Sensitivity: General

Review of TDC Slope Instability Risk Areas

Richmond Foothills, Collingwood, Clifton/ Pohara/ Ligar Bay

Prepared for Tasman District Council
Prepared by Beca Limited

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Revision History

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Executive Summary

Beca Ltd has been commissioned by the Tasman District Council (TDC) to undertake a review of the existing Slope Instability Risk Areas (SIRA) and produce a map outlining land potentially susceptible to slope instability and run-out for the following areas:

- Richmond foothills covering the existing SIRA and extending southwards to the Wairoa River.
- Clifton/Pohara/Ligar Bay areas covering the existing SIRA and extending southwards from Clifton to Takaka River and additional areas that have been previously impacted by the run-out from debris flows.
- Collingwood considering the existing SIRA and extending southwards to the end of Orion Street.

Slope instability is a well-known hazard affecting the Tasman District with key areas of known instability identified by the existing Slope Instability Risk Areas (SIRA). The SIRA is an overlay within the Tasman Resource Management Plan and is used as a planning tool to assist TDC with land development planning and provides high-level guidance to the wider community on areas that could be subject to slope instability. TDC currently identify four SIRA, being the Richmond foothills, Ruby Bay sea cliffs, Clifton/Pohara/Ligar Bay and Collingwood.

Our assessment generally follows the AGS (2007a) guidelines for susceptibility mapping and identifies the following settings as potentially susceptible to slope instability:

- Cliffs.
- Natural slopes steeper than 35 degrees (rapid landslides may occur).
- Natural slopes 20-35 degrees (landslide travel possible).
- 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 slope instability and run-out susceptibility areas identified in our assessment were created in ArcGIS considering available geospatial datasets including topography, aerial imagery, and slope angles, along geomorphic evidence of slope instability, and a review of previous slope failure locations. Mapping was completed at a scale of 1:5,000 and it is intended that any subsequent use is consistent with this scale. The slope instability and run-out susceptibility areas are not considered a replacement for site-specific investigations, nor does it consider risk to individuals or property.

1 Introduction

Beca Ltd has been commissioned by the Tasman District Council (TDC) to undertake a review of the Slope Instability Risk Areas (SIRA) and produce a map that identifies land potentially susceptible to slope instability and associated run-out for the following areas:

- Richmond foothills covering the existing SIRA and extending southwards to the Wairoa River.
- Clifton/Pohara/Ligar Bay areas covering the existing SIRA and extending southwards from Clifton to Takaka River and incorporating hillslopes around Rototai Road and areas that have been previously impacted by the run-out from debris flows.
- Collingwood considering the existing SIRA and extending southwards to the end of Orion Street.

The SIRA is an overlay within the Tasman Resource Management Plan that is used as a planning tool to assist TDC with land development planning and provides high-level guidance to the wider community on areas that could be subject to slope instability. TDC currently identify four SIRA being the Richmond foothills, Ruby Bay sea cliffs, Clifton/Pohara/Ligar Bay, and Collingwood.

Our assessment covered the following aspects, as outlined in the Project Agreement dated 16 December 2020:

- A review of data provided by TDC including geotechnical reports, previous hazard studies, published geology maps, ortho-rectified aerial photographs, and Digital Elevation Models (DEM).
- Identification of the locations and types of instability features present from an assessment of the Hillshade and slope models developed from the DEMs and ortho-rectified aerial photographs, and incorporation into a digital slope instability inventory.
- Assessment of the slope instability inventory, slope angles, historical records, and mapped geology to identify land potentially susceptible to slope instability.
- Identify land potentially within the run-out of slope instabilities based on a review of historic events, slope angles, local knowledge, and engineering judgement.
- Review and update of existing SIRA considering the methodology adopted for our assessment and available datasets.

The output of our assessment is a digital slope instability inventory and GIS map layer produced at a scale of 1:5,000 that outlines areas identified as potentially susceptible to slope instability and run-out. The map outputs are presented in Appendix A.

Our assessment did not consider risk as this is specific to a given site and requires interpretation of the likelihood and associated consequences of the hazard. As such, risk is specific to the element at risk and is dependent on the use and occupancy of the site.

