

## Appendix B – Sector 2 Modeling Results

## Sector 2 Wakefield Avenue

### 1. Site Description

Wakefield Ave forms the western margin of Sumner Bay area, with the rockfall issue arising from the slopes west of Wakefield Ave. The eastern side of Moncks Bay, immediately west of Wakefield Ave, is affected by rockfall from the northern side of the same ridge affecting Wakefield Ave. At both sites the hazard arises as a result of the large number of houses at the base of the slopes, with Wakefield Ave also a Government designated lifeline route.

The area considered in this report for both sites (eastern and western) is shown in Figure 1 below, an area in excess of 4km<sup>2</sup>.

**Figure 1 - Sector 2 site location showing the study area within yellow outline**



The slopes west of Wakefield 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 Wakefield Ave. The main bluff feature is located at approximately mid slope and is up to 20m high at its highest point.

The eastern side of Moncks Bay is mostly affected by a series of smaller bluffs and outcrops scattered over much of the upper slopes. These outcrops have released a number of large boulders during recent ground shaking events. This site has fewer houses at risk of rockfall however the energies of falling boulders in this area are significant.

## 2. Geotechnical Environment

The area is characterized by basalt cliffs along the crest and upper part of the slopes, with lesser numbers 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. We have used these areas as 'seed' areas, or source areas for our modelling. 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 & 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  $0.7\text{m}^3$  with a maximum volume of  $11\text{m}^3$ . 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 main summit area however analysis of these upper rock slopes 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 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

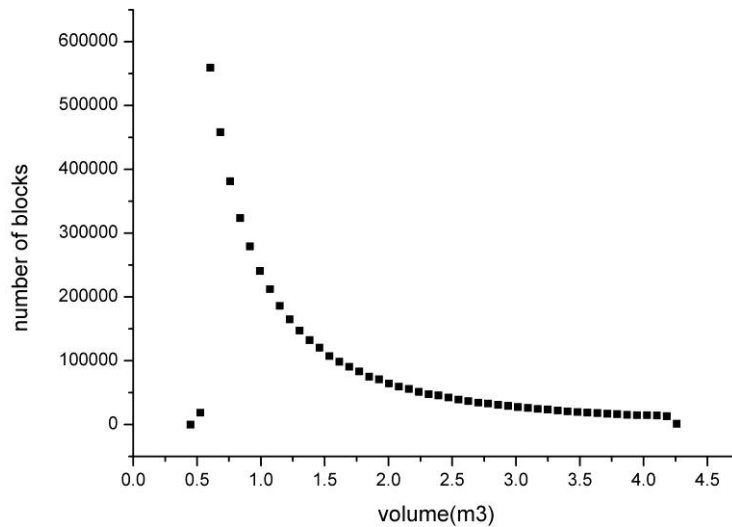
The entire Sector 2 was modeled in 3D using HyStone. The results of this modeling are shown here. In order to check the model for accuracy reasons 2D rockfall modeling was also carried out in some areas. For the purpose of the modeling all vegetation has been completely removed from the ground model. 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<sup>3</sup> and a maximum boulder size of 4.25 m<sup>3</sup>. 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 2.0m in height, other than a few areas where they exceed 5m however this is likely the model showing boulders falling over vertical bluffs. The relatively low bounce heights are 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 Wakefield Ave vary along the length of the study site and range between 100kj to 2000kj with one short section of 5000kj. The highest velocities are recorded around Duncan, Truro and Paisley Streets. For Moncks Bay the highest velocities and bounce heights have been recorded between Cliff Street and Main Road.

An interesting output from the modeling is the extent of gulying 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 gulying 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 platy 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 2 we had three major constraints to consider:

1. **Scale** – Sector 2 is over 5km<sup>2</sup> 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 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 2. 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 2**

Sector (#)	Barrier (ETAG27)	Rating (kJ)	Height (m)	Length (m)	
2	1	2000	4	40	
		1000	3	32	
	2	1000	3	100	
		2000	4	27	
	3	2000	4	50	
		1000	3	60	
		300	7	100	
	4	2000	4	21	
			4	76	
		5	2000	4	50
			5000	6	70
6		2000	4	110	
			1000	3	36
		1000	4	60	
	3		190		
7	2000	4	110		
		3	48		
	2000	4	113		
8	1000	3	60		
		4	50		
9	1000	3	47		
		4	30		
10	5000	7	100		
		7	100		
	2000	5	99		

For Sector 2 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

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availability of suitable land. In all cases the estimated cost for enabling earthworks is prohibitive compared to barrier installation.



