Whenuapai – Private Plan Change

Coastal Hazard Assessment

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SLR Project No.: 850.016583.00001

24 April 2024

Revision: V.1.1

Making Sustainability Happen

Revision Record

Revision	Date	Prepared By	Checked By	Authorised By
V.1.1	19 April 2024	Alison Clarke and Cat Davis	Peter de Ruiter	Tim Baker
V1.1	24 April 2024	Alison Clarke and Cat Davis	Peter de Ruiter	Tim Baker

Basis of Report

This report has been prepared by SLR Consulting New Zealand (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Cabra Developments Limited (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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Acronyms and Abbreviations

AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ASCIE	Area Susceptible to Coastal Instability and Erosion
AUP:OP	Auckland Unitary Plan Operative in Part
CMA	Coastal Marine Area
ECBF	East Coast Bay Formation
GNS	Institute of Geological and Nuclear Sciences Limited
IPCC	Intergovernmental Panel on Climate Change
MFE	Ministry for the Environment
MHWS	Mean High Water Springs
MHWS-10	MHWS level equalled or exceeded by the largest 10% of all high tides
NIWA	National Institute of Water and Atmospheric Research
OLFP	Overland Flow Path
RL	Reduced Level
RSLR	Relative Sea Level Rise
SEA	Significant Ecological Area
SSP	Shared Socioeconomic Pathway
T+T	Tonkin and Taylor
VLM	Vertical Land Movement

1.0 Introduction

SLR has been engaged to undertake a site-specific coastal hazard assessment associated with the proposed private plan change at 10, 14, 16 Sinton Road and 15 Clarks Lane, Whenuapai, Auckland (**Figure 1**). It is understood that the landowners intend to lodge an application to have the land rezoned to residential to facilitate urban development in this area.

The coastal margins of the project site are identified within the Auckland Unitary Plan Operative in Part (AUP:OP) as being potentially subject to a coastal erosion hazard. However, it is recognised that this definition is reasonably generic and based on assumptions around broad coastal classifications of the Auckland coastline. Consequently, it is recommended by Auckland Council that site-specific coastal erosion assessments are undertaken to better understand the actual risk. Some of the lower lying areas of the sites along the coastal fringe are also shown as potentially being subject to future coastal inundation hazard (1% AEP plus 1m Control).

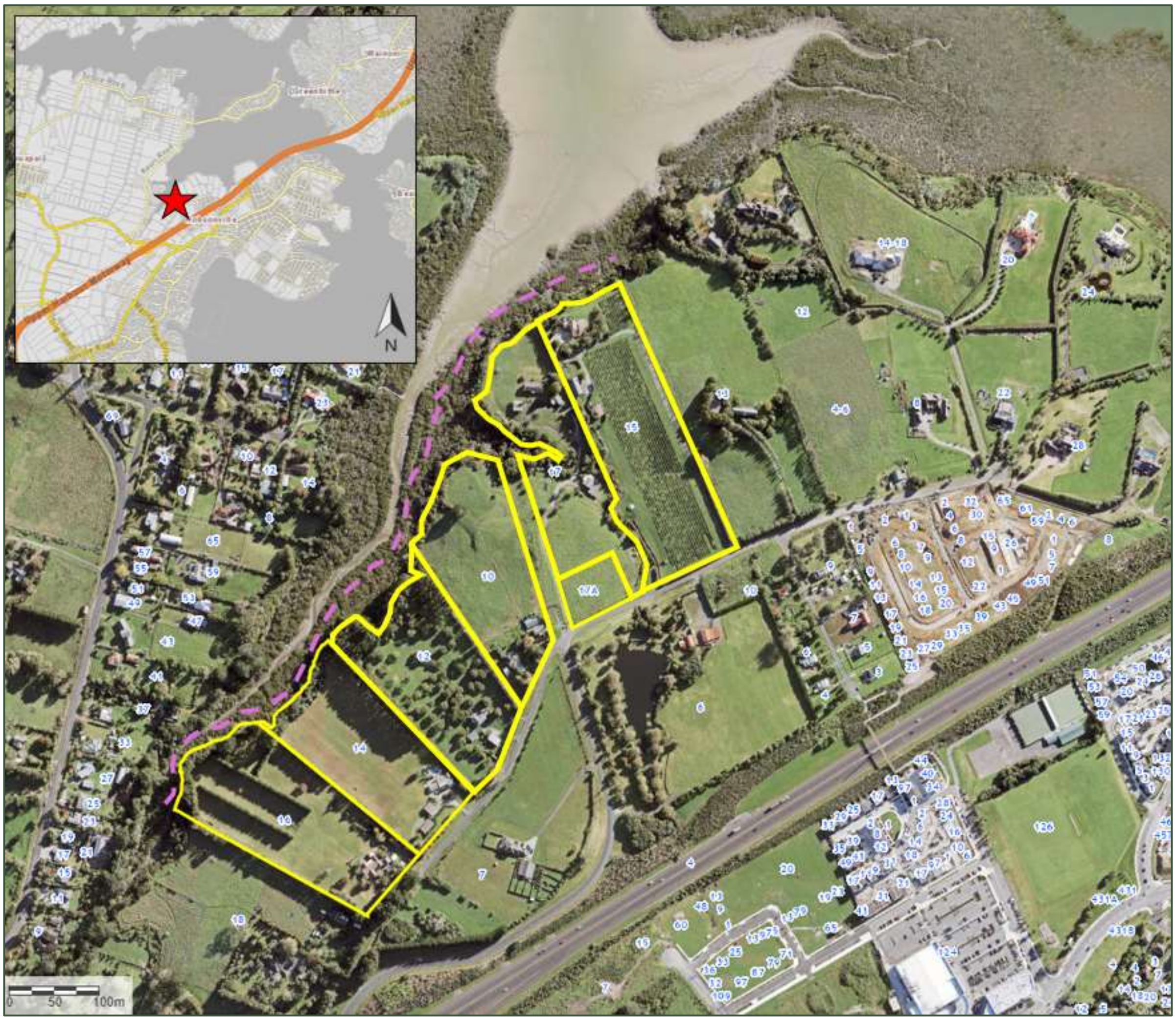

Figure 1: Location of the project coastline at Sinton Road and Clarks Lane, Whenuapai. The extent of the coastal hazard assessment is indicated in pink. Source: Auckland Council GeoMaps.

1.1 Scope of Report

This report evaluates the risk to the site from coastal erosion and inundation hazard in a site-specific context and is intended to inform the structure planning and plan change application. An assessment is made of both the present-day risk to the subject site and the risk over the next 100+ years associated with future projected sea level rise. The methodology used includes a desktop review of the wider coastal processes obtained from previous research and reporting, which has been supplemented by site observations and an analysis of historical aerial photos and satellite imagery. The assessment does not explore the planning merits or limitations of the proposed plan change. No discussions with Auckland Council staff have been undertaken.

1.2 Previous Work

Tonkin and Taylor (2017) undertook a coastal assessment within the Whenuapai structure plan area subject to re-zoning (refer to **Appendix B** for the Stage 1 Coastal Hazard Assessment). The report considered planning timeframes to 2120 and 2150 and applied a probabilistic approach to provide likelihoods of hazard extents based on the methodology outlined in the previous regional assessment of areas susceptible to coastal erosion in Auckland (Tonkin and Taylor, 2006), which was best practise at the time. The Stage 1 assessment determined coastal erosion extents along a much longer section of coast to the current application (**Figure 2**) including approximately 4.5km of cliffed coastline. For the current project coastline (i.e. Cell C in the image below), the report identified a future erosion hazard distance of between 13m and 32m for the 2120 timeframe, and between 13m and 34m for 2150 timeframe.

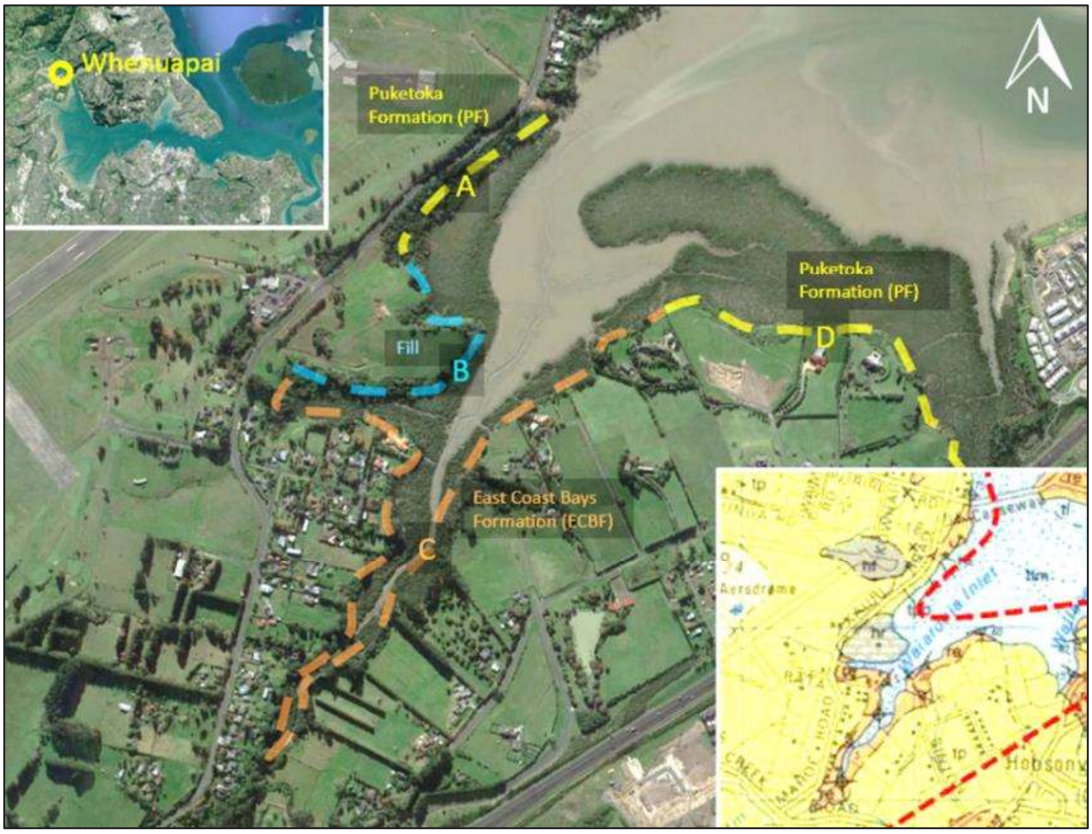

Figure 2: Extent of the Stage 1 Coastal Hazard Assessment undertaken previously. From Tonkin and Taylor (2017).

2.0 Site Description

The subject site is located approximately 12km northwest of Central Auckland and is situated within a discrete tidal arm (the Waiarohia Inlet) in the upper Waitematā Harbour. The plan change area relates to four parcels of land on the northern side of Clarks Lane/Sinton Road as highlighted in yellow in **Figure 1**. We understand that Cabra own the properties at 15 Clarks Lane, 10 Sinton Road, 14 Sinton Road and 16 Sinton Road. The sites are currently used as and are surrounded by lifestyle blocks with pasture and a few residential buildings. The small rectangular property at 17A Clarks Lane is owned by Auckland Council and is to be rezoned open space as part of the current application.

The project site comprises relatively flat to mildly sloping land with a total combined area of approximately 16.65ha. The site's coastal edge is bound by the Waiarohia Inlet to the northwest, where steeper and often vegetated slopes are present over a short distance, fronted by tidal flats. Sinton Road and Clarks Lane border the site in the southeast. Land surrounding the project site comprises a mix of rural, rural residential and pastoral land.

Topographic LiDAR data available for the site on Auckland Council's GeoMaps indicates that existing land elevations are around RL18m near Clarks Lane and Sinton Road, sloping in a north-westerly direction towards the harbour edge, with a coastal bank toe elevation of roughly RL1.5m. The coastal embankment along the project site appears to range from ~1m to 5m in height.

2.1 Coastal Geomorphic Setting

The subject site represents coastal land located on the southern shore of the Waiarohia Inlet, which is an upper tidal arm of the Waitematā Harbour. A narrow meandering channel is centrally located within the inlet, merging into a larger tidal channel north-eastward of the site, which then feeds into the wider estuary roughly 3.5km southeast of the project site. The tidal system can be described as a relatively low energy environment due to its sheltered upper-estuarine location.

The main geomorphic features of the wider area are highlighted in **Figure 3** with the plan change area coastline indicated by the pink dashed line. The intertidal areas fronting the northwestern coastal embankment along the project site are characterised by shallow mudflats with established mangrove forest (~2-3m high). At the bank toe the predominant sediment appears to be estuarine fines.

2.2 Geology

Information from the geological maps available on GNS Geology Web Maps[1] indicate that the northwestern (coastal) sections of the properties within the plan change area are characterised by interbedded sandstone and mudstone deposits belonging to the East Coast Bays Formation (ECBF) of the Waitematā Group. In the southeastern sections, the published geological maps indicate that Takaanini Formation river deposits dominate. An overview of the underlying geology near the site is shown in **Figure 4**.

Broad geotechnical investigations were carried out by ENGEO across the project sites between August and December 2023. Hand auger samples from sites close to the coastal margin confirm the occurrence of ECBF rock mass at depth. The surface soils across the four Cabra sites comprise varying depths of colluvium, alluvium, Puketoka Formation clays and silts and ECBF residual soils.

[1] https://data.gns.cri.nz/geology/

Figure 3: Annotated map of the coastal geomorphic setting of the plan change area. Subject coastline indicated in pink. Source: Auckland Council GeoMaps.

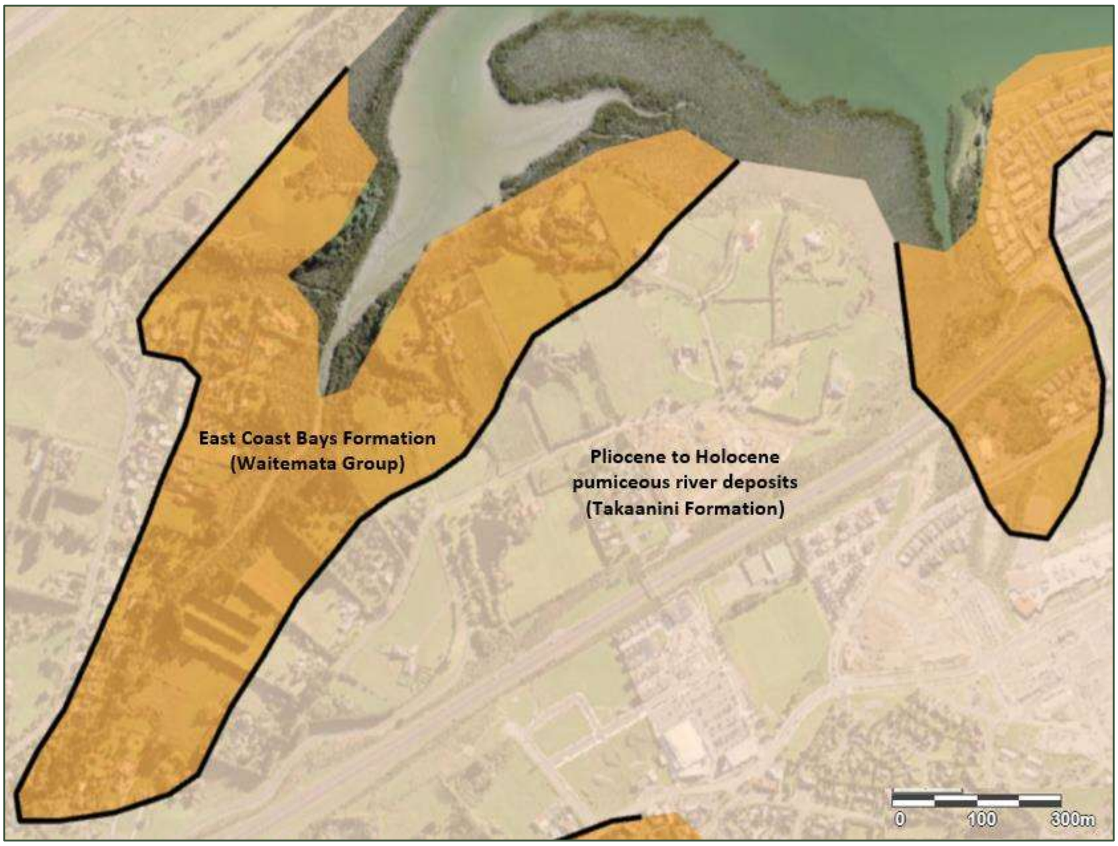

Figure 4: Published geology of the subject area. Source: https://data.gns.cri.nz/geology/

2.3 Historical Coastal Change

A brief analysis of the available historic aerial photos from Auckland Council GeoMaps was undertaken as a part of this investigation to make a qualitative assessment of changes in the area. This analysis identifies a significant widening and expansion of mangroves along the coastal edge of the subject site during the past ~74 years (i.e. 1950 – 2024, refer to **Figure 12** in Section **4.3.2**).

