REPORT

Wolgan Road, NSW

Review of Wolgan Gap Slope Hazards 2022

Submitted to:

Lithgow City Council

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Submitted by:

WSP Australia Pty Ltd

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PS129742-SYD-GEO-REP-001-REV 0

23/01/2023

Distribution List

Jonathon Edgecombe (Director Infrastructure Services, Lithgow City Council)

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1.0 INTRODUCTION

Wolgan Road at Wolgan Gap traverses an area of rockfall and landslide hazard which has been managed by Lithgow Council (Council) in accordance with the Wolgan Road – Wolgan Gap Road Slope Instability Management Plan (Golder Ref. 087622115-003-R-Rev 2). The Instability Management Plan recommends on-going periodic inspection, Quantitative Risk Analysis (QRA) and Slope Risk Assessment (SRA) as part of the management of the slope hazard at the Wolgan Gap site.

This memorandum summarises the geotechnical slope hazards identified as part of the 2022 periodic SRA and an emergency response call out following a landslide which occurred at Wolgan Road on Saturday November 5th 2022. Wolgan Road at the Gap is currently closed to all traffic due the risk to road users from that landslide and other slope hazards. An updated SRA for the geotechnical slope hazards described herein will be provided separately.

This memorandum has been prepared in response to Council's request (Purchase Order 126931-OPER).

2.0 GEOLOGY, INSTABILITY MECHANISMS AND TRIGGERS

The geology of the area comprises sedimentary sequences of sandstone, siltstone, claystone and mudstone with coal measures. Underground coal mining has been undertaken nearby, approximately 0.5 km west of Wolgan Road below the plateau as shown on Figure A1 of Appendix A.

The steep sided walls of Wolgan Valley above Wolgan Road comprise sheer cliff faces up to approximately 100 m high above very steep (in accordance with the terminology of Australian Geoguide LR2 – Landslides) colluvial slopes. The cliffs are formed in Narrabeen Group rock which is dominated by relatively coarser grained (i.e. typically sandstone) and stronger rock than the underlying typically finer grained (e.g. siltstone, claystone and mudstone) strata of the Illawarra Coal Measures and Shoalhaven Group on which the colluvial slopes are formed. Preferential weathering of the finer grained strata below the Narrabeen Group cliffs give rise to the potential for multi-bed rock topples and preferential weathering of finer grained beds within the exposed Narrabeen Group cliffs contribute to large rockfalls.

Bedding typically dips at 2 degrees or less to the east north-east (but is locally steeper) and two major joint sets trend at 340º (i.e. approximately north north-west) and 070º (i.e. approximately north north-east). The major joints in the Narrabeen Group cliffs commonly have lengths of several hundred metres, the north north-east set typically being longer. Typical spacing for the major joints of the north north-east set is 50 m, whereas the north north-west set is typically more closely spaced at approximately 25 m. Vertical to sub-vertical regional lineaments on three major directions of 005º, 035º and 115º also have a marked control on topography, the 005º lineament being the most prominent. The influence of the major joint and lineament orientations on the topography can be seen in the aerial photo and LiDAR plans of Figure A1 of Appendix A.

The colluvial slopes along the 2.7 km section of Wolgan Road show evidence of numerous existing landslides including medium scale (i.e. 50,000 m^3 to 250,000 m^3 in accordance with Fell's 1994 classification). These landslides are inferred to be typically immobile under the average Bureau of Meteorology (BOM) documented rainfall conditions in the area. There are also numerous, typically small scale (i.e. 5,000 m^3 to 50,000 m^3) or less, landslides evident within larger landslide masses and the colluvial slopes. Perspective views of the slopes which show landslide scars within the 15th November 2022 Lidar and photo aerial imagery are provided as Figures C1 to C5 of Appendix C.

Site observations made during 2022 indicate that landslides, including medium scale features, are likely becoming more prone to initiation or, in the case of existing slides, re-activation, under the significantly higher than average annual rainfall conditions experienced during 2022.

Below the Narrabeen Group, large scale landslide rupture surfaces often coincide with the presence of coal members and associated carbonaceous sedimentary strata. This is the case at Site 1I where the Middle River Coal measure is inferred at approximate road level based upon site observations and reference to the notes to the Western Coalfields 1:100,000 Geological Maps (Mineral Resources NSW). Further to the north from site 1I, the inferred Irondale Seam is exposed in the rupture surface of a previous landslide (adjacent to site 2N, shown on Figure A3 of Appendix A).

The dominant trigger for rockfall and landslide at the site is rainfall and reference can be made to the 2019 Post Bushfire Event Slope Risk Assessment and Inspection Report, (Golder Ref. 097622078-016-R-Rev 0) for details regarding the influence of rainfall on rockfall frequency at the site. The dominant contribution of rainfall to triggering landslides is inferred to be build up of pore water pressure, although scour from surface flows also contributes to de-stabilisation of the slopes (particularly where scour removes material supporting the toes of previous landslides).

The landslides observed as part of the review of geotechnical hazards contained herein broadly fit the type classifications of Deere and Patton 1971, reproduced in Figure 1 below. Although Figure 1 specifically refers to an interbedded sandstone and shale stratigraphy, it is broadly applicable to the stratigraphy underlying the colluvial slopes at Wolgan Gap which comprise an interbedded sedimentary sequence of sandstone and finer strata (e.g. siltstone and claystone layers, carbonaceous layers and coal). The landslide types of Figure 1 are summarised as follows.

- Type A – landslide within colluvium triggered by high pore water pressure at weathered rock interface.
- Type B – ‘double slide’ in which the toe of a slide above (i.e. slide 1 in Figure 1) overloads a slide surface of marginal stability below (i.e. slide 2 in Figure 1) resulting in mobilisation of slide 2.
- Type C – deep-seated landslide with rupture surface through weathered rock.

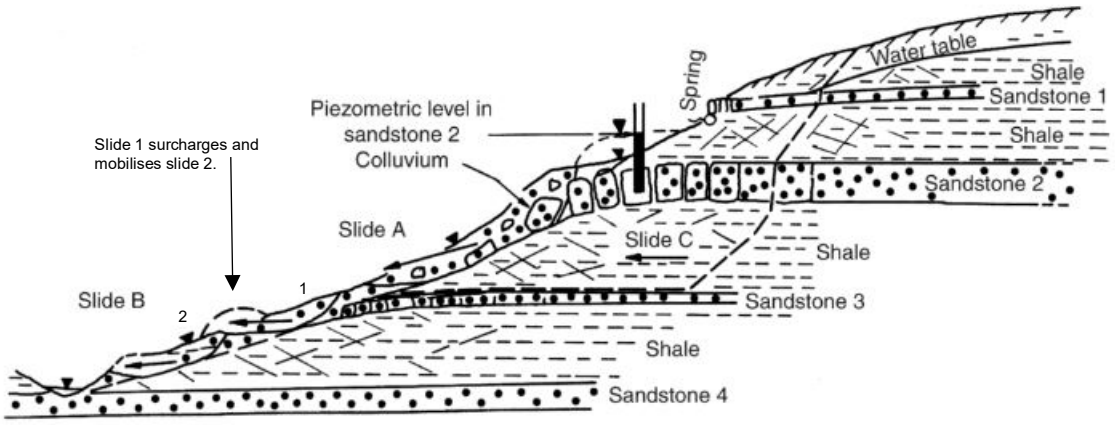

Figure 1 : Example landslide mechanisms in interbedded sedimentary sequences (Adapted from Deere & Patton 1971)

One component of the landslide mechanisms of Figure 1 is the restriction of drainage from the upper sandstone beds by the overlying colluvium generating high pore water pressures at the colluvium weathered rock interface and causing sliding. Evidence for those groundwater conditions were observed at Site 1I in the form of a relatively dry colluvial mass overlying weathered rock with localised seeps and saturated zones close to the weathered rock contact, as well as from behind and adjacent to large (more than 5 m minimum dimension) boulders within the colluvium. Similar observations of a relatively dry colluvial mass overlying

weathered rock with concentrated saturated zones and seeps near the weathered rock interface were made at other landslides which occurred during 2022 including adjacent to Site 3C, as shown in Figure 2 further below.

A frequent observation of landslides within the colluvial slopes at Wolgan Gap in 2022 has been the propensity for relatively wetter, higher velocity and more shallow debris flow type landslides to develop at the edges of colluvial debris cones or landslide lobes more frequently and typically prior to the development of relatively drier, lower velocity and deeper debris slides of the central portion of the cones/lobes. That characteristic is inferred to be a 3 dimensional effect resulting from the relative lack of confinement at the edges compared to within the central portion of the cone/lobe where the colluvium is deeper. The result is that the edges reach a fully saturated state with a mobilised failure surface (typically close to rock contact, in accordance with Slide Type A of Figure 1) sooner than the central portion which has a deeper cover of relatively drier colluvium. An example of a debris flow at the edge of a cone of colluvial debris, at Site 3C is shown in Figure 2 below.

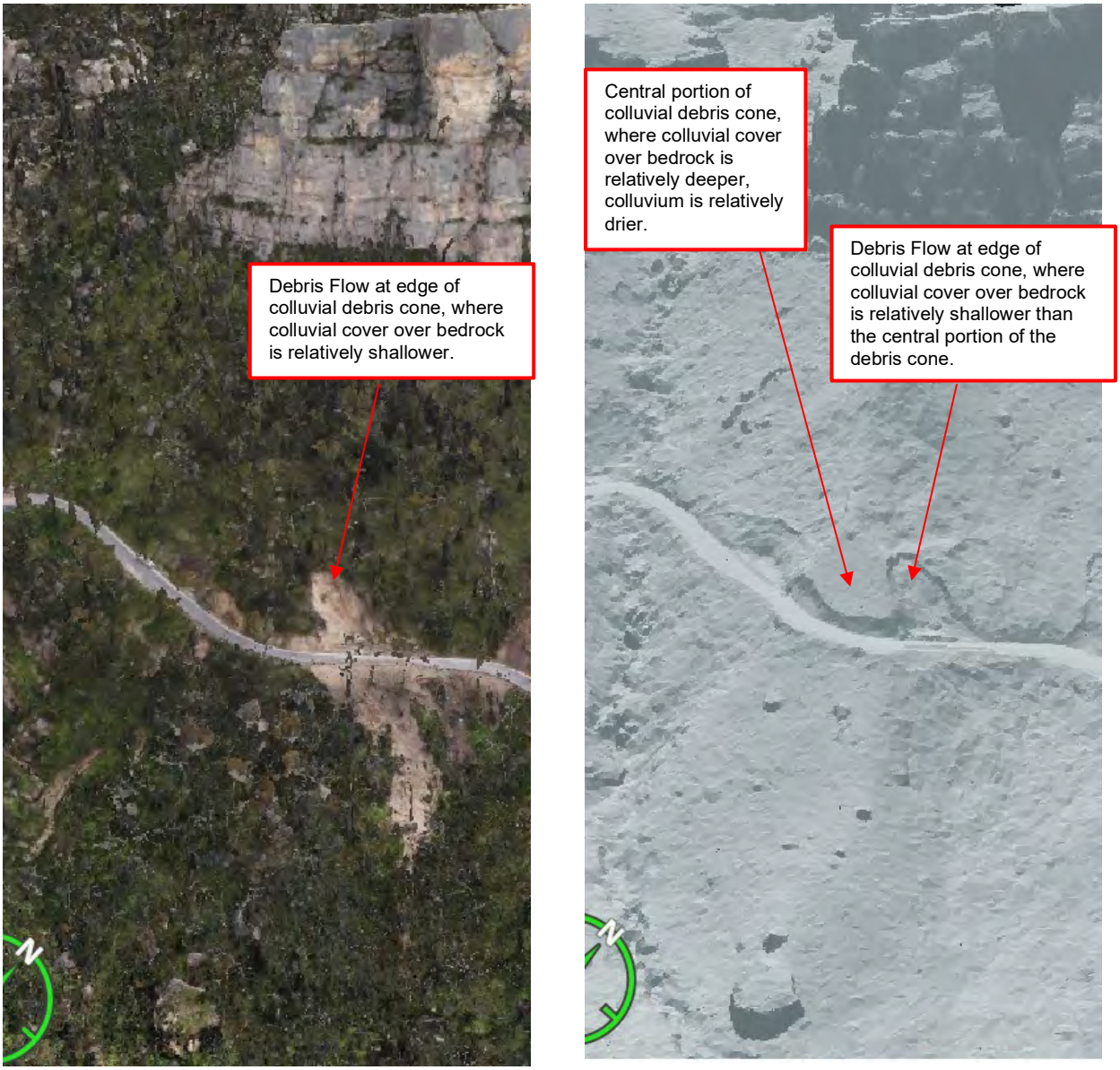

Figure 2 : Example of Debris Flow at edge of colluvial debris cone (Site 3C), shown on 15 November 2022 UAV photo aerial (left image) and LiDAR derived hillshade (right image).

3.0 BACKGROUND TO CURRENT WOLGAN ROAD CLOSURE AT THE GAP

Council keeps an inventory of reported rockfall and landslide events at Wolgan Road as part of their management of slope risk at the site. Based on that inventory, prior to December 2021 the dominant slope hazard affecting the site was rockfall from the slope above the road. Loss of life risk levels calculated as part of on-going periodic SRAs were below Council's risk tolerability threshold (i.e. within Council's acceptable range).

