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Assessment of rock fall risk at Mintaro Hut site on the Milford Track, and evaluation of potential new sites for Mintaro Hut in the upper Clinton valley, Fiordland National Park

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GNS Science Consultancy Report 2012/315
May 2013

DISCLAIMER

BIBLIOGRAPHIC REFERENCE

Hancox, G. T.; Carey, J. M. 2013. Assessment of rock fall risk at Mintaro Hut site on the Milford Track, and evaluation of potential new sites for Mintaro Hut in the upper Clinton valley Fiordland National Park, *GNS Science Consultancy Report* 2012/315. 30 p.

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EXECUTIVE SUMMARY

This report presents the results of rock fall risk assessment and evaluation of potential alternative sites for Mintaro Hut on the Milford Track in Fiordland National Park, which was carried out for the Department of Conservation (DoC) Te Anau Area Office. The geomorphic setting and geological hazards at the current Mintaro Hut site on the Milford Track were assessed in the field during a site visit on 12–14 November 2012. The risk to visitors at the hut site (annual probability of one or more fatalities or serious injuries) from a large rock fall was then assessed quantitatively using the ANCOLD (2003) and AGS (2007) risk assessment criteria. Four other potential sites for Mintaro Hut in the upper Clinton valley were identified during the site visit and preliminarily evaluated in relation to rock falls, landslides, snow avalanches, and flooding hazards.

The site inspection confirmed that Mintaro Hut is located within a rock fall hazard zone, and is built on and surrounded by large angular boulders ranging from ~0.5 to 6 m across, on which mature beech trees up to 0.5 m in diameter (age ~165–180 years) are growing. The rock fall debris is inferred to have been derived from a source area at the top of Mintaro Ridge, about 300–500 m above the hut site. Large rock falls are expected to occur at the hut site during a large (M 7.5–8.0 or >) earthquakes on the Alpine Fault or the Fiordland Subduction Zone, resulting in intensity MM8 shaking or greater at Mintaro Hut. The calculated average return period for MM8 intensity shaking at Mintaro is about **1 in 100** years. For risk assessment purposes the average frequency of a large rock fall at the current Mintaro Hut site is estimated to be 1 every 100 years. This is consistent with data from earthquake-induced landslide studies and other rock fall risk assessments in Fiordland.

The risk (annual probability) of one or more deaths or serious injuries resulting from a large rock fall at the current Mintaro Hut site was assessed using the landslide risk management guidelines and criteria developed by the Australian Geomechanics Society (2007), and the Australian Committee on Large Dams (2003). Using this methodology the annual probability of loss of life at the current Mintaro Hut site due to a large rock fall is estimated to be 5×10^{-3}.

Because of the position of the rock fall source area, remediation options to reduce risk at the site are not practical. The likely high cost and uncertain effectiveness of stabilisation works (e.g., rock bolting) or protection (rock fall fences, barriers) suggests that there is no practical solution to totally eliminate the rock fall risk at the site. Based on the AGS (2007) and ANCOLD (2003) risk criteria the level of risk estimated for loss of life at the current Mintaro Hut site due to a large rock fall (5×10^{-3} annual probability) is too high to be either acceptable or tolerable, and is thus considered to be unacceptable. As consequence, the most suitable risk mitigation option is to avoid the risk by relocating the hut to another lower risk site.

Two sites (Site 3 and Site 4) in the upper Clinton valley upstream from the current hut site are potentially suitable alternative locations for Mintaro Hut. Both of these sites offer a significant reduction in rock fall and landslide risk compared to the current site, although there is a potential risk of flooding at Site 3. Based on the information obtained during this study, Site 4 is the preferred alternative location for Mintaro Hut. Site 4 is outside the rock fall, debris flow, and snow avalanche zones, and is above the flood level of the Clinton River. The interim assessment of risk from such hazards at Site 4 is *Low to Very Low*. However this needs to be verified by a full assessment hazard and risk assessment. Further studies, including topographic surveys and monitoring during future flood events, are recommended at Site 4 to establish a longer-term basis on which to assess the risk from rock falls, debris flows, flooding, and snow avalanche hazards at the preferred site, and provide better information for the possible design and construction of a new hut.

1.0 INTRODUCTION

1.1 BACKGROUND

The Department of Conservation (DoC) has had a hut located at Mintaro in the upper Clinton valley of the Milford Track since 1966. The present hut replaced the original on the same site in 1985 and accommodates up to 40 people per night during the Great Walk Season for a period of 183 days from late October to end of April. There is less to no use of the hut during the winter as the track is generally inaccessible because of snow and avalanche risk. Use of the Milford Track and Mintaro Hut during the Great Walk Season (approx. ½ the year) is close to 100% occupancy, resulting in about 7200 people staying one night at this location. In addition a Hut Ranger is also based at Mintaro for the duration of the Great Walk Season.

GNS Science (GNS) prepared a geological hazard and risk assessment report for the Mintaro Hut site in 2011 (Hancox and Perrin, 2011). That report indicated that Mintaro Hut could be affected by a large rock fall triggered by a ~M 7.5 or greater earthquake on the Alpine Fault, or a large Fiordland Subduction Zone earthquake, causing shaking of intensity MM8 or greater in the Mintaro area. In response to that risk assessment, DoC has requested that GNS carry out a quantitative reassessment of rock fall risk at the current Mintaro Hut site which evaluates the possibility of mitigating that risk to enable DoC to maintain a hut at the present location, and if necessary consider options for another more suitable site on the Milford Track in the upper of the Clinton valley.

1.2 PURPOSE AND SCOPE OF THIS REPORT

This report relates to a review of rock fall risk at Mintaro Hut site, and preliminary evaluation of possible alternative site options for that hut in the upper Clinton valley. The study was undertaken for DoC's Te Anau Area Office, following a request from Ross Kerr (Ranger, Project and Contract Management). In accordance with the terms of reference specified by DoC and GNS Proposal No.121343024, the objectives of the study were to:

1. Review the existing geological report (Hancox and Perrin, 2011) and risk analyses relating to the risk to visitors at Mintaro Hut from a large rock fall or landslide at the current hut site using the ANCOLD (2003) and/or AGS (2007) risk assessment criteria. The risk assessments should be carried out as a numerical calculation (i.e. an estimate of the annual probability of one or more deaths or serious injuries) rather than a descriptive (qualitative) assessment of the risk (e.g. low, medium, high or very high).
2. Confirm or revise the risk assessment for the current hut site, and advise on the practicality of any mitigation measures to reduce risk at the site to an acceptable level.
3. Identify and evaluate any other potential sites for Mintaro Hut in the general area of the current site taking into account rock falls (and other types of landslides), snow avalanches, and flooding hazards in the upper Clinton valley.

As agreed, the assessment and analysis was carried out through a combination of desk-study review of available reports and information, and field inspection of the Mintaro Hut site and adjacent areas downstream and upstream in the upper Clinton valley by the authors (Graham Hancox and Jon Carey) and Ross Kerr (DoC Te Anau) from 12-14 November 2012. This report presents the results of the revised assessment of the risk of a large rock fall at the current Mintaro hut site, and a preliminary assessment of potential alternative site options for Mintaro Hut in the upper Clinton valley. The general location and topographic features at the current Mintaro hut, and four potential alternative hut sites that were identified during the desk-study review and evaluated during the site visit are shown in Figure 1.

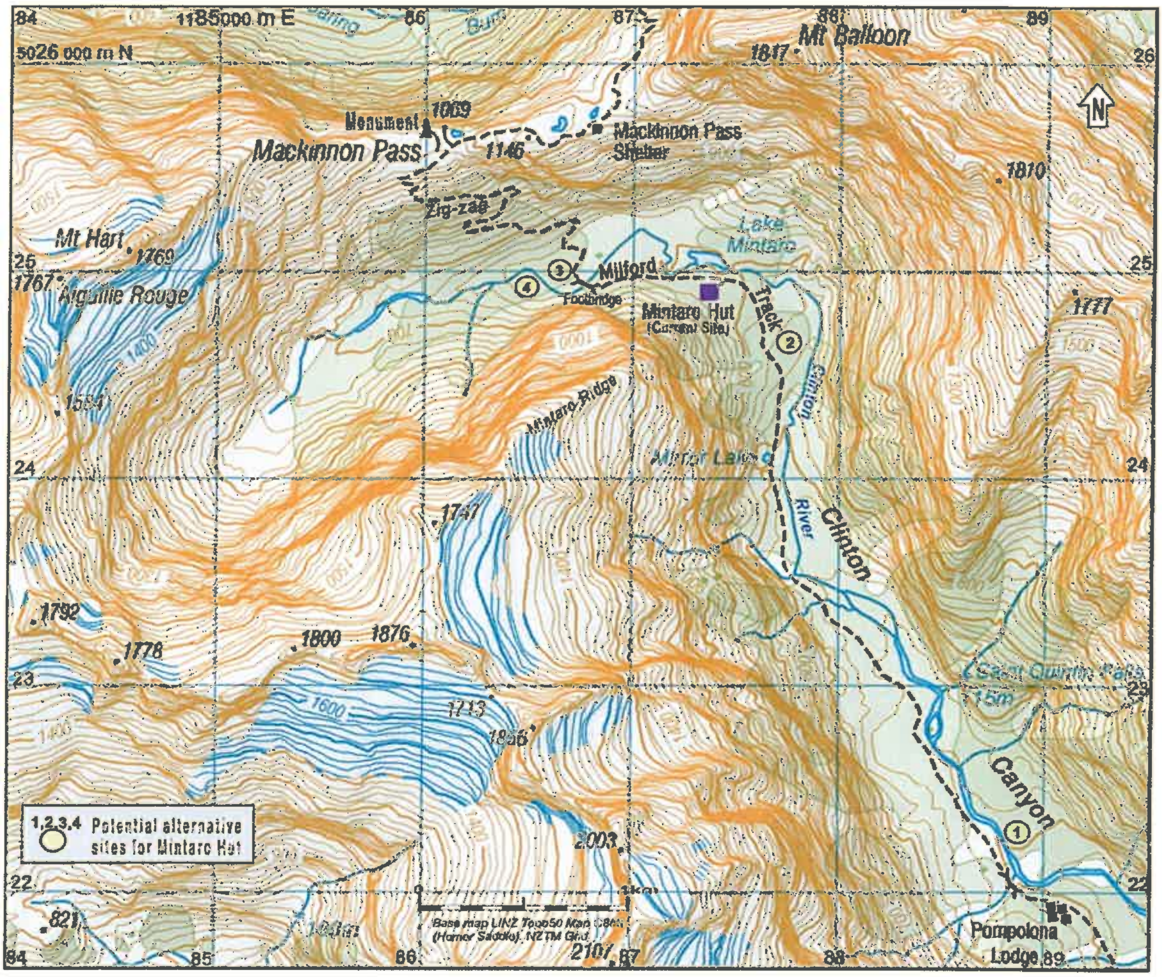

Figure 1 Topographic map showing the location of Mintaro Hut on the Milford Track and significant geomorphic features at the head of the Clinton valley, and the positions of four potential alternative sites for Mintaro Hut that were identified during the desk-study review and evaluated in the field.