1.1 Scope of our assessment

The boundaries of the three study areas were identified by TDC and are based on the existing SIRA boundaries and adjacent areas of known or potential slope instability with current or anticipated future development pressure. The boundaries of the Clifton/Pohara/Ligar Bay study area were limited by the coverage of existing LiDAR data and may be extended once new LiDAR becomes available. TDC decided not to include the Ruby Bay sea cliffs SIRA in this current study as they largely understand slope instability in this area and there is minimal development pressure.

Land outside of the study areas was not considered in our assessment and no comment can be made on the susceptibility of these areas to slope instability nor run-out. TDC may consider assessing slope instability in other areas as part of their ongoing natural hazards programme. Additional areas may be selected based on future development pressure and as additional LiDAR data becomes available. The assessment did not consider erosion nor retreat of sea cliffs as a result of sea level rise.

2 Rationale and Background

The Resource Management Act (1991) places responsibilities associated with natural hazards, such as slope instabilities, on both regional councils and territorial/ district authorities. The regional level approach may include the identification and mapping of susceptible areas, while control at a district level may involve planning rules. As a unitary council, TDC is required to both identify and control the impacts of natural hazards. Guidelines for assessing land instability are provided by the Australian Geomechanics Society (AGS; 2007a) and GNS Science (Saunders and Glassey, 2007 and Saunders et al., 2013).

Slope instabilities, including landslides, are typically defined as 'the movement of a mass of rock, debris, or earth (soil) down a slope' (Cruden, 1991). The terms landslip, slippage, and falling debris are also used for landslide-type features in the Resource Management Act (1991), Earthquake Commission Act (1993), and the New Zealand Building Act (2004). Triggers for slope failures include high rainfall, earthquakes, physical and/or chemical weathering of the underlying rock, and land development. The following settings are identified by AGS (2007a) as 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 such as susceptible rock types, soil type and thickness, and/or watershed size.
- Slopes with a history of instability, including large currently inactive landslides subject to undercutting of the toe or reactivation by development.

AGS (2007a) and GNS (Saunders and Glassey, 2007) recommend that the assessment of slope instability includes a basic inventory of existing landslides and/or instability features. The locations and types of existing features should be identified from historical records, previous mapping, and/or geomorphic evidence observed in aerial photographs, satellite imagery, and/or elevation models and supplemented with local engineering knowledge. Geomorphic evidence of slope instability is outlined by Cruden & Varnes (1996) and includes crescent-shaped depressions representing head scarps, bulges at the toe of the failure indicating run-out extents, debris fans, and irregular gully features, while visual evidence includes hummocky terrain, swamps and ponded water, and soil erosion. The AGS (2007a) and GNS (Saunders and Glassey, 2007) guidelines recommend regional maps be completed at scales of 1:25,000 to 1:250,000 while local maps should be produced at scales of 1:5,000 to 1:25,000.

2.1 Slope Instabilities in the Tasman Region

Slope instability is a well-known hazard affecting the Tasman District. Examples of previous slope failures and the associated triggering event are listed in Table 2-1.

Table 2-1: Summary of previous slope instability events in the Tasman Region.

Year	Area Affected	Trigger event	Damage	Reference
June 1929	Wider Tasman region	Seismicity (Murchison Earthquake)	Widespread deep-seated landslides observed on hillslopes across the western part of the Tasman region.	Hancox et al., 2016
May 2010	Tapawera	Heavy rainfall	Localised landslides and debris flows observed in the wider Tapawera area particularly on recently logged forestry blocks on slopes underlain by weathered Separation Point Granite.	Page, 2013 and newspaper reports
December 2011	Pohara/ Ligar Bay	Heavy rainfall	Landslides, debris flows, and debris floods in areas largely underlain by deeply weathered, highly erodible Separation Point Granite. Debris flows and debris floods severely damaged houses on Nyhane Drive and in the Pohara Valley. Sediment transported by debris floods reached the estuary behind Tata Beach.	Page et al., 2012
April 2013	Richmond foothills	Heavy rainfall	Localised shallow landslips observed on the Richmond foothills.	Nelson Weekly, 23 April 2013
June 2013	Motueka and Takaka	Heavy rainfall	Widespread landslides and debris flows across the wider Motueka area and locally within Takaka on slopes containing deeply weathered Separation Point Granite. ▪ One landslide in the Otuwhero Inlet struck a house resulting in the death of the occupant ▪ one landslide in the Marahau Valley destroyed part of a dwelling.	Page, 2013
February 2018	Tasman region	Heavy rainfall (‘Cyclone Gita’)	Widespread landslides and debris flows recorded across the Tasman region generally on slopes containing Separation Point Granite.	Rosser et al., 2020

