Appendix C – Sector 3 Modeling Results

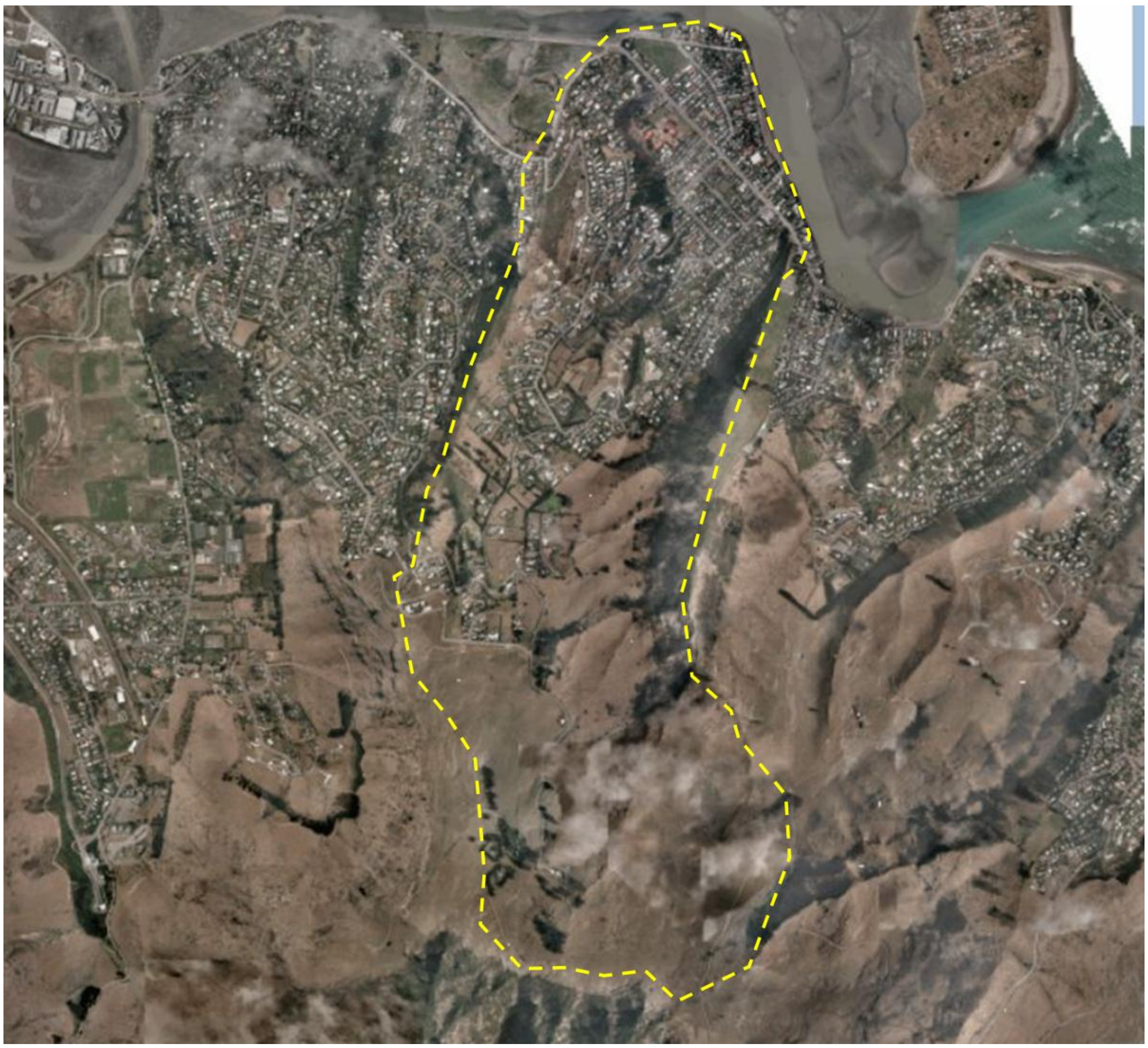
Sector 3 Redcliffs

1. Site Description

The suburb of Redcliffs is located between Mount Pleasant and Moncks Bay and is bounded to the north east by the Brighton Estuary. The suburb rises upwards to the south to slopes in excess of 300m above MSL. The area is locally densely populated on its lower slopes with the upper slopes lightly vegetated with grass and tussocks.

