Review of Proposed Lake Poerua Subdivision, Grey District

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CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

GNS Science has been contracted by Grey District Council to review two Consulting Reports (Bell, 2006; Golder Associates, 2006) in relation to a proposed subdivision along the southeastern edge of Lake Poerua, adjacent to the Alpine Fault, South Island.

The Alpine Fault represents New Zealand's most active onland fault with slip rates of c. 26 ± 5 mm/yr and an average recurrence interval of c. 300 yr. (*Note:* locally the Alpine Fault probably has a slip rate of 10 ± 2 mm/yr and an average recurrence interval of c. 500 yr). As such, the natural hazards related to any development on or adjacent to the Alpine Fault zone need to be carefully considered. We and the authors of the two reports have identified a number of significant natural hazards related to the site of the proposed subdivision.

We consider that neither of the two reports have adequately dealt with the issue of fault location in terms of possible fault rupture at the proposed subdivision. Both reports claim to set out to map or locate active faults, though neither report has actually located the Alpine Fault. We consider it probable that the fault occurs as a zone of rupture traces through the area, i.e. a main trace and secondary rupture traces. The trenches that were dug, were presumably sited to test the possibility that the Swamp depression was bounded by the main or secondary fault traces. The evidence shown in the logs and photographs was difficult to interpret but could possibly represent evidence for faulting or deformation along this linear feature. While it is possible that there is no fault deformation through the site, we do not consider that enough information has been supplied to rule out the possibility of surface deformation at the site. Neither report adequately used the most up-to-date fault maps and interpretations available but instead used 1:250,000 scale maps from the 1960's. The scale and intended use of these maps is thoroughly inappropriate for the assessment of fault location and rupture hazard at the level of individual properties. We recommend that a more detailed geomorphic and/or micro-topographic survey map be made of the site to attempt to identify potential fault rupture traces.

We recommend that at least two additional trenches be excavated, gridded and inspected by trained paleo-seismologists. We have recognised that at the SW end of the subdivision, secondary fault scarps are visible on the ground surface, while at the NE end, traces of the Alpine Fault may be buried by the recent construction of alluvial fans from Mine Creek. Therefore, we also recommend that a shallow geophysical technique (seismic or GPR) be employed to try to locate, or dismiss the possibility of, secondary rupture traces of the Alpine Fault through the proposed site.

We recommend that the Grey District Council adopt the Ministry for the Environment (MfE) approach to addressing the hazard of surface fault rupture. In the "MfE Guidelines" the Alpine Fault is designated as a Class I active fault, i.e. it has a Recurrence Interval of <2000 years. At a "Greenfield" site such as the proposed subdivision site, only Building Importance Category (BIC) 1 (farm sheds etc.) are permitted activities within mapped and designated fault hazard avoidance zones. BIC 2a structures (single-storey wooden-frame houses) are non-complying to discretionary activities (depending on how well-located or well-expressed the fault is). BIC 2b, 3 and 4 structures are non-complying to prohibited activities within designated fault hazard avoidance zones. We recommend that that Grey District Council place a ±500 metre "Special Study Zone" about the mapped trace of the Alpine Fault in Grey

District, which will earmark this corridor for special geological and/or engineering consideration.

As far as other geological site conditions and hazards are concerned, we do not agree with Bell's (2006) overall conclusion *"that the proposed Lake Poerua Development is geotechnically sound, subject to specific recommendations for foundation design,...and construction of an earth bund to protect the most northerly dwelling site from avulsion [debris floods and flows] from Mine Creek".* We agree with the conclusion by Golder Associates Ltd that *"there is a very high level of seismic hazard at the site of the proposed subdivision".* However, we consider that the potential effects and risk of geological hazards *(large landslides, debris flows/avalanches, fault rupture and other ground deformation effects)* that may occur during the next Alpine Fault earthquake (estimated probability 85 % in next 100 years) are not well defined, and appear to be somewhat understated. The subdivision may be 'geotechnically feasible', but because of its location so close to the Alpine Fault we do not regard it as safe from geological hazards.

We do not believe that the report assesses all the possible effects of the next Alpine Fault earthquake on the site adequately enough to expect potential occupiers to accept the consequences of such an event. In particular, it is recommended that landslide risk during the next Alpine Fault earthquake needs to be assessed (possibly using qualitative methodology) so that this information can be made available to potential purchasers, and if necessary protection measures can be used to reduce risk to an acceptable level.

It appears that there is also a relatively high probability of a seiche (wave or surge of lake water) caused either by fault movement (uplift) within Lake Poerua, or a landslide into the lake during an Alpine Fault earthquake. The nature and risk of this hazard needs to be more precisely assessed. Mitigation measures may be needed to protect the subdivision from wave inundation hazards.

Lateral spreading (liquefaction) could occur during an Alpine Fault earthquake (or another earthquake producing shaking intensities of MM8 or greater, and be a hazard to the subdivision. All possible ground deformation effects of lateral spreading (ground fissuring, extension, and subsidence) need to be considered in foundation design and house construction.

In relation to *s106 of the Resource Management Act 1991* we believe that both reports on the proposed subdivision have failed to adequately assess the hazard and risk posed by an earthquake on the Alpine Fault in the Lake Poerua area. In particular, we believe that: (a) there may be significant risk at the site of *material damage by falling debris, subsidence, slippage, or inundation (as defined in s106)*; and (b) that both reports have not adequately assessed the risk associated with such events, or proposed engineering measures to mitigate the possible effects on dwellings within the subdivision.

1.0 INTRODUCTION

A review by GNS Science (GNS) of geological and geotechnical reports on the proposed new subdivision at Lake Poerua, Grey District, Westland was requested by Ms Rebecca Strang, Planning Officer, Grey District Council (GDC) in an email dated 19 September 2006. Located on the southeast side of Lake Poerua, the proposed subdivision includes 24 Lots, with 14 building sites. This review covers the geotechnical (foundation conditions) and geological hazards (landslides, debris flows, slope instability, and rockfall of faulting induced seiches/waves) aspects of two reports that were provided to GNS for review. The two reports that were reviewed for GDC are:

(1) Bell, D.H., 2006. Lake Poerua Development – Geology and Geotechnics. *Consulting Report by Canterprise Ltd, prepared 22 May 2006 for Grant Marshall, Mine Creek Westland, (Appendix C in report by Golder Associates, July 2006).*

(2) Golder Associates, 2006. Geotechnical Site Suitability Assessment: Proposed Subdivision, Lake Poerua, Westland. *Consulting Report prepared July 2006 by Joshu Mountjoy and Cid Chenery for Grant Marshall, Cashmere, Christchurch.*

This review deals with geotechnical and geological hazards aspects of the two reports, and is based mainly on material presented in those reports. The topographic map and aerial photos of the area were also examined to provide a better appreciation of the geomorphic setting and terrain in the subdivision area. In addition, reference was made to relevant technical publications on geological hazards (landsliding, active faulting, seismic risk) in order to judge the validity of the assessments and conclusions presented. Many of the review comments pertaining to the geomorphic setting of the Inchbonnie-Lake Poerua area and the issue of active fault location have been addressed by Dr. Langridge. Many of the comments relating to other natural hazards and geotechnical issues have been addressed by Mr. Hancox. Review comments on these two reports are presented below.

2.0 REVIEWS OF REPORTS

2.1 Report by D. H. Bell (1)

2.1.1 Report sections and comments

The report by Mr D.H. Bell (1) was prepared in May 2006, and based on investigations that included: engineering geology mapping, preparation of an engineering geology map; logging of 8 test pits and 4 trenches (to locate the Alpine Fault), and air photo studies.

A range of topics are discussed in different sections of the report. These sections are listed below along with any comments that are required.

3 *Site Description:* This section refers to the regional and engineering geology maps (Figures.1a, 1b) and Trench Logs (Figure 2).

GTH Comments: *No comments on the content. However, the location of the subdivision (Lots and Building Site positions) and some key geomorphic features referred to later in the report (e.g. Mt Te Kinga and the Alexander Range) are not clearly shown. Details on trench and test pit logs are difficult to read, and so could not be meticulously checked. Generally, the information presented seems to be reasonable and is as expected for the area.*

RML Comments: *This seems like the time to introduce the discussion of the Alpine Fault activity and location summarised on Figures 1 and 2 of the report.*

Figure 1A – To the southwest of Lake Poerua, the Alpine Fault is shown as both a 'bedrock fault' with symbols of right-lateral movement; and as a late Quaternary active fault, in the form of geomorphic scarps. Bell should use one or the other, not both, depending on the purpose and scale of the figure. The fans coming from Mine, Homestead and Poerua Creeks are well defined in this figure. To the northeast of Lake Poerua, the Alpine Fault is dashed and presumably underlies the fan deposits related to Homestead and Poerua Creeks. Other geologic features on this map are summarised from Suggate & Waight (1999).

All of these points will be expanded upon throughout the report.

Figure 1B - The figure shows the Alpine Fault as a straight linear feature at the scale of 1:10,000. The figure also shows the Alpine Fault entering the SE corner of Lake Poerua, paralleling the shorelines c. 100 m offshore and exiting the NE corner of Lake Poerua where the shoreline has turned to the north. The figure shows a linear swamp depression aligned parallel to the lake and mapped fault features. The figure also shows fan-shaped units from Mine Creek, extending across the northern half of the proposed subdivision. The figure shows the location of the four exploratory trenches and most of the Test Pit locations N.B.(the trenches have changed from letters to numbers, and perhaps location, from the Bell to Golder reports). All of these points will be expanded upon throughout the report.

Figure 2A -_Summarises four trenches at a scale of 1:500. The trenches span the width of the proposed subdivision in the area of swamp depression. The stratigraphy of the trenches and test pits is summarised in a stratigraphic profile. All of these points will be expanded upon throughout the report.

Figure 2B - Summarises Test Pits 7-14 at a scale of 1:50. Shows that all of the test pits and trenches, except TP7, are dominated by sandy gravels and finer overbank deposits related to a Taramakau River source. Test Pit 7, being on the Mine Creek fan surface, is dominated by schist-derived gravels and fine deposits. All of these points will be expanded upon throughout the report.

4 Geological Setting:

GTH Comments: *This section also refers to Figures 1a and 1b, and adequately describes the geological setting of the subdivision. However, reference could also have been made to other recent geological publications relating to the area, such as Berryman et al. (1992, see Golder Report), and the latest GNS Science 1:250,000 Geological Map 12 (Nathan et al, 2002).*

RML Comments: *This is an adequate summary of the geologic setting of the site.*

The report correctly states that the proposed development is within the Alpine Fault depression. This fact gives rise to many of the related geologic hazards described in the two reports and this review. The Taramakau River deposits are also described as an important geologic unit. This was also found to be the case at the GNS Inchbonnie trench site of Harris' farm (Figures 2, 3 below).