A summary of the SIRA considered in our assessment and the types of instability features known in these areas are outlined below.

2.1.1 Richmond Foothills

The slope stability of the Barnicoat Range was assessed by Johnson (1991) as part of the Richmond Growth Study. The study considered the risk of slope failures based on the character and inferred susceptibility of the underlying geologic units and identified three risk categories:

- Category I – Rock units considered to have a very low risk of movement including the Moutere, Stoke Fan, and Hope Gravels. The Moutere Gravel is considered susceptible to small superficial failures particularly on steep slopes in damp and shady areas, and in gullies where slope-wash is present.
- Category II – Rocks with a low to moderate risk of slope failure including the Maitai and Richmond Groups which are identified as exhibiting widespread superficial slipping. Surficial deposits were added to this category to account for uncertainties in their thickness and in the nature of underlying rock. It was recommended that any development in these areas includes more detailed engineering geological investigations.
- Category III – Areas within which there is a high potential risk of slope failure. This category is confined to the steep slopes of Richmond Group adjacent to the Waimea and Heslington Faults with large existing deep-seated slope failures and areas underlain by the easily erodible Marsden Coal Measures.

Slope instability within the Richmond Foothills was reassessed by Johnson (2009) who reviewed the area from Hill Street to Haycock Road and extending to the crest of the Barnicoat Range between Champion Road and the Wairoa Gorge. The review was based on personal knowledge, relevant geological maps, paired stereo-paired aerial photographs, unpublished geotechnical reports and/or building consent applications known to the author, existing fault hazard overlays, and field observations. The assessment proposed changes to the existing Slope Instability Risk Management Zone and recommended that any new development in the area include an assessment of slope instability prepared by a chartered professional engineer practising in geotechnical engineering or an experienced engineering geologist.

The assessments by Johnson (1991 and 2009) identified the following types of instabilities in the Richmond foothills:

- Deep landslides - translational or rotational failures with slip surfaces between 4m and 25m deep. These failures are within the Richmond Group near the Waimea Fault trace and were likely seismically triggered however may be reactivated during prolonged rainfall and/or from elevated ground water.
- Shallow slope instability – rotational failures up to 4m deep and involving failures of the surficial clayey soils. These slope failures are widespread across the hillslopes and are typically triggered during periods of 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.

2.1.2 Clifton/Pohara/Ligar Bay

The Clifton/Pohara/Ligar Bay SIRA covers the area west of Wainui Bay to the western end of Pohara Beach. The SIRA was prepared by Soil and Foundations (1996b) from a detailed review of published geological maps, relevant hazard reports, and aerial photographs at scales of 1:15,000 and 1:25,000. The boundaries were defined from aerial imagery and transferred to cadastral maps and are considered approximate. The assessment proposed three zones which informed the SIRA:

- Zone I: encompassing relatively flat to gently sloping ground on the margins of steeper slopes which have the potential for slope failure. These areas have very low potential for slope failure however may be impacted by the run-out of debris from overlying slope failures. The zone incorporates floodplain and low terrace deposits, and marine sands adjacent to the coastline.
- Zone II: consisting of areas of gently to moderately sloping land principally forming high terraces with low to moderate potential for slope failure. These are considered subject to flooding however the risk is considered lower and not as extensive as Zone I.
- Zone III: comprising moderate to very steep slopes underlain by weathered Tarakohe Mudstone and Separation Point Granite that are considered susceptible to shallow superficial failures. The assessment notes that uncontrolled earthworks on these slopes could cause slope failures. Separate designations are given to areas of karst which have the potential for progressive roof collapse, limestone cliffs which pose rockfall hazards, and areas of mining.