2.0 ROCK FALL RISK AT CURRENT MINTARO HUT

2.1 DESCRIPTION OF SITE AND PREVIOUS GEOLOGICAL HAZARD ASSESSMENT

Mintaro Hut is located on the Milford Track in the upper Clinton valley, ~1.5 km southeast of Mackinnon Pass (Figure 1). The hut site lies at an altitude of ~620 m, about 15-20 m above the Clinton River and Lake Mintaro, a ~200 m long rock fall/fan-dammed lake in the valley head (Figure 1). The hut is sited in mature beech forest on an old rock fall deposit, and numerous large angular boulders are scattered around the site.

A baseline geological inspection of Mintaro Hut for DoC in April 2000 (Hancox 2000) identified a potential rock fall hazard at the site which could pose a significant risk to the Hut, especially during large earthquakes. The two large earthquakes in Fiordland in 2003 (M_W 7.2) and 2009 (M_W 7.6), and rock falls near the hut during the October 2007 earthquake (M_L 6.7) suggested that rock fall risk at Mintaro Hut was likely to be greater than previously estimated. GNS Science therefore decided, with the support of DoC (Ross Kerr), to reassess the rock fall and landslide hazard and risk at Mintaro Hut using a qualitative risk assessment approach developed for DoC in 2008 (Hancox, 2008). That reassessment was carried out on site by G Hancox and N Perrin in 2009 and 2010 and, after receiving and responding to feedback from DoC, the report was finalised and issued in August 2011 (Hancox and Perrin, 2011).

The 2011 reassessment (Hancox and Perrin, 2011) confirmed that Mintaro Hut is sited on an ancient rock fall deposit which has been derived from failure(s) from the very steep (45-65°) Mintaro Ridge behind the hut. The rock fall debris, which consists of angular gravel with boulders from 0.5–6 m across, covers an area of ~120,000 m^2, and based on an average thickness of at least 20 m, has an estimated volume of ~650,000 m^3 (Figure 2).

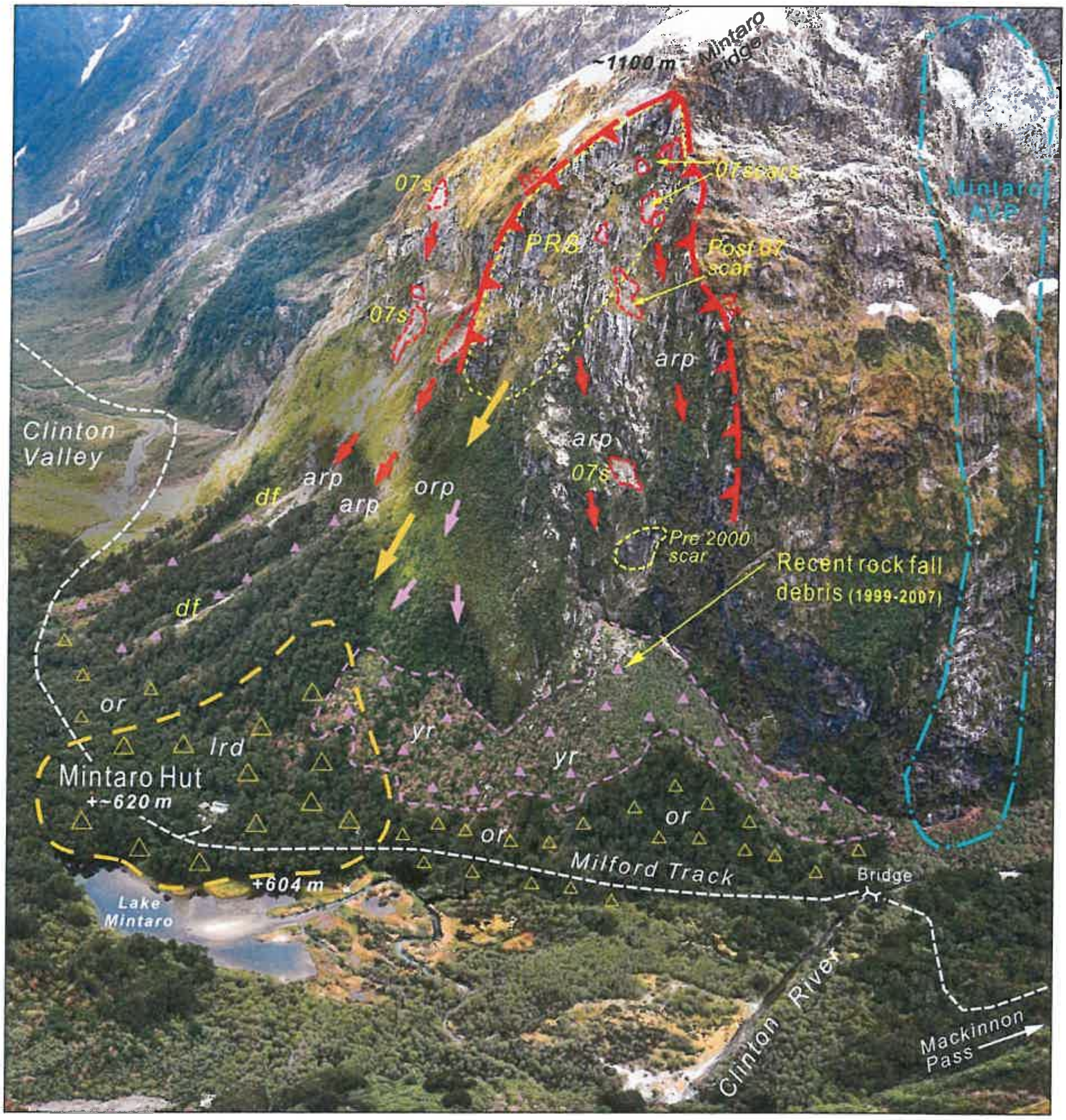

Figure 2 Aerial view of Mintaro Hut sited on old rock fall debris *(lrd, yellow triangles)* on the south side of the upper Clinton valley. The rock fall deposit at the hut site includes angular boulders 1– 6 m across. About 100 m southwest (upstream) of the hut is an area of younger, scrub-covered rock fall debris *(yr)*, which has been built up by periodic rock falls down active *(arp)* and older *(orp)* paths on the end of Mintaro Ridge. Scars of small rock falls triggered by the October 2007 earthquake are outlined in red. Debris from these and other recent rock falls has accumulated at the apex of the debris fan, ~400 m southwest of the hut. The rock mass at the top of the ridge above the hut is well jointed with areas of relaxed open-jointed rock *(OJ)*, and is a potential source *(PRS)* of a future large rock fall at the site, particularly during a large (M 7.5 or >) earthquake. Debris flows *(df)* in two streams just downstream from Mintaro in July 2010 did not affect the hut. The Mintaro avalanche path *(AVP*, Owens and Fitzharris, 1985) about 650 m upstream from the hut does not affect the site *(figure from Hancox and Perrin, 2011)*.

The rock fall deposit which the hut is built on (Figure 2) is inferred to have accumulated in the bottom of the Clinton valley over the last 10,000-12,000 years, since the end of the last glaciation. Silver beech forest on the older rock fall deposits includes mature trees up to ~600 mm diameter growing on boulders near the hut. Incremental coring has shown these trees to be approximately 165-180 years old (Hancox and Perrin, 2011). This indicates that the last large rock fall at the site occurred at least 180-200 years ago, and was possibly triggered by the ~M 8 Fiordland earthquake of 1826 (Downes et al., 2005). However, there are also some ~1–1.2 m diameter (~300-400 year old) beech trees growing on older rock fall debris adjacent to the Milford Track below the hut, which may have been deposited during the last (1717) Alpine Fault earthquake about 300 years ago (Wells et al., 1999, Biasi et al. 2010, Berryman, 2012). Scrub-covered rock fall debris approximately 80 m southwest of the hut (Figure 2) suggests the area has been subjected to periodic smaller rock falls which have prevented the establishment of beech forest. Field evidence, however, indicates that these smaller events did not reach the hut site. No evidence of recent boulders or rock fall deposits were identified in the beech forest near the site.

The 2011 assessment concluded that the current Mintaro Hut site is potentially exposed to a range of geological hazards, mainly resulting from the hut's location within a rock fall hazard zone, and the possible impacts of a future large earthquake in the area. Evidence from the coring of beech trees growing on boulders close to the hut suggests that rock falls from Mintaro Ridge (directly above the site) that are large enough to reach the hut site may occur about every 100-200 years. The last rock fall that reached the hut site is likely to have been triggered by very strong earthquake shaking of intensity MM8–MM9 (Appendix 1). The last recorded event of such a high intensity which is likely to have impacted the site was the 1826 Fiordland subduction zone earthquake. Shaking of a similar intensity in the future could be expected to trigger further large rock falls at the site.

Geological hazards at the current Mintaro Hut site were assessed by Hancox and Perrin (2011) using the qualitative risk analysis method in the revised methodology for assessing geological hazards at DoC hut sites (Hancox, 2008), which was based on the Australian Geomechanics Society (AGS, 2007) Landslide Risk Management Guidelines (Appendix 2). The qualitative assessment of the risk from geological hazards at Mintaro Hut that have been derived using that methodology are summarised in Table 1.

As shown in Table 1 the qualitative ratings of risk posed by landslides and rock falls at Mintaro Hut ranged from *Low to Very Low* for small to moderate rock falls (~10–10^2 m^3, with 1–2 m boulders), to *High to Very High* for a rock fall (~10^3 m^3 or >, with 1–6 m boulders) triggered - by an Alpine Fault earthquake, or possibly a large subduction zone earthquake similar to the 1826 earthquake. Current research has shown that the return period for earthquakes on the Alpine Fault in northern Fiordland is about 330 years, and there is a relatively high probability (up to ~30%) of an Alpine Fault earthquake in the next 50 years (Biasi et al., 2010, Berryman, 2012).

The consequences of a large rock fall at the current Mintaro Hut site is expected to be catastrophic and the consequences are likely to include significant damage to the property and potential loss of life. Consequently the risk of such an event is assessed (qualitatively) as *High to Very High*. Because of the remoteness of the site and the location of the potential rock fall source area ~500 m above the hut, feasible remedial options to reduce risk at the site to an acceptable level were considered to be impractical. It was therefore recommended (Hancox and Perrin, 2011) that consideration should be given to relocating the Mintaro Hut to a lower risk site as soon as reasonably possible.

