Waverley Wind Farm

Coastal environment description and assessment of effects

Prepared for

Chancery Green on behalf of Trustpower Ltd

Dr Martin Single, Shore Processes and Management Ltd

March 2016

Contents

List of Figures

List of Tables

Executive Summary

This report presents a description of the coastal environment for the shore between Whenuakura River mouth and east of Waipipi Point. This shoreline is adjacent to the site of a wind farm proposed by Trustpower Ltd, known as the Waverley Wind Farm project (WWF).

There are no known historical coastal process or environment studies for the specific area, so field observations and an examination of photographic data and application of coastal process principles have been used in this assessment.

The coastal environment adjacent to the WWF site is predominantly an active dune system flanked by sections of shelly conglomerate cliff. The active coastal strip varies in width from a narrow sandy beach up to 50 m wide, fronting eroding cliffs, to active, mobile dune sands extending over 200 m inland from the high tide line. Overall, the shore is relatively stable, although eroding at an estimated rate of about 0.06 to 0.08 m per year. The central area between Waipipi Point and the Whenuakura River mouth is contained between cliff sections that act as headlands. There appears to be a surplus in sediment supply to the area, with sand migrating onshore through the development of foredunes and movement of sand across to the backshore of both the dune area and the low cliffs.

The backshore contains a large but highly modified dune field, known as the Waverley Dune Complex. This area was mined for ironsand between 1971 and 1987. At the conclusion of the mining operation, the area of mined dunes was levelled and sown in pasture. However there are areas of sparse vegetation and bare sand that relate to active dune movement between the project site and the coast.

Projected future change to the coastal environment as a result of on-going processes and potential effects of projected climate change and sea level rise, show that the shoreline could erode by up to 130 m by the year 2115, and that the dunes could be more susceptible to wind erosion and migration inland.

Potential adverse effects of the project on the physical coastal environment and physical coastal processes relate mainly to modification of some of the most inland part of the dune system and changes to terrestrial and ground water flows through construction of the turbine foundations, roads, hard stand areas and ancillary buildings. These effects are recognised in the proposed project works and design through the exclusion of the Environmental Buffer Zone (EBZ) and construction methodology. As a result, the project is likely to have a negligible effect on the coastal environment.

There is potential for blown sand to have an adverse effect on the project. In addition to those measures already undertaken, it is recommended that a dune management plan be implemented to avoid, mitigate or remedy adverse effects that may arise due to coastal hazards. The plan should include a monitoring program to identify changes in the location and size of areas of bare sand, and should identify methods to stabilise those areas that may result in a hazard to the project. Such methods may include planting with plants appropriate for the area and effective at dune stabilising such as, but not limited to, pingao, spinifex, tauhinu, and sand coprosma. Modifying the shape of unstable dunes within the WWF project envelope could also be carried out to provide a more stable dune shape.

1. Introduction

1.1 Background

This report presents a description of the coastal environment in the vicinity of the proposed Waverley Wind Farm, South Taranaki. Trustpower Limited (Trustpower) proposes to construct and maintain a wind power generation facility near Waverley, in South Taranaki. The project is known as the Waverley Wind Farm (WWF), and extends an earlier proposal to build a wind farm at the site put forward by Allco Ltd in 2007.

Figure 1.1 shows the location of the site. It is adjacent to the coast, approximately 6 km southeast of Patea and 7 km southwest of Waverley. The site is landward of a 7km stretch of coastal dunes and cliffs that run between the Whenuakura River mouth and south of Waipipi Point (also known as Pid's Point). The WWF site extends inland 1.3 to 2.2 km, and is almost entirely situated on pasture that was developed following ironsand mining undertaken by the Waipipi Ironsand Company between 1971 and 1987.

Figure 1.1 Location map of the Waverley Wind Farm site showing the site boundaries (source: Heritage Solutions 2012).

Of the 980 ha project site, the project **envelope** comprises an area of approximately 804.37 ha. The remaining 175.47 ha are within areas jointly identified as an EBZ as shown in Figure 1.2. The extent of this zone is based on investigations, site assessments and consultation between Trustpower and consultants. The EBZ determines locations within the project site where the establishment of turbines, ancillary buildings, roads or earthworks are to be avoided. Many of the constraints and buffers identified by the environmental consultants overlap with each other. The project site boundary and the EBZ within the site provide a setback of varying width along the coastal frontage.

Figure 1.2 Environmental Buffer Zone within the proposed WWF site. The area within the site but not within the EBZ is referred to as the project envelope (Source: Isthmus 2016).

1.2 Scope and objectives of this report

This report describes the coastal character, landforms and processes of the site and the adjacent shore. The historical development of the shore is described, including historical changes to the shoreline position related to erosion and development of the dune area. In addition, the potential changes to the coastal environment as a result of climate change and projected sea-level rise are determined. In addition, the potential effects of interaction between coastal processes and the project are described. These include identifying potential coastal hazards to the project, and how the project activities may have an effect on the coastal environment.

