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Golder Associates

REPORT ON

GEOTECHNICAL SITE SUITABILITY ASSESSMENT

PROPOSED SUBDIVISION

LAKE POERUA WESTLAND

Submitted to:

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Cashmere
Christchurch
New Zealand

DISTRIBUTION:

2	Copies	-	Grant Marshall
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September, 2007 R06812016-02-V2

EXECUTIVE SUMMARY

Golder Associates (NZ) Ltd (Golder) was commissioned by Mr Grant Marshall to undertake a geotechnical assessment of site suitability for a proposed subdivision to include 24 parcels of land at Lake Poerua, Westland (Figure 1). It is important to note that this site suitability includes assessment for residential structures on 14 proposed sites on Lots 1A – 10A and 11 – 14 only (Figure 2). Separate investigations by Bell (2006, 2007) were also commissioned by the client and these reports are appended within this document.

Field investigation undertaken included aerial photography, geotechnical logging of 12 test pits, 15 Scala penetrometer tests and logging of trenches. Further trenching and geophysical studies were undertaken concurrently by others and this data is also used in this assessment. The materials encountered underlying the proposed subdivision can be divided into three primary types; Taramakau River Gravel, Overbank Silt, and Schist Fan Gravel. The distribution of materials is shown in Figure 4.

The seismic hazard at this site is considered very high level due to the vicinity of the Alpine Fault. This fault is a major active fault in the South Island of New Zealand and dissects the Lake Poerua valley (Figure 3). It is strongly recommended that that potential owners be notified of the natural hazards and the recommended mitigations measures at this site and to be made aware of guidance available from the Earthquake Commission (EQC) to reduce the risk of personal injury and property damage during an earthquake.

Other natural hazards identified and assessed at the site include liquefaction, fault rupture, flooding, inundation, seiching or surge wave, erosion from Mine Creek at the north end of the site, and possible debris slide from the range to the south. This report details and assesses these natural hazards and where required provides mitigation measures as summarized below:

Hazard	Recommended Mitigation
Seismicity	Design and construction in accordance with NZS1170.5:2004 and inform owners of EQC guidelines.
Fault Rupture & Lateral Spreading	Provision of a building exclusion zone (set-back) of 30m from the lake shore (2007 survey) and 40m from the assessed position of the most recent Alpine Fault trace (Figure 5).
Bearing capacity loss	Use of piling, removal of overbank silts and replacement with engineered fill or provision of reinforced engineered fill or stiffened raft foundation.
Inundation from Lake Poerua flood or wave runup	Provision of a minimum floor level of 124.5m RL shown in Figure 5.
Inundation from Mine Creek	Construction of diversion bunds against the risk of sheet flooding from Mine Creek on Lots 12 and 13.
Debris Slide	No mitigation affects are required for this hazard as the associated risks are considered acceptable.

Suitable foundation treatments for the sites are also provided. Foundation treatment for individual sites is to be confirmed and certified by a Chartered Engineer with suitable experience in ground engineering.

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1.0 BACKGROUND

Golder Associates (NZ) Ltd (Golder) was commissioned by Mr Grant Marshall to undertake a geotechnical assessment of site suitability for a proposed subdivision to include 24 parcels of land at Lake Poerua, Westland (Figure 1). It is important to note that this site suitability includes assessment for residential structures on 14 proposed sites on Lots 1A – 10A and 11 – 14 only (Figure 2).

Mr David Bell acting for Canterprise Limited (Bell 2006), then Bell Geoconsulting Limited (Bell 2007) was separately commissioned by Mr Grant Marshall to undertake parallel investigations for this development in an attempt to satisfy Council audit provisions for geotechnical purposes.

The original Golder report for this proposed subdivision was provided to Council. Council then had this report reviewed by GNS Science who duly responded. This report has been revised in response to GNS review[6] and includes further extensive field work and analyses. This revised report is a stand alone report requiring no reference to any previous reports and supercedes all other report for this proposed subdivision, including the most recent report R06812016_02_V1, dated July 2006.

2.0 SCOPE OF INVESTIGATION

The scope of work included:

- review existing geotechnical documentation and aerial photographs,
- walk-over inspection and aerial fly over,
- test pits to assess shallow ground conditions with associated 'Scala' Penetrometer tests,
- foundation treatment recommendations for proposed residential Lots,
- trenching to assist in ground deformation identification,
- detailed debris flow and risk analyses,
- wave surge analyses from possible debris flow from opposite side of lake,
- seiching analyses on lake from possible fault rupture,
- appended results of initial trenching and engineering geological analyses by Bell (2006, 2007)
    - further engineering geological analyses,
    - results of GPR geophysical investigation for ground disruption,
    - detailed description and analyses of further detailed trenching, and
    - a radio carbon dating result of relevant organic material.

This report includes details on all investigation to date, including reports by Bell (2006, 2007) identifies natural hazards that may impact on the development, assesses and analyses numerous aspects of these hazards and recommends appropriate mitigation methods where required. Foundation treatment for the proposed residential Lots is also included.

3.0 SITE DESCRIPTION

Site location plans are shown in Figures 1 & 2, with selected photographs presented in Appendix A.

3.1 Regional physiography

Lake Poerua lies within a northeast – southwest trending valley about 1.5 km wide (Figure 1). The valley is bounded to the northwest by Mt Te Kinga and to the southeast by the Alexander Range, both of which rise some 900 m above the valley floor. The settlement of Inchbonnie is at the southwest end of the valley with the Taramakau River approximately 1 km further south. Lake Brunner and the settlement of Moana are located well to the northwest, beyond Mt Te Kinga. The valley floor comprises gently undulating plains.

The Alexander Range in the southeast has several large volume alluvial fans extending from steep mountainous catchments onto the valley floor. Small creeks flow from these catchments to join the Crooked River to the northeast, along with the outlet from Lake Poerua.

3.2 Proposed subdivision

The proposed 14 lot subdivision is located on the southeastern side of Lake Poerua, adjacent to the Lake Brunner Road (Figure 1 & 2). The ground slopes overall gently towards Lake Poerua from the east (commonly less than a degree) and at a steeper angle at the lake edge, outside the defined north western boundary of the subdivision. The site is in pasture and is gently undulating. A small volume creek runs diagonally through the property, across proposed Lots 4B, 5B, 7B, 9B, 11 and 12, and exits into the lake. To the north east of proposed Lots 12 and 13, Mine Creek flows across the site and into Lake Poerua.

The Midland Railway (Christchurch to Greymouth) runs along the south eastern boundary of the proposed subdivision, crossing the Inchbonnie Rotomanu Road adjacent to proposed Lot 14.

4.0 PUBLISHED GEOLOGICAL INFORMATION

Published geological mapping[18] indicates that undifferentiated fluvial gravel occurs across the site overlying basement rocks at depth (Figure 3). The Alpine Fault is mapped[18] as passing through the proposed subdivision as a concealed active fault. Further discussion of the Alpine Fault is included in Section 6.

The Alpine Fault forms a major rock type boundary between the western and eastern portions of the South Island[5,18]. To the west, the large hills of Mt Te Kinga and the Hohonu Range are formed of granitic rocks of the Te Kinga and Deutgam Suite. To the east, the Alexander Range is formed in schist of the metamorphic Haast Schist Group. Further east a significant portion of the Taramakau River catchment is in areas underlain by greywacke of the Torlesse Supergroup. It is important to note that greywacke gravel found within the subdivision area indicates provenance well east of the site.

The Lake Poerua/Lake Brunner area has been subject to several glacial episodes. Past glaciations are represented by scour and erosion of bedrock leading to dramatically over steepened valley sides, and extensive glacial deposits comprising till and outwash gravel. No glacial deposits are mapped as occurring in the immediate area of the proposed subdivision

4.1 Aerial photography

Major landforms in the development area were mapped from stereo-pairs of aerial photographs and are presented in Figure 4. Aerial photographs studied are tabulated below

Table 1. Aerial Photograph Stereo Pairs

Source of Photographs	Photo Date	Reference	Comment
NZAM	1943	825/42-44	Stereo pair
NZAM	1962	3613/17-18	Stereo pair

5.0 SUBSURFACE CONDITIONS

Field investigation by Golder includes geotechnical logging of 12 test pits and 15 Scala penetrometer tests. All test pit and Scala logs and selected test pit photographs are presented in Appendix B. Logging was undertaken according to NZGS Guidelines for the Field Classification and Description of Soil and Rock for Engineering Purposes[13].

Data from two field investigations completed by Mr David Bell et al (Appendix C & D) was also used in this assessment.

Based on the field investigations, three primary materials underlie the proposed subdivision:

- Taramakau River Gravel,
- Overbank Silt, and
- Schist Fan Gravel.

The description of materials discussed below can be read in conjcution with the observed distribution of materials as shown in Figure 5.

5.1 Taramakau River Gravel

The site is underlain by dense to very dense, sub to well rounded sandy gravel with maximum clast size generally 0.1 m with occasional boulders up to 0.6 m diameter. Occasional sand layers to 0.8 m thickness were observed near or at the top of the gravels. Iron pans were commonly observed within the sandy gravel.

This gravel is interpreted as being derived from the Taramakau River[18]which currently flows west to the Tasman Sea, passing some 2.5 km to the south of the proposed subdivision. The gravel is easily recognisable as its predominant clast lithotype is Torlesse Greywacke, indicating its provenance in the headwaters of the Taramakau River (refer Sections 4.1). In places the gravel is overlain by up to 3.0 m of overbank silt and schist fan gravel.

The Taramakau Gravel aggradation surface has been assigned an age of 1100 to 1300 years based on weathering rind thickness[2].

5.2 Schist Fan Gravel

An area of loose to very loose, sub-angular gravel with a maximum observed clast size of 0.1 m diameter occurs to the north east of the site. This material is assessed to be derived from Mine Creek, which flows out of one of the steep catchments draining the Alexander Range to the southeast. Schist fan gravel was encountered to 1.8 m depth in the test pit excavated on proposed Lot 12 (GA 09), which is considered representative of the likely thickness of this material across proposed Lots 12 and 13. It is possible that thicker deposits may occur in other abandoned and infilled channels particularly more in the centre of this fan towards the northwest of these proposed lots.

The banks of Mine Creek to the north west of the Midland Railway are currently grassed and the creek has a well defined gravel-bed channel. There is evidence that the stream has breached this current channel to spill gravel into the adjacent paddock in the past and that the gravel is aggrading at the lake edge. The fan delta into the lake from this stream is active having had significant fan development over the time frame (1942 – 2007) indicated by available aerial photography and surveys (Figure 5). This regular activity indicates that this activity is not directly related to earthquake events or specifically an Alpine Fault rupture. This suggests active and continuous erosion from the head of the stream and lower potential for larger debris flow events from this source.

Anecdotal evidence suggests that the creek only remains confined to its current bed because local contractors extract gravel from the river bed (Grant Thomas pers comm., March 2006).

5.3 Overbank Silt

In parts of the proposed subdivision, soft to firm, moist to saturated silt beds up to 1.5 m thick overlie the Taramakau River Gravel. Silt overbank deposits may be locally present in other parts of the site outside mapped areas identified in Figure 5. Silt beds were well exposed in trenches (Appendices C, D & E). The bedded nature of these and the nature of the edge contacts with the adjacent gravel indicate that these are most likely fluvially deposited or overbank silts. In trench exposures the lateral contact with the Taramakau River Gravel was sub-vertical indicating that these silt deposits were most likely deposited rapidly following channel formation.

This stream has been diverted near the lake edge at the intersection with the schist gravel deposits of Mine Creek. This indicates that the stream has likely been blocked by the activity of Mine Creek. Considering the high activity of this mine creek delta, this could lead to quick blockage and subsequent rapid sediment deposition in the pre-existing channel area, followed now by gradual erosion by the meandering stream now present.

5.4 Groundwater

No clear indication of groundwater levels was observed in test pits. Seepage was observed at the base of Overbank Silt (0.5 – 0.6 m below ground surface) in test pit GA11 and some ponding at the base of test pit GA9. Any groundwater is likely to be a perched aquifer bound by an iron pan in the Taramakau gravels below. As indicated by the deep test pits, the main unconfined groundwater level may not be coincident with lake level and could be lower than the nominal level.

6.0 NATURAL HAZARDS

The following categories of natural hazard have been identified as potentially affecting the proposed subdivision:

- Seismicity,
- Fault rupture,
- Liquefaction,
- Inundation, and
- Debris Flows.

These hazards are discussed in the following sections. A flyover of the area was also completed to gather evidence of geological hazards across the site. Relevant oblique aerial photographs are presented in Appendix A. Mitigation measures are considered further in the Section 7.

6.1 Seismic hazards

There is a very high seismic hazard because the Alpine Fault dissects the Lake Poerua Valley and passes very close to the proposed subdivision (Figure 3).

It is assessed from NZS 1170.5:2004[17] that Lake Poerua and adjacent areas have a 10% chance of experiencing a Peak Ground Acceleration (PGA) of 0.6g or greater in any 50 year period, or a 2% chance of experiencing a PGA of 1.08g or greater in the same period. Studies[20] suggest that there is a significant liklehood of the Alpine Fault rupturing within this time period.

The site is assessed to be within Class C (shallow soil site)[17] of NZS 1170.5:2004. This classification is based on the expected depth of less than 100 m of gravel to the underlying bedrock.

Due to the potential high ground acceleration at this site, the following hazard mitigations recommendations are made:

- Residential dwellings and all associated structures must be designed in accordance with NZS 1170.5:2004[17],
- The design is to be completed or independently reviewed by chartered structural engineers experienced in the design of seismic resistant buildings, and
- All prospective landowners are made aware of guidance available from the Earthquake Commission (EQC) to reduce the risk of personal injury and property damage during an earthquake.

These recommended mitigation measures are summarized in Section 7.1

6.2 Fault Rupture

The Alpine Fault is mapped[18] at 1:50,000 scale as passing through the proposed subdivision as a concealed active fault (Figure 3). Berryman et al (1992)[2] mapped the trace of the Alpine Fault between the Taramakau River and Lake Poerua as a series of left stepping en-echelon strands (Appendix F). To the north of the settlement of Poerua, the Alpine Fault is mapped[18] as a concealed trace at the immediate base of the Alexander Range.

Golder used the following methods to assess the location of the Alpine Fault in relation to the proposed subdivision:

- Test pitting to assess ground conditions across the site,
- Scala penetrometer testing to assess the insitu (strength) density of materials,
- Trenching logged by others and viewed by Golder, to check for fault position and displacement,
- Mapping and air photo interpretation to check for fault displacement and position, and

- Oblique aerial photograph acquisition and interpretation for fault offset and likely position.
- Reference to reports by Bell et al in Appendices C & D

A series of photographs were taken from helicopter on 12 April 2006. A selection of annotated photographs is included in Appendix A.

Previous investigative trenches, commissioned by the owner and excavated under the supervision of Mr David Bell (5th March 2006) were also viewed by Golder. Mr Bells' 2006 report is given in Appendix C and annotated photographs of these trenches are presented in Appendix E. The trenches were aligned perpendicular to the expected trend of the Alpine Fault[1] and excavated to a depth of between 1.5 m and 1.8 m. The trenches excavated cover the width of the proposed subdivision from the Lake Brunner Road to the shore of Lake Poerua. Trenches from 2006 can be seen in Figure A1 and the surveyed positions are shown in Figure 5.

Golder viewed the trenches on 7th March 2006. The walls of the trenches had collapsed in places. Trenches T1, T3 and T4 exposed a layer of Overbank Silt up to 1.5 m deep over Taramakau Gravel. The west end of this channel has a steep contact with the adjacent gravel. The silt layer is interpreted as an abandoned river channel that was rapidly filled with silt (overbank deposit).

Golder observed no evidence of fault rupture in any of the test pits, trenches or photographs. This accords with Mr David Bell finding that there was "*...no* evidence for the Alpine Faults' last rupture within *the site...*" (Memo to Grant Marshall dated 6 March 2006).

Further trenching and geophysical investigations were under the supervision of Mr David Bell and others in March 2007 and this report is presented in Appendix D. Golder staff was present during the excavation and assisted in mapping and photography of these trenches. Evidence of faults was not observed in any of these trenches.

The most recent surface trace of the Alpine Fault is considered to be within the Lake Poerua based on the following points:

- No faults were observed within any of the test pits and trenches excavated on site.
- The linear nature of the lake edge at the proposed subdivision.
- The lake also deepens quickly along this alignment as indicated in the 1976 bathymetry survey of the lake.
- This fact is in contrast with the north and south ends of the lake where there is negligible gradient change from dry to inundated land, i.e. no well developed shore platform.
- No major ground displacement features were observed within any of the excavated trenches.

- The only potential ground disturbance anomolie interpreted from the geophysical studies (Bell et al 2007) aligns well with the lake edge.
- The evidence presented in both reports by Mr Bell (Appendices C & D) is in agreement with our assessment.

The weight of evidence suggests that the Alpine Fault most likely passes to the lake side of the development based on the landform at the site, test pitting and geophysical surveys which show no evidence of fault displacement in the sediments on the proposed development site. In that case, the subdivision is unlikely to be directly effected by the most recent fault rupture and so can be developed.

There is some residual risk that the most recent Alpine Fault trace in this area is actually deeper under the proposed development site, masked by younger sediments. In this case in other local body jurisdictions (for instance at Nelson City) as we know it, the development would also most likely be permitted on the evidence that no fault was identified at the site.

A building exclusion zone typically 20m from the assessed location of the rupture trace of a fault is considered appropriate to mitigate against fault rupture hazard[3,12]. Recommended mitigation measures are detailed in Section 7.2.

6.3 Liquefaction

Soil liquefaction is a physical process that may take place during earthquakes having a Modified Mercalli Intensity of MM VII or greater. This intensity could be met or exceeded when the Alpine Fault ruptures.

Liquefaction is considered most likely to occur in saturated sand and silt deposits, generally less than 10,000 years in age, where ground water is within 10 m of surface. Generally, the younger and looser the sediment and the higher the water table, the more susceptible a soil is to liquefaction.

Evidence of liquefaction of sands within the silt over bank deposits was observed by Golder (Figure E2) and reported by Bell et al (2007). This indicates that these shallow materials have liquefied during a previous ground shaking event. The sediments would have been saturated during the event, however no groundwater was observed in any of these materials observed in the trenches at this time.

Evidence from the geophysical survey and Berryman[2] indicates that the land east of the Alpine Fault has been upthrust. This suggests that the sediments may have been at a lower elevation prior to the previous fault movement. A lower level would have been more likely saturated from the levels of the water within the lake. The sediments where the evidence of liquefaction is observed is now near 2m above the lake level and therefore are not expected to be continuously saturated, thereby reducing the risk of liquefaction in these sediments.

Liquefaction can cause several types of ground failure including the loss of bearing strength and lateral spreading. In a land mass not adjacent to open water, i.e. lake shore, the primary affect is loss of bearing capacity through settlement of underlying liquefaction prone soils. Sites adjacent to open water can be susceptible to lateral spreading.

The assessment of possible liquefaction on this site is based on the following points:

Driving Factors

- Evidence of sand liquefaction within the overbank silts has been observed,
- Sand layers up to 0.8m thickness at 3 m depth were observed in test pits and trenches within the Taramakau River Gravel sequence.

Mitigating Factors:

- The materials encountered beneath the Overbank Silt comprise generally medium dense to dense sandy gravel,
- Sandy gravels are not usually considered liquefiable, and provide good drainage for other potentially liquefiable materials if present,
- Any sand beds such as those encountered within the test pits, are thought to be discontinuous across the site, and
- Several iron pans comprising iron cement were noted within the sandy gravel layers, which could increase the apparent strength of the materials.
- The overbank silts are now well above standing lake water levels.

In summary it is considered[4,11] that there is a low risk for lateral spreading on the lake shore front and for loss of bearing within the over bank silt deposits should liquefaction occur during a ground shaking event.

A set back from the open face (lakeshore) can typically be used to mitigate against lateral spreading. A suitable set back from the lake edge can be assessed from several facts including the depth of the lake, height and slope of the land on the lake shore, estimation of liquefiable materials based on test pit observations and the likely water level. Recommended mitigation measures for lateral spreading are detailed in Section 7.3.

Piling through or removal and replacement is considered an appropriate measure to mitigate against loss of bearing capacity from liquefaction of overbank silt deposits. In addition engineered granular fill with geogrid reinforcement can provide additional risk reduction against local spreading and or loss of bearing within the infilled section. Recommended mitigation measures for bearing capacity loss are detailed in Section 7.4.

6.4 Inundation Hazard

There is a hazard due to inundation from:

- Sheet flow from Mine Creek, and

- Elevated level of Lake Poerua during flood events.

6.4.1 Sheet flow from Mine Creek

Sheet flow with associated channel erosion is possible from Mine Creek.

Mine Creek has an active fan delta into Lake Poerua (Figure 5 and Figure A1), and has breached its current channel to spill gravel into the adjacent paddocks in historic times (refer Section 5.2). Aerial photographs suggest that Mine Creek has occupied its current channels at least since 1943, from the earliest photographic evidence studied.

Observations indicate that there is a large lateral extent of Schist Fan Gravel deposited within the boundaries of the proposed subdivision although over all volumes are not significantly large. The fan gravel is in the order of 2.0 m thick and tapering out to the southwest (refer Test Pit GA 01 in Appendix B) over the older Taramakau River Gravel. The southwestern extent of Schist Fan Gravel (Figure 5) is the probable limit to which Mine Creek has flowed in the past.

The hazard from the lateral spread and sheet flow with associated bed load from this active fan can be mitigated using appropriately designed diversion berms. Mitigation for this hazard is only required for significant residential structures adjacent to the hazard and is expected in only a few Lots and not over the entire subdivision. Recommended mitigation measures for protection from Mine Creek is provided in Section 7.6.

6.4.2 Flooding from Lake Poerua Level Rise

Inundation of the low lying parts of the proposed subdivision from Lake Poerua rising is possible due to a landslide damming the outlet from Lake Poerua and or in association with an extremely large storm event.

Records [11] show that the outlet from Lake Poerua was blocked by landslide from Mt Te Kinga between January and August 1991. The dammed lake level rose sufficiently to flood farmland at the northeastern end of the lake. No information was found to describe how long the dam lasted prior to breach. Aerial photography shows remant slope failure debris assumed to be responsible for the damming event (Figure A3). Landslide debris appears to have come from high on Mt Te Kinga in the Brums Creek catchment. The landslide has resulted in a debris fan extending into the Poerua River.

Preliminary hydrologic analyses using 1:50,000 topographic information suggest that a 1 in 150 year storm event of 12 hours duration could raise the lake level area not more than 1.7m higher than standing lake levels. This is a worst case scenario involving fully saturated conditions with no evaporation and all water flow accumulating within the existing lake area. This assumption of no lateral spread of the lake area could only be considered appropriate on the north west and parts of the south east sides of the lake where steeper sides are encountered. In reality the lake will spread to the north east and south west with rising levels. We expect only a portion of the valley floor to be blocked at any one time and this would allow passage of stored water around its perimeter well before this increased height level is obtained.

Topographic survey of the upstream south western margin of the lake, indicates that water will commence to flow west down to Lake Brunner at any level above 124.5m (Appendix G). This level is 2.2m above the standing lake level. In the extremely unlikely event that the water level rose to this level, drainage away from the lake would then be increased significantly draining away to the south west preventing the lake to rise significantly above this level.

Adoption of a suitable minimum floor level of 124.5m for proposed residential structures above the standing lake level is expected to provide protection against this unlikely and extreme flood and damming scenario. This level partially affects 5 proposed residential Lots and wholly one proposed residential Lot. It is considered that sufficient time will be available to further mitigate against these extreme flood hazard with emergency measures such as downstream channelling works and debris clearance, if required. Recommended mitigation measures against flooding are provided in Section 7.5.

6.4.3 Surge Flooding from Debris Flow into lake

Inundation due to flooding by a surge of water could occur should a very rapid and large landslide fall into the lake. Possible large sources of rock mass (probably in-situ) are located along the ridge line on the north western shore of Lake Poerua (Figure 4). Some of these features however could also be interpreted as the result of past landslides or rock fall.

An area, identified in Figure 6 is considered a possible source for a large and rapid landslide. The highest hill side crest near the western side of the lake is about 280m above the lake at a slope 27°. On this slope is a ledge about 70m width, 400m in length at about 140m above lake level at a slope of 34°. This steeper zone is kinematically more likely to fail for its slope is near the accepted angle of repose for loose angular gravel mass, usually about 35° to 38°. This area is at the northern end of the lake and its expected closest deposition path at the shoreline is between a 1km to the shoreline closest to the nearest boundary of the proposed subdivision to over 1.5km from the shoreline at the farthest section of the subdivision. If we assume the worst case is that this area fails to say 27° (same as the higher slope) then a wedge will fall from the top to the lake floor to form a slope at 27°. This is estimated to be about 1,225m^3 per metre length of this area. A reduction of 35m in the width of this mass at the top of the slope, with a corresponding increase of 35m at the base of the slope would result in a slope of about 27°. A width of 35m gives a maximum depth of about 4.5m deep. So if this ledge came down instantly a volume of water of about 79m^3 per metre length of the failure could be displaced.

Empirical estimates were completed by experienced coastal geomorphologist from Golders' Canadian offices and are presented in Appendix H. Based on empirical data and experience the expected wave height generated from this event would be approximately 3.5m at the landslide, reducing without friction losses, in response to conservation of energy to a height of about 0.7m at 1km from the source. Wave runup height can be estimated as twice the nearshore wave height. Thus wave runup associated with the maximum estimated wave height of 3.5 m from a landslide into the lake is 1.4 m above still water level, i.e. to a level of about 123.7m RL. The majority of the proposed residential Lots are above 123.7 m RL. Recommended mitigation measures against wave surge flooding is provided in Section 7.5.

6.4.4 Seiching from fault rupture

An earthquake which involves a rupture along the Alpine Fault has the potential to cause a seismically generated seiche in Lake Poerua since the lake is wide and shallow. Research suggests next rupture of the Alpine Fault could give an earthquake of magnitude MM8[20]. Past ruptures have been in the order of 6m dextral and 3m vertical movements[2].

Based on Japanese research, Golder Canada has also completed an empirical analysis for a seismic generated wave height, runup and period of a possible seiche within the lake. This analysis is also presented in Appendix H.

The analysis indicates that a seismic generated wave could give a shoaling wave of about 1.3m height in approximately 2m depth of water located about 50m out from the lake shore near the subdivision. An empirical run up analyse indicates that wave run up from this wave would be in the order of 1.7m height above the standing lake level, i.e. to 124m RL. The majority of the proposed residential Lots are above 124m RL. The time taken (period) for this wave to repeat across the lake is estimated to be about 260 seconds (just over 4 minutes). Recommended mitigation measures against flooding from seiching is provided in Section 7.5.

6.5 Debris flow analysis and risk assessment

Estimating debris flow travel distance is prone to error even with detailed analyses. The methods used must be realistic and provide a confirmation of conditions as seen on site. Estimation methods Hunter and Fell[10] and Dynamic Analysis (DAN) by Hungr[7] and Hungr and Evans[8,9] have been used to estimate debris flow travel distances.

Hunter and Fell propose an empirical correlation based on confinement of flow paths and the initial failure slope. Three equations for rapid debris flows at different levels of flow path confinement with standard errors of correlation are given. The correlations are not valid at low initial slopes (approx<16°) and an estimation table can be used for these cases. An upper 90% was assessed using the standard error given.

DAN implements a one-dimensional Lagrangian solution of the equations of motion for a mass of earth material which starts from a prescribed static configuration and flows according to one of several rheological relationships. Estimation of these relationships has been made from comparison between field observation and recommendations within the available documentation on this method.

Two significant debris slides have been postulated, one from Mine Creek and a second from the Alexandra Range. These areas have been selected on the basis of concerns by the Councils' reviewer. Debris flow profiles and analyses results are presented in Appendix I.

The results indicate that the flow path from Mine Creek is extremely unlikely to impact on the proposed subdivision in both run out distance and direction and poses insignificant hazard to the residential lots proposed within this subdivision.

The results indicate that the flow path from the possible source rock analysed from the Alexander Range is unlikely to impact on the proposed subdivision. The lots proposed for residential development in the subdivision are not in the flow path direction. Other smaller debris slides are possible from the Alexander Range and are considered in the risk assessment.

A qualitative risk assessment for debris slides was completed under guidelines developed from Australian Geomechanics Society[1] and is tabulated below. It is considered that the risk of debris flow affecting proposed residential lots on this subdivision is at an acceptable level and no mitigation measures are required.

Source	**Likelihood of event**	**Consequence of event**	**Assessed Risk Level**
Alexander Range, obvious knoll on hill side is likely source. (Volume ~100,000m^3, analysed)	Possible (less or equal to likelihood of Alpine Fault rupture)	Insignificant, no residential structures are proposed in analysed flow path, possible fence or field shed damage.	Very Low to Low – Acceptable risk
Alexander Range, no obvious sources, expect shallow small failures (Not analysed)	Likely (more than likelihood of Alpine Fault Rupture, more related to extreme weather event)	Insignificant, No evidence observed of any debris on the areas proposed for residential lots, expect very small volume, and expect small flows to be disrupted by Inchbonnie-Rotomanu road and Midland railway corridors.	Low to Moderate – Acceptable to tolerable risk.

7.0 MITIGATION OF NATURAL HAZARDS

There are significant natural hazards at this site primarily associated with the proximity of the Alpine Fault and Lake Poerua, which require mitigation. The following measures are recommended to mitigate the risk of the identified natural hazards.

7.1 Build for Seismicity

Due to the potential for high levels of ground acceleration at this site it is recommended that residential dwellings and all associated structures be designed or independently reviewed by chartered structural engineers experienced in the design of seismic resistant buildings in accordance with NZS 1170.5:2004[17]. The site is assessed to be within Class C (shallow soil site)[17] of NZS 1170.5:2004. In addition, all prospective land owners should be made aware of guidance available from the Earthquake Commission (EQC) to reduce the risk of personal injury and property damage during an earthquake.

7.2 Set back for Fault Rupture

The active trace of the Alpine Fault has not been identified within the boundaries of the proposed subdivision and we recommend that the development can be consented on this basis.

The fault is a large tectonic feature therefore we also recommend a building exclusion zone to be placed within a distance of 40m from the assessed position of the most recent Alpine Fault rupture to mitigate further against fault rupture hazard. This set back is twice the minimum recommended in guidelines for development of land close to faults by the Ministry for the Environment[12] as referenced by GNS. This set back can be defined as 30m from the lake edge survey of 2007 or 40m from the interpreted fault line and is presented in Figure 5.

7.3 Set back for Liquefaction induced Lateral Spreading

No evidence of lateral spreading from liquefaction was observed on the site. However a building exclusion zone should be placed around the lake edge as due diligence to mitigate the low hazard of possible lateral spreading from liquefaction. Due to the shallow nature of the lake a recommended setback of 30m from the lake edge is considered appropriate mitigation for this hazard. The proposed set back for fault rupture accommodates this recommendation as presented in Figure 5.

7.4 Ground improvement for Liquefaction induced bearing capacity loss

Loss of bearing capacity can occur in areas prone to liquefaction. Mitigation against loss of bearing from liquefaction in the majority of cases is uneconomic. Today there still remains and will remain in the future areas of the cities of Christchurch and Greymouth which are prone to liquefaction.

Where structures are proposed over the overbank deposits as mapped in Figure 5, it is recommended that either piling is used to support the structure on the underlying Taramakau Gravels, or this material is removed and replaced with engineered fill not prone to liquefaction. Silt overbank deposits may be locally present in other parts of the site, and further investigations in the areas of proposed building footprints are recommended once final layouts are known. Where full depth ground improvements are not economical a stiffened raft foundation or reinforced engineered fill is suggested.

7.5 Floor level requirement for inundation from lake

Downstream blockage of the lake outlet leading to a raised lake level is documented to have occurred in the past. Survey has shown that the maximum level that the lake could rise to before over topping upstream and flowing to the west is 124.5m elevation. It is likely that this overtopping will allow sufficient time to clear any exit channels before freeboard between the buildings and normal lake level is breached.

Analyses for surge waves from a large landslide on the opposing side of the lake and seiching (harmonic wave) on the lake from fault movement were also completed. These analyses showed that maximum runup height of waves above standing lake level is lower than the maximum possible flood level.

We recommend a minimum residential floor level of 124.5m elevation to mitigate against possible inundation or wave runup from the lake. This level is highlighted in Figure 5. Any residential structures located below this level will require floor levels above natural ground level. This can be provided by the use of either engineered fill or piled (poled) structures.

7.6 Protection bund for Mine Creek inundation

Due to the risk of a natural realignment of Mine Creek and possibly partial inundation of proposed Lots 12 and 13, a reinforced earth bund is recommended to be constructed alongside the creek bed or upslope and between any residential structure and this creek in these Lots. The bund is to be placed between residential structures and Mine Creek. The length and plan shape of these bunds is to be finalised upon specific design of residential structures on Lots 12 and 13.

A section detail of the protection bund design is shown in Figure 7. The majority particle size in the armouring portion (creek side) of the bund must be $\geq$ 0.1 m diameter based on the observed maximum particle size transported by Mine Creek to this distance.

It is expected that suitable structural fill material will be able to be screened from the Taramakau River Gravel occurring across much of the rest of the site. This material consistently contains particles in excess of 0.1 m diameter and as a well graded gravel it is expected to be suitable as an engineering material for this purpose.

7.7 Debris flow requirements

According to the debris slide analyses and risk assessment undertaken no mitigation affects are required for this hazard as the associated risks are considered acceptable.

8.0 FOUNDATIONS

Good ground as defined by NZS3604[14] can be found in the Taramakau River Gravel at varying depths across the lots as indicated in the Table 2 on the next page. It is recommended that foundation preparation be confirmed and certified by a Chartered Engineer, suitably experienced in ground engineering.

Piles driven into the dense to very dense coarse sandy gravels will be a suitable founding system for the expected loads of residential properties. Should strip and or pad footings be a preferred founding system, improving the ground by excavation, backfilling and recompaction would be required at each site.

If piling or ground improvements do not fully replace the overbank silt deposits it is suggested that ground reinforcement such as the use of a geogrid within the improved ground or stiffened raft be considered to reduce the hazard of bearing loss from liquefaction. These methods can reduce this hazard to an acceptable level and may not be able to eliminate the hazard completely.

Ground improvement could be undertaken by excavation to good ground, proof rolled then back filled and recompacted to NZS 4431[15] Standards. Excavation should not extend lower than 0.3m above any standing groundwater level. All excavated materials free of organic soil or debris with less than 15% fines should be suitable for recompaction. All fill is to be certified according to NZS4431[15]. This will most likely require a method statement for backfilling, as in-situ testing may not be possible due to the expected coarse size nature of the backfill.

Table 2. Estimated depth to good ground at test pit locations

Proposed Lot	Test Pit/DCP	Assessed Depth to Good Ground [1]	Comments
Lot 1A	TP14 & DCP Lot 1A	Below topsoil	Test pit by Bell
Lot 2A	GA01	1.1 m	
Lot 3A	GA02	0.6 m	
Lot 4A	GA03	Below topsoil	
Lot 5A	GA04	1.7 m	DCP in sand channel adjacent to test pit
Lot 6A	GA05	0.1 m	
Lot 7A	GA06	0.2 m	
Lot 8A	TP11 & DCP Lot 8A	0.1 m	Test pit by Bell
Lot 9A	GA07	Below topsoil	
Lot 10 A	GA08	Below topsoil	
Lot 11	TP10 & DCP Lot 11	Below topsoil	Test pit by Bell
Lot 12	GA09	2.5 m	High DCP reading due to clast – depth up to 3.1 m may be required
Lot 13	GA10	0.6 m	
Lot 14	GA11	0.6 m	

Note: 1. Depths are estimated from nearest test pits and may vary above or below that stated.

9.0 CONCLUSIONS

Section 106(1) of the Resource Management Act (RMA) states that the consent authority may grant a subdivision consent subject to conditions if it considers that the land is, or likely to be, subject to material damage by erosion, falling debris, subsidence, slippage or inundation from any source.

Section 106(2) states that conditions under 106(1) must be for the purpose of avoiding, remedying or mitigating the effects referred to in section 106(1).

It is our opinion that the natural hazards identified to impact on the proposed development can be suitably mitigated as outlined in Section 7 above and summarized below:

- Design and construction in accordance with NZS1170.5:2004[17] to protect against strong ground motion and inform owners of EQC guidelines,

- Provision of a building exclusion zone (set-back) of 30m from the lake shore and 40m from the assessed position of the most recent Alpine Fault trace to mitigate against both fault rupture and lateral spreading possible during liquefaction,

- Use of piling, removal of overbank silts and replacement with engineered fill or provision of reinforced engineered fill or stiffened raft foundation to reduce hazard from bearing capacity loss during liquefaction,

- Provision of a minimum floor level of 124.5m RL to mitigate against possible lake flooding or wave runup, and

- Construction of diversion bunds against the risk of sheet flooding from Mine Creek on Lots 12 and 13.

We also find that suitable founding conditions can be found across the site as detailed in Section 8 and as summarized below:

- The use of piles (or ground improvement for shallow footings) for foundations in loose or soft sediments where encountered is recommended, and

- Foundation treatment for individual sites is to be certified by a Chartered Engineer with suitable experience in ground engineering.

