REPORT

Tonkin+Taylor

Coastal Processes and Hazards Assessment

48 Esmonde Road, Takapuna

Prepared for
Kingstone Ltd

Prepared by
Tonkin & Taylor Ltd

Date
May 2020

Job Number
1008826.1000

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Document Control

Title: Coastal Processes and Hazards Assessment					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
Apr 2019	1	Report	Bapon Fakhruddin	Nick Rogers	Nick Rogers
May 2020	2	Final report	Bapon Fakhruddin	Richard Reinen-Hamill	Nick Rogers

Distribution:

Kingstone Ltd 1 electronic copies

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Executive summary

Introduction

Kingston Ltd engaged Tonkin + Taylor (T+T) to undertake a coastal hazard assessment for their site at 48 Esmonde Road, Takapuna, Auckland as a Stage 1 report. This report summarizes the findings on coastal processes and coastal hazards assessment for coastal inundation exposure of the site up to the 1% AEP (Annual Exceedance Probability) with 1 m sea level rise, probabilistic forecast of future erosion and tsunami hazard.

Coastal inundation

Coastal inundation occurs when sea levels are super elevated as a result of astronomical tide, storm surge (barometric and onshore wind set-up) and wave set-up. The Auckland Unitary Plan recommends that for new development and subdivision that a 1% AEP coastal storm tide event with 1 m projected sea level rise should be adopted when setting floor levels. Extreme sea levels in the Waitemata Harbour have been assessed by Stephens et al. (2013) with a 1% AEP water level of 2.39 m AVD (Auckland Vertical Datum 1946) offshore of Esmonde Road. Wave set-up is in the order of 0.2 m based on a 1% AEP significant wave height of 1 m derived from T+T's Waitemata Harbour numerical wave model (SWAN model).

Results (Table A-1) show that land below 2.6 m RL may become intertidal over the next 100 years and is unlikely to have development potential. Land between 2.6 m RL and 3.6 m RL may be intermittently flooded by 2115 with 1 m of sea level rise. Land above 3.6 m RL is likely to be above the coastal inundation hazard. Mapping of the coastal inundation and future tidal extents is included in Appendix A of this report.

Table A.1: Current and future inundation

Situation	Elevation (m AVD)
Current mean high water level (MHWS)	1.59
Current 1% AEP static inundation level (astronomical tide + storm surge + wave set-up)	2.59
Future (2115) mean high water level with 1 m SLR allowance (MHWS + 1 m SLR)	2.59 (rounded to 2.6)
Future (2115) 1% AEP static inundation level (astronomical tide + storm surge + wave setup + 1 m SLR)	3.59 (rounded to 3.6)

Tsunami

Tsunami hazard plots for Waitemata Harbour derived by GNS (2014) are based on the Auckland East, Takapuna hazard curve maximum amplitude values 6.5 meters, which is valid only for the open coast area (e.g. Omaha). The deaggregation plots show that 500- and 2500-year return period Tsunami for this area are likely to be generated from regional (Kermadec) or distance (Peru, Chile, Alaska) sources. The Auckland Regional Council Tsunami Inundation Study (2009) refers to the South American tsunami scenario at MHWS plus 50 cm sea level rise where the water velocity and maximum inundation depth near Te Atatu Peninsula is shown as 2.1-3 m/s and 0.1-1 m respectively (Figure 3.3 and Figure 3.4). This value is more relevant for the Esmonde Road sites. The mangrove in the area will reduce the water velocity in the area. This area is well protected from tsunami inundation. Thus, regional tsunami do not strongly impact this area. The modelling predicts most inundation due to tsunami at the 2500-year exceedance level in this area will be confined to the coastline.

Coastal erosion

The hazard posed by coastal erosion is covered in the geotechnical assessment associated with this report (T+T, 2020). That assessment estimated the rate of regression of both the coastal margin and the top of the low cliffs to be about 1 m per 100 years. As the soft sedimentary rocks extend to at least 2 m above the current high time level, a rise of sea level of 1 m would not be expected to alter this estimated erosion rate or rate of coastal regression.

1 Introduction

Kingston Ltd engaged Tonkin + Taylor (T+T) to undertake a coastal hazard assessment for their site at 48 Esmonde Road, Takapuna, Auckland as a Stage 1 report. Based on the findings, T+T will then conduct a coastal hazard mitigation assessment to provide recommendations and coastal management options and development setbacks allowances in a Stage 2 report.

The site context, geomorphic setting has been described based on Auckland Council's proposed standard templates for the coastal hazard assessment and is further described in section **3**.

This report sets out the details and extent of the coastal process and coastal hazards assessment for coastal inundation exposure of the site up to the 1% AEP (Annual Exceedance Probability) with 1 m sea-level rise, probabilistic forecast of future erosion hazard and tsunami hazard.

2 Coastal processes

The site at 48 Esmonde Road, Takapuna, is located within the estuary of Shoal Bay adjacent to the Esmone Rd Shoal Bay overpass just east of the Northern Motorway. Shoal Bay is open to the Waitemata Harbour between Northcote Point and Stanley Point. The detail of the site context and geomorphological settings are described in Geotechnical Assessment (T+T, 2020)[1]. The coastal process at the site is described here.

