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Appendix A – Sector 1 Modeling Results

Sector 1 Heberden Avenue

1. Site Description

Sector 1 is located on the eastern side of Sumner and is predominantly affected by rockfall from westerly facing steep slopes with multiple bluff features. Taylors Mistake is surrounded on three sides by steep slopes. Other than the area immediately above Heberden Ave, which has a strip of mature pine trees, the slopes are typically covered in grass and tussocks. While Taylors Mistake is sparsely populated (mainly on the shores of the bay) the area around Heberden Ave is a high density residential area.

The area considered in this report is shown in Figure 1 below, an area in excess of 7km2.

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

The slopes east of Heberden Ave rise steeply from near sea level up to in excess of 300m in elevation and are typically between 25˚ to 45˚. The predominant source of rock fall comes from a series of near vertical cliff faces that run the majority of the length of Heberden Ave. The main bluff feature is intermittent but generally located at approximately 100mRL (slightly lower than mid slope) and is up to 15m high at its highest point.

The Taylors Mistake area is mostly affected by a series of smaller bluffs on the western side of the bay.

2. Geotechnical Environment

The area is characterized by basalt cliffs along the mid part of the slopes, with lesser amounts of bluffs and outcrops further up and down slope. 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.

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 0.9m3 with a maximum volume of 100m3. 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 other smaller outcrops located sporadically over the slopes. While these contribute to the main rockfall hazard in this area they have 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.

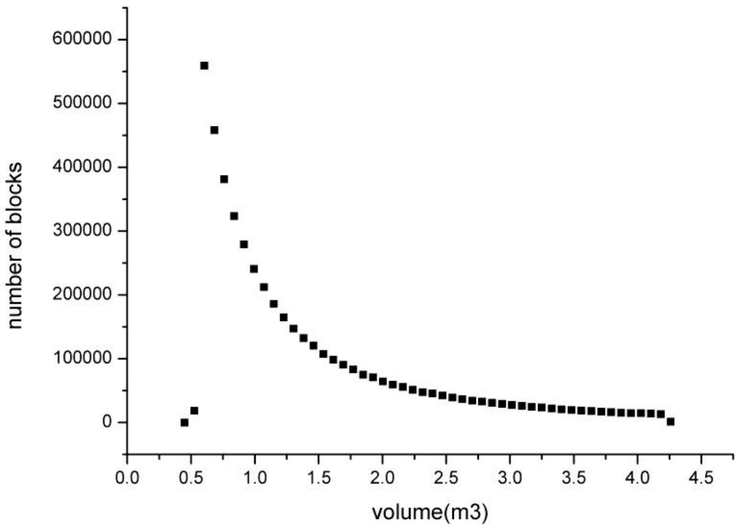
5. Modeling Results

The entire Sector 1 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 m^3 and a maximum boulder size of 4.25 m^3. 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.

Analysing the results for Sector 1 shows that the model is replicating quite accurately the results as mapped in the field by the PHGG. For the southern end of Heberden Ave the boulder runouts are reaching well into La Mar Lane, Awaroa Lane and Ocean View Terrace. While actual boulder runouts are controlled by a thick line of mature pine trees the 3D model is greenfield which is why some boulders are running further downslope than has been recorded in the field.

The northern end of Heberden Ave is at risk more of cliff collapse than rock fall and as such the results of the 3D model will not be discussed here. This is the same for areas of Lyttelton, Redcliffs and other cliff areas.

The rockfall issue in Taylors Mistake is restricted to the slopes themselves and very base area only. Runouts onto flat ground are rare.

Boulder energies are typically between 100kJ and 4000kJ with some localised areas of higher energy (>4000kJ). Bounce heights are typically low (<1.5m) but with localised areas of greater heights. These are normally where boulders drop over small vertical bluffs.

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 shown below. The gullying has a positive effect for 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 1 we had three major constraints to consider:

1. **Scale** – Sector 1 is over 7km^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 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 locally 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 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 1

Sector (#)	Barrier (ETAG27)	Rating (kJ)	Height (m)	Length (m)
1	1	3000	8	150
		5000	8	70
		2000	6	140
		1000	3	35
	2	1000	3	71
	3	3000	6	120
		2000	4	150
		5000	7	40
		5000	7	50
		3000	5	73
	4	3000	5	130
		5000	7	50
		3000	5	350
		5000	6	160
		3000	5	164
	5	3000	5	70
		2000	4	120
	6	3000	5	70
		5000	8	120
		2000	4	465

For Sector 1 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 subject to the availability of suitable land.

