Coastal Erosion Hazard Assessment for the Waipipi Coast, Waverley

A report prepared for Chancery Green Ltd on behalf of TrustPower Ltd.

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Client Report 2013-3B CRep 17 March, 2013

CONTENTS

1. INTRODUCTION

The following report has been prepared by Coastal Systems Ltd (CSL) for Chancery Green Ltd on behalf of TrustPower Ltd (TPL). In September 2012, CLS were instructed by TPL to prepare a coastal erosion hazard assessment as pertains to the site of the proposed wind farm near Waverley on the southwest coast of the New Zealand North Island (Figure 1).

The 980 ha wind farm site is fronted by 7.5 km of coast with the shoreline characterized by cliffs at the south eastern end (0 to 1.2 km), foredune along the central section (from 1.2 km to 5.3 km) and cliffs at the western end (from 5.3 km to 7.5 km) where it meets the Whenakura Rivermouth (Figure 1). This area has undergone substantial environmental modification during the period 1971 and 1984 when Waipipi Irons and Ltd extracted titanomagnetite from overlying dune sands using a dredge-based operation. The modified landscape is now relatively flat and dissected with large drainage ditches.

TrustPower Ltd are seeking planning consent for a development envelope within which 48 wind turbines will be located subject to avoidance of identified constraints. An indicative layout as at September 2012 is shown in Figure 1. Final micrositing will be subject to detailed geotech/civil design for which erosion hazards, as defined in the present report, will be an input.

The closest of the indicative wind turbine sites is some 180 m from the present shoreline and 15 are located either within, or in close proximity to, a belt of sand dunes which extends along the entire wind farm coast (Figure 1). In this assessment the standard (geomorphological) definition of sand dune applies: a mound or hill of sand formed by wind flow. In addition the sand dunes are further classified into stable where vegetated, and unstable where only partially vegetated or bare sand occurs. It is noted that other types of assessment, for example a Landscape Assessment, may use more qualified definitions. Sand dunes cover ~285 ha and extend landward from the shoreline an average distance of 370 m (140 to ~700 m).

Potential coastal erosion hazards affecting the site and investigated in this assessment are marine process-driven shoreline erosion (waves and currents), and wind-driven dune erosion (deflation, burial and airborne sand).

This report begins (Section 2) by describing the information used to carry out this investigation. A geomorphological assessment is then provided (Section 3) upon which the erosion hazard assessments (Section 4) are based. Assessment outputs are displayed on a hazard risk map and the vulnerabilities of the indicative turbine sites are described. Finally, in Section 5, conclusions and recommendations are set out.

2.0 INFORMATION BASE

A range of background literature is listed in the References. A particularly important work being the detailed monograph by Sir Charles Fleming (1953) which describes the geology of all but the western end of the site, this being beyond the western boundary of his study area: the Wanganui (geological) Subdivision which extends some 64 km to the east.

