REPORT

Tonkin+Taylor

Te Tumu Natural Hazard Assessment - Coastal Hazard

Prepared for
Tauranga City Council

Prepared by
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Exceptional thinking together

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1. Introduction

The Te Tumu Urban Growth Area is a 764 ha (approx.) greenfield site located to the east of the Papamoa/Wairakei developed area in Tauranga, Bay of Plenty. The land within the Te Tumu Urban Growth Area is owned by a number of different landowners and is proposed to be converted to residential land use. Tauranga City Council (TCC) is undertaking natural hazard investigations in accordance with Bay of Plenty Regional Council's (BoPRC) Regional Policy Statement (RPS) on natural hazards on behalf of landowners and developers to facilitate a plan change. Tonkin + Taylor (T+T) has been engaged by TCC to a undertake risk assessment in accordance with the RPS for the following natural hazards:

- Coastal Erosion
- Liquefaction
- Tsunami.

The objectives of these natural hazards assessments include identification of the spatial distribution of natural hazard risks by mapping, identification of potential mitigation measures to maintain a low level of risk through the proposed urban development process and to maximise the potentially developable area through these mitigation measures.

In this report coastal erosion hazard has been considered.

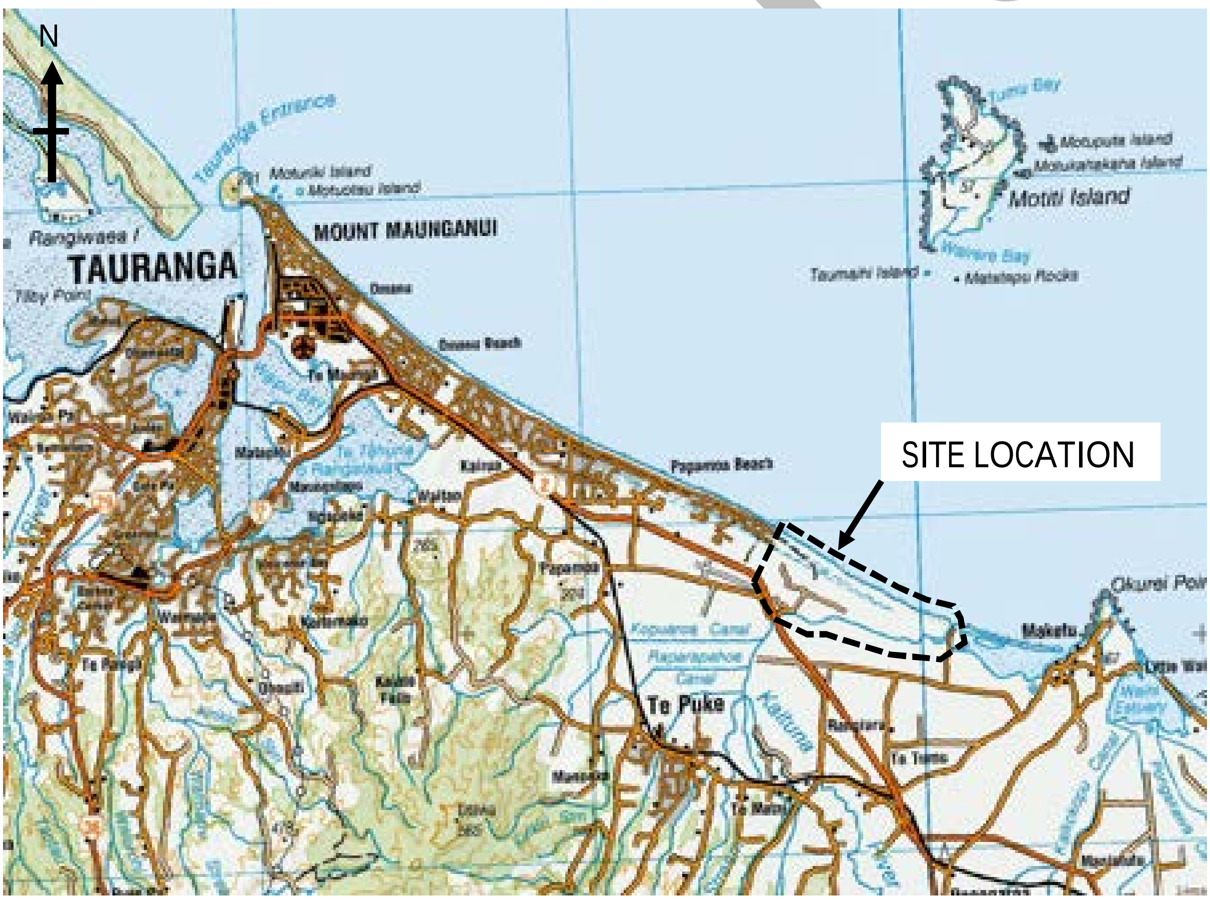

Figure 1.1: Site location

1.1 Scope of work

The following scope of works was required for undertaking a coastal erosion hazard assessment for the proposed urban development area:

- Utilize the T+T methodology developed for WBOPDC recent coastal hazards erosion project
- Produce a susceptibility map and technical report in line with BOPRC RPS requirements

1.2 Site description

The study area is outlined in red in Figure 1.2 and comprises 764 ha (approx.) of existing rural land situated between the Papamoa/Wairakei developed area and Maketu. The Kaituna River is located along the southern and eastern boundary, and Papamoa Beach is located to the north. The topography of the site is undulating, with dune formations running parallel to the shore across the entire site. The top of the dunes range from 7 m RL to 12 m RL in height. There are several ponding areas located in the dune troughs. The largest of these is referred to as the Wairakei Stream, located to the north-west of the site. The existing land use is rural and consists predominantly of pasture with some stands of exotic trees and several rural properties.

Figure 1.2: Site layout (aerial sourced from Google)

1.3 Datum and coordinates

All elevations (levels) within this report are presented in terms of Moturiki Vertical Datum 1953. Coordinates are presented in terms of New Zealand Transverse Mercator (NZTM).

2. Background data

2.1 Previous assessments and existing data

2.1.1 Profile data

The Bay of Plenty Regional Council (BOPRC) and TCC have historically undertaken beach profile surveys from the upper dune down to around the mean sea level contour. BOPRC have two profile locations along Te Tumu beach (CCS33 & CCS35) which have been surveyed annually since 1978 (BOPRC, 2011). TCC have six profile locations along Te Tumu beach however these have only been surveyed quarterly since 2016. A summary of the beach profile dataset for both sites is provided in Table 2.1.

Table 2.1. Summary of beach profile data

Profile Name	Surveys			
	No. of profiles	Start date	Latest survey date	Years
CCS33	36	4/02/1978	10/02/2017	39
CCS35	74	13/04/1978	25/01/2017	28.7
TT1	6	28/01/2016	24/05/2017	1.3
TT2	5	28/01/2016	24/05/2017	1.3
TT3	5	28/01/2016	24/05/2017	1.3
TT4	5	28/01/2016	24/05/2017	1.3
TT5	5	28/01/2016	24/05/2017	1.3
TT6	5	28/01/2016	24/05/2017	1.3

2.1.2 LiDAR data

A 1 m by 1 m DEM was provided by TCC to T+T based on 2011 LiDAR data. LiDAR data was used for determining both dune crest and dune toe elevations. The dune crest elevation is required for calculating the impact of sea level rise on shoreline retreat. The dune crest was digitised based on the DEM and the 2017 aerial image. This process resulted in a 2D GIS polyline of the dune crest alignment. A set of points (sampling locations) were created along the 2D polylines (dune crests) at 5 m spacing to extract the elevations for the dune crest. Each sample point was then assigned the elevation of the DEM cell it fell within. The output is a xyz point file of the dune crest for each cell along the Te Tumu shoreline.

2.2 New data obtained

2.2.1 Site inspection

A site inspection was completed to check that the location of profiles (CCS33 & CCS35) are representative of the surrounding shoreline. The shoreline was also checked for any evidence of recent shoreline erosion and any site characteristics that were not captured from the existing data. Photographs were also taken of the dune within each coastal cell (Appendix C).

2.2.2 Shoreline data

The historical shoreline data was processed from aerial images using standard geo-referencing and digitising GIS methods using ArcGIS software. Available aerial photographs were sourced from BOPRC, TCC and Land Information New Zealand (LINZ). Refer to Table 2.2 for a summary of the historic aerial photographs sourced for this study.

The seaward edge of the dune vegetation was digitised to represent the dune toe, which was taken as the shoreline proxy. This shoreline proxy was chosen because the change in contrast from dune vegetation to beach sand can more accurately be identified on the historic black and white aerial photographs rather than the water line. Verification and quality control focused on the accuracy of the shoreline representation including the position and frequency of the polyline nodes.

This set of shoreline information provides eight time-periods for analysing long-term trends over a 78-year period (1939 - 2017).

Table 2.2. Summary of historic aerial photographs sourced to produce digital shoreline data.

Source	Year
TCC	2017
BOPRC	2014
LINZ	2011
BOPRC	2007
BOPRC	2003
BOPRC	1992
RetroLens	1986
RetroLens	1959
BOPRC	1939

3. Coastal processes

3.1 Water levels

Water levels play an important role in determining coastal erosion hazard both by controlling the amount of wave energy reaching the backshore and causing erosion during storm events and by controlling the mean shoreline position on longer time scales.

Key components that determine water level are:

- Astronomical tides
- Barometric and wind effects, generally referred to as storm surge
- Medium term fluctuations, including El Niño–Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO) effects
- Long-term changes in sea level due to climate change
- Wave transformation processes through wave setup and run-up.

3.1.1 Astronomical tide

Tidal levels for primary and secondary ports of New Zealand are provided by LINZ based on the average predicted values over the 18.6 year tidal cycle. Values for Tauranga in terms of Chart Datum and Moturiki Vertical Datum 1953 (MVD-53 RL) are presented within Table 3.1.

Table 3.1. Tidal levels given for the Port of Tauranga (LINZ, 2017)

Tide state	Chart Datum (m)	(MVD-53 RL)
Highest Astronomical Tide (HAT)	2.13	1.17
Mean High Water Springs (MHWS)	1.94	0.98
Mean High Water Neaps (MHWN)	1.67	0.71
Mean Sea Level (MSL)	1.09	0.13
Mean Low Water Neaps (MLWN)	0.49	-0.47
Mean Low Water Springs (MLWS)	0.14	-0.82
Lowest Astronomical Tide (LAT)	-0.05	-1.01

Source: LINZ Nautical Almanac 2012 -13

3.1.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind set up from winds blowing along or onshore which elevates the water level above the predicted tide (Figure 3.1). Storm-surge applies to the general elevation of the sea above the predicted tide across a region but excludes nearshore effects of storm waves such as wave setup and wave run-up at the shoreline.

A storm surge analysis for the New Zealand coast was done by de Lange (1996) based on measured surges. He found that the maximum expected elevations are in the range of 0.8 to 1 m with a return period of 100 years.

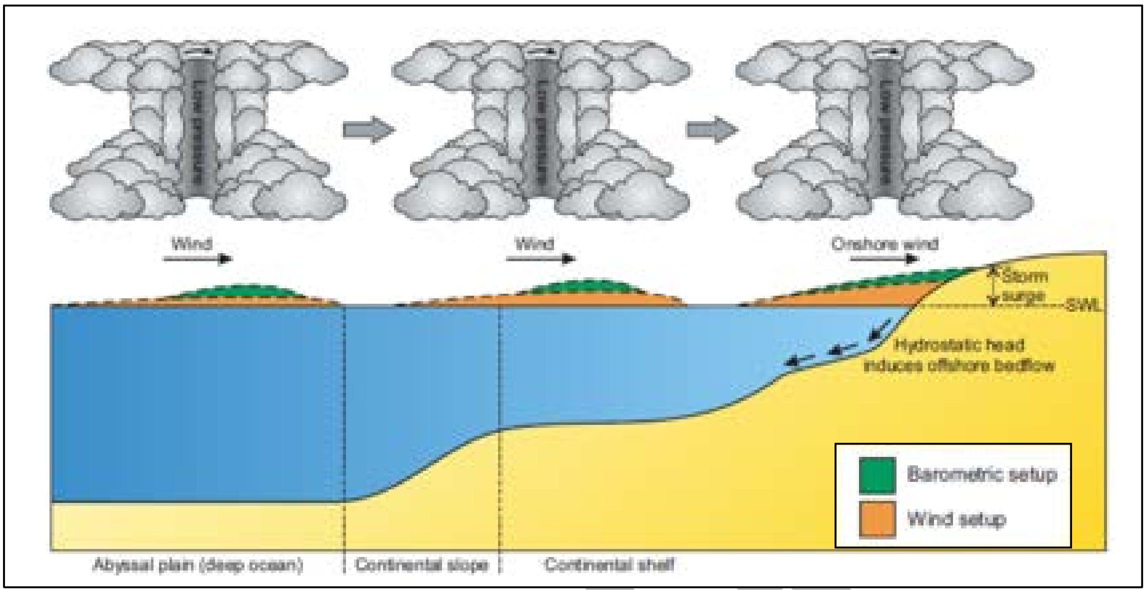

Figure 3.1. Processes causing storm surge (source: Shand, 2010)

3.1.3 Medium term fluctuations and cycles

Atmospheric factors such as season, El Nino-Southern Oscillation (ENSO) and Inter-decadal Pacific Oscillation (IPO) can all affect the mean level of the sea at a specific time (Figure 3.2). The combined effect of these fluctuations may be up to 0.25 m (Bell, 2012).

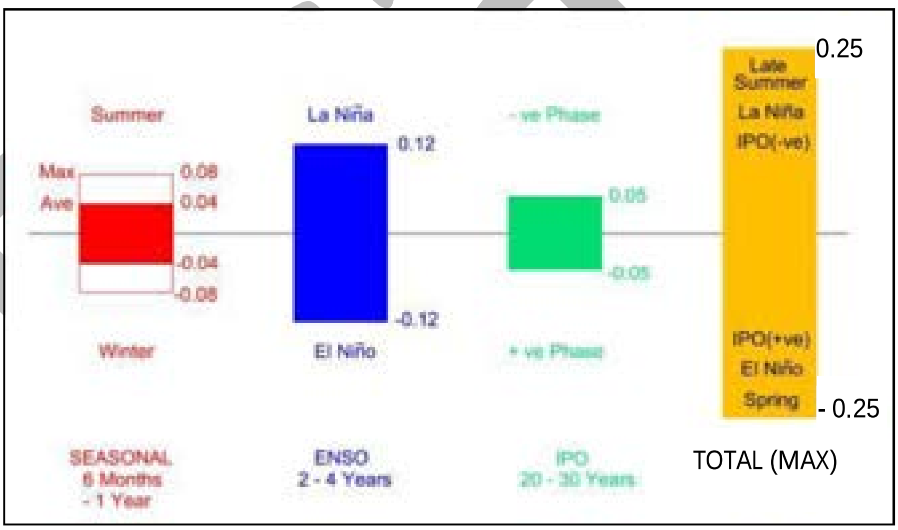

Figure 3.2. Components contributing to sea level variation over long term periods (source: Bell 2012)

3.1.4 Storm tide levels

The combined elevation of the predicted tide, storm surge and medium term fluctuations is known as the storm tide. Extreme storm tide level predicted for the open coast is shown in Table 3.2. The storm tide level is presented for both a 50 year Annual Return Interval (ARI) and a 100 year ARI event.

Table 3.2. Extreme storm tide

Site	Storm tide level (MVD-53 RL)	
	50 year ARI	100 year ARI
Moturiki Island (open coast)[1]	1.78	1.99

[1]Based on NIWA (1997)

3.1.5 Long-term sea levels

Historic sea level rise in New Zealand has averaged 1.7 ± 0.1 mm/yr with Bay of Plenty exhibiting a slightly higher rate of 1.9± 0.1 mm/yr (Bell and Hannah, 2012). Climate change is predicted to accelerate this rate of sea level rise into the future.

Modelling presented within the most recent International Panel of Climate Change (IPCC) report (AR5; IPCC, 2013) show predicted global sea level rise values by 2100 (relative to the 1980-1999 average) to range from 0.27 m to 1 m. The IPCC sea level rise projections range depending on the emission scenario adopted, with the lower bound of 0.27 m being slightly above the rate of rise over the previous 100 years. Extrapolating the RCP8.5 scenario ("business as usual") to 2115 results in a sea level rise in the range from 0.27 to 0.47 m by 2065 and 0.62 to 1.27 m by 2115 (Figure 3.3). The RCP8.5 scenario assumes emissions continue to rise in the 21st century on a "business as usual" scenario. Adopting this scenario is considered prudent until evidence of emission stabilising justify use of a lower projection scenario.

We have used two sea level rise scenarios that are based around two RCP scenarios derived from IPCC (2013). These are the median projection for the RCP8.5 scenario, and the RCP8.5+ projection.

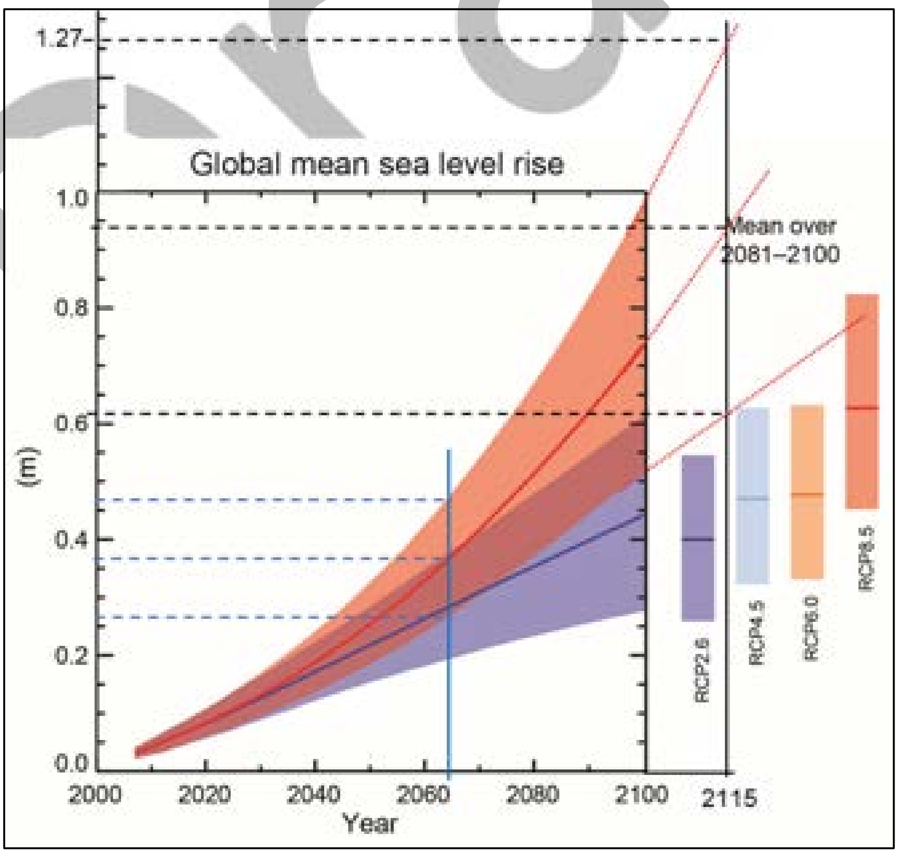

Figure 3.3. Projections of potential future sea level rise presented within IPCC AR5 (IPCC, 2014)

3.2 Waves

Offshore wave data for the Bay of Plenty has been modelled by MetOcean Solutions Ltd. Extreme wave height for the Te Tumu beach section was obtained from MetOcean View (Table 3.3). The 10 year and 100 year Annual Return Interval (ARI) for Te Tumu is used in this study for assessment of storm cut erosion. The 10 year ARI represents a moderate storm event and a 100 year ARI represents a more extreme event.

Table 3.3. Significant wave height

Site	Extreme wave height (m)[1]	
	10 year ARI	100 year ARI
Te Tumu	5.7	7.3

[1]Source: hindcast.metoceanview.com

4. Methodology

4.1 Stochastic forecast approach

The methodology used in this study combines standard and well-tested approaches for defining coastal erosion hazard zones by addition of component parameters (Gibb, 1978; T+T, 2004; 2006; 2012; CSL, 2008, 2012) but rather than including single values for each component and a factor for uncertainty, parameter bounds are specified for each parameter and combined by stochastic simulation. The resulting distribution is a probabilistic forecast of potential hazard zone width.

The method is based on the premise that uncertainty is inherent in individual components due to an imprecise understanding of the natural processes and due to alongshore variability within individual study cells. Stochastic simulation allows the effect of these uncertainties to be explored simultaneously providing estimates of the combined hazard extent (i.e. the central tendency) and information on potential ranges and upper limit values. This contrasts with deterministic models where the combination of individual conservative parameters with additional factors for uncertainty often result in very conservative products and limited understanding of potential uncertainty range.