The report then mentions recent rupture trace with scarps of 3-5 m, two km SW of the proposed subdivision. Importantly, the report does not mention that active traces and scarps have been mapped by Berryman et al. (1992) and by Berryman (1975) as extending to the SE corner of the lake in close proximity to the proposed subdivision. It has been stated that "no fault trace is visible across the land proposed for development". This statement is not true, and in addition, the possibility of buried fault traces and occurrence of the swampy depression have not been adequately investigated or discussed in this report. This will be further addressed in Section 5.

5 Landscape Evolution: Provides good background information for geological hazard assessment (Active Processes) discussed later.

GTH Comments: *None.*

RML Comments: *Paragraph 1 – This is a summary of the current knowledge of the landscape evolution of the Taramakau system between its upper reaches and Lake Brunner via a glacial origin.*

Paragraph 2 – The second half of this paragraph discusses the age of the uppermost part of the Taramakau River gravels and the recent rupture history. These observations sound like discussions that we had with David Bell on site in February 2006, when we were trenching at Inchbonnie and David was working at Lake Poerua. The current best estimate of these gravels is 1100-1300 yr (Berryman et al 1992). We found very little material to radiocarbon date in our study. However, the assertion that the gravels are older than 400 yr (older than the last surface faulting event) is reasonable. I intend to improve the age control on our faulting data by dating tree stumps on the floor of Lake Poerua (discussed later).

Paragraph 3 – Fan deposition. This is a good discussion of the importance of fan deposition along the rangefront. Schistose deposits, such as those shown in TP7 (Bell - Figure 2B) must come from a 'local source', i.e. schist bedrock, as opposed to the greywacke materials seen in most exposures, that have been transported from near the Main Divide, down the Taramakau River system. This difference in materials provides immediate clarification of the source of sediments local to this area (schist in the Taramakau River system is broken up quickly by harder, greywacke clasts). The report correctly states that the active trace of the Alpine Fault is concealed beneath fan deposits beneath Mine Creek and Rotomanu. It has not been possible to thus far map the location of the active trace of the Alpine Fault in this area (K. Berryman, pers. comm., 2005). The report rightly states that the most recent fan activity is, by implication, younger than 400 yr; i.e. since the last Alpine Fault rupture.

6 *Alpine Fault:* This section describes the location and activity of the Alpine Fault.

GTH Comments: *- None- these aspects are dealt with by Dr Langridge.*

RML Comments: *Section 6 on the Alpine Fault does not adequately cover the issues related to the Alpine Fault in the Inchbonnie-Lake Poerua area. Paragraph 1 is a reasonable introduction to the activity and hazard posed by the Alpine Fault. However, I make the following points.*

It is doubtful that the Alpine Fault zone is 2 km wide as stated. The identification of granitic mylonite on the SW corner of the Mt Te Kinga is probably incorrect. From the morphology of this knob (with spot height 390 m) we prefer an origin as a debris flow deposit off the Mt Te Kinga massif.

The earthquake ages quoted in the paragraph are accurate, however, the report has omitted another earthquake at c. AD 1425 ± 25. That is, Yetton et al. (1998) actually indicate that three large surface faulting events occurred along the Alpine Fault since c. AD 1400, including the current earthquake interval of c. 290 yr, this gives an average return time of c. 200 yr for a large earthquake and surface faulting in the Inchbonnie-Lake Poerua area.

The report mentions inspection of the GNS Science trench site at Inchbonnie. We excavated four trenches in total at this site. The morphology of the fault zone was typical of the Alpine Fault in this area, with left-stepping traces linked by oblique-trending folds and faults, forming a broad zone of deformation. While the shear zone in a single location is "not more than 300 m wide" as suggested by the Bell report, the overall surface fault zone here is c. 120 m wide across the en echelon traces. This style of stepping fault traces, while mentioned as being typical for this area in the Bell report, is not considered as a possibility for the area of the proposed subdivision. Instead, the Bell report favours a single trace, which has been 'mapped' in the lake.

Scarp heights in this area are c. 3-6 m in height. It is generally considered that this has occurred in two events (3 m vertical each). However, if 3-4 events have occurred since the deposition of the Taramakau gravel surface, then the vertical deformation per event may be 1.5 m.

7 *Foundation Conditions:* This section describes the variable materials (sandy gravels clayey silts [swamp deposits, 1.5 m thick), and thick sands underlying the proposed subdivision, as revealed by the mapping, test pits and trenches (Figures 1b, 2a, 2b). Because of the local soil variability, specific engineering designs are recommended for the 14 planned building sites.

GTH Comments: *I agree with this recommendation, but I note that this should not be too problematic as the site is generally underlain by compact river gravels at depths of ≤1.5 m. The reason for the presence of the swamp deposits is unclear, and may be involve tectonic subsidence (see Section 2.2-5,6).*

RML Comments: *No comments*

Active Processes: This section discusses *(A) Fault Rupture* (covered by Dr Langridge); and *(B) Flooding and/or Aggradation. Section 8A* of the report states that *'minor seiching could be anticipated' (last paragraph)*, but gives no indication of the cause (landsliding into lake or fault rupture) or the possible effects.

RML Comments:

Section 8A: We strongly agree with the Bell report that "the presence of the Alpine Fault ...provides a significant constraint to the siting of dwellings", and that the probability of an Alpine Fault rupture event here within the next 100 yr is 85 ± 10%. Shaking damage aside, the hazard posed by horizontal and vertical surface faulting and deformation is significant, but generally brushed aside by the Bell report. Paragraph 1 describes the horizontal displacement as being "perhaps 2-3 m, but not 8 m", and that "the slip rate of the Alpine Fault reduces from 25 mm/yr to 12 mm/yr at the Taramakau River".

Published research at Inchbonnie suggests that horizontal displacements are large (c. 6 m) and that the slip rate is 10 ± 2 mm/yr. Vertical displacements of c. 3 m at Inchbonnie are generally correlated to the c. AD 1717 and c. AD 1625 earthquake events.

We assert that the conclusions reached in Paragraph Two are too liberal and have not been reached using all of the best available information. We agree that the main trace of the Alpine Fault is probably just within Lake Poerua along its Southeastern edge. Two good observations that imply this is correct are the very linear, strike-parallel trend of the shoreline over a length of at least 500 m from the SE corner of the lake. Second, coincident with the shore is a break in slope of 1-2 m height that probably represents the fault scarp. The location of the main rupture trace of the fault over this 500 m length is, therefore, likely to be within 10 m of the current lake shore. Northeast of this point, when the Mine Creek fan reaches the lake, the fault trace may exit the lake and be concealed beneath the Mine Creek fan. This possibility has not been investigated by Bell.

We believe that the Bell report takes a simplified view of the faulting in the vicinity of the subdivision, for the following reasons.

Both Berryman (1975) and the simplified Berryman et al (1992) maps show a complex pattern of faulting in the Inchbonnie-Lake Poerua area. This includes a left-stepping pattern of traces, with overlapping and secondary fault traces mapped.

North of the SE corner of the lake these maps show both a main SW-facing scarp and secondary SE-facing scarp. The Berryman (1975) map shows at least six fault traces that project toward the SE corner of the subdivision. It is curious that the mapping of fault traces becomes difficult beyond this point (i.e. into the proposed subdivision). The Berryman maps have not been used by Bell, and the implications of fault traces so close to the proposed subdivision have not been considered rigorously in his thinking.

While the trenches are long and span the width of the proposed subdivision, it is not clear to us that they have been excavated to significant depth, or cleaned and logged in significant detail. We believe that the trenches are inadequately presented at a scale of 1:500 and do *not do justice to the importance of this site being adjacent to the Alpine Fault. These trenches should be logged and presented at a scale of at worst 1:100. Most GNS fault trenches are logged at 1:20 scale.*

The photographs shown in the back of the Bell report suggest that the walls of the trench were not adequately scraped down to view the stratigraphy and possible deformation within the trench. Without "cleaning" it could be easy to overlook small offsets or deformation. In a long trench where there is pressure to "log" the whole exposure, this could also cause one to overlook deformation.

The Bell report endorses the mapping of Warren (1967) and Gregg (1964) which were mapped at c. 1:250,000 scale. This is clearly not useful for the level of detail needed for a property subdivision. The Bell report assures that all of the deformation near the subdivision is taken up along the main trace of the fault – within Lake Poerua.

These other traces have not expressed themselves through the subdivision as would be expected – apart from the swamp depression shown in Figure 1B of the Bell report. This is a suspicious feature as it is sub-parallel to the fault trend and along strike from fault traces shown by Berryman. In particular, the NW margin of the swamp occurs c. 250 m NE of the SE-facing fault scarp shown in Berryman (1992). The swamp depression is likely to be a tectonic-related sag, or down-faulted basin, i.e. an area of secondary deformation related to the Alpine Fault. The swamp is somewhat lower than the surrounding terrace and a high groundwater table is likely to promote the growth of swamp plants. The low form of the depression and high groundwater table may well be a consequence of faults bounding the depression. Trenches cross the margin of this depression, though I am not convinced by the detail of the logs or the photographs that there is no deformation in that area. Even if there are no clear faults related to this feature, it must have a tectonic origin, perhaps due to the fitting or folding of the surface. If this is a zone of deformation, we consider it likely that it is semi-continuous with the traces mapped by Berryman (1975) just to the SE of the subdivision.

It is our view that the Bell report has been too quick to dismiss the possibility of active fault traces or concealed fault traces through the proposed site. This issue has not been adequately addressed. This means that questions over 20 m setbacks from the lake, etc, are irrelevant until the site has been cleared of fault-related deformation.

GTH Comments:

<u>Section 8B</u> I agree that the subdivision area could be flooded by a seiche (wave) caused by uplift (possibly of about 1.5–2.5 m vertical – Section 6) on the Alpine Fault within Lake Poerua. Because there is a high (85 +/-10%) probability of an Alpine Fault movement in the next 100 years (as stated) I believe that the potential seiching damage effects on the subdivision also need to be assessed.

<u>Section 8B</u> discusses the possibility of flooding inundation from the Taramakau River, which is about 3 km to the southwest, but at RL c. 140 m is 15-20 m higher than the subdivision (RL c. 126-129 m). ***Comments:*** *I agree that the flooding from the Taramakau River is*

probably unlikely, except in an extreme, low probability event, possibly because of the higher intervening ground (c. 150 m) along the Midland Railway in the vicinity of Inchbonnie (see 1:50,000 Topographic Map 260-K32).

