Appendix E – Sector 5 Modeling Results

Sector 5 Heathcote

1. Site Description

The suburb of Heathcote is located around the northern tunnel portal of the Lyttelton tunnel and is very close to the epicenter of many of the February 2011 (and many subsequent) earthquakes. It is a very important area of the Port Hills for a number of reasons not least the residential aspect but also the fact that it currently provides access to the only heavy vehicle link into and out of Lyttelton.

The area considered in this report is shown in Figure 1 below, an area in excess of 8km^2.

Figure 1 - Sector 5 site location showing the study area within yellow outline

The site is typified by steep grassy slopes dropping from the local summits (approximately 450mRL) directly to road level at approximate 100mRL. Residential development is predominantly restricted to the main valleys (Morgans Valley, Avoca Valley and Harotane Valley) and the north eastern side of Tunnel Road (SH74). The tunnel portal and the state highway are at significant risk of rockfall from Castle Rock.

The slopes south and east of Heathcote rise steeply to elevations in excess of 450mRL. They are relatively steep, typically between 30˚ to 50˚, and as with much of the remainder of the Port Hills they are very sparsely vegetated with grass and tussock forming the main ground cover.

The predominant sources of rock fall are Mount Pleasant, Castle Rock, the bluffs west of the Avoca Valley and the very large bluffs surrounding Morgans Valley. Numerous other small bluffs and rock outcrops contribute to the rockfall source.

2. Geotechnical Environment

The area is characterized by basalt cliffs and outcrops towards the top of the slopes ranging in height from several metres to in excess of 20m. Three significant features, the Morgans Valley cliffs, Castle Rock and Mount Pleasant have been identified as significant rock source areas. These 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 2.3m3 with a maximum volume of 400m3. 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 Sector 1 originates predominantly from the main bluffs located approximately mid-slope.

A significant source of material is from the main summit area of Castle Rock which is known to release very large blocks of strong to very strong basalt. A number of rock bluffs immediately below Mount Pleasant summit also release significant volumes of rock. Analysis of these upper rock source areas has revealed rockfall from these areas has significant impact on the state highway and tunnel entrance located at the base of the slope. For the purpose of this report we have 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.

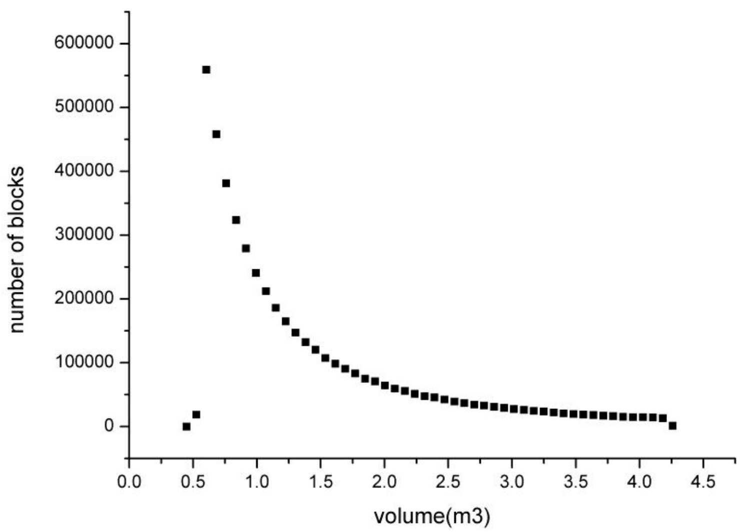
5. Modeling Results

The entire Sector 5 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 for the Horotane Valley area very little rockfall has reached the flat valley floor area where dwellings are located. However for the northern tunnel approach road (SH74) our model shows significant hazard to road users particularly in the 400m from Bridle Path Rd north on SH74. A number of houses also appear to be at risk near Heathvale Place.

