Avalon consulting
high / difficult access
a division of avalon industrial services ltd

P.O. Box 5187
Frankton
Hamilton, N.Z.
ph: 07 846 1686
fax: 07 846 1016
www.avalonltd.co.nz

Report on:

Mauao slopes 2005; Zone 6

Southern campground and hot pools

Rockfall hazard & risk assessment

Client: Tauranga District Council

July 2005

Avalon Report No: 0534 A

Avalon Industrial Services Ltd.
P.O.Box 5187
Frankton
Hamilton
NZ

Ph: (+64) 7 846 1686
Fax: (+64) 7 846 1016
Email: mail@avalonltd.co.nz

Contact: [redacted]

Checked:

Date: 28 July 2005

Avalon
Industrial Services Ltd

EXECUTIVE SUMMARY

In May 2005 a 150 year return period extreme rainfall event occurred in Tauranga and caused significant flood damage. Mauao's tracks and slopes suffered extensive rockfall, surface scour and over forty individual slips and dropouts, the largest of which involved an estimated 8,000m^3 of material.

TDC commissioned Avalon to assess the geotechnical hazards and risks to persons associated with this flood damage on Mauao.

Towards the end of flood damage remediation works, again following heavy rainfall, a 2 to 3m diameter (25 tonne) boulder rolled approximately 25m down slope and came to rest adjacent to the campground boundary fence, directly above the hot pools. Had it not collided with trees and another boulder it would have entered the campground.

This prompted an immediate investigation of potential rockfall hazards on the slopes above the southern campground/hot pools. Ongoing investigations had planned to address this area but had not yet targeted this area in detail.

This report presents the rockfall problem only; separate reports will record the flood damage/remedial works and assess the hazard and risks associated with mass slips.

Potential rockfall sources were identified at many locations on these steep slopes. Nineteen of these were considered relatively severe and additional marginally stable boulders almost certainly exist concealed in the dense bush on the upper slopes, where the inspection team could not gain 100% coverage.

The statistical risk of rockfall causing fatalities in the campground has been recalculated taking into account the new information on the rockfall sources and the likely frequency and nature of rockfall in this area.

The rockfall risks to campers appear to be very marginal when evaluated against societally acceptable/tolerable limits. The calculation indicated an individual campers risk around 1E-6 for a one week stay and a fatality return period around 200 years.

Public resources such as Mauao tend to be expected to meet relatively low risk criteria. It is recommended that the practicality and cost benefit of hazard remediation be considered. Issues not factored into the calculated risk include; politics, public reaction/confidence, property damage, environmental issues and potential consequences of litigation.

Previous reports (2003 and 2004) had suggested investigation of the options for catch fences to protect the campground but this work was not given any particular priority amongst other recommendations, which are currently being enacted or considered by TDC.

The flood damage has refocused attention on what has been demonstrated to be a very real hazard. It is recommended that investigation of catch fence options for protecting the campground from rockfall be given new priority.

Priority must also be given to investigation and assessment of the potential risks of debris flow from mass slips, which now appear likely to be significant. Preliminary work on this is currently underway and will be reported in due course.

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1 INTRODUCTION

Avalon specialises in Geotechnical Engineering consultancy and contracting services in difficult and high access environments.

Avalon has carried out a number of engineering geological investigation and rockfall hazard/risk assessments on Mauao on behalf of Tauranga District Council (TDC), since February 2003. These included; Post fire upper slopes hazard assessment [1], Numerical rockfall risk assessment [2], earthquake damage report and risk reassessment [3].

On 18th May 2005 Tauranga received 350mm of rainfall in 24 hours and the region experienced extensive flood damage which included colluvial mass slips and rockfall on Mauao.

Following this extreme rainfall event [redacted] of TDC contacted [redacted] with Avalon and commissioned investigation of flood damage and assessment of associated hazards. Site work commenced the following week with approval of Tangata Whenua.

The flood damage on Mauao and the consequent slope remedial works will be reported separately [5] as will a hazard and risk analysis for mass slips from Mauao's lower colluvial slopes [6].

Towards the end of the flood damage remediation works, on 22nd June, after a day of heavy rainfall, a 2-3m diameter boulder rolled approximately 25m down slope and came to rest adjacent to the campground boundary fence.

This boulder fall prompted a detailed investigation of potential rockfall hazards on the mid and lower bush and paddock slopes above the southern campground/hot pool area, designated as investigation Zone 6.

This report presents the findings of the zone 6 rockfall hazard investigation and is intended to be referenced in conjunction with Avalon's other reports.

1 Avalon Industrial Services Ltd. Mauao Rock Slopes & Rockfall Hazards. Report to TDC, 12 July 2003.

2 Avalon Industrial Services Ltd. Mauao Rockfall Hazards; Risk Assessment & Management. Report to TDC, 26 June 2004.

3 Avalon Industrial Services Ltd. Mauao Slopes Earthquake Damage and Revised Risk Assessment. Report to TDC, 26 July 2004.

4 Avalon Industrial Services Ltd. Mauao Slopes Zone 6 Hazard Assessment. This Report.

5 Avalon Industrial Services Ltd. Mauao Slopes 2005 Flood Damage & Slope Remedial Works. Report to TDC, Not Yet Completed.

6 Avalon Industrial Services Ltd. Mauao Slopes 2005 Preliminary Colluvial Mass Slip Assessment & Revised Risk Assessments. Report to TDC, Not yet completed.

2 22 JUNE 2005 BOULDER FALL

2.1 Description

Around midday on the 22nd of June, whilst flood damage remedial works were still in progress, the hotpools management heard what sounded to be a large boulder falling through trees immediately up slope of the campground/hotpools.