The possibility of flooding and debris movement on Mine Creek fan, on which the subdivision is sited, is mentioned and assessed, as *'the only stream likely to have an impact'* on the proposed subdivision. *'Landscaped bunding'* is suggested to protect the most northerly house site from debris flood gravel inundations from Mine Creek, but no details are given. ***Comments:*** *I agree with this recommendation, and note that the Golder Report agrees with the assessment and provides design details of the protective earth bunds that are suggested.*

9 *Geotechnical Constraints:*

This section discusses geotechnical issues in the planned subdivision in relation to Resource Management Act requirements, including:

(a) *Erosion* - It is concluded that the subdivision land is not subject to erosion, with minimal likelihood of it in the future. ***GTH Comment:*** *I agree with this assessment.*

(b) *Falling Debris* – Falling debris (rock/debris fall) hazard is low. ***GTH Comments:*** *I agree that the hazard from small-scale rock and debris falls is probably low, but the hazard from large-scale slope failures associated caused by an Alpine Fault earthquake could be much greater (see comments on Slippage (d) below).*

(c) *Subsidence* – Not a problem with standard engineering design. ***GTH Comment:*** *Agreed, but tectonic subsidence, and liquefaction-induced lateral spreading during an Alpine Fault event also needs to be considered in foundation design.*

(d) *Slippage* – Slippage (landslides) is not anticipated from slopes >2 km away to the northwest (Mt Te Kinga) or above the site to the southeast (Alexander Range).

GTH Comment: *Although this may generally be true of slopes to the northwest, I am not convinced that during the next Alpine Fault earthquake (a high probability event in the next 100 years) large landslides will not occur on the slope southeast of the site. The very steep head of Mine Creek steep and narrow (700 m) ridge to the south, directly above the subdivision area, appear to be potential landslide sites during the next Alpine Fault earthquake (see Figure 1 attached). The report recognises the landslide hazard posed by an Alpine Fault earthquake, but does not assess specific hazard events and the degree of risk such events could present to the proposed subdivision.*

<u>I recommend</u> that landslides from slopes above the site be further investigated, and a risk assessment carried out, possibly using the qualitative risk assessment methodology developed by the Australian Geomechanics Society (AGS, 2000) - see Appendix 1. This methodology is now widely used in New Zealand for landslide risk assessments for RMA Applications. It provides a rigorous and transparent basis for assessing the risk associated with landslide hazards.

Using the AGS methodology to assess risk of a ridge-top collapse from the slope southeast of the proposed subdivision, a typical assessment might be as follows:

Likelihood: Possible (RI 100-1000yrs) to Unlikely (RI 1000-5000 yrs), based on the fact that such failures could occur, but not during every Alpine Fault earthquake.

Consequences: Potentially Catastrophic (Dwellings completely destroyed or large scale damage. Deaths likely if buildings occupied and risk not reduced).

Risk: Moderate to High (Implications – Moderate Risk may be tolerable and accepted, if a treatment plan is implemented to maintain or reduce risk. It may require investigation and planning of treatment options. High Risk implies the need for detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels.)

(e) *Inundation* – Flooding inundation is considered to be unlikely from the Taramakau River, but potential for flooding and gravel inundation (presumably *debris floods* and *debris flows* – see landslide definitions in Appendix 1) from Mine Creek. A protective bund 2+m high is recommended to protect the northernmost building site. Rock falls from Mt Te Kinga are discounted as a potential cause of inundation.

GTH Comments: *In general, I agree with this assessment, but Lots 1B and 6B on the north side of Mine Creek may also need to be protected if residential housing is intended in those areas. The greater likelihood of large debris floods and debris flows during rainstorms following an Alpine Fault earthquake (as can be inferred by rapid fan formation in the last 400 years following the last Alpine Fault earthquake, page 7) needs to be given more significance in assessing hazards in the area. I agree that protective bunds need to be at least 2 m high or greater, as suggested. The Golder Report suggests a minimum height of only 1 m (Figure 5).*

RML Comments: *No comments*

2.1.2 Summary of comments and conclusions (RM Langridge)

Most of my comments are summarised in Sections 3.0 and 4.0 of this review. I have attempted to provide an informed view of the geomorphology in the area as related to the Alpine Fault, the activity and location of the Alpine Fault, and by applying the approach of the Ministry for the Environment "Guidelines" to this problem in Section 4.

2.1.3 Summary of comments and conclusions (GT Hancox)

(1) I do not agree with the reports overall conclusion *"that the proposed Lake Poerua Development is geotechnically sound, subject to specific recommendations for foundation design,...and construction of an earth bund to protect the most northerly dwelling site from avulsion [debris floods and flows] from Mine Creek".* I consider that the potential effects and risk of geological hazards (large landslides, debris flows/avalanches, fault rupture and other ground deformation effects) that may occur during the next Alpine Fault earthquake (estimated probability 85 % in next 100 years) are not well defined, and appear to be somewhat understated. The

subdivision may be 'geotechnically feasible', but because of its location so close to the Alpine Fault I do not regard it as safe from geological hazards.

(2) I do not believe the report assesses all the possible effects of the next Alpine Fault earthquake on the site adequately enough to expect potential occupiers to accept the consequences of such an event. I consider that landslide risk during the next Alpine Fault earthquake needs to be assessed (possibly using methodology defined in Appendix 1) so that this information can be made available to potential purchasers, and if necessary protection measures can be used to reduce risk to an acceptable level.

(3) It appears that there is a relatively high probability of a seiche (wave or surge of lake water) caused either by fault movement (uplift) within Lake Poerua, or a landslide into the lake. The nature and risk of this hazard needs to be more precisely assessed. Mitigation measures may be needed to protect the subdivision from this hazard.

(4) Lateral spreading (liquefaction) could occur during an Alpine Fault earthquake (or another earthquake producing shaking intensities of MM8 or greater- see Appendix 2), and be a hazard to the subdivision. This process is not specifically covered in the report, but is mentioned briefly under 'subsidence'. I consider that the possible ground deformation effects of lateral spreading needs to be considered in foundation design.

(5) In relation to *s106 of the Resource Management Act 1991,* I believe that both reports on the proposed subdivision have failed to adequately assess the hazard and risk posed by an earthquake on the Alpine Fault in the Lake Poerua area. In particular, we believe that:

(a) there may be significant risk at the site of material damage by falling debris, subsidence, slippage, or inundation (as defined in s106); and

(b) that both reports have not adequately assessed the risk associated with such events, or proposed engineering measures to mitigate the possible effects on dwellings within the subdivision.

2.2 Report by Golder Associates Ltd (2)

The report by Golder Associates Ltd. (2) was prepared in July 2006, and included the Bell (2006) report as Appendix C. The report includes sections on: (1) Background; (2) Scope of investigation; (3) Site description; (4) Published geological information; information; (5) Subsurface conditions; (6) Natural hazards; (7) Discussion and recommendations. These sections are listed below along with review comments.

2.2.1 Report Sections and Comments

1. *Background*: ***No comments.***

2. Scope of investigation: The work included review of existing geotechnical data and aerial photos; walk-over inspection; test pits and scala penetrometer tests; fault trenching, across faults. ***No comments.***

3. *Site Description:* The text and Figures 1 and 2 adequately describe the site location and relevant features, including the regional physiography, and details of the

proposed subdivision (14 Lots with house sites, slope angles, vegetation/land use, and streams).

(a) ***GTH Comment.*** *No comments*

(b) ***RML Comment.*** *This text adequately describes the regional physiography and introduces the specifications of the subdivision lot.*

4. <u>Published geological information and aerial photos</u>:

GTH Comments: *The Bell (2006) report mentions confusion about the location of the Alpine Fault in the area, with more recent mapping (Suggate and Waight, 1999; Berryman et al., 1992 – Appendix D of Golder Report) showing it passing under the proposed subdivision area. This apparent confusion about where fault traces are located under the more recent deposits (1.5 m of silts and swamp deposits) needs to be clarified, as the trenches may all be too shallow (only 1.5-1.8 m deep) to prove that the underlying gravels are not faulted. Dr Langridge will discuss this aspect in more detail in his report.*

RML Comment*. The Golder report correctly recognises that the Alpine Fault has been mapped as passing through (though concealed) the subdivision. The Golder report states that major landforms in the development area were mapped from stereo pairs of aerial photographs. However, they do not go into what these landforms are in this section and have not supplied a geomorphic map of the area or the proposed subdivision.*

5. <u>Subsurface conditions:</u>

GTH Comments: *The origin or reason for the presence of the 'overbank silt –swamp deposits- up to 1.5 m thick) in central part of the proposed subdivision (parts of Lots 7-11, 14, 24, 25, 27, and 29) is somewhat unclear. Could these deposits have been deposited in an area of tectonic subsidence, within (or just east of) the Alpine Fault Zone? If so, this could have implications for fault location and for fault rupture and ground deformation (subsidence and tilting) hazards within the proposed subdivision area. Why is the drainage apparently disrupted, and ground water levels very high in this area (0.5 -0.6 m below ground surface - Section 5.4)?*

RML Comments:

<u>Section 5.0</u> - the main field techniques and stratigraphic units are outlined.

<u>Section 5.1</u> - the age and origin of the sandy gravels (Taramakau River Gravel) is described well. The estimate of the soil age on the abandoned former surface of the Taramakau gravels (500+ yr) is still considered appropriate.

Note: We had Dr. Peter Almond, Soil Scientist from Lincoln University, visit our site while the trenches were open in February 2006. His assessment of the age of soil development was on the order of several hundred years (soil age is a relative dating technique).

<u>Section 5.2</u> - If the silts are so bedded, could they not be pond deposits ... well, okay probably overbank pond deposits. The Golder report states that the contact between the

gravels and silts is subvertical which is suggestive that the edge of the swamp could be fault-related. It agrees that the thickest silt deposit occur at the NW edge of the swamp, i.e. the unit thickens in a wedge-shaped form toward that margin.

Section 5.3 - The Golder report recognises the presence of schist fan gravels at the NE end of the proposed subdivision and correctly relates them to an active alluvial fan system from Mine Creek. These deposits are at least 1.8-2 m thick in Test Pit 7 and presumably have covered over the Taramakau Gravels and Overbank Deposits during the last c. 500 years. Mine Creek currently does not carry much bed load. It has been recognised that the stream recently? breached its current channel and spilled gravel into an adjacent paddock. The current equilibrium state of the fan and its channel are probably not reflective of the extreme event sedimentation that is likely following an Alpine Fault event.