The entire site lies within the 'Coastal Protection Area' on the planning maps to the South Taranaki District Plan and partly within the Coastal Protection Area of the Proposed South Taranaki District Plan. The Coastal Protection Area in the District Plan identifies areas that reflect the extent of the coastal environment and where coastal processes potentially impact on use, development and subdivision activities. This present report aims to identify the type and degree of coastal influence on the site.

The objectives of this report are:

a) To describe the coastal environment of the project site and adjacent coast.

b) To describe on-going coastal processes and how they may interact with the project.

c) To determine potential future coastal change based on projected sea-level rise and climate change.

d) To identify the potential effects of the proposal on the coastal environment, and the potential hazards that the coastal environment may present for the project.

e) Provide recommendations as to how any potential adverse effects of the project on the coastal environment, or coastal hazards to the project can be avoided, remedied or mitigated.

f) Provide recommendations as to whether any coastal environment monitoring is required.

1.3 Methods

The description of the coastal environment for the purpose of this report is based on a review of literature, maps, and photographs (ground and aerial). Field data and photographs have been made available from Trustpower. In addition, the author visited the site, walking over, and making observations of sections of the dunes, beach and backshore. Additional aerial photograph analysis was carried out to determine the extent of active dunes within the site boundary, and to assess the potential for coastal hazards to the project.

International literature on wind farms in areas of dunes was assessed with regard to identifying potential effects of the project on the coastal environment. International practices of dune management were also referred to in determining potential methods of avoiding hazards relating to mobile dune sands.

2. Coastal geomorphology and processes

The WWF project 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. The coast adjacent to the WWF site is approximately 7.5 km long. The shoreline can be separated into three different sections. The southeastern section is characterised by a 4 to 10 m high cliff, while 4 to 8 m high cliffs also back the western section of shore. Between the cliffs is an approximately 3.9 km long stretch of beach backed by an active dune system.

2.1 Geological setting

A description of the geology of the site is provided in a geotechnical report by Riley (2016), while further information and a geological map can be found in the GNS publication *Geology of the Taranaki area* (Townsend *et al*. 2008) and the *Miscellaneous Series Map 18* (Pillans 1990). Earlier work by Fleming (1953) describes the geology of the Wanganui (geological) Subdivision that covers all but the western end of the WWF project site, and extends some 64 km to the east.

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 beds are identified as the Inaha and Hauriri Terraces, and 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). 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 years ago.

The terrace beds are evident at lower elevation in the cliffs at the eastern end of the site and the Hauriri laminated sand, silt and shelly conglomerate appears as outcrops within the dunes and on the foreshore east of Waipipi Stream and as a surface expression on the eastern side of Waipipi Point. Examples of these bedforms within the sand dunes can be seen in Figure 2.1. Surface expressions of the conglomerate also extend offshore, resulting in irregular reef outcrops that modify shoaling waves near the shore. The conglomerate beds are also evident in the area of Waipipi Stream, inland from the coast.

Figure 2.1 Examples of the sand, silt and shell conglomerate surface within the dunes (top) and in the cliff near Waipipi Beach, east of the WWF site.

Holocene sand deposits cover almost the entire WWF site, and vary in thickness and surface topography. Dunes on the site have been highly modified due to mining for ironsand. Riley (2016) gives details of the subsurface deposits from borehole examination. The Riley report notes the finding of loose to medium dense sand with occasional silt horizons present from the surface to depths of 10m to 15m. The borehole results include natural dune sand deposits and mining tailings fill.

2.2 Wave environment, nearshore and beach processes

Although there has been no previous research on the coastal processes in the vicinity of the WWF site, the general coastal process environment are similar to other parts of the South Taranaki Bight. The beach west of Waipipi Point faces to west-southwest, while east of Waipipi Point the beach faces more to the southwest. Shand (2002) describes the characteristics of the coastal processes near the mouth of the Whanganui River:

> The process conditions affecting the study area are as follows. The mean spring tide range is 2.4 m and the mean neap tide range is 0.8 m. Deepwater significant wave height parameter values are: mean = 1.3 m; 5% exceedence = 2.5 m, and 1%excedence = 3.2 m (Mackey et al., 1988). Wave period ranges between 3.5 sec and 19 sec with the mean value being 10.1 sec. Sea and swell populations usually co-exist, with approximately 75% of the wave energy occurring at sea wave frequencies (Patterson, 1992). Wave observations made during the present study indicate that 34% of waves had a shore-normal approach (±1 degree), 42% approached from the northwest and 24% from the southeast.

The coastal process environment for the area between Patea and Waipipi Point is likely to be similar, with combined sea and swell waves from the west and south. Wave shoaling across the irregular reef outcrops produces areas of higher and lower wave energy at the shore, with no readily apparent dominant alongshore energy flux or sediment transport. Although there is potential for a large gross alongshore transport of sediment, it is likely that the net alongshore transport is low, and probably from the west to east.

The prevailing winds are from the northwest and southeast, with those from the northwest being more dominant. Figure 2.2 shows the pattern of winds for the area. This pattern of wind has resulted in the dune system landward of the foredunes being aligned at an angle to the shoreline, running in a west-northwest to east-southeast direction near Whenuakura River and in a north-northwest to south-southeast direction near Waipipi Point.