Table 1 Qualitative risk assessment of landslides, rock falls, and other natural hazards at the current Mintaro Hut *(revised using AGS (2007) Landslide Risk Assessment Criteria).*

Geological Hazard	Likelihood [1]	Consequences	Risk Level	Basis for Risk Assessment and Risk Management Options
Small rock falls *(~1-10 m^3)* - as have occurred at the site in the last few years.	Almost certain (RI 10 yrs.) (AP~10^{-1})	Insignificant	Low to Very Low	The risk from small rock falls (like those during the October 2007 earthquake) is considered to be acceptable because slope failures of this type appear not to reach the hut site. These smaller rock falls tend to be channeled down gullies away (upstream or downstream) from the hut. However, the site and rock fall source areas should be inspected by an engineering geologist after any such events in the future. The risk is considered to be *acceptable* with this management measure.
Small to moderate rock falls (~10 – 10^2 m^3, with 1–2 m boulders)	Likely (RI 100 yrs.) (AP~10^{-2})	Insignificant	Low	Areas of 'younger' scrub-covered, rock fall debris near (above) the hut suggest that small to moderate rock falls have occurred periodically in the site area over the last few hundred years (probably during strong earthquakes), preventing establishment of mature beech forest. Debris from such falls has travelled mainly down gullies away from the hut, and has not come to within ~80–100 m of the site. In addition, beech trees around the hut provide some protection from smaller boulders (~0.5– 1 m), preventing them from reaching the hut. For these reasons the level of risk for *small to moderate rock falls* is thought to be *acceptable*.
Large earthquake-induced rock falls (~10^3 m^3 or >, with 1–6 m boulders)	Possible (RI 1,000 yrs.) (AP~10^{-3}) to Likely (RI 100 yrs.) (AP~10^{-2})	Major to Catastrophic	High to Very High	Geological and geomorphic evidence shows that there is potential in the future for a large rock fall at the hut site (~1000 m^3 or >, with 1-6 m boulders) especially during a large earthquake (≥ M 7.5–8.0; MM9-10) on the Alpine Fault or the Fiordland Subduction Zone. Earthquake-induced landslides typically affect high, steep slopes and ridges, where shaking effects are amplified. There is a relatively high probability (up to ~30%) of an Alpine Fault earthquake in the next 50 years (Biasi et al. 2010, Berryman 2012). The consequences of a large rock fall at the site is expected to be potentially *major* to *catastrophic (damage and loss of life expected)*, consequently the *risk* of such an event is assessed (quantitatively) as *High* to *Very High*. Treatment options to reduce risk at the site to an acceptable level are probably impractical, and this probably means that the hut should be moved to a new site.

Geological Hazard	Likelihood [1]	Consequences	Risk Level	Basis for Risk Assessment and Risk Management Options
Rainfall-induced Landslides	Almost certain (RI 10 yrs.) (AP~10^{-1})	Insignificant	Very Low	Although rainfall-induced landslides (typically shallow slides and flows) occur frequently, there is no geomorphic evidence to show that such failures have occurred, or can occur, in the immediate hut site area. The risk from such events is therefore considered to be *acceptable*.
Flooding, debris flows	Barely Credible (RI >100,000 yrs.) (AP~10^{-6})	Insignificant	Very Low	The elevated hut site is well above river level and there are no tributary streams close to the hut. Risk *acceptable*.
Snow avalanches *(associated rock and debris flows)*	Unlikely (RI 10,000 yrs.) (AP~10^{-4})	Insignificant	Very Low	The closest known avalanche path *(Mintaro - RP 20yrs, Owens and Fitzharris 1985)* does not affect the hut site. There is no known snow avalanche activity at the site. Risk *acceptable*.
Foundation failure and collapse	Rare (RI 100,000 yrs.) (AP~10^{-5})	Insignificant	Very Low	The materials on which the hut are built are not prone to collapse or erosion given the existing site conditions. Risk *acceptable*.

Notes

1. *Likelihood (%) estimates, based on historical and geological evidence, are given as approximate Indicative Recurrence Interval (RI) and Annual Probability (AP), which are based on the AGS, 2007 Qualitative Risk Assessment Guidelines (see Appendix 2). These estimates differ slightly from those in Hancox and Perrin, 2011, which were based on the AGS, 2000 risk assessment criteria.*
2. *The terms used to describe the relative size landslides and rock falls apply only in the context of this report. The landslide size terms used are qualified by an approximate landslide volume (m^3).*

2.2 REVIEW OF ROCK FALL RISK AT THE CURRENT SITE

The review of the risk of a large rock fall at the current Mintaro Hut site firstly involved re-inspection of the site and the surrounding area by Graham Hancox and Jon Carey, (accompanied by Ross Kerr of DoC) during the 11–14 November 2012 site visit. This was followed by evaluation of the site observations and photos, and development of the numerical risk assessment which provides an estimate of the annual probability of one or more fatalities or serious injuries as a result of a large rock fall at the current Mintaro Hut site.

2.2.1 Data review and site reassessment

From the review of the available geologic, geomorphic and seismicity data relating to the Mintaro Hut site and the November 2012 site inspection it has been determined that:

a. Mintaro Hut is located within a rock fall hazard zone, and is built on and surrounded by large angular boulders ranging from ~0.5 to 6 m in across, on which mature beech trees up to 0.5 m in diameter (age ~165–180 years) are growing. The rock fall debris is inferred to have been derived from a source area at the top of Mintaro Ridge, about 300–500 m above the hut site (see Figure 2 and Figure 3).

b. Based on the size of beech trees growing on rock fall boulders around the hut site, the last large rock fall at the site occurred about 180 (± ~15) years ago, and was possibly triggered by strong shaking (MM8 or greater) associated with the 1826 Fiordland earthquake (Clark et al., 2011, Hancox et al., 2002, 2003; Appendix 1).

c. A large rock fall of 10^3–10^4 m^3 or greater from the crest of Mintaro Ridge about 500 m above the hut is likely to result in multiple blocks up to about 1–2 m in diameter and some possibly up to 6 m across (a boulder of this size is 17 m from the hut). The slight topographic depression behind the hut site is likely to afford some protection from smaller rock falls, but larger falls can (or should) be expected to reach the hut site.

d. Large rock falls may occur at the hut site during a future large (M 7.5 – M 8.0 or >) earthquake on the Alpine Fault, which has a ~30% probability of occurrence in the next 50 years (Berryman et al., 2012), and is expected to cause intensity MM8–9 shaking at the Mintaro Hut site. Similar shaking intensities may also be caused by a Fiordland Subduction Zone earthquake comparable to the 1826 earthquake. The calculated average 1 in 100 years MM Intensity in the Mintaro Hut site area is ~MM8.2, and the 1 in 500 years MMI is ~MM9 (Clark et al., 2011, see Appendix 3). As a result of topographic amplification the MMI intensity on the ridge above the site can be expected to be ~1–2 intensity units greater than the average intensity on the valley floor.

e. The current hut site is also exposed to rock falls from the south face of Mt Balloon on the northern side of the valley. Periodic rock and debris falls and snow avalanches from this very steep face has caused a large debris fan to develop at the base of the slope, which in conjunction with the Mintaro rock fall deposit, is responsible for the impoundment of Lake Mintaro (Figure 3). Several small rock falls occurred on this face during the site visit. A very large (10^6 m^3 or >) rock avalanche from this face, which is possible during an Alpine Fault earthquake, could conceivably reach the hut site.

f. Because of the position of the potential most likely source area of a large rock fall, remediation options to reduce rock fall risk at the site to an acceptable level are considered to be impractical. The likely high cost and uncertain effectiveness of any stabilisation schemes (e.g., rock bolting) or protection works suggests that there is no practical means to totally eliminate the rock fall risk at the site.

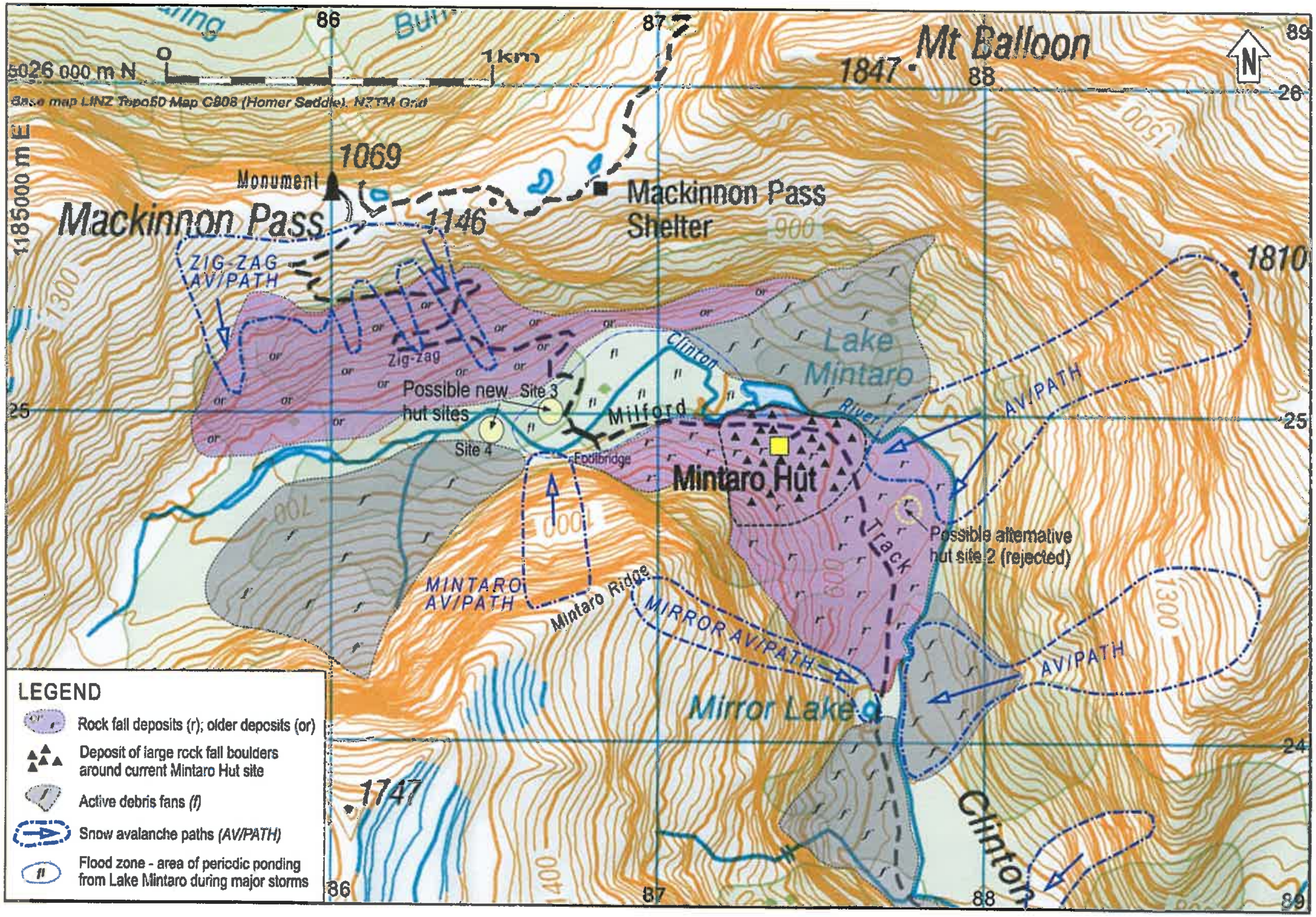

Figure 3 Geomorphic map of the Mintaro Hut area on the Milford Track in the upper Clinton Valley showing rock fall deposits, snow avalanche paths (after Owen and Fitzharris, 1985) and three potential alternative sites for Mintaro Hut (Sites 2, 3, and 4) that were identified and assessed.

2.2.2 Risk assessment method

The risk assessment method used in the review of rock fall risk at the current Mintaro hut site is based on the comprehensive Landslide Risk Management guidelines developed by the Australian Geomechanics Society (AGS, 2007), and have been extensively referenced and peer-reviewed. The revised DoC hut site geological hazard assessment methodology (Hancox 2008) was based on a 2000 version of these guidelines (Appendix 2).

The AGS (2007) landslide risk guidelines are broadly similar to guidelines developed by the Australian Committee on Large Dams for assessing dams and similar structures (ANCOLD, 2003), but are specifically aimed at landslides and other slope movements. The AGS guidelines provide a framework for assessing landslide hazards and developing quantitative risk assessments for both property and loss of life. They were used by URS in their 2010 Bowen Falls Walkway risk assessment for DoC (URS New Zealand Limited, 2010).