10.0 LIMITATIONS

(i). This report has been prepared for the particular purpose outlined in the project brief and no responsibility is accepted for the use of any part in other contexts or for any other purpose.

(ii). Assessments made in this report are based on the ground conditions indicated from published sources, site inspection and subsurface investigation described. Variations in ground conditions may occur between investigatory locations however and there may be special conditions appertaining to the site which have not been revealed by the investigation and which have not therefore been taken into account in the report. No warranty is included; either expressed or implied, that the actual conditions will conform exactly to the assessments contained in this report.

(iii). Where data supplied by the client or other external sources, including previous site investigation data, have been used, it has been assumed that the information is correct unless otherwise stated. No responsibility can be accepted by Golder Associates (NZ) Ltd for inaccuracies within data supplied by others.

(iv). Any comments on groundwater conditions are based on observations made at the time of investigation unless otherwise stated. It should be noted that groundwater levels vary as a result of seasonal or other effects.

(v). This report is provided for sole use by the Client and is confidential to him and his professional advisers. No responsibility whatsoever for the contents of this report will be accepted to any person other than the Client.

(vi). This Limitation should be read in conjunction with Golder Associates (NZ) Ltd's Conditions of Engagement provided separately

11.0 REFERENCES

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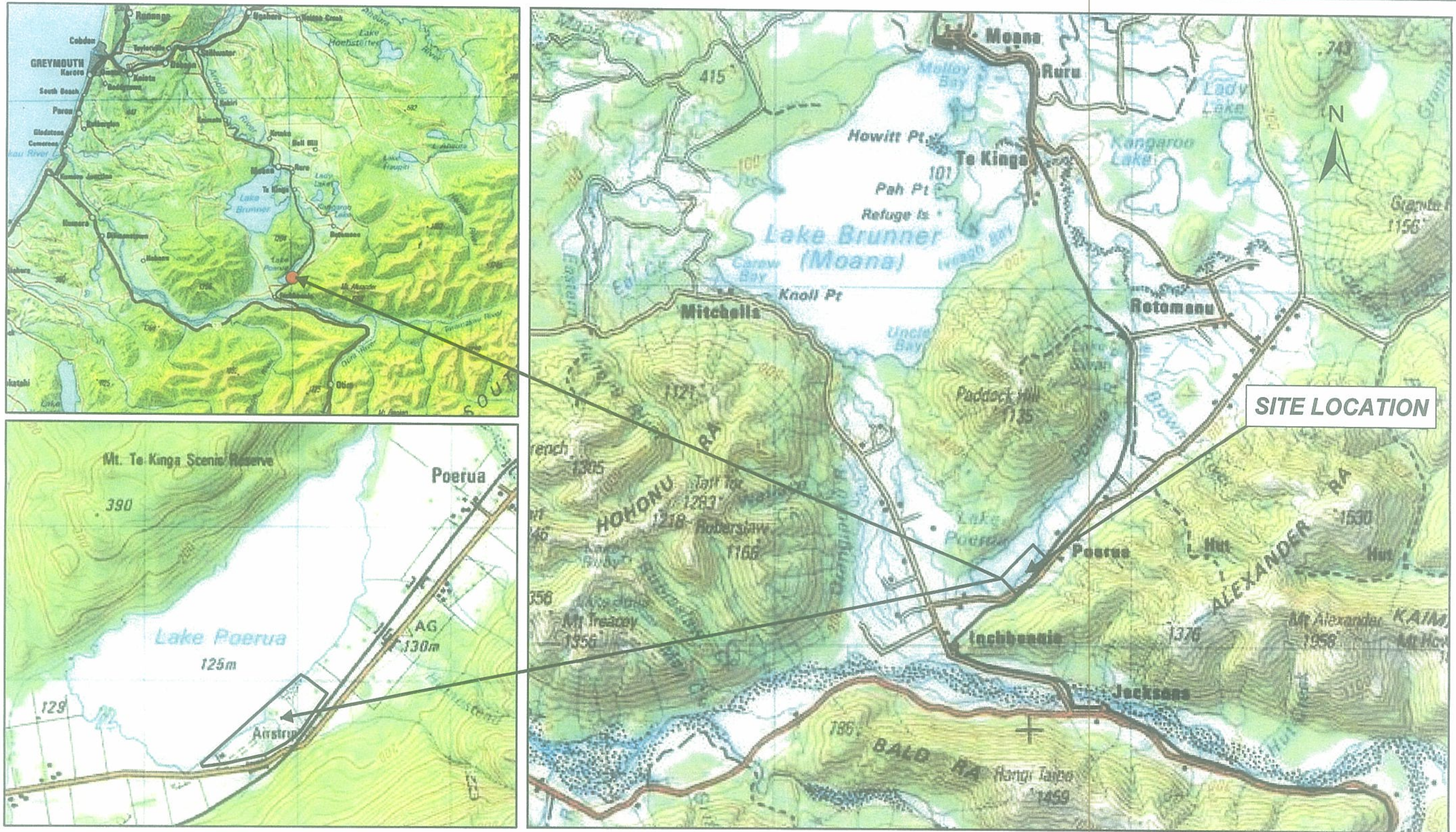
12.0 CLOSURE

We trust this report is suitably informative and should you have any questions please do not hesitate to contact the undersigned.

Yours sincerely,
GOLDER ASSOCIATES (NZ) LTD

Cid Chenery
Senior Geotechnical Engineer



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SOURCE
Land Information New Zealand,
NZMS Topographical Map.
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Datum: NZGD49; Projection: Hokitika Circuit

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Golder Associates

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CHECKED LRC	DATE 24/9/07		
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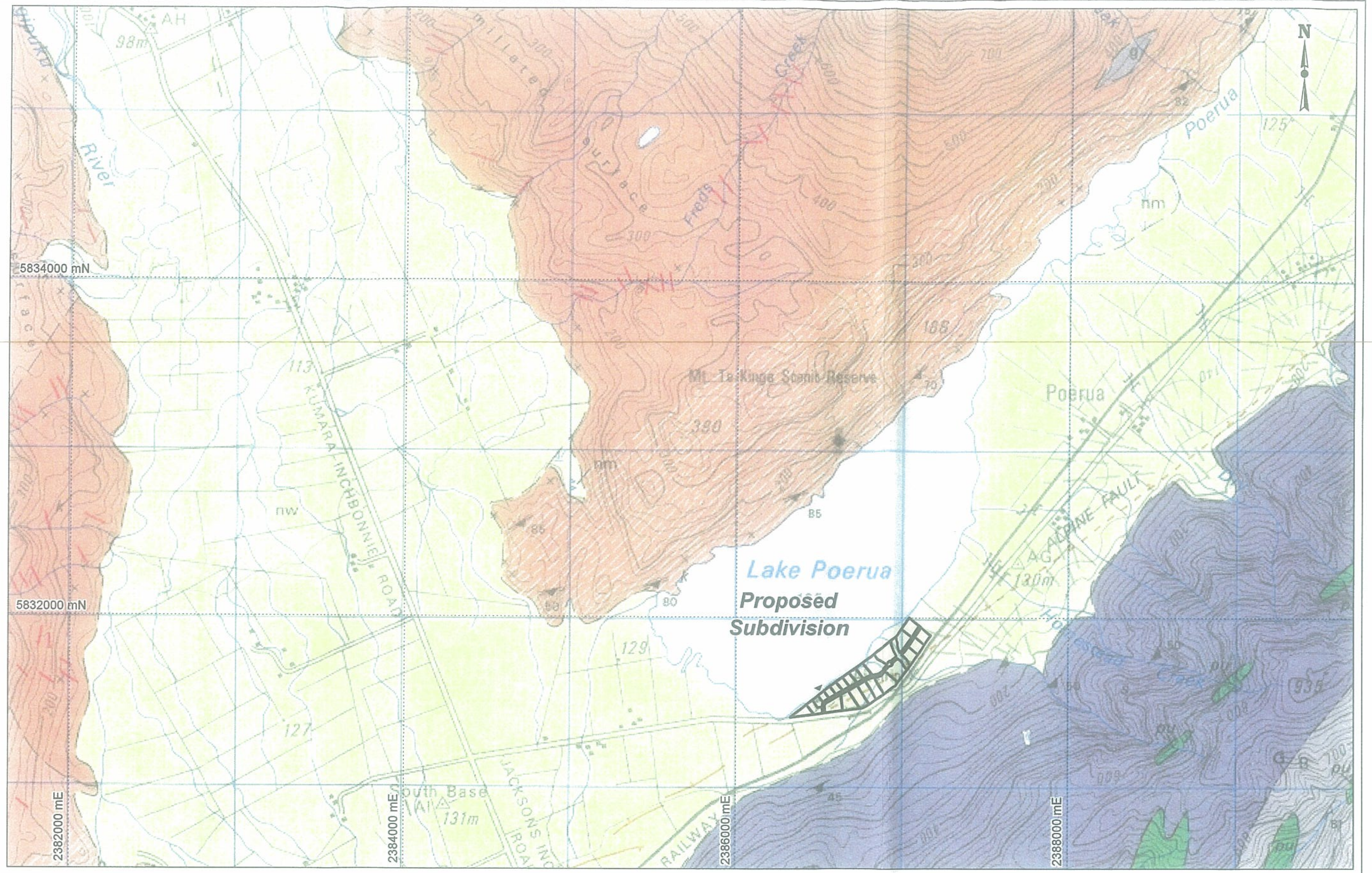

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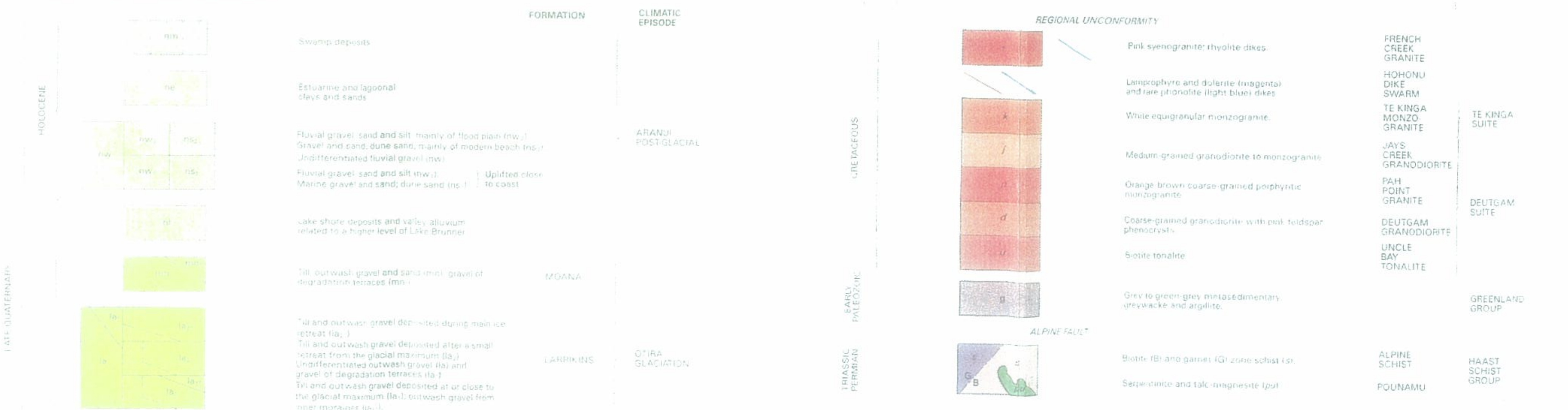

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Golder Associates

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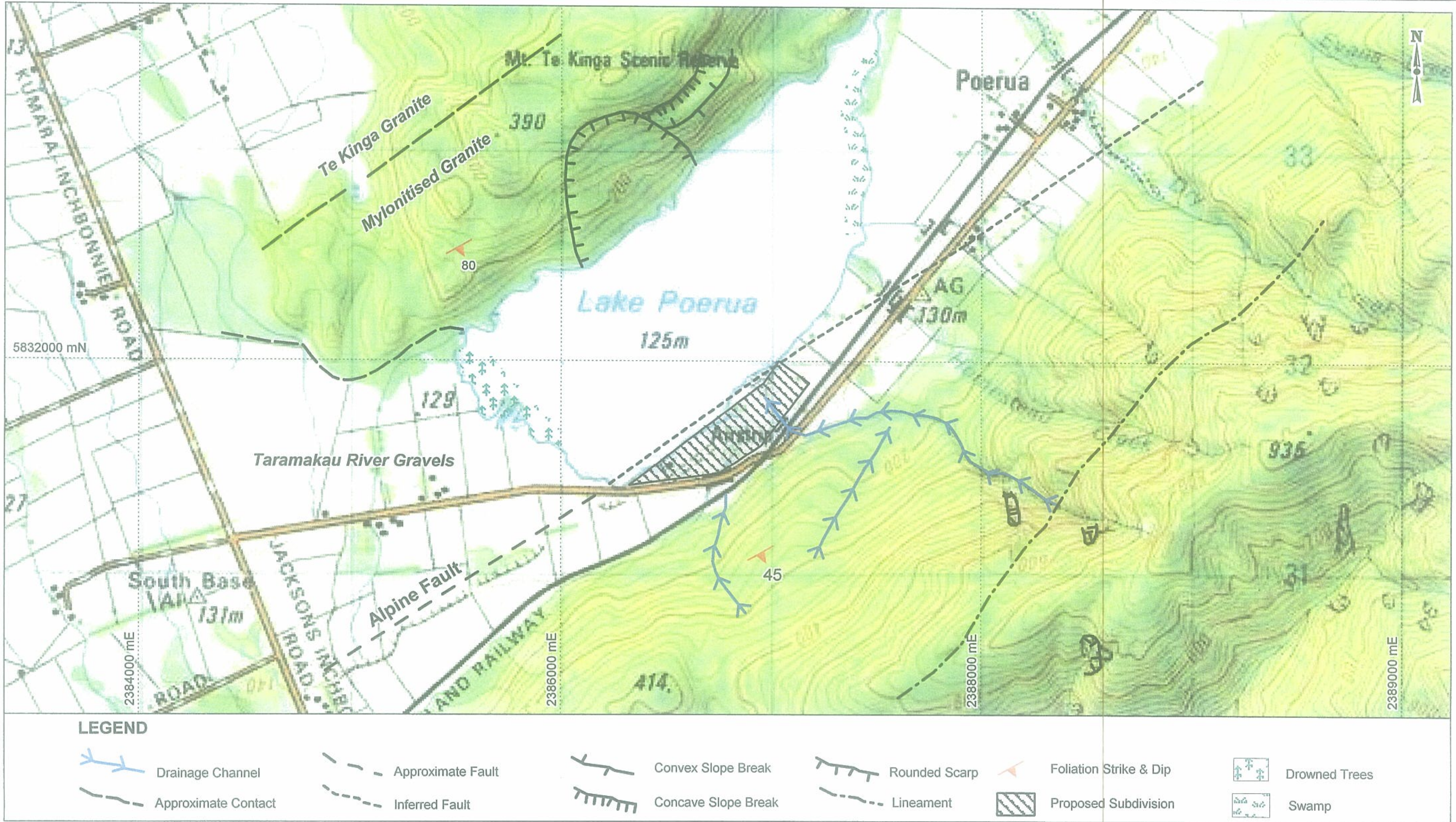

Source: Land Information New Zealand, NZMS Topographical Map
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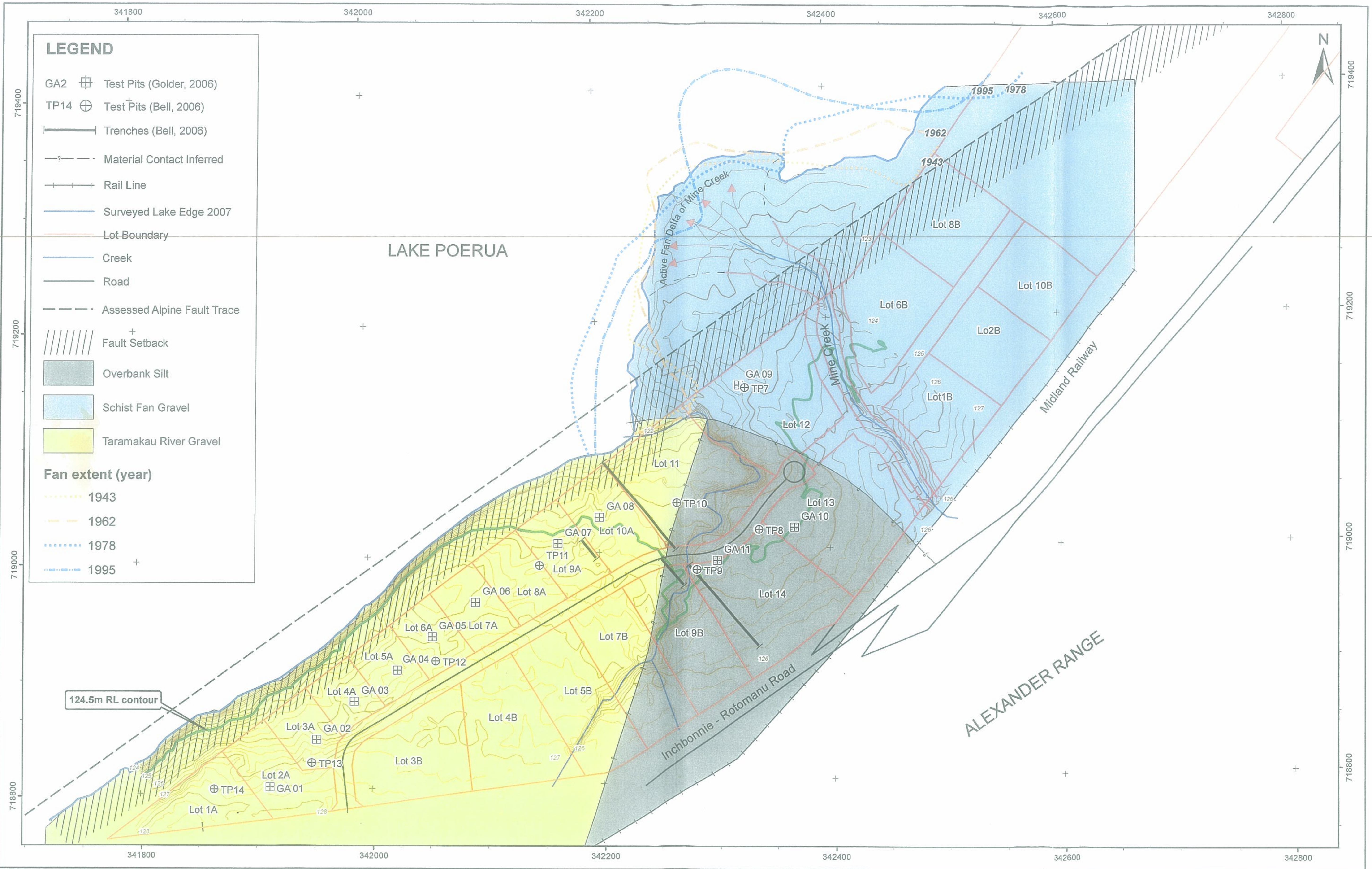

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Golder Associates

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CHECKED	LRC	DATE	24/9/07
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PROJECT No	06812016	REPORT No	R06812016-02-v2
REV No	1	FIGURE No	5

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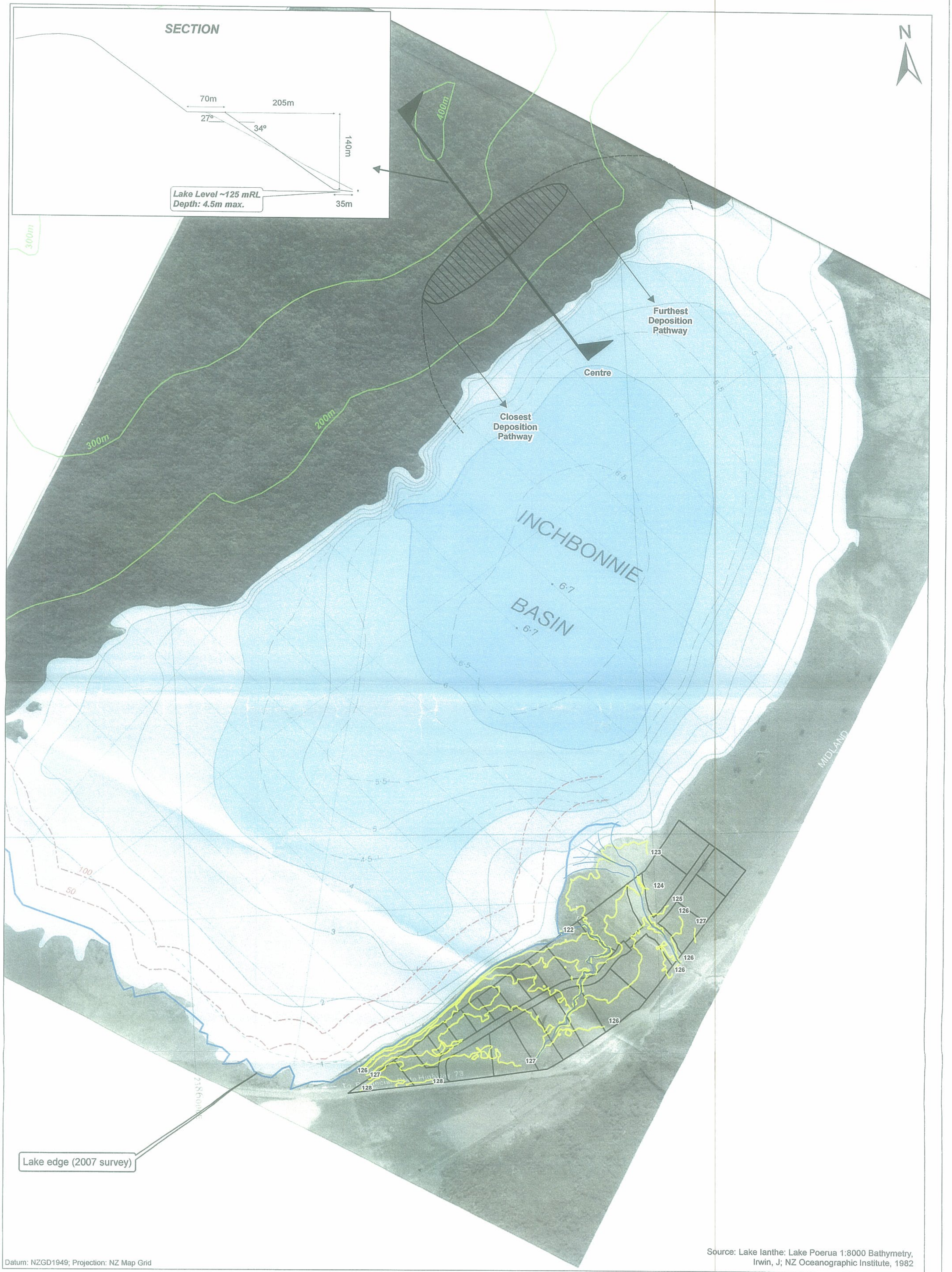

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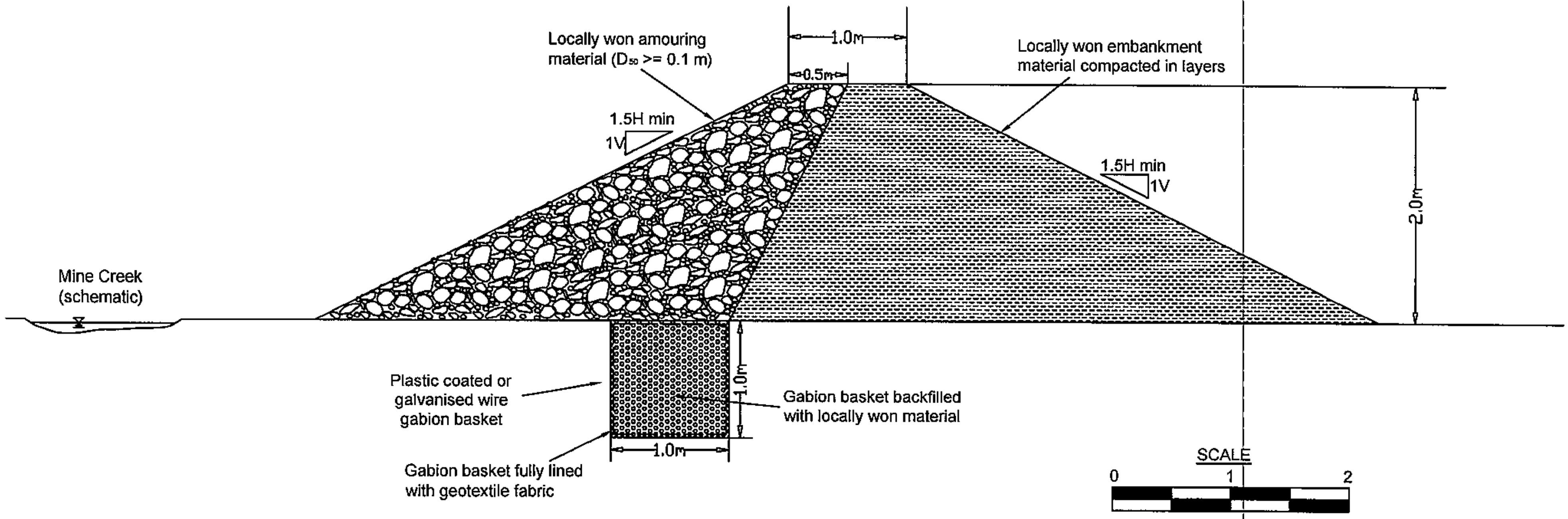

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CHECKED LRC	DATE 24/9/07			
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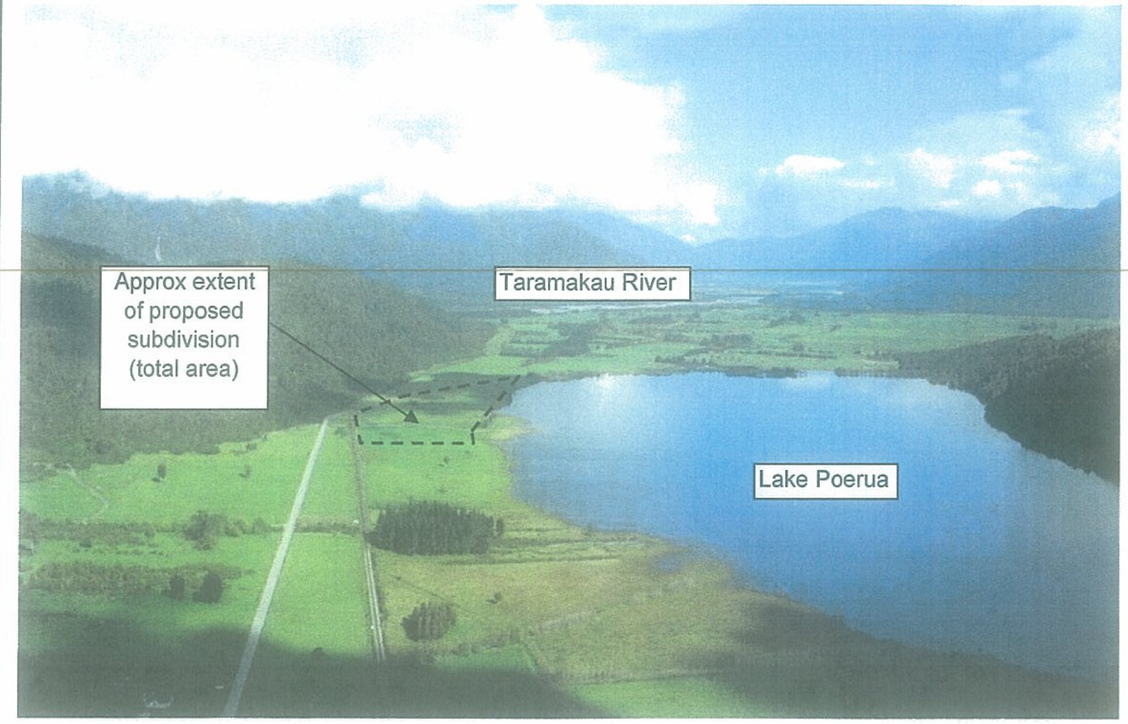
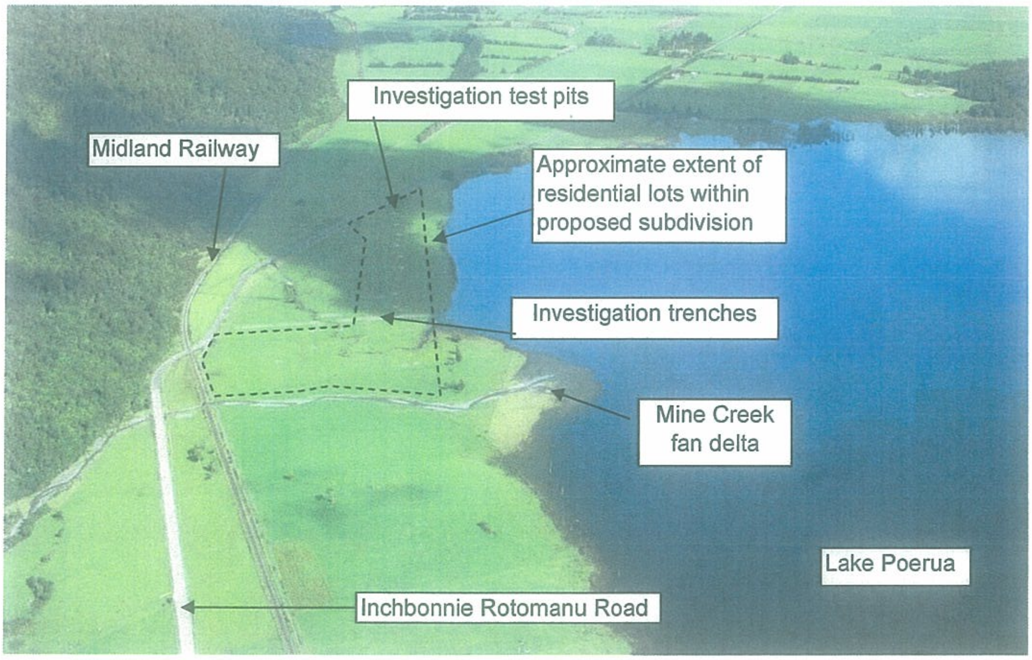
Golder Associates





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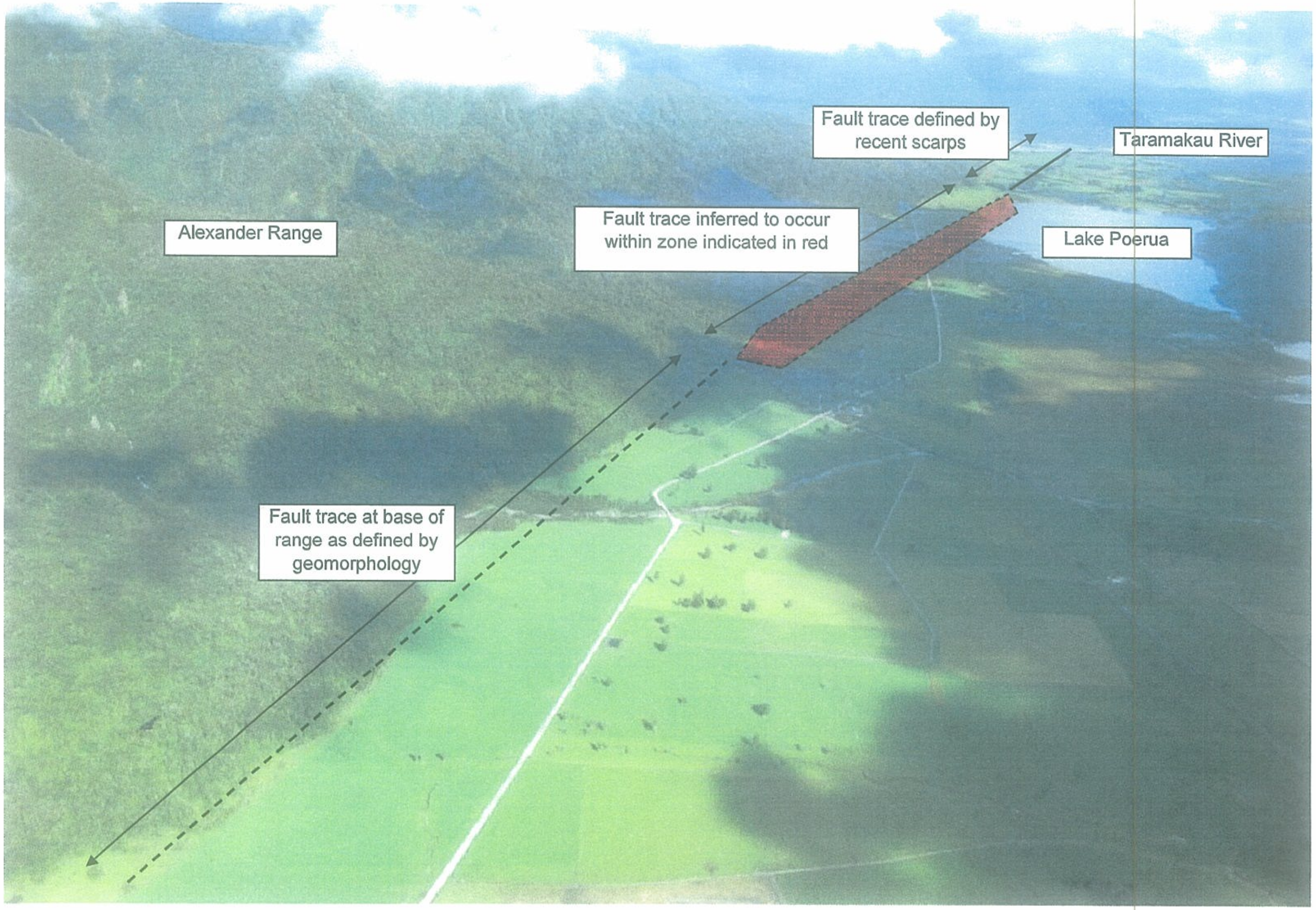
	PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Poerua, Westland			
	CLIENT	Grant Marshall		FIGURE	A1
Comments	DRAWN JM	DATE 21/04/06		PROJECT No.	06812016
	CHECKED LRC	DATE 30/07/07		SCALE na	A4



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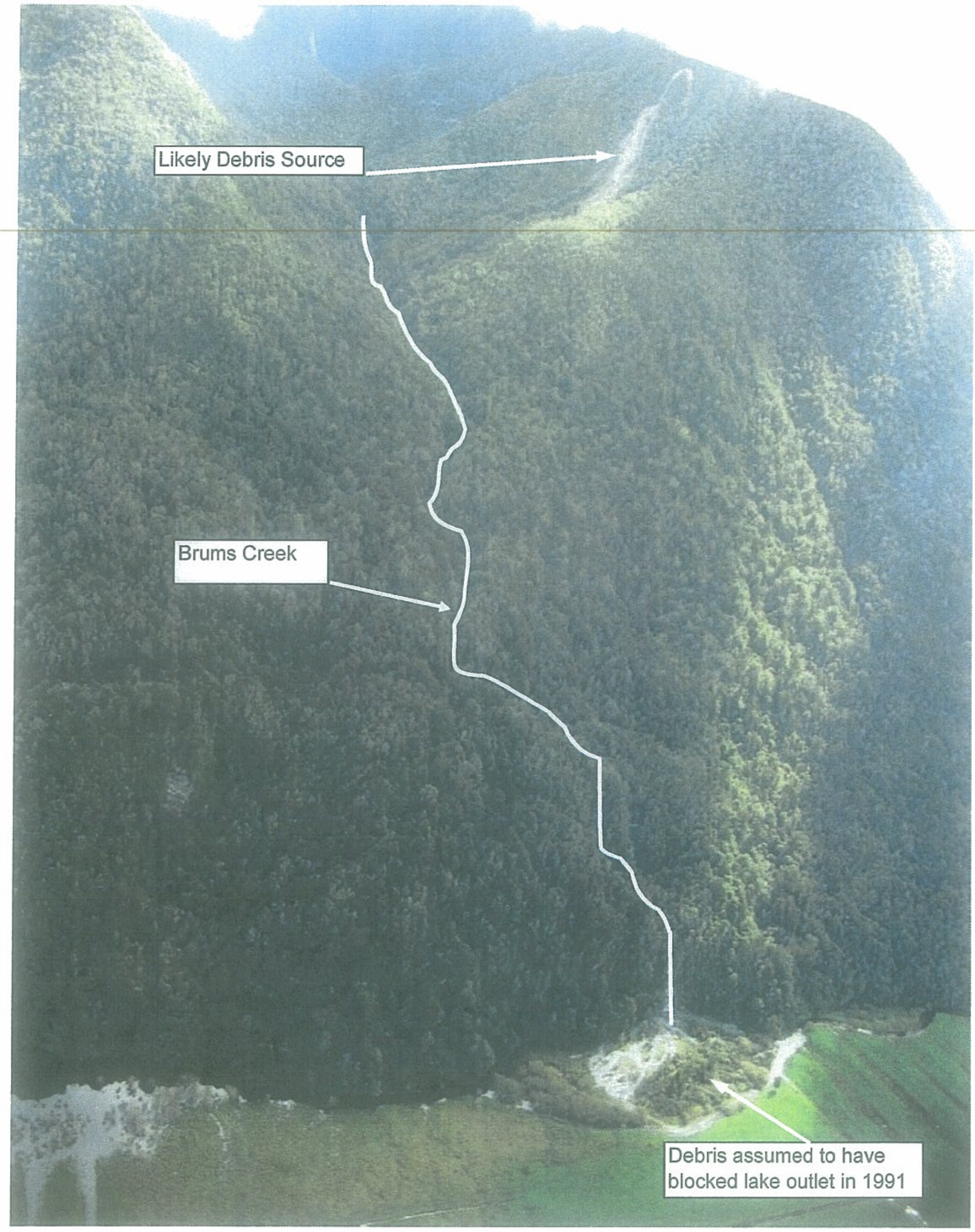

