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Coastal Erosion Hazard Assessment:
4401 Mokau Road, Tongaporutu
North Taranaki

A report prepared as part of a resource consent application for Kate Middleton and Justin Post

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1.0 INTRODUCTION

This erosion hazard assessment (EHA) report was requested by Kate Middleton and Justine Post (the Clients) with the report to accompany their resource consent application to build at 4401 Mokau Road, North Taranaki (Figure 1).

The property appears to have been surplus land (~1.2 Ha) resulting from past highway realignments. Land comprising the original road reserve (highlighted) is now a restricted building area in the New Plymouth District Council's (NPDC) Proposed District Plan (PDP). The potential building area (remaining area) of some ~0.4 Ha is located on undulating elevated ground overlooking a tidal inlet with the open coast beyond subject to long-term cliff erosion.

Three buildings are planned: the main house at the northern end (rebuild), a guest house located centrally (rebuild) and a garage at the southern end (new build).

The present assessment is required as the proposed buildings lie within the NPDC (2019) Proposed District Plan's (PDP) Coastal Erosion Hazard Overlay Area, and Coastal Environment Overlay Area (landward margin is marked on Figure 1). In particular, the PDP states:

1) *The <u>Coastal Erosion Hazard Overlay Area</u>, applies to areas considered likely to be at risk of erosion over a 100 year timeframe, based on historic rates of both sea level rise and shoreline change;*
2) *The <u>Coastal Environment Overlay Area</u>, applies to areas where there is a potential risk of erosion over a 100 year timeframe, acknowledging that accelerated sea level rise resulting from worst-case global emission scenarios may occur.*

These two areas are based on the T&T (2019) District-Wide Erosion Hazard Assessment report. In particular the T&T "Future_ASCE$_1$" (Area Susceptible to Coastal Erosion) being used to define the PDP's "Coastal Erosion Hazard Overlay Area", and the T&T "Future_ASCE$_2$" being used to define the PDP's "Coastal Environment Overlay Area".

The terms of reference for this study are as follows:
-The EHA is to be based on conditions at, and in the vicinity of, the site, i.e. a site-specific assessment is required;
-The local geomorphology is be assessed as pertains to an EHA;
-A shoreline-change analysis is to be carried out based on historical and current information;
-A slope-stability analysis is to be carried out using topographic survey data;
-The erosive impact of predicted climate change is to be incorporated;
-The assessment is to be carried out for at least a 100 year prediction/planning period;
-The investigation is to follow the official guidance and directives contained in NZCPS (2010), IPCC (2014), DOC (2017) and MFE (2008 and 2017), and

- the output enables comparison with the NPDC's Proposed District Plan provisions.

Section 2 describes the local geomorphology (landform characteristics including geology and formative processes). Section 3 describes the erosion hazard model and derives values for its components. Section 4 presents results for the current erosion and future hazard, and Section 5 sets out conclusions relating to the resource consent application.