For this review of the risk of a large rock fall at the current Mintaro Hut site, the AGS guidelines provide guidance on assessing the frequency of landslide hazard events and the consequences to individuals impacted by those events, including the possibility of loss of life (LOL) or serious injury at the site. In accordance with the terms of reference from DoC, this review presents an estimate of the annual probability of one or more fatalities or serious injuries as a result of a large rock fall at the current Mintaro Hut site.

2.2.3 Risk assessment at Mintaro Hut

In this section the risk is calculated for a visitor to Mintaro Hut and stays overnight. Based on information from DoC (Ross Kerr) during the Great Walk Season from late October to the end of April (183 days) a typical visitor could spend 15–18 hours at the hut, although the DoC Hut Warden or one or more visitors could be at the site for most of a day.

The risk (annual probability) of one or more deaths or serious injuries as a result of a *large rock fall at the current Mintaro Hut site* has been estimated using the following equation based on the AGS (2007) methodology:

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

Where,

$R_{(LOL)}$ - Risk (annual probability of loss of life or serious injury to one or more individuals)

H - Hazard event (large rock fall at Mintaro Hut site)

$P_{(H)}$ - Annual probability of a large rock fall at current Mintaro Hut site

$P_{(S:H)}$ - Probability of an impact of large rock fall on Mintaro Hut

$P_{(T:S)}$ - Temporal spatial probability (an individual is at the hut when the rock fall impacts)

$V_{(D:T)}$ - Vulnerability of individual (probability of loss of life given impact).

The following values were used for the partial (one hazard) risk analysis at the Mintaro Hut site (based on information and values presented in Section 2.2.1):

H = Large rock fall (10^3–10^4 m^3 or >, with boulders ~1–6 m across)

$P_{(H)}$ = Annual probability of large rock fall (MM8 intensity RI = 100 years) = 10^{-2}

$P_{(S:H)}$ = Probability of an impact of large rock fall on hut = 1.0

$P(T:S)$ = Temporal spatial probability (occupancy for ½-year) = 0.5

$V_{(D:T)}$ = Vulnerability of individual (probability of loss of life given impact) = 1.0

Therefore, using Equation 1: $R_{(LOL)}$ = 0.01 x 1.0 x 0.5 x 1.0 = 5×10^{-3}

Thus the annual probability of loss of life at the current Mintaro Hut site ($R_{(LOL)}$) due to a large rock fall is estimated to be 5×10^{-3} (or 0.005).

For this calculation the controlling event is the expected frequency (about 1 every 100 years) of MM8 intensity shaking which is likely to trigger a large rock fall at the hut site. If the hut was occupied for all of the year the annual risk would be about 10^{-2}. Conversely, if the assessment related to a track where the time spent by an individual in the rock fall path was only a minute or so, the level of risk would be much lower (as it is at Bowen Falls – 1.4×10^{-9} for a large rock fall with a frequency of 1 every 100 years (URS, 2010.).

2.2.4 Risk criteria and mitigation options for Mintaro Hut

The main purpose of a risk evaluation as described above is usually to decide whether to accept risk or treat the risk. In this regard, levels of risk are generally described as being "Acceptable", "Tolerable", or "Unacceptable" (AGS, 2007):

- *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.
- *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 as practicable.
- *Unacceptable risks* are risks that would generally be regarded as unacceptable whatever the benefits.

Tolerable risks are commonly accepted for use in risk management. Based on the ANCOLD (2003) and AGS (2007) risk criteria, for an existing building (such as the hut at the current Mintaro site), the Tolerable Risk Level (loss of life the person most at risk, in this case any visitor or occupant of the hut) would be 10^{-4} per annum (see Appendix 4).

Based on the risk criteria described above (and Appendix 4) the level of risk estimated for loss of life at the current Mintaro Hut site due to a large rock fall (5×10^{-3} annual probability) is too high to be *acceptable or tolerable*, it is therefore viewed as *unacceptable.* Because *slope stabilisation* is considered to be impractical, and taking *no action* is likely to be *unacceptable* based on the current risk level, the only effective risk mitigation option appears to be to *avoid the risk* by relocating the hut to another site. This option is discussed next.

3.0 ALTERNATIVE SITES FOR MINTARO HUT

3.1 ALTERNATIVE HUT SITES CONSIDERED

Efforts were made during the site visit to identify and evaluate other potential sites for Mintaro Hut in the general area of the current site in the upper Clinton valley, taking into account geological hazards (landslides, rock falls, debris flows), snow avalanches, and flooding. Three potential sites were identified during the desk-study review and closely inspected from the helicopter on the first day of the site visit (Figure 1). Another potential hut site (Site 4) was identified on aerial photos during preparation of this report, and inspected in the field on 4 January 2013 by Ross Kerr, who has provided ground photos of the site.

3.1.1 Site 1

Site 1 is located in mature beech forest about 3 km down valley from the current Mintaro Hut site, on the east (true left) side of the Clinton River ~500 m upstream from Guided Walks Pompolona Lodge owned by Ultimate Hikes (Figure 4).

Figure 4 Aerial view of potential alternative Site 1 *(S1)*, located on the true left (northeast) side of the Clinton River about 500 m upstream from Pompolona Lodge *(P)*. Active snow avalanche paths *(av)* occur immediately upstream and downstream from the site, one of which *(av1)* has previously blocked and diverted the Clinton River, causing bank erosion and ultimately relocation of Pompolona Lodge from its former position *(fp)* to its present location in 1994.

Site 1 was not inspected on the ground because helicopter reconnaissance confirmed it to be at risk from known active snow avalanche paths in the area. A large avalanche/landslide from the west (true right) side of the valley in 1994 blocked and diverted the Clinton River, causing severe bank erosion at the former site of Pompolona Lodge. This caused the lodge to be moved away from the river bank to its present location (Figure 4). The possibility of similar events in the area in the future was the main reason the site was rejected. DoC also had logistic concerns (hut spacing, length of walking day) which also made the site unsuitable.

3.1.2 Site 2

Site is located in beech on the east side of the Milford Track about 500 m downstream from the current Mintaro Hut site. Snow avalanche paths from the eastern side of the valley are present upstream and downstream but do reach the site (Figure 3 and Figure 5).

Figure 5 Aerial view of potential hut Site 2 *(S2)* located in beech forest on the true right left (west) side of the Clinton River, about 500 m down valley from Mintaro Hut. Although the site is generally clear of the avalanche blast zones on the east side of the valley *(av)* and debris flow paths on the western side *(df)*, the site and general area is littered with old rock fall boulders under the bush cover.

The area of Site 2 was inspected from the air and on the ground. The ground inspections showed that below the beech forest canopy, the ground surface around Site 2 and areas on both sides of the Milford Track down to the river was littered with rock fall boulders at least ~0.3 to 1 m or more across. The site was therefore interpreted as being within an ancient rock fall runout zone (Figure 3), probably formed by periodic rock falls from the west (true right) side of the valley.

There was no field evidence of recent rock fall activity at Site 2. However, because there is a strong possibility of future rock falls in the area, especially during strong earthquake shaking, Site 2 was rejected as an alternative location for Mintaro Hut. From a rock fall risk perspective Site 2 was considered to be only marginally lower risk than the current hut site.

3.1.3 Site 3

Site 3 is located near the footbridge on the true left side of the Clinton River, about 650 m up valley from Mintaro Hut. The site area is on a gently rising (estimated 1-5°), bush-covered alluvial terrace about 1–2 m above river level, which is traversed by the Milford Track before beginning its steep climb up toward Mackinnon Pass (Figure 1 and Figure 6).

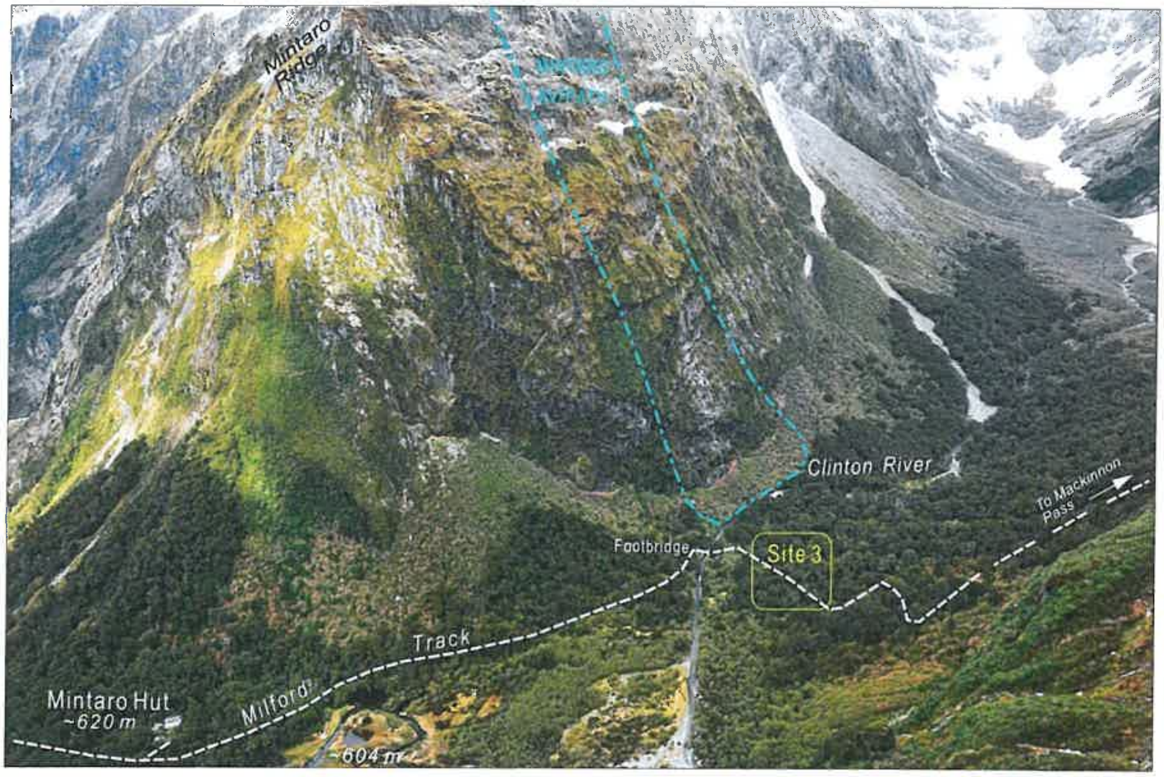

Figure 6 Aerial view of hut Site 3 located in beech forest ~650 m upstream from Mintaro Hut on the north bank of the Clinton River at the start of the climb to Mackinnon Pass. The Mintaro avalanche path on the south side of the valley does not reach the Milford Track or the potential hut site area.

Site 3 was inspected closely from the air and on the ground to determine the potential for rock falls, snow avalanches, and flooding hazards in the area. The potential hut site lies approximately in the centre of the valley bellow Mackinnon Pass, which at this point in the Clinton valley is noticeably wider. The valley walls are also considerably lower than those at the current Mintaro Hut site, which is towered over by ~1200 m high the south face of Mt Balloon (Figure 3, Figure 7 and Figure 8).

The main activities undertaken to assess the site during the field visit included: (a) geomorphic reconnaissance of rock fall, flood zone, and avalanche paths, (b) basic GPS survey of site features, including the Milford Track and footbridge, rock fall boulders, a flood overflow channel, and 5 shallow test pits dug at the site. The locations and extent of these features are shown in the site map of Site 3 (Figure 7). The soil materials found in the test pits are summarised in Table 2. Figure 9 shows the fine gravel and sand deposits found in TP 2, which are generally typical of the river alluvium (gravel and sand) underlying Site 3.

