periods of upper beach contour retreat were checked against the ECan storm database, which recorded storms qualitatively up until 1999, and recorded storms using quantitative data from the ECan wave buoy from 1999 to present day.

For each profile, the inter-survey erosion distances were ranked and a Generalised Extreme Value (GEV) Distribution used to calculate the 100-year ARI (e.g. 1% AEP) erosion event magnitude for that site.

A more detailed description of the methods used to calculate the short-term erosion are presented in Appendix A (Section A.1.2) and the resulting minimum, mean and maximum values of the short-term erosion component for each profile site are presented in Appendix B.

A limitation of this method is that the inter-survey change may not always be the total storm retreat, due to the time delay between the storm event and when the profile was surveyed. In general, this would under-estimate the magnitude of potential retreat for beach sites and the beach could undergo some recovery within the period between the storm event and the profile being surveyed. However, the use of an upper beach contour reduces this under-estimation as much as possible as it is less dynamic and less likely to recover over a short period compared to the 1-2 m contours on the lower foreshore. For cliff sites, the use of the cliff edge feature prevents this potential under-estimation for these sites. It is also noted that for many survey periods, the erosion was from multiple storms-in-series, which would most likely result in greater erosion than individual events.

2.2.4 Impact of sea-level rise (SLR)

2.2.4.1 SLR Scenarios

In this assessment planning timeframes of 50 and 100 years are being applied for the calculation of the erosion distances to the PFSP. Within these timeframes, incremental SLR scenarios since 2020 of 0.2m, 0.4m and 0.6m by 2070 and 0.6m, 0.8, 1.2m and 1.5m by 2120 have been modelled. Table 2.1 shows how these increments compare to the RCP[7] SLR scenarios for New Zealand presented in MfE (2017). As can be seen from the Table, the increments used in the assessment cover the range of SLR magnitudes from the MfE scenarios. Further details on these scenarios are presented in Appendix A (A.1.3.1)

Table 2.2: SLR projections used in this assessment, compared to projections from MfE (2017) for the wider New Zealand region.

Year	SLR from 2020 applied in Timaru District Erosion Assessment (m)	MfE (2017) SLR scenarios for NZ from 1986-2005 base(1)			
		NZ RCP2.6*M* (Median)	NZ RCP4.5*M* (Median)	NZ RCP8.5*M* (Median)	NZ RCP8.5 *H+* (83rd Percentile of RCP8.5)
2070	0.2 m, 0.4 m, 0.6 m	0.32 m	0.36 m	0.45 m	0.61 m
2120	0.6 m, 0.8 m, 1.2 m, 1.5 m	0.55 m	0.67 m	1.06 m	1.36 m

(1) For comparison between the SLR scenarios used in this assessment and those in MfE (2017), need to offset the MfE (2017) projections by -0.05 m to account for SLR that has occurred since 1995 (e.g. mid date of above baseline) to current (e.g. 2020) at an average rate of 2 mm/yr (e.g. NZ average rate of SLR rise over at least the last 50 years).

Since the extrapolation of historical shoreline change already includes the effects of the current rate of SLR, for the calculation of the effect of future accelerated rise, the projected SLR scenarios to be assessed also need to be offset by the current rate of rise (e.g. 2 mm/yr). This has been accommodated within the calculated erosion impacts due to SLR presented in this assessment.

2.2.4.2 Geometric beach retreat models

The impact of future SLR on coastal erosion was assessed at each ECan profile along the Timaru coast. Four geometric models were used to calculate the erosion impact for the different types of shoreline morphology present along the district's coastline as identified from the site visit and using ECan beach profile surveys. Summaries of the four different methods used for the different morphology types are presented below, however,

[7] RCP: Representative Concentration Pathways, based on global population and carbon emissions. From IPCC (2014).

more detailed descriptions of these equations and justifications for use are presented in Appendix A (Section 1.3.2).

1. Sand Beach

Caroline Bay, north of Timaru Harbour, is the only sand beach site along the Timaru District coastline. A standardized 'Bruun Rule' (Bruun 1962) approach was used to determine sand beach retreat with incremental increases in sea level over the 50 and 100-year timeframes.

Under the Bruun Rule, shoreline retreat is expressed as follows:

$$Retreat = \frac{L \times s}{(h+d)}$$

Where:

L = The horizontal distance to the closure depth from the beach crest;
s = projected SLR over the planning timeframe;
h = The height of the dune above Mean Sea Level (MSL); and
d = The average closure depth below MSL

ECan beach profile data was used to determine the onshore input parameters to the Bruun rule equation (beach height, beach width). Closure depths and distances were obtained from data presented in a recent interim ECan assessment on Caroline Bay accretion rates[8]

Limitations of the Bruun Rule are well documented, including the following relevant for Caroline Bay:

- Assumes only two dimensional cross-shore sediment movements hence does not include consideration of longshore sediment transport inputs/losses or plan shape controls (e.g. headlands),
- Is only applicable to equilibrium beach profiles,
- Difficulty in determining a closure depth for offshore sediment transport

2. Mixed Sand and Gravel (MSG) Beaches

Mixed sand and gravel (MSG) beaches dominate the majority of the open coast shoreline both north and south of Timaru. It is generally accepted in the literature that the erosion response of these types of beaches to SLR will be of a lesser magnitude than for sand beaches in terms of total retreat distance. For these beaches, due to gravel-sized material, the transport processes indicate that the closure depth[9] is limited to the vicinity of the toe of the steep nearshore face rather than out on the flat sandy nearshore further offshore that is calculated by the Halliermeiers (1981) closure limits from wave climate. By using a shallower closure depth in combination with a steeper slope, the predicted erosion distances from SLR are much smaller than produced when using the standard Bruun Rule on flatter sloped sand beaches.

For this assessment, as can be seen in Table 1.1, the MSG beaches are separated into two sub-types: 1) being the beaches where the backshore is contained by stopbanks and hinterland such as along the Seadown coast and between the Opihi and Orari Rivers, and 2) barriers in front of coastal lagoons (e.g. Washdyke Lagoon) and river mouths (e.g. Opihi River).

[8] Undated ECan Interim report titled "Caroline Bay Accretion Study" by Cope to the PrimePort Board.
[9] 'Closure depth' is the theoretical depth at which sediment movements between the beach and nearshore due to wave action ceases.

For the contained beaches, much of the time the presence and elevation of the stopbanks/hinterland restricts the rollover of beach sediment, resulting in the response to SLR being foreshore volume losses and retreat of the foreshore profile and nearshore step (Figure A.4). For quantifying this response, the Bruun Rule was modified to use the toe of the nearshore step as the closure depth. A similar modification has been used in the assessment of SLR effects on contained MSG beaches in the Hurunui District (Jacobs, 2020) following sensitivity testing of the barrier rollover model from Measures et al (2014) and Orford et al (1995).

The resulting modified retreat formula is:

$$\boldsymbol{Bruun_{MSG}} = \frac{\boldsymbol{L} \times \boldsymbol{s}}{(\boldsymbol{h} + \boldsymbol{dt})}$$

Where:

L, S, and h are as for the standard Bruun equation; and
dt = Closure depth below MSL defined as the toe of the steep nearshore step

Beach height and slopes for input into the formula were obtained from the five most recent beach surveys at each ECan profile site and applied to the local beaches within that morphological unit. However, due to the difficulty of surveying in the high energy surf zone on MSG beaches, data on the location and depths of the toe of the gravel nearshore step is very limited. Therefore, survey data of the toe position captured along the Washdyke-Seadown coastline in 1987 was used as estimates for the approximate elevation and slope of this step along all of the district's coastline. From these surveys, the average toe elevation of the step was in the order of 4.75m below MSL, with a slope of 1:10.

In addition to the two-dimensional limitations of the Bruun Rule approach, further limitations of this modification for MSG beaches include:

1. Does not account for where gravel sized material is eroded to once eroded from the foreshore. While the sand material can be transported to the flat nearshore seabed to raise the profile (although not as much as for sand beaches under the Bruun Rule, the coarser gravel material not transported alongshore is assumed to accumulate at the nearshore steep.
2. Does not allow any consideration of beach rollover in the times that stopbanks are breached, or located well behind the beach, therefore may under predict the impacts of SLR on retreat under the assumption in section 2.2.1 that current coastal stopbanks will not be maintained or replaced in the future.
3. Uncertainty in the toe elevation and slope of the nearshore step. Low uncertainty of the overall effect of SLR on MSG beaches is strongly influenced by input data limitation on the nearshore profile.

3. Mixed sand and gravel barriers subject to roll-over

As outlined above, MSG barriers are in front of coastal lagoons (e.g. Washdyke Lagoon) and river mouths (e.g. Opihi River) where the beach is un-contained such that overtopping by storm waves results in sediment on the crest ridge of the barrier being 'rolled-over' landward into the backshore resulting in the retreat of the barrier crest. This process occurs during storms when the wave run-up is larger than crest elevation, low barriers tend to be more subjected to this rollover process. The frequency of the barrier being overtopped will increase with SLR (assuming a stable or sediment starved barrier) and therefore the effect of SLR on these environments can be modeled based on the rollover of the barrier with sea-level rise.

The roll-over model used in this assessment was developed by Measures et al (2014) for the MSG barriers on the barrier beach of Kaitorete Spit where roll-over from wave overtopping is the dominant erosion process and where large back slope elevations extend into Te Waihora/ Lake Ellesmere behind the barrier. The model assumes that crest building from waves just overtopping the barrier crest will keep pace with SLR and that the volume required to lift the barrier crest to match SLR is supplied from a slice of equal volume from the beach face, hence causing the beach face to retreat. Mixed sand and gravel barriers are found in several places along the Timaru coast near river-mouth environments. Barriers are masses of gravel which act as the interface between the sea and the backshore water-body environment, such as a lagoon. With overtopping of storm waves, these barriers will 'roll-over' landward onto the backshore. The landward shift occurs when gravel from the face of the barrier is transported up and over the face and deposited on the backshore.

The equation from Measures et al (2014) used for this assessment is:

$$\boldsymbol{R_{Measures} = \Delta S\left(\frac{\Delta S}{2} + H_{bs}\right) \times \frac{\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right)}{H_{fs}}}$$

Where

$R_{Measures}$ is the retreat distance ($\Delta \boldsymbol{y}$)

ΔS is the expected SLR over the planning timeframe,

H_{bs} is the height of the backshore,

α is the corresponding backshore slope,

H_{fs} is the height of the foreshore using the toe of the nearshore step as the base,

and β is the corresponding foreshore slope

As with the contained MSG beaches, data on the location and depths of the toe of the gravel nearshore step is very limited. Therefore, survey data of the toe position captured along the Washdyke-Seadown coastline in 1987 was used as estimates for the approximate elevation and slope of this step for all MSG barriers within the Timaru District. From these surveys, the average toe elevation of the step was in the order of 4.75m below MSL, with a slope of 1:10.

4. Cliff Erosion

There are several locations along the Timaru District coastline which have a cliff shoreline fronted by an MSG beach. The cliff morphologies vary from loess cliffs to loess capped basaltic cliffs and alluvial cliffs.

The literature on the effect of SLR on cliff retreat is developed from sensitivity testing of the SCAPE model (Walkden and Dickson, 2008; Ashton et al, 2011) based on a power relationship (*m* value) between the increase in cliff retreat rates and the ratio of the rate of future SLR to the current rate of rise. However, the relationship is limited to use on cliffs with fronting beaches having volumes less than 30m^3/m and there is uncertainty in the *m* value of the power relationship for the alluvial cliffs as found along the Timaru coast.

To address these limitations and to provide a consistent approach across the whole Canterbury region for the assessment of the effects of SLR on cliff retreat rates, sensitivity testing was carried out for all cliffed sections of the Canterbury coast covering multiple cliff morphologies using data from 37 ECan profile sites across alluvial (27 sites), loess (6 sites) and mudstone (4 sites) cliff types throughout Canterbury. The data used was retreat rates and mean beach volumes over the 30-40 years of profile surveys. Details of this sensitivity analysis are presented in Appendix A (Section 1.3.2.4).

The sensitivity analysis indicated that the best results were obtained by the addition of the Vol_{effect} factor to the Walkden & Dickson (2008) future cliff retreat equation, with the relationship for the effect of an accelerated rate of SLR on cliff retreat in Canterbury being:

$$\boldsymbol{LT_{F(SLR)} = LT_H \times Vol_{effect} \times \left(\frac{S_F}{S_H}\right)^m - LT_H}$$

Where:

$LT_{F(SLR)}$ = Future cliff retreat rate due to sea-level rise

LT_H = Long term historical cliff retreat rate

Vol_{effect} = 1 for mudstone cliffs, 0.95 for loess cliffs, and 0.65 for alluvial cliffs.

S_F = Future rate of SLR

S_H = Historical rate of SLR rate (taken as 0.002 m/yr)

$m = 0.5$

2.3 Probabilistic Approach

A probabilistic approach manages the uncertainty surrounding the data used and the results obtained from the methods used to define each of the components of the PFSP calculation. Under this probabilistic approach, a 'most likely' scenario and a 'very unlikely' scenario have been developed to help guide future coastal management such as land use or asset planning.

The probability calculations involved using the mathematical software MATLAB R2019b to run a 'Monte Carlo' simulation where for each transect and SLR scenario, 10,000 realizations of the PFSP lines were made by combining random values from each of the long-term (LT), short-term (ST) and SLR erosion distributions. The resulting distribution of the PFSP realizations shows the range of where the projected shoreline will be in relation to the present-day shoreline, and what the probability is that the erosion could extend beyond a given distance. Figure 2.1 below shows the PFSP distribution output for a single transect, where the bars represent the number of realizations from the 10,000 trials.

In this assessment, we present the 50th percentile and the 95th percentile of 10,000 random observations of the PFSP erosion distance for each timeframe and SLR scenario. The 50th percentile represents a 'most likely' magnitude of erosion, in which there is a 50% chance that erosion will extend beyond this position and 50% that it will be less than this position, and is the mid position of a 'about as likely as not' range of positions following the terminology of MfE (2017, Appendix F)(e.g. 33-66% probability of occurrence range). It is denoted in the mapping as the P50 position for each timeframe and SLR scenario. The 95th percentile statistically represents the erosion distance that has only a 5% probability of being exceeded therefore is referred to as being a 'very unlikely' magnitude of erosion and is denoted in the mapping as the P5 position for each timeframe and SLR scenario. Our reason for using the P5 notation in the mapping is that in describing the results, it is easier in the context of extreme conditions to explain that there is a 5% chance of the position being exceeded than a 95% chance that it will not be exceeded.

To run the 'Monte Carlo' simulations, a triangular distribution was assumed for each component of the PFSP (LT, ST, SLR) at each transect using minimum, mean, and maximum values obtained or assumed from the data. This was considered the best distribution to apply given the limited nature of data available to define the uncertainty in the value of these components. Sensitivity testing between a normal and a triangular distribution of the LT erosion rates showed that there was minimal difference between the two distributions. However, for cliff sections, the triangular distribution was negatively skewed so that the minimum erosion was set to zero (e.g. stable cliff line). Further details on how the min, mean and max values were determined for each component distribution are provided in Appendix A (section A.2.1).

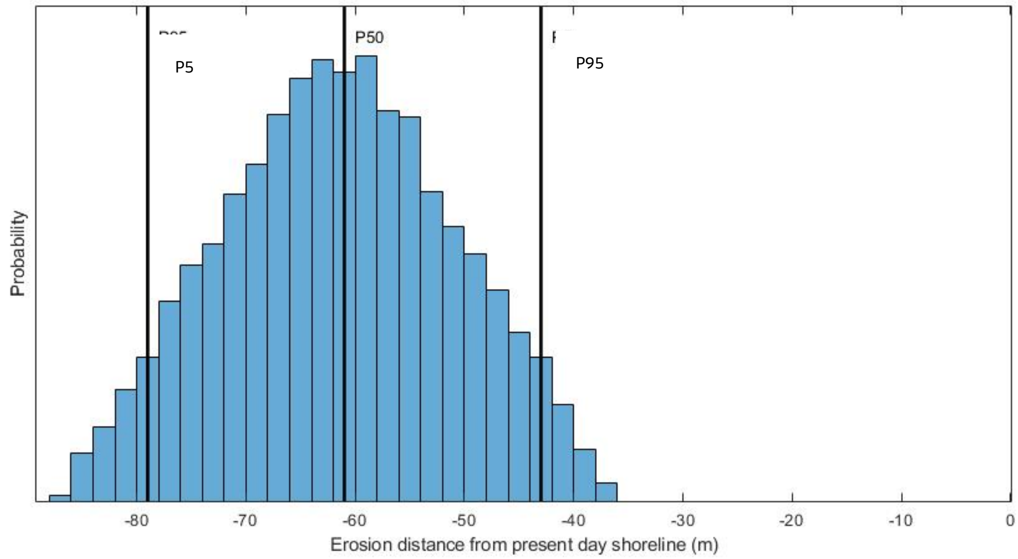


Figure 2.1: Example of Transect 789 (North of the Orari River) the probability of PFSP distances from the present-day shoreline. The bars represent the 10,000 realizations of the projected future shoreline position made from drawing random ST, LT, and SLR from their respective distributions.

2.4 Mapping Projected Future Shoreline Positions

Mapping of the PFSP at each DSAS transect was undertaken in ArcGIS, using the Offset Line tool to create lines offset from the 2019 shoreline based on the P50 and P95 values from the 'Monte Carlo' simulation for each SLR scenario. Once the lines were plotted in ArcGIS, these were smoothed by removing points along the line which created segments of discontinuity along the future shoreline that were not supported by geomorphic plan shape considerations[10] based on knowledge of the coastal processes. This primarily occurred across transitions between morphologies, particularly at the transition between the cliff and gravel barrier morphologies at Dashing Rocks to Washdyke lagoon.

For two additional segments of shoreline, South Beach Timaru and the current Orari River mouth to the former mouth, the projected future shoreline positions based on the PFSP formula are not considered to be likely due to anthropogenic changes which are not accounted for in the mathematical equation. Further details on the considerations in these areas are presented in Appendix A (Section A.3.1).

Overview maps of the Timaru coastline with PFSP lines for 2070 and 2120 are presented in Appendix E. Shapefiles of these lines were also presented with this report to ECan and Timaru District Council. For each mapped PFSP we have provided some high level commentary on notable assets or features which may be affected within a 50 and 100 year timeframe. A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

[10] Geomorphic plan shape considerations: the removal of steps in the shoreline plan shape that do not occur in nature,

3. Results: South of Timaru

The following sections present the findings of this assessment and the calculated PFSP for the coastline south of the Timaru urban area. The findings are presented in cells from south to north based on different geomorphic and contextual settings. Overview maps of both 2070 and 2120 SLR scenarios are presented in Appendix E (Maps 1 & 2, 1A (Pareora Meat Works) and 2A (Saltwater Creek)). Shapefiles of these lines were also provided to ECan and Timaru District Council for use in ArcGIS to provide further detail.

3.1 Pareora River to Pig Hunting Creek

The shoreline cell between the Pareora River and Pig Hunting Creek (transects 1-102) which is approximately 5 km in length can be seen in Figure 3.1. This shoreline cell comprises of MSG beaches, with the southern section (transects 1-18, 32-46) being contained by a low elevation loess hinterland, rising into loess cliffs with elevations in the range of 7-10 m (LVD1937) in the northern section (transects 47-102). The Pareora Meatworks, located near the southern end of the cell (Transects 19-31), is protected by a large rock revetment structure over a 600 m frontage. The revetment, which also extends 400 m south of the Meatworks frontage, was originally constructed as a flood protection stopbank in the 1950s, however, by the late 1960s there had been significant erosion as a result of several large storms and the stopbank was changed into a large revetment in the 1970s. The whole of the shoreline within the cell is orientated NNW to SSE.

There are two ECan profiles that represent the morphologies along this shoreline cell; SCS2718 located at the Pareora works revetment (transects 19-31), but also used to represent short-term storm erosion and input parameters for the MSG beaches in the southern section (transects 1-18, 32-46) and SCS2360 (transects 47-102) covering 2.75 km of shoreline which represents the loess cliffs.

3.1.1 Erosion Components

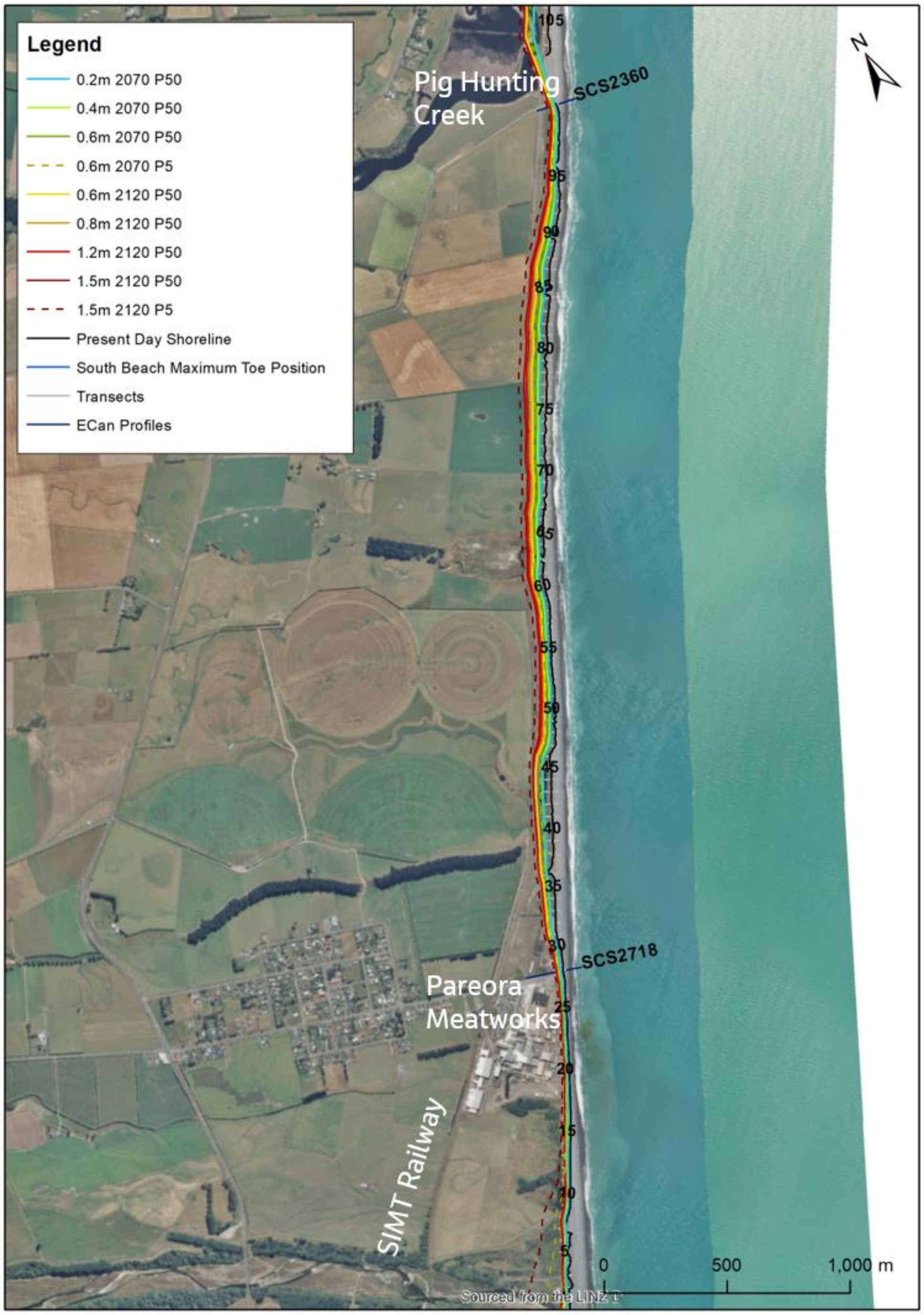
Extrapolation of Long-Term Rates

The extrapolation of long-term erosion rates from 1953 to 2017 and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 3.1. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 3.1, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

The long-term historical erosion rates at transects 1 to 31 (Pareora River & works) are very low, resulting in the extrapolated average retreat of only -2 to -3 m over the next 50 years (e.g. by 2070) and only -4 to -6 m over the next 100 years (e.g. by 2120). Extrapolation of the maximum rate at an individual transect over this 1.5 km length would result in -10 m retreat in 50 years and -20 m in 100 years. It is important to note that although the PFSP were calculated based on the assumption that the revetment is not present/maintained, the past/current presence of the wall does influence the long-term historical rate used in the PFSP calculations, therefore reducing the future projections.

For the MSG beaches north of the Meatworks (transects 32-46), the average historical erosion rate increases to -0.44 m/yr with a maximum of -0.56 m/yr (transect 46), which when extrapolated forward would result in an average retreat of -22 m and maximum retreat of -28 m in 50 years (2070) and double these distances over 100 years (2120).



Note:
P50 is 50% chance the shoreline will be landward of this position
P5 is a 5% chance the shoreline will be landward of this position

Figure 3.1: Pareora River to Pig Hunting Creek to PFSP for various SLR scenarios in 2070 and 2120. 'Most likely' position(P50) is shown for each scenario, and 'very unlikely' (P5) shown for SLR scenarios of 0.6m by 2070 and 1.5m by 2120 (highest SLR scenarios).

Table 3.1 Extrapolation of long-term erosion rates (1953-2017) and resulting projected erosion distances between the Pareora River and Pig Hunting Creek.

Profile	DSAS Transects	Statistic	Erosion Rate (1953-2017)	2070 Erosion Distance	2120 Erosion Distance
SCS2718 (MSG beach)	1-18 (900 m south of Pareora works revetment)	Mean	-0.04 m/yr	-1.9 m	-3.8 m
		Max at individual transect	-0.15 m/yr	-7.3 m	-14.7 m
		Avg Upper 95% Confidence level	-1.00 m/yr	-50 m	-100 m
	19-31 (600 m Pareora works revetment)	Mean	-0.05 m/yr	-2.8 m	-5.5 m
		Max at individual transect	-0.20 m/yr	-9.9 m	-19.7 m
		Avg Upper 95% Confidence level	-0.64 m/yr	-8.9 m	-17.7 m
	32-46 (700 m north of Pareora works revetment)	Mean	-0.44 m/yr	-21.8 m	-43.7 m
		Max at individual transect	-0.56 m/yr	-27.8 m	-55.7 m
		Avg Upper 95% Confidence level	-0.64 m/yr	-32.1 m	-64.3 m
SCS2360 (loess cliff)	47-102 (2.75 km)	Mean	-0.27 m/yr	-13.5 m	-27.0 m
		Max at individual transect	-0.38 m/yr	-19.1 m	-38.1 m
		Avg Upper 95% Confidence level	-0.39 m/yr	-19.7 m	-39.3 m

In general, the 2.75 km of loess cliffs are eroding at approximately half the rate of the gravel beaches, with transects 47-102 having an average long-term erosion rate of -0.27 m/yr and a maximum of -0.38 m (transect 78). Extrapolating these rates into the future, equates to an average retreat of -13.5m and maximum of -19.1 m over the next 50 years (2070), with -27.1 m (average) and -38.1 m (maximum) erosion over the next 100 years (2120).

Table 3.1 also indicates that over approximately 4 km of the length of the cell, we can be 95% confident that uncertainty in the historical rate will not add more than an average of -10 m to the mean erosion distance over a 50-year timeframe and no more than an average of -20 m over a 100-year timeframe. The exception is for the southernmost area within the Pareora River terrace, where there is considerably greater uncertainty in the historical rate obtained from the DSAS analysis due to lack of a linear trend in the shoreline movements

Short Term Storm Erosion

The short-term erosion components were calculated using inter-survey erosion data from ECan profiles SCS2718 and SCS2360.

For profile SCS2718 located at the Pareora Meatworks revetment, the maximum inter-survey erosion recorded was -4.6 m between Aug 1986 and July 1987, which reflects the potential loss of revetment material from the crest of the structure during the three storms events that were recorded during this period. The GEV distribution of inter-survey erosion returned an erosion distance of -5.2 m for the mean value of a 100-year ARI erosion event, with the 99% confidence level of -7.8 m.

The short-term erosion component of SCS2360 is similar to other sites with loess cliff morphologies, with the maximum inter-survey cliff erosion being -1.4 m between Oct 2009 and Mar 2010. Although no storms are recorded in this period on the ECan storm database, this is not unusual for cliff sites due to the influence of other non-coastal drivers in cliff retreat. The GEV distribution of inter-survey erosion also returned the same erosion distance of -1.4 m for the mean value of a 100-year ARI erosion event, with the 99% confidence level of -3 m.

Sea Level Rise Effect

The effect of SLR along this section of coastline was calculated using the modified Bruun rule for MSG beaches represented by SCS2718 and by the modified Walkden & Dickson (2008) relationship for volume effect for the loess cliff segment represented by SC2360. As shown in Table 3.2, the effect of SLR is greater for the loess cliff morphologies than along the MSG beach, with 'most likely' mean retreat of up to -18 m by 2070 and up to -43 m retreat by 2120 under the most extreme SLR scenarios tested, compared to -5 m and -14 m for the MSG beaches under the same SLR scenarios.

Table 3.2 Predicted erosion from future SLR at ECan profiles between the Pareora River and Pig Hunting Creek.

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
SCS2718 (MSG beach)	1-46	Mean	-1.1 m	-3.2 m	-5.4 m	-4.3 m	-6.4 m	-10.7 m	-13.9 m
		Max	-1.5 m	-4.5 m	-7.5 m	-6.0 m	-9.0 m	-15.0 m	-19.5 m
SCS2360 (loess cliff)	47-102	Mean	-4.6 m	-12.2 m	-17.9 m	-17.4 m	-24.3 m	-35.9 m	-43.3 m
		Max	-6.8 m	-17.7 m	-26.1 m	-25.4 m	-35.4 m	-52.2 m	-63.0 m

The results also indicate that the loess cliffs are more sensitive to SLR than the MSG beach, with a 0.4 m difference in SLR by 2070 resulting in a 13 m increase in erosion of the cliffs, compared to a 4 m increase in erosion for the MSG beach sections. There is also more uncertainty in the SLR erosion impacts for loess cliffs, with a maximum retreat for this type of shoreline possibly being in the range of 3 m to 8 m greater than the mean over a 50-year timeframe, and in the range of 8 m to 20 m greater over 100 years depending on the magnitude of SLR. In comparison, uncertainty in MSG beaches only accounts for an additional 1-2 m over 50 years and 2-6 m over 100 years. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.

3.1.2 Projected Future Shoreline Positions (PFSP)

The calculated PFSPs averaged over the length of coast represented by each ECan profile are presented below in Table 3.3 and are presented spatially in Figure 3.1 with the P50 position representing the 'most likely' position and P5 position the 'very unlikely' position under the highest SLR scenarios considered in this assessment of 0.6 m by 2070 and 1.5 m by 2120. Further maps showing the P5 PSFP for all SLR scenarios are presented in Appendix E (Map 1), and an enlargement of the area around the Pareora Meat Works in Map 1A. A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

Table 3.3 shows that the 'most likely' erosion of the 700 m of unprotected MSG beaches north of the Pareora works is predicted to be in the range of -28 m to -32 m by 2070, and -53 m to -63 m by 2120 depending on the magnitude of SLR. The 2.75 km of loess cliffs are predicted to most likely have similar retreat distances in the range of -19 m to -31 m by 2070 and -44 m to -66 m by 2120. As shown in Figure 3.1, these similarities in retreat retain the current plan-shape of the shoreline north of the Pareora works. For both shoreline sections, the probability analysis indicates that the highest SLR 'very unlikely' erosion distances are in the range of 5-10 m higher than the 'most likely' position by 2070, and 10-20 m higher by 2120.

Table 3.3: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP between the Pareora River and Pig Hunting Creek.

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
SCS2718 (Pareora River & Works)	1-31 (1.5 km)	Most likely	-8.3m	-10.4m	-12.6m	-13.8m	-16.1m	-20.4m	-23.7m
		Very unlikely	-29.4m	-31.7 m	-33.9m	-55.6m	-57.9m	-62.5m	-65.8m
SCS2718 (North- MSG beach)	32-46 (700 m)	Most likely	-27.8m	-30m	-32.2m	-52.9m	-55.1m	-59.5m	-62.8m
		Very unlikely	-35.1m	-37.4 m	-39.6m	-67.1m	-69.4m	-74m	-77.4m
SCS2360 (loess cliff)	47-102 (2.75 km)	Most likely	-18.9m	-25.6m	-30.7m	-43.6m	-49.7m	-59.8m	-66.4m
		Very unlikely	-23.7m	-32.3m	-39.2m	-54.9m	-62.9m	-76.7m	-85.8m

At the Pareora works, currently protected by the rock revetment, the shoreline position is projected to 'most likely' be 8 to 13 m landward than present over the next 50 years, and 14 to 24 m landward over the next 100 years. The probability analysis indicated there is greater uncertainty for this section of coast, with the 'very unlikely' erosion distances being in the order 20 m greater by 2070, and 40 m greater by 2120. Although these erosion distances assume that the revetment is not maintained, the low projected retreat is directly influenced by the extrapolation of the slow historical retreat due to the presence of the wall. Conversely, if the current rock revetment structure is maintained it is unlikely that the whole shoreline would retreat in the future, but there would likely be increased loss of beach volume in front of the wall, and SLR could also increase overtopping and back scour behind the structure. However, under both scenarios, the low or nil erosion distances would result in a more convex shoreline plan-shape along the works frontage, hence would have higher exposure to coastal erosion processes in the future.

Relative Contribution of the Components

The relative contribution of the individual components in the PFSP erosion distance under selected scenarios for 2070 and 2120 are presented below in Figure 3.2.

For the loess cliffs (SCS2360) the contribution of existing coastal processes and SLR to erosion over the next 50 years are very similar at around 48% of the projected total retreat. However, over a 100-year timeframe, SLR becomes the dominant process in cliff retreat, contributing around 57% of the projected total retreat.

In contrast, along the unprotected sections of MSG beach (SCS2718 north), extrapolation of the historical erosion due to current processes is the dominant contributor to future erosion over both time frames, accounting for around 72% of the projected erosion over both 50 and 100-year time frames.