6. Natural hazards: These are separated into *seismic* and *inundation* hazards.

RML Comments:

Fault Rupture (6.1.2) – The Golder report recognises that the Alpine Fault has been mapped as passing through the proposed subdivision as a concealed active fault.

Golder's methods to assess the location of the Alpine Fault in relation to the proposed subdivision (and our comments) are as follows:

Discussion with knowledgeable people

We were present for discussions on the Alpine Fault with David Bell and Golder staff in early February 2006. Our research has evolved since that time and our statements should not be used as the definitive word on the Alpine Fault location (e.g. being in the lake)

Test Pitting to assess ground conditions across the site

This alone would not tell you where a fault is located, it only tells you the type and thickness of geologic materials.

Scala Penetrometer testing to assess the in situ (strength) density of materials

This is a 1-D (line) dataset and could not tell you anything about where the fault is located.

(a) Trenching logged by others and viewed by Golder, to check for fault position and displacement.

The Golder report states that the trench walls were partially collapsed when they viewed them on 7 February. We have stated already that we are not convinced that the trenches were scraped or cleaned adequately to view deformation. The Golder report states that the contact between the silt and gravel is steep. If there was *insufficient depth in the trench to view the gravels it may be difficult to recognise faulting. The relationship in Photo A5 is equivocal – for one thing the wall has not been scraped down and, secondly, the relationship between the silt and gravel is not, explainable by regular depositional processes.*

The Golder report states that "the silt layer is interpreted as an abandoned river channel that was rapidly filled with silt". First, the silt layer is not a channel, but, would fill a channel after that channel was cut. Second, the 'channel' is broad (80-120 m) and tabular (gen. 1.5 m thick), but thickens to a maximum at the NW edge of the swamp. This does not appear as a channel should, but rather appears to describe a faulting relationship, that it has developed an asymmetric basin. There is a small (> 0.5 m) step in the topography at the edge of the swamp in the profile of Trench A. This seems like a further indication that the swamp is fault related.

7. Mapping and aerial photo interpretation to check for fault displacement and position.

Golders do not present any geomorphic maps of the site or fault interpretation. A poor representation of surficial deposits is shown on Figure 4. I do not understand how they have addressed fault location?

(a) Oblique aerial photograph acquisition and interpretation for fault offset and likely position.

Again, the Golder report does not have any fault location maps in it that would be suitable for assessing the hazard to the proposed subdivision. It is not good enough to assume that the fault, or all of the deformation has 'stepped' into the lake. I'm not convinced that the helicopter trip gave any new insights on where the fault was located or how much effect there was. If it did, then they did not discuss it.

Both the Bell and Golder reports state that there is no evidence of fault rupture in any of the test pits, trenches or photographs. At face value, this statement by geological consultants should be acceptable. However, given the importance of the location of the proposed subdivision and the incomplete presentation of trench data, I am not convinced that the swamp depression and its fill are not fault controlled. I think it is quite possible that there are secondary fault traces running through the subdivision, perhaps as concealed traces.

However, I agree with the statements regarding the position of (the main trace of) the Alpine Fault as being within the lake, along a straight sub-parallel to-strike reach of the lake edge, in the area discussed.

GTH Comments:

Fault Rupture (6.1.2) – There is clearly some uncertainty about the exact location(s) of the Alpine Fault traces in the subdivision area, hence it is difficult to assess fault rupture hazards and building exclusion zones (set-back distances). Data presented in the report, including the trench logs, conclusively prove where the fault is (or is not) located. A seismic refraction survey may help to better define the fault location at depth, and allow the hazard to be assessed with more certainty. It may also help to resolve uncertainty about the presence of the swamp deposits (which could be post the last Alpine Fault movement about 300 years ago). As discussed above (5), ground surface tilting and subsidence is an additional seismic hazard, but is not mentioned in the report (or Bell, 2006). Such deformation can be significant close to a fault rupture zone and should be assessed so that potential purchasers can be informed of possible effects during an Alpine Fault earthquake.

Strong Ground Motion (6.1.3): There is inconsistency in the strong motion (PGA) probability estimates using NZS 1170.5:2004, compared to what would occur during an Alpine Fault earthquake (85 +/-10% probability in the next 100 years), which could result in PGA of 0.5 to 1.0 g in the subdivision area. This possibility is suggested but the implications for residential dwellings are not discussed.

Liquefaction (6.1.4): The report states that the subdivision site is generally considered susceptible to lateral spreading due to liquefaction. Photo 5B in Appendix E is interpreted as a sand pipe caused by historical liquefaction (within the last 150 years). This feature may date from the 1929 Arthurs Pass earthquake M7.1, which caused liquefaction at Lake Sumner and shaking of about intensity MM7 in the Lake Poerua area (Hancox et al 1997; 2002). I believe that liquefaction (sand boils and lateral spreading - fissuring, water and sand ejections, ground extension and subsidence) is almost certain to occur in the subdivision area during an Alpine Fault earthquake (MM 9-10 shaking locally). Typically this could cause severe damage to road and rail embankments, and damage susceptible ground (alluvial deposits with groundwater table <10 m deep) within the subdivision area. During historical earthquakes in NZ (e.g. Murchison 1929, Inangahua 1968; Edgecumbe, 1987 – Hancox et al. 1997), liquefaction damage has extended for a hundred metres of more beyond river banks and lake edges. I therefore have reservations about the method used in the report to determine a set-back distance from the lake edge (Section 7.2.1). The position of the historical (?) example (Photo 5B) would provide a guide to where liquefaction could occur away from the lake edge. Any set back distance should be taken at least from that point, but should also consider other factors such as the underlying soils, and depth of the water table. As already mentioned (Section 2.1), I consider that the possible deformation effects of lateral spreading (ground fissuring, extension, and subsidence) need to be considered in foundation design and house construction.

Inundation – Sheet Flow from Mine Creek (6.2.1): The report states that "sheet flow" *(debris floods- Appendix 1)* with associated channel erosion is possible from Mine Creek. Earth bunds (Figures 4 and 5) are recommended to protect Lots 12 and 13 from possible inundation effects from Mine Creek *(Section. 7.2.3)*.

***GTH Comments:** I agree with the recommendation of a bund, but not the proposed 1m minimum height (Bell, 2006 recommends at least 2 m or greater, which I support). It is also unclear why a similar bund is not proposed on the north side of Mine Creek to protect Lots 1B and 6B. This appears to be required to prevent debris floods and flows avulsing to the north, especially if it is constrained on the south side.*

Flooding from Lake Poerua (6.2.2): Inundation of the proposed subdivision from Lake Poerua is possible due to a landslide damming the outlet (as is assumed to have occurred in 1991- Figure A3). No specific measures are proposed *(Section 7.2.4)* to prevent such flooding from occurring (or raised lake level due to a severe rainstorm), but the hazard would be mitigated by increased inspections and alerts to allow rapid debris clearance to reduce any flooding effects. ***GTH Comments:*** *I agree that there is a flooding potential in the area from Lake Poerua. Such flooding could occur after an Alpine Fault earthquake, caused not only by landslides from Mt Te Kinga, but also by rapid growth of the Dry Creek debris fan 2 km northeast of the proposed subdivision.*

8. *Mitigation of natural hazards:* Recommendations for the mitigation of natural hazards outlined above have been discussed and commented on in detail *(in Section 6)*. *Foundations (7.3):* The report suggests that piles driven into the underlying very dense coarse sandy gravels (present across the site below c.1.5 m) will provide a suitable founding system for residential houses in the proposed subdivision. ***Comments:*** *In general, agree with this recommendation and the suggestion that excavation depths should not extend lower than 0.3 m above the local ground water table. Groundwater does not appear to have been encountered in any of the test pits or trenches, so drainage is unlikely to be a problem in the area.*

Note: Landslides hazards:

Earthquake or rainfall-induced landslides are not mentioned in the Golder Associates report, except in relation to blockage of the Poerua River, or a landslide into Lake Poerua, causing a surge or wave of water. However, the possibility or large landslides from the slope southeast of the subdivision, particularly during an Alpine Fault earthquake, is not discussed. I believe this to be a significant omission in the report. I have already discussed landslide risk in relation to Bell's (2006) report (Section 2.1.1, page 3), and those comments also apply to the Golder report. Although the report states (page 3) that "data from a previous field investigation completed by Mr David Bell (Appendix C) was also used in this assessment", the Bell report is not referred to, and differences between the two reports (such as the suggested height of the bund) are not discussed.

2.2.2 Summary of comments and conclusions (RM Langridge)

Most of my comments are summarised in Sections 3.0 and 4.0 of this review. I have attempted to provide an informed view of the geomorphology in the area as related to the Alpine Fault, the activity and location of the Alpine Fault, and by applying the approach of the Ministry for the Environment "Guidelines" to this problem.

2.2.3 Summary of main comments (GT Hancox)

(1) I agree with the overall assessment in the report that there is a very high level of seismic hazard at the site of the proposed subdivision at Lake Poerua because of its location within, or very close to the Alpine Fault Zone.

(2) I do not believe that the report fully recognises all potential geological hazards at the site

associated with an earthquake and rupture on the Alpine Fault at Lake Poerua.

(3) The location of the trace of the last fault rupture is uncertain. The fault may be within or along the edge Lake Poerua, but some traces may also underlie the proposed site, buried by swamp deposits and silts deposited since the last fault movement c. 300 years ago.

(4) The proposed site appears to be within the deformation zone of the Alpine Fault. It could therefore be affected by ground tilting and level changes, and also be inundated by a wave (seiche) from Lake Poerua caused by uplift on the southeast side of the fault within the lake (probably less than 100 m from the nearest proposed house sites). The effects and consequences of these hazards have not been assessed. No studies appear to have been carried out to determine what ground deformation could occur, or the size of a fault displacement wave. If the fault does lie within the lake, then the risk of a wave or surge caused by displacement of 1.5 to 2.5 m of lake water surging eastwards towards the proposed dwellings needs to be assessed and any adverse effects mitigated.

(5) The potential risk of earthquake-induced landslides at the proposed subdivision during an Alpine Fault earthquake is not assessed in the Golder Associates report. This aspect has already been discussed in relation to the Bell (2006) report, and the comments made in Section 2.1.1 (illustrated in Figure 1) and my recommendation that a landslide risk assessment of the site should be carried out (see Appendix 1) are reiterated.

