Granity Landslides

Preliminary Risk Analysis

The town of Granity

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Executive summary

A number of damaging landslides occurred in Granity due to a heavy rainfall event in February 2022. As a result of concerns raised by the affected community, Buller District Council is seeking to understand the nature and characteristics of landslides in the Granity area, in particular where those landslides present a risk of harm to people and property.

This preliminary risk analysis identifies two distinct types of landslide that affect the Granity area and it presents corresponding risk zone maps delineating the risks associated with each of these landslide types:

Translational type landslides:

- In the High Risk Zone there are four residential dwellings along with a number of other outbuildings/sheds (with unknown use) as well as a commercial property (the Museum) that are at high risk of impact damage from translational type landslides. For people living in those dwellings there is a calculated risk of loss of life in the order of 8.5×10^{-5} per year[1]. In the 50 year design life of a building, there is a 57% chance of a building in that zone being damaged.
- In the Medium Risk Zone there are approximately twenty residential dwellings and a number of other outbuildings (with unknown use) where the expected risk of loss of life is 2.6×10^{-6} per year[2]. In the 50 year design life of a building there is a 22% chance of being damaged.

The risk to life in both the High and Medium Risk Zones is higher than the risk level for new build homes recommended in the New Zealand Building Code (NZS 1170.5:2004 Structural design actions - Part 5: Earthquake actions).

Debris flow type landslides: There are ten residential dwellings along with a number of other outbuildings/sheds (with unknown use) as well as a commercial property (the Museum) that are at high risk of inundation damage from debris flows. For people living in those dwellings there is a possible risk of harm and it is likely that those buildings will be damaged by debris flows in the future. There are also approximately fifteen residential dwellings and a number of other outbuildings (with unknown use) as well as three commercial properties within the medium risk zone, where property damage may also occur.

It is expected that the risks to life and property will increase over time as climate change progresses.

A range of risk reduction measures are presented and it is expected that these measures be discussed by the affected community and Buller District Council with a view to managing the landslide risk appropriately and cost effectively. That discussion will need to take into account the community's risk tolerance levels and the availability of resources, and will facilitate the development of a landslide risk management plan.

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[1] Can be expressed as 0.085% per year, or approximately one death every 10,000 years

[2] Can be expressed as 0.0026% per year, or approximately one death every 400,000 years

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1. Introduction

The coastal strip of residential development at Granity and Ngakawau has been affected by landslides on numerous occasions in the past, some of which have caused property damage. As a result of a damaging heavy rainfall event in February 2022, Buller District Council (BDC) is seeking to understand the nature and characteristics of the landslides, and the ground surrounding these landslides, in particular where those, or similar landslides could present a risk of harm to people and property. This investigation report presents an initial analysis of the landslide hazards in the area and is intended to help the local residents, property owners and BDC make sensible hazard management decisions with respect to the landslide risk.

2. Study area

The study area is defined as the urban area south of the Ngakawau River covering the entire residential settlements of Ngakawau (excluding the commercial coal load out facility) and Granity. State Highway 67 is the western boundary of the study area with all the land to the west of this feature being distant enough from the landslide hazard to be deemed at negligible risk from landslides. Figure 1, below, shows the study area boundary.

Figure 1. The study area outlined in red.

North of the Ngakawau River to the east of the residences in the town of Hector, the slope is moderate and not high enough to generate damaging landslides, so that area has been excluded from this study.

The Coastal strip north of Hector (between Hector and Miko) has been subject to numerous landslides in the past and is a known land instability area. However, this has been addressed in the recent *Te Tai o Poutini Plan Coastal and Land Instability Hazards Draft Document* as well as being recognised in the Buller District Plan since 2000, when that area was designated as a "rockfall and rapid debris flow hazard zone". Since specific planning requirements have been implemented for the properties in that area, it has been excluded from this study. South of the study area the density of residential development is very low, so that area has also been excluded.

3. Methodology

New Zealand does not have its own formal system for assessing landslide risk in residential land. Risk assessment reports generally follow the landslide risk management methodology published by the Australian Geomechanics Society (Fell *et al*, 2007. Guidelines for landslide susceptibility, hazard and risk zoning for land use planning)[3]. This investigation is based on that methodology, which is used extensively throughout New Zealand (and Worldwide) to provide a uniform and standardised approach to landslide hazard management. Modifications to that methodology have been made to better suit the individual requirements and data availability of this study. Figure 1 within that Guideline illustrates the framework for landslide risk management, which shows the entire process from setting the scope of works, through risk analysis, risk assessment and risk management including implementation of risk reduction measures.

This report addresses the first stage of that landslide risk management framework only (risk analysis) and also provides a range of possible risk mitigation options. It presents the zones of varying landslide risk and estimates the risk to life for residents in those zones. This information will form the basis for BDC, the local community and other parties to make informed, data supported decisions on the final two stages, landslide risk assessment and landslide risk management.

Figure 2, below shows the Framework for Landslide Risk Management with the areas covered in this report highlighted with a purple dashed line and the excluded sections highlighted with a blue dashed line.

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[3] Available from: https://ro.uow.edu.au/engpapers/2823/

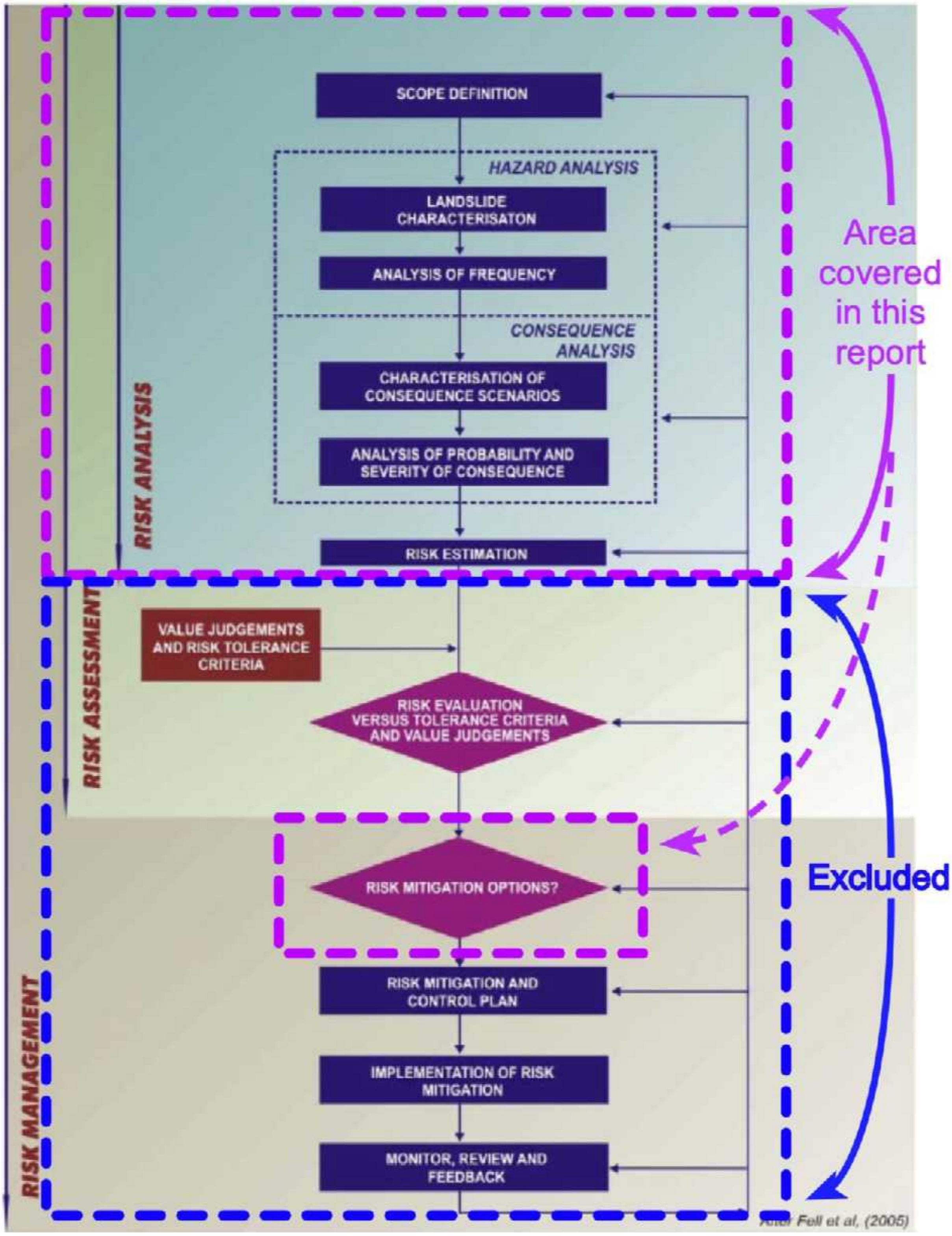

Figure 2. Framework for landslide risk management as defined in the Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning, showing the areas covered in (and excluded from) this report.

This report identifies the past (historic and recent) landslide hazard events in the area based on analysis of:

- Historic aerial photography[4]
- Literature review[5]
- Field mapping of recent landslides
- Aerial imagery provided by BDC (helicopter and drone based)
- Aerial imagery collected by the report author (drone based)

This analysis has created a landslide inventory, which shows all the mapped landslides in the study area. The spatial (mapped land areas) and temporal (events over time) distribution of these landslides has been analysed and compared to other terrain variables (primarily slope angle and geology) within a Geographic Information System[6] to give an estimation of the future likelihood of landslide events within the study area. This information is presented as a **landslide hazard map**, which shows the areas that are more or less likely to experience landslides in the future. The landslide hazard map is then used (along with additional terrain analysis and modelling) to estimate the areas of land that are at risk of being inundated with landslide debris and the level of risk that people and property are exposed to in those areas. That information is presented as a **landslide risk zone map**. So, the hazard map shows where the potential source of harm is located (i.e. where the landslides originate) and the risk zone map shows the areas of lands that may be affected by the hazard (i.e. the runout zones).

There are two distinct types of landslides identified within the study area and these have been analysed separately since they have different mobilisation and runout characteristics; i.e. there are two landslide risk zone maps, one for each distinct landslide type.

The landslide hazards and the consequences to people and property are presented along with a range of potential risk reduction measures.

3. Landslide characterisation

3.1 Landslides overview

The steep range front inland of the Granity area has been uplifted into its current position during a series of earthquakes along the Kongahu Fault Zone[7]. The range front slope is steep (often steeper than 45°) and has a north westerly aspect. The slope is underlain by granitic basement rocks (bedrock) which show varying degrees of fault zone weakening[8]. The weakening of the bedrock has occurred primarily as a result of fracturing and weathering, leaving the exposed rocks susceptible to gravity induced movements. However, in general, the basement rocks are not exposed and are covered by a continuous soil layer. The overlying soils are generally shallow and composed of a 1-2m thick layer of yellowish brown, soft clay with a thin organic soil layer supporting a dense cover of native podocarp forest.

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[4] Available from Land Information New Zealand (LINZ) data service.

[5] Primarily contained within England, K.A. 2011, A GIS approach to landslide hazard Management for the West Coast Region. MSc. Thesis, University of Canterbury.

[6] QGIS is a user-friendly Open Source Geographic Information System (GIS) licensed under the GNU General Public Licence. QGIS is an official project of the Open Source Geospatial Foundation (OSGeo)

[7] Todd, A. 1989. Geology and Coal Resources of the Stockton Sector, Buller Coal Field. Market Information and Analysis Coal Geology Report.

[8] Nathan, S.; Rattenbury, M.S.; Suggate, R.P. (compilers) 2002: Geology of the Nelson area: scale 1:250,000. Lower Hutt: Institute of Geological & Nuclear Sciences. 1:250,000 geological map 9.

During heavy and/or prolonged periods of rainfall (during the heavy rainfall event of February 2022, 166mm of rain fell in 24 hours[9]) the soil layer becomes saturated, which adds additional weight to the soil and at the same time causes a reduction in soil cohesion. This frequently leads to slope instability and landslides occur. Landslides predominantly occur on the steeper (45°+) and higher (upper half) areas of the slope, with the dominant landslide mechanism being **translational type landslide** movements. Often, the debris released in a translational type landslide adds additional weight to the slope below and causes a chain reaction of landsliding, where the debris travels down the slope, adding additional volume as it travels and eventually reaches the base of the slope and accumulates in a debris pile. Sometimes, the debris from a translational landslide can fluidise (usually caused by the addition of excess water either in a creek bed or direct slope runoff in extreme intensity rainfall events) and form a **debris flow**, which can sometimes travel faster and further than the debris from a translational type landslip.

The geological maps of the area show that the geological unit at the base of the slope is a landslide deposit composed of Quaternary age “Earthflow deposits containing poorly sorted clasts up to boulder size in a clay matrix”. This indicates that landsliding is the dominant process contributing to the current landforms in the area and that the base of this slope has been consistently subject to landslide debris deposition for at least the last few thousand years.

3.2 Translational type landslides

3.2.1 Features of translational type landslides

The general layout and features of a typical translational type landslide are shown in figure 3, below:

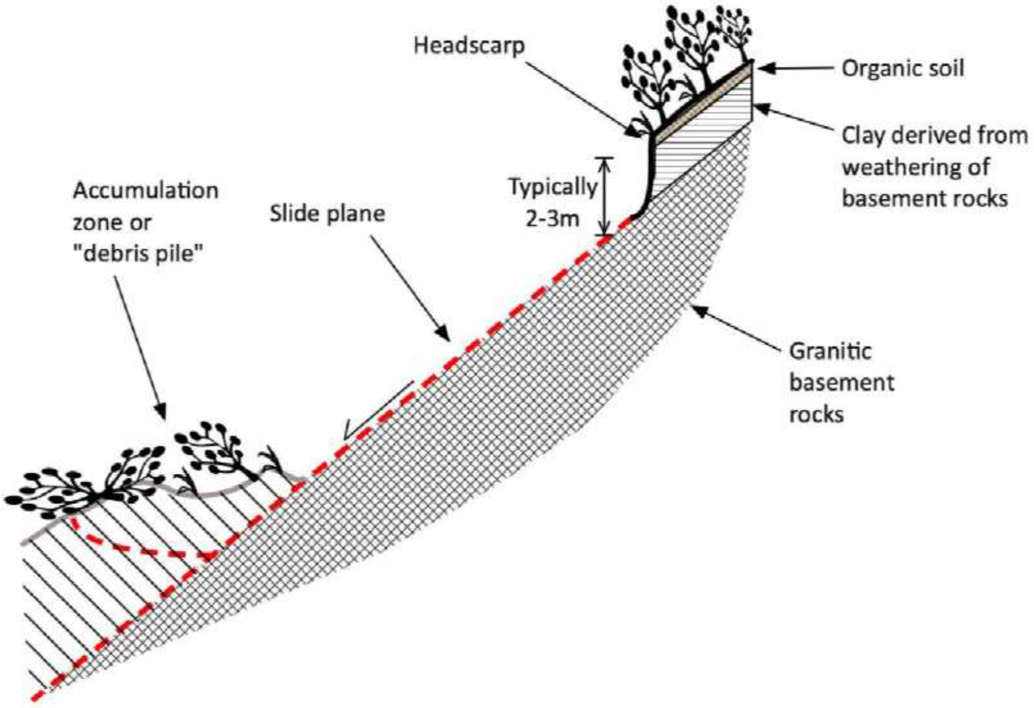

Figure 3. Typical translational type landslide features.