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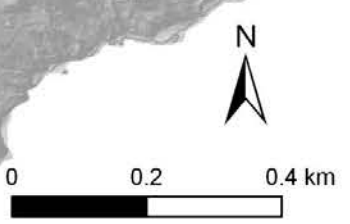
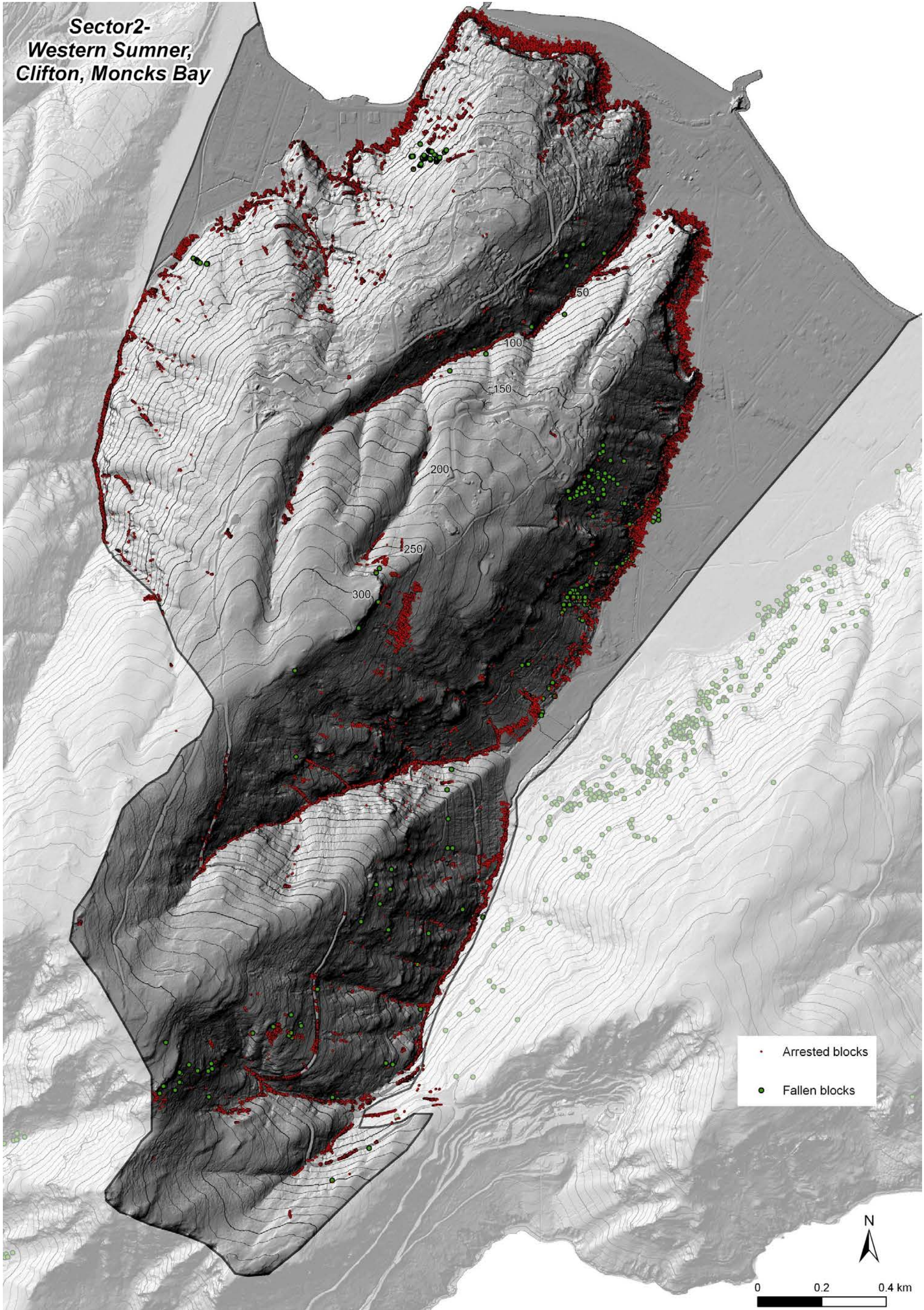


