Timaru Coastal Erosion Assessment

Timaru Coastal Erosion Assessment Appendix

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Environment Canterbury and Timaru District Council

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Appendix A. Detailed Methodology of Calculating Projected Future Shoreline Positions (PFSP)

A.1 Projected Future Shoreline Position (PFSP) Equation

Projected future shoreline positions (PFSP) have been calculated by the following formula to meet the requirements of NZCPS Policy 24:

PFSP = (LT X T) + ST + SL

Where:

T = Time frame (e.g. 50, and 100 years)

LT = Rate of long-term shoreline movement

ST = Storm term storm erosion. Note for cliff coastlines, erosion episodes may occur after storm events due to slope failure mechanisms contributed to by the loss of beach volume at the base of the cliff in coastal storm events as well as sub-aerial processes.

SL = Erosion due to accelerated SLR over the selected time frames

A.1.1 Long-term Historical Shoreline Movements (LT)

Historical aerial imagery was collated from Retrolens and LINZ Online data service for the entirety of the Timaru District coastline between 1938 and 2019, and from TDC for Patiti Point in 2020, in order to analyse long term shoreline trends and rates of change. The dates of the aerial imagery used, and their spatial coverage is presented in Table 2.1 of the main report. Older cadastral maps should as used in Todd (1989) were not used due to the higher level of uncertainty in reference shoreline used and the level of accuracy that the position was mapped.

The aerial imagery was georeferenced in ArcGIS using consistent stable land features such as buildings and roads to ensure the correct positioning and scale of the shoreline. We can be confident with the accuracy of the georeferencing in most recent photographs where there are more stable features which can be accurately identified and have confidence that in the time period between images the position of this feature did not change. However, in earlier photographs where there are fewer stable features that can be identified due to lack of development and the change of housing stock, we are less confident with the accuracy of the georeferencing. We expect that the georeferencing of earlier images could be accurate to +/-5m.

The shorelines in each image were manually digitized in GIS using coastal features which could be observed in all photographs and are considered to be representative of long-term shoreline change. These features were primarily the vegetation line, the back of the gravel barrier (when backed by a lagoon e.g. Washdyke), and the cliff top edge as shown in Figure A.1. The accuracy of this digitization was dependent on the quality of the aerial imagery, and the accuracy of the georeferencing. The resolution, shadowing and light exposure are issues in earlier images, especially around cliffed areas, that makes it difficult to identify features. In areas where the coastal feature was unidentifiable, a shoreline was not produced for that time period.

Figure A.1: Examples of coastal features used in assessment of long-term historical shoreline changes

The digitized shorelines were used in the GIS based DSAS (Digital Shoreline Analysis System) tool to calculate the net shoreline change and rates of the shoreline movements since the earliest available aerial photograph for that coastal cell at 50m spaced transects perpendicular to the shoreline orientation. The long-term regression rate (LRR) was used as the historical trend component of the PFSP equation when the R^2 value for the transect was high, indicating a strong linear trend. Where the R^2 value was low, further analysis was undertaken to determine if using the entire period of analysis was appropriate. In some instances, earlier shorelines were removed from the analysis as the rate of movement in these early periods was not representative of current day processes. For example, the former mouth of the Orari River north of the current position was still active in the early images with vegetation line advance since closure resulting in a mapped trend of localised long-term shoreline accretion when the rest of geomorphic cell displayed long-term erosional trends.

The results of the DSAS analysis are presented in Appendix C., including the historical shoreline positions, transect locations and resulting erosion rates.

Validation of the DSAS results was undertaken by calculating the change from shoreline movements measured by ECan beach profile surveys over the same time period as the recent aerial imagery used in the DSAS analysis. Individual beach profiles were analysed for change at the site over the longest period possible. Start dates for surveying at these sites ranges from the late 1970's to the early 1990's, and therefore the earliest survey corresponding to the closest aerial imagery date was used. The feature used to determine the change in the DSAS analysis was also used to determine the change in the surveyed profile. Often survey notes were relied on to determine the change (e.g. where the vegetation line was). The closest two DSAS transects to the ECan profile were used for the comparison. If there was a noted storm between the date of the survey and the date the aerial imagery was taken, the survey profile was not used. There was a maximum of six months between the aerial imagery date and the survey date. The results of this validation are presented in Appendix D. These results show average difference between the DSAS and profile analysis of 4.4 m at an average rate of 0.2 m/yr, with maximum difference of 13 m at a rate of 0.41 m/yr.

A.1.2 Short-term Storm Erosion (ST)

The inclusion of short-term storm erosion in the PFSP equation is to account for an extreme erosion event occurring at or near the end of the planning timeframe under consideration, such that it would not be accounted for in the extrapolation of the average long-term rates. This is particularly important for dynamic beach systems which experience periods of both erosion and accretion, and for accounting for the more episodic retreat of sections of coastal cliff due to feedback mechanisms in cliff failure.

To determine the short-term storm erosion component, 34 ECan coastal profiles along the Timaru District were analysed to calculate the maximum inter survey erosion distances over the 30-40 year of survey record. The profiles used are part of the ECan beach profile monitoring programme that are surveyed 1-2 times per year. These profiles used in the analysis were chosen as being representative of a stretch of coast with the same morphologies. For example, at Washdyke Lagoon where there are 10 profiles spaced across the lagoon backed gravel barrier, three evenly spaced profiles (South, Central, North) were selected as being representative of the morphology along that stretch of coastline.

BMAP[12] was used to analyse the beach profile data to calculate the magnitude of inter-survey retreat of a specified beach contour or feature than most likely was due to the occurrence of storm events between the surveys. On gravel beaches the chosen contour was close to the crest ridge at the site, as retreat of this feature is primarily due to roll over and/or erosion in storm events, and for cliff sites the chosen feature was the cliff edge, which again retreats due to toe erosion in storm events. Identified periods of upper beach contour retreat were checked against the ECan storm database[13] to ensure that changes were driven by storm events and against the full profile changes to ensure that the upper beach changes were consistent with storm effects (e.g. evidence of rollover or foreshore volume losses). The resulting maximum inter-survey erosion and storms during the period of maximum change are presented in Appendix B.

For each profile, the erosion distances were ranked and a Generalised Extreme Value (GEV) Distribution used to calculate the 100-year ARI (e.g. 1% AEP) erosion event magnitude for that site. For sites which had bi-annual surveys, the data was filtered so that only the maximum inter-survey change for each year was used in the distribution. The minimum threshold of erosion (e.g. the lowest to be considered as storm erosion) was set at 2 m for beaches, and 0 m for cliffs. To give more confidence in the calculation of the 100-year ARI event from the 20-30 erosion periods, a Monte Carlo simulation of 200 events was used to define the GEV distribution and to calculate Confidence Intervals of the distribution.

The resulting minimum, mean and maximum values of the short-term erosion component for each profile site are also presented in Appendix B.

A.1.3 Impact of sea-level rise (SLR)

A.1.3.1 SLR Scenarios

IPCC AR5 (2014) developed four climate change and sea-level rise (SLR) projections, termed RCPs (Representative Concentration Pathways), based on the following global emissions scenarios.

- RCP2.6 – low emission
- RCP4.5 – moderate then declining emissions
- RCP 6.0 – moderate emissions
- RCP8.5 – continuing status quo high emissions

Within each RCP, percentiles are used to quantify the distribution of the sea-level rise projection with the median (50^{th} percentile) plotted as the main curve.

MfE (2017) *Coastal Hazards and Climate Change: Guidance for Local Government* presents four SLR scenarios are developed based on three of the IPCC RCP scenarios (RCP2.6, RCP4.5, RCP8.5) and a higher RCP8.5+

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[12] Profile analysis software part of the Coastal Engineering Design & Analysis System (CEDAS) software package.

[13] Database of storm events. From 1974 to 1995 lists events qualitatively recorded by South Canterbury Catchment Board/ECan staff and reported in University thesis and research studies. From May 1999 includes events recorded on the Ecan deep water wave buoy off Banks Peninsula that had significant wave height above 4 m for greater than 24 hours.

scenario taking into account possible instabilities in the polar ice sheets. The resulting SLR projections from these scenarios extended out to 2150 and including a small additional SLR above the global projections to account for NZ wide regional offset in rates of historical rise, are presented in Figure A.2.

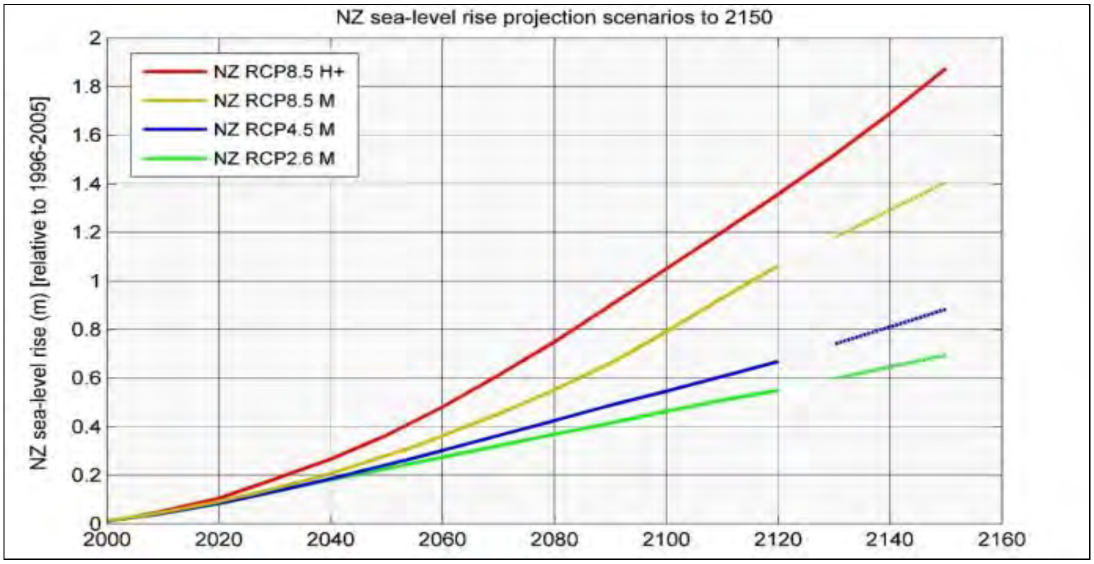

Figure A.2: MfE (2017, Figure 27) Four scenarios of New Zealand-wide regional sea-level rise projections based on IPCC (2014).

For this assessment, instead of directly applying the RCP scenario magnitudes of rise, an incremental approach to SLR scenarios since 2020 over planning timeframes of 50 and 100 years has been applied that covers the range of magnitudes from the MfE (2017) scenarios. Table 2.1 shows how these increments compare to the MfE (2017) scenarios.

Table A.1: SLR projections used in this assessment, compared to projections from MfE (2017) for the wider New Zealand region.

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

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

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

A.1.3.2 Geometric beach retreat models

Geometric shoreline retreat models have been used for a number of years to provide order of magnitude estimates for the predication of shoreline retreat with SLR. This is particularly the case for sand beach environments (e.g. The Bruun Rule), but there has been less development of shoreline retreat models for mixed sand and gravel beach types such as found within the Timaru District. However, it is generally accepted in the international literature that beaches containing gravel components will erode less that sand beaches under SLR as the coarser sediment is moved landward and upwards on the beach ridge rather than large volumes of sediment being lost to offshore.

All of the geometric prediction models have limitations around the assumptions applied and the uncertainty of the data required to be inputted into the models. However, their benefits are that they provide a practical method for obtaining a rapid semi-quantitative assessment of the likely order of magnitude of shoreline response to sea level rise.

Geometric beach retreat models from literature which are relevant to coastal morphologies of the Timaru District and their limitations are summarised below:

A.1.3.2.1 Sand Beach

The only sand beach located in the Timaru District is at Caroline Bay, in the lee of the Timaru Harbour. A standardized 'Bruun Rule' (Bruun 1962) approach was used to determine sand beach retreat with the incremental increases in sea level over the 50 and 100 year timeframes. This method is widely used in the international literature and is recommended in the MfE (2017) guidance. The model involves the assumptions of conservation of an equilibrium profile shape with the volume eroded seaward from the beach being that required to raise the nearshore profile out to the closure depth for cross-shore sediment transport by the same vertical magnitude as the magnitude of sea level rise. Therefore, the resulting horizontal shoreline retreat is dependent on the beach-nearshore slope from dune crest to the closure depth and is expressed by the following equation.

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

Where:

L = The horizontal distance to the closure depth from the beach crest;

s = projected SLR over the planning timeframe

h = The height of the dune above Mean Sea Level (MSL); and

d = The average closure depth below MSL.

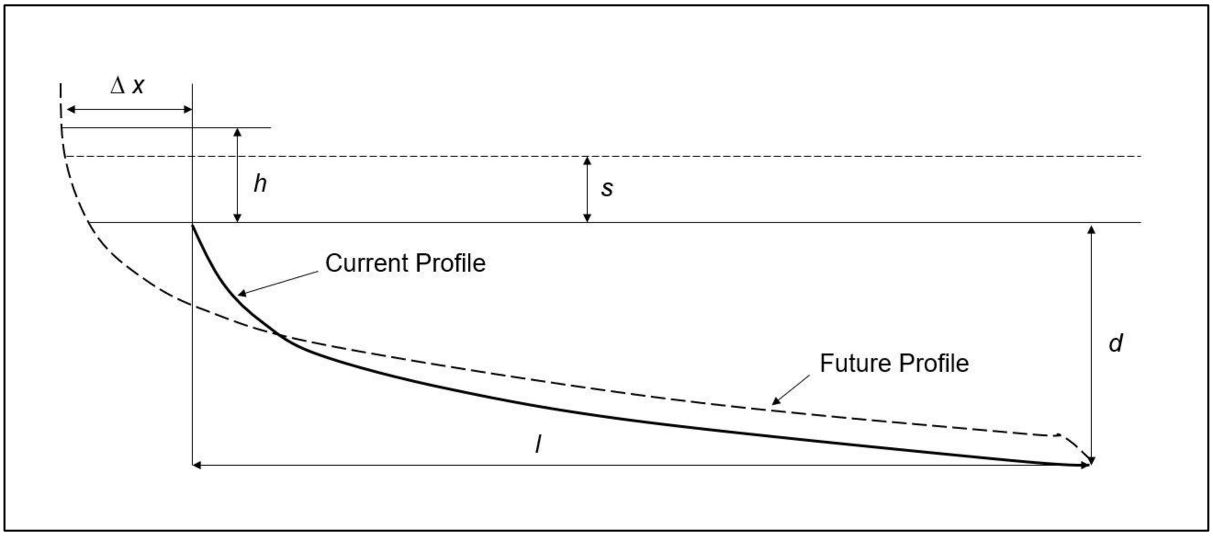

Figure A.3: Schematic of Bruun Rule components

For Caroline Bay, the components for the Bruun equation were determined by the following:

- Height of the dune above MSL was obtained from the average beach profile envelope calculated in BMAP from ECan beach profiles within the bay. Maximum and minimum dune elevations for the probability distribution were obtained from the max and min profile envelopes respectively.
- Closure depth for the limit of cross-shore sediment transport from the beach was set at -4 m LVD1937 from ECan assessment of nearshore sand volume changes in the bay 2000-2016 with distances to the contour from 2010 ECan bathymetry mapping (Figure A.4)[14] This closure depth implies that the wave height exceeded 12 hours a year used to calculate the theoretical Hallermeiers (1981) limit would be in the order of 1.4 m, which compares well with the estimated 1 year ARI significant wave height entering the bay as presented by DTec (2004) of 1.24 m.

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

- Assumes only two dimensional cross-shore sediment movements hence does not include consideration of longshore sediment transport inputs/losses or plan shape controls (e.g. headlands). This is a major limitation for Caroline Bay which has historically been gaining sediment at a rate of 30,000 m/yr from longshore transport around the harbour breakwaters. However, the SLR erosion calculation can be superimposed on the historical accretion trend.
- Is only applicable to equilibrium beach profiles. Clearly Caroline Bay is not in an equilibrium state with the on-going accretion. However, as above the SLR erosion calculation can be superimposed on the historical accretion trend.
- Difficulty in determining a closure depth for offshore sediment transport. For Caroline Bay this has been overcome to use of the ECan bathymetry, which indicates a closure depth of -4 m LVD1937 based on limited change in sea bed elevation at this contour since 2000.

[14] From an un-dated ECan Interim report titled "Caroline Bay Accretion Study" by Cope to the PrimePort Board.

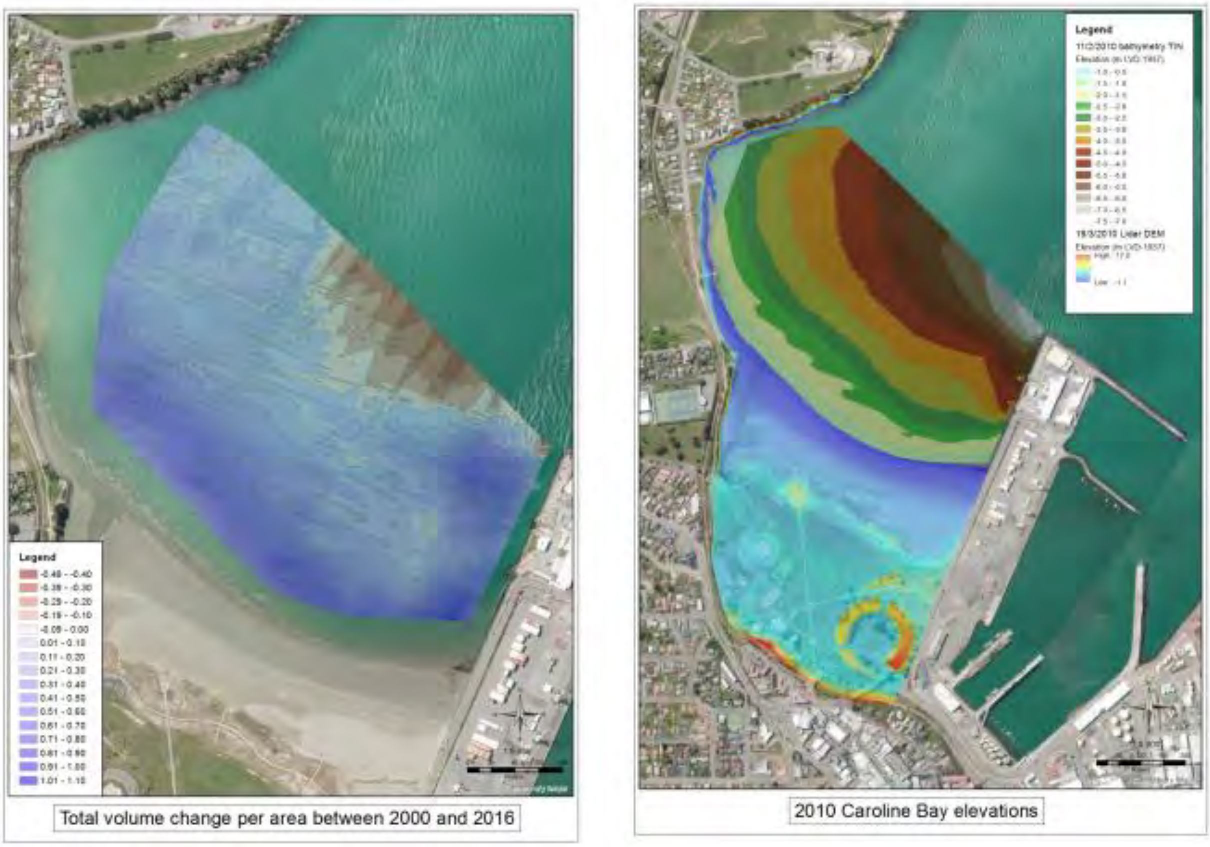

Figure A.4: Caroline Bay Bathymetry and nearshore volume change mapping. Source: Undated ECan Interim report titled "Caroline Bay Accretion Study" by Cope to the PrimePort Board

A.1.3.2.2 Mixed sand and gravel beaches

Mixed sand and gravel (MSG) beaches dominate the majority of the open coast shoreline both north and south of Timaru. It is generally accepted in the literature that the erosion response of these types of beaches to SLR will be less than for sand beaches. While the nearshore profile for most of the Timaru open coast has not been surveyed, a single row or breakers along with the onshore morphological profile and sediment composition suggest these beach types have a steep nearshore step close to the shoreline. For these beaches, the sediment transport processes indicate that the closure depth will be in the vicinity of the toe of this steep nearshore face rather than out on the flat sandy nearshore future offshore that is calculated by the Halliermeiers closure limits from wave climate. By using a shallower closure depth in combination with a steeper slope, the predicted erosion impacts from SLR are much smaller than produced when using the standard Bruun Rule on flatter sloped sand beaches.

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

For the contained beaches, much of the time the presence and elevation of the stopbanks/hinterland restricts the rollover of beach sediment, resulting in the response to SLR being foreshore volume losses and retreat of the foreshore profile and nearshore step resulting in reduction in beach width (Figure A.5). For quantifying this response, the Bruun Rule was modified to use the toe of the nearshore step as the closure depth. A similar

modification has been used in assessment of SLR effects on contained MSG beaches in the Hurunui District (Jacobs, 2020) following sensitivity testing of the barrier rollover model from Measures et al (2014) and Orford et al (1995).
The resulting modified retreat formula is:

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

Where:

L, S, and h are as for the standard Bruun equation, and

dt = Closure depth below MSL defined as the toe of the steep nearshore step

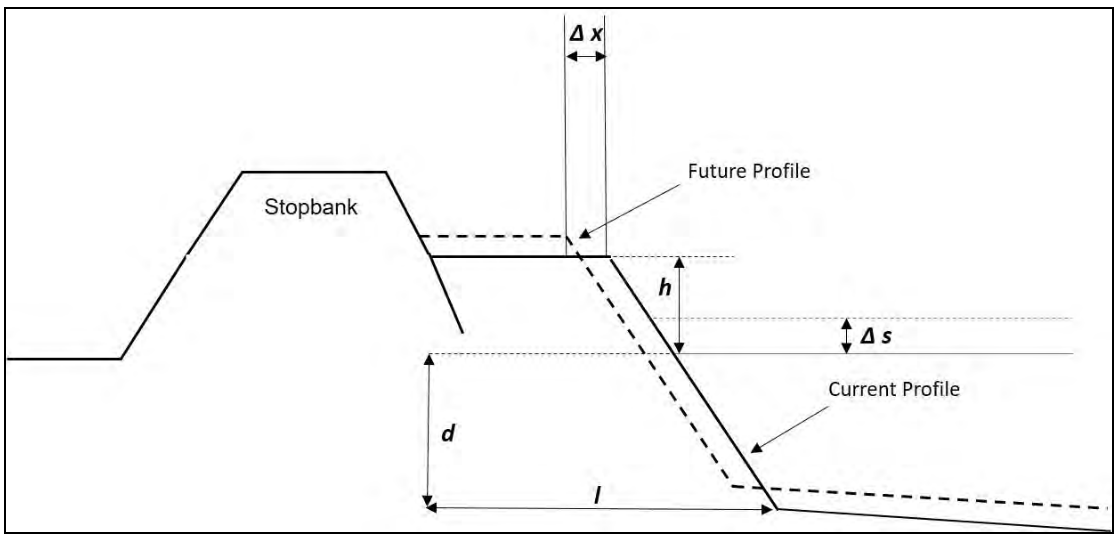

Figure A.5: Schematic of modified Bruun Rule for MSG beaches.

Data inputs into the formula were:

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

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

- Does not account for where gravel sized material is eroded to once eroded from the foreshore. While the sand material can be transported to the flat nearshore seabed to raise the profile (although not as much as for sand beaches under the Bruun Rule, the coarser gravel material not transported alongshore is assumed to accumulate at the nearshore steep.
- Does not allow any consideration of beach rollover in the times that stopbanks are breached, or located well behind the beach, therefore may under predict the impacts of SLR on retreat under the assumption in section 2.2.1 that current coastal stopbanks will not be maintained or replaced in the future.

- Uncertainty in the toe elevation and slope of the nearshore step. Low uncertainty of the overall effect of SLR on MSG beaches is strongly influenced by input data limitation on the nearshore profile.

A.1.3.2.3 Mixed sand and gravel barriers subject to roll-over

As outlined above, MSG barriers seaward of coastal lagoons (e.g. Washdyke Lagoon), and river mouths (e.g. Opihi River) and low-lying hinterlands, where the beach is un-contained. Overtopping by storm waves results in sediment on the crest ridge of the barrier being 'rolled-over' landward into the backshore resulting in retreat of the barrier crest. Since this process occurs during storms when the wave run-up is higher than the crest elevation, therefore low barriers tend to be more subjected to this rollover process and the frequency of the barrier being overtopped will increase with SLR (assuming a stable or sediment starved barrier).

The roll-over model used in this assessment was developed by Measures *et al*. (2014) for the MSG barriers on the Kaitorete Spit where roll-over from wave overtopping is the dominant erosion process and where large back slope elevations extend into Te Waihora Lagoon behind the barrier. The model assumes that crest building from waves just overtopping the barrier crest will keep pace with SLR and that the volume required to lift the barrier crest to match SLR is supplied from a slice of equal volume from the beachface, hence causing the beachface to retreat. The physical process of barrier rollover with SLR is demonstrated in Figure A.6, and the retreat equation is presented below.

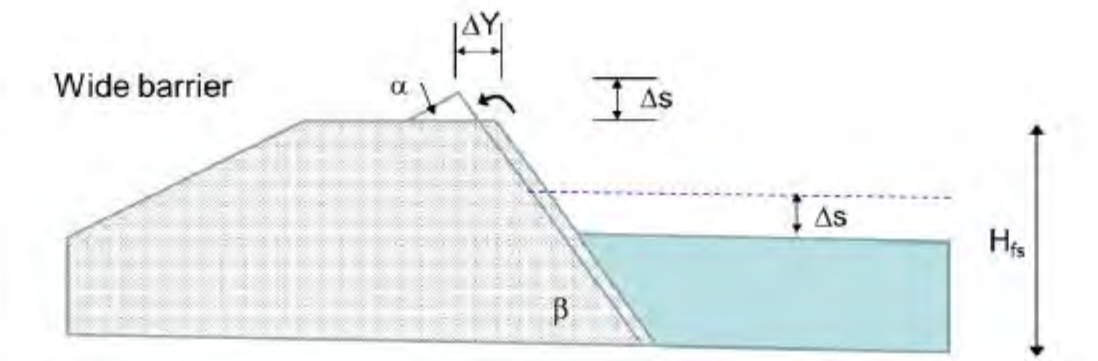

Figure A.6: Schematic of Measures et al. (2014).Gravel barrier response to SLR model.

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

Where

$R_{Measures}$ is the retreat distance (Δy)

ΔS is the expected SLR over the planning timeframe,

H_{bs} is the height of the backshore,

α is the corresponding backshore slope,

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

and β is the corresponding foreshore slope

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

A.1.3.2.4 Cliff Erosion

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

Walkden and Dickson (2008) used sensitivity testing of the SCAPE model (Soft Cliff And Platform Erosion) developed by Hall & Walkden (2005) for retreat of soft cliffs (e.g. soft mudstone to soft clay) to examine the influence of different beach volumes, erosive forces, sea level rises on the development of equilibrium cliff retreat rates over long time periods (e.g. decadal to centuries). The results of this analysis were that for beach volumes below 30 m^3/m (e.g. the cliff retreat does not contribute significant sediment to the beach) there was a power relationship (*m* value) between increase in cliff retreat rates and the ratio of rate of future SLR to the current rate of rise.