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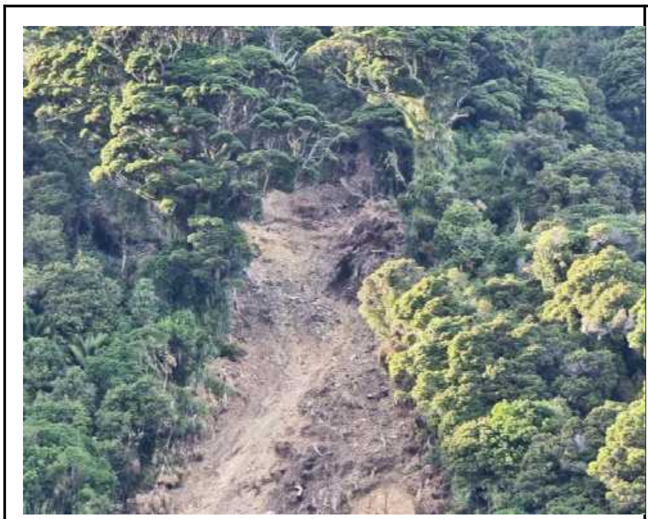
[9] The closest rain gauge is at Mokihinui River at Stoney Creek. Data can be accessed at: https://envirodata.wcrc.govt.nz/dashboards/rainfall/rainfall.php#

From direct and remote observations of the landslides in the Granity area, it can be seen that:

1. The slide plane is generally confined to the overlying clay and organic soils; i.e. the landslides do not appear to have affected the underlying bedrock and ground movement is confined to the superficial soil layer. Occasionally, bedrock is visible within the exposed slide plane, indicating that the slide plane is on the soil/bedrock interface, not within the bedrock (i.e. the bedrock usually remains unaffected during these landslide events). This means that the likelihood of large-scale rockfall sourced from within these rainfall generated landslides is low.
2. The landslides are usually shallow, with the depth of disturbed soil being in the order of 2-3m
3. There is usually a gradual transition across the headscarp areas, with the ground immediately upslope of the headscarp areas (and at the edges of the landslides) being more or less intact, which means that the immediate likelihood of additional landslide debris being released from the headscarp area (headscarp regression) is also low
4. The landslide debris is composed of soft, wet clay with occasional suspended granitic boulders and varying volumes of wood debris derived from trees on the slope
5. The debris usually reaches either the base of a drainage gully on the slope, or the base of the slope
6. The volume of debris in the debris pile is related to the height of the landslip; i.e. where the crest of the slope is higher, the volume of debris will be greater
7. There are very few accumulations of debris within the debris chutes; i.e. the landslide debris generally appears to travel to the base of the slope, leaving the landslide scar more or less free of additional loose material. This means that the presence of a landslide scar does not indicate an elevated likelihood of continued landslide debris deposition at the base of the landslide scar
8. Many of the debris chutes contain flattened or otherwise damaged vegetation. This indicates that revegetation (and subsequent natural ground stabilisation) is likely to be rapid
9. The landslide debris often accumulates in a moderately deep pile (2-3 metres deep) and is usually confined to the immediate vicinity of the break in slope; i.e runout distances are short. The presence of dense native vegetation at the base of the slope appears to very effectively arrest or divert the debris pile motion.
10. Sometimes (particularly where landslide debris reaches a drainage gully), the debris can fluidise and transform into a debris flow and in those cases the debris can travel much further.
11. Rainwater runoff and groundwater seepage can cause a clay rich slurry to flow from the debris pile and cause shallow inundation of land past the toe of the main debris pile, and this may continue for days/weeks after the landslide occurred

Figures 4-9, below, show some of the typical features of the translational type landslides observed in the study area.

 Figure 4. The slide plane is shallow and the surrounding ground appears to be unaffected. Flattened vegetation within the debris chute is likely to encourage rapid revegetation.	 Figure 5. The headscarp area is more or less intact and the slide plane is shallow. Bands of flattened vegetation are also visible. Photo: BDC.
 Figure 6. Exposed granite in the landslide scar indicates that the slip occurred on the bedrock/soil interface. Photo: BDC.	 Figure 7. The headscarp of this landslide shows a gradual transition from disturbed to undisturbed ground and there does not appear to be a high likelihood of headscarp regression. Additionally, flattened vegetation within the landslide scar is likely to regrow quickly. Photo: BDC.
 Figure 8. Landslide debris composed	 Figure 9. The debris has been diverted away from

predominantly of clay and wood has accumulated in a pile at the base of the slope and is likely to have been slowed by the presence of dense podocarp forest. Seepage has caused minor inundation with clay rich slurry in the paddock.	the building by the dense vegetation, preferentially inundating the cleared land in the left of the picture.

3.2.2 Potential harm caused by translational type landslides in Granity and Ngakawau

The recent landslides caused only minimal property damage. However, there are reports of historic landslide events having caused more severe property damage in the study area, including structural damage to residential buildings[10].

To estimate the predicted potential damage to buildings (and the associated risks to people in the area) that may be impacted by landslide debris it is necessary to first estimate the expected velocity of landslide debris as it is deposited at the base of the slope. From observations made in the field and from other similar sites it is estimated that the velocity of the landslide debris at the point where it meets the moderately inclined (<20° slope) residential land is less than 1m/second; i.e. the debris moves relatively slowly.

When landslide debris composed of clay, boulders and trees (as observed in the study area) impacts upon a typical timber framed building, it is common for the building to deform, causing cracks to windows, internal wall linings and external cladding as well as damage to services. Buildings with a piled foundation system can be pushed off the foundations and the building often moves as a single unit being “shunted” along by the debris. Buildings with concrete slab foundations typically do not get pushed off the foundations, but the debris may cause more severe damage to the wall that is impacted. Where the debris contains large amounts of trees (as observed within the study area) it is common for logs to be pushed through the wall that is impacted.

Typically, buildings that are impacted by this kind of landslide do not break apart and people inside the building at the time of the incident are usually not harmed. However, where trees are pushed through walls there may be an elevated risk of harm, including a risk to life, for the people in that room of the building.

Where clay and other debris rests or pushes against external walls of a building there is often inundation inside the building, which causes damage to carpets, furniture, etc. Figures 10 and 11 below, show typical landslide debris damage from damaged properties that are *outside* the study area.

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[10] J. Benn, 2005. Landslide events on the West Coast, South Island, 1867–2002. Available from: https://onlinelibrary.wiley.com/doi/10.1111/j.1745-7939.2005.00001.x


Figure 10. Trees pushed through an external wall of a house impacted by landslide debris (example from Marlborough)


Figure 11. Approximately 2m depth of clay-based landslide debris has pushed this house off its foundation (piles) and moved the building as a complete unit (example from Marlborough).

Note: There is the possibility of much larger landslides affecting properties in the study area, which may have the ability to engulf or bury residential dwellings. However, given the shallow depth of soil overlying the bedrock, the volume of landslide debris is likely to be limited to smaller volumes (<1000m^3), which are unlikely to engulf or bury buildings. The effects of climate change will elevate the risk of larger, more catastrophic landslides in the future. This may include the formation of rock block slide type landslides (or other landslide types), which may affect the underlying bedrock as well as the superficial soil layer, thus creating much larger, more damaging debris movement behaviour. Additionally, strong ground shaking during a very large earthquake may also trigger larger landslides to occur, the scale of which may be unprecedented. Further research would be required to better define these risks.

3.3 Debris flows

3.3.1 Features of debris flow type landslides

When a steep mountainous creek or stream becomes swollen, the stream bed and banks can erode and the eroded material is carried downstream by the high energy water flow. This is normal in any stream or river channel. When stream bank erosion becomes excessive, or if large volumes of debris are added to the stream water flow from other landslides, the volume of debris can often exceed the volume of water. In these cases the stream flow is usually termed a debris flow. When the stream enters a less steep or flat land area the water’s energy decreases and the suspended debris is then deposited in the “runout zone” , which may be either in the creek bed or on any land that may have been flooded by the creek (if the creek broke its banks).

Repeated instances of debris flow deposition (and normal stream flow deposition) where a creek emerges from the steep range front lead to the build up of an alluvial fan (sometimes called a debris fan). An alluvial fan is a conical shaped sedimentary (sand, gravel and rock) deposit that forms by sporadic, flood related and debris flow related deposition of material over time. Typically, a stream will migrate from side to side over the alluvial fan, depositing debris material more or less uniformly to create the conical shaped landform; i.e. on an alluvial fan where the stream bed is positioned towards the north of the fan, the stream bed will migrate back towards the south as material is deposited in the existing stream bed area.

A debris flow can also originate as a translational type landslide and fluidise with excess water in areas remote from existing stream channels. However, given the fluid nature of the flow, the debris will usually enter a stream channel before reaching the base of the slope.

Note: There is a continuum of flow states within any stream, where increased flow will allow for increased sediment transport. When flow is excessive the term “flood” is often used. During a flood, large volumes of sediment and debris are transported by the water. When sediment and debris transport becomes excessive, the term “debris flow” is then adopted. That continuum extends to the point where water is a minor component of the total volume of the debris flow, yet the debris still acts as a fluid.

The general layout and features of a typical debris flow type landslide are shown in figure 12, below:

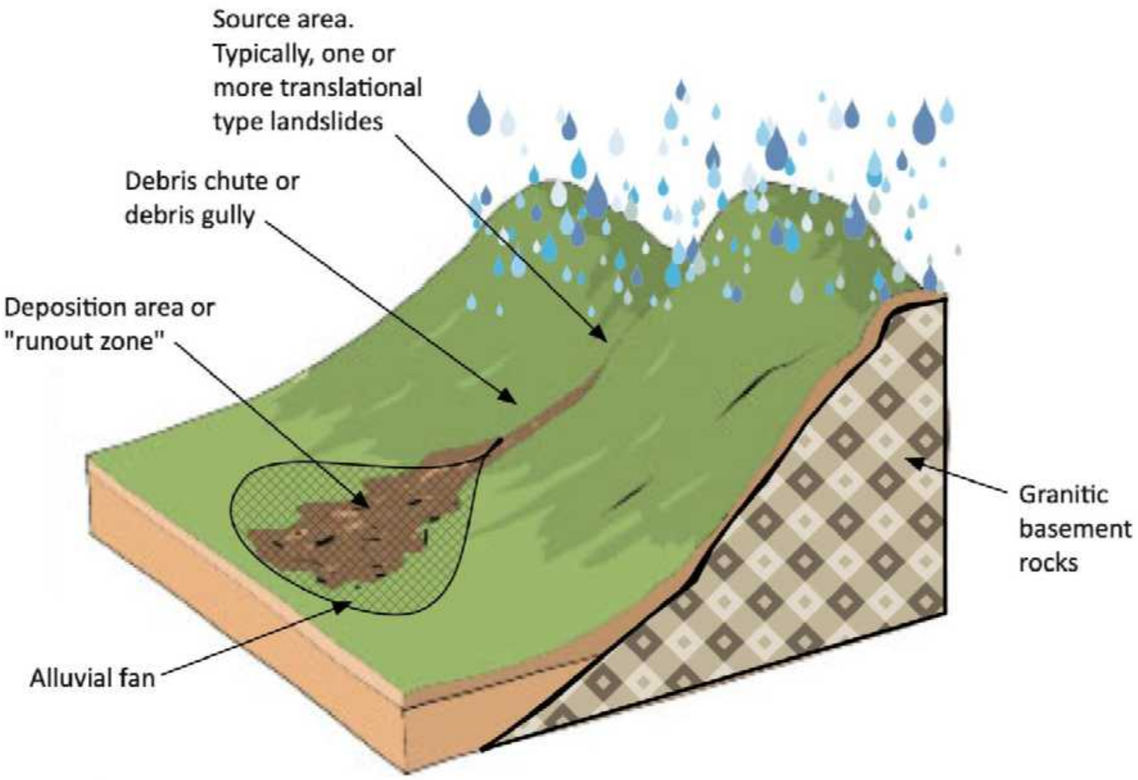

Figure 12. Typical debris flow features

From direct and remote observations within the study area it can be seen that:

1. Debris flows often originate where debris from a translational type landslide (or several) enters a natural drainage gully, which then fluidises with the excess water and travels down the gully
2. In some instances debris flows are formed on the slope, where no drainage gully is present and the debris flow forms a new drainage gully
3. The debris chutes are typically narrow (1-5m wide) and extend all the way to the base of the slope
4. Debris flow velocity is likely to be very rapid (>1m/second) where the slope is steep, but where the slope angle is moderate or flat the velocity and associated energy of the debris is much lower.
5. The debris is deposited on shallowly sloping (or flat) ground at the base of the slope and can inundate large land areas
6. Where debris flows travel down existing stream channels drainage infrastructure can be overwhelmed (culvert blockages) and the debris is then deposited on the surrounding land

7. Debris inundation is generally shallow (less than 0.5m) and is composed primarily of wet, sandy clay, logs and occasional boulders

Figures 13 - 16, below show some of the typical features of the debris flow type landslides observed in the study area.

 Figure 13. Debris flow gully formed as a result of the debris from two small translational type landslides entering a gully.	 Figure 14. Debris flow deposit in a runout zone in residential land in Granity.
 Figure 15. Debris flow deposition around a house in Granity. Approximate depth of inundation is <0.5m. Photo: BDC	 Figure 16. Blocked culverts may have been partly responsible for some of the observed debris inundation in Granity. Photo: BDC.