The area considered in this report for both sites is shown in Figure 1 below, an area in excess of 3.0km^2.

Figure 1 - Sector 3 site location showing the study area within yellow outline



The slopes above Redcliffs rise from near sea level up to in excess of 300m in elevation and are typically between 15˚ to 45˚. The main rockfall issue arises from a number of small localized rock exposures and bluffs throughout the sector and a series of sub vertical historic sea cliffs to the south west of Main Road. These bluffs have been subject to significant cliff collapse however we have not considered cliff collapse in our modelling.

A densely vegetated slope drops steeply east of Moncks Spur Road and is the source for some rockfall. Land use at the base of the slope is a mixture of playing fields and reserve land.

2. Geotechnical Environment

The area is characterized by small basalt outcrops and sporadic large boulders resting on the slopes. The large historic sea cliffs on the northern margin have not been considered as part of this report due to their cliff collapse processes and not rockfall. 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 average rock volume (as recorded by the PHGG) is 0.6m3 with a maximum volume of 3.7m3. 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.

Additionally there is evidence of limited rockfall originating from the area upslope towards Summit Road however analysis of this area has revealed rockfall from these areas has little impact on the residential areas at the base of the slope. It should be noted though 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.

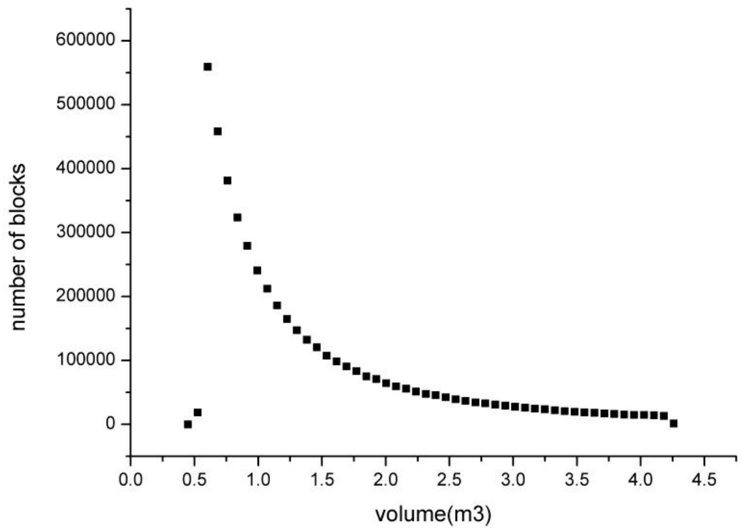
5. Modeling Results

The entire Sector 3 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.

Reviewing the modelled data indicates bounce heights are typically low (less than 2m) but that in some areas easpecially near Puriwheriro Lane and this section of Main Road the bounce heights are significantly higher, in some areas upwards of 6m of bounce height has been recorded. This could be a combination of factors given the high and steep rock faces in this area however suitable protection measures need to be installed to protect against these high bounces.

Impact velocities for Redcliffs vary along the length of the study site and are typically around 1000kJ or lower. There are aeas where energies are higher for example the northern section of Line 1 and middle section of Line 2 where energies are between to 2000 and 3000kJ.

As with many other areas on the Port Hills the rock source areas are widely spread across the study area and interestingly much of the rock channels into narrow gullies (narrower than the source area). This can be seen in the Total Number of Boulders image shown in below. 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 3 we had three major constraints to consider:

1. **Scale** – Sector 3 is over $4km^2$ in area with multiple source areas and runout 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 30% of the study area requires protection.

2. **Topography** – the site is typified by steep near vertical slopes and multiple 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 50 houses and a school 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.

