Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

A coastal hazard screening assessment for Selwyn District

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Executive summary

Background
To help inform the Selwyn District Council's District Plan review process a "high-level" coastal hazard screening assessment is produced. The assessment is equivalent to the "regional-hazard screening" process recommended in the most recent Ministry for the Environment and Department of Conservation guidance on coastal hazards.

The problem
No previous coastal hazard screening assessment has been undertaken for the Selwyn District. The Selwyn District Council requires an assessment to broadly identify areas potentially subject to coastal hazards to assist in the identification of locations where more detailed hazard exposure (and ultimately risk and vulnerability) assessments may need to be undertaken.

What we found
This hazard screening assessment is a collation and discussion of existing coastal hazard information for the Selwyn District. The information concerns both what we know about historic and contemporary coastal hazards, coastal processes and shoreline behaviour as well as an assessment of the potential future exposure of coastal land to climate change effects on coastal hazards.

An area of potential coastal erosion hazard for the next 100 years is identified. The extent of this zone extends approximately 120 metres from the current shoreline. The eroding beach barrier will progressively overwhelm parts of the lowland drainage system which will have future implications for local land drainage.

The prediction of the future stability of the landward part of the coastline fronting the north Rakaia Huts hāpua due to future climate change needs to be treated differently than the open coastline of the District due to fluvial and coastal process interactions.

An area of coastal land potentially exposed to coastal inundation from extreme storm events over the next 100 years has been identified by mapping low-lying land below a 4 m mean sea level elevation contour. Potential inundation exposure is greatest around the low-lying margins of Coopers Lagoon/Muriwai, including Tentburn and some parts of Taumutu.

The lower 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.

What does it mean?
This high-level assessment broadly identifies areas potentially exposed to future coastal erosion and inundation hazards. It does not assess in any detail what settlements, land uses, assets (including cultural assets), infrastructure or future growth areas may be exposed to future coastal hazards. A next step could be a detailed exposure analysis/assessment to help refine (or rule out) locations along the District's coast where detailed coastal hazard assessments may be useful to support future land use planning.

If areas were identified that required a more detailed coastal hazard assessment, consideration could be given to enhancing an existing open coastal erosion model to incorporate possible climate change-induced variability of other weather and oceanic coastal hazard drivers and coastal sediment supply. Thought could also be given to considering hydraulic connections between the open coast and inland area to develop a "connected bath-tub" inundation model if more site-specific information was required.

We recommend Selwyn District Council consider undertaking a more detailed coastal hazard assessment for the north Rakaia Huts settlement to better identify the future coastal hazard risk (erosion and inundation) and vulnerability.

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1 Purpose

The purpose of this report is to provide a high-level, coastal hazard screening assessment for the Selwyn District coastline. It aims to summarise the existing knowledge of contemporary and future coastal hazards in the District and to provide an indication of areas where any additional information or more detailed assessments may be required to enable Selwyn District Council to inform their District Plan Review process. This assessment is equivalent to the "regional-hazard screening" process recommended in both the 2017 Ministry for the Environment's Coastal Hazard and Climate Change guidance report ("the Guidance", MfE 2017) and the Department of Conservation's guidance notes on the 2010 New Zealand Coastal Policy Statement's (NZCPS) coastal hazard objectives and policies (DOC, 2017). We take the term "regional" used in the MfE 2017 guidance to infer a high-level overview applied to the Selwyn District's coastline rather than an assessment covering the entire coastline of the region.

Both the MfE 2017 and DOC 2017 guidance recommend regional (or district) hazard screenings be undertaken to identify areas that require more detailed assessments of coastal hazard exposure, for single or multiple coastal hazards. The purpose is to "broadly identify areas potentially exposed to coastal hazards and to show where more detailed hazard (and ultimately risk and vulnerability) assessments should be focused" (MfE 2017, pg 137).

2 The coastal hazard screening approach for Selwyn District

This hazard screening assessment is a collation and discussion of existing coastal hazard information for the Selwyn District. This available information includes what we know about historic and contemporary coastal hazards, coastal processes and shoreline behaviour along the Selwyn District's coast as well as an assessment of the potential future exposure of coastal land to climate change effects on coastal hazards. No new information has been collected other than to update datasets or to better display the existing hazard information. This assessment is for the open coastline of the Selwyn District and does not consider other natural hazard issues such as flooding associated with Te Waihora/Lake Ellesmere or future pluvial flooding from potential sea level rise-induced rising groundwater levels.

The Selwyn District coast is susceptible to the effects of climate change. A national climate change coastal erosion and inundation sensitivity index (Goodhue *et al.,* 2012) rated the Selwyn coastline, based on its geomorphology and exposure to open coastal processes as moderately to highly sensitive to climate change induced coastal erosion and coastal inundation.

2.1 New Zealand Coastal Policy Statement 2010

Policy 24 of the NZCPS 2010 lays the foundation for risk-based coastal hazard management (DOC, 2017) and is of primary relevance for guiding the technical focus of coastal hazard assessments. Policy 24 directs Councils to give effect to the identification of areas in the coastal environment that are potentially affected by coastal hazards (including tsunami), giving priority to the identification of areas at high risk of being affected.

MfE (2017) and DOC (2017) guidance identify the need for local authorities to undertake early screening assessments as a means of implementing the "giving priority" to the identification of high risk areas aspect of the policy. This screening assessment satisfies this need such that it will assist helping determine priority areas for more comprehensive hazard and risk assessments.

NZCPS Policy 24 lists the physical factors to be assessed when identifying a coastal hazard assessment. These factors are:

- Physical drivers and processes that cause coastal change including sea level rise,
- short-term and long-term natural dynamic fluctuations of erosion and accretion,
- geomorphological character,
- cumulative effects of sea level rise, storm surge and wave height under storm conditions,
- anthropogenic influences
- extent and permanence of built development
- the effects of climate change on the above matters, on storm frequency and intensity and on natural sediment dynamics.

This screening assessment takes these factors into consideration.

3 Coastal hazard drivers considered in this assessment

3.1 Adopted sea level rise value

MfE (2017) considers that ongoing sea level rise is the primary influence on the exacerbation of coastal hazards due to the increased exposure of coastal land to coastal storm inundation and erosion and to rising groundwater levels near the coast.

The Guidance recommends that regional hazard screenings use a high future sea level rise scenario, specifically the RCP8.5H+[1] scenario. RCP scenarios are expressed as a range with the H+ scenario being the upper 83rd percentile of the RCP8.5 range. The Guidance recommends using RCP8.5H+ for regional screening assessments as it reflects the possibility of future surprises due to a more rapid increase in the rate of sea level rise early next century as a result of possible instabilities in polar ice sheets.

Table 3-1 is reproduced from the MfE Guidance (2017). It presents decadal increments for projections of sea level rise for New Zealand for four RCP scenarios. In accordance with the Guidance we use the 2120 (approx. 100 years from present) RCP8.5H+ projected sea level of 1.36 m for this screening assessment.

For planning purposes, the use of the RCP8.5H+ sea level rise scenario enables consideration of land potentially affected by both current and climate change-exacerbated coastal hazards and a range of existing and future land uses. 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.

3.2 Weather related drivers

Climate induced changes in 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. Climate change effects in river catchments such as the Rakaia catchment also have the potential to affect the amount of sediment delivery to the Selwyn coastline and ultimately affect future shoreline patterns of retreat (or advancement).

Weather related coastal hazard drivers such as storm surge, waves and winds and the frequency and intensity of storms are considered secondary to ongoing sea level rise as the principal effects of climate change on coastal hazards (MfE, 2017). The Guidance considers that current understanding of trends

[1] 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.

and projections of future changes in these weather induced coastal and ocean drivers is not as clear or consistent as for sea level rise.

The Guidance recognises that even subtle changes in weather related coastal hazard drivers combined with sea level rise may have a substantial impact on shoreline processes. However, given that current projections of future changes in these drivers are "relatively modest or inconclusive" (MfE, 2017) and considering the purpose of this hazard screening as a higher-level overview, we have restricted our assessment to the impacts of sea level rise on coastal erosion and inundation and have not considered weather related drivers.