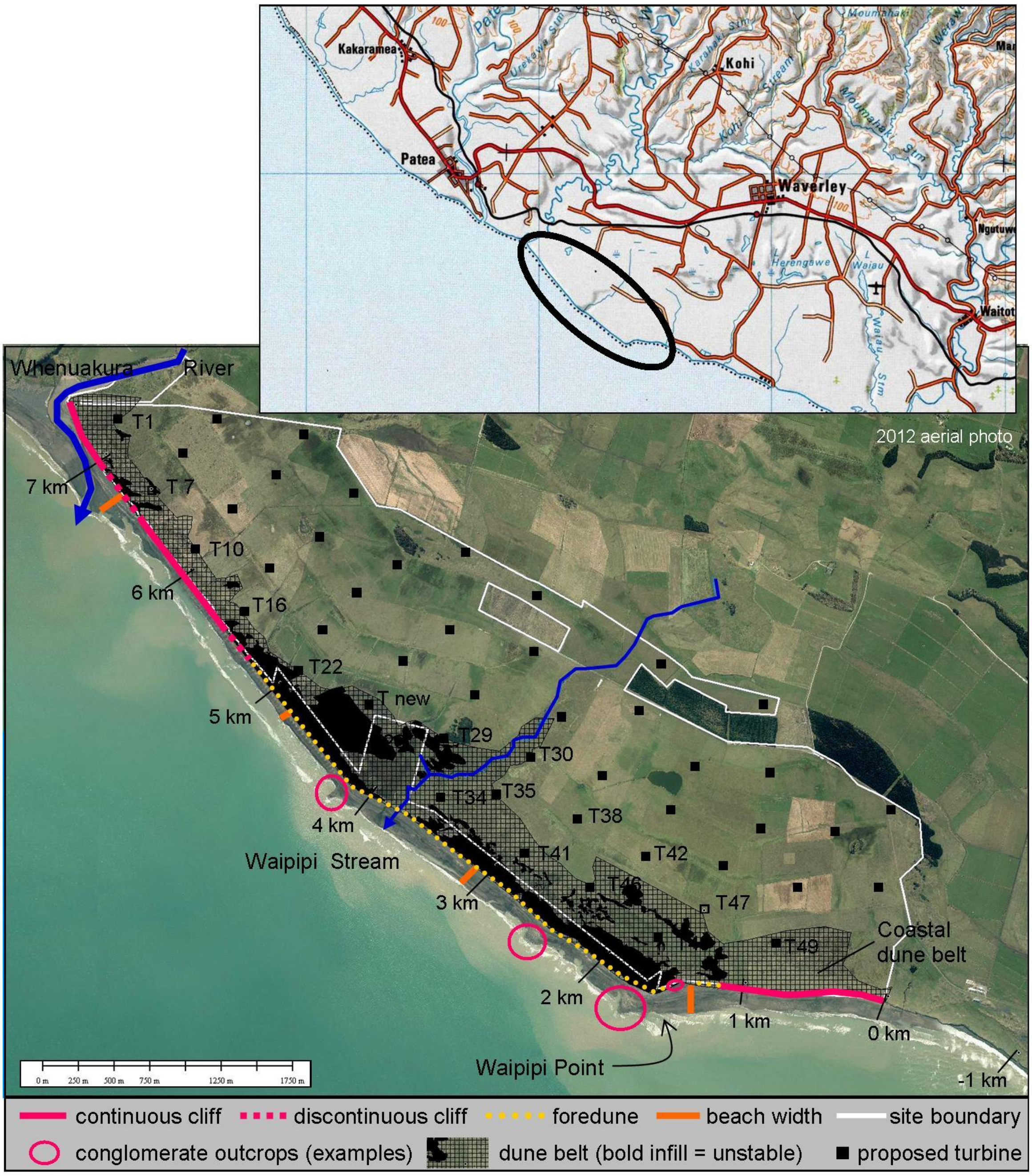

Figure 1 Location map (upper) showing wind farm site on the Waverly coast. Proposed turbine sites, alongshore distances and geomorphological features (lower) with distances marked from the eastern boundary of the proposed wind farm. Examples of the resistant shelly conglomerate outcrops on shoreline and lower beach are marked, with breaking wave patterns indicating subtidal expression (reefs).

The 1905 survey plans SO 15418 and SO 15419 provided the earliest reliable information on shoreline location. These plans were georeferenced by registered surveyors Taylor Patrick Ltd who reconstructed the original surveyor's traverse then digitally transformed the survey plan to best fit the traverse. The average fitting error was 1.5 m (range 0.2 to 3 m). The field book from the original survey labeled the reference shoreline as either the base of the cliff or the vegetation-front of the foredune (only one or the other being present at any location).

Vertical aerial photography was obtained for 1949 (SN 215), 1980 (SN 5778), 2007 (SN 50596D) and 2012 (SN 50794D) from New Zealand Aerial Mapping (NZAM) to identify dune characteristics through time, and to compare the 1905 shoreline with the 2007 shoreline (the latter being the most well defined recent sample). The 1949 and 1980 photos were supplied by New Zealand Aerial Mapping as georeferenced image files with pixel resolutions of 0.25 m and 0.4 m respectively and ground accuracy of 5-10 m and 2-3 m respectively. The 2007 and 2012 image files were provided by NZAM as orthophotos (georeferenced images with relief, camera lens and orientation distortions removed). Pixel resolutions were 0.5 m and 0.4 m respectively and ground accuracy estimated at 1 to 1.5 m.

A site inspection was carried out by Dr Shand and Dr Shepherd on 7th November, 2012.

3.0 GEOMORPHOLOGY

3.1 Underlying geology

The basement beds underlying the wind farm site consist of Pliocene marine strata (about 3.5 million years old) that generally dip gently to the southeast. These Whenuakura Group beds consist mainly of poorly lithified sandstones and siltstones that contain several pebbly or shelly beds that are 0.5-2.5 m in thickness, along with a particularly resistant cemented concretionary shelly sandstone (Fleming, 1953) hereafter referred to as *shelly conglomerate*. This resistant layer is evident at lower elevation in the eastern cliff and also has surface expression on the eastern side of Waipipi Point (Figure 2A) and as discrete lower beach outcrops along the eastern half of the wind farm coast (Figure 2B). In some planning documents (Taranaki Regional Policy Statement) this landform has also been referred to as "Pids Point". Furthermore, the shelly conglomerate beds are either broadly horizontal or have a slight westerly tilt, which contrasts with the southeastward regional pattern evident in cliffs further east and west. This localized variation may be associated with the Waverley Fault Zone, with a normal fault being observed in the eastern cliff (Figure 2C). It is unclear whether a single faulted conglomerate layer causes the multiple outcrops (in the along shore direction) of if there were several discrete layers. Nonetheless, this resistant shelly conglomeritic bed plays a significant role in geomorphological processes controlling the wind farm landscape.

The Whenuakura Group beds commenced uplifting above sea level about a million years ago, a process that continues today with uplift of about 0.6 mm/year in the vicinity of Waverley and the wind farm site. Cut into the Wheauakura Group beds are a series of tectonically uplifted Pleistocene marine terraces that extend about 20 km inland from the present coastline. The terrace surfaces developed successively over the past 700 000 years during discrete warmer periods during the Pleistocene ice ages when sea levels were relatively high. The youngest terrace (Hauriri) developed about 80,000 yrs ago.

3.2 Terrace and cliff

Morphology

The wind farm site is located upon the surface of the Hauriri Terrace which slopes gently seaward and is dissected by a number of drainage lines as well as the Waipipi Stream that meets the sea some 2 km west of Waipipi Point. At its seaward margin, the terrace is truncated by a sea cliff (Figure 1).

At the eastern end of the wind farm site the cliff is about 10 m high and lowers to about 4 m by the 1.2 km mark after which it is covered by dune sand until the shelly conglomerate outcropping along the southern side of Waipipi Point (Figure 3 upper). As illustrated in Figure 2 (upper photo), the lowering cliff (2 to 0.5 m) is then buried by dune sand, with a foredune defining the shoreline until the western cliff begins at 5.3 km (NB Figure 1).