No measurable change to the cliff toe/shoreline position along the coastal edge of the project area over the past ~60 years was detected, highlighting that any long-term erosion at the site has been relatively slow. A more detailed analysis of local coastal regression, which supports the site-specific erosion hazard calculations, is described in **Section 4.3**.

Historic photographs also show the construction of the vehicle causeway joining Whenuapai and Herald Island north of the study area (**Figure 3**) in the 1950's, effectively reducing fetch distances from the northwest from 3km to 1km and thus reducing the exposure of the subject coastline to wind waves. The sheltering effects of the causeway are likely to have contributed to the observed mangrove expansion.

2.4 Site Observations

A site walkover of the coastal margins at 15 Clarks Lane, 10 Sinton Road and 14 Sinton Road were undertaken by a coastal scientist on 25th March 2024 at low tide (**Figure 5 and 6**). 16 Sinton Road was accessed at a later date on the 22nd of April 2024 (**Figure 7**). The following paragraphs describe the site obervations.

The coastal boundaries of 14 and 16 Sinton Road are designated as a Significant Ecological Area (SEA_T_4733) which was characterised by an assemblage of native vegetation including manuka (*Leptospermum scoparium*), red matipo (*Myrsine australis*) and *Coprosma* sp. (**Figure 6a**).

The coastal margin at 15 Clarks Lane, 10 and 14 Sinton Road were observed to be relatively uniform, characterised by a vegetated low-lying bank (1- 5m), intertidal mudflats and large mature mangroves (over 2-3m in height, **Figure 6b**). The steepest banks were found on the northeastern boundary of the site on 15 Clarks Lane approximately 4m high and with a maximum slope of roughly 50°. The lower bank was cracking at the toe and had mud crab holes causing instabiltiy in places at the coastal interface, but no other obvious signs of erosion were observed (**Figure 6c)**. There was an informal riprap seawall in poor condition at the toe of the bank at 14 Sinton Road (**Figure 6d, e)**. The mudflats at 15 Clarks Lane have been dug out with machinery at the boat ramp to presumably enable boating access (**Figure 6f)**.

The coastal margin of 16 Sinton Road was characterised by a higher proportion of exotic vegetation (*Pinus radiata* and *Macrocarpa* sp.) compared to the other sections of the subject coastline. There was some scour, undercutting at the bank toe and areas of bank that had slumped into the Coastal Marine Area (CMA, **Figure 7a, b**). There was incised channel (likely an overland flowpath (OLFP)) that was dry at the time of survey exposed the sandstone and there was a pool of standing water at the discharge point into the CMA (**Figure 7c, d, f**). An outlet from a nova coil pipe (approximately 450mm) from the upstream drainage channel was located half way up the bank, perpendicular to the OLFP (dry at the time of survey, **Figure 7e**).It is possible that the coastal bank more unstable in this location due to the exotic vegetation and the overland flow features.

In several places along this section of coast there was cut vegetation that had been dumped onto the CMA.

Figure 5: Locations of coastal edge characteristics and erosional features observed during site visit (orange stars). Subject site property boundaries shown by the yellow polygons.

Figure 6: Site observations of the vegetated bank looking west towards the Significant Ecological Area (a, SEA_T_4733), fronted by mangroves and tidal flats (b), section of the bank toe with mud crab holes and cracks (c), riprap and concrete of an informal seawall (d, e) and evidence of dug sections of the mudflat by machinery for boating access (e).

Figure 7: Site observations of the coastal edge at 16 Sinton Road. Observations of bank slumping (see green circle in photo a) undercutting and erosion of the bank toe (b), OLFP (c, d with arrow showing likely direction of flow), nova coil pipe that sits above the OLFP (e, arrow showing direction of flow of OLFP) and exposed sandstone and pool in CMA (f).

3.0 Coastal Processes Assessment

In general, the subject coastline is a sheltered environment due to its upper harbour location, along with the prevalence of tidal mudflats and mangroves near the site's coastal frontage. A description of the main coastal processes operating at the site are provided in the respective sections below.

3.1 Wind and Wave Climate

Wind hindcast data has been sourced from MetOceanView[2] to provide an indication of the local wind climate and of how the wind is contributing to the local coastal processes regime. The wind rose in **Figure 8** shows a predominance of winds from the west and southwest. 10-year and 100-year return period wind speeds are 18.8 m/s and 21.7 m/s, respectively, as sourced from MetOceanView.

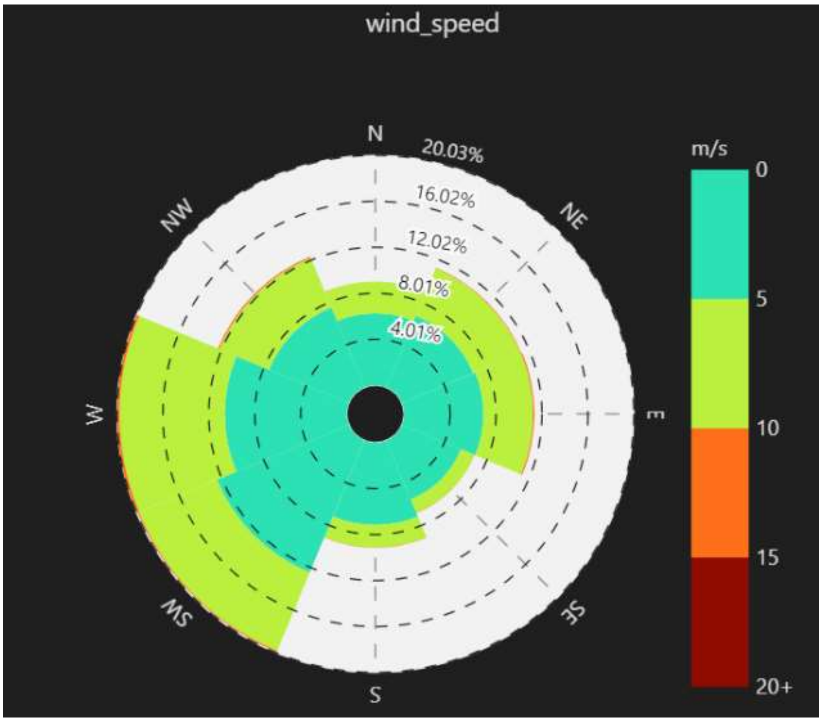

Figure 8: Wind rose data for a modelling point near the subject site (Waitematā Harbour). Source: MetOceanView.

The site has a sheltered nature due to protection both from Herald Island and the remainder of the peninsula to the east. Due to this protection, the fetch distances are restricted to <1km (largest fetch run approximately NNE-SSW from Herald Island). The relatively short fetches, combined with the shallow intertidal water depth and the presence of local mangroves hamper the generation of wind-generated waves near the site's coastal frontage. Therefore, extreme waves heights that could be expected at the site during storm events are likely to be less than 400mm high and will be further restricted by tidal fluctuations.

[2] https://app.metoceanview.com/hindcast-squared/#/stats-point/lng/174.6084/lat/-36.77344

3.2 Tides

The closest long-term tidal station to Whenuapai is at the Port of Auckland located approximately 12km southeast of the project site. Typically, the tidal variation range is 2.83m and 1.73m for spring and neap tides, respectively. The adjusted tidal levels (sourced from LINZ[3]) are shown in **Table 1** relative to Auckland Vertical Datum 1946 (AVD-46). A pragmatic value for Mean High Water Springs for the site has been inferred to be RL1.76m. This value has been taken from Modelling Point 30 (Waitematā Harbour) from Stephens and Wadhwa (2012) and represents the elevation that will only be exceeded by the highest 10% of all tides.

Table 1: Tidal variables at Port of Auckland

Tidal Variable	Water Level (m RL)
Mean High Water Springs (MHWS-10)*	1.76
Mean High Water Neaps (MHWN)	1.60
Mean Sea Level (MSL)	0.18
Mean Low Water Neaps (MLWN)	-0.68
Mean Low Water Springs (MLWS)	-1.23
*MHWS-10 taken from Modelling Point 30 from Stephens and Wadhwa (2012).	

3.3 Extreme Water Levels

Table 2 provides a range of storm surge variables as an indication of extreme water levels at the site. This information has been obtained from modelling of the Waitematā Harbour by Stephens et al. (2013). This study used a hydrodynamic model calibrated against tide-gauge measurements to calculate storm tide elevations at critical locations around the Auckland Region for a number of return period events. All elevations are relative to AVD-46 with a 0.15m offset for baseline mean sea level. As a presented in **Table 2**, the 1 in 100-year return period storm tide for the modelling point nearest to the project site was identified as RL2.6m. Note that these levels exclude local effects of wave set-up that are likely to be relatively minor in a shallow estuary environment.

Table 2: Predicted water level elevations for the subject area. Estimates of maximum storm surge are taken from Modelling Point 67 of NIWA's coastal inundation modelling of the Waitematā Harbour and have been calculated for different Average Recurrence Intervals (ARI). Source: Stephens and Wadhwa (2013).

Storm Surge Variable	Water Level (m RL)
2yr ARI Storm Surge	2.28
5yr ARI Storm Surge	2.36
10yr ARI Storm Surge	2.42
20yr ARI Storm Surge	2.47
50yr ARI Storm Surge	2.54
100yr ARI Storm Surge	2.60

[3] https://www.linz.govt.nz/guidance/marine-information/tide-prediction-guidance/standard-port-tidal-levels

3.4 Future Sea Level Rise

Sea level rise is an ongoing and documented process that is affecting coastlines worldwide. While there is uncertainty in the future rate of sea level rise, the New Zealand government acknowledges that sea level rise is occurring and requires that it is accounted for in the design and planning of structures and developments in the coastal zone.

The AUP:OP requires consideration of the 1% Annual Exceedance Probability (AEP) storm surge with 1m sea level rise over the next 100 years. However, the latest MfE (2024) guidance suggests considering the potential consequence of up to 2m sea level rise for new coastal subdivisions and development, including an allowance for Vertical Land Movement (VLM).

Updated sea level rise projections for New Zealand were released in May 2022 by the NZSeaRise Research Programme[4]. The new localised projections combine the latest sea level rise scenarios from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) with averaged localised rates of VLM around the coast, resulting in relative sea level rise (RSLR) estimations which highlight sea level rise relative to the local landmass. As such, these projections include not only the effect of sea level rise, but also the effect of long-term subsidence or landmass uplift based on recent analysis of satellite radar and GNSS/GPS data.

In **Figure 9** below the NZSeaRise sea level rise curves for the modelling point nearest to the subject site (1181) are presented, based on the five Shared Socioeconomic Pathway (SSP) emission scenarios, noting that these graphs are relative to average baseline sea level from 1995 – 2014 and are zeroed relative to the year 2005. Specific values of projected RSLR for 2130 at modelling point 1181 are listed in **Table 3.** These values have been adjusted to account for the present day 0.06m to 0.14m of sea level rise relative to the baseline value. From this we see that when VLM and the shift from baseline to year 2020 are considered, sea level rise at the project site in 2130 is expected to be between 0.5m and 1.91m.

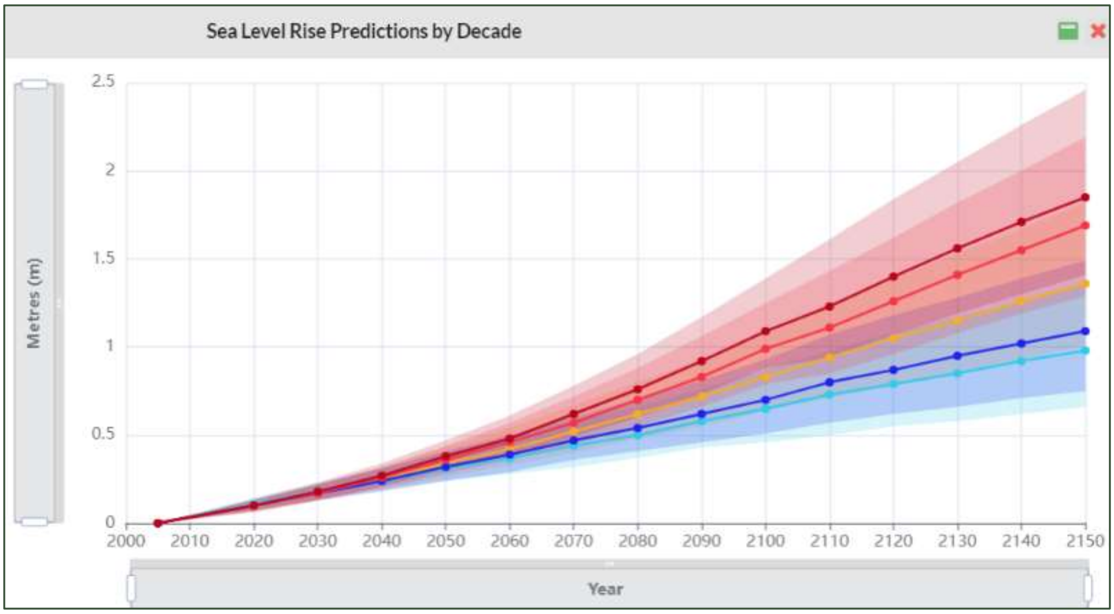

Figure 9: Site-specific RSLR projections for the five SSP scenarios including VLM to 2150 at modelling point 1181. Source: https://www.searise.nz/maps-2.

[4] https://www.searise.nz/maps-2

Table 3: Sea level rise in metres from present day (2020) to 2130 including VLM. Values are displayed for three confidence intervals (p17, p50, and p83 – referring to 17th, 50th, and 83rd percentiles). Source: https://www.searise.nz/maps-2.