Table 3-1: Decadal increments for projections of sea-level rise (metres above 1986–2005 baseline) for the wider New Zealand region (from MfE, 2017)

NZ SLR scenario Year	NZ RCP2.6 M (median) [m]	NZ RCP4.5 M (median) [m]	NZ RCP8.5 M (median) [m]	NZ RCP8.5 H+ (83rd percentile) [m]
1986–2005	0	0	0	0
2020	0.08	0.08	0.09	0.11
2030	0.13	0.13	0.15	0.18
2040	0.18	0.19	0.21	0.27
2050	0.23	0.24	0.28	0.37
2060	0.27	0.30	0.36	0.48
2070	0.32	0.36	0.45	0.61
2080	0.37	0.42	0.55	0.75
2090	0.42	0.49	0.67	0.90
2100	0.46	0.55	0.79	1.05
2110	0.51	0.61	0.93	1.20
2120	0.55	0.67	1.06	1.36
2130	0.60*	0.74*	1.18*	1.52
2140	0.65*	0.81*	1.29*	1.69
2150	0.69*	0.88*	1.41*	1.88

* Extended set 2130–50 based on applying the same rate of rise of the relevant representative concentration pathway (RCP) median trajectories from Kopp et al, 2014 (K14) to the end values of the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) projections. Columns 2, 3, 4: based on IPCC AR5 (Church et al, 2013a); and column 5: New Zealand RCP8.5 H+ scenario (83rd percentile, from Kopp et al, 2014). Note: M = median; m = metres; NZ = New Zealand; SLR = sea-level rise. To determine the local SLR, a further component for persistent vertical land movement may need to be added (subsidence) or subtracted (uplift).

3.3 Tsunami

The effects of Tsunami have been modelled on the Selwyn coast for both a South American distant source tsunami (Power 2013a, 2013b; Lane *et al.,* 2014) and a regional Hikurangi subduction zone tsunami (Lane *et al.,* 2016). These reports model high return period, extreme scenarios in the order of 2500 years. Data from National Probabilistic Tsunami Model (Power, 2013a) have been used for evacuation planning purposes in the Selwyn District Tsunami Plan (2018). Evacuation zones have been developed based on worst case wave heights above sea level along the Selwyn coast in the order of 7 to 11 metres.

MfE (2017) and DOC (2017) guidance recommends that when assessing potentially affected coastal areas for the purposes of evacuation planning and mapping, and considering any targeted land-use planning provisions (e.g. the location of critical facilities), the Ministry of Civil Defence & Emergency Management (MCDEM) Directors guidelines (DLG 08/16) for the development of tsunami evacuation zones should be followed. This includes the identification of areas impacted by maximum credible tsunami events as is the case in the Selwyn District Tsunami Evacuation Plan (2018).

We do not consider tsunami inundation further in this review as the most up to date scientific advice has been used in the development of the Selwyn District evaluation plan. These zones should be regularly reviewed to take into account the latest research.

Put into a climate change context, it is worth noting that any rise in base sea level will also raise the elevation of tsunami waves arriving at the coast.

4 Selwyn coast overview

4.1 Coastal setting

The coastline of the Selwyn District occupies a 14 km section of the northern Canterbury Bight shoreline between the southern banks of the Rakaia River and Taumutu, near the mouth of Te Waihora/Lake Ellesmere (Figure 4-1). It includes the Rakaia River mouth and hāpua (coastal lagoon) and is dominated by a low-lying mixed sand and gravel beach ridge barrier[2] along its length. The coastline is backed by remnant lagoons and channels which historically comprised a continuous wetland system between the Rakaia River at Te Waihora/Lake Ellesmere.

4.2 Historic processes

The relevant historical process environment of the Selwyn District coastline and the Canterbury Bight shoreline in general can be can be thought of as starting approximately 6500 years ago following a period of rapid sea-level rise at the end of the last glacial period (Measures *et al.,* 2014). During the last glacial period ending around 15,000 years ago the Rakaia River built up a large glacial outwash fan which created a bulge in the coastline with the river in the centre. Over the last 6500 years the shoreline near the Rakaia River mouth has been eroding. The Canterbury Bight, as it still is now, was subject to high energy southerly storm waves that easily eroded the soft unconsolidated coastal gravels and sands and transported them northwards. These sediments were supplemented by sediment supplied directly to the coast by the Rakaia River.

This northwardly transported sediment became trapped up against Banks Peninsula and formed what is now known as Kaitorete Barrier. Over the Holocene[3] period accumulation of beach sediments has continued at the north end of the barrier, with erosion continuing to the south along the Rakaia river coast at rates higher than those experienced today as a result of increased rates of longshore transport of beach sediments due to a greater disparity between wave direction and shoreline orientation. This erosion slowly changed the orientation of the shoreline, essentially a clockwise rotation around a "hinge point"[4] (Figure 4-2). This hinge point is now located midway between Taumutu and Birdlings Flat, approximately (between profile site ECE 2515 and ECE2995, Figure 4-1 and Table 5-1).

[2] Beach ridge barrier: A single low, continuous mound or ridge of beach material predominantly built by the action of waves on the backshore of a beach (Goodhue *et al.,* 2012)
[3] The current geological epoch which began around 12,000 years ago.
[4] The "hinge-point" is the location where there is a change from shoreline advance to shoreline erosion. This is where sediment stops accumulating and where the shoreline begins to erode.

Figure 4-1: Overview of the northern Canterbury Bight shoreline with Environment Canterbury beach profile locations

4.3 Contemporary processes

The contemporary process environment is dominated by storm and swell waves from the south to southeast. Waves break close to the shore, generally in a single line of breakers, and form a line that delineates the foreshore from the nearshore seabed. Mixed sand and gravel beaches are different to sand beaches in that there is minimal transfer of gravel sediments on and offshore, and nearly all the coarse sediment (sands and gravels) is transported in the swash zone[5]. In contrast, fine sand is not resident on the beaches, being rapidly removed by wave action and transported in the nearshore and on the seabed, and removed from the beach, but is not transported or resident on the beaches (Single, 2006).

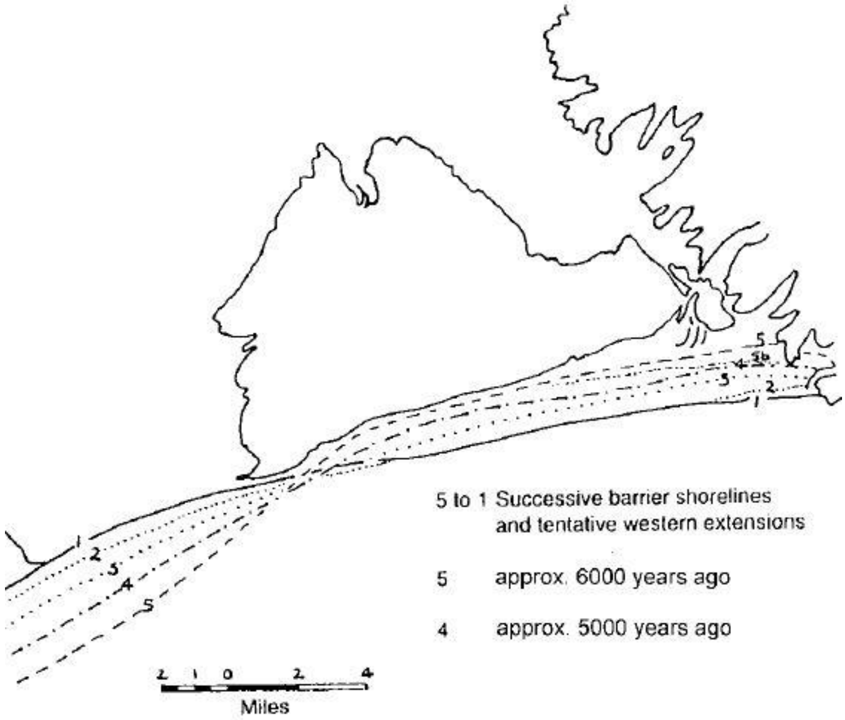

Figure 4-2: Historic clockwise rotation of the Rakaia – Birdlings Flat coastline around a hinge-point (reproduced from Kirk and Lauder (2000), after Kirk (1994))

From aerial photographic analysis described in Section 5.2, erosion of the coast over the past half century between the Rakaia River and Taumutu has occurred at an average rate of about 0.5 m per year. However, the rate of erosion is episodic and is generally greater during years with frequent coastal storms. In many places, the process of retreat is “beach rollover” due to storm waves washing over the crest of the beach and transferring sand and gravel from the foreshore to the backshore. It occurs when the barrier height is lower than the elevation of storm wave runup and where the barrier crest is narrow and backed by low ground, such as the span of shore from Coopers Lagoon/Muriwai to Taumutu (Hicks and Enright, 2010). Rollover results in retreat of both the barrier backshore and foreshore.