Along the cliff line where the shelly conglomerate bed is more elevated, eroded blocks provide armouring at the cliff-base (Figure 3, upper photo). Where this bed is lower a narrow platform (1-2 m) may exist.

Further to the east beyond the wind farm site, the cliffs increase in height to ~20 m and only bare sand exists at the cliff base (Figure 3, upper photo).

The western cliff is about 8 m high and extends from the 5.3 km mark to the Whenakura Rivermouth, a distance of some 2 km (Figure 3, lower photo). Gaps or recessions in the cliff (through which wind-borne beach sand can funnel landward) occur at its eastern terminus, between ~5.3 and ~5.6 km and this may relate to a reduction in strength of overlying eastward dipping fine sandstone-siltstone formations (Figure 3, center photo). Gaps or recession in the cliff also occur between ~6.5 and ~7 km. This may be related to localized weaknesses in rock properties or localized increase in beach width due to rivermouth processes (see Section 3.3). The latter enabling dune sand to ramp up the cliff and perhaps facilitate clifftop erosion.

Figure 2 Upper photos depict shelly conglomerate outcrop at surface (arrowed) along eastern side of Waipipi Point. Center photos depict low tide localised outcrop of shelly conglomerate with apparent submarine extension. Lower photo depicts faulting across shelly conglomerate bed (below dotted line) with eroded blocks forming the debris slope at base.

Figure 3 Upper photo depicts eastern conglomerate controlled cliffs (disappearing at 1.2 km) in middle distance with debris blocks and siltstone cliffs in distance beyond wind farm site with no debris. Central photo depicts boundary between foredune and western cliffs (at 5.3 km) with beds tilting to the east. Lower photo depicts the western continuous cliff section (at 6 km) with no debris accumulation.

Cliffed shoreline behavour

Cliff behaviour was defined using the 1905 and 2007 shorelines. Cross-shore differences at 50 m intervals alongshore were derived (Figure 4) and analysed (Figure 5). Between 1905 and 2007 the average erosion distance of the eastern cliff was 5 m and the western cliff 8.5 m. Note that use of only two bracketing samples is acceptable owing to the time elapsed and cliff recession being essentially a one way process. The lower rate to the east would relate to control by the more resistant shelly conglomerate. Note in Figure 4 how cliff erosion increases dramatically further east from the wind farm site, reflecting the predominance of weaker silt and sandstone strata.

3.3 Beach and nearshore

In general the beach widens toward the east. Beach width is ~50 to 70 in the vicinity of the western cliff, increasing to ~90 to 120 m about the Waipipi Stream and ~150 to 200 m at, and in the vicinity of, Waipipi Point (Figure 1). This increase in width toward the east coincides with the occurrence of localized low tide outcrops of shelly conglomerate which also appear to extend into the surf zone judging by distinct locations of breaking waves (Figures 1 and 2). The development of Waipipi Point, and probably also the lesser shoreline protrusions further west, coincides with the occurrence of the more resistant shelly conglomeratic beds - thereby affecting sedimentation processes. In addition, irregular seabed topography may modify wave patterns, thereby also affecting sediment transport. As noted in the previous section, localized beach widening associated with rivermouth-coastal processes can occur between 6.5 and 7 km and results in the inter-tidal beach width ranging up to 200 m.

As beaches provide the sediment for sand dune development, wider beaches tend to be associated with greater dune activity.

3.4 Sand dunes

Morphology

Prior to sand mining between 1971 and 1987, the wind farm site formed the seaward part of a major transgressive dune field, termed the Waverley Dune Complex by Fleming (1953). In common with many other New Zealand coastal areas, this complex was probably highly active during the early 1900's following the introduction of grazing farm animals (Cockayne 1909). Sand comprising the complex appears to have originated mainly near the Whenuakura River mouth and to have extended eastward beyond Waipipi Point. An area of ~200 hectares, on or seaward of the wind farm site, was still active on the 1949 aerial photos. Its surface topography was characterised by a chaotic assemblage of hummocky dunes, saucer and trough depressions, deflation flats, swamps/wetlands and precipitation ridges. A relatively small number of parabolic dunes, aligned to the regional W-WNW onshore wind resultant (see Appendix A), developed when the sand sheet became partially vegetated and blowouts developed in higher dunes that formed expanding rims around deflation basins. The dune field was largely vegetated with grass and scrubby vegetation, and probably grazed by sheep and/or cattle.

