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Coastal Erosion Hazard Assessment: Johnson property, Kaupokanui Heads Road South Taranaki

A report for Nigel and Heather Johnston as part of a resource consent application prepared by LandPro, New Plymouth

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1.0 INTRODUCTION

The following erosion hazard report was requested by LandPro (New Plymouth) on behalf of Nigel and Heather Johnston (the Client) in December 2019. The report is to accompany the Client's resource consent application to build a dwelling on Lot 1 DP 457685, Kaupokanui Heads Road. The Johnston property's coastline is cliffed and runs southeast for some 600 m from the Kaupokanui Stream Mouth's South Head. The proposed building platform lies approximately in the centre of their coastline on a promontory or headland (Figure 1).

The report was commissioned after the client was informed by South Taranaki District Council Planners that the site may be affected by coastal erosion.

The terms of reference for the erosion hazard assessment (EHA) are as follows:

-The EHA is to be based on conditions at the site , i.e. a site-specific assessment is required;
-A site inspection is to be carried out;
-The local geomorphology is be assessed as pertains to the EHA;
-A shoreline-change analysis is to be carried out based on historical survey plans and aerial/satellite imagery;
-A slope stability analysis is to be carried out using a topographic survey obtained specifically for this study;
-The erosive effect of predicted climate change is to be incorporated;
-The assessment is to be carried out for a 100 year prediction period, and
-The investigation is to follow official guidance and directives contained in NZCPS (2010), IPCC (2014), DOC (2017) and MFE (2008 and 2017).

The author was originally contacted by Mr Johnston in June 2019, and a site visit was carried out on 26 July: this included observation of the cliff-top and cliff-base along the length of the property, sampling of the geology, taking photographs and making notes.

A topographic survey was carried out by LandPro on 21 January, 2020 using vertical aerial photography taken from a drone. Elevation to cm accuracy was derived using mathematical analysis (photogrammetry) of overlapping vertical photographs (stereography). The vertical zero is mean sea level based on New Zealand Vertical Datum 2019 (NZVD 2017), and the positional datum is New Zealand Transverse Mercator 2000 (NZTM 2000). Figure 1 includes the vertical photographic output image superimposed upon a larger satellite image. Note the colour distortions in the drone photography landward of the proposed building site in no way influence the EHA. Various physical features are marked in Figure 1, these being described in later sections of this report.

Distances (chainage) are also marked, these to assist in describing features and for use in the erosion hazard analysis

Section 2 describes the site in terms of its geomorphology and also shoreline (cliff-top) change. Section 3 describes the erosion hazard model and derives values for its components. Section 4 presents results for the current (2020) erosion hazard, the 50 year (2070) hazard and the 100 year (2120) hazard, and Section 5 sets out the conclusions as pertain to the resource consent application for the Johnston's proposed building site.