Ashton et al (2011) expanded the analysis of Walkden and Dickson (2008) looking at generic changes in the feedback power relationship for other types of cliff geology and strength (e.g. rock, alluvial glacial outwash terrace), but still with the assumption of low beach volumes which does not affect the evolution of the cliff-beach/platform profile, and the cliff does not contribute significant beach building sediment. The paper concluded that the most common behaviour of cliffed coasts is likely to be that of a ‘negative feedback’, such as the power relationship found by Walkden and Dickson (2008), with power values in the range $0<m>1$. The paper further concluded that the general type of response to SLR changes will be determined by the coast type, environmental drivers and dominant processes, but unfortunately did not quantify appropriate *m* values for the different cliff types.

Limitation in applying the above relationships to the cliffed coast in the Timaru District include:

- The relationship is limited for use on cliffs with fronting beaches having volumes less than 30m^3/m, which only applies to some loess cliffs in the Timaru District
- There is uncertainty in the *m* value of the power relationship for the alluvial cliffs. It is assumed that this this value would be lower than 0.5, but as above we have no basis for suggesting what value is appropriate.
- The resulting erosion rates are after adequate time for the equilibrium profiles to fully develop, which may be centuries. Therefore, as noted by Ashton et al (2011), “*care should be taken with direct application of the formulations presented, particularly over shorten temporal scales*".

To address the first two of the above limitations and to provide a consistent approach across the whole Canterbury region for the assessment of the effects of SLR on cliff retreat rates, sensitivity testing was carried out for all cliffed sections of the Canterbury coast covering multiple cliff morphologies. The sensitivity testing started with analysis of the relationship between cliff retreat rates and beach volumes from 37 ECan profile sites across alluvial (27 sites), loess (6 sites) and mudstone (4 sites) cliff types throughout Canterbury. The data used included retreat rates and mean beach volumes over the 30-40 years of profile surveys. The results compared with those presented by Walkden and Dickson (2008) from their sensitivity testing of effect of beach volume on equilibrium retreat rate are presented in Figure A.7. An assumption from this comparison is that the current retreat rates are in equilibrium with the environment factors and cliff properties for contemporary rates of SLR. To assist with the analysis, the Canterbury cliff sites are coded for location and type.

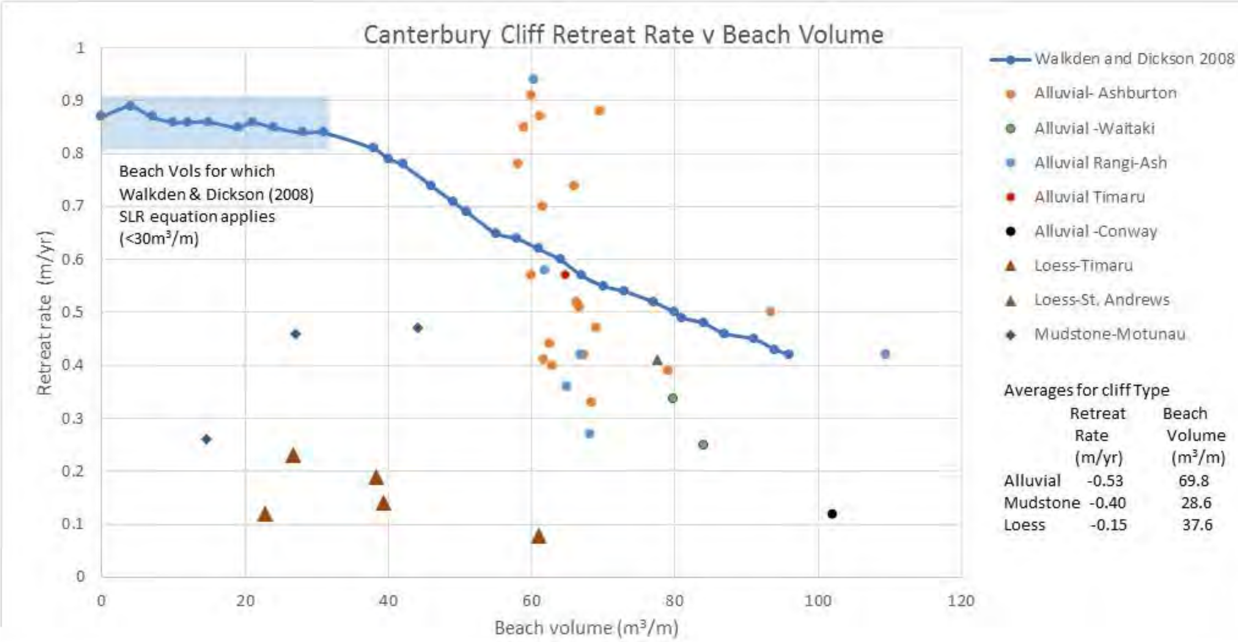

Figure A.7: Relationship between Canterbury cliff retreat rate and beach volumes from 37 ECan profile sites.

The results of the analysis show a large variably in cliff retreat and beach volume across individual sites, but when grouped together in the three cliff types (alluvial, mudstone and loess) the following general patterns emerge:

Mudstone cliffs (Motunau)

- Are the only cliff type to have average volumes (28.6 m^3/m with SD of 12.1 m^3/m) below the threshold (30 m^3/m) for the Walkden & Dickson (2008) relationship for SLR effects, with the erosion products being too fine to remain as a beach at the base of the cliff.
- It is therefore considered appropriate to apply an *m value of* 0.5 for these cliffs.

Loess cliffs (Timaru and St. Andrews)

- Although the erosion of loess cliffs also releases sediment too fine to survive as a beach deposit, the beaches found at the base of these cliffs are of the MSG type from the longshore transport of sediment from rivers and alluvial cliff erosion to the south. These beaches have a greater ability to withstand the erosive forces of waves and water levels, resulting in greater beach volumes at the base of the cliffs (average 37.6 m^3/m with SD = 13.3 m^3/m), which in turn provides greater protection against cliff retreat.
- Since the beach volumes are marginally above the threshold (30 m^3/m) for the Walkden & Dickson (2008) relationship for SLR effects, there is some uncertainty of applying an *m value = 0.5* for the determination for SLR effects on erosion rates for this cliff type.
- As per the finding of the Walkden & Dickson (2008), the greater beach protection is considered to contribute to the lower average cliff retreat rates (-0.15 m/yr with SD of 0.05 m/yr from ECan profiles) for the Timaru loess cliffs compared to the Mudstone cliffs at Motunau, with other factors including differences in landslide vulnerability, and strength of the cliff material.
- As per the Mudstone cliffs, the retreat rates for the Timaru loess cliffs are much lower than those predicted by Walkden & Dickson (2008) for those beach volumes, with the differences again likely to be due to differences between the two locations in the erosive forces (e.g. waves, tides), landslide

vulnerability, and/or strength of the cliff material to resist these forces. This suggests that a lower m value than 0.5 would be appropriate for loess cliffs.

Alluvial Cliffs (Canterbury Wide)

- Beach volumes at the base of alluvial cliffs are higher than both Mudstone and loess cliffs, with the average volume being 69.8 m^3/m (SD = 12.8 m^3/m). For these sites, the majority of the sediment eroded from the cliffs (e.g. gravel and sand) is of sufficient size to survive on the beach and clearly contributes to the beach volume, providing an episodic supply to supplement longshore transport supply.
- Since these beach volumes are well above the above the threshold (30 m^3/m) for the Walkden & Dickson (2008) relationship for SLR effects, there is large uncertainty of applying an *m value = 0.5* for the determination for SLR effects on erosion rates for this cliff type.
- Although there is a relatively narrow range of beach volumes, there is a large scatter of retreat rates for alluvial cliffs, with a mean rate of -0.53 m/yr and a standard derivation of 0.22 m/yr. This is considered to be due to local site characteristics, including cliff height and sediment characteristics. However, there was only a weak relationship between beach volume and distance from river sediment source and no relationship between beach volume and cliff retreat rate.
- The greater cliff retreat rates for alluvial cliffs than mudstone and loess cliffs, despite the larger beach volume providing greater protection to the base of the cliff, is due to the less resistance of the alluvial cliff material to the erosive forces of waves and water levels compared to cohesive properties of mudstone and loess material.
- Despite the scatter in the cliff retreat rates, the relationship between the mean rate and the mean beach volume is very similar to found by Walkden & Dickson (2008) for that volume.

The above analysis was used as a basis for further sensitivity testing to quantify the effect of cliff type and beach volumes on cliff retreat due to SLR along the Canterbury coast. The assumptions applied to this sensitivity testing were:

- An *m value =0.5* is appropriate for mudstone cliffs.
- Greater beach volumes on loess and alluvial cliffs reduce the effects of SLR on erosion rates (e.g. greater negative feedback), therefore should have a lower *m value* than mudstone cliffs, with the *m value* being the lowest for alluvial cliffs due the greater volumes.

The sensitivities considered were:

1. The effects of reducing the *m value* of the Walkden & Dickson (2008) power relationship for loess and alluvial cliffs due to greater beach volume. Based on geomorphic plan shape considerations[15] for the transition of MSG beaches to cliffs in the Timaru District, the combinations of *m values* tested were:
   Test 1a: *m = 0.3* for loess cliffs, and *m= 0.2* for alluvial cliffs.
   Test 1b: *m = 0.4* for loess cliffs, and *m= 0.3* for alluvial cliffs
2. The direct effect of the beach volume on the retreat rate, determined by applying a volume effect (Vol_{effect}) factor to the Walkden & Dickson (2008) future cliff retreat equation. The Vol_{effect} factor was calculated for each cliff type from the relationship of retreat rate to beach volume given by Walkden & Dickson (as shown in Figure A.7), being expressed as the following equation:

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

$$\boldsymbol{Vol_{effect}} = \left(\frac{\textbf{Retreat rate for mean beach volume per beach type}}{\textbf{Retreat rate for 30 m3/m beach volume (e.g 0.85m/yr}}\right)$$

The resulting Vol_{effect} factors applied to each cliff type are presented in Table A.2.

Table A.2: Mean cliff retreat rates, beach volumes, and Vol_{effect} factors for Canterbury cliffs.

Cliff Type	Mean Retreat Rate (m/yr)	Mean Beach Volume (m^3/m)	Vol_{effect} Factor
Mudstone	-0.40	28.6	1.00
Loess	-0.15	37.6	0.95
Alluvial	-0.53	69.8	0.65

The sensitivity testing involved ranking all 37 sites in terms of their current retreat rate, and comparing these ranking for both the total retreat rate (e.g. retreat rate due to historic rate plus the rate due to accelerated SLR) and the retreat rate due to SLR from applying the different *m values* for cliff type and the Vol_{effect} factor for m=0.5 for the rate of accelerated SLR to 2050 and 2120 under the RCP8.5 scenario.

The best results were interpreted as the methodology that best achieved the combination of the following:

- Relative ranking of SLR effects (e.g. separated from extrapolation of historical rates) – highest for mudstone sites, followed by loess sites then alluvial sites.
- Maintained relative ranking of total future erosion over both time periods – highest being alluvial cliff sites, followed by mudstone sites then loess sites
- Maintained geomorphic plan shape requirements for transition from MSG beaches to cliffs as determined by Timaru District sites, so that you don't get an artificial step in the shoreline plan shape between the two morphologies.

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

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

Where:

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

LT_H = Long term historical annual cliff retreat rate

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

S_F = Future annual rate of SLR

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

$m = 0.5$

A.2 Probabilistic Approach

A probabilistic approach is used to manage the uncertainty surrounding the data used and the results obtained from the methods used to define the each of the components of the PFSP calculation. The probability calculations involved using the mathematical software MATLAB R2019b to run a 'Monte Carlo' simulation where for each transect and SLR scenario, 10,000 realizations of the PFSP lines were made by combining random values from each of the long-term (LT), short-term (ST) and SLR erosion distributions. The resulting distribution of the PFSP realizations show the range of where the projected shoreline will be in relation to the present-day shoreline, and what the probability is that the erosion could extend beyond a given distance. Figure A.8 below shows the PFSP distribution output for a single transect, where the bars represent the number of realizations from the 10,000 trials.

In this assessment we present the 50th percentile (P50) and the 95th percentile (P95) of 10,000 random observations of the PFSP erosion distance for each timeframe and SLR scenario. The 50th percentile represents a "most likely" magnitude of erosion, in which there is a 50% chance that erosion will extend beyond this position and 50% that it will be less than this position, and is the mid position of a 'about as likely as not' range of positions following the terminology of MfE (2017, Appendix F)(e.g. 33-66% probability of occurrence range). The 95th percentile statistically represents an "unlikely" scenario, where there is only a 5% probability that erosion will extend beyond this position.

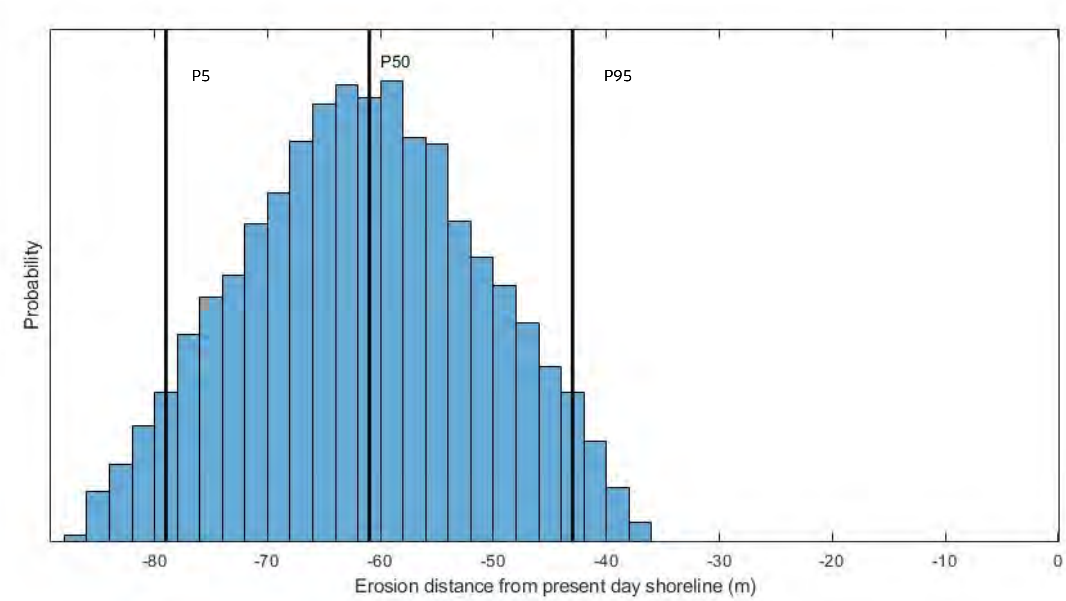

Figure A.8: Example of Transect 789 (North of the Orari River) the probability of PFSP distances from the present day shoreline. The bars represent the 10,000 realizations of the projected future shoreline position made from drawing random ST, LT and SLR from their respective distributions.

To run the Monte Carlo' simulations, a triangular distribution was assumed for each component of the PFSP (LT, ST, SLR) at each transect using minimum, mean and maximum values obtained or assumed from the data. This was considered the most practical distribution to apply given the limited nature of data available to define the uncertainty in value of these components. A sensitivity test was run to determine whether there was a significant difference between using a normal distribution and a triangular distribution for the LT component, with the results showing that although the normal distribution had longer tails in the distribution, the difference between P95 and P5 values were less than 1m. Therefore, it was considered appropriate to apply a triangular distribution to all components.

Further details on how the min, mean and max values were determined for each component distribution are provided below.

A.2.1 Component Triangular Distribution Inputs

Long term historical shoreline movement – per transect

- Mean Value: The average DSAS erosion rate from DSAS for five transects either side of the target transect (as long as in the same morphological cell). Note the use of a 'running average' for the long-term rate is to moderate any outliners in results for individual transects due to digitising shoreline irregularities and to ensure a smoothed result for mapping. At Patiti Point and Dashing Rocks, the number of transects used for smoothing were modified based on the orientation of the shoreline, where the orientation was influencing the erosion rate at the site.
- Max and Min Values: The upper and lower Linear Confidence Interval (LCI95) calculated in DSAS averaged over the same number of transects as the mean. In cliff locations where the lower LCI95 was positive (therefore signaling long term accretion, which is not probable) the minimum value for the shoreline movement was set to zero, implying long-term stability of the cliff position. Where the long-term rates of retreat were very low such as the Waimataitai – Dashing Rocks cell, this results in a skewed triangular distribution with the minimum and mean erosion distances being very close together, and the maximum value still displaying a much wider spread to the UCL95. Consequently, the mean value from the Monte Carlo Simulation is negatively skewed, resulting in a more erosive result than a deterministic approach.

Short term Storm Erosion – per ECan profile site

- Mean Value: The 50th percentile value from the GEV distribution of the 100-year ARI erosion event magnitude as outlined in section A. 1.2
- Max and Min Values: The 99% and 1% Confidence Intervals of the 100-year ARI erosion event magnitude from the GEV distribution. The minimum threshold of erosion was set at 2 m for beaches, and 0 m for cliffs.

Sea Level Rise Effects - per ECan profile site

- Mean Value: Mean values for beach height, closure depth and profile slope from profile survey records.
- Max Values: Combination of beach heights, and closures depths and profile slopes from profile survey records that give the flattest 'closure slope' from beach crest to closure depth.
- Min Values: Combination of beach heights, and closures depths and profile slopes from profile survey records that give the steepest 'closure slope' from beach crest to closure depth.

A summary of the approach used to determine a minimum, maximum and average profile for each shoreline type is presented below in Table A.3

Table A.3: Summary of features used for different shoreline morphologies to determine minimum, average and mean profile extents for defining triangular distribution of erosion distance for SLR effects.

Morphology	Feature used for min, max mean	Calculated by:
Sand	Min effect: max dune height; min across-shore distance. Mean effect: Average dune height and across-shore distance. Max effect: Min dune height, max across-shore distance.	Closure depth: Taken from the Interim ECan report as -4m closure depth and 360-375m from shore. Dune height: Min, average and maximum profile envelopes calculated on BMAP.

Mixed Sand and Gravel Beach	Min effect: Max barrier height and max (shallowest) closure depth. Mean effect: Mean barrier height and mean closure depth. Max effect: Min barrier height and min (deepest) closure depth.	Closure depth: Calculated from Washdyke 1987 surveys of the nearshore step. Distance to step calculated as an average from all surveys. CD: Min -5.75m; Mean -4.75m; Max -3.1m Distance to Nearshore step from 0m: Min 95m; Mean 55m; Max 25m. Barrier height: Min, average and max profile envelopes calculated on BMAP. Low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.
Mixed Sand and Gravel Barrier	Min effect: Max barrier height and max (shallowest) closure depth. Mean effect: Mean barrier height and mean closure depth. Max effect: Min barrier height and min (deepest) closure depth.	Closure depth: Calculated from Washdyke 1987 surveys of the nearshore step. Distance to step calculated as an average from all surveys. Barrier height: Min, average and max profile envelopes calculated on BMAP. Low uncertainty is strongly influenced by input data limitation on the nearshore profile for MSG beaches.
Cliff	Historical long-term trend ($5^{th,}$ 50^{th} and 95^{th} percentiles).	Calculated from DSAS analysis statistics on long term historical rate. Standard error used to determine the main and max values.

A.3 Mapping Projected Future Shoreline Positions

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

There were two additional segments of shoreline where the projected future shoreline positions based on the PFSP formula were not considered to be likely due to other coastal processes occurring which are not accounted for in the mathematical equation. These exceptions are outlined below.

A.3.1 Areas mapped using geomorphological interpretation

South Beach, Timaru

South Beach has a long term accretionary trend due to the construction of the Timaru Harbour Eastern Extension Breakwater across the line of littoral drift, and the further extension of this with a 150 m long spur groyne in 1986. As pointed out in Section 1.3 of the main report, the construction of this breakwater has resulted in large quantities of shingle and coarse sand moving northward as beach drift being trapped to form a large accretionary gravel reclamation covering around 80 hectares between the breakwater and Patiti Point at the southern end. Accretion figures presented in Todd (1988) indicate that accretion rates along the breakwater from 1879 to 1980 were in the order of +9.5 m/yr, and at the southern end of beach were in the order of +1.70 m/yr. Survey information presented by Gabites (2008b) shows that since 1994 the rate of shoreline advance along the spur groyne has been in the order of +2.23 m/yr rate, and +1.24 m/yr at Queen St near the south end of the beach.

However, as presented in Figure A.8 below, the extrapolation of these rates, even allowing for the effect of SLR, would result in the back of the beach/vegetation line being located seaward of the Spur groyne by 2120, which is not possible without further extension of the spur groyne to continue accretion by trapping sediment. Based on the assumption that the groyne is not extended, the future accretion of the beach profile is limited to the toe of the beach extending to the seaward limit of the groyne. As a result, the calculated PFSP has been replaced in the mapping by a "maximum toe extent possible" based on the current width and slope of the beach profile, and plan shape considerations between Patiti Point and the spur groyne. The assessment indicates that this position is likely to be reached by 2070.

Figure A.8: South Beach shoreline showing the position of the 'Shoreline Maximum Toe Extent' against the Eastern Extension Spur Groyne and the calculated PFSP (vegetation) in 2120 (Maroon) extending seaward of the groyne.

Orari River and adjacent coastline

In 1950, a scheme was put in place to divert the lower Orari River to discharge directly out to sea in order to reduce shingle accumulation in the river and to help drainage problems on the adjacent land to the north. Prior to this, the lower river could meander up to 2.4 km north along the coast from its current mouth position. The section of coast from various aerial photographs at different times is shown in Figure A.9. The diversion of the mouth was completed in 1954 (the earliest image in Figure A.9), with mouth training works and short seawall constructed in 1955 to prevent northward migration of the mouth. These works have altered the shoreline movements in this area, giving trends which are not consistent with the adjacent coast.

Former Orari River Mouth

Along the former mouth positions (e.g. Ox-box lagoon and north in Figure A.9), the shoreline mapping indicates a period of rapid erosion following the works as the unvegetated back of beach retreats into the former mouth channels due to overtopping. However, from the 1987 image onwards, this gravel barrier becomes vegetated as it stabilizes, with the feature being used in the shoreline mapping changing to the vegetation line rather than the back of beach. Hence, there is a perception of shoreline accretion since this time as the back of the barrier becomes more vegetated over time. Applying the extrapolation of this accretion rate in the PFSP calculation results in projected shoreline advance in this area. This is not consistent with the projected erosion in adjacent areas that is expected based on coastal processes and plan-shape considerations. Therefore, for the section of shoreline from Transect 741 to 780, the calculated PFSP has been replaced by a straight-line position between the PFSP's at these two transects.

Orari River mouth Seawall

Due to the seawall structure on the north side of the mouth being relatively stable over the past 65 years, the amount of shoreline change recorded is limited. This has restricted the magnitude of long-term historical change and restricts the range of values used to define minimum and maximum values for the triangular distribution for this component in this area. Therefore, for consistency with the adjacent shoreline, the assessment was undertaken assuming there no seawall was present.

Orari River mouth

The transects used along the coastline do not run across the river mouth due to presence and location of the gravel barrier within the confines on the stopbank changing over time, and therefore is not relevant to the assessment of long-term effects at this site. The transects either side of the river mouth (729 and 730) were joined across the river mouth to connect the PFSP line for future SLR scenarios. However, it is noted that this position represents the back of the barrier, and the width of the barrier may change for the shoreline to align along the shoreface with plan shape considerations.

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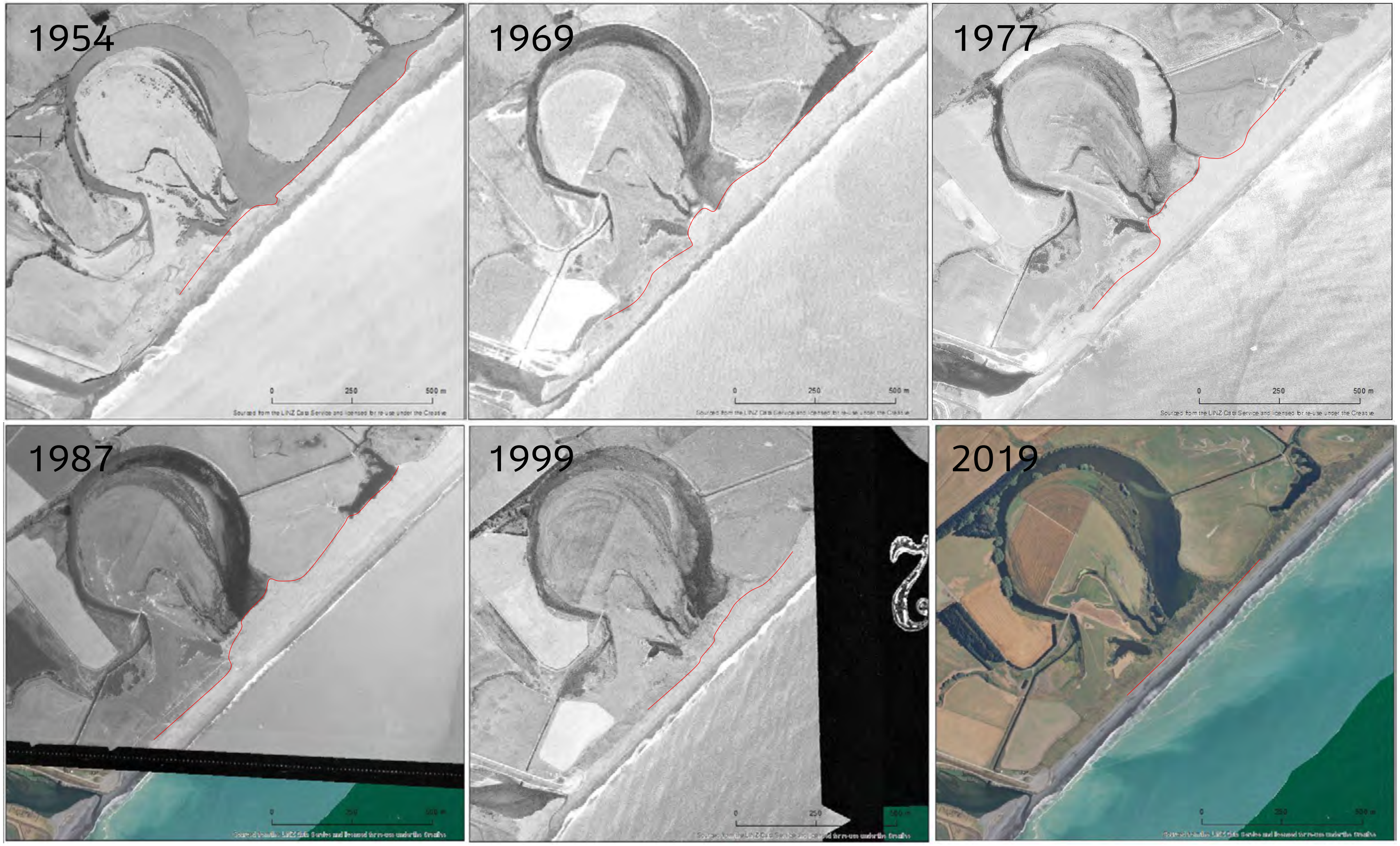


Figure A.9: North Orari River historical imagery showing infilling of the former mouth position with overtopping followed by precieved accretion since 1987 with revegetation of the barrier. The red line shows the approximate vegetation line/back of beach line in the initial 1954 image when the mouth diversion occurred.

