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Appendix D – Sector 4 Modeling Results

Sector 4 Mount Pleasant

1. Site Description

The suburb of Mount Pleasant is the first of the hill suburbs encountered when travelling from the city to Sumner. The large majority of the suburb is located on the ridge top of a large sloping ridgeline that extends from the shores of the Brighton Estuary up to the summit of Mt Pleasant some 250m above MSL. The suburb is locally densely populated towards the lower reaches of the slopes and as the majority of dwellings are located on the top of the slope/ridge the hazard that directly affects the residents of Mt Pleasant is reduced.

The area considered in this report is shown in Figure 1 below, an area in excess of 2.5km^2.

Figure 1 - Sector 4 site location showing the study area within yellow outline

The main area at risk of rockfall in this sector is the Heathcote Valley which forms the western margin on the sector. Here there is significant rockfall hazard from steep (>30deg) slopes that extend from Bridle Path Road (near sea level) to the ridge top at approximately 150 - 200mRL. These slopes are lightly vegetated with scrub and sporadic large trees and contain a number of small rock outcrops and bluff features. They are also moderately densely populated with some 50 dwellings over a distance of 700m at risk of rockfall, with Bridle Path Road also a Government designated lifeline route.

2. Geotechnical Environment

The main hazard area is characterized by basalt bluffs and outcrops located mainly along the upper part of the slopes, with lesser numbers of bluffs and outcrops further down slope, with nothing in the lower half of the slopes. 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.

The rock bluffs are typical basalt with jointing creating slabs and large columnar features. These tend to suffer from erosion of the open joints and form unstable columns and large loose blocks. The rock in this area is typically strong, competent and forms rounded to slabby boulders. The average rock volume (as recorded by the PHGG) is 0.75m3 with a maximum volume of 10.5m3.

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 Sector 1 originates predominantly from the main bluffs located approximately mid-slope.

There is also evidence of rockfall originating from a number of mid slope sources; small bluffs and rock outcrops. Analysis of these source areas has revealed rockfall from these areas has significant impact on the residential areas at the base of the slope. 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.

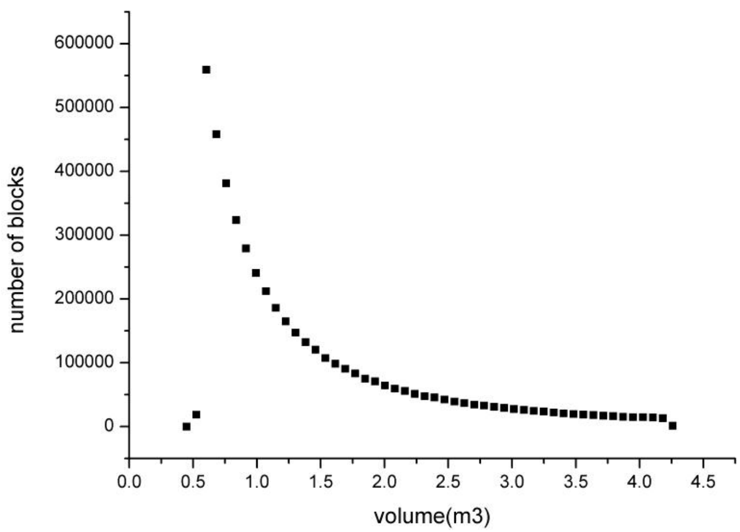
5. Modeling Results

The entire Sector 4 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 m³ and a maximum boulder size of 4.25 m³. 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.

Analysis of the results show that bounce heights across the study site are around 0.5 to 1.0m high. In some areas bounce heights exceed 5m (above Hammerton Lane) however this is likely due to the large vertical bluffs in this area misrepresenting rock drop as rock bounce. Surface conditions are generally typified by dense low vegetation including bracken and general scrub, this will be contributing to the generally low bounce heights.

Impact velocities along Bridal Path Road vary between 300kJ to 5000kJ with typical energies in the range of 2000kJ to 3000kJ. The highest velocities are recorded above and north of Hammerton Lane.

An interesting output from the modeling is the extent of gullying that has occurred, that is the amount of boulders which come from multiple or wide source areas and flow into narrow gully features. This can be seen in the Total Number of Boulders image. 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. However the effects of these concentrations may impact on design loadings if they occur in short time spans, e.g. following an earthquake.

