Coastal Hazard Risk Assessment for Clifftop Developments Ltd., Wanganui

Report prepared for Glasson Potts Fowler on behalf of Clifftop Developments Ltd – Wanganui

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Client Report 05/3

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1. INTRODUCTION

1.1 Terms of Reference

In April, 2005, the writer was commissioned by Glasson Potts Fowler to undertake a natural hazard assessment for the coastal area 3.5 to 4.5 km northwest of the Wanganui Rivermouth (Fig 1). Particular emphasis was to be placed on the cliffs fronting the proposed residential development by Clifftop Development Ltd – Wanganui. In additions, risk-based development setback distances were to be derived which will subsequently be incorporated into a Wanganui District Plan change application to be prepared by consultants Glasson Potts Fowler. The brief for Coastal Systems was as follows:

- Describe the physical characteristics of, and processes affecting, the project site.

- Undertake a coastal hazard assessment and derive 2 risk-based development setback lines such that:

    i. the **primary setback** distance (line) defines an area landward of which there is a very low likelihood of instability occurring within a 100 yr planning horizon. There will be no building seaward of this distance (line);

    ii. the **secondary setback** distance (line) defines land for which the likelihood of failure during the 100 year period is uncertain. In particular this applies to land between the primary and secondary setbacks. Only temporary buildings such as decks, garden sheds and movable structures should be placed in this region.

- Produce a report which will contribute to the landscape concept drawings and the resource consent application.

1.2 Coastal Setting

The location of the proposed development and study site is shown in Fig 1. A 100 m wide beach and 300 m wide surfzone comprising fine sand, derived primarily from the Egmont Volcanic Zone, fronts a 50 m wide strip of dunes and 35-40 m high cliffs. Sixty years ago the beach intersected the base of the cliff. However, construction of the North Mole at the entrance to the Wanganui River during the late 19th and early 20th centuries, resulted in sand accumulation along the toe of the cliff, the beach was displaced seaward and dunes developed – processes which continue today. The cliffs consist of beds of weakly consolidated marine sediments which are overlain by more recent sediments of terrestrial origin. Prior to dune formation, direct wave attack ensured ongoing cliff erosion. However, the dunes now protect the cliff-base and cliff retreat has slowed as slopes adjust toward a stable form; this study will describe and quantify such retreat. While limited studies into shoreline change have been carried out in the past, no study of cliff behaviour has occurred.

1.3 Types of coastal hazard

The Resource Management Act 1991 (S 2) defines natural hazard to mean any atmospheric or earth or water related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire, or flooding) the action of which adversely affects or may adversely affect human life, property, or other aspects of the environment. Maintenance, enhancement and preservation of the coastal environment is required within sections 5 and 6 of the RMS 91 and in particular by the New Zealand Coastal Policy Statement (e.g. policies 1.1.4, 1.1.5, 3.4.3).

Several different types of natural hazard occur at the Clifftop Development site, the most significant of which is landslip of the cliff-face fronting the development area. While this report will concentrate upon quantitatively assessing the hazard associated with cliff retreat (sections 4-6), consideration is also given to several less significant (secondary) hazards (section 7). It is noted that the impact of extreme events such as earthquake, tsunami or extreme rainfall will not be considered.

1.4 Approach

Several lines of approach are used to assess cliff retreat and derive development setback distances.

- A slope analysis of surveyed profiles was carried out to help identify a stable angle. In addition, profiles from nearby sections of cliff closer to the Wanganui Rivermouth, which are known to have had a longer period of wave-protection, were also analysed;
- Computation of stable cliff profiles based on a relevant model of slope evolution;
- Estimation of the rate of cliff retreat with reference to the 100 yr planning horizon. This was carried out using measured retreat at the sites closer to the rivermouth, together with direct observation, and
- Derivation of risk-based primary and secondary setback distances.

The study begins by describing the data used in the study (section 2), and considering the physical characteristics and processes affecting the local coast (section 3).

Note that the following terminology will be adopted: the seaward toe of the cliff is referred to as the cliff-base or cliff-toe; the upper edge of the cliff is referred to as the cliff-edge or cliff-line, the region in between the cliff-toe and cliff-line is referred to as the cliff-face, and the area inland of the cliff-line is referred to as the cliff-top. The study area is that area of coast fronting the proposed residential development.

2 DATA SOURCES

2.1 Site inspection

A field inspection was carried out on the 2nd April, 2005. The entire study area and surrounds were walked and photographed. The geological structure and lithology were recorded, together with the cliff configuration and evidence of recent slope instability.

2.2 Cliff profile survey

Dune and cliff profiles were surveyed on 23rd and 25th of April, 2005. A Geosystems 'LaserAce' Rangefinder was used; unit has an accuracy of 0.03 to 0.1 m over a range of 300m. The instrument was located along the foredune-crest at positions which were fixed using a Garmin 'eTrex' GPS unit with a 12 parallel channel receiver. This instrument has a maximum error of 5 m.

Eight profiles were surveyed at locations marked P1 to P8 in Fig 2. These locations were selected to cover the range of cliff morphologies evident at the site. All changes in slope from the dune-toe to the cliff-edge were recorded in terms of horizontal and vertical distance from the dune-crest. The angles for each slope segment were subsequently derived and analysed (section 5). Photographs of each profile location were also taken to assist subsequent analysis and interpretation of results.

2.3 Aerial photographs

Vertical aerial photographs from 1962, 1974, 1990, 2000 and 2004 were obtained and inspected. Contoured maps, stereographically derived from the 1962 and 2004 vertical aerial photos (distance accuracy +/- 1 m, elevation accuracy +/- 0.2 m), were obtained and analysed.

2.4 Resident observations

Long-term residents whose homes are located along the cliff-top to the east of the study area, were interviewed to obtain their views on changes to the ground surface within their properties.

2.5 Literature

A wide range of literature concerning historical and contemporary coastal processes and hazards was consulted.

3. PHYSICAL SETTING

3.1 Geology

The Wanganui region lies within an extensive sedimentary basin made up of four thousand metres of marine sediments deposited over the last 2.6 million yrs. These deposits consist of sequences of siltstone, shell beds/conglomerates and sandstone which represent the rising sea-level and high-stand portions of long-term (100,000 yr) sea-level fluctuations. The northern and eastern margins of the basin have been subject to ongoing uplift, and consequently along the northwest Wanganui coast in the vicinity of the study area, the strata dip gently to the southeast at 2 to 4 degrees. The uplift rate along the contemporary coastline at the study area is ~0.25 mm per year with this rate increasing both inland and toward the west. Such tectonic adjustment, coupled with the (climate-induced) sea-level fluctuations, have resulted in both the present wave cut cliff fronting the coastline, and the several subdued cliffs further inland which define a series of terraces. The upper portion of the present sea-cliff consists of cover-beds of more recent origin; these comprise dune sand, lignite and ash from the Egmont Volcanic Zone. Figure 3 graphically depicts the alternating strata and their dip from northwest to southeast (left side to right side of photo).

3.2 Geomorphology

The cliff fronting the study area shows distinct longshore variation in form, e.g. see Figure 4. These variations are related to the cliff geology in the following manner. Cliffs which are subject to wave attack typically undergo a 'cycle of erosion', and this occurred at the study site prior to protection of the cliff-base by sand dunes: the formation of these dunes is described later in this section. Wave action results in undercutting of the moderately soft rock outcropping at beach level. Mass movement involving rockfall and landslide then occur on the unsupported cliff-face. This can result in catastrophic failure of several metres at the cliff-top. Marine-induced currents then remove the resulting debris apron, and with the parent material once again exposed to wave action, another cycle of erosion begins.