3.3.2 Potential harm caused by debris flow type landslides in Granity and Ngakawau

Figure 15, above, shows a house in Granity that was inundated with waterborne sand/gravel/clay debris from a debris flow that travelled down an unnamed creek, which was diverted onto the residential property after the downstream culverts became overwhelmed with debris. It appears that the house was not structurally damaged, but that a significant volume of debris was deposited in and around the house. The lack of structural damage to the house and the uniformly flat debris deposit indicates that the flow energy was relatively low. Similarly, Figure 14 shows residential land in Granity that was inundated with debris and caused damage to a plant nursery. In both of these cases the risk of harm to people is low.

The scale of observed debris flow landslides in the study area is limited to low magnitude events, where flooding and associated debris deposition is the most likely outcome. Since the observed debris flows usually occur in existing stream channels, the proximity to these stream channels is the main factor in the level of risk of debris flow inundation at any site. Significantly, the debris flow energy decreases rapidly as the stream gradient decreases, so the further away a site is from steep ground the lower the energy the debris flow will have and thus the less damaging it is likely to be.

Where a building is positioned on an alluvial fan it is likely that it will be affected by debris flows in the future, unless specific mitigation measures are put in place. The nature and scale of these mitigation measures is necessarily location dependent and requires specific engineering design.

Note: There is the possibility of larger, higher energy debris flows affecting properties in the study area, particularly in respect of the effects of climate change. Higher magnitude debris flow events may cause similar damage to the effects of translational type landslides as described above.

4. Landslide inventory

4.1 Data collection

Two aerial photography datasets (one set collected 2009-2011 and the other collected 2015-2016) sourced from Land Information New Zealand (LINZ) were analysed along with a recent drone-based georeferenced aerial photography dataset (collected by the report author in April 2022). Analysis comprised the mapping of landslides present in each of the datasets and has allowed for the presentation of a landslide inventory. The landslide inventory differentiates between landslide type and age and where possible, the deposition area is displayed distinctly from the source area.

The rainfall triggering amounts are not known for the earlier landslides since the exact date of occurrence is unknown. However, for the February 2022 landslides data collected by the West Coast Regional Council[11] shows that at the closest available rain gauge site (Mokihinui River at Stoney Creek) there was 137mm of rainfall in 24hrs on 3 February 2022 and on 10 February 2022 (when these landslides were reported to occur) another 164mm fell in 24hrs. Data presented on the HIRDS[12] database shows that this rainfall amount is currently[13] expected to occur in Granity once every 10 years (Annual Exceedance Probability = 0.1).

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[11] https://envirodata.wcrc.govt.nz/dashboards/rainfall/rainfall.php#

[12] NIWA's High Intensity Rainfall Design System (HIRDS) provides a map-based interface to enable rainfall estimates to be provided at any location in New Zealand. It is available at: https://hirds.niwa.co.nz/

[13] The effects of climate change are expected to cause higher intensity and more frequent heavy rainfall events in the future.

4.2 Landslide inventory map

Figure 17, below, shows the landslide inventory map.

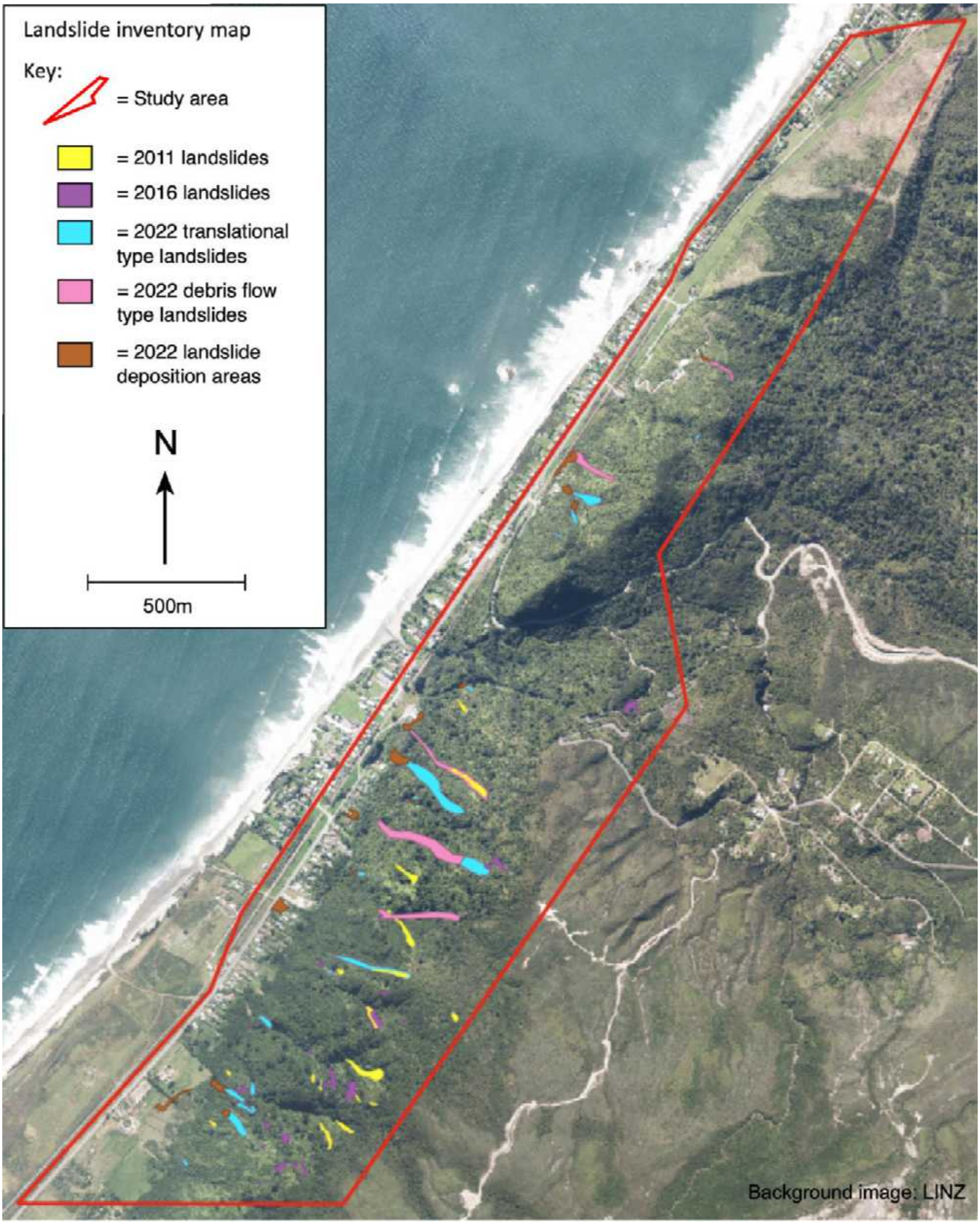

Figure 17. Landslide inventory map

Table 1, below, shows a breakdown of the landslides displayed in the landslide inventory.

Table 1. Landslide inventory data.

Dataset	Number of landslides	Total area/m^2 (rounded to the nearest 10m^2)
2009-2011	18	8,710
2015-2016	22	11,030
2022	22 (5 x debris flows and 17 x translational landslides)	42,570 (19,660 due to debris flows and 22,910 due to translational landslides)
Total	62	62,310

In addition to the landslide areas noted in Table 1, there are also 14 mapped areas where landslide debris has been deposited with a total inundated land area of 12,250m^2.

A basic analysis of this data suggests that there is only a slight increase in landslide numbers over time, but that there is a large increase in landslide area over time. However, this may be due in part to some of the limitations listed below (see Section 11. Limitations). The landslide inventory has been used to produce a landslide hazard zone map and two landslide risk zone maps (one representing the risk from translational type landslides and one representing the risk from debris flows).

5. Landslide hazard map

5.1 Method and description

A landslide hazard map identifies areas which are subject to landslides and is measured from low to high hazard. The landslide hazard map takes into account where the landslides occur and what terrain features contribute to their occurrence (in this case slope angle and geology have been considered). The preparation of this landslide hazard map involved generating a slope angle map[14] and overlaying this with a geology map [15] and the landslide inventory. The relationships between the landslide distribution and the terrain variables (slope angle and geology) are interrogated within the GIS and the resultant zones of high, medium and low hazard are then displayed on the landslide hazard map. Landslide frequency (number of landslides per year) has been based on the average observed landslide numbers over the period of time covered by aerial photography datasets. It is acknowledged that the time period covered by the aerial photography datasets is a short time period, so may not accurately reflect the nature of landslide occurrence over time[16].

Table 2, below, shows the terrain variables, landslide distribution statistics and descriptions associated with each of the landslide hazard zones.

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[14] Generated from the LINZ West Coast - Westport 1M DEM available from: https://data.linz.govt.nz/layer/105446-west-coast-westport-lidar-1m-dem-2020/webservices/

[15] 1:250,000 scale Geology maps from GNS (QMAPS) available from: https://www.gns.cri.nz/Home/Our-Science/Land-and-Marine-Geoscience/Regional-Geology/Geological-Maps/1-250-000-Geological-Map-of-New-Zealand-QMAP/Digital-Data-and-Downloads

[16] See Section 11. Limitations.

Table 2. Landslide hazard zone descriptors

Landslide hazard zone	Geology	Slope angle	Landslide density		Approximate average number of landslides per year	Description
			Number of landslides per 1km^2	Percentage of land affected by landslides		
High	Granite and diorite of the Karamea Batholith	> 40°	52.7	4.6%	5	Landslides occur frequently. Debris may travel from this zone into lower hazard zones below
Medium	Mudstone, sandstone and coal of the Kaiata Formation and Brunner Coal Measures	15-40° (with minor areas exceeding 40°)	2.8	0.2%	0.5	Landslides rarely occur and are usually associated with artificial cuts or where debris travels into this zone.
Low	Sand, gravel and silt beach deposits	< 15°	0*	0%**	0	Landslides generally do not occur in this zone. Debris may travel into this zone (particularly from a debris flow).

* There are four areas where landslide debris has been *deposited* in the low hazard zone

** 0.6% of the land area in the low hazard zone has experienced landslide debris *deposition*

The landslide hazard map as shown in Figure 18, below, illustrates where landslides are more or less likely to originate. It does not show which areas are at risk from landslide impact damage or debris inundation. The landslide hazard map has been used to generate a landslide risk zone map (shown in Section 6.2), which shows the land areas that are likely to be impacted by translational type landslides. It has also been used, in combination with additional terrain analysis (including stream channel and drainage basin catchment delineation) to generate another landslide risk zone map that shows the areas of land that are at risk of being impacted, or inundated by debris flow type landslides (shown in Section 7.2).

5.2 Landslide hazard map

The landslide hazard map illustrates where landslides are likely to originate. It is shown in Figure 18, below.

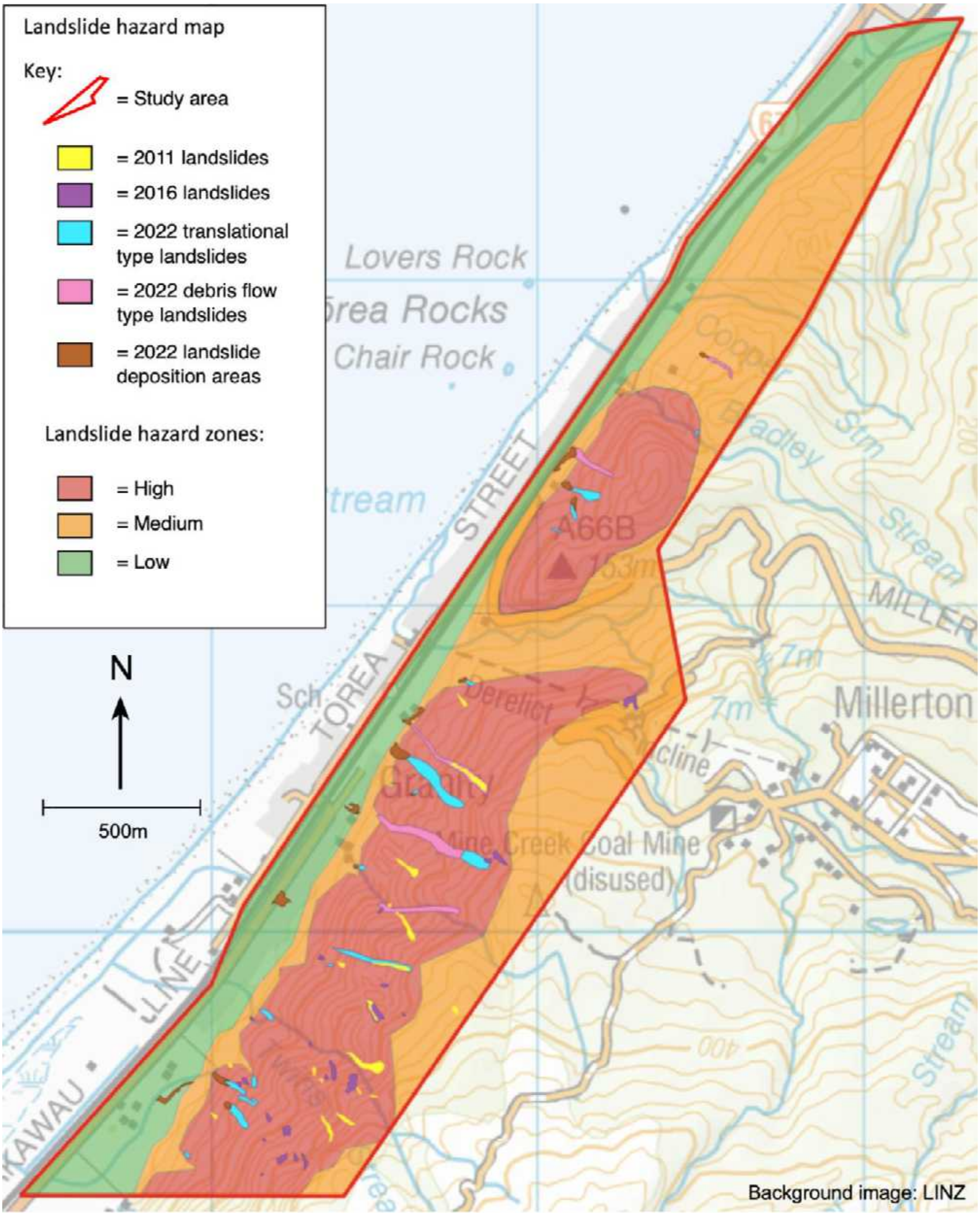

Figure 18. Landslide hazard map. See Table 2 above for descriptors of the three zones.