3.1.4 Site 4

Site 4 is located on the true right of the Clinton River, about 250 m upstream from the foot-bridge (Figure 7, Figure 8, Figure 10, Figure 11, and Figure 12). Site 4 was initially overlooked during the November site visit, but was identified later during preparation of this report, and inspected on the ground at our request by Ross Kerr on 4 January 2013, following a severe weather event.

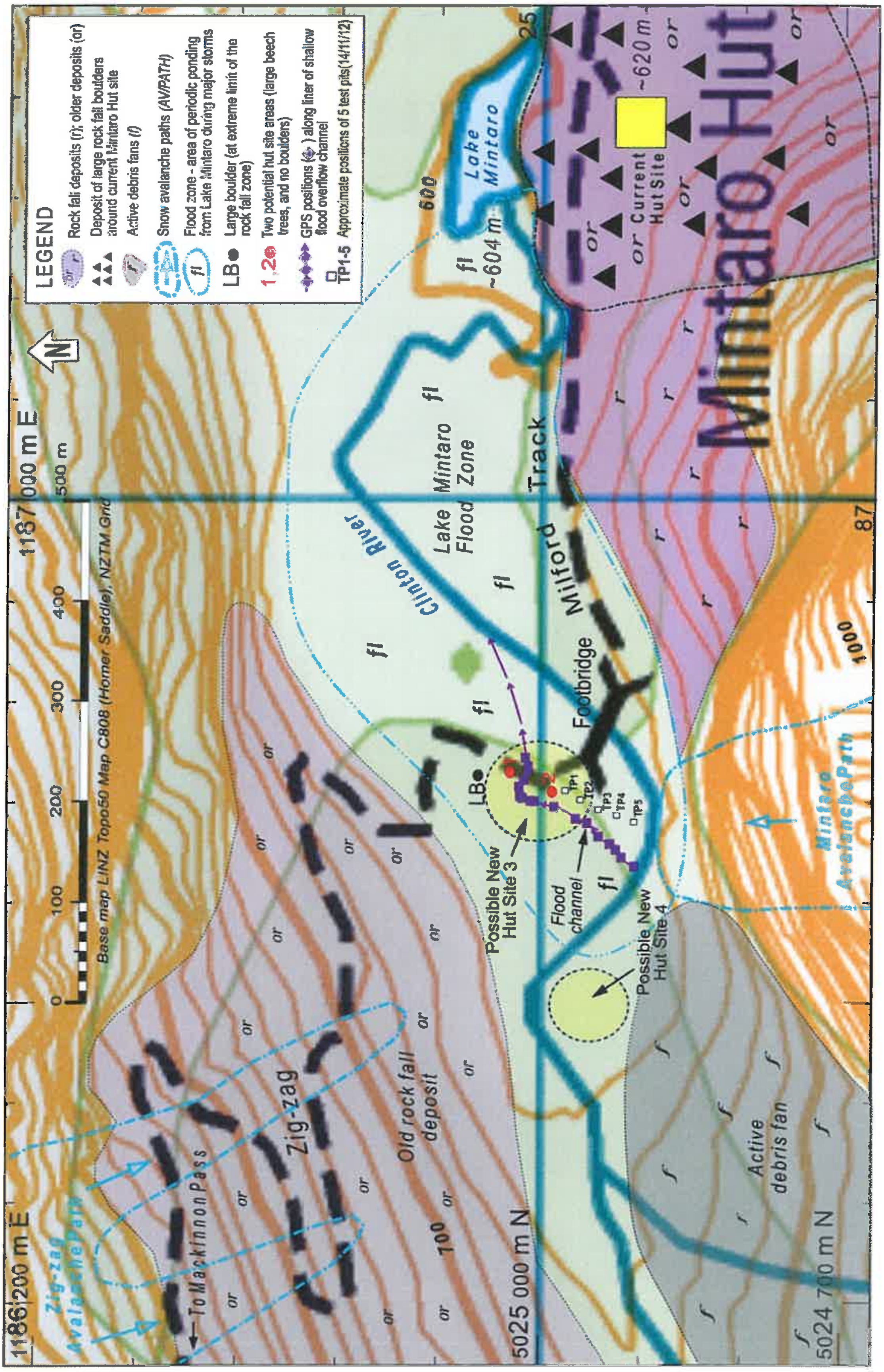

Figure 7 Geomorphic map of potential hut sites 3 and 4 upstream from Mintaro Hut showing old and active rock fall zones, local avalanche paths (Mintaro and Zig-Zag), and the extent of the flooding zone caused by back-up of water from Lake Mintaro during rainstorms. The positions of test pits dug during the site visit, flood overflow channel, and limits of rock fall boulders near the site are also shown. Potential Site 4, which is located ~250 m upstream from the bridge, appears to be outside the rock fall, debris fan, avalanche, and flood hazard areas. This was confirmed by ground inspection by Ross Kerr on 4 January 2013.

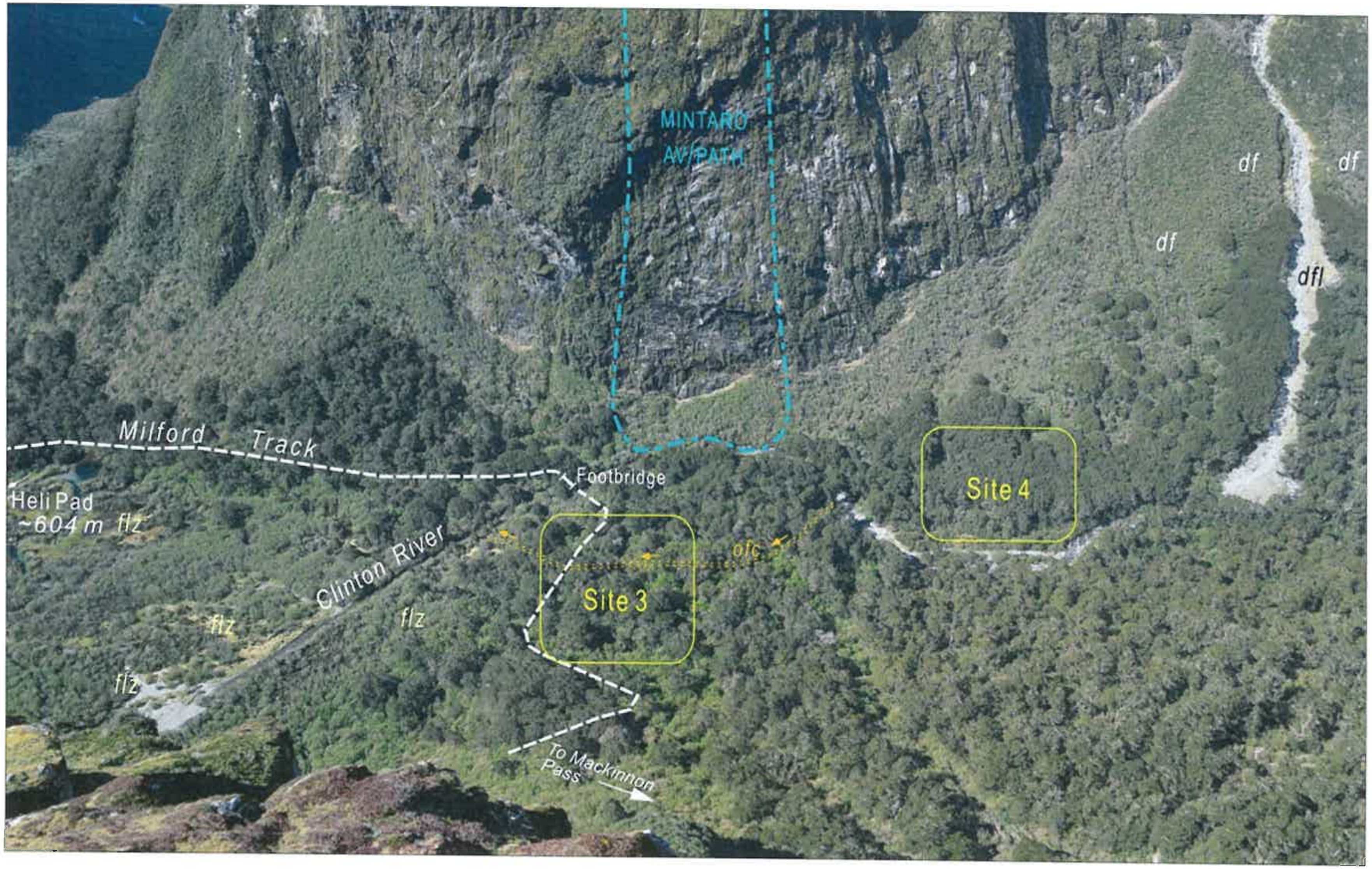

Figure 8 Aerial view of possible hut sites 3 and 4 from the north above Mackinnon Pass. Site 3 is located in an area of beech forest interspersed with tree *fuchsia* and mountain *ribbonwood* (light green trees), which is periodically flooded *(flz)* by a back-up of water from Lake Mintaro. A small flood overflow channel *(ofc)* runs across the Site 3 area. The Mintaro avalanche path on the south side of the valley does not affect the site. Site 4 is located about 250 m upstream from the footbridge in tall, undisturbed sub-alpine beech forest, just downstream from a large debris fan *(df)*.

Table 2 Summary of soil materials found in the test pits at potential hut Site 3.

TP 1	Depth 120 mm (stopped by boulders); dark top soil 50 mm, underlain largely by gravels, cobbles, and some coarse grey sand,
TP 2	Depth 400 mm; dark top soil 50 mm, underlain by 60 mm sub-angular gravel; underlain by medium grey sand with occasional large cobbles and small boulders.
TP 3	Depth 500 mm; dark top soil 50 mm, underlain by medium to coarse grey with occasional sub-angular medium gravel.
TP 4	Depth 400 mm; dark top soil 50 mm, underlain by 60 mm sub-angular cobles/gravels.
TP 5	Depth 150 mm; underlain by sub-angular gravels and cobbles, with occasional coarse sand.

Note:. Approximate locations of the test pits are shown on Figure 7.

Figure 9 Photo of test pit TP2 at hut Site 3 (depth 400 mm) showing the thin (50 mm) brown organic top soil, underlain by 60 mm of sub-angular gravel and medium grey sand with occasional large cobbles. These materials are typical of the alluvium underlying the forest floor across the potential site area.

Figure 10 Aerial view of potential hut sites 3 and 4 looking down the Clinton Valley below Mackinnon Pass *(MP)*. The zig-zag *(z-z)* section of the Milford Track below the pass traverses an old rock rall deposit on the northern side of the valley. Both sites are located in bush near the centre of the valley and are outside the main rock fall zone (left) and the known avalanche paths (Zig-zag and Mintaro, Figure 7). Site S4 is also outside the potential flood zone and debris fan (lower right).

Figure 11 Aerial view looking up the Clinton River towards potential hut Site 3 and Site 4. Site 3 is in an area of large beech trees (dark green) and ribbonwood and fuchsia forest (lighter green). Site 4, which is located in thick beech forest ~250 m upstream from the footbridge *(fb)*, is outside the known rock fall, debris flow, flooding, and snow avalanche hazard zones in the area.