SSP Scenario	p17 +VLM (m)	p50 +VLM (m)	p83 +VLM (m)
SSP1-1.9	0.50	0.74	1.03
SSP1-2.6	0.59	0.85	1.15
SSP2-4.5	0.79	1.05	1.40
SSP3-7.0	1.01	1.31	1.69
SSP5-8.5	1.13	1.46	**1.91**

In accordance with the MfE (2024) guidance, the p83 (i.e. 83th percentile) value for the upper-range SSP scenario (SSP5-8.5 – medium confidence to the year 2130) of **1.91m** has been chosen to 'stress test' the future resilience of the proposed plan change area to future coastal inundation in the following section. This reflects the project site falling under a 'Category B' type activity (i.e. changes in land use and redevelopment). This has been achieved through consideration and assessment of the +2m sea level rise scenario of the coastal inundation modelling that is presented on the Auckland Council GeoMaps (**Figure 10** refers).

4.0 Coastal Hazard Assessment

In general, the degree of risk from coastal hazards at the site will tend to be restricted due to the relatively low energy nature of the site. Brief comment is provided below with respect to the coastal inundation and tsunami risks. A quantitative coastal erosion assessment has been undertaken in order to obtain an understanding of the erosion risk at the site. This approach is consistent with Auckland Council's Coastal Hazard Assessment Guidance Document (Carpenter, 2021).

4.1 Coastal Inundation

Given the relatively elevated nature of the site, coastal inundation hazard is not currently a substantial issue at the subject site. Published maps of the coastal inundation extents for a 1% AEP (or 100-year ARI) storm surge event at present day and with 1m and 2m sea level rise have been obtained from Auckland Council and are presented in **Figure 10**. This shows virtually the entire site (except for a very narrow section of the intertidal area along all of the northern/coastal property boundaries) to be located beyond/above the area considered at risk from a 1% AEP event (darker blue areas).

Even when allowing for a 1-2m rise in sea level (grey and light blue areas, respectively) the subject sites are shown to continue to remain almost entirely unaffected by coastal inundation over the high tide period during future extreme storm events.

As can be seen in **Figure 10**, the extent of this future coastal inundation would be limited to the coastal fringes of the area of interest. Modelled flood extents are shown to be confined to the area (20m inland of MHWS) which is to be vested as esplanade reserve, and therefore future residential development is unlikely to be impacted by future coastal storm surges. Consequently, the potential impact from future coastal inundation on the subject site is considered to be minor, and can be easily mitigated through appropriate building setbacks.

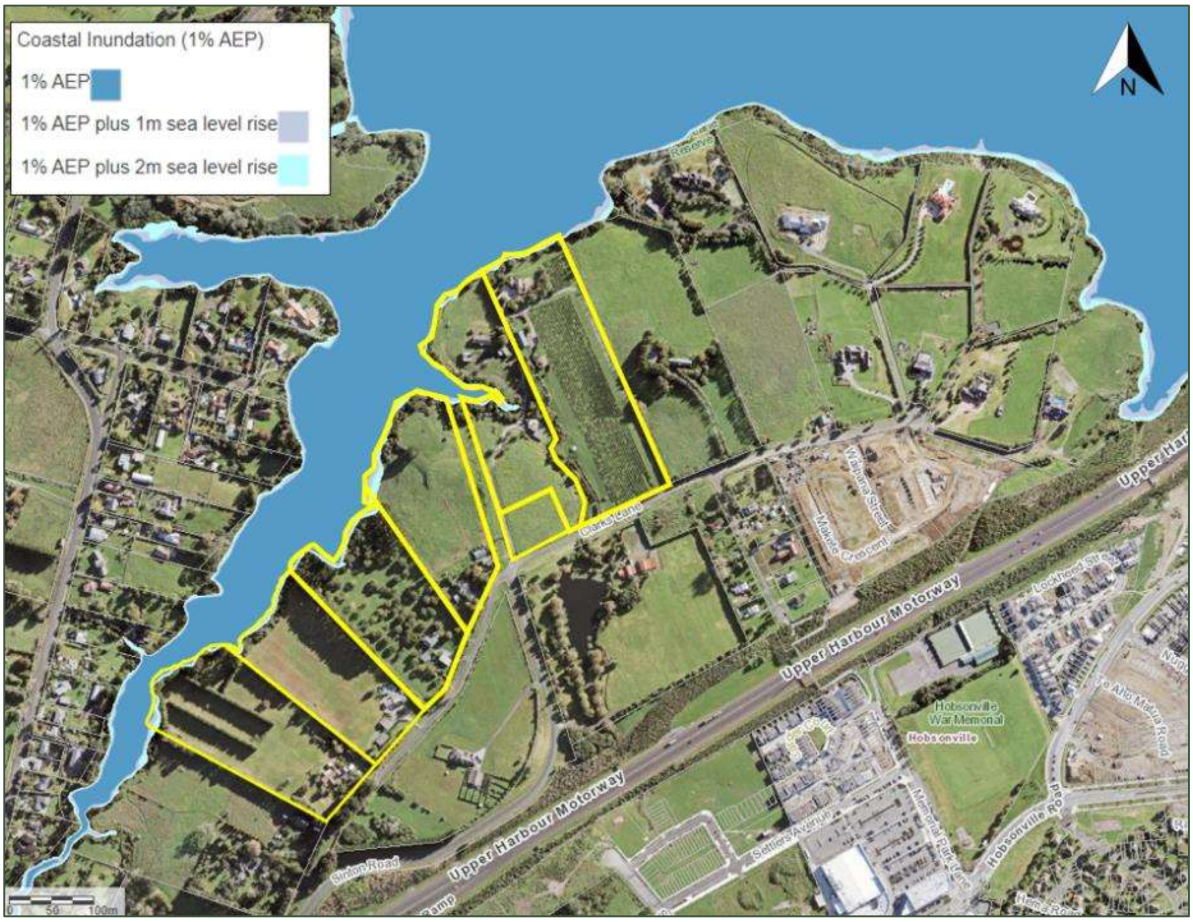

Figure 10: Areas susceptible to coastal inundation (source: Auckland Council GeoMaps) with the yellow shaded polygons indicating the approximate property boundaries within the proposed plan change area.

As noted previously, the 1% AEP storm surge with 1m sea level rise is the current requirement for consideration within the AUP:OP, but MfE guidance suggests considering the potential consequence of up to 1.91m sea level rise for new subdivisions and development. Therefore, maximum inundation level that needs to be considered for the subject coastline is 4.51m AVD-46. This is a combination of the 1% AEP extreme water level of 2.6m AVD-46 (**Table 1** refers), plus a conservative allowance for future sea level rise (including VLM) of +1.91m (**Table 2**) over a 100-year planning horizon. Any future development within the project area will likely require minimum of finished floor levels (FFLs) of 5.01 m RL (AVD-46).

4.2 Tsunami Hazard

Auckland Civil Defence has produced maps highlighting tsunami risk across the Auckland region. For the subject coast the areas below MHWS are highlighted as exclusion zones (red). This covers the foreshore and adjacent relatively low-lying areas most likely to be affected by a tsunami. Above this point a yellow 'land threat' zone is often highlighted, covering the area that may need to be evacuated if there was a threat from a dangerous tsunami.

Figure 11 identifies that a very narrow stretch of land along the coastal edge the of subject sites, which consists of the low-lying intertidal area, is located inside the Shore Exclusion Zone. We note that there are no yellow land threat zones identified along the subject coastline. Given the overall more elevated nature of the rest of the subject site the risk to the proposed area of plan change from a tsunami is considered to be very low. Further, it is recognised that the proposed plan change will not change or worsen the susceptibility of the site to tsunami inundation hazard.

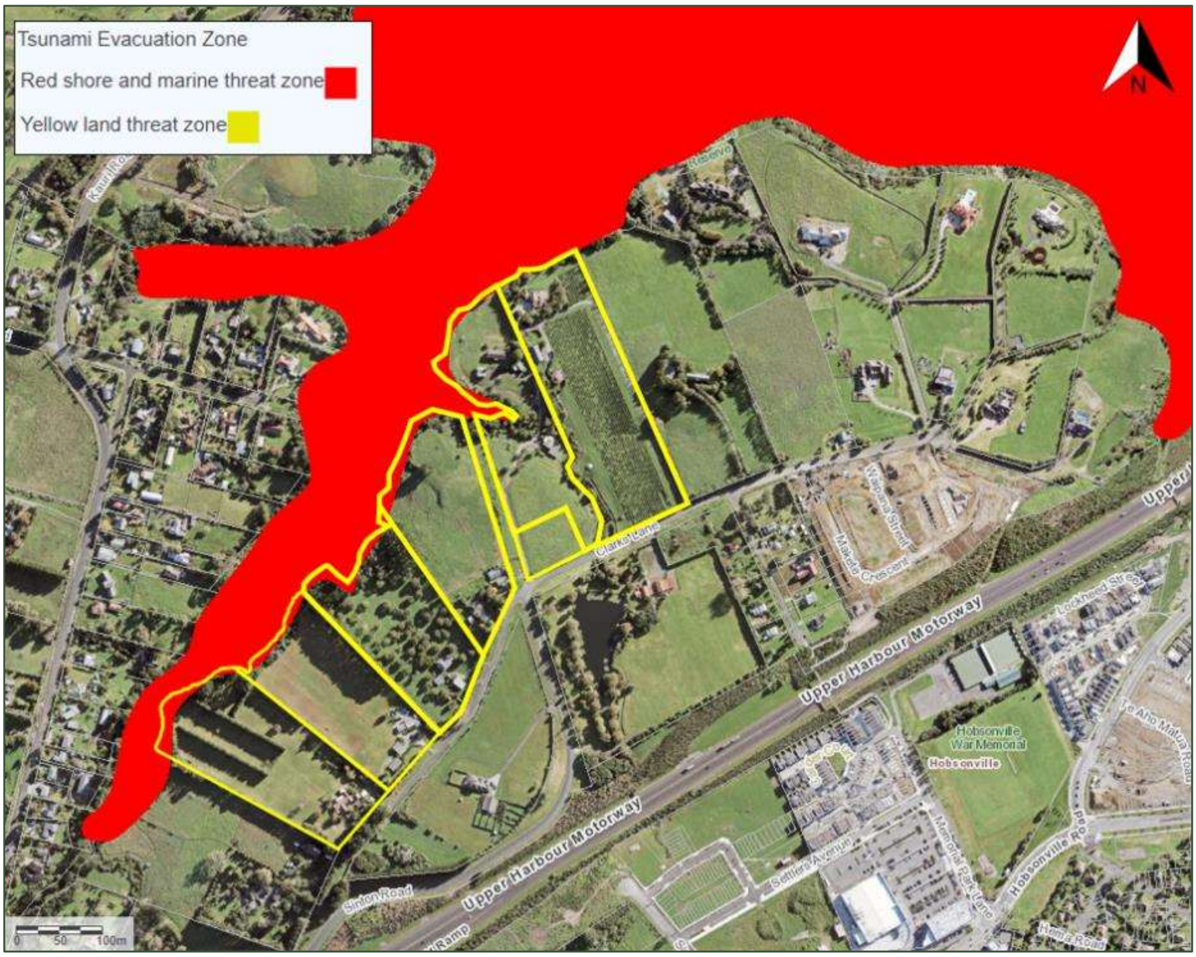

Figure 11: Tsunami risk for the subject coastline with the red area representing an exclusion zone (source: Auckland Council GeoMaps). The yellow shaded polygons identify the approximate property boundaries within the proposed plan change area.

4.3 Coastal Erosion

In general, the degree of risk from coastal hazards at the site will tend to be restricted due to the relatively low energy nature of the project site and the protection afforded by Herald Island. A quantitative coastal erosion assessment has been undertaken in order to obtain an understanding of the erosion risk at the site. This approach is consistent with Auckland Council's Coastal Hazard Assessment Guidance Document (Carpenter, 2021).

The AUP:OP identifies the coastal erosion hazard area as land which is:

a) *within a horizontal distance of 20m landward from the top of any coastal cliff with a slope angle steeper than 1 in 3 (18 degrees); or*

b) *at an elevation less than 7m above mean high water springs if the activity is within:*

   i. *Inner Harbours and Inner Hauraki Gulf: 40m of mean high-water springs; or*

   ii. *Open west, outer and Mid Hauraki Gulf: 50m of mean high-water springs; or*

c) *within a lesser distance from the top of any coastal cliff, or mean high water springs, than that stated in (a) and (b), where identified in a site-specific coastal hazard assessment technical report prepared by a suitably qualified and experienced professional to establish the extent of land which may be subject to coastal erosion over at least a 100-year time frame.*

Under this broad definition parts of the subject site would be considered to be at risk from coastal erosion, and a site-specific erosion assessment should be undertaken to understand the true erosion risk at the site as per part *(c)* of the definition.

Quantitative analysis of the erosion potential across the site has been undertaken based upon the cliff and bank erosion equations provided in the Auckland Council Regional Instability and Erosion Assessment recently completed by Tonkin and Taylor (2021). This high-level assessment utilises standardised shoreline erosion calculations which are based on geological type, exposure, and cliff height, with allowance made for varying timeframes and sea level rise projections. The resulting Area Susceptible to Coastal Instability and/or Erosion (ASCIE) is reported as a distance in metres landward from the current coastline. Because of the adopted approaches and generalisations for the regional-scale assessment, the resulting ASCIE presented in the online mapping and supporting report are considered high-level first pass results. The accompanying report notes that as a result of adopting a blanket cliff instability component for each geological type, there may be areas within a coastal cell where the ASCIE is overpredicted, and vice-versa.

Using the regional scale assessment as a guide, we have undertaken calculations of both current-day and future coastal erosion distances at the subject site based on available geological information. Justification for the selection of variables used in our equations is provided below, and full details including the assumptions and calculation sheets are provided in **Appendix A**.

Recognising there will always be inherent uncertainties within each of the input parameters, our erosion assessment has explored possible variations to certain parameter values. This has resulted in three ASCIE scenarios which we have aligned to probabilities of exceedance to allow consideration of their likelihood of occurrence over the 100-year planning horizon.

4.3.1 Stable Slope Angle

Geotechnical investigations from the site identify that the material which will be exposed to coastal erosion and instability hazard varies somewhat across the four subject properties. A brief summary of the underlying geology for each property is provided below. Adopted local embankment heights of between 3m and 6m have been determined based on the topographic LiDAR data and observations made during the site visit.

15 Clarks Lane – Geological cross section drawings produced by ENGEO for this property identify that the coastal embankment comprises of Puketoka Formation Material.

10 Sinton Road – Colluvium was encountered extending to depths of 3.5m near the coastal edge. Beneath the colluvium, deposits identified as soils of the East Coast Bays Formation were encountered. The ENGEO report indicates a design slope angle of 23˚ for Colluvium.

14 Sinton Road – Geological cross section drawings produced by ENGEO for this property identify completely weathered ECBF residual soils underlain by ECBF transition zone material. These materials are described as having design slope angles of 32˚ and 36˚, respectively.

16 Sinton Road – The results of ENGEO investigations indicate that ECBF rock is encountered at shallow depths close to the slope and dips away from the inlet, which may provide a structural control preventing soil failures from occurring at this site. It has been interpreted from the hand auger logs nearest to the coastal edge that the surface soils within the lower slope areas (which constitute the material that would be subject to erosion and instability) comprise of Puketoka Formation Material underlain by ECBF residual soils.

We have reviewed the stable slope angles presented in the Regional Erosion Assessment relating to Puketoka Formation Material for ‘Medium’, ‘Unlikely’ and ‘Exceptionally Unlikely’ composite slope angles and applied these values to the respective ASCIE scenarios for 16 and 14 Sinton Road, and 15 Clarks Lane. These values appear to be in general agreement with the design slope angles adopted in the slope stability analysis undertaken as part of the geotechnical investigations.