The stochastic method is described in Cowell et al. (2006). The methods used to define probability distribution functions (pdfs) for each parameter are described within the parameter descriptions below. Where pdfs are not defined empirically (i.e. based on data or model results), simple triangular distributions have been assumed with bounding (minimum and maximum) and modal parameters. These triangular distributions can be constructed with very little information yet approximate a normal distribution (Figure 4.1.A) and permit flexibility in defining range and skewed asymmetry. Figure 4.1.B also shows the output displayed in cumulative distribution format (cdf).

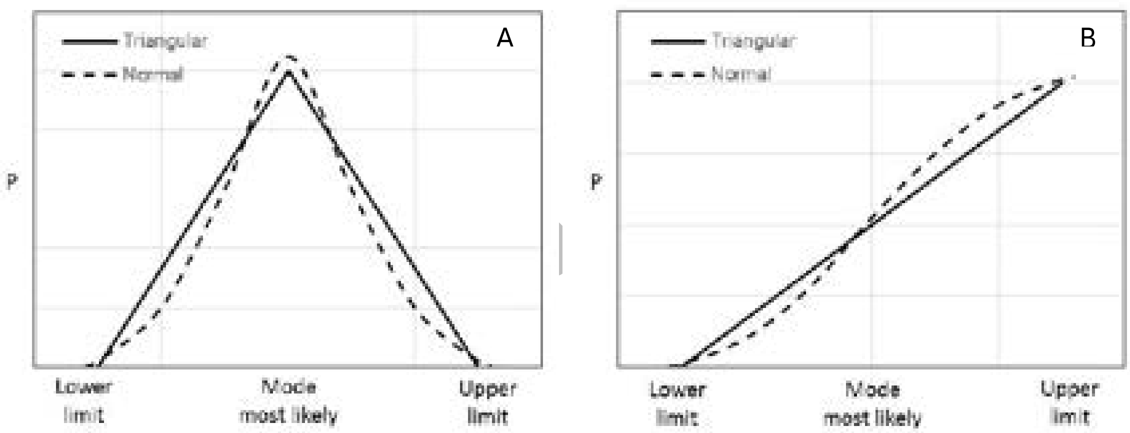

Figure 4.1. Example triangular and normal pdf (A) and cdf (B)

4.2 Defining coastal behaviour cells

The Te Tumu coastline has been divided into 8 coastal cells (A-H) based on shoreline behaviour which can influence the resultant hazard. Four components are defined in Equation 4-1 (presented below) and are calculated separately for each cell. Factors which may influence the behaviour of a cell and which are the basis for the cell division include:

- cell morphology and lithology
- exposure
- profile geometry
- backshore elevation

- historical shoreline trends.

Table 4.1. shows the chainage for each individual cell as a spatial reference point. Chainage is a distance measurement from a fixed point taken at the north western end of the site. The cell types along the Te Tumu shoreline have been identified as either dune or inlet. The dune cell type represents the majority of the Te Tumu shoreline which is characterised by a foredune and sloping sandy beach. One cell at the south-eastern end of the Te Tumu shoreline (cell H) has been defined as an inlet cell type due to its proximity to the Kaituna River mouth. Inlet cells represent shorelines that typically fluctuate more over time due to fluvial processes. The inlet cell was assessed using the same methodology to delineate the coastal erosion hazard zone, except the baseline was taken as the inlet migration curve (IMC) rather than the 2017 dune toe. The IMC is the maximum inland extent of shoreline fluctuation (envelope) over the extent of the cell (refer to Section 4.4).

Table 4.1. Cell divisions for Te Tumu shoreline

Cell	Cell Type	Chainage (m from NW end)
A	Dune	0-1620
B	Dune	1620-2220
C	Dune	2220-2560
D	Dune	2560-2840
E	Dune	2840-4220
F	Dune	4220-5240
G	Dune	5240-6000
H	Inlet	6000-6180

4.3 Coastal erosion hazard methodologies

Coastal erosion hazard methodologies differ slightly for unconsolidated beaches, cliffs and estuarine shorelines. The entire Te Tumu shoreline can be characterised as an unconsolidated beach. The method for unconsolidated beach shorelines is expressed in Equation 4-1, where the CEHZ is established from the cumulative effect of four main parameters (Figure 4.2.):

$$CEHZ_{Beach} = ST + DS + \left(LT \times T\right) + SL \qquad (4\text{-}1)$$

Where:

ST = Short-term changes in horizontal shoreline position related to storm erosion due to singular or a cluster of storms events or fluctuations in sediment supply and demand, beach rotation and cyclical changes in wave climate (m)

DS = Dune stability allowance. This is the horizontal distance from the base of the eroded dune to the dune crest at a stable angle of repose (m)

LT = Long term rate of horizontal coastline movement (m/yr)

T = Timeframe (years)

SL = Horizontal coastline retreat due to the effects of increased mean sea level (m).

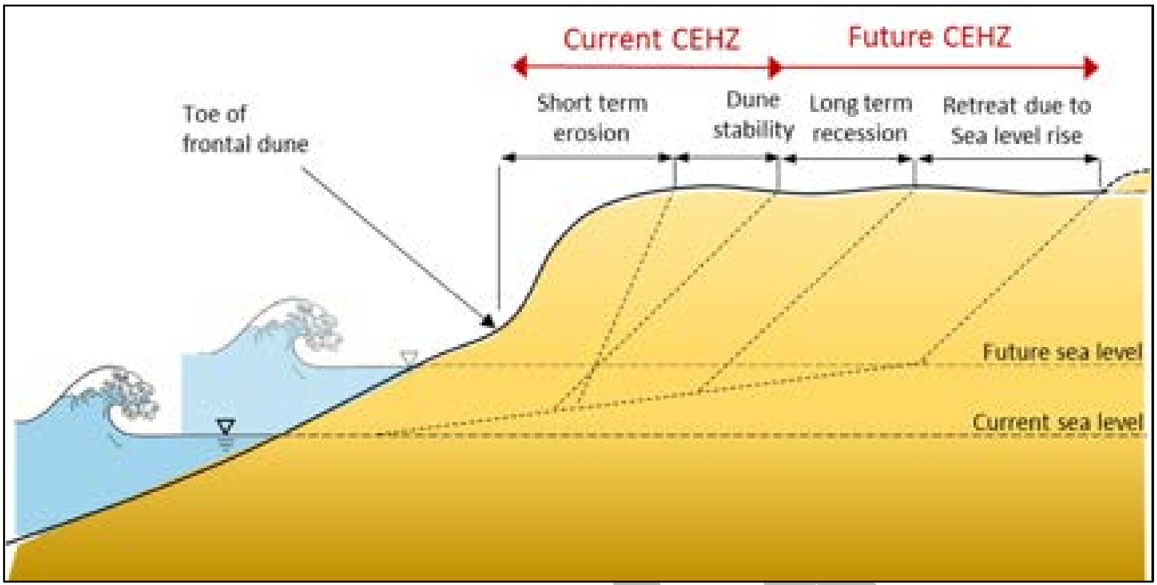

Figure 4.2. Definition sketch for open coast CEHZ

The $CEHZ_{Beach}$ baseline to which values are referenced is the most recent dune toe derived from site survey data or LiDAR, except in some cases of dynamic inlets or spits where the maximum inland extent of fluctuation (envelope) may be adopted (i.e. Shand, 2012). This has been considered on a site-by-site basis and will be discussed within the site-specific assessments.

4.4 Component derivation

4.4.1 Future time horizon scenario (T)

Three future time horizon scenarios were applied to provide information on current hazards and information at sufficient time scales for planning and accommodating future development:

- 2017 coastal erosion hazard zone (Current)
- 2130 coastal erosion hazard zone (110 years)
- 2150 coastal erosion hazard zone (130 years)

4.4.2 Short-term (ST)

Short-term effects apply to non-consolidated beach and estuary coastlines where rebuilding follows periods of erosion. These effects include changes in horizontal shoreline position due to storm erosion caused by singular or clusters of storms events, or seasonal fluctuations in wave climate or sediment supply and demand.

The short-term coastline movements can be assessed from analysis of:

- Existing information sources such as previous reports and anecdotal evidence
- Statistical analysis of shoreline position obtained from aerial photographs or beach profile analysis
- Numerical assessment of storm erosion potential

4.4.2.1 Anecdotal or experience-based

Existing information presented within previous studies has often been derived based on anecdotal or field evidence or experience. Where no better information is available, these existing values may be retained.

The NERMN beach profile monitoring 2011 report (BOPRC, 2011) discusses how at CCS33 the profile history shows significant retreat of the frontal dune position (approximately 6 metres of landward movement between 2002 and 2004). At CCS35 the profile shows stability in the upper beach section with episodic development in the berm. Gibb (1994) shows that between 1903 and 1994 there has been a long-term trend of shoreline retreat of approximately 14 m, ranging from 6 to 22 m, with short-term fluctuations of 10 to 20 m increasing to 30 to 50 m near the Kaituna River mouth.

4.4.2.2 Semi-process based methods

Erosion of the upper beach is dependent on the energy able to reach the backshore, the duration of exposure to that energy and the erodibility of the upper beach material. The energy able to reach the backshore is dependent on water level and the offshore profile which controls wave breaking and energy dissipation. Both of these parameters change over the duration of a storm event.

Semi-process based model description

The numerical cross-shore sediment transport and profile change model SBEACH (Storm Induced BEAch CHange) (Larson and Kraus, 1989) has been used to define storm cut volumes and horizontal movement of the dune toe. SBEACH considers sand grain size, the pre-storm beach profile and dune height, plus time series of wave height, wave period, water level in calculating a post-storm beach profile. Model development involved extensive calibration against both large scale wave tank laboratory data and field data. SBEACH has been verified for measured storm erosion on the Australian east coast (Carley, 1992; Carley et al. 1998). Bay of Plenty east coast beaches, including Te Tumu are subject to similar wave climate and storm events as the Australian east coast and the model is therefore considered applicable for this site.

Model input

A representative cross-shore profile from the dune crest to the RL -10 m contour was assessed for each coastal cell based on average profile surveys information.

Design storm nearshore time series including wave height, period and water level are applied at the outer profile boundary (Figure 4.3). Design storms for 10 year, 100 year and 2x100 year return period events are simulated with the later allowing for potential clustering of storms. Such clustering may result in greater erosion as the first event lowers the beach height and relatively greater wave energy may reach the backshore in subsequent events.

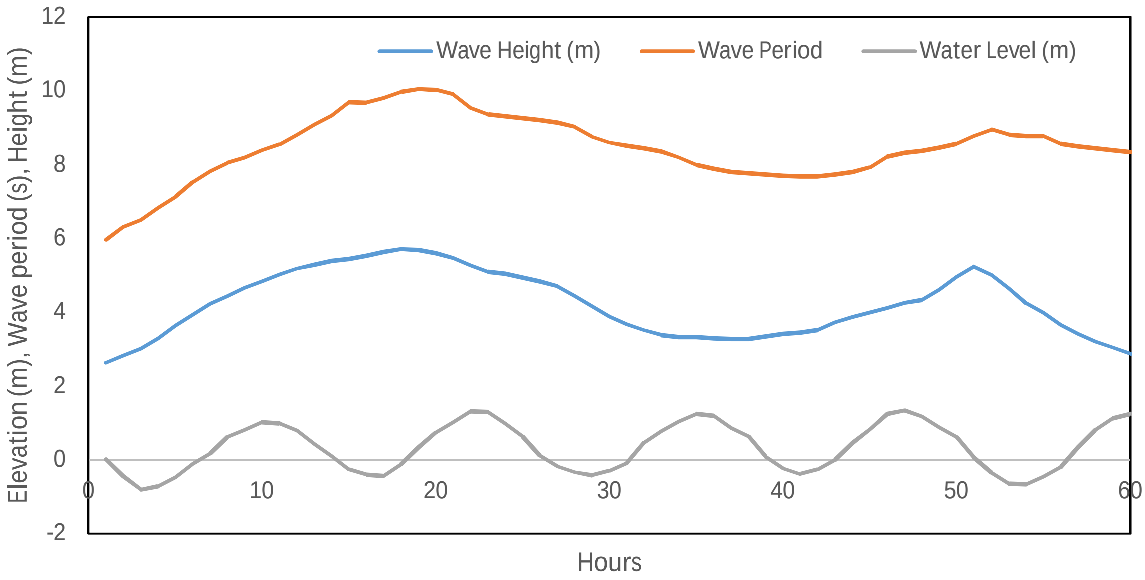

Figure 4.3. Example synthetic 100 year design storm input for Te Tumu.

Model results

SBEACH assumes an equilibrium profile concept which instantly responds to the present wave forcing conditions and calculates an equilibrium profile based on that forcing. Figure 4.4 shows the initial and equilibrium profiles formed due to 10 and 100 year storms for Te Tumu. Changes in horizontal shoreline position at a predefined contour (i.e. the dune toe) provide information on short-term erosion distances. For Te Tumu, these distances are 5 metres and 15 metres for the 10 year and 100 year storm, respectively (Figure 4.4).

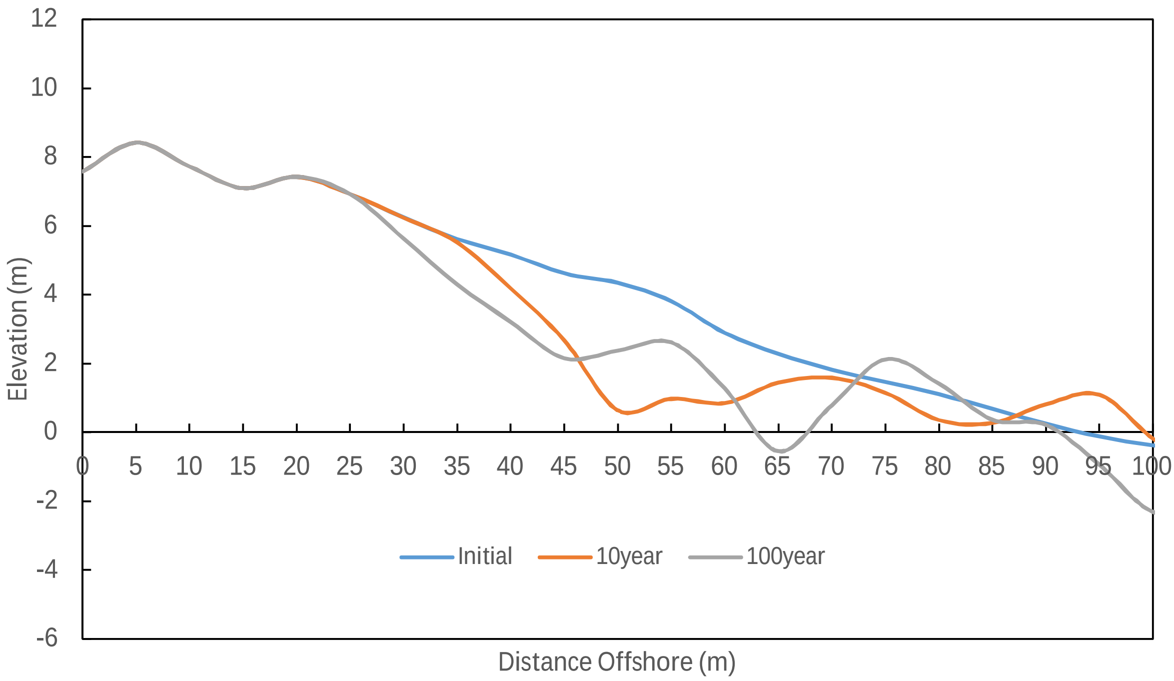

Figure 4.4. Example of SBEACH output for 10 year and 100 year storm events.

4.4.2.3 Statistical methods

The horizontal position of shorelines derived from aerial photographs or contours (typically MHWS) extracted from profile analysis can be used where available to assess short-term fluctuation.

The Beach Morphology Analysis Package (BMAP) has been used to calculate the change in horizontal shoreline position per surveyed beach profile. BMAP is an integrated set of computer analysis routines compiled at the U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Centre (CERC) for analysing beach profile morphology and its change (Larson and Kraus 1992).

Figure 4.5. shows an example of the available (36 surveyed) beach profiles for Te Tumu (CCS33). The excursion of the RL 3 m contour, has been assessed in BMAP to provide a plot of contour position over time (Figure 4.6.). While this plot provides some information on trends the data sets are generally too short to inform the long-term components. The data is therefore de-trended to remove any long-term effects leaving residual excursion distances (Figure 4.7).

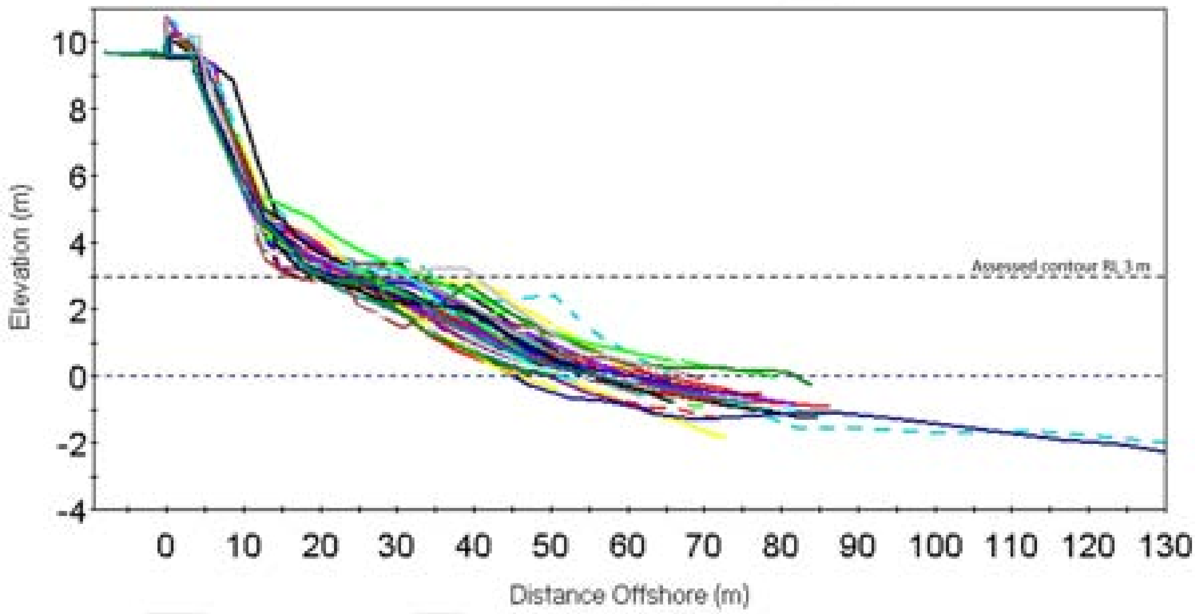

Figure 4.5. Example beach profiles for Te Tumu.

The standard deviation of residual describes the spread of the excursion distances. Previous work by T+T (T+T, 2004; T+T 2006) found that the distribution of annual residual shoreline movement could be considered to be approximately normally distributed. The values at 1 standard deviation (SD), 2 x SD and 3 x SD from the mean will have corresponding annual probabilities of occurrence of 16%, 2.5%, and 0.5% respectively.

With sufficient data, these may be interpreted as the bounding and modal parameters of the short-term fluctuation parameter. However, without frequent survey data, particularly immediately following storm events, it is likely that the maximum impact of storms is omitted as some beach recovery will occur before the next regular survey or aerial photographic record.

