Natural Hazards Assessment

Oparara Arch Track,

Oparara Basin, Karamea

Report prepared for:

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GEOTECHNICAL WATER RESOURCES PAVEMENTS

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1 Executive Summary

Executive Summary

The proposed Oparara Arch Track realignment is at risk from rockfall and landslide natural hazards. Sections 5 and 6 below provide a review of the identified individual hazards (Rockfall and Landslide) and key geomorphological features, these are also shown on Figure 1a & 1b, Appendix A.

A "Basic-Level Analysis' has been undertaken for the proposed Oparara Arch Track realignment, as prescribed by the "Guidelines for Natural Hazard Risk Analysis on Public Conservation Lands and Water", dated June 2020.

The proposed track is a "Short Walk" as classified by the Department of Conservation (DOC) and is popular with the "Short Stop Travellers (SST)" visitor group. DOC have nominated the Oparara Arch Track as a lower risk tolerance visitor site.

Annual individual Fatality Risk (AIFR) numbers are then calculated for each hazard for the following track users:

- AIFR for the visitor risk per trip;
- AIFR for the most exposed worker;
- AIFR for the most member of the public;

An Annual Likelihood of a Severe Event (ALSE) has also been calculated to determine the Societal risk- defined where there are, 1 or more, 5 or more and 10 or more people that could be killed if a natural hazard of a given magnitude were to occur.

A summary of the risk numbers is provided in Section 8 (Table 8 & 9). The Department of Conservation (DOC) have indicated risk tolerance levels for various track users as provided in Appendix C. Based on the results from Table 8 & 9 and guidelines in Appendix C, the evaluation category results are summarised in Table 9.

Table 9: Risk Tolerance Levels for DOC visitor sites

Track User	Calculated DOC Significance Level	Evaluation Category	Action Required
Risk Per visit	Insignificant	Tolerable	None
DOC Worker	Significant	Tolerable if reduced ALARP	Explore practicable risk reduction options
Societal Risk (1+ fatalities)	Insignificant/ Significant	Tolerable/ Tolerable if reduced ALARP	None/ Explore practicable risk reduction options
Societal Risk (5+ fatalities)	Insignificant	Tolerable	None
Societal Risk (10+ fatalities)	Insignificant	Tolerable	None

2 Introduction

2.1 General

We understand that it is proposed to realign the Oparara Arch track in two areas, as shown in Figure 1a & 1b, Appendix A.

The first area of this realignment, named *"Section 1",* comprises:

- an elevated boardwalk- from the existing track to gantry structure
- a gantry structure- from the elevated boardwalk to the proposed bridge
- a glulam bridge- from the gantry structure to a new section of track
- a new section of track- from the proposed bridge to the existing track. The new track is described as "built into the landscape that traverses a side slope of 18-65 degrees for a further 60m to a point joining the existing track."

It is understood the detailed design of the Section 1 track realignment is being undertaken by others. It is understood that *"where the tracks encounter side slope the trench and stone retaining initiative will be employed",* the suitability of any proposed retaining structures are not within the scope of this report.

The second area of this realignment, named "Section 2", comprises:

- Decommissioning of the last part of the existing track, approximately 50 m, which passes beneath the existing natural bridge structure of the Oparara Arch Complex.
- Formation of approximately 227 m length of new track. The new section will climb up from the river valley (from the existing track) and pass underneath an area of overhanging rock associated with the Oparara Arch complex and into the Arch itself where a designated viewpoint will be formed. The viewpoint will be within the southern portal of the Arch.

It is understood the purpose of the Section 2 track realignment is to remove people from below a natural bridge structure associated with the Oparara Arch complex, where a "failure zone" has been identified. The proposed realignment is understood to be outside the failure zone and rockfall source area of the natural bridge feature, which has not been assessed for the purposes of this report. It is understood that assessment of the fatality risk is required for the proposed track realignment of Section 2. Comparison can then be made to the Department of Conservations (DOC) risk tolerance levels.

This report presents the results of a natural hazard assessment undertaken by GeoSolve Ltd for the proposed track realignment in Section 2. The extent of the study area is shown in Figure 1a, Appendix A. Additional natural hazards have been identified outside of this area and have been included for completeness.

The report has been undertaken in general accordance with the recommendations for a "Basic-Level Analysis" provided in the Geological and Nuclear Sciences Limited (GNS Science) report entitled "Guidelines for Natural Hazard Risk Analysis on Public Conservation Lands and Water", dated June 2020.

The work described in this report has been completed in accordance with the agreed terms conditions of contract, and the GeoSolve Job reference is 210073.

The opinions and conclusions presented in this report are based on the following sources of information:

- A walkover inspection and geomorphological mapping of the site by an engineering geologist.
- A review of a previous Geological Inspection Report prepared for Oparara Arch and Honeycomb Caves by Geotech Ground Engineering, dated 16 November 2016.
- A review of a previous Geological Assessment Report prepared for Oparara Arches-Access and Track Upgrade by WSP, dated 05 August 2020.
- A review of the relevant proposed development documents (Source- Department Of Conservation-DOC)
- A review of the 8m Digital Elevation Model (DEM) for the area (Source- LINZ).
- A review of the available current and historic imagery
- A review of the GNS Landslide Inventory & Active Fault Database.
- A review of the published geological map, 'Institute of Geological & Nuclear Sciences Ltd, Geology of the Nelson, 1:25,0000 Geological Map 9'

2.2 Site location and Description

The Oparara Arch complex is located within the Oparara Basin, Kahurangi National Park, approximately 30 minutes from Karamea in the Buller District of the West Coast, as shown in Figure 1.

Figure 1: Location of the subject site-Red Arrow (Source-Topomap.co.nz)

The Oparara Arch complex is located adjacent to the Oparara River, where the outcropping limestone bedrock has been subject to long-term chemical weathering (dissolution) typical of karst landscapes. As the arch is approached from the south two existing limestone bluffs are present on the true left and true right of the Oparara River. The arch feature, trending NE-SW, connects these two bluffs above the river. Granite bedrock underlies the limestone bluffs. Mechanical erosion of the underlying granite has resulted in incision of the floor of the main arch to a depth of approximately 5-6 m below the base of the limestone, as shown in Photograph 4. The arch is approximately 200 m in length, 49 m in width and 37 m in height.

The extent of the two limestone bluffs have been traced, where applicable, the following extents have been noted:

The toe of the eastern limestone bluff (with granite underlying) appears to follow the shoreline of the Oparara River for approximately 200 m downriver of the southern portal of the main arch, before returning into the hillside, as shown in Figure 1a.

The toe of the limestone bluff on the western side of the Oparara River, downriver of the southern portal of the arch, appears to return into the hillside in a north western direction. The limestone bluff is overhanging immediately adjacent to the southern portal, transitions to a subvertical face (absent of an overhang) and continues to track in a north-western/northern direction away from the study area. The proposed Section 2 track realignment is to be located adjacent to the toe of the limestone bluff on the western side of the Oparara River, as shown in Figure 1a.

Adjacent to the southern portal of the arch it is inferred that historic erosion and/or dropout of the limestone has occurred. This has created an isolated natural bridge feature approximately 20-40 m south of the portal of the arch. The natural bridge spans between the eastern limestone bluffs and the overhanging part of the western limestone bluff.

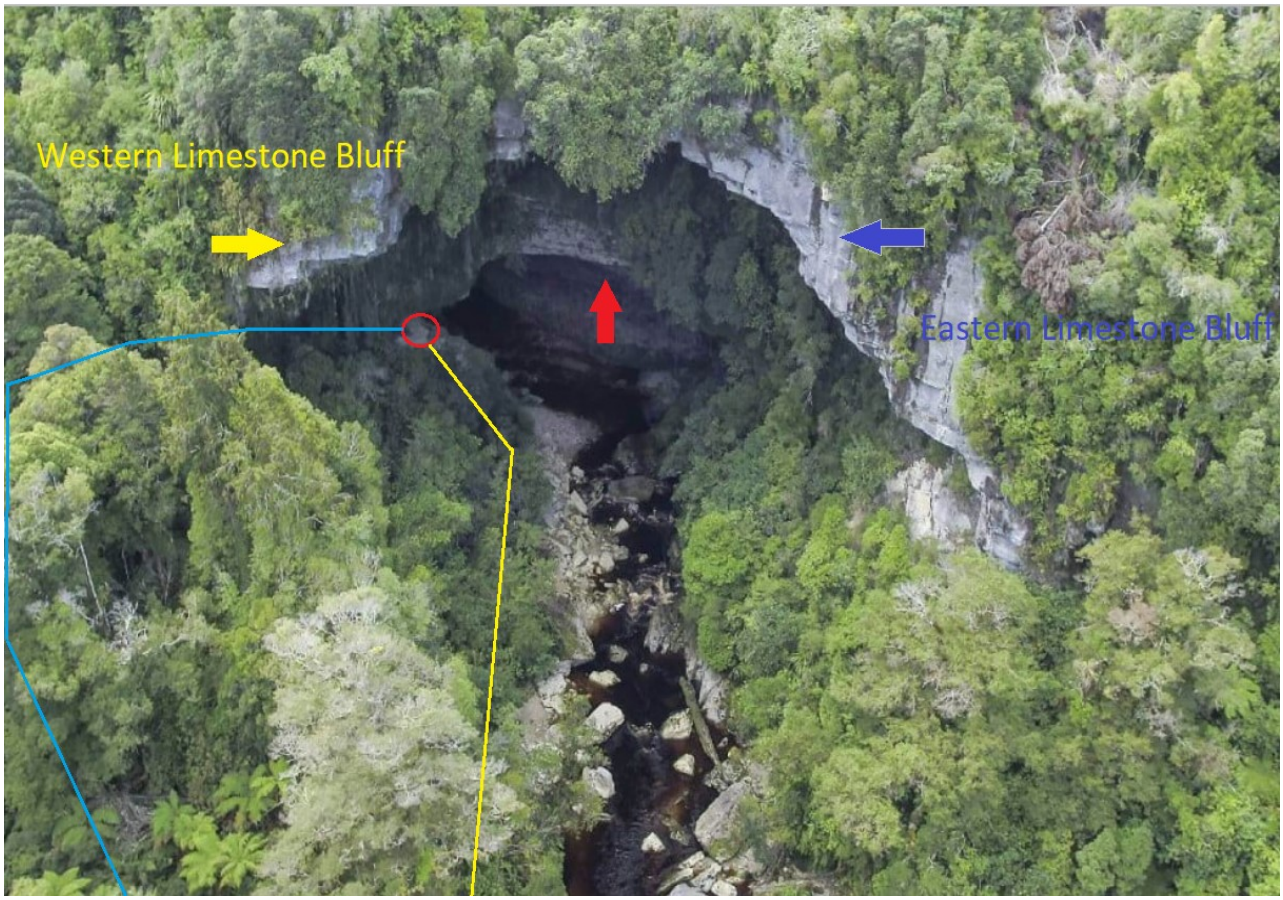
In summary, the Oparara Arch Complex, comprises the following main features:

- The main Arch feature (southern portal)
- A natural overhanging southern bridge feature
- The eastern and western limestone bluffs (with granite underlying)
- A remaining overhanging area adjacent to the bridge feature (above the proposed new track), formed on the western limestone bluff.