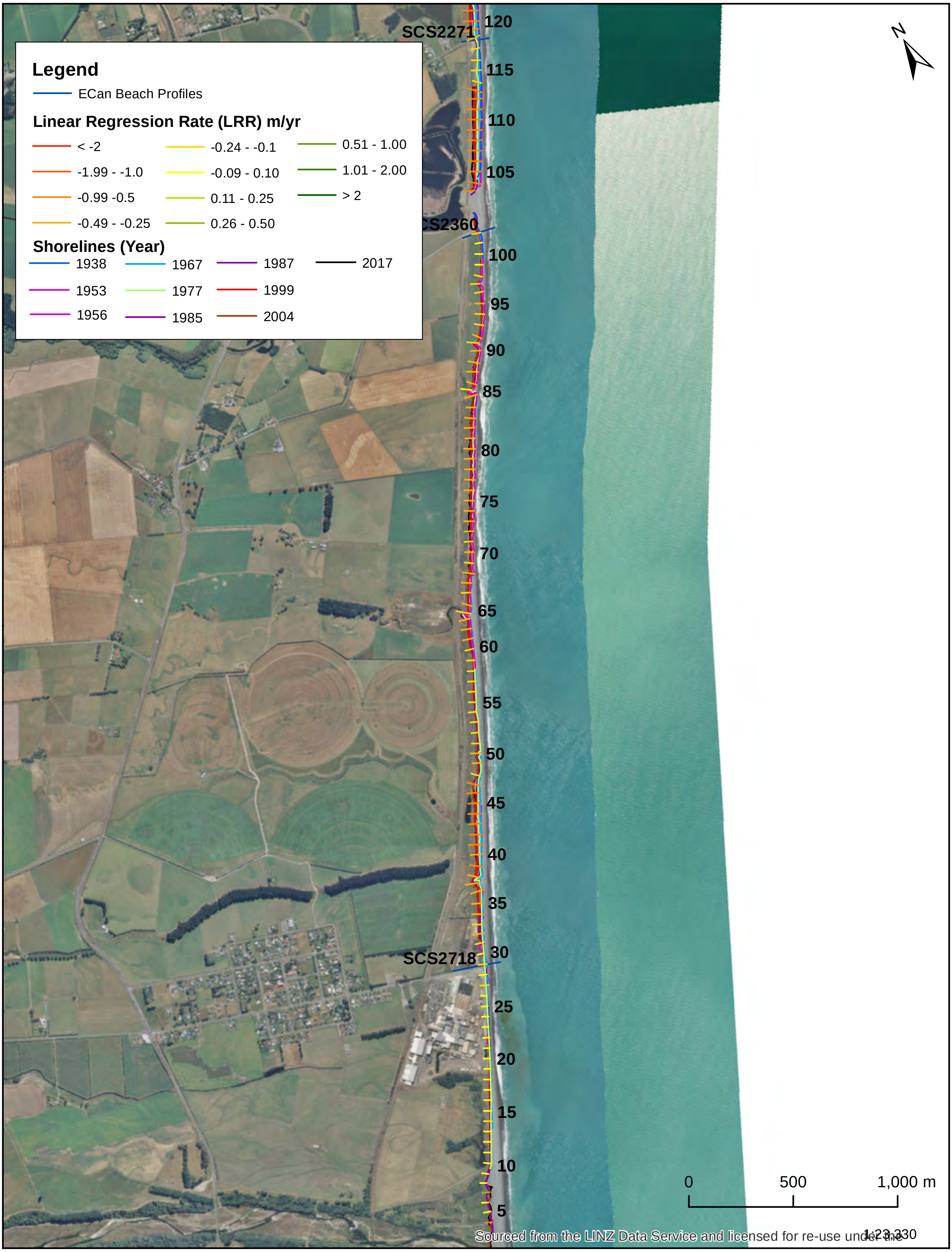
Appendix B. Short Term Erosion Analysis

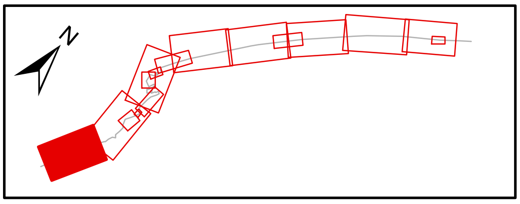
Profile	Contour/ Feature Used	Max Inter - survey Erosion (m)	Survey Dates	Storms Recorded on ECan storm database (antidotal observations to 1999, from Banks Peninsula Wave buoy since May 1999)	GEV 100 yr ARI Erosion Output (m)		
					Min	Mean	Max
SCS2718	4.5m Contour	4.6	21.08.1986 - 29.07.1987	23-Aug-1986, 2-Jul-1987, 26-Jun-1987	1.7	5.2	7.8
SCS2360	Cliff Edge	1.4	19.10.2009 - 19.03.2010	No Notable Storm recorded	0.4	1.4	3.0
SCS2271	Cliff Edge	1.7	16.10.2000 - 5.11.2001	18-19 November 2000, 12-13 July 2001, 20-21 July 2001	0.5	1.7	3.4
SCS2183	Cliff Edge	0.4	18.10.1993- 26.10.1994	17 Nov 1993, 10 May 1994, 29 June 1994, 26 July 1994, 7 Sept 1994	0.3	0.5	0.7
TCS1949	Cliff Edge	1.6	20.03.1985 - 24.09.1986	21 August 1985, 25 Feb 1986, 13 March 1986, 22 June 1986, 30 June 1986, 1-3 July 1986, 8 August 1986, 23 August 1986	0.2	1.1	2.3
TCS1887	4.5m	20.3	09.10.1991 - 14.10.1992	2-Apr-1992, 28-Apr-1992, 8/9-May-1992, 21/22-May-1992, 30-Jun-1992, 8/9-Jul-1992, 28/29-Aug-1992	12.6	28.9	49.4
TCS1732	Cliff Edge	0.9	17.09.1992 - 12.03.1993	No notable Storm recorded- but possibly lagged response to high-frequency storm period in winter 1992	0.5	1.3	2.6
TCS1672	3.5m Contour	4.6	02.03.1992 - 17.09.1992	2-Apr-1992, 28-Apr-1992, 8/9-May-1992, 21/22-May-1992, 30-Jun-1992, 8/9-Jul-1992, 28/29-Aug-1992	4.2	5.4	7.3
TCS1592	4m Contour	3.3	2.03.1992 - 25.05.1992	2-Apr-1992, 28-Apr-1992, 8/9-May-1992, 21/22-May-1992	2.4	3.8	6.0
TCS1466	5m Contour	6.4	18.03.2002 - 27.08.2002	1 - 4 April 2002, 25 - 30 May 2002, 6 - 7 June 2002, 1 - 2 July 2002, 26 - 28 August 2002	2.6	6.8	17.8
TCS1362	1m Contour	40.2	02.03.1992 - 17.09.1992	2-Apr-1992, 28-Apr-1992, 8/9-May-1992, 21/22-May-1992, 30-Jun-1992, 8/9-Jul-1992, 28/29-Aug-1992	21.9	50.9	90.9
TCS1350	1m Contour	20.8	02.03.1992 - 17.09.1992	2-Apr-1992, 28-Apr-1992, 8/9-May-1992, 21/22-May-1992, 30-Jun-1992, 8/9-Jul-1992, 28/29-Aug-1992	13.9	28.3	48.4
TCS1332	Cliff Edge	0.7	21.03.2007 - 11.09.2007	13-14 April 2007, 24-27 April 2007	0.3	0.7	1.3
WCS1195	3.5m Contour	28.6	28.03.1990 - 05.06.1990	4-May-1990, 31-May-1990	20.6	42.0	72.8
WCS1135	3.5m Contour	10.9	09.03.1992 - 29.09.1992	2-Apr-1992, 28-Apr-1992, 8/9-May-1992, 21/22-May-1992, 30-Jun-1992, 8/9-Jul-1992, 28/29-Aug-1992	9.0	13.7	20.2

Profile	Contour/ Feature Used	Max Inter - survey Erosion (m)	Survey Dates	Storms Recorded on ECan storm database (antidotal observations to 1999, from Banks Peninsula Wave buoy since May 1999)	GEV 100 yr ARI Erosion Output (m)		
					Min	Mean	Max
WCS1105	3.5m Contour	10.3	14.03.2001 - 20.09.2001	12 - 13 July 2001, 20 - 21 July 2001	7.9	11.6	16.7
WCS1035	3.5m Contour	12.2	29.03.2017 - 13.09.2013	5 - 7 April 2017, 19 - 22 May 2017, 14 - 15 June 2017, 21 - 23 July 2017	8.8	16.0	26.9
WCS0966	3.5m Contour	11.1	10.03.2015 - 8.06.2015	14-16 April 2015, 29-30 April 2015, 24-28 May 2015	8.2	12.6	20.0
WCS0891	3.5m Contour	11.3	21.02.2019 - 5.09.2019	8 - 9 June 2019, 24 - 25 June 2019, 8 - 9 July 2019	7.0	11.4	17.6
WCS0794	4m Contour	10.8	14.03.2001 - 20.09.2001	12 - 13 July 2001, 20 - 21 July 2001	6.3	12.5	20.7
WCS0693	3.5 Contour	8.9	14.03.2001 - 20.09.2001	12 - 13 July 2001, 20 - 21 July 2001	5.6	9.7	14.9
WCS0626	3.5m Contour	13.3	05.09.1996 - 11.03.1997	No Noteable Storm observed	9.0	18.7	36.5
WCS0439	3.5m Contour	8.5	30.03.2017 - 14.09.2017	19-22 May 2017, 14-15 June 2017, 21-23 July 2017	6.8	11.1	17.2
WCS0329	4m Contour	4.9	04.05.1987 - 16.07.1987	2-Jul-1987, 26-Jun-1987	4.0	8.2	5.6
WCS0081	4m Contour	6.2	14.03.2001 - 31.07.2001	12 - 13 July 2001, 20 - 21 July 2001	3.2	5.7	11.6
WCS0000	3m Contour	34.2	15.07.1986 - 6.11.1986	8 August 1986, 23 August 1986	11.9	23.3	44.4
RCN0130	5m Contour	17.1	08.06.2000 - 30.05.2001	18-19 Nov 2000	11.9	23.3	44.4
RCN0260	4m Contour	11.6	13.08.1999 - 08.06.2000	No Noteable Storms recorded	5.5	15.3	32.8
RCN0460	5m Contour	7.7	31.03.2017 - 15.05.2018	5 - 7 April 2017, 19 - 22 May 2017, 14 - 15 June 2017, 21 - 23 July 2017, 20 - 22 February 2018, 10 - 12 April 2018	4.3	9.0	17.9
RCN0695	4.5m Contour	4.0	28.04.1993 - 16.05.1994	29-May-1993, 1-2 July 1993, 6-7-Sep-1993, 17-18 Sep 1993, 23-25 Sep 1993, 17-Nov-1993, 10 May 1994	2.6	4.5	8.6

Profile	Contour/ Feature Used	Max Inter - survey Erosion (m)	Survey Dates	Storms Recorded on ECan storm database (antidotal observations to 1999, from Banks Peninsula Wave buoy since May 1999)	GEV 100 yr ARI Erosion Output (m)		
					Min	Mean	Max
RCN0952	5m Contour	3.7	30.05.2001-26.06.2002	12 - 13 July 2001, 20 - 21 July 2001, 5 - 6 February 2002, 1 - 4 April 2002, 25 - 30 May 2002, 6 - 7 June 2002	2.5	3.9	7.5
RCN1218	5m Contour	4.7	21.08.1986 - 29.07.1987	23-Aug-86	3.0	5.1	8.8
RCN1548	4.5m Contour	12.8	24.02.1988 - 08.05.1989	13-Jun-1988, 1-Jul-1988, 19-Jul-1988, 6-Feb-1989	9.1	13.0	18.5

Appendix C. DSAS Historical Shoreline Analysis Maps





Map 1
DSAS Analysis

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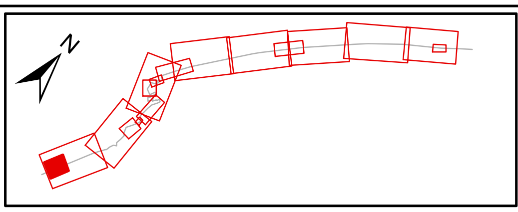

Map 1A
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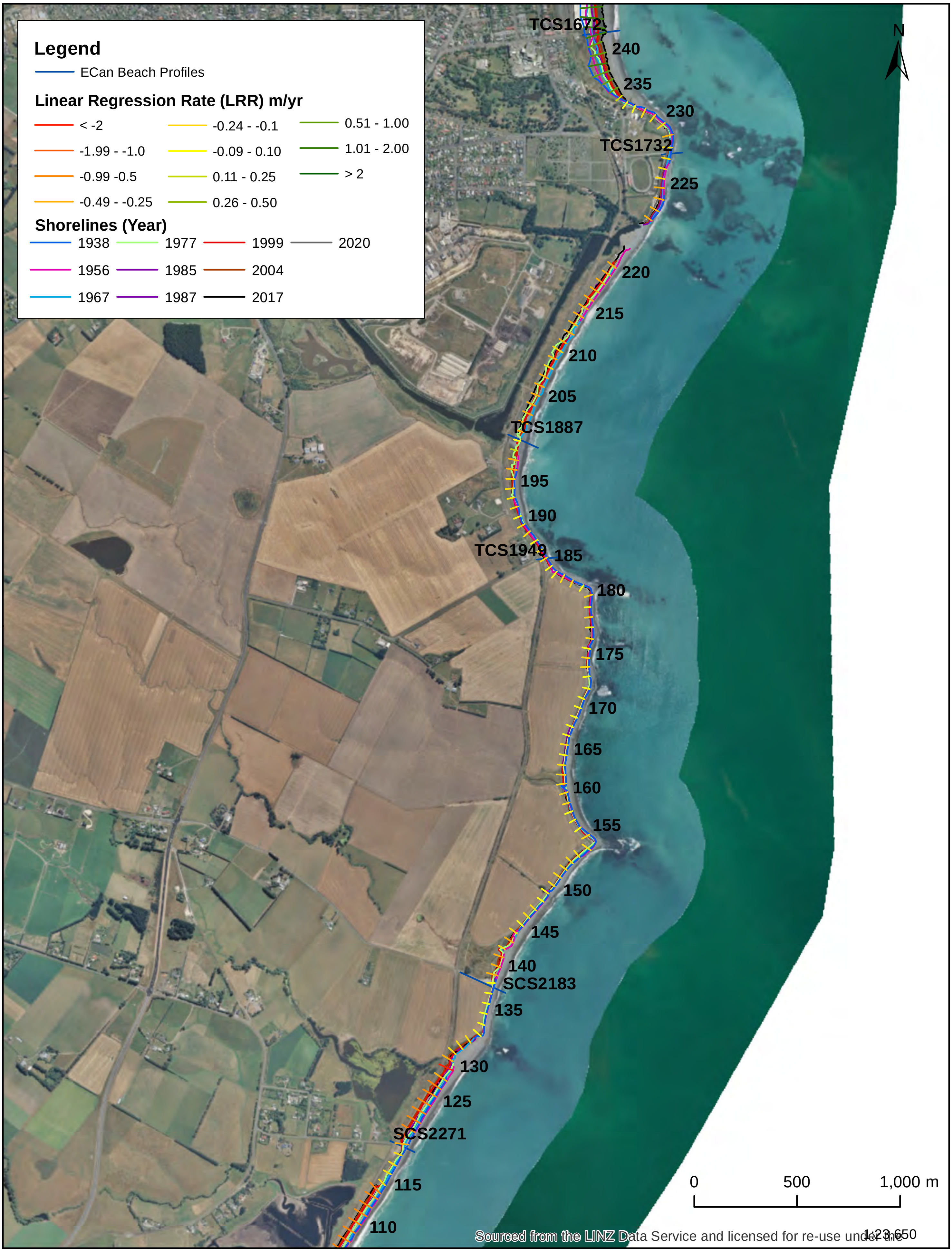

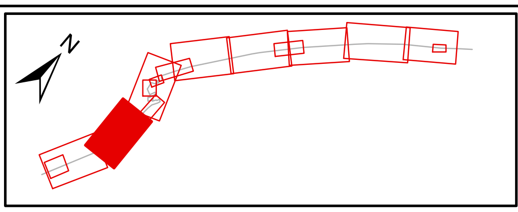

Map 2
DSAS Analysis

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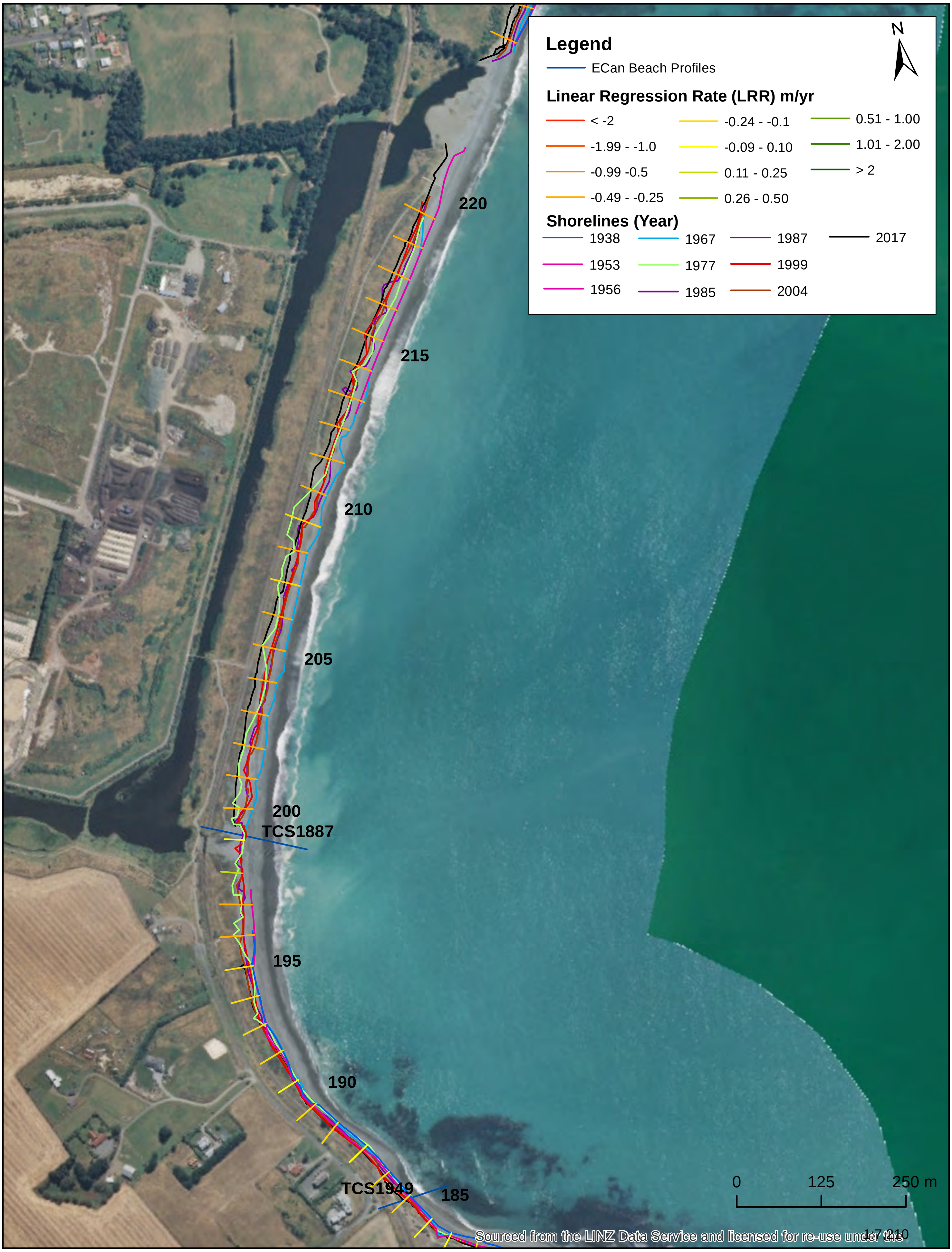

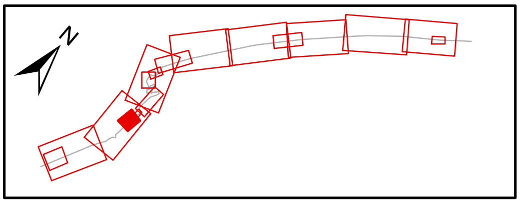

Map 2A
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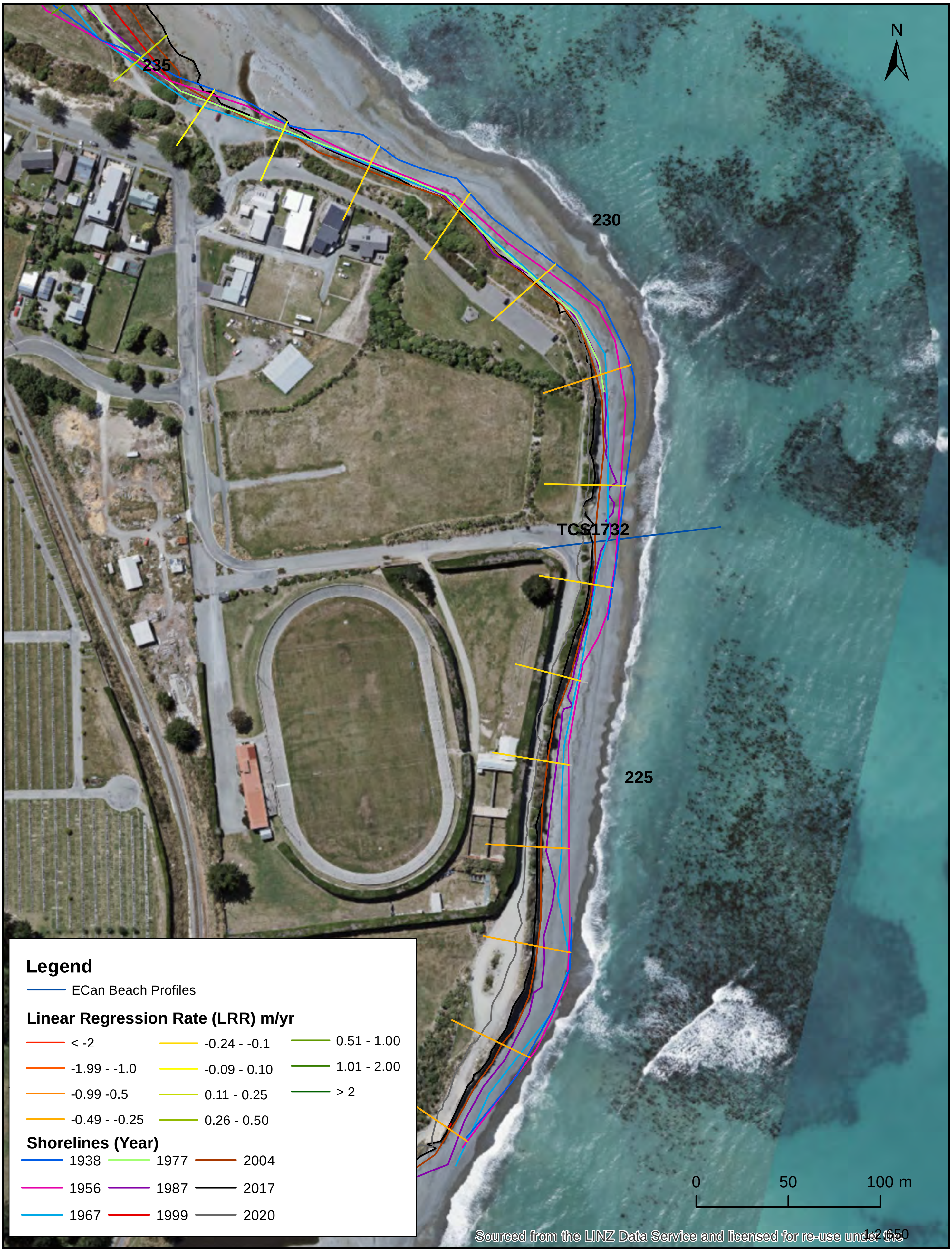


Legend

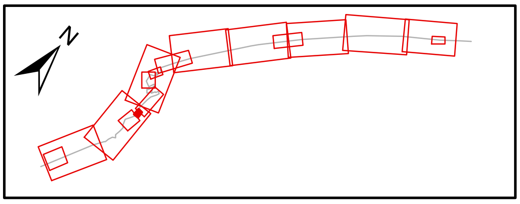
ECan Beach Profiles

Linear Regression Rate (LRR) m/yr

- < -2
- -1.99 - -1.0
- -0.99 -0.5
- -0.49 - -0.25
- -0.24 - -0.1
- -0.09 - 0.10
- 0.11 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00
- > 2

Shorelines (Year)

- 1938
- 1956
- 1967
- 1977
- 1987
- 1999
- 2004
- 2017
- 2020



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Map 2B
DSAS Analysis

JACOBS SPATIAL

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New Zealand
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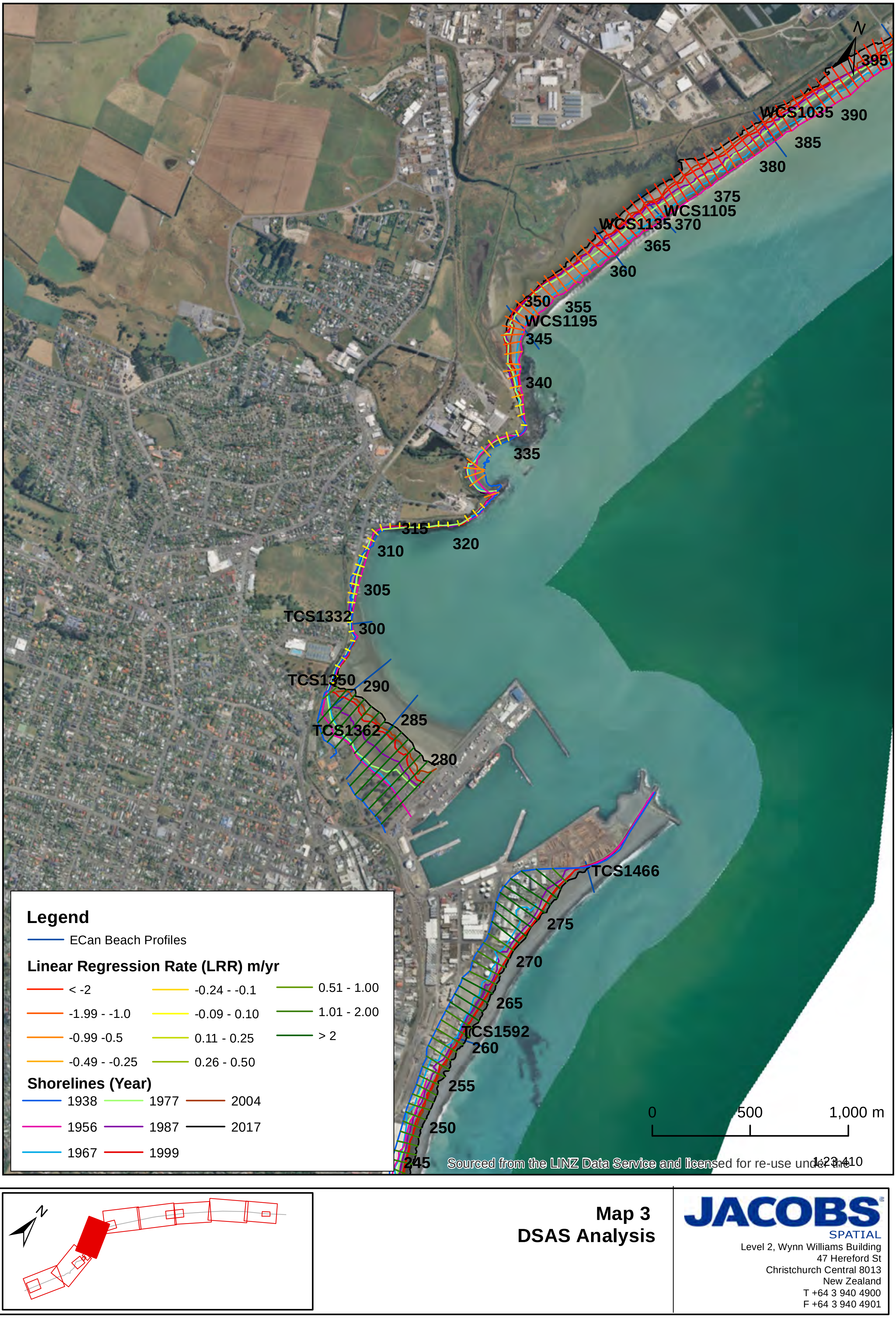

