Wolgan Road, NSW

Review of Wolgan Gap Slope Risk Assessments

Lithgow City Council

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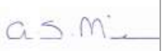
A0	0	A. Hunter D. Field D. Jones	T. Miner		K. Jarvie	Kevin M Jarvie Digitally signed by Kevin M Jarvie DN: E=Kevin.Jarvie@ghd.com, CN=Kevin M Jarvie, OU=Orange Users, OU=Orange, OU=22, OU=Oceania, OU=Offices, DC=ghdnet, DC=internal Reason: I am approving this document Date: 2025.03.05 18:53:54+11'00'	05/03/25

GHD Pty Ltd | ABN 39 008 488 373
Contact: Andrew Hunter, Senior Technical Director - Engineering Geology | GHD
Level 11, 558 Pacific Highway
St Leonards, New South Wales 2065, Australia
T +61 2 9462 4700 | **F** +61 2 9462 4710 | **E** slnmail@ghd.com | **ghd.com**

Executive summary

Wolgan Road was closed to traffic in 2022 by Lithgow City Council due to landslide risks and associated road damage. Wolgan Road is an important access route for the Wolgan Valley community and provides access to the Emirates One&Only Resort. The purpose of this report is to present an independent review of the geotechnical risk assessment (prepared by WSP) that led to the closure of Wolgan Road and assess whether the findings are consistent with the observed conditions as well as the industry methods and guidelines. On Tuesday 18 February 2025, GHD undertook a reconnaissance level site walkover along Wolgan Road for familiarisation purposes.

The risk and hazard assessments prepared by WSP are unusual because there has been an attempt to identify individual (i.e. unique) hazard features (128 unique hazards are stated to have been identified). While this approach is suitable and achievable for sites such as a small road cutting where there are a limited number of hazards, this approach is not appropriate for large escarpment scale sites such as Wolgan Road. The identification of ‘unique’ hazard features, each with an associated likelihood, implies a level of precision and thoroughness that is unrealistic. In these circumstances AGS (2007) states that an understanding of the slope forming process relevant to the landslides and associated process rate is fundamental for evaluation of likelihood. This approach does not appear to have been followed and although a landslide inventory is mentioned in the WSP reports, it does not appear to have been used to assign likelihood values. Furthermore, no geological model or interpretive cross sections are presented, both of which are core requirements of AGS (2007).

Based on the rockfall likelihood values adopted by WSP, on average at least two large (i.e. 3 m diameter) rockfalls and twenty small (0.5 m diameter) rockfalls should have reached the 2.7 km long section of road since the road was closed. During our site visit the largest rockfalls observed on the road comprised gravel sized fragments of rock (up to about 40 mm diameter).

The WSP reports contain little supporting evidence to justify other probability factors such as vulnerability or spatial probability. For a project of this significance, where risk assessments have been used to justify closure of a road, we would expect that rockfall modelling be used to help inform spatial probability (i.e. rockfall runout). Furthermore, some of the vulnerability values adopted significantly exceed values recommended by Transport for NSW.

Despite our disagreement with the approach used by WSP to assess unique, individual hazards, all of the risks presented by WSP are significantly lower than the AGS (2007c) suggested tolerable loss of life risk criteria for the person most at risk of 10^{-5} per annum. However, this is not acknowledged in the report. It is our experience that many asset owners / operators would likely choose to accept risks of this magnitude. Although it is not explicitly stated in the WSP report, it appears that the individual risks were combined using one of two methods that exhibit a positive correlation with the number of risks incorporated (i.e. the more individual hazards that are and included in the calculation, the higher the calculated overall risk).

WSP has reported that the annual risk of loss of life to an individual for the site is 2×10^{-3}. In our experience this is unusual for situations such as this, because the very short exposure periods of mobile elements at risk (i.e. vehicles) typically result in tolerable risks, even when landslides are relatively frequent. Therefore, logic suggests that intense scrutiny should be applied to the risk methodology. However, this is not possible, as the method of calculation has not been provided.

It is important to recognise that the majority of the hazards described by WSP to have caused damage to the road are located along the upper section of the road, which is approximately 750 m in length (i.e. approximately 27% of the total site length). Despite the landslide damage, the road remains trafficable in one lane. The remaining lower section of road appears to be in generally good condition, noting however that the pavement and some of the base layers have been removed in several places along this section of road to supply material to upgrade the Donkey Steps track. In this context there are opportunities to reassess the feasibility of reopening Wolgan Road by adopting pragmatic risk reduction approaches such as the “ALARP” principle (“as low as reasonably practicable”).

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1. Introduction

Wolgan Road was closed to traffic in 2022 by Lithgow City Council due to actual and postulated landslide hazards, assessed risk to road users and associated road damage. Over the years various parties have conducted risk assessments and options assessments for remediation of hazards on Wolgan Road. The latest reports have stated that landslide risks are intolerable, and that restoration and remediation of the existing road is not a practical or cost-effective option.

For a project of this nature, where risk-based decisions have far-reaching consequences for local communities, and tourism, it is common practice for an independent review of landslide risks to be undertaken.

1.1 Purpose of this report

The purpose of this report is to present an independent review of the geotechnical risk assessment that led to the closure of Wolgan Road, ensuring that the findings are consistent with the observed conditions as well as the industry methods and guidelines as presented in the Australian Geomechanics Society (AGS) Landslide Risk Management (LRM) guidelines (AGS, 2007). For comparative purposes we have also undertaken a preliminary risk assessment using the Transport for NSW (TfNSW) Guide to Slope Risk Analysis (TfNSW, 2012).

The reported findings in the following reports are the subject of this review:

- Wolgan Road, NSW – Review of Wolgan Gap Slope Hazards 2022, WSP Australia Pty Ltd, dated 23 January 2023 (WSP, 2023a)
- Wolgan Gap, Wolgan Road – Slope Risk Assessment Update 2022 – Domain 1 and 2, WSP Australia Pty Ltd, dated 17 February 2023 (WSP, 2023b)

1.2 Scope and limitations

This report presents a review of the previous risk assessment undertaken by others and does not present a new risk assessment. This report does not provide recommendations or advice on levels of risk that may be tolerable or acceptable to Council. The Regulator (Lithgow City Council) is the responsible body / authority for setting acceptable / tolerable risk criteria to be adopted for Wolgan Road.

This report has been prepared by GHD for Lithgow City Council and may only be used and relied on by Lithgow City Council for the purpose agreed between GHD and Lithgow City Council as set out in section 1.1 of this report.

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The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section 1.3 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

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1.3 Assumptions

GHD has prepared this report on the basis of information provided by Lithgow City Council, 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.

2. Background

Wolgan Road was closed to traffic in 2022 by Lithgow City Council (Council) due to landslide risks and associated road damage. Wolgan Road is an important access route for the Wolgan Valley community and provides access to the Emirates One&Only Resort. We understand the closure has resulted in the indefinite closure of the resort. Council has constructed an interim alternate access road along the eastern side of the Wolgan Gap, following the route of the historic 'Donkey Steps' track. However, this route is primarily limited to four-wheel drive vehicles and is constructed at very steep grades.

Over the years various parties have undertaken remedial works, conducted risk assessments, and options assessments for Wolgan Road. The most recently published assessment states that, "The slope hazards currently pose an annual individual loss of life risk of more than 200 times greater than industry tolerable limits (2×10^{-3} per annum). The calculated annual societal risk of one or more fatalities is 1000 times greater than industry tolerable limits ($F = 1 \times 10^{-1}$ per annum)." (WSP, 2023b). The assessments concluded that landslide risks are intolerable, and that restoration and remediation of the existing road are not practical or cost-effective options.