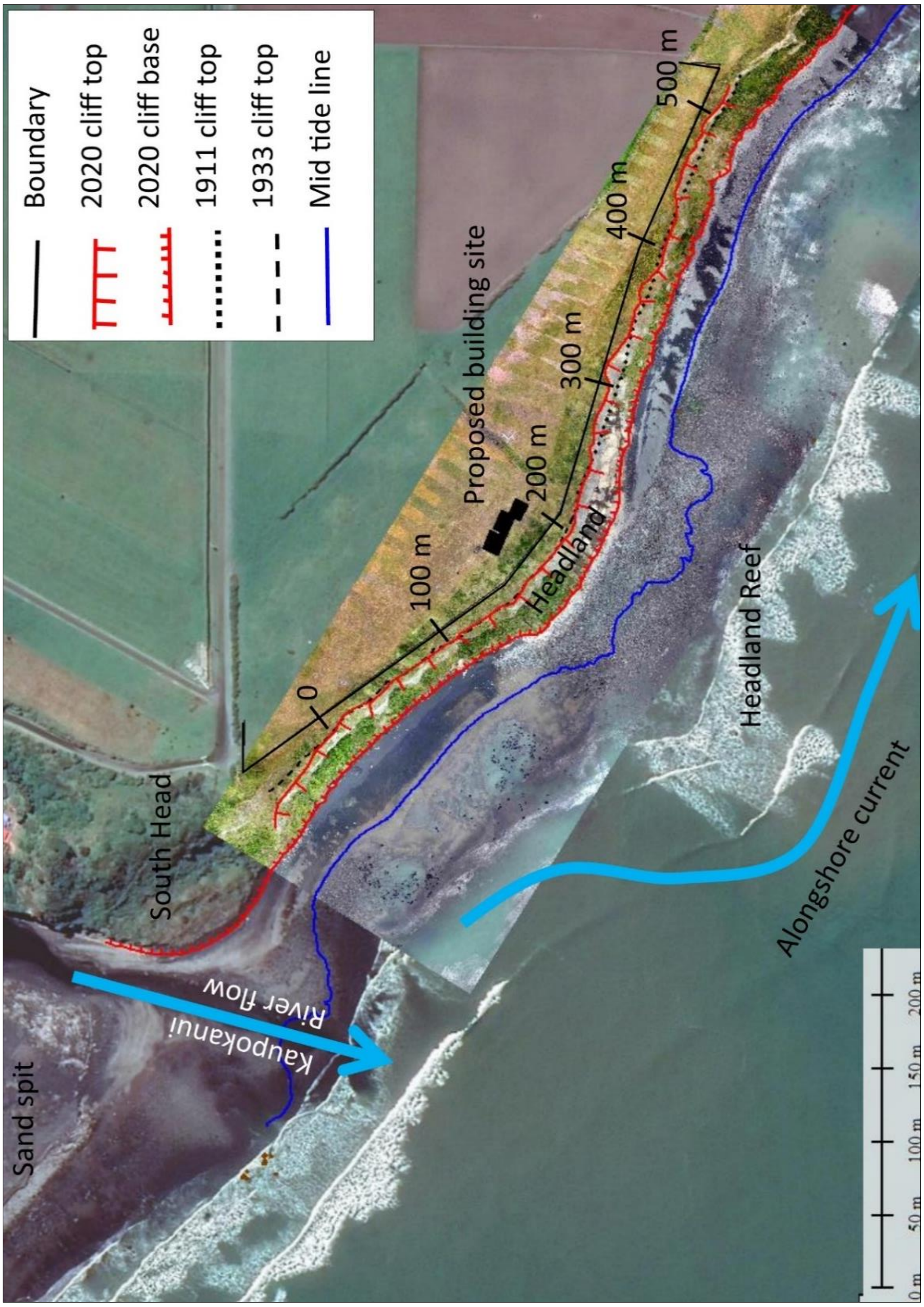

Figure 1 Kaupokanui coast 2020 drone photography superimposed upon a 2018 satellite image to give a wider perspective. The coastal boundary of the Johnston property is marked along with several pertinent features including the current cliff and the 1911 and 1933 historical clifftop locations.

2.0 Geomorphological assessment

The Kaupokanui River has a mountain catchment and enters the sea with a southerly offset between the South Head bluff and a somewhat blunt sand spit on the northern side which is mantled with sand dune. A much smaller area of sand dune fronts the southern bluff with a cliffed coastline stretching to the southeast.

The cliff-face is some 33 to 39 m high measuring from its base some 4 m above mean sea level (MSL). The cliff is a composite type comprising distinct layers of contrasting geology. Three photographs taken from the beach depicting cliff characteristics are shown in Figure 2. The top photo (A) was taken at chainage=0 and looking toward the south shows the cliff with the headland in the distance. In the foreground are resistance sandstone strata each some 20 to 50 cm thick and of marine origin (deposited offshore); these being interspersed with weaker sandstone layers which preferentially erode under wave action facilitating slow retreat of the cliff. Such strata appear to be a seaward extension of the “Inaha Formation” (<100,000 years old) described by McGlone at al. (1984) at the mouth of the Inaha Stream approximately 10 km southeast of Kaupokanui Stream.

Terrestrially deposited material of volcanic origin (boulders, blocks and smaller gravels typically embedded in fine material, often clay), occur in the mid and upper cliff; these comprising the Stratford Formation (below) the Opunaki Formation (above) dating from c. 50,000 and 30,000 thousand years respectively (Townsend et al., 2008). Such deposits are the result of debris avalanches from episodes of mountain crater collapse and associated lahas (mud flows) at times when the mass has higher water content. The mid cliff-face has a lower angle (debris) slope made up of eroded volcanic materials from above. Considerable vegetation cover occurs on the cliff section as viewed in Photo A indicating relative stability.