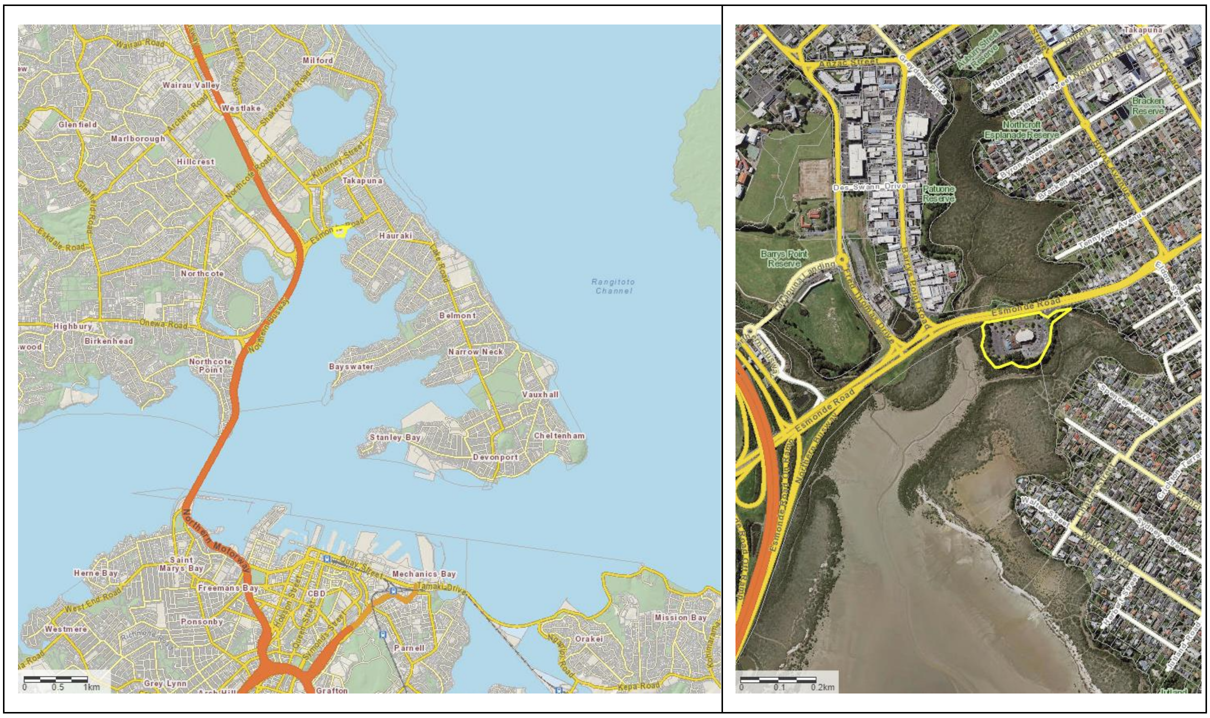


Figure 2.1: Location of site (in yellow) from Auckland Council Geomaps

2.1 Water levels

The potential coastal flood levels at any location varies across a range of time scales. Key components that determine water level are:

- Astronomical tides

[1] Tonkin & Taylor Ltd, May 2020. Geotechincal Assessment: 48 Esmonde Road, Takapuna. Report prepared for Kingstone Ltd.

- 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 (through wave set-up and run-up).

2.1.1 Astronomical tide

Standard Port Tidal Levels given by LINZ (2017-2018) 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 1.01 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 2.1 presented in Auckland Vertical Datum 1946 (AVD-46) and hereafter referred to as the site reduced level (RL).

Table 2.1: Tidal levels for Shoal Bay (Esmonde Road)

Tidal level	Chart Datum CD (m)	Reduced Level RL (m)
Mean High Water Spring (MHWS)	3.33	1.59
Mean High Water Neap (MHWN)	2.83	1.09
Mean Sea Level (MSL)	1.92	0.18
Mean Low Water Neap (MLWN)	0.91	-0.83
Mean Low Water Spring (MLWS)	0.40	-1.34

Note: Levels from NZ Nautical Almanac 2015-16 multiplied by 1.07 co-tidal factor based on Ports of Auckland Co-tidal Chart (2003)

2.1.2 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 (Figure 2.2). 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 for offshore of 48 Esmonde Road for a range of Annual Exceedance Probabilities (AEP) and Average Recurrence Intervals (ARI) are shown in Table 2.2. The 1% AEP storm tide elevation offshore of 48 Esmonde Road is RL 2.39 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.

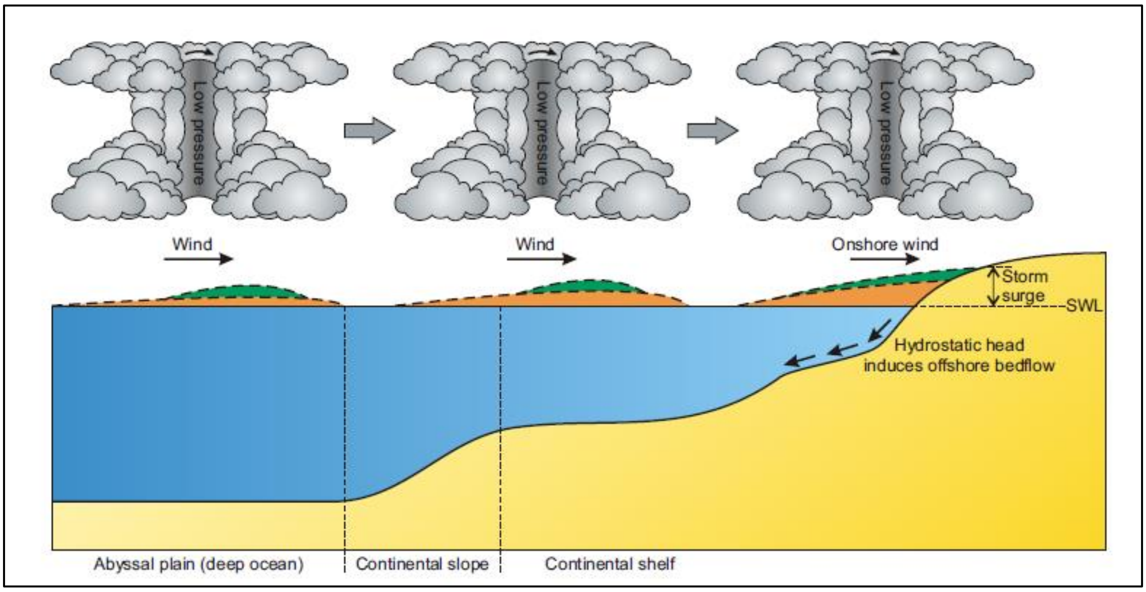


Figure 2.2: Processes causing storm surge (source: Shand, 2010).

Table 2.2: Storm tide elevations offshore of Esmonde Road (Stephens et al., 2013)

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)	2.07	2.15	2.21	2.26	2.33	2.39	2.44

2.1.3 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 (NIWA 2011).

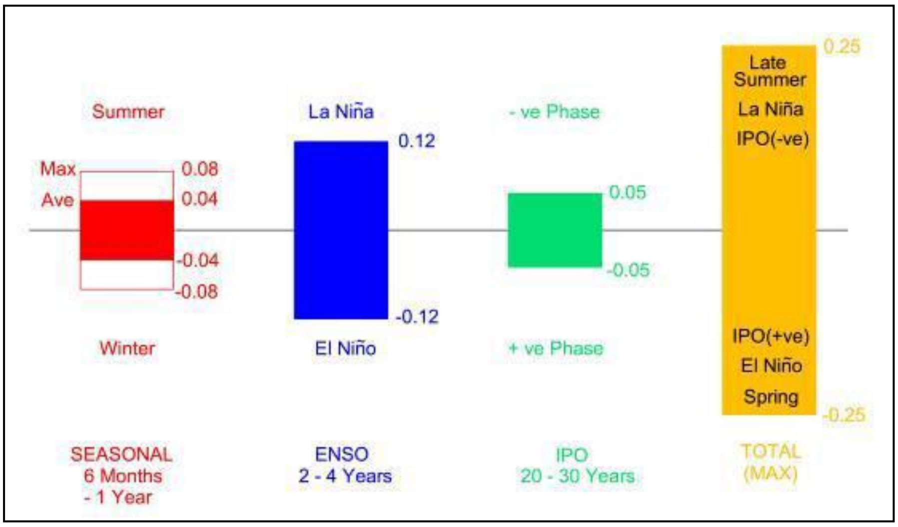


Figure 2.3: Components contributing to sea level variation over long term periods (source: Bell 2012)

2.1.4 Extreme water levels

Extreme water levels for the current, 2070 and 2120 time frames are shown in Table 2.3. The present day 1% AEP extreme water level (includes the medium-term fluctuations) is based on that derived by Stephens et al. (2013). Note that waves approaching the shoreline are deep-water waves and unlikely to break offshore of the proposed cliff toe rock revetment and have super-elevated the extreme water level through wave set-up. The 2070 and 2120 1% AEP water levels include a SLR of 0.5 m and 1 m respectively.