The tunnel portal itself appears to be at risk from a source area to the east at approximately RL150m. This source is situated less than half way up the slope. Boulders coming from further up slope are shown in our model not to reach the tunnel portal area.

Morgans Valley appears to be at greatest risk along the eastern slopes. The rockfall source area here is clearly the very large bluffs that create the great valley rim. Into the head of the valley rockfall energies are around 8000kJ with bounce heights in the upper reaches in excess of 5-

10m. Bounce heights and energies towards the base of the slopes drop to below 1.5m and 1000kJ to 2000kJ respectively.

As with elsewhere on the Port Hills there is a reasonable level of gullying occurring, 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 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. 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 5 we had three major constraints to consider:

1. **Scale** – Sector 5 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 60% 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 150 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.

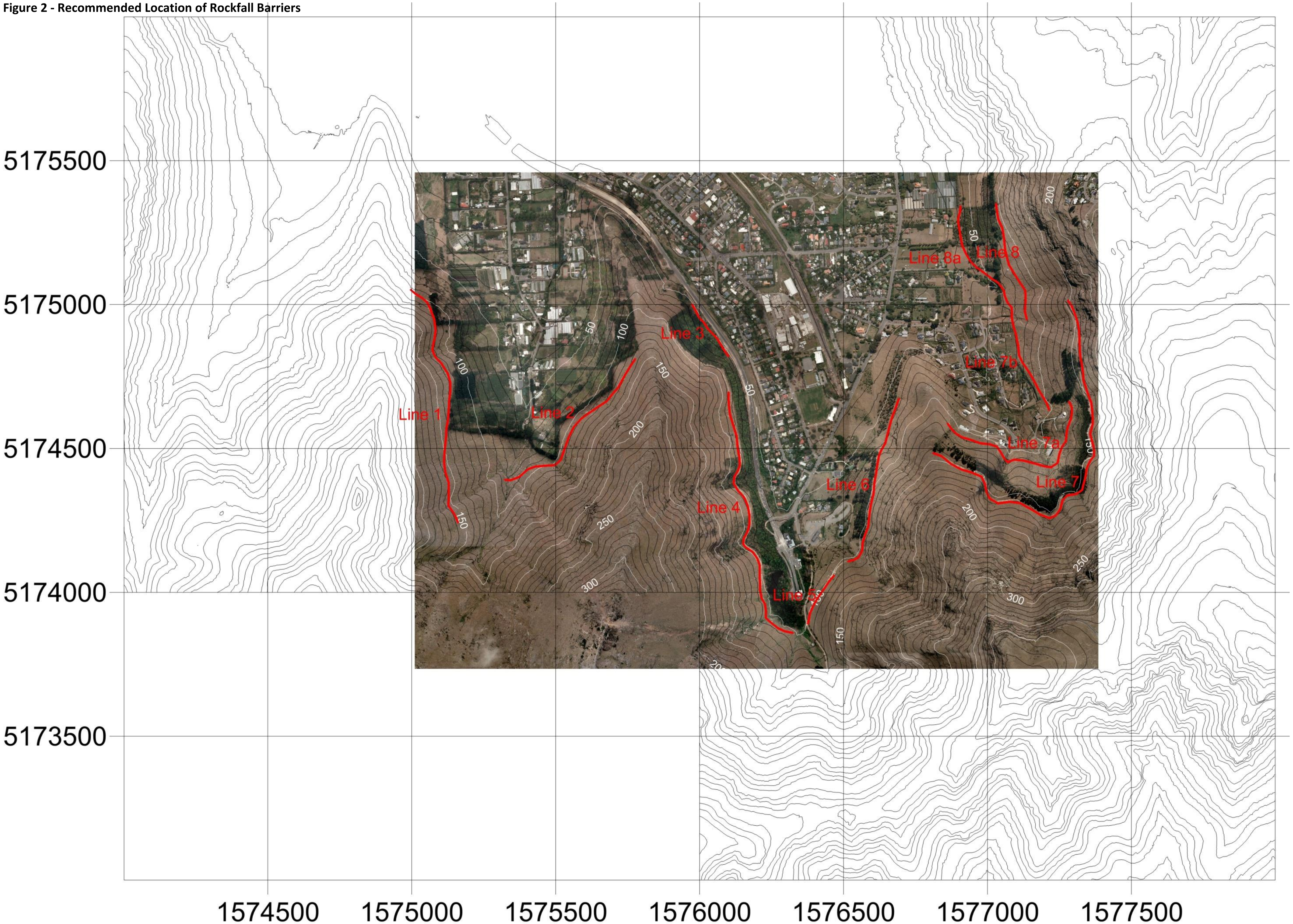
In accordance with Option 4 in the main report text it is recommended that the installation of rockfall barriers is the most suitable means of remediating the rockfall hazard in Sector 5. The size and lengths of the barriers are outlined in Table 2 below while the locations are shown in Figure 2. The results of the modelling are presented in the following graphics.

