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Appendix H – Sector 8 North Modeling Results

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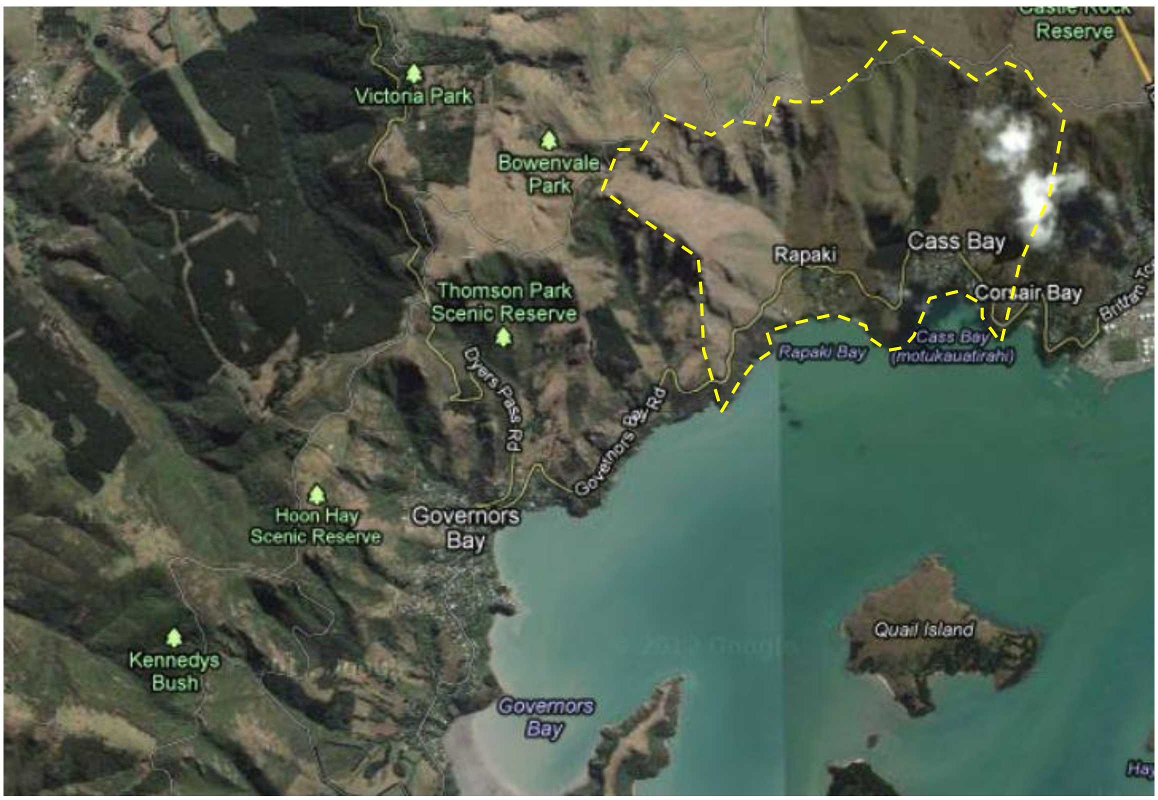
Sector 8N Diamond Harbour

1. Site Description

Rapaki Bay and Cass Bay are located in the upper reaches of Lyttelton Harbour, and are the two bays immediately west of Lyttelton township. A reasonable population exists at Governors Bay with almost 100 dwellings in Cass Bay alone that are potentially affected by rockfall. The rockfall issue arises from the slopes north of areas which vary up to 50degrees in angle and are predominantly grassed with some light scrub cover.

The area considered in this report is shown in Figure 1, an area in excess of 4km^2.

Figure 1 - Sector 8 North site location showing the study area within yellow outline



The slopes to the north rise steeply from sea level up to in excess of 300m in elevation and are typically between 25˚ to 50˚. The predominant source of rock fall comes from the bluffs located towards the top of the slope, with numerous smaller bluff features typically located between midway up and the top of the slope also contribute.

2. Geotechnical Environment

The area is characterized by basalt bluffs and outcrops along the crest and upper part of the slopes, with lesser amounts of bluffs and outcrops further down slope. The slopes shallow out towards the base and vary in angle from 25 degrees to 50 degrees. The rock outcrops are the predominant source of boulders and are therefore identified by the PHGG as potential or known outcrop zones in this sector. Houses and roads are mainly located at the base / lower area of the slopes.

