REPORT

Hawke's Bay Regional Council

Ruataniwha Water Storage Project
Report on Engineering Geological Investigations A7 Site, Volume 1 of 2

Tonkin & Taylor

ENVIRONMENTAL AND ENGINEERING CONSULTANTS

REPORT

Hawke's Bay Regional Council

Ruataniwha Water Storage Project
Report on Engineering Geological Investigations A7 Site, Volume 1 of 2

Report prepared for:

Hawke's Bay Regional Council

Report prepared by:

Tonkin & Taylor Ltd

Distribution:

Hawke's Bay Regional Council	**6 copies**
Tonkin & Taylor Ltd (FILE)	**2 copies**

March 2012

T&T Ref: 27690.200.Final

Table of contents

Volume 1

1 Introduction 1
- 1.1 Background 1
- 1.2 Scope of investigations 1
- 1.3 Development options 1
- 1.4 Site Investigations 2
  - 1.4.1 Geological mapping 2
  - 1.4.2 Drilling investigations 2
  - 1.4.3 Geophysical investigations 2
  - 1.4.4 Alluvial Borrow material investigations 2
  - 1.4.5 Rock Fill 5
  - 1.4.6 Sand 5
  - 1.4.7 Potential Core Material 6
  - 1.4.8 Seismic Hazard & Seismotectonics 7
- 1.5 Bibliography 7

2 Geological setting 8
- 2.1 Introduction 8
- 2.2 Topography 8
- 2.3 Stratigraphy 8
- 2.4 Structure 9
- 2.5 Geological history 9
  - 2.5.1 Basement rocks 9
  - 2.5.2 Alluvial gravel materials 9

3 Dam site geology 12
- 3.1 Detailed geological description of the site 12
- 3.2 Rock material description 13
  - 3.2.1 Lithotype Pt1 13
  - 3.2.2 Lithotype Pt2 13
  - 3.2.3 Lithotype Pt2a 13
  - 3.2.4 Lithotype Pt2b 13
  - 3.2.5 Intact rock strength 13
  - 3.2.6 Petrographic description 13
- 3.3 Rock mass description 15
  - 3.3.1 Rock mass defects 15
  - 3.3.2 Bedding 15
  - 3.3.3 Joints 15
  - 3.3.4 Crush and shear zones 16
  - 3.3.5 Drill Core RQD 17
  - 3.3.6 Classification of greywacke rock mass 20
  - 3.3.7 Rock mass deformation modulii 22
  - 3.3.8 Rock mass seismic velocity 22
- 3.4 Permeability 23
  - 3.4.1 Rock material permeability 23
  - 3.4.2 Rock mass permeability 23
  - 3.4.3 Drill water and Groundwater Levels 26
  - 3.4.4 Piezometers 28
- 3.5 Weathering 29

4 Diversion tunnel 30
4.1 Description of diversion works 30
4.2 Temporary support requirements 30
5 Stability of dam foundation, abutments and reservoir slopes 33
5.1 Cut slope stability and design 33
5.2 Reservoir slope stability 33
5.2.1 Right bank landslide 33
5.2.2 Other landslide areas 34
5.2.3 Reservoir seismic stability and peak ground accelerations 35
5.3 Left bank dilated rock mass feature downstream of dam 35
5.4 Foundation stability and leakage potential 35
5.4.1 Zones of rock weakness 35
5.4.2 Susceptibility to liquefaction 36
6 Sources of construction materials 37
6.1 Rock fill 37
6.2 Alluvial borrow material 38
6.2.1 Q1al Gravel 38
6.2.2 Q2al and Q2af Gravel 39
6.2.3 Q2 Gravel 39
6.2.4 Older Gravels 40
6.2.5 Gravel parent sources and suitability as concrete aggregate 41
6.2.6 Internal stability of gravels 42
6.3 Other fill materials 42
6.3.1 Sand 42
6.3.2 Potential Core Material 43
6.3.3 Rip-rap 43
7 Conclusions and Recommendations 44
7.1 Further Work 45
8 References 46
9 Applicability 48

Volume 2 - Appendices

Appendix A: Drawings
Appendix B: Plates
Appendix C: Opus Seismic Refraction Report
Appendix D: GNS Science Consultancy Report 2011/300
Appendix E: Borehole Logs and Photographs
Appendix F: Rock Permeability Test Results
Appendix G: Piezometer Construction Details
Appendix H: Trial Pit Logs and Photographs
Appendix I: Laboratory Test Results
Appendix J: Results of Zeolite Analyses

Executive summary

A dam approximately 83 m high is currently proposed to store water in the Makaroro River headwaters for distribution as irrigation water on the Ruataniwha Plains. The proposed dam located at the A7 investigation site is central to the Hawke's bay Regional Council (HBRC) planned Water Augmentation Scheme. This report presents the findings of the Stage 2 geotechnical investigation for the site.

The A7 dam site is located within greywacke basement rocks in the Wakarara Block mapped as part of the Waioeka petrofacies within the Pahau Terrane. The Wakarara Block is bounded to the west by the Mohaka Fault and by the Wakarara Fault to the East.

The rock beneath the dam site is mostly unweathered, strong to moderately strong, light grey to grey indurated sandstone with closely to very closely spaced defects. Lesser amounts of dark grey to black mudstone are also present. Tectonic deformation within the rock has occurred preferentially within the mudstone dominated layers and increases in intensity with proximity to the Mohaka Fault.

Unconfined Compressive Strength (UCS) tests indicate that the intact strength of the sandstone is strong. Geological Strength Index (GSI) for rock mass beneath the dam footprint has been estimated at 50 (very blocky). A rock mass modulus of 10GPa is suggested for the site.

The rock mass has five main rock mass defect sets. Four of these defect sets are joints whereas the fifth set is parallel to bedding. Defects within the rock are generally closely to very closely spaced. Sheared and crushed zones were also observed, occurring mostly in mudstone. One significant bedding parallel shear zone was located within the dam footprint and other shear zones are likely to be exposed during detailed design investigations.

The zeolite laumontite is identified as a vein mineral within the rock, but it is not observed in the rock's matrix. Laumontite reversibly swells/shrinks during wetting and drying cycles. Repeated wetting and drying cycles may cause the rock to fragment along veins.

GNS Science has estimate that single event displacements of 4 to 5 m (horizontally) and 0.4 to 0.9 m (vertically) can occur on the nearby Mohaka Fault. Such displacements may generate seiche waves within the reservoir and sympathetic movements of up to 0.42 m on significant zones of rock mass weakness within the dam foot print. Displacements of this magnitude will require specific design of the dam.

Peak ground accelerations of 0.4 g (1 in 1,000 year earthquake) and 0.85 g (1 in 10,000 year earthquake) have been estimated for the ground beneath the dam and will need to be taken into account during design.

The rock mass within the diversion works is classed as 'fair tunnelling ground" which will require systematic rock bolting and lining with shotcrete. Temporary cut slopes within the rock should be no steeper than 1V:1H without specific design.

One large, deep seated landslide is mapped within the proposed reservoir immediately upstream of the dam. The landslide is estimated to contain approximately 360,000 m^3 of disturbed debris and will require further investigation and design to determine whether it should be regraded or removed during dam construction.

A mapped area of dilated mass of rock downstream from the proposed dam which has partially vacated at the upstream end indicates the presence of a potential landslide that

could be triggered by severe earthquake shaking. The volume of rock associated with this feature is estimated at 210,000 m^3.

Construction materials in close proximity to the site include rock fill and alluvial gravels of various geological ages. Based on field observations we expect that the rock close to the dam will require blasting for excavation. The rock is likely to produce fine to medium gravel size fill due to the close spaced nature of the rock mass defects and with the inclusion of mudstone and shear zone material it may be of relatively low permeability for rock fill.

Alluvial gravels are all fine to coarse gravel size with varying amounts of sand. The gravels have undergone different amounts of weathering depending on their age and have been classified according to their age. They are all sourced from the same parent rocks. The most abundant locally available gravel materials are those at the current river level (Q1al) and those underlying a terrace approximately 40 to 45m above river level (Q2).

Other materials close to site that may be considered for construction include low to intermediate plasticity siltstone, silty, fine-grained sandstone and fine to coarse sand within the Q1al gravel.

1 Introduction

1.1 Background

This report presents the findings of the Stage 2 feasibility geotechnical investigations for the proposed A7 dam site located on the Makaroro River in Central Hawke's Bay (see drawings 27690.200-00 to 27690.200-03). The proposed dam is central to the Hawke's Bay Regional Council (HBRC) planned Water Augmentation Scheme that will bring water from the Makaroro River headwaters for distribution as irrigation water on the Ruataniwha Plains.

The Stage 1 investigations comprised the application of selection criteria for on-river storage to identify sites with suitable topography for construction of a dam of sufficient height to store the required volume of water for irrigation. Several potential dam sites on the Makaroro River upstream of the Makaroro road bridge were identified using this topographic criterion. Following reconnaissance site visits the A7 site was found to have the most favourable geological conditions for dam construction.

1.2 Scope of investigations

At the time the T&T Proposal "Ruataniwha Plains Water Augmentation Scheme: Technical Feasibility Study" (T&T Reference 27690, May 2011) was published, the A7 dam site was located close to the present site and, as part of the Stage 1 investigations, preliminary engineering geological mapping had been completed. However, the proposal stated that the Stage 2 investigations for A7 would be re-scoped to match the most appropriate dam type and potential layout that would fit within HBRC funding constrains. This was achieved by undertaking a site visit and workshop with the designers and reviewers and incorporating the known engineering geological constrains at the A7 site to scope out the current investigations.

Subsurface investigations were then carried out in a staged manner with geophysical investigations (seismic refraction surveys) completed first to determine the bedrock profile and identify changes in bedrock seismic velocity. This was followed by fully cored diamond drilling with water pressure testing at locations chosen to suit the range of dam types being considered at that time.

1.3 Development options

The assessment of the irrigation storage potential of the A7 site on the Makaroro River requires that the dam be capable of storing 90 Mm^3. To achieve this, the dam must be able to safely store water to a level of RL 469.5m. The parapet level of the dam is currently set at RL 473.7m giving a maximum embankment height of approximately 83m.

The A7 dam will be founded on unweathered, moderately strong to strong, closely jointed greywacke sandstone with minor interbedded indurated siltstone/mudstone (also commonly named as argillite and collectively referred to as mudstone). The term mudstone is adopted in this report to include siltstone and the term argillite.

While the intact rock has high strength the rock mass is broken up by closely spaced joints and crisscrossed with numerous narrow crushed and sheared zones and, as a result, the foundation is most suitable for a range of gravity or embankment dam types.

The valley cross section at the dam site has unmatched terraced surfaces on both sides of the deeply entrenched river channel. The terrace surfaces are veneered with a thin cover of Post Ohakean age river gravels and mantled with volcanic ash. The slopes above the terraced surfaces are mantled with wind-blown loess.

The main considerations for the dam type are the close proximity of the Mohaka, Mangataura and Wakarara Range Front active faults and the availability of materials suitable for a particular type of dam construction in this seismically active environment. In this respect the lack of a suitable plastic core material close to the site has implications for the cost of construction of a zoned embankment dam.

1.4 Site Investigations

1.4.1 Geological mapping

Engineering geological mapping at the A7 site was started during March 2011 and continued, on an intermittent basis, through to October 2011. The engineering geological maps produced cover the dam site at a scale of 1:2,000 and the reservoir at a scale of 1:20,000 (drawings 27690.200-01 to 27690.200-03. Data from the engineering geological mapping were located in the field using hand held GPS with an accuracy of ±4m. The base maps for data presentations were prepared from LiDAR scans flown for the project.

There are no recent published geological maps available for the dam site area. Kingma's 1962 Sheet 11 Dannevirke "Geological Map of New Zealand 1:250,000" is to be superseded by QMap "Hawke's Bay" to be published by GNS Science in the near future.

1.4.2 Drilling investigations

The diamond drilling programme at A7 site started in September 2011 and was completed mid October 2011. Five drill holes were completed along an alignment proposed in September 2011. Two holes were drilled on the proposed right abutment and three on the left abutment. Data relevant to the drill holes are presented in Table 1.1. All drill holes were drilled with HQ wireline gear and logged at a scale of 1:25 in accordance with New Zealand Geotechnical Society guidelines (2005). Water pressure testing was carried out in all drill holes and core from the holes was stored in length-wise split stiff plastic pipe and covered with lay-flat plastic sheeting. Casagrande type piezometers were installed in each drill hole. Subsequent to drilling the proposed dam alignment was changed by rotating the dam axis downstream about the left abutment to shorten the spillway and to ensure that the upstream toe intersects the sheared zone SZ1 (described in section 3.3.4.1) on a terrace rather than the steep gorge wall. The right abutment is now proposed 200m downstream from the original position. No further holes were drilled at the new location of the right abutment as rock is exposed on the ridge line and seismic line A7-2 shows the rock head at a shallow depth in this area. Further investigations will be carried out in this area during detailed design as described in Section 7.1.

1.4.3 Geophysical investigations

Seismic refraction surveys were undertaken by Opus International Consultants to determine terrace gravel thickness and to collect data on greywacke rock mass seismic P-wave velocities. Four lines were set out on the right abutment, one on the left abutment and one was located on a large landslide on the true left valley side upstream of the proposed dam site. The seismic line layout is shown on drawings 27690.200-02 to 27690.200-04. The report on these investigations may be found in Appendix C and the results are discussed in a following section.

1.4.4 Alluvial Borrow material investigations

There are significant resources of gravel and sand within the vicinity if the proposed dam site. They are potential sources of borrow material for both dam construction and concrete aggregate. Potential borrow materials around the Makaroro River and environs were investigated and sampled

using excavators operated by Gair Contracting and Steven Wilson during March and October 2011. The sampling locations are shown on drawings 27690.200-02, 27690.200-03 and 27690.200-05.

A total of 19 gravel samples were taken during this study. Laboratory testing was scheduled on 18 of these samples to determine their particle size distributions (PSDs). Two samples of Q1al gravel were checked for zeolite content and a compaction test was carried out on a sample of Q2 gravel. In addition to this laboratory data, another sample taken from Wakarara Road during a previous study was also available. The samples taken and laboratory testing are summarised in Table 1.2. The gravels are described in Section 6.2.

Table 1.1 A7 Drill Hole data

Drill Hole	Coordinates (NZTM)		RL m	Depth m	Lugeon Test	Piezometer Screen Depth	
	mE	mN					
BH 701	1880315.2	5592303.4	474.9	27	8.25 to 27.0m	701/1	15m to 20m
						701/2	23m to 27m
BH 702	1880527.4	5592318.0	437.3	49.5	5.25m to 43.5m	702/1	16.6m to 22.5
						702/2	42m to 49.5m
BH 703	1880704.4	5592315.6	425.7	45	6.75m to 40.5m	703/1	15m to 20m
						703/2	39m to 45m
BH 704	1880777.0	5592311.0	457.4	16.5	8.25 to 16.5m	704/1	10.5m to 16.5m
BH 705	188717.8	5592327.8	430.0	27	6.75m to 27.0m	705/1	8m to 12m
						705/2	21m to 27m

Table 1.2 Gravel samples, location and classification. See Section 2.5 for explanation of symbols

Symbol	Sample	Location (NZTM)	Recovery depth	Description	Tests
Q1a	A7/3	1880457mE 5593083mN RL+400m	0 to 1m	Sandy, sub-rounded to rounded, fine to coarse gravel. Gravel clasts are mostly unweathered	PSD, zeolite analysis
Q1a	A7/8	1879842mE 5595537mN RL+435m	0 to 1m	Sandy, sub-rounded to rounded, fine to coarse gravel	PSD, zeolite analysis
Q1a	RG1	1879510mE 5595580mN RL+440m	0 to 1.5m	Sub-rounded to rounded, fine to coarse gravel with some sand. Gravel clasts are mostly unweathered	PSD
Q1a	RG2	1879490mE 5595595mN RL+440m	0 to 1.5m	Sub-rounded to rounded, fine to coarse gravel with some sand. Gravel clasts are mostly unweathered	PSD
Q1a	RG3	1879465mE 5595610mN RL+440m	0 to 1.5m	Sub-rounded to rounded, fine to coarse gravel with some sand. Gravel clasts are mostly unweathered	PSD

Symbol	Sample	Location (NZTM)	Recovery depth	Description	Tests
Q2af	TP2	1880498mE 5591970mN RL+440m	2.5 to 6m	sub-angular fine to coarse gravel	PSD
Q2af	TP3	1880508mE 5592112mN RL+436m	1.2 to 1.7m	sandy sub-angular fine to coarse gravel	PSD
Q2af	TP4	1880484mE 5592180mN RL+438m	1.5 to 4.7m	sandy sub-angular fine to coarse gravel	PSD
Q2af	TP5	1880433mE 5592245mN RL+445m	0.8 to 3.2m	sub-angular fine to coarse gravel with some cobbles and boulders	PSD
Q2af	TP6	1880428mE 5592299mN RL+445m	0.2 to 2m	sandy silt	PSD
Q2af	TP7	1880450mE 5592435mN RL+438m	1 to 1.7	sub-rounded fine to coarse gravel some cobbles	PSD
Q2	A7/11	1885595mE 5586466mN RL+325m	From road side gravel pit	Silty, clayey, fine to very coarse, rounded to sub-rounded gravel	PSD
Q2	A7/12	1889300mE 5582400mN RL+275m	From farm quarry face	Silty, fine to coarse sub-rounded gravel.	PSD
Q2	A7/14	1883200mE 5584700mN RL+360m	Scraping from road cut	Sandy, fine to coarse gravel. Clasts are slightly to moderately weathered. Possibly reworked Q2b deposit	PSD
Likely Po	A7/19	1882700mE 5586700mN RL+325m	0 to 2m	Fine to coarse gravel with some clay and sand. Clasts are slightly to moderately weathered.	PSD
Ma	A7/10	1879936mE 5582640mN RL+515m	From road side quarry face	Silty, fine to coarse sub-rounded gravel. Clasts are slightly weathered	PSD
Ma	A7/13	1888900mE 5581900mN RL+335m	Scraping from farm cut	Rounded, fine to coarse gravel. Clasts are moderately weathered	PSD
Ma	A7/17	1882700mE 5586700mN RL+325m	Scraping from farm cut	Sandy, fine to coarse, rounded to sub-rounded gravel. Clasts are mostly moderately weathered	PSD Compaction
Ma	WRS	1890205mE 5580910mN RL+296m	Trial pit	"Red Metal"	PSD Compaction Permeability

1.4.5 Rock Fill

Greywacke sandstone lithotype is the main rock type available as a fill material with interbedded sandstone/mudstone present in lesser quantities. Both lithotypes are present as a weathered rock mass in a borrow pit close to the proposed A7 site where they are excavated for use on farm tracks. A sample of each lithotype was recovered during investigations carried out during March 2011. The sandstone sample was moderately weathered, orange brown, weak to moderately strong. The material sampled was collected directly from the pit face using a 6t excavator operated by Gair Contracting. The locations of the samples are shown on drawings 27690.200-03 and 27690.200-05.

In addition to this, core samples from various depths were also analysed to determine the presence and type of zeolites in the rock.

The rock samples analysed are summarised in Table 1.3.

Table 1.3 Location and description of rock fill samples

Sample	Location (NZTM)	Sample type	Sample location/depth	Tests
A7/5	1880060mE 5592450mN RL+480m	Moderately weathered, orange brown SANDSTONE	From farm borrow pit	PSD
A7/6	1880060mE 5592450mN RL+480m	Thinly bedded mudstone and sandstone	From farm borrow pit	PSD
BH702	1880527.4mE 5592318.0mN RL+437.3	Unweathered, moderately strong to strong, grey SANDSTONE	12.4m	Zeolite analysis
BH702	1880527.4mE 5592318.0mN RL+437.3	Unweathered, moderately strong to strong, grey SANDSTONE	36.6m	Zeolite analysis
BH703	1880704.4mE 5592315.6mN RL+435.7	Unweathered, moderately strong to strong, grey SANDSTONE	9.2m	Zeolite analysis
BH703	1880704.4mE 5592315.6mN RL+435.7	Unweathered, moderately strong to strong, grey SANDSTONE	11.2m	Zeolite analysis
BH703	1880704.4mE 5592315.6mN RL+435.7	Unweathered, moderately strong to strong, grey SANDSTONE	18.5m	Zeolite analysis
BH703	1880704.4mE 5592315.6mN RL+435.7	Unweathered, moderately strong to strong, grey SANDSTONE	29.1m	Zeolite analysis
BH703	1880704.4mE 5592315.6mN RL+435.7	Unweathered, moderately strong to strong, grey SANDSTONE	31.4m	Zeolite analysis

1.4.6 Sand

Sand is present in the field area within the alluvial gravel and within the Tertiary sedimentary sequence (see section 2.3) to the west and northwest of the dam site. Samples were obtained from

digger pits and by hand from outcrops and river deposits. The grain size of the various sand deposits was determined through laboratory testing. The sand samples taken during this study are summarised in Table 1.4.

Table 1.4 Location and description of sand samples

Sample	Location (NZTM)	Sample type	Sample location/depth	Tests
A7/9	1879914mE 5595437mN RL+435m	Silty, fine Sand (extremely weak sandstone)	Across the river from the old mill site (End of Wakarara Road)	PSD
A7/21	1880217mE 5593748mN RL+469m	Sandy silt (extremely weak sandy siltstone)	Stream gully on Rangimarie Farm	PSD
A7/23	1880493mE 5592788mN RL+414m	Fine to coarse sand	Winnowed sand in Makaroro River bed	PSD

1.4.7 Potential Core Material

Investigations to find potential core material were carried out in March 2011 and September 2011. The potential core materials were siltstone or sandy silt sampled by hand from various locations on Rangimarie Farm. The locations and tests are summarised in Table 1.5.

Table 1.5 Location and description of potential core materials

Sample	Location (NZTM)	Sample type	Sample location/depth	Tests
A7/1	1879215mE 5592402mN RL+440m	Fine sand/sandstone	Adjacent to vehicle track on Rangimarie Farm	PSD & hydrometer Atterberg Limits
A7/2	1880127mE 5593219mN RL+470m	Siltstone	Outcrop on Rangimarie Farm	PSD & hydrometer Atterberg Limits Compaction Permeability
A7/20	1880089mE 5593755mN RL+500m	Siltstone	Adjacent to vehicle track on Rangimarie Farm	Atterbergs, hydrometer
A7/22	1880127mE 5593219mN RL+470m	Siltstone	Outcrop on Rangimarie Farm	Atterbergs

1.4.8 Seismic Hazard & Seismotectonics

GNS Science was commissioned to prepare a site specific assessment of the seismic shaking hazard and report on the seismotectonic setting of the A7 dam site. The report objectives were to map potentially active faults in the vicinity of the dam site, and to provide commentary on:

i. Is it possible that significant fault displacements can occur in, or close to, the A7 site as a result of tectonic movements on any of the three major faults (Mohaka, Wakarara, and Mangataura)?

ii. Could secondary displacements occur as a result of internal deformation within the Wakarara Block as a consequence of movements on the major faults?

iii. If either (i) or (ii) occurs, what is the possible size, style and reoccurrence of the expected displacements?

The GNS report is appended to this report in Appendix D. Their findings are discussed in Section 5.

1.5 Bibliography

Kingma J. T., 1962: Sheet 11 Dannevirke (1st Ed.) "Geological Map of New Zealand" DSIR.

Langridge R.M. Villamor P. 2011 "The A7 Makaroro River dam site Phase 1: Initial site evaluation for active deformation". GNS Science Consultancy Report 2011/117.

Litchfield N. 2003 "Maps, stratigraphic logs and age control data for river terraces in the eastern North Island". GNS Science Report SR2003/31.

Sutherland A. 2011 "Ruataniwha Plans Seismic Refraction Survey" Opus International Consultancy – Central Laboratories Report 11-529B65.00 Task L. (Included in Appendix C)

2 Geological setting

2.1 Introduction

No detailed study has been made of the geology at the A7 dam site in the Makaroro River prior to this report. Kingma (1958) describes the regional geology of the area and includes the area in the 1962 1:250,000 Dannevirke (Sheet 11) Geological Map of New Zealand. Raub (1985) mapped the area including the A7 dam site at 1:25,000.

GNS Science is currently preparing the geological map 'QMap Hawke's Bay' (1:250,000 scale).

As part of this study a geological map at a scale of 1:20,000 (Drawing 27690.200-01) along with more detailed maps of the dam area at a scale of 1:2,000 have been prepared (drawings 27690.200-02 to 27690.200-04).

2.2 Topography

The Makaroro River valley near the dam site is approximately 300m wide with the present river channel deeply entrenched in a narrow gorge cut down to approximately 400m above sea level and 40m below an unpaired set of degradational terrace surfaces (Drawings 27195.200-02 to 04). The topography away from the river rises steeply to a series of NE to SW trending ridges that are structurally controlled by continuous steeply dipping beds of the underlying strong sandstone. These erosion-resistant sandstone beds also control the present NW to SE river course forming a zigzag as the river flows oblique across the strike of the beds from the Ruahine Range through the Wakarara Range towards the lower levels of the Ruataniwha plains.

The rate of down-cutting appears to have been rapid as few of the smaller streams joining the Makaroro River have concordant junctions within the Wakarara Range, and most have waterfalls at, or near to, the geologically recently deepened valley edge.

2.3 Stratigraphy

At the A7 dam site the Makaroro River is deeply incised in the Wakarara Range (or Block), Cretaceous aged, indurated grey greywacke sandstone with minor interbedded dark grey to black mudstone. The greywacke is mapped as the Waioeka petrofacies, part of Pahau terrane (Ktw) by Lee (Lee et al. (QMap "Hawke's Bay" in press) and referred to as Pt1 in this report.

Bedding within the greywacke rock mass is steeply inclined with a consistent NE to SW strike. Both upstream and downstream of the site zones of thinly bedded, often sheared and contorted, indurated sandstone/mudstone are present (referred to as Pt2 in this report).

Thin, fluvial gravel-veneered degradation terraces (Q2al) are cut on the greywacke rock at the dam site, and these, in turn, are mantled by brown volcanic ash. The terrace surfaces are likely to be associated with post-glacial incision or down-cutting, and are part of the post-Ohakea degradational terraces with a probable age of <18 ka (Litchfield N., 2003).

Elsewhere and above the terrace surfaces the greywacke slopes are mantled by windblown loess (silt-size rock flour) covering moderately to slightly weathered rock. Minor colluvium as fan deposits is present on the terrace surface near valley outfalls.

Late Tertiary to Early Pleistocene aged marine and probable freshwater sediments comprising limestone; conglomerate, siltstone and sandstone of the Mangaheia and Kidnappers Group crop out west of the Mohaka fault as part of the Yeoman syncline. These sediments underlie that part of the A7 reservoir upstream of the Mohaka fault.

2.4 Structure

The A7 dam site is located within the Wakarara Range block of greywacke rock mass which is complexly deformed generally about NE to SW trending axes. Folding of bedding within the greywacke rock mass is probable at the dam site but not recognised due to the lack of identifying features (such as bedding younging direction). Multiple sets of defects within the rock mass are very closely to widely spaced, and tight. Locally, very thin to moderately thick sheared and crushed zones occur throughout the rock mass.

The Wakarara block is bounded by active faults; the NNE striking active dextral-slip Mohaka fault 1km to the west, the SE striking, probable strike-slip tear Mangataura fault 1.5 km to the SW, and the Wakarara/Rangefront NNE-striking and west dipping reverse-slip fault pair at the front of the Wakarara range. These active faults are described in detail in the GNS report.

Late Tertiary to Pleistocene-aged sediments west of the Mohaka fault are folded about a NNE to SSW axis forming the double plunging asymmetrical Yeoman syncline.

2.5 Geological history

2.5.1 Basement rocks

The basement greywacke rocks, the Waioeka petrofacies of the Pahau terrane, are interpreted as forming as a sedimentary accretionary wedge adjacent to a continental magmatic arc along the Gondwana margin during Permian-Cretaceous times. The Waioeka petrofacies is predominantly composed of deformed volcaniclastic sedimentary strata, including thick sequences of deformed alternating sandstones and mudstones, frequently interrupted by faults (Bassett & Orlowski, 2004).

The greywacke rocks were uplifted in late Cretaceous times during the Rangitata Orogeny (142 to 99 Ma) and eroded. During the Tertiary period the area was subject to marine incursions with deposition of sediments and about 24 million years ago at the beginning of the Kaikoura Orogeny subduction between Australian and Pacific plates commenced. The relative plate motion was obliquely convergent across the boundary and this resulted in the formation of the 450km long zone of right-lateral oblique slip faulting, (the North Island Dextral Fault Belt (NIDFB) of Beanland, 1995).

In the Ruataniwha area continual movement along the NIDFB has lead to the development of narrow forearc basin seaways within the convergent Australia/Pacific plate boundary zone resulting in limestone, siltstone, and sandstone deposition during the Pliocene and Pleistocene. During early to late Pleistocene times the Wakarara Block emerged and greywacke gravels along with pumiceous sands were deposited in a fluvial and lacustrine environment within the Ruataniwha basin (Erdman & Kelsey, 1992).

2.5.2 Alluvial gravel materials

Gravel within the field area has been deposited during a number of different phases. Each depositional phase is separated by a period of erosion. The change between depositional and erosional environments is usually caused by one of two things (see Figure 1.1):

1) Periods of climatic cooling and warming

2) Periods of tectonic uplift followed by tectonic quiescence.

During episodes of climatic cooling (glaciations) large amounts of erosion take place in mountain ranges. This material is deposited both in the lower reaches of the river valleys and as prograding deltaic deposits out from the range front. During times of climatic warming (interglaciation) erosion in mountain ranges reduces and sediment supply dwindles and the rivers begin to erode back down through these materials and may remove all evidence of the older materials.

This process is mirrored by tectonic uplift. During phases of uplift rivers actively down cut creating gorges and deeply incised river channels with the eroded materials deposited down valley or as prograding deltaic deposits at the range front. Between periods of uplift the river gradient decreases and erosion slows and the rivers erode back down through these materials. The process is shown schematically in Figure 1.1 below.

At Wakarara both processes have been active in the Makaroro River and repeated depositional and erosional cycles have lead to the formation of multiple sets of terraces as is evident in the field area. In general the topographically highest and most dissected terrace will be the oldest whereas the lowest terrace will be the youngest.

Aggradation terrace surfaces are generally the same relative height on either side of the valley (paired) with thick fluvial gravel deposits whereas degradational terraces (slip-off terrace) may not be paired and have a thin fluvial gravel veneer.

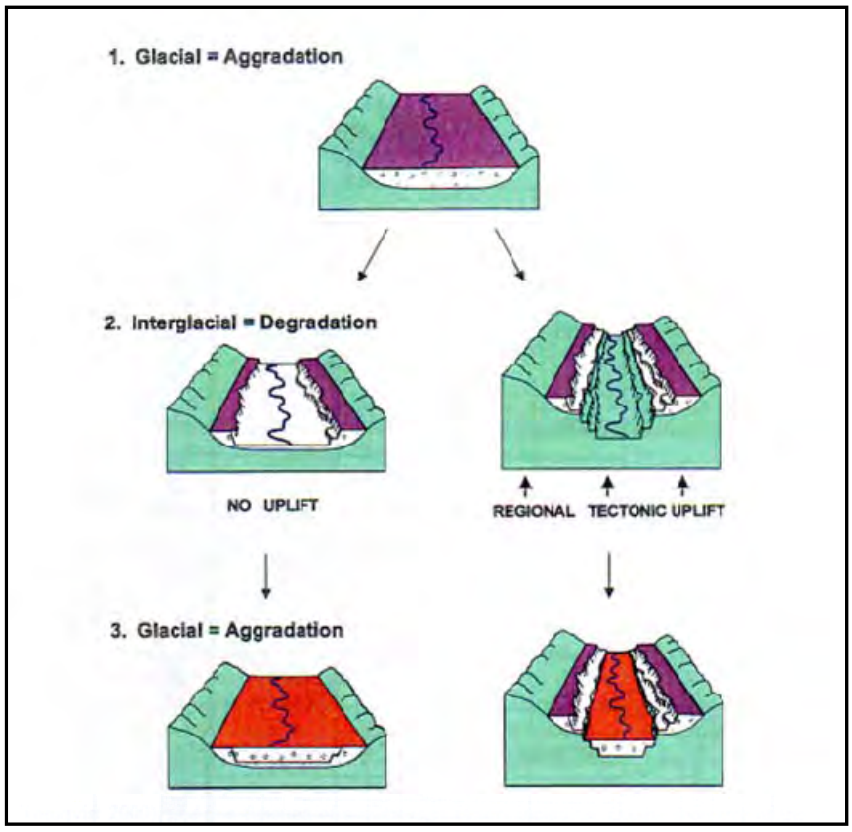


Figure 1.1 – Schematic diagram of aggradation and degradation terrace formation taken from Litchfield (2003).

Where side streams flow out on to the main river terrace surfaces localized alluvial fan deposits may occur at the mouths of these gullies as is the case at the A7 dam site.

The ages of terrace surfaces in the study area are summarised by Litchfield (2003) and provided in Table 2.1. Also included in Table 2.1 are abbreviations for the different aged gravels used in this report along with general descriptions.

In the field the terrace gravels were characterised using a combination of weathering (degree of weathering taken to increase with age) and the height (higher being taken generally as being older) of the terrace surface from which they were sampled. Generally with increased weathering the gravel clasts grade from grey (unweathered) to reddish brown (moderately to highly weathered). The highly weathered (older) gravel deposits are locally known as “red metal” and this term has also

been used to describe all terrace deposits regardless of the degree of weathering. To remove confusion in this report we classify the gravels by their assumed age of deposition as outlined in Table 2.1 below.

Table 1.2 – Summary of age and characteristics of gravel samples

Age (years)	Terrace Age Name	Location	Abbreviation/symbol used in this report	General field description
Present day	Recent	Adjacent to present river systems	Q1al	Generally fine to very coarse gravel with varying amounts of sand and silt. Gravel clasts are dominantly unweathered greywacke sandstone
<18,000	Post-Ohakea	Degradational river terraces (al) and fan deposits (af) 10 to 40 m above present river level	Q2al/af	Silty, sandy fine to medium gravel. Gravel is dominantly slightly weathered greywacke sandstone
18,000 to 30,000	Ohakea	Aggradational river terraces approximately 40 to 45 m above present river level	Q2	Sandy, fine to coarse gravel. Gravel clasts are unweathered to slightly weathered greywacke sandstone
30,000 to 50,000	Rata	Aggradational river terraces approximately 55 to 60 m above present river level	Ra	Sandy, fine to coarse gravel. Gravel clasts are unweathered to moderately weathered greywacke sandstone
70,000 to 80,000	Porewa	Dissected/eroded aggradational river terraces approximately 100 m above present river level	Po	Sandy, fine to coarse gravel. Gravel clasts are unweathered to moderately weathered greywacke sandstone
140,000 to 170,000	Marton	Heavily dissected/eroded aggradational river terraces approximately 200 m above present river level	Ma	Fine to coarse sandy gravel. Gravel clasts are moderately weather greywacke sandstone

3 Dam site geology

3.1 Detailed geological description of the site

The A7 dam site (Geological Map Sheets 1 & 2; Drawing 27690.200-02 to 04, Plates 1 and 2) is located in a north to south trending deeply incised reach of the Makaroro River approximately 40m below the terrace surface on the right abutment and 30m below the terrace surface on the left abutment.

The greywacke rock mass is well exposed along the walls of the gorge where the slopes are steep and consists predominantly of greywacke sandstone (Pahau terrane Lithotype 1 (Pt1)) with minor zones of thinly interbedded sandstone/mudstone (Pahau terrane Lithotype 2 (Pt2)). The thinly interbedded sandstone/mudstone rock mass zones range in structural fabric from minor deformation (Pt2) to moderately sheared (Pt 2a) through to completely sheared (Pt2b). The thinly interbedded zones have suffered moderate deformation with the mudstone beds taking up most of the strain by internal shearing due to tectonic movement where located between beds of massive sandstone. The internal deformation becomes extreme (Pt2b) where the interbedded mudstone/sandstone is close to, or abuts, major faults as is evidenced to the north of the dam site where the Mohaka Fault crosses the Makaroro River (Drawing 27690.200-01 and plates 6 and 7).

Where bedding is observed it dips moderately to steeply SE. Rock mass defects are well developed throughout the rock mass with five defect sets recognised. Defects are parallel with bedding and orthogonal to bedding with one random set sub-horizontal to gently dipping with a wide range of dip directions. This latter set may be of more recent origin and developed as a result of stress relief associated with the rapid uplift of the Wakarara Block in recent geological time.

The subsurface basement geology beneath the dam site was investigated by means of five fully cored HQ size drill holes. Logs of the recovered core are appended to this report (Appendix E). The drill holes were located to provide information on lithology, defects, and permeability on the abutments (BH's 701 and 704) and on the terrace surfaces (BH 702 and 703). BH 702 was deliberately located close to the right abutment gorge wall to check for dilation of the rock mass.

Drill holes BH 701, 702 on the right abutment passed down through closely jointed, massive sandstone (Pt1) with minor mudstone interbeds. BH 703, 704 on the left abutment passed down through similar lithologies.

Immediately upstream of the dam footprint on the left bank a narrow bedding parallel zone (mapped as Zone SZ1) of sheared and contorted, thinly interbedded sandstone/mudstone (lithotype Pt2a) is exposed at river level dipping at a moderate angle SE. This zone is traced to the south where it subcrops along the change slope along the eastern (back) side of the terrace surface on the left abutment. BH 705 was located to drill through this sheared interbedded mudstone/sandstone zone and test pit TP8 was excavated to expose the terrace alluvial materials above the zone looking for any displacement within these materials.

Immediately downstream of the dam site on the left bank rock exposed high above the river shows signs of distress with evidence of a previous buckling/toppling failure at the northern (upstream) end. These slopes are too steep to allow direct inspection but extrapolation along strike indicates that the upper part of this slope may be underlain by the zone of sheared and contorted thinly interbedded sandstone/mudstone (Pt2a) described above.

