IN THE MATTER OF	the Resource Management Act 1991
AND	
IN THE MATTER OF	Proposed South Taranaki District Plan – Coastal Environment and Natural Features and Landscapes
FOR SUBMITTER	**Meridian Energy Limited** (Submitter 26 and Further Submitter 26)

STATEMENT OF EVIDENCE BY ROGER DUNCAN SHAND

South Taranaki District Council Hearing, 27-28 June 2016

INTRODUCTION

1. My name is Roger Duncan Shand.

2. I hold a Bachelor of Science Degree in Mathematics and Physical Geography, a Postgraduate Diploma in Geomorphology, and a PhD in coastal processes (on the southwest coast of the North Island). I have been studying, researching, teaching and working in pure and applied coastal and fluvial science for over 40 years.

3. For the past 12 years, I have been employed as a senior coastal scientist with Coastal Systems Limited (CSL), which is a research-based consultancy specialising in applied coastal research, coastal hazard assessment and coastal management. Prior to this time, I lectured in coastal geomorphology at Massey University.

4. The main part of my consultancy work has been coastal hazard research and assessment. I am particularly familiar with the general characteristics, physical science and dynamics of the coastal systems along the southwest coast of the North Island. Recent nearby projects relevant to my evidence include an 8 year coastal erosion and management study (2008-15) in the vicinity of the Patea Rivermouth for the South Taranaki District Council (STDC), and a cliff and dune hazard assessment of the Waverly Coast for Trustpower in 2012-13.

5. In this matter, I have been engaged by Meridian Energy Limited ("Meridian") to provide a cliff hazard assessment for a 16.5 km section of coast north of the Patea Rivermouth (Figure 1) which informs the definition of the Coastal Environment under the Proposed Plan. My involvement followed on from an earlier assessment of coastal erosion rates at this site by Tonkin and Taylor Ltd (T+T). The T+T report (included in my evidence as Appendix A) concluded that to accurately derive future coastal erosion hazard distances or zones, the nature of cliff instability and future sea level rise should be taken into account and a geologist should inspect the cliffs. Obtaining LIDAR (high resolution three-dimensional data which also captures aerial photography at the same time) was also recommended.

6. I confirm that I have read the 'Expert Witnesses Code of Conduct' contained in the Environment Court of New Zealand Practice Note 2014. My evidence has been prepared in compliance with that Code in the same way as I would if giving evidence in the Environment Court. In particular, unless I state otherwise, this evidence is within my sphere of expertise, unless stated otherwise the material in this evidence has been prepared by myself, and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express.

SCOPE OF EVIDENCE

7. I understand that the primary purpose of the erosion assessment is to assist in quantifying the Coastal Environment (NZCPS 2010, Policy 1) whereas the usual determinants (e.g. topography, biology and experiential) are lacking in some areas. I note that the Coastal Environment is being used to define a Coastal Protection Area (CPA) along the STDC coastline in the District Plan.

Figure 1 Location map with the red shoreline locating the 16.5 km long section of coast under review. Map complied using the NZ Topographical Map series 260-R21 and R22

8. Coastal erosion hazard assessments are typically carried out to assist in the definition of building setback lines (zones with conditions for existing and new development) with a prediction period of at least 100 years (NZCPS 2010, Policy 24) and at the *likely* level of occurrence for existing building (NZCPS 2010, Policy 27) and the *potential* level, interpreted by practitioners as *very unlikely*, (NZCPS 2010, Policy 25) for new development. For the purpose of natural character/Coastal Environment definition the relevant hazard appears to be personal safety. However, there is no guidance or directives for such an assessment in terms of prediction period or level of likelihood. CSL were instructed to carry out the assessment using a *100 year* timeframe at the *likely* level which equates to a 66% to 90% chance of occurrence or exceedance. In my opinion this is an overly conservative combination as personal safety requires a shorter time period (say 10 to 15 years based on District Plan reviews) and potential (very unlikely) level of hazard assessment.

9. In preparing my evidence I visited the site on 28th April, 2016, reviewed past erosion reports and literature relevant to this physical environment, inspected and analysed available maps, aerial photographs and satellite imagery as well as LIDAR taken 30 April this year.

10. My evidence first describes the physical conditions and controls at the site as relevant to the erosion hazard assessment. As well as describing the contemporary cliffs and erosion processes, the energy and sediment regimes are described along the underlying geology. Historical erosion, as defined in the February 2016 T+T report, is described and explained within the aforementioned physical setting (geology and geomorphology). The erosion hazard model is then applied and the coastal erosion (landward) distances defined. The mid-likely (78%) erosion hazard line is depicted in Appendix B.

Coastal orientation and elevation

11. The 16.5 km coastline faces the southwest with its alongshore alignment averaging 315 degrees (northwest). The shoreline has a broad convex shape with maximum offset = 1.14 km. This shape is evident in Figure 1 which includes 1 km graduations that will be used throughout my evidence to identify different areas of the coast. Cliff height ranges from less than 20 to over 50 m above MSL (heights from LIDAR) with the highest cliffs (e.g. Figure 2 upper photo) occurring toward the northern end of the site and the lowest cliffs (e.g. Figure 2 lower photo) in the mid/south.

Lithology (rock characteristics)

12. The site is underlain by massive siltstone deposited in the mid Pliocene (3.5 million years ago). This siltstone intersects the shoreline and reaches an elevation of 12 to 13 m above MSL. Overlying the basal siltstone are well bedded beach deposits and above these recent coverbeds of loess (wind-blown dust), volcanic ash and dune sand (see photos in Figure 2). Inspection of oblique aerial photography taken by the STDC in 2014 indicates the siltstone has a horizontal surface as do the strata above, although there may be some western dip toward the Manawapou Rivermouth. The resistance of the basal siltstone (which controls the rate of erosion) is evidenced by the lack of stream incision over thousands of years, with only the main rivers at each end of the site seemingly able to cut down through this material.

Geological Structure

13. As is typical of cliffed coasts, geological structure is an important control of physical processes. The major Taranaki Fault crosses the shoreline near the western end of the site (albeit concealed, i.e.at depth) and then takes a diagonal line to lie some 25 to 30 km seaward off Patea Rivermouth (as illustrated in Figure 3). A lesser branch of the fault is directed seaward from the Manawapou-Tangahoe rivermouths

14. The 20 m bathymetric contour (see Figure 3) is strongly influenced by these geological structures with its location varying from 14.5 km offshore from the Manawapou-Tangahoe Rivermouths, 8.5 km offshore fronting most of the site and then narrowing to 4 km off the Patea Rivermouth. This irregular bathymetry will have a significant influence on landward wave propagation and shoaling characteristics.

Figure 2 Upper photo depicts the northern cliff (km 4 to 5) approximately 40 m above MSL and displaying a relatively complex profile. The arrows locates the upper surface of the basal Pliocene massive siltstone (about 12 to 13 m above MSL) with less resistant marine and beach deposits above and capped by mobile dune sand. The lower photo depicts the lowest cliff (<20 m above MSL) located at 12 km. In this case a bluff and bay morphology occur and the cliff has a simple profile with the (arrowed) basal mudstone exposed at the bluff end.
Both photos taken by myself on 28 April 2016.

15. The 10 m contour (see Figure 3) has a more uniform plan shape but extends notably seaward in the centre-south of the site. In particular, the 10 m contour is 1.9 km (slope = 0.0053) seaward

at the northern end of the site, then increases to 2.8 km (slope significantly flatter at 0.0036) in the centre-southern of the site before reducing to 2.1 km (slope increasing to 0.0048) seaward of the Patea Rivermouth. The relative shallow/flat seabed fronting the centre-southern coast, itself possibly the product of wave changes produced by the more seaward bathymetrical variation, could induce a longshore wave energy gradient thereby reducing the relative shoreline erosion potential".

16. The axis of the Whangamomona Anticline crosses the coast in the centre of the site (Figure 3). An anticline is a fold of rock layers (strata) that slope downward on both sides of a common crest (axis) and form when compressed by internal (tectonic) forces. The axis location on the GSN geological map is approximate, but the structure is considered to be active. Smaller surface faults on each side of the axis (Figure 3) are likely associated with the compressional forces. Associated fracture and jointing within the basal massive siltstone will have occurred and these weaknesses increase the potential for wave-driven erosion.