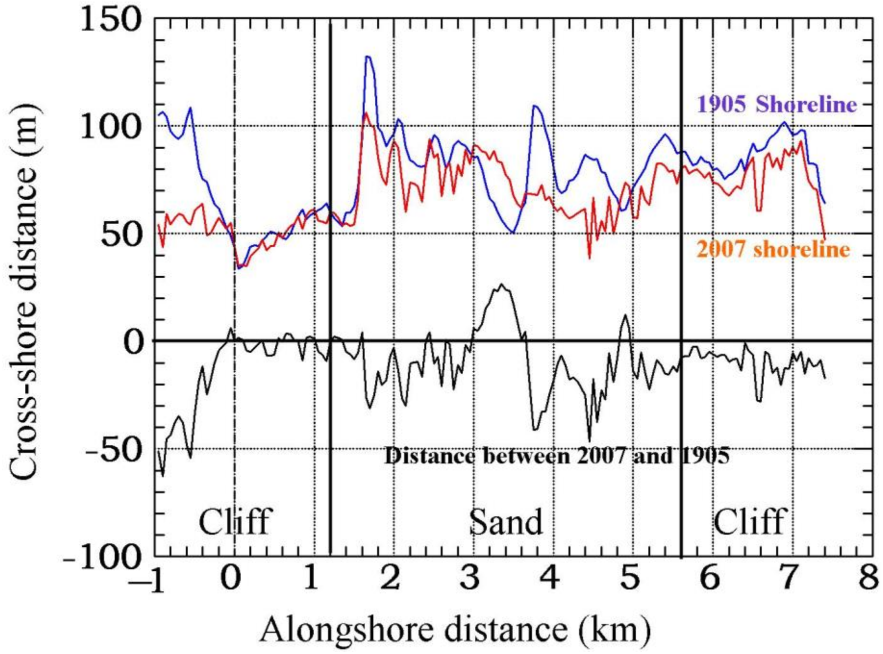

Figure 4 Shoreline (1905 and 2007) locations measured at 50 m intervals from a landward baseline. Lower graph (black line) depicts the distance between the two shorelines with positive values being seaward directed. An additional 1 km of coast immediately east of the wind farm site (-1 to 0 km) has been included to illustrate the rapid increase in erosion of the softer sand and siltstone beds. The Whenuakura River is located at the western extreme (7.6 to 8 km).

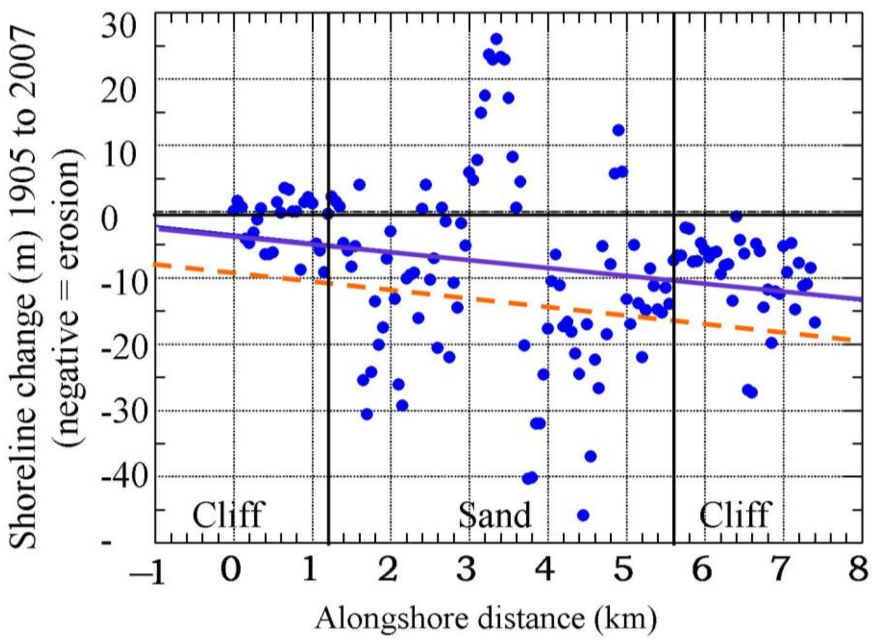

Figure 5 Linear regression model (solid blue line) fitted to 1905—2007 shoreline differences along the coast fronting the wind farm site. Dashed red line denotes long-term rate of change adjusted to base of cliff envelop (excluding outliers). Zero is at eastern end of wind farm site and 8 km is the Whenuakura Rivermouth.

The dredged areas were leveled and successfully sown in pasture. The present dune area forms a strip (belt) between the proposed wind farm and the coastline. The dunes are largely vegetated, but up to 85 ha (30%) are in a bare or partially vegetated state and thus vulnerable to wind erosion (Figure 1).

The nature and extent of the dunes vary according to the presence or absence of a sea cliff, the orientation of the coastline and the width of the beach. The dune strip may be subdivided into the following five sectors, each with different characteristics.

Sector 1: Behind the eastern cliff (0 to 1.2 km).

Along this stretch of coast the sea cliff is well developed and it is also the least exposed to onshore westerly winds. As a result the dunes are relatively low, presently stable and well vegetated mainly with introduced pasture species, and are not receiving a fresh sand supply from the beach (see Figure 3, upper photo).

Sector 2: Between the eastern and western cliffs (1.2 km to 5.6 km)

This sector lacks a continuous sea cliff and northwest of Waipipi Point is exposed to onshore westerly winds that blow sand from the wide beach in an easterly or eastsoutheasterly direction. The most active part of the dune belt consists of a discontinuous, well-dissected foredune and sand blown from the beach is funnelled through gaps and blowouts to feed several advancing parabolic dunes. Dunes in this coastal sector are hummocky, up to about 12 m in height, and vegetated to varying extents.

Between Waipipi Point and the Waipipi Stream mouth (2.3 km of coast), ~35 hectares of unstable dunes front the beach and extend inland up to 200 m. A major depression runs parallel to the coast between a former sea cliff, that trends inland behind Waipipi Point, and the most recent dune belt. Several smaller deflated areas (~11 ha) are associated with a second smaller line of dunes located 300-500 m inland from Waipipi Point.

North of the Waipipi Stream mouth to the western cliff (1.4 km of coast) an unstable area of similar size exists. However, here the shoreline is orientated more to the west and the prevailing wind can blow sand in a more landward direction. A major sloping deflation area (c.15 hectares) dominates the dune assemblage with sand being funneled landwards across this area to form parabolic dunes up to 12 m high and lobes extending into the mined area. The erosional remnant of a former dune lake bed, consisting of a narrow, indurated silt/clay bed rises (1 to 2 m) above the deflated surface at one location (Figure 6, lower right photo), clearly illustrating the extent of past wind erosion and the potential for such future erosion.

