WAITAHA HYDROELECTRIC SCHEME:

GEOLOGICAL FEASIBILITY REPORT

Prepared for:
ElectroNet Services Ltd

Date: October 2013

Reference: 1930

Prepared by:

Dr Mark Yetton, Geotech Consulting Ltd

Ian McCahon
Tel/Fax (03) 332 3628
E-mail mccahon@geotech.co.nz
29 Norwood St, Beckenham
Christchurch, New Zealand

Nick Traylen
Bus (03) 332 0486, **Fax** (03) 332 0281
E-mail ntraylen@geotech.co.nz
18 Dyers Pass Rd, Cashmere
Christchurch, New Zealand

Dr. Mark Yetton
Tel/Fax (03) 329 4044
E-mail myetton@geotech.co.nz
RD1 Charteris Bay
Lyttelton R.D., New Zealand

Summary

Electronet Services Ltd proposes construction of a hydroelectric scheme on the Waitaha River in central Westland. In general the middle and upper river catchment is steep with the river confined for much of its length in deep gorges. The proposed hydroelectric scheme takes water from the upstream end of Morgan Gorge by means of an underground intake and stilling basin and conveys the water to a powerhouse at river level approximately 1.5km downstream of the intake.

The scheme is located east of the Alpine Fault and entirely within schist and schist derived sediments. The scheme location avoids the weakest mylonite material that is located immediately adjacent to the Alpine Fault. The tunnel will be built mainly in strong to very strong foliated high grade schist rock that is broadly similar to the rock recently tunnelled 10km southwest of this area as part of the Amethyst hydroelectric scheme. Relatively dense post glacial aggradation gravels are present as a terrace cap at the downstream (powerhouse) end of the tunnel.

The main tunnel direction is well oriented with respect to the bedrock foliation which has a strike that is approximately perpendicular to the tunnel and a moderately steep dip of 60-85 degrees southeast (upstream). The proposed intake site at the upstream end of Morgan Gorge has the best bedrock quality observed so far in the local Waitaha area. Foliation partings (shears) are spaced at more than 3m intervals and the joint spacing is relatively wide (1.5 – 1.7m). The dominant joint set is oriented with dips to the west and northwest but at this location the intake orientation appears well placed to avoid running exactly parallel to the local dominant joint set. Joint surveys at other locations upstream and downstream of the gorge suggest there may be a set of joints that could present support issues for a tunnel aligned NNW and an alignment as close to north as possible may be preferable. The current proposed tunnel alignment adopts this more northern orientation and incorporates a bend approaching the downstream portal and powerhouse. Depending on the results of detailed joint surveys from drill core at the next phase of subsurface investigations the final tunnel alignment may be straighter and the total tunnel length could be made slightly shorter.

The scheme location avoids the Alpine Fault zone with its network of active fault traces. The closest identified Alpine Fault trace is approximately 250m downstream from the proposed powerhouse. There are other faults in addition to the Alpine Fault that are previously mapped in the area or apparent in the field. It is possible these other faults are also active structures. The main impact of future fault rupture and/or large earthquakes in the scheme area is on the future maintenance and operation of the scheme. There is no proposed significant new water storage structure and the proposed construction of the various scheme components will not create additional seismic hazards or seismic risks for either the local environment or river users.

Subsurface investigations are proposed as the next stage of geological work and in particular cored rotary drill holes in key locations in conjunction with digger pits in the proposed powerhouse area.

Table of contents

Attachments

1. *Introduction*

Electronet Services Ltd proposes construction of a hydroelectric scheme on the Waitaha River in central Westland. The Waitaha catchment extends to an elevation of 2640m over a length of 40km and drains 223km^2 of catchment to the gauging site at the SH6 bridge. The catchment includes the Bromfield and Smythe Ranges with numerous peaks above 2100m and some areas of permanent snow. In general the middle and upper catchment is very steep with the river confined for most of its length in deep gorges. Bush and scrub cover account for only 40% of the catchment area and this is generally below 1200m. The river has a high bed load.

The proposed hydroelectric scheme takes water from the upstream end of Morgan Gorge by means of a tunnel to a powerhouse located approximately 1.5km downstream of the intake [Figure 1]. A civil pre-feasibility report incorporating geological information was prepared in May 2005 that considered a range of tunnel and intake options from which the current proposal has been adopted and further refined.

2. *Background and details of the work undertaken*

The earlier 2005 report was based on approximately one weeks field work consisting of preliminary mapping and examination of obvious outcrops, in addition to aerial photographic interpretation. This report incorporates the earlier information in addition to more detailed information collected during a further 8 days of fieldwork undertaken in May 2013. Satellite images have been used to supplement available aerial photographs of the area to assist with the location of potential faults. To date no subsurface investigation has been undertaken. In the period between this report and our work in 2005 the nearby Amethyst Hydro scheme has been investigated and constructed. The Amethyst scheme is located approximately 10km southwest of Waitaha within very similar geological conditions and provides some guide to the likely subsurface conditions.

3. *Bedrock geology*

The proposed hydroelectric scheme is located east of the Alpine Fault entirely within schist and schist derived mylonite bedrock that is now assigned to the Aspiring lithologic association of the Torlesse composite terrane [Cox and Barrell, 2007] but was formerly assigned to the Haast Schist Group [Warren, 1967]. The schist is a well foliated quartzo-feldspathic biotite schist of the garnet and oligoclase zones that in outcrop is typically a strong to very strong rock. It is important to note that the outcrops tend to be the hardest and most resistant material. Because faulting is widespread in the area, there will be many weaker areas of schist that are not exposed and remain hidden under thick vegetation cover or alluvial cover sediments.

The schist derived mylonite is located closest to the Alpine Fault [generally within a 200 – 400m wide zone] and has an additional finer layering [fabric] that has developed parallel to the fault zone that generally makes it a weaker rock than the normal schist. There is commonly a wavy and undulating foliation surface in a lot of the mylonite material, and where this is present the rock is often referred to as curly schist.