Because the siltstone and shellbed/conglomerate strata are more resistant than the sandstone to wave erosion (when the cliffs at the study site were exposed to wave attack several decades ago), steeper slopes occurred where these formations intersected the shoreline and this gave the cliffs a bluff-like appearance which is still evident today. In addition, localized promontories occur in the bluff areas and these promontories are often separated by back-scars resulting from larger-scale and deeper mass movement (see Fig 4A). By contrast, where (less resistant) sandstone intersected the shore, increased erosion resulted in a detectable landward shift in the cliff-base and reduced angles on the lower cliff-face (e.g. Fig 4B). This variability in slope configuration complicates the coastal hazard assessment with lower slope angles occurring toward the ends of the study area and steeper bluff-like areas common within the central study area.

Because the Wanganui coast is subject to significant longshore sediment transport (littoral drift) from NW to SE, construction of the Wanganui Rivermouth Moles (1884-1930) resulted in the entrapment of sand along the NW coast. The initial effect was most dramatic closer to the North Mole. Between 1884 and 1942, the shoreline in this area was displaced seaward at an average rate of 5 m/yr, but little change occurred to the shoreline position in front of the study area. However, during the period 1942 to 1982 the progradation rate closer to the mole reduced to between 1.5 and 2 m/yr, while the rate at the study site increased to 1 m/yr. During more recent years (1990 to 2005), the rate closer to the mole has reduced further to ~ 0.5 m/yr, and the rate in front of the study area has continued to rise to 1.5 m/yr. The response is therefore nearing completion closer to the North Mole, but is having an increasing effect further west. This overall response pattern is consistent with modelling of littoral barriers. At the study site, an equilibrium shoreline will take several decades to achieve. It is further noted that prior to mole construction the coast in the vicinity of the study area was probably retreating at a rate of ~ 0.3 m/yr which is the present retreat rate for the unprotected cliff further to the west.

With the seaward movement of the shoreline, dune development occurred and a series of up to 3 dunes orientated parallel to the tide-line are now evident along the study area. These dunes form a barrier some 50 m wide both to waves reaching the cliff base, and also to freshwater reaching the sea. The freshwater originates as groundwater seeping from outcropping cliff strata, or surface drainage flowing down the cliff. This situation results in a minor wetland area between the cliff-base and dunes, a situation common on many sand-dominated prograding coasts.

The cliff-face is now substantially covered by vegetation, this being indicative of increasing stability. Figure 5A photographically illustrates the cliff cover in 1945, at a time when waves were still able to attack the cliff-base. By comparison, Fig 5B shows the same area in 2005. The slope is largely stable, although some isolated slip scars are still evident, and the vegetation cover has greatly increased.

4 SLOPE EVOLUTION and SLOPE STABILITY

4.1 Approach

While different rock types can each result in distinctive slope characteristics, other geological factors (e.g. joint spacing, porosity, composite beds, bed orientation), as well as climate and vegetation, may also influence weathering processes and slope development. It is therefore necessary to use empirical-based approaches when investigating slope stability.

4.2 Slope replacement model

For a cliff-face with a protected base, and given the physical and biological characteristics at the study site, it is appropriate to apply the 'Fisher-Lehmann slope replacement model' to represent the process of slope evolution. This model is conceptually depicted in Figure 6. An initial steep slope (> 40 deg), referred to here as a 'free-face', undergoes parallel retreat above an extending debris slope and eventually disappears with the debris slope covering the entire face. Note that debris slopes have approximately constant angles. The overall uniform slope on some cliff locations at the study site (e.g. Fig 4B), provides evidence that the model does apply to the study site, and, at least for some locations, the adjustment is well advanced. Slope replacement theory also has the debris slope ultimately being replaced by a still gentler slope produced when the transport of increasingly weathered debris extends a new depositional unit from the slope foot. However, once vegetation has established, as has occurred at the study site, subsequent change to the debris slope angle should be minimal.

As the free-face recedes, the debris apron extends both upward and also seaward to incorporate the available parent material, all-the-while maintaining a similar angle. The location of the stable (debris) slope once the free-face has been consumed, can be determined using the approach illustrated in Fig 7. It can be mathematically demonstrated that the depicted areas of removed material and infill material, are proportional to the total amounts of removed and deposited material as produced upon application of the Fisher-Lehmann slope replacement model. It is noted that for the material and conditions at the study site, it is reasonable to assume that the depicted areas of removed and deposited material are proportional to the mass of removed and deposited material. The cliff retreat measurement error at the study site is +/- 0.5 m.

4.3 Retreat rate

While application of the slope replacement model identifies the location and form of a final stable slope, the time required for completion of this process also needs to be addressed. In particular, if the rate of retreat can be identified, then the actual retreat experienced during the 100 year planning period can be determined. It is noted that the rate is not expected to be linear, as geomorphic systems tend to change more rapidly following an adjustment to the boundary conditions.

In general, if a suitable historical record of vertical aerials photographs is available, then detailed photogrammetric analysis can be used determine the past rate of change and this can provide a basis for predicting the future rate of retreat. However, this approach was not used in the present study and a worst case approach was adopted when computing the primary setback distance (PSD), i.e. the full cliff evolution leading to stability was assumed to occur within the 100 year planning horizon. This approach has probably resulted in the recommended primary setback being conservative. However, secondary setback distance does incorporate a rate of retreat (see section 6.4) based on other methods of estimation (see sections 5.3 and 5.4).

4.4 Assumption of continued cliff protection

The slope replacement model assumes that the present protection of the cliff-base by sand dunes will continue during the 100 yr planning period. The basis of this assumption is now examined.

As noted in section 3, the dune fronting the study area is encroaching seaward at ~1.5 m/yr, a rate likely to reduce to zero during the present century. However, this expected equilibrium will not occur if either the North Mole reduces in length, for example, through lack of maintenance, or changes occur to sea-level or in the wave/current pattern as a result of global warming. It is unlikely that the Wanganui District Council would allow the moles to fall into serious disrepair as the environmental impacts would affect public assets and property at Castlecliff Beach and along the south coast.

While a rise in sea-level can, all other things being equal, lead to beach and dune erosion, cliff protection at the study site is unlikely to be affected as the estimated dune retreat using two of the most common response models (see Appendix A) predict erosion of between12.9 and 31.9 m (0.129 and 0.329 m/yr) during the 100 yr planning horizon. This is probably not enough to offset the expected future mole-induced accretion during this period, let alone significantly erode the existing 50 m wide dunes.

Climate models predict an increasing prevalence of westerly winds during the next 100 yrs, a change that is expected to lead to more frequent and severe storms. Under these conditions, erosion of the foredune-toe will occur more frequently. While this process may enhance any shoreline retreat associated with a rising sea-level, the net effect is still unlikely to remove the foredune. However, erosion of the foredune occurs by causing a sand escarpment or cliff, and this can result in other, albeit relatively minor, forms of hazard to the Clifftop Developments. These hazards will be discussed in section 7.

5.0 RESULTS

5.1 Profile analysis

The eight surveyed profiles are depicted in Fig 8. The slope angles for each profile segment were calculated and, as an example, are marked on profile 1 in Figure 9. Arrows delineating the debris slope are also shown in Fig 9. The debris slope angle for each profile is listed in Table 1 along with the general cliff morphology in terms of promontory, inter-promontory or uniform topography. While promontory profiles 1 (P1) and 8 (P8) had similar values (30.2^o and 32.3^o) to the four non-promontory profiles (27.7^o to 33.8^o), in the other two promontory cases (P3 and P5) their values (37.1^o and 38.7^o) were significantly greater. Because the higher values lead to more conservative (smaller) cliff-top retreat values, only the four non-promontory (inter-promontory and uniform) profiles were used as a basis for calculating debris accumulation adjustments and retreat distances.

