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Appendix F – Sector 6 Modeling Results

Sector 6 Lyttelton

1. Site Description

The town of Lyttelton is located approximately mid-way down Lyttelton Harbour on the northern side and houses the local port facilities. The main route in and out of the township is via the Lyttelton tunnel which suffered only slightly during the 2011 earthquakes. Alternative routes were badly affected with some still remaining closed.

The slopes surrounding the township are steep, upwards of 20 degrees, and covered in numerous bluffs and rock outcrops. Many of the slopes are vegetated to varying degrees with a mixture of light scrub and mature natives. Some areas of mature forest are also present.

The area considered in this report is shown Figure 1 below, with an area in excess of 6km^2.

Figure 1 - Sector 6 site location showing the study area within yellow outline

The slopes behind Lyttelton rise steeply from sea level up to in excess of 450mRL in elevation and are typically between 30˚ to 45˚. The predominant source of rock fall comes from a series of steep, near vertical cliff faces that extend almost the entire way round the back of Lyttelton.

2. Geotechnical Environment

As with many of the other sectors the area is typified by steep basalt cliffs along the crest and upper part of the slopes, with lesser amounts of bluffs and outcrops further down slope. However as Sector 6 is within the Lyttelton Volcano (on the inside of the crater) the slopes are generally much steeper and contain many more bluffs and areas with outcrop. 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 2.2m3 with a maximum volume of 32m3. 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 Lyttelton area originates predominantly from the main bluffs located towards the top of the slopes, while there are also a number of outcrops and bluffs mid slope at approximately 150mRL and 200mRL.

Lyttelton is located directly south of Sector 5 and is also potentially affected by rockfall from the summit area of Mount Pleasant, as discussed in Sector 5. However analysis of rockfall from this area shows that due to the distance from source to populated area these upper rock slopes have little impact on Lyttelton's 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.

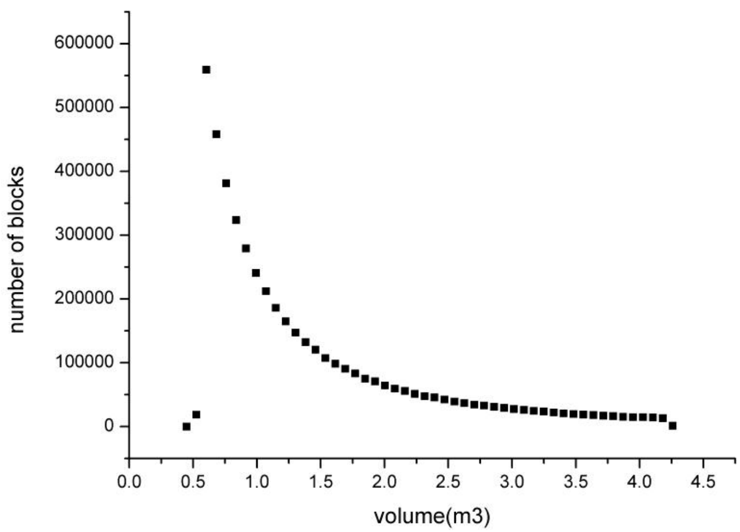
5. Modeling Results

The entire Sector 6 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.

The modelling has shown that the majority of boulders originate from very high up on the slopes. They have bounce heights in the order of 1-2m and energies typically between 200kJ and 1500kJ. Maximum energies are up towards 3500kJ while maximum bounce heights are shown exceeding 10m. In some areas is a realistic representation however in many areas the high bounce heights shown in Appendix A are likely due to the large bluffs in this area misrepresenting rock drop as rock bounce.

While there is extensive rockfall in the Lyttelton area the modelling has shown that many of the boulders only travel 2-300 vertical metres before coming to rest. This is of interest due to the fact that many of the source areas are in excess of 300m above populated areas. This is obvously not the case in all areas.

The model shows the worst affected areas are those around Cressy and Brittan Terraces in the west, Dalleys Lane and Hawkhurst Road in the central area and Foster Terrace to the east.

As with other sectors gullying is quite widespread, however given the scale and extent of the large source areas located at height around the crater rim many of the slopes are extensively affected by rockfall.

In general 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 6 we had three major constraints to consider:

1. **Scale** – Sector 6 is over $6km^2$ 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 around 20% of the study area requiring 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 moderately densely populated with nearly 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 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.

For Sector 6 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.

