Yarra Ranges Shire Council

Warburton Mountain Bike Destination Project

Geotechnical Risk Assessment

December 2019

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1. Introduction

1.1 Background

The Warburton Mountain Bike Destination Project (the Project), is situated near Warburton in the Yarra Ranges, Approximately 70 km north east of Melbourne (Figure 1). The project will involve the construction of world-class mountain bike trails, new accommodation and a visitors hub, to stimulate economic growth in the region through tourism and recreation.

The iconic trails would be eligible for International Mountain Bike Association Gold Trail status, attracting national and international visitors.

The main trail head would be situated near the Warburton golf course, with direct access to the trails from the accommodation facilities. There would be a total of 44 trails comprising of formalised existing trails as well as new trails, providing both downhill and cross-country style experiences.

1.2 Purpose of this report

GHD has been requested by Yarra Ranges Shire Council to undertake a Geotechnical Risk Assessment for the construction of the proposed mountain bike trails.

The purpose of this Geotechnical Risk Assessment is to inform the development of Referrals to government under the Environment Effects Act 1978 and Environment Protection Biodiversity Conservation Act 1999, to guide selection of appropriate planning approvals pathways for the project.

This report follows on from the preliminary geotechnical assessment (GHD report: Preliminary Surface Water & Geotechnical Assessment, Draft dated September 2019) which highlighted a number of trails that required further geotechnical assessment. The assessment is based on the proposed trail plan as of 14 November 2019.

This report will be used to understand the geotechnical risks involved during the construction stage and subsequent post-construction use of the mountain bike trails and outlines control measures which are required to manage these risks.

1.3 Scope

The scope of the geotechnical risk assessment includes the following:

- Review of existing documents; including aerial imagery, topography, geology and existing reports and assessments completed in the Warburton area including the Coffey 1999 Landslip Zoning of the Shire of Yarra Ranges (Ref: M2964/1-CF).
- Site visit to conduct a visual assessment of the site.
- Description of the geotechnical ground model for the site including the ground conditions and identified hazards.
- A qualitative Risk Assessment of the site in relation to mountain bike trails.
- Preparation of a Geotechnical Risk Assessment providing advice on risk minimisation and control measures.

1.4 Available information

A review of available information was undertaken as part of the assessment. The information included:

- 1:250,000 Geological Survey of Victoria map of Warburton (1997)
- LiDAR data
- Yarra Ranges Council landslide inventory (https://intramapspublic.yarraranges.vic.gov.au/intramaps90public/?project=Public&module=Landslide%20Assessment, Accessed November 2019)
- Coffey Report: Landslip Zoning of the Shire of Yarra Ranges (1999) (ref: M2964/1-CF)

1.5 Limitations

This report: has been prepared by GHD for Yarra Ranges Shire Council and may only be used and relied on by Yarra Ranges Shire Council for the purpose agreed between GHD and the Yarra Ranges Shire Council as set out Section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Yarra Ranges Shire Council 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. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Yarra Ranges Shire Council 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.

The opinions, conclusions and any recommendations in this report are based on information obtained from visual assessment of the site. Investigations undertaken in respect of this report are constrained by the particular site conditions, such as the location of roads and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

2. Geotechnical Assessment

2.1 Review of existing data

2.1.1 Regional geology

The 1:250,000 Geological Survey of Victoria map of Warburton (1997) and Coffey Report (ref: M2964/1-CF) suggest the geology of the site is made up of several major units that can be roughly divided between north and south of Warburton town, highlighted on Figure 2.

Donna Buang Rhyodacite dominates the north of the site. Two major units dominate the south of the site, the Humevale Siltstone on the west and Warburton Granodiorite on the east. A series of linear feeder Felsic Dykes outcrop through the north and south of the site, with a general north south orientation.

Minor units include Ythan Creek Rhyodacite outcropping in the centre of the site at the base of the valley and colluvium found at the base of slopes and within gully systems in the northern half of the site.

Table 1 Geological descriptions

Geological unit	Geological age	Description	Figure 2 reference
Donna Buang Rhyodacite	Late Devonian	A thick extrusive volcanic deposit which has formed a mountainous area	Dyad
Humevale Siltstone	Silurian to Early Devonian	Siltstone that has undergone contact metamorphism to produce hornfels as a result of baking from the Warburton Granodiorite	Dxh
Warburton Granodiorite	Late Devonian	An igneous intrusion	G235
Felsic Dykes	Silurian to Carboniferous	A series of intrusive felsic dykes with similar composition	Y-F
Ythan Creek Rhyodacite	Late Devonian	Extrusive volcanic deposit	Dyay
Colluvium	Quaternary	Deposits include poorly sorted gravel, sand, silt and clay with zones of cobbles and boulders	Qc1

2.1.2 Previous landslides

The occurrence of landslides in the Yarra Ranges has been well documented in the past. Using the Yarra Ranges landslide inventory system and reviewing the Coffey Landslip Zoning report we are able to identify the type and distribution of historical landslides in the Warburton area.

Table 2 below lists some of the large scale landslides recorded within the Yarra Ranges landslide inventory.

Table 2 Historical landslides recorded in the Yarra Ranges Council inventory

Location	Type	Date reported	Approximate dimensions	Geological unit (mapped)
80 Donna Buang Road, Warburton	Rotational/translational	22 Sep 1999	432 x 268 m	Colluvium
49 Upper Blackwood Avenue, Warburton	Debris slump/block slide	1 May 1982	371 x 226 m	Colluvium
23 Yuonga Road, Warburton	Rotational/translational	22 Sep 1999	125 x 337 m	Colluvium
21 Patricia St, Millgrove	Rotational/translational	1 Feb 1985	1287 x 497 m	Donna Buang Rhyodacite
265 Dee Road, Millgrove	Rotational/translational	1 Feb 1985	2302 x 2607 m	Donna Buang Rhyodacite
26 Brett Road, Warburton	Rotational/translational	22 Sep 1999	70 x 169 m	Colluvium

The distribution of these landslides are concentrated north of Warburton town within the northern section of the site. They are mapped within colluvium on lower basal, shallow angle slopes or as larger scale landslides mapped within areas mapped as Donna Buang Rhyodacite that spread across shallow to steep hillsides.

The Coffey Landslip Zoning report produced a list of known mappable landslides that have occurred in natural ground within the Yarra Ranges study area. Of these landslides, 7 are located in the Warburton area, all of which are north of Warburton within the Donna Buang Rhyodacite unit.

Some of the key notes from the Coffey landslide zoning exercise considered relevant to our geotechnical assessment are summarised below:

- The geographic distribution of known landslides generally reflects the presence of sloping ground and particular geological units (Donna Buang Rhyodacite or colluvial soils likely to have been derived from such materials).
- Landslide movements are typically episodic with long periods of no apparent movement.
- Heavy rainfall events have been known to trigger numerous landslides such as those to occur in 1958 and 1994. Artificial concentrations of water known to have caused or contributed to landslides including: irrigation of horticultural lands, relocation of watercourses and poor design of stormwater run-off.
- Many landslides have occurred/moved within the shire in the last 150 years. These landslides range from falling boulders and rapidly moving fluid debris flow type landslides to very slow and episodically moving very large landslides involving entire hillsides.