Photograph 1: Strong regularly foliated schist bedrock exposed in the true right bank of the Waitaha River 200m upstream of the proposed location of the powerhouse.

The foliation orientation of the schist bedrock is discussed later in Section 7 along with the bedrock joint orientations.

4. Surficial Materials

There are two main types of surficial material in the area of proposed scheme:

Post-glacial aggradation gravels

Shortly after the end of the most recent glaciation [12,000 – 14,000 years ago] the various Southern Alps catchments flowing northwest to the Tasman sea underwent a major period of erosion as the ice and snow melted and the river flows rapidly increased. The intense first flushing of the formally frozen catchments led to a rapid aggradation of the river beds to elevations typically 100m or more above the current bed levels. The gravel sediment produced from that period is typically rich in silt and sand as a matrix material and the gravel sized clasts are generally smaller than much of the current river bedload. The clasts are also often more angular than the current river bedload.

Since the immediate post glacial period the catchments have vegetated and stabilised so that the river has cut down into the post glacial aggradation surface creating a series of erosion terraces. The process of river downcutting has also been accelerated by the uplift of the Southern Alps that is occurring east of the Alpine Fault trace.

Photograph 2: Post glacial aggradation [pga] gravels exposed in Alpha Creek approximately 100m downstream of the proposed powerhouse.

Because of the high fines content, angularity and age of the post glacial aggradation gravels [the age has allowed some cementing over the elapsed time] the pga material is relatively cohesive and strong and will frequently stand vertically for tens of metres for long periods. When failure does eventually occur [for example due to earthquake or rainfall triggers] cliffs in pga gravels most often fail as falls and topples of exfoliation slabs [layer between 1 and 5m thick] that have developed sub-parallel to the cliff face.

Younger river and creek fan alluvium

Alluvial material that is younger than the last 5-10,000 years is generally less fines rich than the older gravels and contains a wider range of gravel sizes that are often more rounded, with individual boulders up to 2-5m in diameter. In addition to the young gravel sediments of the Waitaha River in the scheme area there are fan sediments from the various side creeks that feed into the main river. The fan sediments tend to be more angular and generally slightly smaller in their maximum boulder size than the main river sediments. Due to the inherent strength of the gravel clasts, which have been tested and selected by river transport, the young alluvial gravels are generally strong materials in compression [e.g. under foundation loading] but they have a low cohesion and do not stand well in steep cuts, especially under saturated conditions close to river or stream level.

Photograph 3: Young alluvial gravels in the true right bed of the Waitaha River near the confluence with Douglas Creek.

5. Alpine Fault

The main geological structural control in the scheme area is the Alpine Fault which is located approximately 500m downstream of the proposed powerhouse site [Figure 1, purple fault traces]. The Alpine Fault is an east dipping, oblique dextral and thrust fault system that often has multiple surface fault traces trending southwest-northeast. Our most recent mapping shows at least three surface traces of the fault in a zone approximately 500m wide.

The Alpine Fault is an active structure that transfers an estimated 70 percent of the plate tectonic deformation that is occurring in the central South Island and has a dextral strike slip [horizontal] average movement of 25-30mm/year and a vertical component of uplift of about 10mm/year. This movement is occurring uniformly over time, and only occurs during large earthquake events. There has not been a Alpine Fault earthquake since European historical settlement. Research suggests the most recent event occurred in 1717AD [Yetton et al. 1998; Wells et al. 1998] and appears to have affected a fault length in the order of 350km. Based on rupture lengths, and recorded single event fault offsets, Alpine Fault earthquakes are likely to have magnitudes in the range 7.5<**M**>8.5.

Given the complexity and width of the mapped fault zone in the Waitaha River it is not possible to predict exactly where the fault deformation in future Alpine Fault earthquakes will occur, although it is likely that the majority of horizontal and vertical movement will occur close to, or within, the mapped fault traces shown in Figure 1. We discuss potential seismicity and fault deformation issues in relation to the scheme in Sections 8 & 9 of the report.

6. Other faults

There are a number of other faults that have been recently identified in the area during mapping of the most new 1:250,000 geological map [Cox and Barrell, 2007]. We show these in Figure 1 [orange dashed lines]. We also show in Figure 1 various orange dotted lines used to represent generally smaller faults we infer are present from aerial photograph interpretation and satellite images, and in some case field verification.

These faults are also probably active structures, but with considerably less displacement per event and less frequent episodes of movement than the main Alpine Fault. However, when these smaller faults do move they most likely move in conjunction with an Alpine Fault earthquake event.

Each of these recognised faults, and others that likely remain hidden, will have associated zones of crushed and weakened rock and fault gouge [clay] similar to the conditions encountered in parts of the tunnel for the Amethyst Scheme, where weakened fault zones were observed up to 50m in overall width.

7. Bedrock Joint Patterns

From an engineering geological perspective joints include partings parallel to the schist foliation. The foliation orientation [strike and dip] is shown in Figure 1 at all the bedrock exposures that have been located in the fieldwork to date. The foliation is notably consistent with a strike of approximately 060 degrees [northeast to southwest] and dips that are more variable but typically around 60-85 degrees to the southeast. Given the presence of significant faults the consistency in foliation strike is a positive sign implying that the bedrock may not be extensively disturbed. Variation in foliation dip is quite common in the general area as a result of broad scale folding and can be observed in some areas over scales of hundreds of metres [photograph 4].

We have been limited in the number of areas where the schist bedrock is exposed well enough over a large enough area to allow joint surveys. The best survey has been undertaken close to the Kiwi Flat hut, at the junction of the tributary of Whirling Water with the Waitaha River, where bedrock outcrops just above the normal river level. Here a total of 45 joints were able to be measured in addition to numerous foliation partings. The foliation partings, which are being picked out by preferential river erosion, are likely to be fine shears that have developed along foliation. The foliation partings have an average spacing at Whirling Water of 1.2m.

Photograph 4: View looking southwest along bedrock foliation strike. The recent snow is picking out the bedrock defect patterns where the steep foliation dips at 75-85 degrees in the middle and left of photo, but reduces to closer to 60 degrees at the right. There is a joint set creating a sub-horizontal trace on the snowy face and dipping towards the southwest which is the northwest-southeast striking joint set showing up in the joint survey data.