Currently, the preferred option for restoring access to the valley involves constructing a new road on the opposite side of the valley. This new route would encroach on the Gardens of Stone State Conservation Area and sites of Aboriginal heritage. It will also leave a lasting environmental legacy, involving the construction of very large multi-bench rock cuttings more than 50 metres high in currently undisturbed terrain.

3. Site Observations

On Tuesday 18 February, GHD undertook a reconnaissance level site walkover along Wolgan Road for familiarisation purposes. The walkover was undertaken from road level only. The site visit was attended by our Senior Technical Directors; Daniel Jones and Andrew Hunter in the company of Mark Schofield from Wassabi Group. The walkover started at the locked gate at Wolgan Valley Lookout and ended near the bottom of the pass at the intersection with the Donkey Steps' track. A summary of pertinent observations relevant to this review are below:

- The largest rockfalls observed on the road comprised gravel sized fragments of rock (up to about 40 mm diameter) below the section of road that traverses near-vertical cliffs at the top of the pass (Figure 1). No other rockfalls were observed on the road for the remainder of the approximately 2.7 km section of road. We are not aware whether the road is regularly being cleared of rockfall debris.
- A small downslope failure of a 'drystone' retaining wall near the top of the pass appears to have been temporarily treated with shotcrete (Figure 2).
- Many of the culvert inlets were full of debris and appear to be at least partially blocked.
- The upslope concrete table / spoon drains were typically observed to contain relatively little soil or rock debris.
- The upper sections of the road (i.e. first few hundred metres) appear to be constructed with relatively little side-cast embankment fill. Rock shelves are visible on the downslope side at several locations below the road. Localised tension cracking of the pavement was observed in the downslope lane at some locations across this length of road, suggestive of instability of the fill embankments (Figure 3). No prominent tension cracks suggestive of large-scale landsliding were observed in the pavement.
- Several small slides of the upslope batters occur along the first few hundred metres of the road (Figure 4). The debris appears to have been mostly cleared from the road however it is not known when this occurred. The slides are predominantly in colluvial soils, talus and weathered rock. The slides are all relatively shallow failures and have often exposed weathered rock, suggesting the colluvial soil thickness is quite shallow (i.e. a few metres).
- Approximately 650 m from the lookout there is a series of coalescing downslope embankment failures which extend along an approximately 100 m length of road (Figure 5). The failures appear to have involved retrogressive slumping of the outer side-cast embankment fill. It appears that this could have been due to scouring exacerbated by poor road drainage. It is important to note that the failures have only affected the downslope lane, with the upslope lane still trafficable. The failures appear to be shallow and have only occurred in fill materials, with the upslope lane likely constructed at or near grade. The upslope pavement was not observed to contain obvious tension cracks.
- The section of road below the abovementioned embankment failure descends down the mid to lower sections of the escarpment talus slope and becomes progressively further away from the upper escarpment cliff-line. The pavement and some of the base layers have been removed in several places along this section of road. We understand this was to supply material to sheet the Donkey Steps track. Despite this, the road and remaining sections of pavement appear to be in good condition (Figure 6), with no tension cracking or other obvious signs of instability observed.
- The first few hundred metres of road, below the section of embankment failure contains several scarps associated with upslope batter slides (Figure 7). The failures appear to have comprised relatively shallow slides in colluvium and weathered rock. Bedrock is exposed in the failure scarps, again suggesting the thickness of colluvium and talus is relatively shallow. The failure material has since been cleared off the road.
- The upper cliffs that cap the escarpment typically exhibited characteristic, case-hardened patinas, typical of a Sydney Basin escapement associated with infrequent, episodic rockfall events.

Figure 1 *Example of small gravel sized rockfalls observed on road, February 2025.*

Figure 2 *Localised failure of drystone wall.*

Figure 3 *Localised tension cracking in downslope lane.*

Figure 4 *Upslope batter failure in colluvium, talus and weathered rock.*

Figure 5 *Embankment failure comprising slumping of fill materials below downslope lane. Upslope lane remains trafficable.*

Figure 6 *Example of lower section of Wolgan Road in apparent good condition. Asphalt and subbase removed for reuse on Donkey Steps track.*

Figure 7 *Example of upslope batter failure in colluvium, talus and weathered bedrock along of lower section of Wolgan Road.*

4. Landslide risk management guidelines

4.1 Australian Geomechanics Society landslide risk management framework

The 1998 Thredbo landslide, in which 18 people were killed, highlighted the challenges faced from building upon steep slopes and led to the development of the Australian Geomechanics Society (AGS) Landslide Risk Management (LRM) guidelines, published in 2007 and now commonly referred to as AGS (2007). The suite of guidelines is recognised nationally (Australia) and internationally as world-leading practice. The reader of this report is encouraged to consult the freely available Landslide Risk Management guidelines (LRM) resources which can be accessed at: **https://australiangeomechanics.org/downloads/**

The 'Practice Note Guidelines for Landslide Risk Management' (AGS, 2007c) provides technical guidance in relation to the processes, tasks and reporting standards undertaken by geotechnical practitioners who prepare LRM reports including appropriate methods and techniques. The Practice Note is a statement of what constitutes good practice by a competent practitioner for LRM, including defensible and up to date methodologies and provides guidance on the quality of assessment and reporting, including the outcomes to be achieved and how they are to be achieved.

The framework for landslide risk management is presented in Figure 8 and represents a framework widely used internationally.

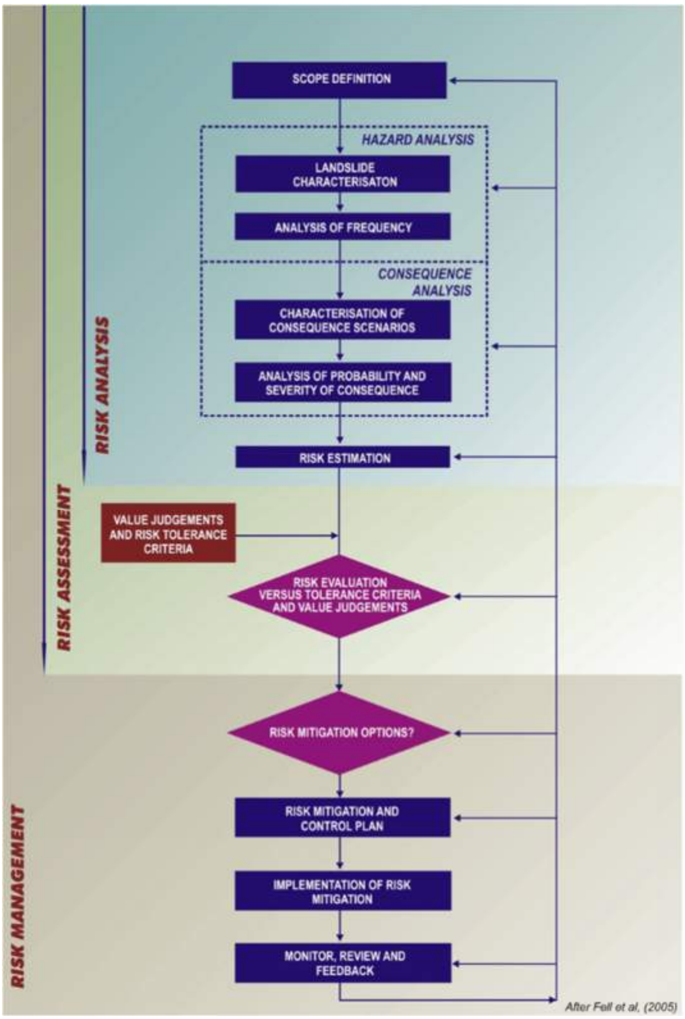

Figure 8 ***Framework for landslide risk management***

4.1.1 Risk estimation methodology

AGS (2007c) requires risks to loss of life to be estimated quantitatively for the person most at risk. The person most at risk will often, but not always be, the person with the greatest spatial temporal probability (i.e. the person most exposed to the risk). The individual risk to life is defined as the risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide. In the context of Wolgan Road, elements at risk would predominantly be individuals in vehicles (i.e. motorists).