2.2 Preliminary geotechnical assessment report findings

Our preliminary geotechnical assessment consisted of a desktop study of available information which was used to classify potential areas of high risk. The following is a summary of those areas:

- Areas of known historical landslides and those covered under the Yarra Ranges Erosion Management Overlay (EMO).
- Where the underlying geology is Donna Buang Rhyodacite or Felsic Dyke and the slopes are greater than 25°.

The landslide risk of each trail was subsequently ranked based on based on a number of geotechnical factors. An outcome of the assessment was to highlight which trails would require further geotechnical assessment. Table 3 below presents the trails which required further assessment.

Table 3 Results of the preliminary geotechnical assessment

Trail number	Geological conditions	Recorded landslides/EMO	Risk ranking (out of 36 trails)	Further assessment required (Y/N)
1	Donna Buang Rhyodacite, Colluvium, Felsic Dyke	Yes	1	Y
2	Donna Buang Rhyodacite, Colluvium, Felsic Dyke	Yes	2	Y
5	Donna Buang Rhyodacite, Colluvium	Yes	3	Y
11	Humevale Siltstone, Warburton Granodiorite, Felsic Dyke	Yes	4	Y
17	Warburton Granodiorite	Yes	10	Y
18	Warburton Granodiorite	Yes	11	Y
19	Warburton Granodiorite, Ythan Creek Rhyodacite	Yes	12	Y
20	Warburton Granodiorite	Yes	13	Y
21	Warburton Granodiorite	Yes	14	Y
22	Warburton Granodiorite	Yes	6	Y
23	Warburton Granodiorite	Yes	5	Y

2.3 Site visit

A site inspection was undertaken by two GHD Engineering Geologists on 14 and 15 November 2019. Site photographs were taken during the inspection and are included in Section 2.4.

Accessing the trail locations during the site inspection proved difficult due to thick vegetation, remote locations and steep slopes. Much of the site assessment focussed on road cuttings and accessible areas close to the proposed trails. The aim of the inspection was to develop an appreciation of the natural slope conditions across the site, an understanding of the geotechnical ground conditions and observe any existing or potential landslide features and develop a conceptual ground model.

The results of our inspection are documented in Section 2.4 and 2.5 below.

2.4 Geotechnical ground model

The review of historical landslide data and our site inspection have formed the basis of the following simplified geotechnical ground models for each geological unit. A description of the typical ground conditions and the failure types recorded within them are provided.

2.4.1 Donna Buang Rhyodacite

The Donna Buang Rhyodacite has a variable but often thick weathering profile consisting of residual to extremely weathered soil overlying high strength rock. Where observed in road cuttings, the soil generally consists of intermediate to high plasticity orange brown and red sandy clay with gravel and cobbles/boulders of rhyodacite. Less weathered rhyodacite rock was rarely observed, therefore the weathering profile is considered to be up to several metres thick. Photo 1 below shows the typical weathered rhyodacite profile observed in road cuttings.

Photo 1 Typical weathered rhyodacite soil (2m high face)

The common failure type recorded within the Donna Buang Rhyodacite is debris flows. This was confirmed during the site inspection. Evidence of debris flows were generally observed at the location of channel/gully systems in the form of debris deposits (colluvium) and cleared/fallen vegetation, described in photos 2, 3 and 4 below.

According to the Coffey Landslip Zoning report, historical failures in the Donna Buang Rhyodacite have often been associated with high rainfall events. Debris flows are likely to become channelised during these events eventually depositing in gully systems.

Rock fall is also considered as a potential failure type within the rhyodacite. Boulders present in the weathered soil matrix may be able to come loose following erosion and travel downslope. Photo 6 below is the result of a rockfall.

Photo 2 Colluvial deposit observed either side of channel slopes, underlying and down slope of the road. Tension cracking is observed in the road as well as slumping of the colluvial material downslope. Cleared/fallen trees within gully system that appear to be have been caused by the debris flow.

Photo 3 Colluvial deposit at the base of a gully. Road is constructed on colluvium which is also observed at the base of the gully sides. Ponding is also occurring at the surface of the colluvial material

Photo 4 Interface between colluvium and rhyodacite rock. Colluvium consists of loose debris including rounded gravels and cobbles of rhyodacite.Outcrop in road cutting at the side of gully system

Photo 5 Rhyodacite boulder (>1m) transported from upslope. Evidence of rock fall event after boulder dislodging from weathered soil matrix following erosion

2.4.2 Colluvium

Quaternary colluvium deposits have been mapped on the footslopes of the Donna Buang Rhyodacite slopes north of Warburton. The colluvium is considered to be the result of slope-wash and gravitational action including landslide debris sourced from the rhyodacite slopes above. Reactivation of the debris material has been recorded in the past as historical landslides in the form of translational slides and creep. Photo 7 below shows the typical shallow angle, undulating landform produced by these colluvial deposits. Colluvium was also observed in gully systems across the Mount Donna Buang slopes during the site inspection.

The common failure type in colluvial deposits is the slow moving reactivation of debris material derived from weathered rhyodacite soils observed in the field as creep and historically recorded as translational failures. Small scale failures such as slumping is also observed in the colluvium at road cutting locations caused by over steepening due to its low strength and unstable nature.

Photo 6 Unstable colluvium deposited within a gully which appears to have failed from over steepening of road cutting

Photo 7 Shallow, undulating slopes at the base of steeper rhyodactie slopes

2.4.3 Felsic Dykes

The felsic dykes are considered a minor geological unit due to the lack of geographical coverage across the site. No historical failures within the dykes were recorded during the Coffey Landslip Zoning exercise. A single small-scale cut batter failure was recorded in the Yarra Ranges landslide inventory along the Warburton rail trail in 2016. It was along the rail trail that most of our observations were taken.

The dyke outcrops generally consist of rock slopes with little soil cover. Photo 8 and 9 below show some of the typical outcrops observed. The quality of rock mass in terms of density and orientation of jointing appears to vary significantly and the intact rock has consistently high strength.

Photo 8 Rock mass observed in dyke cutting along Warburton rail trail

Photo 9 Dyke outcrop making up a rocky ridge on the slopes of Mount Donna Buang. Wider joint spacing and higher quality rock mass

The variable condition of the rock mass observed can be attributed to a number of factors. These include varying frequency of intersecting joint sets and a dilated stress relieved rock mass being subjected to deterioration by the growth and intrusion of roots into the rock mass. A number of minor rock falls were observed along the rail trail as well as a larger failure (Photo 10 below) that occurred in the recent past. The cause of the failure appears to be the release of a rock fall that has subsequently unravelled. Discontinuity controlled failure of the less weathered rock outcrops due to wedge or planar failure is expected to the primary mechanism affecting the stability of these slopes. Rockfalls from outcrops then produces debris which can then be later incorporated into debris flows. Photo 11 below shows the evidence of a recent small scale debris flow sourced from the slopes above the rock outcrop that has channelled into a rock chute. Photo 12 shows a thin layer of colluvium containing dyke gravel and cobbles overlying dyke outcrop. This indicates the potential for failures within weathered dyke material.

