Appendix J – Sector 9 Modelling Results

Sector 9 Cashmere

1. Site Description

Cashmere is located on the north western side of the Port Hills, with the rockfall issue arising from the slopes above Cashmere, Bowenvale and Huntsbury. At all sites the hazard arises as a result of the large number of houses at the base of the slopes.

The area considered in this report is shown in Figure 1 below, an area in excess of 3.5km^2.

Figure 1 - Sector 9 site location showing the study area within yellow outline

The slopes west of Cashmere rise steeply from near sea level up to in excess of 250m in elevation and are typically between 20˚ to 45˚. The predominant source of rock fall comes from a number of small bluffs and vertical cliff faces scattered around the slopes above these suburbs.

2. Geotechnical Environment

The area is characterized by small basalt bluffs generally located towards the upper part of the slopes, with lesser amounts of bluffs and outcrops further down slope, followed by more or less vegetated talus slopes continuing towards the valley floor. 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 1.13m3 with a maximum volume of 12m3. 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 along Cashmere area originates predominantly from the main bluffs located towards the upper reaches of the slopes.

Additionally there is evidence of limited rockfall originating from the mid slope area and as such we have included these as seed areas for the modelling. It should be noted though that for the purpose of this report we considered both these 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.

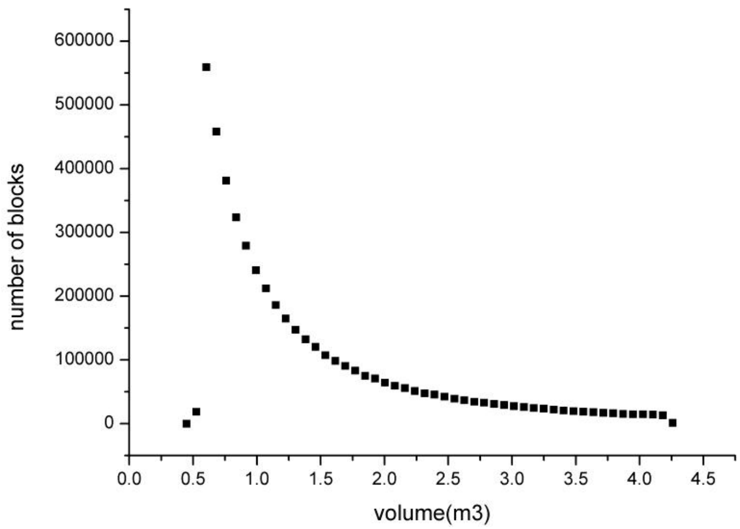
5. Modeling Results

The entire Sector 9 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 nowhere across the study site exceeded 4m in height. The highest bounce heights occur on Centaurus Road and are possibly a result of cliff collapse rather than rock fall as has been described in the main boby of this report. Typically bounce heights are below 3m across the site. This is likely due to the surface conditions and shape of the boulders. While large vegetation has been removed from the model the light vegetation cover, predominamtly tussock, contributes to reduced bounce heights.

Impact velocities for the study site vary throughout the sector and nowhere exceed 3000kJ. The highest velocities are recorded around the upper reaches of Bowenvale Ave on the western side. Typically impact velocities are around 1000kJ to 2000kJ.

This sector has less gullying than other sectors probably resulting from the broader flatter slopes. This can be seen in the Total Number of Boulders image shown below. Also interesting is the limited number of boulders that have reached the valley floors. This is possibly the result of lower slope angles and smaller source areas compared with other Sectors.

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 9 we had three major constraints to consider:

1. **Scale** – Sector 9 is over 3.5km^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 100 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 9. 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 9

Sector (#)	Barrier (ETAG27)	Rating (kJ)	Height (m)	Length (m)
9	1	500	3	40
		1000	3	112
	2	1000	3	148
	3	2000	4	92
	4	1000	3	70
		2000	4	50
		1000	3	120
		2000	4	60
		3000	5	40
		2000	4	115
	5	1000	3	60
		2000	4	220
		1000	3	43
	6	1000	3	40
		2000	4	54
	7	500	3	80
		1000	3	72

For Sector 9 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.