6. Translational type landslides risk zone map

6.1 Method and description

To classify and delineate the risks to people and property associated with translational type landslides in the study area the frequency of landslides is first established (see Table 2) and then the likely runout zones from those landslides are estimated based on observed landslide debris deposits and GIS based terrain analysis. As previously stated, there are two distinct landslide types that create hazards in the study area and the methods for delineating these hazards and the risks that they present to people and property are different. This section presents the risks associated with translational type landslides and Section 7 presents the risks associated with debris flow type landslides.

The landslide hazard map shown above indicates where landslides are more or less likely to occur. Since the terrain variables are generally uniform throughout each hazard zone. In a high level assessment, it is sensible to assume that the likelihood of landsliding within each zone is also uniform[17]. From observations made of the landslide debris runout distances observed at the base of the slopes it can be seen that the landslide debris derived from translational type landslides generally stops within 20m of the break in slope, where the slope angle changes from steeper than 20° to less than 20°. Therefore, all the land upslope of that point can be expected to be inundated with landslide debris if a translational type landslide occurs upslope of that point. This line has been used to delineate the high risk zone (i.e. all the land upslope of the 20m buffer from the 20° break in slope). Below this line is the medium risk zone, where landslide debris is less likely to inundate the land.

Given that the slope in this area has been created by the deposition of landslide debris over time, it is also sensible to assume that any of the sloping land below the high hazard areas could be inundated with landslide debris, albeit with a much lower likelihood of occurrence. The flat (less than 5°) land at the base of the slope is considered to be at low risk (not zero risk) of inundation and would only be inundated in the event of an extremely large (low likelihood) landslide event. So, the delineation between the Medium Risk Zone and the Low Risk Zone is the 5° break in slope.

To quantitatively calculate the risk to life in each of the zones the following equation[18] has been used:

$$R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}$$

Where:

$R_{(LOL)}$	is the risk (annual probability of loss of life of an individual).
$P_{(H)}$	is the annual probability of the landslide occurring.
$P_{(S:H)}$	is the probability of a landslide impacting a building (a spatial location) taking into account the travel distance and travel direction given the event.

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[17] Site specific investigation work may be able to further identify specific areas within each zone and more accurately delineate the landslide risks. However, that is outside the scope of this report (See Section 11. Limitations)

[18] From Section 7.1, Quantitative Risk Estimation in Fell, *et al*: Practice Note Guidelines for Landslide Risk Management 2007" Journal and News of the Australian Geomechanics Society Volume 42 No 1 March 2007

$P_{(T:S)}$	is the temporal spatial probability (e.g. of the building or location being occupied by the individual at the time of impact) and allowing for the possibility of evacuation if there is warning of the landslide occurrence.
$V_{(D:T)}$	is the vulnerability of the individual (probability of loss of life of the individual given the impact).

Table 3, below, presents an explanation of the input variables to calculate the annual risk to life in each of the landslide risk zones. It also shows the total risk to life ($R_{(LOL)}$) which is calculated as a combination of all the input variables and presents a description of the expected property damage for each zone. Note that the data used for these calculations excludes any projected future effects of climate change.

Table 3. Loss of life risk calculation and risk level descriptors for the three landslide risk zones.

	High Risk Zone	Medium Risk Zone	Low Risk Zone
$P_{(H)}$	Landslides occur at a rate of 5/year so the annual probability of occurrence is **1**	Landslides occur at a rate of 0.5 / year so the annual probability of occurrence is **0.5**	Landslides rarely enter this zone so the probability of occurrence is estimated at **0.1**
$P_{(S:H)}$	The combined length of the two High Risk Zones is 2670m and a 45m length of that was affected by landslides in the Feb 2022 floods. From this it follows that the spatial probability of any point being affected during a landslide event is **0.017**	The length of the Medium Risk Zone is 4345m and a 22m length of that was affected by landslides in the Feb 2022 floods. From this it follows that the spatial probability of any point being affected during a landslide event is **0.0051**	During the Feb 2022 event, there were no landslide debris deposits (from translational type landslides) recorded in the Low Risk Zone. However, it may be sensible to assume that the spatial probability of occurrence is approximately half that of the Medium Risk Zone: **0.0025**
$P_{(T:S)}$	Evacuations are not usually implemented in this area, so the temporal probability of a person being present in a residential dwelling is **1**	Evacuations are not usually implemented in this area, so the temporal probability of a person being present in a residential dwelling is **1**	Evacuations are not usually implemented in this area, so the temporal probability of a person being present in a residential dwelling is **1**
$V_{(D:T)}$	Given that buildings generally do not break apart or drastically deform, but that logs can be pushed through walls, it may be sensible to assume that a person within a building impacted by a landslide would have a 99.5% chance of survival. So, vulnerability is estimated at **0.005**	Given the points mentioned for vulnerability in the High Risk Zone combined with the decreased energy of the landslide debris in the Medium Risk Zone, that a person within a building impacted by a landslide would have a 99.9% chance of survival. So, vulnerability is estimated at **0.001**	Given the points mentioned for vulnerability in the High and Medium Risk Zones combined with the decreased energy of the landslide debris in the Low Risk Zone, that a person within a building impacted by a landslide would have a 99.99% chance of survival. So, vulnerability is estimated at **0.0001**
RISK $R_{(LOL)}$	8.5×10^{-5} (Can be expressed as 0.0085% per year Or one death every 10,000 years)	2.6×10^{-6} (Can be expressed as 0.00026% per year Or one death every 400,000 years)	2.5×10^{-8} (Can be expressed as 0.0000025% per year Or one death every 40 Million years)
Property damage	There is an annual probability of 0.017 of severe damage to a building. I.e. in the 50 year design life there is a 57%[19] chance of being damaged. Damage may require a complete rebuild.	There is an annual probability of 0.0051 of damage to buildings. I.e. in the 50 year design life there is a 22% chance of being damaged. Damage is likely to be moderate and repairable.	There is an annual probability of 0.0025 of damage to buildings. I.e. in the 50 year design life there is a 9% chance of being damaged. Damage is likely to be minor and easily repairable.

Note: Fatalities caused by landslides are not common in New Zealand. Data presented by Te Ara – The Encyclopaedia of New Zealand[20], shows that a total of eighteen fatal landslides have occurred in New Zealand since records began. These eighteen landslides caused a total of eighty eight fatalities in residential land.

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[19] Calculated using binomial distribution.

[20] Available from: https://teara.govt.nz/files/d-8801-enz.pdf

6.2 Translational Landslide Risk Zone Map

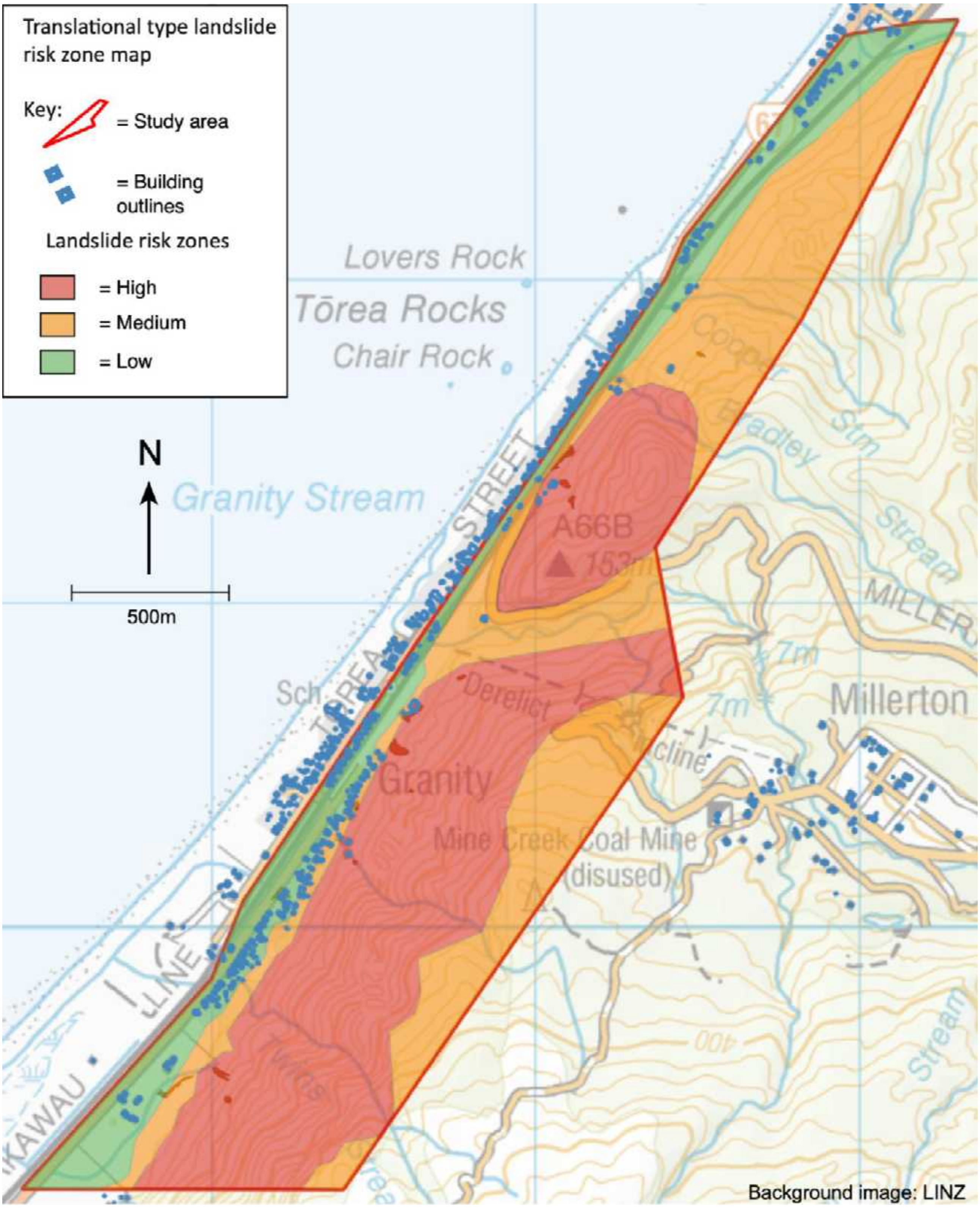

Figure 19. Translational Landslide Risk Zone Map (for descriptions of zones see table 3).

To allow for easier viewing of fine details, smaller scale representations of this map are shown in Appendix A. Additionally, BDC has been provided with vector and raster GIS files for electronic display at any scale.

7. Debris flow type landslides risk zone map

7.1 Method and description

The occurrence, behaviour and consequences of debris flows is not easy to predict. For this reason it has not been possible to produce a quantitative risk assessment (as was done for translational type landslides), so a qualitative method has been adopted. With the following assumptions the debris flow hazards can be classified and the resultant risks to properties can be qualitatively estimated[21].

Assumptions:

- Debris flows usually occur as a result of oversaturation of landslide debris, often derived from translational landslides
- Debris flows can occur in any of the high (or medium) hazard areas and may reach the base of the steep slope
- Debris flows are likely to travel down existing watercourses
- A drainage basin with more landslides is more likely to experience more and larger debris flows than a drainage basin with fewer landslides
- The risk of damage to properties will be related to that property's proximity to the steep, high hazard area and proximity to a watercourse that is likely to experience debris flows
- The energy (and destructive force) carried by a debris flow will be greater where the gradient of the ground is steeper (and energy will be lower in flatter ground). This means that debris flow inundation usually causes minor damage (non-structural) to dwellings, where those dwellings are located on flat ground. More severe damage may occur if a dwelling is positioned on sloping ground closer to a debris flow source area
- Where an alluvial fan is present there is an equal risk of debris flow inundation laterally across the entire alluvial fan (unless specific and well engineered mitigation measures are put in place)
- Where culvert blockages occur this can lead to debris flow diversion over a wide area

To classify and delineate the risks to people and property associated with debris flow type landslides in the study area the following process was used:

1. The zones from the translational type landslide risk zone map have been adopted to also represent the risk zones with respect to debris flows
2. Additional risk areas are added to the risk zone map based on the characteristics of the drainage basins (see Figure 20 and Table 4, below):
    a. Using a GIS, the individual drainage basins on the steep range front were identified and the area of each calculated
    b. The landslide inventory was then overlaid on the drainage basin map and the areas of landslides within each basin were extracted
    c. The proportion of each drainage basin affected by landslides was then calculated
    d. The drainage basins were then classified as High, Medium or Low hazard, based on the % of land within each drainage basin affected by landslides (Below 1% = Low, 1-5% = Medium, over 5% = High)
    e. Evidence for debris flow deposition was correlated between the hazard zones and it was found that all but one of the High hazard drainage basins showed evidence of debris flow

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[21] These estimations are based primarily on expert judgement, field observations and limited terrain analysis. Therefore, the level of confidence in these estimations is low. Please see Section 11. Limitations.

deposition, three of the eight Medium hazard drainage basins showed evidence of debris flow deposition and one of the eighteen low hazard basins showed evidence of debris flow deposition. This served to validate the hazard zone classification

f. Three Risk Zones (High, Medium and Low) were established and added to the Risk Zone Map based on the proximity to a watercourse and the terrain in the vicinity of that watercourse (primarily the presence or absence of an alluvial fan). Each drainage basin has been individually analysed and the following rules applied:
   i. For High hazard drainage basins:
      1. The entire alluvial fan (if one is present) and all land within 10m of the watercourse as far as the highway (or railway) has been classed as High risk
      2. All land between 30m and 10m either side of the watercourse has been classed as Medium Risk
      3. Remaining land is low risk
   ii. For Medium hazard drainage basins:
      1. The entire alluvial fan (if one is present) and all land within 10m of the watercourse as far as the highway (or railway) has been classed as Medium risk
      2. Remaining land is low risk
   iii. For Low hazard drainage basins, no additional risk areas have been applied

Figure 20, below, shows the drainage basin areas colour coded to illustrate the debris flow hazard of each basin and Table 4 shows the input data used to classify each of the drainage basins.

