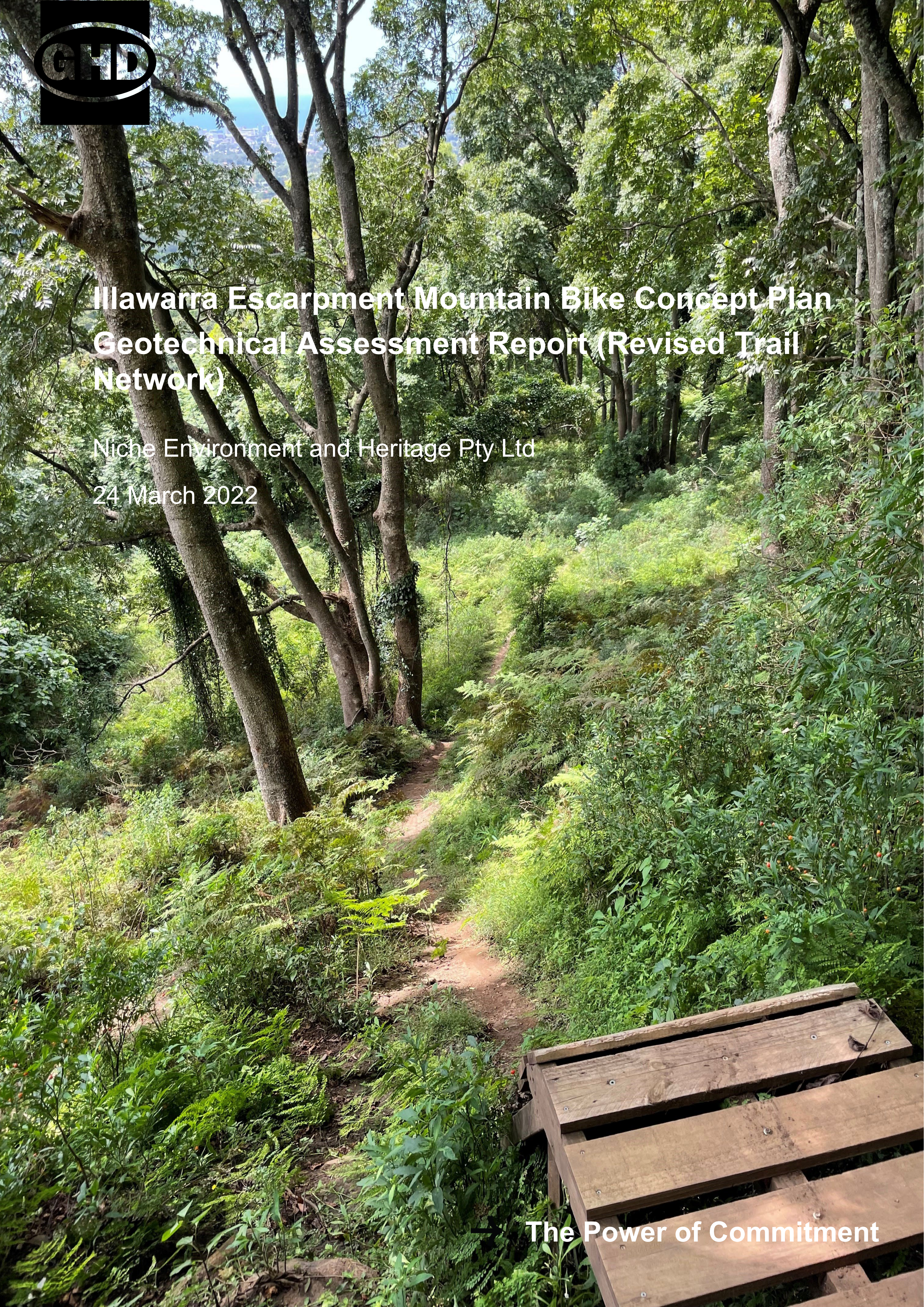


Illawarra Escarpment Mountain Bike Concept Plan Geotechnical Assessment Report (Revised Trail Network)

Niche Environment and Heritage Pty Ltd

24 March 2022

The Power of Commitment

GHD Pty Ltd | ABN 39 008 488 373

29 Christie Street, Level 2

St Leonards, New South Wales 2065, Australia

T +61 2 9462 4700 | **F** +61 2 9462 4710 | **E** slnmail@ghd.com | **ghd.com**

Printed date	24/03/2022 11:34:00 PM
Last saved date	24 March 2022
File name	https://projectsportal.ghd.com/sites/pp15_05/illawarraescarpmentm/ProjectDocs/12547309-REP-1_Illawarra Escarpment Mountain Bike Concept Plan - Geotechnical Assessment Report_Revised Trails.docx
Author	David Field, Andrew Hunter, Daniel Deen
Project manager	Daniel Deen
Client name	Niche Environment and Heritage Pty Ltd
Project name	Illawarra Escarpment Mountain Bike Concept Plan
Document title	Illawarra Escarpment Mountain Bike Concept Plan | Geotechnical Assessment Report (Revised Trail Network)
Revision version	Rev 1
Project number	12547309

Document status

Status Code	Revision	Author	Reviewer		Approved for issue		
			Name	Signature	Name	Signature	Date
S3	0	D. Field A. Hunter D. Deen	J. Thompson	<on file>	J. Thompson	<on file>	03/11/2021
S3	1	D. Field A. Hunter D. Deen	J. Thompson	<on file>	J. Thompson	<on file>	24/03/2022
[Status code]							
[Status code]							
[Status code]							

Executive summary

GHD Pty Ltd (GHD) has been engaged by Niche Environment and Heritage Pty Ltd (Niche), who are working on behalf of New South Wales National Parks and Wildlife Service (NPWS), to undertake a geotechnical assessment for the Illawarra Escarpment Mountain Bike Concept Plan. As sub-consultant to Niche, GHD is providing specialist advice to Niche on the geotechnical hazards and associated risks with the development of the mountain bike network, as part of their broader environmental service offering to NPWS.

The revised trail network has been developed by NPWS and their selected construction contractor, Synergy Trails Pty Ltd (Synergy). The network design provided to GHD by Niche includes both individual trail numbering and colour-based difficulty classification systems. Where trail numbers or colours are referred to in this report, they are in accordance with the design provided to us.

As part of our geotechnical assessment, GHD has carried out a desktop geological hazard study of the area covered by the trail network, as well as walking a large portion of the proposed trails.

Based on the results of the desktop study and fieldwork, we have undertaken a risk assessment of conceivable landslide hazards observed during our assessment. The individual loss of life risks and societal risks from our assessment are within the acceptable ranges as proposed by AGS (2007c) and NPWS (2020) respectively.

While we did not observe specific geotechnical hazards necessitating deviation or re-routing of trails, it should be recognised that the occurrence of rapid landslides (such as rockfalls or debris flows) could locally damage trail infrastructure. Our assessment of such events is statistical, and as such, it is not possible to accurately predict their location or frequency. Furthermore, the trails traverse inferred, slow moving landslides which may exhibit creep behaviour now, or in the future. Over time, this may lead to deviation, deformation, tree falls, or other adverse changes to the trails. It is therefore recommended that periodic inspection and, where necessary, maintenance of the trails be undertaken to manage these hazards and their effects.

The assessment does not assess risk to persons occupying the trails for other purposes, such as construction teams that may occupy the area for longer periods of time to undertake initial construction, remedial or upgrade works to the trails. This would require careful consideration of the specific project construction requirements and measures to be included in the project health and safety plan.

We recommend that decisions about acceptable and / or tolerable risk and risk management be based on the AGS (2007c) Landslide Risk Management Guidelines and the NPWS Guidelines for Quantitative Risk to Life Calculations for Landslides (2020). This report outlines our observations of geotechnical site features and assessment of landslide and rock fall hazards observable at the time of the fieldwork. Natural features will change and may deteriorate over time, which could change existing hazards or create new ones. Additional investigations may be required to further assess landslide hazards, risk mitigation measures, ongoing monitoring and maintenance requirements.

This report is subject to, and must be read in conjunction with, the limitations set out in sections 1.4 and 1.5 and the assumptions and qualifications contained throughout the Report.

Contents

Table index

Figure index

Appendices

1. Introduction

1.1 General

GHD Pty Ltd (GHD) has been engaged by Niche Environment and Heritage Pty Ltd (Niche), who are working on behalf of New South Wales National Parks and Wildlife Service (NPWS) to undertake a geotechnical assessment for the Illawarra Escarpment Mountain Bike Concept Plan. As sub-consultant to Niche, GHD is providing specialist advice to Niche on the geotechnical hazards and associated risks with the development of the mountain bike network, as part of their broader environmental service offering to NPWS.

Revision 0 of this report dated 3 November 2021, was undertaken based on a trail network developed by NPWS and their selected construction contractor, Synergy Trails Pty Ltd (Synergy) in 2021. This revision comprised:

– Desktop study
– Initial and final 3D rockfall modelling
– Initial and final site walkovers
– Landslide risk assessment

Since the issue of Revision 0, the trail network has been revised a number of times by NPWS and Synergy. While many of the changes to the trail network were assessed to be minor in regard to landslide risk, it was noted that a small number of the modified trails had moved closer to landslide hazard areas identified in GHD's 3D rockfall modelling.

As a result, GHD recommended that an additional site walkover to assess these areas be undertaken and the landslide risk assessment be revised. This additional work was approved by Niche and a third site walkover was undertaken by GHD on 28 January 2022. The version of the trail network used during the site walkover was issued to GHD by Niche on 24 January 2022.

Since the site walkover, an additional trail network revision was issued to GHD by Niche on 11 February 2022, however in the context of landslide risk the changes were assessed by GHD to be minor, and a further site walkover was not required. This current revision of the report is Revision 1, and is based on the trail network provided to GHD by Niche on 11 February 2022.

The network design provided to GHD by Niche includes both individual trail numbering and colour-based difficulty classification systems. Where trail numbers or colours are referred to in this report, they are in accordance with the design provided to us.

The revised Illawarra Escarpment mountain bike trail network is located on the slopes of the Escarpment, and the broken ridgeline that marks the boundary of the Escarpment. The bike trail network is located between approximately 4.5 km and 8.5 km from the Wollongong city centre (Figure 1), covering an area of approximately 300 ha. The bike trail network extends:

– Approximately 5 km along the escarpment in a north-east to south-west direction, from O'Briens Drift to Mount Kembla
– Approximately 1.5 to 2 km from the trails at the top of the escarpment (north-west), to those at the lowest elevations (south-east)

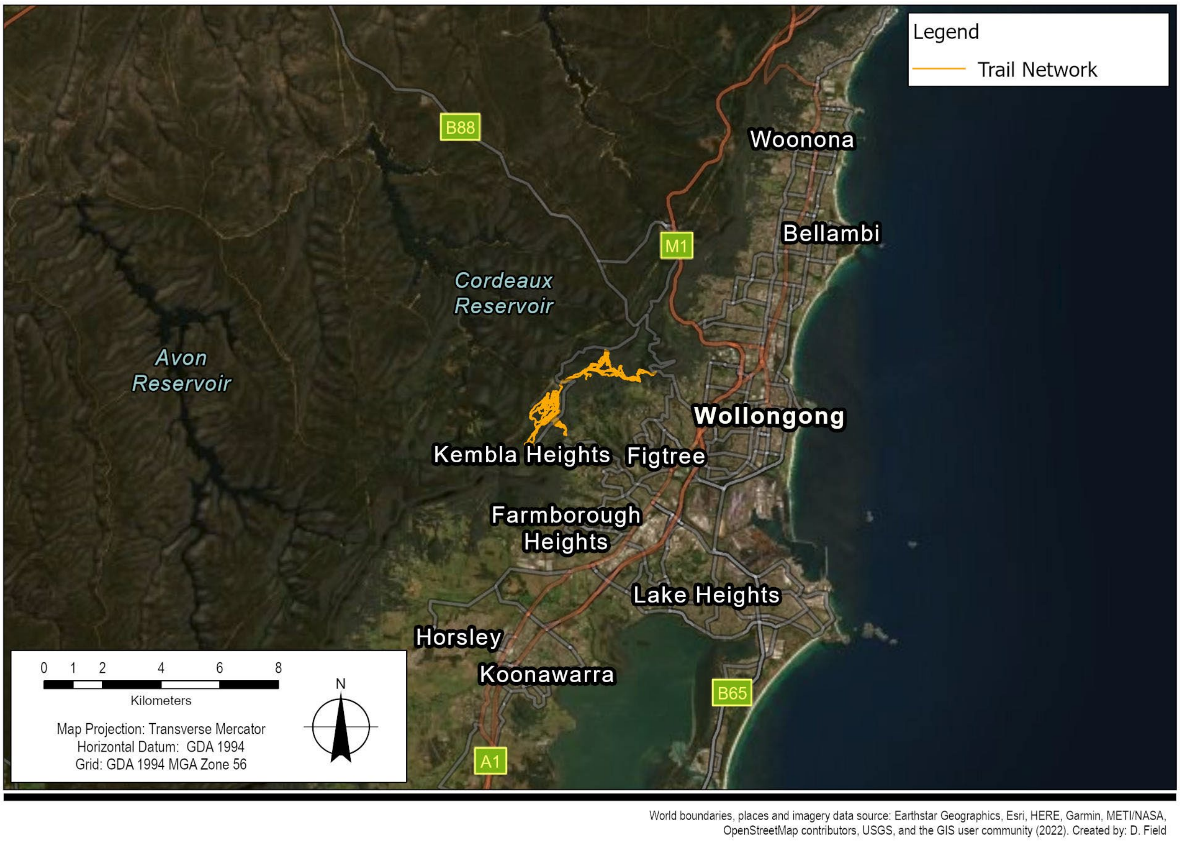


Figure 1: Locality Plan - Illawarra Escarpment Mountain Bike Trail Network

Figure 2 presents the overall trail layout and associated facility locations currently proposed by NPWS and Synergy. It is understood that the development is intended to comprise both the formalisation of existing informal mountain bike trails and construction of new trails. Detailed trail layout plans are presented in Appendix A

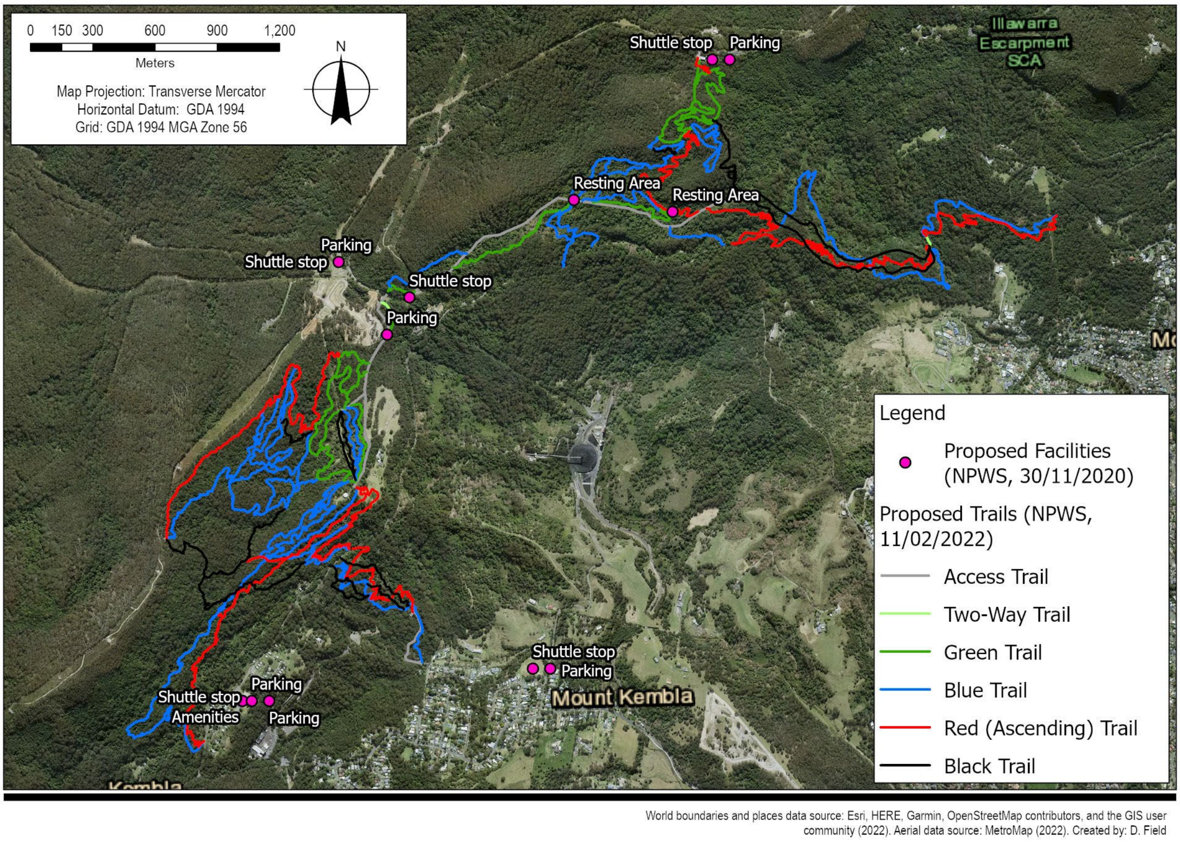


Figure 2: Proposed trail layout and facility locations - Illawarra Escarpment Mountain Bike Trail Network

Where illustrative to the text, small report insert figures are presented within the report. In addition to these figures, a detailed A3 figure set is also presented in Appendix A. The figures within this appendix are referred to throughout the report.

1.2 Background

The following excerpt is taken from the NPWS request for tender for the Illawarra Mountain Bike Concept Plan, providing some background to the current proposal:

> *"In 2020, NPWS engaged Synergy Trails to help develop a Concept Plan for a network of dedicated MTB [Mountain Bike] trails between O'Brien's Drift and Mount Kembla.*
>
> *The Concept replaces a proposal (Draft Illawarra Escarpment MTB Strategy, NPWS & WCC 2019) for the development of formal MTB networks at Balgownie, Mt Keira and Mt Kembla. Adverse environmental assessments and public feedback led NPWS and WCC [Wollongong City Council] to set aside the Draft Strategy and develop an alternative proposal.*
>
> *The primary aims of the Concept Plan are safe sustainable recreation for a broad range of riders and an alternative to unsanctioned trails at Mount Keira, which are to be closed.*
>
> *Wollongong City Council and key stakeholders contributed to the Concept Plan via a[n] MTB Advisory Group.*
>
> *The Concept Plan proposes a network of 44 kilometres of MTB trails spanning five land tenures (NPWS, WCC, WaterNSW, Sydney Water, and South32) between O'Brien's Drift and Mount*

Kembla. The Concept proposes the development of 31 kilometres of new single trails, plus improvements to 10 kilometres of existing single trails and 3 kilometres of management roads.

36 kilometres of trail would be provided on NPWS tenure (Illawarra Escarpment State Conservation Area). Trail heads and parking and access would be developed on WCC lands, due to physical and environmental constraints on NPWS tenure. A main access hub at O'Briens Drift and the first two kilometres of trail leading from the hub require development within scheduled drinking water catchment."

Minor alterations have since been made by NPWS and Synergy to the proposed trail network in terms of the number of trails and their exact alignments, however this constitutes a small percentage of the overall development and in essence, the scope and intent of the development is consistent with the above excerpt.

1.3 Purpose of this report

The purpose of this report is to present Niche with the findings of our geotechnical assessment of the proposed NPWS Illawarra Escarpment Mountain Bike Network Concept Plan.

1.4 Scope and limitations

This report has been prepared by GHD for Niche Environment and Heritage Pty Ltd and may only be used and relied on by Niche Environment and Heritage Pty Ltd for the purpose agreed between GHD and Niche Environment and Heritage Pty Ltd as set out in Section 1.3 of this report.

GHD otherwise disclaims responsibility to any person other than Niche Environment and Heritage Pty Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section(s) 1.5 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Niche Environment and Heritage Pty Ltd and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.5 Assumptions

Our geotechnical assessment report has been prepared on the basis of a number of assumptions, as follows:

– The trail layout of the Illawarra Escarpment mountain bike trail network and the location of its associated facilities has been provided by Niche in the form of two GIS "shapefiles". For this revision of the report, the shapefiles for the trail layout and facility locations were provided on 11/02/2022 and 30/11/2020 respectively. Should the trail layout or facility locations change significantly after the issue of this report, further geotechnical assessment is recommended.
– Further to the limitations set out in Section 1.4, our risk assessment has been prepared based on site conditions observed during our site walkover assessments, the dates of which are presented in Section 5. It should be noted that ground conditions at the location of the trail network are likely to change over time, both as a result of natural slope weathering processes (e.g. erosion, landslides) and also the bike trail construction

works themselves (e.g. alteration to vegetation and slope drainage). These changes could create new hazards that were not observable at the time of our fieldwork.

– The assessment considers the risk to life that landslides hazards pose to individuals mountain biking on the official bike trails. The assessment does not assess risk to persons occupying the trails for other purposes, such as construction teams that may occupy the area for longer periods of time to undertake initial construction, remedial or upgrade works to the trails. This would require careful consideration of the specific project construction requirements and measures to be included in the project health and safety plan.

2. Summary of appendix figures

Eleven A3 figures have been prepared in order to present the findings of our assessment in greater detail than is possible within the body of the report. These figures are presented in Appendix A.

Table 1 provides a list of the figures in the appendix, as well as brief summary of information presented in each.

Table 1: Summary of appendix figures

Figure number	Title	Description
A1	Site location plan	Proposed trail network and facility locations, overlaid on aerial imagery
A2	Soil landscape series	Wollongong – Port Hacking 1:100,000 Soil landscape Series map (Hazelton & Tillie, 2010), overlaid on digital terrain model
A3	Seamless geology	NSW Seamless Geology Dataset (Colquhoun et al, 2021), overlaid on digital terrain model
A4	Known mine workings	Known underground mine workings and relevant site observations, overlaid on digital terrain model
A5	Interpreted landslide activity	Interpreted landslide footprints and relevant site observations, overlaid on digital terrain model
A6	Rockfall hazard modelling	Rockfall hazard modelling, geohazard risk assessment sites and relevant site observations, overlaid on digital terrain model
A7	Site feature plan – tile index	Site feature plan tile extents, overlaid on digital terrain model
A8 – A11	Site feature plan – tiles 1 – 4	Site feature observations and photographs, overlaid on digital terrain model

3. Proposed development

3.1 National Parks and Wildlife Service concept design

Based on our understanding of the trail network provided to GHD by Niche on 11 February 2022, the network comprises approximately 48 kilometres of mountain bike trails spanning four land tenures (NPWS, Wollongong City Council (WCC), Sydney Water, and South32) between O'Brien's Drift and Mount Kembla. Furthermore, the development approximately comprises:

– Development of 33 kilometres of new single trails
– Improvements to 15 kilometres of existing single trails
– Improvements to three kilometres of management roads
– Forty kilometres of the total trail length would be provided on NPWS tenure (Illawarra Escarpment State Conservation Area)
– Trail heads, parking and access would be developed on WCC lands, due to physical and environmental constraints on NPWS estate

Figure A1 presents the trail layout and associated facility locations currently proposed by NPWS.

3.2 Synergy and National Parks and Wildlife Service guidance

Whilst the design for the Illawarra Escarpment Mountain Bike Concept Plan has not yet been finalised, both Synergy and NPWS have provided guidance on the nature of the trails, and the methods of construction that are likely to be employed.