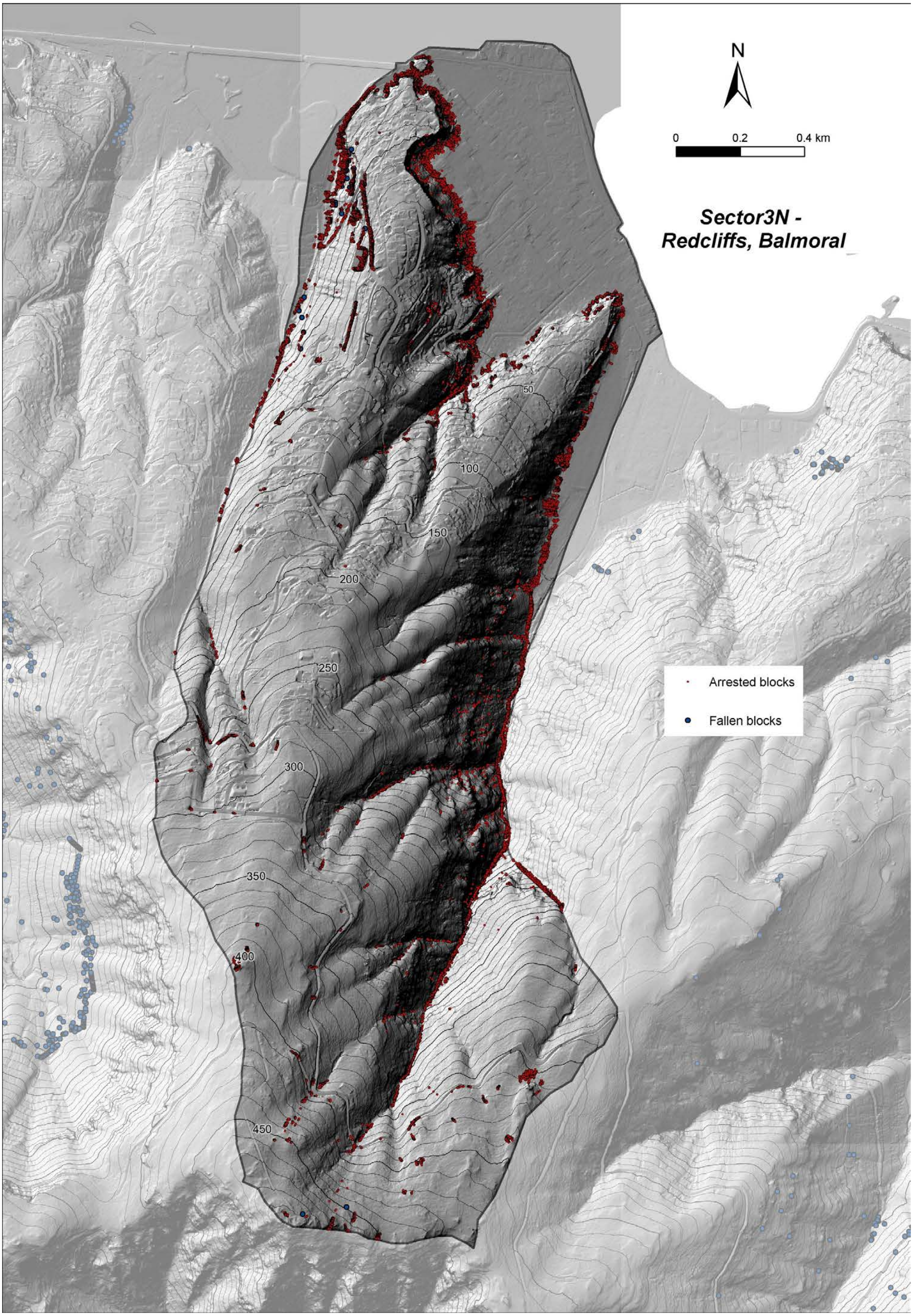
In accordance with 4 in the main report text it is recommended that the installation of rockfall barriers is the most suitable means of remediating the rockfall hazard in Sector 3. The size and lengths of the barriers are outlined in Table 2 below while the locations are shown in Figure 2. The results of the modelling are presented in the following graphics.