Photo 10 Back scarp of recent failure

Photo 11 Recent debris material transported from above soil slopes down rock chute

Photo 12 Thin cover of colluvium overlying dyke rock outcrop

2.4.4 Warburton Granodiorite

Covering a large section of the site south of Warburton, the Warburton Granodiorite forms hillsides with smooth slopes of varying grades. Road cuttings up to 4-5 m in height were observed to be stable with a slope angle of 50-60° from horizontal.

The subsurface conditions are exposed in numerous road cuttings which show a highly variable profile ranging from massive strong rock to deep soil profiles with or without corestones. Photos 12 and 13 show the typical weathered profile. The residual soils consist of low plasticity orange brown sandy clay.

Landslides have not been recorded in the natural terrain of the Warburton Granodiorite and our site inspection did not encounter evidence of instability.

Photo 13 Granodiorite soil profile with large (up to 4 m) corestones in a soil matrix

Photo 14 Road cutting in granitic soil standing at approximately 50-60 degrees

2.4.5 Humevale Siltstone

The Humevale Siltstone forms a large part of the south west portion of the site and typically comprises gentle to steep hills with a thin soil cover over weathered rock, shown on photos 15 and 16 below. The soil has a thickness observed as 1 to 4 m and consisted of residual to extremely weathered siltstone that can be described as low plasticity sandy clay. The cut slopes in this unit appeared stable at relatively steep angles. Failure of cut slopes is expected to be mostly controlled by relict discontinuities in the residual to extremely weathered rock or discontinuities in the less weathered rock. The cutting in photo 16 appears to have been cut at the angle of a high persistence discontinuity such as bedding. Had the slope been cut at a steeper angle, localised instability may have occurred.

No historical landslides have been recorded in this unit and no evidence of instability was observed during our site inspection.

Photo 15 Steep road cutting in residual to extremely weathered siltstone

Photo 16 Road cutting showing thin soil cover (1-2 m) overlying siltstone rock

2.5 Identified hazards

Based on our assessment, the site can be classified into three zones based on a combination of the ground conditions and their associated landslide failure modes.

Figure 3 has outlined these three zones across the site, which are defined by their underlying geology:

Zone 1: Donna Buang Rhyodacite and Colluvium

Zone 2: Felsic Dykes

Zone 3: Humevale Siltstone and Warburton Granodiorite

. Much of the Erosion Management Overlay (EMO) defined in the Yarra Ranges landslide inventory in the Warburton area covers the Mt Donna Buang slopes, particularly the large gully systems and colluvium of the foot slopes. It also covers the Felsic Dyke outcrop, which occurs along the Warburton rail trail. There is very little coverage on the Humevale Siltstone and Warburton Granodiorite slopes.

The following hazards are identified within each zone and are considered to form part of the assessment in Section 3:

2.5.1 Zone 1

- Small to large scale shallow failure in the form of debris flows, which are known to occur within gully systems on the Mt Donna Buang slopes. These are linked to extreme weather events (high rainfall).
- Rock falls from boulders dislodging from soil matrix on steep slopes. These can occur at any time but are most likely triggered by weather events.
- Slow moving landslides within colluvium. These are generally linked to high rainfall events.
- Small scale slumping of unstable deposits

2.5.2 Zone 2

- Rock falls from outcrops. These are generally linked to high rainfall events but can occur at any time.
- Debris flows derived from weathered dyke material channelised into rock chutes. These are linked to high rainfall events

2.5.3 Zone 3

- There are no significant hazards associated with this zone.

3. Qualitative risk assessment

3.1 General

A qualitative risk assessment has been undertaken for the site, including a qualitative assessment of "*Likelihood*" and "*Consequence*" using descriptions based upon the Australian Geomechanics Society guidelines for Landslide Risk Management (AGS 2007). Extracts from the AGS guidelines are presented in Appendix A.

The risk likelihood and risk consequence have been used to determine a risk rating from the Risk Matrix provided in the AGS (2007) guidelines and reproduced in Section 3.2.

The qualitative risk assessment has been completed to assess the risk to infrastructure and assets only.

Details of the qualitative risk assessment are provided below.

3.2 Likelihood of failure

The likelihood of failure for various failure mechanisms are provided in Table 7. These ratings are qualitative indications of how *likely* a failure is without consideration of the *consequences* of this failure. The assessment of the likelihood of failure of each hazard has been determined based on the following factors:

- Site observations made during the site inspection
- Historical and publicly available information
- Engineering experience

3.3 Risk rating

The matrix in Table 6 has been used to rate each of the risks identified based on the likelihood and consequence determined. The risk matrix is based on the AGS Guidelines for Landslide Risk Assessment, 2007.

Table 4 Risk rating matrix

		Consequences				
		Catastrophic	Major	Medium	Minor	Insignificant
Likelihood	Almost Certain	VH	VH	VH	H	M or L
	Likely	VH	VH	H	M	L
	Possible	VH	H	M	M	VL
	Unlikely	H	M	L	L	VL
	Rare	M	L	L	VL	VL
	Not Credible	L	VL	VL	VL	VL

Risk ratings for each of the hazards are summarised in Table 5 below.

Table 5 Risk rating

Type of Failure	Zone	Applicable Trails	Initial Risk Rating			Control Measures	Residual Risk Rating		
			Likelihood	Consequence	Risk Rating		Likelihood	Consequence	Risk Rating
Existing Conditions									
Debris flow (following high rainfall events)	1		Possible – have occurred in the past (historical recorded landslides and debris flow deposits observed in gully systems during site inspection).	Insignificant – likely to occur within mountainous area away from existing infrastructure	Very Low	-	Possible	Insignificant	Very Low
Rock falls from steep slopes (boulders that dislodge from soil matrix)	1		Rare – no recorded evidence of historical rock falls. Rare boulders observed during site inspection. Slopes densely vegetated.	Major - potential for rocks to fall onto Donna Buang Road from slopes above	Low	-	Rare	Major	Low
Slow moving failures (translational/creep) within colluvium	1		Unlikely – historical slow moving landslides recorded. There are large areas of mapped colluvium	Minor – potential to cause damage to roads and trails where constructed over colluvial deposits. Minor maintenance may be required	Low	-	Unlikely	Minor	Low