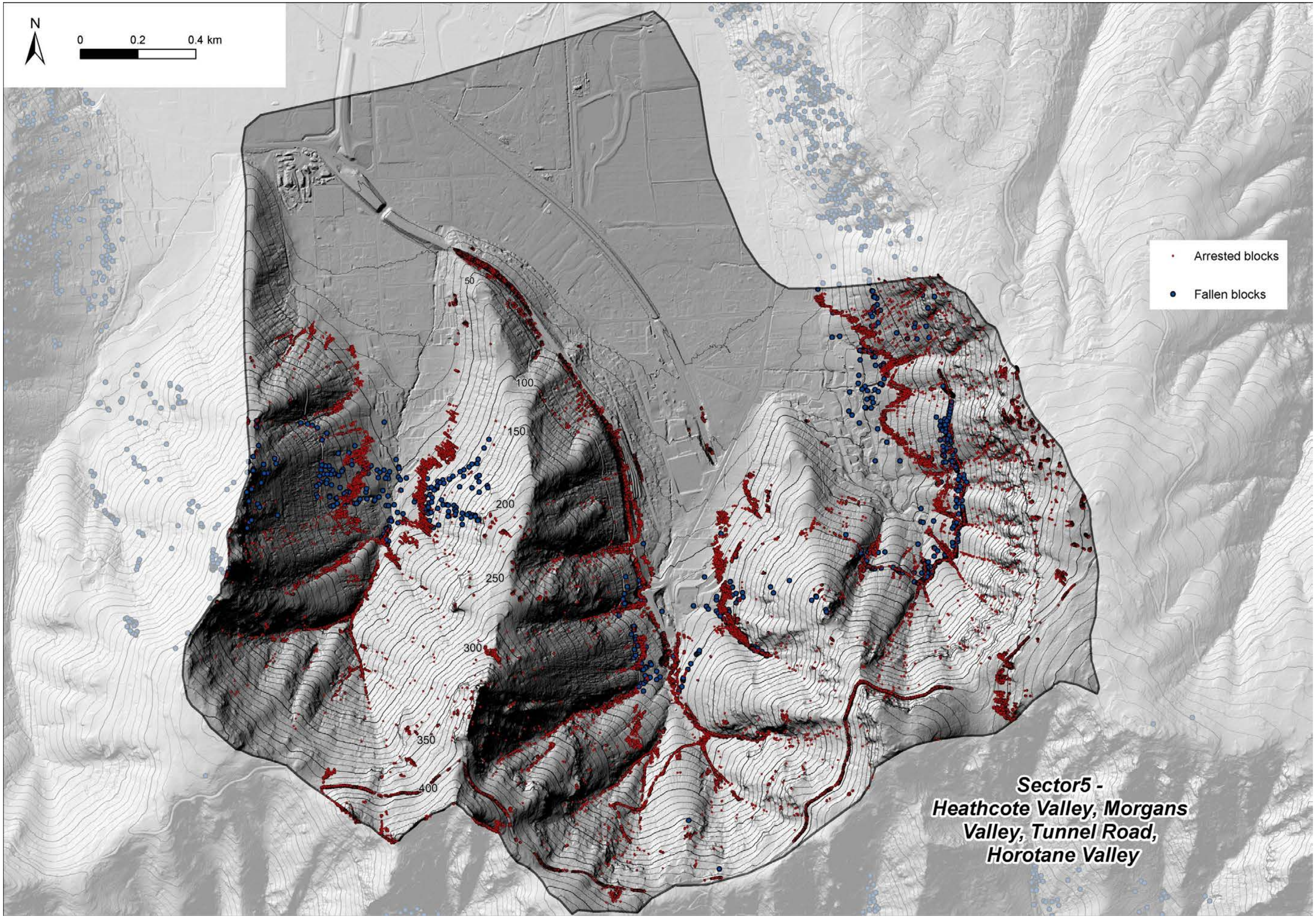
For Sector 5 the decision to recommend barriers over bunds is mainly due to topographical constraints. It is possible for a small length of bunds to be constructed around the back of Morgans Valley however due to the high energies modeled in this area the installation of barriers is preferable as they are tested and approved systems