3.2 PRELIMINARY HAZARD ASSESSMENT OF SITE 3 AND SITE 4

Of the possible hut sites that were considered, Site 3 and Site 4 appear to offer the best prospects as an alternative site for Mintaro Hut in terms of natural hazards and location. From on our observations during the November site visit our preliminary hazard assessments of these sites are as follows:

(a) Rock falls and landslide hazard:

No rock fall boulders were observed in the immediate vicinity of Site 3. Observations during the site visit indicate that this site is outside the zone of rock fall deposit on the northern side of the valley below Mackinnon Pass, which is crossed by the zig-zag section of the Milford Track (Figure 3). A single large bolder about 50 m north of Site 3 appears to lie outside the main rock fall zone that mantles the base of the slope. Sites 3 and 4 are located outside the rock fall zone and an active debris fan on the south side of the valley (Figure 7, Figure 8, and Figure 10). The ground inspection of Site 4 by Ross Kerr on 4 January 2013 confirmed the absence of boulders or landslide debris around that site, which is underlain by fine river alluvium.

From these observations the landslide/rock fall hazard at Site 3 and Site 4 is tentatively assessed as *Low to Very Low* using the AGS (2007) qualitative methodology (Appendix 2): *Likelihood:* Unlikely: RI ~10,000 years, AP ~10^{-4}; *Consequences*: Medium to Minor. *Risk:* Low to Very Low. A quantitative assessment of the rock fall risk at Site 3 and Site 4 using the ANCOLD (2003) and AGS (2007) criteria (Appendix 4) has not been carried out as that is beyond the scope of this study. However, based on the above data the annual risk (LOL) from a large rock fall and/or landslide at Site 3 and Site 4 is about 10^{-4} – 5 x 10^{-5} per annum (assuming occupancy for ½ year). This needs to be verified by a full assessment.

(b) Snow avalanche hazard:

Our site observations indicate that both Site 3 and Site 4 are outside the known snow avalanche zones in the area (Figure 7). The Zig-zag path on the northern side of the valley below Mackinnon Pass does not appear to reach the valley floor, and the relatively small Mintaro Path on the south side of the valley affects a small area at the foot of the slope, but does not cross the river (Owens and Fitzharris, 1985). Accordingly, the risk from snow avalanches at Site 3 and Site 4 is estimated to be low to very low.

(c) Flooding hazard:

Site 3: There is both physical and anecdotal evidence of minor flooding hazard in the area of Site 3 (Figure 7 and Figure 10). Flooding caused by a back-up of water from Lake Mintaro periodically overtops the heli-pad and covers the Milford Track upstream to the footbridge and across the Site 3 area to a depth of up to 1 m during severe rainstorms, possibly every 5 years or so (pers comm. Hamish Angus, DoC Te Anau, 14/11/2012).

Physical evidence of periodic flooding at Site 3 includes the small (~0.4 m deep 1.5 m wide) flood overflow channel (which contains coarse sand and a few cobbles), and the presence of fuchsia and ribbonwood species in the beech forest across the site. In the field, however, no physical signs of flooding were observed (erosion, damaged vegetation, trash lines and recent surface silt and sand deposits) on the forest floor across the site.

As shown by the test pits, a thin (~50 mm) dark brown organic top soil is present across the site area (Table 2). This suggests that Site 3 is periodically inundated by ponded or slow-flowing flood water backed up from Lake Mintaro, and that the overflow channel across the site occasionally carries flood water from the river.

Flooding inundation is perceived to be the most significant hazard at Site 3, but more detailed site data are required to assess the nature of that hazard and the risk it might present to an elevated hut at the site. Factual information on river and flood water levels in the area during future rainstorms are required to assess the extent and severity of flooding hazard in the potential sites areas.

The following information has been provided by Ross Kerr on flooding in the Mintaro Hut area during two severe weather events that affected Fiordland in January 2013:

Severe Weather Event of 29 December 2012 to 01 January 2013:

A total of 671 mm rain was recorded at Mintaro Hut over a three day period. This event resulted in the helicopter pad being flooded by 50 mm of water for a couple of hours and ponded water on Site 3. There was no evidence of flooding at Site 4.

Severe Weather Event of 08-09 January 2013:

A total of 354 mm recorded over a period of 20 hours of more intense precipitation, which resulted in the helicopter pad being under 50 to >150 mm of water for up to four hours, with extensive ponded water on Site 3, together with overflow spillage from the flood overflow channel to the back of the site. Once again there was no evidence of flooding at Site 4.

Site 4: Following a site inspection on 4 January 2013, Ross Kerr reports that: *"the alternative Mintaro Hut Site 4 appears on the ground to be a better site than Site 3 in terms of any potential risk of inundation. The lower part of Site 4 is gently sloping, and is covered by tall undisturbed beech forest. The site is approximately 250 m upstream from the suspension bridge, and is downstream from a large debris fan. The site is approximately 2-3 m above Clinton River level, at location E1186502; N5024928, and altitude of ~625 m".*

Based on the vegetation at the site, which is generally undisturbed tall sub-alpine beech forest (see Figure 12 and Figure 13), and its slightly elevated position above river level, Site 4 is considered to be located outside the flood inundation zone from the Clinton River and back-up from Lake Mintaro. This interpretation appears to have been confirmed by Ross Kerr's ground inspection report (above) following the major floods that hit the area in January 2013. However, ongoing monitoring of Site 4 during future flood events is needed to establish a longer-term basis on which to assess the rock fall, debris flow, flooding, and snow avalanche hazards at the site.

Figure 12 Ground view of Site 4 showing the undisturbed sub-alpine beech forest growing across the area. The site is gently sloping, free of rock fall boulders, and is well elevated about 2–3 m above river level. *Photo by Ross Kerr, 04/01/2013.*

Figure 13 View of Site 4 (upper left) from river level. The site is elevated about 2–3 m above the upper Clinton River, and shows no evidence of past flood damage. *Photo by Ross Kerr, 04/01/2013.*

3.3 DISCUSSION

The November 2012 site inspection and preliminary hazard assessment showed that the relocation of the Mintaro Hut to either Site 3 or Site 4 is the best approach to reduce the risk posed by large rock falls and landslides to the current Hut. The studies have indicated that rock fall and landslide risk is likely to be acceptably low at Site 3, but is somewhat lower at Site 4, which is further away from the rock fall zones on both sides of the valley.

Following the November site visit, flooding was identified as a potential hazard at Site 3 and an unknown quantity at Site 4. Information from the 4 January 2013 ground inspections of these sites following a severe weather event between 29/12/2012 and 01/01/2013 confirmed that extensive ponding of water is likely to be an ongoing problem at Site 3. However, Site 4 is located 2–3 m above the level of the Clinton River ~250 m upstream from the footbridge, and was not affected but the January 2013 floods, and shows no signs of old flood damage.

Based on the information obtained during the recent sites visits and discussed above, Site 4 is the preferred alternative location for Mintaro Hut. Flooding is likely ongoing problem at Site 3, and earthquake-triggered rock falls are potentially a significant problem at Site 2.

3.4 FURTHER WORK

The following information is needed to undertake a detailed assessment of the geological hazard and risk at Site 4, and possible requirements for construction of a new hut on the site.

1. Flood water levels should be routinely monitored in the vicinity of Site 4, at the heli-pad, the footbridge, and along the Milford track during future storms when rainfall of ~150 mm or greater in 24 hours is expected to occur in the area.
2. A topographic survey of area of Site 4 is required (possibly using precise RTK GPS survey methods) to determine accurate positions and levels on the following features:
    a. The river channel for ~400 m upstream and 200 m downstream from the foot bridge.
    b. The Milford Track from 200 m downstream from the bridge to the start of the zig-zag.
    c. Ground profiles across Site 4 from the river channel to ~50 m above the bush edge.
    d. The position of bush-line up-slope of the site.
    e. Locations (grid reference/elevations) of boulders (~300 mm or >) in the site area.
    f. The position of the incised stream channel upstream from the site.
    g. Areas of river bank erosion, vegetation damaged by rock falls, floods, avalanches.
3. Tree age analysis of the trees at Sites 4 to determine the age of the forest and get better data on the geological and geomorphic history of the site.
4. Aerial reconnaissance (helicopter) survey of the catchment area above Sites 4 following extreme flooding or rock fall events by a suitably qualified person to assess change and activity within the catchment and any effects on the sites.

4.0 CONCLUSIONS

1. The geomorphic setting and geological hazards at the current Mintaro Hut site on the Milford Track were re-examined in the field during the 12–14 November 2012 site visit. The risk to visitors at the hut site (annual probability of one or more fatalities or serious injuries) from a large rock fall was then assessed quantitatively using the ANCOLD (2003) and AGS (2007) risk assessment criteria. Other potential sites for Mintaro Hut in the upper Clinton valley were identified during the site visit and preliminarily evaluated in relation to rock falls, landslides, snow avalanches, and flooding hazards.
2. The site inspection confirmed that Mintaro Hut is located within a rock fall hazard zone, and is built on and surrounded by large angular boulders ranging from ~0.5 to 6 m across, on which mature beech trees up to 0.5 m in diameter (age ~165–180 years) are growing. The rock fall debris is inferred to have been derived from a source area at the top of Mintaro Ridge, about 300–500 m above the hut site.
3. Large rock falls are likely to occur at the site during large (~M 8.0 or >) earthquakes on the Alpine Fault or the Fiordland Subduction Zone, resulting in intensity MM8 shaking or greater at Mintaro Hut. The calculated average return period for MM8 intensity shaking at Mintaro is about 1 in 100 years. The average frequency of a large rock fall at the current Mintaro Hut site is estimated to be 1 every 100 years.
4. The risk (annual probability) of one or more deaths or serious injuries resulting from a large rock fall at the current Mintaro Hut site was assessed utilising the landslide risk management guidelines and criteria developed by the Australian Geomechanics Society (AGS, 2007), and the Australian Committee on Large Dams (ANCOLD, 2003). Using this methodology the annual probability of loss of life at the current Mintaro Hut site due to a large rock fall is estimated to be 5×10^{-3}.
5. The location of the rock fall source area means that remediation options to reduce risk at the site are not practical. The likely high cost and uncertain effectiveness of any stabilisation works (e.g., rock bolting) or protection works (rock fall fences or barriers) suggests that there is no practical solution to totally eliminate the rock fall risk at the site.
6. Based on the AGS (2007) and ANCOLD (2003) risk criteria the level of risk estimated for loss of life at the current Mintaro Hut site due to a large rock fall (5×10^{-3} annual probability) is too high to be either *acceptable* or *tolerable*, and is thus considered to be *unacceptable*. As consequence, the most suitable risk mitigation option is to avoid the risk by relocating the hut to another lower risk site.
7. Two sites (Site 3 and Site 4) in the upper Clinton valley upstream from the current hut site are potentially suitable alternative locations for Mintaro Hut. Both of these sites offer a significant reduction in rock fall and landslide risk compared to the current site, although there is a potential risk of flooding at Site 3.
8. Based on the information obtained during this study, Site 4 is the preferred alternative location for Mintaro Hut. Site 4 is outside the rock fall, debris flow, and snow avalanche zones in the area, and is above the flood level of the Clinton River. The interim assessment of risk from such hazards at Site 4 is Low to Very Low. However this needs to be verified by a full assessment hazard and risk assessment.
9. Further studies, including topographic surveys and monitoring during future flood, are recommended at Site 4 to establish a longer-term basis on which to assess the risk from rock falls, debris flows, flooding, and snow avalanche hazards at the preferred site, and provide better information for the possible design and construction of a new hut.