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Map 3
DSAS Analysis

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Christchurch Central 8013
New Zealand
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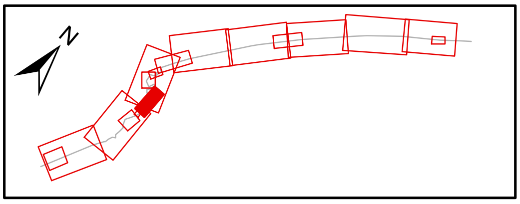

Map 3A
DSAS Analysis

JACOBS
SPATIAL

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Christchurch Central 8013
New Zealand
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F +64 3 940 4901

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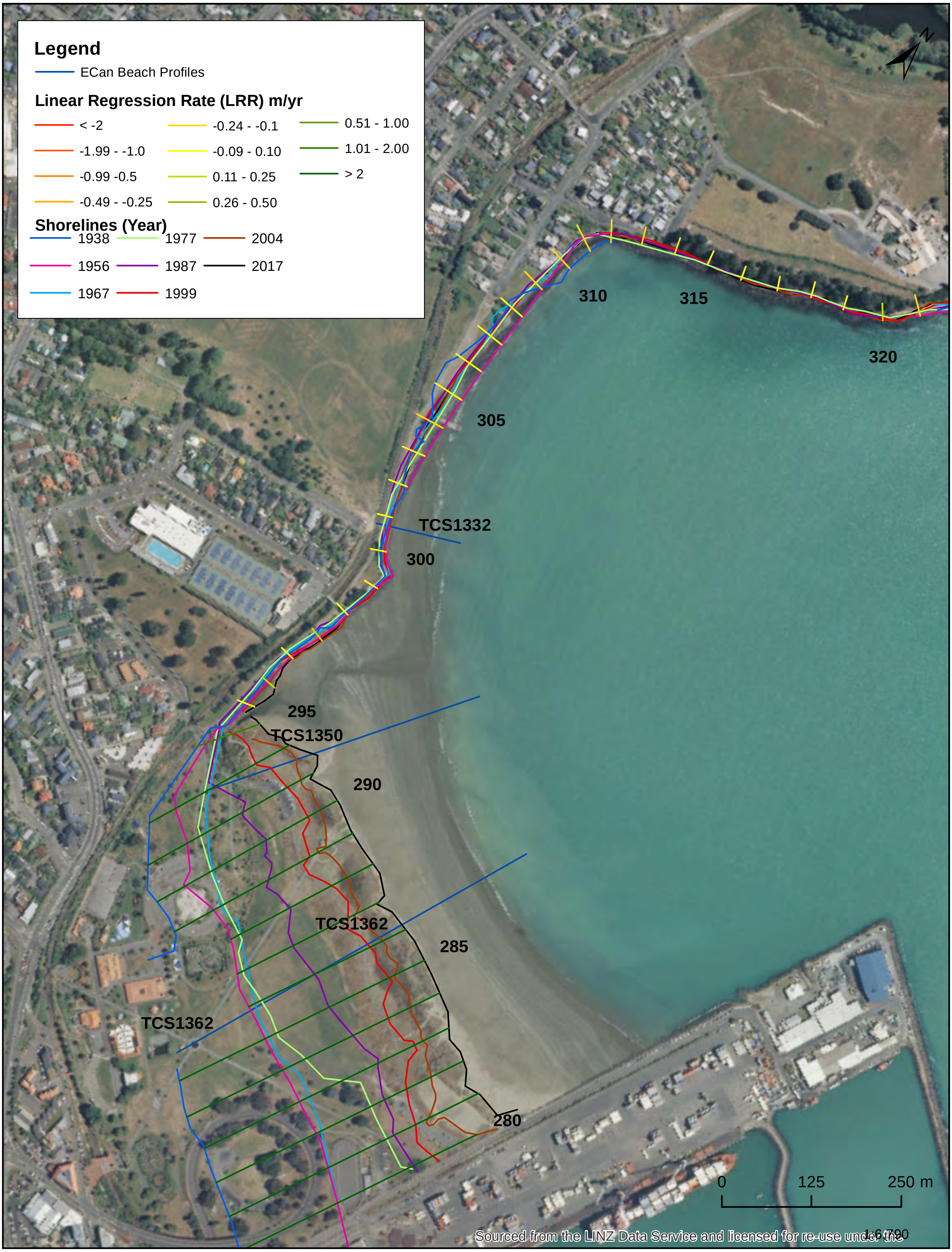

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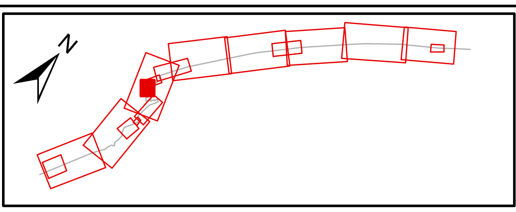

Map 3B
DSAS Analysis

JACOBS SPATIAL

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47 Hereford St
Christchurch Central 8013
New Zealand
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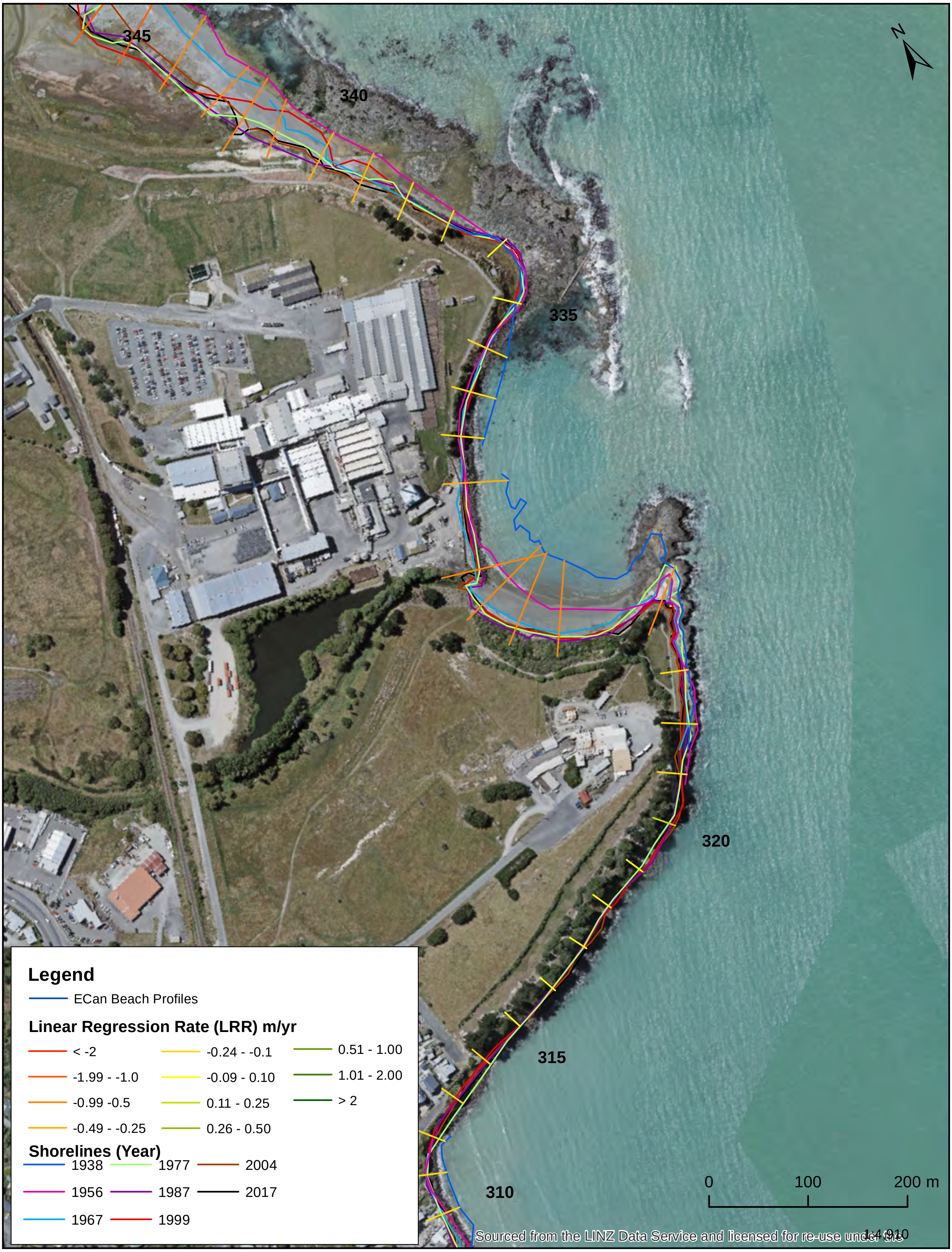

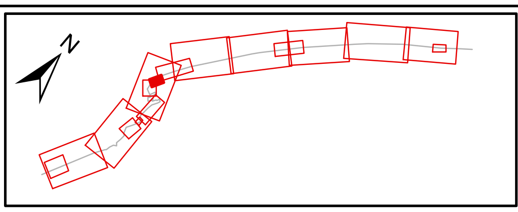

Map 3C
DSAS Analysis

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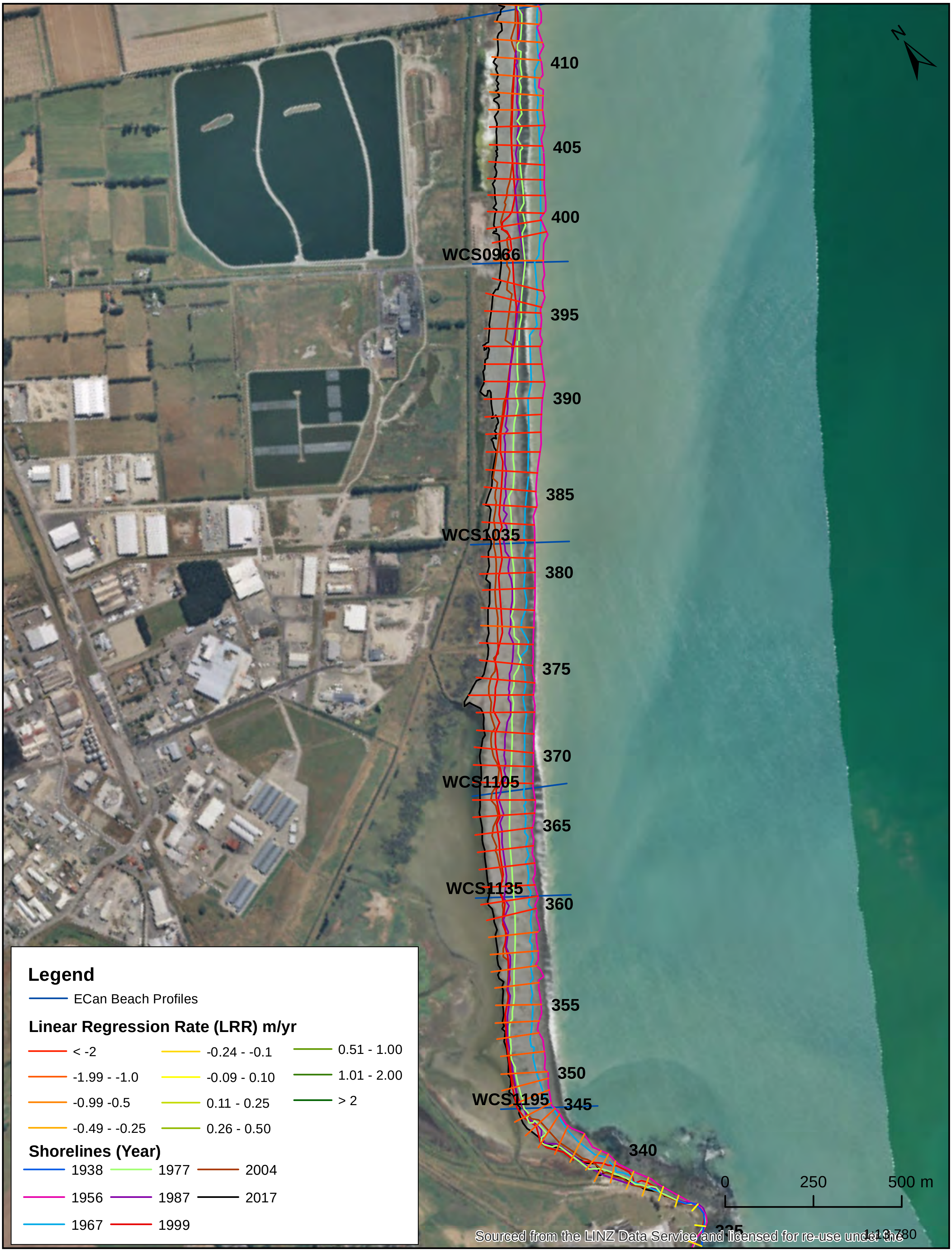

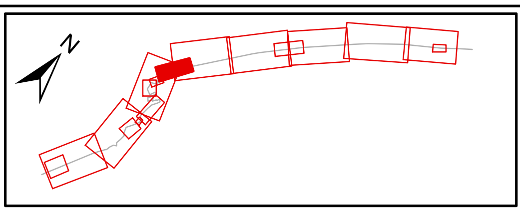

Map 3D
DSAS Analysis

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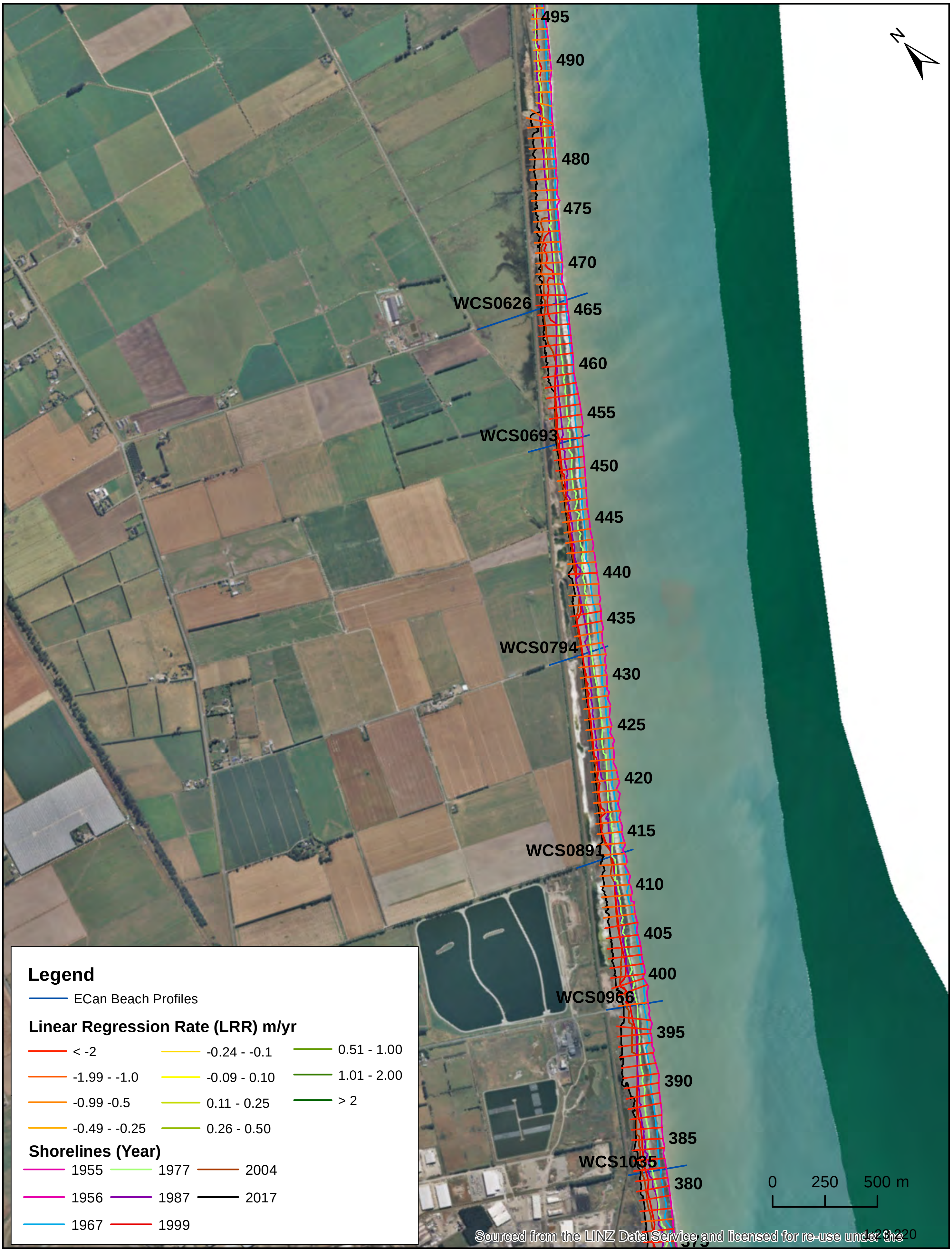

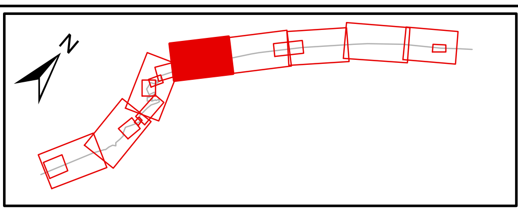

Map 4
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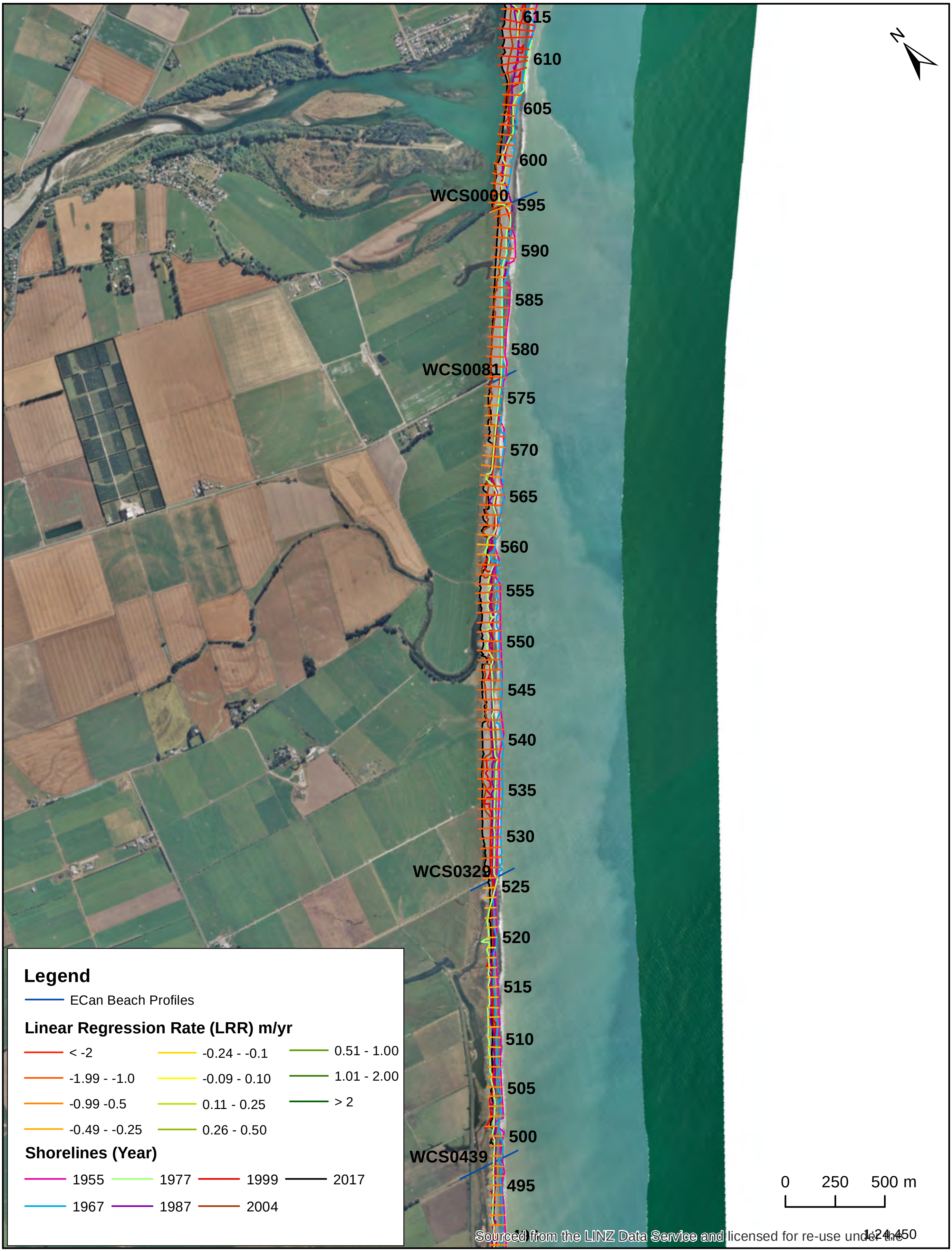

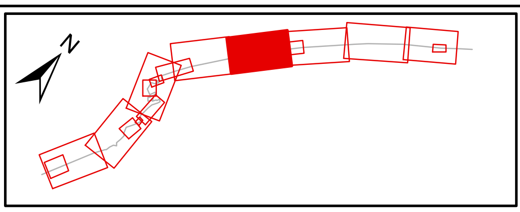

Map 5
DSAS Analysis

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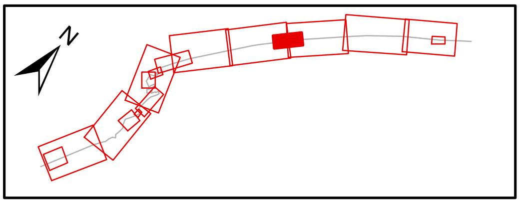

Map 5A
DSAS Analysis

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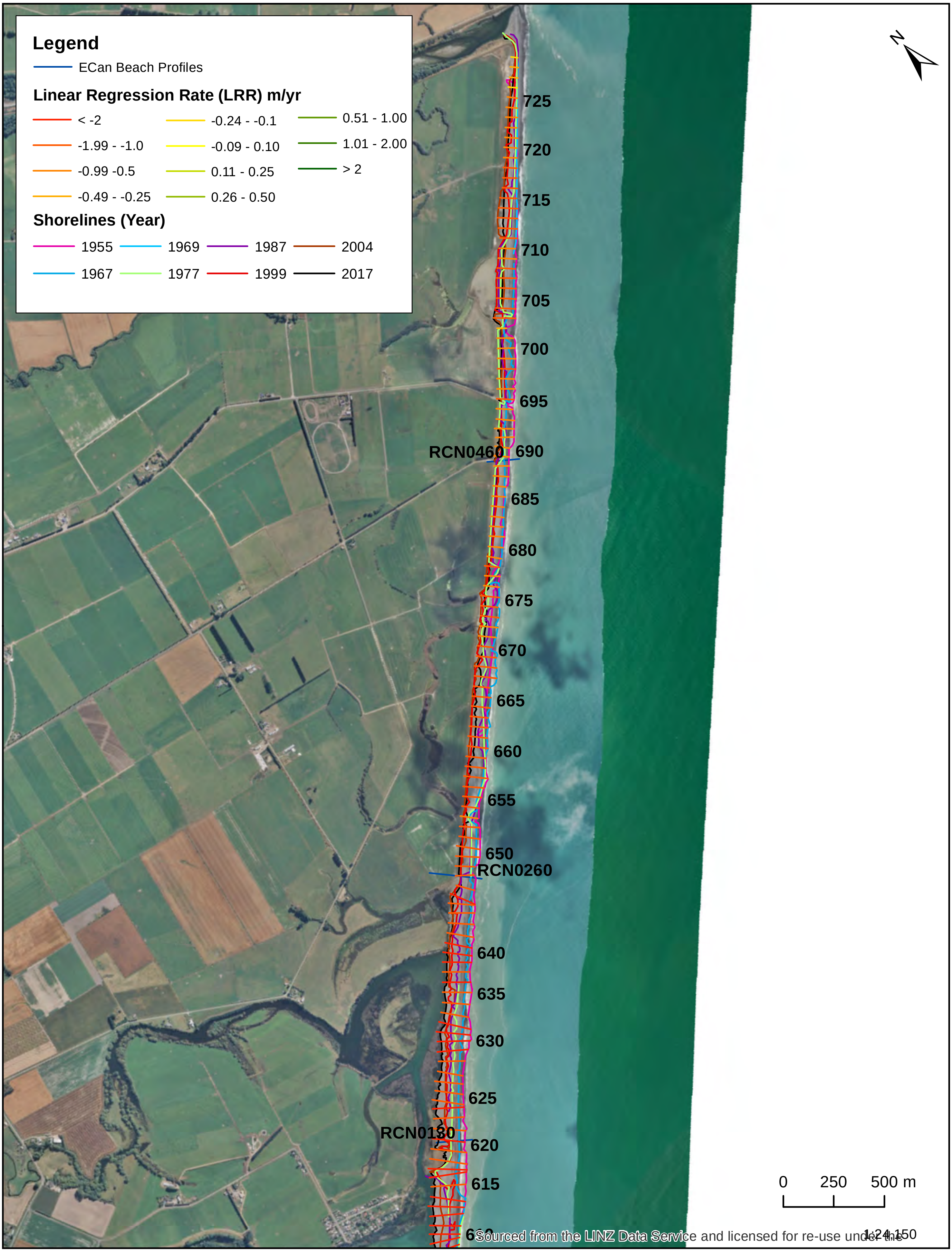