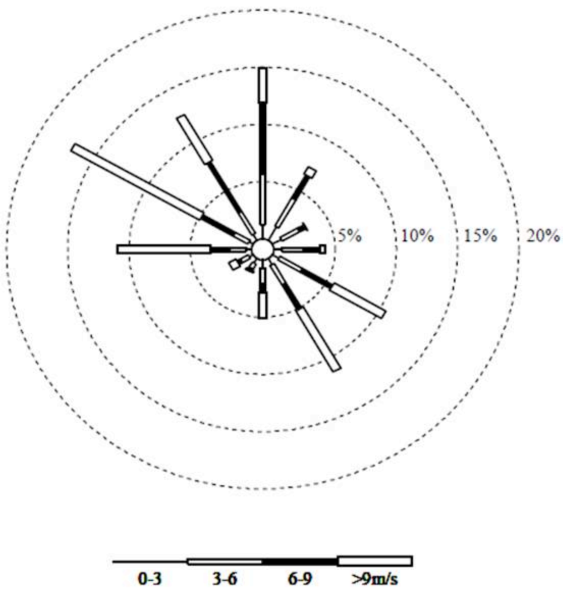

Figure 2.2 Long-term wind rose for the Waverly Wind Farm site (at 80 m elevation). Length of bars indicates % time from that direction, while width of bars indicates wind speed (Source: Trustpower)

It should be noted that sand transport by wind is a factor of the wind resultant. The wind resultant is computed from wind records with consideration of only winds that exceed 5 metres per second. Sand transport is proportional to the cube of the wind velocity. The wind resultant direction differs from the predominant wind direction due to this analysis. The direction of the wind resultant is 274º for the WWF site.

2.3 Beach and nearshore morphology

Beach widths adjacent to the WWF site vary as a function of the backshore morphology. To the west, where there are cliffs behind the beach, the beach is approximately 50 to 70 m wide. However during storms, wave run-up reaches the base of the cliffs at high tide. In the vicinity of Waipipi Stream, the beach width is approximately 90 to 120 m wide, with the wider beach area located adjacent to an area of active dunes, east of the stream mouth along to Waipipi Point.

The increase in beach width toward the east also coincides with the occurrence of localised low tide outcrops or reefs. The reefs also cause waves to break offshore, dissipating energy in a wide surf zone. There is a similar nearshore reef outcrop just west of Waipipi Stream. While these outcrops will affect sedimentation processes and hence influence the coastal outline, irregular seabed topography may modify wave patterns, thereby also affecting sediment transport in the nearshore and on the beach.

River mouth processes also modify the local beach topography and can result in erosion of the cliff backshore. This is especially noticeable near the Whenuakura River mouth. The mouth is often offset to the east, with the river running along the back of the beach against the cliff.

2.3.1 Cliff sections of shore

The seaward margin of the Hauriri Terrace is a sea cliff. At the eastern end of the WWF site the cliff is about 10 m high and lowers to about 4 m by about 1.2 km along the shore. Figure 2.3 (upper photograph) shows the cliffs east of the site, and the different strata within the exposure.

Along the cliff line where the shelly conglomerate bed is more elevated, eroded blocks provide armouring at the cliff-base (Figure 2.3, centre photograph). Where this bed is lower, a narrow platform (1-2 m wide) is evident near the base of the cliff.

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 2.3 upper photo), indicating that wave action regularly reaches the base of the cliffs.

The cliffs at the western end of the site are about 8 m high and extend south from the Whenakura River mouth for a distance of about 2 km (Figure 2.3, lower photograph). Gaps or recessions in the cliff occur along this section. Wind-borne beach sand can funnel landward through these gaps, and is deposited on the terrace surface forming sand dunes.

Figure 2.3 Examples of the cliff along the shore adjacent to the WWF site. Upper photograph shows the conglomerate controlled cliffs east of the site, with debris at the base of the cliff. Centre photograph shows the vertical cliffs protected at the base by eroded blocks and less erodible material. The nearshore shore platform is also visible. The lower photograph shows the near-continuous cliffs along the western end of the site, with gaps where sand blows from the beach to the dune complex (Sources: Author and Isthmus Group Limited)

2.3.2 Sand dune section of shore

The beach system appears well supplied with sand, with the sources being the local rivers, the nearshore seabed and erosion of the cliffs to the west and east. Although the coast has an overall erosional trend, the dune system sediment budget is possibly in surplus. The wider erosional trend is likely the result of retreat of the cliffs, which act as headlands to the sand dune section of the shore. There is also likely to be a small net loss of sediment from the beach system to the dunes landward of the foredune. However the dune system is dynamically stable to accretional, with mobile dunes growing in size and stabilising due to a varied and healthy vegetation cover.