Marine terraces

17. Uplifting along this coast averages 0.45 mm/yr, and this, coupled sea-level fluctuations of about 120 m at 100,000 year intervals has resulted in a series of marine terraces characterising the Wanganui-Hawera coast (Pillans, 1990). Note we are presently experiencing a sea-level maximum within the 100,000 yr (Ice Age) cycle.

18. The more seaward terrace surfaces have been mapped in Figure 3. The terraces fronting the coast between the Patea and Manawapou Rivers range in age between 100,000 years BP in the centre/south to 210,000 years BP at the northern end of the site. Note that south of Patea a still younger terrace (80,000 yrs) fronts the coast. The terrace configuration implies significantly greater erosion has occurred in the north over the past 6500 years (that period when sea-level has been approximately at its present level and cliff erosion has been able to occur). This is evidence supporting the bathymetrically-based alongshore variation in wave erosion potential discussed earlier. As increasing terrace age is directly related to surface height, this explains the occurrence of higher cliffs in the north.

Energy regime

19. The Patea coast experiences high levels of wind and wave energy which drive sediment transport within the nearshore/surfzone, beach (tidal), backshore (above tidal) and further inland. The mean (significant) wave height is here estimated to be 1.97 m in 30 m depth, with waves in excess of 5 m occurring <1% of the time (Gorman et al., 2003). The energy spectrum is dominated by periods of 12 second "swell" waves with a secondary set of 7 second "sea" waves, with waves approaching predominantly from west to southwest. Winds predominately occur from the west to northwest with a secondary southerly component (Wanganui airport data). Total onshore sand-moving wind energy measured by the drift potential (Freyberger, 1979) classifies Wanganui as classified as high.

20. Waves are of fundamental control of cliff erosion on this coast, not only by direct hydraulic forcing against the cliff base but also by driving littoral sediment transport which protects the cliff base from erosion and subsequently removes cliff debris thereby facilitating further erosion.

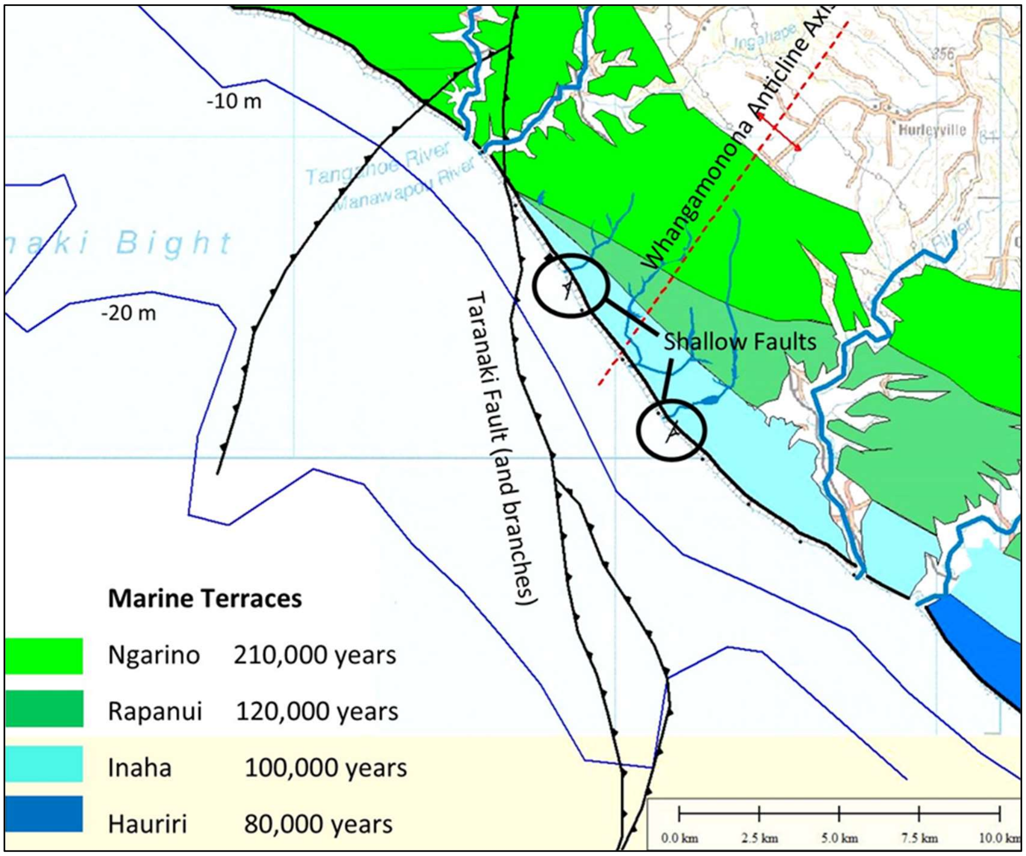

Figure 3 Geological and geomorphological features with relevance for cliff erosion in the study area. I compiled this map using materials from the NZ Topographical Map series 260-R21and R22, the New Zealand Geological Survey Miscellaneous Series Map 17 (1990) and the Institute of Geological and Nuclear Sciences Map 7 (2008). Maps were scanned, georeferenced and feature definition made using Global Mapper version 17.1

21. Water level is also an important erosion control as this dictates the level and duration the cliff base is subject to erosive forces. Water level varies across a range of timescales with key determinants consisting of tide, storm surge, wave breaking effects, mid-term controls such as ENSO (2-4 year cycle) and IPO (20 to 30 yr cycle), and longer-term variants such as solar radiation, CO_2 and geological processes. Allowance for longer-term controls are considered in the following hazard assessment section. Medium term changes cause sea-level fluctuation of up to about 0.15 m and this is largely incorporated within the Taranaki Vertical Datum 1970 (TVD-70) offset from MSL. The first three determinants effect water level regularly and are defined as follows:

- Tides (TVD-70): MSL = 0.125m, MHWN = 0.955, MHWS = 1.745 (Port Taranaki, LINZ 2012)
- Storm surge (barometric pressure and the effect of wind blowing water against the land): 12 m/s wind yields approximately 0.1 m set-up, 2 year return period = 0.31 m, 10 yr return period = 0.38 m, 100 yr return period =0.44 m (source: Bell et al., 2008)

- Wave set-up is a super-elevation of the mean water surface over normal 'still' water level due to the momentum of broken waves. An associated process is individual wave run-up at the shoreline. Run-up becomes splash when striking a wall or cliff and elevation reached depends on morphology (reefs, sandbars, platforms) and beach/offshore slope, water level at the base of the wall/cliff, wave height and period between waves. I have observed splash reaching the top of the lower cliffs on the Patea Coast.

Sediment Regime

22. Beach sediments are primarily derived from erosion of Mt Taranaki and the Ring Plain with material transported to the coast by local streams and rivers then moved south under the predominant southerly directed littoral drift (Gibb, 1978). Beach sediments comprise fine to medium iron sands and andesite cobbles. While no littoral transport studies have been undertaken for the site, calculations for New Plymouth found the net southwest to northeast rate is 110 to 160 m3/yr, and for Wanganui the net northwest to southeast rate is about 300 m3/yr (CSL, 2015). Fluctuations occur within the littoral drift supply as evidenced by recent erosion episode at Patea beach where up to 30 m of dune erosion has occurred over the past 5 years (CSL 2015).

23. LIDAR analysis demonstrates alongshore variation in beach sediment levels with cliff-base levels averaged along 1 km sectors varying between 1.2 m and 2.7 above MSL (Figure 4) with considerable within-sector variation (0.3 to 4 m). The sampling excluded bluff and bay locations where water levels fronting bluffs could reach the limit of LIDAR measurement (-1.0 m) and elevation along the bluff to bay wall and in the embayment itself was typically zero.

24. The water-level values indicate the cliff base will typically be submerged and/or within wave reach during mid to high tides with bluffs bases being submerged for much of the tidal cycle (as illustrated by the various photos included with my evidence), thus making the entire coast frequently vulnerable to wave impact erosion processes.

25. Given that this coast is already experiencing high levels of water/wave contact, the long-term effect of rising sea-levels may be less significant than on cliffed coasts currently subject to less wave and water contact.

