ALEXANDRA RANGE

GEOTECHNICAL RISK ASSESSMENT

PREPARED FOR

DOUGLAS SHIRE COUNCIL

Trinity Engineering and Consulting

design | consult | manage

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DOCUMENT CONTROL SHEET

Trinity Engineering and Consulting Cairns Office: 21-23 Sheridan Street Cairns QLD 4870 PO Box 7963 Cairns QLD 4870 Telephone (07) 4040 7111 www.trinityengineering.com.au	**Title:** **Alexandra Range – Geotechnical Risk Assessment** **Project Manager:** **Rudd Rankine** **Author:** **Rudd Rankine** **Client:** Douglas Shire Council **Client Contact:** **Michael Mathews** **Synopsis:** A report summarising the findings of a geotechnical risk assessment of the Alexandra Range

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1. INTRODUCTION

1.1 Background

The World Heritage Listed Daintree Rainforest is located approximately an hour drive North of Cairns. It covers an area of approximately 1200km^2 with more than 50km of ocean frontage. Cape Tribulation Road runs from the iconic Daintree River ferry crossing and connects to the Bloomfield Track – which starts approximately 10km south east of Wujal Wujal.

Cape Tribulation Road traverses Mount Alexandra, and is commonly referred to as the Alexandra Range. At its peak, the road reaches an elevation of approximately 200m. The Alexandra Range is the primary route to reach the highly regarded and environmentally significant tourist destinations at Cow Bay and Cape Tribulation.

1.2 Scope of the Assessment

The scope of the report is:

- To undertake a geotechnical inspection and review of the Alexandra Range sites;
- To identify a suitable risk assessment framework and methodology for assessing risk at each site;
- To undertake an evaluation of risk using the accepted methodology and framework for each site;
- To provide recommendations for further investigation, concept remediation work or actions for each site; and
- To provide a list of recommended actions for consideration and potential future operational and or capital works planning.

Whilst every effort has been made throughout the process to ensure that the information included in the assessments is accurate and relevant, there will inevitably be a requirement for the application of engineering judgement based on assumptions made. It is not practical or indeed financially viable to collect sufficient geotechnical information to confirm the assumptions made. It is for these reasons that TEC has approached the assessment on a semi-quantitative basis. The framework provided will allow for Council to progressively update the assessment with the inclusion of higher quality information, which may result from future investigations and work.

2. SITE DESCRIPTION

The geotechnical sites for this study have been described using the following standard classification methods:

- Geology;
- Topography;
- Climate;
- Geology;
- Geomorphology; and
- Structures.

2.1 REGIONAL CONDITIONS

2.1.1 Regional Geology

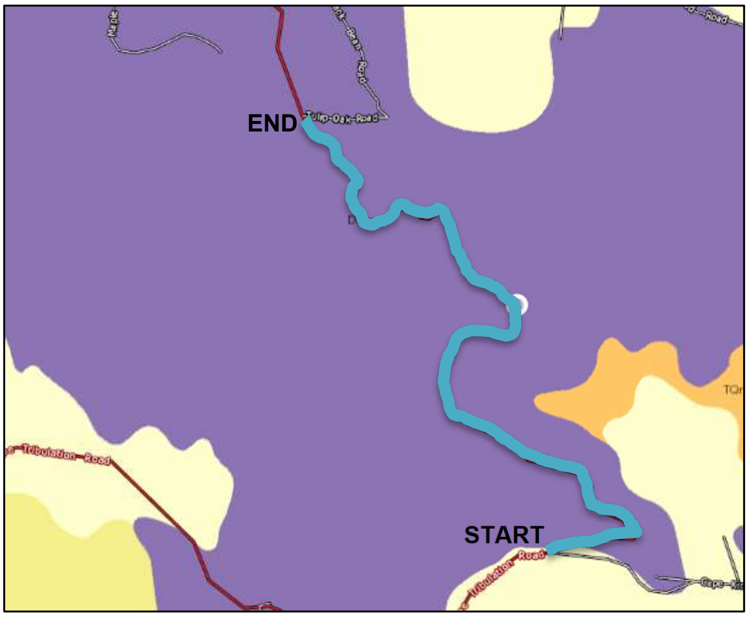

Figure 1: Regional Geology of the Alexandra Range

The points to note here are:

- The majority of site is a Hodgkinson formation (which is shown in purple).
    - Hodgkinson formation is characterised as mainly pale to dark or greenish grey, fine to medium-grained, medium to thick-bedded, quartz-intermediate arenite, rhythmically interbedded with siltstone and mudstone, minor conglomerate, conglomeratic arenite. Sparsely fossiliferous (Australian Stratigraphic units Database 1).
- The start of Alexandra Range is in the light-yellow section, which is Alluvium.
    - Alluvium is a dominantly sandy facies of alluvial plain deposits, which comprise of silt, clay, sand; minor gravel (Australian Stratigraphic units Database 2). It is noted that no sites are contained within this portion

2.1.2 Regional Topography

The major topographical features are shown in Figure 2 and include:

- The East-West Trending spur of the Great Dividing Range over which the Cape Tribulation Road traverses (Alexandra Range).
- Elevation of the road through this section varies from 20m AHD to 200m AHD
- There are constrained pockets of cleared vegetation to the North and South of the Range used for agricultural purposes.
- The Daintree River is located to the South of the Range, and is serviced by the Daintree ferry
- There are a number of Daintree settlements, both north and south of the Alexandra Range.
    - North – Cow Bay, Diwan, Cape Tribulation (Thornton Beach).

- South – Forest Creek and Kimberly.

Figure 2: Regional Topography

2.1.3 Regional Climate

The regional climate is characteristic of a tropical rainforest.

- The temperature typically varies between 26-32 degrees[1].
- Annual rainfall is approximately 4000-6000mm.
- The wet Season typically spans from November to April.
- Humidity during the Wet Season is significant and is typically upwards of 80%.

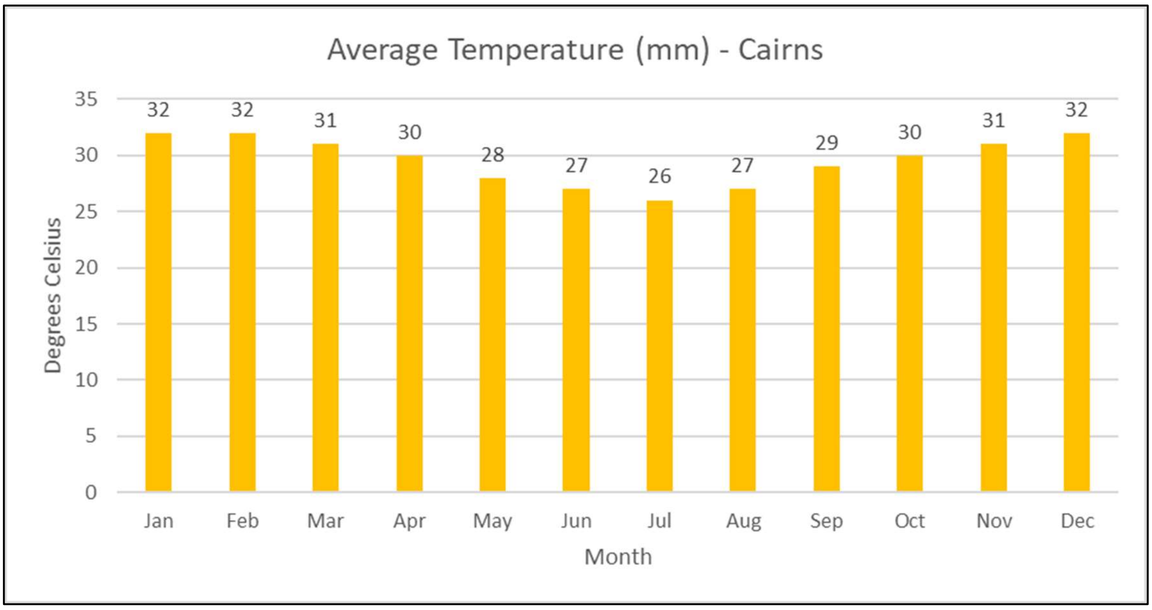

Figure 3: Regional Average Temperature

[1] https://www.daintree.com/daintree-weather.html

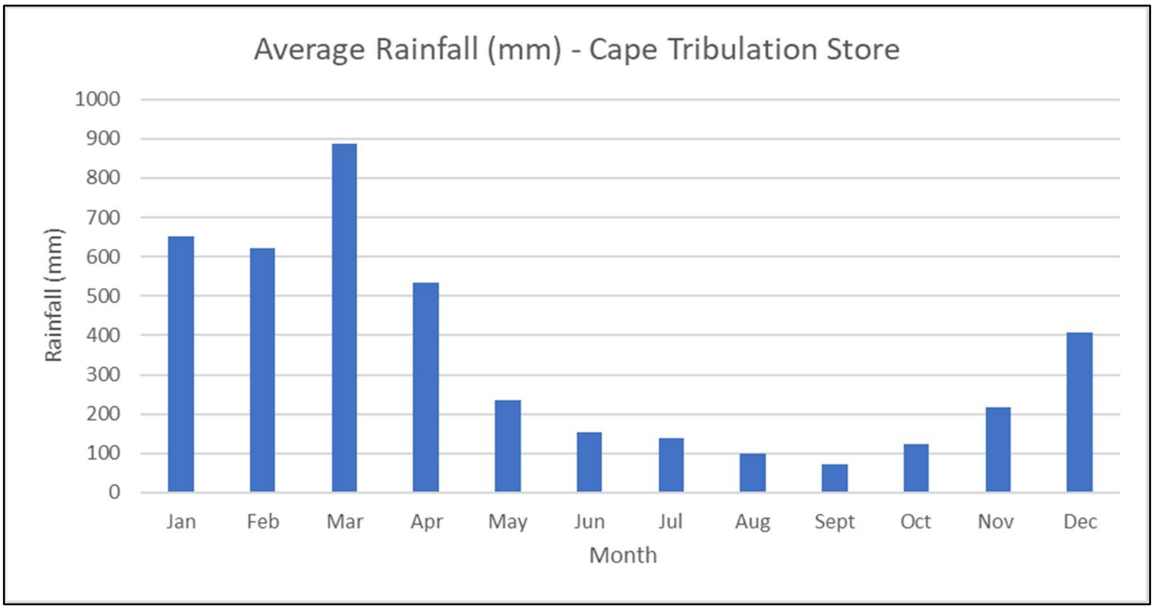

Figure 4: Regional Average Rainfall

2.2 SITE CONDITIONS

2.2.1 Soil Types

The Regional Mapping of soil types suggest all soils fall within the mapping of the LN2 block (Figure 5). The LN2 soil block is characterised by a uniform medium, smooth faced dense peds, high hills, mountains, and steep scarped margins.

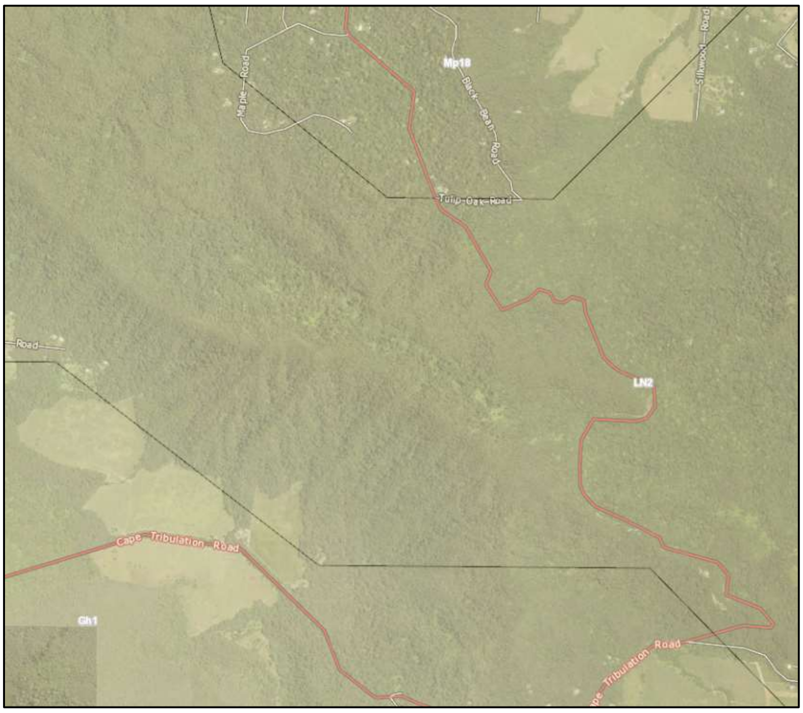

Figure 5: Mapping of Soil Types

The homogeneity of the soil type mapping is inconsistent with that which was observed on site. There were several soil types present in the faces of the upslope (cut) batters, throughout the study site. A summary of the soil types that were observed has been provided in Table 1.