Figure 2.4 shows the wider extent of the dunes that extend from the beach to within the WWF site, mostly within the EBZ, but with some areas of active dunes in the project envelope. The area of dunes includes foredunes at the landward limit of the beach, a primary dune system (or main dune complex) that has a patchy vegetation cover and contains mobile dune forms and areas of bare sand, and a secondary dune system that is mostly well vegetated and has relatively stable dunes. There are also remnant dunes landward of the EBZ. Some of these are unstable and poorly vegetated. These and other areas of bare sand, as of an aerial photograph from July 2013, are outlined in black on Figure 2.4.

Figure 2.4 The area of dunes in the vicinity of the WWF site (in Blue). The site boundary is shown in red, with the EBZ shown by the white shaded areas with green speckles. Blue dots are indicative turbine sites. Dune topography and processes are prevalent seaward of the blue line. Approximate areas of bare sand are outlined by or seaward of the black lines (Base photograph source: Trustpower).

The central section of the shore adjacent to the WWF site is a sand beach with an active foredune and dune system. Examples of the types of dunes and vegetation cover are shown in Figure 2.5. The sand is medium to fine in size, although there are areas where pebbles and cobbles are present. The coarse sediment is likely to be eroded from the exposed conglomerate deposits, although there are patches of pebbles and cobbles offshore (McDougall and Gibb 1970).

Figure 2.5 Examples of the dune field: a) Top left, semi-vegetated dunes, mobile and stable areas of sand, seaward of the WWF site; b) Top right, foredune, occasionally eroded, but also source of sand for the main dune complex; c) Middle left, small stream channel crossing the foredunes east of Waipipi Stream, seaward of the WWF site; d) Middle right, deflational dune landward of the EBZ and on the project envelope; e) Bottom left, sand plateau landward of the coastal dunes within the EBZ, also showing range of vegetation from natives introduced pastoral grasses; f) Bottom right, highest inland dune at margin of Waipipi Stream within the EBZ

The foredunes are the seaward facet of the broad dune system (Figure 2.5b and c). There are areas that are well vegetated, and also bare dune features, including some stable and some very unstable dunes. Sand dunes extend inland for some 140 to 700 m from both the cliff and foredune shoreline. Overall the dune belt covers approximately 135 ha of the coastal margin adjacent to and within the WWF site (this area is seaward of the blue line on Figure 2.4). Dunes near the coast are up to 12 m high with approximately 26% being bare or partially vegetated and vulnerable to wind erosion. These areas are outlined or seaward of the black outlines on Figure 2.4. Dunes landward of the coast, and within the EBZ and the WWF envelope can be up to 12 m higher than the surrounding land, with the elevation of the peak of the highest dune (near Waipipi Stream) over 30 m above sea level (Figure 2.5f). Approximately 15 ha of area within the WWF project envelope can be considered as part of the active dune complex.

Areas with bare sand (deflation areas) and erosional remnants of a former lake or coastal lagoon associated with Waipipi Stream are evidence of dune instability and past episodes of erosion of the conglomerate sediments. There is evidence of present-day mobility within the dune system (Figure 2.5d), including migrating parabolic dunes. Active or presently unstable dunes are also present within the EBZ and the project envelope. It is likely that dune instability is associated with sand moving from the beach and bare dune areas near the coast, and loss of vegetation, possibly due to stock grazing on inland dunes.

Landward of the main areas of dunes, the land surface is relatively flat. It is also dissected with large drainage channels. The flat land is a result of ironsand extraction activities during 1971 to 1987. Prior to sand mining, the area was part of a major transgressive dune field named the Waverley Dune Complex (Fleming 1953). In common with many other New Zealand coastal areas, this complex was probably highly mobile (with unstable, un-vegetated dunes) 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.

Aerial photographs taken in 1949 show that an area of approximately 200 ha on or seaward of the WWF site, contained actively mobile dunes. The surface topography was characterised by a chaotic assemblage of hummocky dunes, saucer and trough depressions, deflation flats, dune slacks, swamps, wetlands and ridges. These are all characteristic of an active dune system. More recent aerial photographs show a relatively small number of parabolic dunes developed as and after the sand sheet became partially vegetated. However blowouts have also developed in the higher dunes and formed expanding rims around deflation basins.

Ironsand mining resulted in many of the dunes being levelled and sown in pasture. The inland part of the dune system is therefore heavily modified by past human activities. Up to 35 ha of the dune field is in a bare or partially vegetated state and thus vulnerable to wind erosion, with most of the areas of bare sand within or seaward of the EBZ.

Landward of the cliffs east of Waipipi Point, the dunes are relatively low in elevation above the general topography, and appear stable and well vegetated. Between Waipipi Point and the Waipipi Stream mouth, approximately 26 ha of unstable dunes front the beach and extend inland up to 200 m, mainly seaward of the WWF site, although partly within the EBZ (as shown on Figure 2.4). A major depression runs parallel to the coast between a former sea cliff, which runs inland behind Waipipi Point, and the youngest dunes near the coast. Some smaller areas of bare sand (deflated dune sections), of less than 2 ha in area, are associated with a second smaller line of dunes located 300-500 m inland from Waipipi Point. These areas are within the WWF project envelope.