It is usual in slope stability studies to select a representative or characteristic slope angle. A conservative representative value for the four non-promontory values under consideration (32.8^o, 27.8^o, 33.8^o and 33.5^o) would be 30^o. However, because of the small number of samples, cliff-top retreat values were also computed for 28^o (to account for the minimum angle), and 32^o (the mean debris slope angle). Processing these three values will also demonstrate the sensitivity of cliff-top retreat to variation in slope angle. But before proceeding with the debris slope adjustment, it is noted that Gibb (1999) adopted a stable slope angle of 40^o for the cliffs at Mowhanau Beach to the west of the study area. While this value is greater than those proposed for the study site, stability angles for non-protected cliff-bases are typically several degrees greater than values for protected cliffs.

The cliff-top retreat values for non-promontory profiles (P2, P4, P6 and P7), as derived by applying the debris accumulation adjustment, are shown in Table 2. Retreat values range between 8.2 m and 11.8 m for the 32 degree slope, and these increase to 12 m and 14.5 m for the 28 degree slope, with mean values of 10.1 and 13.3 m respectively.
Note that a slope angle of 1^o results in a cliff-edge shift of 1.3 to 2 metres.

5.2 Upper Karaka Street cliff: slope angles

Because the seaward adjustment of the shoreline to North Mole construction began nearer the structure and slowly extended up the northwest coast to the study site, the sea cliff closer to the river has been protected from wave action for a longer time. The form of the cliff closer to the river, in particular the 1 km stretch fronting upper Karaka Street (see Fig 1), may therefore provide information on how the cliffs fronting the study area could appear in the future. It is noted that the cliff in the upper Karaka Street area is geologically similar to that at the study area. However, there are some difficulties to be taken into account when deriving and applying the upper Karaka Street cliff data to the study site.

Firstly, there are timing issues. It is possible some protection of the cliff-base existed prior to mole construction. Nonetheless, sand accumulation associated with the North Mole construction, which began in 1884, would quite probably have been affecting the upper Karaka Street cliffs by 1900. This suggests at least 40 yrs of accumulation had already occurred by the time the first vertical aerial photograph was taken in 1942.

That photo shows the Upper Karaka Street cliff-base to be fully protected by a well established foredune and wetland, the entire cliff-face to be covered in low vegetation, and the cliff-face to be stable, i.e. there are no slip-scars. By comparison, the photo shows waves still reaching the cliff-base at he study site.

Secondly, the 1962 contour map used to determine slope angles for the upper Karaka Street cliff-face, is biased toward lower angles. This is because the contours were derived from an aerial photograph and vegetation in the photo smoothes the underlying form of the cliff. The 1962 photo shows the vegetation to be denser than that in the 1942 photo. In addition, only 10 foot contours were processed due to resolution constraints. Critical slope changes were therefore not necessarily detected and this would also lead to lower angles.

Thirdly, the Upper Karaka Street cliffs are lower (25-30 m above MSL) than those at the study site (35-40 m), so adjustment to a stable profile would be completed more quickly at Karaka Street.

Finally, the extensive swamp that formed between the cliff-base and the foredune is expected to add an additional element of flow to the debris, thereby resulting in slope replacement to slightly lower angles.

Slope angles for the upper Karaka Street cliffs were measured at 10 profiles, the locations of which were selected so as to avoid promontory areas. Furthermore, only segments with angles between 20 ^{o} and 40 ^{o} were included so as to exclude non-debris areas. The mean angle was 28 ^{o} degrees and the range was 25 ^{o} to 31 ^{o}.
While these vales are lower than those from the study site (mean = 32^{o}, range 27.8 ^{o} to 33.8 ^{o}), this will partially be due to the smoothing influences noted above. Nonetheless, it would be prudent to select the lower value for the study site (say 28 ^{o}) as being a 'safer' representative stable slope angle.

5.3 Upper Karaka Street cliff-line change

To give some quantitative-based indication as to whether or not the upper Karaka Street cliff-edge is still active, the 1962 cliff-line was compared with the 2004 line using contoured maps and field inspection. Sampling occurred every 50 metres along the cliff-line. Surprisingly, the mean change in cross-shore location of the cliff-edge was 0.5 m in the seaward direction! This was found to result from land reclamation associated with retaining walls, constructed by residents. When all samples with such seaward change were excluded, the mean change was a retreat of 1.2 m over 42 yrs, i.e. 3 cm /yr or 3 m/100 yr. While the combined (rms) error associated with map accuracy and cliff-line detection is +/- 1.5 m, the sample size and averaging processes tend to cancel the errors, thereby ensuring the result is real, i.e. signal rather than measurement noise.

Relating the rate of retreat of the upper Karaka Street cliff to that at the study area is based upom the following reasoning. As argued earlier, the Karaka Street cliff protection and hence slope replacement and associated recession, occurred at least 40-50 yrs before that at the study area. This temporal difference is also supported by correlating the nature of the vegetation cover at the two locations, with the 1942 cover on the Karaka Street cliffs being similar to the present cover at the study site. The 0.03 m rate of retreat at Karaka Street for the period 1962-2004 will therefore occur at the study site in the future, with a somewhat higher rate probably occurring at the present time. The present retreat rate at the study site is likely to be at least 5 m/100 yrs.

5.4 Observed cliff change

Residents along Karaka Street observe occasional ‘dropouts’ on the face, and note that the cliff-top appears to subside and cracks appear in concrete structures near the cliff edge. These observations are consistent with ‘soil creep’ associated with weathering on the cliff-face, and constitute a slow long-term processes of cliff-face adjustment which is in keeping with the above minimal cliff recession rate.

Observation of rockfall and landslides on the cliff-face within and adjacent to the study site, have been observed by the writer over the past 15 years. While no depth measurements, or sequential mapping has been carried out, isolated cliff exposures several metres across and 0.5 to 1.0 m in depth are observed, especially during the winter (wetter) months. Event frequency at any particular location does not appear to exceed 10 yrs. These values suggest that the average retreat rate could range up to 10 m/100 yrs.

6.0 ASSESSEMENT OF CLIFF RETREAT HAZARD

6.1 Reference and setback line continuity

For this study, the existing cliff-edge is used as the reference for determining setback distances. While it is desirable to measure the hazard zone and setback distances continuously along the cliff, the level of morphological variation meant that profiles would have had to be measured, and processed using the slope replacement technique, every 10 m in the longshore direction. A conservative approach was adopted, with a single (maximum) setback distance being derived (section 6.2) and this value then applied to all non-promontory locations along the cliff-edge. The setback line is interpolated across promontory areas.

6.2 Primary Setback Distance (PSD)

The **primary setback** distance (line) defines an area landward of which subsidence is unlikely to occur within the 100 yr planning horizon. The following equation is used to define this primary setback distance:

$$PSD = D_{max} + F \qquad \text{Eqn 1}$$

Where:

D_{max} = maximum measured horizontal retreat of the cliff-edge associated with a slope angle of 28 degrees.

F = factor which consists of a 20% safety margin (which is the typical value used for this type of hazard assessment), plus the root mean square error from the profile survey and debris slope adjustment.

