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Southern Land Ltd

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Dear Tim:

Rock Fall Risk Assessment: Cromwell Gorge Trail

1. Introduction

An assessment has been made of the rock fall risk that may pertain to the proposed trail on the true right (west) bank of the Cromwell Gorge. Sections of this trail pass across known rock falls and travel paths or lie below steep bluffs which have a potential for shedding rocks.

We understand that an opposing submission has been made which cites the risk of rockfall being unacceptably high. The purpose of this note is to quantify the risk in a more rigorous manner than a subjective assessment and to propose ways to manage this risk to an acceptable level.

The assessment is not specific to any particular section of track nor covers any particular failure scenario. The scope of this exercise is to consider a range of failure modes and a range of failure likelihoods and determine risks given an estimated usage pattern. These risks are then compared to similar activities and assessed against acceptable levels of individual and societal risks.

2. Risk Assessment Methodology

In this exercise, a quantitative risk assessment (QRA) will be undertaken to determine the levels of risk to cyclists for a number of different scenarios. The level of risk is determined by combining likelihood of an event occurring and the resultant consequences. The context of the risk assessment is that trail usage is considered to involve both positive risk whereby a desired recreation opportunity is obtained by the predominant visitor group despite any negative risks associated with usage. Negative risks arise both from the user and from nature. Cycling, by its very nature, is a hazardous pursuit with the following adverse events likely to occur:

- Failure to stay on track through speed, inexperience, surface conditions
- Collision with other trail users
- Fatigue and muscular injury over the course of a long journey
- Sudden rain, snow or thunder storm.

Natural hazards are most likely to occur through rockfall impacting a trail user and, to a lesser extent, a cyclist impacting a fallen rock on the trail.

It is the former set of occurrences that this risk assessment will focus on.

Risk can be considered as the sum of conditional probabilities:

$$R(DI) = P(H) \times P(S/H) \times P(T/S) \times V(L/T) \times 1\text{-}P(A/S) \quad \ldots\ldots\ldots (1)$$

Where:

R(DI) = Risk (annual probability of loss of life to an individual)

P(H) = Annual probability of the hazardous event (rockfall)

P(S/H) = Probability of spatial impact (i.e. of a rockfall impacting a trail)

P(T/S) = Probability of a temporal impact (i.e. of a trail user being impacted by rockfall)

V(L/T) = Vulnerability of the individual (probability of loss of life given impact).

1-P(A/S) = Probability that the individual will be alerted by a rockfall event and take evasive action to avoid that event.

All of the above inputs require some assumptions for which there is limited information. Nevertheless, it is possible to put some numbers to each with qualifying comment alongside (see Table 1).

The biggest unknown is the likelihood of rock fall occurrence, P(H). We have assumed two scenarios, one of an individual block of approximate radius 0.15 m and that of a small rock slide (2x2x2.5 m). The larger the failure, the longer the return interval is expected to be, hence the lower probability associated with larger events. The two scenarios encompass a plausible range of probabilities that may affect the trail over its lifetime (say 100 years).

Table 1

Probability	Value	Comments
P(H)	0.2-0.02	Once every 5 to 50 years for volumes ranging from 0.01-10 m^3. This estimate is informed by the author undertaking annual walkover surveys of the true right bank following lake fill as well as working on the new SH8 alignment on the true left bank of the Cromwell Gorge.
P(S/H)	(1.5/32)x 0.1 = $5x10^{-3}$	Rock must be bouncing to reach 'fatality' height of between 1.5-2.0 m. Implies slopes must exceed 45° above track or shortly above track. 1.5 km of 32 km total trail length is estimated to match this criterion. Falling rock must remain intact and include the trail within its runout path. Only about 10% of rockfall are estimated to match this criterion.
P(T/S)	(10/60x24 x365)/3 = $4x10^{-4}$	If cyclist's travel speed is 15 km/h then would take 6 mins (say 10 mins) to cover 1.5 km danger zone. Assumes no stopping within that zone (to be controlled by signage). Cyclists could be within danger zone 8 hours of every day of the year
V(L/T)	0.5	Chance of survival following rock impact is estimated at 50%
P(A/S)	1-0.9 = 0.1	Individuals can either accelerate past impact zone, stop beforehand or retreat to avoid impact. Estimate this could be achieved 90% of the time.