During our initial and third site walkovers, Synergy provided commentary on the proposed trail network as it was at the time and anticipated construction methods for specific areas. Following completion of the site walkover, Synergy also provided GHD with annotated example photographs of previously constructed trails on other sites and their associated features. These photographs have been incorporated into our geotechnical review of trail constructability and maintenance, presented in Appendix B.

In additional to the guidance provided by Synergy during the initial site walkover, NPWS were also present for the initial site walkover, and provided background to the proposed development from their perspective. Further to this, we note that NPWS have specified that Synergy are to design and construct the trail network in accordance with the NPWS Park Facilities Manual (2010), and that while alterations have been made to the proposed trail alignments over time, we assume that the construction methods employed will largely remain the same.

4. Geology and geomorphology

4.1 Soil landscapes

Figure A2 presents the Illawarra Escarpment mountain bike trail network (“the site”) overlaid on the Wollongong – Port Hacking 1:100,000 Soil Landscape Series Map (Hazelton and Tillie, 2010). A summary of the soil landscapes intersected by the trail network is presented in Table 2.

Table 2: Summary of soil landscapes intersected by the Illawarra Escarpment mountain bike trail network (Hazelton and Tillie, 2010)

Symbol	Landscape	Process	Limitations
COha	Hawkesbury	Colluvial	Extreme soil erosion hazard, mass movement (rock fall) hazard, steep slopes, rock, outcrop, shallow, stony, highly permeable soil, very low soil fertility
COie	Illawarra Escarpment	Colluvial	Mass movement and rock fall hazard. Steep slopes and extreme erosion hazard. Reactive, low wet bearing strength subsoils. Low to moderate soil fertility.
COwb	Warragamba	Colluvial	Mass movement hazard, steep slopes, severe soil erosion hazard, rock fall hazard.
REgw	Gwynneville	Residual	Extreme erosion hazard, steep slopes, mass movement hazard, local flooding. Reactive subsoils and impermeable, low wet bearing strength clay subsoils.

Unsurprisingly, the majority of soils traversed by the trail network are colluvial, with the only exception being the residual soils of the Gwynneville landscape, which are located towards the base of the escarpment.

Limitations of relevance to the proposed trail network are severe to extreme erosion hazard, steep slopes and mass movement hazard. These limitations are consistent across all landscapes encountered by the trail network.

4.2 Geology

4.2.1 Overview

The Illawarra Escarpment mountain bike trail network traverses a variety of terrain and geological units. Referring to the NSW Seamless Geology Dataset (v2.1, Colquhoun et al, 2021), the Illawarra Escarpment mountain bike trail network broadly intersects two main geological groups:

– The Narrabeen Group in the portions of the trail located within the upper elevations of the escarpment
– The Illawarra Coal Measures on the lower slopes of the escarpment

Figure 3 presents a plan of the Illawarra Escarpment mountain bike trail network, overlaid on the above the two geological groups.

A generalised stratigraphic column of the Illawarra region is presented in Figure 4 below.

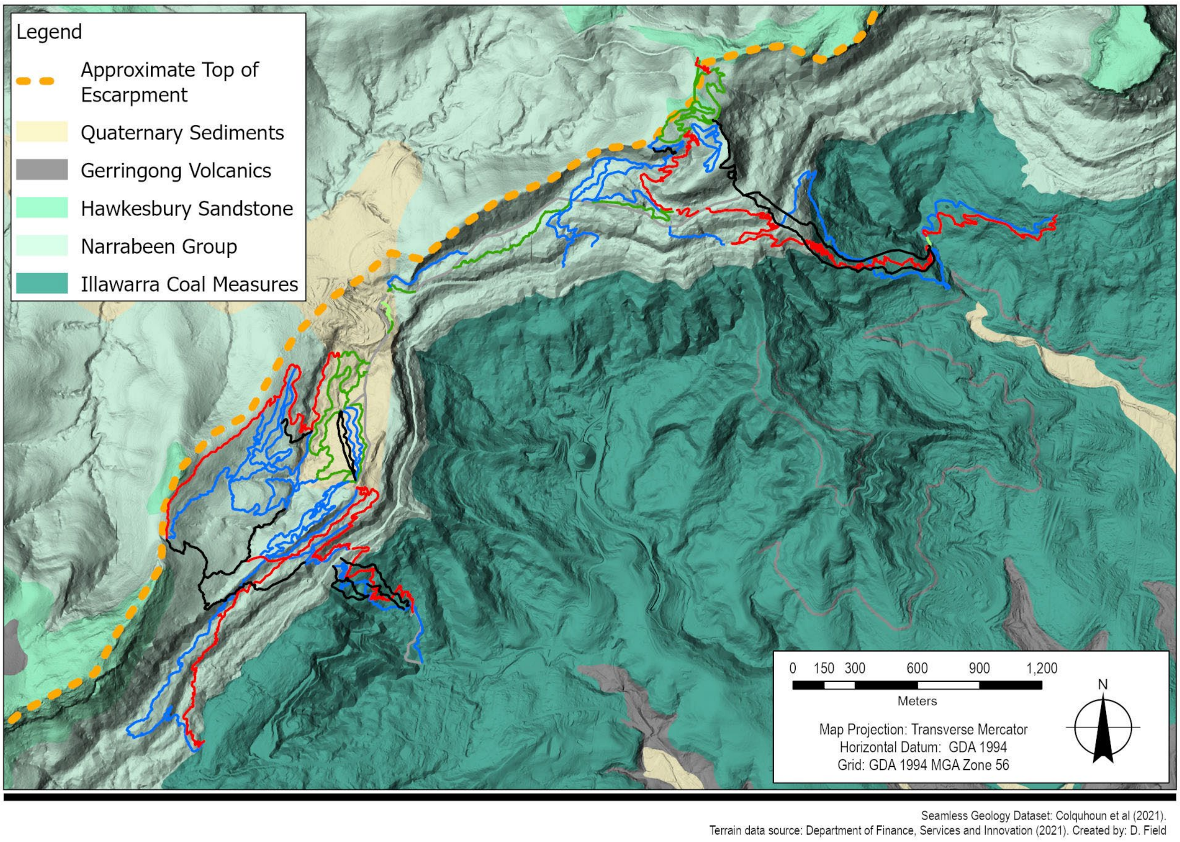


Figure 3: Geological groups intersected by the Illawarra Escarpment Mountain bike trail network, overlain by the trail network itself (11/02/2022)

Showing the geology in further detail, Figure A3 presents a plan of the geological units intersected by the trail network. It is useful to note that boundary of the Narrabeen Group presented in Figure 3 above is located at the base of the Coal Cliff Sandstone (Tncc). This boundary varies in elevation between approximately RL 240 m AHD at the northern and southern ends of the site, and approximately RL 220 m AHD towards the centre of the network.

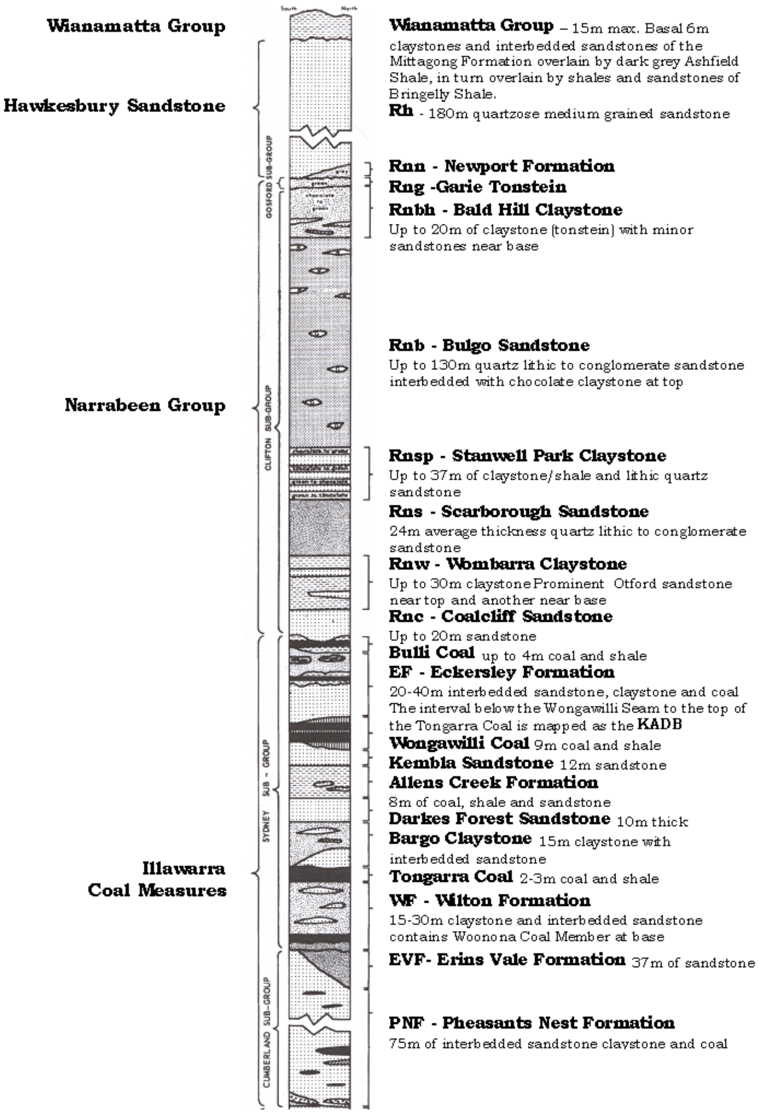


Figure 4: Generalised Stratigraphic Column of the Illawarra region (Bowman 1974)

4.2.2 Narrabeen Group – upper section of Illawarra Escarpment

The top of the escarpment in the vicinity of the bike trails is marked by a north-east to south-west trending, broken ridgeline. Within the site the ridgeline is mostly formed within the Bulgo Sandstone, however to the north and south this unit is capped by remnants of the Bald Hill Claystone and Hawkesbury Sandstone.

It should be noted at this point that the Hawkesbury Sandstone is actually a separate stratigraphic unit, and not part of the Narrabeen Group. However it has been described with the Narrabeen Group for convenience.

To the east of the broken ridgeline are the upper slopes of the Illawarra Escarpment. These slopes comprise a sequence of alternating sandstone and claystone units which are presented below in stratigraphic order (note this is also in order of elevation from highest elevation to lowest):

– Hawkesbury Sandstone
– Bald Hill Claystone
– Bulgo Sandstone
– Stanwell Park Claystone
– Scarborough Sandstone
– Wombarra Claystone
– Coal Cliff Sandstone

Table 3 presents a summary of the geological descriptions of the above units. We have also included colluvial talus deposits as a standalone “unit” as per the regional geological mapping. The talus deposits are discussed briefly, later in this section.

Table 3: Summary of geological units of the Narrabeen Group to be traversed by the Illawarra Escarpment Mountain bike trail network (Colquhoun et al, 2021)

Unit Code	Unit Name	Description
Tuth	Hawkesbury Sandstone	Medium- to coarse-grained quartz sandstone with minor shale and laminite lenses.
Tng_b	Bald Hill Claystone	Interbedded quartzose and quartz-lithic sandstone and mudrock and chocolate shale
Tncu	Bulgo Sandstone	Fine- to medium-grained grey-brown to green quartz-lithic sandstone with lenticular brown shale/claystone and siltstone interbeds; sporadic minor polymictic pebble conglomerates down sequence.
Tncs	Stanwell Park Claystone	Brown and brown-grey shale up sequence, grading to olive-green and grey shale down sequence; fine- to coarse-grained quartz-lithic green-grey sandstone, rare pebble polymictic conglomerate beds.
Tnca	Scarborough Sandstone	Coarse-grained quartz-lithic sandstone (fines up sequence), sporadically pebbly down sequence.
Tnco	Wombarra Claystone	Green-grey to brown shale and claystone, minor fine-grained thin-bedded quartz-lithic sandstone; calcareous foraminifera recorded.
Tncc	Coal Cliff Sandstone	Medium-grained quartz-lithic sandstone with calcareous-cemented; also contains sideritic oolites.
Q_ct	Colluvial talus deposits	Poorly sorted, weakly cemented to unconsolidated coalescing fans of pebble- to cobble-sized polymictic conglomerate with medium- to very coarse-grained clayey sand matrix; sporadically caped with sandy loam, weakly modified by pedogenesis.

Across most of the site, these units tend to form an alternating series of steep, broken sandstone cliff-lines and more gentle, colluvial terraces. Where observed on site, the cliffs vary in height from about two to forty metres. On the terraces below the cliffs, there were often extensive talus deposits comprising boulder fields of variable-sized rock masses. While the talus deposits were typically limited to the slopes immediately below the cliffs, there was evidence of some isolated rock blocks that appeared to have travelled considerable distances from the source cliffs onto the terraces below.

A number of ephemeral drainage gullies and creeks are present on the upper slopes of the Escarpment; however they are typically shallower and less well-formed than those found at lower elevations.

In the approximate centre of the study area, near the Wollongong Motorcycle Club, the ridgeline that marks the top of the Illawarra Escarpment is broken by a valley, approximately 700 m wide, that runs in a roughly south-easterly direction towards the Escarpment. Within this valley is one of the tributaries of Brandy and Water Creek, and along the northern edge of the valley is an unnamed fault, which is indicated to strike in an approximately south-easterly direction. It is not clear if the formation of the valley is associated with this fault.

The Seamless Geology dataset indicates that this gully has been infilled by Quaternary-aged colluvial deposits in the form of weakly cemented to unconsolidated, conglomerates with a clayey sand matrix. This deposit also extends along a terrace to the south of the motorcycle club and is indicated to underlie a number of the mountain bike trails in this area.

4.2.3 Illawarra Coal Measures – lower section of Illawarra Escarpment

On the lower slopes of the Illawarra Escarpment are the units of the Illawarra Coal Measures. At the location of the Illawarra Escarpment Mountain bike trail network, the coal measures comprise, from highest elevation to lowest, the following units:

– Eckersley Formation
– Wongawilli Coal
– Sydney Subgroup
– Wilton Formation
– Erins Vale Formation
– Unanderra Coal Member
– Pheasants Net Formation

Table 4 presents a summary of the geological descriptions of the above units.

Table 4: Summary of geological units of the Illawarra Coal Measures intersected by the Illawarra Escarpment Mountain bike trail network (Colquhoun et al, 2021)

Unit Code	Unit Name	Description
Pise	Eckersley Formation	Sandstone, siltstone, claystone and coal.
Pice	Erins Vale Formation	Fine- to medium-grained lithic sandstone, matrix is carbonaceous with secondary calcite, sporadically bioturbated, minor quartz pebble conglomerate up sequence.
Picp	Pheasants Nest Formation	Shale, siltstone, sandstone with lenticular coal seams; sporadic thin cherty tuff(s) and syenite intrusives (in the southwest).
Pis	Sydney Subgroup	Quartz-lithic sandstone, siltstone, mudstone, claystone, tuffaceous claystone, carbonaceous claystone, coal, torbanite, minor conglomerate.
Picpu	Unanderra Coal Member	Shale and coal.
Pisw	Wilton Formation	Dark claystone and dark siltstone, interbedded with sandstone; bioturbation, sideritic concretions, plant fossils.
Pisi	Wongawilli Coal	Coal, carbonaceous shale, claystone, and tuff. Tuff and claystone form distinctive bands.

The unit descriptions of the Illawarra Coal Measures in Table 4 present a geological setting that is in some ways similar to the Narrabeen Group above, in that it comprises a sequence fine-grained claystones, shales and mudstones, interbedded with coarser sandstone units. However during the site walkovers it was noted that this unit has limited exposure, mainly because stratigraphically it is located below the escarpment cliffs and is mostly mantled by thick colluvial deposits.

On ridgelines colluvial soils were typically thinner, with rock commonly exposed, whereas in valley features away from ridgelines, the colluvial slopes were often irregular, frequently terraced, and hummocky, reflective of slope creep and landside process that are common across the Illawarra Escarpment. Further to this, a number of landslide scarps comprising relatively shallow colluvial slope failures and patches of distressed or fallen trees were observed. Figure A5 presents a number of locations where these features were observed during GHD's site walkovers.

The lower colluvial slopes of the escarpment are steeper than those above, and they are generally more deeply incised by creeks and ephemeral drainage gullies.

4.2.4 Structural geology

A number of east-north-east to south-west trending faults are mapped across the study area. Two south-east striking dykes are also mapped in the southern part of the site. The lithology of the dykes in the published mapping is not reported. However, a doleritic dyke has been observed by GHD upslope of Harry Graham Drive. These faults and dykes typically appear to be associated with some of the drainage features that dissect the escarpment.

We also note that igneous gravel and boulders were observed along a ridgeline traversed by Trail 32. It is unclear if these are the surface remnants of a dolerite dyke, or the O'Briens Monchiquite unit, which is mapped to the east of this area.

4.3 Groundwater and seepage

Along the escarpment it is common to observe seepage emanating from the slopes of the escarpment along the upper boundary of claystone units, as well as some of the more localised fine-grained colluvial deposits. This is usually associated with groundwater migrating through overlying, more permeable sandstone rock masses prior to encountering relatively impermeable rock units such as claystone.

During GHD's the site walkovers, seepage was observed at a number of locations, particularly within the Narrabeen Group units on the upper portion of the Escarpment. These observed seepage locations are presented in Figure A5. The wettest areas occurred over gently sloping terrace areas where surface flows have likely added to the groundwater seepages, with some locally ponded water and areas of saturated soft soil.

5. Methodology

5.1 Desktop study

Prior to attending site, GHD undertook a desktop study of the area covered by the Illawarra Escarpment Mountain bike trail network. The desktop study incorporated the following data sources:

– NPWS and Synergy's initial proposed trail network and facility location datasets, provided by Niche
– Publicly available elevation data from the NSW Department of Finance, Services and Innovation
– The 1:100,000 Soil Landscape Series Sheet 9029-9129 (Edition 1, Hazelton and Tillie, 2010)
– Seamless Geology Dataset (v2.1, Colquhoun et al, 2021)
– GHD's in-house data on rockfall activity on the Illawarra Escarpment at or near to the site

Following this review, GHD produced a GIS database and preliminary site sketches to assist in the collection of data during the initial site walkover. The GIS database was uploaded to GHD's "Atlas" platform, so that it could be interrogated while on site.

5.2 Initial 3D rockfall hazard modelling

Following completion of the desktop study, GHD undertook initial 3D rockfall hazard modelling in order to assess potential areas across the mountain bike trail network where rockfalls may pose a hazard to trail users. The procedure for developing the modelling was as follows:

– Using the publicly available elevation data, identify areas where steep slopes (generally >45°) and significant rock outcrops occur. These are areas where rockfalls are most likely to initiate from, and so were used as propagation sources during the rockfall hazard modelling.
– Create broad site domains based on slope angle and geomorphology
– Based on GHD's experience on the Illawarra Escarpment, develop preliminary detached block sizes and slope parameters
– Based on modelled block runouts, identify areas of anticipated moderate and high rockfall hazard

5.3 Initial site walkover

Following completion of the desktop study and initial 3D rockfall modelling, GHD attended a three-day site orientation and walkover. The walkover was undertaken on 10, 13 and 14 May 2021 and included personnel from Niche, NPWS, Synergy and GHD. Attending on behalf of GHD were Jon Thompson (Technical Director – Geotechnical) and David Field (Senior Geotechnical Engineer).

The scope of the walkover was to provide Niche and GHD consultants an opportunity to walk over a range of the existing and proposed mountain bike trails, in order to understand the nature of the proposed development, the environmental impact it may have, and the types of geotechnical hazards the trails (and bike riders) may be exposed to.

Using GHD's Atlas GIS platform and a submeter GNSS receiver, our field personnel were able to map the areas that were walked, record georeferenced site observations and photographs, and mark areas of geotechnical hazard or significance, so that they could be further assessed during the second site walkover. Additionally, rock block size and slope parameters for the rockfall hazard modelling were also reviewed and finalised.

Figure 5 presents a plan of the areas walked during the initial site walkover, as well as all the site observation points that were recorded. Note: for context, this figure shows an earlier, superseded version of the trail network (10 September 2021) noting some trails that were walked at the time have since been altered or removed.

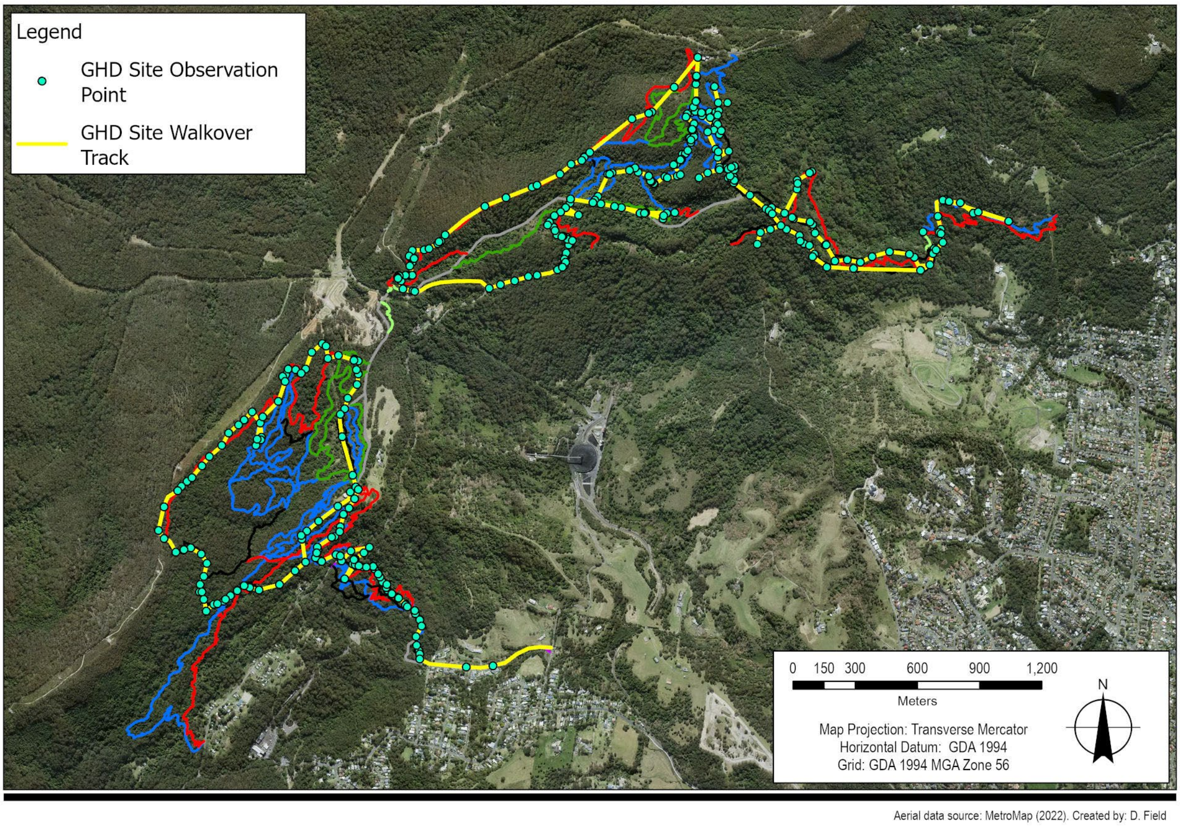


Figure 5: Map of areas walked during the initial site walkover, including site observation points and the trail network (10/09/2021)

5.4 Second site walkover

Upon completion of the initial site walkover, GHD updated the 3D rockfall hazard modelling with the finalised rock block size and slope parameters. Additionally, site observations made during the initial site walkover were reviewed, and a list of 13 sites was developed for further inspection on the second site walkover.