Of particular significance is a lens of boulders evident high in the cliff fronting the headland at chainage approximately 150 m (Figure 1). These boulders are just discernable in the distance in Figure 2A and a closeup view is provided in Figure 2B. These boulders are released as the cliff erodes and remain as a “lag”on the beach, eventually forming part of the headland reef as the cliff recedes. Such boulder outcrops are thought to have originated in laha flowing down a stream channel and as such the deposit likely extends inland, thus ensuring headland longevity - albeit retreating over time.

The final photo (2C) is taken on the southeastern side of the headland (chainage 250 m) and shows recent collapse of the mid-face onto the beach. Such failure is typically associated loss of support at the base. Such debris at the cliff base provides temporary protection until removed by wave action.

A.

B.

C.

Figure 2 Geological features photographed on 26 July, 2019. Photo A shows the sandstone basal strata overlain by a debris slope and volcanic deposits above. Photo B shows the headland cliff: well vegetated and a lens of boulders exposed in the upper face. Photo C is taken just beyond (southeast) the headland and shows recent earth slip and associated debris at the base which is being truncated (eroded) by wave action.

The lack of vegetation on the cliff face immediately southeast of the headland indicate greater erosion potential; although vegetation cover then increases toward another headland about 1 km beyond the Johnston's southeastern boundary.

Thick volcanic ash mantles the upper cliff, and low sand dunes (1 to 3 m high) form a natural hummocky surface immediately landward of the cliff-top.

A gravel delta fronts the rivermouth – protruding seaward some 150 m. A gravel-sand beach up to 40 m wide (MSL to cliff base) fronts the Johnston property. Sand is largely absent across the lower intertidal beach which is about 60 m wide. However, satellite imagery (8 samples from 2001) show considerable variation can occur in beach width and form (morphology). Indeed, by way of example, toward the southeastern end of the Johnston property the lower beach was absent at the time of the drone survey (Figure 1, lower right).

The boulder field fronting the headland cliff extends at least 300 m seaward as evidenced by wave pattens in satellite images. This reef protects the cliff base by causing waves to break further offshore thereby dissipating energy.

The Kaupokanui Coast has particularly high energy (wind, waves and currents) which approach from the westerly-quarter. This results in a net northwest to southeast longshore current and sediment transport.   Study from the Opunaki area (Gregory, 1982) indicate 30,000 to 60,000 m^3 of sand is transported southward annually with river input exceeding that of cliff erosion. The headland and reef extension act as a groyne to this longshore stream of sediment, both trapping it on its updrift (northwestern) side or deflecting it seaward around the headland reef and then dispersing it southeastward where it eventually rejoins the beach (see annotation in Figure 1). The coast immediately downdrift of such a littoral barrier can typically be starved of sediment and thus be more prone to erosion – a situation that appears to occur at this site.

The above geomorphological description indicates relative stability northwest and fronting the headland, and increased instability (erosion) to the southeast. This is further investigated and quantified via a shoreline analysis carried out in Section 3.3.

3.0 EROSION HAZARD ASSESSMENT COMPONENTS

3.1 Background

The erosion hazard assessment process involves computing three components: (1) slope stability, (2) long-term historical shoreline retreat, and (3) erosion from projected future sea-level rise. These components are described below and are combined as follows to generate current (2020) and future (50 year/2070 and 100 year/2120) hazard lines.

CEHD_current = SS *eq 1*

CEHD_future = SS + LT + RSLR *eq 2*

Where:
CEHD = **C**oastal **E**rosion **H**azard **D**istance inland from the current shoreline (cliff-base in this case);
SS = **S**table **S**lope distance;
LT = **L**ong-**T**erm shoreline erosion distance;
RSLR= **R**etreat caused by **S**ea-**L**evel **R**ise.

LT and RSLR are time-dependent and computed by multiplying the time period of interest (in years) by the annual rate of change for each parameter.