From equation (1), R(DI) = $2x10^{-8}$ to $2x10^{-9}$ for failures involving individual rock falls to small rock slides. An individual rock fall can only impact one person but a larger volume of rock (as in a small rock slide of $10m^3$) may spread out over a broad area and affect more than one. For a party of four, the risk could increase to $8x10^{-9}$. Compare this to the odds of being struck by lightning being 10^{-7} or winning Lotto Division 1 (without Powerball) being $3.3x10^{-6}$.

Estimated numbers of trail users range from 7,000 people in the first year rising to 14,000 after 14 years (assume 10^4 users). Total risk then becomes 10^4 x $2x10^{-8}$ = $2x10^{-4}$

for all users. By comparison, white water rafting is determined to have an annual fatality rate of 10^{-5} since the industry started in 1976[1].

An estimate of risk of injury through rock fall impact is the same as that for fatality given a vulnerability of 0.5. However, all other injuries from mountain bike activities reported to ACC amount to 1,480 annually for all trails in New Zealand suggesting 1 or 2 injuries per year could be expected on a trail of this length.

Risk Evaluation

An acceptable level of risk needs to be established to determine whether the risk posed by rockfall is reasonable. The literature on risk evaluation for slope failures displays variable values of acceptable risk ranging from 10^{-4} to 10^{-8} reflecting a wide diversity of risk attitudes. Major engineering structures, e.g large dams, nuclear power plants and commercial aircraft, have lower levels of acceptability due to the risks being involuntary. However, voluntary activities such as mountain biking, car driving and smoking[2] tend to have higher levels of acceptability.

The following diagram[3] shows the societal risk criteria for dam failures with the Cromwell Gorge risk assessment overlain.

[1] https://www.newzealand.com/int/article/exactly-how-much-danger-is-there-when-you-white-water-raft/

[2] Risk of smoking 30 cigarettes a day has an annualised risk of premature death of 10^{-2} compared to risk by natural causes at 40 years of age of 1.25×10^{-3}.

[3] Quantitive Risk Assessment of Soil and Rock Slopes course notes, March 1999

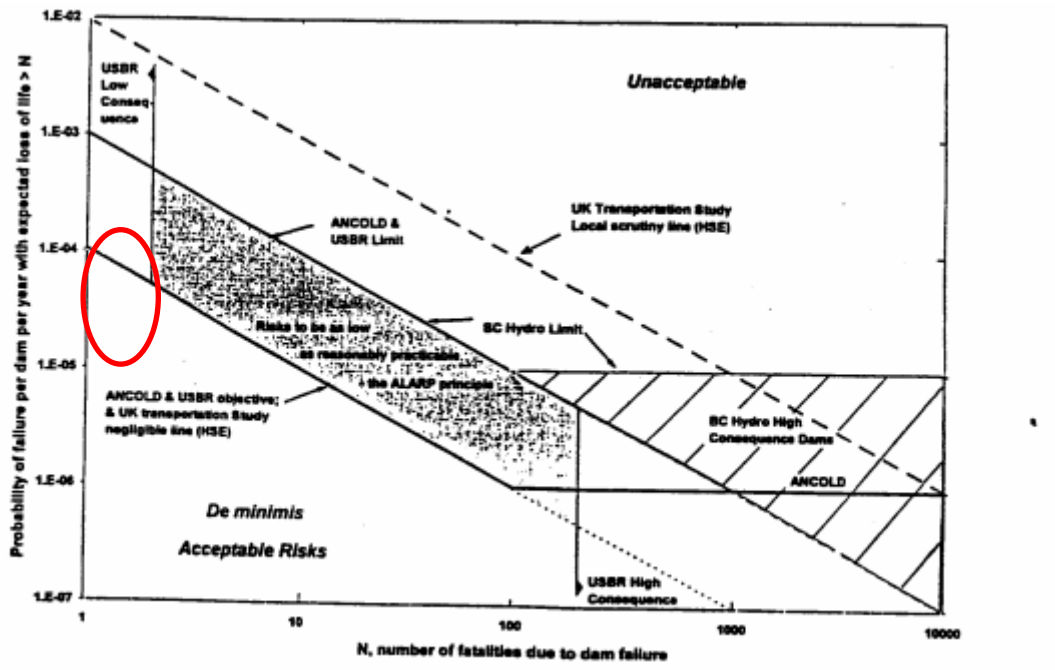


Figure 1: Frequency/fatality plot with Cromwell Gorge Trail marked in red.