The second site walkover was undertaken on 10 June 2021 by Andrew Hunter (Technical Director – Engineering Geology) and David Field (Senior Geotechnical Engineer).

The aim of the second site walkover was to undertake further inspection of a selection of 13 sites that were assessed to be characteristic of landslide hazard areas across the trail network in order to inform the geotechnical risk assessment. Examples of the sites inspected included:

- Areas of recent landslide activity
- Rockfall hazard areas identified in the 3D rockfall hazard modelling
- Areas with significant seepage

Figure 6 presents a plan of the areas walked during the second site walkover, as well as the site observation points recorded. Note: for context, this figure shows an earlier, superseded version of the trail network (10 September 2021) noting some trails that were walked at the time that have since been altered or removed.

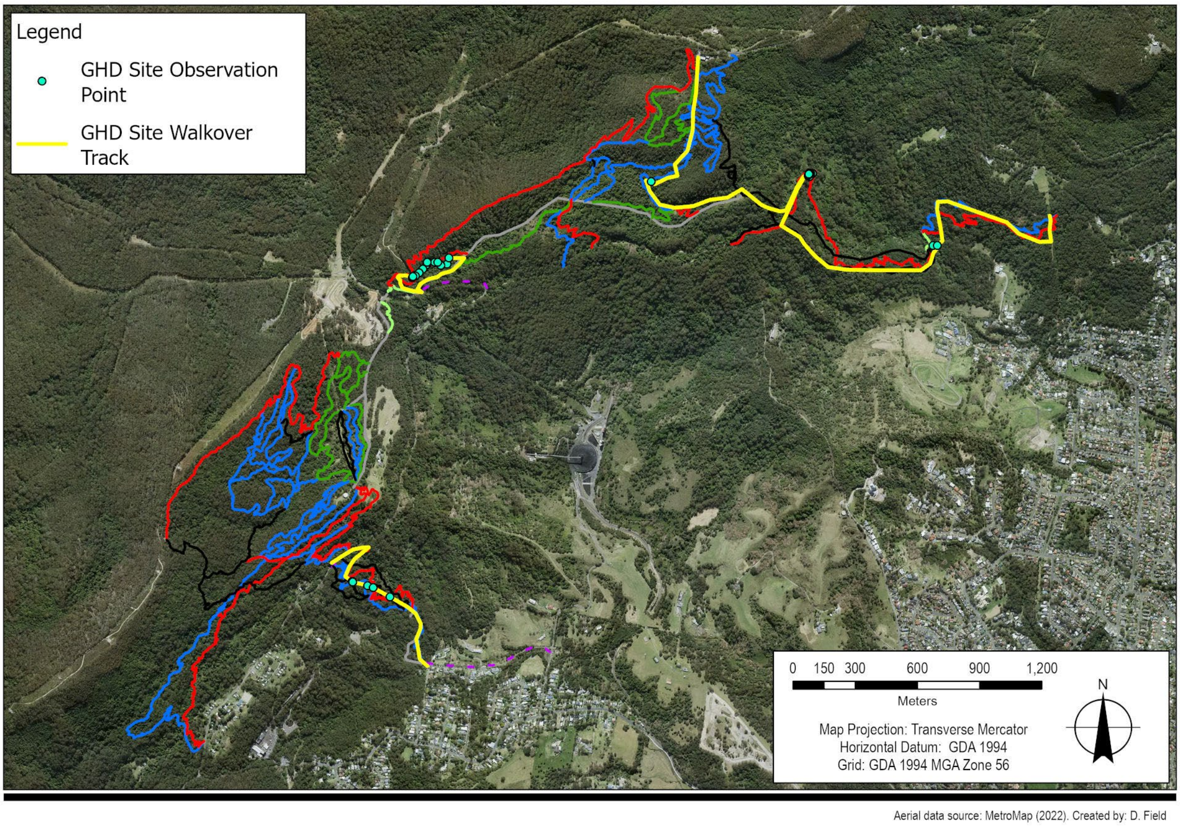


Figure 6: Map of areas walked during the second site walkover, including site observation points and the trail network (10/09/2021)

5.5 Third site walkover

Following the submission of revision 0 of this Geotechnical Assessment Report, GHD were provided with an updated version of the trail by Niche. On review of the new trail network, GHD advised Niche that, due to a significant increase in the extent of trail within the area that is referred to as Geohazard Risk Assessment Site RA3 in Section 7 an additional site visit was recommended which Niche and their client NPWS agreed to. This third site walkover was undertaken on 28 January 2022 by Andrew Hunter (Technical Director – Engineering Geology) and David Field (Senior Geotechnical Engineer).

As described above, the main aim of the third site walkover was to undertake further inspection of the landslide hazards at Geohazard Risk Assessment Site RA3. In addition to this, while on site, the following works were also undertaken:

- Additional observations at two hazard sites in the north-east of the network where adjustments had brought trails closer to modelled landslide hazards
- Additional photographs of Geohazard Risk Assessment Site RA4

Based on proposed trail changes communicated to GHD by Niche on 30 November 2021, an additional site had been earmarked for review on the south-western slope of a ridge traversed by Trail 32. However, it was noted that this trail had been removed from the next revision of the trail network dated 24 January 2022 (four days prior to the site walkover) and so this site was not assessed.

Figure 7 presents a plan of the areas walked during the third site walkover, as well as the site observation points recorded.

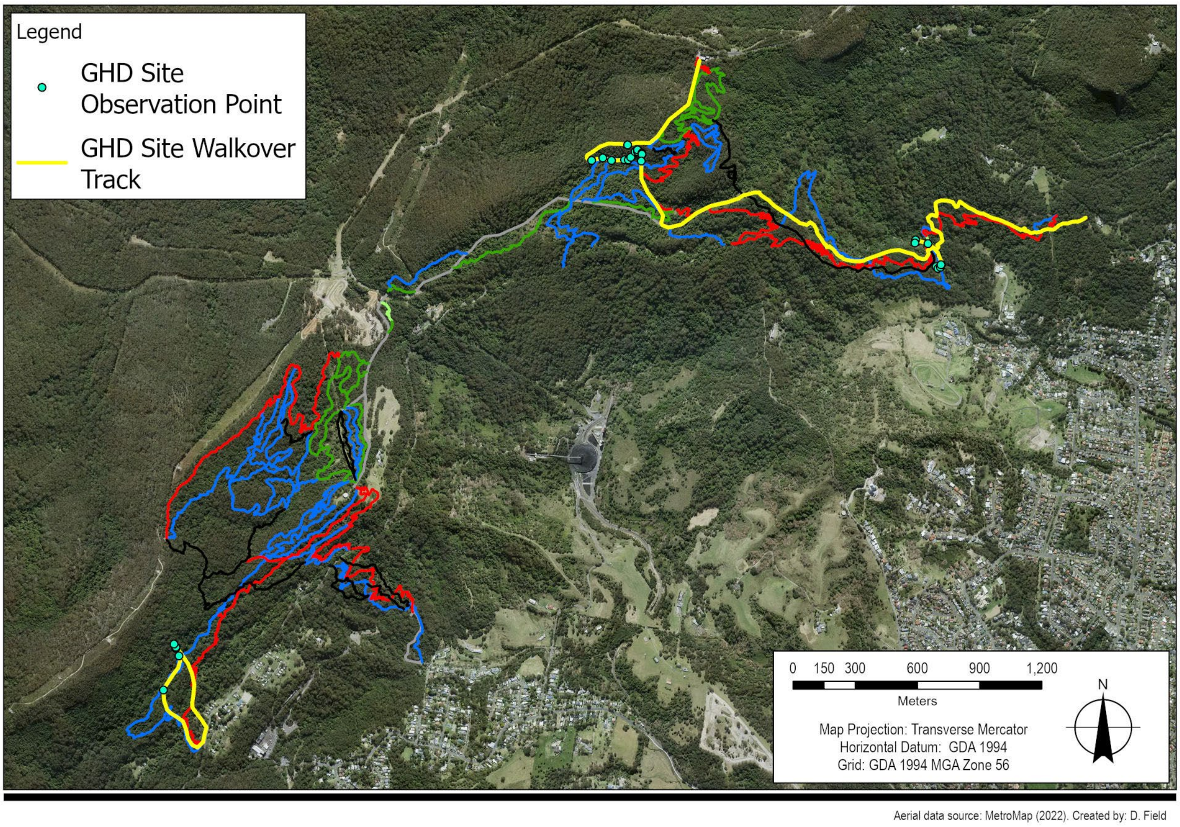


Figure 7: Map of areas walked during the second site walkover, including site observation points and the trail network (11/02/2022)

Figures A4 to A6 have been updated to present site observations from the initial, second and third site walkovers.

Figures A7 to A11 have been updated to present site feature plans developed following the completion of the second and third site visits and include photographs of noteworthy features.

5.6 Finalised 3D rockfall hazard modelling

Following completion of the initial site walkover and based on the review of block size and slope parameters undertaken during the walkover, GHD undertook the 3D rockfall hazard modelling for the Illawarra Escarpment Mountain bike trail network.

As described in Section 5.4, the results of the modelling were used to scope the inspection sites for the second and third site walkovers. This also helped to 'field-proof' the results of the modelling. Following completion of the second site walkover, some minor iterations were made to cut-off thresholds for the rockfall hazard areas, and the modelling was finalised.

Figure A6 presents the results of this modelling, with areas of anticipated moderate and high rockfall hazard identified in orange and red respectively. Also identified on the plan are a number of rockfall-related site observations, recorded during GHD's site walkovers.

6. Site geotechnical hazards

6.1.1 Mine waste and workings

Figure A4 presents a map of known mine workings beneath the area of the Illawarra Escarpment occupied by the mountain bike trail network. It is important to note that we do not consider this database to be exhaustive. There are likely to be other, older historical workings under parts of the trail network that have not been captured in the included datasets due to incomplete or non-existent records.

It is also important to note that a mine subsidence assessment was not part of the scope for this geotechnical assessment and has not been undertaken. The intent of this section is to highlight that mine workings underlie a significant proportion of the trail network, and that surface disturbances comprising excavations and filling, as well as disused infrastructure, occur over parts of the site. These underground and surface features associated with past mining may present geotechnical hazards that can be divided into two main categories: surface deposits of mine waste, and underground voids.

Most of the historical mining of coal seams in this area in this area would have been undertaken by bord and pillar techniques. The 'bord' refers to the room or void space created to access the coal with pillars of coal left behind to support the roof as the coal is extracted. Occasionally long after mining has ceased local collapse of the coal pillars may occur resulting in subsidence which may be reflected at the ground surface as a shallow depression or other irregular surface feature (e.g. undulations, cracks in rock where exposed). In rare cases, where occurring on steep slopes or where landslides have occurred in the past, subsidence may trigger a landslide. Other mine workings that may include voids would include shafts, drifts and tunnels that may have been poorly backfilled or sealed. This may result in subsidence occurring that may be reflected at the surface as depressions, or possible voids occurring as sink holes at the surface where soil and rock cover over drifts and tunnels is shallow.

During the site walkover, terraces of mine waste were observed near the Mount Kembla (Dendrobium) mine pit top. These observations are presented in Figures A4 and A5. Due to the uncontrolled and unmaintained nature of the deposited fill material, particularly where occurring over natural steep slopes, slope instability leading to landslides (and possible rockfalls where loose cobbles and boulders occur within the fill) may occasionally occur. Instability is more likely to occur if the stockpiles are disturbed / trafficked, if vegetation is removed, or during / after significant rainfall events. Rockfall and landslide hazards are discussed further in Sections 6.1.2.3 and 6.1.2.3 respectively.

6.1.2 Slope instability

6.1.2.1 Factors contributing to slope instability

As discussed in section 4, the soil landscapes traversed by the Illawarra Escarpment mountain bike trail network have a number of limitations that are associated with increased landslide hazard, namely:

- Severe to extreme erosion hazard
- Steep slopes
- Mass movement hazard

Furthermore, as described in Section 6.1.1, terraces of uncontrolled mine waste were also observed near the Mount Kembla mine site, which are expected to have similar limitations.

The colluvium that blankets large parts of the escarpment slopes comprises a mix of rocky debris with some extremely large boulders and smaller fragments derived from the sandstone, mudstone, siltstone and coal units. This coarse material is supported in a matrix of sands and clays and is derived from the Hawkesbury Sandstone and Narrabeen Group formations, and the Illawarra Coal Measures. The colluvial material is associated with both ancient / historical and active contemporary landsliding on the escarpment.

Also as discussed in section 4, the geological setting of the upper part of the Illawarra Escarpment at the location of the trail network includes a sequence of prominent, alternating claystone and sandstone units. It is common in this environment for groundwater which has migrated down through the weathered sandstone units to collect at, and flow along the top of the underlying, very low permeability claystone, exiting the Escarpment where the sandstone / claystone contact daylights. This process is observable at many locations along the Escarpment as visible seepage and / or wet, waterlogged soil, which can often be seen at or near the upper boundary of the major claystone units, particularly after significant rainfall events. Figure A5 presents the locations where seepage and waterlogged soil was observed during GHD's site walkovers.

This accumulation of groundwater is significant to landslide activity as it:

- Promotes chemical weathering at the contact surface between the sandstone and claystone units, creating sub-horizontal seams of soils with lower shear strength than the parent rock
- Can create zones of increased pore water pressure within soil and rock, lowering effective stress

The above processes, in combination with steep terrain, colluvial soil deposits, uncontrolled mine fill stockpiles / terraces, rock mass discontinuities and vegetation root-jacking on cliffs or other weathering / erosion features can lead to instability and eventual downslope movement of soil and / or rock masses.

This downslope movement can occur in a number of forms, including (in general order of decreasing frequency and increasing severity):

- Scour / erosion
- Minor rockfalls containing small, single blocks, or volumes of debris (<1 m^3)
- Creep movements of colluvium on steep slopes
- Shallow, translational landslides
- Major rockfalls containing large, single blocks, or volumes of debris (>1 m^3)
- Deep-seated, rotational landslides

6.1.2.2 Scour / erosion

Due to the severe to extreme erosion hazard present in all soils underlying the trail network, it is anticipated that scour and erosion will be a common occurrence, particularly after significant rainfall events. These occurrences may range from the formation of small drainage channels or gullies in or adjacent to trails, to large downslope washouts. Generally, the extent of disturbance to the bike trail disturbance will be proportional to the severity of the weather event, but not always.

The effects of scour or erosion may result in damage to trails due to gullying and rilling. These are predominantly environmental and occupational hazards and are not considered to be geotechnical hazards and are not assessed in the risk assessment below. However, significant scour or erosion from runoff, particularly in creeks and drainage gullies, may increase the likelihood of localised landslide activity due to undercutting or oversteepening of slopes. Landslides are discussed further in Section 6.1.2.4.

6.1.2.3 Rockfalls

As indicated in Section 6.1.2.1, the term "rockfall" is broad, and encompasses a wide range of events according to the following definition:

> *Abrupt movement of rocks that become detached from steep slopes or cliffs. Mass in motion travels most of the distance through the air and includes free fall, bouncing and rolling. They can vary in size by several orders of magnitude, such as:*

- Small, individual rock blocks to very large rock blocks up to several metres across, to
- Large scale cliff failures such as the 2007 Mount Keira rockfall, which may have volumes of hundreds, or thousands of cubic metres

Generally, the frequency of these events is inversely proportional to size.

There are a number of mechanisms that may trigger rockfall events, including:

- Rainfall
- Concentrated surface water flows into adversely oriented joints, fractures and seams

– Preferential erosion of weaker rock units leading to undercutting of cliffs
– Softening of rock defect surfaces during wet weather
– Root jacking from trees and other vegetation
– Tree falls from cliffs due to wind or die-back including bush fire effects
– Animal disturbance (e.g., goats, wallabies, deer)
– Gradual changes to the rock structure in cliffs due to temperature and moisture variations
– Ground movement or vibration caused by mining activity
– Seismic activity, although quite rare in this region

While rockfalls are commonly associated with periods of wet weather, “sunny day” failure is also possible and does occur. When rockfalls occur, the trajectory and runout distance of debris is highly dependent on the slope properties, the size of the block(s), type and abundance of vegetation, and the topography (e.g., ridges and obstructions inhibit, while gullies funnel and promote).

As described in section 5, GHD has carried out high-level rockfall hazard modelling in order to highlight areas where rockfall activity may be more likely to occur. While it is possible for rock blocks on colluvial slopes to be remobilised (particularly if disturbed by erosion or by riders), generally the areas of highest rockfall hazard are located on steep slopes below sandstone escarpments. Figure A6 presents the trail network, overlaid on the rockfall hazard modelling.

6.1.2.4 Landslides

It should also be noted that the term ‘Landslide’, as adopted by AGS (2007c) is used to describe all forms of mass movement. That is, the movement of a mass of rock, debris, or earth (soil) down a slope. As with rockfalls, the term “landslide” and can cover a wide range of events, ranging from small, translational failures to large slides extending over the full height of the escarpment. Generally, the frequency of these events is inversely proportional to their size. Small events may occur many times per year within an area as big as the Illawarra Escarpment Mountain bike trail network, whereas very large events may not occur more than once in one thousand or even ten thousand years.

According to Flentje (2012) processes and mechanisms of slope instability are controlled on the Illawarra Escarpment by factors that include: the local geology and its stratigraphy, the geotechnical strength parameters of the bedrock material and their derivatives of alluvium and colluvium, the discontinuities in the bedrock mass (including faults, dykes and joints etc), hydrogeology, geomorphology, slope inclination, rainfall and runoff, pore water pressure and the actions of people.

Along much of the Illawarra Escarpment, these factors combine to create an environment that is conducive to landslides, and site walkover observations throughout the trail network confirm that there has been significant landslide activity, evidenced by:

– Large main scarps in the upper parts of the Escarpment
– Smaller main scarps along a number of ridgelines
– Exposed bedrock where translational slides have removed colluvial soil cover
– Leaning and distressed trees, and large swathes of broken canopy
– Terraced and hummocky downslope toe areas

Figure A5 presents a number of locations where the above evidence has been observed within the trail network, as well as a number of interpreted historical landslide footprints. These footprints have been identified by interpretation of the site LiDAR terrain model. Many of these historical landslides are likely many thousands of years old and may currently be inactive or subject to slow creep movements. The reason they have been included is simply to illustrate that landslide activity is common and widespread at the site.

While more rapid debris flow landslides can occur on the escarpment, these are typically associated with very high intensity rainfall events such as the August 1998 event. The landslides inferred or observed as part of this study typically comprise large landslide features that are most likely subject to creep movements. Such movements are likely to increase during, or in the days and weeks after rainfall events. Due to the slow-moving nature of these landslides, for the most part they do not pose an appreciable hazard to trail users.

7. Geohazard risk assessment sites

7.1 General

Based on the findings of the desktop study, site walkovers and rockfall hazard modelling, four main site geohazard risk assessment sites were identified: RA1 to RA4. Sections 7.2 to 7.5 discuss the sites in further detail and present large-scale plans, cross sections and photos. Due to size constraints, location inserts could not be included on the plans. The sites have therefore also been presented overlaid on the overall trail network and rockfall hazard mapping in Figure A6.

7.2 Geohazard risk assessment site RA1

Geohazard risk assessment site RA01 is located towards the toe of a steep talus slope downslope of a sandstone cliff up to approximately 30 m high. It includes 209 m of access trail (Stafford Farm Trail), 41 m of green trail (Trail 28) and 319 m of blue trail (Trail 45).

Figure 8 presents a large-scale plan (a), a cross section of the slope (b) and a photograph of the site (c). Due to the relatively low resolution of publicly available LiDAR (a), the cliff area visible in cross section (b) appears significantly less steep than it is in reality. This is well illustrated by the site photo (c).

As well as possible rockfall hazards originating from the cliff (a), evidence of landslide activity was also noted on the lower slopes including, broken vegetation and areas of open tree canopy.

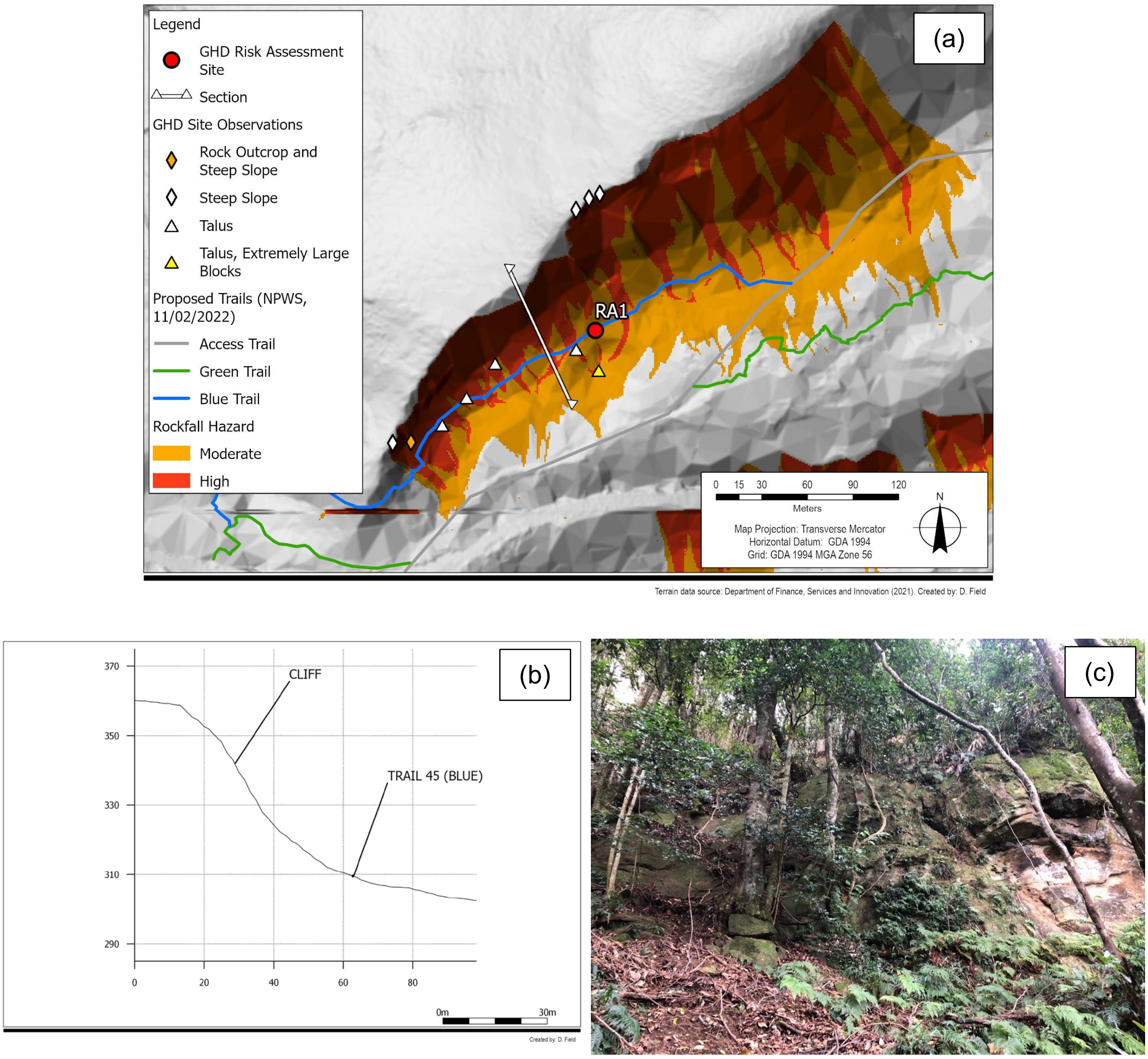


Figure 8: Geohazard risk assessment site RA1 large scale plan (a), cross section (b) and site photo (c)

7.3 Geohazard risk assessment site RA2

Geohazard risk assessment site RA02 is located on a steep colluvium and talus covered slope downslope of a broken sandstone cliff up to approximately 40 m high. It includes 152 m of access trail (Stafford Farm Trail) and 232 m of red trail (Trails 35, 50 and 52).

