REPORT

Coastal Hazard Assessment Whenuapai Plan Change

Stage 1

Prepared for
Auckland Council
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Date
August 2017
Job Number
1003234.v2

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Executive summary

This report considers coastal erosion hazard within the Stage 1 area proposed for re-zoning in Whenuapai. We have considered planning time frames to 2120 and 2150 and applied a probabilistic approach for our hazard assessment that provides likelihoods of hazard extent. This assessment indicates future erosion hazard extending landward of the current cliff toe baseline of between 26 m and 41 m for the 2120 time frame, and between 27 and 43m for 2150 time frame (adopting an RCP8.5+ sea level rise scenario).

Setting

The coastal edge in this area comprises Puketoka Formation (PF) pumiceous sands and silts to the north, each side of the inlet. The southern extent of the inlet is surrounded by lower, more protected and more densely vegetated coastal edge comprising East Coast Bays Formation (ECBF) material. A headland comprising largely fill material is located adjacent to the Whenuapai RNZAF Base.

The base of cliffs are typically located approximately 1m below the high tide level of Mean High Water Springs (MHWS), protected in many areas by mangrove forest up to 150 m in width, with a very gradual (less than 3 degrees) sloping mudflats extending out of the study area towards the upper Waitemata Harbour. This section of coast has a low energy wave climate, only being exposed to wind waves from the east over limited fetch distances (less than 2.5 km) during the upper half of the tide.

Erosion hazard model

Erosion hazard along cliffed coastlines is influenced by erosion of the cliff toe caused by marine and biological processes, weathering and slumping of the over steepened cliff face. Sea level rise may influence cliff erosion by allowing higher wave energy to reach the cliff toe, increasing hydraulic loading and more effectively removing protective landslide debris. An erosion model has been adopted that incorporates these components including the uncertainty associated with each.

Input parameters for the probabilistic hazard assessment include:

- Cliff heights along defined stretches of the coast with heights ranging from 5.5 m to 13.5 m determined from LiDAR
- Stable angle of cliff ranging from 18-35°
- Long-term retreat rate of up to -0.03 m/year based on walkover observations and review of aerial photos
- Sea level rise factors to allow for erosion due to sea-level rise, selected by weighing up the relative exposure to erosion within the context of it geomorphological setting, and the relative susceptibility of each material type to erosion
- Future sea level rise rates for a range of potential future emission scenarios based on the median values of the Intergovernmental Panel of Climate Change (IPCC) scenarios RCP2.6, RCP4.5 and RCP8.5 as well as the 83rd percentile of RCP8.5 (RCP8.5+). These scenarios have been adjusted to the New Zealand regional scale. A historical rate of sea level rise of 1.7 mm/ year has been deducted from these rates.

Limitations

These results are to estimate the hazard extents. Based on our discussions with Auckland Council (AC, 8 July 2017) we understand building platforms are required to be located behind the RCP 8.5+ 5% setback distance.

In addition, detailed analysis of Auckland Council LiDAR information indicate a number of surface features likely to be indicative of historical instability in the form of landslips. In the absence of detailed walkover observations and subsurface geotechnical investigations there is insufficient information to explicitly relate deep seated instability to coastal erosion hazard. Accordingly, we recommend site specific slope stability assessments for building development within 100m of the 2016 shoreline.

1 Introduction

1.1 Previous work

Tonkin + Taylor (T+T, 2006) undertook a regional assessment of areas susceptible to coastal erosion in the Auckland region for Auckland Regional Council. This did not define the hazard extents, but identified areas potentially susceptible to erosion.

AECOM (2016) undertook a coastal assessment within the Whenuapai structure plan area subject to re-zoning. While the AECOM assessment followed the same methods outlined in T+T (2006) the report identified a zone 100 m in width requiring further site specific investigation and assessment.

1.2 This study

Auckland Council commissioned T+T to complete a coastal erosion hazard assessment for a section of coast identified in Figure 2-1, which forms part of the section of coast that was assessed by AECOM. This report sets out our erosion hazard assessment for this area.

2 Site context

2.1 Geographic location and proposed development

The study area is located within the Brigham Inlet, in the northern reaches of the Waitemata Harbour and includes approximately 4.5 km of cliffed coastline around a shallow mangrove filled estuarine embayment (Figure 2-1). Land surrounding the inlet comprises a mix of rural, rural residential and property maintained by the New Zealand Airforce.

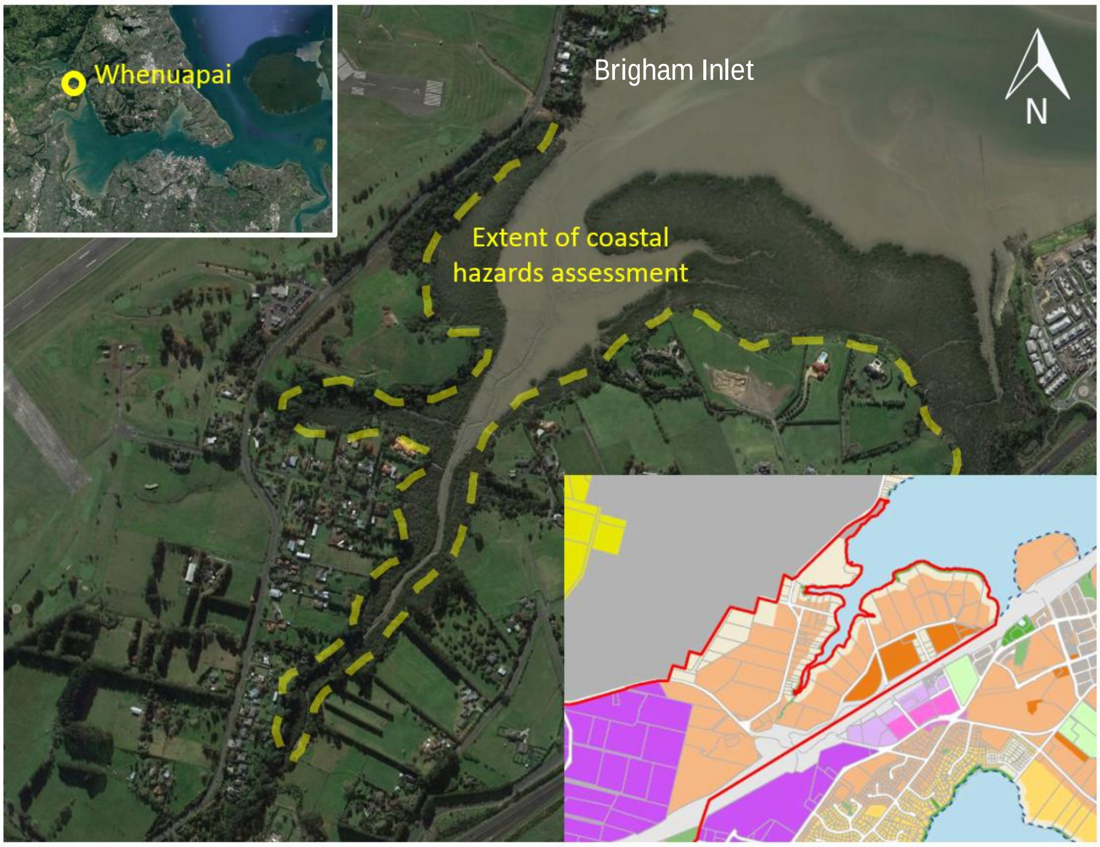

Figure 2-1 Location (inset) and extent of study area

2.2 Identification of existing structures

A coastal engineer from T+T inspected the site on 14 May 2017 and noted local rock armouring in one location at the northern end of Cell A (Figure 3-1). It is likely that similar forms of protection exist in other areas of the study area, however limited access into these areas has prevented further information being gathered regarding this.