The following types of instabilities were identified in the Clifton/Pohara/Ligar Bay SIRA :

- Shallow slope instability – rotational failures up to 3m deep and involving failures of the surficial clayey soils on hillslopes containing Separation Point Granite and Tarakohe Mudstone. These are typically triggered during periods of heavy rainfall.
- Earthflows – Slow moving or creeping slope instability which are predominately clayey with entrained angular rock debris within Motupipi Coal Measures. Triggers can be seismicity, prolonged rainfall, and/or elevated groundwater.
- Rockfall – Localised detachment of rocks from steep abandoned sea cliffs containing Takaka Limestone. Triggers can be rainfall, seismicity, and/or general weathering.

The assessment did not identify areas susceptible to debris flow nor the run-out from debris flows. Debris flows are triggered by heavy rainfall over a short duration and involve the downslope mass movement of water and material comprising at least 50% of sand-size particles or larger. Debris flows were observed in the Clifton/Pohara/ Ligar Bay area during the 2011 rainfall event (see Table 2-1).

2.1.3 Collingwood

The SIRA for Collingwood was prepared by Soil and Foundations (1996a) and covers the hillslope immediately southeast of the township and along the Golden Bay coastline to the end of Excellent Street. The assessment considered local geological maps, relevant hazard reports, stereo pairs at scale of 1:15,000, and a site visit and proposed two zones which informed the SIRA:

- Zone I: comprising flat to gently sloping ground on the periphery of land assessed as susceptible to slope failure. The area has no to very low potential for slope failure however may be impacted by run-out of debris from overlying slope failures. The zone includes flat terrace deposits of terrestrial gravels and marine sand and gravel adjacent to the coastline.
- Zone III (Corresponding with Zone III in the Clifton/Pohara/ Ligar Bay SIRA): includes moderate to steep slopes developed on Tarakohe Mudstone and adjacent peripheral areas that are considered prone to shallow failures within the weathering layer. The assessment notes that modification of the Tarakohe Mudstone by uncontrolled earthworks such as excavations, placement of fill, and changes to water courses may cause local slope instability. The zone incorporates a 25m set back from top of the slope to allow for progressive failures.

The assessment identified the following types of instability features:

- Shallow slope instability – rotational failures up to 3m deep and involving failures of the surficial clayey soils typically triggered during periods of heavy rainfall.

3 Slope Instability and Run-Out Assessment Methodology

Areas potentially susceptible to slope instability and the associated run-out are identified from the datasets outlined in Table 3-1. The uses and limitations of each dataset are additionally are summarised. Our assessment considers all land incorporated within the study areas however only land identified as potentially susceptible to slope instability and run-out is shown on the output maps included in Appendix A.

Our assessment generally follows the AGS (2007a) and GNS (Saunders and Glassey, 2007) guidelines for landslide susceptibility mapping including creating an inventory of slope instability features supplemented with a literature review on the locations and mechanisms of previous slope failures.

Table 3-1: Summary of datasets considered in our assessment

Data Source	Use	Limitations
Hillshade Models developed from the following 1-m resolution Digital Elevation Models (DEM): ▪ *2018_GoldenBay* ▪ *2017_Riwaka_Pohara _Onekaka* ▪ *2016_Richmond _Mapua_Motueka*	▪ 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. ▪ Resolution often enables boundaries of instability to be 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 models developed from Hillshade Models	▪ Outlines overall distribution of slope angles. ▪ Subtitle changes in slope profiles provide geomorphic evidence for existing instability features (i.e. scarps and toe bulges). ▪ Changes in slope profile used to infer anticipated run-out extents.	▪ Accuracy may be impacted by vegetation. ▪ Subtle topographic variation may be difficult to observe due to resolution of the models. ▪ Models represent slope across the 1m cell and do not indicate the overall steepness of the slope.
2m elevation contours	▪ Subtitle changes in contour spacing and orientation identify instability features (i.e. scarps and toe bulges). ▪ Spacing of contours used to infer source regions and run-out extents.	▪ Spacing and resolution of contours may miss subtle topographic features and changes in slope profiles.
1:250,000 Geological Map (QMap)	▪ Areas mapped as 'Undifferentiated Pleistocene - Holocene deposits' in QMap identifies locations of large deep-seated landslides. ▪ Geologic map outlines hillslopes containing units considered susceptible to instability, as summarised in Section 3.	▪ 1:250,000 scale of geologic map does not provide sufficient resolution to inform area boundaries. ▪ Not all deep-seated landslides are included in the geologic map.
GNS Landslip Database	▪ Identifies large deep-seated instability based on geomorphology and historical movement. ▪ Provides a guide for slope instability inventory mapping.	▪ Only largest instability features are included in the database. ▪ Boundaries do not always match observed geomorphic features.