Sector 3: Behind the continuous section of western cliff (5.6 to 6.5 km)

This section is exposed to onshore westerly winds but a 4-8 m cliff forms a barrier to the present landward transport of sand from the (relatively narrow) beach. In recent aerial photos it appears that no new dunes are forming and most existing dunes are stable.

Sector 4: Behind the discontinuous western cliff (6.5 to 7 km)

This 500 m length of coast is exposed to onshore westerly winds, and in addition is strongly influenced by the accumulation of sediment immediately downdrift (southeast) from the Whenakura River mouth. This can result in the localized development of a relatively wide beach from which the sand blown inland towards proposed turbine T7 (WT_7) via active parabolic dunes (e.g. Figure 7). The 1949 aerial photo shows even more extensive dune instability along this reach, indicating the relative importance of the sector as it was from here that much of the sand comprising the original Waverley Dune Complex was transported inland.

Sector 5: Behind the westernmost section of continuous cliff (7.0 to 7.4 km)

This 500 m length of coast is exposed to onshore westerly winds but the close proximity of the river prevents an accumulation area and the formation of a wider beach, so this sector behaves similarly to Sector 3 (5.5 km to 6.5 km) with no new dunes forming and most existing dunes are stable.

Foredune shoreline behaviour

The vegetation front on the 1905 survey plan and the 2007 aerial photos were defined, digitized and cross-shore differences measured at 50 m intervals in the alongshore direction (Figure 4). These differences were then subject to space-based linear regression analysis (Figure 5). The long-term retreat value (6.75 m) lies between the bounding eastern cliffs (5 m) and the western cliffs (8.5 m). However, unlike the cliffed sections, considerable cross-shore fluctuation is evident within the sandy shoreline with differences ranging between 35 m seaward to 35 m landward of the average position. The use of numerous alongshore sampling locations provides a detailed distribution of differences and the linear regression analysis provides statistics which can be scaled to derive a realistic hazard parameter value despite the lack of temporal samples (Section 4).

Figure 6 Upper right photo shows the dissected foredune which extends between Waipipi Point and the western cliff. Upper left photo shows the windward side of a 12 m high hummocky parabolic dune with its associated landward lobe in the central photo (note this dune system is advancing toward turbine site T29 which is marked). Lower left shows the extensive deflation area feeding the landward parabolics, with indurated silt/clay of a previous interdune lake bed (arrows) in the lower right photo indicating the (minimum) extent of wind erosion in this area.

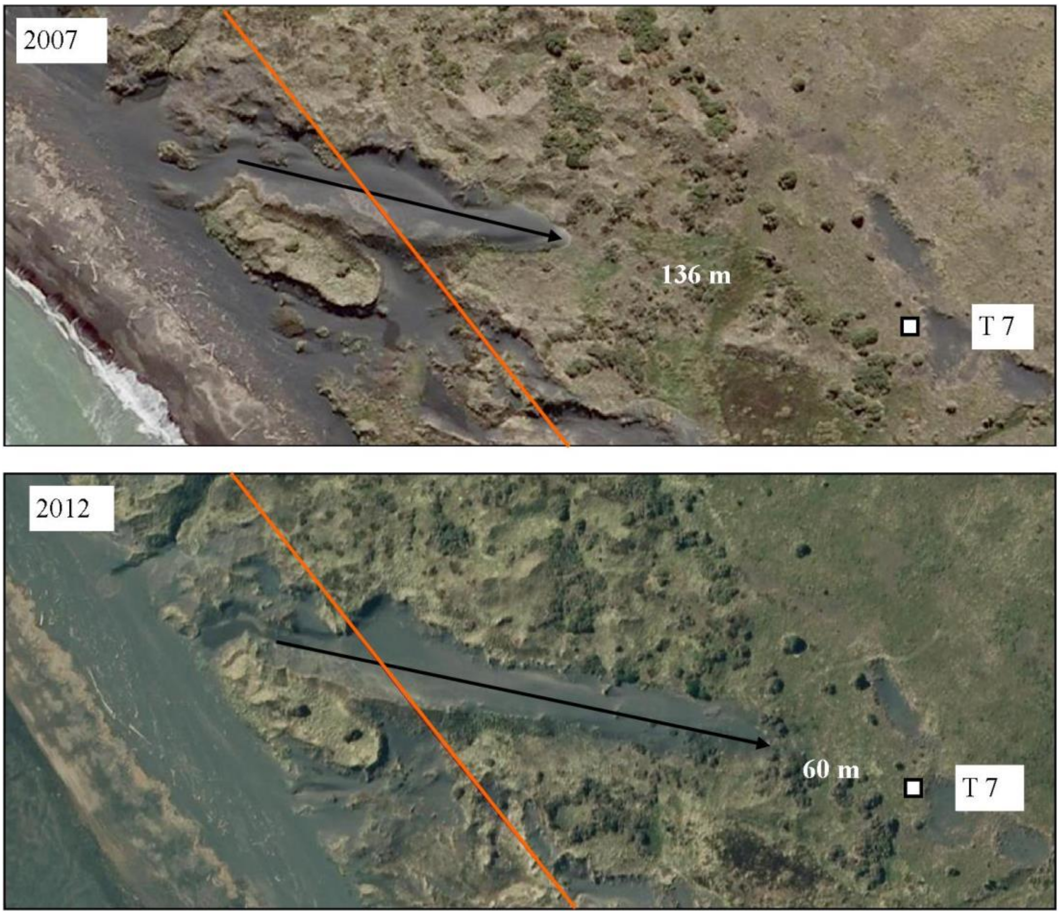

Figure 7 Parabolic dune migration (~14 m /yr) between 2007 and 2012 approaching proposed turbine site T7. Orange line depicts 100 yr predicted shoreline.