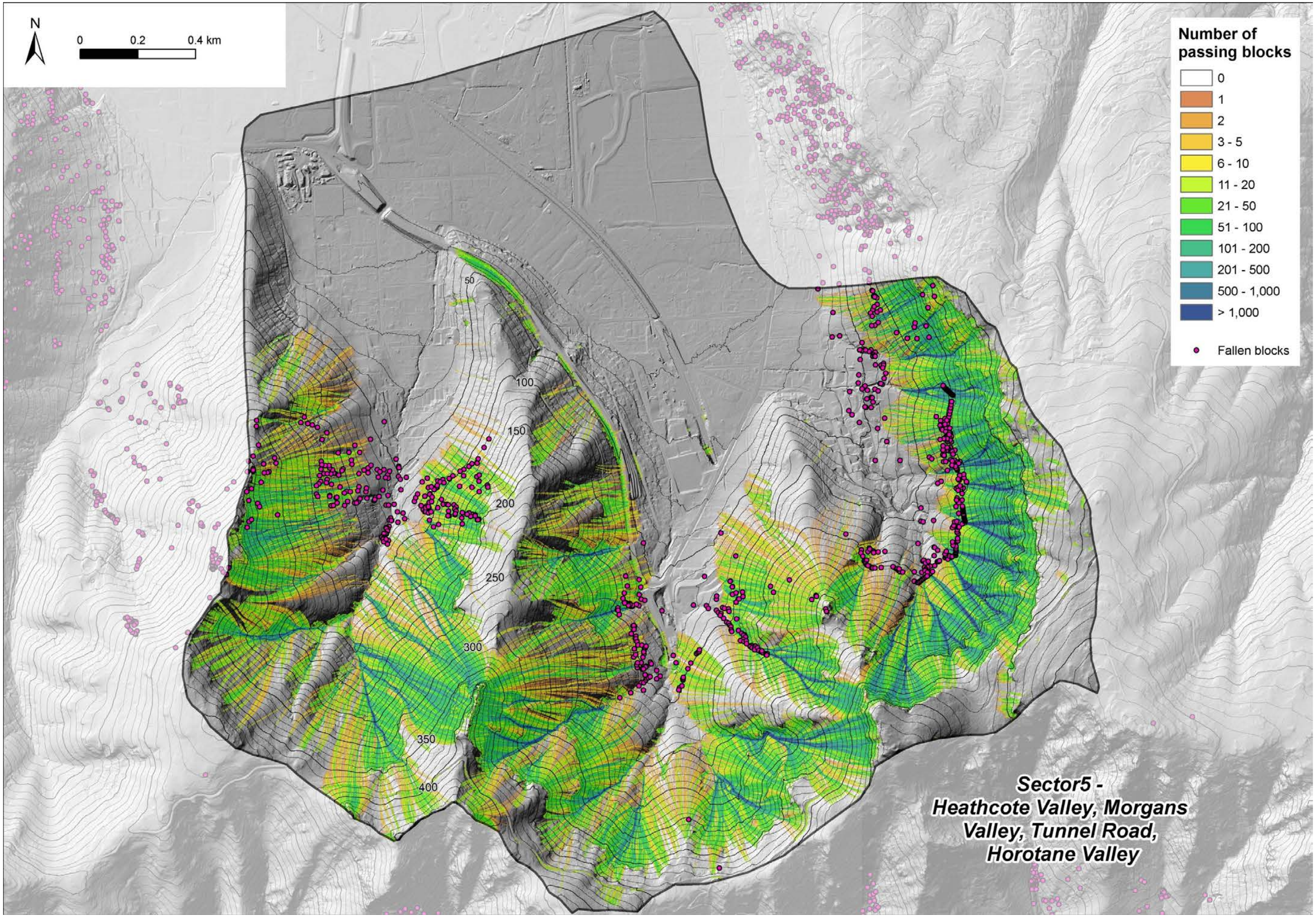
Table 2 - Recommended Barriers for Sector 5