The joints at Whirling Water fall into three groups averaging 015/78NE [11 out 45], 126/64SW [8/45], and the most common set at 152/50SW [26/45]. We show stereographic projections for each of the various joint surveys in Figure 2 and discuss the results with respect to tunnel orientation in Section 8. The average joint spacing at Whirling Water is 650mm.

Photograph 5: The most common joint orientation at all the sites [orange arrow], in this case showing up at Whirling Water, where the dips average 50 degrees to the southwest [strike 152 degrees]. The foliation is at approximate right angles to this joint set and is dipping at 80 degrees southeast [red arrow].

Other joint surveys were undertaken at the proposed intake at upper Morgan Gorge and at two outcrops at the other end of gorge near the proposed powerhouse and tunnel exit [Figure 2]. A total of 17 joints were recorded at the intake that fell into two sets at 050/48NW and 072/40W with joint spacings averaging approximately 1.5m. The two locations are the downstream end had far fewer joints exposed for measurement. The joints in these areas generally had a SE-NW strike [160 degrees approx. average] with dips around 30-60 degrees in both directions [NE and SW]. The joint spacings were closer to 1m on average.

8. Scheme components and local geology

8.1 Intake area

The proposed intake at the upstream end of Morgan Gorge has the best bedrock quality that we have observed so far in the local Waitaha area. The schist itself is strong, and contains relatively few obvious foliation parallel partings [small shears]. Those present on average are spaced at more than 3m intervals. The joint spacings are also the widest of any of the surveyed areas [1.7m average spacing True Right, 1.5m True Left].

Photograph 6: The bedrock exposed across both sides of upper Morgan Gorge [river is in centre just below this view]. The proposed intake will be located just to the right of this photograph. Foliation dip shown by red arrow, the dominant west and northwest dipping joint set by the orange arrow.

Once again the dominant joint set is oriented with dips to the west and northwest [Photograph 6 and Figure 2] but based on this exposure the initial tunnel orientation is well placed to avoid running exactly parallel to the dominant joint set. The initial tunnel direction here is also perfectly placed [i.e. perpendicular] with respect to the foliation orientation, and the foliation will be the main control on tunnel stability [Photograph 7].

Photograph 7: The bedrock bench on which the intake will be located [river cleaned rock at right of photograph] with the tunnel entry in the direction of the green arrow and at right angles to the bedrock foliation shown by the red arrow. Dominant joint set dip at this location is shown by the orange arrow.

There is a fault that is parallel to foliation and located immediately upstream of the intake site which has been responsible for uplifting the bedrock into the path of the river in the Morgan Gorge area [Figure 1]. Minor shears associated with the fault can be found on the true left bank close to the start of the gorge [Photograph 8]. Fortunately the fault appears to have little influence on the quality of the rock at the proposed intake.

Photograph 8: Small fault parallel to foliation on true left bank 30m upstream from

There has been a rockfall near the intake site in the past that has dumped large angular boulder talus down into the start of the gorge. Rockfalls such as this may have been earthquake triggered and could occur again during strong earthquake shaking. The intake will need to take into consideration the possibility of future rockfall impact by ensuring robust design.

Photograph 9: Angular boulder talus from rockfall into the modern river channel level on the true right of the Waitaha River 20m upstream of the intake. An arcuate scarp and 'basin' marking the approximate extent of the failure can be seen picked out by the shadow.

8.2 Tunnel

There will be relatively large underground excavations required for the stilling basins and bypass in the first section of the tunnel at the intake. There can be little flexibility in the orientation of these initial components but, as noted above, provided the joint orientations further into the hill remain similar to the surface exposure at the swing bridge, then excavations trending between 140-160 degrees appear reasonably well placed with respect to the dominant joint sets at this end of tunnel.

It is highly likely some faults will be encountered in the tunnel. Figure 1 shows a fault inferred to run down Gorge Creek and another approximately 100m further north. There will probably be others. Faults in the Amethyst area were observed to have weakened gouge zones up to 50m in width. The tunnel crosses the known faults at a high angle [75 degrees], which is relatively favourable. However, we also infer other faults closer to the east side of Morgan Gorge that have orientations almost parallel to the tunnel direction. The current tunnel curve tunnel position takes a broadly northern trend, and thereby avoids the known northwest-southeast trending faults, but other faults with a similar orientation may remain hidden. The more northerly trend of the bulk of the tunnel is also a better orientation with respect to the northwest dipping joint sets observed in the two joint surveys at the downstream end of the tunnel. It is possible the final tunnel orientation will be more northwest-southeast than the curved tunnel option to shorten the tunnel length, particularly if the tunnel diameter is relatively small.

We recommend for costing purposes that it be assumed that at least 50% of the tunnel will require rock bolting and shotcreting during excavation, and that a significant proportion of the excavations be concrete lined [both walls and floor]. The final tunnel design will also depend on the preferred configuration i.e. either a large diameter pipe with an adjacent access track, or a concrete lined pressure tunnel.

One of the surprises in the Amethyst tunnel was the amount of groundwater that enters the tunnel 1- 3 days following major episodes of rainfall. A similar level of permeability, with flows proportionally larger given the greater tunnel dimensions, should initially be assumed for the Waitaha tunnel. There is a hot spring located on the true left of the Waitaha River 100m upstream of Glamour Glen. The flow during fieldwork was observed to be 10 – 20 litres per second with a temperature of approximately 40 – 60 degree Celsius. The area around Glamour Glen has several faults converging along which the hot water may be running, but it also possible that hot water could be encountered in the fault zones on the true right of the river down at tunnel level.

8.3 Tunnel – Powerhouse transition

There is a 60-70m high near-vertical terrace edge approximately 50m from the proposed river level powerhouse. The tunnel may start at the base of this slope. Recent slip scars 100m upstream of the proposed powerhouse show the terrace in that area consists of pga gravels over schist bedrock extending 30m vertically up from river level. However, there are no exposures of bedrock at equivalent elevations 100m downstream of the powerhouse in Alpha Creek. Hopefully there will be bedrock in the lower part of the terrace edge at the powerhouse but confirmation requires subsurface investigation.