Table 2.3: Extreme water levels for 48 Esmonde Road

	Present day	2070	2120
Water level component	**Elevation (RL m)**	**Elevation (RL m)**	**Elevation (RL m)**
SLR allowance	0	0.5	1.0
MHWS	1.59	2.09	2.59
1% AEP storm tide level	2.39	2.89	3.39

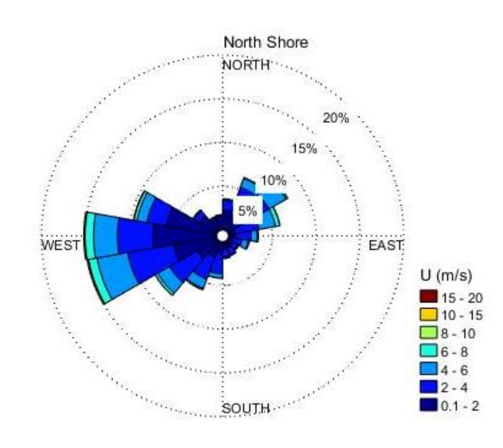
The existing flood elevation along the shoreline is above the 2120 1% AEP storm tide (Appendix A). We recommend that design and construction of any surface water drainage on the site considers the 1% AEP storm tide level for 2120.

2.2 Wind and wave climate

The site is located in the north-eastern part of the inner Waitemata Harbour, facing towards the south and is exposed to wind-waves from south to south-west (clockwise). The height of wind-generated waves is dependent on water depth, fetch length, wind speed and duration. The predominant wind direction in the Auckland region is from the southwest. This is particularly so in winter and spring, but in summer the proportion of winds from the northeast increases. This arises from 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 wind rose for the closest weather station on the North Shore shows main winds come from the west to south-west (anti-clockwise) (see Figure 2.4). The highest wind speed measured at the North Shore station between 1994 and 2017 is 50 m/s. The maximum average monthly mean wind speed is 3.2 m/s in the months of October-November (Figure 2.4).

The site is exposed to the south to south-west, with the maximum fetch length to the south-west of approximately 5 km. Due to the shallow depths within Shoal Bay and mangroves surrounding the site it is expected that waves are negligible at the site.



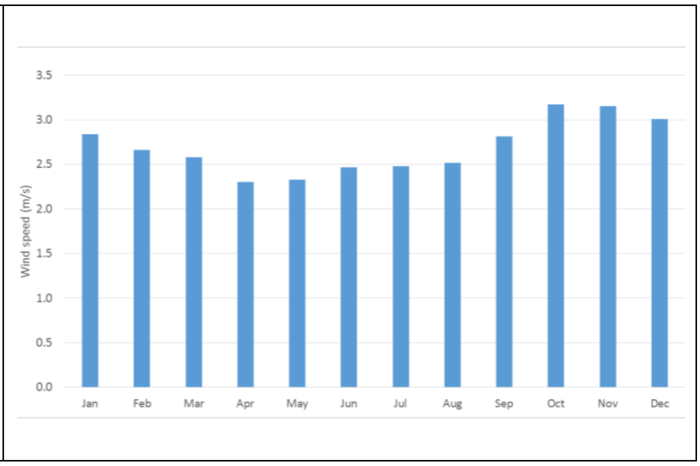


Figure 2.4: Wind Rose and monthly mean wind speed (1994-2017) for North Shore station, around 3 km apart (Source: Clifo, NIWA).

2.3 Long-term sea levels

Historic sea level rise in New Zealand has averaged 1.7 ± 0.1 mm/year (Hannah and Bell, 2012). However, ongoing changes in the global climate are predicted to result in acceleration of this sea level rise in coming decades. The Ministry of the Environment (2008) guideline recommends a base value sea level rise of 0.5 m by 2100 (relative to the 1980-1999 average) with consideration of the consequences of sea level rise of at least 0.8 m by 2100 with an additional sea level rise of 10 mm per year beyond 2100. This gives SLR values ranging from 0.65 m to 0.95 m to 2115 (100 years).

The Auckland Unitary Plan ('the AUP-OP') recommends that for new development, subdivision and structure planning in areas which may be subject to coastal inundation that 1 m SLR plus 1% AEP storm tide should be used for both vulnerable and less vulnerable activities. We have adopted a sea level rise of 0.5 m and 1.0 m for the 2065 and 2115 time frames respectively.

2.4 Large scale processes

In exposed environments a longshore (littoral) current will develop when the angle of swell approach is oblique to the beach orientation. In general, flows in the subject area are expected to be very low due to the presence of the motorway to the north and dense mangroves to the west, south and east, significantly limiting wave height and wave-induced currents.

The sediment in the area is mostly silt and sand and retained within the mudflats. The base of the low cliffs or banks is mainly a swampy sedimentary area and not a wave cut platform. The historical aerial photographs from the T+T air photo library shows that there has been no significant change over the past 80 years in the shoreline and sediment deposition with the increase of mangroves.

3 Coastal hazard assessment

Coastal hazards include coastal inundation, coastal erosion (both hard and soft) and tsunami, along with the ongoing changing risk presented by the future impacts of climate change, including sea level rise. As a result, the site-specific hazard assessment and their future impact over at least the next 100 years in alignment with the New Zealand Coastal Policy Statement (2010) has been recommended by Auckland Council. Based on guidance from Auckland Council, coastal inundation and tsunami hazards have been assessed here. As the coastal erosion hazard is associated with soft sedimentary rocks, this is covered in the geotechnical assessment report (T+T, 2020).

3.1 Coastal inundation

Inundation from the sea occurs when sea levels are super elevated as a result of one or more components controlling water level. Components which may elevate water levels resulting in inundation are shown in Figure 5 and include astronomical tide, storm surge (barometric and onshore wind set-up) and wave set-up. Inundation from the sea is likely to be enhanced by any catchment flows.

3.1.1 Methodology

For this study, 1% AEP inundation levels are calculated by combining the extreme values of water level components of storm tide, wave set-up and future sea level rise. A conservative assumption is made that 1% AEP wave conditions occur concurrently with respect to the 1% AEP storm tide conditions due to the short length of data used for the joint probability assessment. While wave height and storm surge are often closely correlated, being generated by similar meteorological mechanisms, astronomical tide and medium-term sea level fluctuations are independent and this assumption is therefore conservative.