For new development, *hazard avoidance* is a requirement of the official guidance (NZCPS (2010), Policy 25) so a low likelihood of occurrence is used when determining the erosion hazard. In particular, Policy 25 uses the term "potential erosion" and this is interpreted by hazard practitioners to be "very unlikely" (Shand et al., 2015) which has a probability of occurrence of 5 % (MFE, 2008). Probabilities less than 1% are defined as exceptionally unlikely.

But each component has its own likelihood of occurrence suite, so at what level should they be to give the combined (CEHD) of 5%? As the three hazard components are essentially independent a "probabilistic" computation routine is required to determine the actual probability for the output (CEHD) hazard distance; such procedures are described in Shand et al. (2015). As a probabilistic approach is time consuming and expensive, in the first instance, high values are determined for all three components thus ensuring the combination produces a so called "worst case" scenario, i.e. the CEHD is less than 1%. If the proposed development is landward of this extreme location, then there is no need to apply the probabilistic technique to identify the actual 5% likelihood of occurrence value.

3.2 Slope stability (SS)

Where a cliff is composed of a single type of material, following an episode of cliff collapse the typically over-steepened scarp subsequently reduces in slope until a single stable angle is achieved; the cliff-top thus retreats landward. However, complex cliffs, such as at Kaupokanui, are made up of multiple strata making theoretical modelling to define a stable slope difficult and potentially unreliable. Consequently, a practical field-based approach measures the slope on vegetated cliff-faces as the vegetation can only exist/survive if the cliff-face attains stability. Such an approach requires comprehensive topographic data and the recent drone survey has provide such information. The horizontal distance from the cliff base (the 4 m contour in this case) to the top of the stable (vegetated) slope thus defines SS which can be calculated using equation 3.

$$SS = h_C/\tan\alpha \qquad eq\ 3$$

Where h_C = height of the in metres and α = the representative stable slope angle in degrees

Vegetated slopes were identified in the northwestern sector at chainage 25, 110 and 130 m. No fully vegetated sites were evident in the Johnston's southeastern sector. However, drone coverage extended a further 350 m and vegetated slopes were identified at 660 m, 720 m and 775 m. From the 3D digital elevation model, profiles were extracted for these 6 locations and overall slope angles determined for each site; these ranged between 46 and 56 degrees. As the lower angle results in greater (conservative) landward adjustment, an α value of 46 degrees was selected for deriving SS.

Slope stability distances were subsequently derived every 12.5 m alongshore between chainage 100 and 275 m (15 sites in total) which adequately covers the area of interest. An example is shown in Figure 3. SS values ranged between 34.9 m and 39.8 m and all values are listed later in Table 5, along with the hazard results (SS values are in the first (2020) column as SS is the only component relevant in defining the current hazard distance).

3.3 Historical shoreline change (LT)

The present cliff line was identified on the 2020 drone imagery; this being facilitated by use of a 3D digital elevation model overlain with the aerial photography, which enabled the cliff edge to be accurately identified. This shoreline was compared with the earliest surveyed shorelines: these being 1911 (LINZ plan DP 3007) which extends from the headland to, and beyond, the Johnston's southeastern boundary, and 1933 (LINZ plan DP 5415) which extends from the Johnston's headland to their northwestern boundary. An earlier plan (SO 44/8) from 1887 shows the clifftop along the entire property but this was discarded as the means by which the cliff-line was determined is not evident. i.e. there were no marked offsets as on the other plans, so the cliff-top location may have been estimated rather than measured.