Some anomalies do occur and they usually relate to platey or slabby boulders which often traverse slopes parallel to contour lines. It is inevitable that there will always be a small percentage of boulders that do not match the model.

6. Recommendations

In our approach to define solutions for Sector 4 we had three major constraints to consider:

1. **Scale** – Sector 4 is over 2.5km^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 40% 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 75 houses likely affected by rock fall. The extent of development in the area spreads to very close beneath the base of the slopes below the rock fall source areas, 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 1. 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 4

Sector (#)	Barrier (ETAG27)	Rating (kJ)	Height (m)	Length (m)
4	1	5000	6	230
		5000	8	52
	2	5000	6	60
		3000	5	50
		5000	8	80
		3000	8	90
		5000	8	77
	3	3000	5	50
		2000	4	130
		1000	3	70
		2000	4	25
	4	2000	4	70
		3000	5	70
		2000	4	195
	5	2000	4	115

For Sector 4 the decision to recommend barriers over bunds is predominantly due to topographical constraints. For the purpose of protecting property there is no suitable land (low angle slopes) to install large earth bunds. If barrier locations can be moved then the construction of bunds could be reassessed.

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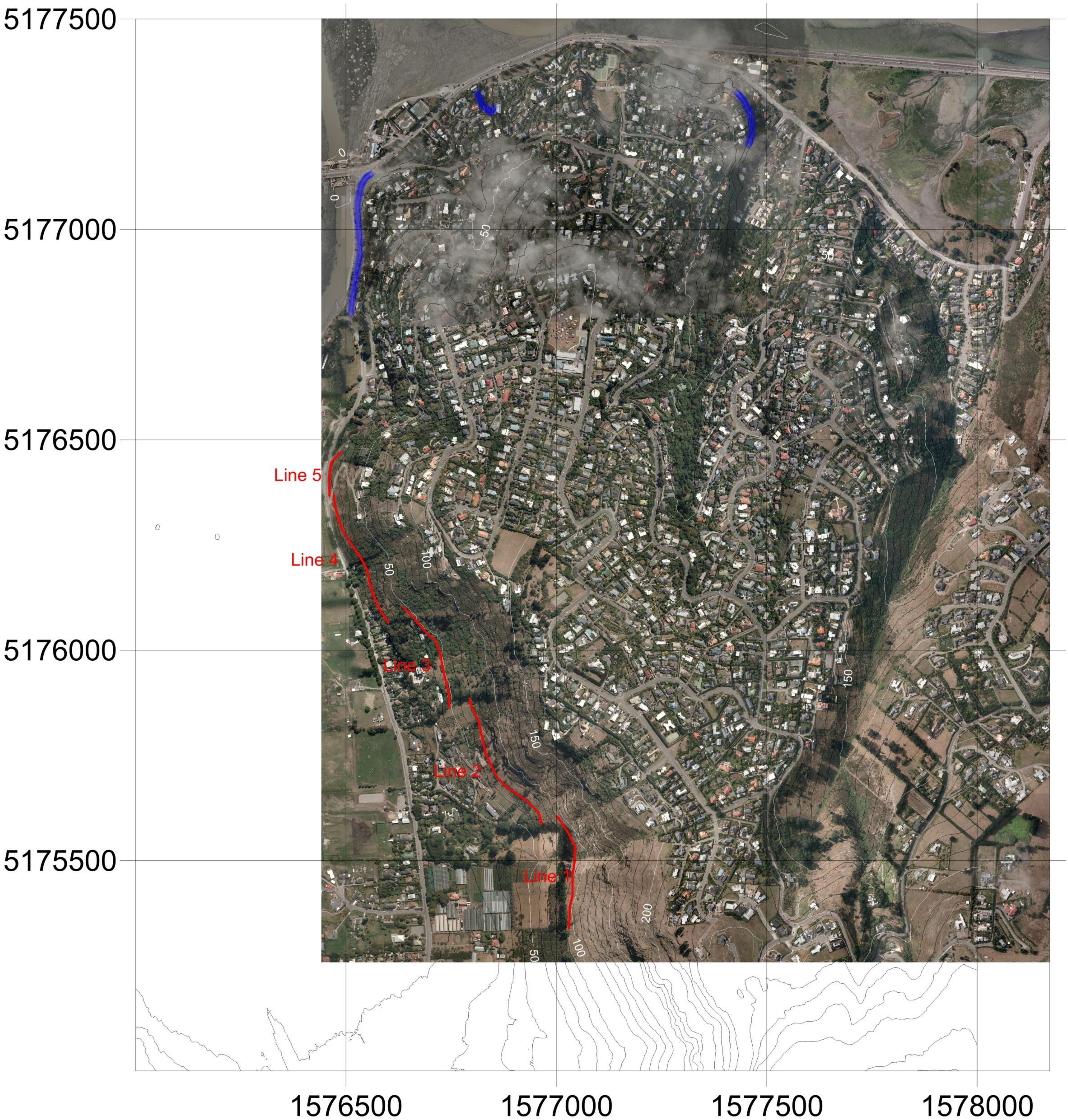
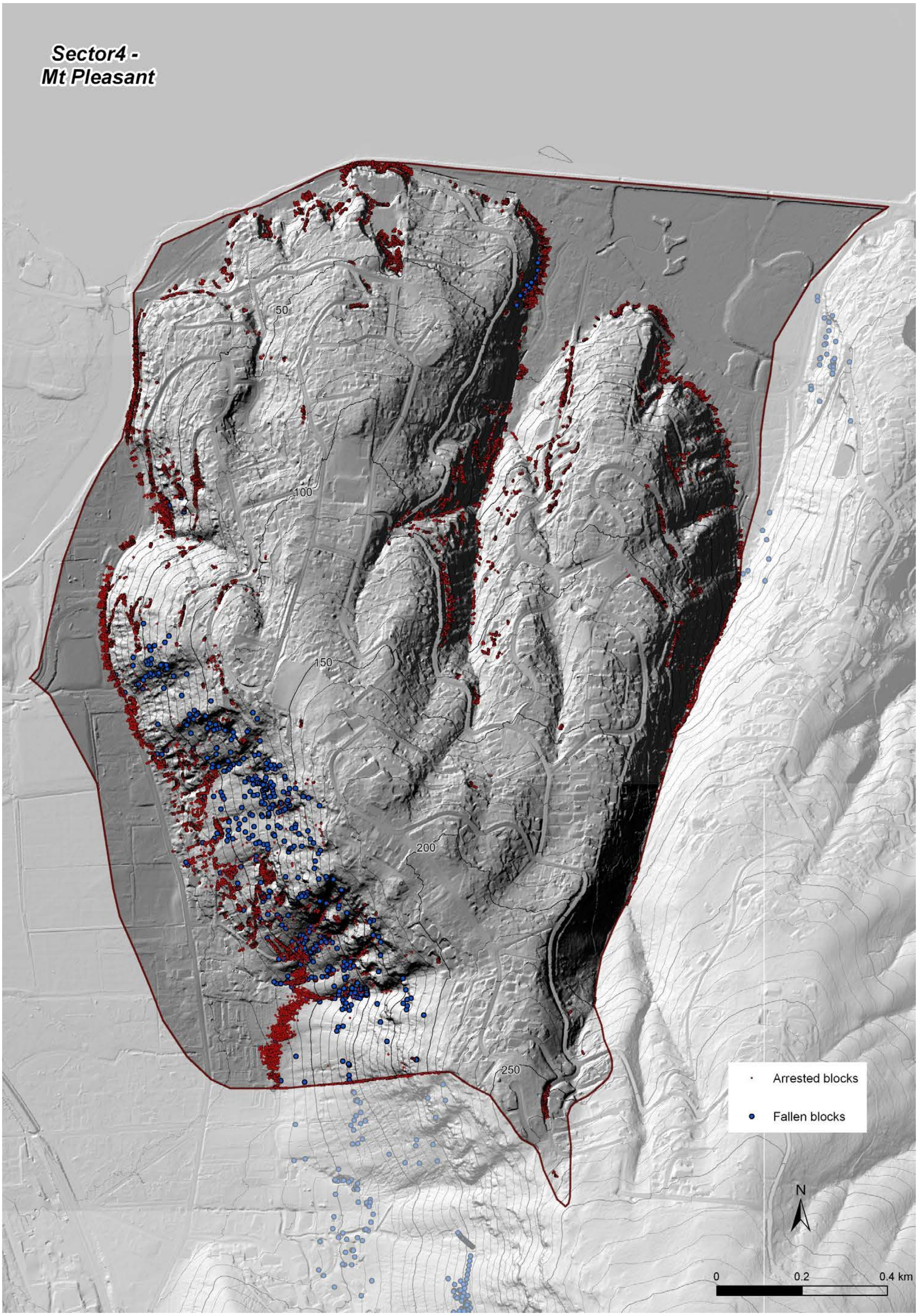
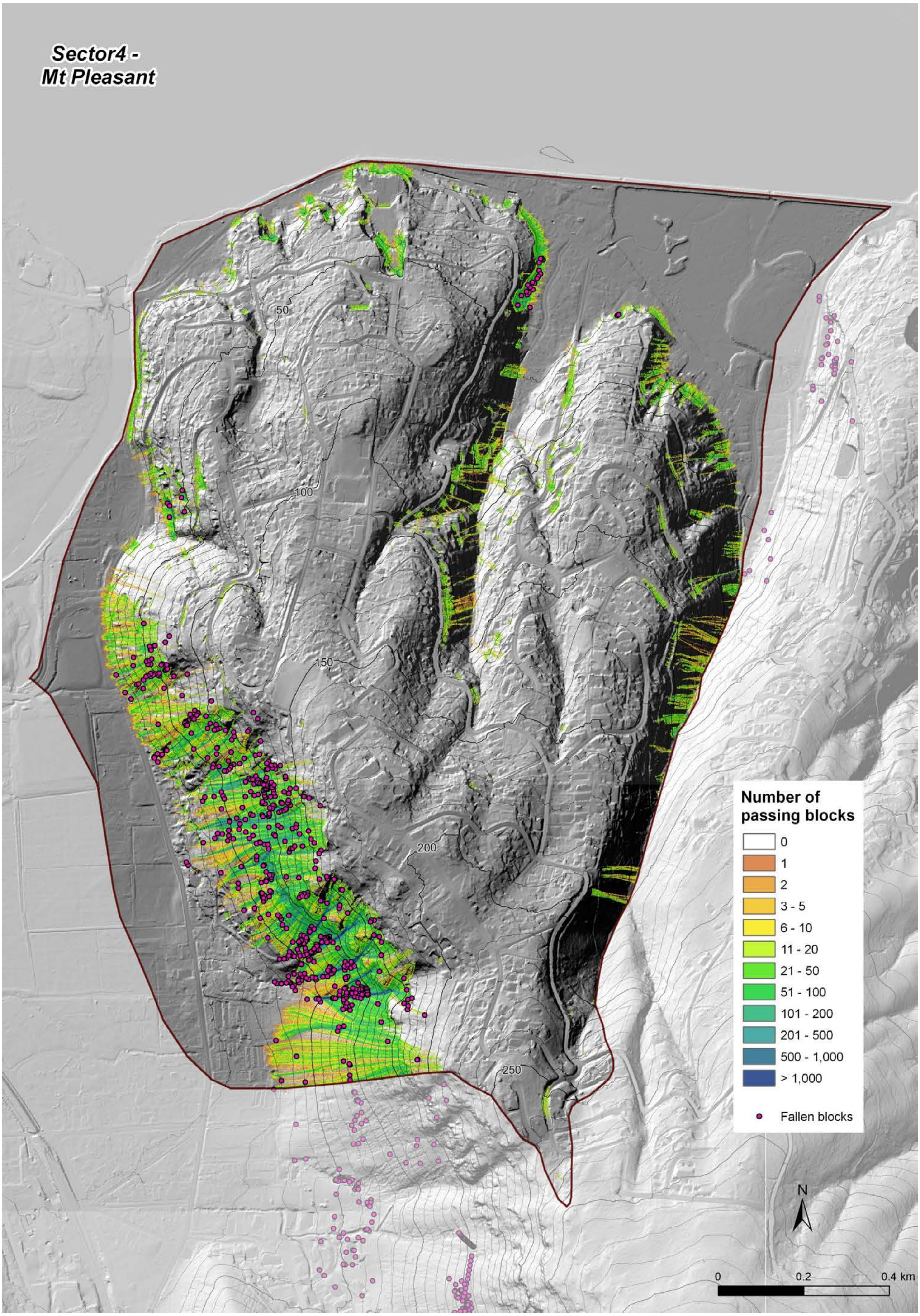
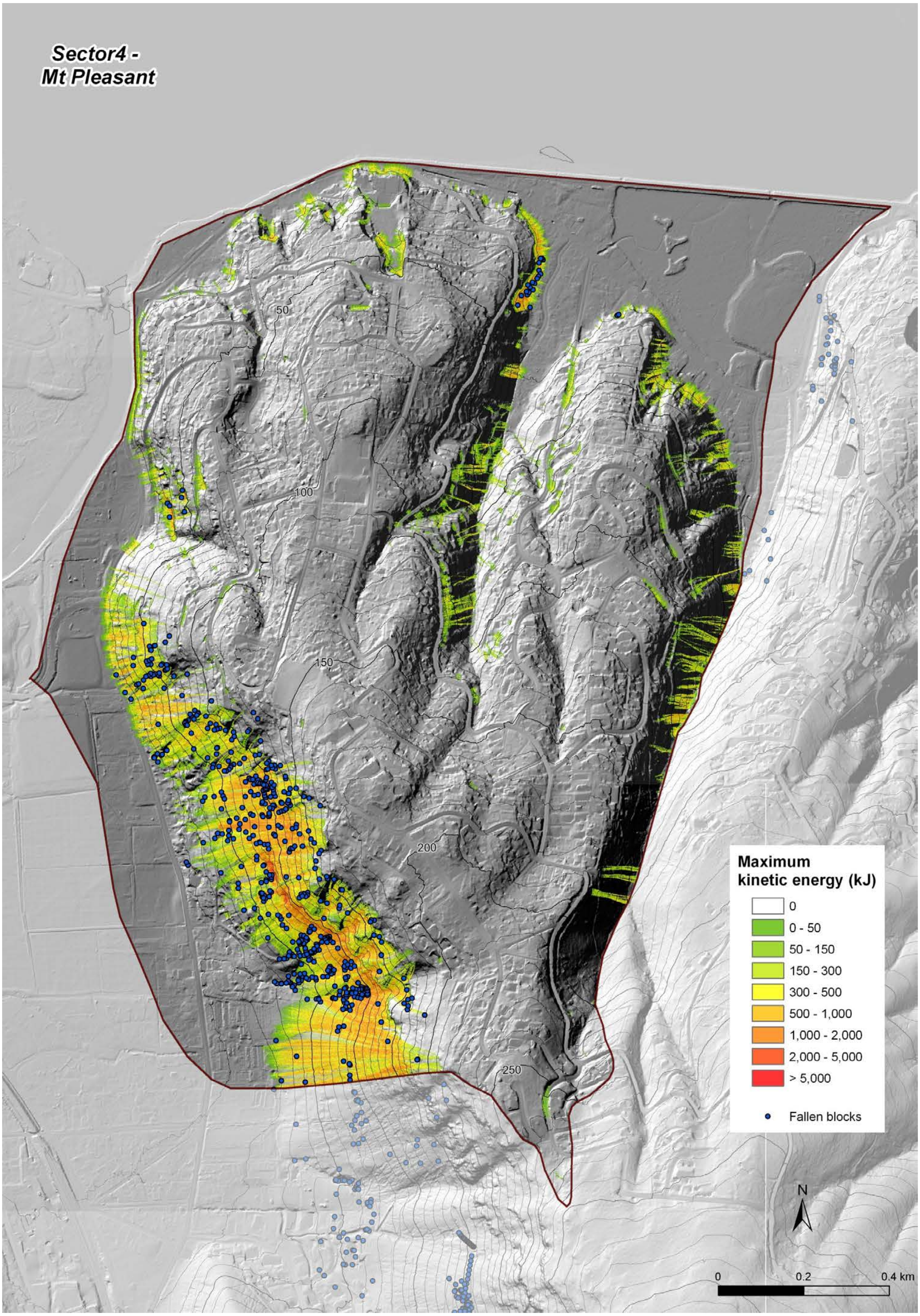
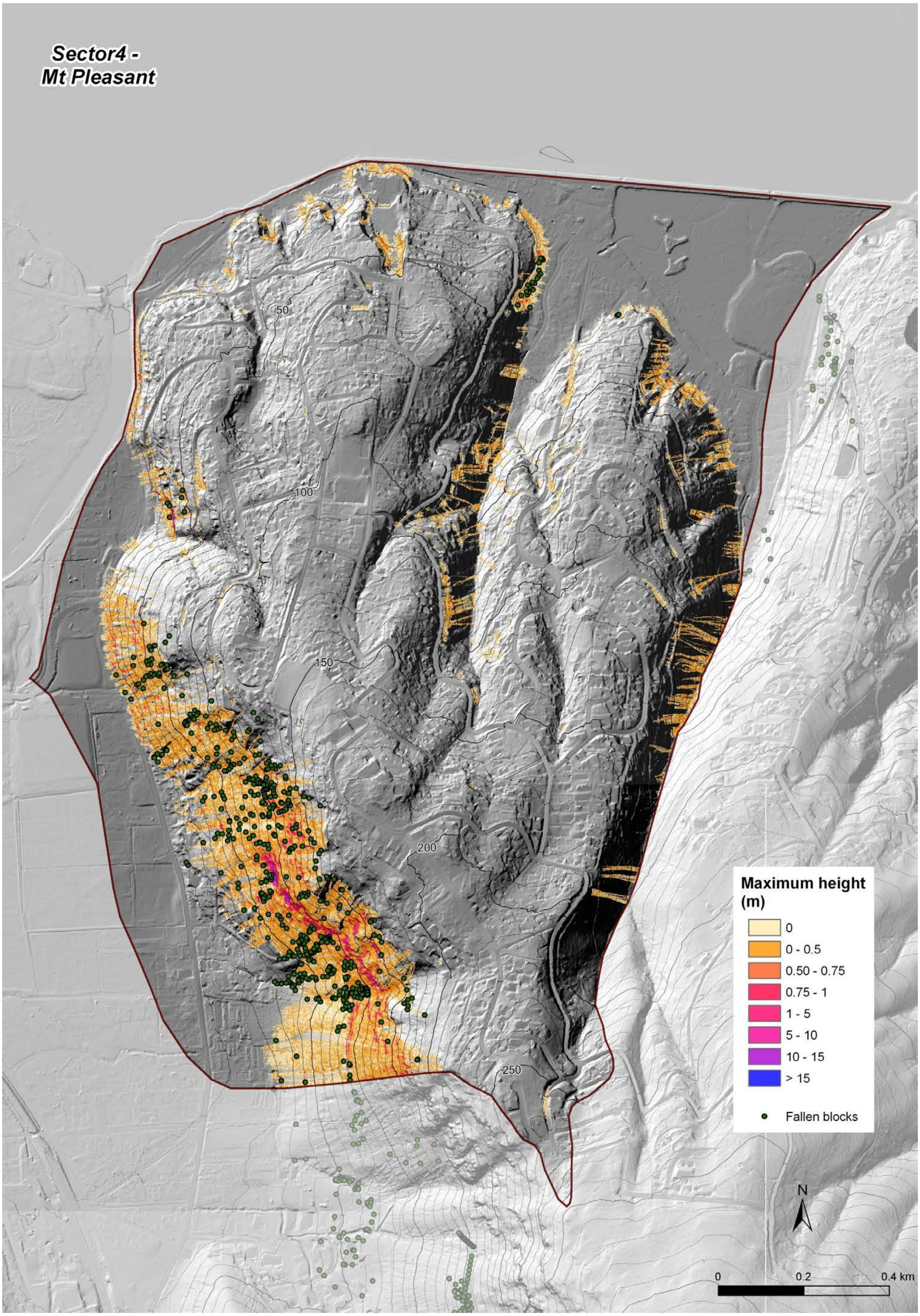
Figure 2 - Recommended Location of Rockfall Barriers