The rollover process is episodic. In between rare large wave events, the barrier is ‘repaired’ by waves that nearly reach the crest but don’t quite overtop. These waves deposit sediment that build the beach up again. In general, the lower the barrier on average, the more likely storm waves will overtop and the more rapid the rollover process is likely to be.

[5] The zone on foreshore between the wave break point and the upper limit of the wave up-rush.

5 Historic and contemporary coastal erosion information

5.1 Beach profiles

Environment Canterbury undertakes regular monitoring of beach profiles at 22 locations along the northern Canterbury Bight between the Rakaia river mouth and Birdlings Flat. Six of these profile sites are within the Selwyn District (Figures 5-1 and 5-2, Table 5-1) and have been monitored since 1991. Before then, some surveys concentrated around culverts draining Muriwai/Coopers Lagoon were undertaken by the Ellesmere County Council in the 1940s and 1960s. However, there is uncertainty about the accuracy of directly comparing these earlier surveys with post-1991 surveys so they have not been considered in this analysis. The profile site (E0000) at the Rakaia River mouth is heavily influenced by river mouth processes so has not been included. The beach profile surveys are undertaken annually, generally in Autumn. From 1991 to 2015 survey data was captured using total station and prism. From 2016 the surveys have been captured using differential GPS.

To consider the Selwyn District coastline in the context of the entire northern Canterbury Bight process environment we also include an analysis of the remaining profile sites along Kaitorete Barrier between Taumutu and Birdlings Flat (Figures 4-1 and Table 5-1).

The surveys are undertaken relative to Lyttelton Vertical Datum 1937 (LVD-37), extend across the beach profile from the landward limit of the active beach and typically terminate and or beyond 1 m above vertical datum. Mean High Water Springs (MHWS) on the Selwyn Coast is at 1.04 m above Mean Sea Level LVD-37 (Stephens *et al.,* 2015).

Various shoreline parameters can be calculated from the beach profile data including horizontal shoreline movement (either positive, indicating accretion or negative, indicating erosion), beach volume, beach height, beach width and beach slope. Table 6-1 presents a summary of the linear regression rates of the MHWS and 5 m elevation contour and beach volumes at the 14 surveyed beach profile sites between the Rakaia River and Birdlings Flat[6]. The MHWS line is approximated by the 1.0 m elevation contour above LVD-37. The 5.0 m elevation contour approximates the storm tide runup extent on the beach and is comparable with the vegetation line shoreline proxy determined from aerial photographs as described further in Section 6.2. Beach volume is defined as the volume (per metre length of shore) enclosed by the surveyed profile, the 1 m above MSL LVD-37 datum and a fixed offset point determined to be landward of the active beach.

5.2 Historic aerial photography

Digitised shorelines were developed using geo-referenced historic aerial photographs from 8 aerial photograph runs between 1943 and 2016 (Table 5-2). This set of shoreline information provides a total of seven time-periods for analysing long-term trends over a 73-year period (1943–2016). The long-term rate of coastline movement includes both ongoing trends and long-term cyclical fluctuations. These may be due to changes in sea level, fluctuations in coastal sediment supply or associated with long-term climatic cycles (Tonkin and Taylor, 2015).

The historic shorelines are based on digitising a shoreline proxy, taken to be the seaward edge of vegetation. The seaward edge of the vegetation represents the landward toe of the beach. This shoreline proxy was chosen because the seaward extent of vegetation growth is a good indicator of the active beach system where storm waves are encroaching regularly enough to limit the growth of vegetation. The change in contrast from vegetation to beach sediments can more accurately be identified on the historic black and white aerial photographs rather than the water line. The mapping of the vegetation was also preferred as using the water or wetted line as a shoreline proxy is problematic due to the wetted line varying widely between photographs depending on antecedent tide and wave runup conditions.

[6] There are 22 sites in total. However, sites influenced by multiple processes (i.e. Rakaia river mouth and Te Waihora lake mouth processes) have been omitted from the summary data for clarity.

The historic shoreline data was analysed using the GIS-based Digital Shoreline Analysis System (DSAS) to evaluate long-term trends. DSAS processes the shoreline data and calculates shoreline change statistics at user-determined intervals along the entire site. We chose 50 m intervals for the Selwyn coast. Rates of long-term shoreline movement are derived using linear regression analysis. By calculating trends along the entire shoreline, rather than at a low number of discrete points (i.e. beach profile surveys), alongshore variation in long-term trends can be determined more accurately (Tonkin and Taylor, 2015).

Table 5-1: Summary of results of beach profile linear trend movements of the MHWS and 5 m elevation contours (above MSL LVD-1937 datum) and beach volume over the 1991-2018 period for Canterbury Bight, Rakaia River to Birdlings Flat

Grey shaded rows are sites north of Taumutu and outside of the Selwyn District. The green shaded row marks the profile site closest to the approximate location of the accretion/erosion hinge point discussed in section 4.2.

Profile	5m Contour (m/yr)	MHWS Contour (m/yr)	Beach Volume (m^3/m/yr)
ECE0210	0.53	0.42	3.20
ECE0392	-0.70	-0.16	-0.90
ECE0533	-0.52	-0.50	-2.41
ECE0720	-0.42	-0.40	-2.60
ECE1010	-0.61	-0.60	-2.68
ECE1183	*-0.20*	*-0.57*	*-0.16*
ECE1320	*-0.74*	*-0.58*	*-4.63*
ECE1620	*-1.07*	*-0.93*	*-5.42*
ECE1980	*-0.84*	*-0.72*	*-4.10*
ECE2515	*-0.29*	*-0.15*	*-2.16*
ECE2995	*-0.07*	*0.13*	*0.74*
ECE3560	*0.90*	*0.96*	*6.98*
ECE3755	*1.17*	*1.18*	*8.75*
ECE3800	*1.36*	*1.47*	*10.93*

Table 5-2: Summary of aerial photographs used to digitise historic shorelines

Date Captured	Run	Source
06/05/1943	SN224	Environment Canterbury
02/05/1952	SN804	NZAM
02/10/1966	SN1904	Environment Canterbury
17/09/1975	SN2860	Environment Canterbury
28/10/1984	SN8389	Environment Canterbury
01/07/2004	Ortho75	Environment Canterbury
01/07/2012	PGRM2392 Canterbury Rural	Environment Canterbury
28/12/2015	11236D01NON Mid Canterbury	Environment Canterbury