North and west of the Waipipi Stream mouth, there is an unstable area of dunes landward of the foredune. Here the shoreline is orientated more toward the west so the wind resultant (the predominant wind direction related to potential sand movement) is directed more onshore and there is greater potential for sand to blow inland from the beach. A major sloping deflation area (greater than 5 ha) is present within the EBZ, with sand being funnelled landwards across this area to form dunes up to 12 m high and lobes of sand extending into the area that was mined in the 1970s.

The dune vegetation includes grasses such as pingao (*Ficinia spiralis*), marram (*Ammophila arenaria*) and spinifex (*Spinifex sericeus*) and small woody shrubs such as boxthorn (*Lycium ferocissimum*), blackberry (*Rubus fruticosus*), lupin (*Lupinus arboreus*), tauhinu (*Ozothamnus leptophyllus*) and sand coprosma (*Coprosma acerosa*) (see also Sanders 2015).

3. Historical morphological changes

Work was undertaken by Trustpower to identify the historical changes to the shore morphology and position from aerial photographs and survey plans and from field examination. Shoreline positions were identified on the 1905 survey plans SO 15418 and SO 15419, and the orthophoto version of the 2007 aerial photograph of the area.

The plans were georeferenced to ground co-ordinates 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 labelled 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 shoreline position. The 1949 and 1980 photographs were supplied as image files with pixel resolutions of 0.25 m and 0.4 m respectively. The 2007 and 2012 image files were provided 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. The 2007 aerial photograph was used to determine shoreline position, as it contained a better-defined image of the shoreline than the 2012 photograph.

Between 1905 and 2007 the cliff sections of shore eroded. The average erosion distance of the cliff at the eastern end of the WWF site was 5 m, while the average erosion distance of the cliff at the western end was 8.5 m. The use of only two time samples is acceptable owing to the relatively long period of time between them, and that cliff recession is essentially a one-way process. The lower rate of cliff retreat along the eastern section of cliffs is likely related to control of the process by the more resistant shelly conglomerate.

The 1905 and 2007 shorelines were identified and digitised along the dune section of coast. Differences between the shorelines were measured at 50 m intervals along the coast. Overall, the dune section of shoreline shows long-term retreat, calculated at 6.75 m over the 102-year period. In contrast to the cliff sections, there is considerable variation in the changes for different positions along the shore. This is due to the irregular nature of erosion and subsequent rebuilding of the foredunes along the shore, resulting in the shoreline not being a linear feature, and being dynamic over short periods of time in response to changes in wave energy and direction of wave approach.

4. Potential future shoreline position adjacent to the WWF site

Although dynamically stable, the coast adjacent to the WWF site is subject to episodic periods of fluctuation relating to changes in the process environment. Periods of storm waves can result in prolonged episodes of erosion of the cliff and foredune, while periods of strong winds can result in dune blowouts and movement of bare sand across the backshore. In addition, climate change scenarios indicate changes in sea level and weather patterns over the next 100 years. Sea level rise, for example is projected to result in erosion of sandy shores.

Long-term climate changes may also result in more sand moving off the beach onto the backshore area or may increase the occurrence of such events. Shoreline change can also result in destabilisation of the foredune with sand drifts then able to destabilise the landward dunes. Other aspects of climate change can also affect stability of the landward dune system. While there are no official guidelines to quantify such effects, a qualitative appreciation can be derived from first principles. Table 1 summarises the potential effects relevant to the coast adjacent to the WWF site.

Table 1 Impacts of climate change on coastal sand dunes

Expected climate change parameter	Potential impact on sand dunes
Increase in westerly mean/extreme wind strength	Increase in both foredune and landward dune erosion
Increase in storm frequency	Increase in both foredune erosion and landward dune erosion
Increase in El Nino extreme events	Increase in both foredune erosion and landward dune erosion
Increase mean and extreme rainfall	Increased vegetation so reduction in wind erosion

Sources: MfE (2008), Spence (2011), NIWA (2013), Cai *et al.* (2014)

Long-term changes to the shoreline position, based on common, recommended methods of study, such as guidance notes published by Ministry for the Environment (MfE 2008), the New Zealand Coastal Policy Statement (NZCPS, 2010) and NIWA (2012a, 2012b) have been determined. The NZCPS provides that coastal hazards risks should be considered to 100 years and should include a consideration of the effects of climate change. This consideration results in a determination of the possible, or projected erosion hazard that might arise. Projected erosion of the cliffs and the dune sections of coast related to the effects of climate change to the year 2115 have been undertaken based on a Shoreline Erosion Hazard Distance (SHED) have been calculated.

The method of calculating the SEHD is based on guidance in MfE (2008), NZCPS (2010) and NIWA (2012a, 2012b) and can be summarised by equation 1.

$$SEHD = LT + ST + RSLR + (DS \text{ or } SS) + FoS \quad (1)$$

Where: *LT = Longer-Term historic shoreline change, ST = Shorter-Term shoreline fluctuation, RSLR = Retreat associated with predicted Sea-Level Rise (SLR) induced by global warming, DS = Dune Stability adjustment, and FoS = Factor of Safety*

The distance of projected erosion for the dune section of coast ranges between 131 m in the east and 101 m in the west.