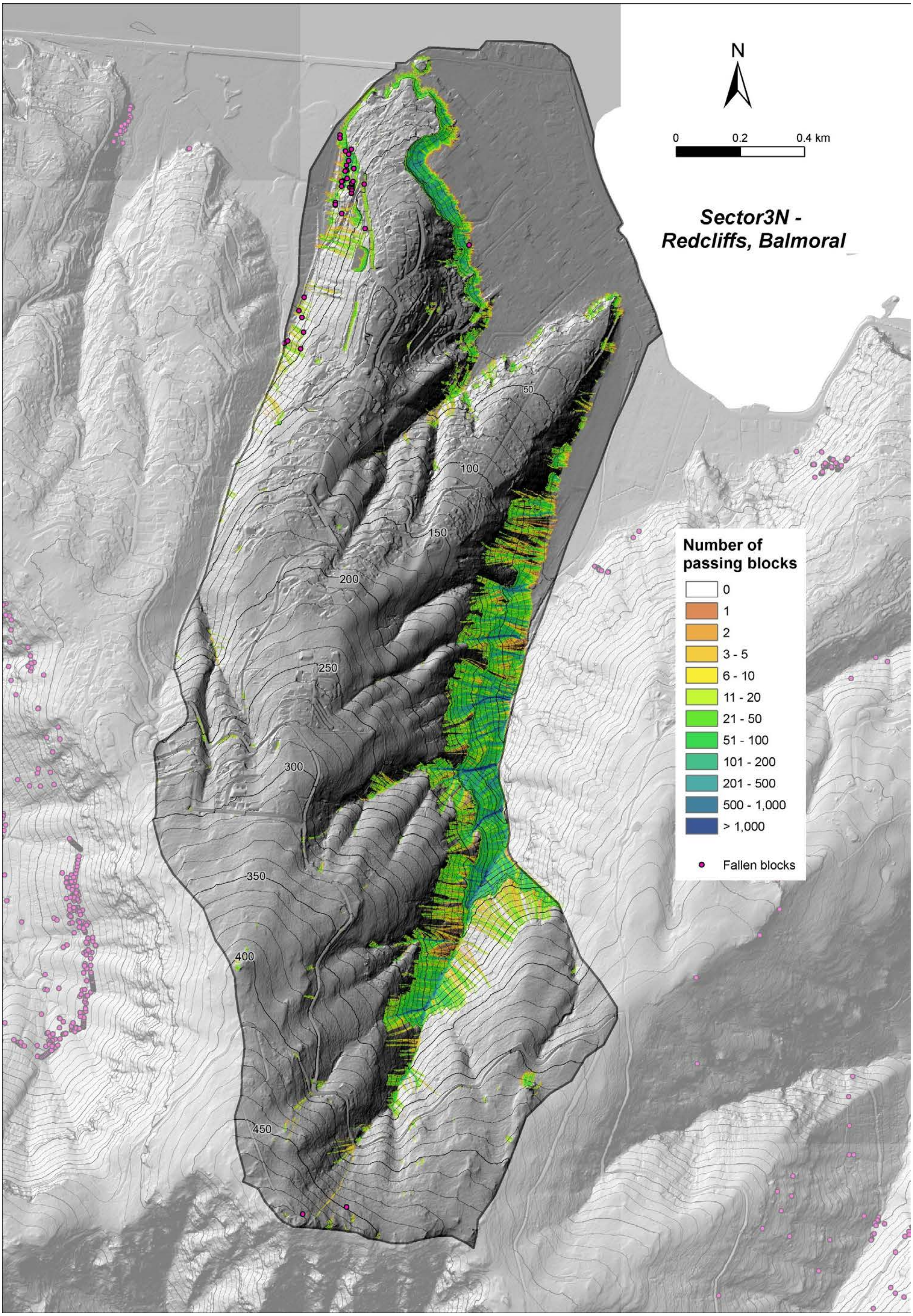
Table 2 - Recommended Barriers for Sector 3