Table 2 - Recommended Barriers for Sector 6

Sector (#)	Barrier (ETAG27)	Rating (kJ)	Height (m)	Length (m)
6	1	2000	4	397
	2	3000	5	210
		2000	4	120
		1000	3	88
	3	3000	5	55
	4	5000	6	70
		3000	5	38
	5	5000	6	80
		8000	7	30
		5000	6	55
	6	1000	3	60
		3000	5	130
		2000	4	40
		3000	5	86
	7	1000	3	90
		2000	4	60
		5000	6	70
		2000	4	96
	8	2000	4	95
	9	2000	4	160
	10	2000	4	80
		5000	6	40
		8000	7	260
		5000	6	90
		8000	7	30
		5000	6	65
	11	5000	6	30
		2000	4	106
	12	3000	5	40
		5000	6	30
		3000	5	58
	13	5000	6	93
	14	1000	3	90
		2000	4	70
	15	3000	5	70
		2000	4	60
		5000	6	55
	16	2000	4	50
		3000	5	47
	17	2000	4	70
		3000	5	30
		2000	4	39
	18	2000	4	120
		3000	5	30
		2000	4	238
	19	2000	4	72
	20	0	0	140
	21	1000	3	127
	22	500	3	60
		2000	4	30
		500	3	97
	23	2000	4	140
		3000	5	140
		2000	4	180
		3000	5	160
		2000	4	36

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Figure 2 - Recommended Location of Rockfall Barriers

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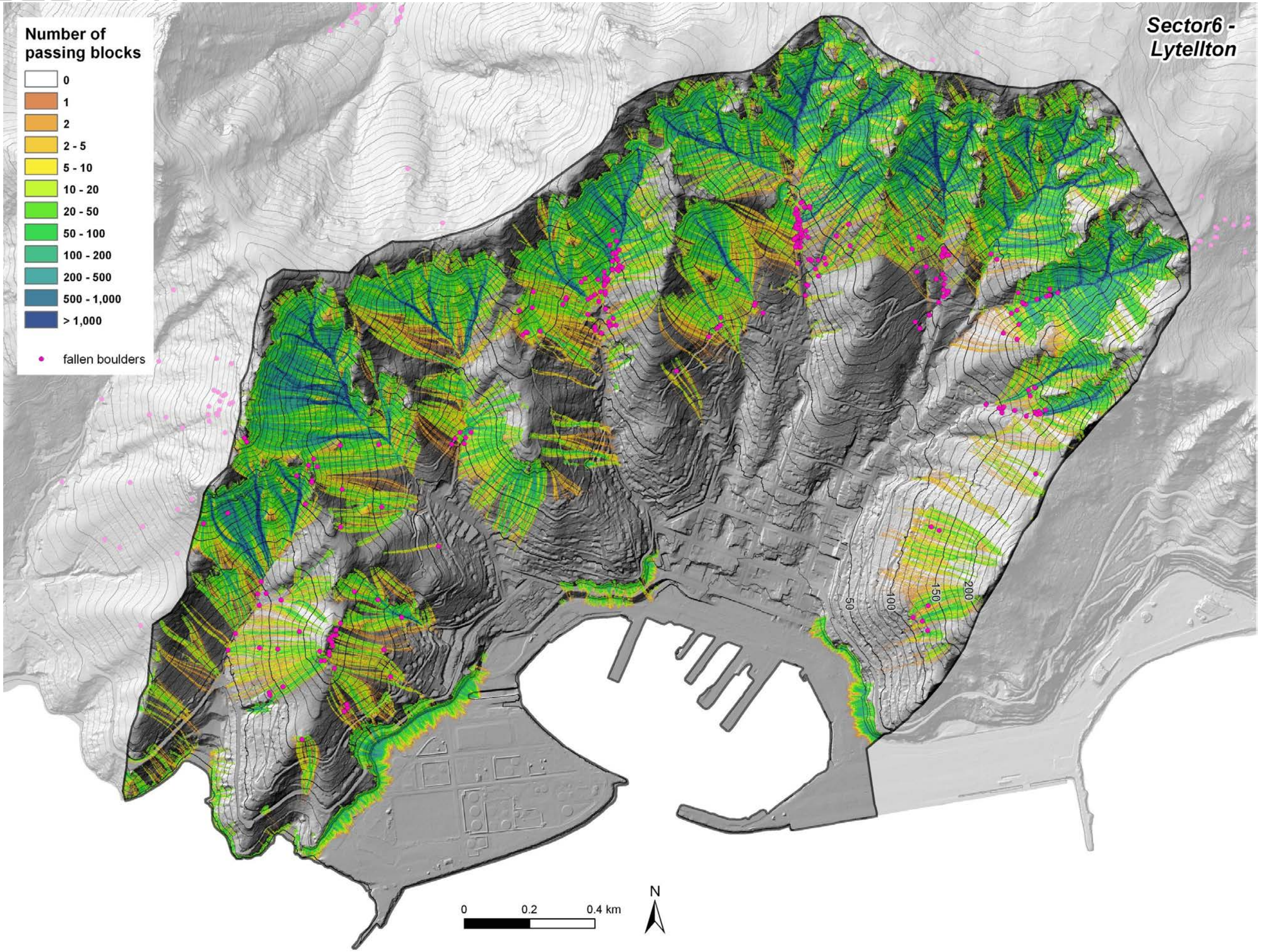
Sector6 -
Lytellton
Number of
passing blocks
0
1
2
2 - 5
5 - 10
10 - 20
20 - 50
50 - 100
100 - 200
200 - 500
500 - 1,000
> 1,000
fallen boulders
50
100
150
200
0
0.2
0.4 km
N