Stereo-paired Aerial Photographs of Barnicoat Range taken in 1948, 1969, 1976, 1986 and 2000	▪ Geomorphic evidence of existing instability identified from engineering judgement and include toe bulges, hummocky terrain, head scarps, and ponded water.	▪ Features hard to cross-locate because of modification and development of the landscape. ▪ Geomorphic features do not always align with features identifiable in the Hillshade models.
TDC Aerial Imagery flown post-2011 rainstorm event	▪ Visible locations of slope instability failures outline susceptible areas. ▪ Run-out extent of failures approximate maximum run-out distances and paths of similar instability failures.	▪ Observed failures only partially cover observed geomorphic features in Hillshade Models suggesting partial failures. ▪ Run out only covers parts of low-lying channels in some areas, potential for variation in extents in future events.
Historical Aerial Imagery from Top of the South Website (1940-1949 and 1980-1989)	▪ Locations of previous slope instability failures visually identifiable and outline susceptible areas. ▪ Run-out extent of previous failures approximate maximum run-out distances and paths of similar instability failures. ▪ Extent of head scarp regression identifiable.	▪ Features can be difficult to locate on recent imagery. ▪ Difficult to identify slope failures over slope deposits in black and white imagery. ▪ Extents of identifiable features do not always align with features identifiable in Hillshade models.
Previous records of slope instability (see Table 2.1)	▪ Identifies areas previously impacted by slope instability failure and run-out within the region.	▪ Resolution provided in reports is not sufficient to identify exact locations and/or boundaries of the instability features.
GNS Active Fault Database	▪ Outlines distribution of mapped active faults.	▪ Does not consider likelihood of fault rupture. ▪ Map scale does not provide sufficient resolution to inform area boundaries. ▪ Mapped position does not always correspond with actual location.
Existing SIRA	▪ Identifies areas of known instability within the region.	▪ Individual instability features are not mapped. ▪ Boundaries do not always correspond with mapped geologic units and geomorphic features observed in Hillshade models.

3.1 Slope Instability Inventory

Geomorphic evidence of existing slope instability features has been mapped in ArcGIS using aerial imagery and Hillshade models. Features are identified according to Cruden & Varnes (1996) and includes the head scarp, which indicates the boundary between the upper part of the instability and the upslope undisturbed material, and bulges marking the toe of the displaced material associated with the instability. The types of slope instability failure are inferred from a detailed review of the geospatial datasets coupled with local engineering geology knowledge, and the classification scheme outlined by Cruden & Varnes (1996).

3.2 Slope Instability Susceptibility Area

A methodology tree outlining the steps taken in our assessment is presented in Figure 1 and is described in detail in Appendix B. Land meeting the prescribed criteria is considered potentially susceptible to slope instability and is included within the identified area.