Following a period of protracted above-average rainfall in December 2021, additional geotechnical slope hazards were identified as requiring immediate response (e.g. temporary support), monitoring and long-term remediation. For details of immediate response measures and monitoring of those hazards reference can be made to the document "Wolgan Gap – Immediate Response Measures and On-going Maintenance and Monitoring" (Golder Ref. 097622078-018-Rev 0).

On-going protracted above average rainfall continued throughout 2022. The highest cumulative rainfall in any 12 month period on record at the Maddox Lane Bureau of Meteorology (BOM) Rainfall Station (BOM Station 63132) was surpassed on 10th October 2022. A cumulative total of 1271 mm of rainfall was recorded compared to an annual average of 758 mm which was the most rainfall in a 12 month period since January 1974). A new rolling 12-month record was set a further 4 times in October 2022 and a further 3 times in November 2022, up to the current maximum recorded on 4th November 2022 (i.e. 1336 mm recorded in 12 months at BOM Station 63132).

On Sunday 6th November 2022 Council reported to WSP Golder that a new landslide had been observed on Saturday 5th November 2022 at the approximate location shown in Figure 3 below. Temporary remediation works were on-going elsewhere on the site in the week prior but no works had occurred at the site of the new landslide, referred to hereafter as Site 1l.

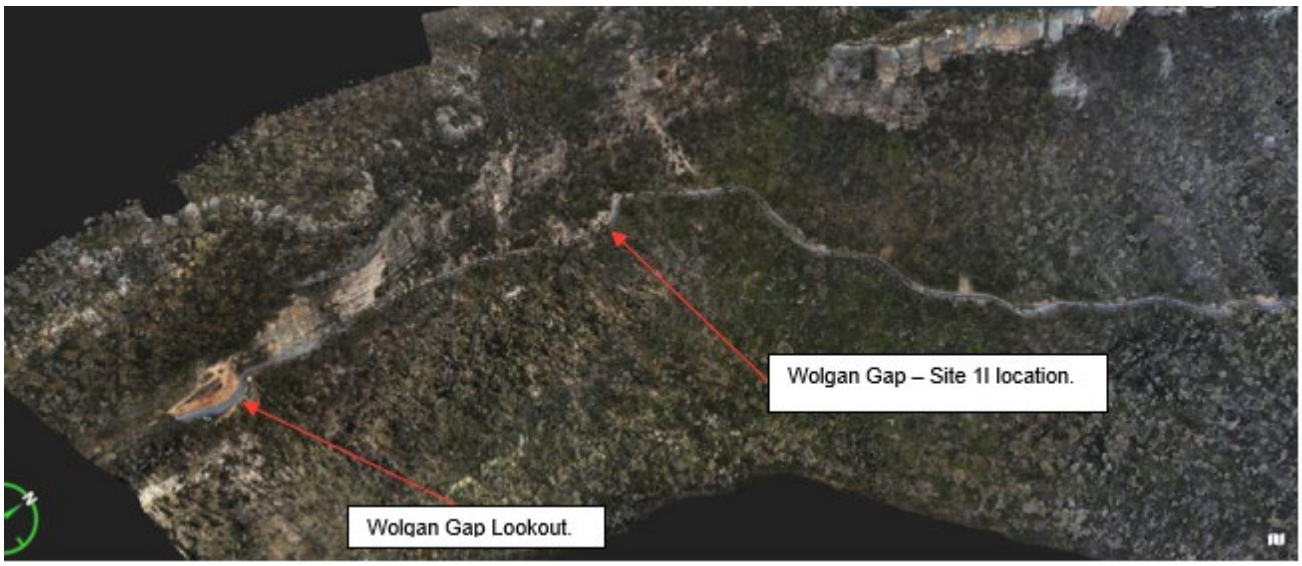

Figure 3 : Wolgan Gap, Site 1l location

In response to Council's request our Principal Geotechnical Engineer undertook a site visit with Council on 7th November 2022 to assist Council with identifying immediate response measures and further steps required to manage and mitigate the slope risk to road users, as follows:

1) Identification of hazards affecting inspection of the upslope area and agree on actions required to visually assess that area.

2) Clean-up of debris where safe to do so.

3) Installation of traffic control measures (including barriers to restrict vehicular traffic).

The mobile colluvial mass observed at Site 1I includes sandstone boulders of minimum dimension greater than 5 m. Slide debris which had reached the road by 7th November 2022 included up to approximately 2 m diameter sandstone boulders. Approximately 250 m^3 of slip material was removed from the road. In accordance with Item 1 above the risk posed by leaning trees was assessed by a team of professional arborists contracted by Council. Following completion of that risk assessment on 11th November 2022, a safety line was established by a professional rock climber to enable access to steep terrain above the landslide by our Principal Geotechnical Engineer with chaperone by a team of arborists. Our Principal Geotechnical Engineer observed three clearly visible features upslope of the crest of Site 1I consistent with the mobilisation of a landslide, as follows:

a) An approximately crescent shaped crack, 0.3 m wide and 0.5 m deep.

b) An approximately 0.1 m wide and 0.3 m deep tension crack.

c) An approximately 1.5 m high scarp (depth unable to be safely determined at the time of observation.

The landslide was assessed to be small (i.e. 5,000 m^3 to 50,000 m^3) in accordance with Fell's 1994 classification. However, we inferred that the landslide could form part of a medium landslide (i.e. in the range 50,000 m^3 to 250,000 m^3) on the basis of observed areas of adjacent instability (e.g. colluvial material below road level which displayed an approximately 30 m long tension crack at road level).

Due to the loss of life risk at site 1I, Council closed Wolgan Road at the gap on 11th November 2022. An updated Unmanned Aerial Vehicle (UAV) high resolution LiDAR and photogrammetry survey of the site was completed on 15th November 2022 to aid in identification of areas of instability and inform understanding of the instability mechanisms. The survey covered the area shown in Figure A1 of Appendix A. A review of slope hazards affecting the approximately 2.7 km length of Wolgan Road was undertaken following the survey and is reported further below.

The locations of site observations a, b and c above are annotated on Figure 4 and 5 below, which are a hill shade image and photo aerial image derived from the 15th November 2022 UAV survey respectively. The location of adjacent surface features inferred to be indicative of slope instability are shown on Figure 4 and Figure 5. Those adjacent instabilities have the potential to contribute to a landslide in the medium scale category via a regressive mechanism whereby movement of downslope material removes support to upslope material and/or a successive mechanism (i.e. a Type B slide as shown in Figure 1 above). The location of the primary and minor scarp inferred from site observations and reference to the UAV survey are shown by the blue dashed lines of Figure 4 and 5.

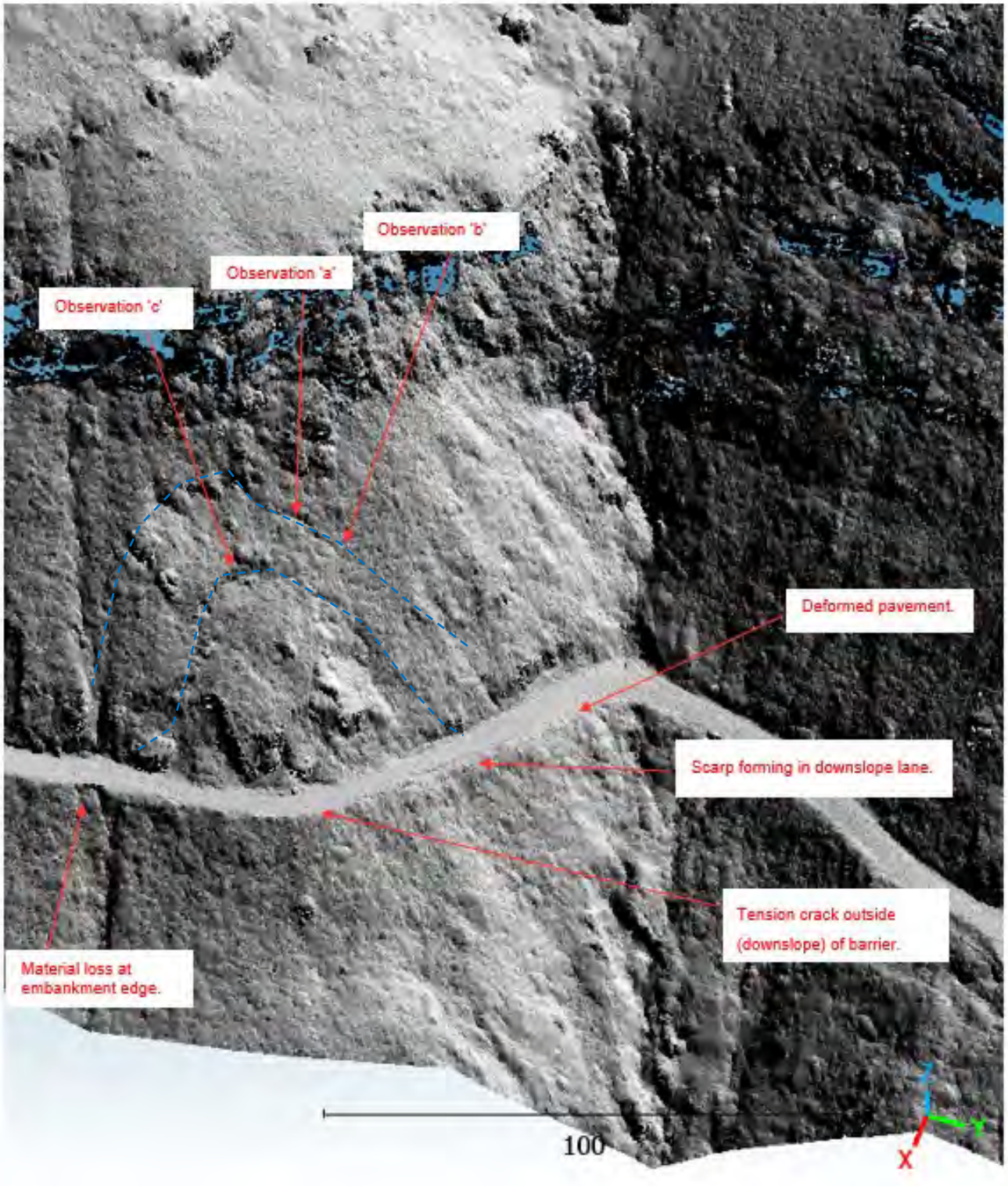

Figure 4 : Surface features inferred to correspond with slope instability observed at Site 1l, November 2022, annotated on 15.11.22 LiDAR derived hillshade.

Figure 5 : Surface features corresponding with slope instability observed at Site 1l, November 2022, annotated on 15.11.22 aerial photogrammetric survey.

The active landslide at Site 1l is categorised as a slow moving (i.e. with a speed of between approximately 5 mm per day and 500 mm per day) translational debris slide in accordance with Appendix B of the Practice Note Guidelines for Landslide Risk Management 2007 (AGS 2007) based on the overall rate of movement observed between 6th November 2022 and 15th November 2022. However, individual portions of the landslide mass up to approximately 50 m^3 in volume released to road level during that period at an extremely rapid velocity (i.e. more than 20 km per hour). It is possible that the overall landslide mass could mobilise at an extremely rapid velocity.

The active landslide at Site 1l and inferred larger landslide present an unacceptable loss of life risk when assessed against Council's risk tolerability threshold, justifying the road closure.

4.0 SUMMARY OF GEOTECHNICAL SLOPE HAZARDS AT WOLGAN GAP BASED ON 15.11.2022 UAV SURVEY AND NOVEMBER 2022 SITE VISITS

Based on observations made by our Principal Geotechnical Engineer during site visits undertaken in November 2022 and review of the results of the 15th November 2022 UAV survey, geotechnical slope hazards at the Wolgan Road site at Wolgan Gap have been classified into the following simplified categories in general accordance with Appendix B of the Practice Note Guidelines for Landslide Risk Management, AGS 2007.

- H1.1 – Rockfall, typically extremely rapid (i.e. greater than 20 km per hour)
  - H1.1.1 Small rockfall (nominally 0 m to 1 m diameter).
  - H1.1.2 Large rockfall (nominally 1 m to 5 m diameter).
- H1.2 – Rock Topple (typically extremely rapid and comprising multiple beds of rock and greater than 5 m minimum dimension).
- H1.3 – Rock Slide (slides with failure surface extending into bedrock, e.g. Type C in accordance with Figure 1 above and with a slide mass typically small or greater, i.e. > 5,000 m^3, in accordance with Fell's 1994 classification, rock slides at the site are expected to vary in velocity from less than 1 mm per month such as for an extremely slow moving rock block slide on bedding to more than 20 km per hour such as for an extremely rapid complex, wet rock slide – debris avalanche, depending on the specific characteristics of individual slides).
- H2.1 – Upslope Debris Flow (typically initiating off the right or left flank of an existing lobe of colluvium or previous slide mass as a very rapid velocity, i.e. with a speed between approximately 0.2 km per hour and 20 km per hour, movement of wet material). Source zone upslope of Wolgan Road.
- H2.2 – Upslope Debris Slide (typically initiating within the central portion of an existing lobe of colluvium or previous slide mass as a very or extremely slow velocity movement, i.e. with a speed of less than 5 mm per day, of dry material above moist layers overlying bedrock). Source Zone upslope of Wolgan Road.
- H3.1 - Downslope Debris Flow (typically initiating off the right or left flank of an existing lobe of colluvium or previous slide mass as a very rapid velocity movement of wet material). Source zone downslope of Wolgan Road.
- H3.2 – Downslope Debris Slide (typically initiating within the central portion of an existing lobe of colluvium or previous slide mass as a very or extremely slow velocity movement of dry material above moist layers overlying bedrock). Source Zone downslope of Wolgan Road.
- H4.1 – Retention Element Failure (e.g. sandstone block retaining wall).
- H4.2 – Drainage Element Failure (e.g. culvert).