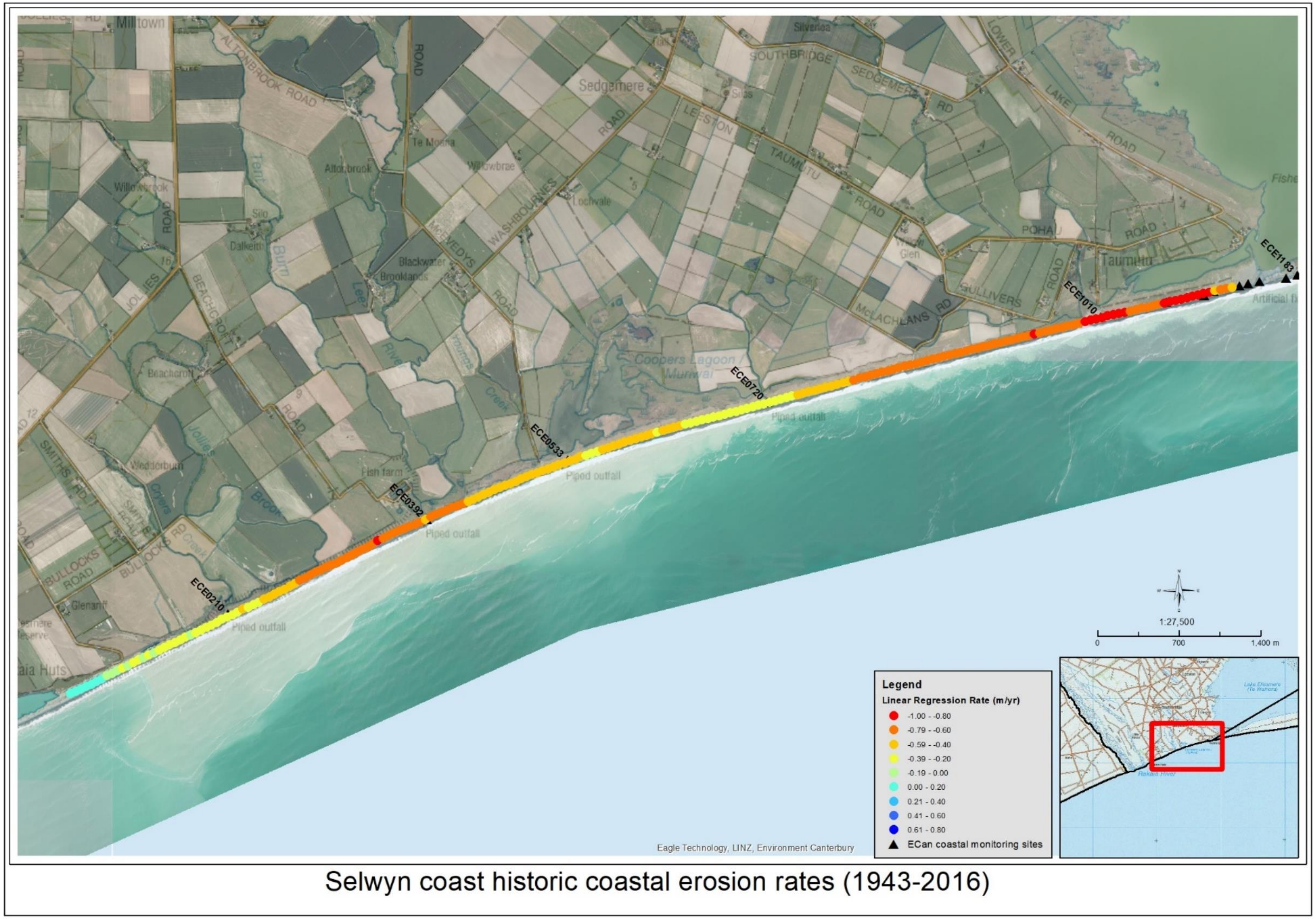

Figure 5-1: Erosion rates from DSAS historic aerial photography analysis and Environment Canterbury coastal profile monitoring sites

5.3 Erosion results and discussion

5.3.1 Historic digital shoreline analysis (DSAS)

Figure 5-1 shows the DSAS rate of shoreline change output results at 50 m intervals along the Selwyn shoreline. Figure 5-2 plots the linear regression rate of shoreline movement alongshore along with the more discrete and shorter term (27 years) survey data from Table 5-1. From the long term (73-year) data in Figure 5-1 and Figure 5-2 we see a coastline which is predominantly eroding, although with shoreline movement ranging between a small amount of accretion immediately north of the river mouth to -0.9 m/yr at Taumutu. The average long term linear rate of erosion is -0.53 m/yr.

Over the longer-term dataset, the shoreline immediately north of the river mouth has been stable to moderately erosional. The shorter-term survey data since 1991 indicates that the shoreline adjacent to the river mouth has accreted in both position and volume (Table 5-1 and Figure 5-2). This is consistent with the findings of Hicks and Enright (2010) and McHaffie (2010) who both noted an advancing shoreline at the Rakaia Mouth barrier. It appears that this shoreline advance at the river mouth also extends to the shoreline immediately north of the river mouth barrier. Hicks and Enright (2010) suggest that over recent decades there has been a temporary phase of relative dominance of river processes over coastal processes with the advancing river mouth deltas pushing the beach barrier forwards. Hicks and Enright (2010) note that this is a multi-decadal river mouth cycle between stability and erosion and that a change back to an erosional cycle is likely in the near future.

A distinct pattern of historic shoreline movement can be seen in Figure 5-1 and 5-2 with an obvious node of greater historic shoreline retreat focused around the Rakaia No. 2 Culvert at the Tentburn salmon farm (approximately 4 km north of the river mouth). Figure 5-2 shows that the shoreline elevation is lowest around the Tentburn node. Here, lower beach elevations have resulted in greater beach rollover and hence greater shoreline retreat. The surveyed beach profile at this site (E0392, Table 5-1 and Figure 5-2) show that the upper beach elevation retreated further than the lower beach but with beach volume losses less than sites to the north. This is symptomatic of a beach eroding through rollover due to regular overtopping.

Moving north from this Tentburn node of erosion, historic erosion rates reduce for 2-3 km before increasing again south of Taumutu (Figures 5-1 and 5-2).

5.3.2 Beach profiles

Beach profiles complement the historic shoreline analysis. The DSAS analysis of historic aerial photographs gives an overview of historic erosion rates over the past 73 years, but while only covering a third of the amount of time, the beach profile data set offers more nuanced information on trends in beach volume and geometry across the whole beach profile.

From Table 5-1 we see the same general trend in the shorter-term beach profile data as in the DSAS analysis except nearer the Rakaia river mouth where there is an accretional trend in the profile data at site ECE0210 compared to a slight erosional trend from the longer term DSAS data (Figure 5-1 and Figure 5-2). This is likely due to the multi-decadal river mouth cycles discussed in section 5.3.1.

The discrete profile sites also show the higher erosion rate around Tentburn (site ECE0392), the slight reduction in erosion rate at sites north of ECE0392, and the transition to higher rates of erosion towards Taumutu (site ECE1010). North of Taumutu and on to the Kaitorete Barrier coastline, shoreline retreat and beach volume losses increase and peak at site ECE1620, approximately 6 km north of Taumutu (Figure 4-1 and Table 5-1). North of ECE1620, rates of retreat and volume loss reduce until there is a complete switch to shoreline aggradation around profile site ECE2995. This coastline progradation continues for the final northern 10 km of Kaitorete Barrier. This transition between shoreline erosion and shoreline progradation is the hinge point where clockwise shoreline rotation is continuing to occur as discussed in section 4.2.