3 Geomorphic setting

3.1 Geology

The published 1:50 000 geological map by Kermode (1992) indicates this area is underlain by Pleistocene age fine-grained alluvial and shallow marine sediments comprising Puketoka Formation (PF) of the Tauranga Group, and mid-Miocene age East Coast Bays Formation (ECBF), and fill material (Figure 3-1).

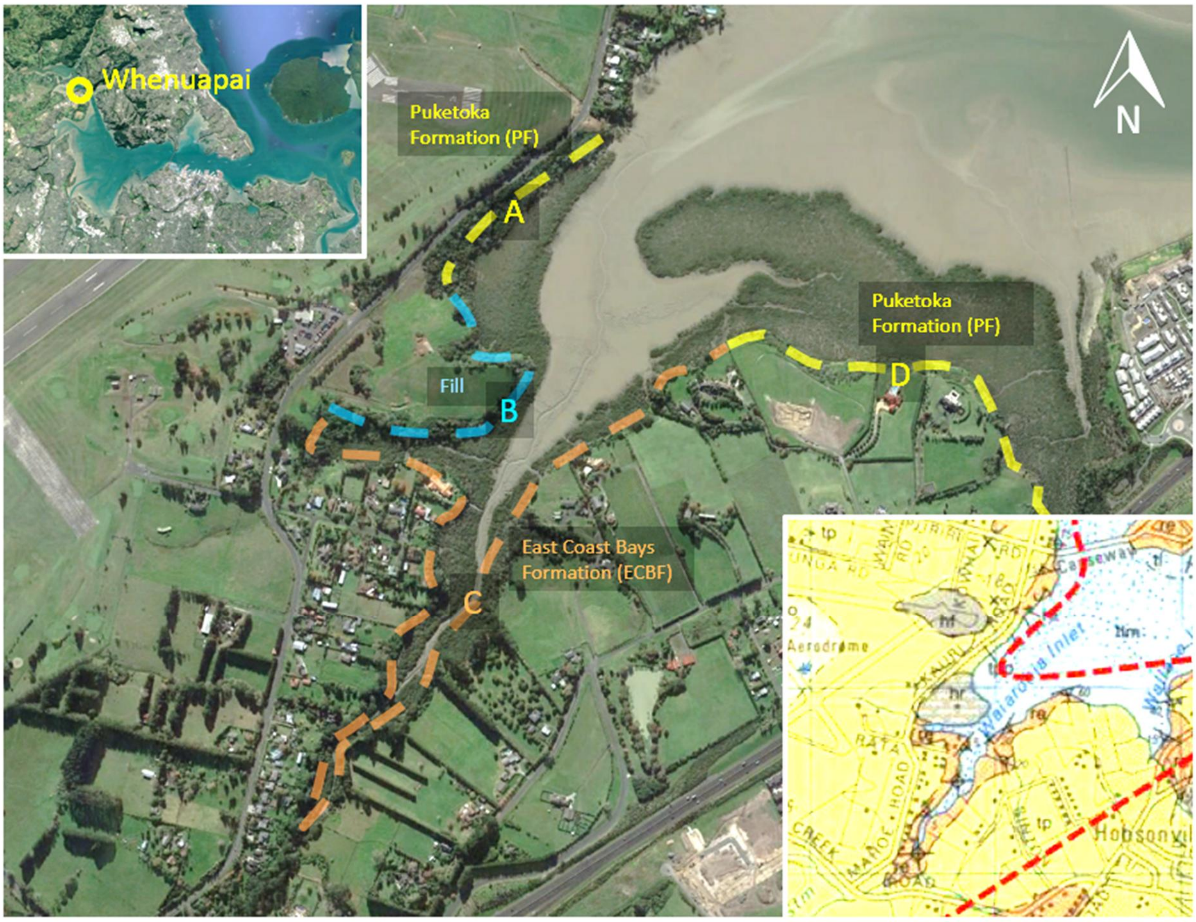

Figure 3-1 Geological units and excerpt map (Kermode, 1992)

Our site observations confirmed the presence of PF coastal cliff outcrops within the section of coast denoted as Cell A in Figure 3-1 (photographs of outcrops in Figure 3-2 and Figure 3-7).

Figure 3-2 - Outcrops of PF in Cell A

3.2 Topography

Levels are reported in terms of RL which is taken to be Auckland Vertical Datum 1946. Coastal morphology comprises a combination of inner Waitemata Harbour estuarine flats, backed by a relatively steep backshore. Coastal cliffs within the northern half of the study area are generally higher cliffs (8.5 to 13.5 m height) separated by approximately 400m of estuarine flats. Towards the southern end of the study area the embayment narrows to less than 100m in width and surrounded by lower ECBF cliffs (5.5 to 9.5 m height). Cliff slopes (angle measured to the horizontal from slope toe to slope crest) in the study area were primarily determined from LiDAR (Auckland Council, 2013) due to difficulties accessing these areas by foot, and were found to generally range from approximately 18° and 60°.

3.3 Bathymetry

Bathymetry within the study area is gently sloping, typically sloping less than 2 degrees within fringing mangroves, and extending out over intertidal flats with slopes less than 3 degrees but typically around 1 degree (Figure 3-3). The base of these cliffs are generally located at approximately RL 1m, approximately 1 m below Mean High Water Spring (MHWS) level. A narrow meandering water course is centrally located within this inlet (Figure 3-4, left side).

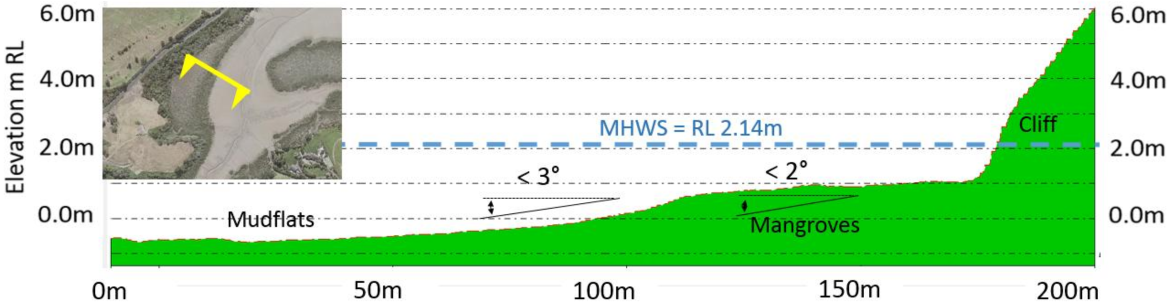

Figure 3-3 Typical cross shore bathymetry

Figure 3-4 Photograph looking south within Cell A

3.4 Foreshore characteristics

At the base of cliffs beach sediment appears to be predominantly estuarine fines mixed with variable quantities of sand and broken shell.

In areas such as Figure 3-4 within the southern end of Cell A where an established mangrove forest exists, other forms of vegetation have colonised weathered material at the base of these cliffs. With the majority of these areas typically inundated every high tide the increased vegetation provides an areas for debris and beach sediment to collect.

Figure 3-5 View south from Cell A where an established mangrove forest exists and other forms of vegetation have colonised weathered material at the base of these cliffs

Mangrove forests are less established in areas more exposed to higher levels of wave energy. At these locations weathered material intermittently collects at the base of cliffs but is more regularly washed away by tidal and wave action.

3.5 Cliff face stability

During our walkover inspection signs of erosion in exposed areas included surface weathering (Figure 3-6 left), bio-erosion (Figure 3-6 centre) and root pressure (Figure 3-6 right).

Figure 3-6 Surface weathering, bio-erosion and root pressure

Slopes in Cell A with less mangrove protection were less densely vegetated, with shallow landslips and related instability being more common in these areas (Figure 3-7). Exposures in ECBF or fill material were less visible due to vegetation cover and lack of access.

Figure 3-7 Instability within Cell A PF exposures (Photo top and bottom taken at the same location)

A review of the Auckland Council LiDAR information identified a number of surface features indicative of historical instability in the form of landslips, particularly within Cell C in ECBF material (Appendix B – surface features indicative of historical slope instability). The shape of these features are indicative of low angle (i.e. 10 degree) failure planes. The height and orientation of failure planes associated with this instability in relation to future shoreline position are not well understood based on available site specific geological information.