At the Pareora Meatworks, the contribution of extrapolation of the low long-term historical rate is minimal in calculating the PFSP, making up the smallest component of future erosion over both 50 and 100-year time frames (20%). At this site over a 50-year timeframe, short term storm erosion is the largest component (50%), dropping to around 25% over a 100-year period as erosion due to SLR increases.

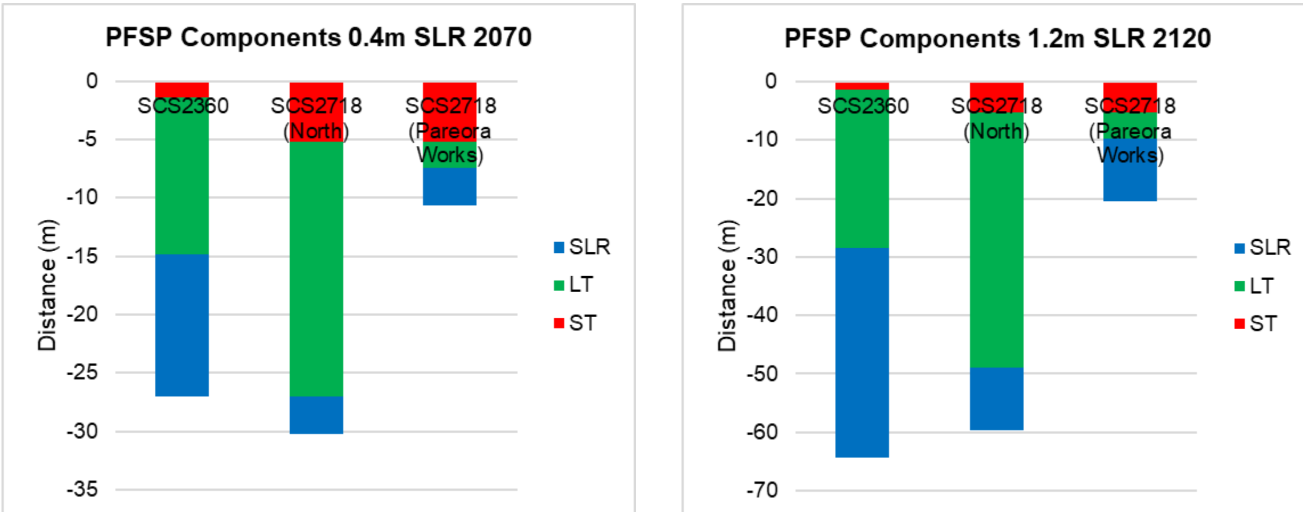


Figure 3.2: Contribution of each component of the erosion to the PFSP at ECan profiles sites between the Pareora River and Pig Hunting Creek for SLR scenarios of 0.4m by 2070 (Left) and 1.2m by 2120 (Right)

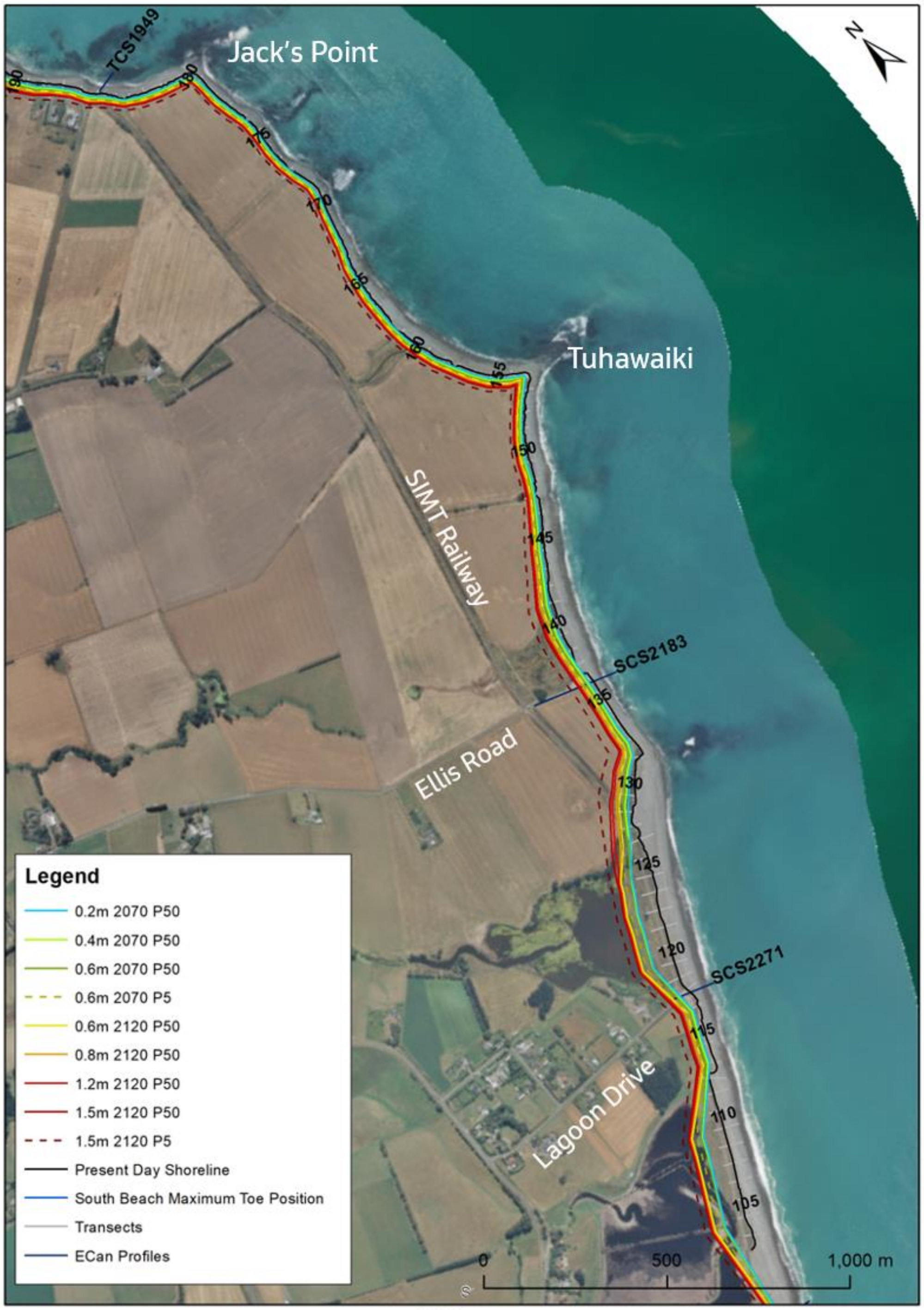
Potentially Impacted Assets

In addition to likely erosion of the rock revetment protecting the Pareora works, sections of the South Island Main Trunk (SIMT) Railway which runs close to the coast are projected to most likely be compromised by erosion over a 100-year timeframe under all SLR scenarios.

3.2 Normanby - Scarborough

The Normanby - Scarborough coastal cell from Pig Hunting Creek to Jacks Point is approximately 4.5 km long and consists of a series of loess cliffs separated by MSG beach ridges across the mouths of small coastal creeks and wetlands. This shoreline cell is presented in Figure 3.3. In a number of locations, the loess cliffs form small headlands where underlying seams of volcanic rock extend to the coast to form nearshore rock reefs (e.g. Tuhawaiki Point and Jacks Point). In the southern section of the cell, the shoreline has a general NNW-SSE orientation, turning to a more NW-SE orientation north of Tuhawaiki Point, and W-E north of Jacks Point.

The shoreline reference position for mapping this coastline interchanged between the cliff edge for the loess cliff morphologies and the vegetation line for the MSG beach ridge morphologies. Four ECan profiles which are used to represent the different morphologies along the section of shoreline. SCS2271 (transects 114-117) covering 150 m of shoreline, SCS2183 (transects 126-181) covering 2.75 km, and TCS1949 (transects 182-198) covering 800 m of shoreline, represent the loess cliffs along this shoreline section. Profile TCS1887 is located at Saltwater Creek immediately north of this section of coastline and is used to represent the 800 m of MSG beach ridge areas (transects 104-113 and 118-125). ECan profile SCS2178 was not used in the analysis as short term movement is restricted by the presence of the rock revetment structure confining the beach.



Note:
P50 is 50% chance the shoreline will be landward of this position
P5 is a 5% chance the shoreline will be landward of this position

Figure 3.3: Normanby – Scarborough PFSP for various SLR scenarios in 2070 and 2120. 'Most likely' position (P50) is shown for each scenario, and 'very unlikely' (P5) shown for SLR scenarios of 0.6m by 2070 and 1.5m by 2120 (highest scenarios).

3.2.1 Erosion Components

Extrapolation of Long-Term Rates

The extrapolation of long-term erosion rates from 1938 to 2017 and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 3.4. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 3.4, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

Table 3.4 Extrapolation of long-term erosion rates (1938-2017) and resulting projected erosion distances for Normanby and Scarborough area

Profile	DSAS Transects	Statistic	Erosion Rate (1938-2017)	2070 Erosion Distance	2120 Erosion Distance
TCS1887 (MSG beach)	104-113 (450 m north of Pig Hunting Creek)	Mean	-0.56 m/yr	-28.1 m	-56.1 m
		Max at individual transect	-0.58 m/yr	-28.8 m	-57.5 m
		Avg Upper 95% Confidence level	-0.72 m/yr	-35.9 m	-73.0 m
	118-125 (350 m North of Normanby)	Mean	-0.55 m/yr	-27.3 m	-54.5 m
		Max at individual transect	-0.55 m/yr	-27.7 m	-55.4 m
		Avg Upper 95% Confidence level	-0.76 m/yr	-38.4 m	-76.8 m
SCS2271 (loess cliff)	114-117 (150 m Normanby)	Mean	-0.19 m/yr	-9.6 m	-19.3 m
		Max at individual transect	-0.19 m/yr	-9.6 m	-19.3 m
		Avg Upper 95% Confidence level	-0.33 m/yr	-16.6 m	-33.2
SCS2183 (loess cliff)	126-181 (2.75 km Tuhawaiki Point to Jacks Point)	Mean	-0.14 m/yr	-7.0 m	-14.0 m
		Max at individual transect	-0.36 m/yr	-17.8 m	-35.7 m
		Avg Upper 95% Confidence level	-0.26 m/yr	-13.2 m	-26.5 m
TCS1949 (loess cliff)	182-198 (800 m north of Jacks Point)	Mean	-0.12 m/yr	-6.2 m	-12.4 m
		Max at individual transect	-0.16 m/yr	-8.1 m	-16.3 m
		Avg Upper 95% Confidence level	-0.27.4 m/yr	-13.7 m	-27.4 m

The historical erosion rate of the loess cliff within this coastal cell is low, with mean rates per cliff section ranging between -0.12 to -0.19 m/yr, with the higher rates generally being along the section Normanby section of cliffs. Extrapolating these rates into the future would result in 5 m to 9 m of cliff retreat over a 50-year timeframe, and 10 to 18.5 m over a 100-year timeframe. From the probability analysis, over this 3.8 km stretch of loess cliffs we can be 95% confident that uncertainty in the historical rate will not add more than around -6 m to the erosion distance over a 50-year timeframe and more than an average of -15 m over a 100-year timeframe.

The 800 m of MSG beach ridge morphologies have much higher historical erosion rates, with the average rate of these transects (104-113 and 118-125), being -0.56m/yr. Projecting these rates into the future equates to -27 m of erosion over the next 50 years and -55 m of erosion over the next 100 years. As shown in Table 3.4, we can be 95% confident that uncertainty in the historical rate will not add more than 10 m to the erosion distance over a 50-year timeframe and more than an average of -20 m over a 100-year timeframe. Based on the projections, there would be a larger disconnect in shoreline orientation of the beach ridges and the loess cliffs with the formation of more distinct small pocket beaches at the creek mouths and wetlands between the loess headlands.

Short Term Storm Erosion

The short-term erosion component was calculated along this section of shoreline using inter-survey data from the four ECan profiles. As shown by the following results the short-term storm erosion effects on the loess cliffs is significantly less than on the MSG beach ridges. However, it is noted that the position of the beach ridges is dynamic having the ability to recover post-storm, whereas cliff retreat is permanent.

- TCS1887: Maximum inter-survey erosion of the 4.5 m beach contour was -20.3 m between Oct 1991 and Oct 1992, a period within which seven storms were recorded including three events classified as being significant (May, June and August 1992). The GEV distribution of inter-survey erosion returned an erosion distance of -28.8 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of -49.4 m. It is noted that the mean value is most likely a conservative estimate due to the effect of multiple storms-in series on the distribution of surveyed erosion used to calculate the extreme values.
- SCS2271: Maximum inter-survey change of the edge of the loess cliff was -1.7 m between Oct 2000 and Nov 2001, a period within which three storms are recorded on the ECan storm database, including the July 2001 event which inundated 1150 hectares in South Canterbury. The GEV distribution of inter-survey erosion also returned an erosion distance of -1.7 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of -3.4 m.
- Profile SCS2183: Maximum inter-survey change of the edge of the loess cliff was -0.4 m between Oct 1993 and Oct 1994, a period within which six storms were recorded. The GEV distribution of inter-survey erosion returned an erosion distance of -0.5 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of -0.7 m.
- Profile TCS1949: Maximum inter-survey change of the edge of the loess cliff was -1.6 m between Mar 1985 and Sept 1986, a period within which eight storms were recorded including two events classified as being significant (May & July 1995). The GEV distribution of inter-survey erosion returned an erosion distance of -1.1 m for the mean value of a 100-year ARI erosion event with the 99% confidence level of -2.3 m. It is noted that the mean value is a less erosion that the maximum recorded inter-survey change as the result of multiple storm events.

Sea Level Rise Effects

The effect of SLR along this section of coastline was calculated using the modified Walkden & Dickson (2008) relationship for volume effect for the loess cliff segments represented by ECan profiles SCS2271, SCS2183 and TCS1949, and by the modified Bruun rule for MSG beaches for transects represented by TCS1887. The results of this analysis are presented in Table 3.5.

As shown in Table 3.5, the erosion effect of SLR is predicted to be slightly greater on the loess cliffs than on the MSG beach ridge morphologies. For the loess cliffs, average retreat due to SLR over the next 50 years is projected to be up to -8 m at Scarborough and -13 m at Normanby, and up to -20 m and -30 m respectively for SLR over the next 100 years. For the MSG beach ridge morphologies, the erosion caused by SLR is likely to be up to -5 m over the next 50 years, and up to -14 m over the next 100 years.

Table 3.5: Predicted erosion caused by future SLR at ECan profiles in Normanby – Scarborough area

Profile	DSAS Transects	Statistic	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
TCS1887 (MSG ridge)	104-113, 118-125	Mean	-1.1 m	-3.2 m	-5.3 m	-4.2 m	-6.3 m	-10.6 m	-13.7 m
		Max	-1.5 m	-4.4 m	-7.4 m	-5.9 m	-8.8 m	-14.7 m	-19.2 m
SCS2271 (loess cliff)	114-117	Mean	-3.3 m	-8.7 m	-12.8 m	-12.4 m	-17.3 m	-25.5 m	-30.8 m
		Max	-5.7 m	-15.0 m	-22.1 m	-21.5 m	-29.9 m	-44.1 m	-53.3 m
SCS2183 (loess cliff)	126-181	Mean	-2.4 m	-6.3 m	-9.3 m	-9.1 m	-12.6 m	-18.6 m	-22.5 m
		Max	-4.6 m	-11.9 m	-17.6 m	-17.1 m	-23.8 m	-35.1 m	-42.4 m
TCS1949 (loess cliff)	182-198	Mean	-2.1 m	-5.6 m	-8.2 m	-8 m	-11.2 m	-16.5 m	-19.9 m
		Max	-4.7 m	-12.3 m	-18.2 m	-17.7 m	-24.6 m	-36.3 m	-43.8 m

There is also more uncertainty in the SLR erosion impacts for loess cliffs, with a maximum retreat for this type of shoreline possibly being in the order of 10 m greater than the mean over a 50-year timeframe, and in the range of 20 m to 25 m greater over 100 years depending on the magnitude of SLR. In comparison, uncertainty in MSG beaches only accounts for an additional 2 m over 50 years and 6 m over 100 years. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.

The results also indicate that the loess cliffs are more sensitive to SLR than the MSG beach ridges, with a 0.4 m difference in SLR by 2070 (e.g. an increase from 0.2 m to 0.6 m) which is predicted to result in up to a 10 m increase in erosion of the cliffs, compared to a 4 m increase in erosion for the MSG beach ridges.

3.2.2 Projected Future Shoreline Positions

The calculated PFSP for the Normanby – Scarborough coast averaged over the length of shorelines represented by each ECan profile are presented below in Table 3.6 and are presented spatially in Figure 3.3 with the P50 position representing the 'most likely' position and P5 position the 'very unlikely' position under the highest SLR scenarios considered in this assessment of 0.6 m by 2070 and 1.5 m by 2120. Further maps showing the P5 PSFP for all SLR scenarios are presented in Appendix E (Map 2). A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

The 'most likely' erosion over the next 50 years for the 3.7 km stretch of loess cliff morphologies are in the order of -15 m to -24 m at Normanby and in the order of -10 m to -15 m at Scarborough depending on the magnitude of SLR. Over a 100-year timeframe for the range of SLR scenarios assessed these erosion distances are likely to increase to -33 m to -50 m at Normanby and -22 to -33 m at Scarborough.

As a result of higher historical rates and much larger short-term storm erosion, the predicted 'most likely' erosion of the 800 m of MSG beach ridges is up to four times that the loess cliffs over 50-year, being in the order of 60 m within this timeframe. This discrepancy in retreat between the beach types reduces to approximately three times higher over the 100-year time frame with predicted most likely erosion on the beach ridges being in the order of – 90 to -100 m over this period.

Table 3.6: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP for the Normanby – Scarborough coast

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
TCS1887	104-113 118-125 (800 m)	Most likely	-58.9m	-61.1m	-63.2m	-90m	-92.1m	-96.5m	-99.7m
		Very unlikely	-73.4m	-75.5m	-77.8m	-108m	-110.2m	-114.7m	-118m
SCS2271	114-117 (150 m)	Most likely	-14.6m	-19.7m	-23.6m	-32.9m	-37.5m	-45.4m	-50.5m
		Very unlikely	-19.8m	-26.4m	-32m	-44.5m	-50.9m	-61.7m	-69.1m
SCS2183	126-181 (2.75 km)	Most likely	-10m	-13.9m	-16.9m	-23.8m	-27.4m	-33.4m	-37.2m
		Very unlikely	-14.4m	-19.5m	-23.9m	-33.7m	-38.6m	-47.2m	-53m
TCS1949	182-198 (800 m)	Most likely	-9.6m	-12.9m	-15.3m	-21.7m	-24.6m	-29.4m	-32.6m
		Very unlikely	-15.2m	-20.3m	-24.6m	-34.5m	-39.3m	-48.1m	-53.9m

The probability analysis indicates that due to uncertainties in the data there is a 5% chance that these erosion distances could be up to 10 m greater than the 'most likely' within 50 years, and 20 m greater over 100 years for both shoreline types.

The mapping of the PFSP's indicates that coastline is likely to generally retain its current shoreline shape with small loess capped headlands at the volcanic rock reefs remaining as headlands, but with a greater degree of MSG beach ridge re-orientation and pocket beach formation along the mouths of the coastal creeks and lagoons.

Relative Contribution of the Components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 3.4. The graphs indicate that the much larger total erosion at the MSG beach ridge sites (TCS1887) is due to the higher historical erosion rate and the significantly higher short term erosion component, with these two components contributing around 45% each of the PFSP line over a 50 year period. At the gravel ridge sites, the SLR component is insignificant, and the long term erosion and short term erosion components make up almost 50% each of the PFSP line.

At the loess cliff sites, the short-term component is insignificant. The long-term erosion and SLR components are approximately equal over a 50 year timeframe (around 45-50%). The SLR component slightly dominates over a 100 year timeframe (around 55%). The short term component over both timeframes for loess cliffs makes up approximately 5% of the PFSP distance.

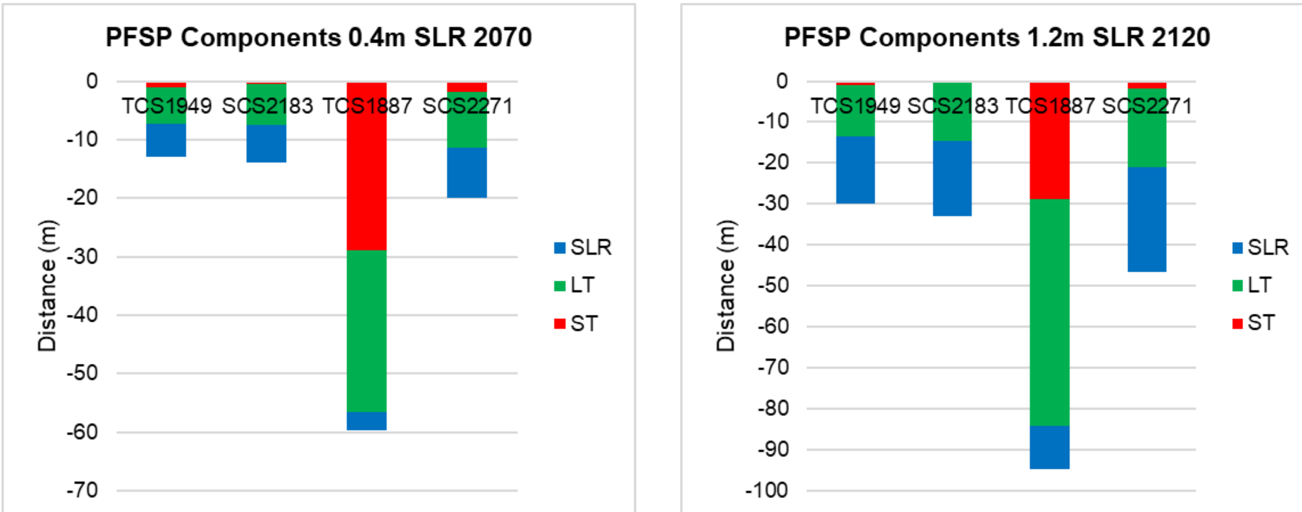


Figure 3.4: Contribution of each component of the erosion to the PFSP at ECan profiles sites along the Normanby – Scarborough coast for SLR scenarios of 0.4m by 2070 (Left) and 1.2m by 2120 (Right).

Potentially Impacted Assets

The section of SIMT railway line between transects 104 and 130, where the tracks are in very close proximity to the shoreline is projected to most likely be compromised by erosion within the next 50 years. The road ends at Lagoon Drive and Ellis Road may also be compromised by erosion within this period. At Lagoon Drive the road end is protected by the railway and any future protection measures for the railway lines (rather than relocation) would also protect the end of the road.

3.3 Saltwater Creek

Saltwater Creek coastal cell comprises of a 1100 m long and 100 m wide vegetated MSG beach ridge with elevations in the order of 5-6 m (LVD1937). This shoreline cell is presented below in Figure 3.5. The SIMT railway line runs along the backshore of the gravel barrier and the lower channel of Saltwater Creek is located behind the barrier, running parallel to the shoreline. Landward of this channel is the Timaru District landfill, which is protected from flooding in lower Washdyke Creek by a stopbank system.

This landfill site was originally the site of the Timaru Airport, formed in 1935 by draining the Opitua Lagoon, and rediverting Saltwater Creek mouth from the north end of the bay to the south end. However, since this time ongoing issues with flooding and drainage have resulted in one or both ends being used as Saltwater Creek outlet to the sea, including wooden 'box' structures to aid natural discharge to sea being constructed and later abandoned at both outlets. The current practice is for the creek to discharge at the northern outlet either naturally or via a bulldozed channel when water levels in the creek reach a pre-determined level at SH1.

Up to 1978, the beach was also a site for gravel extraction, with around 35,500 m^3/yr being removed between 1963 and 1976.

This coastal cell is defined by transects 199 to 220 and is represented by ECan profile TCS1887 located near the southern outlet.

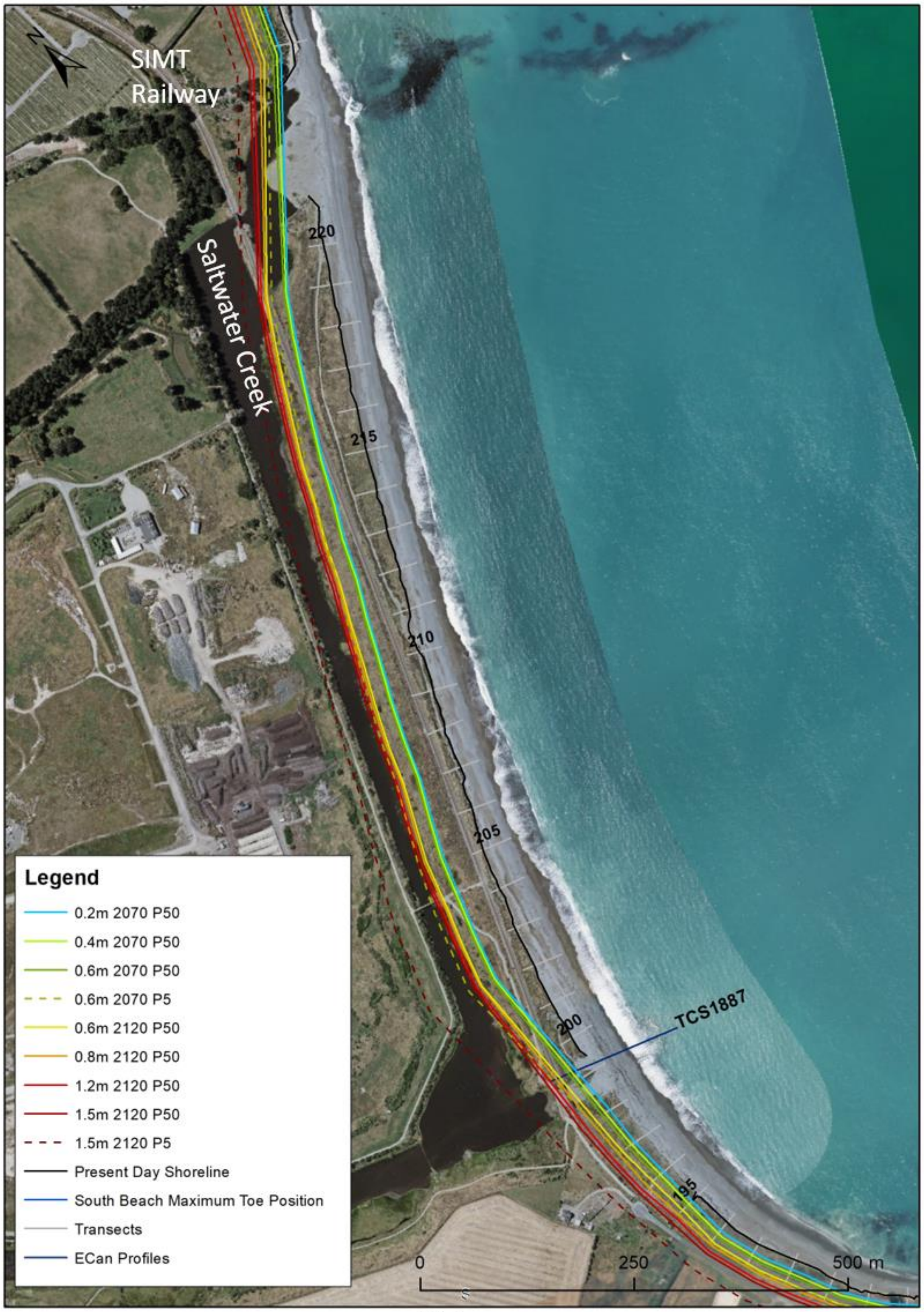


Figure 3.5: Saltwater Creek PFSP for various SLR scenarios in 2070 and 2120. 'Most likely' position(P50) is shown for each scenario, and 'very unlikely' (P5) shown for SLR scenarios of 0.6m by 2070 and 1.5m by 2120 (highest SLR scenarios).

3.3.1 Erosion Components

Extrapolation of Long-Term Rates

The extrapolation of long-term erosion rates from 1956 to 2017 and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 3.7. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 3.7, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

Table 3.7 Extrapolation of long-term erosion rates (1956-2017) and resulting projected erosion distances at Saltwater Creek

Profile	DSAS Transects	Statistic	Erosion Rate (1956-2017)	2070 Erosion Distance	2120 Erosion Distance
TCS1887 (MSG barrier)	199-220 (1100 m)	Mean	-0.36 m/yr	-18.2 m	-36.4 m
		Max at individual transect	-0.43 m/yr	-21.6 m	-43.2 m
		Avg Upper 95% Confidence level	-0.89 m/yr	-44.5 m	-88.9 m

There is a long-term erosional trend at the beach fronting Saltwater Creek, with an average erosion rate across the whole cell of -0.36 m/yr and a maximum of -0.43 m/yr at the northern end. Extrapolation of these mean rates would result in erosion of -18 m of erosion over the next 50 years and -36 m over the next 100 years, with slightly more at the northern end. However, the probability analysis indicates that there is considerable uncertainty around the historic rates, with the upper 95% confidence level more than doubling the projected erosion distances from the extrapolation.

Short Term Storm Erosion

At ECan profile TCS1887, the maximum inter-survey change recorded was 20.3m of erosion between Oct 1991 and Oct 1992, a period within which seven storms were recorded including three events classified as being significant (May, June and August 1992). The GEV distribution of inter-survey erosion returned an erosion distance of -28.8 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of -49.4 m.

It is noted that the mean value is most likely a conservative estimate due to the effect of multiple storms-in series on the distribution of surveyed erosion used to calculate the extreme values.

Sea Level Rise Effects

Since the barrier beach is very wide and well-vegetated with little evidence of overtopping and rollover[11], the erosion effect of SLR at Saltwater Creek was calculated using the adjusted Bruun rule for MSG beaches. The results of this analysis for the selected SLR scenarios over 50 and 100-year time frames are presented in Table 3.8.

[11] During 2015 storm event, overtopping deposited gravel on the railway line in northern part of the cell (Justin Cope, Ecan, pers comm). However, this is infrequent occurrence and beach is not subject to rollover processes with the same frequency or magnitude as Washdyke Beach.

Table 3.8: Predicted erosion from future SLR at ECan profileTCS1887.

Profile	DSAS Transects	Statistic	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
TCS1887 (MSG ridge)	199-220	Mean	-1.1 m	-3.2 m	-5.3 m	-4.2 m	-6.3 m	-10.6 m	-13.7 m
		Max	-1.5 m	-4.4 m	-7.4 m	-5.9 m	-8.8 m	-14.7 m	-19.2 m

The results indicate that the MSG ridge is not particularly sensitive to SLR, with only an additional 5 m of erosion over 50 years for a 0.6 m increase in SLR, and 14 m over 100 years for a 1.5 m SLR. The results also indicate that uncertainty in the input parameters of the calculations would only account for an additional 2 m over 50 years and 6 m over 100 years. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.

3.3.2 Projected Future Shoreline Positions

The averaged PFSP calculated along Saltwater Creek are presented below in Table 3.9 and are presented spatially in Figure 3.5, where the PFSP 'most likely' (P50) and selected highest SLR 'very unlikely' (P5) lines are displayed. Further maps showing the P5 PSFP for all SLR scenarios are presented in Appendix E (Map 2A). The mapping results show that there is minimal alongshore variation in the position of PFSP lines at each of the SLR scenarios. A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

Table 3.9: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP for the Saltwater Creek coastal cell.

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
TCS1887 (MSG ridge)	199-220 (1100 m)	Most likely	-49.2m	-51.6m	-53.8m	-70.9m	-73.1m	-77.3m	-80.7m
		Very unlikely	-71.7 m	-74.1 m	-76.3 m	-109.3 m	-111.5 m	-116.0 m	-119.2 m

Over a period of 50-years, the 'most likely' shoreline position under the highest SLR scenario mapped is predicted to be on average up to 54 m landward of its current position, and over 80 m landward within in 100 years. The probability analysis indicates that the greatest 'very unlikely' erosion distances are in the order of 20 m further than the 'most likely' position by 2070, and up to 40 m further by 2120.

Relative Contribution of the Components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 3.6. The graphs show that SLR is the least significant component of the erosion over both time frames, contributing only 6% and 14% of the total erosion over 50 and 100-year timeframes respectively. The short-term component is the most significant component over 50 years (56%) and is almost equal to the projected historical trend over 100 years.

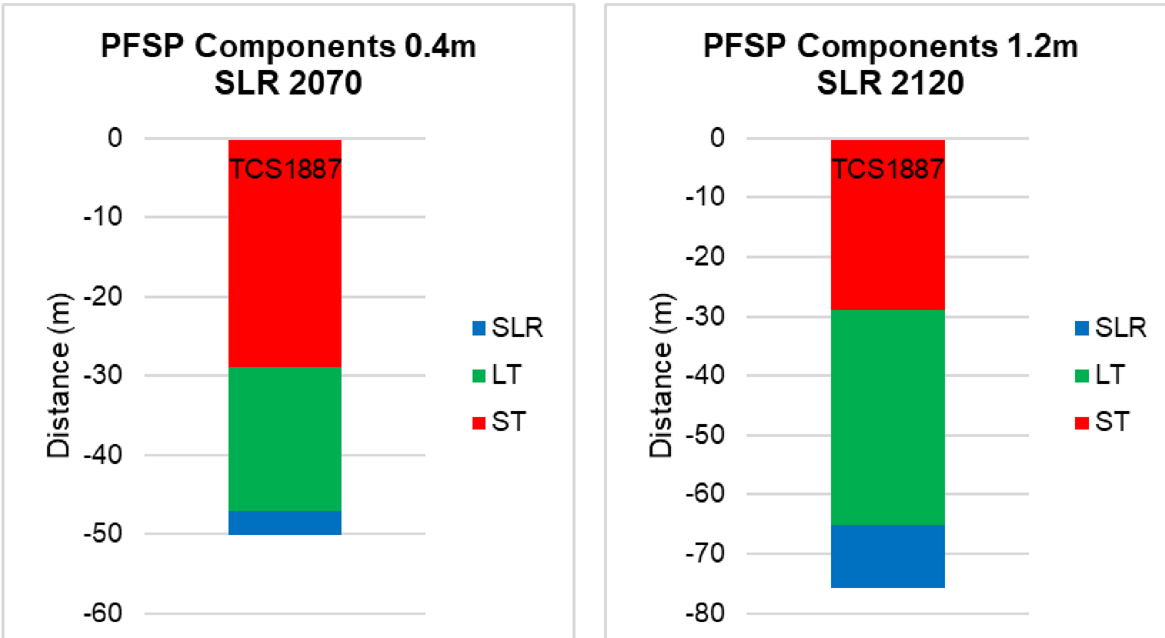


Figure 3.6: Contribution of each component of the erosion to the PFSP at ECan profile site TCS1887 along the Saltwater Creek coast for SLR scenarios of 0.4m by 2070 (Left) and 1.2m by 2120 (Right).