[redacted] of TDC was on site managing the Mauao flood damage remedial works and contact [redacted] with Avalon, who immediately visited the site.

Photograph 1. Main boulder at rest adjacent to campground fence.

Photograph 2. View down fall line from source location.

The boulder can be seen in the foreground of photograph 1 at rest behind the fence above camp site location No 98.

The failure was from approximately the position of the photographer in photograph 2, 25m up the slope which lies at approximately 30˚. The boulder was well rounded and approximately 2 to 3m in diameter.

A few metres down slope it collided with the small trees in the foreground of photograph 2 and then continued to roll through a few more trees before, approximately two thirds of the way down its track, striking a glancing blow to and dislodging a second boulder. This second boulder was approximately 1.5 to 2m in diameter and rocked forward approximately 1m and came to rest against a tree.

Upon inspection it was concluded that the larger lower boulder was now in an acceptably stable position but that the smaller upper boulder should be moved forward into a stable position where it was no longer supported by the tree.

Avalon returned the following day and with the aid of winches rolled the smaller upper boulder into to a safe and stable position.

Prior to failure the main boulder appears to have been shallowly embedded and sat above a rotted out tree stump.

Shell middens were found backed up against and around the sides of the boulder and some shells were found below, indicating the boulder had probably moved post Maori occupation.

The slopes in this vicinity contain many highly rotted stumps. The decay of roots is causing localised subsidence as can be seen in photograph 3 below.

Photograph 3. Localised subsidence due to decaying root systems.

2.2 Conclusions

The main triggers for the boulder failure appears to have been localised ground movement due to the saturation of decayed tree root systems in conjunction with minor surface erosion and increased ground water pressure due to the extreme rainfall.

It appears likely that the 18 May rainfall initially decreased stability but not quite enough to induce failure. There may have been some movement on the 18th but it was not until the next intense rainfall on the 22nd June that the stability balance was tipped and the boulder rolled forward.

Compression of dead roots as a trigger mechanism has been shown to be significant in other locations on Mauao's slopes where falling rocks have come to rest against trees or root jacking has opened up joints in rock outcrops.

The boulders are both now in stable positions.

Had the boulder not collided with trees and the embedded smaller boulder it would almost certainly have retained enough energy to have entered the campground.

Priority should be given to more detailed investigation and hazard/risk analysis of the slopes above the southern campground and hot pools.

3 ROCKFALL HAZARD INVESTIGATION

3.1 Previous works

The 22nd June boulder fall has refocused attention on the slopes in this vicinity. Avalon's previous works had not addressed these slope areas in any detail.

The scope of the 2003 (post fire) investigation [1] was restricted to areas affected by the burn off and subsequent one day monitoring visits have only involved checking the bluff survey benchmarks and the scour condition of the upper slopes. Previous work has not investigated potential for mass slips in the colluvial soils, which were also a major component of the 18th May flood damage.

The slope areas in question were considered in a report to TDC by Dr Laurie Richards in 1999 [7]. That investigation included a walkover survey and, among many other items, reported a number of potential rockfall hazards directly above camp sites 93 to 98.

The conclusion of the report was that no immediate major investigations or remedial works were required but that as a matter of routine a detailed topographic and geomorphological plan should be produced for the slopes above the camping ground and hot pools and that annual walkover surveys should be undertaken.

Avalon's 2003 investigations had commenced this process but had not as yet extended to the slope above the hot pools. A recommendation had been made that further targeted investigation of specific areas be carried out concurrently with an annual rock scaling program.

The intention of proposing the undertaking of the work in this manner was that the knowledge base and degree of confidence in the risk assessments made would increase each year and TDC would have a program which could be easily budgeted for and which due to its annual nature would not be forgotten.

The statistically determined rockfall risk (see Avalon's 2004 risk reports [2 & 3]) was such that this annual incremental approach was deemed appropriate and with a relatively short period of site investigation (and follow up desk work) each year we would quickly build up a knowledge base covering all areas and geological processes on Mauao in detail. An additional benefit of this approach is that it would allow the ongoing investigations to react to changing conditions or newly revealed information.

This approach remains valid as despite having had a 10 year return period earthquake and 150 year flood events in the previous two years no boulders entered the camp ground and no casualties have been reported due to rockfall incidents, although significant rockfall has certainly crossed the upper tracks.

Having said the above, the fact that this very large boulder came to rest at the campground boundary was clearly of concern and new priority needed to be given to the possibility of similar failures.

[7] Dr Laurie Richards, Rock Engineering Consultant. Mauao Stability Assessment. Report to TDC, 31 May 1999.

3.2 Site investigation works; June 2005

In the week following the fall Avalon's team spent a few days investigating the slopes above the southern camp ground and hot pools. All potential hazards found were inspected by the Engineering Geologist.

The lower and mid slopes were relatively easy to investigate as there are only scattered trees and the boulders are clearly visible. The upper slopes are a very different proposition; the vegetation is extremely dense and being relatively young there are very few under canopy areas. Tracks must be forced and there is generally little chance of seeing boulders more than a few metres distant.