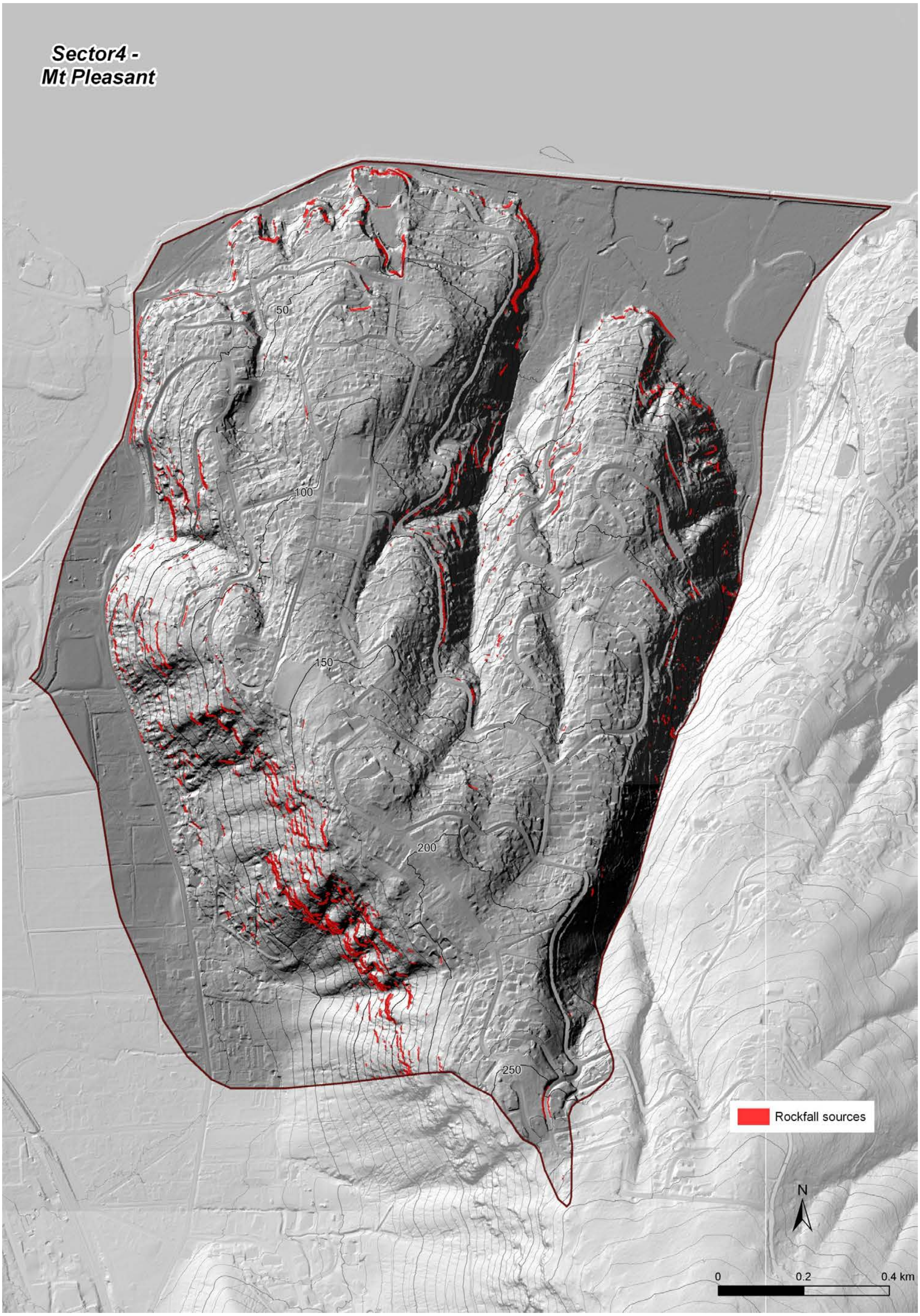



Sector4 -
Mt Pleasant
50
100
150
200
250
Arrested blocks
Fallen blocks
N
0
0.2
0.4 km


Sector4 -
Mt Pleasant
50
100
150
200
250
Number of passing blocks
0
1
2
3 - 5
6 - 10
11 - 20
21 - 50
51 - 100
101 - 200
201 - 500
500 - 1,000
> 1,000
Fallen blocks
N
0
0.2
0.4 km


Sector4 -
Mt Pleasant
50
100
150
200
250
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


Sector4 -
Mt Pleasant
50
100
150
200
250
Maximum height
(m)
0
0 - 0.5
0.50 - 0.75
0.75 - 1
1 - 5
5 - 10
10 - 15
> 15
Fallen blocks
N
0
0.2
0.4 km


Sector4 -
Mt Pleasant
50
100
150
200
250
Rockfall sources
N
0
0.2
0.4 km