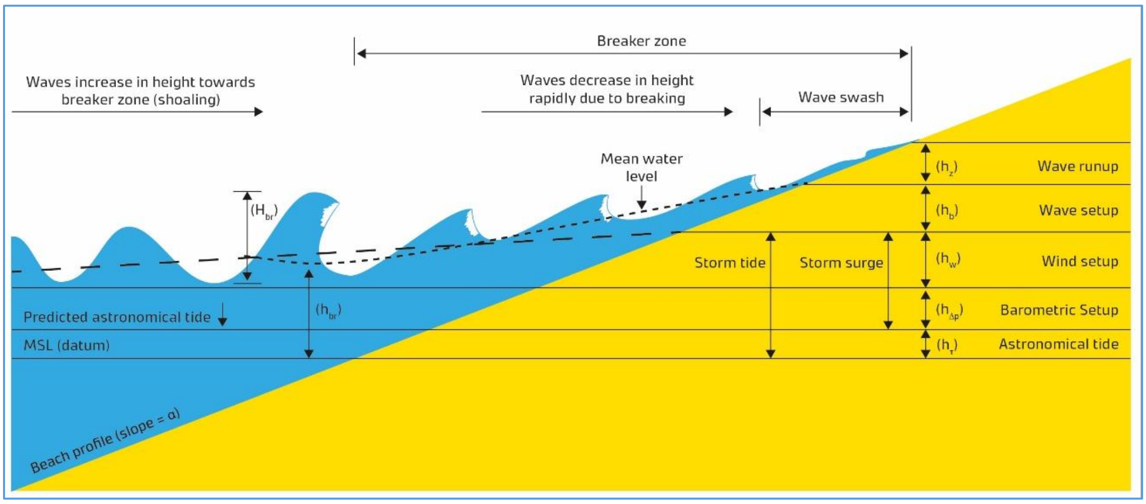


Figure 3.1: Schematic diagram showing components of coastal inundation

Current Inundation Hazard Zone (CIHZ): Those areas below the calculated 1% AEP combined tide, storm surge and wave set-up event. CIHZ = ST + SU
2115 Inundation Hazard Zone (2115IHZ): Those areas below the calculated 1% AEP combined storm tide, wave set-up and SLR component to 2115. 2115IHZ = ST + SU + SLR_{2115}

Where:

- ST: Storm Tide incorporating astronomical tide, storm surge and medium-term sea level fluctuations as determined by NIWA (2013)
- SU: Maximum wave set-up
- SLR2115: Adopted Sea Level Rise to 2115

3.1.2 Coastal inundation hazard

Extreme sea levels in the Waitemata Harbour have been assessed by Stephens et al. (2013) with a 1% AEP (Annual Exceedance Probability) water level of 2.39 m AVD (Auckland Vertical Datum 1946) offshore of Esmonde Road. As concluded in section 2.2 waves are likely negligible at the site and low within Shoal Bay. Wave set-up is therefore very minor to negligible and we assumed 0.2 considering extreme situation.

The Auckland Unitary Plan Independent Hearings Panel (July 2016) recommends that Unitary Plan provisions deal with coastal inundation on the basis of a projected 1 m sea level rise within 100 years (i.e. to 2115) and we have adopted this value (AC, Technical report 2016/2017). Table 3.1 shows the existing and future (2115) flood elevations. A freeboard is generally applied above the inundation level dependent on usage. Here no freeboard was considered.

Based on survey data of the site in combination with 2013 LiDAR data around the site the flood elevation for 2.6 m and 3.6 m has been drawn using the bathtub approach (Appendix B). Land between 2.6 m RL and 3.6 m RL may be intermittently flooded by 2115 with 1 m of sea level rise. Land above 3.6 m RL is likely above coastal inundation hazard. Note this assessment does not consider catchment flooding/inundation or the joint likelihood of coastal and catchment flooding. Future (2115) 1% AEP static inundation therefore will not inundate the land significantly.

Table 3.1: Existing and future flood elevations

Situation	Elevation (m AVD)
Current mean high water level (MHWS)	1.59
Current 1% AEP static inundation level (astronomical tide + storm surge + wave set-up)	2.59
Future (2115) mean high water level with 1 m SLR allowance (MHWS + 1 m SLR)	2.59 (rounded to 2.6)
Future (2115) 1% AEP static inundation level (astronomical tide + storm surge + wave set-up + 1 m SLR)	3.59 (rounded to 3.6)

3.2 Tsunami risk

Tsunamis may be broadly categorised as being either local (wave arriving within 1 hour of the associated event), regional (wave arriving between 1 and 3 hours of the associated event), or distant (wave arriving more than 3 hours after the associated event). Tsunami hazard plots for Waitemata Harbour derived by GNS (2014) based on the Auckland East, Takapuna hazard curve are presented within Figure 3.2 along with deaggregation (tsunami source) plots. The amplitudes shown are the maximum modelled within the 20 km open coast cell. The maximum amplitude values are valid for the open coast only which will not be similar at the Waitemata Harbour. The deaggregation plots show that the 500- and 2500-year return period Tsunami for this area are likely to be generated from regional (Kermadec) or distance (Peru, Chile, Alaska) sources. This value is only relevant for the open coast area. The Auckland Regional Council Tsunami Inundation Study (2009) refers to the South American tsunami scenario at MHWS plus 50 cm sea level rise where the water velocity and maximum inundation depth near Te Atatu Peninsula is shown as 2.1-3 m/s and 0.1-1 m respectively (Figure 3.3 and Figure 3.4). The mangroves in the area will reduce the water velocity in the area. The probabilistic tsunami hazard assessment for Auckland Region by NIWA-GNS (2010) has summarized the 2500-year ARI probabilistic maximum speed as generally not high, less than 0.1 m/s. This area is well protected from tsunami inundation. Thus, regional tsunami do not strongly impact this area. The modelling predicts most of the inundation due to tsunami at the 2500-year exceedance level in this area will be confined to the coastline.

Monitoring within the Pacific ensures distant tsunami are identified and early warning including anticipated arrival time and wave height, are provided. The Tonga-Kermadec trench to the east and northeast of Auckland could generate earthquakes greater than magnitude 9.0 with large tsunami but travel times would likely exceed 60 minutes.