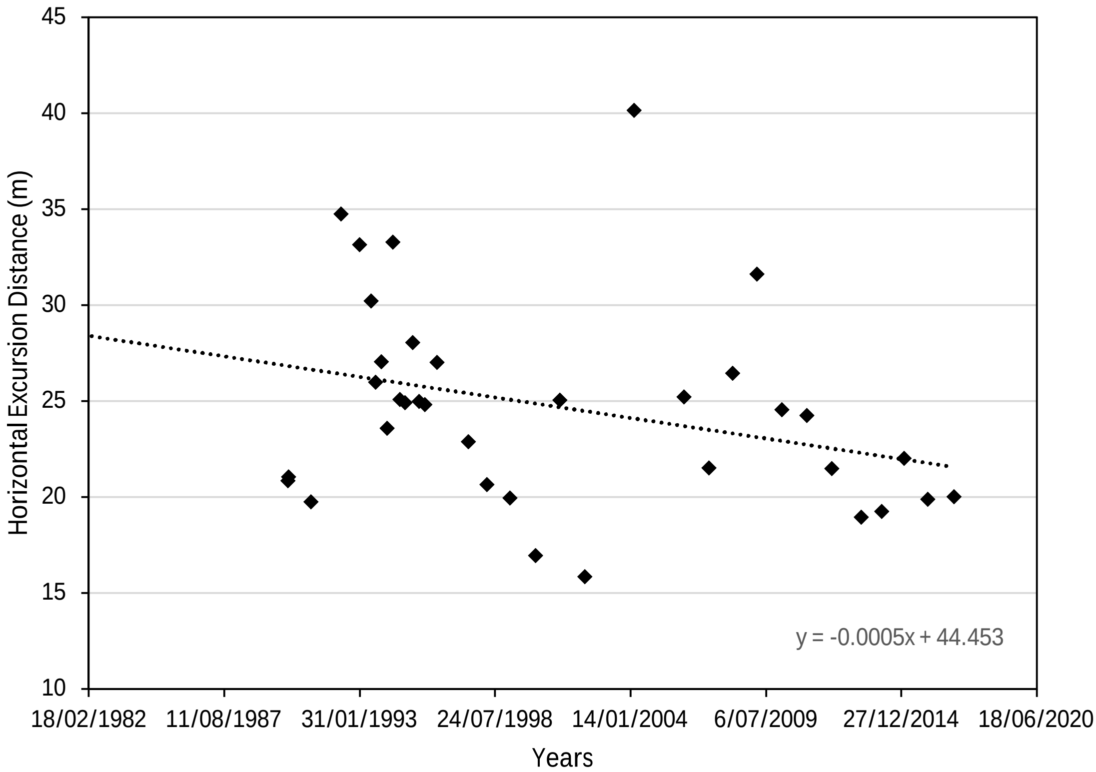

Figure 4.6. Example Linear Regression for Te Tumu.

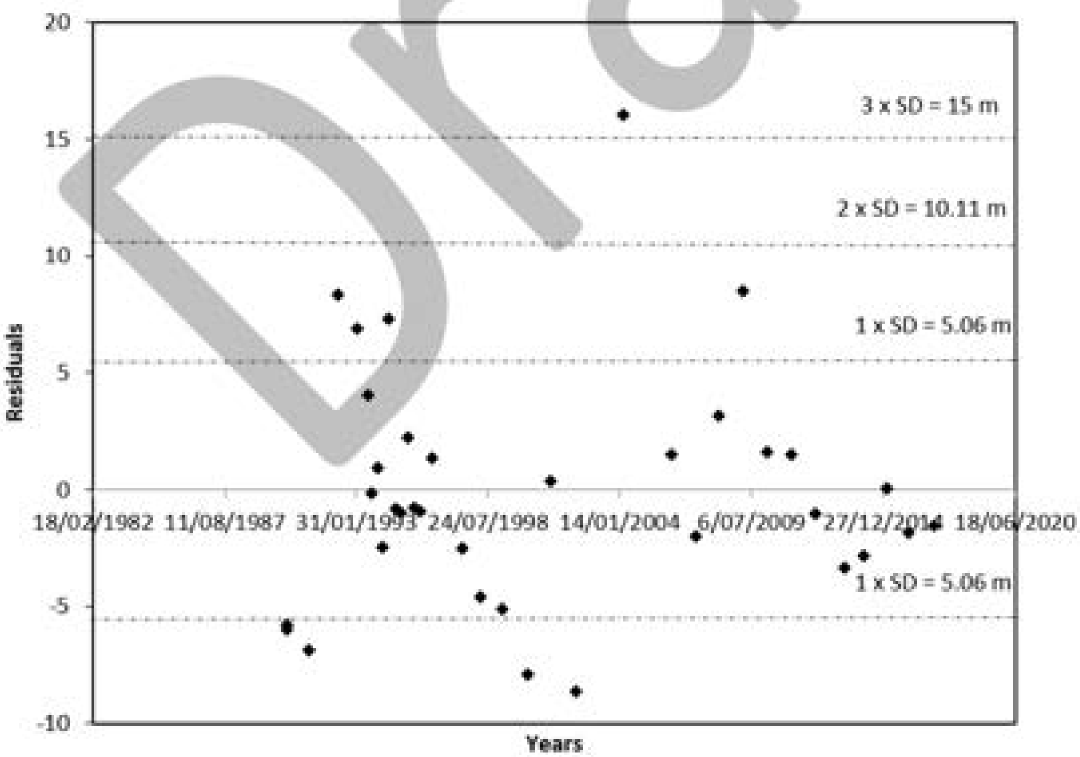

Figure 4.7. Example contour excursion residuals (de-trended) for Te Tumu.

4.4.3 Dune stability

The dune stability factor delineates the area of potential risk landward of the erosion scarp by buildings and their foundations. The parameter assumes that storm erosion results in an over-steepened scarp which must adjust to a stable angle of repose for loose dune sand. The dune stability width is dependent on the height of the existing backshore and the angle of repose for loose dune sand. This has been obtained from an examination of historic reports, a review of the beach profile data and our assessment of the beach sediments obtained in this study. The dune stability factor is outlined below:

$$DS = \frac{H_{dune}}{2(\tan \alpha_{sand})} \qquad (4\text{-}5)$$

Where H_{dune} is the dune height from the eroded base to the crest and α_{sand} is the stable angle of repose for beach sand (ranging from 30 to 34 deg). In reality, dune scarps will stand at steeper slopes due to the presence of binding vegetation and formation of talus slope at the toe, however, these have been ignored for the present assessment as any development immediately landward of the scarp and within the area defined by the formula may still be vulnerable. Parameter bounds are defined based on the variation in dune height along the coastal behaviour cell and potential range in stable angle of repose.

4.4.4 Long-term trends (LT)

The long-term rate of horizontal coastline movement includes both ongoing trends and long-term cyclical fluctuations. These may be due to changes in sea level, fluctuations in coastal sediment supply or associated with long-term climatic cycles such as IPO.

Long-term trends have been evaluated by the analysis of the historic shoreline positions. These have been derived from geo-referenced historic aerial photographs, augmented with cadastral surveys and surveyed dune toe data obtained in the first phase of this study.

The shoreline data has been analysed using Matlab, where shoreline change statistics are calculated at 20 m intervals along each site. Rates of long-term shoreline movement are derived using weighted linear regression analysis with the 90% confidence intervals providing bounding values for the parameter distribution (WCI) (Figure 4.8.). In a weighted linear regression, more reliable data (lower error values) are given greater emphasis or weight towards determining a best-fit line. By calculating trends along the entire shoreline, rather than at a low number of discrete points, alongshore variation in trends can be determined and either used to inform parameter bounds or separated into separate coastal behaviour cells.

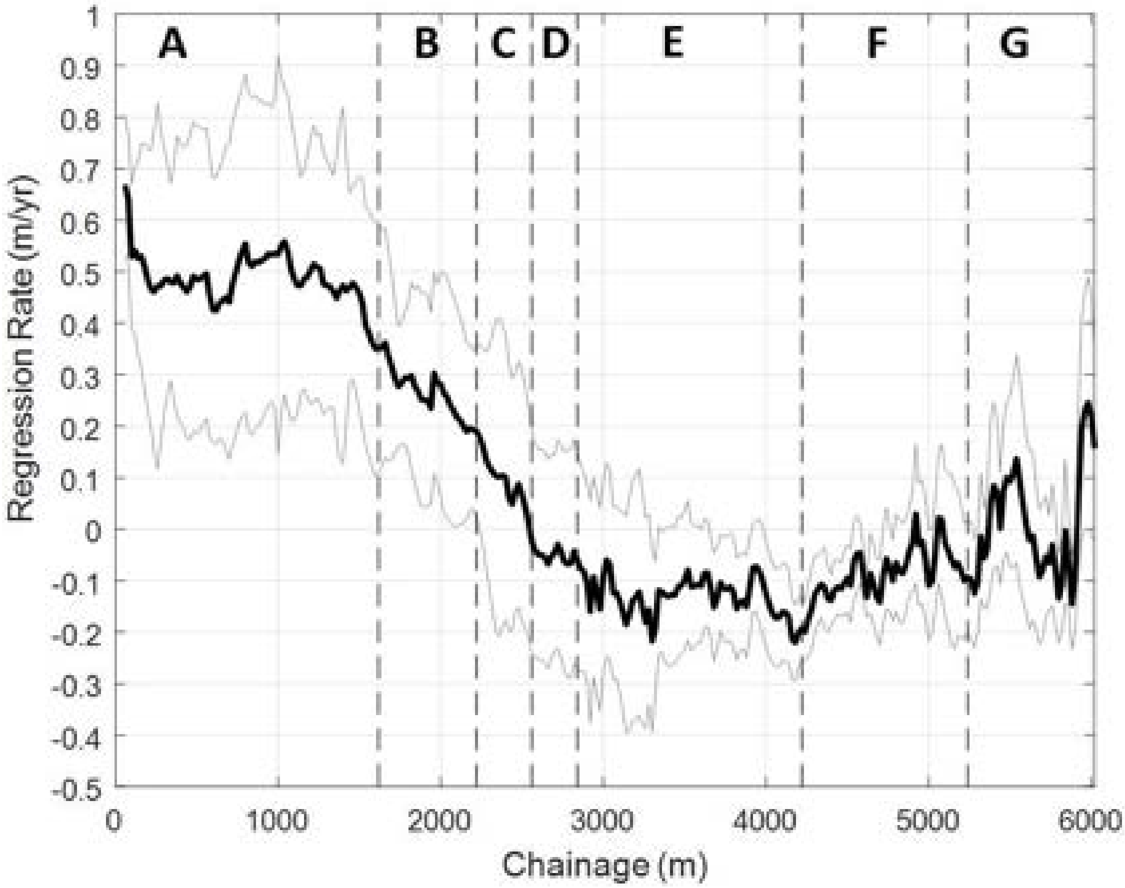

Figure 4.8. Example of regression results for Te Tumu with coastal cells indicated by letter A to G. Light grey lines represent 90% confidence intervals.

4.4.5 Effects of sea level rise (SLR)

4.4.5.1 Adopted SLR values

We have adopted two SLR values over the two required timeframes (i.e. 110 and 130 years). For the year 2130 the SLR value projected for the RCP8.5 (median) scenario is used and for the year 2150 the SLR value projected for the RCP8.5+ scenario is used (Table 4.2.).

An average historic rate of sea level rise of 1.9 mm/year has been deducted from the adopted sea levels for use in this assessment on the basis that the existing long term trends and processes already incorporate the response to the historic situation. Table 4.2. presents the sea level values used in this present assessment.

Table 4.2. Sea levels (m) utilised in assessment.

Year	SLR projections (metres above 1986–2005 baseline MSL)[1]	SLR corrected to baseline year (meters above 2017 baseline MSL)[2]
2130 RCP8.5 *M* (median)	1.18	1.10
2150 RCP8.5+ *M* (median)	1.88	1.80

[1]Source: NIWA (2015) referencing IPCC (2013) Assessment Report 5

[2]Correction of 0.08m applied to adjust for observed sea level from 1995 to 2017 (present day).

4.4.5.2 Beach response

Geometric response models propose that as sea level is raised, the equilibrium profile is moved upward and landward conserving mass and original shape (Figure 4.9). The most well-known of these geometric response models is that of Bruun (Bruun, 1962, 1988) which proposes that with increased sea level, material is eroded from the upper beach and deposited offshore to a maximum depth, termed closure depth. The increase in sea bed level is equivalent to the rise in sea level and results in landward recession of the shoreline. The model may be defined by the following equation:

$$SL = \frac{L_*}{B + d_*} S \qquad (4\text{-}6)$$

Where SL is the landward retreat, d_* defines the maximum depth of sediment exchange, L_* is the horizontal distance from the shoreline to the offshore position of d_*, B is the height of the berm/dune crest within the eroded backshore and S is the sea level rise.

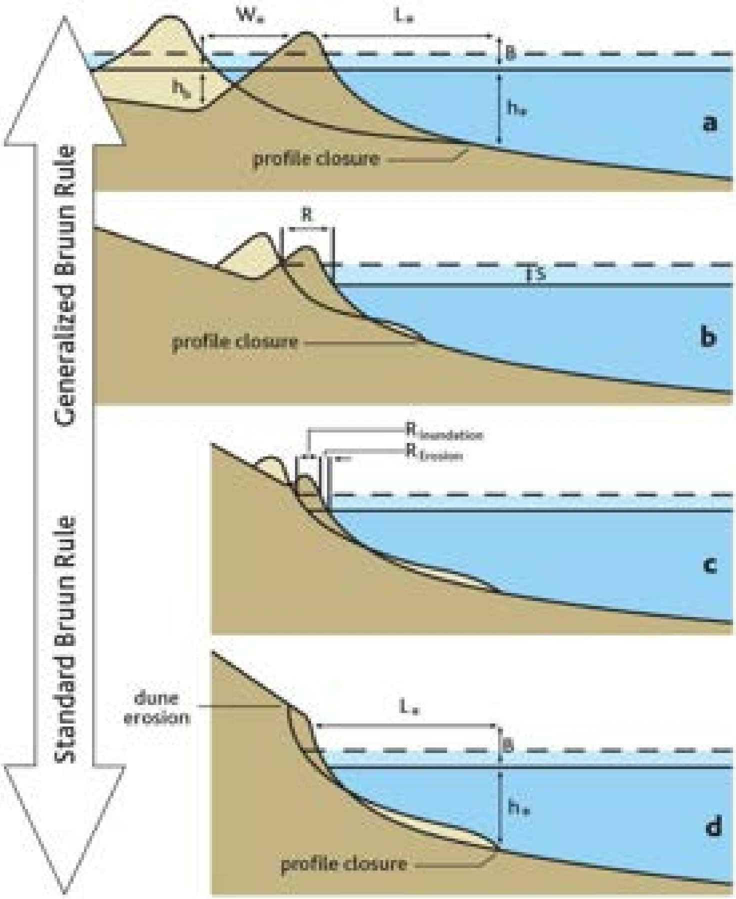

Figure 4.9. Schematic diagrams of the Bruun model modes of shoreline response (after Cowell and Kench, 2001)

The rule is governed by simple, two-dimensional conservation of mass principles and assumes no offshore or onshore losses or gains and an instantaneous profile response following sea level change. The rule assumes an equilibrium beach profile where the beach may fluctuate under seasonal and storm-influences but returns to a statistically average profile (i.e. the profile is not undergoing long-term steepening or flattening). Losses or gains to the system and changes to the equilibrium profile are likely accounted for within the long-term change parameter (LT) (Section 4.4.4) and therefore are not likely to introduce additional uncertainty. The definition of a closure depth (maximum seaward extent of sediment exchange) and the lag in response of natural systems have been cited as significant limitations in the method (Hands, 1983).

The inner parts of the profile exposed to higher wave energy are likely to respond more rapidly to changes in sea level. For example, Komar (1999) proposes that the beach face slope is used to predict coastal erosion due to individual storms. Deeper definitions of closure including extreme wave height-based definitions (Hallermeier, 1983), sediment characteristics and profile adjustment records (Nicholls et al., 1998) are only affected during infrequent large-wave events and therefore may exhibit response-lag.

Shand et al. (2013) argue that as sea level rise is expected to be ongoing, then the outer limit of profile adjustment is likely to be 'left behind' before it can reach equilibrium. The closure depth can therefore be more realistically defined as the point at which the profile adjustment can 'keep up' with sea-level change and becomes a calibration parameter in lieu of an adequate depth-dependent lag parameter. Shand et al. (2013) tested a range of closure depth definitions against a non-equilibrium model calibrated using 30 years of beach data (Ranasinghe et al., 2011). Results (Figure

4.10.) show the various definitions of closure to predict Recession/SLR values straddling the entire probabilistic (2 – 99%) range predicted by the Ranasinghe's probabalistic model.

To define parameter distributions, the Bruun rule estimates using the outer Hallermeier closure depth definition (di) have been adopted as upper bound values, estimates using the inner Hallermeier closure definition (dl) provides the modal (most likely) values, and results using the beach face slope (Komar, 1999) provide the lower (almost certain) bounds. The beach face is defined by the average mean low water spring position and average beach crest height. The Hallermeier closure definitions are defined as follows (Nicholls et al., 1998):

$$d_l = 2.28H_{s,t} - 68.5(H_{s,t}^2 / gT_s^2) \cong 2 \times H_{s,t} \quad (4\text{-}7)$$

$$d_i = 1.5 \times d_l \quad (4\text{-}8)$$

Where d_l is the closure depth below mean low water spring, $H_{s,t}$ is non-breaking significant wave height exceeded for 12 hours in a defined time period, nominally one year, and T_s is the associated period.

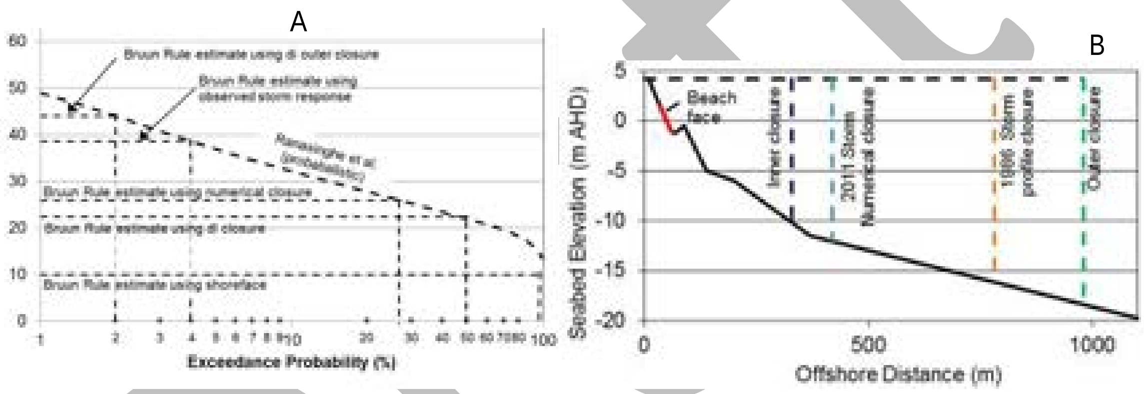

Figure 4.10. Probabilistic estimate of relative coastal recession at Narrabeen Beach (from Ranasinghe et al., 2011) with Bruun Rule estimates (A) using a variety of closure estimators (B).

An exception to this are the non-consolidated shorelines within estuaries or beaches perched on rock platforms where the beach and fronting material do not interact. In this case, the beach slope above the intersection of the beach and fronting platform is adopted. This is consistent with the principles described in the eShorance estuary shoreline response model (Stevens and Giles, 2010).

4.5 Anthropogenic effects

Human influences on coastal erosion hazard assessments can include:

- Construction of land protection works (seawalls/revetments, etc.)
- Mining and removal of beach sand, or nourishment
- Concentration of storm water and surface flows down cliff and bank faces
- Modification of dune vegetation

The Te Tumu shoreline currently shows little evidence of anthropogenic modification. There has been the establishment of exotic pines along the back dune area at the south-eastern end. Based on the aerial photographs these pines were established between 1992 and 2003.

Due to the current undeveloped state behind the dune, there has been minimal human foot traffic through the frontal dune area. However vehicle traffic is evident along this section of the coast.

Modifications to natural dune vegetation can alter dune recovery patterns following storm events.

4.6 Combination of parameter components to derive CEHZ

For each coastal cell, the relevant parameters influencing the CEHZ and parameter bounds have been defined according to the methods described above as summarised in Table 4.3. Probability distributions constructed for each parameter are randomly sampled and the extracted values used to define a potential CEHZ distance. This process is repeated 10,000 times using a Monte Carlo technique and probability distribution of the resultant CEHZ width is forecast.

Table 4.3. Theoretical erosion hazard parameter bounds

Parameter	Lower bound	Mode	Upper Bound
ST (m)	10% AEP storm cut or 1 x standard deviation (SD) of contour excursion	1% AEP storm cut or 2 x SD	2 x 1% AEP cut or 3 x SD or existing ST value
DS (m)	H_{max} & α_{min}	H_{mean} & α_{mean}	H_{min} & α_{max}
LT (m/yr)	-90% CI of regression trend	Mean regression trend	+90% CI of regression trend
Closure slope	Slope across active beach face to typical swash excursion	Slope from dune crest to inner Hallermeier depth	Slope from dune crest to outer Hallermeier closure depth

Figure 4.11. presents an example component and CEHZ histogram cumulative distribution functions for Te Tumu Cell E at 2130. Results show the possible coastal erosion hazard distance (R) to range from 25 to 83 m, with a $P_{50\%}$ (50% probability of exceedance) value of 51 m. The $P_{5\%}$ (5% probability of exceedance) is 66 m, which is substantially below the maximum extent.