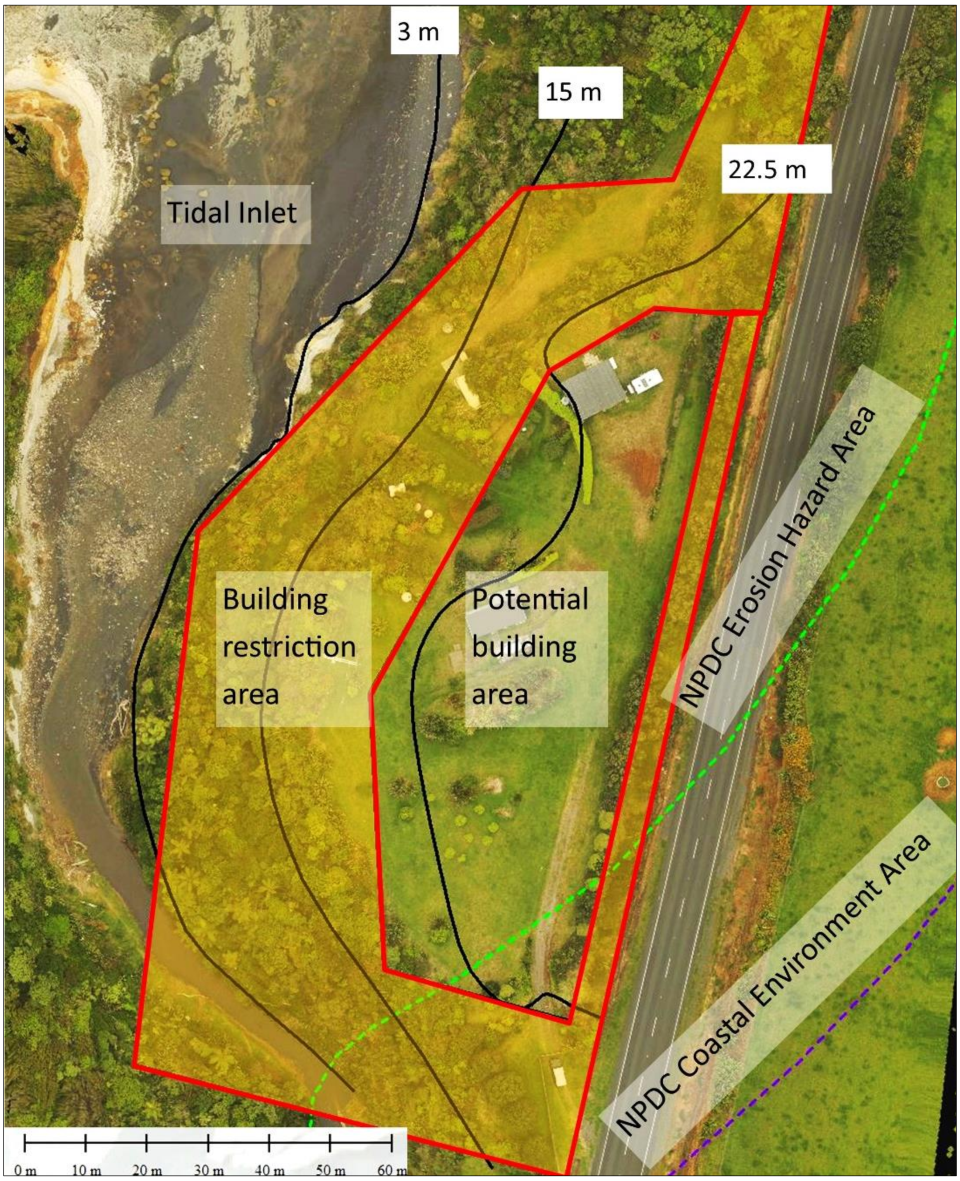

Figure 1 Location of the Middleton/Post property at 4401 Mokau Road with the build restriction area highlighted. The base image (and contours) are from a 2020 drone survey by Dave Armstrong Surveyors with elevations in metres above MSL (Taranaki Vertical Datum 1970). The NPDC Proposed District Plan erosion hazard and coastal environment overlay landward margins marked with dashed green and dashed purple lines respectively.

2. GEOMORPHOLOGICAL ASSESSMENT

Geomorphology is the study of landforms – their description, the processes responsible for their formation and how they may behave in the future based on such findings along with any expected future change to the system drivers (e.g. predicted sea-level rise from global warming). Carrying out such an assessment is an obvious pre-requisite for any project incorporating environmental change and in the case of erosion hazard assessment it is of such fundamental importance that it is a stipulated requirement in the New Zealand Coastal Policy Statement (2010), Policy 24.

This section is based on the following information sources: Edbrooke (2005); Townsend et. al. (2008); Miller (2009); Masalimova et. al. (2016); T&T (2019); an area-inspection on 26 March 2021; historical survey plans dated 1888, 1898 and 1906 acquired from LINZ; historical aerial photography dated 1945, 1964 and 2011-12 acquired from LINZ, post 2000 satellite images from Google Earth Pro, and 2020 drone-based aerial photography and contoured topography of the property from Taranaki surveyor Dave Armstrong Ltd. The 2019 regional aerial photography and LIDAR survey carried out by Landpro Ltd for the NPDC did include did not include this section of coast.

All plans and images, with the exception of 1964 and 2020 were georeferenced in-house to NZTM co-ordinates based on the 2011-12 LINZ orthophotography. The 1964 aerials are very detailed so were transformed to orthophotos (corrected for camera/lens distortion and relief) and a (3D) digital elevation model (DEM) generated by Skyview Ltd. Shoreline comparisons were made based on the seaward location of the vegetation line derived from the 1964 and 2011-12 aerial photography with more recent contributions where higher quality satellite and drone imagery were available. Unfortunately the early survey plans could not be reliably georeferenced for use in the comparison.

The property and its setting within the wider environment is depicted in Figure 2. The site is located at the back of a tidal inlet which has two separate entrances – one upcoast and one to seaward (see Figure 3, photo A), which result in an island at high tide upon which Te Kawau Pa is located. The inlet is terrestrially fed by the Kuwhatahi Stream which has been realigned immediately upstream of the property for past highway reconstructions (see Figure 7). The extent of wave penetration within the inlet, based on observed sediment distribution and bank effects, is marked on Figure 2 (dotted white line).

To describe shoreline behaviour, the inlet and open coast have been divided into 8 sectors based on geophysical characteristics and their descriptive statistics are included in Figure 2. All sectors are erosional with the open coast range of representative (median) rates being approximately twice that of those within the inlet (0.054 to 0.092 m/yr c.f. 0.024 to 0.058 m/yr.