We have interpreted from the Regional Erosion Assessment (Tonkin and Taylor, 2021) that a stable slope angle of 26˚ is typical or ‘possible’ for Colluvium, with 18˚ representing a lower bound estimate. We have therefore adopted these values for the ‘Medium’ and ‘Exceptionally Unlikely’ erosion scenarios respectively for 10 Sinton Road. An ‘Unlikely’ value of 23˚ has been adopted as a mid-point between the two, but also to cover the design slope angle for Colluvium as noted in the ENGEO assessment.

The adopted stable slope angles utilised in this assessment for the three erosion scenarios are included in **Table 4** below.

Table 4: Adopted stable slope angles.

Geological Unit	50% Exceedance or ‘Medium’	10% Exceedance or ‘Unlikely’	1% Exceedance or ‘Exceptionally Unlikely’
Tauranga Group	48˚	34˚	31˚
Colluvium	26˚	23˚	18˚

4.3.2 Long-Term Erosion and Mangrove Expansion

As noted previously, an analysis of historical and current aerial imagery sourced from Auckland Council GeoMaps uncovered no measurable change to the bank toe/shoreline position along the coastal edge of the subject site over the past ~60 years. This is largely due to sheltered location of the subject site, and the presence of shallow intertidal flats and mangroves along the coastal edges of the site. Consequently, long-term cliff toe and crest regression have been slow.

In addition to cliff regression, changes in mangrove coverage along the northwestern borders of the subject coastline were also analysed using the historic imagery. **Figure 12** shows the seaward limits of mangrove growth in 1950 (orange line) and 2024 (green line), highlighting the steady mangrove expansion in the sheltered estuarine environment fronting the coastal boundaries of the subject site. From the present situation (2024; green line in **Figure 12**), it is apparent that the entire subject coastline is protected by coastal vegetation, as also established during the site visit (**Section 2.4**).

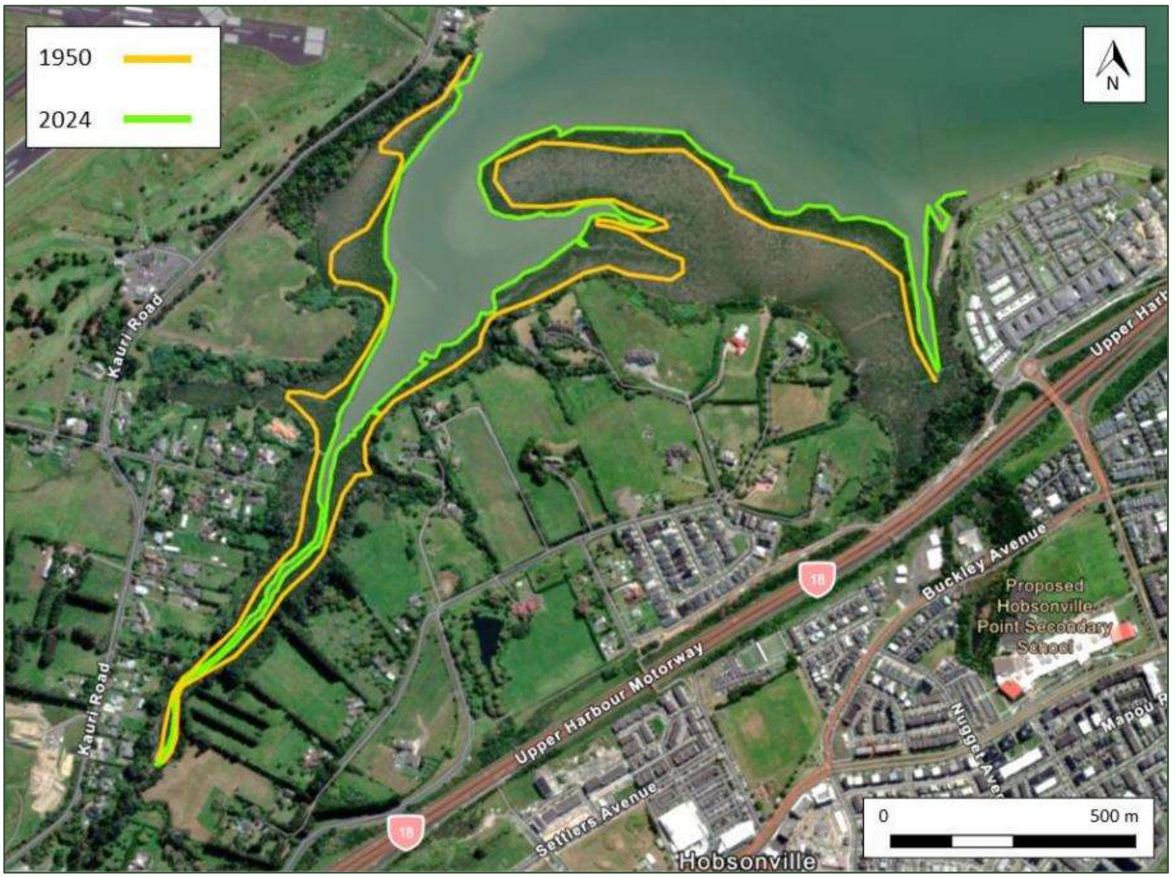

Figure 12: Mangrove expansion near the subject site for the past 74 years, showing the seaward limit of the mangroves in 1950 (orange) and 2024 (green).

Previous work undertaken by Tonkin and Taylor (2017) utilised historic aerial photographs and the most recent aerial imagery available at the time to calculate the horizontal shoreline change between 1940 and 2016. From digitised cliff toe positions (refer to Figure 3-8 of the T+T report contained within **Appendix B**), the analysis indicates no change or a mild accretionary trend for the vast majority of subject shoreline (i.e. Cell C) associated with the accumulation of weathered material. The assessment reports a maximum of 0.03m/year of erosion along the subject coastline for the 76-year analysis period, which is subsequently adopted as the toe erosion rate within the erosion hazard equations. Inspection of the region-wide erosion assessment similarly identifies a long-term erosion rate of 0.03m/year for this section of coastline (Tonkin and Taylor, 2021).

Considering the sheltered and upper-harbour location of the site, the lack of substantial signs of long-term and recent coastal erosion, and the extensive intertidal flats and mangrove coverage present near the site, it is recognised that the shallow estuarine environment fronting the site likely represents a depositional environment rather than an erosional one. Consequently, a local long-term erosion rate of 0.03m/year (3cm/year) is considered relatively conservative for this section of coastline.

4.3.3 Cliff Response to Future Sea Level Rise

In considering the effects of future predicted sea level rise on bank response, reference to Table 5-6 of the region-wide erosion assessment (Tonkin and Taylor, 2021) has been made. Geotechnical investigations by ENGEO have indicated a predominance of weaker materials within the lower bank slopes which may be exposed to coastal processes. A 'high' material susceptibility has therefore been assumed for the subject coastline. Assuming a 'low' exposure classification given the fetch-limited conditions and protection afforded by dense mangrove habitat, sea level rise response factors of between 0.2-0.4 could be expected for the soil slopes materials.

Table 5 presents the 'm' values which have been adopted within the erosion hazard equations for each respective ASCIE scenario.

Table 5: Adopted 'm' value.

Risk	Adopted 'm' value
Medium	0.2
Unlikely	0.3
Exceptionally Unlikely	0.4

4.3.4 Toe Erosion

The following conceptual model is used to determine the long-term toe erosion potential:

$$\text{Cliff Toe Erosion} = (LT_F \times T)$$

Where,

LT_F = Potential future cliff toe retreat due to SLR effects

T = Timeframe over which erosion occurs (100 years estimate).

The potential future cliff toe retreat (LT_F) is calculated as:

$$LT_F = LT_H \times (S_F/S_H)^m$$

The following parameters have been adopted for the coastal banks along the subject site coastline:

LT_H = Historical long-term retreat (regression rate), **0.03m/year** (i.e. 3m/100 years).

S_F = Future rate of sea level rise, **19.1mm/year** (1.91m RSLR to 2130 (SSP5-8.5 p.83) as per MfE, 2024).

S_H = Historical rate of sea level rise, **1.7mm/year** (Port of Auckland tide gauge; Hannah and Bell, 2021).

m = Sea level rise response factor, **0.2-0.4** (range of values for highly susceptible material, low exposure, as per Table 5.6 of Tonkin and Taylor, 2021).

Based on the above parameters, the following potential future toe erosion (LT_F) rates are calculated.

Table 6: Future bank toe erosion rates

Risk	Future Toe Erosion (m/100 yrs)
Medium	4.9
Unlikely	6.2
Exceptionally Unlikely	7.9

4.3.5 Assessment of Area Susceptible to Coastal Instability and Erosion (ASCIE)

The adopted parameters for the three erosion scenarios are set out below:

<u>‘Medium’ Erosion Scenario</u>

Minimum ‘m’ value for high material susceptibility, low exposure = 0.2

50% exceedance composite slope profile angle of 48˚ (Tauranga Group) and 26˚ (Colluvium)

<u>‘Unlikely’ Erosion Scenario</u>

Mode ‘m’ value for high material susceptibility, low exposure = 0.3

10% exceedance composite slope angle of 34˚ (Tauranga Group) and 23˚ (Colluvium)

<u>‘Exceptionally Unlikely’ Scenario</u>

Maximum ‘m’ value for high material susceptibility, low exposure = 0.4

1% exceedance composite slope angle = 31˚ (Tauranga Group) and 18˚ (Colluvium)

For the subject site, we have adopted four representative cross sections in our erosion hazard assessment (see **Figure 13** for locations). The results of the site-specific calculations of erosion hazard are shown in **Table 7**, which identifies the future ASCIE distance for the four cross sections under the three erosion scenarios. The impact of future sea-level rise has been accounted for in the future ASCIE by applying a +1.91m RSLR which is based on the latest available guidance and information (MFE, 2024; **Section 3.2** refers).

Table 7: Summarised results from the quantitative erosion assessment.

Cross section	Representative Bank Height (m)	Medium Scenario ASCIE (m)	Unlikely Scenario ASCIE (m)	Exceptionally Unlikely Scenario ASCIE (m)
Cross section A	4	8.5	12.1	14.6
Cross section B	3	11.0	13.6	17.1
Cross section C	6	10.3	15.1	17.9
Cross section D	5	9.4	13.6	16.2
* Refer to **Appendix A** for erosion hazard calculations				

Although not presented above, the current day ASCIE for the subject site was calculated to be approximately 4-10m and is largely influenced by the composite stable slope angle adopted. The current day ASCIE relates to the natural slope settlement only, whereas the future ASCIE is a function of both cliff instability and cliff toe regression.

The calculated 'Exceptionally Unlikely' future ASCIE distances of 14.6m (Cross Section A - 15 Clarks Lane), 17.1m (Cross Section B - 10 Sinton Road), 17.9m (Cross Section C - 14 Sinton Road) and 16.2m (Cross Section D - 16 Sinton Road), which are indicative of the maximum area at risk from potential retreat over the next 100 years, are mapped on the latest aerial imagery related to the proposed plan change in **Figure 13**. The blue line in the figure represents the approximate location of the present bank toe as determined from aerial imagery; the red line highlights the future ASCIE (until 2130). The results demonstrate that the area at risk from retreat is located seaward from the approximate landward boundary of the planned local 20m wide esplanade reserve (light purple line). Since future residential development would be located landward of the esplanade reserve, such future development should be adequately set back from the areas potentially susceptible to coastal erosion risk.

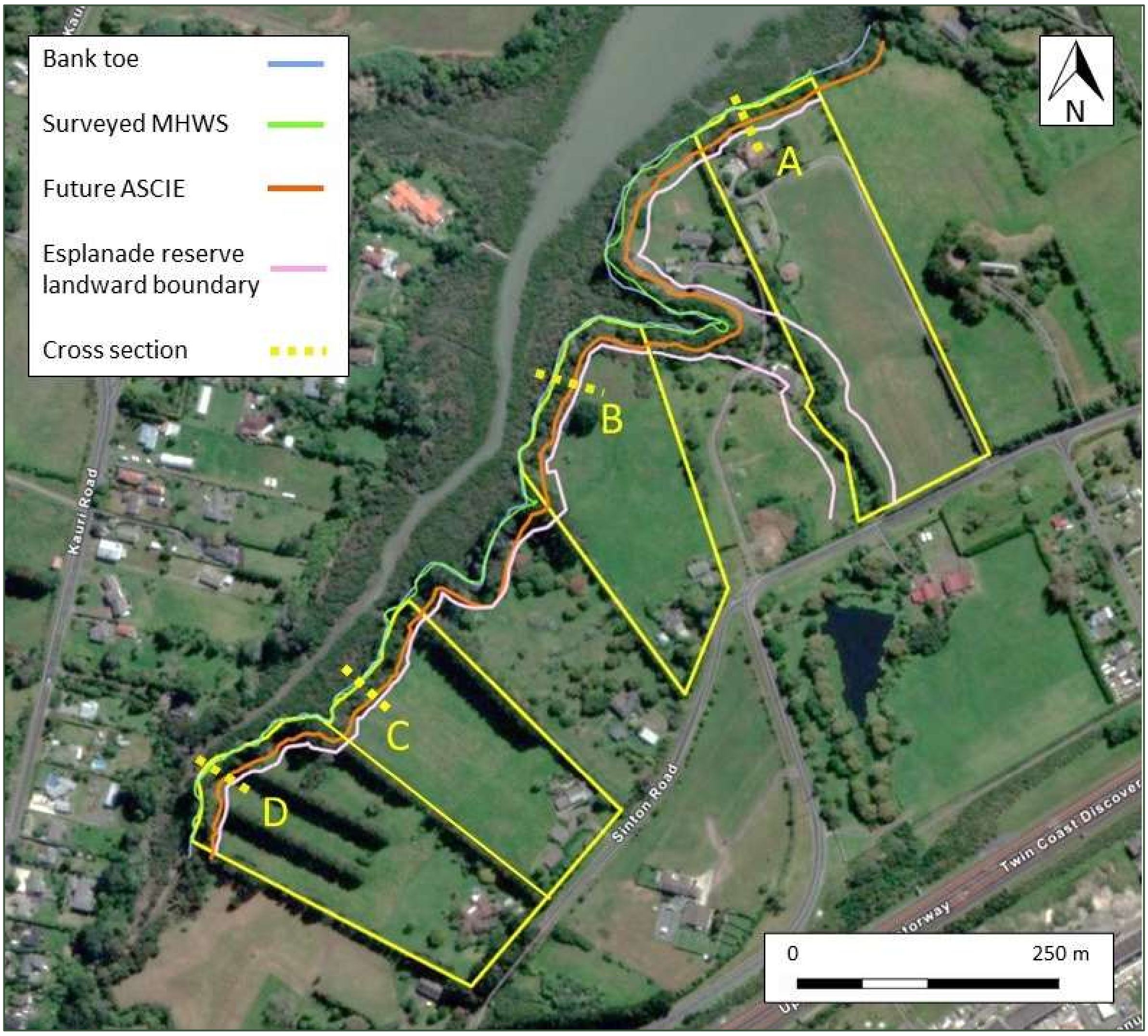

Figure 13: Site overview showing the approximate bank toe location (blue line) and the indicative ASCIE over the next 100 years (to 2130) (red line). The light purple line landward of the ASCIE line represents the esplanade reserve boundary.