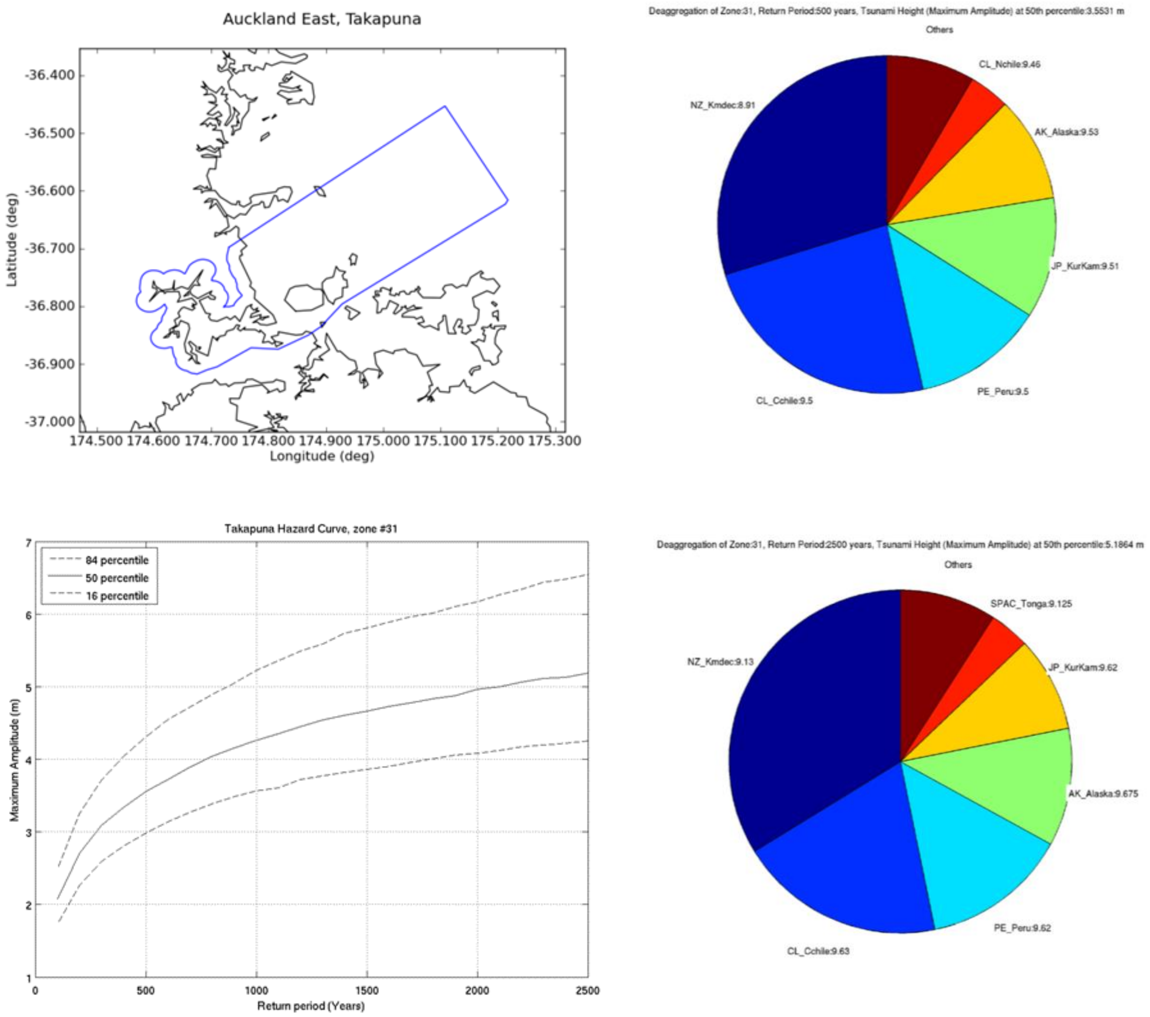


Figure 3.2: Tsunami hazard curves and deaggregation (source) plots for Whangaparoa Bay (source: GNS, 2014)

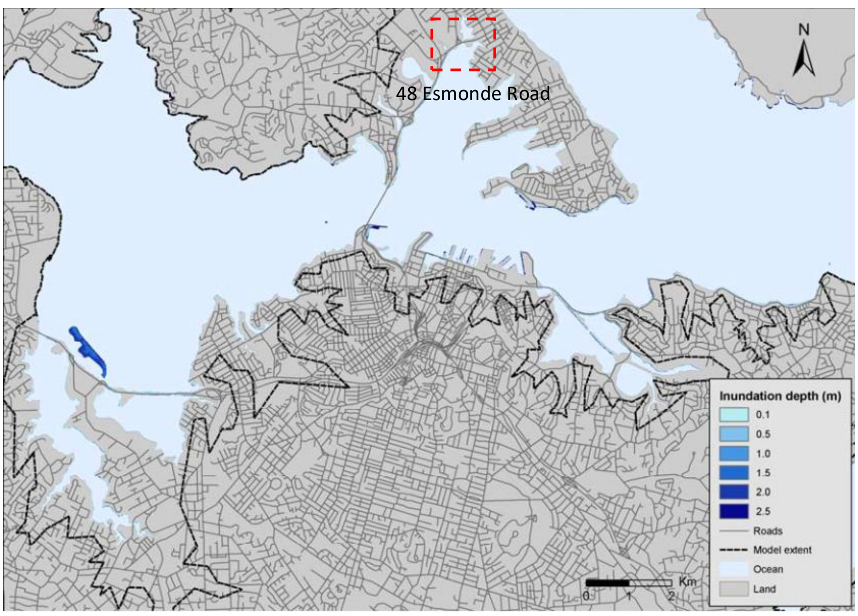


Figure 3.3: ARI 2500-year exceedances for regional probabilistic tsunami inundation including tidal effects (NIWA-GNS, 2010).

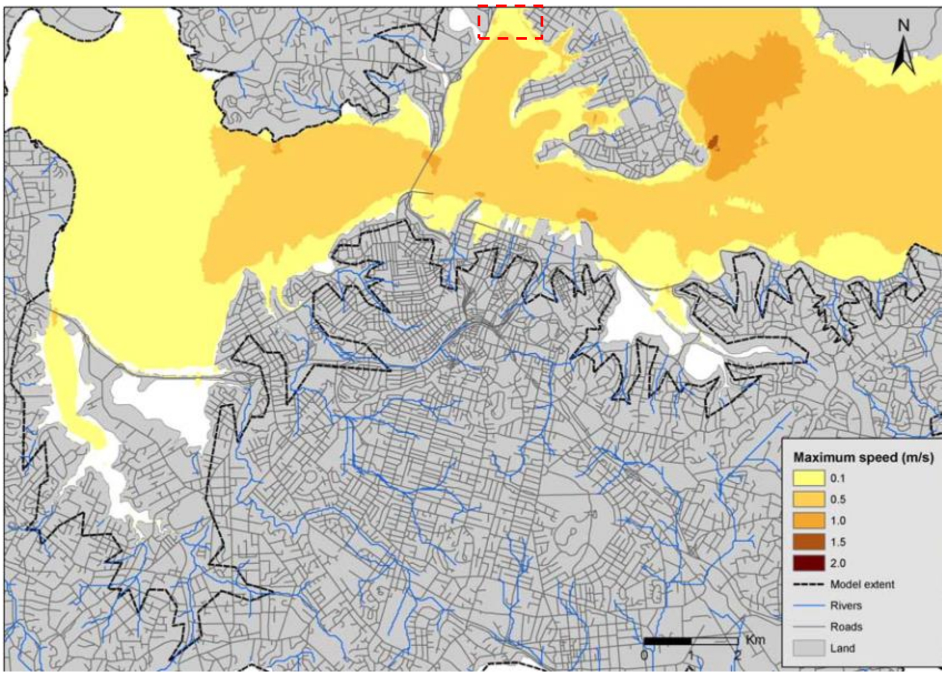


Figure 3.4: ARI 2500-year exceedances of maximum speed for probabilistic tsunami hazard (NIWA-GNS, 2010)

Auckland Civil Defence and Emergency Management have compiled comprehensive sites potential exposure to tsunami evacuation maps for the Auckland Region (http://www.aucklandcivildefence.org.nz/community/tsunami-evacuation-maps/). These indicate that the proposed development site is partially located within the “red” zone, and some parts of land are in the “orange” zone (Figure 3.5). This estimation probably utilised base data presented in Figure 3.2, and thus is quite conservative.