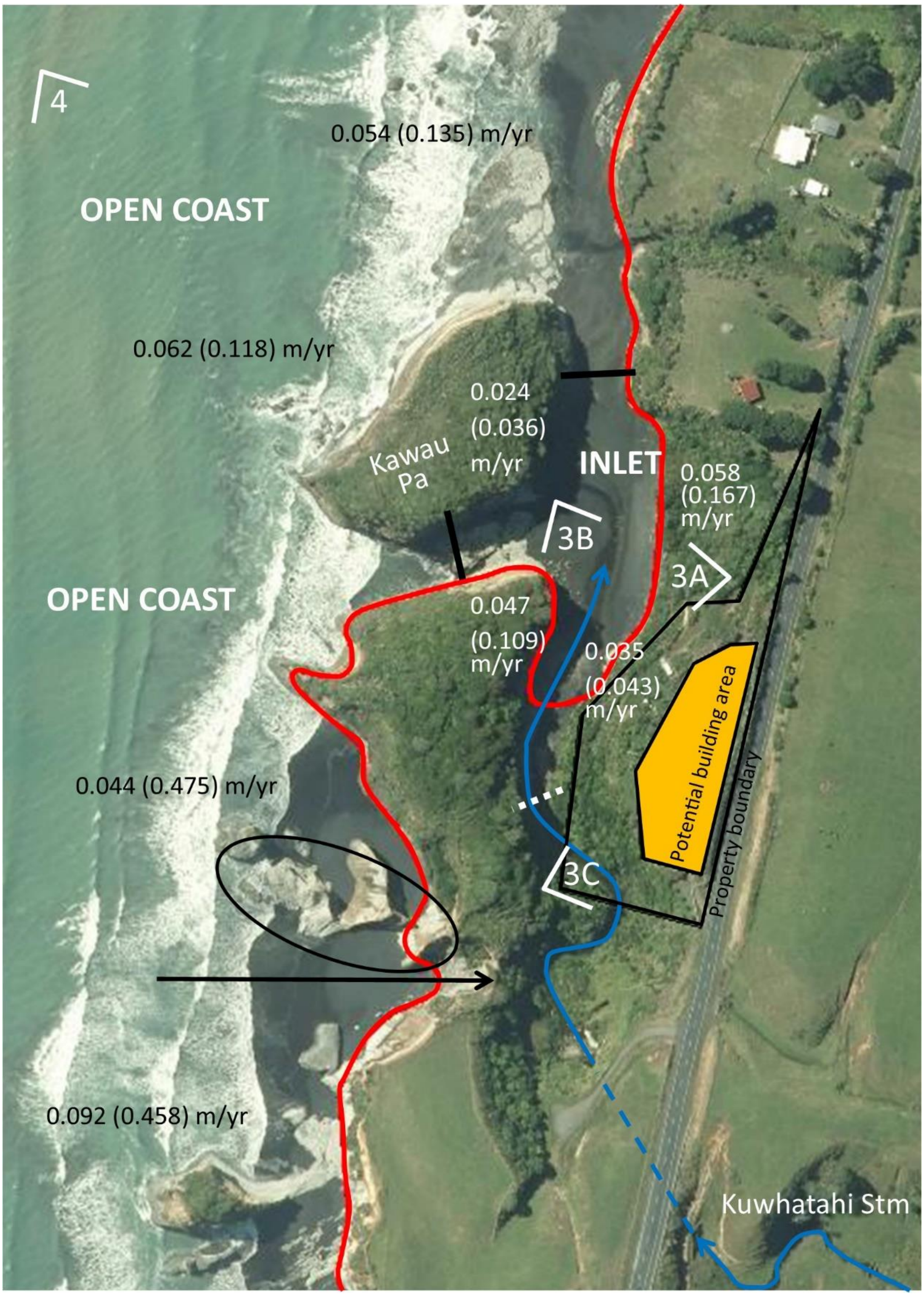

Figure 2 Features of the wider environment described in the text are shown, along with representative (median) shoreline change statistics (maximum rate bracketed), and photo locations (Figure 3 and 4). The continuous red line is the shoreline (cliff base) used in the T&T 2019 district wide erosion hazard assessment. The base image is 2011-12. The black ellipse locates a headland in an advanced state of decay and the black arrow locates a "saddle" with potential for a future break-through – these processes are described below and implications for the hazard assessment are discussed in Section 4.

The shoreline change rates within the inlet infer variation in wave exposure with highest rates opposite and adjacent to the seaward entrance (@ and * in Figure 3A), although the latter appears to be associated with the upper strata erosion. The lowest values are in the lee of Kawau Pa (# Figure 3A) and in the mud and siltstone cliff fronting the property (Figure 3B). Most wave energy must therefore enter the inlet via the seaward entrance, a conclusion also supported by the exposed mudstone base within the entrance (& in Figure 3A). Further upstream and beyond the effects of wave penetration, the bank fronting the property is entirely vegetated and stable (Figure 3C).

The open coast rates show a broad increase from north to south and this is associated with the effect of local "hot spots" where very high rates result in dramatic landforms (see Figure 4) and unique processes that are described below. The highest sector rates of 0.458 to 0.475 m/yr approach the (intentionally conservative) value used in the T&T (2019) districtwide assessment of 0.55 m/yr.

The floor of the inlet consists of a veneer of beach sand over a mudstone base and comparison of available aerial and satellite imagery indicates the sand supply to the inlet, and hence the extent of the veneer, can vary considerably.

The inlet side walls are steep and rise to about 20 m above the mean high water spring line (MHWS). On the inland side of the inlet the side wall is mostly vegetated which is indicative of relative stability. However, closer to the inlet entrances they become less stable with areas of current/recent slippage evident especially within the upper sandstone strata and cover beds (Figure 3A).

This geomorphology is the result of coastal agents (waves, tides etc) interacting with complex geology that will now be described. The site lies within the Lower Mt Messenger Formation which comprises up to 650 m (thick) of fine to very fine grained sandstone interbedded with mudstone and siltstone that was deposited during the Miocene Epoch some 11 million years ago. Massive and particularly resistant mudstone and overlying sandstone outcrop along the base of the coastal cliffs. The formation is overlain by the younger Upper Mt Messenger Formation and then the Urenui Formation. The cliffs fronting the site have thus undergone greater compaction and theoretically are more resistant than the overlying strata (which outcrop along the coast to the south). However, the site materials are part of the Otukehu group which were mass transported into their current position and consequently are characterised by fractures and faulting; this results in alongshore variation in weathering and wave resistance. Indeed, such faulting and fractures are both evident and inferred in the vicinity of the site by reorientation of bedding planes and the dramatic/nonuniform three-dimensional landforms clearly depicted in Figure 4.

Figure 3 Inlet sub-environments described in the text. Photo orientations are marked in Figure 2. Photo A was supplied by the Client.

Sea cliffs comprising horizontally-bedded rock of medium hardness coupled with jointing or fault zones – such as occur on this section of the Mokau-Tongaporutu coast, offer medium resistance to abrasion and attrition along the lines of weakness. These cracks expand into caves and bay/headland topography may occur. Where caves wear through a headland an arch may form which in time will collapse leaving a pillar or stack. This in turn is worn away to leave a stump and eventually a rock platform. Such a dramatic landform evolution sequence (and localised high erosion rate of 0.475 m/yr) has occurred within the ellipse marked in Figure 2.

Figure 4 The open coast fronting the Middleton/Post property and the inlet. Caves, stacks and intertidal rock platforms attest to ongoing sequential and cyclic landscape change.
Photo: Taranaki Regional Council, 2012.

The Miocene marine strata are capped with several meters of terrestrial sediment including volcanic ash (tephra), wind-blown dust (loess) and sand, lignite and soils; these deposits are referred to as cover beds and are visible as the uppermost sediment in Figure 3A. Local drainage, to some extent is also likely aligned with fractures and faults, has helped result in the undulatory surface in the vicinity of the building area with the applicant's geotech investigation showing the top 2 metres consists of soft sandy silt with some clay.

3.0 EROSION HAZARD ASSESSMENT COMPONENTS

3.1 Background

An erosion hazard assessment for a cliffed coast involves computing three components: (1) shoreline (cliff) adjustment to achieve a stable slope, (2) long-term historical shoreline retreat, and (3) additional erosion resulting from projected future sea-level rise. These components are described below and are combined to generate the erosion hazard distances (EHDs) defined by equations 1 to 3: the current hazard distance (EHD_Current); the future (at least 100 years is required in the NZCPS, 2010) hazard distance based on a continuance of historical erosion (EHD_Future1), and the future hazard distance that also includes the effect of projected sea-level rise from predicted climate change (EHD_Future 2).