Type of Failure	Zone	Applicable Trails	Initial Risk Rating			Control Measures	Residual Risk Rating		
			Likelihood	Consequence	Risk Rating		Likelihoo d	Consequenc e	Risk Rating
Small scale failures (rotational/translational) within colluvium	1		Possible – small scale failures such as slumping within colluvium observed during site inspection. Failure types common in colluvium	Insignificant – likely to occur away from existing infrastructure	Very Low	-	Possible	Insignificant	Very Low
Rock falls from exposed dyke outcrops	2		Possible – where dyke outcrop is present along Warburton rail trail. Cobble and boulder size rocks observed at the base of dyke outcrop along Warburton rail trail as well as a recent failure following heavy rainfall	Minor – unlikely to cause significant damage to rail trail	Moderate	• Remove loose material from exposed rock faces during construction to reduce risk • Install rock slope protection along Warburton rail trail such as rock fall mesh to prevent failure	Rare	Major	Low
Small scale debris flow of weathered dyke material (following high rainfall events)	2		Unlikely – have occurred in the past, evidence observed during site inspection along the Warburton rail trail	Minor – unlikely to impact Warburton rail trail users or other existing infrastructure	Low	-	Unlikely	Minor	Low

Type of Failure	Zone	Applicable Trails	Initial Risk Rating			Control Measures	Residual Risk Rating		
			Likelihood	Consequence	Risk Rating		Likelihood	Consequence	Risk Rating
During Trail Construction									
Debris flow from slopes above work area (following high rainfall events)	1	1, 2, 3, 4, 5, 6, 7, 8, 9 Construction across gullies	Possible – have occurred in the past (historical recorded landslides and debris flow deposits observed in gully systems during site inspection).	Major – potential damage to the trail. Potential to impact construction equipment. Risk increase during construction at watercourse crossings due to channelised debris flows. Delays to the project	High	• Complete construction during drying months (November – March) • Do not undertake construction work during or immediately after a heavy rainfall event • Store equipment and materials out of gullies • Do not stockpile or discard cut vegetation, soil or rock in gullies • Follow IMBA guidelines to ensure diversion of surface water off the trail, avoiding erosion and ponding • If a failure occurs during construction, halt works and seek geotechnical advice prior to recommencing • Seek geotechnical advice when cutting into natural slopes greater than 2:1 • Follow trail construction IMBA Guidelines • An inspection by an experienced geotechnical engineer or engineering geologist along the entire length of the trail should be performed prior to trail opening to identify any additional hazards	Unlikely	Major	Moderate

Type of Failure	Zone	Applicable Trails	Initial Risk Rating			Control Measures	Residual Risk Rating		
			Likelihood	Consequence	Risk Rating		Likelihood	Consequence	Risk Rating
Rock falls from steep slopes above work location (boulders that dislodge from soil matrix)	1	1, 2, 3, 4, 5, 6, 7, 8, 9	Unlikely – no recorded evidence of historical rock falls. Rare boulders observed during site inspection. Slopes densely vegetated. May be exposed during construction	Major – potential for large rocks impact construction equipment. Delays to the project	Moderate	• Complete construction during drying months (November – March) • Do not undertake construction work during or immediately after a heavy rainfall event • If a failure occurs during construction, halt works and seek geotechnical advice prior to recommencing • Seek geotechnical advice when cutting into natural slopes greater than 2:1 • Follow trail construction IMBA Guidelines • An inspection by an experienced geotechnical engineer or engineering geologist along the entire length of the trail should be performed prior to trail opening to identify any additional hazards	Unlikely	Medium	Low

Type of Failure	Zone	Applicable Trails	Initial Risk Rating			Control Measures	Residual Risk Rating		
			Likelihood	Consequence	Risk Rating		Likelihood	Consequence	Risk Rating
Slow moving failures (translational/creep) within colluvium	1	1, 2, 7, 8, 9	Unlikely – historical slow moving landslides recorded. There are large areas of mapped colluvium	Minor– potential damage to the trail. Delays to construction of trails	Low	• Complete construction during drying months (November – March) • Follow IMBA guidelines to ensure diversion of surface water off the trail, avoiding erosion and ponding • If a failure occurs during construction, halt works and seek geotechnical advice prior to recommencing • Follow trail construction IMBA Guidelines • An inspection by an experienced geotechnical engineer or engineering geologist along the entire length of the trail should be performed prior to trail opening to identify any additional hazards	Unlikely	Minor	Low
Small scale failures (rotational/translational) within colluvium	1	1, 2, 7, 8, 9	Possible – small scale failures such as slumping within colluvium observed during site inspection. Failure types common in colluvium	Insignificant – potential minor damage to the trail.	Very Low		Possible	Insignificant	Very Low

Type of Failure	Zone	Applicable Trails	Initial Risk Rating			Control Measures	Residual Risk Rating		
			Likelihood	Consequence	Risk Rating		Likelihood	Consequence	Risk Rating
Rock falls from exposed dyke outcrops	2	1, 2, 4, 8, 11	Possible – where dyke outcrop is present along Warburton rail trail. Cobble and boulder size rocks observed at the base of dyke outcrop along Warburton rail trail as well as a recent failure following heavy rainfall	Medium – potential for large rocks impact construction equipment. Delays to the project.	Moderate	• Complete construction during drying months (November – March) • Do not undertake construction work during or immediately after a heavy rainfall event • Stabilise rock faces where necessary during construction • If a significant rock outcrop is encountered during construction, seek geotechnical advice prior to attempting construction • Seek geotechnical advice for design and installation of rock slope protection measure • Remove loose material from exposed rock faces prior to construction to reduce risk • An inspection by an experienced geotechnical engineer or engineering geologist along the entire length of the trail should be performed prior to trail opening to identify any additional hazards	Rare	Medium	Low

Type of Failure	Zone	Applicable Trails	Initial Risk Rating			Control Measures	Residual Risk Rating		
			Likelihood	Consequence	Risk Rating		Likelihood	Consequence	Risk Rating
Small scale debris flow of weathered dyke material (following high rainfall events)	2	1, 2, 4, 8, 11	Unlikely – have occurred in the past, evidence observed during site inspection along the Warburton rail trail	Medium – potential damage to the trail. Delays to construction of trails	Low	• Complete construction during drying months (November – March) • Do not undertake construction work during or immediately after a heavy rainfall event • Follow IMBA guidelines to ensure diversion of surface water off the trail, avoiding erosion and ponding • If a failure occurs during construction, halt works and seek geotechnical advice prior to recommencing • Seek geotechnical advice when cutting into natural slopes greater than 2:1 • Follow trail construction IMBA Guidelines	Unlikely	Minor	Low