Cliff erosion is a complex one-way process such that the cliff face cannot recover a previous seaward position once it has retreated due to erosional from a combination of weathering and slope processes coupled with wave action removing underlying less lithified bed material and reducing basal support.

With a factor of safety included, the projected erosion of the cliffs was calculated at 25 m for the eastern cliff section, and 43 m for the western section of cliffs over a 100-year period.

5. Potential coastal hazards for the WWF site

5.1 Hazard identification

The types of coastal processes adjacent to the site that may result in coastal hazards include long-term erosion that may result from climate change, and in particular the effects of sea level rise, and wind erosion and landward migration of sand dunes. In addition, there is potential for inundation of low lying land adjacent to Waipipi Stream due to extreme wave run-up or impounding of floodwaters by natural blocking of the stream outlet through the beach. International studies of wind farms located on or near active sand dune environments highlight the need to consider the effects of wind-blown sand on the installation infrastructure, external surfaces, turbines, blades, access roads and maintenance costs (for example Spatuzza 2014). Such matters are beyond the scope of this report.

The coast adjacent to the site is subject to historical erosion rates of less than 0.1 m per year, with retreat of the cliff shoreline of about 8 m between 1905 and 2007, and erosion of the seaward line of dunes by about 6 m over the same time period.

The New Zealand Coastal Policy Statement provides that the potential effects of climate change are to be considered. The Ministry for the Environment (MfE 2008) guidelines with respect to planning for climate change and sea level rise recommend allowance for a rise in sea level of 0.5 m by 2100, and the consequences of a rise of 0.8 m relative to the 1980 to 1999 average sea level should be examined. For the purposes of assessing the effects of climate change and projected sea level rise, MfE guidelines (2008) and subsequent reports on coastal change (NIWA 2012a, 2012b), sea level rise issues (Royal Society of New Zealand 2010) and defining coastal hazard zones (Ramsay *et al.* 2012) have been considered.

Potential erosion of the adjacent shoreline as a result of climate change and sea level rise was calculated using recommended methods. Retreat of 25 m and 43 m of the cliff shores to the east and west of the site respectively could occur by 2115 under the recommended scenario, and erosion of the sand dune backed low-lying beach could be up to 131 m.

The resulting shoreline erosion hazards do not extend into the WWF site. It is concluded that the site is not susceptible to coastal erosion when considering a 100-year period with regard to climate change and sea-level rise.

The areas of potential inundation from coastal flooding over a 100 year period are located either seaward of the WWF site, along the Waipipi Stream or in areas within the EBZ and coastal flooding is not considered to present a hazard to the project site.

The areas within the project envelope that may be subject to wind erosion and landward migration of sand dunes are shown on Figure 5.1. These areas were determined, based on historical precedence for the area and theoretical principles of wind potential and sand transport properties. The main factors in locating these areas are the presence of un-vegetated sand over the last ten years. These areas are larger than the areas of bare sand shown in Figure 2.4 due to the potential for the margins of the bare sand to extend onto vegetated land. Areas that appear vegetated in 2013 but based on historical incidence are susceptible to future erosion are also included.

Figure 5.1 Areas potentially susceptible to wind erosion. These are areas of recently active dunes and mobile sand, and are outlined by the black lines.(Base photograph source: Trustpower).

5.2 Coastal hazard mitigation for the WWF site

The only potential coastal hazard identified for the WWF site is encroachment of sand, either wind-blown or by movement on the ground surface. Coastal erosion is unlikely to have an effect on the project site, and inundation by coastal flooding (impeded drainage of terrestrial flooding or seawater inundation of low-lying backshore areas) is limited to areas seaward of the landward boundary of the EBZ.

Management of areas of bare sand within the site may effectively avoid wind erosion hazards. A dune management plan should be prepared and implemented. The plan should include monitoring of the areas of bare sand to identify changes in size of the area and movement of the extent of vegetation cover. Planting on bare sand within the WWF project envelope will enhance avoidance or mitigation of wind-blown sand and dune movement. Areas to be planted should be those within the WWF site that may present a hazard to infrastructure once locations for turbines etc. are decided. Sand binding plants such as pingao (*Ficinia spiralis*) and silvery sand grass, spinifex (*Spinifex sericeus*) could be used. However small shrubs such as tauhinu (*Ozothamnus leptophyllus*) or sand coprosma (*Coprosma acerosa*) at the leading edge of mobile dunes would also act to retard or halt the movement of migrating dunes. In addition, unstable dunes within the project envelope may be reshaped to produce a more stable form before planting.

6. Potential adverse effects of the project on the coastal environment

6.1 Identifying potential adverse effects

International literature on the effects of wind farms on sand dune areas is limited. However projects in Brazil (Spatuzza 2014, Meireles *et al*. 2013), Japan (Matsushima 2012) and

Western Europe (Bolle *et al*. 2013, Degraer *et al*. 2013) provide insight as to the possible effects on the physical coastal environment adjacent to the WWF site.