EHD_Current = SS *eq 1*

EHD_Future1 = SS + LT *eq 2*

EHD_Future2 = SS + LT + RSLR *eq 3*

Where:
SS = **S**table **S**lope retreat distance;
LT = **L**ong-**T**erm shoreline erosion distance;
RSLR= **R**etreat caused by **S**ea-**L**evel **R**ise.

The NPDC's PDP Erosion Hazard and Coastal Environment overlay areas are defined in terms of the T&T (2019) Areas Susceptible to Coastal Erosion (ASCE), and directly relate to the hazard distances defined above in that they (equations 1 to 3) define the landward margin of these areas. So the landward margin of the T&T (2019) Current_ASCE is as computed using equation 1 for EHD_Current. And likewise T&T's Future_ASCE1 (NPDC 2019 Proposed District Plan's Coastal Erosion Hazard Area) is as computed using equation 2 for EHD_Future1, and T&Ts Future_ASCE2 (NPDC's Coastal Environment Area) is as computed using equation 3 for EHD_Future2.

LT and RSLR are time-dependent and computed by multiplying the time period of interest by the annual rate of change for each parameter. For the present exercise the planning horizon is 2130.

The NPDC's PDP refers to the Coastal Erosion Hazard Area as an area likely to be at risk of erosion, while the Coastal Environment Area as an area potentially at risk of erosion. Likely is defined in MFE (2008) as having a 66 to 90% probability of occurrence so the more conservative bound (66%) is used in hazard assessment. The term "potential erosion" is interpreted by hazard practitioners as being "very unlikely" (Shand et al., 2015), with a probability of occurrence of 5 % (MFE, 2008).

Uncertainty is inherent when assigning individual component values due to an imprecise understanding of coastal processes/change, and also due to alongshore variability. Each component can thus have its own likelihood range, so selecting values such that the output has a predetermined likelihood is extremely difficult and invariably leads to over-estimation of the hazard likelihood. By contrast, a "probabilistic" computation routine has recently been developed (Shand et al., 2015) to address these difficulties and at the present time this is industry best practice.

Briefly, the range and central value for each parameter are determined from historical, collected or modelled data and a probability distribution then generated (for each parameter). Random combinations of parameter values from these distributions are next carried out and applied to the hazard model. This is repeated 10,000 times and from the resulting distribution of hazard distances all probabilities of exceedance (likelihoods of occurrence) are derived.

Because of the property's topographic variation, measurements were made for 10 transects arranged at approximate right angles to the shoreline and extending up to the building area (Figure 6). It is also noted that the 3 m contour was found to approximate the cliff base so this was used for topographic and hazard distance measurements.

3.2 Slope stability retreat distance (SS)

Cliff erosion occurs when storm waves are able to remove material at the base and the unsupported material above collapses leaving an oversteepened cliff. The slope is then reduced by subsequent avalanching and slumping and if the base remains protected by debris, or by a shorter-term influx of sediment, a stable slope may be achieved. The rate of adjustment depends on a range of factors such as geological type, weathering profile, local bedding and faulting characteristics, and groundwater. To achieve this stable slope, the clifftop has to retreat landward, and when assessing the Current hazard the potential retreat distance (SS) is calculated from the base of the cliff as illustrated in Figure 5. When time- dependent components are also involved (equations 2 and 3), the slope-stability component is applied last (landwardmost).

Where a cliff is composed of a single type of material, a single stable angle can be determined to define the cliff-top retreat. However, more complex cliffs comprise multiple strata or formations as well as terrestrial cover beds and identification of a stable angle for each layer is difficult and potentially unreliable. A practical field-based approach measures the slope on vegetated cliff-faces as the vegetation can only exist/survive if the cliff-face has attained a basic level of stability.

Because the cliff (inlet side-wall at the site) is well vegetated, but topographically varied due to early road construction, all transect angles were considered when determining the parameter values. After inclusion of measurement error a minimum stable angle of 39 degrees was selected for use at all transects, along with a maximum value of 50 degrees and a central value of 46.5 degrees.

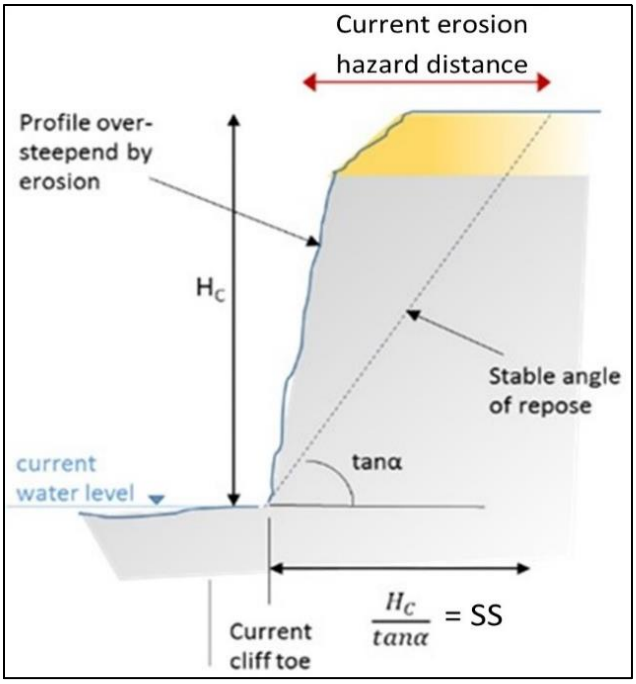

Figure 5 Definition sketch for determining the slope stability (SS) component in an erosion hazard assessment for a cliffed coast. In this case SS defines the current erosion hazard distance. However, when future assessments are made the slope-stability component is applied last (landwardmost), unless the surface is flat in which case Hc is constant so SS will also be constant. Modified from T&T 2019

The stable slope retreat distance (SS) is calculated for each using equation 4.

$$SS = H_C/\tan\alpha \qquad \text{eq 4}$$

Where H_C = height of the cliff in metres and α = the representative stable slope angle in degrees.

The results, in terms of cliff height upper and lower bounds and a central value for the current and future scenarios are listed in Table 1 for the 3 hazard models. The variation reflects topographic variation at the site.