The risk of 'loss-of-life' to an individual is calculated by multiplying four probability factors together as follows:

$$R_{(LoL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)} \qquad (1)$$

Where:

$R_{(LoL)}$ is the risk (annual probability of death of an individual).

$P_{(H)}$ is the annual probability of the landslide (event).

$P_{(S:H)}$ is the probability of spatial impact of the event impacting an individual taking into account the travel distance and travel direction given the event. For example, the probability of an individual in a vehicle being impacted by a rockfall / landslide at a given location or alternatively the probability of a vehicle impacting a rock (or driving into a void created by an embankment failure) that is already on the road.

$P_{(T:S)}$ is the temporal spatial probability (e.g. of the location being occupied by the individual at the time of impact) given the spatial impact and allowing for the possibility of evacuation / avoidance given there is warning of the event occurrence.

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

4.2 TfNSW (RMS) Guide to Slope Risk Analysis

The TfNSW system has been used extensively to assess slopes adjacent to roads in New South Wales and Queensland and has more recently been adopted for use on New Zealand's State Highways. This form of risk analysis is used to rapidly analyse the risk to life and property associated with cut/ fill slopes and soil retaining structures adjacent to roads. The procedure is based primarily on visual assessment, however additional supporting data / information can be used when available. The risk analysis provides information for use in setting priorities for investigation, monitoring and remediation of such slopes and structures.

The procedure has been progressively established since 1999 to allow TfNSW to rank landslide hazards on severity of risk to life. It is based on an underlying quantitative framework and was developed to systematically analyse geotechnical risks associated with slopes adjacent to roads in NSW. The framework was primarily based on landslide risk literature available at the time including the Australian Geomechanics Society Landslide Risk Management guidelines. TfNSW-trained practitioners select defined ratings based on field observations which are then incorporated into a risk matrix to generate an Assessed Risk Level (ARL). There are five ARL levels ranging from ARL1 (highest risk level) to ARL5 (lowest risk level). Baynes, Lee and Stewart (2002) provide the following commentary on the TfNSW risk assessment system with respect to risk to life:

> *"the median quantitative probability of loss of life implied by the five ARL levels are roughly one order of magnitude apart, with the highest risk level (ARL1) roughly equating to an annual risk of loss of life of >10-3 " (i.e. an annual risk of about 1 in 1000) "and the lowest risk level (ARL5) roughly equating to an annual risk of loss of life of <10 -6" (i.e. an annual risk of about 1 in 1,000,000)".*

WSP (2023b) did not present a risk assessment using the TfNSW guidelines.

5. Review comments

5.1 Overview

The following sections provide comments on each of the key risk components of the risk assessment presented in WSP (2023b), including hazard assessment, likelihood, spatial probability, temporal probability and vulnerability. We have also provided comments on the methodology used to estimate risks to loss of life for road users. It is important to note that we have only provided comments on key aspects of the report that have a significant impact on the outcome of the risk assessment.

5.2 Hazard assessment

The hazard assessment presented in WSP (2023a and 2023b) has attempted to identify individual (i.e. unique) hazard features (128 unique hazards are stated to have been identified by WSP). While this approach is suitable and achievable for small sites such as a small road cutting where there are a limited number of hazards that are readily observable from road level, this approach is rarely used for large escarpment scale sites such as Wolgan Road. The identification of 'unique' hazard features, each with an associated likelihood, implies a level of precision and thoroughness that is unrealistic.

Wolgan Road traverses a Sydney Basin escarpment very typical of the western Blue Mountains region, comprising a prominent upper cliff-line formed in the Triassic-aged Narrabeen Group of rocks, while the lower elevation portions of the road are underlain by the Illawarra Coal Measures. Extensive talus slopes are located below the cliffs that extend most of the way to the valley floor below. The talus slopes are densely vegetated by established forest and are practically inaccessible. In remote terrain such as this, identifying unique hazard features is essentially impossible due to the vastness of the site, vegetation cover and access conditions. This problem is further illustrated by the hazard plans provided in WSP (2023a and 2023b). The plans show that the majority of 'unique' hazards are mapped on the upslope areas, directly adjacent to the road, presumably because these areas were readily observable and may have experienced recent instability. The majority of the other 'unique' hazards are shown to be located on the upper cliff-line, presumably because these areas were also readily observable either from the road or via remotely piloted aircraft (drone).

We note that no 'unique' hazards have been mapped on the vast talus slopes located between the cliff-line and the road. The lidar imagery shows these slopes to be littered with numerous large talus blocks and scarps associated with previous debris flows. Again, these features are typical of Sydney Basin escarpments, however no 'unique' hazards have been identified. This issue further highlights the futility of attempting to identify unique, specific hazards across an escarpment of this scale. Landscapes such as these are dynamic and constantly evolving due to natural weathering processes resulting in mass wasting events such as rockfalls and landslides, which ultimately leads to the retreat of cliffs and development of talus slopes. In landscapes such as these the number of 'unique' hazards is essentially infinite. We note an attempt to include these hazards in the risk assessment as 'general hazards' was undertaken. This is discussed further in Section 5.7.

In circumstances with large escarpment scale sites with many hazards, AGS (2007c) recommends developing a geotechnical model, identifying geomorphic processes and associated process rates. Section 5.2.5 of AGS (2007c) states that hazard analysis for a risk assessment should comprise preparation of cross section drawings (to scale) through selected parts of the site to demonstrate the geotechnical model of site conditions and on which landslides may be identified. Section 5.2.6 of AGS (2007c) recommends practitioners:

> "*Take into account slope forming process rates associated with the geotechnical model and landslides"*

and that:

> *"An understanding of the slope forming process relevant to the landslides and associated process rate is fundamental for evaluation of likelihood"*.

These tasks are not presented in either WSP (2023a) or WSP (2023b); there are no interpretive cross sections, no discussion on process rates or overall presentation of a geological model for the site. An example of an interpretive cross section prepared for the now iconic Sea Cliff Bridge along Lawrence Hargrave Drive is presented in Figure 9 showing process rates associated with different geological units.

The absence of these important elements appears to have led to subsequent issues with the estimation of appropriate likelihood values for hazards, which is discussed further in Section 5.3.

