Boulder Hazards Study - Phase 2A
Boulder Hazard Inventory for A83 Beinn Luibhean

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Boulder Hazards Study - Phase 2A

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Contents

1. Introduction

1.1 Background

This report presents an inventory of boulders on the slopes of Beinn Luibhean that pose a hazard to the A83 on the westbound approach to the Rest and be Thankful viewpoint in Scotland. This section of road is located within Glen Croe, a steep sided glaciated valley that has a history of hillside instability, in particular on the SW-facing slopes of Beinn Luibhean. Closure of this section of road following landslides and boulder fall incidents results in traffic delays and has wider socio-economic costs across the Argyll and Bute region due to the A83 being the main link between the region and the central belt of Scotland.

While methodologies to assess rock fall hazards and landslide hazards are widely available, there have been few studies relating to hazards posed by individual boulders resting on the hillside. In recognition of this, Scottish Road Research Board (SRRB) commissioned a research project in 2019 to develop a boulder hazard assessment methodology using a 7.1Ha (71,000m^2) trial site on Beinn Luibhean, with the intention that the methodology could be used or adapted for other sites on the road network where boulders are identified as a potential hazard.

In developing the boulder hazard assessment methodology, analysis of boulder run-out paths using specialised fall path modelling software was undertaken to determine the boulder and hillside characteristics that are most likely to affect the run-out distances of boulders released from the slope, and thus the likelihood of boulders impacting the A83. The key results from the analysis were in line with those of previous authors, highlighting the significance of boulder shape on run-out trajectory (e.g. flat boulders are more likely to be stopped by surface depressions than round boulders). Other parameters found to have an impact on run-out trajectory include slope characteristics (i.e. hardness of the ground) and boulder volume.

The developed hazard assessment methodology requires data on boulder properties (approximate dimensions and shape) as well as observations on the terrain surrounding the boulder that could increase the likelihood of boulder mobilisation (e.g. evidence of hillside instabilities such as tension cracks or erosion). A series of matrices then score these observations in terms of:

- The likelihood of a boulder being mobilised from the slope
- The likelihood of a mobilised boulder continuing downslope and impacting the A83; and
- The potential effects to the A83 depending on the impact intensity (i.e. size of the boulder).

A detailed description on the application of the boulder hazard assessment methodology is provided in Section 2.

Following development of the methodology, including fieldwork to determine typical boulder and hillside characteristics, the hazard assessment methodology was applied to over 450 boulders within the trial area. It was found that the majority of the boulders (83.3%) were classified as Low hazard, with 14.5% and 2.2% classified as Medium and High hazard, respectively. This initial research project with the aim of developing the hazard assessment methodology was completed in 2020 and the report is available to view on the SRRB website (https://www.transport.gov.scot/media/50981/boulder-hazard-study-report-scottish-road-research-board.pdf).

Following on from the initial research project, SRRB commissioned a second phase of works (Phase 2a) to expand the inventory of boulders across the remainder of the SW facing hillside on Beinn Luibhean, encompassing a total area of approximately 80.7Ha (807,000m^2). The data compiled will provide Transport Scotland and the Trunk Road Operating Company with sufficient information to consider the hazards posed by boulders with respect to the maintenance and safe operation of the A83 Trunk Road in Glen Croe.

The location of the trial area and the wider study area are provided in Figure 1-1 overleaf.

1.2 Objectives

The objectives of this commission are to:

- Compile an inventory of boulders across the 80.7Ha study area on the SW facing slope of Beinn Luibhean.
- Undertake a hazard assessment for the boulders identified using the hazard matrix developed in Phase 1 of the Boulder Hazard Study.
- Provide a photo-identification appendix of boulders rated as High hazard so that these boulders can be easily identified on site.

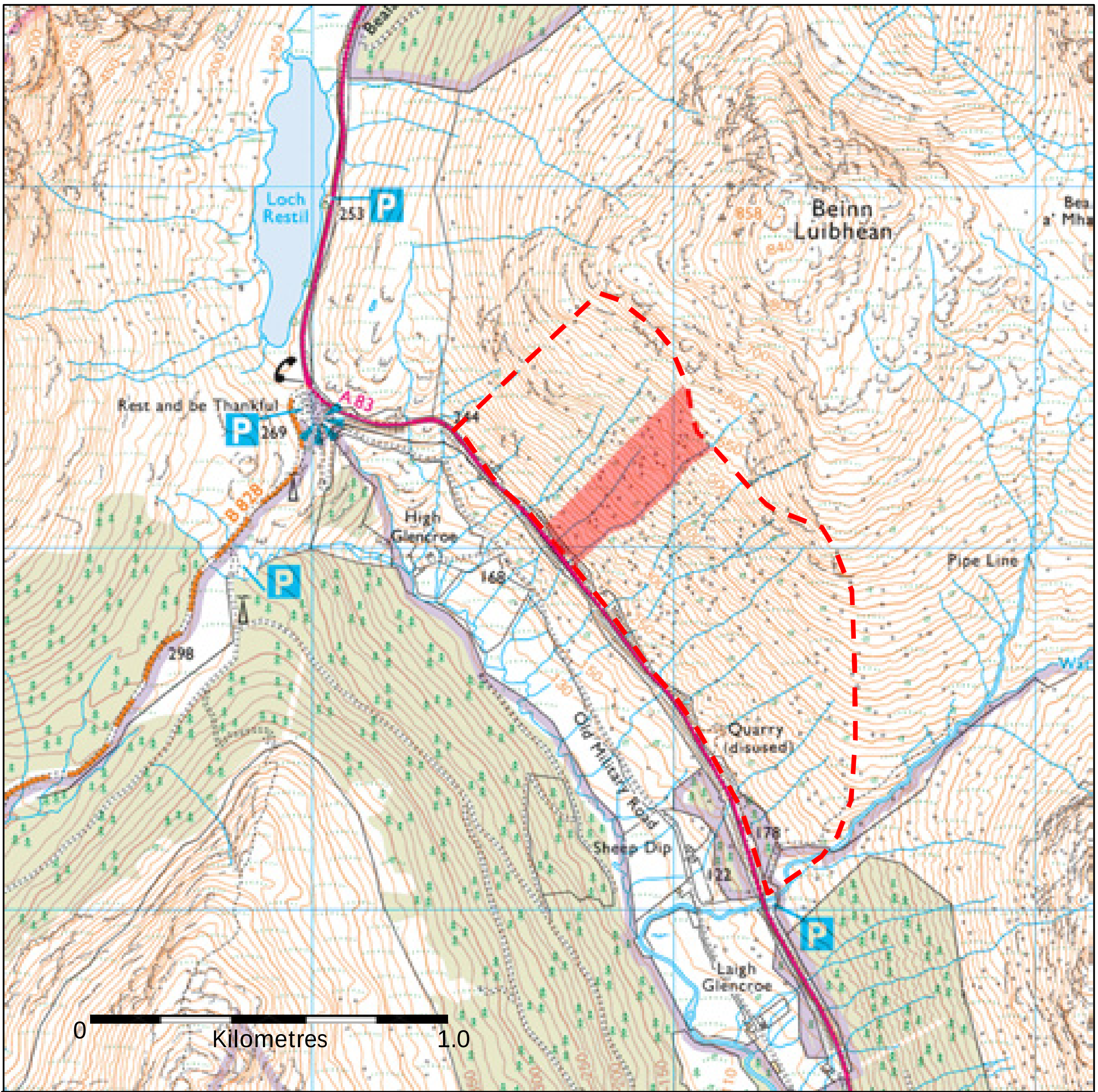


Figure 1-1 Plan showing the trial area (red shading) and the wider study area (red dashed line)

1.3 Project Assumptions, Limitations and Constraints

The scope of this commission examines hazards associated with discrete boulder falls and as such does not consider boulders that are mobilised during debris flow events (i.e. that become entrained within debris flow material). The hazard and risks associated with debris flows and suggested methodologies relating to the assessment of these are widely discussed in other literature (e.g. Lee and Jones 2014, Winter et al 2009, Winter and Wong, 2020).

The scope of this commission is to provide details of hazard assessment only. Risk assessment in relation to the boulder hazards identified on Beinn Luibhean is not within the scope of this study.

The Old Military Road (OMR) is located below the A83 and is often used as a diversion route during periods of trunk road maintenance, or when the A83 is closed due to failure events or an elevated likelihood of such. A small area of natural terrain containing a number of discrete boulders lies between the A83 and the OMR. However, this area of slope is outwith the study area, and as such the hazards associated with boulder fall originating from this area that could affect the OMR have not been considered in this report.

From previous studies, it is known that there are a significant number of boulders on the hillside, ranging in size from 0.3m in one dimension, to in excess of 8m in one dimension. In order to make the fieldwork and subsequent data processing more manageable, boulders with a maximum dimension of <1.0m were excluded from the scope of this study. This decision was supported by the results of the detailed fall path modelling in Phase 1, which suggest that due to lower kinetic energy values and higher likelihood of stopping in surface depressions, small rocks tend to have significantly shorter run-out distances than large rocks.

A number of mitigation measures including debris barriers and catch pits have been constructed immediately above the A83 with the aim of reducing the impact to it from the effects of landslide events. The location of mitigation measures above the A83 are shown on Drawing No. 1 in Appendix A. In some areas, such as at Phase 1, debris barriers have been constructed above catch pits. This combined mitigation provides the most robust mitigation solution on the slope to date. Given the relatively high frequency of debris flow events compared to boulder fall, the mitigation measures were not specifically designed with boulder fall hazards in mind. As boulder bounce heights, velocities and energies have not been considered, and it is currently unknown whether the designs contain sufficient capacity to prevent boulder fall impacting the A83. As such, the presence of mitigation measures has not been taken into consideration during the boulder hazard assessment.

It should be noted that geohazards such as boulder fall form part of a dynamic system. The dynamic nature of the physical environment on the slopes of Beinn Luibhean is influenced by a number of factors including inclement weather conditions, soil conditions, channelisation and vegetation. The nature, timing, triggers, and magnitude of natural terrain hazards cannot always be predicted. The boulder inventory and resulting hazard assessment compiled during Phase 2A is largely based on the observations of experienced Engineering Geologists using the methodology established during the initial research project in 2019 and documented in the Boulder Hazard Assessment Report (Jacobs, 2020). The information provided is in good faith, however, it is highlighted that the observations during site inspections reflect the conditions evident at the time of inspection, and these may change as the hillside evolves. With respect to boulder hazards, changes in hillside conditions are particularly evident following debris flow events which can significantly alter the boulder density and hillside characteristics in the vicinity of the failure areas. It is the responsibility of the user of this report and associated digital data to satisfy themselves that the site conditions have not significantly changed in the intervening time between the fieldwork period and the time at which the data is being utilised.

1.4 Study Area Description

The A83 Trunk Road stretches for approximately 157km between Tarbet on the western shore of Loch Lomond, to Campbeltown, located at the southern end of the Kintyre Peninsula. The road provides a strategic link between populations in Argyll and Bute, and the rest of Scotland.

For the purpose of this report, the 'Study Area' is used to describe the 1.5km section of the A83 road within Glen Croe and the SW-facing hillside of Beinn Luibhean above the road. The boundaries of the Study Area are the bridge over the Croe Water (NGR 224242 706032) and the bend in the road before the Rest and be Thankful viewpoint (NGR 223385 707342). In terms of height, the Study Area reaches a maximum elevation of approximately 600mAOD. The characteristics of the slope change above this level from a predominantly soil covered slope to a shallower slope with numerous crags and rock outcrops approaching the 858mAOD summit of Beinn Luibhean.

The A83, a two-lane carriageway, passes uplink through Glen Croe in a north westerly direction and is formed on side-long ground. The road rises steadily uplink through the Study Area at a gradient of around 5% (1 in 20) before reaching a high point beside the Rest and be Thankful viewpoint.

The hillside within the Study Area is very steep, typically around 30° from horizontal, increasing to more than 35° from horizontal in some areas. Boulders of varying size and shape litter the hillside and rock outcrops are also common. The boulders typically comprise psammite and pelite, which is typical of the underlying solid geology across much of the surrounding hillsides.

The Study Area is incised by many channels, which typically flow to the south-west, are culverted beneath the A83 and OMR, and discharge into a larger stream that meanders through the valley floor to join the Croe Water.

Landslide scars, both relict and recent and of various sizes are evident across the hillside. Since the Boulder Hazard Assessment Report (Jacobs, 2020) was compiled, two large-scale debris flows occurred in August and September 2020, within the 3A and 3B channel (SE of the Phase 1 Trial Area). The morphology of the hillside affected by the 2020 debris flows has been significantly altered.

Since the August and September 2020 debris flows there has been a geotechnical engineering presence on the A83 at Beinn Luibhean to oversee works to repair damaged infrastructure, and to construct enhanced mitigation measures to protect the A83 and the OMR. In the months following the debris flows, enhanced monitoring of boulder movement was undertaken due to the unstable nature of the affected hillside. Generally, small boulder movements associated with boulders exposed within the debris flow scars and channels were recorded. These areas are prone to boulder movement immediately following the debris flow events due to erosion of the exposed soil and due to the landslide debris still being relatively mobile and unsolidified. Other triggers such as continuing expansion of tension cracks in the vicinity of the scar and downward movement of soil rafts are also common in the weeks following a debris flow event where the hillside is often still highly active.

Since August 2020, significant boulder movement was recorded by site personnel on several occasions, three of which impacted the A83 (in August and September 2020, and December 2021). The August and September 2020 debris flow events resulted in mobilisation of numerous large boulders which detached from debris flow deposits between the 3A and 3B channel, generally coming to rest on the hillside. However, during both events, at least one mobilised boulder impacted the A83 and one stopped on top of the higher retaining wall adjacent to the 3B channel. The December 2021 boulder fall comprised a small boulder (250mm diameter) which impacted the A83 adjacent to the 3B channel. As the road was already partially closed due to the ongoing works, the September 2020 and December 2021 boulder fall incidents did not affect operation of the A83. Boulder fall was also recorded in August 2021. This 550mm diameter boulder originated from an area high up on the hillside, and while it had a substantial run-out distance (approx. 250m), it came to rest on the slope and did not impact the A83. It is noted that this may not be an exhaustive record of all discrete boulder travel on the hillside.

Debris flow mitigation measures including debris flow barriers and a series of debris catch pits have been constructed immediately above the A83. At the time of writing, catch pits were being constructed within the study area at Phase 1 and 3Bin an attempt to mitigate against natural terrain hazards in the short-medium term, while studies are ongoing to select a route option to achieve a more resilient section of the A83 in this area. The location of the mitigation measures is shown on Drawing 1 in Appendix A.

A photograph of the Beinn Luibhean hillside taken from the opposite valley side with key features annotated is provided in Figure 1-2.