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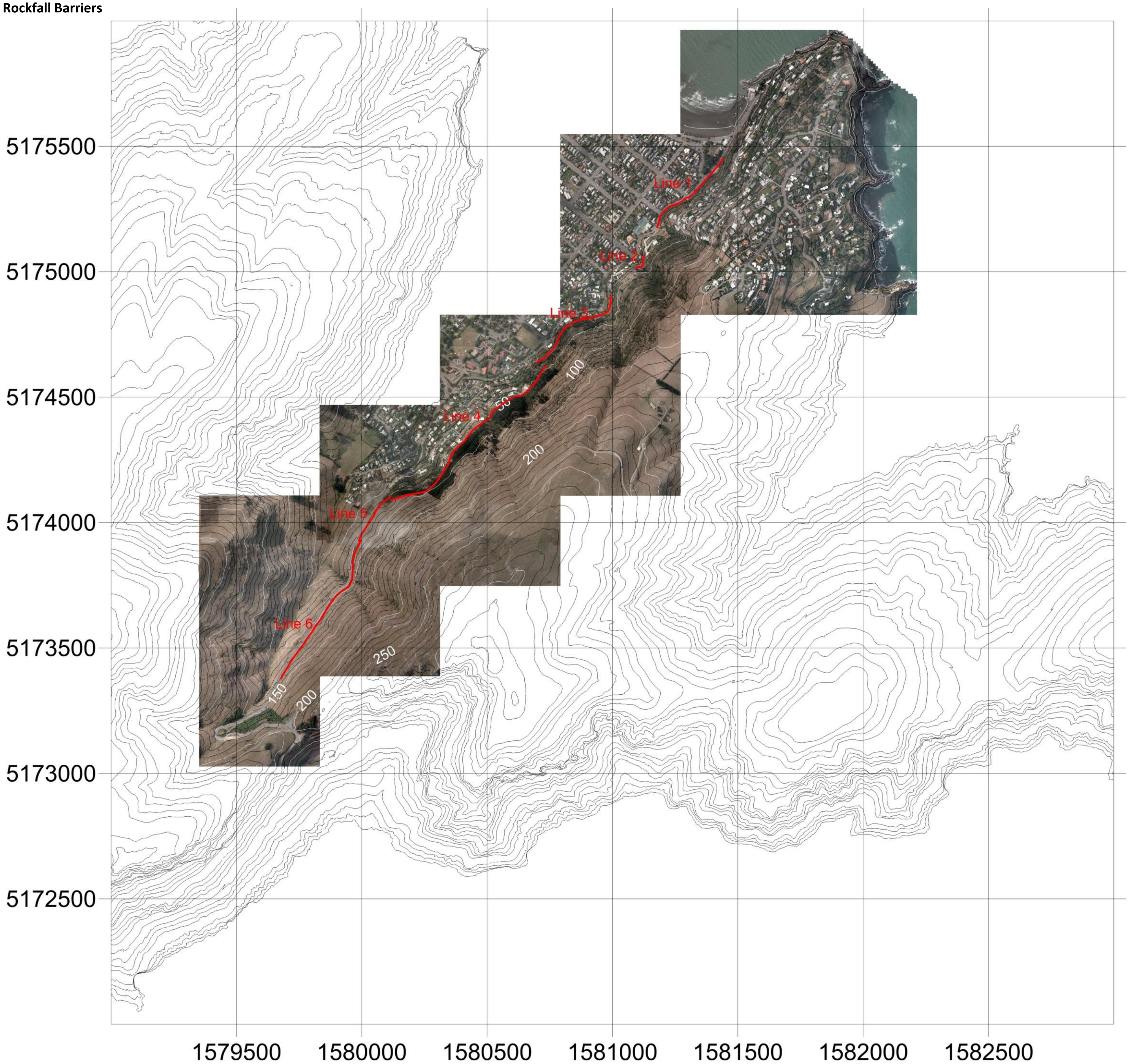
Figure 2 - Recommended Location of Rockfall Barriers