Substituting values for the components in Eqn 1 gives:

$$PSD = 14.5 + 2.9 + 0.6 = 18.0 \text{ m}$$

The PSD will therefore be 18 m (see Fig 10)

6.3 Visual impact of PSD

To determine the effect that the 18 m PSD will have on dimensions of residential buildings if the building is not to be visible from the beach, a profile extending from the spring low tide mark to inland of the cliff-line was analysed. Because the beach width can vary substantially, the average width at spring low tide was used, this being based on several years of profile data collected by the author. The visibility condition may be required to minimise development impact on the natural character of the coast. The profile, and eye-line of a 1.5 m high observer standing at spring low tide, are shown in Fig 11. To remain hidden from the beach observer, a building must be lower than 2.9 m at the PSD. In addition it can be seen that a 6.5 m high building, this being the proposed maximum for the development, will need to be located 20.5 m inland from the PSD.

It is noted that this calculation only applies to an observer standing directly in front of the cliff. Buildings not visible from that point may become evident with increased distance alongshore. Because of additional complicating factors including narrower beach width closer to the rivermouth, curvature of the shoreline, and reduced viewing because of cliffs intersecting the beach further to the west, it will be necessary to empirically determine the visibility pattern and development constraints. These issues will be discussed further in a landscape assessment by John Hudson and Associates.

6.4 Secondary Setback Distance (SSD)

The **secondary setback** distance (line) defines land for which there exists considerable uncertainty as to the likelihood of failure within the 100 yr planning horizon. In particular this applies to land between the primary and secondary setbacks The following equation is used to define the SSD:

$$SSD = D_{mean} \qquad \text{Eqn 2}$$

Where:

D_{mean} = mean retreat of the cliff-edge associated with the slope angle 32 degrees.

Note that factor F has been removed from the secondary setback equation, this being the usual practice in coastal hazard assessment in New Zealand..

Substituting the value for D_{mean} into Eqn 2 gives:

$$SSD = 10.1 \text{ m}$$

This compares well with the maximum retreat of 10.0 m/100 yr based on direct observation (section 5.4), and also encompasses the retreat distance of 5 m/100yr based on the upper Karaka Street cliff retreat analysis (section 5.3).

The SSD therefore be 10.0 m (see Fig 10).

6.5 Review and Monitoring

It is usual to carry out a cliff recession hazard review every 15 to 20 yrs and this is recommended should the Clifftop Developments proceed. While a conservative approach has been used in the present hazard assessment, several assumptions have been made, especially regarding the secondary setback distance, and these need to be tested.

Monitoring should consist off locating the cliff-edge every 5 yrs. Ideally this should be by direct measurement from survey monuments located back from the cliff-line. In addition, profile monitoring every 5 years should be carried out. This information will enable the nature and rate of cliff recession to be accurately identified, and the present setback model can, if necessary, be modified.

It is also noted that there is scope for the proposed setback distances to be reassessed by individual property owners seeking a plan change. A more detailed investigatory approach would include surveying closely spaced profiles (a LIDAR aerial survey would be ideal) and applying the slope replacement model to the debris slope on each profile. In addition, detailed photogrammetric analysis of the historical record of vertical aerials photographs could identify the actual rate of cliff retreat. This information should enable the primary setback distance to be reduced.

7 SECONDARY HAZARDS and MANAGEMENT ISSUES

7.1 Cliff-face vegetation

It is important to maintain the existing vegetation cover on the cliff-face as the selected stable slope angle is based on the presence of vegetation. Vegetation reduces weathering and mass movement firstly by increasing shear strength from roots which mechanically reinforce the soil, and secondly by decreasing shear stress by reducing soil moisture via transpiration and interception. Should the vegetation cover be reduced, slope stability could occur at a lower angle. The issue of vegetation preservation will be discussed further in the landscape assessment report and the plan change application.

7.2 Gully development

Surface drainage water flowing over the cliff-edge will rapidly incise through the cover-beds and then into the marine strata until reaching more resistant conglomerate or siltstone. At the same time headwall retreat will occur into, and eventually beyond, the setback areas. Several such examples of gully development are evident at the study area, including a recent example which appears to be incising at about 1m/yr. Particular attention will need to be given to removal (piping) of cliff-top surface water. Infiltration near the cliff-edge, including soak holes, should also be controlled to minimise hydraulic loading.

7.3 Beach drainage

Surface runoff and drainage from the clifftop residential area will be substantial at times and lead to ponding between the cliff-base and foredune. This situation will promote flowage within the lower debris slope which may affect the design stable slope angle and setback distances.

The impounded water will seep through the foredune and reach the beach thereby raising the water table and beach intersect. Raised water tables are known to promote beach erosion and this can contribute to cliffing of the foredune. Such cliffing is a primer to the development of blowouts and parabolic dunes – the relevance of this to the Clifftop Developments is discussed below.

Attention needs to be given to getting drainage water onto the beach more directly. Options include piping under the dune, a practice done elsewhere, e.g. along the Kapiti Coast, (although this could visually compromise the natural character of the Wanganui coastal environment), or excavating through the dune as has been done to drain water from the Karaka Street cliff area.

7.4 Foredune instability

Significant erosion (cliffing) of the foredune could be induced by several methods already discussed. In particular: via a sea-level rise and/or change in wind/wave climate from global warming; via shortening of the rivermouth moles through lack of maintenance, or raising the beach water table by surface run-off ponding between the cliff-base and foredune. Such cliffing could have consequences for the Clifftop Developments via the occurrence of blowouts and the parabolic dunes; processes which, along the Wanganui coast, are primarily initiated through such dune-front instability. Blowouts are erosional features where dune vegetation is removed and wind funneling causes guts to form through the foredune which can lead to the crest being ‘blown out’. Blowouts may enlarge into a parabolic shape and such parabolic dunes can migrate inland, losing contact with their beach origin. Large blowouts and parabolic dunes are able to jet sand inland for several hundred metres, and parabolics can ‘climb’ cliffs; indeed, the present clifftop dunes along the Wanganui coast, and dune-sand within the cliff-top cover-beds, originate from such processes. Should sustained cliffing be observed along the foredune fronting the study area, contingency plans should exist for dune stabilization.

7.5 Clifftop dune instability

The threat to residences from wind-blown sand originating from the existing cliff-top dunes also exists. Removal of vegetation at the clifftop via landslide or rockfall is the typical initiation mechanism for such instability; although stock grazing, fire, and development practices that remove vegetation may also initiate dune mobilization. Again, stabilizing measures will need to be quickly put in place.

8 CONCLUSIONS

i. The cliffs fronting the proposed Clifftop Developments are likely to continue to retreat into the foreseeable future, thereby creating an ongoing hazard.

ii. With the cliff-base permanently protected by sand dunes, wave-induced erosion of the cliff-case does not occur. The slope will continue to evolve via a process of slope replacement, toward a stable angle of 28 degrees. It is not known when this equilibrium slope will be reached. However, it is assumed that it will be achieved within the 100 yr planning horizon; this is a precautionary approach which maximizes the setback distance.

ii For a planning horizon of 100 yrs, an 18 m primary setback distance (PSD) is recommended. This distance is measured inland from non-promontory locations. The likelihood of cliff failure affecting the area landward of the PSD is very low and all types of building should occur (see Fig 10)

iii For a planning horizon of 100 yrs, a 10 m secondary setback distance (SSD) is recommended. This distance is measured inland from non-promontory locations. The likelihood of cliff failure affecting land between the PSD and the SSD is uncertain so only temporary or removable structures should occur (see Fig 10)

iv For a planning horizon of 100 yrs, cliff failure affecting the area seaward of the SSD is highly likely and no building or structures of any kind should occur (see Fig 10).

v. Secondary hazards and management practices associated with vegetation and drainage, together with dune and beach stabilization are outlined.

vi. The setback distances (section 6) and management practices (section 7) outlined in this report will preserve the natural character of the coast including the visual perspective for beach-users.

vii Ongoing 5 yearly monitoring practices, and 15 to 20 year review procedures are outlined.