3.3 Geomorphology & topography

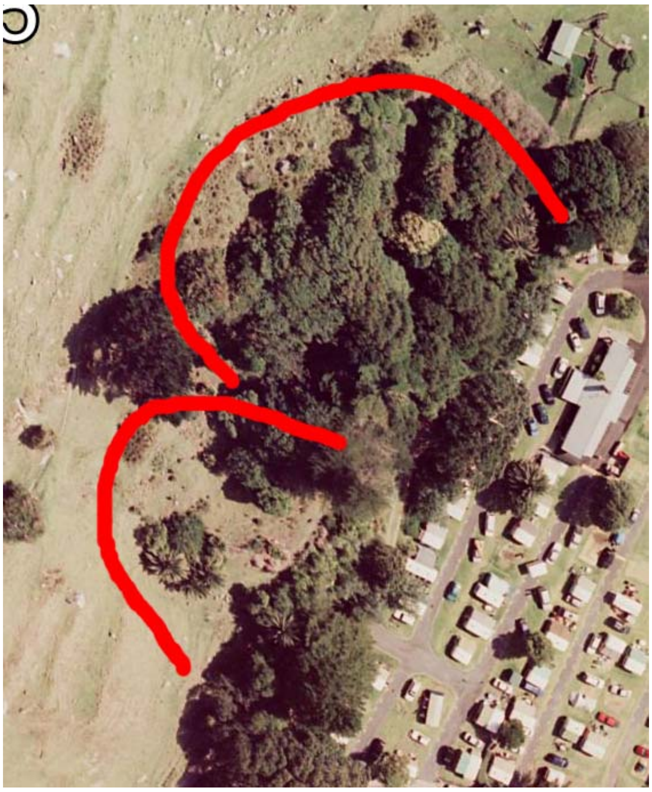
Photograph 4; General view up into this zone looking from the N campground.

Photograph 5; View from bushline to hotpools & S campground.

The slopes were heavily terraced during Maori occupation. The terracing has left over steepened soil slopes up to a few metres in height.

Large boulders sitting on top of some terraces and might initially appear to represent boulder fall since terracing, however, boulders were deliberately sited by tangata whenua for rolling defensively and others may have been too difficult to move and terraces could have been constructed around them.

3.4 Brief comment on mass slips



Photograph 6; Very approximate locations of two typical historical mass slips.

Photograph 6 indicates historical circular mass slips in the colluvial slopes immediately above the campground (others are also present). These events appear likely to have been over five times larger than the 18th may 2005 slip on the south western slopes and probably released a fast liquefied debris flow.

Should such an event now occur above the campground the consequences could be extremely serious.

In some locations the toe of the colluvial slope has been excavated to create level cap sites. Such excavations reduce stability.

A preliminary investigation of the potential risks from mass slips is currently being undertaken and will be reported in due course [6].

Further site investigation is very likely to be justified and could include geophysics such as a resistivity survey in an attempt to determine colluvial thicknesses and location of watercourses and springs.

Other investigation techniques applicable could include installation of piezometers to monitor groundwater and detailed engineering geological logging of exposed sections through the colluvium.

In addition to defining the geology, estimating frequency of slip events will be critical. Identification and dating of ash shower beds or dating of organic material within the colluvium could be of some value in this.

3.5 Rockfall hazards; General comments

This area has been designated as Zone 6, following on from the reporting system established in Avalon's July 2003 Hazard Report [1].

The slopes can be divided into three areas;

1. The lower areas - the sites of historical mass slips.
2. The mid slope - open paddock slopes.
3. The upper slope – steep regenerating bush & scrub slopes.

Areas 1 and 2 were thoroughly investigated. The search in the upper area found a number of specific hazards; however, in its current state of vegetation it is impractical to achieve 100% certainty of having identified all hazardous boulders.

Many of the surface boulders showed fresh signs of animal burrowing under and around them. Rats and rabbits are contributing to the rockfall problem. Burrowed soil also scours far more easily during heavy rainfall.

Due to the steep nature of the slopes and potential for boulders to roll into the campground the potential for rockfall in this vicinity obviously demands very careful consideration.

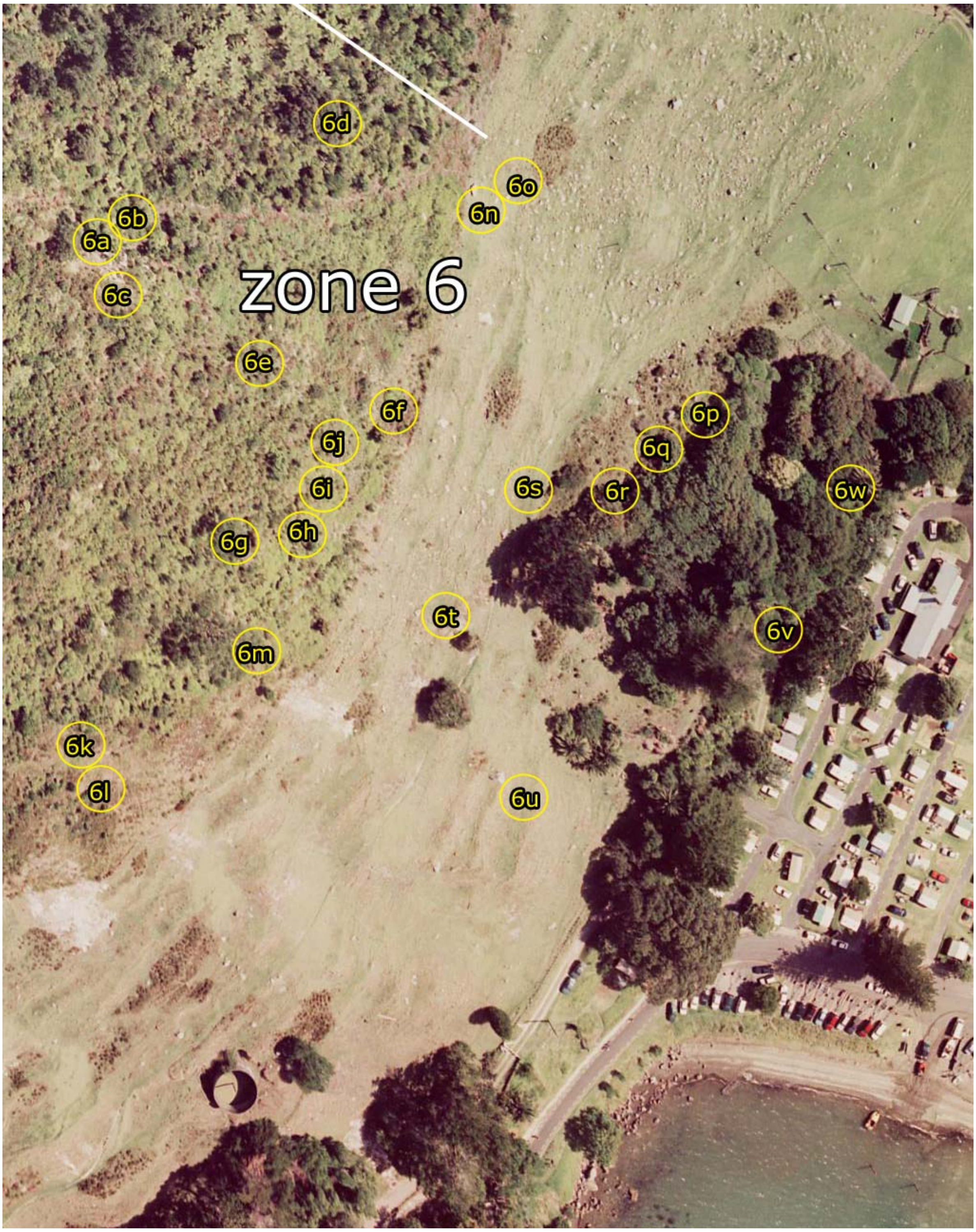
Given the difficulty in identifying all potential hazards the possibility of rockfall hazard mitigation via catch fences begins to appear more attractive.