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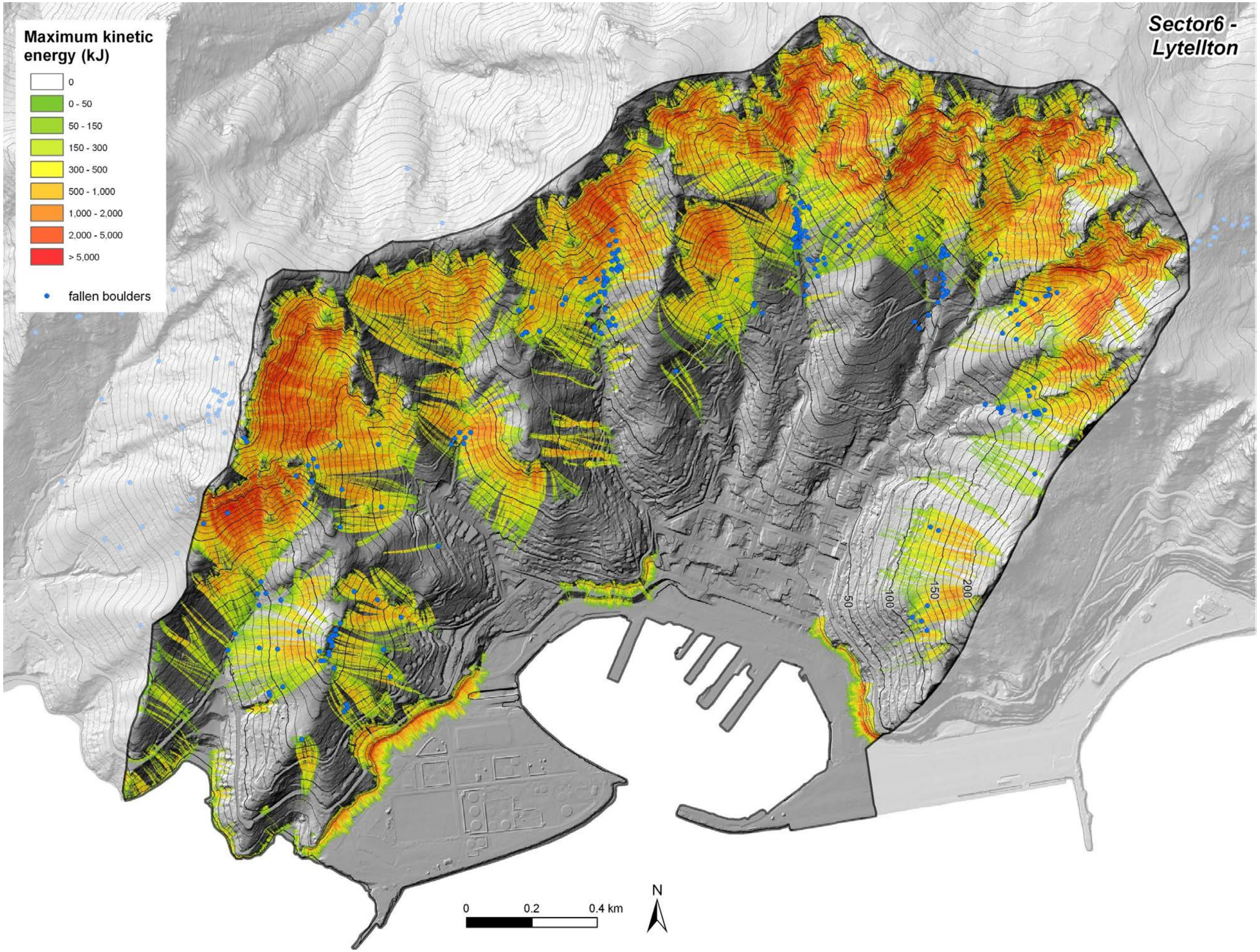