Figure 2 - Recommended Location of Rockfall Barriers





**Sector2-  
Western Sumner,  
Clifton, Moncks Bay**

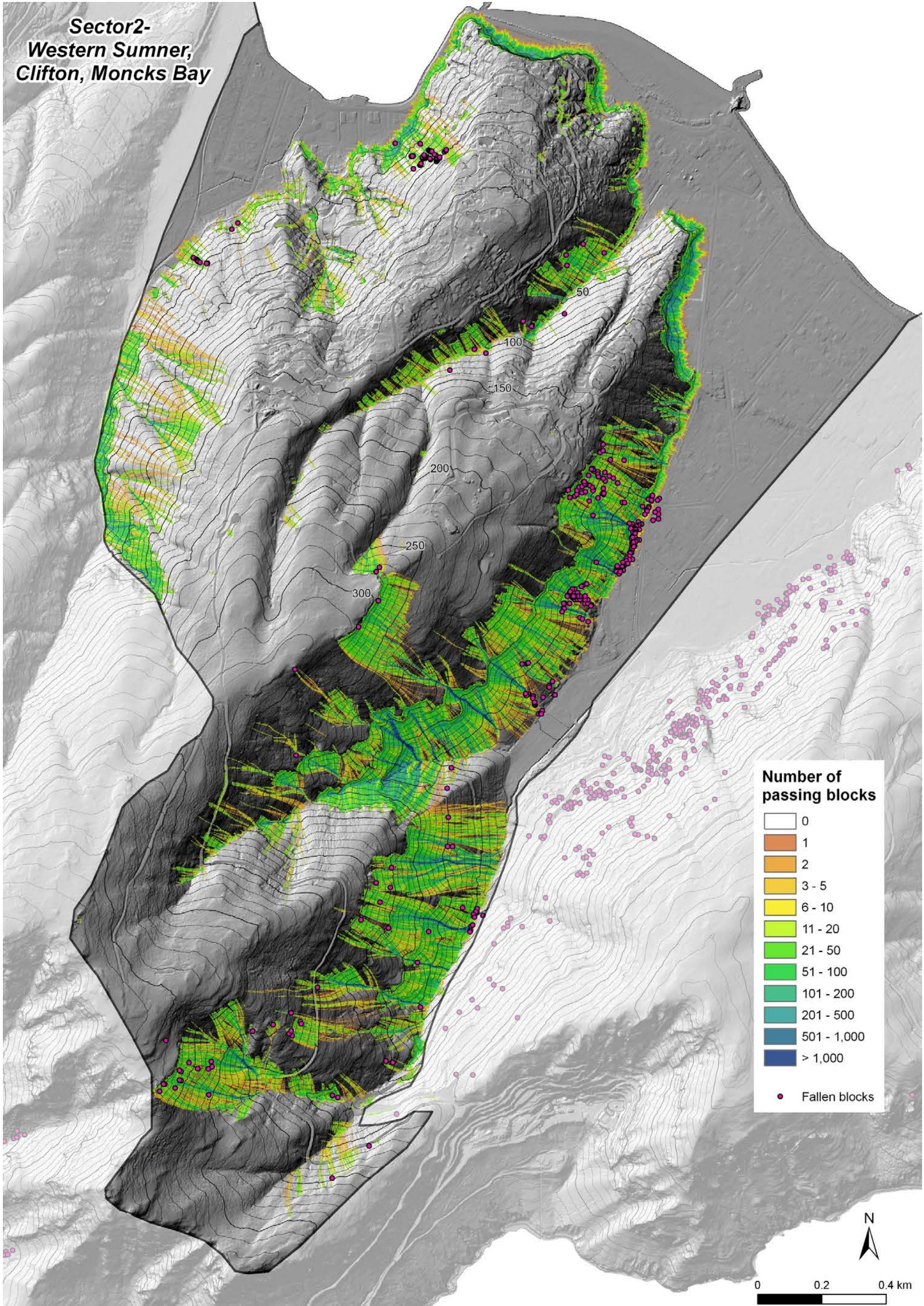






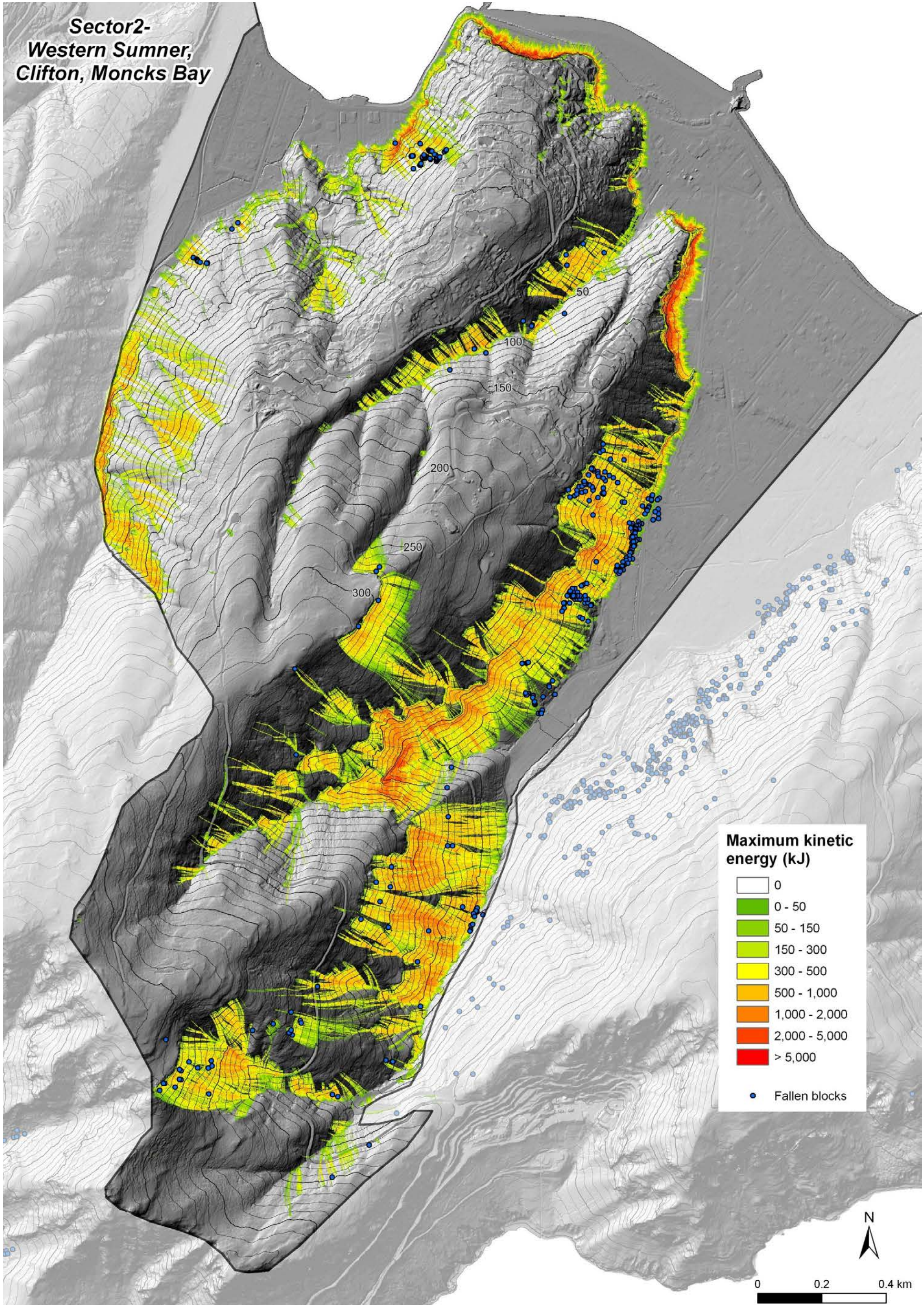


**Sector2-  
Western Sumner,  