Although catch fences could certainly mitigate individual rockfall they will be less effective at retaining debris flow from large mass slips.

3.6 Specific hazards

The following aerial photograph indicates locations of individually identified potentially hazardous boulders which are then described on the following pages.

Engineering judgment was used to determine what level of hazard was sufficiently significant to deserve this individual reporting.

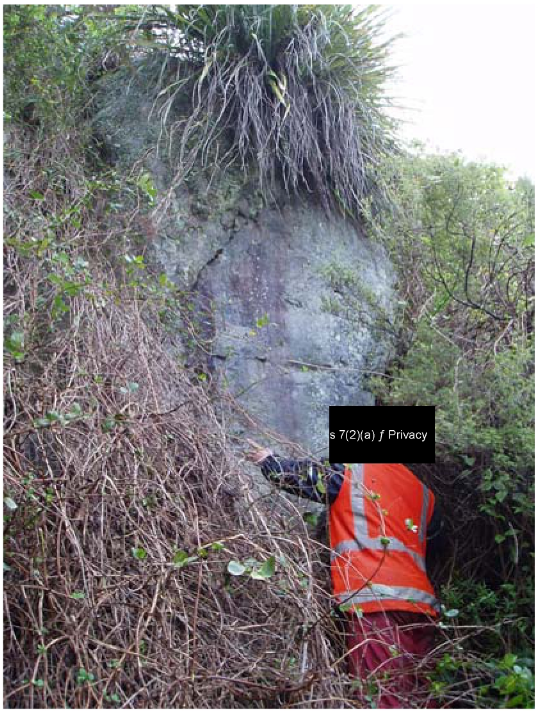


Photograph 7. Zone 6 specific boulder hazard locations.

3.6.1 **6a**; detached boulder on face of outcrop

A broken bluff up to 4m in height runs from 6a to 6b and 6c. At 6a a ‘flake’ of rock approximately 1 x 1 x 0.4m has become detached, mostly due to root jacking. The rear joint is open over 100mm. Very marginally stable. The disc shape could allow this boulder to roll a considerable distance.

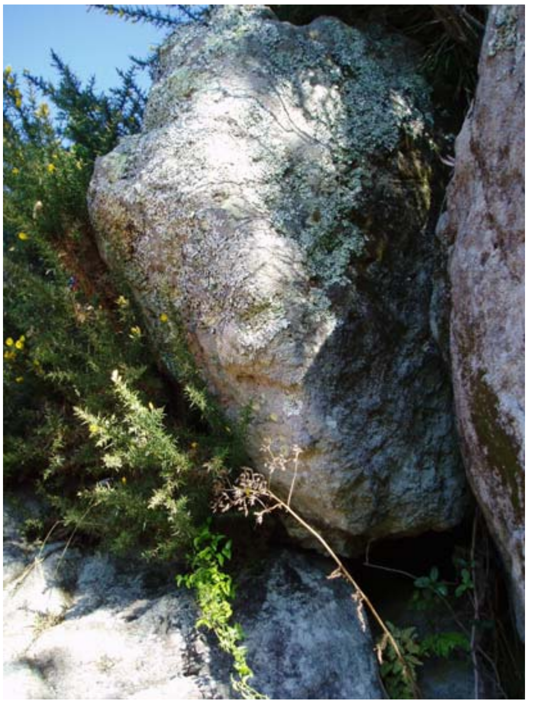
3.6.2 **6b**; detached boulder forms face of outcrop



The lower area of this outcrop shows very fresh looking stress fractures. A ‘flake’ approximately 2.5 x 2 x 0.5m is marginally stable. The rear joint is open 30-50mm and seeping water. Freshness of fractures suggests they could have formed in last year’s earthquake event.

Appears likely to split on failure but main piece would remain disc shaped.

3.6.3 **6c**; detached boulder on top of outcrop



A relatively small boulder, 1 x 0.5 x 0.5m. Detached and temporarily wedged but root jacking could destabilise.