Potentially Impacted Assets

The SIMT railway lines which runs parallel to the shoreline on the backshore of the barrier, approximately 50 m landward of the current vegetation line, is most likely to be compromised by erosion within the next 50 years under all SLR scenarios. Within the 50 to 100 year period, it is likely that the back of the beach will be encroaching on the channel of Saltwater Creek to the northern outlet, which given that the channel position is fixed on the landward side by the landfill stopbank, is likely to impact on the drainage capacity of the channel and ability to continue to use the northern outlet to discharge the creek to the ocean.

4. Results: Timaru Urban Area

The following sections present the findings of this assessment and the calculated PFSP for the coastline of the Timaru urban area. The findings are presented in cells from south to north based on different geomorphic and contextual settings. Overview maps of both 2070 and 2120 SLR scenarios are presented in Appendix E (Maps 2, 2B (Patiti Point), 3, 3A (South Beach), 3B (Caroline Bay) & 3C (Dashing Rocks)). Shapefiles of these lines were also provided to ECan and Timaru District Council for use in ArcGIS to provide further detail.

4.1 Patiti Point

Patiti Point is a loess capped headland with elevations up to 10m (LVD1937) overlying a seam of resistant volcanic rock which forms an exposed low reef in the surf zone. A MSG beach extends around the cliff, burying any evidence of the volcanic rock seam, and transitioning into Saltwater Creek beach to the south and South Beach to the north. Although this cliff line has been subject to long-term erosion, the rates of retreat have accelerated considerably since the mid to late 2010s. The reasons for this rapid acceleration are yet to be fully investigated. This shoreline cell is presented below in Figure 4.1.

This coastal cell is 650 m in length and is defined by transects 221 to 234. ECan profile TCS1732 is used as a representative profile for the morphology along Patiti Point. However, the investigations for this assessment revealed a strong relationship between the orientation of the cliff line and the historical erosion rate within the coastal cell, therefore, the transects have been split into the following three orientations for further analysis:

- South-East facing cliff line: Transects 221-223 (Approximately 125 m),
- East facing cliff line at the apex of the Patiti Point headland: Transects 224-229 (Approximately 300 m), and
- North-East facing cliff line in the lee of the headland: Transects 230-234 (Approximately 225 m).

4.1.1 Erosion Components

Extrapolation of Long-Term Rates

To include the recent accelerated erosion at Patiti Point in the consideration of historical erosion rates, this assessment included aerial imagery taken in January 2020 of the more exposed SE and East facing sections of the cliff line. Figure 4.2 presents the temporal trends in cliff retreat measured from the six aerial imagery dates between Sept 1953 and Jan 2020 (only five dates to March 2017 for the NE facing cliff). The figure confirms there has been a long-term erosional trend at the exposed sections of the cliff line with retreat from 1953 to 2017 being in the range -13 m to -20 m for the SE facing transects, and -10 m to -16 m for the east-facing transects. Over the same period, retreat of the NE facing transects was less, ranging from -10 m (transect 230, closest to apex of the headland) down to -1 m (transect 234 closest to South Beach). However, from 2017 to 2019, transects on the SE facing section retreated a further -8 m to -10 m, and transects on the NE facing section retreated a further -3 m to -6 m, except for the most northern transect (229) that retreated only -1 m.

A recent undergraduate research project from the University of Canterbury (Crosswell et al 2019) investigated potential reasons for the recent accelerated erosion. They found that a combination of lower than average beach volumes and a cluster of significant coastal storms which had a more easterly directional component were a contributing factor to the accelerated cliff retreat. Certainly, from the analysis of the temporal changes in beach volume at ECan beach profile site TCS1732, it is clear that the accelerated erosion period from 2017 to 2020 coincided with the period of lowest beach volume, with volumes at the time of surveys between November 2017 and March 2019 being only 20-35% of the average volume over the last 30 years of profile surveys. Therefore, during this recent period, the beach provided minimal natural protection against storm event erosion. The next

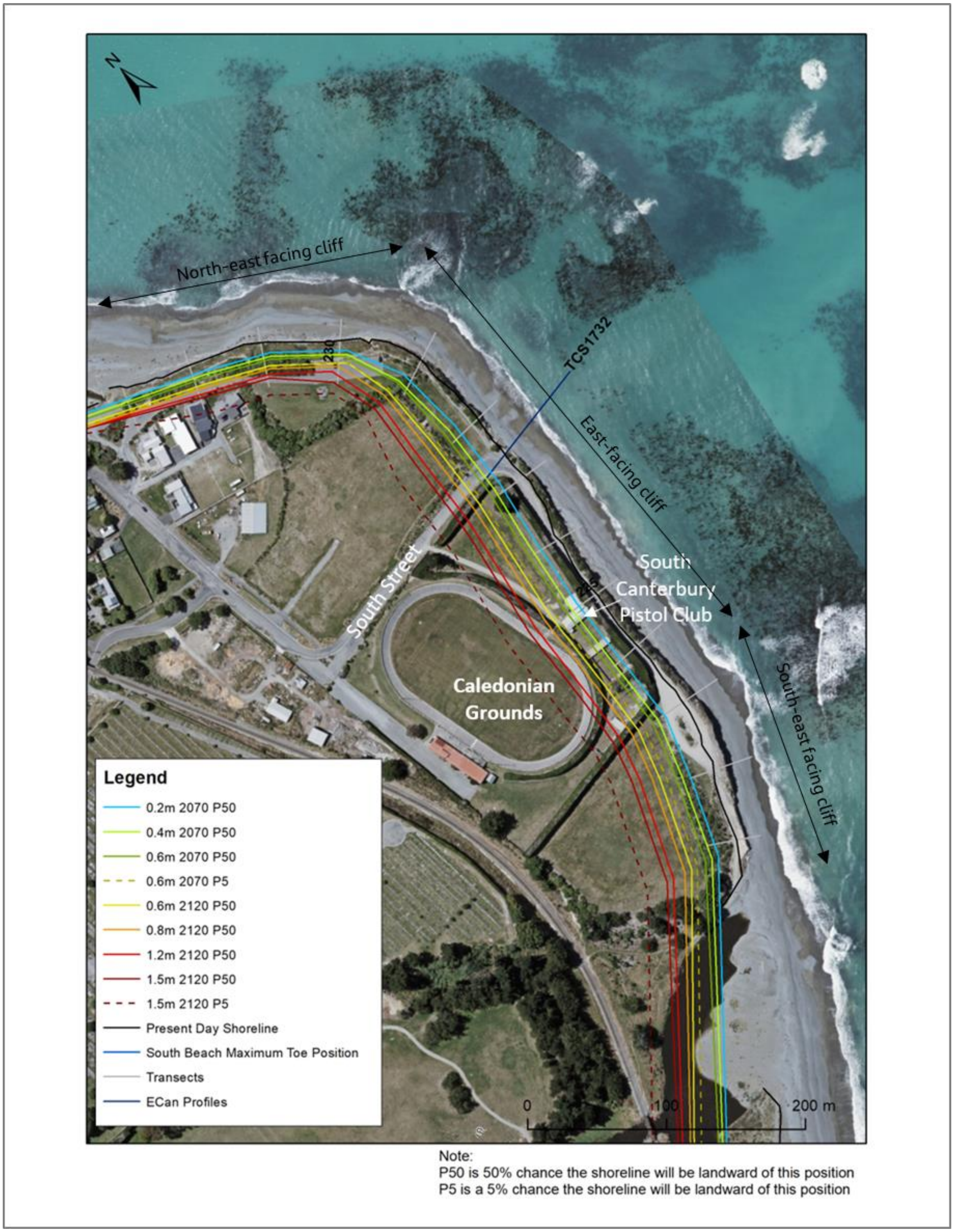


Figure 4.1: Patiti Point PFSP for various SLR scenarios in 2070 and 2120. 'Most likely' position (P50) is shown for each scenario, and 'very unlikely' (P5) shown for SLR scenarios of 0.6m by 2070 and 1.5m by 2120 (highest SLR scenarios).

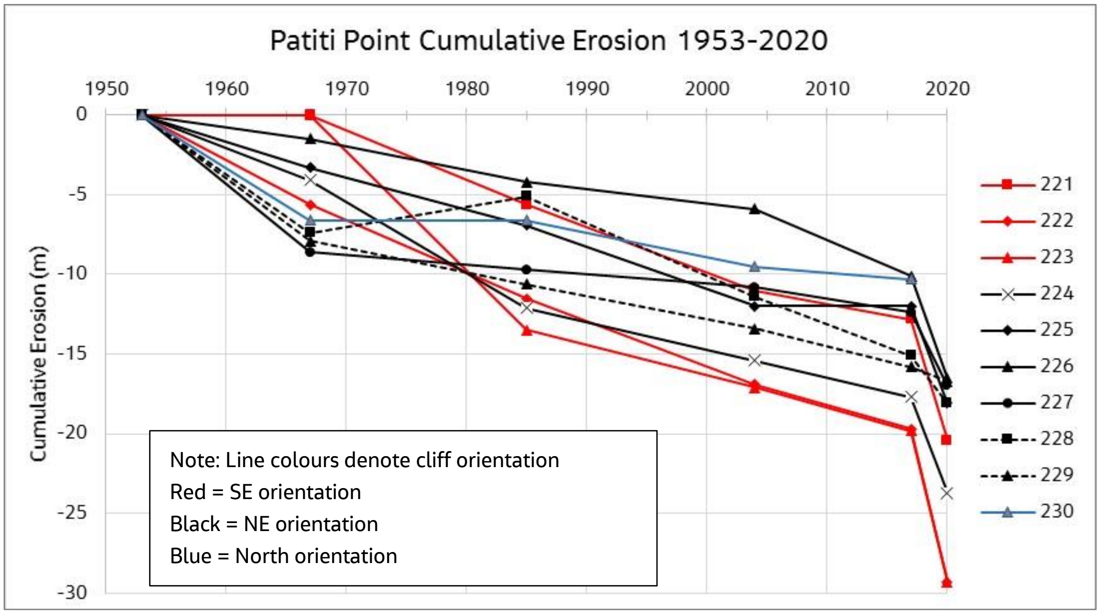


Figure 4.2: Cumulative erosion of transects 221-230 at Patiti Point from 1953-2020. Note transects in Red are orientated to the SE, in Black to the NE, and in Blue to the North.

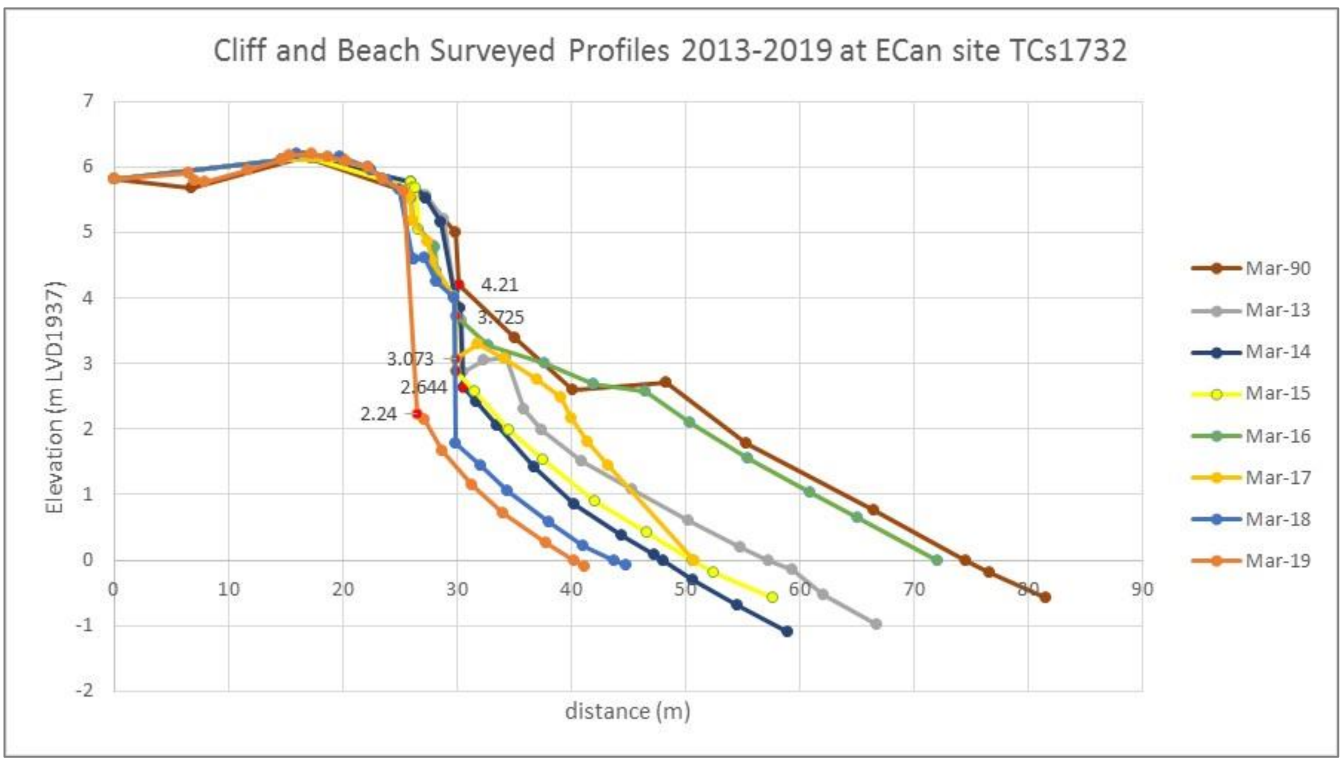


Figure 4.3: Surveyed cliff and beach profiles at ECan site TCS1732, Patiti Point.

lowest period was Sept 2013 to Sept 2015, when beach volumes were 40-50% of the 30-year average, with above-average volumes in the intervening period from late 2015 to late 2016. The comparison of the profiles over the period 2013 to 2019 is shown in Figure 4.3. Our analysis aligns with Crosswell et al (2019) that the lack of volume is most likely due to short-medium changes in longshore sediment supply (i.e. known as 'sediment slug' effect from variable supply from rivers and cliffs), aided by a high frequency of storms during this period with 11 events recorded on the ECan storm database during 2017 to 2019, including three from SE directions (rather than the more common southerly direction) that can penetrate through gaps in the reef to attack the base of the cliff.

Although continued monitoring of the cliff line will be required to determine the ongoing erosional trends, the recent acceleration is not considered to be a permanent change to long-term trends, with beach volumes showing an increase back to more than 50% of the 30-year average by the Sept 2019 survey. It is possible that periods of accelerated erosion could occur again in the future, therefore, the extrapolation of historical trends for input into PFSP includes this recent high erosion period along with the earlier more benign erosion periods.

The extrapolation of long-term erosion rates and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 4.1. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 4.1, several statistics are computed for each transect section including:

- The ‘Mean’ which is the average of the mean erosion distances for the defined section of shoreline;
- The ‘Max at an Individual Transect’ which is the maximum of all the transect ‘means’ within the shoreline section; and
- The ‘Average Upper 95% Confidence Level’ which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

Table 4.1 Extrapolation of long-term erosion rates (1953-2020) and resulting projected erosion distances for Patiti Point

Profile	DSAS Transects	Statistic	Erosion Rate (1953-2020)	2070 Erosion Distance	2120 Erosion Distance
TCS1732 (loess cliff)	221-223 (150 m facing SE)	Mean	-0.32 m/yr	-16.2 m	-32.3 m
		Max at individual transect	-0.36 m/yr	-18 m	-36.0 m
		Avg Upper 95% Confidence level	-0.41 m/yr	-20.7 m	-41.3 m
	224-229 (300 m facing East)	Mean	-0.24 m/yr	-12.2 m	-24.3 m
		Max at individual transect	-0.33 m/yr	-16.5 m	-33 m
		Avg Upper 95% Confidence level	-0.36 m/yr	-17.8 m	-35.7 m
	230-234 (200 m facing NE)	Mean	-0.1 m/yr	-4.9 m	-9.8 m
		Max at individual transect	-0.19 m/yr	-9.5 m	-19.m
		Avg Upper 95% Confidence level	-0.21 m/yr	-10.4 m	-20.8 m

For the cliff line facing SE, the average long-term erosion rate is -0.32 m/yr, equating to -16 m of erosion when extrapolated over the next 50 years, and -32 m of erosion over the next 100 years. For the cliff line facing east at the apex of the headland, the average historical erosion rate is slightly less at -0.24 m/yr, equating to -12 m and -24 m of erosion when extrapolated over the next 50 and 100 years respectively. For the cliff line facing NE in the lee of the headland, historical erosion rates have been less than half of those on the more exposed section of the headland, with average erosion of -0.1 m/yr. When extrapolated into the future, this average rate equates to -4.9 m of erosion over the next 50 years and -9.8 m of erosion over the next 100 years.

The probability analysis indicates that we can be 95% confident that the erosion distances should not be more than 5 m greater than the above distances over a 50-year timeframe and not more than approximately 10 m more over a 100-year timeframe over the total 650 m stretch of shoreline.

Short Term Storm Erosion

The short-term erosion component at Patiti Point was assessed using the 5.5 m contour at profile TCS1732 as representative of cliff face erosion. Although there has been a rapid recent cliff retreat, the maximum recorded inter-survey erosion was -0.9 m of retreat between Sept 1992 and March 1993. Although no storms were recorded on the ECan storm database for this period, there were seven storms recorded during the 1992 winter, including three classified as significant events (May, June & Aug). Maximum inter-survey retreat during the recent high erosion period was similar, -0.8 m cliff retreat between March and Sept 2019, with a slightly less -0.64 m retreat from Nov 2017 to March 2018. However, it is noted that erosion distances were greater at the cliff line to the south of the profile position. The GEV distribution of inter-survey erosion returned an erosion distance of -1.3 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of -2.6 m.

Sea Level Rise Effects

The effect of SLR along this section of coastline was calculated using the modified Walkden & Dickson (2008) relationship for volume effect for the loess cliff segments represented by ECan profiles TCS1732 (see Appendix A for details). The results of this analysis for each of the different facing cliff line segments around Patiti Point are presented in Table 4.2. Due to the impact of historical erosion on the calculation method, the results indicate a similar pattern, with the SE facing cliff segment being affected by SLR slightly more than the east facing segment, and much more than the NE facing segment.

Table 4.2: Predicted erosion caused by future SLR at Patiti Point.

Cliff line segment/Transects	Statistic	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
Facing South-east Transects 221-223	Mean	-5.6 m	-14.6 m	-21.5 m	-20.9 m	-29.1 m	-42.9 m	-51.8 m
	Max	-7.1 m	-18.6 m	-27.5 m	-26.7 m	-37.2 m	-54.9 m	-66.2 m
Facing East Transects 224-229	Mean	-4.2 m	-11.0 m	-16.2 m	-15.7 m	-21.9 m	-32.3 m	-39.0 m
	Max	-6.1	-16.1 m	-23.7 m	-23.0 m	-32.1 m	-47.3 m	-57.1 m
Facing North-east Transects 230-234	Mean	-1.7 m	-4.4 m	-6.5 m	-6.3 m	-8.8 m	-13.0 m	-15.7 m
	Max	-3.6 m	-9.4 m	-13.8 m	-13.4 m	-18.7 m	-27.6 m	-33.3 m

The results in Table 4.2 indicate that accelerated SLR over the next 50 years is predicted to account for up to an additional -22 m of erosion over the extrapolation of historical rates for the SE facing cliff line, up to an additional -16 m for the east-facing cliff segment, and an additional -7 m for the NE facing cliff segment. Over a 100-year timeframe, these additional erosion distances due to SLR are projected to be up to -52 m, -39 m, and -16 m for the SE, east, and NE facing cliff segments respectively.

The results also indicate that the projected erosion distances are very sensitive to the magnitude of SLR and uncertainties in the historical rates inputted in the SLR affect calculations. For example, a 0.4 m difference in SLR by 2070 (e.g. increase of 0.2 m to 0.6 m) is predicted to result in up to a 16 m increase in cliff retreat for the SE facing cliff segment, and up to 12 m increase for east-facing cliffs. The results also indicate that uncertainty in the SLR erosion impacts could add another -6 m to erosion distances over 50 years and up to an additional -15 m over 100 years for the highest SLR scenarios assessed.

4.1.2 Projected Future Shoreline Positions

The calculated PFSP for Patiti Point averaged over the length of shorelines represented by each cliff line orientation are presented below in Table 4.3, and are presented spatially in Figure 4.1 with the P50 position representing the ‘most likely’ position and P5 position representing the ‘very unlikely’ position under the highest

SLR scenarios considered in this assessment of 0.6 m by 2070 and 1.5 m by 2120. Further maps showing the P5 PSFP for all SLR scenarios are presented in Appendix E (Map 2B). A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

The 'most likely' erosion over the next 50 years for the loess cliff at Patiti Point is in the order of -22 m to -35 m for the SE facing cliff line and in the order of -17 m to -28 m for the east-facing segment depending on the magnitude of SLR. Over a 100-year timeframe for the range of SLR scenarios assessed these erosion distances are likely to increase to in the order of -50 m to -80 m for the SE facing cliff segment and -40 m to -60 m for the east-facing segment. Projected 'most likely' erosion at the northeast-facing cliff in the lee of the headland is less, being in the magnitude of -12 m to -20 m within 50 years, and -27 to -42 m over a 100-year time frame. With the capacity of continued accretion at South Beach (see Section 4.2), which would provide further protection for this northeast facing cliff section, these projections are likely to be conservative.

Table 4.3: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP for Patiti Point.

Cliff line segment/Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
Facing South-east Transects 221-223 (150 m)	Most likely	-21.9 m	-29.5 m	-35.2 m	-50.7 m	-57.6 m	-69.2 m	-76.7 m
	Very unlikely	-25.8 m	-35.3 m	-42.4 m	-60.3 m	-69.3 m	-84.7 m	-94.6 m
Facing East Transects 224-229 (300 m)	Most likely	-17.1 m	-23.1 m	-27.8 m	-39.3 m	-44.9m	-54.0m	-59.8 m
	Very unlikely	-21.5 m	-29.2 m	-35.4 m	-49.7 m	-57.0 m	-69.3 m	-77.6 m
Facing North-east Transects 230-234 (200 m)	Most likely	-8.3 m	-11.3 m	-13.5 m	-18.4 m	-21.0 m	-25.6 m	-28.5 m
	Very unlikely	-12.1 m	-16.0 m	-19.3 m	-26.7 m	-30.5 m	-37.3 m	-41.6 m

The probability analysis indicates that due to uncertainties in the data there is a 5% chance that these erosion distances could be around 8 m greater than the 'most likely' within 50 years, and up to 18 m greater over 100 years.

Relative Contribution of the Components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 4.4. The graphs show that the long term erosional trend and the effect of SLR components make very similar contributions to the 50-year erosion distances, with the SLR effect being the slightly more dominant component (55%) over a 100-year time frame. The contribution of short-term erosion is very small in comparison.

Potentially Impacted Assets

As shown in Figure 4.1, the projected erosion at Patiti Point under all SLR scenarios over the next 50 years will 'most likely' completely erode the extension of South Street that provides access along the cliff to the south with the cliff line projected to lie within the existing footprint of the South Canterbury Pistol Club facilities on the east side of the Caledonian Grounds. We understand that the footprint of building shown on the aerial imagery (2017) has now reduced as the South Canterbury Deerstalkers Association Building was separated from the Pistol club building in August 2019 when it was relocated. While the erosion is 'very unlikely' to have reached the cycle track over this timeframe, it could be within 20 m of the south-east corner of the track under the highest 50-year 0.6 m SLR scenario. The Patiti Point clifftop carpark & lookout at Transect 230 will also 'most likely' be affected by erosion within a 50-year time frame. Within 100 years, under all SLR scenarios, the cliff line is 'most likely' to lie within the current footprint of the cycle track at the south-east corner, and access to the Patiti Point clifftop carpark & lookout at Transect 230 will 'most likely' have been impacted by erosion.

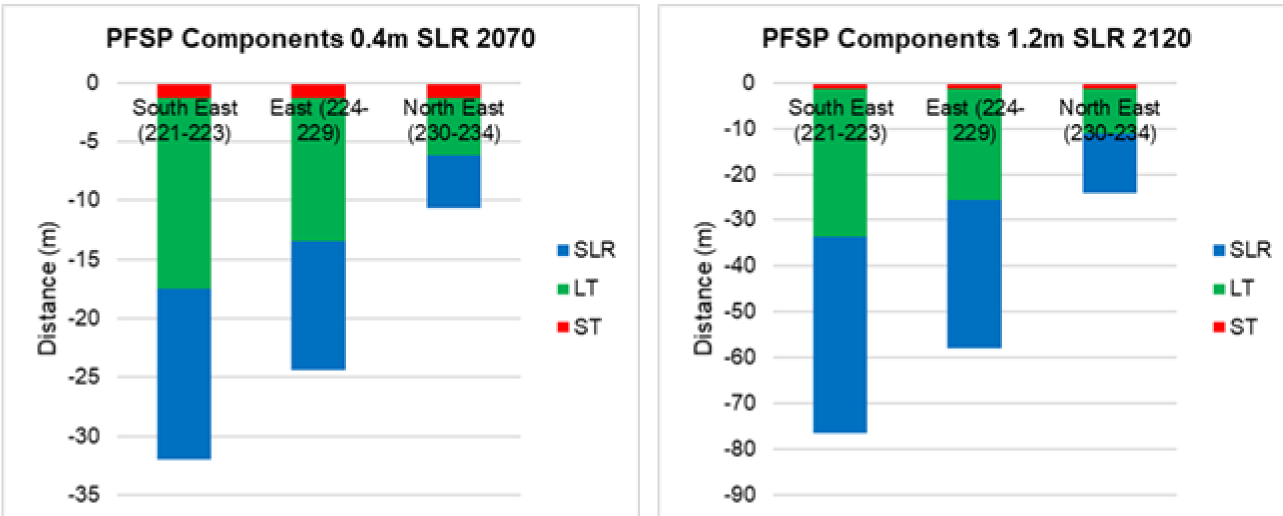


Figure 4.4: Contribution of each component of the erosion to the PFSP for the three cliff line orientations at Patiti Point for SLR scenarios of 0.4m by 2070 (Left) and 1.2m by 2120 (Right)

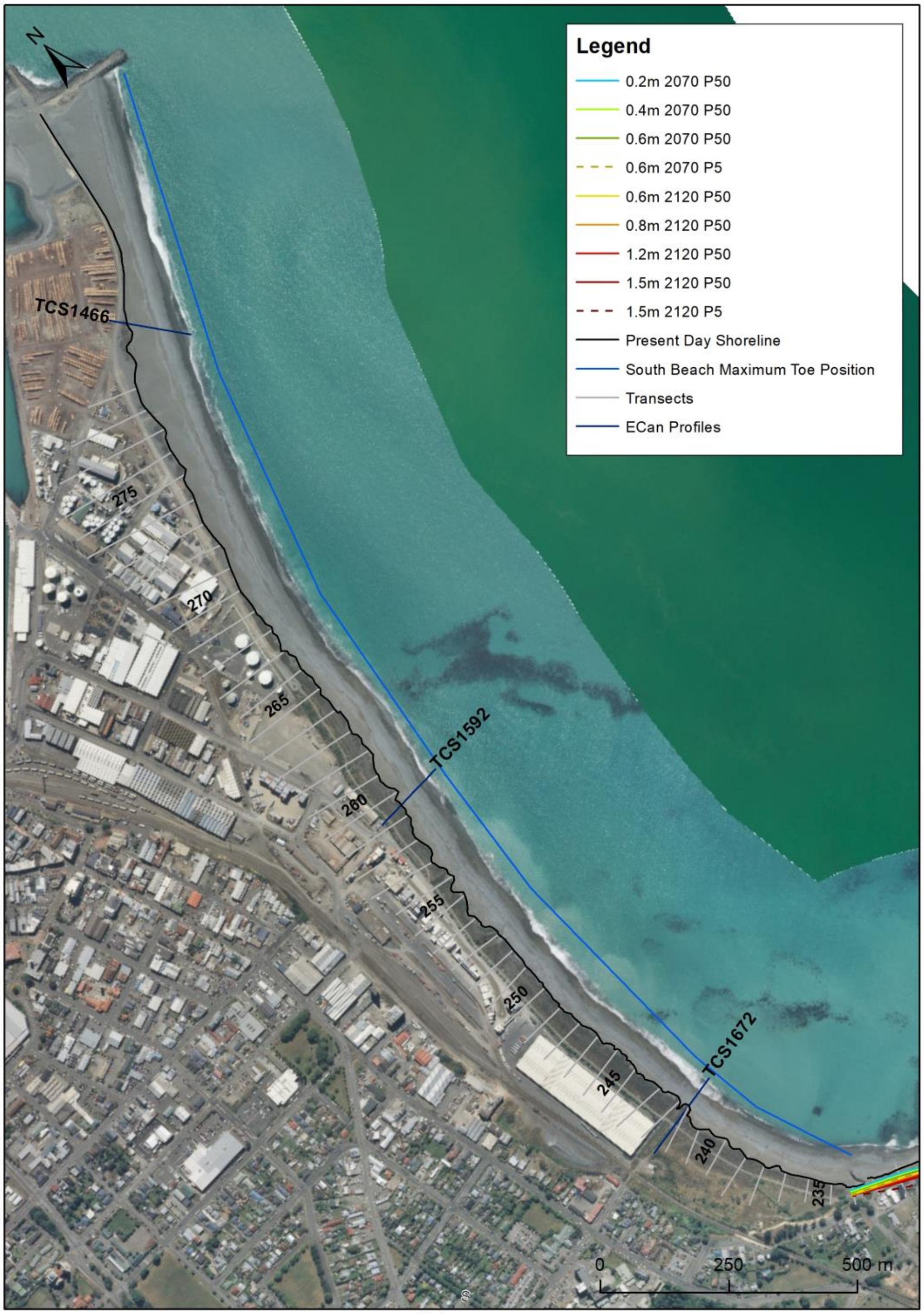
4.2 South Beach

The South Beach coastal cell is a long term accretionary MSG beach south of the Timaru Harbour, in which the Eastern Breakwater at the northern end of the beach has trapped gravel traveling north by longshore beach drift, resulting in shoreline advance since its construction in 1887. This shoreline cell is presented in Figure 4.5. Accretion rates were very rapid immediately following the construction of the breakwater, up to +18.1 m/yr in the first 17 years (Hassall,1955), and approximately half of the total shoreline progradation occurred in the 30 years up to 1909 (Kirk, 1984). After the construction of the Eastern Extension Breakwater in 1915, the gravel accumulation moved into deeper water and the shoreline advancement rate began to slow.

In 1986, the 150m long Outer Spur Groyne at the end of the Eastern Extension was constructed which allowed for more sediment to be trapped along the northern section of the beach. However, future accretion is limited by the length of this spur groyne, with sediment being able to bypass the groyne once the beach toe extends past the end of the groyne. Historical shoreline advance has been slower at the south end of the beach towards Patiti Point, being a function of the shoreline plan shape controlled by the groyne length and the beach orientation. Historical shoreline advances at Queen Street, towards the south end of the beach was reported to be in the order of 150 m from 1879 to 1967 at an average rate of 1.7 m/yr (Tierney, 1977).

Three ECan profiles have been used to represent the 2.2 km of MSG beach at South Beach. These profiles are

- TCS1672 – 775m stretch of shoreline at the southern end of South Beach (transects 235-250);
- TCS1592 – 1250 m stretch of shoreline along the central area of South Beach (transects 251-275); and
- TCS1466 – 175 m of shoreline at the northern end of South Beach (transects 276-279).



Note:
P50 is 50% chance the shoreline will be landward of this position
P5 is a 5% chance the shoreline will be landward of this position

Figure 4.5: Projected maximum South Beach toe position.

4.2.1 Shoreline Change Components

Extrapolation of Long-Term Rates

The extrapolation of long-term shoreline accretion rates at South Beach since 1956 and resulting projected accretion distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented below in Table 4.4. The extrapolated distances are purely of the historical accretion rate and do not take into account the effects of SLR into the future. In Table 4.4, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all of the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

As expected, the results show an increase in accretion rates in a northward direction, with the highest accretion rates occurring adjacent to the Outer Spur Groyne (e.g. around transects 276-279), and lowest rates occurring at the southern end near Patiti Point (e.g. around transects 235-250).

Table 4.4: Extrapolation of long term rates (1956-2017) and resulting extrapolated accretion at South Beach.

Profile	DSAS Transects	Statistic	Accretion Rate (1956-2017)	2070 Accretion Distance	2120 Accretion Distance
TCS1672 (south end)	235-250 (775 m)	Mean	+1.02 m/yr	+51.1 m	+102.3 m
		Max at individual transect	+0.74 m/yr	+37.2 m	+74.3 m
		Avg Upper 95% Confidence level	+0.71 m/yr	+35.5 m	+71.1 m
TCS1592 (central)	251-275 (1250 m)	Mean	+1.94 m/yr	+97 m	+194 m
		Max at individual transect	+1.28 m/yr	+63.9 m	+127.7 m
		Avg Upper 95% Confidence level	+1.17 m/yr	+58.7 m	+117.3 m
TCS1466 (north end)	276-279 (175 m)	Mean	+2.65 m/yr	+132.5 m	+264.9 m
		Max at individual transect	+2.62 m/yr	+130.8 m	+261.6 m
		Avg Upper 95% Confidence level	+1.69 m/yr	+84.5 m	+168.9 m

At the most southern site profile TCS1672) the average historical accretion rate is +1 m/yr, which when extrapolated into the future equates to +50 m of accretion over 50 years and +102 m of accretion over 100 years. For the central part of the beach (profile TCS1592) extrapolation of the historical accretion rates over the last 60 years gives shoreline advance distances nearly double those at the southern end, in the order of 100 m over 50 years and 195 m over 100 years. At the northern end adjacent to the Spur Groyne, the extrapolated accretion gives shoreline advance in the order of 130 m over 50 years and 265 m over 100 years.