Maximum kinetic energy (kJ)
0
0 - 50
50 - 150
150 - 300
300 - 500
500 - 1,000
1,000 - 2,000
2,000 - 5,000
> 5,000
fallen boulders
Sector6 - Lytellton
50
100
150
200
0
0.2
0.4 km
N

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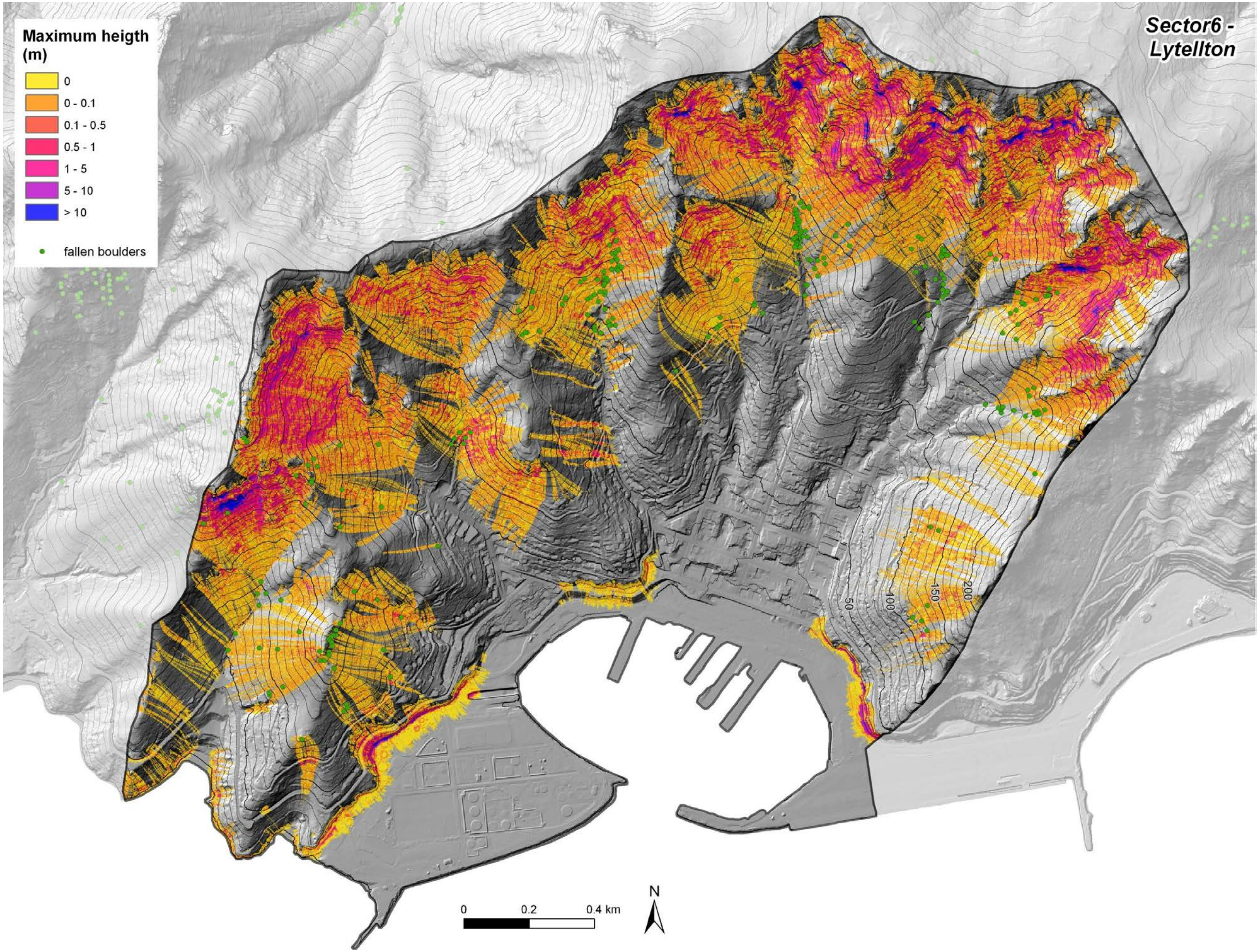