Figure 9 presents a large-scale plan (a), cross section (b) and photograph (c) of the site. As at RA1, due to the relatively low resolution of publicly available LiDAR (a), the cliff area visible in cross section (b) appears significantly less steep than it is in reality (c).

As well as possible rockfall hazards originating from the cliff (a), evidence of landslide activity was also noted on the lower slopes including, broken vegetation, seepage and undulating / hummocky ground.

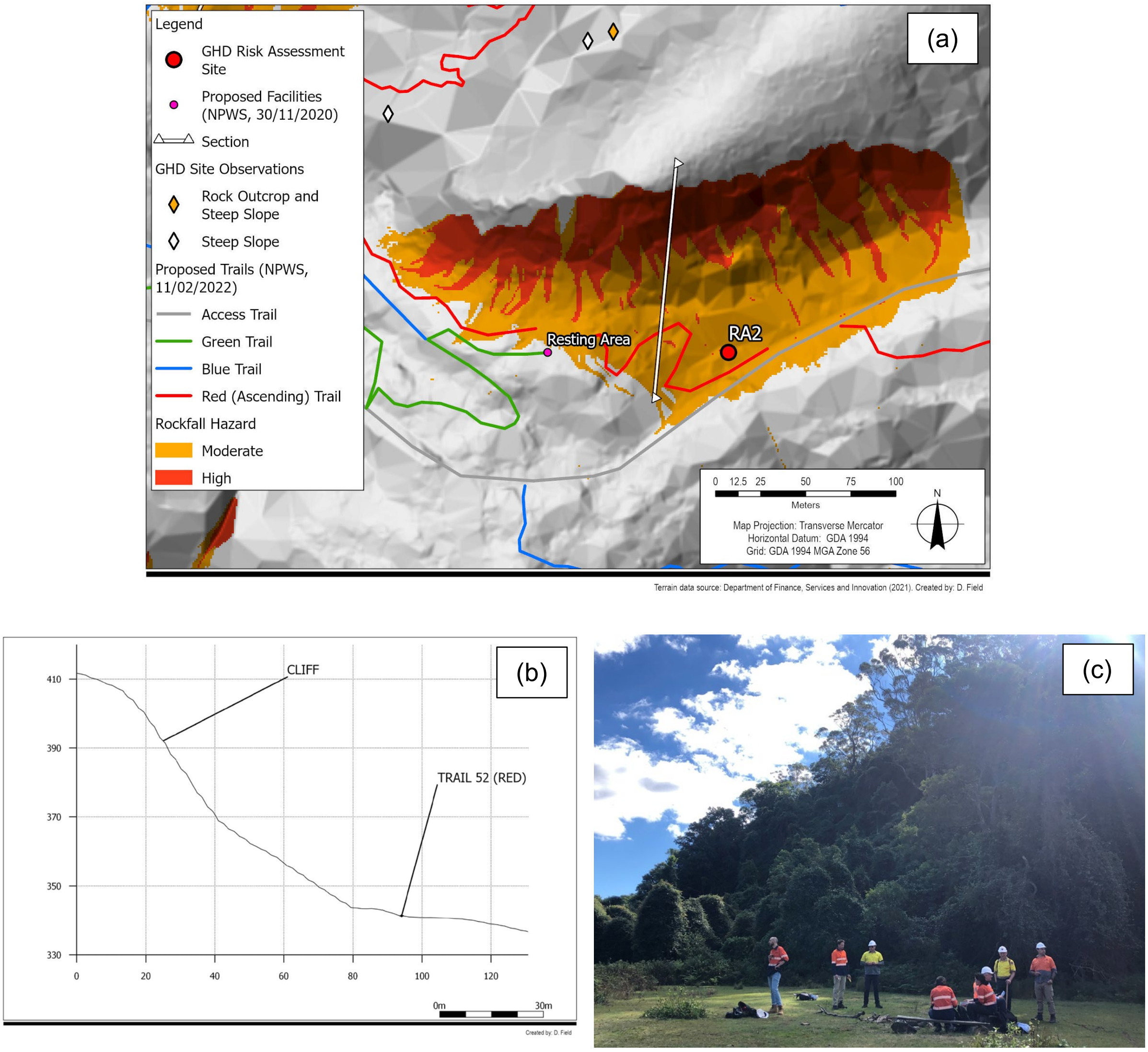


Figure 9: Geohazard risk assessment site RA2 large scale plan (a), cross section (b) and site photo (c)

7.4 Geohazard risk assessment site RA3

Geohazard risk assessment site RA03 is located on a steep colluvial slope downslope of an approximately 5-10 m high broken sandstone cliff. It includes 465 m of blue trail (Trails 36, 37, 38 and unnamed) and 47 m of red trail (Trail 50).

Figure 10 presents a large-scale plan (a), cross section (b) and photograph (c) of the site.

As well as rockfall hazards originating from the cliff (a), evidence of landslide activity was also noted on the lower slopes including, broken vegetation canopy and leaning / distressed trees, small headscarps and translational slides in colluvial soils.

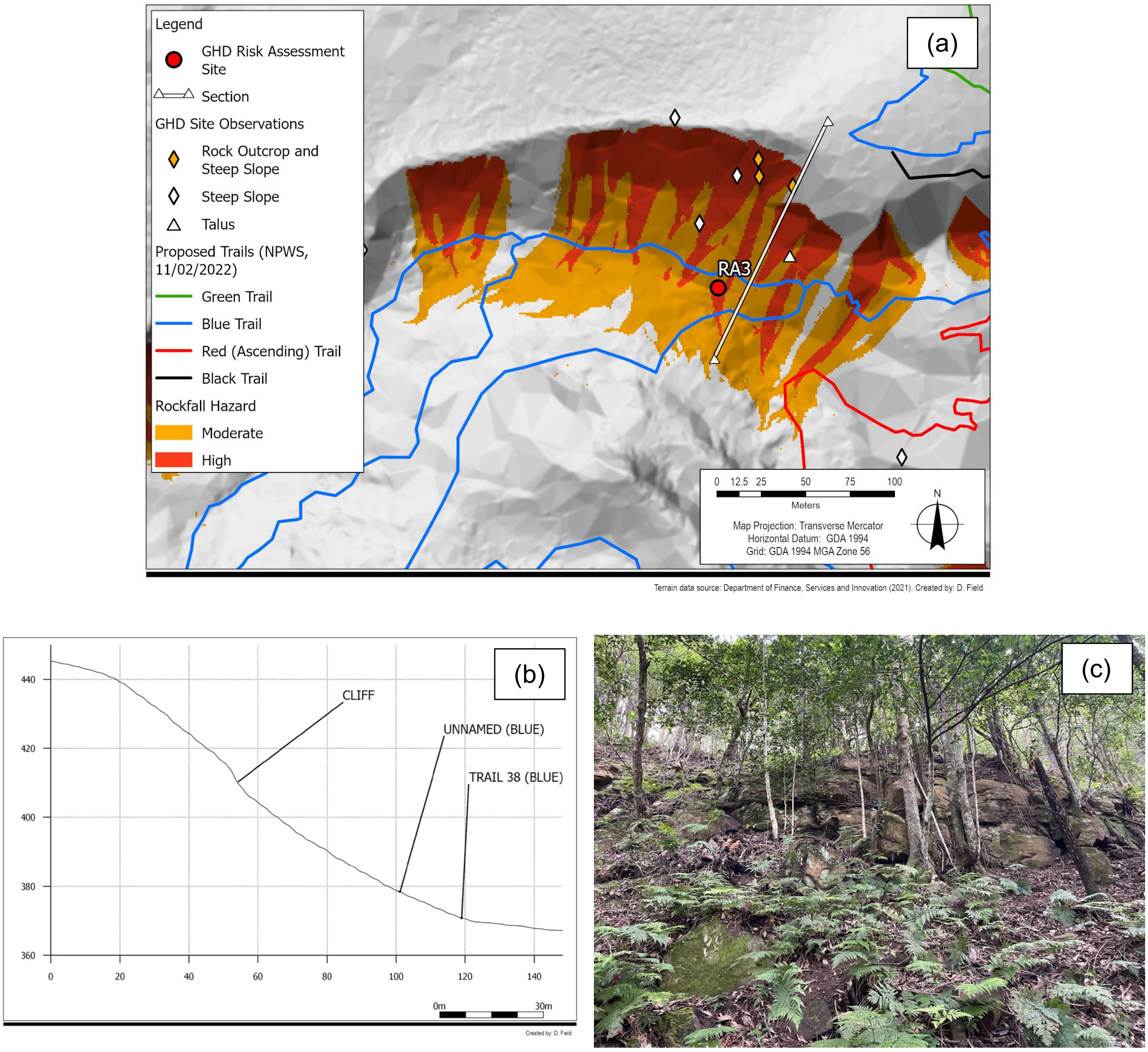


Figure 10: Geohazard risk assessment site RA3 large scale plan (a), cross section (b) and site photo (c)

7.5 Geohazard risk assessment site RA4

Geohazard risk assessment site RA04 is located on a natural terrace near the toe of a steep colluvial slope, downslope of two broken sandstone cliffs. At the locations where the lower cliff was observed it was approximately 6 m high. The site includes 392 m of blue trail (Trails 64).

Figure 11 presents a large-scale plan (a), cross section (b) and photograph (c) of the site.

As well as possible rockfall hazards originating from the cliff (a), evidence of landslide activity was also noted on the lower slopes including, broken vegetation and areas of open tree canopy.

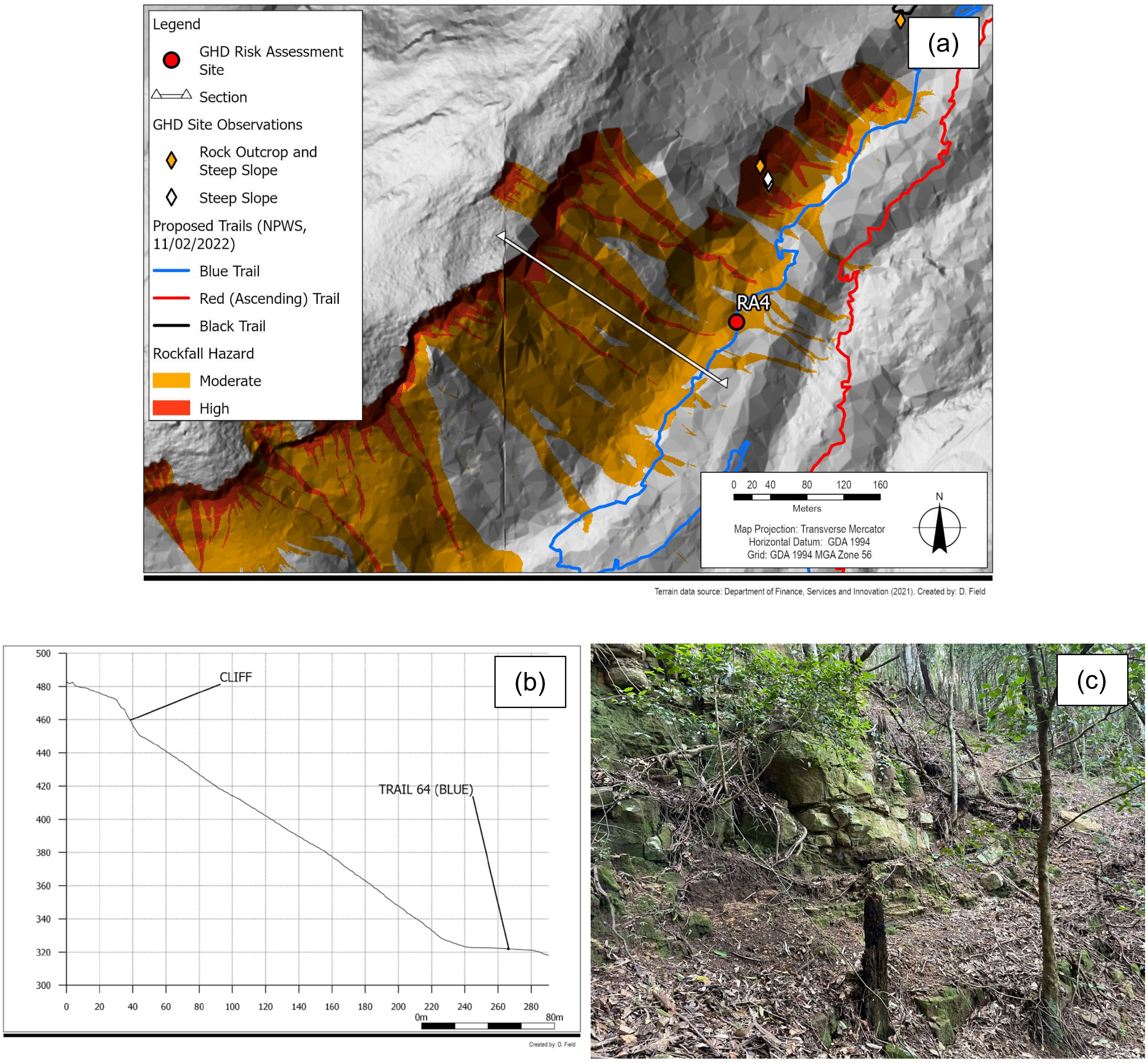


Figure 11: Geohazard risk assessment site RA4 large scale plan (a), cross section (b) and site photo (c)

8. Landslide volume frequency model

Records of past landslides can provide some information on what has happened but are invariably incomplete. Slope models can be used to support judgements about what might happen which go beyond the limitations of the historical record. Although slope models provide simplified views of reality, they enable prediction and they can be tested and updated with local and regional knowledge and relevant knowledge from elsewhere.

For the purpose of this project, we have developed a landslide volume frequency model (Figure 12) which predicts the long-term average number and volume of rockfalls detaching from the upper escarpment cliff-lines each year. Given that the geology and geomorphic conditions at each geohazard risk site are similar, and there is no specific rockfall frequency data available, we have developed one general model to represent landslide processes. Using knowledge about rockfall reach probability, the model can be used to estimate the likelihood of rockfall debris reaching the mountain bike trails. The approach to developing and using landslide volume frequency models is given in Moon et al. (2005). Figure 12 provides an example of interpreting landslide volume frequency models.

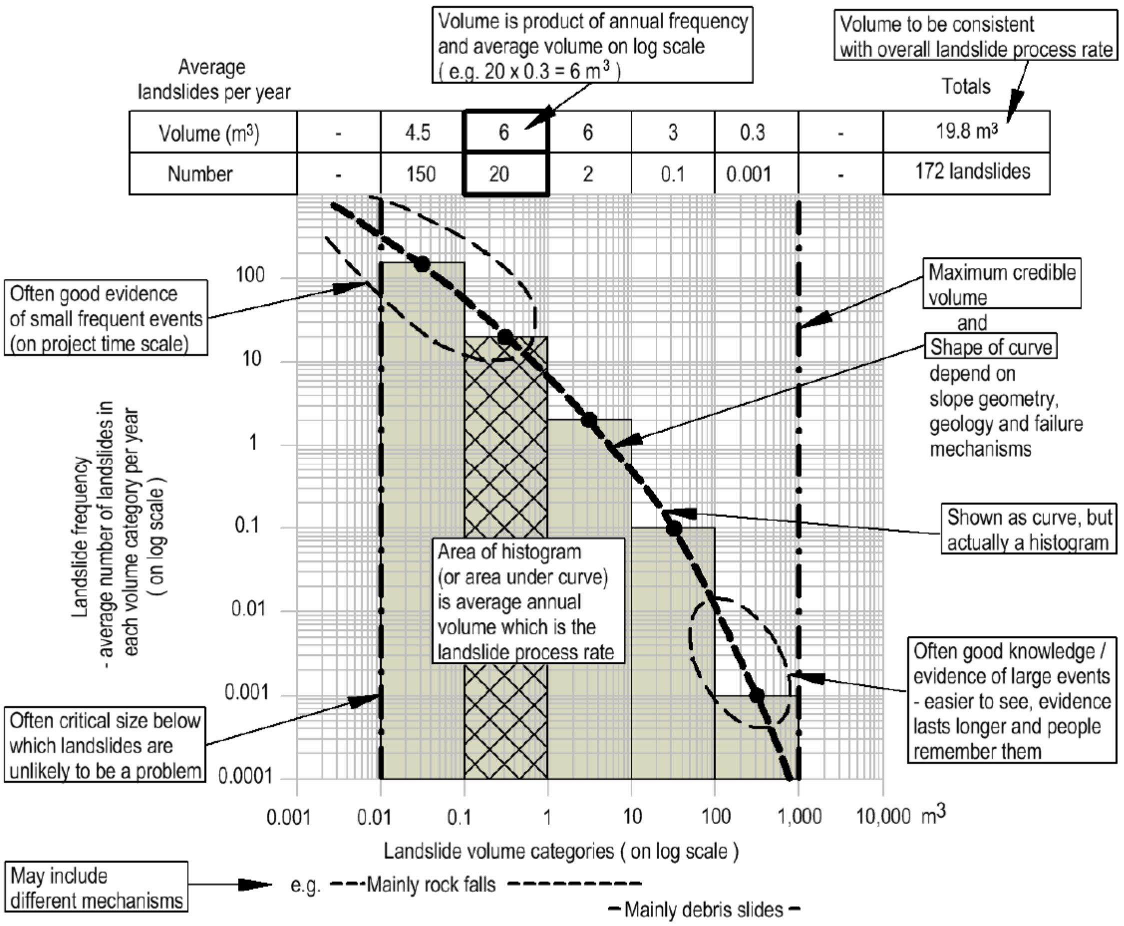


Figure 12: Explanation of the graphical presentation of a Landslide Volume Frequency Model (Moon et al. (2005))

The landslide volume frequency model developed for the cliff sites associated with the four geohazard sites is based on knowledge and interpretation of evidence on:

– The geological and geomorphological history of the region
– Cliff retreat rates in the region and elsewhere
– Landslide failure mechanisms in general

In developing the landslide model we have made the following assumptions:

- The escarpment retreat rate is approximately 0.6 m / 1000 years as proposed by Flentje (2012). This corresponds to a long-term average annual volume of rockfall material detaching from the cliff lines of about 2.2 m^3 / 100 m
- The maximum credible volume is likely to be about 3,500 m^3 for a single rockfall event involving a large cliff failure. This is based on observed cliff geometry and joint spacing. The ARI for these events is assumed to be about 1 in 10,000 years
- Several 'very small' and 'small' rockfalls are likely to occur each year (i.e. < 1 m^3)
- 'Medium' sized rockfalls (i.e. volumes of 1 m^3 to 10 m^3) could be expected to occur about every 10 years
- 'Large' sized rockfalls (i.e. volumes of 10 m^3 to 100 m^3) could be expected to occur about every 50 years
- 'Very large' sized rockfalls (i.e. volumes of 100 m^3 to 1000 m^3) could be expected to occur about every 1,000 years

The landslide model is presented in Figure 13. The model has been normalized to show the size and frequency of landslide debris detaching from a 100 m length of the escarpment cliff-line.

Average landslides per year	Very small	Small	Medium	Large	Very large	Extremely large	Totals
Volume (m^3)	0.20	0.20	0.39	0.78	0.39	0.20	2.2
Number	5.000	0.500	0.100	0.020	0.001	0.0001	6 landslides

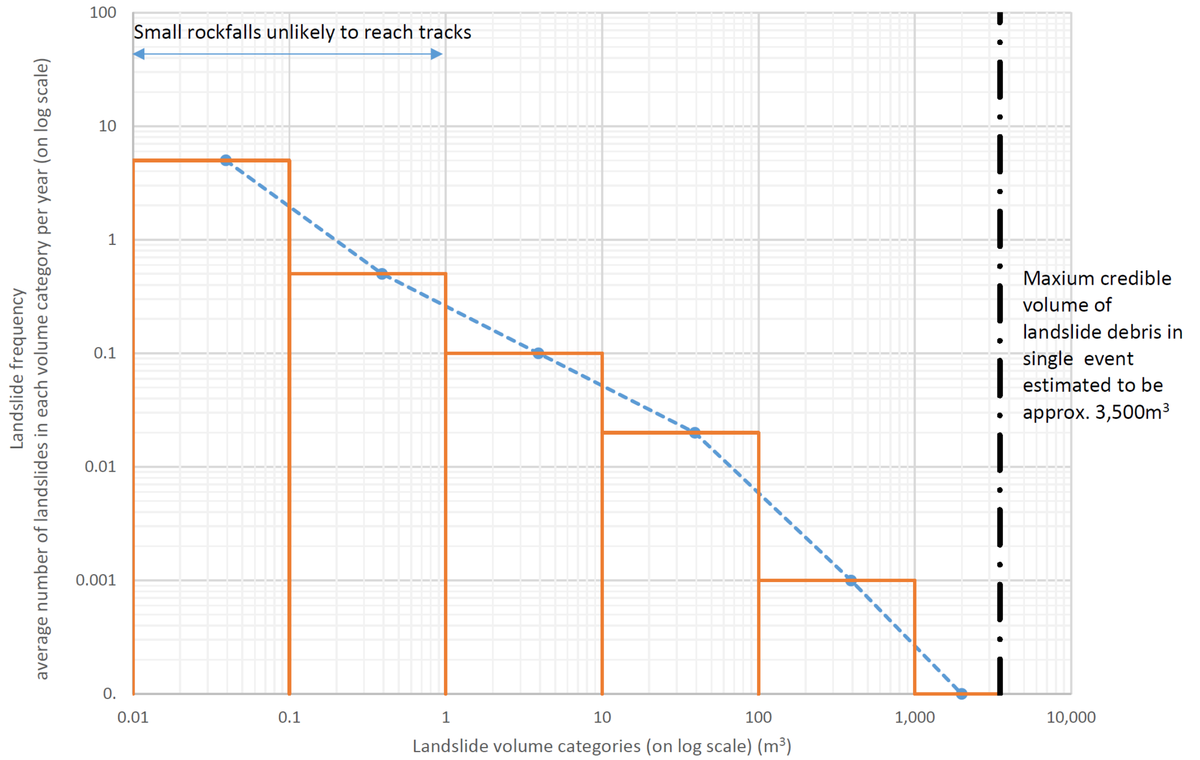


Figure 13: Landslide volume frequency model for Upper Cliff-Lines normalised for each 100 m escarpment

9. Risk assessment

9.1 General

GHD has undertaken a quantitative risk assessment for the four geohazard risk assessment sites (RA1 to RA4) in accordance with NPWS Guidelines for Quantitative Risk to Life Calculations for Landslides (2020). The following section documents this process and includes the assumptions, and assessments made in developing the input parameters.