Some 300m upstream of the dam site (Drawings 27690.200-01 and 27690.200-02) the river channel turns sharply to the southwest (looking upstream) exposing sandstone (Pt1) more or less continuously along the right bank to the next bend in the river channel where the river swings abruptly to the north. Sandstone (Pt1) is exposed at this bend. Immediately upstream of this bend the dominant rock mass type exposed in the river banks changes to sheared and contorted, thinly

interbedded sandstone/mudstone (Pt2a) dipping SE into the valley. A large structurally controlled landslide has occurred within this lithology immediately upstream of the bend on the right bank sometime in the past which may have blocked the river. More recently erosion by the river has removed most of the toe of the landslide debris and over steepened the toe. This feature is discussed in more detail in Section 5.2.1.

3.2 Rock material description

3.2.1 Lithotype Pt1

Typically slightly weathered, moderately strong to strong intact, light grey to grey muddy fine to medium sandstone, with zones of close to widely spaced dark grey to black mudstone. The mudstone comprises less than 10% of the rock mass. Bedding is typically steeply inclined with a generally consistent NE to SW strike. The rock mass has closely to very closely spaced defects (joints) and is crisscrossed by very widely spaced sheared and crushed zones. Typical exposures of lithotype Pt1 are shown in plates 3 and 4 (Appendix B)

3.2.2 Lithotype Pt2

Typically dark grey to black mudstone dominated and thinly interbedded sequences with minor zones of bedding parallel thin shear zones and partings and poorly persistent orthogonal defect sets (Plate 5). The rock mass has very closely to extremely close spaced joints.

3.2.3 Lithotype Pt2a

As per lithotype Pt2 but with increasing structural deformation such as localized minor folds along with sheared and crushed mudstone (Plate 6).

3.2.4 Lithotype Pt2b

Deformation is extreme, with intense structural deformation and chaotic structure (Plate 7).

3.2.5 Intact rock strength

A limited number of UCS tests were carried out on core from the investigation drilling. UCS testing to determine the intact strength of greywacke rock is notoriously difficult due the number and close spacing of micro-fractures throughout the rock mass and the rock at the A7 site is no exception. The results from the testing not significantly affected by micro-fracturing are summarized below. The UCS values measured were 35.88 MPa, 41.38 MPa, 40.71 MPa (all moderately strong) and 55.31 MPa, 71.90 MPa, and 84.81 MPa (all strong). The full suite of UCS testing data is presented in Appendix I.

3.2.6 Petrographic description

Petrographic descriptions of the greywacke rock samples taken from drill core at the A7 site and grab samples from the Makaroro River were prepared by Dr P Black (Auckland University). Dr Black reports the presence of the reversibly swelling zeolite mineral laumontite as a vein material within the Pt1 rock mass at the dam site. Dr Black describes Pt1 rock as follows:

"The Waioeka petrofacies rocks (Pt1) are volcaniclastic sandstones and mudstones. Laumontite and calcite are common as veins cutting the sandstone. Laumontite, when it occurs in the rock itself, is a very minor component (estimated less than 5 wt %) of the matrix of the sediments. The more siliceous and hydrous calcium-rich zeolite, heulandite, has also been observed in some samples as a vein mineral and in the sediment matrix.

Rakaia terrane arkosic sandstones and argillites, from the headwaters of the Makaroro River, are the dominant component of the gravels. Both sacks of gravels contained small amounts of Waioeka and ?Pahau terrane sediments that contained some vein (and presumably also matrix) laumontite. One sack of the gravels contained very minor amounts of shell material and fragments of Pliocene sediments (mudstone and sandstone) that outcrop locally.

The Rakaia terrane rocks are notably much larger and tougher / harder than the local Waioeka and Pahau sandstones. The Rakaia terrane cobbles could be separated from the other sediments by screening and crushed to provide a good quality fine and coarse-grade concrete aggregate.

It is recommended that, since the Waioeka petrofacies rocks contain two minerals with expansive properties (smectite and laumontite), the durability of these sediments and their potential for use as fill be further investigated by determining their Weathering Quality Index and Clay Index values (NZS 4407: 1991 Tests 3.11 and 3.5 respectively)".

The main conclusions are that the reversibly swelling zeolite mineral occurs only in the Pt1 lithology at the dam site as a vein mineral and this mineral is not present in the river gravels at the site (the river gravels originate from the Ruahine Range (Rakaia or Kaweka terrane)).

Dr Black's full report is presented in Appendix J.

3.3 Rock mass description

3.3.1 Rock mass defects

Defects in the rock mass are defined by ISRM (1978) as any mechanical discontinuity having zero or low tensile strength. They include open, filled or healed joints (no visible displacement); weak bedding planes; and faults.

The Pahau terrane rock mass has been subjected to multiple phases of tectonism resulting in a complex occurrence of defects both macroscopic and microscopic in scale.

Faults are defined by ISRM (1978) as having visible displacements ranging from a few mm to hundreds of metres. Within the Pahau terrane in the study area faults refer to large scale features that are mappable at a scale of 1:20,000 to differentiate them from outcrop scale discrete crushed and sheared zones which have been observed throughout the rock mass.

Representative defect orientation data were collected during the engineering geological mapping and are presented in the following sections. Defects with persistence of less than 3m were not sampled.

3.3.2 Bedding

Bedding plane partings are well developed in Lithotype Pt2 between the thin sandstone/ mudstone beds. However, in Lithotype Pt1 bedding defects are only recognisable as such in the field where associated with thin mudstone interbeds. Bedding parallel defects may be present within the sandstone and mistakenly recorded as a joint set. The bedding parting could subsequently be distinguished on stereo plots (Figure 3.1).

3.3.3 Joints

Joints are grouped (IRSM, 1978) as:

- Systematic jointing occurring as well defined joint sets that dissect the rock mass
- Sub-systematic cross joints that mostly terminate on the systematic joints
- Random joints that generally have low persistence but locally dissect the rock mass.

Principal defect sets as determined from the field mapping are summarised in Table 3.1 and shown as poles on the stereonet presented in Figure 3.1.

Table 3.1 Principal joint sets

Type	Set	Group	Dip → Dip Direction	
Bd/J1	1	1	50° →100°	Bedding parting
J2	2	1	85°→ 146°	Structural joint
J3	3	1	32°→ 276°	Structural joint conjugated with Bd/J1
J4	4	1	90°→ 090°	Structural joint
J5	5	2/3?	02°→ 084°	Sub-horizontal – vertical stress relaxation joint?

Note: Joint groups: 1 = systematic; 2 = sub-systematic; 3 = random

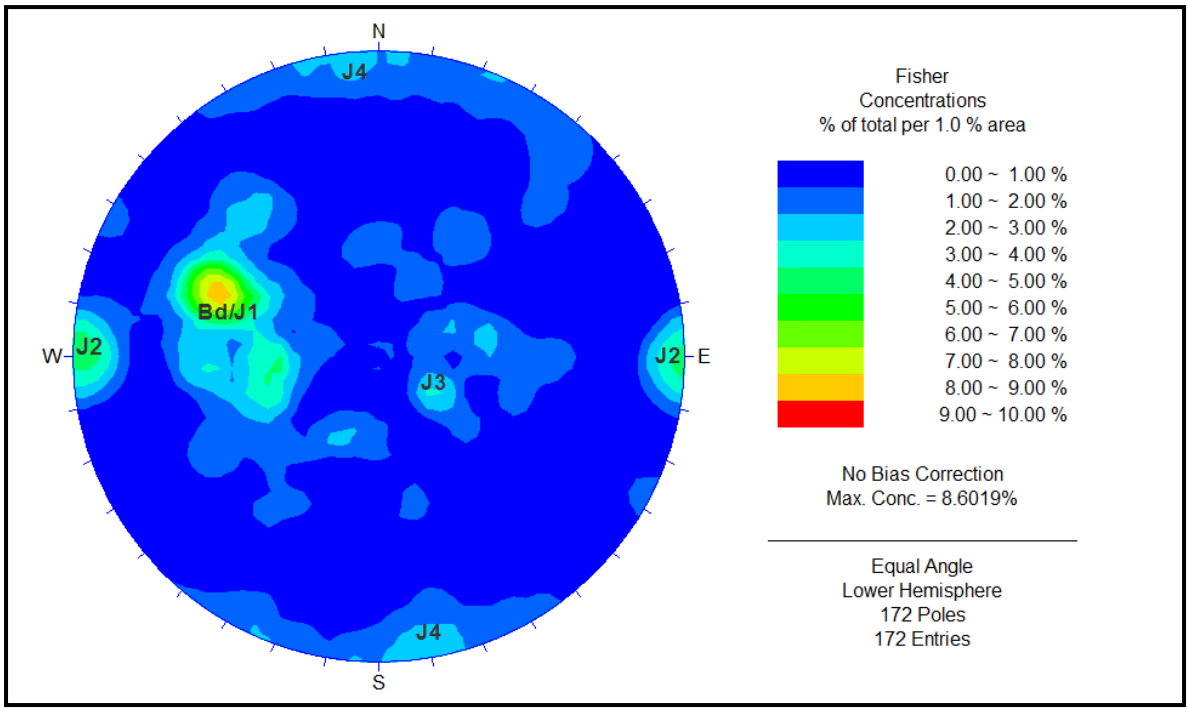


Figure 3.1: Summary Stereonet of Poles to all Defect Planes in Study Area

3.3.4 Crush and shear zones

The distributions of all crushed and sheared zones as poles in the study area are presented in Figure3.2. The distribution of poles is not as well developed as the data presented in Figure 3.1 (poles of all defect data) but shows the presence of the sub-horizontal to gently dipping sheared and crushed zones. The presence of these low angle shears will require consideration in the stability analyses for embankment stability.

Discrete sheared and crushed zones are common throughout the sandstone (Pt1). These zones are generally not wider than 100mm and may contain up to 10mm clayey gouge material.

Strain accumulated during tectonism has been preferentially accommodated by mudstone in bedding parallel sheared zones (Pt2) which in a few locations is associated with buckling and folding (Pt2a) such as seen on the left abutment. The left bank sheared/contorted mudstone zone was investigated by BH 705 and exposed in Trench 8 and is discussed below.

Deformation adjacent to the Mohaka fault zone (Pt2b) increases in intensity towards the fault trace reducing the rock fabric to that of a granular soil.

3.3.4.1 Zone SZ1

A zone of deformed interbedded sandstone/mudstone with bedding parallel sheared zones (Zone SZ1) dipping at a moderate angle to the east is mapped from below a waterfall in a side stream draining Donovan Gully upstream of the dam site on the true left bank of the Makaroro River to the dam site. The zone is exposed in the left bank of the Makaroro River immediately upstream of the dam site and was traced up the gorge rock face on to the back of the left abutment terraced surface. The zone appears to be a continuation of a feature mapped as an “inactive fault” on QMap and trends parallel with the regional bedding structure.

The zone was further investigated by trench TP8 and BH 705. Trench TP8 was excavated down through terrace alluvial deposits to expose the zone and to note whether the terrace cover deposits were disrupted above the feature. No disruption to cover materials was noted. The log for trench TP8 is provided on Drawing 27690.200-07 in Appendix A. Drill hole BH 705 was drilled through Zone SZ1 to determine the width of the feature and presence of clayey gouge material. The information from BH 705 and nearby BH 703 indicates that the Zone SZ1 has a thickness of 15m and contains several narrow zones of plastic clayey gouge within a re-healed breccia.

The potential for ground movement on Zone SZ1 (and therefore displacement of the dam foundation) during a major nearby seismic event is a possibility that is being reviewed by GNS Science. Further investigations are also required to assess any past seismic or co-seismic activity on Zone SZ1 and the scope of these investigations are described in the GNS report.

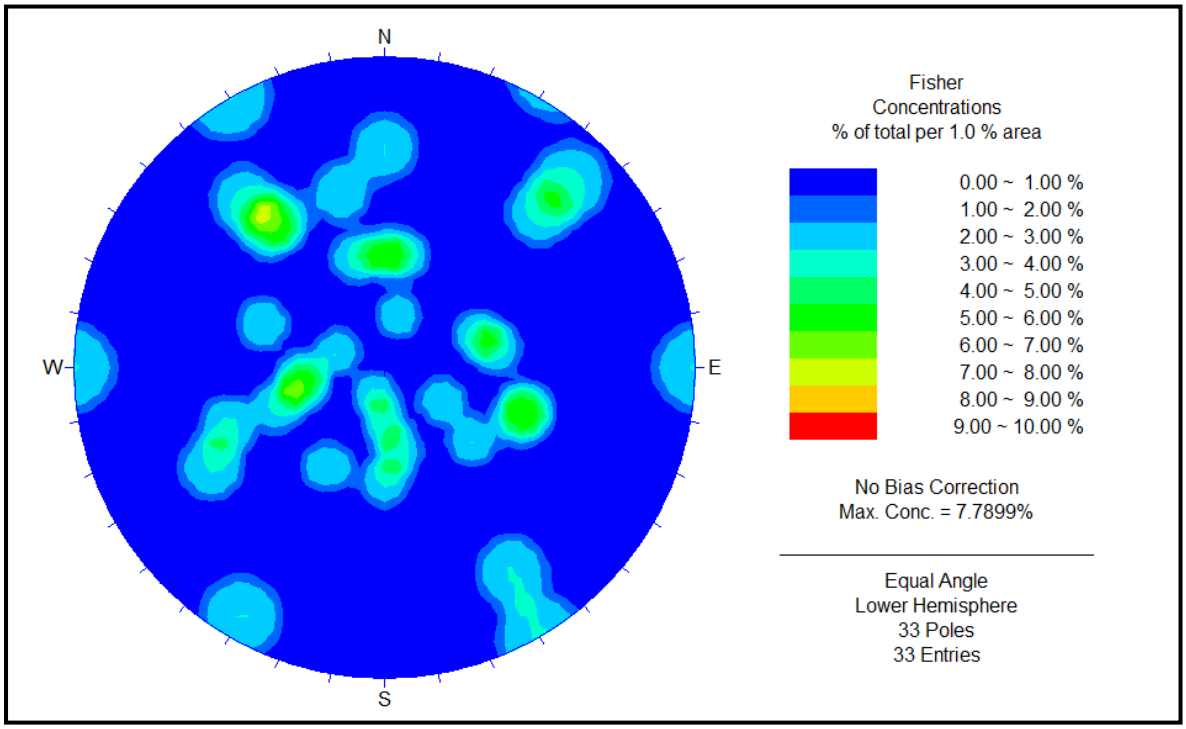


Figure3.2: Summary Stereonet of poles to all crush and shear zones in study area

3.3.5 Drill Core RQD

Rock Quality Designation (RQD) was measured during drilling as it is an input parameter for most rock mass classification systems (Deere, D.U. et al, 1967). RQD is defined as the percentage of intact core pieces longer than 10cm in the total length for each core run as shown below (Figure 3.3).

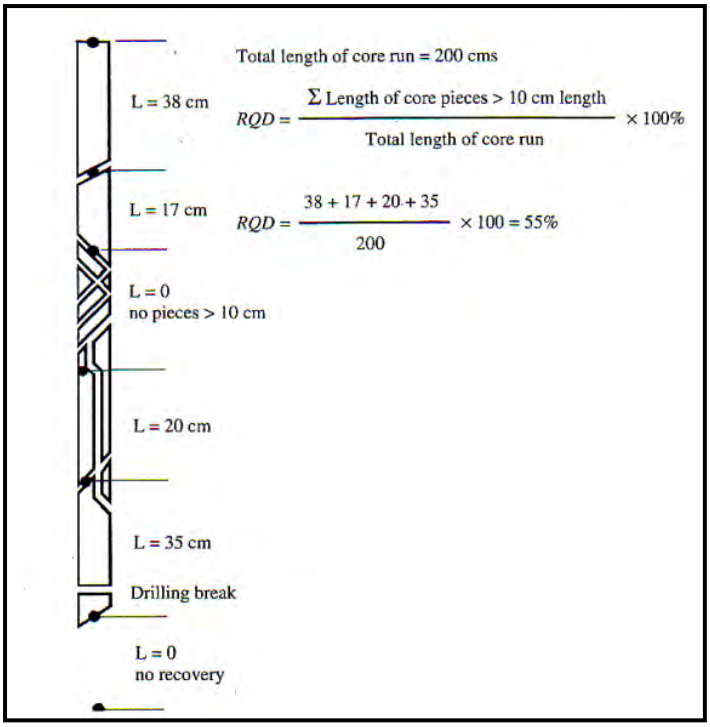


Figure 3.3: Graphic description of showing the method for measuring Rock Quality Designation (taken from Deere, D.U., Hendron, A.J. Patton, F.D. Cording, E.J,. 1967).

RQD data for each drill hole is presented in figures 3.4 to 3.8 and also shown on the drill hole logs along with the frequency of naturally occurring fractures.

New Zealand greywacke rock mass is typically well jointed and Cooke (Cook G.K., 2001) noted from detailed scan-line mapping of New Zealand greywacke that joint persistent was short, typically less than 0.5m, due to the highly fractured mass in which it occurs. He further commented that while individual joints intersect and truncate each other and appear to be irregularly oriented, stereographic analysis indicates that only two or three dominant joints sets are present.

On a smaller scale the rock mass may contain micro-fractures with a persistence of less than 5cm.

Together, the varying scales of defect spacing usually combine to give core retrieved from a greywacke rock mass a low RQD. Consequently, RQD by itself is not a particularly good indicator of overall rock mass quality and this aspect has been thoroughly researched in New Zealand by S.A.L. Read, R.L. Richards and others whose works are discussed in the following section.

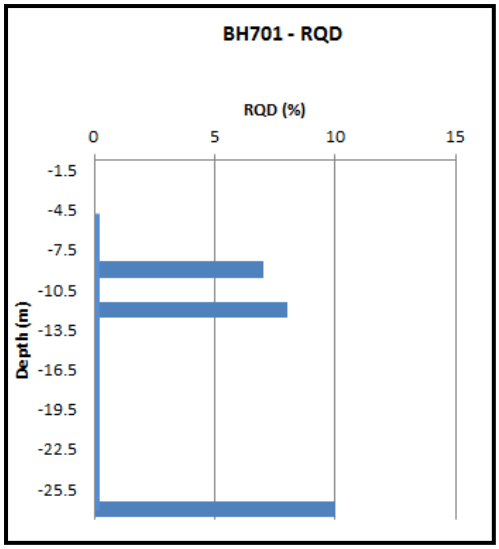


Figure 3.4- BH701 variation of Rock Quality Designation with depth.

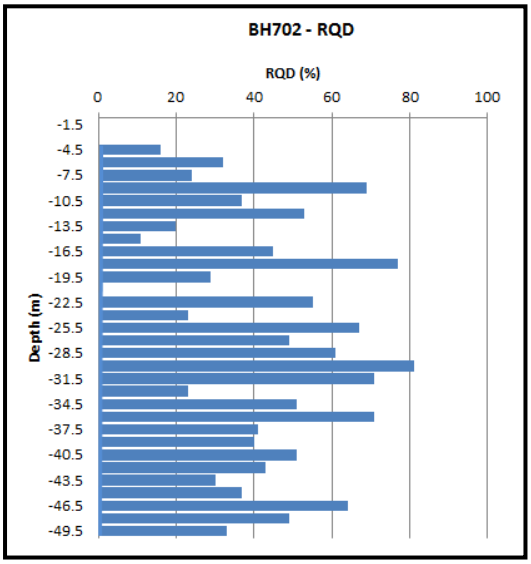


Figure 3.5- BH702 variation of Rock Quality Designation with depth.

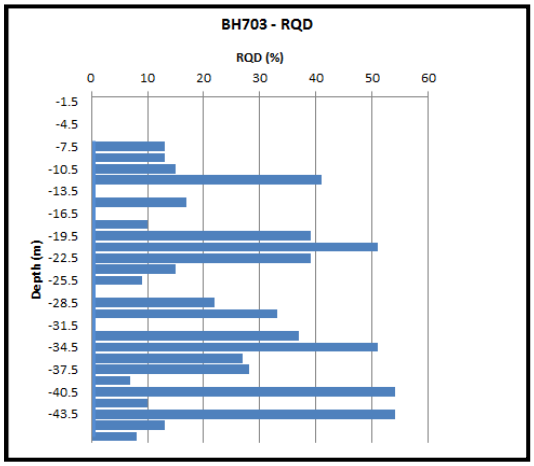


Figure 3.6 - BH703 variation of Rock Quality Designation with depth.

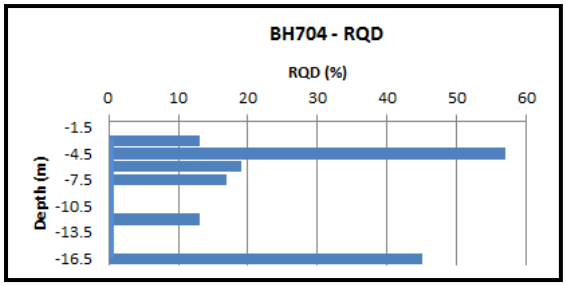


Figure 3.7 - BH704 variation of Rock Quality Designation with depth.

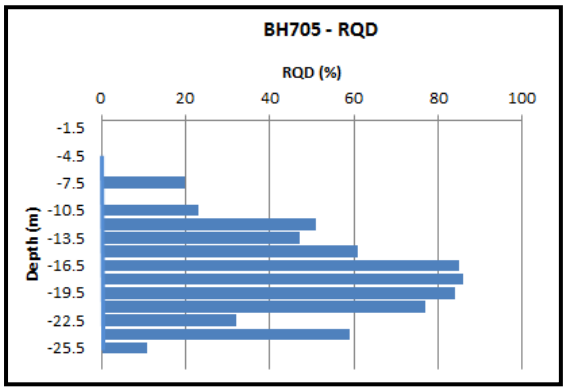


Figure 3.8- BH705 variation of Rock Quality Designation with depth.

3.3.6 Classification of greywacke rock mass

A rock mass classification system for New Zealand greywacke (Table 3.2 and figures 3.9 and 3.10) has been developed based on the characterisation of the rock mass quality (Read et al., 1998 and Read et al., 1999). The classification system provides a basis for assessing rock mass conditions to be encountered in foundation excavations and during diversion tunnel excavation.

Table 3.2 New Zealand Greywacke Rock mass Classification (Read et al., 1998)

Descriptive classification for New Zealand greywacke rocks (after Read et al. 2000).

Class	Lithology	Strength	Defects	Comments
I	Homogeneous or faintly bedded medium-grained sandstone. Fine-grained sandstone with some widely spaced interbeds of mudstone.	Extremely strong to very strong	Joint spacing > 150mm, typically 200 – 300 mm, surfaces rough to smooth. Sheared, crushed or shattered zones generally absent.	Little indication of major tectonic deformation in rock mass.
II	Fine or very fine-grained sandstone with mudstone laminae. Interbedded sandstone and mudstone. Mudstone / sandstone with coarse podding.	Very strong to strong	Joint spacing 60 – 200mm, surfaces rough to slickensided. Minor narrow (< 300mm wide) sheared, crushed or shattered zones.	Rock mass may contain minor very widely spaced zones of sheared and crushed rock.
III	Mudstone with extensive recrystallisation. Interbedded sandstone and. mudstone, often with podding and some veining.	Strong to moderately strong	Joint spacing < 100mm, surfaces smooth to slickensided. Narrow (< 300mm wide) sheared, crushed, or shattered zones.	Characterized by closely spaced defects (may be shattered) or recrystallised rock mass.
IV	Interbedded sandstone and mudstone, often with extensive podding. Mudstone or very fine sandstone with extensive veining.	Strong to moderately strong	Joint spacing < 60mm, surfaces smooth to clay-lined. Sheared with crushed zones (typically < 500mm wide), and may contain thin (< 25mm) gouge zones.	Characterised by very closely spaced fractures with sheared zones (i.e. shattered and sheared rock mass with some crushed zones associated with fault zones).
V	Mudstone or fine sandstone (rock material generally sheared and crushed).	Strong to moderately strong (or n/a)	Joint spacing < 20mm, surfaces slickensided to clay-lined. Generally sheared or crushed zones which contain gouge zones.	Characterised by very or extremely closely spaced fractures with crushed zones and gouges (i.e. crushed rock mass associated with major faulting).

Classification based on rock mass in the unweathered (fresh) or fresh-stained state.
Podding refers to the disruption of bedding into irregular lenses or pods. Recrystallisation refers to recementation of the rock mass and is often accompanied by veining.

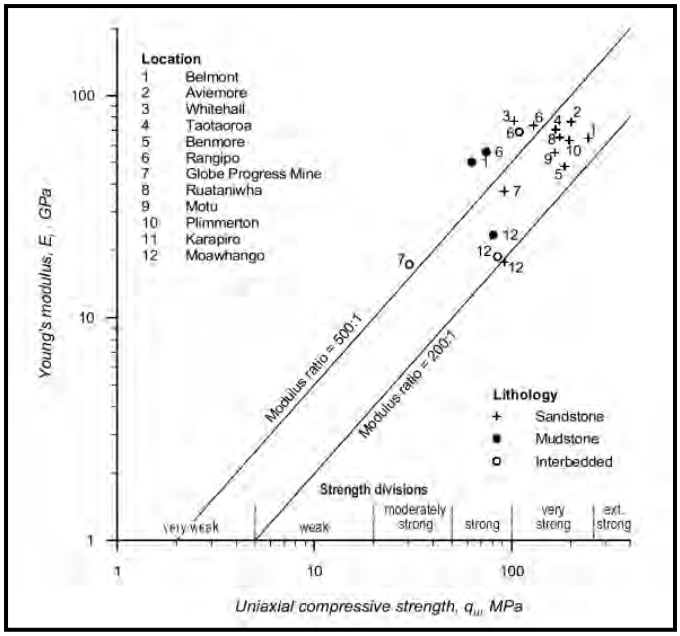


Figure 3.9: Typical modulus ratio for New Zealand greywacke rock

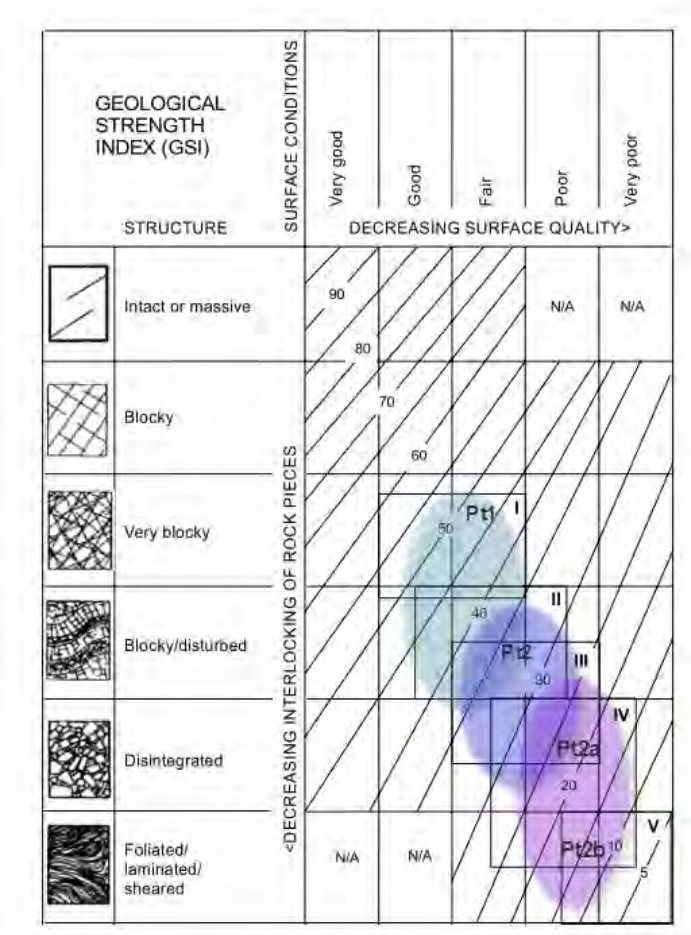


Figure 3.10: Geological Strength Index and rock mass class (I-V) for different classes of greywacke discussed in Section 3.2 showing distribution of A7 lithotypes (chart taken from Read et al., 1998).

Based on inspection of the rock mass exposed in the gorge section of the river channel and drill holes BH 702 and BH 703 we expect that the rock mass underlying the dam footprint in the central section and within the diversion works (underlying the terraced surfaces) to be mainly Class II with some Class I. The rock mass quality in the dam abutments based on core from BH701 and BH 704 appears to be of lower quality lying within Classes III to IV.

3.3.7 Rock mass deformation modulii

No direct measurement of rock mass modulus was undertaken during the present phase of investigations. Rock mass deformation modulus may be estimated using RocLab using input parameters based on field observations. For the sandstone dominated lithotype (Pt1) within the central section of the dam footprint estimated values for GSI of 50 and UCS of 80MPa using a modulus ratio of 400 (Read et al., 2006) suggest a rock mass modulus of 5 to 10 GPa.

3.3.8 Rock mass seismic velocity

Seismic velocities of between 2900 m/s to 3300 m/s were measured along four seismic refraction lines with a total length of 800m in the greywacke rock mass at the A7 site. Sonic velocities measured along intact core samples of greywacke sandstone and mudstone from Rangipo are typically 5000m/s (Bryant J.M., 1977). The difference in velocities between the intact rock and the main rock mass is due to the presence of defects in the latter (bedding plane partings, joints, crush and shear zones) which slow the propagation of seismic waves.

A relationship between seismic velocity and drill core RQD for greywacke rock mass at Rangipo was proposed by Hegan (1976) as shown in Figure 3.11.

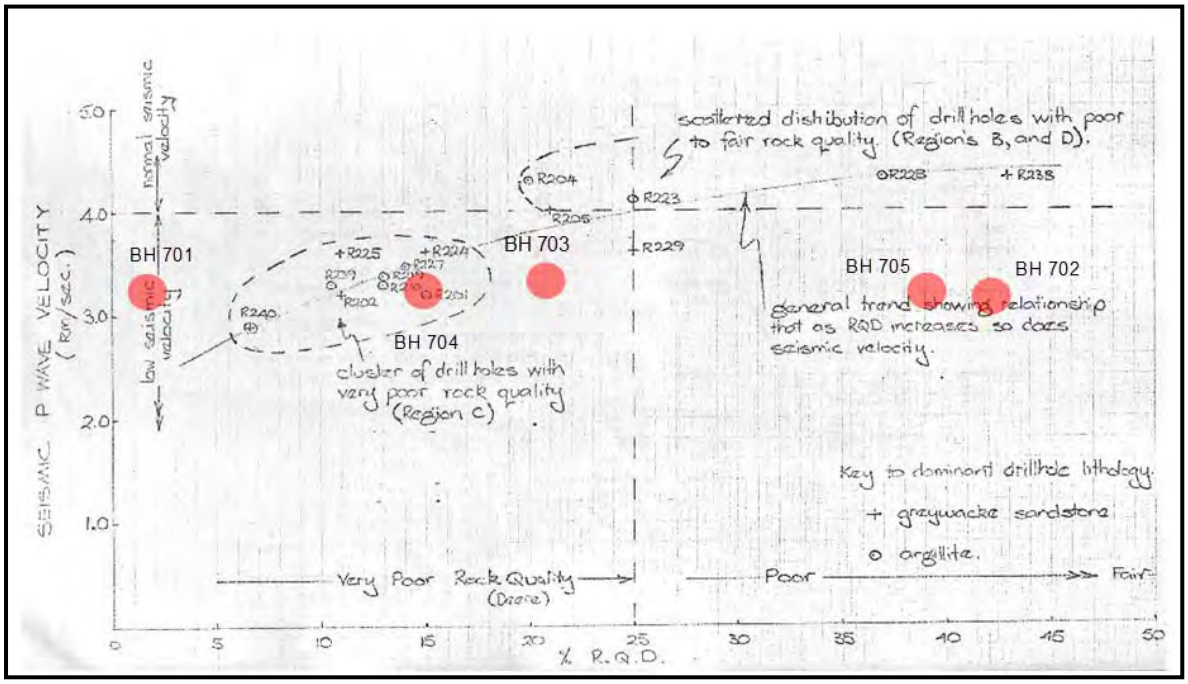


Figure 3.11: Relationship between seismic wave velocity and RQD (after Hegan 1976). The red dots represent the RQD measured in the A7 boreholes vs P-wave velocity measured during the seismic refraction surveys.

At Rangipo there was a general increase in seismic velocity with increasing RQD. However this does not seem to be the case at the A7 site where the seismic P-wave velocity across the dam footprint remains at 3300 m/s regardless of RQD. The lower measured velocity may be due to the presence of

micro-fractures within the rock mass which strongly influenced UCS data or the younger (Cretaceous) age of the A7 greywacke.

3.4 Permeability

3.4.1 Rock material permeability

The intact rock material in the foundation excavation for the dam is indurated moderately strong to strong greywacke sandstone with less than 10% interbedded indurated moderately strong to strong mudstone. The matrix of both the sandstone and the mudstone is re-crystallized by low grade metamorphism. Porosity measurements (n%) reported for Rangipo Power Project greywacke sandstone and mudstone (Kaweka terrane, part Torlesse Super group) by Bryant (Bryant 1977) averaged at 0.25% for sandstone and 0.34% for interbedded sandstone/siltstone/mudstone. For the purposes of this study the intact rock material permeability is taken as less than 10^{-10} m/sec.

3.4.2 Rock mass permeability

Rock mass permeability was assessed in each of the investigation drill holes by undertaking a Lugeon test at the completion of each core run (1.5m intervals). The maximum test pressures used were the lesser of overburden pressure or reservoir pressure. The Lugeon test was carried out as a "pressure loop" as shown in Table 3.3.

Table 3.3 Lugeon test carried out as a "pressure loop"

Test Stage	Description	Pressure Step
1st	Low	$0.50 \cdot P_{MAX}$
2nd	Medium	$0.75 \cdot P_{MAX}$
3rd	Maximum (peak)	P_{MAX}
4th	Medium	$0.75 \cdot P_{MAX}$
5th	Low	$0.50 \cdot P_{MAX}$

The following Table 3.4 describes the condition of the rock mass defects associated with the different Lugeon values.

Table 3.4 Rock mass defects with different Lugeon values

Lugeon Range	Classification	Hydraulic Conductivity Range (cm/sec)	Condition of Rock Mass Discontinuities	Reporting Precision (Lugeons)
<1	Very Low	$< 1 \times 10^{-5}$	Very tight	<1
1-5	Low	1×10^{-5} - 6×10^{-5}	Tight	± 0
5-15	Moderate	6×10^{-5} - 2×10^{-4}	Few partly open	± 1
15-50	Medium	2×10^{-4} - 6×10^{-4}	Some open	± 5
50-100	High	6×10^{-4} - 1×10^{-3}	Many open	± 10
>100	Very High	$> 1 \times 10^{-3}$	Open closely spaced or voids	>100

The test pressures were increased with depth up to a maximum which reflected the head of water in the proposed reservoir. The maximum pressure depended on the location and elevation of the drill hole. Lugeon values for the five drill holes drilled as part of the current investigations are summarized on the Figures below, the full test results may be found in Appendix F.

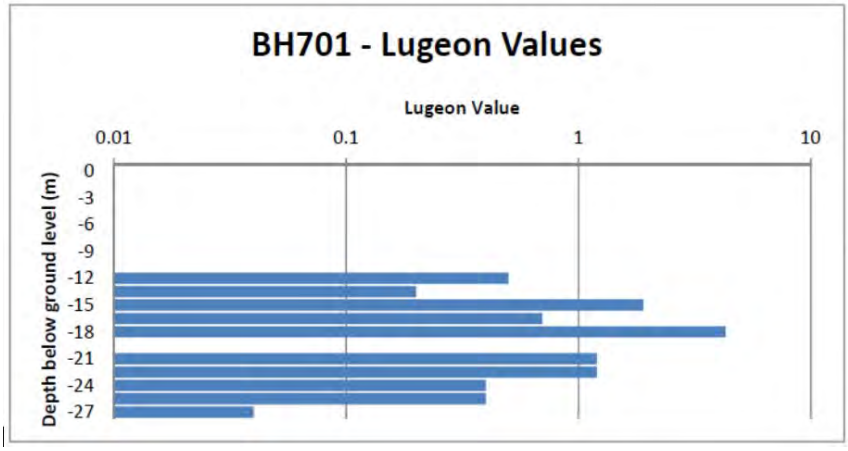


Figure 3.12: BH701 Lugeon values

BH701 (Figure 3.12) is located on the right abutment just below dam crest level (the dam axis was subsequently shifted and the BH701 location is now upstream of the dam footprint). The rock mass consisted of closely to very closely jointed (RQD average <10%) interbedded fine sandstone and mudstone. Lugeon values in BH701, however, are all low suggesting that defects in the rock mass are tight.

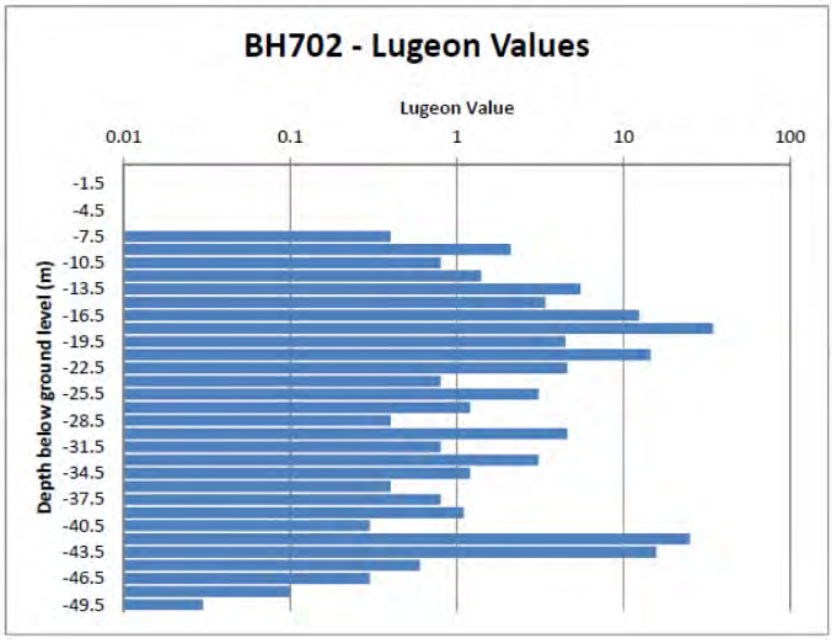


Figure 3.13: BH702 Lugeon values

BH 702 (Figure 3.13) is located close to the true right side of the river channel gorge to determine the amount of rock mass relaxation that might be present due to stress relief of the gorge wall. The rock mass consisted of closely jointed sandstone with minor mudstone. Although the Lugeon values measures are generally in the range <1L (very low) to 10L (low to moderate) two zones of higher water loss were encountered. The first was between 16.5 and 19.5 mbgl where steeply dipping and vertical joints were logged in the core and it is likely that water was able to bypass the packer by flowing along the vertical joint. The vertical joints may have the J4 orientation in which case water could flow towards the gorge wall.