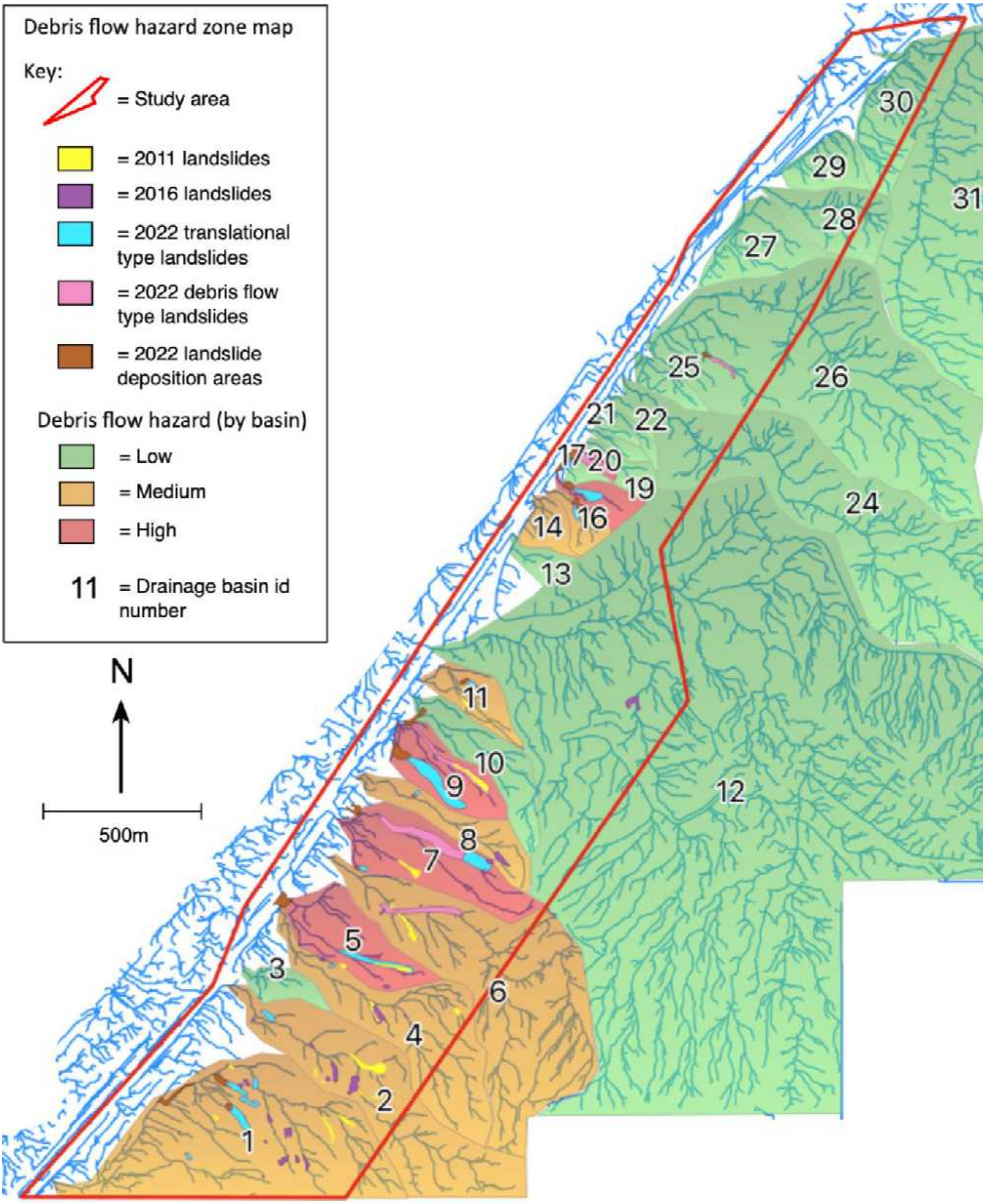

Figure 20. Debris flow hazard zones (watercourses shown as blue lines).

Table 4. Input data used to classify each of the drainage basins.

Drainage basin number	Area / m^2	Total area of landslides within basin / m^2	% of land within basin affected by landslides	Evidence for debris flow deposition	Debris flow hazard	Comment
1	398,520	7,971	2	Yes	Medium	
2	257,398	5,204	2	No	Medium	Twins Stream
3	26,687	0	0	No	Low	
4	200,340	2,677	1	Yes	Medium	
5	9,9902	4,733	5	Yes	High	Debris flow caused dwelling damage in 2022
6	387,868	5,074	1	Yes	Medium	
7	134,722	12,134	9	Yes	High	Debris flow caused dwelling damage in 2022
8	68,393	899	1	No	Medium	
9	76,792	11,848	15	Yes	High	Debris flow caused damage to Museum in 2022
10	83,077	0	0	No	Low	
11	46,790	591	1	No	Medium	
12	2,729,918	904	0	No	Low	Granity Stream
13	19,041	0	0	No	Low	
14	27,089	238	1	No	Medium	
15	22,106	583	3	No	Medium	
16	28,631	1,977	7	No	High	
17	8,386	0	0	Yes*	Low	
18	6,843	2,249	33	Yes	High	Debris flow caused residential land damage in 2022
19	21,733	0	0	No	Low	
20	9,864	0	0	No	Low	
21	6,496	0	0	No	Low	
22	11,704	0	0	No	Low	
23	8,528	0	0	No	Low	Bradley Stream
24	463,664	189	0	No	Low	
25	23,589	0	0	No	Low	
26	586,477	878	0	No	Low	Cooper Stream
27	77,658	0	0	No	Low	
28	78,646	0	0	No	Low	
29	44,434	0	0	No	Low	
30	90,394	0	0	No	Low	
31	529,557	0	0	No	Low	

*Whilst Basin 17 has been classified as Low Hazard (from debris flows) there is evidence of debris flow deposition. This has occurred due to overspill of debris from Basin 18 (a High Hazard basin) due to culvert blockage.

7.2 Debris Flow Risk Zone Map

The debris flow risk zone map was generated using the methodology described above. The risk zone descriptors are shown in the qualitative risk analysis matrix[22] below (Table 5):

Table 5. Risk matrix to be used with the debris flow risk zone map.

	Consequences		
Likelihood	Major. Severe property damage. Injuries to people are possible.	Moderate. Some property damage. People unharmed.	Minor. Inconvenience caused. Debris easily removed.
Highly likely (may occur once every 10 years or more)	High	High	Medium
Possible (may occur once every 100 years)	High	Medium	Low
Rare (may occur once every 1000 years)	Medium	Low	Low

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[22] This risk matrix is a simplification of the risk matrix suggested in Fell *et al.* 2008.

Figure 21, below, shows the debris flow risk zone map.

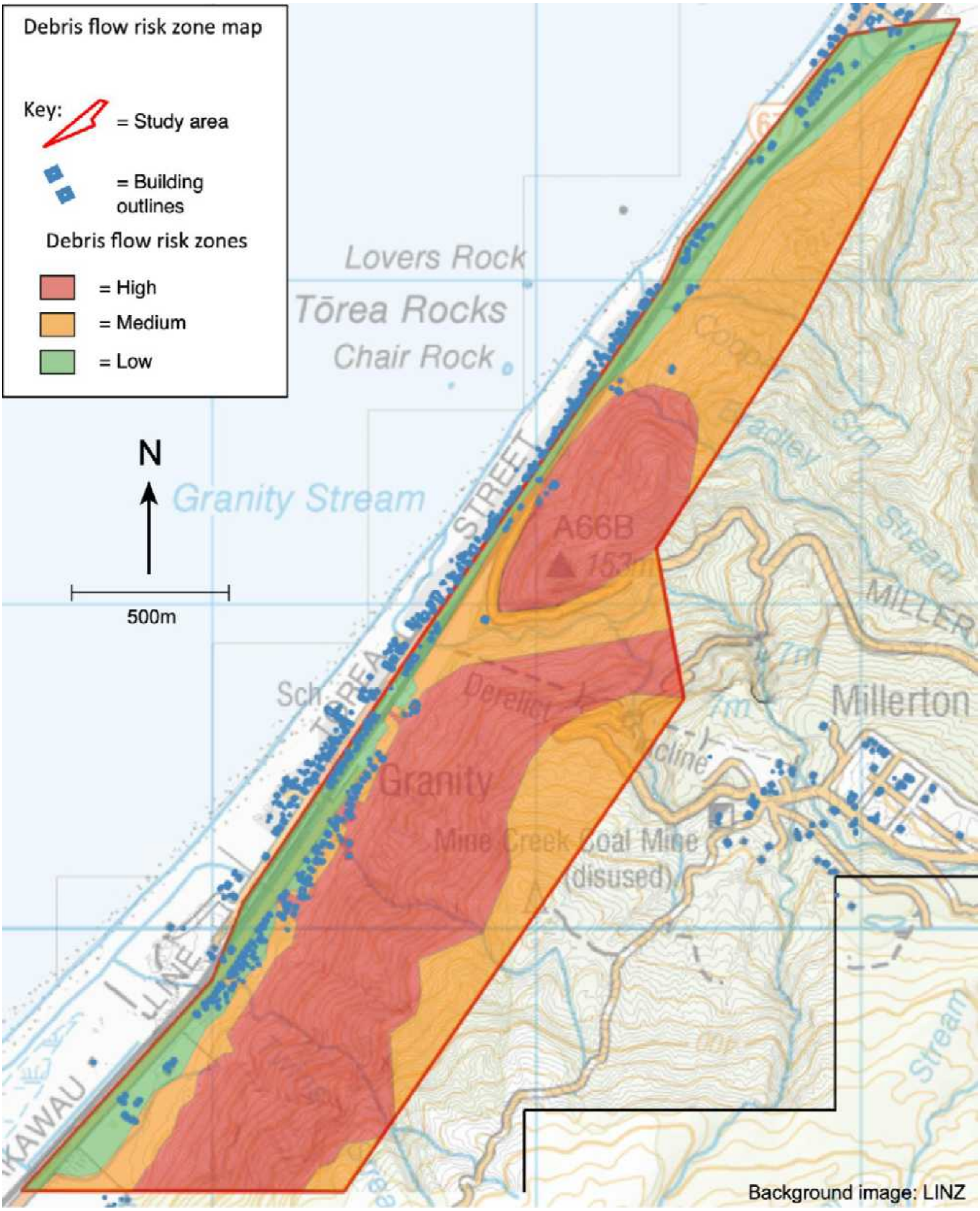

Figure 21. Debris flow risk zone map.

To allow for easier viewing of fine details, smaller scale representations of this map are shown in Appendix B. Additionally, BDC has been provided with vector and raster GIS files for electronic display at any scale.

8. Other factors affecting landslide risk

This study delineates the risk to people and property as a result of landslides that are triggered by heavy rainfall events. It does not take into account the risk of coseismic landslides (earthquake generated landslides) or the potential for increased landslide risk due to climate change.

8.1 Coseismic landslide risk

An earthquake with a peak ground acceleration (PGA) of 0.2 or above would be expected to cause coseismic landslides to occur within the study area[23]. This precedent behaviour is well established. Previous low frequency seismic events in the Buller area have caused some very large and damaging landslide events with multiple fatalities (i.e. Murchison earthquake in 1929 and Inangahua earthquake in 1968). The National Seismic Hazard Model[24] shows that an earthquake with PGA 0.2 is expected to occur once every 475 years[25]. Therefore, the annual chance of a coseismic landslide at this site is 0.2% per year or a probability of 0.002. However, the scale of this kind of landslide event and the consequences of its occurrence are not known. Further research would be required to meaningfully assess the risk of coseismic landsliding.

8.2 The effects of climate change

Climate change is likely to cause an increase in heavy rainfall event magnitude and frequency. This increase in rainfall is likely to cause a corresponding increase in the magnitude and frequency of landslide events. This means that future landslide events in the Granity area are expected to be more common, bigger and more damaging than the current and past observed landslides.

During the heavy rainfall event of February 2022, 166mm of rain fell in 24 hours. The HIRDS[26] database shows that this is approximately a 1 in 10 year event. Another function of the HIRDS database is to model the potential future rainfall intensity and return intervals with respect to varying climate prediction models. Assuming an RCP2.6 scenario[27], the HIRDS database shows that in the time period 2031-2050 this rainfall intensity is likely to be a 1:5 year event and that a 1:10 year event is likely to be in the order of 187mm of rain in 24 hours (12% more rain). Assuming an RCP8.5 scenario, the HIRDS database shows that in the time period 2031-2050 this rainfall intensity is still likely to be a 1:5 year event and that a 1:10 year event is likely to be in the order of 191mm of rain in 24 hours (13% more rain). From this climate modelling it is expected that landslide events will become more frequent (possibly twice the frequency), and that the magnitude of landslide events may also increase significantly.

The relationship between rainfall intensity and landslide magnitude (size) is not well understood. However, recent observations of a number of very large landslides (40,000m^3+) in close proximity to the study area

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[23] From Table 4.8 in de Vilder SJ, Massey CI, Guidelines for natural hazard risk analysis on public conservation lands and waters – Part 3: Analysing landslide risk to point and linear sites. Lower Hutt (NZ): GNS Science. 52 p. Consultancy Report 2020/52.

[24] Accessed from: https://www.gns.cri.nz/Home/Our-Science/Natural-Hazards-and-Risks/Earthquakes/National-Seismic-Hazard-Model-Programme

[25] https://hazard.openquake.org/gem/models/NZL/

[26] High Intensity Rainfall Design System accessed at: https://hirds.niwa.co.nz/

[27] A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC. Four pathways were used for climate modelling with 2.6 being the best case scenario and 8.5 being the worst case scenario.

(Charming Creek Walkway[28]) suggest that the locally unprecedented scale of those landslides may indicate that larger scale landslides may occur in the Granity area in the future.

Given that rainfall intensity is expected to increase in the order of 12-13% by 2050, it should be expected that landslide magnitude will also increase by at least that amount. This increase in magnitude may have a significant effect on the expected risk to life, particularly for those properties located within the High Risk Zone.

Further research is required to more accurately predict the risks associated with increased magnitude and frequency of landslide events due to climate change. However, the establishment of well planned monitoring systems (including locally installed rain gauges, and post-rain event landslide surveys used to support landslide trend analysis and the establishment of a rainfall intensity landslide triggering threshold) and an appropriate warning system may help to define and manage the climate change related risks as more data becomes available.

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[28] England and Company Ltd. Consulting Letter Report to Department of Conservation (Westport Office), dated: 07 December 2021.