Regardless of bedrock elevation we recommend the tunnel in plan view should enter the terrace edge as close to perpendicular to the face as is possible. We suggest there be a pre-cast concrete section at the portal to act as a shield to commence the tunnel excavations. Poor quality rock as result of weathering and proximity to the Alpine Fault should be expected in the first 100- 300m of the portal. The concrete shield section could ultimately be covered over to better protect it from subsequent falls from the terrace edge, and also allow planting to minimise visual impacts. Consideration should also be given to forming a bund over the buried tunnel section closer to the powerhouse to reduce the risk of falling debris from the terrace edge reaching the actual powerhouse. This bund could also be planted.

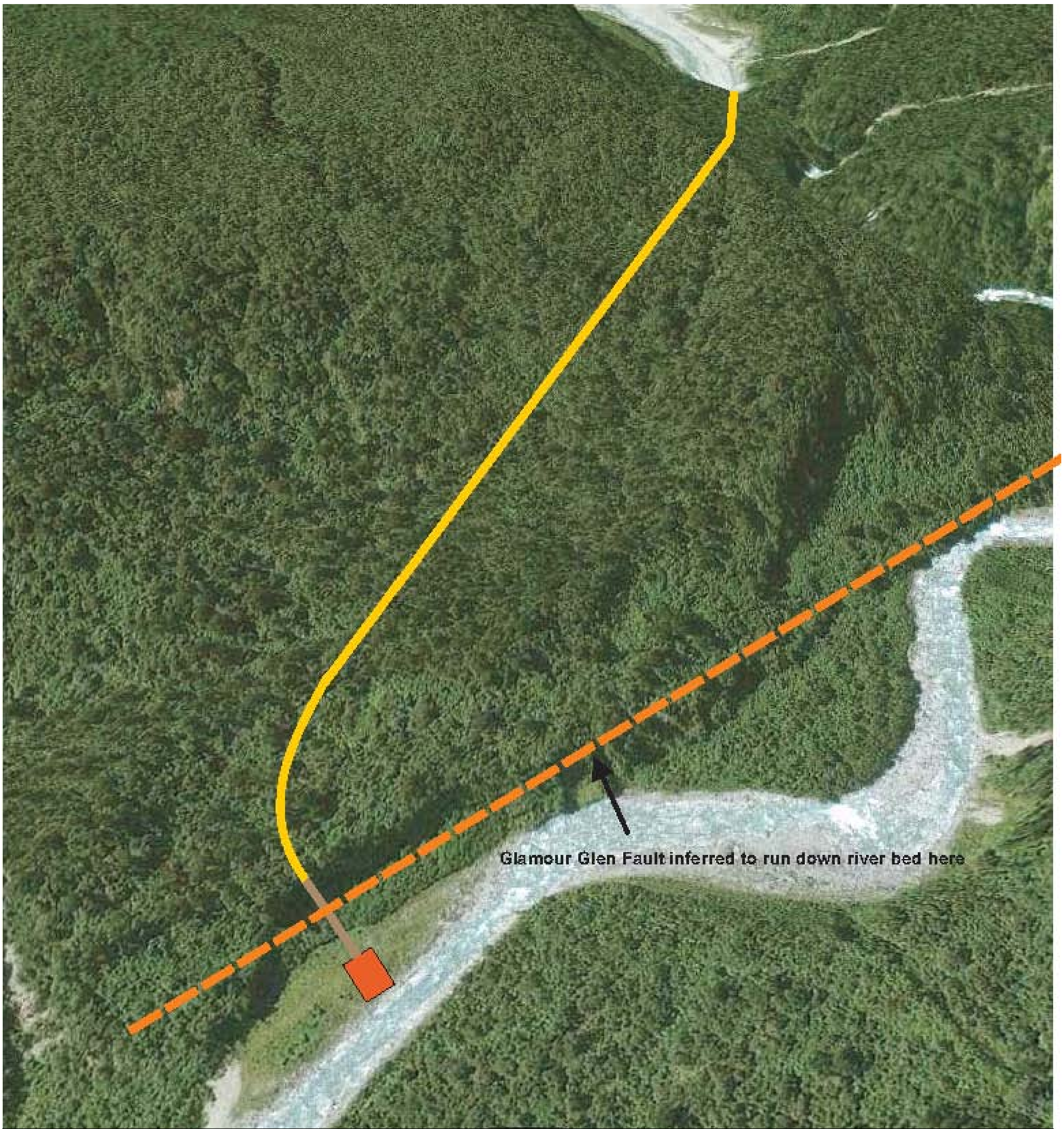
Photograph 10: The proposed powerhouse site near rive level with the 60-70m high terrace edge in the background.

It is also possible that a higher level tunnel may be favoured with a portal up on the terrace, close to the intersection of the terrace with the steeper slopes above [Figure 1]. A penstock would then take the water down to the powerhouse. A similar protective portal structure will be required for the high level tunnel, to deal with the colluvium and weathered bedrock transition, as well as the possibility of future debris flows that fall from the higher steep slopes.

8.4 Powerhouse

The powerhouse will be built on a relatively low and young alluvial gravel surface with no significant old vegetation implying regular past flooding [Photograph 10]. Extensive flood protection works will be required for the powerhouse area.

The latest mapping for the new 1:250,000 geological map [Cox and Barrell, 2007] shows a fault running down Glamour Glen and on into the bed of the main Waitaha River. We can see good evidence for the fault in Glamour Glen itself and running up the hill further to the southwest of Glamour Glen. At the northeast end Cox and Barrell show the fault continuing as straight line immediately east of the powerhouse to terminate at Alpha Creek. This exact position is an inference, but it is not unreasonable to expect the fault to somehow connect down the main river valley to the Alpine Fault zone. There is nothing obvious across the young alluvial surface on which the powerhouse will be located. An active fault under the alluvium in this location would mean a risk of possible ground deformation [tilting or offset] affecting the powerhouse at some time in the future. Subsurface investigation at the next stage of work is recommended to check for any obvious sign of a fault near the powerhouse, but we expect the alluvium under the powerhouse to be so young that it will not show any obvious indications of the presence of a fault, or if a fault is present deeper down, the reliable location of the fault. The potential for future tilting of the powerhouse or offset of the penstock at this location may need to be an accepted risk in undertaking the scheme. There is still a much lower risk of tilting and deformation in this area than if the powerhouse was to be moved further downstream and into the main Alpine Fault Zone.