Two Domains have been designated as shown in Figure A1 of Appendix A for the 2.7 km of Wolgan Road assessed. The road within Domain 1 is relatively more susceptible to geotechnical slope hazards than Domain 2. Examples of the above hazards are provided in Figures B1 to B14 inclusive of Appendix B. Some of the specific hazards identified can be inferred as active or potential re-mobilisations and/or enlargements and/or internal displacements of prior failure masses. However, for the purposes of this hazard identification those distinctions have not been reported.

In addition to rockfall (i.e. H1.1.1 and H1.1.2 hazards), 128 specific geotechnical slope hazard locations were identified which present a loss of life risk to users of Wolgan Road and a property risk to the road itself. The geotechnical slope hazard locations are shown in plan on Figures A2 to A4 inclusive of Appendix A. Hazards

which have mobilised and are assessed as not having yet reached a state of long-term static equilibrium have been categorised as active. Of the 128 specific geotechnical slope hazard locations identified, 37 were identified as active as of 15th November 2022, based upon observed displacements of slide material and the potential for further movement. The active nature of those sites presents a significant challenge to the safe investigation and potential remediation of slope hazards on Wolgan Road, particularly at Site 1I, where multiple slope hazards are active within close proximity to one another with the potential to combine into a mobile mass of material of medium size (i.e. greater than 50,000 m^3) according to Fell's classification. Geotechnical slope hazards identified as active on 15th November 2022 are summarised in Table D1 of Appendix D. An additional 91 specific geotechnical slope hazards (to the 37 active hazards) have been identified as potential hazards (i.e. they have not been identified as displaying sufficient recent displacement to yet be categorised as active). Those hazards are summarised in Table D2 of Appendix D.

Table 1 below summarises the proportion of Domains 1 and 2 at risk to particular hazards. In addition to the proportions shown in Table 1, the remainder of the length of road assessed is also subject to slope instability hazards as it has been founded on and locally cut into an unsupported colluvial slope which shows signs of on-going movement of at least an extremely low velocity (i.e. less than 1 mm per month) over nearly all of the 2.7 km length assessed. That is the entire 2.7 km length of Wolgan Road assessed is subject to slope hazards, albeit of varying likelihood. The additional hazard length to that calculated for the specific hazard sites of Tables D1 and D2 must be taken into account in the updated SRA for the site, although it is anticipated that the relative likelihood of hazards releasing in those areas will be lower than for the locations of hazards summarised in Table 1 below.

Table 1: Proportion of Wolgan Road at the Gap affected by particular Geotechnical Slope Hazards, November 15th 2022

Domain	Hazard Type	Approximate Proportion of road length affected by hazards (%)	Approximate Proportion of road length affected by active hazards (%)
1	H1.1.1 and H1.1.2 Rockfall	100	N/A
	H1.2 and H1.3 Rock Topples and Slides	60	
	H2.1 and H2.2 Upslope Debris Flow and Slides	65	10
	H3.1 and H3.2 Downslope Debris Flow and Slides	60	45
	H4.1 Retention element	5	5
	H4.2 Drainage element	15	10
2	H1.1.1 and H1.1.2 Rockfall	100	N/A
	H1.2 and H1.3 Rock Topples and Slides	5	
	H2.1 and H2.2 Upslope Debris Flow and Slides	35	15
	H3.1 and H3.2 Downslope Debris Flow and Slides	15	10
	H4.1 Retention element	2	-
	H4.2 Drainage element	10	1

5.0 SUMMARY

Wolgan Road at Wolgan Gap traverses an area of rockfall and landslide hazard which has been managed by Lithgow Council (Council) in accordance with the Wolgan Road – Wolgan Gap Road Slope Instability Management Plan (Golder Ref. 087622115-003-R-Rev 2). Prior to 2022 the dominant slope hazard affecting the road was rockfall with an upslope source zone in the area described as Domain 1 herein (i.e. up to approximately 700 m north of the Wolgan Gap lookout).

Following protracted above average rainfall during 2022, the mobilisation of additional hazards (to rockfall) in the form of upslope and downslope debris flows and slides resulted in obstruction of Wolgan Road, damage and loss of the road embankment in some areas, and prompted an increase in the extent of Wolgan Road assessed for geotechnical slope hazards, along with a review of the hazards affecting the road over that length. That review has been reported herein.

The 2.7 km length of Wolgan Road assessed is subject to significant geotechnical slope hazard due to its position below an up to 100 m high sheer cliff-line and founded on an up to approximately 500 m long very steep colluvial slope. The cliff is a source of small and large rockfall, rock topples and rock slides and the very steep colluvial slopes are a source of re-mobilising rockfall (i.e. rockfall which has come to rest on the colluvial slopes but has the potential to re-mobilise and reach the road below), debris flows and slides and contains numerous previous landslides. Some sections of the road are cut into the steep colluvial slopes which increases the potential for movement and material loss from the unsupported upslope material. At some locations the road has been cut into the toe of previous landslides or founded on previous landslides, both of which further increase the potential for movement of the slope material (compared to where removal of a portion of the toe of an existing landslide or surcharge of an existing slide has been avoided). Culverts and retaining structures within the site are themselves geotechnical slope hazards with a potential for failure within their design life and approximately 40% of those drainage and retention structures have already failed over the 2.7 km length of the road assessed, either individually or as part of a larger slope hazard which has mobilised.

The majority of the road embankment displays pavement deflection and cracking inferred to be consistent with on-going movement of the entire colluvial slope on which the road is founded.

Our review has identified 128 hazard sites which are considered likely to present the highest loss of life risk to road users and the major property (i.e. loss of value) risk to the road infrastructure itself. Of those 128 hazard sites, 37 are active landslides, failed retaining walls or culverts which are experiencing on-going movement and material loss. Safe access for further investigation of landslide mechanisms, development and implementation of remedial measures is not possible in some areas due to the on-going loss of life risk which the hazards present. That is the case at Site 1I which comprises an enlarging approximately 10,000 m^3 debris slide extending more than 50 m upslope of the road and which is bound by similar extent mobilising landslide masses adjacent and below the road embankment. Council has closed the 2.7 km length of Wolgan Road due to the loss of life risk which those hazards and the additional hazards described within this report present to road users and workers.

In order to develop safe methods to clean-up further debris which may accumulate on the road, investigate and remediate the hazards described herein, careful consideration of the risk posed by the individual hazard targeted (for investigation and/or remediation) as well as the numerous surrounding (and often active) hazards would be required. Investigation and remediation strategies would need to consider the cliff line source zone, slopes, retention and drainage elements wholistically. Investigation and remediation measures which only target individual hazards in isolation have the potential to be rendered ineffective by the action of surrounding hazards and as such even small scale hazards (e.g. those with a relatively small length nominated in Table D1 and D2 of Appendix D) will require careful consideration of the surrounding hazards in developing appropriate investigation and remediation strategies.

Remediation of some of the highest risk hazards, (particularly Site 1I and its surrounding sites) via carefully staged and controlled access would be necessary to enable continuation of investigation and remediation works across the 2.7 km length of road targeted towards achieving a calculated loss of life risk level for road users which meets Council's risk tolerability criteria.

In order to quantify the extent of remediation which may be required to meet Council's risk and property tolerability criteria and re-open the 2.7 km length of Wolgan Road, an updated SRA for the geotechnical slope hazards described herein will be provided separately. That SRA will calculate the loss of life risk to road users and the property risk for the hazards described herein. It is emphasised that property risk represents a loss of value risk and does not reflect actual costs to re-instate property damaged or lost which should include investigation, design and remediation costs where appropriate.

Slope conditions over the 2.7 km length of Wolgan Road reviewed herein will continue to change in response to on-going natural geological slope processes. We recommend that an updated aerial survey be undertaken in the first quarter of 2023 to enable review of the condition of hazards described herein and identification of new slope hazards which may have initiated.

6.0 IMPORTANT INFORMATION

Your attention is drawn to the document – 'Important Information Relating to This Report' (LEG04, RL2), which is included in Appendix E of this memorandum. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be. The document is not intended to reduce the level of responsibility accepted by WSP Golder, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing. We would be pleased to answer any questions the reader may have regarding the 'Important Information'.

Signature Page

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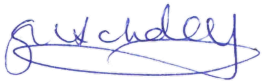

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Principal Geotechnical Engineer

Graham Scholey
Technical Executive

NRS/GKS/nrs

ABN 80 078 004 798

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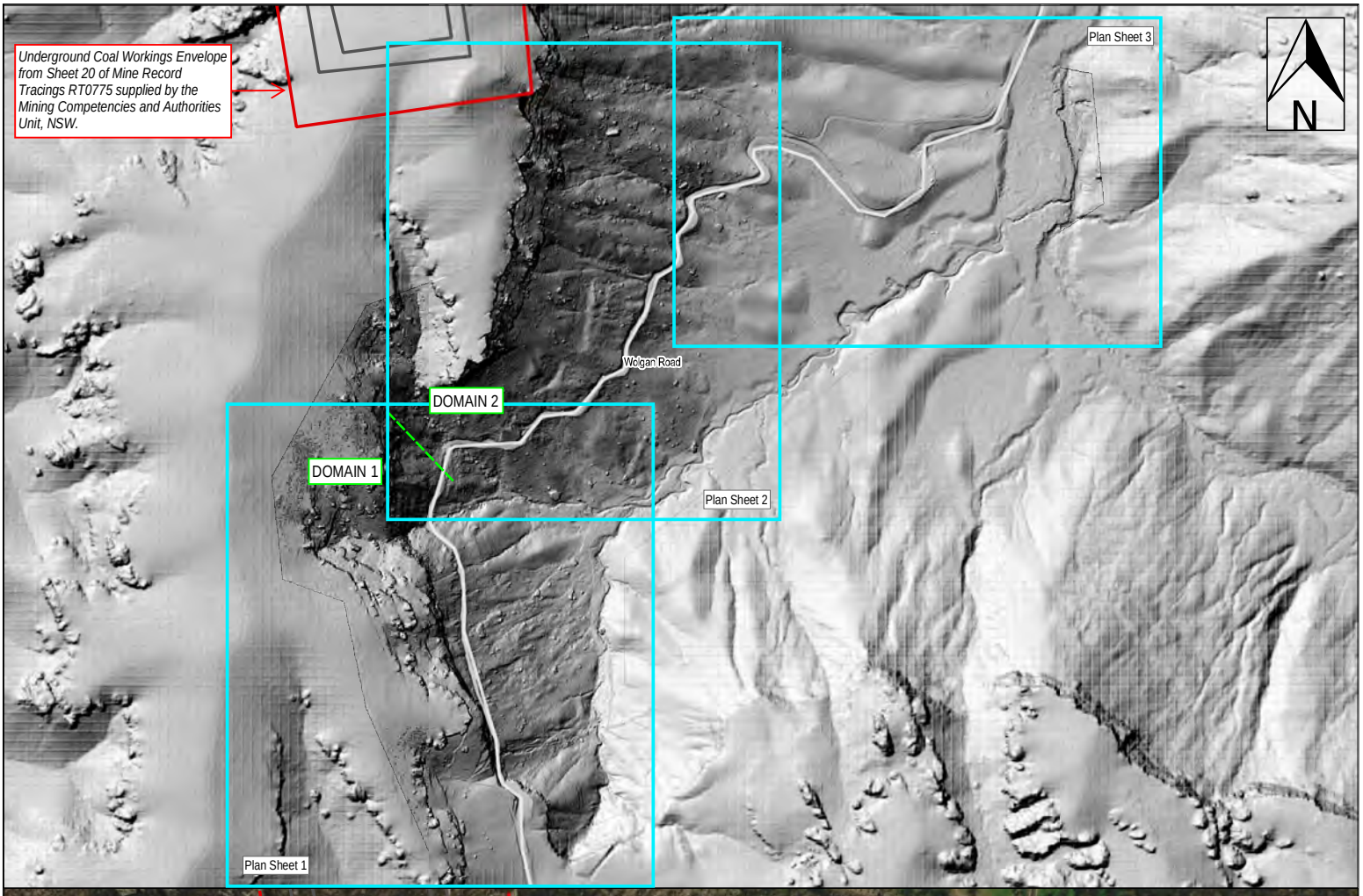
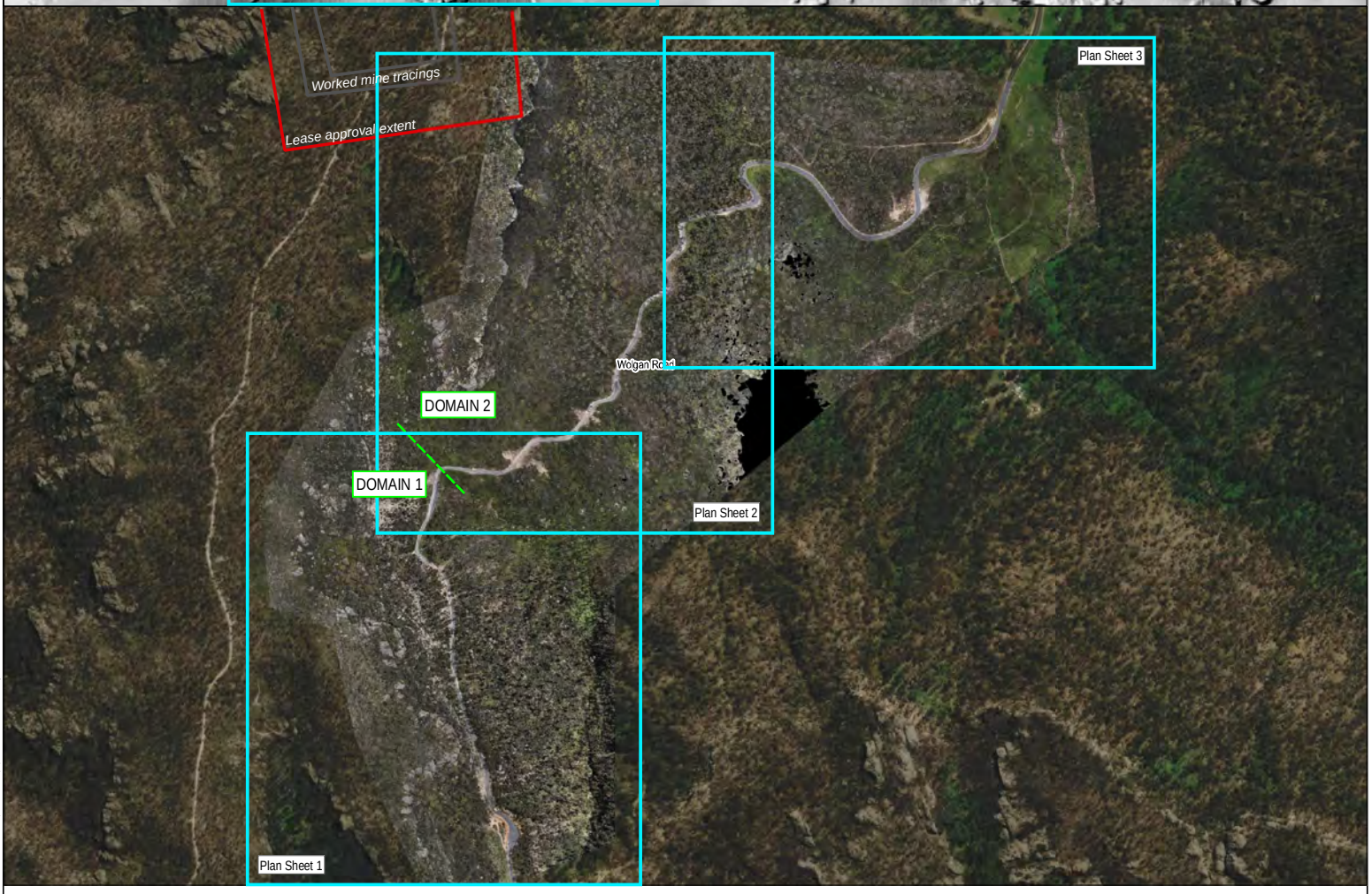
APPENDIX A