Sector6 -
Lytellton
Maximum heigth
(m)
0
0 - 0.1
0.1 - 0.5
0.5 - 1
1 - 5
5 - 10
> 10
fallen boulders
50
100
150
200
0
0.2
0.4 km
N

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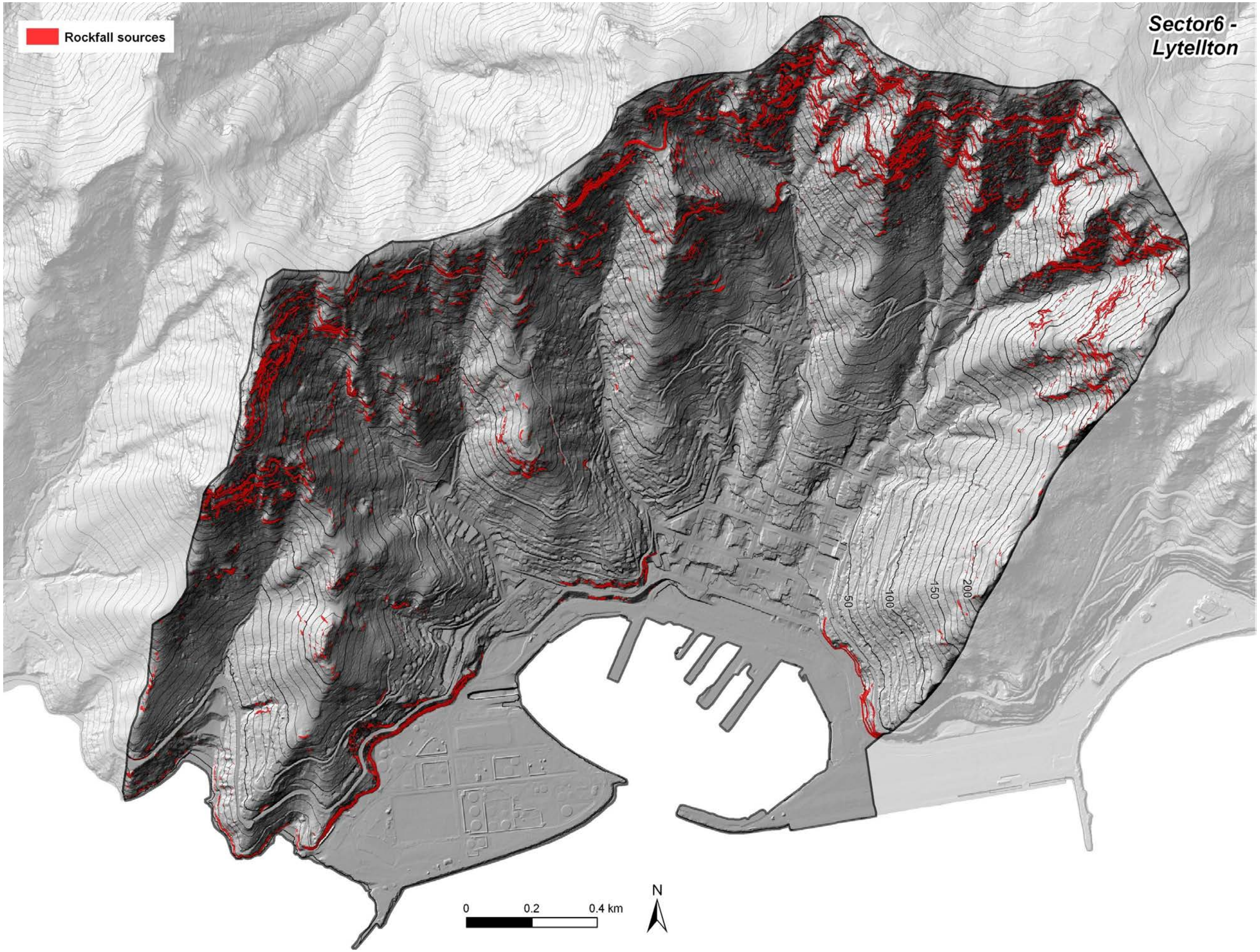

Rockfall sources
Sector6 -
Lytellton
50
100
150
200
0
0.2
0.4 km
N