Type of Failure	Zone	Applicable Trails	Initial Risk Rating			Control Measures	Residual Risk Rating		
			Likelihood	Consequence	Risk Rating		Likelihood	Consequence	Risk Rating
Post Trail Construction									
Debris flow (following high rainfall events) impacting track from above or causing debris flow below	1	1, 2, 3, 4, 5, 6, 7, 8, 9	Possible – have occurred in the past (historical recorded landslides and debris flow deposits observed in gully systems during site inspection)	Major – potential damage to the trail. Trail would require remediation/maintenance works. Risk increase where trails cross channels/gullies due to channelised debris flows.	High	• Site foundations and piers outside of main gullies. • Construct track so as not to promote collection of debris in gullies • If a failure occurs seek geotechnical advice prior to reopening trail	Possible	Medium	Moderate
Rock falls from steep slopes (boulders that dislodge from soil matrix) above track	1	1, 2, 3, 4, 5, 6, 7, 8, 9	Unlikely – no recorded evidence of historical rock falls. Rare boulders observed during site inspection. Slopes densely vegetated. May be exposed during construction	Medium or Minor – potential for large rocks to block trail. Potential for rocks to fall onto Donna Buang Road from slopes above	Moderate	• Do not leave loose boulders in soil matrix in batter slopes • Avoid removal of mature vegetation that is providing a natural barrier from rock falls • When placing boulders on outslope ensure they are secure and not likely to fall or roll down slope • If a rock fall occurs seek geotechnical advice prior to reopening trail	Unlikely	Medium	Low
Slow moving failures (translational/creep) within colluvium	1	1, 2, 7, 8, 9	Unlikely – historical slow moving landslides recorded. There are large areas of mapped colluvium areas of mapped colluvium	Medium – potential damage to the trail. Trail may require remediation/maintenance	Moderate	• If a failure occurs seek geotechnical advice • Follow IMBA guidelines to ensure diversion of surface water off the trail, avoiding erosion and ponding	Unlikely	Minor	Low

Type of Failure	Zone	Applicable Trails	Initial Risk Rating			Control Measures	Residual Risk Rating		
			Likelihood	Consequence	Risk Rating		Likelihood	Consequence	Risk Rating
						• Follow trail construction IMBA Guidelines			
Small scale failures (rotational/translational) within colluvium	1	1, 2, 7, 8, 9	Possible – small scale failures such as slumping within colluvium observed during site inspection. Failure types common in colluvium	Insignificant – potential damage to the trail. Trail may require remediation/maintenance	Very Low	- Follow trail construction IMBA Guidelines - Seek geotechnical advice if failures become more common in similar areas which may indicate larger scale slope failures	Possible	Insignificant	Very Low
Rock falls from exposed dyke outcrops	2	1, 2, 4, 8, 11	Possible – where dyke outcrop is present along Warburton rail trail. Cobble and boulder size rocks observed at the base of dyke outcrop along Warburton rail trail as well as a recent failure following heavy rainfall	Major – potential rocks to block trail and impact trail users	High	• Remove loose material from exposed rock faces during construction to reduce risk • Install rock slope protection along Warburton rail trail such as rock fall mesh to prevent failure	Rare	Major	Low
Small scale debris flow of weathered dyke material (following high rainfall events)	2	1, 2, 4, 8, 11	Unlikely– have occurred in the past, evidence observed during site inspection along the Warburton rail trail	Medium – potential damage to the trail. Trail may require remediation/maintenance.	Low	• If a failure occurs seek geotechnical advice prior to reopening trail	Unlikely	Medium	Low

3.3.1 Summary

A number of hazards have been identified as high or moderate risk without mitigation/control methods. However, we have assessed that these hazards can be managed to moderate risk or lower if the controls mentioned in Table 7 are implemented.

Low risks are usually acceptable to regulators, with ongoing maintenance/monitoring of treatment measures where these have been implemented.

Moderate risks may be tolerated in certain circumstances by regulators. Where possible, these should be reduced to low risk by implementing treatment options.

The qualitative risk assessment methods utilised have assisted in identifying two hazards as high risk;

- Debris flows within the Donna Buang Rhyodacite within gully systems, due to their channelised nature; and
- Rock fall from the exposed Felsic Dyke outcrop along the Warburton rail trail as observed during the site inspection.

The most effective control measure to reduce the risk of debris flows post trail construction is where possible to site any structure piers and foundations outside of the main section of the gully, to construct any trails in such a way as to avoid accumulation of debris, to not dump vegetation, rock and soil in the gullies and follow good hillside practices with regards to surface water disposal. The most effective control measure to reduce risk of rock fall from any rock outcrops will be to scale and clean up any rock faces exposed as part of the works during construction and have them inspected by a geotechnical engineer or engineering geologist prior to opening to advise of any features that require stabilisation.

It is also advised that an inspection by an experienced geotechnical engineer or engineering geologist of the entire length of the trails is completed prior to opening to identify any additional hazards.

3.4 Risk to life assessment

Due to some hazards being identified as having qualitative risk as higher than low, a quantitative assessment of risk to life of the user has also been completed. No risk to life of people below the identified possible hazards such as debris flows has been completed. For the purposes of the risk assessment we have assumed that no control measures have been implemented. We have also assumed that whilst the tracks are recommended to be closed during and after extreme weather events that a proportion of the projected daily users of the track will ignore closure signage. Conservatively this has been estimated at 25% of total daily projected users.

The following scenarios have been assessed:

- Debris flow within rhyodacite during construction
- Debris flow within rhyodacite post construction
- Rock fall from dyke outcrop under existing conditions and post construction

The assessment completed is more appropriately termed a "semi-quantitative assessment" to reflect the uncertainties with factors such as landslide frequency and vulnerability of the individual.

The approach below is adopted from the *The Practice Note Guidelines For Landslide Risk Management, in Australian Geomechanics Journal, Volumes 42, Number 1, March 2007 (AGS 2007)* for assessment of risk to an individual.

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

$R_{(LOL)}$ = the risk (annual probability of loss of life (death) of an individual)

$P_{(H)}$ = the annual probability of landslide (refer appendix C of LMR-AGS Journal)

$P_{(S:H)}$ = the probability of spatial impact by a landslide on the site/structure (travel distance & direction)

$P_{(T:S)}$ = the temporal spatial probability (the probability of the site/structure being occupied by an individual) also allowing for evacuation given warning

$V_{(D:T)}$ = vulnerability of the individual (probability of loss of life of the individual given the impact)

Debris flow within rhyodacite during construction:

$R_{(LOL)} = 0.1 \times 0.9 \times 8.5\times10^{-4} \times 1 = \mathbf{7.7 \times 10^{-5}}$

Notes:

P(H) derived from probability of debris flows occurring once every 5 years (based on historical data and observations from site inspection). In reality, the probability would be lower as a debris flow is assumed to occur every 5 years across the whole site rather than every 5 years in a single gully location.

P (S:H) based on the nature of a channelised debris flow which is unlikely to be stopped by vegetation and will therefore cover the majority of the site.

P (T:S) was calculated based on 3 people undertaking construction of a watercourse crossing over 2.5 days of the year. It is assumed a watercourse crossing is within a gully feature exposed to debris flows. It also assumes construction will be undertaken during the summer months and workers will not work during or post heavy rainfall events.

V (T:D) is set at 1, as a debris flow could potentially bury construction workers and equipment.