4.3.6 Esplanade Reserve

An esplanade reserve (typically 20m width) is normally required under s230 of the RMA and within E38 of the AUP:OP. As this is a Private Plan Change that would enable future subdivision development, a 20m setback is required from the MHWS along the entire coastal margin of the development area. The location of MHWS as indicated in the Figure above has been determined through topographical survey at 15 Clarks Lane, 10 Sinton Road, 14 Sinton Road and 16 Sinton Road[5]. We understand that the remaining properties along the project coastline (17 Clarks Lane and 12 Sinton Road) have not been surveyed and MHWS is based on old boundary data downloaded from LINZ.

Figure 13 confirms that the provision of a 20m esplanade reserve is considered appropriate to account for potential future coastal erosion hazard.

5.0 Closure

The properties owned by Cabra Developments Limited at 15 Clarks Lane and 10, 14 and 16 Sinton Road in Whenuapai are being considered for a private plan change which will comprise rezoning the land to residential. A description of the site's geomorphology, coastal processes and coastal hazards has been provided above. A brief summary of the key conclusions and recommendations of this report are provided below:

- Coastal inundation resulting from extreme storm tides is not generally considered to be an issue with regard to the project area, under both current day and future sea level rise scenarios over the next 100+ years. With consideration of up to 2m sea level rise, coastal inundation is expected to be limited to the low-lying coastal fringes with the vast majority of the subject area remaining unaffected. Overall, it is concluded that the potential impact from future coastal inundation on the project area will be minor and can easily be avoided/mitigated through appropriate building setbacks. No specific mitigation is required.
- The risk to the project area from a tsunami is considered to be very low. All key infrastructure and development will be located landward of tsunami extents and presented in **Figure 11**. It is also recognised that the proposed plan change will not change or worsen the susceptibility of the site to tsunami inundation hazard.
- Site-specific calculations of shoreline retreat undertaken as part of this assessment have identified a current day slope settlement distance of approximately 4-10m. Future maximum cliff regression potential was found to be in the order of 14.6m (15 Clarks Lane), 17.1m (10 Sinton Road), 17.9m (14 Sinton Road) and 16.2m (16 Sinton Road) measured inland from the slope toe over the 100-year planning horizon. It is recognised that based on this very conservative cliff regression scenario (i.e. 1% exceedance probability), erosion is not expected to encroach within the area of the future residential development as a result of the plan change. Future erosion potential will likely be confined to the coastal areas of the site which are to be vested as esplanade reserve (i.e. 20m inland of MHWS).

In consideration of the above, the overall risk to the subject site from coastal hazards is considered low.

Sincerely,

[5] Topographical survey undertaken by Capture Land Development Consultants.

SLR Consulting New Zealand

Alison Clarke, CEnvP
Principal Consultant - Coastal

Cat Davis
Senior Consultant - Coastal & Ecology

6.0 References

Carpenter, N. (2021). Coastal Hazard Assessment in the Auckland Region Guidance Document. Guideline Document 2021/010. August 2021.

Ministry for the Environment. (2024). Interim guidance on the use of new sea-level rise projections. August 2022. Wellington: Ministry for the Environment.

Stephens, S. and Wadhwa, S. (2012). Development of an updated Coastal Marine Area boundary for the Auckland Region. Prepared by NIWA for Auckland Council. July 2012.

Stephens, S., Wadhwa, S., Gorman., R., Goodhue, N., Pritchard, M., Ovenden, R. and Reeve, G. (2013). Coastal inundation by storm-tides and waves in the Auckland region. Prepared by NIWA for Auckland Council. September 2013.

Tonkin and Taylor. (2006). Regional Assessment of Areas Susceptible to Coastal Erosion. Prepared by Tonkin and Taylor for Auckland Council. May 2006.

Tonkin and Taylor. (2017). Coastal Hazard Assessment Whenuapai Plan Change – Stage 1. Prepared by Tonkin and Taylor for Auckland Council. August 2017.

Tonkin and Taylor. (2021). Regional Assessment of Areas Susceptible to Coastal Instability and Erosion. Prepared by Tonkin and Taylor for Auckland Council. January 2021.

7.0 Feedback

At SLR, we are committed to delivering professional quality service to our clients. We are constantly looking for ways to improve the quality of our deliverables and our service to our clients. Client feedback is a valuable tool in helping us prioritise services and resources according to our client needs.

To achieve this, your feedback on the team's performance, deliverables and service are valuable and SLR welcome all feedback via https://www.slrconsulting.com/en/feedback. We recognise the value of your time and we will make a $10 donation to our Charity Partner - Lifeline, for every completed form.

Appendix A Coastal Erosion Hazard Equations

Whenuapai – Private Plan Change

Coastal Hazard Assessment

Cabra Developments Limited

SLR Project No.: 850.016583.00001

24 April 2024

Areas Susceptible to Coastal Instability and Erosion (Tonkin and Taylor, 2021)

SLR

Site:	**Whenuapai Plan Change**
Project No:	850.016583.00001
Client:	Cabra Developments Limited
Date:	18/04/2024
Designed by:	Alison Clarke
Reviewed by:	Peter de Ruiter

Cross Section A - 15 Clarks Lane

	M	U	EU	
Current ASCIE$_{cliffs}$ =	3.6	5.9	6.7	*Assumed settlement retreat
Future toe erosion =	4.9	6.2	7.9	
Future ASCIE$_{cliffs}$ =	8.5	12.1	14.6	

'M' = Medium
'U' = Unlikely
'EU' = Exceptionally Unlikely

Material subject to erosion/instability identified as Puketoka Formation Material

Variable	Value			
LT_H	0.03			0.03m/yr (3 cm/yr) considered appropriate and conservative given the sheltered, inner harbour location of the project site and dense mangrove forest which is present
LT_F	1.62	2.07	2.63	Potential increase in long term retreat from SLR $(S_F/S_H)^T$
S_F	19.1			1.91m RSLR to 2130 (SSP5-8.5 p83) at modelling point 1181 = 1.91mm/yr (NZSeaRise)
S_H	1.7			Average historic rate of SLR of 1.7 mm/year for Port of Auckland tide gauge (Hannah & Bell, 2012)
m	0.2	0.3	0.4	Min, mode and max value for highly susceptable material and low exposure, Table 5.6, T+T (2021)
T	100			Timeframe of erosion (100 year estimate)
H_{cr}	4			Max cliff height obtained from Council LiDAR and site observations
α_r	48	34	31	Composite slope profile based on Tauranga Group lithology taken from Table 5.9 of T+T (2021) for 50% (Medium), 10% (Unlikely) and 1% (Exceptionally Unlikely) exceedance
	1.110612515			0.837758041 *Convert to Radians
tan α_r	0.674508517			0.593411946
	0.600860619			0.541052068

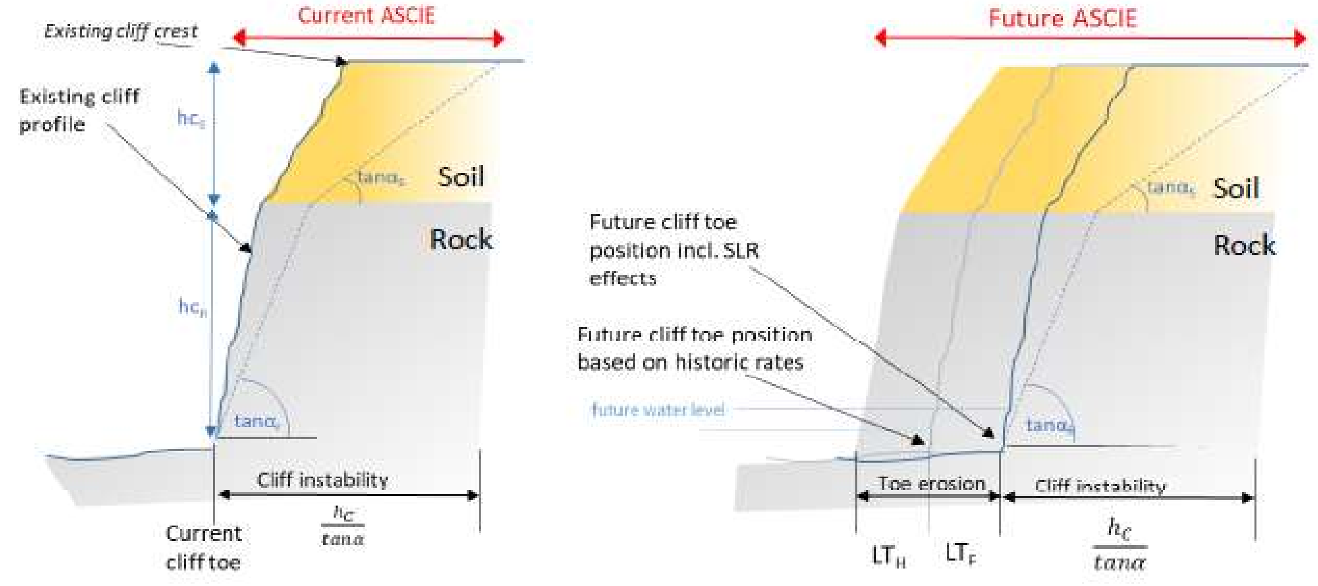

Figure 4.6 Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on consolidated (cliff) shoreline

4.3.1 Cliff shorelines

The models for consolidated shorelines are expressed in Equation 4.3 (current ASCIE) and Equation 4.4 (future ASCIE), where the ASCIE is established from the cumulative effect of the components (Figure 4.6):

$$\text{Current ASCIE} = (h_{cr}/tan\alpha_r) + (h_{cs}/tan\alpha_s) \qquad \text{(Equation 4.3)}$$

$$\text{Future ASCIE} = ((LT_H \times LT_F) \times T) + (h_{cr}/tan\alpha_r) + (h_{cs}/tan\alpha_s) \qquad \text{(Equation 4.4)}$$

Where:

- h_{cr} = Height (m) of the rock layer of the cliff
- h_{cs} = Height (m) of the soil layer of the cliff
- α_r = The slope angle (degrees) of the rock layer
- α_s = The slope angle (degrees) of the soil layer
- LT_H = Historical long-term retreat (regression rate), (m/year)
- LT_F = Factor for the potential increase in future long-term retreat due to SLR effects.
- T = Timeframe over which erosion occurs (years)

$$R = LT_H \left(\frac{S_F}{S_H}\right)^m \qquad \text{(Equation 5.3)}$$

Table 5.9: Adopted ASCIE cliff slope angles

Lithology	Composite slope profile (°)		
	Medium	Unlikely	Exceptionally Unlikely
	50% exceedance	10% exceedance	1% exceedance
Tauranga Group	48	34	31
Awhitu Group	38	33	30
AVC/CVZ	42	32	28
Waitakere Group	63	38	28
ECBF	45	27	24
Pākiri Formation	54	28	25
Northland Allochthon	26	14	9
Waipapa Group	42	31	26

Table 5.6: Adopted consolidated shoreline response factors to SLR for Auckland geological units and exposures (*m*)

Geological unit	Material susceptibility	Exposure	Min	Mode	Max
• AVF/CVZ • Waitakere Group	Low	Any	0	0.05	0.1
• Pākiri Formation • Waipapa Group	Med	Low	0	0.1	0.2
		Med	0.1	0.2	0.3
		High	0.2	0.3	0.4
• ECBF • Āwhitu Group • Northland Allochthon	Med-High	Low	0.1	0.2	0.3
		Med	0.2	0.3	0.4
		High	0.3	0.4	0.5
• Tauranga Group	High	Low	0.2	0.3	0.4
		Med	0.3	0.4	0.5
		High	0.4	0.5	0.5

Areas Susceptible to Coastal Instability and Erosion (Tonkin and Taylor, 2021)

Site:	**Whenuapai Plan Change**
Project No:	850.016583.00001
Client:	Cabra Developments Limited
Date:	18/04/2024
Designed by:	Alison Clarke
Reviewed by:	Peter de Ruiter

Cross Section B - 10 Sinton Road

	M	**U**	**EU**		
Current ASCIE$_{cliffs}$ =	**6.2**	**7.4**	**9.2**	*Assumed settlement retreat	'M' = Medium
Future toe erosion =	**4.9**	**6.2**	**7.9**		'U' = Unlikely
Future ASCIE$_{cliffs}$ =	**11.0**	**13.6**	**17.1**		'EU' = Exceptionally Unlikely

Material subject to erosion/instability identified as Colluvium

Variable	**Value**			
LT_H	0.03			0.03m/yr (3 cm/yr) considered appropriate and conservative given the sheltered, inner harbour location of the project site and dense mangrove forest which is present
LT_F	1.62	2.07	2.63	Potential increase in long term retreat from SLR $(S_F/S_H)^T$
S_F	19.1			1.91m RSLR to 2130 (SSP5-8.5 p83) at modelling point 1181 = 1.91mm/yr (NZSeaRise)
S_H	1.7			Average historic rate of SLR of 1.7 mm/year for Port of Auckland tide gauge (Hannah & Bell, 2012)
m	0.2	0.3	0.4	Min, mode and max value for highly susceptable material and low exposure, Table 5.6, T+T (2021)
T	100			Timeframe of erosion (100 year estimate)
H_{cr}	3			Max cliff height obtained from Council LiDAR and site observations
α_r	26	22	18	Medium' and 'Exceptionally Unlikely' values interpreted from T+T (2006), ENGEO Design stable angle adopted for 'Unlikely' scenario

	0.487732589	0.453785606	***Convert to Radians**
tan α_r	0.404026226	0.383972435	
	0.324919696	0.314159265	

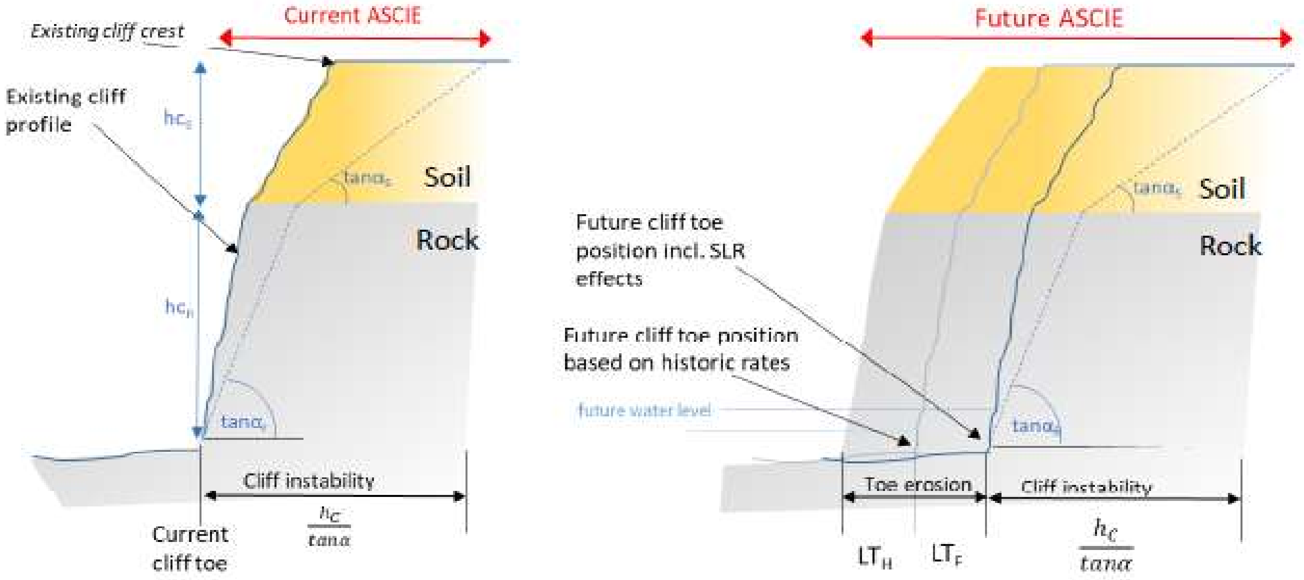

Figure 4.6 Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on consolidated (cliff) shoreline

