

NCC Slope Instability Overlay Report

Prepared for Nelson City Council
Prepared by Beca Limited

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Executive Summary

Beca Ltd has been commissioned by the Nelson City Council (NCC) to produce a map overlay outlining land potentially susceptible to slope instability and impacts from the run-out of slope instability. The overlay is intended to identify areas requiring geotechnical assessments during the early stages of land planning and development for the purpose of managing or mitigating natural hazards and will help fulfil the Council's obligations under Section 30 of the Resource Management Act and inform the Councils' new resource management plan, (Whakamahere Whakatū Nelson Plan).

Hillslopes in the wider Nelson region exhibit slope instability ranging from large landslides of several square kilometres to shallow instability in the order of 10 m wide. The type and distribution of instability are closely related to the underlying geologic units and may be triggered by seismicity and/or high rainfall.

The identification of land potentially susceptible to slope instability generally followed the AGS (2007a) guidelines which identify the following settings as potentially susceptible;

- Cliffs.
- Natural slopes steeper than 35 degrees (rapid landslides may occur).
- Natural slopes 20-35 degrees (landslide travel possible).
- Steep slopes degraded by recent logging, forest fires, and/or road construction.
- Slopes where geologic and geomorphic conditions are such that sliding is possible.
- Slopes with a history of instability, including large currently inactive landslides subject to undercutting of the toe or reactivation by development.

Mapping was completed in ArcGIS considering available geospatial datasets including topography and slope angles, along with visible geomorphic evidence of existing slope instability, and a review of previously recorded slope instability in the region. Land downslope from areas considered susceptible to instability was subsequently assessed to determine whether the run-out of debris (i.e. soil and rock) may cause land damage. Mapping was completed at a scale of 1:5,000 and it is intended that any subsequent use is consistent with this scale.

The overlay identifies land considered susceptible to slope instability and within the run-out zone of debris from the instability. The overlay is not a replacement for site-specific investigations, nor does it consider risk to individuals and property.



1 Introduction

Beca Ltd has been commissioned by the Nelson City Council (NCC) to produce an overlay that defines land potentially susceptible to slope instability, including debris run-out zones. The overlay is intended as a tool to identify areas that warrant further geotechnical assessment during the early stages of land planning and development and to inform updates to the Nelson Draft Plan.

This report outlines the methodology and assumptions of our assessment and presents a map and associated GIS shapefile outlining the proposed areas of slope instability and run out. Our assessment considered the following aspects, as outlined in our proposal dated 14 April 2020:

- A review of readily available data sources including NCC landslide database, published geology, aerial imagery, and NCC-supplied hill shade model derived from the NCC Digital Elevation Model (DEM).
- Assessment of NCC's hill-shade model to identify locations and types of instability in the region, and subsequent incorporation into a slope instability inventory.
- Review of NCC's hill-shade model alongside mapped geology, slope angles, and NCC landslide records
 to identify land considered susceptible to slope instability and produce an overlay of zones to be
 considered in development planning.
- Assessment of slope instability run-out zones based on a review of historic events, slope angles, local knowledge and engineering judgement.

The output of our assessment includes development of a digital slope instability inventory and GIS map layer outlining proposed zones of slope instability and run-out which can be included in NCC planning maps/systems.

Risk is not considered in our assessment as it is specific to a given site and requires interpretation of the likelihood and associated consequences of the hazard.

2 Rationale and Background

The Resource Management Act (1991) requires councils to have specific functions to manage natural hazards, including slope instability. Hazard management may include the identification/ mapping of susceptible areas, zoning to manage development in susceptible areas, requirement of site investigations and/or engineering works to reduce risk, and/or rules for activities in impacted areas. Guidelines for assessing land instability are provided by the Australian Geomechanics Society (AGS; 2007a).

Slope instability, including landslides, are referred to by AGS (2007a) as the movement of a mass of rock, debris, or earth (soil) down a slope in areas where topography enables sliding to occur. The following settings are identified by AGS (2007a) as land potentially susceptible to instability;

- Cliffs.
- Natural slopes steeper than 35 degrees (rapid landslides may occur).
- Natural slopes 20-35 degrees (landslide travel possible).
- Steep slopes degraded by recent logging, forest fires, and/or road construction.
- Slopes where geologic and geomorphic conditions are such that sliding is possible.
- Slopes with a history of instability, including large currently inactive landslides subject to undercutting of the toe or reactivation by development.