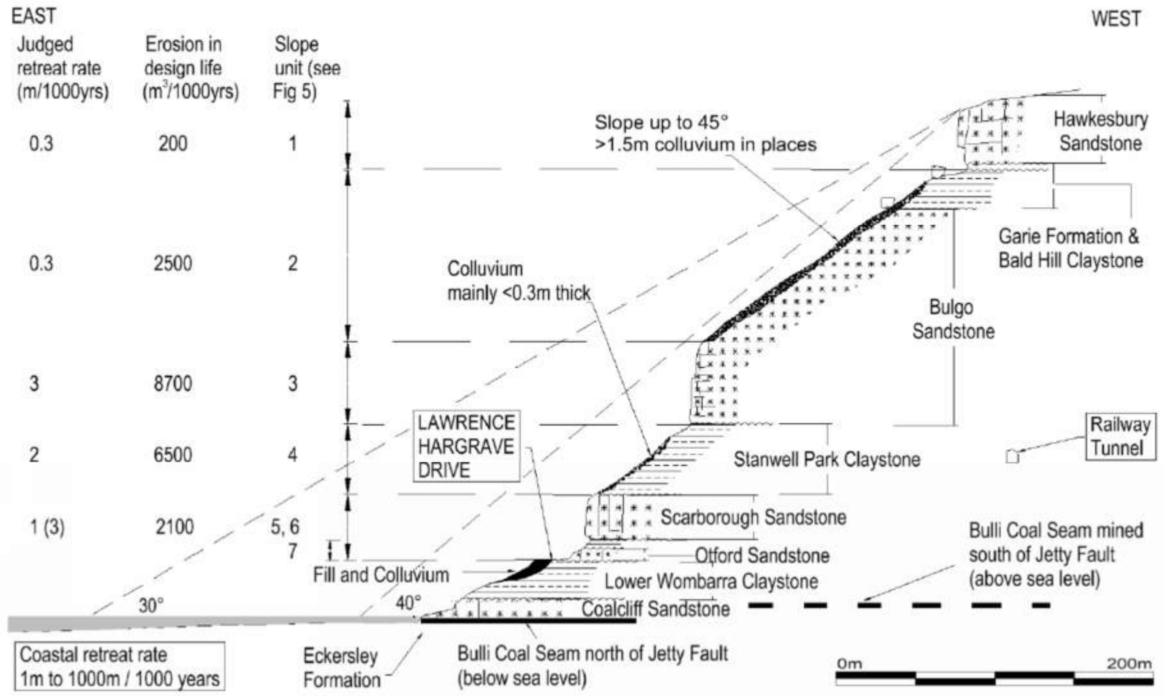

Figure 9 ***Example of cross section of coastal escarpment at Lawrence Hargrave Drive (Sea Cliff Bridge) showing slope units and slope retreat rates (Moon, Wilson, & Flentje, 2005).***

5.3 Likelihood ($P_{(H)}$ annual probability of the landslide)

WSP (2023b) states the:

> "*Adopted probability of rockfall values have been based upon Council's inventory of rockfall events (Golder 2021a). For large rockfalls the following $P_{(H)}$ and diameter value has been adopted, (i.e. in the High hazard descriptor category in Table 5 of AGS 2007a).*"

The inventory data is not presented in the reports provided to GHD. It should also be noted that that the method used to adopt a likelihood for large rockfalls using the qualitative descriptions in Table 5 of AGS (2007a) is not in accordance with the recommendations of AGS (2007c). The purpose of Table 5 in AGS (2007a) is to provide guidance on qualitative terms that can be used for hazard zoning once likelihood has been estimated. This table should not be used to determine likelihood.

Section 5.4 of AGS (2007c) provides guidance to practitioners for the assessment of likelihood. These methods should have been followed, rather than the method used by WSP.

Furthermore WSP (2023b) states that the following likelihood values were adopted:

- Large rockfall H1.1.2 (3 m diameter adopted for calculations), $P_{(H)}$ = 0.4 per km per annum.
- Small rockfall H1.1.1 (0.5 m diameter adopted for calculations), $P_{(H)}$ = 4 per km per annum.

Given that the road was closed in November 2022 (about 2.5 years ago), the current road conditions provide an important insight into rockfall frequencies because as far as we are aware, since the initial clean up, no maintenance or clearing of rockfall debris from the road has been carried out. According to the WSP rockfall likelihood values above, on average at least two large (i.e. 3 m diameter) rockfalls and twenty small (0.5 m diameter) rockfalls should have reached the 2.7 km long section of road. During our site visit no rocks of either size were observed. The largest rockfalls observed on the road comprised gravel sized fragments of rock (up to about 40 mm diameter) below the section of road that traverses near-vertical cliffs at the top of the pass (Figure 1). No other rockfalls were observed on the road for the remainder of the approximately 1.8 km section of road.

As discussed in Section 5.2, an understanding of the slope forming process relevant to the landslides and associated process rate is fundamental for evaluation of likelihood. The report has allocated specific likelihood values to each of the individual 128 hazard features. The values are typically 'order of magnitude' likelihoods (i.e. 1, 0.1, 0.01, 0.001 etc.). This implies unrealistic precision and knowledge of each individual feature. WSP (2023b) has also considered 'general' hazards, apparently to account for hazards that were not specifically identified. It states:

> *"there remains the potential for slope movement consistent with those hazard types to occur elsewhere along the length of Wolgan Road assessed".*

These hazards appear to have been given likelihoods that are not 'order of magnitudes' (e.g. 0.0128) and may be based on an inventory, however this is not explained. The result of this is effectively doubling the potential number of hazards that could reach or effect the road because two different likelihood estimation approaches have been used in tandem.

As discussed in Section 5.2, 'escarpment scale' sites such as Wolgan Road typically require an understanding of process rates to assess likelihood because it is unrealistic to identify every possible hazard, and it is equally unrealistic to assign each hazard with a likelihood. Development of process rate models (Figure 10) overcome these challenges; but they require a good understanding of the geological model, geomorphology and slope forming processes and usually historical data such as a landslide inventory. The development of a process rate model allows for a more holistic approach to risk assessment because the frequency of landsliding is intrinsically linked to the process rate. Process rate models can be used to support judgements about what might happen which go beyond the limitations of the historical record (Moon, Wilson, & Flentje, 2005). Hazards can then be assigned likelihoods based on geological processes and past history, rather than the 'unique' hazard approach adopted by WSP.

There is a clear discrepancy (i.e. 'mismatch') between the postulated WSP likelihood values and expected rates of cliff retreat for site escarpment at the site. Numerous upslope debris flow hazards have been assigned likelihood values of 1, implying these events are expected to occur annually. This is almost inconceivable because the rates of cliff erosion are too slow to supply this quantity of debris to the talus slopes. Furthermore, this frequency of landsliding would likely require a cliff regression rate significantly higher than any of the rates of cliff retreat published for NSW by Flentje (2012). To add to this, the upper cliffs observed during our site visit did not exhibit obvious rockfall 'scars' that would be needed to support these process rates. Instead, the cliff exhibited the characteristic, case-hardened patina, typical of a Sydney Basin escapement associated with infrequent, episodic rockfall events.