From an assessment of international studies, the main areas of potential effect of a wind farm on the physical coastal environment are:

- **Removal of the vegetation from fixed dunes** for the construction of access roads and the operation of earth-moving equipment and auxiliary vehicles. This could result in the elimination of sectors of the remaining inland fixed dunes;
- **Burial of fixed and mobile dunes** to level the ground for the installation of the turbines on areas of dune. This may be necessary for the preparation of the land for the construction of access roads and the installation of electric cables, construction sites and administration buildings, and the storage and maintenance of industrial equipment. This work could result in the removal of quantities of sand from the mobile and fixed dunes, to be replaced with coarser sediments and the compaction of soil for the construction of roads;
- **Impacts to the fluvial systems** are discussed in the terrestrial and freshwater ecology assessment (Sanders 2015, section 8). Work includes riparian enhancement;
- **Burial of inter-dune swales and lakes** for the construction of the access roads for the turbines;
- **Input of sedimentary substrates** and compaction of soils for the construction of access roads, construction sites and areas for the storage of materials. The compaction of the soil is essential to permit the transit of vehicles over the sandy substrate;
- **Artificial retention of mobile dunes** in order to impede their migration and potential burial of infrastructure. It may be necessary to retain the dunes during the construction and operation of the wind farm in order to prevent the dunes from burying the installations or provoking erosion at construction sites (turbine foundations and mountings, maintenance buildings and substations, and ditches for the installation of the electric cables). (Adapted from Meireles *et al.* 2013, p82)

The proposed WWF site covers an area that is highly modified. Areas of old and active dunes have been mined and the topography artificially contoured. Most of the area is flat rural pasture, and there is a network of access roads and tracks through the site. In comparison to many wind farm developments in New Zealand, the WWF will require minimal earthworks for turbine platforms, hard stand areas and the construction of a road network.

The formulation of an EBZ within the project site was based on environmental assessments. The EBZ encompasses locations identified within the project site where the establishment of turbines, ancillary buildings, roads or earthworks will be avoided. The EBZ also results in avoidance of adverse effects of the project on the adjacent coastal area. Areas of dunes, both where the topography retains a less-modified character in shape and vegetation, and where there are active dune processes (bare sand and migrating dune form), are generally contained within the EBZ, or seaward of the WWF site boundary.

There is flexibility in "micro-siting" of the turbines to ensure the most efficient use is made of the available wind resource. This flexibility also allows for accommodation of avoidance of areas where construction works may result in potentially adverse effects on the physical coastal environment.

Additional existing mitigation measures that recognise potential adverse effects on the wider coastal environment have also been adopted in the proposed work for the project. These include:

- Where possible, the internal road network will be aligned along existing farm access tracks.

- Roads will maintain a vertical alignment in order to minimise the interception of stormwater.
- Once construction is complete, there will be reduction of the width of the internal access roads, from 10 m to approximately 5 m, with the superfluous area rehabilitated and re-vegetated.
- Stormwater run-off that is collected from the internal access road network and hard stand areas, will be conveyed by channel and / or pipe systems to designated disposal locations (e.g. soak pits or discharges into the existing drainage channels on site).
- Excess spoil from the construction activities will be placed in specific spoil disposal areas within the project envelope. These areas will not be in the EBZ.

After consideration of the mitigation measures in the proposed work for the project, it is considered that the WWF will likely have negligible effects on the coastal environment.

7. Conclusions and recommendations

The coastal environment adjacent to the WWF site is predominantly an active dune system bounded by cliffs to the east and west. The project site is highly modified, with both old and active sand dunes mined for ironsand in the 1970s and 80s. The mined area was levelled and planted in pasture.

Historically, the shore adjacent to the WWF site is erosional, but at slow long-term rates. The site is located landward of projected long-term coastal erosion, but could be subject to the effects of blown sand and migrating sand dunes.

The EBZ effectively encompasses most areas of active sand dunes, and projected future coastal hazards. However as shown on Figure 5.1, there are areas of bare sand and potentially mobile dune forms that are not included in the EBZ.

Potential adverse effects of the project on the physical coastal environment and physical coastal processes relate mainly to modification of some of the most inland parts of the dune system and changes to terrestrial and ground water flows through construction of the turbine foundations, roads, hard stand areas and ancillary buildings. These effects are recognised and effectively mitigated in the proposed project works and design through the designation and exclusion of work within the EBZ and through construction methodology.

However in addition to those measures already undertaken, it is recommended that a dune management plan be implemented to avoid, mitigate or remedy adverse effects that may arise due to coastal hazards or that may result from the project. The plan should include a monitoring program to identify changes in the location and size of areas of bare sand within the project envelope, and should identify methods to stabilise those areas that may result in a hazard to the project. Such methods may include planting with plants appropriate for the area and effective at dune stabilising such as, but not limited to, pingao, spinifex, tauhinu, and sand coprosma. Modifying the shape of unstable dunes within the WWF project envelope could also be carried out.