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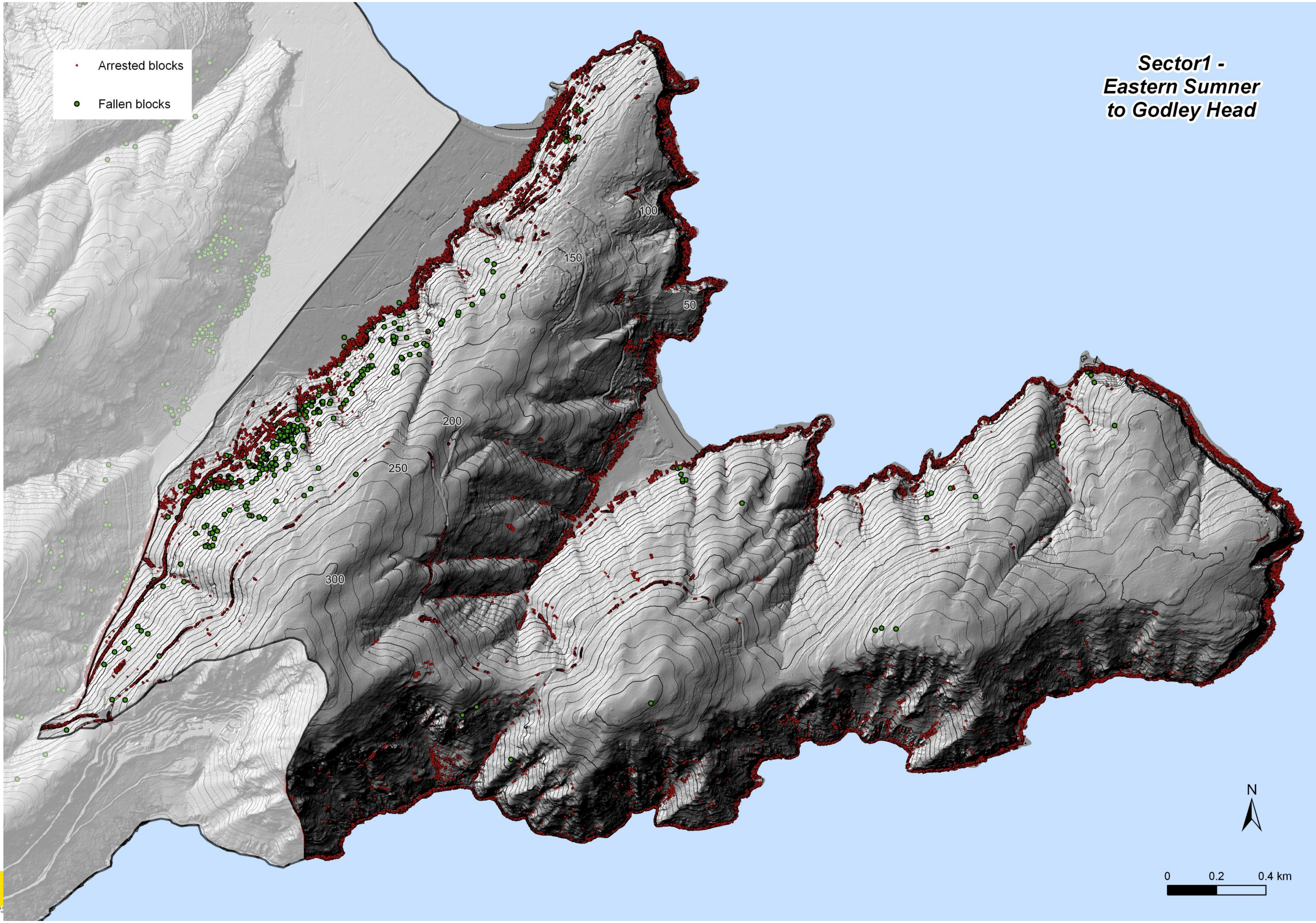

Arrested blocks
Fallen blocks
Sector1 -
Eastern Sumner
to Godley Head
100
150
50
200
250
300
N
0
0.2
0.4 km

