Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

North Rakaia Huts future coastal hazard assessment

Report No. R19/126
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October 2019

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

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Executive summary

Background
A high-level coastal hazard screening assessment for the Selwyn District (Cope, 2018) recommended that a more detailed coastal hazard assessment should be undertaken for the north Rakaia Huts settlement that can be used to identify future coastal hazard risk and vulnerability.

The problem
Some lower-lying parts of the north Rakaia Huts settlement are currently susceptible to combined fluvial and coastal flooding events. Future sea level rise is likely to increase this susceptibility. Cope (2018) recognised that the river and coastal process interactions at the Rakaia river mouth meant that the methodology used to identify areas of potential coastal erosion and flooding for the Selwyn District in the Selwyn District coastal hazard screening assessment (Cope, 2018) was not applicable to the north Rakaia Huts.

What we did
We have taken a more focussed look at the factors which cause coastal and hāpua/lagoon flooding and erosion at the north Rakaia Huts and how these might be affected by future sea level rise.

We looked at factors that contributed to previous flooding events at north Rakaia Huts. Contributing factors are the antecedent state of the river channel outlet and barrier beach crest height, river freshes that don’t directly breach the coastal barrier, and/or coastal storm wave overtopping of the beach barrier. Using these factors, alongside the RCP8.5+ sea level rise scenario from the 2017 MfE coastal hazard and climate change guidance, we developed a potential future floodable area that identifies land that may be affected during future coastal lagoon flooding events within the Rakaia Huts Residential Zone within the next 100 years.

We developed a potential coastal erosion area for the north Rakaia Huts. Creation of a localised area for the Rakaia Huts was necessary as we determined the previous District-wide coastal erosion would likely overestimate the erosion hazard if applied to the north Rakaia Huts situation.

What we found:
When the river mouth outlet is offset away from the main river channel, the lagoon becomes perched and during river fresh events or coastal storm events, the lagoon will fill up with water until it “spills” through low points in the lagoon beach barrier. The height of the beach barrier may play a fuse-like role in controlling the point to which ponding in the lagoon occurs. Barrier beach elevation may increase in response to sea level rise and tides also exert some control over lagoon water levels. As sea levels increase, lagoon water levels will also increase, with a subsequent increase in future flood potential.

The potential future floodable area incorporates all land under 5.8 m (Lyttelton Vertical Datum 1937) within the north Rakaia Huts Residential Zone.

There is considerable uncertainty around how the Rakaia hāpua and its landward shoreline might evolve over a 100-year planning timeframe. However, by analysing the relative historic movements of the landward hapua shoreline and projecting those movements to forward 100 years, a potential erosion area of 30 metres is presented. For pragmatic purposes the potential erosion area is mapped to existing private and District Council property boundaries. The coastal erosion area identifies the potential for some future erosion but recognises that the amount, although difficult to quantify, is unlikely to be on the same scale as that identified in the Selwyn District screening assessment for the remainder of the Selwyn District coastline.

What does it mean?
The potential future floodable and erosion areas can be used to identify future coastal hazard risk and vulnerability at the north Rakaia Huts and to inform future land use planning decisions.

How we have considered climate change

Future sea level rise scenarios have been used to examine how increasing sea levels might affect the coastal erosion and inundation hazard at the north Rakaia Huts. We have adopted a single projected sea level rise value of +1.36 metres out to 2120 (approximately 100 years from present). This projected level is the Ministry for the Environment's Guidance (2017) RCP8.5H+ scenario (the upper 83rd percentile of the RCP8.5 range). The use of RCP8.5H+ is precautionary and reflects a high future emissions scenario including the possibility of future surprises due to a more rapid increase in the rate of sea level rise early next century due to possible instabilities in polar ice sheets.

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1 Introduction

A high-level coastal hazard screening assessment has previously been undertaken for the Selwyn District coastline (Cope, 2018) following national guidance (MfE, 2017; DOC, 2017). The intended purpose of a screening assessment is to identifying areas that may require more detailed assessments of coastal hazard exposure, for single or multiple coastal hazards. A screening assessment should “broadly identify areas potentially exposed to coastal hazards” and shows “where more detailed hazard (and ultimately risk and vulnerability) assessments should be focused” (MfE, 2017).

Based on the screening assessment, Cope (2018) recommended that a more detailed coastal hazard assessment should be undertaken for the north Rakaia Huts settlement. The recommendation for further work arose from the fact that some lower-lying parts of the north Rakaia Huts settlement are currently susceptible to combined fluvial and coastal flooding events and that future sea level rise is likely to increase this susceptibility. Cope (2018) recognised that the river and coastal process interactions at the Rakaia river mouth meant that the methodology used in the Selwyn District coastal hazard screening assessment to identify areas of potential coastal erosion and inundation for the Selwyn District was not applicable to the north Rakaia Huts.

This report takes a more focussed look at the factors which cause coastal and hāpua/lagoon inundation and erosion at the north Rakaia Huts and how these might be affected by future sea level rise.

We recommend that this report be read in conjunction with Cope (2018).

2 Inundation – current situation

We already know that the lower elevations of the Rakaia Huts are vulnerable to inundation under some present-day conditions due to river and coastal interactions at the hāpua/lagoon.

An example of this type of flooding occurred on September 11, 2013 (Figure 2-1). This event inundated some parts of the settlement to levels of around 4 m above LVD-37. The main factors contributing to this event seem likely to be an offset and restricted outlet coupled with a river fresh (approximately 1700 m^3/s at Rakaia Gorge) with the peak likely arriving during the flood-tide period of a perigean (highest monthly) tide. The combination of high tide and channel restriction caused a rapid increase in lagoon level. The river flow was not great enough to create a direct breach in the barrier beach.

Unfortunately, the telemetered water level recorder at the lagoon was overwhelmed during this event so we do not know what the peak water level was, or the exact time that the peak level was reached. However, an analysis of photographs taken during the event compared with known ground elevations from LiDAR elevation data, enabled an estimation of flood water levels during this event to be made. Near the peak of the flood event, the level of flood water reached approximately 4 metres above Lyttelton Vertical Datum 1937[1] (LVD-37) (N. Griffiths, Environment Canterbury, pers. com. 2018).

4 metres above LVD-39 is the level to which Cope (2018) mapped land adjacent to the open coast of the Selwyn District that is potentially exposed to coastal inundation from extreme storm events (including storm tide, wave setup and sea level rise), over the next 100 years (out to 2120). Given that we know that flooding at the north Rakaia Huts can reach at least 4 metres under existing conditions, this 4 metre level, used in the screening assessment for the open coastal areas of the Selwyn District, inadequately reflects the potential future flood hazard at the north Rakaia Huts when considering the exacerbating effects of future sea level rise.

[1] Present day mean sea level is approximately 0.17 m above LVD 1937 datum. 4 m above LVD-37 is therefore approximately 3.83 m above present day mean sea level.

2.1 River mouth flooding dynamics

Tide levels exert some temporary control over lagoon levels through a backwater effect. Direct storm wave overtopping of the beach barrier also causes lagoon levels to rise, either independently of, or concurrently with river flood events (Hicks, 2012).