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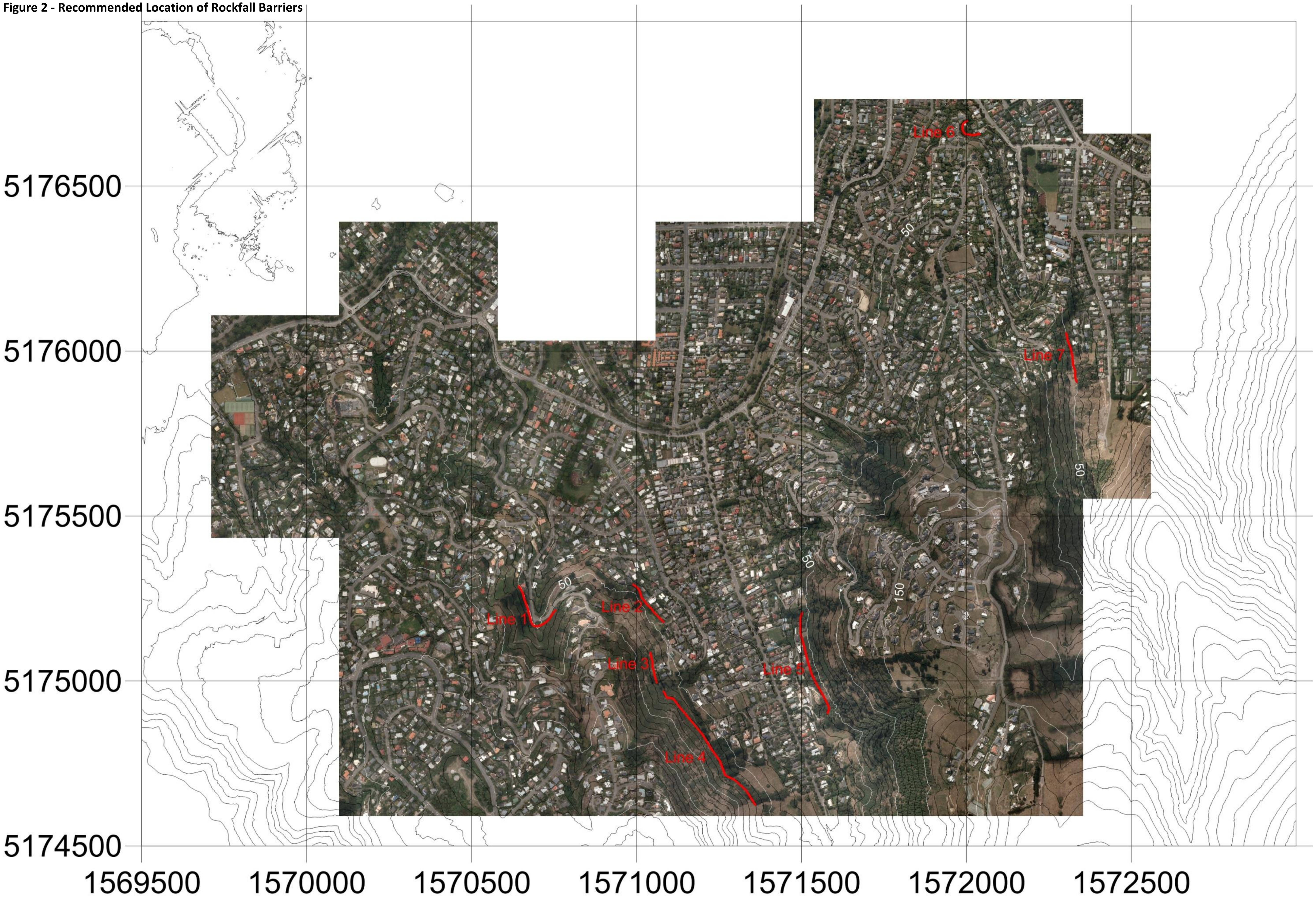