Table 1: Soil Types Summary

Type	Description	Comment
Fill	Variable in composition. Unknown compaction (limited compaction assumed). Unknown composition – may include, organics, variable size rocks or construction material(s)	Likely to be materials side-cast onto the downslope during construction. The outside lane of the road may be constructed over the side cast material. Expected to have been used as general/ embankment fill to raise the vertical profile of the road through any crossings (gullies etc). **SITE BASED OBSERVATION(S)** Uncontrolled fill was identified on several downslope failure sites. Anecdotal evidence and advice from the Council's construction foreman supports the assumption that the Cape Tribulation road was cut into the side of the Alexandra Range, with material being cut from up slope and side cast forming the "fill" portion of the road. It is expected that this portion of the road has variable levels of compaction and have fill inclusive of cuttings, waste, vegetation etc. Large Rock Boulders were reported as being used in the location where a waterfall crosses the road (Ch. 10.75km). When the spanning slab was removed large cavities had formed. These cavities were filled with a no fines concrete
Residual Soils	Hodgkinson Formation Typically – red/ brown Silty-Sandy or Gravelly Clay	**SITE BASED OBSERVATION(S)** Residual soils present clearly on many of the upslope cutting through the full extent of the range. They are red brown in appearance and support the mapping as Hodgkinson Formation. Several rock intrusions were observed on the up-slope failures, with sizes ranging from gravels and cobbles up to large boulders.
Colluvium	A general term that applies to any loose heterogeneous and incoherent mass of soil material and/ or rock fragments deposited by rain wash, sheetwash, or slow continuous downslope creep, usually collecting at the base of gentle slopes or hillsides[1] Sometimes referred to as hill-wash	Colluvium was observed throughout the sites.
Alluvium	A general term for clay, silt, sand, gravel or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream or other body of running water, as a sorted or semi-sorted sediment[1]	Alluvium was not observed in any of the tributaries or road crossing.

[1] Reference :
https://mrdata.usgs.gov/geology/state/sgmc-lith.php?text=colluvium#:~:text=Colluvium,of%20gentle%20slopes%20or%20hillsides.

2.3 Rocks

Table 2: Rock Summary

Types	Description	Comment
Extremely Weathered Rock	Very weak rock <1MPa Derived from competent rock through the processes of weathering and erosion over time. Weakly bonded, dense material.	Most of the rock structures observed in the upslope (cut) batters presented as extremely weathered rock derived from the Hodgkinson Formation. It was red brown in colour and crumbled between the fingers when pressure was applied.
Competent Rock	Typically comprised of Coarse Grained : Quartzite and Arenite or Fine Grained: Siltstone, Phillite and Argillite Strength > 1MPa Observed Geological Structures included foliations, shear planes and fracturing.	 **Figure 6: Morphological Feature (Folding) Visible in Upslope Cutting**

3. GEOTECHNICAL RISK ASSESSMENT

3.1 Methodology

The adopted methodology has been based on the principles outlined in AGS (2007) – Landslide Risk Management Concepts and Guidelines and the AS ISO 31000: 2018 Risk Management Guidelines

3.2 Geotechnical Audit

An audit of all geotechnical information of the study zone was conducted, using historical records, observations, and available survey data. A summary of the findings from each has been summarised below.

3.2.1 Records

There were no formal records available from Council relating to

- Previous geotechnical investigations or assessments of the study area; and
- The frequency, type or location of the various types of failures or the mechanisms of failure (e.g. sliding rock failure, soil base instability).

Informal advice as to the geotechnical history and performance was obtained during a walk-over of the site with one of Council's more experienced construction foreman. Valuable information and advice was provided with anecdotal evidence including:

- The number of failures along the range can be significant (between 10-15 failures) during and following a period of significant and extended rainfall; and
- Failures of sites which have had engineering remediation undertaken on the sites are rare. There were no reported failures, for works occurring over the last 15 years. Through an abundance of caution, failures of engineering structures have been assumed to have occurred once every 15 years.

3.2.2 Observations

Site Inspections were undertaken by Trinity Engineering and Consulting's Principal Civil Engineer (1/4/2020, 14/5/2020, 10/6/2020) and a Senior Geotechnical Engineer (10/6/2020). Detailed records made during the site investigations have been compiled for future reference. It is anticipated that as this is the first assessment of the range, the information will provide the base line or datum against which future assessments can be made. Appendix A has the compiled the information on each site investigated. This includes information relating to

- Slope risk analysis;
- Cross sections at 10m intervals based on 1m Lidar;
- Photographic records; and
- Site based risks assessment (upslope and downslope – as required).

3.2.3 Survey

A comprehensive survey program of the range was undertaken to provide a base line of information for the current (and future) studies. The survey was undertaken in two parts.

i) Survey: Detailed survey of the road surface and installation of control points along the length of the road by a certified surveyor (RPS). The control points are useful reference points for the design and set-out of any future construction or rehabilitation works that may be required, as these points provide a "fixed" point in space against which to reference.

ii) 3-Dimensional Laser Survey: The laser survey was conducted using a Leica BLK360, scanner, to produce a point cloud of survey points. These points are located in an array at approximately 10mm centres, across the surveyed locations. The technology is ideally suited to obtaining high quality and accurate information for geotechnical failures where access to and across the site can be difficult and/or dangerous.

The integration of the two survey types allows the point cloud data to be "calibrated" and "verified" against the control points provided.

This provides a base for current and future design commissions required by Douglas Shire Council.

3.3 Geotechnical Analysis

3.3.1 General

An assessment of the upslope (cut) batter and the downslope (fill) batters was done using a qualitative and semi-quantitative approach.

3.3.2 Preliminary Qualitative Risk Assessment for Downslope (Fill) Batters

The major geotechnical risk associated with fill slopes, is the downslope failure within the fill mass. This may occur in the form of the formation of the classical slump failures within the fill batters, or by other forms of failure such as earth, debris, or mudslides. A summary of the various types of failures are shown in Figure 7.

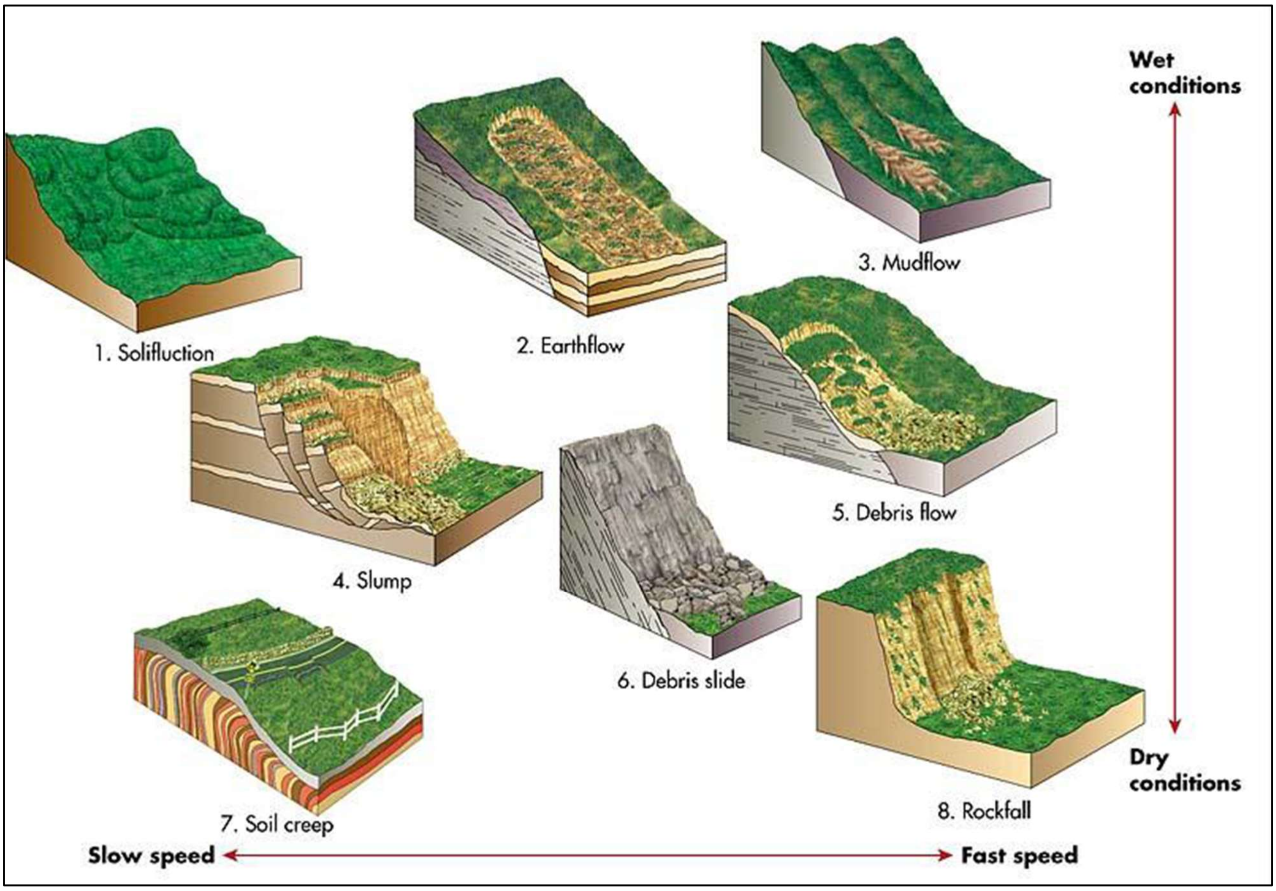

Figure 7: Various forms of potential geotechnical failures

For the case of the risk assessment, the actual *mechanism* of failure is not considered particularly relevant, but more-so the risk of failure of the fill batter, and consequential risk encountered thereafter.

These would include:

1) The loss of life due to persons being caught in the failures in the fill batter, *when* the event occurs; and

2) The loss of life due to persons falling or driving into the resulting failure, *after* the event has occurred.

Within the study area, the fill batters were located exclusively on the downslope side. From the anecdotal evidence (information from Council Officers) and the observance of the formation of scarps immediately adjacent to the road pavement, and tension cracks appearing in the pavement surface; it is anticipated that most of the failures experienced within the fill batters will be of a classical slump or debris flow type. There does not appear to be any evidence of any large-scale mudflows or channelised debris-slides in any fill batters within the study area.

There are currently no residential or commercial developments within, or downslope from the study corridor. There are also no areas identified for future development within this region. The risk assessments have therefore focussed on the risks to users of the Alexandra Range Road and have ignored other risks that may be considered in risk assessment in a more urban setting (e.g. persons living or working below a fill batter).

3.3.3 Preliminary Qualitative Risk Assessment for Upslope (Cut) Batters

The potential forms of instability hazards from the cut batters include:

- Rock Falls from within (or above) the cut onto the road;
- Slumps or Debris Failures originating within (or above) the cut batter, with the resulting materials affecting the road; or
- Natural Boulders rolling or sliding from above the cut batter and falling onto the road.

The cut batter angles on the upslope side of the road were typically between 40 and 70 degrees. Batters at the lower end of this range tend to be formed within the colluvium layer. The steeper batters have been formed within the weathered rock formations.

All failures were noted to have occurred within in the colluvium layer. The presence and depth of any bedrock is unknown. In all cases, there appears to be some material removed, but additional failed colluvium still present in the upslope cut batters. It is anticipated that there is a very high probability of further failures at these sites into the future.

Advice provided by the Council's Operational staff as well as the anecdotal evidence collected during the site visit, would indicate that at these sites of larger failures, the failed material would have impacted the road and then continued on downslope. Reported quantities of failed materials at these sites was greater than 750m^3 (Site A9, CH. 11.15km)

There was also some advice provided that:

- The soil "flowed" down the road and slope (similar to the *mudflow* failure as shown in Figure 7);
- Rock falls or boulders being dislodged from within or above the cut batters has been observed, but is infrequent;
- Volumes of failed materials vary significantly 10m^3- 1500+ m^3
- The periods of high rainfall events are typically within the wet season (November – April). The volume and intensity rainfall is exacerbated by tropical cyclones which frequent the area; and
- It is typical for the road to be shut for periods of between 2-4 days to clear debris from the road (including trees and or geotechnical failures). Council Officers also note that this can be offset from the immediate clean-ups undertaken from the rest of the Local Government Area due to the increased flood levels of the Daintree River, streams, tributaries and cross-road flows within the area – which restrict access.

4. RISK ANALYSIS MODELLING

4.1 General

The geotechnical analysis was done using a semi-quantitative approach to classifying and determining risk for both up and downslope batters along Alexandra Range Road. The assessment of risk was undertaken in accordance with the principles outlined in the Australian Geomechanics Society Guidelines (AGS, 2007). These have been explained in more detail in Section 4.4.

4.2 Road Users

Road users are predominantly Vehicles with limited exposure to pedestrians and/or bicycle traffic.

Multiple scenarios for traffic were considered as follows;

- Single occupant;
- Multiple occupants (work vehicle – assumes 3);
- Commercial Vehicles (assumes 25 occupants); and
- Other (assumes 5 occupants).

Traffic (AADT) = 500 vehicles per day (wet season).

Limited allowance for growth over the next 10yrs (the primary access across the Daintree River is by ferry, which is constrained (by vehicle capacity on each ferry load, operating hours and crossing cycle times).

The timeline for the assessment is 10 years, per the project brief requirements.

4.3 Risk Scenarios

The different risk scenarios considered at each site have been summarised in Table 3.

Table 3: Typical Site Risk Scenarios Considered

SITE	SLOPE	RISK FACTORS	PERSON(S) AT RISK	CONDITIONS
Site : No. XX **CH** :XXX	**Upslope** *(Cut batters)*	Rock / Boulder Falls from within or above slope, Soil/ colluvium failures from within or above the cut batter:	○ *Person(s) impacted by the risk factor, causing death - **AT THE TIME OF THE EVENT*** *(e.g. A person who is directly impacted by a rock fall from the slope above the road and dies)*	**Wet** (Saturated conditions)
				Dry (Dry conditions)
			○ *Person(s) who fails to negotiate the risk factors causing death - **AFTER THE TIME OF THE EVENT*** *(e.g. A person who drives into an existing debris slide onto the road and dies).*	**Wet** (Saturated conditions)
				Dry (Dry conditions)
	Downslope *(Fill batters)*	Soil/ colluvium failures in the downslope (fill batter) below the road: ○ *Impacting on, and causing a fatality of a road user **AT THE TIME OF THE EVENT*** ○ *A road user failing to negotiate the failure resulting in a fatality - **AFTER THE TIME OF THE EVENT***	○ *Person(s) impacted by the risk factor, causing death - **AT THE TIME OF THE EVENT*** *(e.g. Person(s) who are driving over the location and are consequently included in the downslope failure when it occurs, and dies)*	**Wet** (Saturated conditions)
				Dry (Dry conditions)
			○ *Person(s) who fails to negotiate the risk factors causing death - **AFTER THE TIME OF THE EVENT*** *(e.g. A person who drives into the cavity left after the downslope failure has occurred and dies).*	**Wet** (Saturated conditions)
				Dry (Dry conditions)

The detailed assessments for each site have been included in Appendix A. The summary of findings have been included in Section 5 and Appendix B

4.4 Risk Factors

The assessed risk for the loss of life, $R_{(LOL)}$, has been determined using the following formula.