A comparison can also be made with the Department of Conservation's Standard Operating Procedure for managing risk[1]. The following graphs illustrate where the proposed activity (highlighted in red) would plot on their risk matrix.

[1] DoCDM-2852133 – Managing Risks to Visitors on Public Conservation Land. Standard Operating Procedure

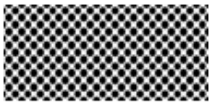
1.11 Risk consequence for visitors

Level	Descriptor	Consequence to participants	Consequence to the visitor experience
1	Negligible/not a risk	No injuries or injuries that don't require first aid; "fright factor". No incident follow-up.	Inconvenience - delay to plans (up to 1/2-hour loss).
2	Low	Minor injuries requiring first aid treatment - managed by those at the visitor site, e.g., minor cuts and bruises. No incident follow-up.	Interruption to plans, e.g. forced track closure for a day or rescheduled plans/postponement.
3	Medium	Medical treatment required, including immediate off-visitor site assistance, e.g., follow-up emergency medical treatment. Incident reported.	Incident visitor site investigated. Interruption to plans, e.g., forced track closure (more than week) or trip cancellation.
4	High	Serious injuries to an individual requiring rescue party, or moderate injuries to multiple subjects. Incident investigated.	Incident visitor site investigated; future facility management assessed. Forced cancellation/ rescheduling of current visits.
5	Very High	Single person fatality or major injury to multiple (more than 3) victims. Search and rescue involvement. Incident investigated, possibly by coroner.	Incident visitor site and visitor site management investigated. Future visitor site management assessed. Current and future trips cancelled/ rescheduled.
6	Extreme	Multiple fatalities. Search and rescue involvement. Incident investigated by coroner.	Immediate visitor site closure and future visitor site management assessed. Current and future trips cancelled/ rescheduled.

1.12 Risk likelihood

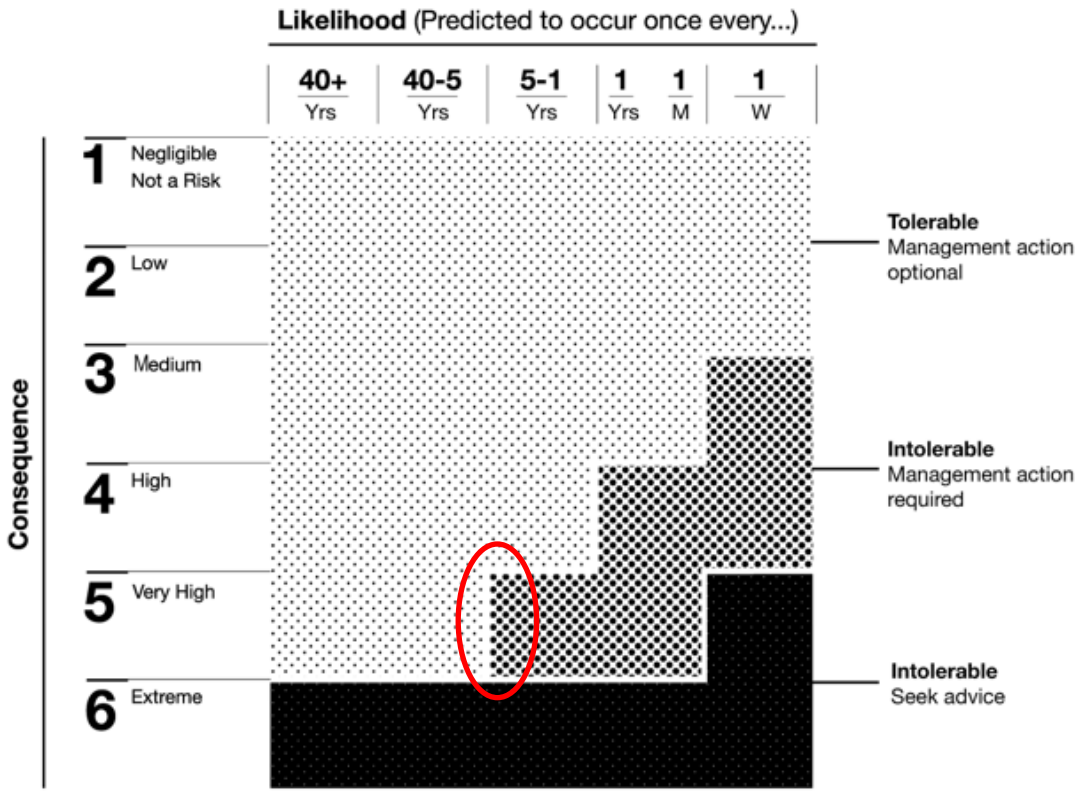
Level	Measure	Explanation
A	Predicted to occur once every 40 years or more	Possible, but no visitor risk assessment team member has knowledge of event occurring more than once during their career.
B	Predicted to occur once every 5 years to once every 40 years.	The event is likely to occur from time to time.
C	Predicted to occur once a year to once every 5 years.	
D	Predicted to occur once a month to once a year.	
E	Predicted to occur at least once a week.	Occurs frequently