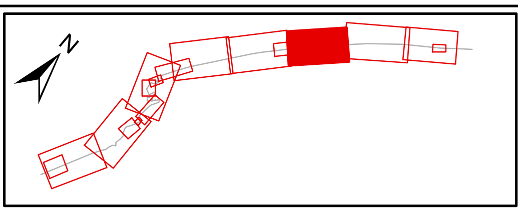

Map 6
DSAS Analysis

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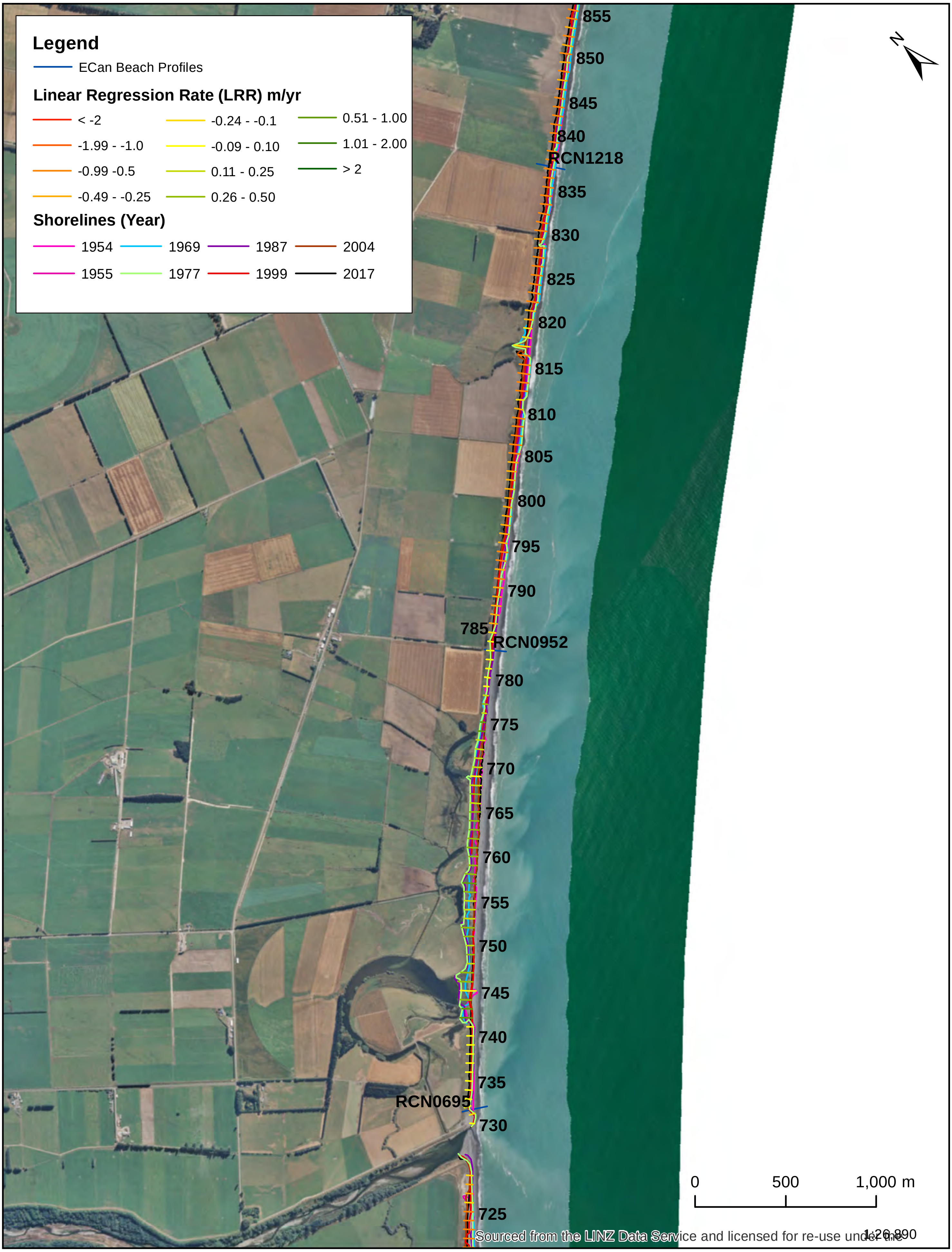

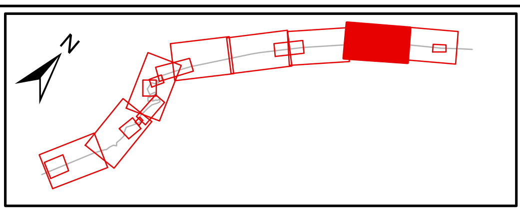

Map 7
DSAS Analysis

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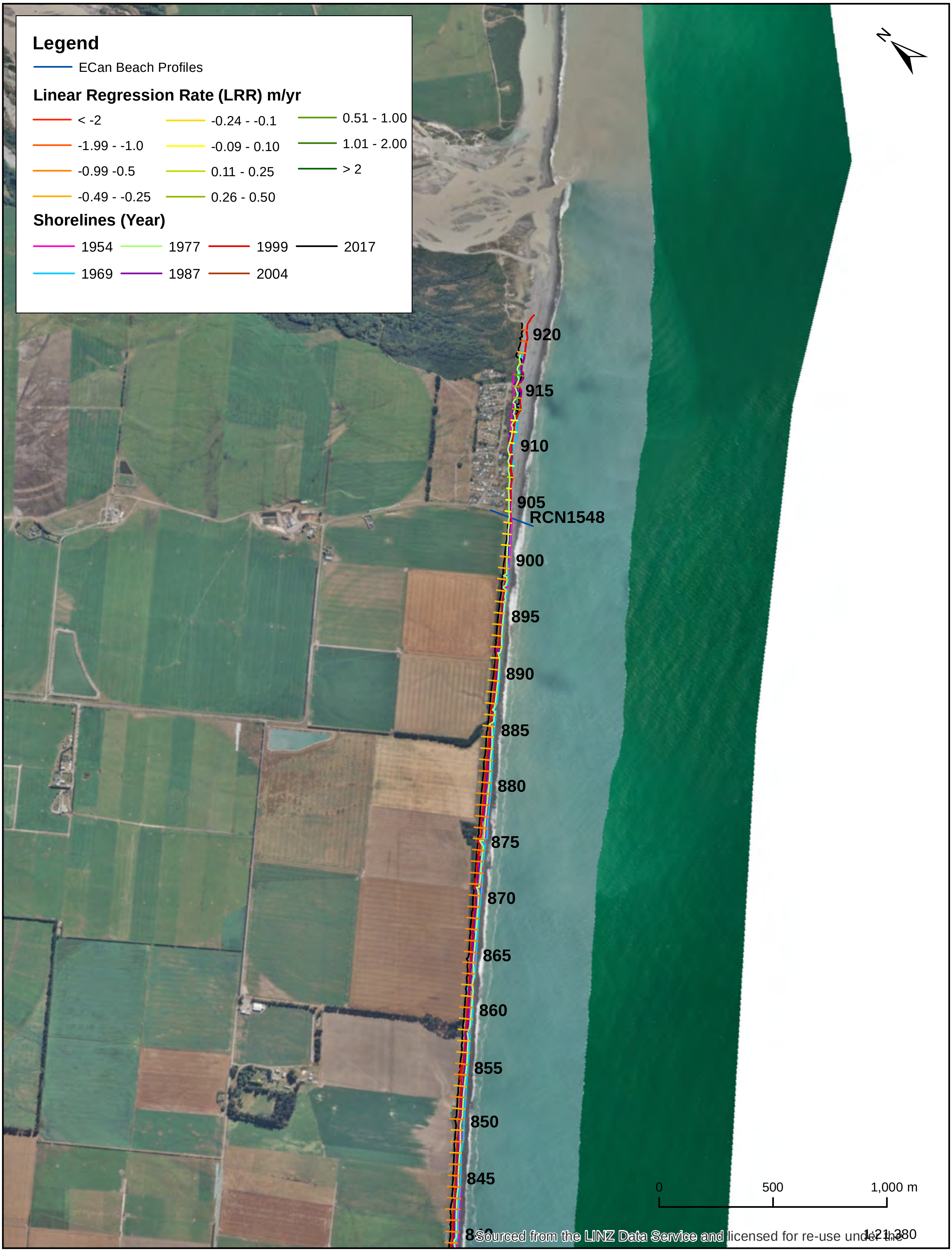

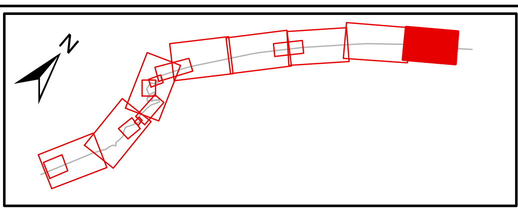

Map 8
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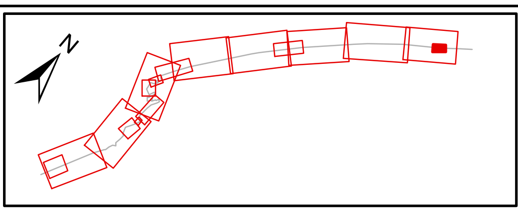

Map 8A
DSAS Analysis

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Appendix D. DSAS Validation

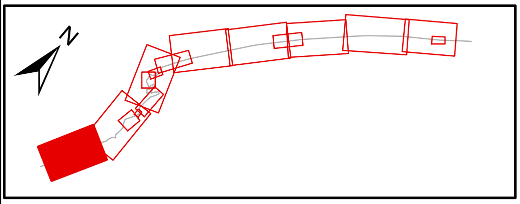
The DSAS results were validated by calculating the change from beach profile surveys over the same time period as the aerial imagery used in the DSAS analysis. Individual beach profiles were analysed for change at the site over the longest period possible. Surveying at these sites start data ranges from the late 1970s to the early 1990s, and therefore the earliest survey corresponding to the closest aerial imagery date was used. The feature used to determine the change in the DSAS analysis was also used to determine the change in the surveyed profile. Often survey notes were relied on to determine the change (e.g. where the vegetation line was). The closest two DSAS transects to the ECan profile were used for the comparison. If there was a noted storm between the date of the survey and the date the aerial imagery was taken, the survey profile was not used. There was a maximum of six months between the aerial imagery date and the survey date.

Profile	Aerial Imagery Dates used	Survey Date Used	Time Period Analysed (yrs)	Storm Between Survey and Aerial (Y/N)	Feature Used**	Survey Change (m)	ArcGIS Change (m)	Difference (m)	Difference (m/yr)
RCN1548	22.07.1987 and 07.01.2019	24.02.1988 and 11.04.2019	31	N	BT	0	-2	1	0.05
RCN1218	22.07.1987 and 07.01.2019	24.02.1988 and 16.04.2019	31	N	CT	-19	-20	1	0.04
RCN0952	22.07.1987 and 07.01.2019	24.02.1988 and 08.04.2019	31	N	VL	-13	-18	5	0.15
RCN0695	19.01.1999 and 07.01.2019	13.08.1999 and 08.04.2019	20	Y - 5-6 May 1999	BT	-4	-2	2	0.09
RCN0460	22.07.1987 and 07.01.2019	24.02.1988 and 08.04.2019	31	N	BT	-11	-8	3	0.08
RCN0260	19.01.1999 and 07.01.2019	13.08.1999 and 08.04.2019	20	Y - 5-6 May 1999	BT	0	-3	3	0.16
RCN0130	19.01.1999 and 07.01.2019	13.08.1999 and 08.04.2019	20	Y - 5-6 May 1999	VL	-40	-47	7	0.37
WCS0000	22.07.1987 and 07.01.2019	16.07.1987 and 22.03.2019	32	N	VL	-62	-68	6	0.19
WCS0081	22.07.1987 and 07.01.2019	16.07.1987 and 22.03.2019	32	N	VL	-72	-65	8	0.25
WCS0329	22.07.1987 and 07.01.2019	16.07.1987 and 22.03.2019	32	N	VL	-32	-38	6	0.18
WCS0439	22.07.1987 and 07.01.2019	16.07.1987 and 21.03.2019	32	N	VL	0	-2	2	0.07
WCS0626	22.07.1987 and 07.01.2019	16.07.1987 and 21.03.2019	32	N	WE	-73	-69	4	0.13
WCS0693	22.07.1987 and 07.01.2019	16.07.1987 and 21.03.2019	32	N	VL	-36	-29	7	0.22
WCS0794	22.07.1987 and 07.01.2019	16.07.1987 and 21.03.2019	32	N	VL	-45	-35	10	0.31
WCS0891	22.07.1987 and 07.01.2019	16.07.1987 and 21.03.2019	32	N	VL	-51	-47	4	0.12
WCS0966	22.07.1987 and 07.01.2019	16.07.1987 and 21.03.2019	32	N	VL	-68	-65	3	0.09
WCS1035	22.07.1987 and 07.01.2019	10.07.1987 and 20.03.2019	32	N	VL	-45	-37	8	0.25
WCS1105	22.07.1987 and 07.01.2019	09.07.1987 and 20.03.2019	32	N	WE	-47	-60	13	0.41
WCS1135	22.07.1987 and 07.01.2019	10.07.1987 and 20.03.2019	32	N	WE	-48	-51	3	0.08
WCS1195	22.07.1987 and 07.01.2019	10.07.1987 and 20.03.2019	32	N	WE	-20	-11	9	0.28
TCS1332	19.01.1999 and 07.01.2019	15.03.1999 and 19.03.2019	20	N	VL	2	4	2	0.12
TCS1362	19.01.1999 and 07.01.2019	15.03.1999 and 19.03.2019	20	N	VL	56	64	8	0.40
TCS1466	19.01.1999 and 07.01.2019	15.03.1999 and 19.03.2019	20	N	BOB	8	12	4	0.20
TCS1592	19.01.1999 and 07.01.2019	15.03.1999 and 18.03.2019	20	N	VL	30	29	1	0.03
TCS1672	19.01.1999 and 07.01.2019	15.03.1999 and 22.03.2019	20	N	VL	34	39	4	0.22
TCS1732	02.11.2004 and 07.01.2019	01.09.2004 and 19.03.2019	15	N	CT	-2	-2	0	0.03

Profile	Aerial Imagery Dates used	Survey Date Used	Time Period Analysed (yrs)	Storm Between Survey and Aerial (Y/N)	Feature Used**	Survey Change (m)	ArcGIS Change (m)	Difference (m)	Difference (m/yr)
TCS1949	19.01.1999 and 07.01.2019	15.03.1999 and 19.03.2019	20	N	VL	-3	-2	1	0.04
SCS2183	19.01.1999 and 07.01.2019	21.09.1998 and 08.10.2018	20	N	BT	2	-2	4	0.20
SCS2271	19.01.1999 and 07.01.2019	21.09.1998 and 08.10.2018	20	N	BT	-2	0	2	0.11
SCS2360	19.01.1999 and 07.01.2019	21.09.1998 and 08.10.2018	20	N	BT	4	2	2	0.09
SCS2718	19.01.1999 and 07.01.2019	21.09.1998 and 08.10.2018	20	N	RT	-3	1	4	0.20
							Average:	**4.4**	**0.2**

*** TCS1348, TCS1378 and TCS1887 were not validated because the aerial imagery was not clear enough to analyse.**
**** BT= Beach Toe; CT=Cliff Top; VL=Vege Line; WE=Waters Edge; BOB=Back of Beach; RT=Revetment Toe**

Appendix E. Overview Maps of projected shoreline positions in 2070 and 2120



Map 1
Projected Future Shoreline Position (PFSP) 2070

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

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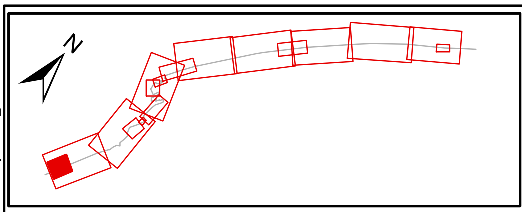

Map 1A
Projected Future Shoreline Position (PFSP) 2070

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

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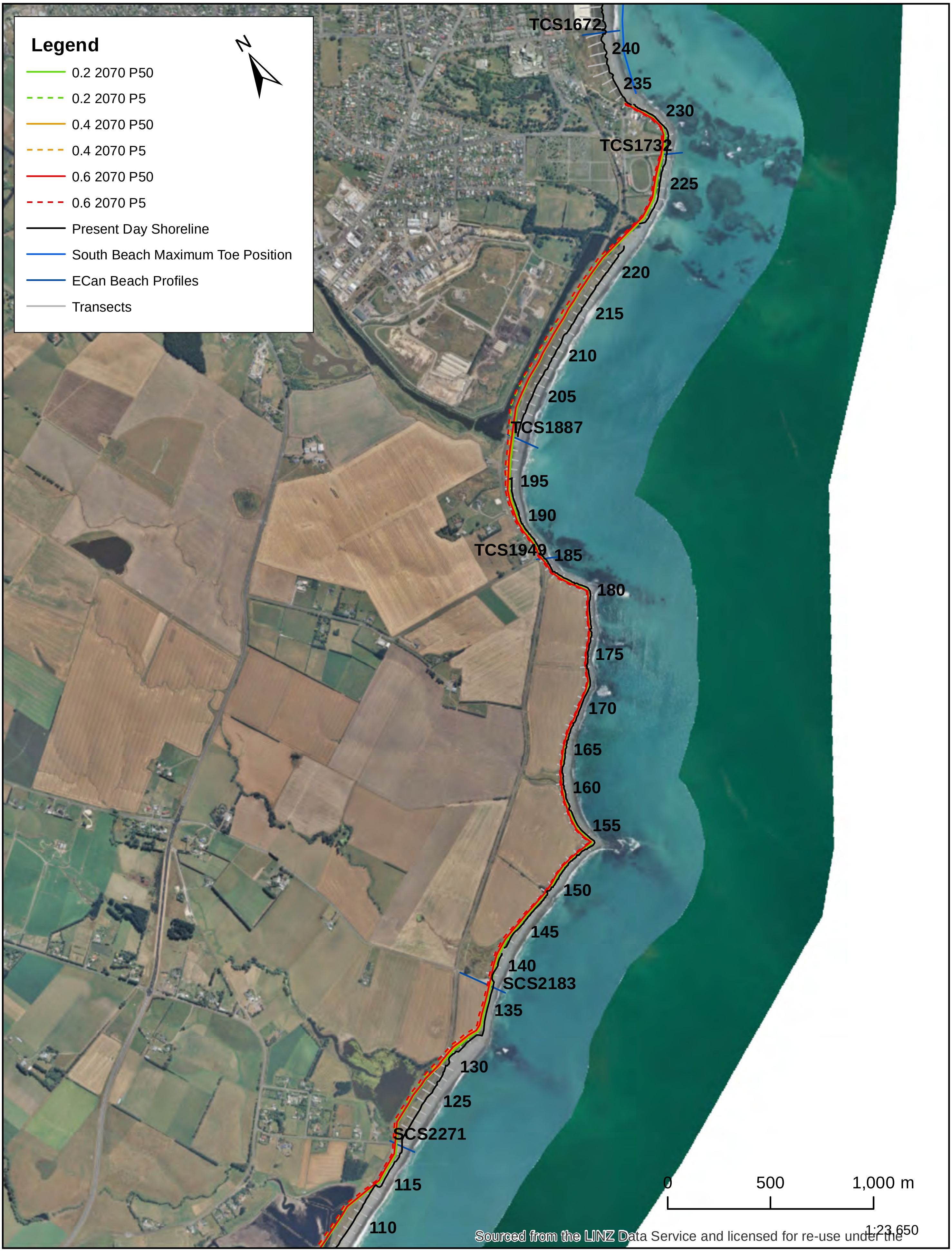

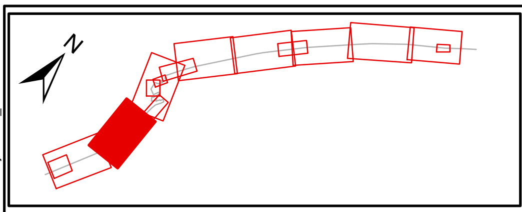

Map 2
Projected Future Shoreline Position (PFSP) 2070

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

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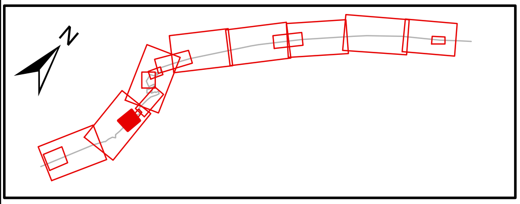

Map 2A
Projected Future Shoreline Position (PFSP) 2070

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

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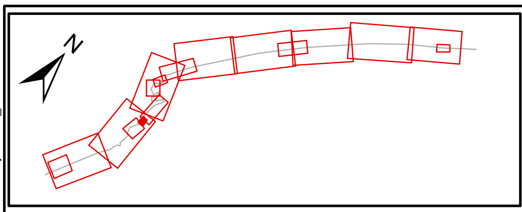

Map 2B
Projected Future Shoreline Position (PFSP) 2070

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

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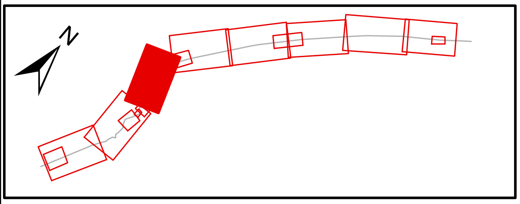

Map 3
Projected Future Shoreline Position (PFSP) 2070

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

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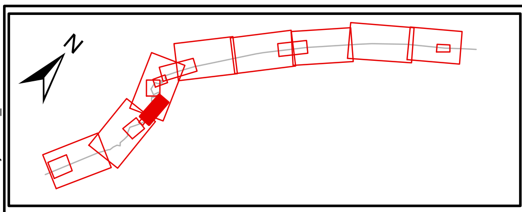

Map 3A
Projected Future Shoreline Position (PFSP) 2070

Note
P50 is 50% chance the shoreline will be landward of this position
P5 is 5% chance the shoreline will be landward of this position
South Beach Maximum Toe extent is the most seaward position the toe of the beach will move to, likely to be in this position by 2070.

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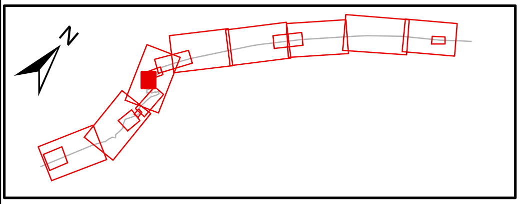

Map 3B
Projected Future Shoreline Position (PFSP) 2070

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

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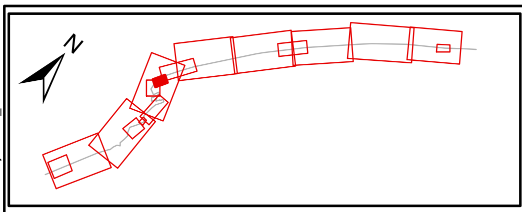

Map 3C
Projected Future Shoreline Position (PFSP) 2070

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

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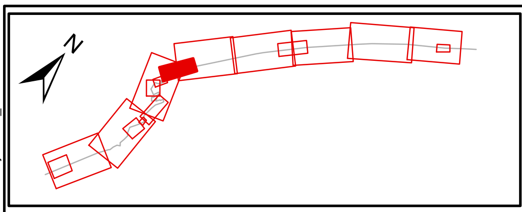

Map 3D
Projected Future Shoreline Position (PFSP) 2070

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

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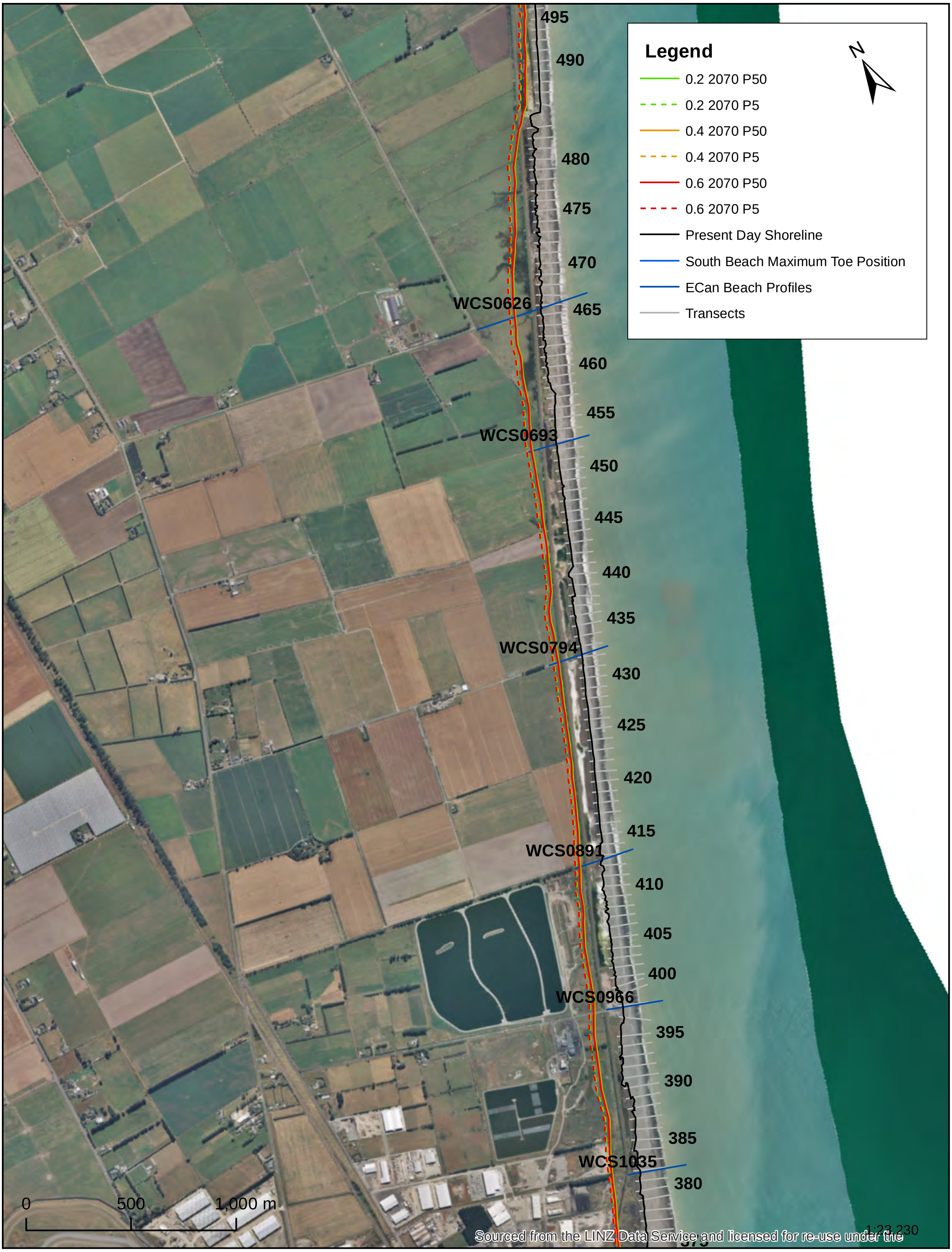

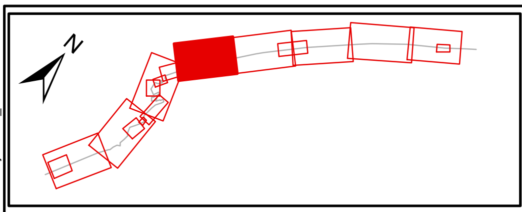

Map 4
Projected Future Shoreline Position (PFSP) 2070

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

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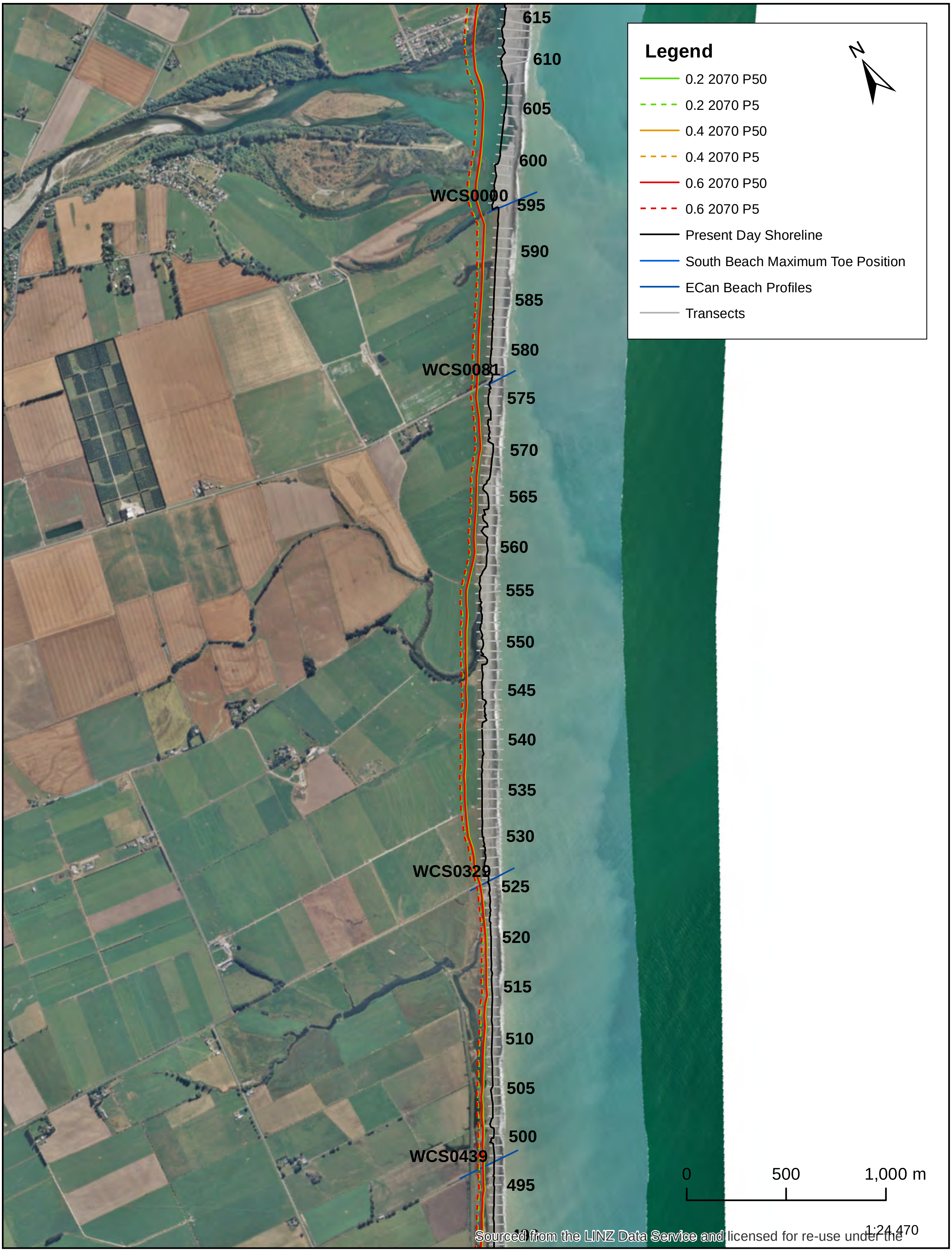