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	CLIENT	Grant Marshall		FIGURE	A3
Comments	DRAWN	JM	DATE 21/04/06	PROJECT No.	06812016
	CHECKED	LRC	DATE 30/07/07	SCALE	na A4

APPENDIX B

TEST PIT AND SCALA LOGS AND PHOTOGRAPHS

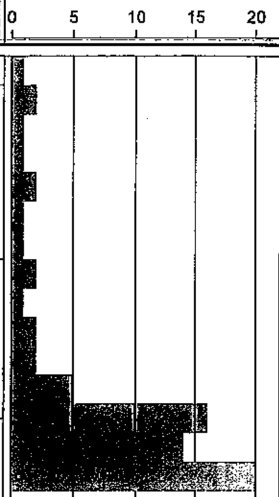
REPORT OF TEST PIT: GA 01

Golder Associates

SHEET: 1 OF 1

CLIENT:	Grant Marshall	COORDS: 2386465 m E 5831450 m N LOCAL		MACHINE: ZX120	
PROJECT:	Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL		CONTRACTOR: Grant Thomas	
LOCATION:	Westland	PIT DEPTH: 3.50 m		LOGGED: JM/RB	DATE: 20/3/06
JOB NO:	06812016	BUCKET TYPE: 900mm toothed		CHECKED: LRC	DATE: 24/9/07

Excavation					Sampling		Field Material Description							
METHOD	EXCAVATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	USC Symbol	SOIL / ROCK MATERIAL DESCRIPTION	WEATHERING	MOISTURE	CONSISTENCY DENSITY	DCP TEST (AS1289.6.3.2) Blows per 100 mm	STRATIGRAPHIC UNIT
EX	L		0.0	0.10				OL	ORGANIC SILT dark brown organic SILT - firm, moist (TOPSOIL)		M	F		
			0.5	0.70	Shear Vane test FV=67/13kPa at 0.5 m			SM	SILTY SAND grey and brown silty SAND - medium density, moist (ALLUVIUM)			MD		
			1.0	1.25	Shear Vane test FV=66/16kPa at 0.8 m Shear Vane test FV=63/13kPa at 1.0 m			ML	SILT grey and brown SILT - firm, moist (ALLUVIUM)			F		
	H	not encountered	1.5 2.0 2.5 3.0	3.50				GW	SANDY GRAVEL dark brownish grey coarse sandy GRAVEL - dense, moist, well graded, subrounded, greywacke clasts up to 0.6m diameter (ALLUVIUM)			D		
			3.5 4.0 4.5 5.0						TEST PIT DISCONTINUED @ 3.50 m GROUNDWATER NOT ENCOUNTERED Backfilled					



This report of test pit must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

GAP gINT FN. F01f RL2

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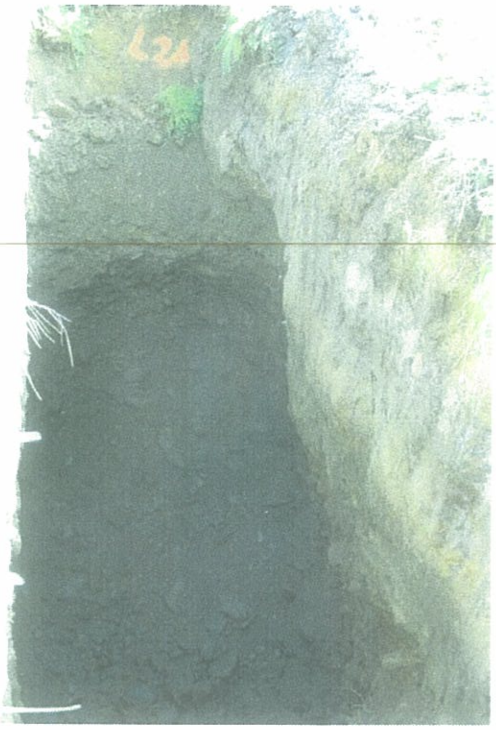


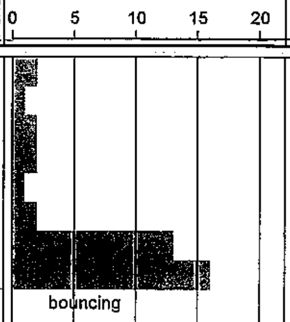
Golder Associates	TITLE	Test Pit (GA 01) and Spoil Pile Photographs for Lot 2a				
	PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland				
	CLIENT	Grant Marshall		FIGURE	B1	
Comments	DRAWN	JM/RB	DATE 23/03/2006	PROJECT No.	06812016	
	CHECKED	LRC	DATE 24/09/2007	SCALE	na	A4

Golder Associates

REPORT OF TEST PIT: GA 02

CLIENT: Grant Marshall	COORDS: 2386505 m E 5831491 m N LOCAL	SHEET: 1 OF 1	
PROJECT: Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL	MACHINE: ZX120	
LOCATION: Westland	PIT DEPTH: 3.80 m	CONTRACTOR: Grant Thomas	
JOB NO: 06812016	BUCKET TYPE: 900mm toothed	LOGGED: JM/RB	DATE: 20/3/06
		CHECKED: LRC	DATE: 24/9/07

METHOD	EXCAVATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	USC Symbol	SOIL / ROCK MATERIAL DESCRIPTION	WEATHERING	MOISTURE	CONSISTENCY DENSITY	DCP TEST (AS1289.6.3.2) Blows per 100 mm	STRATIGRAPHIC UNIT
EX	L	not encountered	0.0–0.15	0.15				OL	SANDY SILT dark brown sandy SILT - firm, moist (TOPSOIL)		M			
	L		0.15–0.80	0.80				ML	GRAVELLY SILT light brown SILT with some gravel - firm, moist, well graded, subrounded greywacke gravel clasts (ALLUVIUM)		M	F	bouncing	
	M-H		0.80–3.80	3.80				GW	SANDY GRAVEL WITH SOME SILT dark greyish brown sandy GRAVEL with some silt - dense, moist, well graded, subrounded greywacke gravel clasts to 0.1m diameter - iron pans from 1.2m to 3.8m - boulders up to 0.35m diameter from 2.5m - pit walls caving in below 0.8m (ALLUVIUM)		M	D		
			3.80						TEST PIT DISCONTINUED @ 3.80 m GROUNDWATER NOT ENCOUNTERED Backfilled					



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Golder Associates	TITLE	Test Pit (GA 02) and Spoil Pile Photographs for Lot 3a				
	PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland				
	CLIENT	Grant Marshall		FIGURE	B2	
Comments	DRAWN	JM/RB	DATE 23/03/2006	PROJECT No.	06812016	
	CHECKED	LRC	DATE 24/09/2007	SCALE	na	A4

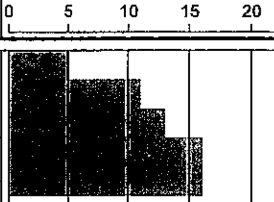
REPORT OF TEST PIT: GA 03

Golder Associates

SHEET: 1 OF 1

CLIENT:	Grant Marshall	COORDS: 2386537 m E 5831524 m N LOCAL		MACHINE: ZX120	
PROJECT:	Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL		CONTRACTOR: Grant Thomas	
LOCATION:	Westland	PIT DEPTH: 4.00 m		LOGGED: JM/RB	DATE: 20/3/06
JOB NO:	06812016	BUCKET TYPE: 900mm toothed		CHECKED: LRC	DATE: 24/9/07

METHOD	EXCAVATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	USC Symbol	SOIL / ROCK MATERIAL DESCRIPTION	WEATHERING	MOISTURE	CONSISTENCY DENSITY	DCP TEST (AS1289.6.3.2) Blows per 100 mm	STRATIGRAPHIC UNIT
EX	L		0.0	0.30				ML	ORGANIC GRAVELLY SILT dark brown organic gravelly SILT - firm, moist (TOPSOIL)		M	F		
	L			0.45				GW	SANDY GRAVEL orange brown silty sandy GRAVEL - very dense, moist, well graded, subrounded greywacke gravel - weakly cemented due to iron pan development (ALLUVIUM)			VD		
	H		0.5	0.80				SP	SAND dark brownish grey SAND - moderately dense, moist, poorly graded medium sand (ALLUVIUM)			MD		
	H	not encountered	1.0 – 4.0	4.00				GW	SANDY GRAVEL orange brown sandy GRAVEL with some silt - dense, moist, well graded, subrounded greywacke gravel clasts up 60mm diameter - discontinous no fines gravel layer at 1m depth approximately 0.2m thick, appears on both sides of the pit - multiple iron pans from 1m to pit base (ALLUVIUM)			D		
			4.0 – 5.0						TEST PIT DISCONTINUED @ 4.00 m GROUNDWATER NOT ENCOUNTERED Backfilled					



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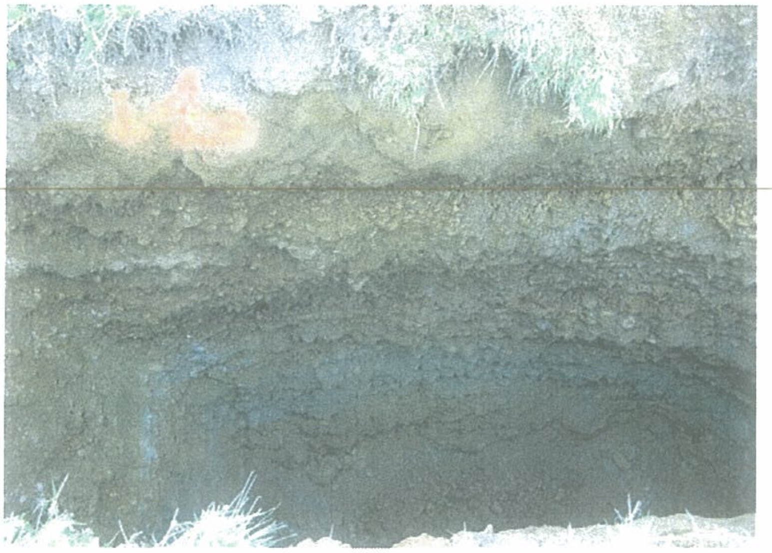
GAP gINT FN. F01f RL2



Golder Associates	TITLE	Test Pit (GA 03) and Spoil Pile Photographs for Lot 4a		
	PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland		
	CLIENT	Grant Marshall	FIGURE	B3
Comments	DRAWN JM/RB	DATE 23/03/2006	PROJECT No.	06812016
	CHECKED LRC	DATE 24/09/2007	SCALE na	A4

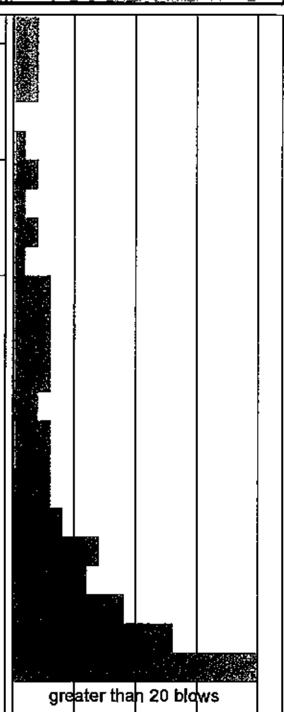
REPORT OF TEST PIT: GA 04

Golder Associates

CLIENT: Grant Marshall	COORDS: 2386574 m E 5831551 m N LOCAL	SHEET: 1 OF 1	
PROJECT: Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL	MACHINE: ZX120	
LOCATION: Westland	PIT DEPTH: 3.70 m	CONTRACTOR: Grant Thomas	
JOB NO: 06812016	BUCKET TYPE: 900mm toothed	LOGGED: JM/RB	DATE: 20/3/06
		CHECKED: LRC	DATE: 24/9/07

Method	Excavation Resistance	Water	Depth (metres)	Depth RL	Sample or Field Test	Recovered	USC Symbol	Soil / Rock Material Description	Weathering	Moisture	Consistency Density
EX	L	not encountered	0.0 – 0.10	0.10			OL	ORGANIC SILT WITH SOME GRAVEL dark brown organic SILT with some gravel - firm, moist, greywacke gravel clasts (TOPSOIL)		M	F
EX	L		0.10 – 0.50	0.50			ML	SANDY SILT WITH SOME GRAVEL light brown sandy SILT with some gravel -firm, moist, greywacke gravel clasts - greywacke gravel concentrated in lenses approximately 200mm thick (ALLUVIUM)		M	F
EX	L		0.50 – 0.90	0.90			SW	SAND grey SAND - loose-very loose, moist, well graded - gradational change into overlying unit (ALLUVIUM)		M	VL
EX	L (to ~2.7 m), H (below)		0.90 – 3.70	3.70			GW	SANDY GRAVEL grey sandy GRAVEL - medium dense, moist, well graded, subrounded greywacke gravels - several fines free gravel beds in sequence - channel infilled with grey loose sand in one wall approximately 1m deep - pit walls collapsing below 0.9m - becoming dense at 2.7m (ALLUVIUM)		M	MD (to 2.7 m), D (below)
			3.70					TEST PIT DISCONTINUED @ 3.70 m GROUNDWATER NOT ENCOUNTERED Backfilled			

DCP TEST (AS1289.6.3.2) Blows per 100 mm



Depth scale (metres): 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0

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GAP gINT FN. F01f RL2

Golder Associates

TITLE	Test Pit (GA 04) and Spoil Pile Photographs for Lot 5a
PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland

CLIENT	Grant Marshall			FIGURE	B4	
DRAWN	JM/RB	DATE	23/03/2006	PROJECT No.	06812016	
CHECKED	LRC	DATE	24/09/2007	SCALE	na	A4

Comments

Golder Associates

REPORT OF TEST PIT: GA 05

CLIENT: Grant Marshall	COORDS: 2386605 m E 5831580 m N LOCAL	SHEET: 1 OF 1	
PROJECT: Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL	MACHINE: ZX120	
LOCATION: Westland	PIT DEPTH: 3.70 m	CONTRACTOR: Grant Thomas	
JOB NO: 06812016	BUCKET TYPE: 900mm toothed	LOGGED: JM/RB	DATE: 20/3/06
		CHECKED: LRC	DATE: 24/9/07

METHOD	EXCAVATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	USC Symbol	SOIL / ROCK MATERIAL DESCRIPTION	WEATHERING	MOISTURE	CONSISTENCY DENSITY	DCP TEST (AS1289.6.3.2) Blows per 100 mm (0 5 10 15 20 25)	STRATIGRAPHIC UNIT
EX	L		0.0	0.15				ML	ORGANIC GRAVELLY SILT dark brown organic gravelly SILT - firm, moist, well graded, subrounded greywacke gravels (TOPSOIL)		M	F	bouncing	
				0.60				GW	SILTY GRAVEL WITH SOME SAND light brown silty GRAVEL with sand -medium dense, moist, well graded, subrounded greywacke gravel clasts (ALLUVIUM)			MD		
	H	not encountered	0.5–3.5	3.70				GW	SANDY GRAVEL dark brownish grey sandy GRAVEL - medium dense, moist, well graded, subrounded greywacke gravel clasts up to 150mm diameter - fines free channelised gravel 0.2m thick 1m wide below 0.6m - minor iron pan development - pit walls collapsing below 1.8m and the sandy GRAVEL becomes dark grey (ALLUVIUM)			MD		
			4.0–5.0						TEST PIT DISCONTINUED @ 3.70 m GROUNDWATER NOT ENCOUNTERED Backfilled					

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GAP gINT FN. F01f RL2

Golder Associates

TITLE	Test Pit (GA 05) and Spoil Pile Photographs for Lot 6a					
PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland					
CLIENT	Grant Marshall			FIGURE	B5	
DRAWN	JM/RB	DATE	23/03/2006	PROJECT No.	06812016	
CHECKED	LRC	DATE	24/09/2007	SCALE	na	A4

Comments

REPORT OF TEST PIT: GA 06

Golder Associates

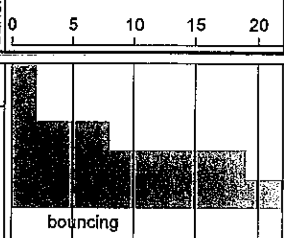
SHEET: 1 OF 1

CLIENT: Grant Marshall	COORDS: 2386642 m E 5831610 m N LOCAL	MACHINE: ZX120	
PROJECT: Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL	CONTRACTOR: Grant Thomas	
LOCATION: Westland	PIT DEPTH: 3.70 m	LOGGED: JM/RB	DATE: 20/3/06
JOB NO: 06812016	BUCKET TYPE: 900mm toothed	CHECKED: LRC	DATE: 24/9/07

METHOD	EXCAVATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	USC Symbol	SOIL / ROCK MATERIAL DESCRIPTION	WEATHERING	MOISTURE	CONSISTENCY DENSITY
EX	L		0.0	0.15			OL	ORGANIC GRAVELLY SILT dark brown organic gravelly SILT - firm, moist, well graded, sub rounded greywacke gravels (TOPSOIL)		M	F
	M			1.10			GW	SANDY GRAVEL WITH SOME SILT brown sandy GRAVEL with some silt - medium dense, moist, well graded, subrounded greywacke gravel clasts - discontinous band of gravels at 0.7m. minimal fines and 10% voids (ALLUVIUM)			MD
	M-H	not encountered		3.70			GW	SANDY GRAVEL light grey sandy GRAVEL - dense, moist, moderately well graded, subrounded greywacke gravels - discontinous 0.2m thick grey medium-coarse SAND layer at 1.3m depth. medium dense, moist -discontinous 0.2-0.4m thick horizon of no fines gravels at 2.5m depth (ALLUVIUM)			D / MD / D
								TEST PIT DISCONTINUED @ 3.70 m GROUNDWATER NOT ENCOUNTERED Backfilled			

Depth scale: 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0

DCP TEST (AS1289.6.3.2) Blows per 100 mm



STRATIGRAPHIC UNIT

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GAP gINT FN. F01f RL2

TITLE	Test Pit (GA 06) and Spoil Pile Photographs for Lot 7a		
PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland		
CLIENT	Grant Marshall	FIGURE	B6
DRAWN	JM/RB	DATE	23/03/2006	PROJECT No.	06812016
CHECKED	LRC	DATE	24/09/2007	SCALE	na	A4

Golder Associates

Comments

REPORT OF TEST PIT: GA 07

Golder Associates

SHEET: 1 OF 1

CLIENT:	Grant Marshall	COORDS: 2386712 m E 5831661 m N LOCAL		MACHINE: ZX120	
PROJECT:	Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL		CONTRACTOR: Grant Thomas	
LOCATION:	Westland	PIT DEPTH: 3.60 m		LOGGED: JM/RB	DATE: 20/3/06
JOB NO:	06812016	BUCKET TYPE: 900mm toothed		CHECKED: LRC	DATE: 24/9/07

METHOD	EXCAVATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	USC Symbol	SOIL / ROCK MATERIAL DESCRIPTION	WEATHERING	MOISTURE	CONSISTENCY DENSITY
EX	L		0.0–0.40	0.40			ML	ORGANIC SILT WITH GRAVEL brown organic SILT with gravel - firm, moist, uniformly graded, subrounded greywacke clasts, coarse gravel (TOPSOIL)		M	F
EX	M		0.40–0.80	0.80			SW	COARSE SAND WITH GRAVEL dark brown coarse SAND with gravel - dense, moist, well graded, subrounded greywacke clasts (ALLUVIUM)		M	D
EX	M	not encountered	0.80–3.60	3.60			GW	COARSE SANDY GRAVEL grey coarse sandy GRAVEL - medium dense, moist, subrounded greywacke gravel clasts - becoming dark grey at 1.4m (ALLUVIUM)		M	MD

TEST PIT DISCONTINUED @ 3.60 m
GROUNDWATER NOT ENCOUNTERED
Backfilled

DCP TEST (AS1289.6.3.2) Blows per 100 mm

STRATIGRAPHIC UNIT

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GAP gINT FN. F01f RL2

Golder Associates

TITLE	Test Pit (GA 07) and Spoil Pile Photographs for Lot 9a		
PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland		
CLIENT	Grant Marshall	FIGURE	B7
DRAWN JM/RB	DATE 23/03/2006	PROJECT No.	06812016
CHECKED LRC	DATE 24/09/2007	SCALE na	A4

Comments

REPORT OF TEST PIT: GA 08

Golder Associates

CLIENT: Grant Marshall	COORDS: 2386748 m E 5831684 m N LOCAL	MACHINE: ZX120	
PROJECT: Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL	CONTRACTOR: Grant Thomas	
LOCATION: Westland	PIT DEPTH: 4.10 m	LOGGED: JM/RB	DATE: 20/3/06
JOB NO: 06812016	BUCKET TYPE: 900mm toothed	CHECKED: LRC	DATE: 24/9/07

Method	Excavation Resistance	Water	Depth (metres)	Depth RL	Sample or Field Test	Recovered	USC Symbol	Soil / Rock Material Description	Weathering	Moisture	Consistency Density	Stratigraphic Unit
EX	L		0.0 – 0.30	0.30			GM	SILTY GRAVEL dark brown organic silty GRAVEL - medium dense, wet (TOPSOIL)			MD	
EX	L		0.30 – 2.20	2.20			GM	SILTY COARSE SANDY GRAVEL orange brown silty coarse sandy GRAVEL - dense, wet, well graded, subrounded greywacke gravel clasts - partial cementation due to iron pan development - old stream channel with grey gravelly SILT to 1.1m - firm, wet, strikes NE-SW, approximately 5m wide (ALLUVIUM)		W	D	
EX	L		2.20 – 3.00	3.00			SW	SAND WITH SOME GRAVEL dark grey medium SAND with some gravel - medium dense, moist, well graded, subrounded greywacke gravel clasts (ALLUVIUM)				
EX	M-H	not encountered	3.00 – 4.10	4.10			GW	COARSE SANDY GRAVEL dark grey coarse sandy GRAVEL - loose-medium dense, moist, rounded-subrounded graywacke clasts - pit walls collapsing from 3.5m depth to the surface (ALLUVIUM)		M	MD	

TEST PIT DISCONTINUED @ 4.10 m
GROUNDWATER NOT ENCOUNTERED
Backfilled

DCP TEST (AS1289.6.3.2) Blows per 100 mm (0, 5, 10, 15, 20, 25)

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Golder Associates	TITLE	Test Pit (GA 08) and Spoil Pile Photographs for Lot 10a			
	PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland			
	CLIENT	Grant Marshall		FIGURE	B8
Comments	DRAWN	JM/RB	DATE 23/03/2006	PROJECT No.	06812016
	CHECKED	LRC	DATE 24/09/2007	SCALE na	A4

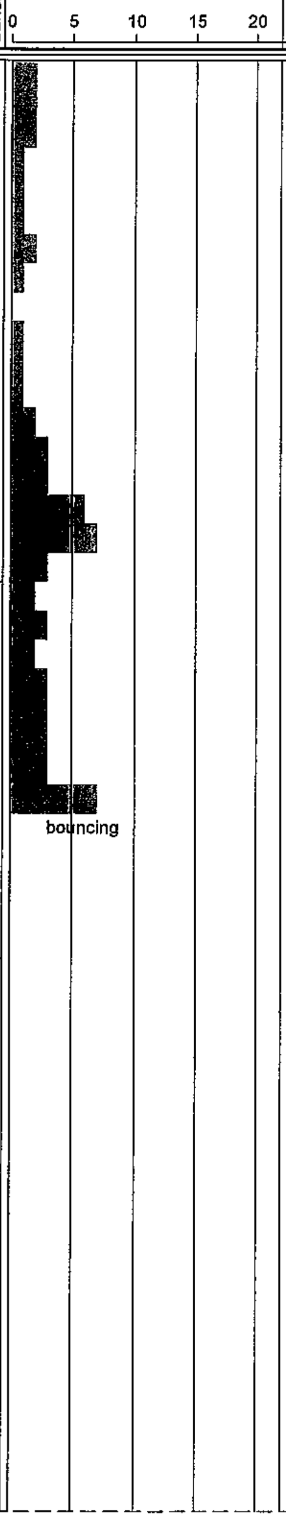
Golder Associates

REPORT OF TEST PIT: GA 09

CLIENT: Grant Marshall	COORDS: 2386868 m E 5831799 m N LOCAL	SHEET: 1 OF 1	
PROJECT: Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL	MACHINE: ZX120	
LOCATION: Westland	PIT DEPTH: 4.40 m	CONTRACTOR: Grant Thomas	
JOB NO: 06812016	BUCKET TYPE: 900mm toothed	LOGGED: JM/RB	DATE: 20/3/06
		CHECKED: LRC	DATE: 24/9/07

Excavation					Sampling		Field Material Description							
METHOD	EXCAVATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	USC Symbol	SOIL / ROCK MATERIAL DESCRIPTION	WEATHERING	MOISTURE	CONSISTENCY DENSITY	DCP TEST (AS1289.6.3.2) Blows per 100 mm	STRATIGRAPHIC UNIT
EX	L		0.0 – 1.80	1.80				GW	SANDY GRAVEL dark grey coarse sandy GRAVEL - loose to very loose, moist, well graded, subangular clasts of schist up to 0.1m diameter. - at 1.4m becoming dark brown with increased large clast content (ALLUVIUM)		M	VL-L		
EX	L		1.80 – 3.10	3.10				ML	CLAYEY SILT yellow grey mottled orange brown clayey SILT - soft, wet, discontinous 0.2m thick organic soil on silt surface (buried topsoil) (ALLUVIUM)		W	S	bouncing	
EX	M	water pooling in base of pit	3.10 – 4.40	4.40				GW	SANDY GRAVEL dark grey coarse sandy GRAVEL (alluvium) - dense, wet, well rounded clasts of greywacke - two iron pans approximately 0.3m apart - water pooling in the base of the pit (ALLUVIUM)		W	D		
			4.40						TEST PIT DISCONTINUED @ 4.40 m Backfilled					

Depth scale (metres): 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0



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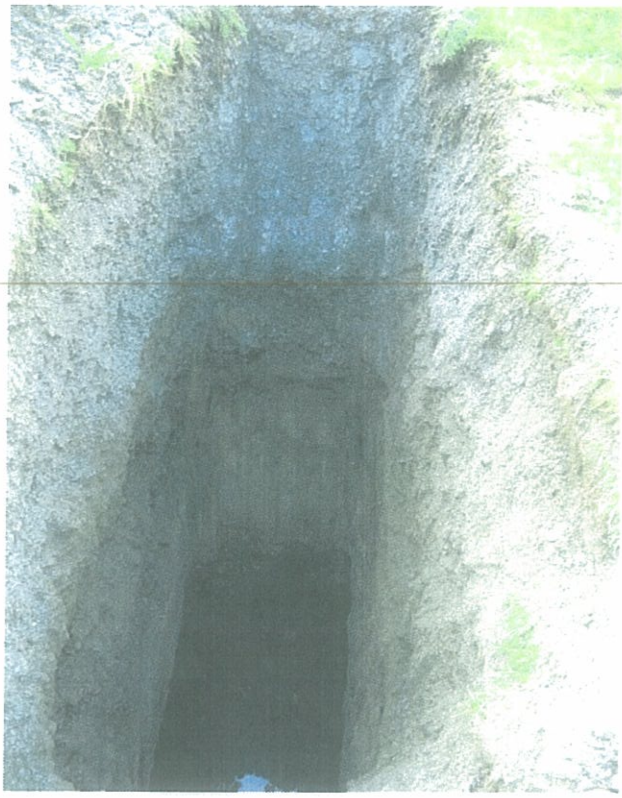
GAP gINT FN. F01f RL2



Golder Associates	TITLE	Test Pit (GA 09) and Spoil Pile Photographs for Lot 12			
	PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland			
	CLIENT	Grant Marshall		FIGURE	B9
Comments	DRAWN	JM/RB	DATE 23/03/2006	PROJECT No.	06812016
	CHECKED	LRC	DATE 24/09/2007	SCALE na	A4

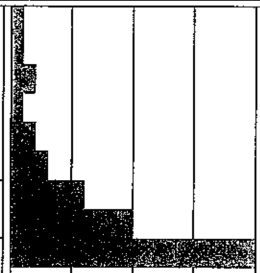
REPORT OF TEST PIT: GA 10

Golder Associates

CLIENT: Grant Marshall	COORDS: 2386917 m E 5831676 m N LOCAL	SHEET: 1 OF 1	
PROJECT: Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL	MACHINE: ZX120	
LOCATION: Westland	PIT DEPTH: 3.00 m	CONTRACTOR: Grant Thomas	
JOB NO: 06812016	BUCKET TYPE: 900mm toothed	LOGGED: JM/RB	DATE: 20/3/06
		CHECKED: LRC	DATE: 24/9/07

METHOD	EXCAVATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	USC Symbol	SOIL / ROCK MATERIAL DESCRIPTION	WEATHERING	MOISTURE	CONSISTENCY DENSITY
EX	L	not encountered	0.0 – 0.60	0.60	Shear Vane Test FV=79/20kPa at 0.2m			ML	GRAVELLY SILT yellowish brown gravelly SILT - firm, moist, uniformly graded, rounded, coarse greywacke gravel (ALLUVIUM)		M	F
			0.60 – 0.80	0.80				SM	SILTY SAND light grey silty SAND - medium dense, moist (ALLUVIUM)			MD
			0.80 – 2.00	2.00				GW	SANDY GRAVEL brownish grey sandy GRAVEL - loose, moist, fine-medium sand, well graded, subrounded greywacke gravel - sand becoming coarse below 1.1m - discontinous iron pan at 1.4m - 0.3m thick no fines coarse gravel layer, continous across pit (ALLUVIUM)			L
			2.00 – 2.40	2.40				SW	SAND grey sand layer - medium dense-dense, moist (ALLUVIUM)			MD-D
	H		2.40 – 3.00	3.00				GW	SANDY GRAVEL brownish grey sandy GRAVEL - dense, moist, coarse sand, well graded, subrounded greywacke gravels (ALLUVIUM)			D
			3.0						TEST PIT DISCONTINUED @ 3.00 m GROUNDWATER NOT ENCOUNTERED Backfilled			

DCP TEST (AS1289.6.3.2) Blows per 100 mm



STRATIGRAPHIC UNIT

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GAP gINT FN. F01f RL2

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Golder Associates	TITLE	Test Pit (GA 10) and Spoil Pile Photographs for Lot 13			
	PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland			
	CLIENT	Grant Marshall		FIGURE	B10
Comments	DRAWN	JM/RB	DATE 23/03/2006	PROJECT No.	06812016
	CHECKED	LRC	DATE 24/09/2007	SCALE na	A4

REPORT OF TEST PIT: GA 11

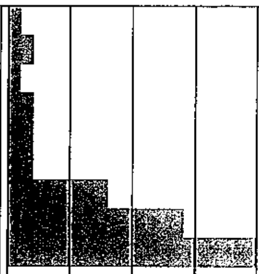
Golder Associates

CLIENT: Grant Marshall	COORDS: 2386850 m E 5831647 m N LOCAL	SHEET: 1 OF 1	
PROJECT: Lake Poerua Subdivision	SURFACE RL: m DATUM: LOCAL	MACHINE: ZX120	
LOCATION: Westland	PIT DEPTH: 3.00 m	CONTRACTOR: Grant Thomas	
JOB NO: 06812016	BUCKET TYPE: 900mm toothed	LOGGED: JM/RB	DATE: 20/3/06
		CHECKED: LRC	DATE: 24/9/07

Method	Excavation Resistance	Water	Depth (metres)	Depth RL	Sample or Field Test	USC Symbol	Soil / Rock Material Description	Moisture	Consistency Density
EX	L		0.0–0.20	0.20		OL	ORGANIC SILT dark brown organic SILT - very soft, saturated (TOPSOIL)	W	VS
EX	L-M	High seepage rate between 0.5-0.6m (▽ at 0.5)	0.20–0.60	0.60	Shear Vane Test FV=43/8kPa at 0.5m	OL	CLAYEY SILT grey clayey SILT - soft, saturated, wood/roots present, high seepage rate between 0.5-0.6m - lateral change to yellow brown clayey SILT with no wood (OVERBANK/SWAMP DEPOSITS)	W	S
EX	L-M (to 2.0), H (2.0–3.0)		0.60–3.00	3.00		GW	SANDY GRAVEL brownish grey coarse sandy GRAVEL - medium dense-dense, wet, well graded, subrounded greywacke clasts - pit walls collapsing below depth of 0.6m - iron pan at 1m - grey SAND bed at 1.8-2m depth, medium dense - gravel becoming very dense at 2m, dark grey, well rounded greywacke gravels to 0.2m diameter (ALLUVIUM)	W	MD-D (to 2.0), VD (2.0–3.0)
			3.00				TEST PIT DISCONTINUED @ 3.00 m Backfilled		

Columns also present: RECOVERED, GRAPHIC LOG, WEATHERING, STRATIGRAPHIC UNIT.

DCP TEST (AS1289.6.3.2) Blows per 100 mm (0, 5, 10, 15, 20, 25)



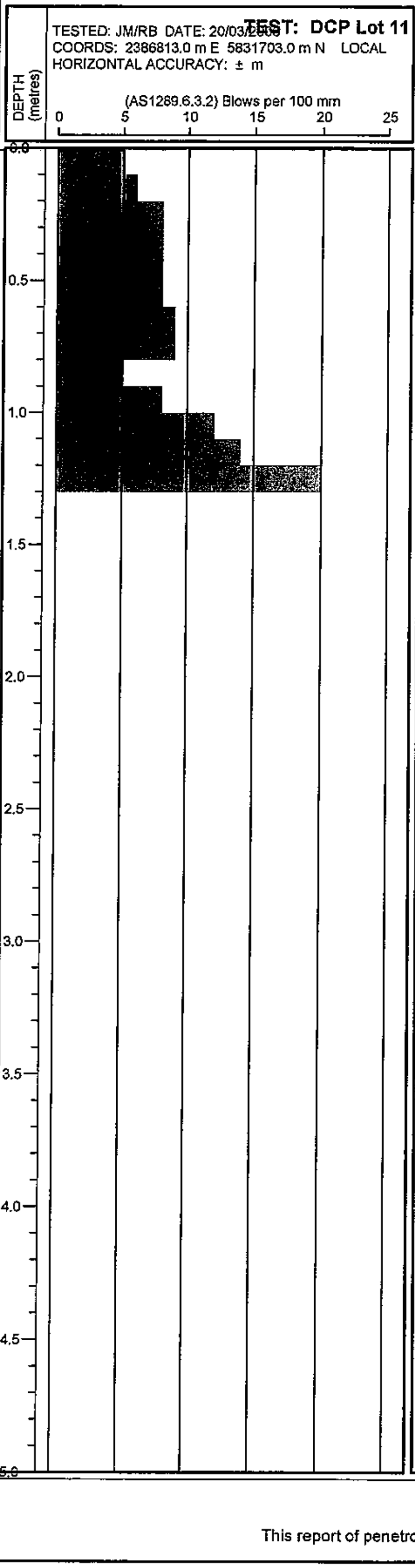
This report of test pit must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

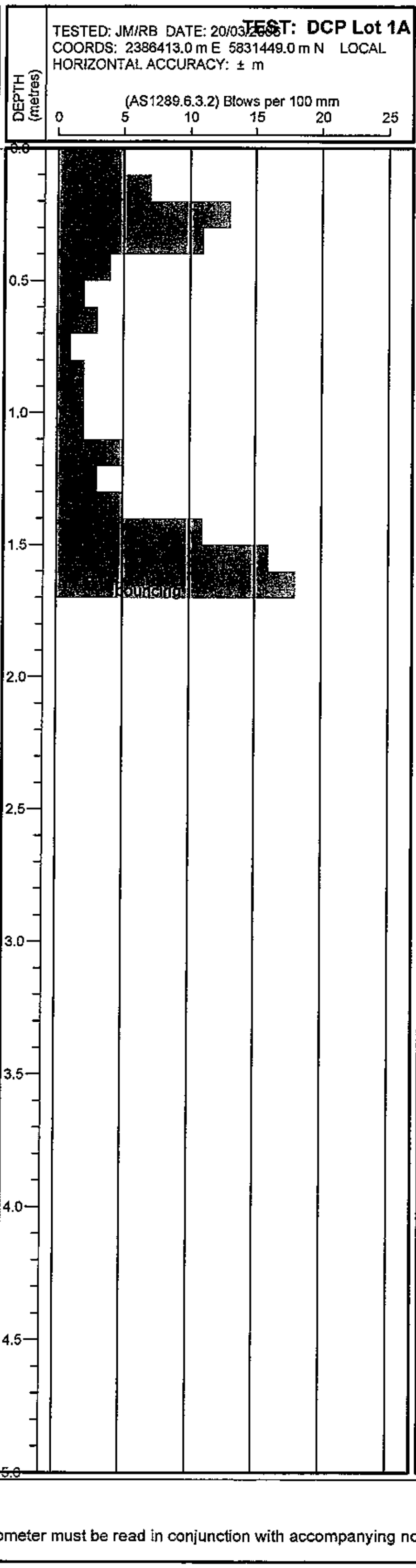
Golder Associates	TITLE	Test Pit (GA 11) and Spoil Pile Photographs for Lot 14			
	PROJECT	Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland			
	CLIENT	Grant Marshall		FIGURE	B11
Comments	DRAWN	JM/RB	DATE 23/03/2006	PROJECT No.	06812016
	CHECKED	LRC	DATE 24/09/2007	SCALE na	A4

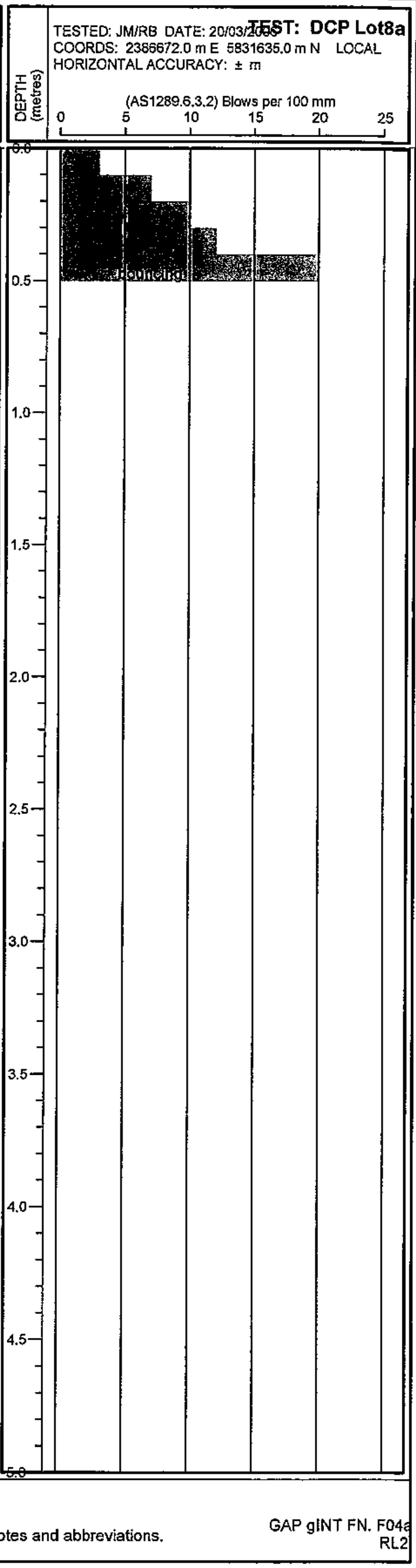
REPORT OF DCP TESTS

Golder Associates

CLIENT:	Grant Marshall	SHEET: 1 OF 1	
PROJECT:	Lake Poerua Subdivision		
LOCATION:	Westland	CHECKED BY:	DATE:
JOB NO:	06812016		







This report of penetrometer must be read in conjunction with accompanying notes and abbreviations.