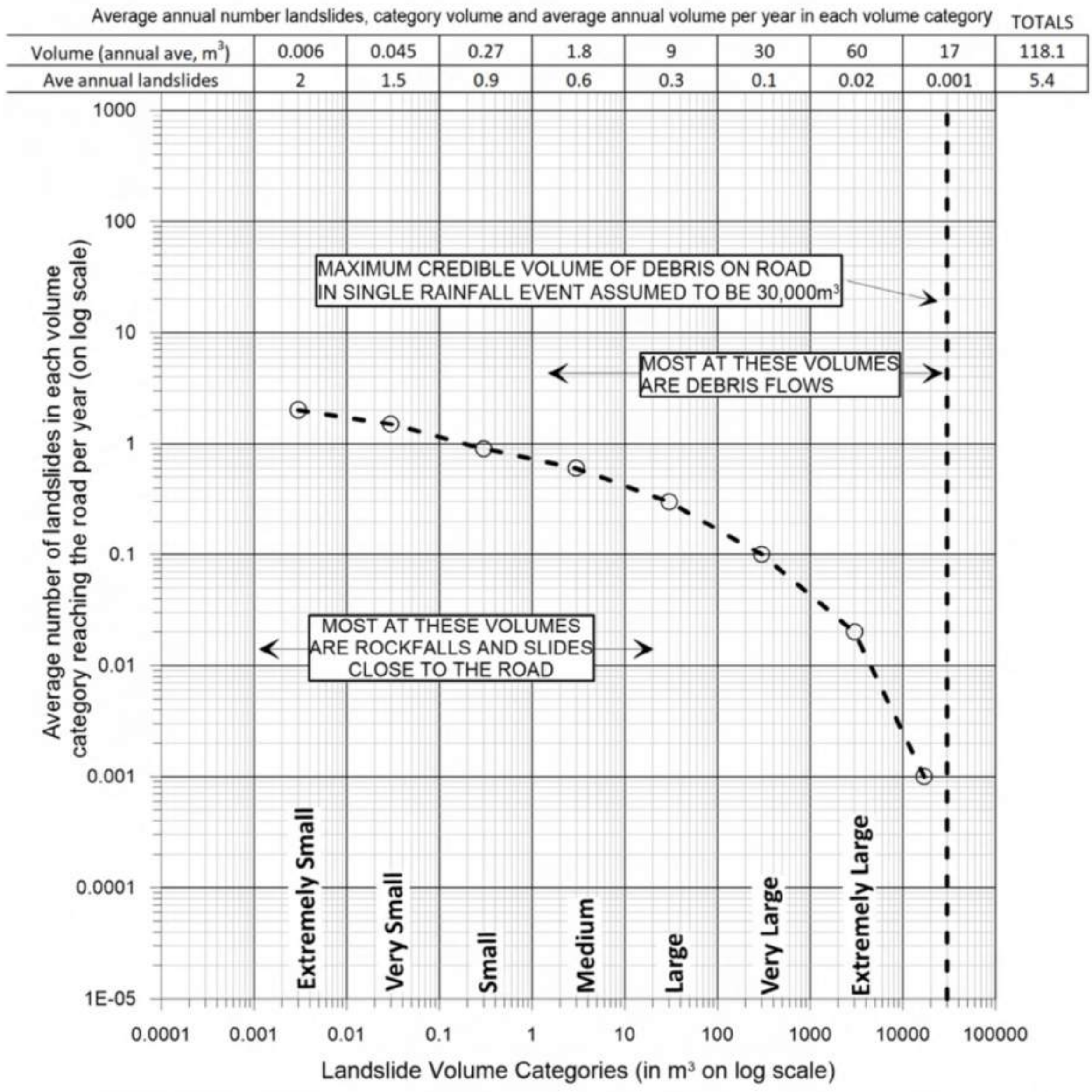

Figure 10 ***Example of process rate model used to assess landslide risk for Princes Highway, NSW (Hunter, Flentje, & Moon, 2022).***

5.4 Probability of spatial impact ($P_{(S:H)}$)

The probability of spatial impact is the probability of a landslide or rockfall impacting or affecting the element at risk (in this instance, Wolgan Road), taking into account the travel distance and travel direction given the event. WSP (2023b) states:

> *"As the rockfall inventory has only recorded events which have impacted the road a $P_{(S:H)}$ value of 1 has been applied in conjunction with $P_{(H)}$ values for rockfall above."*

This approach would be reasonable if the risk assessment was relying solely on an inventory approach, however as discussed is Section 5.3, two different likelihood estimation approaches have been used in tandem. In relation to the unique hazard features WSP (2023b) states:

> *"Probability of landslide (i.e. $P_{(H)}$) and spatial impact (i.e. $P_{(S:H)}$) values for all other slope hazards as defined in Section 2.1 than rockfall have been adopted based on engineering geological judgement, our current understanding of the instability mechanisms and our observations of the performance of the slopes above and below Wolgan Road."*

The majority of $P_{(S:H)}$ values used in the WSP assessment are either 1 or 0.5, implying it is certain or about a 50% chance of rockfalls reaching the road. For a project of this significance, where risk assessments have been used to justify closure of a road, more sophisticated rockfall modelling would typically be used to help inform spatial probability (i.e. rockfall runout). Modelling software is readily available and widely used including both two-dimensional and three-dimensional software packages.

Studies by Field and Hunter (2024) of rockfall behaviour on a very similar Sydney Basin escarpments above a road owned by Transport for NSW showed the rockfall runout probability decreases significantly with increasing distance from the cliff (Figure 11). This study also demonstrated that topographical features such as gullies funnel and confine rockfall debris downslope into narrow paths, increasing runout probability compared to more open areas of adjacent slope. More confined gullies can have the opposite effect by 'trapping' rockfalls amongst other rockfall debris. This phenomenon is typical of almost all talus slopes in the Sydney Basin and is evident in the lidar imagery for Wolgan Valley. The lidar shows the highest concentrations of rockfall debris are situated on the upper slopes below the cliff-line, with the concentration of rockfall debris decreasing in the downslope direction. As Wolgan Road descends the escarpment, the alignment becomes increasing further away from the cliff-line, which will result in progressive reduction of $P_{(S:H)}$ values the further the road gets from the escarpment.

The $P_{(S:H)}$ values used in the WSP assessment do not appear to be based on modelling or empirical methods and do not reflect the distribution expected for the topographic variations across the length of the escarpment. For example, the higher values of 1 and 0.5 may be reasonable for the upper sections of the road where the road is in very close proximity to the cliff, however these values are likely to be significantly too high for lower sections of the road.

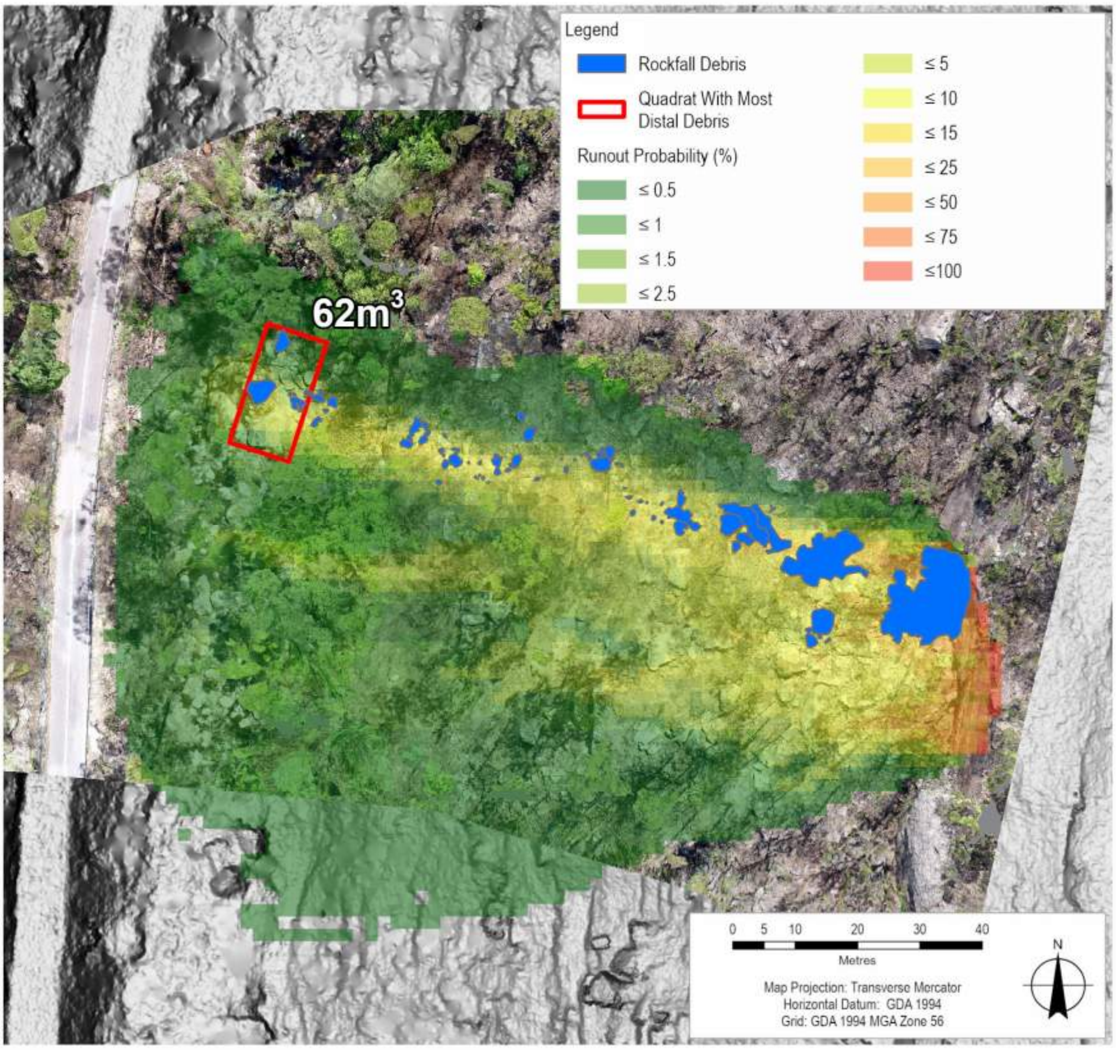

Figure 11 ***Example of rockfall runout distribution on steep talus slope above a main road in NSW (Field & Hunter, 2024).***

5.5 Temporal probability ($P_{(T:S)}$)

The temporal probability $P_{(T:S)}$ is the probability that the element at risk will be present when a landslide occurs. This is estimated based on the amount of time that the element at risk is anticipated to be located on the portion of the road that would be affected by each hazard.