Overview Plans





References:

Coal tracings - RT0775.R10000783.RT775 Sheets 15&20

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

Aerial imagery - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)

1:9,000

80 0 80 160 240 320 m

CLIENT
Lithgow City Council

PROJECT
Wolgan Gap

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2023-01-20
DESIGNED	GW
PREPARED	GW
REVIEWED	GKS
APPROVED	GKS

TITLE
Wolgan Gap, Wolgan Road 2022 Geotechnical Slope Hazard Review
Overview Plans

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**A1**

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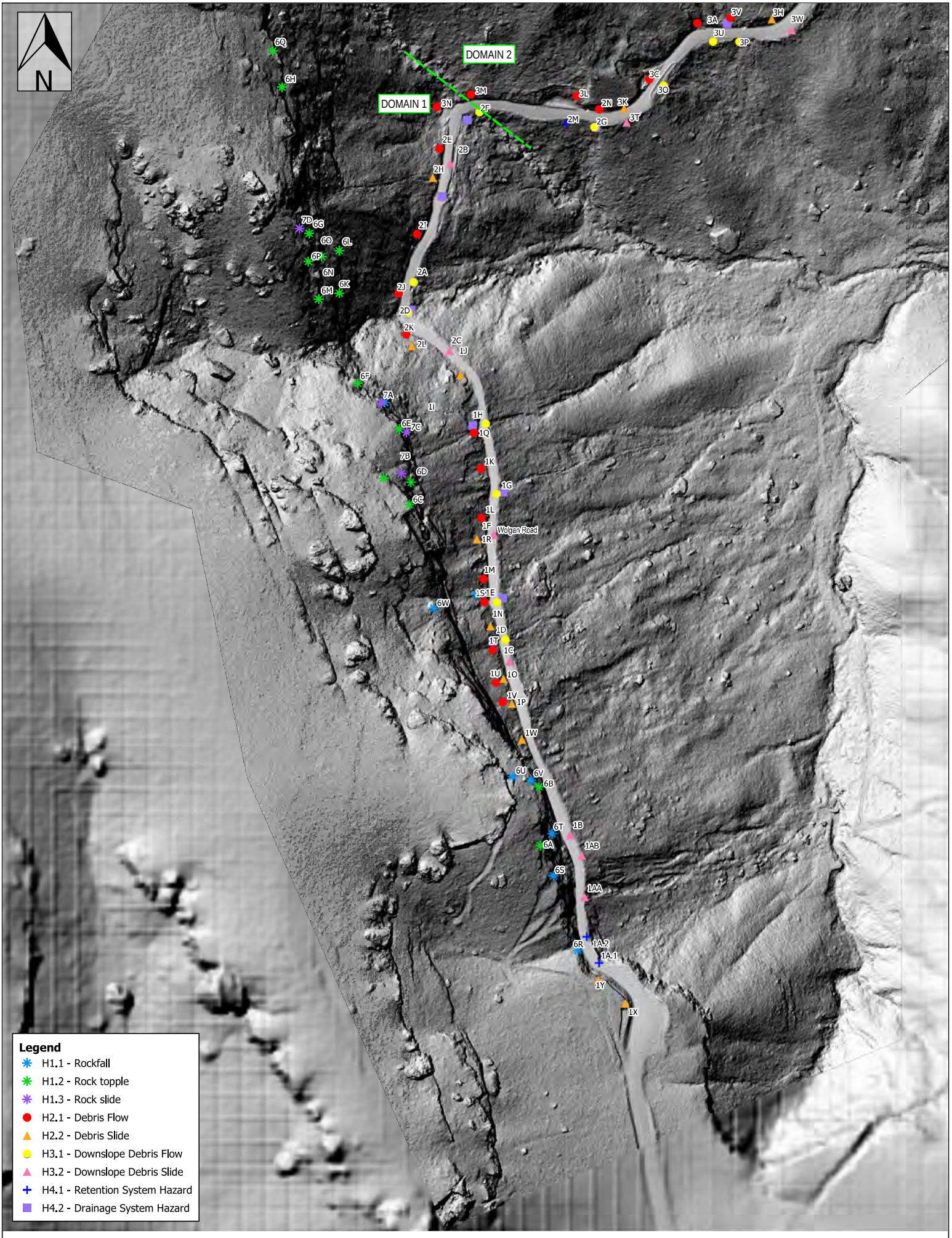

References
LiDAR - Combined
1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and
2) detailed LiDAR '221115_22AU072_Wolgan

1:2,500

20 0 20 40 60 80 m

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Lithgow City Council

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2023-01-20
DESIGNED	GW
PREPARED	GW
REVIEWED	GKS
APPROVED	GKS

PROJECT
Wolgan Gap

TITLE
Wolgan Gap, Wolgan Road 2022 Geotechnical Slope Hazard Review Overview Plans

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**A2**

QGIS v3.16.9+hannover - printed by: Wetherell, Genni - path: \\corp.pbwan.net\ANZ\Projects\AU\PS133xxx\PS133509_LCC_SRA_Cal_Outs\4_WIP\Docs\QGIS\WORKING\PS133509 - LCC SRA.qgz

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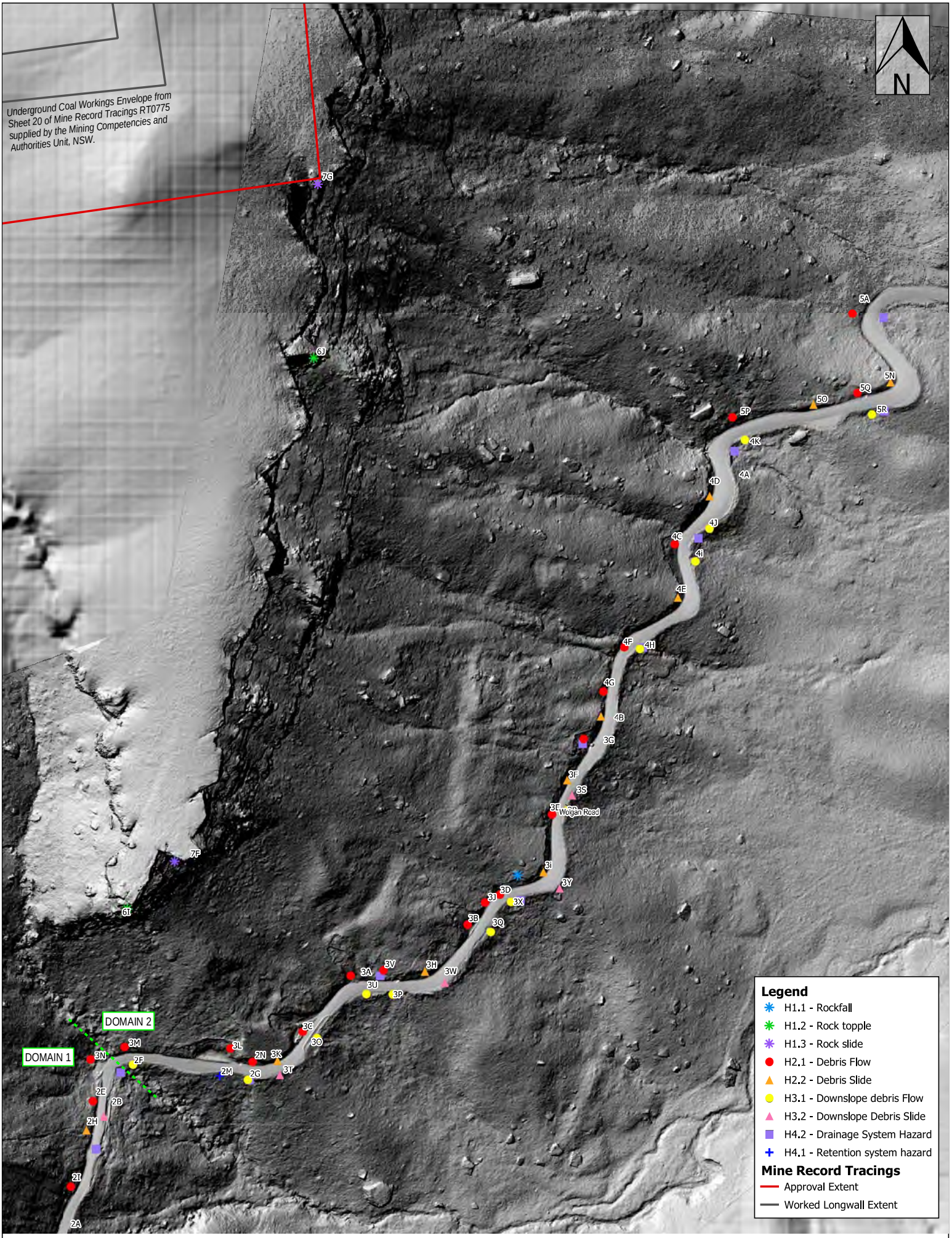

References

Coal tracings - *RT0775.R10000783.RT775 Sheets 15&20*

LiDAR - Combined
1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and
2) detailed LiDAR '221115_22AU072_Wolgan