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

Where:

- **R(LoL)** is the risk (annual probability of loss of life (death) of an individual).
- **P(H)** is the annual probability of the landslide.
- **P(S:H)** is the probability of spatial impact of the landslide impacting a location (vehicle) considering the travel distance and travel direction given the event.
- **P(T:S)** is the temporal spatial probability (e.g. of the vehicle or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence.
- **V(D:T)** is the vulnerability of the individual (probability of loss of life of the individual given the impact).

The determination of the annual probability of occurrence $P_{(H)}$ for the event (rockfall, landslide etc.) was determined in two separate ways. These include:

i) Undertaking a frequency Analysis – to determine the probability of an event occurring based on available data and assumptions based on engineering judgement; and

ii) Determining the qualitative risk level, using

iv) Table 4, and using an accepted correlation to link qualitative risk to level to Annual Probability (Table 5).

The annual probability of occurrence $P_{(H)}$ was typically adopted using second approach. This was favoured for this (initial) study for a two key reasons

i) There is no solid evidentiary base to support or validate the frequency analysis that has been undertaken. Assumptions were made, and anecdotally supported by the recollections from the Council's operational staff, but no referable documentation of the failures is available, and

ii) When comparing the results from the frequency analysis to the adopted values from the qualitative risk assessment (Table 5), the second approach tended to yield a higher value (i.e. predicts that the event will occur more often). So, in this regard, it was considered a more conservative approach.

Spatial Probability $\mathbf{P_{(S:H)}}$ ranges from 0 to 1 and is a function of the size, volume and end position of the failure. For each location, the volume of the material likely to impact the road has been calculated and the expected debris slope angle / or width of road affected determined. The spatial probability can be calculated. When the failure is expected to close both lanes of traffic - the Spatial Probability $\mathbf{P_{(S:H)}}$ = 1

Temporal probability $P_{(T:S)}$ – is a function of the probability that the road user either occupies or encounters the failure path.

$P_{(S:T)} = (N_V/24) * (L/1000) * (1/ V_V)$

Where:

- $P_{(S:T)}$ is the temporally spatial probability of vehicles either occupying or encountering the risk element.
- N_V is the number of vehicles per day that use the road (AADT)
- L is the average length of the vehicle
- V_V is the average speed of the vehicle (km/hr)

Table 4: Qualitative Risk Analysis Matrix

		Consequence				
		Catastrophic	Major	Medium	Minor	Insignificant
Likelihood	Almost Certain	Very High	Very High	Very High	High	Moderate or Low
	Likely	Very High	Very High	High	Moderate	Low
	Possible	Very High	High	Moderate	Moderate	Very Low
	Unlikely	High	Moderate	Low	Low	Very Low
	Rare	Moderate	Low	Low	Very Low	Very Low
	Barely Credible	Low	Very Low	Very Low	Very Low	Very Low

Table 5: Correlation between Qualitative Risk Descriptor and Annual Probability of occurrence $P_{(H)}$

Qualitative Risk Descriptor	P(H)
Very High	1
High	0.1
Moderate	0.01
Low	0.001
Very Low	0.0001

The values of Vulnerability, **V** $_{(D:T)}$, range from 0 (no injury) to 1(death). The vulnerability factors were considered in the context of each risk element, for the upslope and downslope cases. The values adopted are based on engineering judgement[1].

4.5 Risk Evaluation Criteria

4.5.1 General

There are two (2) levels of acceptability criteria used when evaluating the level of geotechnical risk. These are *"Acceptable Risk" and "Tolerable Risk".* It is important to distinguish between the two.

> *"Tolerable Risks" are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.*
>
> *"Acceptable Risks" are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.*
>
> *Most organisations have adopted Tolerable Risk as the measure to gauge risk. This is because there is a trade-off between the benefits and cost of risk mitigation, and the costs to achieve acceptable risk levels are often high. (AGS, 2007)*

4.5.2 Individual Risk Criteria

The regulator (Council) is ultimately responsible for setting the standards for tolerable risk. This may involve consideration of factors such as perceived safety and government policy. It is important to understand and consider the level of tolerable risk that is suitable for the community, as the implementation of the limit has significant impact, both in terms of relative safety, cost and economic impact on the community. The AGS (2007) guidelines provide recommended tolerable risk limits to loss of life. These are shown in Table 6.

[1] A study by Finley et al, (1999) did provide guidance as to the proposed figures for road users in vehicles. These were not adopted as published, as they didn't appear to give sufficient consideration to the localized conditions and context for the Alexandra range study. For example it was consider that in some sections the value of Vulnerability would increase due to reduced site distances,

Table 6: AGS Suggested Tolerable Loss of Life Individual Risk

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	10^{-4}/annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	10^{-5}/annum

Furthermore, the AGS (2007) guidelines recommended that risks be assessed only for the person most at risk, and not for the average person. This is a deviation from previous recommendations from AGS (2000[1], 2002[2]). ANCOLD (2003)[3] reported that the person most at risk always controlled, and that average risks were difficult to define and determine.

For the current study, a Tolerable Risk limit for loss of life of 1x10^{-4} / annum has been adopted.

4.5.3 Societal Risk Criteria

> *"Societal Risk" is defined by the AGS (2007) guidelines as "The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses."*
>
> *If the possible loss of large numbers of lives from a landslide incident is high, society will generally expect that the probability that the incident might occur should be low. This accounts for society's intolerance to incidents that cause many simultaneous casualties and is embodied in the criteria for tolerable societal risk.*

An example of the societal risk assessment is a comparative assessment of the risk of travelling in airplanes versus that of driving in a car. Air travel may be considered "risky" by some. Footage of airplane crashes or reports of aeroplanes being lost at sea are 'spectacular' and often sensationalised by media outlets in the delivery of content. This does effect people's perceptions of risk and acceptance of the loss of multiple lives at a single point in time.

There are a range of estimates out there, based some analysis of US Census data (by others[4]), the odds of dying as a plane passenger at 1 in 205,552. That compares with odds of 1 in 4,050 for dying as a cyclist; 1 in 1,086 for drowning, and 1 in 102 for a car crash.

Similarly, in cases where there will be more than one landslide hazard (e.g. rockfall, which may lead to one or two lives lost; medium volume rapid landslide which may lead to several lives lost; and large rapid landslide which may lead to many lives lost). The frequency (annual probability, "f") of the "event" and the number of lives lost (N) should be estimated for each landslide hazard.

The total annual risk = $\sum$ (f x N) was also estimated.

An assessment of the Societal Risk has been made and is reported in Section 5.

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[1] AGS (2000) Australian Geomechanics Society "Landslide Risk Management Concepts and Guidelines" Australian Geomechanics, Vol35 No1 March 2000 pp49-92

[2] AGS (2000) Australian Geomechanics Society "Landslide Risk Management Concepts and Guidelines" Australian Geomechanics, Vol37 No2 May 2002

[3] ANCOLD (2003) "Guidelines on Risk Assessment" Australian National Committee on Large Dams Inc , BCA Building Code of Australia, Australian Building Codes Board

[4] https://www.sbs.com.au/news/how-safe-is-flying-here-s-what-the-statistics-say#:~:text=There%20are%20a%20range%20of,102%20for%20a%20car%20crash.&text=You%20don't%20have%20that,car%2C%20train%20or%20bus.%E2%80%9D

5. SUMMARY AND RECOMMENDATIONS

5.1 Individual Risk Assessment

The detailed assessment of the risk of the loss of life for the individual has been done at each site for both the upslope and downslope (as applicable). The detailed assessments have been included in Appendix A.

Table 7 and Figure 8 provide a summary of the outputs of the assessments.

Table 7: Risk of Individual Loss of Life (By Site)

Site Specification			Risk to Individual	
Sites	**Start CH (m)**	**End CH (m)**	**Upslope**	**Downslope**
1	9123	9141	4.54E-05	7.84E-05
2	9291	9301	2.58E-06	7.98E-05
3	9373	9402	-	1.13E-07
4	9535	9535	1.61E-02	4.13E-05
A1	9555	9693	9.36E-05	4.52E-05
5	9713	9713	1.69E-03	2.69E-05
A2	9733	9858	7.46E-03	1.13E-07
A3	9871	10087	7.46E-03	1.13E-07
6	10097	10132	7.07E-03	3.50E-05
A4	10171	10229	2.85E-05	3.15E-06
7	10239	10299	9.36E-05	7.98E-05
A5	10309	10358	2.82E-05	1.13E-07
8	10386	10406	7.97E-07	4.50E-05
A6	10416	10535	9.36E-05	7.98E-05
9	10545	10584	9.36E-05	-
A7	10594	10815	4.68E-05	3.99E-05
10	10825	10831	6.92E-05	7.14E-05
A8	10841	10966	1.18E-03	-
11	10973	10995	8.51E-03	1.71E-04
A9	11193	11470	2.03E-03	8.34E-05
A10	11585	11851	9.36E-05	5.25E-05
A11	11888	11975	9.39E-05	1.04E-04
A12	12024	12229	7.80E-05	3.15E-05
12	12504	12524	6.91E-03	6.19E-05
A13	12719	12784	7.22E-06	8.87E-05
13	12850	12859	6.94E-05	3.15E-05
14	12906	12933	-	4.83E-05
15	13013	13023	6.30E-05	3.46E-05
16	13160	13175	-	1.13E-05

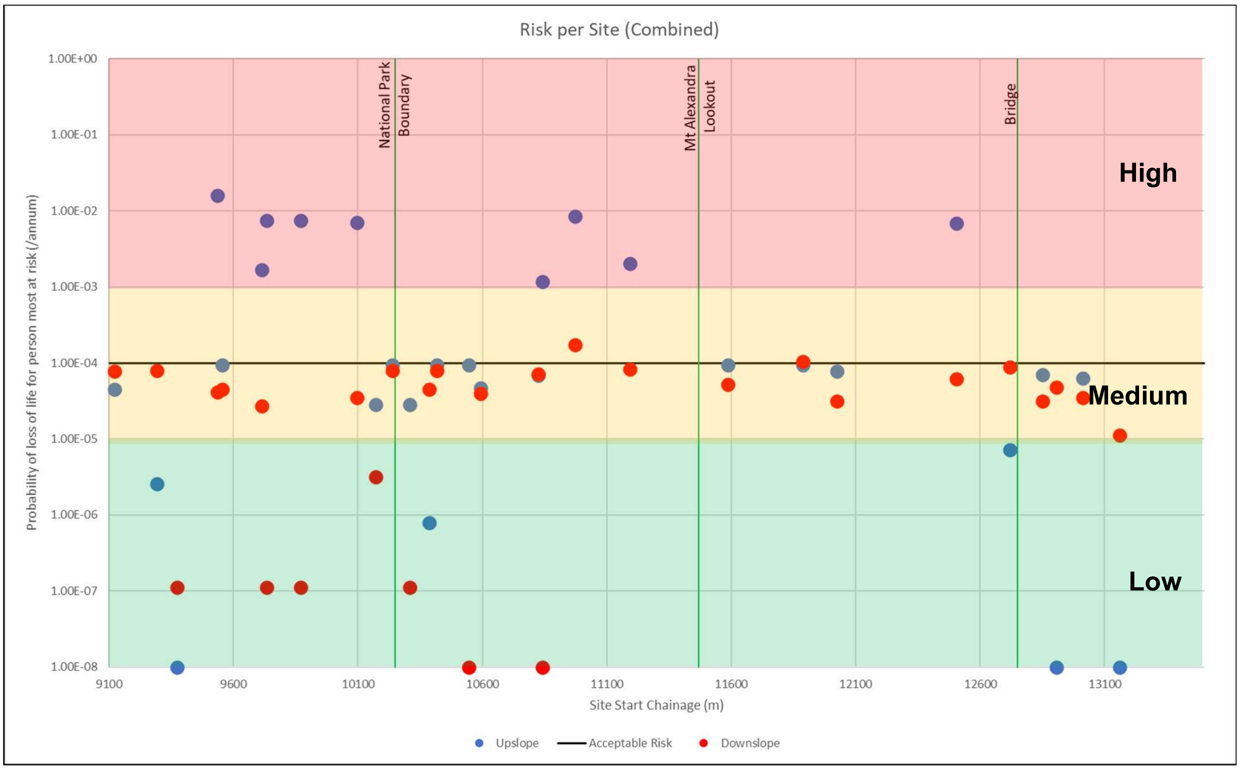

Figure 8: Risk Assessment for Loss of Life (By Site)

The important findings can be summarised as:

1) Upslope sites tend to pose a higher risk to loss of life than the downslope risks.

There are several contributors to this finding.

- Upslope (cut) batters have more individual risk factors to be considered which may cause the loss of life (including rock / boulder falls from within or above the batter, soil based failures from within or above the batter impacting the road users) when compared to downslope sites (failure of the downslope batter).
- Where the upslope (cut) batters are large, there is an increased risk to users as the temporal, spatial and vulnerability all increase, in these locations.

2) All sites that are above the defined *"Tolerable* risk level", should be addressed.