The rock bluffs are typical basalt with intermittent lava flows and ash and scoria lenses. These tend to suffer differential weathering resulting in unstable columns and blocks of typically strong, competent rock. The average rock volume (as recorded by the PHGG) is 4.5m3 with a maximum volume of 245m3. Block shape is variable.

A number of causes initiate failure including weathering over time but also excessive ground shaking as has been recently witnessed.

3. Slope Instability

Assessment of slope stability and in particular the stability of the basalt cliffs was not part of the scope of this study and therefore has not been taken into consideration at this stage of the report. However it should be noted that there is extensive evidence of past and recent rockfalls of various scales on these slopes.

4. Rockfall Hazards

Rockfall is the only hazard considered in this present study. Rock falls into the investigated area can be powerful events consisting of numerous different size boulders and small rock avalanches as documented in the boulder inventory. The rockfall hazard in the Rapaki Bay and Cass Bay areas originates predominantly from the main bluffs located towards the top of the slope.

Additionally there is evidence of limited rockfall originating from the multitude of smaller outcrops mid slope. These smaller source areas tend to contribute to the overall rockfall hazard in the area. It should be noted that for the purpose of this report we considered all source areas contributing to the hazard, directly by releasing material immediately from the rock face and also indirectly in the form of blocks from past rock releases that have been arrested mid slope. All slopes that are steeper than 45 degrees assumed to be sources.

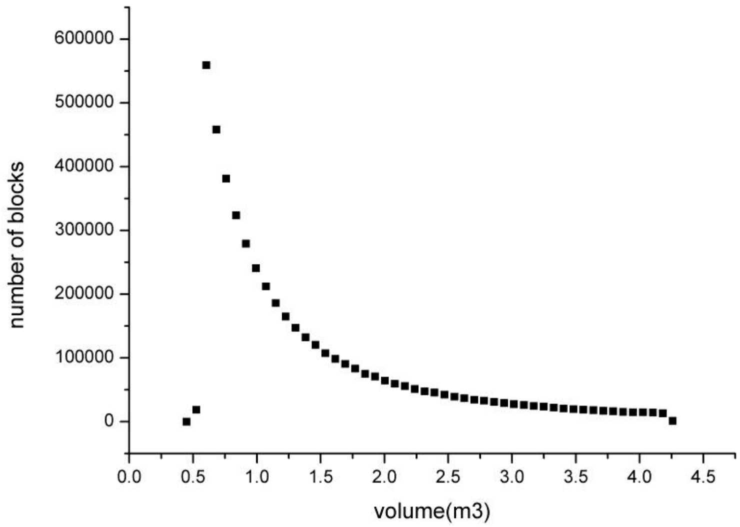
5. Modeling Results

The entire Sector 8 North was modeled in 3D using HyStone. The results of this modeling are shown here. In order to check the model for accuracy reasons 2D rockfall modeling was also carried out in some areas. For the purpose of the modeling all vegetation has been completely removed from the ground model. While larger vegetation can sometimes have a positive effect on reducing the hazard for the sake of this report any vegetation cannot be considered effective in the long term (i.e. there is a real risk of fire removing the vegetation).

Variables that have been entered include rock type, size and shape (from the PHGG database), slope angles (from the DEM), surface roughness and surface stiffness/hardness (rock, soil). This data is adjusted for each Sector and where necessary calibrated by either 2D modeling or real life one to one boulder rolling exercises.

For the modeling an exponential boulder size distribution was used with a minimum boulder size of 0.3 m^3 and a maximum boulder size of 4.25 m^3. This distribution curve is represented below in Table 1.

Table 1 - Boulder size distribution used for modeling



Note - this distribution covers all Sectors on the Port Hills. Individual Sectors may vary.

Unlike other sectors on the Port Hills bounce heights are typically relatively high. Analysis of the results show that bounce heights are typically 5-6 metres high and in places they reach 7m in height (Line 6). This is controlled by a number of factors including surface conditions and shape of the boulders. Numerous large bluffs are also contributing to the bounce heights, indicating in reality that they may be lower than modelled. Evidence from the field however suggests that in some places bounce heights are quite high.

Impact velocities for the study area vary along the length of the site and often exceed 5000kJ. The highest velocities are on Line 2 and Line 6. As with other sectors gullying is widespread however given the etent of source areas the rockfall issue is extensive throughout the site. This can be seen in the Total Number of Boulders image shown in Appendix A. The gullying has a positive effect on remedial option design as the highest concentrations of boulders occur in very localized areas. Mitigation structures can be located in these areas meaning smaller (shorter) structures, while outside these areas lower levels of treatment, in some cases none, are required. Boulder run outs are not excessive with many boulders coming to rest before reaching the road (Governors Bay Road).