WSP (2023b) indicates that the temporal probability has been calculated based on an anticipated vehicular speed of 40 km/hr and the estimated widths (along the slope) that would be affected by each hazard. The estimated widths are set out in Table B2 of Appendix B of the report.

Section 2.3.1 of the report states that:

> *"The [person most at risk] has been assumed to be a road user who traverses the road on average 2 times per day (i.e. one return trip), every day of the year."*

In other words, the person most at risk is anticipated to undertake 730 passes of each hazard site per year, on average. This is not incorporated into the temporal probabilities presented in Table B2. Instead, the calculated temporal probabilities are presented on a "one pass" basis, with the number of traverses incorporated into the risk estimation process at a later stage. This is slightly unusual, as Section 6.2 of AGS (2007c) suggests that temporal probability for mobile elements should represent the total time *per year* that elements will be in the area affected by the landslide. However as long as the number of traverses are incorporated later in the process (and this appears to be the case) it would not be expected to affect the final estimated risk.

5.6 Vulnerability ($V_{(D:T)}$)

Vulnerability refers to the degree of loss to a given element or set of elements within the area affected by a hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss) (Fell et al, 2005). For persons, vulnerability is the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

The vulnerability assessments WSP (2023b) appear to be based on a hazard directly impacting a moving vehicle, not a moving vehicle impacting the hazard.

WSP (2023b) makes the following assumptions for vulnerability:

- *"Vulnerability (i.e. $V_{(D:T)}$)value of 0.3 has been adopted for hazards H1.1.1 (small rockfall), H2.3 (Upslope Debris Flow/Slide General), H3.3 (Downslope Debris Flow/Slide General) (H1.1.1) and selected specific hazards as shown in Table B2."*
- *"Vulnerability (i.e. $V_{(D:T)}$) value of 0.9 has been adopted for all other hazards."*

We are in agreement that the adopted vulnerability of 0.3 is reasonable for small rockfalls and a value of 0.9 is reasonable for large rockfalls. However, as mentioned above WSP have adopted a vulnerability of 0.9 for a large proportion of other hazards, implying there is a 90% chance of death should the hazard affect the element at risk (i.e. person in a vehicle). In many instances we find this value to be too conservative. While we have not given an opinion on each scenario, some examples with case histories are provided below.

For 'downslope' hazards that involve loss of a section the road (described as retention elements, culverts and debris flows in WSP 2023b), a vulnerability of 0.9 has commonly been adopted. We consider this to be significantly too high for a vehicle travelling at low speed (40 km/hr) traversing a developing failure or driving into a void after the failure has occurred. For example, the Transport for NSW (TfNSW) Guide to Slope Risk Analysis (TfNSW, 2012) publishes a range of recommended vulnerability ranges for different hazard scenarios on roads (Figure 12). At low speeds (<50 km/hr), the TfNSW guide states that a rating of V3 must be used. As is illustrated in Figure 12, a rating of V3 corresponds to a vulnerability range of 0.01 to 0.1. This is 9 to 90 times lower than the value generally adopted by WSP for downslope hazards.

Rating	Probability Range	Definition
V1	> 0.5	Person in the open unable to evade rockfall or other debris (movement very/extremely rapid), or buried, or engulfed in a building collapse. Vehicle impacting a block > 1 m high or lost into a deep, narrow void at highway speeds.
V2	0.1 – 0.5	Partial building collapse. Person in open may be able to evade debris. Vehicle impacting a 0.5 – 1 m high block at highway speeds or a block > 1 m high at urban speeds or lost into a shallow void.
V3	0.01 – 0.1	Building penetrated, no collapse. Emergency evacuation possible. Most people in open able to evade debris. Vehicle impacting a 0.5 – 1 m high block at urban speeds, or a block > 1 m high at low speeds. Vehicle impacting loose or wet mixed soil/rock debris (or crossing a stepped surface with c 0.1 – 0.2 m steps caused by a developing embankment failure) at highway speeds.
V4	0.001 – 0.01	Building struck, damaged but not penetrated. Vehicle impacting a block around 0.2 m high at highway speeds or a 0.5 – 1 m high block at low speeds. Vehicle impacting loose or wet mixed soil/rock debris (or crossing a stepped surface with c 0.1 – 0.2 m steps caused by a developing embankment failure) at urban speeds. Vehicle interacting with a shallow void/depression where the guardfence may prevent a vehicle from leaving the road.
V5	< 0.001	Building struck, only minor damage etc. Vehicle impacting a block around 0.2 m high at urban speeds or a smaller block at highway speeds. Vehicle impacting loose or wet mixed soil/rock debris at low speeds. Vehicle traversing an irregular surface formed by soil or small (< 100 mm min dimension) rock, or by a developing embankment failure, at highway speeds.

Figure 12 Recommended vulnerability ratings provided in the TfNSW Guide to Slope Risk Analysis (TfNSW, 2012).

WSP (2023b) also allocates a vulnerability of 0.9 to the majority of the 'unique' upslope debris flow hazards. The TfNSW Guide to Slope Risk Analysis (TfNSW, 2012) does not provide a vulnerability recommendation for this specific scenario, rather it provides guidance for a vehicle impacting debris already on the road.

Given the low vehicle speeds, our project experience with vehicle accidents associated with direct impacts from landslides suggests a value of 0.9 is also too high. For example, on 17 August 1998, the Princes Highway near Wollongong was affected by more than 30 of debris flows and numerous rock falls along a section of the highway at Bulli Pass. The landsliding was initiated by an extreme rainfall event, resulting in debris flow landslides flowing down the escarpment slopes and across the road. Approximately 15 cars were trapped amongst the debris, with some cars becoming partially inundated up to bonnet level (Figure 13). People were forced to flee their vehicles in an attempt to escape the debris. One car was swept over the downslope embankment by a debris flow. Despite these hazards, there were no fatalities.

Figure 13 Vehicle partially inundated by debris flow on Princes Highway, Bulli Pass - 18 August 1998.

In 2009, an elderly driver was driving along Riverside Drive in Nambucca Heads, NSW when the vehicle was directly impacted by a large landslide originating from a steep hillside above the road (Figure 14). The vehicle was rolled over and came to rest on a riverbank. Despite the drivers advanced age, they were able to climb out of the vehicle without injury.

Figure 14 Landslide in Nambucca Heads that directly impacted a vehicle in 2009.

Both the abovementioned examples involved roads with similar or higher speed limits than Wolgan Road. Whilst the absence of deaths or injuries from either of these landslide events does not amount to an exhaustive study it does highlight the considerable uncertainty associated with vulnerability.