The tolerable risk threshold for an individual loss of life is 1×10^{-4}. This shown as the black horizontal line in Figure 8. These results indicate that the risk of a fatality in this region is above the suggested tolerable threshold limits.

Understanding the need to be able to prioritise sites above the tolerable risk level, the assessment has further considered the grouping of the sites and have shown three (3) distinct bands of sub-risk; notably High (Red), Orange (Medium) and Green (Low).

5.2 Societal Risk Assessment

Along with the assessment of risk to the individual loss of life, risks can also be evaluated in terms of societal risk. Societal risk assessment allows for the consideration of the perception of risk associated with a hazard and its consequences. The assessment reflects the wider view that risks or hazards with the potential for multiple deaths are considered less acceptable than those causing only a single fatality. (eg. plane crashes vs. single car accident).

Societal risks are typically presented in an F-N chart. These plot the frequency (F) of N or more fatalities against the number (N) of fatalities. The F-N charts define a number of different regions, including;

- **UNACCEPTABLE:** Above this threshold, the level of annualised risk is generally regarded by society as unacceptable. Actions should be taken to hazards identified in this region to reduce to acceptable levels
- **ALARP (AS LOW AS REASONABLY PRACTICAL):** Hazards identified within this region should be reduced where practical, including the consideration of the costs and benefits of doing so.
- **INTENSE SCRUTINY REGION:** Hazards in this region need further consideration and detailed assessment to be made. The expected number of fatalities in this region are significant.

- **BROADLY ACCEPTABLE:** Risks are typically acceptable

An assessment of the societal risk for an *individual site* is shown in Figure 9 and Figure 10 represent a societal risk assessment of the entire length of road investigated by this study. The assessment of risks for each individual site have been added together to produce an assessment of cumulative risk.

When considering any individual site (localised assessment), the risks are generally acceptable, or within the ALARP region. When the risks of all sites are added together, the risk generally moves to the upper bounds of the ALARP region. The risks for a Standard Vehicle (3 people) generally fall within the ALARP and broadly acceptable regions.

It is noted that the cumulative risk associated with the Commercial Vehicles (school bus – 25 people) plots within the unacceptable region for the downslope assessment. However, this is based on 15% of the daily traffic being Commercial Vehicles with 25 occupants. This is considered to be a conservative assessment and it is expected that with a more detailed assessment of Commercial Vehicles traversing the road that the cumulative risk would be reduced to the ALARP region.