Photograph 11: Oblique satellite image looking southeast showing suggested tunnel alignment, powerhouse and the position of the inferred continuation of the Glamour Glen fault down the Waitaha River as mapped by Cox and Barrell, 2007.

8.5 Access road

The existing gravel road would require some minor widening and metalling and probably new culverts at two creek crossings in the approach to McGregor Creek. McGregor Creek has a very wide and unstable creek bed fan that has formed since a major rainfall triggered landslide [“Robinson Slip’, Figure 1] occurred in 1903 in the upper catchment near the Alpine Fault [Yetton, 2000]. Accounts from the time indicate the slip occurred after a sustained period of heavy rain and extreme local flooding. The debris flow associated with the landslide completely buried a large area of mature forest with the coarse debris. Finer sediment ‘flowed’ north along Waitaha Valley road where horses reportedly got stuck in the ‘quick sand’. The fan continued to grow for many years after 1903 before downcutting in the middle catchment, re-exposing the buried forest, and triggering further aggradation and avulsion of the lower creek catchment. This process has continued in the lower creek catchment to the present day.

Photograph 12: The bottom end of McGregor Creek near the junction with the Waitaha River. The 1903 Robinson slip occurred in the area arrowed. The creek channel in this lower fan continues to shift about in response to the massive sediment load released 110 years ago.

During floods the creek channel in the lower fan continues to shift about [avulse]. Temporary access via fords can easily be provided, subject to periodic reconstruction of flood damaged sections of the road, but permanent access will require a relatively long bridge [50m?] with extensive protection and river training works for both abutments. This is another area where tunnel spoil could be usefully disposed of as part of the river protection works.

Smaller bridges will be required to cross Granite Creek and Alpha Creek. Granite Creek has a much more stable bed than McGregor Creek, but Alpha Creek has had recent debris flow damage and may require more engineering. The road grades from McGregor Creek to the proposed powerhouse are not an issue.

9. ***Hazards and potential impacts to the scheme***

Table 1 summarises the various hazards that could affect the scheme and the options, where possible, for their mitigation.

Hazard	Components at risk	Duration of impact	Mitigation options if any
Flood	Intake Powerhouse Access road	Short term, to medium term if damage arises	Design based on conservative flood levels
Landslides *Small scale local events*:	Intake [e.g. past rockfall] Powerhouse [failure of terrace edge] Access Road	Short term to medium term if damage arises	Robust intake design Bunding behind powerhouse
Medium scale; Robinson Slip scale of debris flow in middle or upper catchment	Intake, e.g. Kiwi Flat subject to aggradation pulse burying intake but wide area of flat will tend to attenuate impacts and may be little worse than existing high bedload.	Short and medium term impacts potentially up to 50 years or longer depending on proximity?	Not readily designed for
Large scale; e.g. 1999 Mt Adams rock avalanche of 10 – 15 million cubic metres into the Poerua River	Intake, Powerhouse and access road inundated by full scale valley aggradation.	Medium to long term impacts of more than 50 years	Not readily designed for
Earthquakes			
Large earthquakes in Southern Alps other than the Alpine Fault	Intake affected due to river aggradation, possible rockfall at intake and direct shaking damage. Portal at powerhouse end affected by local cliff collapse. Powerhouse affected by shaking damage and possible shaking induced foundation settlement. May also be flood issues caused by aggradation.	Medium term impacts for aggradation. Shorter term impacts for other aspects.	Structural design for Alpine Fault seismicity levels should handle more distant events. Other aspects such as aggradation not readily designed for.
Alpine Fault earthquake	Potentially could significantly affect all components of scheme i.e. Intake due to aggradation and rockfall. Tunnel and settling basin due to shaking and possible secondary fault offsets. Powerhouse	Medium to long term impacts resulting particularly from aggradation issues that could last for 100 years	Potential to mitigate shaking damage by conservative structural design but most other aspects not readily designed for.

	portal or higher level portal due to cliff or slope collapse. Also the powerhouse due to shaking damage and shaking induced settlement. There could also be tilting and offset associated with movement of the Glamour Glen fault and on-going flood issues due to the main river aggradation. The access road could be affected by aggradation of both the main river valley and the side creeks.	or longer.	

Table 1: Summary of natural hazards and their potential impact on the proposed scheme

The potential for an Alpine Fault earthquake is the obvious worst case scenario for the proposed scheme. There have been various estimates of the probability of the next Alpine Fault earthquake. Initial estimates by Yetton et al. 1998 and Yetton 2000 were as high as 65% [+/- 15%] in the next 50 years. Rhoades and Van Dissen [2003] adopt a new method of probability estimation that better allows for uncertainties in the paleoseismic data. Their 50 year probability range is 22 – 44% and the 100 year range is 39 – 68%. Estimates of likely ground accelerations for the area have only been made prior to the recent series of earthquakes that have affected Christchurch since September 2010. The estimates of Stirling et al. [2007] are presented below in Table 2.

	50 yr return period	150 yr return period	475 yr return period	1000 yr return period
Estimated peak horizontal ground acceleration	0.2g	0.5g	0.9g	1-3g

Table 2: Seismicity estimates for the Waitaha River area based on Stirling et al. 2007

A site specific seismicity evaluation is recommended in the next stage of work to assist in the final design for the project. That work can incorporate the new data from the Christchurch earthquake sequence and appropriate site specific topographic and subsurface effects for the various scheme components. Given that the relatively low magnitude [**M** 6.3] February 22 2013 earthquake in Christchurch generated horizontal peak ground accelerations of 2.1g and vertical accelerations as high as 2.2g it is likely the estimates in Table 2 will increase significantly from their current values.