1:2,500

20 0 20 40 60 80 m

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PROJECT
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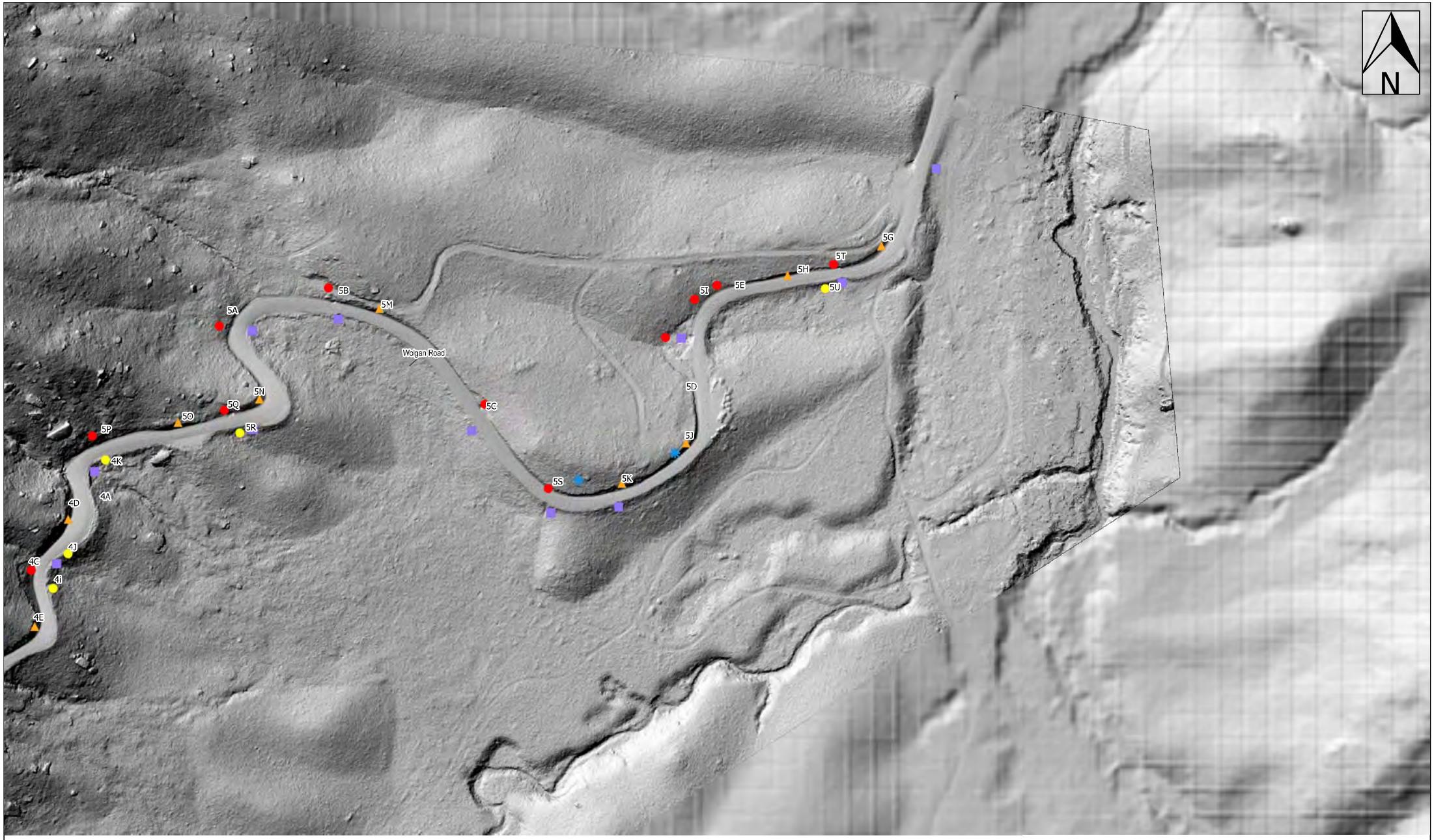
TITLE
Wolgan Gap, Wolgan Road 2022 Geotechnical Slope Hazard Review Overview Plans

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**A3**



Legend

- H1.1 - Rockfall
- H1.2 - Rock topple
- H1.3 - Rock slide
- H2.1 - Debris Flow
- H2.2 - Debris Slide
- H3.1 - Downslope debris Flow
- H3.2 - Downslope Debris Slide
- H4.2 - Drainage System Hazard
- H4.1B - Retention System Hazard

References
LiDAR - Combined
1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and
2) detailed LiDAR '221115_22AU072_Wolgan

1:2,500

20 0 20 40 60 80 m

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PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**A4**

APPENDIX B

Hazard Type Examples

Example H1.1.2 Rockfall (re-mobilisation) Hazard (Approx. diameter 2 m)

Example H1.1.2 Rockfall (Kinematic) Hazard (Approx. diameter 2 m)

Example H1.1.1 Rockfall (re-mobilisation) Hazard (Approx. diameter 0.5 m)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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TITLE
Review of Wolgan Gap Slope Hazards 2022
Figure B1 - Example H1.1.1 and H1.1.2 Rockfall Hazards Domain 1 - Upper Source Zone

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B1**

Example H1.1.1 Rockfall (re-mobilisation) Hazard (Approx. diameter 0.5 m)

Example H1.1.2 Rockfall (re-mobilisation) Hazard (Approx. diameter 3 m)

Example H1.1.2 Rockfall (kinematic) Hazard (Approx. diameter 3 m)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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Review of Wolgan Gap Slope Hazards 2022
Figure B2 - Example H1.1.1 and H1.1.2 Rockfall Hazards Domain 2 - Upper Source Zone

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B2**

Example H1.1.2 Rockfall (re-mobilisation) Hazard (Approx. diameter 3 m)

Example H1.1.1 Rockfall (re-mobilisation) Hazard (Approx. diameter 0.5 m)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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Review of Wolgan Gap Slope Hazards 2022
Figure B3 - Example H1.1.1 and H1.1.2 Rockfall Hazards Domain 1 - Road Cut Crest Zone

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B3**

Example H1.1.1 Rockfall (re-mobilisation) Hazard (Approx. diameter 0.5 m)

Example H1.1.2 Rockfall (re-mobilisation) Hazard (Approx. diameter 3 m)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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Review of Wolgan Gap Slope Hazards 2022
Figure B4 - Example H1.1.1 and H1.1.2 Rockfall Hazards Domain 2 - Road Cut Crest Zone

PROJECT NO	DOC	REV.	FIGURE
PS129742	001	0	B4

Example H1.2 Rock Topple Hazard (Approx. 65 m long)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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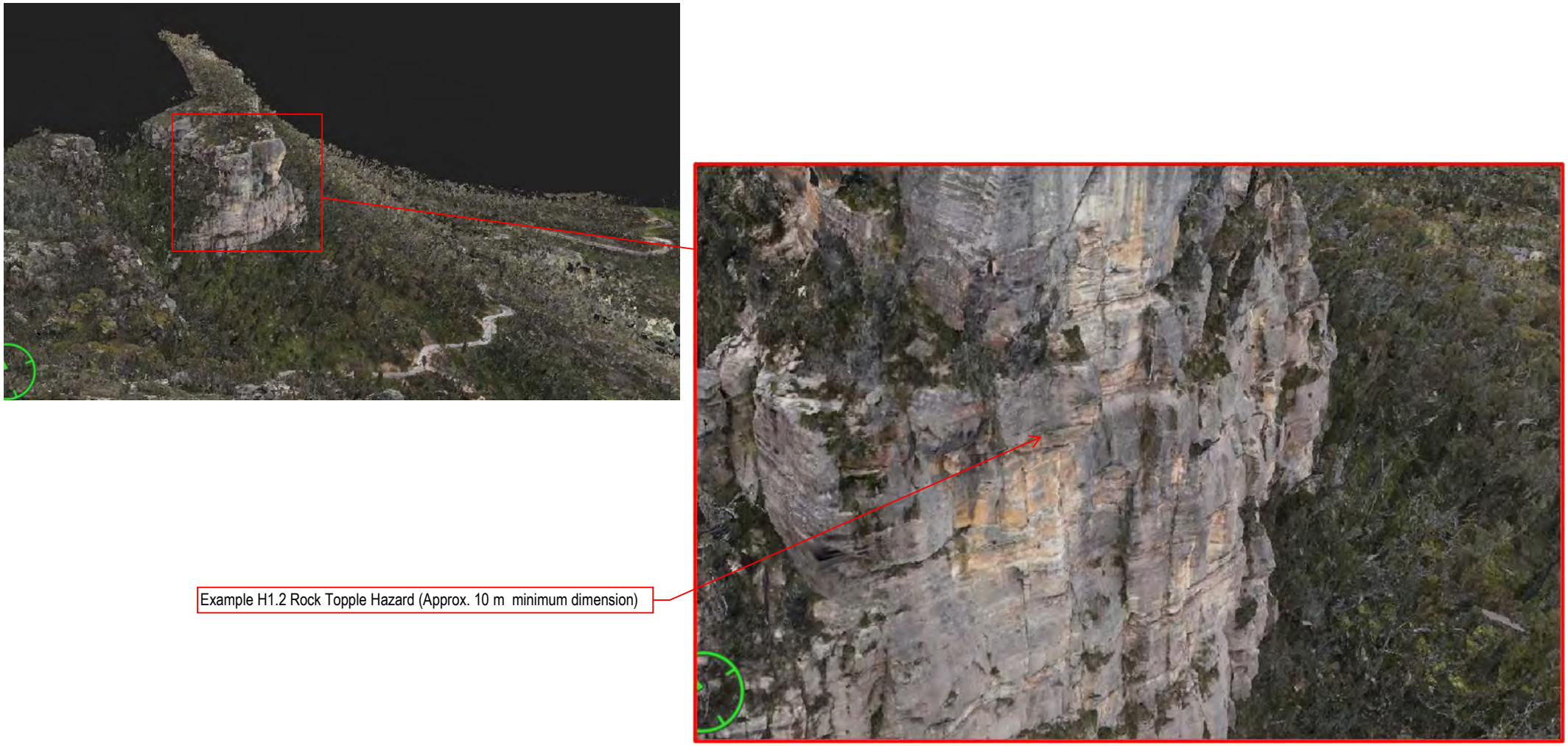
Review of Wolgan Gap Slope Hazards 2022
Figure B5 - Example H1.2 Rock Topple Hazards Domain 1

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B5**



References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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TITLE
Review of Wolgan Gap Slope Hazards 2022
Figure B6 - Example H1.2 Rock Topple Hazards Domain 2

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B6**

Example H1.3 Rock Slide Hazard (Estimated >5,000 m^3)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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TITLE
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Figure B7 - Example H1.3 Rock Slide Hazards Domain 1

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B7**

Example H1.3 Rock Slide Hazard (Estimated >5,000 m^3)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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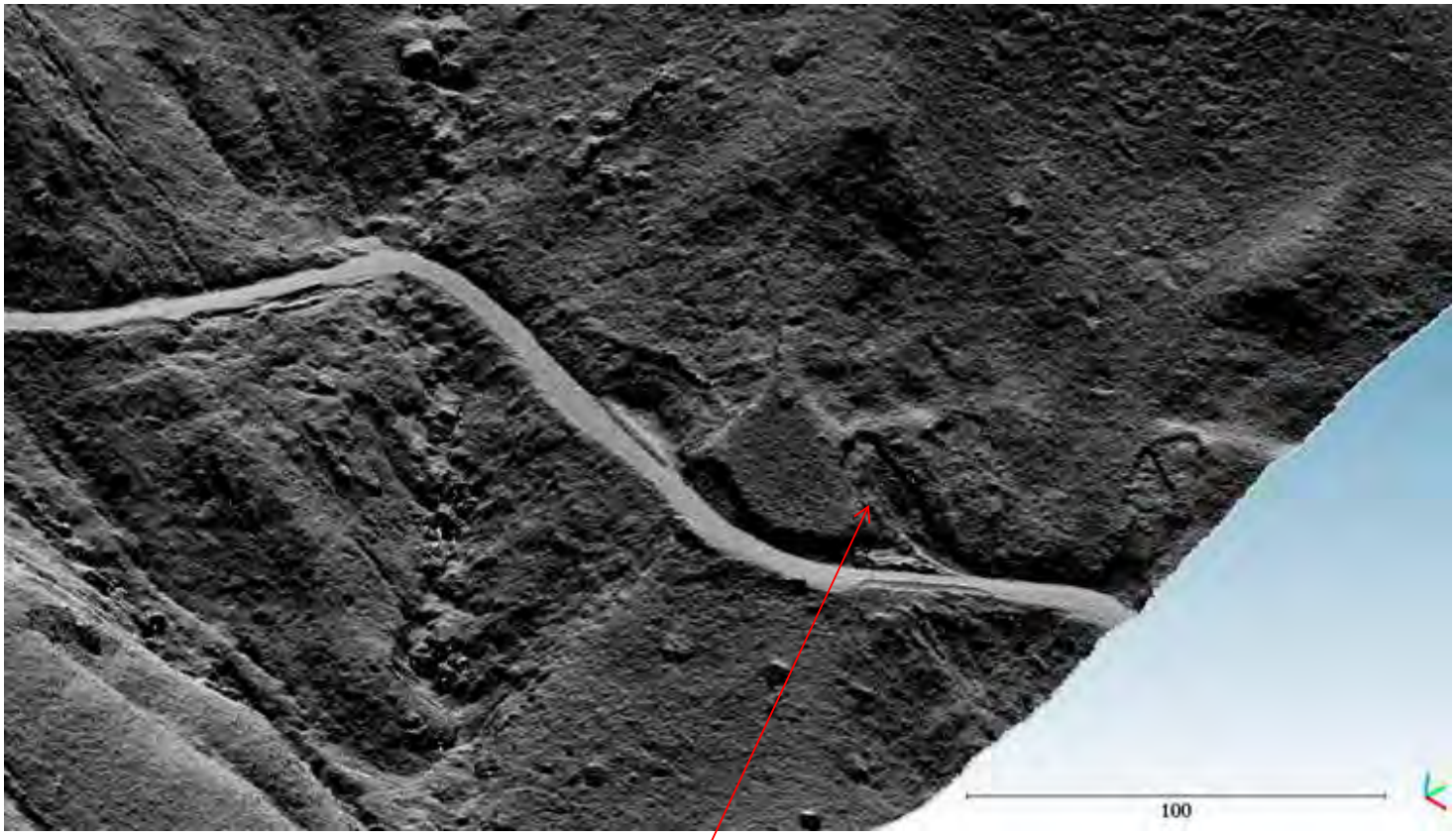
Review of Wolgan Gap Slope Hazards 2022
Figure B8 - Example H1.3 Rock Slide Hazards Domain 2