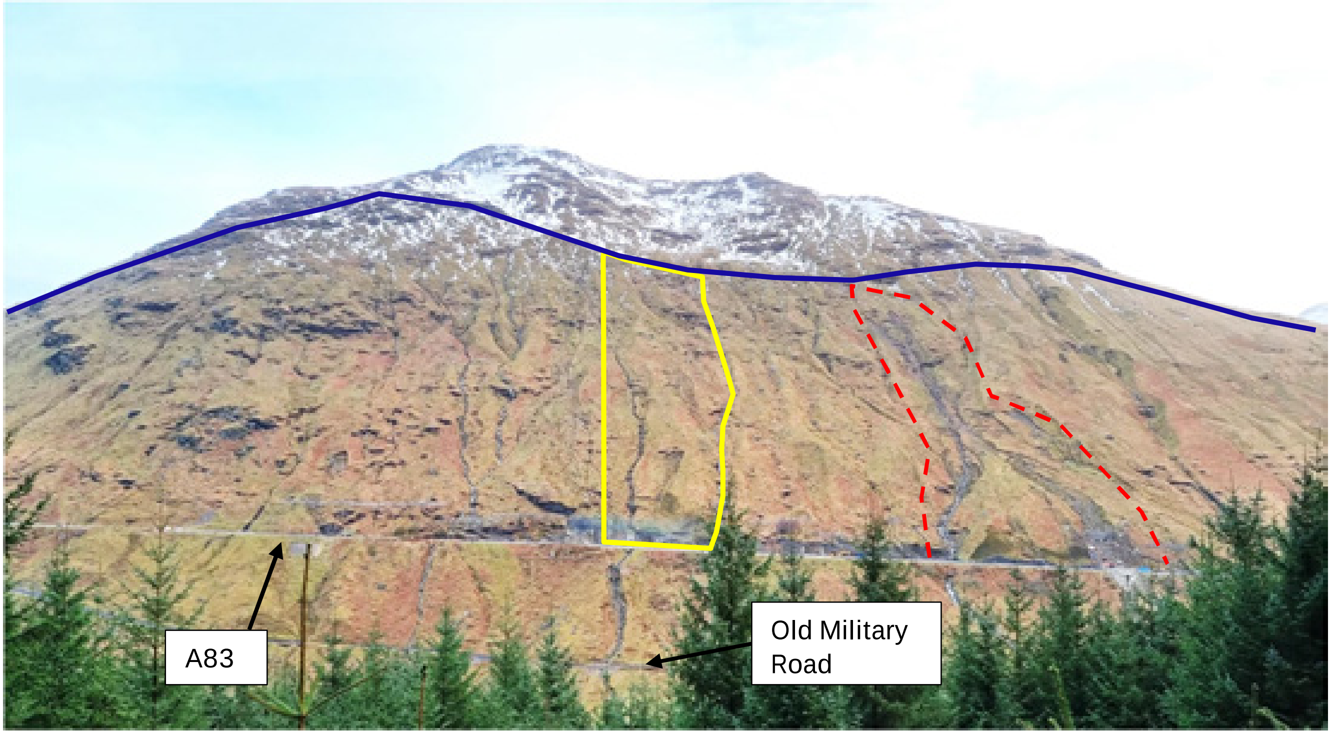


Figure 1-2 Photograph of the Beinn Luibhean hillside highlighting key features of the Study Area. The blue line marks the upper boundary of the study area. The red dashed line marks the area affected by the 2020 debris flows. The area with the yellow boundary outlines the Phase 1 trial area.

2. Fieldwork and Boulder Inventory

Since the Boulder Hazard Assessment Report was compiled in early 2020, two large-scale debris flows have occurred at the site, thus changing the appearance and geomorphology of part of the slope. However, the debris flows did not affect the Phase 1 trial area and thus, it is considered that the data collected during this period is still valid and does not need to be re-mapped. Details of the fieldwork undertaken across the remainder of the Study Area are provided below.

2.1 Data Collection

A UAV photogrammetry survey of the study area was commissioned for this project, the aim of which was to assist with remotely identifying and characterising boulders, thus reducing the amount of time required on site. The data was of high quality and boulders could easily be identified. However, it was found that the data was not appropriate for assessing the presence of characteristics relating to hillside instabilities. These are often very subtle hillside characteristics (e.g. seepages) and could not be picked up from the photogrammetry data. These subtle characteristics are important to note as they infer potential hillside instabilities, details of which feed into the hazard assessment developed in Phase 1. If these characteristics are not adequately determined, the outcome of the hazard assessment is considered less robust. To ensure accurate recording of hillside instabilities the primary method of data collection reverted back to fieldwork.

The fieldwork period commenced in August 2021 but was postponed until October 2021 to allow dense vegetation on the hillside that was obscuring the position of boulders to die back. A further pause in fieldwork occurred between December 2021 and March 2022 to account for poor weather conditions and snow cover at the site. The fieldwork was completed in May 2022.

Data gathering in the field was streamlined using tablets and mobile phones pre-installed with the ArcGIS Collector application. Collector allows map-driven forms to be created and project-specific data to be collected. The application integrates with ArcGIS Pro software, allowing other tasks to be completed such as creating GIS-based drawings, without having to transfer data between devices.

The types of data fields chosen to be included within the ArcGIS Collector form were refined based on lessons learned from the 2020 Boulder Hazard Study in which some superfluous data was gathered that is not required to determine a hazard rating using the boulder hazard matrix. The data collected is listed in Table Table 21. It should be noted that the spatial accuracy of the GPS system was generally +/- 5m; however, there were occasional instances observed where GPS accuracy was less than this value. The locations of the boulders have been recorded with as great an accuracy as possible within the limitations of the tablet and mobile phone GPS systems.

Data was collected for each boulder that met the minimum size criterion (Section 1.3) within the Study Area where it was considered safe to do so, with minor exceptions that are described below. To ensure systematic coverage of the study area, the hillside was split into a series of more manageable parcels of approximately 3 – 5 Ha in size, numbered 1-24. The parcel locations are shown in Drawing 1 in Appendix A.

To expedite the field mapping process, where boulders with similar properties were in close proximity to each other, these were recorded as clusters, with the worst-case properties for a single boulder within the cluster being recorded, along with the number of boulders in the cluster.

Where boulders were located in particularly steep or hazardous terrain such as in the base or sides of deeply incised channels or within areas of loose debris material, the dimensions of the boulders were estimated from a safe distance.

Several areas immediately above the A83 were not surveyed due to the slopes in these areas forming part of an active construction site where works to install landslip mitigation measures were ongoing at the time of the surveys. Further areas that were not mapped due to access restrictions or unsafe terrain include the historic quarry and an area of forestry. Areas where no mapping was undertaken are shown on Drawing No.2 in Appendix B.

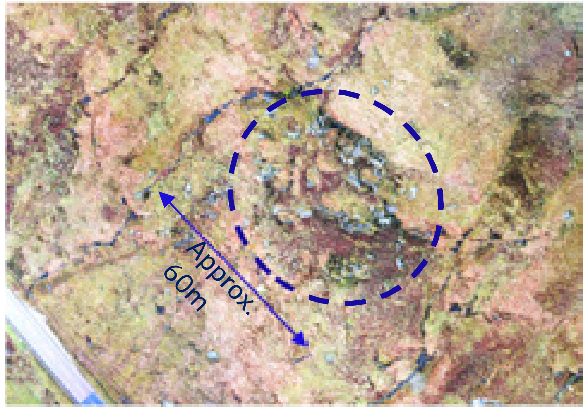
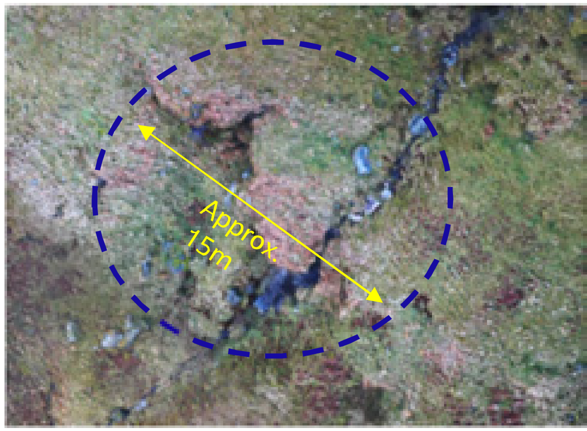
During the field mapping, several distinct geomorphological features were identified on the western side of the Study Area that do not conform with the typical conditions across the remainder of the hillside. These features are summarised in Table 2-2 below and their locations are shown on Drawing No. 2 in Appendix A. It should be noted that it was not possible to map Features A, B and C in their entirety due to safety concerns during the fieldwork. Boulders were mapped where safe to do so around the periphery of these features but due to steep slopes and crags, access was at times constrained.

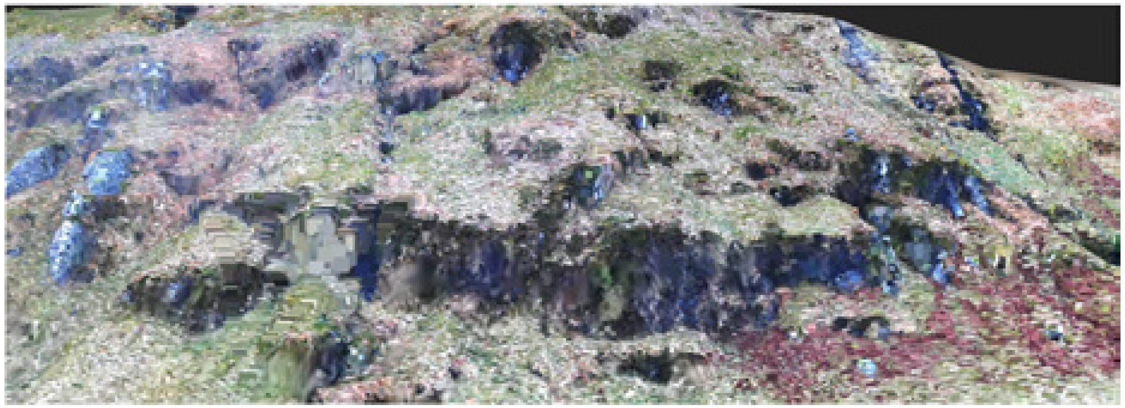
The implications that these features have on the results of the hazard assessment are discussed in Sections 3 and 5 of this report.

Table 21: Information recorded during fieldwork

Information Category	Details
General Attributes	• Boulder ID • Date • Surveyors • Coordinates
Boulder Attributes	• Approximate Dimensions (Length, breadth and height) • Boulder Shape: - Flat/Tabular - Long, cylindrical or cubic - Equant/spherical - Irregular
Hillside attributes	• Evidence of instability • Surface drainage
Photographs	• General photograph of single boulder or boulder cluster • Where relevant, additional photographs capturing particular hillside features that could lead to instability. (e.g. tension cracks, erosion etc.)

Table 2-2: Geomorphological features descriptions

Feature Description	Photographs / Images
Feature A – Approx. 60m long area of very large boulders below a series of rock cliffs. It is suspected that these boulders have been deposited following a rockslide due to their position on the slope. The boulders are stacked on top of one another, sometimes forming caves/hollows that are several metres in height. This area does not conform with the typical boulders found on the hillside that are usually discrete, or within a small cluster. Many of the boulders in this area are not resting upon soil, but on top of other boulders as illustrated in the accompanying photograph. The aerial view image was generated from the DEM, provided by GeoRope Ltd, using Pix4D viewing software (GeoRope ,2020)	 
Feature B – This feature is similar to Feature A but smaller in area. The feature is approximately 15m long and comprises stacked boulders. The aerial view image was generated from the DEM, provided by GeoRope Ltd, using Pix4D viewing software (GeoRope, 2020)	 

Feature C – Comprises an approximate13,500m^2 (1.35Ha) area of rock cliffs interspersed with narrow grassy ledges. Field mapping in this area was restricted due to safety concerns relating to accessing the narrow ledges between the cliffs. Mapping was undertaken in this area where it was considered safe to do so. The oblique image was generated from the DEM, provided by GeoRope Ltd, using Pix4D viewing software (GeoRope, 2020) The image shows rock cliffs in the lower section of Feature C.	

3. Hazard Assessment

3.1 Background

The term ‘hazard’ has been defined by Lee and Jones (2014) as “…a perceived peril, threat or possible source of harm or loss.” To determine the scale of hazard posed by boulders on Beinn Luibhean, a hazard assessment matrix was developed as part of the Phase 1 Boulder Hazard Study (Jacobs, 2020). The matrix was developed following an analysis of fall-path modelling using RAMMS:Rockfall modelling software, which identified the boulder parameters and hillside parameters that were most likely to influence the run-out distance should a boulder be dislodged. A full account of the fall path modelling is provided in the Phase 1 Boulder Hazard Assessment Report (Jacobs 2020). The results and relationships established in the modelling along with observations from previous hillside instabilities at the site, were used to formulate a hazard assessment methodology that could be applied to the Beinn Luibhean site but could also be easily adapted for use at other hillsides affecting the transport network.

The hazard assessment methodology which is outlined in the following paragraphs, considers the probability and intensity of potential boulder falls. A Likelihood Class (L) and Intensity Class (V) is established based on field observations and these are then applied to the boulder hazard matrix, allowing each boulder to be given a Low, Medium or High hazard rating.

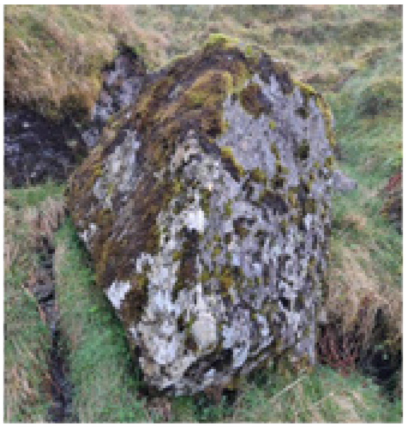
3.2 Likelihood Class (L)

The probability of a boulder reaching the A83 is determined by two main factors; whether boulder fall is likely to initiate, and the likely runout distance. These factors have been considered to determine a Likelihood Class, which will later feed into the hazard matrix. The Likelihood Class (L) is determined by applying factors A, B and C to each boulder, as defined below:

Shape Factor (A) – Run out distance

During detailed modelling, it was found that boulder run-out distances are predominantly controlled by the shape of the boulder. Through undertaking a sensitivity analysis on various boulder shapes, it was found that tabular or flat shaped boulders are extremely unlikely to have significant run-out distances. As such, these boulders have been automatically given a hazard rating of Low without further consideration in the hazard matrix. The sensitivity analysis indicated that other boulder shapes have much longer run-out distances and thus are more likely to reach the A83 upon release from the slope. When considering shape, there is evidence to support that equant or spherical boulders have a greater run-out length than long, cylindrical or irregularly shaped boulders. Shape factors for each boulder are given in Table 3-1 below.