Additional features to note are:

- The Oparara Arch Walking Track (proposed and existing);
- The Oparara viewpoint- within the southern portal of main arch feature.
- Photograph 1, Photograph 2 below, and Figure 1a &1b (Appendix A) show the location of these areas and key features of the site.

The subject site is located in an area of dense native bush vegetation, subject to warm temperatures and high rainfall. This promotes rapid growth of vegetation potentially obscuring historic and relatively recent geomorphological features.



Photograph 1: General view of the Oparara Arch Complex from the south. The Natural Bridge feature (blue arrow) is located in front of the southern portal of the main arch (red arrow). The existing track is shown as a yellow line and the proposed track realignment is shown as a blue line. An overhanging area exists (yellow arrow) above the proposed track and is attached to the bridge feature, and southern portal of the arch feature. The existing viewpoint area (underneath the main arch) is shown by a red circle. Rockfall debris material can be observed within the active Oparara River channel. (Source-AirNewZealand)

Photograph 2: General view of the Oparara Arch Complex. The existing area of dropout between the bridge feature and the southern portal of the arch feature, as shown by the red arrow. The existing track is shown as a yellow line and the proposed track is shown as a blue line. The overhanging area of the western limestone bluff is shown by the yellow arrow, and is located above the proposed track (blue line). The overhang is attached to the natural bridge and southern portal of the arch. The existing viewpoint area (underneath the main arch) is shown by a red circle.

3 Geological Conditions

3.1 General

All opinions, conclusions and recommendations that are presented in this report are based on observed surface exposures. Figure 1a & 1b, Appendix A, illustrates the indicative shallow subsurface ground conditions for the study area. Geological materials present in the study area are described below.

Uncontrolled Fill- is sporadically present and variable in composition. These areas are inferred to be recently placed to create erosion protection structures and for the formation of the access track.

Alluvial deposits- Deposits of alluvial river gravels and sands are present within, and adjacent to, the Oparara River and tributaries. These sediments comprise fine to coarse sandy subrounded gravels with granite and limestone cobbles and boulders.

Colluvium- Surficial bouldery colluvium extending to the underlying limestone and granite bedrock is present on the slopes surrounding the site.

Limestone- The Oparara Arch complex comprises a relatively thin layer of undifferentiated Nile Group Limestone, comprising "crystalline to sandy limestone and calcareous mudstone and sandstone" of Palaeogene age. Additional exposures were identified at isolated high points within the northern parts of the Oparara Arch Track. Exposures were also identified adjacent to the existing track and along the Oparara River shoreline, within the southern part of the Oparara Arch Track.

Granite- The Oparara Basin is founded on the Karamea Suite (Batholith), comprising "megacrystic K-feldspar-biotite granite, of Carboniferous age. Granite exposures were identified underlying the Oparara Arch Complex, adjacent to the Oparara Arch Track, and Oparara River shoreline.

Seismic- A review of the GNS active fault database has been conducted for the purposes of this report. No active fault traces are known by GeoSolve to exist in the immediate vicinity of the site, although an inactive fault trace (Kohaihai Fault) is shown to be present approximately 3500 m to the east.

The greatest known seismic risk exists from potentially strong ground shaking associated with a rupture of the Alpine Fault, located 90 km northwest of the Oparara Arch along the West Coast of the South Island. There is a high probability that an earthquake with an expected magnitude of over MW 8 will occur along the Alpine Fault in the next 50 years.

The Glasgow Fault and northern part of White Creek Fault complex are located over 25 km to the south of the site and are understood to have an unknown or very high reoccurrence interval period based on the GNS active fault database. However, the Glasgow Fault is suspected to merge into the Inangahua Fault (that last ruptured in 1968) and the southern part of the White Creek Fault ruptured in 1929 Murchison earthquake. Therefore, seismic risk exists from potentially strong ground shaking associated with a rupture on the Glasgow and White Creek Faults.

3.2 Natural Hazards

The natural hazards identified on site, and covered by this report include:

a) Rockfall
b) Landslide

Each hazard is discussed in detail in the Sections below.

4 Risk Assessment - General

4.1 General

Sections 5 and 6 below provide a review of the identified individual hazards (rockfall and landslide) and key geomorphological features. Annual individual Fatality Risk (AIFR) numbers and societal risk are then calculated for each hazard. Assumptions made to calculate the AIFR and societal risk numbers are provided in each relevant Section. A summary of the risk numbers is then provided in Section 7, Table 7 & 8. Risk calculations are provided in Appendix B.

The risk assessment method generally follows the approach used for assessing the annual probability for loss of life (death) of an individual from rockfalls[1] and cliff collapse[2] of the Port Hills, this approach was adapted from AGS 2007[3]. These methods have been adopted in the GNS guideline documents for risk analysis.

4.2 Oparara Arch Track Occupancy Rates

4.2.1 General

A key assumption for the AIFR calculation is the occupancy rate of track within a particular hazard zone for various users. The track users outlined below have been considered:

- AIFR for the visitor risk per trip;
- AIFR for the most exposed worker;
- AIFR for the most exposed member of the public;
- An Annual Likelihood of a Severe Event (ALSE) has also been calculated to determine the societal risk - defined into three separate categories:
    - the likelihood of 1 or more fatalities per annum
    - the likelihood of 5 or more fatalities per annum
    - the worst-case scenario (assumed to be the likelihood of 10 or more fatalities per annum)

4.2.2 Primary Hazard Zone (Rockfall)- Oparara Arch Complex

As discussed, the proposed track is located adjacent to the toe of a limestone bluff on the western side of the Oparara River. The track users within this location are subject to rockfall from the southern portal of the Oparara Arch and the overhanging and sub-vertical sections of the western limestone bluff. The track occupancy rates used in the

[1] Massey, C. I., et al. "Canterbury earthquakes 2010/11 Port Hills slope stability: life-safety risk from rockfalls (boulder rolls) in the Port Hills." *GNS Science Consultancy Report* 123 (2012): 34

[2] Massey, C. I., et al. "Canterbury Earthquakes 2010/11 Port Hills Slope Stability: Pilot study for assessing life-safety risk from cliff collapse." *GNS Science Consultancy Report* 57 (2012)

[3] Australian Geomechanics Society, Volume 42, No. 1 March 2007.

assessment are provided in Table 1 below. The occupancy rates reflect projected visitor numbers of approximately 26,000 people per year, as provided by DOC. Current visitor numbers have not been assessed.

Table 1: The assumed occupation rates for the various track users within the Oparara Arch Complex

Track Users	Description (below the Oparara Arch Complex)	Occupation Proportion (per year)
Risk Per Visit	15 mins per year (assuming one trip to arch per year) - 0.25 hours/8760 hours	2.85E-05 or 0.0000285
DOC worker	96 hours per year (assuming one day (8hours) per month for maintenance)- 96/8760 hours	1.10E-02 or 0.011
Most Exposed member of the public	65 hours per year (guided trip leader, assuming 15 mins per day, 5 days per week) 65/8760 hours	7.42E-03 or 0.00742
Societal Risk (1 or more fatalities)	2737.5 hours per year (assuming 30 groups per day of 1 or more persons, spending 15 mins in area= 7.5hours per day)	3.13E-01 or 0.3125
Societal Risk (5 or more fatalities)	273.5 hours per year (assuming 3 groups per day of 5 or more persons, spending 15mins in area= 45mins per day)	3.12E-02 or 0.0321
Societal Risk (Worst case scenario- 10 or more fatalities)	39 hours per year (assuming 1 group per day of 10 or more persons, spending 15mins in area= 15mins per day, 3 days per week)	4.45E-03 or 0.00445

4.2.3 Secondary Hazard Zones-Northern Facing Rock Fall Area

The track occupancy rates for time spent beneath the north facing rock fall area, and used in the assessment, are provided in Table 2

Table 2: The assumed occupation rates for various track users on northern facing rock fall area.