The second occurred between 42 and 43.5 mbgl where disrupted mudstone beds and a crushed zone were observed in the core. A drop in water level was noted during drilling at this level and a low water level was observed in the piezometer that screened 42 to 49.5mbgl (see section 3.4.4). The high Lugeon values and low standing water level in the piezometer indicates water leakage at this level, most likely towards the gorge wall.

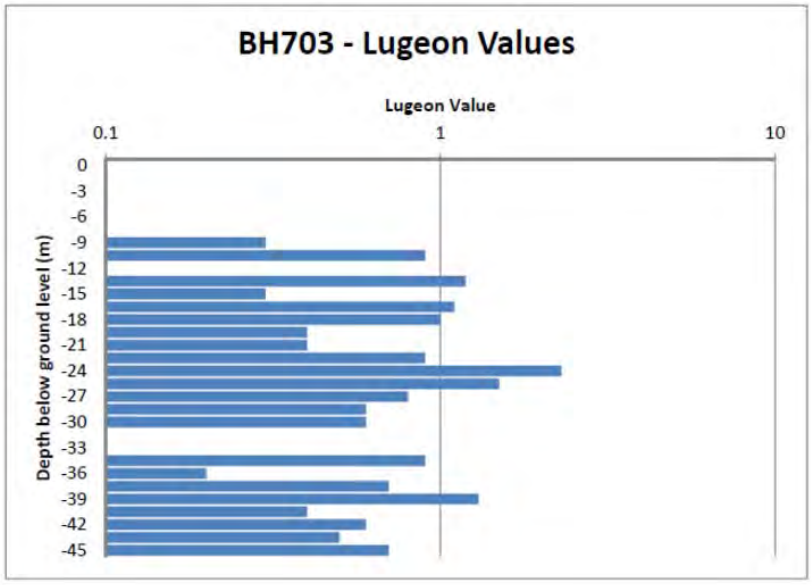


Figure 3.14: BH703 Lugeon values

BH703 (Figure 3.14) located close to the break in slope at the back of the left bank terrace surface was drilled through closely spaced jointed sandstone. Water losses were low and the Lugeon values are generally < 1L (very low). The low Lugeon values are likely to be due to the nature of the jointing within the rock mass where individual joints intersect and truncate each other.

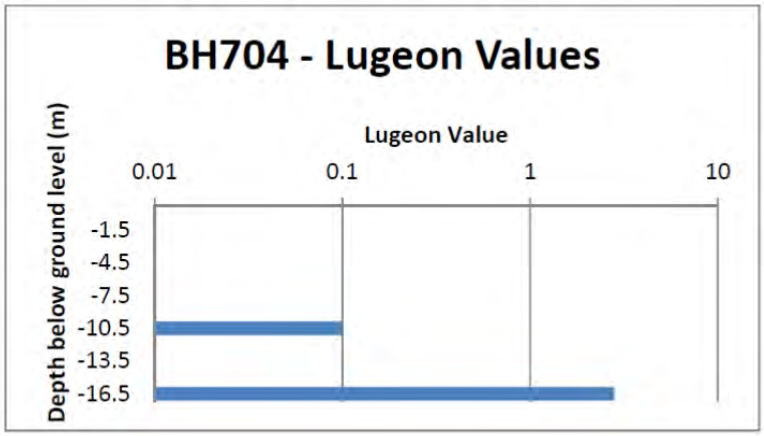


Figure 3.15: BH704 Lugeon values

BH704 located high on the left abutment near crest level was drilled through closely jointed sandstone (Figure 3.15). Lugeon values in this borehole were mostly close to zero with only two test values being greater than 0.1L.

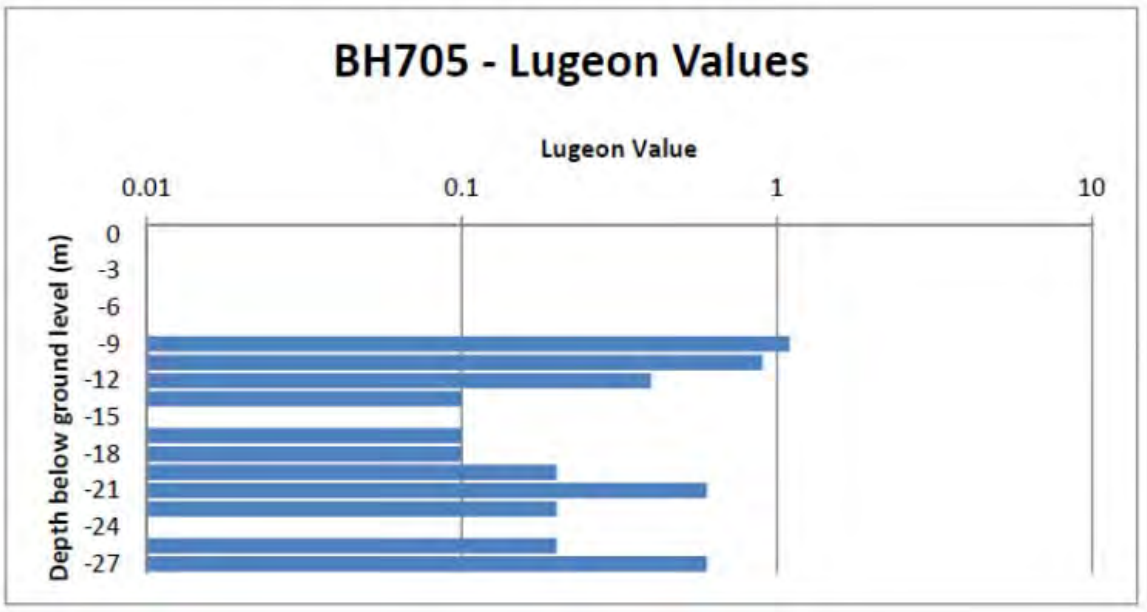


Figure 3.16: BH705 Lugeon values

BH 705, located close to BH703, was drilled to investigate the rock mass conditions associated with Zone SZ1. Lugeon tests were carried out as the drill hole location is close to the upstream extent of the footprint. Lugeon values recorded (Figure 3.16) are very low and similar to those recorded in BH 703.

3.4.3 Drill water and Groundwater Levels

Standing water levels were recorded daily during drilling each hole and the measurements are presented as a plot of standing water versus depth for each hole below. Apart from BH 702 standing water levels remained constant during drilling. The drop in standing water level recorded in BH 702 occurred where the high Lugeon value was recorded near the bottom of the hole with the probability that drill water was able to flow out through the open vertical joint.

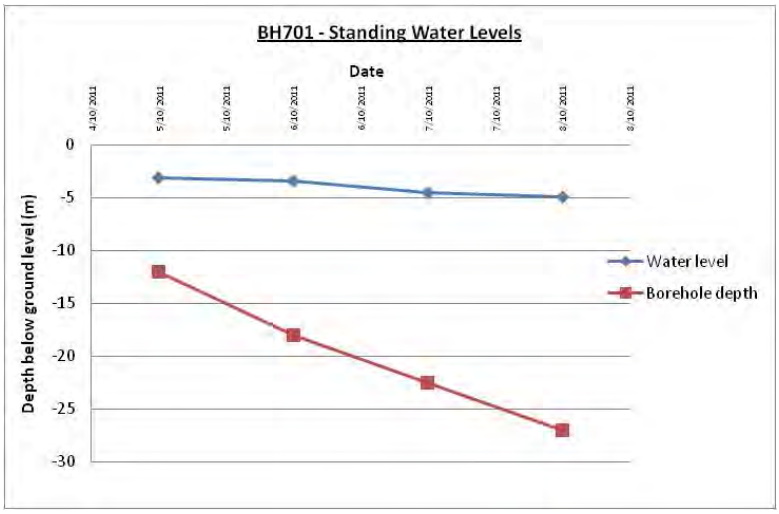


Figure 3.17: BH701 standing water level and borehole depth vs date.

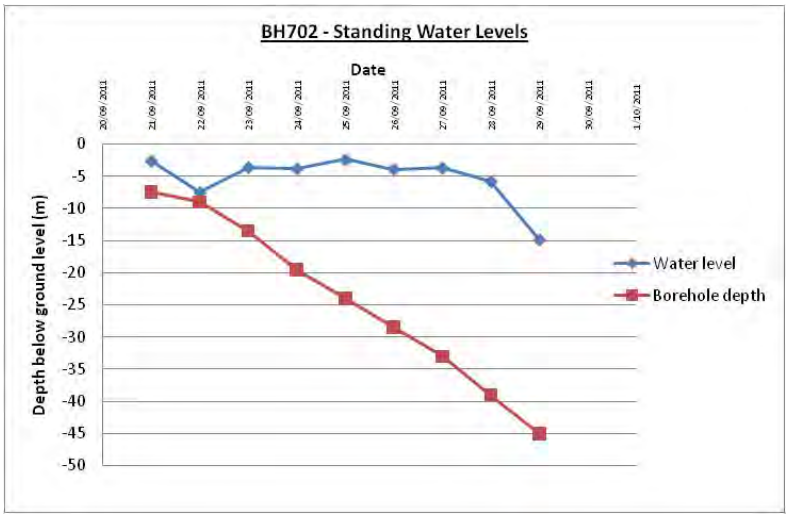


Figure 3.18: BH702 standing water level and borehole depth vs date. The drop in water level observed on 29 September 2011 reflects the intersection of a crushed zone by the drill hole.

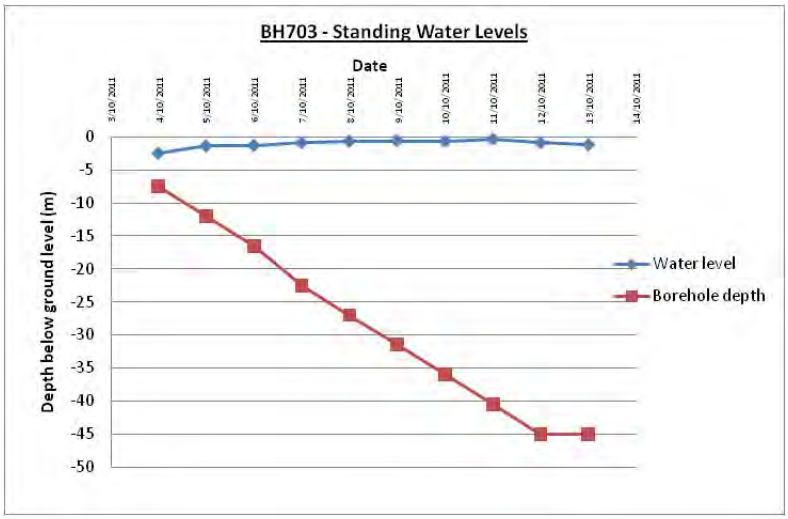


Figure 3.19: BH703 standing water level and borehole depth vs date.

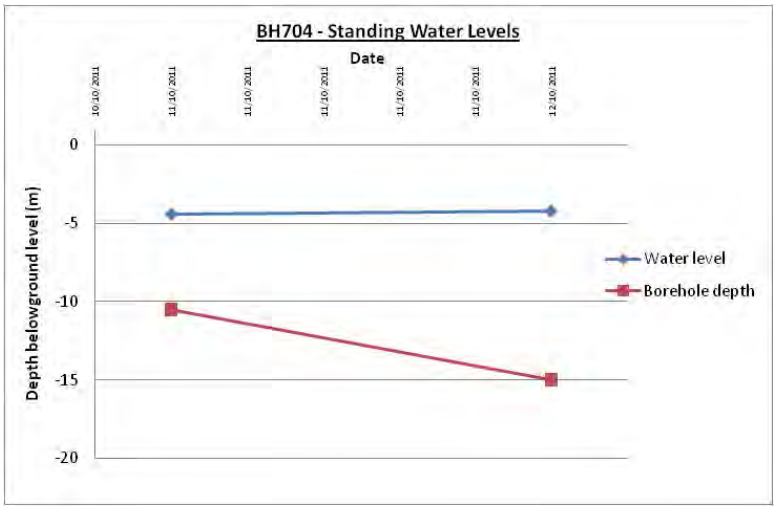


Figure 3.20: BH704 standing water level and borehole depth vs date.

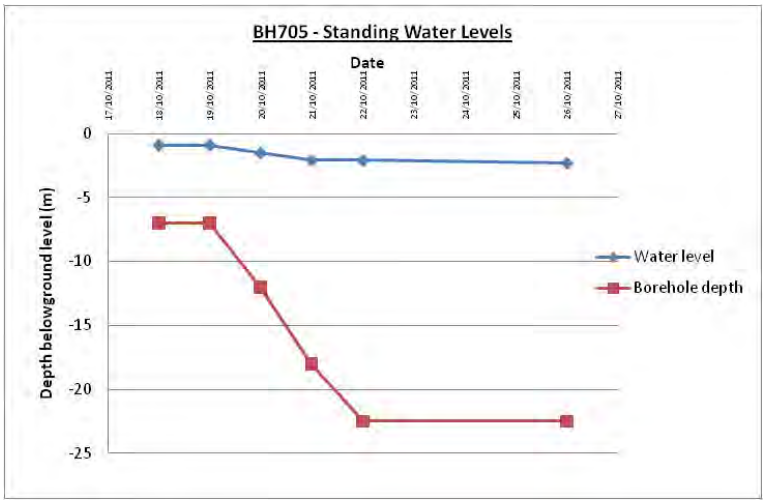


Figure 3.21: BH705 standing water level and borehole depth vs date.

3.4.4 Piezometers

Casagrande-type piezometers are installed in all investigations drill holes with screen depths based on changes in daily standing water levels or high Lugeon values recorded during drilling. Construction details for the piezometers are included in Appendix G. Following installation the piezometers were developed by bailing out the water (by airlifting) and allowing the groundwater to re-establish. The subsequent water levels in the piezometers were measured on 31 October 2011 (Table 3.5)

Table 3.5 Piezometer water levels recorded on Monday 31 October 2011

Borehole	Piezometer Number	Screened Interval (mbgl)	Water level (mbgl)	
			Date	Level
701	701/1	15m to 20m	31/10/2011	5.47m
701	701/2	23m to 27m	31/10/2011	5.55m
702	702/1	16.5m to 22.5m	31/10/2011	2.99m
702	702/2	42m to 49.5m	31/10/2011	27.15m
703	703/1	15m to 20m	31/10/2011	Artesian*
703	703/2	39m to 45m	31/10/2011	Artesian*
704	704/1	10.5m to 16.5m	31/10/2011	10.04m
705	705/1	8m to 12m	31/10/2011	1.27m
705	705/2	21m to 27m	31/10/2011	1.3m

*Artesian head approximately 1m above ground surface, flow estimated at 1litre/10 min

The low water level observed in piezometer 702/2 shows that the hydrostatic head is not uniformly developed in borehole 702. This reflects contrasts in permeability that are likely due to structural controls in the rock mass and the close proximity of the borehole to the gorge wall.

The artesian head in piezometers 703/1 and 703/2 may be related to the presence of persistent vertical joints in the core in the screened interval, presumed to be the J4 set, trending east to west and able to transmit water from further up slope.

3.5 Weathering

There is very little weathering of the rock mass in the central section of the dam foundation as the weathered rock had been removed by the river erosion that created the degradational terrace surfaces and the river channel gorge. Unweathered rock was encountered in BH's 702, 703 and 704 within a few metres of the rock head level (see drawings 27690.002-02 to 04 for rock head contours based on boreholes, trial pits and seismic refraction lines). BH 701 (right abutment) and BH 704 (left abutment) located above the terrace surface encountered unweathered rock at 8.5 mbgl. The deeper weathering on the two abutments likely reflects the greater period of time for which these areas have been exposed.

4 Diversion tunnel

4.1 Description of diversion works

A nominal 4m diameter D shaped tunnel on the right abutment is currently proposed for river diversion during construction. At completion of construction the tunnel will also be used as part of the water supply system. The length of the diversion tunnel is dependent on the final layout of the diversion works but is likely to be at least 280m long.

4.2 Temporary support requirements

Based on the field mapping around the perimeter of the right terrace surface as exposed in the gorge wall and the nearby drill hole BH 702, the full length of the diversion tunnel is expected to be excavated in Pt1 greywacke sandstone with minor interbedded mudstone. The excavation method most commonly used in greywacke rocks is drill and blast with temporary support by either rock bolts and shotcrete or steel sets and cast in place concrete lining.

Temporary support requirements for the tunnel have been assessed using both the Q system (Barton and Grimstad, 1994) and RMR (Bieniawski, 1993). Input of rock mass descriptive parameters based on the field mapping and drill core logging in both Q system and RMR give very similar results of Q=4 (fair tunnelling ground) and RMR = 48 (fair tunnelling ground) as presented on the following pages. Support requirements indicated are systematic bolting at 1.5m spacing (bolt length 2.4m) and 50mm of unreinforced shotcrete (Figure 4.1).

Note: The relationship between RMR and Q is given as RMR =9 log Q +44. Substitution of Q=4 into this equation gives RMR=49.

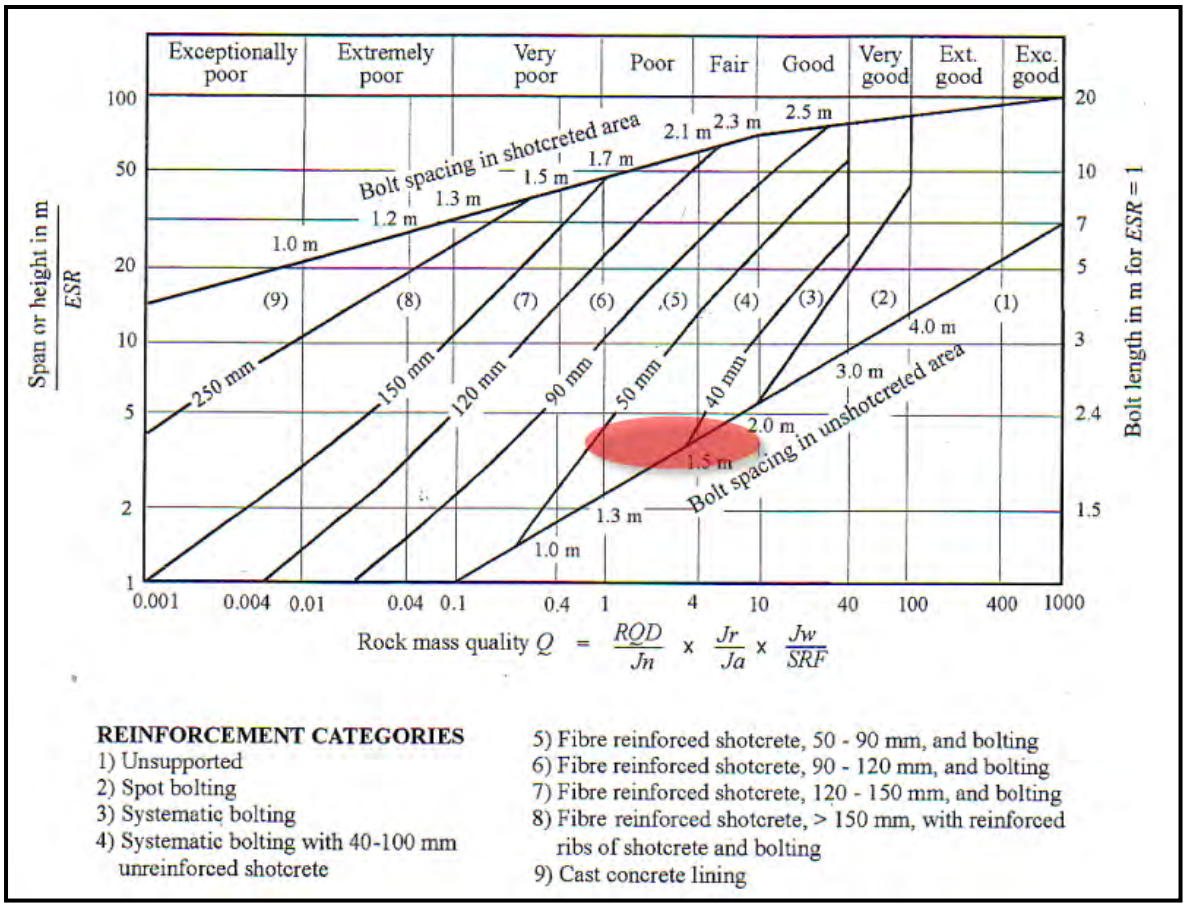


Figure 4.1: Estimated support based on tunnelling quality index Q (red shaded area)

Table 4.1: Q system classification table for Pt1 lithotype

Q SYSTEM CLASSIFICATION

Reference: Barton N & Grimstad E. *The Q-system following twenty years of application in NMT support selection.* Felsbau 12, No 6, 1994

PROJECT:

	1. Rock Quality Designation	**RQD**
A	Very poor	0-25
B	Poor	25-50
C	Fair	50-75
D	Good	75-90
E	Excellent	90-100
i)	*Where RQD is reported or measured as <= 10 (including 0), a nominal value of 10 is used to evaluate Q*	
ii)	*RQD intervals of 5, i.e. 100, 95, 90 are sufficiently accurate*	

RQD = **40**

	2. Joint Set Number	**Jn**
A	Massive, no or few joints	0.5-1.0
B	One joint set	2.0
C	One joint set plus random joints	3.0
D	Two joint sets	4.0
E	Two joint sets plus random joints	6.0
F	Three joint sets	9.0
G	Three joint sets plus random joints	12.0
H	Four or more joint sets, random, heavily jointed, "sugar cube" etc	15.0
J	Crushed rock, earthlike	20.0
i)	*For intersections, use 3.0 x Jn*	
ii)	*For portals, use 2.0 x Jn*	

0.0

Jn = **12.0**

Intersection or portal factor = **1.0**

	3. Joint Roughness Number	**Jr**
	a) Rock-wall contact, and b) rock-wall contact before 10cm shear	
A	Discontinuous joints	4.0
B	Rough or irregular, undulating	3.0
C	Smooth, undulating	2.0
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
i)	*Descriptions refer to small scale features and intermediate scale features, in that order*	
	c) No rock-wall contact when sheared	
H	Zone containing clay minerals thick enough to prevent rock-wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1.0
i)	*Add 1.0 if the mean spacing of the relevant joint set is greater than 3m*	
ii)	*Jr = 0.5 can be used for planar slickensided joints having lineations provided the lineations are oriented for minimum strength*	

Jr = **3.0**

	4. Joint Alteration Number	**Phi basic**	**Ja**
	a) Rock-wall contact (no mineral fillings, only coatings)		
A	Tightly healed, hard, non-softening, impermeable filling, i.e. quartz or epidote		0.8
B	Unaltered joint walls, surface staining only	25-35	1.0
C	Slightly altered joint walls. Non softening mineral coatings, sandy particles, clay-free disintegrated rock etc	25-30	2.0
D	Silty or sandy clay coatings, small clay fraction (non-softening)	20-25	3
E	Softening or low friction clay mineral coatings, i.e. kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc and small quantities of swelling clays	8-16	4.0
	b) Rock-wall contact before 10cm shear (thin mineral fillings)		
F	Sandy particles, clay-free disintegrated rock etc	25-30	4.0
G	Strongly over-consolidated non-softening clay mineral fillings (continuous but < 5mm thickness)	16-24	6.0
H	Medium or low overconsolidation, softening, clay mineral fillings (continuous but < 5mm thickness)	12-16	8.0
J	Swelling-clay fillings, i.e. montmorillonite, (continuous but < 5mm thickness). Value of Ja depends on percent of swelling clay-size particles and access to water, etc	6-12	8-12
	c) No rock-wall contact when sheared (thick mineral fillings)		
KLM	Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition)	6-24	6, 8, or 8-12
N	Zones or bands of silty or sandy clay, small clay fraction (non-softening)		5.0
QPR	Thick, continuous zones or bands or clay (see G, H, J for description of clay condition)	6-24	10, 13, or 13-20

Ja = **1.0**

	5. Joint Water Reduction Factor	**kg/cm^2**	**Jw**
A	Dry excavations or minor inflow, i.e. < 5 l/min locally	<1	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings	1-2.5	0.66
C	Large inflow or high pressure in competent rock with unfilled joints	2.5-10	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings	2.5-10	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time	>10	0.2-0.1
F	Exceptionally high inflow or water pressure, continuing without noticeable decay	>10	0.1-0.05
i)	*Factors C to F are crude estimates. Increase Jw if drainage measures are installed.*		
ii)	*Special problems caused by ice formation are not considered*		

Jw = **1.0**

	6. Stress Reduction Factor			**SRF**
	a) Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated			
A	Multiple occurences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)			10.0
B	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation < 50m)			5.0
C	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation > 50m)			2.5
D	Multiple shear zones in competent rock (clay-free), loose surrounding rock (any depth)			7.5
E	Single shear zones in competent rock (clay-free) (depth of excavation <= 50m)			5.0
F	Single shear zones in competent rock (clay-free) (depth of excavation > 50m)			2.5
G	Loose, open joints, heavily jointed or "sugar-cube" etc (any depth)			5.0
i)	*Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation*			
	b) Competent rock, rock stress problems	**sigc/sig1**	**sigtheta/sigc**	**SRF**
H	Low stress, near surface, open joints	>200	<0.01	2.5
J	Medium stress, favourable stress conditions	200-10	0.01-0.3	1.0
K	High stress, very tight structure. Usually favourable to stability, may be unfavourable for wall stability	10-5	0.3-0.4	0.5-2
L	Moderate slabbing after > 1 hour in massive rock	5-3	0.5-0.65	5-50
M	Slabbing and rock burst after a few minutes in massive rock	3-2	0.65-1	50-200
N	Heavy rock burst (strain-burst) and immediate dynamic deformations in massive rock	<2	>1	200-400
ii)	*For strongly anisotropic virgin stress field (if measured): when 5<= sig1/sig3<=10, reduce sigc to 0.75sigc. When sig1/sig3>10, reduce sigc to 0.5sigc. Sigc = unconfined compressive strength, sig1 and sig3 are major and minor principal stresses, sigtheta = maximum tangential stress*			
iii)	*Few case records availaBle where depth of crown below surface is less than span width. Suggest SRF increase from 2.5 to 5 for such cases.*			
	c) Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure		**sigtheta/sigc**	**SRF**
O	Mild squeezing rock pressure		1-5	5-10
P	Heavy squeezing rock pressure		>5	10-20
	d) Swelling rock: chemical swelling activity depending on pressure of water			
R	Mild swelling rock pressure			5-10
S	Heavy swelling rock pressure			10-20

Jr and Ja classification is applied to the joint set or discontinuity that is least favourable for stability from the point of view of orientation and shear resistance (where tau = signxtan^-1(Jr/Ja)

SRF = **2.5**

$$Q = \frac{RQD}{J_n} * \frac{J_r}{J_a} * \frac{J_w}{SRF}$$

Q = **4.0**

Table 4.2: RMR classification for rock type PT1 observed on site.

RMR CLASSIFICATION

Reference: Bieniawski ZT. Classsification of rock masses for engineering: The RMR system and future trends. Comprehensive Rock Engineering, Pergamon Press, 1993

	Parameter	Units	Value	Rating
1	*Uniaxial compressive strength*	MPa	100	9
2	*Drill core quality, RQD*	%	50	9
3	*Spacing of discontinuities*	m	0.1	6
4	*Condition of discontinuities*			
	-Persistence	m	5	3
	-Separation	mm	1	3
	-Roughness	Table 1	4	3
	-Infilling	Table 2	2	4
	-Weathering	Table 3	1	6
5	*Groundwater*	Table 4	3	7
	(For GSI, use 1)			
6	*Rating adjustment*	Table 5	2	-2
	(For GSI, use 1)			

RMR	48
CLASS	III
DESCRIPTION	Fair
GSI	43

Table 1: Roughness

1	Very rough	6
2	Rough	5
3	Rough-Slightly rough	4
4	Slightly rough	3
5	Slightly rough - Smooth	2
6	Smooth	1
7	Slickensided	0

Table 2: Infilling

1	None	6
2	Hard < 5mm	4
3	Hard 5mm	3
4	Hard >5mm	2
5	Soft < 5mm	2
6	Soft 5mm	1
7	Soft >5mm	0

Table 3: Weathering

1	Unweathered	6
2	Slightly weathered	5
3	SW - Moderately weathered	4
4	Moderately weathered	3
5	MW - Highly weathered	2
6	Highly weathered	1
7	Decomposed	0

Table 4: Groundwater

1	Completely dry	15
2	Damp	10
3	Wet	7
4	Dripping	4
5	Flowing	0

Table 5: Rating adjustment

Tunnels	1	Very favourable	0
	2	Favourable	-2
	3	Fair	-5
	4	Unfavourable	-10
	5	Very unfavourable	-12
Foundations	6	Very favourable	0
	7	Favourable	-2
	8	Fair	-7
	9	Unfavourable	-15
	10	Very unfavourable	-25
Slopes	11	Very favourable	0
	12	Favourable	-5
	13	Fair	-25
	14	Unfavourable	-50
	15	Very unfavourable	-60

A further check of the support requirements was undertaken using *Unwedge version 3.019* using the defect data presented in Table 3.1. This confirmed that fully grouted 2.4 m long passive bars with 100 kN tensile capacity at 1.5 m spacing in the tunnel crown (5 in number bars) and 1.5m out of plane along with 50mm of unreinforced shotcrete would support the likely kinematic wedges.

5 Stability of dam foundation, abutments and reservoir slopes

5.1 Cut slope stability and design

Existing slopes in the river channel gorge are up to 40m high and range in steepness between 2V:1H to 4V:1H. The slopes are largely defect controlled and defect controlled dropouts have occurred leaving unsafe overhangs. For design of slopes in the rock mass two options – maximum cut slope without meshing/bolting and cut slope with meshing/bolts could be considered. However, work place safety will be a consideration as the present work programme has significant excavation to get the diversion in place before in river construction can start. For preliminary consideration the maximum cut slope without bolting/meshing should not be steeper than 1V:1H from a work place safety perspective. However, steeper benched cut slopes with bolting/meshing could provide significant savings by reducing the required stockpiling/double handling, as could extending the diversion tunnel.

5.2 Reservoir slope stability

5.2.1 Right bank landslide

A large landslide is mapped upstream of the dam site on the true right side of the valley (plates 8 and 9). The landslide was investigated by engineering geological field mapping and a seismic refraction survey. The landslide has occurred within a zone of Pt2a lithotype (thinly interbedded sandstone/mudstone) where bedding is dipping out of the slope. The surface topography of the landslide is indicative of a large block of the Pt2a rock which has failed by slumping controlled by bedding parallel defects, most likely under strong earthquake shaking, which has then had the toe area over-steepened by river erosion leading to further slumping of the landslide debris.

Sheared and buckled thinly interbedded mudstone/sandstone is exposed by local down cutting by a small stream along the right lateral margin of the landslide. The base of the landslide debris was determined by the seismic refraction survey. An interpretative section of the landslide based on this data is presented in Figure 5.1. The volume of the landslide is estimated at 360,000 m^3.

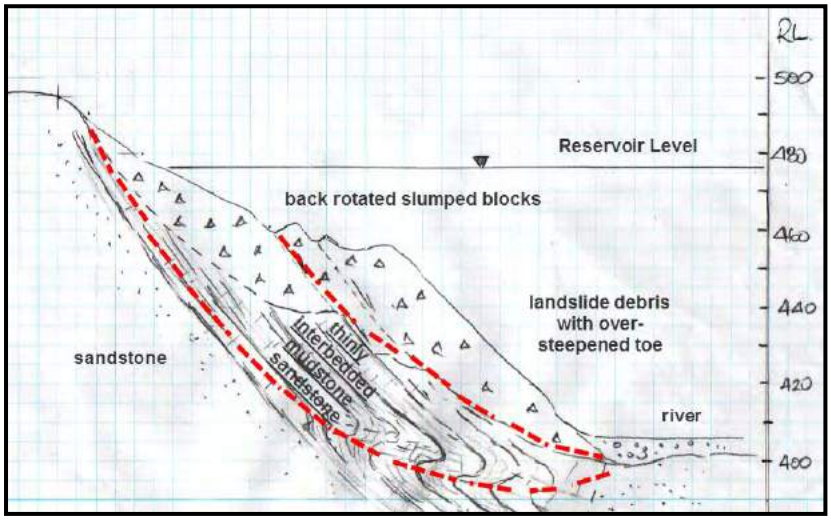


Figure 5.1: Preliminary geological model (red dashed lines show shallow and deep failure surfaces).

A series of preliminary slope stability analyses were undertaken using the landslide geometry presented in Figure 5.1 using assumed shear strength characterisation (outlined in Table 5.1) to

model the effects of partially drowning the landslide under static conditions. The groundwater in the models was assumed to be the same as the reservoir level.

Table 5.1 Assumed shear strength characterisation

Material	Shear strength assumed
Gravel	C'= 5 kPa, Ø'=35°
Landslide debris	C'= 30 kPa, Ø'=40°
Sheared interbedded mudstone/sandstone	Generalised Hoek-Brown Classification UCS = 15 MPa; GSI = 15; m_i = 7 Mohr-Coulomb fit ; C'= 110 kPa, Ø'=26°

Table 5.2 Preliminary stability analyses results

Reservoir level (RL)	Factor of Safety	Failure mode
405m	1.30	Shallow failure in debris layer
420m	1.27	Shallow failure in debris layer
430m	1.29	Shallow failure in debris layer
440m	1.44	Deep failure into sheared rock mass
450m	1.50	Deep failure into sheared rock mass
460m	1.57	Deep failure into sheared rock mass
470m	1.64	Deep failure into sheared rock mass

The results presented in Table 5.2 show that as the reservoir level is raised the factor of safety decreases passing through a minimum value when the reservoir level is at RL 420m and then increases with increasing reservoir level. The stability analyses also show that the style of failure changes from shallow at low reservoir levels to deep seated when the reservoir depth exceeds RL 440m.

The landslide stability was further assessed at full reservoir level for seismic stability. The initial results show that the landslide reaches limiting equilibrium at a horizontal acceleration of 0.2g. It should be noted that these analyses are based on broad assumptions about the geometry and characteristics of the landslide and as such are considered indicative only at this stage. Further study is required to determine the magnitude of the wave generated by failure of the landslide mass into the reservoir. If mitigation measures are required further investigations of the landslide to determine the most cost effective solution to manage the risk it presents will be needed. These investigations would include cored drill holes to determine the depth to the failure surface(s) and the rock mass quality below the landslide.

5.2.2 Other landslide areas

No other areas of deep seated landsliding have been identified within the proposed reservoir. Shallow landslides are present on the slopes close to the Mohaka Fault and some slumping of these slopes is expected during reservoir drawdown.

5.2.3 Reservoir seismic stability and peak ground accelerations

The large right bank landslide described in Section 5.2.1 above may require the implementation of stability measures, yet to be designed, for seismic stability.

The active Mohaka fault trace passes through the reservoir and a future rupture along this segment of the fault will change the reservoir floor levels and displace it laterally. The magnitude of the horizontal and vertical displacement has been estimated by GNS as 4 to 5 m (horizontal) and 0.4 to 0.9 m (vertical). Such displacements may create a seiche within the reservoir and change levels relative to the dam crest.

In addition to the above, GNS science have presented site specific seismic hazard spectra for the A7 location. Their results are summarised in Table 5.3.

Table 5.3- Peak ground accelerations (PGA) estimated by GNS Science for the A7 site

Earthquake return period	Peak ground acceleration
1,000 years	0.4 g
2,500 years	0.55 g
5,000 years	0.7 g
10,000 years	0.85 g

5.3 Left bank dilated rock mass feature downstream of dam

The topography of the steep slope immediately downstream of the dam site on the left bank is indicative of a vacated area due to a previous landslide/rock slide within the zone of SZ1 along with a more general area of dilated rock mass. This is characterised by what appear to be rock pinnacles leaning out of the slope, most likely as part of a structurally controlled toppling/buckling failure. The apparently dilated area is between 60m to 90m above river level. Access on to the slope was not attempted due to the steep nature of the terrain.

The vacated rock slope failure and zone of dilated rock mass are judged to be as a result of strong earthquake shaking. The volume of rock debris that could originate from the zone of dilated rock is estimated at 210,000 m^3 based on extrapolation of the contours from the back slope of the vacated area.

5.4 Foundation stability and leakage potential

5.4.1 Zones of rock weakness

The present investigations (field mapping and drill core logging) indicated that the dam will be mainly founded on closely to very closely jointed sandstone (Pt1) containing minor (<10%) interbedded mudstone with some bedding parallel sheared zones. The rock mass will also be crisscrossed with variably orientated, widely spaced narrow crushed and sheared zones.

Field mapping has identified a zone (shown as SZ1 on Drawings 27690.200-02 to 04 and 27690.200-06) of contorted and sheared thinly interbedded mudstone (Pt2a) within the dam footprint.

A second narrow sheared zone containing a thin veneer of plastic clay gouge was observed in a rock exposure on the recently cut access track down to the terrace surface on the left bank. It strikes ENE to WSW with a steep dip. The lateral extent of this sheared zone could not be determined during this investigation.

A number of low angle to sub-horizontal defects some with narrow (1 to 2mm wide) sheared and crushed zones were also observed in the gorge walls during the field investigations. These defects have a continuity of up 20 m in the gorge and their effect on embankment stability will require consideration during detailed design.

All of these zones are discussed in more detail in Section 3.3.4 and will require further investigations.

5.4.2 Susceptibility to liquefaction

Liquefaction is the phenomenon of partial or complete strength loss in response to earthquake shaking in saturated materials. Liquefaction of materials within the dam foundation, (or near to the foundation) could contribute to the development of instability during an earthquake.

In general soils that are prone to liquefaction are loose, saturated, cohesionless to low plasticity fine grained soils. Investigations have identified localised deposits of such materials within much coarser gravel deposits on the terraces; there are discrete lenses/beds of silt and fine sand within the gravel beneath the site, but they were not traced laterally for any significant extent and they were not saturated. Particle size distributions indicate the potential for lenses of liquefiable material within the gravels in the river channel is lower. This suggests that the overall liquefaction potential at the site is very low.