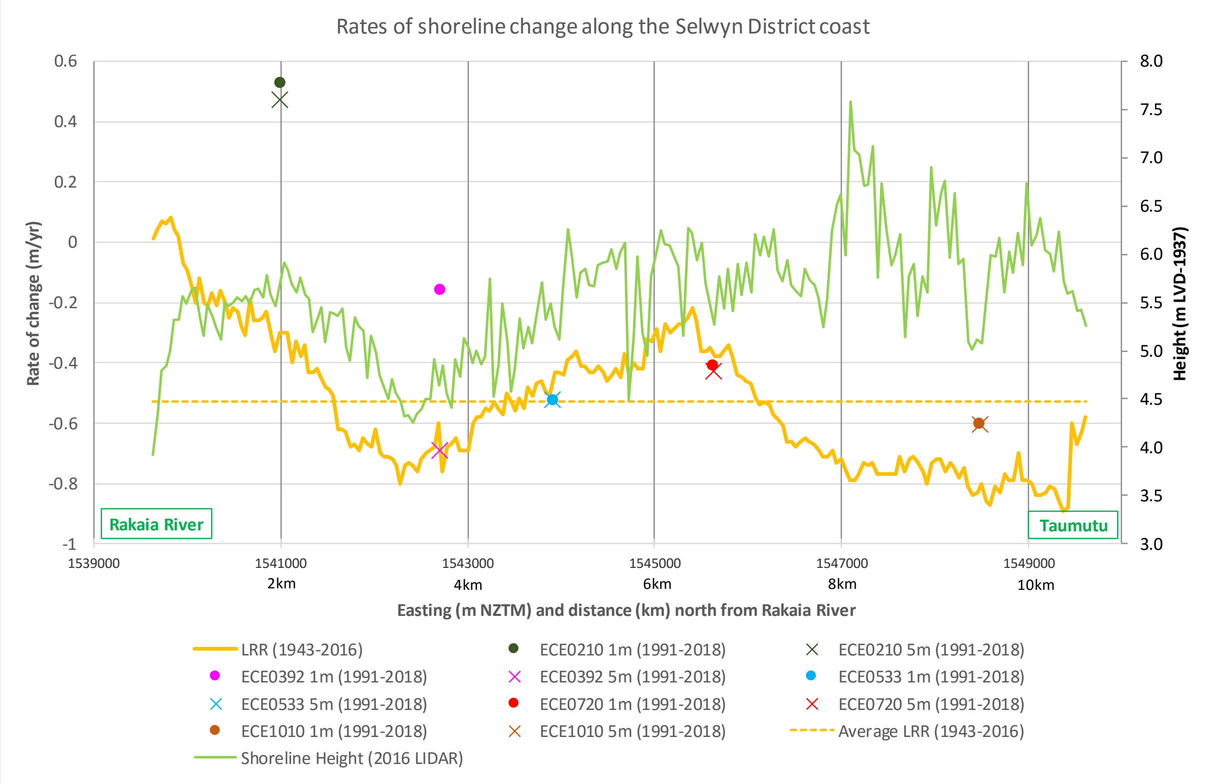

Figure 5-2: Linear regression rate (LRR) of shoreline movement along the Selwyn District coast. Discrete points of shoreline movement at the 5 m and MHWS contours are plotted as points. Shoreline heights at the shoreline proxy location (vegetation line) derived from the 2016 LiDAR digital elevation model are plotted in green

6 Future coastal erosion

Existing coastal erosion hazard zones in the Regional Coastal Environment Plan (RCEP) and the Canterbury Regional Policy Statement (CRPS) were identified using a methodology established in the early 1990s. The coastal erosion zones for Selwyn District were updated in 2015 using the same methodology. They identify land that is at risk from continued contemporary coastal erosion patterns within 100 years. The simple methodology used to establish the widths of these zones involved determining the historic rate of shoreline erosion and multiplying that by the specified planning timeframe (e.g. 100 years). This simple deterministic approach assumes that past erosion rates will continue and predicts a single future coastline.

This approach is now inconsistent with NZCPS (Policy 24), MfE and DOC guidance (2017) on coastal hazards and other national guidance (e.g. Ramsey *et al.,* 2012). For example, it does not include the possible effects of future accelerated sea level rise and its impact on future coastal erosion rates. This is a matter that Environment Canterbury will consider in a future RCEP review.

However, we are interested in which areas of Selwyn District could potentially be affected by future coastline retreat, including any additional erosion due to sea level rise. This will help to assess exposure and identify locations where more detailed coastal erosion assessments may be needed.

6.1 Future coastal erosion modelling for Selwyn – Measures *et al.* (2014)

Measures *et al.* (2014) have developed a “1-line” shoreline model for the 46 km span of shore between the northern end of the Rakaia hāpua and Banks Peninsula to predict shoreline movement over the next 100 years. A “1-line” model predicts the movement of the beach plan shape (a birds-eye view of the shoreline at a single reference point such as the MHWS beach contour) through time. The model is run by inputting information about sediment volumes arriving and leaving the coastal cell (a sediment budget), the beach shape and waves.

The model also added a shoreline-response-to-sea-level rise component, specific to the mixed sand and gravel beach barrier characteristics of the Selwyn coast. The authors modelled what would happen to existing shoreline retreat in response to an increase in the rate of sea level rise from 2 mm/yr (observed historic sea level rise from the Lyttelton tide gauge) to 10 mm/yr, the equivalent of a 1 m rise in sea level by 2100. This 1 m sea level rise was determined from the 2008 Ministry for the Environment sea level guidance, now superseded by the 2017 guidance (MfE, 2017). Measures *et al.* (2014) found that modelled erosion rates increased by 22% when the rate of sea level rise was increased from 2 mm/yr to 10 mm/yr.

6.2 Area of potential coastal erosion hazard

We have taken the average long term historic erosion rate from the DSAS analysis (section 5.3.1) along the Selwyn District coast from Figure 5-2 (approximately -0.5 m/yr) and then increased that rate by 22% (to approximately -0.6 m/yr) as modelled by Measures *et al.* (2014). This is then projected forward 100 years from the 2016 mapped shoreline to create a potential 100-year shoreline (Figure 6-1).

There is uncertainty associated with determining a single shoreline, and by applying the average long-term rate of erosion across the whole of the district’s coast there is an overprediction of future erosion at locations where historic erosion is less than the average rate and an underprediction where the historic erosion has been higher than the average. Therefore, we have incorporated this modelled shoreline information within a wider band of potential coastal erosion hazard. The seaward boundary of the zone is the mapped 2016 shoreline. The upper or landward limit of the zone is the highest long term historic erosion rate for the Selwyn coast at Taumutu (-0.9 m/yr) rounded up to -1 m/yr, increased by 22% (to -1.22 m/yr) and projected forward 100 years. While this approach may further overpredict future erosion at locations where historic erosion rates have been lower, we consider the added conservatism to be acceptable in line with the broad-brush approach of a hazard screening assessment.

The coastal erosion area has no level of quantifiable probability associated with it but indicates the potential area over which shoreline retreat could be experienced within the next 100 years.