(6) Lateral spreading (liquefaction) could occur during an Alpine Fault earthquake (or another earthquake producing shaking intensities of MM8 or greater), and be a hazard to the subdivision. However, I have doubts about the method proposed to determine a set-back distance from the lake edge and would prefer to see evidence of previous liquefaction (Appendix E -Photo 5B, in Trench 1, but location not given), and factors such as the underlying soils, and depth of the water table used to determine a safe setback distance. All possible deformation effects of lateral spreading (ground fissuring, extension, and subsidence) need to be considered in foundation design and house construction.

(7) Overall conclusion: The report recognises the high level of seismic hazard at the proposed subdivision site because of its location so close to and probably within the deformation zone of the Alpine Fault. However, it will not be possible to inform potential property owners of the natural hazards at the proposed subdivision site (as recommended in the report) until all geological hazards and associated risks have been assessed in more detail, and it is shown that credible protection measures will be constructed to reduce risk to an acceptable level. I believe that the present report fails to do this.

3.0 DISCUSSION ABOUT GEOMORPHOLOGY AND FAULT ACTIVITY

This discussion is intended to provide a background of current research studies being undertaken in the Inchbonnie-Lake Poerua on the Alpine Fault and its geomorphic setting. This section is written by Dr. Langridge.

3.1 Tectonic geomorphology of the Inchbonnie-Poerua area

Recent research work in the Lake Poerua area point toward the current lake having a reasonably unique origin and of very recent age. Lake Poerua appears to be dammed on its sides by several geomorphic features and its current level may have been reached since only the last earthquake on the Alpine Fault c. 300 yr ago. At the NW side of the lake, it is dammed by the granite pluton of Mt Te Kinga (Nathan et al. 2002) and a very large debris avalanche deposit that has collapsed off this mountain (Fig. 1). The age of this event is unknown.

To the southwest, the lake is bordered by relatively young gravels of the Taramakau River Figs. 1,2). The braided channels related to the deposition of these gravels can still be seen clearly in aerial photographs. Weathering rind ages of 1100-1300 years have been calculated from greywacke clasts in these gravels (Berryman et al. 1992). A mat of buried grass within deposits that fill one of these channels near Inchbonnie was dated (Fig. 2), yielding an age of post-AD 1760 (Yetton et al 1998). Older (c. 1200 yr) greywacke-dominated Taramakau River gravels underlie the GNS trench site at Inchbonnie and form the scarp of the Alpine Fault between there, Lake Poerua and Mine Creek. In rare instances where the cover stratigraphy is thin, a faint paleo-braid pattern can be seen on this surface in aerial photographs.

On its southeast side, the lake has a linear, northeast trend and is almost certainly 'dammed' by the main scarp of the Alpine Fault over a length of c. 500 m from near the Dept. of Conservation jetty toward Mine Creek, as described by both the Bell and Golders reports. A recent visit to the site showed that the northwest edge of Lot 1 of the proposed subdivision is bordered by an active trace of the Alpine Fault. It is clear that rather than having a single fault trace, there are multiple rupture traces of the Alpine Fault in this area.

The northeastern margin of Lake Poerua is curvilinear and is defined by the broad form of large alluvial fans emanating from Mine, Homestead and most particularly Poerua Creek (Fig. 2). Schistose debris from the rangefront of the Alexander Range has collapsed and poured out over the fault and valley as alluvial fans. Drilling at Poerua swamp by Les Busher has shown that at least 7 metres of relatively fine sands and gravels of alluvial fan origin underlie Poerua Swamp (Fig. 2). One radiocarbon date from near the base of the section yielded an age of 711 ± 74 radiocarbon yr BP. This corresponds to a sedimentation rate of c. 1 m/100 yr at the toe of the fan, with perhaps higher rates farther up the fan. Another radiocarbon date near the top of this core suggests there has been a re-juvenation of the fan during the last 250 years. As the fan and its channel are relatively stable at present, we envisage that the bulk of the sediment is released or supplied to the system following intense earthquake shaking related to Alpine fault rupture, as observed along other parts of the Alpine Fault.

To support this notion, the Basher core contains two paleosols, i.e. buried, former soils, that represent past periods of stability in the landscape when soils could form. The record implies at least three major fan building episodes in the last c. 700 yr; the fans probably being replenished following Alpine Fault rupture. The high rates of young fan deposition in this area imply that the Alpine Fault scarp is simply buried by debris from the rangefront, and probably explains the absence of a mapped fault trace across these fans.

Ultimately, Lake Poerua exists as a function of the level of the water table relative to the barriers around it. Its current level is probably due in part to building of the fault scarp and the deposition of fans on its eastern side. The floor of Lake Poerua is covered in tree stumps beneath >2 m of water. At the southeast end of the lake, several dead trees protrude from the water. Two of these stumps have been sampled for radiocarbon dating to test the age of drowning by the lake. Clearly, at some recent time, the current floor of the lake was covered by a forest. In all likelihood these tree stumps date to the last or penultimate faulting event on the Alpine Fault. Anecdotal evidence also suggests there is a drowned *'umu'* on the floor of the lake, presumably co-incident with the forest and must certainly be <800 yr in age.

GNS Science currently holds a DoC permit to investigate the ages of the protruding and drowned tree stumps as part of its Alpine Fault project. Discussions over whether the fault trace is in the lake, or whether rupture will trigger seiche waves are important, but curiously, they depend on the current hydrologic system, which will no doubt be altered by the next Alpine Fault rupture in this area.

3.2 Location of the Alpine Fault near Mine Creek

We accept that over a c. 500 m stretch from the southeast corner of the lake to near Mine Creek, that the main trace of the Alpine Fault is just offshore (in the lake), and that the fault scarp forms the lake edge.

It is not clear, however, that this is the case for the next c. 750 m to the northeast, even though the lakeshore is still rather linear. As discussed, Test Pit 7, located on the Mine Creek fan, is dominated by schistose gravel, i.e. schistose debris derived from the rangefront. Mine Creek fan is the smallest of three fans (Homestead, Poerua) that emanate from the rangefront. These fans bury the trace of the Alpine Fault near Poerua Station. What is not clear is whether the main fault trace comes back onshore at Mine Creek, or closer to Poerua.

The outcome of this question has implications for the designated property lots near Mine Creek, namely lots 6B and 8B. The possibility that the main trace of the Alpine Fault underlies these property lots needs to be investigated. These lots may face the hazard of fault rupture, in addition to inundation by fan gravel related to the next Alpine Fault event.

3.3 The Record of Faulting at Inchbonnie

Four trenches were excavated on the Harris farm at Inchbonnie in February 2006 to investigate the recent rupture history of the Alpine Fault. Three trenches crossed zones of active faulting and deformation related to a fault-controlled channel system, while the fourth trench was excavated to log the shape and deposits of this channel (Fig. 3).

Only three organic samples were able to be collected from one of these trenches, Harris-3 trench. This is because the site is an organic-poor environment, dominated by coarse sandy gravels (Taramakau Gravels). However, the record of stratigraphy and faulting could be followed consistently through the site, so that the same earthquake displacements could be viewed in each trench.

We observed evidence for 1-2 earthquake events in the covering sand-silt units (Overbank Silts) and likely a previous earthquake event that formed the structural morphology that guided the stream and channel fill/overbank deposits. The three radiocarbon dates are all young, ranging from 439 ± 30 radiocarbon yr BP to modern, i.e. formed since post-1950 radioactivity. The dates in relation to structural evidence suggest that 1-2 events have occurred since c. AD 1443, these events most likely being the c. AD 1717 and c. AD 1620 events. These results confirm that large ruptures along the Cook segment of the Alpine Fault extend into the Inchbonnie-Poerua area as suggested by Yetton et al. (1998). Based on our observations and those of Berryman et al. (1992), the average recurrence of surface faulting at the Inchbonnie–Lake Poerua is considered to be c. 500 years.

4.0 ACTIVE FAULT GUIDELINES AND RECOMMENDATIONS

The following section consists of a discussion on the Ministry for the Environment Active Fault Guidelines and a series of conclusions and recommendations concerning the mapping and study of active traces of the Alpine Fault, with respect to the proposed subdivision.

4.1 Ministry for the Environment Guidelines

The Ministry for the Environment, has published Guidelines on "Planning for Development of Land on or Close to Active Faults1, 2 (Kerr at al. 2003, see also King et al. 2003; Van Dissen et al. 2003). The aim of the MfE Guidelines is to assist resource management planners tasked with developing land use policy and making decisions about development of land on, or near, active faults. The MfE Guidelines provide information about active faults, specifically fault rupture hazard, and promote a risk-based approach when dealing with development in areas subject to fault rupture hazard. The guidelines are accessible via the MfE Quality Planning website (www.qualityplanning.org.nz).

The MfE Guidelines recommend that we:

- **Identify** all known active fault traces
- **Map** as many fault traces as possible
- **Classify** faults in terms of Guidelines
  - Recurrence Interval Class
  - Fault Complexity
  - Fault Avoidance Zones
- **Apply planning controls** for all Fault Avoidance Zones based on:
  - Fault activity (Recurrence Interval Class)
  - Location and complexity of fault rupture (Fault Avoidance Zones)
  - Type of proposed development (Building Importance Category – e.g. a critical facility = 5, structure with a low degree of hazard to life/property =1)
  - Existing land use (Undeveloped vs. developed site)

In the MfE Guidelines, the surface rupture hazard of an active fault at a specific site is characterised by two parameters: a) the average recurrence interval of surface rupture of the

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[1] The Ministry for the Environment's Guidelines "Planning for Development of Land on or Close to Active Faults: A guideline to assist resource management planners in New Zealand" is now available on both their main website and their Quality Planning website.

[2] Throughout the remainder of this report, the Ministry for the Environment's Guidelines will be referred to as the MfE Guidelines.

fault, and b) the complexity of surface rupture of the fault. In this report, these two fault rupture hazard parameters are defined for the Alpine Fault for the Inchbonnie-Lake Poerua area adjacent to the proposed subdivision.

Recurrence Interval: As described in this report, the recurrence interval for the Alpine Fault is short. Estimates based on the occurrence of recent surface faulting in the area, or from slip rate based calculations suggest that the recurrence interval for the Alpine Fault locally is c. 200-500 years. In terms of the MfE Guidelines, this categorises the Alpine Fault as a Recurrence Interval Class I fault, i.e. it has an average recurrence time of 0-2000 years.

Table x shows how the Recurrence Interval Classification is presented in the MfE Guidelines.

Table x Recurrence Interval Class, as defined in the MfE Guidelines, based on the average return time for surface rupture along an active fault. The Alpine Fault is clearly a RI Class I fault.