On this basis the site is not expected to be susceptible to liquefaction on a broad scale, but localised deposits may be prone if they were to become saturated. Installation of drains within the in situ materials, sufficient to ensure the materials do not become saturated in the future would mitigate this potential. Alternatively, the potential for liquefaction could be eliminated by stripping the site to bedrock beneath the dam footprint. This should be evaluated further during detailed design.

6 Sources of construction materials

Proposed Dam

The dam is proposed to be 83 m high from the river bed and approximately 480 m long, by 310 m wide (at its widest point). It will take some 1.7 Mm^3 of materials for construction including:

- 1.5 Mm^3 of rock fill
- 100,000 m^3 of filter material
- 98,000 m^3 of undifferentiated fill to buttress the upstream face
- 12,000 m^3 of concrete for the upstream face

This section investigates the various construction materials that are located in the environs around the dam.

6.1 Rock fill

Greywacke sandstone lithotype (Pt1) is the main rock type available as a fill material. At the present time no testing has been carried out to determine the degree of fragmentation that will occur during excavation. Based on field observations and local experience it is expected that the sandstone (Pt1) will require blasting for excavation while the interbedded sandstone/mudstone (Pt2) may be ripped by heavy bulldozer (but perhaps not at an economic rate). The degree of fragmentation will be an important parameter as it will influence the permeability of rock fill within the structure of the dam. Micro-fracturing observed in some samples during the UCS testing will also lead to the further breakdown of rock fragments during fill placement.

The presence of the zeolite, laumontite, has been confirmed by XRD analysis of the rock core as a common vein mineral (Black, 2011). Laumontite is a zeolite that has the capacity to reversibly hydrate/dehydrate. In hydrating the mineral experiences an increase in volume which is sufficient to break the rock along the vein margins. This process can occur where the mineral is exposed to the atmosphere, and repeated expansion and contraction due to changes in moisture content can result in the zeolite crumbling into a powder resulting in breakage along the vein.

Further studies, as outlined in Dr Black's report (Black, 2011), are required to determine the effect this zeolite may have on both the durability of the rock fill and the performance of exposed rock surfaces to repeated wetting and drying.

Based on typical greywacke defect proportions as shown in Table 6.1 (Read et al., 2005) 80% to 100% of the rock mass could contain joints with a spacing of 20-60 mm with the potential to break down further to smaller sizes due to the presence of micro-fractures. Based on this information and depending on the handling and compaction during placement, the rock fill is likely to be composed of fine grained, angular clasts and, with the inclusion of mudstone and material from crushed and sheared zones, likely to be of lower permeability.

Table 6.1 Greywacke defect descriptions and proportions (Read et al., 2005)

Greywacke defect descriptions.

	Bedding [1]	Vein [1]	Joint	Sheared zone	Crushed zone [2]
Physical description	Defect where parting is parallel with rock texture	Defect with secondary mineralisation	Defect with little or no displacement	Roughly parallel sided zone with closely spaced joints	Roughly parallel sided zone with angular fragments including clay and/or gouge
Proportion(%)	0 – 8%	0 – 10 %	80 – 100 %	0 – 2 %	0 – 2 %
Spacing	10mm – 5m	Where present: 10mm – 2m	20 – 600 mm	Where present: 1 – 20 m	Where present: 1 – 20 m
Persistence	< 1m - > 10m	< 1m – < 10m	<1m – 10m	10 – > 100m	10 – > 100m
Width	n/a	n/a	n/a	< 1m	< 2m
Filling	Clean or silt/clay infill where relaxed	Secondary min-eralisation (e.g. calcite or zeolite)	Clean or silt/clay infill where relaxed	n/a	n/a

[1] Not considered a defect where bedding is textural only (has no parting) or vein is annealed
[2] Fault is a generic term for crushed zones with development of gouge (may be > 2m) from significant tectonic displacement

6.2 Alluvial borrow material

Alluvial borrow materials were investigated as potential construction materials and/or concrete aggregate. The particle size distributions are shown on figures 6.1 to 6.5. The different aged gravels are described below. The locations of the samples are shown on Drawing 27690.200-05.

6.2.1 Q1al Gravel

Recent gravels (Q1al) were sampled from five excavator pits dug to between 1 and 1.5 metres below ground level (mbgl) adjacent to the present Makaroro river channel as a source for concrete aggregate and sand. They contain varying amounts of sand and silt which is likely to be dependent on the sampling location within the river channel. They are dominantly made up of unweathered (with some slightly weathered), strong to very strong greywacke sandstone clasts eroded from the Ruahine Range to the west of the site. The greywacke rock mass in the Ruahine Range is from the Kaweka Terrain, part of the Torlesse Composite Terrain, and is of a higher metamorphic grade than the Waioeka petrofacies and does not contain the zeolite mineral, laumontite. These gravels are suitable for concrete aggregate.

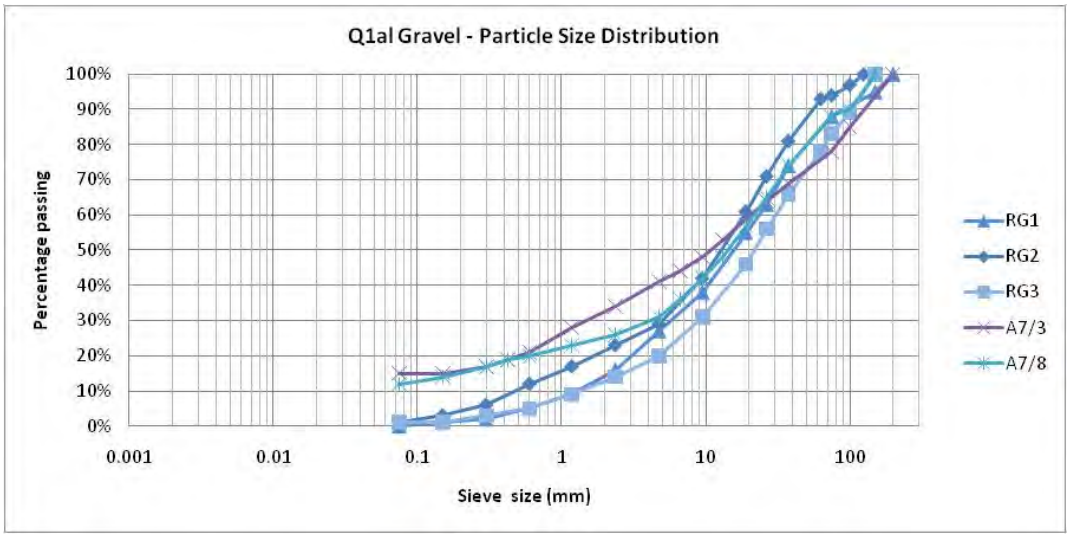


Figure 6.2- Particle size distribution curves for Q1al gravels.

6.2.2 Q2al and Q2af Gravel

Q2al (alluvial) and Q2af (fan) gravels are located on degradational terraces around the A7 dam site approximately 30 to 40 m above the current river level. They were investigated by seven trial pits excavated within the right abutment dam footprint using a 20t excavator operated by Gair Contracting Ltd. These pits were logged by an engineering geologist and photographed prior to backfilling. The logs and photographs of the pits are provided in Appendix H.

Q2al gravel in the trial pits was of variable thickness and directly overlying bedrock reflecting the degradational nature of the terrace. The maximum thickness of Q2al gravel was 2m and the gravel was absent or thin (< 0.5 m) in a number of the trial pits. Q2al gravel was not sampled during the investigation due to the thin nature of the deposit over much of the site. Where observed it was brown sandy fine to very coarse GRAVEL with varying quantities of slightly weathered, strong to very strong, rounded boulder-sized clasts up to 0.4 m diameter.

Q2af gravel overlies the Q2al gravel and comprises light brown to brown sandy fine to medium grained, subrounded to subangular GRAVEL. It was generally between 2 and 3 m thick, but was in excess of 5 m thick in TP2 which was located centrally within an alluvial fan. Q2af gravel is a mixture of material of colluvial and fan origin. Samples of Q2af gravel were taken from five of the pits. The results of laboratory tests carried out on these samples are provided in Appendix I and Figure 6.2. Individual gravel clasts were strong to very strong.

Both the Q2al and Q2af gravel deposits in this area are covered by volcanic ash (brown fine sandy silt) and loess (windblown silt and very fine sand) up to 1.5 m thick. The grain size of the gravel is highly dependent on the depth of sampling. The coarsest material was generally encountered at the base of the trial pits immediately overlying bedrock where the gravel was fine to very coarse. At intermediate depths the gravels were finer, contained greater proportions of sand and silt and contained silt beds (probable loess origin). The gravel at the base of the pits is likely to be alluvial (Q2al). The gravel at intermediate depths is likely to be of colluvial or fan origin (Q2af).

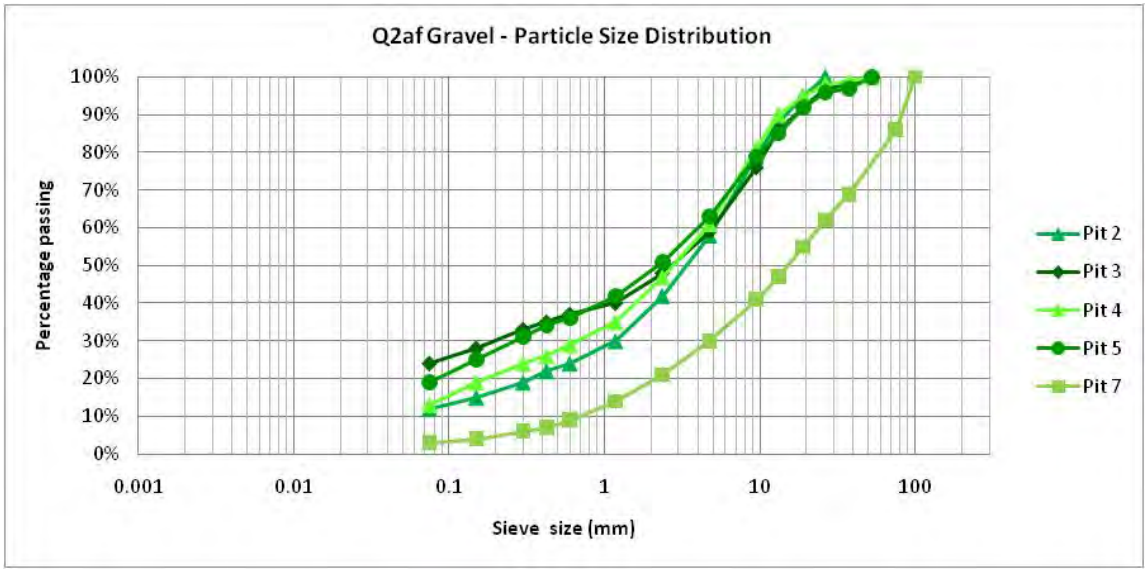


Figure 6.2 – Particle size distribution curves for Q2af gravels.

6.2.3 Q2 Gravel

Q2 gravel was sampled from borrow pits and road cuts approximately 10 to 15 km downstream from the proposed dam site from terraces 40 to 45 m above the current river level. These gravels are of alluvial origin and were deposited during the Otira glacial period (Ohakea terrace age), a time when a large amount of material was eroded from the axial ranges (Litchfield, 2003).

The Q2 gravel samples analysed were slightly weathered with some moderately weathered, fine to coarse GRAVEL with minor sand and silt. Individual clasts were moderately strong to strong. Cobbles were also observed in one of the samples taken.

The Q2 gravel samples tested during this investigation were all taken downstream from the proposed dam site. Analysis of the LiDAR data for the area indicates that the Q2 terrace surface extends upstream from the sampling location and through the dam site. Gravel deposits up to 20 m thick underlie parts of Gwavas Forest 3 to 4 km the north of the dam site (beneath Q2al and Q2af surfaces, see Plate 10). Litchfield (2003) also shows Q2 gravel surfaces approximately 2 km to the west of the dam site. The gravels within Gwavas Forest and to the west of the dam site were not sampled during this investigation due to access and time restraints.

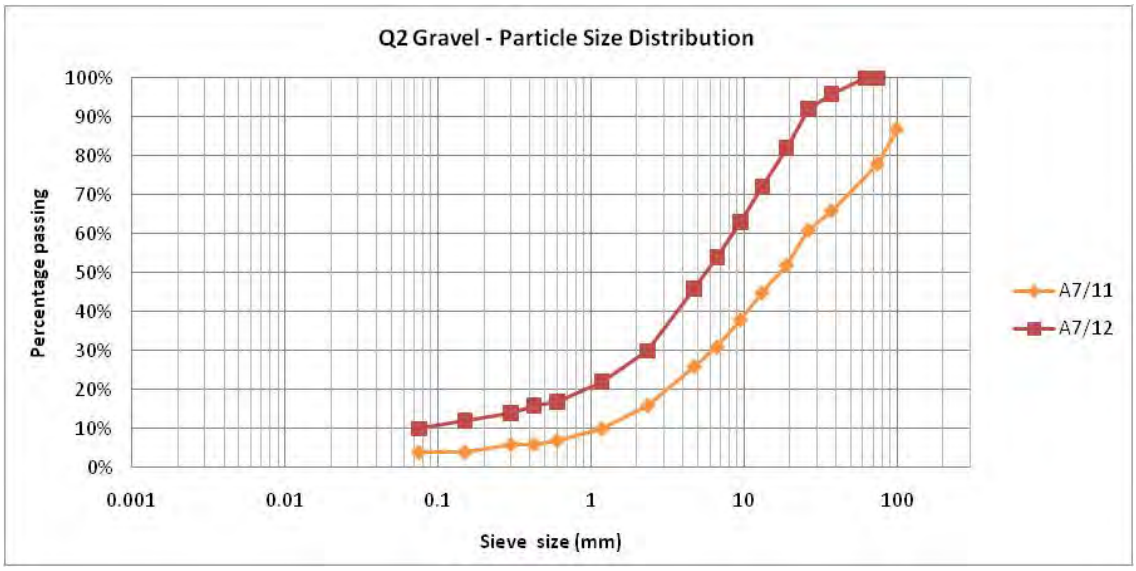


Figure 6.3 – Particle size distribution curves for Q2 gravels.

6.2.4 Older Gravels

The oldest gravels sampled during the study were mostly taken from the high terraces 10 to 15 km downstream of the dam site. These samples were taken from terraces suspected to be of Rata Age (Ra, 30,000 to 50,000 years old and approximately 55 to 60 m above river level), Porewa age (Po, 70,000 to 80,000 years old and approximately 100 m above river level) and from a Marton-age (Ma, 140,000 to 170,000 years old and approximately 200 m above river level). The exception to this is A7/17 which was sampled close to the present level of Makaroro River, but it is considered to be a remnant of a Marton-aged terrace. Litchfield (2003) indicates that sporadic exposures of Po and Ra gravels are located within 4 km of the dam site.

All of the Ra, Po and Ma gravels are sandy, fine to coarse GRAVEL (see Figure 6.5). The gravel clasts were mostly moderately to highly weathered with very weak (UCS 1 to 5 MPa) to weak (UCS 5 to 20 MPa) strength.

Two compaction tests have been carried out on Ma gravel samples. One of these tests (Wakarara Road Sample) showed the Ma gravel to have an optimum moisture content of 11% for compaction. The optimum moisture content could not be established for the second sample (A7/17). This may reflect the breakage of gravel clasts during the test. The compacted WRS sample was also tested for permeability giving results of 1.67×10^{-2} cm/s at 95% compaction decreasing to 2.72×10^{-4} cm/s at 100% compaction.

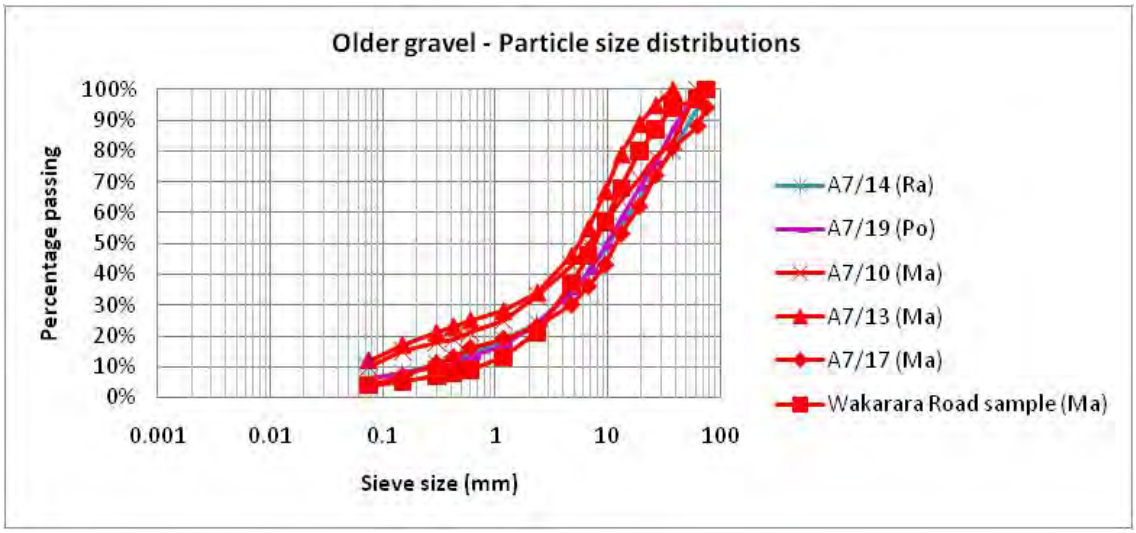


Figure 6.4 – Rata, Porewa and Marton aged gravel particle size distributions

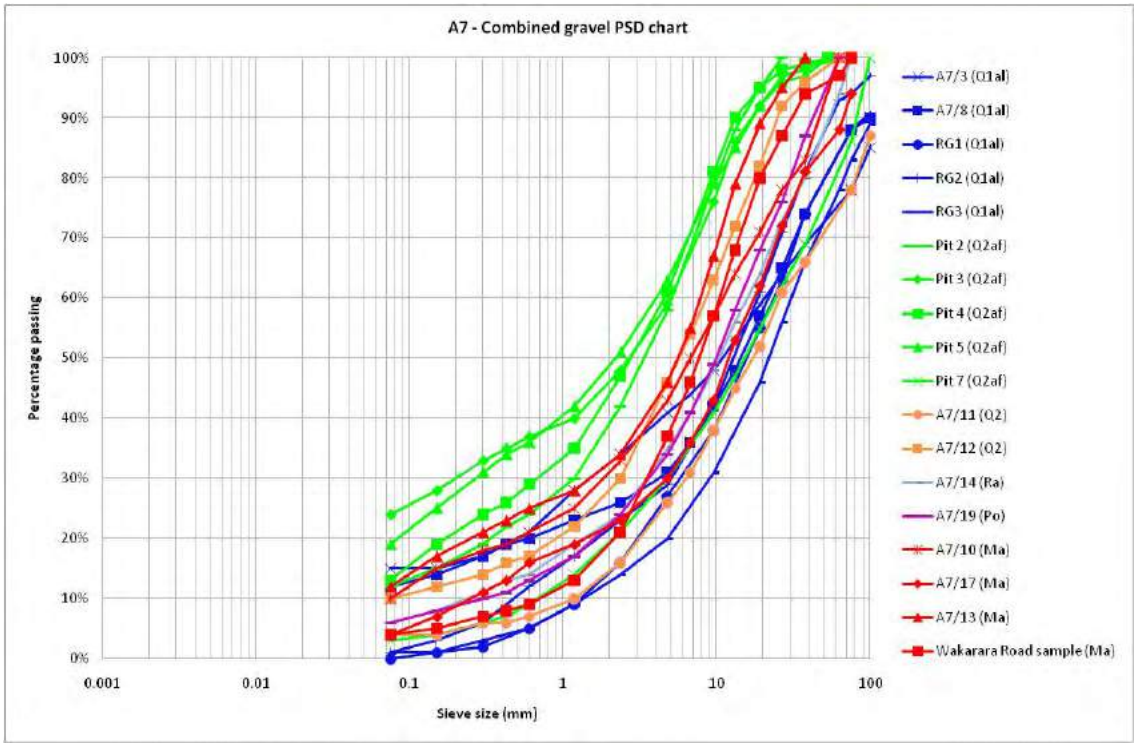


Figure 6.5 – Combined plot of particle size distributions for gravel samples taken from Makaroro River and environs.

6.2.5 Gravel parent sources and suitability as concrete aggregate

The gravels sampled in the field area are mostly upstream of the Wakarara Block and therefore are sourced mainly from the Ruahine Range (Black 2011). Rock from the Wakarara Range contains laumontite (the zeolite mineral discussed in Section 6.1). This mineral swells and shrinks during cycles of wetting and drying and can be detrimental to concrete causing it to crack.

Gravel within the present river system (Q1a) is the most likely source of concrete aggregate within the field area. Analyses carried out by Dr Black (report included in Appendix J) on two samples of Q1al gravel indicate that it is mostly sourced from the Ruahine Range (Torlesse Composite Terrane) with the laumontite bearing clasts comprising a minor component. The findings of Dr Black's report

also indicate that the laumontite bearing clasts tend to make up the finer fraction of the river gravels and that they could be easily separated by screening. The remaining gravel would be good quality aggregate for concrete.

6.2.6 Internal stability of gravels

The potential for internal stability issues has been identified in some samples of gravel recovered within the river (Q1al). A7/3 and RG1 in particular are on the boundary of suffusive and non-suffusive grading when considered in terms of Berenkova (1993). Other samples of similar material are identified within the non-suffusive range (Figure 6.6).

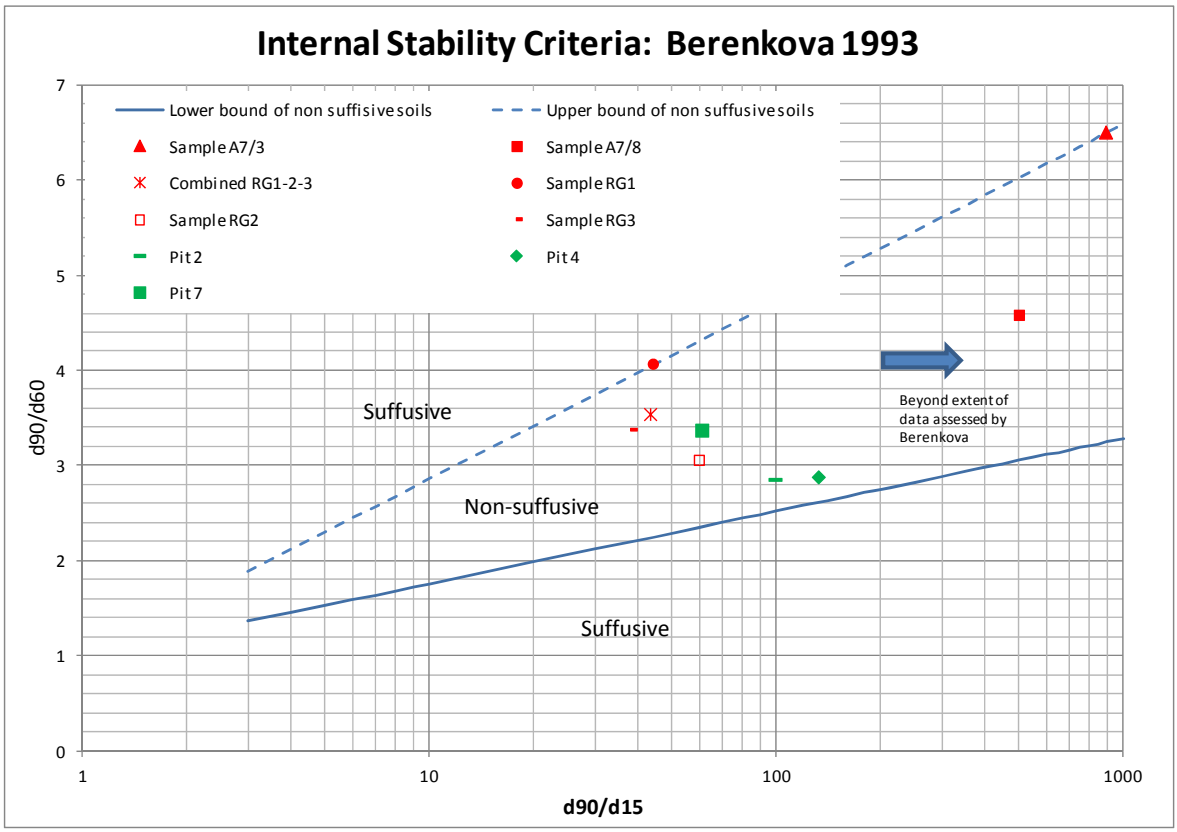


Figure 6.6- Internal Stability of gravels

Care will be needed to ensure that if construction material is sourced from the river channel that it is selected based on its appropriateness for the requirements of particular zones. The potential for internal instability within Q1al materials should be considered.

An option to alleviate the potential may be blending. The blended sample comprising RG1, RG2 and RG3 (all Q1al material) is identified as non-suffusive.

6.3 Other fill materials

6.3.1 Sand

Sand in the field area was sampled to look for potential borrow areas for filter materials. Samples were obtained from the Tertiary sequence to the west and northwest of the dam site and from a winnowed deposit from Q1a gravel from the present river bed. Particle size distributions of the samples are shown in Figure 6.7. Samples taken from the Tertiary sequences were disaggregated prior to testing.

The Tertiary sediments comprise extremely weak, silty to very silty fine grained sandstone interbedded with extremely weak to very weak fine sandy siltstone. This material is present in outcrops at the end of Wakarara Road 3 km to the north of the dam site and adjacent to the Rangimarie Farm access track 1.2 km west of the dam site.

The winnowed Q1a sand is well graded and fine to coarse grained. Other particle size distribution tests carried out on samples adjacent to the present river bed indicate that variable amounts of sand are present within the gravel. The gravel would need to be processed if large amounts of sand are required from this source.

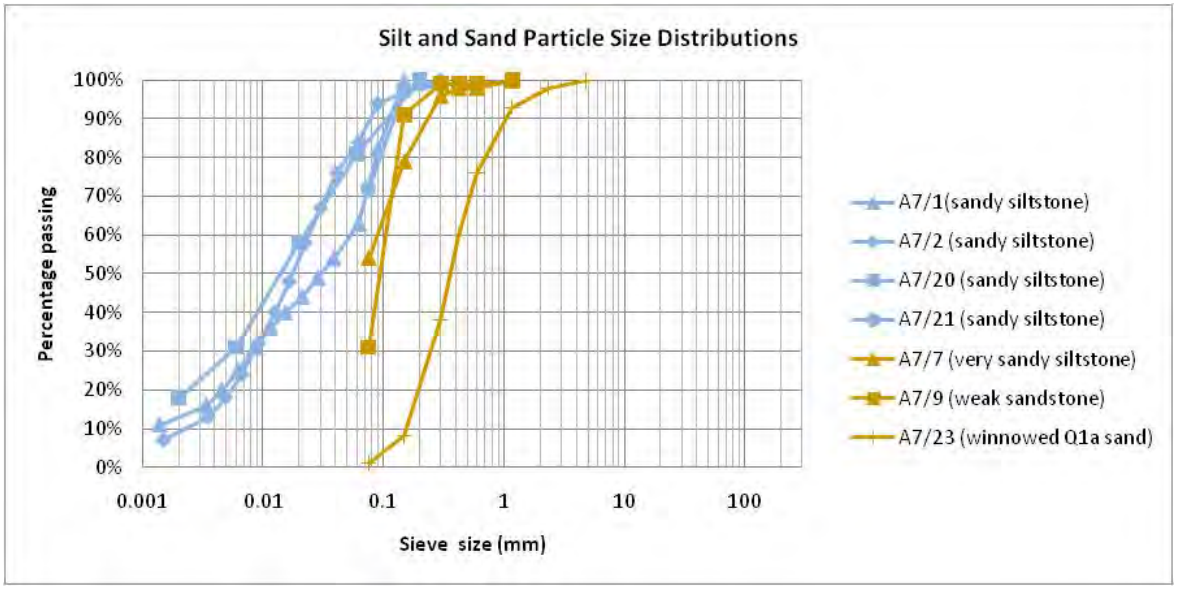


Figure 6.7 – Particle size distributions for sand and silty sand deposits proximal to A7.

6.3.2 Potential Core Material

Investigations were undertaken to locate a source of core material for an embankment dam close to the site. Outcrops of grey, very weak SILTSTONE was found at two locations on Rangimarie Farm between 1 and 1.5 km northwest from the dam site. Samples were taken and crushed and tested for plasticity. The crushed siltstone returned silt with some clay with low to medium plasticity. Laboratory testing carried out on one sample of this material showed it to have a maximum bulk density of 2.081 t/m^3 at a moisture content of 16% and a permeability of 3.3×10^{-6} cm/s.

This borrow site has an estimated 2 m of overburden which will need to be stripped. The estimated volume of material available may be between 40,000 and 120,000 m^3. The thickness of the overburden and quantity of material available will need to be confirmed prior to detailed design if it is deemed suitable for use in the dam.

It should be noted that the current design is a concrete faced rock fill dam (CFRD) that does not require core material.

6.3.3 Rip-rap

No rock or gravel within the field area was identified as suitable for use as rip-rap. No large clast sizes were observed within the various aged gravels and the rock beneath the dam site contained too many micro-fractures to allow the formation of sufficiently sized blocks.

The closest locations of potential rip-rap sources include the Ruahine Range approximately 6 km to the west of the site and the outcrops of limestone close to Waipawa, approximately 30 to 40 km to the southeast of the site.

7 Conclusions and Recommendations

A dam has been proposed for the Ruataniwha Plains Water Storage Project to provide a supply of water for farming downstream. The dam is proposed to be approximately 83. m high and located on the Makaroro River. As part of a feasibility study for the site (A7) T&T have carried out investigations to determine the ground conditions at the site. These investigations have comprised:

- Field mapping
- Seismic refraction investigations
- Borehole investigations and in situ testing
- Laboratory Testing.

The proposed dam site is located at the southern end of the Wakarara Range in greywacke rock of the Waioeka petrofacies within the Pahau Terrane characterised by volcaniclastic sedimentary rocks which have been subjected to low-grade metamorphism. The Pahau Terrane is unconformably overlain by Tertiary-aged sediments which are in turn overlain by more recent alluvial gravel deposits.

The Wakarara block is bounded by active faults; the NNE striking active dextral-slip Mohaka fault 680m to the west, the SE striking, probable strike-slip tear, Mangataura fault 1.5 km to the SW, and the Wakarara/Rangefront fault pair of NNE-striking and west dipping reverse-slip at the front of the Wakarara range.

The rock beneath the dam site is mostly unweathered strong to very strong, very closely to closely jointed greywacke sandstone with minor interbedded mudstone and sandstone. While the intact rock has high strength the rock mass is broken up by closely spaced joints and numerous narrow crushed and sheared zones and, as a result, the foundation is more suitable for a range of rockfill or embankment dam types.

A mappable shear zone was located within the footprint of the dam. This zone may be capable of sympathetic displacement during seismic events, but the extent and nature requires further investigation. The presence of this feature, and the possibility of others not yet located, favours the construction of a dam type that can resist differential movements and strong earthquake shaking which precludes rigid structures such as concrete gravity dams (Wieland et al., 2008a and b).

The rock is regarded as fair tunnelling ground and will need appropriate stabilisation measures during construction of the diversion works. Temporary cut slopes within the rock should be no steeper than 1V:1H without specific design.

A deep-seated structurally controlled landslide lies within the proposed reservoir immediately upstream of the dam site. The stability of this landslide during reservoir filling and strong earthquake shaking along with the consequences of landslide mobilization will need further investigation.

A zone of dilated rock downstream from the proposed dam within river valley has the potential to collapse by toppling/buckling during strong earthquake shaking and requires further investigation.

Potential construction materials in close proximity (within 4 km) to the site include:

- Greywacke bedrock
- Alluvial gravels of varying ages, clast weathering and clast strength
- Tertiary-aged sand and very weak sandstone
- Tertiary-aged siltstone

Further work will be required to further determine the properties and quantities of some of these materials if found to be appropriate for construction (see below).

7.1 Further Work

Based on the above, the following investigations are recommended at the detailed design stage:

- Detailed engineering geological mapping of the critical sections of the dam footprint (e.g. the core section of an earth embankment dam or the plinth of a concrete faced rock fill dam). Such analysis would include the locations, attitudes, widths and persistence of the exposed sheared zones and a commentary on the general rock mass condition and will require sub-excavation to expose the rock head across the full width of dam in either the core trench for an embankment dam or along the plinth of a concrete faced rock fill dam.
- Lugeon testing of the rock mass in critical sections of the dam footprint down to diversion tunnel level in the central dam section.
- Drilling and Lugeon testing of the rock mass at the new right abutment and along the proposed spillway.
- Excavation, compaction and permeability trials of the rock mass near the dam footprint to determine suitability as use for rock fill in dam construction and the need for specific internal drainage zones.
- Laboratory testing on the local greywacke rock such as weathering quality index and clay index tests to determine the breakdown and swelling properties.
- Quantification of the volume, grading, clast strength and permeability of the gravel available beneath the terraces 40 to 45m above the present river of the dam site if this is considered to be a potential construction material.
- Further investigations of the landslide upstream from the dam to determine the most appropriate methods of stabilisation.
- Quantification of the volume and properties of siltstone resource if this is considered to be a potential construction material.

8 References

Barton N & Grimstad E., 1994, The Q-system following twenty years of application in NMT support selection. Felsbau 12, No 6.

Bassett & Orlowski, 2004, Pahau Terrane type locality: fan delta in an accretionary prim trench-slope basin. NZ Journal of Geology & Geophysics, vol 47: 603-623.

Beanland S., 1995, The North Island Dextral Fault Belt: Hikurangi Subduction Margin, New Zealand., unpublished PhD thesis, Victoria University of Wellington, New Zealand.

Bieniawski Z.T., 1993, Classification of rock masses for engineering: The RMR system and future trends. Comprehensive Rock Engineering, Pergamon Press.

Black, P., 2011, Ruataniwha Project. Report of petrography of sediments (core samples and river gravels). Appended to this report as Appendix J.

Bryant J.M., 1977. Some Properties of Kaimanawa Greywacke. MOW Report No 2-77/1.

Cook G K., 2001, Rock mass structure and intact rock strength of New Zealand greywacke, MSc thesis, University of Canterbury, New Zealand.

Deere, D.U., Hendron, A.J. Patton, F.D. Cording, E.J., 1967, "Design of surface and near surface construction in rock" in Failure and breakage of rock, proc. 8th U.S. symp. rock mech., (ed C. Fairhurst), 237-302. New York: Soc. Min. Engrs. Am. Inst. Min. Inst. Metall. Petrolm. Engrs.

Erdman & Kelsey, 1992, Pliocene and Pleistocene stratigraphy and tectonics, Ohara Depression and Wakarara Range, North Island, New Zealand. New Zealand Journal of Geology & Geophysics, vol 35: 177-192.

Hegan B. D., 1976, Engineering Geology of the Rangipo Tailrace Tunnel. N.Z. Geological Survey Engineering Geology Report EG 253.

International Society of Rock Mechanics, 1978, Suggested Method for Quantitative Description of Discontinuities in Rock Masses.

Kingma, 1962, Geological Map of New Zealand 1:250,000, Sheet 11-Dannevirke.

Kingma, 1958, Geology of the Wakarara Range, Central Hawke's Bay. New Zealand Journal of Geology and Geophysics, vol1: 76-91.

Litchfield N., 2003, Maps, stratigraphic logs and age control data for river terraces in eastern North Island. GNS Science, Science Report SR2003/31.

New Zealand Geotechnical Society, 2005, "Guidelines for the Field Classification and Description of Soil and Rock for Engineering Purposes".

Raub M L., 1985, The Neotectonic Evolution of the Wakarara Area, Southern Hawkes Bay, New Zealand. PhD thesis, University of Auckland, New Zealand.

Read, S. A. L., Richards, L. R. & Perrin N.D., 1998, Engineering parameters of closely-jointed rock – Mapping and strength testing of greywacke from Aviemore and Belmont. IGNS Science Report 98/19.

Read S. A. L., Richards, L. R., and Perrin N. D., 1999 "Applicability of the Hoek-Brown failure criteria to New Zealand Greywacke Rocks" Proceedings 9th International Congress of Rock Mechanics, Paris. Vol. 2, pp 655-660. Rotterdam: Balkema.

Richart F.E., Hall, J.R., and Woods R.D. (1970) Vibrations of Soils and Foundations. Prentice-Hall, 414 pages.

Wieland M., Brenner, R.P. and Bozovic A., (2008a) Potentially active faults in the foundations of large dams part I: Vulnerability of dams to seismic movements in dam foundations. Proceedings of the 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.

Wieland M., Brenner, R.P. and Bozovic A., (2008b) Potentially active faults in the foundations of large dams Part II: Design aspects of dams to resist fault movements. Proceedings of the 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.

9 Applicability

This report has been prepared for the benefit of Hawke's Bay Regional Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

Report prepared by:

.....

Bernard Hegan
Senior Engineering Geologist

David Milner
Engineering Geologist

Authorised for Tonkin & Taylor Ltd by:

.....

David Bouma
Project Director

Reviewed by:

Mark Foley
Senior Engineering Geologist

dmmm/bdh

t:\auckland\projects\27690\issueddocuments_ 350 a7 dam design\02 geology and si\engineering geological report\120306.a7 eg report.final.docx

Appendix A: Drawings

QUATERNARY DEPOSITS

UQa	Q1al	Unweathered Holocene alluvium Poorly consolidated alluvial gravel, sand, mud
	Q2al	Ohakea alluvial and colluvial fan deposits Poorly sorted gravel, sand, clay, loess
	Q2af	Ohakea alluvial and colluvial fan deposits Poorly sorted gravel, sand, silt, minor fan deposits, loess
	eQp	Kidnappers Group gravel Poorly sorted gravel, sand, silt, minor fan deposits, loess
		Undifferentiated Quaternary deposits

MANGAHEIA GROUP

IPm	Undifferentiated Pliocene Conglomerates, mudstone, sandstone, limestone
IPml	Undifferentiated lower late Pliocene Conglomerates, mudstone, sandstone, limestone

WAIOEKA PETROFACIES PAHAU TERRANE

Pt1	Lithotype Pt1 Greywacke Slightly weathered, moderately strong to strong intact material, light grey to grey, unweathered, fine to medium grained sandstone with minor interbedded mudstone (less than 10%). Bedding is typically steeply inclined with a NE to SW strike.
Pt2	Lithotype Pt2 Thinly interbedded sandstone and mudstone in similar proportions. These sequences are relatively weaker. Mudstone may be preferentialy sheared parallel to bedding.
Pt2a	Sublithotype Pt2a As above but increased deformation with shear zones, extremely closely spaced defects, contorted bedding.
Pt2b	Sublithotype Pt2b As above but extreme deformation associated with nearby fault movement. Rock fabric completely destroyed near fault.