Table 1 Cliff height (Hc) values for lower, central and upper slope stability angles, for use in the three EHD models (equations 1 to 3)

Model	Transect	Timing	Cliff height (m)		
			Lower	Central	Upper
Present	1	2021	8.5	11.4	13.2
Present	2	2021	11.9	12.1	12.3
Present	3	2021	11.5	11.9	12.1
Present	4	2021	11.2	11.5	11.8
Present	5	2021	10.1	10.3	10.9
Present	6	2021	8.9	9.4	10
Present	8	2021	4.5	6.1	7.7
Present	10	2021	7.7	8.1	8.6
Future 1	1	2130	12.9	13	13.1
Future 1	2	2130	12.3	15.3	18.7
Future 1	3	2130	11.6	12	13.9
Future 1	4	2130	10.8	11	11.5
Future 1	5	2130	16.1	16.2	16.4
Future 1	6	2130	9.5	14.5	17.6
Future 1	8	2130	8.1	8.3	8.4
Future 1	10	2130	8.6	13.9	19
Future 2	1	2130	11.8	12.1	12.5
Future 2	2	2130	13.3	16	17.6
Future 2	3	2130	11	13	14.3
Future 2	4	2130	10.7	10.8	11.4
Future 2	5	2130	15.2	15.3	15.5
Future 2	6	2130	16.5	16.6	16.7
Future 2	8	2130	7.2	12	16.9
Future 2	10	2130	8	13	17.8

3.3 Historical shoreline change (LT)

The shoreline can be defined using a range of indicators, with that chosen in any particular situation depending upon physical characteristics of the coast and the available data. For cliffed coasts the cliff top or the cliff base is typically used as this is identified on early survey plans and often identifiable on historical aerial photography. However, the vegetation line may also be used and for the present exercise this was found to be the most reliable indicator.

The cliff and its vegetation fronting the property are depicted in Figure 3B. Shoreline change based on the 1964 and 2020 georeferenced photography was found to range between 1.4 and 2.4 m with a central value of 2.0 m. To these (independent) values was added the error estimates which included photogrammetric, measurement and indicator identification and ranged between 1 and 2.3 m with a central value of 1.2 m. Adjusting for the 56 year measurement period gave the following rates for use in the probabilistic erosion hazard model: lower bound = 0.018 m/yr, central = 0.057 m/yr, and upper bound = 0.084 m/yr.

Ocean waves are not able to affect the shoreline for the most upstream transects (9 and 10) so vegetation line shoreline change was reassessed and the following values derived: lower bound = 0.0 m/yr, central = 0.031 m/yr, and upper bound = 0.063 m/yr.

3.4 Retreat from sea-level rise (RSLR)

Sea-level rise is expected to increase retreat rates of low 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 four 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.

Each pathway has separate sea-level rise (SLR) values. The T&T (2019) district-wide erosion hazard assessment computed output using all four RCP/SLR options (ASCE2_RCP26, ASCE2_RCP45, ASCE2_RCP85, ASCE2_RCP85H+). The NPDC 2019 PDC then adopted the most extreme scenario, RCP85H+, to define the Coastal Environmental. The present assessment will thus only compute the EHD for RCP 8.5H+.

The SLR value for RPC 8.5H+ as provided in MFE (2017), Table 10, is 1.52 m to 2130. However, this must be modified for use in coastal erosion hazard assessments firstly to adjust for the MFE (2017) base of 1986-2005 (0.11 m), and secondly to account for historical SLR (0.0017 m/y = 0.187 m) which is already incorporated into the LT shoreline measurements and modelling. The resulting SLR value for use in the present hazard modelling assessment is 1.22 m.

The computation method currently used for predicting cliff erosion from SLR is explained in Shand et al. (2013) and expressed by equation 5.

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

Where R_2 is the future rate of retreat (incorporating both 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 negative feedback coefficient determined by the response system.

The lower mudstone strata provides moderate resistance to hydraulic processes so a lower bound of m = 0.2 is selected, along with a central value of m = 0.3 and an upper value of m = 0.4. This is also reasonable consistent with the T&T (2019) district wide erosion assessment which used a single value of m = 0.25.

4 EROSION HAZARD RESULTS AND DISCUSSION

4.1 Modelling

Erosion hazard distance (EHD) probabilistic modelling outputs for the three scenarios (Current, Future 1 and Future 2) for critical likelihoods stipulated in the NPDC (2019) Proposed District Plan definitions of Erosion Hazard and Coastal Environment overlays are listed in Table 2 and plotted in Figure 6.

The Current erosion hazard lines 5% and 66% likelihoods) fronting the property are located between 5.6 to 13.8 m (mean 9 to 11.1 m) landward of the cliff base (3 m contour) depending on transect location and exceedance probability (likelihood). This contrasts with the current hazard line in T&T (2019) which is some 25 m landward of their cliff-base shoreline. The EHD_Current line is dependent on the slope stability adjustment which is itself dependent on the slope stability angle (angle of repose) and the cliff height. T&T (2019) used a cliff height of 21 m and slope of 40 degrees which results in the greater slope stability distance than for the lesser cliff heights (Table 1) and greater slope angle values of 39 to 50 degrees (central value = 46.5 degrees) actually measured at the site and used in the present site-specific assessment.

Table 2 Modelled erosion hazard distance (EHD) output for the difference scenarios (described in the text) and exceedance probabilities relevant to the NPDC's 2019 PDP Erosion Hazard and Coastal Environment overlays. All distances in meters with negative values being distances measured landward from the shoreline. Note colours co-ordinate with lines in Figure 6.