Some anomalies do occur and they usually relate to platey or slabby boulders which often traverse slopes parallel to contour lines.

6. Recommendations

In our approach to define solutions for Sector 8 we had three major constraints to consider:

1. **Scale** – Sector 8 North is over 4km^2 in area with multiple source areas and runnout zones. Rockfall velocities are varied throughout this area. Combined with the topographical scale is the extent of residential development below the rockfall source areas, resulting in over 65% of the study area requires protection.

2. **Topography** – the site is typified by steep slopes and multiple bluffs/source areas. This leads to constraints on construction methods due to access and the provision of a safe and stable working platform.

3. **Land use** – the area is densely populated with over 100 houses likely affected by rock fall. The extent of land development in the two bays is generally restricted to around and above the road area, restricting the type or protection available.

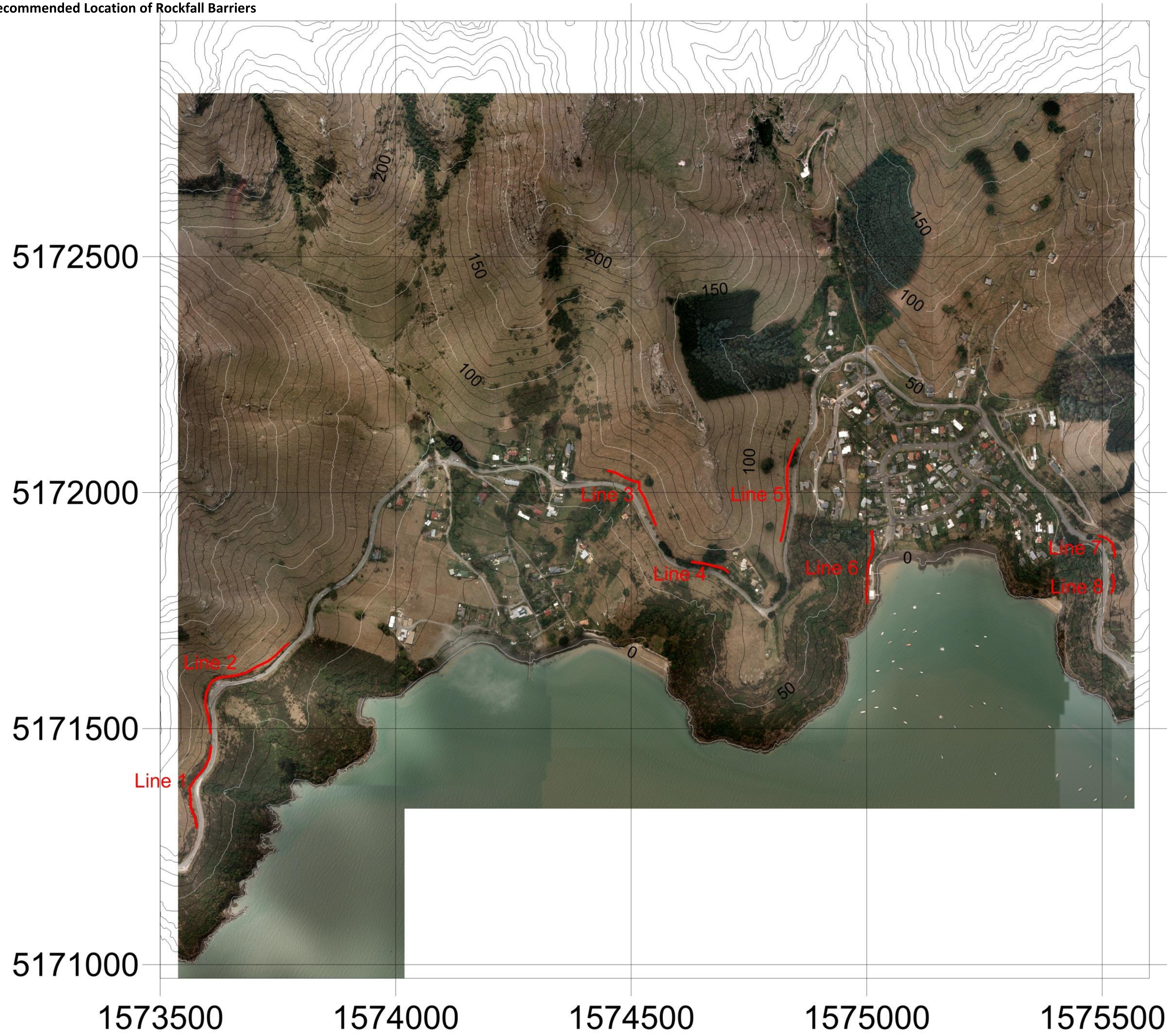
In accordance with Option 4 in the main report text it is recommended that the installation of rockfall barriers is the most suitable means of remediating the rockfall hazard in Sector 8 North. The size and lengths of the barriers are outlined in Table 2 below while the locations are shown in Figure 2. The results of the modelling are presented in the following graphics.