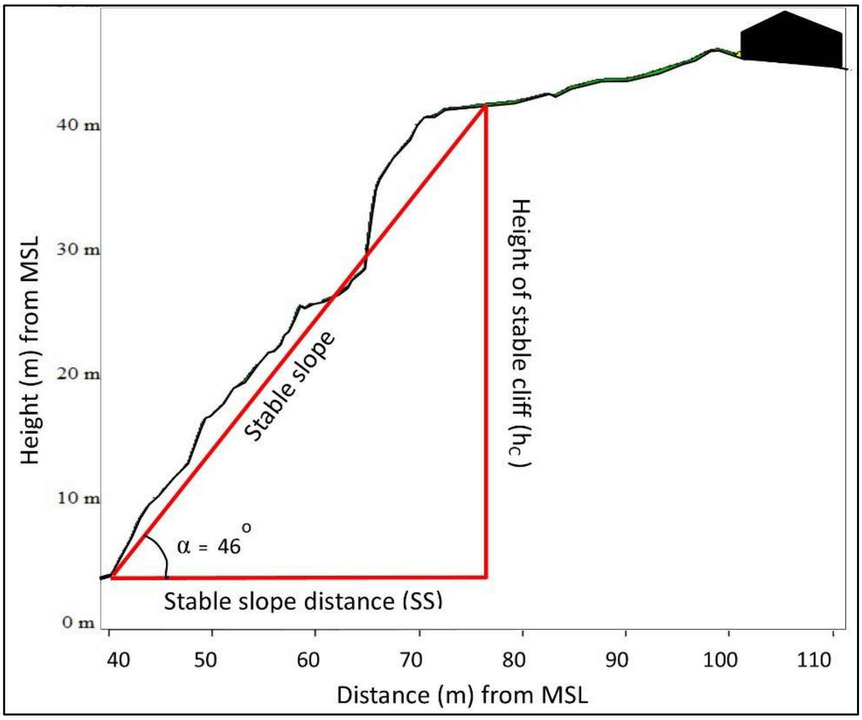

Figure 3 Cliff profile fronting the proposed building (marked). The stable slope parameters are depicted by the red lines.

While the current (2020 drone) image and the detected cliff-line may be up to ±0.5 m out, the historical surveyed shorelines are subject to several additional errors including accuracy of the original measurements and drafting (up to ±1.5 m), digitizing (up to ±0.5 m) and georeferencing (transforming to a standard orientation and scale) which could incur an error up to ±1 m. These errors terms are essentially independent, so the chance of having all high values occurring together (or all low values) is very low. Such independent variables are combined using the properties of variance addition (Larson and Karl, 1986) which can be expressed as equation 4.

$$CE = \sqrt{(E_1^{\,2} + \ldots\ldots\ldots + En^2)} \qquad eq\ 4$$

where CE = combined error (shoreward directed), E_1 = first error term, and En = n^{th} error term. In this case CE = 1.9 m, so a value of 2.0 m will be added to shoreline measurement results in this assessment.

For this investigation, the distance between the 1911 or 1933 cliff-top and the current 2020 cliff-top were measured every 25 m alongshore from the chainage datum marked in

Figure 1. Measurement excluded the westernmost 60 m of the Johnston property as the 1933 survey had measured a landward (now stable) cliff-line. The measured changes were converted to (average) yearly rates of change and these are plotted in Figure 4. Clearly a change in cliff behavior occurs at about 240 m (vertical dashed line), or at 40 m southeast of the proposed building (silhouetted on the graph).

Descriptive statistics are listed in Table 1 and show that overall the northwestern sector has a slight positive value (9 mm/yr) which relates to seaward creep of the upper cliff-face, while the southeastern sector averages 3.6 cm of erosion per year. However, it is the lower rates of change that are applied in the hazard analysis.