Model	EHD_Current	EHD_Current	EHD_Future1	EHD_Future2
Time frame	2021	2021	2130	2130
Exceedance probability	66%	5%	66%	5%
T1	-10.3	-13.1	-18.0	-27.8
T2	-11.4	-13.8	-20.1	-31.5
T3	-11.2	-13.5	-17.4	-28.5
T4	-10.8	-13.1	-16.1	-26.6
T5	-9.9	-11.9	-21.0	-31.0
T6	-8.9	-10.8	-18.5	-32.5
T7	-7.3	-9.1	-15.9	-30.6
T8	-5.6	-7.5	-13.4	-28.7
T9	-6.7	-8.4	-14.7	-26.8
T10	-7.7	-9.3	-16.0	-25.0
Max	, -5.6 to -11.4	, -7.5 to -13.8	, -13.4 to -21.1	, - 25 to -32.5
Mean	-9.0	-11.1	-17.1	-28.9

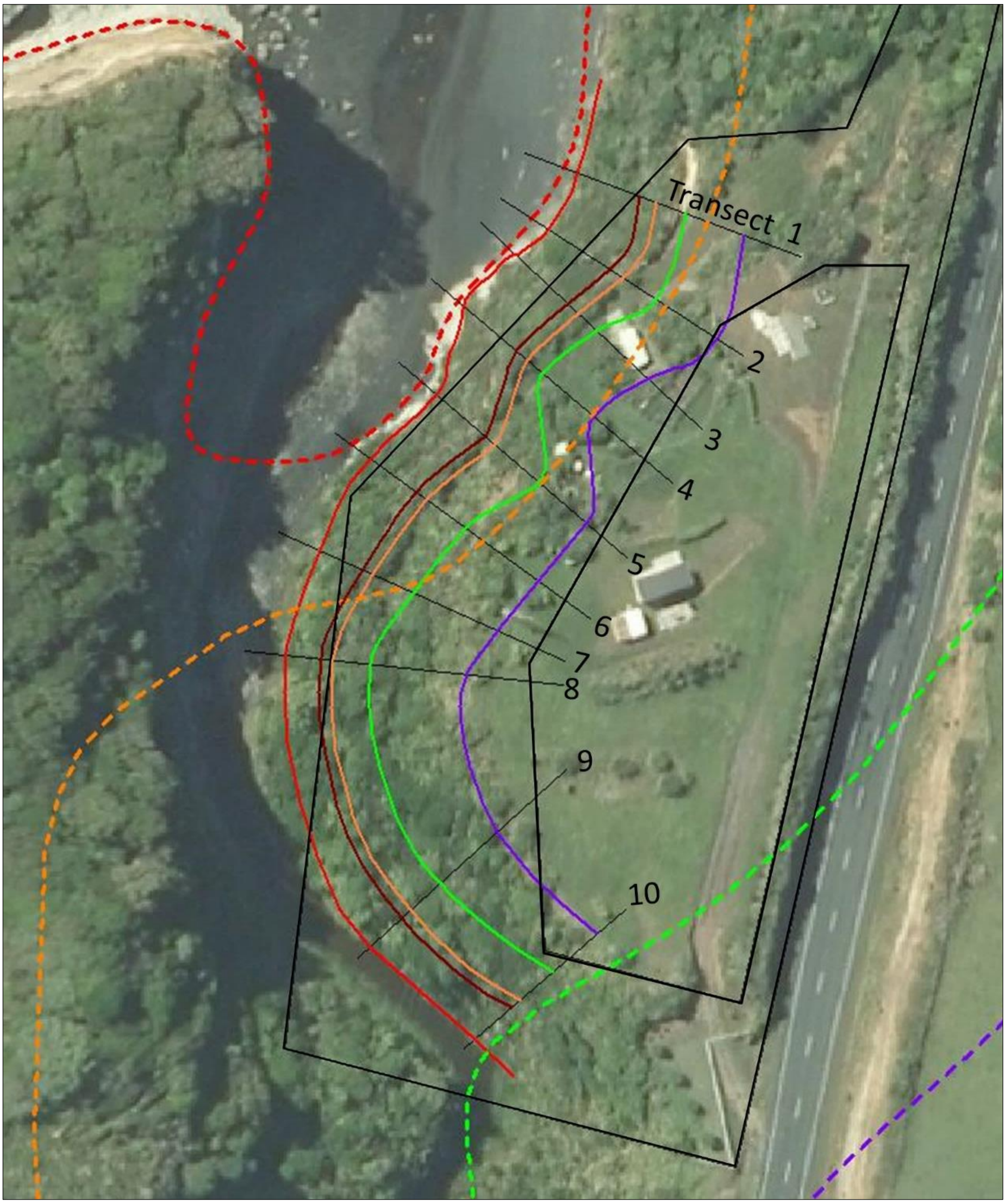

Figure 6 Modelled erosion hazard lines for critical scenarios: EHD_Current (66% probability dark brown solid line, 5% light brown solid line), EHD_Future 1 at 66% (solid green line), and EHD_Future 2 at 5% (solid purple line). The same colour dashed lines locate the equivalent T&T (2019) district wide assessment lines and NPDC Erosion Hazard and Coastal Environment Overlay Area boundaries. Solid red line is the distance measurement line used in the present assessment (3 m contour which approximates the cliff base), and the dashed red line is the measurement shoreline used in T&T (2019). The thin black lines are measurement transects used for data abstraction and output plotting in the present assessment. Property boundary and building area shown by black line enclosures.

The EHD_Future 1 (erosion hazard) line - which incorporates historical shoreline change but no additional sea-level rise, and the EHD_Future 2 (coast environment) line - which, in addition to historical chsnge, incorporates the effect of the most extreme sea-level rise scenario (RCP 8.5H+), are located 17.1 m (13.4 to 21.1 m) and 28.9 m (25 to 32.5 m) landward of the red base line respectively. The Future 2 line can be seen in Figure 6 to just reach the building area at the northern end (Transect 2) and to also encroach at the southern end (Transect 10).

As can be seen in Figure 6, these lines differ considerably with those from the PDP which were based on the T&T (2019) districtwide assessment. In particular, the erosion hazard distance is 92 m and the extreme sea-level-rise (coastal environment) distance is 136 m. The reason for these discrepancies is that both computations are heavily reliant of the LT value (based on historical shoreline change), and the districtwide assessment applied the open coast rate (0.55 m/yr) to the inlet whereas the actual measured rate at the site is 0.018 m/yr to 0.043 m/yr with a central value of 0.035 m/yr (Figure 2).