3.6 Historical shoreline movement

Historic aerial photographs and the most recent aerial photographs have been obtained and used to digitise the shoreline in order to calculate the historic change between the shorelines. The following datasets are available:

- 1940 aerial photograph (source: Retrolens, 2016)
- 1950 aerial photograph (source: Retrolens, 2016)
- 1972 aerial photograph (source: Retrolens, 2016)
- 1980 aerial photograph (source: Retrolens, 2016)
- 1988 aerial photograph (source: Retrolens, 2016)
- 2004 aerial photograph (source: Retrolens, 2016)
- 2016 aerial photograph (source: Auckland Council GIS, 2016)

Historic and most recent aerial photographs have been georeferenced using distinct land features (e.g. houses, roads, vegetation or other topographic features) as a reference that are present at multiple aerial photographs. The cliff toe is defined as the transition of the steep cliff face into the flatter mangrove and mud flat environment

Digitised shoreline positions have been mapped in the 1940, 1972, 2004, 2016 photographs. Due to the lower resolution of many of these images, comparison of the historical shoreline position has been limited to the 1940 and 2016 photographs (Refer Appendix A). Horizontal offsets between these two shoreline positions have been measured and plotted at 200 m intervals (Figure 3-8).

Due to the increased vegetation obscuring cliff lines in more recent photographs, as well as shadows and reduced resolution of the 1940 photograph, we consider an interpretive error of 4 m in our assessment of shoreline features.

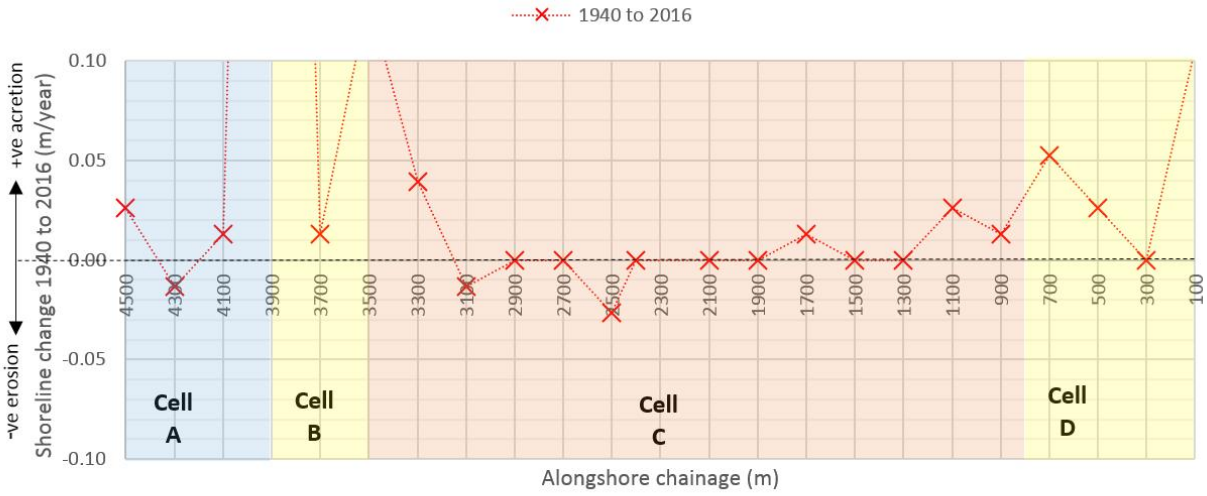

Figure 3-8 Horizontal cliff toe change rate between 1940 and 2016, alongshore chainage (m) measured from the south-eastern end of the site

From digitised cliff toe positions in Figure 3-8 changes in shoreline position indicate:

1. Cell A - accumulation of weathered material, and up to -0.02 m/year of erosion
2. Cell B – significant land reclamation between 1940 and 1972
3. Cell C - accumulation of weathered material and in some areas land reclamation, and up to -0.03 m/year of erosion.
4. Cell D - accumulation of weathered material and in some areas land reclamation.

4 Coastal processes

4.1 Water levels

Water levels play an important role in determining coastal erosion hazard both by controlling the amount of wave energy reaching the backshore 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 sea level fluctuations, including the effects of ENSO and IPO
- Long-term changes in sea level
- Wave breaking can also contribute to water level through wave set-up and run-up.

4.1.1 Astronomical tide

Standard Port Tidal Levels given by LINZ (2015) are based on the average predicted values over the 18.6 year astronomical tidal cycle. Tidal levels available for the Port of Auckland have been adjusted by a co-tidal factor of 1.10 based on the co-tidal chart by Ports of Auckland Limited (2003). This co-tidal factor adjustment accounts for semi-enclosed basin effects occurring in the inner Waitemata Harbour as determined by the Auckland Harbour Board. The adjusted tidal levels are shown in Table 4-1 both in Chart Datum and reduced level (RL).

Table 4-1 Tidal levels adjusted for the study area

Tidal level	Chart Datum CD (m)	Reduced Level RL (m)
Mean High Water Spring (MHWS)	3.88	2.14
Mean High Water Neap (MHWN)	3.27	1.53
Mean Sea Level (MSL)	2.21	0.47
Mean Low Water Neap (MLWN)	1.06	-0.68
Mean Low Water Spring (MLWS)	0.35	-1.39

Note: Levels from NZ Nautical Almanac 2015-16 multiplied by 1.10 co-tidal factor based on Ports of Auckland Co-tidal Chart (2003)

4.1.2 Storm surge

Storm surge results from the combination of barometric set-up from low atmospheric pressure and wind stress from winds blowing along or onshore which elevates the water level above the predicted tide. The combined elevation of the predicted tide and storm surge is known as the storm tide. Stephens et al. (2013) derived storm tide estimates for the Hauraki Gulf and Waitemata Harbours by probabilistically combining the astronomical tide, with storm surge and the monthly mean sea level anomaly.

Results within the study area for a range of Annual Exceedance Probabilities (AEP) and Average Recurrence Intervals (ARI) are shown in Table 4-2. The 1% AEP storm tide elevation is RL 2.60 m. The majority of these high water level events occur with the combination of tropical cyclones or extra-tropical depressions and high tide levels with winds and waves predominantly from the north to east.

Table 4-2 Storm tide elevations for the study area (Stephens et al., 2016)

Annual exceedance probability (AEP)	50%	20%	10%	5%	2%	1%	0.5%
Average recurrence interval (ARI)	2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	200 yr
Elevation (RL m)	2.28	2.36	2.42	2.47	2.54	2.60	2.65

The majority of these high water level events occur with the combination of tropical cyclones or extra-tropical depressions and high tide levels. In this situation, winds and waves are predominantly from the north to north east. Due to the protection both from Herald Island and the man made causeway that leads to Herald Island, the study area is largely protected from erosive forces generated by these events.

4.1.3 Medium-term sea level fluctuations

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 (MLOS) at a specific time. The combined effect of these fluctuations is up to 0.25 m (Bell, 2012).

4.1.4 Long-term sea levels

Historic sea level rise for the Auckland region has averaged 1.7 ± 0.1 mm/yr (Bell and Hannah, 2012). Climate change is predicted to accelerate this rate of sea level rise into the future. NZCPS (2010) requires that the identification of coastal hazards includes consideration of sea level rise over at least a 100 year planning period (i.e. 2120 as a practical minimum and 2150 representing some time beyond 100 years).

We have used four sea level rise RCP (Representative Concentration Pathways) scenarios derived from IPCC (2014). These are the median projections of the RCP2.6, RCP4.5 and RCP8.5 scenarios, and an RCP8.5+ projection representing the 83rd percentile of the RCP8.5 scenario. The projections of the potential future scenarios adjusted to the New Zealand regional scale in Table 4-3 below for the two time periods.