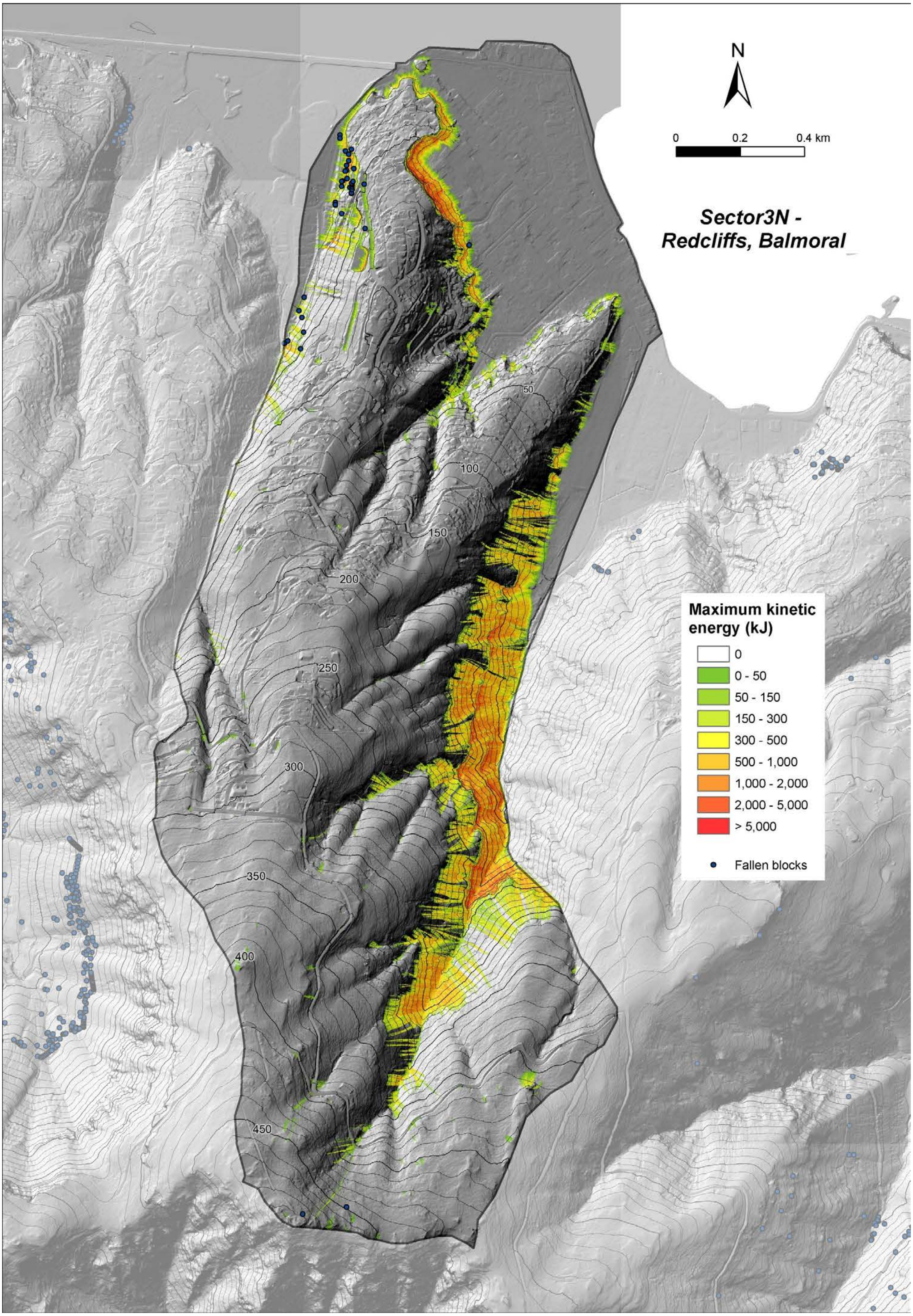
Sector (#)	Barrier (ETAG27)	Rating (kJ)	Height (m)	Length (m)
3	1	500	3	200
		1000	7	100
		1000	4	170
		1000	5	90
		500	5	142
	2	500	3	70
		500	5	136
		500	3	162
	3	500	3	85