4.3.1 Cliff shorelines

The models for consolidated shorelines are expressed in Equation 4.3 (current ASCIE) and Equation 4.4 (future ASCIE), where the ASCIE is established from the cumulative effect of the components (Figure 4.6):

$$Current\ ASCIE = (h_{cr}/tan\alpha_r) + (h_{cs}/tan\alpha_s) \qquad \text{(Equation 4.3)}$$

$$Future\ ASCIE = ((LT_H \times LT_F) \times T) + (h_{cr}/tan\alpha_r) + (h_{cs}/tan\alpha_s) \qquad \text{(Equation 4.4)}$$

Where:

h_{cr}	=	Height (m) of the rock layer of the cliff
h_{cs}	=	Height (m) of the soil layer of the cliff
α_r	=	The slope angle (degrees) of the rock layer
α_s	=	The slope angle (degrees) of the soil layer
LT_H	=	Historical long-term retreat (regression rate), (m/year)
LT_F	=	Factor for the potential increase in future long-term retreat due to SLR effects.
T	=	Timeframe over which erosion occurs (years)

$$R = LT_H\left(\frac{S_F}{S_H}\right)^m \qquad \text{(Equation 5.3)}$$

Table 5.9: Adopted ASCIE cliff slope angles

Lithology	Composite slope profile (°)		
	Medium	Unlikely	Exceptionally Unlikely
	50% exceedance	10% exceedance	1% exceedance
Tauranga Group	48	34	31
Awhitu Group	38	33	30
AVC/CVZ	42	32	28
Waitakere Group	63	38	28
ECBF	45	27	24
Pākiri Formation	54	28	25
Northland Allochthon	26	14	9
Waipapa Group	42	31	26

Table 5.6: Adopted consolidated shoreline response factors to SLR for Auckland geological units and exposures (*m*)

Geological unit	Material susceptibility	Exposure	Min	Mode	Max
• AVF/CVZ • Waitakere Group	Low	Any	0	0.05	0.1
• Pākiri Formation • Waipapa Group	Med	Low	0	0.1	0.2
		Med	0.1	0.2	0.3
		High	0.2	0.3	0.4
• ECBF • Āwhitu Group • Northland Allochthon	Med-High	Low	0.1	0.2	0.3
		Med	0.2	0.3	0.4
		High	0.3	0.4	0.5
• Tauranga Group	High	Low	0.2	0.3	0.4
		Med	0.3	0.4	0.5
		High	0.4	0.5	0.5

Areas Susceptible to Coastal Instability and Erosion (Tonkin and Taylor, 2021)

Site:	**Whenuapai Plan Change**
Project No:	850.016583.00001
Client:	Cabra Developments Limited
Date:	18/04/2024
Designed by:	Alison Clarke
Reviewed by:	Peter de Ruiter

Cross Section D - 14 Sinton Road

	M	U	EU		
Current $ASCIE_{cliffs}$ =	5.4	8.9	10.0	*Assumed settlement retreat	'M' = Medium
Future toe erosion =	4.9	6.2	7.9		'U' = Unlikely
Future $ASCIE_{cliffs}$ =	10.3	15.1	17.9		'EU' = Exceptionally Unlikely

Material subject to erosion/instability identified as ECBF Residual /Transition Zone Soils

Variable	Value			
LT_H		0.03		0.03m/yr (3 cm/yr) considered appropriate and conservative given the sheltered, inner harbour location of the project site and dense mangrove forest which is present
LT_F	1.62	2.07	2.63	Potential increase in long term retreat from SLR $(S_F/S_H)^T$
S_F		19.1		1.91m RSLR to 2130 (SSP5-8.5 p83) at modelling point 1181 = 1.91mm/yr (NZSeaRise)
S_H		1.7		Average historic rate of SLR of 1.7 mm/year for Port of Auckland tide gauge (Hannah & Bell, 2012)
m	0.2	0.3	0.4	Min, mode and max value for highly susceptable material and low exposure, Table 5.6, T+T (2021)
T		100		Timeframe of erosion (100 year estimate)
H_{cr}		6		Max cliff height obtained from Council LiDAR and site observations
α_r	48	34	31	Composite slope profile based on Tauranga Group lithology taken from Table 5.9 of T+T (2021) for 50% (Medium), 10% (Unlikely) and 1% (Exceptionally Unlikely) exceedance
	1.110612515	0.837758041		*Convert to Radians
tan α_r	0.674508517	0.593411946		
	0.600860619	0.541052068		

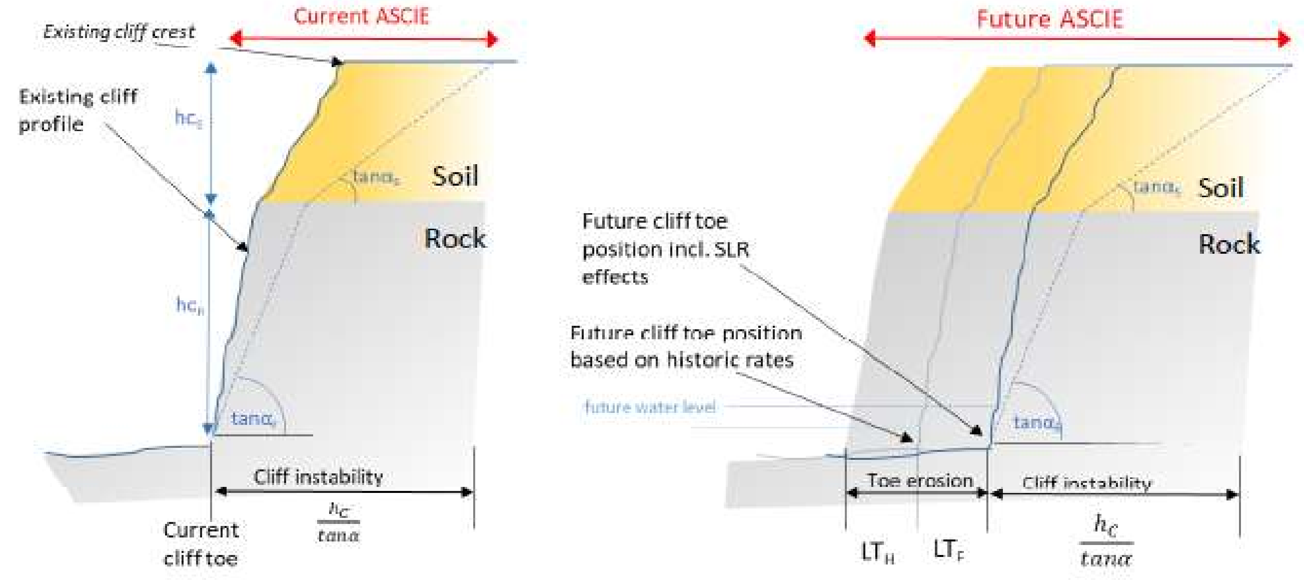

Figure 4.6 Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on consolidated (cliff) shoreline

4.3.1 Cliff shorelines

The models for consolidated shorelines are expressed in Equation 4.3 (current ASCIE) and Equation 4.4 (future ASCIE), where the ASCIE is established from the cumulative effect of the components (Figure 4.6):

$$Current\ ASCIE = (h_{cr}/tan\alpha_r) + (h_{cs}/tan\alpha_s) \qquad (Equation\ 4.3)$$

$$Future\ ASCIE = ((LT_H \times LT_F) \times T) + (h_{cr}/tan\alpha_r) + (h_{cs}/tan\alpha_s) \qquad (Equation\ 4.4)$$

Where:

- h_{cr} = Height (m) of the rock layer of the cliff
- h_{cs} = Height (m) of the soil layer of the cliff
- α_r = The slope angle (degrees) of the rock layer
- α_s = The slope angle (degrees) of the soil layer
- LT_H = Historical long-term retreat (regression rate), (m/year)
- LT_F = Factor for the potential increase in future long-term retreat due to SLR effects.
- T = Timeframe over which erosion occurs (years).

$$R = LT_H\left(\frac{S_F}{S_H}\right)^m \qquad (Equation\ 5.3)$$

Table 5.9: Adopted ASCIE cliff slope angles

Lithology	Composite slope profile (°)		
	Medium	Unlikely	Exceptionally Unlikely
	50% exceedance	10% exceedance	1% exceedance
Tauranga Group	48	34	31
Awhitu Group	38	33	30
AVC/CVZ	42	32	28
Waitakere Group	63	38	28
ECBF	45	27	24
Pākiri Formation	54	28	25
Northland Allochthon	26	14	9
Waipapa Group	42	31	26

Table 5.6: Adopted consolidated shoreline response factors to SLR for Auckland geological units and exposures (*m*)

Geological unit	Material susceptibility	Exposure	Min	Mode	Max
• AVF/CVZ • Waitakere Group	Low	Any	0	0.05	0.1
• Pākiri Formation • Waipapa Group	Med	Low	0	0.1	0.2
		Med	0.1	0.2	0.3
		High	0.2	0.3	0.4
• ECBF • Āwhitu Group • Northland Allochthon	Med-High	Low	0.1	0.2	0.3
		Med	0.2	0.3	0.4
		High	0.3	0.4	0.5
• Tauranga Group	High	Low	0.2	0.3	0.4
		Med	0.3	0.4	0.5
		High	0.4	0.5	0.5

Areas Susceptible to Coastal Instability and Erosion (Tonkin and Taylor, 2021)

Site:	**Whenuapai Plan Change**
Project No:	850.016583.00001
Client:	Cabra Developments Limited
Date:	18/04/2024
Designed by:	Alison Clarke
Reviewed by:	Peter de Ruiter

Cross Section C - 16 Sinton Road

	M	U	EU	
Current ASCIE$_{cliffs}$ =	**4.5**	**7.4**	**8.3**	*Assumed settlement retreat
Future toe erosion =	**4.9**	**6.2**	**7.9**	
Future ASCIE$_{cliffs}$ =	**9.4**	**13.6**	**16.2**	

'M' = Medium
'U' = Unlikely
'EU' = Exceptionally Unlikely

Material subject to erosion/instability identified as Puketoka Formation Material underlain by Residual ECBF Soils

Variable	**Value**			
LT_H	0.03			0.03m/yr (3 cm/yr) considered appropriate and conservative given the sheltered, inner harbour location of the project site and dense mangrove forest which is present
LT_F	1.62	2.07	2.63	Potential increase in long term retreat from SLR $(S_F/S_H)^T$
S_F	19.1			1.91m RSLR to 2130 (SSP5-8.5 p83) at modelling point 1181 = 1.91mm/yr (NZSeaRise)
S_H	1.7			Average historic rate of SLR of 1.7 mm/year for Port of Auckland tide gauge (Hannah & Bell, 2012)
m	0.2	0.3	0.4	Min, mode and max value for highly susceptable material and low exposure, Table 5.6, T+T (2021)
T	100			Timeframe of erosion (100 year estimate)
H_{cr}	5			Max cliff height obtained from Council LiDAR and site observations
α_r	48	34	31	Composite slope profile based on Tauranga Group lithology taken from Table 5.9 of T+T (2021) for 50% (Medium), 10% (Unlikely) and 1% (Exceptionally Unlikely) exceedance

	1.110612515	0.837758041	***Convert to Radians**
tan α_r	0.674508517	0.593411946	
	0.600860619	0.541052068	

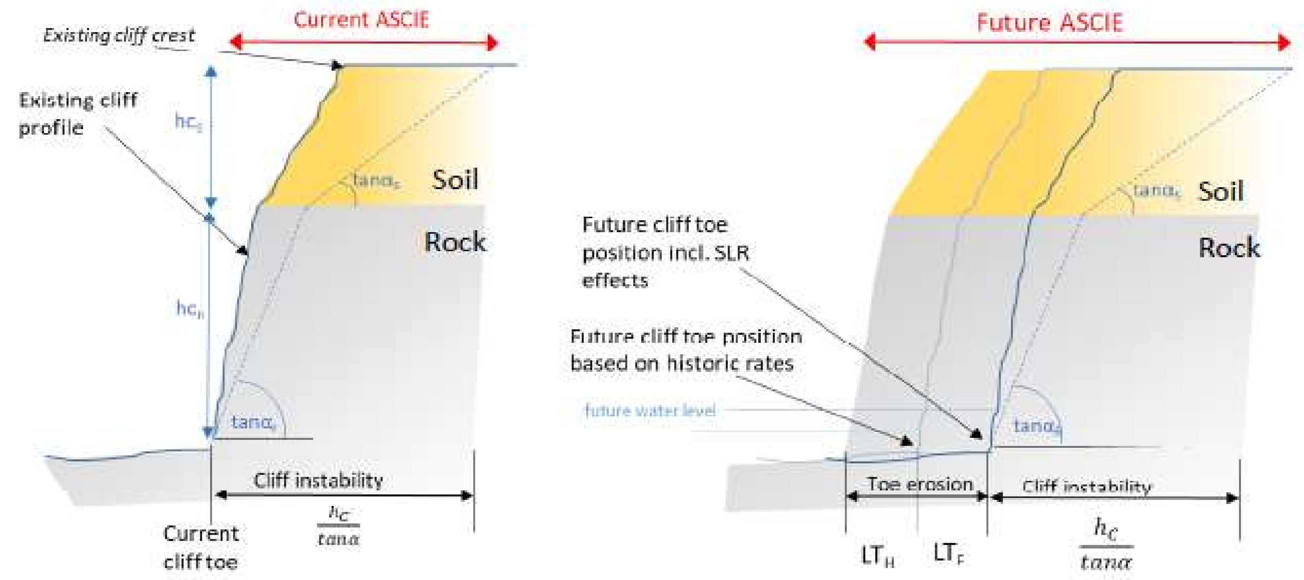

Figure 4.6 Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on consolidated (cliff) shoreline

SLR

4.3.1 Cliff shorelines

The models for consolidated shorelines are expressed in Equation 4.3 (current ASCIE) and Equation 4.4 (future ASCIE), where the ASCIE is established from the cumulative effect of the components (Figure 4.6):

$$\text{Current ASCIE} = (h_{cr}/\tan\alpha_r) + (h_{cs}/\tan\alpha_s) \quad \text{(Equation 4.3)}$$

$$\text{Future ASCIE} = ((LT_H \times LT_F) \times T) + (h_{cr}/\tan\alpha_r) + (h_{cs}/\tan\alpha_s) \quad \text{(Equation 4.4)}$$

Where:

h_{cr} = Height (m) of the rock layer of the cliff

h_{cs} = Height (m) of the soil layer of the cliff

α_r = The slope angle (degrees) of the rock layer

α_s = The slope angle (degrees) of the soil layer

LT_H = Historical long-term retreat (regression rate), (m/year)

LT_F = Factor for the potential increase in future long-term retreat due to SLR effects.