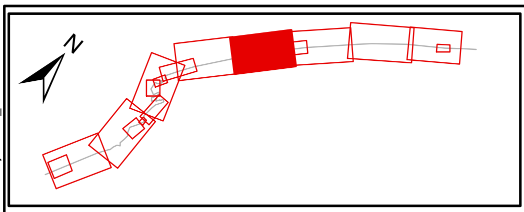

Map 5
Projected Future Shoreline Position (PFSP) 2070

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

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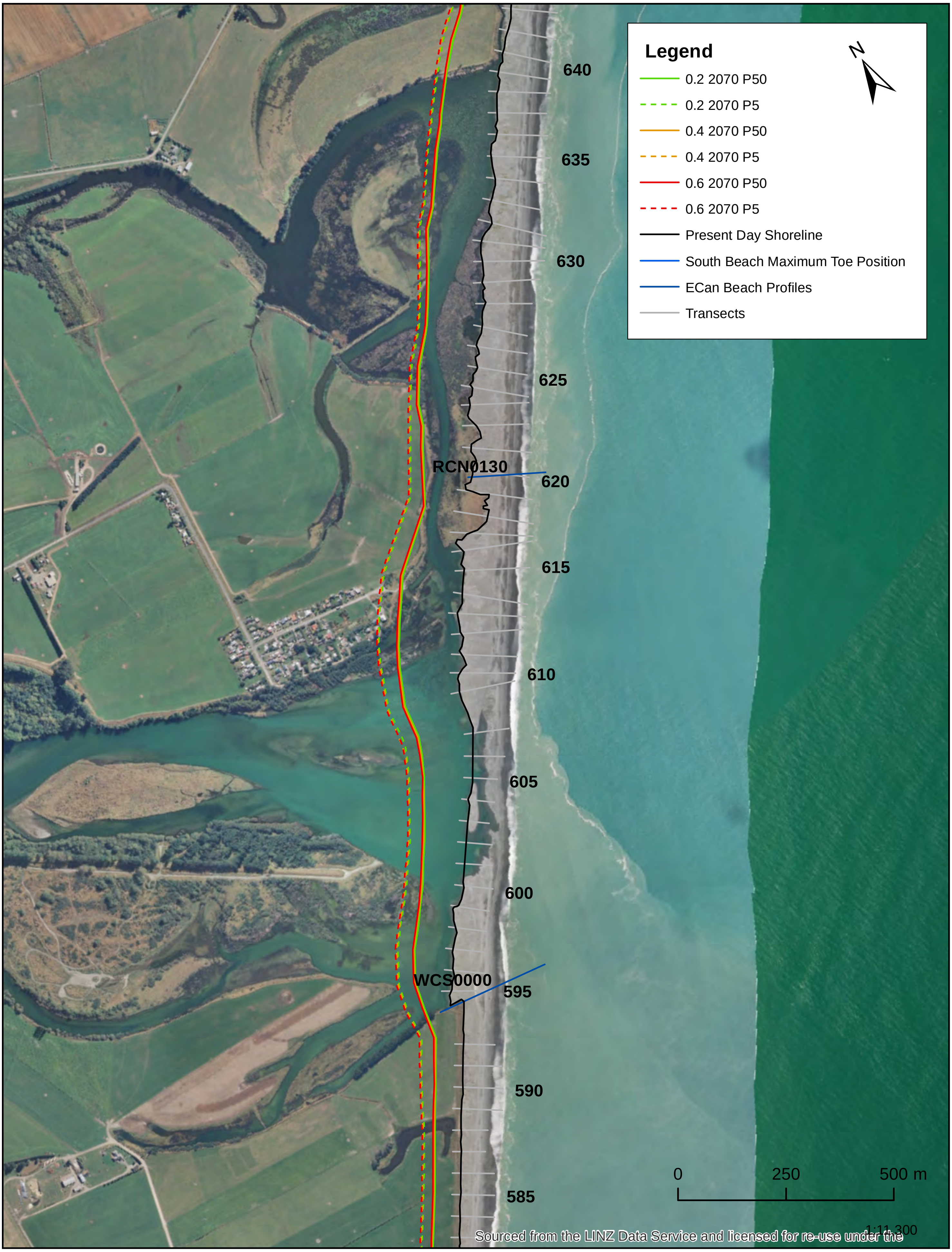

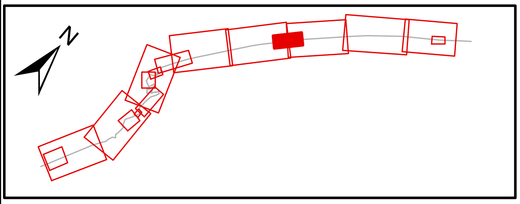

Map 5A
Projected Future Shoreline Position (PFSP) 2070

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

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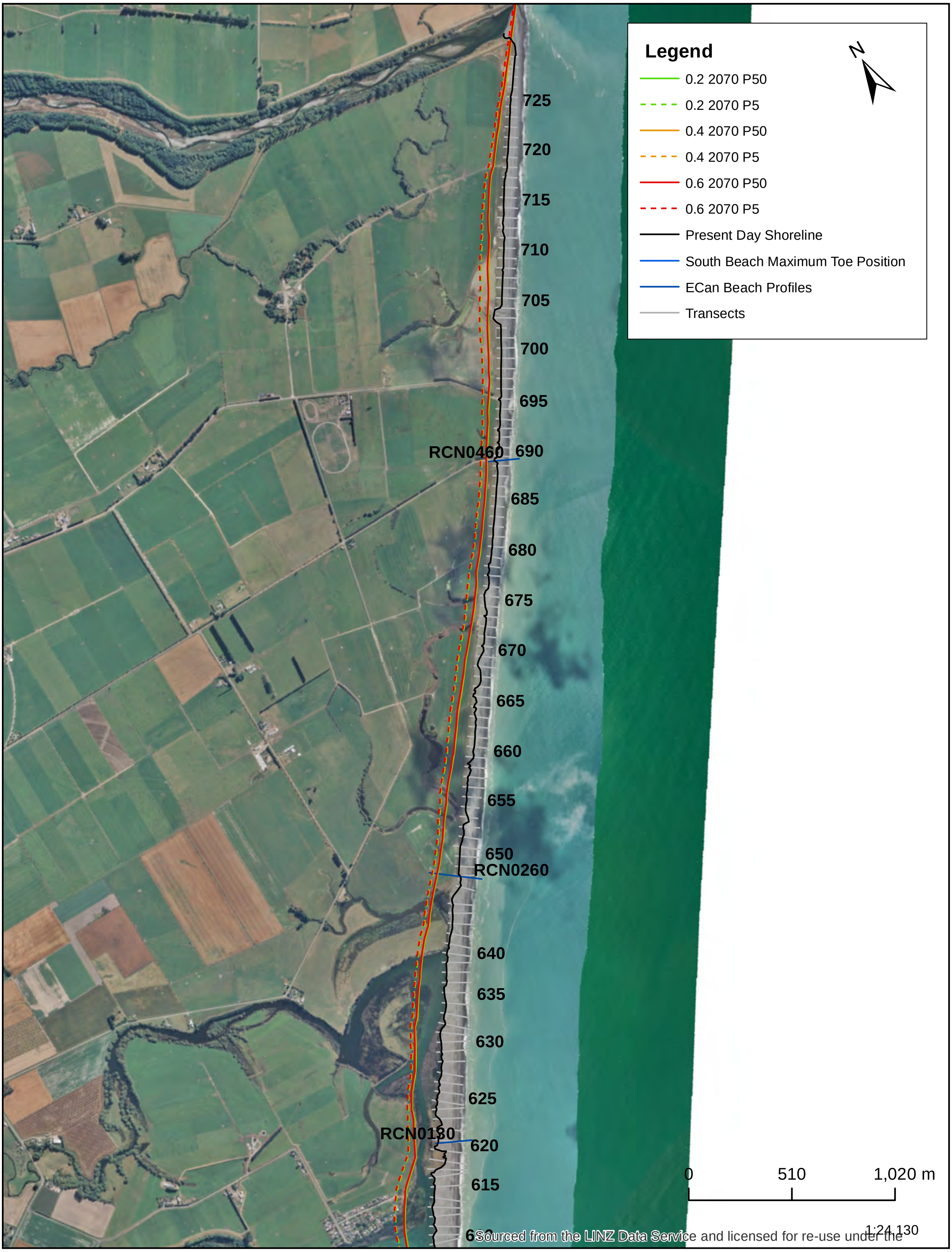

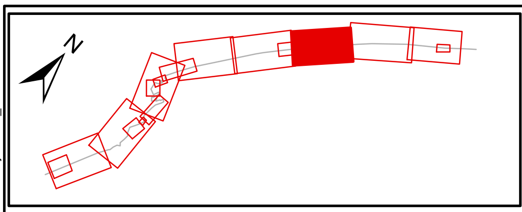

Map 6
Projected Future Shoreline Position (PFSP) 2070

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

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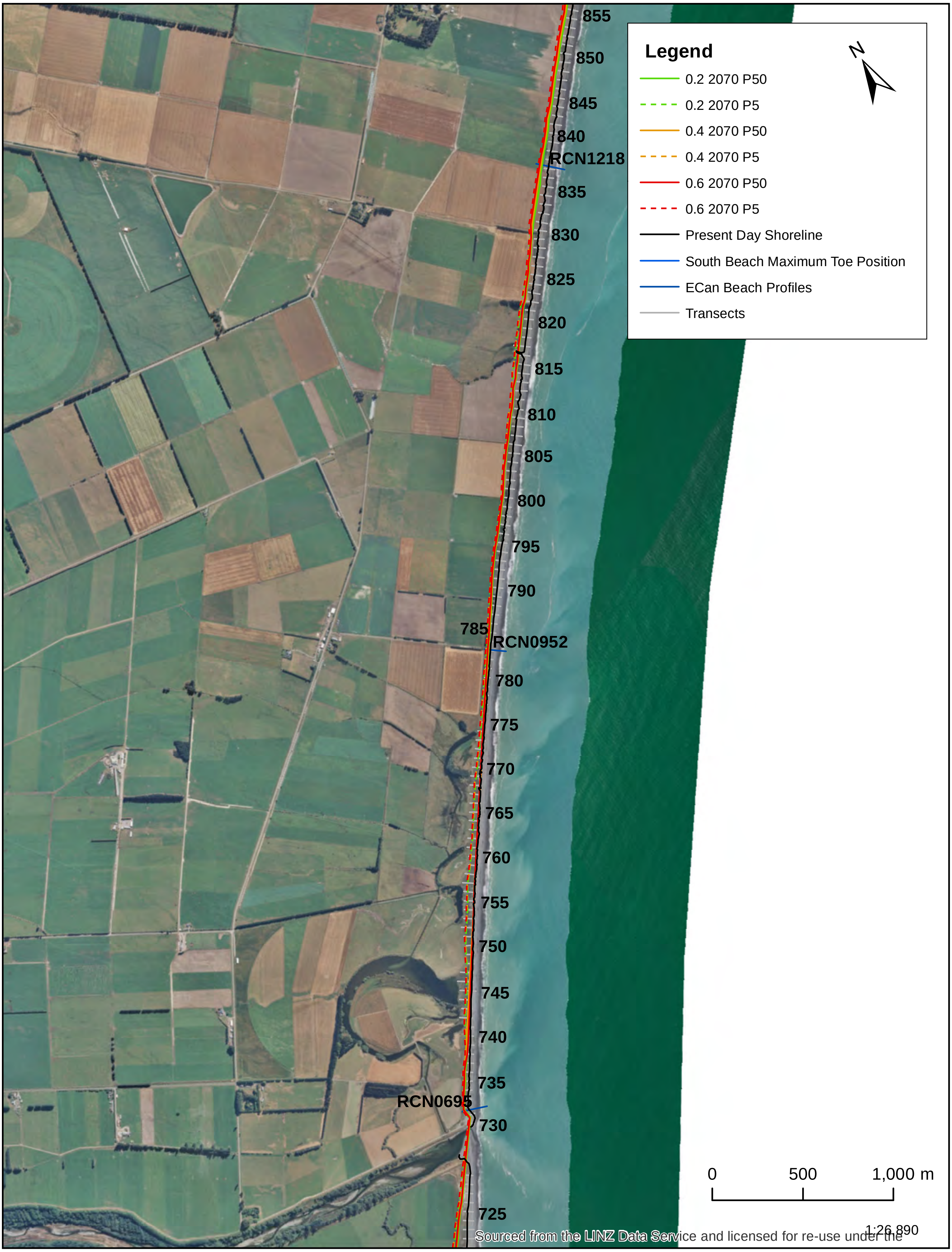

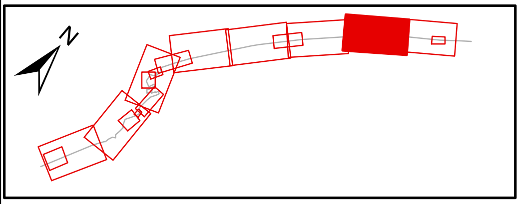

Map 7
Projected Future Shoreline Position (PFSP) 2070

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

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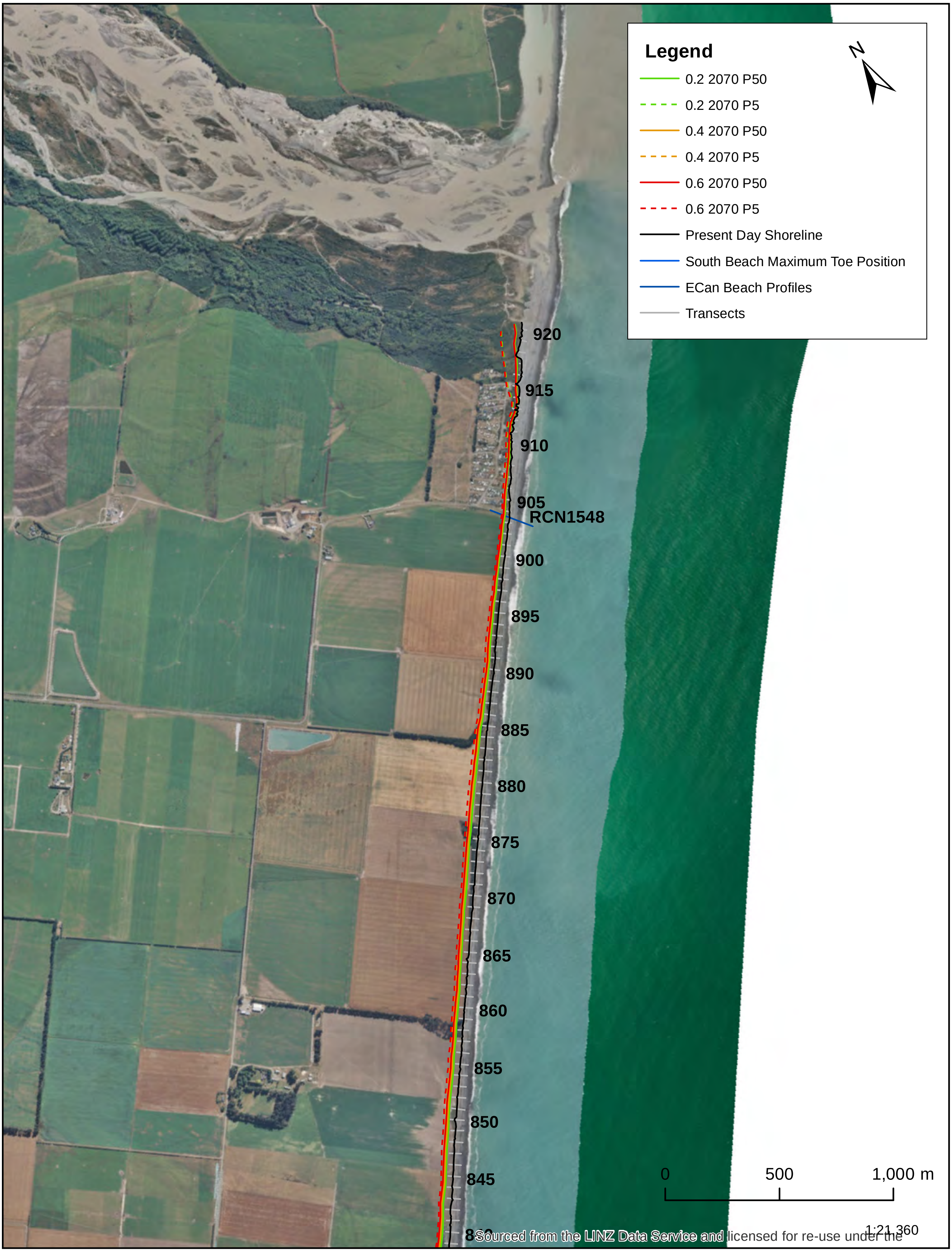

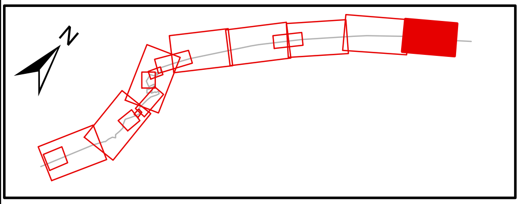

Map 8
Projected Future Shoreline Position (PFSP) 2070

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

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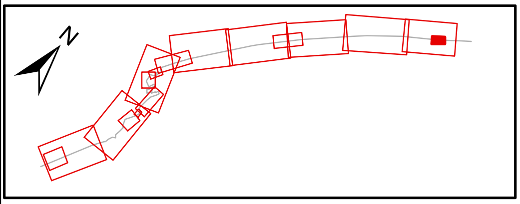

Map 8A
Projected Future Shoreline Position (PFSP) 2070

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

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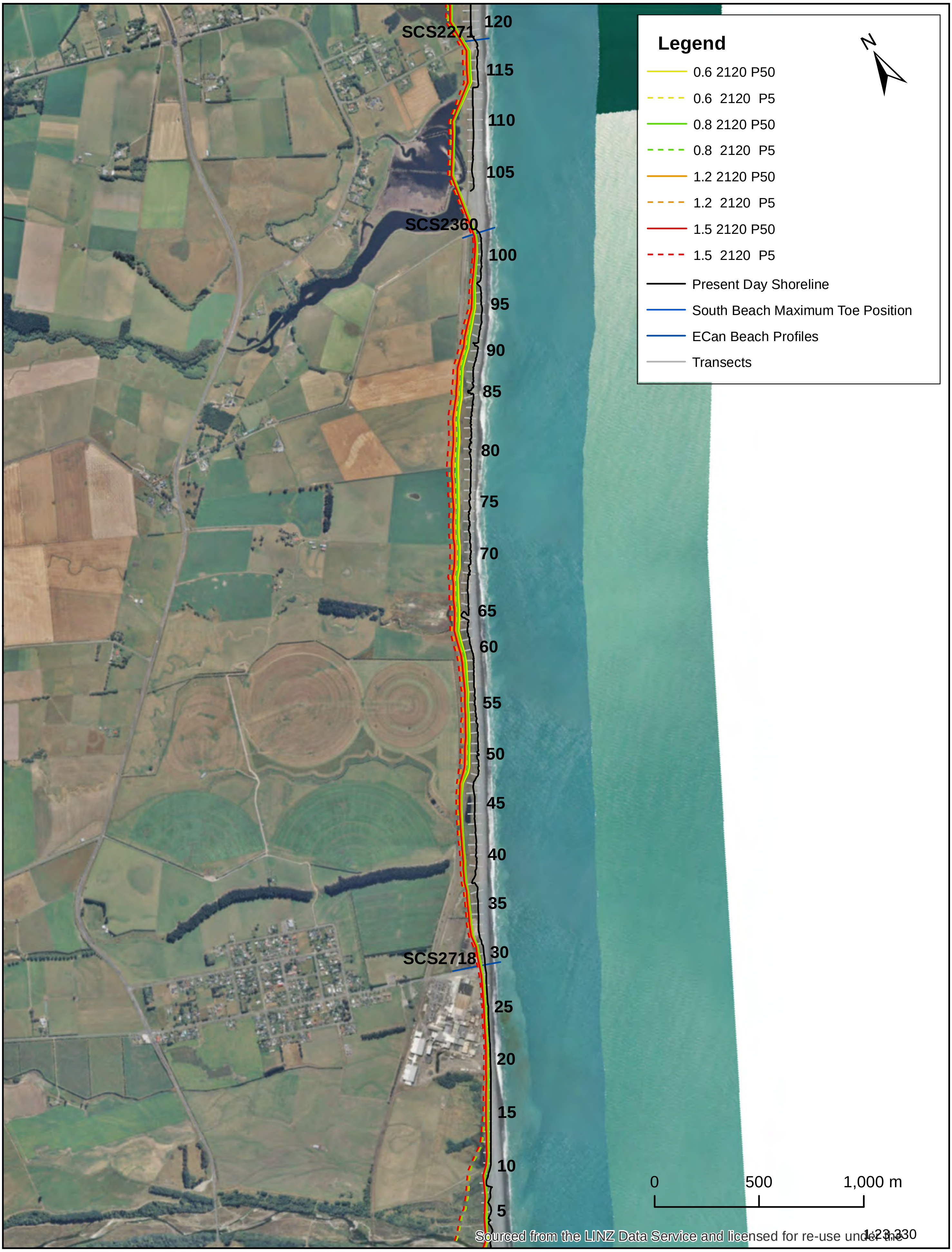

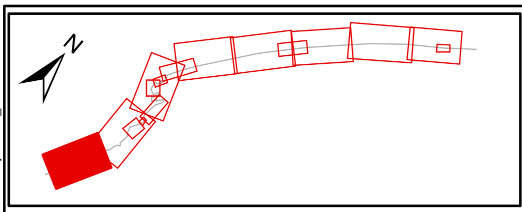

Map 1
Projected Future Shoreline Position (PFSP) 2120

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

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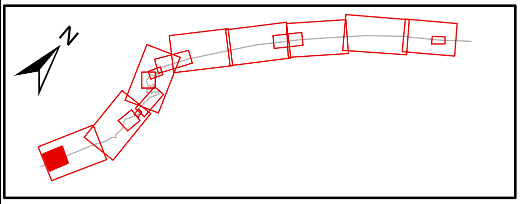

Map 1A
Projected Future Shoreline Position (PFSP) 2120

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

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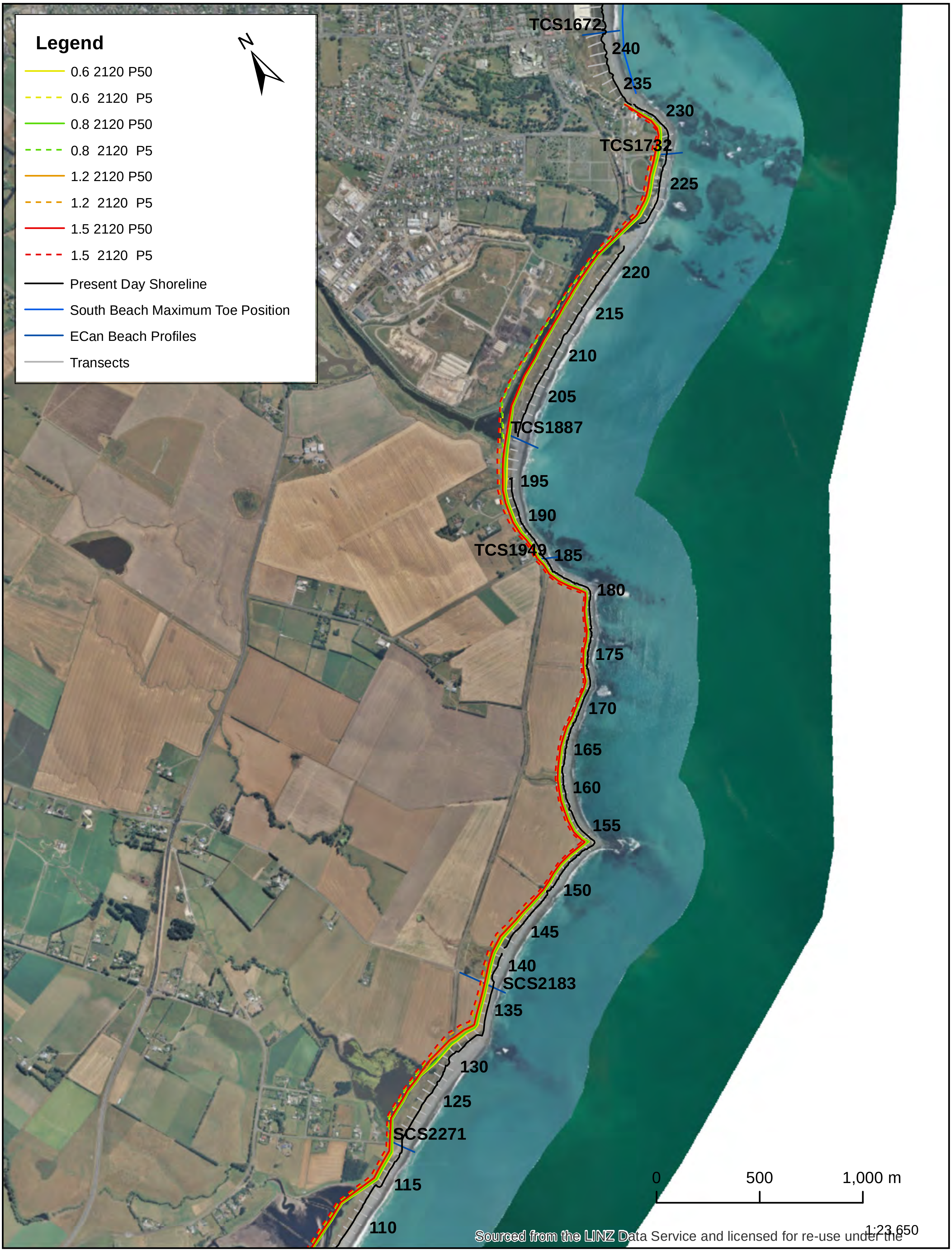