Table 4-3: Sea level rise projections from the 1986-2005 baseline for the four emission scenarios

Year	RCP 2.6 M[1]	RCP 4.5 M	RCP 8.5M	RCP 83rd %
2120	0.55 m	0.67 m	1.06 m	1.36 m
2150	0.69 m	0.88 m	1.41 m	1.88 m

[1] - M = median

4.2 Wind and wave climate

Wind data was available from the National Institute of Water and Atmospheric Research (NIWA) weather gauging station at Whenuapai (NIWA Cliflo data point A64761). The wind data used was collected on an hourly basis from January 1960 to October 2013. The wind rose comprising wind speeds (m/s) and probability of occurrence per direction have been presented in Figure 4-1.

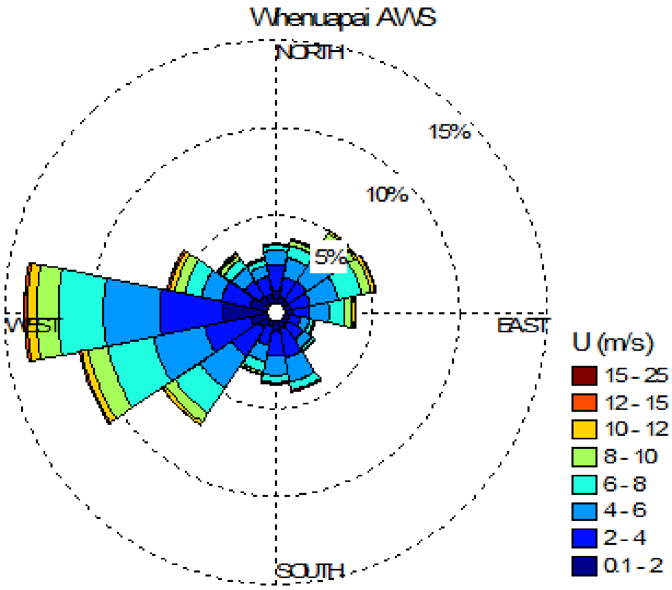

Figure 4-1 Wind Rose and monthly mean wind speed for Whenuapai (NIWA, 2013).

The site is located in the north-western extent of the inner Waitemata Harbour, exposed to wind-waves from the east and to a lesser extent the north east. Figure 4-1 shows winds from north east and east directions only occur approximately 15% of the time. In summer the proportion of winds from the northeast increases. Due to the changing location of the high pressure belt which is further south in summer and early autumn than it is in winter and spring (Chappell, nd).

The height of wind-generated waves is dependent on water depth, fetch length, wind speed and duration. Largest wind generated waves are expected to develop from the east with an approximate fetch distance of 2.5km. AS/NZS 1170.2:2002 (Standards Australia, 2002) provides a means for estimating yearly maximum three second gust wind speeds of 26 m/s. From Figure II-2-1 of Part II of the USACE Coastal Engineering Manual (2008) this corresponds to a 1 hr duration wind speed of 20 m/s. LINZ hydrographic chart (LINZ, 2016) indicates intertidal flats extending approximately 2km to the east at depths of around -0.5m RL before dipping into a narrow channel.

Fetch limited wave heights entering the embayment have been assessed by assuming an average water depth at MHWS of approximately 2 m over the 2.5 km fetch distance. Using the method of Wilson revisited by Goda (2003), fetch limited waves of 0.7m and a peak wave period of 2.5 s could be associated with a one year return period event.

Depth limited breaking will reduce wave heights as they approach the coastal edge. Storm tide water levels in Table 4-2 ranging between 2 years and 100 years indicate water depths at the cliff toe ranging between 1.3 and 1.6 m (allowing for approximate ground level variation at the cliff toe of 1 m RL). We estimate depth limited wave heights of up to 0.7m for a 2 year event, and up to 0.9m for a 100 year event.

The effects of mangrove forests on wave heights are discussed in Section 4.3.

4.3 Large scale processes

Historical aerial photographs indicate substantial widening and expansion of fringing and overwash mangrove forests since 1940 (Figure 4-2, indicating 1940 mangrove extents in red over the 2016 historic aerial). The greatest level of mangrove expansion appears to have occurred between 1950 and 1980.

Historic photographs also show the construction of the vehicle causeway joining Whenuapai and Herald Island north of the study area in the 1950's, effectively reducing fetch lengths to the north west from 3km to 1km and reducing exposure to wind waves within the study area.

The settlement of mangrove seedlings ordinarily requires a low wave energy environment (Vos, 2004) with sheltering effects of the causeway likely to have contributed to the observed mangrove expansion.

Expansion of fringing mangroves themselves are likely to have further reduced wave energy at the cliff toe due to:

- wave energy dissipation from increased bottom friction and interaction with trees (Vos, 2004), whereby the level of energy dissipation within the study area would primarily vary as a function of cross sectional width and mangrove density
- a reduction in depth limited wave heights due to shallowing effects associated with sediment deposition within mangrove forests due to increased bed friction (Bird, 1972).

Comment regarding future effects of sea level rise on mangroves forest and in-turn the level of protection they afford these cliffs is discussed in Section 5.2.3.6.

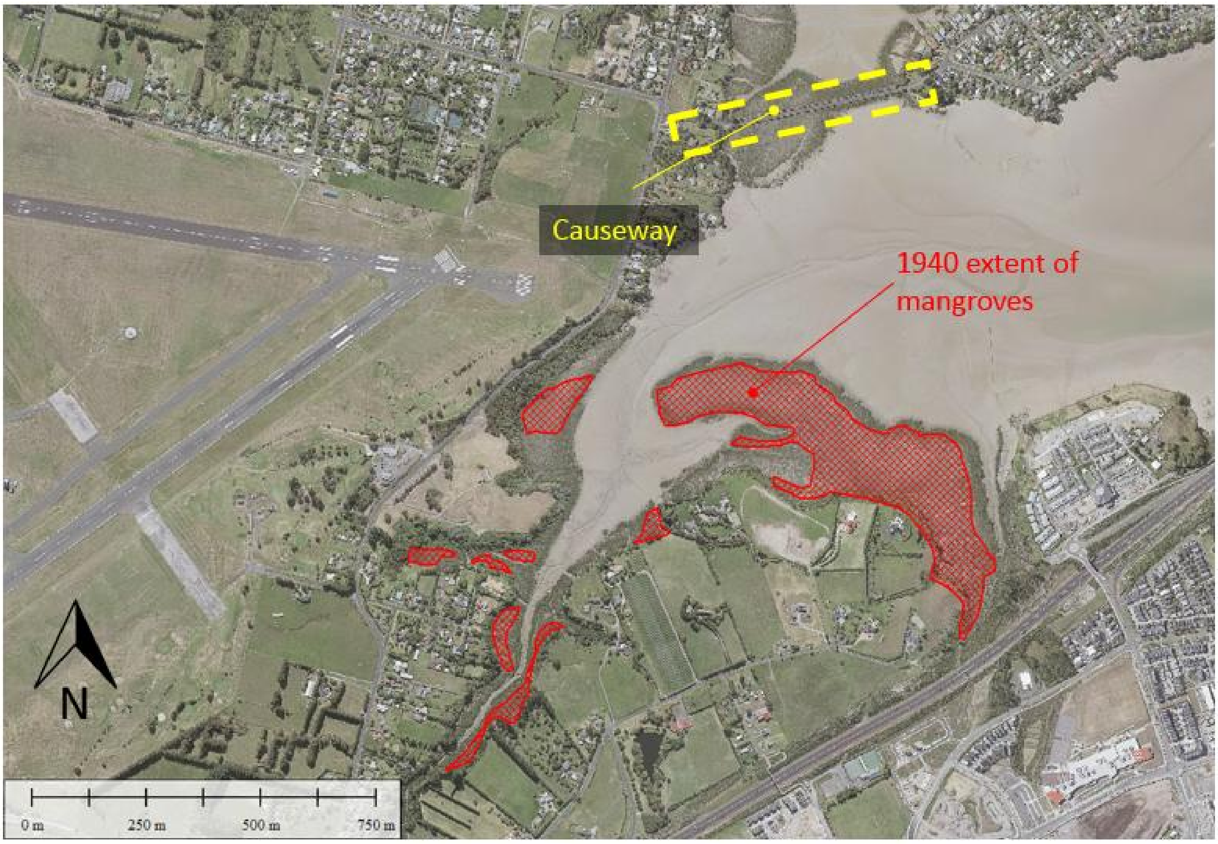

Figure 4-2 Change in extent of mangrove forests between 1940 and 2016 and location of causeway

5 Coastal erosion hazard

5.1 Previous assessments

A summary of key coastal hazard components from T+T (2006) and AECOM (2016) is included in Table 5-1 below. These previous assessments were undertaken using deterministic techniques that evaluate independent components separately, and combine them to produce an erosion hazard setback in a way that differs from this assessment (refer Section 5.2 below).