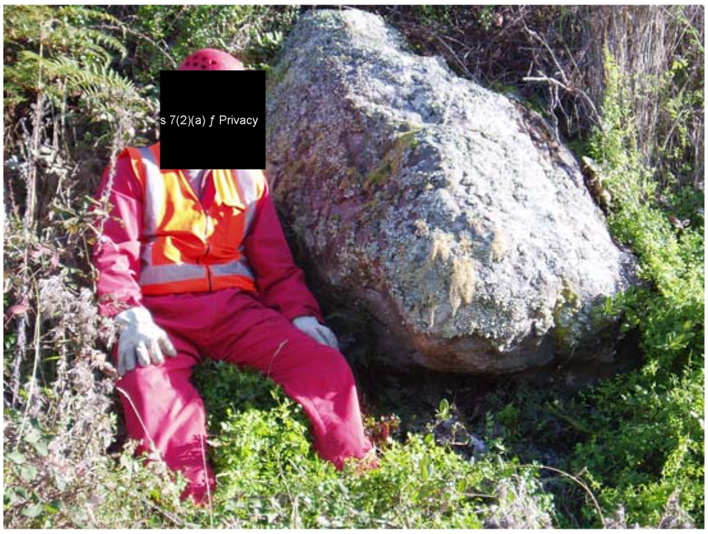
3.6.4 **6d**; surface boulder

Approximately 1.2 x 1.0 x 0.8m. Toe undercut by erosion but relatively stable in the short term. Further erosion and growth of tree behind could further destabilise.

3.6.5 **6e**; outcrop boulders

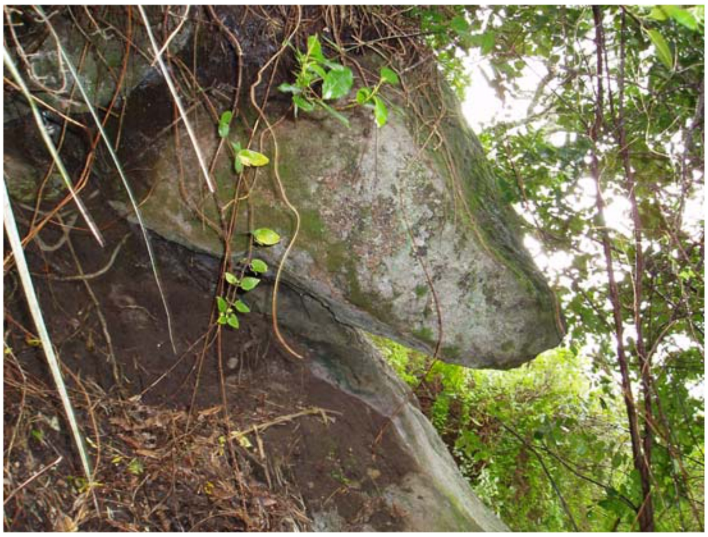
Two 2m to 3m diameter boulders resting against each other. Large boulders but relatively stable in the short term.

3.6.6 **6f**; surface boulder



Approximately 1.2 x 0.8 x 0.8m. Toe undercut by erosion. Further erosion could destabilise. Ground immediately below is very steep.

3.6.7 **6g**; weathered outcrop with detached boulder on top



A relatively severe hazard, appears to have very marginal stability. Approximately 2 x 3 x 1.2m. Tree behind is jacking the upper block forward. Steep slope immediately below.

Wedge shape will resist rolling but mass of boulder and steepness of ground are not favourable.

6g view from north side

3.6.8 **6h**; three small surface boulders resting on each other

Upper & largest block is 1 x 0.8 x 0.4m. Relatively stable in the short term.

3.6.9 **6i**; surface boulder

1.5 x 1.5 x 1m. Moderately eroded and undercut base. Steep ground below but relatively stable in the short term.

3.6.10 **6j**; small surface boulder

0.4 x 0.4 x 0.3m. Small and relatively stable in the short term.

3.6.11 **6k**; large outcrop boulder

5 x 5m outcrop with boulder of 1.5 x 2 x 2m resting on top. Low angle contact between boulder and outcrop is stable regarding erosion but potentially becomes a hazard given seismic loading.

3.6.12 **6l**; surface boulder

0.6 x 0.6 x 0.4m. Relatively stable in the short term but erosion is occurring below.

3.6.13 **6m**; surface boulder disturbed by recent mass slip (slip item 9).

1.2 x 1.2 x 0.6m. Has been rolled to a relatively stable position.

3.6.14 **6n**; surface boulder in paddock

2 x 2.5 x 0.8m. Moderately stable in short term but on steep ground and with potential for erosion below. Hazardous in earthquake. Could split into two on rolling.

3.6.15 **6o**; surface boulder in paddock

2 x 2 x 1.5m. A few metres north of 6n. Stable in the short term but also on steep ground and with potential for further erosion below.

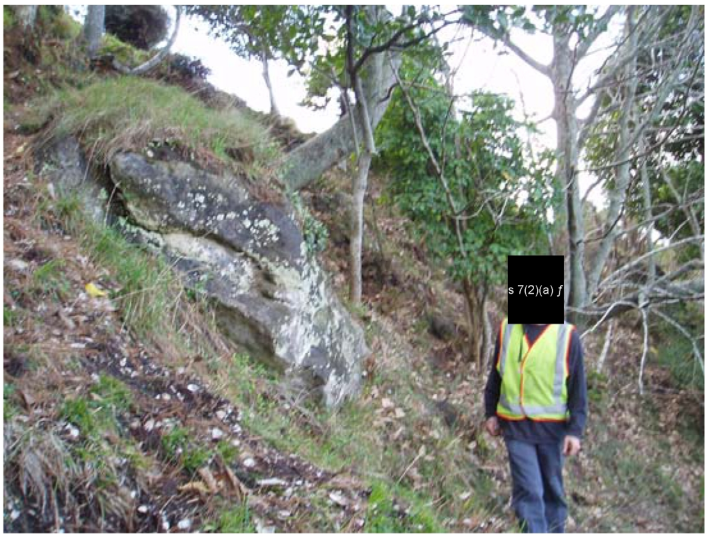
3.6.16 **6p**; surface boulder on margin of historical mass slip

0.8m diameter and well rounded. Embedded in steep rear scarp of historical mass slip. Stable in the short term.