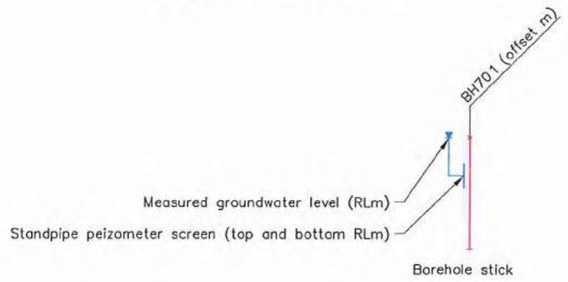
KAWEKA TERRANE

Jtk	Undifferentiated greywacke rock mass.

ORIGINAL IN COLOUR

GEOLOGICAL MAPS

- Existing ground contour 25m interval
- Existing ground contour 5m interval
- A7/19 — Tonkin & Taylor Ltd Gravel Sampling location (March, October & November 2011)
- BH 1 — Tonkin & Taylor Ltd Borehole location (October 2011)
- TP 1 — Tonkin & Taylor Ltd Testpit location (October 2011)
- 90° 40° — Bedding – Dip°
- 90° 30° — Joint – Dip°
- 90° 20° — Sheared zone (sz) – Dip°
- 90° 60° — Crushed zone (cz) – Dip°
- Existing ground profile (on cross section)
- Inferred geological contact
- Geological Contact
- Inferred elevation of rock head
- Landslip Headscarp
- Debris
- Reservoir design level
- Topographic lineation
- Seismic lines
- Active fault showing sense of movement
- Inactive fault showing sense of movement
- Syncline showing plunge direction
- Sheared surface
- Possible disrupted zone adjacent to Mohaka Fault
- 1/03 — Geological section location



LOCATION PLAN
SCALE 1: 1,000,000

SCALE 1: 1,000,000
0 10 20 30 40 50 (km)

Topomap sourced from Land Information New Zealand data (Crown Copyright Reserved).

DRAWING STATUS: FOR INFORMATION ONLY

REVISION DESCRIPTION	BY	DATE
1 Report Issue	Drawn	23/12

DESIGNED : BDH Nov.11
DRAWN : BNRB Nov.11
DESIGN CHECKED : Drawn 23/12
DRAFTING CHECKED : BDH 23/12
CADFILE : \\27690.200-00.dwg
APPROVED :
NOT FOR CONSTRUCTION
This drawing is not to be used for construction purposes unless signed as approved
COPYRIGHT ON THIS DRAWING IS RESERVED

NOTES :
1. Coordinate Datum: NZ Geodetic 2000
   New Zealand Transverse Mercator
   Level Datum: MSL minus 10m.
2. All levels, dimensions, cut and batter slopes shown on the Drawings are subject to confirmation in detailed design.

REFERENCE :

HAWKE'S BAY REGIONAL COUNCIL

Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
Tel. (09) 355 6000 Fax. (09) 307 0265
www.tonkin.co.nz

CLIENT, PROJECT
HAWKE'S BAY REGIONAL COUNCIL
RUATANIWHA WATER STORAGE PROJECT
TITLE
FEASIBILITY DESIGN
Geological Legend
SCALES (AT A3 SIZE) AS SHOWN
DWG. No. 27690.200-00
REV. 1

L:\27690\Working\CAD\DWG\200\27690.200-00.dwg, 00, 12/03/2012 11:07:02 a.m., vtg, 1:1

1880000 mE
5598000 mN
5597000 mN
5596000 mN
5595000 mN
5594000 mN
5593000 mN
1878000 mE
1877000 mE
Jtk
Q2af
IPml
Q2al
Q1al
uQaf
IPm
EQp
Pt1
Pt2
Pt2a
YEOMAN SYNCLINE
DONOVAN GULLY
Lineament mapped as an inactive fault by GNS (Langridge etal 2011)
Refer Drawing 27690.200-02
Refer Drawing 27690.200-03
Refer Drawing 27690.200-04
Landslide/dilated rock mass
Landslide
Possible limit of disruption adjacent to Mohaka Fault
MOHAKA FAULT
MANGATAURA FAULT
10°
16°
8°
20°
20°
70°
42°
80°

SCALE 1:20,000
0 200 400 600 800 1000 (m)

ORIGINAL IN COLOUR

DRAWING STATUS: FOR INFORMATION ONLY

REVISION	DESCRIPTION	BY	DATE
1	Report Issue	DHunn	3/12

DESIGNED :	BDH	Oct. 11
DRAWN :	BNRB	Oct. 11
DESIGN CHECKED :	DHunn	3/12
DRAFTING CHECKED :	BDH	3/12
CADFILE : \\27690.200-01.dwg		
APPROVED : NOT FOR CONSTRUCTION		

This drawing is not to be used for construction purposes unless signed as approved

COPYRIGHT ON THIS DRAWING IS RESERVED

NOTES :
1. Coordinate Datum: NZ Geodetic 2000 New Zealand Transverse Mercator Level Datum: MSL minus 10m.
2. Shaded Relief Model generated from LiDAR supplied by Hawkes Bay Regional Council (Date of Acquisition: 2010 & 3 March 2011).
3. Geological boundaries supplied by GNS Science.

REFERENCE :

HAWKE'S BAY REGIONAL COUNCIL

Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
Tel. (09) 355 6000 Fax. (09) 307 0265
www.tonkin.co.nz

CLIENT, PROJECT
HAWKE'S BAY REGIONAL COUNCIL
RUATANIWHA WATER STORAGE PROJECT

TITLE
FEASIBILITY DESIGN
Geological Map

SCALES (AT A3 SIZE)	DWG. No.	REV.
1:20,000	27690.200-01	1

L:\27690\Working\CAD\DWG\200\27690.200-01.dwg, 01, 9/03/2012 10:37:03 a.m., vtg, 1:1

1880200 mE
1880300 mE
1880400 mE
1880500 mE
1880600 mE
1880700 mE
1880800 mE
1880900 mE
5592800 mN
5592700 mN
5592600 mN
5592500 mN
5592400 mN
N
Seismic line A7-8
Seismic line A7-7
Proposed Diversion Channel
TP7
DONOVAN GULLY
A7-7
A3 SCALE 1:2000
0 20 40 60 80 100 (m)
ORIGINAL IN COLOUR

DRAWING STATUS: FOR INFORMATION ONLY

DESIGNED :	BDH	Oct. 11
DRAWN :	BNRB	Oct. 11
DESIGN CHECKED :	Duncan	5/12
DRAFTING CHECKED :	BDH	3/12
CADFILE : \\27690.200-02.dwg		
APPROVED : NOT FOR CONSTRUCTION		
This drawing is not to be used for construction purposes unless signed as approved		
COPYRIGHT ON THIS DRAWING IS RESERVED		

REVISION	DESCRIPTION	BY	DATE
1	Report Issue	Duncan	5/12

NOTES :
1. Coordinate Datum: NZ Geodetic 2000
New Zealand Transverse Mercator
Level Datum: MSL minus 10m.
2. Shaded Relief Model generated from LiDAR supplied by Hawkes Bay Regional Council. (Date of Acquisition: 2010 & 3 March 2011)

HAWKE'S BAY REGIONAL COUNCIL

REFERENCE :

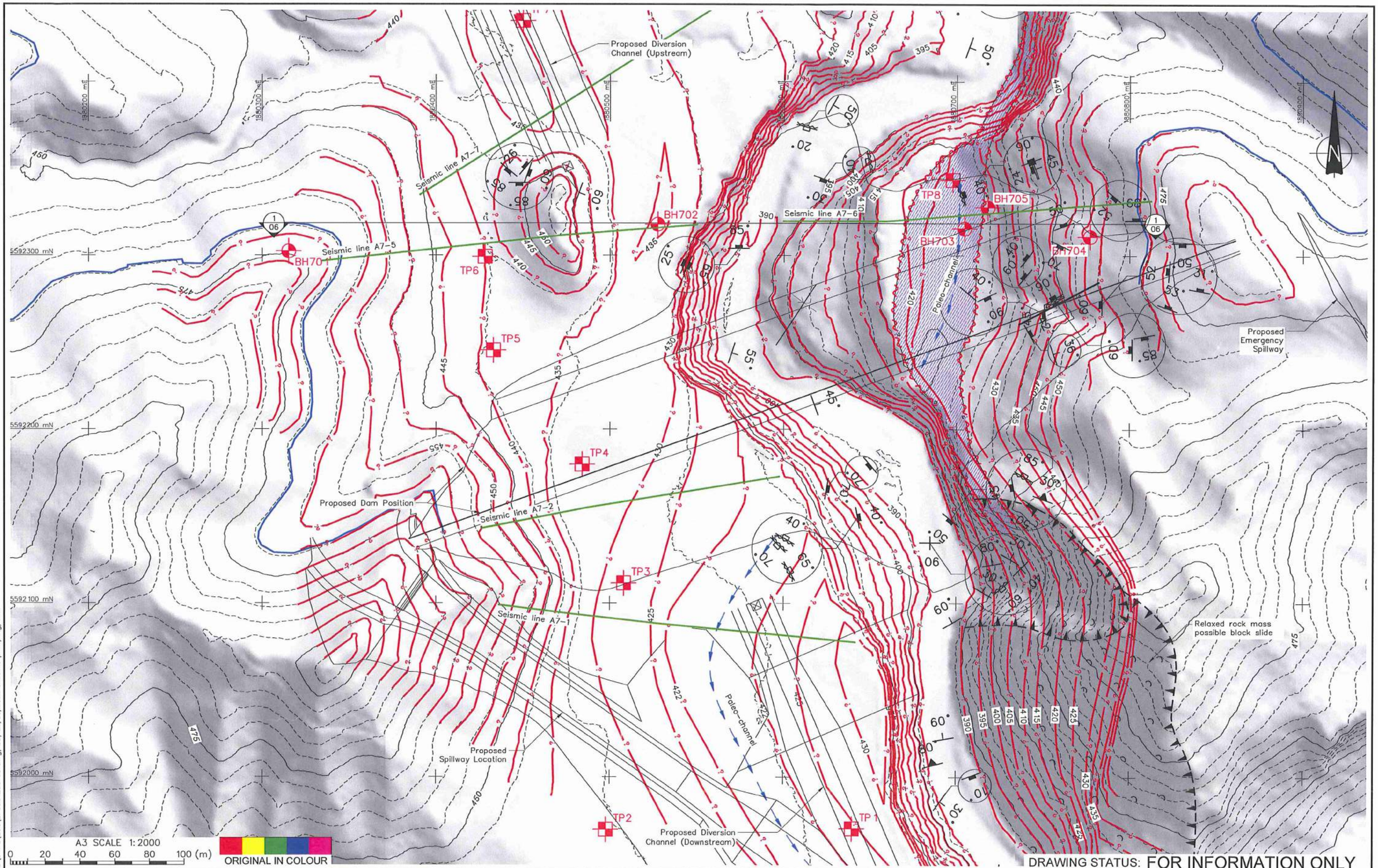
Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
Tel. (09) 355 6000 Fax. (09) 307 0265
www.tonkin.co.nz

CLIENT, PROJECT
HAWKE'S BAY REGIONAL COUNCIL
RUATANIWHA WATER STORAGE PROJECT

TITLE
FEASIBILITY DESIGN
Defects Attitude & Rockhead Map Showing Investigation Locations – Sheet 1

SCALES (AT A3 SIZE)	DWG. No.	REV.
1: 2,000	27690.200-02	1

L:\27690\Working\CAD\DWG\200\27690.200-02.dwg, 02, 9/03/2012 10:38:48 a.m., vtg, 1:1



DRAWING STATUS: FOR INFORMATION ONLY

REVISION DESCRIPTION	BY	DATE
1 Report Issue	Drawn	03/12

DESIGNED :	BDH	Nov. 11
DRAWN :	BNRB	Nov. 11
DESIGN CHECKED :	Drawn	03/12
DRAFTING CHECKED :	BDH	03/12
CADFILE : \\27690.200-03.dwg		
APPROVED : NOT FOR CONSTRUCTION		

This drawing is not to be used for construction purposes unless signed as approved

COPYRIGHT ON THIS DRAWING IS RESERVED

NOTES :

1. Coordinate Datum: NZ Geodetic 2000
   New Zealand Transverse Mercator
   Level Datum: MSL minus 10m.
2. Shaded Relief Model generated from LiDAR supplied by Hawkes Bay Regional Council. (Date of Acquisition: 2010 & 3 March 2011)

REFERENCE :

HAWKE'S BAY REGIONAL COUNCIL

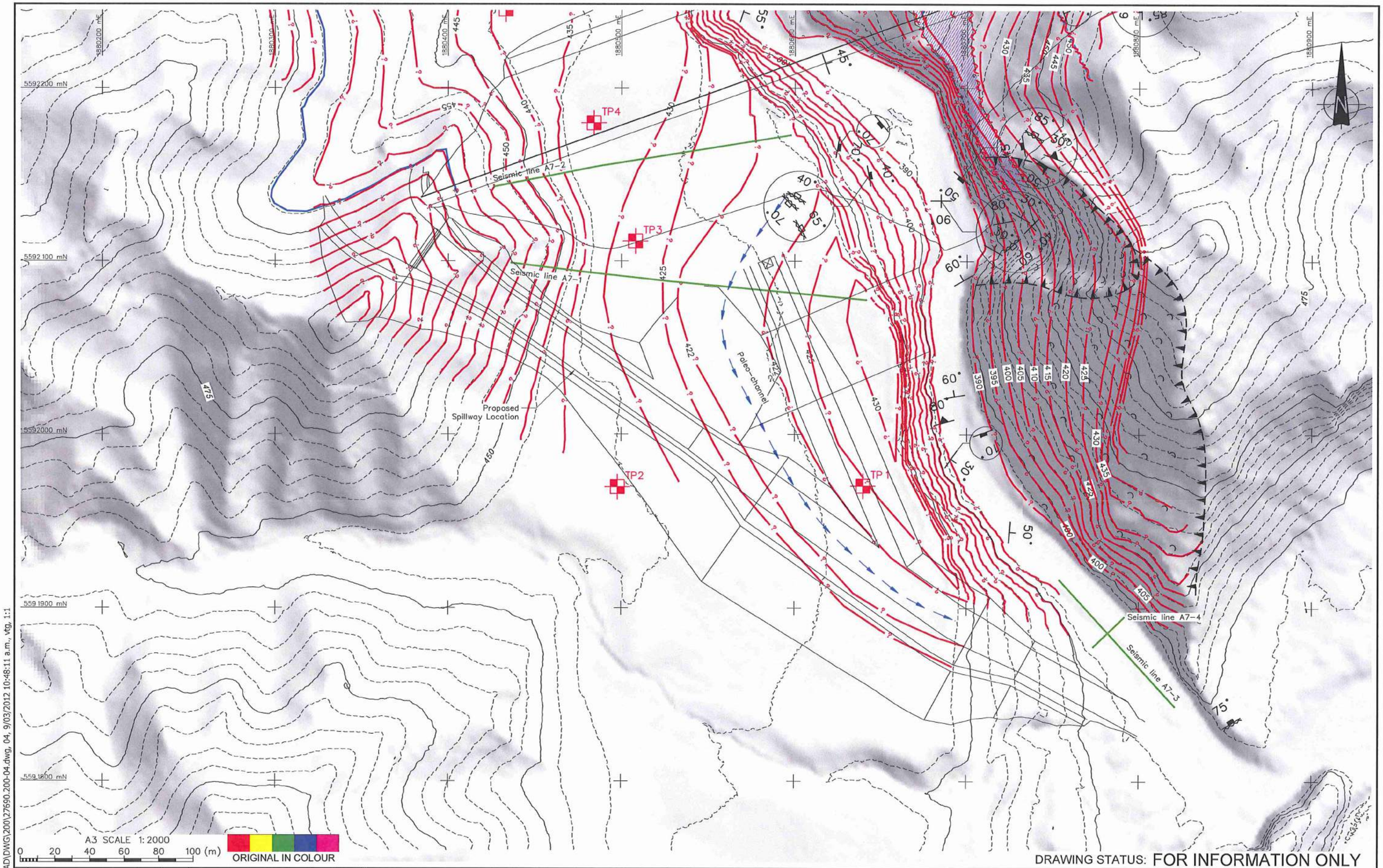
Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
Tel. (09) 355 6000 Fax. (09) 307 0265
www.tonkin.co.nz

CLIENT, PROJECT
HAWKE'S BAY REGIONAL COUNCIL
RUATANIWHA WATER STORAGE PROJECT

TITLE
FEASIBILITY DESIGN
Defects Attitude & Rockhead Map Showing Investigation Locations – Sheet 2

SCALES (AT A3 SIZE)	DWG. No.	REV.
1: 2,000	27690.200-03	1

L:\27690\Working\CAD\DWG\200\27690.200-03.dwg, 03, 12/03/2012 3:16:45 p.m., vtg, 1:1



DRAWING STATUS: FOR INFORMATION ONLY

REVISION DESCRIPTION	BY	DATE
1 Report Issue	Drawn	3/12

DESIGNED :	BDH	Dec. 11
DRAWN :	BNRB	Dec. 11
DESIGN CHECKED :	Drawn	3/12
DRAFTING CHECKED :	BDH	3/12
CADFILE : \\27690.200-04.dwg		
APPROVED : NOT FOR CONSTRUCTION		

This drawing is not to be used for construction purposes unless signed as approved

COPYRIGHT ON THIS DRAWING IS RESERVED

NOTES :

1. Coordinate Datum: NZ Geodetic 2000
   New Zealand Transverse Mercator
   Level Datum: MSL minus 10m.
2. Shaded Relief Model generated from LiDAR supplied by Hawkes Bay Regional Council. (Date of Acquisition: 2010 & 3 March 2011)

REFERENCE :

HAWKE'S BAY REGIONAL COUNCIL

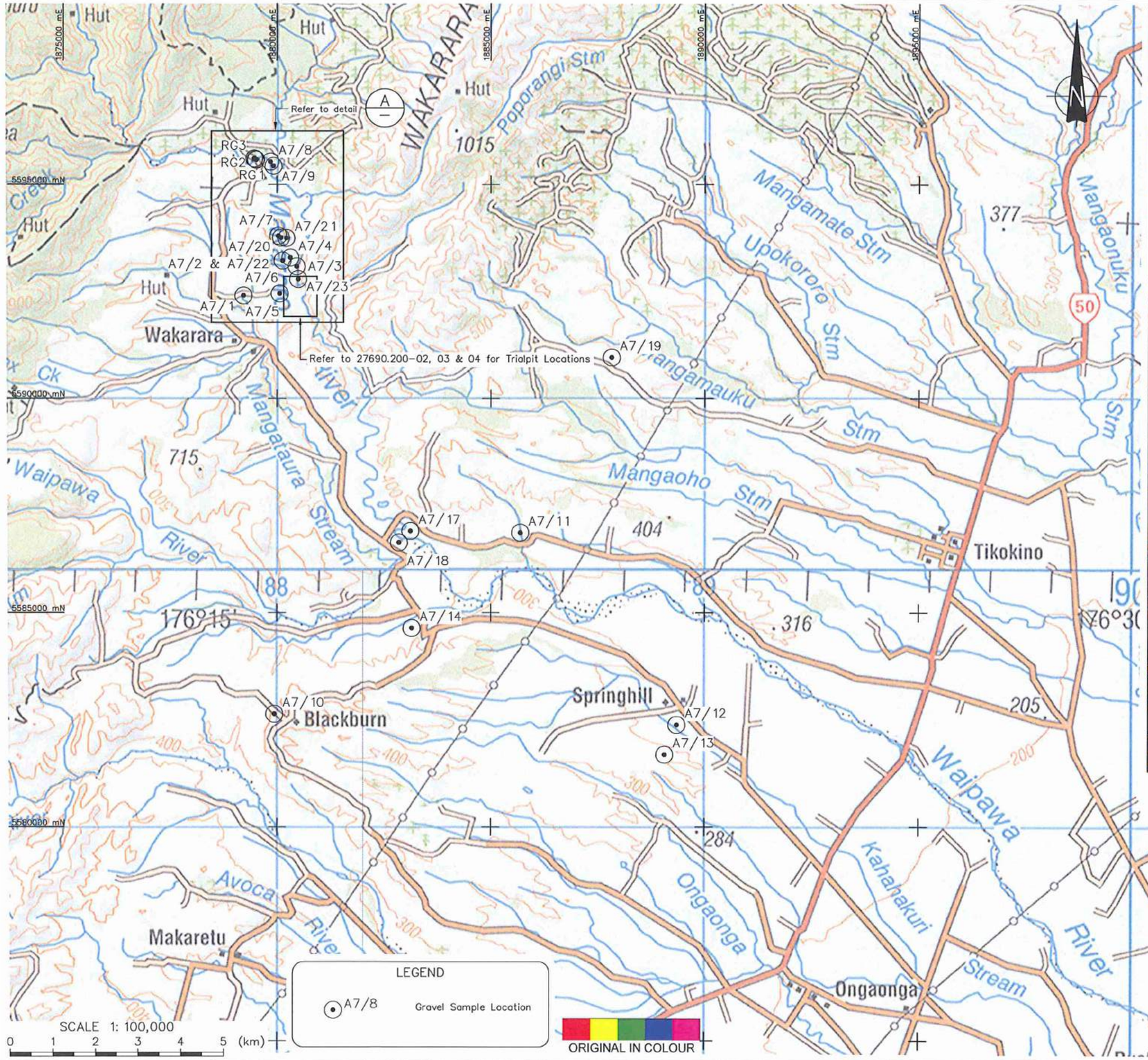
Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
Tel. (09) 355 6000 Fax. (09) 307 0265
www.tonkin.co.nz

CLIENT, PROJECT
HAWKE'S BAY REGIONAL COUNCIL
RUATANIWHA WATER STORAGE PROJECT

TITLE
FEASIBILITY DESIGN
Defects Attitude & Rockhead Map Showing Investigation Locations – Sheet 3

SCALES (AT A3 SIZE)	DWG. No.	REV.
1: 2,000	27690.200-04	1

L:\27690\Working\CAD\DWG\200\27690.200-04.dwg, 04, 9/03/2012 10:48:11 a.m., vtg, 1:1



L:\27690\Working\CAD\DWG\200\27690.200-05.dwg, 05, 12/03/2012 2:47:42 p.m., vtg, 1:1

REVISION DESCRIPTION	BY	DATE
1 Report Issue	Dmm	3/12

DESIGNED :	DMMM	Nov. 11
DRAWN :	BNRB	Nov. 11
DESIGN CHECKED :	BNH	03/12
DRAFTING CHECKED :	Dmm	3/12
CADFILE : \\27690.200-05.dwg		
APPROVED : NOT FOR CONSTRUCTION		

This drawing is not to be used for construction purposes unless signed as approved

COPYRIGHT ON THIS DRAWING IS RESERVED

NOTES :
1. Coordinate Datum: NZ Geodetic 2000 New Zealand Transverse Mercator
2. Topomap sourced from Land Information New Zealand data (Crown Copyright Reserved).

REFERENCE :

HAWKE'S BAY REGIONAL COUNCIL

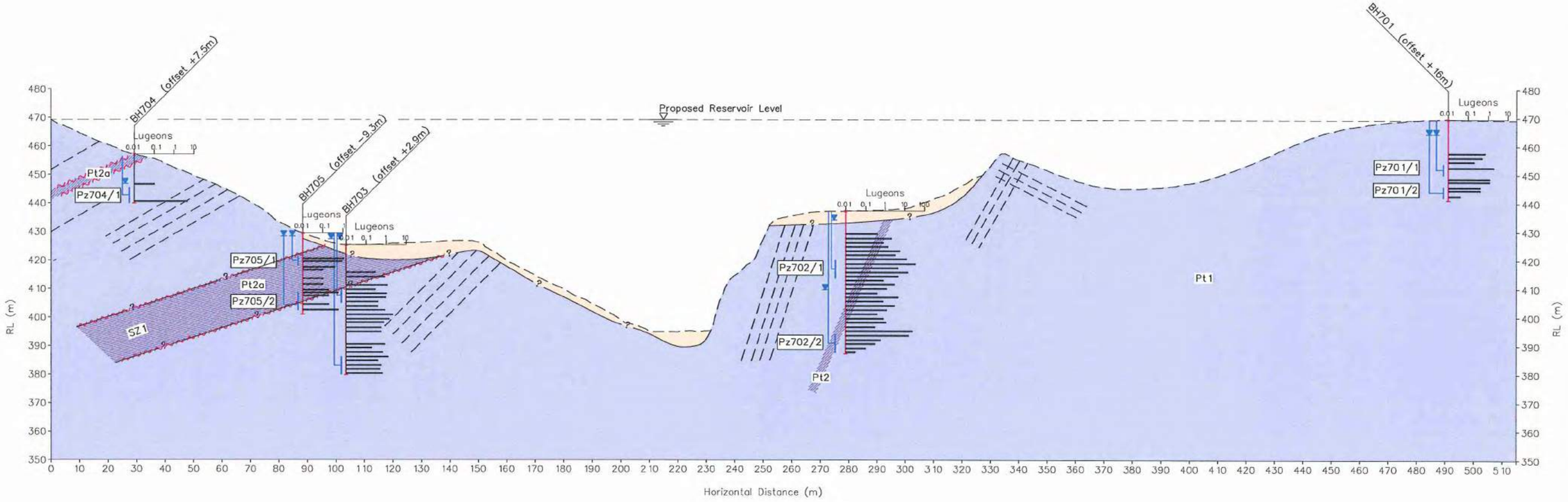
Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
Tel. (09) 355 6000 Fax. (09) 307 0265
www.tonkin.co.nz

DRAWING STATUS: FOR INFORMATION ONLY

CLIENT, PROJECT
HAWKE'S BAY REGIONAL COUNCIL
RUATANIWHA WATER STORAGE PROJECT

TITLE
FEASIBILITY DESIGN
Gravel Sampling Locations

SCALES (AT A3 SIZE)	DWG. No.	REV.
AS SHOWN	27690.200-05	1



SECTION 1 / 03
SCALE 1: 1500

SCALE 1: 1500
0 15 30 45 60 75 (m)
ORIGINAL IN COLOUR

DRAWING STATUS: FOR INFORMATION ONLY

REVISION	DESCRIPTION	BY	DATE
1	Report Issue	Dunn	3/12

DESIGNED :	BDH	Nov. 11
DRAWN :	BNRB	Nov. 11
DESIGN CHECKED :	Dunn	3/12
DRAFTING CHECKED :	ROll	3/12
CADFILE : \\27690.200-06.dwg		
APPROVED : NOT FOR CONSTRUCTION		

This drawing is not to be used for construction purposes unless signed as approved

COPYRIGHT ON THIS DRAWING IS RESERVED

NOTES :
1. Coordinate Datum: NZ Geodetic 2000
New Zealand Transverse Mercator
Level Datum: MSL minus 10m.
2. All levels, dimensions, cut and batter slopes shown on the Drawings are subject to confirmation in detailed design.

REFERENCE :

HAWKE'S BAY REGIONAL COUNCIL

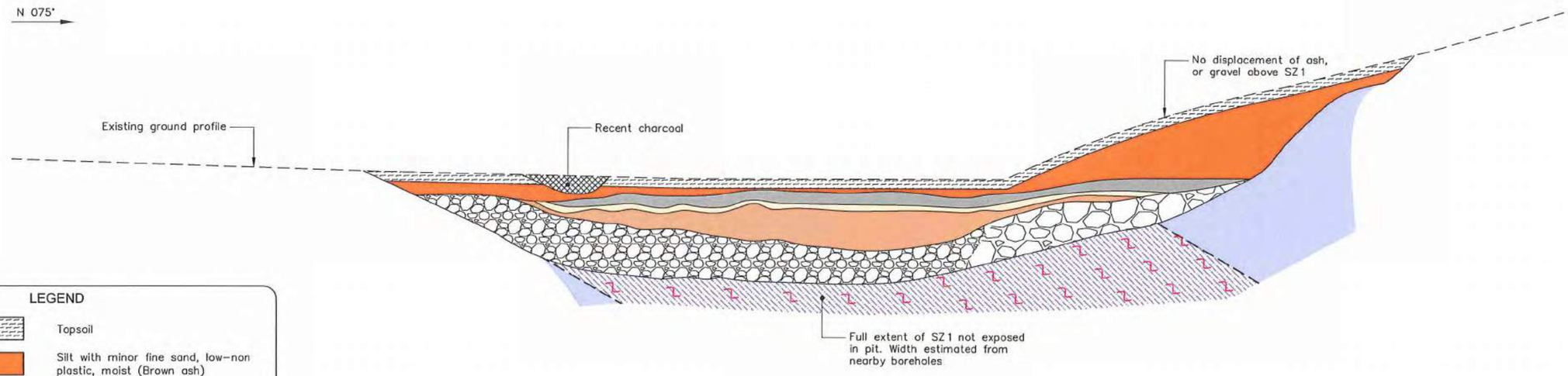
Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
Tel. (09) 355 6000 Fax. (09) 307 0265
www.tonkin.co.nz

CLIENT, PROJECT
HAWKE'S BAY REGIONAL COUNCIL
RUATANIWHA WATER STORAGE PROJECT

TITLE
FEASIBILITY DESIGN
Geological Section

SCALES (AT A3 SIZE)	DWG. No.	REV.
1: 1500	27690.200-06	1

L:\27690\Working\CAD\DWG\200\27690.200-06.dwg, 06, 9/03/2012 10:49:12 a.m., vtg, 1:1



SECTION 1 TESTPIT 8
SCALE 1: 150

LEGEND

- Topsoil
- Silt with minor fine sand, low–non plastic, moist (Brown ash)
- Paleosol in loess
- Sandy silt, light brown, low plasticity (loess) sand is fine grained
- Fine sand with some silt and gravel, moist, poorly graded (colluvium ?)
- Sandy fine to coarse gravel & boulders, loosely packed, moist to wet. Gravel & boulders are slightly to unweathered fine greywacke sandstone (River gravels)
- Sandstone (Pt1), light gray, slightly to unweathered, strong with closely to very closely spaced joints.
- SZ1 — Interbedded sandstone & mudstone. (Pt2a), SZ1 sheared SZ1 (Pt2a). Sandstone as per Pt1, Mudstone is dark grey to black, slightly to unweathered, with moderatly widely to very closely spaced joints.

SCALE 1: 150
0 1.5 3.0 4.5 6.0 7.5 (m)

ORIGINAL IN COLOUR

DRAWING STATUS: FOR INFORMATION ONLY

REVISION	DESCRIPTION	BY	DATE
1	Report Issue	Drmm	3/12

DESIGNED :	BDH	Nov. 11
DRAWN :	BNRB	Nov. 11
DESIGN CHECKED :	Drmm	3/12
DRAFTING CHECKED :	BDH	3/12
CADFILE : \\27690.200-07.dwg		
APPROVED : NOT FOR CONSTRUCTION		

This drawing is not to be used for construction purposes unless signed as approved

COPYRIGHT ON THIS DRAWING IS RESERVED

NOTES :
1. Coordinate Datum: NZ Geodetic 2000
New Zealand Transverse Mercator
Level Datum: MSL minus 10m.

REFERENCE :

HAWKE'S BAY REGIONAL COUNCIL

Tonkin & Taylor
Environmental and Engineering Consultants
105 Carlton Gore Road, Newmarket, Auckland
Tel. (09) 355 6000 Fax. (09) 307 0265
www.tonkin.co.nz

CLIENT, PROJECT
HAWKE'S BAY REGIONAL COUNCIL
RUATANIWHA WATER STORAGE PROJECT

TITLE
FEASIBILITY DESIGN
Trial Pit Log TP8

SCALES (AT A3 SIZE)	DWG. No.	REV.
1: 150	27690.200–07	1

L:\27690\Working\CAD\DWG\200\27690.200-07.dwg, 07, 9/03/2012 10:07:55 a.m., vtg, 1:1

Appendix B: Plates

Plate 1 – The dam site in the middle ground viewed from the northwest.

Plate 2 – Looking across the dam site from west to east. The drilling rig is in the foreground.

Plate 3 – A large outcrop of sandstone (Pt1 lithotype). Folded mudstone beds (Pt2a) are exposed at the base of the face.

Plate 4 – An outcrop of sandstone (Pt1).

Plate 5 – Alternating mudstone and sandstone beds (Pt2).

Plate 6 – Folded mudstone and sandstone beds (Pt2a).

Plate 7 – Mudstone adjacent to the Mohaka Fault. The structure of the rock has completely disintegrated (Pt2b).

Plate 8 – The landslide upstream from the dam as viewed from the left abutment.

Plate 9 – The landslide upstream from the dam site.

Plate 10 – Q2 gravel outcropping above Tertiary sandstone.

Appendix C: Opus Seismic Refraction Report

Central Laboratories Report 11-529B77.00 Task L

Ruataniwha Plains: Supplementary Seismic Refraction Survey

September 2011

Central Laboratories Report 11-529B77.00

Ruataniwha Plains: Supplementary Seismic Refraction Survey

A.J. Sutherland

Prepared By: Alan Sutherland
Geophysical Consultant
Physical & Engineering Sciences

Opus International Consultants Limited
Central Laboratories
138 Hutt Park Road
PO Box 30 845, Lower Hutt
New Zealand

Reviewed By: Peter Cenek
Work Group Manager
Physical & Engineering Sciences

Date: September 2011

This report has been prepared solely for the benefit of Hawkes Bay Regional Council. No liability is accepted by Opus International Consultants or any employee or subconsultant of this company with respect to its use by any other person.

This disclaimer shall apply notwithstanding that the report may be made available to other persons for an application for permission or approval or to fulfil a legal requirement.

This document and its contents are the property of Opus International Consultants Limited. Any unauthorised employment or reproduction, in full or part is forbidden

© Opus International Consultants Limited 2011

Table of Contents

1 Introduction 1

2 Seismic Refraction Surveying Procedures 2

3 Data Processing and Interpretation 3
3.1 Calibration 3

4 Survey Results 4
4.1 Site Location A7 Makaroro 4
4.1.1 Location of Seismic Lines 5
4.1.2 Seismic Line A7-5 5
4.1.3 Seismic Line A7-6 5
4.1.4 Seismic Line A7-7 5
4.1.5 Seismic Line A7-8 6

5 Conclusions 7

Appendix A: Seismic Refraction Cross Sections 8

Appendix B: Seismograph Calibration 13

1 Introduction

This report describes the test procedures and results of a seismic refraction survey, comprising four lines at site A7 Makarora. This is in addition to a seismic refraction survey completed on this site in March 2011. Three of the lines were located on the right bank with access from Wakarara Road. The fourth line was on the left bank, with access off Smedley Road. The site work for these lines was completed between 17 and 20 August 2011.

The lines ranged in length from 150 m to 250 m and marked out during the survey. The position of the geophones was taped out and a peg placed at the ends of each line. The relative elevation of each of the geophones was determined from levels measured with a portable survey level and a datum taken from the contour map. Therefore, the elevations provided are only approximate.

2 Seismic Refraction Surveying Procedures

The seismic refraction survey was carried out using small explosive charges (shots) placed in holes formed with a crowbar. For each shot, the compression wave (i.e. p-wave) arrival times were measured on a spread of up to 24 geophones at a time, connected to cables laid along the ground. Most lines consisted of two spreads of 24 geophones. For this survey, the spacing between geophones was generally 5 m with some 10 m spacing used to extend the coverage of two of the lines. These distances were measured as slope distance where the lines extended up a slope. The lines were marked out during the survey, with the relative elevations between geophones being measured with a portable survey level.

The levels shown on the cross-sections of the seismic lines presented in Appendix A are approximate only and are obtained from contour maps provided.

Shots were placed at regular intervals along the line and, where possible, offset from the end of the spread. A total of up to 22 shots were fired for each line.

The outputs from the geophones were recorded on a 24 channel ABEM™ digital seismograph, which was attached to the shot firing equipment. Shot firing was controlled by the geophysicist operating the seismograph after receiving an “all clear” from the geophysicist placing the charges. The explosive used in this survey was Powergel™ initiated with instantaneous electric detonators.

3 Data Processing and Interpretation

The first stage of the data processing, involving measurement of the p-wave arrival times for each shot, was carried out using LabView™ routines. Subsequent processing was carried out interactively using spreadsheet calculations, rather than by relying on semi-automatic processing software.

Seismic velocities and depths to shallow layers were determined using the Plus-Minus method, which is essentially the same as the Generalized Reciprocal Method (GRM) for shallow refractors. The program GRAPHER™ was used to plot the depth and velocity data and to measure the seismic velocities from the gradients of linear fits applied to appropriate segments of the data. The slope distance was used in the velocity calculations due to the steepness of the lines.

The calculations used to produce the profiles are based on some assumptions. For example, both velocity and depth calculations assume that seismic waves travel along the survey line in two dimensions (longitudinal and vertical). If there are major lateral variations in the refractor depth, then this assumption may be inaccurate and the calculated "depth" may in fact be a slope distance to a point on the refractor surface to the side of the seismic line.

The interpretation also assumes that layers will increase in velocity with depth. Any layer with a velocity lower than the layer above will not be detected and will lead to an error in the depth calculation.

The velocities calculated are the velocity at the top of a particular layer and these velocities may increase slightly within the layer.

Intercepts and delay times from either direction were also used to determine depths to rock to supplement the depths calculated by the Plus-Minus method. This was generally used on sections of line where the layers were thin and there was insufficient overlap to use the Plus-Minus method for all geophone positions.

3.1 Calibration

The seismograph was calibrated to determine the accuracy of the timing by recording a 100Hz pulse wave from a function generator. The frequency was checked by an HP™ Universal Counter, which itself has traceable calibration.

The calibration results are shown in Appendix B. The calibration determined that the seismograph under-reads the time by 2.3%. Therefore, arrival times measured from the seismograph records were corrected by increasing their value by 2.3%. This correction was made before any other calculations were performed. As a result, no correction had to be applied to velocities calculated subsequently.