4.0 EROSION HAZARD ASSESSMENT

4.1 Shoreline erosion

Foredune (1.2 to 5.3 km)
Foredune erosion occurs when storm waves (facilitated by higher than normal tides) impact directly on the upper beach/lower foredune.

The method of predicting erosion for sandy shorelines is based on the general guidance in MfE (2008), DOC (2010) and NIWA (2012) which can be summarized by equation 1.

$$SEPD = LT + ST + RSLR + (DS \text{ or } SS) + CU \qquad (1)$$

Where SEPD = shoreline erosion prediction distance, LT = longer-term shoreline change, ST = shorter-term shoreline fluctuation, RSLR = shoreline retreat associated with sea-level rise (SLR), DS= dune stability adjustment, SS = slope stability adjustment, and CU = combined uncertainty. The shoreline is defined by the vegetation-front and the assessment period for new uses must be at least 100 yrs.

Using the results depicted in Figure 5, the relevant LT values for three equispaced locations within the sandy section (1.2 to 5.3 km) are listed in Table 1. The ST value is based on 3* the standard error of estimate for the sandy section domain which gives 99% certainty of capturing the associated population value. RSLR used a projected sea-level

Table 1 Shoreline erosion hazard parameter values and resulting cross-shore distances (SEPDists) for different types of shoreline along the proposed wind farm coast.

Segment Shoreline type	East (0 to 1.2 km) Cliff (hard)	Central (1.2 to 5.6 km) Sand dune			West (5.6 to 7.4 km) Cliff (moderate)
Component		E	C	W	
Long-term change (m)	10	6.5	8.0	9.5	17
Short-term change (m)	NA	46.5	46.5	46.5	NA
Retreat from SLR (m)	10	48.0	33.0	21	17
Dune stability (m)	NA	3.7	3.7	3.7	NA
Factor of safety	1.25	1.25	1.25	1.25	1.25
SEHDist (m)	25	131	114	101	43

rise of 0.9 m and the associated shoreline retreat is determined using a profile translation method (Komar et al., 1999). The dune scarp stability adjustment is based on a 34 degree angle of repose and 50% redistribution after Clark and Small (1982). Finally the CU value is based on a 25% safety margin (factor of safety = 1.25) which is appropriate given the minimal samples the assessment is based on. The resulting SEPDs range between 131 in the east and 101 m in the west of the foredune section.

These SEPDs were then plotted and the shoreline erosion prediction line drawn, with intermediate distances being linearly interpolated. The resulting shoreline erosion hazard zone is depicted in Figure 8 and no development should occur in this area – this area is excluded from the development area proposed by TrustPower Distances from the proposed turbine sites were measured and values listed in Table 2. The closest proposed turbine site to the predicted erosion hazard line is T 22 (WGT_22) at 111 m.

Cliff (1 to 1.2 km and 5.3 to 7.4 km)
Cliff erosion occurs by a combination of weathering and slope processes coupled with wave action removing underlying less litherfied bed material or basal support.

Because cliff erosion is a complex one way process, the ST component is not relevant so there was no requirement to use the average cross-shore location when determing LT. Consequently, LT was based on the lower values within the envelope (dashed red line in Figure 5).

Determining the effect of sea-level rise on cliffed coasts is not well specified in general guidance, with available methods varying depending on the lithology. To ensure precautionarity (as required by DOC, 2010), the cliffs were assumed to be composed of mid range soft rock, and based on materials in Sunamura (1992), Bray and Hooke (1997), and Walkden and Hall (2005) the RSLR value is taken as equal to the long-term (100 yr) recession value.

With cliffed coasts the dune-scarp stability (DS) component is replaced by the slope stability (SS) component. However, given that climate change effects will, if anything, increase the rate of erosion, there will be less recession toward equilibrium than at present and this is incorporated with the LT value. For the eastern cliff SEPD = 25 m and for the western SEPD = 43 m.

After plotting these SEPDs in Figure 4, and drawing the shoreline erosion prediction line, distances from the proposed turbine sites were measured and values listed in Table 2. The closest turbine site to the predicted erosion hazard line is T 10 (WGT_10) at 134 m.

In summary, all the proposed turbine sites from both foredune-fronted and cliff-fronted shorelines, are at least 100 m from the SEPLine and thus shoreline erosion poses no direct hazard to the wind farm turbines. However, such erosion does pose an indirect hazard as it initiates and/or enhances wind erosion of sand dunes (see next section).