Table 2 - Recommended Barriers for Sector 8 North

Sector (#)	Barrier (ETAG27)	Rating (kJ)	Height (m)	Length (m)
8N	1	500	3	30
		5000	6	158
	2	5000	6	30
		8000	7	60
		5000	6	30
		8000	7	30
		5000	6	50
		3000	5	99
	3	2000	4	80
		3000	5	90
	4	5000	6	82
	5	5000	6	140
		3000	5	83
	6	8000	7	90
		5000	6	65
	7	3000	5	63
	8	5000	7	39

For Sector 8 North the decision to recommend barriers over bunds is predominantly due to topographical constraints. For the purpose of protecting property only a small length of the recommended remedial solution could be replaced by large earth bunds due to the limited availability of suitable land. In all cases the estimated cost for enabling earthworks is prohibitive compared to barrier installation.

Figure 2 - Recommended Location of Rockfall Barriers



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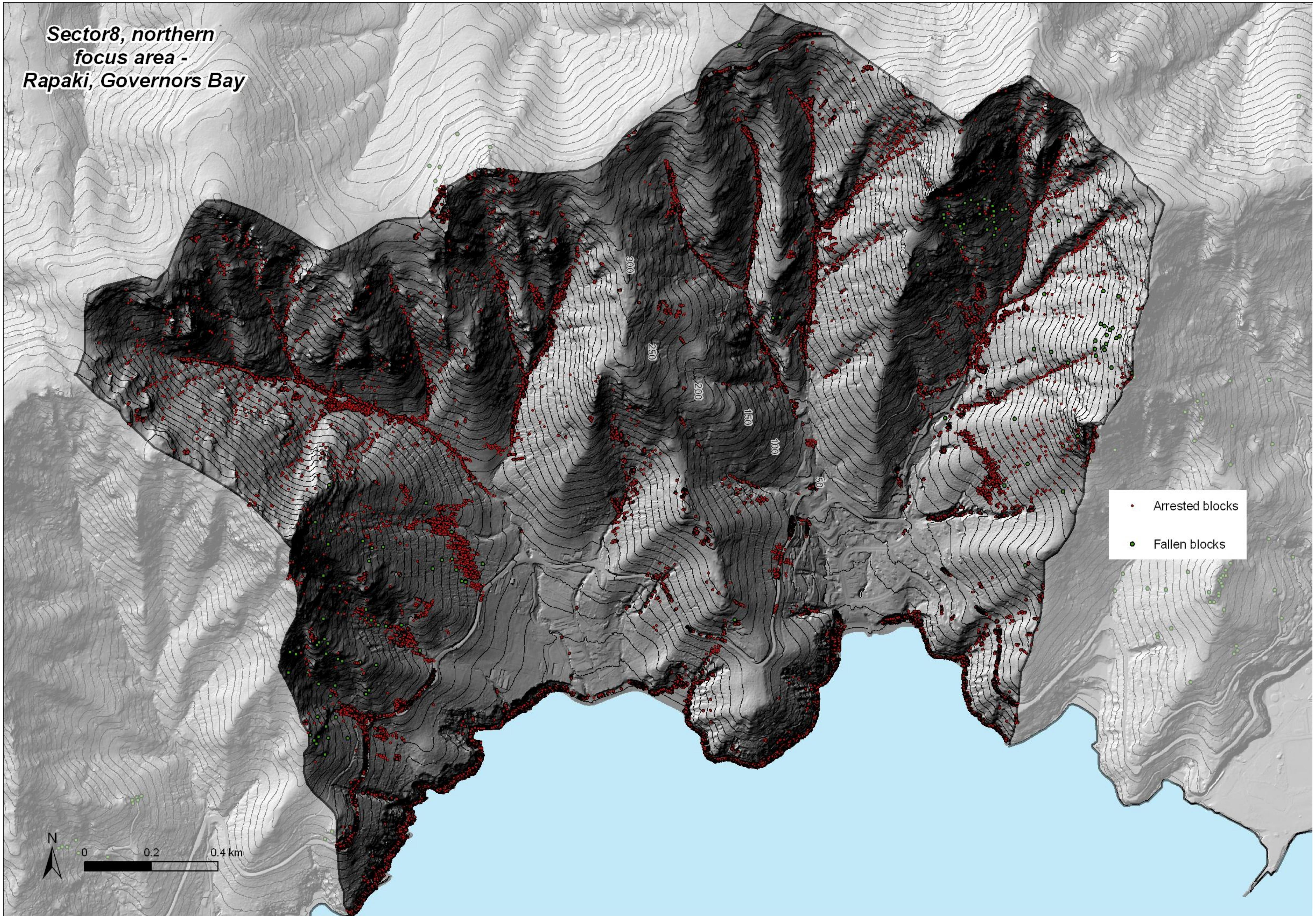