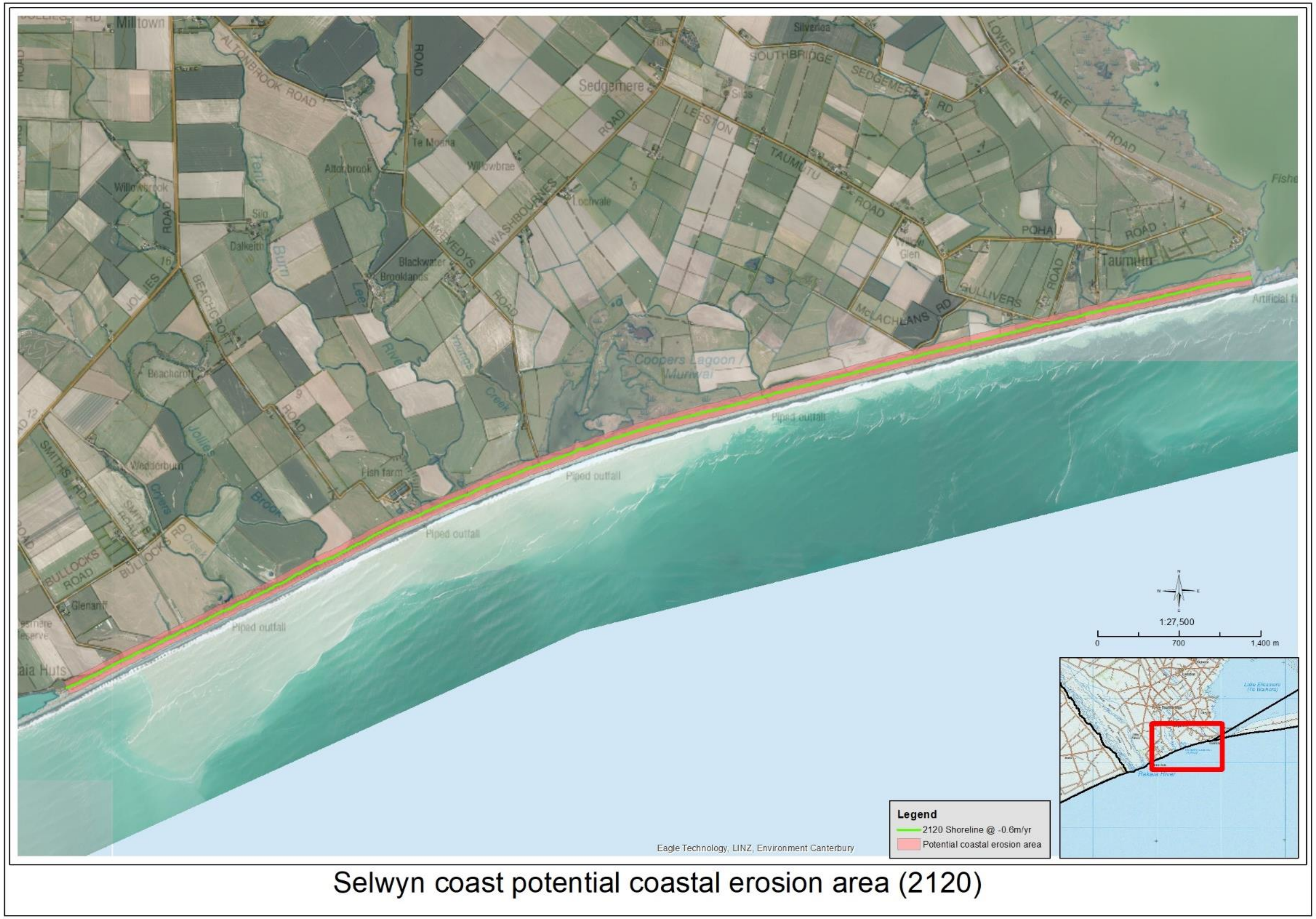

Figure 6-1: **Area of potential coastal erosion for the Selwyn District coast to 2120. The green shoreline is the 2120 shoreline using Measures *et al.* (2014) modelled shoreline response to sea level rise with the average historic coastal erosion rate (total of -0.6 m/yr)**

7 Coastal inundation

Coastal storm inundation, or flooding (excluding tsunami) usually occurs when higher than normal high tides correspond with a coastal storm event. The result is seawater encroachment onto land either directly through overtopping of the beach barrier or via waterway connections to the coast such as rivers, estuaries or artificial structures like culverts.

There are number of meteorological and astronomical phenomena that produce an extreme storm-tide and storm wave event. These processes can combine in several ways to cause coastal flooding and/or coastal erosion (Stephens *et al.,* 2015). Storm tide is the maximum level of the sea reached during a storm event from a combination of the astronomical tide, including the mean sea level anomaly, plus storm surge. Storm surge is the increase in sea level that occurs during storms where low barometric pressure draws up the sea surface and strong winds push water onshore. The mean sea level anomaly is the variability in the average level of the sea due to seasonal or climatic cycles such as La Niña/El Niño. The mean sea level anomaly can increase or decrease sea levels by a few tens of centimetres. Waves also raise the sea level at the coastline through the process of 'wave-setup' where the energy released by breaking waves increases average water level. On top of these processes, wave runup (the up-rush of broken water up the beach after waves break) also carries water to higher elevations on the beach. Figure 7-1 is a schematic of these meteorological and astronomical sea level components.

Sea level rise will increase the exposure of coastal land to coastal storm water inundation (MfE, 2017). The frequency of coastal flooding above the present-day level, for example the crest of the beach, will increase as sea levels rise and will cause inundation events to reach further inland.

The RCEP and CRPS identify seawater inundation zones in the coastal hazard zone planning maps. These zones only identify areas where historic coastal storm events have caused flooding and where the extent of that flooding has been recorded and mapped. Environment Canterbury does not hold any information on significant historic coastal flooding events for the Selwyn coast except for at the north Rakaia Huts which have flooded in the past due to extreme water levels in the coastal hāpua related to a combination of river and coastal interactions. On the open coast, past coastal inundation events have been localised and generally non-damaging. However, under future sea level rise the Selwyn coast may be more vulnerable to the effects of coastal flooding.

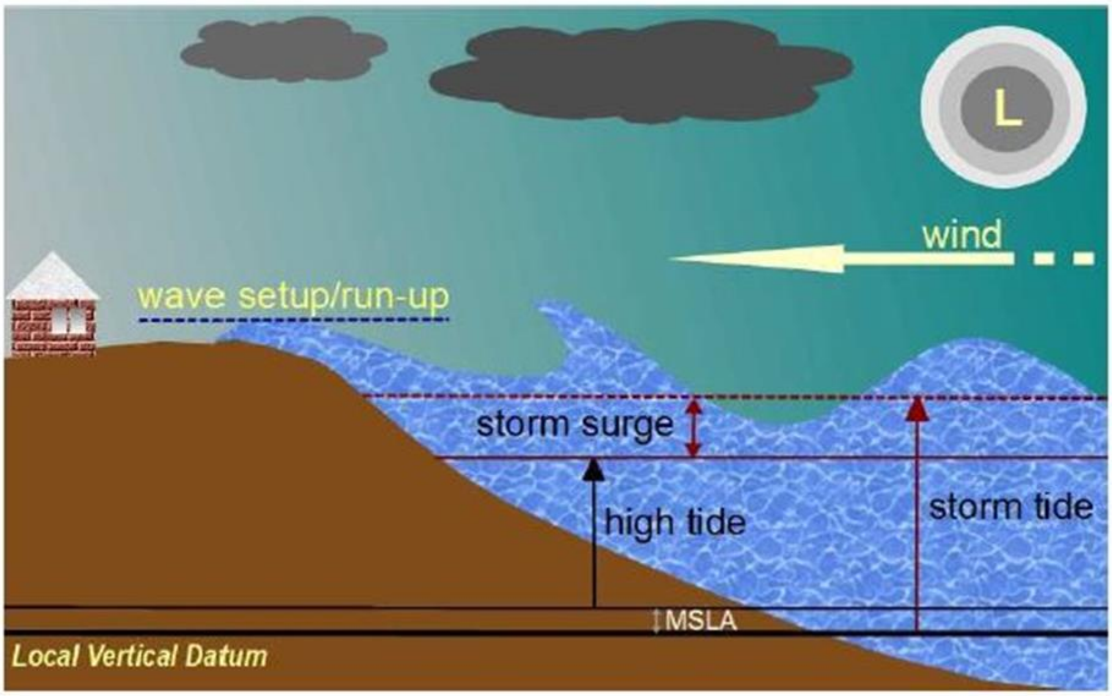

Figure 7-1: Schematic illustrating components of coastal inundation (from Stephens *et al.,* 2015)

7.1 Coastal inundation potential mapping

Potential inundation maps have been created within ArcGIS using extreme sea levels previously determined at output locations along the Selwyn coast by Stephens *et al.* (2015) (Figure 7-2). The water level used in this analysis was the joint probability 1% Annual Exceedance Probability (AEP) level of storm tide (astronomical tide, storm surge and wind setup) and coastal storm wave effects (wave setup). The 1% AEP is an event that is rare on an annual basis (it has a 1% chance of occurring or being exceeded in any given year) but that has an increasing likelihood of occurring over longer timeframes e.g. there is a 63% likelihood of a 1% AEP event occurring over a 100-year timeframe. The use of a 1% AEP event in coastal hazard assessments is supported by the MfE (2017) guidance as it overcomes potential over-prediction from treating storm surge and storm wave effects as independent components of extreme water levels (Stephens *et al.,* 2015).