5.7 Risk calculations and risk evaluation

5.7.1 Risk of loss of life - individual

Table B2 of Appendix B of WSP (2023b) presents the estimated risks of loss of life for the person most at risk from each specific hazard identified during the investigation as well as ‘general’ hazards, which appears to be an attempt to estimate the total risk from other, similar hazards that were not specifically identified during the investigation. The risks are presented on a “one pass” basis – in other words, the risk of loss of life from one traverse through the area affected by the hazard(s). These risks are generally very low, ranging from approximately $2x10^{-7}$ to $4x10^{-13}$. All of these calculated risks are significantly lower than the AGS (2007c) suggested tolerable loss of life risk criteria for the person most at risk of 10^{-5} per annum. However, this is not acknowledged in the report. It is our experience that many asset owners / operators would likely choose to accept risks of this magnitude.

Section 2.3.2 of the report presents the results of loss of per annum life risk calculations from the landslide hazards identified during the investigation. It then goes on to present additional risk calculations for subsets of hazards based on whether they have been designated as Category 1, 2 or 3 hazards. Lists of the hazards included in these subsets are presented in Tables B3 to B5.

The calculated per annum risk of loss of life for the person most at risk from **all hazards** is reported as $2x10^{-3}$. This reported risk is unusually high, especially given the very low traffic volume (114 vehicles per day). As reported in WSP (2023b), it is 200 times higher than the tolerability threshold suggested in AGS (2007c) for existing landslide areas. In situations such as this, logic suggests that intense scrutiny should be applied to the risk methodology because the very short exposure periods of mobile elements at risk (i.e. vehicles) typically result in tolerable risks, even when landslides are relatively frequent.

The methodology used to calculate the per annum risks in Section 2.3.2, from all of the specific “one pass” risks presented in Table B2 is not provided in WSP (2023b). We were able to reproduce comparable overall risk of loss of life results from the WSP “one pass” individual risks using the following two methodologies:

1. Summing all of the “one pass” risks and then multiplying this by the number of annual traverses of the person most at risk (estimated by WSP to be 730 passes).
2. Approximating the probability of the person most at risk being impacted by one of the identified hazards by calculating the probability that none of hazards impact the person, and then subtracting this from 1. While not referenced in WSP (2023b), an example of this approach is provided by the New South Wales National Parks and Wildlife Service in their “Guidelines for Quantitative Risk to Life Calculations for Landslides” (NPWS, 2023) as follows:

$$R_{(LoLC)} = 1\ 1\ [(1 - R_{(LoL1)}) \text{ x } (1 - R_{(LoL2)}) \text{ x } (1 - R_{(LoL3)}) \text{ x } (1 - R_{(LoL4)}) \ldots\ldots (1 - R_{(LoLx)})] \qquad (2)$$

Where:

$R_{(LoLC)}$ is the combined risk of loss of life to the individual from multiple hazards.

$R_{(LoL1)}$ is the risk of loss of life from hazard 1.

If method 1 is consistent with WSP’s approach, it raises questions regarding the validity of the risk assessment. Mathematically, when individual probabilities are summed (i.e. added together) in this manner, the result is a number (i.e. an index) that is no longer a probability. This is sometimes referred to as “total risk”. However, as these numbers are not probabilities, they cannot be assessed against the tolerability criteria that are provided in AGS (2007c).

More importantly however, is that for both of the methods outlined above, when risks for individual hazards remain in a consistent range, there is a positive relationship between the total number of individual hazards incorporated into the assessment and the overall risk. In other words, the more hazards that are mapped / identified, the higher the overall risk for the site becomes. This is particularly problematic for method 1, where if the number of individual hazards is high enough, the final estimated risk can actually exceed 1. Using an inventory-based approach for the site would eliminate this issue.

5.7.2 Risk of loss of life - societal

No details on the methodology that has been used for calculating societal risk have been provided in WSP (2023b). However, it is noted that for Category 1, 2 or 3 hazards the calculated risk of one or more fatalities is $1x10^{-1}$. In other words, on average, an event that causes 1 or more fatalities is expected to occur every ten years. Considering the very low traffic volumes, we find it difficult to comprehend how the risks could be this high. Prior to its closure in 2022 the road had been in operation along this alignment for several decades and to our knowledge, no landslide or rockfall related fatalities have occurred to date. Assuming the road has been open for 100 years, then on average about 10 people should have been killed.

It is indicated in Section 2.3.1 of WSP (2023b) that the Council-supplied count for Wolgan Road is 114 vehicles per day, or 41,610 per annum. AGS (2007c) states: that societal risk is typically only considered for situations where there is a potential for large numbers of lives to be lost in a single landslide event, such as buildings with high numbers of occupants (e.g. schools, hospitals, hotels or motels), or areas where large numbers of people may be gathered (e.g. lookout platforms). Based on the assumed daily vehicle volumes, this is considered unlikely and therefore it is questionable whether societal risk criteria should be considered for the road at all.

5.7.3 Risk to property

WSP (2023b) presents a risk to property assessment for the road using the AGS (2007) methodology. The report states:

> *"Property risk represents a loss of value risk and does not reflect actual costs to re-instate property damaged or lost which would include investigation, design and remediation costs."*

The risk to property methodology in AGS (2007c) was primarily designed for residential purposes (i.e. houses), although it can be applied more broadly. The methodology requires an estimate of the annual loss of property value and approximate costs of damage to the property as a proportion of the property value. WSP adopted an asset value of $20 million dollars for the 2.7 km length of Wolgan Road. Assuming this value is based on a like-for-like replacement of the existing road, we find this unrealistic. Applying value to the road based on like-for-like replacement potentially ignores the intrinsic value of the road to the community as well as other intangible aspects of the road such as heritage and cultural values.

The report then considered certain hazards resulting in a 'loss of value' for the road such as:

- Clean up works associated with rockfalls and debris flows
- Pavement repairs
- Roadside barrier replacement
- Culvert / drainage repairs

While a number of different scenarios were presented in WSP (2023b), the calculated annual property risk for 'Category 1, 2 and 3 Hazards' (i.e. loss of value risk) is $6.2 million p.a., representing an annual loss of value risk of approximately 30% of the assumed value of the asset, per year. Based on this percentage the risk to property was assessed to be 'very high'. We have not reviewed the cost estimates in WSP (2023b) that the calculations are based on. However, we find it somewhat unusual and potentially misleading that the risk to property assessment has been applied in this manner. Road maintenance costs are an essential part of maintaining all roads, and it is likely that many council and state-owned roads would be rated as 'very high risk' if the methodology was applied in this way.

The TfNSW Guide to Slope Risk Analysis (TfNSW, 2012) consequence rating methodology is concerned with repair time and costs required to reinstate roads that have suffered a significant impairment of function as a result of a landslide. All other repairs and maintenance costs are not considered.

Finally, it is also important to recognise that the majority of the hazards described in WSP (2023b) that have caused damage to the road, or may do so in future, are located in 'WSP Domain 1'. This portion of the road is approximately 750 m in length (i.e. approximately 27% of the total site length). Using the AGS (2007c) qualitative methodology, this would be described as 'minor' to 'medium' consequence, resulting in a risk level of 'high' to 'moderate'.

Given the issues and subjectivity discussed above, we don't consider a risk to property assessment is appropriate for this situation.

5.8 Comparison with TfNSW Risk Methodology

We have carried out a preliminary risk assessment using the TfNSW Guide to Slope Risk Analysis (TfNSW, 2012) for comparison purposes. The slope risk analysis has considered the typical hazards and likelihood values discussed in WSP (2023b). A summary of the various input ratings and Assessed Risk Levels (ARL) are presented in Table 1. This assessment has only considered consequences for loss of life and has not considered consequences for damage to property and consequential effects. A traffic volume 114 vehicles per day corresponds to a temporal probability rating of T4.