The Director’s Guideline for Civil Defence associated with the tsunami evacuation plans indicates the red zone as being “intended as a shore-exclusion zone that can be designated off limits in the event of any expected tsunami. This represents the highest risk zone and is the first place people should evacuate from in any sort of tsunami warning. People could expect ‘activation’ of this zone several times during their life”. The orange zone is intended to be used for official warnings of distant or regional source tsunami and hence highlights areas that “may need to be evacuated if there was a threat from a medium- to large-scale tsunami”.

The red zone extends up to the 10 m RL contour in the south of the property and up to the 5-7 m RL contour from the west all around the south to the east. The orange zone extends up to 7 m RL in the northern part of the property at Esmonde Road. While the risk of occurrence is very low and therefore provision for such events within land-use planning (i.e. development restrictions) is not likely necessary, we consider that allowance for evacuation by foot to above the 25 m contour would be prudent in any development plans. The required walk distance to achieve this elevation would be at most 700 m from any part of the proposed development, and easily achievable within the travel time for a regional or distant source event, particularly when some early warning is able to be provided.

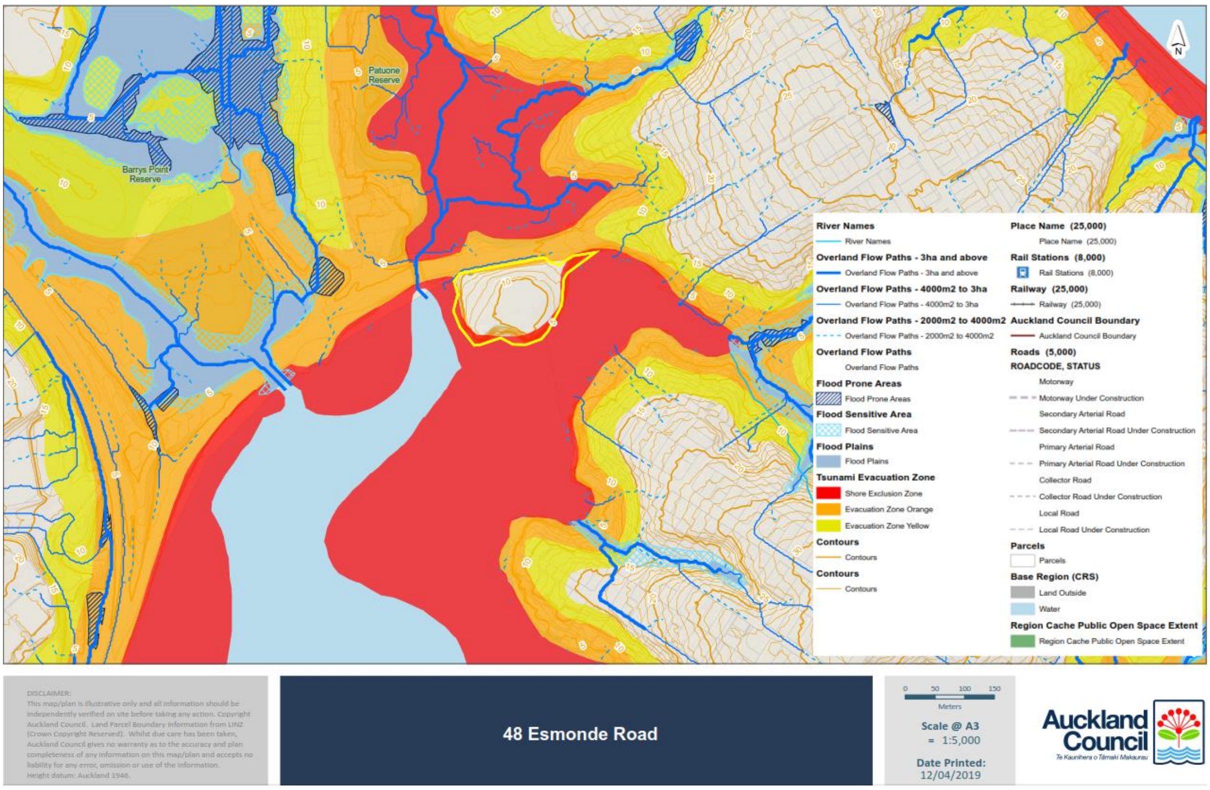


Figure 3.5: Tsunami hazard zones for 48 Esmonde Road area (source: Auckland Council GIS)

3.3 Coastal erosion

The hazard posed by coastal erosion is covered in the geotechnical assessment associated with this report[2]. That assessment concluded the following:

- The banks and low coastal cliffs around the site exhibit a high degree of stability.
- The existing large Pohutukawa vegetation is contributing positively to the stability locally.
- There are two areas of recent and currently active instability at the western and eastern extremities of the site, but both appear to be shallow and associated with minor fill placement from the 1980's.
- There is no evidence to suggest that coastal erosion is resulting in instability.
- Based on aerial surveys and site inspections, the rate of coastal erosion is clearly very slow.
- There is evidence of localised bio-erosion at the base of the cliffs in the inter-tidal area, and some preferential weathering of the siltstone.
- The rate of regression of both the coastal margin and the top of the low cliffs is estimated to be about 1m per 100 years.
- As the soft sedimentary rocks extend to at least 2m above the current high time level, a rise of sea level of 1m would not alter the estimated erosion rate or rate of coastal regression.

[2] Tonkin & Taylor Ltd, May 2020. *Geotechincal Assessment: 48 Esmonde Road, Takapuna*. Report prepared for Kingstone Ltd.

4 Summary and conclusion

In this study, T+T have undertaken a coastal process and coastal hazard assessment at the site. Coastal inundation occurs when sea levels are super elevated as a result of astronomical tide, storm surge (barometric and onshore wind set-up) and wave set-up. The Auckland Unitary Plan recommends that for new development and subdivision that a 1% AEP coastal storm tide event with 1 m projected sea level rise should be adopted when setting floor levels. Extreme sea levels in the Waitemata Harbour have been assessed by Stephens et al. (2013) with a 1% AEP water level of 2.39 m AVD (Auckland Vertical Datum 1946) offshore of Esmonde Road.

Wave set-up is negligible (most likely zero) in the area but we have considered 0.2 m as a conservative assessment. Results show that land below 2.6 m RL may become intertidal over the next 100 years and is unlikely to have development potential. Land between 2.6 m RL and 3.6 m RL may be intermittently flooded by 2120 with 1 m of sea level rise. Land above 3.6 m RL is likely to be above the coastal inundation hazard.

Tsunami hazard plots for Waitemata Harbour derived by GNS (2014) are based on the Auckland East, Takapuna hazard curve maximum amplitude values 6.5 meters, which is valid only for the open coast area (e.g. Omaha). The deaggregation plots show that 500- and 2500-year return period Tsunami for this area are likely to be generated from regional (Kermadec) or distance (Peru, Chile, Alaska) sources.

The Auckland Regional Council Tsunami Inundation Study (2009) refers to the South American tsunami scenario at MHWS plus 50 cm sea level rise where the water velocity and maximum inundation depth near Te Atatu Peninsula is shown as 2.1-3 m/s and 0.1-1 m respectively (Figure 3.3 and Figure 3.4). This value is more relevant for the Esmonde Road site. The mangrove vegetation in the area will reduce the water velocity locally.