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APPENDIX A Model of shoreline response to a global rise in sea-level

A rise in sea-level associated with global warming is expected to cause coastal erosion of sandy beach and foredunes such as those fronting the Clifftop Developments area. Two empirically-based approaches are now used to estimate the erosion distance; the Bruun Rule (Bruun 1983) and the Geometric Translation technique (Komar et. al., 1999). Each of these methods will now be described and applied to the study site.

1. The Bruun Rule

The Bruun Rule states that "for a shore profile in equilibrium, as sea-level rises, beach erosion takes place in order to provide sediment to the nearshore such that the nearshore sea-bed can be elevated in direct proportion to the rise in sea-level".
The Bruun Rule makes two assumptions:

- that the maximum offshore location beyond which no significant sediment exchange occurs is identified, this location is referred to as the closure point) . Several methods have been developed to identify the location of closure, and two of these will be used in this application; (a) the location at which the elevation standard deviation of a profile bundle becomes constant, and (b) the location seaward of the surf zone where a change in slope is evident. Data from Shand et al. (2000) is used to determine these values;

- that the volume of longshore drift moving into the area under study balances the volume moving out. The Wanganui coast has substantial littoral drift and longshore flux is inevitable. The derived dune retreat values should therefore be considered as a maximum as eroded beach sediment may well be replaced from longshore sources.

The equation proposed by Bruun is:

$$X = (l*a)/h \qquad \text{Eqn 3}$$

Where:
X = rate of shore (dune-toe) retreat;
a = rate of sea-level rise (a 100 yr value of 0.0045 m/yr is currently proposed by NIWA);
l = maximum cross-shore length over which sediment is exchanged. The distance from the foredune-crest to the closure point is typically used in NZ (see Gibb and Aburn, 1986). For closure method (a), l = 790 m, and for closure method (b), l = 1680 m;
h = maximum height across which sediment is exchanged. The elevation between the dune-crest and the closure depth is typically used in NZ. For closure method (a), h = 15.5 m, and for closure method (b), h = 23.7 m.

Applying these values to Eqn 3 gives a retreat distance of 0.229 m/yr (22.9 m for the 100 yr planning period) for closure method (a) and 0.319 m (31.9 m for the 100 yr period) for closure method (b).

2. The Geometric Translation approach

The geometric translation method involves translating the dune landward along the average inter-tidal beach profile until the design sea-level elevation is reached.

The model uses the equation:

$$E = s/\tan\beta \qquad \text{Eqn 4}$$

Where:
E = erosion measured landward from the present dune-toe;
s = rise in sea-level associated with global warming (0.0045 * 100 = 0.45 m using NIWA predictions);
β^o = average slope of the inter-tidal beach. In the case of the study site, the average slope is 2^o as derived from the profile bundle (Shand et al., 2000).
.
Applying these values to Eqn 4 gives an erosion distance of 12.9 m, (or 0.129 m/yr).

3. Interpretation

These two models provide dune retreat values ranging between 12.9 m and 31.9 m. While the actual value is likely to be at the lower end of the range based on the littoral drift situation outlined above, even the upper value will still not result in breaching of the 50 wide sand dune.

Table 1 Debris slope angles for each profile

Profile	Angle (degrees)	Morphology (see text)
1	30.2	Promontory
2	32.8	Uniform
3	37.1	Promontory
4	27.8	Inter-promontory
5	38.5	Promontory
6	33.8	Uniform
7	33.5	Inter-promontory
8	32.3	Promontory

Table 2 Cliff-edge retreat values (m) for selected slope angles after debris slope accumulation adjustment. Non-promontory profiles only.

Profile	Slope Angle (degrees)			Morphology (see text)
number	28	30	32	
2	12.0	10.0	8.2	Uniform
4	14.3	12.8	11.2	Inter-promontory
6	12.5	10.7	9.2	Uniform
7	14.5	13.2	11.8	Inter-promontory
Mean	13.3	11.7	10.1	
Max	14.5	13.2	11.8	

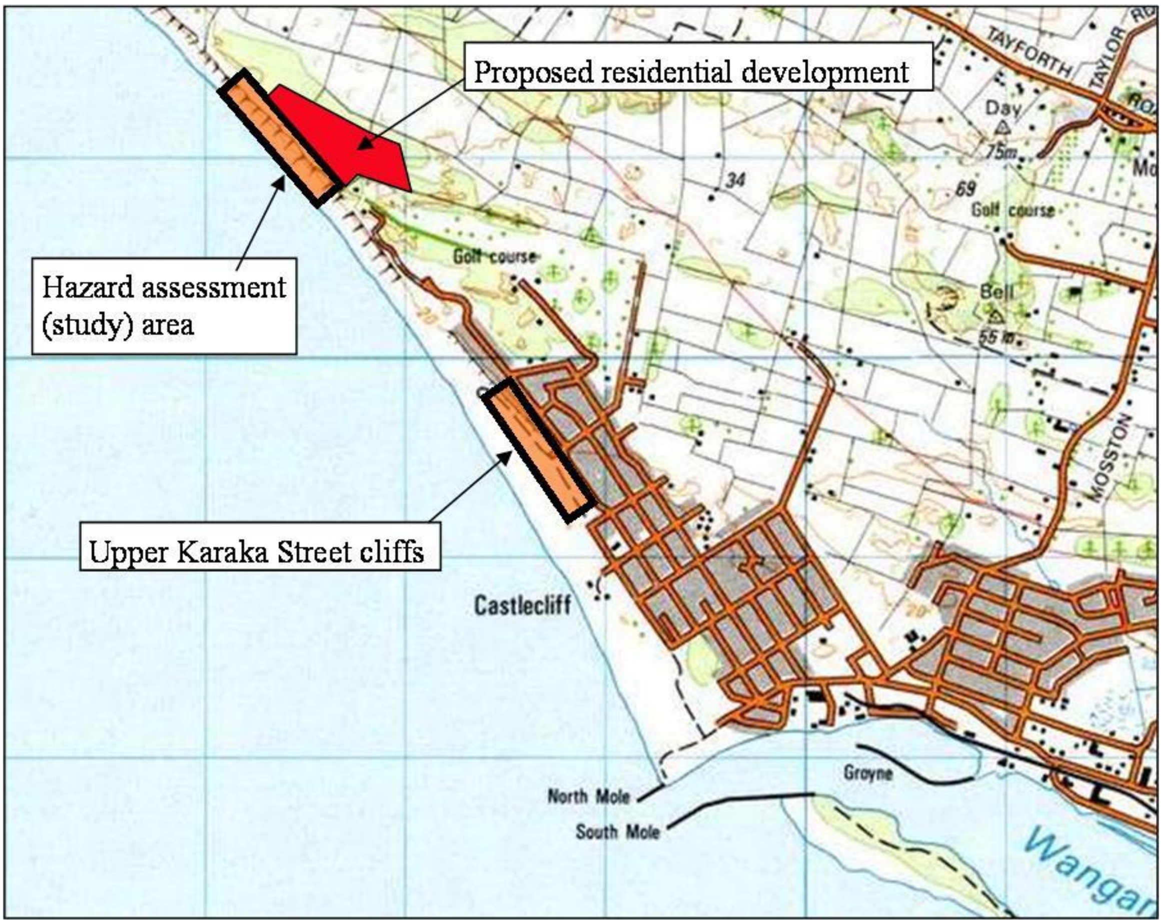

Figure 1 Location map of the study area. Upper Karaka Street cliffs are referenced in the text.