Table 3-1: Determination of Shape Factor, A

Boulder Shape	Photographic Example	Shape Factor, A
Flat / Tabular		N/A – boulder automatically categorised as Low hazard
Long / Cylindrical / Cubic		1
Irregular		2
Equant, Spherical		3

Likelihood of initiation – Release Factor B, and Instability Factor, C

Based on the boulder fall-path modelling as well as observations from fieldwork, it is considered that boulder initiation is controlled by two factors: boulder magnitude and hillside instability. When considering boulder magnitude during the modelling, it was found that there is a positive trend between boulder volume and the initial free-fall required to trigger movement. For modelling purposes, the length of free-fall element of movement is called the Z-offset.

The RAMMS: Rockfall software (Bartelt et al, 2016) used to undertake the modelling terms the free-fall required to trigger movement as the Z-offset. If real boulder fall events are considered, the Z-offset measured during the modelling can broadly be compared to the amount of soil displacement on the hillside required to trigger a movement: i.e., larger boulders require a greater amount of soil displacement, or potential energy, to trigger a failure than smaller boulders.

It has been observed from annual reporting on the slope condition of Beinn Luibhean, as well as from numerous site visits to the Study Area, that small soil disturbances are more frequent than large debris flow events. Therefore, boulders that require a lower Z-offset to become mobilised are more likely to be dislodged than larger boulders that require a greater Z-offset. As such, by comparing the Z-offset required to trigger boulder falls of a certain volume, a likelihood of release factor, termed Release Factor B, can be applied to boulder volumes recorded in the inventory. Release Factor B has been calculated as shown in Table 3-2.

Table 3-2: Calculation of Release Factor B

Z-offset required to trigger movement	Equivalent boulder volume from fall-path modelling results	Comments	Release Factor B
Up to 1.0m	< 1.25m^3	Likely to occur frequently. Causes may include tension crack formation, minor landslips, small washout failures	3
1.01m – 2.50m	1.25m – 16m^3	Likely to occur less frequently. Boulder dislodgement could occur during low volume debris flow events or open hillslope failures. May also occur due to localised channel washout during rainstorm events.	2
>2.50m	>16m^3	Likely to occur rarely, mostly during large debris flow events.	1

The likelihood of boulder initiation is also dependent on features of the slope surrounding the boulder. Boulders located in areas of active instability (e.g. evidence of tension cracks or seepage that could wash out the soil beneath the boulder) are more likely to mobilise than boulders that are located on areas of hillside that show no signs of instability. Evidence of instability on the hillside has been recorded during the fieldwork. Instability Factor C is applied to each boulder to represent varying degrees of hillside instability. The instability factor categories that have been applied during this hazard assessment are provided in Table 3-3.

Table 3-3: Calculation of Instability Factor C

Evidence of Instability	Examples of observed instabilities	Instability Factor C
No instability recorded	No instabilities recorded during fieldwork. The boulder is not located within a drainage channel.	1
Minor instability recorded	- Evidence of minor washout of soil below the boulder - Seepage below the boulder / evidence of soil saturation - Boulder located within a stream channel	2
Significant instability recorded	- Tension cracks - Evidence of recent boulder movement - Evidence of active erosion or scour	3

By considering both Release Factor B and Instability Factor C, the likelihood of boulder initiation is calculated as:

*Release Factor B * Instability Factor C*

The Likelihood matrix shown in Figure 3-1 considers the two likelihood of initiation factors (B*C) and the likelihood of the boulder reaching the road (Shape Factor A) to calculate a Likelihood Class of L1, L2 or L3 which then feeds into the boulder hazard matrix.

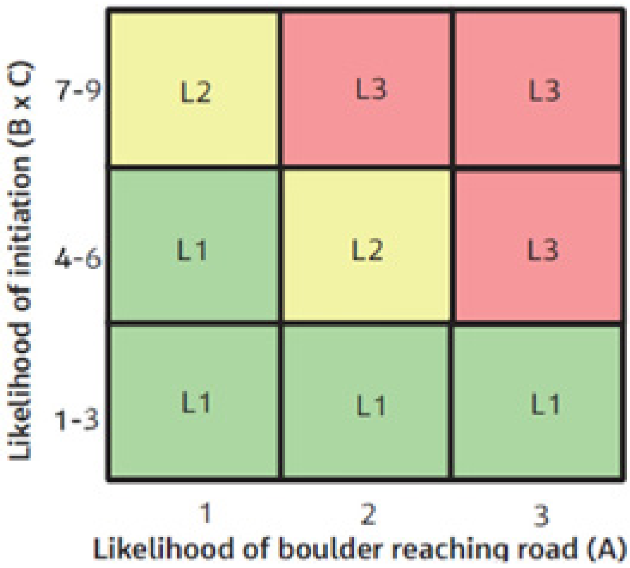


Figure 3-1: Likelihood Matrix used to calculate Likelihood Class (L)

3.3 Intensity Class (V)

With respect to hazard intensity, it was observed from fall-path modelling that kinetic energy and bounce height typically increase with boulder volume. As such, it can be considered that the larger the boulder, the more destructive any potential impact will be should a boulder reach the A83 upon release. When considering the intensity in relation to boulder hazard, a semi-quantitative / qualitative category has been assigned to boulders with respect to volume. These categories are referred to as Intensity Class V. Each boulder in the inventory has been allocated an Intensity Class based on the categories provided in Table 3-4: Determination of Intensity Class.

It should be noted that in many cases, boulders on the hillside are partially embedded into the ground and thus a true measurement of boulder volume is not possible for these boulders as only the above-ground dimensions can be recorded. It is noted that this results in a degree of uncertainty within the hazard assessment; however, boulder volume is only one factor within a larger assessment of overall hazard.

Table 3-4: Determination of Intensity Class

Boulder Volume	Potential effects upon impact	Intensity Class
< 0.5 m^3	Boulder is comparatively small when compared to the size of a vehicle travelling along the A83. An impact to a vehicle will cause significant damage, but not necessarily to the entire vehicle. Depending on where the boulder hits the vehicle. The impact may or may not cause an injury/fatality	V1
0.5m^3 to 1.0m^3	It is considered that boulders of this size will cause a greater degree of damage to a vehicle on impact compared to Intensity Class V1. The likelihood if causing injury/fatality is considered greater than in comparison to Intensity Class V1.	V2
>1.0m^3	It is considered that boulders of this size will cause a greater degree of damage to a vehicle on impact compared to Intensity Classes V1 and V2. The likelihood of causing injury /fatality is considered greater in comparison to Intensity Classes V1 and V2.	V3

3.4 Hazard Matrix

A hazard matrix is used to enable classification of boulders within the boulder inventory in terms of the relative degree of hazard that they pose to the A83 road. The hazard matrix compares the Intensity Class and the Likelihood Class given to each boulder to give a hazard rating of Low, Medium or High. The boulder hazard matrix used in this study to assign the hazard ratings is given in

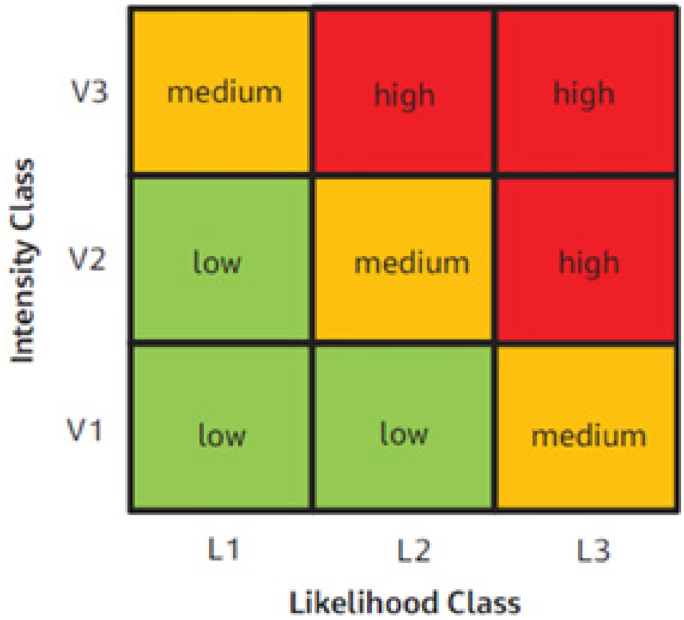


Figure 3-1: Boulder hazard matrix

Figure 3-1: Boulder hazard matrix

3.5 Exceptions to the methodology

The hazard assessment methodology outlined in Sections 3.1 to 3.4 assumes that boulders are released due to movement of the soil from below them due to hillside instabilities, or removal of soil surrounding the boulder from erosion. It is considered that two areas of boulders in the western end of the Study Area, termed Feature A and Feature B, and described in Section 2, do not align with the suggested hazard assessment methodology due to their unique features. Features A and B are accumulations of very large boulders and were likely deposited following a rock fall / rock slide event from crags upslope. In these areas, the boulders are stacked on top of one other as exemplified in the photographs on Error! Reference source not found.. In the event of ground movement resulting in the release of one of the boulders at the base of the stack, this could destabilise a number of boulders on the stack, resulting in multiple impacts on the A83 depending on the boulder run-out distances.

The modelling software used in the Phase 1 Boulder Hazard Study to model boulder fall paths cannot take account of this unique situation. It is therefore considered that the use of Z-offset to estimate the likelihood of boulder release in the case of stacked boulders is not appropriate. Furthermore, given the possibility of multiple impacts on the A83 from movement from below a stack of boulders, it is not considered appropriate to allocate an

Intensity Class for a single boulder in this area as the severity of an impact could be much higher if several boulders are released. Given the issues outlined above, it is not considered appropriate to use the methodology outlined in Section 3.1 to 3.4 to assign hazard ratings to boulders in these areas.

When considering the hazard posed by boulders within Features A and B, boulders that have been mapped as flat/tabular in shape are still considered to pose a Low hazard, as modelling has shown that the runout distance of flat-shaped is short. It is considered that the run-out distance for flat-shaped boulders is unlikely to be affected by the stacked nature of the boulders in this area.

With respect to other boulder shapes, run-out distances are greater, and if mobilised, there is a greater likelihood of boulders reaching the A83 from Features A and B. Although the effect of Z-offset is unknown, there is the potential for higher magnitude boulder fall events originating from these areas due to the possibility that multiple boulders could be mobilised downslope and reach the A83 if a boulder at the base of a stack was to be released. As such, it is considered prudent to categorise all other boulders (i.e. boulders not mapped as flat/tabular) within Features A and B as High hazard until further modelling is undertaken to confirm the degree of hazard posed by boulders in these areas.

Further discussion on hazards posed by Feature A and Feature B is provided in Section 5.

4. Results

Using the methodology described in Section 3, a hazard rating has been applied to boulders within the inventory. The boulder inventory includes boulders mapped in 2019 as part of the Phase 1 boulder hazard study research (453 No.), as well as the boulders mapped during the Phase 2A fieldwork conducted in 2021 and 2022 (6556 No.), giving a total number of boulders mapped on the slopes of Beinn Luibhean of 7009. This number includes 81 boulders that are associated with Features A and B.

Of the 7009 boulders identified, the number of boulders given a Low, Medium or High hazard rating is shown in Table Table 4-1. The locations of the boulders and their associated hazard rating are shown on Drawing No. 2 in Appendix B. The hazard assessment matrix along with fieldwork photographs for all boulders has been provided as a digital appendix (Appendix C).

Of the 81 boulders associated with Features A and B, nine of them were flat/tabular in shape and automatically categorised as Low hazard as per the boulder hazard assessment methodology developed in Phase 1 of this project. The remaining 72 boulders comprise amalgamations of stacked boulders and the likely mechanism of boulder failure does not conform with the intended use of the boulder hazard matrix, i.e., for individual boulders on the hillside. Without modelling to ascertain the run-out of boulders from these areas, the remaining 72 boulders have been automatically categorised as High hazard due to the potentially larger event magnitude associated with multiple boulder releases during a single boulder fall event. Boulders with a High hazard rating that are associated with Feature A and Feature B have been separately identified on Figure No.2 in Appendix B, as well as within the boulder inventory (provided digitally, Appendix C).

It should be noted that due to access constraints within Features A and B, that many boulders could not be mapped. As such, there is the potential for a greater number of High hazard boulders within features A and B than the 72 No. that have been assessed within this report.

Table 4-1 - Summary of boulder hazard ratings

Hazard Rating	Number of boulders	Percentage of total (6928 Boulders) Note: total and percentages do not include Boulders associated with Area A and B as these areas could not be fully mapped.
Low	4123 (+ 9 associated with Features A and B)	59.5 %
Medium	2457	35.5 %
High	348 (+72 associated with Features A and B)	5.0 %

Boulders designated as Low hazard are generally tabular in shape. Of the Low hazard boulders that are not tabular in shape, the boulders are not typically associated with significant existing instability features on the hillside and tend to have a lower volume in comparison with Medium and High hazard boulders.

Of the 2457 boulders assigned as Medium hazard, the majority fall into Likelihood Class L1 indicating that there is a relatively low chance of the boulder mobilising in most cases. However, the majority of Medium hazard boulders fall into Intensity Class V3 due to their large volume, so although the likelihood of initiation is low, if mobilisation occurs, the intensity of the event is more severe.

Of the 348 boulders that were given a High hazard rating (excludes boulders associated with Features A and B), the majority record some form of hillside instability while also having an intensity class of V2 or V3, indicating that these boulders are not only more likely to mobilise from the slope, but they are also likely to cause more significant damage upon impact with a vehicle on the A83. Evidence of recent boulder movements such as detachment scars (e.g. boulder No.160) or fresh faces where no moss/lichen was growing (e.g. boulder No. 2817), was visible on some of the High hazard boulders. Photographs of boulders that have been allocated a High hazard rating along with a summary of their properties are provided in Appendix B.

5. Discussion and Recommendations

5.1 Boulder hazard data, future use

The compilation of the boulder inventory and subsequent boulder hazard assessment developed using the Phase 1 Study has allowed discrete boulders on the Beinn Luibhean hillside to be categorised as either Low, Medium or High hazard. There were over 7000 boulders recorded on the hillside. The details on boulder distribution on Beinn Luibhean along with the raw data compiled during this study (see Appendix C) can be used by Transport Scotland, Operating Companies and designers to assist with remedial work prioritisation and could potentially feed into risk assessments undertaken to ascertain the level of risk posed to the A83 and Old Military Road by natural terrain hazards. Further information on boulder distribution and recommendations for considering hazard reduction priorities are provided in the following sections.