Track Users	Description (below the north facing rockfall area)	Occupation Proportion (per year)
Risk Per Visit	2 min per year (assuming one trip to arch per year) 0.033/8760 hours	3.80E-06 or 0.00000380
DOC worker	12 hours per year (assuming one day (1hour) per month for maintenance) 12/8760	1.37E-03 or 0.00137
Most Exposed member of the public	8.8 hours per year (guided trip leader, assuming 2 mins per day, 5 days per week) 8.8/8760	1.00E-03 or 0.001
Societal Risk (1 or more fatalities)	365 hours per year (assuming 30 groups per day of 1 or more persons, spending 2 mins in area= 1hours per day)	4.17E-02 or 0.0417
Societal Risk (5 or more fatalities)	36.5 hours per year (assuming 3 groups per day of 5 or more persons, spending 2 mins in area= 6mins per day)	4.17E-03 or 0.00417
Societal Risk (Worst case scenario- 10 or more fatalities)	5.2 hours per year (assuming 1 group per day of 10 or more persons, spending 2 mins in area= 2 mins per day, 3 days per week)	5.94E-04 or 0.000594

5 Rockfall Hazard

5.1 Rockfall- Oparara Arch Complex

5.1.1 Geomorphological Observations:

The proposed track is located within, and adjacent to, the Oparara Arch Complex. The track users within this location are subject to rockfall from:

- The southern portal of the Oparara Arch.
- The overhanging and sub-vertical sections of the western limestone bluff.

This rockfall hazard is inferred to be the primary natural hazard risk to users of the proposed track. A summary of the key geological mapping observations are presented below.

Western Limestone Bluff – Subvertical Section

The far western part of the limestone bluff is sub-vertical with no obvious overhanging sections. The bluff in this location is heavily vegetated and the full vertical extent could not be determined and could not be inspected in detail.

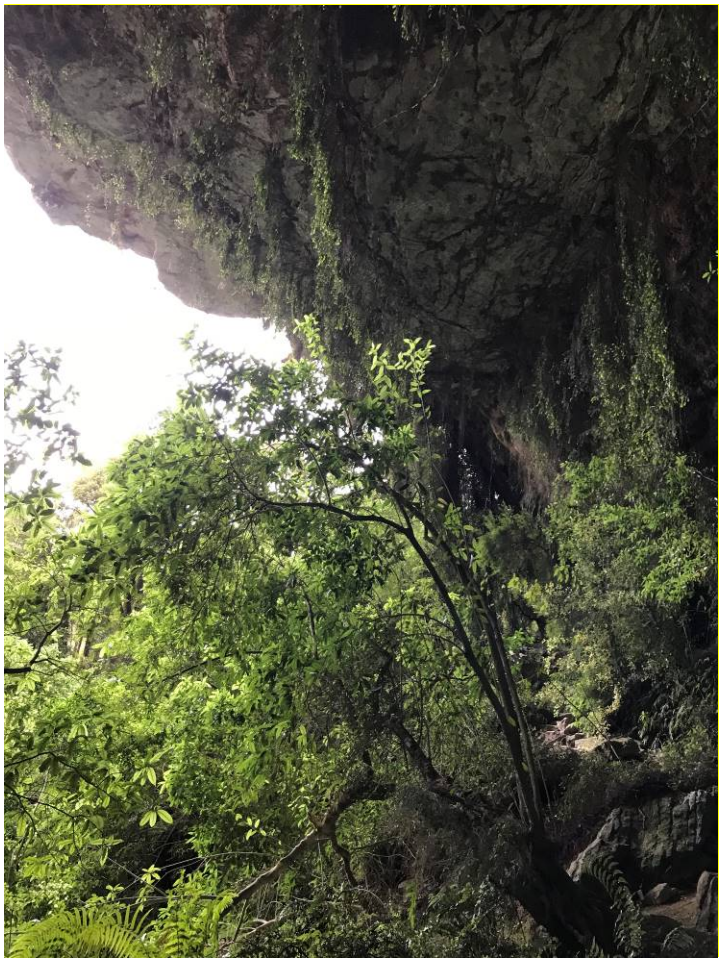
Cross-sections provided for the proposed track location show the bluff is up to approximately 30 m in vertical height. The distance between the proposed track and the toe of the sub-vertical limestone bluff varies between approximately 10-30 metres.

Isolated rockfalls were located at the toe of the bluff, with volumes ranging between 0.25-1.0m^3. An assessment of the rockmass determined that future rockfall of the larger observed volumes could be possible from a seismic trigger. Rockfall triggered under typical daily conditions (i.e. weathering, rainfall and erosion) are inferred to result in smaller volumes of 0.5m^3 or less.

Western Limestone Bluff- Overhanging Section

This sub-vertical bluff meets the overhanging section that then continues to the southern portal of the Oparara Arch. For the overhanging section the proposed track is located approximately 3-5 metres from the toe of the bluff.

The overhanging section extends horizontally out from the bluff toe by an estimated 15-20+ metres at its longest reach. Photograph 3 below, shows a general view of the overhang.



Photograph 3 – Western Limestone Bluff Overhang Section. The proposed track is located at the toe of this bluff and under the overhang.

The overhang is controlled by the limestone bedding plane with persistent stacked cantilevered limestone beds rising to the extent of the overhang. The bedding dips gently back into the bluff and is typically moderately thick (02-0.6 m).

The limestone mass directly above the proposed track (inner section of the overhang) is generally free from fresh or recent rockfall scarps, and reduced secondary defect occurrence.

The overhang is vegetated, as shown in Photograph 3, and root jacking is expected to be acting as a rockfall trigger in this area. The extent of this trigger mechanism is inferred to be limited to the surface of the rock mass.

Isolated cracks within the overhanging rock mass provide areas of preferential erosion/seepage from above and are potential rockfall source areas. Triggering mechanisms are unclear however loss of strength through long term dissolution or increase groundwater pressure during periods of high rainfall, coupled with seismic shaking are inferred.

The observed cracks are inferred to be defect/joint controlled and are observed to dip steeply to the south-west with very wide spacing. This defect orientation appears to control the horizontal extent of the natural bridge structure, being present on the northern

and southern aspects. The defect is persistent and continues into the rock mass of the Oparara Arch complex.

The rockmass of the outer section of the overhang appears to be controlled by a widely spaced to very widely spaced SE/NW trending subvertical joint set.

The 2 defect sets are present throughout the Oparara Arch Complex, specifically the outer edges of the overhanging sections. Intersection of the joint sets with the sub-horizontal bedding forms "drop-out" rockfall blocks of various volumes

The proposed track is located on an existing ledge adjacent to the toe of the bluff. The ledge is observed to comprise a granite base with overlying colluvium and historic rockfall boulders.

The existing rockfall boulders at the location of the proposed track are generally embedded into the colluvium soils. This suggests a significant period of time since failure. It is understood, anecdotally, that no rockfall has been observed at this location since informal records have begun, circa 1980's, and no indications of fresh or recent rockfall was observed during the inspection.

The rockfall boulders observed within the area of the proposed track are generally of lower volume (approximately 0.2 to 1.0m^3) than the defect controlled "drop-out" rockfall boulders falling from the outer edge of the overhang area, the bridge feature and southern portal of the Oparara Arch. In these locations volumes of approximately 1.0-10m+^{3} where observed.

For the overhanging section, the proposed track location appears to be protected from the potential of larger "drop-out" rockfall, which is occurring on the outer edge of the overhang.

Seismic and non-seismic triggers are inferred to produce rockfall of similar volume to that observed at the location of the proposed track (approximately 0.3 to 1.0m^3).

Southern Portal of the Oparara Arch

The viewpoint area is located within the main arch feature, adjacent to the southern portal, see Photograph 4.

The proposed access to the viewpoint is via the toe of the western limestone bluff.

The viewpoint is located on a natural ledge feature comprised of historic rockfall debris, alluvium deposits and underlying granite bedrock. The ledge slopes moderately to the Oparara River forming a stable bench for the location of the viewpoint, which also buttresses the western wall of the arch structure, limiting further incision to the area.

The historic rockfall in this area is of large volume and inferred to be defect controlled and caused by incision of the Oparara River. Inspection of the source areas for this rockfall shows the surface is generally free from fresh or recent rockfall scarps, and reduced secondary defect occurrence.

No intersecting defects causing large volume rockfall potential were observed within this area. The rockfall potential of the area is inferred to be similar to the western limestone bluff, i.e. smaller volume rockfall potential.

It is understood, anecdotally, that no rockfall has been observed at this location since informal records have begun, circa 1980's.

Stalactites are present at the southern portal and pose a minor rockfall risk.

Photograph 4 –Southern Portal of the Oparara Arch and viewpoint location. Note large limestone rockfall boulders adjacent to the viewpoint ledge. The limestone/granite boundary is visible on the east wall and stalactites can be seen on the west wall.

5.1.2 Trigger Events

The timing of the last significant rockfall event on the proposed track realignment is unknown.

Initial rockfall is expected to have resulted from dissolution and incision of the Oparara river into the limestone, forming a weakened, defect-controlled rock mass that was susceptible to instability given its overhanging profile.

Ongoing large seismic events (with high reoccurrence interval periods) are likely to have caused large scale rockfall of the outer overhanging sections

Large seismic events could also produce isolated rockfall of smaller volume potential, at proposed track location.

Lower volume rockfall events are also evident and are inferred to be occurring on a more frequent basis from the following non-seismic triggering events:

- Weathering of the limestone- chemical or mechanical.
- Stress induced failures- release of the cantilevered limestone beds.
- Vegetation drop out- root jacking of the rock mass.

As discussed, small volume rockfall (>1.0m^3) was observed on the proposed track adjacent to toe of the western limestone bluff. The volume of the mapped rockfall boulders shows that only smaller scale rockfall events have occurred in this area, with no obvious significant events occurring for 40+ years (anecdotal).

Historic large rockfall boulders were observed below the outer edges of the overhanging areas and below the natural bridge feature. The presence of these larger rockfall boulders is in agreement with the geomorphological observations made of the rockmass, which indicates greater potential for larger volume failures on the outer edge of the overhang.

As noted above, no fresh rockfall scarps or rockfall boulders were identified at the site and since anecdotal rockfall record keeping has commenced no obvious rockfall events have been noted. This provides a rough indication of the return period of rockfall events and is in agreement with the site observations.