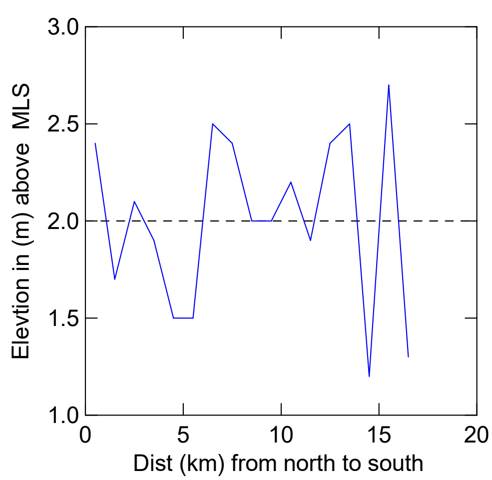

Figure 4 Elevation of beach sand against cliff base at 1 km averages based on 2016 LIDAR. Mean value is 2.0 m and there is no statistically significant alongshore trend.

Cliff erosion processes

26. The cliffs along the entire study area are active (eroding) and two mechanisms are evident.

i. The first occurs on most cliffed coasts with the base eroded by wave action and this removes support for material above which consequently slumps or slides down the face and onto the beach, platform or into the sea if neither exist. The resulting debris accumulation at the base is subsequently removed by waves and currents and the base is once more exposed to direct wave attack thereby completing the cycle (Figure 5A).

   Above the basal strata a similar process of erosion and collapse of material above occurs. Terrestrial processes weaken (weather) and remove material preferentially from less resistant formations and, as occurs at the cliff base, support is thus removed from materials above and collapse follows. As different materials succumb to different processes, complex cliff profiles can occur (Figure 2 upper photo). Furthermore, as strata beneath the dune sand capping collapses, dune erosion occurs with drifts extending along the clifftop and inland (illustrated in Figure 5B).

ii. The second mechanism of cliff erosion occurs where the basal formation comprises relatively resistant material containing fractures and joints. The process begins with wave excavation of caves which increase in size and facilitate collapse of cliff material above (as by the first process), to form a localised embayment. Adjacent bays are separated by a bluff which subsequently narrows under wave action often forming islands (stacks) that eventually disappear (Figure 5B).

   In the present study, the occurrence of most bluff and bay morphology coincide with that alongshore reach bounded by the Whangamomona Anticline and its adjacent surface faults.

Historical erosion rates

27. Historical change in cliff location was defined in the recent T+T study (Appendix A) by comparing the cliff top (edge) from survey plans (1927 to 1936) and from 2012 aerial photos. The early survey plans gave 78% cover of the site and this provides an adequately sample for defining long-term erosion. The cross-shore change was determined every 10 m alongshore and the average rate of change computed over the 76 to 85 yr inter-survey period. The T+T results here reproduced as Figure 6.

28. Upon receiving the LIDAR and aerial photographs from 30 April, the clifftop was accurately defined using a digital terrain model. However, there was no significant change from the 2012 cliff line so the rate of change analysis was not subsequently updated.

29. The earlier study by Gibb (1978) provided 4 spot erosion rates along this coast and these are marked by the red squares in Figure 6. The Gibb rates at kms 5.6 and 10.1 are in close agreement the T+T rates and it is noted that their inter-sampling periods were 53 and 77 years respectively. However, Gibb's other two erosion rates are significantly greater and were based on only a 23 year inter-sampling difference. These variations illustrate the potential error when using short-term data to infer long-term change. As discussed below,

under-sampling may also apply to the T+T study regarding the high erosion rates in the central sector.

Figure 5 Upper photo (km 13) illustrates the basic cliff recession process where waves have eroded the basal support and material above has collapsed onto the beach where it provides temporary wave protection to the cliffbase before it is removed by waves and currents. The lower photo (km 3.5 to 4) illustrates bluff and bay erosion whereby waves first excavate caves from areas with local weakness (joints), the wave action expands the caves to form bays separated by bluffs and these are subsequently reduced to island remnants (stacks) before complete disappearance. Note the eroding clifftop sand dunes - their instability initiated by cliff erosion. These photos were provided by the STDC and I understand they were taken in 2014.

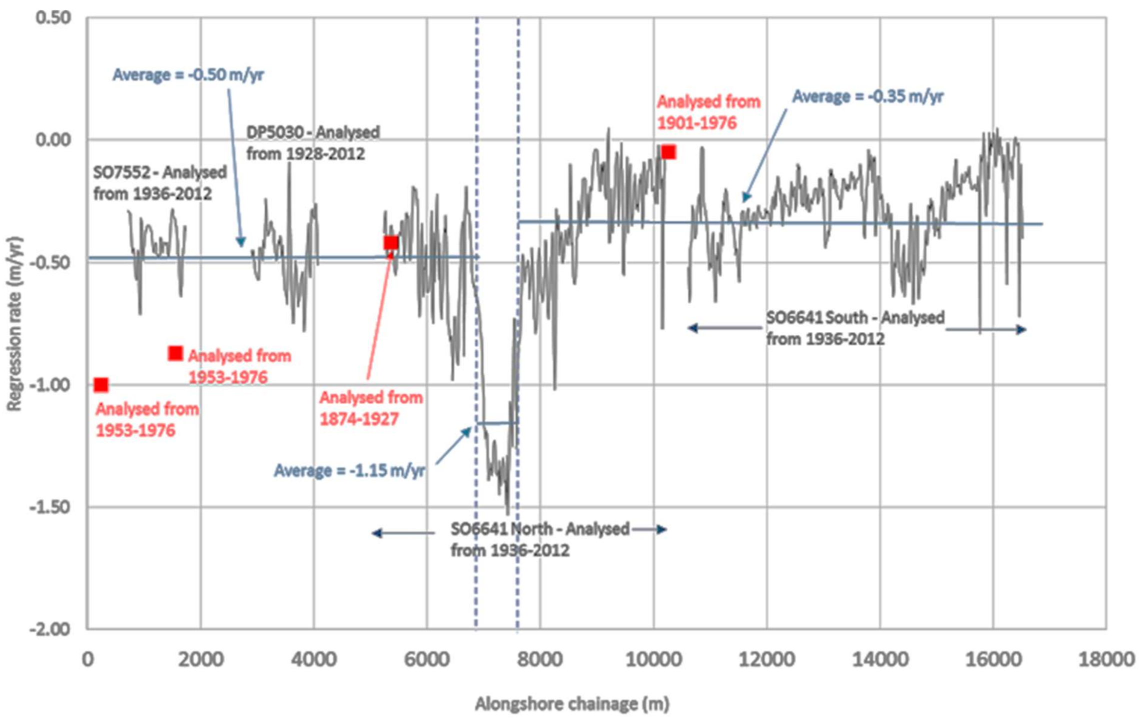

Figure 6 Calculated historic recession rates between 2012 and stipulated earlier survey years. Note the SO6641 plan was surveyed 1927 not 1936 as marked; however, the corresponding average rates were correctly calculated. The red squares relate to discrete measurements from Gibb (1978) for the stipulated time spans. This figure is reproduced from the T+T report (Appendix A).

30. The rate of change results show considerable fluctuation, typically ranging over +/-0.3 m/yr, and this was found to be associated with changeability in location of bluff and bay topography which is in keeping with the dynamical cliff erosion process described earlier. However, spatial averaging compensated for this effect and two main suites were identified by T+T and marked in Figure 6 by the straight horizontal line segments.

- 0.5 m/yr of erosion along the northern sector (0 to 6.7 km), and
- 0.35 m/yr or erosion along the southern sector (7.6 to 16.8 km).

31. Such alongshore variation in longer-term erosion is consistent with the geological and geomorphological evidence presented earlier. In particular the inferred alongshore variation in erosion potential associated with shallower offshore depths fronting the central-southern sector (which appears to be influenced by the structural geology). And the two most recent Marine Terrace configurations with the older/higher surfaces to the north demonstrating greater long-term erosion at this end and this processes has been occurring over the past 200,000 years.

32. Regarding the higher erosion rates between these two sectors, i.e. the 1.15 m/yr across the 6.7 to 7.6 km reach, his location lies close to the Whangamomona Anticline and northern side fault. As noted earlier, upward folding of the underyling stata very likely results in areas of fracture and jointing of the massive siltstone and this in turn makes the area more prone to bluff and bay development. The high erosion rates were immediately downdrift (south) of an area of very well developed bluff and bay morphology (Figure 7) which could be expected to effect

downdrift wave processes (and induced erosion) in the same way headlands and groynes effect wave processes and induce such a morphological response.

33. It is further noted that such large erosion values cannot be ongoing or a well defined and expanding embayment would characterise the coast at this location, but that does not occur.