9. Discussion and risk mitigation options

9.1 Review of findings

A brief review of the two risk zone maps shows that:

- **Translational landslides**:
    - **Risk to life in the High Risk Zone.** There are four residential dwellings along with a number of other outbuildings/sheds (with unknown use) as well as a commercial property (the Museum) that are at high risk of impact damage from translational type landslides. For people living in those dwellings there is a calculated risk of loss of life in the order of 8.5 x 10^{-5} per year[29]. As stated in the commentary to NZS 1170.5[30] an accepted basis for building codes is an annual fatality rate of 10^{-6} (this would be an accepted basis for *new builds*, not existing developments). However, other authors (such as Fell *et al*. 2008) have suggested that 10^{-4} is a more suitable risk tolerance threshold for existing developments. An important point to note is that in the High Risk Zone, the risk level is almost two orders of magnitude higher than the accepted level suggested in the commentary to NZS1170.5 for new builds. However, it is within the risk tolerance level suggested by Fell *et al* for existing developments.
    - **Property risk in the High Risk Zone.** In the 50 year design life of a building, there is a 57% chance of being damaged.
    - **Risk to life in the Medium Risk Zone.** There are approximately twenty residential dwellings and a number of other outbuildings (with unknown use) within the medium risk zone where the expected risk of loss of life is 2.6 x 10^{-6} per year[31]. Within the Medium risk zone, the risk to life is approximately double the suggested level (for new builds) in the commentary to NZS 1170.5 (although, given the limitations of the accuracy of these risk level estimations, the actual risk may be within the suggested risk tolerance levels in NZS 1170.5.)[32] However, it is well within the risk tolerance level suggested by Fell *et al* for existing developments.
    - **Property risk in the Medium Risk Zone.** In the 50 year design life of a building there is a 22% chance of being damaged.
- **Debris flow type landslides:** There are ten residential dwellings along with a number of other outbuildings/sheds (with unknown use) as well as a commercial property (the Museum) that are at high risk of inundation damage from debris flows. For people living in those dwellings there is a possible risk of harm and it is likely that those buildings will be damaged by debris flows in the future. There are also approximately fifteen residential dwellings and a number of other outbuildings (with unknown use) as well as three commercial properties within the medium risk zone, where property damage may also occur.

From these findings it is clear that some form of risk reduction work may be appropriate.

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[29] Can be expressed as 0.085% per year, or approximately one death every 1,000 years

[30] Structural design actions - Part 5: Earthquake actions - New Zealand Commentary: Amendment 1:2016

[31] Can be expressed as 0.0026% per year, or approximately one death every 40,000 years

[32] See Point 1 in Section 11.2 Limitations of the landslide risk zone maps.

9.2 Risk mitigation options

This report presents a risk analysis of the identified landslide hazards in the study area. The tolerability (or intolerability) of those risks is a matter for discussion within the community (including BDC and commercial stakeholders). That discussion will evaluate the risks against the community's value judgements and existing risk tolerances. Depending on the outcomes of that discussion a range of risk mitigation options can be developed and implemented in a risk control plan (see Figure 2. Framework for landslide risk management).

Broadly, the risk mitigation options are[33]:

1. ***Accept the risk***, which is only an option subject to the criteria set by the regulator (in this case BDC in discussion with the community). Where the risk is not tolerable then risk mitigation measures are required.
2. ***Avoid the risk***, by relocation of the affected high risk buildings and by limiting future development within the High (and possibly Medium) risk zone.
3. ***Reduce the frequency of landsliding***, by stabilisation measures to control the initiating circumstances, such as by re-profiling the surface geometry where existing slopes are 'over steep', by provision of improved surface water drainage measures, by provision of subsurface drainage scheme, by provision of physical works such as retaining walls, anchored walls or ground anchors.
4. ***Reduce the consequences***, by provision of defensive stabilisation measures or protective measures such as debris deflection bunds, or amelioration of the behaviour of the landslide.
5. ***Manage the risk by establishing monitoring and warning systems,*** such as by weather monitoring and alerting residents potentially affected to a change in the landslide risk conditions. Such systems may be regarded as a method of reducing the consequences provided it is feasible for sufficient time to be available between the alert being raised and appropriate action being implemented.
6. ***Transfer the risk,*** such as by requiring another authority to accept the risk or by provision of insurance to cover potential property damage.
7. ***Postpone the decision,*** where there is sufficient uncertainty resulting from the available data, provided that additional investigations or monitoring are likely to enable a better risk assessment to be completed. Postponement is only a temporary measure and implies the risks are being temporarily accepted, even though they may not be acceptable or tolerable.

Assuming that the risk is not simply accepted then the other risk mitigation options should be investigated and suitable solutions agreed upon. Avoiding the risk by relocating buildings (Point 2, above) from the high (and possibly medium) risk zone is by far the most effective risk reduction option. However, forced relocations are usually unpopular, expensive and may not be a suitable option in this instance. Some of the more passive, non-regulatory methods available to local authorities to encourage people to *avoid* the landslide risk include[34]:

- Acquiring or purchasing at-risk land for passive recreational purposes
- Exchanging at-risk land with Council owned land more suitable for the purpose
- Allowing greater development rights on other land if at-risk land is retired or covenanted
- Using structure plans to actively identify and avoid areas with stability concerns

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[33] Modified from Section 9.1, Risk mitigation principles in Fell, *et al*: Practice Note Guidelines for Landslide Risk Management 2007" Journal and News of the Australian Geomechanics Society Volume 42 No 1 March 2007

[34] From Guidelines for assessing planning policy and consent requirements for landslide prone land. Compiled by W. Saunders and P. Glassey GNS Science, GNS Science Miscellaneous Series 7. Available from: http://www.qualityplanning.org.nz/sites/default/files/Guidelines%20for%20assessing%20planning%20policy%20and%20consent%20requirements%20for%20la.pdf

- Ensuring at-risk land forms part of the reserves contribution as a condition of subdivision consent
- Using financial incentives (for example, rates relief for at-risk land if it is not developed)
- Promoting and helping fund the use of covenants (privately or through the QEII National Trust) for voluntary protection from development of open space on private land
- Education to raise awareness of the risk, and to encourage people to locate buildings away from the hazard

For various reasons (existing use rights, community acceptance, cost, etc.) relocations and land-use changes may not be appropriate for this area. Also, reducing the frequency of landsliding (Point 3, above) by installing stabilisation structures is not a feasible option in this area. That means that the most suitable methods of risk reduction may be to reduce the consequences of landslide events by utilising a suite of defensive measures. Table 6, below, shows a range of potential risk reduction measures that may help to reduce the consequences of future landslide (translational type and debris flow) events. These are presented in no particular order.

Table 6. Risk mitigation options.

Risk reduction measure	Description	Expected risk reduction benefits	Other factors to consider
Debris deflection bunds	Earth bunds can be an effective method of diverting or stopping the downslope motion of landslide debris. These would require Specific Engineering Design (SED) to protect vulnerable properties. Other deflection structures such as concrete tilt panel walls, steel poles and timber pole walls could be considered, but earth bunds are generally accepted to offer the best cost/benefit ratio of these defensive structures.	Very effective within the design parameters. Benefits should be able to be quantified during the SED process	These may be obtrusive and may not be a welcome feature of a residential property. Moderately high cost of installation.
Encourage dense vegetation growth	Healthy, dense tree cover on the ground upslope of a vulnerable building can be an effective means of stopping, slowing or diverting landslide debris. Establishing new growth and limiting the felling of existing trees may be appropriate	Effectiveness may be variable, but is expected to provide some benefits, particularly in respect to the smaller, more frequent events.	Establishing new tree growth takes considerable time.
Debris flow control structures; i.e. debris dams / debris nets	Structures built to detain debris upslope of the elements at risk.	Can be very effective at reducing risks from debris flows	Ongoing maintenance requirements.
Install larger culverts (to reduce the risks from debris flows only)	Some of the observed debris flow inundation damage was likely caused by culvert blockages leading to debris flow diversion onto residential land. Suitably sized culverts may reduce the likelihood of blockage. These would require SED.	Very effective within the design parameters. Benefits should be able to be quantified during the SED process. Would also help to reduce flood risk	High cost. Although some (or all) of the cost may be shared with NZTA and Kiwi Rail.

Risk reduction measure	Description	Expected risk reduction benefits	Other factors to consider
Maintain upslope waterways (to reduce the risks from debris flows only)	To reduce the risk of debris flow diversion it may be sensible to maintain waterways upslope of a residential dwelling and try to encourage flow away from a vulnerable structure, by construction of channels and bunds. Care needs to be taken with this technique to avoid over sedimentation and alluvial fan aggradation, which can lead to an *elevated* risk if done inappropriately	Can be effective in the short term. Long term, this technique may be counter productive.	Constant work is required to ensure effectiveness of this technique
Monitor and maintain downstream waterways (to reduce the risks from debris flows only)	This will involve ensuring culverts and downstream channels are not blocked so that debris flows are encouraged to stay within the existing waterway channels.	May be effective for small events, but unlikely to be effective for larger events or for prolonged periods of heavy rain, where sedimentation may be constant and overwhelming.	Monitoring can be done cheaply and the results used to cost-effectively allocate resources
Modify residential building usage to favour spending time in lower risk areas of the same building	When landslide debris strikes the side of a building it will cause an elevated risk of harm to people who may be positioned in that side of the building. So, moving a bedroom to the downslope side of a house may help to reduce the amount of time spent in the higher hazard area (reduce hazard exposure time).	Risk to life can be very effectively reduced by this method.	Potentially easy and cheap to implement
Issue landslide warnings based on weather forecasts	A warning can be issued to the entire community (or select high risk individuals) based on forecast rainfall amount. Threshold could be set at 150mm/24hrs, or some other threshold, based on the level of risk tolerance. Actions derived from these warnings may include evacuations, or simply to raise awareness of the temporarily elevated risk	Highly effective risk reduction measure. Evacuations may be unpopular, particularly if these become frequent.	Easy and cheap to implement. May become increasingly important in respect to climate change.
Issue warnings based on locally installed monitoring devices	Rainfall sensors could be installed in various locations along the Granity rangefront, with the intention of providing better, more accurate, site specific information about rainfall amounts. This may become increasingly important as climate change progresses.	If a communication strategy is developed to ensure action is taken on warnings, this could be highly effective	Sensors may require ongoing maintenance. Installation costs should be low. May become increasingly important in respect to climate change.
Apply rules (regulatory) to limit further	Rules can be included in the District plan to discourage further development in high risk areas. These rules may range from a	Depending on the approach taken these rules can be effective	Usually unpopular

Risk reduction measure	Description	Expected risk reduction benefits	Other factors to consider
development in high and medium risk zones	requirement for detailed risk mitigation works for future developments, up to a blanket ban on future development.	at reducing the occupancy rates of the higher risk areas over time and will become increasingly mainstream as insurance becomes harder and more costly to obtain.	
Information provision	Informing the community about the landslide risks[35] will help residents to make their own, informed decisions about landslide risk reduction.	People are able to choose the risk reduction methods most suitable for their own circumstance and risk tolerance levels.	Easy to provide. Required by law.
Monitoring of existing landslides	Geotechnical observations of existing landslides may give pre-warning of imminent debris inundation allowing for immediate evasive action.	Risk reduction benefits may be considerable if monitoring is done effectively with appropriate warning systems in place.	Requires ongoing geotechnical input.
Site specific investigations for high risk sites	For properties that are positioned within the high risk zone, it may be appropriate for these sites to be assessed in more detail to provide a higher degree of confidence in the risk level and to identify the most suitable risk mitigation options that are specific to that site.	Since this would provide site specific advice, this should provide for a high degree of risk reduction benefit.	Costs would likely need to be covered by the individual property owners and may not be seen as beneficial to them.
Insurance provision	Private and Government insurance (EQC) can help to significantly offset the costs associated with natural disaster damage, including landslides. However, property owners should understand the areas and items of insurance coverage (and exclusions) as well as the relevant deductible costs.	Insurance can reduce the costs (to the property owner) associated with landslide damage.	Does not reduce the risks to life or personal safety. Often significant financial shortfalls are experienced upon claim settlement, leaving the insured parties unable to complete the required remediation works.

Note: The inclusion of these options within this report does not constitute advice or a requirement to implement any of these options.

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[35] This is also a basic requirement of the RMA, 1991 and the CDEM Act, 2002.

10. Conclusions

10.1 This report

Two landslide risk zone maps have been produced showing the calculated risk to people and property from translational landslides and debris flow landslides. In the case of the translational type landslide risk zone map, four residential dwellings and one commercial property have been identified within the High Risk Zone. The calculated annual risk to life for people resident in those dwellings is in the order of 8.5×10^{-5} (which can be expressed as 0.0085% per year, or one death every 10,000 years). This figure is considerably higher than accepted normal annual risk to life for new builds, but within the suggested acceptable risk tolerance threshold for existing developments. The debris flow risk zone map presents a qualitative risk analysis of the debris flow hazards and highlights additional properties that may experience property damage due to debris inundation. The reported risk levels are expected to increase with time as climate change progresses.

A range of risk mitigation options has been suggested and explained, to help BDC and the local community to effectively manage the landslide risk. Additional work is required to define the landslide risks associated with climate change (and earthquake effects).

10.2 Next steps

Upon receipt of this report, BDC should provide the community with this information, and ensure as far as possible that it is understood by the people who are affected by the landslide risk. This can be done by making this report easily available in electronic and print formats as well as at least one community engagement session, where interested parties can verbally ask questions of the report author and of BDC. Community members should be given an effective forum for community engagement and feedback to help achieve the following:

1. BDC needs to understand the local community's risk acceptance/risk tolerance levels in regards to the landslide risk. This will help BDC to make sensible landslide hazard management decisions that are suited to the community that is affected.
2. People will have the opportunity to ask questions and become more aware of the landslide risk
3. BDC is able to to provide the types of support necessary to help the community reduce their exposure to the landslide risk in ways that are appropriate and accepted by the community (eg. if early warning systems, requiring more rainfall monitoring sites are deemed to be a good method of risk reduction by the community, then resources should be made available to make that happen).
4. A landslide risk management plan should be developed taking into account the advice in this report, the community's risk tolerance levels and any applicable legislative requirements.
5. The landslide risk management plan should be reflected in the District Plan and Regional Policy Statement
6. The effectiveness and efficiency of the final adopted landslide risk management plan will require structured ongoing monitoring and review, particularly to accommodate any changes to the risk profile that occur as a result of climate change

It may also be appropriate to undertake further research to better understand the increased risks due to climate change (and coseismic landslide risk).