Table 5-1 Summary of components in previous erosion susceptibility and hazard studies

Parameter	T+T (2006)		AECOM (2016)		Symbol (unit)
Geology	ECBF[1]	PF[2]	ECBF	PF	
Cliff height	5	7	9		H_c (m)
Long-term retreat	5	10	10		LT_H (m)
Stable cliff slope (possible-unlikely)	36-26	26-18	35-26 (18 for unlikely)		α (deg)
Historical sea level rise	1.3		1.7		SLR_H (mm/year)
Predicted future sea level rise	3.5		9.8		SLR_F (mm/year)
Erosion susceptibility/hazard zone	19 -26 (possible-unlikely)	39 -46 (possible-unlikely)	100		EHZ (m)

[1] - East Coast Bays Formation

[2] – Puketoka Formation

5.2 Methodology

5.2.1 Cliff toe baseline

This assessment indicates future erosion hazard extending landward of the cliff toe baseline. The cliff toe baseline follows the toe of the cliff in the 2016 aerial photograph. Vegetation growth around the crest and base of these slopes and collection of talus material at the base of the cliffs has obscured the precise cliff position in many areas in the 2016 photograph. This line has been compared to the cliff toe in the 1940 aerial photographs which has generally less vegetation cover and in some areas has been used to correct the cliff toe baseline.

5.2.2 Erosion hazard

Future erosion hazard extending landward of the cliff toe baseline can be calculated in a number of ways. Deterministic techniques used in previous assessments outlined above have advantages in being easily understood, interpreted and updated in the future as additional data is collected. However, these methods can result in conservative (large) values along with a limited understanding of the combined uncertainty range.

From Shand et al (2015)… *New policy documents in New Zealand guiding the sustainable use of coastal resources such as the New Zealand Coastal Policy Statement 2010 (NZCPS) advocate the use of a risk-based approach to managing coastal hazard. This requires consideration of both the likelihood and consequence of hazard occurrence. Specifically, the policy statement requires consideration of areas both 'likely' to be affected by hazard (i.e. focussing existing development) and areas 'potentially' affected (focussing on new development). Such a requirement is at odds with* *traditional techniques where single values are produced with limited understanding of the likelihood of occurrence or the potential uncertainty of the prediction.*

The Envirolink guide to good practice (Enviro, 2016) recommends moving from deterministic predictions (used in previous assessments outlined above) to probabilistic projections, and that the recognition and treatment of uncertainty is a key source of variance between CEHZ predictions by practitioners.

The present day coastal erosion hazard zones for cliffs are established from the effect of slope instability and depends on the cliff height as outlined in Equation 1 (Shand et al, 2015):

$$\mathrm{CEHZ}_{\mathrm{Cliffs}} := \underbrace{\left(\frac{\mathrm{H_c}}{\tan(\alpha)}\right)}_{\text{Cliff crest}} + \underbrace{\mathrm{LT_H}\cdot\mathrm{T}\cdot\left(\frac{\mathrm{SLR_F}}{\mathrm{SLR_H}}\right)^{\mathrm{m}}}_{\text{Cliff toe}} \tag{1}$$

Where:

H_C = Cliff height (m) Section 5.2.3.1

α = Stable cliff stable (degrees) Section 5.2.3.2

LT_H = Historic long-term retreat (m/yr) Section 5.2.3.3

T = Planning time frame (years) Section 5.2.3.4

SLR_H = Historical sea level rise (mm/year) Section 5.2.3.5

SLR_F = Future sea level rise (mm/year) Section 5.2.3.5

m = Sea level rise factor Section 5.2.3.6

The historic long-term retreat rate above relates to erosion of the cliff slope itself and not weathered material that has collected at the base of it. A coastal baseline that best follows the base of existing sea cliffs from which future Coastal Erosion Hazard Zones (CEHZ) can be measured generally follows the 1940 aerial photograph where the base of cliffs are less obscured by vegetation. Where erosion can be seen in the 2016 photograph (i.e. since 1940), the baseline follows the 2016 shoreline.

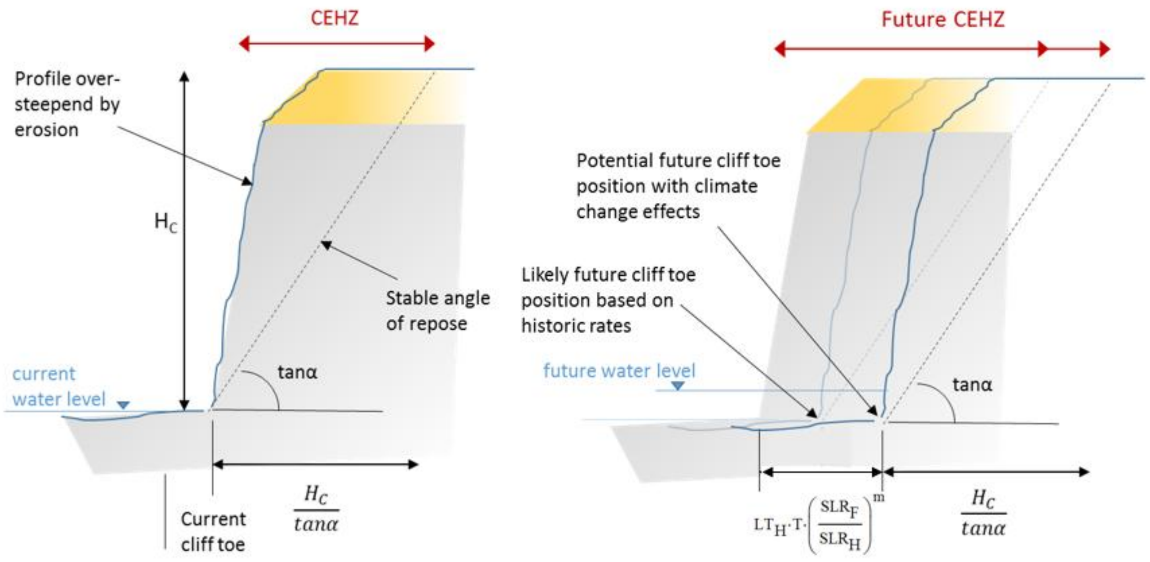

Figure 5-1 Definition sketch for cliff shore coastal erosion hazard zones for the present day (left) and future (right)

We have adopted a probabilistic approach which is consistent with the Envirolink guide, and includes the following steps:

- Break the shoreline into cells based on their geology, morphology and exposure
- The use of triangular probability distribution functions to contain the best estimate (mode), lower and upper bounds for cliff height, stable cliff angle, long-term retreat and sea level rise factor components (refer following sub sections)
- Randomly sample the probability distributions for the components and repeat this 10,000 times using a Monte Carlo technique. These distributions multiplied forecast the resultant cliff toe for a specific location at specific time frames

The probabilistic approach recognises there will always be inherent uncertainties associated with projections and provides a much more transparent way of capturing and presenting such uncertainty. We note that this method results in a range of potential hazard zone distances and that the selection of the appropriate probabilistic value will be based on discussions with Council. The probabilistic method also aligns with risk assessment approach where the results can be aligned with a range of likelihood scenarios if required.