It should be noted that no large seismic events (Alpine, Glasgow & White Creek Fault ruptures) have occurred since anecdotal rockfall record keeping commenced and no correlation between a seismic trigger and extent/nature of rockfall could be made. The relationship between rockfall and seismicity has therefore been inferred.

Given the nature of the rockfall source areas, and seismic environment, four rockfall scenarios have been calculated for the purpose of the risk assessment:

- Scenario One- 1:10-year event: representing “background/general” conditions. For this scenario isolated small rockfall are considered possible, less than 0.3m3.
- Scenario Two- 1:50-year non-seismic event: representing a larger than normal “background/general” condition. For this scenario small to moderate rockfall are considered possible, 0.3-1.0m3.
- Scenario Three- 1:100-year seismic & non-seismic event: representing a significant seismic or natural triggering event. For this scenario the maximum observed rockfall boulders at the location of the proposed track are inferred, approximately 1.0-2.0m3.
- Scenario Four- 1:1000-year seismic event: representing the largest volume failure scenario. For the purposes of the risk assessment a volume of 25m3 has been adopted within the highest risk zone of the site. Ongoing dissolution of the overhanging limestone features weakening the rock mass and large-scale collapse during a large seismic event. This event is possible over a geological time scale; however, the return period of such triggering event is likely to be very high (larger than that suggested). This triggering event has been included in this assessment for completeness. The underlying granite base aids in the long-term stability of the feature above the proposed track location and significantly reduces future rates of mechanical incision.

The bridge structure, as previously identified is subject to ongoing rockfall and potential future collapse in a high return period event. It should be noted that the proposed track is outside the failure zone of this area and therefore the natural bridge structure has not been assessed for the purposes of this report.

5.1.3 Quantitative Risk Assessment

5.1.3.1 General

This section presents the results of a quantitative risk assessment to clarify the risk of rock fall to track users from the Oparara Arch Complex.

The proposed track length within primary rockfall hazard zone is approximately 50-60 metres, from the "saddle area" to the viewpoint terminus. The track is understood to be approximately 1.2 m in width with a slightly larger viewpoint area. A total track surface area within the rockfall hazard zone of 75 m^2 has been assumed for the assessment and an individual track user's footprint of 0.5m^2 has been inferred.

Based on the above, the probabilities for spatial impact (rockfall impact) for the various track users within the Oparara Arch Complex that have been used in the assessment are shown in Table 3 below.

Table 3: The assumed probability of spatial impact for the various track users within the track at the Oparara Arch Complex

Track Users	Description	Spatial Impact probability
Risk Per Visit, Doc Worker & Most Exposed member of the public	1 person assumed- 0.5m^2 footprint with a 75m^2 hazard footprint	6.67E-03
Group of 2 or more	2 person assumed- 1.0m^2 footprint with a 75m^2 hazard footprint	1.30E-02
Group of 5 or more	5 person assumed- 2.5m^2 footprint with a 75m^2 hazard footprint	3.30E-02
Group of 10 or more	10 person assumed- 5m^2 footprint with a 75m^2 hazard footprint	6.67E-02

5.1.3.2 Scenario One-Assumptions and Inputs

The probability of a non-seismic triggering event is inferred to be 1 in 10 years (1.0×10^{-1}) for this scenario.

Table 1 outlines the inferred track occupation rates within the rockfall hazard zone.

Table 3 outlines the spatial impact probability within the rockfall hazard zone.

A person in open space if struck by rockfall may be injured however death is unlikely to results and a vulnerability of 0.2 has been adopted (inundation not expected-high chance of survival) for an individual present in the rock fall path (AGS 2007c, Practice Note for Landslide Risk Management, Appendix F).

It is inferred that rockfall impact from this hazard will only affect an individual person, due to the small volume, and therefore a societal risk is not present.

5.1.3.3 Scenario Two-Assumptions and Inputs

The probability of a non-seismic triggering event is inferred to be 1 in 50 years (2.0×10^{-2}).

Table 1 outlines the inferred track occupation rates within the rockfall hazard zone.

Table 3 outlines the spatial impact probability within the rockfall hazard zone.

A person in open space if struck by rockfall will be at greater risk of death. A vulnerability of 0.50 has been adopted for an individual present in the rock fall path (AGS 2007c, Practice Note for Landslide Risk Management, Appendix F).

With respect to societal risk it is inferred that rockfall impact from this volume could affect a group of 2 or more people but will not affect a group of 5 or more people.

5.1.3.4 Scenario Three-Assumptions and Inputs

The probability of a non-seismic and seismic triggering event is inferred to be 1 in 100 years (1.0×10^{-2}) for this scenario.

Table 1 outlines the inferred track occupation rates with the rockfall hazard zone.

Table 3 outlines the spatial impact probability within the rockfall hazard zone.

A person in open space if struck by rockfall has an equal likelihood of injury or death and a vulnerability of 0.50 has been adopted for an individual present in the rock fall path (AGS 2007c, Practice Note for Landslide Risk Management, Appendix F).

With respect to societal risk it is inferred that rockfall impact from this volume could affect a group of 5 or more people, however a group of 10 or more people would not be affected.

5.1.3.5 Scenario Four-Assumptions and Inputs

The probability of a natural triggering event that could strike a track user is inferred to be 1 in 1000 years (1.0×10^{-3}).

Table 1 outlines the inferred track occupation rates with the rockfall hazard zone.

Table 3 outlines the spatial impact probability within the rockfall hazard zone.

A person in open space will be inundated by rockfall and a vulnerability of 1.0 has been adopted for an individual present in the rock fall path (AGS 2007c, Practice Note for Landslide Risk Management, Appendix F).

For societal risk inundation of a significant portion of the track is assumed and 10+ fatalities is considered possible.

5.1.4 Summary

Table 4 below summarises the risk assessment assumptions and inputs for the 4 scenarios described above.

Table 4: Summary of assumptions and inputs for the risk assessment

Scenario	Event Description	Rock fall volume (m^3)	Return Period	Vulnerability	Societal Risk
1	Non-seismic, typical background conditions, smaller volume and more frequent return interval.	0.3	1:10 years (1×10^{-1})	0.2 Unlikely to result in death	Non Individual only
2	Non-seismic, typical background conditions, with a larger volume and longer return period when compared to Scenario 1.	0.3 to 1.0	1:50 years (2×10^{-2})	0.5 Equal likelihood of death or injury if struck	1+ fatalities only. 5+ fatalities not considered credible
3	Large seismic event, e.g. Alpine Fault, resulting in an increased rock fall volume when compared to Scenarios 1 and 2.	1.0 to 2.0	1:100 years (1×10^{-2})	0.5 Equal likelihood of death or injury if struck	Up to 5+ fatalities considered credible, 10+ not credible.
4	Major Collapse effecting a significant portion of the track	> 25	1:1000 years (1×10^{-3})	1 Full inundation and death expected.	10+ considered credible, worst case scenario.

From Table 4 it can be seen that the 4 scenarios present a staged increase in failure volume, and corresponding reduction in likelihood of occurrence e.g. the least likely to occur is a major collapse, whilst small volume failures are more frequent. Vulnerability also reflects the change in volume, i.e. the greater the volume the more likely death is to occur if the person is struck by the rock fall.

5.1.4.1 Results

Based on the assumptions outlined above, the AIFR and ALSE results have been calculated for the 4 scenarios outlined above and are shown in Table 5.

Table 5: The AIFR & Societal Risk for various track users from the Oparara Arch rockfall hazard

Person Most at Risk	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Total
AIFR Risk Per Trip	3.80E-09	1.90E-09	1.90E-09	1.90E-10	**7.79E-09**
AIFR DOC Worker	1.47E-06	7.33E-07	7.33E-07	7.33E-08	**3.01E-06**
AIFR-Most Exposed Public	9.89E-07	4.95E-07	4.95E-07	4.95E-08	**2.03E-06**
Societal Risk (1+ fatalities) (ALSE)	n/a	4.06E-05	4.06E-05	4.06E-06	**8.53E-05**
Societal Risk (5+ fatalities) (ALSE)	n/a	n/a	1.06E-05	1.06E-06	**1.17E-05**
Societal Risk (10+ fatalities) (ALSE)	n/a	n/a	n/a	2.97E-07	**2.97E-07**

5.1.4.2 Sensitivity Analysis

The results in Table 5 reflect the assumptions used, which we feel are reasonable. However, as there is some subjectivity involved, a sensitivity analysis has been conducted to provide an upper bound range of AIFR and ALSE values assuming a higher occupation of the track by the various users. The other assumptions remain constant. The upper bound occupation proportion by the various track users is provided in Table 6 and the results are presented in Table 7.

Table 6: The assumed upper bound occupation rates for the various track users within the track at the Oparara Arch Complex

Track Users	Description	Occupation Proportion (per year)
Risk Per Visit	30 mins per year (assuming one trip to arch per year) - 0.5hours/8760 hours	5.71E-05 or 0.0000571
DOC worker	192 hours per year (assuming two days (16 hours) per month for maintenance)- 192/8760 hours	2.19E-02 or 0.0219
Most Exposed member of the public	130 hours per year (guided trip leader, assuming 30mins per day, 5 days per week) 130/8760 hours	1.48E-02 or 0.0148
Societal Risk (1 or more fatalities)	3650 hours per year (assuming 30 groups per day of 1 or more persons, spending 30mins in area= 10 hours per day- some overlap assumed)	4.17E-01 or 0.417
Societal Risk (5 or more fatalities)	546 hours per year (assuming 3 groups per day of 5 or more persons, spending 30mins in area= 1.5 hours per day)	6.42E-02 or 0.0642
Societal Risk (Worst case scenario- 10 or more fatalities)	78 hours per year (assuming 1 group per day of 10 or more persons, spending 15mins in area= 30mins per day, 3 days per week)	8.90E-03 or 0.00890

Table 7: The AIFR & Societal Risk for various track users from the Oparara Arch Complex rockfall hazard (Sensitivity Analysis- for higher occupation time)

Person Most at Risk	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Total
AIFR Risk Per Trip	7.61E-09	3.81E-09	3.81E-09	3.81E-10	**1.56E-08**
AIFR DOC Worker	2.92E-06	1.46E-06	1.46E-06	1.46E-07	**5.99E-06**
AIFR-Most Exposed Public	1.97E-06	9.87E-07	9.87E-07	9.87E-08	**4.04E-06**
Societal Risk (1+ fatalities) (ALSE)	n/a	5.42E-05	5.42E-05	5.42E-06	**1.14E-04**
Societal Risk (5+ fatalities) (ALSE)	n/a	n/a	2.12E-05	2.12E-06	**2.33E-05**
Societal Risk (10+ fatalities) (ALSE)	n/a	n/a	n/a	5.94E-07	**5.94E-07**

5.1.5 Conclusions

Geomorphic evidence suggests there is a very low probability of large rockfall events affecting the various track users of the proposed track, adjacent to the toe of the western limestone bluff. No recent rockfall events have been observed at the site. However, there is

the potential for relatively frequent smaller rockfall events to affect the proposed track location.