It is important to note that the main impact of future fault rupture and/or large earthquakes in the scheme area is on the future maintenance and operation of the scheme itself. Because there is no proposed significant new water storage structure the construction of the various scheme components will not create additional seismic hazards or seismic risks to either the local environment or river users.

10. Future site investigations

Table 3 summarises the recommended additional subsurface investigations for the various scheme components:

Scheme component	Investigation method	Objective of investigation
Intake	Horizontal core drilling from intake face for the first 50m of excavations	Confirm rock quality and obtain joint and fault data
Stilling basins, bywash tunnel and main tunnel.	Two vertical cored drill holes to 100m to assess cover and tunnel rock conditions.	Confirm rock quality and obtain joint and fault data
Powerhouse portal	Digger scrape down of terrace face. One horizontal cored hole at tunnel level into face for the first 50m. A second vertical hole will be required from the terrace surface to check cover.	Confirm presence of rock in lower cliff face. Assess rock quality and obtain joint and fault data
Powerhouse area	Pits at powerhouse perimeter and trenches upstream from river to terrace edge.	Check foundation materials. Check in trenches for possible evidence of continuation of Glamour Glen fault.

Table 3: Recommended subsurface investigations for the proposed Waitaha Scheme

11. Conclusions

The proposed Waitaha hydroelectric scheme appears to be a feasible project from an engineering geological perspective. The main challenges are associated with the construction of the intake and underground stilling basin area, along with the excavation and support of an approximately 1.5km long tunnel. The bedrock in the Waitaha area is strong biotite schist that has a foliation attitude almost perpendicular to the tunnel alignment, and is steeply dipping in an upstream direction. This is a generally favourable orientation with respect to tunnel stability. There are indications of NNW joint sets in some areas that may be less favourable for tunnel stability, depending on the final tunnel alignment. In general the bedrock conditions are likely to be very similar to those encountered in the recently excavated Amethyst tunnel located 10km southwest of the proposed Waitaha scheme. At this stage a tunnel for the Waitaha scheme that is oriented as close to north as possible is the best orientation with respect to the joint sets recorded so far. Much better joint information from the most critical areas close to the proposed tunnel will be obtained during future drilling investigations, and this information can be used to help to determine the final tunnel alignment.

The rock at the upstream intake site at the upper end of Morgans Gorge is of good quality and is well suited for the intake and portal construction. The tunnel cover is relatively thin at first but improves to approximately 50m above the bulk of the stilling basin excavations. At the downstream portal the tunnel will be close to, and possible above, the bedrock contact with overlying dense post glacial outwash gravels. Subsurface investigations are required to assist the portal design in this area.

The powerhouse site is located beside the river on relatively young alluvial gravels that are likely to have a high bearing capacity due to the strength of the individual gravel cobbles and boulders but have generally low cohesion. Some of the boulders are very large, and we expect the saturated gravels will be very permeable. Excavations in these materials will need to be designed and assessed accordingly.

Vehicle access as far as the powerhouse is generally straightforward with the main issue being adequate route robustness across the ephemeral McGregor Creek fan area. We understand the type and extent of vehicle access further upstream is still under review.

There are significant risks to the scheme from natural hazards in the area, in particular the future possibility of an Alpine Fault earthquake during the lifetime of the scheme. However, because the proposal does not involve the storage of significant amounts of water the proposed construction of the various scheme components will not create additional seismic hazards or seismic risks to either the local environment or river users.

References

Cox, S.C.; Barrell. D.J.A. [compilers] 2007: Geology of the Aoraki area. Institute of Geological and Nuclear Sciences 1:250,000 geological Qmap 15. 1 sheet + 71p. Lower Hutt, New Zealand. GNS Science.

Rhoades, D.A.; Van Dissen, R. [2003]; Estimates of the time-varying hazard of rupture of the Alpine Fault, allowing for uncertainties. New Zealand Journal of Geology and Geophysics vol. 46:479-489.

Warren, G. [1967]. Sheet 17 Hokitika [1st edition] Geological Map of New Zealand 1:250,000. DSIR, Wellington, New Zealand.

Wells, A; Yetton, M.D.; Stewart, G.H.; Duncan, R.P. [1998]: Prehistoric dates of the most recent Alpine Fault earthquakes, New Zealand. Geology 27[11], 995-998.

Stirling, M.; Gerstenberger, M.; Litchfield, N.; McVerry, G.; Smith, W.; Pettinga, J.; and Barnes, P. [2007]: Updated probabilistic seismic hazard assessment for the Canterbury region. Prepared for Canterbury Regional Council, CRC Report No. U06/6.

Yetton, M.D.; Wells, A.W.; Traylen, N. [1998]: The probability and consequences of the next Alpine Fault earthquake. EQC research report 95/193.