5.2 Boulder Distribution

On review of the spatial distribution of the boulders, the following patterns have been observed:

- There is a higher density of High hazard boulders associated with drainage lines and where previous failures have occurred. This is likely a result of boulders being exposed in these areas due to channel erosion. The presence of High hazard boulders close to drainage lines is also partly a function of soil disturbance, which is more likely near drainage lines and where previous failures have occurred.

- Apart from the High hazard boulders associated with Features A and B, there is a relatively low concentration of High hazard boulders in the following areas:

  A) The area to the west of the Phase 1 test area. The likely cause of a lower density of High hazard boulders in this area is due to a greater proportion of rock outcrops and cliffs in this area. Poor access for mapping due to the cliffs has also resulted in lower concentrations of boulders on the upper slopes to the west of the Phase 1 test area.

  B) The upper hillside between the Phase 3b working area and the quarry (parcels 9, 18 and 21 on Drawing No.1). Parcel 21 is in an area with many rock outcrops and cliffs, and as such, boulders are less likely to be deposited there due to the thinner soil covering. Parcels 18 and 21 are in an area where there is an absence of drainage channels. These areas of the hillside are considered to be less dynamic than areas of the hillside containing numerous drainage lines. There is less likelihood of boulders within the glacial till being exposed by erosion and other hillside processes in these areas.

5.3 Features A and B

The properties of boulders in this area, apart from those that were flat/tabular in shape, were found to be incongruous with the boulder hazard assessment methodology. Without the benefit of modelling information for these particular boulders and a lack of understanding or evidence from previous events on how these stacked boulders will fail, it is considered prudent to address the hazard posed by these boulders separately.

As noted in Section 4, flat/tabular boulders within features A and B have been categorised as Low hazard as per the usual hazard assessment methodology. The remaining boulders, the majority of which are stacked, are problematic due to uncertainties over how to establish the Z-offset. Without this factor, it is not possible to derive the likelihood class required for the hazard matrix. Based on field observations and engineering geological judgement, it is considered that boulders originating from these areas are hazardous due to the potential for multiple releases of boulders should an entire stack, or part of a stack become mobilised. As such, a conservative hazard rating of “High” has been applied to these boulders.

Consideration could be given to further research to better understand the mechanisms involved with the release of multiple boulders from a single point. Further modelling could also be undertaken using appropriate software to confirm the likely fall paths and impact magnitudes from boulder fall originating from these locations. At present, there is insufficient information for these areas, in particular Area A, to model potential failures. It is recommended that prior to modelling, further assessment of the boulder numbers, sizes, shapes, degree of embedment and locations with respect to stacking is undertaken. This would allow better understanding of the relationship between multiple releases from areas of stacked boulders and the resulting hazard to the A83.

5.4 Hazard Reduction

As works progress to develop medium-term and long-term solutions to improve resilience of the A83, this boulder inventory and hazard assessment can be utilised when considering natural terrain hazards that could affect the proposed solutions. Consideration could be given to hazard reduction by removing the boulder from the slope, reducing the size of boulder, or by stabilising it in situ depending on the individual characteristics and position on the slope.

While some of the boulders are unlikely to fail imminently due to embedment, there is potential for them to fail in the future due to ongoing hillside processes which could lead to removal of the material currently supporting the boulder. It is recommended that the distribution of boulders is considered during the design of future mitigation works / scheme developments at the A83 Rest and be Thankful site.

In terms of mitigating against boulder fall, there are several options for designers and network operators:

- Remove the receptor – With respect to this site, this can be largely achieved by diverting traffic from the A83 to the OMR at times where there is higher likelihood of an event. This option is likely to be valid in the short-medium term until a long term solution to achieve improved resilience is completed. For other sites, consideration could be given to local diversion routes where the hillside conditions and/or weather conditions render this a necessary option.

- Remove the hazard – the hazard can be removed (or largely eliminated), either by removing the boulder from the hillside (likely only practical for boulders close to the slope toe, or by breaking up large boulders on the hillside into smaller flatter rock fragments using explosives. This method has previously been employed at the site, successfully reducing the hazard associated with several boulders that were at risk of potential failure following debris flow events.

- Reduce the hazard – on-slope retention. Depending on the ground conditions at individual boulder locations, there is the potential for boulders to be retained on the hillside using a restraint system of rock anchors and wire ropes or anchored mesh. Although this can reduce the hazard to the slope below, it does not completely remove the hazard as there are always inherent uncertainties in the ground conditions that reduce the capacity of the system and lead to failure. The system is only likely to be cost effective for very large boulders and it will also require maintenance over time. An example of this method has been employed on Beinn Luibhean. In 2010 a boulder with approximate mass of 250 metric tons, was stabilised in situ using Kevlar tendons high above the Phase 10 barrier. An image of the stabilised boulder is provided in Figure 5-1 below.

Figure 2.1 - Large boulder stabilised in situ on Beinn Luibhean

- Reduce the hazard – impact prevention. Impact prevention systems are designed to prevent a mobilised boulder from impacting the A83. This could include the installation of rock fall barriers or designing rock traps/catch pits above the A83 to intercept boulders. Debris shelters can also be constructed to prevent an impact. Further modelling would be required to determine the likely velocities, kinetic energies, bounce heights and fall paths generated during failure of a boulder. It is likely that these hazard reduction methods could be designed to incorporate mitigation with respect to debris flows which are known to affect the hillside in this area. When designing mitigation above the A83, it may be prudent for designers to undertake further fall path modelling to ensure that the mitigation is appropriately designed to account for the anticipated boulder fall magnitude and bounce heights that could be expected.

In terms of prioritising hazard reduction methods, it is recommended that priority is given to High hazard boulders in the following locations:

1) Boulders located in areas where no mitigation is currently installed above the A83.

2) Boulders that are in areas of active slope movement.

Several areas of the slope have been identified as ‘active’ (Jacobs 2022). In particular, a spreading wedge of material has been identified close to the 3b channel. Boulders are more likely to be disturbed and released in this area due to ongoing movement of the soil mass.

5.5 Appraisal of the Hazard Assessment Methodology

5.5.1 Beinn Luibhean

The methodology used to assess the hazard posed by boulders on Beinn Luibhean followed the methodology developed in Phase 1 of the study. It considers the likelihood of boulder initiation and the magnitude of potential boulder fall to give a Low, Medium or High hazard rating.

Accurate input of information to the hazard assessment processes is key in delivering a robust hazard assessment output. During the fieldwork, it was found that the GPS accuracy limited the precise recording of boulder locations to approximately +/- 5m; however it has been noted that on occasions, glitches with location recording meant that boulder coordinates were highly inaccurate. Where this has occurred, the boulders have been manually plotted based on field notes and photographic evidence of their location. Where changes have been manually made, these have been recorded on the boulder inventory. It is recommended that a thorough check is made on boulder locations once plotted to capture and amend any significant location errors.

In terms of fieldwork, undertaking this process for the entire study area was extremely time consuming. The progress of the fieldwork was limited by several factors including adverse weather conditions and vegetation growth, the latter often obscured boulder locations. Although airborne LiDAR and photogrammetry of the site was available for the majority of the Study Area and could have been used to determine boulder locations and approximate volumes, this data could not be used to identify some of the subtle features of the hillside that are required to determine likelihood of boulder initiation using the hazard matrices, and thus, a walkover of the entire site was required. Features such as tension cracks, seepages and erosion were too subtle in some cases to be identified from the imagery, and thus, extensive fieldwork was required to confirm the presence/absence of these features. In cases where the scale of the site is too large to facilitate cost effective fieldwork, there is potential for the hazard methodology to be modified to omit or limit the requirement for hillside features relating to instability to be recorded. For example, when determining the likelihood class (L), the likelihood of initiation (Factor B x Factor C), Stability Factor C could be omitted, and the likelihood of initiation could be based only on Release Factor B (Z-offset). Consideration on the appropriateness of using a modified hazard matrix and the implications on the resulting hazard scores should be given prior to using a modified method.

5.5.2 Potential use on other hillsides

If considering using or adapting this methodology for other schemes, it would be prudent to explore whether it would be advantageous to use advanced remote sensing technologies which would reduce the requirement for extensive fieldwork, or provide more accurate information for modelling purposes. It should be noted that using advanced techniques requiring a lot of data processing, or for sites where large datasets are to be captured, the processing power of the user's hardware should be taken into consideration, as the average laptop is unlikely to have the processing power required. Some considerations for using the hazard assessment methodology on other sites are provided below:

- In some circumstances, e.g., for sites where there is a significant variation in slope angle across the site, consideration could be given to refining the hazard matrix to consider slope angle as well as boulder shape when considering factors that affect run-out distance (factor A in this assessment).

- For large sites where there are many boulders, and a limited covering of vegetation, consideration could be given to modifying the hazard matrix to exclude the need for calculating the instability factor (C). If high quality point cloud information is available, the shape and approximate volumes can be identified manually from the DEM using point cloud processing and visualisation software (e.g. Pix4D or Pointerra). Alternatively, if time and budget were available, a deep learning model could be developed to identify boulder locations and volumes from a photogrammetry dataset. A deep learning model was trialled during Phase 1 of the Boulder Hazard Study; however, it had limited success in identifying boulders as only a LiDAR point cloud was available at the time. If photogrammetry data had been available, allowing the model to identify boulders based on both shape and colour, it is considered that boulder identification would likely have been more effective.

- For small sites where information is required for fall path modelling, highly accurate point cloud data to ascertain volume and shape characteristics can be acquired using hand-held laser scanners or by using backpack drones. As boulder shape and volumes would be based on actual representations of boulders on the site, rather than using pre-loaded shapes from the software library, this would lead to more accurate fall-path modelling data, potentially leading to a better establishment of the hazard posed by individual boulders. This is only recommended for small sites where carrying out fieldwork of this nature is feasible. Though this was not an appropriate technique for the entire Rest and be Thankful site, it could potentially be applied to small areas of the Rest and Be Thankful site where further boulder fall modelling is to be undertaken where mitigation measures are being designed.

- It is recommended that the method of assessment should also consider the potential form of protection. For discrete areas of hillside requiring protection, it may be prudent to gather very detailed information in this area, particularly in relation to size and velocity. For continuous systems over a larger area e.g. debris shelters, the degree of accuracy on boulder size and velocity may not be quite as important. In terms of the design, consideration should also be given to other hazards on the hillside to ensure a holistic approach to the design. For example, frequent debris flow hazards are more likely to drive decisions on the nature of the protection system than low frequency boulder hazards in the same area.

6. Conclusions

The A83 at the Rest and be Thankful has a history of hillside instability and while significant investment has been made to understand and mitigate the hazards relating to debris flows, until now, the hazards posed by boulders on the slopes above the A83 were not well understood.

The boulder hazard assessment methodology, developed in Phase 1 of this project in 2020, has been used to expand the boulder hazard inventory for the NW facing slopes of Beinn Luibhean. The inventory covers discrete boulders resting on the hillside but does not include hazards from rockfall from crags or man-made slopes. Rockfall from man-made slopes is common in Scotland, and there are other hazard assessment methodologies in place (e.g. McMillan and Matheson,1998) for this type of geohazard.

Over 7000 boulders with one dimension greater than 1m have been mapped on the hillside and have been given a hazard rating of either Low, Medium or High. Approximately 5% of boulders on the hillside have been classed as High hazard to the A83, with 35.5% and 59.5% being classed as Medium and Low hazard respectively. Additional High hazard boulders associated with Features A and B have been identified. These boulders are stacked on top of one another and failure of boulders in these areas may result in multiple impacts on the A83. Due to access difficulties, the total number of High hazard boulders within Features A and B has not been fully determined and there is the potential for further High hazard boulders to be present within these areas. It should be noted that although only boulders with one dimension in excess of 1m have been considered in this study, there is still the potential for smaller boulders to become detached and impact the A83.

Following commission of the A83 Access to Argyle project, development work relating to delivering an alternative route or protection system to the existing A83 is underway. It is recommended that this report and accompanying data is provided to the Transport Scotland Project Manager for the A83 Access to Argyle project so that this data, where appropriate, can be used to inform the design of the long-term solution.

The timescales involved developing a long-term solution mean that short to medium term interventions to improve the resilience of the A83 are also required. With respect to the short to medium term work, it is recommended that the data held within the boulder hazard inventory is used to inform the design of future mitigation measures. Designers may wish to undertake fall-path modelling during the detailed design phase to ascertain specific design parameters such as velocities, energies and bounce heights of potential boulder falls to ensure the capacity of the mitigation considers boulder hazards as well as debris flows.

While the mitigation works to the A83 form substantial investment to help reduce the frequency of road closures, the design of the current mitigation did not consider boulder fall hazards. It is therefore recommended that fall path modelling for High hazard and select Medium hazard boulders is undertaken to ascertain whether individual phases of mitigation have sufficient capacity to retain boulders and prevent an impact on the A83. Recommendations could then be provided for considering enhancing mitigation in selected areas in the short to medium term.

The boulder hazard assessment methodology was developed with a view that it could be used or adapted for other sites where boulders are likely to pose a hazard to infrastructure. It is recommended that the advice given on the use of the methodology for other sites (Section 5.2 of this report) is consulted prior to designing surveys and fieldwork at other sites. Adaptation of the recommended methodology may be required in circumstances where certain hillside conditions are significantly different from those at Beinn Luibhean.