The state of the river mouth exerts a significant influence on lagoon water levels. A wide mouth that is aligned with the main channel connects the ocean directly to the lagoon and the lagoon level becomes close to the level of the sea and the tidal range in the lagoon aligns closely to the ocean tidal range (Hicks, 2012).

If the mouth channel migrates and is offset (usually north) of the main river channel due to favourable wave conditions and prolonged periods of lower river flow, the mouth becomes restricted. This restricted mouth causes the lagoon level to become perched to provide enough hydraulic head for the outlet to remain open (Hicks, 2012). In this situation there is very little tidal range in the lagoon. This high lagoon water level can persist for months and can increase the potential for flood hazard if a moderate fresh occurs in the river and the outlet does not immediately widen to accommodate the increased volume of water in the lagoon.

Hicks (2012) observed that lagoon flooding can occur when:

- there is a transient “fill and spill” mouth closure event driven by wave-forced deposition of shingle in the outlet channel. Generally, with a prolonged offset mouth creating a perched lagoon, the lagoon water will fill up until it “spills” through low points in the lagoon beach barrier,
- during river floods and freshes where the outlet does not immediately “blowout” or widen the outlet to cope with incoming floodwaters, and
- when storm waves inundate the lagoon with seawater either by overtopping the beach barrier or through a widened outlet.

Often these factors can combine, for example when a river flood or fresh coincides with a coastal storm event. The September 2013 flood event did not coincide with a coastal storm but did occur during a high monthly perigean tide.

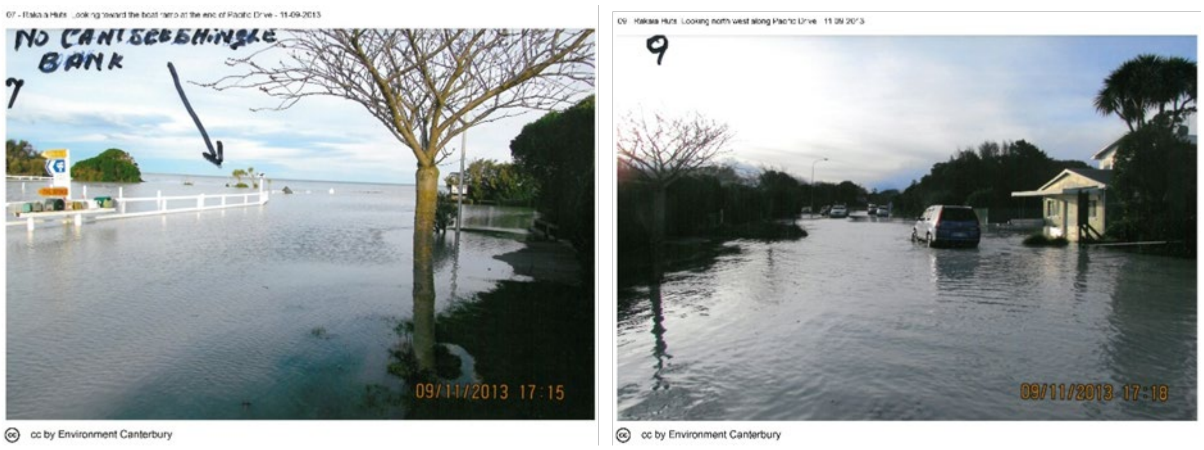

Figure 2-1: Flooding at north Rakaia Huts due to a moderate fresh and constricted hāpua outlet, September 2013. Source: Bill Southward/Environment Canterbury

2.2 Role of beach barrier elevation in flooding

The height of the lagoon beach barrier may play a fuse-like role in controlling high lagoon water levels which arise because of the factors, or combination of factors outlined in section 2.1. Hicks (2012) describes an example from May 2012 where high waves both moved shingle alongshore to choke an elongated outlet channel and overtop the beach barrier, causing the hāpua level to rise to around 2.5 m (LVD-37), flooding part of the Rakaia Huts carpark. A beach crest topographic survey just prior to this event showed several low points in the barrier at approximately at 2.5 m elevation. These low points were likely to be old river mouth locations. It appears that the lagoon filled to this level and spilled through the low point in the barrier to create a new mouth position. It is the low point in the barrier which controls the level of flooding.

We have no information on the antecedent heights of the beach barrier prior to the September 2013 event. If we assume a "fill and spill" response as occurred in the May 2012 event, then the lowest point on the barrier in September 2013 may have been approximately 4 m above LVD-37.

Beach crest elevation information along the length of the beach barrier fronting the Rakaia hāpua is scarce. Hicks (2012) undertook a barrier crest survey in April 2012 and found crest heights ranging from approximately 2.5 – 4.5 metres (LVD-37). An analysis of 2016 LiDAR elevation data has shown crest elevations of between 3.5 and 5 m, with an average crest height of 4.5 m. Environment Canterbury has undertaken an annual cross section survey through the hāpua and barrier since 1991. Between 1991 and 2018 the beach crest elevation at this site has ranged from 3.5 – 5.8 m, also with an average height of 4.5 m.

Barrier heights are variable because they depend on several factors, namely, the time since a previous breach event occurred, the location of the breach, the wave conditions to (re)build the barrier and potential variability in gravel supply rate. Therefore, the role that the barrier height plays in controlling the potential limit of flooding (through the height of low points) is as variable as the position of the river mouth in prompting flooding.

3 Inundation - future sea level rise

3.1 Assumptions

To estimate the potential effects of future coastal/lagoon flood events at the north Rakaia Huts, several assumptions relating to the future behaviour of the beach barrier and lagoon are made.

Firstly, we assume that the height of the beach barrier will keep pace with future sea level rise. MfE (2017) state that, providing there is no change in the current patterns or rates of longshore sediment transport, then where a wide gravel beach barrier is supplied with adequate sediment, the barrier "is likely to retreat slightly and increase in height in response to the rising sea level, increase in wave height, or increase in the frequency or magnitude of extreme storms". There is uncertainty in this assumption in that beach response described by MfE (2017) may not be representative of a highly dynamic river mouth environment such as the Rakaia. For example, if sediment supply stays the same and barrier height increases, there may be a greater risk of barrier breaching in high storm tide/wave events as beach crest widths narrow to accommodate for greater crest heights. Therefore, there is the possibility that sediment supply may need to increase for the barrier height to keep pace with sea level rise.

The sediment volume in the hāpua barrier is highly variable over time. Hicks and Enright (2010) analysed Environment Canterbury's coastal cross section data at the lagoon barrier between 1991 and 2010 and determined that the barrier's beach crest height and volume has been reducing over this time even though the whole lagoon system, including the beach barrier had generally moved seawards since 1952 (McHaffie, 2010). 1991-2010 cross section data at the hāpua beach barrier confirm this seaward movement continued until at least 2010 (Figure 3-1 and 3-2). Hicks and Enright (2010) attributed the loss in volume and beach height to this seaward migration of the river mouth shoreline into deeper water where a "deeper foundation" is required and therefore barrier volume and height is reduced, reflecting the maximum dimensions that the barrier can maintain given the supply of gravel available. Figure 3-3 shows this decrease in beach volume as the barrier moves seawards from the coastal cross section data. Hicks and Enright (2010) attribute this shoreline advance over recent decades to multi-decadal river mouth cycles between stability and erosion and predict a switch back to an erosional cycle.