5.2.3 Component derivation

5.2.3.1 Cliff height (H_c)

The cliff crest position has been digitised from AC LiDAR data. Allowing for an approximate cliff toe level of 1.5 m RL, from LiDAR cliff crest elevation has obtained the following approximate cliff heights in Table 5-2.

Table 5-2 Cliff height component values

Cell	Lower (m)	Mode (m)	Upper (m)
A	10.5	12	13.5
B	10.5	12	13.5
C	5.5	7.5	9.5
D	8.5	10.5	11.5

5.2.3.2 Stable cliff angle (α)

The following stable cliff angles (

Table 5-3) have been determined by reviewing the previous assessments in this area, walkover observations and experience with similar geology:

- In Cell B we have applied conservative values for fill material based on available contour information as no reliable information exists on the quality and characteristics of the fill
- In Cell C we have reviewed values presented in AECOM (2016) relating to ECBF for *likely, possible* and *unlikely* slope angles and applied these values to Lower, Mode and Upper values respectively
- In Cells A and D we have applied the PF T+T (2006) *possible* slope angle to the Upper value. The possible angle for PF in T+T (2006) of 18 degrees has been considered more suitable as a Lower value on the basis of our recent site observations, with the Mode being interpolated between the Upper and Lower values.

Table 5-3 Stable cliff angle component values

Cell	Lower (degrees)	Mode (degrees)	Upper (degrees) possible
A, D	18	22	26
B	18	22	26
C	18	26	35

5.2.3.3 Historic long-term retreat (LT_H)

The increased development of vegetation at the base of cliffs has obscured cliff line features by vegetation estimated to typically extend up to 3m in the 2016 aerial from the true cliff line. This reduction in the horizontal accuracy of the 2016 shoreline position is significant in context to the relatively low rates of shoreline change observed.

Walkover inspection within Cell A identified shallow instability and weathering processes in PF exposures associated with maximum mode and minimum erosion rates of -0.03 m/year, -0.01 m/year and 0 m/year respectively (applicable over the planning time frames below). The same long-term retreat rates were applied throughout due to there being no trends in Figure 3-8 that would suggest any difference in retreat rates in these areas.

5.2.3.4 Planning time frame (T)

This site specific hazard assessment and their future impact over at least the next 100 is consistent with the New Zealand Coastal Policy Statement (2010).

Two planning time frames were applied at the request of AC to provide information on current erosion hazards for the planning of future development:

- 2120 Coastal Erosion Hazard Zone (approx. 100 years)
- 2150 Coastal Erosion Hazard Zone (approx. 130 years)

5.2.3.5 Sea level rise effects ($SLR_{H,}$ SLR_F)

A historic sea-level rise rate (S_H) for Auckland of 1.7mm/yr (Hannah and Bell, 2012) has been adopted for this assessment.

The future sea level rise rates (S_F) have been based on the four SLR scenarios; RCP2.6, RCP4.5 and RCP8.5 median scenarios, and an RCP8.5+ (83^{rd} percentile) scenario. These value, adjusted for New Zealand are presented in Table 4-3.

5.2.3.6 Sea level rise coefficient (m)

Sea-level rise is expected to affect the retreat rates of soft cliffed shorelines (Defra, 2002), increasing the height of depth limited waves as more wave energy is able to reach the cliff base increasing hydraulic erosion and the removal of toe-protecting debris. It is also difficult to judge the longevity of mangrove forests growing within the embayment with sea level rise. To allow for this, an extra factor for ‘erosion due to sea-level rise’ has been included in the establishment of areas susceptible to erosion for cliffs.

Aston et al. (2011) proposed a generalised expression for future recession rates of cliff coastlines where a coefficient ‘m’ is determined by the response system. No feedback ($m \rightarrow 0$) indicates that the cliff is insensitive to sea level rise effects and future recession will occur at historic rates. This could occur where cliffs are in deep water and changes in sea level have no effect on wave energy reaching the cliff, or where the cliff erosion processes are insensitive to wave impact. An instantaneous response ($m = 1$) indicates that the future rate of recession will increase proportional to the increase in SLR, i.e. due to increased wave energy reaching the cliff toe. A negative/damped feedback system ($0 < m < 1$) occurs where rates of recession are slowed by development of a shore platform or fronting beach.

There is limited guidance on selection of appropriate coefficients for increased recession under SLR. Defra (2002) suggested that for soft cliffs an instantaneous response ($m = 1$) should be assumed. Walkden and Dickson (2008) found that for soft cliffs in the UK (recession rates of 0.8 – 1m/year) a factor of $m = 0.5$ could be assumed over the long term. Although these rates are higher than observed at this site, material strength is likely comparable and we propose $m = 0.5$ is adopted as an upper bound value.

Coefficients for each cell were selected by weighing up the relative erodibility to wave action (principally functions of material strength and condition), and the relative increase in wave action (principally functions of material strength and surface condition). Coefficients for the cells are shown in Table 5-4.

Table 5-4 Sea level rise coefficient

Cell	Geological unit	Relative erodibility to wave action	Relative increase in wave action	Min	Mode	Max
A	PF	High	Large	0.3	0.4	0.5
B	FILL	High	Minor	0.2	0.3	0.4
C	ECBF	Medium	Minor	0.1	0.2	0.3
D	PF	High	Moderate	0.2	0.3	0.4

5.3 Coastal erosion assessment results

Table 5-5 and Appendix B shows the $P_{50\%}$ and $P_{5\%}$ future erosion hazard extending landward of the cliff toe baseline for 2120 and 2150 (i.e. the $P_{5\%}$ value for 2120 is the future toe distance with a 5% probability of being exceeded by 2120).

Based on discussions with Auckland Council (8 July 2017) we have considered a planning horizon of 100 years (2120) with a SLR scenario based on the RCP8.5+ emission scenario, and hazard probability of $P_{5\%}$ to be a suitable minimum building setback distances for private development. Our assessment indicates only 5m to 6m of land separates the $P_{5\%}$ and $P_{50\%}$ setback distances.

Setback distances in Table 5-5 below have been increased by a further 3m to allow for errors associated with increased cliff toe vegetation and difficulties accurately digitising shoreline position. An example of the numerical output from which values in Table 5-5 were derived is provided in Figure 5-1.

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.

Table 5-5 Future erosion hazard extending landward of the cliff toe baseline

Cell	Scenario	2120				2150			
		MIN	$P_{50\%}$	$P_{5\%}$	MAX	MIN	$P_{50\%}$	$P_{5\%}$	MAX
A	RCP2.6	-26	-34	-40	-45				
	RCP4.5	-26	-35	-40	-46				
	RCP8.5	-26	-35	-41	-47				
	RCP8.5+	-26	-36	-41	-48	-27	-37	-43	-50
B	RCP2.6	-26	-34	-40	-45				
	RCP4.5	-26	-34	-40	-45				
	RCP8.5	-26	-35	-40	-46				
	RCP8.5+	-26	-35	-41	-46	-27	-36	-42	-49
C	RCP2.6	-12	-19	-25	-32				
	RCP4.5	-12	-20	-25	-32				
	RCP8.5	-13	-20	-26	-32				
	RCP8.5+	-13	-20	-26	-32	-13	-21	-27	-34
D	RCP2.6	-22	-30	-35	-41				
	RCP4.5	-22	-30	-35	-41				
	RCP8.5	-23	-30	-35	-42				
	RCP8.5+	-23	-31	-36	-42	-22	-31	-37	-43

-ve denoted landward of the current cliff toe

5.4 Limitations

This report considers coastal erosion hazard primarily based on aerial imagery and available LiDAR data.