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B8**



Example H2.1 Upslope Debris Flow Hazard, left flank
(Approx. 40 m wide, 40 m long, 2 m deep)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and 2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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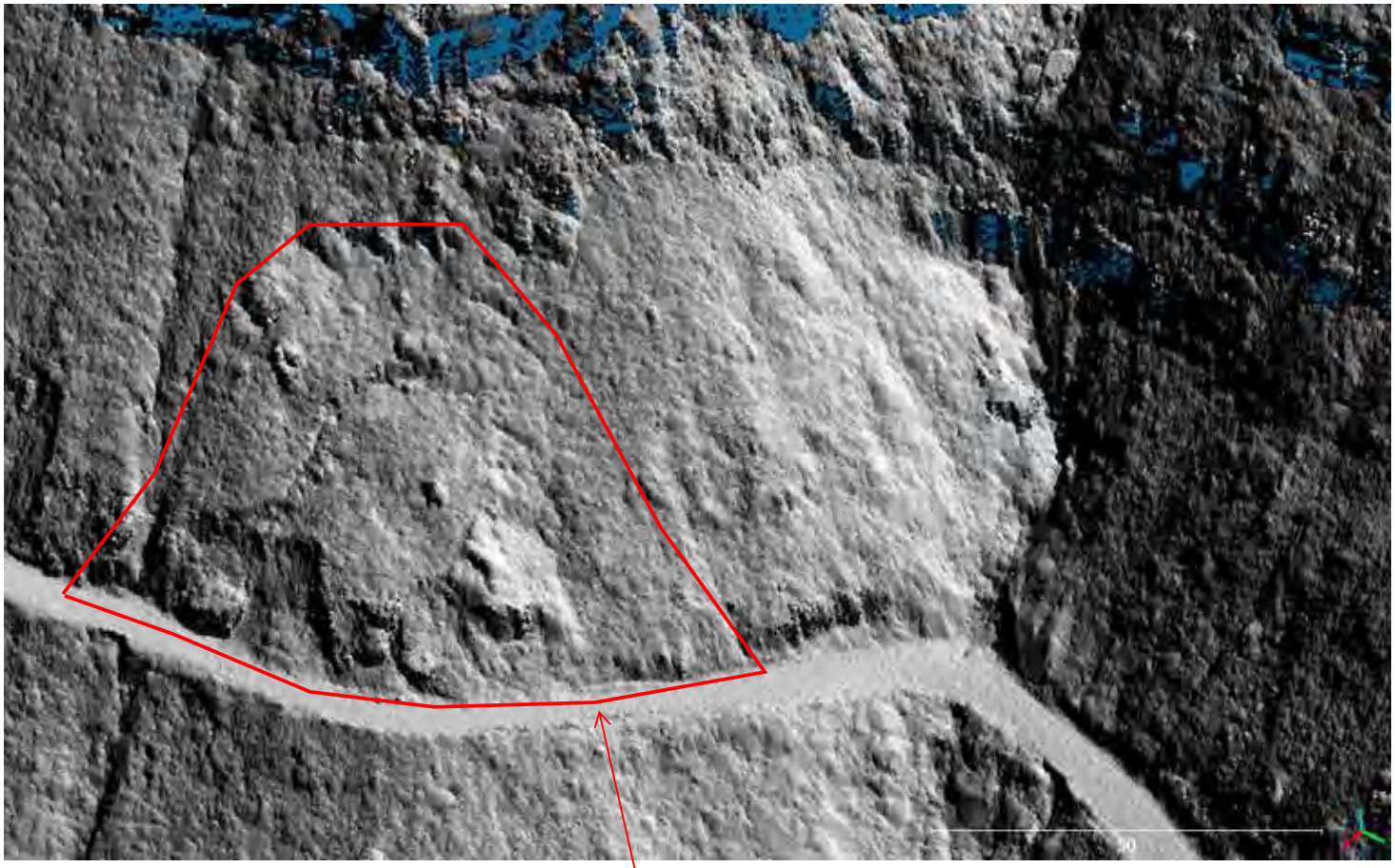
Review of Wolgan Gap Slope Hazards 2022
Figure B9 - Example H2.1 Upslope Debris Flow

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B9**



Example H2.1 Upslope Debris Slide Hazard, enlarging
(Approx. 60 m wide, 60 m long)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and 2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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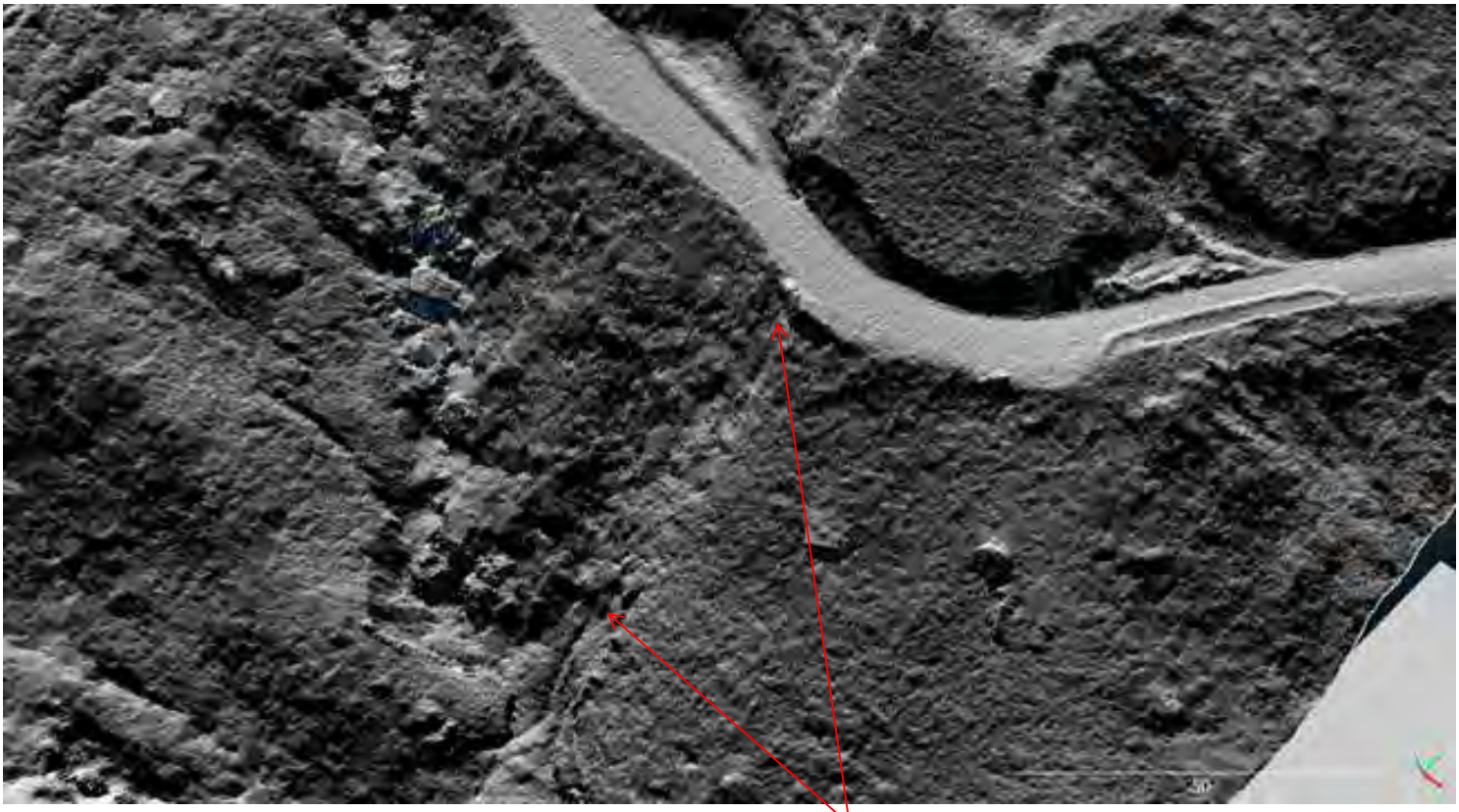
TITLE
Review of Wolgan Gap Slope Hazards 2022
Figure B10 - Example H2.2 Upslope Debris Slide

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B10**



Example H3.1 Downslope Debris Flow Hazard, right flank
(Approx. 5 m wide, 10-20 m long, 2 m deep)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and 2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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DESIGNED	NS
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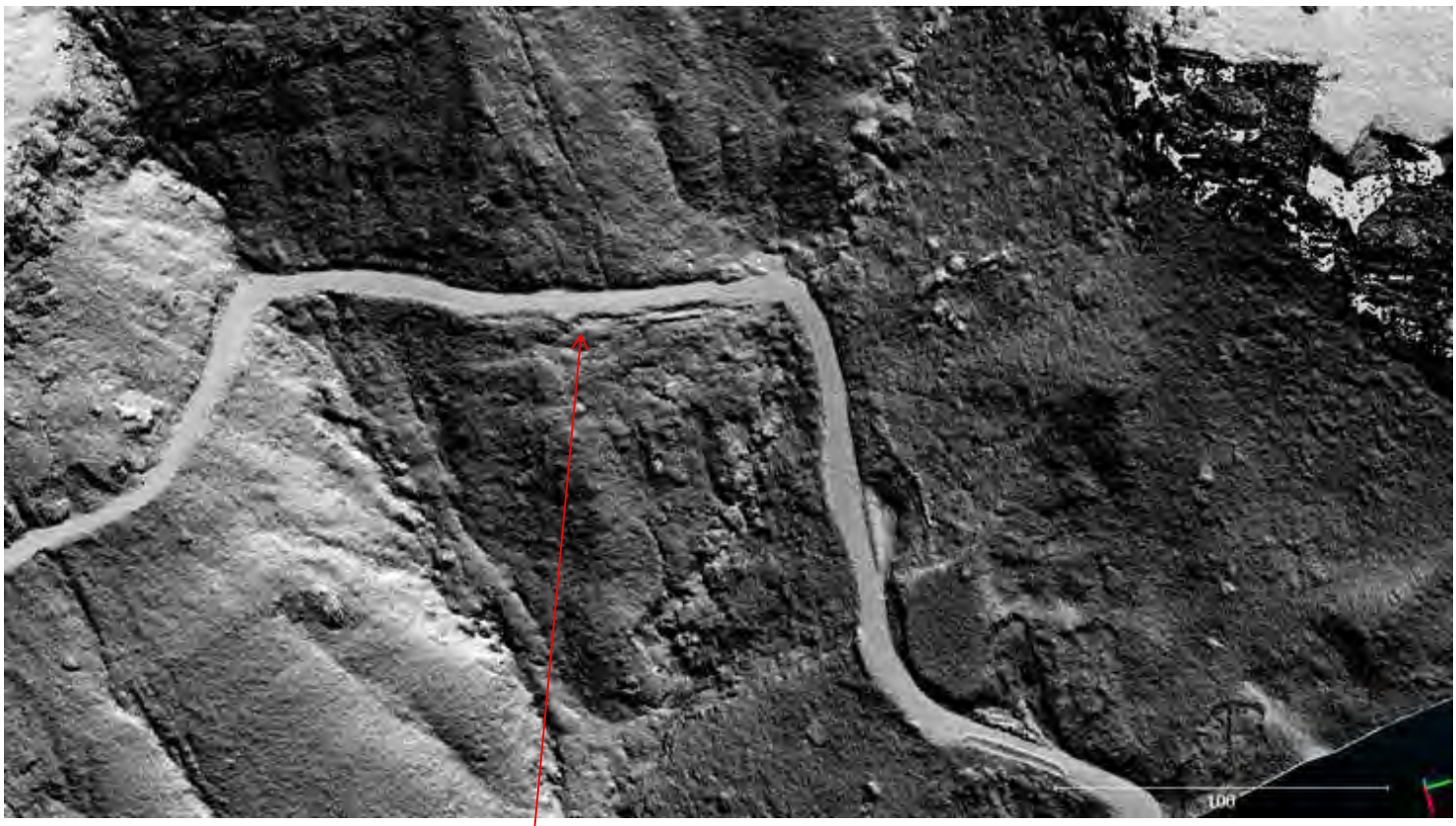
APPROVED	GKS

TITLE
Review of Wolgan Gap Slope Hazards 2022
Figure B11 - Example H3.1 Downslope Debris Flow

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B11**



Example H3.2 Downslope Debris Slide Hazard, (Approx. 100 m wide)

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and 2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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Figure B12 - Example H3.2 Downslope Debris Slide

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B12**

Example H4.1 Retention Element Failure Hazard, (Sandstone block wall approximately 5 m high and 20 m long). Temporary fibrecrete and mesh treatment in place.