Key

	Visitors can tolerate the risk. Management actions may be appropriate (e.g. pre-visit information).
	Visitors are not able to tolerate the risk without management actions. Answer the questions in the VRM tool to check if the current management actions are adequate. When best practice management actions are implemented visitors can tolerate the risk.
	Visitors are not able to tolerate the risk without management actions. Seek advice from the Visitor Safety Manager on how to assess the hazard correctly. Seek approval from Operations Manager to proceed once you have the advice.

Back Country Adventurer (BCA) destinations

Visitors to these destinations have a medium to high tolerance to risk.



The above plot, with Cromwell Gorge Trail highlighted in red, indicates that the proposed activity is marginally tolerable/intolerable.

Risk Management

The risk profile can be adjusted by undertaking some remedial measures at the time of trail construction. Further management of the risk can be undertaken by erection of appropriate signage at the start of high risk areas (i.e. at the start of sections comprising a majority of slopes greater than 45°). A combination of the above actions will result in movement of the red ellipse (above diagram) further to the left and into the tolerable zone.

It would not be feasible to apply corrective measures to every loose rock or potential area of rock fall. However, it would be appropriate to have loose rock scaled off the slopes above sections vulnerable to free-falling rock, e.g. where the route traverses sheer rock faces (e.g. Hartley and Reilly bluffs) prior to construction of the trail

structure. Scaling of rock usually requires specialised abseil crews experienced in this type of work.

Signs warning trail users of a rock fall hazard do not eliminate or mitigate the hazard but have the following benefits:

- Give trail users the option to turn back if they are particularly risk averse.
- Alert users to be aware of warning signs of falling rock and to take evasive action.
- Provide some comfort to the authorities and trail administrators against trail users claiming they weren't warned.

Appropriate signage should be located at entrance points to the trail and at the start of steep, sidling slopes (where there is a predominance of slopes above the trail exceeding 45°. Note that signs will need to be placed at both ends of the trail and both ends of steep sections to warn users travelling in either direction.

Summary and Conclusions

Rockfall is recognised as a hazard that may affect trail users with the potential to cause either injury or fatality. The risk associated with rockfall can be quantified using an established risk assessment methodology (QRA) which takes into account a combination of conditional probabilities. The risk to an individual and the annualised risk to users has been determined and compared to other activities/threats.

The values obtained are then evaluated by plotting on a likelihood-consequence graph established for large dams and a similar matrix established for outdoors activity by the Department of Conservation. The latter plot is considered the more relevant and indicates that the rockfall risk associated with the proposed activity is marginally tolerable.

Risk levels can be mitigated either directly by undertaking some remedial action during the construction period and indirectly by appropriate signage. It is recommended that some scaling or light removal of loose rock with the potential for failure be undertaken prior to the main construction phase. The main areas to be treated are those where the trail traverses beneath very steep or overhanging slopes or where structures such as bridge abutments or gantries (e.g. round Hartley and Reilly bluffs) are threatened by rockfalls.

Signage containing appropriate warnings should be established at the track ends and at either end of sections considered to be particularly vulnerable to rockfall.

A combination of pre-construction rock scaling and signage is considered an appropriate response to what has been established as a marginally tolerable activity to a tolerable activity in line with public expectations.

Sincerely,

Geoconsulting Ltd

per J.M.Bryant

M.Sc. F.G.S.

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