Sector8, northern
focus area -
Rapaki, Governors Bay
300
250
200
150
100
50
Arrested blocks
Fallen blocks
N
0
0.2
0.4 km

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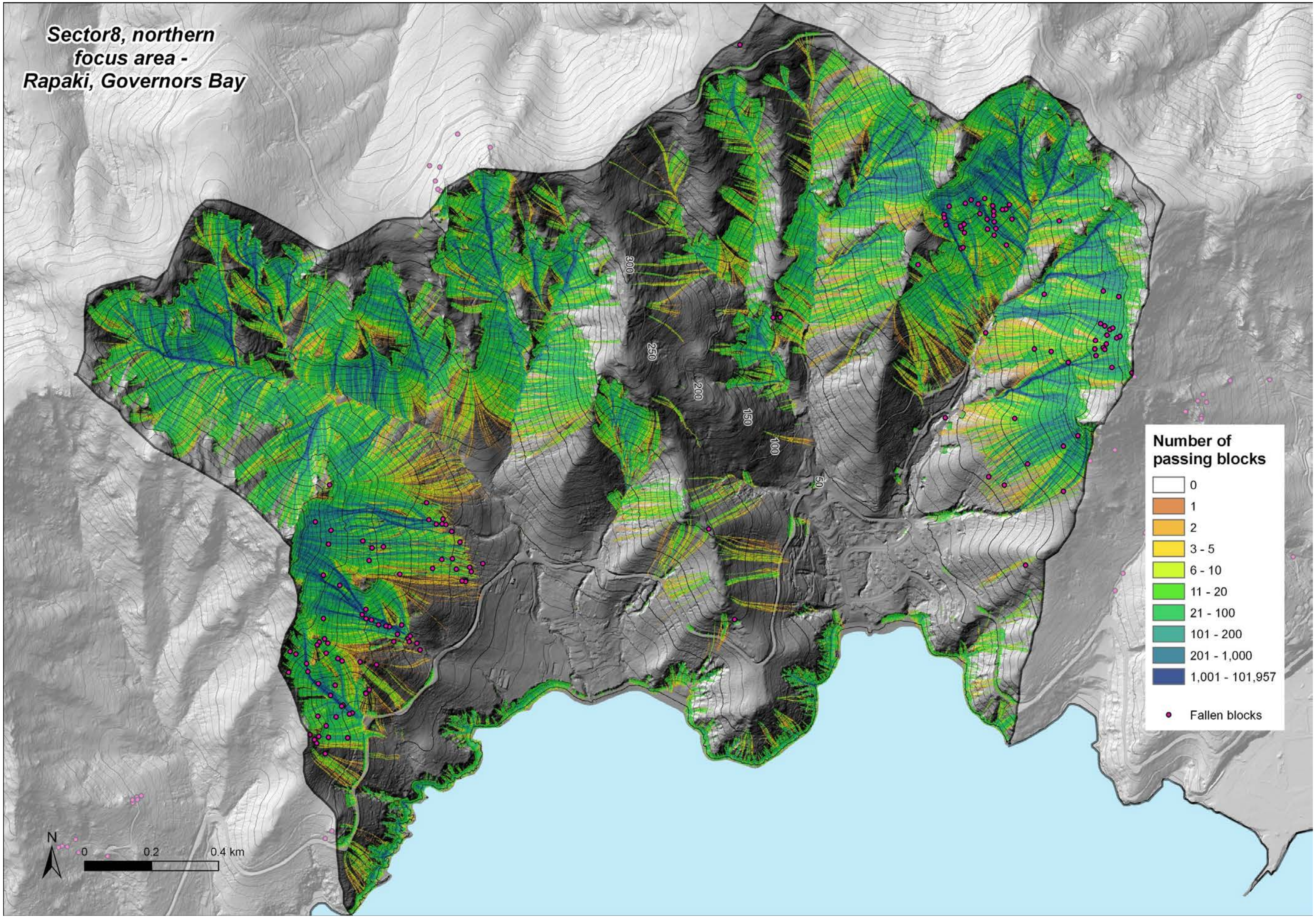
Sector8, northern focus area - Rapaki, Governors Bay
300
250
200
150
100
50
Number of passing blocks
0
1
2
3 - 5
6 - 10
11 - 20
21 - 100
101 - 200
201 - 1,000
1,001 - 101,957
Fallen blocks
N
0
0.2
0.4 km