Recurrence interval class	Average fault recurrence interval of surface rupture
I	≤2000 years
II	>2000 years to ≤3500 years
III	>3500 years to ≤5000 years
IV	>5000 years to ≤10,000 years
V	>10,000 years to ≤20,000 years
VI	>20,000 years to ≤125,000 years

The second fault parameter that is taken into consideration in the MfE Guidelines is the Fault Complexity. This parameter relates to both how well–expressed the fault is in nature and how well the fault can be mapped. The three Fault Complexity categories defined in the MfE are: well defined; distributed; and uncertain.

With respect to this study, fault complexity is an important issue. Southeast of Lake Poerua, where mapped by Berryman (1975), the Alpine Fault is well-defined, but has a distributed form, i.e. several fault traces in a fault stepover. Through the subdivision itself, the fault cannot be considered as "well defined". At worst, the Alpine Fault is uncertain through this area, and at best, I have considered that the scarp/ rangefront area adjacent to the lake must be a zone of "distributed" deformation as it is southeast of the lake. The designation of fault complexity is important when considering what restrictions should be placed to buildings considered for construction on or adjacent to the fault.

The third and fourth parameters used to designate the Resource Consent Activity for a given site when considering the MfE Guidelines are: a) the Building Importance Category (BIC); and b) the previous subdivision history of the site. The latter has two options: i) previously subdivided or developed sites; or ii) Greenfield sites. The proposed subdivision is certainly "greenfield" in mature.

Building Importance Category relates to the NZ Building Code and is summarised in Table y below. In terms of risk and disaster preparedness, the BIC ranges from lowest risk or vulnerability, e.g. sheds and isolated structures (BIC 1) through to high vulnerability (critical) structures, e.g. post-disaster facilities (BIC 4).

Table y Building Importance Categories (BIC) and representative examples. For more detail see Kerr et al. (2003), and King et al. (2003).

BIC	Description	Examples
1	**Temporary structures** with low hazard to life and other property	• Structures with a floor area of <$30m^2$ • Farm buildings, fences • Towers in rural situations
2a	**Timber-framed** residential construction	• Timber framed single-story dwellings
2b	**Normal structures** and structures not in other categories	• Timber framed houses with area >300 m^2 • Houses outside the scope of NZS 3604 "Timber Framed Buildings" • Multi-occupancy residential, commercial, and industrial buildings accommodating <5000 people and <10,000 m^2 • Public assembly buildings, theatres and cinemas <1000 m^2 • Car parking buildings
3	**Important structures** that may contain people in crowds or contents of high value to the community or pose risks to people in crowds	• Emergency medical and other emergency facilities not designated as critical post disaster facilities • Airport terminals, principal railway stations, schools • Structures accommodating >5000 people • Public assembly buildings >1000 m^2 • Covered malls >10,000 m^2 • Museums and art galleries >1000 m^2 • Municipal buildings • Grandstands >10,000 people • Service stations • Chemical storage facilities >$500m^2$
4	**Critical structures** with special post disaster functions	• Major infrastructure facilities • Air traffic control installations • Designated civilian emergency centres, medical emergency facilities, emergency vehicle garages, fire and police stations

As shown in Table z, fault-related parameters are combined with structural/ building type parameters to produce a Resource Consent activity table that can be used as a guide for planning decisions. Table z is specific for Recurrence Interval Class I faults, such as the Alpine Fault, with the land being deemed to be in a "greenfield" setting. In this case, all structures of BIC Class 2b, 3 and 4 are deemed to be Non-complying to prohibited activities. At the level of BIC 2a, the resource consent activity varies between Non-complying (when the fault complexity is well defined) to Discretionary (when the fault complexity is distributed to uncertain in nature).

Table z Resource Consent Activity Status for the proposed Lake Poerua subdivision.

Proposed "greenfield" Subdivision site at Lake Poerua, adjacent to Alpine Fault					
Fault Recurrence Interval Class I (average recurrence interval ≤2000 years)					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Trace Complexity	**Activity Status**				
Well Defined	Permitted	Non-Complying	*Non-Complying*	*Non-Complying*	Prohibited
Distributed, & Uncertain - constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Uncertain – poorly constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying

Note: It is important to realise that these Resource Consent activities apply to designated Surface Fault Hazard Zones placed around active faults. These are often defined by mapping. These hazard zones are generally recommended as a ± 20 m wide buffer zone around a fault zone – if the fault is well-defined, that fault may be as wide as the fault scarp, though if the fault is poorly-defined, then the zone of uncertainty related to surface deformation may be rather wide. In my opinion, in the case of the Lake Poerua subdivision, adequate geomorphic mapping and/or trenching to identify rupture traces has not been undertaken by the consultants.

Initial trenching was not undertaken to a degree to determine whether the boundary of the swampy depression was fault-related. In addition, no fault races are mapped through the subdivision, though during a recent site visit, I recognised a fault trace marking the western boundary of Lot 1, at the southern end of the lake.

4.2 Conclusions & Recommendations w.r.t. Active Faulting (R. Langridge

1 The two reports by Bell and Golder do not adequately address the hazard posed by surface faulting in the proposed subdivision site adjacent to the Alpine Fault. While the consultants have made some efforts to excavate trenches through the width of the subdivision, it is my opinion that they have not adequately 'cleaned' or logged these trenches in critical areas, to absolutely rule out the possibility of secondary fault rupture traces through the site.

Recommendation: As this subdivision site has to deal with considerable geological hazards at the scale of individual properties, I recommend that a geomorphic or micro-topographic map with scale 1:5000 be created of the proposed subdivision site.

2. The two reports acknowledge other scales of fault mapping from as small as 1:250,000 (e.g. Warren, 1967; Gregg 1964) down to scales of 1:50,000 (Suggate &

Waight, 1999) and c. 1:37,000 (Berryman et al, 1992). In general the reports use the older smaller scale, geological maps of the 1960's to define the location of the Alpine Fault.

Recommendation: Following on from 1. I consider it necessary to undertake more sub-surface investigations to attempt to identify active faults (that could represent future surface rupture hazards) through the site. I recommend that the 0.5 m high east-facing edge of the swamp depression be trenched again, to a depth of 3 metres or more and that it be adequately cleaned, gridded and logged at a scale of 1:40 or better. Geophysical techniques may also aid in the identification of active faults. Shallow seismic and/or Ground Penetrating Radar should be considered as viable techniques to locate fault traces at this site.

3. The Golder report presents the Berryman et al. (1992) fault map at Inchbonnie as an Appendix, but does not consider that the Alpine Fault traces mapped adjacent to the subdivision could continue on into that property. The Golder report claims to have addressed fault location through a number of techniques. However, in my opinion, none of these techniques is useful in addressing fault location.

   Recommendation: Following on from 1-3, I consider that it is essential to test whether the faults mapped by Berryman (1975) (Fig. 3) continue on into the site. I recommend that a trench be excavated across the width of the subdivision along the boundary between Lots 1 and 2.

4. The Ministry for the Environment Guidelines related to active faulting have not been quoted in either of the two consulting reports, though both refer to setback distances from faults.

   Recommendation: Grey District Council, in association with the West Coast Regional Council, need to consider adoption of the MfE Guidelines into normal working practice. The Alpine Fault is the most onland active fault in New Zealand, and as stated has a probability of 85 ± 10 % of rupture in the next 100 yr. Any consideration of future development along the fault zone of this fault needs adequate consideration. The District Council should have an adequate plan which may include a "Special Study Zone" of ± 500 metres around the currently best-mapped location of the fault (see http://data.gns.cri.nz/af/index.jsp) The Alpine Fault may however, represent the only fault in Grey District that needs to be mapped in such detail; others in the District may be wholly within Conservation lands and would therefore not be subject to future development.

5. The reports do not consider the possibility that the Alpine Fault has a complex rupture pattern of main and secondary fault traces. Most of the deformation associated with the next rupture of the Alpine Fault is likely to occur on its "main trace". However, secondary traces, tilting, warping and folding need to be considered as fault-related deformation in the hangingwall (upthrown side) of the fault along the margin of the lake.

5.0 ACKNOWLEDGEMENTS

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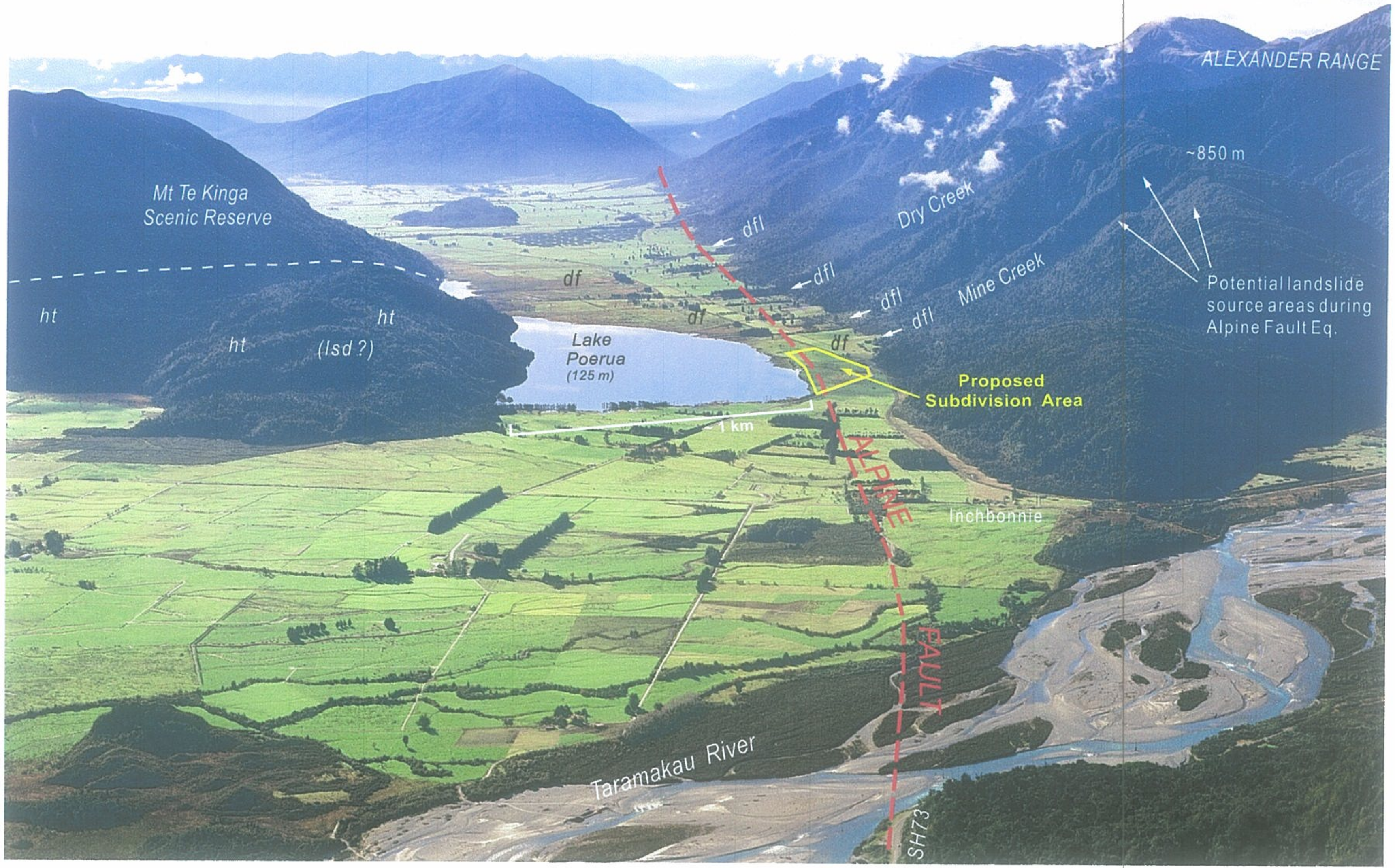