AIFR numbers have been calculated for the various track users assuming various failure volumes and frequencies. A sensitivity analysis which assumes increased time in the hazard zone was then completed.

The results of the sensitivity analysis shows that increasing the time spent within the hazard zone will affect the AIFR and ALSE numbers by less than an order of magnitude.

Based on the above sensitive review, the AIFR and ALSE numbers calculated above are considered to be reasonable and within the correct order of magnitude.

A risk to life assessment has been conducted and is considered to be low to moderate (10^{-6} –10^{-8}).

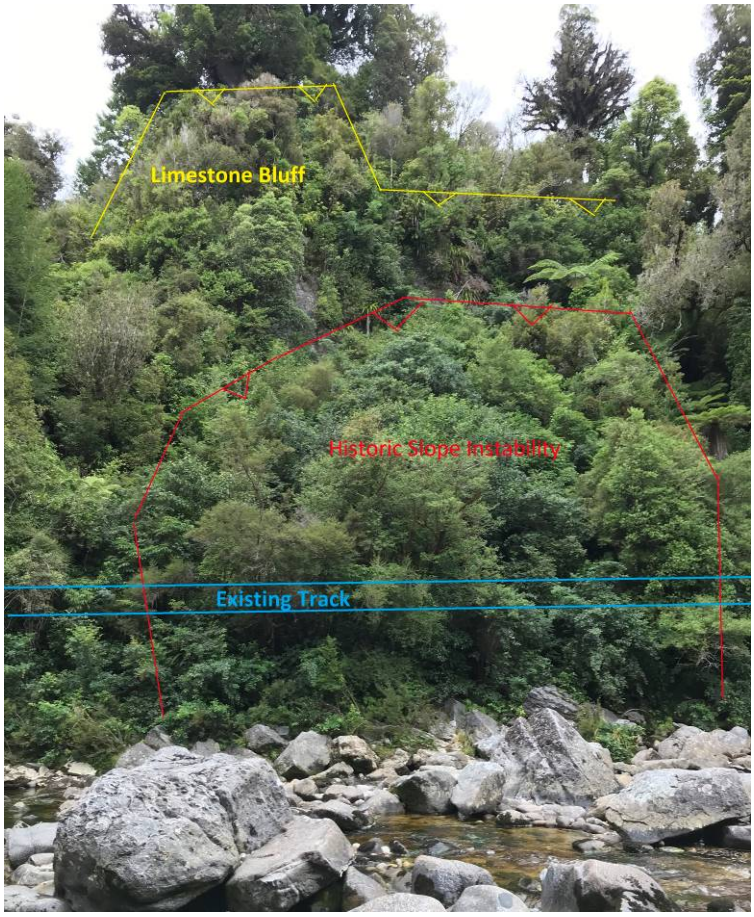
An Annual Likelihood of a Severe Event has been conducted and is considered to be low to moderate (10^{-4} –10^{-7}).

5.2 Rockfall- North Facing Slopes

5.2.1 Geomorphological observations

Historic slope instability of the north facing slopes adjacent to the existing track has been identified. The slope instability removes the soil veneer exposing limestone bedrock in isolated locations, as shown on Photograph 5. The head scarp contains limestone bedrock outcrops of varying heights (2-10m+ high) that are considered to be source areas for rockfall. The location of this area is shown on Figure 1a, Appendix A.

Limestone boulders are located adjacent (upslope and downslope) to the existing track and are inferred to be landslide debris from the historic slope instability. Mapped fallen boulders typically ranged in size from 0.5-5m³, with a large boulder perched immediately above the exiting track.



Photograph 5 –North Facing Slopes. Historic slope instability (Red) & rockfall source area (Yellow)

5.2.2 Quantitative Risk Assessment

This section presents the results of a quantitative risk assessment to clarify the risk of rock fall to track users from the limestone bluff.

5.2.2.1 Assumptions and Inputs

The probability of a non-seismic event generating rock fall that could impact the existing track is inferred to be 1 in 100 years (annual probability of 0.01 or 1%).

The probability of a seismic event (alpine fault rupture) is inferred to be certain in the next 100 years (0.01 or 1%).

Table 2 outlines the inferred track occupation rates within the rockfall hazard zone.

The length of track within of this rockfall hazard zone is approximately 30 m in length. The width of a person is assumed to be 1 m., resulting in a spatial impact probability of 3.33E-02.

A person in open space if struck by rockfall may be in injured but is unlikely to cause death (inundation not expected) and a vulnerability of 0.50 has been adopted for an individual present in the rock fall path (AGS 2007c, Practice Note for Landslide Risk Management, Appendix F).

No societal risk numbers have been calculated for this source area as it is judged that rockfall impact from this hazard will only affect an individual person.

5.2.2.2 Results

Based on the assumptions outlined above, the following AIFR results have been calculated for a 1:100 a non-seismic and seismic event;

- Risk Per Visit- An AIFR of 1.27 x 10-9 is calculated.
- DOC Worker- An AIFR of 4.57 x 10-7 is calculated.
- Most Exposed Member of Public- An AIFR of 3.33 x 10-7 is calculated.

A sensitivity analysis was conducted to reduce the triggering period to a 1:50 natural and seismic event. The following AIFR results have been calculated for a 1:50 natural and seismic event;

- Risk Per Visit- An AIFR of 2.53 x 10-9 is calculated.
- DOC Worker- An AIFR of 9.13 x 10-7 is calculated.
- Most Exposed Member of Public- An AIFR of 6.67 x 10-7 is calculated.

5.2.3 Conclusions

A risk to life assessment has been conducted and is considered to be very low (10^{-7} –10^{-9}) and has only been included for completeness in the assessment. The primary rockfall hazard to the proposed track development is Oparara Arch Complex. No significant additional risk to users of the track results from the north facing rockfall hazard.

Based on the above sensitive review, the AIFR numbers calculated above are considered to be reasonable and within the correct order or magnitude.

6 Landslide Hazard

6.1 North Facing Slopes

As mentioned above and shown in Photograph 5 and Figure 1a Appendix A, a historic landslide is present on the north facing slopes of the site. The slope instability is inferred to be rainfall triggered landslide, potentially in combination with toe incision from the Oparara River. The initial translational failure is reported to be approximately 30 years ago and is approximately 2000-3000 m^3.

Anecdotal reports indicate that the slide mass covered the track, approximately 1-2m deep and earthworks were required to reinstate the operations of the track. Subsequent erosion of the fines within the slide mass has left bouldery debris within the Oparara River channel and upslope of the existing track. The boulders appear to provide some natural riverbank protection to further incision of the riverbank.

This landslide may still be slowly creeping in response to high rainfall. However, the risk of further rapid failure is considered very low. The risk to life of a landslide event is considered negligible given its characteristics and size. No specific quantitative risk assessment is considered necessary for this hazard, however future damage to property may be possible.

6.2 Oparara River Terrace Slopes

Slope instability of the Oparara River terrace slopes, located between the existing track and the shoreline of the Oparara River, has been observed at two locations and is inferred to principally be the result of bank erosion by the Oparara River.

Ongoing low volume fretting and incision/scour of these slopes is probable. Warning of imminent slope failure is inferred to be recognisable by the track users/DOC staff and action can be taken to avoid affected areas. Vulnerability to track users is therefore expected to be very low.

Further, the annual time spent within this this hazard zone is very low. No specific risk to quantitative risk assessment is considered necessary for this hazard, however future damage to property may be possible. Should scour continue or accelerate then the hazard will develop over a period of time allowing remedial works to occur, as has previously be undertaken in other locations.

As discussed in Section 2.1, it is understood that *"where the tracks encounter side slope the trench and stone retaining initiative will be employed",* the suitability of any proposed retaining structures have not been considered in this report.

7 Limitations

Due to the nature of the hazards some elements of the GNS Guidelines have not been completed. These are outlined as follows:

Landslide susceptibility classes and frequency-magnitude scaling for the landslide areas have been excluded. Only 1 landslide feature considered capable of generating fatality risk area was identified. The risk posed by this feature is considered insignificant when compared to the rock fall from the Oparara Arch Complex. Therefore, further detailed data analysis beyond that presented in this report is considered unnecessary for risk estimation.

No attempt to correlate the landslide events observed at the site with specific rainfall and seismic events was completed as the date of the observed mass movements is unknown.

A review of Retrolens was undertaken, however due to the relatively small study area and vegetation growth, no meaningful information was available.

8 Risk Assessment- Summary

8.1 Total AIFR & Societal Risk for Track Users

The calculated AIFR and Societal Risk from natural hazards for each track user is provided in Table 8 below. Table 9 provides the upper bound results from the sensitivity analysis.