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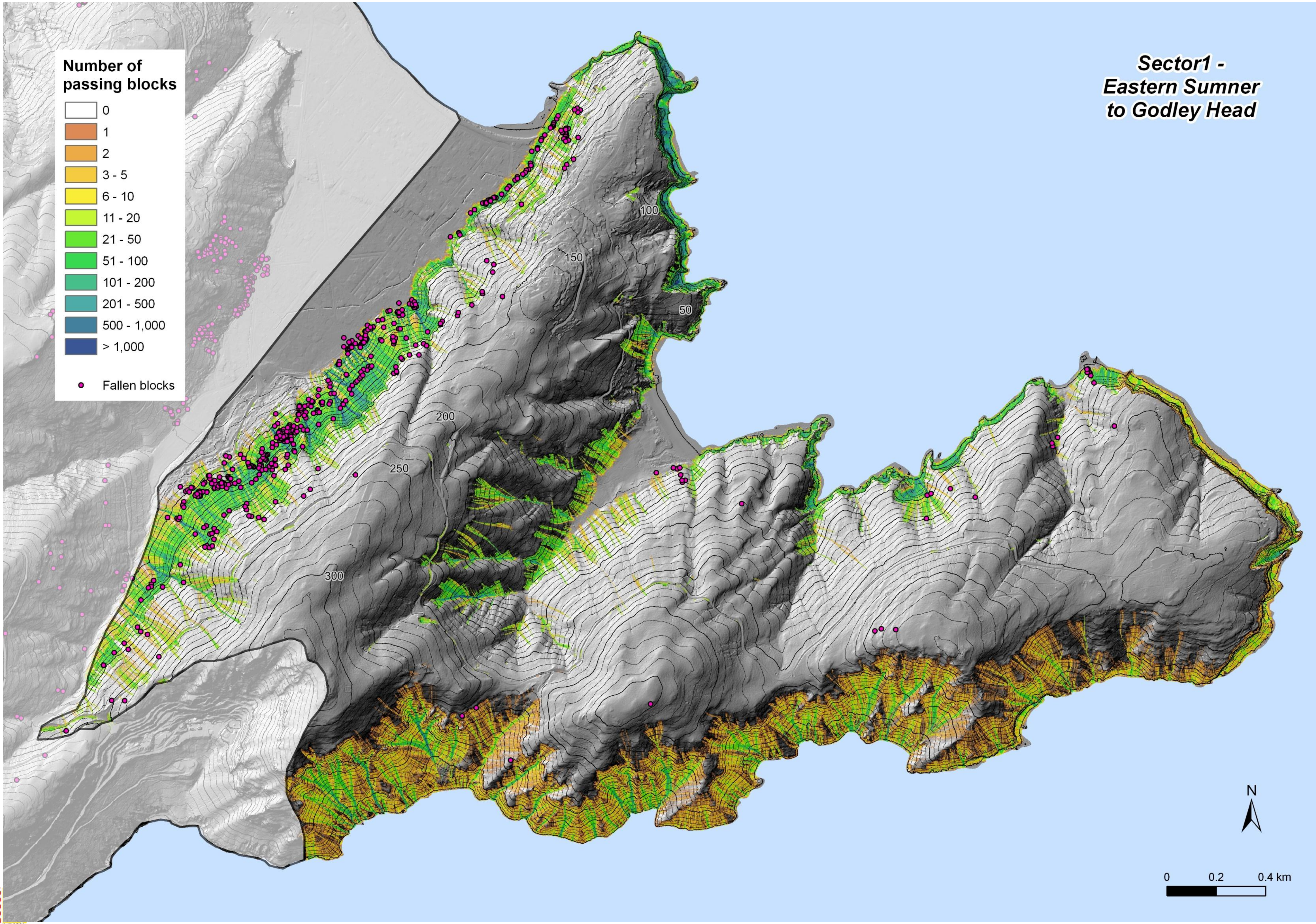

Number of passing blocks
0
1
2
3 - 5
6 - 10
11 - 20
21 - 50
51 - 100
101 - 200
201 - 500
500 - 1,000
> 1,000
Fallen blocks
Sector1 -
Eastern Sumner
to Godley Head
100
150
50
200
250
300
N
0
0.2
0.4 km