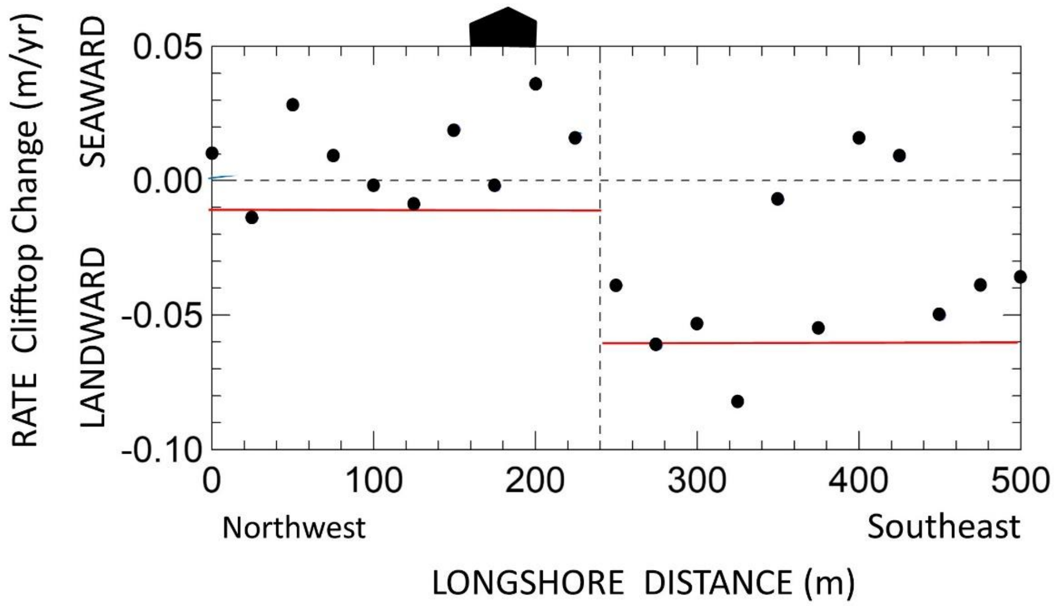

Figure 4 Rates of shoreline (cliff-top) change (m/year) along the Johnston coastline at 25 m intervals based on the chainage shown in Figure 1. The proposed building location is marked. The red lines locate conservative representative values for use in the hazard assessment to derive LT.

A rate of 0.01 will be adopted to represent the northwestern sector and 0.06 m/yr for the southeastern sector (see the bold horizontal red lines marked in Figure 4). In this case the highest erosion value was excluded because of the larger sample size. The measurement error of 2 m was also included giving rates of 0.03 and 0.08 m/yr respectively and LT values of 1.5 for 2070 and 3.0 m for 2120 for use in the hazard model (Equation 2).

Table 1 Descriptive statistics of rates of cliff-top change for the northwestern and southwestern sectors.

	Number of Samples	**Minimum (m/yr)**	**Maximum (m/yr)**	**Mean (m/yr)**
Northwestern Sector	10	-0.014	0.036	0.009
Southeastern Sector	11	-0.082	0.016	-0.036

Where negative values denote landward change (erosion) and positive values refer to seaward change (creep)

3.4 Retreat from sea-level rise (RSLR)

Sea-level rise is expected to increase retreat rates of soft to moderate strength cliffed shorelines as more wave energy is able to reach the cliff base increasing hydraulic erosion and the removal of toe-protection debris.

Sea-level rise (SLR) scenarios for the New Zealand coast are provided in MFE (2017). These guidelines define the following Representative Concentration Pathway (RCP) scenarios of future radiative forcing:

- RCP 2.6 the peak and decline in global emissions occurs soon;
- RPC 4.5 emission peak around 2050;
- RPC 8.5 no effective emissions reduction, and
- RPC 8.5H+ as for RPC 8.5 with faster polar ice sheet melt later in this century.

The RCP 8.5H+ scenario was adopted for the present assessment.

However, the associated sea-level rise (SLR) values provided in MFE (2017) must be modified for use in coastal erosion hazard assessments. In particular, these values require discounting for the 1986-2005 baseline that MFE use (0.11 m), and also to account for historical SLR (1.7 mm/y), the effect of which has already been incorporated into the historical shoreline change value. The modified SLR values are given in Table 2 with the RCP 8.5H+ values of 0.42 m to 2070 and 1.08 m to 2120 used in the hazard model (equation 2).

Table 2 Mean SLR (m) projections[1,2]

	RCP 2.6	RCP 4.5	RCP 8.5	RCP 8.5H+
2020	0	0	0	0
2070	0.16	0.20	0.28	0.42
2120	0.30	0.42	0.80	1.08

1. Adjusted to 2020 as MFE (2017) guidance values are based on 1996 (1986 to 2005).
2. Subtracts historic rate of 1.7 mm/year to avoid double-counting erosion from SLR already incorporated within the historically-based LT values.

Recession rates of sea cliffs are controlled by the geological composition of the cliffs and the configuration of the fronting beach as well as other lesser influences. The computation method currently used for predicting cliff erosion from SLR is explained in Shand et al. (2013) and expressed by equation 5.

$$R_2 = R_1\left(\frac{S_2}{S_1}\right)^m \qquad \text{eq 5}$$

Where R_2 is the future rate of retreat (incorporating LT and RSLR), R_1 is the current rate of retreat, S_2 is the future rate of sea-level rise, S_1 is the past rate of sea level rise, and m is a feedback coefficient determined by the response system.