Review of the Auckland Council LiDAR information show a number of surface features indicative of low angle deep seated geotechnical instability, particularly within Cell C in ECBF material (Appendix B).

In the absence of site specific geological (sub-surface) information it is difficult to ascertain how changes in the future shoreline position will affect the stability of these mechanisms. As a minimum we recommend site specific geotechnical slope stability assessments for building development within 100m of the 2016 shoreline in Appendix B. Slope stability analyses should disregard land seaward of P_5% setback distance (landward translation of the existing cliff and shoreline profile showing future crest levels parallel with the P_5% setback distance).

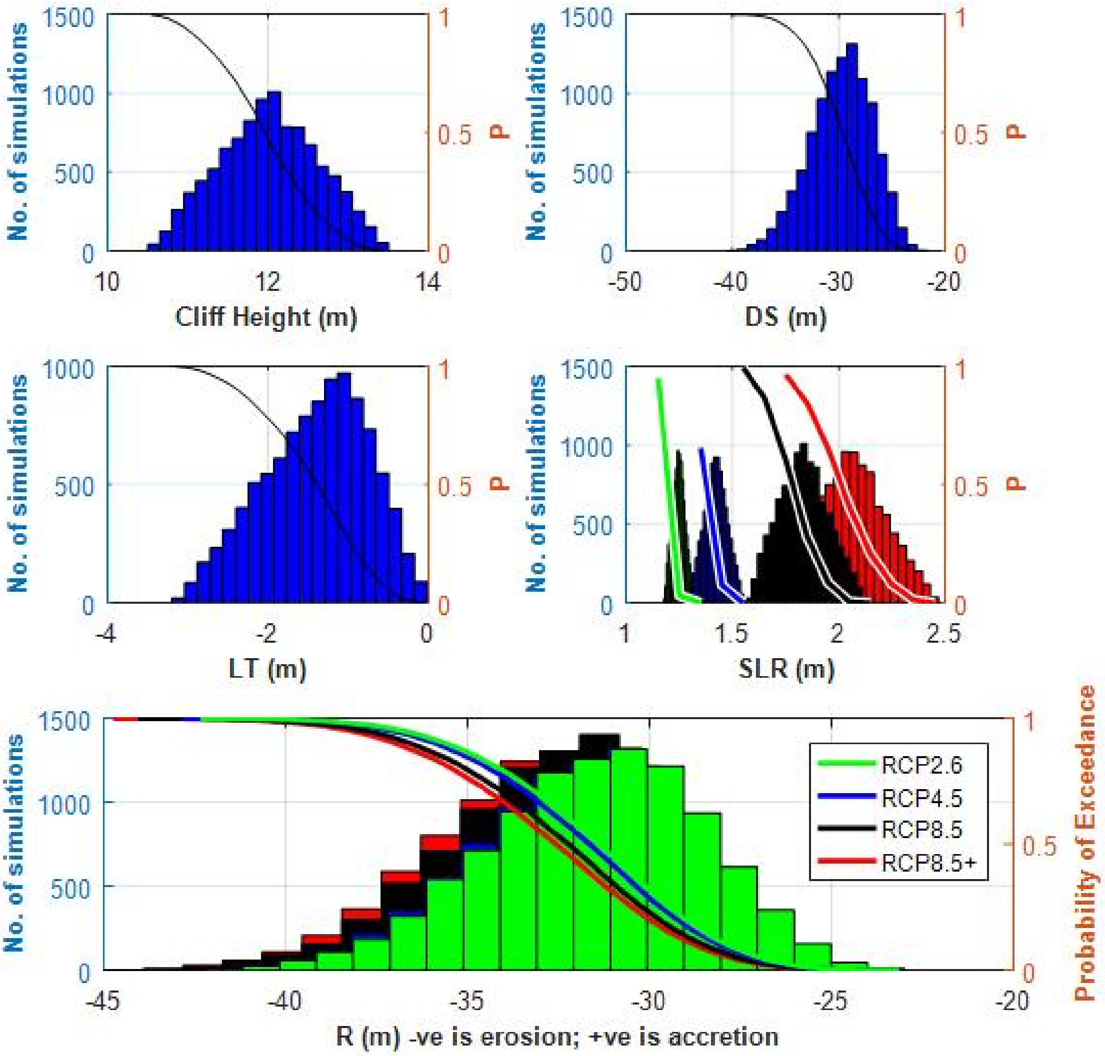

Figure 5-1 Example of cumulative distribution functions of parameter samples and the resultant CHZ distances for Cell A, 2120 time frame

6 Summary

This report considers coastal erosion hazard within the Stage 1 area proposed for re-zoning in Whenuapai. We have considered planning time frames to 2120 and 2150 and applied a probabilistic approach for our hazard assessment that provides likelihoods of hazard extent. This assessment indicates future erosion hazard extending landward of the current cliff toe baseline of between 26 m and 41 m for the 2120 time frame, and between 27 and 43m for 2150 time frame (adopting an RCP8.5+ sea level rise scenario).

Setting

The coastal edge in this area comprises Puketoka Formation (PF) pumiceous sands and silts to the north, each side of the inlet. The southern extent of the inlet is surrounded by lower, more protected and more densely vegetated coastal edge comprising East Coast Bays Formation (ECBF) material. A headland comprising largely fill material is located adjacent to the Whenuapai RNZAF Base.

The base of cliffs are typically located approximately 1m below the high tide level of Mean High Water Springs (MHWS), protected in many areas by mangrove forest up to 150 m in width, with a very gradual (less than 3 degrees) sloping mudflats extending out of the study area towards the upper Waitemata Harbour. This section of coast has a low energy wave climate, only being exposed to wind waves from the east over limited fetch distances (less than 2.5 km) during the upper half of the tide.

Erosion hazard model

Erosion hazard along cliffed coastlines is influenced by erosion of the cliff toe caused by marine and biological processes, weathering and slumping of the over steepened cliff face. Sea level rise may influence cliff erosion by allowing higher wave energy to reach the cliff toe, increasing hydraulic loading and more effectively removing protective landslide debris. An erosion model has been adopted that incorporates these components including the uncertainty associated with each.

Input parameters for the probabilistic hazard assessment include:

- Cliff heights along defined stretches of the coast with heights ranging from 5.5 m to 13.5 m determined from LiDAR
- Stable angle of cliff ranging from 18-35°
- Long-term retreat rate of up to -0.03 m/year based on walkover observations and review of aerial photos
- Sea level rise factors to allow for erosion due to sea-level rise, selected by weighing up the relative exposure to erosion within the context of it geomorphological setting, and the relative susceptibility of each material type to erosion
- Future sea level rise rates for a range of potential future emission scenarios based on the median values of the Intergovernmental Panel of Climate Change (IPCC) scenarios RCP2.6, RCP4.5 and RCP8.5 as well as the 83rd percentile of RCP8.5 (RCP8.5+). These scenarios have been adjusted to the New Zealand regional scale. A historical rate of sea level rise of 1.7 mm/ year has been deducted from these rates.

Limitations

These results are to estimate the hazard extents. Based on our discussions with Auckland Council (AC, 8 July 2017) we understand building platforms are required to be located behind the RCP 8.5+ 5% setback distance.

In addition, detailed analysis of Auckland Council LiDAR information indicate a number of surface features likely to be indicative of historical instability in the form of landslips. In the absence of detailed walkover observations and subsurface geotechnical investigations there is insufficient information to explicitly relate deep seated instability to coastal erosion hazard. Accordingly, we recommend site specific slope stability assessments for building development within 100m of the 2016 shoreline.