7. References

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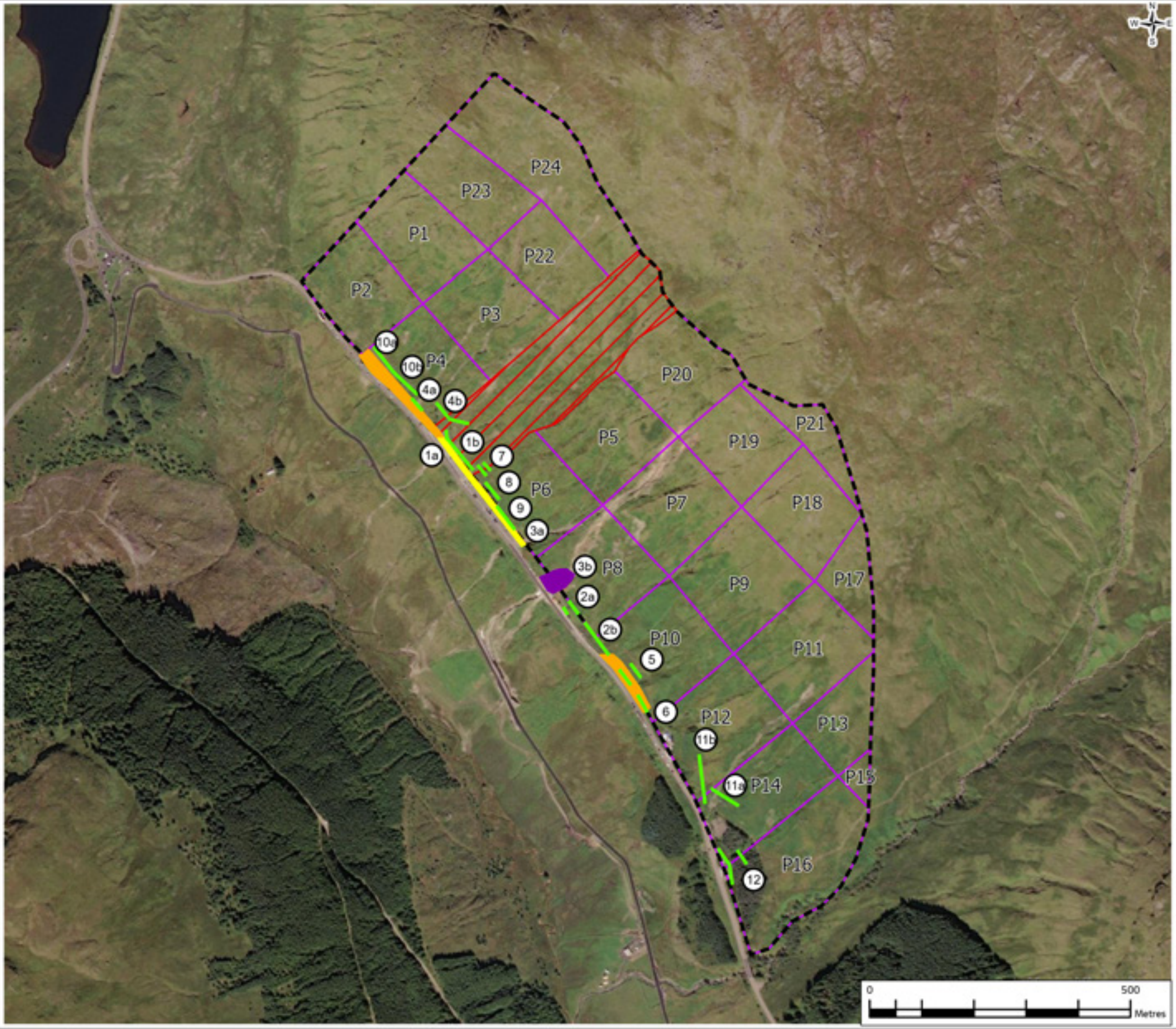
Appendix A. Drawings



Drawing 1

Legend

- Study Area 2A
- Study Area for Phase 1
- Field Mapping Area
- 1b Remedial work phase number
- Approximate locations of debris flow risk reduction measures
- Proposed catch pits
- Existing catch pit channel protection
- Catch pits under construction

0	NOV 22	Initial Issue	AH	JT	CAH	[illegible]
Rev	Date	Purpose of revision	Drawn	Check'd	Rev'd	App'd

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Phase 2A

Drawing Title

Study Area Layout Plan

Sheet 1 of 1

Drawing Status: DRAFT

Scale @ A3	1:10,000	DO NOT SCALE
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Client No.		

Drawing No.

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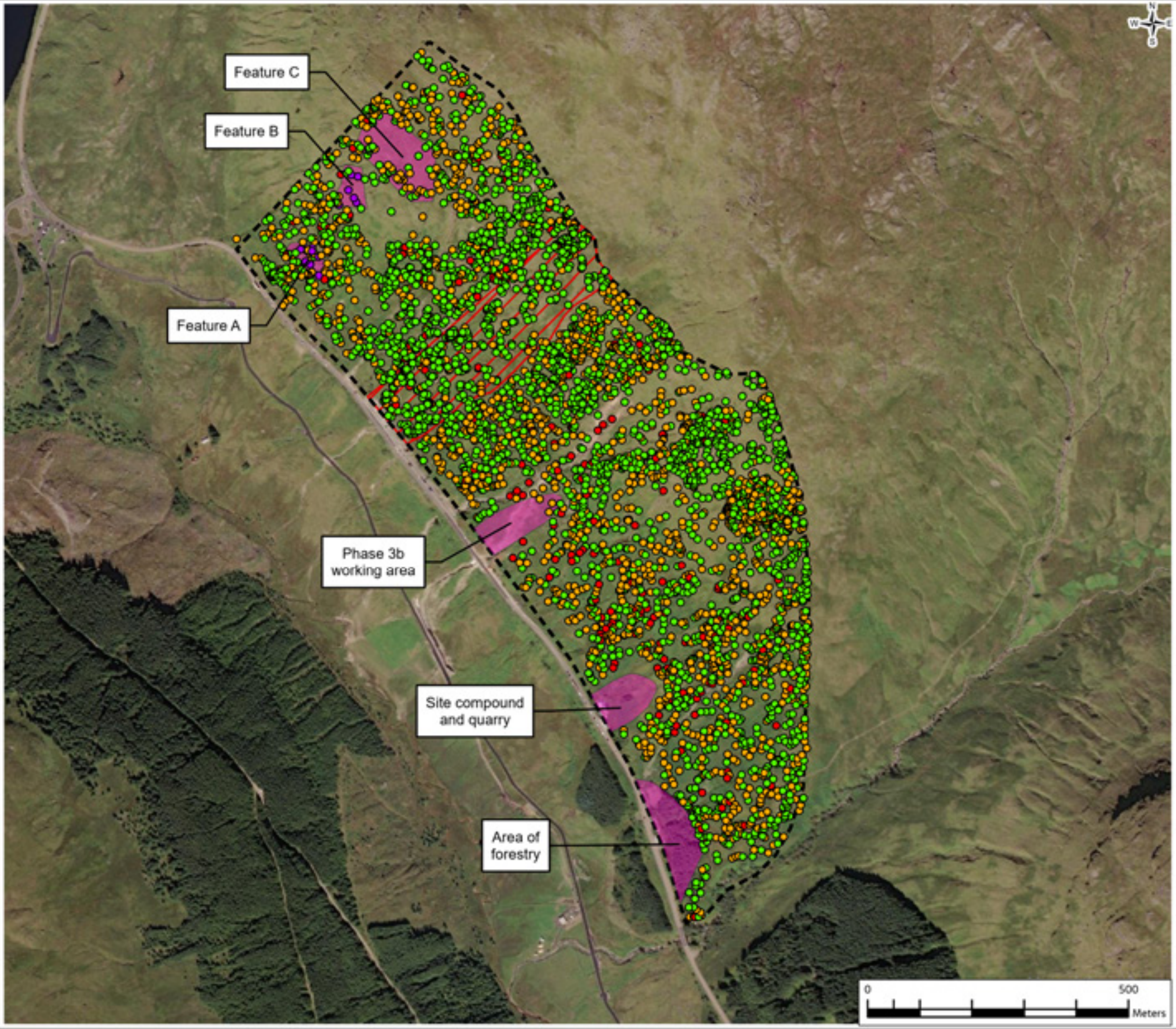

Drawing 2a

Legend

Hazard Rating

- High Hazard Boulder
- Low Hazard Boulder
- Medium Hazard Boulder
- High Hazard Boulder Associated with Features A and B
- Study Area 2A
- Study Area for Phase 1
- Site features

1) This drawing should be read in conjunction with following report "Boulder Hazards Study - Phase 2A. Boulder Hazard Inventory for A83 Beinn Luibhean."
2) Please refer to report section 2 for further information on site features.

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Phase 2A

Drawing Title

Boulder Hazard Location Plan

Sheet 1 of 4

Drawing Status: DRAFT

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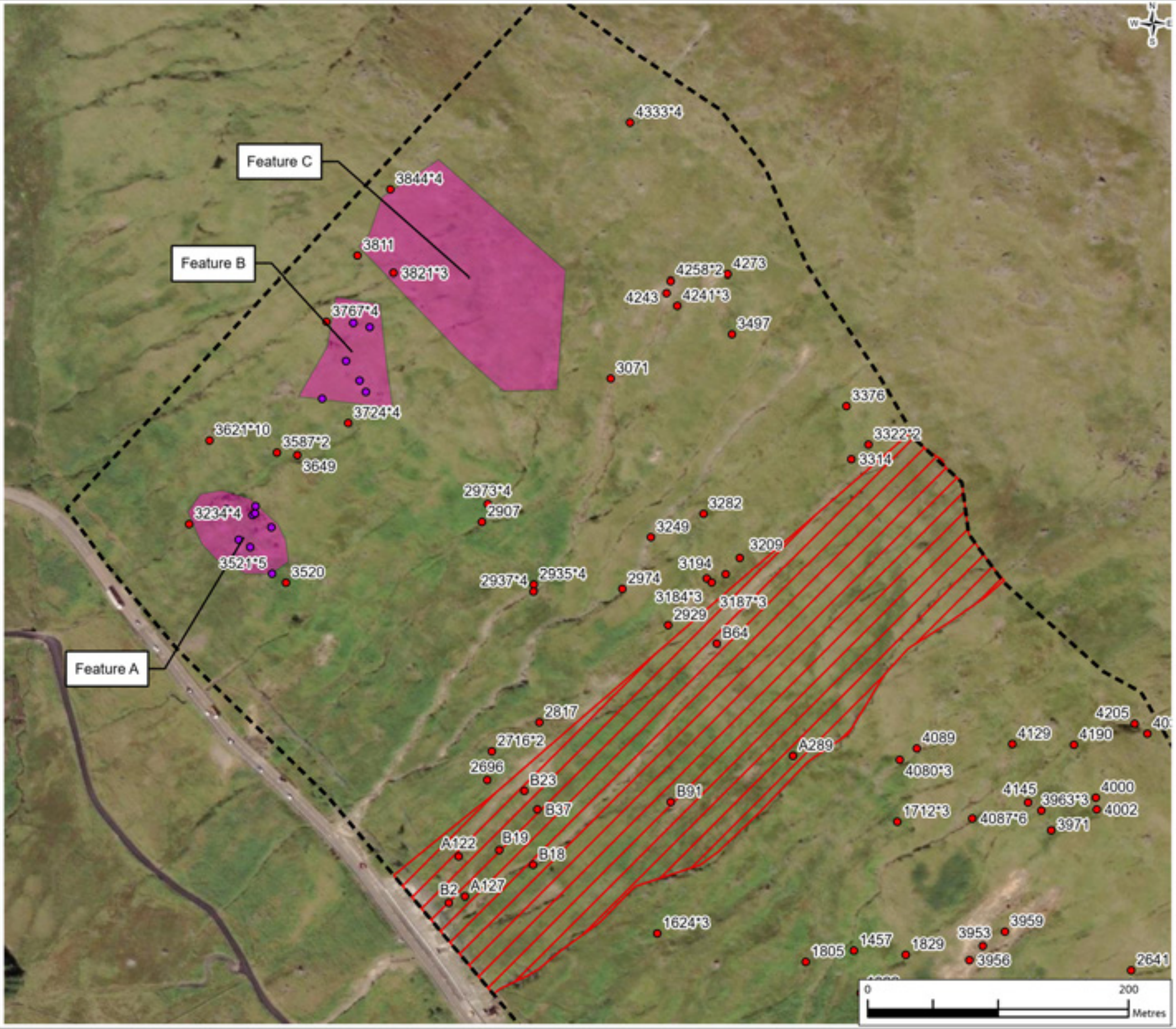

Drawing 2b

Legend

Hazard Rating

- High Hazard Boulder
- High Hazard Boulder Associated with Features A and B
- Study Area 2A
- Site features

1) *X following a boulder ID denotes the number of boulders mapped within a cluster of boulders. The hazard rating applies to the worst-case boulder within the cluster.
2) This drawing should be read in conjunction with following report "Boulder Hazards Study - Phase 2A. Boulder Hazard Inventory for A83 Beinn Luibhean."
3) Please refer to report section 2 for further information on site features.

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Boulder Study
Phase 2A

Drawing Title
Boulder Hazard Location Plan

Sheet 2 of 4

Drawing Status
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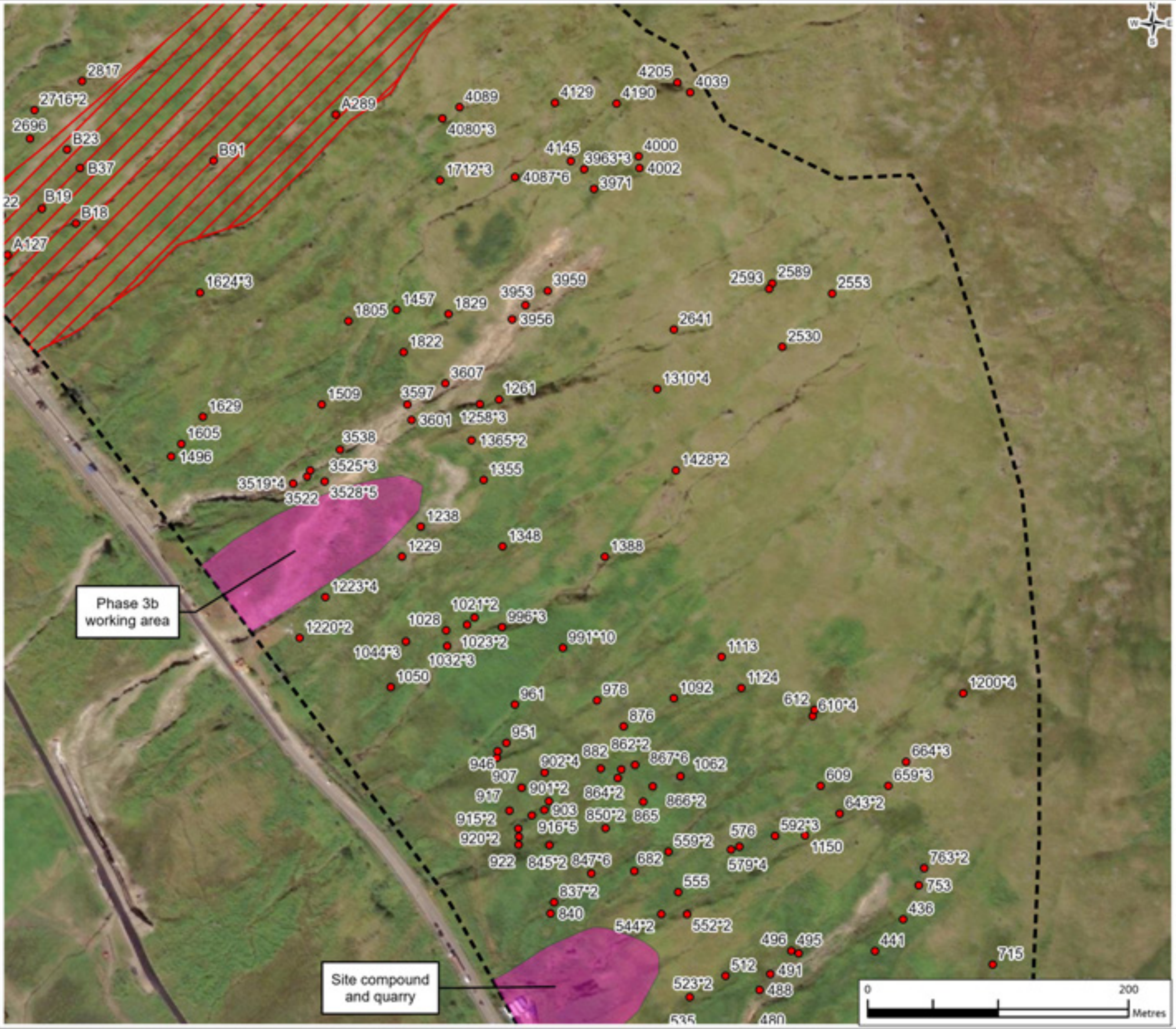

Drawing 2c

Legend

Hazard Rating

- High Hazard Boulder
- High Hazard Boulder Associated with Features A and B
- Study Area 2A
- Site features

1) *X following a boulder ID denotes the number of boulders mapped within a cluster of boulders. The hazard rating applies to the worst-case boulder within the cluster.
2) This drawing should be read in conjunction with following report "Boulder Hazards Study - Phase 2A. Boulder Hazard Inventory for A83 Beinn Luibhean."
3) Please refer to report section 2 for further information on site features.