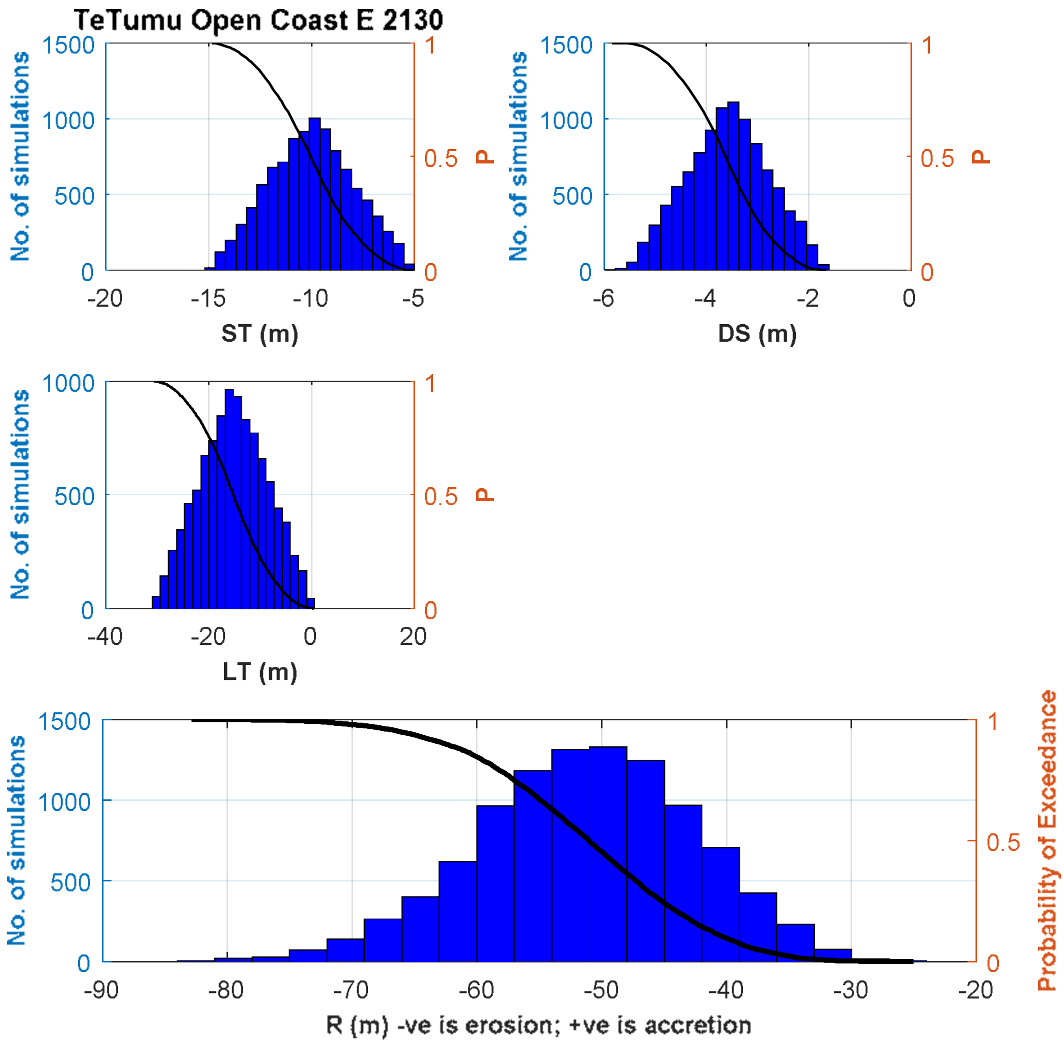

Figure 4.11. An example component and CEHZ histogram cumulative distribution functions for Te Tumu at 2130

4.7 Mapping of the CEHZ

Coastal erosion hazard zones are mapped as offsets to the existing baseline. Figure 4.11. shows the range of CEHZ values for Te Tumu Cell E at the year 2130. Where the hazard values differ between adjacent coastal cells, the mapped CEHZ is merged over a distance of at least 10 x the difference between values providing smooth transitions, or along contours or material discontinuities where these are present.

4.8 Uncertainties and limitations

Uncertainty may be introduced to the assessment by:

- An incomplete understanding of the parameters influencing the coastal erosion hazard zone
- An imprecise description of the natural processes affecting (and the subsequent quantification of) each individual parameter
- Errors introduced in the collection and processing of data

- Variance in the processes occurring within individual coastal cells

Of these uncertainties, the alongshore variance of individual coastal cells may be reduced by splitting the coast into continually smaller cells. However, data such as beach profiles are often available only at discrete intervals, meaning increasing cell resolution may not necessarily reduce these uncertainties. Computational and resource limitations also restrict the practical number of cell divisions. We believe we have refined the cells as far as practical based on factors which could significantly affect the results. Residual uncertainty may be allowed for by selecting a lower probability CEHZ value.

The first two components are being continually developed within coastal research fields. However, there is generally a lag time between scientific developments, and their use in practical assessment as they are refined, tested and made generically applicable. This assessment has used relatively new techniques by incorporating probabilistic assessment of parameters.

Similarly, numerical models are beginning to better resolve the physical processes responsible for coastal erosion. However, complex models are computationally expensive and heavily reliant on quality, long-term data. Without such data, complex model results are largely meaningless. We have attempted to balance the use of numerical modelling where useful (wave and beach response) with analytical and empirical assessment to ensure results are robust and sensible.

Uncertainties in individual parameter components will reduce as better and longer local data is acquired, particularly around rates of short- and long-term shoreline movement and shoreline response to SLR. Data collection programmes such as beach profiling are essential to reducing this uncertainty and should be continued.

5. Erosion hazard assessment

5.1 Component values

Components have been assessed for each coastal cell based on the data and methodologies described in the preceding sections. Adopted components are presented for each cell within Table 5.1.

Table 5.1. Component values for erosion hazard assessment

Site		Te Tumu							
Cell		A	B	C	D	E	F	G	H
Cell centre (NZTM)	E	1896362	1897247	1897625	1897871	1898551	1899630	1900432	1900805
	N	5819421	5818781	5818525	5818346	5817907	5817279	5816873	5816621
Chainage, m (from N/W)		0-1620	1620-2220	2220-2560	2560-2840	2840-4220	4220-5240	5240-6000	6000-6180
Morphology		Dune	Dune	Dune	Dune	Dune	Dune	Dune	Inlet
Short-term (m)[1]	Min	5	5	5	5	5	5	5	0
	Mode	10	10	10	10	10	10	10	0
	Max	20	20	20	15	15	15	15	0
Dune elevation (m above toe)	Min	1.50	3.10	3.20	2.30	2.08	2.82	3.17	2.98
	Mode	2.57	4.70	4.11	3.41	4.42	4.76	5.47	5.65
	Max	3.55	6.50	6.31	5.42	6.92	6.47	7.52	7.6
Stable angle (deg)	Min	30	30	30	30	30	30	30	30
	Mode	32	32	32	32	32	32	32	32
	Max	34	34	34	34	34	34	34	34
Long-term (m/yr) -ve erosion +ve accretion	Min	0.22	0.10	-0.16	-0.26	-0.27	-0.18	-0.15	0
	Mode	0.49	0.29	0.09	-0.05	-0.13	-0.08	-0.02	0
	Max	0.75	0.47	0.33	0.16	0.01	0.01	0.12	0
Closure slope (beaches)	Min	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.062
	Mode	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.062
	Max	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.062

[1] Short-term changes in horizontal shoreline position

[2] Long term average rate of horizontal coastline movement

5.2 CEHZ values

A summary of the CEHZ values is presented in Table 5.2. and values are mapped with respect to the adopted 2017 baseline. These lines are presented within Appendix A and are provided in digital form. The present day CEHZ values represent the current erosion hazard from short term storm erosion (ST), plus the dune stability factor (DS). The CEHZ values for 2130 and 2150 represent the future erosion hazard, taking into account the short term storm erosion (ST), the dune stability factor (DS), plus the long-term erosion trends (LT) and the effect from sea level rise (SL) (section 4.3).

Table 5.2. Coastal erosion hazard zones for the three scenarios (Present Day, Year 2130 and Year 2150).

	Present Day (2017)		Year 2130		Year 2150	
			SLR Scenario RCP8.5 (median)[1]		SLR Scenario RCP8.5+[1]	
Cell	50% (m)	5% (m)	50% (m)	5% (m)	50% (m)	5% (m)
A	-13	-19	18	-8	9	-27
B	-15	-21	-8	-29	-20	-52
C	-15	-21	-30	-54	-47	-82
D	-13	-16	-42	-61	-59	-85
E	-14	-17	-51	-66	-69	-92
F	-14	-17	-45	-59	-63	-85
G	-14	-18	-39	-54	-55	-78
H	-4	-6	-19	-20	-29	-31

[1]See Section 4 for SLR scenario definitions and values.

5.3 Discussion

The 5% exceedance distance for the 2150 RCP8.5+ scenario represents the greatest erosion distance along the entire Te Tumu shoreline, with shoreline retreat ranging from 27 to 92 m. The greatest erosion is likely to occur within cell E, with the shoreline 'most likely' to move 69 m landward from its current position and 'possibly' 92 m landward by 2150. At the western end of the shoreline (Cell A and B) there is currently a long term accretion trend, whereas at the eastern end there is a long term erosion trend. This difference in long term trends can most likely be explained by the difference in exposure to wave energy. The western end of the Te Tumu shoreline is in the lee of Motiti Island, hence it has slightly lower wave energy and greater sediment accretion compared to the eastern end of the shoreline.

For most of the coastal cells the future CEHZs (2130 and 2150) are further landward than the current day CEHZ. This is because the future scenarios include the effect of long-term shoreline trends (LT) and sea level rise (SL), whereas the current day scenario only includes the effect from short term storm erosion and the dune stability factor. Within the cells where there is a long term erosion trend, the shoreline is expected to continue eroding. Furthermore, the impact of SLR on future scenarios also results in the shoreline shifting further landward.

Cell A differs from the other seven cells as the 'most likely' CEHZ for the current day scenario is further landward than the 'most likely' CEHZ for the future scenarios (2130 and 2150). This is because the long term trend within Cell A shows accretion. Although the future CEHZs within Cell A also take into account the impact of SLR, the impact from the long term accretion trend is likely to counteract any recession due to SLR.

6. Proposed Te Tumu development

The coastal erosion hazard zones have been overlaid over the proposed Te Tumu development plan to identify if there are any parts of the proposed development that may be subject to a coastal erosion hazard. By the year 2150 there is approximately 1.06 hectares of land within proposed development areas that may be subject to future coastal erosion (a plan is shown in Appendix D).

The areas within the proposed development that may be subject to potential coastal erosion hazard are only highlighted under the Year 2150 (5% probability of exceedance) scenario considered in this assessment. Under no other scenarios analysed do areas of proposed development intersect with the coastal erosion hazard zones. The Year 2150 (5% probability of exceedance) intersects the area for proposed development at the edge of the Landowner F and Landowner G areas (within the coastal cells E, F, G and H). Although there are these small sections of the proposed development within the 2150 erosion zone, there is only 5% probability that the shoreline will erode to this extent and hence it is considered 'very unlikely' that such a situation would occur, within the scenarios modelled.

7. Applicability

This report has been prepared for the exclusive use of our client Tauranga City Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Rebekah Haughey	[Type name here]
Coastal Scientist	[Title]

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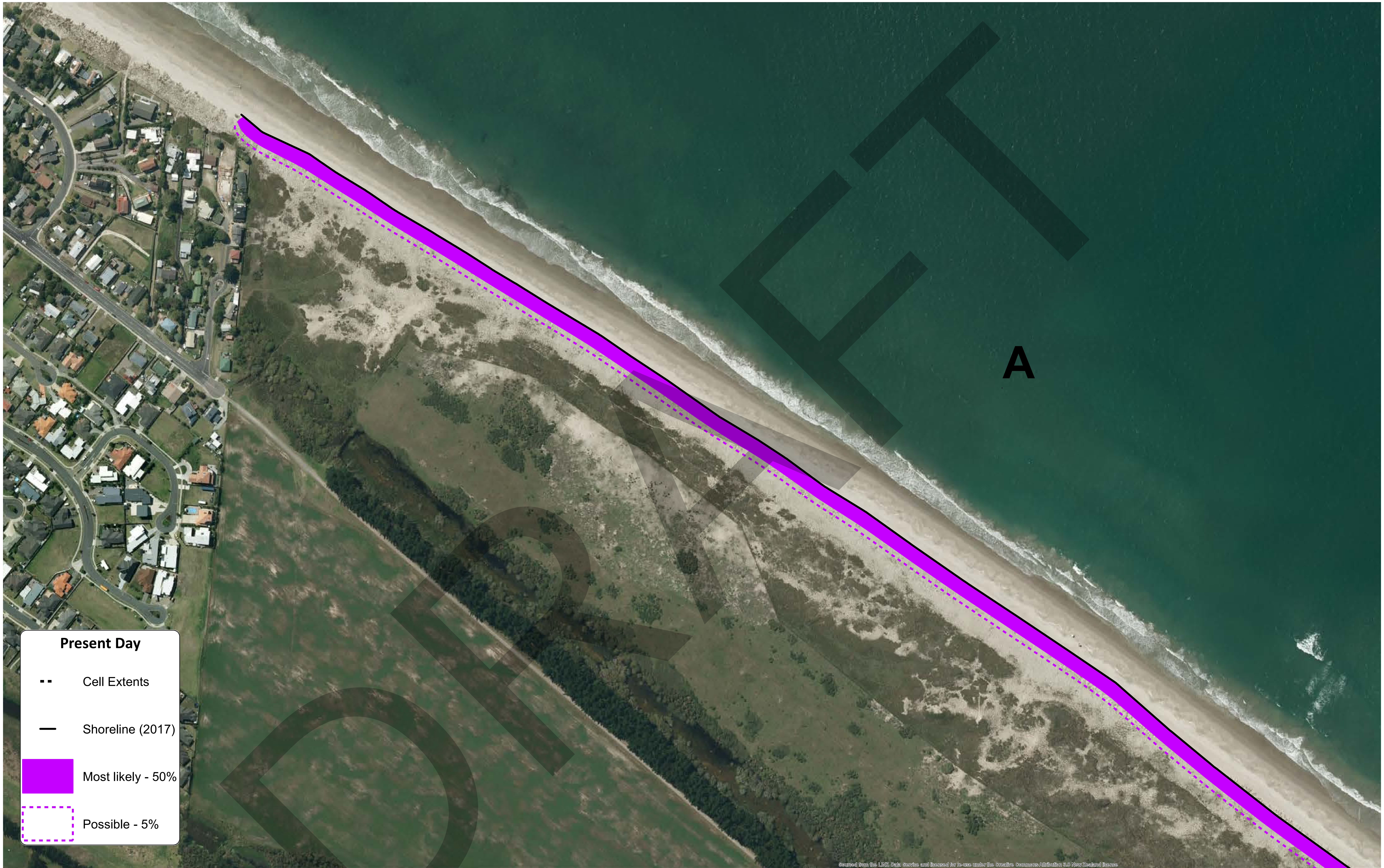
Appendix A: Coastal erosion hazard zones



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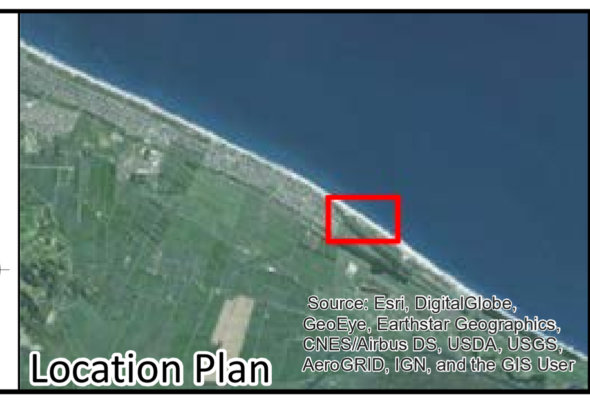

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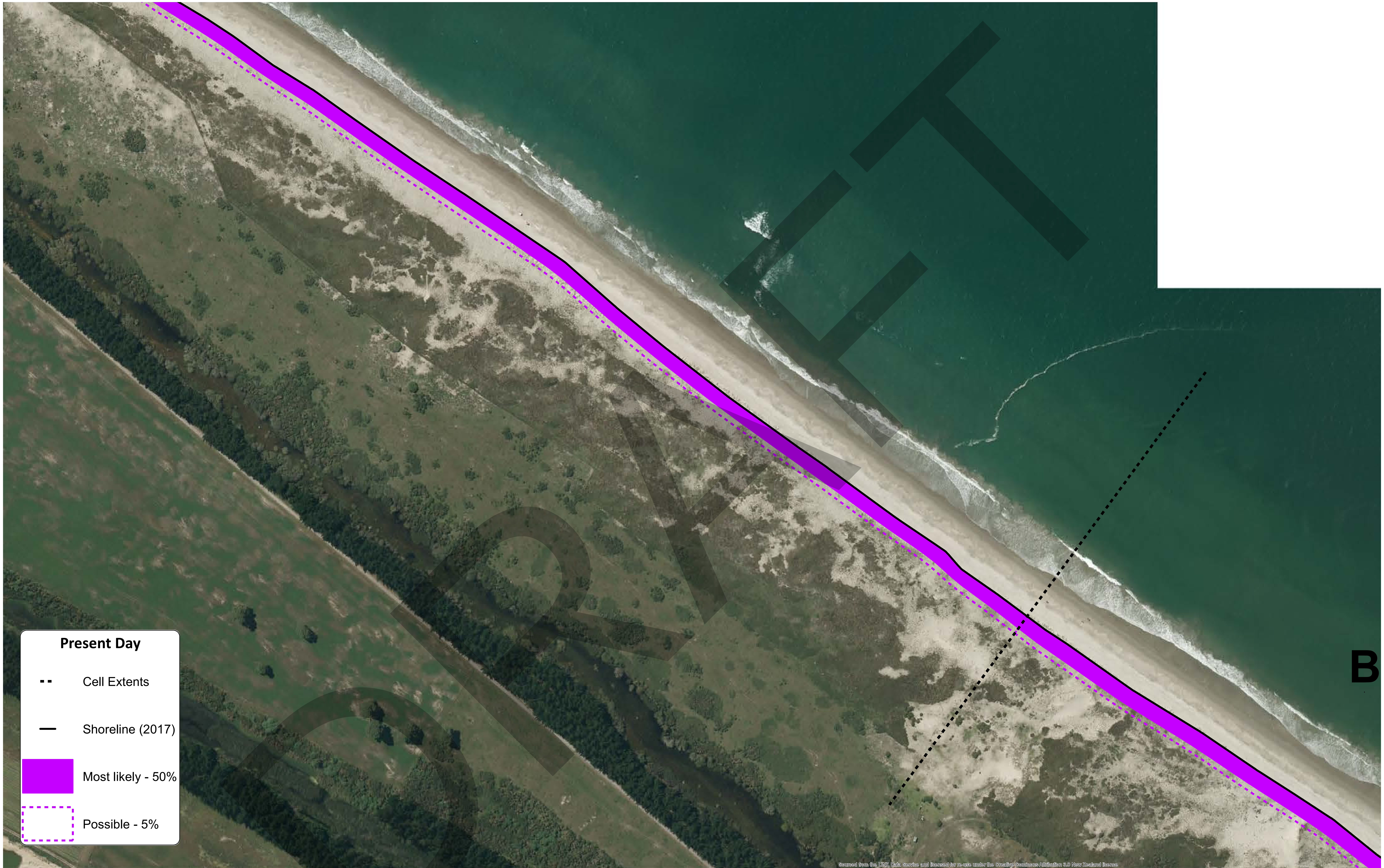

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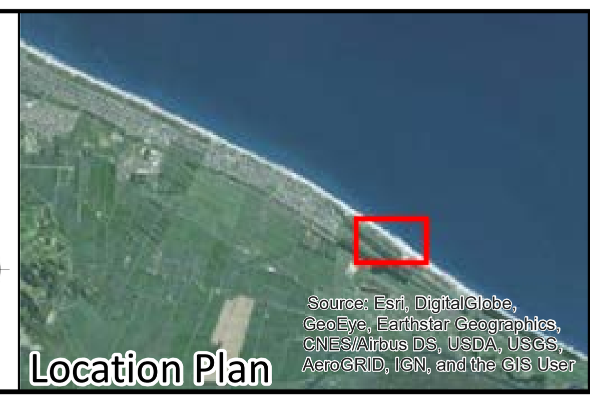