GAP gINT FN. F04a RL2

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REPORT OF DCP TESTS

CLIENT: Grant Marshall
PROJECT: Lake Poerua Subdivision
LOCATION: Westland
JOB NO: 06812016

SHEET: 1 OF 1

CHECKED BY: DATE:

TEST: DCP Lot 11
TESTED: JM/RB DATE: 20/03/2006
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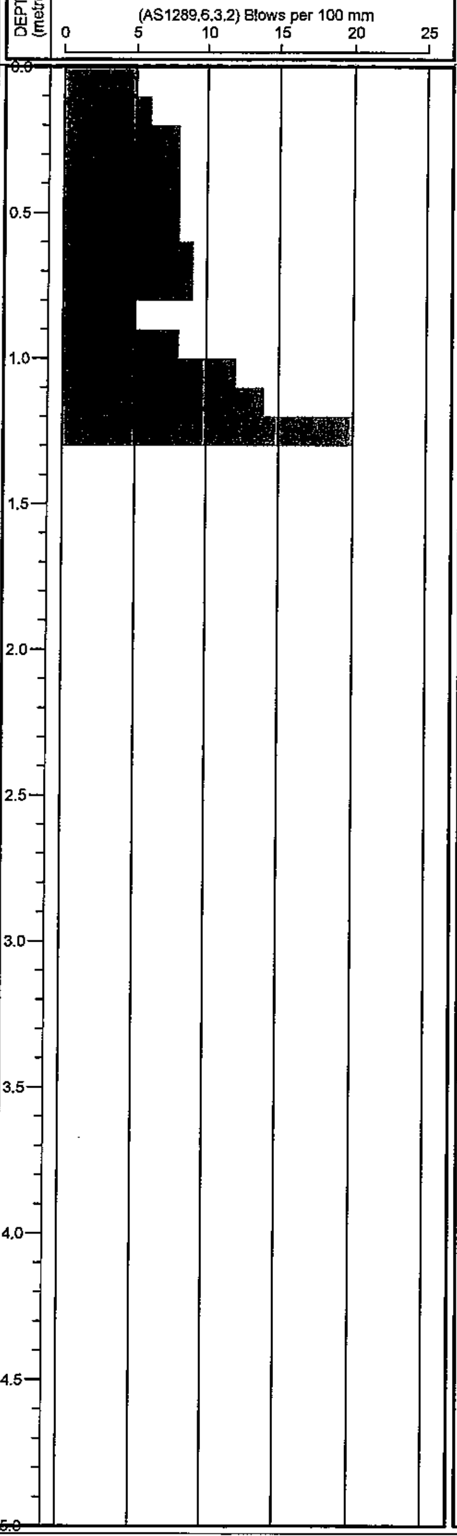
HORIZONTAL ACCURACY: ± m



TEST: DCP Lot 1A
TESTED: JM/RB DATE: 20/03/2006
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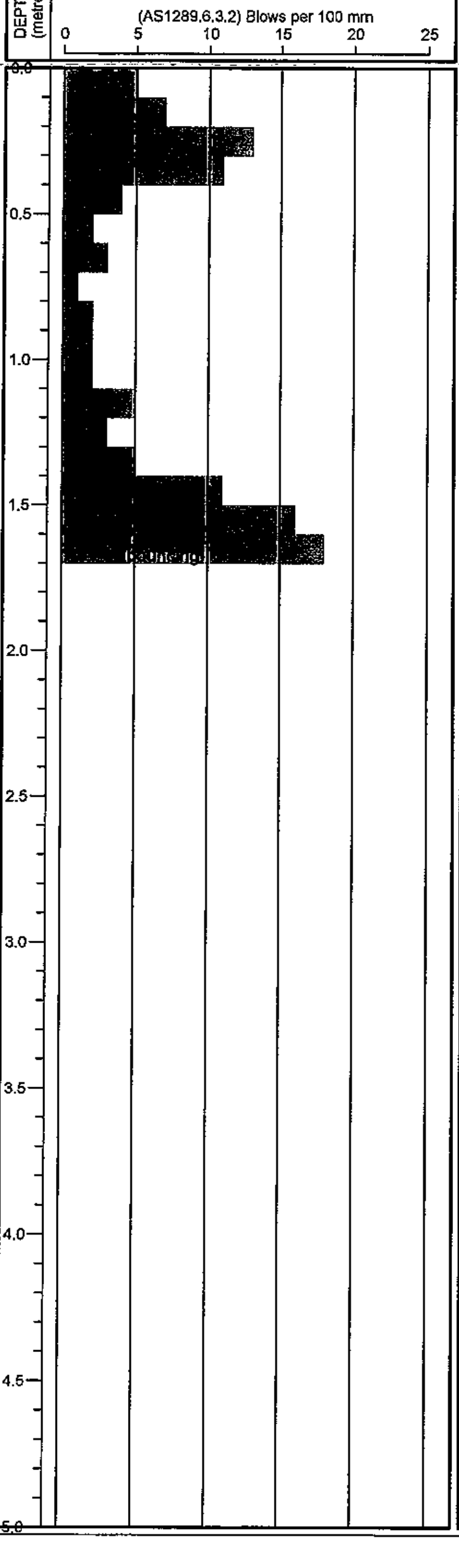
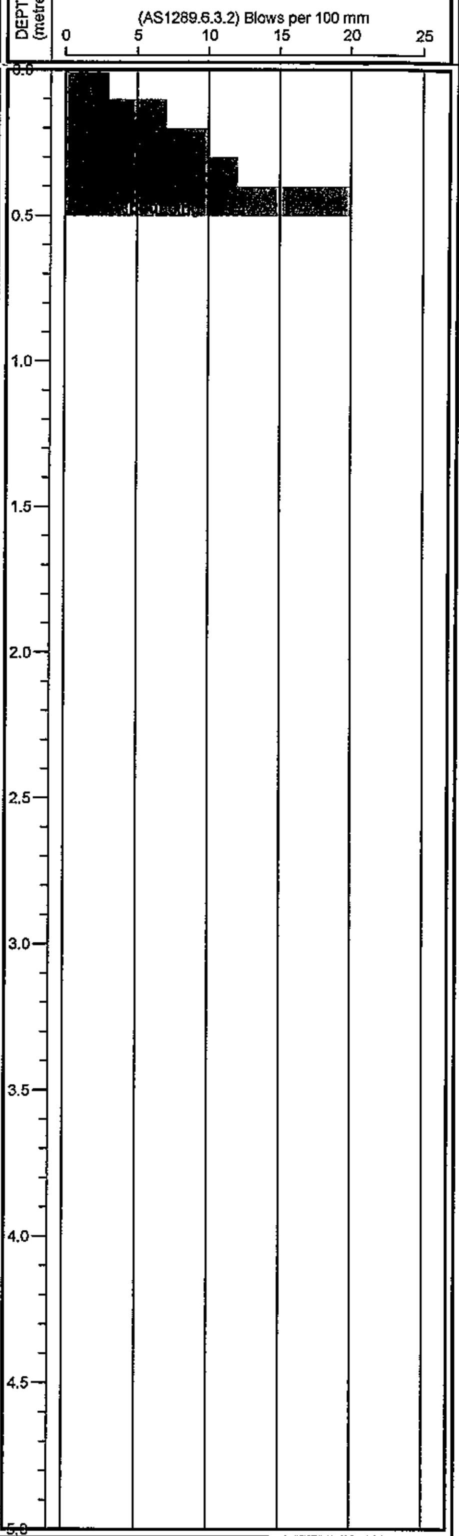


TEST: DCP Lot8a
TESTED: JM/RB DATE: 20/03/2006
COORDS: 2386672.0 m E 5831635.0 m N LOCAL
HORIZONTAL ACCURACY: ± m



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This report of penetrometer must be read in conjunction with accompanying notes and abbreviations.

GAP gINT FN. F04a RL2

APPENDIX C

GEOLOGY AND GEOTECHNICS REPORT

BY

DAVID BELL (2006)

CANTERPRISE LIMITED
University of Canterbury
Private Bag 4800
Christchurch New Zealand

BGL 1161/01
CP/04/06/012

22 May 2006

Mine Creek Westland Limited
c/- Grant Marshall
298 Worsleys Road
Cracroft
~~CHRISTCHURCH~~

Dear Sir

Re: **LAKE POERUA DEVELOPMENT – GEOLOGY & GEOTECHNICS**

1. Introduction

Further to your request I have carried out an engineering geological and geotechnical assessment of the proposed Lake Poerua Development, Westland. My investigations have involved the following:

- Engineering geology site mapping and logging of eight test pits (TP7-14) on 09 February 2006, with assistance from Rob Kinney and yourself.
- Excavation and logging of four trenches totalling approximately 250m in length on 05 March 2006, in an attempt to locate the position of the Alpine Fault.
- EDM surveys on 18 March 2006 to fix the position of the four trenches relative to the lake, although not in absolute elevation or NZ Map Grid coordinates.
- Interpretation of aerial photograph Runs 3613/16-19 and 3614/16-19 flown 16 March 1962, as well as SN 9493 Run E/11-13 flown on 22 February 1996.
- Compilation of a geological map of the Lake Poerua area at 1:25,000, and an engineering geology plan at 1:10,000 of the immediate development area.

2. Report Objectives

The present report provides relevant geological and engineering geological data on:

- the geomorphological evolution of the site and surrounding landscape;
- natural hazards potentially affecting the Lake Poerua development; and
- foundations and other site-specific geotechnical requirements.

In preparing my report I have referred to published maps and reports relating to the site, and to the history of Alpine Fault rupture: trenches excavated across the Alpine Fault trace at the nearby Inchbonnie site were also inspected with staff from IGNS on 09 February 2006. Correspondence from various parties relating to an earlier subdivision proposal on behalf of yourselves in 2003-4 has been reviewed, insofar as it is relevant to the current development plan for a different but nearby parcel of land.

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A wholly owned subsidiary of the University of Canterbury

3. Site Description

The proposed Lake Poerua Development is located on the south-eastern side of the lake in an area bounded by the shoreline reserve, Midland Railway and Lake Brunner (Inchbonnie-Rotomanu) Road (Figure 1). The land proposed for residential usage is essentially flat lying, with a gentle slope to the north-east and ground elevations from EDM survey between about 1.5 and 3.5m above the adopted datum of 125.0m for the present level of Lake Poerua. An airstrip on part of the site shows accompanying minor surface modification due to localised cut and fill, although it was not present in 1962 and the surface then was unmodified except for farming activities. Materials underlying this relatively flat surface are Taramakau River-derived sandy greywacke gravels that are rounded to sub-rounded, with an infilled "swamp depression" area and the Mine Creek alluvial fan surface to the immediate north (Figures 1A & 1B). The locations of Test Pits 7 to 14 inclusive are shown on Figure 1B, and logs are given in Figure 2B: logs for the trenches (A to D) across the site on an orientation of 145°T are given in Figure 2A, and their locations are shown in Figure 1B.

4. Geological Setting

The land proposed for development at Lake Poerua is located within the Alpine Fault zone depression, which separates high rank garnet and biotite schist on the eastern side from the Te Kinga granite suite to the immediate west of Lake Poerua (Figures 1A & 1B). Following Suggate & Waight (1999) the schists are assigned to the Haast Schist Group of Permo-Triassic age, and the granite is described as a *"white equigranular monzogranite"* of Cretaceous age. A zone of intensely sheared granite or mylonite has been mapped by Suggate and Waight (1999) to the immediate north-west of Lake Poerua, and is shown on Figures 1A & 1B as *"mylonitised granite"*. The Taramakau-derived gravels that extensively infill the Alpine Fault depression exceed 60m in thickness based on geophysical surveys over the area (Grant Marshall, pers. comm.), whilst the fan gravels are clearly younger and involve a combination of debris flow and alluvial processes. The most recent rupture trace of the Alpine Fault is shown by 3-5m vertical terrace offsets at Inchbonnie some 2km to the south-west, but no fault trace is visible across the land proposed for development. Landscape evolution and fault history are further discussed in Section 5 of this report.

5. Landscape Evolution

The course of the lower Taramakau Valley is partially controlled by the Alpine Fault (Warren, 1967), and its upper alignment by a continuation of the Hope Fault (Gregg, 1964). The Taramakau Valley has been extensively glaciated by westwards-moving ice, and the most recent moraines are referred to the Moana Formation by Suggate & Waight (1999). These deposits have been mapped near Kumara, at Moana and near Te Kinga, and ice probably retreated from the lower valley by about 14,000 years BP (= before present). This is thought to have created an enlarged proto-Lake Brunner that included the present Lake Poerua at an elevation about 130m above sea level, although subsequent downcutting by the Arnold River through the moraine at Moana has lowered modern Lake Brunner to about RL 90m (cf Lake Poerua at 125m).

The exposed bedrock on the Alexander Range and at Mt Te Kinga has been clearly glaciated to form the general U-shaped depressions, and the valley floors have since been infilled by alluvium sourced from the major river systems and by fan deposits from tributary gullies/watercourses following ice retreat. From near Inchbonnie thick deposits of Taramakau-derived alluvium (sandy gravels and gravelly sands) infill the valleys towards Lake Brunner and Lake Poerua respectively, and the surface braid channels are still clearly evident on the aerial photographs examined. As noted in Section 4 the ages of these gravels are uncertain, but the near-surface gravels are almost certainly younger than 1,000 years BP but must be older than 400 years BP ~~where they are offset by probably two Alpine Fault rupture events at Inchbonnie.~~

Fan deposition has involved debris-flow events forming the upper steeper segments of most range-front features from schist sources in the Alexander Range, whilst air-photo evidence shows that many of these fans have subsequently been modified by alluvial processes to form more gently sloping lower surfaces. The Mine Creek Fan, which affects the northern part of the proposed development area, involves an upper debris-flow unit ("UF" on Figure 1B) and a lower alluvial surface ("LF" in Figure 1B) that has modified and partly eroded into the older debris-flow deposits. Although the ages of both fan-forming events are not known, the active trace of the Alpine Fault is concealed beneath both types of fan and is not visible until the range-front above Rotomanu. This implies that the most recent activity on both types of fan is younger than 400 years, as discussed in Section 6 below.

6. Alpine Fault

The Alpine Fault forms the boundary between the Pacific (eastern) and Australian-Indian (western) Plates in Westland, and occupies a zone of shearing probably up to 2km in width in places. The most recent trace, which offsets the Taramakau gravels near Inchbonnie, is considered to be active, and Yetton et al (1998) have recognised two rupture events at 1715 ± 15 and 1625 ±15 AD in central Westland with a further major earthquake at about 950 ± 50 AD from clustering of rock avalanche ages. The Alpine Fault trace at Inchbonnie was inspected on 09 February 2006 in trenches excavated by staff from the Institute of Geological & Nuclear Sciences (IGNS), where rotated alluvial gravels in a shear zone not more than 300mm wide were identified as the last rupture trace. According to Yetton et al (1998) the two most recent rupture events on the Alpine Fault extended through the Lake Poerua area, and it is reasonable to conclude from the height of terrace offset at Inchbonnie that both are recorded in the 3-5m scarp given that dominant movement is right-lateral or dextral.

There is considerable confusion about where the most recently active Alpine Fault trace extends in the vicinity of Lake Poerua. Both Gregg (1964) and Warren (1967) show it as extending beneath the lake near its south-eastern shore, whilst Suggate & Waight (1999) map it as concealed beneath the area proposed for development. A plan provided from Grey District Council, which is presumably the most recent IGNS interpretation, shows the fault as a single trace in essentially the same position as Suggate & Waight. Trenching over a distance of 210m at right angles to this "trace" did not reveal the Fault to a depth of 2m+ (Figure A2; Appendix Two), and air-photo evidence indicates that it is actually present below the lake as shown in Figure 1B.

7. Foundation Conditions

In summary the following general site profile has been recognised from the surface downwards, based on data from TP 7-14 and Trenches A-D (Figures 1B, 2A & 2B):

- Mine Creek alluvial fan deposits of sub-angular sandy schistose gravels and associated clayey silt lenses, with thick massive medium sands below 2.2m in TP7 suggesting at least partial deposition into an enlarged Lake Poerua.
- Grey clayey silts with some fine sands occupying a former depression some 3ha in area, which contains significant organics and appears to be a former swamp comprised mostly of overbank deposits up to about 1.5m thick.
- Underlying and/or surrounding Taramakau-derived coarsely-layered sandy gravels and gravelly sands to depths exceeding 2.5m, rarely with boulders up 250mm in size and interfingering northwards with Mine Creek Fan sediments.

The Taramakau-derived sandy gravels contain sedimentary structures which provide evidence for deposition from a south-westerly source (ie the present Taramakau River), and also include locally cross-bedded deltaic fine gravelly sediments that are suggestive of at least local deposition into a standing body of water (Figure 2A). This in turn implies that Lake Poerua may have been higher and more extensive at the time of fan and fluvial sedimentation, which is assumed to have been within the last 1,000 years based on the known Alpine Fault rupture history. Dating of organics from within the swamp depression using ^{14}C techniques will provide a probable minimum age for overbank sedimentation, and samples have been collected for this purpose.

The Taramakau-derived materials are typically compact, but locally loose interbeds up to about 300mm thick have been identified and in one locality (TP 12) these fine-medium gravels contained boulders up to 250mm in size. Beds are coarsely layered and vary from sandy gravels to gravelly sands, generally with a maximum clast size of 150mm and a median close to 30mm (Appendix 2). The "swamp" deposits which cover a significant part of the proposed development area are typically soft clayey silts that are potentially compressible, and as such should preferably be excavated and replaced by suitably compacted gravel fill if raft footings are to be used. It is considered appropriate to require specific engineering design of foundations for the planned building sites given the soil variability, even though the surface is relatively flat and underlain by compact river-deposited gravels at depths ≤1.5m.

8. Active Processes

A. Fault-Rupture: The presence of the Alpine Fault controlling the valley within which development is proposed provides a significant constraint to siting of dwellings. It is suggested by Yetton et al (1998) that the probability of rupture for this segment of the Alpine Fault is 85 ± 10% within the next 100 years, implying a strong likelihood of shaking damage, but it should also be noted that substantial strain partitioning to the Hope Fault is occurring in the vicinity of the Taramakau River south of the proposed development site. Movement on the Alpine Fault is dominantly dextral strike-slip, with a component of vertical uplift on the south-eastern side at Inchbonnie: Yetton et al

(1998) suggest that lateral movements in this vicinity will be of the order of 2-3m, unlike the much more substantial strike-slip displacements of around 8m in South Westland accompanying a rupture of M_L~8.0. It has also been suggested that the slip rates on the Alpine Fault reduce from around 25 mm/yr to about 12 mm/yr at the Taramakau River (Rob Langridge, IGNS, pers comm, 2006).

The most recent rupture trace of the Alpine Fault at Inchbonnie offsets Taramakau-derived gravels by some 3-5m, and it is likely that the 1715 AD and 1625 AD events are both recorded by these quite substantial scarp heights. Preliminary observations of the IGNS trenching on 09 February 2006 showed that the recently active fault trace was "stepping" to the north-west, and this is confirmed by detailed air-photo interpretation and field observations. The scarp feature appears to trend into Lake Poerua close to its south-eastern shoreline, and this is certainly considered to be the most realistic interpretation given that continuous trenching over a distance of 210m normal to the projected fault trace did not identify any fault or related tectonic feature. The gravels forming this Taramakau-derived aggradation surface are the same as those offset by the Inchbonnie traces, and it is concluded that the interpretations of Gregg (1964) and Warren (1967) were in fact more realistic than those from later workers such as Suggate & Waight (1999).

Given the proposed locations for dwellings within the Lake Poerua Development it can therefore be concluded that the closest buildings to the Alpine Fault trace will be at least 70m to the south-east, and located on the land that is likely to rise if the next rupture event is similar to the last two as predicted by Yetton et al (1998). This offset is significantly greater than the normally accepted figure of 20m setback from a known major active fault structure, and is considered acceptable given that the Alpine Fault does not on the evidence obtained from my investigations lie within the proposed subdivision footprint. This does not alter the fact, however, that substantial ground shaking (~MM IX) is still expected to occur when the Alpine Fault ruptures next at this site, and that other effects such as minor seiching could be anticipated.

B. Flooding and/or Aggradation: Two possibilities exist for flooding or aggradation potentially affecting the proposed development site. It is certainly conceivable that an extreme flood in the Taramakau River could breach protection measures, with waters moving towards Lake Brunner which is some 50m lower than the river bed near Inchbonnie. However, it is considered much less likely that these floodwaters would enter Lake Poerua given its elevation at about RL 125m, and the land proposed for development is in fact still higher at about 126-129m. An extreme Taramakau River flood event is therefore most unlikely to impact the site, unless the river bed is altered by major sediment movement or the system otherwise affected by natural processes such as landslide dam break.

Flooding, and particularly debris movement from fans on the northern side of the Alexander Range, could possibly affect the site, but again Mine Creek is the only stream likely to have an impact. The steeper debris flow fans near the range-front imply large quantities of sediment in storage at the time of formation, most probably (but not definitely) associated with landsliding consequential on an Alpine Fault earthquake event. This would certainly explain the burial of the most recently active fault trace across these fans, especially given the subsequent modification by the lower alluvial fan systems that have reworked sediment in response to entrenchment of the fan-head streams. In the case of Mine Creek the lower alluvial fan is stable, and there is no evidence of any activity on the 1962 aerial photographs other than the Mine Creek floodplain itself. The highway and railway culverts and embankments also provide significant protection towards Lake Poerua, and apart from landscaped bunding for the most northerly dwelling no direct fan-derived sediment or water issues are considered relevant to the proposed Lake Poerua Development.

9. Geotechnical Constraints

In terms of s106 of the Resource Management Act 1991 as amended the following geotechnical issues are considered relevant to the proposed land subdivision:

- *Erosion:* Erosion from the Mine Creek catchment, or along the strong bedrock exposures to the south-east of the railway and highway, are not considered relevant to the planned development. Shoreline erosion on the southern side of Lake Poerua, whilst possible for example under seiche conditions, is also not considered to be a significant geotechnical concern with this site as there is substantial setback of dwellings required by the shore reserve. The land is certainly not subject to erosion at present, and the future likelihood is minimal.

- *Falling Debris:* There is no evidence for rockfall debris accumulating from the ice-shorn slopes of either Mt Te Kinga or the Alexander Range, and there is not considered to be any possibility of rock debris "running out" onto the development footprint. Falling debris is therefore not an issue with this site.

- *Subsidence:* Minor subsidence could result if foundations were constructed on the soft clayey silts without appropriate strengthening, but this aspect will be addressed by the requirement for specific foundation design by a suitably experienced chartered engineer. Limited subsidence could occur due to lateral movement of gravels following an Alpine Fault rupture beneath Lake Poerua, but there is more than adequate setback provided by the shoreline reserve. Ground subsidence is therefore not considered to be a significant factor in site development given normal engineering prudence with foundation design.

- *Slippage:* Slippage is not anticipated from either the Mt Te Kinga granite slopes or from the schist slopes to the south-east, and there is no air-photo evidence to suggest either past large-scale instability or present potential for such slope failures. Ice erosion has effectively stripped any shallow cover from the bedrock surfaces, and the principal "off-site" source of slippage could be renewed debris flow activity on the upper Mine Creek Fan: however, there is no evidence from the air-photos or field observations that this is likely to occur, but the impact of the next Alpine fault earthquake may still be significant in the schist catchments. Slippage within gravels at the southern edge of Lake Poerua is also possible accompanying an Alpine Fault rupture event, but there is no evidence for significant shoreline collapse from past earthquakes. Again the setback of 70m+ for dwellings from the fault trace is considered more than adequate given the shallow nature of Lake Poerua and the presence of compact Taramakau-derived river gravels to depths in excess of 60m beneath the development site.

- *Inundation:* The potential for inundation of the site from extreme flooding within the Taramakau River catchment is considered most unlikely give the elevation of the land proposed for development. There is potential for Mine Creek to avulse towards the unnamed stream to the south, especially if the relatively small railway culvert was to block under extreme rainfall conditions, and this could affect the northernmost building site. Protection of this land by 2m+ high landscaped bunds is considered realistic in the circumstances, especially as sediment movements in Mine Creek could affect stream-bed position, but the likelihood of inundation is still relatively low (probably about 1 in 50 years). Other sources of inundation include rockfalls into Lake Poerua, extreme discharge from several streams into Lake Poerua raising its level by 2m+, or seiche effects accompanying an Alpine Fault rupture event. Rockfalls from Mt Te Kinga are discounted as a possible trigger for inundation, and seiche effects are unlikely to exceed 1m in height given the small volume of the lake. Although Lake Poerua could probably rise by 1m under extreme fan inflows, it would require outlet blockage to cause inundation to the proposed subdivision and there is no field or air-photo evidence to suggest that is likely.

On the basis of the above assessment I consider that the proposed Lake Poerua Development is geotechnically sound subject to specific dwelling foundation design by a suitably experienced chartered engineer, and the construction of landscaped bunds to protect the northern part of the development area from avulsion by Mine Creek. However, the consequences of a future Alpine Fault rupture event, the probability of which is high in the next 100 years, must be accepted by all occupiers of the site, and this report (together with any other relevant data) should be made available to prospective purchasers.

10. Further Investigations

In my opinion sufficient investigation has been undertaken to confirm the suitability of the land for the proposed Lake Poerua Development, and consent for the subdivision can be issued subject to the following specific matters being addressed:

- Specific foundation investigation and design is to be undertaken for each dwelling site at the building consent stage to deal with the presence of soft clayey silts on a number of the sites proposed.
- Engineered and landscaped bunding is recommended for the dwelling site at the northern end of the development because of its proximity to Mine Creek, and to allow for possible stream avulsion under exceptional flow conditions.
- Further consideration should be given to the 1 in 50 year design inflows to Lake Poerua from all sources in terms of building floor levels, especially for any sites that are within 2m of the present lake level.

11. Conclusions

1) The site proposed for the Lake Poerua Development is underlain by sandy gravel alluvium derived from the Taramakau River valley, with up to 1.5m of clayey silt overbank deposits occupying a 3ha former "swamp depression": in the north of the property the Mine Creek alluvial fan, sourced from schist catchments to the south-east, interfingers with and partially overlies the Taramakau-derived alluvium.

2) In terms of s106 of the Resource Management Act 1991 as amended the land proposed for subdivision is not subject to erosion, falling debris, subsidence, slippage or inundation: however, the potential for inundation from various sources has been recognised, although the risks are not considered to be high, and both subsidence and slippage are possible issues associated with the southern Lake Poerua shore.

3) Detailed investigations (including a 210m long trench) have been undertaken to locate the most recent trace of the Alpine Fault, which has been projected through the subdivision footprint: my investigations have shown that it is most probably located beneath Lake Poerua close to its southern shoreline and at least 70m from any proposed dwelling site, these conclusions agreeing with studies in the 1960s.

4) Whilst it is considered geotechnically feasible to proceed with the subdivision as planned, the consequences of the next Alpine Fault earthquake (with an estimated probability of 85% in the next 100 years) will be severe in terms of shaking and possible ground damage: purchasers of sections should therefore be advised of the potential geological and geotechnical implications for the site.

5) Limited further geotechnical data input is considered necessary, in particular specific foundation design for all dwelling sites at the building consent stage: the northern part of the development should also be protected by suitably engineered bunding in case of avulsion by Mine Creek during an extreme rainfall event.

12. References

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SUGGATE, R P; WAIGHT, T E (1999) Geology of the Kumara-Moana area, scale 1:50,000 *Institute of Geological & Nuclear Sciences geological map 24: 1 sheet + 124p*

WARREN, G (1967) Sheet 17 Hokitika *1st edition, Geological Map of New Zealand 1:250,000", DSIR, Wellington*

YETTON, M D; WELLS, A; TRAYLEN, N J (1998) Probability and Consequences of the Next Alpine Fault Earthquake *EQC Research Report 95/193: 161p*

I trust that the above report is sufficient for your immediate needs, but do not hesitate to contact me if I can be of further assistance in this matter.