However, assuming that the Spur Groyne is not extended to keep up with the accretion rate, these magnitudes of advance would not be possible due to the beach width being limited by the length of the groyne. Based on the 2017 aerial image presented in Figure 4.5, there is potentially only 50 m of future accretion possible, which under the current accretion rates at the groyne implies than future beach growth would only occur for another 20 -30 years (from lower 95% confidence accretion rate). For plan shape considerations, the corresponding accretion at the central part of South Beach would be limited to around 40 m, and around 20 m at the southern end.

Short Term Storm Effect

Along this section of the coastline, the effect of short term storm erosion at each of the three ECan profiles is relatively similar. The following summarises the short term storm effect at each ECan profile used at South Beach:

- For profile TCS1672, the maximum recorded inter-survey erosion was -4.6 m between March and September 1992, in which seven storms were recorded including significant events in May, June, and August. The GEV distribution of inter-survey erosion returned a mean erosion distance of -5.4 m erosion for a 100-year ARI erosion event, with a 99% confidence level of -7.3 m.
- For profile TSC1592, the maximum inter-survey erosion was -3.3 m of erosion between March and May 1992, in which four storms were recorded, including the May significant event. The GEV distribution of inter-survey erosion returned a mean erosion distance of -3.8 m of erosion for a 100-year ARI erosion event, with a 99% confidence level of -6 m.
- For profile TCS1466, the maximum inter-survey erosion was -6.4 m of erosion between March and August 2002, in which five storms were recorded on the ECan storm database. The GEV distribution of inter-survey erosion data returned a mean erosion distance of -6.8 m of erosion for a 100-year ARI erosion event, with a 99% confidence level of -17.7 m.

Sea Level Rise Effect

The erosion effect from SLR was calculated using the modified Bruun rule adjusted for the gravel ridges (See Section 2.2.4 and Appendix A for methodology). The predicted amount of erosion from accelerated SLR at each profile is summarised below in Table 4.5.

The results indicate that each of the three parts of South Beach will have a very similar erosion response to accelerated SLR. Over the next 50 years, South Beach could expect to see up to -8 m of erosion, with a 95% confidence level of retreat less than -10 m. Over 100 years, the effect of SLR could result in up to -20 m of erosion, with a 95% confidence level of up to -24 m. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches. This response to SLR assumes no sediment accumulation or subsequent change in beach profile as the beach continues to accrete as a result of the long term historical accretion rate.

These erosion rates are significantly smaller than rates of long term accretion at this beach, and therefore the effect of SLR will slow the rate of accretion at the beach, but over the next 100 years, the long term accretionary trend will not be changed into a stable or erosional state.

Table 4.5: Predicted erosion from future SLR at ECan profiles along South Beach.

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
TCS1672 (south end)	235-250 (775 m)	Mean	-1.2 m	-3.6 m	-5.9 m	-4.7 m	-7.1 m	-11.9 m	-15.4 m
		Max	-1.6 m	-4.8 m	-8 m	-6.4 m	-9.6 m	-15.9 m	-20.7 m
TCS1592 (central)	251-275 (1250 m)	Mean	-1.5 m	-4.5 m	-7.6 m	-6.1 m	-9.1 m	-15.1 m	-19.7 m
		Max	-1.9 m	-5.6 m	-9.3 m	-7.5 m	-11.2 m	-18.6 m	-24.2 m
TCS1466 (north end)	276-279 (175 m)	Mean	-1.5 m	-4.5 m	-7.5 m	-6 m	-8.9 m	-14.9 m	-19.4 m
		Max	-1.8 m	-5.4 m	-9.1 m	-7.2 m	-10.9 m	-18.1 m	-23.5 m

4.2.2 Projected Future Shoreline Positions (PFSP)

PFSP's for 50 and 100 years were not produced for the South Bay coastal cell due to the extrapolation of historical accretion rates resulting in the beach toe at the northern end extending beyond the Spur Groyne before these timeframes. Instead, as shown in Figure 4.5, we have mapped the indicative seaward position of the beach nearshore step for this coastal cell. As indicated above, this position 'most likely' will be reached in around 20 years. Note this is a different beach reference position that is mapped for other coastal cells, where we have used the vegetation line as a proxy for the beach crest. However, this is not appropriate at South Beach due to the disturbed nature of the beach at this location, and the inability of this position to represent the limits on accretion distances.

4.3 Caroline Bay

Caroline Bay is the only Sand Beach along the Timaru District coastline and owes its existence to the presence of breakwaters at the Timaru Harbour. Prior to the construction of the Timaru Harbour, Caroline Bay was a gravel beach backed by loess cliffs. Following the construction of the harbor this gravel was eroded by longshore transport following the harbour construction and not able to be replenished due to the trapping effect of the Eastern breakwater. However, sand began accumulating in Caroline Bay in the lee of the northern breakwater following its construction in 1887. The bay has continued to accrete at a rapid rate with Fahy (1986) reporting that shoreline advancement of 640 m occurred between 1887 and 1986 at an average rate of 6 m/yr. Accretion has continued at Caroline Bay to the present day with sand at the western end of the bay now extending around Benvenue cliff and spreading around into the eastern end of Waimataitai Bay. This shoreline cell is presented below in Figure 4.6.

Two ECan profiles were used to represent the sand beach morphology at Caroline Bay: TCS1362 (transects 280-287) covering a 375 m section of shoreline in the centre of the bay, and TCS1350 (transects 288 to 293) covering a 275 m section of shoreline at the western end of the bay.

4.3.1 Shoreline Change Components

Extrapolation of Long-Term Rates

The extrapolation of long-term accretion rates since 1938 and resulting projected advance distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 4.6. The extrapolated distances are purely of the historical accretion rate and do not take into account the effects of SLR into the future. In Table 4.6, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

The results indicate that based on the historical rates of accretion over the last 80 years, shoreline advance over the next 50 years is projected to be in the order of +225 m around the centre of the bay and +160 m at the western end. Over a 100 year timeframe, the extrapolation of historical rates equates to +450 m in the centre and +325 m at the western end.

Figure 4.6: PFSP at Caroline Bay. "Most likely" (P50) is shown for each scenario except 1.5m at 2120 and "very unlikely" (P5) shown for 0.6m at 2070 and 1.5m at 2120 (highest SLR scenarios).

Table 4.6 also indicates that based on the past trends, we can be 95% confident that accretion will continue by at least 120 -170 m over the next 50 years and by at least 240-350 m over the next 100 years. However, as accretion continues into deeper water, the wave energy arriving at the shore will increase, which is likely to reduce the rates and magnitudes of future beach accretion. Any assessment of how the wave climate would change with continued accretion is out of scope for this project, however, such an assessment would provide information on the maximum extent the shoreline could advance with a changing wave climate.

Table 4.6: Extrapolation of long-term rates (1938-2017) and resulting extrapolated accretion at Caroline Bay

Profile	DSAS Transects	Statistic	Accretion Rate (1938-2017)	2070 Accretion Distance	2120 Accretion Distance
TCS1362 (east - central bay)	280-287 (375 m)	Mean	+4.51 m/yr	+225.5 m	+451 m
		Max at individual transect	+4.19 m/yr	+209.3 m	+418.6 m
		Avg Upper 95% Confidence level	+3.46 m/yr	+173.1 m	+346.2 m
TCS1350 (western bay)	288-293 (275 m)	Mean	+3.25 m/yr	+162.7 m	+325.4 m
		Max at individual transect	+2.78 m/yr	+139.1 m	+278.3 m
		Avg Upper 95% Confidence level	+2.40 m/yr	+119.9 m	+239.8 m

Short Term Storm Effects

The backshore of the beach at Caroline Bay is very stable due to the long term accretionary trend. Short term storm erosion was therefore calculated from the top of the beach face, at approximately 1 to 1.5m contour. The erosion experienced here is conservative given the face of the profile at Caroline Bay is very dynamic, however, we would expect storms to erode the beach face even more as the beach continues to accrete outwards.

At ECan profile TCS1362, the maximum inter-survey erosion was -40.2 m, which occurred between March and September 1992, in which seven storms were recorded including three significant events in May, June, and August. Hence, the erosion distance can be considered to be conservative as it is a response to multiple storms in series rather than an individual event. For this profile, the GEV distribution of inter-survey erosion returned a mean value of -50.9 m erosion in a 100-year ARI event, with a 99% confidence level of -90 m.

At TCS1350 the maximum inter-survey erosion was -20.8 m which also occurred between March and September 1992. The GEV distribution of inter-survey erosion returned a mean value of -28.3 m of erosion in a 100-year ARI event, with a 99% confidence level of -48.4 m of erosion.

Sea Level Rise Effect

The erosion effect of accelerated SLR at Caroline Bay was calculated using the Bruun Rule (1962). The shallow gradient of the sand beach and the finer material which is easily moved creates larger erosion effects at sand beaches when compared to gravel beach environments. As shown below in Table 4.7, for both parts of the bay the effects of accelerated SLR are similar, with projected erosion of around -40 m in 50 years, and up to -110 m over the next 100 years.

Although these erosion distances seem large relative to adjacent gravel beaches, they are less than the long-term accretion rates, hence, the projected accretionary trend is not likely to be overturned into a stable or erosional trend under any of the SLR scenarios.

Table 4.7: Predicted erosion from future SLR at ECan profiles in Caroline Bay.

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
TCS1362	280-287	Mean	-8.1 m	-24.3 m	-40.5 m	-32.4 m	-48.6 m	-81.1 m	-105.4 m
		Max	-8.4 m	-25.2 m	-42.1 m	-33.6 m	-50.5 m	-84.1 m	-109.3 m
TCS1350	288-293	Mean	-8.4 m	-25.1 m	-41.8 m	-33.4 m	-50.1 m	-83.6 m	-108.7 m
		Max	-8.5 m	-25.5 m	-42.5 m	-34 m	-51 m	-85.1 m	-110.6 m

4.3.2 Projected Future Shoreline Positions

The PFSP at Caroline Bay, presented in Figure 4.6, show continued advancement of the shoreline with slightly more advancement in the southeast corner due to the higher historical accretionary trend occurring there. Further maps showing the P9 PSFP for all SLR scenarios are presented in Appendix E (Map 3B). It should be noted that the shoreline positions mapped are the vegetation edge, and that foreshore advance at the western end will continue to extend around Benvenue cliff into eastern Waimataitai Bay. A summary of the projected accretion distances to the PFSP from the present-day shoreline is presented below in Table 4.8. A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

The advancement of this shoreline on average could be up to +130 m over the next 50 years, and in the order of +290 m over the next 100 years. The high historical accretion rates at Caroline Bay indicate that accretion will continue in the future well beyond the next 100 years, but at a slower rate due to the effects of SLR. However, it is noted that the 100-year PFSP is likely to be an overestimate because the wave energy arriving at the shore is likely to increase as the shoreline advances into less sheltered water. Although further modeling to better understand the change in nearshore wave climate with continuous shoreline advancement is out of scope for this assessment, it is included as a recommendation of further investigations required to reduce uncertainties of this assessment.

Table 4.8: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP at Caroline Bay.

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
TCS1362 (east – central bay)	280-287 (375 m)	Most likely	+163.1 m	+146.8 m	+130.8 m	+364.2 m	+347.9 m	+315.5 m	+291.7 m
		Very unlikely	+120.3 m	+104.1 m	+88 m	+289.2 m	+272.9 m	+240.5 m	+216.3 m
TCS1350 (western bay)	288-293 (275 m)	Most likely	+124.3 m	+107.9 m	+91.6 m	+262.2 m	+246.4 m	+213.4 m	+189.1 m
		Very unlikely	+92.9 m	+76.7 m	+60.1 m	+202.9 m	+186.5 m	+153.8 m	+129.3 m

Relative Contribution of the Components

As shown in Figure 4.7, the largest component of the shoreline change to the PFSP at Caroline Bay, is the extrapolation of the long term accretion. The erosional components of short term storm effect and SLR effects are relatively similar, however when combined only equate to 25-33% of the long term accretion rate. Therefore, Caroline Bay will continue to accrete over at least the next 100 years rather than change into a stable or erosional trend.

Potentially Impacted Assets

The predicted continued future accretion at Caroline Bay means that there will be no loss of infrastructure around Caroline Bay and the public can expect to still utilise the amenities and public infrastructure located near the beach.

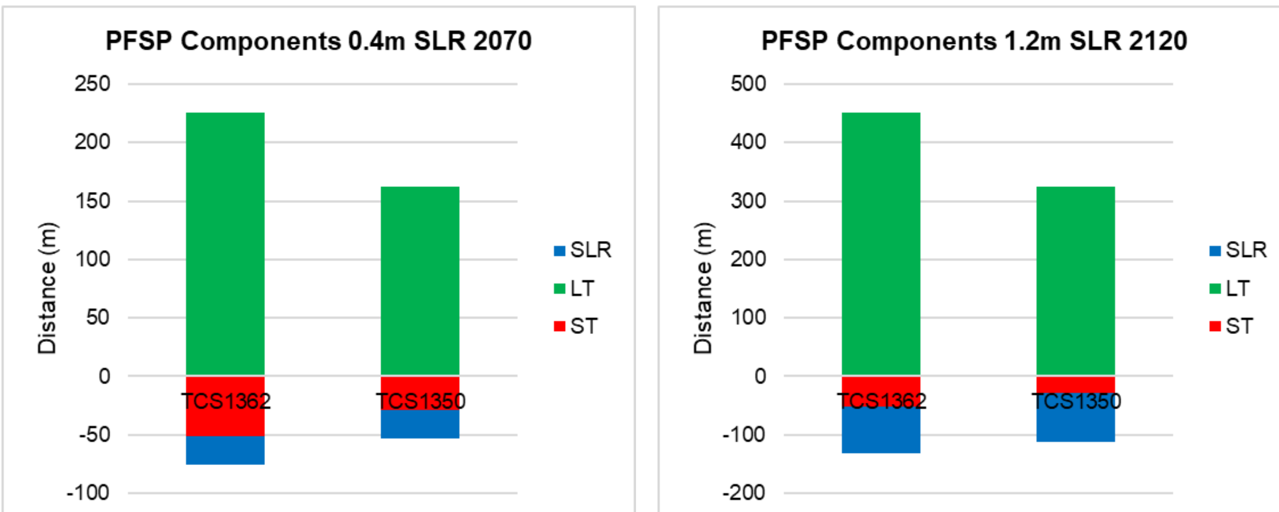
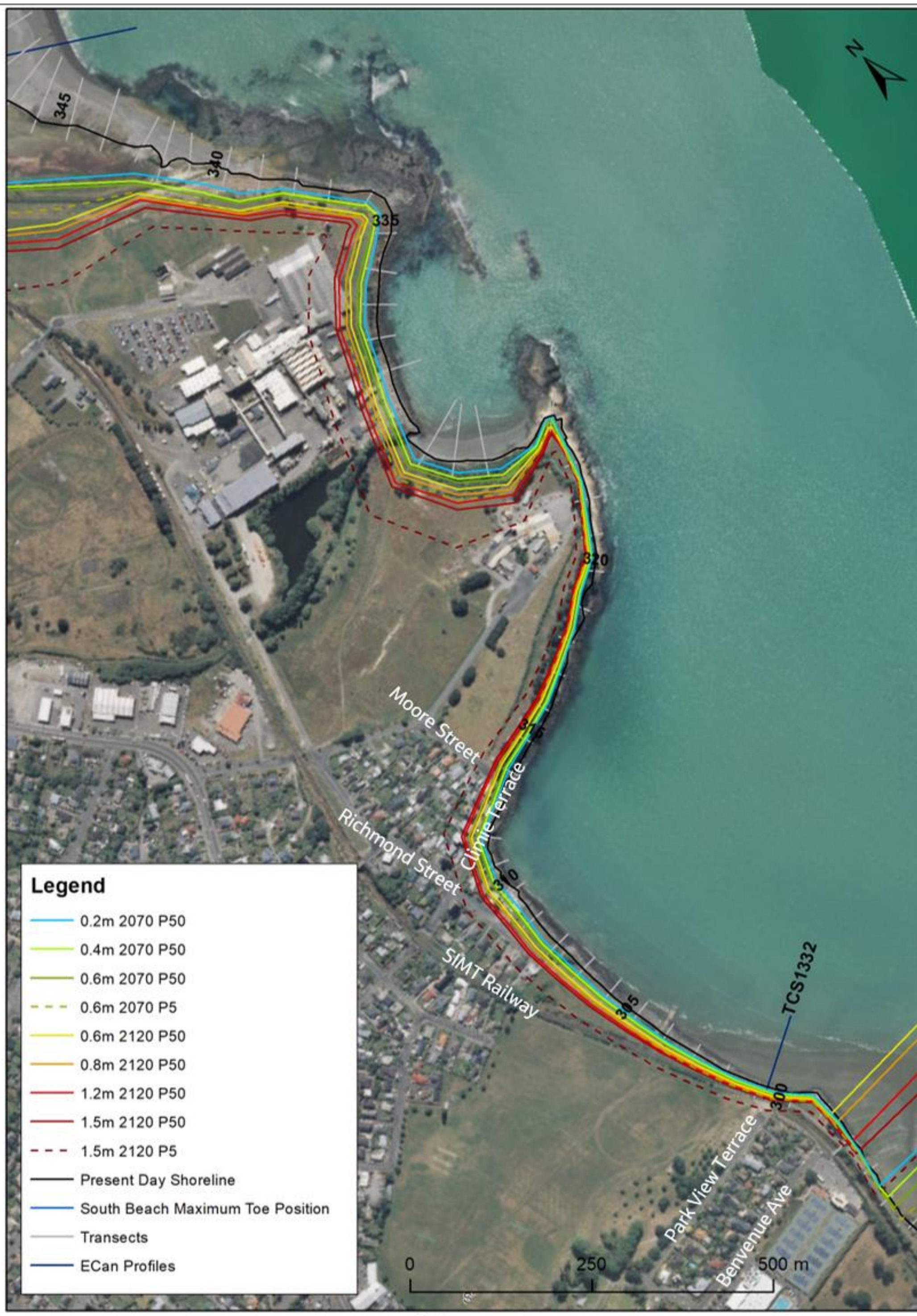


Figure 4.7: Average component makeup of PFSP lines at two ECan profiles at Caroline Bay, showing the different component inputs into calculating PFSP lines for (left) 0.4m of SLR by 2070, and (right) 1.2m of SLR by 2120. Negative numbers indicate erosion and positive numbers indicate accretion.

4.4 Waimataitai Bay and Dashing Rocks

The Waimataitai Bay section of this coastal cell is a combination of a protected raised railway embankment or loess cliff, while Dashing Rocks is a basaltic headland topped with a loess cliff. At the embayment in front of the Smithfield Works there is also a revetment structure protecting the frontage of the works. This shoreline cell is presented below in Figure 4.8.

Prior to the construction of the Timaru Harbour, there was a continuous shingle beach from Caroline Bay through to Washdyke Lagoon, with Waimataitai Bay being a lagoon separated from the sea by a large gravel barrier from Benvenue cliffs to the south-east corner of Dashing Rocks. Following the construction of the harbour, there was significant erosion to the gravel barrier due to sediment starvation. From the late 1880s to the early 1900s, the rolling back of the barrier reduced the size of the lagoon, and by 1933 it had completely disappeared. By the 1940s erosion was a significant issue in the Waimataitai and Dashing Rocks area, and by 1954 the large boulder revetment structure was constructed along the current shoreline of the east-facing section of Waimataitai Bay. This structure is reasonably stable, and the historical erosion was calculated based on the position of the back of the structure. At Dashing Rocks, erosion was calculated from the movement of the top of the loess cliff taking into account changes in orientation of the cliff line between the SSE, ESE, NE facing sections. Between transects 330 to 334 there is a protective rock revetment structure in front of the Smithfield works, which from aerial imagery can be seen in 1956 at the mouth of the Taitarakihi Creek, and progressively built in a north east direction along the cliff face, being completed to its current footprint in 1977 (from aerial imagery).



Note:
P50 is 50% chance the shoreline will be landward of this position
P5 is a 5% chance the shoreline will be landward of this position

Figure 4.8: PFSP at Waimataitai Bay and Dashing Rocks. "Most likely" (P50) is shown for each scenario except 1.5m at 2120, and "very unlikely" (P5) shown for 0.6m at 2070, and 1.5m at 2120 (highest SLR scenarios).

There are two ECan profiles used to represent the shoreline along the Dashing Rocks and Waitmataitai Bay shoreline. Profile TCS1332 (transects 295 to 321) is used to represent the 1.3 km revetment east-facing section of Waimataitai Bay and the naturally protected SSE facing section of Dashing Rocks. Profile TCS1732 is used to represent the 1 km of more exposed ESE facing section of Dashing Rocks (transects 322 to 343) and NE facing transition section into the MSG barrier at Washdyke Lagoon, including the rock revetment from transects 330-334 in front of the Smithfield Works. TCS1732 is situated at Patiti Point, but its morphology is similar to Dashing Rocks and is therefore used for input into the short-term storm erosion component in the absence of a profile being located at Dashing Rocks itself. Note that profile input is not required for the calculation of the SLR effects on erosion as for cliff environments this is calculated by accelerating the historical erosion rate by a ratio of the future SLR to the current rate of rise.

4.4.1 Erosion Components

Extrapolation of Long-Term Rates

The extrapolation of long-term erosion rates from 1938 to 2017 and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 4.9. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 4.9, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

The long-term erosion observed at both segments of this coastal cell are most likely to be sub-aerial processes such as wave splay and slope failure mechanisms due to surface water run-off on the loess cliffs behind or above the placed and natural protection material.

Table 4.9: Extrapolation of long-term erosion rates (1938-2017) and resulting in projected erosion at Dashing Rocks and Waimataitai Bay.

Profile	DSAS Transects	Statistic	Erosion Rate (1938-2017)	2070 Erosion Distance	2120 Erosion Distance
TCS1332 (protected Waimataitai Bay)	295-321 (1.3 km)	Mean	-0.03 m/yr	-1.7 m	-3.3 m
		Max at individual transect	-0.10 m/yr	-4.9 m	-9.8 m
		Avg Upper 95% Confidence level	-0.21 m/yr	-10.7 m	-21.4 m
TCS1732 (Exposed Dashing Rocks)	322-343 (1 km)	Mean	-0.21 m/yr	-10.3 m	-20.5 m
		Max at individual transect	-0.47 m/yr	-23.6 m	-47.2 m
		Avg Upper 95% Confidence level	-0.58 m/yr	-28.9 m	-57.8 m

For the section of Waimataitai Bay protected by the revetment the average long term historical erosion rate is -0.03 m/yr, which when extrapolated into the future, equates to -1.7 m of erosion in the next 50 years and -3.3 m in the next 100 years. This rate is very low as the shoreline is a hard structure that has been maintained in its current position since its construction over 60 years ago. As indicated in Table 4.9, there is a relatively large degree of uncertainty in the long-term erosion rates due to a poor definition of the linear trend, with there being a 5% chance that erosion distances could exceed -10 m over the next 50 years, and over -21 m over the next 100 years. However, these results would imply the current protection revetment is not maintained in the future.

For the exposed Dashing Rocks section (transects 322 to 343), the average long term historical erosion rate across all transects is -0.2 m/yr. When this is extrapolated into the future, this equates to -10 m of erosion over the next 50 years and -20 m over the next 100 years. However, the erosion rates across this section of the headland vary significantly in relation to shoreline orientation, with the NE facing transects at the northern end of the headland (e.g. transects 340-343) positioned across the transition between the gravel barrier and cliff morphologies having higher erosion rates (-0.5 m/yr). These higher rates at these transects have been taken into account when mapping the PFSP lines, with the running averages that were used to construct PFSP being limited to transects with similar orientations. At the section of rock revetment across transects 330-334, the average historical erosion rate is -0.16 m/yr, which includes the period of erosion (1938-1956) prior to the construction of the revetment between 1956-1977.

Short Term Storm Effects

The short term erosion components at both ECan profiles are minimal due to the resistant nature of the shoreline morphologies which are subject to very infrequent episodic erosion.

At ECan profile TCS1332 in Waimataitai Bay, the maximum inter-survey erosion was -0.7 m, which occurred between March and September 2007, in which two storms were recorded in the ECan storm register. For this profile, the GEV distribution of inter-survey erosion returned a mean value of -0.7 m erosion in a 1 in 100-year ARI event, with a 99% confidence level of -1.3 m.

As previously mentioned, the short-term erosion at Dashing Rocks is represented by proxy transect TCS1732 located at Patiti Point. The short-term erosion component at this site was assessed using the 5.5 m contour as representative of cliff face erosion. Although there has been a rapid recent cliff retreat, the maximum recorded inter-survey erosion was -0.9 m between Sept 1992 and March 1993. The GEV distribution of inter-survey erosion returned an erosion distance of -1.3 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of -2.6 m.

Sea Level Rise Effect

The effect of SLR along this section of coastline was calculated using the modified Walkden & Dickson (2008) relationship for volume effect for the loess cliff segments represented by ECan profiles. Since under this method the rate of future erosion is determined from the past rate, the presence of highly resistant basalt at both Dashing Rocks (natural) and Waimataitai Bay (placed) has resulted in minimal historical erosion rates. The projected future rates due to accelerated SLR as presented in Table 4.10 are also low.

Table 4.10: Predicted erosion from future SLR at ECan profiles at Waimataitai and Dashing Rocks

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
TCS1332 (Waimataitai Bay)	295-321	Mean	-0.6 m	-1.5 m	-2.2 m	-2.2 m	-3.0 m	-4.5 m	-5.4 m
		Max	-3.7 m	-9.6 m	-14.2 m	-13.8 m	-19.3 m	-28.4 m	-34.3 m
TCS1732 (Dashing Rocks)	322-343	Mean	-3.5 m	-9.2 m	-13.6 m	-13.3 m	-18.5 m	-27.2 m	-32.9 m
		Max	-9.9 m	-26 m	-38.3 m	-37.3 m	-52 m	-76.7 m	-92.5 m

At Waimataitai Bay, projected erosion due to accelerated SLR over the next 50 years is only -2.2 m and –5 m over 100 years. The occurrence of this erosion implies that the protection works are not maintained. At Dashing rocks, the projected erosion due to accelerated SLR are higher being -15 m over 50 years and around -32 m over the next 100 years due to increased wave interaction with the cliff loess cliff above the protective natural basalt layer at the base of the cliff. However, these distances are likely to be conservative due to the greater widening of the basalt platform as the loess cliff retreats.

4.4.2 Projected Future Shoreline Positions

The calculated PFSP for the Waimataitai-Dashing Rocks coastal cell are presented below in Table 4.11 and are presented spatially in Figure 4.8 with the P50 position representing the 'most likely' position and P5 position representing the 'very unlikely' position under the highest SLR scenarios considered in this assessment of 0.6 m by 2070 and 1.5 m by 2120. Further maps showing the P5 PSFP for all SLR scenarios are presented in Appendix E (Maps 3B and 3C). A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

As pointed out in Appendix A (Section A.2.1), the erosion distances presented in Table 4.11 are higher than would be expected due to the influence of the negatively skewed triangular distribution for long-term erosion used in the Monte Carlo simulation. For Waimataitai Bay, assuming the continued maintenance and upkeep of the current revetment structure, the PFSP would be expected to be similar to the current shoreline position. However, the erosion distances given in the Table can be considered to be relevant for a "non-maintenance" scenario, under which 'most likely' erosion could be up to -10 m within 50 years and up to -20 m within 100 years. The probability analysis indicates that due to uncertainties in the data there is a 5% chance that these erosion distances could be up to 7 m greater within 50 years, and up to 17 m greater over 100 years.

For the exposed loess cliffs at Dashing Rocks, the results indicate that the erosion distances may be up to -30 m within 50 years and -65 m within 100 years. However, erosion distances are also conservative due to the negatively skewed triangular distribution for long-term erosion used in the Monte Carlo simulation. At Transects 330-334, the PFSP distances are on average -14 to -26 m over the next 50 years, and -34 to -55 m over the next 100 years. These distances are considered to be relevant for a "non-maintenance" scenario, however, assuming the continued maintenance and upkeep of the current revetment structure, the PFSP would be expected to be similar to the current shoreline position.

Table 4.11: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP at Waimataitai and Dashing Rocks.

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
TCS1332 (Waimataitai Bay)	295-321 (1.3 km)	Most likely	-6m	-8.5m	-10.2m	-13.9m	-16.2m	-19.6m	-21.7m
		Very unlikely	-10.9m	-14.3m	-17.4m	-24.3	-27.7m	-33.9m	-38.2m
TCS1732 (Dashing Rocks)	322-343 (1 km)	Most likely	-17.2m	-24.7m	-30.3m	-41.2m	-47.9m	-59.1m	-66.3m
		Very unlikely	-29.7m	-39.6m	-48.4m	-68.2m	-77.7m	-95.3m	-106.9m

Relative Contribution of the Components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 4.9. At Waimataitai Bay, the contribution of the extrapolation of the long term rate and SLR effect are similar over a 50-year timeframe both contributing around 40% each, while over 100 years the SLR contribution increases to 50%.

At Dashing Rocks, within a 50-year timeframe, the long term erosion contributes around 50% of the total erosion and SLR affects around 45%. These contributions are reversed within a 100-year time frame with the SLR effect becoming the dominant contribution.

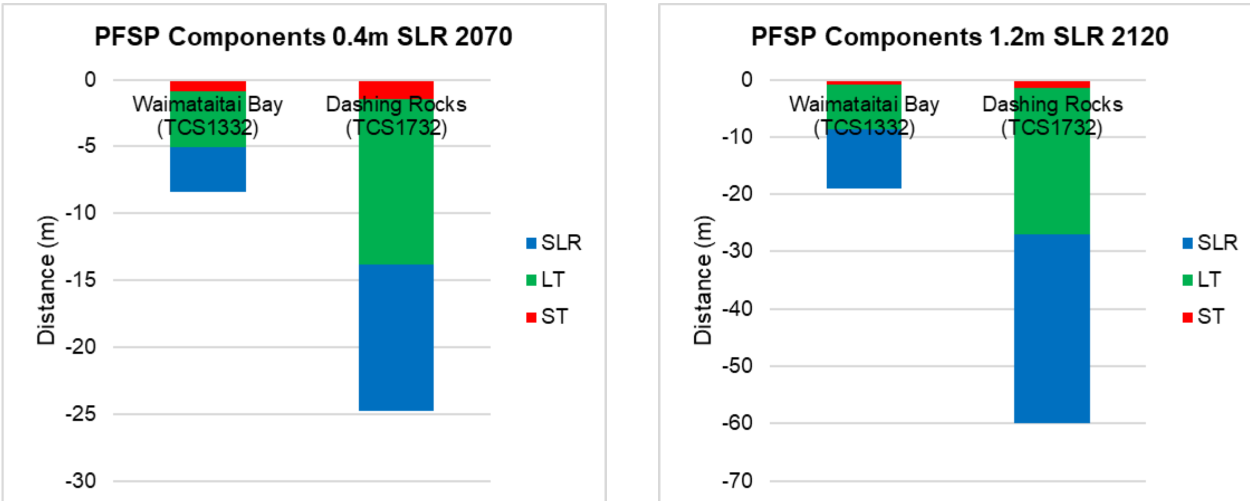


Figure 4.9: Contribution of each component of the erosion to the PFSP at Waimataitai Bay-Dashing Rocks for SLR scenarios of 0.4m by 2070 (Left) and 1.2m by 2120 (Right)

Potentially Impacted Assets

As shown in Figure 4.8, at the southern and of Waimataitai Bay near Park View Terrace, the SIMT railway line could be compromised by erosion within 50 years, and most likely effected within 100 years if the current rock revetment is not maintained. Similarly, road ends of Richmond Street, Climie Terrace, and Moore Street could be affected within 50 years, and most likely will be eroded within 100 years without continuation of the protection works. Only small sections of these roads are likely to be compromised by erosion, and maintenance of the revetment structure would provide protection in the future.

5. Results: North of Timaru

The following sections present the findings of this assessment and the calculated PFSP for the coastline north of the Timaru urban area. This coastline is the southern 30 km of the Canterbury Bight. The findings are presented in sections from south to north based on different geomorphic and contextual settings. Overview maps of both 2070 and 2120 SLR scenarios are presented in Appendix E (Maps 3-8, 3D (Washdyke Lagoon), 5A (Opihi Mouth), and 8A (south Rangitata Huts)). Shapefiles of these lines were also provided to ECan and Timaru District Council for use in ArcGIS to provide further detail.

5.1 Washdyke Lagoon

Washdyke Lagoon, located in the lee of Dashing Rocks is a regionally significant ecological feature and classified as a wildlife refuge. The lagoon collects drainage water from the Seadown Plain via the Seadown Drain and Washdyke Creek but has no natural opening to the sea through the MSG barrier that forms the shoreline. However, the lagoon drains via culvert pipes located at the southern end and is known to periodically breach the barrier in this location when the lagoon is full.

As stated in Section 1.3, over the past 150 years this section of shoreline has experienced on-going rapid erosion due to limited gravel input from the south and a high frequency of beach rollover of the beach barrier which is progressively reducing in elevation, with retreat distances in the order of 440 m at the southern to central parts of the lagoon. Since 2001 material dredged from the Port of Timaru entrance channel is placed approximately 1 km offshore of the barrier to provide some degree of potential beach renourishment. However, there is no conclusive evidence on how successful this practice has been in reducing erosion rates on the Washdyke barrier and further north along the Seadown coast.

The shoreline covered in this lagoon cell is approximately 1.9 km long, extending north to Aorangi Road and is includes DSAS transects 344 – 382 (Figure 5.1). Four ECan profiles are used to represent the gravel barrier morphology along this section of coastline. These profiles from south to north and the corresponding DSAS transects are:

- WCS1195 (transects 344 to 355) approximately 575 m;
- WCS1135 (transects 356 to 363) approximately 400 m;
- WCS1105 (transects 364 to 375) approximately 600 m; and
- WCS1035 (transects 376 to 382) approximately 325 m

5.1.1 Erosion Components

Extrapolation of Long-Term Rates

For this assessment, the long-term historical erosion rate for Washdyke Lagoon is limited to shorelines mapped from aerial imagery since May 1956. This more than 60-year period avoids the extremely rapid retreat at rates in the order of -4 m/yr to -5 m/yr for the 1932 – 1956 period as reported by Todd (1989), as they are not considered to be relevant to the current coastal processes regime.