Figure 3-1: Rakaia hāpua cross section surveys at 5 yearly intervals 1991-2010. Ocean to right of plot. Note decrease in beach volume and height as barrier extends seaward. Also of note is the artificial fill of the landward shoreline associated with construction of a boat ramp and carpark occurring between 1996 and 2001

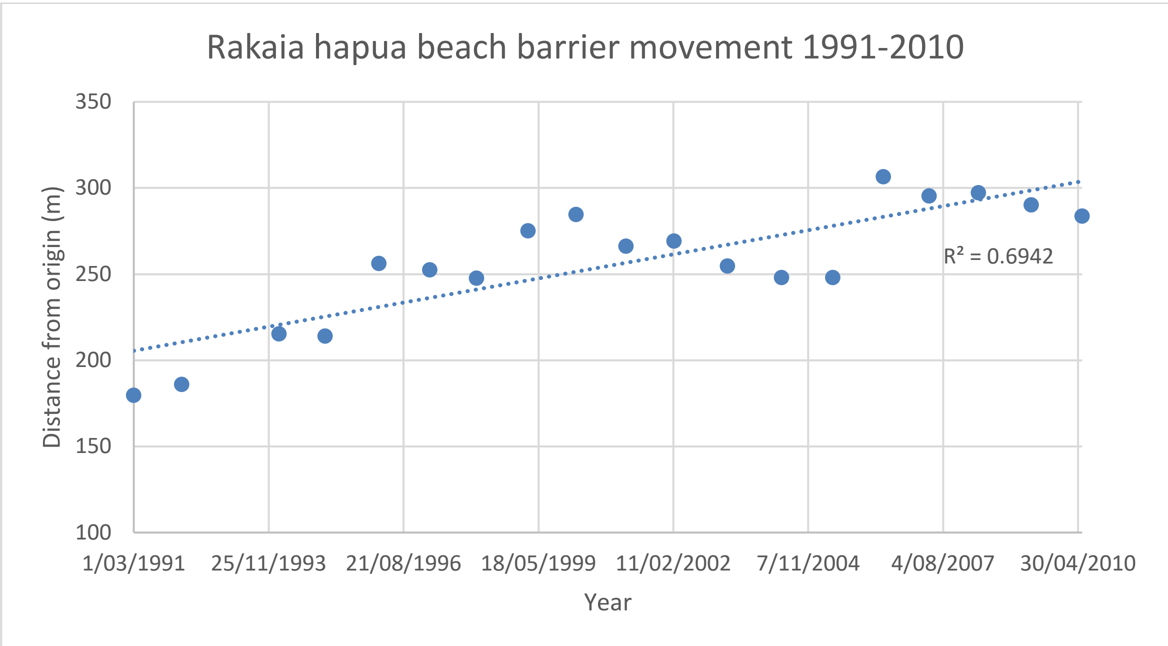

Figure 3-2: Barrier beach crest movement over time (1991-2010). Increasing distance from origin is in a seaward direction

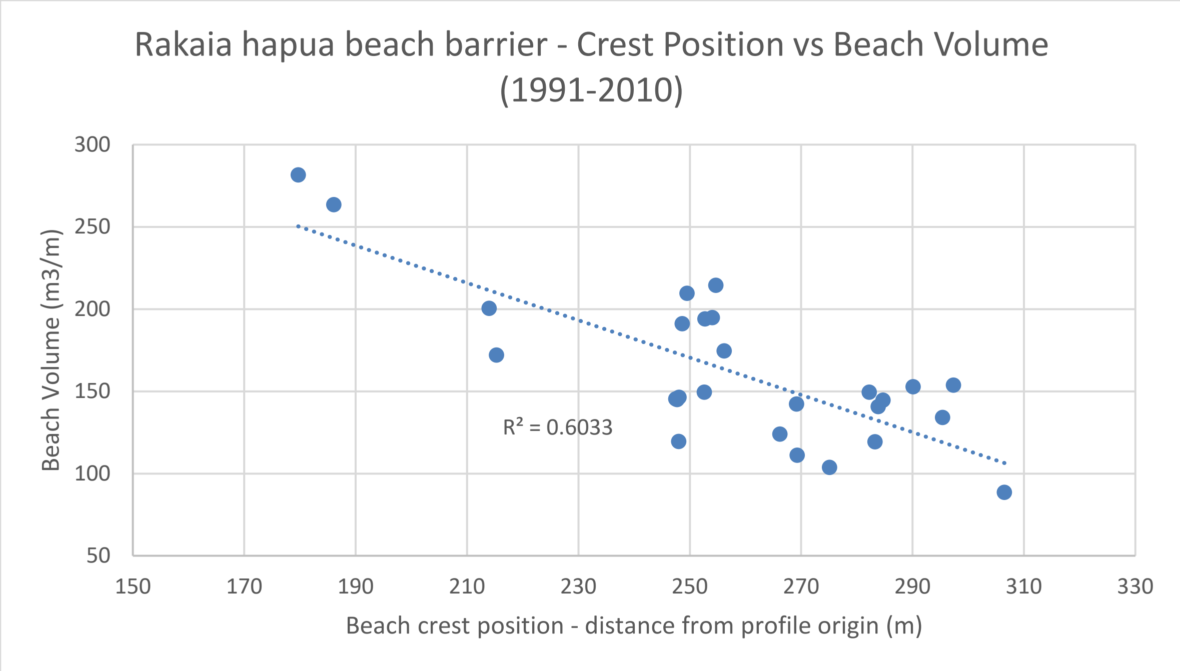

Figure 3-3: Relationship between beach barrier position and beach volume (1991-2010). Beach volume decreases with distance seaward

An analysis of subsequent Environment Canterbury surveys from 2010 through to 2019 shows that seaward movement and reducing beach volume identified by Hicks and Enright (2010) has weakened and possibly reversed. Between 2010 and 2019 the beach crest has moved landward and gained volume (Figures 3-4 and 3-5) in line with Hicks and Enright's (2010) assertion. We are uncertain whether this indicates a definitive reversal towards a longer-term cycle of erosion, but it does suggest it is not appropriate to attribute any certainty to a continuing reduction in beach volume.

Cross sections at the open coast immediately to the north and south sides of the Rakaia river mouth have shown an increase in beach volume since 1991 which indicates that sediment supply/storage near and around the Rakaia river beach barrier and delta has been sufficient in the last 27 years to prograde the coastline close to the river. This is consistent with McHaffie's (2010) observations of the river mouth shoreline environment since 1952 which in general has built out. Hicks and Enrights' (2010) prediction is that the river mouth beach barrier will eventually switch back to erosion to "catch up' with the rest of the eroding Canterbury Bight coastline. What is unclear, given the measured variability in beach sediment volume in the hāpua barrier and a switch to barrier retreat and volume increase over the past decade, is whether the beach volume and crest heights will be sufficient to keep pace with rising sea levels as this erosion takes place. We are assuming here that they are.