7 Applicability

This report has been prepared for the exclusive use of our client Auckland 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

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Appendix A: Historic shorelines

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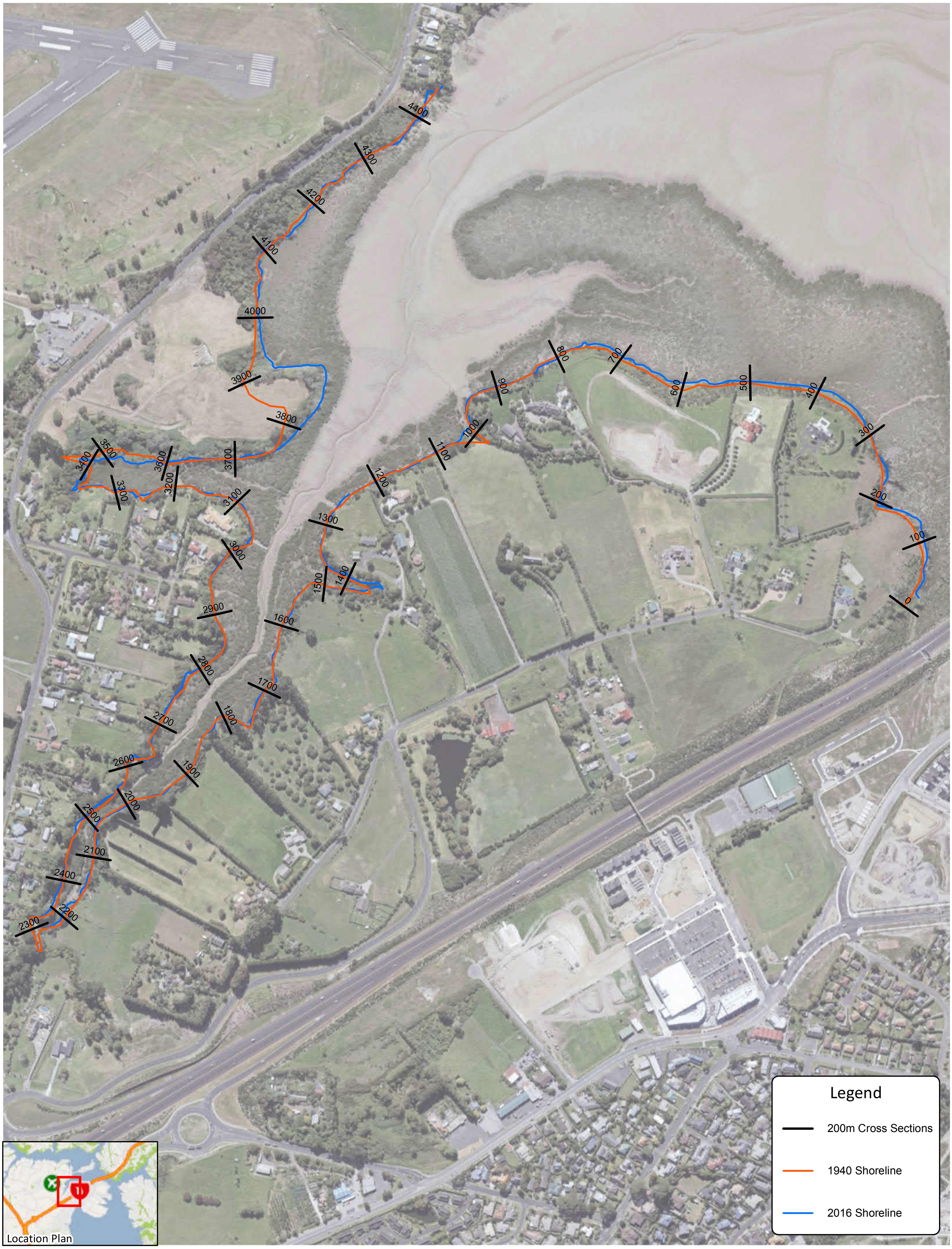

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Land Information New Zealand, Eagle Technology

A3 SCALE 1:5,000

0 0.05 0.1 0.15 0.2 0.25 (km)

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SCALE (AT A3 SIZE)
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1940 and 2016 Shoreline Positions

FIGURE No.
Appendix A

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Appendix B: Coastal erosion hazard zones

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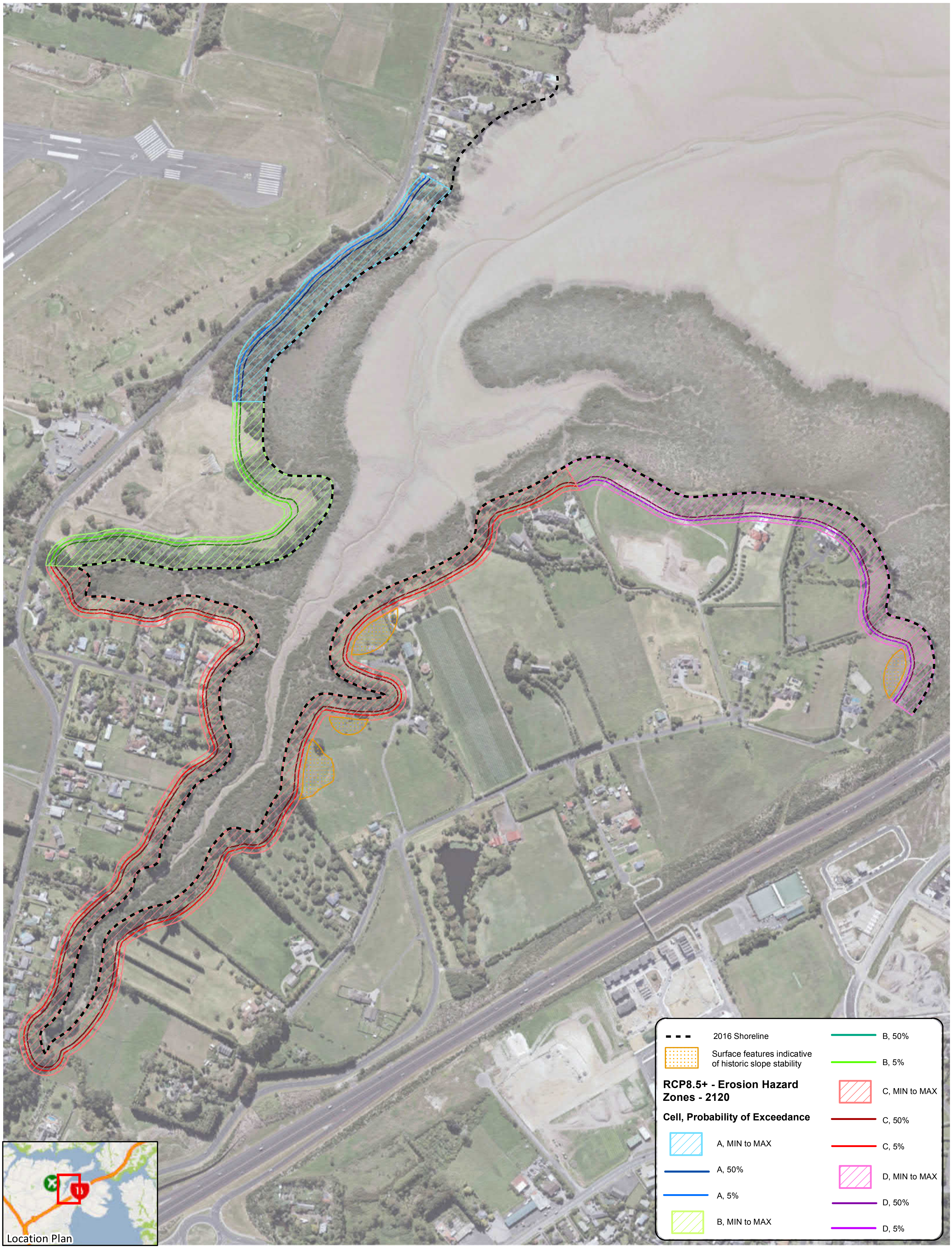

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A3 SCALE 1:5,000

0 0.05 0.1 0.15 0.2 0.25 (km)

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RCP8.5+ - Erosion Hazard Zones 2120

FIGURE No. Appendix B.

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