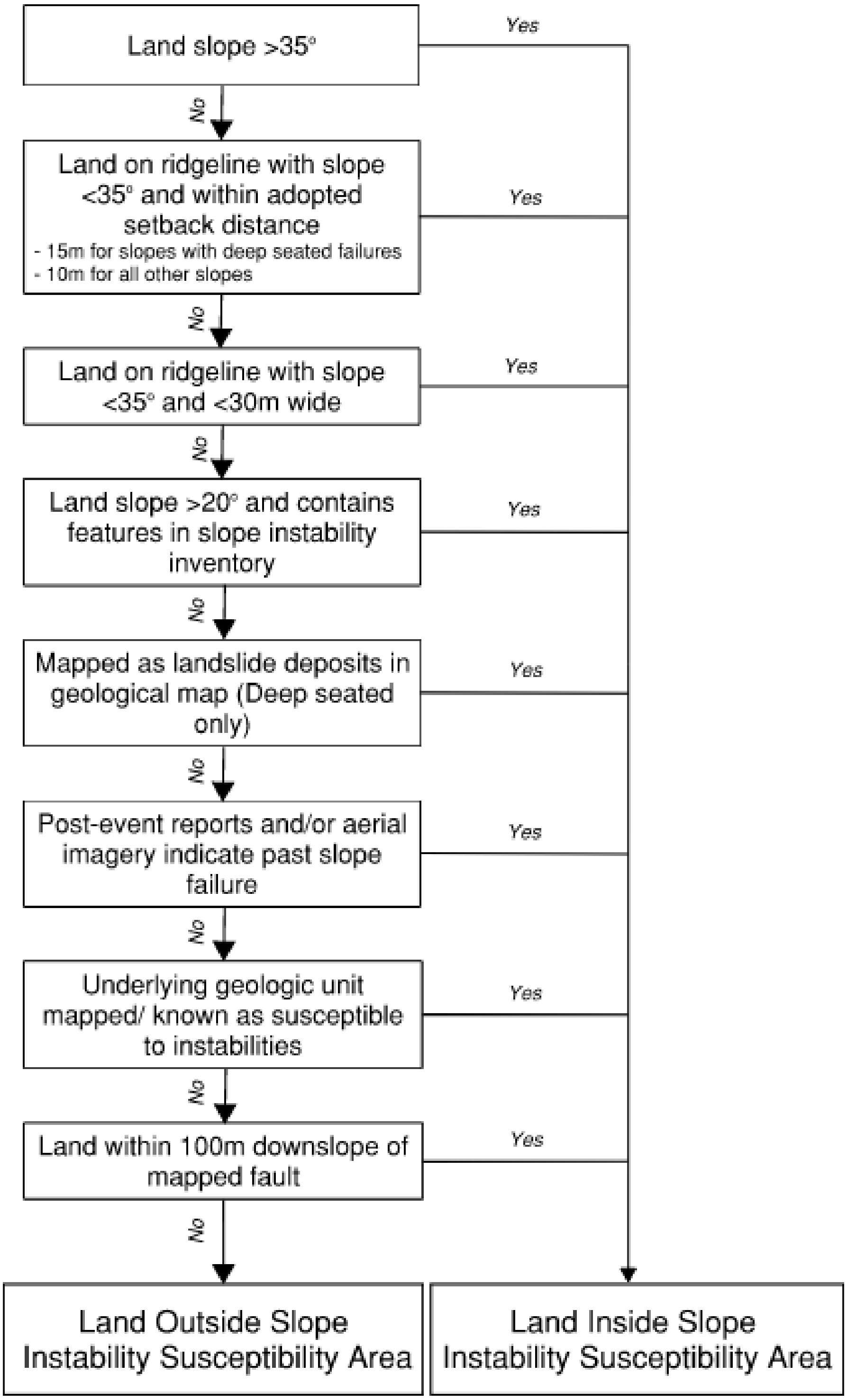

Figure 1: Methodology tree outlining steps taken in assessment of slope instability susceptibility.

3.3 Run-Out Susceptibility Area

A methodology tree outlining the steps taken to identify land within the area potentially susceptible to debris run-out is presented in Figure 2 and summarised in Appendix B. The assessment identified land outside the instability susceptibility area that may be impacted from soil and rock debris from upslope failures with potential to cause land damage. The area is not intended to represent the maximum extent of debris nor muddy water from debris flows. Land with no instability features mapped or identified upslope of the site has been excluded from the run-out assessment.