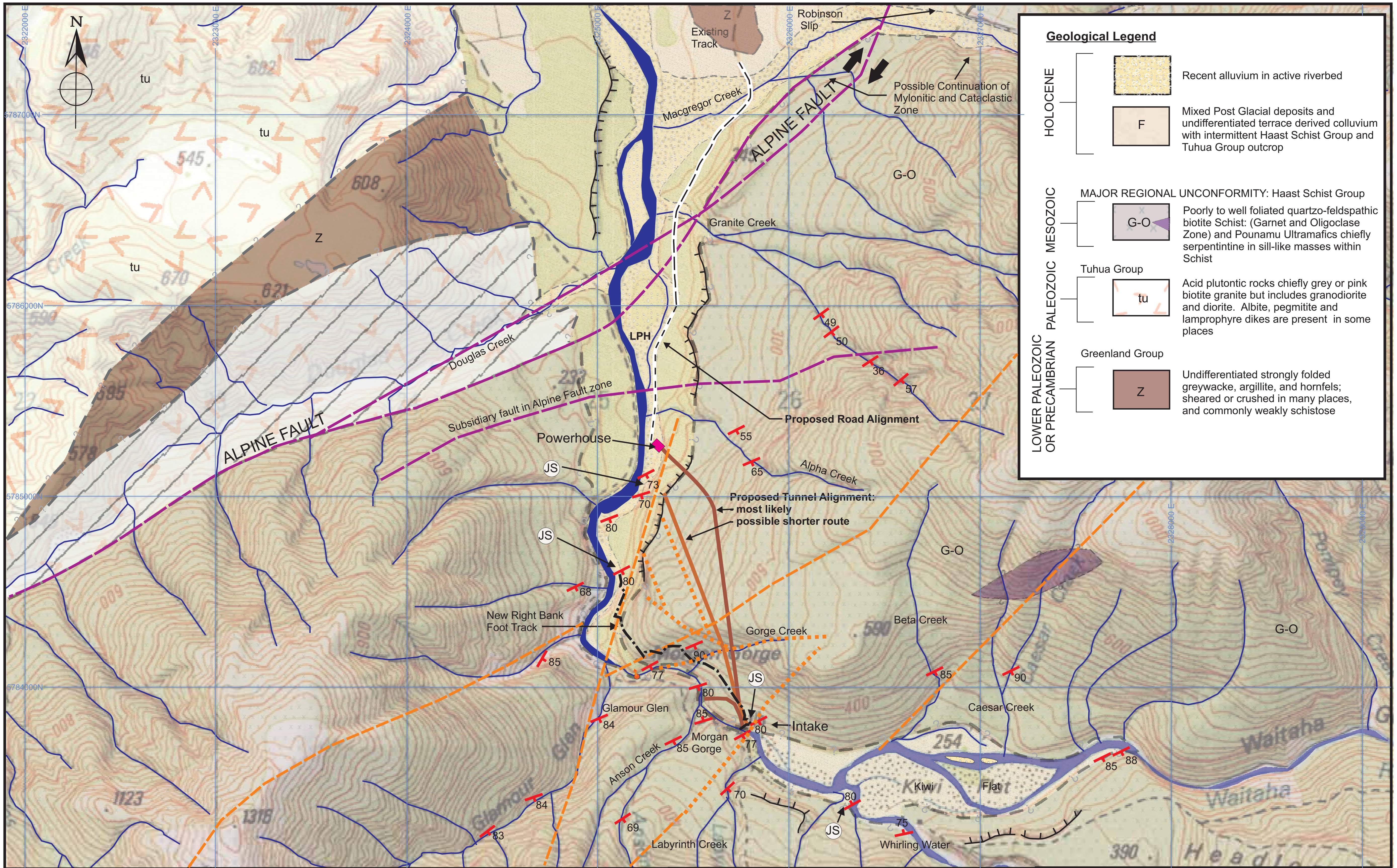
Yetton, M.D. [2000]: The probability and consequences of the next Alpine Fault earthquake, South Island, New Zealand. PhD thesis, University of Canterbury Library, Christchurch, New Zealand.

Standard Limitations

This report has been prepared for the benefit of, and under specific instruction of Electronet Services Ltd as our client with respect to the brief. The reliance by other parties on the information or opinions contained in the report shall be at such parties' sole risk. There has been no subsurface work carried out and estimates of rock quality and continuity as based solely on available surface exposures.

Opinions and judgements made in this report are preliminary and based on our understanding and interpretation of current regulatory standards and should not be construed as legal opinions. Where opinions or judgements are to be relied on they should be independently verified with appropriate legal advice.

Technical recommendations and opinions in this report follow current practice and are based on information and professional inferences derived from a discrete number of natural exposures, geomorphic observations, and walkover inspections in terrain with dense local vegetation cover. The nature and continuity of subsoil and geomorphic conditions away from the data locations is inferred and it must be appreciated that actual conditions could vary from the assumed model.



NOTE: Geological information is derived from Warren, 1967 Sheet 17 Hokitika (1st Ed.) Geological Map of New Zealand 1 : 250 000 DSIR, Wellington, New Zealand and Topographic map series 1: 50 000 (260) Sheet I34 Ed 1 1994

Geomorphic Legend

- Approximate position of Alpine Fault
- Inferred fault or foliation shear
- Inferred lithological contact
- Mylonite and Cataclasite zone
- Hot Spring
- Terrace riser
- Prominent fan
- Watercourse
- Track
- JS Joint Survey

CLIENT:

Electronet Services Ltd

GEOTECH

DATE DRAWN:	October 2013
DRAWN BY:	MDY
CHECKED BY:	IMcC
ISSUE NUMBER:	1

SHEET TITLE:

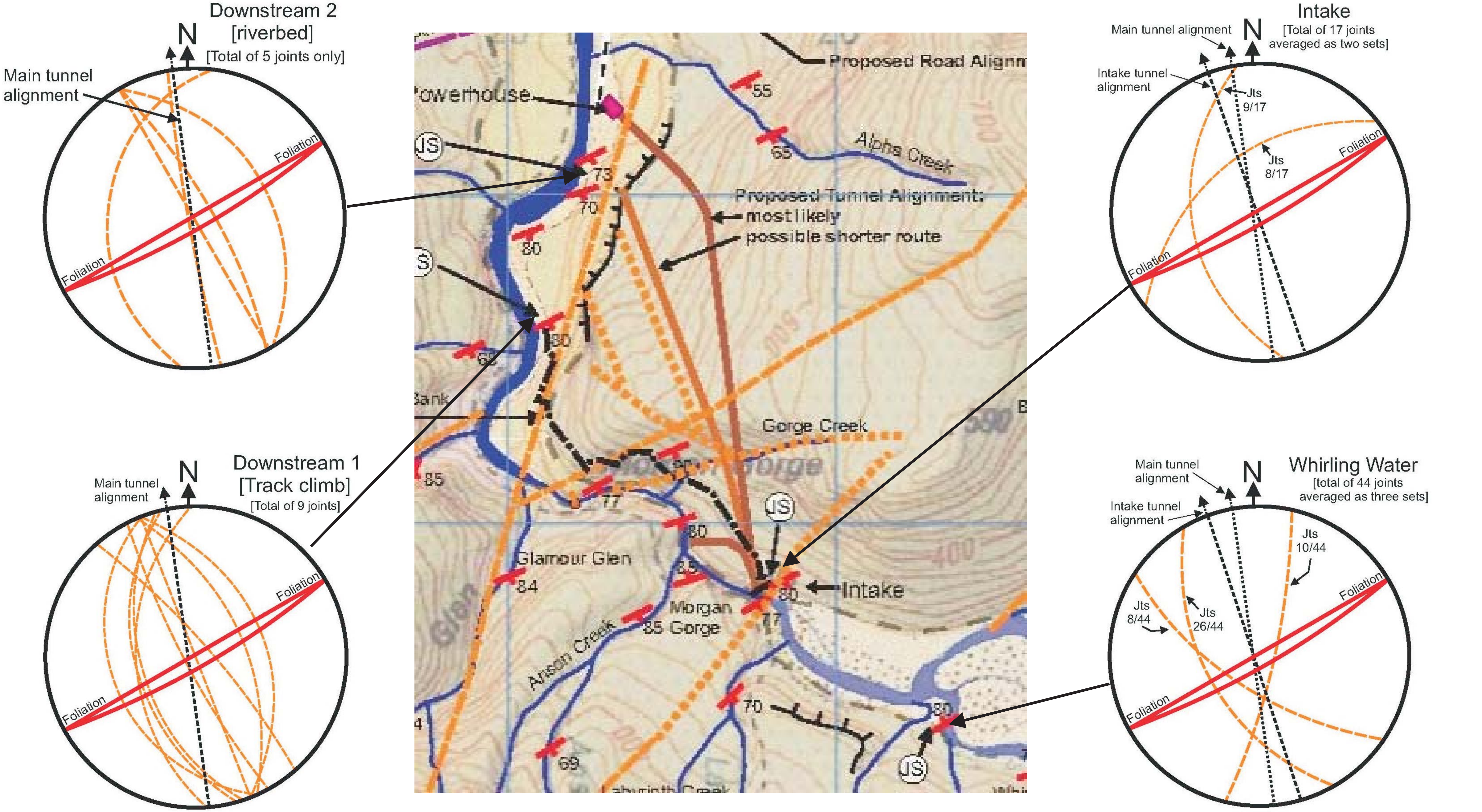
Geological map of the Waitaha River area from Robinson Slip to Kiwi Flat

SCALE: 1:20 000 @ A3 approximately

PROJECT:

Waitaha River Hydro Scheme

FIGURE 1/1930

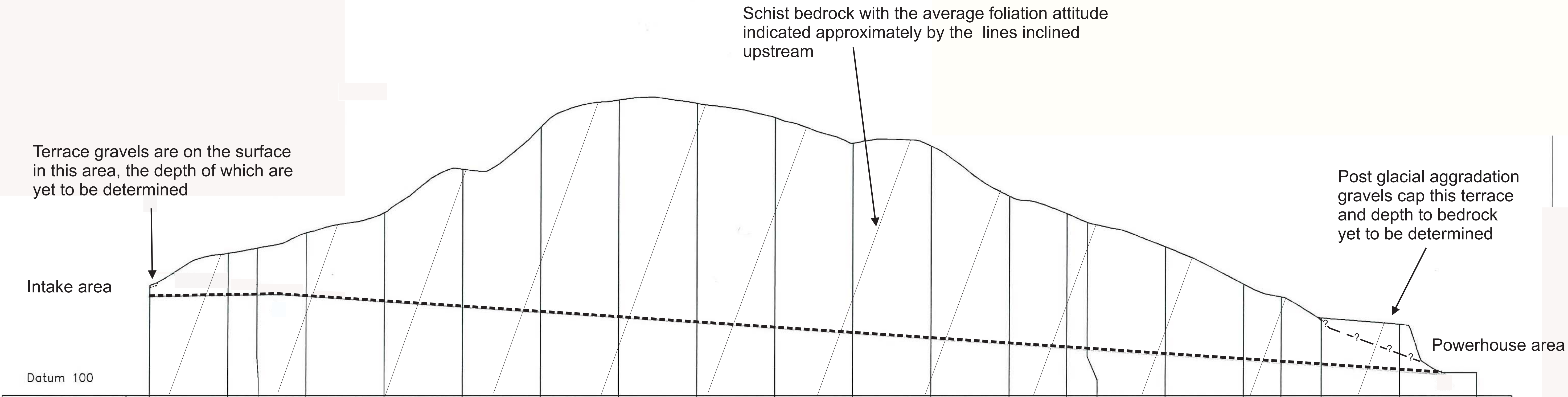


All joint plots lower hemisphere stereographic projections on Wulf nets. Refer key on Figure 1/1930 for features on map insert

GEOTECH

Proposed Waitaha River Hydro Scheme, Westland: All available bedrock joint survey data from four locations bracketing the proposed intake tunnel and the main tunnel.

Map insert not to fractional scale	Drawn:MDY/HA Client: Electronet
Date: August 22, 2013	Figure 2/1930



5m Contour	240.447	281.519	287.948	307.601	333.473	388.665	442.780	476.939	472.607	454.490	421.950	418.200	354.340	332.176	320.934	289.972	242.381	226.025	199.538	191.262	130.000
Depth	240.447	281.519	287.948	307.601	333.473	388.665	442.780	476.939	472.607	454.490	421.950	418.200	354.340	332.176	320.934	289.972	242.381	226.025	199.538	191.262	130.000
Chainages	0.000	100.000	136.998	200.000	300.000	400.000	500.000	600.000	700.000	800.000	900.000	1000.000	1100.000	1173.796	1200.000	1300.000	1400.000	1448.496	1500.000	1600.000	1699.016

GEOTECH	Cross section along the proposed Waitaha River hydroelectric scheme tunnel following the curved route tunnel route shown in Figure 1/1930.	Drawn: Mark Yetton	Scale: 1: 5000 approx. at A3
		Date: October 2013	Figure 3/1930