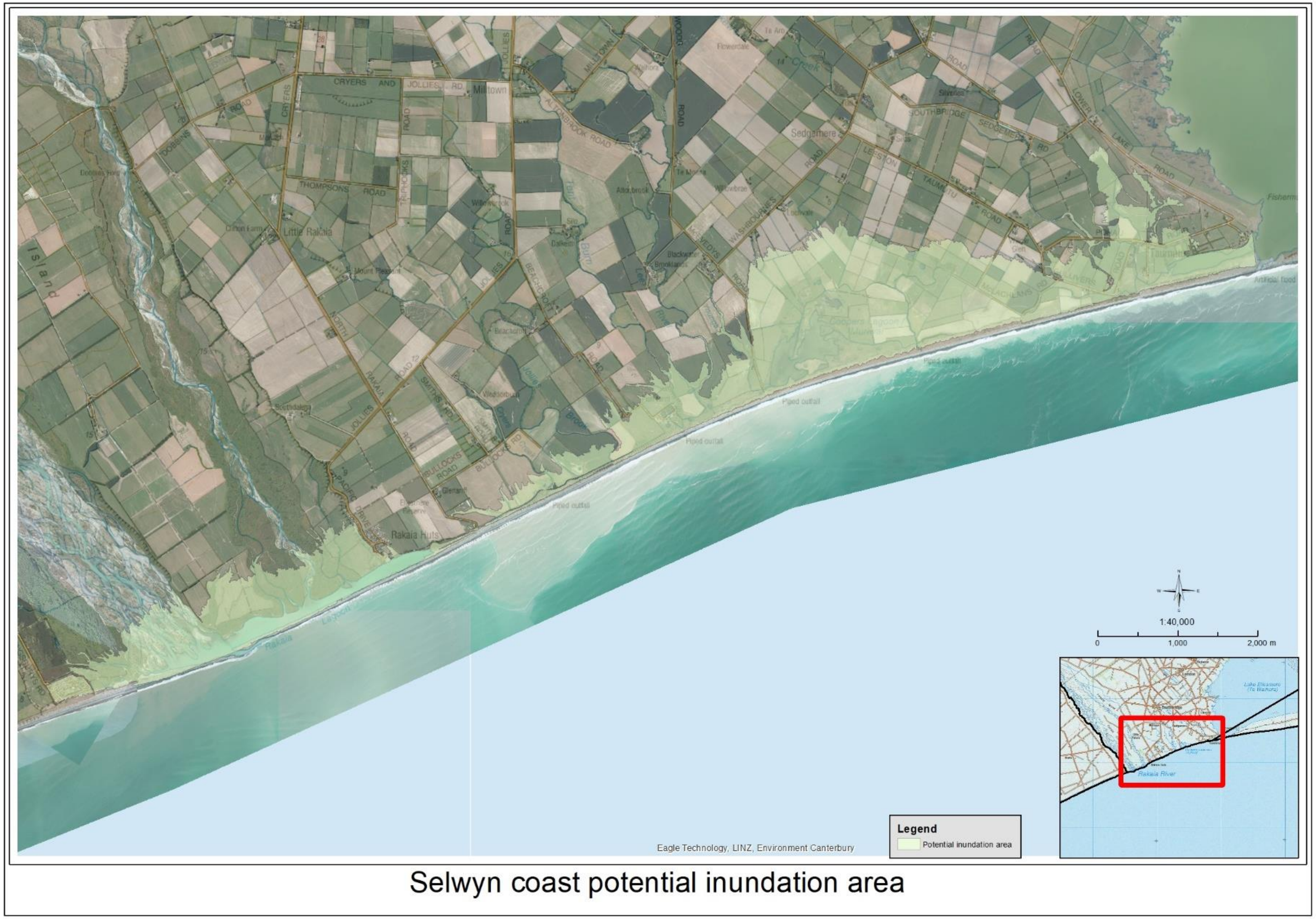

Figure 7-2: **Coastal inundation map for Selwyn District showing land potentially exposed to coastal inundation from extreme storm events over the next 100 years (2120). Shaded area is land below the 4m elevation contour (LVD-1937)**

The components of sea level used in the mapping for Selwyn District are presented in Table 7-1. The components were derived from the Stephens *et al.* (2015) coastal storm tide and wave runup calculator for the Canterbury region using a site-specific node at Taumutu. The 100-year (2120) RCP8.5H+ sea level (Section 3.1) was used as the sea level rise component. Storm tide and wave setup elevations were 1% AEP elevations derived from the statistical joint occurrence (joint probability) of storm tide and wave effects. The "datum offset" is an elevation correction to MSL (LVD-37) for the observed sea level rise that has occurred since this datum was established.

This assessment includes wave setup in the calculations for extreme sea-level elevations but does not include wave runup elevations. Wave setup is an integral component of the total water level that potentially could cause direct or near continuous inundation of coastal margins (MfE, 2017; Stephens *et al.,* 2016). Wave runup elevations can be significantly higher than wave setup. However, 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).

The potential inundation map for Selwyn (Figure 7-2) takes the 4 m extreme storm tide level from Table 7-1 and intersects this with a 2015 LiDAR derived digital elevation model (DEM) to create GIS polygons that identify land lower than the 4 m elevation scenario.

This technique can be described as a "conservative bathtub approach" (D. Todd (peer reviewer) personal communication). It is not the equivalent of what is often referred to as a "connected bathtub" model which extrapolates the storm inundation level inland where there is a connection to the open coast, i.e. natural or artificial drainage systems.

Bathtub models in general assume the inland area will be inundated to the equivalent static storm tide level as the adjacent open coast. Although we have attempted to remove any obvious low-lying ponding areas, we have not attempted to identify where possible connections exist between the open coast and inland areas during extreme storm events. For a high-level screening assessment, the use of the conservative bathtub approach is justified in that it incorporates any future uncertainty in future coastal geomorphology such as possible future barrier breaches, uncertainties around future barrier elevations as beach rollover continues and lowering base topography behind the barrier.

Therefore, our inundation map provides a conservatively high indication of areas where there is the potential for coastal storm inundation in the next 100 years. This is consistent with the high-level screening approach which can be used to assess exposure where high value assets or populated areas have the potential to be exposed to an inundation hazard and where more detailed coastal hazard assessments may be required.

Table 7-1: Sea level components used to derive coastal storm inundation mapping level. From the NIWA coastal calculator for Canterbury (Stephens *et al.,* 2015)

Sea level component	Contribution (m)
Storm tide (astronomical tide plus storm surge)	1.28
Wave setup	1.23
Sea level rise (RCP8.5H+ 2120 scenario)	1.36
Mean sea level datum offset	0.17
TOTAL	**4.04**

8 Discussion

8.1 Inundation

We have identified areas of the Selwyn coast potentially subject to coastal inundation from extreme storm events over the next 100 years by mapping a 4 m above mean sea level (LVD-37 datum) elevation band. These are areas potentially subject to coastal inundation in a 1% AEP coastal storm event with allowance for a 100-year sea level rise of 1.36 m (RCP8.5H+ scenario). Potential inundation is greatest around the low-lying margins of Coopers Lagoon/Muriwai, including Tentburn and north to include some parts of Taumutu.

8.1.1 North Rakaia Huts inundation

Some lower elevations of the north Rakaia Huts settlement are identified as potentially exposed to future inundation (Figure 8-1). However, 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.

The state of the river mouth exerts a significant influence on lagoon water levels. If the mouth channel migrates and is offset (usually north) of the main river channel due to favourable wave conditions 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). This high lagoon level can persist for months and can increase the potential for flood hazard at the Huts. If a moderate fresh occurs in the river when the lagoon level is sufficiently high, and the outlet does not immediately widen to accommodate the increased volume of water in the lagoon then flooding to a hazard level can occur.