4.2 Behavioural continuance

The most important matter of just how certain can we be that past shoreline (long-term) behaviour will endure in the future must be addressed as firstly both Future 1 and Future 2 scenarios are based on the assumption of behavioural continuity, and secondly, the Geomorphological Assessment (Section 2) showed that this coast is dynamic and subject to discontinuous/episodic change.

The average open coast rates of shoreline change (Figure 2) indicate shoreline erosion over the next 100 years will, in the 4 sectors, average 5.4 m in the north, 6.2 and 4.4 in the centre, and 9.2 in the south. While the central/northern sector values may enable an increase in wave penetration into the inlet and hence an increase in erosive pressure upon the shoreline fronting the property, the geological resistance of the cliff material coupled with potential sand influxes associated with climate change (MFE, 2008) could potentially compensate for any increase in erosion potential. In addition, potential infill of the upper inlet described below would reduce future erosion.

While the maximum erosion values in the centre/north (13.5 m and 11.5 m/100 yrs) and their effects may be similarly compensated, the higher values (47 m and 45 m/100 yrs) in the two southward sectors are cause for concern. These high values are associated with the latter stages of decay of a headland located within the ellipse drawn in Figure 2, by processes described in Section 2.

Topographic change in this area is illustrated by the series of aerial photos in Figure 7. At the base of the headland, marked by an asterisk, is a narrow strip of elevated land separating the open coast from the Kuwhatahi Stream valley, i.e. a “saddle” is

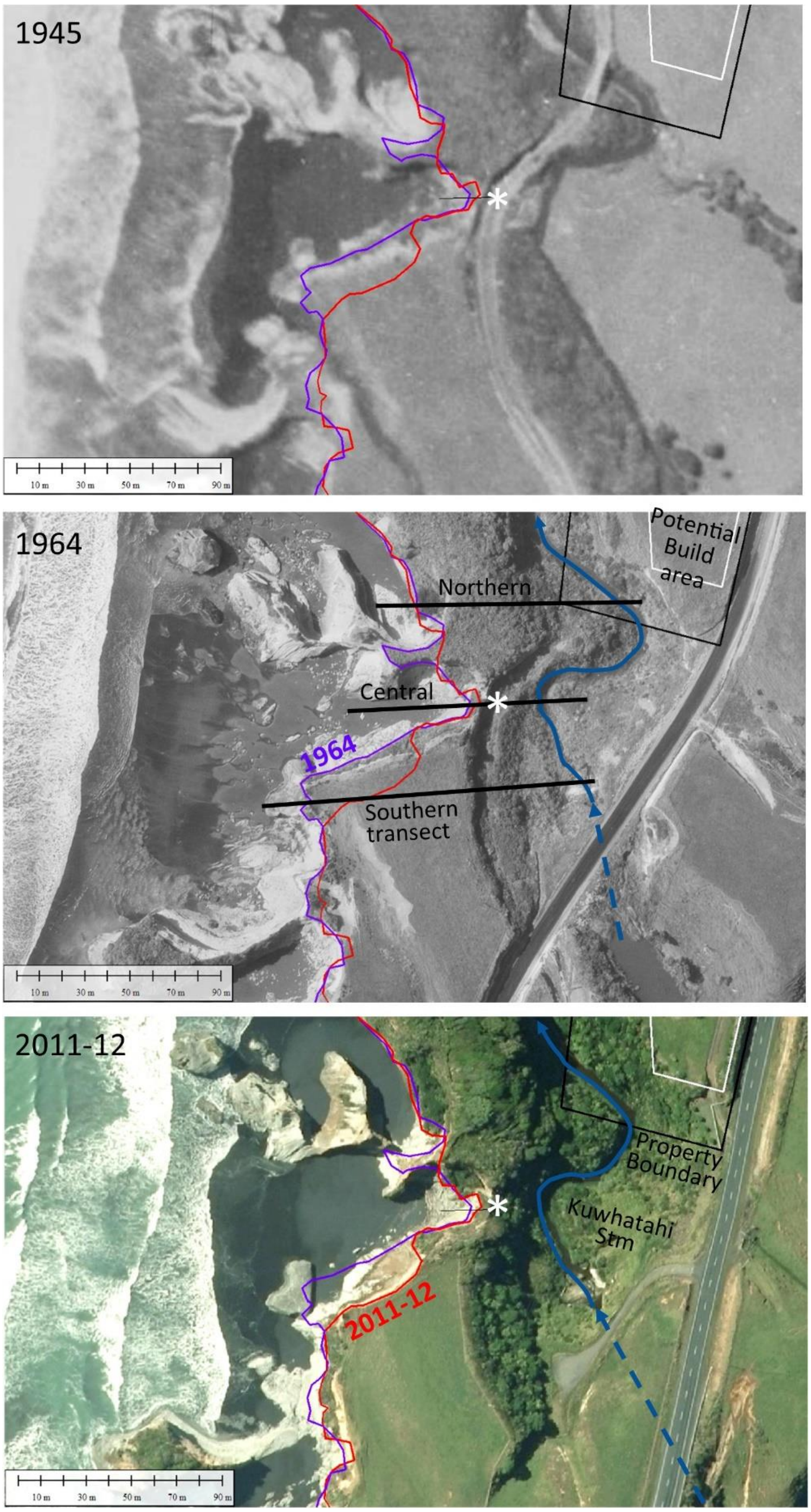

Figure 7 Potential open coast break-through location south of the property marked by asterisk (NB arrow in Figure 2) referred to as the "saddle". Coastal change is illustrated by 1945, 1964 and 2011-12 aerial photos with the 1964 and 2011-12 vegetation-front based shorelines marked. The black lines on the 1964 photo denoted Northern, Central and Southern transects, locate the profiles shown in Figure 8.