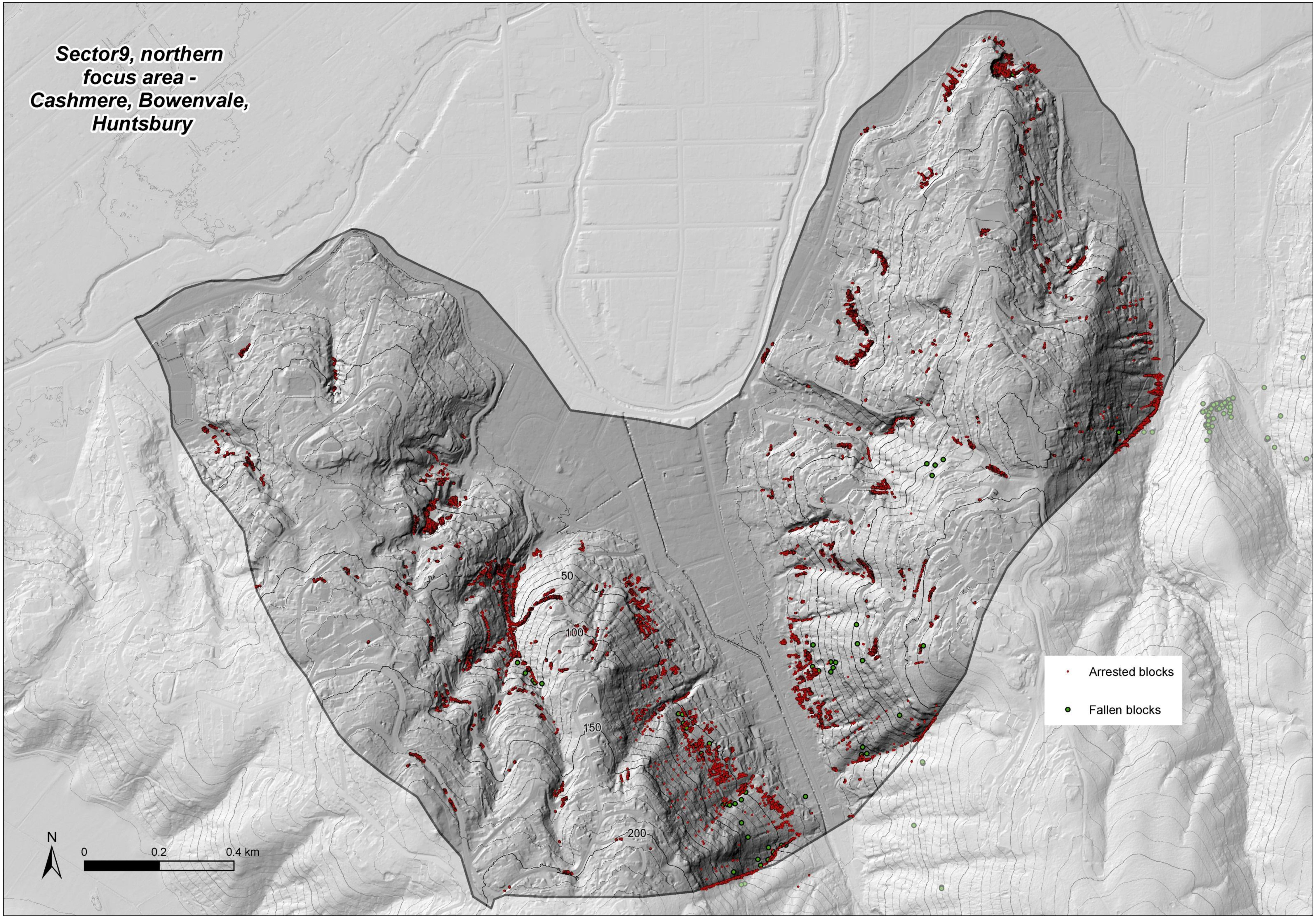
Figure 2 - Recommended Location of Rockfall Barriers