9.2 Terminology

The following risk assessment uses terminology defined in both AGS 2007a and NPWS (2020). The following selected definitions are quoted from the texts indicated in each sub-heading.

9.2.1 AGS 2007a

Acceptable risk: a risk which, for the purposes of life or work, society is prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Consequence: the outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Elements at risk: the population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Frequency: a measure of likelihood expressed as the number of occurrences of an event in a given time.

Hazard: a condition with the potential for causing an undesirable consequence.

Likelihood: used as a qualitative description of probability or frequency.

Probability: a measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity or the likelihood of the occurrence of the uncertain future event.

Qualitative risk analysis: an analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.

Quantitative risk analysis: an analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

Risk: a measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Temporal-spatial probability: the probability that the element at risk is in the affected area at the time of the landslide.

Tolerable risk: a risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Vulnerability: the degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

9.2.2 NPWS

Mobile element at risk: an element at risk that is mobile. For example, a hiker or a vehicle.

Track: a pathway along which a mobile element at risk might move, for example a hiking track or road (or trail).

Traverse: the pass of a mobile element at risk through a zone at risk from a landslide.

Individual most at risk: see individual risk to life.

Individual risk to life: the risk of fatality or injury to any identifiable (named) individual who is within the zone impacted by the landslide or who follows a particular pattern of life that might subject the individual to the consequences of the landslide. In this guideline, individual risk to life is assessed for the individual most at risk, which is typically the person who has the greatest exposure to the landslide hazard.

9.3 Information provided by Synergy

The risk assessment requires information regarding anticipated trail usage numbers, and travel speeds for riders. Table 5 presents information provided by Synergy, which has been used in our assessment.

Table 5: Mountain bike trail usage information provided by Synergy

Trail designation	Average rider speed (km / hr)	Rider frequency (riders / hr)
Access trail	5-15	10
Green trail	10-15	20
Blue trail	15-20	10
Black trail	20-30	5

We note that no information was presented regarding expected average speeds and number of riders for red (ascending) trails. In this instance, we adopted the speeds and frequencies for walking / access trails, which is considered conservative.

9.4 F-N risk assessment equations

The NPWS risk assessment process requires the development of F-N plots for the range of foreseeable hazards at a site, where N represents the number of expected fatalities from a hazard, and F represents the assessed annual probability of N or more fatalities.

Where N is based on our assessment of nature of the hazard itself, and its likely consequence (discussed further in Section 9.7.8), the calculation of F requires the use of a number of equations as follows:

Risk of loss of life to the individual most at risk:

$$R_{(LOL)} = \frac{P_{(H)}V_{(D:T)}n_I wfd \; x \; 1.1x10^{-7}}{sI} \qquad (1)$$

Risk of loss of life to the average individual:

$$AvR_{(LOL)} = \frac{s_I R_{(LOL)}}{n_I s} \qquad (2)$$

Annual probability of N or more fatalities:

$$F = 1 - \left(1 - \; AVR_{(LOL)}\right)^n \qquad (3)$$

The development of the input parameters used in the above equations are discussed in Section 9.5 below. A summary of the parameters adopted is presented in the risk assessment tables in Appendix C.

9.5 Scenario description

Due to similarities between the sites, the risk assessment was carried out based on two "scenarios", defined by the minimum speed a rider would be expected to be travelling within the geohazard risk assessment site as follows:

> **Scenario 1:** Rider with minimum speed defined by access trail / red trail (risk assessment sites RA1 RA2 and RA3)
>
> **Scenario 2:** Rider with minimum speed defined by blue trail (risk assessment sites RA3 and RA4)

Note: as described in Section 7.4, risk assessment site RA3 includes a large amount of faster, blue trail (465 m) and a small amount of slower, red trail (47 m). In order to demonstrate that both have been considered, risk assessment site RA3 has been included in both of the scenarios described above.

For both scenarios, the input parameters are the same, with the exception of the anticipated rider travel speeds (Section 9.7.6).

9.6 Hazard description

The hazards assessed at each site are in accordance with those developed in the landslide volume frequency model in Section 8. A summary of the hazards and their logarithmic average volumes is presented in Table 6.

Table 6: Summary of landslide hazards assessed

Hazard	Description	Logarithmic average volume (m^3)
1	Small	0.4
2	Medium	4
3	Large	40
4	Very large	400
5	Extremely large	2,000

Section 8 also identifies a "very small" rockfall hazard, with an estimated volume of less than 0.1 m^3, however at the sites assessed, we do not anticipate that debris from an event of this size could conceivably reach the trails given the dense vegetation and other obstacles such as talus deposits including large boulders embedded in the surface soils. This hazard has therefore not been included in our risk assessment.

9.7 Parameter selection

9.7.1 $P_{(H)}$ – annual probability of landslide reaching trails

For Hazards 1 to 5, the annual probability of their reaching a trail $P_{(H)}$ has been calculated using the following formula:

$$P_{(H)} = annual\ expected\ landslide\ frequency\ x\ likelihood\ of\ debris\ reaching\ trail \qquad (4)$$

The annual expected frequency for each hazard is based on the landslide frequency model presented in Section 8.

The likelihood of debris reaching the trail is a modifier that takes into account the fact that the trail is always offset some distance downslope of the landslide initiation point so that even if an event occurs, debris from events will not always reach the trail. For this assessment, we have developed likelihood estimates based on a combination of our rockfall hazard modelling, our experience at the site, and discussions with Phil Flentje (University of Wollongong) regarding rockfall travel distance back-analysis carried out for rockfalls at the Mount Keira landslide site.

Table 7 presents annual expected landslide frequencies, likelihoods of debris reaching trails and assessed probabilities of landslides reaching trails.

Table 7: Annual expected landslide frequencies, likelihoods of debris reaching trails and assessed probabilities of landslides reaching trails (Scenarios 1 and 2)

Hazard	Annual landslide frequency	Likelihood of reaching trail	Annual probability of landslide reaching trail
			$P_{(H)}$
1	0.5	0.05	0.025
2	0.1	0.1	0.01
3	0.02	0.1	0.002
4	0.001	0.1	0.0001
5	0.0001	0.5	0.00005

9.7.2 $V_{(D:T)}$ – vulnerability of individual impacted by a hazard

This parameter describes the likelihood of an individual fatality, given that that individual is impacted by a hazard. Given the size, velocity and energy anticipated to be associated with the five hazards, vulnerability is considered to be 1 for all except Hazard 1, which is estimated to be 0.6 (Table 8).

Table 8: Vulnerability of an individual impacted by a hazard (Scenarios 1 and 2)

Hazard	Vulnerability of individual impacted
	$V_{(D:T)}$
1	0.6
2	1
3	1
4	1
5	1

9.7.3 n_i, n, e – number of traverses and exposed population

Two input estimates for the number of rider traverses along a trail are required as follows:

n_i – estimated number of traverses of individual that most frequently uses a trail in a year (individual most at risk)

n – estimated sum of all traverses of all individuals along a trail in a year

Furthermore, n requires an estimate of the total number of unique individual riders that are expected to traverse trail in a year (e).

To calculate the above parameters, the following assumptions have been made by GHD:

- The individual most at risk makes an average of 3 traverses along a trail per week, every week of the year (156 total)
- An average of 10 unique, new riders will traverse a trail per week, every week of the year (520 total)
- The average rider will traverse a trail 3 times per year, every year (1,560 total traverses per trail, per year).

Table 9 presents the values adopted for n_i, n and e.

Table 9: Estimated number of traverses per year and exposed population (Scenarios 1 and 2)

Hazard	Number of traverses, individual most at risk	Exposed population	Total number traverses, all individuals
	n_i	e	n
All	156	520	1560

9.7.4 w, d – proportion of track impacted and affected slope length

The proportion of track impacted w represents the proportion of a trail that is anticipated to be affected by a landslide, where 1 represents the full width of the trail and 0 represents none of the trail. Due to the nature of the hazards in this risk assessment, it is anticipated that the entirety of the track would be affected (w=1) for all but the smallest hazard (w=0.5).

The affected slope length is defined by the length of track that is impacted by a landslide. The guidance in NPWS (2020) indicates that for a rockfall (comprising a single block), the affected slope length d, can be equated to the block diameter.

Based on the logarithmic average volumes of Hazards 1 and 2 (Table 7), it is conceivable that these two hazards could be represented by a single block. The d for these two hazards has therefore been estimated by taking the logarithmic average and calculating an equivalent diameter for a single block of that volume.

For Hazards 3 to 5, it is expected that these landslides would take the form of a number of blocks, or a debris flow. The d for these hazards has therefore been estimated based on our experience assessing landslides of similar size. We have also incorporated observations of the 2007 Mount Keira landslide, provided by the University of Wollongong.

Table 10 presents a summary of w and d values for each hazard.

Table 10: Proportion of track impacted and affected slope length for each hazard (Scenarios 1 and 2)

Hazard	Proportion of track impacted	Affected slope length (m)
	w	d
1	0.5	1
2	1	2
3	1	5
4	1	15
5	1	30

9.7.5 f – reduction factor

The reduction factor f is a modifier used to represent the probability of a person being present when a landslide occurs. For example, this can be used to convey a reduction in likelihood if there is a demonstrated, positive correlation between landslide triggers and rainfall, and there is a demonstrated, negative correlation between trail usage rates and rainfall. While it is reasonably likely that this is the case at this site to some degree, for conservatism, we have adopted f = 1 for all hazards (Table 11).

Table 11: Reduction factor for all hazards (Scenarios 1 and 2)

Hazard	Proportion of track impacted
	w
All	1

9.7.6 s_i, s – travel speeds

The travel speeds of the individual most at risk s_i, and the average individual s, have been assigned based on the expected trail travel speeds provided by Synergy in Section 9.3. As described in Section 9.5, for conservatism, the minimum expected average speed of all trails / tracks within the geohazard risk assessment sites (Section 7) has been adopted, resulting in two risk assessment scenarios (Table 12).

Table 12: Travel speeds for Scenarios 1 and 2

Scenario	Hazard	Travel speed, individual most at risk (km/hr)	Travel speed, average individual (km/hr)
		s_i	s
1 Rider with minimum speed defined by access trail / red trail (risk assessment sites RA1, RA2 and RA3)	All	5	5
2 Rider with minimum speed defined by blue trail (risk assessment sites RA3 and RA4)	All	15	15

9.7.7 $R_{(LOL)}$ equation constant

In the general equation for the probability of risk of loss of life to the individual most at risk $R_{(LOL)}$ (Equation (1)), there is a constant equal to $1x10^{-7}$. While Appendix C of NWPS (2020) presents the derivation of Equation (1) in detail, it is worthwhile touching briefly on the source of this constant.

As presented in Appendix C of NWPS (2020), the source equation for the risk of loss of life for an individual most at risk as follows:

$$R_{(LOL)} = P_{(H)}\ x\ P_{(S:H)}\ x\ P_{(T:S)}\ x\ V_{(D:T)} \qquad (5)$$

While $P_{(H)}$ and $V_{(D:T)}$ have been retained and are discussed in Sections 9.7.1and 9.7.2 respectively, given the specific scenario of the individual most at risk moving along a track or trail, the spatial probability $P_{(S:H)}$ and temporal probability $P_{(T:S)}$ can be further reduced to the following:

$$P_{(S:H)} = \frac{wd}{l} \qquad (6)$$

$$P_{(T:S)} = \frac{fn_i l}{24\ x\ 365\ x\ 1000s} \qquad (7)$$

where:

w, d, f, n_i and s are defined in Sections 9.7.3 to 9.7.6 above

l represents the length of the track subject to the hazard being assessed

the constant 1 / (24 x 365 x 1000) is introduced in order to maintain unit consistency within and between Equations (6) and (7) (specifically, converting metres to kilometres, and hours to years)

When Equations (6) and (7) are substituted back into Equation (5), the length of track l is cancelled out, and 1 / (24 x 365 x 1000) is simplified to the constant $1x10^{-7}$, as presented in Equation (1).

9.7.8 N – number of expected fatalities

The number of expected fatalities n in the event of a landslide event is estimated based on the size and nature of the landslide and the anticipated distribution of riders on the trail. Estimates of affected slope lengths for each hazard have been presented in Table 10 and anticipated minimum travel speeds of riders have been presented in Table 12. It is also assumed that the trails and tracks will typically be traversed in single file, at or above minimum travel speeds. On this basis, it is anticipated that Hazards 1 to 4 would result in a single fatality (N = 1). Due to the larger anticipated affected slope length of Hazard 5 (30 m), it is anticipated that this would result in two fatalities (N = 2).

Table 13 presents a summary of the number of expected fatalities from each hazard.

Table 13: Number of expected fatalities from each hazard (Scenarios 1 and 2)

Hazard	Number of expected fatalities
	N
1	1
2	1
3	1
4	1
5	2

9.8 Risk assessment results

9.8.1 Individual risk to life

Individual risk to life is calculated based on the individual most at risk whom, in this case, is the person using the assessed trails most frequently each year. The individual risk to life for Hazards 1 to 5 in Scenarios 1 and 2 have been calculated based on the equations and parameters set out in Sections 9.4 to 9.7 above.

NWPS (2020) provides criteria for what is considered acceptable or tolerable for individual risk to life for new developments. The individual risk to life for Scenarios 1 and 2 has been assessed against these categories and are presented in Table 14.

Table 14: Individual risk to life for Scenarios 1 and 2

Scenario	Hazard	Individual risk to life	NPWS (2020) risk category
		$R_{(LoL)}$	
1 Rider with minimum speed defined by access trail / red trail (risk assessment sites RA1, RA2 and RA3)	1	2.6×10^{-08}	Acceptable
	2	6.9×10^{-08}	Acceptable
	3	3.4×10^{-08}	Acceptable
	4	5.1×10^{-09}	Acceptable
	5	5.1×10^{-09}	Acceptable
2 Rider with minimum speed defined by blue trail (risk assessment sites RA3 and RA4)	1	8.6×10^{-09}	Acceptable
	2	2.3×10^{-08}	Acceptable
	3	1.1×10^{-08}	Acceptable
	4	1.7×10^{-09}	Acceptable
	5	1.7×10^{-09}	Acceptable

Based on the NPWS criteria, the assessed individual risk to life for Hazards 1 to 5 in both Scenarios 1 and 2 fall within the "acceptable risk" category, as defined by NPWS (2020).

Summary tables, presenting input parameters and assessed individual risk to life for Scenarios 1 and 2, and Hazards 1 to 5 are presented in Appendix C.

9.8.2 Societal risk

As indicated in Section 9.7.8, it is considered unlikely that landslide events resulting from Hazards 1 to 4 will result in greater than one fatality. However due to the size and scale anticipated for a Hazard 5 event, it is foreseeable that multiple fatalities may result. As such, societal risk F-N plots have been developed for Scenarios 1 and 2 using the equations and parameters set out in Sections 9.4 to 9.7 above. NWPS (2020) provides criteria for the following societal risk categories:

– Acceptable

– Tolerable
– Unacceptable
– Intense scrutiny

The F-N risk plots for Scenarios 1 and 2, assessed against the NWPS risk categories are presented in Figure 14 and Figure 15 respectively.

As illustrated in the F-N plots, the assessed risks for Hazards 1 to 5 in both Scenarios 1 and 2 fall within the "acceptable risk" category, as defined by NPWS (2020).

Summary tables, presenting the input parameters derived and assessed societal risks for Scenarios 1 and 2, and Hazards 1 to 5 are presented in Appendix C.

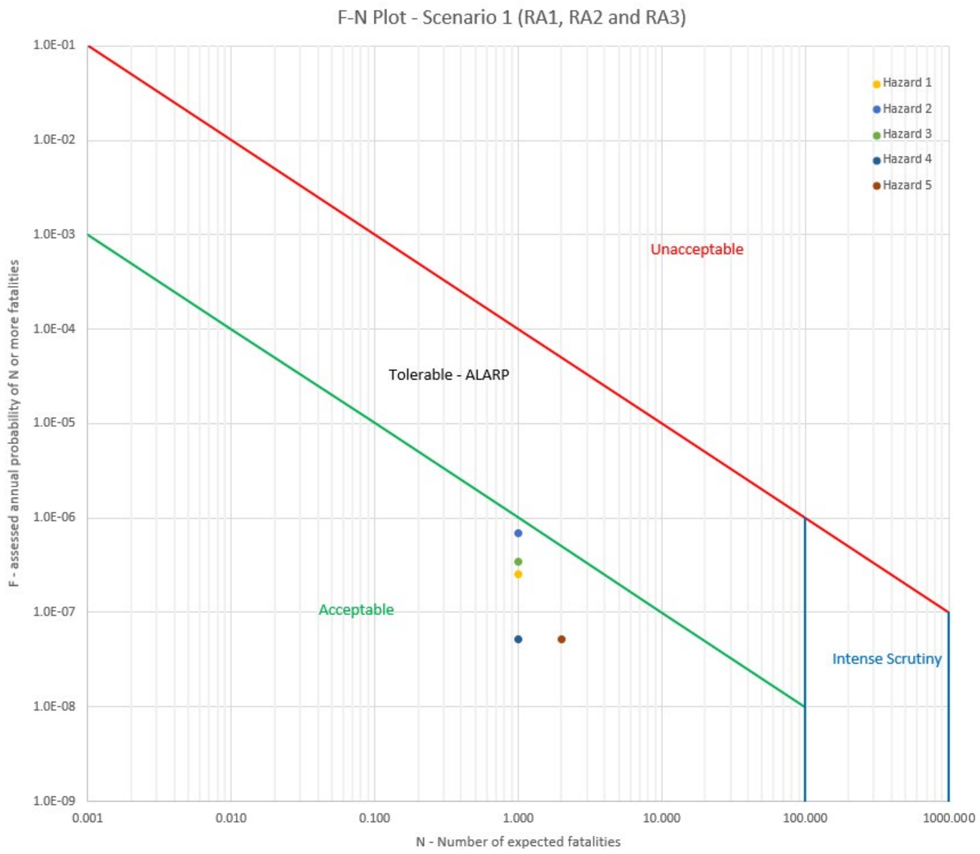


Figure 14: F-N plot for Scenario 1 (RA1, RA2 and RA3), including societal risk thresholds for new developments

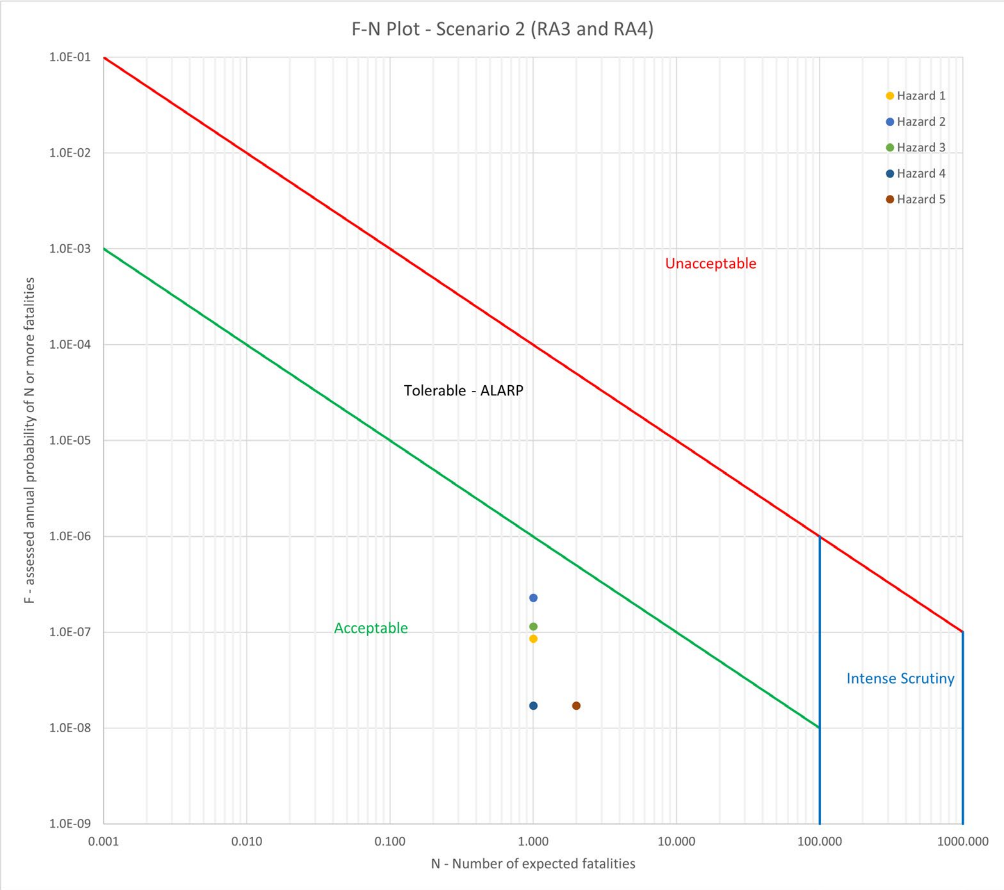


Figure 15: F-N plot for Scenario 2 (RA3 and RA4), including societal risk thresholds for new developments

10. Trail construction

Construction of the mountain bike trails will involve a number of challenges particularly where crossing steep terrain; areas of thick vegetation including medium to dense forest, areas of wet to saturated soils and protruding bedrock or rocks forming part of the colluvium and talus; and creek or gully crossings.

We understand the proposed mountain bike trail network will include:

- Existing trails previously formed by private individuals predominantly for mountain biking, with some areas currently used for trailbike (motorbike) riding and walking trails. Other trails include fire trails or access roads along gas and power line easements.
- Construction works along existing trails that may include minor re-alignment and re-grading involve some trimming of vegetation, minor cut to fill earthworks, and placement and compaction of a thin gravel layer on the trails where necessary to improve traction.
- New trails formed over predominantly undisturbed terrain, however they may also cross areas of disturbed ground or fill where past activities such as mining or farming have occurred. Formation of new trails will involve the clearing of vegetation along the alignment (while maintaining as many large trees as possible), followed by limited stripping of topsoils and root affected soils up to 200mm thickness, grading to provide crossfall for drainage (where necessary), compaction of the exposed surface, and placement and compaction of a thin gravel surface where necessary to improve traction.
- Construction of bridge crossings over watercourses may be required, replacing existing makeshift bridges, include rock armouring of creek banks to protect bridge supports.
- Construction of minor culverts to divert drainage paths under trails.
- General improvements to drainage and erosion protection measures will be required in the steep slope areas and areas of poor drainage where surface water may be ponded or where runoff is currently concentrated or directed onto the bike trails. Runoff should be directed away from trails by use of closely spaced cut-off drains with rock protection at discharge points or drained to watercourses where in close proximity to trails.

In relation to constructability, from the geotechnical perspective, the objective will be to undertake the construction works without increasing the likelihood, scale or frequency of a landslide event, as well as considering the safety of individuals working on the trails. Measures that may be considered to reduce landslide risk during construction should include:

- Use of small earthmoving plant such as mini-excavators to clear vegetation to form new trails and re-grading of existing trails
- Use of workers on foot (with harnesses where necessary) and hand-held equipment in sensitive areas such as steep slopes that cannot be safely accessed by trailed excavators or similar plant
- Use of appropriate sedimentation controls to ensure trail construction or improvements are not subject to significant erosion that may in turn trigger a soil mass to mobilise e.g. silt fence, vegetation regrowth both upslope and downslope of the trail
- Use of appropriate controls to minimise the impact of surface water drainage flowing on to the trails and in turn leading to ponding and potential water infiltration that may trigger a soil mass or imported trail materials to mobilise e.g. upslope drainage swales or mounds to redirect surface water to existing creeks & tributaries
- Removal of loose rocks on steep slopes including minor cliffs that may occur above the trails in advance of construction.