The susceptibility of a slope to instability may be impacted by lithology (i.e. rock type), soil type and thickness, watershed size, and/or vegetation cover. Triggers for slope movement include rainfall, earthquakes, physical and/or chemical weathering, and land development. Rainfall is the most common trigger of instability however it is dependent on the duration and intensity of rainfall, along with pre-existing ground saturation and groundwater conditions. AGS (2007a) outlines that the best documented historical events have been triggered by high rainfall and involved saturated soils within the upper soil and rock profile (0.5 to 2.0m deep) on moderately to steeply inclined slopes and associated with relatively short duration (12-48hr) high intensity rainfall events. High intensity and/or prolonged rainfall may also re-activate large deep-seated landslides.

AGS (2007a) and GNS (2007) recommend that landslide susceptibility zonation include a basic inventory of existing landslides or instability features within the region of interest. Locations and types of existing features may be identified from historical records, previous mapping, and/or geomorphic evidence observed in aerial photographs, satellite imagery, or elevation models, and supplemented with local engineering knowledge. Geomorphic evidence of slope instability includes bulges at the toe of the failure, fans, irregular gully features, and scarps, and visual evidence including hummocky terrain, ponded water, and soil erosion. AGS (2007a) recommends map scales for susceptibility zonation to be in the order of 1:25,000 to 1:5,000.

3 Documented Instability in the Nelson Region

Slope instability in the wider Nelson region range from large landslides several square kilometres in area to shallow slope instability in the order of 10 m wide. Triggering mechanisms for instability include seismicity and/or high rainfall. Seismically induced landslides were reported in the wider Nelson region following the 1929 Murchison, 1968 Inangahua, and 2016 Kaikoura earthquake.

Types of instability previously observed in the area include:

- Deep landslides translational or rotational failures with slip surfaces between 3 and 25m deep. These
 landslides are typically observed close to mapped fault traces suggesting seismic triggering. Landslides
 may be reactivated during prolonged rainfall and/or elevated groundwater.
- Shallow slope instability rotational failures up to 3m deep and involving failures of the surficial clayey soils. Triggering is typically due to heavy rainfall.
- Earthflows Slow moving or creeping slope instability which are predominately clayey with entrained angular rock debris. Triggers can be seismicity, prolonged rainfall, and/or elevated groundwater.
- Rockfall Localised detachment of rocks from steep abandoned sea cliffs. Triggers can be rainfall, seismicity and/or general weathering.



The type and distribution of slope instability in the Nelson region are closely related to the underlying geologic units. The susceptibility of the underlying mapped geologic units has previously been described by Johnston (1991) and is summarised below.

- The Port Hills Gravel of the Tadmor Group has a low likelihood of movement. Small superficial slides may
 occur at the interface between the gravels and the overlying weathered and more permeable layer when
 the slope is saturated.
- The Marsden Coal Measures of the Jenkins Group is at high risk of movement with widespread shallow, superficial, and deep-seated movements. Instability typically result from high saturation levels as a result of the high-clay content impeding groundwater flows. Movement appears to be on-going or has the potential to be reactivated.
- The Matai and Richmond Groups generally have a high degree of stability although small superficial
 failures may occur within the weathering profile, particularly where the adjacent softer rocks have been
 eroded. Deep seated instability is present between the Waimea and Heslington Faults and were likely
 seismically triggered. Much of the instability is regarded as inactive however may be re-activated during
 future seismicity and/or earthworks.
- Superficial deposits including slope wash, scree, slump, and earthflow deposits are prone to shallow
 earthflows which are visible on the slope profile as hummocky ground, cracking, and/ or water seepages.
 Some earthflows appear stable however may easily be reactivated through interferences with drainage
 and/or earthworks.

4 Slope Instability and Run Out Assessment Methodology

Areas of potential slope instability and associated run-out zones have been identified in ArcGIS from a detailed review of geospatial datasets. Datasets considered in our assessment are outlined in Table 4-1 along with a summary of the uses and limitations. The overlay considered slope instability and run-out separately to account for varied land damage and trigger for land damage (i.e. slope failure versus debris run-out).