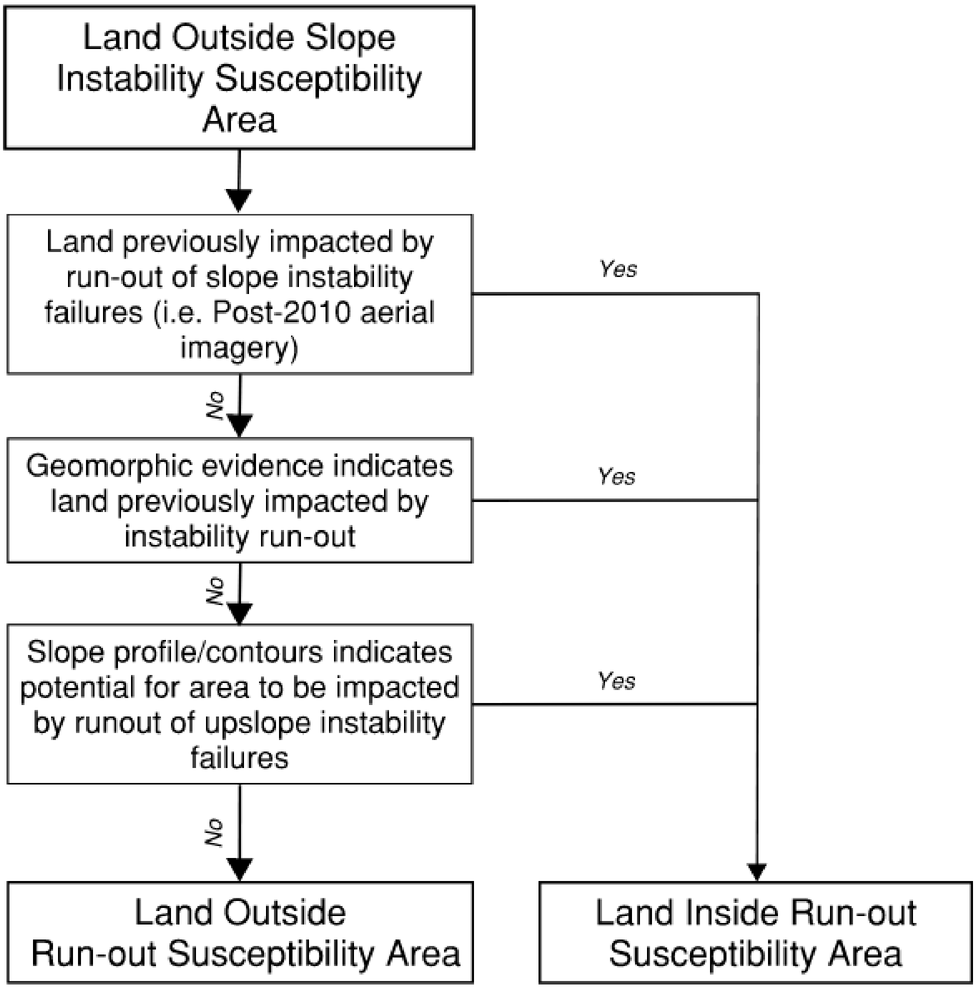

Figure 2: Methodology tree outlining steps taken in assessment of run-out susceptibility.

4 Comparison with Existing SIRA

Maps comparing our proposed areas with the existing SIRA are shown in Appendix C. Variations between the proposed instability and run-out susceptibility areas and the existing SIRA are outlined below.

4.1 Richmond Foothills

- The aerial imagery flown following the 2011 event outlines locations and extents of slope failures. These areas have been incorporated into the slope susceptibility and run-out susceptibility areas and include areas that did not have evidence for previous slope instability failure and/or run-out in the 1991 and 2009 studies.
- The proposed extent of the run-out susceptibility area varies from the SIRA in some valleys and on the Waimea Plains. The variations reflect the ability of the 1m-resolution Hillshade and slope models to highlight subtitle geomorphic features such as toe bulges which are not identifiable in the stereo-pairs.
- Areas within the SIRA with slopes of less than 20 degrees, where there is no evidence for previous slope failures, and where there is local engineering geologic observations confirming a lack of previous slope instability failures, have been excluded from the slope susceptibility and run-out areas.

4.2 Clifton/Pohara/Ligar Bay

The boundaries of the existing Clifton/Pohara/Ligar Bay SIRA do not match topographic features observed in the Hillshade and slope models in some areas. The variations are likely due to the transfer of the SIRA boundaries from aerial imagery, and results in some variations between our proposed slope instability and run-out susceptibility areas and the SIRA. As noted in Section 1.1, the boundaries of this study area were limited by existing LiDAR data and may be extended once new LiDAR becomes available.