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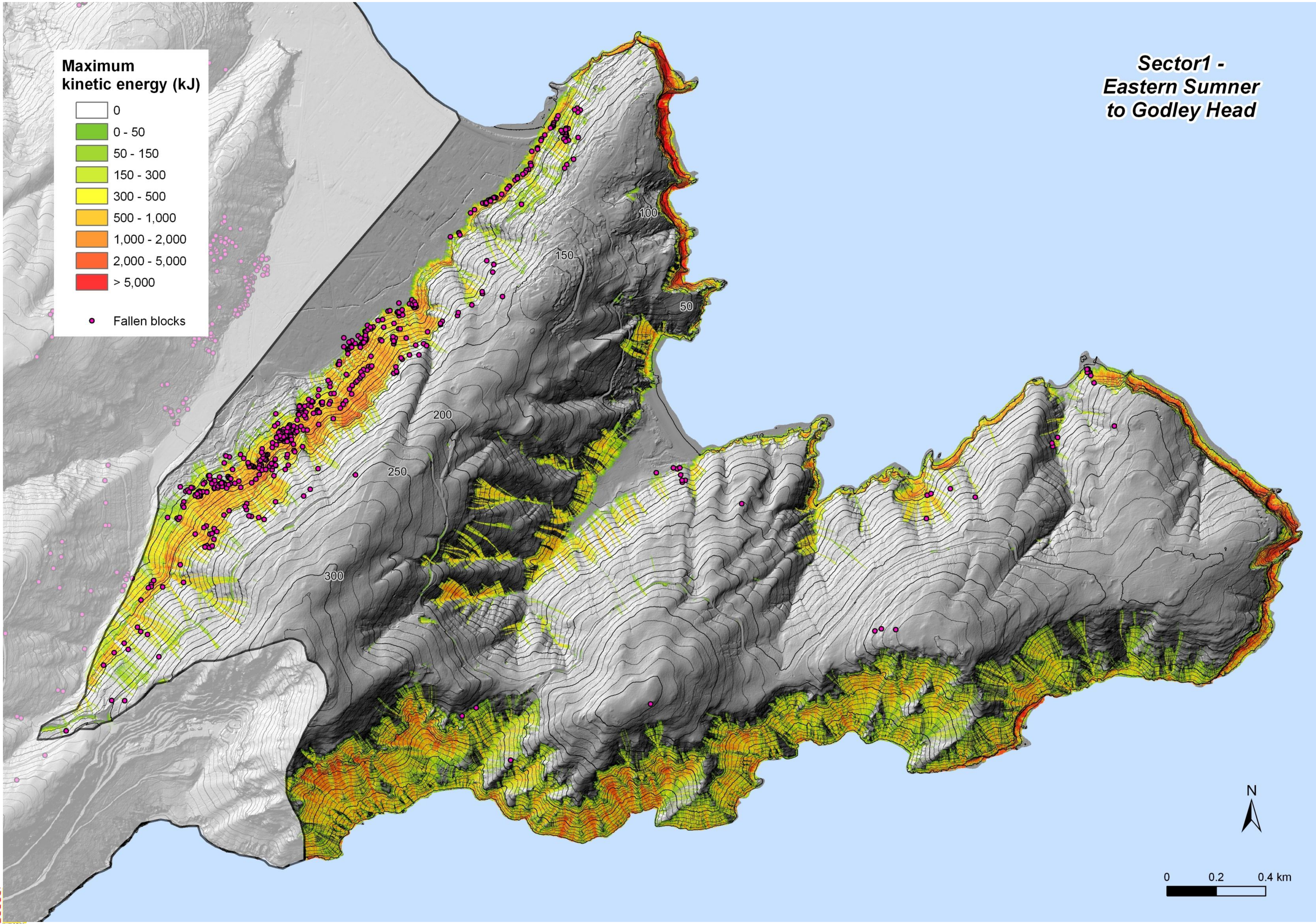

Maximum kinetic energy (kJ)
0
0 - 50
50 - 150
150 - 300
300 - 500
500 - 1,000
1,000 - 2,000
2,000 - 5,000
> 5,000
Fallen blocks
Sector1 - Eastern Sumner to Godley Head
100
150
50
200
250
300
N
0
0.2
0.4 km