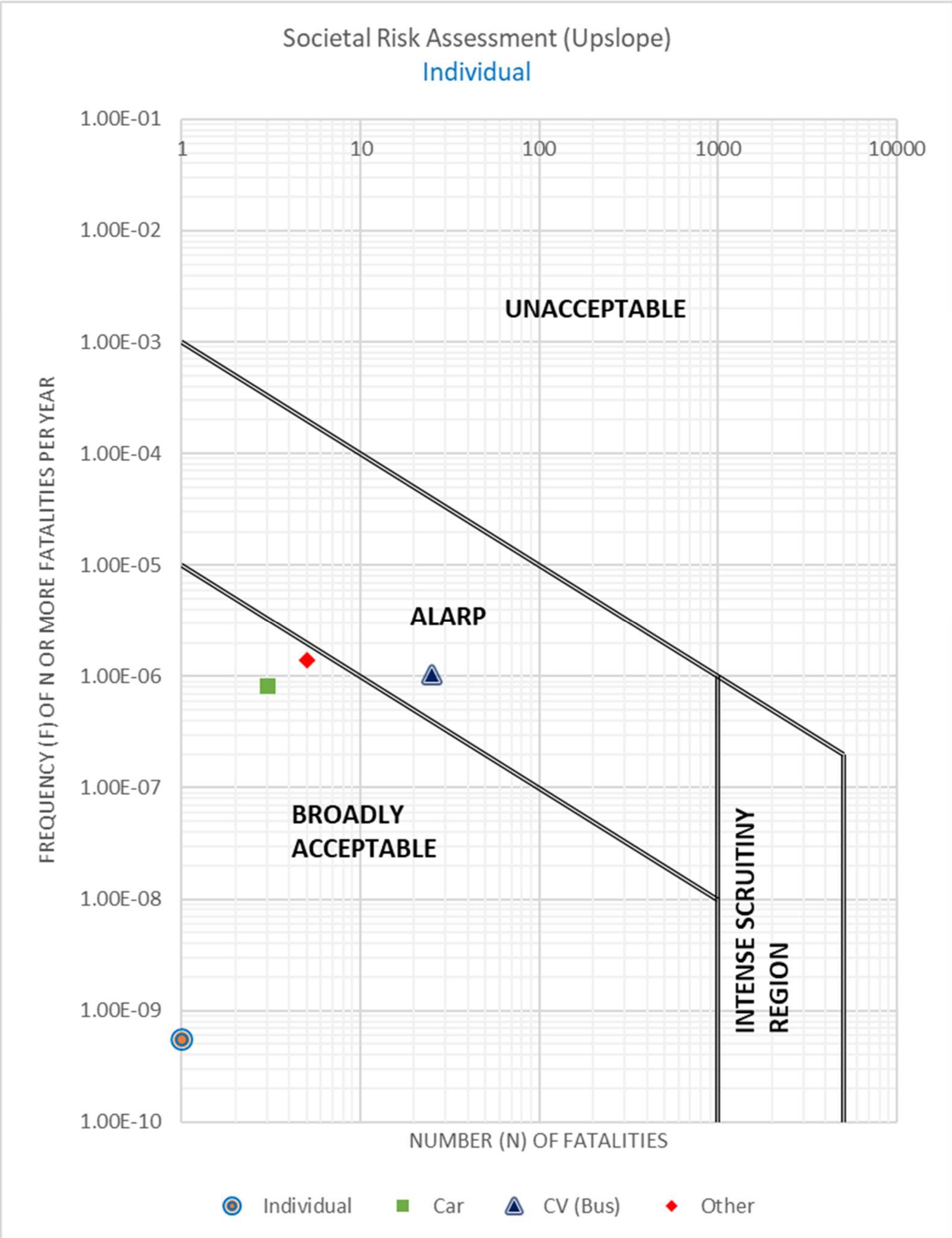

Figure 9: Upslope Societal Risk Assessment - Individual Risk

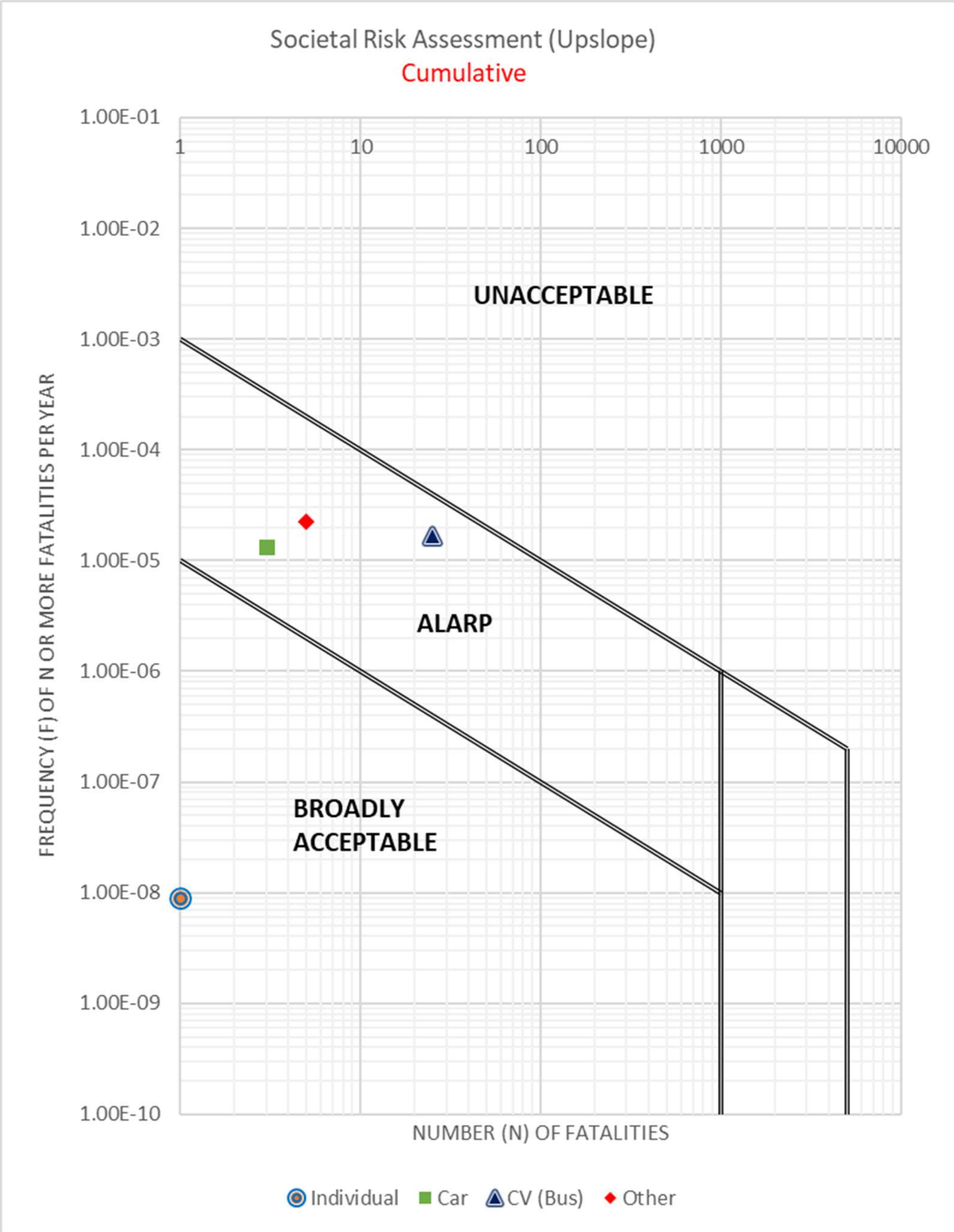

Figure 10: Upslope Societal Risk Assessment: Cumulative Risk

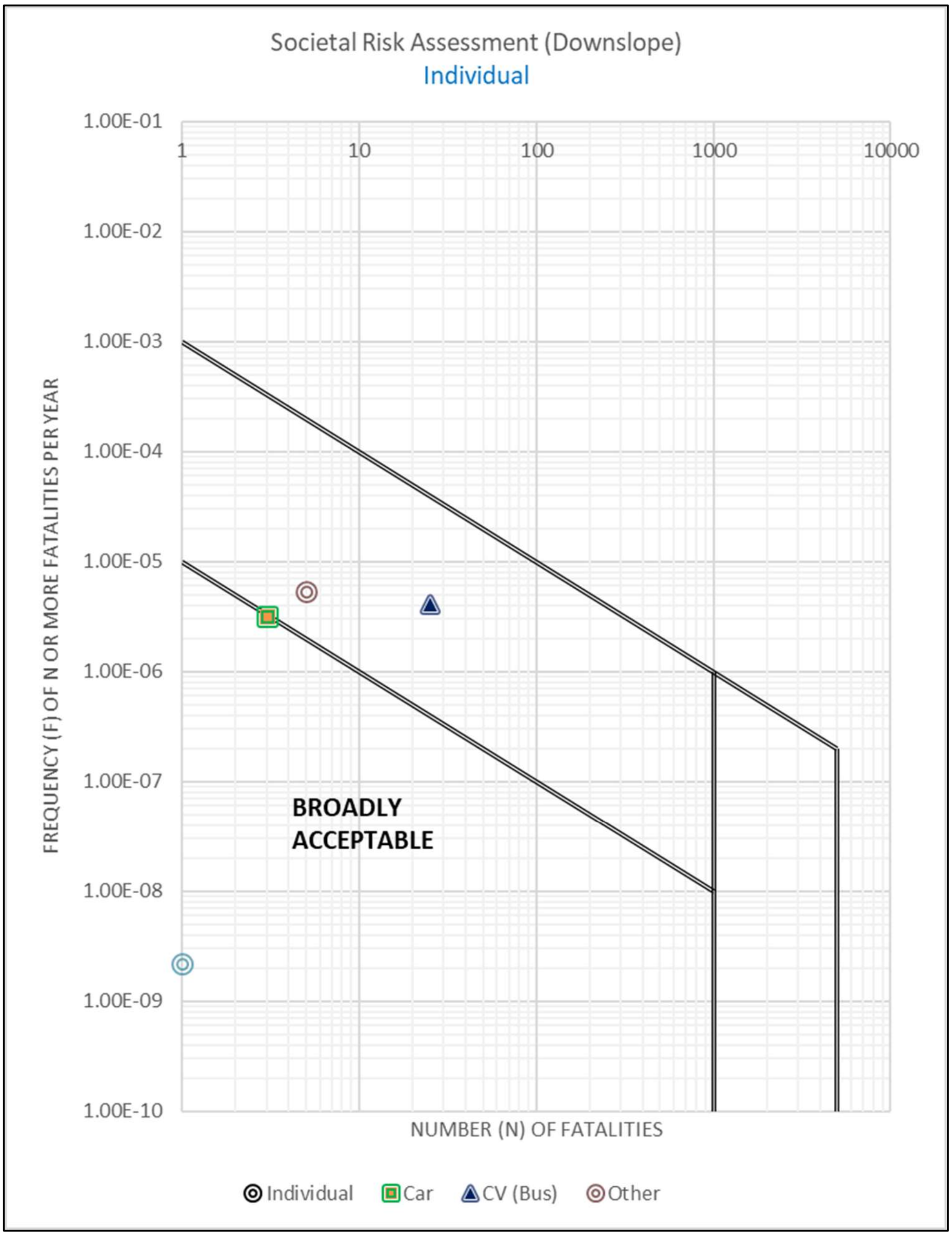

Figure 11: Downslope Societal Risk Assessment: Individual Risk

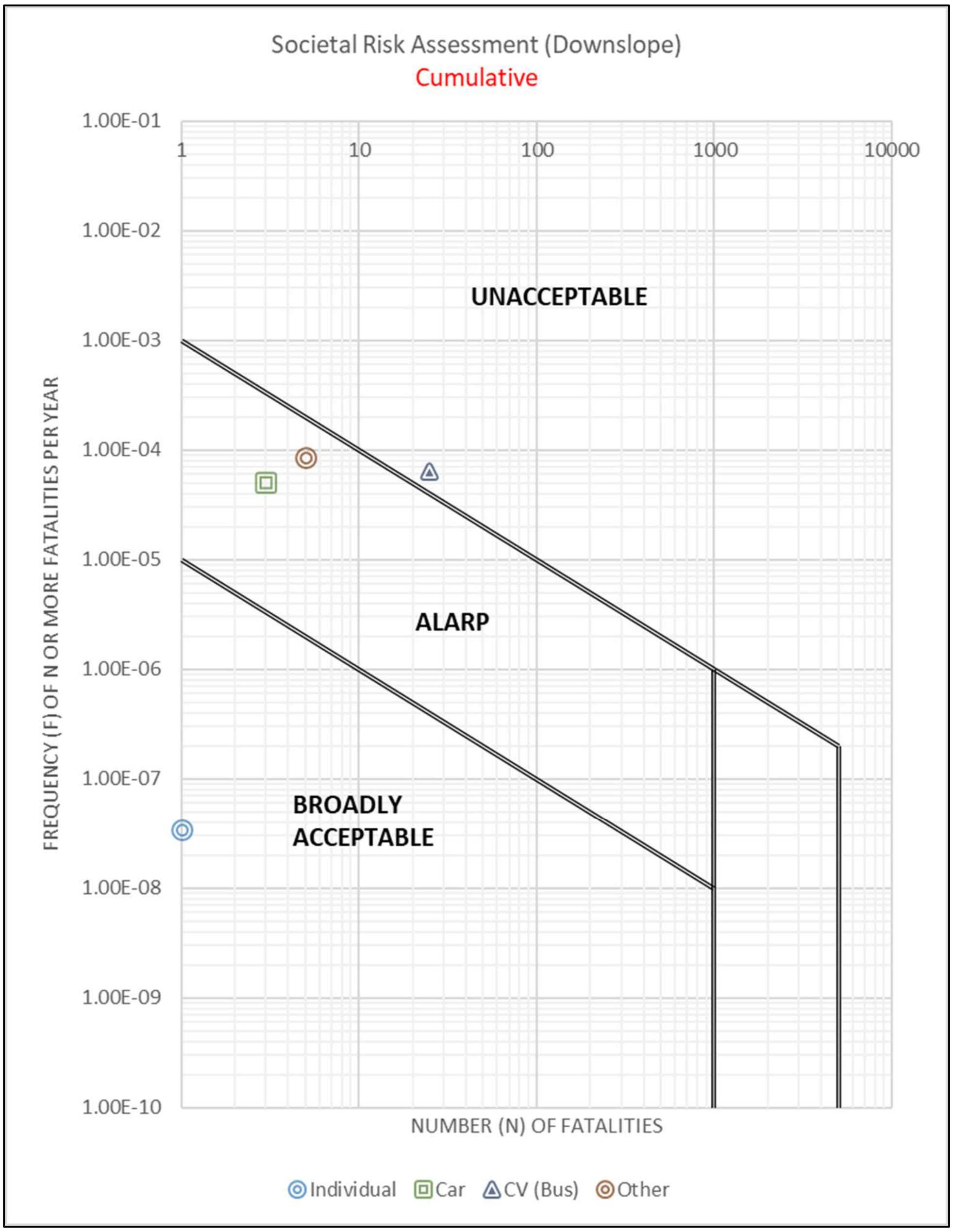

Figure 12: Downslope Societal Risk Assessment: Cumulative Risk

5.3 Risk Management Options

The options for managing risk include:

1) Accept the Risk;
2) Avoid the Risk;
3) Reduce the Hazards;
4) Reduce the Consequences, or
5) Monitor Potential Slope Failure Activities.

Risk Management options have been considered for each individual site assessment and are included at the bottom of the risk assessment (Refer Appendix A). In locations where remediation options have been recommended, an option assessment has been undertaken with a preliminary cost estimate provided for the concepts proposed. These have been included in Appendix C.

The options of temporary or permanent road closures have been identified by Council Officers as being particularly unpalatable to the community, and on that basis were not considered further within the risk management assessments. Practically, temporary road closures occur frequently during heavy rain events due to flooding of the Daintree river or tree/ debris falling severing the road. This provides an informal approach risk management of the geotechnical risks. Further consideration of road closures would need to be undertaken by Council after consultation with the affected stakeholders.

There are some cost-effective measures which may be able to be used to reduce the risk. These include:

- Signage (No Stopping, High Rockfall area);
- Improved maintenance of the road and existing geotechnical remediations;
- Improved monitoring of high-risk sites, the current study provides high quality laser survey of various sites, which can be used as a datum against which to compare future surveys. These surveys may provide pre-warning and indications of slope deterioration or movement.

  - Detailed investigations of the medium and high-risk sites identified in this study

  - Council to create a register to record all failures along the road, which is to be updated with information as it becomes available. Ideally this would be recorded in a GIS based database, to allow for easy identification and interrogation of data. This data will allow for the refinement of the current and future models as more data becomes available.

A summary of the proposed remediation options for each site, and prioritisation of the proposed works has been included in Appendix C. The prioritisation tool has been provided to Council in an Excel format, and can be manipulated and changed as required.

6. REFERENCES

Australian Stratigraphic units Database 1, 'Stratigraphic Unit Details – Hodgkinson Formation', viewed 26 May 2020, https://asud.ga.gov.au/search-stratigraphic-units/results/8404

Australian Stratigraphic units Database 2, 'Stratigraphic Unit Details – sandy alluvial 33695', viewed 26 May 2020, https://asud.ga.gov.au/search-stratigraphic-units/results/33695

Australian Stratigraphic units Database 3, 'Stratigraphic Unit Details – limestone screen and colluvium 72824', viewed 26 May 2020, https://asud.ga.gov.au/search-stratigraphic-units/results/72824

Australian Government Bureau of Meteorology 1, 'Monthly rainfall – Cape tribulation Store', viewed 26 May 2020, http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=139&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=031012

Australian Government Bureau of Meteorology 2, 'Monthly mean maximum temperate – Cairns Aero', viewed 26 May 2020, http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=36&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=031011

APPENDIX A

Site Assessments

Site 1.0
CH 9123 – CH 9141


IMG_8048.JPG


IMG_8038.JPG


IMG_8039.JPG


IMG_8040.JPG


IMG_8041.JPG


IMG_8042.JPG


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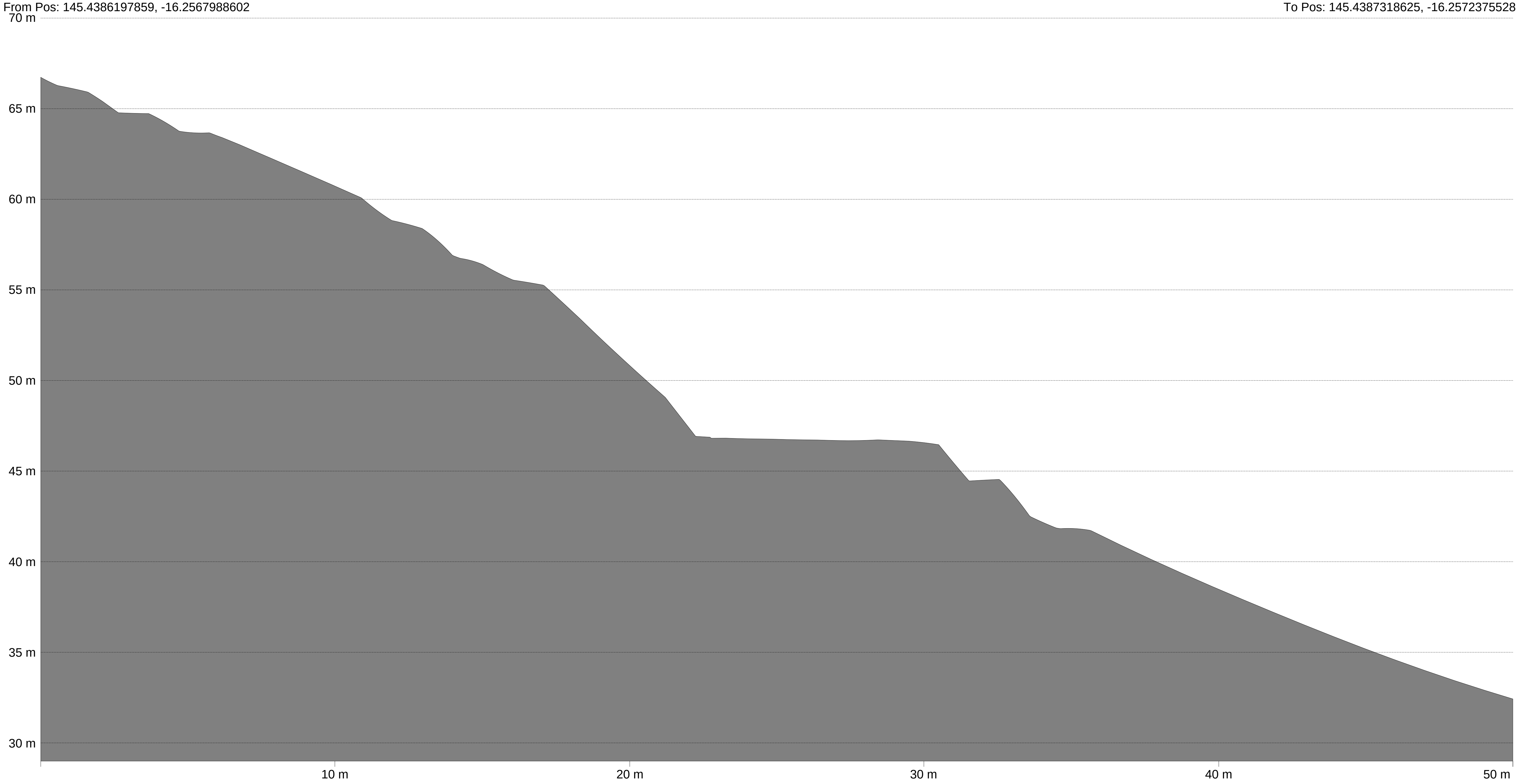
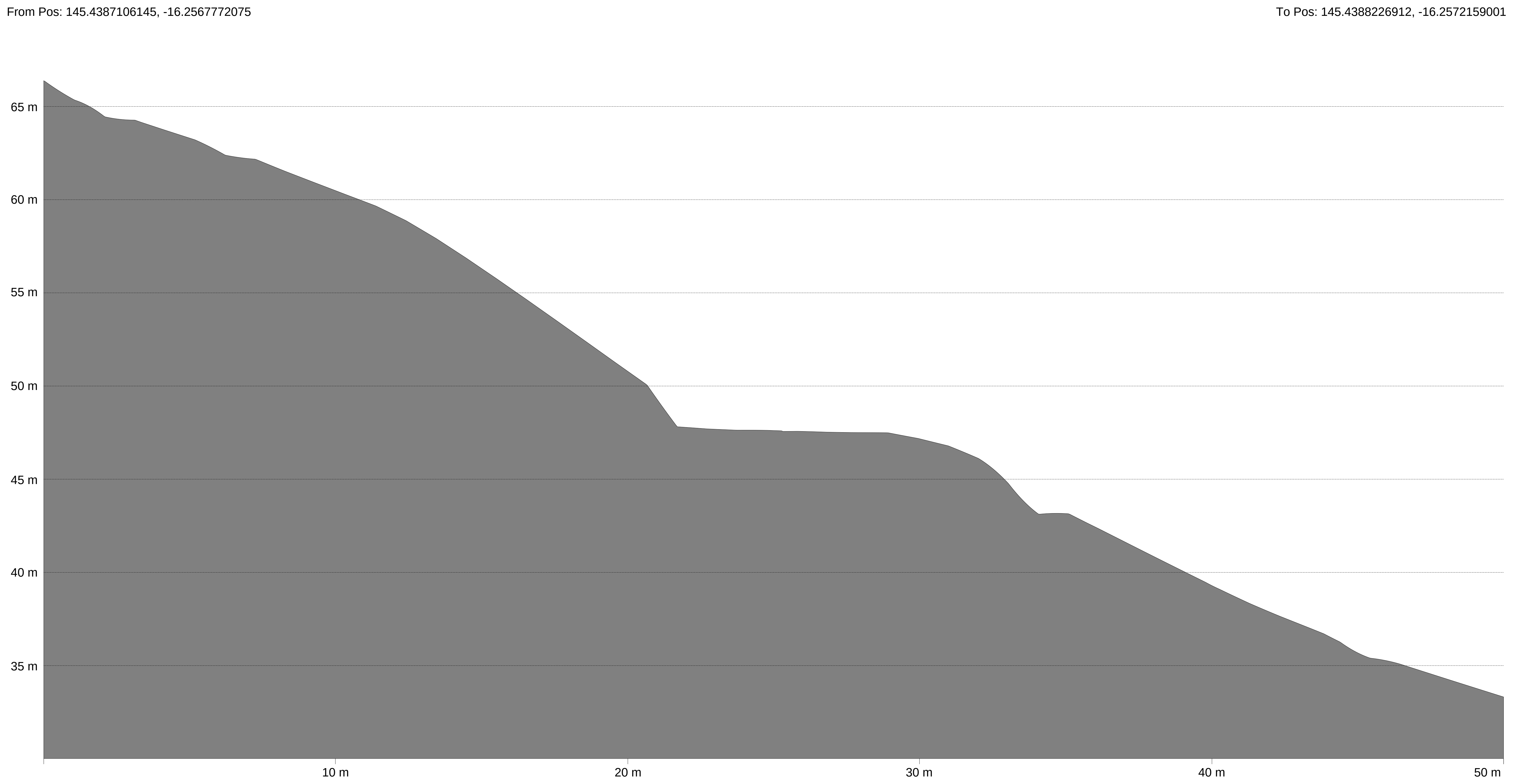
IMG_8047.JPG