3.6.17 **6q**; surface boulder on margin of historical mass slip

2 x 1.5 x 1m. Embedded in top of steep historical mass slip scarp. Moderately stable in the short term but eroding slowly below.

3.6.18 **6r**; surface boulder on margin of historical mass slip



2 x 2m. Embedded in steep historical slip scarp. Stable in short to medium term.

3.6.19 **6s**; surface boulder in paddock

1 x 0.8 x 0.6m. Embedded and moderately stable in the short term.

3.6.20 **6t**; surface boulder in paddock

2 x 2 x 1.5m. Stable in short term but potentially hazardous should steep soil slope drop out from below.

3.6.21 **6u**; surface boulder in paddock

2 x 1.5 x 1.5m. Moderately stable in the short term but undercut and on very steep ground.

3.6.22 **6v**; surface boulder at campground boundary

1.5m diameter. No significant hazard but appears likely to have been creeping down cut slope. Now bearing on the small palm trees.

3.6.23 **6w**; 22 June 2005; site of failed boulder at campground boundary.

See above.

4 ROCKFALL RISK CALCULATION

4.1 General

As mentioned Avalon's previous rockfall risk assessments [2 & 3] considered rockfall from the summit bluffs and upper slopes but did not take into account the Zone 6 areas under consideration here.

The 2004 blast however did release rockfall which included 19 boulders entering the open paddock above the shearing shed paddock. Of these none crossed into the shearing shed paddock. Collisions with embedded boulders appeared to significantly reduce the energy of the falling rocks.

Rockfall from the northern extreme of Zone 6 may also enter the paddock above the shearing shed paddock. This blast result might suggest that such rockfall would be unlikely to enter the campground, however, of the 19 boulders which came to rest only 3 were as large as $0.6m^3$ and none were categorised as $1.2m^3$. Conversely all of the blast boulders which had sufficient energy to enter the campground to the north were categorised as $1.2m^3$.

The conclusion is that boulders falling from Zone 6 slope areas must be considered to have the potential to enter the campground and hot pools areas.

The probability of any given falling rock entering the campground in this area appears likely to be similar to that in Zone 1, where only boulders above the $1m^3$ size range were considered to have the energy to constitute a significant hazard.

4.2 Rockfall frequency

In 1999 Dr Laurie Richards [7] noted "According to the lessee of the camping ground there have been no instances of boulders entering the camp ground, apart from one dislodged by children. A brief search through Tauranga Library did not reveal any instances of rockfall problems."

On the Zone 6 slopes this site investigation has revealed 19 specific marginally stable boulders and there are expected to be others hidden in the bush on the upper slopes.

The May 2005, 150 year rainfall event (directly and indirectly) appears to have triggered at last two significant boulder falls from the Zone 6 slopes, one of which involved a very large boulder which came to rest at the campground boundary.

The 2004 earthquake swarm appears to have disturbed at least one Zone 6 boulder and on other slope zones of Mauao this 10 year return period seismic event did initiate failure of at least one boulder in the $1m^3$ range (along with many smaller).

The 18 specific boulder hazards reported include at least a few which appear marginally stable to the degree that under normal erosional (including intense rainfall and animal disturbance) processes they would not be expected to remain in their current locations in, say, 100 years.

The risk analysis process is dependent on assumptions made using engineering judgment and rockfall frequency is one of the parameters subject to the most uncertainty.

If we make an allowance for boulders which may be concealed by bush we might reach a total of say 4 boulder falls in 100 years.

In the analysis of rockfall from the upper bluffs in Avalon's 2004 post earthquake report [3] the total seismic component of 1m boulders was estimated as being equal to the 'erosional' rate. Refer to that report for more detail.

So we might assume 8 boulders per 100 years, of which say 4 might be in the 1m and over range which could be expected to enter the campground. This gives a frequency of one per 25 years.

In the first instance this analysis will consider a rockfall frequency of one per 25 years entering the campground.

This figure might initially appear high but it must be remembered that it includes e erosional falls and rockfall during earthquakes. See reports [2 & 3].

4.3 Consequence analysis

This analysis only considers the risk to camp ground occupants from Zone 6 rockfall.

The camp ground has a Zone 6 boundary length of approximately 250m. Individual camp sites are typically 5m in width. If we assume a boulder might roll say 50m into the camp it would typically roll forward through three rows of camp sites. The southern camp ground and hot pools (Zone 6 target area) contains approximately 60 sites within 50m of the boundary fence.

Previous analysis [2 & 3] assumed a 50% camp site occupancy rate when averaged through the year and assumed that a typical stay involved 4 persons on each site for one week of 12 hours per day.

It was previously assumed that vulnerability to fatality would be 0.5 for campers (vulnerability being probability of death if directly in boulders path).

4.4 Risk estimation

The method used here is relatively simple and considers the probability of a typical visitor being in the affected area when a rockfall occurs, along with their vulnerability, to calculate the risk to an individual on a single visit.