- Delivery of materials into steep slope areas remote from road access by helicopter, including construction materials for bridges, small culverts, trail edge support, drainage and surface improvements
- Planning works to avoid excessive clearing of vegetation in advance of the trail formation works, which reduces the risk of erosion and landslide in sensitive steep slope areas
- Planning of works to minimise impacts of wet weather, by staged construction limiting disturbance of large lengths of trail works, limiting stockpiling of materials on site and completing drainage works as the trails progress

Table B.1 within Appendix B presents a high-level geotechnical assessment of some typical trail features that may be applicable for the proposed mountain bike trails. Images, description & trail classification are provided courtesy of the trail designers, Synergy Trails. Table B.1 provides a general assessment of geotechnical constraints & risks for each of those trail features for the overall project with respect to the ground conditions discussed in previous sections above. It is not an assessment of those trail features for each individual trail section. Further assessment may be required in subsequent design or construction phases of work for specific ground conditions or geohazards encountered on each trail.

11. Conclusion

This report has presented the results of our geotechnical assessment for the Illawarra Escarpment Mountain Bike Concept Plan. The primary objectives of the study were to assess landslide hazards that could affect the proposed trails across the study area and to estimate loss of life risks these hazards pose to individuals mountain biking on the official bike trails. The estimated individual loss of life risks and societal risks are within the acceptable ranges as proposed by AGS (2007c) and NPWS (2020) respectively. The trail alignments are therefore considered feasible from a geotechnical perspective.

While we did not observe specific geotechnical hazard features necessitating deviation or re-routing of trails, it should be recognised that the occurrence of rapid landslides such as debris flows that are typically associated with intense rainfall events could locally damage trail infrastructure. It is not possible to predict the location or frequency of such events. Furthermore, it is likely that some of the trails traverse slow moving landslides exhibiting creep behaviour, however these features are unlikely to result in damage to the trails that could affect serviceability. Periodic inspection and maintenance of the trails will be required to manage these hazards.

The assessment does not assess risk to persons occupying the trails for other purposes, such as construction teams that may occupy the area for longer periods of time to undertake initial construction, remedial or upgrade works to the trails. This would require careful consideration of the specific project construction requirements and measures to be included in the project health and safety plan.

We recommend that decisions about acceptable and / or tolerable risk and risk management be based on the AGS (2007c) Landslide Risk Management Guidelines and the NPWS Guidelines for Quantitative Risk to Life Calculations for Landslides (2020). This report outlines our observations of geotechnical site features and assessment of landslide and rock fall hazards observable at the time of the fieldwork. Natural features will change and may deteriorate over time, which could change existing hazards or create new ones. Additional investigations may be required to further assess landslide hazards, risk mitigation measures, ongoing monitoring and maintenance requirements.

12. References

Australian Geomechanics Society, 2007a, "Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning", Australian Geomechanics Journal, 42 (1), March 2007.

Australian Geomechanics Society, 2007c, "Practice Note Guidelines for Landslide Risk Management", Australian Geomechanics Society. Australian Geomechanics, Vol 42, No1, March 2007.

Bowman, H. N., 1974, Geology of the Wollongong, Kiama and Robertson 1:50,000 Sheets 9029-II 9028-I&IV Sheets, Department of Mines, Geological Survey of New South Wales.

Colquhoun, G.P., Hughes, K.S., Deyssing, L., Ballard, J.C., Folkes, C.B, Phillips, G., Troedson, A.L. & Fitzherbert, J.A., 2021, New South Wales Seamless Geology dataset, version 2.1 [Digital Dataset]. Geological Survey of New South Wales, Department of Regional NSW, Maitland.

Flentje, P., 2012, Evolution of the Illawarra Escarpment terrain. Australian Geomechanics Journal, 47 (1), 1-16, March 2012.

Hazelton, P. & Tillie, P., 2010, The Wollongong – Port Hacking 1:100,000 Soil Landscape Series Sheet 9029-9129 (Edition 1). NSW Department of Environment, Climate Change and Water.

Moon, A., Wilson, R and Flentje P., 2005, "Developing and using landslide size frequency models" In Landslide risk management, Balkema.

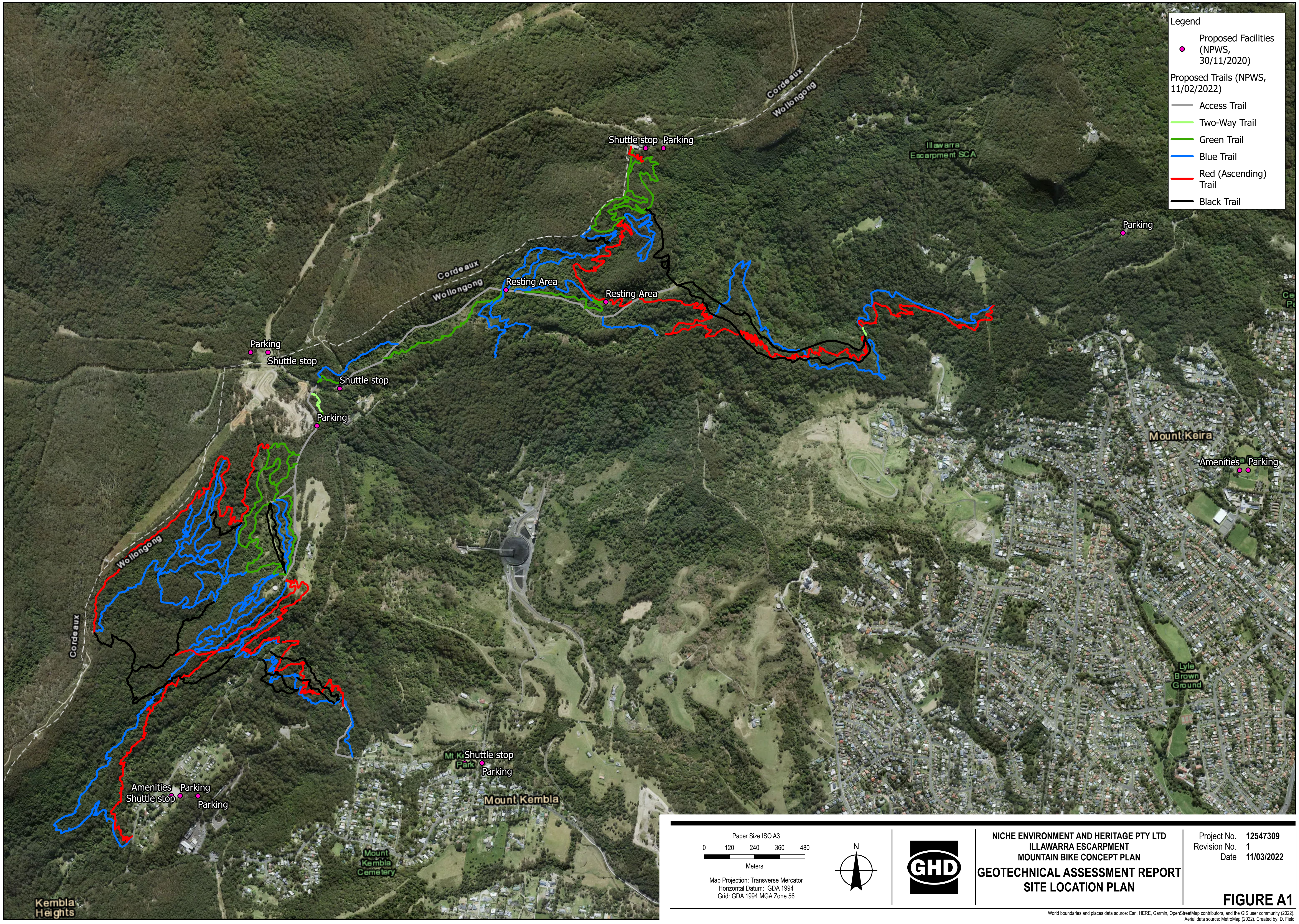
New South Wales National Parks and Wildlife Services, 2010, "Park Facilities Manual", Department of Planning, Industry and Environment, July 2010.

New South Wales National Parks and Wildlife Services, 2020, "Guidelines for Quantitative Risk to Life Calculations for Landslides", Department of Planning, Industry and Environment, 16 January 2020.

New South Wales National Parks and Wildlife Services and Wollongong City Council, 2018, "Draft Illawarra Escarpment MTB Strategy", State of New South Wales and Office of Environment and Heritage, October 2018.

Appendix A

Figures



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

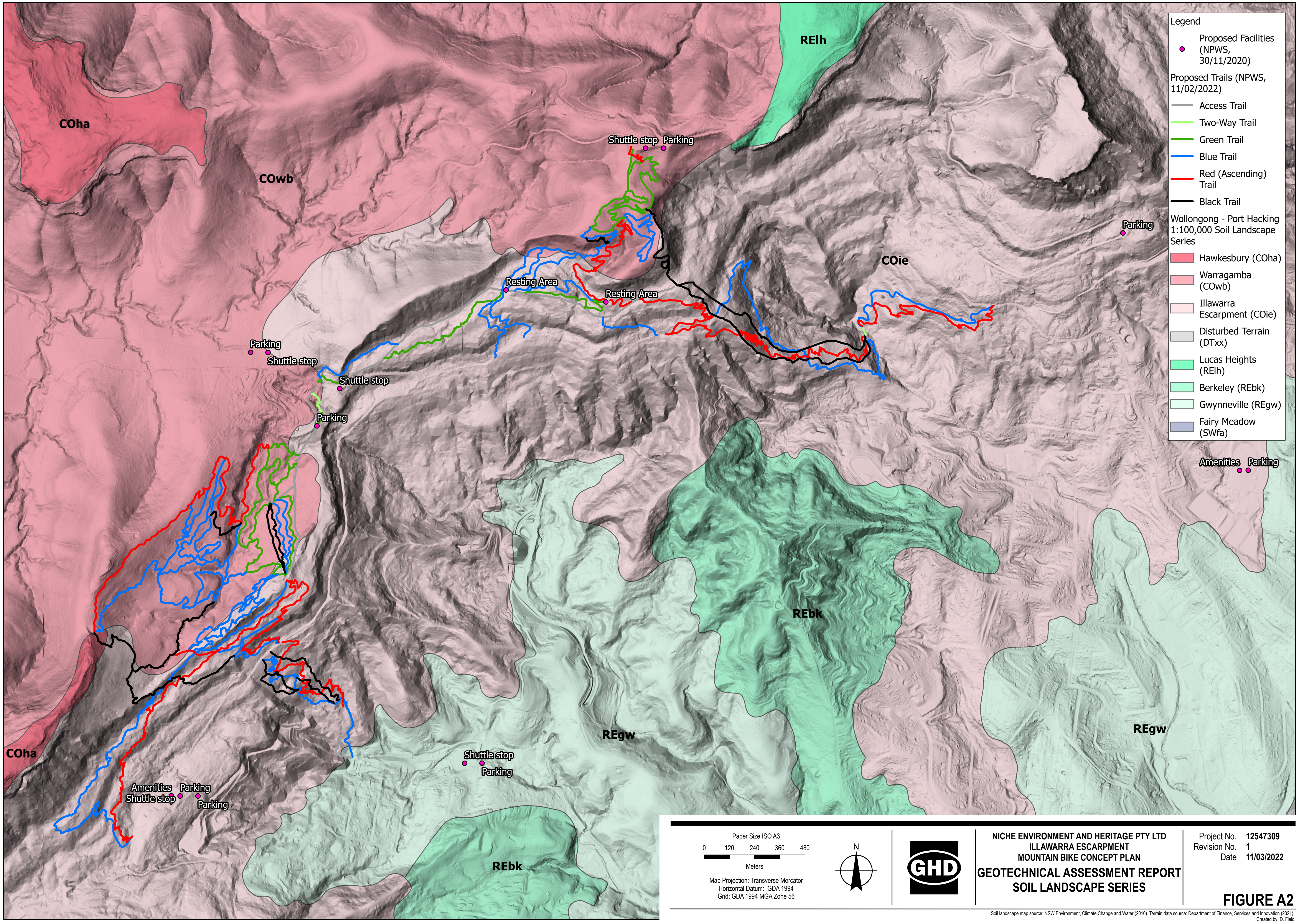
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN

GEOTECHNICAL ASSESSMENT REPORT
SITE LOCATION PLAN

Project No. 12547309
Revision No. 1
Date 11/03/2022

FIGURE A1

World boundaries and places data source: Esri, HERE, Garmin, OpenStreetMap contributors, and the GIS user community (2022).
Aerial data source: MetroMap (2022). Created by: D. Field



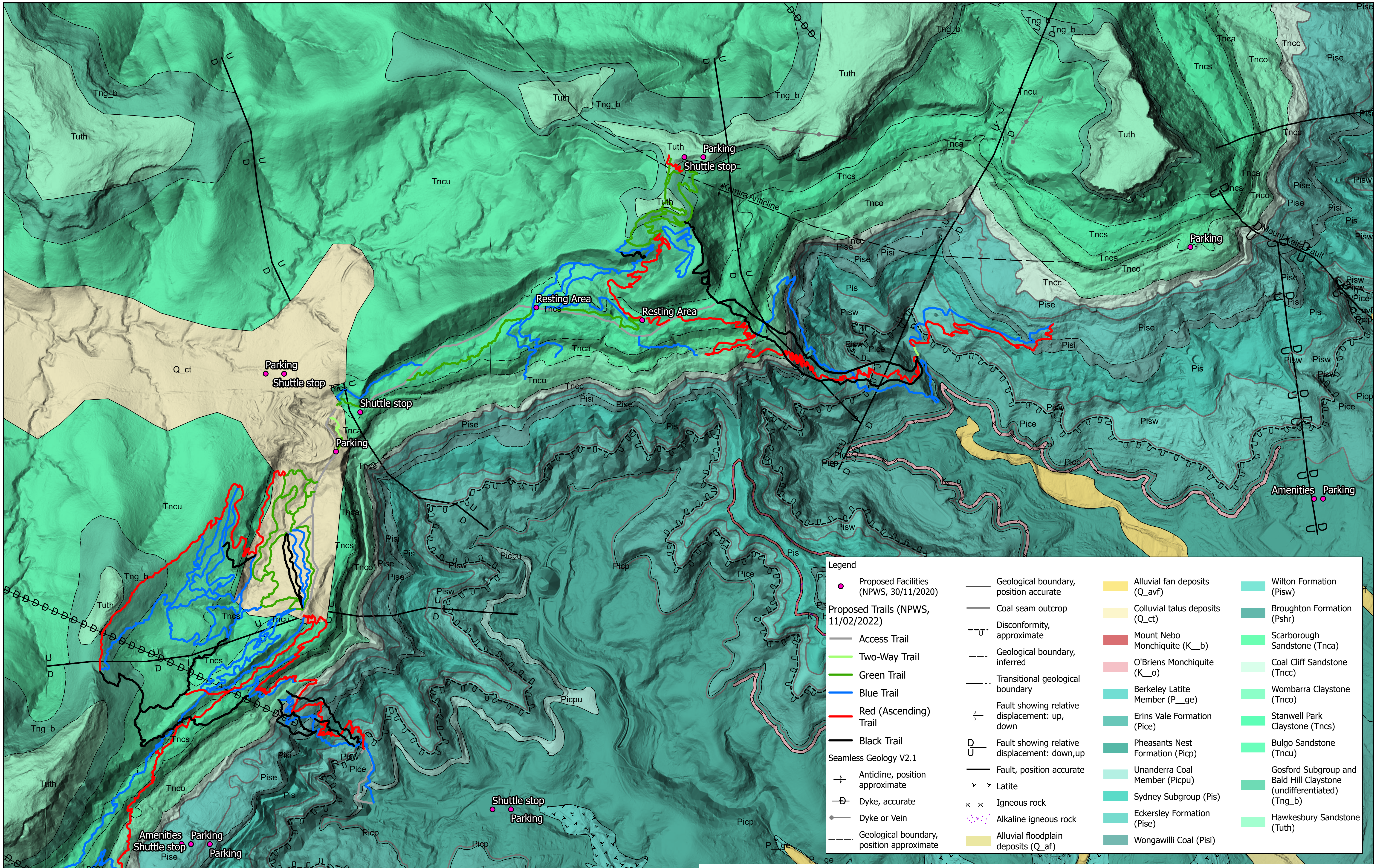
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN

GEOTECHNICAL ASSESSMENT REPORT
SOIL LANDSCAPE SERIES

Project No. 12547309
Revision No. 1
Date 11/03/2022

FIGURE A2

Soil landscape map source: NSW Environment, Climate Change and Water (2010). Terrain data source: Department of Finance, Services and Innovation (2021).
Created by: D. Field



Paper Size ISO A3

0 120 240 360 480

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

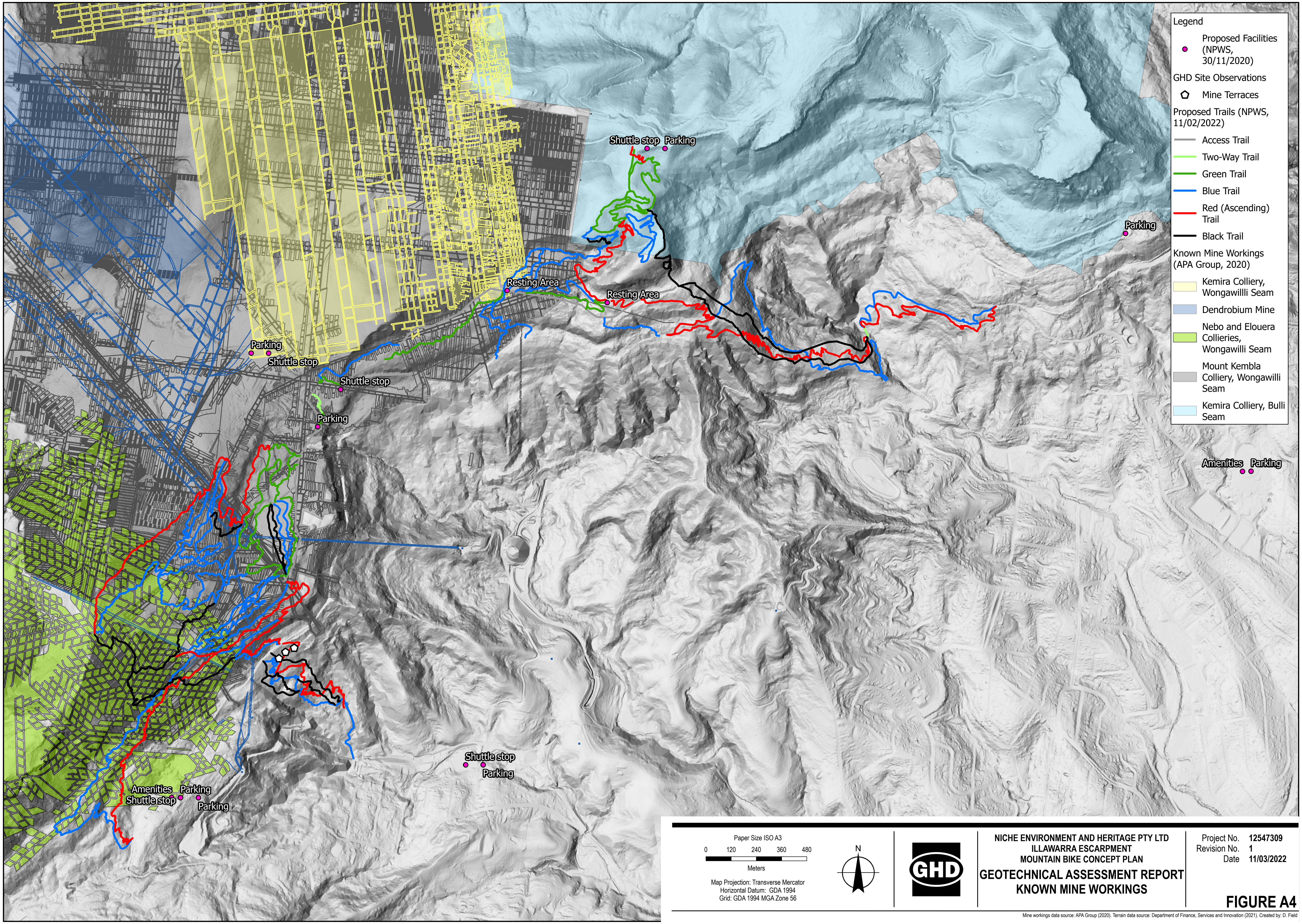
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN

GEOTECHNICAL ASSESSMENT REPORT
SEAMLESS GEOLOGY

Project No. 12547309
Revision No. 1
Date 11/03/2022

FIGURE A3

Seamless Geology Dataset: Colquhoun et al (2021). Terrain data source: Department of Finance, Services and Innovation (2021). Created by: D. Field



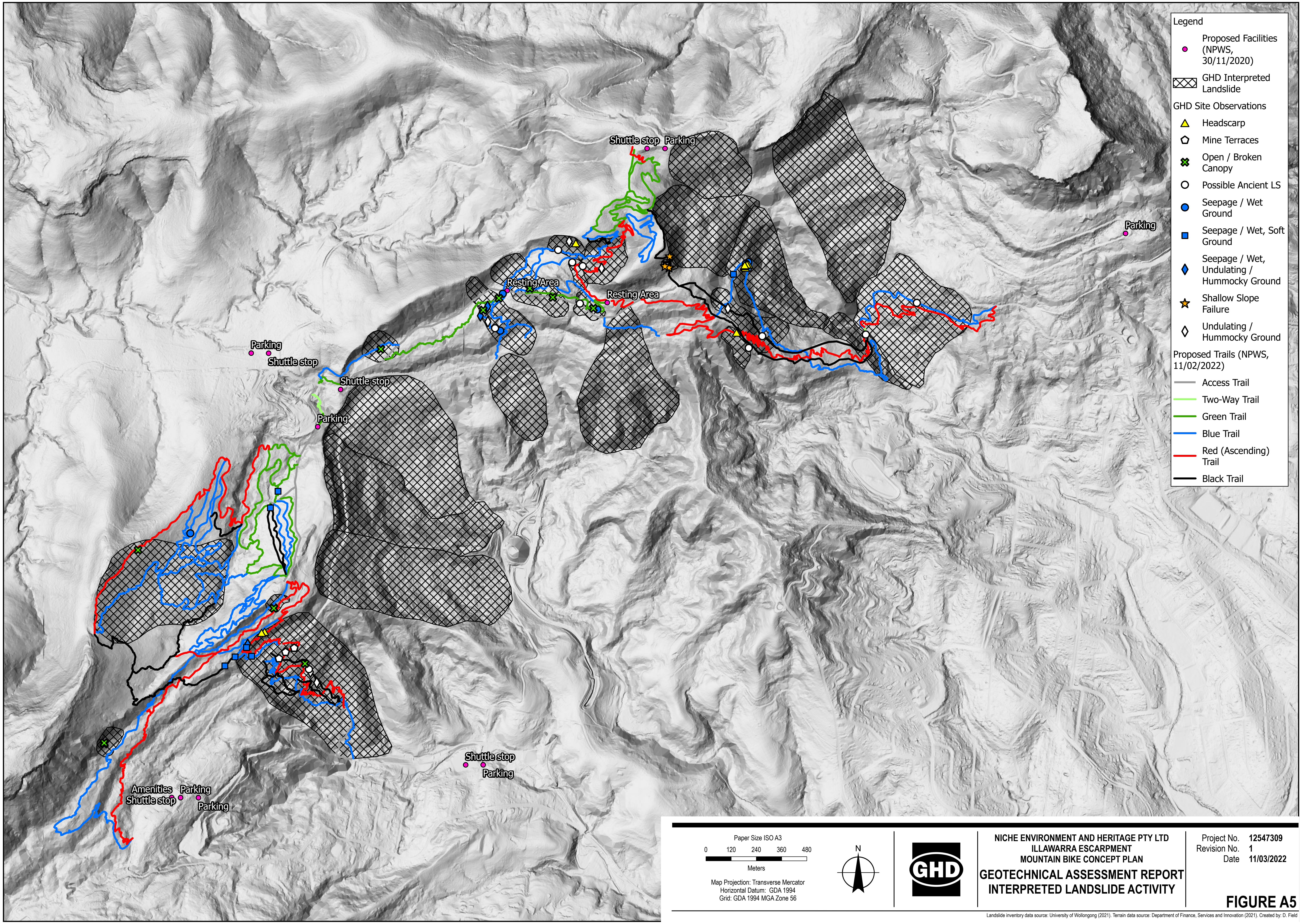
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN

GEOTECHNICAL ASSESSMENT REPORT
KNOWN MINE WORKINGS

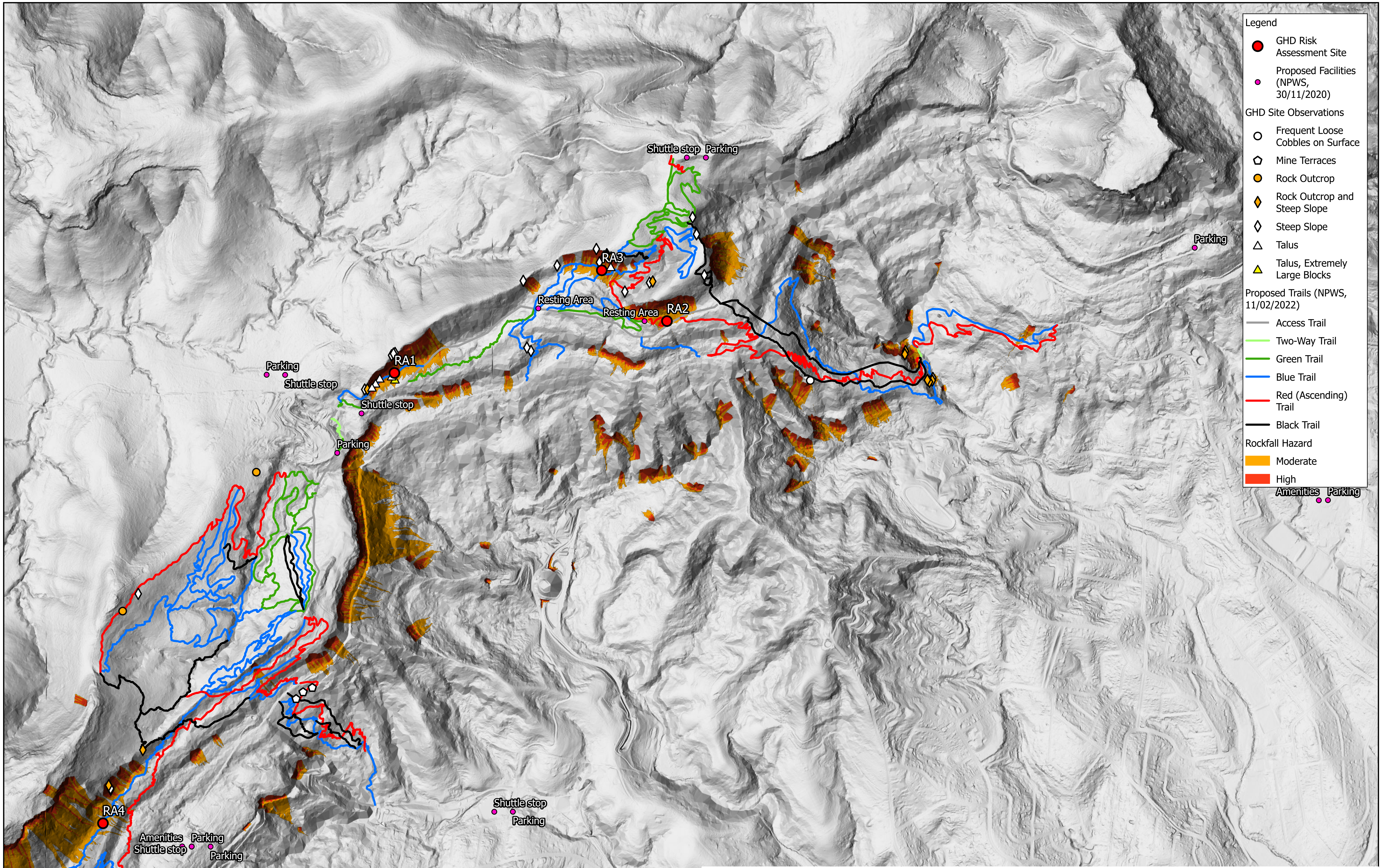
Project No. 12547309
Revision No. 1
Date 11/03/2022

FIGURE A4

Mine workings data source: APA Group (2020). Terrain data source: Department of Finance, Services and Innovation (2021). Created by: D. Field



Legend
Proposed Facilities (NPWS, 30/11/2020)
GHD Interpreted Landslide
GHD Site Observations
Headscarp
Mine Terraces
Open / Broken Canopy
Possible Ancient LS
Seepage / Wet Ground
Seepage / Wet, Soft Ground
Seepage / Wet, Undulating / Hummocky Ground
Shallow Slope Failure
Undulating / Hummocky Ground
Proposed Trails (NPWS, 11/02/2022)
Access Trail
Two-Way Trail
Green Trail
Blue Trail
Red (Ascending) Trail
Black Trail
Shuttle stop
Parking
Resting Area
Resting Area
Parking
Parking
Shuttle stop
Shuttle stop
Parking
Shuttle stop
Parking
Amenities
Shuttle stop
Parking
Parking
Paper Size ISO A3
0
120
240
360
480
Meters
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56
N
GHD
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN
GEOTECHNICAL ASSESSMENT REPORT
INTERPRETED LANDSLIDE ACTIVITY
Project No. 12547309
Revision No. 1
Date 11/03/2022
FIGURE A5
Landslide inventory data source: University of Wollongong (2021). Terrain data source: Department of Finance, Services and Innovation (2021). Created by: D. Field



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

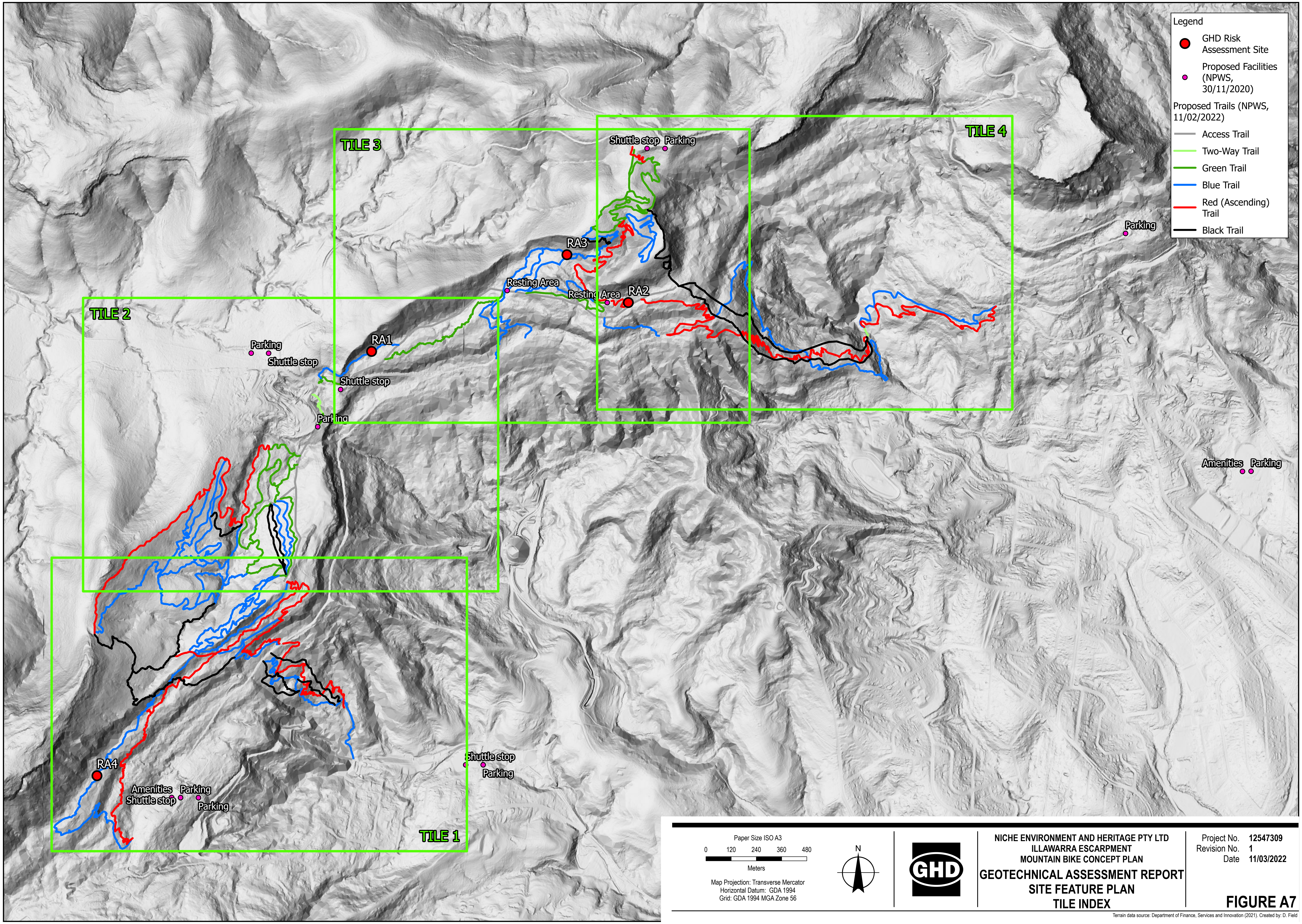
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN

GEOTECHNICAL ASSESSMENT REPORT
ROCKFALL HAZARD MODELLING

Project No. 12547309
Revision No. 1
Date 11/03/2022

FIGURE A6

Terrain data source: Department of Finance, Services and Innovation (2021). Created by: D. Field



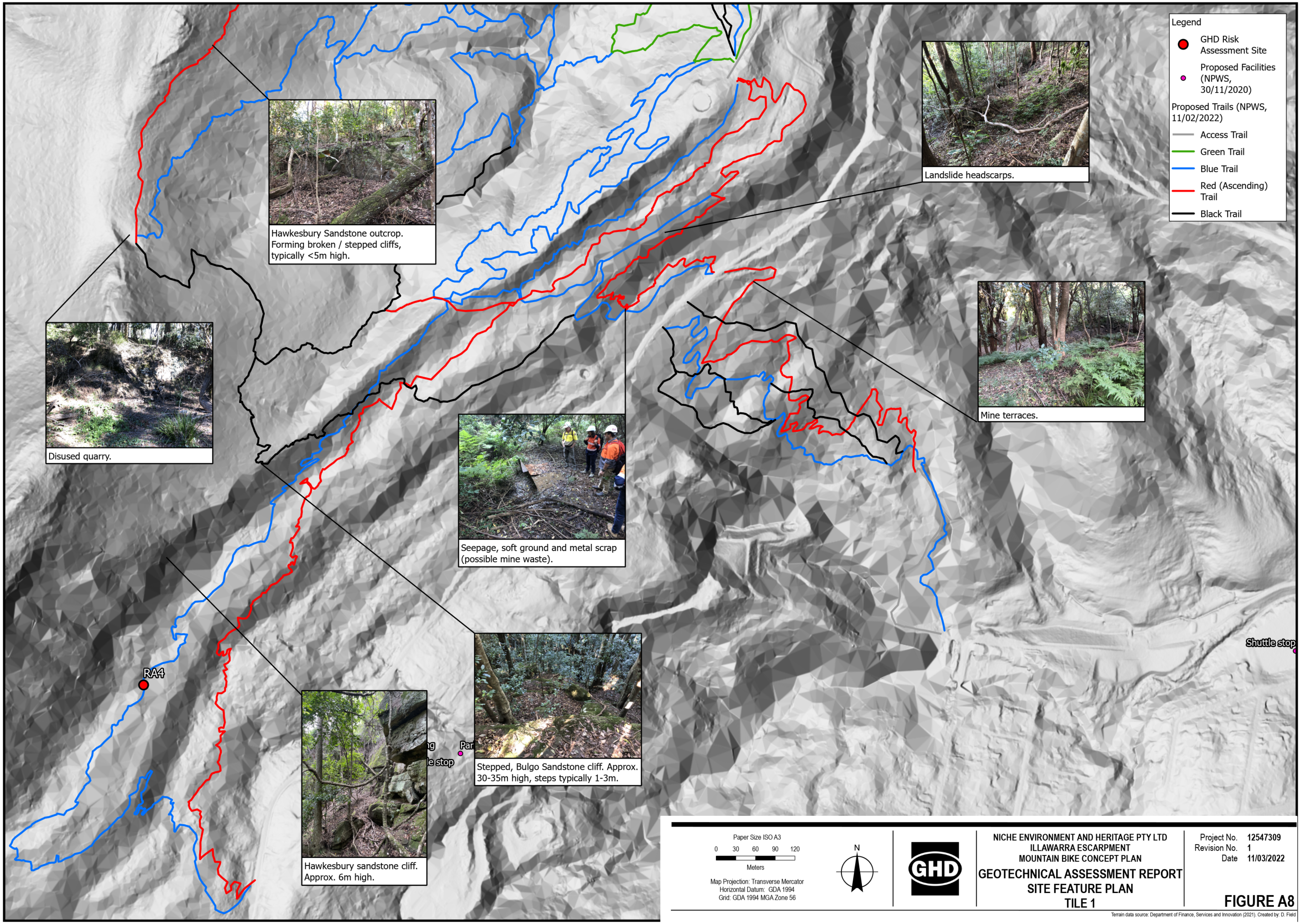
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN

GEOTECHNICAL ASSESSMENT REPORT
SITE FEATURE PLAN
TILE INDEX

Project No. 12547309
Revision No. 1
Date 11/03/2022

FIGURE A7

Terrain data source: Department of Finance, Services and Innovation (2021). Created by: D. Field



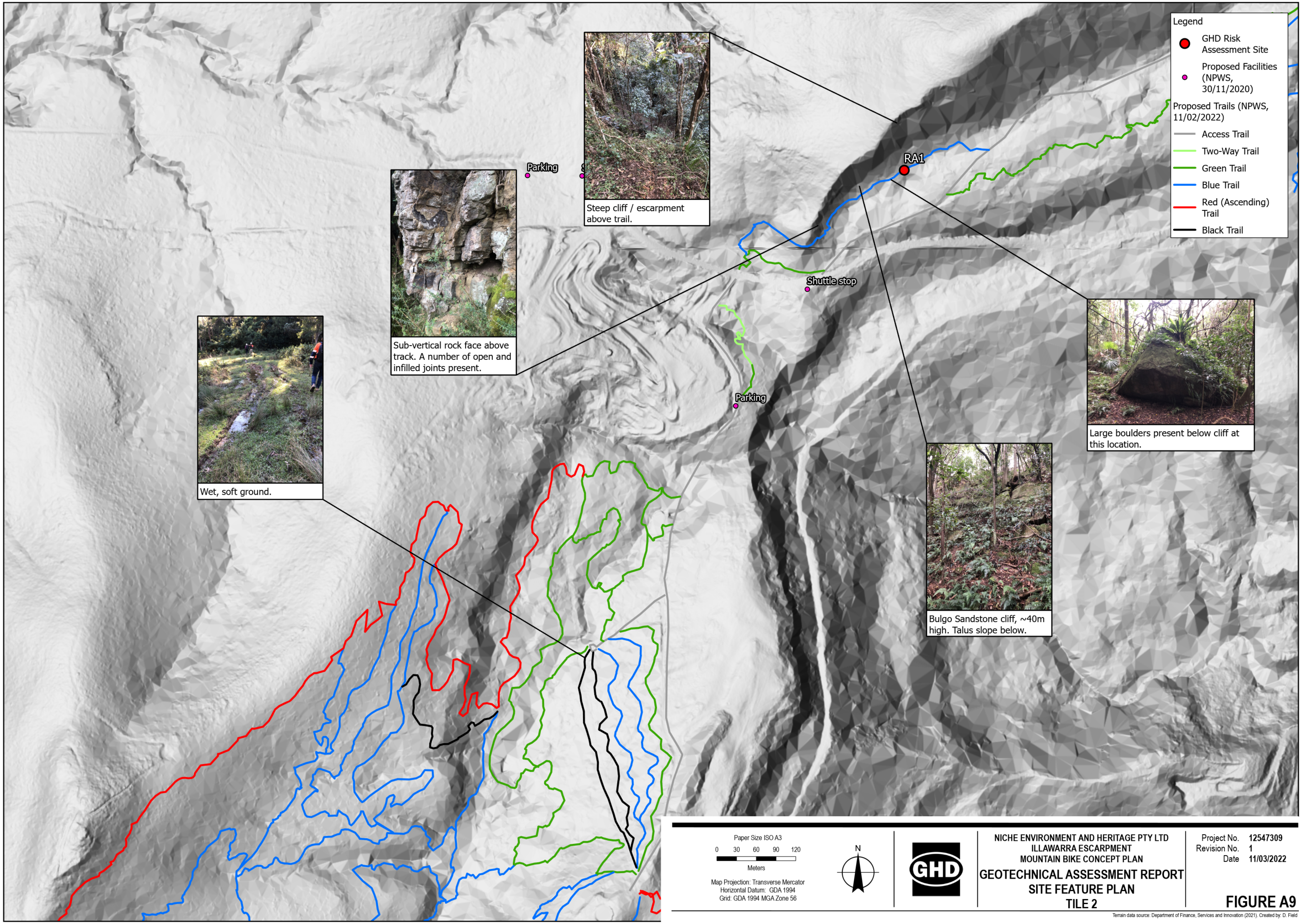
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN

GEOTECHNICAL ASSESSMENT REPORT
SITE FEATURE PLAN
TILE 1

Project No. 12547309
Revision No. 1
Date 11/03/2022

FIGURE A8

Terrain data source: Department of Finance, Services and Innovation (2021). Created by: D. Field



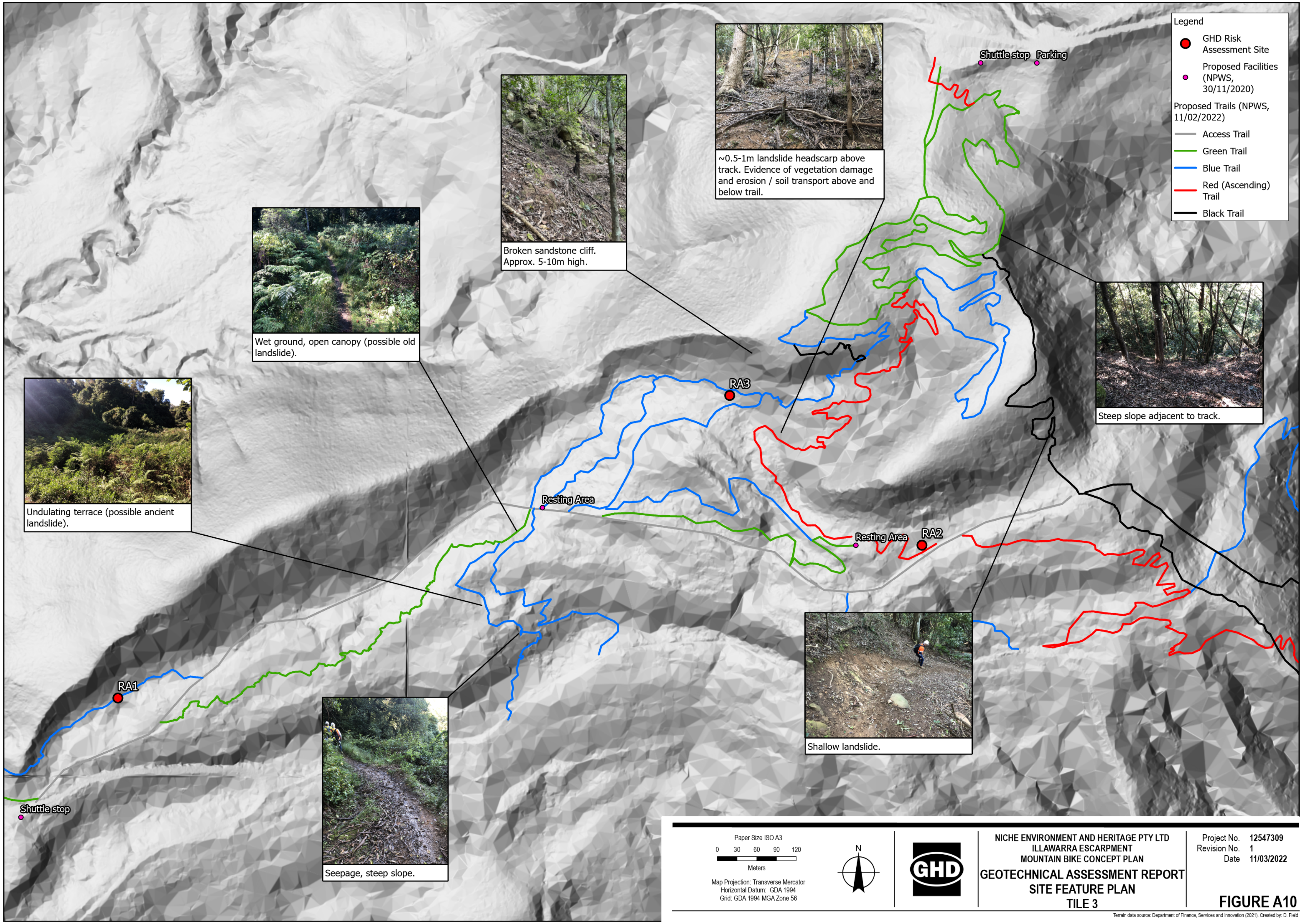
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN

GEOTECHNICAL ASSESSMENT REPORT
SITE FEATURE PLAN
TILE 2

Project No. 12547309
Revision No. 1
Date 11/03/2022

FIGURE A9

Terrain data source: Department of Finance, Services and Innovation (2021). Created by: D. Field