Figure 1 Aerial view looking northeast showing the proposed Lake Poerua subdivision area, and the generalised location of the Alpine Fault where it cuts across the Taramakau Valley and heads northeast past Lake Poerua and along the foot of the Alexander Range *(Nathan et al. 2002)*, where it is largely obscured by debris fans *(df)* deposited since the last Alpine Fault earthquake about 300 years ago. Possible source areas of large landslides at the head of Mine Creek, and possible and debris flow paths *(dfl)* are also shown. The hummocky terrain *(ht)* to the north of Lake Poerua could be ice smoothed granite, but may also be the debris of a very large (c.5 km^2) prehistoric landslide collapse feature on the southwest side of Mt Te Kinga (the Nathan et al. 2002 geological map shows a large landslide feature in this area out of picture to the left).

Figure 2 Satellite image view of the Inchbonnie-Lake Poerua area with key sites used for geomorphic interpretation of fault activity described in text. The area of the proposed subdivision shown in yellow. The Alpine Fault is not mapped on this image, but was trenched at the GNS site at Harris farm. Field boundaries W and NE of this site mark the approximate location of the fault.

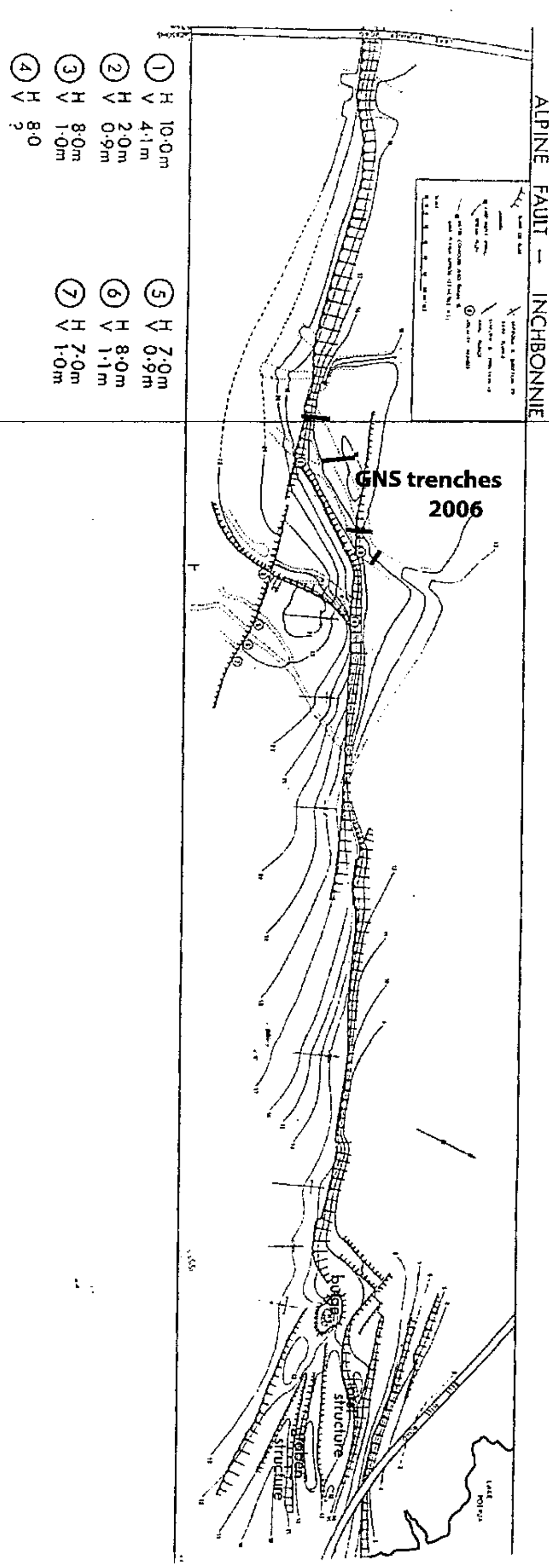

Figure 3 Scan of Berryman (1975) active trace map of the Alpine Fault at Inchbonnie. Figure has been reduced in size and rotated from original view. North, and Lake Poerua, are toward lower right corner. Note the detail of active fault traces mapped at the GNS trench site and near the SE corner of Lake Poerua.

APPENDIX 1 — QUALITATIVE LANDSLIDE RISK ASSESSMENT

1. Methodology

Qualitative assessments of the risk of landslides, rock falls, and debris flows have been carried by GNS out at several proposed coastal sub division sites in the Wellington Region for Resource Management Applications. The risk assessment methodology used was developed in 2000 by the Australian Geomechanics Society (AGS, 2000). This methodology is similar to the Risk Management Standard developed (for all hazards) for use in New Zealand and Australia (AS/NZS 4360:2004 Risk Management, SNZ, 2004), but is designed specifically for landslide hazards. The AS/NZ Standard has been adopted by the Ministry of Civil Defence and Emergency Management (MCDEM, 2002).

The qualitative landslide risk assessment and management process is summarised on a flowchart in Figure A1-1, and the criteria, terminology, and risk analysis matrix used is shown in Figure A1-2. The main steps in the risk assessment procedure are as follows:

(a) <u>Define Brief</u>: This defines the scope of work, purpose, and context in which the risk assessment will be used (e.g., Resource Consents Application for housing subdivision).

(b) <u>Landslide hazard assessment</u>: This involves identification of landslide hazard events (see definitions below) that could occur in the proposed development area based on: (i) Mapping of existing landslides and geomorphic features (streams, debris fans, cliffs and extensive steep slopes and rock outcrops; (ii) mapping of landslide susceptible slopes, runout and collapse zones; potential debris flow and debris flood paths etc; and (iii) identification of triggering events for landslide hazards (heavy or prolonged rainfall; strong earthquakes; excavations for roads, materials, buildings, structures; slope loading by fills; runoff and storm water disposal; leakage from pipes and water mains etc.).

(c) <u>Qualitative Risk Analysis:</u> Assess risk from identified landslide hazard events, using *Risk Analysis Matrix (3), and Risk Level Implication (4)* shown in Figure A1-2. In this methodology *Landslide Risk* is defined as the combination of the *likelihood* and *consequences* of a landslide hazard (a potentially harmful event) affecting a site. Likelihood is a general description of the probability or frequency of a hazard event occurring, expressed qualitatively in words. The indicative frequency or return period of these hazard events can be estimated from historical and prehistoric evidence of geological hazards and processes at a specific site. *Consequence* is the likely impact of the hazard event on the site, expressed in terms of possible building damage and loss of life if the event occurs. The Level of Risk for each landslide hazard event is estimated by cross matching *Likelihood (Classes A–F)* against *Consequences (Classes 1–5)*. The consequences of a particular landslide event will depend on the building or structural damage, and possibly loss of life, that could occur. Generally this will depend on the landslide type, size, and the speed of movement.

(d) <u>Evaluate response to estimated risk:</u> –The response required to the assessed level of risk is determined from the expected or possible building damage and effects on people (injuries, loss of life). Examples of Risk Level Implications and responses are given in Figure A1-2 (4).

(e) <u>Response to Risk Assessment</u>: (i) Accept Risks: for some landslide events the Level of Risk may be acceptable for development to proceed without conditions being imposed during the Resources Consents process. *(ii) Risk unacceptable:* the risk posed by some landslide events may be unacceptable, unless mitigation or protective works are carried out to reduce the level of risk. This may involve slope stabilisation works, protective fences or earthworks, slope drainage and runoff controls, or slope maintenance and monitoring.

If mitigation measures are not possible to reduce the level of risk at a particular site from a major landslide hazard (because of cost or planning restrictions), building exclusion zones may be imposed, or some sites may have to be abandoned.

In accordance with guidelines provided with the AGS methodology and the AS/NZS 4360:2004 Standard, descriptions of likelihood (indicative return periods), consequences, and risk implications (possible effects and mitigation measures) can be modified to suit a particular case. This would normally be based on the professional judgement and experience of suitably qualified landslide specialists.

The acceptability of an assessed level of risk *(very high to very low - Figure A1-2)* is subjectively judged (based on available data and experience) on the likelihood and consequences of an event occurring at particular site, and the practicality and effectiveness of any mitigation or protective measures that could be provided to reduce the risk to an acceptable level. If the analysis shows the risk from a hazard to be unacceptable, the risk would have to be avoided, either by abandoning the site, or by construction of protective engineering works that reduce the risk to an acceptable level to make it safe for dwellings.

2. Definitions of landslides and associated features

Landslide is a general term for gravitational movements of *rock or soil* down a slope (as a mass along discrete shear surfaces). In this context, *'soil'* includes both *earth (material smaller than 2 mm) and debris (material larger than 2 mm)*; *rock* is a hard or firm intact mass and in its natural place before movement. *Landslides* are most often triggered by *heavy rainfall or strong earthquakes*, but they can also occur 'spontaneously', without an obvious triggering event. Such failures are often caused by undercutting the toes of slopes (by natural erosion or man-made slope modification), combined with long-term weathering and weakening of slopes. Shaking of Modified Mercalli intensity MM7 can cause small failures ($<10^3$ m^3), but MM8 or greater is generally required for larger landslides ($\geq 10^3$–10^6 m^3 – see Appendix 2).