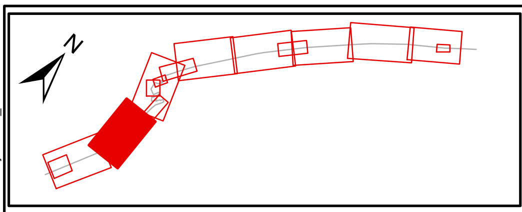

Map 2
Projected Future Shoreline Position (PFSP) 2120

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

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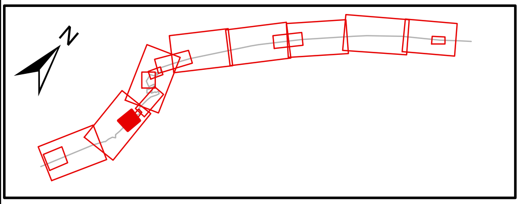

Map 2A
Projected Future Shoreline Position (PFSP) 2120

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

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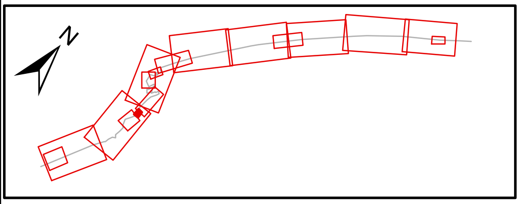

Map 2B
Projected Future Shoreline Position (PFSP) 2120

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

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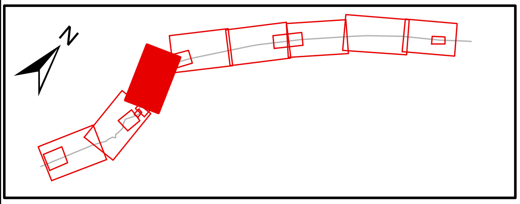

Map 3
Projected Future Shoreline Position (PFSP) 2120

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

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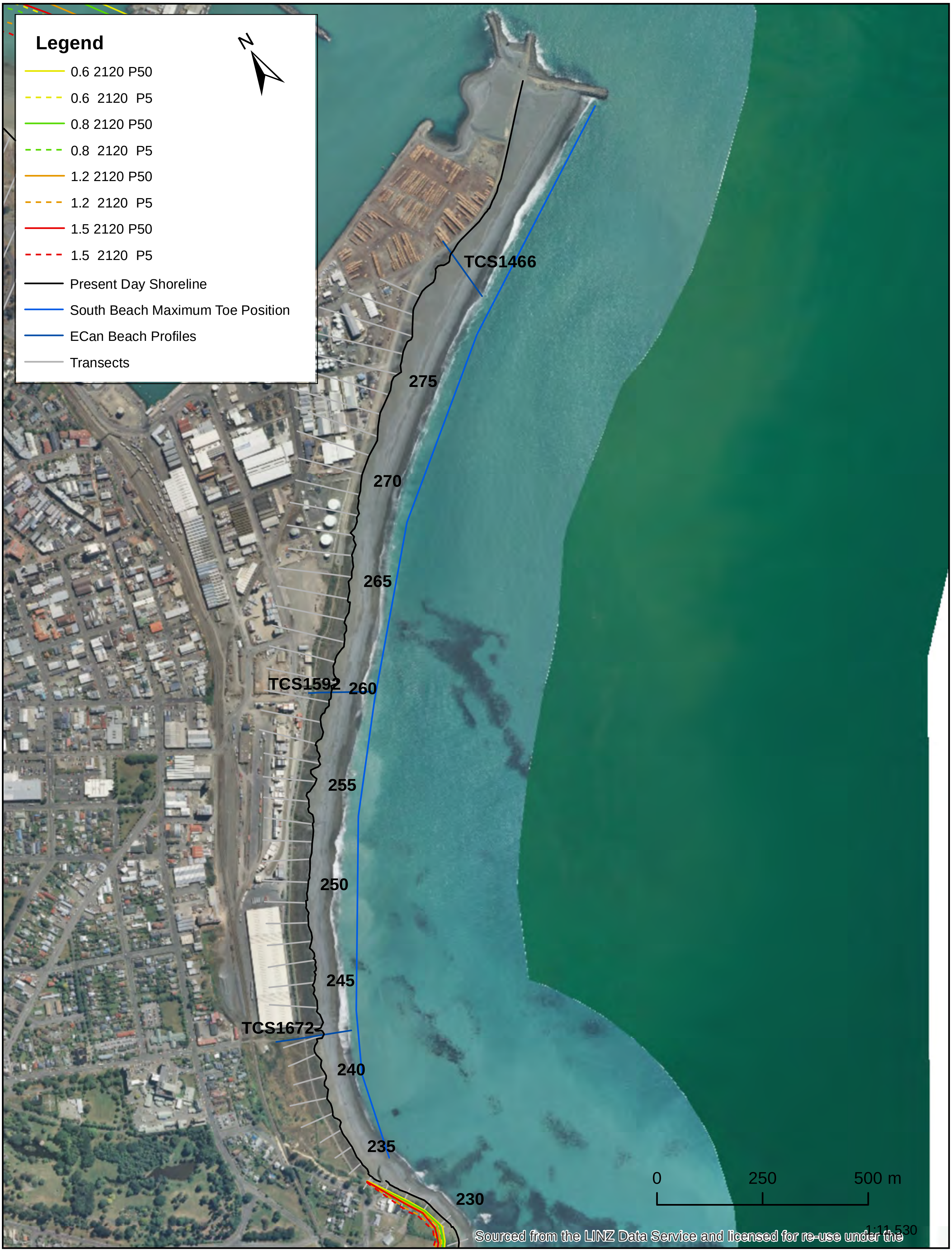

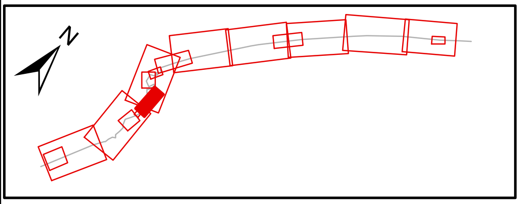

Map 3A
Projected Future Shoreline Position (PFSP) 2120

Note
P50 is 50% chance the shoreline will be landward of this position
P5 is 5% chance the shoreline will be landward of this position
South Beach Maximum Toe extent is the most seaward position the toe of the beach will move to, likely to be in this position by 2070.

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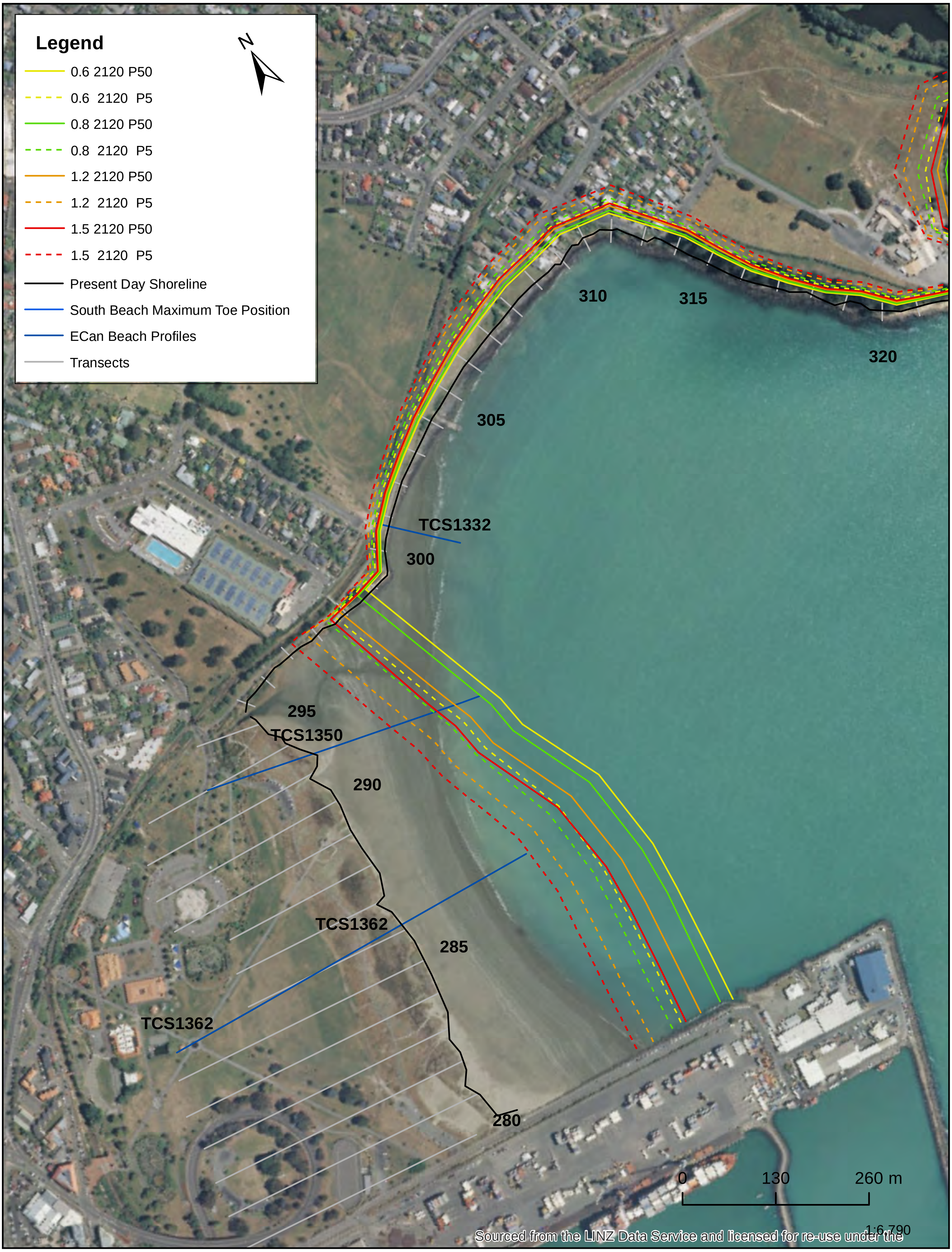

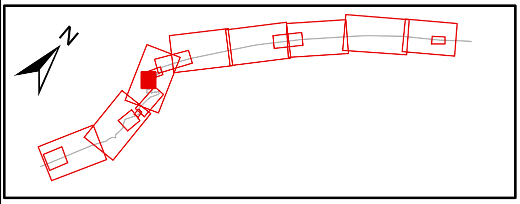

Map 3B
Projected Future Shoreline Position (PFSP) 2120

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

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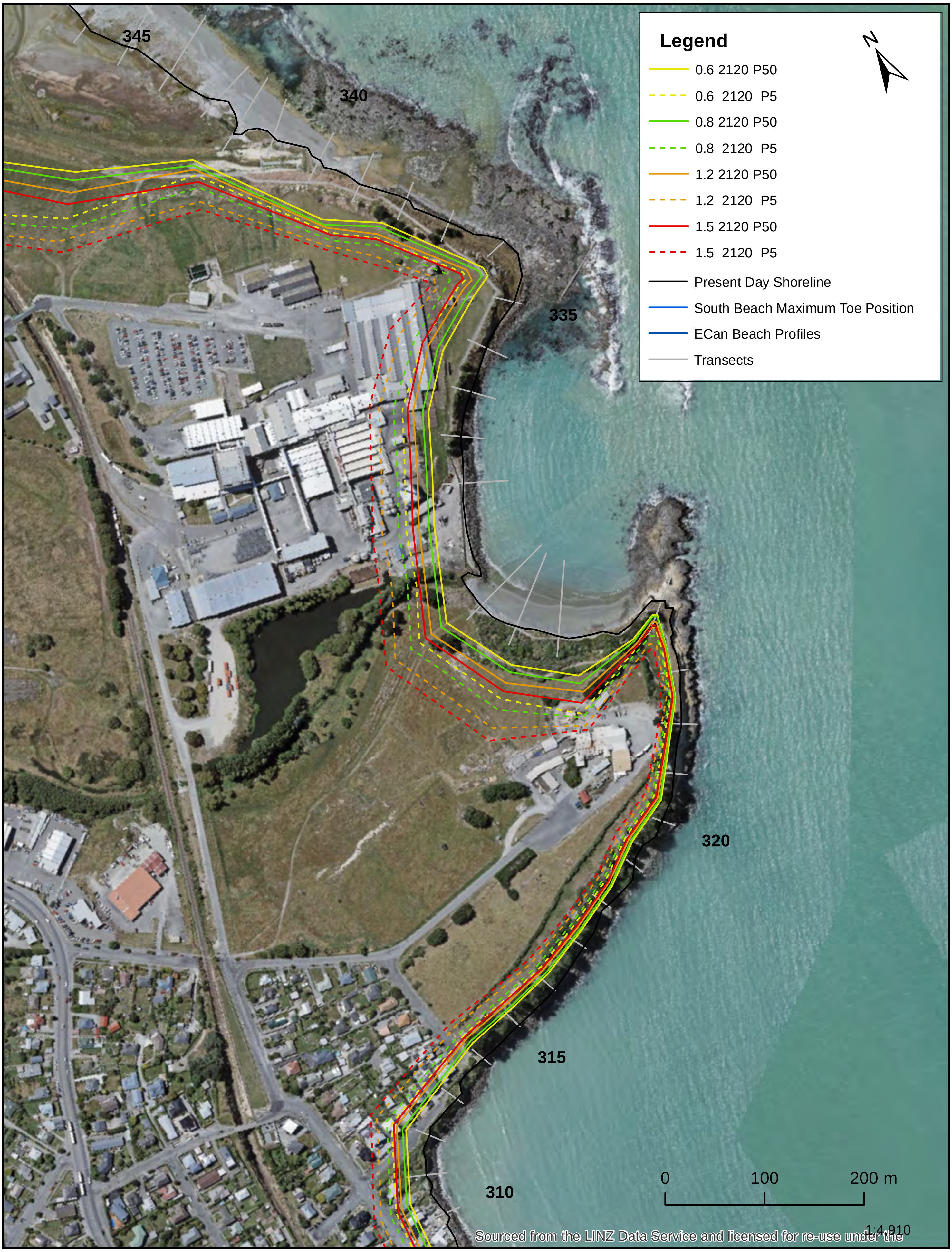

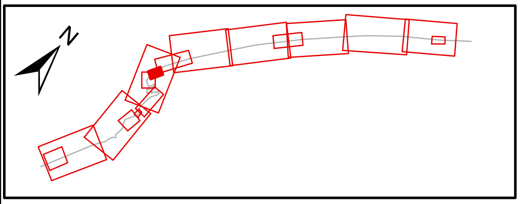

Map 3C
Projected Future Shoreline Position (PFSP) 2120

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

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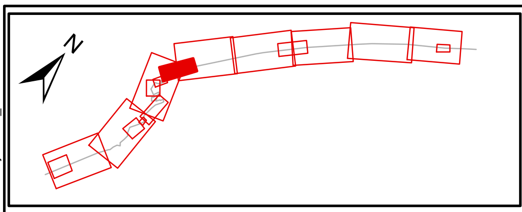

Map 3D
Projected Future Shoreline Position (PFSP) 2120

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

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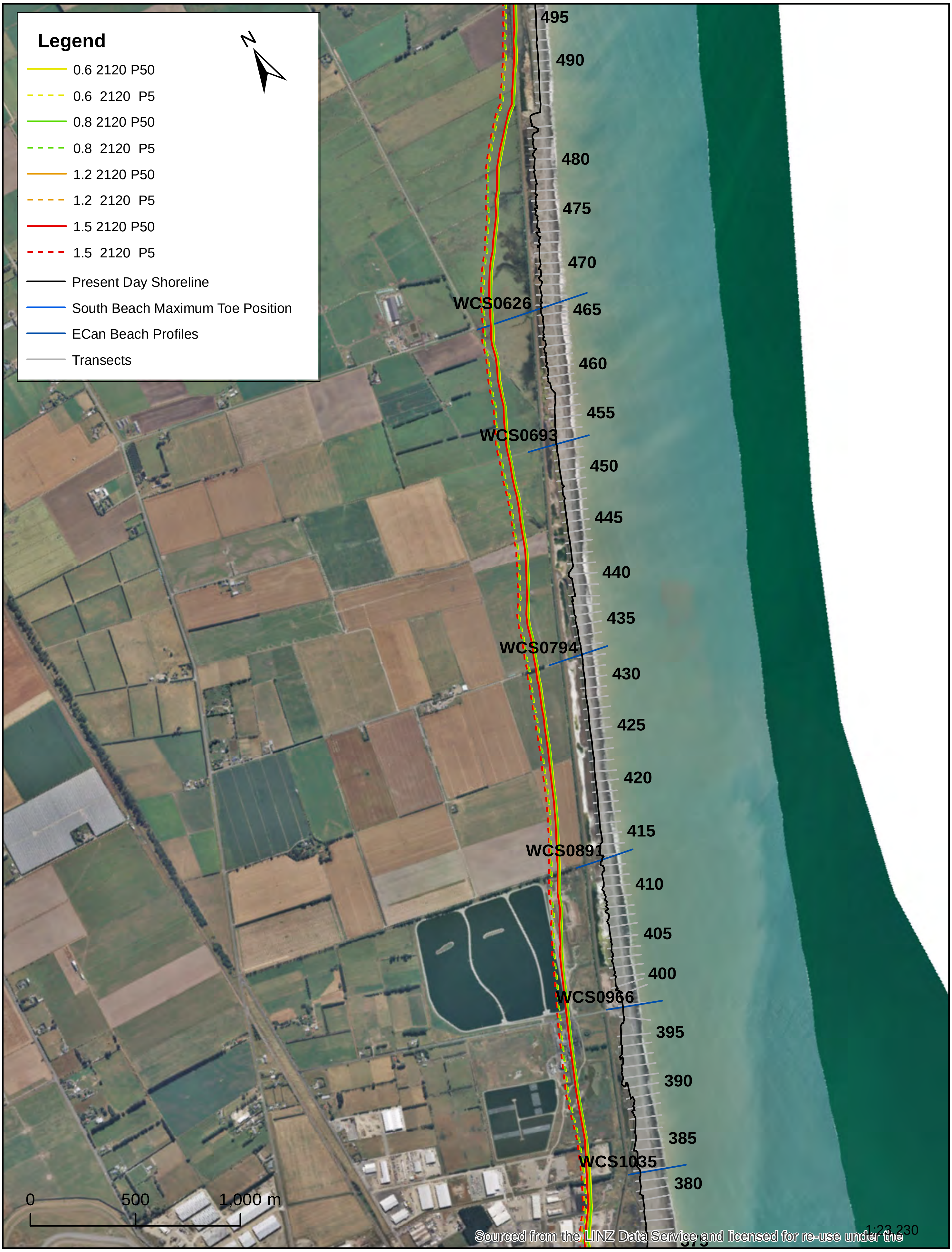

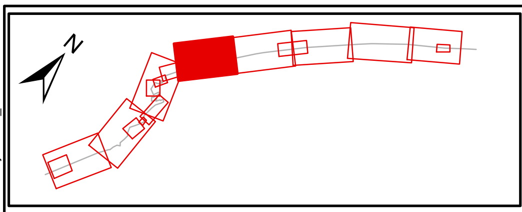

Map 4
Projected Future Shoreline Position (PFSP) 2120

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

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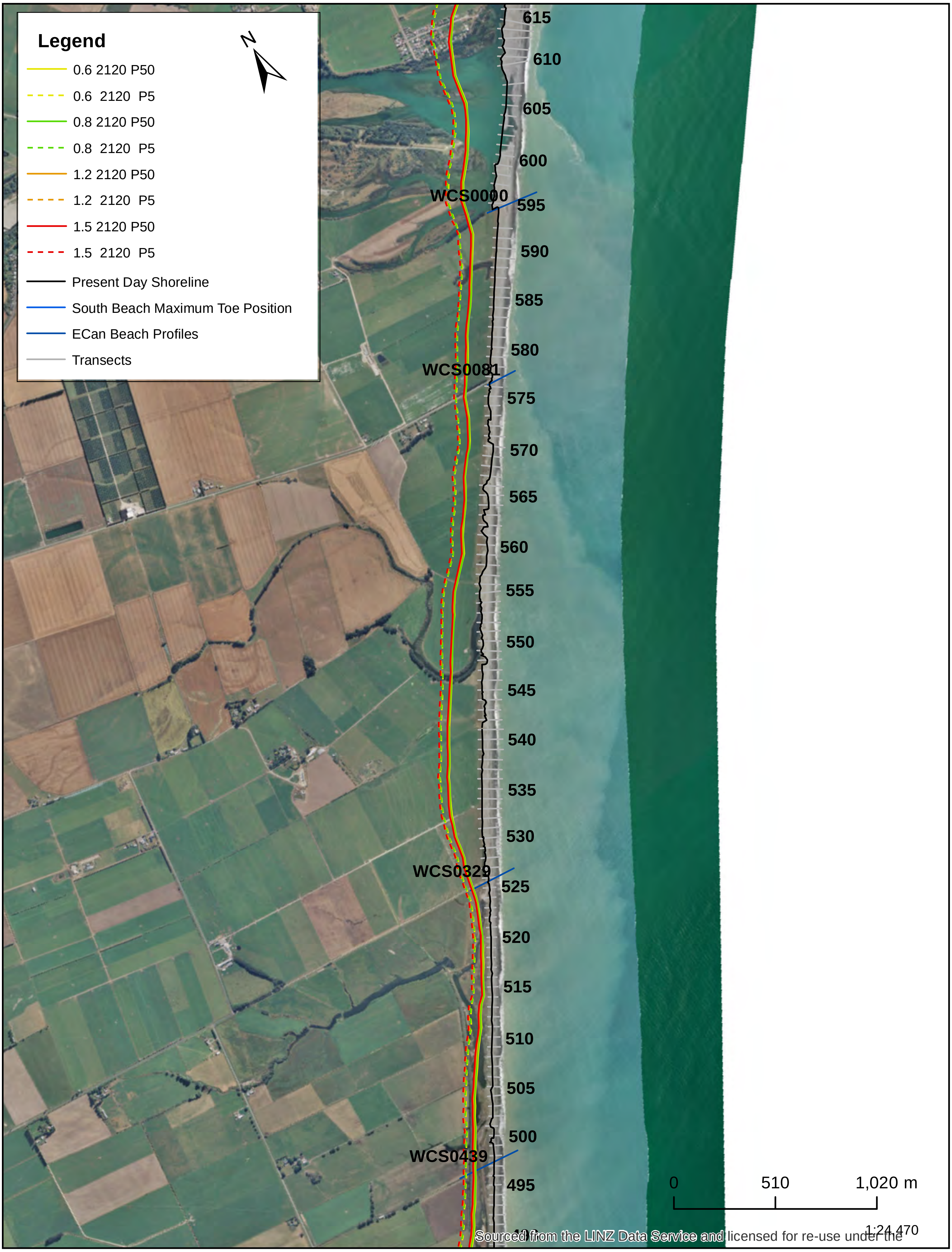

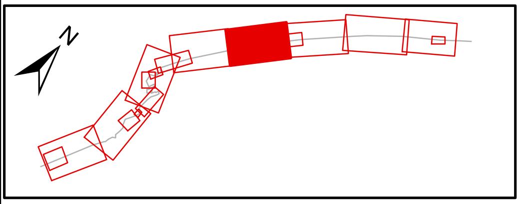

Map 5
Projected Future Shoreline Position (PFSP) 2120

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

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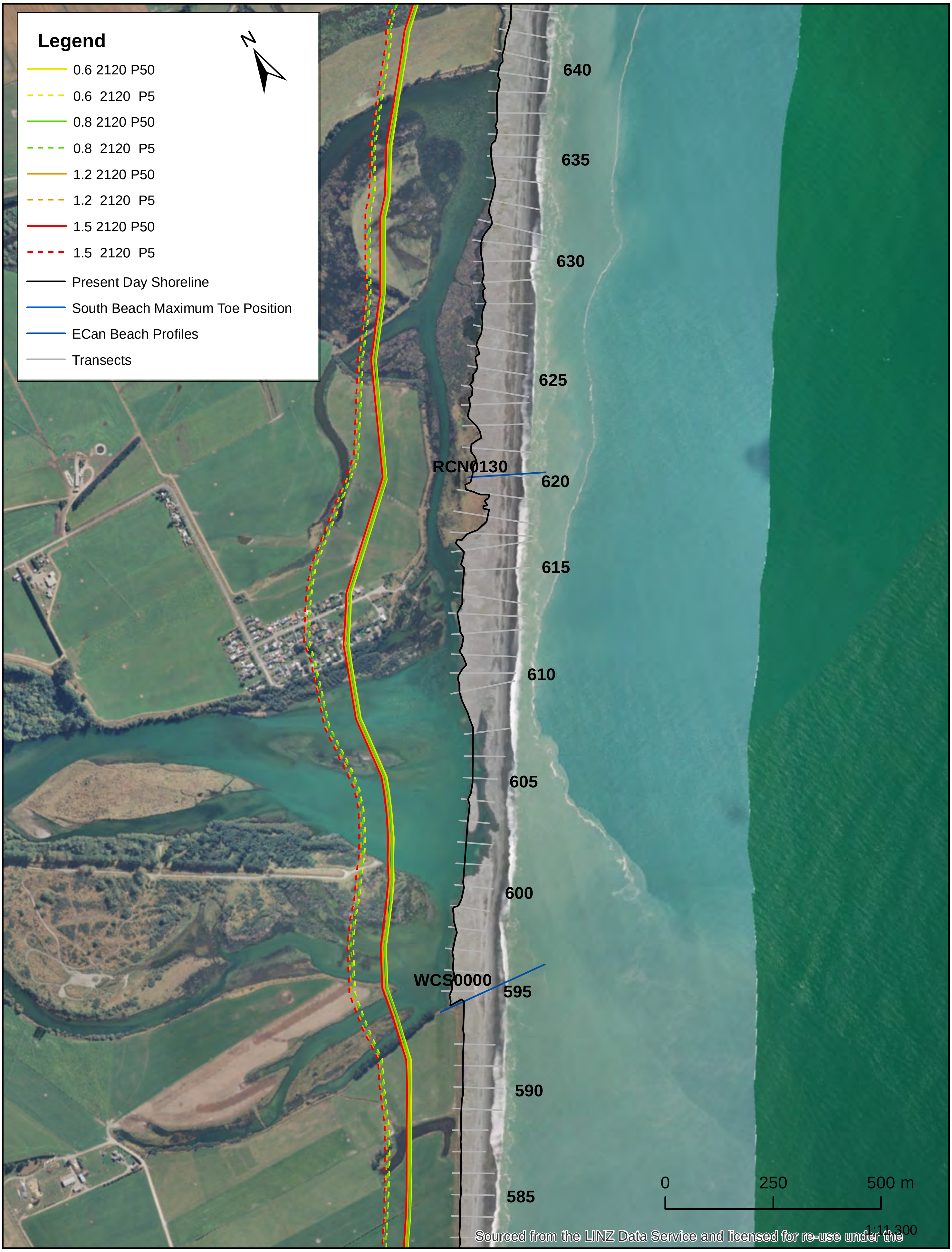