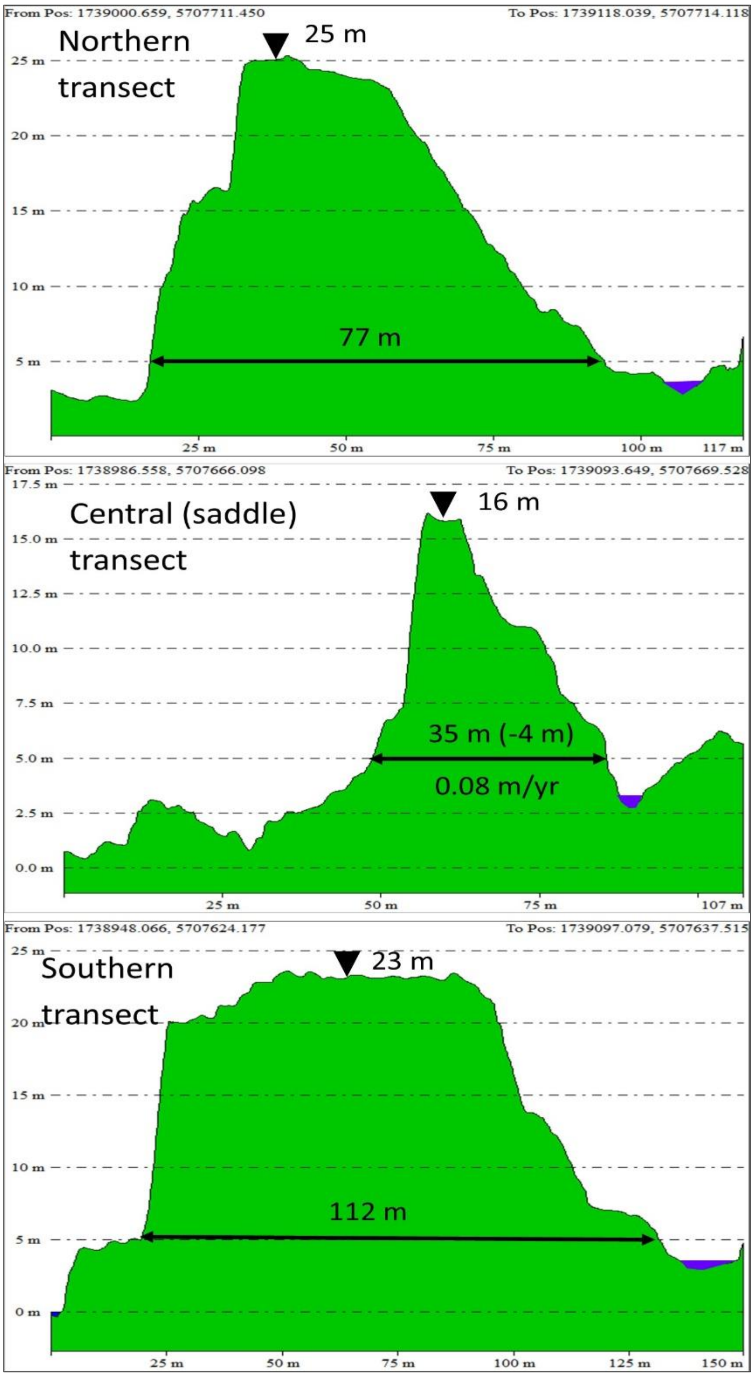

Figure 8 Profiles at transects marked on the 1964 aerial in Figure 7, define the "saddle" (central profile) and illustrate its vulnerability. The profiles are from the 1964 aerial photo DEM obtained as part of this assessment. The open coast is on the left and the Kuwhatahi stream on the right side of each graph. The 5 m elevation width is marked – this being the height when storm wave overwash and beach sand could begin to impact the stream system. The bracketed number in the saddle (central) profile is the erosion between 1964 and 2011-12 and the associated rate of change is also given.

developing. Indeed, the configuration of the stream at this location could be assisting the narrowing which is further illustrated by the series of profiles depicted in Figure 8 (their locations being shown on the 1962 aerial photograph in Figure 7).

Storm-wave overwash can be expected once the saddle elevation lowers to about 5 m (above MSL) as marked in Figure 8. At the current erosion rate (0.08 m/yr) this will take centuries. However, as the headland decay progresses, the nearby enhanced erosion (0.45 m/yr) may transfer to this area and overwash could occur within the planning period.

Once storm-wave overwash begins, beach sand will be swept into the valley; this being a one way process. With the continued influx of sand and the reducing ability the of the stream to flush, raising of the stream bed and impeded drainage are likely which in turn should reduce erosion potential along the Middleton-Post property. Eventually the stream will divert thought the lowering saddle and this will further facilitate sedimentation within the upper inlet and further increase the stability of the Middleton-Post shoreline.

In the very long term (centuries) this area may well take on a configuration like the seaward inlet channel of the present inlet and possibly join with the existing inlet to from another high-tide island. Shoreline erosion fronting the property could then become enhanced; however, that is well outside the time-scale of relevance to this assessment.

5 CONCLUSIONS

This site-specific erosion hazard analysis has been carried out using probabilistic modelling – the most accurate from of assessment available and industry best practice (MFE, 2017).

The results show the current and 100+ year erosion hazard to be considerably less than defined in T&T's (2019) district-wide assessment (as illustrated in Figure 6). This was somewhat to be expected as the T&T assessment was a high-level study applying conservative input values over wide areas of coast with the objective of red flagging areas with potentially higher risk of erosion.

This assessment found the allowable building area lies some 10.9 to 25 m landward of the EHD_Future 1 line, this being the 100^{+} year erosion hazard line which is equivalent T&T's Future ASCE1 used to define the NPDC Proposed District Plan's Coastal Erosion Hazard Area. In addition, the allowable building area is 3 to 10.5 m landward of the EHD_Future 2 line at all but two transects – these being at T2 and T10 for which the building line is 0.5 and 5.5 m seaward respectively. The EHD_Future 2 line is the 100^{+} year scenario that includes the effects of additional sea-level rise and is equivalent to T&T's Future ASCE2 which was used to define the NPDC Proposed District Plan's Coastal Environment Area.

The site's wider environment is subject to discontinuous and episodic geomorphological change which could potentially compromise the behavioural continuity assumption underlying the erosion hazard modelling. However, a detailed quantitative assessment concluded that historical change is likely to continue throughout the planning period, and under the most extreme change scenario erosion rates fronting the property could actually be reduced.

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