This area is well protected from tsunami inundation. We conclude that the regional tsunami hazard does not strongly impact this particular area. The modelling predicts most inundation due to tsunami at the 2500-year exceedance level in this area will be confined to the coastline.

Regarding coastal erosion, the associated geotechnical assessment (T+T, 2020) estimated the rate of regression of both the coastal margin and the top of the low cliffs to be about 1 m per 100 years. And as the soft sedimentary rocks extend to at least 2 m above the current high time level, a rise of sea level of 1 m would not be expected to alter this estimated erosion rate or rate of coastal regression.

5 Applicability

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

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Bapon Fakhruddin	Nick Rogers
Patrick Knook	Project Director

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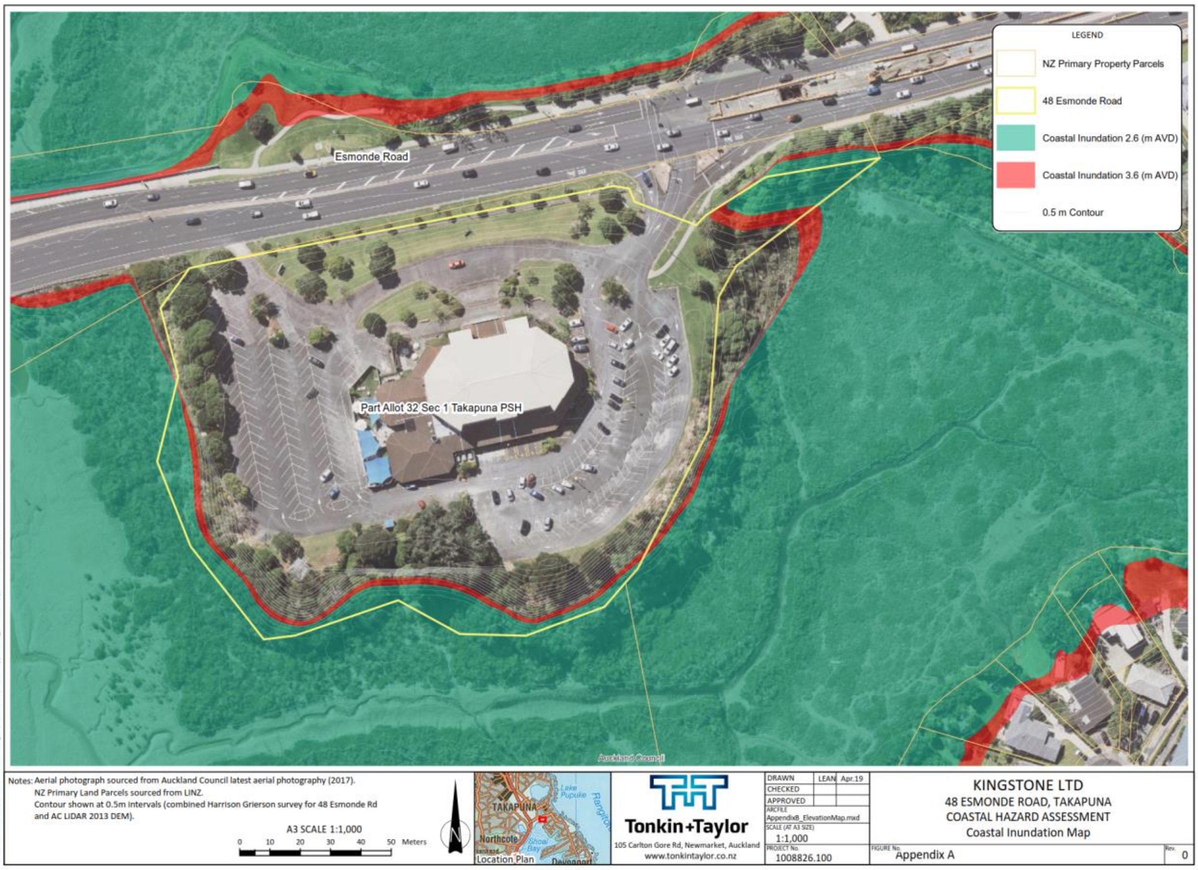
Appendix A: Coastal Inundation Elevation for 48 Esmonde Road



Memo

To:	**Abu Hoque**	**Job No:**	**1008826**
From:	**Richard Reinen-Hamill**	**Date:**	**3 September 2021**
cc:	**Michael Campbell**		
Subject:	**Coastal Hazard Report clarification response**		

1 Purpose

This memo responds to the following request from Ashishika Sharma for Auckland Council regarding the Tonkin + Taylor coastal hazard assessment report:

1. The applicant has not clarified how the value of 1m regression in the next 100 years has been reached. Will appreciate it if they could show us the calculation for the ASCIE.

2 Hazard parameters

The erosion hazard assessment was based on geotechnical inspection and observation as set out in our geotechnical report[1]. The following key parameters were observed:

- Cliff type competent East Coast Bays Formation, with measured slope angles ranging from 55 to 75 degrees with no observed wave undercutting due to wave action as site very sheltered and fringed by mangroves.
- Cliff heights ranged from 5 to 10m (see Figure 2.1).
- Long term retreat based on visual observation and aerial photograph inspection suggested toe erosion rates at less than 1m/100 years, but conservatively a value of 1m/100 years was applied.
- Weathers soil mantle of up to 2m present with slope angle of around 26 degrees (2(H):1(V)).

3 Hazard methodology

Consolidated shorelines, which include soil and rock cliffs, are not able to rebuild following periods of erosion but rather are subject to a one-way process of degradation. The coastal erosion hazard along cliff (consolidated) shorelines typically have two components:

Toe Erosion

A gradual retreat of the cliff toe caused by weathering, marine and bio-erosion processes. This retreat will be affected by global process such as SLR and potentially increased soil moisture. Future cliff toe position based on historical erosion rates with a factor applied to allow for the effect of future SLR.

[1] T+T (2020) Coastal hazards and geotechnical assessment, prepared for Kingstone Ltd, T+T ref: 1008826.1, May 2020

Figure 3-1: Contours showing maximum cliff height of 10m at steepest part of slope with remaining height ranging from 5m to 8m (Source: AC GIS viewer)

Cliff Instability

Episodic instability events are predominately due to a change in loading or material properties of the cliff or yielding along a geological structure. In soft cliffs, instability causes the cliff slope to flatten to a slope under which it is 'stable'. Soil cliff slope instabilities are influenced by processes that erode and destabilise the cliff toe, including marine processes, weathering and biological erosion or change the stress within the cliff slope. Most of the hard cliffs are stable at very steep angles. Instability events may range from small-scale instabilities (block or rock falls) or discontinuities, to cliff slope instability cause by large-scale and deep-seated mass movement. The latter mode of failure in hard cliffs is rare.