11. Limitations

This report has been produced using the best currently available data and site observations. However, there are various limitations that could affect the accuracy of the results presented. Understanding these limitations will encourage people to make the appropriate decisions based on the information presented in this report

11.1 Limitations of the landslide inventory map

Whilst every care has been taken to produce a landslide inventory that is as accurate as possible, this landslide inventory has the following limitations:

- It is based on three datasets, spanning the past 13 years only. Landslides that occurred prior to 2009 may not be represented. This means that the expected future behaviour and occurrence of landslides in the study area may not be accurately predicted by the behaviours observed over the past 13 years
- The image resolution of the datasets varies (the 2009-2011 dataset has 0.4m pixels, the 2015-2016 has 0.3m pixels and the recent, 2022 dataset has 0.15m pixels). This may mean that landslides are more easily identified in the later datasets
- The LINZ datasets were collected as routine data collection tasks that were not related to landslide occurrence, therefore the landslides shown in these datasets may have occurred a number of months or years prior to the data collection. This may mean that some of the landslides that occurred in that time period (particularly the smaller ones) are not visible in those datasets (either due to resolution or revegetation over time)
- The dataset collected in April 2022 was collected to specifically document the February 2022 landslides (less than 2 months prior to data collection), so the landslides in that dataset are likely to be more visible than the previous two datasets, meaning that comparisons between the three datasets may not be representative of the actual trends over time
- Location accuracy of the LINZ datasets is reported as +/- 2.5m for the 2009-2011 dataset and +/- 0.6m for the 2015-2016 dataset. Location accuracy for the drone imagery collected in April 2022 is estimated to be +/3.5m
- Where dense vegetation covers the ground surface small landslide features, or narrow chutes that may carry debris flows, may not be visible from aerial photography, so these will be omitted from the landslide inventory
- Observations of landslide areas may be affected by areas obscured from view by overhanging vegetation, quality of aerial photography, image resolution and other factors, making the measurement of landslide areas approximate only

11.2 Limitations of the landslide risk zone maps

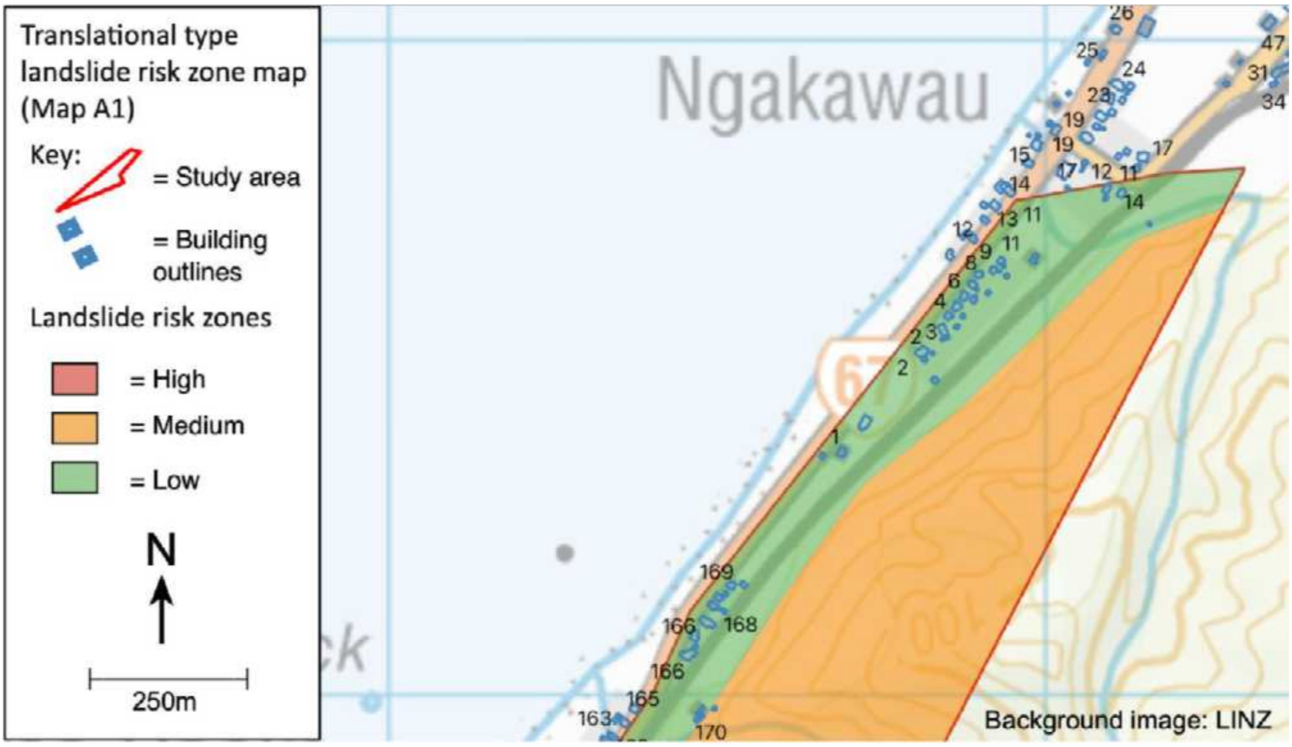
1. Uncertainty in the input variables may account for an accuracy of the final risk levels being +/- 1 order of magnitude.
2. The methodology used in this report (AGS, 2007) suggests that for residential dwellings a temporal exposure probability of 1 be adopted. A probability of 1 would mean that a person is present in that house 100% of the time. However, in reality a person may only be present in that house for 50% of the time (or some other proportion of time), which would mean that the actual risk is 50% less than reported.
3. The estimation of vulnerability is extremely subjective and this introduces uncertainty into the calculation of the probability of loss of life. I.e. A person's ability to avoid harm during a landslide incident will be dependent on a long list of factors including personal experience, fitness, awareness

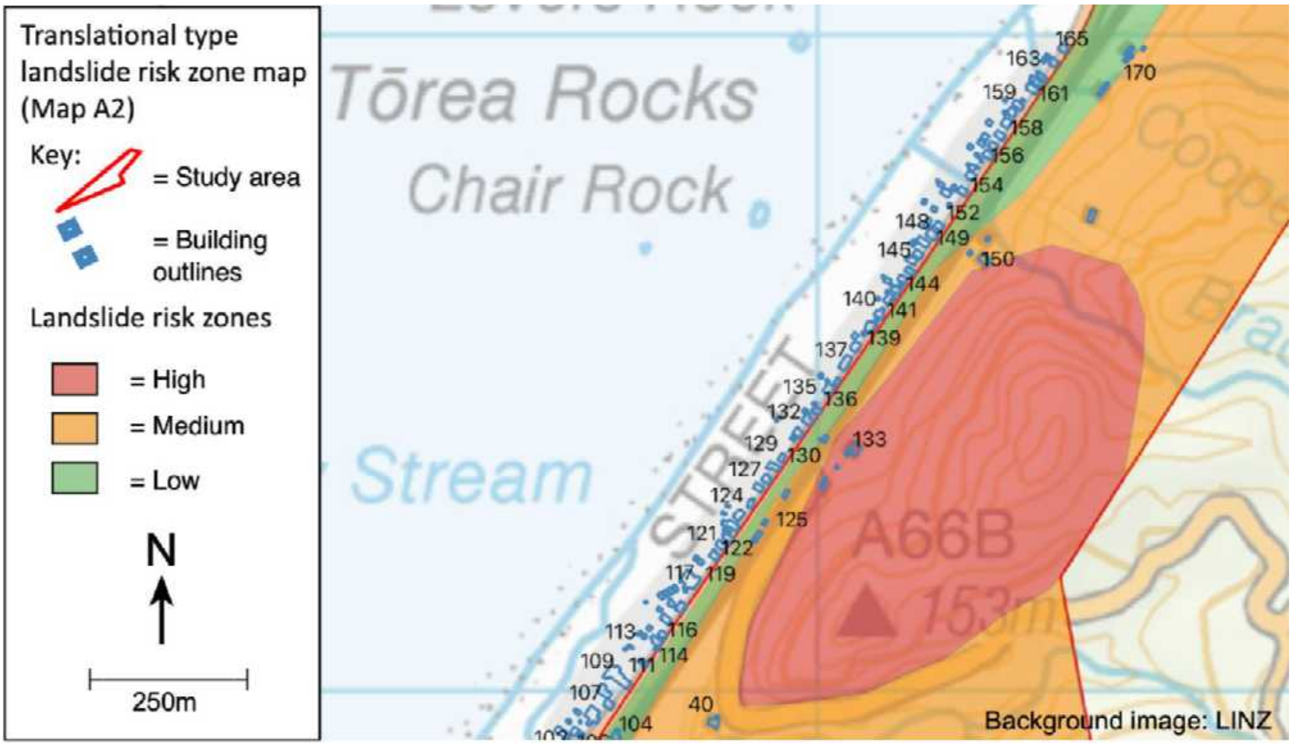
and reactiveness as well as the physical characteristics of the building they are in or the terrain on which they are positioned. The overall estimation of risk to life is highly sensitive to this input data and this may also have a large effect on the eventual calculated risk level.

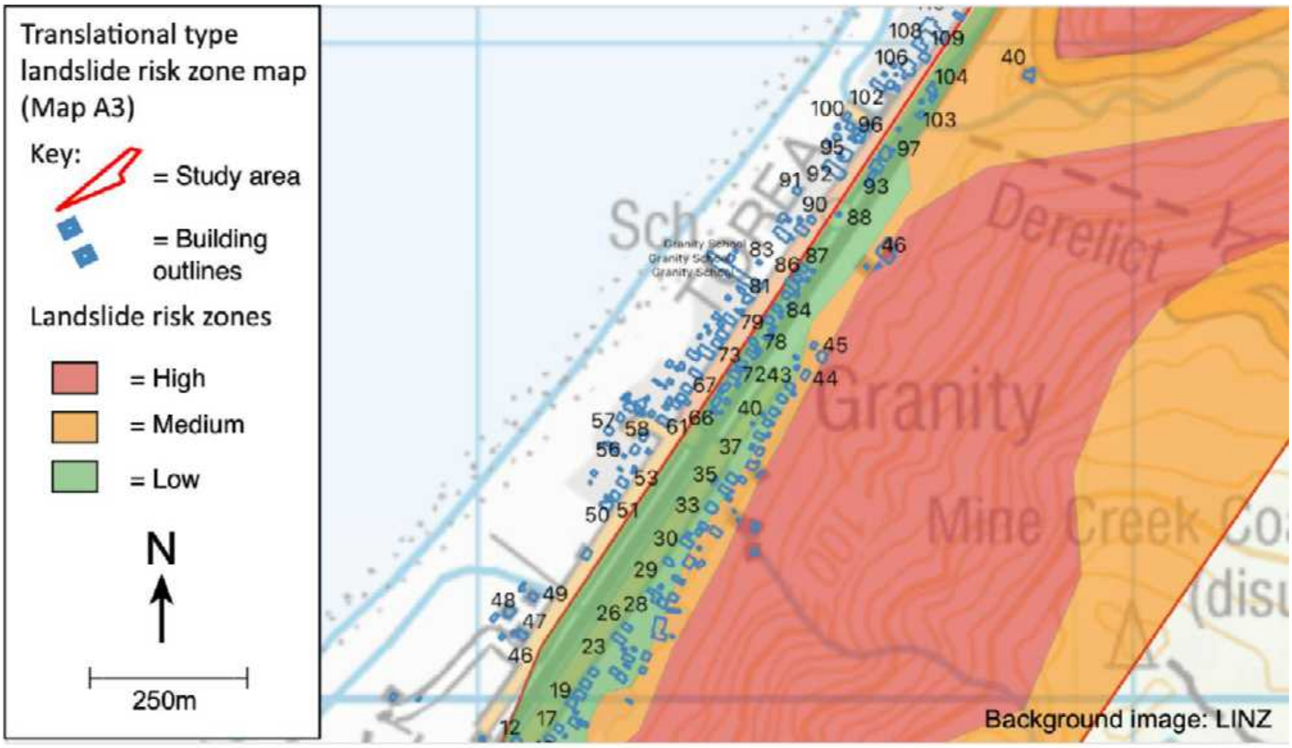
4. Landslide events are most likely to occur during heavy rainfall and it may be that people living within the study area already take certain defensive actions during these rainfall events, which would also affect the calculated risk level.
5. This report does not quantify the expected level of risk reduction benefits from each of the identified risk reduction options. This information can be provided at a later date if required.
6. This report presents the risk to life from rainfall generated landslide hazards only. It does not quantify the risk to life from coseismic landsliding, the expected increased risks due to climate change, or the risks from other natural hazards such as floods and coastal erosion. Some of these other factors may present significant individual and societal risk.
7. The landslide risk zoning has taken a statistical approach to landslide spatial occurrence (i.e. landslides are assumed to be evenly distributed across areas with similar terrain variables). However, more detailed terrain analysis and site specific investigation work may be more accurate in predicting the actual future likelihood of landslide occurrence in specific locations.

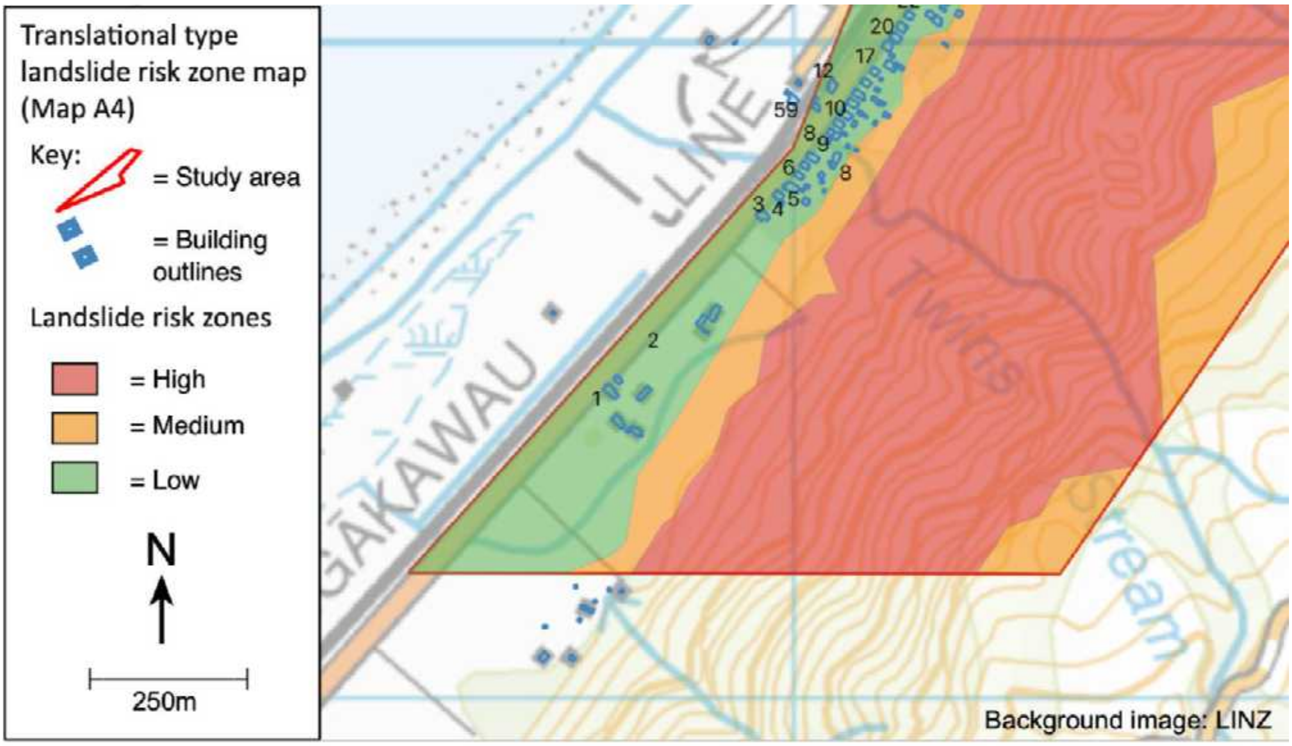
Appendix A

Small scale (approximate scale at A4 1:11,000) translational landslide risk zone maps. Street address numbers are shown next to the building outlines.