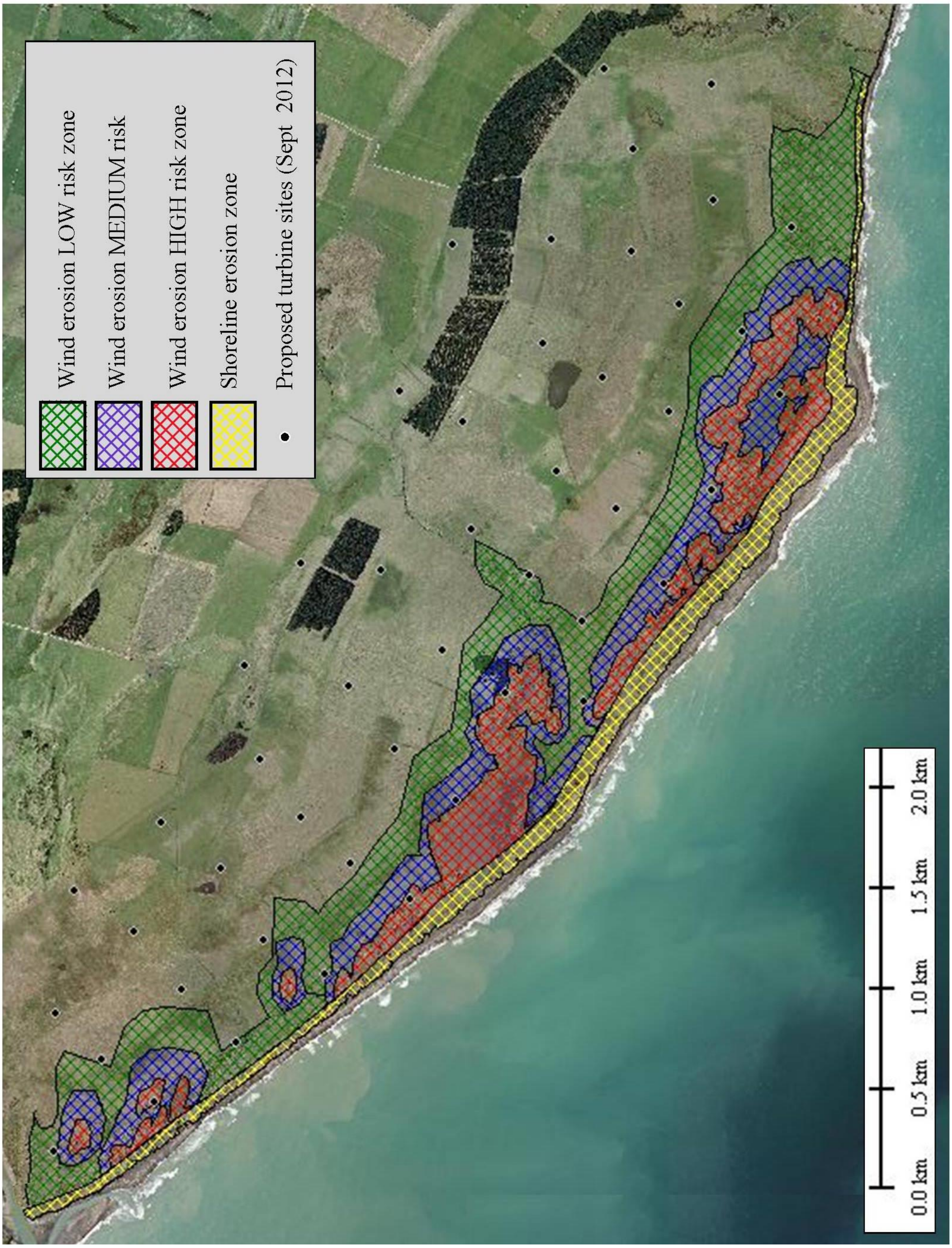

Figure 8 Erosion hazard risk map depicting the three risk zones associated with wind effects, together with that area to seaward potentially subject to shoreline erosion by waves and sea-level variation. Zones definitions are defined in text. Wind turbine sites proposed prior to the present assessment are also shown.

Table 2 Cross-shore distances between the Shoreline Erosion Prediction Line (SEPLine) and seawardmost wind turbine sites.

Turbine site (WGT_)	Alongshore distance (km)	Cross-shore dist (m) from SEPLine	Type of coast
49	0.8	306	Cliff, sand upper beach, rock outcrops lower bch
48	1.56	224	Waipipi Point#
46	2.35	258	Sand shoreline, sand upper beach, rock outcrops lower
41	2.91	139	Sand shoreline, sand upper beach, rock outcrops lower
34	3.59	133	Sand shoreline, sand upper beach, rock outcrops lower
28 new	4.40 4.48	136 347	Sand shoreline, sand upper beach, rock outcrops lower?
22	4.99	111	Sand shoreline, sand upper and lower beach
16	5.55	129	Cliff (discontinuous). Sand upper and lower beach
10	6.15	141	Cliff. Sand upper and lower beach
7	6.62	134	Cliff (discontinuous). Sand upper and lower beach with occasional river effects
1	7.21	225	Cliff. Sand upper and lower beach and frequent river influence.

Waipipi Point has a sandy shoreline backed by dunes apart from a section of rock outcropping along its eastern side. Rock also outcrops along the lower beach and these appear to extend seaward to form reefs within the surfzone.

4.2 Wind erosion

Wind erosion of landward sand dunes occur where there is a loss of vegetative cover. Areas fronted by the foredune are vulnerable to stormwave-initiated erosion and burial from an increased littoral supply, while areas behind the continuously cliffed shorelines would be susceptible to stock, traffic and fire devegetation. A prolonged sequence of gale-force winds, as sometimes occurs during extreme El Nino conditions, may also initiate, or increase, dune instability. When viewing the extent and location of instability on the 1949 and 2012 aerials it appears that that the entire belt of sand dunes is potentially at risk of wind erosion. It is noted that the predicted shoreline erosion along the foreduned shorelines will further increase the chance of frontal vegetation destruction and the onset of wind erosion.