The identification of land potentially susceptible to slope instability generally followed the AGS (2007a) guidelines including an inventory of mapped slope instability features, and supplemented with a literature review on the locations and failure mechanisms of previous slope instability. Land downslope of the slope instability overlay was subsequently assessed to determine whether it may be impacted by debris associated with the run out of the instability. The assessment considered whether geomorphology and/or historical records indicated that the area may be impacted by solid debris (i.e. soil and rock) from upslope instability resulting in land damage. The overlay is not intended to represent the maximum downslope extent of debris, including muddy-water, resulting from the instability failure.



Table 4-1: Summary of datasets considered in our assessment

Hill-shade Model derived from DEM with 1m resolution and 2m elevation contours.	 Geomorphic evidence of existing instability identified based on engineering judgement (i.e. scarps and toe bulges). Classification of the different types of slope instability features (e.g. shallow/deep slope instability, gradual creep, rockfall etc). Resolution of models often enables boundaries of instability to be identified and mapped. 	 Accuracy of models may be impacted by vegetation. Subtle topographic variation may be difficult to observe due to aspect, shading, and overall relief of the slope.
Slope angle model developed from hill shade	Outlines steepness of slope profiles. Subtitle changes in slope profiles provide geomorphic evidence for existing instability (i.e. scarps and toe bulges).	 Accuracy of models may be impacted by vegetation. Subtle topographic variation may be difficult to observe due to aspect, shading, and overall relief of the slope. Model represents slope of the cells; resolution does not indicate the overall steepness of the slope.
1:250,000 Geological Map (QMap)	 Areas mapped as 'Undifferentiated Pleistocene - Holocene deposits' in QMap highlights locations of large deep-seated landslides. Mapped geology outlines hillslopes containing geologic units known as susceptible to instability, as summarised in Section 3. 	 1:250,000 scale of geologic map does not provide sufficient resolution to inform overlay boundaries. Not all deep-seated landslides are included in the geologic map.
NCC Landslip records	 Documents land instability previously recorded/ observed by NCC. Provides input to slope instability inventory. 	Records generally relate to the local failures of retaining walls and/or cut and do not capture broader scale instability (i.e. spanning multiple properties).
GNS Landslip Database	 Identifies large deep-seated instability based on geomorphology and historical movement. Provides input to slope instability inventory. 	 Only largest instability mapped in the Nelson region are included in the database Boundaries loosely defined/ do not always match geomorphology.
GNS Active Fault Database	Outlines faults mapped in the region.	 Does not consider likelihood of rupture. Map scale does not provide sufficient resolution to inform overlay boundaries.



Existing Nelson hazard zones/ designation of slope instability	 Existing Tahunanui Slump core and fringe zones and Grampian slope hazard zones identify land with previously recognised slope instability risk. 	 Individual slope instability not identified on hillslope.
Previous reports on slope instability in the Nelson Region.	 Johnston et al. (1978) outlines locations and styles of slope instability within the upper York Stream catchment. Johnston (1984) summarises slope instability and geology in the Atawhai area including inferred boundaries and types of instability. Johnston (1991) outlines locations and types of slope instability on the Barnicoat Range. Johnston et al (1993) discusses landslide hazards in Nelson City. 	Scale of maps and photographs difficult to transfer and/or spatially locate on existing slope profile.

4.1 Slope Instability Inventory

Geomorphic evidence of slope instability has been mapped in ArcGIS from the 1 m hill-shade model developed from the DEM and aerial imagery. Geomorphic features have been identified according to the system by Cruden & Varnes (1996). Features include the head of the instability, indicating the edge between the upper part of the instability and the overlying undisturbed material, bulges marking the toe of the displaced material associated with the instability, and irregular hummocky surfaces reflecting the main body of the instability. Mapping had not previously been completed for the region and aimed to capture a representation of slope failure locations and types and is not considered a complete record. Locations of the mapped instabilities have been used as the evidential basis to inform our assessment of the slope instability and run-out zones.

4.2 Slope Instability Overlay

A methodology tree outlining the steps taken in our assessment is presented in Figure 1. Land meeting the criteria outlined in the methodology tree is considered susceptible to slope instability and is included within the slope instability overlay. Further commentary on the various steps is given below.