Debris flow within rhyodacite post construction:

$R_{(LOL)} = 0.1 \times 0.9 \times 4\times10^{-4} \times 1 = \mathbf{3.8 \times 10^{-5}}$

Notes:

P(H) derived from probability of debris flows occurring once every 5 years (based on historical data and observations from site inspection). In reality, the probability would be lower as a debris flow is assumed to occur every 5 years across the whole site rather than every 5 years a single gully location.

P (S:H) based on the nature of a channelised debris flow which is unlikely to be stopped by vegetation and will therefore cover the majority of the site.

P (T:S) was calculated based on a trail user travelling 10km/h over a watercourse crossing of 5m. It is assumes 20 people will use the crossing each day despite warnings following heavy rainfall events (it is advised that signage is erected warning users and the track closed due to landslide risk immediately after extreme weather events)

V (T:D) is set at 1, as a debris flow could potentially bury construction workers and equipment.

Rock fall from dyke outcrop along Warburton rail trail under existing conditions:

$R_{(LOL)} = 0.5 \times 0.2 \times 0.006 \times 0.2 = \mathbf{1.2 \times 10^{-4}}$

Notes:

P(H) derived from probability of a rock fall happening every 6 months (based on observations made during site inspection and communication with Yarra Ranges council worker onsite with regards to most recent failure).

P (S:H) based on the nature of a rock fall and characteristics of travel path. Rocks will generally land before the rail trail and not have the energy required to reach the rail trail.

P (T:S) was calculated based on a person walking at 5 km/h along 50 m long section of rock slope (observed on site) with an average of 50 people walking past each day. A factor has been added to allow for warning trail users not to use the rail trail following heavy rainfall.

V (T:D) is set at 0.2, as a person struck by a rock fall may be injured but unlikely to cause death**.**

3.5 Risk management

Table 1 under section 8.2 of AGS 2007 provides guidelines on the tolerable risk to loss of life however the acceptable level of risk should be determined by the regulator. This table is reproduced below (Table 8). According to this table, the acceptable risk to loss of life (R_{LOL}) at the trails at risk from debris flows and the existing rail trail is 10^{-5} and 10^{-4} per individual, respectively. The values determined above are of the order of magnitude suggested, hence the risk for people travelling through, or working on the sites is assessed as being tolerable**. It** should be noted that some of the factors used in our calculation are considered conservative.

It is recommended that the risk control measures in Table 7 are implemented. The risk to life will reduce considerably along the Warburton rail trail if rock slope protection, such as rock fall mesh is installed.

Table 6 Suggested Tolerable Loss of Life Risk

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope /Existing Development	10^{-4}/annum
New Constructed Slope /New Development / Existing Landslide	10^{-5}/annum

4. Geotechnical risk control measures

The following sections summarise the risk control measures that should be implemented to reduce, manage and maintain the assessed landslide hazards across the site.

4.1 Risk control measures under existing conditions

- It is recommended that rock slope protection is installed on the (Felsic Dyke) rock slope cutting exposed along the Warburton rail trail. A simple rock mesh would reduce the risk of rock fall along this section of the rail trail.
- Advise users of the rail trail of rock fall risk following periods of heavy rainfall.

4.2 Risk control measures during construction

- Construction should be undertaken during drying months (November – March). This particularly applies to the slopes of Mt Donna Buang where hazards are at greatest risk during rainfall events.
- Do not undertaken construction work (particularly earthworks) during or immediately after a heavy rainfall event.
- Follow IMBA guidelines with respect to the design and construction of the trails. This particularly applies to their guidelines around the diversion of surface water off the trail to avoid erosion and ponding.
- During construction of watercourse crossing within gullies, store equipment and materials out of gullies and do not stockpile or discard cut vegetation, soil or rock into the gullies.
- If a significant rock outcrop is encountered during construction, seek geotechnical advice prior to attempting construction.
- If a failure occurs during construction, half works and seek geotechnical advice prior to recommencing.
- Position excavated material in a stable manner
- Seek geotechnical advice prior to excavating significant areas of rock
- Do not store equipment or supplies in gullies
- Do not dispose of vegetation, soil and rock debris into gullies
- Seek geotechnical advice when cutting into natural slopes greater than 2:1. This particularly applies to Donna Buang Rhyodacite and Colluvium deposits as these deposits are unstable at steeper angles.
- An inspection by an experienced geotechnical engineer or engineering geologist along the then entire length of the trail should be performed prior to trail opening to identify any additional hazards.
- Position structure pillars and foundations outside of main sections of gullies to avoid collection of debris during operation
- Construct tracks in such a way so as not to accumulate debris during operation

4.3 Risk control measures post construction

Complete full inspection by experienced geotechnical engineer or engineering geologist along all trails post construction prior to opening to identify any additional hazards (preferably completed prior to full completion of works to allow rectification to be completed).

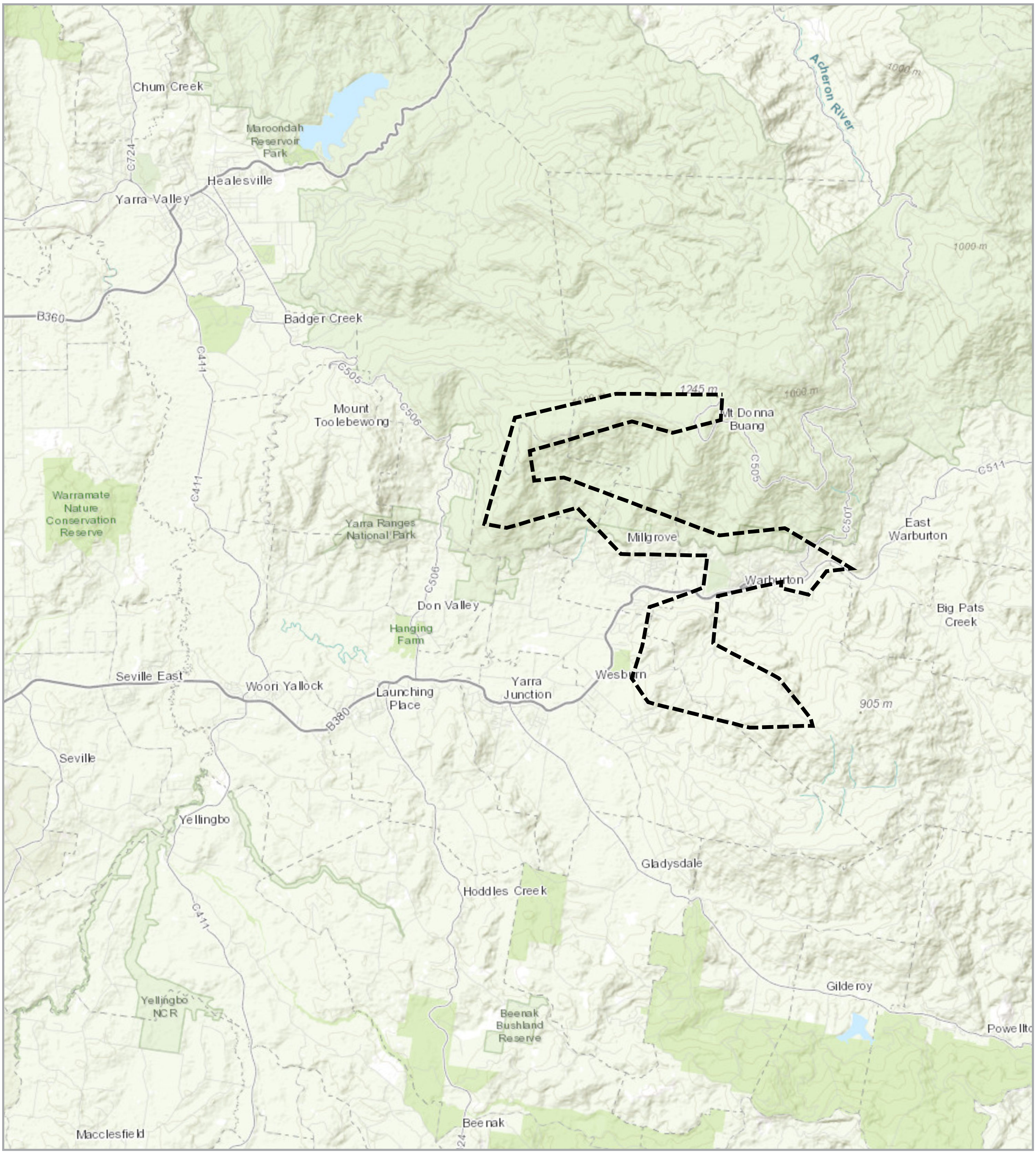
- Advise trail users to not enter trails that cross gully systems (most watercourse crossings) and/or known landslides during and immediately following periods of significant rainfall. This applies to the trails north of Warburton within Donna Buang Rhyodacite and colluvium deposits.
- Complete inspection of trails after significant rain events.
- If a failure occurs along the trail system, seek geotechnical advice to confirm trail is safe for use.