The extrapolation of long-term erosion rates and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 5.1. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 5.1, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;

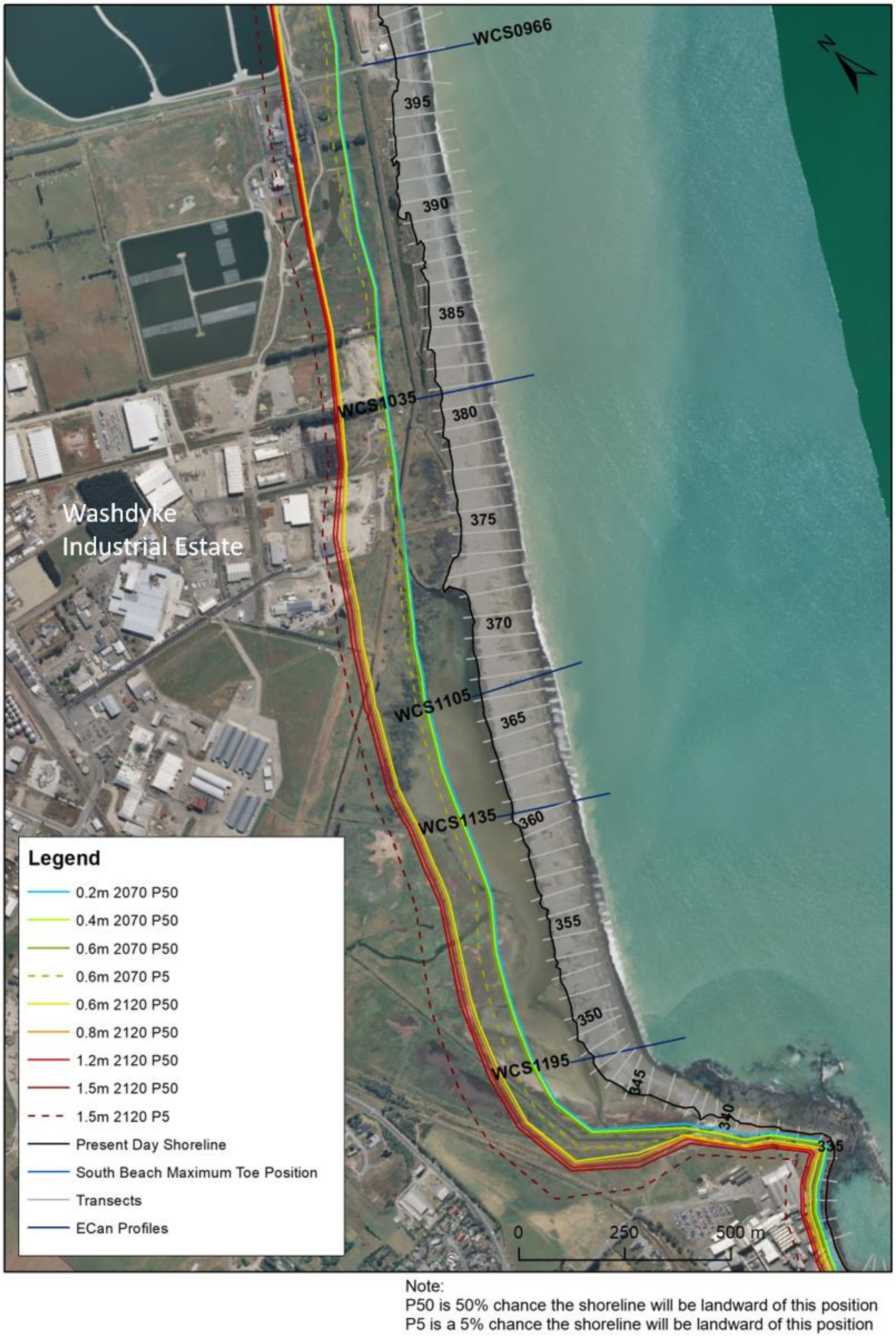


Figure 5.1: Washdyke Lagoon PFSP for various SLR scenarios in 2070 and 2120. 'Most likely' position(P50) is shown for each scenario, and 'very unlikely' (P5) shown for SLR scenarios of 0.6m by 2070 and 1.5m by 2120 (highest SLR scenarios).

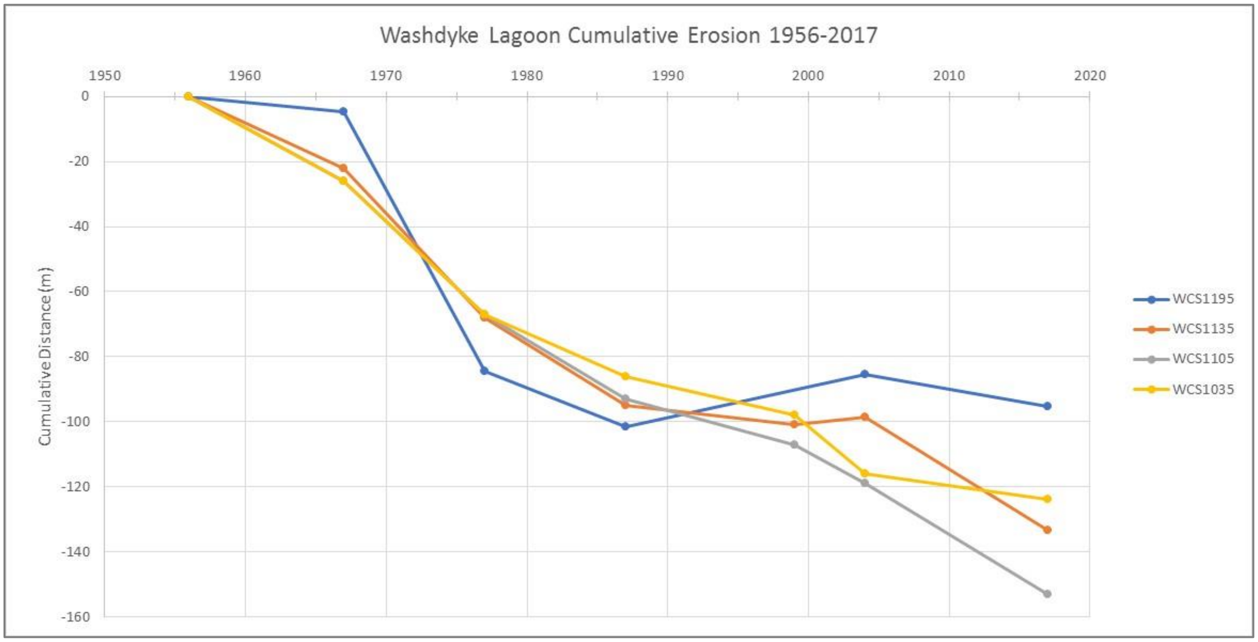


Figure 5.2: : Cumulative erosion of ECan profile sites at Washdyke Lagoon from 1956-2017.

- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

Table 5.1: Extrapolation of long-term erosion rates (1956-2017) and resulting projected erosion at Washdyke Lagoon.

Profile	DSAS Transects	Statistic	Erosion Rate (1956-2017)	2070 Erosion Distance	2120 Erosion Distance
WCS1195 (south end of lagoon)	344-355 (575 m)	Mean	-1.58 m/yr	-79.2 m	-158.5 m
		Max at individual transect	-1.78 m/yr	-89.0 m	-177.9 m
		Avg Upper 95% Confidence level	-2.62 m/yr	-131.1 m	-262.1 m
WCS1135 (central lagoon)	356-363 (400 m)	Mean	-1.98 m/yr	-99.3 m	-198.6 m
		Max at individual transect	-2.19 m/yr	-109.4 m	-218.7 m
		Avg Upper 95% Confidence level	-2.66 m/yr	-133.1 m	-266.2 m
WCS1105 (central lagoon)	364-375 (600 m)	Mean	-2.34 m/yr	-116.8 m	-233.6 m
		Max at individual transect	-2.41 m/yr	-120.6 m	-241.3 m
		Avg Upper 95% Confidence level	-2.76 m/yr	-137.9 m	-275.7 m
WCS1035 (north lagoon)	376-382 (325 m)	Mean	-2.1 m/yr	-109.5 m	-219.0 m
		Max at individual transect	-2.41 m/yr	-114.4 m	-228.7 m
		Avg Upper 95% Confidence level	-2.58 m/yr	-128.8 m	-257.6 m

As can be seen from Table 5.1, retreat rates are the lowest at the southern end of the lagoon, where the beach is now protected to some degree from south-easterly events by the increasing headland effect of Dashing Rocks. Average retreat rates in this 575 m section over the last 60 years are in the order of -1.6 m/yr, which when extrapolated in the future equate to around -80 m of retreat in the next 50 years, and around -160 m of retreat over a 100-year timeframe. However, the probability analysis indicates that due to temporal variability in the historical erosion rates, we have considerable uncertainty in the calculated rates, with there being a 5% probability that erosion distances at this end of the lagoon cell could be up to 50 m greater over a 50-year time frame and up to 100 m more over a 100-year time frame.

The historical erosion rate increases toward the central section of the lagoon, peaking at -2.4 m/yr for transects 369-371, where there is no sheltering effect of Dashing Rocks on SE events, and the barrier rollover is into the deepest part of the lagoon, hence the barrier is likely to suffer greater elevation reduction with limited sediment supply. When extrapolated into the future these erosion rates result in projected retreat under current sea level and process conditions of up to -120 m in the next 50 years and -240 m over 100 years across 150 m of shoreline. There is little temporal variability in the historical trends for these transects, resulting in small uncertainty in the future projections, with there being a 5% probability that erosion distances could be up to 20 m greater in 50 years, and 40 m greater over 100 years.

The rates of retreat then reduce towards the northern end of the lagoon as barrier rollover is on to higher elevation lagoon bed and the beach benefits from the longshore supply of sediment from erosion of the barrier to the south. Average historical erosion rates for this northern section of Washdyke Lagoon are in the order of -2.1 m/yr, resulting in extrapolated future erosion distances of -110 m in 50 years and -220 m in 100 years. Again, there is little temporal variability in the historical rates, resulting in low uncertainty of the extrapolated erosion distances.

However, it is noted that the extrapolated future erosion distances do not account for likely sediment volume losses from the barrier as the barrier rolls back into the lagoon and the loss of elevation as the remaining volume is stretched over a greater shoreline length. Therefore the assessment does not address the possibility of future permanent breaching and disintegration of the barrier due to lack of sufficient volume (e.g. as had previously occurred at Waimataitai), which would have a significant effect on the future erosion rates and adds considerable uncertainty to the time that barrier may be located along the western edge of the lagoon.

Short Term Storm Erosion

Details of the maximum inter-survey period erosion at each of the ECan profile sites used in the assessment to determine the short-term storm erosion component of the PFSP are as follows:

- WCS1195 (South end of the lagoon): Maximum inter-survey erosion of -28.6 m between March and June 1990, in which there were two storms recorded in the ECan storm database, including an event in May classified as being significant. The GEV distribution of inter-survey erosion returned an erosion distance of -42 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of –72.8 m. This demonstrates a high degree of uncertainty of the magnitude of short-term erosion possible along this section of the Lagoon barrier.
- WCS1135 (Central lagoon): Maximum inter-survey erosion of -10.9 m between March and Sept 1992, a period within which there were seven storms recorded in the ECan storm database, including three events classified as being significant (May, June, and August). The GEV distribution of inter-survey erosion returned an erosion distance of –13.7 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of –20.2 m, indicating a higher degree of certainty than for the barrier segment to the south.
- WCS1105 (Central lagoon): Similar maximum inter-survey erosion of -10.3 m between March and Sept 2001, in which two storms occurred including the event of 19-22 July – reported to be the most significant storm to affect the South Canterbury coast in 16 years (Cope & Young, 2001), resulting in approximately

1150 hectares of land south of Timaru being inundated by seawater and large scale beach erosion right throughout South Canterbury. This is the largest easterly event on the database since this time. The GEV distribution of inter-survey erosion returned an erosion distance of –11.6 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of -16.7 m, indicating a similar level of certainty as the above profile.

- WCS1035 (north lagoon): Again, a similar magnitude of maximum inter-survey erosion of -12.2 m between March and September 2017, a period in which four storms occurred, including two significant events in May and June 2017 both ranked in the top 10 events since wave buoy recordings began in 1999. The GEV distribution of inter-survey erosion returned an erosion distance of -16 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of -26.9 m, indicating a higher level of uncertainty than for the central segment of the lagoon barrier.

It is noticeable that these short-term storm effects are greater than for coastal cells to the south, due to the combination of the high frequency of rollover events, the lack of resistance of the lagoon to retreat, and the shoreline movements being dynamic in nature with the ability for a degree of post-storm recovery.

Sea Level Rise Effect

The erosion effect from SLR was calculated using Measures et al (2014) method for wide gravel barriers along the length of this section (See Section 2.2.4 and Appendix A for methodology). The difference in predicted erosion is minimal between the four profiles. However, it does slightly increase in erosion effect from north to south. The amount of predicted erosion due to SLR at each profile is detailed below in Table 5.2. In 50 year SLR scenarios, the erosion effect ranges between -7.5 m at the northern end and -12.2m at the southern end with 0.6 m of SLR. This increases to -22.2 m at the northern end and -35.4 m at the southern end in the highest SLR scenario with 1.5m of SLR over the next 100 years.

Table 5.2 also indicates that the range of possible input parameters does not result in a large degree of uncertainty of the projected SLR effects, with the maximum predicted retreat only being 3 m greater over 50-years and up to 10 m greater over 100 years. The uncertainty is slightly higher at the southern end of the lagoon than the north. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.

The results also indicate that the magnitude of retreat is not particularly sensitive to the magnitude of SLR, with only around 10 m of additional retreat for an additional 0.4m increase in magnitude of rise over both time frames.

Table 5.2: Predicted erosion from future SLR at ECan profiles along the Washdyke Lagoon gravel barrier.

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
WCS1195 (south lagoon)	344-355	Mean	-2.3 m	-7.1 m	-12.2 m	-9.6 m	-14.9 m	-26.2 m	-35.4 m
		Max	-2.9 m	-9.0 m	-15.4 m	-12.1 m	-18.7 m	-33.0 m	-44.6 m
WCS1135 (central lagoon)	356-363	Mean	-2.3 m	-7.0 m	-12.0 m	-9.5 m	-14.7 m	-25.7 m	-34.7 m
		Max	-2.8 m	-8.6 m	-14.8 m	-11.7 m	-18.0 m	-31.6 m	-42.7 m
WCS1105 (central lagoon)	364-375	Mean	-2.2 m	-6.8 m	-11.7 m	-9.2 m	-14.3 m	-25.1 m	-33.9 m
		Max	-2.7 m	-8.4 m	-14.4 m	-11.4 m	-17.5 m	-30.8 m	-41.7 m
	376-382	Mean	-1.4 m	-4.3 m	-7.5 m	-5.9 m	-9.1 m	-16.3 m	-22.2 m

WCS1035 (north lagoon)		Max	-1.6 m	-4.9 m	-8.5 m	-6.7 m	-10.4 m	-18.6 m	-25.4 m

5.1.2 Projected Future Shoreline Positions (PFSP)

The calculated PFSP averaged over the length of shorelines represented by the ECan profiles along the Washdyke Lagoon gravel barrier are presented below in Table 5.3, and are presented spatially in Figure 5.1, where the PFSP 'most likely' (P50) and selected highest SLR 'very unlikely' (P5) lines are displayed. A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

As shown in these results, the erosion distances to the PFSP are very similar over the length of the lagoon, being projected to 'most likely' be in the order of -120 to -150 m over the next 50 years depending on the magnitude of sea-level rise, and in the range of -215 m to -280 m over 100 years for SLR ranging from 0.6 m to 1.5 m.

The probability analysis indicates that there is a 5% chance that over a 50-year time frame these erosion distances could be up to 40 m greater than the 'most likely' at the south end of the lagoon and up to 15 m greater at the north end. Over a 100-year time frame this uncertainty increases, with a 5% chance that the erosion distances could be up to 75 m greater at the southern end and up to 35 m greater at the northern end. However, these greater erosion distances would result in the shoreline beginning to interact with the land surface landward of the lagoon and at the southern end of the lagoon with the elevated sewer and SIMT railway embankments, which have the potential to reduce the erosion rates.

Table 5.3: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP at Washdyke Lagoon.

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
WCS1195 (south lagoon)	344-355 (575 m)	Most likely	-126.7 m	-131.8 m	-137.1 m	-213.5 m	-219.2 m	-231.1 m	-240.8 m
		Very unlikely	-165.8 m	-171.2 m	-176.4 m	-286.3 m	-292.2 m	-303.8 m	-313.7 m
WCS1135 (central lagoon)	356-363 (400 m)	Most likely	-116.1 m	-121.1 m	-126.3 m	-222.8 m	-228.4 m	-240.4 m	-249.9 m
		Very unlikely	-139.3 m	-144.6 m	-149.8 m	-269.4 m	-274.6 m	-286.7 m	-296.4 m
WCS1105 (central lagoon)	364-375 (600 m)	Most likely	-131.2 m	-136.1 m	-141.2 m	-255.4 m	-260.8 m	-272.1 m	-281.4 m
		Very unlikely	-145.9 m	-150.8 m	-156.0 m	-284.4 m	-289.7 m	-301.1 m	-310.4 m
WCS1035 (north lagoon0	376-382 (325 m)	Most likely	-128.1 m	-131.2 m	-134.4 m	-242.3 m	-245.7 m	-253.1 m	-259.1 m
		Very unlikely	-142.7 m	-145.6 m	-148.9 m	-269.4 m	-272.8 m	-280.0 m	-286.3 m

However, as noted in section 5.1.1., the assessment does not address the possibility of future permanent breaching and disintegration of the barrier due to lack of sufficient volume over the 100 year time frame, which adds considerable uncertainty to the time frame for the PFSP to be located along the western edge of the lagoon. It is therefore recommended a more detailed volumetric assessment of the barrier be undertaken to determine the likely change in barrier volume as it continues to roll back into the lagoon and the loss of elevation as the remaining volume is stretched over a greater shoreline length. This assessment would provide a better indication of whether there is enough volume available for the barrier to retreat inland as far as what has been assessed in this report, or whether the barrier is likely to breach and disintegrate earlier before reaching that point due to lack of volume.

Relative contribution of the Components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 5.3.

As can be seen from these graphs, the dominant contribution to the erosion is the extrapolation of the historical long-term rate, contributing more than 80% of the projected erosion over both time periods at the central and northern end of the lagoon. The percentage is lower at the southern end (60-70%) only because of the higher contribution of short-term storm effects (20-30%). The contribution of the SLR effects is consistently low along the length of the lagoon, being 3-6% of the projected erosion over a 50-year timeframe and increasing to 6-12% over a 100-year time frame. Therefore, the Washdyke Lagoon shoreline is expected to erode by significant distances under all SLR scenarios due to the on-going effects of starvation of coarse gravel-sized sediment.

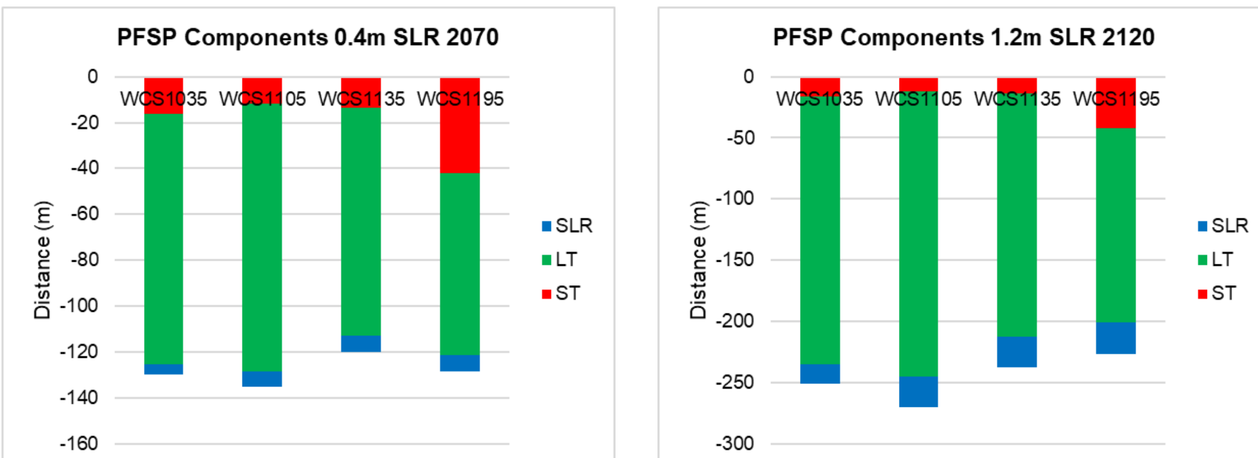


Figure 5.3: Contribution of each component of the erosion to the PFSP at ECan profiles sites along the Washdyke Lagoon coast for SLR scenarios of 0.4m by 2070 (Left) and 1.2m by 2120 (Right)

Potentially Impacted Assets

Over the next 100 years, Washdyke lagoon is going to continue to decrease in size, with the current lagoon projected to most likely be completely reduced to a wetland within 100 years.

The drainage network around the lagoon is most likely to be compromised at the northern and southern ends within 50 years. While only a small section of the drainage network is shown to intersect with the PFSP over the 50-year period, the back of the barrier beach will have moved and will most likely be interacting with the stopbank system around the seaward side of the drainage network. The result of this is that it is likely the drainage network will be subjected to more frequent coastal inundation due to overtopping, which will reduce the functionality of the network. At the northern end of the lagoon, this has the potential to impact the most seaward of the developments in the Washdyke Industrial Estate in this area.

An increased amount of the drainage network intersects with the PFSP in 100 years as identified by the shoreline position shown in Figure 5.2. This would most likely impact the sewage line and potentially the SIMT railway line at the south end of the lagoon and lie within the industrial estate at the northern end.

5.2 Southern Seadown Coast: Aorangi Road to ECan Profile WCS0439

The Southern Seadown Coast consists of 6 km of MSG ridges backed by stopbanks from Aorangi Road (ECan profile WCS0966) to ECan profile WCS0439 located between Phar Lap Road and Beach Road. As shown in Figure 5.4, there have been two series of coastal stopbanks built along this section of shoreline to prevent coastal inundation, with the older 1939 banks having been lost to coastal erosion over time to be replaced by stopbanks built between 1984-86 in a more landward position. The Seadown drain has also been relocated landward in parallel to these stopbank relocations, being located on the landward side of the stopbanks. Previous studies (e.g. Todd 1989) indicate that the presence of these stopbanks likely slows down the erosion rate for a period when the beach is constrained by the bank, but beach volumes losses are increased through greater backwash velocities due to the impermeable stopbank core in the beach profile. However, once the banks become breached or overwhelmed, erosion rates trend to re-accelerate as the reduced volumes infill the former drainage channels and form lower beaches ridges on the hinterland.

As shown in Figure 5.4, there are six ECan profiles which represent the MSG beach ridges along this section of coastline, being from south to north:

- WCS0966 (Aorangi Rd) - Transects 383-405, approximately 1.1 km of shoreline;
- WCS0891 - Transects 406-425, approximately 1 km of shoreline;
- WCS0794 (Seaforth Rd) - Transects 426-445, approximately 1 km of shoreline;
- WCS0693 - Transects 446-460, approximately 750 m of shoreline;
- WCS0626 (Phar Lap Rd) - Transects 461-483, approximately 1.1 km of shoreline; and
- WCS0439 - Transects 486-494, approximately 400 m of shoreline.

5.2.1 Erosion Components

Extrapolation of Long-Term Rates

As for the previous coastal cell, the long-term historical erosion rate for the Southern Seadown Coast is limited to those mapped from aerial imagery since May 1956. This 60-year period avoids the extremely rapid retreat at rates in the order of -4 m/yr to over -5 m/yr for the 1932/34 – 1956 period as reported by Todd (1989), as they are not considered to be relevant to the current coastal processes regime. The erosion trends since 1956 are shown in Figure 5.5 with the resulting average rates of retreat and the projected erosion distances from the extrapolation of these rates over 50-year (e.g. by 2070) and 100-year (e.g. by 2120) timeframes being presented in Table 5.4.

Figure 5.4: Southern Seadown coastal stopbank locations

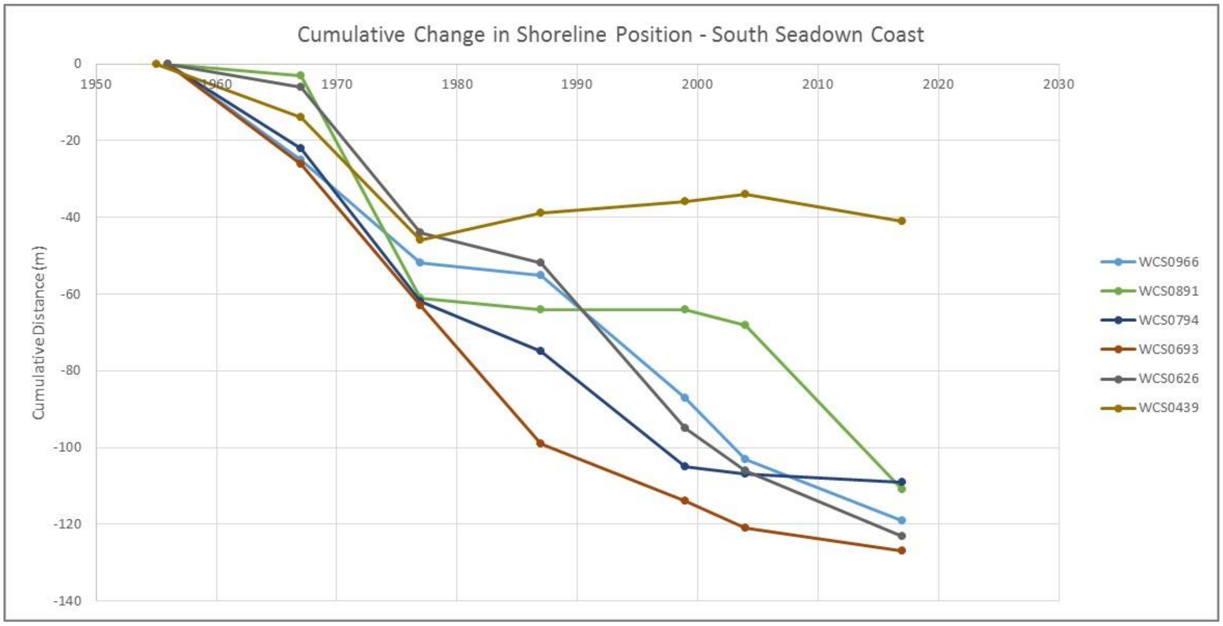


Figure 5.5: Cumulative erosion of ECan profile sites at South Seadown from 1956-2017

As can be seen from Figure 5.5, all sites except the most northern one (WCS0439) have similar erosion distances, in the range of -110 m to -130 m with average rates in the range of -1.7 m/yr to -2.2 m/yr. These rates are generally slightly less than the historical rates for central and north Washdyke. All sites show the influence of the former coastal stopbanks reducing erosion, followed by an acceleration of retreat once the banks have been breached or overwhelmed. The northern site (WCS0439) has experienced the least erosion (-40 m at -0.9 m/yr), with the erosion trend indicating that the former bank is still containing the backshore of the beach and reducing erosion.

The extrapolation of long-term erosion rates and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 5.4. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 5.4, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

From Table 5.4, the extrapolated mean erosion distances over the next 50 years are similar from Aorangi Rd (WSC0966) to Phar Lap Rd (WSC0626) ranging from -110 m to -85 m, with this being reduced to around half further north at WSC0439. Over a 100 year timeframe, these extrapolated erosion distances are in the order of-220 m to -170 m from Aorangi Road to Phar Lap Road, and around -90 m at Profile site WSC0439.

The uncertainty in the historical shoreline mapping results in there being a 5% probability that erosion distances could be more than 30 m further landward over a 50-year period, and from 55 m to 70 m further landward over a 100-year timeframe.

Table 5.4: Extrapolation of long-term erosion rates (1956-2017) and resulting projected distances along the Southern Seadown Coast.

Profile	DSAS Transects	Statistic	Erosion Rate (1956-2017)	2070 Erosion Distance	2120 Erosion Distance
WCS0966 (Aorangi Rd)	383-405 (1.1 km)	Mean	-2.17 m/yr	-108.4m	-216.8m
		Max at individual transect	-2.23 m/yr	-111.3m	-222.6m
		Avg Upper 95% Confidence level	-2.79 m/yr	-139.5m	-279.1m
WCS0891	406-425 (I km)	Mean	-1.86 m/yr	-93.0 m	-185.9 m
		Max at individual transect	-2.07 m/yr	-103.6 m	-207.2 m
		Avg Upper 95% Confidence level	-2.4 m/yr	-120.7m	-241.4m
WCS0794 (Seaforth Rd)	426-445 (1 km)	Mean	-1.93 m/yr	-96.3 m	-192.7 m
		Max at individual transect	-1.99 m/yr	-99.5 m	-198.9 m
		Avg Upper 95% Confidence level	-2.56 m/yr	-128.1 m	-256.1 m
WCS0693	446-460 (750 m)	Mean	-2.09 m/yr	-104.4 m	-208.8 m
		Max at individual transect	-2.16 m/yr	-108.1 m	-216.1 m
		Avg Upper 95% Confidence level	-2.77 m/yr	-138.4 m	-276.9 m
WCS0626 (Phar Lap Rd)	461-483 (1.1 km)	Mean	-1.69 m/yr	-84.3 m	-168.6 m
		Max at individual transect	-2.14 m/yr	-107.0 m	-213.9 m
		Avg Upper 95% Confidence level	-2.33 m/yr	-116.7 m	-233.4 m
WCS0439	486-494 (400 m)	Mean	-0.88 m/yr	-44.2 m	-88.4 m
		Max at individual transect	-1.06 m/yr	-53.1 m	-106.3 m
		Avg Upper 95% Confidence level	-1.66 m/yr	-82.9 m	-165.8 m

Short Term Storm Erosion

Along this section of shoreline, the effect of short term storm erosion at all six profiles is relatively similar and in the range of -10 m to -19 m for a 100-year ARI event. The short term inter-survey erosion at each ECan profile site used to calculate these 100-year ARI values are detailed below in Table 5.5. These erosion distances are a similar to central and north Washdyke lagoon effects and are considered to be for periods following the former stopbanks being breached/overwhelmed, hence the variably in the periods of maximum retreat. However, it is noticeable that at two sites the maximum occurred in the March – Sept 2001 period in which the most significant storm in the previous 16 years occurred (Cope & Young, 2001), and is the largest easterly event on the database since 1985.

The results also indicate a relatively high level of certainty for the magnitude of the short-term component, except for profile WCS0626, where there is a high level of uncertainty with the 99% confidence interval being double the mean value.

Table 5.5: Summary of the observed maximum inter-survey erosion, mean and maximum 100-year ARI short-term erosion at each ECan profile between Aorangi Road (WCS0966) and WCS0439

Profile	Maximum inter-survey Erosion	Period of max change	Number of storms in survey period	Mean 100-year ARI event	Max 100-year ARI event (99% CI)
WCS0966	-11.1 m	Mar-June 2015	3	-12.6 m	-20.0 m
WCS0891	-11.3 m	Feb-Sept 2019	3	-11.4 m	-17.6 m
WCS0794	-10.8 m	Mar-Sept 2001	2	-12.5 m	-20.7 m
WCS0693	-8.9 m	Mar-Sept 2001	2	-9.7 m	-14.9 m
WCS0626	-13.3 m	Sept 1996 to Mar 1997	Not available	-18.7 m	-36.5 m
WCS0439	-8.5 m	Mar-Sept 2017	3	-11.1 m	-17.2 m

Sea Level Rise Effect

The erosion effect from SLR was calculated using the modified Bruun rule adjusted for the gravel ridges present along this section of coastline (See Section 2.2.4 and Appendix A for methodology).

The amount of predicted erosion due to SLR at each profile is detailed below in Table 5.6, with similar results being obtained for each of the six ECan profile sites. For the 50 year SLR scenarios, the difference between profiles is less than 1m, with predicted mean erosion to be within -6.3 m and -7.3 m for 0.6 m of SLR by 2070. The difference between profiles is still minimal in 100 years, with mean erosion due to SLR predicted to be between -16.3 m and -18.9 m along this section of coastline. These erosion distances from accelerated SLR over a 50-year timeframe are less than the short-term storm component of the PFSP and are approximately equal over a 100-year time frame.

Table 5.6: Predicted erosion from the future SLR at ECan profiles along the Southern Seadown Coast.

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
WCS0966	383-405	Mean	-1.3m	-3.9m	-6.5m	-5.2m	-7.8m	-13.1m	-17m
		Max	-1.7m	-5.1m	-8.5m	-6.8m	-10.2m	-17.0m	-22.1m
WCS0891	406-425	Mean	-1.3m	-3.9m	-6.6m	-5.3m	-7.9m	-13.1m	-17.1m
		Max	-1.7m	-5.1m	-8.6m	-6.8m	-10.3m	-17.1m	-22.2m
WCS0794	426-445	Mean	-1.3m	-3.8m	-6.3m	-5.0m	-7.5m	-12.6m	-16.3m
		Max	-1.7m	-5.0m	-8.3m	-6.6m	-9.9m	-16.6m	-21.5m
WCS0693	446-460	Mean	-1.3m	-3.9m	-6.4m	-5.1m	-7.7m	-12.9m	-16.7m
		Max	1.7m	-5.0m	-8.4m	-6.7m	-10.1m	-16.8m	-21.9m
WCS0626	461-483	Mean	-1.3m	-3.9m	-6.6m	-5.3m	-7.9m	-13.1m	-17.1m
		Max	-1.7m	-5.1m	-8.5m	-6.8m	-10.3m	-17.1m	-22.2m
WCS0439	486-494	Mean	-1.5m	-4.4m	-7.3m	-5.8m	-8.7m	-14.5m	-18.9m
		Max	-1.8m	-5.4m	-9.1m	-7.3m	-10.9m	-18.1m	-23.6m

Table 5.6 also indicates that the range of possible input parameters does not result in a large degree of uncertainty of the projected SLR effects, with the maximum predicted retreat only being in the order of 3 m greater over 50-years and around 10 m greater over 100 years. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.