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and

2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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Review of Wolgan Gap Slope Hazards 2022
Figure B13 - Example H1.4 Retention Element Failure

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B13**

Example H4.2 Drainage Element Failure Hazard
Culvert has lost integrity and headwall has 'blown out'

References

LiDAR - Combined

1) State wide LiDAR dataset 'Wallerawang 201704-LID2-AHD-2m' and
2) detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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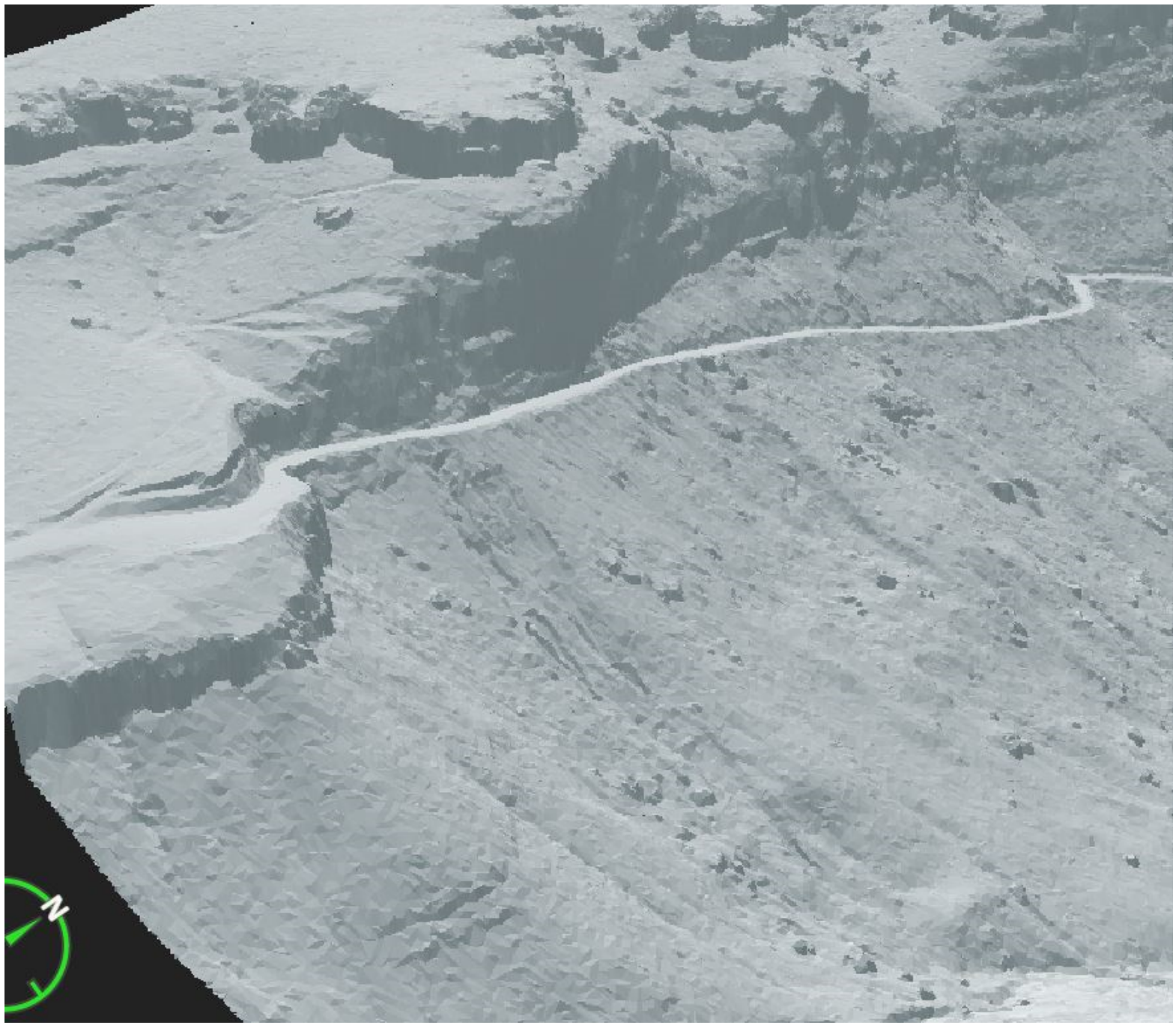
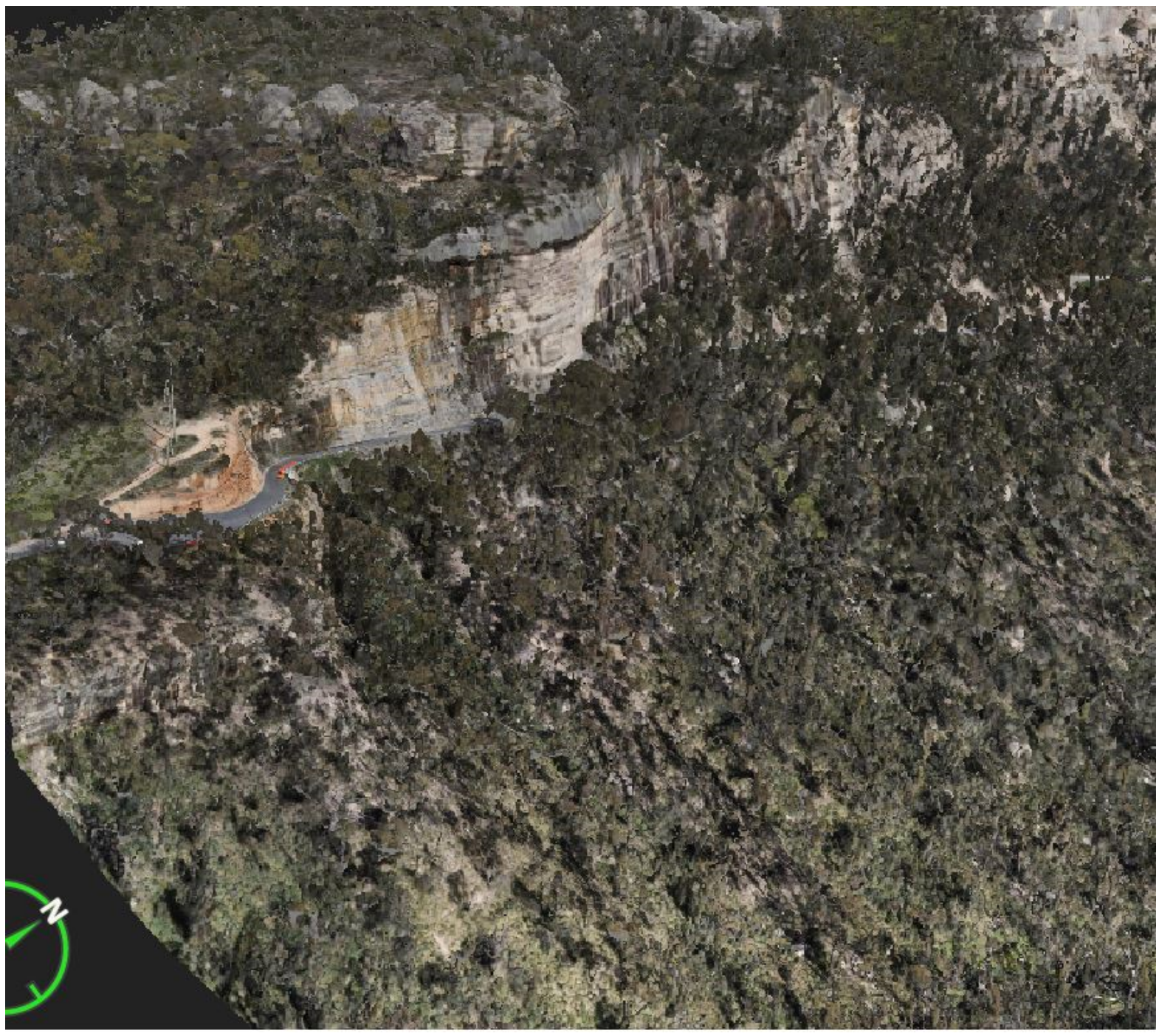
Review of Wolgan Gap Slope Hazards 2022
Figure B14 - Example H4.2 Drainage Element Failure

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**B14**

APPENDIX C

Photo Aerial and LiDAR Slope Perspectives (15.11.22)





References

***LiDAR** - Detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)*

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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TITLE
Wolgan Gap, Wolgan Road 2022 Geotechnical Slope Hazard Review Perspective Views

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**C1**

References

***LiDAR** - Detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)*

***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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TITLE
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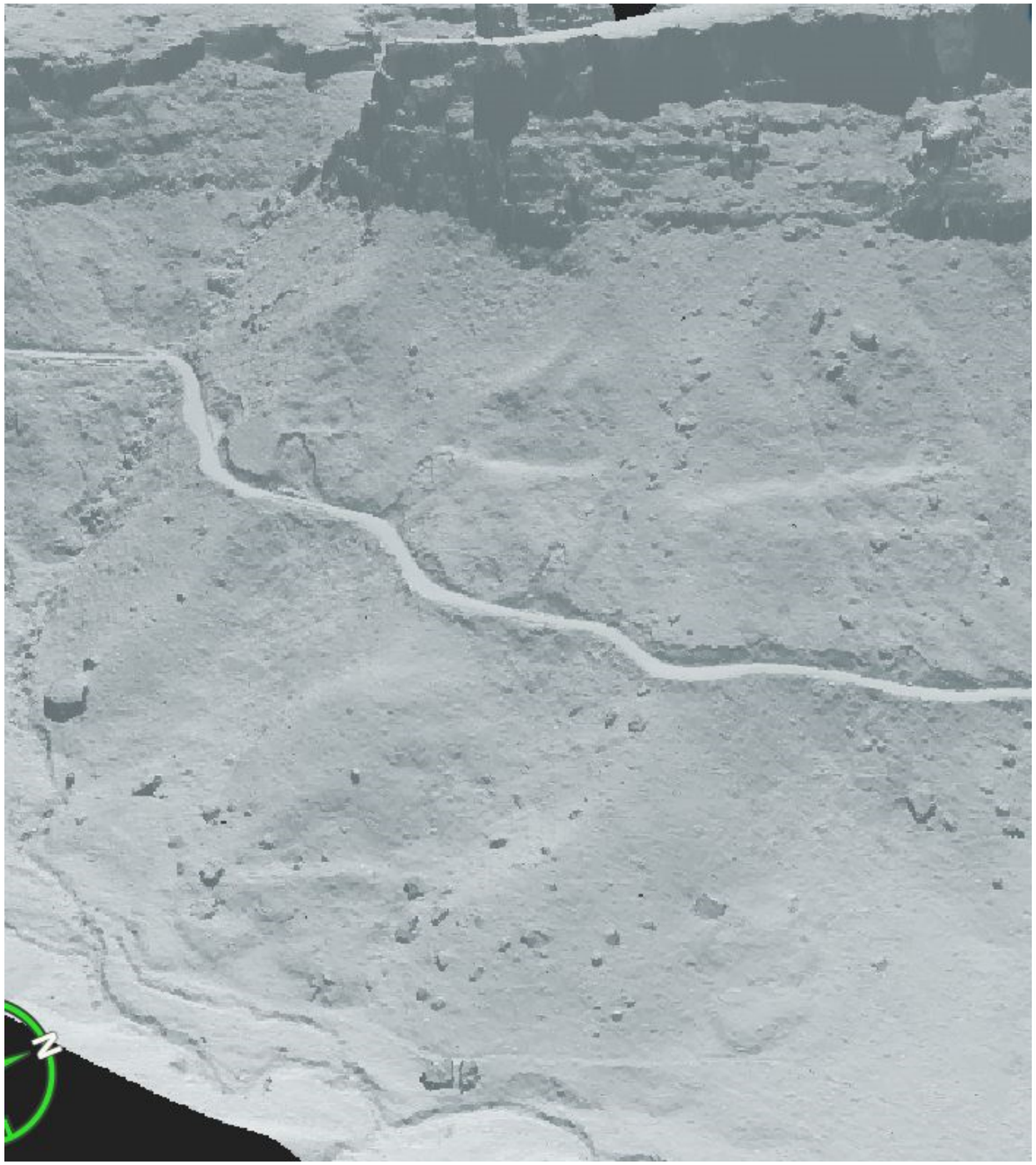
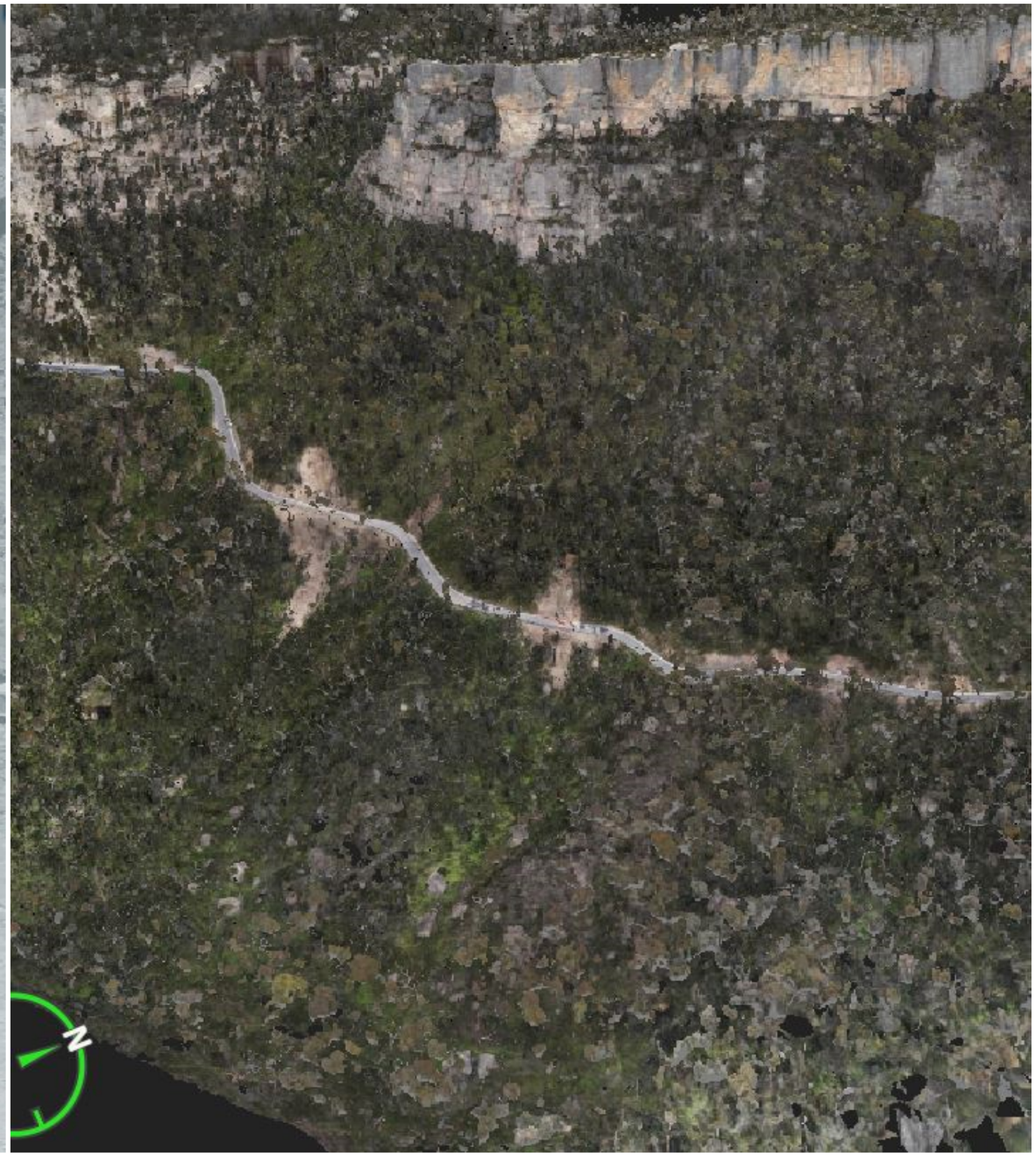
Perspective Views