T = Timeframe over which erosion occurs (years).

$$R = LT_H \left(\frac{S_F}{S_H}\right)^m \quad \text{(Equation 5.3)}$$

Table 5.9: Adopted ASCIE cliff slope angles

Lithology	Composite slope profile (°)		
	Medium	Unlikely	Exceptionally Unlikely
	50% exceedance	10% exceedance	1% exceedance
Tauranga Group	48	34	31
Awhitu Group	38	33	30
AVC/CVZ	42	32	28
Waitakere Group	63	38	28
ECBF	45	27	24
Pākiri Formation	54	28	25
Northland Allochthon	26	14	9
Waipapa Group	42	31	26

Table 5.6: Adopted consolidated shoreline response factors to SLR for Auckland geological units and exposures (*m*)

Geological unit	Material susceptibility	Exposure	Min	Mode	Max
• AVF/CVZ • Waitakere Group	Low	Any	0	0.05	0.1
• Pākiri Formation • Waipapa Group	Med	Low	0	0.1	0.2
		Med	0.1	0.2	0.3
		High	0.2	0.3	0.4
• ECBF • Āwhitu Group • Northland Allochthon	Med-High	Low	0.1	0.2	0.3
		Med	0.2	0.3	0.4
		High	0.3	0.4	0.5
• Tauranga Group	High	Low	0.2	0.3	0.4
		Med	0.3	0.4	0.5
		High	0.4	0.5	0.5

Appendix B Stage 1 Coastal Hazard Assessment (T+T, 2017)

Whenuapai – Private Plan Change

Coastal Hazard Assessment

Cabra Developments Limited

SLR Project No.: 850.016583.00001

24 April 2024

REPORT

Tonkin+Taylor

Coastal Hazard Assessment Whenuapai Plan Change

Stage 1

Prepared for
Auckland Council

Prepared by
Tonkin & Taylor Ltd

Date
August 2017

Job Number
1003234.v2

Exceptional thinking together

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Table of contents

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.

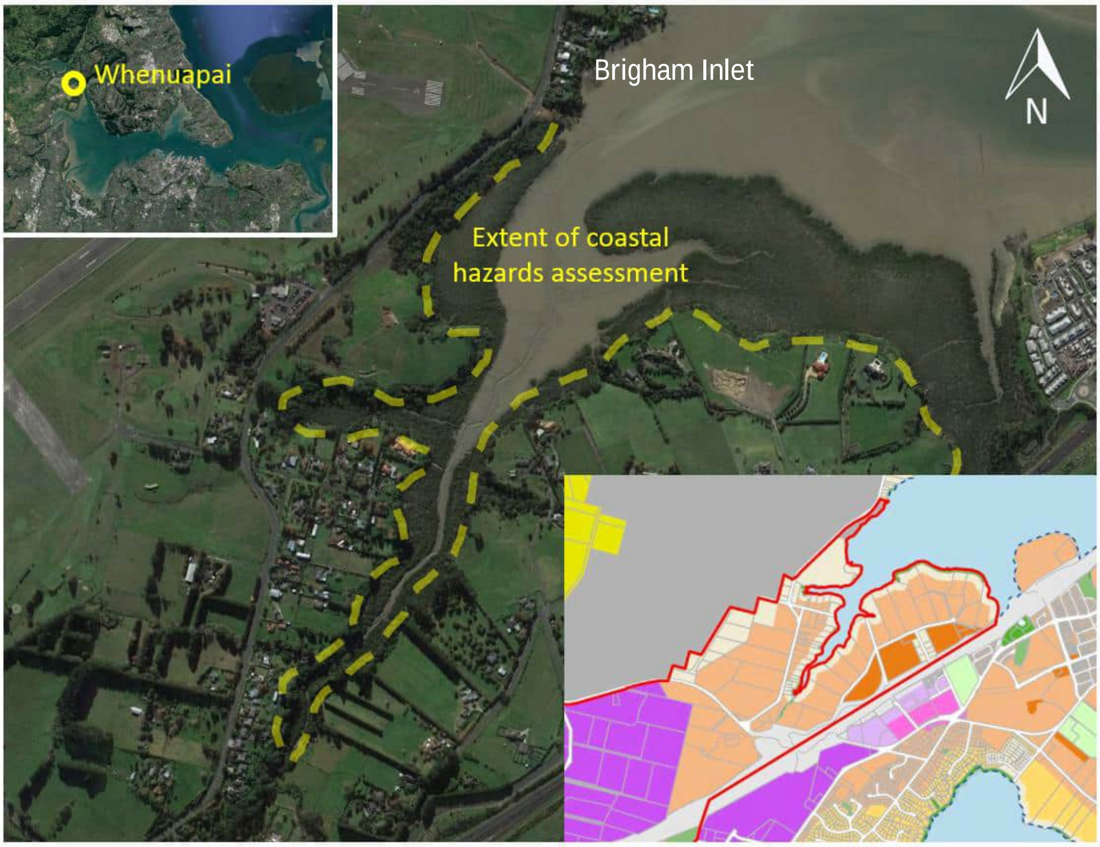

Figure 2-1 Location (inset) and extent of study area

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).

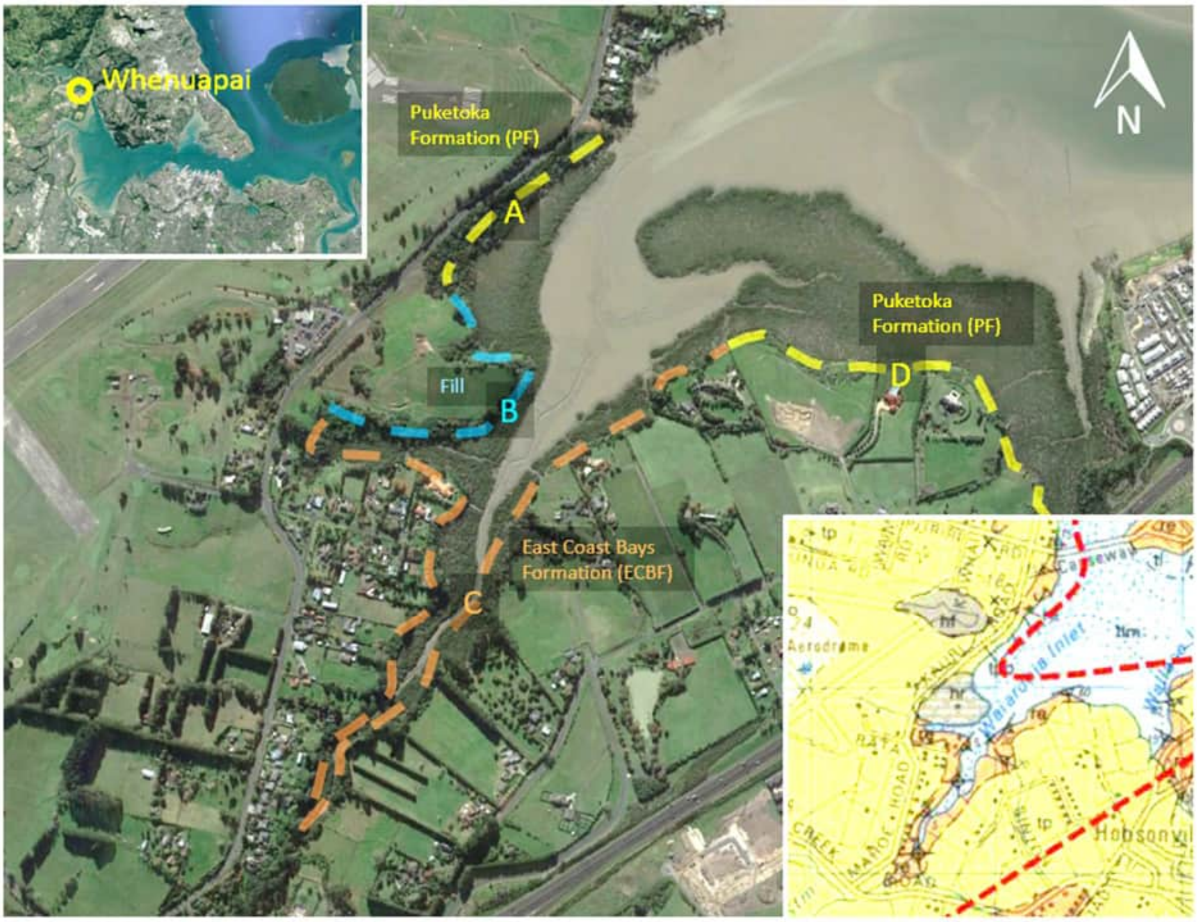

Figure 3-1 Geological units and excerpt map (Kermode, 1992)

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).

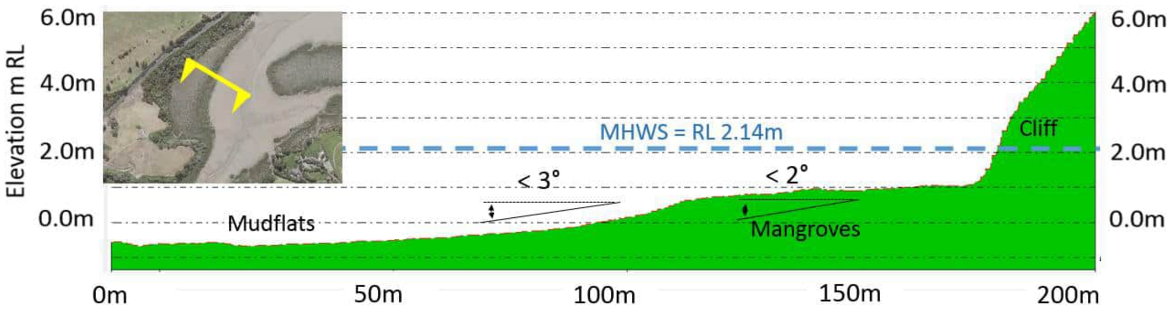

Figure 3-3 Typical cross shore bathymetry

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.

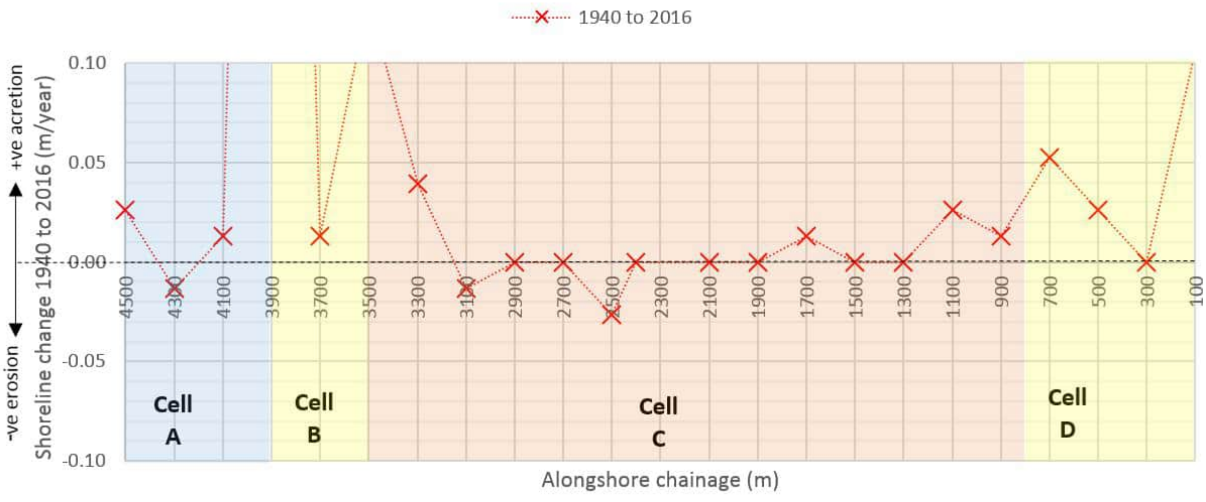

Figure 3-8 Horizontal cliff toe change rate between 1940 and 2016, alongshore chainage (m) measured from the south-eastern end of the site

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.

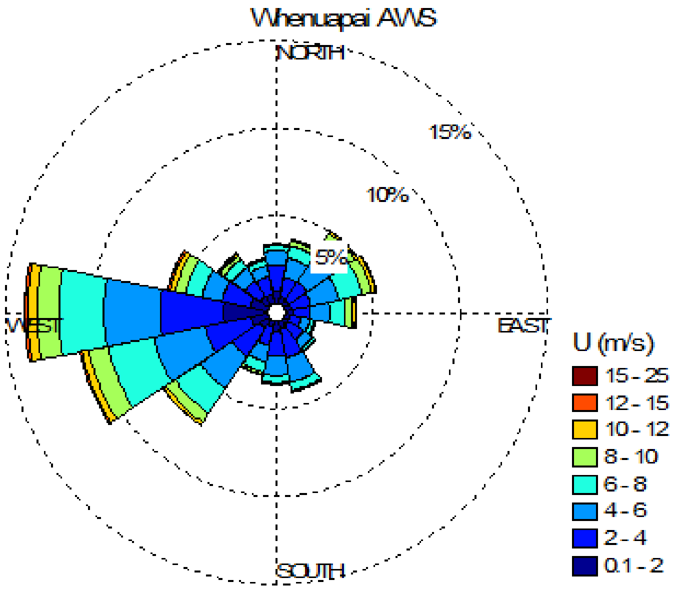

Figure 4-1 Wind Rose and monthly mean wind speed for Whenuapai (NIWA, 2013).

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.

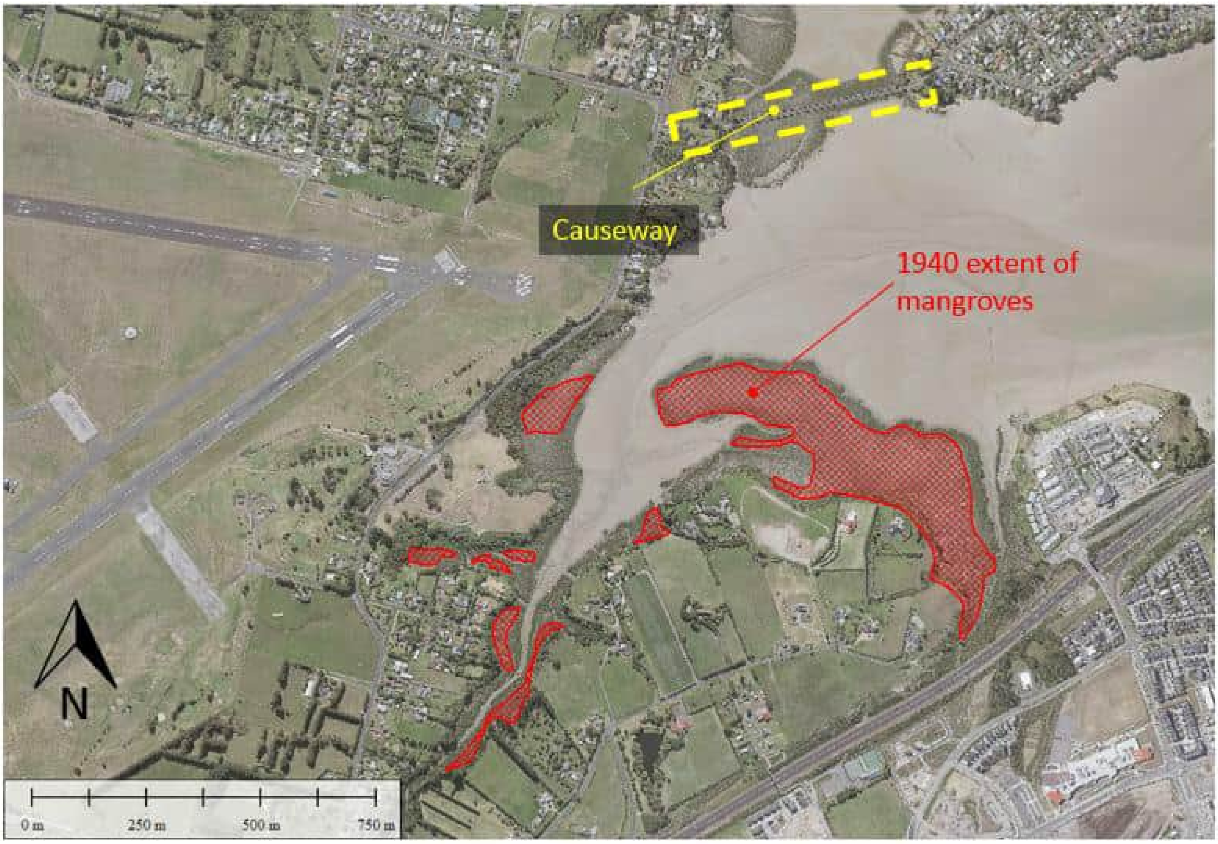

Figure 4-2 Change in extent of mangrove forests between 1940 and 2016 and location of causeway

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):

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

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.