5.0 ACKNOWLEDGEMENTS

The authors wish to thank Ross Kerr of DoC for facilitating the site visit, accompanying us in the field during the site inspections, and providing the additional information on the January 2013 rainstorms and ground conditions at Site 4. We also wish to thank our GNS Science colleagues Sally Dellow and Nick Perrin for constructive reviews of the report, and Mauri Mc Saveney and Chris Massey for helpful discussions during the study.

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APPENDICES

APPENDIX 1: MODIFIED MERCALLI INTENSITY SCALE

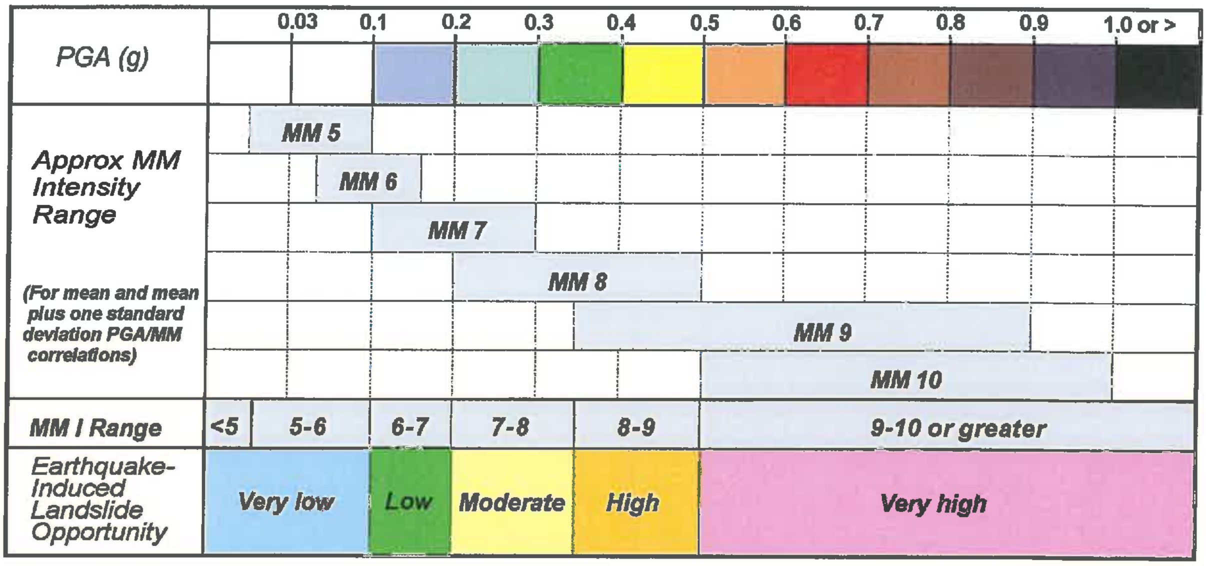
LANDSLIDE CRITERIA IN THE MODIFIED MERCALLI (MM) INTENSITY SCALE

1. Landslide and Environmental Effects (MM5 –10) – NZ 2008

MM5	▪ Loose boulders may occasionally be dislodged from steep slopes.
MM6	▪ Trees and bushes shake, or are heard to rustle. ▪ Loose material may be dislodged from sloping ground, e.g. existing slides, talus and scree slopes. ▪ A few very small ($\leq 10^3$ m^3) soil and regolith slides and rock falls from steep banks and cuts. ▪ A few minor cases of liquefaction (sand boil) in highly susceptible alluvial and estuarine deposits.
MM7	▪ Water made turbid by stirred up mud. ▪ Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings common. ▪ Instances of settlement of unconsolidated, or wet, or weak soils. ▪ A few instances of liquefaction (i.e. small water and sand ejections). ▪ Very small ($\leq 10^3$ m^3) disrupted soil slides and falls of sand and gravel banks, and small rock falls from steep slopes and cuttings are common. ▪ Fine cracking on some slopes and ridge crests. ▪ A few small to moderate landslides (10^3 – 10^5 m^3), mainly rock falls on steeper slopes (>30°) such as gorges, coastal cliffs, road cuts and excavations. ▪ Small discontinuous areas of minor shallow sliding and mobilisation of scree slopes in places. ▪ Minor to widespread small failures in road cuts in more susceptible materials. ▪ A few instances of non-damaging liquefaction (small water and sand ejections) in alluvium.
MM8	▪ Cracks appear on steep slopes and in wet ground. ▪ Significant landsliding likely in susceptible areas. ▪ Small to moderate (10^3-10^5 m^3) slides widespread; many rock and disrupted soil falls on steeper slopes (steep banks, terrace edges, gorges, cliffs, cuts etc.). ▪ Significant areas of shallow regolith landsliding, and some reactivation of scree slopes. ▪ A few large (10^5-[illegible] m^3) landslides from coastal cliffs, and possibly large to very large ($\geq 10^6$ m^3) rock slides and avalanches from steep mountain slopes. ▪ Larger landslides in narrow valleys may form small temporary landslide-dammed lakes. ▪ Roads damaged and blocked by small to moderate failures of cuts and slumping of road-edge fills. ▪ Evidence of soil liquefaction common, with small sand boils and water ejections in alluvium, and localised lateral spreading (fissuring, sand and water ejections) and settlements along banks of rivers, lakes, and canals etc. ▪ Increased instances of settlement of unconsolidated, or wet, or weak soils.
MM9	▪ Cracking of ground conspicuous. ▪ Landsliding widespread and damaging in susceptible terrain, particularly on slopes steeper than 20°. ▪ Extensive areas of shallow regolith failures and many rock falls and disrupted rock and soil slides on moderate and steep slopes (20°-35° or greater), cliffs, escarpments, gorges, and man-made cuts. ▪ Many small to large (10^3-10^5 m^3) failures of regolith and bedrock, and some very large landslides (10^6 m^3 or greater) on steep susceptible slopes. ▪ Very large failures on coastal cliffs and low-angle bedding planes in Tertiary rocks. Large rock/debris avalanches on steep mountain slopes in well-jointed greywacke and granitic rocks. Landslide-dammed lakes formed by large landslides in narrow valleys. Damage to road and rail infrastructure widespread with moderate to large failures of road cuts and slumping of road-edge fills. Small to large cut slope failures and rock falls in open mines and quarries. ▪ Liquefaction effects widespread with numerous sand boils and water ejections on alluvial plains, and extensive, potentially damaging lateral spreading (fissuring and sand ejections) along banks of rivers, lakes, canals etc.). Spreading and settlements of river stop-banks likely.
MM10	▪ Landsliding very widespread in susceptible terrain. ▪ Similar effects to MM9, but more intensive and severe, with very large rock masses displaced on steep mountain slopes and coastal cliffs. Landslide-dammed lakes formed. Many moderate to large failures of road and rail cuts and slumping of road-edge fills and embankments may cause great damage and closure of roads and railway lines. ▪ Liquefaction effects (as for MM9) widespread and severe. Lateral spreading and slumping may cause rents over large areas, causing extensive damage, particularly along river banks, and affecting bridges, wharfs, port facilities, and road and rail embankments on swampy, alluvial or estuarine areas.

Notes: *(1) "Some or "few" indicates that threshold for response has just been reached at that intensity. (2) Environmental damage (response criteria) occurs mainly on susceptible slopes and in certain materials, hence the effects described above may not occur in all places, but can be used to reflect the average or predominant level of damage or MM intensity in an area. (3) Environmental criteria not defined for MM11 and 12, as those intensities have not been reported in New Zealand. Earlier versions of the MM intensity scale suggest that environmental effects at MM11-12 are similar to MM9- 10, but are more widespread and severe. (4) This appendix is based on Hancox et al. 1997, 2002, and Dowrick et al., 2008.*

2. Relationship of MM Intensity to Peak Ground Acceleration (PGA) and earthquake-induced landslide opportunity *(after Hancox et al. 2002)*



The graph above shows the relationship of MM Intensity to peak ground acceleration (PGA) range based on the mean and mean plus one standard deviation correlations of Murphy and O'Brien (1977) landslide opportunity on New Zealand (from Hancox et al. 2002). The overlap in the PGA values for different MM intensities reflects the scatter in PGA/MM data. The blue squares indicate PGA /MMIs and return periods modelled for the Plateau Hut area (Table 2).

The EIL Opportunity classes define the relative likelihood of earthquake-induced landslides occurring in areas of different shaking (PGA/MM Intensity) based on ground damage effects established for New Zealand. Five classes of relative EIL opportunity are recognised, as follows:

1. Very Low (≤ MM5-6): *Very small rock and soil falls on the most susceptible slopes.*
2. Low (MM6-7): *Small landslides, soil and rock falls may occur on more susceptible slopes (particularly road cuts and other excavations), along with minor liquefaction effects (sand boils) in susceptible soils.*
3. Moderate (MM7-8): *Significant small to moderate landslides are likely, and liquefaction effects (sand boils) expected in susceptible areas. Noticeable damage to roads.*
4. High (MM8-9): *Widespread small-scale landsliding expected, with a few moderate to very large slides, and some small landslide-dammed lakes; many sand boils and localised lateral spreads likely. Severe damage to roads, with many failures of steep high cuts and road-edge fills.*
5. Very high (≥MM9): *Widespread landslide damage expected. Many large to extremely large landslides; sand boils are widespread on alluvium, and lateral spreading common along river banks; landslide-dammed lakes are often formed in susceptible terrain. Extensive very severe damage to roads - failures of steep high cuts and road-edge fills.*

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APPENDIX 2: QUALITATIVE GEOLOGICAL HAZARD AND RISK ASSESSMENT

1. Qualitative Measures of Likelihood for Landslide Hazard Events

Level	Descriptor	Description	Indicative Recurrence Interval		Approximate Annual Probability	
			Indicative Value	Notional Boundary	Indicative Value	Notional Boundary
A	ALMOST CERTAIN	Event expected to occur over the design life of a building (~50 years)	≤ 10 years	- 20 years	10^{-1}	- 5 x10^{-2}
B	LIKELY	Event will probably occur under adverse conditions over design life.	100 years	- 200 years	10^{-2}	- 5 x10^{-3}
C	POSSIBLE	Event could occur under adverse conditions over design life.	1000 years	- 2000 years	10^{-3}	- 5 x10^{-4}
D	UNLIKELY	Event might occur under very adverse circumstances over design life.	10,000 years	- 20,000 years	10^{-4}	- 5 x10^{-5}
E	RARE	Event conceivable only under exceptional circumstances over design life.	100,000 years	- 200,000 years	10^{-5}	- 5 x10^{-6}
F	BARELY CREDIBLE	The event is inconceivable or fanciful over the design life.	1,000,000 years		10^{-6}	

Notes: 1. Descriptions define the likelihood of a hazard event impacting on a building during its nominal design life (~50 years).
2. The recurrence intervals and probabilities are approximate and may vary depending on the hazard type, site conditions, and the period of concern.

2. Qualitative Measures of Consequences to Property and People from Landslide Hazard Events

Level	Descriptor	Description
1	CATASTROPHIC	Structure completely destroyed or large scale damage requiring engineering works for stabilisation. Fatalities and severe injuries are likely.
2	MAJOR	Extensive damage to most of structure, or extending beyond site boundaries requiring significant stabilisation works. Severe injuries to people and some fatalities possible.
3	MEDIUM	Moderate damage to some of structure, or significant part of site requiring stabilisation works. Injuries requiring medical treatment, hospitalisation; fatalities unlikely.
4	MINOR	Limited damage to part of structure or part of site requiring some reinstatement or stabilisation works. Minor injuries, without hospitalisation.
5	INSIGNIFICANT	Little damage. No injuries.