The results also indicate that the magnitude of retreat is not particularly sensitive to the magnitude of SLR, with only around 5 m to 6 m of additional retreat for an additional 0.4 m increase in magnitude of rise over both time frames.

5.2.2 Projected Future Shoreline Positions (PFSP)

The calculated erosion distances to the PFSP averaged over the length of shorelines represented by the ECan profiles along the Southern Seadown Coast is presented below in Table 5.7 and are spatially presented in Figure 5.6, where the PFSP 'most likely' (P50) and selected highest SLR 'very unlikely' (P5) lines are displayed. A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

Due to the large contribution of the extrapolated long-term rate to the PFSP, the erosion distances are relativity similar for Aorangi Road (WCS0966) to Phar Lap Road (WCS0329) with retreat distances projected to 'most likely' be up to -130 m at Aorangi Road over the next 50 years, and -122 m at Phar Lap Road over the same timeframe under the 0.6 m SLR scenario. Over 100 years, projected erosion is 'most likely' to be in the order of 235 -250 m at Aorangi Road and -195 m to -210 m at Phar Lap Road for the range of SLR scenarios. The probability analysis indicates that there is a 5% chance that over a 50-year time frame these erosion distances could be in the order of 20-25 m greater, and in the order of 45 m greater over a 100-year period.

Due to the influence of a lower historical erosion rate (due to beach being contained by the stopbank over the historic erosion period of calculation), the projected erosion distances to the PFSP are lower at the northern end of the cell (WCS0439) being up to 65 m over 50 years, and 120 m over 100 years. However, the uncertainty is a little higher, being up to +50 m over 100 years.

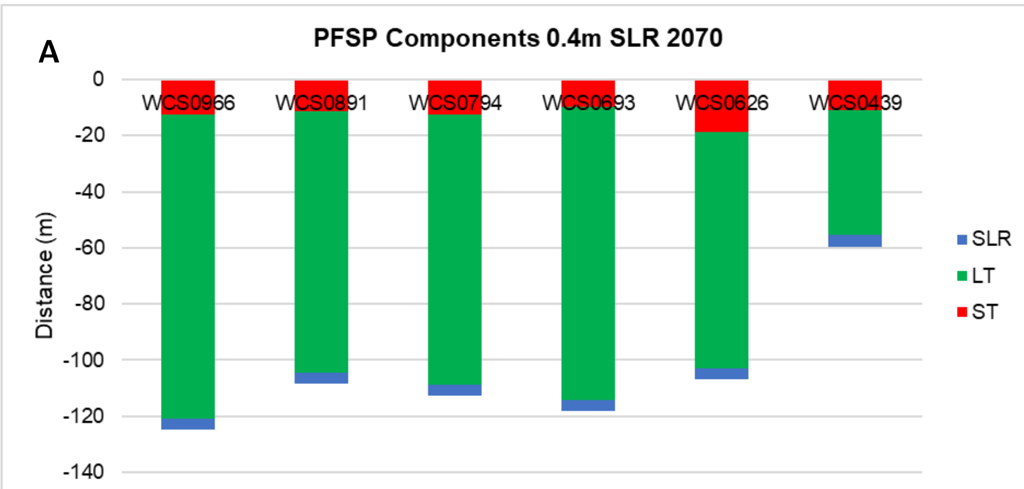
Table 5.7: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP along the South Seadown Coast.

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
WCS0966 (Aorangi Rd)	383-405 (1.1 km)	Most likely	-123.3m	-126m	-128.7m	-235.8m	-238.4m	-243.8m	-248.0m
		Very unlikely	-144.9m	-147.6m	-150.3m	-278.5m	-281.2m	-286.6m	-290.8m
WCS0891	406-425 (1 km)	Most likely	-106.3m	-108.9m	-111.8m	-203.3m	-205.9m	-211.4m	-215.5m
		Very unlikely	-125.5m	-128.2m	-131.0m	-241.4m	-244.0m	-249.5m	-253.7m
WCS0794 (Seaforth Rd)	426-445 (1 km)	Most likely	-110.8m	-113.4m	-116m	-211m	-213.6m	-218.7m	-222.8m
		Very unlikely	-133.0m	-135.6m	-138.1m	-254.6m	-257.4m	-262.4m	-266.3m
WCS0693	446-460 (750 m)	Most likely	-115.8m	-118.4m	-121m	-224.3m	-226.8m	-232.1m	-236.1m
		Very unlikely	-139.2m	-141.9m	-144.5m	-270.8m	-273.5m	-278.6m	-282.9m
WCS0626 (Phar Lap Rd)	461-483 (1.1 km)	Most likely	-107m	-109.7m	-112.4m	-195.4m	-198.1m	-203.5m	-207.6m
		Very unlikely	-131.0m	-133.7m	-136.4m	-240.6m	-243.3m	-248.8m	-252.9m
WCS0439	486-494 (400 m)	Most likely	-57.3m	-60.4m	-63.4m	-105.9m	-108.9m	-115.1m	-119.7m
		Very unlikely	-84.0m	-87.1m	-90.0m	-158.9m	-162.2m	168.3m	-172.8m

Figure 5.6: South Seadown Coast PFSP for various SLR scenarios in 2070 and 2120. 'Most likely' position (P50) is shown for each scenario and 'very unlikely' (P5) shown for SLR scenarios of 0.6m by 2070 and 1.5m 2120 (highest SLR scenarios).

Relative contribution of the Components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 5.7. Like the adjacent Washdyke section, it shows that extrapolated historical erosion rate due to sediment starvation and longshore transport is the dominant contribution to future erosion distances, contributing over 70% of the total retreat. The contribution of accelerated SLR is only 3-4 % of the total retreat over 50 years, and 5-7 % over 100 years.



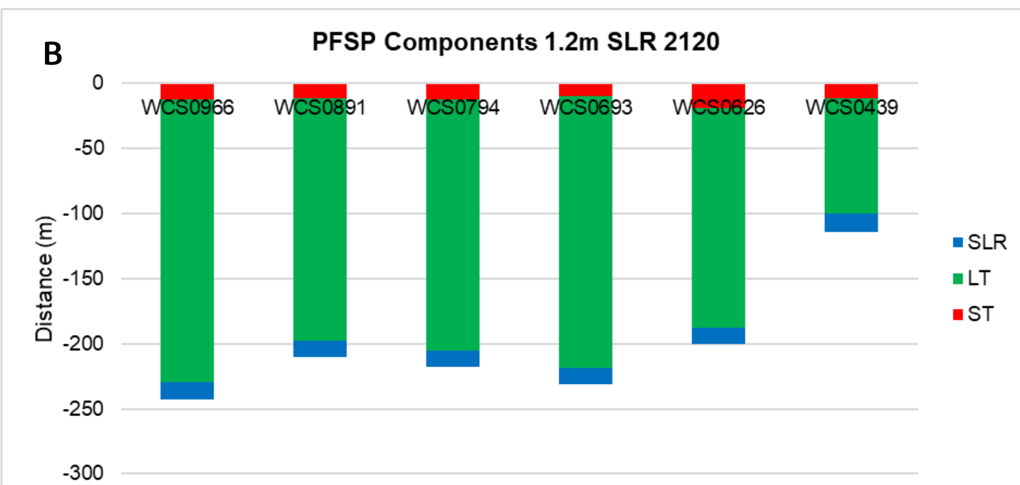


Figure 5.7: Average component inputs across ECan profiles WCS0966, WCS0891, WCS0794, WCS0693, WCS0626 and WCS0439 showing the different component inputs into calculating PFSP lines for (A) 0.4m of SLR by 2070, and (B) 1.2m of SLR by 2120, where negative numbers indicate landward movement of the shoreline.

Potentially Impacted Assets

Figure 5.6 indicates that the current stopbanks are most likely to be severely compromised by erosion in the next 50 years and are potentially not likely to provide any inundation protection function beyond this period if not maintained, protected or relocated. Apart from the potential drainage issues associated with the coastal stopbanks, the Timaru District wastewater treatment plant and oxidation ponds at Aorangi Road are unlikely to be adversely affected by the projected erosion within the 50 year period, but due to erosion, will most likely begin to be affected within a 100-year time frame with the back of the beach being projected to be at the edge of the seaward edge of the ponds.

5.3 Northern Seadown Coast: WCS0439 to the Opihi River

The northern Seadown coastal cell is taken as the 4.8 km section of shoreline from ECan profile WCS0439 to the south bank of the Opihi River. Like south Seadown, the entire length of the cell is MSG ridge beaches backed by stopbanks. As shown in Figure 5.8, coastal stopbanks to prevent seawater inundation have been a dominant protection feature along this coastline since the late 1930s, with up to three series of banks having been constructed in some locations due to coastal erosion breaching or overwhelming the older banks.

As shown below in Figure 5.8, three ECan profiles are used to represent the gravel ridge morphologies along this section of coastline:

- WCS0439 - Transects 495 to 513, approximately 900 m of shoreline;
- WCS0329 (Beach Road) - Transects 514 to 555, approximately 2.1 km of shoreline; and
- WCS0081 (Connolly's Road) - Transects 556 to 592, approximately 1.8 km of shoreline.

5.3.1 Erosion Components

Extrapolation of Long-Term Rates

As for Southern Seadown, the long-term historical erosion rate for the North Seadown coast is limited to the shorelines mapped from aerial imagery since May 1956. This 60-year period avoids the extremely rapid retreat at rates in the order of -2 m/yr for the 1932/34 – 1956 period as reported by Todd (1989), as they are not considered to be relevant to the current coastal processes regime. The erosion trends since 1956 are shown in Figure 5.9 with the resulting average rates of retreat and the projected erosion distances from the extrapolation of these rates over 50-year (e.g. by 2070) and 100-year (e.g. by 2120) timeframes being presented in Table 5.8. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 5.8, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

As can be seen from Figure 5.9, unlike the south Seadown sites, there is very little consistency in shoreline movement between the sites. However, the influence of the former coastal stopbanks reducing erosion, followed by an acceleration of retreat once the banks have been breached or overwhelmed is clearly evident, particularly at Connolly's Road (WCS0081). The southern site (WCS0439) has experienced the least erosion (-40 m at -0.9 m/yr), with the erosion trend indicating that the former bank is still containing the bank and reducing erosion.

To further this effect, we undertook a short analysis as a part of this assessment at Beach Rd (WCS0329), where based on aerial imagery and profile data, periods where the back of the beach interacted with the front of the stopbank could be determined, including how this affected the rate of erosion at the shoreline through the stopbank. Throughout the period that this site has been surveyed, the shoreline has eroded through two series of stopbanks, a later one which was built in the 1980s is still in place behind the current shoreline.

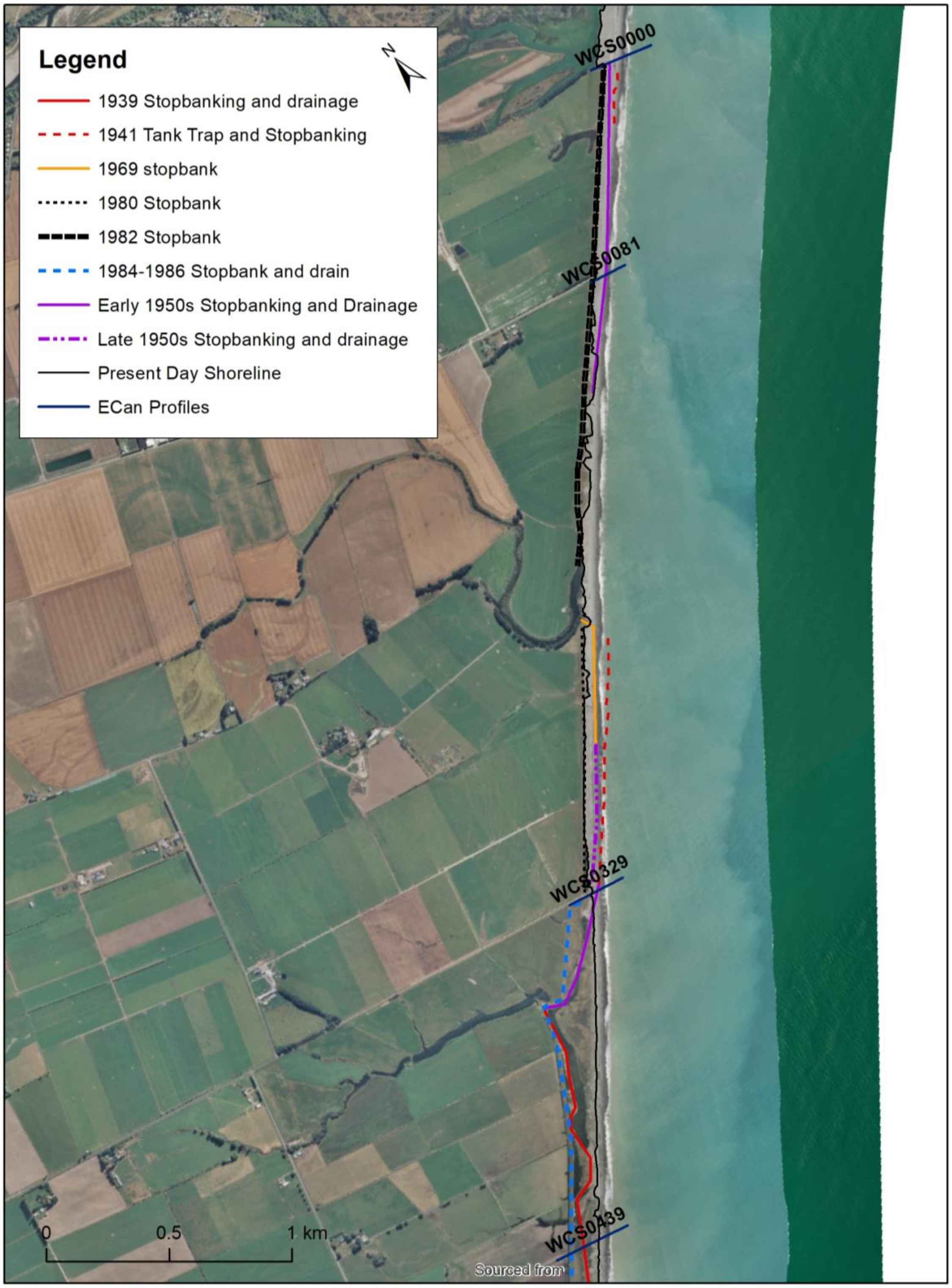


Figure 5.8: Northern Seadown coastal stopbank locations

Based on the survey data and the location of the coastal stopbanks shown in Figure 5.8, it appears that the back of the beach was interacting with the front of the most seaward stopbank (built early 1950's) since at least 1977 with the bank being eroded through by 1986. . Over this period, the rate of erosion at the 4 m contour (approximately the back of beach/stopbank front) was -0.5m/yr. Between 1986 and 1994, a period when the back of the beach was not interacting with the front of the 1980's stopbank, erosion continued at a faster rate, approximately -2 m/yr. Between 1995 and 2013 when the back of the beach was interacting with the front of the 1980's stopbank, the erosion rate slowed again to -0.85 m/yr, then accelerated again to -1.2 m/yr when the stopbank had eroded in 2013. This analysis indicates that when the back of the beach is interacting with the stopbank, the rate of erosion is likely to be less than -1 m/yr, and when there is no stopbank directly confining the back of the beach, this erosion rate is accelerated above -1 m/yr. The average rate over the 41 years in the analysis was -1.4 m/yr.

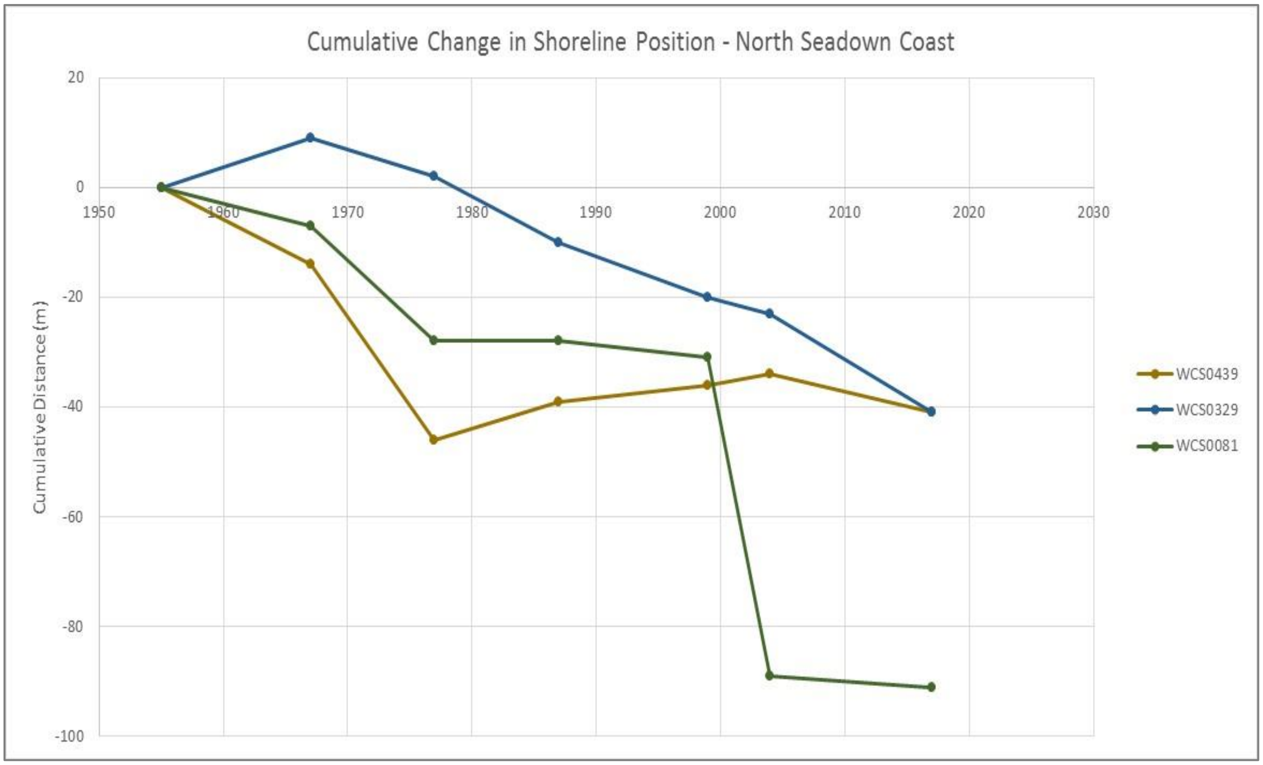


Figure 5.9: Cumulative erosion of ECan profile sites at North Seadown from 1956-2017

Table 5.8: Extrapolation of long-term erosion rates (1956-2017) and resulting projected erosion distances along the Northern Seadown Coast.

Profile	DSAS Transects	Statistic	Erosion Rate (1956-2017)	2070 Erosion Distance	2120 Erosion Distance
WCS0439	495-513 (900 m)	Mean	-0.61 m/yr	-30.5 m	-61.0 m
		Max at individual transect	-0.75 m/yr	-37.4 m	-74.8 m
		Avg Upper 95% Confidence level	-1.32 m/yr	-66.0 m	-132.1 m
WCS0329 (Beach Rd)	514-555 (2.1 km)	Mean	-1.06 m/yr	-53.2 m	-106.3 m
		Max at individual transect	-1.55 m/yr	-77.4 m	-154.8 m
		Avg Upper 95% Confidence level	-1.70 m/yr	-85.0 m	-170.0 m
WCS0081 (Connolly's Rd)	556-592 (1.8 km)	Mean	-1.06 m/yr	-53.2 m	-106.3 m
		Max at individual transect	-1.17 m/yr	-58.5 m	-116.9 m
		Avg Upper 95% Confidence level	-1.85 m/yr	-92.5 m	-185.0 m

When extrapolated into the future, the resulting erosion distances for this section of the Seadown coast are in the range 30 m to 55 m in 50 years, and 60 m to 105 m over the next 100 years. However, due to the temporal variations in the erosion trends as a result of the stopbank effects (e.g. varying slow and accreted rates over time depending on when stopbanks are reduce erosion and breached/over-run), there are large uncertainties with the historical erosion rates, with 5% chance that retreat distances could be up to 40 m greater over the next 50-years (e.g. nearly double the mean rates), and up to 80 m greater over 100 years.

Short Term Storm Erosion

Along this section of the Seadown coast, the effect of short term storm erosion has been relatively similar at each of the three ECan profile sites. At profile WCS0439, the short term erosion component is the largest of the three, with the maximum inter-survey erosion of -5.6 m between March and September 2017, and a mean value of a 100-year ARI erosion event of -11 m.

At profile WCS0329 (Beach Road) the maximum recorded inter-survey erosion was -4.9 m between May and July 1987, in which there were two storms recorded in the ECan storm database. The GEV distribution of inter-survey erosion returned an erosion distance of -5.6 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of –8.2 m.

At profile WCS0081 (Connolly’s Road), the maximum inter-survey erosion was -6.2 m between March and July 2001 and 31/07/2001, in which two storms occurred including the event of 19-22 July – reported to be the most significant storm to affect the South Canterbury coast in 16 years (Cope & Young, 2001), resulting in approximately 1150 hectares of land south of Timaru being inundated by seawater and large scale beach erosion right throughout South Canterbury. This is the largest easterly event on the database since 1985. The GEV distribution of inter-survey erosion returned an erosion distance of –5.7 m for the mean value of a 100-year ARI erosion event with a 99% confidence level of -11.6 m, indicating a similar level of certainty as the above profile.

Sea Level Rise Effect

The erosion effect from SLR was calculated using the modified Bruun rule adjusted for the gravel ridges present along this section of coastline (See Section 2.2.4 and Appendix A for methodology). The calculations of the independent erosion effect due to SLR for each profile are presented below in Table 5.9.

Table 5.9: Predicted erosion from future SLR at ECan profiles along the Northern Seadown Coast.

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
WCS0439	495-513	Mean	-1.5 m	-4.4 m	-7.3 m	-5.8 m	-8.7 m	-14.5 m	-18.9 m
		Max	-1.8 m	-5.4 m	-9.1 m	-7.3 m	-10.9 m	-18.1 m	-23.6 m
WCS0329 Beach Rd)	514-555	Mean	-1.2 m	-3.5 m	-5. 8 m	-4.6 m	-7.0 m	-11.6 m	-15.1 m
		Max	-1.6 m	-4.8 m	-7.9 m	-6.3 m	-9.5 m	-15.8 m	-20.6 m
WCS0081 (Connolly’s Rd)	556-592	Mean	-1.1 m	-3.4 m	-5.6 m	-4.5 m	-6.8 m	-11.3 m	-14.7 m
		Max	-1.6 m	-4.7 m	-7.8 m	-6.2 m	-9.3 m	-15.5 m	-20.2 m

The difference across the areas represented by the three profiles is very minimal. The largest calculated retreat is at profile WCS0439, with the most likely erosion over 50 years of accelerated SLR being up to -7.3 m, and in 100 years up to -19 m of erosion. The amount of erosion caused by SLR is less at profiles WCS0329 (Beach Road) and WCS0081 (Connolly’s Road) areas, with the calculated mean erosion due to accelerated SLR over the next 50 years being up to – 6 m, and up to -15 m over the next 100 years.

The results also indicate that the range of possible input parameters does not result in a large degree of uncertainty of the projected SLR effects, with the maximum predicted retreat only being in the order of 2 m greater over 50-years and around 5 m greater over 100-years. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.

5.3.2 Projected Future Shoreline Positions

The calculated PFSP averaged over the length of shorelines represented by the ECan profiles along the northern Seadown coast are presented below in Table 5.10, and are presented spatially in Figure 5.10, where the PFSP 'most likely' (P50) and selected highest SLR 'very unlikely' (P5) lines are displayed. A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

The 'most likely' erosion distances along this section of coastline are in the range of -50 m to -65 m over the next 50 years and -90 m to -130 m over the next 100 years. Projected erosion distances at the northern area of this coastal cell are greater than at the southern end due to the influence of a larger historical erosion rate.

The probability analysis indicates that there is a 5% chance that over a 50-year time frame these erosion distances could be in the order of 20-25 m greater, and in the order of 45-55 m greater over a 100-year period.

Table 5.10: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP along the Northern Seadown Coast.

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
WCS0439	495-513 (900 m)	Most likely	-43.7 m	-46.6 m	-49.7 m	-78.8 m	-81.7 m	-87.8 m	-92.3 m
		Very unlikely	-68.2 m	-71.1 m	-74.2 m	-127.6 m	-130.4 m	-136.6 m	-141.2 m
WCS0329 (Beach Rd)	514-555 (2.1 km)	Most likely	-60.3 m	-62.7 m	-65.1 m	-117.0 m	-119.4 m	-124.2 m	-127.8 m
		Very unlikely	-82.1 m	-84.5 m	-86.9 m	160.7 m	-163.1 m	-167.7 m	-171.5 m
WCS0081 (Connolly's Rd)	556-592 (1.8 km)	Most likely	-61.2 m	-63.5 m	-65.8 m	-117.8 m	-120.2 m	-124.8 m	-128.2 m
		Very unlikely	-88.1 m	-90.5 m	-92.8 m	171.6 m	-174.1 m	-178.7 m	-182.1 m

Relative contribution of the Components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 5.11. Similar to the adjacent gravel beach morphologies, the results show that extrapolated historical erosion rate due to sediment starvation and longshore transport is the dominant contribution to future erosion distances, contributing 85% of the total retreat for the northern part of the cell, and 65-70% for the southern part with the difference being due to the higher contribution of short-term short erosion at profile WCS0439. The contribution of accelerated SLR is only 5-9 % of the total retreat over 50 years, and 9-17 % over 100 years.

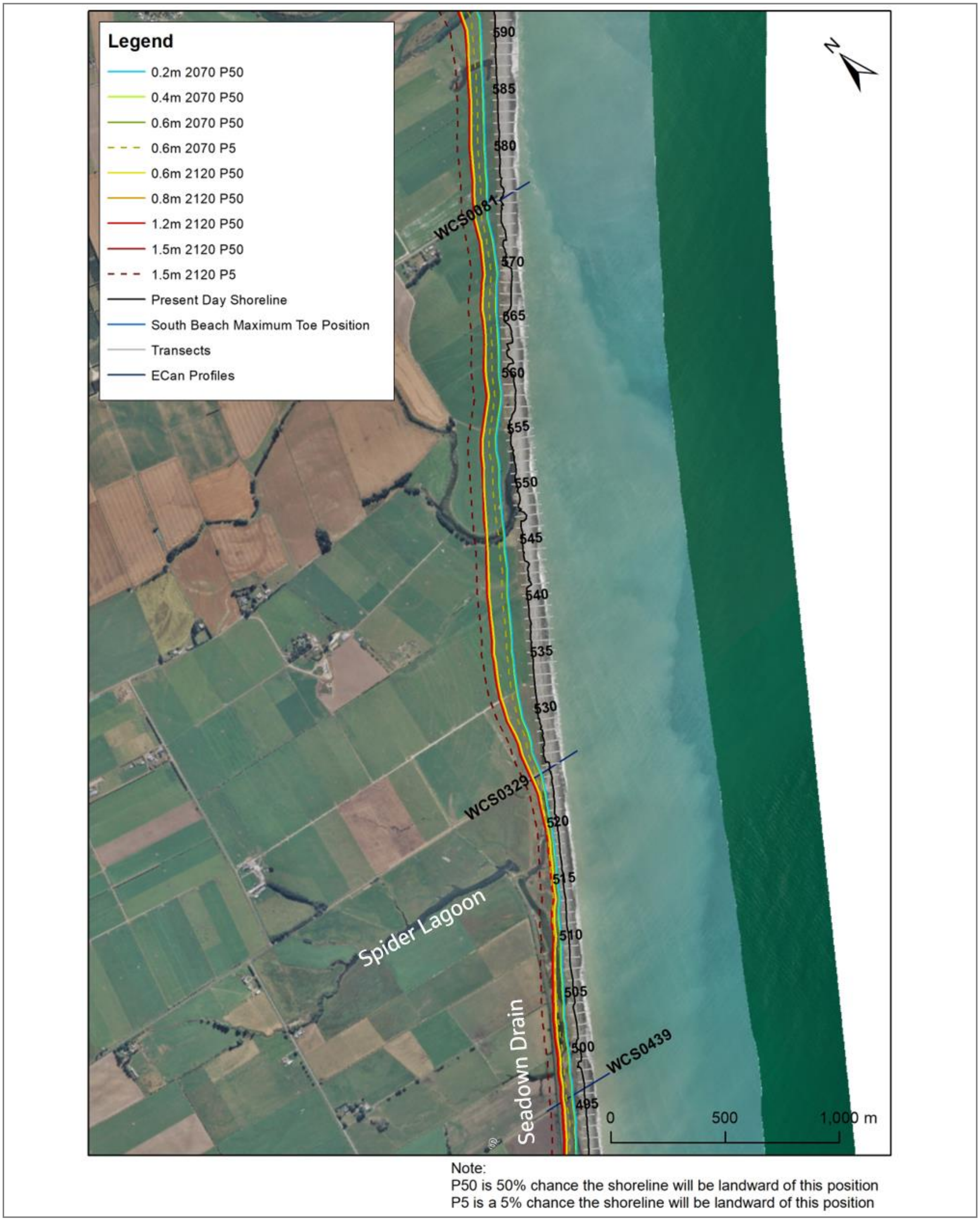
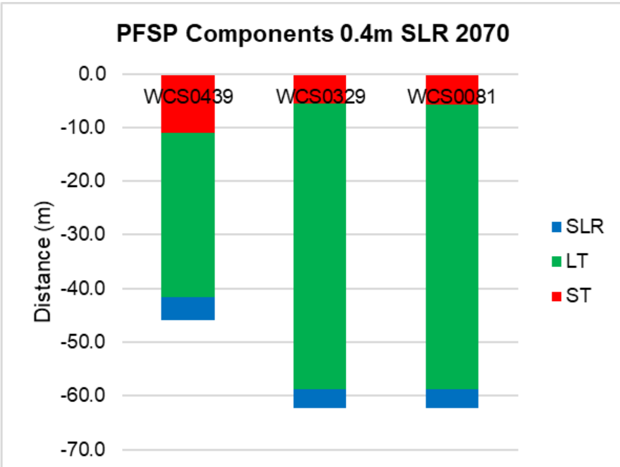


Figure 5.10: ECan profile WCS0439 to the Opihi River. Most likely" (P50) is shown for each scenario except 1.5m at 2120, and "very unlikely" (P5) shown for 0.6m at 2070 and 1.5m at 2120 (highest SLR scenarios).



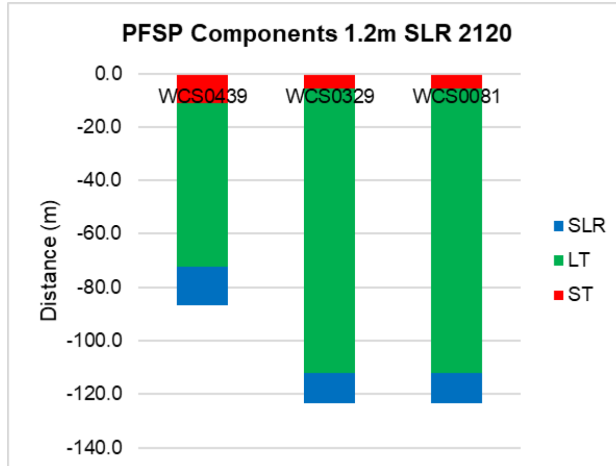


Figure 5.11: Average component inputs across ECan profiles WCS0439, WCS0329, and WCS0081, showing the different component inputs into calculating PFSP lines, where negative numbers indicate erosion.

Potentially Impacted Assets

As shown in Figure 5.10, the northern Seadown coastal stopbanks are likely to be severely compromised or overwhelmed by erosion within a 50-year time frame. The northern section of the Seadown Drain at Spider Lagoon to the south of Beach Road is likely to be similarly compromised.

5.4 Opihi River and Milford Huts

The Opihi River mouth and Milford Huts section of coastline is the 2.2 km section of shoreline taken as DSAS transects 595 to 640. This coastal cell is presented below in Figure 5.12. These transects are located across a MSG ridge/ barrier morphology at the mouth of the Opihi River. Along some sections of the gravel barrier, the back of the barrier is the lagoon and along other sections, it is vegetated along the 750 m long channel linking Orakipaoa Creek to the Opihi Lagoon (e.g. transects 617-632). A small settlement "Milford Huts" is located on the northern side of the Opihi River mouth lagoon. There are around 900 m of coastal stopbanks along the northern flanks of the Opihi lagoon towards Orakipaoa Creek to protect Milford Huts from high lagoon water levels.

The two ECan profiles used to represent this section of coastline are WCS0000 and RCN0130. Both profiles however are of a MSG ridge beach, and therefore there is no information available at this site about the elevations and width of the MSG barrier across the mouth of the Opihi River. Therefore, for this section of coastline, the modified Bruun rule for MSG ridges has been used to calculate SLR effects along the whole section despite the morphology change.

Given that the SLR effect calculations between adjacent gravel barrier and gravel ridge transects have been similar at other sites along this coastline (e.g. Washdyke Lagoon), and given that the long term historical trend has significantly more influence on the PFSP, using the gravel ridge calculations from profiles either side of the gravel barrier was determined to be the most appropriate method to calculate change with SLR along this section of coastline.