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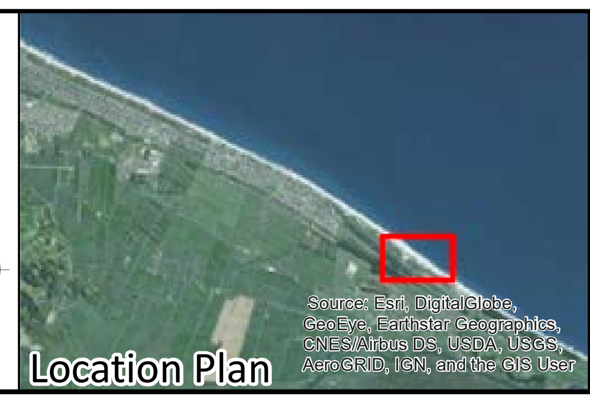

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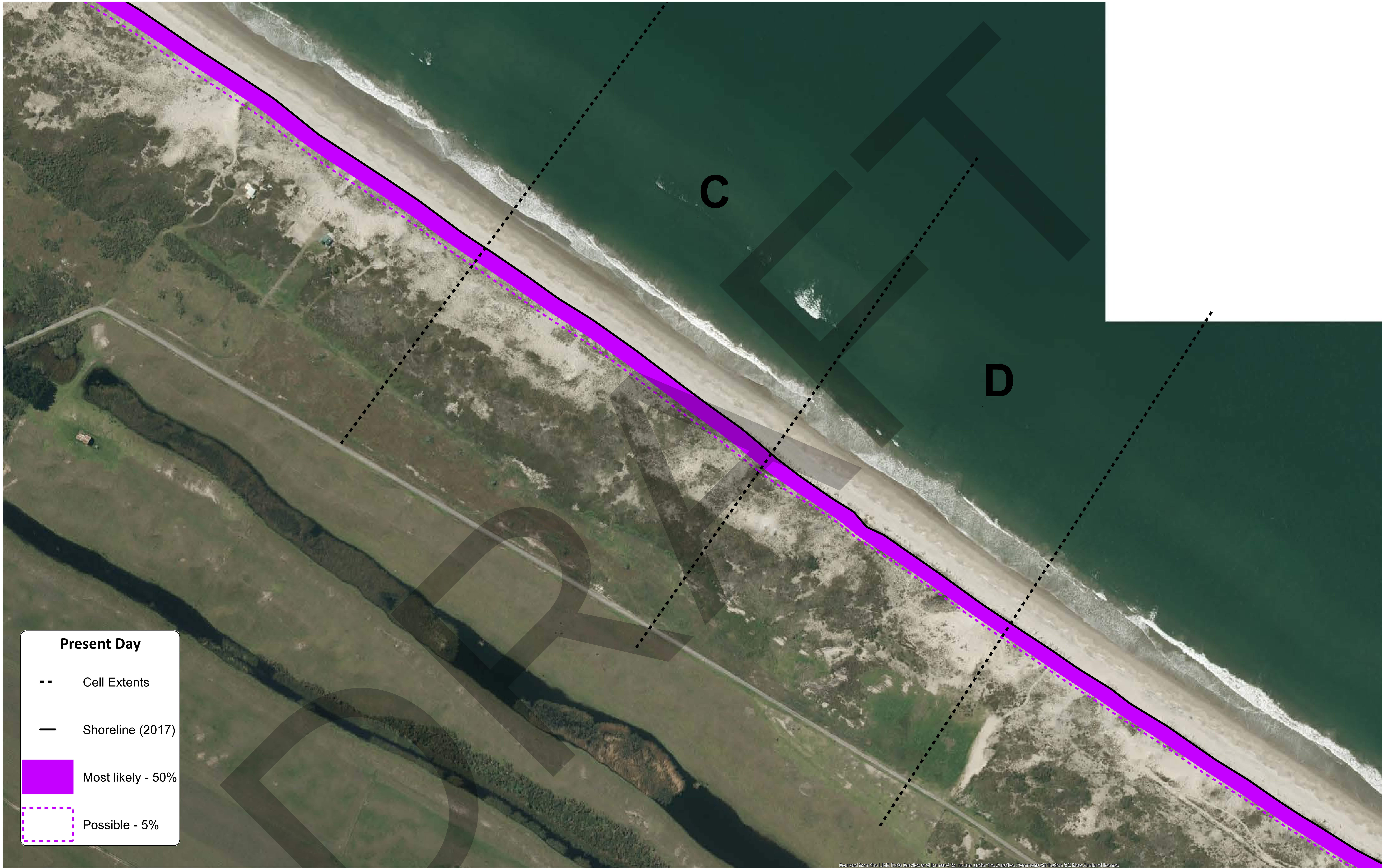

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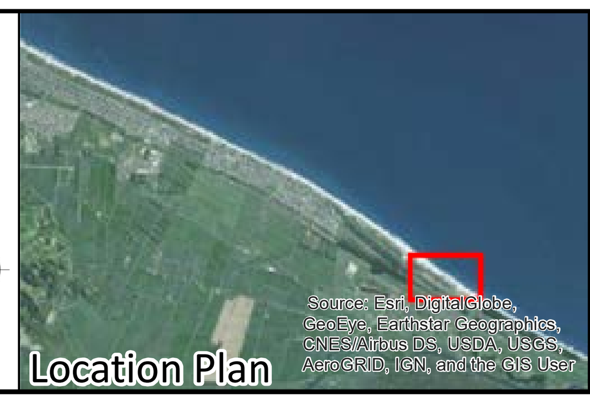

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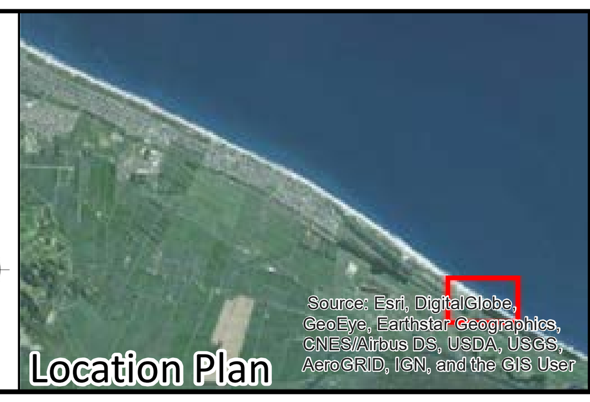

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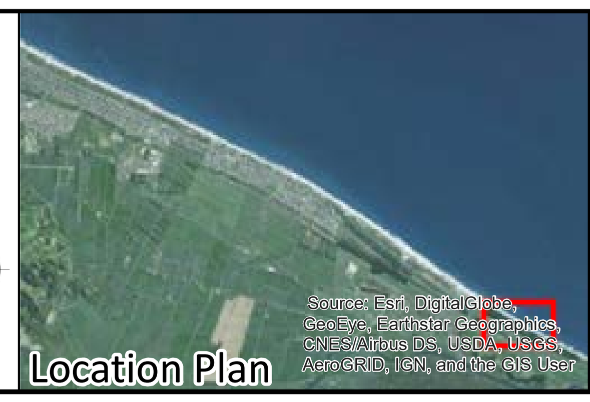

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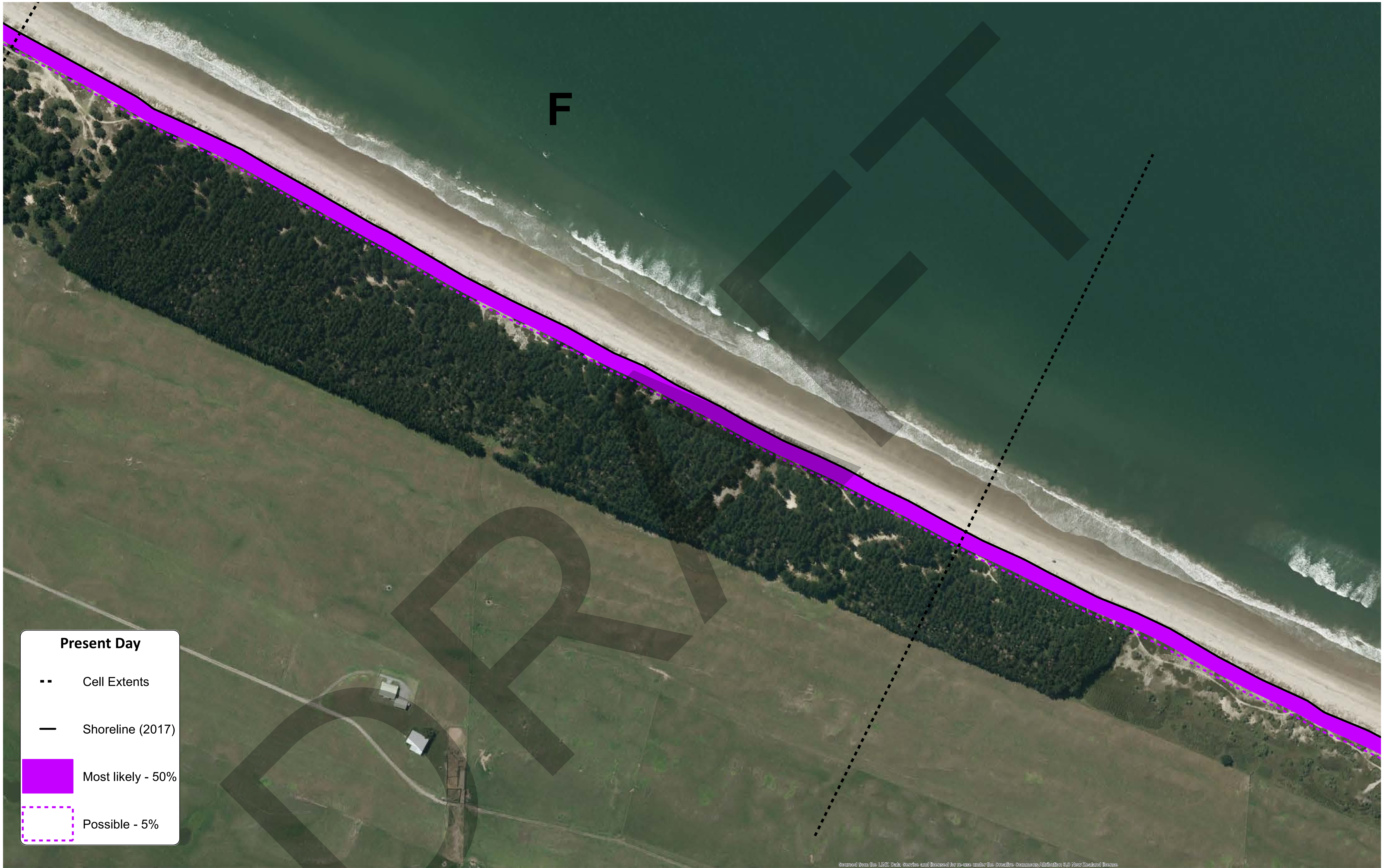

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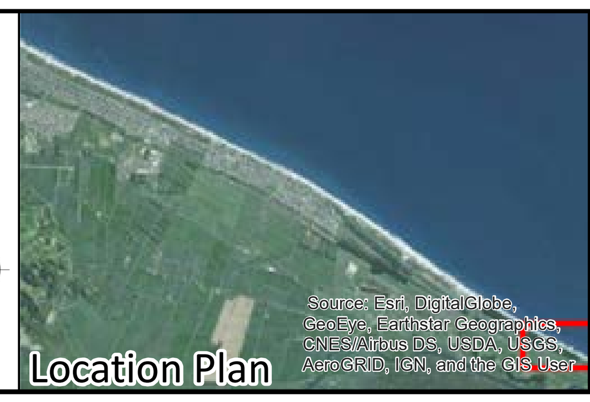

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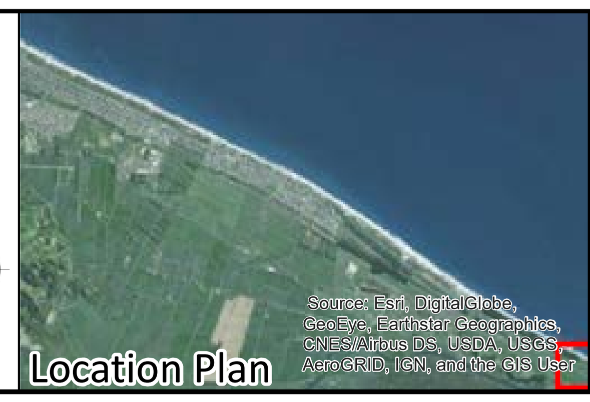

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Coastal Erosion Hazard Assessment

Te Tumu Urban Development

FIGURE No. Figure 1.8

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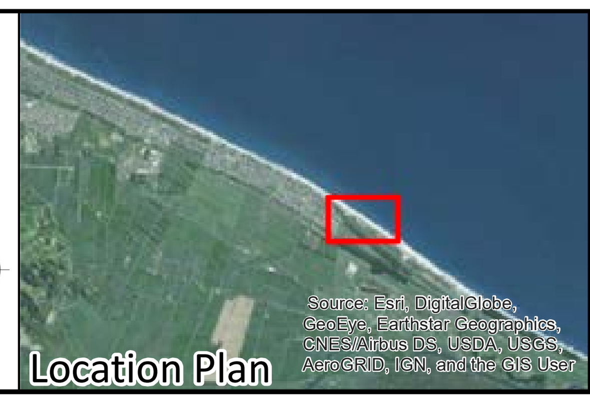

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Sheet: 1

FIGURE No. Figure 1.1

Rev. 0

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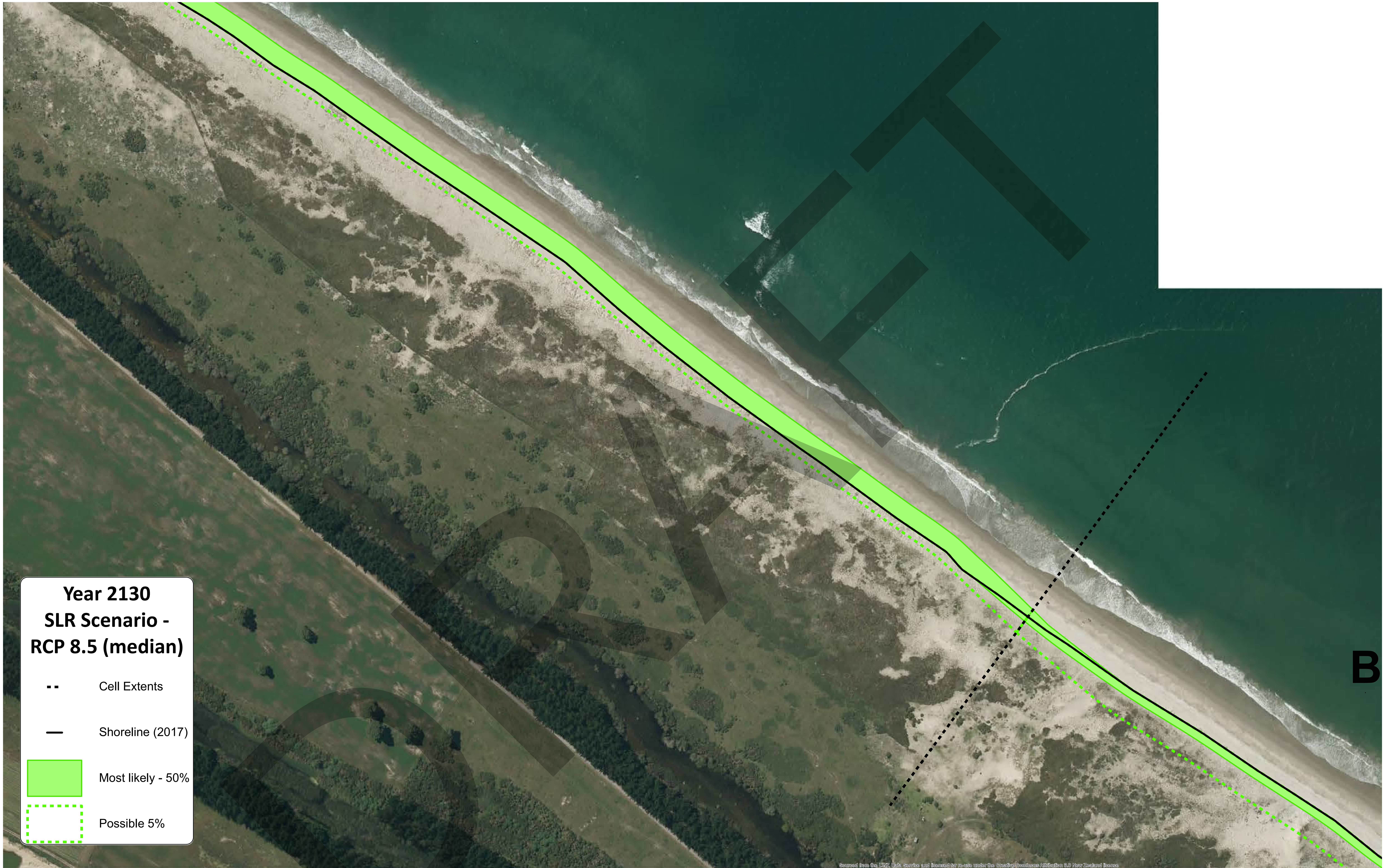

Notes: Aerial photograph........

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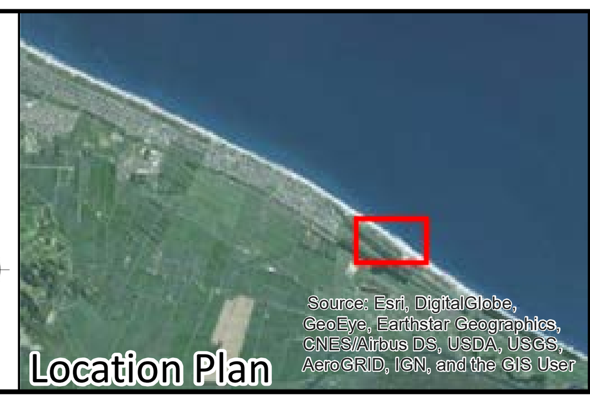

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Coastal Erosion Hazard Assessment

Te Tumu Urban Development

Sheet: 2

FIGURE No. Figure 1.2

Rev. 0

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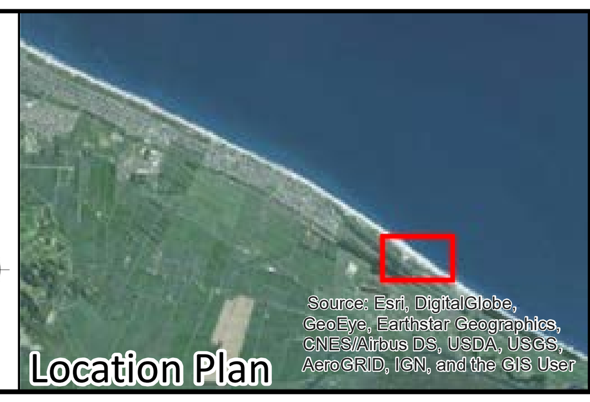

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Coastal Erosion Hazard Assessment

Te Tumu Urban Development

Sheet: 3

FIGURE No. Figure 1.3

Rev. 0

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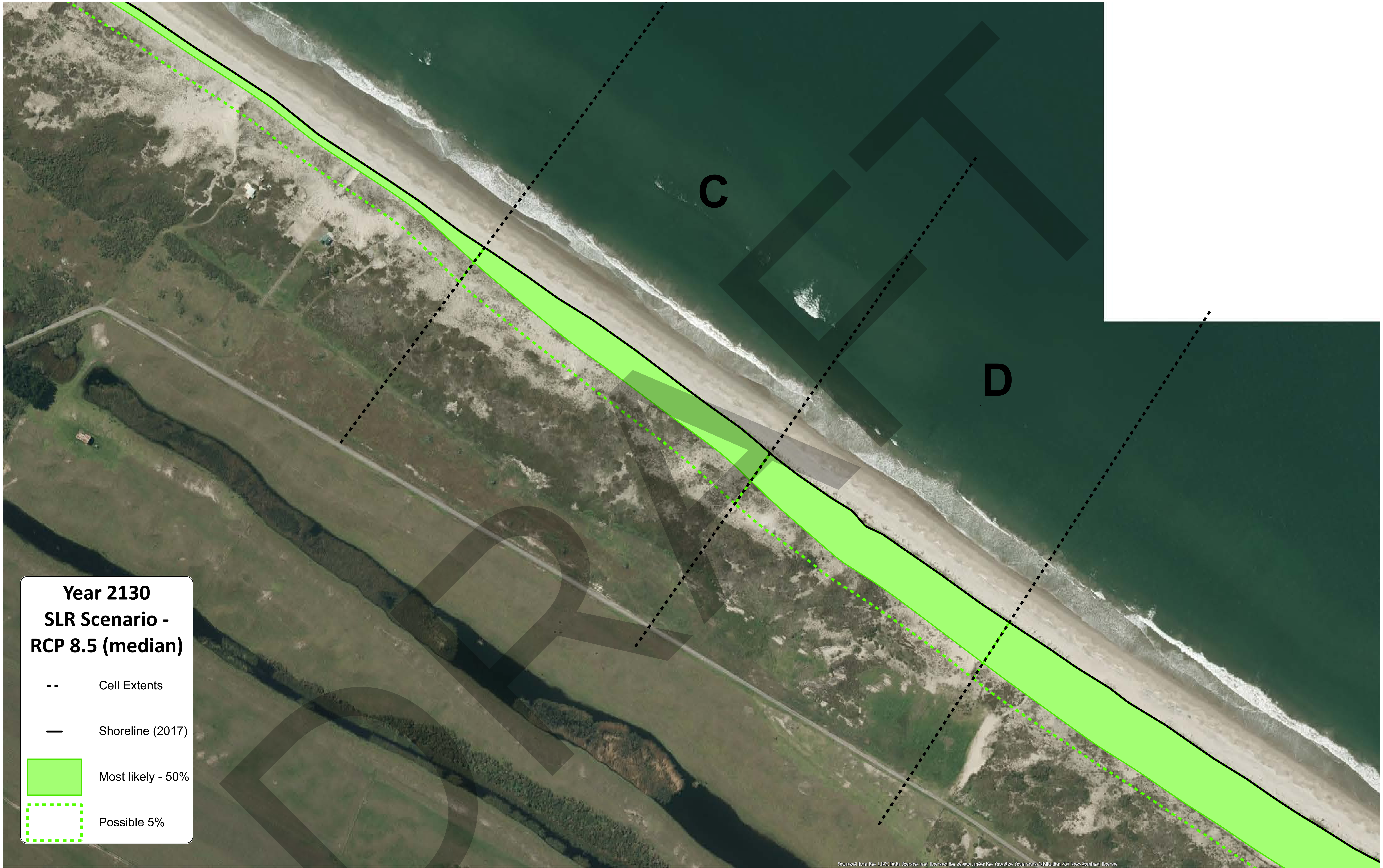

Notes: Aerial photograph........