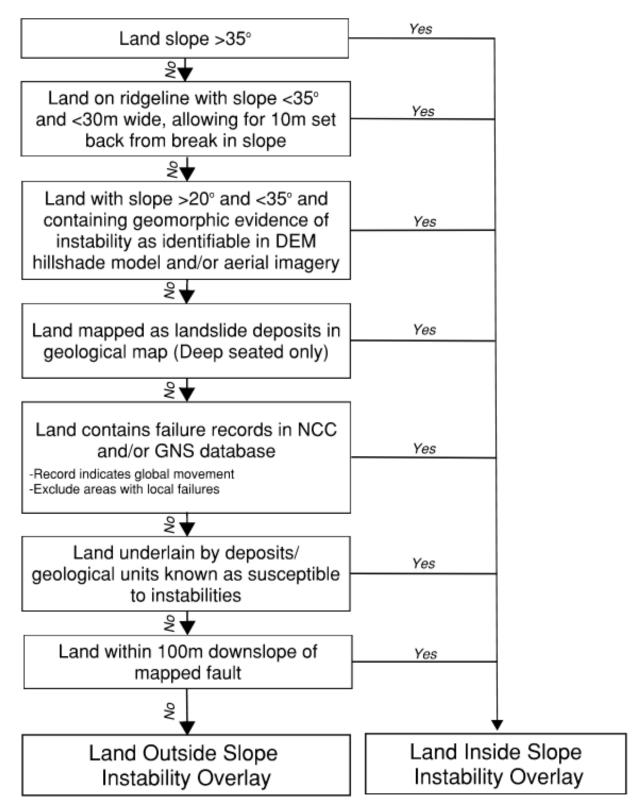


Figure 1: Methodology tree outlining steps taken in our assessment of slope instability.

Steps included in methodology tree:

- Land with slopes steeper than 35 degrees has been included in the slope instability overlay (including ridgelines).
 - AGS (2007a) identifies natural slopes steeper than 35 degrees as potentially susceptible to instability with the potential for rapid landslides.
 - Properties with retaining walls resulting in localised linear slopes greater than 35 degrees, and where remainder of the property is at slopes of less than 35 degrees, have been excluded from the overlay.
 - Engineering judgement has been used to determine whether slope profiles partially greater than 35 degrees have been included in the overlay. Judgement was based on the overall steepness of the slope profile using the 2 m elevation contours, overall topography, and underlying geologic units.
- Ridgelines with land slopes less than 35 degrees and less than 30 m wide have been included in the instability overlay. A 10 m set back from the break in slope was incorporated into the 30 m width.
 - Land with slopes of less than 35 degrees and located immediately adjacent to ridgelines may be impacted by head scarp regression, with up to 10 m of regression considered possible.
 - Ridgelines with widths of less than 30 m, including consideration of 10 m set back, are considered too narrow to allow for property boundaries.
- Land with slopes steeper than 20 degrees and less than 35 degrees and containing geomorphic evidence
 of slope instability, as included in the slope instability inventory, have been incorporated into the slope
 instability overlay.
 - Slopes adjacent to features in the slope instability inventory and where geomorphic evidence suggests
 the area may be impacted by failure of the instability and/or regression of the head scarp have been
 included within the overlay.
- Land mapped as 'Undifferentiated Pleistocene Holocene landslide deposits' in 1:250,000 Geological QMap has been included within the slope instability overlay.
 - The distribution of mapped landslide deposits identifies locations of deep-seated landslides which may be re-activated during heavy rainfall, seismic events, and/or due to construction activities.
 - Boundaries of the landslide deposits have been inferred from the slope model as the resolution of QMap does not allow for property specific assessment.
- Slopes with failure records in the NCC database that indicate global movement have been included in slope instability overlay.
 - Areas previously impacted by slope instability are considered susceptible to future instability.
 - Land with NCC records relating to local instability (i.e. localised retaining wall or cut-slope failures)
 have not been incorporated into the overlay as these are considered unlikely to result in global
 instability.
- Slopes underlain by geologic units identified by Johnson (1991) as susceptible to instability have been included in the overlay.
 - Land underlain by Marsden Coal Measure deposits and exhibiting irregular hummocky topography has been included within the overlay.
 - Land adjacent to slopes with widespread failures where there is a potential for similar failures to occur based on underlying geologic units have been included within the overlay.
- Land up to 100 m downslope of mapped active faults have been incorporated into overlay. The
 distribution of active faults was taken from the GNS active faults database (GNS, 2020).
 - Rocks near mapped active faults are generally highly fractured and/or sheared due to strong ground shaking during ruptures and accumulation of tectonic stresses. The rocks subsequently have a higher susceptibility to instability and there are commonly areas of groundwater seepage associated with the fault zone. Material may additionally be dislodged and/or transported downslope during a fault rupture.