4 Survey Results

Cross sections of each seismic line are provided in Appendix A. The cross sections show:

- the ground surface profile along each line;
- seismic compression wave (p-wave) velocity and thickness of the surface layers; and
- the compression wave velocity of the rock layer.

All velocities referred to are compression wave velocities measured in metres per second (m/s).

Brief descriptions of any notable features found on each of the seismic lines are given below.

4.1 Site Location A7 Makaroro

This site is on the Makaroro River, upstream from the location of the previous survey. Three of the seismic lines, A7-5, A7-7 and A7-8 were accessed from Wakarara Road. The fourth line, A7-6, located on the right bank was accessed from Smedley Road. The approximate locations of the lines are shown in Figure 1 below.

Figure 1: Site plan

4.1.1 Location of Seismic Lines

The locations of the ends of each line are shown in Table 1 below. The coordinates are in terms of the NZMG, with the Datum NZGD1949.

Line Name	Northing	Easting
A7-5 start	6153982	2790548
A7-5 end	6153961	2790331
A7-6 start	6153984	2790587
A7-6 end	6153996	2790810
A7-7 start	6154131	2790595
A7-7 end	6153999	2790388
A7-8 start	6154299	2790360
A7-8 end	6154369	2790255

4.1.2 Seismic Line A7-5

This line runs from the fence at the top of the river bank, across the terrace, over an outcropping ridge and up the slope.

The line is 217 m long, measured horizontally and has a geophone spacing of 5 m. On the slope, these are measured as slope distances.

A surface layer, ranging in velocity from 250 m/s to 450 m/s with a thickness of up to 2.5 m is present along the length of the line. An intermediate layer with a velocity of 500 m/s to 950 m/s is present along the line. The rock velocity of 3300 m/s is constant along the line with a maximum depth to the rock of 8.6 m.

4.1.3 Seismic Line A7-6

This line, on the right bank runs from the edge of the river, up a bushclad slope, across a terrace and continues up the slope.

The line is 211 m long, measured horizontally, and has a geophone spacing of 5 m. On the slopes, these are measured as slope distances.

A surface layer of 400 m/s with a thickness of up to 3.0 m is present along the length of the line. An intermediate layer is present along the line, with a velocity of 900 m/s over most of the line but increasing to 1450 m/s at the top end of the line. The rock velocity of 3300 m/s is constant along the line with a maximum depth to the rock of 8.9 m.

4.1.4 Seismic Line A7-7

This line runs across the terrace to the north of line A7-5 and has a gradual slope along the line, crossing a small stream several times.

The line is 247 m long, measured horizontally, and mostly has a geophone spacing of 5 m with a few 10 m spaced geophones at the top end. On the slope, these are measured as slope distances.

A surface layer with a velocity of 200 m/s to 250 m/s with a thickness of up to 1.5 m is present along the length of the line. An intermediate layer with a velocity of 900 m/s to 1000 m/s is present along the line. The rock velocity of 3300 m/s is constant along the line with a maximum depth to the rock of 8.8 m.

4.1.5 Seismic Line A7-8

This line runs across the river gravels and up a sleep slip and across a track at the top of the slip.

The line is 129 m long, measured horizontally. The geophone spacing is 5 m across the gravel flat and part way up the slope and then increases to 10 m spacing for the upper part of the slope. On the slope, these are measured as slope distances.

A surface layer, with a velocity of 400 m/s and a thickness of up to 2.3 m is present along the line. An intermediate layer with a velocity of 900 m/s to 1000 m/s is present along the line. The rock velocity has a velocity increases from of 2900 m/s below the river flats to 3300m/s on the slope. The depth to the rock is relatively shallow across the river gravels with a maximum depth of 6.7 m but increases toward the top of the slip to a maximum of 18.3 m.

5 Conclusions

The following conclusions are made from the data collected:

- The data was considered to be of good quality, with good contrast between the various layers.
- No low velocity zones are evident in the rock.
- The rock velocity was in the range of 2900 m/s to 3300 m/s.

Report authored by:

Alan Sutherland
Geophysical Consultant
Physical & Engineering Sciences

Report reviewed by:

Peter Cenek
Research Manager
Physical & Engineering Sciences

Appendix A: Seismic Refraction Cross Sections

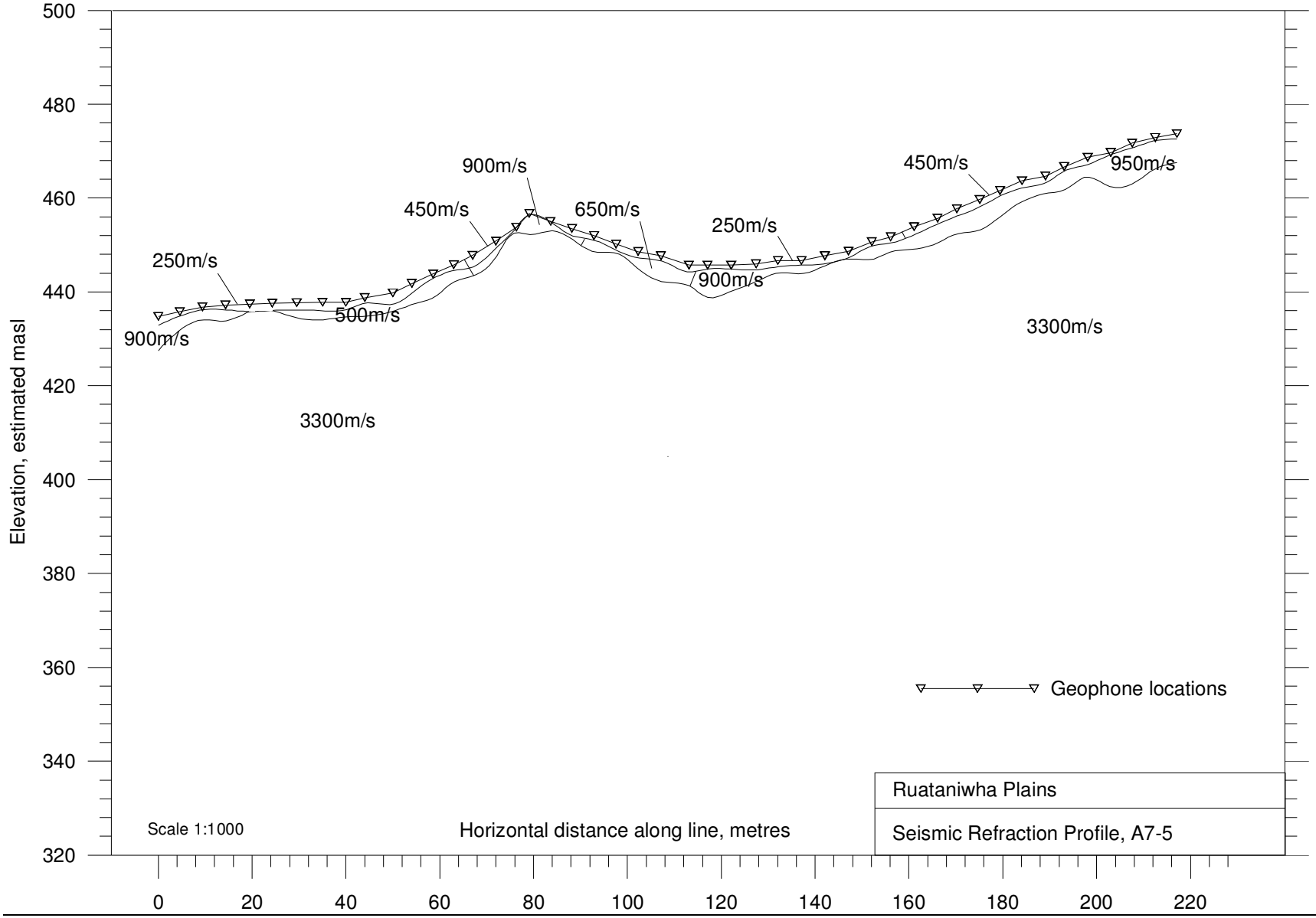


Figure A1:

Seismic refraction profile, A7-5

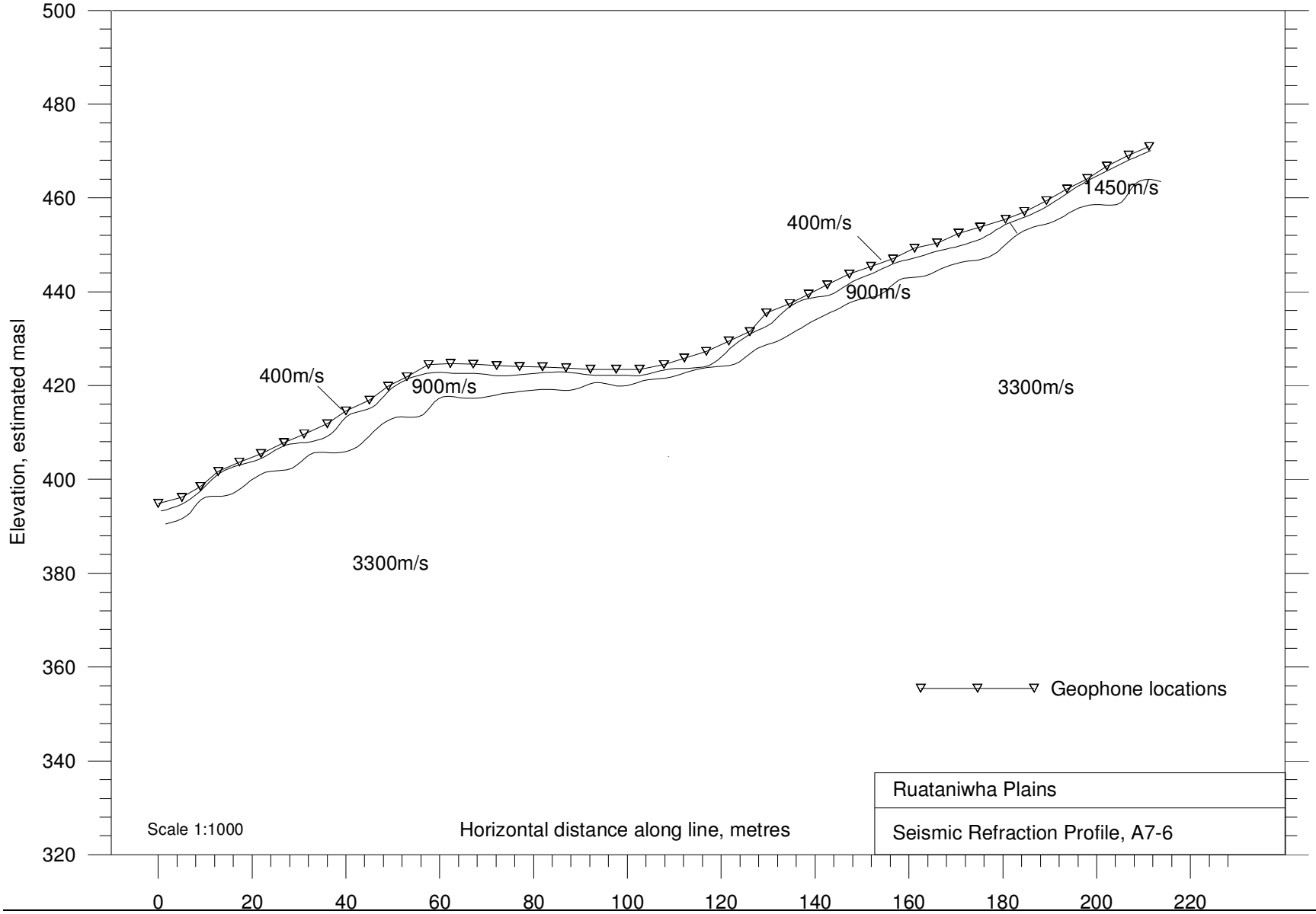


Figure A2:

Seismic refraction profile, A7-6

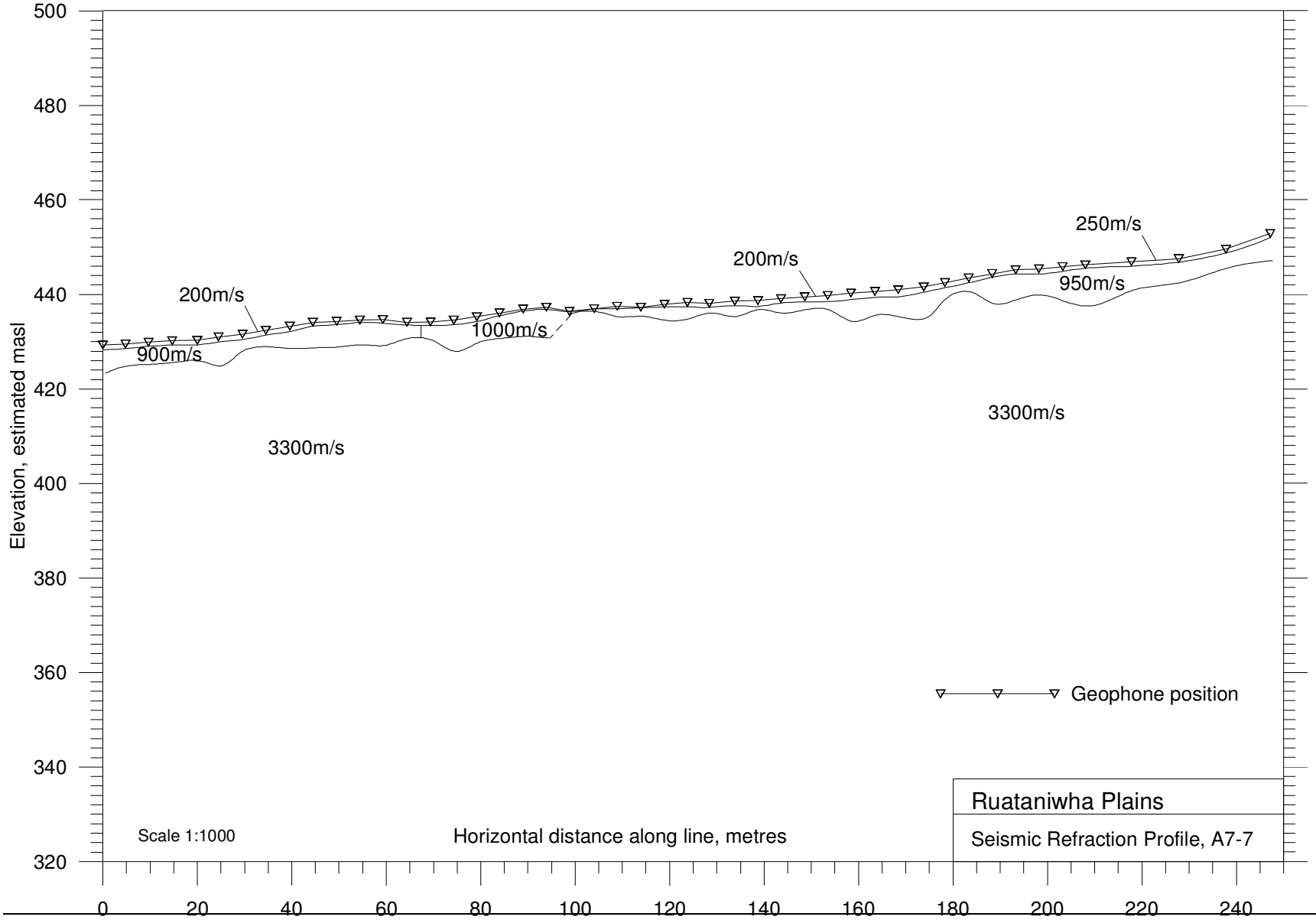


Figure A3:

Seismic refraction profile, A7-7

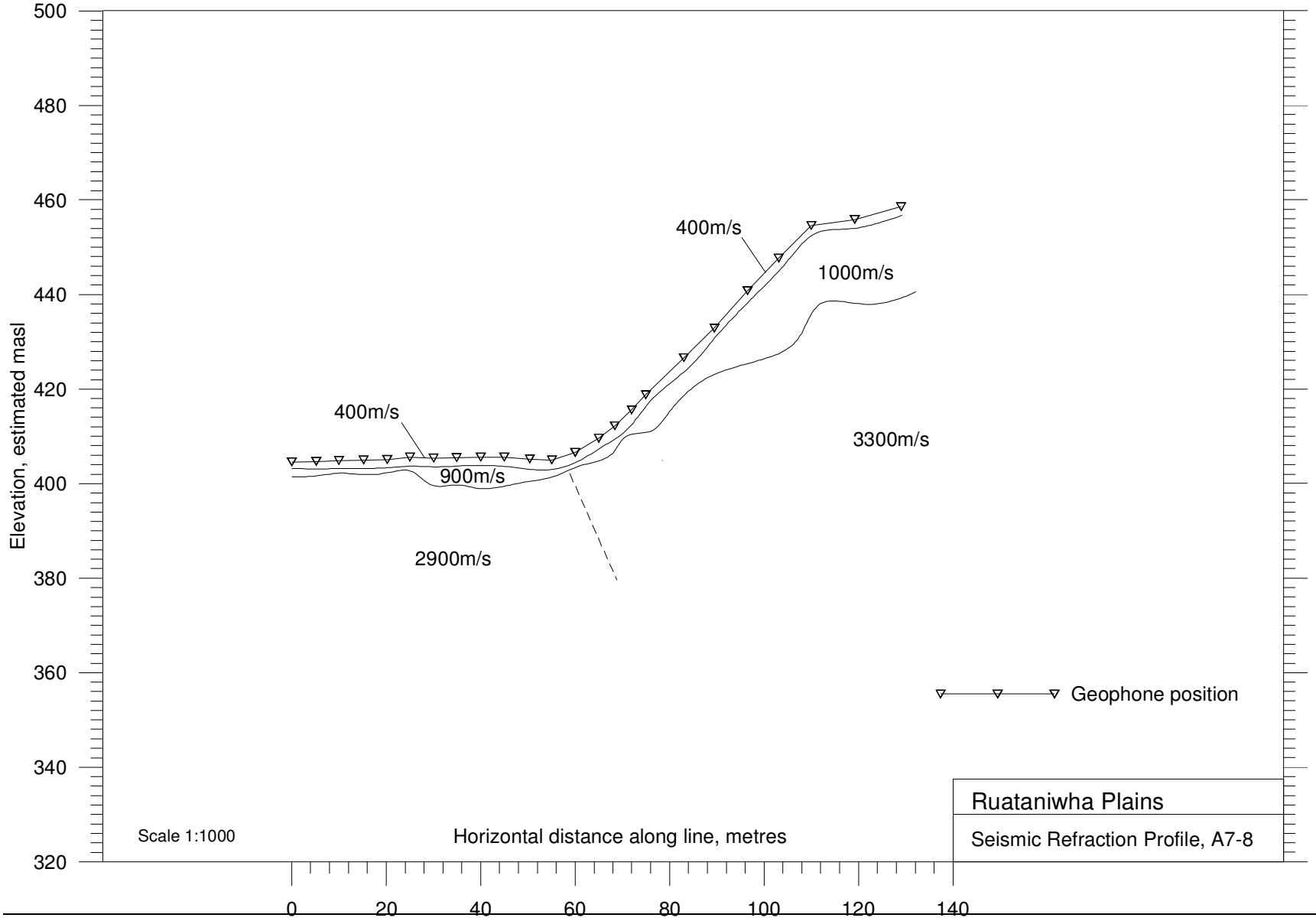


Figure A4:

Seismic refraction profile, A7-8

Appendix B: Seismograph Calibration

CALIBRATION CERTIFICATE

Test	Time accuracy	Instrument Make	ABEM
Instrument	Terraloc Mk3 Seismograph	Serial No	9027091
Standard	N/A	Tested by	Russell Kean
Calibration interval	2 Yearly	Date	1.03.2011
Next calibration	1.03.2013	Checked by	Alan Sutherland

REFERENCE EQUIPMENT/TESTING PROCEDURE

8-023 HP53131A Universal Counter (Serial number: KR0120658)
Calibration certificate held in Instrument Section

CALIBRATION RESULTS

Reference Voltage: 100mV
Reference Frequency: 100 Hz

Record Length (ms)	Cycles measured	Start time (ms)	End time (ms)	Elapsed time (ms)	Actual time (ms)	Error (%)	Correction Required
48	4	6.5	45.6	39.1	40	2.25	Yes
48	4	5.7	44.8	39.1	40	2.25	Yes
100	9	1.3	89.2	87.9	90	2.33	Yes
100	9	8.8	96.8	88	90	2.22	Yes
200	19	5.5	191.1	185.6	190	2.32	Yes
200	19	5.7	191.3	185.6	190	2.32	Yes

Mean Error 2.28%

COMMENTS

Sampling rate is 1/1000th of the record length
Seismograph is under reading times by 2.3%

REQUIRED ACCURACY

Accuracy requirements met	No
Correction Required	Yes

OPUS

Appendix D: GNS Science Consultancy Report 2011/300

A7 Makaroro River dam site – Phase 1B: Updated active fault and surface rupture displacement hazard and acceleration response spectra reassessment

R.M. Langridge
G.H. McVerry
P. Villamor
M. Cabeza

GNS Science Consultancy Report 2011/300
December 2011

DISCLAIMER

This report has been prepared by the Institute of Geological and Nuclear Sciences Limited (GNS Science) exclusively for and under contract to Hawke's Bay Regional Council. Unless otherwise agreed in writing by GNS Science, GNS Science accepts no responsibility for any use of, or reliance on any contents of this Report by any person other than Hawke's Bay Regional Council and shall not be liable to any person other than Hawke's Bay Regional Council, on any ground, for any loss, damage or expense arising from such use or reliance.

The data presented in this Report are available to GNS Science for other use from December 2011.

BIBLIOGRAPHIC REFERENCE

Langridge, R.M.; McVerry, G.H.; Cabeza, M. 2011. A7 Makaroro River dam site – Phase 1B: Updated active fault and surface rupture displacement hazard assessment and acceleration response spectra reassessment, *GNS Science Consultancy Report* 2011/300. 68 p.

CONTENTS

EXECUTIVE SUMMARY V

1.0 INTRODUCTION 1

1.1 The A7 Makaroro River dam site 2
1.2 Hazards from Earthquakes 3
1.2.1 Regional tectonic and earthquake setting 4
1.2.2 Active earthquake faulting in Central Hawke's Bay 7
1.2.3 Potential active faulting hazards at the proposed A7 damsite: primary, secondary faulting 7

2.0 LITERATURE REVIEW OF STRIKE-SLIP FAULT ZONE WIDTH AND DEFORMATION 9

2.1 Types of fault displacements 9
2.2 Fault complexity 10
2.3 Amount of displacement on primary and secondary features from historic ruptures 14
2.4 Summary 19

3.0 MAPPING OF ACTIVE FAULTS AND LINEAMENTS 20

3.1 Methodology 20
3.2 Results from field reconnaissance 21

4.0 PRIMARY FAULT DEFORMATION 22

4.1 Mohaka Fault 23
4.1.1 Seismic hazard parameters 23
4.1.2 Vertical slip per event 24
4.2 Wakarara Fault 27
4.2.1 Previous work 27
4.2.2 Field reconnaissance 28
4.2.2.1 South part of Smedley Station 29
4.2.2.2 West of Smedley Station 31
4.2.2.3 West of Matheson Road 31
4.2.3 Wakarara Fault Summary 32
4.3 Rangefront Fault 32
4.4 Mangataura Fault 33
4.5 The Ruahine Fault and faults in the Ruahine Range 34
4.6 Other faults 35
4.6.1 Cullens Fault 35
4.6.2 Hinerua Thrust and Pukenui Fault 35
4.7 Kinematic fault model of the A7 site area 36
4.8 Summary of the location, size and timing of primary surface fault rupture deformation in the study area 40

5.0 POTENTIAL FAULT DISPLACEMENTS AT THE A7 DAM SITE (PRIMARY AND SECONDARY) 41

5.1 Observations from Langridge & Villamor (2011) relevant to this study 41
5.2 Inferences on potential primary and secondary fault displacement and deformation at the damsite from the literature review and mapping 44
5.3 Presence of weak zones between the Mohaka Fault and the damsite from new structural data 47
5.4 Summary of the potential for primary and/or secondary displacements at the damsite 49

6.0 ESTIMATION OF ACCELERATION RESPONSE SPECTRA FOR A7 SITE 50

6.1 Summary of previous results from Langridge et al. (2010) 50

7.0 CONCLUSIONS 53

8.0 RECOMMENDATIONS 54

9.0 ACKNOWLEDGEMENTS 55

10.0 REFERENCES 55

FIGURES

Figure 1.1 Regional plan of the Ruataniwha Water Storage Project. The proposed A7 Makaroro River damsite and reservoir are shown in the top left of the map. 3

Figure 1.2 Plate tectonic setting of northern and central New Zealand showing the major tectonic zones in and the representative style of movement within the zones. Grey lines are active faults. The wider study area in central Hawke's Bay is outlined by a bold box. NIDFB refers to the North Island Dextral Fault Belt of Beanland (1995). Inset: Simplified plate tectonic setting of New Zealand with convergence rates in mm/yr. 4

Figure 1.3 Generalised active fault map of central Hawke's Bay and surrounds draped over Digital Elevation Models. The study area for the A7 Makaroro River damsite is shown by the white circle, representing a 10 km radius around the site (green dot). Red lines represent known active fault traces from the GNS Science Active Faults database (http://data.gns.cri.nz/af/). Labelled active faults include the Rangefront (RFF); Wakarara (WF); Mangataura (MF), Ruataniwha (RTF) faults, Waipukurau (WFZ), Poukawa (PFZ), and Tukituki (TFZ) Fault Zone, as well as the Mohaka and Ruahine faults. WB is the Wakarara Block, a small greywacke block located between the Mohaka and Wakarara faults. 5

Figure 1.4 Epicentral locations of large earthquakes in New Zealand from 1848-2010 (http://www.geonet.org.nz/). 6

Figure 1.5 Pre-existing data on active fault (red) and active fold traces (black dashed lines) that are in proximity to the proposed irrigation scheme; study area is within 10 km of the A7 dam site. Geology and faults from 1:250,000 scale geological map of the Hawke's Bay area prior to this study (i.e. Lee et al. in press). In addition, possible fault (red dashed lines) and fold (thin black lines) locations are also included. Up-thrown side of reverse faults is shown with triangles; black arrows indicated sense of strike-slip movement; and tick/ball symbols indicate down-thrown side of normal faults. Proposed A7 dam site is located within the Wakarara Block within greywacke bedrock (light blue). Yellow patterns indicate Quaternary sediments. A2 through C3 locations are other proposed dam sites within the Water Storage Project. MF = Mangataura Fault. 8

Figure 2.1 3-D block diagram displaying examples of displacements on main fault and secondary fault and triggered displacement on a distant fault. +/- shows movement in/out of the plane. 10

Figure 2.2 Simplified plan view models of strike-slip faulting (modified from Villamor 2001). A). PDZ is the primary fault (principal displacement zone), shown in the orientation of the Mohaka Fault. R refers to Riedel or right-lateral shears; R' to left- lateral shears; and P to thrust shears B) Types of tectonic structures on the main fault plane of strike-slip faults in bedrock. and C) Secondary tectonic features around main fault plane in bedrock, Price and Cosgrove, 1990). Ø is the friction angle. 11

Figure 2.3 Laboratory models of strike-slip faults. **A)** Evolutionary sand-box model over a rigid separated base (Naylor et al., 1986). Stage 1: development of Riedel fractures ("R"). Stage 2: development of splays at the terminations of Riedel fractures. Stage 3: appearance of temporary low-angle shears. Stage 4: formation of an anastomosing pattern in that the principal displacement moves to the principal planes ("P" planes of Riedel, 1929). 12

Figure 2.4 Structures associated with the bends in the trace of strike-slip faults. A) Types of bends and steps: restraining bend, releasing bend, stepover, separation, onlap. B) pull-apart basin formed in a step. C) Push-up structure formed in a step. D) Pull-apart basin and push-up structure formed at fault bends. E) Duplex formed without uplift or subsidence. Figures A, D and E taken from Woodcock and Fisher (1986). Figures B and C taken from Aydin and Nur (1985). 13

Figure 2.5 Examples of fault complexity from three historical strike-slip surface faulting events in California. A). 1987 Superstition Hills; B. 1992 Landers; and C) 1999 Hector Mine earthquakes. Fault traces compiled by Petersen et al. (2011). 14

Figure 2.6 Distributed-fault displacement data (labelled as connected) showing net slip as a function of distance from the mapped fault. Triggered rupture displacements are plotted but are not used in the regressions. Source: Petersen et al. (2011). 17

Figure 2.7 Distributed-fault displacement data and regression lines colour-coded by magnitude (for M 6.5 to 7.5). Source: Petersen et al. (2011). The distance from the site to the principal fault is r, and the displacement at the site is d. 17

Figure 2.8 Examples of hazard displacement curves. Probability of annual exceedance of surface displacements at two sites located at 64 and 120 m away from the main fault trace. Hazard curves include probability of primary and secondary faulting as a consequence of a Mw 7.0 earthquake on the main fault with a recurrence of 140 years. The sites are 25 x 25m. 18

Figure 4.1 Known active faults mapped in this study (red) and inactive faults (thin black lines) within 10 km of the proposed A7 scheme. Geology from 1:250,000 scale QMap (Lee et al. in press).

Abbreviations: HT, Hinerua Thrust; PF, Pukenui Fault; LRF, Lookout Road Fault; MF, Mangataura Fault. The A7 dam site is sited within the Wakarara Block (blue; greywacke) between the Mohaka and Wakarara faults. 22
Figure 4.2 Uphill-facing scarp of the Mohaka Fault on Rangimarie Station, marked by red arrows. At this locality a ponded basin has formed behind the scarp and the original drainage has been displaced from its source by 27-37 m. Rounded to conical hillocks of greywacke occur on the east (far) side of the fault trace. The dashed line shows an example of profiles that were constructed from the LIDAR DEMs to estimate vertical SED, i.e. the line represents the fall line of the offset ridge. 24
Figure 4.3 LiDAR DEM emphasising the mapped trace of the Mohaka Fault near the A7 dam site, which is typically characterised by a single straight trace. However, fault complexities including a small stepover zone and fault bifurcation (splay) are identified. Profiles used to develop vertical SED estimate occur on Rangimarie Station between Fig. 4.2 and the Makaroro River. 25
Figure 4.4 LiDAR DEM emphasising mapped traces of the Wakarara Fault visited during this study. Fault traces are not typically continuous along their length. 28
Figure 4.5 View to the North of a small, uphill-facing scarp (marked by arrows) at the southern end of the Wakarara Fault on Smedley Station. The fault trace crosses topography without which implies that the fault is steeply-dipping here (See Fig. 4.4. for location; grid ref. U22/931509). 29
Figure 4.6 View to the north of NNE-striking uphill-facing scarp (marked by arrow) near the southern end of the Wakarara Fault on Smedley Station (See Fig. 4.4. for location; grid ref. U22/931509). This fault trace provides evidence of active faulting on a steeply-dipping fault plane. 30
Figure 4.7 View to the south of zone of en echelon active fault traces (marked by arrow) at the southern end of the Wakarara Fault on Smedley Station. These fault trace crop out to the east of the folded ridge of limestone associated with the Wakarara Monocline. 30
Figure 4.8 View to the north of a fault scarp (marked by arrow) west of Matheson Road (See Fig. 4.4. for location; grid ref. U22/982560). The 1-1.5 m high scarps displace a surface here (green paddock) which is correlated to the Q2 alluvial surface. 31
Figure 4.9 Four-metre high scarps of the active Rangefront Fault across Tukituki Road near the Ruahine Ranges (background). Here the fault is expressed as a double scarp across a probable Q2 or Ohakean (c.15 ± 3 kyr old) alluvial terrace. Photo is c. 12 km south of the A7 site. 33
Figure 4.10 View to the southeast along the scarp of the Mangataura Fault from Wakarara Road. The fault is characterised by a series of stepping mound-like surface traces up to 2 m high and 10 m wide (shown by red arrows and highlighted by power pylons) across a probable Q2 surface. Greywacke slopes of the southern edge of the Wakarara Block are just visible at left. 34
Figure 4.11 Simplified kinematic fault motion model involving the key active faults within 5 km of the proposed dam site. The dextral-slip Mohaka Fault is both the closest and most active fault to the A7 damsite. The Mangataura Fault is interpreted as a left-lateral (sinistral) fault. The sinistral motion (single black arrow) is explained if the reverse-slip Rangefront Fault is more active than the Wakarara Fault, which will cause faster SSE movement of the southern side of the Mangataura Fault compared with movement of the northern side (diagrammatically depicted by relative size of blue arrows). Black dashed line is arbitrary break between the Rangefront and Wakarara faults. 37
Figure 4.12 Simplified fault map including key active faults and lineaments within 5 km of the proposed A7 dam site. 38
Figure 4.13 Simplified geologic cross-section running NW-SE through the proposed A7 dam site on the Makaroro River. Three models for the dip of the Wakarara Fault are shown. A series of geomorphic lineaments/valleys are marked in the vicinity of the Mohaka Fault and A7 site. Location of cross-section line is shown on Figures 4.11 and 4.12. 39
Figure 5.1 Map of active faults, faults, lineaments and bedding attitudes within 4 km of the A7 damsite (at centre). Attitude data comes from GNS Science QMap and Tonkin & Taylor. Numbered sites in circles refer to key deformation features that impact the A7 site, are discussed in the text. 42
Figure 5.2 Map of active faults, bedrock faults, lineaments and bedding attitudes within 1-2 km of the A7 damsite (next to 4 at centre right). Numbered sites in squares refer to key deformation features referred to in the text. 48
Figure 5.3 A) Photo of the main plane (red arrow) of the Mohaka Fault showing a 330 mm wide zone of fault gouge (Location 1 in Figure 5.2). B) Photo of faults displacing bedded Mesozoic greywacke at 400 m distance from the main trace of the Mohaka fault (arrowed; Location 2 in Figure 5.2). Displacements are of the order of centimetres to metres. Faults have apparent dip-slip senses of movement. These faults would probably move as secondary rupture displacements. 49
Figure 6.1 Active fault earthquake source model(s) encompassing the Central Hawke's Bay area. The base map comes from QMap geology (e.g. Lee and Begg 2002, Lee et al. in press). The black lines represent the active fault sources as they are in the 2010 version of the NSHM

(i.e. Stirling et al., in review; many have abbreviated names). The blue lines are the new and modified seismic shaking sources developed for Langridge et al. (2010). Dam sites A7 and B1 are shown by green dots. 51
Figure 6.2 Unsmoothed magnitude-weighted rock spectra for site A7 vs. site A1 using the standard NSHM fault model for 1000, 2500, 5000 and 10,000 years. PGA is plotted at 0.03s. 52
Figure 6.3 Unsmoothed magnitude-weighted rock spectra for site A7 vs. site A1 using the revised Hawke's Bay fault model developed by Langridge et al. (2010) for 1000, 2500, 5000 and 10,000 years. PGA is plotted at 0.03s....52

TABLES

Table 2.1 Examples of magnitude, length and displacement from historic strike-slip surface ruptures....15
Table 2.2 Estimation of fault location accuracy (from mapping) vs. accuracy of actual historic surface ruptures; Source: Table 2 of Petersen et al. (2011). 16
Table 2.3 Estimation of fault complexity (from mapping) vs. accuracy of actual historic surface Source: Table 3 of Petersen et al. (2011)....16
Table 4.1 Horizontal and vertical slip data for the Mohaka Fault on Rangimarie Station 26

APPENDIX

Appendix 1 GIS Layers....60

EXECUTIVE SUMMARY

GNS Science has undertaken an analysis of active faulting including mapping and literature review of primary, secondary and distributed fault deformation with regards to a revised location for the proposed damsite A7 on the Makaroro River, central Hawke's Bay. The new A7 site is c. 700 m from the active Mohaka (strike-slip) fault. In addition to geologic studies GNS has updated acceleration response spectra for the new A7 site.

Due to the proximity of the proposed site to the known active Mohaka Fault a literature review was regarding the complexity of strike-slip fault zones in historic surface ruptures was undertaken. Rupture of principal fault traces (primary rupture) can be either concentrated in a narrow simple zone, or distributed within complex zones. In the complex zones, the main fault zone consists of parallel or oblique principal traces that can be separated by several kilometres (usually less than 4 km). Stepovers, bends and terminations of faults are complex zones. Displacements along main fault traces during fault rupture are large, ranging from a few centimetres to several meters (Wells & Coppersmith 1994). Displacements associated with fault rupture are dependent on the earthquake magnitude.

In worldwide examples of historical surface rupture faulting, secondary or distributed faulting with displacements of 0.1-0.5 m can be found up to >2 km away from the principal traces. Distributed faulting tends to occur in traces that splay from principal faults or that are parallel to them. Complex zones, such as those with stepovers, and fault terminations, are areas of prominent distributed displacements. During fault rupture, such areas can have triggered displacements of up to 0.35 m and up to 10 km distance can also occur along sections of know mapped active faults. Petersen et al. (2011) have developed a regression equation to assess distributed displacements associated with rupture on main faults. The amount of displacement is dependent on the earthquake magnitude associated with the main fault rupture and the distance of the site to the main fault. This type of analysis could be applied to the A7 dam site in future, if sufficient local data is acquired.

Geological mapping undertaken as part of this investigation has differentiated active fault traces, inferred fault traces, bedding-related features, lineaments, and fold traces within 5 km of the new site. Major active faults have been mapped out to a distance of 10 km from the new site and include the Mohaka, Wakarara, Rangefront and Mangataura faults. Many of the other features (inferred fault traces, bedding-related features, lineaments, and fold traces) have NNE strikes or trends, consistent with the regional tectonic fabric. This shows that there is a high correlation between the major active faults and secondary fabric and structures in the area.

The Mohaka Fault is an active, NNE-striking dextral-slip fault that will generate large earthquakes (est. M_w 7.5) every c. 1300 yr on average (Stirling et al., in review). The horizontal single-event displacement (SED) is c. 4.5 ± 1 m. In this study we have estimated the vertical SED for the Mohaka Fault based on reconstructing offset landscape profiles. These show that vertical SED is in the range of 0.4-1.0 m (west-side-up), but may range from 0-1 m.