Sector9, northern focus area - Cashmere, Bowenvale, Huntsbury
50
100
150
200
Arrested blocks
Fallen blocks
N
0
0.2
0.4 km

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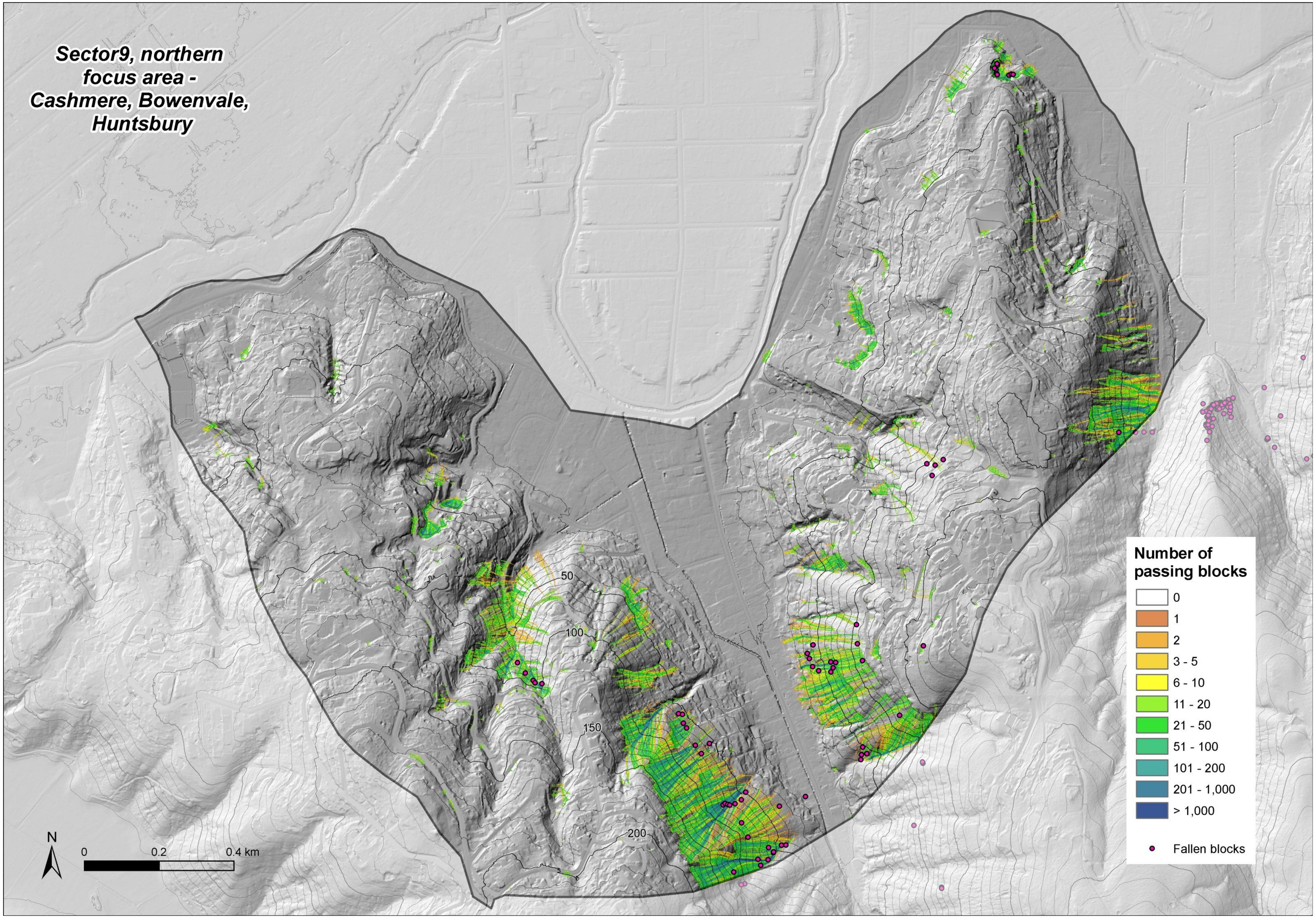
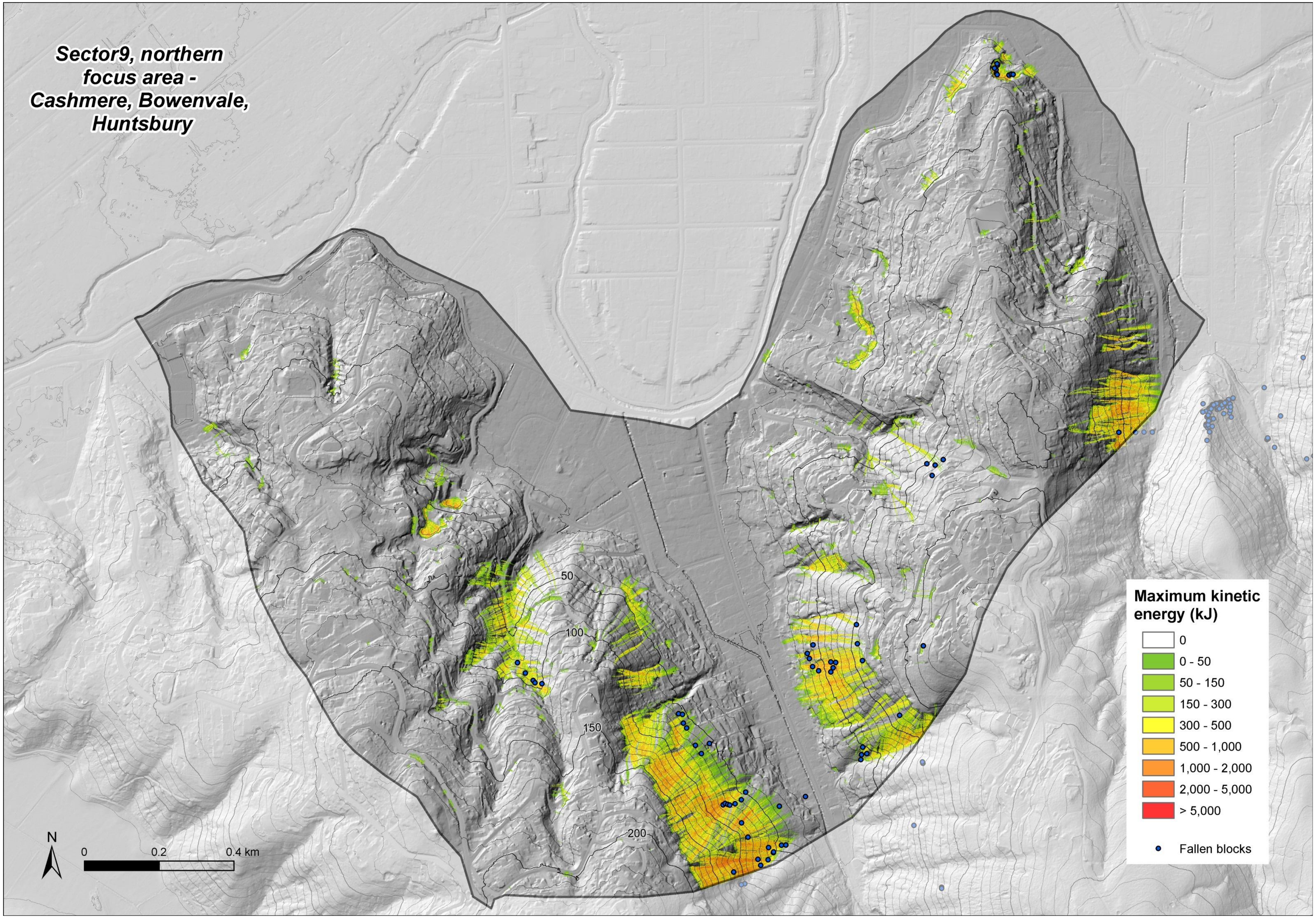