34. It therefore appears that the anticlinal structure has pre-disposed the basal siltstone to strong bluff and bay morphology and thus to effect downdrift erosion; but the episodic nature/cycle of bluff and bay behaviour means such extreme erosion is episodic and erosion rates in keeping with those of the adjacent northern and southern sectors are more appropriate at the century time scale. As noted in paragraph 29, a longer shoreline sampling interval could have compensated for the bluff and bay cycle effect.

Erosion Hazard Assessment

35. The NZCPS, 2010 requires a risk-based approach when dealing with coastal hazards with different levels of risk (or probability of occurrence – see Table 1) applying for different uses. As noted earlier in paragraph 8, for the present situation there is no guidance/directives as to either the assessment (prediction) period or level of likelihood of hazard occurrence so CSL were instructed to carry out the assessment using a 100 year timeframe and the *likely* level of occurrence (this equates to a 66% to 90% chance of occurrence or exceedance). The central value of 78% was also required.

Figure 7 The high erosion reach (6.7 to 7.6 km) with the bluff-headland responsible for driving the erosion in the distance. I took this photograph on 28 April 2016.

Table 1 Likelihood and probability relationship for coastal erosion

Likelihood	Probability of occurrence	Can also be represented by a percentage
Virtually certain	>0.99	>99%
Very Likely	0.9 to 0.99	90 to 99%
Likely	0.66 to 0.9	66 to 90%
As likely as not	0.33 to 0.66	33 to 66%
Unlikely	0.1 to 0.33	10 to 33%
Very unlikely	0.01 to 0.1	1 to 10%
Exceptionally unlikely	<0.01	<1%

Source: MFE (2008), p55

36. Traditional methods of assessing coastal erosion hazard have typically been based on separating and evaluating discrete components (long term erosion, future erosion potential associated with climate change, slope stability and uncertainty) before summing them to produce a single (usually very conservative) erosion hazard distance.

37. The coastal erosion hazard distance (CEHD) model for cliffs was typically established from the cumulative effect of the long-term erosion of the cliff material (LT_H) derived by studying historical shoreline positions, potential increase in future long-term retreat due to projected sea-level rise (LT_F), all applied for a timeframe (T years). In addition, slope adjustment to a stable configuration (SA) following an episode of (basal) erosion, along with a Factor of Safety (FoS), typically 20 to 30%, was applied to account for uncertainties and measurement errors. This model is represented by equation 1.

$$\text{CEHD cliffs} = \{[(LT_H + LT_F) * T] + SA\} * FoS \qquad (1)$$

38. Since 2012, NIWA (2012) has been advocating the use of probability-based methods to derive the full range of hazard likelihoods and better address uncertainty. Recently (Shand et al., 2015) developed such a probabilistic approach which has been applied to the New Zealand coast in Northland and the Western Bay of Plenty and implemented by the local government; this approach will be applied in the present assessment. Briefly, the range of values each component may take, along with a modal value, are identified and subject to random sampling and combined to provide 10,000 discrete erosion hazard retreat distances. From the resulting distribution, probabilities can be derived.

39. The probabilistic method incorporates uncertainty by the selection of variable ranges making FOS unnecessary. In addition, the slope adjustment component becomes less significant in situations where the cliff-top was used to define the shoreline (the cliff-base is typically used) and where weakly consolidated upper (cover) beds occur as these are subject to more uniform adjustment compared with the episodic changes that occurs at the base. This component also minimises in situations where a long prediction period is applied to a systematically eroding coast as a stable slope configuration is unlikely to be achieved and any increase in SLR will increase the unlikelihood. The cliff erosion model thus reduces to two terms (Equation 2).

$$\text{CEHD cliffs} = (LT_H + LT_F) * T \tag{2}$$

40. Historical long-term erosion (LT_H) parameter values are based on the T+T analysis discussed earlier and input parameter values for the three sectors are listed in Table 2.

Table 2 Parameter values for the three erosion rate sectors for application in probabilistic model

		Northern (0 to 6.7 km)	Central (6.7 to 7.6 km)	Southern (7.6 to 16.6 km)
LT_H		-0.9, -0.5, -0.2 m/yr	-0.65, -1.15, -1.55 m/yr	-0.77, -0.35, 0 m/yr
LT_F				
	SLR:	3.3, 6.2, 9.1 mm/yr	3.3, 6.2, 9.1 mm/yr	3.3, 6.2, 9.1mm/yr
	m:	0.25, 0.5, 0.75	0.25, 0.5, 0.75	0.25, 0.5, 0.75

41. Deriving the retreat associated with future projection in sea-level rise (LT_F) is based on equation 3 where the coefficient m is determined by the response system ranging from no response (m=0), where hard cliff or damped response from a shore platform or beach slow the increase, to an instantaneous response (m=1) where soft cliffs and no damping occur and the rate of future recession is proportional to the increase in sea-level rise (SLR).

$$LT_F = LT_H\left(\frac{SLR_F}{SLR_H}\right)^m \tag{3}$$

42. Cliffs are broadly classified into hard and soft depending on material type, resistance, properties such as bedding plane orientation, porosity and fronting morphological features such as shore platforms, reefs or sandbars to dampen incoming wave energy. Sedimentary rock can form both hard and soft cliffs with rates of erosion ranging 0.1 to 1 m/yr (Gupta, 2011). The measured rates of 0.35 to 0.5 m/yr indicate a cliff of moderate strength with vertical face and low porosity of the basal formation coupled with horizontal bedding indicating further hardness. The hardness coefficient (m) was thus allowed to range between 0.25 and 0.75 (Table 2).

43. The historical SLR wave was taken to be 1.7 mm/year, the New Zealand average. The future sea-level values were based on RPC 6.0 (Representative Concentration Pathways [RPC] are greenhouse gas concentration trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. RCP 6 is the central scenario in which emissions peak around 2080 then decline; its SLR values range between 3.3 and 9.1 mm/year (Table 2).

44. Note that the regional uplift of 0.45 mm/yr (paragraph 17) would act to reduce the SLR erosion effect; however, this has not been taken into account because such uplift does not occur uniformly though time but episodically so may not have any effect during the prediction period. The safety margin may be further increased by the present frequency of water-level/wave action along the cliff-base which could reduce the level of future effects of climate change as discussed earlier (paragraph 25).

Erosion hazard output

45. The resulting Coastal Erosion Hazard Distance (CEHD) values for the likely scenario percentiles are listed in Table 2 and range between 63 and 84 m (mid percentile value at 78% = 76 m) of retreat by 2015 along the northern coast, 30 to 55 m (mid percentile value at 78% = 43 m) along the southern coast and 150 to 196 m (mid percentile value at 78% = 167 m) in the narrow central section.

46. As discussed earlier, the extreme erosion values in the central sector are considered episodic and erosion rates more in keeping with those of the adjacent northern and southern sectors are more appropriate at the century time scale. The present clifftop line was therefore translated landward the prescribed hazard distances in the northern and southern sectors and interpolated across the central sector

47. Finally, a mathematical filter was applied to the translated shoreline to remove bluff and bay fluctuations which are unlikely to persist though the longer-term as discussed earlier.

48. The likely (78%) erosion hazard line is depicted in Appendix B. The likely bracketing lines (66% and 90%) can be located by offsetting the differences from Table 3.

Table 3 Erosion hazard distance output for 'likely' level scenario on northern and southern coasts.

	Probability of Exceedance		
	66%	78%	90%
Northern coast (0 to 6.7 km)	84 m	76 m	63 m
Central coast (6.7 to 7.6 km)	196 m	167 m	150 m
Southern Coast (7.6 to 16.6 km)	55 m	43 m	30 m

Conclusions

49. The 16.5 km coastline is fronted by an eroding cliff which is likely to remain active in the future and may be subject to enhanced erosion should climate change predictions eventuate.

50. Historical erosion rates vary along the coast and this strongly correlates with variation in geological structure (faulting and folding) and their effect on the wave regime. Marine Terrace form shows that this alongshore variation in erosion has been occurring for millennium.

51. This study carried out an erosion hazard analysis using shoreline (clifftop) data comparing 1927 to 1936 with 2012 to 2016 positions. A LIDAR survey provided current 3D data to maximise accuracy. Cliff location differences were calculated at 10 m intervals alongshore and 100 year hazard distances computed using recently developed probabilistic software to yield output with the highest possible resolution and accuracy.