5. Conclusions

A number of landslide risks associated with the construction and use of the proposed Warburton mountain bike trails were identified and qualitatively assessed to present Very Low to High risk. It is considered that with the implementation of control measures as detailed in Section 3 and summarised in Section 4, the residual risk rating can be reduced to Low to Moderate. Due to the nature of two hazards identified, debris flows on the slopes of Mt Donna Buang and rock fall along the Warburton rail trail rock slope cutting, a Moderate risk has been assigned. With the recommended mitigation and ongoing control measures, this level of risk can be controlled.

The semi-quantitative risk assessment undertaken to assess risk to life produced a risk level equating to tolerable risk. The AGS 2007 guidelines define a tolerable risk as being within a range that society can live with so as to secure certain net benefits. Tolerable risks need to be kept under review and reduced further where practicable.

Figures



Legend

Trail Area

Paper Size ISO A4

0 1 2 3 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA94 MGA zone 55

N

Yarra Ranges Council
Warburton Mountain Bike Destination

Warburton Mountain Bike Destination Location

Project No. **31-37322**
Revision No. **A**
Date **04/12/2019**

Figure 1

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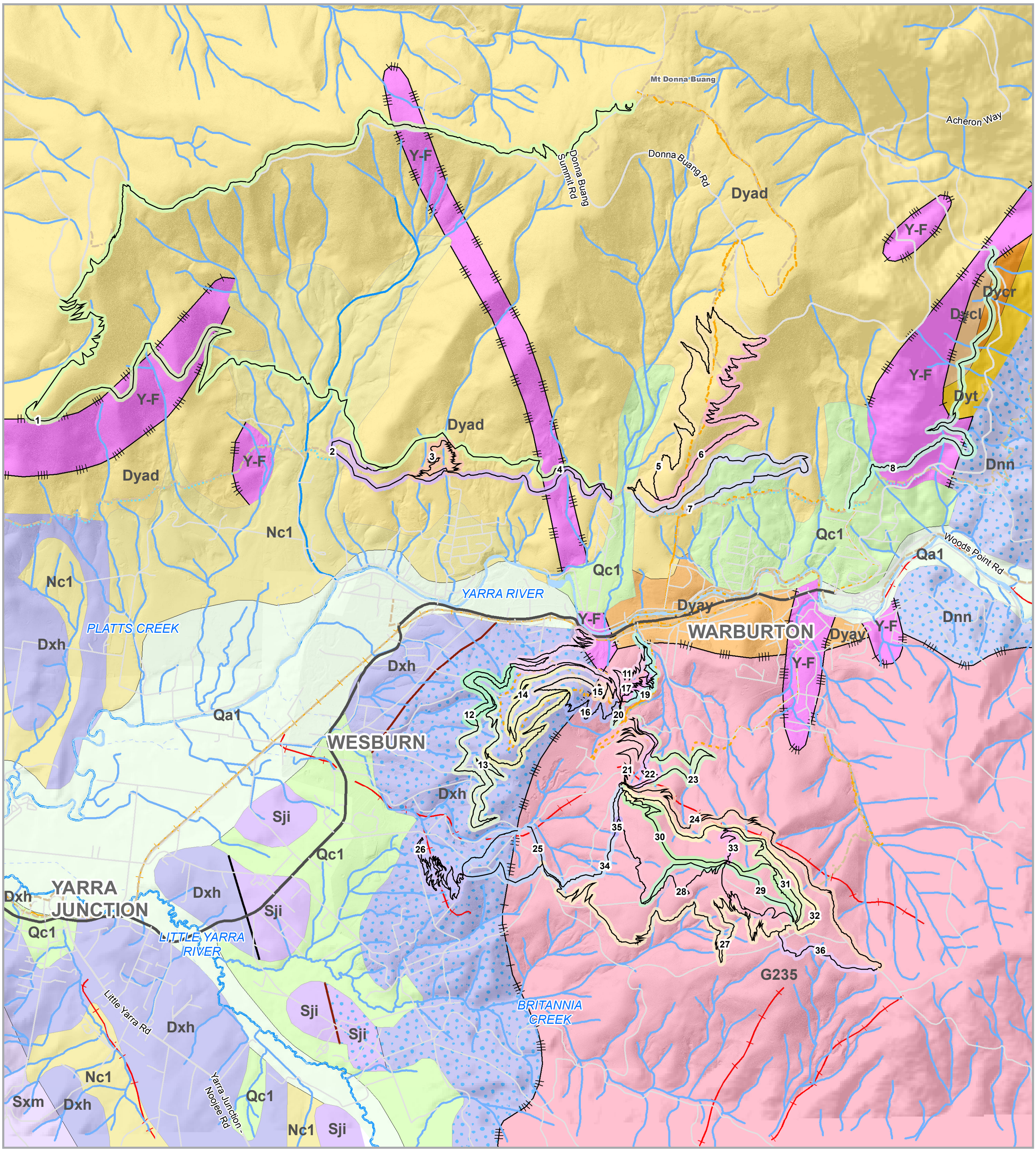