The Wakarara Fault is an active reverse fault that bounds the eastern side of the Wakarara Range. Mapping has indicated the presence of fault scarps c. 3.8 km east of the A7 site. The Wakarara Fault dips to the NW beneath the site at presumably shallow to moderate dips (c.

30-60°). The exact relationship between the Wakarara Fault and its along-strike equivalent to the south, the active Rangefront Fault, is not known at this time. The Mangataura Fault is a 3.4 km long, SE-striking active fault which separates the Rangefront and Wakarara faults. The Mangataura Fault appears to accommodate left-lateral movement.

Because the new A7 damsite is in close proximity to the Mohaka Fault we have had to consider whether primary, secondary and/or distributed fault deformation could occur within the dam foundations as a consequence of co-seismic displacement on the fault. Based on our field observations and literature review, we interpret that primary (i.e. metre-scale) faulting is unlikely to directly affect the proposed new damsite, because no prominent fault scarps, topographic features or well-developed soft shear zones associated with major surface fault rupture have been identified in the immediate vicinity of the A7 site. However, secondary faulting effects are considered a distinct possibility. Despite the fact there are clear topographic lineaments and exposure of sheared rock and crushed zones in close proximity to the proposed new site, e.g. along Donovan Gully, analysis of DEMs derived from LiDAR data have not shown evidence of clear sharp recent (i.e. since the last glacial period) faulting along those lineaments typical of primary rupture along the Mohaka Fault. However, evidence from historic surface ruptures of similar (strike-slip) faults, together with the presence of clear lineaments and exposed shear zones close to the damsite, strongly suggests that secondary (or distributed) displacements is an important consideration with regards to displacement hazards at the new site.

Revised acceleration response spectra for the A7 damsite identifies no significant difference (1-2 %) from the analysis run by GNS Science in 2010 for the A1 site (see Langridge et al., 2010). These runs use the National Seismic Hazard Model and an updated model which includes additional Hawke's Bay region fault sources. The largest shaking hazard posed to the proposed new A7 damsite comes from the 'Mohaka South segment' of the Mohaka Fault (Stirling et al., in review).

To be able to assess the possible size of co-seismic secondary displacement at the A7 dam site, we need to better understand the rupture characteristics of Mohaka Fault earthquakes, e.g. the size and recurrence of co-seismic displacements will influence the amount and frequency of secondary displacements within the A7 dam site area.. We recommend undertaking further mapping and paleoseismic trenching to gain understanding on the extent of secondary faulting adjacent to the Mohaka Fault and the potential displacements values at the damsite, and to gain further understanding on the extent of faulting on other active faults in the local vicinity of the A7 damsite. These recommendations were previously described in GNS report 2011/117 as parts of Phases 2a, 2b and 3. The timing of this work should be discussed and agreed between GNS, Tonkin & Taylor and Hawke's Bay Regional Council.

1.0 INTRODUCTION

The Hawke's Bay Regional Council (HBRC; the Client) through Tonkin & Taylor Ltd (T&T) has requested that the Institute of Geological and Nuclear Sciences Ltd (GNS Science) provide a report which re-visits issues concerning active faulting in the vicinity of a planned Ruataniwha Water Storage Project in Central Hawke's Bay, and to provide recommendations concerning the proposed A7 damsite on the Makaroro River. The technical content of the project brief stated:

In Phase 1B of the feasibility study for the Ruataniwha project, our objective is to present updated findings, including acceleration response spectra, geological mapping, and active fault data, for the revised location of the A7 dam site. To achieve this, we have highlighted four tasks.

Review the results of the GNS Science regional scale report (i.e. Langridge et al., 2010) and consider whether there have been any significant changes in these findings with respect to the new A7 site location, concerning regional earthquake magnitude acceleration response spectra.

a) Review the findings of the recent GNS Science report regarding the seismic hazard assessment of the previous A7 site (i.e. Langridge and Villamor, 2011) and consider whether there have been significant changes in these findings with respect to the new A7 site, taking into account a 10 km radius around the site.

b) Undertake field reconnaissance near the revised A7 site and along the rangefront of the Wakarara Fault in order to identify fault scarps and/or shear zones.

c) Undertake a global literature search regarding deformation surrounding historical surface-rupturing earthquakes to assess the likely displacement on faults adjacent to the Mohaka Fault and in the vicinity of damsite A7, with an emphasis on possible displacements under the damsite.

d) Report on the findings of a-d.

This represents a significant and new effort which will contribute to a better understanding of the geology and seismic hazards relating to the new A7 dam site on the Makaroro River. The report concludes with a series of conclusions and recommendations for the forward planning of the site and project. Our goal is that the Client makes informed decisions and avoids both economic and natural risks associated with this project.

Subsequent to the field reconnaissance in September 2011, GNS Science has been also asked to provide data on the vertical component of co-seismic slip on the Mohaka Fault. This report also contains information on this subject.

In Section 1 we outline the seismological and tectonic setting for the dam site area. In Section 2 we present a summary of research concerning the width of deformation around strike-slip faults from an analysis of global studies. In Sections 3-4, we outline our geological

observations concerning active faults and the potential for primary and secondary deformation at, or close to, the proposed site (i.e. from Langridge and Villamor 2011). In Section 5 we discuss the potential for primary and/or secondary rupture at the new A7 dam site, based on the analysis in Section 2. In Section 6 we provide updated acceleration response spectral for the new A7 dam site. In Sections 7 and 8 we provide conclusions and recommendations for the new A7 dam site location with regards to further characterising the surface fault rupture hazard.

1.1 The A7 Makaroro River dam site

The A7 Makaroro River dam is an integral part of a wider Ruataniwha Water Storage Project that will bring water from the Makaroro River and headwaters and to distribute it into four areas for storage and irrigation (Fig. 1.1). With regards to seismic hazard and fault deformation, the A7 dam is the most significant structure required for the proposed irrigation development.

The revised A7 Makaroro River dam site - c. 240 m upstream of the previous site - is located in Central Hawke's Bay District, 60 km southwest of Napier, near the locale of Wakarara at NZMS 260 U22/906540 (Fig. 1.1). The site is located within a gorge section of the Makaroro River, a tributary of the Waipawa-Tukituki river system that drains to Hawke Bay. The site is located within the "Wakarara Block", a narrow (5 km wide) greywacke range to the east of the Ruahine Ranges. The damsite is located in close proximity to a number of active faults including the Mohaka, Ruahine, Wakarara/ Rangefront and the Mangataura faults (Figs. 1.2, 1.3). Some of the geology and earthquake shaking hazards that could affect the district and areas near to this damsite were outlined in earlier GNS reports (Langridge and Villamor, 2011; Langridge et al. 2010).

The current dam design plan is for a c. 75 m high dam to be constructed as a Concrete Faced Rockfill (CFRD) structure. The left abutment of the dam will be sited in greywacke bedrock against a hillslope above the river. The right abutment of the dam will be sited in greywacke bedrock traversing an alluvial terrace and a knob of isolated greywacke bedrock. On the true left side of the Makaroro River near the A7 dam site, much of the land is on, and approaches are through, Smedley Station. On the true right bank the main access points to the site are from Wakarara Road and Rangimarie Station.

In addition to reports by GNS Science (Langridge and Villamor, 2011; Langridge et al. 2010), preliminary studies by T&T at the A7 site included aerial photo analysis and interpretation, bedrock and shear mapping along the Makaroro River, shallow geophysical studies, drilling and the excavation of a trench adjacent to the proposed right abutment of the dam. The A7 reservoir related to this dam will extend c. 5.8 km upstream and will flood farm land and overlap the trace of the active Mohaka Fault. Bedrock geology changes to the northwest of the Mohaka Fault, where folded Tertiary marine rocks predominate.

Figure 1.1 Regional plan of the Ruataniwha Water Storage Project. The proposed A7 Makaroro River damsite and reservoir are shown in the top left of the map.

1.2 Hazards from Earthquakes

The proposed A7 Makaroro dam site is located within the southwestern part of Hawke's Bay region (Figs. 1.1, 1.2), located just to the east of the Ruahine Ranges and west of the Dannevirke and Ruataniwha Depressions. The depressions are areas of subdued topography and typically young surficial (Quaternary) geology with somewhat lesser tectonic activity compared to the ranges to the northwest and southeast of it (Fig. 1.3).

1.2.1 Regional tectonic and earthquake setting

New Zealand straddles the boundary between the Australian and Pacific plates, where relative plate motion (which varies from 30 to 50 mm/year) is obliquely convergent across the plate boundary (Fig. 1.2). That relative plate motion is expressed in New Zealand by movement on many active faults (Figs. 1.2, 1.3), a high rate of "small-to-moderate" earthquakes (M<7), the occurrence of many "large" earthquakes (M 7-7.9), and one "great" earthquake (M>8) in historical time (Fig. 1.4). The most recent moderate to large earthquakes in New Zealand's historical record are the 2010 Darfield and 2011 Christchurch earthquakes, which caused surface rupture and deformation, respectively (Gledhill et al., 2010).

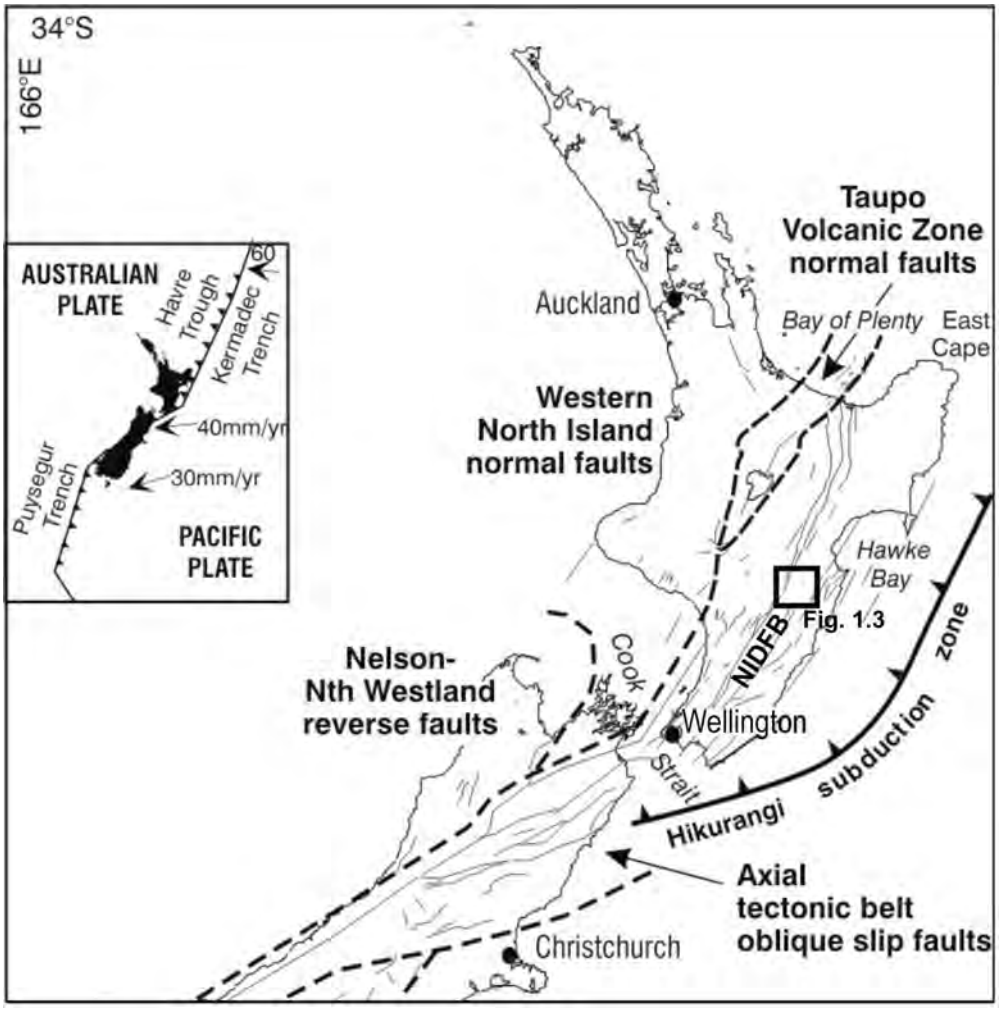


Figure 1.2 Plate tectonic setting of northern and central New Zealand showing the major tectonic zones in and the representative style of movement within the zones. Grey lines are active faults. The wider study area in central Hawke's Bay is outlined by a bold box. NIDFB refers to the North Island Dextral Fault Belt of Beanland (1995). Inset: Simplified plate tectonic setting of New Zealand with convergence rates in mm/yr.

The North Island is dominated by deformation related to the Hikurangi subduction margin. This margin is characterised by a northwest-dipping subduction zone and by a 450 km long zone of right-lateral oblique slip faulting, called the North Island Dextral Fault Belt (NIDFB; Beanland 1995). A significant proportion of the relative plate motion across North Island is accommodated by slip and large earthquakes on the faults of the NIDFB (Beanland et al., 1998). The proposed Ruataniwha Water Storage Project lies within the NIDFB, between the eastern edge of the North Island Axial Ranges and the western edge of the Hawke's Bay coastal ranges, within one of the more tectonically active parts of this boundary zone (Fig. 1.3). In addition to upper plate faults the eastern North Island, including Hawke's Bay is underlain by the Hikurangi subduction zone. In this region, the subducting Pacific plate also provides a potential source of large to great (i.e. M 7-8^{+} earthquakes).

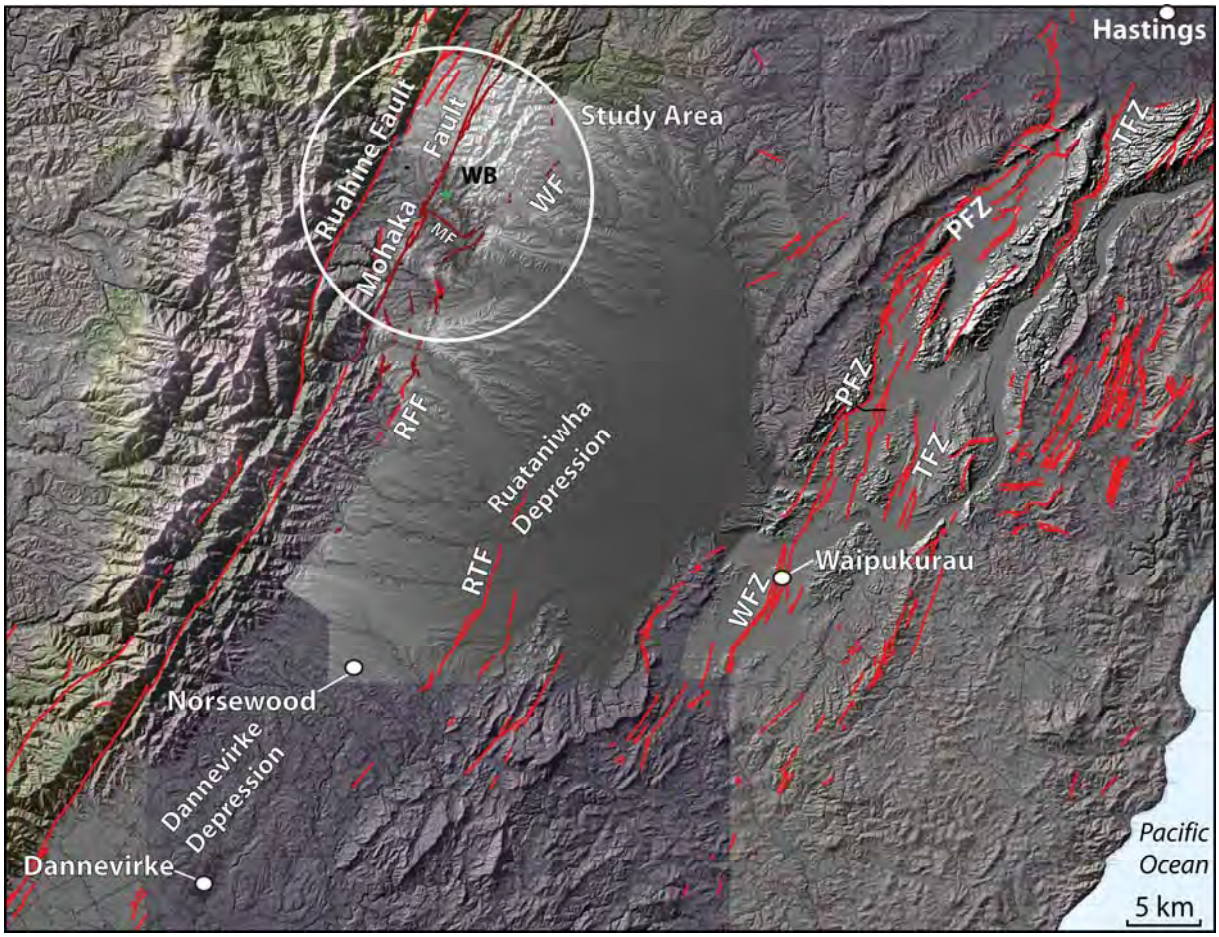


Figure 1.3 Generalised active fault map of central Hawke's Bay and surrounds draped over Digital Elevation Models. The study area for the A7 Makaroro River damsite is shown by the white circle, representing a 10 km radius around the site (green dot). Red lines represent known active fault traces from the GNS Science Active Faults database (http://data.gns.cri.nz/af/). Labelled active faults include the Rangefront (RFF); Wakarara (WF); Mangataura (MF), Ruataniwha (RTF) faults, Waipukurau (WFZ), Poukawa (PFZ), and Tukituki (TFZ) Fault Zone, as well as the Mohaka and Ruahine faults. WB is the Wakarara Block, a small greywacke block located between the Mohaka and Wakarara faults.

The Hawke's Bay region has a well-documented record of historical earthquakes (Fig. 1.4) that have been both damaging and destructive. Early in New Zealand's historic record, two significantly large (M 7+) earthquakes occurred between during the mid-19th century near or within Hawke's Bay region. A large event in 1843 has now been assigned to the area of the Axial Ranges in Hawke's Bay, based on shaking intensity contours. In 1863, the M 7.5 Waipukurau earthquake is believed to have occurred on a reverse fault source in the vicinity of that town (Grouden 1966; Downes and Dowrick, in prep.). These events and the M 8.2 1855 Wairarapa earthquake produced strong ground motions in the study area. During the early part of the 20th century, Hawke's Bay was rocked by a number of large earthquakes, including the M 7.8 1931 Hawke's Bay earthquake which killed 256 persons and destroyed the cities of Napier and Hastings. This event also caused damaging to very damaging (MM 7-8) ground motions in the vicinity of the study area. Other 20th century damaging earthquakes in the region include the M 6.9 1932 Wairoa, M 7.4 1934 Pahiatua, and M 7.2 1942 Masterton earthquakes (Downes 1995; Schermer et al. 2004). Subduction zone earthquakes along the Hikurangi margin are recognised as a large to great (M 7-8+) earthquake source.

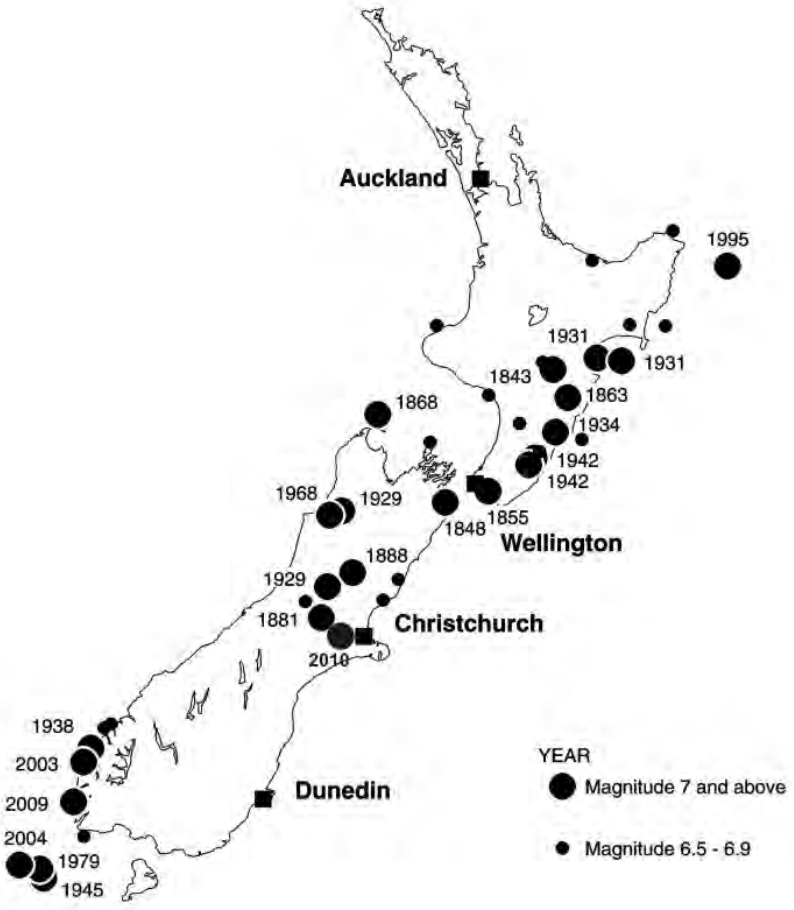


Figure 1.4 Epicentral locations of large earthquakes in New Zealand from 1848-2010 (http://www.geonet.org.nz/).

1.2.2 Active earthquake faulting in Central Hawke's Bay

The large earthquakes in the region have been and will be associated with the major active faults. In addition to being underlain by the subducting Pacific plate (Fig. 1.2), the study area is traversed by a number of significant active faults, including the Mohaka Fault, Ruahine Fault, Ruataniwha Fault, and Waipukurau Fault Zone (Fig. 1.3), which can generate earthquakes of estimated magnitudes in the range of about M 6.8 to 7.6, and with average recurrence intervals ranging from <1000 years to in excess of 10,000 years (Berryman and Beanland 1991; Stirling et al., in review). Such earthquakes on these faults would generate large (i.e. metre-scale) single-event surface rupture displacements. Active upper plate faults in the Hawke's Bay region have a variety of structural styles, ranging from strike-slip, e.g. Mohaka Fault, to reverse or reverse-oblique slip, e.g. Ruataniwha Fault (Klos 2009).

1.2.3 Potential active faulting hazards at the proposed A7 damsite: primary, secondary faulting

The proposed A7 damsite is located within the geological Wakarara Block which is bounded by the Mohaka and Wakarara faults (Fig. 1.5). These faults, together with the Mangataura Fault, require attention in terms of understanding potential surface fault displacement effects and strong ground motions as outlined in Langridge and Villamor (2011).

One of the major issues facing the viability of the A7 Makaroro site is whether there is evidence of, or potential for: (i) primary fault displacement (displacement along major active fault traces) through the footprint of the proposed damsite; or (ii) secondary displacement (minor displacement that occurs off the main fault trace) consequent on rupture of nearby active faults.

The presence of active faults in the vicinity of the dam site is a clear hazard because of the metre-scale displacement that the dam could be subjected to during fault rupture. Even if no major active fault were to be present at the proposed A7 damsite, the proximity of the site to known major faults implies the possibility that smaller secondary deformation on fault-parallel structures and/or bedding within the bedrock could occur during co-seismic movements.

An important set of questions for the proposed A7 damsite are:

(i) Is it possible that primary fault displacements can occur in, or close to, the A7 site as a result of tectonic movements on either of the three major faults (Mohaka, Wakarara, Mangataura)?

(ii) Could secondary displacements occur as a result of internal deformation within the Wakarara Block as a consequence of movements on the major active faults (i.e. from fault displacement, bending, folding, uplift etc.)?; and

(iii) If either (i) or (ii) occurs, what is the possible size, style and recurrence of the expected surface rupture displacements?

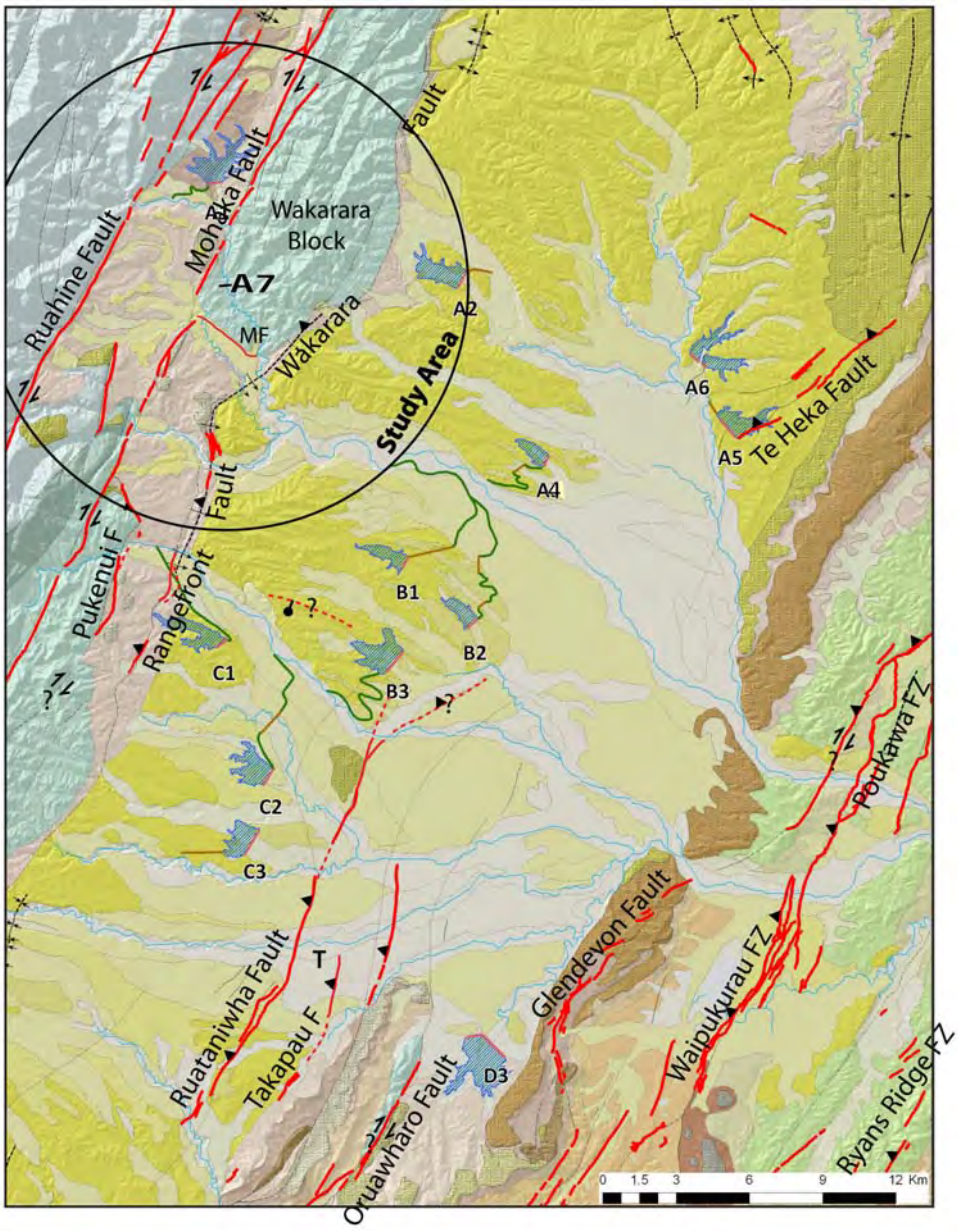


Figure 1.5 Pre-existing data on active fault (red) and active fold traces (black dashed lines) that are in proximity to the proposed irrigation scheme; study area is within 10 km of the A7 dam site. Geology and faults from 1:250,000 scale geological map of the Hawke's Bay area prior to this study (i.e. Lee et al. in press). In addition, possible fault (red dashed lines) and fold (thin black lines) locations are also included. Up-thrown side of reverse faults is shown with triangles; black arrows indicated sense of strike-slip movement; and tick/ball symbols indicate down-thrown side of normal faults. Proposed A7 dam site is located within the Wakarara Block within greywacke bedrock (light blue). Yellow patterns indicate Quaternary sediments. A2 through C3 locations are other proposed dam sites within the Water Storage Project. MF = Mangataura Fault.

2.0 LITERATURE REVIEW OF STRIKE-SLIP FAULT ZONE WIDTH AND DEFORMATION

In this section we set out to describe the nature of faulting along strike-slip faults including the width and complexity of primary deformation and the observation of secondary deformations along such faults. The Mohaka Fault, the closest primary fault source to the A7 dam site, is a strike-slip fault and thus we have focused our literature review on this type of fault zone and displacement. The aim is to assess whether there is a likelihood of secondary displacement at the dam site coincident with primary rupture on the Mohaka Fault.

2.1 Types of fault displacements

Different types of fault displacement can occur at, or in the vicinity of, active faults during fault rupture. Fault displacements can occur along different types of fault traces, the main or principal fault trace, secondary fault traces (or distributed faults) associated with the main trace, and distant active faults. This is relevant to the A7 site because the amount of displacement will be dependent on whether the displacements are primary (on the principal fault trace) or secondary. In this study we have followed the definitions set out by Petersen et al. (2011, p. 2-3 of their Data supplement) for the different types of faulting:

> "The term principal faulting refers to co-seismic surface rupture that occurs along the fault or faults responsible for the release of seismic energy during an earthquake (Coppersmith and Youngs, 2000). Principal faulting is commonly expressed at the surface as a narrow zone of faulting a few meters to tens of meters wide as a mostly continuous fault trace that is the manifestation of fault slip at the earth's surface.
>
> In contrast to principal fault rupture, we define the term distributed faulting as surface ruptures that occurs along faults off of the principal fault trace and in response to an earthquake along the principal fault. Distributed ruptures can occur from tens of meters to many kilometres away from the principal fault trace, are often discontinuous, and can occur on a variety of structures either related to the principal fault that ruptures during an earthquake, or along separate structures with no direct connection to the principal fault either at the surface or at depth. Such structures include parallel to sub-parallel faults, splay faults that branch away from the principal fault trace, as well as regional faults that are structurally unrelated to the principal fault that produced the earthquake. Unlike the hazard presented by the principal fault trace, where the location is usually known from geologic mapping, distributed ruptures and their associated displacements can be along faults and structures that are unrecognised or are too small to be considered an independent seismogenic source.
>
> In general, there are three categories of distributed ruptures: 1) ruptures located on distinct faults other than the one that produced the earthquake, 2) rupture along faults that splay off of the principal fault trace, and 3) rupture along faults that are parallel and sub-parallel to the principal rupture."

Fault displacements are defined as “on-fault” if the displacement occurs on the principal trace, and off-fault if it occurs on secondary and distant faults. The main and larger displacements tend to occur on the main trace and smaller displacements occur on secondary and distant traces. Displacement on known mapped active faults distant to the primary rupture is regarded as triggered faulting. Faulting of unmapped features that are parallel or sub-parallel to the principal fault and may or may not merge with the faults at depth are still regarded as distributed secondary faulting. Petersen et al. (2011) do not include triggered faulting in their analysis. Figure 2.1 shows a cartoon explaining the three types of faulting.

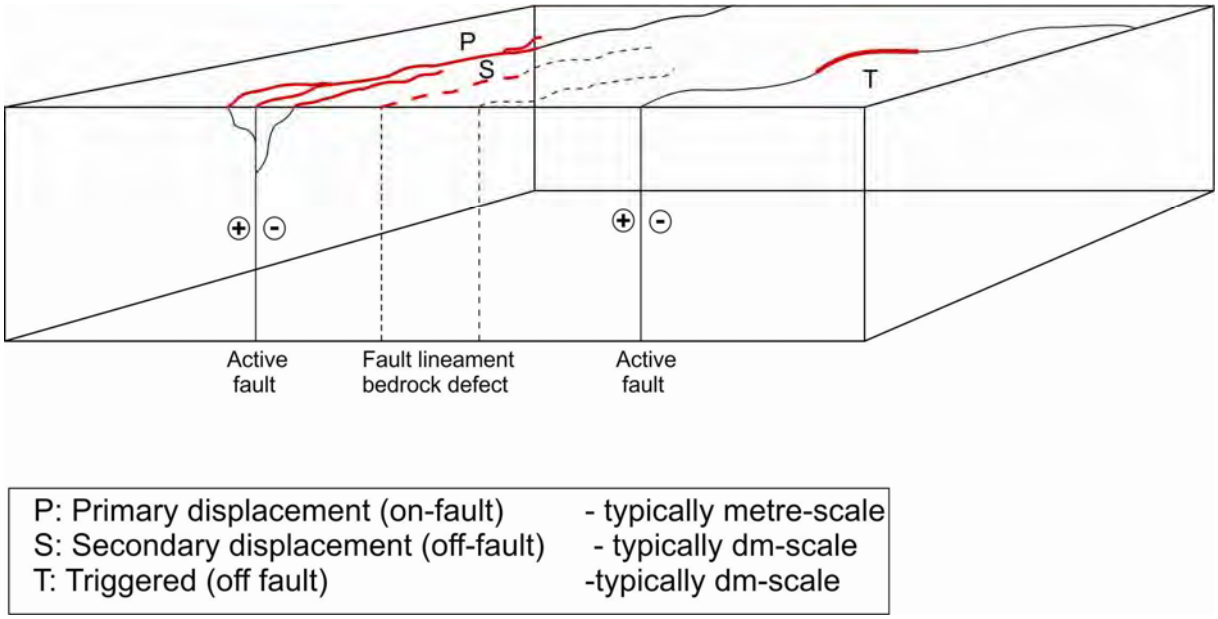


Figure 2.1 3-D block diagram displaying examples of displacements on main fault and secondary fault and triggered displacement on a distant fault. +/- shows movement in/out of the plane.

To understand the amount of displacement and the distance perpendicular to the main fault trace at which secondary or triggered displacement may occur, we have undertaken a literature review.

Firstly, we present the type of features and complexity of the strike-slip faulting to understand the different levels of complexity that strike-slip fault ruptures can display. This will give good insight into the concept and geometry of secondary faulting. Next, we present a review of the amount of displacement on secondary and distant faults recorded in historic surface ruptures. Finally, we will derive some constraints on potential faulting (in proximity to the Mohaka Fault) at the A7 dam site based on the literature review (see Section 5).

2.2 Fault complexity

Strike-slip faulting results from relative horizontal movement between the two blocks on either side of a fault plane. Different features can be found along strike-slip faults that are caused by this type of movement and by irregularities in the fault plane surface (e.g. Tchalenko, 1970; Sylvester 1986). The fault plane that is parallel to the movement vectors (Principal Displacement Zone = PDZ line on Fig. 2.2) is the one that ends up accommodating

most of the deformation (in particular for evolved faults, see below). However, there are other structures associated with the PDZ. If we consider a fault with right-lateral displacement along the main fault (PDZ), other structures that form are right-lateral shears, or R faults, that occur at a relatively moderate angle to the PDZ and, left-lateral shears with a much higher angle to the PDZ called R' shears (Figure 2.2). Also P, or thrust shears develop at the same angle as R but have an anticlockwise strike. Fissures (no relative displacement across the fissure) and folding can also be found in association with such strike-slip shear zones. All these types of features have been described for soft homogeneous materials (e.g., experiments with clay: Tchalenko 1970; or with sand: McClay and Dooley 1995) and for basement rocks (McKinstry, 1953, Price and Cosgrove, 1990) (Fig. 2.2).

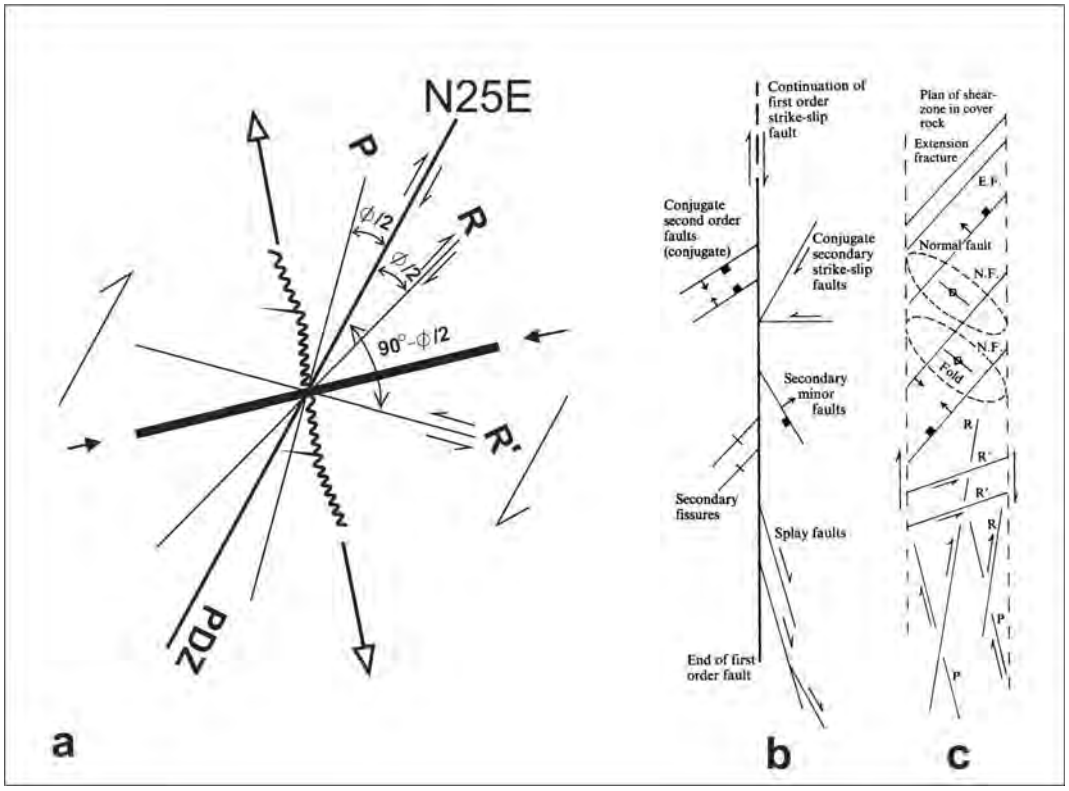


Figure 2.2 Simplified plan view models of strike-slip faulting (modified from Villamor 2001). A). PDZ is the primary fault (principal displacement zone), shown in the orientation of the Mohaka Fault. R refers to Riedel or right-lateral shears; R' to left- lateral shears; and P to thrust shears B) Types of tectonic structures on the main fault plane of strike-slip faults in bedrock. and C) Secondary tectonic features around main fault plane in bedrock, Price and Cosgrove, 1990). Ø is the friction angle.