0	NOV 22	Initial Issue	AH	JT	CAH	NW
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A83 Rest and Be Thankful
Boulder Study
Phase 2A

Drawing Title

Boulder Hazard Location Plan

Sheet 3 of 4

Drawing Status: DRAFT

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Client No.		

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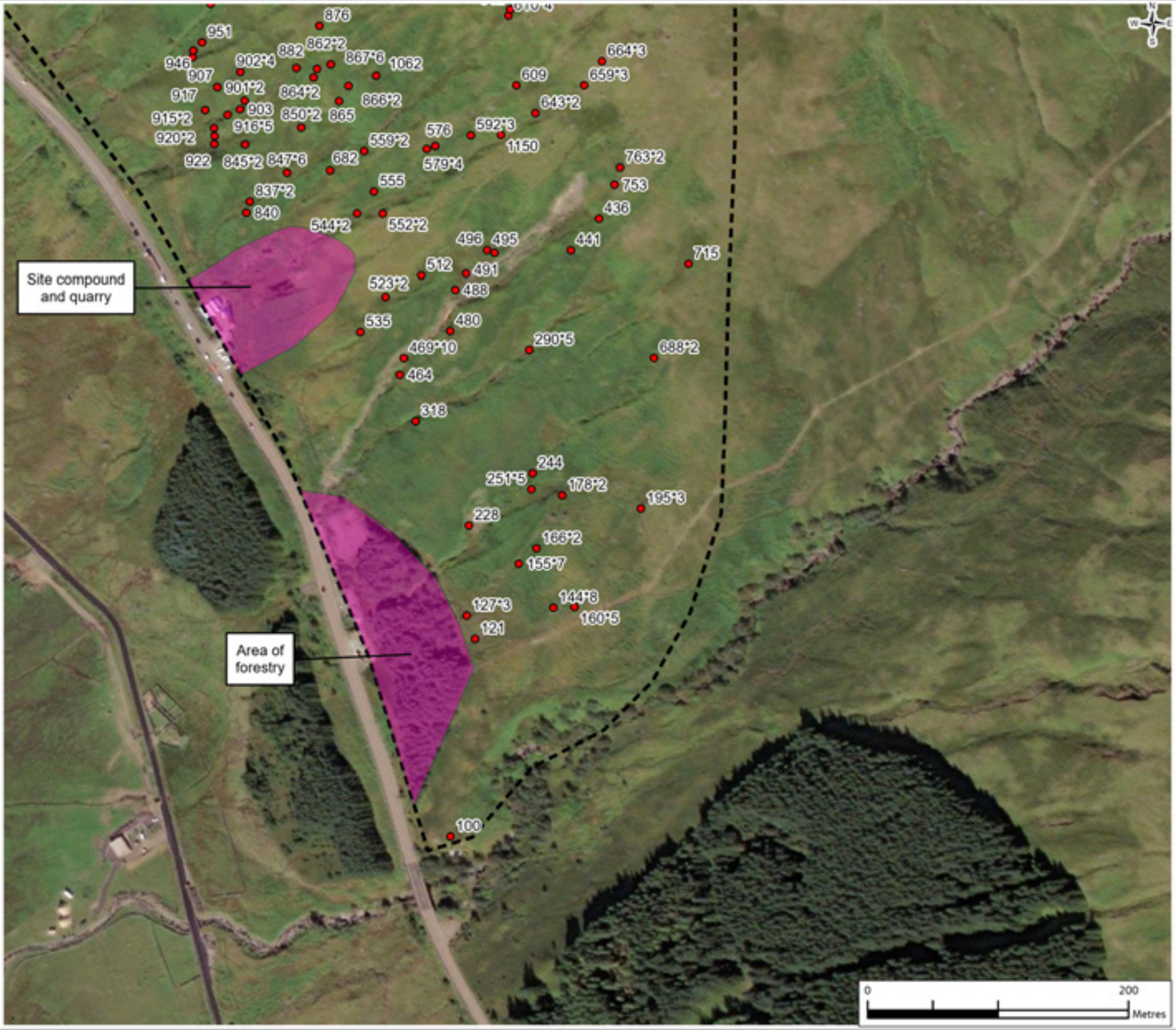

Drawing 2d

Legend

Hazard Rating

- High Hazard Boulder
- High Hazard Boulder Associated with Features A and B
- Study Area 2A
- Site features

1) *X following a boulder ID denotes the number of boulders mapped within a cluster of boulders. The hazard rating applies to the worst-case boulder within the cluster.
2) This drawing should be read in conjunction with following report "Boulder Hazards Study - Phase 2A. Boulder Hazard Inventory for A83 Beinn Luibhean."
3) Please refer to report section 2 for further information on site features.

Rev	Date	Purpose of revision	Drawn	Check'd	Rev'd	App'd
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Boulder Study
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Drawing Title
Boulder Hazard Location Plan

Sheet 4 of 4

Drawing Status
DRAFT

Scale @ A3: 1:4,000 DO NOT SCALE
Jacobs No.: B2359902
Client No.:
Drawing No.: B2359902_Draw2bd_Boulder_Study_Phase2A_Rev0_4K

Appendix B. Summary of High Hazard Boulders

B.1 Summary of High hazard boulders

Table A.1 presents a summary of the 348 boulders that have been assigned a High hazard rating using the boulder hazard matrix developed during the Phase 1 boulder hazard study. An additional 72 boulders which represent the high hazard boulders associated with Features A and B are provided in Table A.2. Corresponding photographs of the high hazard boulders are provided in Appendix B.2.

Where clusters of boulders were identified during the fieldwork, details were recorded for what was considered to be the worst-case boulder within the cluster to expedite the fieldwork. This was based on the judgement of the fieldwork team at the time. As such, it is possible that not all of the boulders within a cluster will fall into the High hazard category.

Table A1: Properties and coordinates of boulders rated high hazard

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
100	Irregular	1.1	2	0.8	224266.1	706062.6	16
121	Equant, Spherical	0.8	1	0.7	224284.9	706214.2	16
127a	Irregular	1.4	0.8	1	224278.5	706231.8	16
127b	Irregular	1.4	0.8	1	224278.5	706231.8	16
127c	Irregular	1.4	0.8	1	224278.5	706231.8	16
144a	Irregular	1	2.1	0.8	224345.1	706237.9	16
144b	Irregular	1	2.1	0.8	224345.1	706237.9	16
144c	Irregular	1	2.1	0.8	224345.1	706237.9	16
144d	Irregular	1	2.1	0.8	224345.1	706237.9	16
144e	Irregular	1	2.1	0.8	224345.1	706237.9	16
144f	Irregular	1	2.1	0.8	224345.1	706237.9	16
144g	Irregular	1	2.1	0.8	224345.1	706237.9	16
155a	Irregular	1	1.9	1.8	224318.4	706271.9	16
155b	Irregular	1	1.9	1.8	224318.4	706271.9	16
155c	Irregular	1	1.9	1.8	224318.4	706271.9	16
155d	Irregular	1	1.9	1.8	224318.4	706271.9	16
155e	Irregular	1	1.9	1.8	224318.4	706271.9	16
155f	Irregular	1	1.9	1.8	224318.4	706271.9	16

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
155g	Irregular	1	1.9	1.8	224318.4	706271.9	16
160a	Irregular	0.8	1.5	1	224361.2	706238.5	16
160b	Irregular	0.8	1.5	1	224361.2	706238.5	16
160c	Irregular	0.8	1.5	1	224361.2	706238.5	16
160d	Irregular	0.8	1.5	1	224361.2	706238.5	16
160e	Irregular	0.8	1.5	1	224361.2	706238.5	16
166a	Irregular	1.2	1.7	1.3	224332.1	706283.7	16
166b	Irregular	1.2	1.7	1.3	224332.1	706283.7	16
178a	Irregular	0.9	2.5	1	224351.7	706324.5	16
195a	Irregular	1.1	2	0.7	224412.1	706314.3	16
195b	Irregular	1.1	2	0.7	224412.1	706314.3	16
195c	Irregular	1.1	2	0.7	224412.1	706314.3	16
228	Irregular	0.6	1.7	1.3	224280.2	706301.2	14
244	Irregular	1.6	2.7	2.1	224329	706341.3	14
251a	Irregular	1.1	1.7	1.5	224328.1	706329	14
251b	Irregular	1.1	1.7	1.5	224328.1	706329	14
251c	Irregular	1.1	1.7	1.5	224328.1	706329	14
251d	Irregular	1.1	1.7	1.5	224328.1	706329	14
251e	Irregular	1.1	1.7	1.5	224328.1	706329	14
291a	Irregular	0.5	1.6	1.5	224326.4	706435.9	14
291b	Irregular	0.5	1.6	1.5	224326.4	706435.9	14
291c	Irregular	0.5	1.6	1.5	224326.4	706435.9	14
291d	Irregular	0.5	1.6	1.5	224326.4	706435.9	14
291e	Irregular	0.5	1.6	1.5	224326.4	706435.9	14
318	Irregular	0.5	2.4	2.1	224239.5	706381.3	14
436	Irregular	0.6	1.8	0.7	224379.9	706536.2	13
441	Irregular	2	2.1	0.3	224358.3	706511.9	13
464	Irregular	1.3	1.8	1	224227.2	706417	12
469a	Irregular	1.2	2.1	1.4	224230.3	706429.7	12
469b	Irregular	1.2	2.1	1.4	224230.3	706429.7	12

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
469c	Irregular	1.2	2.1	1.4	224230.3	706429.7	12
469d	Irregular	1.2	2.1	1.4	224230.3	706429.7	12
469e	Irregular	1.2	2.1	1.4	224230.3	706429.7	12
469f	Irregular	1.2	2.1	1.4	224230.3	706429.7	12
469g	Irregular	1.2	2.1	1.4	224230.3	706429.7	12
469h	Irregular	1.2	2.1	1.4	224230.3	706429.7	12
469i	Irregular	1.2	2.1	1.4	224230.3	706429.7	12
469j	Irregular	1.2	2.1	1.4	224230.3	706429.7	12
480	Irregular	0.6	1.7	1	224265.9	706450.5	12
488	Irregular	1.1	1.9	0.5	224269.8	706482	12
491	Irregular	0.8	1.5	1.7	224278.1	706494.2	12
495	Irregular	1.1	1.5	1.9	224294.2	706512	12
496	Irregular	1	1.1	1	224299.8	706510.1	12
512	Irregular	2.2	2.6	0.5	224243.7	706492.8	12
523a	Irregular	0.9	2.1	1	224216.2	706476.5	12
523b	Irregular	0.9	2.1	1	224216.2	706476.5	12
535	Irregular	1	2.8	1.5	224197	706449.8	12
544a	Irregular	2	1.6	1.5	224194.4	706540.2	12
544b	Irregular	2	1.6	1.5	224194.4	706540.2	12
552a	Irregular	0.9	1.8	1.1	224214.2	706540	12
552b	Irregular	0.9	1.8	1.1	224214.2	706540	12
555	Irregular	1.4	1.2	1	224207.4	706557	12
559a	Irregular	1.1	2.3	1.4	224199.9	706588.1	12
559b	Irregular	1.1	2.3	1.4	224199.9	706588.1	12
576	Irregular	0.7	1.9	1.5	224247.9	706589.7	12
579a	Irregular	1.9	1.5	2	224254.4	706592	11
579b	Irregular	1.9	1.5	2	224254.4	706592	11
579c	Irregular	1.9	1.5	2	224254.4	706592	11
579d	Irregular	1.9	1.5	2	224254.4	706592	11
592a	Irregular	1.2	1.9	1.6	224281.7	706600.2	11

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
592b	Irregular	1.2	1.9	1.6	224281.7	706600.2	11
592c	Irregular	1.2	1.9	1.6	224281.7	706600.2	11
609	Irregular	1.4	2.3	1.9	224316.5	706638.6	11
610a	Irregular	1	1.2	1	224310.5	706692.1	11
610b	Irregular	1	1.2	1	224310.5	706692.1	11
610c	Irregular	1	1.2	1	224310.5	706692.1	11
610d	Irregular	1	1.2	1	224310.5	706692.1	11
612	Irregular	1.3	1	2	224311.9	706696.8	11
643a	Irregular	0.6	1.9	1.1	224331.2	706617.3	11
643b	Irregular	0.6	1.9	1.1	224331.2	706617.3	11
659a	Irregular	1	3	2.5	224368.6	706638.6	11
659b	Irregular	1	3	2.5	224368.6	706638.6	11
659c	Irregular	1	3	2.5	224368.6	706638.6	11
664a	Irregular	1	1.4	0.8	224382.2	706657	11
664b	Irregular	1	1.4	0.8	224382.2	706657	11
664c	Irregular	1	1.4	0.8	224382.2	706657	11
682	Irregular	0.9	1.7	1.4	224173.7	706573.2	12
688a	Irregular	0.6	1.3	1	224422.1	706429.9	13
688b	Irregular	0.6	1.3	1	224422.1	706429.9	13
715	Irregular	0.7	2	1.3	224448.6	706501.5	13
753	Irregular	0.8	1.8	1.4	224391.9	706562.3	11
763a	Irregular	0.8	1.7	1.1	224396.1	706575.4	11
763b	Irregular	0.8	1.7	1.1	224396.1	706575.4	11
837a	Irregular	2	3.1	1.6	224112.2	706549.3	10
837b	Irregular	2	3.1	1.6	224112.2	706549.3	10
840	Irregular	1.3	2	1.7	224109.5	706540.7	10
845a	Equant_Spherical	1.4	1.6	1.2	224108.6	706593.1	10
845b	Equant_Spherical	1.4	1.6	1.2	224108.6	706593.1	10
847a	Irregular	0.7	2.1	1.6	224140.8	706571.4	10
847b	Irregular	0.7	2.1	1.6	224140.8	706571.4	10