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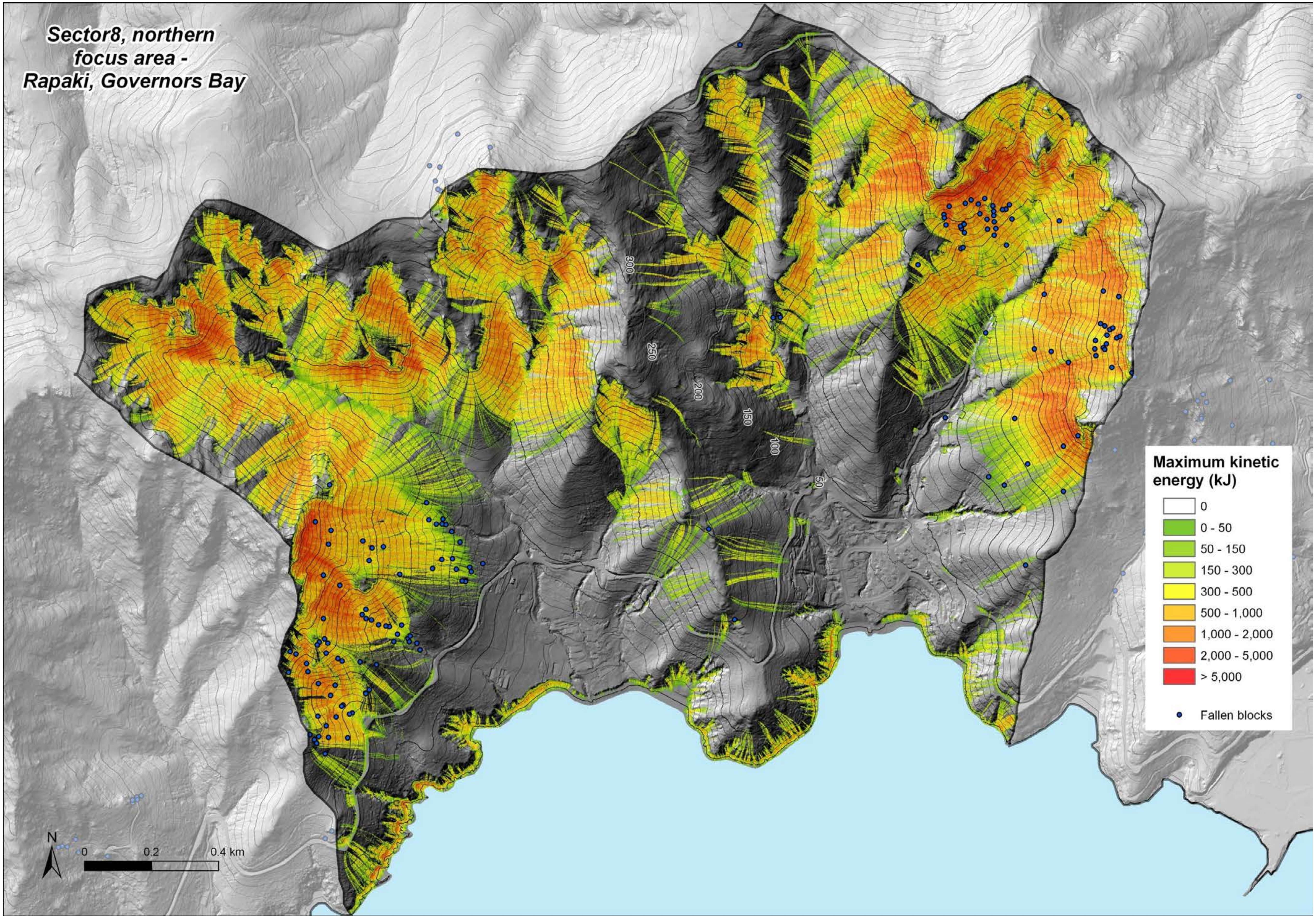