Table 8: The AIFR & Societal Risk for various track users for all risk assessments

Hazard	AIFR Risk Per Trip	AIFR DOC Worker	Societal Risk (1+ fatalities) (ALSE)	Societal Risk (5+ fatalities) (ALSE)	Societal Risk (10+ fatalities) (ALSE)
Primary Hazard (Rockfall)- Oparara Arch Complex (Section 5.1)	7.79E-09	3.01E-06	8.53E-05	1.17E-05	2.97E-07
Secondary Hazard (Rockfall)- North Facing Slopes (Section 5.2)	1.27E-9	4.57E-07	-	-	-
Total	**9.06E-09**	**3.47E-06**	**8.53E-05**	**1.17E-05**	**2.97E-07**

Table 9: The AIFR & Societal Risk for various track users for all risk assessments- Sensitivity Analysis (upper bound)

Hazard	AIFR Risk Per Trip	AIFR DOC Worker	Societal Risk (1+ fatalities) (ALSE)	Societal Risk (5+ fatalities) (ALSE)	Societal Risk (10+ fatalities) (ALSE)
Primary Hazard (Rockfall)- Oparara Arch Complex (Section 5.1)	1.56E-08	5.99E-06	1.14E-04	2.33E-05	5.94E-07
Secondary Hazard (Rockfall)- North Facing Slopes (Section 5.2)	2.53E-09	9.13E-07	-	-	-
Total	**1.81E-08**	**6.90E-06**	**1.14E-04**	**2.33E-05**	**5.94E-07**

8.2 Risk Acceptance

Tolerable and acceptable risk from a natural hazard is a complex subject with much research and debate published. GeoSolve cannot prescribe a level of tolerable risk for the site. This decision must be made by the relevant stakeholders and the regulating body. Acceptable and tolerable risks are described as follows:

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 practicable.

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.

8.3 Risk Tolerance

The Department of Conservation (DOC) have established AIFR and ALSE tolerance levels for various track users, see Appendix C, which are to be used for natural hazard assessments. Based on the results from Table 8 & 9, and the guidelines in Appendix C, the following evaluation categories has been calculated for the various track users:

Table 10: Risk Tolerance Levels for DOC visitor sites

Track User	Calculated DOC Significance Level based on AIFR Values in Tables 8 and 9 above	Evaluation Category	Action Required
Risk Per visit	Insignificant	Tolerable	None
DOC Worker	Significant	Tolerable if reduced ALARP	Explore practicable risk reduction options
Societal Risk (1+ fatalities)	Insignificant/ Significant (depending on use of upper bound value)	Tolerable/ Tolerable if reduced ALARP	None/ Explore practicable risk reduction options
Societal Risk (5+ fatalities)	Insignificant	Tolerable	None
Societal Risk (10+ fatalities)	Insignificant	Tolerable	None

9 Recommended Future Works

Consideration of the risk numbers and appropriate management.

Management of the risks outlined above will need to be considered by the stakeholders (DOC). The AIFR for DOC staff and Societal (1+) cases both fall into the Tolerable category, if reduced (ALARP). Practical risk reduction will therefore need to be explored.

For DOC staff:

- Personal protective equipment
- Visual familiarity and monitoring of the hazard area
- Reduction of expected time spent in the hazard area
- Assessment of the area following any large rainfall event or seismic event

For the public:

- Signage could be used

Refining the risk assessment

Refining the above risk assessment and AIFR numbers is feasible. Assumptions have been made for the purpose of this assessment. Refinement of the input, for example the time spent within the hazard area, could be conducted to improve accuracy.

Other Recommendations

Any proposed development in the viewing area inside the arch portal should avoid locating infrastructure directly beneath the stalactites.

Any future track development considers the potential for slope instability on the terrace slopes of the Oparara River.

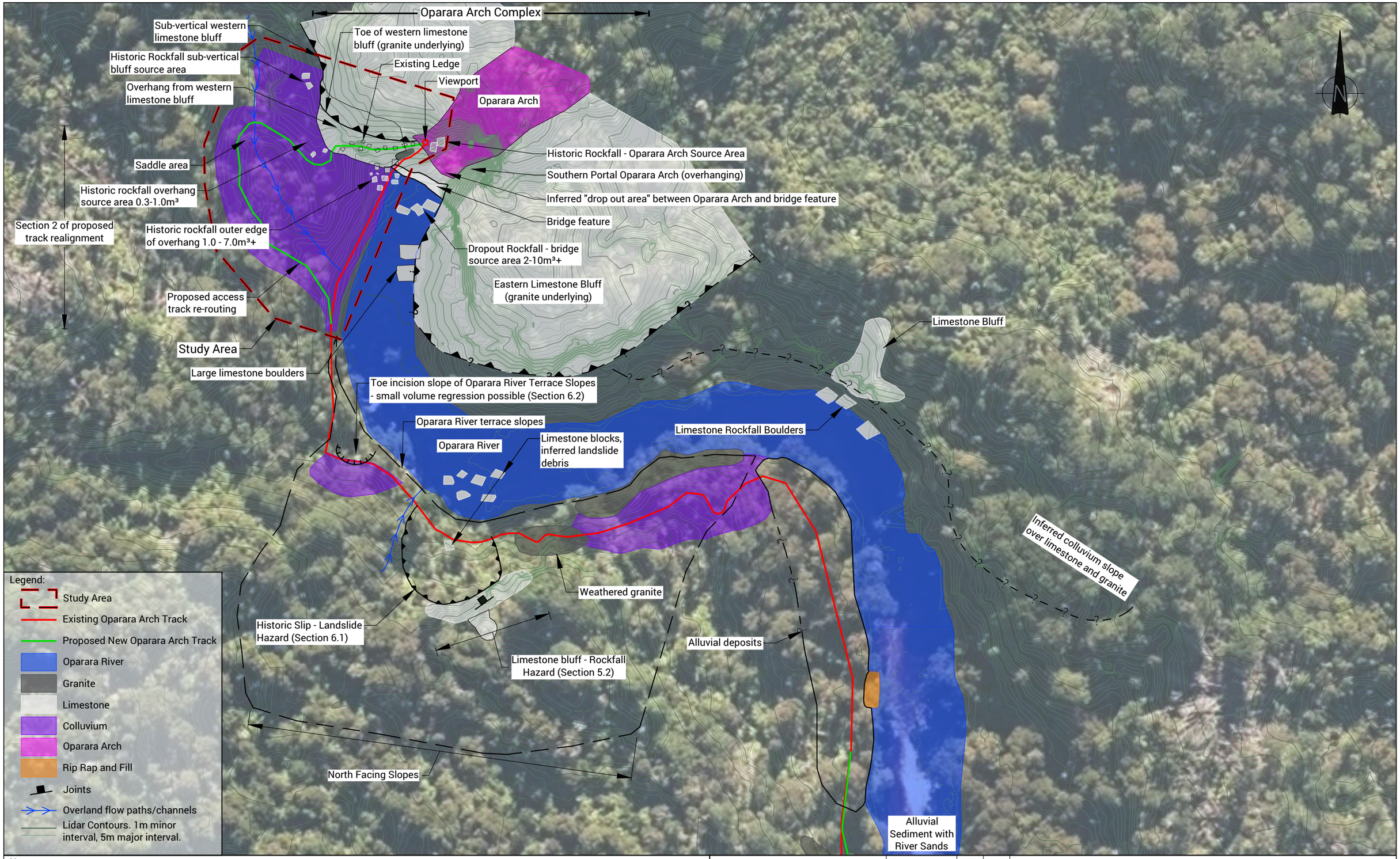
10 Applicability

This report has been prepared for the benefit of the Department of Conservation with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

It is important that we be contacted if there is any variation in subsoil conditions from those described in this report.

Report prepared by:	Reviewed for GeoSolve Ltd by:
	
.....	.....
Simon Reeves Senior Engineering Geologist	Paul Faulkner Senior Engineering Geologist

Appendix A: Site Plans



Notes:
1. These drawings have been prepared for the benefit of Department of Conservation with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