Landslides are usually classified or described in terms of: (a) the type of material involved (rock, earth, debris, or sometimes sand, mud etc.), and (b) the type of movement – *fall, topple, slide, flow, spread*, which are kinematically-distinct modes of movement. Combining these two terms gives a range of landslide types such as: *rock fall, rock slide, rock topple, debris fall, debris slide, debris flow, earth flow etc. Landslides* involving soils and bedrock are often called *slips or landslips*, while small failures with rotational slide surfaces are generally referred to as *slumps*. Small landslides often do little damage, but very large failures of thousands or millions of cubic metres moving bodily downslope can overrun and bury buildings and roads, or cause foundation collapse at the tops of slopes. Effects of landslides can range from minor deformation of foundations and structural failures to total destruction of sites and all buildings, lifelines and infrastructure above or below slopes.

Debris flows and debris floods: These are both hydrological mass-transport phenomena but have different hazard and risk implications. *Debris floods* are very rapid hyper-concentrated flows in stream channels of water charged with sediment. *Debris flows* are a type of landslide: they have much higher sediment concentrations than *debris floods*, with a consistency rather like wet concrete. *Debris flows* have the ability to transport large boulders, and are therefore potentially much more hazardous and destructive. A *debris flood* is not a landslide, but is a mass-transport *(sheet flow)* phenomenon with destructiveness similar to that of water, but less than debris flows. Objects impacted by debris floods are surrounded or buried by flood debris but are often largely undamaged.

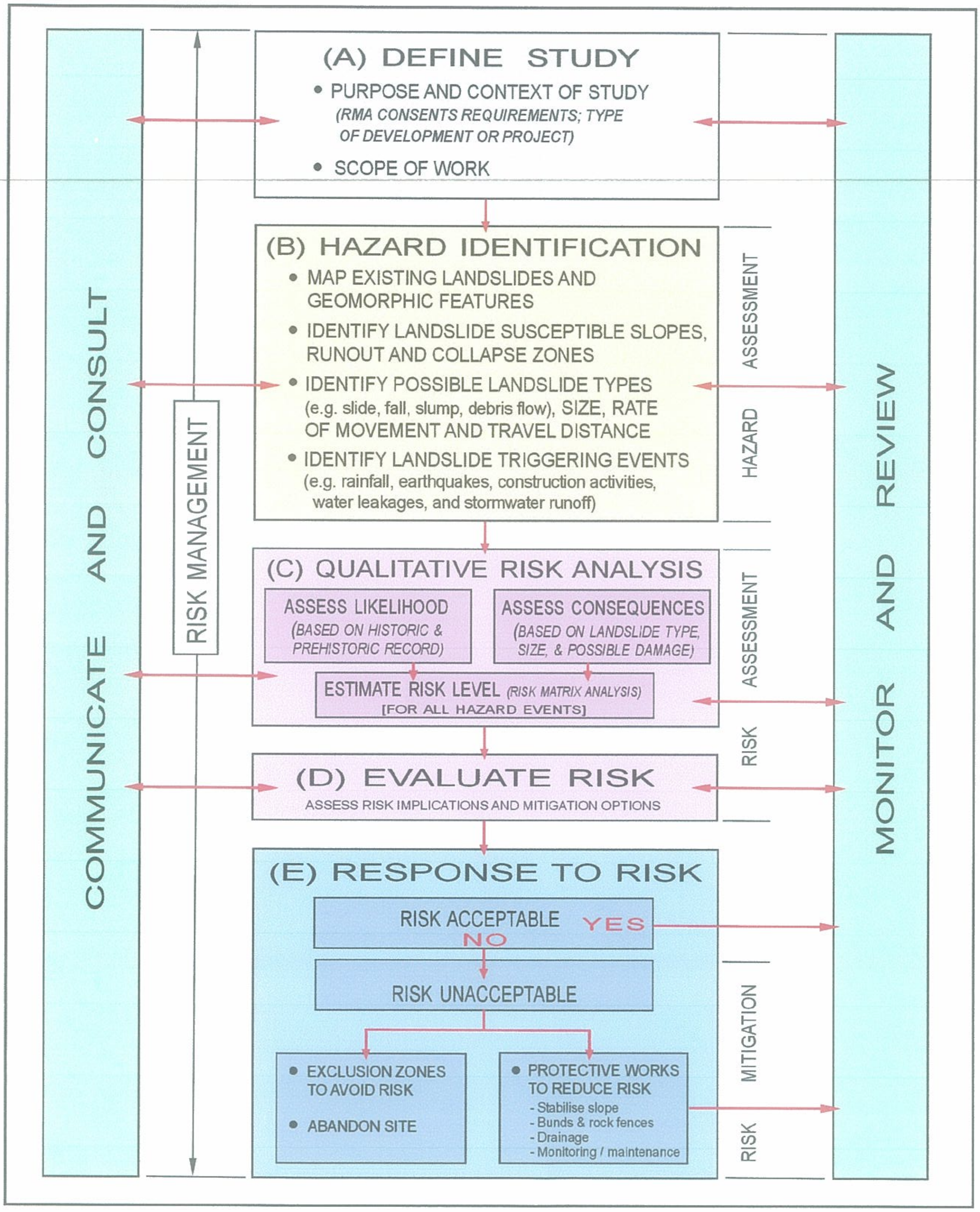

Figure A1-1 Flow chart showing the main stages and interrelationships of the qualitative landslide hazard and risk management process *(adapted from AGS, 2000*[1] *and AS/NZS 4360:2004).*

1- Qualitative Measures of Likelihood

Level	Descriptor	Description	Indicative Probability (Return Period)
A	ALMOSTCERTAIN	The event is expected to occur (during life of buildings).	~1–10 years
B	LIKELY	The event will probably occur under adverse conditions.	~10–100 years
C	POSSIBLE	The event could occur under adverse conditions.	~100–1000 years
D	UNLIKELY	The event might occur under very adverse circumstances.	~1,000–5,000 years
E	RARE	The event is conceivable under exceptional circumstances.	~5,000–10,000 years
F	NOT CREDIBLE	The event is inconceivable (under present conditions).	> 10,000 years

Note: "~▯" means that the indicative value may vary by possibly ±½ an order of magnitude, or more.

2 - Qualitative Measures of Consequences to Property and People

Level	Descriptor	Description
1	CATASTROPHIC	Structure completely destroyed or large scale damage requiring major engineering works for stabilisation. Deaths likely if buildings occupied and risk not reduced.
2	MAJOR	Extensive damage to structure, or extending beyond site boundaries and requiring significant stabilisation works. Injuries or deaths possible if risk not reduced.
3	MEDIUM	Moderate damage to some of structure, or significant part of site requiring large stabilisation works. Injuries or deaths may occur, but less likely.
4	MINOR	Limited damage to part of structure or part of site, and requiring some reinstatement / stabilisation works. Injuries unlikely.
5	INSIGNIFICANT	Little damage or risk to people.

Note: Descriptions may be adapted to suit a particular case.

3 - Qualitative Risk Analysis Matrix – Level of Risk to Property and Lives

LIKELIHOOD	CONSEQUENCES TO PROPERTY				
	1: CATASTROPHIC	**2: MAJOR**	**3: MEDIUM**	**4: MINOR**	**5: INSIGNIFICANT**
A – ALMOST CERTAIN	VH	VH	H	M	L
B – LIKELY	VH	H	H	M	L
C – POSSIBLE	H	H	M	L–M	VL–L
D – UNLIKELY	M–H	M	L–M	VL–L	VL
E – RARE	M–L	L–M	VL–L	VL	VL
F – NOT CREDIBLE	VL	VL	VL	VL	VL

4 - Risk Level Implications

Risk Level		Example Implications (1)
VH	VERY HIGH RISK	Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to acceptable levels; may be too expensive and not practical.
H	HIGH RISK	Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels.
M	MODERATE RISK	Tolerable provided treatment plan is implemented to maintain or reduce risks. May be accepted. May require investigation and planning of treatment options.
L	LOW RISK	Usually accepted. Treatment requirements and responsibility to be defined to maintain or reduce risk.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Notes: (1) The implications for a particular situation are to be determined by all parties to the risk assessment; these are only given as a general guide.
(2) Judicious use of dual descriptors for Likelihood, Consequence and Risk to reflect uncertainty of the estimate may be appropriate in some cases.

Figure A1-2 Criteria, risk analysis matrix, risk levels and implications for qualitative assessment of landslide risk *(adapted from Appendix G' of AGS, 2000[1]).*

APPENDIX 2 — LANDSLIDE AND ENVIRONMENTAL CRITERIA FOR N Z MODIFIED MERCALLI INTENSITY SCALE [4]

MODIFIED MERCALLI (MM) INTENSITY SCALE – Landslide and Environmental Criteria	
MM 6	▪ Trees and bushes shake, or are heard to rustle. Loose material dislodged on some slopes, e.g. existing slides, talus and scree slope. ▪ A few very small ($<10^3$ 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.
MM 7	▪ Water made turbid by stirred up mud. ▪ Very small ($<10^3$ m^3) disrupted soil slides and falls of sand and gravel banks, and small rock falls from steep slopes and cuttings common. ▪ Fine cracking on some slopes and ridge crests. ▪ A few small to moderate landslides (10^3 – 10^5 m^3), soil/rock falls on steep slopes (>30°) on coastal cliffs, gorges, road cuts/excavations etc. ▪ 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.
MM 8	▪ 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 steer slopes (terrace edges, gorges, cliffs, cuts etc). ▪ Significant areas of shallow regolith landsliding, and some reactivation of scree slopes. ▪ A few large (10^5-10^6 m^3) landslides from coastal cliffs, and possibly large to very large ($>10^6$ 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.
MM 9	▪ Landsliding widespread and damaging in susceptible terrain, particularly on slopes steeper than 20°. Cracking on flat and sloping ground. ▪ 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 (10^3-10^6 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 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.
MM 10	▪ Landsliding very widespread in susceptible terrain(3). ▪ 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 'a few' indicates that threshold for an effect or response has just been reached at that intensity. Effects below MM 6 generally insignificant in NZ.*

(2) *Intensity is principally a measure of damage. 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 a given area.*

(3) *Environmental response criteria have not been suggested for MM11 and MM12, as those levels of shaking have not been reported in New Zealand. However, earlier versions of the MM intensity scale suggest that environmental effects at MM11 and MM12 are similar to the new criteria proposed for MM9 and 10 above, but are possibly more widespread and severe.*

(4) *Appendix 1 based on Hancox et al. 1997, 2002.*