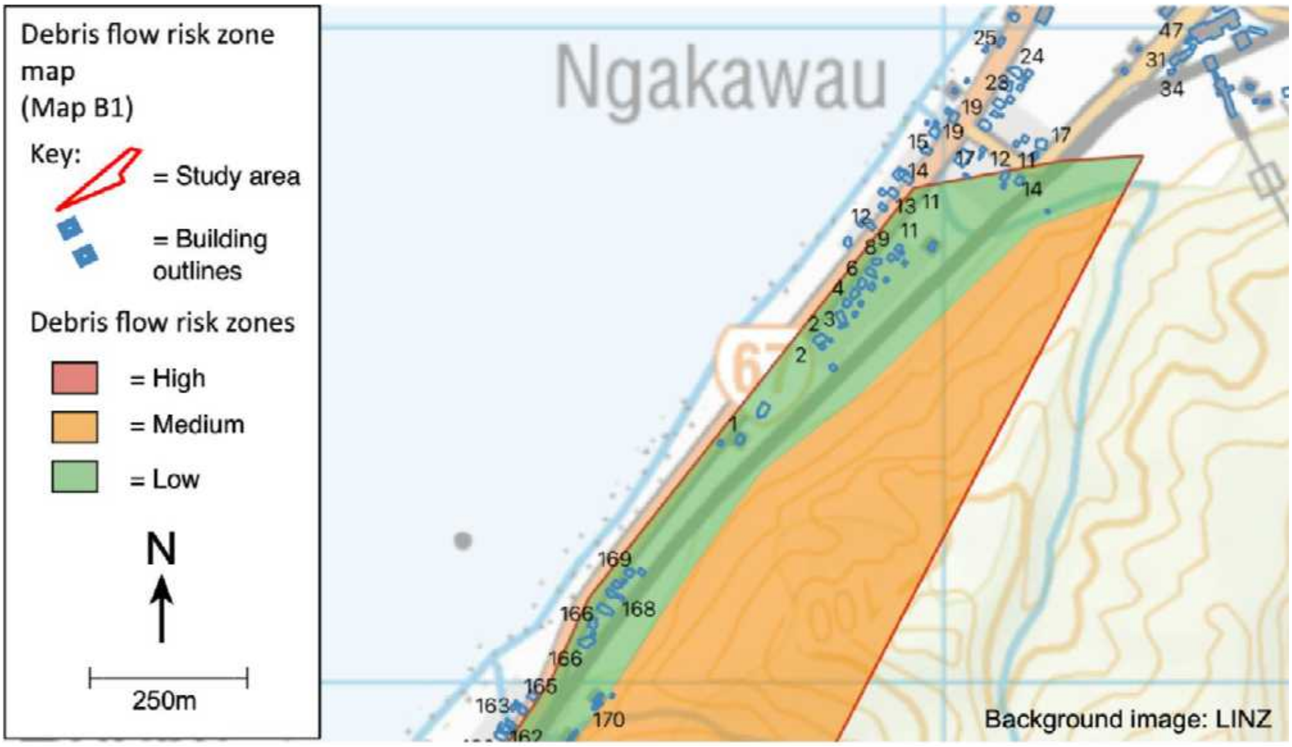


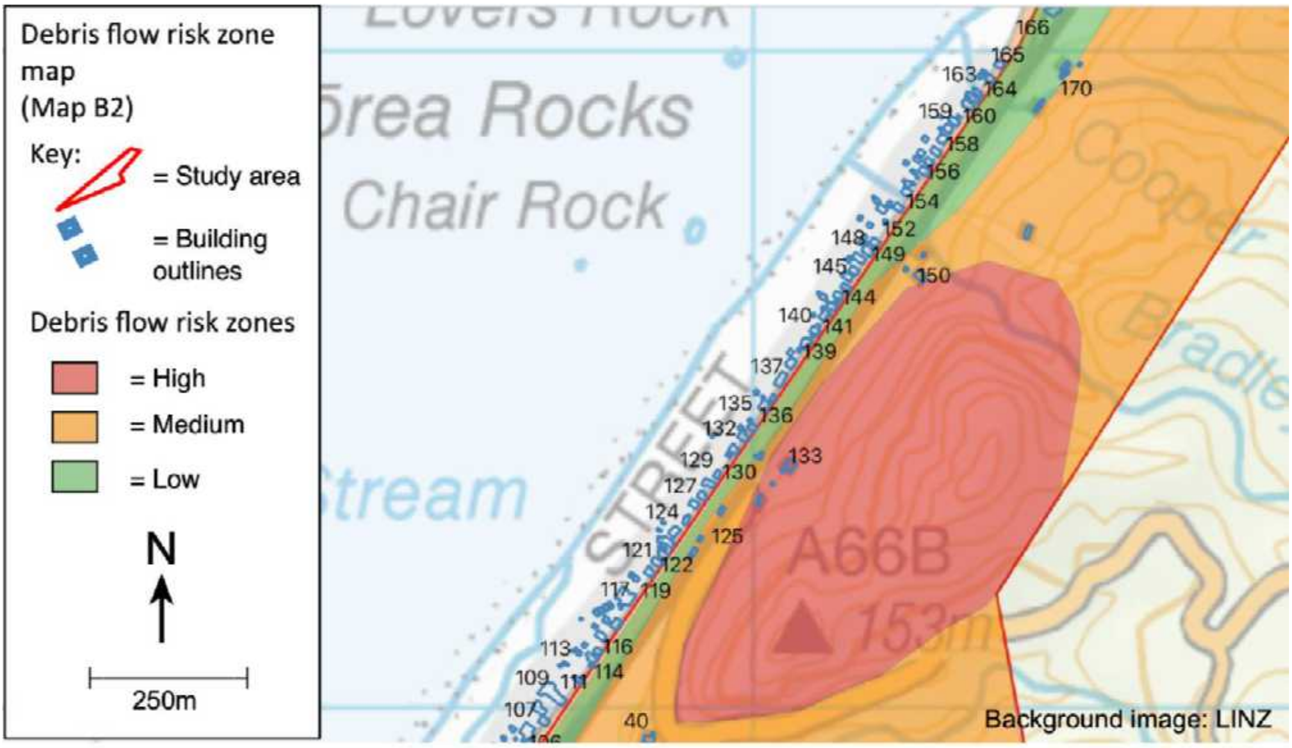

Translational type landslide risk zone map (Map A3)
Key:
= Study area
= Building outlines
Landslide risk zones
= High
= Medium
= Low
N
250m
Granity
Derelict
Mine Creek Co
Granity School
Background image: LINZ

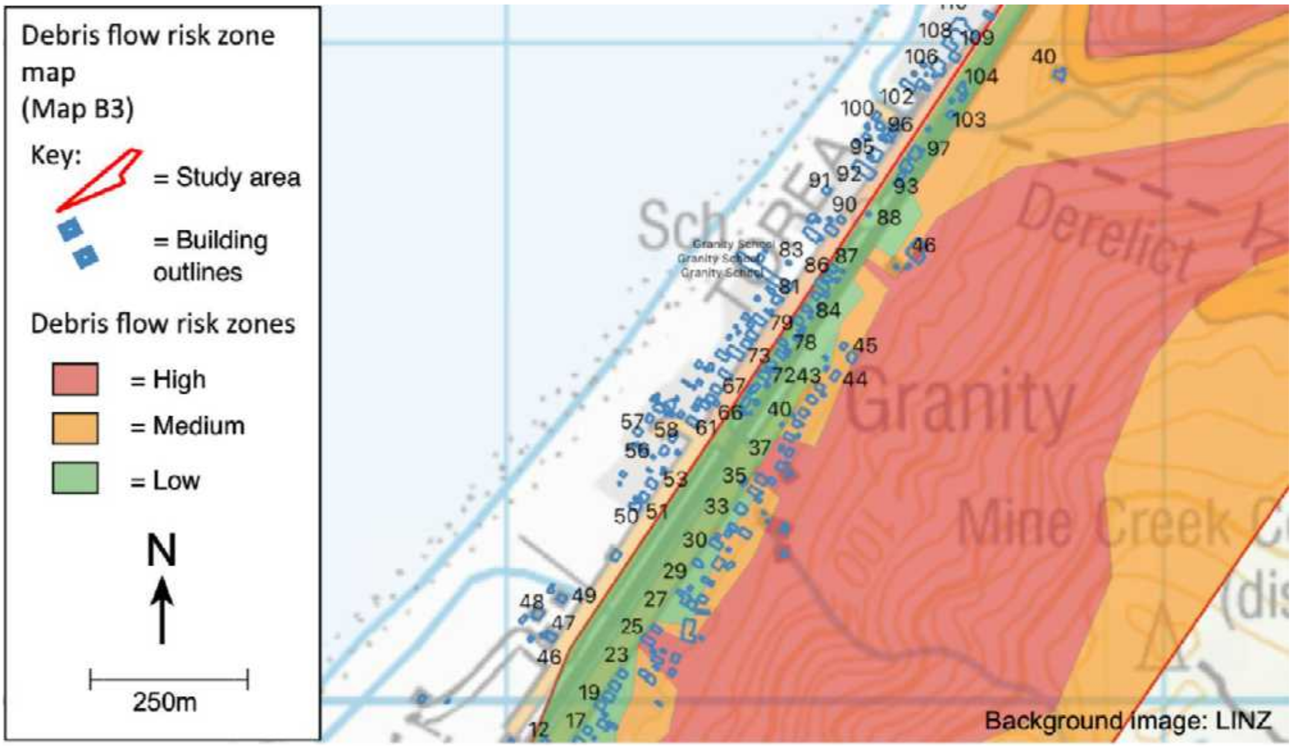

Translational type landslide risk zone map (Map A4)
Key:
= Study area
= Building outlines
Landslide risk zones
= High
= Medium
= Low
N
250m
Twins
Stream
GĀKAWAU
LINE
Background image: LINZ

Appendix B

Small scale (approximate scale at A4 1:11,000) debris flow risk zone maps. Street address numbers are shown next to the building outlines.

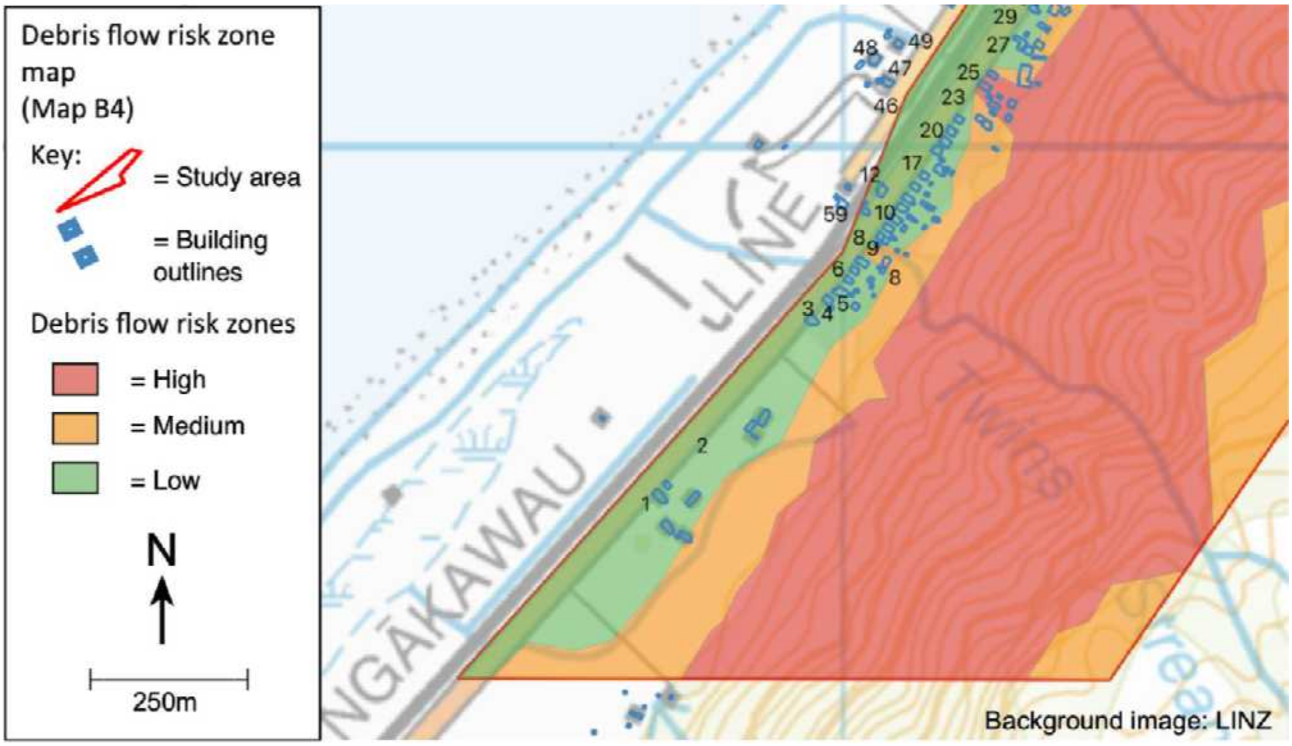






Debris flow risk zone map (Map B3)

Background image: LINZ



Debris flow risk zone map (Map B4)

Background image: LINZ