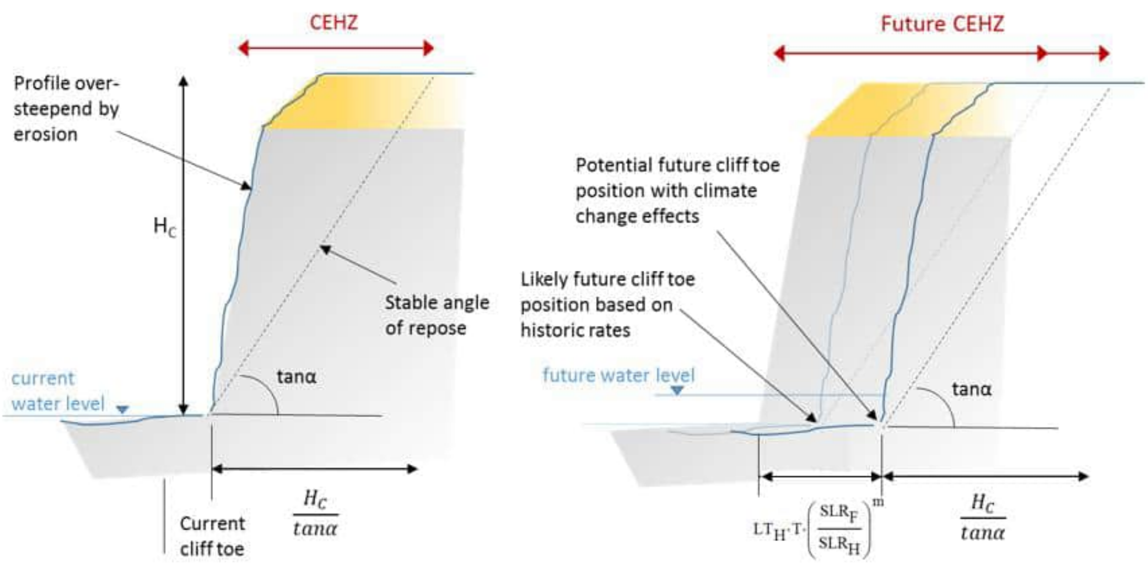

Figure 5-1 Definition sketch for cliff shore coastal erosion hazard zones for the present day (left) and future (right)

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+ (83rd 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).

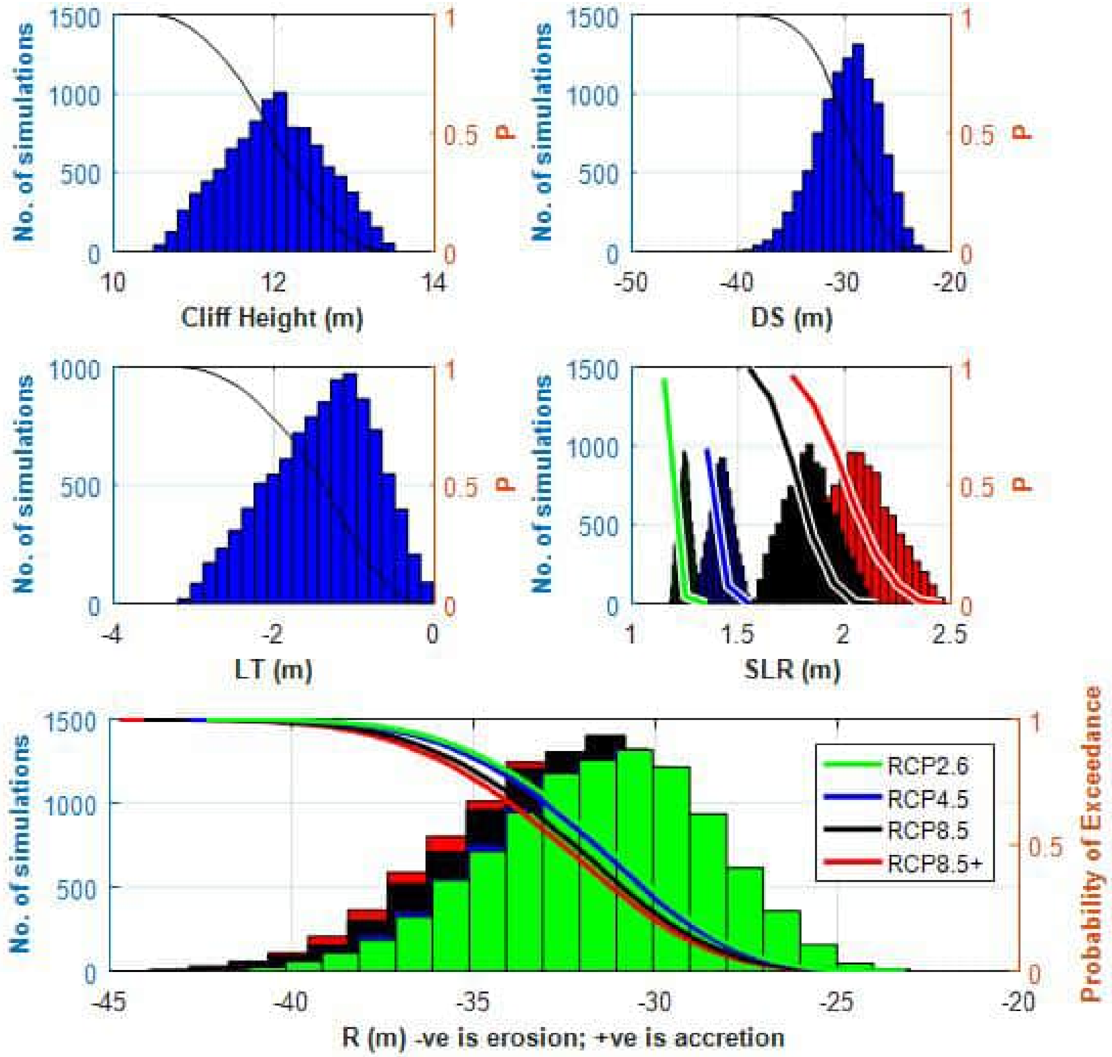

Figure 5-1 Example of cumulative distribution functions of parameter samples and the resultant CHZ distances for Cell A, 2120 time frame

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^{o}
- 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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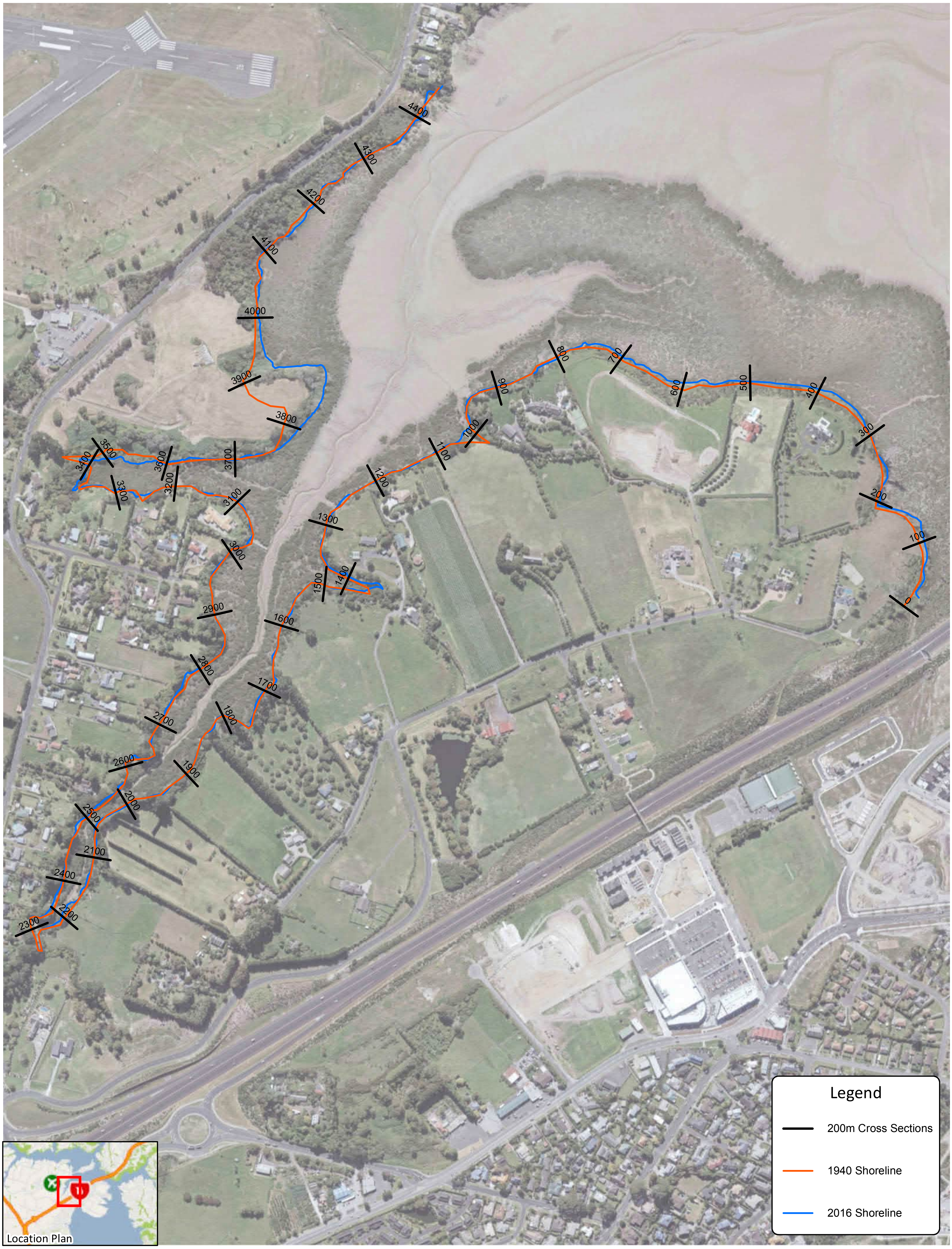
Appendix A: Historic shorelines



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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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AUCKLAND COUNCIL
WHENUAPAI
Coastal Hazard Assessment
1940 and 2016 Shoreline Positions

FIGURE No. Appendix A

Rev. 1

Appendix B: Coastal erosion hazard zones

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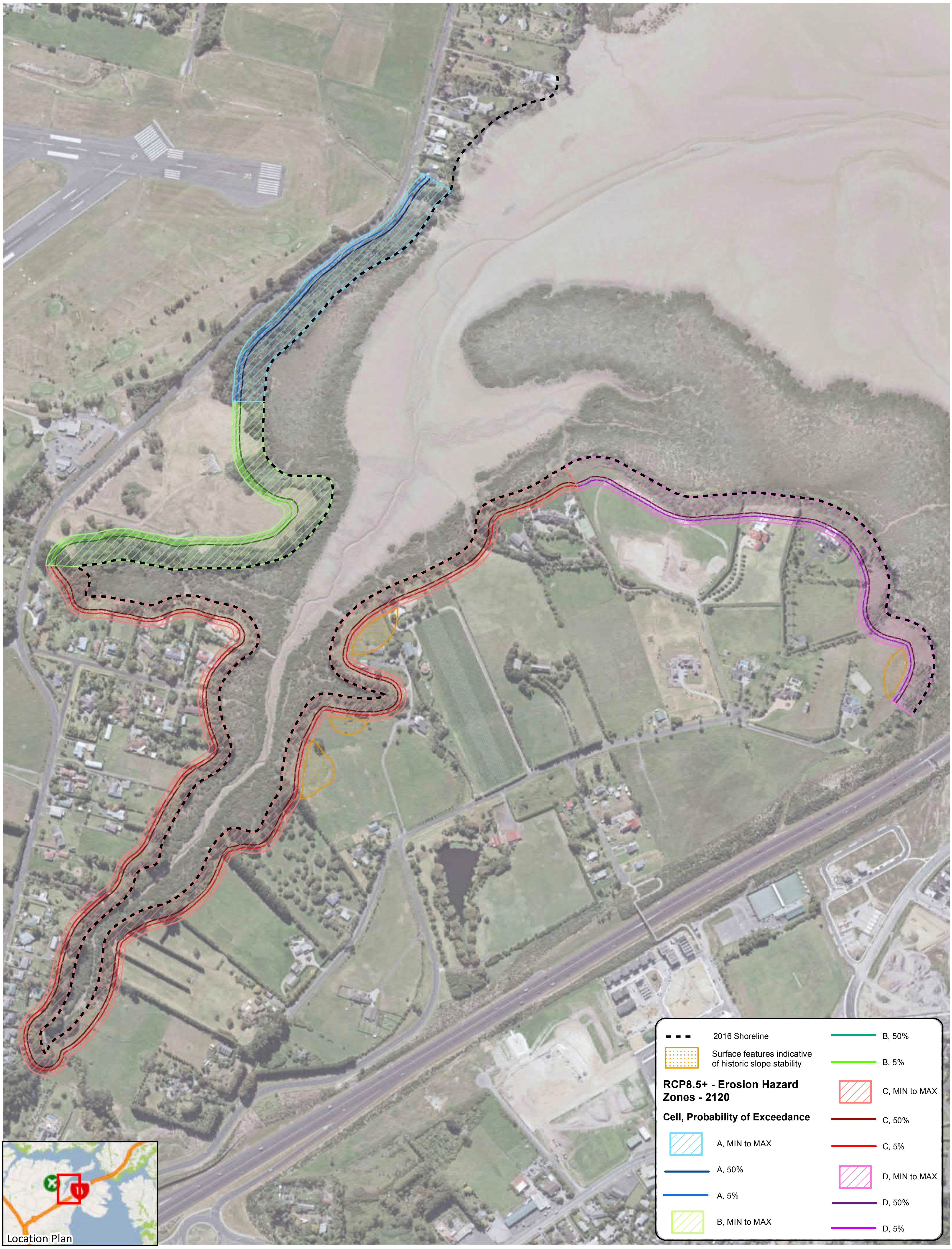

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A3 SCALE 1:5,000

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FIGURE No. Appendix B. Rev. 1

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