The conceptual models for the toe erosion component and cliff instability component are as follows:

$$\textit{Cliff Instability} = (h_{Cr}/\tan\alpha_r) + (h_{Cs}/\tan\alpha_s) \qquad \text{(Equation 3.1)}$$

$$\textit{Cliff Toe Erosion} = ((LT_H \times LT_F) \times T) \qquad \text{(Equation 3.2)}$$

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).

These can then be combined into the models for consolidated shoreline for the future hazard extent. The future erosion hazard is a function of both cliff instability and cliff toe regression, with the latter likely being affected by increased SLR rate effects.

The model for consolidated shorelines are expressed in 2.3 (current ASCIE) and Equation 2.4 (future ASCIE), where the ASCIE is established from the cumulative effect of the components (*Figure 3-2*):

$$\text{Current ASCIE} = (h_{Cr}/\tan\alpha_r) + (h_{Cs}/\tan\alpha_s) \qquad \text{(Equation 3.3)}$$

$$\text{Future ASCIE} = ((LT_H \times LT_F) \times T) + (h_{Cr}/\tan\alpha_r) + (h_{Cs}/\tan\alpha_s) \qquad \text{(Equation 3.4)}$$

Note that coastal cliffs may be comprised of more than one geological type with different characteristics. If the cliff slope is comprised of two geotechnical domains, soil and rock, they will have different observed field angles. If a cliff is composed of only one geotechnical domain, only the relevant component (i.e., either rock or soil) should be used in the equations. The height and slope for each domain are assessed separately where applicable (see definition sketch *Figure 3-2*). For those cliffs where the cliff height (h_c) and the slope angle (α) are subdivided in an upper “soil” (h_{cs} and α_s) and lower “rock” (h_{cr} and α_r) section, the composite slope profile (i.e., combination of rock and soil slopes) is used to derive the horizontal cliff instability distance.

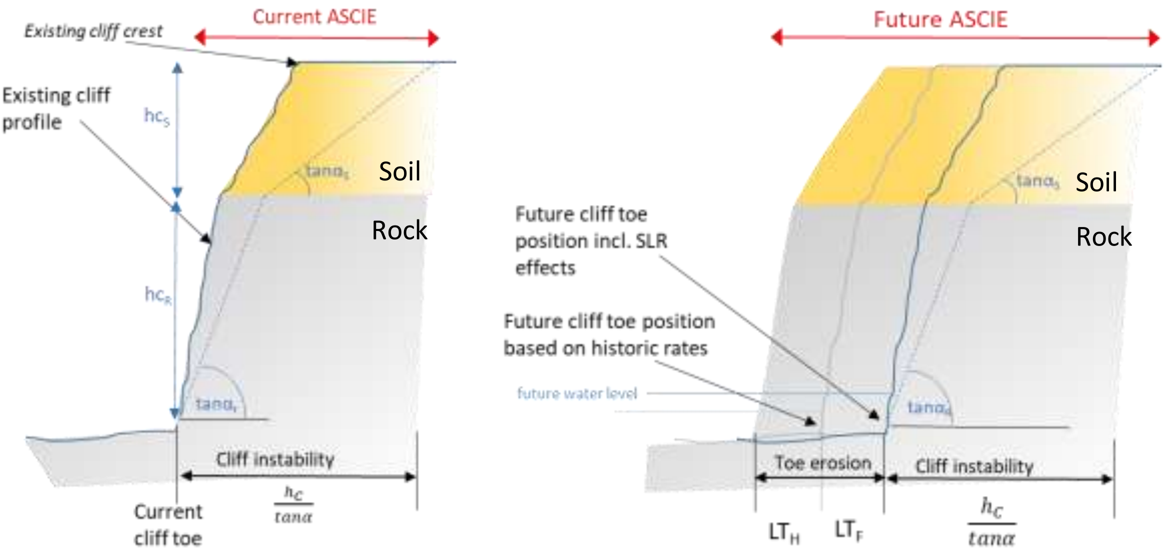


Figure 3-2 Definition sketch for Areas Susceptible to Coastal Instability and/or Erosion on consolidated (cliff) shoreline

A short-term component (ST) has not been included in deriving ASCIE for cliffs and unconsolidated shorelines as these shorelines are unable to rebuild after storm events. The purpose of ST is to allow for the dynamic shoreline movements over a short-term period, including erosion following storms and accretion during calm periods.

4 Hazard outcomes

A determinist assessment was made using the maximum cliff height (10m) with no change in the long term rate of sea level rise. The results of this assessment is shown in Table 1. The total future ASCIE is 10.7m. Applying an uncertainty factor of 50% resulted in the ASCIE extent increasing to 16.1m.

Table 1: Hazard extent with highest cliff and flattest observed slope, no allowance for increased erosion rate due to sea level rise and 50% uncertainty

Cliff type	Short-Term (m)	Long-Term (m/year)	Cliff height (m)	Stable Slope (Deg)	Historic SLR (m/year)	SLR (m)	*m* value	Time frame (years)		Future ASCIE (m)
ECBF	0	0.01	8	55	0.0017	1	0	100		6.6
Residual soil	0	0	2	26	0.0017	1	0	100		4.1
								Subtotal (m)		10.7
								Uncertainty (50%)		5.4
								Total (m)		16.1

With an increase in the stable slope angle from 55 to 75 degrees, the erosion hazard extent decreases to 7.2m, or 10.9m with uncertainty (Table 2).

Table 2: Highest cliff with steepest slope, no allowance for increased erosion rate due to sea level rise, 50% uncertainty

Cliff type	Short-Term (m)	Long-Term (m/year)	Cliff height (m)	Stable Slope (Deg)	Historic SLR (m/year)	SLR (m)	*m* value	Time frame (years)		Future ASCIE (m)
ECBF	0	0.01	8	75	0.0017	1	0	100		3.1
Residual soil	0	0	2	26	0.0017	1	0	100		4.1
								Subtotal (m)		7.2
								Uncertainty (50%)		3.6
								Total (m)		10.9

A sensitivity test was carried out based on a conservative assumption that the rate of long term erosion will increase. A value of 0.3 was used which is the maximum potential response for this formation based on the regional assessment prepared for Auckland Council[2]. The results of this sensitivity test is shown in Table 3. There is modest increase in erosion hazard to 11.4m, or 17.1m including a 50% uncertainty.

Table 3: Sensitivity with highest cliff and flattest observed slope, allowance for increased erosion rate due to sea level rise of 0.3 on ECBF, 50% uncertainty

Cliff type	Short-Term (m)	Long-Term (m/year)	Cliff height (m)	Stable Slope (Deg)	Historic SLR (m/year)	SLR (m)	*m* value	Timeframe (years)		Future ASCIE (m)
ECBF	0	0.01	8	55	0.0017	1	0.3	100		7.3
Residual soil	0	0	2	26	0.0017	1	0	100		4.1
								Subtotal (m)		11.4
								Uncertainty (50%)		5.7
								Total (m)		17.1

Based on these values the geotechnical concluded a buffer of 20m around the site, the development area will not be affected by erosion or instability.

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[2] T+T (2021) Regional assessment of areas susceptible to coastal instability and erosion, T+T ref 1007104.v5, prepared for Auckland Council, January 2021