Clifton, Moncks Bay**





**Sector2-  
Western Sumner,  
Clifton, Moncks Bay**



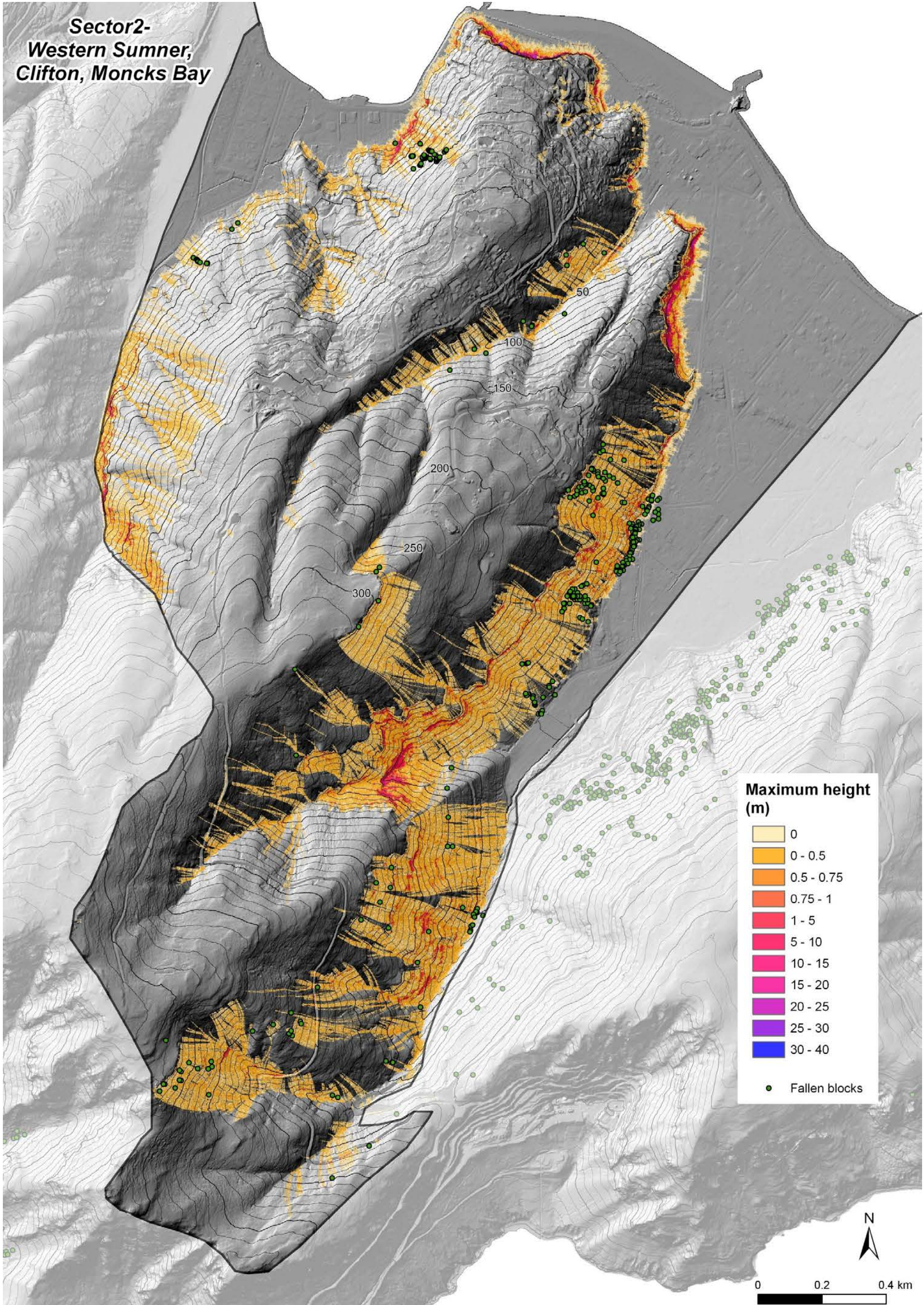
**Maximum kinetic energy (kJ)**

- 0
- 0 - 50
- 50 - 150
- 150 - 300
- 300 - 500
- 500 - 1,000
- 1,000 - 2,000
- 2,000 - 5,000
- > 5,000

• Fallen blocks



**Sector2-  
Western Sumner,  
Clifton, Moncks Bay**





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Western Sumner,  
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