52. Output compared well with two spot erosion rates calculated by Gibb (1978) where a long sampling time-span (53 and 77 years) applied However, Gibb also computed two erosion rates

using short timespans (23 years) and these varied significantly from the present study output, illustrating the potential error in using short term change to represent long-term trend.

53. Erosion hazard distances to 2115 range between 63 and 84 m along the northern coast and 30 to 55 m along the southern coast. A 1 km wide band within the central was been subject to higher erosion rates; however, at the century time-scale this is considered to be an episodic rather than sustained long-term process and the northern and southern hazard distances have thus been interpolated across this reach.

54. While the hazard assessment period and level of hazard (likelihood of occurrence or probability of exceedance) are defined for development in the NZCPS, 2010, (very unlikely = 1 to 10% for new development and likely = 66 to 90% for existing development), values are not provided for the use of hazard to define the Coastal Environment. The present assessment assumes a 100 year prediction period and likely level of occurrence. In my opinion, as noted in paragraph 8, this combination is overly conservative as the relevant hazard concerns personal safety and a shorter duration/higher level assessment combination is more appropriate.

R D Shand

Dr Roger Shand
14 June 2016

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APPENDIX A Tonkin +Taylor report on Patea Coastline Erosion 2 Feb. 2016

Tonkin+Taylor

Job No: 85483.001
2 February 2016

Meridian Energy
Level 1, 33 Customhouse Quay
PO Box 10840
Wellington, New Zealand

Attention: Steve Harding

Dear Steve

Patea coastline historic erosion assessment

1 Introduction

South Taranaki Coastline between Patea and Manawapou Rivers is experiencing ongoing natural coastal erosion. Gibb (1978) previously estimated rates of erosion between -0.05 m/yr and -1 m/yr.

Meridian Energy has commissioned Tonkin + Taylor to undertake an assessment of local coastal erosion rates along the South Taranaki Coastline between Patea and Manawapou Rivers (refer to Figure 1). The assessment provides information on long-term cliff erosion rates based on evaluated historic coastal erosion rates. This information would be used to assess future erosion hazard zones.

2 Evaluating historic coastal erosion rates

2.1 Shorelines

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

- 1927 cadastral survey SO6641 (North and South)
- 1928 cadastral survey DP5030
- 1936 cadastral survey SO7552
- 2011/2012 aerial photographs (source: LINZ)

The cadastral survey has been split up in 4 sections for the given survey dates. Figure 1 shows the extent of these sections. Historic cadastral surveys have been georeferenced to a local projection by a registered surveyor, Harrison and O'Sullivan surveyors, using survey field notes, sourced from LINZ. The cliff edge as defined by surveyors during the cadastral survey has been digitised.

The most recent (2011/2012) georeferenced aerial photographs have been obtained via the LINZ data service. The top of the cliff has been digitised and used to define the 2011/2012 shoreline. Appendix A shows the historic cliff top positions from 1927, 1928 and 1936 including the most recent cliff top position 2011/2012 (refer to Figure 1 for location of Figure A1, A2 and A3).

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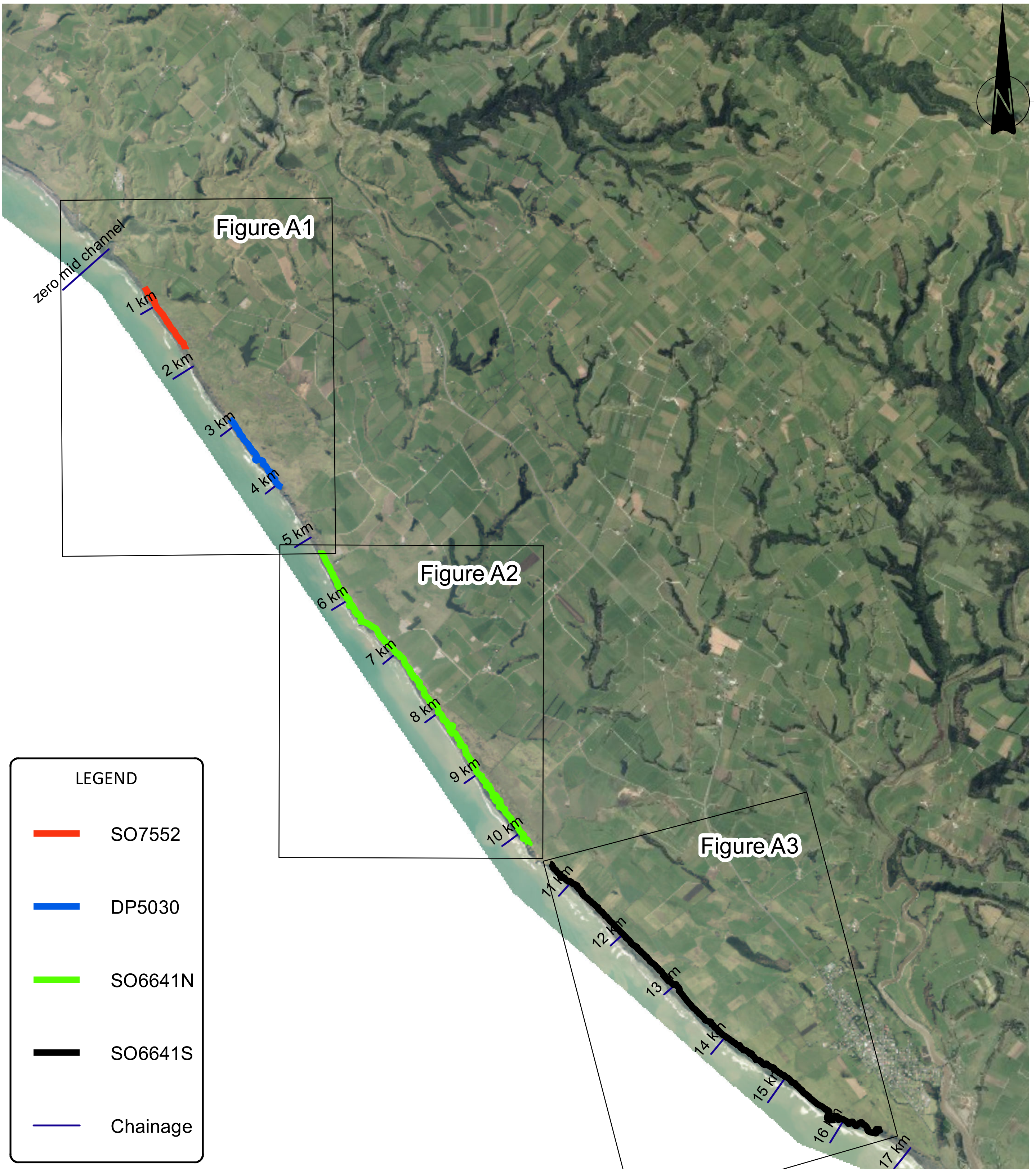
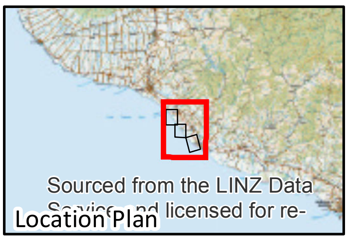
PO Box 5271, Wellesley St, Auckland 1141 P +64-9-355 6000 F +64-9-307 0265 E akl@tonkintaylor.co.nz





Location Plan

Notes:
Aerial photograph: 2011/2012 (Source: LINZ)

A4 SCALE 1:75,000

0 1 2 (km)

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Site Plan

FIGURE No. Figure 1

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2.2 Analysis of long-term rates of cliff erosion

Long-term rates of cliff erosion have been evaluated by the analysis of the two shoreline positions. The shoreline data has been analysed using the GIS-based Digital Shoreline Shoreline Analysis System (DSAS) model. DSAS processes the shoreline data and calculates linear regression shoreline change statistics at 10 m intervals along the entire extent of each site. By calculating the regression rate along the entire shoreline, rather than at a low number of discrete points, alongshore variation in trends can be determined. Although only 2 data points have been available, the long time interval between surveys should provide reasonable indication of average erosion rates.

2.3 Results

The assessed rate of shoreline change along the length of coastline between Manawapou River (Chainage 0 m) and Patea River (Ch 18 km) is shown within Figure 2. The erosion rates can be seen to vary from up to -1.5 m/yr near Lower Ball Rd to 0 m/yr further south (Ch 16 km). On average the erosion rates calculated are:

- -0.5 m/yr in the north
- increasing to an average of -1.15 m/yr along Lower Ball Rd
- decreasing to an average of -0.35 m/yr in the south.