- The 2011 post-event aerial imagery outlines the extents of debris flows and other slope instability failures that were not present in the 1996 assessment. These areas have been incorporated into the updated study area and result in an expansion of the run-out susceptibility area around Tata and Pohara. Additional areas where the run-out susceptibility area has been expanded reflects subtle geomorphic evidence identified in the Hillshade model that is not captured in the aerial imagery.
- The area identified as potentially susceptible to slope instability has been reduced in some areas based on local site observations and a lack of geomorphic evidence of previous slope instability.

4.3 Collingwood

The existing SIRA overlay incorporates a 25m setback distance from the top of the slope. The aerial imagery and historical photographs do not show evidence for significant head scarp regression. The setback distance has subsequently been reduced to 15m adjacent to the mapped deep-seated instability and 10m for the remainder of the area. The remainder of the slope instability and run-out susceptibility boundaries closely approximate the SIRA.

5 Assumptions and Limitations of our Assessment

Our assessment is completed at a scale of 1:5,000 and it is intended that the slope instability and run-out susceptibility areas are used at a consistent or coarser scale. These areas are not considered a replacement for site-specific assessments.

Limitations of the datasets considered in the assessment are outlined in Table 3-1 and overall assumptions and limitations are outlined below.

- Mapping considered the following Digital Elevation Models (DEM) that were supplied by TDC. It is assumed that these models are representative of the current ground surface elevations.
  - Richmond foothills: 2016_Richmond_Mapua_Motueka
  - Clifton/Pohara/Ligar Bay: 2017_Riwaka_Pohara_Onekaka
  - Collingwood: 2018_GoldenBay
- Mapping was limited by the aspect and shading of the Hillshade models combined with overall relief of the slope and the scale at which mapping was completed. The instability inventory is not considered to be a complete record of all instability features within the region but sufficient to show the distribution of slope instabilities in the study areas.
- Boundaries of the instability features have been inferred from geomorphic evidence visible in the Hillshade 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. It is possible that failures may 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 Hillshade model was derived.

6 Recommendations for Future Work

Additional work may be undertaken by TDC as a future exercise to refine and/or verify the locations and extents of the proposed slope instability and run-out susceptibility areas, and/or to assess risk in relation to the identified areas.

6.1 Additional steps to verify area extents

The areas set out in this report have been prepared from a desk study only. While we consider this appropriate for the intended regional planning purpose, refinement of the slope instability and run-out susceptibility areas may be completed as a future exercise from field mapping. This step may be applicable for developed areas on land particularly prone to slope instability and/or land earmarked for future development.

- The physical extent of the slope instability and run-out susceptibility areas may be expanded to include other areas of interest, such as other SIRA, land earmarked for future development and/or areas of existing development. The process would follow the same methodology as that outlined in Section 3 above.
- Beca recommends that TDC completes an internal review of our report and commissions an external peer review of the technical content of our assessment. The peer review should be completed by an independent consultant with relevant experience in the field, ideally with local knowledge.

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 slope instability nor run-out susceptibility areas given their primary purpose is to identify areas warranting 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, property or infrastructure.
- The consequence may be injury or death (of persons), or damage (to property/infrastructure).
- 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 area 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 area and is considered more suited to individual sites where there may be specific concerns rather than a general regional-based assessment.

7 Planning Considerations

The slope instability and run-out susceptibility areas were identified from a technical assessment of the datasets listed in Table 3-1 and are intended to identify land potentially susceptible to slope instability and run-out. TDC may consider using the output of our assessment to inform planning rules. There are a number of small areas assessed as not being susceptible to slope instability, such as those present along ridgelines. As such, when TDC considers developing planning regulations, it may be pragmatic to include these small areas within the wider slope instability planning overlay. TDC may consider calling the planning overlays 'Slope Instability Susceptibility Areas' (SISA) rather than the current 'Slope Instability Risk Areas' (SIRA) as these areas do not incorporate an assessment of risk.

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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