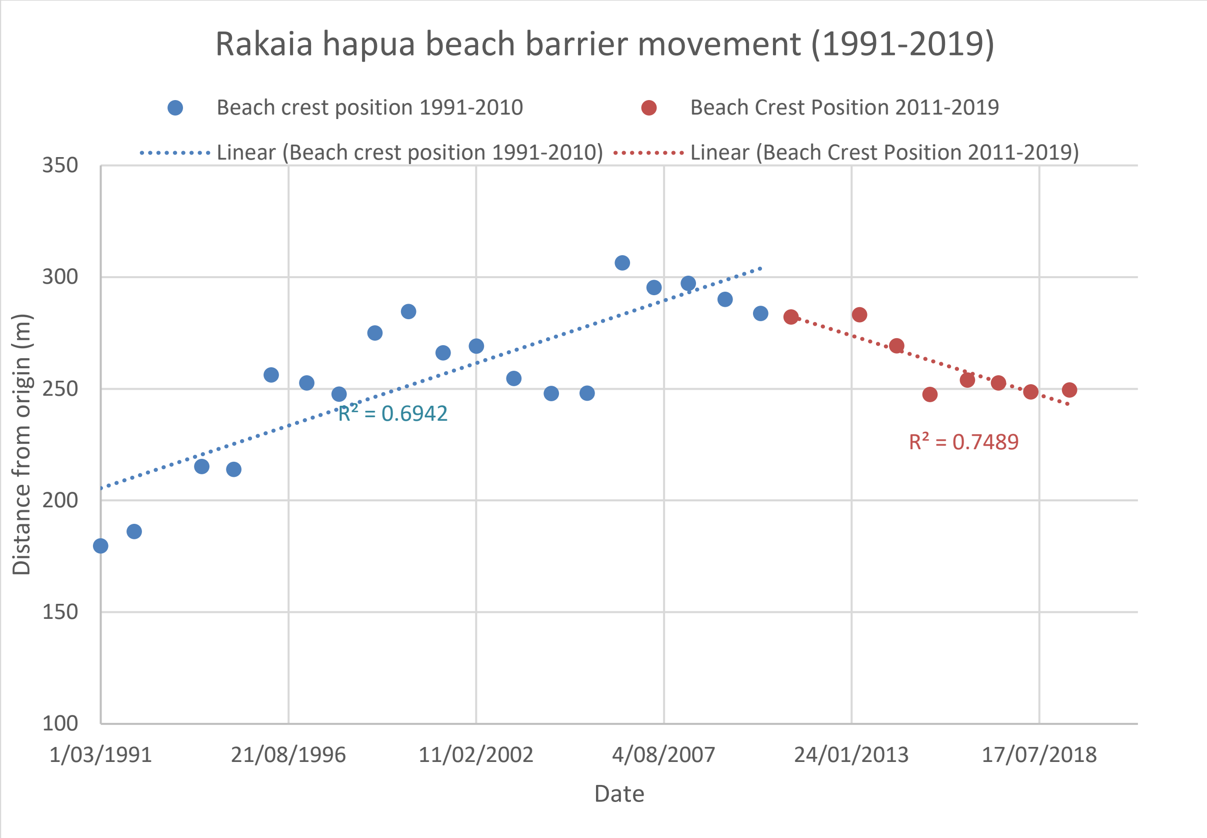

Figure 3-4: Movement of Rakaia hāpua beach barrier crest 1991-2019 showing post-2010 retreat of beach crest (in red)

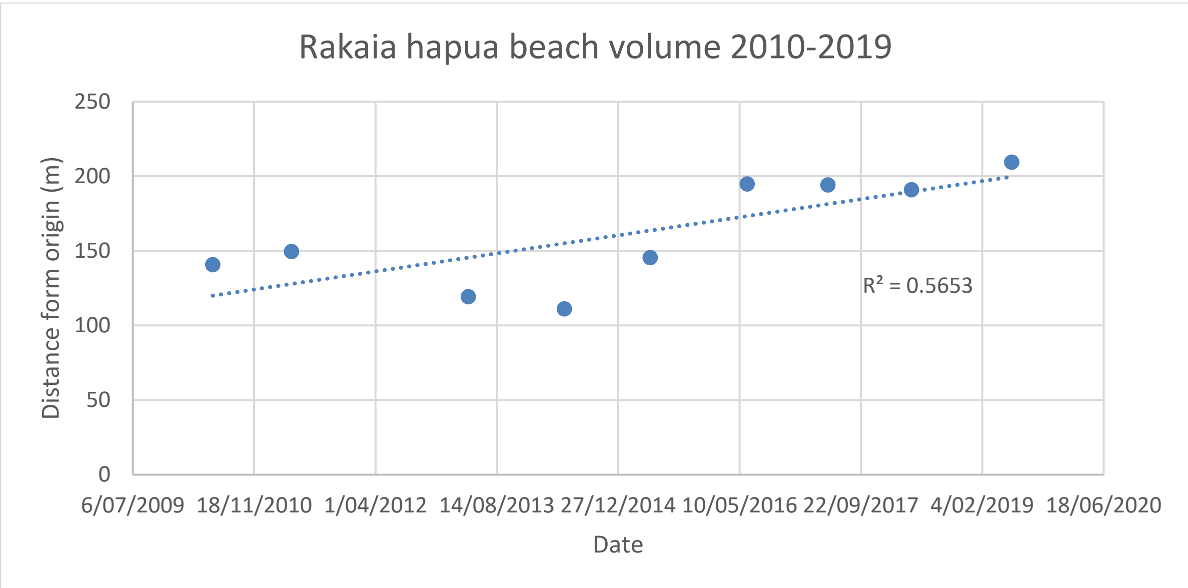

Figure 3-5: Changes in barrier beach volume at the Rakaia hāpua 2010-2019

The second assumption is that river and coastal sediment supply and the hydrology of the Rakaia River will remain constant. Climatic changes and/or future river management practices could change the hydrology of the river, with consequent effects on river mouth/hāpua behaviour and river sediment supply. Climate induced changes in coastal storminess could affect the frequency and magnitude of storm effects that may influence the drivers of coastal hazards such as storm surges, wave heights and wave direction. Subtle changes in wave direction and storm frequency may influence the longshore transport of coastal sediments both onto and away from parts of the Selwyn coast. The 2017 MfE guidance considers that current understanding of trends and projections of future changes in these weather induced coastal and ocean drivers is not as clear or consistent as for sea level rise.

Increased storminess or more extreme wave heights could contribute greater sediment supply from cliff erosion to the south which could in turn increase beach barrier height and volume. Conversely, higher storm tides and/or waves could also increase frequency of overtopping of the barrier, cancelling out the positive effects of increased sediment supply. MfE (2017) consider weather related coastal hazard drivers such as storm surge, waves and winds and the frequency and intensity of storms to be secondary to ongoing sea level rise as the principal effects of climate change on coastal hazards. Given this, and the uncertainty associated with future projections of weather induced coastal drivers, we have not taken any of these factors into consideration.