A1 SCALE 1:1,690

0 0.035 0.07 0.105 0.14 0.175 (km)

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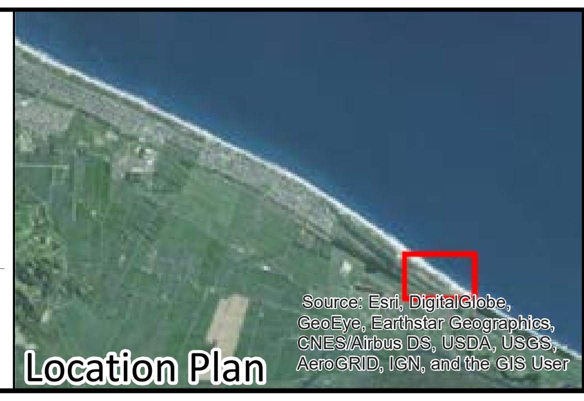

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Coastal Erosion Hazard Assessment
Te Tumu Urban Development
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FIGURE No. Figure 1.4

Rev. 0

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Notes: Aerial photograph........

A1 SCALE 1:1,690

0 0.035 0.07 0.105 0.14 0.175 (km)

N

Location Plan

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Coastal Erosion Hazard Assessment

Te Tumu Urban Development

Sheet: 5

FIGURE No. Figure 1.5

Rev. 0

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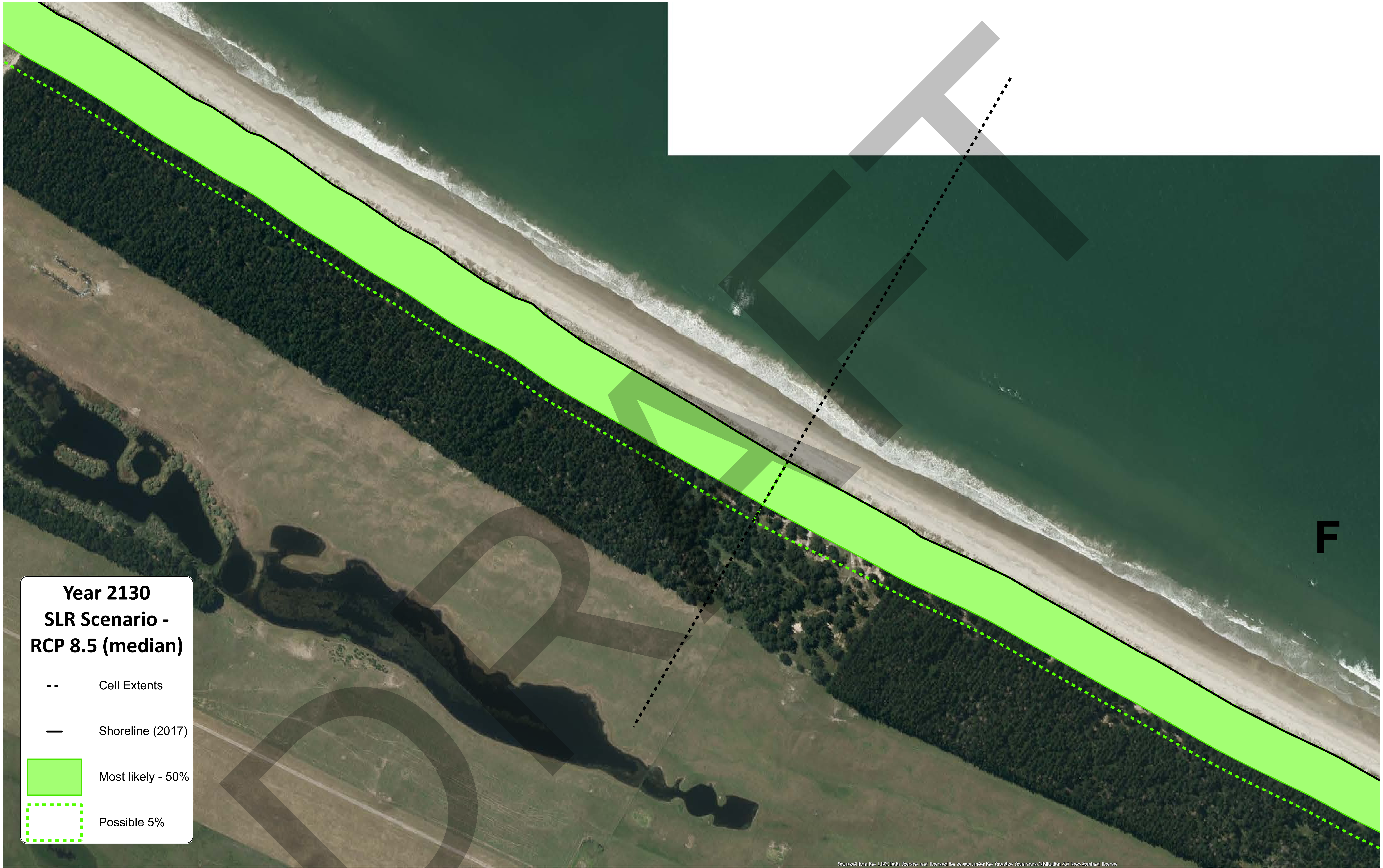

Notes: Aerial photograph........

A1 SCALE 1:1,690
0 0.035 0.07 0.105 0.14 0.175 (km)

Location Plan

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FIGURE No. Figure 1.6
Rev. 0

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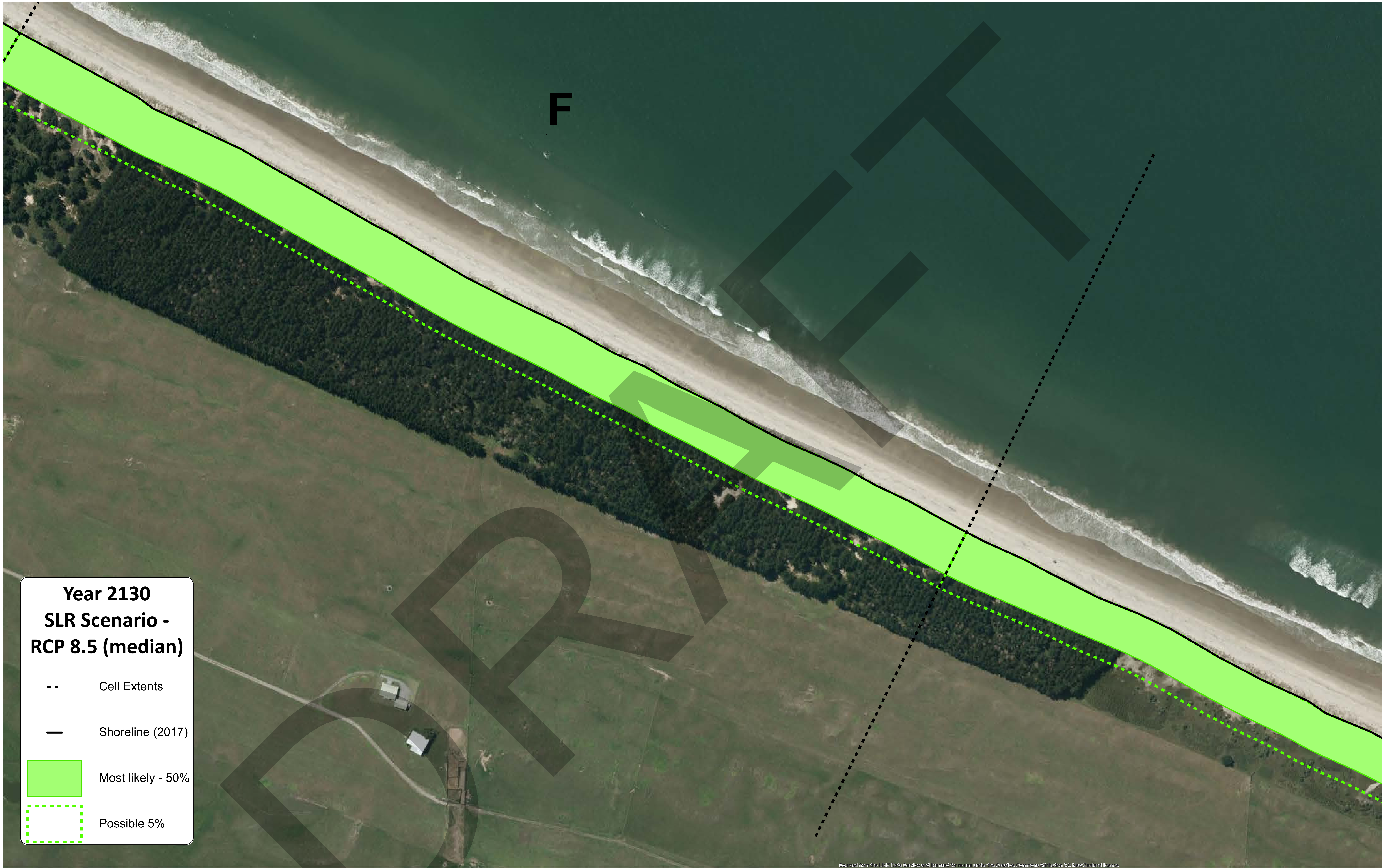

Notes: Aerial photograph........

A1 SCALE 1:1,690

0 0.035 0.07 0.105 0.14 0.175 (km)

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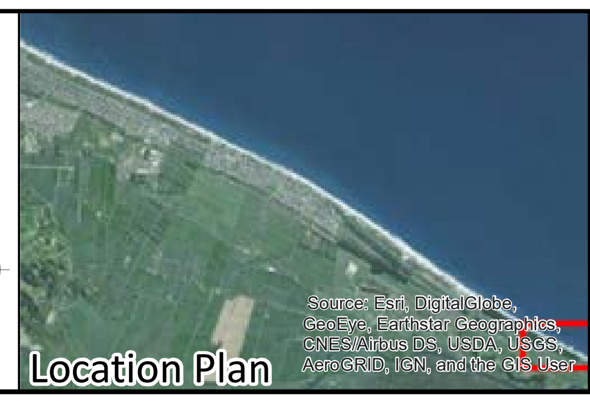

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Coastal Erosion Hazard Assessment

Te Tumu Urban Development

Sheet: 7

FIGURE No. Figure 1.7

Rev. 0

Notes: Aerial photograph........

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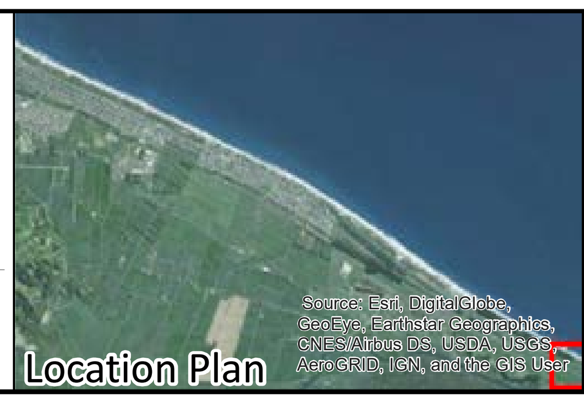
0 0.035 0.07 0.105 0.14 0.175 (km)



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Sheet: 8

FIGURE No. Figure 1.8

Rev. 0

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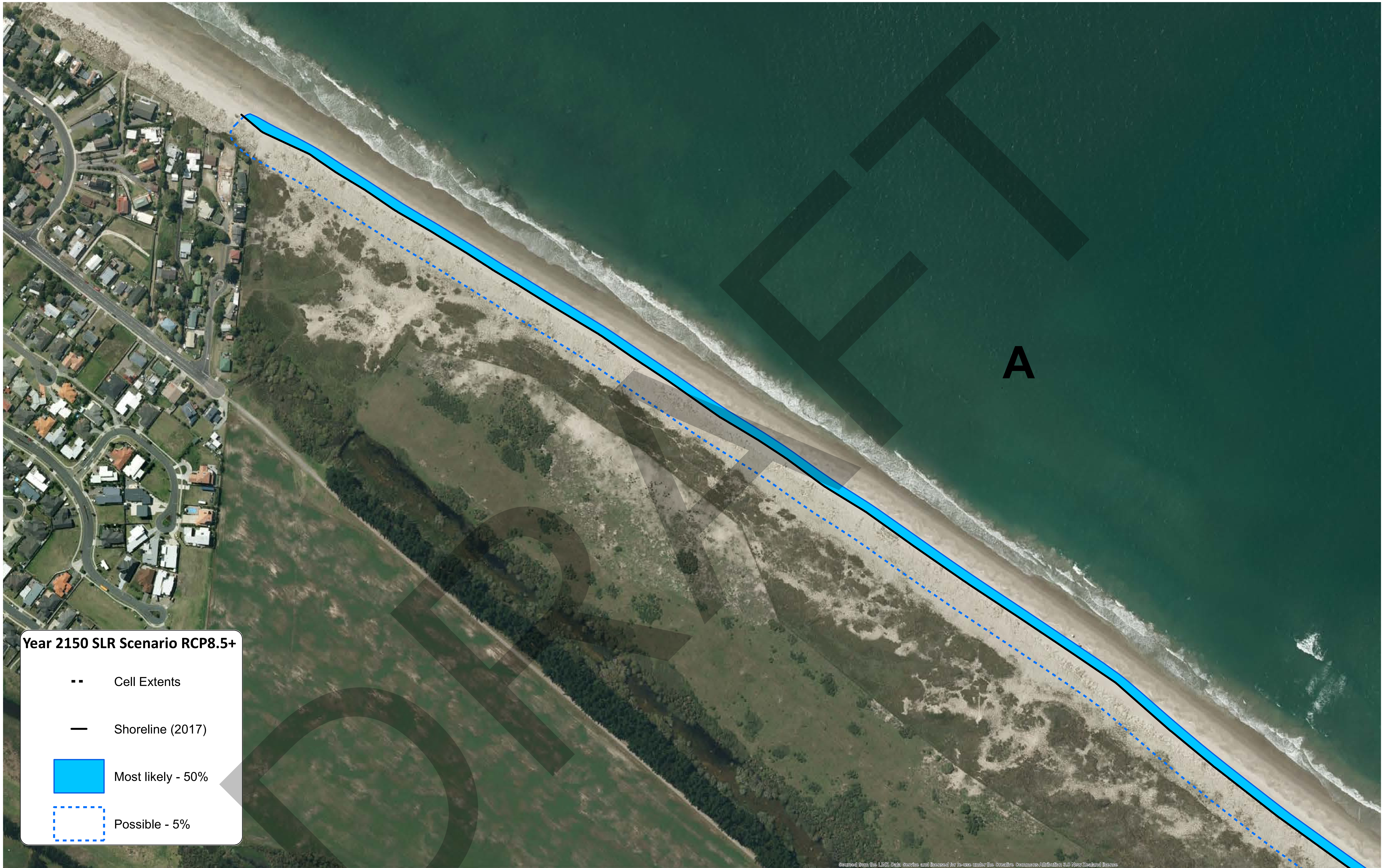

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Notes: Aerial photograph........

A1 SCALE 1:1,690

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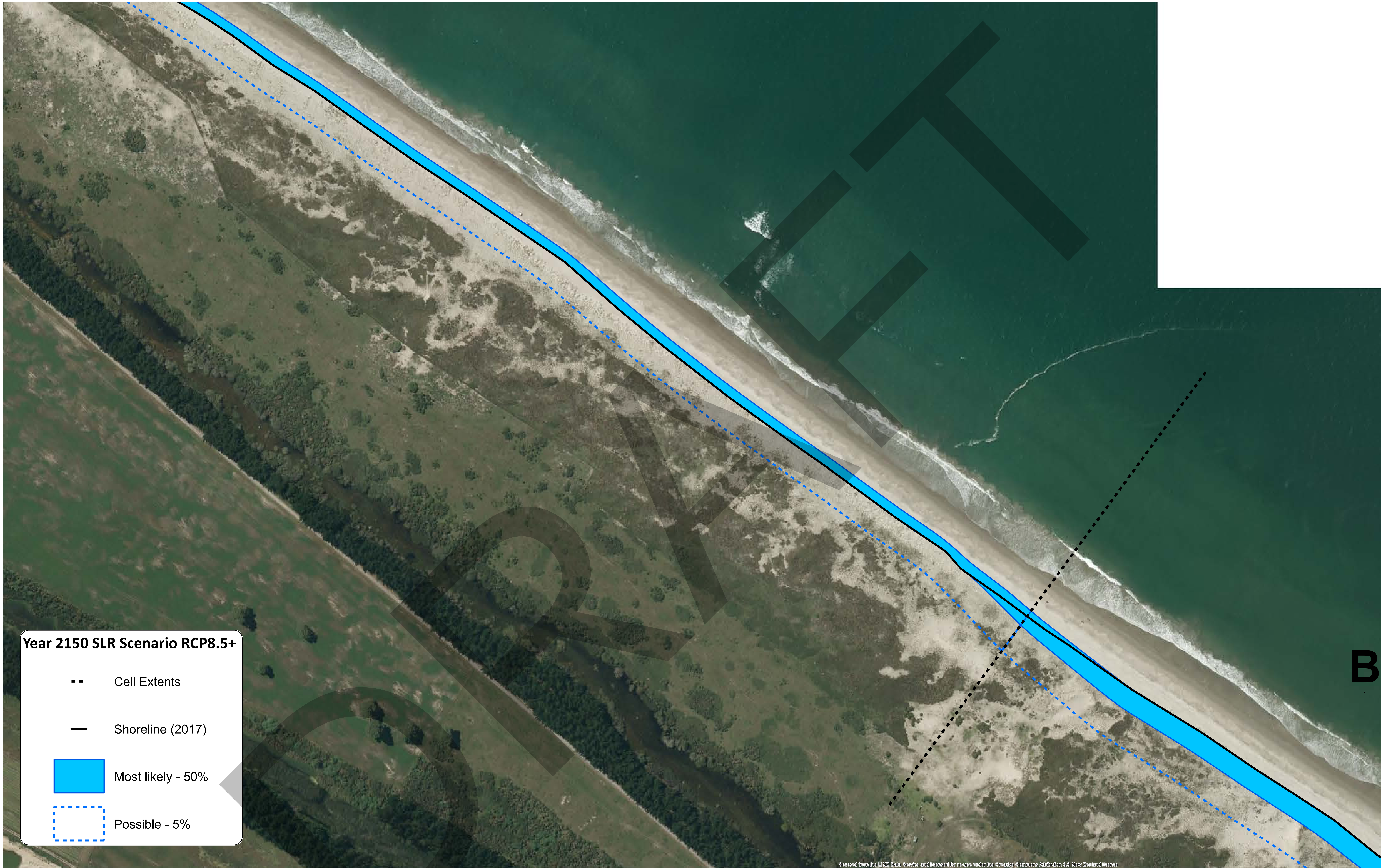
Te Tumu Urban Development

FIGURE No. Figure 1.1

Rev. 0



Notes: Aerial photograph........