The calculated regression rates south of Lower Taumaha Rd (Ch 0 and 1.5 km) are slightly less than the erosion rate found by Gibb (1978) of -0.9 to 1.0 m, likely due to the short length of record used by Gibb (23 years). Gibb's assessment in other locations based on longer record lengths are similar to findings of this analysis, except that there is significant variation in the erosion rates either side of Gibb's assessment positions which are not allowed for.

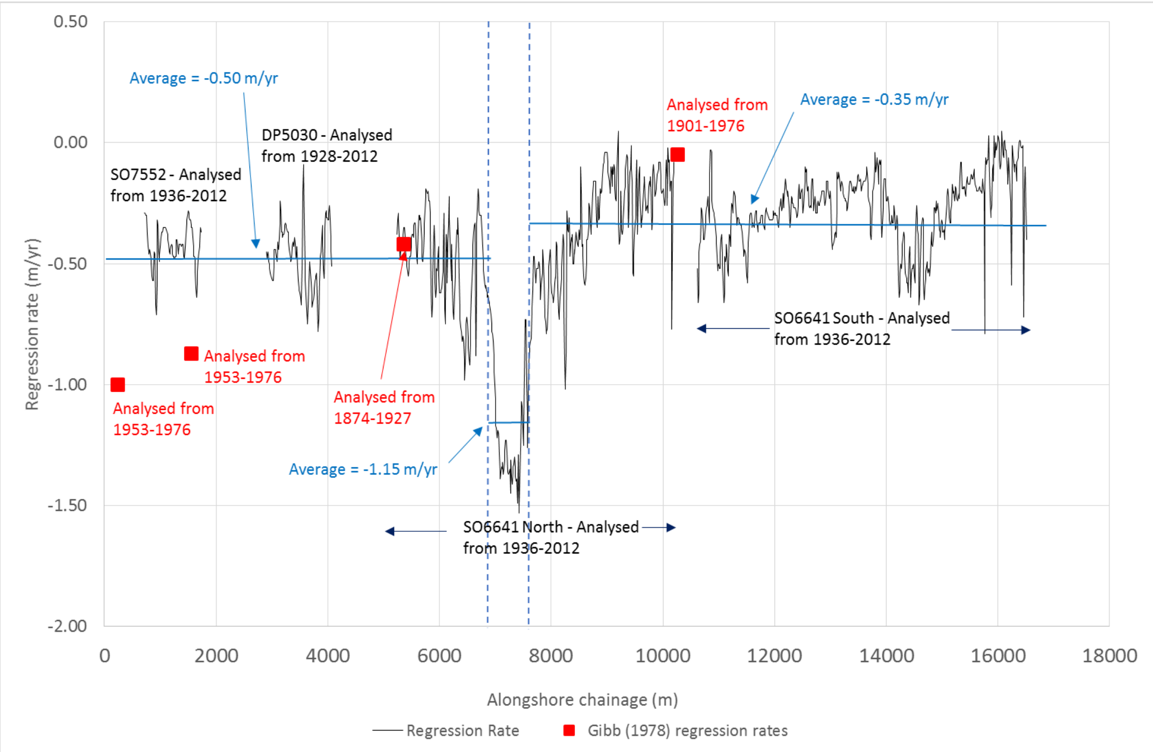

Figure 2 Calculated historic regression rates and historic rates found by Gibb (1978)

Figure 3 shows the locations of the average, min and max erosion rates for the four sections, as indicated in Figure 2, on a site plan.

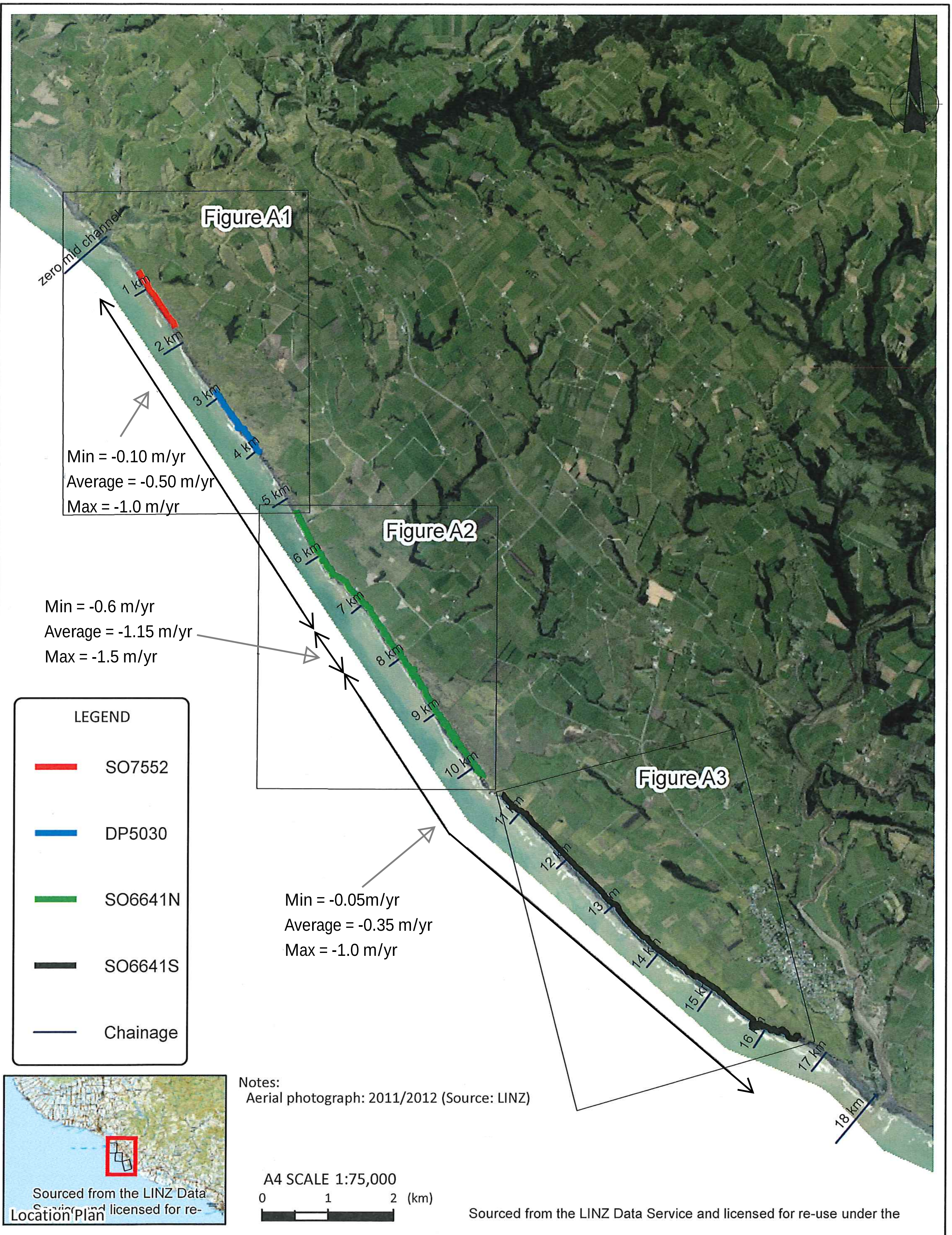

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FIGURE No. Figure 3

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3 Conclusions and recommendations

The South Taranaki Coastline between Patea and Manawapou Rivers is experiencing ongoing natural coastal erosion. Gibb (1978) previously estimated rates of erosion between -0.05 m/yr and -1 m/yr. T+T has analysed the long-term erosion based on historic cadastral surveys, varying from 1927 to 1936, and the most recent aerial photographs (2011/2012). On average the erosion rate is slightly higher in the north (-0.47 m/yr), increasing to an average of -1.14 m/yr along Lower Ball Rd and -0.60 m/yr just south of Lower Ball Rd, and decreasing to an average of -0.24 m/yr in the south. The calculated regression rates compare well with the erosion rate found by Gibb (1978) in the south and are lower in the north.

To accurately derive future Coastal Erosion Hazard Zones, the effect of cliff instability and future sea level rise should be taken into account. Further refinement in the likely future hazard zone could be obtained by having a geologist inspect the cliffs to better understand local rock controls on cliff stability and likely stable angles of repose.

4 Applicability

This report has been prepared for the exclusive use of our client Meridian Energy, 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

Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Patrick Knook Coastal Engineer	Bruce Symmans Project Director

Reviewed by:

....