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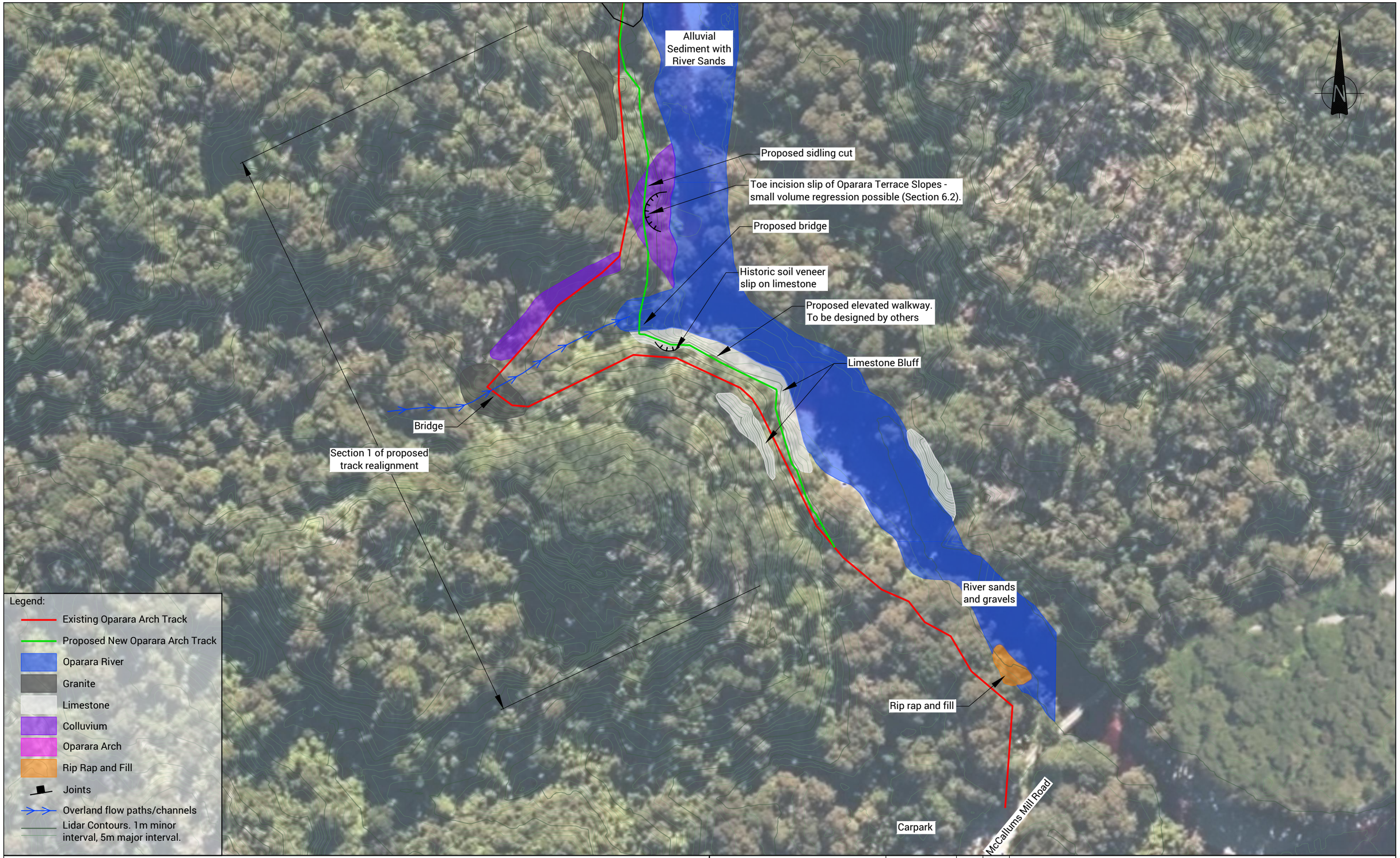
DRAWN	WCG	Mar.21
DRAFTING CHECKED		
APPROVED		
CADFILE: 210073.dwg		
SCALES (AT A3 SIZE): 1:1250		
PROJECT No: 210073	FIG No: Figure 1a	REV. 0

Department of Conservation
Oparara arch track, Karamea
Risk assessment for track realignment
Site Geomorphological Plan 1/2



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SCALE 1:1250

0 12.5 25.0 37.5 50.0 62.5 (m)

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CADFILE: 210073.dwg		
SCALES (AT A3 SIZE): 1:1250		
PROJECT No: 210073		

Department of Conservation

Oparara arch track, Karamea

Risk assessment for track realignment

Site Geomorphological Plan 2/2

FIG No: Figure 1b

REV. 0

Appendix B: Risk Calculations

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Rockfall Assessment- Scenario One- Oparara Arch Track- DOC
Western Limestone Bluff & Southern Portal of Oparara Arch 1:10 year natural event

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	Annual probability of Event				Probabilities					
Calculation		Natural (1:10 Year event)		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Conditions AIFR		Total AIFR Or Societal Risk
		Proportional notation (1 in x years)	Scientific notation							
1		1.00E+01	1.00E-01	Risk per trip	6.67E-03	2.85E-05	2.00E-01	3.80E-09		3.80E-09
2		1.00E+01	1.00E-01	AIFR-DOC Worker	6.67E-03	1.10E-02	2.00E-01	1.47E-06		1.47E-06
3		1.00E+01	1.00E-01	AIFR-Most Exposed Public	6.67E-03	7.42E-03	2.00E-01	9.89E-07		9.89E-07
								Annual Likelihood of Severe Event (ALSE)		
4		1.00E+01	1.00E-01	Societal Risk (1+ fatalities)	1.30E-02	3.13E-01	2.00E-01	8.13E-05		8.13E-05
5		1.00E+01	1.00E-01	Societal Risk (5+ fatalities)	3.30E-02	3.21E-02	2.00E-01	n/a		n/a
6		1.00E+01	1.00E-01	Societal Risk (10+ fatalities)	6.67E-02	4.45E-03	2.00E-01	n/a		n/a

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Rockfall Assessment- Scenario One- Oparara Arch Track- DOC
Western Limestone Bluff & Southern Portal of Oparara Arch 1:50 year natural event

2/03/2021
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	Annual probability of Event				Probabilities					
Calculation		Natural (1:50 Year event)		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Conditions AIFR		Total AIFR Or Societal Risk
		Proportional notation (1 in x years)	Scientific notation							
1		5.00E+01	2.00E-02	Risk per trip	6.67E-03	2.85E-05	5.00E-01	1.90E-09		1.90E-09
2		5.00E+01	2.00E-02	AIFR-DOC Worker	6.67E-03	1.10E-02	5.00E-01	7.33E-07		7.33E-07
3		5.00E+01	2.00E-02	AIFR-Most Exposed Public	6.67E-03	7.42E-03	5.00E-01	4.95E-07		4.95E-07
								Annual Likelihood of Severe Event (ALSE)		
4		5.00E+01	2.00E-02	Societal Risk (1+ fatalities)	1.30E-02	3.13E-01	5.00E-01	4.06E-05		4.06E-05
5		5.00E+01	2.00E-02	Societal Risk (5+ fatalities)	3.30E-02	3.21E-02	5.00E-01	n/a		n/a
6		5.00E+01	2.00E-02	Societal Risk (10+ fatalities)	6.67E-02	4.45E-03	5.00E-01	n/a		n/a

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Rockfall Assessment- Scenario One- Oparara Arch Track- DOC
Western Limestone Bluff & Southern Portal of Oparara Arch 1:100 year natural and seismic event

2/03/2021
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	Annual probability of Event				Probabilities					
Calculation	Seismic Event (1:100 Year event)	Natural (1:100 Year event)		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Natural AIFR	Seismic AIFR	Total AIFR Or Societal Risk
		Proportional notation (1 in x years)	Scientific notation							
1	1.00E-02	1.00E+02	1.00E-02	Risk per trip	6.67E-03	2.85E-05	5.00E-01	9.50E-10	9.50E-10	1.90E-09
2	1.00E-02	1.00E+02	1.00E-02	AIFR-DOC Worker	6.67E-03	1.10E-02	5.00E-01	3.67E-07	3.67E-07	7.33E-07
3	1.00E-02	1.00E+02	1.00E-02	AIFR-Most Exposed Public	6.67E-03	7.42E-03	5.00E-01	2.47E-07	2.47E-07	4.95E-07
								Annual Likelihood of Severe Event (ALSE)		
4	1.00E-02	1.00E+02	1.00E-02	Societal Risk (1+ fatalities)	1.30E-02	3.13E-01	5.00E-01	2.03E-05	2.03E-05	4.06E-05
5	1.00E-02	1.00E+02	1.00E-02	Societal Risk (5+ fatalities)	3.30E-02	3.21E-02	5.00E-01	5.30E-06	5.30E-06	1.06E-05
6	1.00E-02	1.00E+02	1.00E-02	Societal Risk (10+ fatalities)	6.67E-02	4.45E-03	5.00E-01	n/a	n/a	n/a

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Rockfall Assessment- Scenario One- Oparara Arch Track- DOC
Western Limestone Bluff & Southern Portal of Oparara Arch 1:1000 year seismic event

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	Annual probability of Event				Probabilities					
Calculation	Seismic Event (1:1000 Year event)	Natural		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Natural AIFR	Seismic AIFR	Total AIFR Or Societal Risk
		Proportional notation (1 in x years)	Scientific notation							
1	1.00E-03			Risk per trip	6.67E-03	2.85E-05	1.00E+00		1.90E-10	1.90E-10
2	1.00E-03			AIFR-DOC Worker	6.67E-03	1.10E-02	1.00E+00		7.33E-08	7.33E-08
3	1.00E-03			AIFR-Most Exposed Public	6.67E-03	7.42E-03	1.00E+00		4.95E-08	4.95E-08
								Annual Likelihood of Severe Event (ALSE)		
4	1.00E-03			Societal Risk (1+ fatalities)	1.30E-02	3.13E-01	1.00E+00		4.06E-06	4.06E-06
5	1.00E-03			Societal Risk (5+ fatalities)	3.30E-02	3.21E-02	1.00E+00		1.06E-06	1.06E-06
6	1.00E-03			Societal Risk (10+ fatalities)	6.67E-02	4.45E-03	1.00E+00		2.97E-07	2.97E-07

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Rockfall Assessment- Scenario One- Oparara Arch Track- DOC
Western Limestone Bluff & Southern Portal of Oparara Arch 1:10 year natural event- Sensitivity Analysis

2/03/2021
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Rev-1

	Annual probability of Event occurring					Probabilities					
Calculation			Natural (1:10 Year event)		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Condition sAIFR		Total AIFR Or Societal Risk
			Proportional notation (1 in x years)	Scientific notation							
1			1.00E+01	1.00E-01	Risk per trip	6.67E-03	5.71E-05	2.00E-01	7.61E-09		7.61E-09
2			1.00E+01	1.00E-01	AIFR-DOC Worker	6.67E-03	2.19E-02	2.00E-01	2.92E-06		2.92E-06
3			1.00E+01	1.00E-01	AIFR-Most Exposed Public	6.67E-03	1.48E-02	2.00E-01	1.97E-06		1.97E-06
									Annual Likelihood of Severe Event		
4			1.00E+01	1.00E-01	Societal Risk (1+ fatalities)	1.30E-02	4.17E-01	2.00E-01	1.08E-04		1.08E-04
5			1.00E+01	1.00E-01	Societal Risk (5+ fatalities)	3.30E-02	6.42E-02	2.00E-01	n/a		n/a
6			1.00E+01	1.00E-01	Societal Risk (10+ fatalities)	6.67E-02	8.90E-03	2.00E-01	n/a		n/a