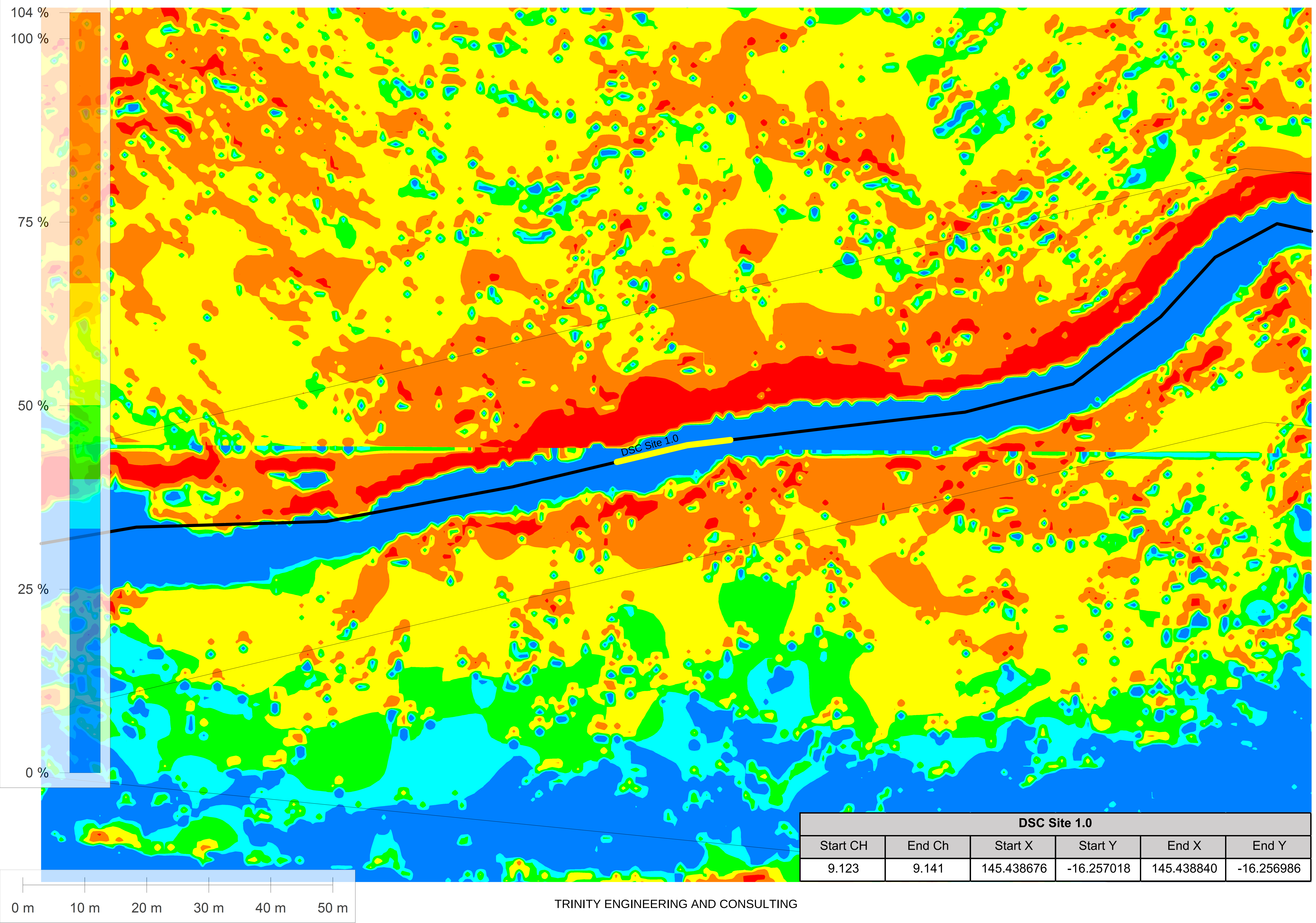
CROSS SECTION CH 9.123 - DSC SITE 1.0



CROSS SECTION CH 9.133 - DSC SITE 1.0



SLOPE ASSESSMENT - DSC SITE 1.0



DSC Site 1.0					
Start CH	End Ch	Start X	Start Y	End X	End Y
9.123	9.141	145.438676	-16.257018	145.438840	-16.256986

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SITE DETAILS

Site : 1

CH: 9123 to 9141 m

			Assumption	Known	Calc'd	Comment
Batter Material	Rock/ Soil/ Engineered Structure	Upslope: Rock Downslope: Colluvium/rock	x			
Type (if known)		Upslope: Hodgkinson formation Downslope: Soil/Colluvium	x			
Evidence of Previous instability		Upslope: No Downslope: Yes	x			
Evidence of Current instability		Upslope: No Downslope: Yes	x			
Joints						
Orientation		Unfavourable/ Neutral	x			
Spacing		150-300 mm	x			
Water						
Present		Yes	x			
Controlled/ Uncontrolled		Uncontrolled	x			
Weathering		Weathered Yes	x			
Strength		High	x			

SITE ANALYSIS

Risk of Individual Loss of Life

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

Where

R(LoL) is the risk (annual probability of loss of life (death) of an individual).

P(H) is the annual probability of the landslide.

P(S:H) is the probability of spatial impact of the landslide impacting a location (vehicle) taking into account the travel distance and travel direction given the event.

P(T:S) is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence.

V(D:T) is the vulnerability of the individual (probability of loss of life of the individual given the impact).

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SITE DETAILS

Site : 1
CH: 9123 to 9141 m

AGS (2007) - Risk Assessment (Upslope)

Frequency Analysis, $P_{(H)}$

	Value	Unit	Assumption	Known	Calc'd	Comment
Yr of Construction	30/06/1983			X		https://www.google.com/search?q=cape+tributation+road+%2B+year+of+construction&rlz=1C1GCEA_enAU862AU863&oq=cape+tributation+road+%2B+year+of+construction&aqs=chrome..69i57j0l7.15777j0j7&sourceid=chrome&ie=UTF-8
Date:	21/07/2020			X		
Yrs since Construction	37	yrs			X	
Total Number of Similar Sites (Upslope)	50	Sites	X			Identify Number at site if known, Otherise - from Council Officer Estimates
Total Number of Upslope Sliding Failures/ Yr (Av.)	13	/yr	X			Identify Number at site if known, Otherise - from Council Officer Estimates
Total Number of Upslope Rock/ Boulder Failures/ Yr (Av.)	1	/yr	X			
Total Number of Engineered Solution Failures/ Yr (Av.)	0.07	/yr	X			Failure of retaining Walls. Gabions, Soil Nails etc.
Frequency of Sliding (Failures)	7.03E-03	/yr			X	
Frequency of Rock/ Boulder (Failures)	5.41E-04	/yr			X	
Frequency of Engineered Solution (Failures)	3.60E-05	/yr			X	

Consequence Analysis

Spatial Probabilty, $P_{(S:H)}$

Spatial Probabilty (P(S:H) ranges from 1->0 and is a function of the size/ Volume of the slope failure and end position of the failure

The probability of a vehicle occupying the length of Road onto which the failure occurs

		Value	Unit	Assumption	Known	Calc'd	Comment
Road Width		6	m	X			Estimated during site visit
Failure Length (m)		18	m	X			Estimated from site photos
Failure Height (m)		4	m	X			Estimated from site photos
Av. Failure Depth (m)		0.1	m	X			Estimated from site photos
Total Volume of the Failure (m3)		25.4	m^3			X	
Assumed Failure Angle		45	deg	X			
Assumed Length of Flow across the road		4.00	m			X	
Partial Closure of the Road by Upslope Debris	$P_{(S:H)}$	0.5		X			
Closure of the Road by Upslope Debris	$P_{(S:H)}$	1		X			
Calculated Spatial Probability	$P_{(S:H)}$	100%				X	

Temporal Spatial Probabilty, $P_{(T:S)}$

(a) Temporal Spatial Probability ($P_{(S:T)}$) of Vehicles

The probability of a vehicle occupying the length of Road onto which the failure occurs

$P_{(S:T)} = (N_V/24) * (L/1000) * (1/V_V)$

	Value	Unit	Assumption	Known	Calc'd	Comment
N_V =	500	vpd	X			Av. No of Veh/day (AADT)
L =	5	m	X			Av. Vehicle Length (m)
V_V=	40	km/hr	X			Av. Vehicle Velocity (km/hr)
% CV	15%		X			% commercial Veh

(b) Vulnerability of Persons at Risk $V_{(D:T)}$
Scale from 0 (no injury to 1 (death)

		Value	Assumption	Known	Calc'd	Comment
Direct Impact on Road User -Debris Slide	$P_{(S:T)}$ =	30%	X			% chance of fatality - Assumes no ability to avoid, Fast failure, triggered event, No warning. Assumes No pedestrians or cyclist vehicle only. Adopted over both lanes)
Collision by Road User with Upslope Debris	$P_{(S:T)}$ =	5%	X			% chance of fatality, limited time to respond, slower failure).
Rock Boulder from Adjacent Cut Batters	$P_{(S:T)}$ =	20%	X			% chance of fatality - Assumes no ability to avoid, Fast failure, triggered event, No warning. Assumes No pedestrians or cyclist vehicle only. Adopted over both lanes)
Bedrock Failure (Large Scale Failure) - triggering additional Failures	$P_{(S:T)}$ =	30%	X			
Failure of Existing Geotechnical Remediation	$P_{(S:T)}$ =	0%	X			% chance of fatality - Assumes no ability to avoid, Fast failure, triggered event, No warning. Assumes No pedestrians or cyclist vehicle only. Adopted over both lanes)
Rock / Boulder from Above the failure	$P_{(S:T)}$ =	66%	X			% chance of fatality - Assumes no ability to avoid, Fast failure, triggered event, No warning. Assumes No pedestrians or cyclist vehicle only. Adopted over both lanes)
For each lane		9.38E-03			X	Peak hour volume assumed as 15% of AADT
For a particular vehicle travelling once each day in either direction	$P_{(S:T)}$ =	5.21E-06			X	

AGS (2007) - Risk Assessment (Upslope)

Preliminary Quantitative Assessment of Upslope Risk to Persons

RISK ANALYSIS

Potential Hazard	Risk to	Conditions	"Existing" or "New Slope"	WITHOUT Engineering Controls: Consequence	Likelihood	Qualitative Risk	Annual Probability P(H)	Spatial Probability P(S:H)	Temporal Probability P(T:S)	Vulnerability V(D:T)	Risk to Individual R(LoL)	Suggested Tolerable Risk (AGS 2007c)	Assessment Against Suggested Tolerable Risk Criteria (AGS 2007c)
Earth Slides in Batters above the Site	Individual Person	Dry	Existing Slope	Medium	Unlikely	Low	1.00E-03	100%	9.38E-03	30%	2.81E-06	1.00E-04	Risks within Tolerable Limits
		Wet	Existing Slope	Medium	Possible	Moderate	1.00E-02	100%	9.38E-03	30%	2.81E-05	1.00E-04	Risks within Tolerable Limits
Rock/ Boulder Fall from Existing Cut Batters adjacent to the Site	Individual Person on Road (Cape Tribulation Road)	Dry	Existing Slope	Minor	Rare	Very Low	1.00E-04	100%	9.38E-03	20%	1.88E-07	1.00E-04	Risks within Tolerable Limits
		Wet	Existing Slope	Minor	Unlikely	Low	1.00E-03	100%	9.38E-03	20%	1.88E-06	1.00E-04	Risks within Tolerable Limits
Bedrock Failure (through toppling/ sliding in rocky outcrop) – triggering additional failures.	Individual Person	Dry	Existing Slope	Medium	Unlikely	Low	1.00E-03	100%	9.38E-03	30%	2.81E-06	1.00E-04	Risks within Tolerable Limits
		Wet	Existing Slope	Medium	Rare	Low	1.00E-03	100%	9.38E-03	30%	2.81E-06	1.00E-04	Risks within Tolerable Limits
Boulder / Rock Fall down the hill	Individual Person	Dry	Existing Slope	Major	Barely Credible	Very Low	1.00E-04	100%	9.38E-03	66%	6.19E-07	1.00E-04	Risks within Tolerable Limits
		Wet	Existing Slope	Major	Rare	Low	1.00E-03	100%	9.38E-03	66%	6.19E-06	1.00E-04	Risks within Tolerable Limits
Failure of Existing Geotechnical Remdiation and resulting earth slide	Individual Person	Dry	Existing Slope	Insignificant	Barely Credible	Very Low	1.00E-04	100%	9.38E-03	0%	0.00E+00	1.00E-04	Risks within Tolerable Limits
		Wet	Existing Slope	Insignificant	Rare	Very Low	1.00E-04	100%	9.38E-03	0%	0.00E+00	1.00E-04	Risks within Tolerable Limits
											4.54E-05	1.00E-04	Risks within Tolerable Limits