Sector9, northern focus area - Cashmere, Bowenvale, Huntsbury
50
100
150
200
N
0
0.2
0.4 km
Number of passing blocks
0
1
2
3 - 5
6 - 10
11 - 20
21 - 50
51 - 100
101 - 200
201 - 1,000
> 1,000
Fallen blocks


Sector9, northern focus area - Cashmere, Bowenvale, Huntsbury
50
100
150
200
N
0
0.2
0.4 km
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

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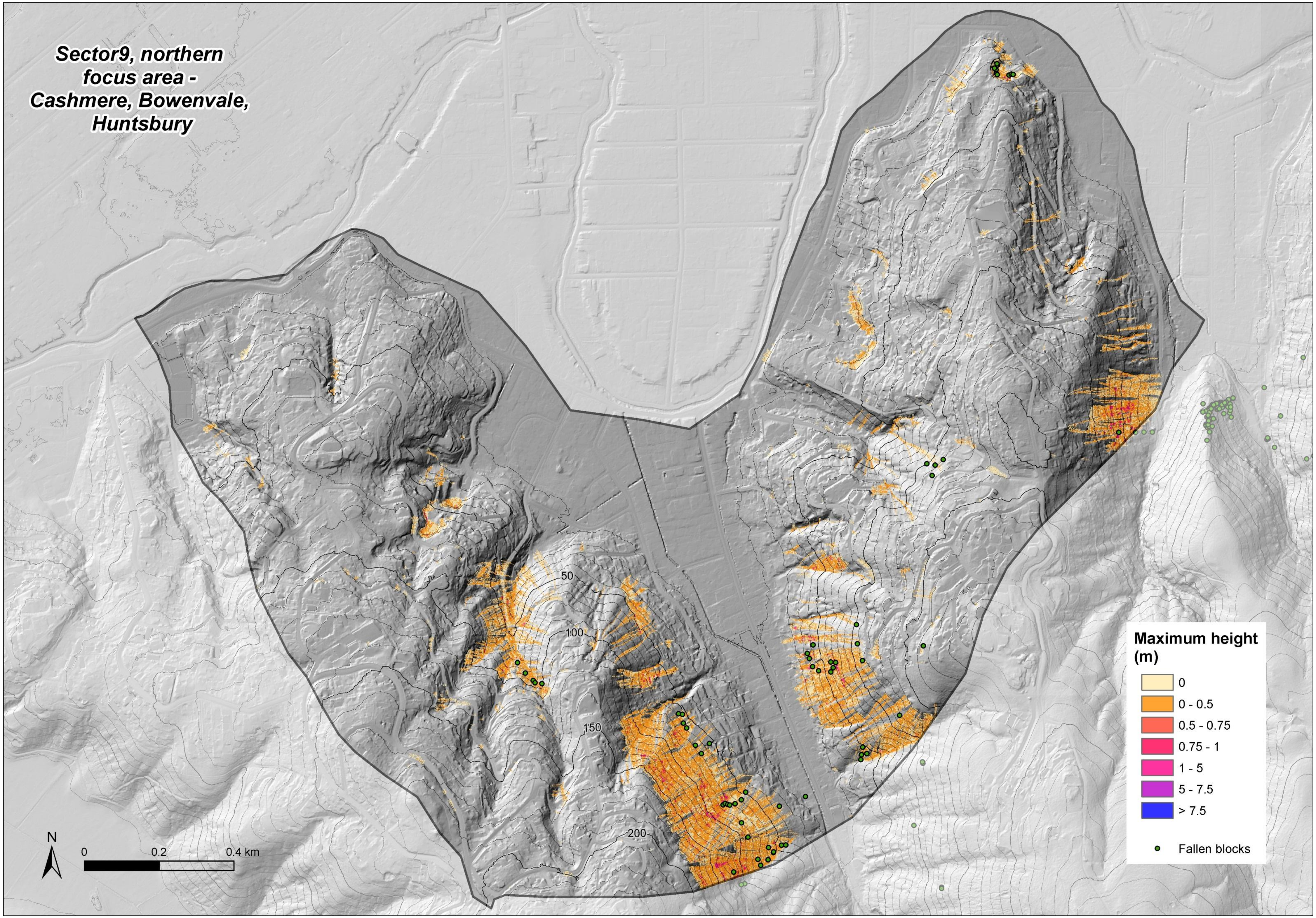

Sector9, northern focus area - Cashmere, Bowenvale, Huntsbury
50
100
150
200
N
0
0.2
0.4 km
Maximum height (m)
0
0 - 0.5
0.5 - 0.75
0.75 - 1
1 - 5
5 - 7.5
> 7.5
Fallen blocks