Land identified in the preceding steps is considered susceptible to slope instability and has been included in the slope instability overlay.



4.3 Run-Out Zone Overlay

Land outside the slope instability overlay could still be affected by the run-out from instability occurring upslope. Steps outlining the methodology taken to assess areas potentially impacted by run out from slope instability are shown in Figure 2 and summarised below. Mapping was completed for areas where geomorphic and/or historic evidence suggests debris may go beyond the slope instability overlay. The overlay is intended to outline areas considered susceptible to impact from solid debris, including soil and rock, from failures or movement of upslope instability. The overlay is not intended to represent the maximum extent of debris. A methodology tree outlining the steps taken to identify land within the run-out zone is presented in Figure 2 and is outlined below.

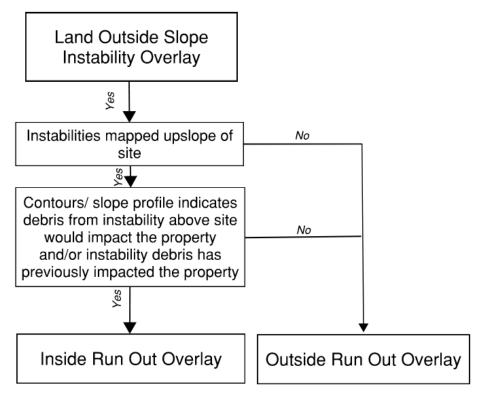


Figure 2: Methodology tree outlining steps taken in our assessment of run-out.

- Land with no instability mapped or identified upslope of the site, and outside the slope instability overlay, has been excluded from the run-out assessment.
- Slopes where NCC landslip records indicate that land has previously been impacted from the run-out of global slope movement has been included in the run-out zone overlay.
 - Areas previously impacted by instability run outs are considered susceptible to being impacted during future events.
- Land downslope of mapped instability where geomorphic evidence indicates that the land is within the run-out zone of previous instability has been included within run-out zone overlay.
 - Geomorphic evidence of previous run-out zones has been assessed from the hill shade model and includes bulges and/or irregular profiles at the base of slopes.
- Land where the slope profile and 2 m contours indicate potential impact from debris sourced from upslope instability has been included within the overlay zone.
 - Engineering judgement was used to assess run-out distances of slope instability included in the slope instability inventory. The slope model and spacing of 2 m contours have been used to inform the assessment on the size of the instability and the steepness of the slope profile beneath the instability.



5 Assumptions and limitations of our assessment

The overlay is not a replacement for site-specific assessments. Mapping of slope instability features and our assessment of slope instability and run-out was completed at a scale of 1:5,000. It is intended that any subsequent use is completed at a consistent scale. Limitations of the datasets considered in our assessment are outlined in Table 4-1. The use of multiple geospatial datasets reduces the effects of the variations in accuracy.

Assumptions and limitations of our assessment are outlined below.

- The slope instability inventory outlines approximate locations of slope instability recognisable at the 1:5,000 map scale in the 1 m hill-shade model.
 - Mapping of instability was limited by the aspect and shading of the DEM hill-shade model, combined with overall relief of the slope, and the scale at which mapping was completed. Mapping is not considered to be a complete record of all instability within the region but sufficient to show the distribution of slope instability on hillslopes in the Nelson area.
 - Boundaries of the instability have been inferred from geomorphic evidence visible in the hill-shade and slope models at scales of between 1:2,000 and 1:5,000. Source regions and downslope extents of the features are considered representative of the failure locations. It is possible that failures have been sourced and/or terminate further upslope or downslope than that presented.
 - The accuracy in the location of the mapped features is a function of the manual process by which
 mapping was completed, the scale at which mapping was conducted, and the accuracy of the LiDAR
 from which the hill-shade was derived. The accuracy of the LiDAR was not included in the metadata
 supplied by LINZ.
 - Slope instability classifications have been inferred from a detailed review of the geospatial datasets coupled with local engineering geology knowledge, and a review of the classification scheme outlined by Cruden & Varnes (1996).



6 Recommendations for future work

Additional work may be undertaken to refine and/or verify the locations and extents of the proposed zones, and/or to assess risk in relation to the zones.

The physical extent of the slope instability overlay may additionally be expanded to include areas of interest outside those included in this study, such as land earmarked for future development.

6.1 Additional steps to verify overlay extents

The following additional steps are suggested to verify overlay extents.