Remediation Options

Accept the Risk ☑

Avoid the Risk

☐ Closing the road in part or in sections to some or all of the user groups when risk levels are identified as being unacceptable
- ☐ Cyclones
- ☐ Heavy Rainfall
- ☐ Light Rainfall
- ☐ Dry

☐ Close Road and Establish a new route with Accetable levels of Risk

Reduce the Hazard

Remedial Measures to control slope failure hazard to acceptable levels

ROCK	☑	Scaling of Rocks - to remove unstable
	☐	Netting of Rock Cut Slope
	☐	Rock Bolting
SOIL	☐	Soil Nails , Anchors etc (Positive Retention)
	☐	Retaining Walls
	☐	Shot-crete and Mesh
	☐	Battering back of slopes to stable batter angles.
	☐	Drainage Works - (Surface Drains at top and toe of batter
	☐	Drainage Works - Sub-Surface: Horizontal or Vertical Drain installation

Reduce the Consequence

Action	☐	Road Realignment - improved road Geometry (Site Distance) near hazards
	☐	Road Geometry Overaking or additional width near high risk sites
	☑	Signage (No Standing, No Stopping, High Rock fall areas etc.)
Monitoring	☑	Monitoring of slopes -
	☐	Tension Cracks
	☐	Survey
	☐	Administrative / Operational Interventions
	☐	Close Road during heavy rainfall
	☐	Close Road to particular users during high risk events (Cyclones, high Rainfall - buses etc)
Investigate Further	☑	Obtain Further information on specific sites or aspects of sites to provide further information and detail to assist in the making of a decision

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SITE DETAILS

Site :	1		
CH:	9123	to	9141 m

AGS (2007) - Risk Assessment (DownSlope)

Frequency Analysis, $P_{(H)}$

Item	Value	Unit	Assumption	Known	Calc'd	Comment
				x		
Yr of Construction	30/06/1983			x		
Date:	21/07/2020				x	
Yrs since Construction	37	yrs	x			Identify Number at site if known, Otherise - from Council Officer Estimates
Total Number of Similar Sites (Downslope)	50	Sites	x			Identify Number at site if known, Otherise - from Council Officer Estimates
Total Number of Downslope Sliding Failures/ Yr (Av.)	10	/yr	x			Failure of retaining Walls. Gabions, Soil Nails etc.
Total Number of Downslope Engineered Solution Failures/ Yr (Av.)	0.07	/yr				
Frequency of Sliding (Failures)	5.41E-03	/yr			x	
Frequency of Engineered Solution (Failures)	3.60E-05	/yr			x	

Consequence Analysis

Spatial Probabilty, $P_{(S:H)}$

Spatial Probabilty (P(S:H) ranges from 1->0 and is a function of the size/ Volume of the slope failure and end position of the failure

Item	Symbol	Value	Unit	Assumption	Known	Calc'd	Comment
							The probability of a vehicle occupying the length of Road onto which the failure occurs
Road Width		6	m	x			Estimated during site visit
Failure Length (m)		10	m	x			Estimated from site photos
Failure Height (m)		3	m	x			Estimated from site photos
Av. Failure Depth (m)		0.75	m	x			Estimated from site photos
Total Volume of the Failure (m3)		58.9	m^3	x			
Width of Potential Fill		3	m	x			Estimated from Existing Batter profile
Partial Closure of the Road by Downslope Failure	$P_{(S:H)}$	0.5		x			
Closure of the Road by Downslope Failure	$P_{(S:H)}$	1		x			
Calculated Spatial Probability	$P_{(S:H)}$	100%				x	

Temporal Spatial Probabilty, $P_{(T:S)}$

(a) Temporal Spatial Probability ($P_{(S:T)}$) of Vehicles

$P_{(S:T)} = (N_V/24) * (L/1000) * (1/ V_V)$

Item	Symbol	Value	Unit	Assumption	Known	Calc'd	Comment
							The probability of a vehicle occupying the length of Road onto which the failure occurs
	$N_V =$	500	vpd	x			Av. No of Veh/day (AADT)
	$L =$	5	m	x			Av. Vehicle Length (m)
	$V_V =$	40	km/hr	x			Av. Vehicle Velocity (km/hr)

(b) Vulnerability of Persons at Risk $V_{(D:T)}$
Scale from 0 (no injury) to 1 (death)

Item	Symbol	Value	Assumption	Known	Calc'd	Comment
Direct Impact on Road User - Downslope Failure -Slide	$P_{(S:T)} =$	66%	x			% chance of fatality - Assumes no ability to avoid, Fast failure, triggered event, No warning. Assumes No pedestrians or cyclist vehicle only. Adopted over both lanes)
Road User fails to negotiate and collides with Existing Downslope Failure	$P_{(S:T)} =$	10%	x			% chance of fatality, limited time to respond, slower failure).
For each lane		9.38E-03			x	Peak hour volume assumed as 15% of AADT
For a particular vehicle travelling once each day in either direction	$P_{(S:T)} =$	5.21E-06			x	

AGS (2007) - Risk Assessment (DownSlope)

Preliminary Quantitative Assessment of Upslope Risk to Persons

RISK ANALYSIS

Potential Hazard	Risk to	Conditions	"Existing" or "New Slope"	WITHOUT Engineering Controls: Consequence	Likelihood	Qualitative Risk	Annual Probability P(H)	Spatial Probability P(S:H)	Temporal Probability P(T:S)	Vulnerability V(D:T)	Risk to Individual R(LoL)	Suggested Tolerable Risk (AGS 2007c)	Assessment Against Suggested Tolerable Risk Criteria (AGS 2007c)
Earth Slides in Fill Batters below the Site - Direct Impact	Individual Person	Dry	Existing Slope	Medium	Unlikely	Low	1.00E-03	100%	9.38E-03	66%	6.19E-06	1.00E-04	Risks within Tolerable Limits
		Wet	Existing Slope	Medium	Possible	Moderate	1.00E-02	100%	9.38E-03	66%	6.19E-05	1.00E-04	Risks within Tolerable Limits
Earth Slides in Fill Batters below the Site - Failure to Negotiate	Individual Person	Dry	Existing Slope	Medium	Unlikely	Low	1.00E-03	100%	9.38E-03	10%	9.38E-07	1.00E-04	Risks within Tolerable Limits
		Wet	Existing Slope	Medium	Possible	Moderate	1.00E-02	100%	9.38E-03	10%	9.38E-06	1.00E-04	Risks within Tolerable Limits
Failure of Existing Geotechnical Remdiation and resulting earth slide - Direct Impact	Individual Person	Dry	Existing Slope			NA	NA	NA	NA	NA	NA	NA	Not Applicable - no geotechnical remediation downslope.
		Wet	Existing Slope			NA	NA	NA	NA	NA	NA	NA	Not Applicable - no geotechnical remediation downslope.
Failure of Existing Geotechnical Remdiation and resulting earth slide - Failure to Negotiate	Individual Person	Dry	Existing Slope			NA	NA	NA	NA	NA	NA	NA	Not Applicable - no geotechnical remediation downslope.
		Wet	Existing Slope			NA	NA	NA	NA	NA	NA	NA	Not Applicable - no geotechnical remediation downslope.
											7.84E-05	1.00E-04	Risks within Tolerable Limits

Remediation Options

Accept the Risk ☐

Avoid the Risk ☐

☐ Closing the road in part or in sections to some or all of the user groups when risk levels are identified as being unacceptable
- ☐ Cyclones
- ☐ Heavy Rainfall
- ☐ Light Rainfall
- ☐ Dry

☐ Close Road and Establish a new route with Accetable levels of Risk

Reduce the Hazard

Remedial Measures to control slope failure hazard to acceptable levels

ROCK	☐	Scaling of Rocks - to remove unstable
	☐	Netting of Rock Cut Slope
	☐	Rock Bolting
SOIL	☑	Soil Nails , Anchors etc (Positive Retention)
	☑	Retaining Walls
	☑	Shot-crete and Mesh
	☐	Battering back of slopes to stable batter angles.
	☑	Drainage Works - (Surface Drains at top and toe of batter
	☑	Drainage Works - Sub-Surface: Horizontal or Vertical Drain installation

Reduce the Consequence

Action	☐	Road Realignment - improved road Geometry (Site Distance) near hazards
	☐	Road Geometry Overaking or additional width near high risk sites
	☐	Signage (No Standing, No Stopping, High Rock fall areas etc.)
Monitoring	☑	Monitoring of slopes -
	☐	Tension Cracks
	☐	Survey
	☐	Administrative / Operational Interventions
	☐	Close Road during heavy rainfall
	☐	Close Road to particular users during high risk events (Cyclones, high Rainfall - buses etc)
Investigate Further	☑	Obtain Further information on specific sites or aspects of sites to provide further information and detail to assist in the making of a decision. Known site of geotechnical failure recommend future investigations to identified remedial options to protect long term integrity of asset.
	☑	Concept design for remediation options for existing Downslope failure to stabilise batter and protect long term integrity of asset.

APPENDIX B
Risk Assessment: Summary

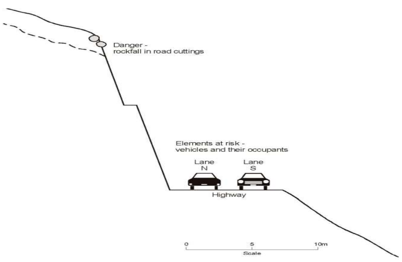
Trinity Engineering and Consulting
design | consult | manage

SOCIETAL RISK ASSESSMENT

Site : Alexandra Range Road

AGS (2007) - Risk Assessment (Upslope)

Scope Definition :
Determine the risk to persons travelling on the road below the existing failure on Cape Tribulation Road.



RISK ANALYSIS

Danger Characterisation (Landslide)			Assumption	Known	Calc'd	Comment	
No of Similar Cuts	50		X			In DSC - Similar Geology, topography and climactic conditions	
No of Failures / Annum/ Cutting	0.2		X			1 failure per Cutting/5yrs	from Maintenance records
Typical Volume	300	m^3	X			(typical < 500m3)	estimated from site
% Chance of Failure Material Impacting on							
Lane N	60%		X				
Lane S	10%		X				

Frequency Analysis			Assumption	Known	Calc'd	Comment
Frequency of Failures at Cutting (N_F)	5.48E-04	/day			X	Considers Current Failure only
Frequency of Failures into Lane N	3.29E-04	/day			X	Considers Current Failure only
Frequency of Failures into Lane S	5.48E-05	/day			X	Considers Current Failure only

Consequence Analysis			Assumption	Known	Calc'd	Comment
(a) Temporal Spatial Probability ($P_{(S:T)}$) of Vehicles						The probability of a vehicle occupying the length of Road onto which the failure occurs
$P_{(S:T)} = (N_V/24) * (L/1000) * (1/V_V)$					X	
N_V =	500	vpd	X			Av. No of Veh/day (AADT)
L =	5	m	X			Av. Vehicle Length (m)
V_V=	40	km/hr	X			Av. Vehicle Velocity (km/hr)
% CV	15%		X			% commercial Veh
(b) Vulnerability of Persons at Risk $V_{(D:T)}$						
Lane N	30%		X			% chance of fatality
Lane S	15%		X			% chance of fatality
For each lane						
$P_{(S:T)}$ =	2.60E-03				X	
For a particular vehicle travelling once each day in either direction						
$P_{(S:T)}$ =	5.21E-06				X	

Risk Estimation			Assumption	Known	Calc'd	Comment
The annual probability of the person most at risk of losing his/ her life bt driving along the road is:						
$P_{(LOL)} = P_{(S)} \times V_{(D:T)} = (1-(1-P_{S:T})^{N_F}) \times V_{D:T}$						
Lane N	5.14E-10				X	
Lane S	4.28E-11				X	
Total	**5.57E-10**				X	
Total Probability of the person most at risk	5.57E-10	/annum			X	
The probability of the person most at risk of losing his/ her life - who travels the road only once per yr:	1.52E-12	/annum			X	
No. of people / car N_P=	3	ppl/car	X			
Total Annual Risk	8.35E-07	/annum			X	

Risk Assessment	Assumption	Known	Calc'd	Comment

(a) Individual Risk

Individual most at risk **5.57E-10** /annum

Table 1: AGS Suggested Tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	10^{-4} / annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	10^{-5} / annum

		Assumption	Known	Calc'd	Comment
Situation	Existing Slope		x		
Tolerable Risk (LOL)	1.00E-04			x	From Table 1 - AGS (2007)

Check: Individual Risk Level - Satisfactory

(a) Societal Risk

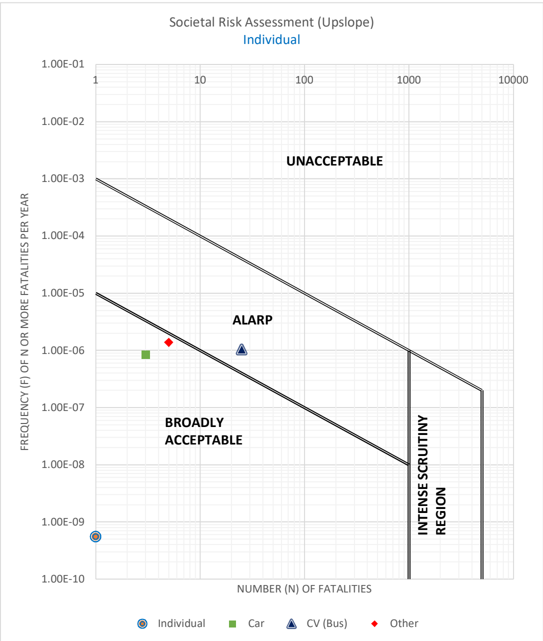
Individual Assessment

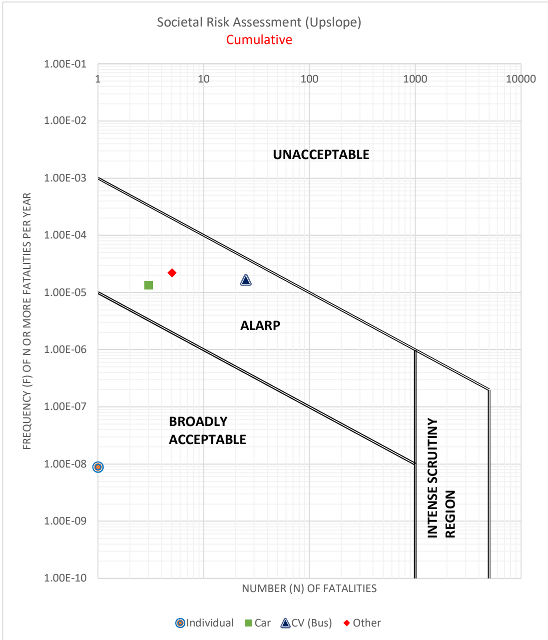
	Persons at Risk	$P_{(LOL)}$		Vulnerability	No. of Fatalities
Individual	1	5.57E-10	/annum	45%	1
Car	3	8.35E-07	/annum	45%	2
CV (Bus)	25	1.04E-06	/annum	45%	12
Other	5	1.39E-06	/annum	45%	3