Sector8, northern focus area - Rapaki, Governors Bay
300
250
200
150
100
50
Maximum kinetic energy (kJ)
0
0 - 50
50 - 150
150 - 300
300 - 500
500 - 1,000
1,000 - 2,000
2,000 - 5,000
> 5,000
Fallen blocks
N
0
0.2
0.4 km

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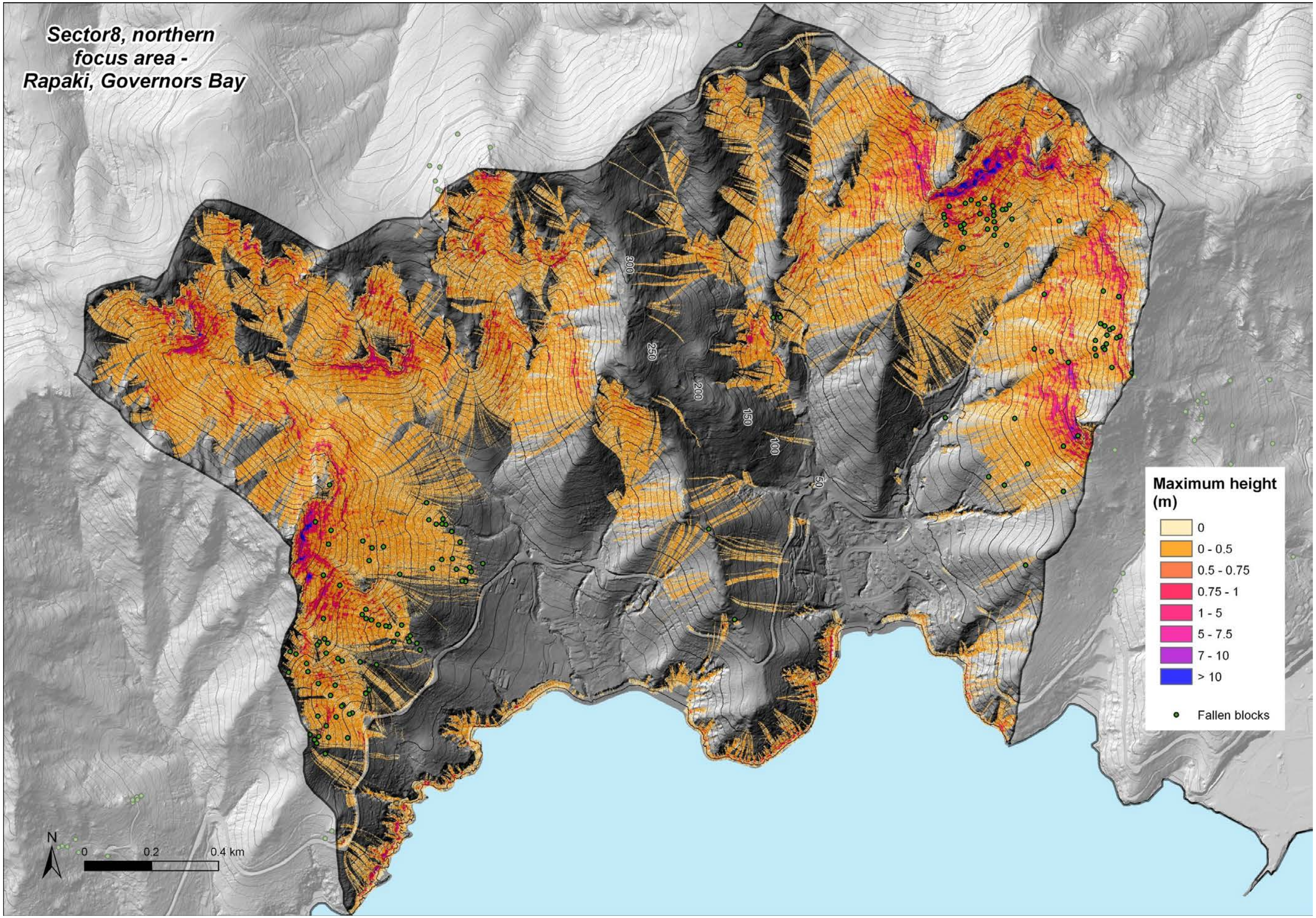
Sector8, northern focus area - Rapaki, Governors Bay
300
250
200
150
100
50
Maximum height (m)
0
0 - 0.5
0.5 - 0.75
0.75 - 1
1 - 5
5 - 7.5
7 - 10
> 10
Fallen blocks
N
0
0.2
0.4 km