Table 1 Preliminary TfNSW Risk Assessment (based on likelihood values and hazard descriptions from WSP 2023b)

Hazard	Likelihood (L)	Temporal Probability (T)	Vulnerability (V)	Consequence (C)	Assessed Risk Level (ARL)
Small Rockfall	L1	T4	V4	C4	ARL2
Large Rockfall	L2	T4	V3	C4	ARL3
Upslope Debris Flow	L2	T4	V5	C5	ARL4
Downslope road failure (debris flow / culvert / retaining wall failures)	L2	T4	V3	C4	ARL3
'Rock Topple'	L3	T4	V4	C4	ARL4

1. The terms and abbreviations used in the above table are in accordance with those outlined in 'The TfNSW Guide to Slope Risk Analysis, Version 4 (TfNSW, 2012)

Managing authorities such as TfNSW and councils typically accept risk levels that are ARL3 or lower risk (i.e. ARL4 and ARL5). However, in some circumstances managing authorities recognise it is not feasible or financially viable to reduce risks to acceptable levels due to the costs of reducing risks to tolerable levels and/or competing funding priorities. We are aware of many instances where TfNSW and other road authorities will tolerate ARL1 and ARL2 sites for decades or even indefinitely.

Is it also noteworthy that the TfNSW system does not have a process for combining hazards, instead the system prioritises management of slopes based on their individual ratings. Similarly, the TfNSW doesn't combine risks from multiple sites along a length of road (i.e. sites are typically less than about 500 m in length). This approach prevents issues such as those discussed in Section 5.7.1 where overall risk increases as more individual hazards are incorporated into the total journey. If an individual hazard approach like this was to be undertaken everywhere (i.e. a "journey rating") many more roads in Australia would eventually be unacceptable simply due to the fact if a vehicle travelled far enough, it would encounter enough hazards to exceed the threshold of risk tolerability or acceptability. This is particularly important to consider in the context of Wolgan Road.

5.9 Discussion

We understand that the escarpment at the site was affected by bushfires in 2019. This was followed by a few years of above rainfall periods, particularly in 2020 and 2022. It is well established that there is a highly likelihood of landslides and rockfalls in the years following a bushfire because of increased runoff caused by the loss of topsoil and beneficial vegetation. These circumstances were not unique to Wolgan Road, with many roads in NSW experiencing similar geotechnical problems over this period. We acknowledge that following events associated with intense rainfall events it is possible to overestimate the frequency of landsliding due to the quantum of road damage observed in a single event. The regrowth of vegetation over the last few years and apparent absence of events since the road closure suggests the likelihood values adopted need to be reviewed.

It is also important to recognise that the majority of the hazards described by WSP to have caused damage to the road are located along the upper section of the road (‘WSP Domain 1’), which is approximately 750 m in length (i.e. approximately 27% of the total site length). WSP (2023a) and WSP (2023b) give the impression that the entirely of the 2.7 km section of the road is in a poor state of repair with extensive exposure to hazards. In contrast, the remaining section of road (‘WSP Domain 2’) appears to be in generally good condition, noting however that the pavement and some of the base layers have been removed in several places along this section of road to supply material to upgrade the Donkey Steps track. We recognise there have been several upslope batter slides along this section of the road however such hazards are to be expected on old, steep mountain pass roads. Similar failures occur relatively regularly on comparable roads across NSW.

GHD have highlighted issues with the approach taken by WSP to uniquely identify individual hazard features and subsequently assign probabilities to each feature. This method largely ignores geological processes such as process rates and implies a level of precision and thoroughness that is unrealistic. Despite our concerns with this approach all of the calculated risks for each ‘unique’ hazard are significantly lower than the AGS (2007c) suggested tolerable loss of life risk criteria for the person most at risk of 10^{-5} per annum. However, this is not acknowledged in the report.

WSP (2023a) and WSP (2023b) do not go into detail on what ‘tolerable’ risks mean. For example, AGS (2007d) states that:

> *“there are no internationally accepted risk criteria for landsliding. It is necessary therefore to develop tolerable loss of life criteria for each situation, taking account of the legal framework of the country and regulatory controls in place”.*

Furthermore, WSP (2023a) and WSP (2023b) do not discuss the “ALARP” principle (“as low as reasonably practicable”). This is an important risk concept discussed in AGS (2007), which states that in many cases reduction to acceptable levels is not viable in the context of the cost to the individual or community, and that instead, in the interest of keeping the asset available to stakeholders / the community, it may be pragmatic to apply the ALARP principle to reduce risks to some lower level, but above the levels suggested by the guideline. It is unclear why the ALARP principle was not discussed or why Wolgan Road was not compared with other NSW roads with similar issues.

In terms of geology and associated slope hazards and risks, Wolgan Road is not unique. There are many roads both in the Sydney Basin and in other locations across NSW that traverse steep escarpments and exhibit similar or higher frequencies of landsliding. In some of these instances, reducing risks to tolerable or acceptable levels is unviable. However, the road(s) remain open with the ALARP principle applied. These roads typically have significantly higher traffic volumes than Wolgan Road and have been subject to various levels of risk mitigation works. A summary of some of these roads we are aware of is provided below:

- Putty Road (Wilberforce to Singleton)
- Harry Graham Drive (Mt Kembla)
- Wisemans Ferry Road (Mangrove Mountain to Wisemans Ferry)
- Kempsey to Armidale Road (Wollomombi to Kempsey)
- River Road (Wisemans Ferry to Sackville)
- Old Grafton Road (Glen Innes to Grafton)
- Wombeyan Caves Road (Wombeyan Caves)
- Bells Line of Road (Richmond to Lithgow)
- Cunningham Highway at Cunninghams Gap (QLD)

6. Recommendations

In the interest of improving access for the residents, business owners and other visitors to the Wolgan Valley, particularly those that do not own a four-wheel drive, or are unable to travel along the Donkey Steps, we recommend the following steps be undertaken:

- A comprehensive revision of the landslide risk assessment for Wolgan Road. It is recommended that this revision incorporate:
- Consideration of the role geological processes play in the evolution of the escarpment and the development of slope hazards. This will require development of a geological model and interpretive cross sections.
- Undertake a new risk assessment using alternative approaches that are more appropriate for the scale of the escarpment and the nature of the hazards. Published examples of hazard and risk assessments for large escarpments above major roads in NSW include the now famous Sea Cliff Bridge along Lawrence Hargrave Drive in the northern suburbs of Wollongong (see Moon, Wilson and Flentje 2005, Hendrickx et al. 2005 and Wilson et al. 2005) and the Princes Highway at Bulli Pass (see Hunter, Flentje and Moon 2022). Other examples are provided in Lee and Jones (2023). These approaches typically require development of landslide volume frequency models (process rate models) using all available information including, but not limited to; Council’s landslide inventory, survey information and historical records such as newspaper articles, local historical accounts, council records and other historical information.
- 3D and 2D runout modelling to assess the variations in probability of spatial impact along the road alignment.
- Revaluation of vulnerability values adopted for persons in vehicles impacted by and driving over landslides.
- Re-assessment of risk to loss of life of the person(s) most at risk in accordance with AGS (2007) guidelines. This will allow for risks to be evaluated against the recommended AGS (2007c) risk criteria.
- Development of a short-term management plan to re-open the existing Wolgan Road on a limited / restricted basis.
- Development of possible concept options for long-term risk mitigation measures to allow permanent re-opening of Wolgan Road.
- Design and construction of a preferred option that provides a pragmatic level of risk reduction whilst maintaining value for money.

We would like to thank Council for the opportunity to undertake this review. We hope to work with you and your team and would be happy to discuss any of the content of this report. Should you wish to do so please do not hesitate to contact Andrew Hunter or Daniel Jones.

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