Sector (#)	Barrier (ETAG27)	Rating (kJ)	Height (m)	Length (m)
5	1	2000	4	70
		1000	3	300
		2000	4	70
		1000	3	290
		2000	4	80
		1000	3	64
	2	500	3	150
		2000	4	310
		1000	3	201
	3	500	3	180
		1000	3	40
	4	1000	3	200
		2000	4	150
		1000	3	90
		2000	4	80
		2000	6	60
		1000	3	370
	5	1000	3	100
		2000	4	92
	6	2000	6	100
		2000	4	80
		1000	3	332
	7	1000	3	200
		2000	4	70
		1000	3	210
		2000	4	40
		5000	6	120
		8000	8	200
		5000	6	60
		8000	8	200
		5000	6	242
	8	1000	3	70
		2000	4	80
		1000	3	30
		2000	4	180
		500	3	65

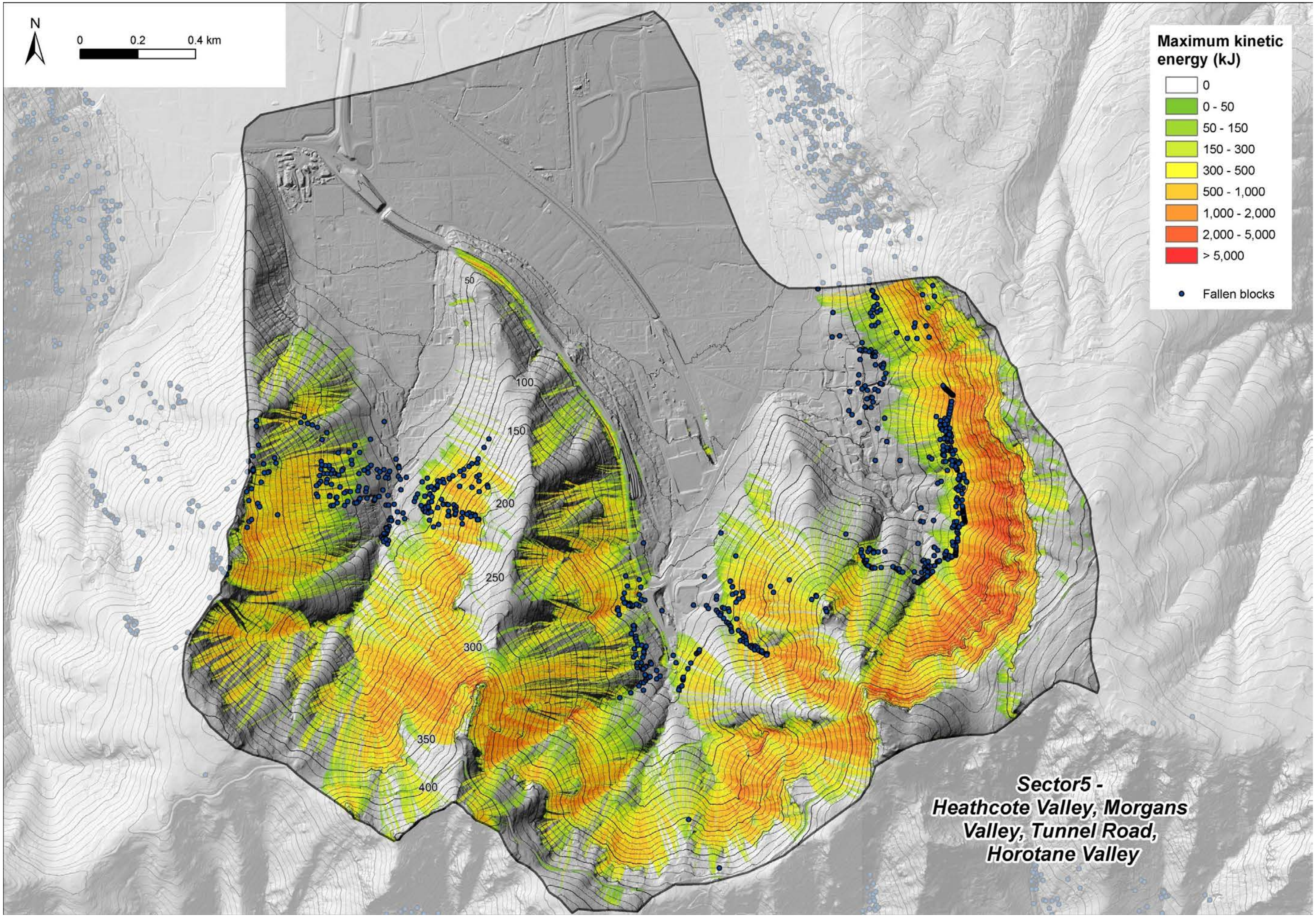
Figure 2 - Recommended Location of Rockfall Barriers




N
0
0.2
0.4 km
Arrested blocks
Fallen blocks
50
100
150
200
250
300
350
400
Sector5 -
Heathcote Valley, Morgans
Valley, Tunnel Road,
Horotane Valley