A third assumption is that lagoon water levels will also keep pace with sea level rise. The tide and ocean water levels exert some control on hāpua water levels through a backwater effect rather than a tidal flood and ebb as would be experienced in an estuary. When there is a wide outlet channel there is a direct connection between water levels in the lagoon and ocean resulting in tidal levels in the lagoon closely aligned with ocean water levels. When the outlet channel is constricted and offset it does not have the same direct connection or effect on tidal range. Instead, the sea level exerts its influence on lagoon water levels through controlling the hydraulic head required to maintain an open outlet. The higher the base sea level, the higher the lagoon water level will need to be to maintain the hydraulic head. During a river fresh or flood event when the outlet is offset and restricted the ocean sea level plays an important role in temporarily restricting outflow and accelerating lagoon filling to flood hazard levels. This relationship between sea level and lagoon water level is an important one and the assumption that increasing base sea level will also raise lagoon water levels appears valid.

A fourth assumption is related to future river mouth flood mitigation. Options exist for flood mitigation works at the mouth of the Rakaia River that could alleviate the effects of flooding. Mitigation measures include mechanically “resetting” the mouth position to relieve the potential impact of high lagoon levels due to an elongated outlet channel or mechanically creating artificially low or weak points in the beach barrier so that the lagoon will spill over or break through during a high river flow event. These are important considerations for the future management of flooding at the north Rakaia Huts but have not been taken into consideration in this assessment.

3.2 Future sea level rise

For consistency with the previous coastal hazard screening assessment for the Selwyn District we have adopted the same single projected sea level rise value out to 2120 (approximately 100 years from present) of 1.36 m. This projected level is from the 2017 MfE guidance and is derived specifically from the RCP8.5H+[2] scenario. RCP scenarios are expressed as a range, with the R8.5H+ scenario being the upper 83rd percentile of the RCP8.5 range. The use of RCP8.5H+ reflects the possibility of future surprises due to a more rapid increase in the rate of sea level rise early next century due to possible instabilities in polar ice sheets. Therefore, it is a relatively conservative, or precautious approach, applying a high future emissions scenario. For planning purposes, the use of the RCP8.5H+ sea level rise scenario (sea level rise of 1.36 m by 2120) enables consideration of land potentially affected by both current and climate change-exacerbated coastal hazards and a range of existing and future land uses (MfE, 2017). This range of potential land uses range from new short-lived assets with a functional need to be near the coast through to Greenfield developments. It can also be used to incorporate planning for existing developments and/or changes in land use e.g. redevelopment or intensification.

[2] Representative Concentration Pathway (RCP) 8.5 is a climate change projection scenario which assumes there will be continuing high greenhouse gas emissions for at least another 100 years with associated global temperature increases and sea level rise.

3.3 Future potential inundation levels

Due to the complex interactions of oceanic and river processes at the river mouth/hāpua environment, application of the same sea level components of potential inundation mapping as done in the previous district-wide screening assessment is not appropriate. For example, the combination of sea level factors, including 1.36 m of sea level rise and a 1% AEP coastal storm used in the district-wide inundation mapping produced a potential coastal flood level of 4 m (LVD-37). However, from recorded experience, flooding has previously occurred at the north Rakaia Huts up to 4 m (LVD-37) and this is even before any allowance for the effects of future sea level rise.

To identify potential floodable areas at Rakaia Huts under the RCP8.5H+ sea level rise scenario we have used the assumptions presented in section 3.1; that the beach barrier height and lagoon levels will increase in unison with rising sea level. Coupled with this is the assumption that beach barrier height exerts a control over the level to which flood ponding can occur, until spilling occurs as lagoon levels reach a critical height for drainage controlled by the minimum height of the beach barrier.

While recognising that lower beach barrier levels will often exist we have, as a conservative/precautious approach taken an average beach barrier height of 4.5 m (from section 2.2) and added the RCP8.5H+ 2120 sea level rise estimate of 1.36 m to determine the possible future height of the beach barrier (5.86 m LVD-37).

Because sea level estimates based on the RCP projections are based on a mean sea level between 1986 and 2005, a further deduction has been applied to discount the sea level rise that has occurred between 1995 (average of 1986-2005) and 2018 based on the historic long-term sea level rise for Lyttelton of 2.5 mm per year (MfE, 2017), see Table 3-1.

Table 3-1: Components used to determine potential flooding elevation at north Rakaia Huts

Component	Contribution (m)
Average beach barrier height (present day)	4.5
Sea level rise (RCP8.5H+ 2120 scenario) minus historic sea level discount (-0.058 m)	1.302
TOTAL	**5.802**

An alternative approach could be to simply add the adjusted RCP8.5H+ sea level rise (1.302 m) to the existing observed maximum inundation level of 4 m (see section 2). This gives a bathtub inundation level of 5.3 m. This could be assessed as a possible lower level 100-year inundation level, however, maximum current inundation levels may be higher. Therefore, a range of flood elevations out to 2120 using the RCP8.5+ sea level rise scenario could be 5.3-5.8 metres.

3.4 Mapping potential future inundation

The mapping of potential future inundation is a conservative bathtub approach. Bathtub models in general assume the inland area will be inundated to the equivalent static sea level as the adjacent open coast, or in the case of the Rakaia hapua the water level in the lagoon.

Using ARCGIS we have rounded the combined flood components from Table 3-1 to the nearest 0.1 m (5.8 m), mapped ground elevations below 5.8 m (LVD-37) using the most recently available elevation data (a 2015 LiDAR survey) and clipped this area to the north Rakaia Huts Residential Zone layer. The area potentially floodable below 5.8 m using sea level rise estimates for the next 100 years based on the RCP8.5H+ scenario is presented in Figures 3-5 and 3-6.