- Internal review by NCC.
- The overlay set out in this report has been prepared from desk study only. While we consider this
 appropriate for the intended purpose, refinement of the instability and run-out zones may be completed
 from field mapping. This step may be applicable for developed areas on land particularly prone to
 landslides and/or land earmarked for future development.
- Peer review of the map outputs by an independent consultant/ authority with relevant experience in the
 field, ideally with local knowledge. We understand that this has been completed by Martin Williams of
 CGW consulting engineers and that no recommendations for amendments to the methodology or output
 overlays were provided.
- Public consultation around the distribution and extents of the overlay zones.

6.2 Additional work required for instability risk assessment

Risk assessments require additional considerations, including likelihood of slope failure and the potential consequences to a particular element at risk. Neither of these are considered in our susceptibility overlay given its primary purpose is to inform the need for further geotechnical assessment.

Risk may be defined as:

The probability that an element at risk suffers a consequence due to a hazardous event.

In order to consider risk, the element at risk, consequence, and hazardous event must be defined.

In the context of this study:

- Element at risk may be a person or property
- The consequence may be injury or death (of persons), or damage (to property)
- The hazardous event is slope instability, potentially subdivided into different failure types.

Risk may be defined as the product of a series of conditional probabilities:

- The probability that a slope failure occurs (probability of failure)
- The probability that the slope failure reaches the element at risk (spatial probability)
- The probability that the element at risk is present (temporal probability, 1 for fixed infrastructure, but variable for persons or mobile elements)
- The likelihood that the consequence is realised in the event of impact (vulnerability)



The following steps would be required to assess risk, using the instability overlay as a starting point:

- Evaluate the likelihood of a slope instability event impacting the given region, represented as the annual probability of occurrence.
- Define the element at risk to be considered i.e. people/property/assets. Different risk levels/ consequences may be assigned for varying levels of building damage (i.e. collapse, burial etc) and are specific to the building type, use, and occupancy, and the size and type of landslide that could affect the site.
- Assess the exposure of the elements to the hazard, considering:
 - Property types (i.e. residential, business, industrial, rural).
 - Population who live, work, and travel through the area based on the number of houses, buildings, roads, railways, and services permanently in the area, and considering property such as vehicles which travel through the area.
- Assess the likelihood of a failure reaching the element at risk, and, in the case of life risk, the likelihood a
 person is present.
- Assess the vulnerability of the element at risk in the event of being impacted by slope instability.
 Guidance may be found in AGS (2007a).

Risk assessment requires significantly more information than has been collected in developing the instability susceptibility overlay and is considered more suited to individual sites where there may be specific concerns rather than a general regional-based assessment.

7 Suggested Planning Requirements

The proposed slope instability and run-out zone overlay is intended to identify areas that require further geotechnical assessment by a suitably qualified geo-professional during the early stages of land use planning and development. The overlay is intended to control the use of land for the purpose of managing or mitigating natural hazards which will help to fulfil the Council's obligations under section 30 of the Resource Management Act and inform the Councils' new resource management plan, (Whakamahere Whakatū Nelson Plan).

It is recommended that a site-specific geotechnical assessment be undertaken to support land use development proposed in the slope instability and run-out zone overlay that involves the construction of structures and facilities, including habitable and non-habitable, and / or earthworks requiring consent.

The purpose of the geotechnical assessment would be to:

- Characterise expected ground conditions at the site, supported by subsurface investigation where appropriate
- Identify and assess the actual and potential effects of the proposed activity on slope instability; and
- Identify and assess the actual and potential effects of any existing or potential slope instability to the proposed activity; and
- Identify any measures that are required to offset or compensate for any adverse effects that will or may result from allowing the activity.
- Recommendation of any remedial measure required for the prosed development

It is expected that a site-specific geotechnical assessment will be provided in support of any building consent application or resource consent application for land use development in the slope instability and run-out zone overlay.



Applicability

This report has been prepared by Beca on the specific instructions of our Client. It is solely for our Client's use for the purpose for which it is intended in accordance with the agreed scope of work. Any use or reliance by any person contrary to the above, to which Beca has not given its prior written consent, is at that person's own risk.

Should you be in any doubt as to the applicability of this report and/or its recommendations for the proposed development as described herein, and/or encounter materials on site that differ from those described herein, it is essential that you discuss these issues with the authors before proceeding with any work based on this document.

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