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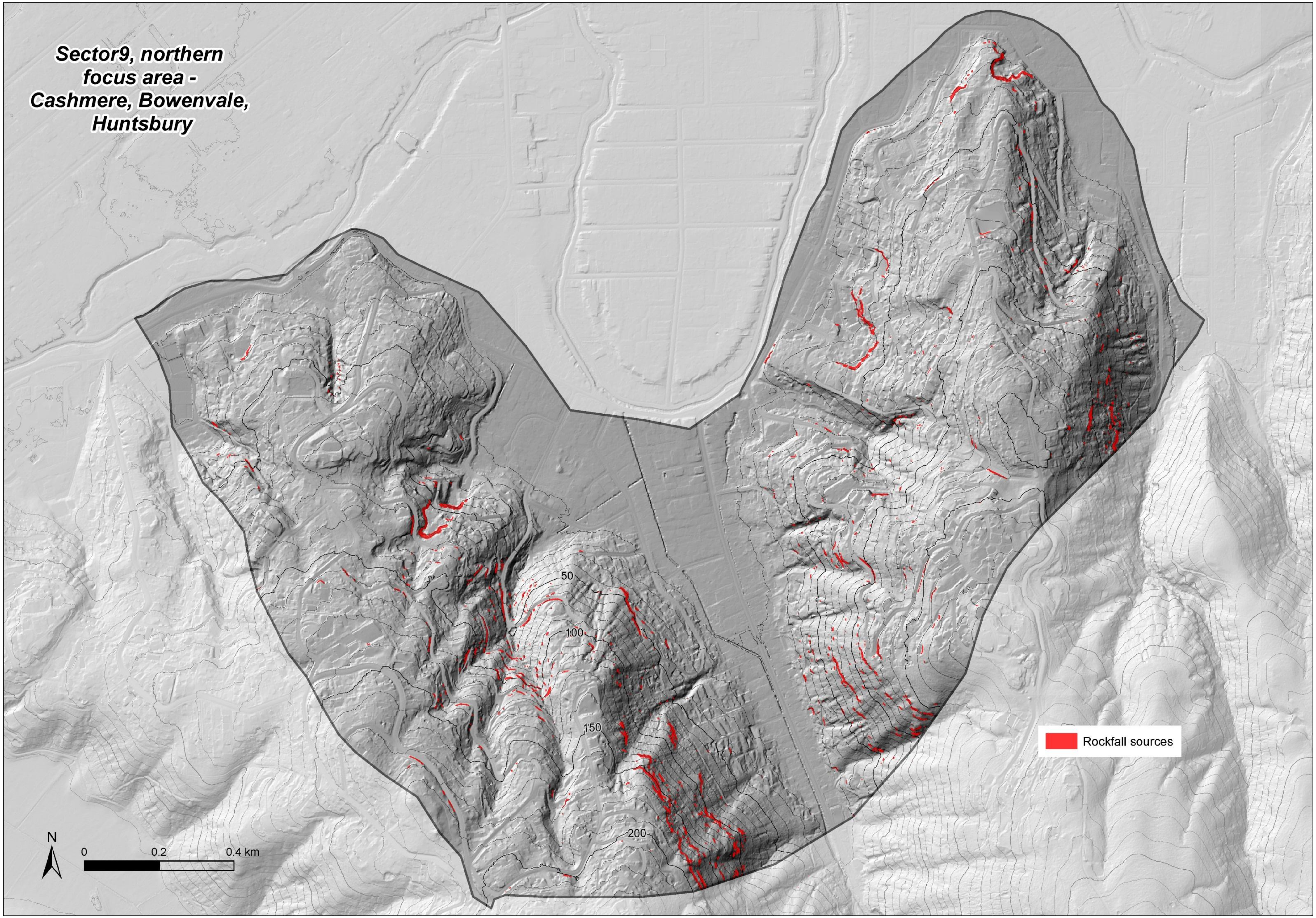
Sector9, northern focus area - Cashmere, Bowenvale, Huntsbury
50
100
150
200
Rockfall sources
N
0
0.2
0.4 km