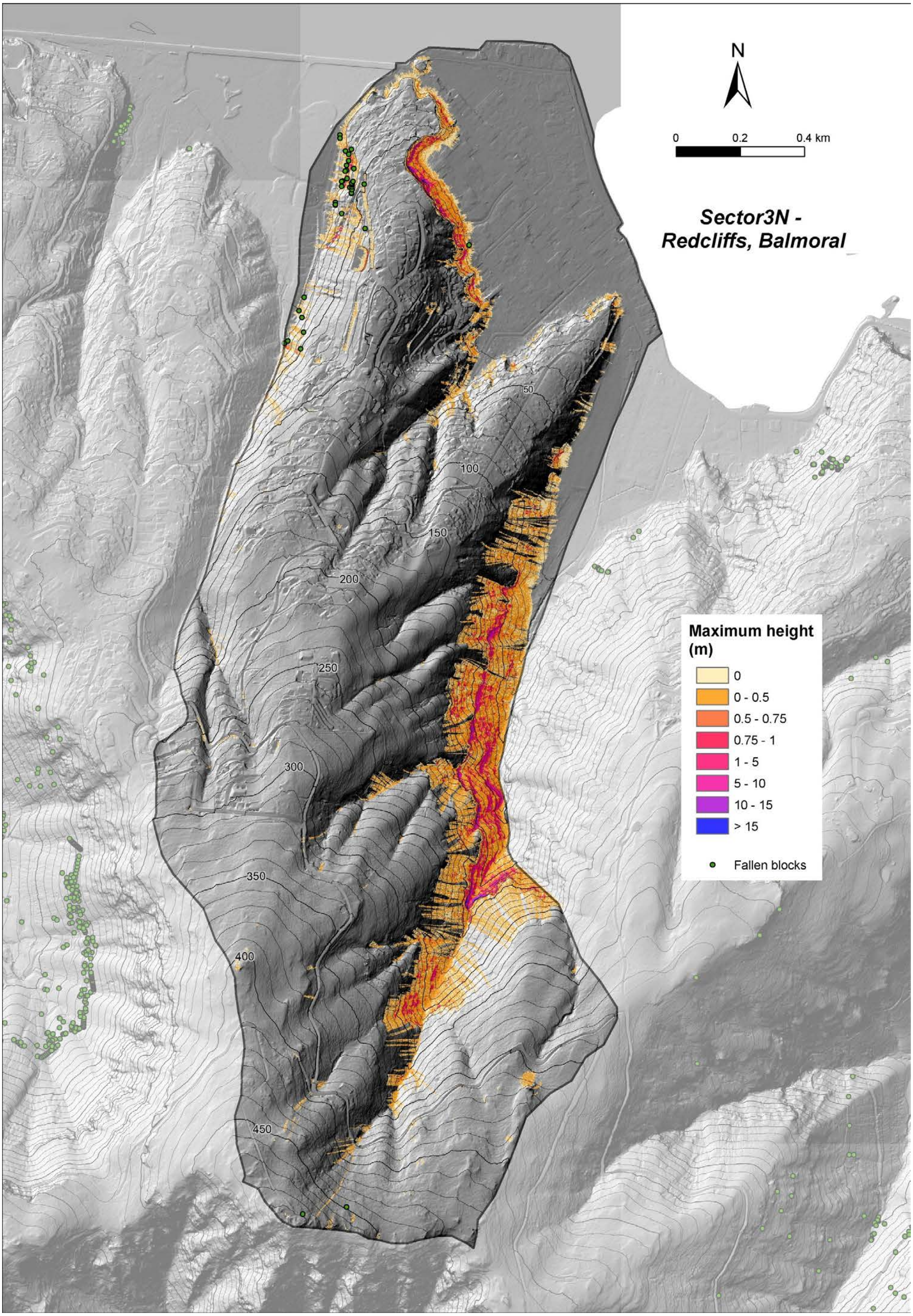
For Sector 3 the topography and runout zones are such that bunds would be able to be constructed on relatively flat ground for a 300m long section of Line 1. However this area is located behind the school grounds and the scope of this report was focused on residential property not Government land. Everywhere else the slopes are steep and barriers are better suited. Note however that if more suitable land was made available at the base of the slopes, bunds could be used more widely in this sector.