Legend

Walking Tracks	Stream	**Geological structure 250k**
Highway	Channel	<all other values>
Arterial	Drain/Channel/Other	**TYPE**
Collector	**Rail**	conformity
Tracks	Rail dismantled	faulted contact
Watercourse	Rail trail	geological unit boundary
River		intrusive contact

nonconformity	Dyad	Qa1
unconformity	Dyay	Qc1
Geological unit 250k	Dycl	Sji
Geographic Feature ID	Dycr	Sji
Dnn	Dyt	Sxm
Dxh	G235	Y-F
Dxh	Nc1	

Paper Size ISO A4

0 0.4 0.8 1.2 1.6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA94 MGA zone 55

N

GHD

Yarra Ranges Council
Warburton Mountain Bike Destination

Surface Geology

Project No. **31-37322**
Revision No. **0.0**
Date **02/12/2019**

Figure 2

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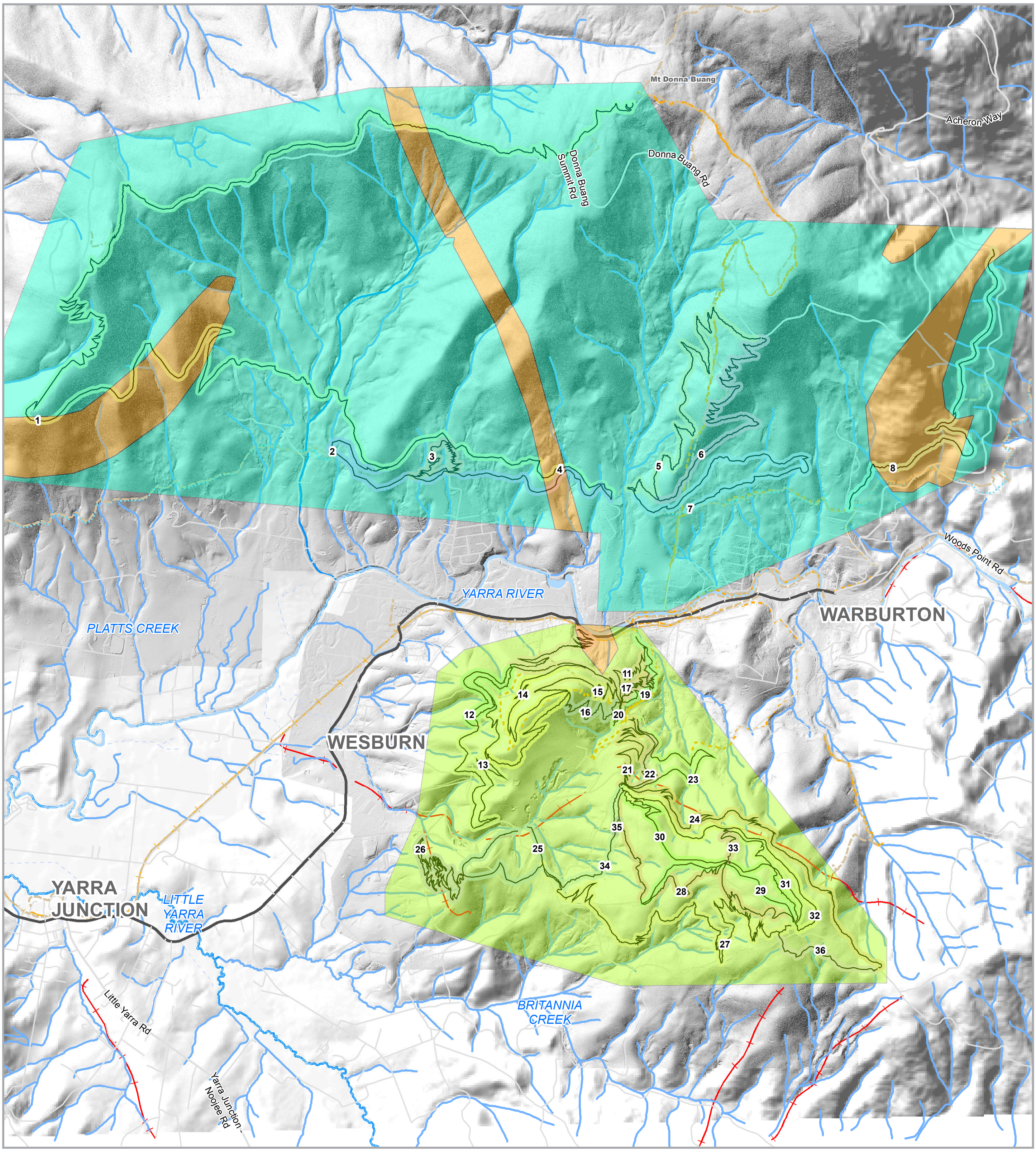

Legend

Risk Zones

- 1
- 2
- 3
- Walking Tracks
- Highway
- Arterial
- Collector
- Tracks
- Watercourse
- River
- Stream
- Channel
- Drain/Channel/Other

Rail

- Rail dismantled
- Rail trail

Paper Size ISO A4

0 0.4 0.8 1.2 1.6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA94 MGA zone 55

N

Yarra Ranges Council
Warburton Mountain Bike Destination

Geomorphological Mapping

Project No.	31-37322
Revision No.	0.0
Date	02/12/2019

Figure 3

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Print date: 02 Dec 2019 - 17:31

Data source: DELWP, VicMap, 2019; GHD, 2019 Created by: tworth

Appendices

Appendix A – AGS Guidelines for Qualitative terminology

APPENDIX C: LANDSLIDE RISK ASSESSMENT

QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		**Implied Indicative Landslide Recurrence Interval**		**Description**	**Descriptor**	**Level**
Indicative Value	**Notional Boundary**					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	$5x10^{-3}$	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-4}$	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-5}$	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-6}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		**Description**	**Descriptor**	**Level**
Indicative Value	**Notional Boundary**			
200%	100%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	10%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa

APPENDIX C: – QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (CONTINUED)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		**CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)**				
	Indicative Value of Approximate Annual Probability	**1: CATASTROPHIC 200%**	**2: MAJOR 60%**	**3: MEDIUM 20%**	**4: MINOR 5%**	**5: INSIGNIFICANT 0.5%**
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (5)
B - LIKELY	10^{-2}	VH	VH	H	M	**L**
C - POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D - UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E - RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F - BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.

(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

Risk Level		**Example Implications** (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

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3137322-55605/https://projects.ghd.com/oc/Victoria3/warburtonmtbdestinat/Delivery/Documents/3137322-REP-0_Geotechnical Risk Assesment v2.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	R.Hayes	A.Schofield	A.J. Schofield	G.Jones		06/12/2019

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