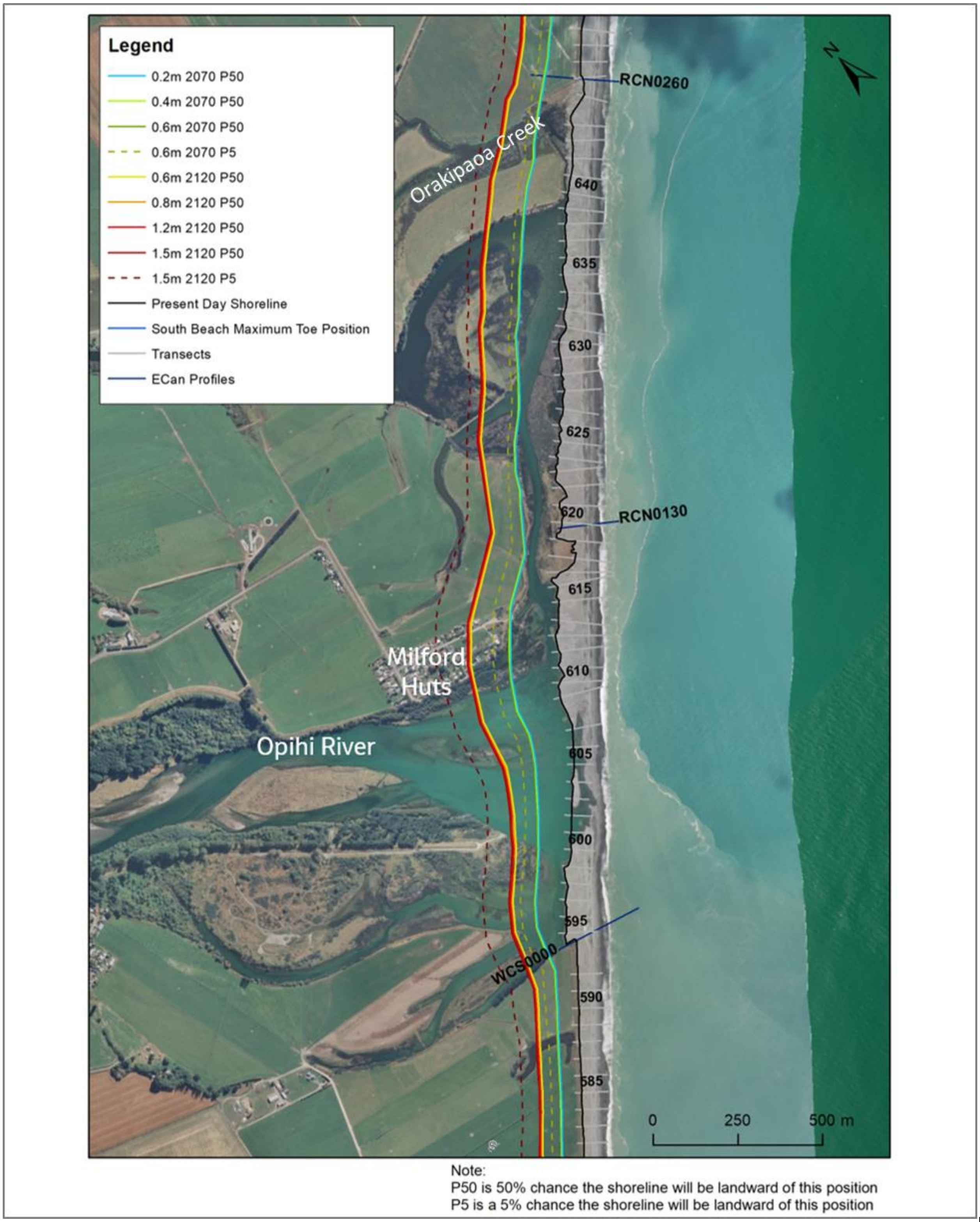


Figure 5.12: Opihi River and Milford Huts. Most likely" (P50) is shown for each scenario except 1.5m at 2120, and "very unlikely" (P5) shown for 0.6m in 2070 and 1.5m at 2120 (highest SLR scenarios).

5.4.1 Erosion Components

Extrapolation of Long-Term Rates

The extrapolation of long-term erosion rates from 1955 to 2017 and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 5.11. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 5.11, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

It is noted that these erosion rates are distances from the back of the beach rather than a crest position, therefore are influenced by beach rollover processes and river mouth processes.

Table 5.11: Extrapolation of long-term erosion rates (1955-2017) and resulting projected erosion distances at the Opihi River and Milford Huts.

Profile	DSAS Transects	Statistic	Erosion Rate (1956-2017)	2070 Erosion Distance	2120 Erosion Distance
WCS0000 (south side of river mouth barrier)	595 to 610 (800 m)	Mean	-1.51 m/yr	-75.3 m	-150.7 m
		Max at individual transect	-2.05 m/yr	-102.3 m	204.6 m
		Avg Upper 95% Confidence level	-2.55 m/yr	-127.5 m	-255.0 m
RCN0130 (north MSG ridge)	611 to 639 (1.4 km)	Mean	-2.05 m/yr	-102.3 m	-204.6 m
		Max at individual transect	-2.26 m/yr	-113.2 m	-226.5 m
		Avg Upper 95% Confidence level	-2.80 m/yr	-140.2 m	-280.3 m

The long term historical rate along this stretch of coastline increases in a northward direction, however in general erosion rates along this shoreline cell are between -1.5 to -2.5 m/yr, with the highest rates found on 400 m stretch of gravel barrier from transects 609 to 617.

For 750 m of shoreline between transects 595 to 610 (ECan profile WCS0000), the average erosion rate is -1.5 m/yr, which is a similar rate to those assessed at adjacent segments of coastline and are a result of net longshore sediment transport deficit. When extrapolated into the future, these rates result in -75 m of erosion over the next 50 years and -150 m over the next 100 years. Table 5.12 also indicates that there is considerable uncertainty in the historical rate obtained from the DSAS analysis, which could add up to 50 m to the erosion distances over 50 years, and up to 100 m to erosion distances over the next 100 years.

In the northern 1.4 km of the cell, (transects 611 to 639 represented by ECan profile RCN0130), the average long term historical erosion rate is slightly higher at -2.05 m/yr, which when extrapolated into the future result in retreat in the order of -100 m over the next 50 years, and -205 m in the next 100 years. Uncertainty in the historical rates is slightly less, with the 95% confidence level being ± 40 m over a 50-year timeframe and ±75 m over the next 100 years.

Short Term Storm Erosion

Short term erosion values could not be calculated for ECan profile WCS0000 as the river mouth often cuts through the profile, which calculates 'false' erosion events. Therefore, the short-term erosion component along this section of shoreline was calculated using inter-survey erosion data from ECan profile RCN0130.

The maximum inter-survey erosion recorded at this profile was -17.1 m at the beach crest between June 2000 and May 2001, a period within which there was one significant storm event recorded on the ECan storm database. The GEV distribution of inter-survey erosion returned an erosion distance of -23.3 m for the mean value of a 100-year ARI erosion event, with the 99% confidence level of -44.4 m.

Sea Level Rise Effect

As outlined above, the erosion effect caused by accelerated SLR was calculated using the modified Bruun rule for MSG ridges along this entire section of coastline. The calculations of the erosion effect for areas represented by the two ECan profiles are presented below in Table 5.12.

For both profiles, the 'most likely' mean retreat could be up to -7 m by 2070 and up to -18 m by 2120 under the most extreme SLR scenarios tested. As indicated in the results, uncertainty in the gravel beach inputs would account for only small additions to the projected erosion distances, being in the order of an additional 1-2 m over 50 years and 2-5 m over 100 years. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.

Table 5.12: Predicted erosion from future SLR at ECan profiles at the Opihi River and Milford Huts.

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
WCS0000	595 to 610	Mean	-1.4m	-4.0m	-6.7m	-5.4m	-8.1m	-13.5m	-17.5m
		Max	-1.7m	-5.2m	-8.6m	-6.9m	-10.4m	-17.3m	-22.5m
RCN0130	611 to 639	Mean	-1.3m	-3.8m	-6.4m	-5.1m	-7.6m	-12.7m	-16.5m
		Max	-1.7m	-5.0m	-8.3m	-6.7m	-10.0m	-16.7m	-21.7m

5.4.2 Projected Future Shoreline Positions (PFSP)

The calculated PFSP averaged over the length of coast represented by each ECan profile are presented below in Table 5.13 and are presented spatially in Figure 5.12 with the P50 position representing the 'most likely' position and P5 position the 'very unlikely' position under the highest SLR scenarios considered in this assessment of 0.6 m by 2070 and 1.5 m by 2120. Further maps showing the P5 PSFP for all SLR scenarios are presented in Appendix E (Map 5A). A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

Table 5.13 shows that the 'most likely' erosion of the gravel beaches at the southern and central portion of the Opihi River mouth (transects 595-610) are predicted to be in the range of -103 to -109 m by 2070, and -183 m to -196 m by 2120 depending on the magnitude of SLR across 750 m of shoreline. For this shoreline section, the probability analysis indicates that the highest SLR 'very unlikely' erosion distances are in the order of 40 m higher than the 'most likely' position by 2070, and 70-75 m higher by 2120.

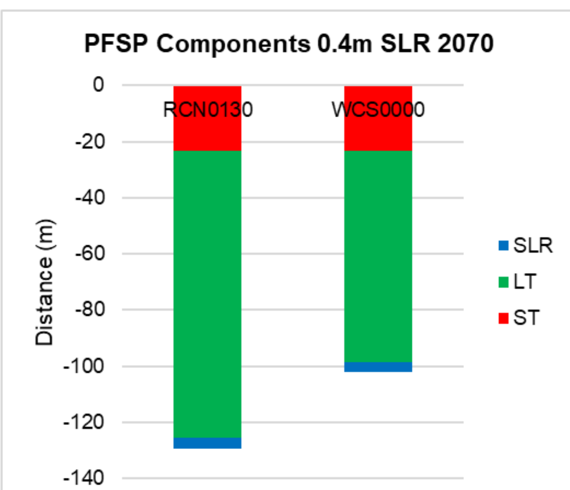
Table 5.13: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP at Opihi River and Milford Huts.

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
WCS0000 (south side of river mouth barrier)	595 to 610 (800 m)	Most likely	-103.3 m	-106.1 m	-108.6 m	-182.8 m	-185.7 m	-190.9 m	-195.4 m
		Very unlikely	-140.4 m	-143.0 m	-145.9 m	-254.8 m	-257.6 m	-263.3 m	-267.4 m
RCN0130 (north MSG ridge)	611 to 639 (1.4 km)	Most likely	-130 m	-132.7 m	-135.3 m	-236.4 m	-238.9 m	-244.1 m	-248.0 m
		Very unlikely	-158.5 m	-161.2 m	-163.6 m	-289.3 m	-291.9m	-297.4 m	-301.0m

The gravel beaches along the 1.4 km northern arm of the lagoon (transects 611-639) are predicted to 'most likely' have larger retreat distances in the range of -130 to 135 m by 2070 and -236 m to -248 m by 2120 due to higher extrapolation of historical erosion rates. For this shoreline section, the probability analysis indicates that the highest SLR 'very unlikely' erosion distances are in the order of 30 m higher than the 'most likely' position by 2070, and 50-55 m higher by 2120.

Relative contribution of the components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 5.13



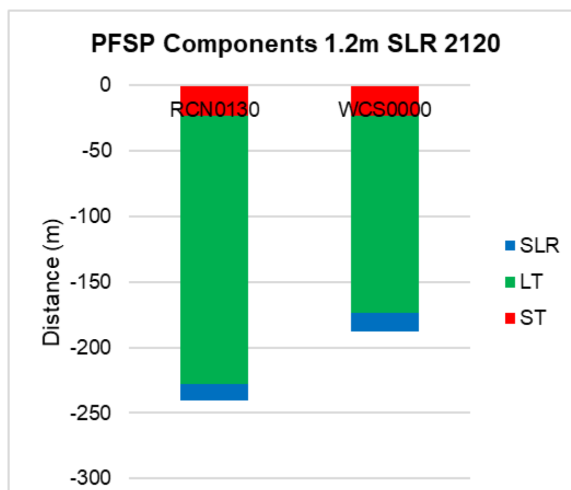


Figure 5.13: Average component inputs across ECan profiles RCN0130 and WCS0000, showing the different component inputs into calculating PFSP lines, where negative numbers indicate erosion.

Similar to the adjacent gravel ridge morphologies along this coastline, it shows that over the next 50 and 100 years the extrapolated historical erosion rate makes up the biggest component of the PFSP distances, with 75-80% over 50 years and 80-85% over 100 years. Short term erosion is likely to make up around 20% over the next 50 years, which reduces to around 10% over the 100 year period. The effect of SLR has a minimal contribution, making up 3% of the PFSP over 50 years, increasing to around 5% over 100 years. Therefore, erosion is likely to be a significant hazard along this section of coastline in the future under all SLR scenarios.

Potentially Impacted Assets

The coastal stopbanks along the northern flanks of the Opihi lagoon to Orakipaoa Creek that protect Milford Huts from high lagoon water levels are as shown in Figure 5.12 most likely to be compromised by erosion within a 50-year period. However, the presence of these banks could slow down the erosion rate for a period of time once they interact with the beach profile. It is very unlikely that any of the hut settlement will be affected by erosion within this period but could do so within a 100-year time frame if the banks are not maintained or relocated.

5.5 Opihi River to Orari River

The coastline between the Orari and Opihi Rivers (Transects 640-729) comprises of 4.5 km of MSG ridge beaches for the length of this cell. We consider the on-going erosional trend along this section of shoreline to be a result of sediment budget deficit. As shown in Figure 5.14, this section of shoreline is represented by two ECan beach profiles, RCN0260 located at the north of Orakipaoa Creek and RCN0460 located at the end of White Road approximately halfway between the Opihi and Orari River mouths.

5.5.1 Erosion Components

Extrapolation of Long-Term Rates

The extrapolation of long-term erosion rates from 1955 to 2017 and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 5.14. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 5.14, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

Table 5.14: Extrapolation of long-term erosion rates (1955-2017) and resulting projected erosion distances between the Opihi River to Orari River.

Profile	DSAS Transects	Statistic	Erosion Rate (1955-2017)	2070 Erosion Distance	2120 Erosion Distance
RCN0260 (north of Orakipaoa Ck)	640 - 670 (1.5 km)	Mean	-1.52 m/yr	-75.9 m	-151.7 m
		Max at individual transect	-1.99 m/yr	-99.4 m	-198.7 m
		Avg Upper 95% Confidence level	-2.36 m/yr	-118.1 m	-236.1 m
RCN0460 (White Rd)	671 - 729 (3 km)	Mean	-0.93 m/yr	-46.4 m	-92.9 m
		Max at individual transect	-1.23 m/yr	-61.7 m	-123.5 m
		Avg Upper 95% Confidence level	-1.77 m/yr	-88.4 m	-176.9 m

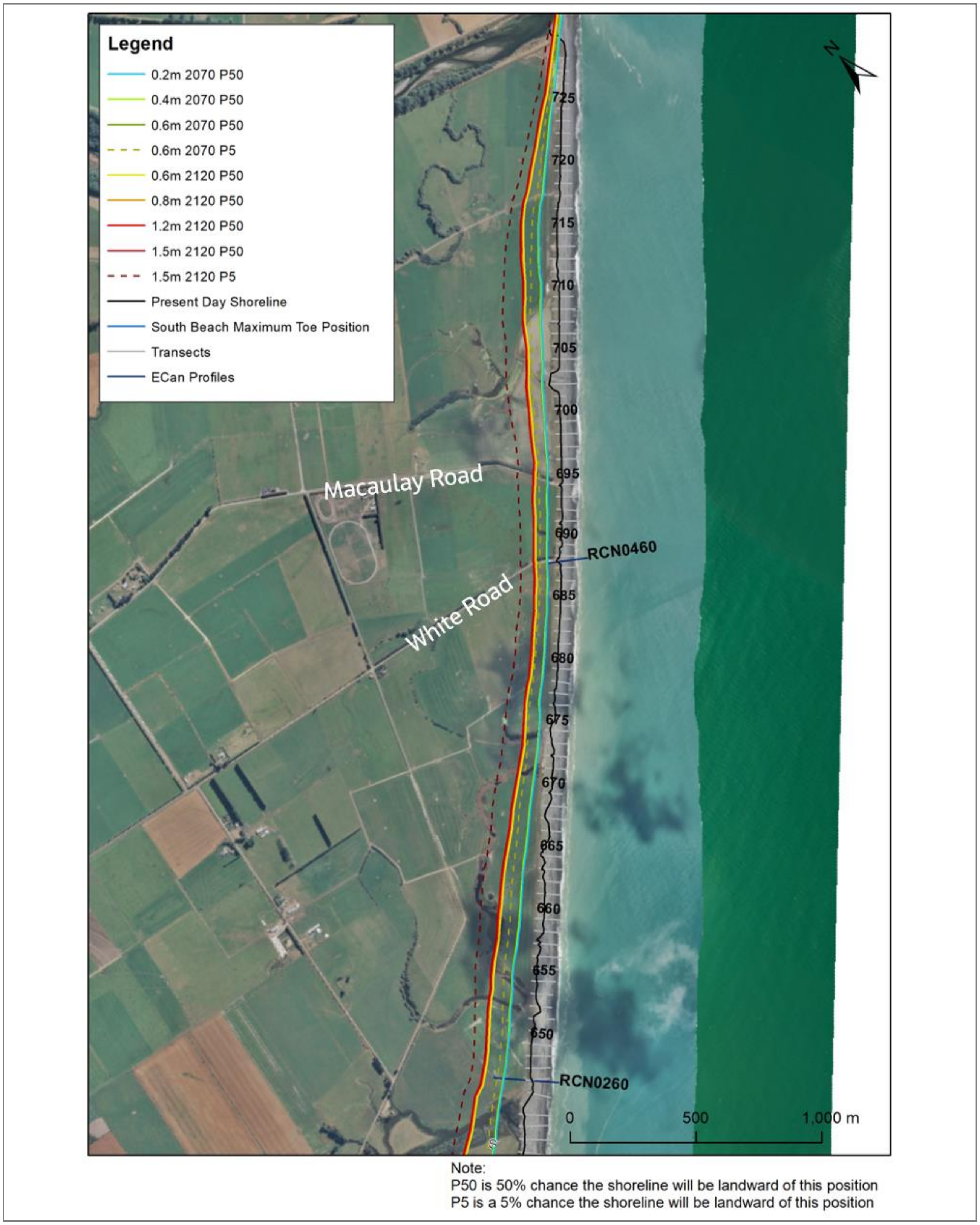


Figure 5.14: Orari River to Opihi River. Most likely" (P50) is shown for each scenario except 1.5m at 2120, and "very unlikely" (P5) shown for 0.6m in 2070 and 1.5m at 2120 (highest SLR scenarios).

The long term historical rate along this stretch of coastline generally decreases in a northward direction, with the highest erosion rates found along the 1.5 km stretch of shoreline across transects relating to ECan profile RCN0260 (transects 640-670). On average, the erosion rate for these transects is -1.5 m/yr, which when extrapolated into the future equates to -76 m of erosion over the next 50 years and -152 m of erosion over the next 100 years. As indicated in Table 5.14, there is considerable uncertainty in the extrapolated rates of future erosion, with a 5% chance that there could be up an additional 45 m of retreat over the next 50 years and an additional 85 m over the next 100 years.

The erosion rate averaged across the 3 km stretch of shoreline along the central and northern parts of the cell (transects 671-729) is -0.9 m/yr, which when extrapolated into the future equates to -46 m of erosion over the next 50 years and -93 m of erosion over the next 100 years. There is a similar level of uncertainty in this extrapolation.

Short Term Storm Erosion

Short term erosion was measured at the two ECan profiles which represent the morphological and geographic make up of this stretch of coastline. Both profiles are surveyed annually, RCN0260 since 1996, and profile RCN0460 since 1988.

At profile RCN0260, the maximum inter-survey erosion was -11.6 m at the beach crest, which occurred between August 1999 and June 2000. There were no storms recorded in this period. The GEV distribution of inter-survey erosion returned an erosion distance of -15.3 m for the mean value of a 100-year ARI erosion event, with the 99% confidence level of -33 m.

The maximum inter-survey erosion at profile RCN0460 was s -7.7 m at the 5 m contour, which occurred between March 2017 and May 2018. During this period six storms were recorded on the ECan storm database. The GEV distribution of inter-survey erosion returned a mean 9m erosion distance for a 1 in 100-year ARI event, with a 99% confidence level of -18 m.

Sea Level Rise Effect

The effect of SLR along this section of coast was calculated using the modified Bruun rule for MSG ridges, with the results presented below in Table 5.15. As shown in the table, the erosional effect of SLR is very similar for both ECan profiles, being in the order of -6 m over 50 years and -16 m over 100 years for the most extreme SLR scenarios. The results indicate around 5 m of sensitivity in the erosion distances around the range of SLR estimates used for the 50-year time frame and around 10 m sensitivity over the 100-year timeframe.

Table 5.15: Predicted erosion from future SLR at ECan profiles between the Opihi River to Orari River.

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
RCN0260	640-670	Mean	-1.3m	-3.8m	-6.4m	-5.1m	-7.6m	-12.7m	-16.5m
		Max	-1.7m	-5.0m	-8.3m	-6.7m	-10.0m	-16.7m	-21.7m
RCN0460	671-729	Mean	-1.2m	-3.6m	-6m	-4.8m	-7.1m	-11.9m	-15.5m
		Max	-1.6m	-4.8m	-8.0m	-6.4m	-9.6m	-16.0m	-20.8m

5.5.2 Projected Future Shoreline Positions (PFSP)

The calculated PFSP for the Opihi - Orari coast averaged over the length of shorelines represented by each ECan profile are presented below in Table 5.16 and are presented spatially in Figure 5.14 with the P50 position representing the 'most likely' position and P5 position the 'very unlikely' position under the highest SLR scenarios considered in this assessment of 0.6 m by 2070 and 1.5 m by 2120. Further maps showing the P95 PSFP for all SLR scenarios are presented in Appendix E (Map 6). A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

Table 5.16 Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP between the Opihi River and the Orari River.

Profile	DSAS Transects	likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
RCN0260 (north of Orakipaoa Ck)	640-670 (1.5 km)	Most likely	-95.0m	-97.7m	-100.3m	-174.7m	-177.4m	-182.7m	-186.5m
		Very unlikely	-125.2m	-127.9m	-130.6m	-233.0m	-235.8m	-241m	-244.8m
RCN0460 (White Rd)	671-729 (3 km)	Most likely	-58.0m	-60.5m	-62.9m	-108.1m	-110.5m	-115.6m	-119.2m
		Very unlikely	-87.1m	-89.6m	-92.0m	-165.7m	-168.2m	-173.2m	-176.8m

As can be seen in the table, the averaged erosion distance to the PFSP is significantly higher for transects relating to profile RCN0260, due to the influence of the higher historical erosion rate to the south and decreasing in a northern direction. Along this section of coastline erosion distances are projected to most likely be a maximum of around -100 m over the next 50 years, and around -185 m over the next 100 years. For the northern 3 km section of the cell (Transects 671-729) maximum predicted retreat is most likely to be in the order of 60-65 m over a 50-year time frame, and a maximum -120 m over a 100-year time frame.

The probability analysis indicates that due to uncertainties in the data there is a 5% chance that these erosion distances could be up to 30 m greater than the 'most likely' within 50 years, and 60 m greater over 100 years.

Relative contribution of the components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 5.15. This figure shows that future projected erosion is totally dominated by the extrapolation of the long term erosional trends, making up 80% of the total projected erosion distances. The short term storm component (15%) is also larger than the SLR component over a 50-year timeframe (5%) and is similar over the 100-year time frame. Overall, based on historical trends, erosion will be a significant issue in the future along this piece of coast regardless of the amount of sea-level rise.

Potentially Impacted Assets

Public assets located between the Orari River and the Opihi River include road ends at both White Road and Macaulay Road, as well as stopbanks which were put in place between 1968 and 1975. The road ends and stopbanks are all likely to be affected in the next 50 years. The rate at which the shoreline retreats could be slowed by the presence of the stopbank, however, this assessment has indicated that the lifetime of the banks could be compromised over the next 50 years, even under 'best-case' scenarios of 0.2m of SLR by 2070. This is significantly influenced by the long term erosion rate due to sediment starvation along this section of coastline.

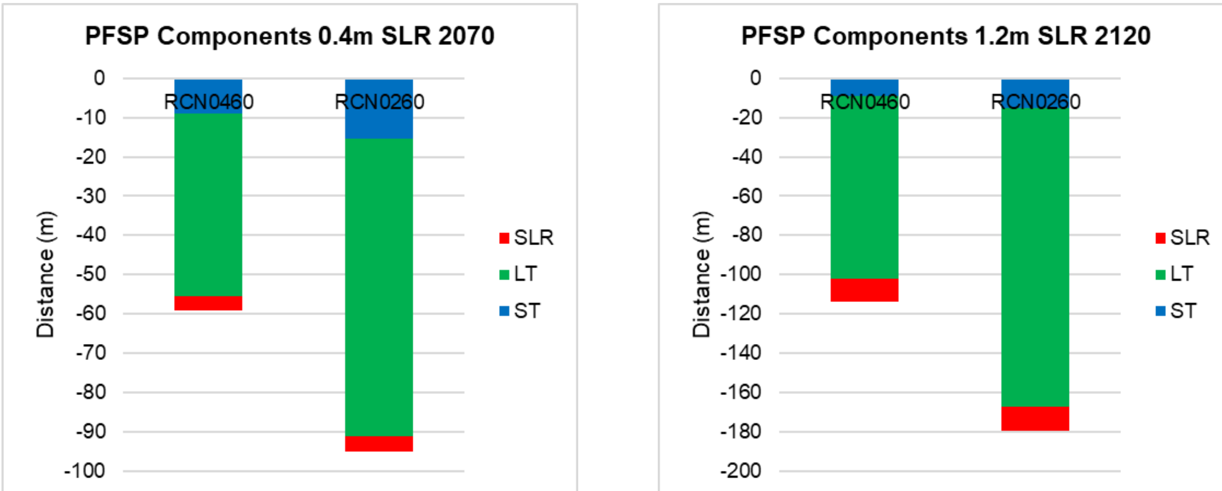


Figure 5.15: Contribution of each component of the erosion to the PFSP at ECan profiles RCN0460 and RCN0260, for SLR scenarios of 0.4m by 2070 (Left) and 1.2m by 2120 (Right).

5.6 Orari River to the Rangitata River

The 8.6 km stretch of coastline from north of the Orari River to the Rangitata River consists of MSG beach ridge in the southern and central segment, transitioning into alluvial cliffs of the Rangitata River terrace at the northern end. This coastal cell is presented below in Figure 5.16 and 5.17. There is also a river mouth training wall and 100 m small seawall on the north side of the Orari River mouth constructed in 1955 to prevent northward migration of the relocated mouth position diverted in 1954. Before this intervention, the mouth opening could migrate along the coast for up 2 km to the north. Following the diversion, the beach along the length of the former mouth channels has been stabilized by vegetation as shown in Appendix A.3.

Shoreline morphologies along this section of coastline are represented by ECan profiles RCN0695 immediately north of the Orari Mouth Seawall, RCN0952 located on the MSG ridge north of the former mouth position, and RCN1218 located on the alluvial cliffs at the northern end of the cell.

5.6.1 Erosion Components

Extrapolation of Long-Term Rates

The extrapolation of long-term erosion rates from 1954 to 2017 and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 5.17. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 5.17, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

Figure 5.16: Orari River to the Rangitata River (south) PFSP for various SLR scenarios in 2070 and 2120. 'Most likely' position (P50) is shown for each scenario, and 'very unlikely' (P5) is shown for SLR scenarios of 0.6 m by 2070 and 1.5 m by 2120 (highest SLR scenarios).

Figure 5.17: Orari River to the Rangitata River (north) PFSP for various SLR scenarios in 2070 and 2120. 'Most likely' position (P50) is shown for each scenario, and 'very unlikely' (P5) is shown for SLR scenarios of 0.6 m by 2070 and 1.5 m by 2120 (highest SLR scenario).

Along the former mouth channels to the north of the current mouth (transects 742-780) the vegetation advance is not considered representative of the rest of the shoreline, and therefore has not been used in the following analysis. This advancement of vegetation is discussed in more detail in Appendix A (Section A.3). For this section of the shoreline, long-term rates were interpolated from the adjoining transects on either side of this area.

Table 5.17: Extrapolation of long-term erosion rates (1954-2017) and resulting projected erosion distances between the Orari River and the Rangitata River.

Profile	DSAS Transects	Statistic	Erosion Rate (1954-2017)	2070 Erosion Distance	2120 Erosion Distance
RCN0695 (south end MSG beach ridge)	730-741 (550 m)	Mean	-0.28 m/yr	-13.9 m	-27.8 m
		Max at individual transect	-0.45 m/yr	-22.5 m	-45.0 m
		Avg Upper 95% Confidence level	-0.51 m/yr	-25.6 m	-51.2 m
RCN0952 (central MSG beach ridge)	781-829 (2.4 km)	Mean	-0.45 m/yr	-22.6 m	-45.2 m
		Max at individual transect	-0.61 m/yr	-30.6 m	-61.3 m
		Avg Upper 95% Confidence level	-0.78 m/yr	-38.9 m	-77.7 m
RCN1218 (northern alluvial cliff)	830-903 (3.65 km)	Mean	-0.48 m/yr	-24.2 m	-48.5 m
		Max at individual transect	-0.64 m/yr	-31.8 m	-48.5 m
		Avg Upper 95% Confidence level	-0.69 m/yr	-34.8 m	-69.5 m

For the southern end MSG ridge, the influence of the seawall at transects 730-731 on the running average historical rates results in a lower mean rate for this section than the other sections, with extrapolated erosion distances in the order of -14 m over 50 years and -28 m over 100 years.

The long term historical rate across both the central MSG beach ridges and the northern alluvial cliffs are very similar due to the retention of a linear plan shape, with alluvial cliffs having an assessed erosion rate of -0.48 m/yr, and MSG beach ridges having an erosion rate of -0.46 m/yr. Over the assessed 50 and 100 year periods, the extrapolation of these rates results in -22 m to -24 m and -45 m to -49 m of erosion respectively. However, erosion rates do begin to slow down in a northward direction from transect 880. Due to uncertainty in the historical trends, there is a 5% chance that these erosion distances could be up to 15 m greater over a 50-year time frame and up to 35 m greater over a 100-year time frame.

Short Term Storm Erosion

The short term erosion component was assessed by measuring the inter-survey erosion at the three ECan beach profiles. Both RCN1218 and RCN0952 profiles have been surveyed annually since 1988, and profile RCN0695 has been surveyed annually since 1993.

The maximum inter-survey erosion measured at RCN1218 was -4.7 m at the beach crest (5 m contour) between June 1997 and May 1998, a period within which there were no storms recorded. The GEV distribution of inter-survey erosion returned an erosion distance of -5.1 m for the mean value of a 100-year ARI erosion event, with the 99% confidence level of -8.8 m.

The maximum inter-survey erosion recorded at RCN0952 was -3.7 m at the beach crest (5 m contour) between May 2001 and June 2002, a period within which there were six storms recorded on the ECan storm database. The

GEV distribution of inter-survey erosion returned an erosion distance of -3.9 m for the mean value of a 100-year ARI erosion event, with the 99% confidence level of -7.5 m.

The maximum inter-survey erosion recorded at RCN0695 was -3.7 m also between May 2001 and June 2002. The GEV distribution of inter-survey erosion returned an erosion distance of -4.5 m for the mean value of a 100-year ARI erosion event, with the 99% confidence level of -8.6 m.

Sea Level Rise Effect

The erosion effect from sea level rise was calculated using two different methods along this section of coastline – one method for alluvial cliffs and the other for gravel ridges. The average amounts of predicted erosion due to SLR along this section of coast is detailed below in Table 5.18. As can be seen in this table, the effect of SLR is greater on alluvial cliff morphologies than gravel ridge morphologies.

Table 5.18: Predicted erosion from future SLR at ECan profiles between the Orari River and the Rangitata River.

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
RCN0695 & RCN0952	730-741 781-829	Mean	-1.1 m	-3.4 m	-5.7 m	-4.5 m	-6.8 m	-11.3 m	-14.7 m
		Max	-1.5 m	-4.6 m	-7.7 m	-6.2 m	-9.3 m	-15.4 m	-20.0 m
RCN1218	830-903	Mean	0 m	-7.3 m	-14.4 m	-6.1 m	-14.5 m	-28.7 m	-37.8 m
		Max	0 m	-10.4 m	-20.6 m	-8.7 m	-20.9 m	-41.2 m	-54.2 m

At the 3 km of MSG beach ridges, the estimated effect of accelerated SLR is erosion of up to -5.7 m in 50 years and up to -14.7 m over the next 100 years under the highest SLR scenarios. Along the 3.6 km of alluvial cliffs, the effect of SLR is greater, being up to -14.4 m over the next 50 years, and around -37.8 m over the next 100 years under the same highest SLR scenarios. This indicates that alluvial cliffs will be more sensitive to SLR than the MSG beach ridges.

The results also indicate there is more uncertainty in the SLR erosion impacts for alluvial cliffs, with a maximum retreat for this type of shoreline possibly being in the order of 6 m greater than the mean over a 50-year timeframe, and up to 17 m greater over 100 years for the highest SLR scenarios. In comparison, uncertainty in MSG beaches only accounts for an additional 2 m over 50 years and 6 m over 100 years for the same SLR scenarios. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.

5.6.2 Projected Future Shoreline Positions (PFSP)

The calculated PFSP averaged over the length of coast represented by each ECan profile are presented below in Table 5.19 and are presented spatially in Figures 5.16 and 5.17 with the P50 position representing the 'most likely' position and P5 position the 'very unlikely' position under the highest SLR scenarios considered in this assessment of 0.6 m by 2070 and 1.5 m by 2120. Further maps showing the P5 PSFP for all SLR scenarios are presented in Appendix E (Map 7 & 8). A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

Table 5.19: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP between the Orari River and the Rangitata River.

Profile	DSAS Transects	Likelihood	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
RCN0695 (south end MSG beach ridge)	730-741 (550 m)	Most likely	-16.7 m	-19.2 m	-21.6 m	-30.8 m	-33.1 m	-37.9 m	-45.5 m
		Very unlikely	-28.1 m	-30.4 m	-33.0 m	-53.1 m	-55.6 m	-60.4 m	-64.1 m
RCN0952 (central MSG beach ridge)	781-829 (2.4 km)	Most likely	-28.4m	-30.7m	-33.0m	-55.4m	-56.8m	-61.4m	-64.9m
		Very unlikely	-39.6m	-42.0m	-44.3m	-76.7m	-79.1m	-83.8m	-87.5m
RCN1218 (north end alluvial cliff)	830-903 (3.65 km)	Most likely	-29.8m	-35.8m	-41.7m	-59m	-66.0m	-77.7m	-85.5m
		Very unlikely	-37.3m	-44.0m	-51.5m	-73.8m	-82.0m	-97.2m	-107.4m

For the section of coastline north of the Orari River beyond the influence of the seawall, it is estimated that the most likely shoreline retreat could be in the order of -20 m over the next 50 years and in the order of -45 m within 100 years with the highest SLR scenario. These erosion distances would be independent of whether the seawall is maintained or not, however they are influenced by the extrapolation of the slow historical retreat at the wall.