Figure 2 - Recommended Location of Rockfall Barriers

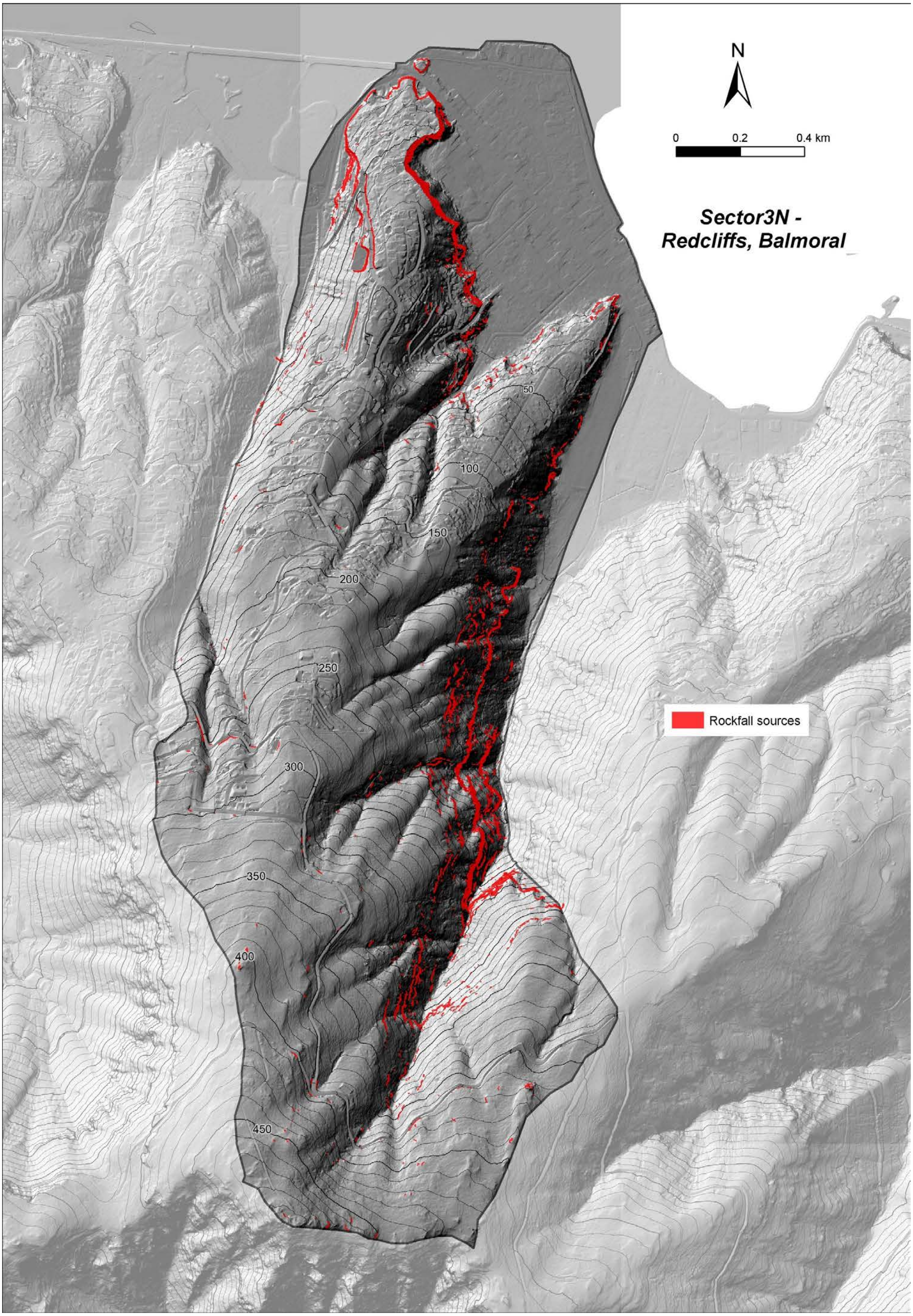

N
0
0.2
0.4 km
Sector3N -
Redcliffs, Balmoral
50
100
150
200
250
300
350
400
450
Arrested blocks
Fallen blocks


N
0
0.2
0.4 km
Sector3N -
Redcliffs, Balmoral
50
100
150
200
250
300
350
400
450
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
Sector3N -
Redcliffs, Balmoral
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
450



N
0
0.2
0.4 km
Sector3N -
Redcliffs, Balmoral
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
450


N
0
0.2
0.4 km
Sector3N -
Redcliffs, Balmoral
Rockfall sources
50
100
150
200
250
300
350
400
450