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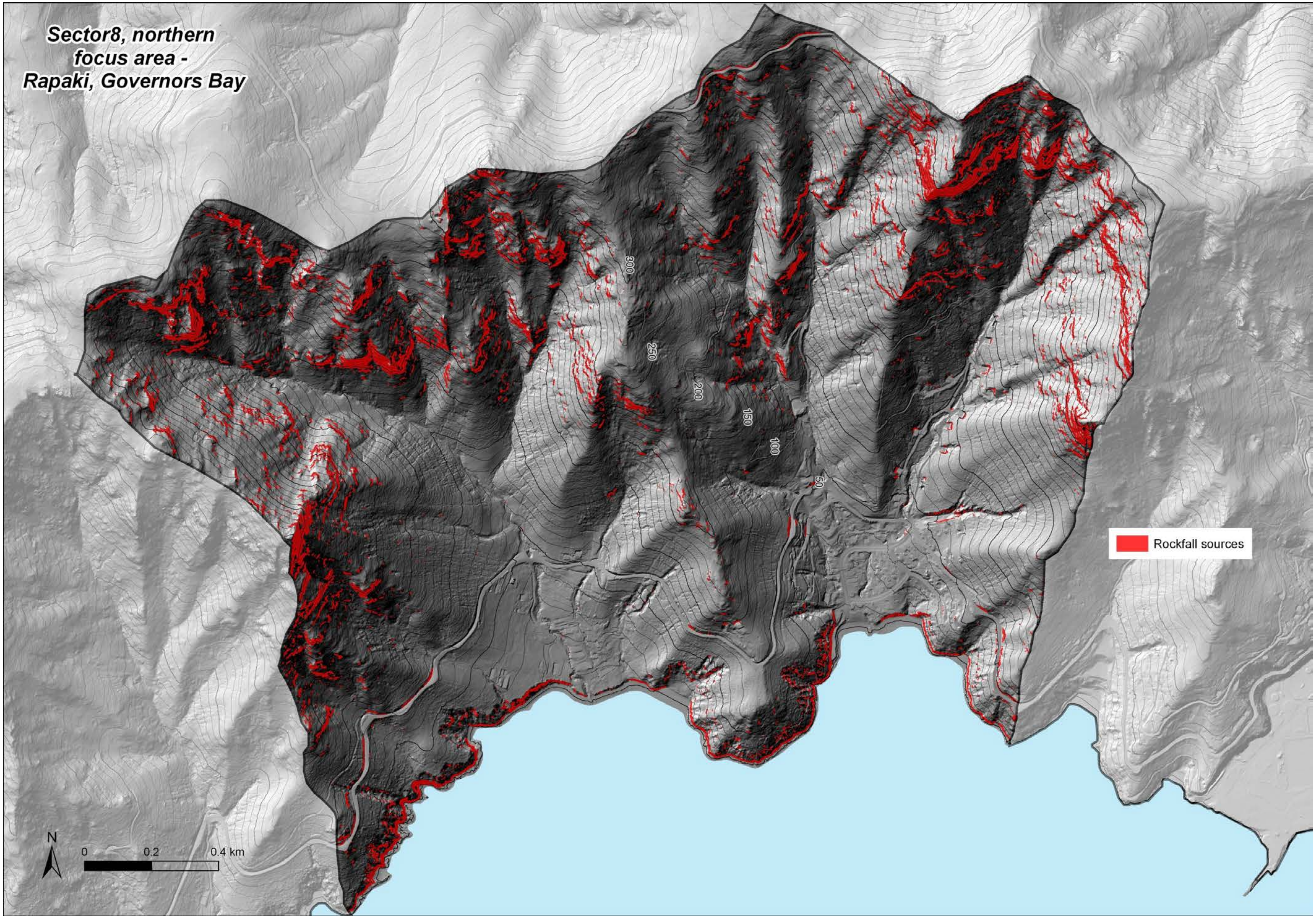

Sector8, northern
focus area -
Rapaki, Governors Bay
300
250
200
150
100
50
Rockfall sources
N
0
0.2
0.4 km