Note: Examples of possible consequences are given as a general guide, and can be adapted to suit particular cases or sites.

3. Qualitative Risk Analysis Matrix – Level of Risk to Property and People from Landslide Hazard Events

LIKELIHOOD	CONSEQUENCES to PROPERTY and PEOPLE				
	1: CATASTROPHIC	2: MAJOR	3: MEDIUM	4: MINOR	5: INSIGNIFICANT
A – ALMOST CERTAIN	VH	VH	VH	H	M / L-VL
B – LIKELY	VH	VH	H	M	L-VL
C – POSSIBLE	VH	H	M	M	VL
D – UNLIKELY	H	M	L	L	VL
E – RARE	M	L	L	VL	VL
F – BARELY CREDIBLE	L	VL	VL	VL	VL

Notes: 1. Cell A5 may be subdivided such that a (insignificant) consequence of damage of less than 0.1% is Low Risk. The risk is Very Low if the landslide event will not reach the site. 2. Dual descriptors of Likelihood, Consequence and Risk may be appropriate in some cases to reflect uncertainty of the estimate.

4. Risk Level Implications for Landslide Hazard Events

Risk Level		Example Implications
VH	VERY HIGH RISK	Unacceptable without treatment. Investigation, planning and implementation of treatment options essential to reduce risk to an acceptable level. This may be too expensive or impractical, and may require moving to a new site.
H	HIGH RISK	Unacceptable without treatment. Investigation, planning and implementation of treatment options required to reduce risk to an acceptable level. May be too expensive or impractical, and require moving to a new site.
M	MODERATE RISK	May be tolerable provided treatment plan is implemented to maintain or reduce risks. May be accepted if treated, but requires investigation and planning of hazard mitigation measures.
L	LOW RISK	Usually acceptable. Minor treatment options may need to be defined to maintain or reduce risk.
VL	VERY LOW RISK	Acceptable. Manage by normal inspection and monitoring procedures.

Note: The implications for a particular situation should be determined by all parties to the risk assessment; those given above are as a general guide only.

Figure A 1 Criteria for Qualitative Risk Assessment of landslides and related geological hazards at DoC Hut Sites. (*adapted from Landslide Risk Management and Guidelines AGS, 2000 and AGS, 2007*).

APPENDIX 3: MEAN GROUND SHAKING (MMI) RETURN TIME ESTIMATES IN THE MINTARO HUT AREA

Table A 1 Mean ground shaking (MMI) return time estimates for the Te Anau and Manapouri areas.

	MMI	6	7	8	9	10	11
Return Time (yrs)	Lake Te Anau (-45.2, 167.77)	6	22	126	1,235	18,182	-
	Lake Manapouri (-45.51, 167.5)	6	23	136	1,429	15,385	-

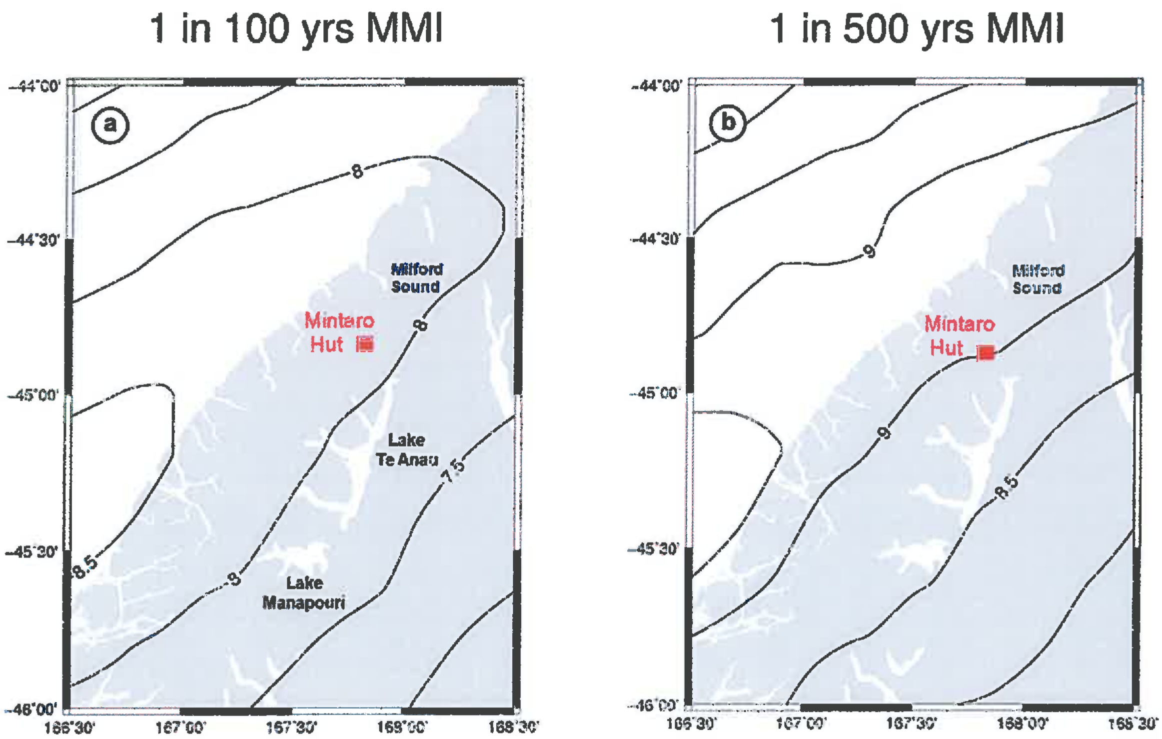

Figure A 2 Maps showing mean ground-shaking estimates (MMI) for 100 and 500 year return times in the Lake Te Anau and Mintaro Hut area. These estimates have been derived from distributed seismicity and fault source data using the attenuation functions of Dowrick and Rhoades (2005) and Smith (2002). The estimated 1 in 100 years MM intensity at Mintaro Hut is ~MM8.2, and the 1 in 500 years intensity is MM9 *(Figure after Clark et al. 2011)*.

References:

Clark, K.; Hancox, G.; Forsyth, P.J.; Pondard, N.; Power, W.; Strong, D. and Lukovic, B. 2011. Identification of potential tsunami and seiche sources, their size and distribution on Lakes Te Anau and Manapouri, *GNS Science Consultancy Report 2011/96*. 74 p.

Dowrick, D.J., Rhoades, D.A. 2005. Revised models for attenuation of Modified Mercalli Intensity in New Zealand earthquakes. *Bulletin of the New Zealand National Society for Earthquake Engineering, v. 38: 185-214.*

Smith, W.D. 2002. A model for MM Intensities near large earthquakes. *Bulletin of the New Zealand National Society for Earthquake Engineering, v. 35: 96-107.*

APPENDIX 4: ANCOLD (2003) RISK CRITERIA IN RELATION TO THE CURRENT MINTARO HUT SITE

Previous risk assessments for DoC on the Bowen Falls walkway have used risk criteria developed by the Australian National Committee on Large Dams (ANCOLD, 2003) as a guide for selecting risk criteria appropriate for use for the Bowen rock face (URS 2010). Based on ANCOLD criteria, the Tolerable risk limit is 10^{-4} for existing dams, subject to ALARP. ALARP refers to the concept of *"as low as reasonably practicable"*, which means that although this level of risk is "Tolerable", attempts to further reduce the risk should be made if there is a feasible means to achieve a reduction.

The ANCOLD (2003) tolerable risk limit of 10^{-4} per annum is consistent with the value proposed by the Australian Geomechanics Society (AGS, 2007), which suggests that for existing slopes or existing developments (as at Mintaro Hut) the Tolerable LOL Risk for the individual most at risk is 10^{-4} per annum. Figure A 3 shows the risk (annual probability of loss of life) estimated for a large rock fall at the current Mintaro Hut site (5 x 10^{-3}) plotted in terms of the "Acceptable" and "Tolerable" risk limits currently in use by ANCOLD.

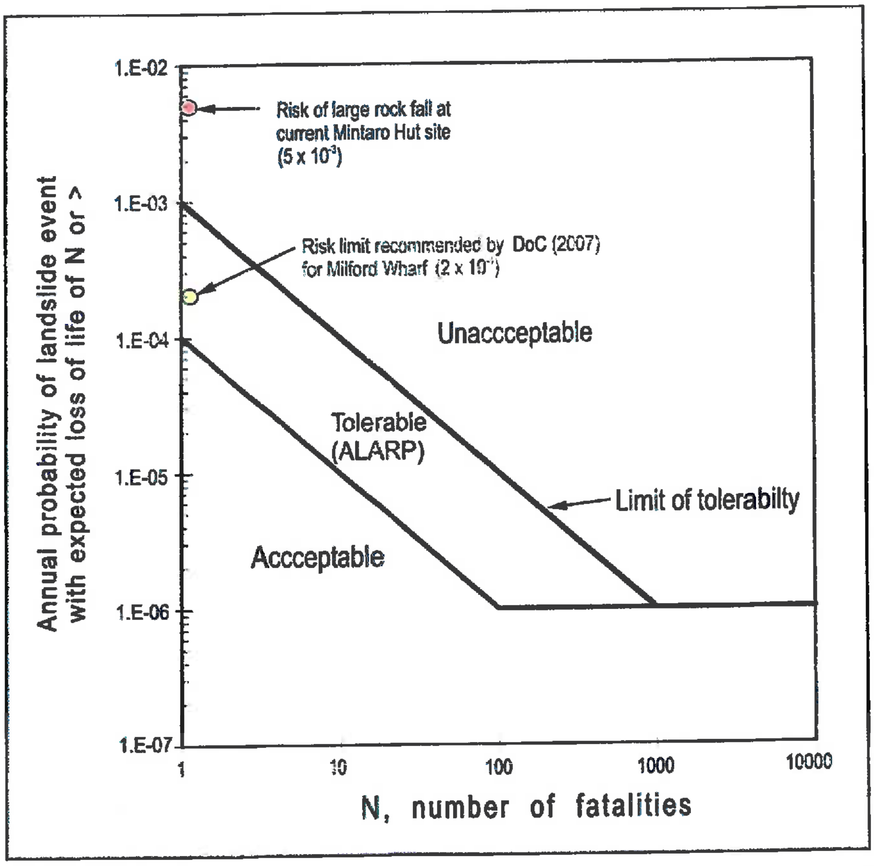

Figure A 3 Estimated annual risk from a large rock fall at the current Mintaro Hut site in relation to the ANCOLD (2003) Risk Criteria and the risk limit proposed by DoC for the Milford Wharf.

References:

Australian Geomechanics Society, 2007. Practice note guidelines for landslide risk management. *Australian Geomechanics, 42 (1) 62-114, March 2007.*

ANCOLD, 2003. Guidelines on Risk Assessment. Guidelines developed by the Australian National Committee on Large Dams Inc., *Melbourne. ISBN: 0731 027 620.*

URS New Zealand Limited, 2010. Bowen Fall Walkway Risk Assessment. Report *(Reference 42174867/01/02) prepared for Department of Conservation, Te Anau, 23 August 2010.*