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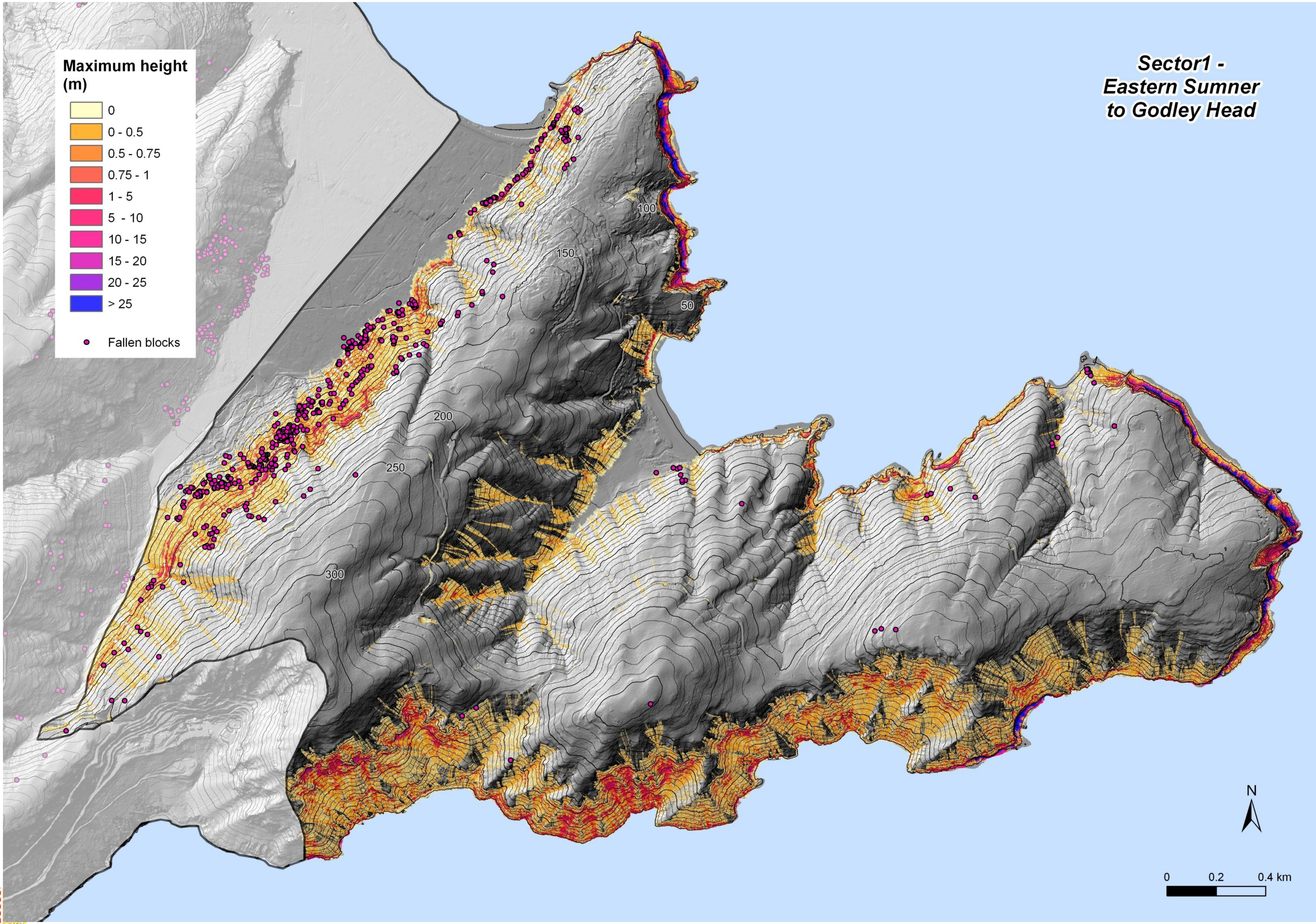
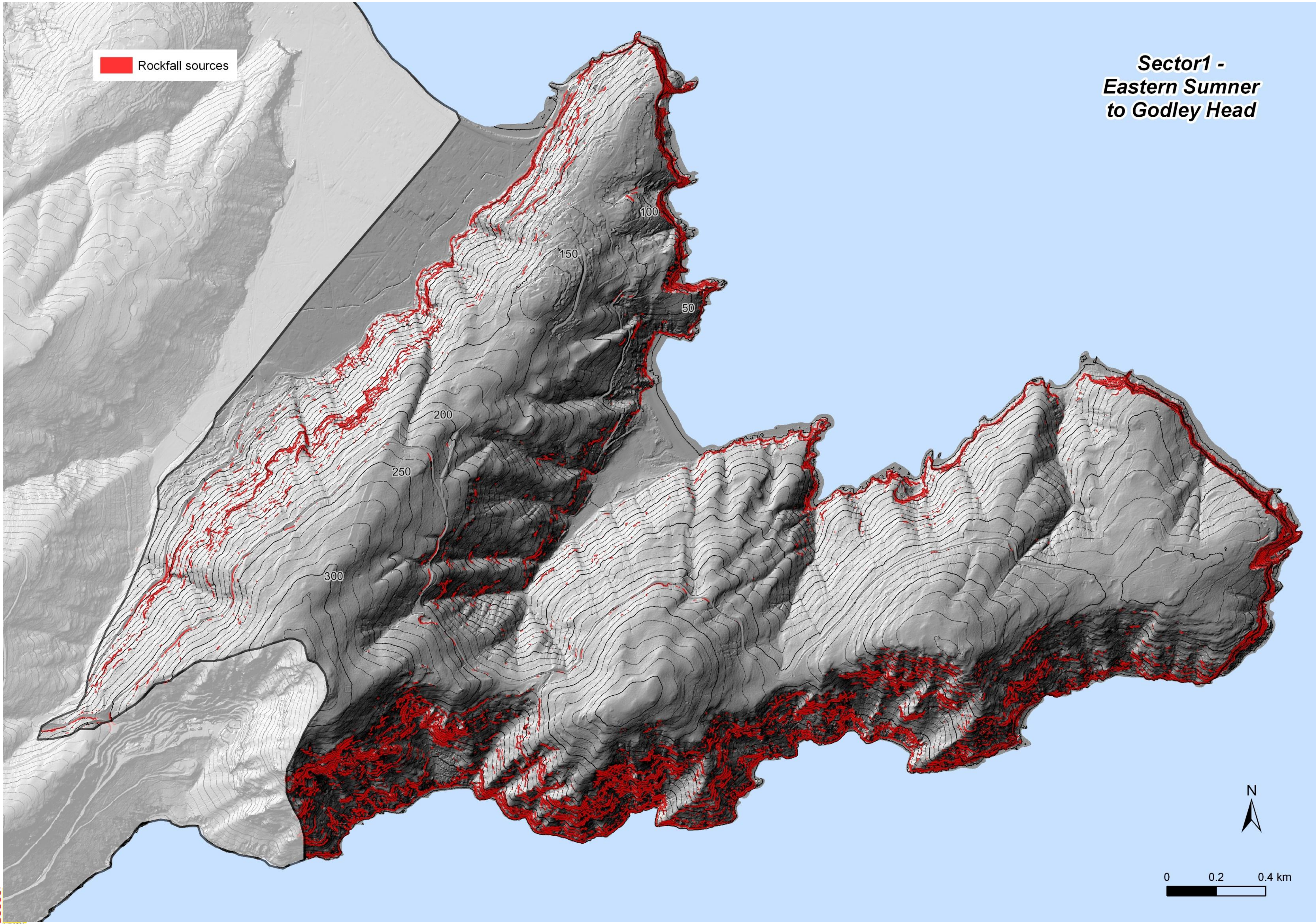


Sector1 -
Eastern Sumner
to Godley Head
Maximum height
(m)
0
0 - 0.5
0.5 - 0.75
0.75 - 1
1 - 5
5 - 10
10 - 15
15 - 20
20 - 25
> 25
Fallen blocks
100
150
50
200
250
300
N
0
0.2
0.4 km


Rockfall sources
Sector1 -
Eastern Sumner
to Godley Head
100
150
50
200
250
300
N
0
0.2
0.4 km