A1 SCALE 1:1,690

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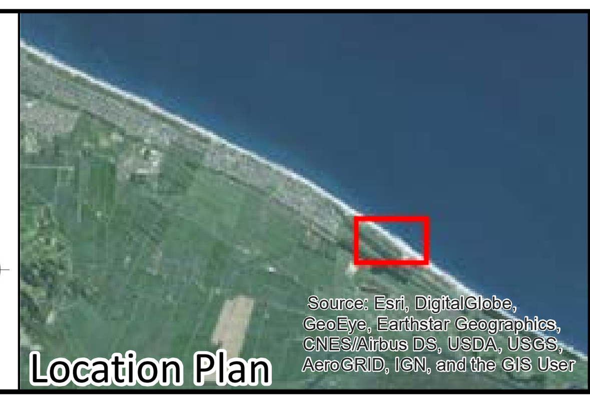

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FIGURE No. Figure 1.2

Rev. 0

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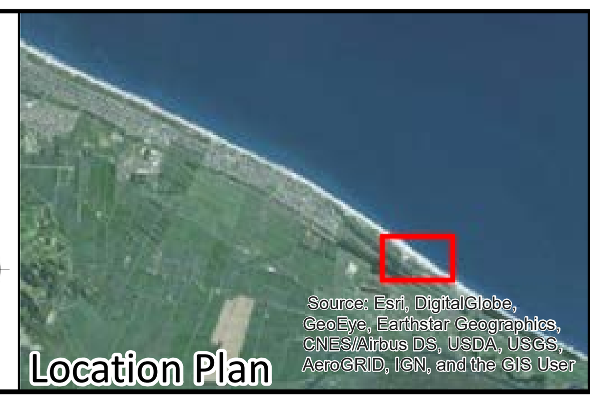

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FIGURE No. Figure 1.3

Rev. 0

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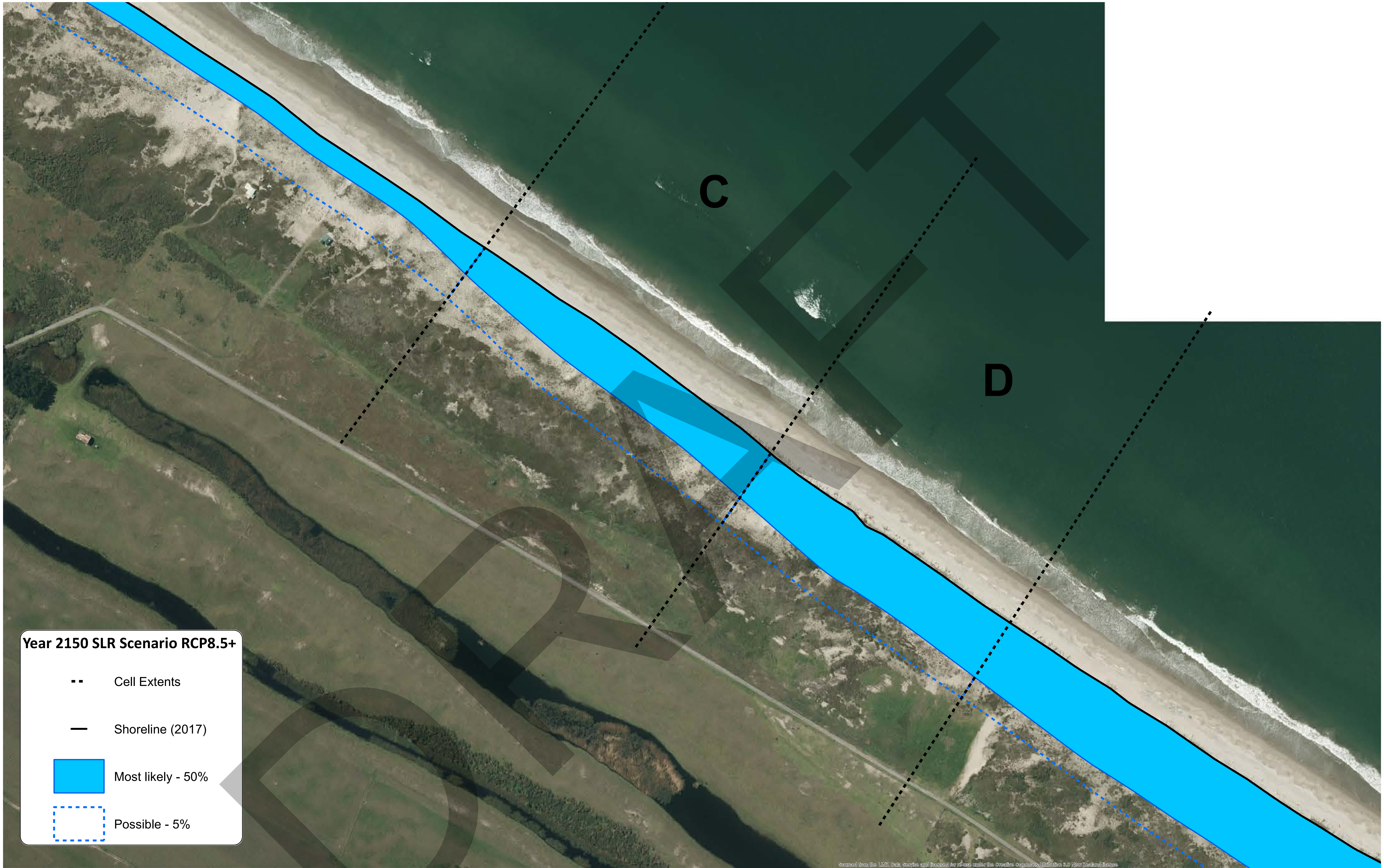

Notes: Aerial photograph........

A1 SCALE 1:1,690

0 0.035 0.07 0.105 0.14 0.175 (km)

N

Location Plan

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FIGURE No. Figure 1.4

Rev. 0

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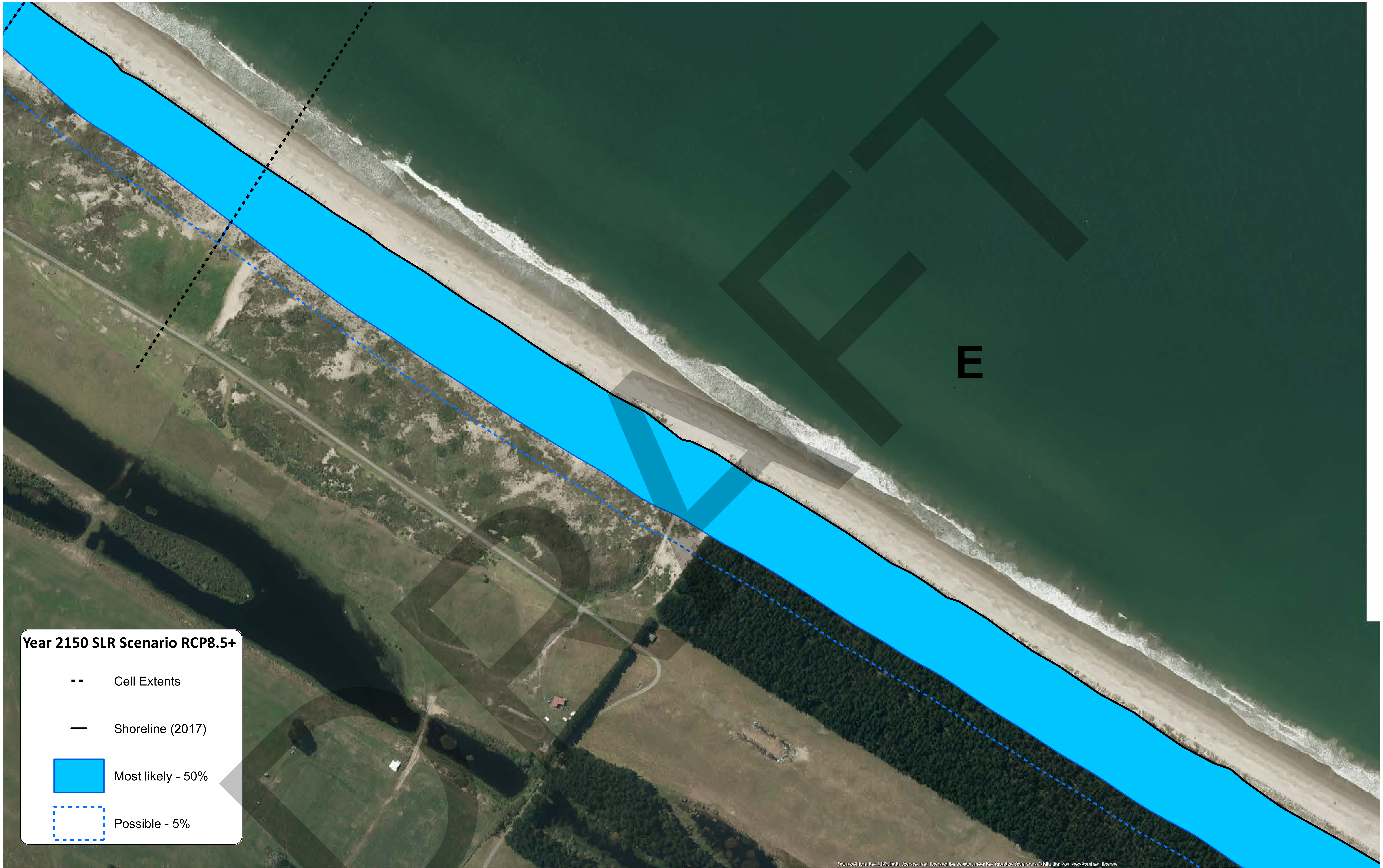

Notes: Aerial photograph........

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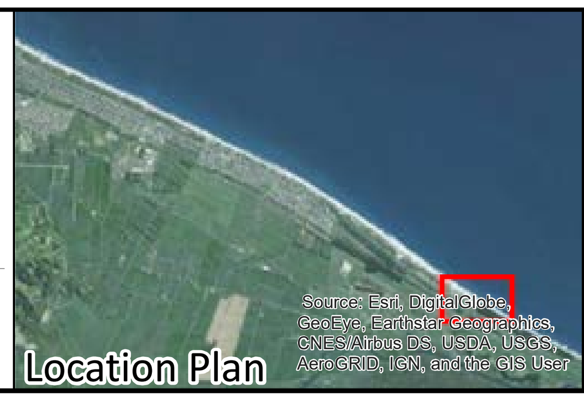

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FIGURE No. Figure 1.5

Rev. 0

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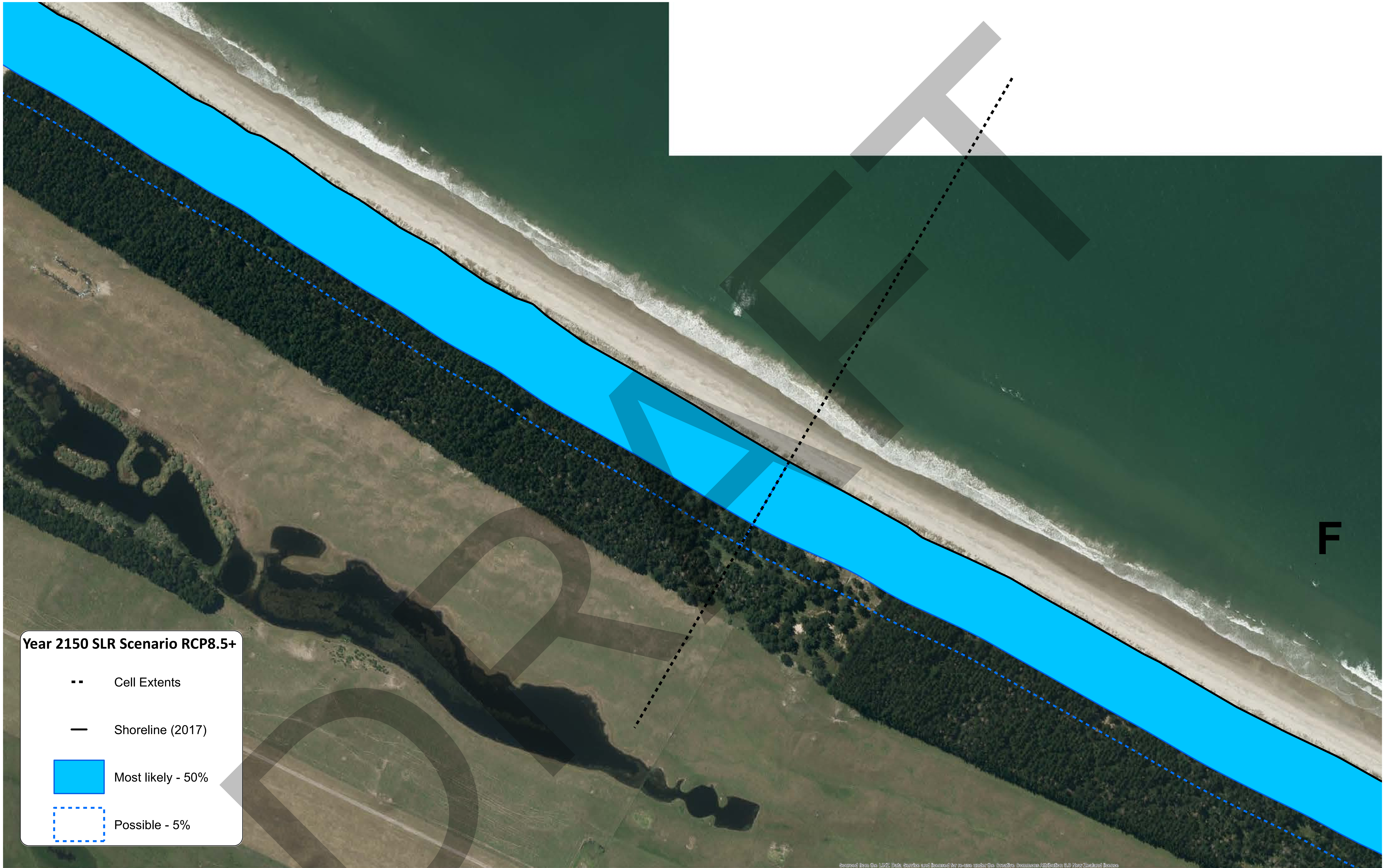

Notes: Aerial photograph........

A1 SCALE 1:1,690
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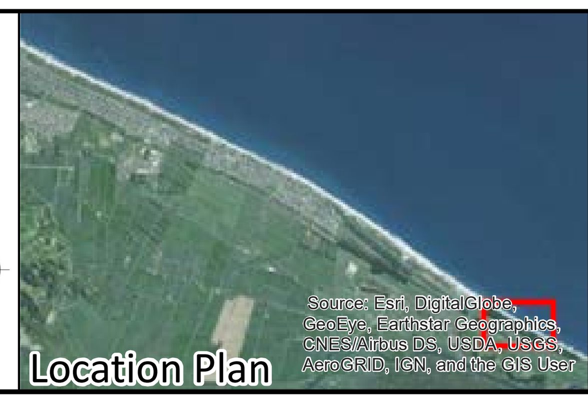

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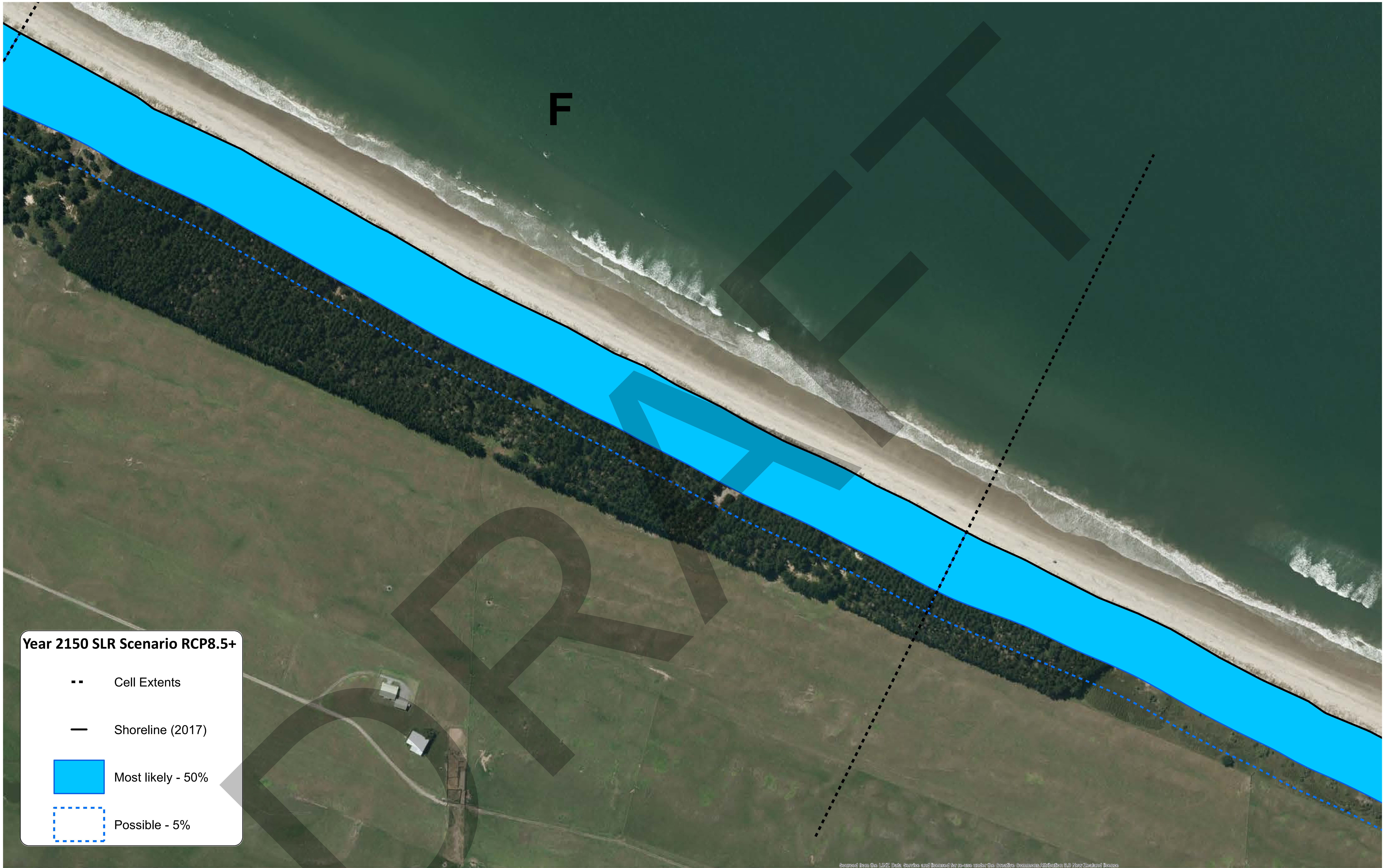
FIGURE No. Figure 1.6
Rev. 0



Notes: Aerial photograph........