Yours sincerely

DAVID H BELL
Director – Bell Geoconsulting Limited

APPENDIX ONE

Lake Poerua Development

for Mine Creek Westland Ltd

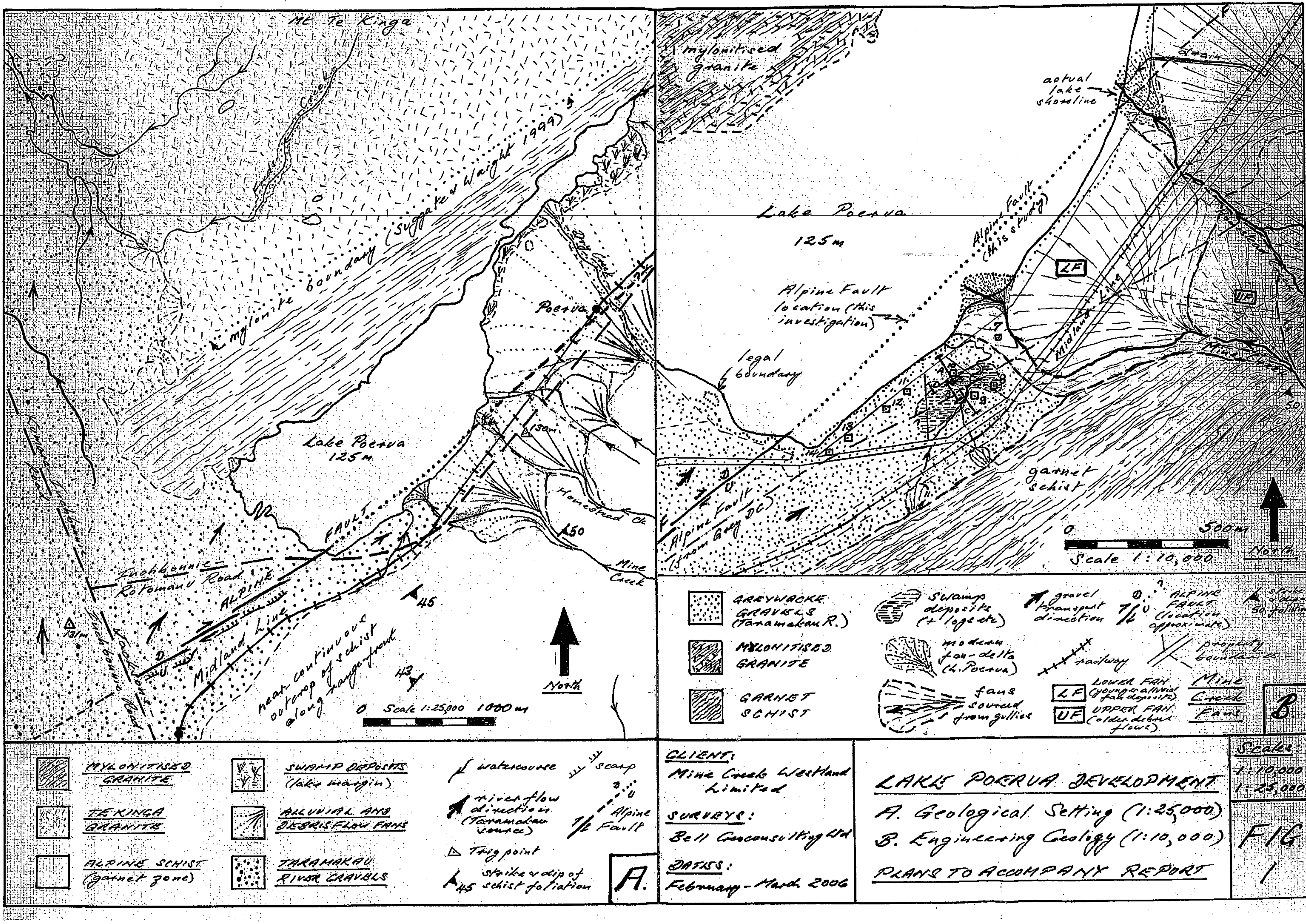
TEST PIT COORDINATES – 09 February 2006

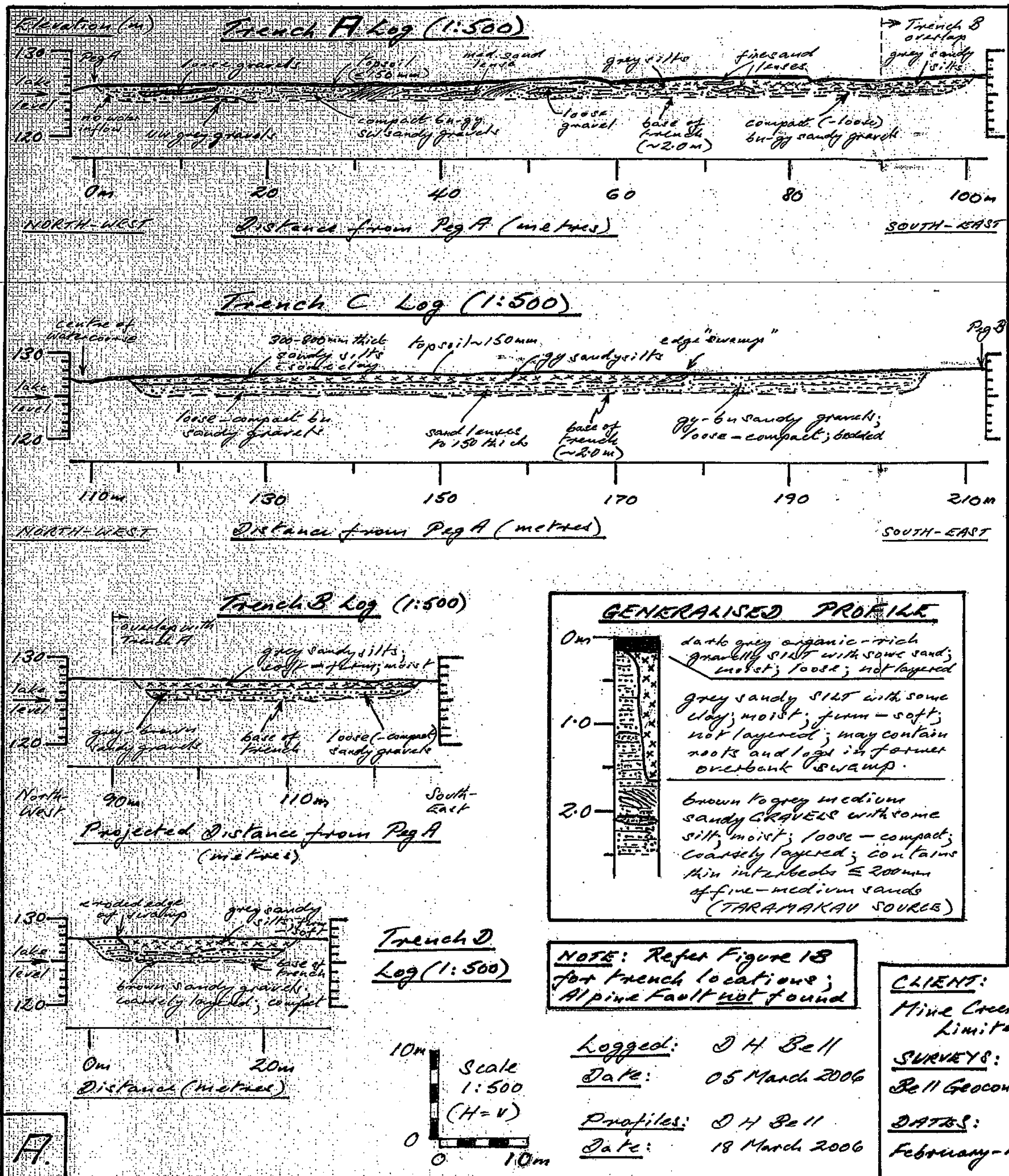
GPS Data Provided by: *Rob Kinney*

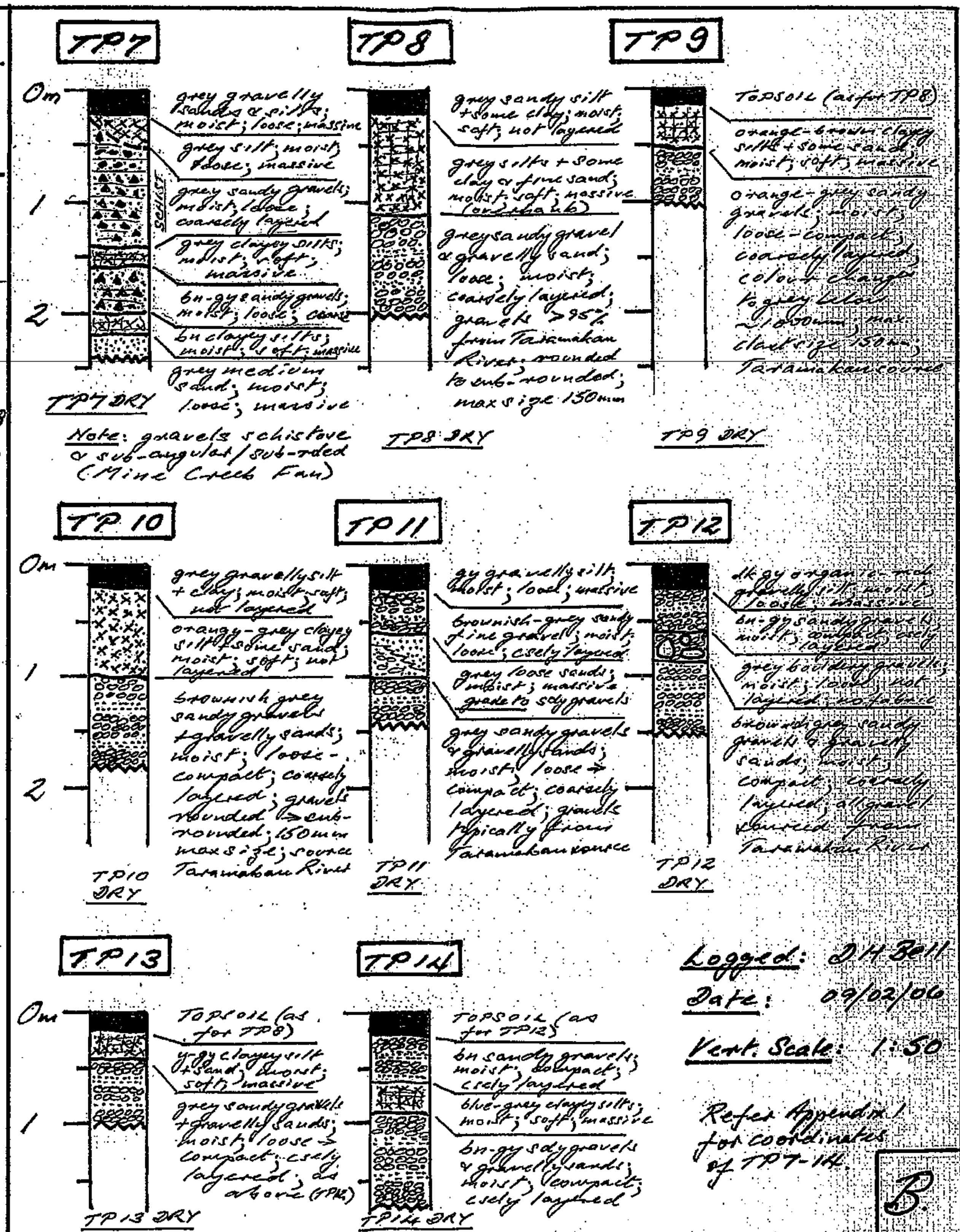
GPS LOCATIONS FOR TEST PITS

Test Pit Number	*Eastings*	*Northings*	*Location*
TP1	2387925	5832253	Homestead Ck Fan
TP2	2387919	5832231	Homestead Ck Fan
TP3	2387962	5832320	Homestead Ck Fan
TP4	2388035	5832382	Homestead Ck Fan
TP 5	2387666	5832588	Kahikatea "Swamp"
TP6	2387684	5832626	Kahikatea "Swamp"
TP7	2386873	5831797	Mine Creek Fan
TP8	2386886	5831674	Lake Poerua Site
TP9	2386844	5831620	Lake Poerua Site
TP10	2386815	5831697	Lake Poerua Site
TP11	2386696	5831642	Lake Poerua Site
TP12	23866608	5831559	Lake Poerua Site
TP13	2386501	5831471	Lake Poerua Site
TP14	2386417	5831448	Lake Poerua Site

Note: *Coordinates in metres on NZ Map Grid; no reliable elevation data*


Mt Te Kinga
mylonite boundary (Suggate & Waight 1999)
Lake Poerua 125m
Poerua
Dry Creek
130m
Homestead Ck
Mine Creek
50
45
43
FAULT
ALPINE
Midland Line
Kumara Junction Road
Inchbonnie - Rotomanu Road
131m
near-continuous outcrop of schist along range-front
0 Scale 1:25,000 1000 m
North
mylonitised granite
actual lake shoreline
drain
Alpine Fault (this study)
Alpine Fault location (this investigation)
legal boundary
LF
UF
Midland Line
Mine Creek
garnet schist
Alpine Fault (from Grey DC)
0 500m
Scale 1:10,000
North
GREYWACKE GRAVELS (Taramakau R.)
MYLONITISED GRANITE
GARNET SCHIST
swamp deposits (+ logs etc)
modern fan-delta (L. Poerua)
fans sourced from gullies
gravel transport direction
railway
LOWER FAN (younger alluvial fan deposits)
UPPER FAN (older debris flows)
ALPINE FAULT (location approximate)
property boundaries
strike of 50 foliation
Mine Creek Fans
B
MYLONITISED GRANITE
TE KINGA GRANITE
ALPINE SCHIST (garnet zone)
SWAMP DEPOSITS (lake margin)
ALLUVIAL AND DEBRIS FLOW FANS
TARAMAKAU RIVER GRAVELS
watercourse
scarp
river flow direction (Taramakau course)
Alpine Fault
Trig point
45 strike & dip of schist foliation
A
CLIENT: Mine Creek Westland Limited
SURVEYS: Bell Geoconsulting Ltd
DATES: February - March 2006
LAKE POERUA DEVELOPMENT
A. Geological Setting (1:25,000)
B. Engineering Geology (1:10,000)
PLANS TO ACCOMPANY REPORT
Scales: 1:10,000 1:25,000
FIG 1





CLIENT: Mine Creek Westland Limited SURVEYS: Bell Geoconsulting Ltd DATES: February-March 2006	LAKE POERUA DEVELOPMENT A. Trench Logs A-D (1:500) B. Test Pit Logs (1:50) FIGURES TO ACCOMPANY REPORT	Scales: 1:50 & 1:500	FIG. 2

APPENDIX TWO

Lake Poerua Development

for Mine Creek Westland Ltd

TRENCH PHOTOGRAPHS – 05 March 2006

Photographs by: *David H Bell*
Bell Geoconsulting Ltd

Figure A1: General view to north towards Lake Poerua and Mt Te Kinga, showing airstrip. Test Pits 11 to 13 excavated on western side of clear grassed area beyond first fence.

Figure A2: View along Trench C looking north-west towards Lake Poerua, with excavation to typical depth of 2m over distance of ~100m. Note absence of groundwater in trench.

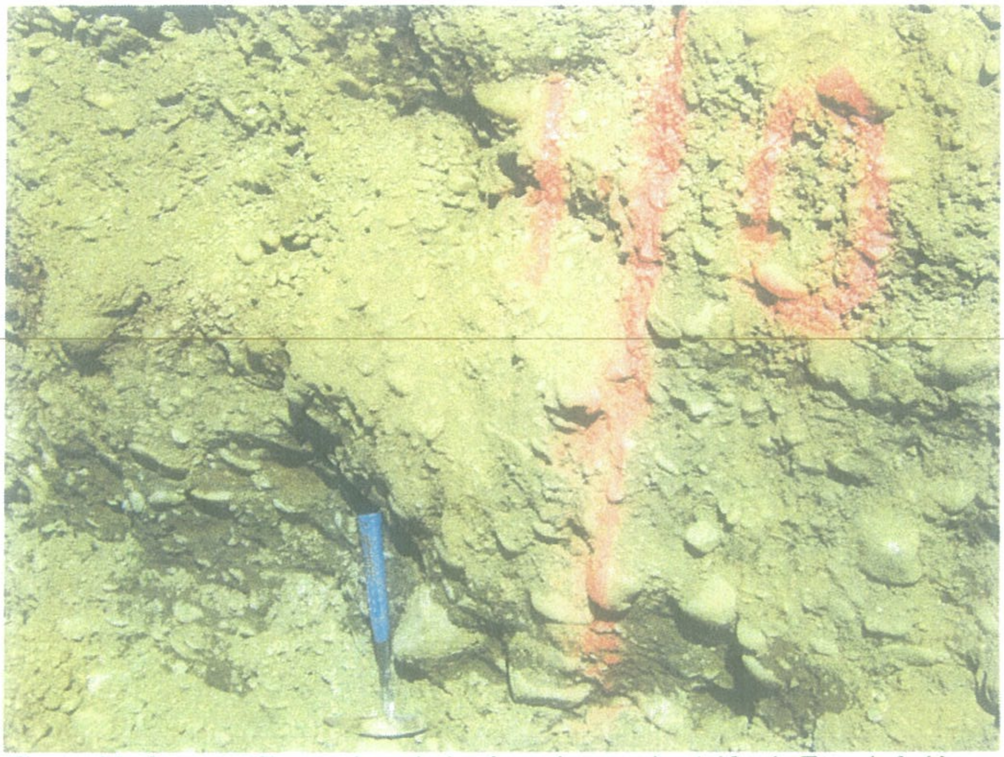


Figure A3: *Compact Taramakau-derived sandy gravels at 10m in Trench A. Upper part of exposure in photo shows lense of loose gravel to about 400mm in thickness.*

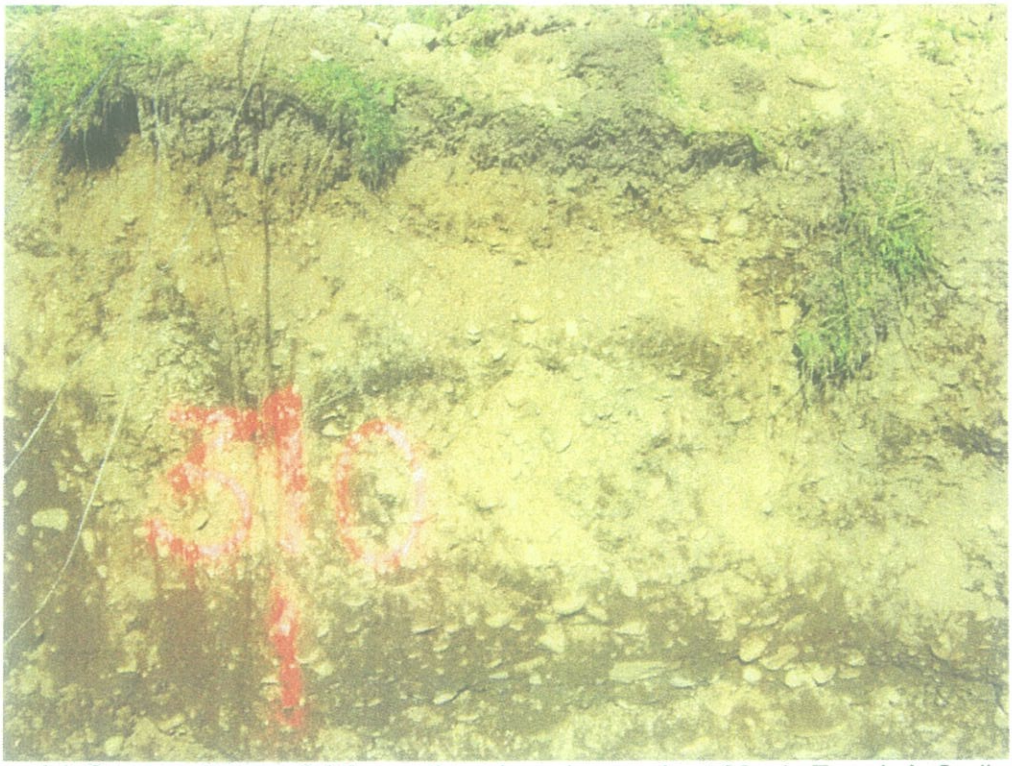


Figure A4: *Compact brown slightly weathered sandy gravels at 30m in Trench A. Sediments locally bedded at this location, with suggestion of deposition as delta into body of water.*

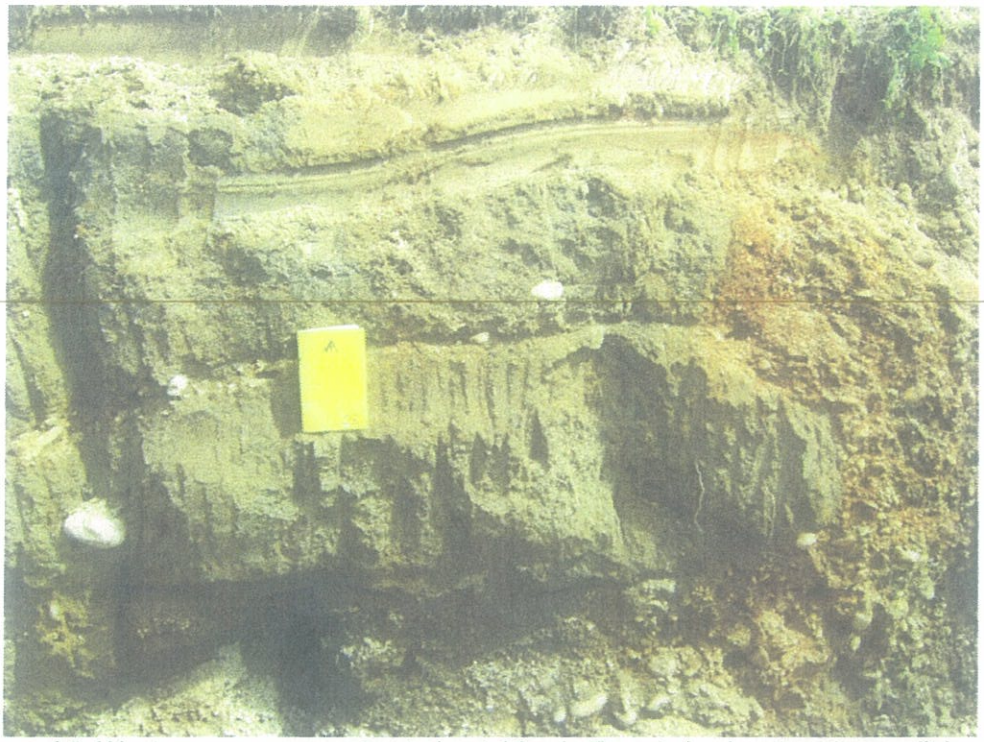


Figure A5: Western swamp margin at about 60m in Trench A, showing clayey silt lenses partially enveloped by gravels. Contacts definitely sedimentary and erosional/depositional.

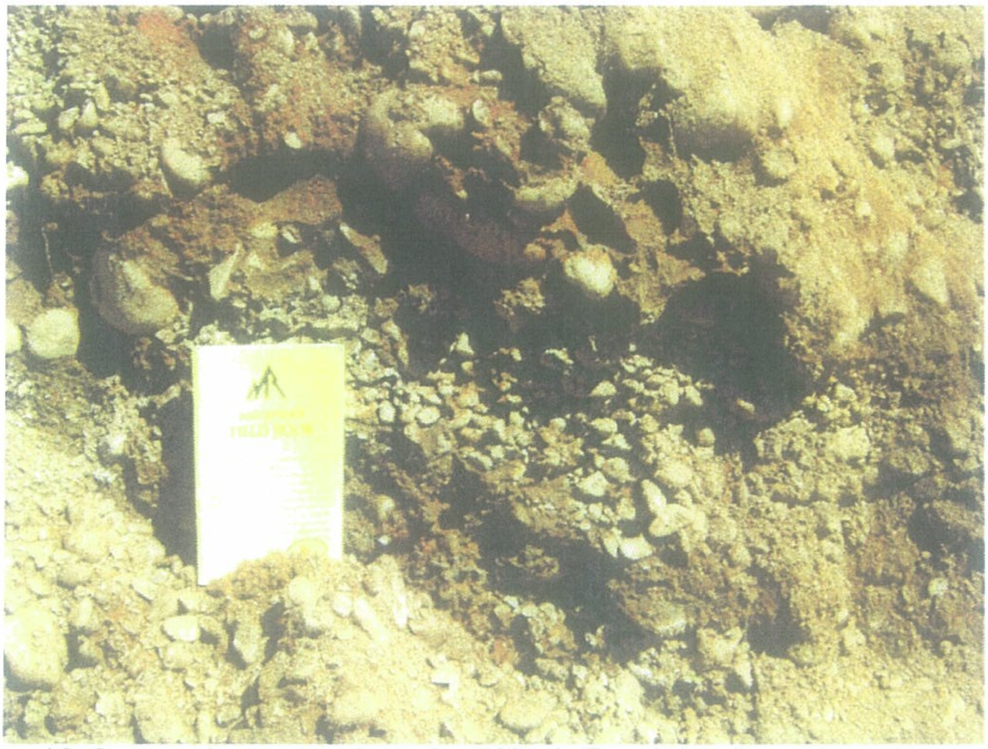


Figure A6: Compact brown gravels at about 60m in Trench A, adjacent to western swamp margin. Iron oxides attributed to permeability barrier formed by adjacent clayey silts.

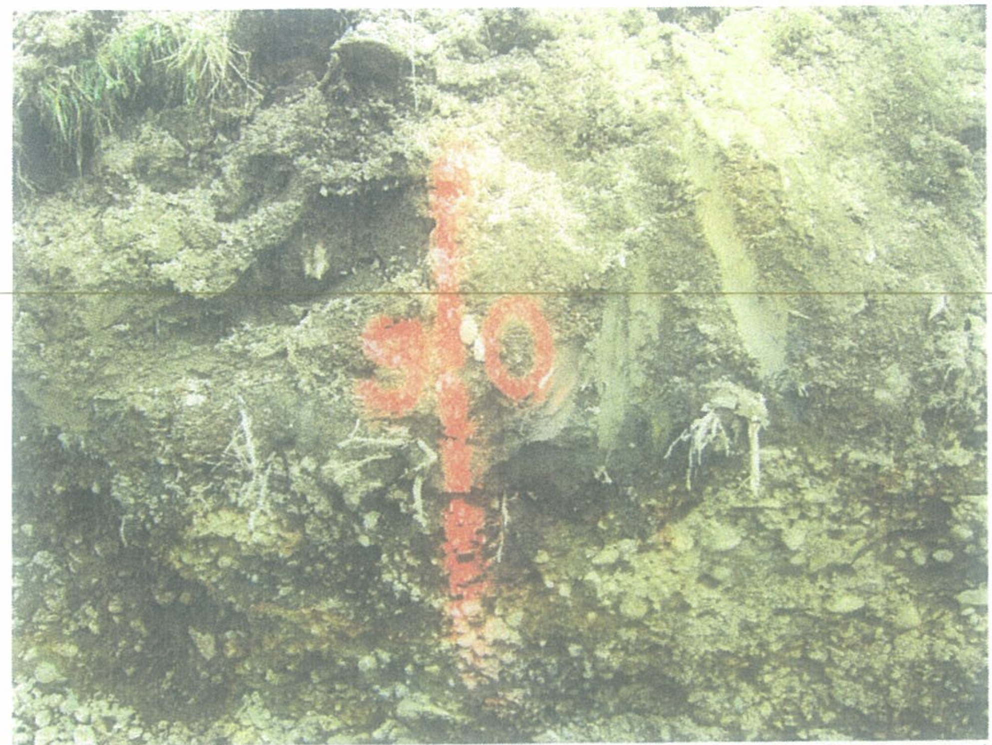


Figure A7: Organic-rich grey clayey silts at 90m in Trench A showing numerous rootlets. Interpreted as overbank swamp deposits overlying Taramakau-derived sandy gravels.

Figure A8: Soft grey clayey silts overlying loose sandy gravels at 100m in Trench B.

Figure A9: Grey clayey silt "overbank swamp" deposits overlying compact sandy gravels at 170m in Trench C. Eastern margin of "swamp" deposits is located at 178m.

Figure A10: Compact grey Taramakau-derived sandy gravels at 190m in Trench C.

APPENDIX D

SUPPLEMENTARY REPORT

BY

DAVID BELL (2007)

BELL GEOCONSULTING LIMITED
ENGINEERING AND ENVIRONMENTAL GEOLOGY
PO BOX 31-031, ILAM, CHRISTCHURCH 8444

BGL 1161/05

25 September 2007

Mine Creek Westland Limited
c/- Grant Marshall
298 Worsleys Road
Cracroft
CHRISTCHURCH

Dear Sir

Re: **LAKE POERUA DEVELOPMENT – SUPPLEMENTARY REPORT**

1. Introduction

The Lake Poerua Subdivision proposal was reviewed for Grey District Council by officers from GNS via Science Consultancy Report 2006/221 dated 06 December 2006, and in a later letter (GNS Job No 430W1243) dated 19 January 2007. The following geological and geotechnical report has now been prepared as a supplementary document specifically in relation to:

- Geophysical surveys of the planned development area by Southern Geophysical Limited using ground penetrating radar (GPR) methods on 02 February 2007 (Appendix 1).
- Trenching on 24 March 2007of specific features along the GPR profile lines that may have indicated ground deformation in order to assess their actual nature (Appendix 2).
- Results from radiocarbon dating of a wood sample collected from Trench B (excavated and logged 05 March 2006) insofar as this bears on the interpretation of geological history (Appendix 3).

It is noted at the outset that the original interpretations regarding the Alpine Fault location, as presented in BGL Report 1161/01 dated 22 May 2006, remain unchanged as a result of the above surveys. The present supplementary report (BGL 1161/05) should therefore be read in conjunction with my original professional opinion, and in relation to independent confirmatory assessments by Golder Associates (NZ) Limited. Aspects of these additional studies are reported separately by that company, and this report includes as Appendix 1 the independent review by Southern Geophysical Ltd of Christchurch and GPR Geophysical Services of New Plymouth. Appendix 2 contains an independent review of the March 2007 trench logging by Jocelyn K Campbell, Active Tectonics Specialist and Senior Lecturer in Geology from the University of Canterbury, Christchurch.

2. Specific Issues Raised by GNS

GNS Science Consultancy Report 2006/221

The following specific comments in relation to the earlier BGL and Golder reports were made in the December 2006 GNS report:

- GNS were of the opinion that neither report adequately addressed the location of the Alpine Fault in relation to the proposed subdivision.
- GNS suggested that the 1960s 1:250,000 geological maps referenced in the reports were unsatisfactory and had been superceded.
- GNS indicated that their research had located secondary fault scarps potentially affecting the proposed subdivision area.
- GNS recommended further trenching investigations by "trained paleo-seismologists", and geophysical methods such as seismic or GPR.
- GNS recommended the establishment of a 1km wide "Special Study Zone" extending 500m either side of the mapped Alpine Fault trace.
- GNS were of the opinion that the proposed development was not "geotechnically sound" because of risks from landsliding and faulting.
- GNS commented that the two reports "understated" the effects of the next Alpine Fault Earthquake, and failed to satisfy s106 of the RMA.
- GNS were of the opinion that significant risk of lateral spreading and seiching existed at the site from both landsliding and faulting.

GNS Letter Job No 430W1243

After initial responses to the GNS Science Consultancy Report, the following specific comments were made in the January 2007 letter from GNS:

- The proposed response from the developer did not adequately address the landslide issues and concerns raised by the reviewers.
- The GNS reviewers were in agreement with the proposal to assess the seiching effects as proposed by the developer.
- Further work would be required to better define the potential effects of liquefaction at the site during the next Alpine Fault Earthquake.
- The location of the Alpine Fault requires further consideration and the south-western subdivision boundary *"......is a fault trace".*
- The scale of mapping carried out to date does not allow adequate definition of the surface faulting or deformation hazard at the site.

The second GNS letter contained as Figure 1a an oblique aerial photograph that shows the Alpine Fault as a single trace through the centre of the subdivision area, in the same position as on Figure 8 of Nathan et al (2002), even though the earlier BGL and Golder mapping and logging had indicated that this was not correct. It also appeared that the reviewers did not fully appreciate the proposed subdivision layout, and had assumed that building was planned on the Mine Creek Fan.

3. Alpine Fault Location – Background

The GNS reviewers clearly regard location of the Alpine Fault trace (or traces) as being critical to this project, and this is accepted as relevant given the likelihood of future rupture events affecting the development. However, it should be noted that a variety of fault positions and structures have been identified in the vicinity of Lake Poerua, as follows:

- Gregg (1964) on the 1:250,000 Hurunui sheet shows the Alpine Fault as a single trace emerging from the north-eastern part of the lake, and continuing as a concealed structure beneath the Mine Creek and Homestead Creek fans to the north-east.
- Warren (1967) on the 1:250,000 Hokitika sheet shows the Alpine Fault as a single concealed trace passing through the western part of the subdivision area, close to the shoreline of Lake Poerua but not below the lake surface itself.
- Suggate & Waight (1999) on the 1:50,000 Kumara-Moana sheet show multiple northwards-stepping discontinuous traces of the Alpine Fault to the south-west of the Lake Brunner Road, and a concealed active trace beneath the subdivision to the south-east of the airstrip.
- Nathan et al (2002) on the new 1:250,000 Greymouth sheet show the Alpine Fault as a single active trace at the south-western corner of the subdivision, and as a concealed active trace passing beneath the approximate centre of the subdivision itself.
- The Grey District Council planning map of the Lake Poerua area shows the Alpine Fault as a single concealed trace beneath the approximate centre of the proposed subdivision, in essentially the same position as shown by Nathan et al (2002) and on the oblique air-photo supplied.

Given the data available at the outset of this investigation from the previous geological mapping, it could reasonably be concluded that a concealed single trace of the Alpine Fault passed beneath the subdivision area. The Grey District planning map indicates a dip of 60° to the south-east for the structure, with a dominant dextral strike-slip sense of movement and a subsidiary reverse component in the dip direction. The trenching that was carried out in March 2006 was designed to cross this supposed structure approximately at right angles, and to provide confirmation (or otherwise) of fault position and activity. The detailed air-photo analysis carried out had already revealed that there was no surface trace in the position shown, and that the interpretation of Suggate and Waight (1999) to the south-west of the subdivision was the most realistic (BGL Report 1161/01). It was assumed that a concealed fault trace (or traces) would be evident within the top 2-3m of the profile, and that any ground deformation related to past earthquake events would also be visible at shallow depth. In light of this investigation framework, the comments by the GNS reviewers about the conclusions reached from the 2006 surveys are surprising, as was their recommendation that further studies be undertaken.

4. Alpine Fault Location – Review

Additional Investigations

As a result of the GNS review, and the consequent request for further information, the following additional investigations were carried out under my direction in February and March 2007:

- Five GPR profiles were completed on 02 February 2007 across the subdivision footprint, and on the property to the south-west of Lake Brunner Road, by Southern Geophysical Limited of Christchurch (Dr Mike Finnemore), in conjunction with G.P.R. Geophysical Services – Sub Surface Solutions of New Plymouth (Martin King).
- Following provisional interpretation of the GPR data, trenching was carried out along each of Profiles 1, 2 and 4 on 24 March 2007 to further evaluate shallow geology, and to aid with final interpretation of the geophysical data. Logs were prepared by Jocelyn Campbell of the University of Canterbury, who is an expert paleo-seismologist.
- In addition to the above two investigations that were conducted to meet the requirements of the GNS review, a sample of wood from near the base of the shallow swamp deposits in Trench B (0.50-0.55m depth) was submitted to the Radiocarbon Dating Laboratory at the University of Waikato to obtain a C-14 date (Wk20708).

The geophysical survey report is included as Appendix One, the additional trench logs and geological comment by Jocelyn Campbell are presented as Appendix Two, and the radiocarbon dating information forms Appendix Three.

GPR Investigation Results

The following extracts from the Geophysical Survey Report (Appendix One) summarise the key conclusions from that work:

- *"The GPR profiles undertaken on the subdivision site show a series of well defined, coherent and discontinuous reflectors..............similar to previously seen profiles in fluvial and lacustrine/marsh settings." (p3)*
- *"Within the depth of penetration of the GPR systems (6m and 13m) no obvious displacement of the near surface sedimentary units are seen... (but) several diffractions are seen which are.........likely to be buried features such as logs or boulders...." (p3)*
- *"The GPR profiles to the southwest of the subdivision......show a strong discontinuity......more typical of fault related features......." (p4)*

The probable Alpine Fault last rupture location is associated with the strong discontinuity on neighbouring land to the south-west of the subdivision, is coincident with faulting mapped by Suggate & Waight (1999), and is in the position identified from site geomorphology in my earlier report (Bell, 2006).

Further Trenching (E, F & G)

The following extracts from the report prepared by Jocelyn Campbell on the three additional trenches (E, F & G) excavated on 24 March 2007 (Appendix Two) provide confirmation of the absence of faulting on the subdivision:

- *"No evidence of shearing or fault displacement was found" (p1)*
- *"...the stratigraphy* (in Trench G) *indicates that the fluidisation event post-dates both deposition of the grey silts and overlying gravel...." (p2)*
- *"The site, lying east of the projected rupture trace of the last two events, would have been lifted relative to lake level at the time of the last earthquake* (c. 1715 AD)*......" (p3)*
- *"Despite proximity of the projected fault trace no evidence of secondary faulting or intense deformation of the sequence was observed...." (p3)*
- *".... there is no evidence of the introduction of any locally derived material..., such as schist landslide or debris flow deposits, associated with this shaking event* (ie the 1715 earthquake)*......" (p3)*

Several ground deformation features most probably related to strong shaking during a major earthquake were identified, confirming the nature of sand injection structures previously recognised, but the additional trenching has again established the absence of primary or secondary faulting within the subdivision footprint. This is consistent with the results of the GPR surveys to depths of 10m+, and the location of the most recent Alpine Fault rupture trace is almost certainly some 50-100m offshore beneath Lake Poerua as shown in Figure 1 of Bell (2006). Any suggestion that the previous trench logging (ie of Trenches A-D inclusive) was inadequate or incompetent is strongly rejected.

Radiocarbon Dating Interpretation

A sample of wood, probably a log or root of *kahikatea*, was sampled between depths of 0.50 and 0.55m at chainage 108m in Trench B (Bell, 2006, Figure 2; Appendix Three). Sample Wk20708 gave a preferred age of 254 ± 38 BP, suggesting a calendar age of about 1700AD and probably pre-dating the last Alpine Fault rupture: however, as discussed in Appendix Two the wood could possibly be older than the radiocarbon age provided by Waikato University. Irrespective of this point, the radiocarbon dating and the trench logging carried out (Trenches A to G inclusive) do together indicate that the swamp feature in which the silts and logs/roots are present predates the 1715 ± 15 event.

This in turn suggests that the Taramakau River continued to deposit sediment into a somewhat enlarged Lake Poerua at least between the 1620 and 1715 faulting events, but that uplift of 2 to 3m during the latter Alpine Fault rupture stopped further river gravel and overbank silt deposition in the vicinity. There is no evidence for schist-derived sediment from the Mine Creek catchment within the area planned for residential housing, confirming that there were no debris flows from this source generated during recent fault rupture events.

5. Alpine Fault Location – Conclusions

Fault Position beneath Lake Poerua

All the geomorphological evidence from site mapping at 1:10,000 and smaller, and from detailed air-photo analysis using 1962 and 1996 sets, shows that the last rupture trace (and almost certainly the two preceding traces) lies a short distance (~50m to 100m at most) offshore beneath Lake Poerua as plotted by Bell (2006) in Figure 1. The 250m of trenching undertaken in 2006 failed to disclose the existence of any fault trace within the subdivision, suggesting that the advice previously given to Grey District Council was incorrect: the GPR and additional trenching investigations conducted in early 2007 have similarly shown that there is no evidence for any fault trace within the subdivision. In fact GPR profile E-E' provided clear evidence of major ground disturbance, probably associated with active faulting, on neighbouring land to the south-west in the position predicted by my earlier mapping and consistent with some of the features mapped by Suggate & Waight (1999) in this vicinity.

Of the four GNS and Geological Survey maps referred to in Section 3 of this report, however, only that by Gregg (1964) is considered realistic in relation to the subdivision itself, and he does not show the full extent of Lake Poerua because of the map boundary position. The GPR data, which provides information on subsurface geology to depths greater than 10m (Appendix One), and the swamp being less than 1m deep formed on Taramakau-derived gravels prior to the last (1715 AD) Alpine Fault rupture (Appendix Two), together in my professional opinion establish conclusively that the last (and earlier) Alpine Fault rupture traces do not pass beneath that part of the subdivision proposed for residential housing. In fact the actual fault position is at least 70m from any planned dwelling site, compared to the 20m setback normally advised (Kerr et al, 2003).

Planning Implications

On the basis of the detailed investigations undertaken both prior to and as a result of the GNS review, it is concluded that the information shown on the Grey District Council planning map is incorrect. Similarly, neither of the recently published GNS maps (Suggate & Waight, 1999; Nathan et al, 2002) is correct in terms of the Alpine Fault location shown on the land proposed for residential housing. In addition the detailed investigations carried out for this subdivision proposal do not provide any justification for the recommendation in GNS Report 2006/221 that a 1km wide "Special Study Zone" be established 500m either side of the mapped trace of the Alpine Fault. Trenching has been completed for more than 200m across the suggested fault trace, GPR surveys have identified a probable location for the Alpine Fault in the position mapped during this study, and subsurface data to depths exceeding 10m have been provided by geophysical methods within the subdivision footprint.

7. Other Geotechnical Matters

Ground Deformation Features

The stratigraphy exposed in Trenches E, F and G is essentially the same as that exposed in the earlier trenches, especially Trench D across the channel margin on the western side of the former swamp. A lower unit of clayey silt with scattered pebbles rests on a scoured channel base in Taramakau River-derived sandy gravels with rare sandy interbeds. The clayey silts are overlain by a unit of grey sandy silts, and in turn by a yellow-brown silty medium sand (Appendix Two). Although complex stratigraphically the sequence is explained by periodic channel occupation and normal sedimentary processes, and in places injection and possible fluidisation structures have been recognised, as follows (Appendix Two):

- Trench E shows evidence for two sand injection structures that are most probably related to the last Alpine Fault rupture (c. 1715 AD) at a time when the sediments were clearly saturated at shallow depth.
- Trenches F and G both show possible sand fluidisation features that suggest a groundwater table within about 1m of the surface, but the evidence is less convincing and may be due to human disturbance.

The earlier trench and test-pit investigations also showed occasional local sand injection structures probably related to liquefaction, and this was one of the bases for recommending specific engineering design of foundations for each dwelling. Although it is possible that the channel feature identified in Trench F is due to subsidence, careful logging suggests that the primary dips reflect original sedimentation and not lateral spreading. It is also recorded that all three trenches (E, F & G) are located on the margins of the airstrip that was constructed prior to the 1960s, and that some shallow ground disturbance features may relate to tree removal and later backfilling.