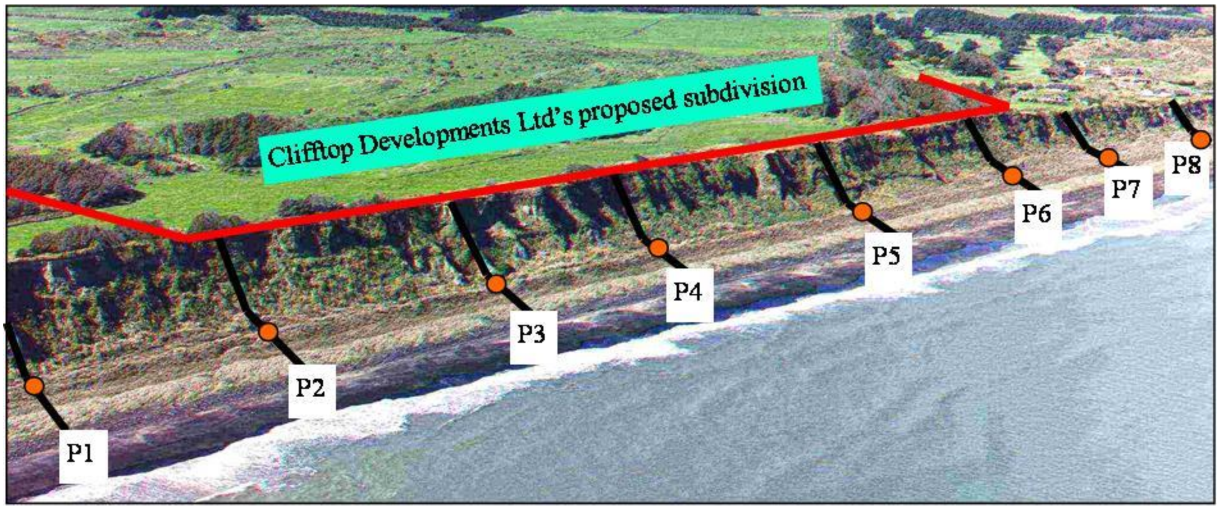

Figure 2 Surveyed profile locations at the study site. The red dots depict instrument locations along the foredune-crest.

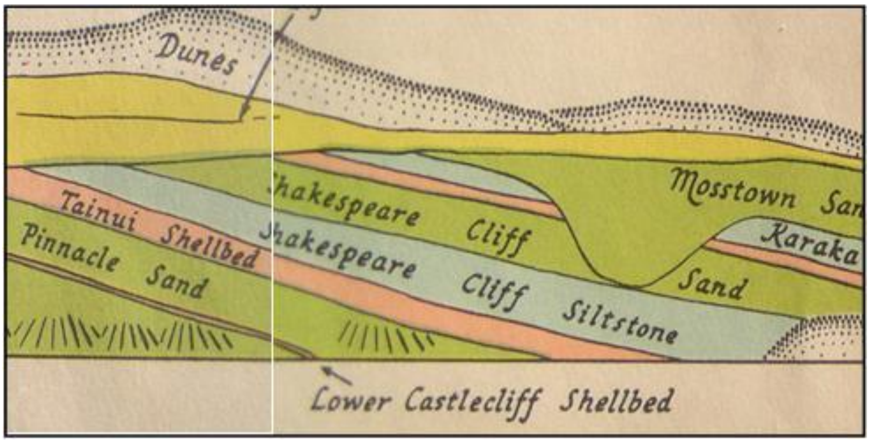

Figure 3 Cliff lithology and structure along 2 km of coast encompassing the study area (from Fleming, 1953).

Figure 4 Longshore variation in cliff form. In A, the cliff consists of promontories on each side of the photo and a central entrenched back-scar region. By contrast, B depicts a relatively uniform slope.

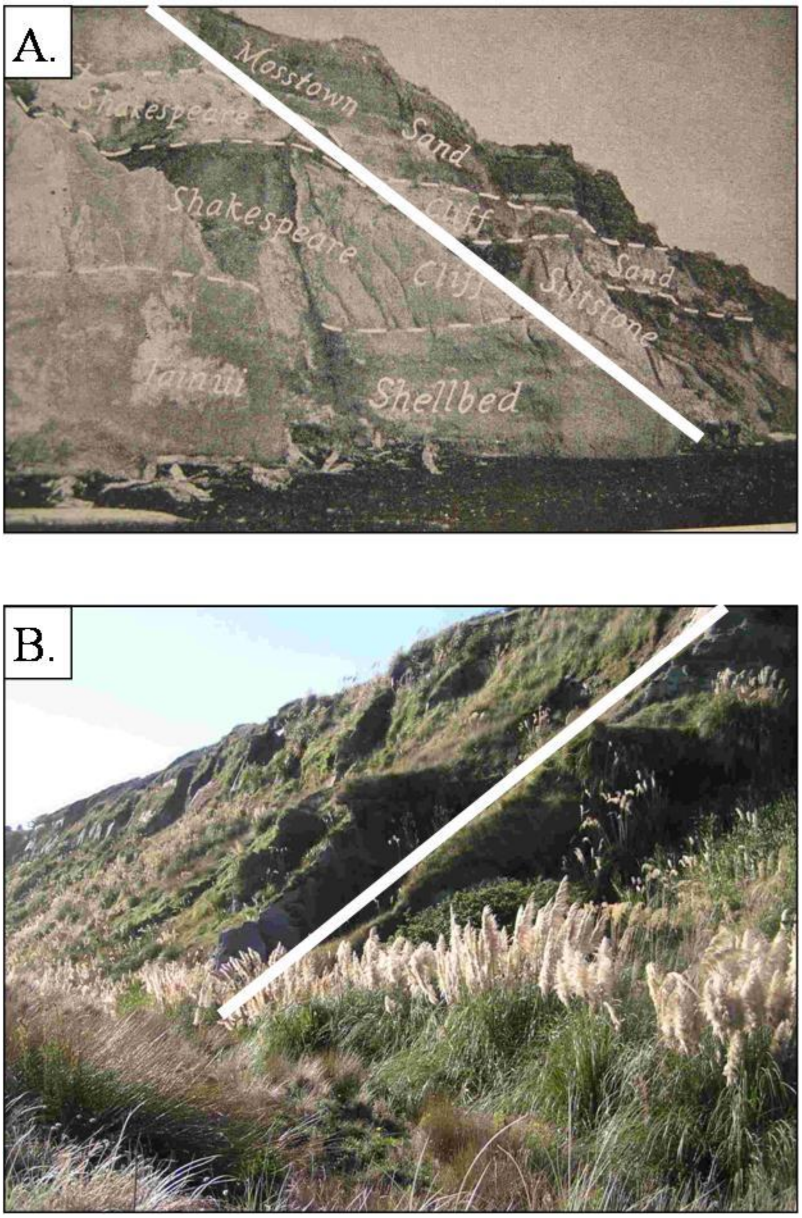

Figure 5 Increase in vegetation cover and cliff-face stability between 1945 (A) when the waves were able to attack the cliff base, and 2005 (B) when dunes protect the base. The while lines locate the corresponding slope profile within the two photographs.