Over a 50-year period, the average PFSP erosion distance is projected to be up to -42 m for the alluvial cliffs and up to -33 m for gravel ridges under the highest SLR scenarios tested. Over a 100 year period, these increase to up to -86 m for alluvial cliffs and -65 m for MSG beach ridges.

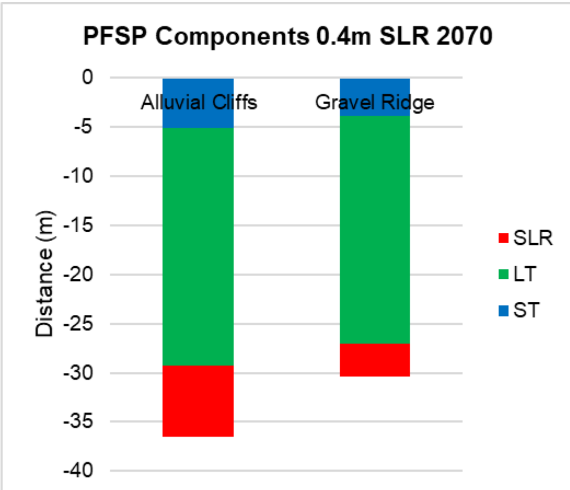
There are also similar levels of uncertainties across both morphologies, with the difference between the 'most likely' and the 'very unlikely' PFSP being 8-12 m over 50 years and 16-23 m over 100 years.

Relative contribution of the components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented below in Figure 5.18.

Over the 50-year timeframe, Figure 5.18 shows that the long term historical erosion rate is the most significant component of the PFSP erosion distances at both morphologies (65-75%), with the short term component only having a small effect on the PFSP line (15%). For alluvial cliffs, the SLR component over 50 years contributes 20% of the PFSP line, while for gravel ridges this only makes up 10%.

For the 100-year time frame, the SLR component at the alluvial cliffs increases to around 35% of the total erosion, with the long term historical erosion component making up around 60%, and short-term storm effect reducing to around 5%. For gravel ridge morphologies under the same scenario, the SLR component only makes up approximately 20% of the total erosion, with the historical erosion component contributing 75%.



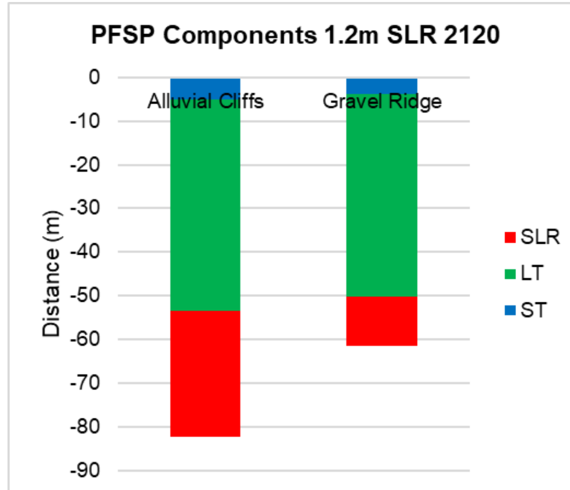


Figure 5.18: Contribution of each component of the erosion to the PFSP at alluvial cliffs and MSG ridges between the Orari and Rangitata Rivers, for SLR scenarios of 0.4m by 2070 (Left) and 1.2m by 2120 (Right).

Potentially Impacted Assets

The only public asset along the section of coastline likely to be affected is the sea wall and mouth training works at the mouth of the Orari River. The PFSP at the sea wall was calculated with reduced historical erosion rates due to the stability of this structure in the past, however ongoing maintenance of the structure will be required to ensure the current shoreline position is held over this period.

5.7 Rangitata Huts

The Rangitata Huts settlement is located on the lower terrace of the Rangitata River, with the shoreline being 800 m of MSG beach ridges which can be influenced by periodic southern migration of the river mouth channel. DSAS transects 904-920 cover this gravel ridge morphology, which is represented by ECan profile RCN1548 located on the boundary of the lower and upper terrace to the south of the settlement. This coastal cell is presented below in Figure 5.19.

5.7.1 Erosion Components

Extrapolation of Long-Term Rates

The extrapolation of long-term erosion rates from 1954 to 2017 and resulting projected retreat distances over 50 (e.g. by 2070) and 100-year (e.g. by 2120) timeframes are presented in Table 5.20. The extrapolated distances are purely of the historical erosion rate and do not take into account the effects of SLR into the future. In Table 5.20, several statistics are computed for each transect section including:

- The 'Mean' which is the average of the mean erosion distances for the defined section of shoreline;
- The 'Max at an Individual Transect' which is the maximum of all the transect 'means' within the shoreline section; and
- The 'Average Upper 95% Confidence Level' which is the average of all upper 95% confidence levels for this defined group of transects, demonstrating the average uncertainty of the long term extrapolation within the section of shoreline.

Figure 5.19: Rangitata Huts PFSP for various SLR scenarios in 2070 and 2120. 'Most likely' position (P50) is shown for each scenario, and 'very unlikely' (P5) shown for SLR scenarios of 0.6m by 2070 and 1.5m by 2120 (highest SLR scenarios).

The results presented in this table indicate that the long term historical shoreline trend determined from the movement of the vegetation line varies along the lower terrace. The 525 m southern end of the section in front of the settlement (transects 904-914) has experienced an average long term accretionary rate of +0.09 m/yr, while the 275 m long northern section of abandoned river channel (transects 915-920) has experienced an average long term erosion rate of -0.17 m/yr. When extrapolated forward over the next 50 and 100 years, transects 904-914 on the lower terrace can be expected to accrete +5 m and +9 m respectively, and in contrast, the shoreline between transects 915-920 on the abandoned river channel could be expected to erode on average -9 m and -17 m respectively over the same periods. We consider that the accretion trend at the hut settlement is due to sediment supply from the Rangitata River periodically being deposited south of the river mouth, whereas the erosion trend immediately to the north is a result to more frequent influence of a southerly river channel in this area causing barrier instability.

Table 5.20: Extrapolation of long-term erosion rates (1954-2017) and resulting projected erosion distances at Rangitata Huts.

Profile	DSAS Transects	Statistic	Erosion Rate (1954-2017)	2070 Erosion Distance	2120 Erosion Distance
RCN1548	904-914 (550 m Hut settlement)	Mean	+0.09 m/yr	+4.6 m	+9.1 m
		Max at individual transect	+0.02 m/yr	+1.2 m	+2.3 m
		Avg Upper 95% Confidence level	-0.32 m/yr	-15.8 m	-31.6 m
	915-920 (250 m abandoned river channel)	Mean	-0.17 m/yr	-8.6 m	-17.2 m
		Max at individual transect	-0.33 m/yr	-16.3 m	-32.5 m
		Avg Upper 95% Confidence level	-1.88 m/yr	-93.8 m	-187.7 m

Importantly the results also show a high degree of uncertainty in the historical trends with a 'highly unlikely' scenario of long-term erosion at the huts settlement. The probability analysis indicated that there is a 5% probability that erosion will occur at the hut settlement by up to -16 m within 50 years and around -30 m within 100 years. For the northern section, there is even higher uncertainty, with probability analysis indicating a 5% probability that the extrapolated erosion in this area could be up to -95 m within 50 years and up to -190 m in 100 years. However, these erosion rates are not considered representative of the processes that will occur, with the future river mouth erosion more likely to be in line with the adjacent coast due to plan shape and sediment transport considerations on this linear coast.

Short Term Storm Erosion

Profile changes at ECan profile RCN1548 surveyed annually since 1988 were used to determine the short-term storm erosion. Maximum inter-survey erosion was -12.8 m at the 4.5 m contour (beach crest) between February 1988 and May 1989, a period within which four storms in June/July 1988 and February 1989 were recorded. The GEV distribution of inter-survey erosion returned an erosion distance of -13 m for the mean value of a 100-year ARI erosion event, with the 99% confidence level of -18.4 m.

Sea Level Rise Effect

The erosion effect from SLR was calculated using the modified Bruun rule for gravel beaches with closure depth at the toe of the steep nearshore step. The results of this analysis are presented in Table 5.21.

Table 5.21: Predicted erosion from future SLR at ECan profiles at Rangitata Huts

Profile	DSAS Transects	Statistic	0.2m SLR By 2070	0.4m SLR By 2070	0.6m SLR By 2070	0.6m SLR By 2120	0.8m SLR By 2120	1.2m SLR By 2120	1.5m SLR By 2120
RCN1548	904-920	Mean	-1.1 m	-3.2 m	-5.3 m	-4.3 m	-6.4 m	-10.7 m	-13.9 m
		Max	-1.5 m	-4.4 m	-7.4 m	-5.9 m	-8.9 m	-14.8 m	-19.2 m

As shown in this table, the calculated effect of SLR at this site is relatively small, being retreat of up to -5 m by 2070 and up to -14 m retreat by 2120 under the most extreme SLR scenarios tested. Uncertainty in the effect of SLR on gravel beaches could add an additional 1-2 m over 50 years and 2-6 m over 100 years. This low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.

5.7.2 Projected Future Shoreline Positions (PFSP)

The calculated PFSP averaged over the length of coast represented by each ECan profile are presented below in Table 5.22 and are presented spatially in Figure 5.19 with the P50 position representing the 'most likely' position and P5 position the 'very unlikely' position under the highest SLR scenarios considered in this assessment of 0.6 m by 2070 and 1.5 m by 2120. Further maps showing the P5 PSFP for all SLR scenarios are presented in Appendix E (Map 9). A summary of mean inputs and outputs for each shoreline section is found in Appendix F.

Table 5.22: Calculated average erosion distances to the 'most likely' (P50) and 'very unlikely' (P5) PFSP at Rangitata Huts.

Profile	DSAS Transects	Likelihood	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120
RCN1548	904-914 (550 m lower terrace at Huts)	Most likely	-10.1 m	-12.2 m	-14.4 m	-8.8 m	-10.9 m	-15.4 m	-18.5 m
		Very unlikely	-24.4 m	-26.7 m	-28.8 m	-36.8 m	-39.0 m	-43.6 m	-46.9 m
	915-920 (250 m abandoned river channel)	Most likely	-23.0 m	-25.4 m	-27.2 m	-35.2 m	-37.5 m	-41.9 m	-44.8 m
		Very unlikely	-81.8 m	-83.9 m	-85.7 m	-151.0 m	-153.8 m	-157.7 m	-161.6 m

The results show that along the lower terrace at the front of the settlement (transects 904-914) the effects of short-term storms and SLR is most likely going to override any trend of long-term accretion due to sediment supply resulting in projected erosion is in the range of -10 m to -14 m over the next 50 years, and between -9 m and -18.5 m over the next 100 years, depending on the magnitude of sea-level rise. Along this shoreline section, the probability analysis indicates that the highest SLR 'very unlikely' erosion distances are in the range of 10-15 m greater than the 'most likely' position by 2070, and 25-30 m greater by 2120.

At transects 915-920 along the front of the abandoned river channel immediately to the north of the settlement, the analysis projects that shoreline movement is predicted to be on average double that predicted for in front of the hut settlement. However, as indicated above it is considered that these high rates of erosion are unlikely to occur due to the high degree of uncertainty in the historical trends and consideration of longshore sediment transport and plan-shape processes.

Relative contribution of the Components

The relative contribution of the individual components in the PFSP erosion distance under selected SLR scenarios for 2070 and 2120 are presented in Figure 5.20.

For both sections of shoreline in this coastal cell, the short term erosion component is the dominant component of the erosion distance over the next 50 years, accounting for over 50% of the erosion distance to the PFSP. The long term component differs between the two transect groups, as described above, with the extrapolation of the small long term accretion trend along transects 904-914 offsetting some of the short term and SLR erosional components.

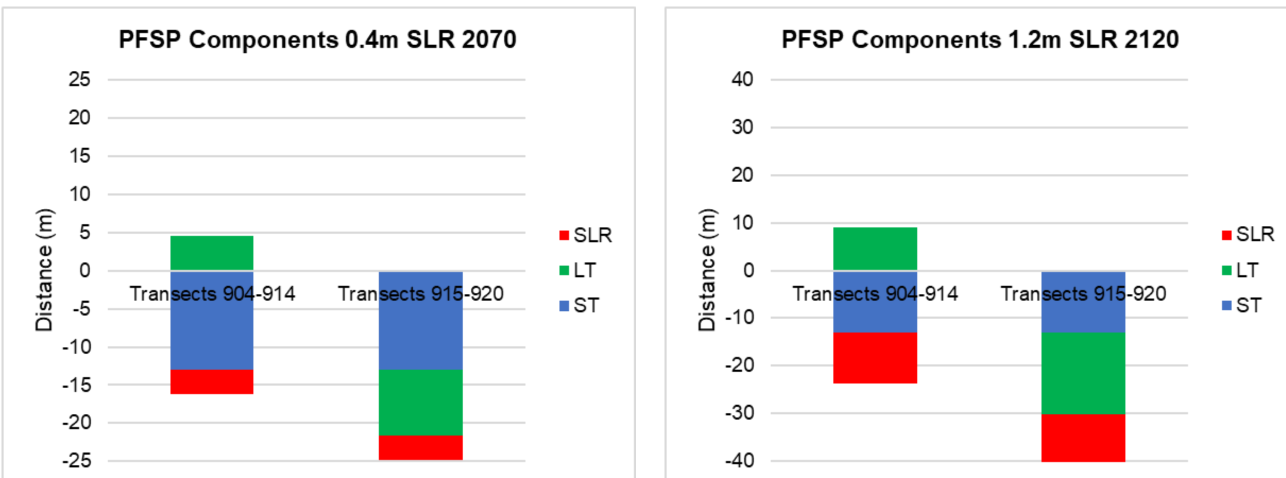


Figure 5.20: Contribution of each component of the erosion to the PFSP at the Rangitata Huts, for SLR scenarios of 0.4m by 2070 (Left) and 1.2m by 2120 (Right). Note positive distances indicate accretion and negative numbers indicate erosion.

Potentially Impacted Assets

As shown in Figure 5.19, Rangitata Huts Road would not be intersected by the PFSP line under any 'most likely' SLR scenario. However, a segment of the road at the northern end and some of the settlement is shown to be potentially affected under the 100 year 'very unlikely' scenarios.

6. Conclusions

The coastal erosion assessment of the Timaru District coastline has assessed and mapped the potential future shoreline position over the next 50 and 100 years under various SLR scenarios. For each of the SLR scenarios, ranging from 0.2 m to 0. 6 m by 2070, and 0.6 m to 1.5 m by 2120, there is a large variability in the projected future shoreline positions throughout the 45 km of coastline, which is largely driven by variations in shoreline morphology and orientation. Given this variability in the magnitude of future erosion, it is not appropriate to present a district wide conclusion of the results. Therefore, a summary of the results is presented below for each of the three identified coastal compartments of the Timaru District coastline: South of Timaru, Timaru Urban Area, and North of Timaru.

6.1 South of Timaru

The South of Timaru compartment extends 11 km from the Pareora River in the south to Saltwater Creek in the north. The shoreline comprises of MSG beaches, largely being backed by loess cliffs, which at a number of locations form small headlands where underlying seams of volcanic rock extend to coast to form nearshore rock reefs. At the southern end of the compartment, the Pareora Meatworks is protected by a large rock revetment structure over a 600 m frontage. At the northern end of the compartment, Saltwater Creek comprises of a 1200 m long and 100 m wide vegetated MSG beach ridge in front of the creek mouth channel.

Historically the whole length of this coastal compartment has suffered coastal erosion over the last 60-80 year, at a variety of rates due to different coastal morphologies and shoreline orientations. Average rates of historical retreat ranged from -0.01 to-0.05 m/yr for the beach at the Pareora Meatworks and south to the Pareora River, -0.14 to -0.27 m/yr for the loess cliffs, and -0.36 m/yr to -0.56 m/yr for other MSG beach ridges unprotected by engineering works. The extrapolation of these rates into the future, along with the impacts of SLR and short-term storm erosion, resulted in the following projected 'most likely' erosion to a PFSP (Projected Future Shoreline Position) over the assessed range of SLR scenarios over the next 50 and 100-years. For each beach type there is also a different relative contribution of the three components to the future projected erosion:

- Pareora Meatworks and south: -8 m to -13 m over the next 50 years, and -14 m to -24 m over the next 100 years, assuming the revetment structure is not maintained in its current position. Over a 50-year time frame, the short-term storm erosion is the largest component of the projected erosion at 50%, reducing to around 25% over a 100-year period as erosion due to SLR increases. Due to the past stability of the beach position due to the presence of coastal armouring, the contribution of the continuation of the long-term trend is the smallest contribution to the projected future erosion.

- Loess cliffs: -10 m to -31 m over the next 50 years, and -22 m to -66 m over the next 100 years. The greatest erosion occurs south of Pig Hunting Creek, and the smallest at Scarborough. The contribution of continued long-term erosion and SLR effects are very similar over 50-year time frames (e.g. 45-50%), with SLR effects being slightly more dominant over 100-year timeframes (e.g. up to 55%). Short-term storm effects are projected to only contribute around 5% of the total erosion over both time frames for these types of cliffs.

- MSG beaches: -20 m to -63 m over the next 50 years, and -53 m to -100 m over the next 100 years. The greatest erosion distances occur at the wetlands around the mouth of Pig Hunting Creek, and smallest being to north of the Pareora Meatworks. For these beaches, the extrapolation of the historical long-term retreat is the largest contribution to future erosion, with the effect of SLR being the smallest component contributing only around 10% of the total retreat over both time frames.

The mapping of the PFSP's indicates that the coastline is likely to generally retain its current shoreline character with the small loess capped headlands at the volcanic rock reefs remaining as headlands, but with a greater degree of MSG beach ridge re-orientation and pocket beach formation along the mouths of the coastal creeks and lagoons.

The probabilistic approach used in the assessment indicated that due to the uncertainties in the data for this coastal compartment it is 'very unlikely' that the erosion distances will be more that 10-20 m greater than given above over a 50 year timeframe or more than 20-40 m greater over a 100 year timeframe.

6.2 Timaru Urban Area

The Timaru Urban Area coastal compartment extends approximately 6.5 km from the loess cliffs at Patiti Point to the northern extent of the Dashing Rocks headland, which marks the start of the Canterbury Bight coastline. This coastal compartment is characterized by a number of pocket beach cells separated by loess cliff headlands overlaying seams of resistant volcanic rock, and the breakwater systems of the Port of Timaru. Due to the wide differences in geology, shoreline morphology and orientation, and coastal processes, each cell has very different past shoreline changes and future projected shoreline positions. These are summarised as follows:

- At the southern end of the compartment, the historically erosional loess cliffs at the Patiti Point headland have undergone a recent rapid acceleration of retreat since 2017 along the more exposed cliff line facing to the SE and east due to very low sediment volumes on the MSG barrier beach in front of the cliff that transitions into South Beach to the north. As a result mean historical erosion rates (incorporating recent accelerated rates) for these parts of the headland are in the order of -0.24 m/yr to -0.32 m/yr over the last 65 years, with the 'most likely' erosion to the PFSP over the next 50 years being in the order of -22 m to -35 m for the SE facing cliff line and in the order of -17 m to -28 m for the east-facing segment. Over a 100-year timeframe, these erosion distances increase to -50 m to -80 m for the SE facing cliff segment and -40 m to -60 m for the east-facing segment. The probability analysis indicates that due to uncertainties in the data there is a 5% chance that these erosion distances could be around 8 m greater within 50 years, and up to 18 m greater over 100 years. For the less exposed NE facing cliff that transitions into south Beach, mean historical erosion rates have been much lower, in the order of -0.1 m/yr, with the 'most likely" erosion to the PFSP being -8 to –14 m over the next 50 years, and -18 m to -42 m over 100 years depending on the magnitude of sea-level rise. For all cliff segments, the long term erosional trend and the effect of SLR components make very similar contributions to the projected 50-year erosion distances, with the SLR effect being the slightly more dominant component (55%) over a 100-year timeframe. The contribution of short-term erosion is very small in comparison.

- South Beach is a long-term accretionary MSG beach south of the Port of Timaru due to gravel traveling north by longshore beach drift being trapped by the Harbour Eastern Breakwater since 1887. Historical rates of accretion over the last 60 years have been in the order of +1 m/yr at the southern end and up to +2.65 m/yr at the northern end. For this coastal cell, PFSP's for 50 and 100 years were not produced as extrapolating the high historical accretion rates would result in the beach toe at the northern end extending beyond the Eastern Spur Groyne within around 20 years, therefore limiting further accretion. The effect of SLR and short-term erosion is not large enough along this section of coast to offset the high accretion rates.

- Caroline Bay, located in the lee of the Port's northern breakwater, is the only sand beach along the district's coastline and has also been rapidly accreting since 1887 due to the influence of the harbour breakwater structures. Historical rates of accretion over the last 80 years have been in the order of +4.5 m/yr in the centre of the bay, and around +2.65 m/yr at the western end. The extrapolation of these rates into the future due to the continuation of the current coastal processes will dominate over the effect of SLR and short-term storm erosion. The continued advancement of the shoreline is expected to be on average up to +130 m over the next 50 years, and in the order of +290 m over the next 100 years. However, it is noted that the 100-year PFSP is likely to be an overestimate because the wave energy arriving at the shore is likely to increase as the shoreline advances into less sheltered water.

- At Waimataitai Bay, the shoreline is protected by a large rock revetment, placed in the 1950s in response to erosion issues following the loss of Waimataitai Lagoon in the 1930s. As a result, the shoreline along this segment of coast has been stable since this time and assuming the continued maintenance and upkeep of the revetment structure, the PFSP would be expected to be similar to the current shoreline position. However, under a "structure non-maintenance" scenario, the 'most likely' erosion of the shoreline in this area could be up to -10 m within 50 years and up to -20 m within 100 years.

- At Dashing Rocks, the segment of loess cliff facing to the south into Waimataitai Bay is projected to have similar future erosion distances the remainder of Waimataitai Bay shoreline due to the presence of the natural basalt protection. However, for the exposed east-facing section at the end of the headland, mean long-term erosion rates are in the order of -0.2 m/yr, with projected 'most likely' future erosion distances in the range of -17 m to -30 m within 50 years, and -40 to -65 m within 100 years depending on the magnitude of SLR. The contribution of the extrapolation of the long-term rate and SLR effect are similar over a 50-year timeframe both contributing around 40% each, while over 100 years the SLR contribution increases to 50%. The contribution of short-term erosion is very small in comparison. The probability analysis indicates there is considerable uncertainty with these projections, with there being a 5% chance that the erosion distance could be more than 20 m greater in 50 years and more than 40 m greater over 100 years.

6.3 North of Timaru

This coastal compartment is the southern 30 km of the Canterbury Bight coastline from Washdyke Lagoon to the Rangitata River, the northern extent of the Timaru District. The southern 25 km of the compartment is lowland coast comprising of MSG barriers backed by coastal lagoons (Washdyke), river mouths (Opihi, Orari) and wetlands (north of both river mouths), or MSG ridges confined by stopbanks (Seadown, Opihi – Orari). The northern part of the compartment includes a section of alluvial cliffs forming the eastern edge of the Rangitata River upper terrace, the lower river terrace containing the Rangitata Huts settlement, and the southern side of the river channel.

Historically the whole length of this coastal compartment has suffered a large amount of coastal erosion, with rates generally being the highest at the southern end due to coarse sediment starvation from the south and decreasing in a northward direction as the beach receives increasing supply from longshore transport. Average rates of shoreline retreat over the last 60 years have ranged from -2.3 m/yr at Washdyke Lagoon, reducing to -1 m/yr to -1.5 m/yr between Opihi and Orari Rivers, and down to -0.45 m/yr of the lowland and alluvial cliff to the north of the Orari River. At the Rangitata River mouth, there have been low rates of long-term accretion (+ 0.09 m/yr) at the hut settlement, but there is a high degree of uncertainty in historical trends due to the influence of the river mouth, with a 5% probability that the shoreline could erode at rates up to -0.32 m/yr. The extrapolation of these rates into the future, along with the impacts of SLR and short-term storm erosion, resulted in the following projected 'most likely' erosion to a PFSP (Projected Future Shoreline Position) over the assessed range of SLR scenarios over the next 50 and 100 years:

- Washdyke Lagoon is projected to suffer the greatest coastal erosion within the Timaru District over the next 50 and 100 years, with erosion distances 'most likely' being in the order of -120 m to -150 m over the next 50 years, and in the range of -215 m to -280 m over 100 years. The probability analysis indicates there being a 5% chance that the erosion distance could be more than 40 m greater in 50 years and more than 75 m greater over 100 years.

- At Aorangi Road on the southern Seadown coast future erosion is projected to be in the order of -120 m to -130 m over the next 50 years, and between -195 m to -250 m over 100 years depending on the magnitude of SLR. These distances reduce significantly at the northern end of the Seadown Coast (Connolly's Road), with average erosion distances to the PFSP being -50 m to -65 m over the next 50 years and -90 m to -130 m over the next 100 years. The probability analysis indicated that it is 'very unlikely' that these erosion distances would be more than 20-25 m greater over 50 years or more than 50 m greater over 100 years.

- At the Opihi River mouth and Milford Huts, the 'most likely' erosion of the gravel barrier is in the range of -103 to -135 m by 2070, and -183 m to -248 m by 2120, with slightly larger projected retreat along the northern arm of the lagoon due to higher extrapolation of historical erosion rates. Uncertainty is higher along this coastal cell with the probability analysis indicating that it is 'very unlikely' that erosion distances would be more than 40 m greater over 50 years or more than 75 m greater over 100 years.

- Between the Opihi River and the Orari River, 'most likely' erosion distances over the majority of the cell are projected to be up to -100 m over the next 50 years, and around -185 m over the next 100 years. For the northern section of the cell, from White Road to the Orari River mouth, the predicted retreat is 'most likely' going to be in the order of -40 m over the next 50 years and -125 m over the next 100 years. The probability analysis indicates that it is 'very unlikely' that erosion distances would be more than 30 m greater over 50 years or more than 60 m greater over 100 years.

- From the Orari River to the Rangitata River, the average erosion distance to the 'most likely' PFSP within a 50-year timeframe is projected to be up to -33 m for MSG ridges and up -42 m for alluvial cliffs under the highest SLR scenarios tested. Over a 100-year period, these erosion distances increase to -65 m for MSG beach ridges and up to -86 m for the alluvial cliffs. There are similar levels of uncertainties across both morphologies, with the difference between the 'most likely' and the 'very unlikely' (P5) PFSP being 8-12 m over 50 years and 16-23 m over 100 years.

- At the Rangitata Huts, the effects of short-term storms and SLR is most likely going to override any trend of long-term accretion due to sediment supply, resulting in projected erosion distances in the range of -10 m to -14 m over the next 50 years, and between -9 m and -18.5 m over the next 100 years. The probability analysis indicates that the 'very unlikely' erosion distances are in the range of 10-15 m higher than the 'most likely' position by 2070, and 25-30 m higher by 2120.

For all of the lowland coast cells from Washdyke Lagoon to north of the Orari River, the extrapolation of the long term erosion component is the most dominant contribution to the PFSP, contributing in the range of 70-80% of the total projected erosion distances. For these shoreline type, SLR effects generally contributed 5-10% of the projected erosion distance over a 50-year time frame, and a maximum of 20% over a 100-year timeframe. These results indicate that for these shoreline types, erosion hazards will be significant regardless of the magnitude of future SLR. For the alluvial cliffs at the northern end of the compartment, the contribution of SLR effects is higher, in the order of 20% over 50 years, and up to 35% over 100 years.

6.4 Recommendations

It is recongnised that there are limitations in the future erosion projections and PFSPs due to deficiencies with the data availability, assumptions on how this data is used to develop the assumptions and uncertainties with the methods. To reduce these limitations and uncertainties, and to validate the results of this assessment, we recommend that the following investigations be continued or initiated:

- Monitoring of Patiti Point be continued by both profile surveying and collection of LiDAR and aerial imagery to allow the continued surveillance of the temporal component and magnitude of the recent rapid increase in erosion rates at this location, and undertake further investigation into understanding the physical processes around the recent acceleration of erosion rates to determine the likelihood and frequency of these occurring again.

- Address the uncertainty around the long term position of accreting beaches at Caroline Bay and South Beach from the two-dimensional nature of the erosion assessment carried out in this assessment, by undertaking 3-Dimensional modelling of longshore transport processes to better define the potential future shoreline positions at these locations which would better account for the changing interaction between wave regime and sediment transport potential with shoreline advance.
- At Washdyke Lagoon, undertake a more detailed volumetric assessment of the barrier to determine the likely change in barrier volume as it continues to roll back into the lagoon and the loss of elevation as the remaining volume is stretched over a greater shoreline length. This assessment would provide a better indication of whether there is enough volume available for the barrier to retreat inland as far as what has been assessed in this report, or whether the barrier is likely to breach and disintegrate earlier before reaching that point due to lack of volume.

- Along the Seadown coast, a more in-depth investigation of the magnitude and temporal/spatial patterns of accelerated erosion rates associated with stopbanks being breached of over-run by coastal erosion should be undertaken as these could greatly influence the time and location of the PFSP's.

- A more detailed assessment should also be carried out on the revetment structures along the shoreline (e.g. Pareroa, Waimataitai, Dashing Rocks) to determine in more detail the erosion consequences of not maintaining these structures, or to better determine to how much maintenance will be required to maintain these structures under various SLR scenarios in the future.

7. References

Ashton, A. D., Walkden, M. J., & Dickson, M. E. (2011). Equilibrium responses of cliffed coasts to changes in the rate of sea level rise. *Marine Geology*, *284*(1-4), 217-229.

Bosserelle, C (2020). Timaru District Coastal Hazards Assessment Coastal Inundation. Prepared for Environment Canterbury.

Bruun, P., (1962). Sea Level Rise as a cause of shore erosion. *American Society Civil Engineers Proceedings, Journal Waterways and Harbors Division,* 88, 117-130.

Crosswell, J., Pahlen, S., van Waelsden, H., Gunn, O., Hanlon, N. (2019). Coastal Erosion at Patiti Point, Timaru. *University of Canterbury GEOG309: Research Methods Report*

Department of Conservation (2010) New Zealand Coastal Policy Statement.

DTec (2004) Analysis of coastal storm inundation and erosion risk for beach front developments at Caroline Bay, Timaru. Report for TDC. 47 pps.

Gabites B (2008a) A summary of Environment Canterbury's coastal environment monitoring programme for the Washdyke coastline, 1994-2007. *Environment Canterbury Report No. R08/98.*

Gabites B (2008b) A summary of Environment Canterbury's coastal environment monitoring programme for the Timaru coastline, 1994-2007. *Environment Canterbury Report No. R08/97.*

Gibb J.G, Adams J. (1982) a sediment budget for the East coast between Oamaru and Banks Peninsula, South Island, New Zealand. *NZ Jl Geology & Geophysics* 25, 335-352.

Griffiths G.A. & Glasby G.P. (1985) Input of river-derived sediment to the New Zealand continental shelf: I. Mass. *Estuarine, coastal and Shelf Science 21(6)* 773-787.

Hallermeier, R. J. (1981). Seaward limit of significant sand transport by waves: an annual zonation for seasonal profiles (No. CERC-CETA-81-2). *Coastal Engineering Research Center Fort Belvoir VA.*

Hassall C.E. (1955) A short history of the Port of Timaru. Timaru Harbour Board. 212 pps.

Hicks D.M. (1994) Modelling Historical and future Change of the Washdyke – Opihi Shoreline. NIWA Report to Canterbury Regional council. *NIWA consultancy Report No. CRC581.*

Hicks D.M. (2006): North Bank Tunnel Concept – Water Consents: River Geomorphology, Sediment Transport, Coastal Processes and Flood Hazard Management. Report for Meridian Energy Ltd. *NIWA Client Report CHC2006-090.*

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. R.K. Pachauri and L.A. Meyer (eds.). 151151, Geneva, Switzerland: IPCC

Jacobs (2020) Hurunui District coastline hazard and risk assessment. Report for Hurunui District Council.

Kirk R.M. (1984) Enhancement of coastal protection by beach realignment, South Beach Timaru. Report to Engineers Department, Timaru Harbour Board. 29pps.

Measures et al., (2014). Analysis of Te Waihora lake level control options: A Whakaora Te Waihora science project. *Prepared for Ngai Tahu and Environment Canterbury.*

MfE (2017) Coastal Hazards and Climate Change: Guidance for Local Government

Orford, J.D., *et al* (1995). The relationship between the rate of mesoscale sea-level rise and the rate of retreat of swash-aligned gravel-dominated barriers. *Marine Geology* (124) 17-186.

Stephens *et al* (2015) Storm tides and wave runup in the Canterbury region. *NIWA report HAM2015-132*. Prepared for ECan.

Thompson S.M., Adams S.J (1979) Suspended sediment load in some major rivers of New Zealand. In *Physical Hydrology – New Zealand Experience.* D.L Murray and P. Ackroyd (eds). *NZ Hydrological Society*. P213-228

Tierney B.W. (1977) Coastal change around the Port of Timaru. *NZ Geographer 33(2),* p80-83.

Todd, D. (1988). Annotated Coastal Bibliography of South Canterbury. *South Canterbury Catchment & Regional Water Board Publication No. 57.*

Todd, D. (1989). Washdyke – Opihi Coastal Erosion Study. *South Canterbury Catchment & Regional Water Board Publication No. 62.*

Walkden M.J.A. & Dickson M. (2008) Equilibrium erosion of soft rock shores with shallow or absent beach under increased sea level rise. Marine Geology 251(2008) 75-84.

Walkden M.J.A. & Hall J.W (2005) A predictive Mesoscale model of the erosion and profile development of soft rock shores. *Coastal Engineering* 52 (2005) 535-563