Liquefaction Potential Assessment

Careful trench logging suggests that local sand injection has occurred during past earthquake events, either from lenses within the underlying Taramakau River gravels or from saturated silty sands filling channels associated with the swamp area (Bell, 2006, Figure 1). A key point made in Appendix Two by Jocelyn Campbell is, however, that significant uplift (of the order of 2 to 3m) almost certainly occurred during the last Alpine Fault rupture, resulting in subsoil drainage of the sandy lenses such that they are no longer saturated. None of the seven trenches (A to G) excavated and logged contained any seepages or showed evidence for present saturation, and in fact trenches cut to within 3m of Lake Poerua and below the existing lake level remained dry for up to 2 weeks prior to backfilling. Therefore it can be reasonably argued that future liquefaction is much less likely than in 1715 AD given that the groundwater table is now at a depth greater than 3m over the entire site.

Next Alpine Fault Earthquake

It is accepted that a high likelihood of major damage to any building constructed at Lake Poerua exists during its design life (ie the next 100 years), and that this could be due to ground shaking, including substantial aftershocks, and/or liquefaction, seiching or lateral spreading. Our detailed studies have shown that the identified fluidisation features are much less likely to occur because of the lowering of the water table as a result of the last rupture, however, and it is noted that the next Alpine Fault event will also involve significant reverse movement and additional uplift to the east of Lake Poerua (within the subdivision footprint). Aspects of inundation, lake outflow, lateral spreading and seiching have been addressed in the supplementary report prepared by Golder Associates (NZ) Ltd, and their comments and conclusions are endorsed.

A critical part of the design of any dwellings within the subdivision is that they must be survivable in the event of such an earthquake, hence the advice that site-specific foundation design *"by a suitably experienced chartered engineer"* must be undertaken. It was also recommended that intending purchasers be advised of the location of the subdivision in relation to the Alpine Fault, and the potential consequences of such an event, at the time of section purchase. The risk of future damage associated with the next Alpine Fault earthquake is significantly less than elsewhere along the plate boundary, for example Franz Josef Township where the Alpine Fault passes beneath several buildings, and the recommended engineering design must reduce the risk to occupiers. It is also noted that significant strain partitioning is taking place to the south of the Taramakau River onto the Hope-Kelly fault system, and that the frequency, magnitude and character of future Alpine Fault ruptures from Inchbonnie to the north may well be changing and the risk reducing somewhat.

Comment on Landsliding

With regard to the risk and/or consequences of landsliding I note the following:

- There is no geomorphic or air-photo evidence to indicate large bedrock failures affecting the proposed subdivision, either in schists from the Alexander Range or in granites from Mt Te Kinga, despite probably 30-40 Alpine Fault earthquakes in the period since ice left the valley.
- There is no evidence in the trenched or test-pitted sediments for any debris flow deposits sourced from the Mine Creek catchment within the proposed residential subdivision, and the measures planned (such as bunding) will ensure that future avulsion of Mine Creek is not an issue.
- Any channellised debris flows that potentially affect the present outlet of Lake Poerua from either the north-west or south-east may cause temporary blockage, but detailed topographic surveys have shown that this will result in overflow to the south-west and towards Lake Brunner.

8. Land Suitability for Residential Subdivision

RMA s106 Assessment

This section of the Resource Management Act 1991 (as amended) requires the territorial authority to refuse subdivision approval unless satisfied that all matters relating to *erosion, falling debris, subsidence, slippage or inundation* have been or will be adequately addressed. I previously concluded that the planned subdivision satisfied s106 of the RMA, and in summary the detailed investigations now completed have established the following:

- The land proposed for subdivision is not subject to erosion, falling debris or slippage, and there is no evidence for any likelihood of these processes affecting the property in the future.
- One feature was identified in Trench F that might relate to ground subsidence accompanying lateral spreading, but it was concluded from careful logging that this was in fact a sedimentary channel.
- After careful logging of some 300m of trenches and eight test pits, it has been concluded that ground subsidence is not a concern with this site but that possible sand liquefaction should be remedied by design.
- Inundation could result from either seiching or outlet blockage of Lake Poerua, but detailed topographic surveys have shown that overflow to the south-west would occur at an elevation below house floor levels.
- It has thus been concluded that inundation can be addressed either by landscaped bunds (in the case of Mine Creek overflow), or by the adoption of floor levels taking account of potential inundation effects.

I remain satisfied that any potentially damaging effect from future earthquakes can be addressed by appropriate engineering design of foundations and built structures on a site-specific basis, and that any risks to occupiers will be minimised accordingly.

Ministry for the Environment Guidelines

The planning guidelines developed by the Ministry for the Environment for land development on or close to active faults (Kerr et al, 2003) has also been reviewed in the context of the proposed Lake Poerua subdivision, and in summary the following are noted:

- The Alpine Fault is clearly a Class 1 active structure capable of generating M = 8.0+, with a recurrence interval of ~150-300 years.
- The trace appears to be well defined near and beneath Lake Poerua, and is at least 70m from any proposed dwelling site.
- On this basis it is feasible to locate at least BIC 2a structures on the site, given that these will be well outside any fault avoidance zone.

9. Conclusions

1) As a result of comments by the GNS reviewers GPR surveys and additional trenching have been undertaken within the residential footprint of the planned subdivision, and on neighbouring land to the south-west: these studies have confirmed earlier conclusions that there is no active trace of the Alpine Fault concealed beneath the development area, and that the last few ruptures at least are located some 50-100m offshore under Lake Poerua (Bell, 2006).

2) Evidence for local liquefaction and fluidisation structures has been verified by the additional investigations, and it has also been concluded that the water table must have been considerably higher and shallower at the time of the last Alpine Fault rupture c.1715 AD: no seepages or groundwater inflows were found in any of the trenches, which now total some 300m in length, and even adjacent to Lake Poerua no inflows resulted from excavation below lake level.

3) A single radiocarbon age of 254 ± 38 BP (Wk 20708) has been obtained from a wood sample collected at a depth between 0.50 and 0.55m in Trench B and suggests that the swamp in the eastern part of residential footprint pre-dates the last Alpine Fault rupture event: the need for site-specific design of dwelling foundations has been confirmed by the additional studies, and all residential buildings must be survivable in a likely large earthquake event.

4) Conclusions by Golder Associates (NZ) Ltd in relation to potential seiching and lateral spreading are endorsed, and it is confirmed that there is still no subsurface evidence of ground subsidence due to lateral spreading within the subdivision footprint: large landslides possibly affecting the development site are rejected, and topographic surveys show that Lake Poerua will overflow to the south-west before inundation of house sites if the natural outlet is blocked.

5) Whilst it is accepted that the Alpine Fault is a Class 1 active structure with the likelihood of large magnitude earthquakes, and a recurrence interval of ~150-300 years near Inchbonnie, it is also concluded that any residential dwelling would be sited ≥50m outside any fault avoidance zone: I am satisfied that buildings and foundations can be engineered to withstand any ground shaking effects, given that there is no active or inactive fault trace within the subdivision footprint, and therefore that the conditions of s106 of the Resource Management Act 1991 are adequately met.

10. References

BELL, D H (2006) Lake Poerua Development – Geology & Geotechnics *Unpublished BGL Report 1161/01 to Mine Creek Westland Ltd dated 22 May 2006: 9p + 2 figs + 2 app*

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KERR, J; NATHAN, S; VAN DISSEN, R; WEBB, P; BRUNSDON, D; KING, A (2003) Planning for Development on or Close to Active Faults *ME Report No 483*: *67p*

NATHAN, S; RATTENBURY, M S; SUGGATE, R P (compilers, 2002) Geology of the Greymouth Area *IGNS 1:250,000 geological map 12, 1 sheet + 58p*: *IGNS Ltd, Lower Hutt*

SUGGATE, R P; WAIGHT, T E (1999) Geology of the Kumara-Moana area, scale 1:50,000. *IGNS geological map 24, 1 sheet + 124p*: *IGNS Ltd*

WARREN, G (1967) Sheet 17 – Hokitika *Geological Map of New Zealand 1:250,000*: *DSIR, Wellington*

YETTON, M D; WELLS, A; TRAYLEN, N J (1998) Probability and Consequences of the Next Alpine Fault Earthquake *EQC Research Report 95/193*: *161p*

I trust that this supplementary report adequately addresses the matters raised by the GNS reviewers, and I confirm again that this review should be read in conjunction with my original report on the proposed development (Bell, 2006).

Yours sincerely

DAVID H BELL (Director)

APPENDIX ONE

Lake Poerua Development for Mine Creek Westland Ltd

GPR SURVEY REPORT

Southern Geophysical Ltd &
G.P.R. Geophysical Services

Lake Poerua

Ground Penetrating Radar survey

Data collection and report prepared by:

M.L.King. BSc.C.Eng.
and
M. Finnemore. Ph.D.

For

David H Bell

June 2007.

G.P.R. Geophysical Services - Sub Surface Solutions and Southern Geophysical Ltd.
Email : mking.gpr@xtra.co.nz or
mike@southerngeophysical.com

AKE POERUA SUBDIVISION PROJECT
SUMMARY OF GEOPHYSICAL METHODOLOGY
February 2007

Summary:

The GPR profiles undertaken at the Lake Poerua subdivision show no evidence of faulting in the near surface (top 13 m). Further to the south a subsurface discontinuity has been clearly imaged which may be a fault trace.

Method:

A ground penetrating radar (GPR) survey was carried out on 2 February in the Lake Poerua area, using two separate GPR systems. One system was the GSSI SIR-2 digital radar system together with a 200MHz shielded antenna and the other was a Sensors & Software Pulse Ekko System together with a 100MHz unshielded antenna.

GPR is a non-invasive electromagnetic radio frequency (25MHz to 1000MHz typically) technique for subsurface exploration. It is widely used to locate lost utilities, land mine detection, environmental monitoring, void, cave and tunnel detection, archaeological and forensic investigation, as well as many other applications. It has the highest resolution of any geophysical method for imaging the subsurface, with centimetre scale resolution possible in most instances.

GPR operation in the field is conducted by moving an antenna across the surface of the ground along pre-determined grid lines. The antenna is connected to the central control computer via special high frequency co-axial or fibre optic cable. The antenna transmits pulses of high frequency Electro Magnetic (EM) signal into the ground and detects the reflected signal from subsurface features. The control computer collects, displays and stores the data received at the antenna.

The strength of the reflected signal is dependent largely upon the dielectric coefficient contrast between the subsurface materials encountered. GPR can, in addition to detecting discrete subsurface objects, also 'see' soil strata lines. Soil strata water content varies slightly with the natural layering and density changes formed as a result of the natural ground formation over the years and/or deformations caused by fault line activity. The dielectric coefficient of a material is modified by the moisture content so that this varying soil dielectric coefficient enables radar to plot variations in the soil strata lines.

Results:

The resolution possible with GPR is controlled by the wavelength of the propagating electromagnetic signal, the higher the frequency the greater the resolution possible. Depth of penetration decreases however, with increasing frequency, so that an optimum balance between depth of penetration and resolution has to be established at each site depending on expected target depth and size. In this case, the targets were there appeared to be evidence of subsurface slippage or deformation liable to have been caused by the Alpine Fault: The frequencies chosen for this survey were a 200MHz shielded antenna and a 100MHz unshielded antenna, which gave an apparent penetration of 6 and 13 metres, respectively, with good soil strata resolution.

A total of 6 radar profiles were run in North-Westerly and South-Easterly directions consisting of a total of 20 separate radar data files. The location and direction of each scan line was designed to be perpendicular to the known direction of the Alpine Fault line in this area in order to maximise the detection potential of this radar survey.

The GPR profiles undertaken using the lower frequency (deeper penetration) Pulse Ekko 100MHz system and the 200MHz GSSI system (shallower penetration) are shown in Figure 1.

The 100 MHz Pulse Ekko GPR profiles undertaken on the development site are (Figure 2):

Lake A-A' Peg 3-5 and Lake C-C' Peg 0-2

The 100 MHz Pulse Ekko GPR profiles undertaken on the inferred location of the Alpine fault are (Figure 3):

Lake E-E', Lake E-E' East and Lake E-E' West

The 200 MHz GSSI profiles undertaken on the development site are (Figure 4 – 11):

File 47,48,49,50,51,52,54,55,56,57,60,61

The 200 MHz GSSI profiles GPR profiles undertaken on the inferred location of the Alpine fault are (Figure 12):

File 58 & 59.

The GPR profiles undertaken on the subdivision site show a series of well defined, coherent and discontinuous reflectors. The radar facies seen in the profiles are similar to previously seen profiles in fluvial and lacustine/marsh settings. The profiles show a series of interfingering horizontal to sub-horizontal reflectors with sub-meter to decimetre size units. Several more continuous reflectors extending over a large area (>50m) are also seen. These are interpreted to be large scale deposition/ersoinal events such as lake level changes or fluvial overbank deposits.

Within the depth of penetration of the GPR systems (6 m and 13 m) no obvious displacement of the near surface sedimentary units are seen within the subdivision. Several diffractions are seen which indicate strong discontinuities in the subsurface, but the radar facies indicates these are likely to be buried features such a logs/large boulders or slumping (File 54, 60 and 61, Lines B-B' and C-C'). These features appear to be at around 5 m in depth and do not appear to have affected the overlaying sedimentary units.

The GPR profiles to the southwest of the subdivision (File 58 & 59, Lake E-E', Lake E-E' West, Lake E-E' West) show a strong discontinuity in the profiles near the base of the hill slope extending to a depth of 7-10 m below the surface.

Conclusions:

The profiles undertaken within the subdivision show no obvious, through-going, fault zone in the near surface (13 m). Several diffractions are evident but appear to be discontinuous across the proposed subdivision and appear to be subsidence-related features.

Further to the southwest, the profiles along E-E' appear to show a well developed, near surface discontinuity, near the base of the hill slope. The character and lateral extent of this discontinuity (seen clearly in all 3 profiles) indicates that it may be a large-scale feature such as a fault splay, buried fault or fluvial terrace.

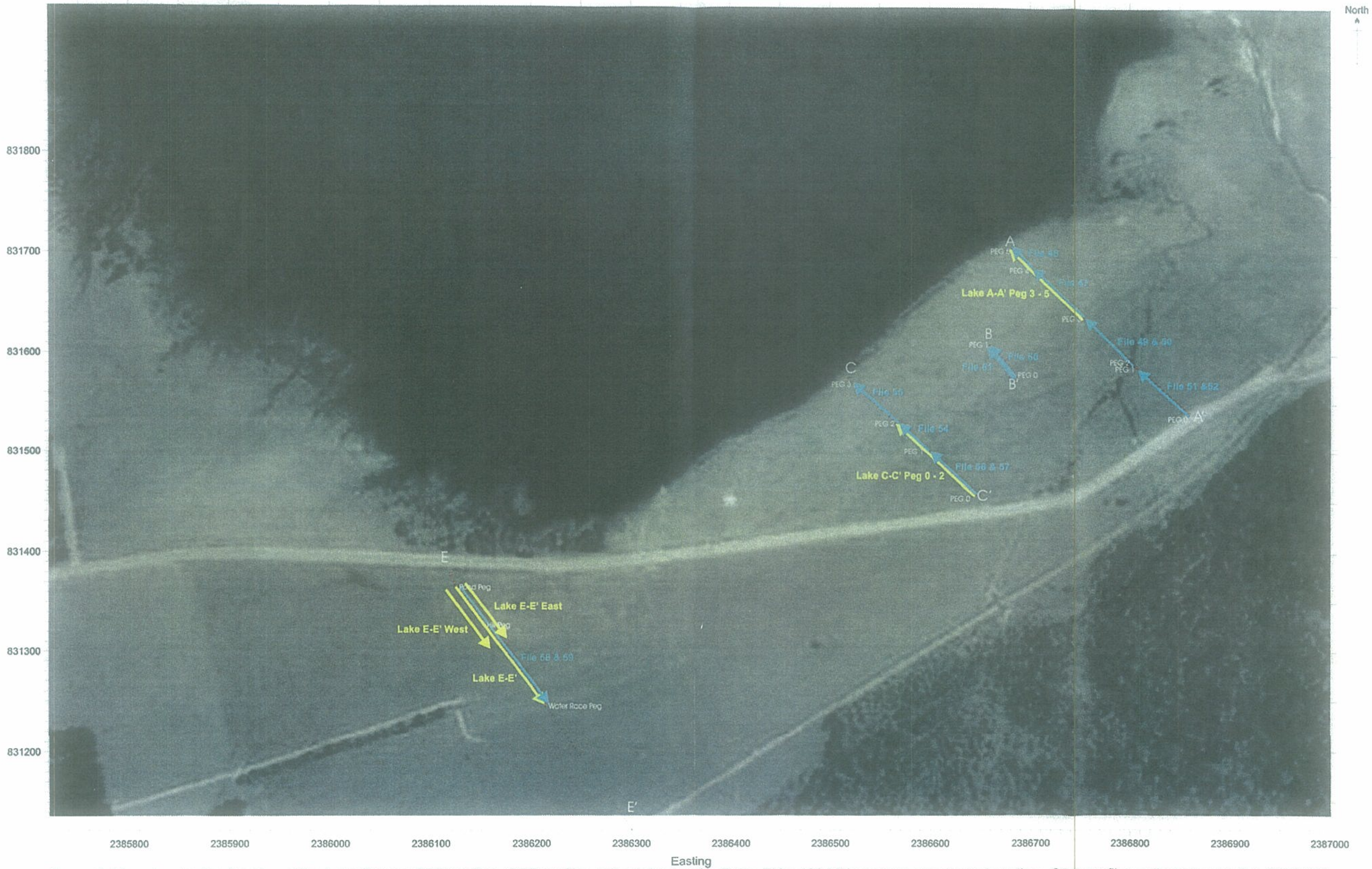
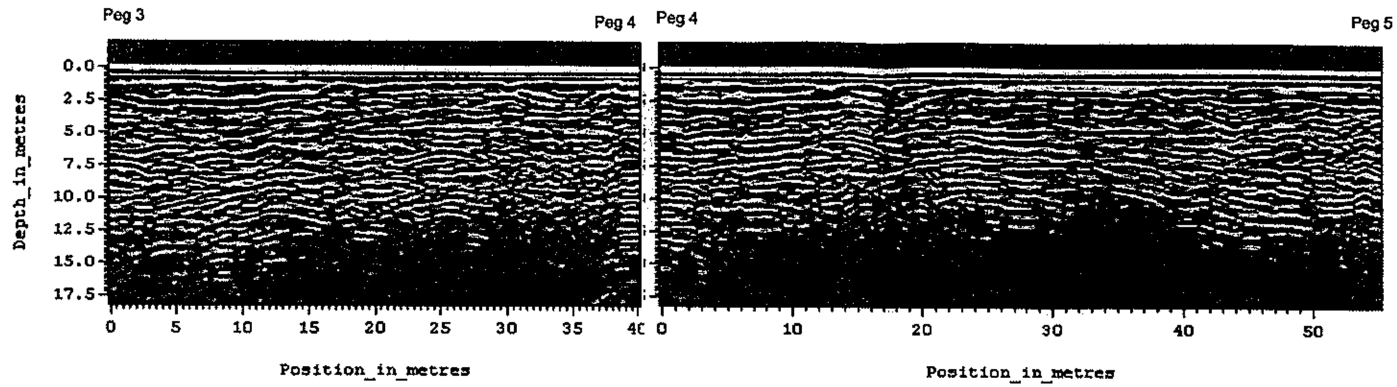


Figure 1: Map showing the location of the Lake Poerua GPR profiles. GPR profiles collected using the Pulse Ekko 100 MHz system are shown in yellow. GPR profiles collected using the GSSI 200 MHz system are shown in blue. Easting and Northing are in NZ Map grid 1949

Profile Lake A-A' Peg 3-5



Profile Lake C-C' Peg 0-2

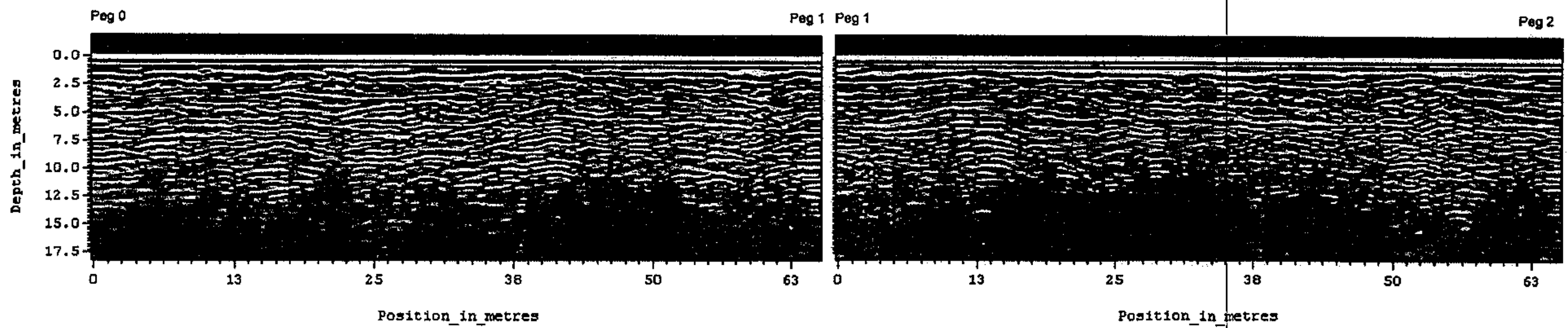


Figure 2: GPR Profiles Lake A-A' and Lake C-C' Pulse Ekko GPR system 100 MHz antenna

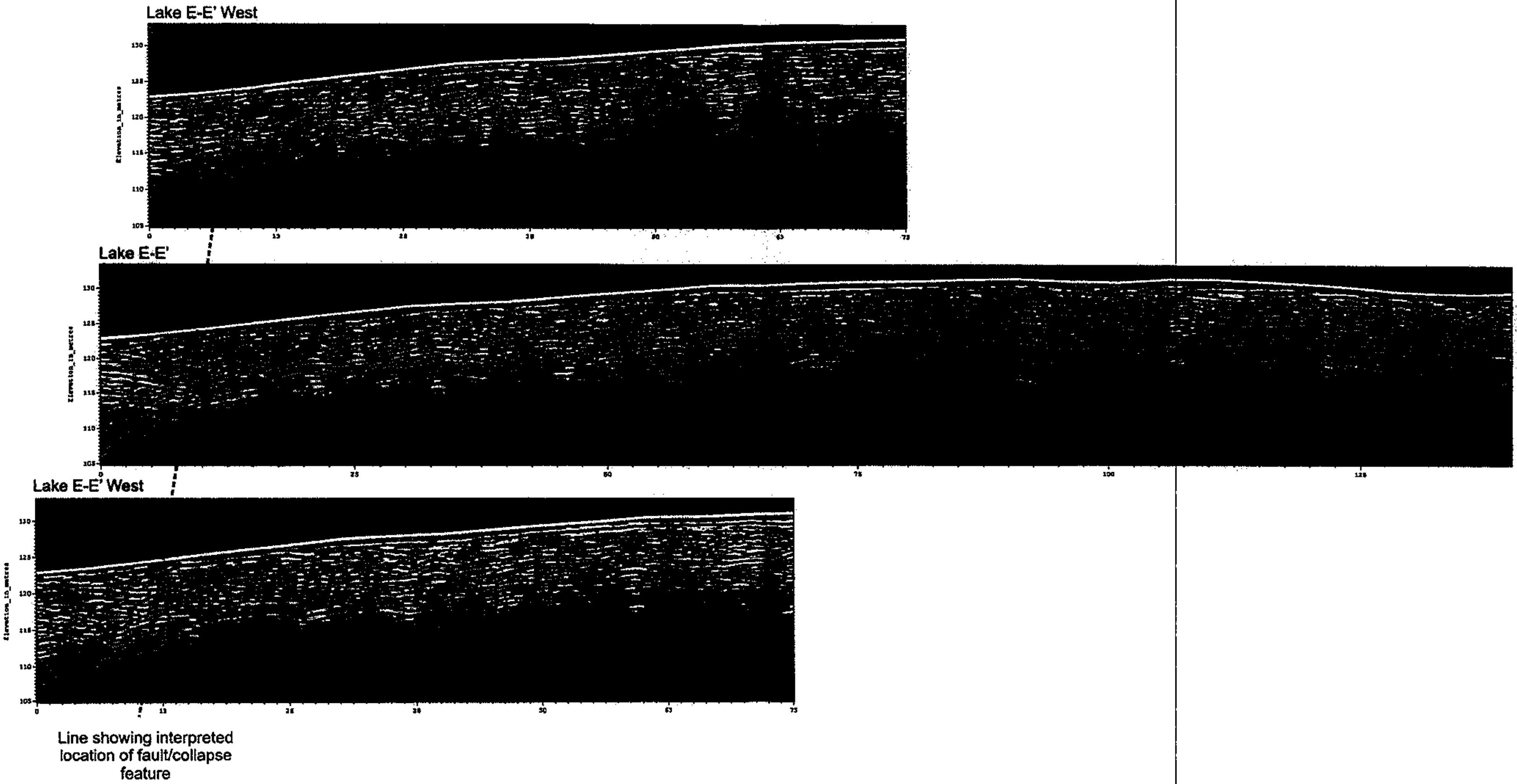


Figure 3: Showing the three GPR profiles Lake E-E', Lake E-E' East and Lake E-E' West going uphill from the Pond. Profiles were collected using the Pulse Ekko GPR system with 100MHz antenna.

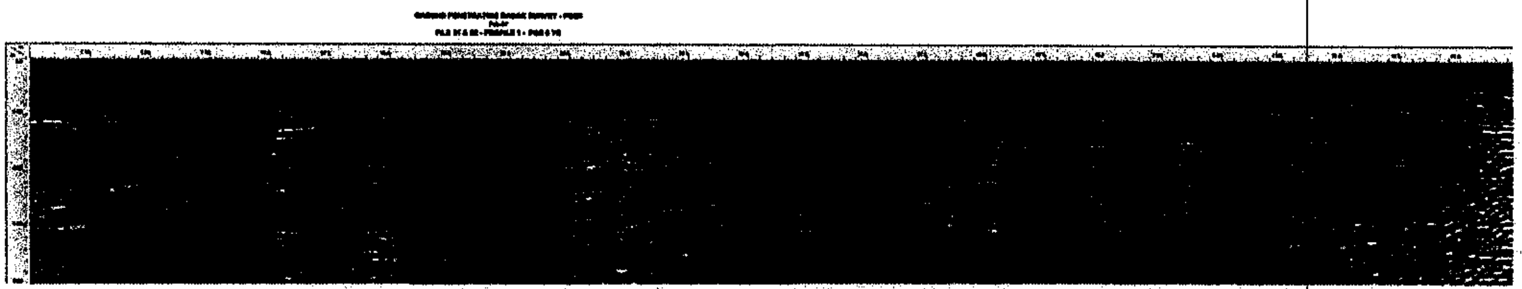


Figure 4: File 51 & 52

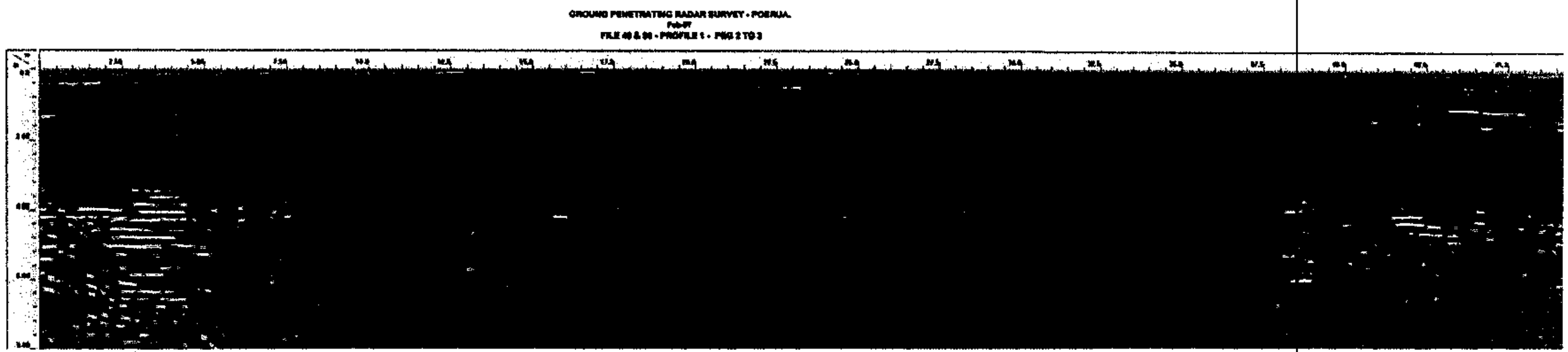


Figure 5: File 49 @ 50 GSSI 200MHz GPR

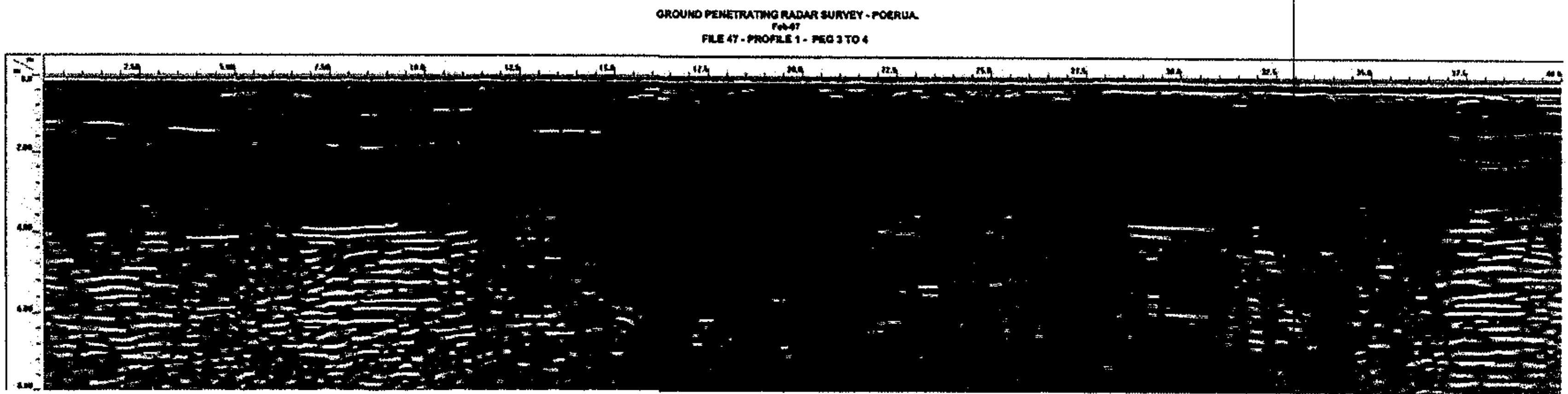


Figure 6: File 47 GSSI 200MHz GPR

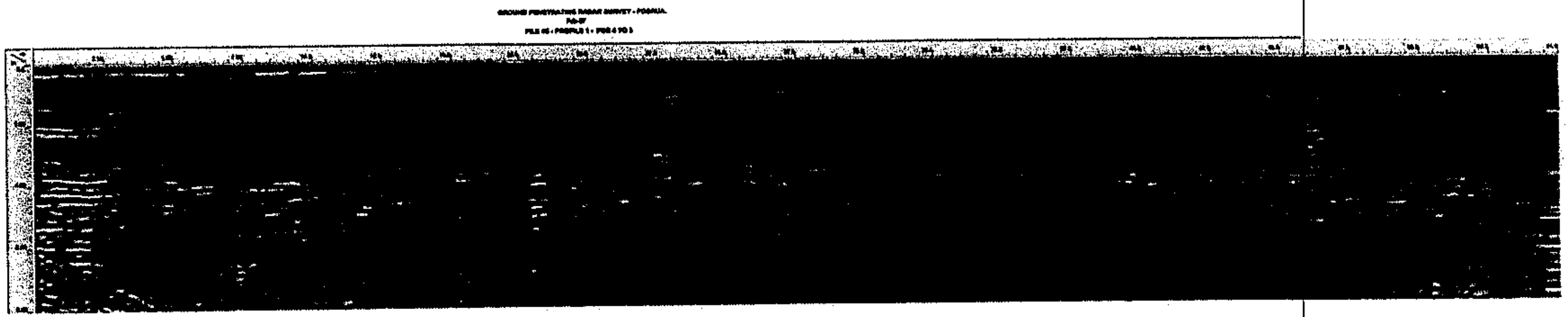


Figure 7: File 48 GSSI 200MHz GPR

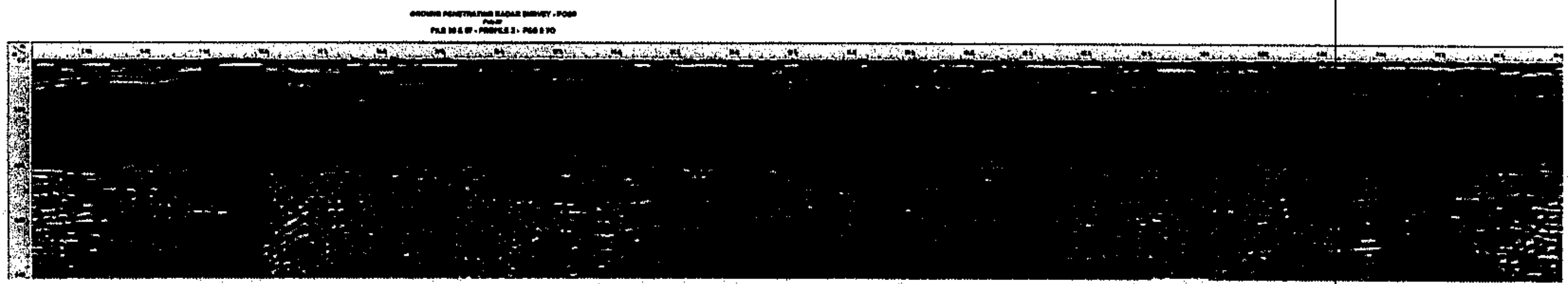


Figure 8: File 56 & 57 GSSI 200MHz GPR

Figure 9: File 54 GSSI 200MHz GPR

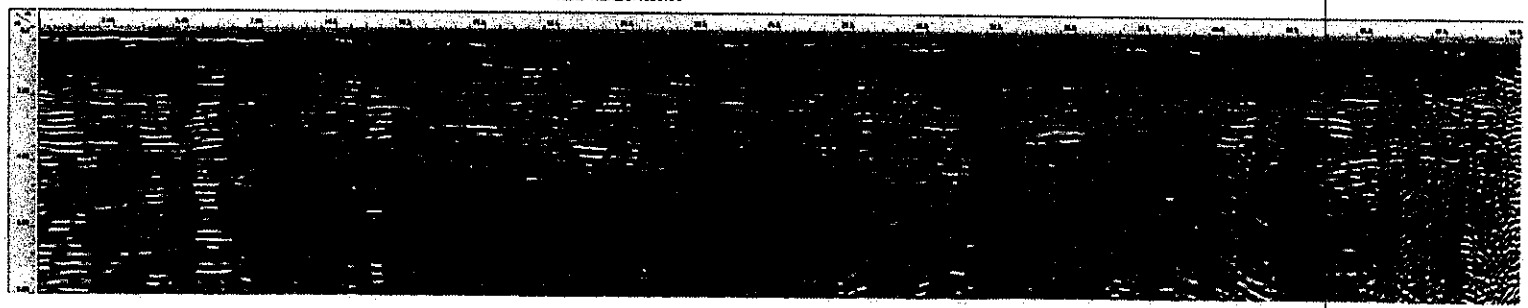


Figure 10: File 55 GSSI 200MHz GPR

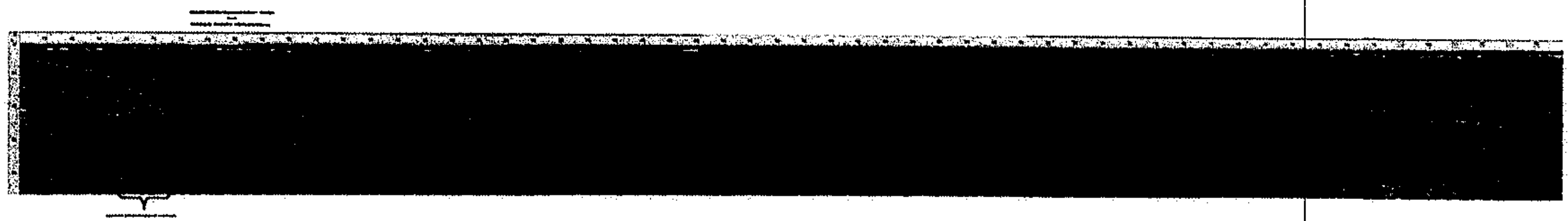


Figure 11: File 58 & 59 GSSI 200 MHz GPR

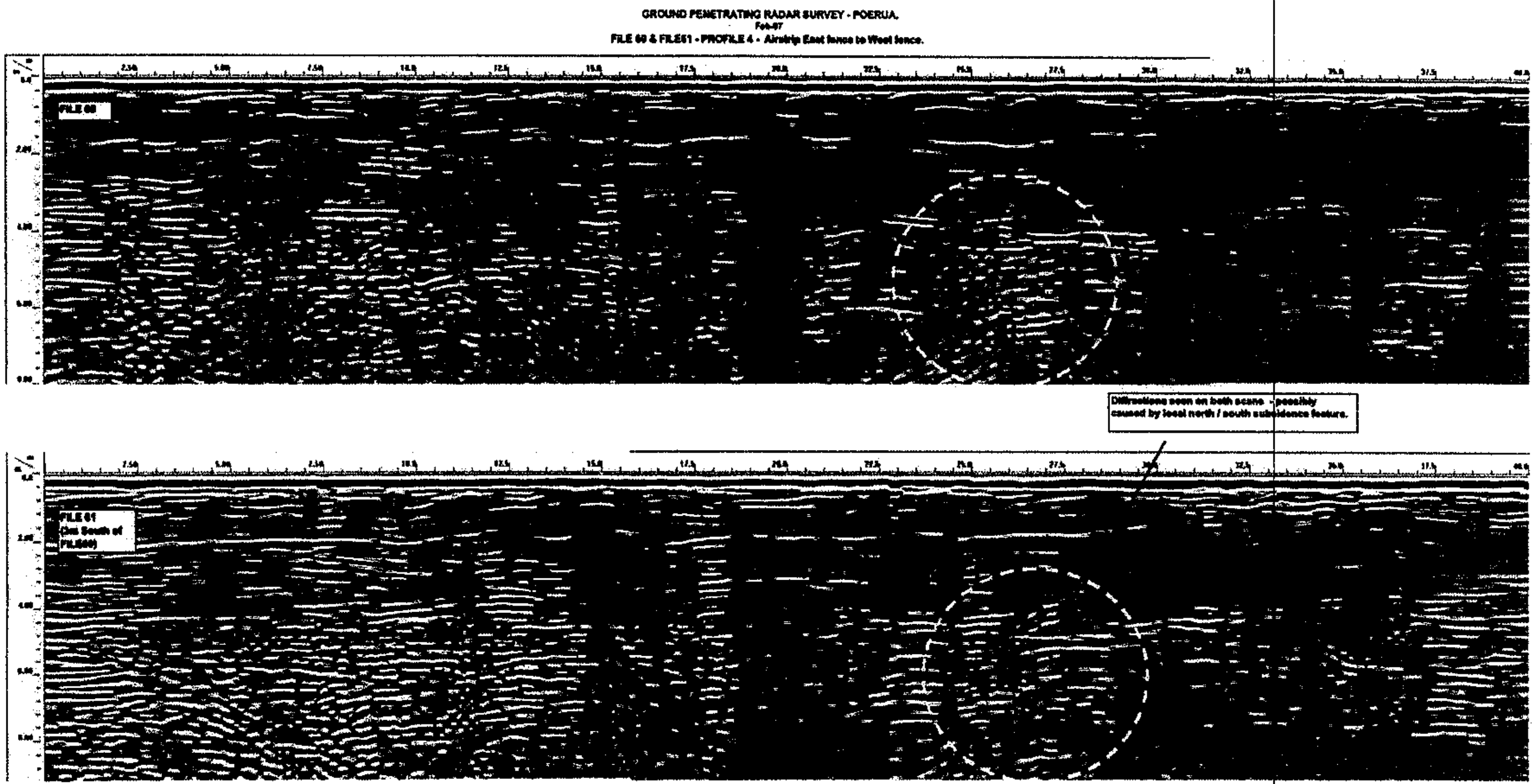


Figure 12: File 60 & 61 GSSI 200MHz GPR

APPENDIX TWO

Lake Poerua Development for Mine Creek Westland Ltd

LOGS & INTERPRETATION OF TRENCHES E, F & G

Report by Jocelyn K Campbell, Department of Geological Sciences, University of Canterbury, Christchurch

COMMENT ON SUPPLEMENTARY TRENCH SITES E TO F LAKE POERUA SUBDIVISION

INTRODUCTION

The three trenches logged in the accompanying figures were excavated on 24th March, 2007. The trenches are aligned with the geophysical transects previously documented (Appendix One), and were designed to ground-truth identified features.