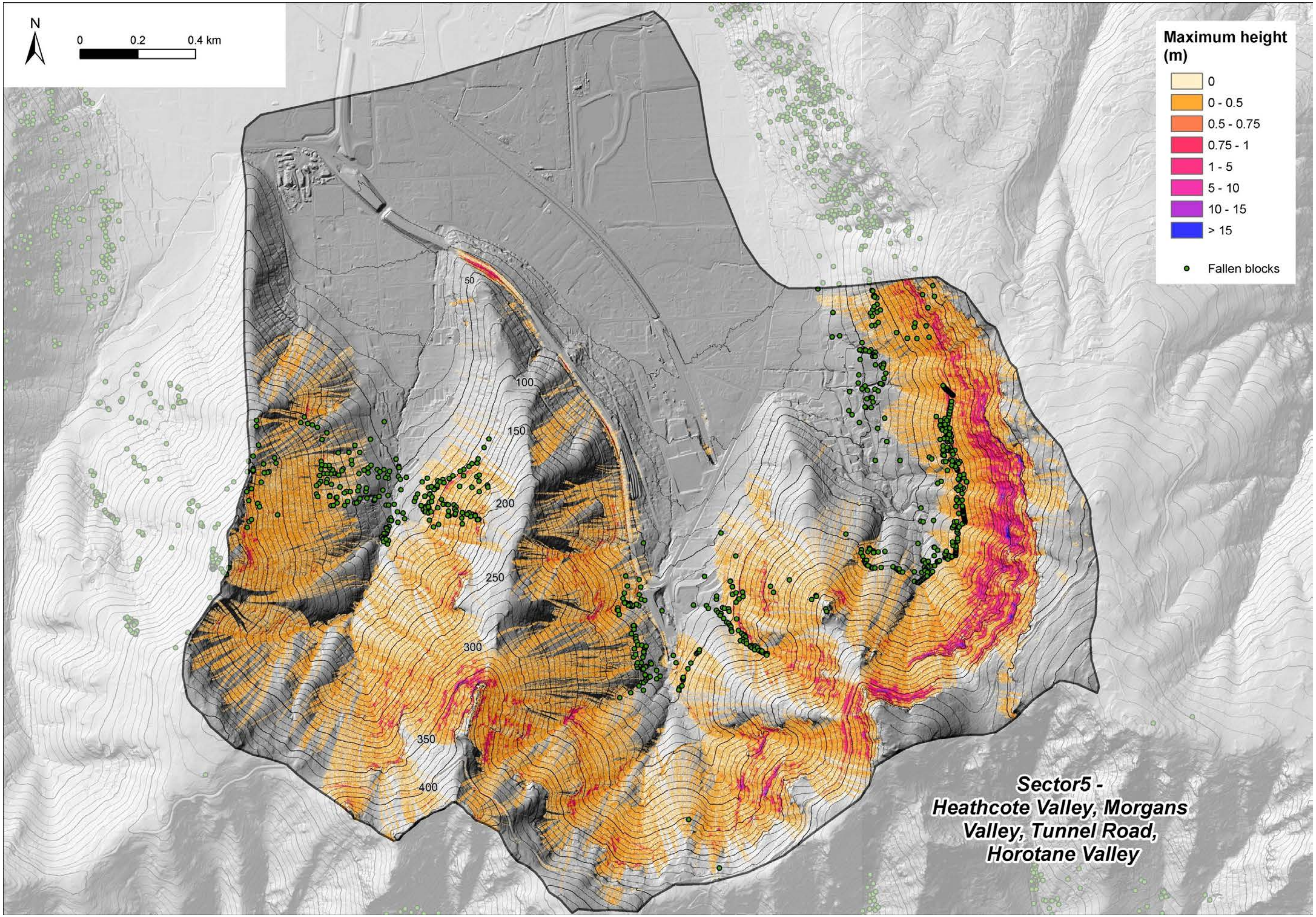

N
0
0.2
0.4 km
Number of passing blocks
0
1
2
3 - 5
6 - 10
11 - 20
21 - 50
51 - 100
101 - 200
201 - 500
500 - 1,000
> 1,000
Fallen blocks
50
100
150
200
250
300
350
400
Sector5 -
Heathcote Valley, Morgans Valley, Tunnel Road, Horotane Valley