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
847c	Irregular	0.7	2.1	1.6	224140.8	706571.4	10
847d	Irregular	0.7	2.1	1.6	224140.8	706571.4	10
850a	Irregular	1.1	2.6	1.4	224151.6	706606.1	10
850b	Irregular	1.1	2.6	1.4	224151.6	706606.1	10
862a	Irregular	1	1.7	1.2	224161.1	706644.6	10
862b	Irregular	1	1.7	1.2	224161.1	706644.6	10
864a	Irregular	2.1	1.9	0.6	224163.8	706651.2	10
864b	Irregular	2.1	1.9	0.6	224163.8	706651.2	10
865	Irregular	0.7	1.8	1	224180.6	706626.4	10
866a	Irregular	1	1.7	1.5	224187.9	706638.2	10
866b	Irregular	1	1.7	1.5	224187.9	706638.2	10
867a	Irregular	2.6	3.4	0.5	224174.4	706654.6	10
867b	Irregular	2.6	3.4	0.5	224174.4	706654.6	10
867c	Irregular	2.6	3.4	0.5	224174.4	706654.6	10
867d	Irregular	2.6	3.4	0.5	224174.4	706654.6	10
867e	Irregular	2.6	3.4	0.5	224174.4	706654.6	10
867f	Irregular	2.6	3.4	0.5	224174.4	706654.6	10
876	Irregular	0.7	2.2	1.5	224165.6	706684.2	10
882	Irregular	1.1	2.1	2.4	224148	706651.8	10
901a	Irregular	0.9	1.5	1	224108.2	706626.8	10
901b	Irregular	0.9	1.5	1	224108.2	706626.8	10
902a	Irregular	0.8	2.3	1.5	224105	706648.8	10
902b	Irregular	0.8	2.3	1.5	224105	706648.8	10
902c	Irregular	0.8	2.3	1.5	224105	706648.8	10
902d	Irregular	0.8	2.3	1.5	224105	706648.8	10
903	Irregular	1.3	2.1	0.7	224104.7	706620.1	10
907	Irregular	1.5	2.3	1.5	224087.3	706637.1	10
915a	Irregular	0.9	1.9	2	224084.8	706605.8	10
915b	Irregular	0.9	1.9	2	224084.8	706605.8	10
916a	Irregular	0.9	2.3	1.7	224095.2	706615.9	10

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
916b	Irregular	0.9	2.3	1.7	224095.2	706615.9	10
916c	Irregular	0.9	2.3	1.7	224095.2	706615.9	10
916d	Irregular	0.9	2.3	1.7	224095.2	706615.9	10
916e	Irregular	0.9	2.3	1.7	224095.2	706615.9	10
917	Equant_Spherical	0.5	1	1	224078	706619.6	10
920a	Irregular	1.3	2.1	1.2	224085.2	706599.6	10
920b	Irregular	1.3	2.1	1.2	224085.2	706599.6	10
922	Irregular	0.5	2.1	1.4	224085	706593.4	10
944b	Irregular	0.6	2.1	1.5	224068.4	706660.1	10
946	Irregular	1	1.8	1.5	224068.9	706665.2	10
951	Irregular	0.8	1.9	1.3	224075.6	706671.6	10
961	Irregular	0.9	2.1	1.5	224082.2	706701	10
978	Irregular	0.7	2.3	1.4	224145.2	706704.2	10
991a	Irregular	0.6	1.7	1.1	224119	706744.5	10
991b	Irregular	0.6	1.7	1.1	224119	706744.5	10
991c	Irregular	0.6	1.7	1.1	224119	706744.5	10
991d	Irregular	0.6	1.7	1.1	224119	706744.5	10
991e	Irregular	0.6	1.7	1.1	224119	706744.5	10
991f	Irregular	0.6	1.7	1.1	224119	706744.5	10
991g	Irregular	0.6	1.7	1.1	224119	706744.5	10
991h	Irregular	0.6	1.7	1.1	224119	706744.5	10
991i	Irregular	0.6	1.7	1.1	224119	706744.5	10
991j	Irregular	0.6	1.7	1.1	224119	706744.5	10
996a	Irregular	0.7	2	1.4	224072.3	706760.3	10
996b	Irregular	0.7	2	1.4	224072.3	706760.3	10
996c	Irregular	0.7	2	1.4	224072.3	706760.3	10
1021a	Irregular	0.7	1.9	1.5	224051.3	706767.7	8
1021b	Irregular	0.7	1.9	1.5	224051.3	706767.7	8
1023a	Irregular	1.3	2	1.6	224045.5	706762.2	8
1023b	Irregular	1.3	2	1.6	224045.5	706762.2	8

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
1028	Irregular	1	1.8	1.3	224029.4	706757.8	8
1032a	Irregular	0.8	2	1.6	224030.2	706745.8	8
1032b	Irregular	0.8	2	1.6	224030.2	706745.8	8
1032c	Irregular	0.8	2	1.6	224030.2	706745.8	8
1044a	Irregular	1	1.7	1.2	223998.6	706749.4	8
1044b	Irregular	1	1.7	1.2	223998.6	706749.4	8
1044c	Irregular	1	1.7	1.2	223998.6	706749.4	8
1050	Irregular	1	1.5	2	223987	706714.3	8
1062	Irregular	2.3	1.9	2	224209.1	706646	9
1092	Irregular	1	1.5	0.8	224204	706705.8	9
1113	Irregular	1.7	1.1	0.8	224240.6	706737.6	9
1124	Irregular	1.1	1.7	1.4	224255.7	706713.6	9
1150	Irregular	1.2	1.7	2	224304.7	706600.5	11
1200a	Irregular	0.7	2	1.3	224425.9	706709.6	9
1200b	Irregular	0.7	2	1.3	224425.9	706709.6	9
1200c	Irregular	0.7	2	1.3	224425.9	706709.6	9
1200d	Irregular	0.7	2	1.3	224425.9	706709.6	9
1220a	Irregular	1.1	1.8	2.6	223917	706752.1	8
1220b	Irregular	1.1	1.8	2.6	223917	706752.1	8
1223a	Irregular	1.6	2	2.6	223936.8	706783.4	8
1223b	Irregular	1.6	2	2.6	223936.8	706783.4	8
1223c	Irregular	1.6	2	2.6	223936.8	706783.4	8
1223d	Irregular	1.6	2	2.6	223936.8	706783.4	8
1229	Irregular	0.5	1.4	1	223995.5	706814.7	8
1238	Irregular	1.6	1	1.2	224010	706837.7	8
1258a	Irregular	1.7	1.5	1	224055.3	706931.9	7
1258b	Irregular	1.7	1.5	1	224055.3	706931.9	7
1258c	Irregular	1.7	1.5	1	224055.3	706931.9	7
1261	Irregular	1.7	1	0.7	224070.1	706935.4	7
1310a	Irregular	1.9	2.3	1.5	224191.3	706943.4	7

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
1310b	Irregular	1.9	2.3	1.5	224191.3	706943.4	7
1310c	Irregular	1.9	2.3	1.5	224191.3	706943.4	7
1310d	Irregular	1.9	2.3	1.5	224191.3	706943.4	7
1348	Irregular	1.5	2.5	2	224072.7	706822.5	7
1355	Irregular	2	2.7	1.9	224058.2	706873.7	7
1365a	Irregular	1.2	1.9	1	224048.8	706904.1	7
1365b	Irregular	1.2	1.9	1	224048.8	706904.1	7
1388	Irregular	1	1.2	0.9	224151.2	706814.6	9
1428a	Irregular	1.1	1	1.3	224205.7	706881	9
1428b	Irregular	1.1	1	1.3	224205.7	706881	9
1457	Irregular	0.8	2	2.4	223991.4	707004.4	5
1496	Irregular	1.5	2.6	2	223818.6	706891.6	6
1509	Irregular	0.7	1.3	1.4	223934.1	706931.5	6
1605	Irregular	0.5	2	3	223826.3	706901.3	6
1624a	Irregular	0.6	1.7	1.2	223840.7	707017.6	6
1624b	Irregular	0.6	1.7	1.2	223840.7	707017.6	6
1624c	Irregular	0.6	1.7	1.2	223840.7	707017.6	6
1629	Irregular	1.2	0.8	1.4	223842.9	706922.2	6
1712a	Irregular	0.9	1.8	1.3	224024.7	707103.2	5
1712b	Irregular	0.9	1.8	1.3	224024.7	707103.2	5
1712c	Irregular	0.9	1.8	1.3	224024.7	707103.2	5
1805	Irregular	1.2	1.1	2	223954.5	706995.7	5
1822	Irregular	1.4	2.7	3	223996.8	706971.8	5
1829	Irregular	1.1	2.5	1.9	224031.2	707001.2	5
2530	Irregular	0.3	1.8	1.6	224287.2	706975.9	19
2553	Irregular	1.6	2.1	2	224325.4	707016.9	19
2589	Irregular	2	6	1	224279.5	707024.7	19
2593	Irregular	0.5	1.7	1.5	224277.1	707020.5	19
2641	Irregular	1.6	3	1	224204.1	706989.2	19
2696	Irregular	1.6	3	2	223710.3	707135.3	4

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
2716a	Irregular	1	2	1.5	223713.8	707157.2	4
2716b	Irregular	1	2	1.5	223713.8	707157.2	4
2817	Irregular	0.7	1.5	1	223750.2	707179.4	3
2907	Irregular	0.4	1.7	1.5	223706.2	707333.6	3
2929	Irregular	1.3	2	1.8	223849	707254	3
2935a	Irregular	0.5	1.8	1.4	223746	707285.2	3
2935b	Irregular	0.5	1.8	1.4	223746	707285.2	3
2935c	Irregular	0.5	1.8	1.4	223746	707285.2	3
2935d	Irregular	0.5	1.8	1.4	223746	707285.2	3
2937a	Irregular	0.8	1.9	1.1	223745.8	707279.9	3
2937b	Irregular	0.8	1.9	1.1	223745.8	707279.9	3
2937c	Irregular	0.8	1.9	1.1	223745.8	707279.9	3
2937d	Irregular	0.8	1.9	1.1	223745.8	707279.9	3
2973a	Irregular	0.6	2	1.5	223710.7	707347.3	3
2973b	Irregular	0.6	2	1.5	223710.7	707347.3	3
2973c	Irregular	0.6	2	1.5	223710.7	707347.3	3
2973d	Irregular	0.6	2	1.5	223710.7	707347.3	3
2974	Irregular	1.4	2	1.5	223813.8	707281.9	3
3071	Equant_Spherical	3	2.5	3	223805	707443.7	22
3184a	Irregular	1.5	2.5	2	223878.6	707289.9	22
3184b	Irregular	1.5	2.5	2	223878.6	707289.9	22
3184c	Irregular	1.5	2.5	2	223878.6	707289.9	22
3187a	Irregular	1.4	2	1.6	223882.4	707286.8	22
3187b	Irregular	1.4	2	1.6	223882.4	707286.8	22
3187c	Irregular	1.4	2	1.6	223882.4	707286.8	22
3194	Irregular	0.8	1.5	1.1	223893.2	707293.2	22
3209	Irregular	0.7	2.5	2	223903.9	707305.8	22
3234a	Irregular	2	1.6	1.2	223481.7	707331.8	2
3234b	Irregular	2	1.6	1.2	223481.7	707331.8	2
3234c	Irregular	2	1.6	1.2	223481.7	707331.8	2

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
3234d	Irregular	2	1.6	1.2	223481.7	707331.8	2
3249	Irregular	1.3	2	1.2	223835.8	707321.8	22
3282	Irregular	1.1	2.2	1.6	223876.1	707339.7	22
3314	Irregular	1	2	1.4	223989.5	707381.7	24
3322a	Irregular	1.5	2.5	2	224002.7	707393	24
3322b	Irregular	1.5	2.5	2	224002.7	707393	24
3376	Irregular	1.1	2	1.4	223985.7	707422.5	24
3497	Irregular	1.3	2	1.5	223897.9	707477.7	24
3519a	Irregular	0.9	1.2	1.5	223912.1	706870.9	8
3519b	Irregular	0.9	1.2	1.5	223912.1	706870.9	8
3519c	Irregular	0.9	1.2	1.5	223912.1	706870.9	8
3519d	Irregular	0.9	1.2	1.5	223912.1	706870.9	8
3520	Irregular	0.8	2	1.1	223555.9	707286.6	2
3522	Irregular	2	1.5	1.8	223922.8	706876.3	8
3525a	Irregular	2	2.5	1	223925.2	706880.9	8
3525b	Irregular	2	2.5	1	223925.2	706880.9	8
3525c	Irregular	2	2.5	1	223925.2	706880.9	8
3528a	Irregular	3	2	2	223936.3	706872.5	6
3528b	Irregular	3	2	2	223936.3	706872.5	6
3528c	Irregular	3	2	2	223936.3	706872.5	6
3528d	Irregular	3	2	2	223936.3	706872.5	6
3528e	Irregular	3	2	2	223936.3	706872.5	6
3538	Irregular	1	2	2	223948	706896.9	8
3587a	Irregular	1.5	2.5	2	223549	707386.8	2
3587b	Irregular	1.5	2.5	2	223549	707386.8	2
3597	Irregular	3	0.4	1	223999.7	706931.5	7
3601	Irregular	2	1.5	2	224002.9	706919.7	7
3607	Irregular	0.8	1.4	1	224028.8	706947.8	7
3621a	Irregular	1.1	3	1.7	223497.3	707396.1	2
3621b	Irregular	1.1	3	1.7	223497.3	707396.1	2