An example of this type of flooding occurred in September 2013 (Figure 8-2). Unfortunately, the lagoon water level recorder was overwhelmed during this event, but estimated water levels reached approximately 4 m above MSL (LVD-37) (N. Griffiths, Environment Canterbury, pers. com. 2018). Coincidently this is the level to which we have mapped future inundation. However, this inadequately reflects the potential future flood hazard when considering potential exacerbating effects of future sea level rise. Tide levels exert some temporary control over lagoon levels through a backwater effect and 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). Due to the control that oceanic processes have on lagoon water levels, we recommend that a more detailed assessment be undertaken on the influence of future sea level rise on the potential inundation hazard at the north Rakaia Huts.

8.2 Erosion

An area of potential coastal erosion out to 2120 has been identified (Figure 6-1). The maximum landward extent of this zone extends inland from the current coastline approximately 120 metres. This area can be used to identify coastal features, assets or land uses that could be affected by coastal retreat within the next 100 years.

For example, between Te Waihora/Lake Ellesmere and the Rakaia River there are four culvert structures draining spring water (and flood waters) to the sea. These culverts are known (from north to south) as Forsyth's Culvert, McEvedy's Culvert, Rakaia No.2 (McIlrath's) Culvert, and Rakaia No.1 Culvert. The culverts are exposed to a high-energy wave environment and all have a long history of damage from coastal storm events, exacerbated by ongoing coastal retreat. Regular maintenance and the landward extension of the culverts have been required in the past to maintain the function of these coastal structures (Measures *et al.,* 2014). As the beach rolls back, it will progressively overwhelm parts of the lowland drainage system, particularly around Tentburn, Jollies Brook and Coopers Lagoon/Muriwai.

8.2.1 North Rakaia Huts erosion

River and coastal process interactions at the Rakaia river mouth mean that the methodology used in this assessment to identify an area of potential coastal erosion for the Selwyn District is not applicable to the coastal frontage adjacent to the Rakaia Huts. McHaffie (2010) and Hicks and Enright (2010) have previously identified that the whole of the lagoon system, including the barrier shoreline and landward shore has migrated seawards since 1952 (the date of the earliest aerial photograph analysed by McHaffie (2010)). 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. This outcome is consistent with the findings of previous hāpua evolution research (Hart, 2009a and 2009b; 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 to maintain their lagoon area. For the Rakaia hāpua the unknown factor is in the timing of when the next cycle of retreat will occur, particularly in the face of accelerated sea level rise. This could be an additional focus of the recommended work on future flood hazard for the Rakaia Huts.

Figure 8-1: North Rakaia Huts and Rakaia River hāpua indicating land below 4 m elevation (above mean sea level LVD-1937)

Figure 8-2: Flooding at north Rakaia Huts due to a moderate fresh and constricted hāpua outlet, September 2013. Source: Environment Canterbury

9 Summary and recommendations

Areas of potential future coastal erosion and coastal inundation have been identified as part of a high-level coastal hazard screening assessment for the Selwyn District. The coastal hazard screening broadly identifies areas potentially subject to coastal erosion and inundation and can be used to indicate locations where more detailed hazard exposure (and ultimately risk and vulnerability) assessments may need to be undertaken.

An area of potential coastal erosion hazard for the next 100 years is identified. The extent of this area extends approximately 120 metres from the current shoreline.

The prediction of future erosion of the landward edge of the hāpua fronting the north Rakaia Huts needs to be treated differently than the open coastline elsewhere in the district due to fluvial and coastal process interactions.

An area of coastal land potentially subject to coastal inundation during extreme storm events over the next 100 years has been identified by mapping low-lying land below a 4 m mean sea level elevation contour. Potential inundation is greatest around the low-lying margins of Coopers Lagoon/Muriwai, including Tentburn and some parts of Taumutu.

Land with lower elevations at the north Rakaia Huts settlement is currently susceptible to combined fluvial and coastal flooding events and future sea level rise is likely to increase this susceptibility.

Recommendations to Selwyn District Council for further work:

1. A more detailed coastal hazard assessment should be undertaken for the north Rakaia Huts settlement to better identify the future coastal hazard risk and vulnerability.

2. This high-level assessment broadly identifies areas potentially exposed to future coastal erosion and inundation hazards. It does not assess in detail what settlements, land uses, assets (including cultural assets), infrastructure or future growth areas may be exposed to these future hazards. A more detailed exposure analysis/assessment would help refine (or rule out) locations along the District's coast where detailed coastal hazard assessments may be useful to support future land use planning.

If further areas were to be identified in an exposure analysis (recommendation 2) and a more detailed hazard assessment undertaken, then consideration should be given to;

3. refining the Measures *et al.* (2014) open coastal erosion model to incorporate possible climate change-induced variability in other weather and oceanic coastal hazard drivers and coastal sediment supply. This would refine the shoreline modelling to consider in greater detail the physical factors identified in Policy 24 of the NZCPS,

4. refining the coastal inundation analysis to incorporate any hydraulic connections identified between the open coast and inland areas during extreme storm events, and

5. including an analysis of the combined influence of ongoing beach erosion and the potential effects that sea level rise may have on beach crest elevations and the related impact on future coastal inundation.

10 Peer Review

This report has been externally peer reviewed by Derek Todd, Principal Coastal and Hazards Scientist at Jacobs Consulting Ltd.

Mr Todd's general comment was that *"the report successfully collates the existing information and presents it in a manner that allows the SDC to identify locations where more detailed hazards assessments would be warranted*." Specifically, he states "*the recommendations on the high-level areas identified, and the need for more detailed assessment at North Rakaia Huts are appropriate"* and he considers *"the report meets the requirement of a regional/district coastal hazard assessment as per the MfE (2017) guidance and sets a good template for other similar assessments in other districts".*

Mr Todd made some specific recommendations for improvement on the presentation and accuracy of some of the background information and suggests *"the coastal erosion section would greatly benefit from including results from beach profiles and aerial photo analysis for Kaitorete Barrier to put the results for Taumutu into a wider process/shoreline orientation context"* These recommendations have been accepted and included in the final report.

The relevant section of the peer review is attached in the Appendix.

11 Acknowledgements

Thank you to Bruce Gabites (Environment Canterbury) who undertook the DSAS historic shoreline analysis and created the GIS layers and maps.

Thank you to the Environment Canterbury reviewers Jane Doogue, Bruce Gabites and Tim Davie and an external reviewer Derek Todd (Jacobs Ltd) for the helpful comments, suggestions and recommendations for improvements.

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Appendix 1: Peer review

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11 October 2018

Attention: Justin cope
Environment Canterbury
PO Box 345
Christchurch

Project Name: ECan Coastal Hazards Reviews
Project Number: IZ117900

Subject: Review of Draft Selwyn District Screening Report

Dear Justin

Please find attached my tracked changes review of this draft report.

My general comment is that the report successfully collates the existing information and presents it in a manner that allows the SDC to identify locations where more detailed hazards assessments would be warranted. Most of the comments and suggestions relate to the presentation and accuracy of the background information rather than the hazard results.

Regarding the matters set out in your request to review, my findings are:

- The technical information presented is largely appropriate (bearing in mind my suggestions for improvement). However, I think the coastal erosion section would greatly benefit from including results from beach profiles and aerial photo analysis for Kaitorete Barrier to put the results for Taumutu into a wider process/shoreline orientation context. After all, this section of shoreline is all one coastal cell, which the district boundary cuts in half. This wider context may alter your findings and discussion around the Taumutu erosion node and location of erosion/accretion hinge point; but is unlikely to alter the conclusions on the broad scale of hazard risk within the Selwyn District.

- Even bearing in mind the above points about applying a wider coastal cell approach to the analysis, I believe the recommendations on the high-level areas identified, and the need for more detailed assessment at North Rakaia Huts are appropriate.

- With the above-mentioned addition, I consider the report meets the requirement of a regional/district coastal hazard assessment as per the MfE (2017) guidance, and sets a good template for other similar assessments in other districts.

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