In the T&T (2018) district-wide erosion hazard assessment of the central and northern Taranaki Coast, a negative feedback of m=0.25 was used for papa (mudstone/siltstone) cliffs and m=0.5 for the softer laha cliffs. A value of m=0.5 will be used in the present assessment. However, this is a conservative value as the basal sandstone strata are more resistant than tephra so a somewhat lesser m value (and consequently a lesser RSLR value) could be justified.

Both LT and RSLR are incorporated into equation 5, so the RSLR term on its own is expressed by equation 6

$$RSLR = (R_2 * T) - LT \qquad (6)$$

Where:
T is the prediction period in years.

Applying the various parameter values selected above to equations 5 and 6, gives RSLR to 2070 = 1.0 m and to 2120 = 4.6 m for the northwestern sector. For the southeastern sector RSLR to 2070 = 4.9 m and to 2120 = 14 m.

4 Erosion hazard results and discussion

Hazard distances computed using equations 1 and 2 and measured from the cliff base (4 m contour) are listed in Table 3. CEHDs were determined for 15 transects equally spaced between chainage 100 and 275, this length being selected as is adequately brackets the area of interest for the proposed building platform located between 160 to 200 m. Note that both the 50 and 100 year values increase at chainage 237.5, this corresponding to the shoreline change sectors defined in Section 3.3. The corresponding erosion hazard lines are plotted in Figure 5. Note that these lines have been slightly smoothed to better fit the intervening topography.

Of particular significance is a new slump scar fronting the northwestern side of the building site (marked in Figure 5). This feature was identified in the 3D digital elevation model with aerial photo overlay. Of further note, the current cliff-line at this location is seaward of the 1933 cliff-line; this being evidence that a mass failure is underway. The slump scar is seaward the current hazard line giving confidence in the method used to estimate the slope stability component – the component that makes the largest contribution to the CEHD output.

Table 3 Coastal erosion hazard distances (CEHDs) in the vicinity of the proposed building for different prediction periods. Bolden values front the proposed building platform.

	Coastal erosion hazard distances (m)		
Chainage (m)	Current (2020)	50 yrs (2070	100 yrs (2120)
100.0	39.2	42.6	46.8
112.5	39.1	42.5	46.7
125.0	38.6	42.0	46.2
137.5	35.5	38.9	43.1
150.0	34.9	38.3	42.5
162.5	**36.3**	**39.7**	**43.9**
175.0	**36.8**	**40.2**	**44.4**
187.5	**38.1**	**41.5**	**45.7**
200.0	**38.0**	**41.4**	**45.6**
212.5	38.3	41.7	45.9
225.0	38.1	41.5	45.7
237.5	39.3	48.2	61.3
250.0	39.0	48.7	61.8
262.5	39.6	48.5	61.6
275.0	39.0	47.9	61.0