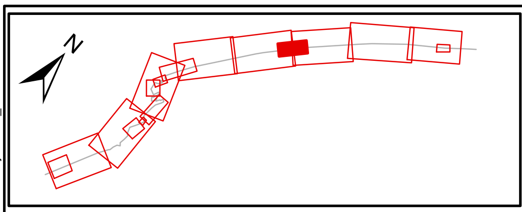

Map 5A
Projected Future Shoreline Position (PFSP) 2120

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

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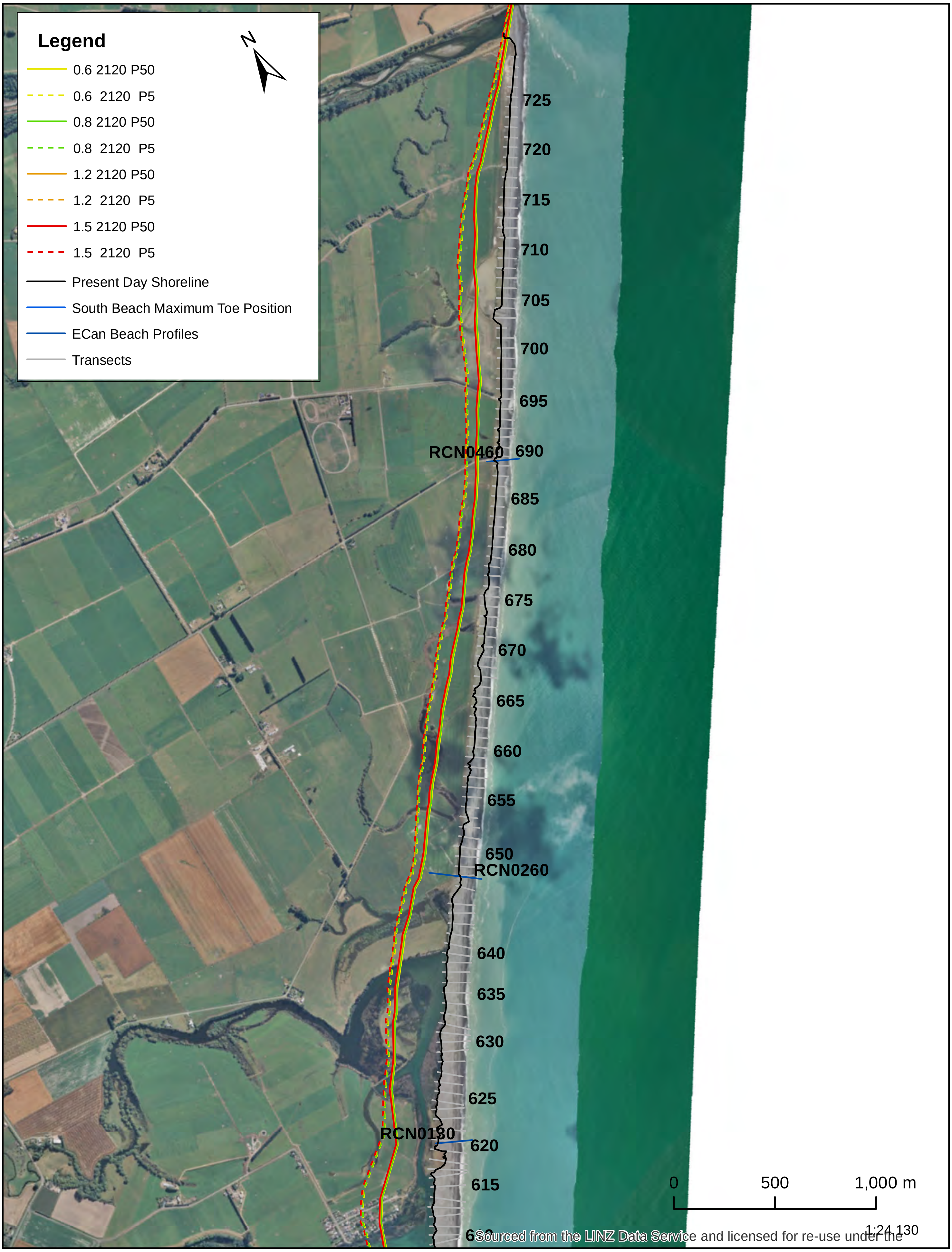

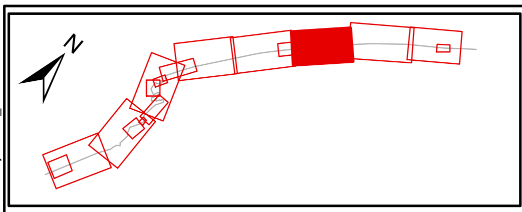

Map 6
Projected Future Shoreline Position (PFSP) 2120

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

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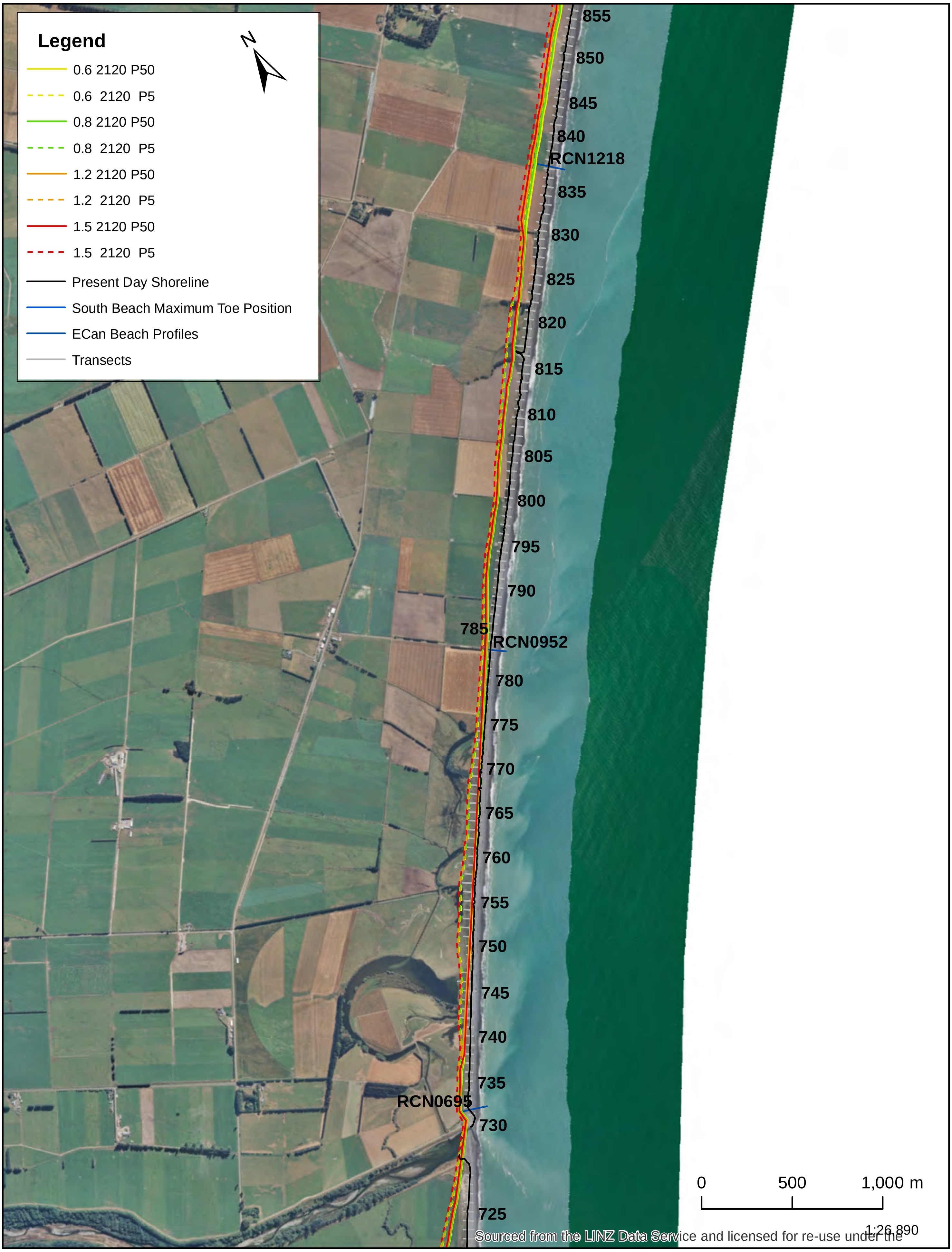

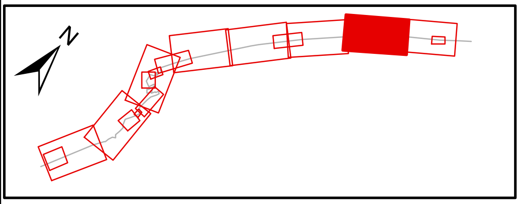

Map 7
Projected Future Shoreline Position (PFSP) 2120

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

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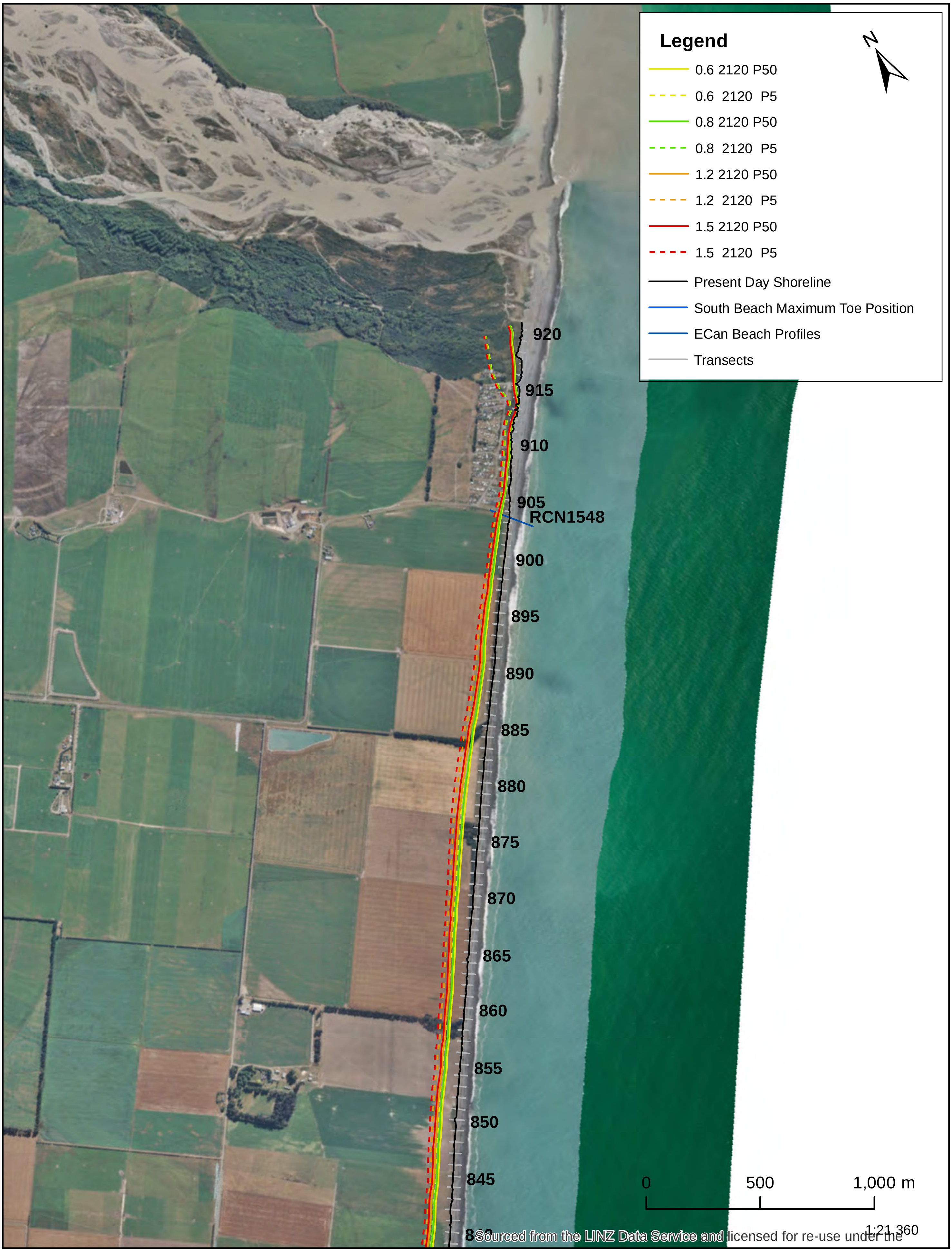

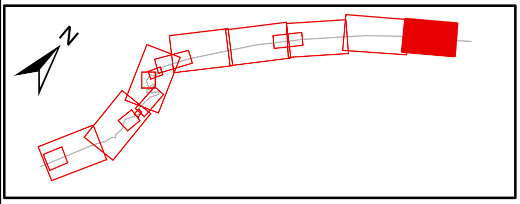

Map 8
Projected Future Shoreline Position (PFSP) 2120

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

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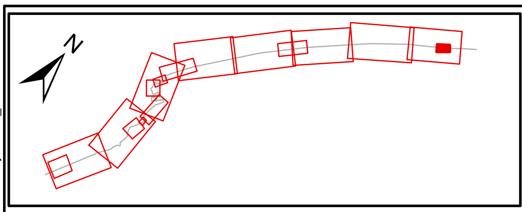

Map 8A
Projected Future Shoreline Position (PFSP) 2120

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

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Appendix F. Summary of PFSP Inputs and Outputs

Profile		Inputs										Outputs													
		ST	LT 2070	LT 2120	0.2m SLR 2070	0.4m SLR 2070	0.6m SLR 2070	0.6m SLR 2120	0.8m SLR 2120	1.2m SLR 2120	1.5m SLR 2120	0.2m SLR 2070		0.4m SLR 2070		0.6m SLR 2070		0.6m SLR 2120		0.8m SLR 2120		1.2m SLR 2120		1.5m SLR 2120	
ECan Profile	DSAS Transects	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	P5	P50	P5	P50	P5	P50	P5	P50	P5	P50	P5	P50	P5	P50
SCS2718	1-18	-5.2	-1.9	-3.8	-1.1	-3.2	-5.4	-4.3	-6.4	-10.7	-13.9	**-41.0**	**-8.0**	**-43.2**	**-10.0**	**-45.4**	**-12.3**	**-78.8**	**-13.1**	**-81.2**	**-15.4**	**-85.8**	**-19.6**	**-88.8**	**-23.0**
SCS2718	19-31	-5.2	-2.8	-5.5	-1.1	-3.2	-5.4	-4.3	-6.4	-10.7	-13.9	**-13.3**	**-8.8**	**-15.7**	**-11.0**	**-18.0**	**-13.2**	**-23.5**	**-15.0**	**-25.9**	**-17.2**	**-30.5**	**-21.6**	**-34.0**	**-24.7**
SCS2718	32-46	-5.2	-21.8	-43.7	-1.1	-3.2	-5.4	-4.3	-6.4	-10.7	-13.9	**-42.0**	**-33.9**	**-44.3**	**-36.0**	**-46.3**	**-38.3**	**-80.9**	**-65.0**	**-83.1**	**-67.1**	**-87.6**	**-71.3**	**-90.6**	**-74.8**
SCS2360	47-102	-1.4	-13.5	-27.0	-4.6	-12.2	-17.9	-17.4	-24.3	-35.9	-43.3	**-23.7**	**-18.9**	**-32.3**	**-25.6**	**-39.2**	**-30.7**	**-54.9**	**-43.6**	**-62.9**	**-49.7**	**-76.7**	**-59.8**	**-85.8**	**-66.4**
TCS1887	104-113	-28.9	-28.1	-56.1	-1.1	-3.2	-5.3	-4.2	-6.3	-10.6	-13.7	**-73.9**	**-60.1**	**-76.1**	**-62.0**	**-78.6**	**-64.3**	**-109.0**	**-92.2**	**-110.9**	**-94.3**	**-115.1**	**-98.4**	**-118.3**	**-101.8**
SCS2271	114-117	-1.7	-9.6	-19.3	-3.3	-8.7	-12.8	-12.4	-17.3	-25.5	-30.8	**-19.7**	**-14.6**	**-26.2**	**-19.6**	**-32.2**	**-23.6**	**-44.5**	**-33.0**	**-50.9**	**-37.5**	**-61.7**	**-45.4**	**-69.1**	**-50.6**
TCS1887	118-125	-28.9	-27.3	-54.5	-1.1	-3.2	-5.3	-4.2	-6.3	-10.6	-13.7	**-73.9**	**-58.6**	**-75.9**	**-60.7**	**-78.1**	**-62.8**	**-109.3**	**-89.3**	**-111.6**	**-91.3**	**-116.1**	**-95.9**	**-119.7**	**-98.9**
SCS2183	126-181	-0.5	-7.0	-14.0	-2.4	-6.3	-9.3	-9.1	-12.6	-18.6	-22.5	**-14.4**	**-10.0**	**-19.5**	**-13.9**	**-23.9**	**-16.9**	**-33.7**	**-23.8**	**-38.6**	**-27.4**	**-47.2**	**-33.4**	**-53.0**	**-37.2**
TCS1949	182-198	-1.1	-6.2	-12.4	-2.1	-5.6	-8.2	-8.0	-11.2	-16.5	-19.9	**-15.2**	**-10.2**	**-20.3**	**-14.1**	**-24.6**	**-17.0**	**-34.5**	**-23.4**	**-39.3**	**-26.9**	**-48.1**	**-32.6**	**-53.9**	**-36.4**
TCS1887	199-220	-28.9	-18.2	-36.3	-1.1	-3.2	-5.3	-4.2	-6.3	-10.6	-13.7	**-71.7**	**-49.2**	**-74.1**	**-51.6**	**-76.3**	**-53.8**	**-109.3**	**-70.9**	**-111.5**	**-73.1**	**-116.0**	**-77.3**	**-119.2**	**-80.7**
TCS1732	221-223	-1.3	-16.2	-32.3	-5.6	-14.6	-21.5	-20.9	-29.1	-42.9	-51.8	**-25.8**	**-21.9**	**-35.3**	**-29.5**	**-43.0**	**-35.2**	**-60.3**	**-50.7**	**-69.2**	**-57.6**	**-84.7**	**-69.2**	**-94.5**	**-76.7**
TCS1732	224-229	-1.3	-12.2	-24.3	-4.2	-11.0	-16.1	-15.7	-21.9	-32.3	-39.0	**-21.5**	**-17.1**	**-29.2**	**-23.1**	**-35.4**	**-27.8**	**-49.6**	**-39.3**	**-56.9**	**-44.9**	**-69.4**	**-54.0**	**-77.6**	**-59.8**
TCS1732	230-234	-1.3	-4.9	-9.8	-1.7	-4.4	-6.5	-6.3	-8.8	-13.0	-15.7	**-12.1**	**-8.3**	**-16.0**	**-11.3**	**-19.3**	**-13.5**	**-26.8**	**-18.4**	**-30.5**	**-21.0**	**-37.2**	**-25.6**	**-41.7**	**-28.5**
TCS1672	235-250	-5.4	51.1	102.3	-1.2	-3.6	-5.9	-4.7	-7.1	-11.9	-15.4	**33.6**	**44.3**	**31.1**	**41.9**	**28.6**	**39.5**	**70.4**	**91.9**	**67.9**	**89.3**	**63.0**	**84.5**	**59.2**	**80.8**
TCS1592	251-275	-3.8	97.0	194.0	-1.5	-4.5	-7.6	-6.1	-9.1	-15.1	-19.7	**65.2**	**91.4**	**62.1**	**88.3**	**59.0**	**85.3**	**131.2**	**183.8**	**128.2**	**180.6**	**122.0**	**174.4**	**117.4**	**169.9**
TCS1466	276-279	-6.8	132.5	264.9	-1.5	-4.5	-7.5	-6.0	-8.9	-14.9	-19.4	**88.9**	**122.1**	**85.6**	**118.6**	**82.6**	**115.7**	**184.6**	**249.7**	**181.0**	**246.9**	**174.8**	**240.3**	**170.6**	**236.2**
TCS1362	280-287	-50.9	225.5	451.0	-8.1	-24.3	-40.5	-32.4	-48.6	-81.1	-105.4	**120.3**	**163.1**	**104.1**	**146.8**	**88.0**	**130.8**	**289.2**	**364.2**	**272.9**	**347.9**	**240.5**	**315.5**	**216.3**	**291.7**
TCS1350	288-293	-28.3	162.7	325.4	-8.4	-25.1	-41.8	-33.4	-50.1	-83.6	-108.7	**92.9**	**124.3**	**76.7**	**107.9**	**60.1**	**91.6**	**202.9**	**262.2**	**186.5**	**246.4**	**153.8**	**213.4**	**129.3**	**189.1**
TCS1332	295-321	-0.7	-1.7	-3.3	-0.6	-1.5	-2.2	-2.2	-3.0	-4.5	-5.4	**-10.9**	**-6.0**	**-14.3**	**-8.5**	**-17.4**	**-10.2**	**-24.3**	**-13.9**	**-27.7**	**-16.1**	**-33.9**	**-19.6**	**-38.2**	**-21.7**
TCS1732	322-343	-1.3	-10.3	-20.5	-3.5	-9.2	-13.6	-13.2	-18.5	-27.2	-32.9	**-29.6**	**-17.2**	**-39.6**	**-24.7**	**-48.4**	**-30.3**	**-68.2**	**-41.2**	**-77.7**	**-47.9**	**-95.3**	**-59.1**	**-107.0**	**-66.3**
WCS1195	344-355	-42.0	-79.2	-158.5	-2.3	-7.1	-12.2	-9.6	-14.9	-26.2	-35.4	**-165.8**	**-126.7**	**-171.2**	**-131.8**	**-176.4**	**-137.1**	**-286.3**	**-213.5**	**-292.2**	**-219.2**	**-303.8**	**-231.1**	**-313.7**	**-240.8**
WCS1135	356-363	-13.7	-99.3	-198.6	-2.3	-7.0	-12.0	-9.5	-14.7	-25.7	-34.7	**-139.3**	**-116.1**	**-144.6**	**-121.1**	**-149.8**	**-126.3**	**-269.3**	**-222.8**	**-274.6**	**-228.4**	**-286.7**	**-240.4**	**-296.4**	**-249.9**
WCS1105	364-375	-11.6	-116.8	-233.6	-2.2	-6.8	-11.7	-9.2	-14.3	-25.1	-33.9	**-145.9**	**-131.2**	**-150.8**	**-136.1**	**-155.9**	**-141.2**	**-284.4**	**-255.4**	**-289.7**	**-260.8**	**-301.1**	**-272.1**	**-310.4**	**-281.4**
WCS1035	376-382	-16.0	-109.5	-219.0	-1.4	-4.3	-7.5	-5.9	-9.1	-16.3	-22.2	**-142.7**	**-128.1**	**-145.6**	**-131.2**	**-148.9**	**-134.4**	**-269.3**	**-242.3**	**-272.8**	**-245.7**	**-280.0**	**-253.1**	**-286.2**	**-259.1**
WCS0966	383-405	-12.6	-108.4	-216.8	-1.3	-3.9	-6.5	-5.2	-7.8	-13.1	-17.0	**-144.9**	**-123.3**	**-147.6**	**-126.0**	**-150.3**	**-128.7**	**-278.5**	**-235.8**	**-281.2**	**-238.4**	**-286.6**	**-243.8**	**-290.8**	**-248.0**

WCS0891	406-425	-11.4	-92.9	-185.9	-1.3	-3.9	-6.6	-5.3	-7.9	-13.1	-17.1	-125.5	-106.3	-128.2	-108.9	-131.0	-111.8	-241.4	-203.3	-244.0	-205.9	-249.5	-211.4	-253.7	-215.5
WCS0794	426-445	-12.5	-96.3	-192.7	-1.3	-3.8	-6.3	-5.0	-7.5	-12.6	-16.3	-133.0	-110.8	-135.6	-113.4	-138.1	-116.0	-254.6	-211.0	-257.4	-213.6	-262.4	-218.7	-266.3	-222.8
WCS0693	446-460	-9.7	-104.4	-208.8	-1.3	-3.9	-6.4	-5.1	-7.7	-12.9	-16.7	-139.2	-115.8	-141.9	-118.4	-144.5	-121.0	-270.8	-224.3	-273.5	-226.8	-278.6	-232.1	-282.9	-236.1
WCS0626	461-483	-18.7	-84.3	-168.6	-1.3	-3.9	-6.6	-5.3	-7.9	-13.1	-17.1	-131.0	-107.0	-133.7	-109.7	-136.4	-112.4	-240.6	-195.4	-243.3	-198.1	-248.8	-203.5	-252.9	-207.6
WCS0439	486-494	-11.1	-44.2	-88.4	-1.5	-4.4	-7.3	-5.8	-8.7	-14.5	-18.9	-84.0	-57.3	-87.1	-60.4	-90.0	-63.4	-158.9	-105.9	-162.2	-108.9	-168.3	-115.1	-172.8	-119.7
WCS0439	495-513	-11.1	-30.5	-61.0	-1.5	-4.4	-7.3	-5.8	-8.7	-14.5	-18.9	-68.2	-43.7	-71.1	-46.6	-74.2	-49.7	-127.6	-78.8	-130.4	-81.7	-136.6	-87.8	-141.2	-92.3
WCS0329	514-555	-5.6	-53.2	-106.3	-1.2	-3.5	-5.8	-4.6	-7.0	-11.6	-15.1	-82.1	-60.3	-84.5	-62.7	-86.9	-65.1	-160.7	-117.0	-163.1	-119.4	-167.7	-124.2	-171.5	-127.8
WCS0081	556-592	-5.7	-53.2	-106.3	-1.1	-3.4	-5.6	-4.5	-6.8	-11.3	-14.7	-88.1	-61.2	-90.5	-63.5	-92.8	-65.8	-171.6	-117.8	-174.1	-120.2	-178.7	-124.8	-182.1	-128.2
WCS0000	595-610	-23.3	-75.3	-150.6	-1.3	-4.0	-6.7	-5.4	-8.1	-13.5	-17.5	-140.4	-103.3	-143.0	-106.1	-145.9	-108.6	-254.8	-182.8	-257.6	-185.7	-263.3	-190.9	-267.4	-195.4
RCN0130	611-639	-23.3	-102.3	-204.6	-1.3	-3.8	-6.4	-5.1	-7.6	-12.7	-16.5	-158.5	-130.0	-161.2	-132.7	-163.6	-135.3	-289.3	-236.4	-291.9	-238.9	-297.4	-244.1	-301.0	-248.0
RCN0260	640-670	-15.3	-75.8	-151.7	-1.3	-3.8	-6.4	-5.1	-7.6	-12.7	-16.5	-125.2	-95.0	-127.8	-97.7	-130.6	-100.3	-233.0	-174.7	-235.8	-177.4	-241.0	-182.7	-244.8	-186.5
RCN0460	671-729	-9.0	-46.4	-92.9	-1.2	-3.6	-5.9	-4.8	-7.1	-11.9	-15.5	-87.1	-58.0	-89.5	-60.5	-92.0	-62.9	-165.7	-108.1	-168.2	-110.5	-173.2	-115.5	-176.8	-119.2
RCN0695	730-741	-4.5	-10.3	-20.6	-1.2	-3.5	-5.9	-4.7	-7.1	-11.8	-15.3	-28.1	-16.7	-30.4	-19.2	-33.0	-21.6	-53.1	-30.8	-55.6	-33.1	-60.4	-37.9	-64.1	-41.5
RCN0952	781-829	-3.9	-22.6	-45.2	-1.1	-3.4	-5.7	-4.5	-6.8	-11.3	-14.7	-39.6	-28.4	-42.0	-30.7	-44.3	-33.0	-76.7	-54.4	-79.1	-56.8	-83.8	-61.4	-87.5	-64.9
RCN1218	830-903	-5.1	-24.2	-48.5	0.0	-7.3	-14.4	-6.1	-14.5	-28.7	-37.8	-37.3	-29.8	-44.0	-35.8	-51.5	-41.7	-73.8	-59.0	-82.0	-65.9	-97.2	-77.7	-107.4	-85.5
RCN1548	904-914	-13.0	4.6	9.1	-1.1	-3.2	-5.4	-4.3	-6.4	-10.7	-13.9	-24.4	-10.1	-26.7	-12.2	-28.8	-14.4	-36.8	-8.8	-39.0	-10.9	-43.6	-15.4	-46.8	-18.5
RCN1548	915-920	-13.0	-8.6	-17.2	-1.1	-3.2	-5.4	-4.3	-6.4	-10.7	-13.9	-81.8	-23.0	-83.9	-25.4	-85.7	-27.2	-151.0	-35.2	-153.8	-37.5	-157.7	-41.9	-161.6	-44.8