GEOVERT

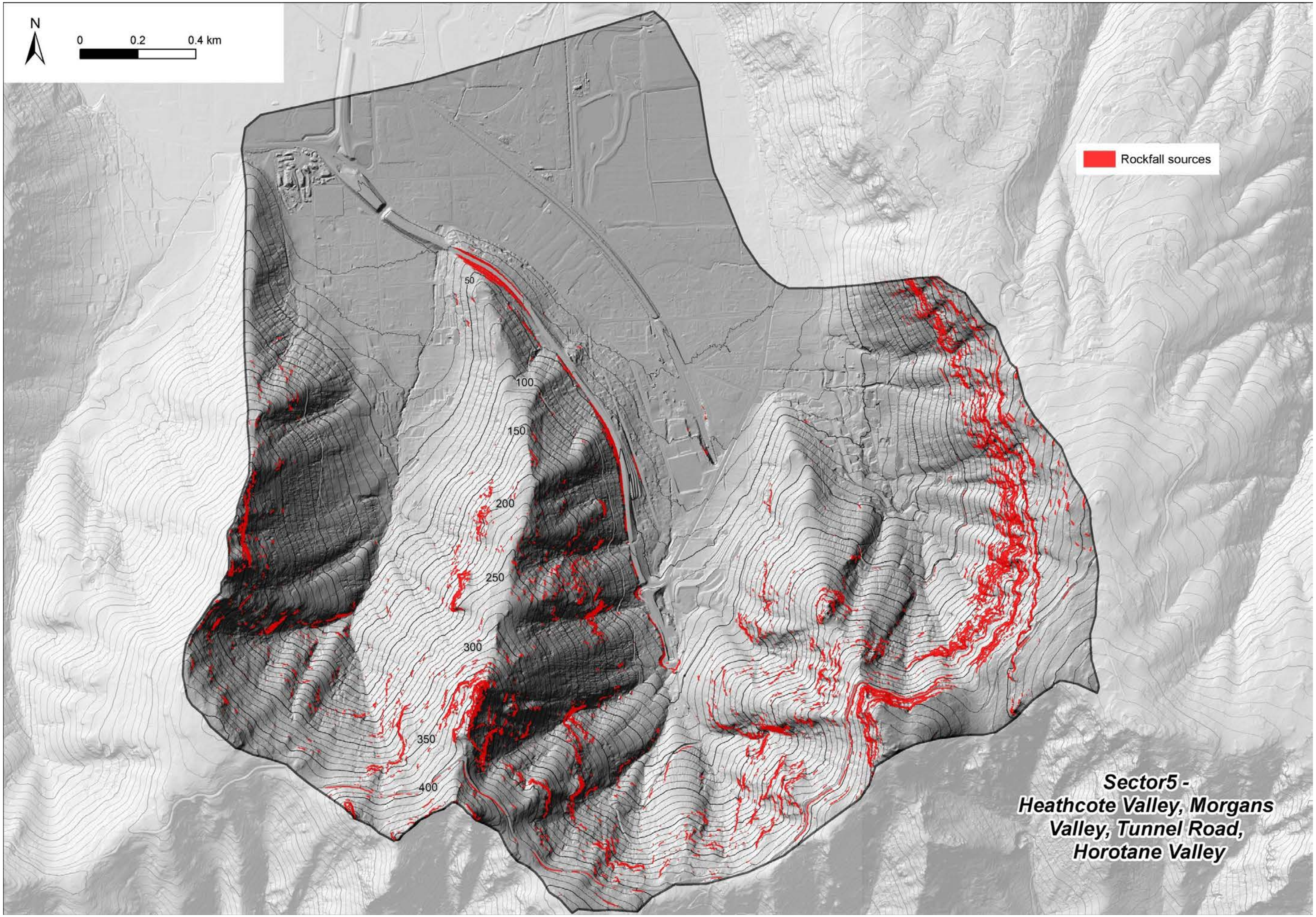


N
0
0.2
0.4 km
Maximum kinetic energy (kJ)
0
0 - 50
50 - 150
150 - 300
300 - 500
500 - 1,000
1,000 - 2,000
2,000 - 5,000
> 5,000
Fallen blocks
50
100
150
200
250
300
350
400
Sector5 -
Heathcote Valley, Morgans Valley, Tunnel Road, Horotane Valley

GEOVERT


N
0
0.2
0.4 km
Maximum height (m)
0
0 - 0.5
0.5 - 0.75
0.75 - 1
1 - 5
5 - 10
10 - 15
> 15
Fallen blocks
50
100
150
200
250
300
350
400
Sector5 -
Heathcote Valley, Morgans Valley, Tunnel Road, Horotane Valley

GEOVERT


N
0
0.2
0.4 km
Rockfall sources
50
100
150
200
250
300
350
400
Sector5 -
Heathcote Valley, Morgans
Valley, Tunnel Road,
Horotane Valley