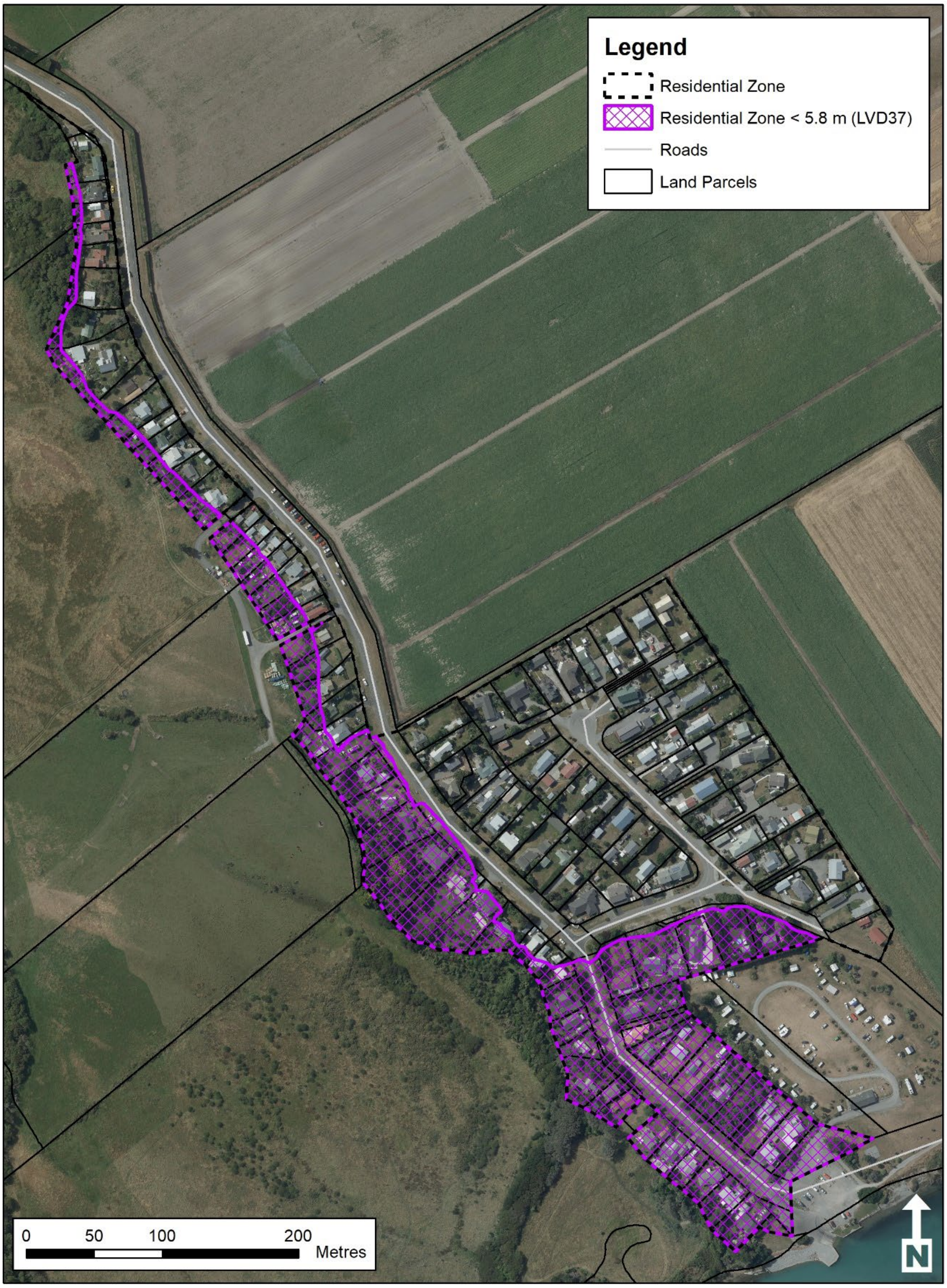

Figure 3-6: Potential future floodable area (<5.8 m LVD-37) within Residential Zone, north Rakaia Huts

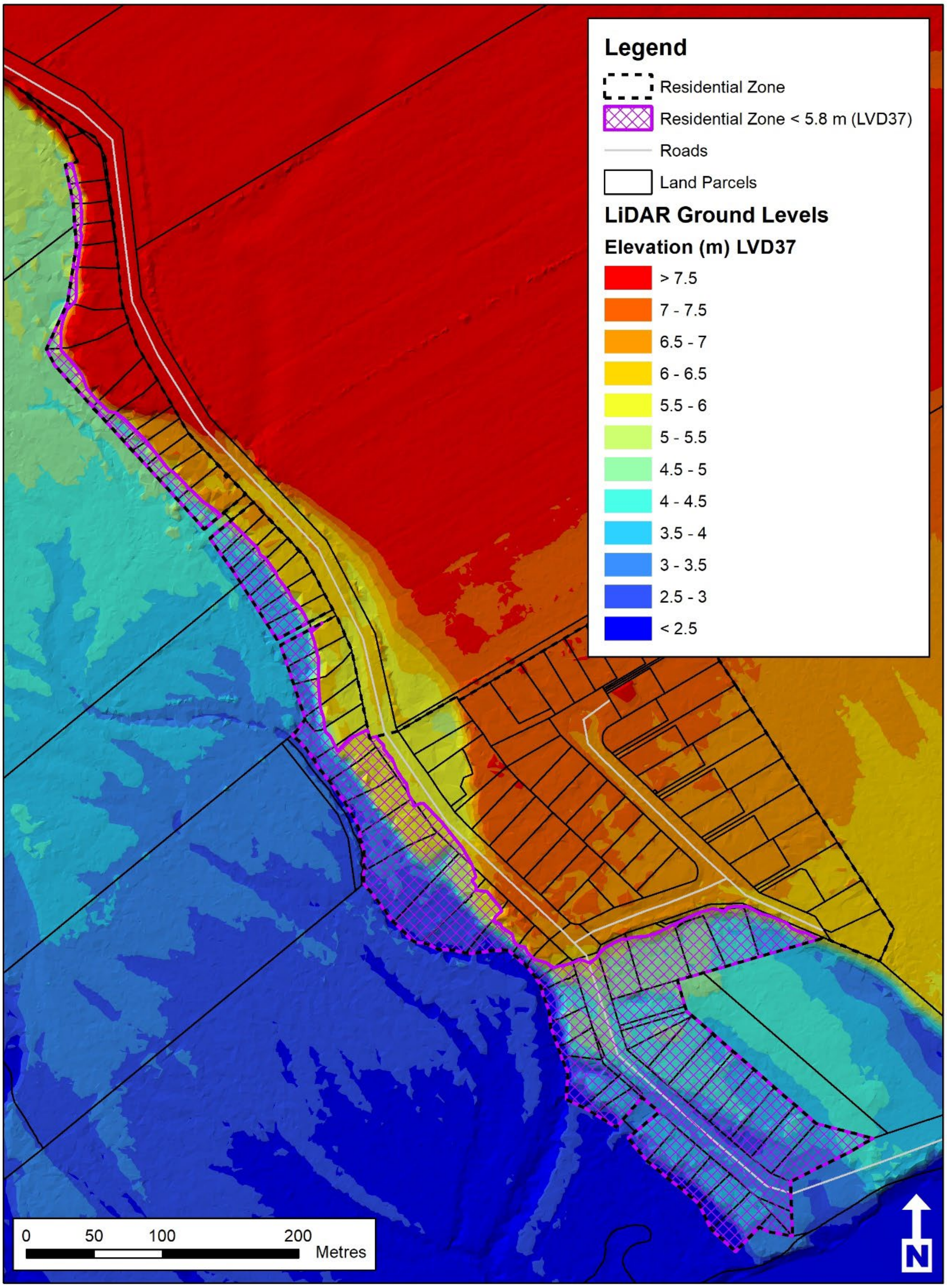

Figure 3-7: Potential future floodable area within Residential Zone (<5.8 m LVD-37), north Rakaia Huts with ground elevation

4 Shoreline erosion

4.1 Previous work

In the 2018 Coastal Hazard Screening Assessment for Selwyn District, an area of potential coastal erosion out to 2120 was identified. The maximum landward extent of this zone extended approximately 120 m inland from the current coastline. However, river and coastal process interactions at the Rakaia river mouth mean that the methodology employed for determining potential future coastal erosion for the open coastline of the Selwyn District is not applicable at the Rakaia Huts.

McHaffie (2010) and Hicks and Enright (2010) previously identified that the whole of the Rakaia lagoon system, including the barrier shoreline and landward shore migrated seawards between 1952 and 2004 Hicks and Enright (2010) attribute this shoreline advance over recent decades to multi-decadal river mouth cycles between stability and erosion and they predict a switch back to an erosional cycle. This outcome is consistent with the findings of previous hāpua evolution research (Kirk and Lauder, 2000) which has shown that the landward shorelines of hāpua, although demonstrating some lag-time, do eventually retreat in line with the adjacent coast.