8. References

Bolle, A.; Mathys, M.; Haerens, P. 2013 How the Belgian wind farm business made us discover the challenging environment of marine sand dunes, in: Van Lancker, V., Garlan, T., (Eds.). *Proceedings of 4th International Conference on Marine and River Dune Dynamics*, 15 -16 April 2013, Brugge, Belgium, 45-52

Bray, M.J.; and Hooke, J.M. 1997 Prediction of soft-cliff retreat with accelerating sea-level rise. *Journal of Coastal Research*, 13(2), 453-467.

Cai, W.; Borlace, S.; Lengaigne, M.; van Rensch, P.; Collins, M.; Vecchi. G.; Timmermann, A.; Santoso, A.; McPhaden, M.; Lixin, W.; England, M.H.; Wang, G.; Guilyardi, E.; Jin, R. 2014 *Increasing frequency of extreme El Nino events due to greenhouse warming*. Nature Climate Change Letter.

Cockayne, L. 1909 Report on the sand dunes of New Zealand: The geology and botany with their economic bearing. *Appendix, Journal of the House of Representatives New Zealand C-13*, 1-76.

Degraer, S.; Brabant, R.; Rumes, B. (Eds.) 2013 *Environmental impacts of offshore wind farms in the Belgian part of the North Sea: Learning from the past to optimise future monitoring programmes*. Royal Belgian Institute of Natural Sciences, Operational Directorate Natural Environment, Marine Ecology and Management Section. 239 pp.

Department of Conservation 2010 *New Zealand Coastal Policy Statement* 2010. Department of Conservation, New Zealand Government, 28p.

Fleming, C.A. 1953 *The Geology of the Wanganui Subdivision*. New Zealand Geological Survey Bulletin n.s. 362p.

Komar, P.D.; McDougal, W.G.; Marra, J.J.; Ruggiero, P. 1999 The rational method of setback distances: applications to the Oregon Coast. *Shore and Beach, 67 (1)*, 41-49.

McDougall, J.C.; Gibb, J.G. 1970 *Patea Sediments*. New Zealand Oceanographic Institute Chart, Coastal Series, 1:200,000

Meireles, A.J.A.; Gorayeb, A.; Silva, D.R.F.; Lima, G.S. 2013 Socio-environmental impacts of wind farms on the traditional communities of the western coast of Ceará, in the Brazilian Northeast, Proceedings 12th International Coastal Symposium (Plymouth, England), *Journal of Coastal Research, Special Issue No. 65*, pp. 81-86

Ministry for the Environment 2008 *Coastal hazards and climate change: A guidance manual for local government in New Zealand, 2nd edition*. Ministry for the Environment, New Zealand Government, 129p.

NIWA 2012a *Defining coastal hazard zones for setback lines: a guide to good practice.* National Institute of Water and Atmospheric Research, 91p.

NIWA 2012b *Coastal adaption to climate change. Pathways to change* National Institute of Water and Atmospheric Research Ltd, Hamilton NZ

NIWA 2013 *Climate change scenarios for New Zealand.* https://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios

Pillans, B. 1990 *Late Quaternary marine terraces South Taranaki-Wanganui.* New Zealand Geological Survey Miscellaneous Series Map 18. New Zealand Geological Survey publication. 46p plus map

Ramsay, D.L.; Gibberd, B.; Dahm, J.; Bell, R.G. 2012 *Defining coastal hazard zones and setback lines – a guide to good practice* National Institute of Water and Atmospheric Research Ltd, Hamilton NZ.

Royal Society of New Zealand 2010 *Sea level rise: Emerging issues* Emerging issues paper produced by Royal Society of New Zealand, September 2010

Sanders, M.D. 2015 *Waverley Wind Farm Terrestrial and freshwater ecology assessment.* Ryder Consulting Ltd report prepared for Chancery Green on behalf of Trustpower Ltd. 103p.

Shand, T.D.; Shand, R.D.; Reinen-Hamill, R.; Carley, J.; Cox, R. 2013 A review of shoreline response models to changes in sea-level. *Proceedings of the Australasian Coast and Ports Conference, Sydney*.

Shand, T.D; Reinen-Hamill, R; Kench, P; Ivamy, M; Knook, P.; Howse, B. 2015 Methods for probabilistic coastal hazard assessment. *Proceedings Australasian Coasts and Ports Conference, Auckland.*

Spatuzza, A. 2014 Avoiding excess erosion in a sandy environment. *Wind Power Monthly*, e-journal accessed through: http://www.windpowermonthly.com/article/1281868/avoiding-excess-erosion-sandy-environment

Spence, H. 2011 *Climate Change Effects and the Importance of Sand Dunes.* Dune Restoration Trust of New Zealand. Technical Article 4.1. 8p.

Sunamura, T. 1992 *Geomorphology of Rocky Coasts.* J. Wiley, Tokyo, 302p.

Townsend, D.; Vonk, A.; Kamp, P.J.J. (compilers) 2008 *Geology of the Taranaki area: scale 1:250,000*. Lower Hutt: GNS Science. Institute of Geological & Nuclear Sciences 1:250,000 geological map 7. 77 p. + 1 folded map

Walkden, M.J.A.; Hall, J.W. 2005 A predictive mesoscale model of the erosion and profile development of soft rock shores. *Coastal Engineering, 52*, 535-563.