The calculated risk can then be multiplied by the number of visitors per year to determine the annual probability of a fatality and the return period for each area of Mauao.

The stages are a follows:

a) Estimate the annual frequency of rockfall which will enter the campground. This calculation will initially assume one boulder per 20 years travelling typically 50m into the camp ground.

Frequency = 0.04 per year.

b) Time spent by a single visitor in the affected zone. T (in years)

For the campground we assume 12 hours/day on site for one week. Therefore time spent at risk is 84 hours per week visit. = 0.0096 yrs.

c) The space inhabited at any one time by a single visitor is assumed to be 1m wide so the ratio of target area length to that occupied by one person at any time is therefore 1m / 250m = 0.004.

d) The probability of coincidence of a rockfall and person in the same space is given by a) x b) x c) = 0.04 x 0.0096 x 0.004 = 1.5E-06

e) The incremental probability of a fatality per person visit is given by multiplying by the vulnerability. = 0.75E-06

f) The probability of a fatality in any area per year is simply 5) multiplied by the number of visitors per year to that area = 0.75E-6 x 4 persons per site x 60 at risk sites x 52 weeks x 50% occupancy= 4.5E-03

g) The return period is the average interval between fatalities and is the reciprocal of the annual probability of a fatality = one fatality per 222 years.

4.4.1 Sensitivity analysis

The above calculation is clearly very dependent on the assumptions made and the assumption with the greatest degree of uncertainty is that of rockfall frequency.

The next step in this risk analysis process is to look at the sensitivity of the result to the likely margin of error in the assumptions made.

The actual rockfall figure is likely to not be more than one boulder per 12.5 years (as we would expect more recorded incidents) and appears very likely to be greater than one boulder per 125 years.

This would gave us a maximum frequency of say 0.08 and a minimum of 0.008.

Running through the risk calculation using the upper and lower frequencies gives the following results.

Mauao Zone 6 Campground Rockfall Risk; Sensitivity Analysis

1m Rockfall frequency	*Probability of fatality per person visit*	*Return period for fatality (years)*
0.008 (one per 100yrs)	3.1E-07	517
0.04 (one per 25 years)	7.5E-07	213
0.08 (one per 4 years)	1.5E-06	106

Table 1. Risk calculation; sensitivity analysis.

5 ROCKFALL RISK EVALUATION

The following section quotes much from Avalon's previous reports.

5.1 Discussion

Risk is by definition a measure of the probability and severity of the consequences of a hazard. Estimates of rockfall risk are inevitably approximate.

The aim of Risk Evaluation is to determine whether the estimated risks (and their anticipated accuracy) are within acceptable or tolerable limits and whether they should be accepted or treated.

Tolerable risk criteria are not often absolute boundaries and society shows a wide range of tolerance to risk; risk criteria are only a mathematical expression of societal opinion.

Some inputs into risk analysis are largely judgmental. Information gained during the recent investigations has helped more accurately define some variables but rockfall frequency is still essentially based on judgement.

Risks can change with time due to natural processes or human intervention. Revisiting an analysis of this type can often lead to significant change due to increased data.

Public resources such as Mauao, with very extensive recreational use and under local government management can reasonably be expected to be subject to meeting relatively low risk criteria. This may be particularly so for the camp ground/hot pools where the public are directly paying for facilities.

This evaluation does not consider issues such as damage to property, public reaction/confidence, environmental issues or potential consequences of litigation.

The accurate quantification of rockfall and landslide risks is entirely dependent on the recognition and understanding of the geological and geomorphological processes involved. The risks will always be subject to reinterpretation following further investigation and are in a large proportion based on engineering geological judgment, knowledge and experience.

5.2 The calculated Mauao rockfall risk

Mauao Zone 6 Campground Rockfall Risk Summary		
1m Rockfall frequency	*Probability of fatality per person visit*	*Return period for fatality (years)*
0.04 (one per 25 years)	7.5E-07	213

Table 2. Risk; Initial calculation.

7.5E-7 can be written as 0.000,000,75 and within the margin of error can be assumed to be around 1 in a million.

The assumed vulnerability was 0.5 therefore there will be twice as many accidents as fatalities, on per 106 years.

The assumed total frequency of boulders entering the camp ground, which might be publicly interpreted as a ‘near miss’ is one every 25 years.

5.3 *Accepted societal risks*

The risk calculated above can now be evaluated with reference to accepted and tolerable societal risks.

Guidance has been taken from the Australasian Geomechanics Society, Sub-Committee on Landslide Risk Management [8]:

There are no established individual or societal risk acceptance criteria for loss of life due to rockfall, in Australasia or internationally. It is however possible to obtain some general principles from other engineering industries:

a) The incremental risk from a hazard should not be significant compared to the risks to which a person is exposed in everyday life.

b) The incremental risk should, wherever reasonably practicable, be reduced.

c) If the possible loss of large numbers of lives from an incident is high, the probability that the incident might actually occur should be low. This accounts for society’s particular intolerance to incidents that cause many simultaneous casualties and is embodied in societal tolerable risk criteria.

d) Persons in society will often tolerate higher risks than they regard as acceptable when they are unable to control the risk because of financial or other limitations.

e) Acceptable risks are generally considered to be an order of magnitude smaller than tolerable risks.

The following table summarises some quoted individual risk criteria:

Source	*Lower bound (acceptable)*	*Upper limit (tolerable)*
HSE (1989a)	10^{-6}	10^{-5}
HSE (1988)	10^{-6} broadly acceptable	10^{-3} divides just tolerable and intolerable. 10^{-4} any member of public from large scale industrial hazard.
NSW Dept of Planning (1994)		10^{-6} residential.
HK Gov't Planning (1994)		10^{-5}
BC Hydro (1993)		10^{-4}
ANCOLD (1994)		10^{-5} average. 10^{-4} person most at risk.
NZ Geomechanics News [8] 2000 (existing slopes)	10^{-4} persons at most risk.	10^{-5} average of persons at risk.
NZ Geomechanics News [8] 2000 (new slopes)	10^{-5} persons at most risk.	10^{-6} average of persons at risk.