4.2 Hāpua approach

We have re-analysed historic aerial photographs of the Rakaia hāpua between 1942 and 2019. McHaffie (2010) used the edge of the water body as a shoreline position to examine the change in hāpua/lagoon area over time. However, we are more concerned with the movement of the eroding bank top as the “shoreline” feature rather than the lagoon/shore interface. The bank top is an erosional feature that reflects long term movement and will not undergo any natural positive (seaward) movement (growth). It is the retreat of this feature that will be most relevant to the assessment of future erosion potential for management purposes.

Figure 4-1 compares the position of the landward bank top/edge between 1942 and 2019 in the vicinity of the north Rakaia Huts settlement. The most significant erosion of the hāpua shoreline has occurred immediately south of the settlement boat ramp and car park (-20 metres). Obvious fill has taken place around the boat ramp area, erosion is indeterminate immediately north of the boat ramp (due to difficulty in determining a bank edge in the two photographs) and the bank along the northern end of the hāpua has eroded by approximately 12 metres.

As part of this analysis we wanted to determine if there was any identifiable ratio between open coast erosion and hāpua erosion that could be applied to the projection of potential future hāpua shorelines. Table 4-1 presents the range of movement of the landward hāpua shoreline for the Rakaia River and two other Canterbury Bight rivers (Ashburton and Rangitata) over the past 76 to 82 years. The erosion rates of the hāpua shoreline are also expressed as a percentage of historic open coast erosion of the shorelines adjacent to the respective hāpua. The mean erosion rate of the open coastline north of the Rakaia hāpua was determined from a DSAS[3] analysis of historic aerial photographs by Cope (2018) as being approximately 0.5 metres per year. Open coast shoreline erosion rates north of the Ashburton and Rangitata river mouth were determined from nearly four decades of Environment Canterbury coastal profile monitoring.

Results show considerable variability in erosion along the length of the landward hāpua shorelines at the Rakaia, Ashburton and Rangitata river mouths (Table 4-1). This translates into a very wide range of annual historic erosion rates and therefore wide ranges of erosion rates when expressed as a percentage of open coast erosion. There is no comparative consistency between the three hāpua in terms of the ratio of open coast to hāpua shoreline erosion. The Rakaia hāpua shoreline had the least variability in historic shoreline erosion, although this still varied by up to 20 metres, which equates to up to 50% of the historic open coastline erosion.

[3] DSAS (Digital Shoreline Analysis Software) is an add-in to Esri ArcGIS that enables a user to calculate rate-of-change statistics from multiple historical shoreline positions.

We also attempted to examine if there was any relationship between the movement of the hāpua beach barrier shoreline and the landward shoreline of the hāpua using Environment Canterbury's coastal profile monitoring data. Unfortunately, the location of the coastal profile locations are not conducive to this analysis. The profile through the hāpua shoreline at the Rakaia is located at the hardened shoreline where the boat ramp/carpark is located, and the north Rangitata river cross sections are located where there has been erosion protection rock work installed. At the Ashburton river cross section site there is evidence of artificial earth works along the bank top at the cross section location as well as evidence that localised storm water runoff is exacerbating the erosion of the bank top along with river mouth/coastal processes. Therefore, coastal profile data on the movement of the landward edge of the hāpua cannot be used to compare with movements of the hāpua barrier shoreline at the three hāpua used in this analysis.

Figure 4-1: Landward shoreline (top edge of bank) of Rakaia hāpua 1942 and 2019. Base photograph 9/2/2019

Table 4-1: Historic movement of the landward shoreline for three Canterbury Bight river hāpua and that movement as a percentage of the adjacent open coast rate of erosion

i: A seaward net movement most likely due to artificial filling at boat ramp/carpark rather than a natural accretion
ii: Mean linear regression erosion rates for the Selwyn coast from Cope (2018)
iii: From Environment Canterbury survey results (1983-2019)
iv: From Environment Canterbury survey results (1981-2019)

River Hāpua	Measurement Period	End point shoreline movement (min/max) (m)	End point rate (m/yr.) (min-max)	% of open coast rate (min-max)	Long term open shoreline movement rate (m/yr.)
Rakaia	1942-2019 (77 years)	Positive[i]/-20	0/-0.25	0-50%	-0.50[ii]
Ashburton	1941-2017 (76 years)	-5/-46	-0.07/-0.6	9%-75%	-0.70[iii]
Rangitata	1937-2019 (82 years)	-7/-39	-0.08/-0.47	16%-94%	-0.50[iv]

Previous studies of Canterbury hāpua have identified variability in the recent shoreline evolution between Canterbury hāpua environments. Hart (2009) identified that the lagoon area of several Canterbury hāpua, namely the Ashburton, Rangitata and Opihi rivers have reduced in size and volume as their beach barriers erode, but landward lagoon shorelines remain stable. Hart (2009) suggests this indicates "that non-estuarine river mouth lagoons on eroding coasts are not always able to maintain their surface areas through parallel lagoon and barrier retreat". However, Hart (2009) also concludes that it is unlikely that hāpua will be entirely lost since open ocean wave processes (including longshore drift) prevent rivers from permanently maintaining mouth openings direct to the ocean without offsetting.

The analysis of the Rakaia, Ashburton and Rangitata landward hāpua shorelines in this investigation has shown that there is considerable spatial variability along some of these landward hāpua shorelines. While the landward shorelines of parts of the three hāpua have remained stable as Hart (2009) has identified, other parts have retreated but at considerably variable rates. The landward retreat of hāpua shorelines are not uniform and are complicated by localised erosion effects and in some instances artificial infilling and protection works.

For land-use planning, the lag-time between open coast retreat and hāpua landward shoreline retreat is an important factor for identifying a zone of potential future erosion. This investigation has not been able to identify any consistent historic relationship between the two features for three Canterbury Bight hāpua that might be used to project future hāpua shoreline erosion. While the lagoon shoreline will likely erode to "catch up" with the adjacent open coast, there is uncertainty around the timing of when the next cycle of retreat may occur, particularly in the face of accelerated sea level rise.

The rather challenging question then arises of where the Rakaia hāpua landward shoreline might erode to within the next 100 years. We have chosen to use the Rakaia-specific information from Table 4-1 where the maximum distance of landward hāpua shoreline erosion is approximately 20 m over the last 77 years. This is approximately 50% of the open coast erosion rate of the shoreline north of the river mouth, or a notional[4] rate of -0.25 m/year. We have then used this rate and projected it forward by a 100-year planning timeframe and made allowances for any potential increase in erosion rates due to accelerating sea level rise.

Measures *et al.* (2014) modelled future shoreline erosion for the open coast between the Rakaia River and Taumutu and found that modelled erosion rates increased by 22% with a rise in sea level of around 1 m by 2100. We assume a similar rate of increase out to 2120 and apply that to the historic erosion rate of the hāpua shoreline (-0.25 m/year x 22% = -0.30 m/year) and project that forward 100 years to 2120 to get a projected erosion distance of approximately 30 m.