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**C2**





References

LiDAR *- Detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)*

Aerial imagery *- Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**C3**

References

LiDAR *- Detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)*

Aerial imagery *- Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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TITLE
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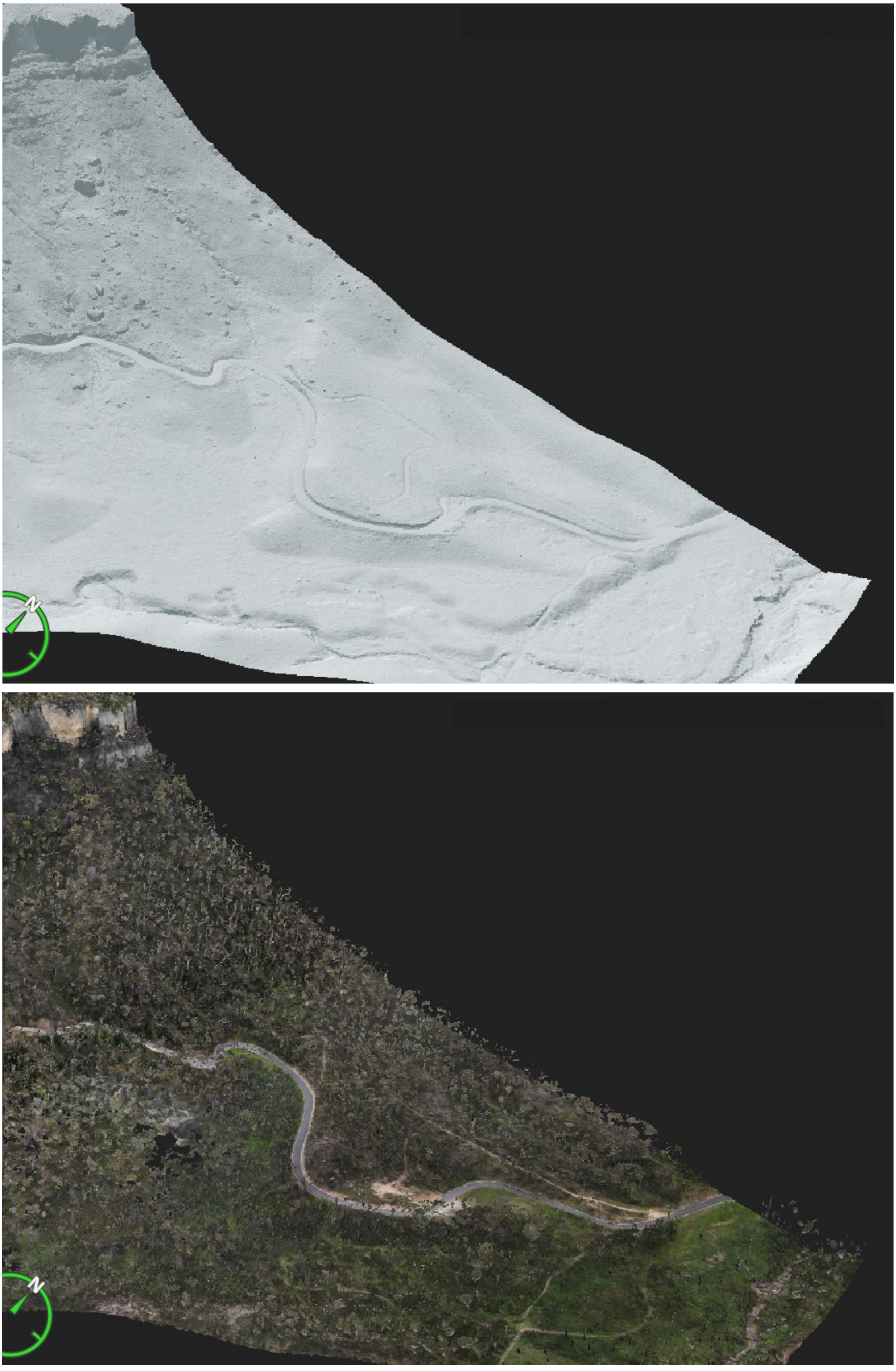
PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**C4**



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Lithgow City Council

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References
***LiDAR** - Detailed LiDAR '221115_22AU072_Wolgan Gap_DTM25cm' (Diospatial 15.11.22)*
***Aerial imagery** - Aerial orthophoto 2cm pixel resolution (Diospatial 15.11.22)*

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Wolgan Gap, Wolgan Road 2022 Geotechnical Slope Hazard Review
Perspective Views

PROJECT NO	DOC	REV.	FIGURE
PS129742	**001**	**0**	**C5**

APPENDIX D

Geotechnical Slope Hazard Summary Tables

Table D1: Active Geotechnical Slope Hazards Sites Wolgan Road, November 15th 2022

Domain	Hazard ID	Hazard Type	Estimated length of road at risk from hazard (m)	Adjacent active slope hazards
1	1Q	H2.1 Upslope Debris Flow	25	At right flank of active 1I and above active Culvert 04.
1	1I	H2.2 Upslope Debris Slide	60	Surrounded by active hazards, 1Q, 1J, 1H, Culvert 04
1	2A	H3.1 Downslope Debris Flow	40	Adjacent to active hazards, Culvert 05 and 2B.
1	1G	H3.1 Downslope Debris Flow	25	Adjacent to active hazard Culvert 03.
1	1H	H3.1 Downslope Debris Flow	50	Downslope of right flank of active hazard 1I.
1	1B	H3.2 Downslope Debris Slide	20	-
1	1C	H3.2 Downslope Debris Slide	25	-
1	1J	H3.2 Downslope Debris Slide	60	Downslope of active hazard 1I.
1	2B	H3.2 Downslope Debris Slide	100	Incorporating active hazard Culvert 06 and adjacent to active hazards Culvert 07 and 2A.
1	1A.1	H4.1 Retention element	20	-
1	Culvert 03	H4.2 Drainage element	15	Adjacent to active hazard 1G.
1	Culvert 04	H4.2 Drainage element	15	Below right flank of active hazard 1I.
1	Culvert 05	H4.2 Drainage element	25	Adjacent to active hazard 2A.
1	Culvert 06	H4.2 Drainage element	15	Within active hazard 2B.
1	Culvert 07	H4.2 Drainage element	15	Adjacent to active hazard 2B.
2	3C	H2.1 Upslope Debris Flow	40	Above active hazard 3O and adjacent to active 3A.
2	3A	H2.1 Upslope Debris Flow	15	Adjacent to active hazard 3C.
2	3B	H2.1 Upslope Debris Flow	10	Above active hazard 3Q.
2	3E	H2.1 Upslope Debris Flow	10	Adjacent to active hazard 3F and above active hazard 3R.
2	3F	H2.1 Upslope Debris Flow	10	Adjacent to active hazard 3E and above active hazard 3S.
2	4C	H2.1 Upslope Debris Flow	45	Adjacent to active hazard 4D and above active hazard 4I.

Domain	Hazard ID	Hazard Type	Estimated length of road at risk from hazard (m)	Adjacent active slope hazards
2	2N	H2.1 Upslope Debris Flow	20	Adjacent to active hazard 3L and above active hazard 2G.
2	3L	H2.1 Upslope Debris Flow	10	Adjacent to active hazard 2N.
2	4G	H2.1 Upslope Debris Flow	20	Adjacent to active hazard 4B.
2	3K	H2.2 Upslope Debris Slide	30	Adjacent to active hazards 2N and 3C.
2	4B	H2.2 Upslope Debris Slide	25	Adjacent to active hazards 4G and 3F.
2	4D	H2.2 Upslope Debris Slide	40	Adjacent to active hazard 4C and above active hazard 4J.
2	3H	H2.2 Upslope Debris Slide	70	Surrounded by active hazards 3A (right flank, adjacent), 3P (right flank, below), 3B (left flank, adjacent), 3Q (left flank below).
2	2G	H3.1 Downslope Debris Flow	5	-
2	3O	H3.1 Downslope Debris Flow	50	Below active hazard 3C.
2	3P	H3.1 Downslope Debris Flow	30	Below active hazard 3A and adjacent active hazard Culvert 09.
2	3Q	H3.1 Downslope Debris Flow	45	Below active hazard 3B and adjacent (downslope) active hazard 3H.
2	3R	H3.1 Downslope Debris Flow	10	Below active hazard 3E and adjacent active hazard 3S.
2	4I	H3.1 Downslope Debris Flow	20	Below active hazard 4C and adjacent active hazard 4J.
2	4J	H3.1 Downslope Debris Flow	15	Below active hazard 4D and adjacent active hazard 4J.
2	3S	H3.2 Downslope Debris Slide	25	Below active hazard 3F and adjacent active hazard 3R.
2	Culvert 09	H4.2 Drainage element	15	Adjacent active hazards 3A and 3P.

Table D2: Potential Geotechnical Slope Hazards Sites Wolgan Road, November 15th 2022

Domain	Hazard Type	Number of specific Hazard Sites additional to active sites of Table 1	Estimated length of road at risk from nominated hazard sites (m)
1	H1.2 Rock Topple	15	305
2	H1.2 Rock Topple	2	40
1	H1.3 Rock Slide	4	135
2	H1.3 Rock Slide	2	100
1	H2.1 Upslope Debris Flow	11	170
2	H2.1 Upslope Debris Flow	12	190
1	H2.2 Upslope Debris Slide	9	195
2	H2.2 Upslope Debris Slide	10	190
1	H3.1 Downslope Debris Flow	1	15
2	H3.1 Downslope Debris Flow	3	90
1	H3.2 Downslope Debris Slide	4	85
2	H3.2 Downslope Debris Slide	-	-
1	H4.1 Retention element	-	-
2	H4.1 Retention element	1	30
1	H4.2 Drainage element	2	20
2	H4.2 Drainage element	15	150

APPENDIX E

Important Information

The document ("Report") to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

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At any location relevant to the Services conditions may exist which were not detected by Golder, in particular due to the specific scope of the investigation Golder has been engaged to undertake. Conditions can only be verified at the exact location of any tests undertaken. Variations in conditions may occur between tested locations and there may be conditions which have not been revealed by the investigation and which have not therefore been taken into account in this Report.

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Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

Where permitted by the Contract, Golder may have retained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder's affiliated companies or the employees, officers or directors of any of them.

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