Table 3. Some acceptable/tolerable risk criteria.

8 Australasian Geomechanics Society, Sub-Committee on Landslide Risk Management. "Landslide Risk Management Concepts and Guidelines". NZ Geomechanics News. 60, December 2000.

5.4 Evaluation of Mauao Zone 6 rockfall risk to campers

The acceptability of the incremental risk level of fatality on a single person 1 week visit appears to be marginal.

In addition to the incremental risk the high visitor numbers and almost permanent occupancy in the hazardous area results in calculated fatality/accident/'near miss' return periods which appear unlikely to be acceptable in the public realm.

The practicability and cost benefit of hazard remediation should be considered, as should issues such as public reaction/confidence and potential consequences of litigation.

6 MANAGEMENT & TREATMENT OPTIONS

6.1 Discussion

Risk Treatment is the final part of the Risk Management process and provides the methodology for controlling the risk. It is recommended that TDC implement an ongoing Management Plan.

Treatment options for Mauao could include:

1. Passive options
    - Accepting the risk
    - Avoiding the risk
2. Active options
    - Reducing the likelihood
    - Reducing the consequences
    - Monitoring and warning systems

Accepting the risk requires the calculated risk to be within the determined acceptable or tolerable range.

Avoiding the risk would in this case mean preventing or discouraging public access.

Reducing the likelihood of the risk can in part be achieved by rock scaling and slope reinforcement (e.g. suitable vegetation planting, rock anchors or active slope meshing, retaining structures etc).

Reducing the consequences could be achieved by rockfall defences (e.g. rockfall catch structures).

Monitoring systems will keep track of and improve the reliability of the hazard and risk assessments and allow adaptation to meet changing circumstances.

The next recommended steps regarding individual rockfall would be:

- Investigate design options and costings for catch structures.
- Scale the worst of the identified specific boulder hazards.

This assessment has not included the hazards and risks of mass slips in the colluvial slopes. These will be reported separately but appear likely to be as significant as individual rockfall.

6.2 Options

6.2.1 Controlling access

Closing the campground and restricting public access on Mauao appears likely to be unacceptable.

6.2.2 Slope reinforcement

Slope reinforcement would consist of physical measures installed to prevent rocks failing.

This includes works such as rock dowels and bolts, tensioned rockfall mesh, tensioned wire strops, various 'geotextile' mats etc.

The dispersed and nature of the Zone 6 rockfall source areas and the dense vegetation would make slope reinforcement options impractical. Such works would be likely to be visually and environmentally unacceptable and difficult and expensive to install.

6.2.3 Rockfall defences

Rockfall defences stop and trap moving rockfall before it reaches the at risk areas, generally they include catch fences and structures.

Rockfall catch fences at the campground boundary may be an excellent risk mitigation measure and merit further detailed investigation. Such fences would need to be relatively robust as they would be required to catch high energy boulders of $1m^3$ and greater.

There are a number of different types of fence options which could be implemented and the cost benefit returns of these can differ greatly.

Environmental and political acceptability will be an issue with any proposed catch fence works on Mauao but works could be designed so as to be unobtrusive and procedures could ensure installation with minimal environmental disruption.

Whether or to what degree catch fences might mitigate mass slips is still under investigation.

6.2.4 Regular rock scaling

Annual rock scaling programs are a practical and internationally accepted (and commonly applied) means of hazard management on slopes such as Mauao's although no rock scaling program will ever clear the slopes of all loose rock and erosion will continue to create new hazards.

An ongoing annual rock scaling program is recommended on Mauao and has been discussed previously.

Rock scaling will be very effective on the upper slopes and rock bluffs in Zones 1 to 5 but scaling alone may not reduce the Zone 6 risks to acceptable levels.

6.2.5 Regular monitoring

Mauao's rockfall hazards are being monitored on an ongoing basis.

TDC has already established a monitoring programme. Every six months a one day geotechnical walkover is being carried out on the upper slopes by Avalon's Engineering Geologist.

TCD's Mauao Ranger is keeping watch for any evidence of actual or potential rockfall and scour and is advising Avalon of as necessary.

For future monitoring it has been recommended that annual geotechnical inspections are combined with a routine annual, say 1 week duration, rock scaling program. The most appropriate time for inspections and regular scaling would be after winter and before the main tourist season.

The scope of annual inspection, as previously recommended whould include:

- Brief visual inspection of all areas by an appropriately experienced roped access Engineering Geologist (with reference to Avalon's 2003 reports and this Risk Assessment).
- Measurement for movement at established survey markers.
- Special attention to close inspection of areas above Western Oruahine track and Campground.
- Targeted detailed inspection of any other specific areas of concern.
- Installation of additional survey markers if necessary.
- Review and re-estimation of risk levels in the light of any new data.
- Presentation of a written report including recommendations.

Due to the extensive nature of Mauao's slopes the site work might be expected to take up to a week on site but could be achieved concurrently whilst directing the operations of a rock scaling team.

The presentation of the inspection report would be followed up by a review of TDC's Management Plan and implementation of any changes as necessary.

Greater experience and understanding of the rockfall processes will improve the reliability of the risk analysis.

In the event of any major changes (for example; further fires, earthquakes or natural collapse of rock columns) it is recommended that all affected areas be reassessed in detail.