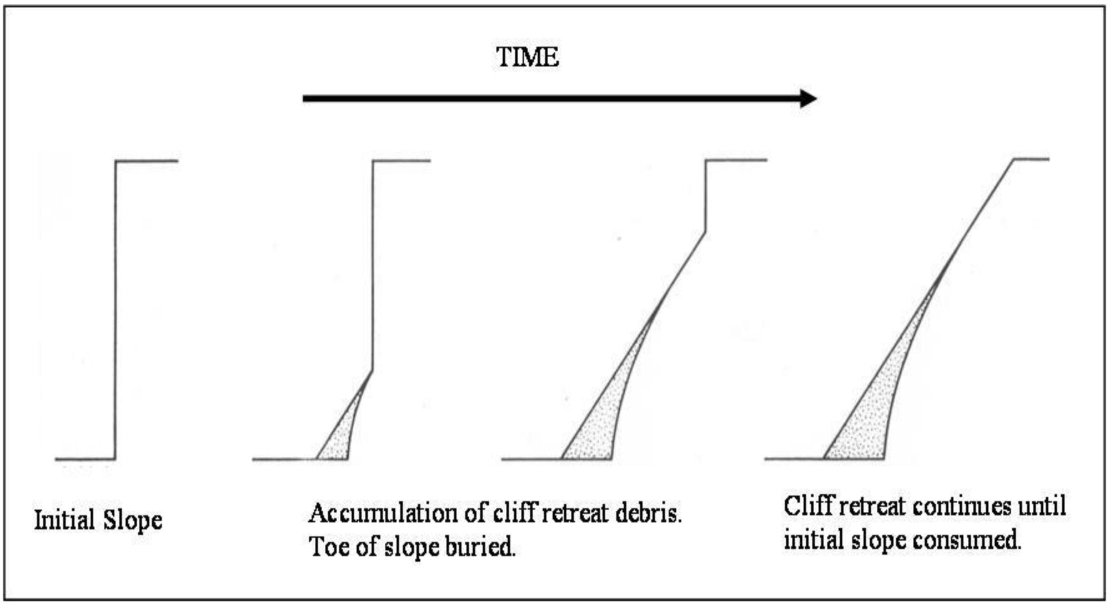

Figure 6 Fisher-Lehmann slope replacement conceptual model

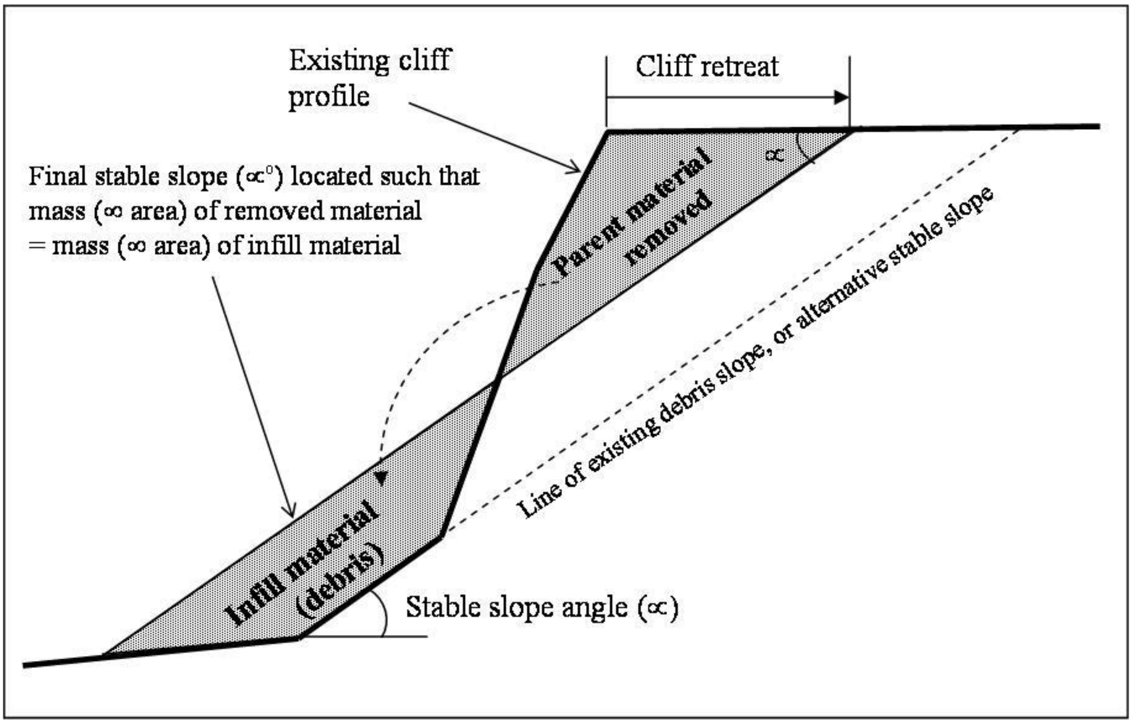

Figure 7 Debris slope adjustment diagram for locating final position of stable slope as determined by the Fisher-Lehmann slope replacement model.

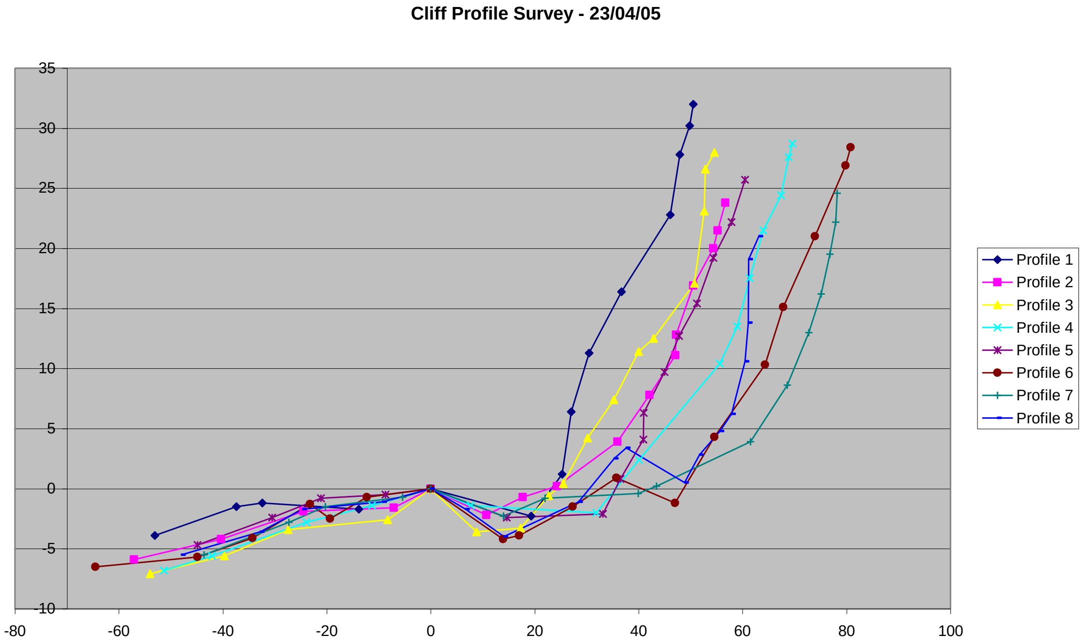

Figure 8 Superimposed dune/cliff profiles using the dune-crest as the elevation and distance datum.