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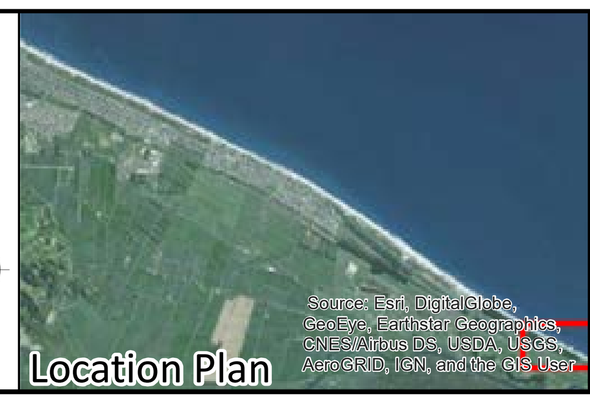

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FIGURE No. Figure 1.7

Rev. 0

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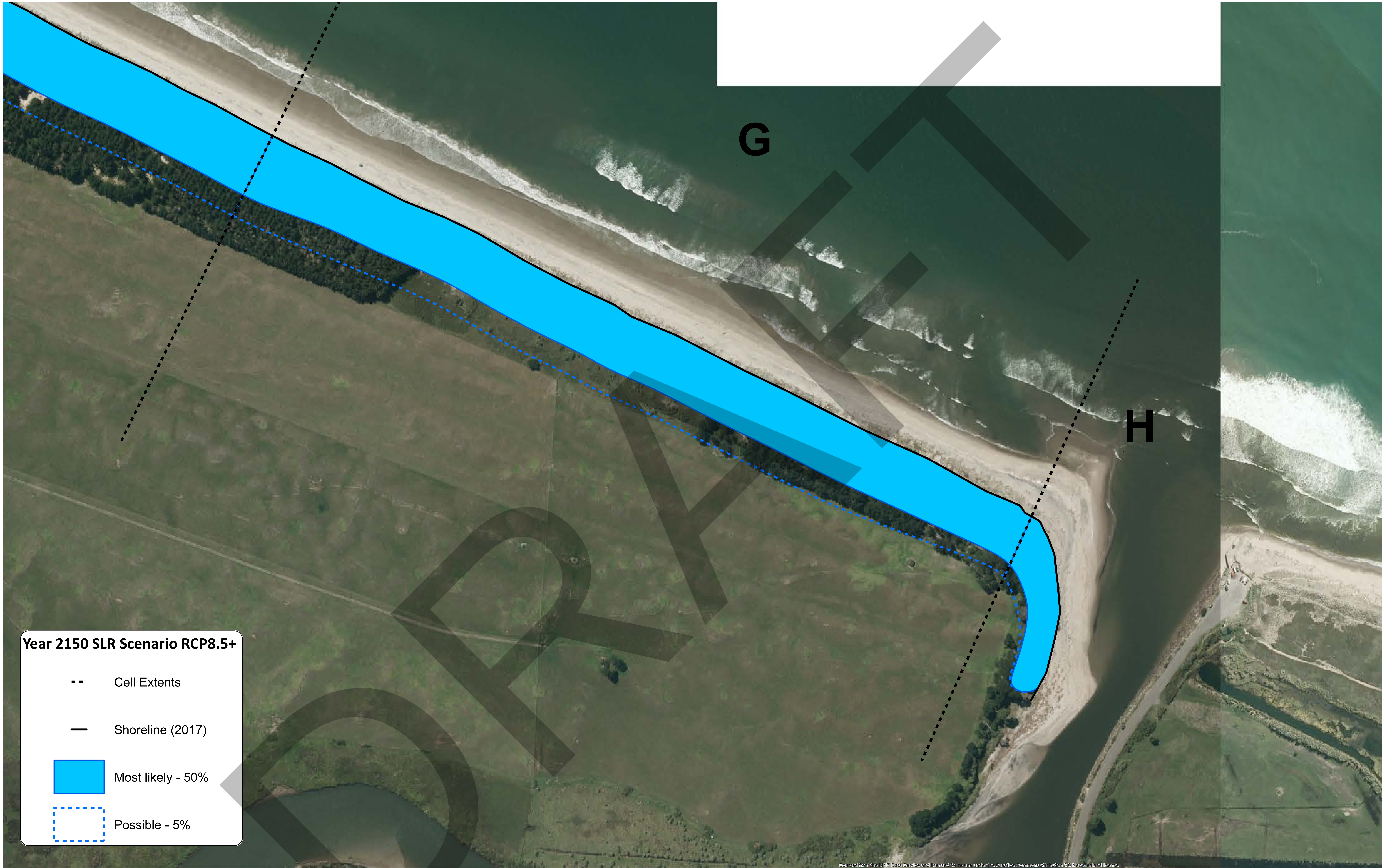

Notes: Aerial photograph........

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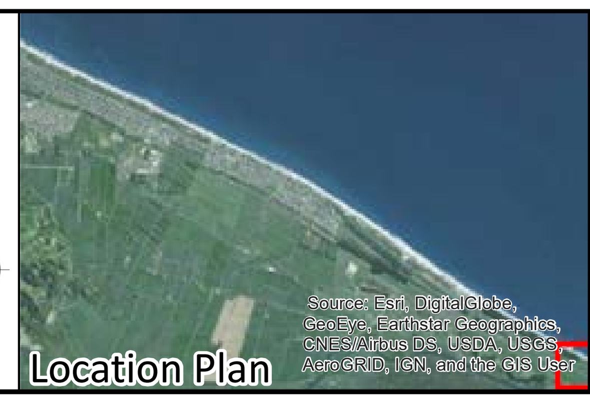

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FIGURE No. Figure 1.8

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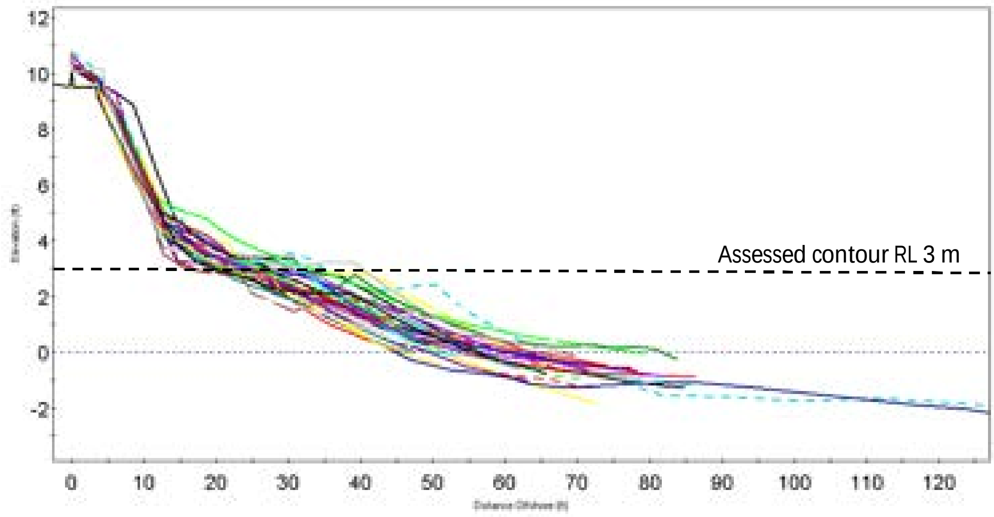
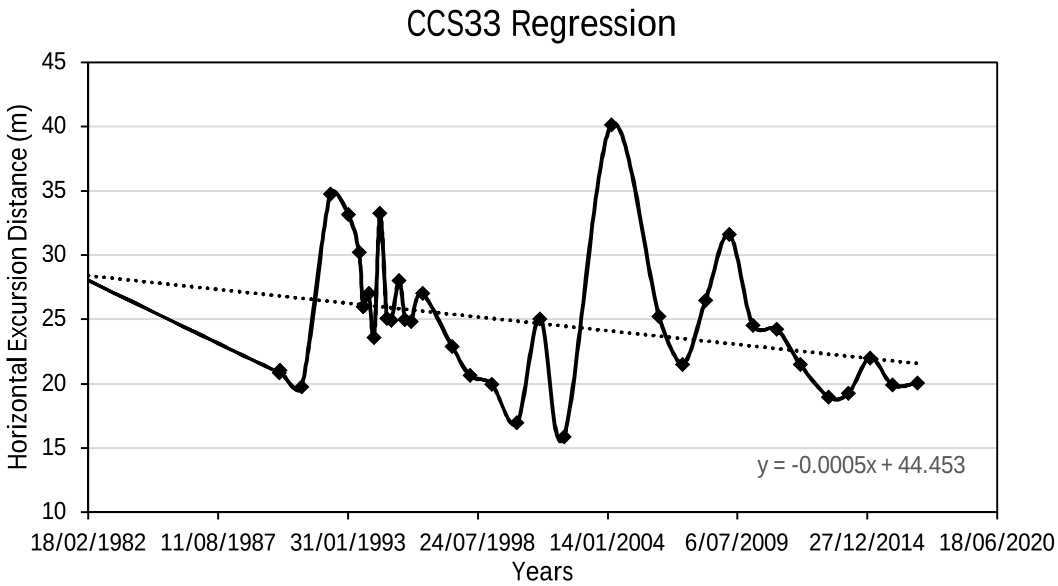
Appendix B: Beach profile analysis plots





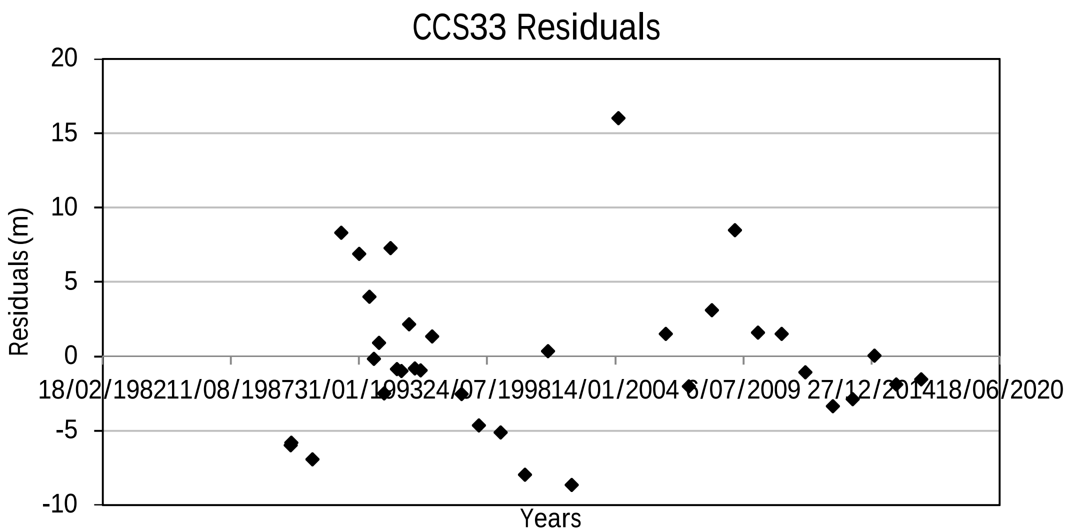


Figure B1 Beach profile surveys (top panel), linear regression plots for RL 3 m contour (middle panel), and residual plot for RL 3 m (lower panel) for profile CCS33

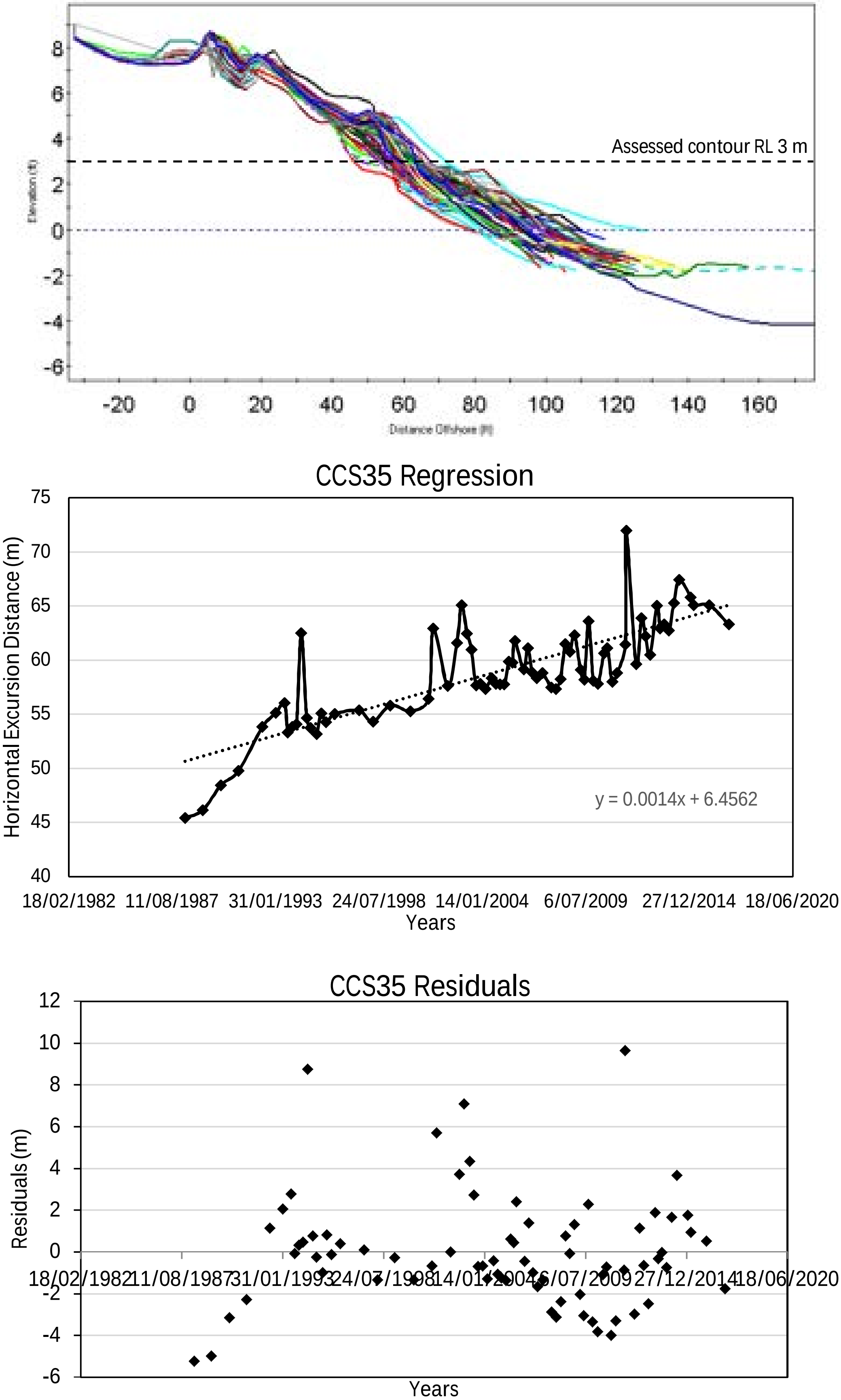
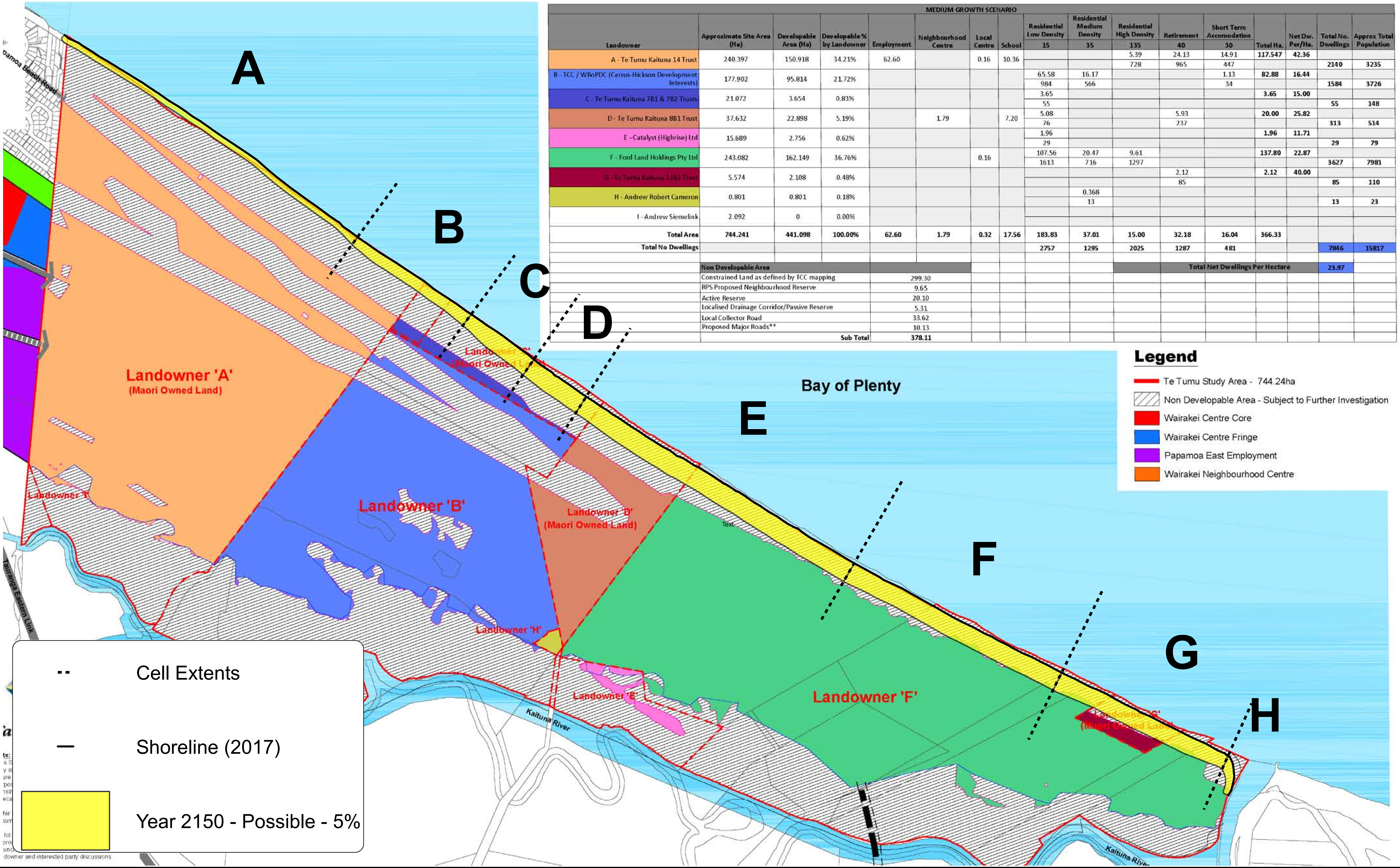


Figure B2 Beach profile surveys (top panel), linear regression plots for RL 3 m contour (middle panel), and residual plot for RL 3 m (lower panel) for profile CCS35.

Appendix C: Site photographs


A
B
C
D
E
F
G
H

Appendix D: Proposed Te Tumu development



MEDIUM GROWTH SCENARIO																
Landowner	Approximate Site Area (Ha)	Developable Area (Ha)	Developable % by Landowner	Employment	Neighbourhood Centre	Local Centre	School	Residential Low Density 15	Residential Medium Density 35	Residential High Density 135	Retirement 40	Short Term Accomodation 30	Total Ha.	Net Dw. Per/Ha.	Total No. Dwellings	Approx Total Population
A - Te Tumu Kaituna 14 Trust	240.397	150.918	34.21%	62.60		0.16	10.36			5.39	24.13	14.91	117.547	42.36		
										728	965	447			2140	3235
B - TCC / WBoPDC (Carrus-Hickson Development Interests)	177.902	95.814	21.72%					65.58	16.17			1.13	82.88	16.44		
								984	566			34			1584	3726
C - Te Tumu Kaituna 7B1 & 7B2 Trusts	21.072	3.654	0.83%					3.65					3.65	15.00		
								55							55	148
D - Te Tumu Kaituna 8B1 Trust	37.632	22.898	5.19%		1.79		7.20	5.08			5.93		20.00	25.82		
								76			237				313	514
E - Catalyst (Highrise) Ltd	15.689	2.756	0.62%					1.96					1.96	11.71		
								29							29	79
F - Ford Land Holdings Pty Ltd	243.082	162.149	36.76%			0.16		107.56	20.47	9.61			137.80	22.87		
								1613	716	1297					3627	7981
G - Te Tumu Kaituna 11B2 Trust	5.574	2.108	0.48%								2.12		2.12	40.00		
											85				85	110
H - Andrew Robert Cameron	0.801	0.801	0.18%						0.368							
									13						13	23
I - Andrew Siemelink	2.092	0	0.00%													
Total Area	**744.241**	**441.098**	**100.00%**	**62.60**	**1.79**	**0.32**	**17.56**	**183.83**	**37.01**	**15.00**	**32.18**	**16.04**	**366.33**			
Total No Dwellings								**2757**	**1295**	**2025**	**1287**	**481**			**7846**	**15817**
	Non Developable Area										**Total Net Dwellings Per Hectare**				**23.97**	
	Constrained Land as defined by TCC mapping				299.30											
	RPS Proposed Neighbourhood Reserve				9.65											
	Active Reserve				20.10											
	Localised Drainage Corridor/Passive Reserve				5.31											
	Local Collector Road				33.62											
	Proposed Major Roads**				10.13											
	Sub Total				**378.11**											

Notes: Year 2150 (5%) CEHZ overlaying TCC structure plan for Te Tumu urban development area

A1 SCALE 1:8,000

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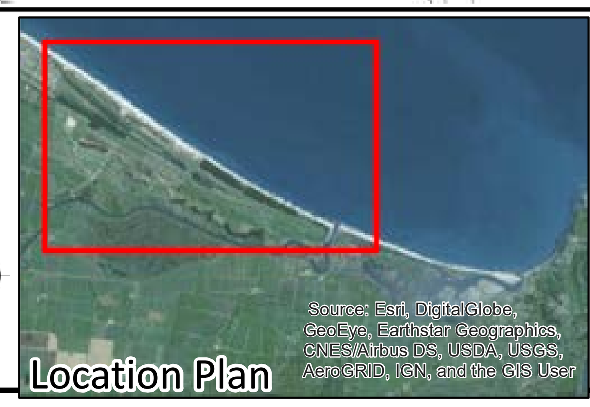
N



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Appendix D

FIGURE No.

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