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
3621c	Irregular	1.1	3	1.7	223497.3	707396.1	2
3621d	Irregular	1.1	3	1.7	223497.3	707396.1	2
3621e	Irregular	1.1	3	1.7	223497.3	707396.1	2
3621f	Irregular	1.1	3	1.7	223497.3	707396.1	2
3621g	Irregular	1.1	3	1.7	223497.3	707396.1	2
3621h	Irregular	1.1	3	1.7	223497.3	707396.1	2
3621i	Irregular	1.1	3	1.7	223497.3	707396.1	2
3621j	Irregular	1.1	3	1.7	223497.3	707396.1	2
3649	Irregular	1.5	2	1.6	223564.6	707384.9	2
3724	Irregular	1	2	1.8	223603.6	707409.5	2
3724	Irregular	1	2	1.8	223603.6	707409.5	2
3724	Irregular	1	2	1.8	223603.6	707409.5	2
3724	Irregular	1	2	1.8	223603.6	707409.5	2
3767a	Irregular	2	3	2	223587	707487.4	1
3767b	Irregular	2	3	2	223587	707487.4	1
3767c	Irregular	2	3	2	223587	707487.4	1
3767d	Irregular	2	3	2	223587	707487.4	1
3811	Irregular	1.5	2.5	1.5	223610.7	707537.6	23
3821a	Irregular	1.1	2.5	1.7	223638.3	707524.4	23
3844a	Irregular	1.7	2.5	2	223636	707588.4	23
3844b	Irregular	1.7	2.5	2	223636	707588.4	23
3844c	Irregular	1.7	2.5	2	223636	707588.4	23
3844d	Irregular	1.7	2.5	2	223636	707588.4	23
3953	Irregular	2	1.5	2.3	224090.3	707007.9	7
3956	Irregular	1.4	2	1.7	224080.1	706997	7
3959	Irregular	1	1.5	1.5	224107.3	707018.9	7
3963a	Irregular	0.7	1.7	1.5	224135.2	707111.8	20
3971	Irregular	1.7	2.2	1.5	224142.8	707096.6	20
4000	Irregular	1.8	2.5	2	224177	707121.7	20
4002	Irregular	1.3	2.5	1.8	224177.7	707112.7	20

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
4039	Irregular	1.1	1.5	1.3	224216.6	707170.7	20
4080a	Irregular	2	3	2	224026.6	707150.7	20
4080b	Irregular	2	3	2	224026.6	707150.7	20
4080c	Irregular	2	3	2	224026.6	707150.7	20
4087a	Irregular	0.8	1.5	1	224082.2	707105.7	20
4087b	Irregular	0.8	1.5	1	224082.2	707105.7	20
4089	Irregular	2	1.6	2	224039.7	707159.5	20
4129	Irregular	1.5	2	1.7	224112.9	707162.8	20
4145	Irregular	0.9	1.7	1.4	224125	707118	20
4190	Irregular	1.6	2.5	2	224160.2	707162.2	20
4205	Irregular	0.6	2.2	1.7	224206.8	707178.4	20
4241a	Irregular	0.5	1.8	1.4	223856	707499.6	24
4243	Irregular	1.2	2	1.6	223847.8	707509.3	24
4258a	Irregular	1.2	1.7	1.4	223851	707518.4	24
4258b	Irregular	1.2	1.7	1.4	223851	707518.4	24
4273	Irregular	0.8	2	1.4	223894.6	707523.4	24
4333a	Irregular	1.5	2.7	2	223819.8	707639.8	24
4333b	Irregular	1.5	2.7	2	223819.8	707639.8	24
4333c	Irregular	1.5	2.7	2	223819.8	707639.8	24
4333d	Irregular	1.5	2.7	2	223819.8	707639.8	24
B2	Spherical	2.2	2.1	1.2	223680.7	707041.0	Phase 1
B18	Spherical	1.2	1.2	1.5	223745.5	707070.2	Phase 1
B19	Irregular	1.8	0.9	1.2	223719.5	707081.5	Phase 1
B23	Irregular	2.0	1.6	1.2	223738.7	707126.9	Phase 1
B37	Irregular	2.2	1.8	1.5	223748.7	707112.7	Phase 1
B64	Irregular	1.8	1.2	1.0	223886.3	707240.0	Phase 1
B91	Irregular	2.3	2.1	1.1	223851.0	707118.3	Phase 1
A122	Irregular	2.5	2.2	1.5	223688.3	707076.6	Phase 1
A127	Irregular	1.7	1.3	0.7	223693.1	707046.0	Phase 1

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
A289	Irregular	1.3	1.5	3.0	223944.7	707153.8	Phase 1

Table A1: Properties and coordinates of boulders associated with Features A and B rated high hazard

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
3521a	Irregular	1.3	1.7	3	223545.2544	707293.4986	2
3521b	Irregular	1.3	1.7	3	223545.2544	707293.4986	2
3521c	Irregular	1.3	1.7	3	223545.2544	707293.4986	2
3521d	Irregular	1.3	1.7	3	223545.2544	707293.4986	2
3521e	Irregular	1.3	1.7	3	223545.2544	707293.4986	2
3527	Irregular	10	10	15	223528.4887	707314.1423	2
3529a	Irregular	4.5	5	7	223519.6992	707319.8607	2
3529b	Irregular	4.5	5	7	223519.6992	707319.8607	2
3529c	Irregular	4.5	5	7	223519.6992	707319.8607	2
3529d	Irregular	4.5	5	7	223519.6992	707319.8607	2
3529e	Irregular	4.5	5	7	223519.6992	707319.8607	2
3539a	Irregular	2	2.5	3	223530.2576	707338.75	2
3539b	Irregular	2	2.5	3	223530.2576	707338.75	2
3539c	Irregular	2	2.5	3	223530.2576	707338.75	2
3539d	Irregular	2	2.5	3	223530.2576	707338.75	2
3539e	Irregular	2	2.5	3	223530.2576	707338.75	2
3539f	Irregular	2	2.5	3	223530.2576	707338.75	2
3539g	Irregular	2	2.5	3	223530.2576	707338.75	2
3539h	Irregular	2	2.5	3	223530.2576	707338.75	2
3539i	Irregular	2	2.5	3	223530.2576	707338.75	2
3539j	Irregular	2	2.5	3	223530.2576	707338.75	2
3543a	Irregular	3	2	5	223544.7958	707329.3502	2
3543b	Irregular	3	2	5	223544.7958	707329.3502	2
3543c	Irregular	3	2	5	223544.7958	707329.3502	2
3543d	Irregular	3	2	5	223544.7958	707329.3502	2
3543e	Irregular	3	2	5	223544.7958	707329.3502	2
3543f	Irregular	3	2	5	223544.7958	707329.3502	2
3543g	Irregular	3	2	5	223544.7958	707329.3502	2
3543h	Irregular	3	2	5	223544.7958	707329.3502	2

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
3543i	Irregular	3	2	5	223544.7958	707329.3502	2
3543j	Irregular	3	2	5	223544.7958	707329.3502	2
3611a	Irregular	7	5	5	223532.5904	707345.6429	2
3611b	Irregular	7	5	5	223532.5904	707345.6429	2
3611c	Irregular	7	5	5	223532.5904	707345.6429	2
3611d	Irregular	7	5	5	223532.5904	707345.6429	2
3611e	Irregular	7	5	5	223532.5904	707345.6429	2
3616a	Irregular	2.5	3	4	223532.2174	707340.101	2
3616b	Irregular	2.5	3	4	223532.2174	707340.101	2
3616c	Irregular	2.5	3	4	223532.2174	707340.101	2
3616d	Irregular	2.5	3	4	223532.2174	707340.101	2
3616e	Irregular	2.5	3	4	223532.2174	707340.101	2
3616f	Irregular	2.5	3	4	223532.2174	707340.101	2
3616g	Irregular	2.5	3	4	223532.2174	707340.101	2
3616h	Irregular	2.5	3	4	223532.2174	707340.101	2
3616i	Irregular	2.5	3	4	223532.2174	707340.101	2
3616j	Irregular	2.5	3	4	223532.2174	707340.101	2
3618a	Irregular	10	15	20	223510.1496	707343.3245	2
3618b	Irregular	10	15	20	223510.1496	707343.3245	2
3618c	Irregular	10	15	20	223510.1496	707343.3245	2
3618d	Irregular	10	15	20	223510.1496	707343.3245	2
3618e	Irregular	10	15	20	223510.1496	707343.3245	2
3728	Irregular	2.5	5	8	223583.6708	707428.2103	2
3764a	Irregular	5	3	4	223617.1882	707433.427	1
3764b	Irregular	5	3	4	223617.1882	707433.427	1
3764c	Irregular	5	3	4	223617.1882	707433.427	1
3765a	Irregular	3	3	5	223612.3908	707442.1311	1
3765b	Irregular	3	3	5	223612.3908	707442.1311	1
3765c	Irregular	3	3	5	223612.3908	707442.1311	1
3765d	Irregular	3	3	5	223612.3908	707442.1311	1

Boulder Ref.	Shape	Length (m)	Breadth (m)	Height (m)	X Coordinate	Y Coordinate	Parcel No.
3766a	Irregular	10	8	14	223601.9384	707457.1601	1
3766b	Irregular	10	8	14	223601.9384	707457.1601	1
3766c	Irregular	10	8	14	223601.9384	707457.1601	1
3766d	Irregular	10	8	14	223601.9384	707457.1601	1
3766e	Irregular	10	8	14	223601.9384	707457.1601	1
3770a	Irregular	5	4	7	223607.5577	707486.4452	1
3770b	Irregular	5	4	7	223607.5577	707486.4452	1
3770c	Irregular	5	4	7	223607.5577	707486.4452	1
3770d	Irregular	5	4	7	223607.5577	707486.4452	1
3780a	Irregular	2	3	5	223620.1527	707483.1739	1
3780b	Irregular	2	3	5	223620.1527	707483.1739	1
3780c	Irregular	2	3	5	223620.1527	707483.1739	1
3780d	Irregular	2	3	5	223620.1527	707483.1739	1

B.2 Photographs of High hazard boulders

<table>
<tr><th>Boulder 100</th><th>Boulder 121</th></tr>
<tr><td></td><td></td></tr>
<tr><th>Boulder 127a-c</th><th>Boulder 144a-g</th></tr>
<tr><td></td><td></td></tr>
</table>

Boulder 127a-c	Boulder 144a-g
	
Boulder 155a-g	Boulder 160 a-e (boulder 160a shown in photo)
	

Boulder 166a-b	Boulder 178a
	

Boulder 195a-c (boulder 195a shown in photo)	Boulder 228
	
Boulder 244	Boulder 251a-e
	

Boulder 291a-e	Boulder 318
	
Boulder 436	**Boulder 441**
	

Boulder 464	Boulder 469a-j
	
Boulder 480	Boulder 488
	

Boulder 491	Boulder 495
	
Boulder 496	Boulder 512
	

Boulder 523a-b	Boulder 535
	
Boulder 544a-b	Boulder 552a-b
	

Boulder 555	Boulder 559a-b
	
Boulder 576	**Boulder 579a-d**
	

Boulder 592a-c	Boulder 609
	
Boulder 610a-d	Boulder 612
	

Boulder 643	Boulder 659
	
Boulder 664	Boulder 682
	

Boulder 688	Boulder 715
NO PHOTO AVAILABLE	
Boulder 753	**Boulder 763**
	

Boulder 837	Boulder 840
	
Boulder 845	Boulder 847
	

Boulder 850	Boulder 862
	
Boulder 864	Boulder 865
	

Boulder 866	Boulder 867
	
Boulder 876	Boulder 882
	

Boulder 901	Boulder 902
	
Boulder 903	**Boulder 907**
	

Boulder 915	Boulder 916
	
Boulder 917	**Boulder 920**
	

Boulder 922	Boulder 944
	
Boulder 946	Boulder 951
	

Boulder 961	Boulder 978
	
Boulder 991	**Boulder 996**
	

Boulder 1021	Boulder 1023
	
Boulder 1028	Boulder 1032
	

Boulder 1044	Boulder 1050
	
Boulder 1062	Boulder 1092
	

Boulder 1113	Boulder 1124
	
Boulder 1150	**Boulder 1200**
	

Boulder 1223	Boulder 1229
	
Boulder 1238	**Boulder 1258**
	

Boulder 1261	Boulder 1310
	
Boulder 1348	Boulder 1355
	

Boulder 1365	Boulder 1388
	
Boulder 1428	Boulder 1457
	

Boulder 1496	Boulder 1509
	
Boulder 1605	Boulder 1624
	

Boulder 1629	Boulder 1712
	
Boulder 1805	**Boulder 1822**
	

Boulder 1829	Boulder 2530
	
Boulder 2553	Boulder 2589
	

Boulder 2593	Boulder 2641
	
Boulder 2696	Boulder 2716
	

Boulder 2817	Boulder 2907
	
Boulder 2929	Boulder 2935
	

Boulder 2937	Boulder 2973
	
Boulder 2974	Boulder 3071
	

Boulder 3184	Boulder 3187
	
Boulder 3194	Boulder 3209
	

Boulder 3234	Boulder 3249
	
Boulder 3282	Boulder 3314
	

Boulder 3322	Boulder 3376
	
Boulder 3497	Boulder 3519
	

Boulder 3520	Boulder 3521
	
Boulder 3522	Boulder 3525
	

Boulder 3528	Boulder 3538
	
Boulder 3587	Boulder 3597
	

Boulder 3601	Boulder 3607
	
Boulder 3621	Boulder 3649
	

Boulder 3724	Boulder 3767
	
Boulder 3811	Boulder 3821
	

Boulder 3844	Boulder 3953
	
Boulder 3956	Boulder 3959
	

Boulder 3963	Boulder 3971
	
Boulder 4000	Boulder 4002
	

Boulder 4039	Boulder 4080
	
Boulder 4087	Boulder 4089
	

Boulder 4129	Boulder 4145
	
Boulder 4190	Boulder 4205
	

Boulder 4241	Boulder 4243
	
Boulder 4258	Boulder 4273
	

Boulder 4333	Boulder B2 (Phase 1)
	
Boulder B18 (Phase 1)	Boulder B19 (Phase 1)
	

Boulder B23 (Phase 1)	Boulder B37 (Phase 1)
	
Boulder B64 (Phase 1)	Boulder B91 (Phase 1)
	

Boulder A122 (Phase 1)	Boulder A127 (Phase 1)
	
Boulder A289 (Phase 1)	Boulder
	

Boulder 3521 (Feature A)	Boulder 3527 (Feature A)
	
Boulder 3529 (Feature A)	Boulder 3539 (Feature A)
	

Boulder 3543 (Feature A)	Boulder 3611 (Feature A)
	
Boulder 3616 (Feature A)	Boulder 3618 (Feature A)
	

Boulder 3728 (Feature A)	Boulder 3764 (Feature B)
	
Boulder 3765 (Feature B)	Boulder 3766 (Feature B)
	

Boulder 3770 (Feature B)	Boulder 3780 (Feature B)
	

Appendix C. Digital Data

C.1 Boulder inventory and hazard assessment spreadsheet

C.2 Site photographs

C.3 GIS shapefiles