Tom Shand

Senior Coastal Engineer

PPK/TDS
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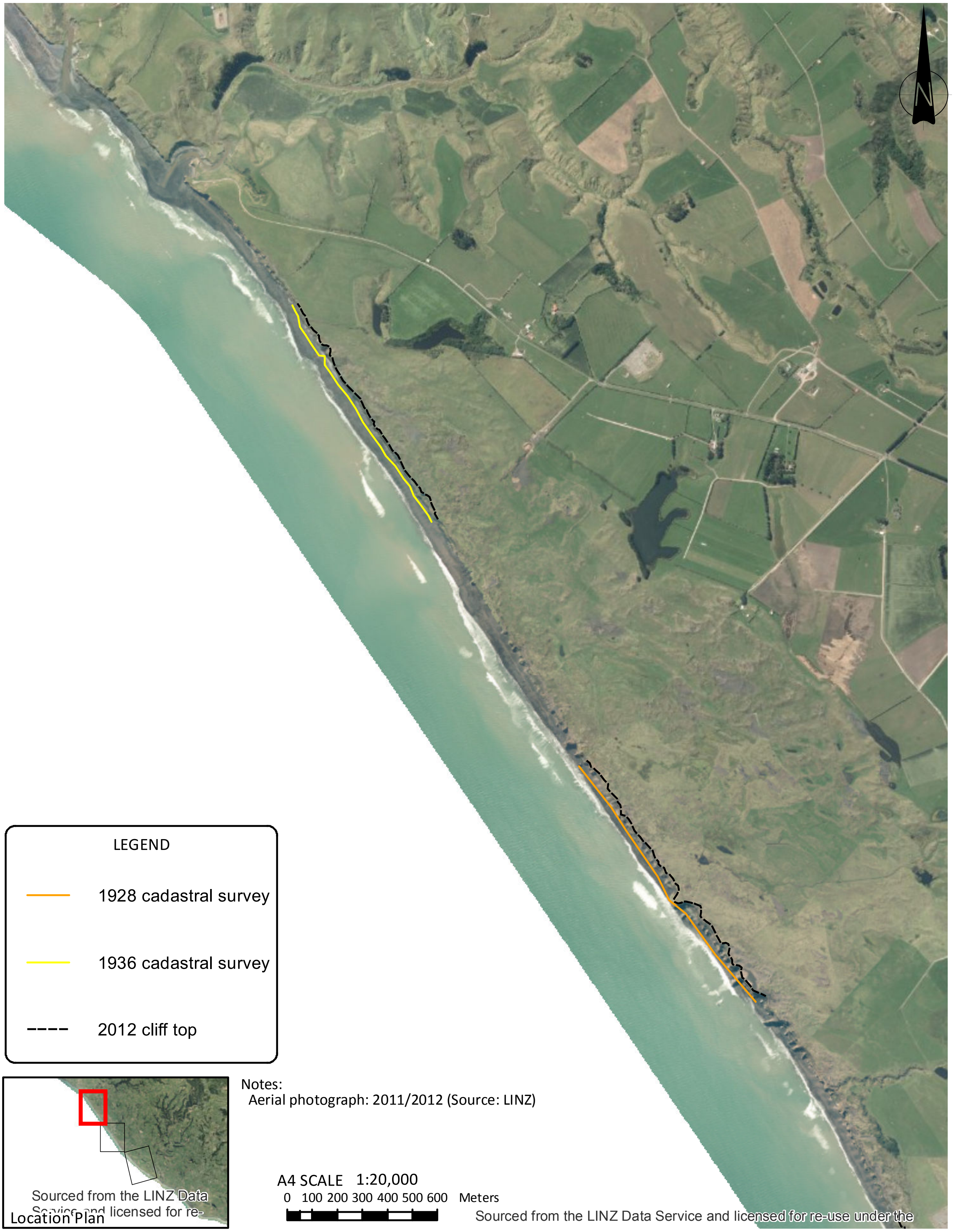
Appendix A: Historic cliff top positions



Notes:
Aerial photograph: 2011/2012 (Source: LINZ)

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Historic cliff top positions

FIGURE No. Figure A1
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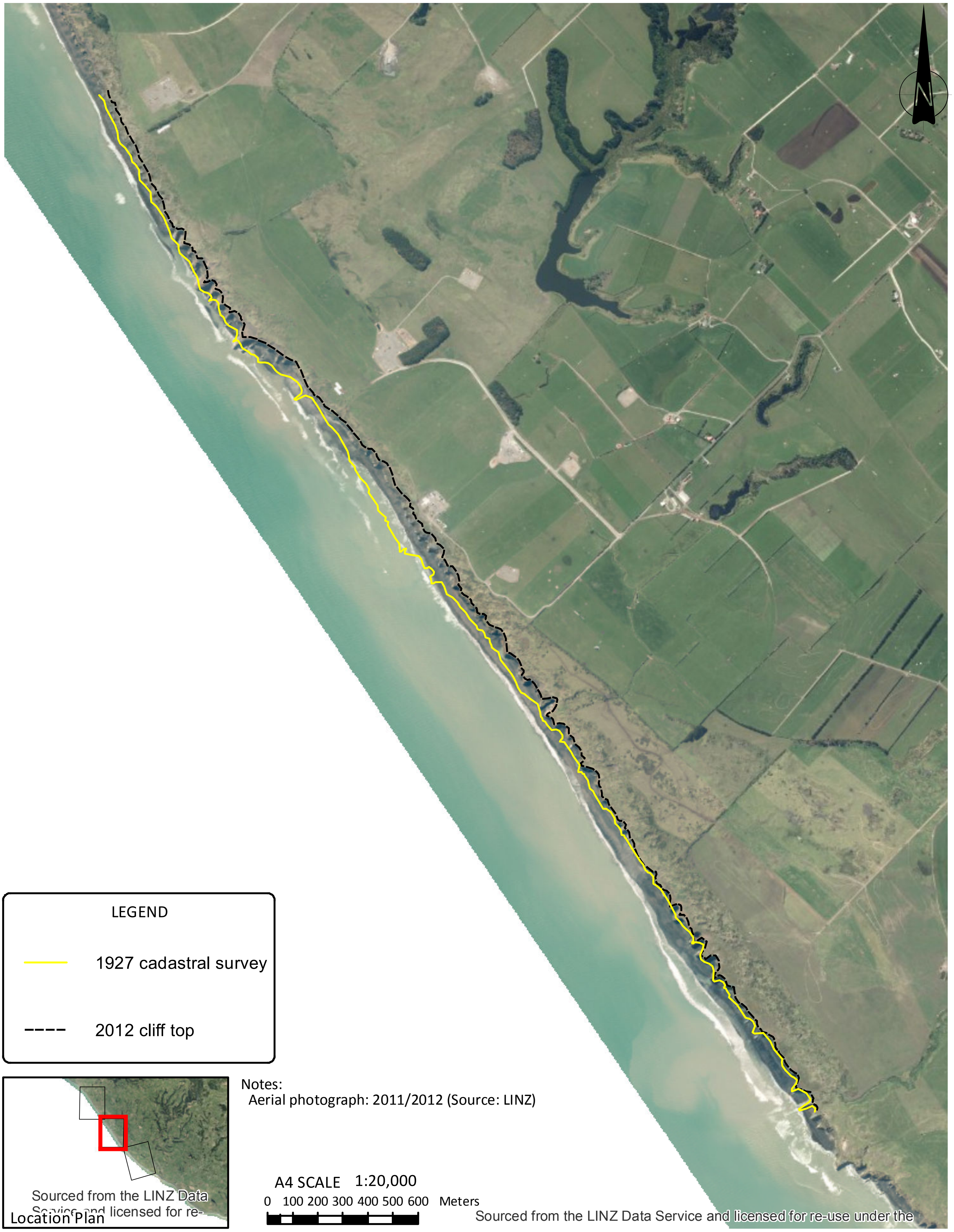

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Patea coastline erosion assessment
Historic cliff top positions