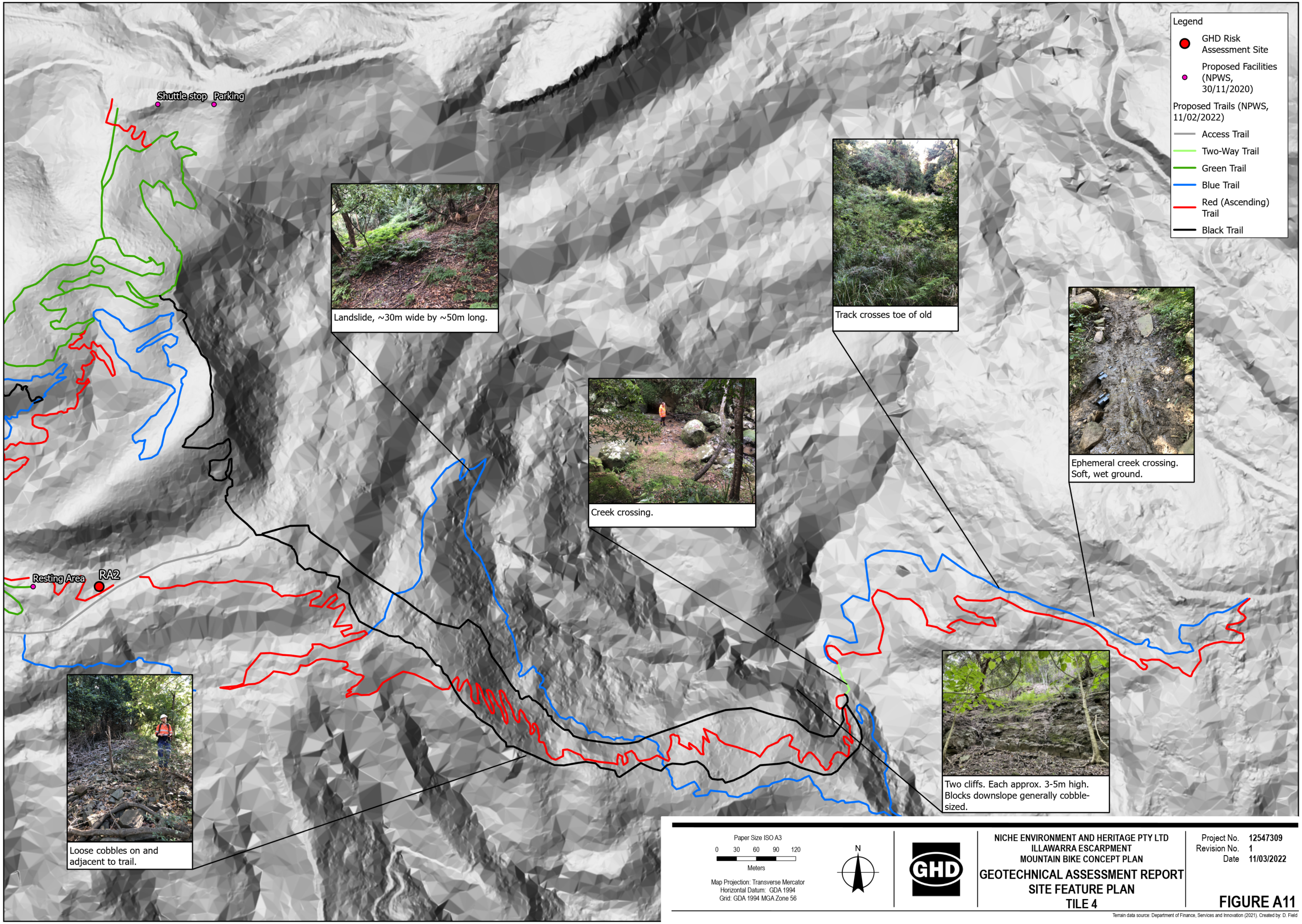
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN

GEOTECHNICAL ASSESSMENT REPORT
SITE FEATURE PLAN
TILE 3

Project No. 12547309
Revision No. 1
Date 11/03/2022

FIGURE A10

Terrain data source: Department of Finance, Services and Innovation (2021). Created by: D. Field

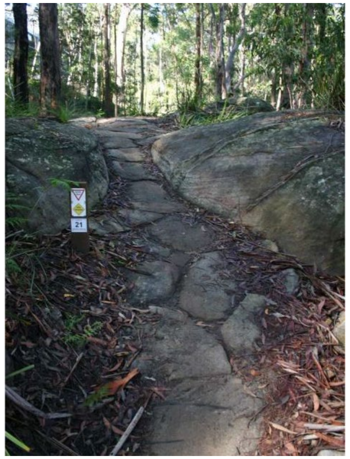


Legend
GHD Risk Assessment Site
Proposed Facilities (NPWS, 30/11/2020)
Proposed Trails (NPWS, 11/02/2022)
Access Trail
Two-Way Trail
Green Trail
Blue Trail
Red (Ascending) Trail
Black Trail
Shuttle stop
Parking
Resting Area
RA2
Landslide, ~30m wide by ~50m long.
Track crosses toe of old
Creek crossing.
Ephemeral creek crossing. Soft, wet ground.
Two cliffs. Each approx. 3-5m high. Blocks downslope generally cobble-sized.
Loose cobbles on and adjacent to trail.
Paper Size ISO A3
0 30 60 90 120
Meters
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56
N
GHD
NICHE ENVIRONMENT AND HERITAGE PTY LTD
ILLAWARRA ESCARPMENT
MOUNTAIN BIKE CONCEPT PLAN
GEOTECHNICAL ASSESSMENT REPORT
SITE FEATURE PLAN
TILE 4
Project No. 12547309
Revision No. 1
Date 11/03/2022
FIGURE A11
Terrain data source: Department of Finance, Services and Innovation (2021). Created by: D. Field

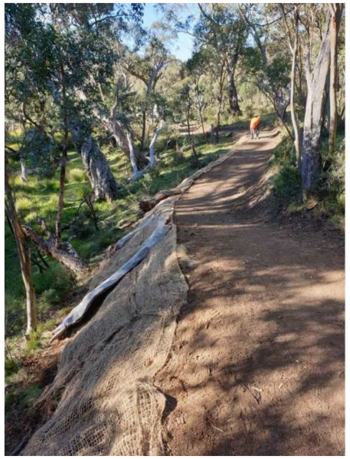
Appendix B

Constructability & maintenance – geotechnical review

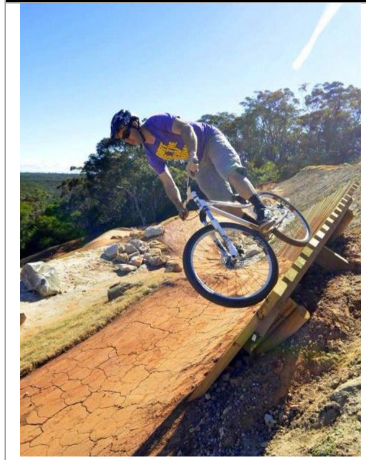
Table B.1: High level assessment – geotechnical constraints and risk of trail features (images & description from Synergy Trails)

Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
	Natural rock face trail. No build required, other than hand built run in/out	**Black** only	**General comment**: Provided example indicates a solid rock face, possibly sandstone. It assumes these type of trail features would be used for traversing claystone units of the escarpment such as the Stanwell Park & Wombarra Claystone units of the Narrabeen Group. Not applicable where rock is loose or partially detached from rock face or where adverse structure occurs such as open joints or weak seams, or where loose cobbles and boulder from colluvium or talus may encroach onto the rock face. **Construction**: Rock armouring or erosion protection measures may be required for the transition at the base of the rock face where it interacts with soil units. Avoid forming a drainage path for surrounds over the rock surface which could contribute to erosion and landslide activity within soil mass downslope.
	Rock armouring between rocks. Built between climbing areas.	**Green**, Blue, Black	**General comment**: Assumed use is limited to sandstone units of the Narrabeen Group and not the claystone units such as the Stanwell Park & Wombarra Claystone units. **Construction**: No comment. Good solution for this type of terrain on gentle to moderate slopes.

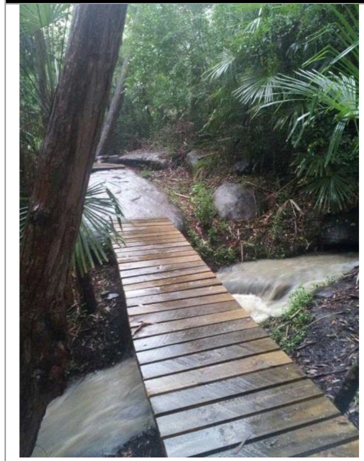
Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
	Trail descent, machine built, rock armoured	Blue, Black	**General comment**: Potential for descent trails to create drainage pathways for surface water runoff. **Construction**: Sediment control measures required to retain sediment and to reduce the likelihood of scour & erosion between rock armouring. Shallow cut-off channels at the top of the descent and regularly spaced along the trail to ensure that surface water runoff does not lead to erosion & scour and subsequent compromising of rock armouring. Ensure suitable compaction of fill placed in trail formation. **Maintenance**: Regular inspection to ensure sediment control measures are in place and to assess adequacy of drainage measures. Check for slumping of trail walls and erosion of trail base.
	Trail with rock jump feature, machine built	Blue, Black	**General comment**: In-sufficient detail available on the proposed construction methodology & materials. Further assessment required for site specific locations. **Construction**: Structural jump features e.g. timber framed , should be supported or anchored into stiff soils or weathered rock. Ensure suitable base preparation and compaction for jump formed with soil and rock. **Maintenance**: Dependent on proposed materials for creating rock jump.

Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
	Machine built trail (on a slope), soil placement, fabric placement on batter slopes	Green, Blue, Black	**General comment**: Trail susceptible to upgradient surface water runoff leading to erosion and scour and downslope batter failure. Saturation of fill formation and possible slumping of batter. **Construction**: Assume an appropriate level of compaction is applied to fill material to ensure the trail is not subject to settlement and/or erosion. Construct appropriate upgradient drainage is in place to ensure surface runoff is directed to designated drainage channels. Batter slope assumed to be constructed at no steeper than 1V:2H for soil slope. Rock armouring likely required in addition to erosion matting. **Maintenance**: Regular inspection of upgradient drainage control measures.
	Machine built trail (relatively flat), soil placement/cut, no batter slope	**Green**, Blue, Black	**General comment**: Trails over flat or gently sloping terrace areas on the escarpment generally susceptible to collection of surface water and seepages **Construction**: Raised trails should be considered either using free draining rock, with geotextile fabric then trail surface or raised structural platform. Drainage channels to be provided to drain excess water and maintain water levels below bike trail surface. **Maintenance**: Potential for sediments at the end of the section to be washed away or flow into the subsequent section. May require regular inspection and regrading of the trail to limit deep rutting and potholes.
	Machine built trail with rock jump feature, soil placement/cut, no batter slopes	**Blue**, Black	**General comment**: Assumed this is cut to fill exercise with no imported fill. **Construction**: For soil placed at the transition to the rock jump, recommend some form of erosion control on the sides of the jump. For fill placement, an appropriate level of compaction is required . **Maintenance**: Regular inspection of the jump and trail to ensure no excessive erosion due to surface water runoff.

Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
	Rock armouring through natural slots in rocks, hand construction only, using local sourced rocks within or near the trail	Blue, Black	**General comment**: Source rocks to be limited from sandstone boulders of sandstone units of the Narrabeen Group such as the Coal Cliff Sandstone (lower escarpment) Scarborough (middle escarpment) and Bulgo Sandstone (upper escarpment). **Construction**: Assumed some form of bedding material will be used underneath the sandstone boulders to assume they are secure. Unclear if a stabilised bedding sand may be used to secure the boulders. May require some upgradient surface water drainage control measures to ensure water doesn't flow through the 'natural slots' and undermines placed sandstone boulders. **Maintenance**: regular inspection of the rock armouring to ensure surface runoff has not eroded sediments beneath sandstone boulders causing them to be understand.
	Flow trail, machine built with imported clay material	Green, Blue, Black	**General comment**: Trail susceptible to ponding of surface water and runoff. **Construction**: Suggest excess fill material be used to form berms at the side of the trails to prevent surface runoff onto the trail. **Maintenance**: May require regular inspection and if needed regraded of the trail to avoid rutting or potholes

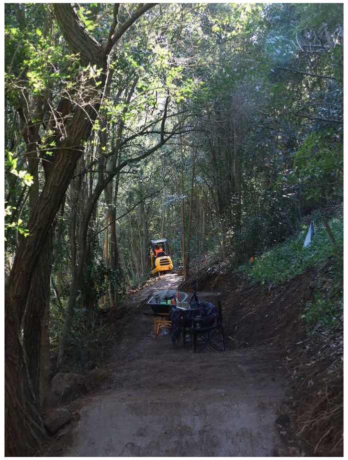
Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
	Technical Trail Feature (TTF) - Wall ride (timber construction), machine built	Green, Blue, Black	**General comment**: Timber wall appears to be resting directly on a slope made with fill material. **Construction**: Appropriate compaction of fill to create the batter slope adjacent to the timber ramp. Ensure structure is well anchored to ground. **Maintenance**: Potential for rock armouring under timber if settlement becomes an issue.
	Roller section, flat terrain, machine built, imported material	Blue, Black	**General comment**: Soil material placed at the edge of the trail may be susceptible to erosion. **Construction**: Suitable for low grades on plateau areas Assume suitable compaction of fill is achieved, with adequate drainage provided. **Maintenance**: Regular inspection and maintenance of formation and drainage.

Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
	Full bench on '20% side slope', machine cut	Blue, Black	**General comment**: Trail susceptible to upgradient surface water runoff leading to erosion scour and slumping of cut and fill batters. **Construction**: Assume an appropriate level of compaction is applied to fill material. Construct appropriate upgradient drainage to direct surface runoff to designated drainage channels. Batter slope assumed to be constructed at no steeper than 1V:2H. If gradient is greater than 1V:2H, construction may need to consider some support such as rock revetment. **Maintenance**: Regular inspection of upgradient drainage control measures
	Rock armouring using locally sourced sandstone	Trail type not disclosed	**General comment**: Assumed use is limited to sandstone units of the Narrabeen Group (Coal Cliff, Scarborough & Bulgo) and not the claystone units such as the Stanwell Park & Wombarra Claystone units. **Construction**: No comment
	Jump lines, machine built with imported VENM	Blue, Black	**General comment**: Edges of the raised trail may be susceptible to erosion. **Construction**: Ensure suitable compaction of imported fill and provision of drainage and erosion control where trail intercepts runoff. **Maintenance**: Regular inspection of trail surface and drainage.

Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
	Short bridge over creek, bolted to insitu rock either side	Trail type not disclosed	**General comment**: Assumed these structures are in place where there are large boulders or massive rocks which are not susceptible to movement. Likely to be in areas of historic rock falls in creeks and tributaries. **Construction**: Prior bolting to medium strength to fresh sandstone boulders/rocks, a visual assessment of the rocks to confirm they are well embedded into soil mass with no undercutting present. **Maintenance**: Regular inspection of the bridge condition and underlying rocks.
	Fly over, timber post construction, concrete footings, trail beneath fly over	Fly over – **Blue**, Black Trail beneath – **Green**, Blue, Black	**General comment**: This type of structural trail should be assessed by a structural engineer and footings design specifically for the site ground conditions **Construction**: Not clear if timber posts will be bottled to a shallow concrete pad footing or embedded in concrete. Ground anchors may be required. **Maintenance**: Regular inspection of the structure, concrete pad footings and the post connection
	Example of elevated trail for getting over root, swampy ground or critical vegetation, timber construction on "Y spreader" post system to minium number of footings	Trail type not disclosed, ssumed **Green**, Blue, Black	**General comment**: Assumes the reference to "Y spreader" and "footing", refers to a small concrete pad footing for the ramp to be bolted to. **Construction**: Pad footing to be installed as per requirements for the "Y spreader". Assessment of ground condition to assess footing or ground anchor requirements. **Maintenance**: No comment

Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
	Low raised trail for steep grades to minimise impact to ground and growth beneath	**Blue**, Black	**General comment**: Unclear in description how the elevated section will be supported of the ground. GHD assume it will be similar to the system used for the elevated trail above. **Construction**: This is a structural trail and will require suitable foundation support with pad or post footings or ground anchors. Depending on location, will determine the ground conditions for which the pad footing will be sitting in. For steep slopes on potentially colluvium soils, an assessment will be required to assess ground conditions for footing support. . **Maintenance**: if being placed on steep colluvium slopes, potential for slopes to become activated and slip. Recommend regular inspection of the trail section for evidence of landslip e.g. drop in pad footings, buckling of timber slats, erosion or movement of soils adjacent and underlying the trail.
His 	Low raised boardwalk, wet area, timber post construction set in concrete with fibre reinforced panels (FRP) top, bolted to large rocks where present of tiber post supports	Trail type not indicated, assumed **Green**, Blue, Black	**General comment**: Assumed to be used in damp or wet ground conditions. **Construction**: Synergy description refers to use of timber posts set in concrete. Need to ensure suitable ground condition for foundation. **Maintenance**: Regular inspection of support posts.

Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
	Rock armoured trail, approximately 15m section, imported or locally sourced rock	Trail type not indicated	**General comment**: Assumed use is limited to sandstone units of the Narrabeen Group and not the claystone units such as the Stanwell Park & Wombarra Claystone. **Construction**: No comment **Maintenance**: Maintain drainage to prevent erosion and undercutting of rock slabs.
	Timber bridge with handrail over small creek, bolted to rock either side, treated pine timber can be replaced with FRP panels as shown above	Trail type not indicated, assumed **Green**, Blue, Black	**General comment**: Check stability of creek banks at crossing. **Construction**: Ensure suitable foundation for bridge support. Provision of creek bank protection by revetment rock or similar. **Maintenance**: Regular inspection of the bridge condition and underlying rock armouring of creek where provided.
	Trail corridor clearing, flagged line by builder approved on site by landowner before cut vegetation. Vegetation used to shut down illegal trail nearby. Before & after photo. After photo indicated full bench cut with 1m high cut back	**Blue**, Black	**General comment**: Soil material placed at the edge of the trail on the downslope side may be susceptible to erosion. Limit extent of clearing to areas ready for trail construction **Construction**: Recommend some form of protection to the upslope cut batters **Maintenance**: Regular inspection and hand tool corrective works, and maintenance of drainage.

Trail Feature	Description	Trail Location (Red, Green, Blue, Black)	Geotechnical Constraints/Risks
			

Appendix C

Risk assessment summary tables

Quantitative Risk Estimation (Individual Loss of Life Risk)

LOCATION: Illawarra Escarpment Mountain Bike Trail Network
CALCULATIONS BY: David Field
DATE: 16/03/2022

CLIENT: NPWS
PROJECT: Illawarra Escarpment Mountain Bike Trail Network - Geotechnical Risk Assessment
PROJECT: 12547309

Scenario	Hazard	Hazard description	Annual landslide frequency	Likelihood of reaching trail	Annual probability of landslide reaching trail	Vulnerability of individual impacted	Number of traverses, individual most at risk (assume 3 runs / week, every week)	Proportion of track impacted	Reduction factor (probability of person being present)	Affected slope length (m)	Constant	Travel speed, individual most at risk (km/hr)	Travel speed, average individual (km/hr)	Risk, individual most at risk	Risk, average individual	Exposed population (assume 10 new riders / week, every week)	Total number traverses, all individuals (assume avg. 3 runs / year, per person)	Probability of impact to element at risk	Combined risk from multiple hazards to individuals	Number of expected fatalities	Cumulative risk from multiple hazards to multiple people	Equation used
					$P_{(H)}$	$V_{(D:T)}$	n_i	w	f	d	Constant	s_i	s	$R_{(LoL)}$	$AvR_{(LoL)}$	e	n	F	$R_{(LOLC)}$	N	F_C	
1 Rider with minimum speed defined by access trail / red trail (risk assessment sites RA1, RA2 and RA3)	1	Small (~0.4 m3)	0.5	0.05	0.025	0.6	156	0.5	1.0	1.0	1.10E-07	5.0	5.0	2.6E-08	1.7E-10	520	1560	2.6E-07		1.0	1.4E-06	Equation 1 - general case
	2	Medium (~4 m3)	0.1	0.1	0.01	1.0	156	1.0	1.0	2.0	1.10E-07	5.0	5.0	6.9E-08	4.4E-10	520	1560	6.9E-07		1.0	1.1E-06	Equation 1 - general case
	3	Large (~40 m3)	0.02	0.1	0.002	1.0	156	1.0	1.0	5.0	1.10E-07	5.0	5.0	3.4E-08	2.2E-10	520	1560	3.4E-07	1.4E-07	1.0	4.5E-07	Equation 1 - general case
	4	Very large (~400 m3)	0.001	0.1	0.0001	1.0	156	1.0	1.0	15.0	1.10E-07	5.0	5.0	5.1E-09	3.3E-11	520	1560	5.1E-08		1.0	1.0E-07	Equation 1 - general case
	5	Extremely large (~2,000 m3)	0.0001	0.5	0.00005	1.0	156	1.0	1.0	30.0	1.10E-07	5.0	5.0	5.1E-09	3.3E-11	520	1560	5.1E-08		2.0	5.1E-08	Equation 1 - general case

Scenario	Hazard	Hazard description	Annual landslide frequency	Likelihood of reaching trail	Annual probability of landslide reaching trail	Vulnerability of individual impacted	Number of traverses, individual most at risk (assume 3 runs / week, every week)	Proportion of track impacted	Reduction factor (probability of person being present)	Affected slope length (m)	Constant	Travel speed, individual most at risk (km/hr)	Travel speed, average individual (km/hr)	Risk, individual most at risk	Risk, average individual	Exposed population (assume 10 new riders / week, every week)	Total number traverses, all individuals (assume avg. 3 runs / year, per person)	Probability of impact to element at risk	Combined risk from multiple hazards to individuals	Number of expected fatalities	Cumulative risk from multiple hazards to multiple people	Equation used
					$P_{(H)}$	$V_{(D:T)}$	n_i	w	f	d	Constant	s_i	s	$R_{(LoL)}$	$AvR_{(LoL)}$	e	n	F	$R_{(LOLC)}$	N	F_C	
2 Rider with minimum speed defined by blue trail (risk assessment sites RA3 and RA4)	1	Small (~0.4 m3)	0.5	0.05	0.025	0.6	156	0.5	1.0	1.0	1.10E-07	15.0	15.0	8.6E-09	5.5E-11	520	1560	8.6E-08		1.0	4.6E-07	Equation 1 - general case
	2	Medium (~4 m3)	0.1	0.1	0.01	1.0	156	1.0	1.0	2.0	1.10E-07	15.0	15.0	2.3E-08	1.5E-10	520	1560	2.3E-07		1.0	3.8E-07	Equation 1 - general case
	3	Large (~40 m3)	0.02	0.1	0.002	1.0	156	1.0	1.0	5.0	1.10E-07	15.0	15.0	1.1E-08	7.3E-11	520	1560	1.1E-07	4.6E-08	1.0	1.5E-07	Equation 1 - general case
	4	Very large (~400 m3)	0.001	0.1	0.0001	1.0	156	1.0	1.0	15.0	1.10E-07	15.0	15.0	1.7E-09	1.1E-11	520	1560	1.7E-08		1.0	3.4E-08	Equation 1 - general case
	5	Extremely large (~2,000 m3)	0.0001	0.5	0.00005	1.0	156	1.0	1.0	30.0	1.10E-07	15.0	15.0	1.7E-09	1.1E-11	520	1560	1.7E-08		2.0	1.7E-08	Equation 1 - general case

ghd.com

→ The Power of Commitment