The trenches all expose swamp deposits created by back-filling former river channels with sandy silts and clay, and were clearly produced during episodic channel migration on a low-lying gravel flood plain. All the evidence suggests that this was generated by the Taramakau River spilling from its present course north-eastward into the formerly glaciated valley that is now occupied by Lake Poerua: this is entirely compatible with the interpretations given in the original and supplementary report on the Lake Poerua Developpment. The infill sediments show variation in character as discussed below, and may represent some combination of overbank deposits and low velocity traction current deposition, together with finer grained, clay-rich stillwater deposition, probably indicative of close proximity to lake level at the time. Two of the trenches show partial or complete capping of the channel fills by a flush of coarse gravels indicating that the river was still active to the time of deposition of the modern surface. The 20 to 25 cm thickness of modern organic soil A horizon developed on this surface also indicates that this depositional environment was abandoned quite abruptly without further natural modification.

Although the trenched area lies in a slightly depressed area of poor drainage, it is also clear that these sediments were previously much more waterlogged in the past, and the stiff clay-bearing silts were noted as only moist, but not saturated, at the time of excavation. There are extensive zones of oxidation in both gravels and silts. Evidence of past saturation comes from structures indicative of fluidisation associated with injection and foundering of overburden gravels described below, and very probably associated with past co-seismic shaking. No evidence of shearing or fault displacement was found.

TRENCH E (GPR Lake A-A'; starts at Peg 3 & extends 16.5m to NW; Figure 1; Appendix One)

This was the most stratigraphically informative of the three trenches. At the northwestern end the margin of a channel incised into Taramakau fluvial gravels is exposed. Within the channel three units of finer grained infill sediments are indicative of marked changes in depositional environment. The lowest unit consists of a light-coloured clay rich silt containing scattered small rounded clasts and well-sorted sand lenses presenting some problems in interpreting the origin. At the contact with the channel bank this unit appears to fill an undercut slot in the face, similar to the relationship shown in Trench A (Fig. A5) where a similar clay unit is inset into gravels and clearly overtopped by a separate silt unit. Above the basal unit, the bulk of the channel fill is a moist, grey, fine sandy silt capped by a yellow-brown, silty medium sand, clearly requiring a return to a slightly higher energy mode of deposition and more free draining oxygenated sediment. Accumulation of the grey silts either coincided with, or post-dated, ongoing colluvial degradation of the channel bank, with capping by a veneer of larger cobbles incorporated into the silts at the contact. Clearly the channels were abandoned yet remained open, with local ponding or connection to the lake for a period before being reoccupied by weak traction currents carrying entrained silt and sand.

At the northeastern end there is a distinctive injection of sand fed from one of the sand lenses in the basal unit and penetrating to the surface. Another small fluidisation structure is seen between stations 10 and 11 metres where pebbles from the underlying conglomerates have been rotated upwards into the base of a small injection in the clays involving sand, but not penetrating into the grey silts.

<u>TRENCH F</u> (GPR Lake A-A'; starts 12m to NW of Peg 4 & extends SE to Peg 4; Figure 1; Appendix One)

Similar sediments occupy the channel fill in Trench F. The stratigraphic relationships are more ambiguous but may reflect a similar history. The underlying gravels contain a sand lens with gravel bands clearly dipping to the southeast that may be cross-bedding or indicative of tilting. At the southeastern end the gravels are capped by a light coloured clayey silt similar to the basal unit of fill in Trench E. This is truncated by a grey silty sand following an erosional event that further scoured out the channel. Clay partings pick out bedding close to the southeastern unconformity dipping back towards the northwest. These opposing dips are the only evidence of possible ground deformation observed in any trench, and although they may indicate warping or subsidence, equally they may be primary dips produced during the normal processes of scour and fill. The infill sequence is discordantly capped by gravels similar to those underlying the channel, but with fewer coarse clasts. This contact is highly irregular and is again indicative of fluidisation and foundering of the gravels into the underlying silts. The geometry is strongly suggestive of load structures, but could be a product of tree-throw or man-made disturbance.

<u>TRENCH G</u> (GPR Lake C-C'; starts 2.0m SE from Peg 2 & extends 14m towards Peg 1; Figure 1; Appendix One)

The third trench has the grey silt unit directly overlying gravels, but is sandier and incorporates some gravel clasts and bands towards the base. Any bedding structure is lost towards the centre of the logged section and the lithology becomes increasingly mixed. The gravel capping comes in again locally but is separated from the grey silt by a brown, mouldable silty clay. Again the top contact is highly irregular but may be partially a product of scouring as well as possible fluidisation in the disturbed zone.

DISCUSSION

The clear evidence of injection in Trench E, coupled with the indications of foundering and load structures in Trench F and G, suggest a significant disturbance event post-dating deposition of the whole sequence. Wood recovered 0.5 m down in similar grey channel fill silts in Trench B (Wk20708) returned a radiocarbon age of 254 ± 38 yrs BP. This young age lies in an ambiguous zone of calibrated ages that could conceivably encompass the older 1620 ± 10 date for the penultimate Alpine

Fault event (Yetton et al. 1998) at the second standard deviation, but ranges up to dates that would overlap the last 1715 ± 15 event at the young end within the first standard deviation (calibration diagram appended in Appendix Three). Since the stratigraphy indicates that the fluidisation event post-dates both deposition of the grey silts and the overlying gravel, the balance of probability favours correlation of this disturbance with the more recent Alpine Fault event.

The observations from the trenches raises four significant points with respect to the subdivision:

i. The site, lying east of the projected rupture trace of the last two events, would have been lifted relative to lake level at the time of the last earthquake. This would account for the observation of deltaic and related lake level deposits above present water level, rather than inferring a former higher stand of the shoreline. The saturated, fine-grained sediments in the channel fills probably deposited at, or close to, lake level are now uplifted above the static water table. They are unlikely to undergo similar fluidisation again, although some differential settlement could still occur across former channels because of the differences in sediment properties and degree of compaction.

ii. Despite proximity to the projected fault trace no evidence of secondary faulting or intense deformation of the sequence was observed, apart from some possible subsidence coinciding with a disturbed zone in Trench G.

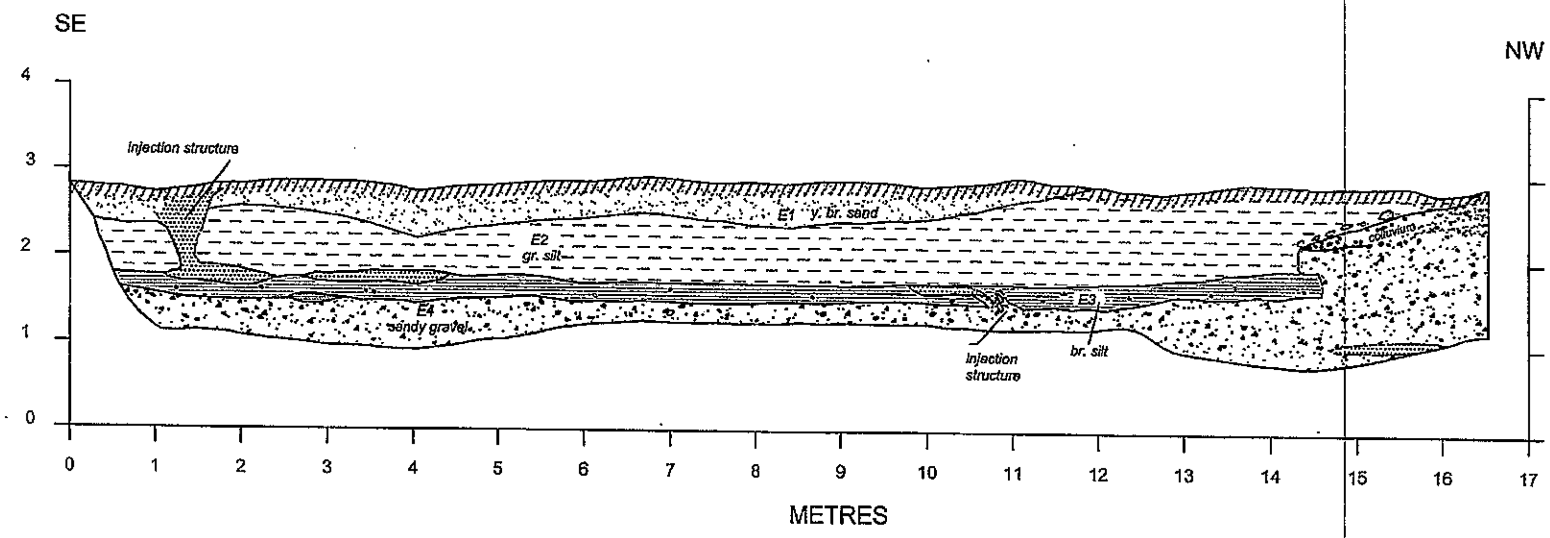
iii. As noted in the main report, there is no evidence for the introduction of any locally derived material over the old gravel surface, such as schist landslide or debris flow deposits associated with this shaking event, that could be attributed to slope failure in the adjacent hillslopes affecting the residential subdivision area.

iv. At least some fluvial activity was still taking place over this area up to, or shortly preceding, the last rupture event. There is no evidence of further reworking or overbank flooding since, indicating that this area was now above river level, and it is likely that any drainage from the Taramakau River into this catchment had ceased at this time (ie immediately after the last Alpine Fault rupture event).

Jocelyn K Campbell
September 2007

POERUA SUBDIVISION

TRENCH E



E1 yellow-brown, silty medium sand

E2 grey, sandy silt, soft and moist

E3 cream grey-brown, clayey silt with scattered rounded small clasts and lenses of loose sand

E4 grey-brown, loose, sandy coarse gravel with subangular greywacke clasts

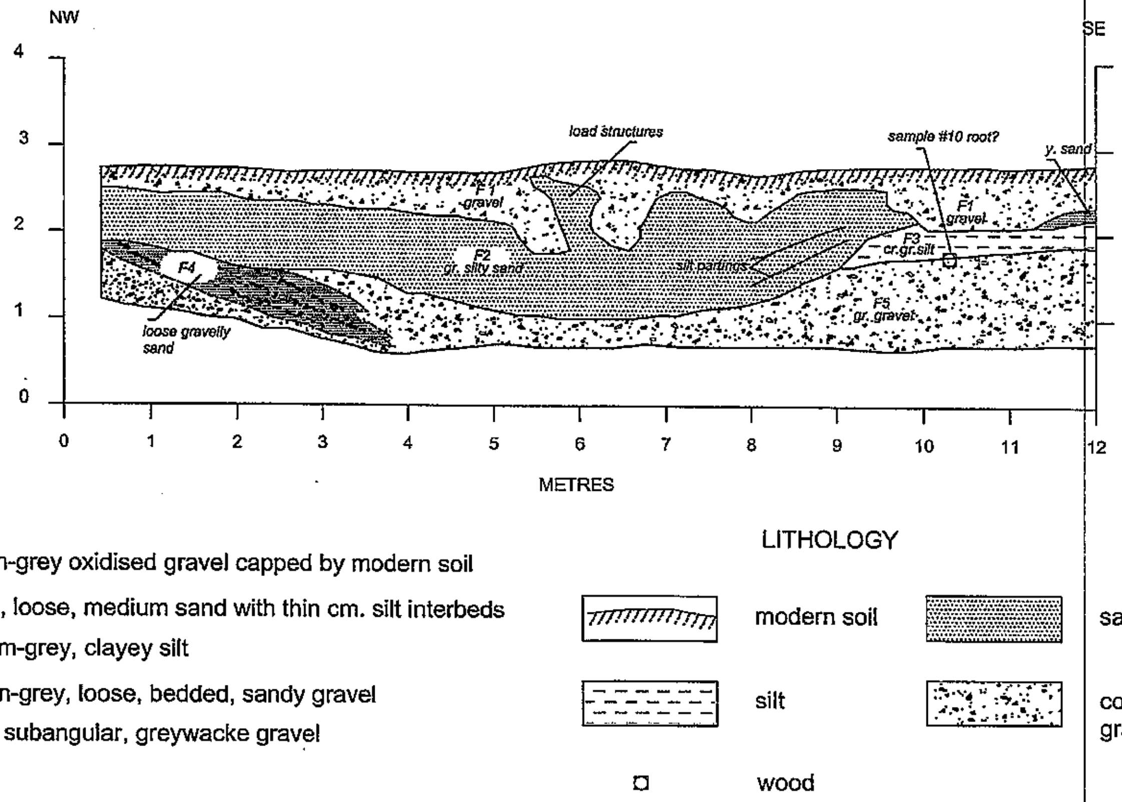
LITHOLOGY

- modern soil
- silt
- silty sand
- sand
- silt with scattered clasts
- coarse sandy gravel

LOGGED BY	D.H. Bell, J.K. Campbell, C. Chenery
DATE	24/ 03 /07

POERUA SUBDIVISION

TRENCH F



F1 brown-grey oxidised gravel capped by modern soil

F2 grey, loose, medium sand with thin cm. silt interbeds

F3 cream-grey, clayey silt

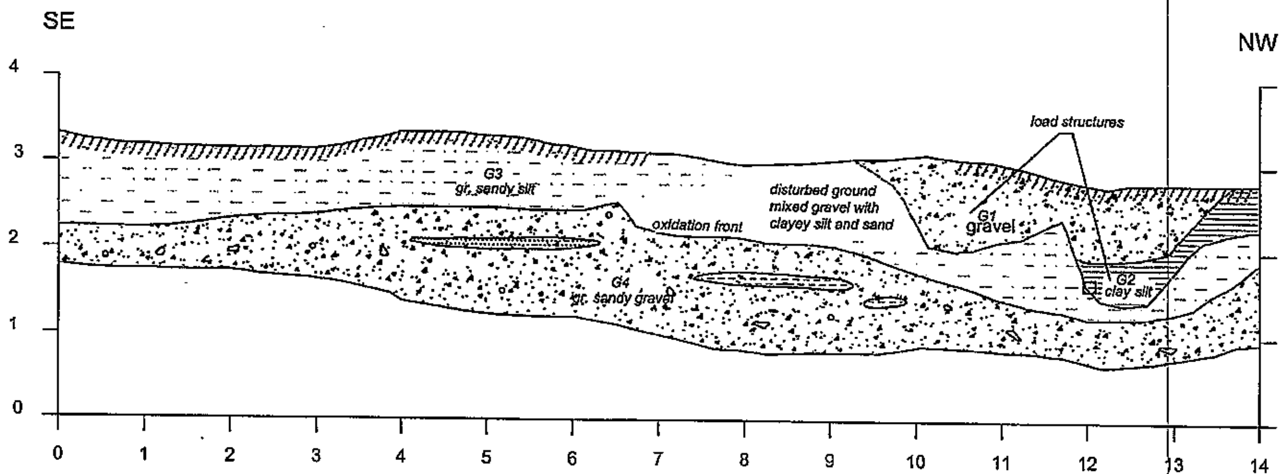
F4 brown-grey, loose, bedded, sandy gravel

F5 grey, subangular, greywacke gravel

LOGGED BY	D.H. Bell, J.K. Campbell, C. Chenery
DATE	24/ 03 /07

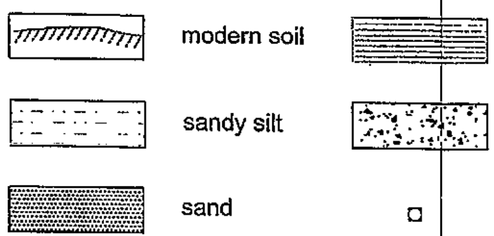
PÓERUA SUBDIVISION

TRENCH G



G1	grey-brown, unsorted, subangular sandy greywacke clast gravel
G2	grey-brown, clayer silt
G3	medium grey, clayey silt with sandy laminae becoming gravelly near the base
G4	grey, coarse sandy gravel with subangular clasts of greywacke

LITHOLOGY



LOGGED BY	D.H. Bell, J.K. Campbell, C. Chenery
DATE	24/ 03 /07

APPENDIX THREE

Lake Poerua Development for Mine Creek Westland Ltd

DETAILS OF RADIOCARBON SAMPLE & AGE RESULT FOR Wk 20708

Analysis by Radiocarbon Dating Laboratory, University of Waikato

Type of site (eg. bog, glacial, midden, artefact): overbank silts in extensive depression formed in Taramakau R. gravels — possibly fault related (Alpine Fault)

Country: New Zealand

National grid ref: NZMS 260 Sheet K32 Lat: Long: 867 316 Grid Ref.

STATEMENT OF STRATIGRAPHY:

overbank silts

Taramakau River gravels with sand & silt

?kahikatea logs @ ~108m & depth 0.50 → 0.55m

swamp deposits within 100m of Alpine Fault may post-date last rupture c.1700 AD. Chance of swamp is in tectonic ?depression

Please attach stratigraphic drawing with clearly indicated sample position(s) and other environmental details:

ESTIMATE AGE: 300-500 yrs **AGE LIMITS**

Basis of estimate: Less than 500 years — pond ?fault-related

From: Modern To: >1,000 yrs

RADIOCARBON DATING OPTIONS: (Please see current price list, or contact lab directly)

(Please tick)

(✓) Standard Radiometric

( ) AMS

(✓) Express date (Applicable only to Standard Radiometric determinations)

( ) Holocellulose extraction (Advised for samples of wood >20K)

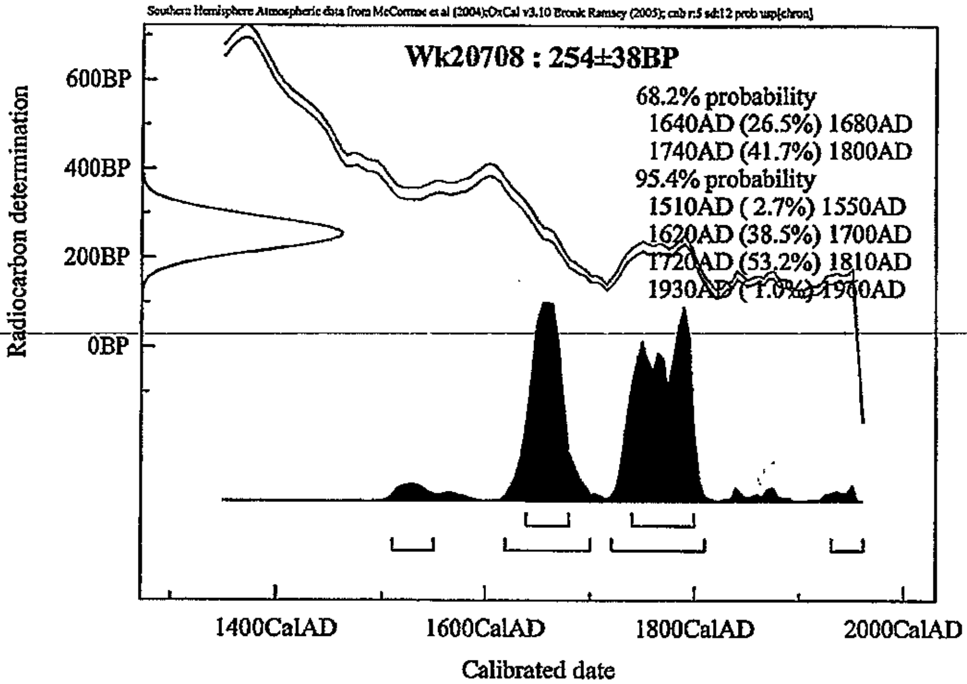
( ) Bone gelatinisation (Recommended for all bone samples. Includes %N, $\delta 13C$ and $\delta 15N$ analysis)

RESULT TO BE SENT TO: DAVID BELL

c/- Bell Geoconsulting Ltd

PO Box 31-031

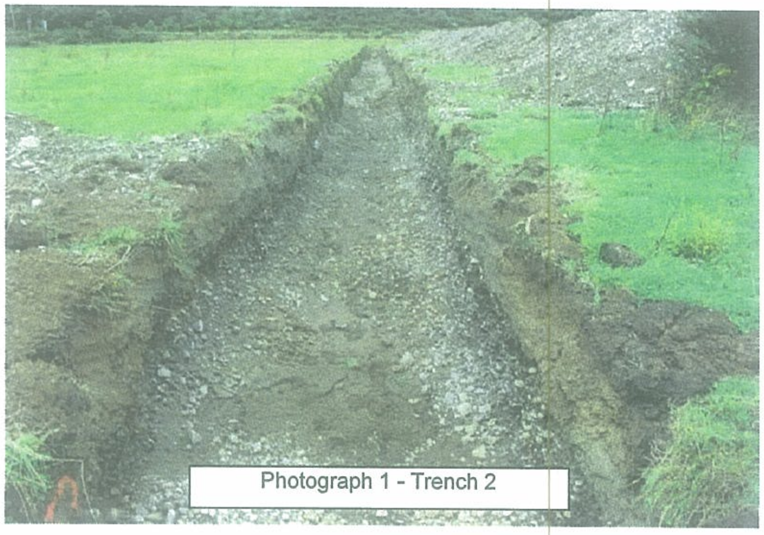
CHRISTCHURCH 8041.


Southern Hemisphere Atmospheric data from McCormac et al (2004);OxCal v3.10 Bronk Ramsey (2005); cub r:5 sd:12 prob usp[chron]
Wk20708 : 254±38BP
68.2% probability
1640AD (26.5%) 1680AD
1740AD (41.7%) 1800AD
95.4% probability
1510AD (2.7%) 1550AD
1620AD (38.5%) 1700AD
1720AD (53.2%) 1810AD
1930AD (1.0%) 1960AD
600BP
400BP
200BP
0BP
Radiocarbon determination
1400CalAD
1600CalAD
1800CalAD
2000CalAD
Calibrated date

APPENDIX E

ANNOTATED TRENCH PHOTOGRAPHS

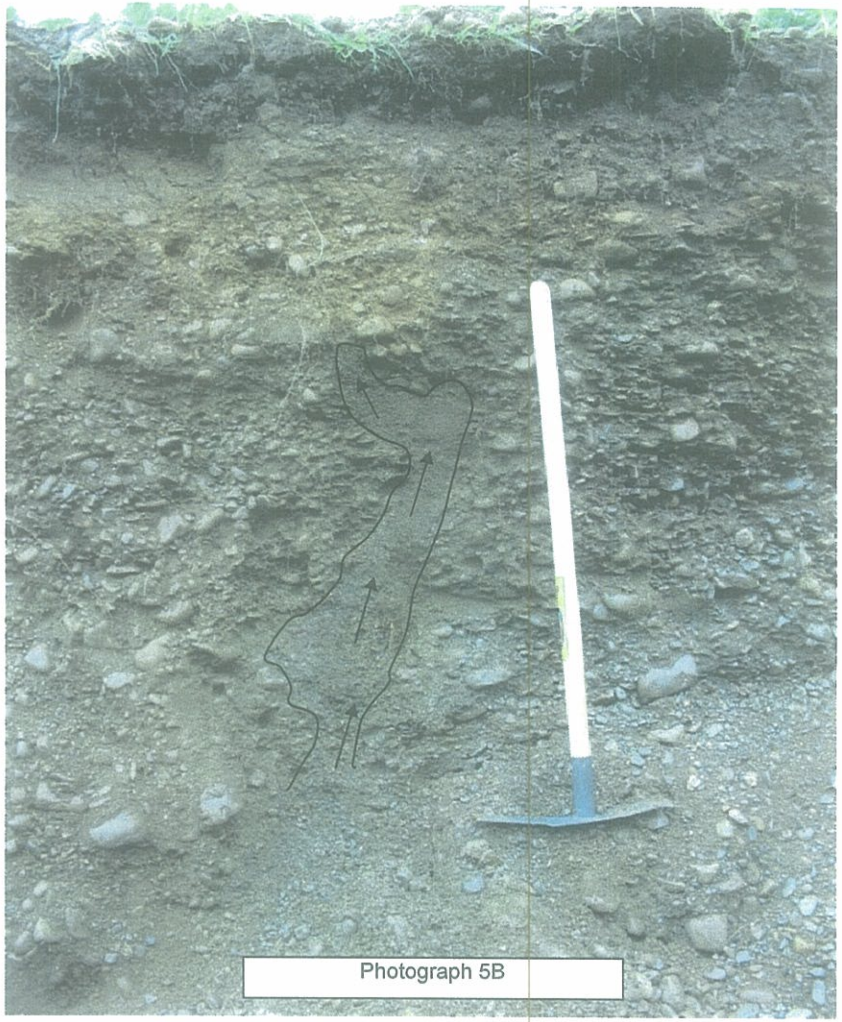

Photograph 1 - Trench 1


Photograph 1 - Trench 2


Photograph 1 - Trench 3


Photograph 1 - Trench 4

Comment: All photos taken looking south east	CLIENT: Grant Marshall		TITLE: Annotated Trench Photographs (2006)	
	DRAWN: JM	DATE: 13/03/2006	PROJECT: Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland	
	CHECKED: LRC	DATE: 30/07/2007		
Golder Associates	SCALE: na	A4	PROJECT No. 06812016	FIGURE: E1



Comment: Flathead grubber is 1.0 m long	Golder Associates	CLIENT: Grant Marshall		TITLE: Annotated Trench Photographs (2006)	
		DRAWN: JM	DATE: 13/03/2006	PROJECT: Geotechnical Assessment, Proposed Subdivision, Lake Porerua, Westland	
		CHECKED: LRC	DATE: 30/07/2007		
		SCALE: na	A4	PROJECT No.: 06812016	FIGURE: E2

APPENDIX F

LATE HOLOCENE FAULT TRACES IN THE VICINITY OF INCHBONNIE

MAP TAKEN FROM PAPER BY

FROM BERRYMAN ET AL., 1992[3]

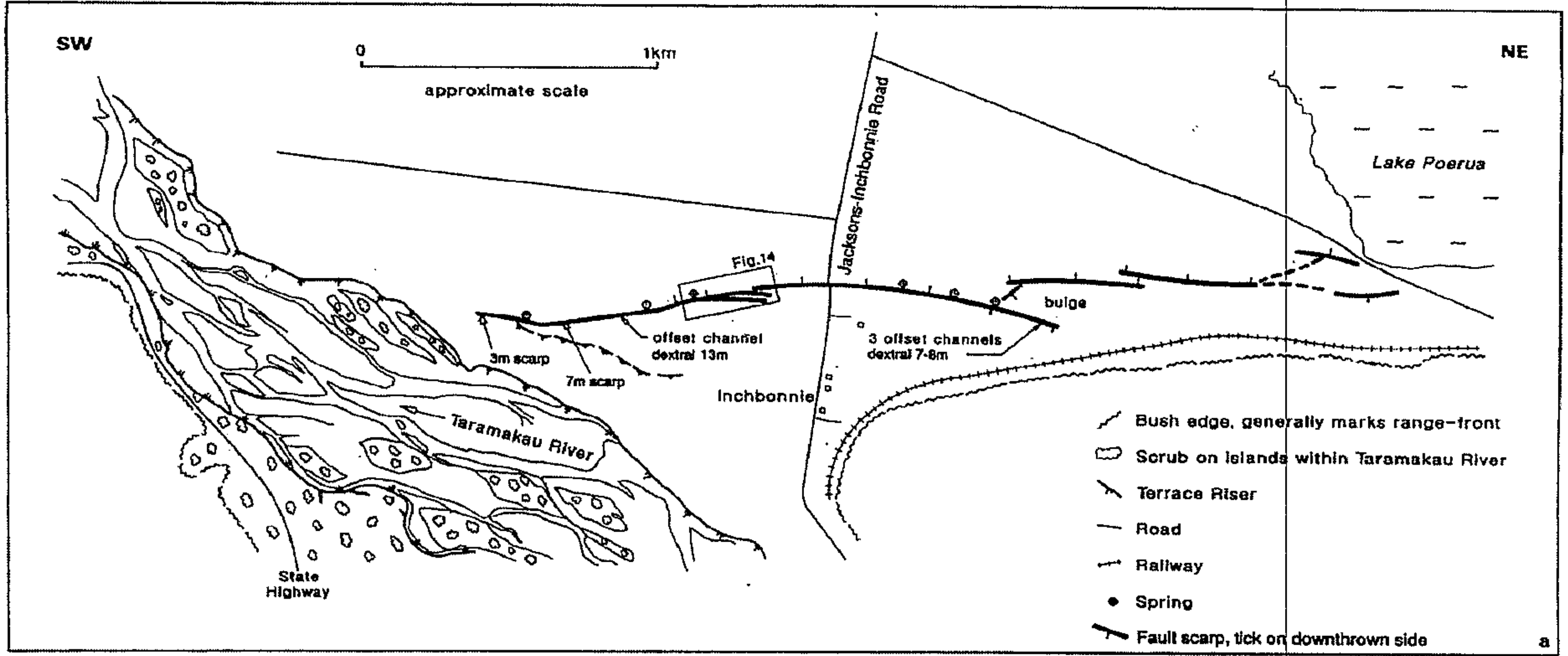


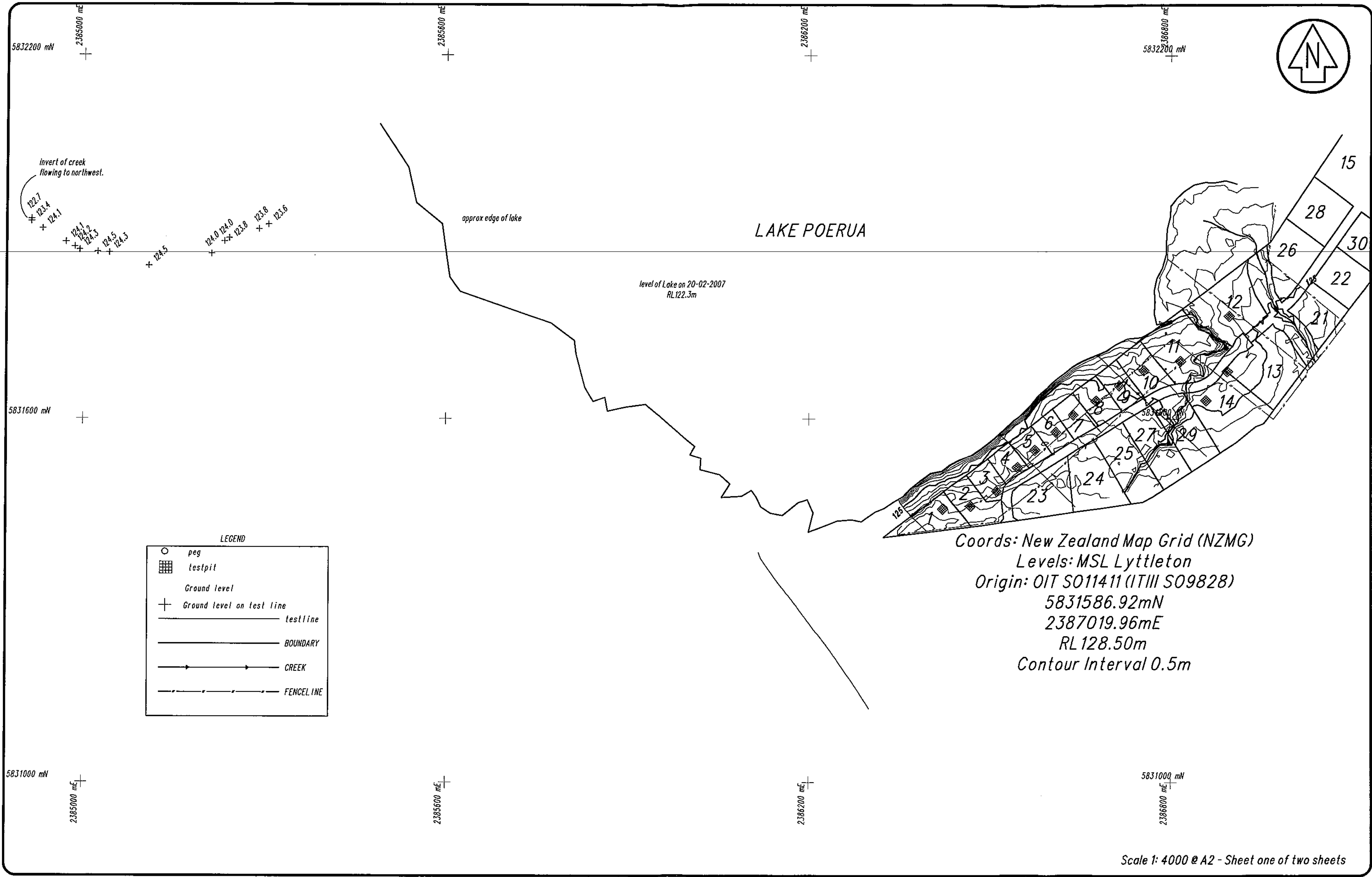
Fig. 13a - Late Holocene fault traces in the vicinity of Inchbonnie. Note the left-stepping en-echelon pattern with bulges between fault strands.