FIGURE No. Figure A2

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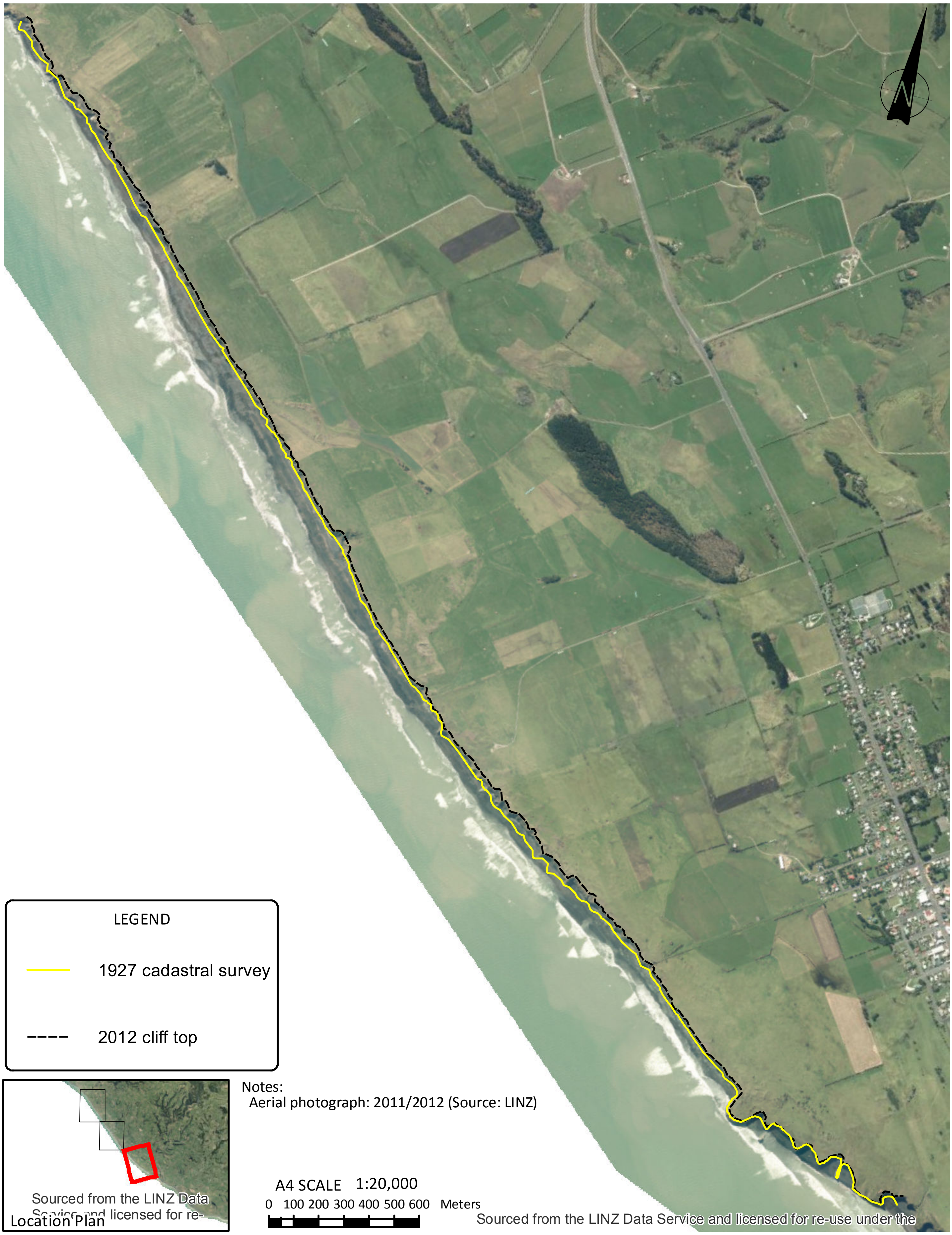

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Patea coastline erosion assessment
Historic cliff top positions

FIGURE No.
Figure A3

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APPENDIX B Likely erosion hazard line (78% probability of exceedance) superimposed on 2012 vertical aerial photograph.

Likely boundary lines (66 and 90% probability of exceedance) can be located from the differences in Table 3.

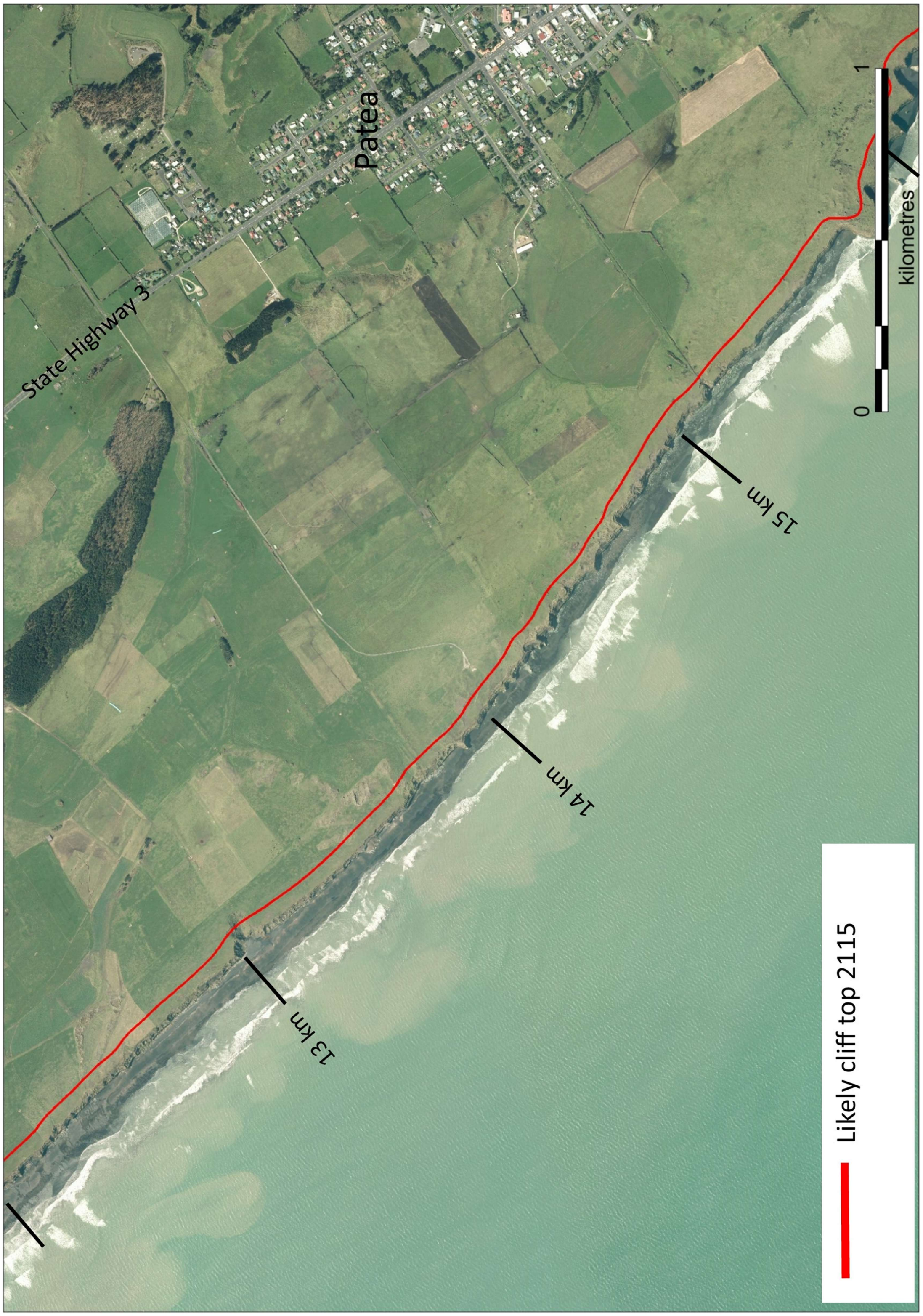
Distance markers at 1 km intervals as in Figure 1.


Manawapou Rivermouth
Manawapou Road
Lower Taumaha Road
1 km
2 km
3 km
0
1
kilometres
Likely cliff top 2115


Lower Manutahi Road
Lower Taumaha Road
Manawapou Road
Waikaikai Stm
3 km
4 km
5 km
6 km
0
1
kilometres
Likely cliff top 2115

Spence Road
Lower Ball Road
Mangaroa Stm
6 km
7 km
8 km
9 km
0
1
kilometres
Likely cliff top 2115


State Highway 3
Spence Road
Kaikura Stm
10 km
11 km
12 km
0
1
kilometres
Likely cliff top 2115


Patea
State Highway 3
13 km
14 km
15 km
0
1
kilometres
Likely cliff top 2115