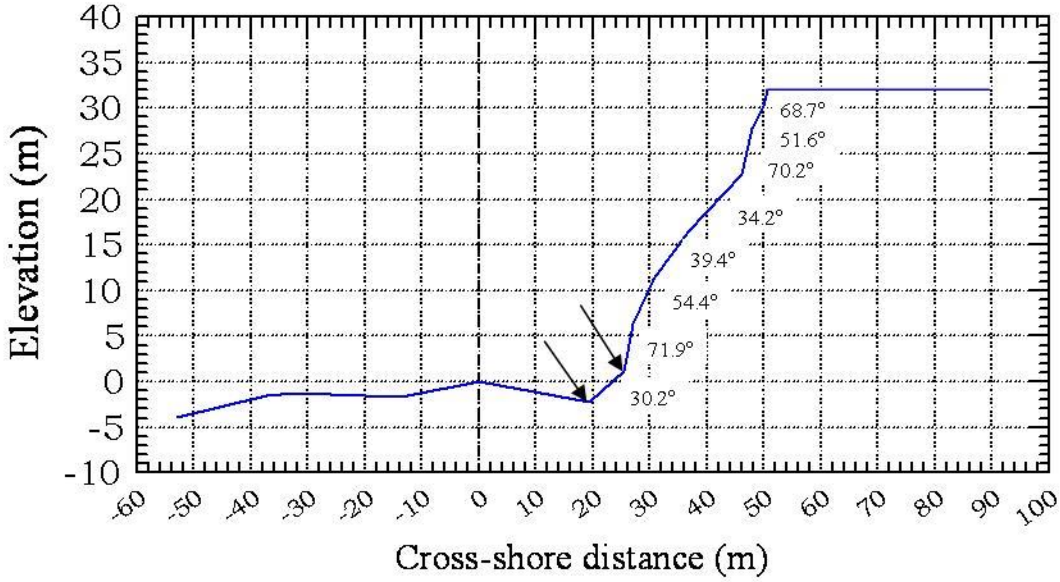

Figure 9 Profile 1 (for example) showing slope segments. Arrows define the debris slope.

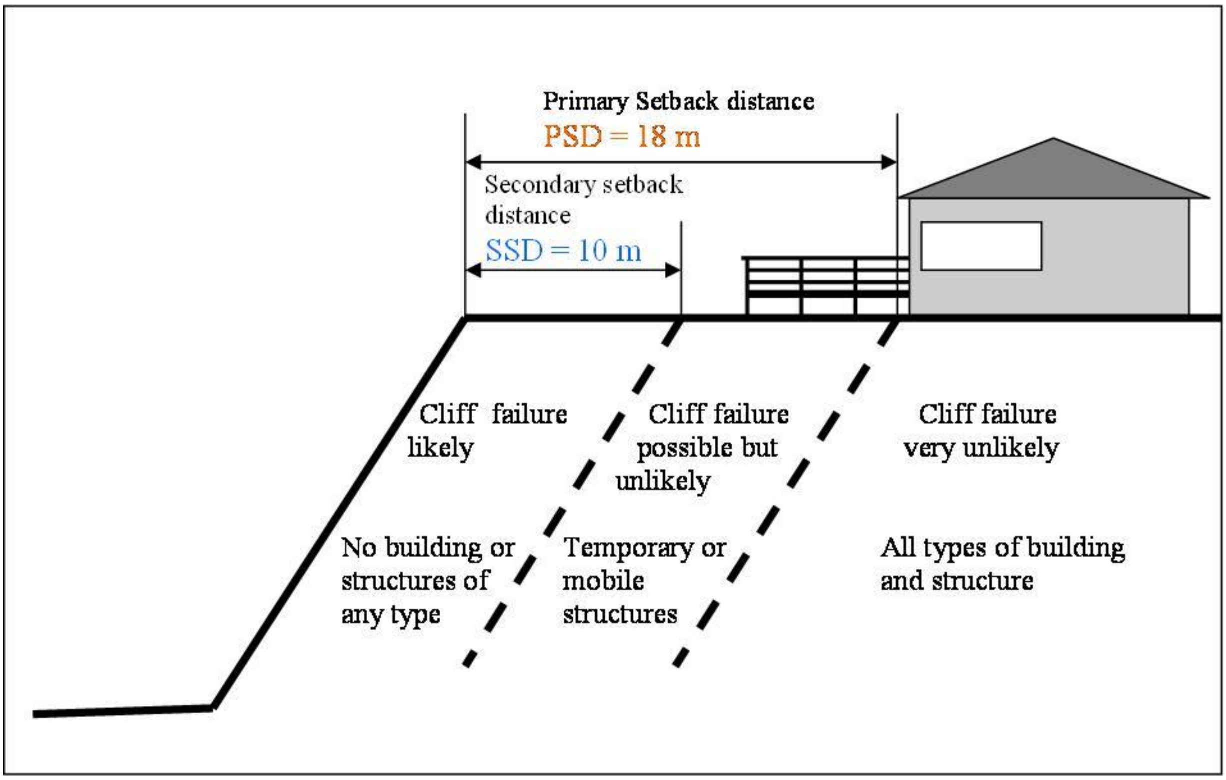

Figure 10 Risk-based setback distances for different types of development, as derived from the cliff retreat hazard assessment.

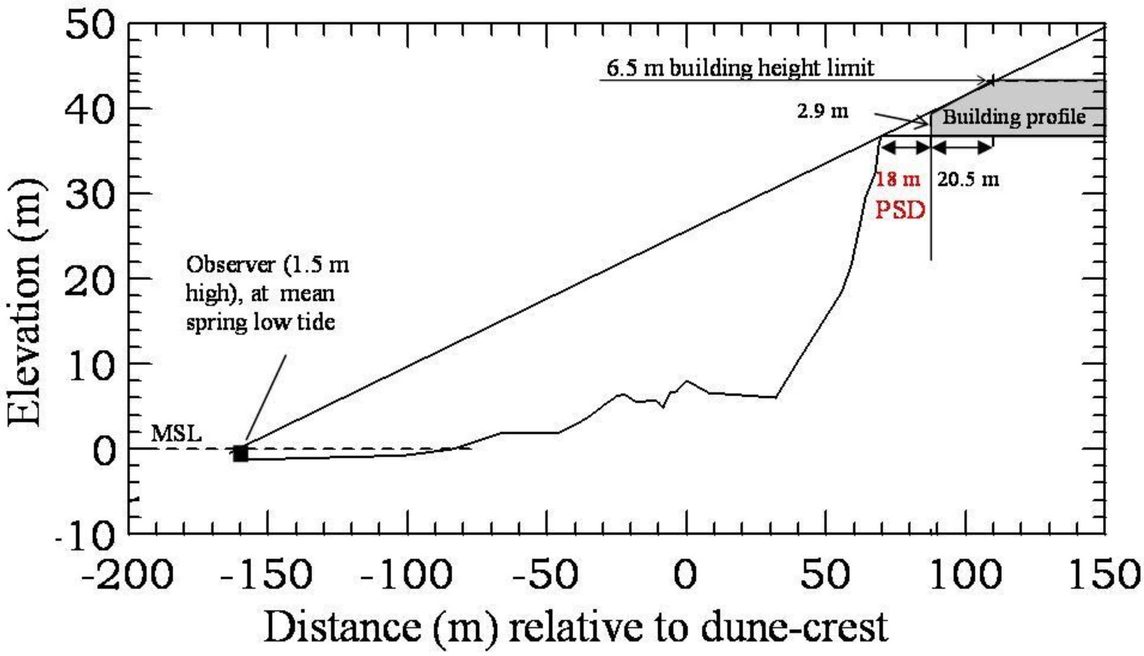

Figure 11 Viewing geometry, primary set-back distance and building height restrictions to hide development from beach observer locater directly in front of cliff.