The determination of sand-stability risk in this assessment used a classification approach distinguished by distance between proposed turbine sites and the nearest location of bare (unstable) sand. The three (risk) categories were: high (occurrence rating of virtually certain to certain), medium (likely to very likely), and low (possible). Corresponding distances downdrift of the wind resultant (274 degrees ± 15 degrees) were: high risk = 0 to 49 m, medium risk = 50 to 199 m and low risk = 200 to 400 m. To account for the reduced wind duration and/or magnitude for other directions these threshold values were lowered by 66.6%, i.e. high risk = 0 to 17 m, medium risk = 18 to 65 m and low risk = 66 to 133 m. In addition, any areas within the dune belt (Figure 1), but not falling within these instability criteria, were also mapped as low risk given their potential for erosion as noted above. It is further noted that the methodology is based on practitioner experience in this environment and provides a relative and plausible basis for analysis. While greater precision could be incorporated, the method provides adequate detail given the dynamic nature of the dune environment.

The results of the wind erosion risk analysis are depicted in Figure 8 and implications for the indicative turbine sites are summarized in Table 3. Where proposed sites are located along the margins (within ±10 m of a zone boundary) this is indicated by appropriately location of the symbol in Table 3. Also listed in Table 3 are results from analyzing the 1949 photos, these being included to provide greater appreciation of sand instability potential as some sites which currently have a lesser risk have had a greater risk level in the past and visa versa.

The results in Table 3 show two proposed, or indicative, sites (T7 and T22) are well within the high risk zone with a further three proposed sites (T29, T41 and T48) lie within the high/medium risk margin. Two of the proposed sites (Tnew and T46) are located well within the moderate risk zone with a further proposed site (T34) lies within the medium/low risk margin. Six proposed sites (T1, T10, T16, T30, T47 and T49) lie within the low risk zone and one (T35) is within the outer risk margin.

The following recommendations are made regarding locating turbines within the wind erosion risk zones as based on current environmental conditions.

- High risk zones: preferable to avoid these locations, otherwise pre-construction stabilization of the associated unstable dune areas will be required and will need to be factored into the final detailed design of the site works.

- Medium risk zones: suitable for initial development, but ongoing monitoring is required along with planning for stabilization in the shorter-term as conditions could quickly deteriorate.

- Low risk zones: suitable for initial development, but ongoing monitoring is required along with planning to stabilize in the longer-term if conditions require.

Table 3 Relative risk of seaward turbine sites being affected by sand erosion during the assessment period based on the 1949 (o) and the 2012 (■) aerial photographs. Categories are defined in text.

Turbine site	Wind-erosion risk categories		
(WGT_)	High	Medium	Low risk
T49			■
T48	■		o
T47		o	■
T46		o■	
T41	o ■		
T35			o ■
T34		■	
T30			■
T29	■		o
Tnew	o	■	
T22	■	o	
T16	o		■
T10			o■
T7	o■		

T1 o■

If dunes within the dune belt are not adequately managed then sites further inland could also be at risk of encroachment over the next 50 yrs. Once destabilized, dunes can advance at alarming rates and develop into major transgressive dunes if left unchecked. In the Manawatu, a low lobe of sand advanced 300 m during only three months owing to persistent, strong winds related to peak 1982-3 El Nino conditions (Holland, 1983). Larger parabolic dunes in the Manawatu were observed to advanced at up to 50-80 m/year.

A range of sand stabilization techniques are available with mechanical contouring and placement of clay suiting more exposed and degraded sites. Stock fencing and planting with dune grasses can be effective on moderately eroded sites. Locations with less wind exposure and/or more even topography may self repair simply by fencing out stock. A Soil (or Farm) Conservation Plan prepared by a qualified and experienced Soil Conservator would be a useful first step.

5. CONCLUSIONS

While predicted **shoreline erosion** does not pose a direct hazard to the proposed turbine sites, such a process has the potential to destabilize the seaward dune belt. Indeed, foredune erosion initiated by marine processes is one of the main instigators of large-scale dune erosion.

Potential wind erosion is a the greater hazard threat and final location of turbine sites needs to be mindful of the risk zones defined in Figure 8. Where practicable, sites should avoid the high risk zone otherwise extensive pre-development sand stabilization work will be required. While development can proceed in the medium and low risk zones, sand stabilization may well be required in the shorter and longer-terms respectively.

Ongoing **monitoring and plans** for prompt implementation of appropriate sand stabilization practices are recommended. In conjunction with land owners, commissioning a Soil Conservation Plan from a qualified and experienced Soil Conservator at an early stage of the project is recommended.

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COASTAL SYSTEMS LTD

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APPENDIX A Wind resultant

When discussing sand and dune movement in this report we have referred to the 'resultant for sand moving winds'. This resultant is computed from wind records by including only winds exceeding 10 knots, as lower velocities do not initiate sand movement, and by cubing the wind speeds as sand transport is proportional to the cube of the wind velocity. This resultant may differ from the predominant wind direction. Most coastal dune research uses a resultant computed from only onshore wind directions, as dune sand is normally sourced from the beach.

The resultant referred to in this report was computed by Muckersie (1989) from wind data recorded at Wanganui Airport, using the Freyberger method (1979). The onshore wind resultant derived in this manner was 274º for both Wanganui and the Patea coast. This is consistent with the observed direction of dune migration at the wind farm site.

Total onshore sand-moving wind energy may be measured by calculating the drift potential (Freyberger, 1979). The value for Wanganui is classified as high.