Cumulative

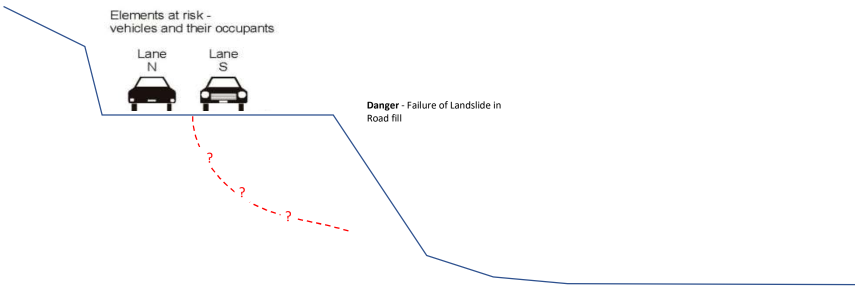
	Persons at Risk	$P_{(LOL)}$		Vulnerability	No. of Fatalities
Individual	1	8.90E-09	/annum	45%	1
Car	3	1.34E-05	/annum	45%	2
CV (Bus)	25	1.67E-05	/annum	45%	12
Other	5	2.23E-05	/annum	45%	3

		Assumption	Known	Calc'd	Comment
No of Cuttings	16	x			





AGS (2007) - Risk Assessment (DownSlope)



RISK ANALYSIS

Danger Characterisation (Landslide)			Assumption	Known	Calc'd	Comment
No of Similar Cuts	100		X			In DSC - Similar Geology, topography and climactic conditions
No of Failures / Annum/ Cutting	1		X			1 failure per Cutting/5yrs
Typical Volume	180	m^3	X			(typical < 500m3)
% Chance of Failure affecting						
Lane N	20%		X			
Lane S	60%		X			

Frequency Analysis			Assumption	Known	Calc'd	Comment
Frequency of Failures at Cutting (N_f)	2.74E-03	/day			X	Considers Current Failure only
Frequency of Failures into Lane N	5.48E-04	/day			X	Considers Current Failure only
Frequency of Failures into Lane S	1.64E-03	/day			X	Considers Current Failure only

Consequence Analysis			Assumption	Known	Calc'd	Comment
(a) Temporal Spatial Probability ($P_{(S:T)}$) of Vehicles						The probability of a vehicle occupying the length of Road onto which the failure occurs
$P_{(S:T)} = (N_V/24) * (L/1000) * (1/ V_V)$					X	
(a) Temporal Spatial Probability ($P_{(S:T)}$) of Vehicles						The probability of a vehicle occupying the length of Road onto which the failure occurs
N_V =	500	vpd	X			Av. No of Veh/day (AADT)
L =	5	m	X			Av. Vehicle Length (m)
V_V=	40	km/hr	X			Av. Vehicle Velocity (km/hr)
% CV	15%		X			% commercial Veh
(b) Vulnerability of Persons at Risk $V_{(D:T)}$						
Lane N	30%		X			% chance of fatality
Lane S	15%		X			% chance of fatality
For each lane $P_{(S:T)}$ =	2.60E-03				X	
For a particular vehicle travelling once each day in either direction $P_{(S:T)}$ =	5.21E-06				X	

Risk Estimation

The annual probability of the person most at risk of losing his/ her life bt driving along the road is:

$P_{(LOL)} = P_{(S)} \times V_{(D:T)} = (1-(1-P_{S:T})^{N}{}_{F}) \times V_{D:T}$

			Assumption	Known	Calc'd	Comment
Lane N	8.56E-10				X	
Lane S	1.28E-09				X	
Total	**2.14E-09**				X	
Total Probability of the person most at risk	2.14E-09	/annum			X	
The probability of the person most at risk of losing his/ her life - who travels the road only once per yr:	5.86E-12	/annum			X	
No. of people / car N_P=	3	ppl/car	X			
Total Annual Risk	3.21E-06	/annum			X	

Risk Assessment	Assumption	Known	Calc'd	Comment

(a) Individual Risk

Individual most at risk **2.14E-09** /annum

Table 1: AGS Suggested Tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	10^{-4} / annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	10^{-5} / annum

		Assumption	Known	Calc'd	Comment
Situation	Existing Slope		x		
Tolerable Risk (LOL)	1.00E-04			x	From Table 1 - AGS (2007)

Check: Individual Risk Level - Satisfactory

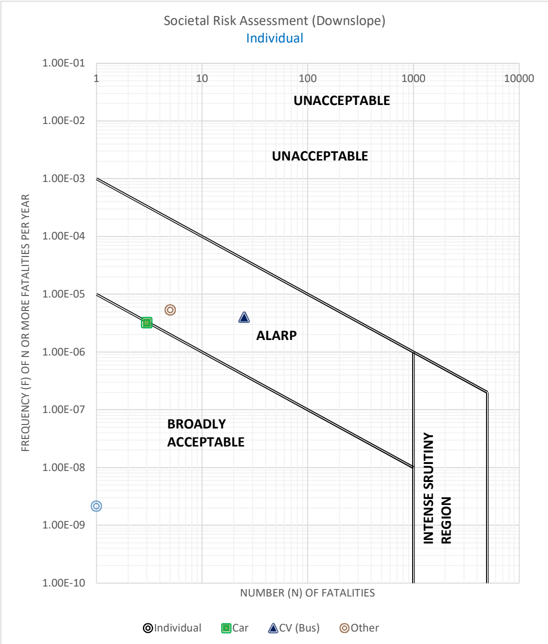
(a) Societal Risk

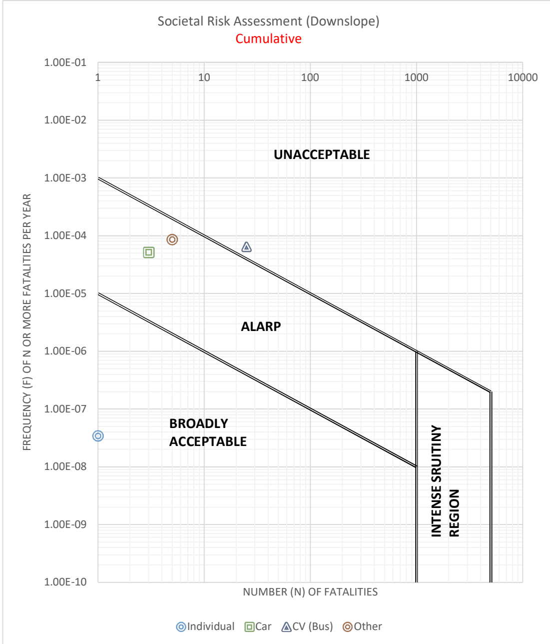
	Persons at Risk	$P_{(LOL)}$		Vunerability	No. of Fatalities
Individual	1	2.14E-09	/annum	45%	1
Car	3	3.21E-06	/annum	45%	2
CV (Bus)	25	4.01E-06	/annum	45%	12
Other	5	5.35E-06	/annum	45%	3

Cumulative

	Persons at Risk	$P_{(LOL)}$		Vunerability	No. of Fatalities
Individual	1	3.42E-08	/annum	45%	1
Car	3	5.14E-05	/annum	45%	2
CV (Bus)	25	6.42E-05	/annum	45%	12
Other	5	8.56E-05	/annum	45%	3

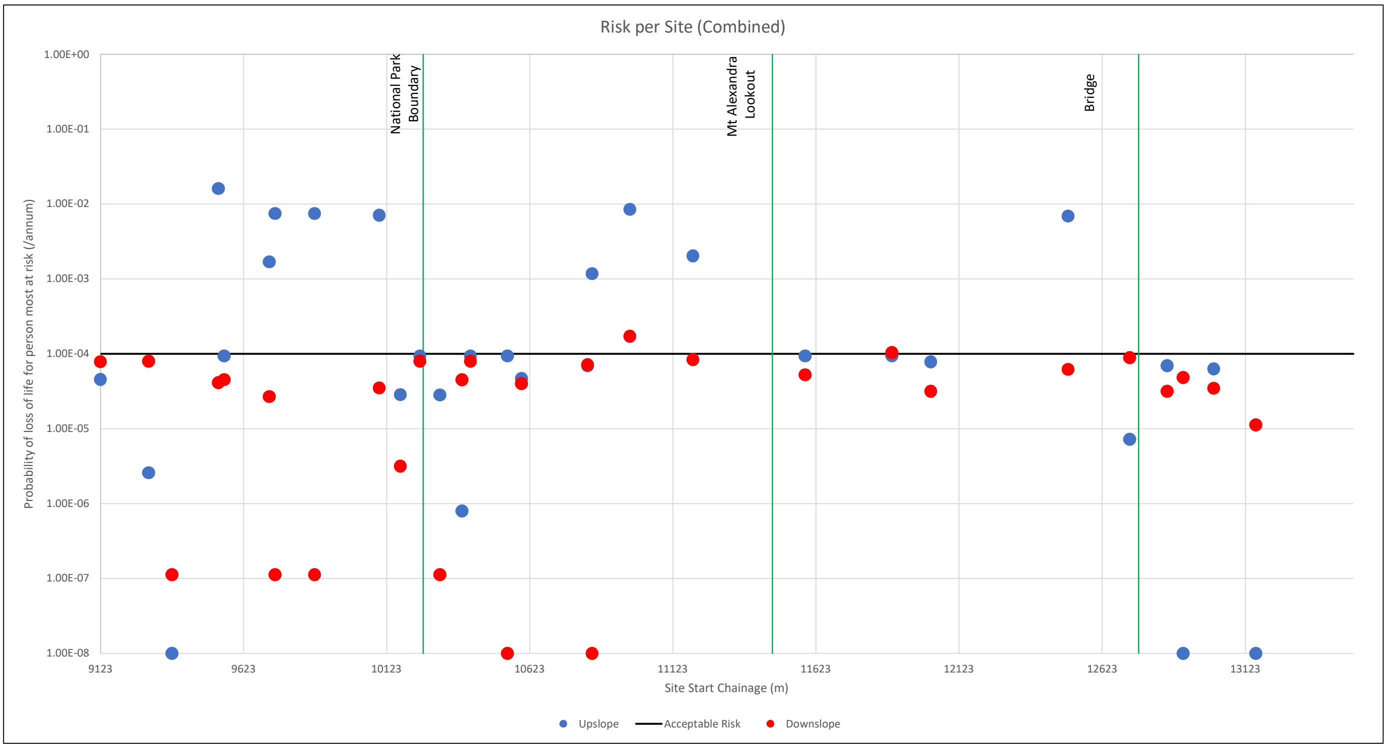
		Assumption	Known	Calc'd	Comment
No of Cuttings	16	x			





RISK ANALYSIS - RISK TO INDIVIDUAL SUMMARY

Site Specification			Risk to Individual	
Sites	Start CH (m)	End CH (m)	Upslope	Downslope
1	9123	9141	4.54E-05	7.84E-05
2	9291	9301	2.58E-06	7.98E-05
3	9373	9402	1.00E-08	1.13E-07
4	9535	9535	1.61E-02	4.13E-05
A1	9555	9693	9.36E-05	4.52E-05
5	9713	9713	1.69E-03	2.69E-05
A2	9733	9858	7.46E-03	1.13E-07
A3	9871	10087	7.46E-03	1.13E-07
6	10097	10132	7.07E-03	3.50E-05
A4	10171	10229	2.85E-05	3.15E-06
7	10239	10299	9.36E-05	7.98E-05
A5	10309	10358	2.82E-05	1.13E-07
8	10386	10406	7.97E-07	4.50E-05
A6	10416	10535	9.36E-05	7.98E-05
9	10545	10584	9.36E-05	1.00E-08
A7	10594	10815	4.68E-05	3.99E-05
10	10825	10831	6.92E-05	7.14E-05
A8	10841	10966	1.18E-03	1.00E-08
11	10973	10995	8.51E-03	1.71E-04
A9	11193	11470	2.03E-03	8.34E-05
A10	11585	11851	9.36E-05	5.25E-05
A11	11888	11975	9.39E-05	1.04E-04
A12	12024	12229	7.80E-05	3.15E-05
12	12504	12524	6.91E-03	6.19E-05
A13	12719	12784	7.22E-06	8.87E-05
13	12850	12859	6.94E-05	3.15E-05
14	12906	12933	1.00E-08	4.83E-05
15	13013	13023	6.30E-05	3.46E-05
16	13160	13175	1.00E-08	1.13E-05



APPENDIX C
Concept Design, Costings and Prioritisation