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	Annual probability of Event occurring					Probabilities					
Calculation			Natural (1:50 Year event)		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Condition sAIFR		Total AIFR Or Societal Risk
			Proportional notation (1 in x years)	Scientific notation							
1			5.00E+01	2.00E-02	Risk per trip	6.67E-03	5.71E-05	5.00E-01	3.81E-09		3.81E-09
2			5.00E+01	2.00E-02	AIFR-DOC Worker	6.67E-03	2.19E-02	5.00E-01	1.46E-06		1.46E-06
3			5.00E+01	2.00E-02	AIFR-Most Exposed Public	6.67E-03	1.48E-02	5.00E-01	9.87E-07		9.87E-07
									Annual Likelihood of Severe Event		
4			5.00E+01	2.00E-02	Societal Risk (1+ fatalities)	1.30E-02	4.17E-01	5.00E-01	5.42E-05		5.42E-05
5			5.00E+01	2.00E-02	Societal Risk (5+ fatalities)	3.30E-02	6.42E-02	5.00E-01	n/a		n/a
6			5.00E+01	2.00E-02	Societal Risk (10+ fatalities)	6.67E-02	8.90E-03	5.00E-01	n/a		n/a

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	Annual probability of Event occurring					Probabilities					
Calculation	Seismic Event (1:100 Year event)		Natural (1:100 Year event)		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Natural AIFR	Seismic AIFR	Total AIFR Or Societal Risk
			Proportional notation (1 in x years)	Scientific notation							
1		1.00E-02	1.00E+02	1.00E-02	Risk per trip	6.67E-03	5.71E-05	5.00E-01	1.90E-09	1.90E-09	3.81E-09
2		1.00E-02	1.00E+02	1.00E-02	AIFR-DOC Worker	6.67E-03	2.19E-02	5.00E-01	7.30E-07	7.30E-07	1.46E-06
3		1.00E-02	1.00E+02	1.00E-02	AIFR-Most Exposed Public	6.67E-03	1.48E-02	5.00E-01	4.93E-07	4.93E-07	9.87E-07
									Annual Likelihood of Severe Event		
4		1.00E-02	1.00E+02	1.00E-02	Societal Risk (1+ fatalities)	1.30E-02	4.17E-01	5.00E-01	2.71E-05	2.71E-05	5.42E-05
5		1.00E-02	1.00E+02	1.00E-02	Societal Risk (5+ fatalities)	3.30E-02	6.42E-02	5.00E-01	1.06E-05	1.06E-05	2.12E-05
6		1.00E-02	1.00E+02	1.00E-02	Societal Risk (10+ fatalities)	6.67E-02	8.90E-03	5.00E-01	n/a	n/a	n/a

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	Annual probability of Event occurring					Probabilities					
Calculation	Seismic Event (1:1000 Year event)		Natural		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Natural AIFR	Seismic AIFR	Total AIFR Or Societal Risk
			Proportional notation (1 in x years)	Scientific notation							
1		1.00E-03			Risk per trip	6.67E-03	5.71E-05	1.00E+00		3.81E-10	3.81E-10
2		1.00E-03			AIFR-DOC Worker	6.67E-03	2.19E-02	1.00E+00		1.46E-07	1.46E-07
3		1.00E-03			AIFR-Most Exposed Public	6.67E-03	1.48E-02	1.00E+00		9.87E-08	9.87E-08
									Annual Likelihood of Severe Event		
4		1.00E-03			Societal Risk (1+ fatalities)	1.30E-02	4.17E-01	1.00E+00		5.42E-06	5.42E-06
5		1.00E-03			Societal Risk (5+ fatalities)	3.30E-02	6.42E-02	1.00E+00		2.12E-06	2.12E-06
6		1.00E-03			Societal Risk (10+ fatalities)	6.67E-02	8.90E-03	1.00E+00		5.94E-07	5.94E-07

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	Annual probability of Event occurring					Probabilities					
Calculation	Seismic Event (1:100 Year event)		Natural (1:100 Year event)		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Natural AIFR	Seismic AIFR	Total AIFR Or Societal Risk
			Proportional notation (1 in x years)	Scientific notation							
1		1.00E-02	1.00E+02	1.00E-02	Risk per trip	3.33E-02	3.80E-06	5.00E-01	6.33E-10	6.33E-10	1.27E-09
2		1.00E-02	1.00E+02	1.00E-02	AIFR-DOC Worker	3.33E-02	1.37E-03	5.00E-01	2.28E-07	2.28E-07	4.57E-07
3		1.00E-02	1.00E+02	1.00E-02	AIFR-Most Exposed Public	3.33E-02	1.00E-03	5.00E-01	1.67E-07	1.67E-07	3.33E-07
									Annual Likelihood of Severe Event		
4		1.00E-02	1.00E+02	1.00E-02	Societal Risk (1+ fatalities)		4.17E-02	5.00E-01	n/a	n/a	n/a
5		1.00E-02	1.00E+02	1.00E-02	Societal Risk (5+ fatalities)		4.17E-03	5.00E-01	n/a	n/a	n/a
6		1.00E-02	1.00E+02	1.00E-02	Societal Risk (10+ fatalities)		5.94E-04	5.00E-01	n/a	n/a	n/a

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	Annual probability of Event occurring					Probabilities					
Calculation	Seismic Event (1:50 Year event)		Natural (1:50 Year event)		Person Most at Risk	Probability of spatial impact	Probability of person present	Vulnerability	Natural AIFR	Seismic AIFR	Total AIFR Or Societal Risk
			Proportional notation (1 in x years)	Scientific notation							
1		2.00E-02	5.00E+01	2.00E-02	Risk per trip	3.33E-02	3.80E-06	5.00E-01	1.27E-09	1.27E-09	2.53E-09
2		2.00E-02	5.00E+01	2.00E-02	AIFR-DOC Worker	3.33E-02	1.37E-03	5.00E-01	4.57E-07	4.57E-07	9.13E-07
3		2.00E-02	5.00E+01	2.00E-02	AIFR-Most Exposed Public	3.33E-02	1.00E-03	5.00E-01	3.33E-07	3.33E-07	6.67E-07
									Annual Likelihood of Severe Event		
4		2.00E-02	5.00E+01	2.00E-02	Societal Risk (1+ fatalities)		4.17E-02	5.00E-01	n/a	n/a	n/a
5		2.00E-02	5.00E+01	2.00E-02	Societal Risk (5+ fatalities)		4.17E-03	5.00E-01	n/a	n/a	n/a
6		2.00E-02	5.00E+01	2.00E-02	Societal Risk (10+ fatalities)		5.94E-04	5.00E-01	n/a	n/a	n/a

Appendix C: Department of Conservation Risk Tolerance Levels

Risk tolerance levels for DOC visitor sites

Last updated 25 January 2021

The following risk tolerance levels should be used when doing natural hazard risk assessments for DOC visitor sites

In most cases the department will want to know the individual risk of one trip for a visitor, the risk to staff members and the societal risk, Contract instructions will specify what is required.

The department will specify whether the visitor site is one being managed as a lower risk, medium risk or higher risk site.

Individual one trip

If the site is a there and back trip the risk needs to be for the full trip the visitor does not just a one-way trip. For sites where visitors have options of one way or doing a return trip then the risks for both options need to be worked out.

For places with multiple overlapping visitor experiences the contract will specify what combinations of activities and sites need their risks calculated.

			Fatality risk per Day/Single Visit		
Significance Level	**Evaluation Category**	**Action Required**	**Lower Risk**	**Medium Risk**	**Higher Risk**
Extreme	Intolerable	HALT until risk reduced	$>10^{-5}$	$>3x10^{-5}$	$>10^{-4}$
High		Continue ONLY after corporate review etc	$>10^{-6}$	$>3x10^{-6}$	$>3x10^{-5}$
Substantial	Tolerable if reduced ALARP	Explore practicable risk reduction options (prioritise SUBSTANTIAL)	10^{-7} to 10^{-6}	$3x10^{-7}$ to $3x10^{-6}$	$3x10^{-6}$to $3x10^{-5}$
Significant			$3x10^{-8}$ to 10^{-7}	$>10^{-7}$ to $3x10^{-7}$	$3x10^{-7}$ to $3x10^{-6}$
Insignificant	Tolerable	None	$<3x10^{-8}$	$<10^{-7}$	$<3x10^{-7}$

Person most at risk (DOC staff)

Significance Level	Evaluation Category	Action Required	Annual Fatality Risk Permanent or Temporary Staff Regularly Exposed to Natural Hazard	Daily Fatality Risk One-off or Occasional exposure to Natural Hazard
Extreme	Intolerable	HALT until risk reduced	$>3x10^{-4}$	$>3x10^{-5}$
High		Continue ONLY after corporate review etc	$>10^{-4}$	$>3x10^{-6}$
Substantial	Tolerable if reduced ALARP	Explore practicable risk reduction options (prioritise SUBSTANTIAL)	10^{-5} to 10^{-4}	$3x10^{-7}$ to $3x10^{-6}$
Significant			10^{-6} to 10^{-5}	10^{-7} to $3x10^{-7}$
Insignificant	Tolerable	None	$<10^{-6}$	$<10^{-7}$

Societal risk

Unless otherwise specified in the contract societal risk should be calculated for the likelihood of 1 or more fatalities per annum, 5 or more fatalities per annum and the worst-case scenario. F/N charts are not required unless specifically requested.

Significance Level	Evaluation Category	Action Required	Frequency of Severe Events (per year)
Extreme	Intolerable	HALT until risk reduced	>0.1
High		Continue ONLY after corporate review etc	0.01 to 0.1
Substantial	Tolerable if reduced ALARP	Explore practicable risk reduction options (prioritise SUBSTANTIAL)	0.001 to 0.01
Significant			10^{-3} to 10^{-4}
Insignificant	Tolerable	None	$<10^{-4}$