Given the variability in the historic landward hāpua shoreline movement, the fact we are applying a notional 0.5 ratio of hāpua shoreline erosion to open coast erosion and the assumptions made in applying the increased future erosion rate from Measures *et al.* (2014) to a process environment quite different to the open coast, there is considerable uncertainty around using this 30 m figure as potential future shoreline position. However, given that the maximum amount of historic erosion recorded over the past 77 years is 20 m, the 30 m distance although notional, is not unrealistic.

In the existing north Rakaia Huts Residential Zone there is no private property within 30 m of the current landward hāpua shoreline. Existing private and District Council property boundaries (Figure 4-2) are in the range of 20-40 m from the current landward shoreline of the hāpua. Given the uncertainty around how the Rakaia hāpua and its landward shoreline might evolve over a future 100-year planning timeframe and the fact that it is likely that any future erosion of the shoreline will be spatially variable and episodic in nature we consider a pragmatic way to address future coastal erosion is to map a potential erosion area with the landward extent of the area meeting the existing private and District Council property boundaries (Figure 4-2).

This zone broadly incorporates the 30 m projected shoreline position and identifies the potential for some future erosion but recognises that the amount, although difficult to quantify, is unlikely to be on the same scale as that identified in the Selwyn District screening assessment (Cope, 2018) for the coastline away from the river mouth environment. Adopting the width (approximately 120 m) of the

[4] Notional in the sense that the shoreline will never erode at a constant rate of 0.25 mm per year, rather it will move episodically in response to certain erosive natural events such as river flooding or coastal storms.

potential coastal erosion area identified for the rest of the Selwyn District would be an overestimate for the North Rakaia Huts.

Figure 4-2: Potential coastal erosion area, north Rakaia Huts. The yellow line represents the landward extent of the area

5 Uncertainty

Due to the nature of river mouth environments and interactions of both fluvial and coastal hazard processes, this assessment report contains several uncertainties. These uncertainties are related to assumptions made, future sea level predictions, an incomplete understanding of the behaviours of these complex environments and accuracy of ground elevation data. The main points of uncertainty are:

- Due to the complex nature of the interactions of both coastal and river processes in the hāpua environment, several important assumptions have been made about the response of the beach barrier and lagoon level to future sea level rise, particularly the assumption that both beach crest height and lagoon levels will rise in unison with sea level. This introduces an unquantifiable level of uncertainty as to the final future flood level estimate.
- The use of the RCP8.5H+ 2010 sea level rise scenario projections has considerable uncertainty. The RCP8.5 scenario assumes that high levels of global greenhouse gas emissions will continue with no effective global emissions reduction until after 2100 (MfE, 2017). The higher RCP8.5H+ scenario also considers possible instabilities in polar ice sheets, the future behaviour

of which again is very unclear. There is certainty that the sea is rising and will continue to do so for centuries to come. But what is uncertain is how rapidly it will rise (PCE, 2015). Because it is not possible to attribute any likelihood to sea level rise, the uncertainty is around what future point in time flood water levels might reach the predicted 5.8 m level during hāpua flood events under future sea level rise. Using a possible flood level of 5.8 m during high flood events out to 2120 using the RCP8.5H+ sea level rise scenario is a conservative/precautious approach.

- LiDAR has a vertical accuracy of +/- 0.15 m.
- Uncertainty exists around the effects of climate change on coastal storm magnitude, frequency and direction which may impact the effects of direct storm wave overtopping of the hāpua beach barrier i.e. if coastal storms become more frequent and/or intense they may increase sediment supply from greater cliff retreat to the south, but also result in more barrier overtopping flood events, even if the beach crest height keeps pace with sea level rise.
- No account has been taken of the effects of storm wave runup. During coastal storm events severe enough to overtop the beach barrier, storm waves will propagate across the lagoon. The potential inundation area does not account for this process. However, we consider that the use of the RCP8.5+ sea level rise scenario to be conservative enough to cover any additional future wave runup scenarios. In addition, wave runup may not necessarily cause substantial flooding compared with more direct 'green water' flooding from wave setup (MfE, 2017) and storm-tide plus wave setup level is considered most important for largescale inundation mapping (Stephens *et al.,* 2016).
- There is uncertainty around the future evolution response of the hāpua shoreline to both future climate change/sea level rise and catchment management practices.

6 Conclusions

Some parts of the north Rakaia Huts settlement are currently susceptible to combined fluvial and coastal flooding events. Future sea level rise is most likely to increase this susceptibility.

This report builds on a coastal hazard screening assessment for the Selwyn District coastline by identifying areas of the north Rakaia Huts settlement that may potentially be affected by combined coastal/fluvial flooding and erosion over the next 100 years.

A potential future floodable area has been created that identifies land that may be affected during future coastal lagoon flooding events within the Rakaia Huts Residential Zone, using the RCP8.5+ sea level rise scenario from MfE (2017) guidance. As a conservative/precautious approach, this area incorporates all land under 5.8 m (Lyttelton Vertical Datum 1937) within the Residential Zone.

A potential coastal erosion area for the north Rakaia Huts has been created. Creation of a localised area for the Rakaia Huts was necessary as we determined the previous district-wide coastal erosion would likely overestimate the erosion hazard if applied to the north Rakaia Huts situation.

The potential future floodable and erosion areas can be used to identify future coastal hazard risk and vulnerability at the north Rakaia Huts and to inform future land use planning decisions.

7 External Peer Review

A draft of this report was been externally peer reviewed by Derek Todd, Principal Hazards and Coastal Scientist at Jacobs Consulting Ltd.

The reviewer stated that the technical information presented on coastal inundation levels is appropriate and relevant and the assumptions applied in the coastal inundation assessment in general appear to be appropriate. However, he recommended that several points be addressed before releasing a final report. The reviewer's main points were:

1. Data from the aerial photograph and beach profile analysis for the river mouth barrier position and height/volume changes through to 2018 could have been presented rather than just summarised.

2. Further information is required about some of the assumptions, particularly regarding how some of them shape the degree of conservativeness of the results.
3. The assessment would benefit from assumptions around relative 'rate of lag' of erosion of the landward mouth channel shoreline based on some technical information to justify the future erosion distance presented in the results.
4. Should explain that the inundation mapping is from a 'conservative bathtub' approach.
5. [For inundation component derivation], the datum offset from LVD-37 to MSL does not need to be applied as the barrier height and land elevation are already in terms of LVD-37, and sea level rise is independent of datum. Therefore, the mapping of inundation should be to the 5.8m contour not the 6.0m contour.
6. Apply a sensitive testing to the results, by adding SLR (1.30m with offset to current levels) to existing observed maximum inundation level (4m), to give future 100 year inundation level under RCP8.5+ of 5.3m LVD-37. This, givens a range for 100-year future inundation of 5.3 to 5.8m for RCP8.5+ SLR scenario.
7. For the coastal erosion assessment, the resulting erosion limit appears to be very arbitrary without an adequate justification being given. My suggestion is that you could use the aerial photograph and beach profile analysis to look at relative movements of landward shoreline against the barrier movement and/or the open coast to the north to try and get a general relationship between rates of movements, then apply this as a percentage of open coast predictions from the district wide screening. For sensitivity testing a similar assessment could be carried out at other similar river mouths such as Rangitata and Opihi.

All of these recommendations have been incorporated into this final version.

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