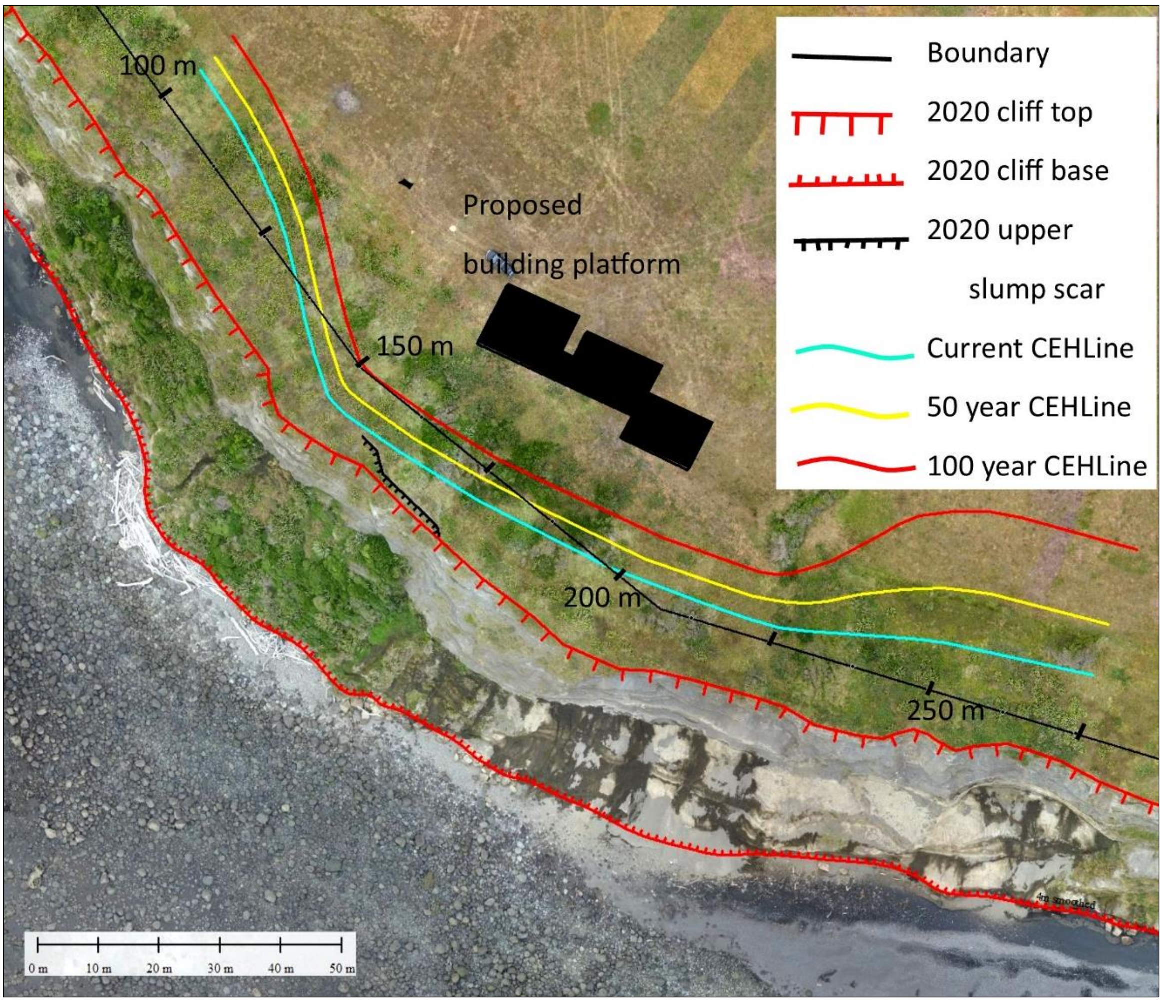

Figure 5 Coastal erosion hazard lines (CEHLines) for 2020, 2070 and 2120 in the vicinity of the proposed building platform. The present cliff is defined along with an upper slump scar indicative of cliff collapse in the future (see text for discussion).

Separation distances between the frontage of the proposed building, the Johnston's seaward boundary, the present clifftop and the hazard lines are listed in Table 4. On the northwestern side of the building, the clifftop could recede up to 12.8 m by 2120, be just landward of the boundary (0.5 m), and 14.5 m from the building frontage By comparison, on the southeastern side of the building, the clifftop could recede up to 21.7 m by 2120, be 7.7 m landward of the boundary, and 12.8 m from the building frontage.

Table 4 Seaward distances from the proposed building frontage to key features and hazard lines.

	Northwestern side (m)	Southeastern side (m)
Boundary	15.0	20.5
Present clifftop	27.3	34.5
Current (2020) hazard line	22.0	20.3
50 year (2070) hazard lines	18.5	17.1
100 year (2120) hazard line	14.5	12.8

5 Conclusions

The erosion processes identified in this assessment are likely to continue into the future as predicated when determining the LT and SS components. In addition, the slump scar opposite the northwestern end of the proposed building platform, which is indicative of potential collapse, is seaward of the current hazard line giving confidence to the method used to determine SS.

Climate change may enhance the erosion process and this has been well accounted for when calculating the RSLR component.

This erosion hazard analysis has been carried out essentially using a worst case scenario (extreme conditions and less than 1% likelihood of occurrence) and found the clifftop could be at most 14.5 m from the proposed building on its northwestern end and 12.8 m at its southeastern end after 100 years. As such, further computational refinement using a probabilistic approach to define the less stringent “very unlikely” location is not necessary.

The proposed building platform is not subject to any potential erosion hazard within at least a 100 year timeframe.

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