APPENDIX G

TOPOGRAPHIC SURVEY

BY

COWAN AND HOLMES LTD (2007)



AMENDMENTS

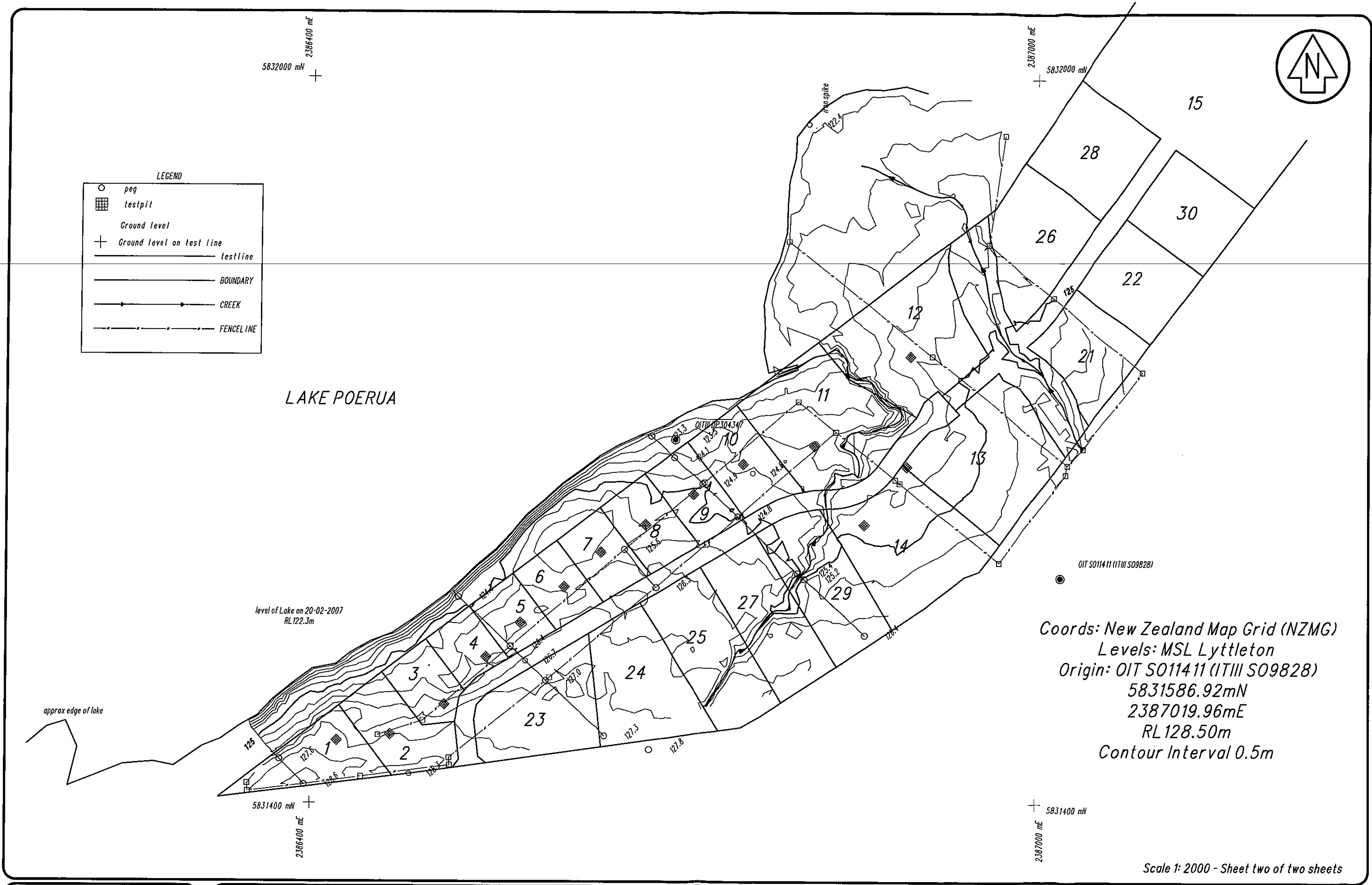
Site Plan of proposed subdivision - Lake Poerua -

CLIENT:
Mine Creek Westland Limited
298 Worsleys Road
Cashmere
CHRISTCHURCH

Cowan and Holmes Limited
Surveyors and Resource Managers
PO Box 156 ph 03 768 6299 fax 03 768 5017
GREYMOUTH office@chsurvey.co.nz

DATE: Feb 2007
5386

CAD file: W:/5386 MINE CREEK Subdv/5386 Survey/mine creek topo.lcd
Print file: W:/5386 MINE CREEK Subdv/5386 Survey/mine creek topo.pdf
Export file: W:/5386 MINE CREEK Subdv/5386 Survey/mine creek topo.dwg



AMENDMENTS

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CLIENT:
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GREYMOUTH office@chsurvey.co.nz

DATE: Feb 2007

5386

CAD file: W:/5386 MINE CREEK Subdv/5386 Survey/mine creek topo.lcd
Print file: W:/5386 MINE CREEK Subdv/5386 Survey/mine creek topo.pdf
Export file: W:/5386 MINE CREEK Subdv/5386 Survey/mine creek topo.dwg

APPENDIX H

SURGE AND SEICH WAVE ANALYSES

BY

GOLDER ASSOCIATES LTD (CANADA)

Golder Associates Ltd.

2640 Douglas Street
Victoria, British Columbia, Canada V8T 4M1
Telephone (250) 881-7372
Fax (250) 881-7470

July 19, 2007

E/07/325
068-12016

Golder Associates (NZ) Ltd.
Level 1, 79 Cambridge Terrace
Christchurch, New Zealand

Attention: Mr. Cid Chenery

RE: EMPIRICAL LANDSLIDE AND EARTHQUAKE WATER LEVEL SURGE ASSESSMENT, LAKE POERUA, NEW ZEALAND

Dear Cid:

At your request, Golder Associates Ltd. (Golder) carried out an empirical assessment of potential water level surges on Lake Poerua caused by a landslide into the lake or an earthquake along the Alpine Fault which runs adjacent to the lake on the southeast side. The purpose of the assessment was to provide empirical approximations of water level surges which might affect a proposed land development along the southeast side of Inchbonnie Basin. Debris flows from the west side of the lake that have previously affected lake levels have been recorded[1].

1.0 OBJECTIVES

The objectives of the assessment were to:

- Assess maximum wave runup at the proposed development caused by a potential landslide into the Lake.

- Assess the potential lake seiche amplitude or water level surge caused by a rupture of the Alpine Fault and displacement of the lake bed.

These estimated wave runup and seiche amplitudes are anticipated to be used to guide flood construction elevations on the proposed development.

[1] West Coast Regional Council: Natural Hazards Review. 2002. Report by DTEC Consulting to the WCRC

2.0 BACKGROUND

The proposed development is located on the southeastern shore of the Inchbonnie Basin in Lake Peorua. The lake is approximately 1,000 m wide in the northwest-southeast direction at this location. Water depths in the Inchbonnie Basin attain at least 6.5 m with several areas reaching 6.7 m. Water depths along the shoreline of the proposed development are approximately 3 m at 100 m from the shoreline and 1 m at 50 m from the shoreline[2]. Steep slopes are located on the northern side of the lake across from the development. Landslide scars have been recorded on these slopes[3]. A debris flow channel and fan is situated towards the north end of the proposed development. The active Alpine Fault is located on the eastern margin of the lake.

3.0 ANALYSIS

Available, existing data were used for the analysis. No additional data were collected for this assessment.

3.1 Estimated Maximum Landslide Generated Wave Run-up

A landslide may be treated as a point impact on the water surface creating waves which propagate away from the site of impact. Waves generally decrease in wave height with propagation distance from the source since the wave energy is conserved over a longer and longer wave arc similar to the decay of ripples from a pebble tossed in a pond.

Waves from a debris flow event along the debris flow channel situated to the north of the site will propagate out into the lake away from the site. Since these waves will have to travel across the lake twice, they will be smaller than waves generated on the far shore for a similar sized event.

A landslide from the steep slopes across the lake could be large enough to generate a wave in the lake which could impact the proposed development. An estimate, provided by Golder Associates (NZ) Ltd., of design landslide volume potentially delivered instantaneously to the lake is 79 m^3 per metre length of a wedge type failure. This volume would deposit 35 m out into the lake, in water depths of 4.5 m approximately, at a minimum of 1 km from the shoreline nearest to the proposed development.

The maximum wave height generated by this landslide would be limited by depth of water. A conservative estimate of the depth limited wave height is to take 0.78 times

[2] Lake Ianthe: Lake Poerua 1:8000 Bathymetry, Irwin. J; NZ Oceanographic Institute 1982
[3] Mapworld NZ TopoMAP, Sheet: K32 Ed 2 2000. 1:25,000.

the water depth. Thus the estimated largest wave generated by this landslide would be approximately 3.5 m.

Assuming the waves generated by the landslide propagate across the lake with no loss of energy, as the wave arc lengthens the wave height reduces to meet conservation of energy requirements. An estimate of wave height on the opposite shore can be made by equating the product of the initial wave energy per unit wave width and wave arc length with the final wave energy per unit wave width and final arc length. Wave energy is proportional to wave height squared.

The initial arc length has a radius of 35 m. The final arc length has a minimum radius of approximately 1,000 m. Using these radii and the conservation of energy approach, the final wave height is approximately 0.19 times the initial wave height. With an initial wave height of 3.5 m, the estimated landslide generated wave height along the shore of the development is approximately 0.7 m.

Based on empirical data and experience, wave runup can be estimated as twice the nearshore wave height. Thus wave runup associated with the maximum estimated wave height of 3.5 m from a landslide into the lake is 1.4 m above still water level.

3.2 Estimated Earthquake Generated Wave and Water Level Surge

An earthquake which involves a rupture along the Alpine Fault has the potential to cause a seismically generated seiche in Lake Poerua since the lake is wide and shallow. A seiche is an oscillation of the water surface around a central location caused by stress on the water resulting in the lake surface rising and falling along the shoreline like water sloshing back and forth in a shallow pan. In the case of an earthquake, the seiche is caused by vertical displacement of the lake bed displacing the overlying water and creating a seismically generated wave, rather like a tsunami in the deep ocean.

Based on data provided by Golder Associates (NZ) Ltd., the anticipated vertical rupture of the Alpine Fault may be on the order of 3 m[4]. Large earthquake ruptures in the ocean typically create less than 1 m of vertical displacement in the water surface[5]. Assuming the 3 m displacement produces no more than a 1 m wave in the mean water depth of 5.5 m, which behaves like a seismically generated wave (tsunami), Green's law may be used to estimate shoaling as the wave comes ashore:

[4] Berryman, K.R.; Beanland, S.; Cooper, A.F.; Cutten, H.N.; Norris, R.J.; Wood, P.R. 1992 The Alpine Fault, New Zealand: variation in Quaternary structural style and geomorphic expression. Annales Tectonicae, Special issue - supplement to v.6: 126-163

[5] http://www.appstate.edu/~abbottrn/tsunami/prprts.html

$Hd^{0.25}w^{0.5}$ = constant,

Where H = wave height, d = water depth and w = width of the bay[6].

Since Lake Poerua is approximately rectangular, w may also be considered constant. A maximum 1 m wave in 5.5 m of water transforms into approximately a 1.3 m wave in 2 m of water 50 m from the shore.

An empirical formula used in Japan to estimate run-up from seismically generated waves is:

$$\log_{10}(R/H) = 0.421 - 0.095\log_{10}(l/L) - 0.254\{\log_{10}(l/L)\}^2$$

Where R = runup height (m), H = shoaled wave height (m), l = distance from shore of the shoaled wave height, L = wavelength of wave[7].

Assuming a unimodal seiche event, the wavelength of the wave will be equal to the width of the lake or 1,000 m. The distance from shore of the shoaled wave is approximately 50 m and the estimated wave height is 1.3 m. Simplifying the equation using the numbers above yields wave runup (R) = 1.3 times the seismically generated wave height (H) or approximately 1.7 m.

A preliminary estimate of the seiche period was made using an online seiche period estimator maintained by the University of Delaware[8]. The lake parameters input into the estimator included a lake width of 1,000 m perpendicular to the fault and a maximum lake depth of 6.5 m. A unimodal seiche event was considered allowing the lake water level to oscillate around one point in the lake. The estimator provided a period of approximately 250 s or slightly over 4 minutes.

An estimate of seismic wave velocity using $V = (dg)^{0.5}$ where V is wave velocity, d is water depth and g is gravity, yields an approximate velocity of 8 m/s, resulting in a period of approximately 270 s, using an estimated mean water depth of 5.5 m.

4.0 SUMMARY

Preliminary estimates of wave runup associated with landslides and water level surge (seiching) associated with an earthquake were developed for a proposed land development on the southeastern shore of Lake Poerua in New Zealand. The preliminary estimated maximum wave height generated by a landslide is 1.4 m at the proposed site. The preliminary estimated seismically generated seiche amplitude is

[6] Shelton Liu, Golder Associates, pers. comm. June 3, 2007
[7] Shelton Liu, Golder Associates, pers. comm. June 3, 2007
[8] http://www.coastal.udel.edu/faculty/rad/seiche.html

1.7 m at the proposed site. The preliminary estimated seismically generated seiche period is of the order of 250-270 s.

5.0 CLOSURE

We trust that the information contained within this letter meets your present needs. Please contact the undersigned should you have questions.

Yours very truly,

GOLDER ASSOCIATES LTD.

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RJA/PWM/knb
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APPENDIX I

DEBRIS FLOW ANALYSES

AND

RISK ANALYSES

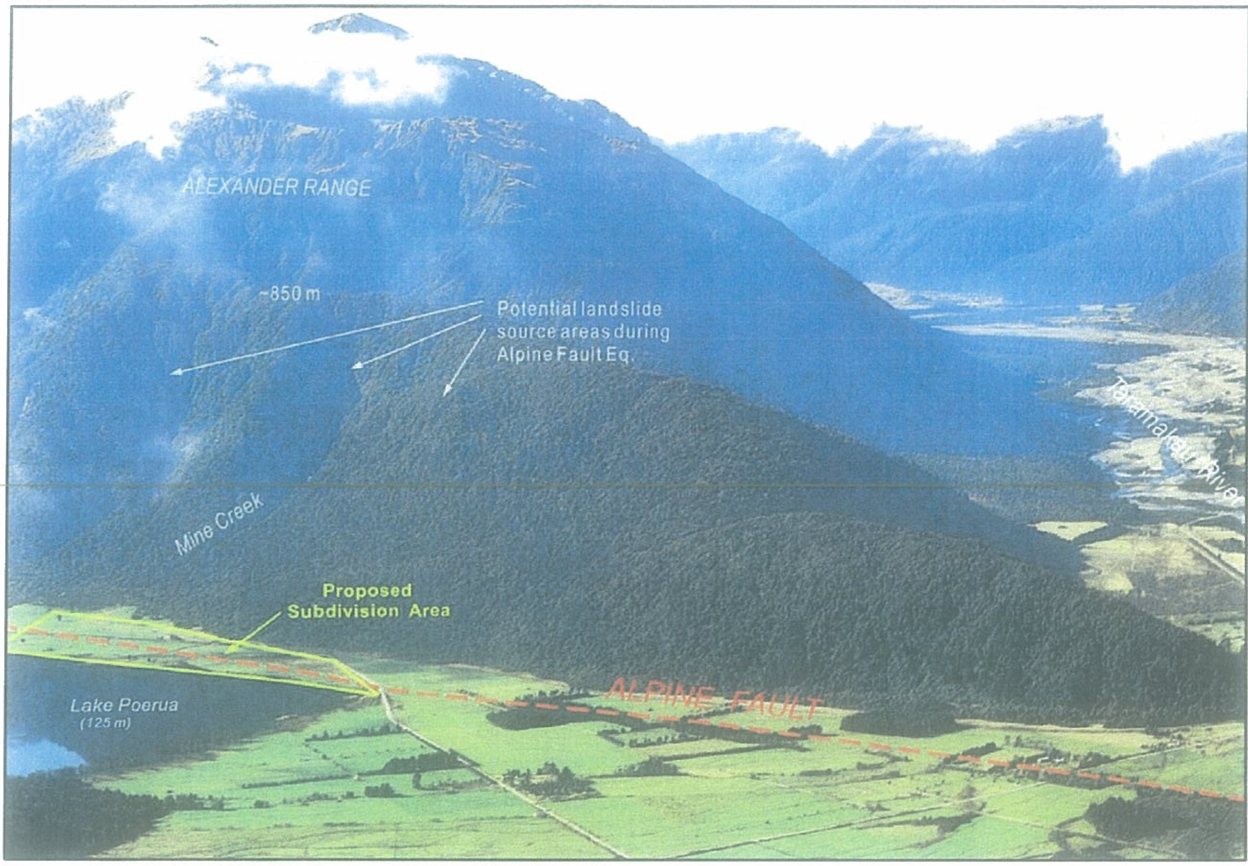
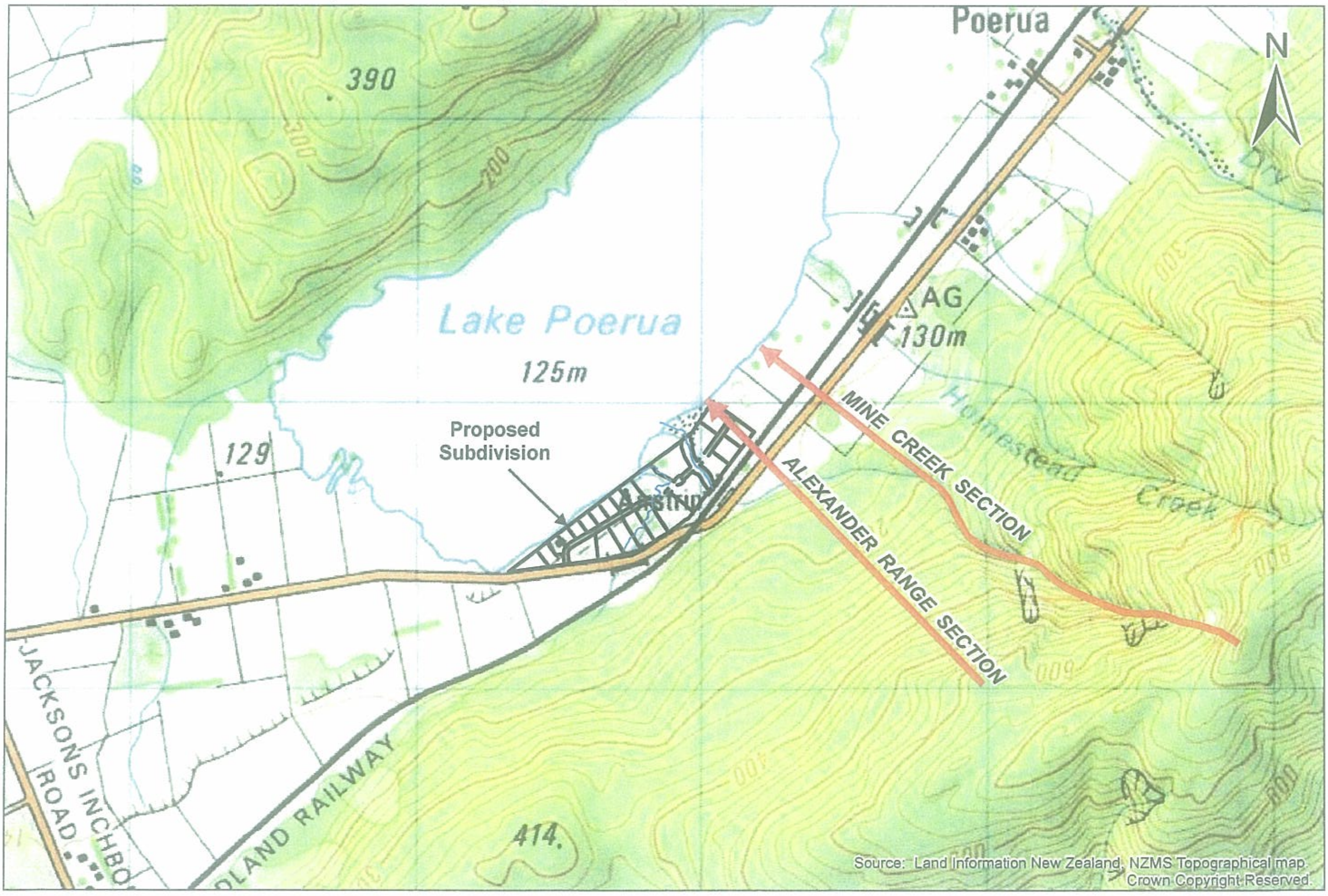
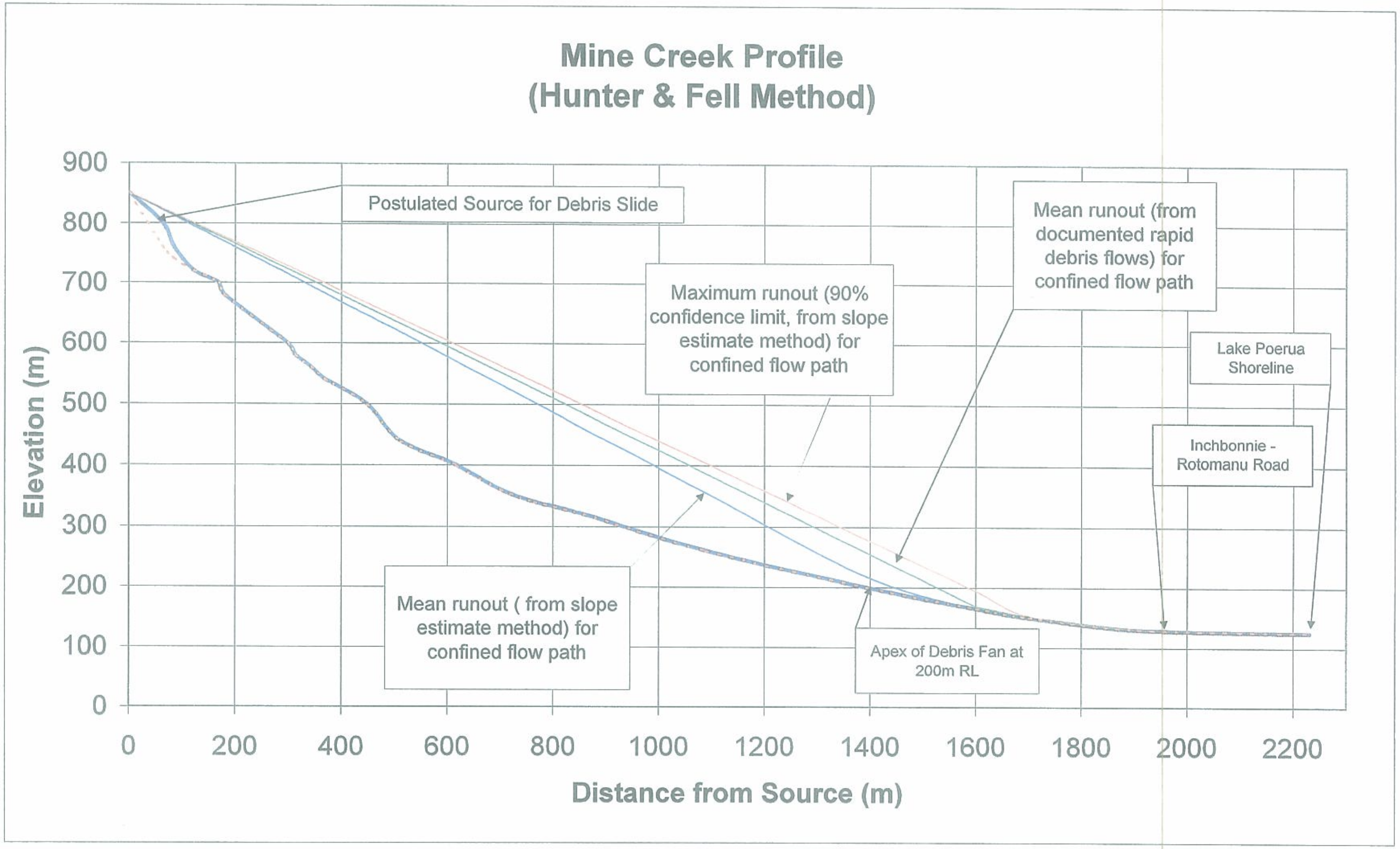


Photo from GNS review (Hancox and Langridge 2006) [6]



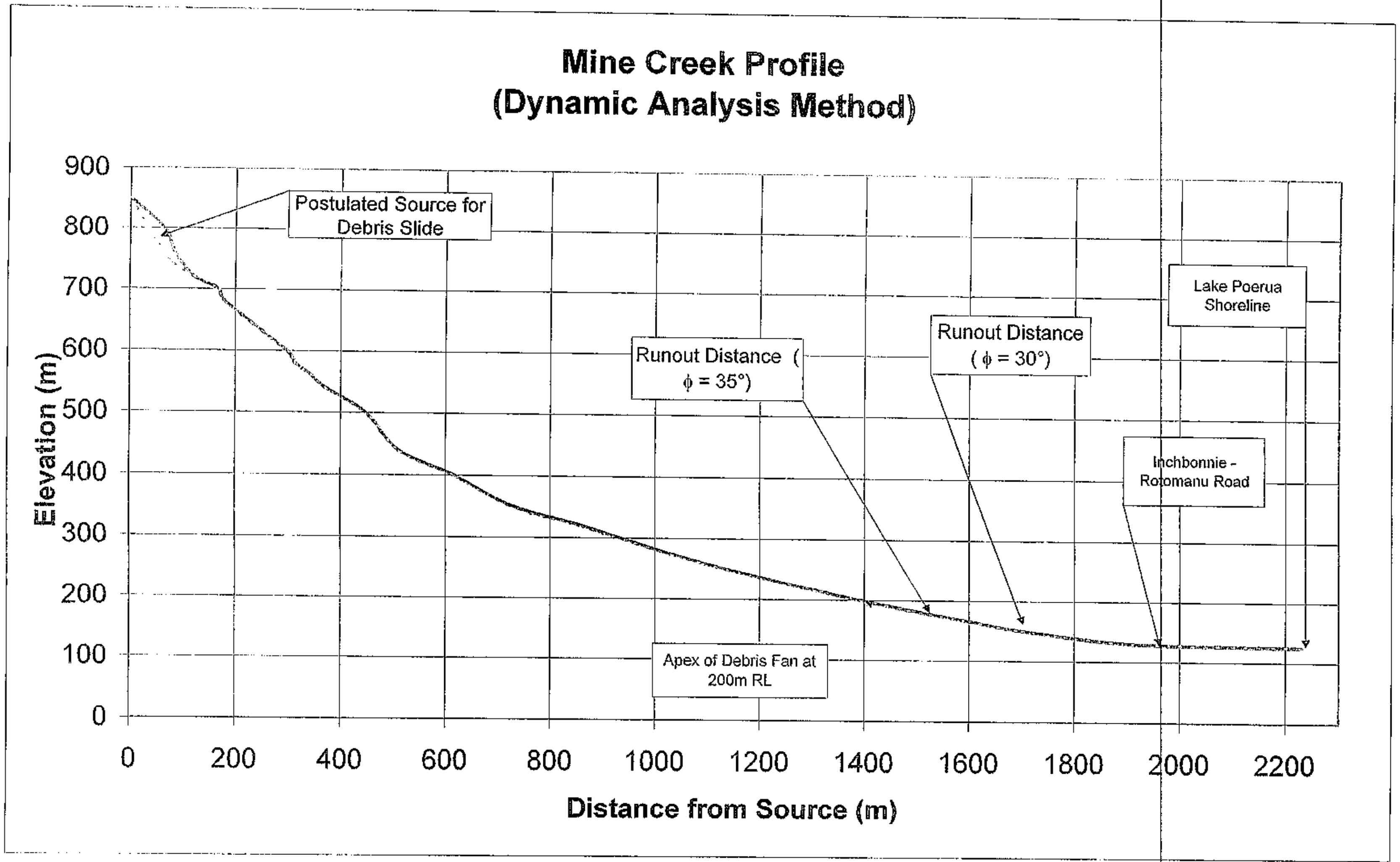
Golder Associates					
CLIENT	Grant Marshall		PROJECT	Geotechnical Site Suitability Assessment, Proposed Subdivision, Lake Poerua, Westland	
DRAWN	MCD	DATE July 2007	TITLE	DEBRIS FLOW SECTION LOCATIONS	
CHECKED	LRC	DATE 24/9/07			
SCALE	1:25,000	A4	PROJECT No 06812016	REPORT No R06812016-02-V2	REV No 0 / APPENDIX I1

File Location: S:\2006Jobs\06812016_Marshall_Subdivision_Poerua\2_Tech_Info\ArcGIS\2007\DebrisFlowSections.mxd

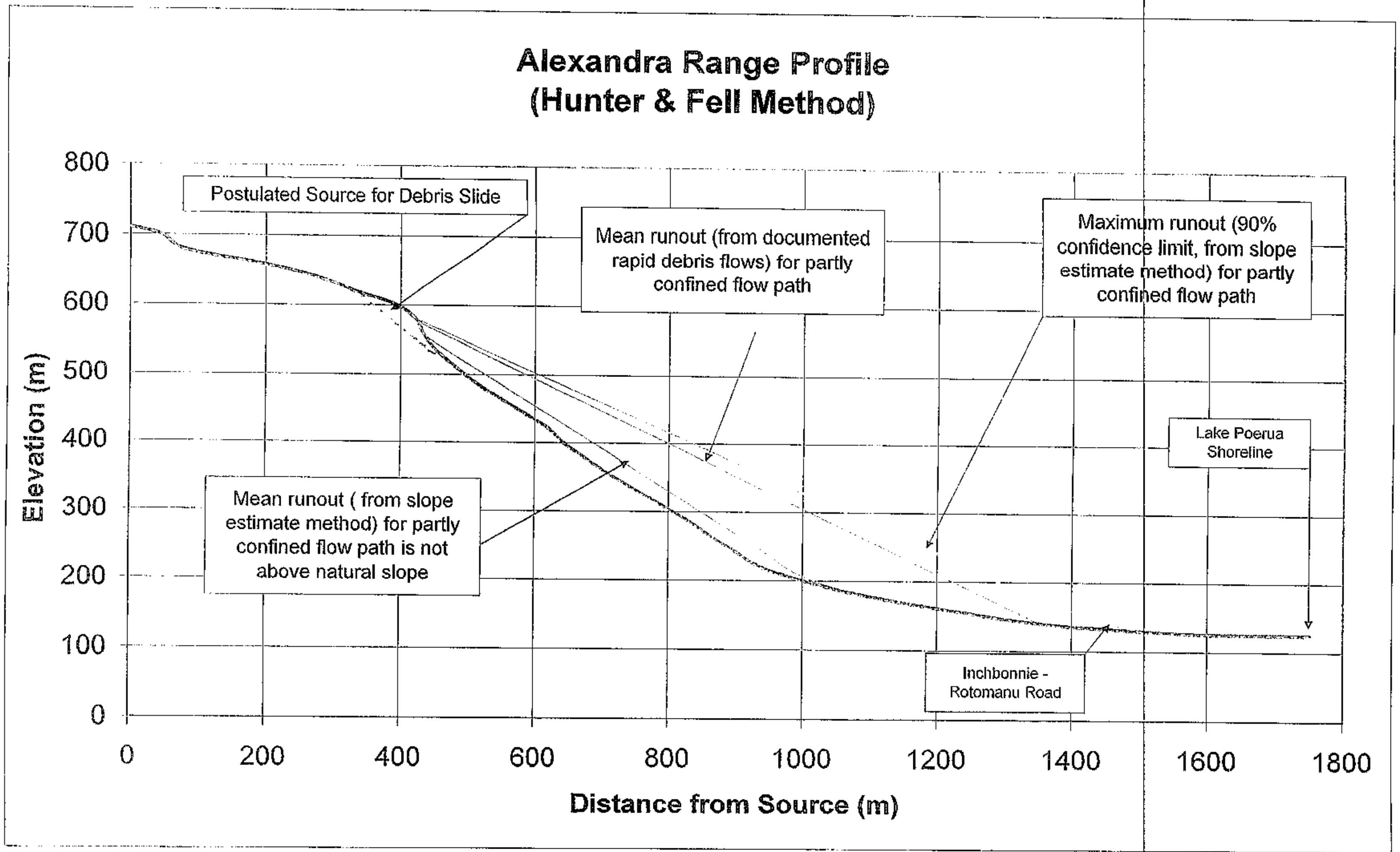


Hunter & Fell Estimation				Calculated H/L			
Pathway	Equation	Claculated Angle α_2		S.Error	-45%	Mean	+45%
Confined	H/L = 0.54*(tan a2) + 0.147	From Source	29.6	0.027	0.410	0.454	0.499

Table 3 Estimated H/L					
SD	Low	-45%	**Mid**	+45%	High
0.11	0.22	0.245	0.426	0.608	0.67

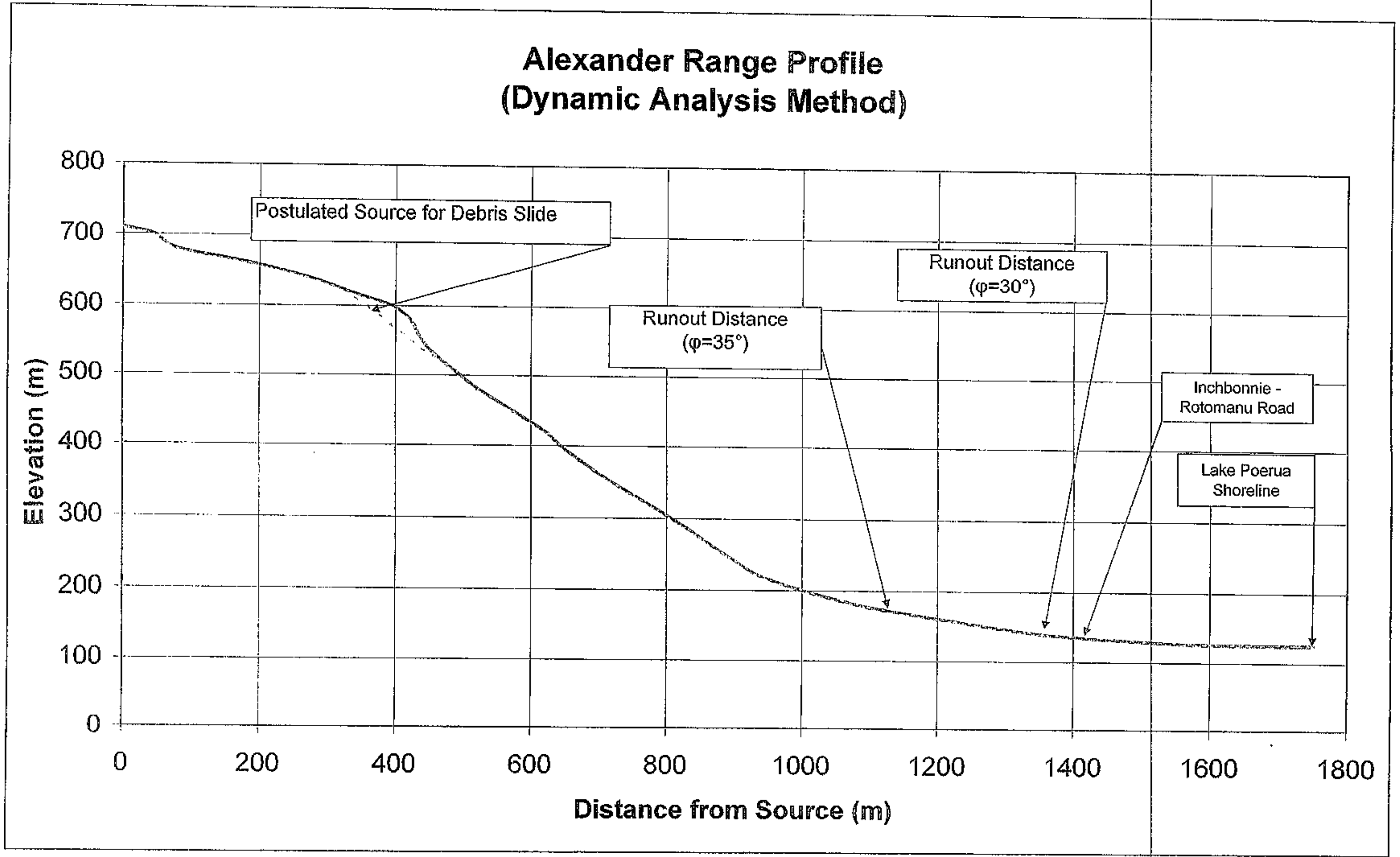


Slope	Volume (m³)	Angle of Internal Friction (°)	Runout Distance (m)	Endpoint
Mine Creek	117000	30	1527	In top of fan
	116000	35	1905	In middle of fan



Hunter & Fell Estimation				Calculated H/L		
Pathway	Equation	Claculated Angle α_2	S.Error	-45%	Mean	+45%
Partly	$H/L = 0.69*(\tan \alpha_2) + 0.086$	From Source 37.6	0.11	0.435	0.617	0.798

Table 3 Estimated H/L					
SD	Low	-45%	Mid	+45%	High
0.114	0.280	0.282	0.470	0.658	0.620



Slope	Volume (m³)	Angle of Internal Friction (°)	Runout Distance (m)	Endpoint
Alexander Range	124000	30	1374	Well uphill of Inchbonnie - Rotomanu Road
	124000	35	1140	Just above Inchbonnie - Rotomanu Road