Several authors have studied the evolution of strike-slip faulting (Tchalenko 1970, Naylor et al 1986) (Fig. 2.3) and showed that there is a transition from a pattern dominated by R shears at the early stages of deformation, to that dominated by shears parallel to main plane, i.e., PDZ faults. Because R shears become inactive the width of deformation becomes narrower as the fault evolves. Studies on the complexity of strike-slip faults (see more on fault complexity below) in relation to the activity of the fault, also suggest that young or slow faults tend to have more complexities (Stirling et al., 1996), because they are less evolved.

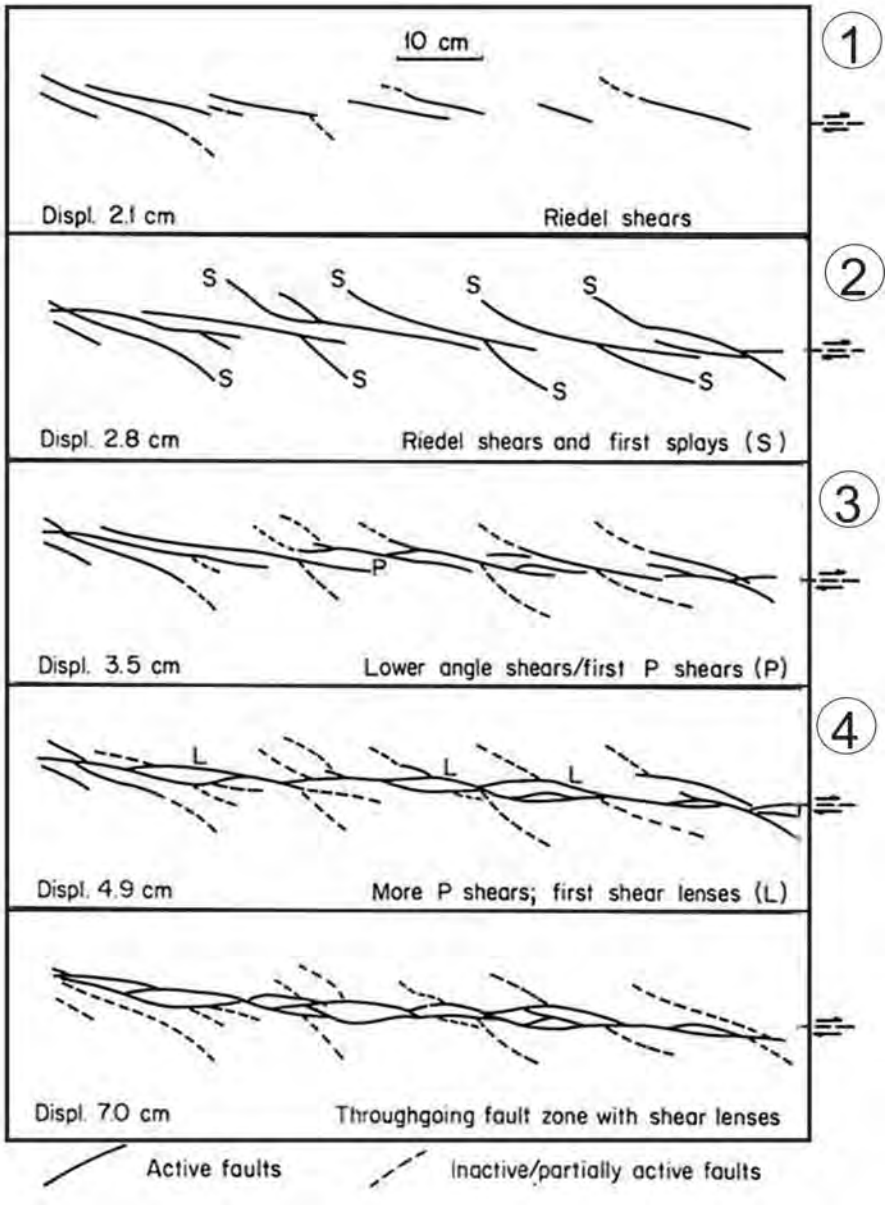


Figure 2.3 Laboratory models of strike-slip faults. **A)** Evolutionary sand-box model over a rigid separated base (Naylor et al., 1986). Stage 1: development of Riedel fractures ("R"). Stage 2: development of splays at the terminations of Riedel fractures. Stage 3: appearance of temporary low-angle shears. Stage 4: formation of an anastomosing pattern in that the principal displacement moves to the principal planes ("P" planes of Riedel, 1929).

Irregularities along the fault plane cause additional structures. When the fault plane bends or steps sideways, localised areas of transpression and transtension occur (Segall and Pollard, 1980) (Fig. 2.4). For example, in a right lateral strike-slip fault, a right bend or step will produce a transtensional zone where normal faults developed connecting the main fault traces across the step. The stepover becomes an area of subsidence commonly called a 'pull-apart' basin. If the step is towards the left, the connecting faults are reverse and the stepover zone becomes an elevated area called a 'push-up'.

The separation across the step between the main traces can vary greatly. This is shown by mapped active or inactive faults as well and by analysis of recent historic surface ruptures. Wesnousky (2006; 2008) undertook a compilation of 22 historic strike-slip surface ruptures and analyses the pattern of surface faulting. He found that for 2/3 of the fault terminations studied, surface ruptures have stopped at steps or bends with separations (distance between main trace across the step, perpendicular to the main fault) larger than 3 to 4 km. In addition, smaller steps can stop fault rupture propagation, but only in 40 % of these cases. This means that mapped primary active fault traces at steps or bends that are separated by less than 3-4 km may rupture simultaneously in a complex fault pattern. Therefore, the location of steps is important in understanding the complexity of future fault rupture and potential distributed faulting. Furthermore, assessing the possible future location of fault terminations is important for the assessment of fault rupture length and thus earthquake magnitude associated with rupture.

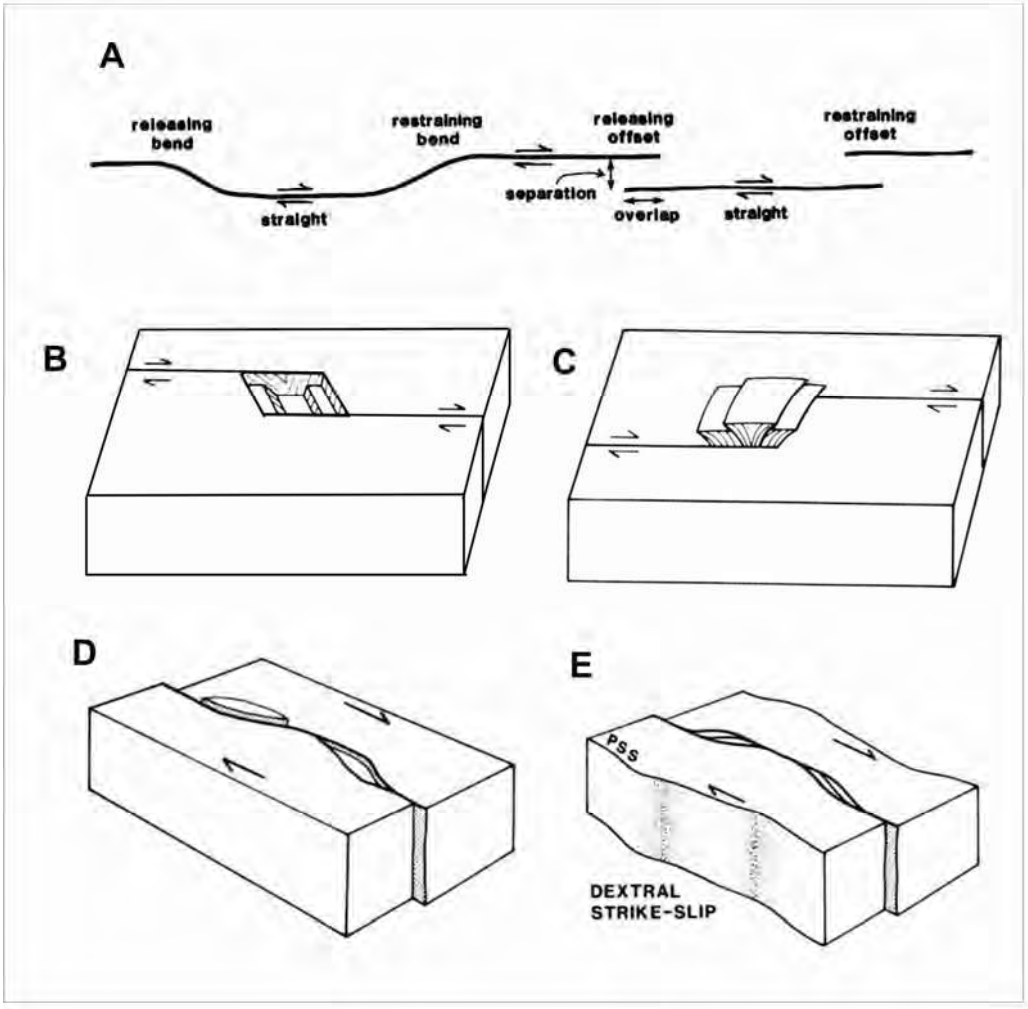


Figure 2.4 Structures associated with the bends in the trace of strike-slip faults. A) Types of bends and steps: restraining bend, releasing bend, stepover, separation, onlap. B) pull-apart basin formed in a step. C) Push-up structure formed in a step. D) Pull-apart basin and push-up structure formed at fault bends. E) Duplex formed without uplift or subsidence. Figures A, D and E taken from Woodcock and Fisher (1986). Figures B and C taken from Aydin and Nur (1985).

Identifying the potential terminations of fault rupture is also important because the end point of fault ruptures appear to be complex zones which could have a significant amount of distributed faulting associated with them (e.g., 1987 Superstition Hills rupture; Fig. 2.5). In addition, after the initial surface rupture has occurred, at the areas beyond the rupture terminations of strike-slip faults, the crust is stressed. For example, the well documented sequence of historic surface ruptures along the North Anatolian Fault represents a series of stress-triggered earthquake ruptures (Stein et al. 1997). It is common that these areas are the nucleation of the next event along the fault if the fault is mapped beyond the rupture (e.g., Izmit and Düzce ruptures occur consecutively in adjacent sections of the North Anatolia Fault; Langridge et al., 2002), or at least displays abundant aftershock seismicity. Secondary and triggered faulting can also occur in these regions.

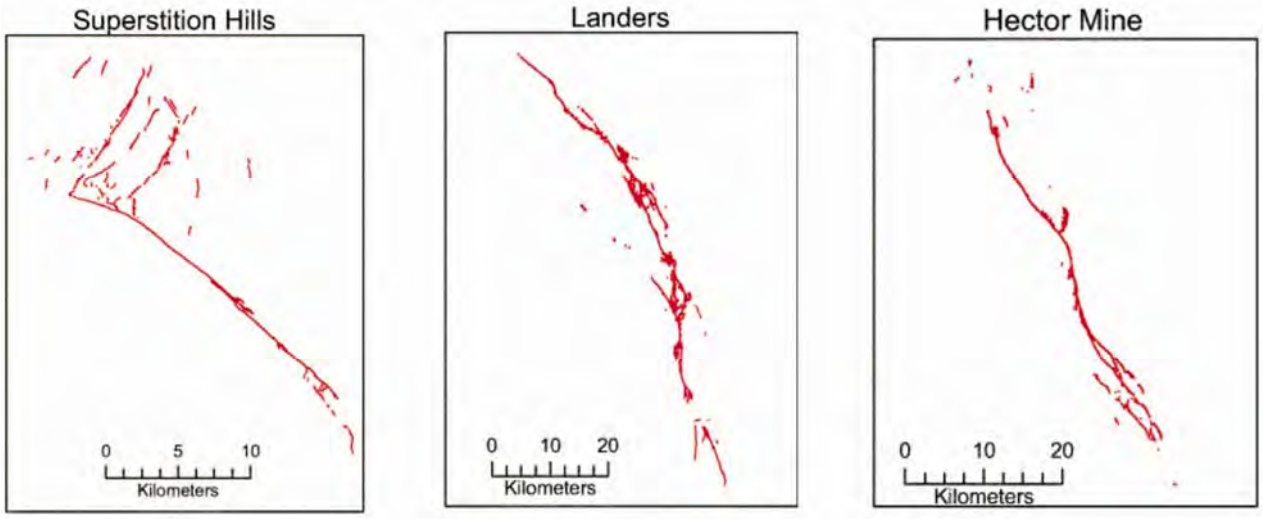


Figure 2.5 Examples of fault complexity from three historical strike-slip surface faulting events in California. A). 1987 Superstition Hills; B. 1992 Landers; and C) 1999 Hector Mine earthquakes. Fault traces compiled by Petersen et al. (2011).

All the features described above are necessary to understand the concept of fault complexity for strike-slip faults. For example, Petersen et al. (2011) describe the faults as simple, when they are narrow, relatively straight and represented by a small number of traces; and complex at steps, bends and fault terminations. These authors incorporate this concept in their assessment of fault displacement hazard presented below. The New Zealand Ministry for the Environment (MfE) Guidelines for building on or adjacent to active faults (Kerr et al. 2003) also use this concept for assessing the potential presence of unmapped faulting and the associated uncertainty in the location of those traces. Some examples of fault complexity of historic surface ruptures are shown in Figure 2.5.

2.3 Amount of displacement on primary and secondary features from historic ruptures

The most recent study on displacement values that occur in on- and off–fault situations during strike-slip fault ruptures is presented by Petersen et al. (2011). They present a methodology to assess the probability of a co-seismic displacement to occur at a site on- or off- an active fault. These authors combine the probability of fault rupture occurring along the main active fault with the probability of a certain amount of displacement occurring at a site of

interest whether on- or off-fault. Their method can be used for faults within 2 km of the main fault trace. For this, they extend the probabilistic fault displacement hazard method developed for the Yucca Mountain high-level nuclear waste repository in Nevada (Stepp et al. 2001; Youngs et al. 2003). While the Yucca Mountain studies deal with normal faults, Petersen et al (2011) deals with strike-slip faults. They also compiled on- and off-fault surface deformation of 9 historic seismic events with magnitudes between M 6.5 and 7.6 and use the information compiled by Wesnousky (2008) on another 13 events of up to M 7.9. The new information compiled by Petersen et al. (2011) includes on- and off- fault displacement data, while Wesnousky (2008) only deals with on-fault data. Relevant information for our study is extracted from Petersen et al. (2011) and presented in Table 2.1.

Table 2.1 Examples of magnitude, length and displacement from historic strike-slip surface ruptures

Event	Rupture length (km)	Average net slip (m)	Maximum net slip (m)	Mw
Apr 08, 1968 Borrego Mountain, California	31	0.13	0.4	6.5
Oct 15, 1979 Imperial Valley, CA	36	0.28-0.41	0.6-0.78	6.5
Nov 23, 1987 Superstition Hills, CA	25	0.3-0.6	0.5-1.1	6.6
Jun 28, 1992 Landers, CA	77	2.3	6.7	7.3
Aug 17, 1999 Izmit, Turkey	107 (145)	1.1	5.1	7.4
Oct 16, 1999 Hector Mine, CA	44	1.56	5.2	7.1
Nov 12, 1999 Düzce, Turkey	40	2.1	5	7.1

In the study by Petersen et al. (2011) they base the probability of a fault rupturing on the fault slip rate (mm per year) or the fault recurrence interval (how often it ruptures) of the main fault, while the amount of displacement is based on published regression equations that relate displacement to magnitude (for on-fault displacement, Wells & Coppersmith, 1994) or that they produced from their data compilation for off-fault displacement.

An important aspect of the probabilistic methodology developed by Petersen et al. (2011) is that it allows for the incorporation of uncertainties related to fault mapping. That is, if the principal fault is mapped as accurate, approximate, concealed or inferred the uncertainty of the location of the fault will vary. For example, Petersen et al. (2011) compared the location of a faults mapped before and after a rupture and assessed the error associated with how accurately the fault was mapped. For accurately mapped faults errors were in the range of 20 (± 20) m while for inferred faults they were in the range of 45 (± 57) m (Table 2.2). Petersen et al. (2011) also attempted to incorporate the fault complexity in the assessment of fault location uncertainties. Very complex and inferred faults can have location uncertainty of more than 160 m (see Table 2.3). These uncertainties have important effects on the final probabilities of the amount of displacement in either on- or off-fault rupture.

The compilation of off-fault displacements shows that secondary faulting has occurred to distances up to 2 km from the principal trace (Fig. 2.6). Triggered displacement can occur from distances as close as a few hundred meters to distances of 10 km (Fig. 2.7). The data compilation shows that while they have a robust data set for on-fault rupture (the main focus of most post-rupture studies), the off-fault data is scarce. However, they develop a robust off-fault regression equation with good analysis of the uncertainties. These authors only consider secondary displacement in their study, but not triggered displacement.

Table 2.2 Estimation of fault location accuracy (from mapping) vs. accuracy of actual historic surface ruptures; Source: Table 2 of Petersen et al. (2011).

Mapping Accuracy	Mean (m)	Standard Deviation (m)
All	30.64	43.14
Accurate	18.47	19.54
Approximate	25.15	35.89
Concealed	39.35	52.39
Inferred	45.12	56.99

Table 2.3 Estimation of fault complexity (from mapping) vs. accuracy of actual historic surface Source: Table 3 of Petersen et al. (2011)

Complexity	Mean (m)	Standard Deviation (m)
Simple, concealed	36.58	49.96
Simple, inferred	31.49	38.29
Complex, concealed	90.31	73.12
Complex, inferred	83.23	81.30

The regression equation relating displacement at a site with earthquake magnitude and distance from the principal fault trace developed by Petersen et al (2011) for secondary faulting is:

$$\ln(d) = 1.4016m - 0.1671 \ln(r) - 6.7991 \quad (1)$$

where d is the secondary displacement value at the site, m is the moment magnitude associated with the fault rupture and r is the perpendicular distance from the site to the principal fault. The data and the fit to a linear regression are shown on Figure 2.7. The displacement d at a site is therefore dependent on the magnitude of the event and the distance to the principal fault trace. This equation has a standard deviation of 1.1193 ln units and a standard error on the slope of 0.0476.

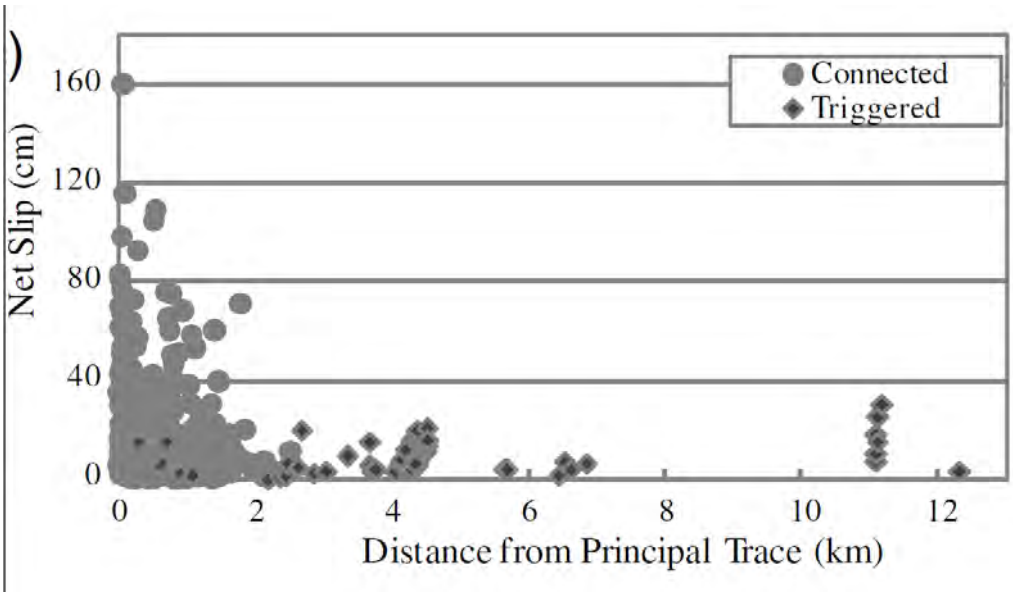


Figure 2.6 Distributed-fault displacement data (labelled as connected) showing net slip as a function of distance from the mapped fault. Triggered rupture displacements are plotted but are not used in the regressions. Source: Petersen et al. (2011).

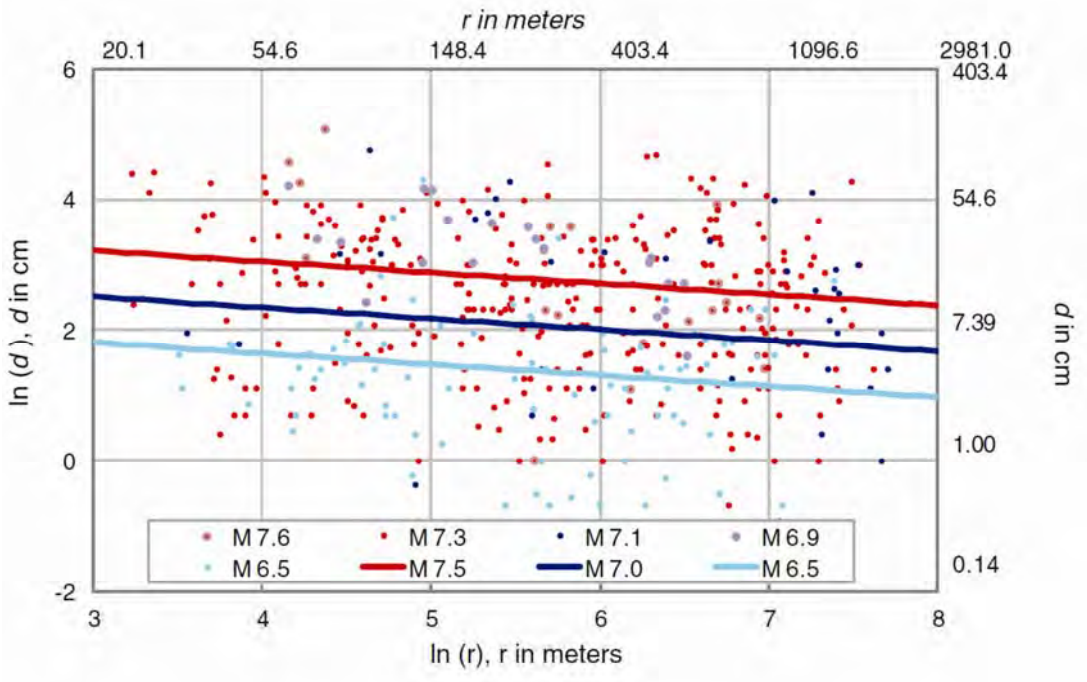


Figure 2.7 Distributed-fault displacement data and regression lines colour-coded by magnitude (for M 6.5 to 7.5). Source: Petersen et al. (2011). The distance from the site to the principal fault is r, and the displacement at the site is d.

This equation can be used to assess the possible size of displacement at a site in a deterministic fashion, simply by applying the equation to a distance (r) and magnitude of earthquake on a principal fault. It can also be incorporated into a probabilistic assessment. Figure 2.8 shows an example from Petersen et al. (2011) of the probability of fault rupture at 25 x 25 m-size sites located 64 and 120 m away from the principal mapped trace, for a M 7.0 earthquake along the principal fault plane that occurs on average every 140 years. The probabilistic values incorporate contributions from on- and off-fault data (i.e., principal and secondary displacement) because both can occur at such close distances from the principal mapped trace. For example, a displacement of 1 m at the most distant site has an annual exceedance rate of ~ 0.00003, that is, a 1.5 % chance of exceedance in the next 500 years, or 26% in the next 10,000 years. This type of analysis could be undertaken for the Mohaka Fault at the location of interest.

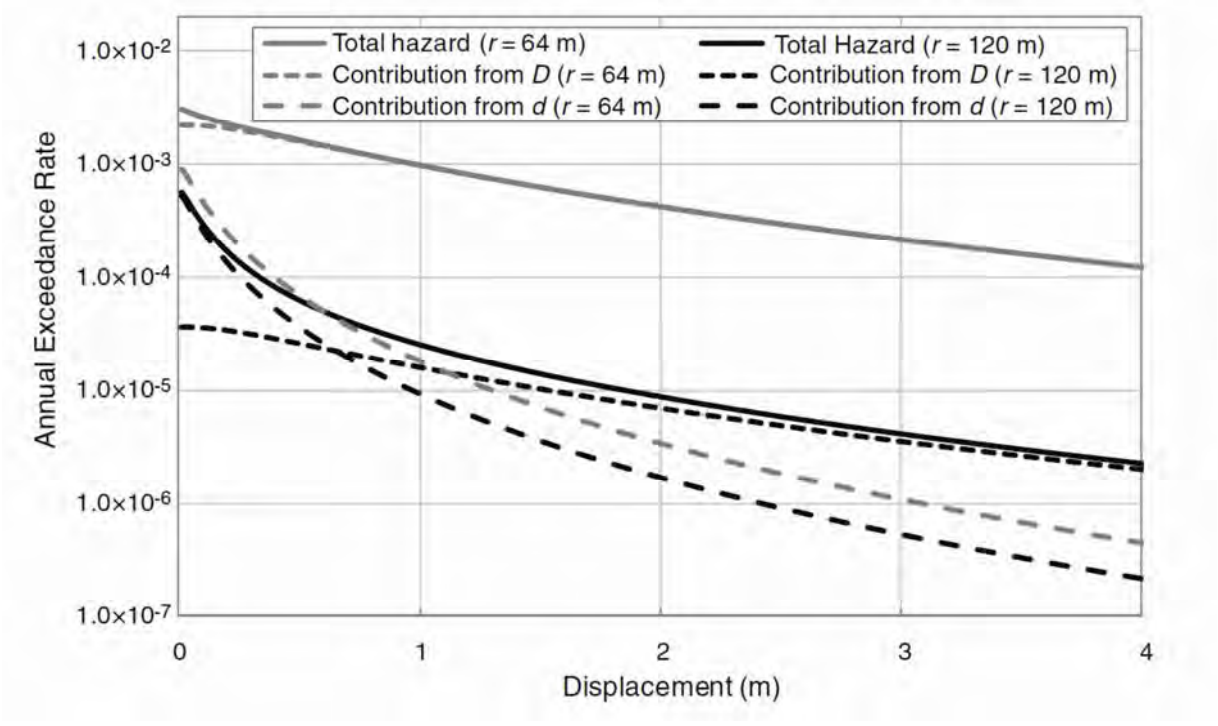


Figure 2.8 Examples of hazard displacement curves. Probability of annual exceedance of surface displacements at two sites located at 64 and 120 m away from the main fault trace. Hazard curves include probability of primary and secondary faulting as a consequence of a Mw 7.0 earthquake on the main fault with a recurrence of 140 years. The sites are 25 x 25m.

The advantage of using a probabilistic approach rather than a deterministic one is that the results can be better used to assess engineering design in a risk-based approach. Also an important outcome of Petersen et al. (2011) study is that the best results for a particular site will come from using the specific information at that site, including careful mapping of fault location, and paleoseismic trenching to determine earthquake recurrence.

2.4 Summary

Literature review has shown that surface ruptures along strike-slip faults can be very complex. Rupture of principal fault traces (primary rupture) can be either concentrated in a narrow simple zone, or be widespread within complex zones. In the complex zones, the main fault consists of parallel or oblique principal traces that can be separated by several kilometres (usually less than 4 km). Stepovers, bends and terminations of faults are complex zones. Displacements along main fault traces during fault rupture are large, ranging from a few centimetres to several meters (Wells & Coppersmith 1994). Displacements associated with fault rupture are dependent on the earthquake magnitude.

In worldwide examples, secondary or distributed faulting with displacements of 0.1-0.5 m can be found up to >2 km away from the principal traces (Fig. 2.6). Distributed faulting tends to occur on traces that splay from principal faults or that are parallel to them. Complex zones, such as stepover, and fault termination, are areas of prominent distributed displacements. During fault rupture, triggered displacements of up to 0.35 m and up to 10 km distance can also occur along sections of un-related active faults.

Petersen et al. (2011) have developed a regression equation to assess distributed displacements associated with rupture on primary faults. The amount of displacement is dependent on the earthquake magnitude associated to the main fault rupture and the distance of the site to the main fault.

In Section 5, we will apply this approach to the area of the A7 Makaroro River damsite, which occurs in close proximity to the active Mohaka (strike-slip) Fault.

3.0 MAPPING OF ACTIVE FAULTS AND LINEAMENTS

A large component of the Langridge and Villamor (2011) report involved a preliminary characterisation of the important geological structures (e.g. faults) and potential types of deformation within 5 km of the original A7 dam site. This work involved: (i) compilation of existing GNS information such as QMap geology and the Active Faults database (Fig. 1.5); (ii) analysis of LiDAR data made available to GNS by the Client; and (iii) geological field reconnaissance's to the site area to investigate faults, structures and lineaments. The context for this work was to understand the nature of primary and secondary active faults near of through the potential dam site, and therefore to characterise the amount of potential fault displacement near or through the dams site. In the current report the scope of interest has been widened to consider the broader geological and structural implications of active faulting from the perspective of block and intra-block active faulting.

3.1 Methodology

Fault mapping was undertaken within a GIS onto LiDAR DEMs (digital elevation models) of the area surrounding the damsite. Hawke's Bay Regional Council supplied LiDAR (Light Detection and Ranging) data prior to this project that was used for earlier mapping of active faults in the central Hawke's Bay area (Langridge et al., 2006; 2010). As part of the current project, a small (60 km^2) area of LiDAR coverage was acquired and added to pre-existing surveys to include the area of the proposed damsite and in order to have complete LiDAR coverage within c. 4 km of the damsite. In addition, aerial photographs have been analysed in conjunction with LiDAR to verify the nature of geological features observed on the DEMs and in the field. In this study we have extended our scope of mapping faults and other structures out from 5 km to 10 km from the dam site.

Within the GIS a number of Shapefiles have been created to categorise the types of features that have been mapped. These mapped features have the following definitions:

1. Active Fault – a definite fault trace can be identified if it breaks an alluvial or hillslope surface creating a vertical scarp, e.g. the Rangefront Fault, or if the trace shows clear horizontal displacements, as the Mohaka Fault does in many places [Shapefile = Wakarara-Makaroro_faults];

2. Inferred Fault – where an active fault cannot be seen but is inferred to occur based on extension of well-mapped active fault traces and/or other geological features. For example, where a river has removed evidence for the fault we infer the location of the fault from scarps on opposite banks of the river [Shapefile = Inferred Faults];

3. Lineaments – this is a broad category referring to geomorphic indications of linear features in the landscape. The term lineaments will include linear possible fault traces, secondary fault traces, or features of unknown origin. The term 'lineaments' is also used for landscape-scale geomorphic features within the greywacke hill country, such as linear valleys and linear bumps within these valleys. We also include clearly linearly-oriented stretches of gorges in the Makaroro catchment under the term lineament [Shapefile = Lineaments].

4. Bedding-related features – this term refers mainly to features such as those observed where ribbed bedrock spurs form geomorphic lineations in the landscape. This category of features is mainly located adjacent to the parallel sections of the Makaroro River and Mohaka Fault upstream of the A7 damsite [Shapefile = Bedrock-Bedding_features].

5. Folds – these linear features include active folds such as anticlinal warps that form on the upthrown side of active reverse fault traces, and also fold axes observed in Tertiary rocks, such as the Yeoman Syncline which can be seen in rocks on Rangimarie Station [Shapefile = folds].

Finally, a Shapefile is developed to summarise our best estimate of the continuous nature of faulting along some active faults, such as the Mohaka Fault, that are shown to determine the probable extent of its continuous trace [Shapefile = Faults(continuous)]. This is typically a combination of 1 and 2 above. The Shapefiles are presented within the text (e.g. Fig. 4.1) and are presented on a CD (see Appendix 1)

3.2 Results from field reconnaissance

Field reconnaissance trips have been undertaken in conjunction with T&T geologists during previous phases of this project including a regional study (Langridge et al., 2010) and for the previous A7 dam site (Langridge and Villamor 2011). The objectives of these reconnaissance trips were to investigate: (i) evidence for active faulting along several of the faults in the area and, (ii) the nature of bedrock and fault deformation near the A7 site and within the Makaroro River gorge.

As part of this report the authors undertook a field reconnaissance of the new A7 Makaroro damsite area and surrounding region on September 20-21, 2011. The first day focused on assessing the location, sense of movement, and activity of the Wakarara Fault. The second day was spent in conjunction with Bernard Hegan of T&T looking at bedrock relationships in proximity to the proposed site during two river traverses in the Makaroro River gorge. This was focused toward better understanding possible features of secondary deformation proximal to the dam site.

A second one-day reconnaissance trip was undertaken by the lead author on 14 October, 2011 to visit a trench excavation on the true left side of the Makaroro valley on Smedley Station. The trench was excavated by T&T to investigate the possibility of (and timing of) active secondary deformation adjacent to the proposed dam site. That trench is not discussed in detail in this report.

4.0 PRIMARY FAULT DEFORMATION

This chapter includes summary information from published and unpublished studies of active faults and deformation within 10 km of the new A7 damsite, including observations and photographs from our field reconnaissance trips (Figs. 1.5, 4.1). Many of these observations were presented in Langridge and Villamor (2011). The new work undertaken for this report focuses on: (i) estimating the single-event vertical displacement for the Mohaka Fault; (ii) confirming the activity of the Wakarara Fault; and (iii) identifying important active faults in the area, out to a distance of 10 km from the A7 site.

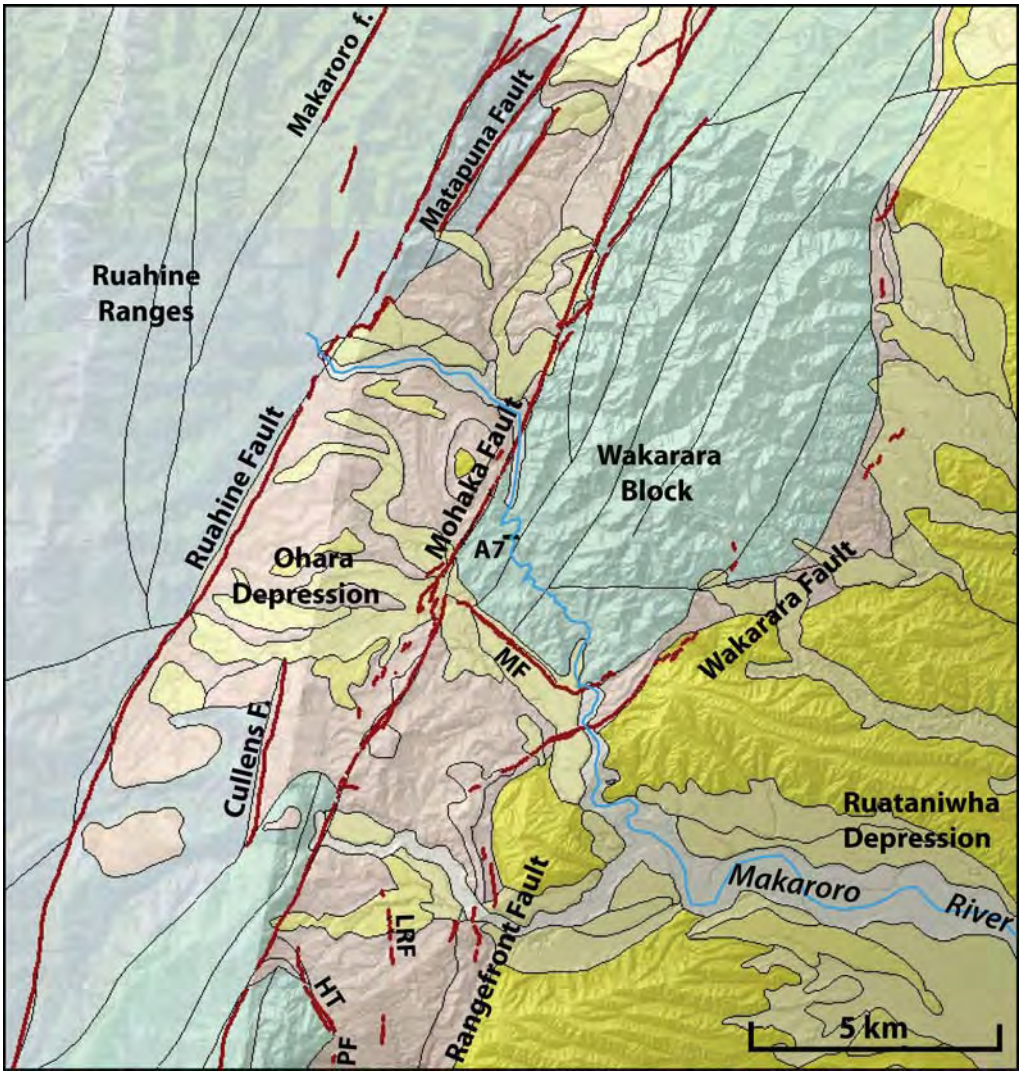


Figure 4.1 Known active faults mapped in this study (red) and inactive faults (thin black lines) within 10 km of the proposed A7 scheme. Geology from 1:250,000 scale QMap (Lee et al. in press). Abbreviations: HT, Hinerua Thrust; PF, Pukenui Fault; LRF, Lookout Road Fault; MF, Mangataura Fault. The A7 dam site is sited within the Wakarara Block (blue; greywacke) between the Mohaka and Wakarara faults.

4.1 Mohaka Fault

The Mohaka Fault is a NNE-striking active right-lateral strike-slip fault that runs through the entire length of the Hawke's Bay region (Figs. 1.3, 1.5, 4.1; Beanland 1995). The Mohaka Fault, along with the Ruahine Fault, comprise the main faults within the western strand of the North Island Dextral Fault Belt (NIDFB) within the central sector of the eastern North Island (Fig. 1.2). The Mohaka Fault is the northern continuation of the Wellington Fault (Beanland 1995; Langridge et al. 2005). North of Hawke's Bay region the Mohaka Fault becomes the Whakatane Fault and merges with the Taupo Fault Belt offshore in the Bay of Plenty (Fig. 1.2; Mouslopoulou et al., 2007; 2009).

4.1.1 Seismic hazard parameters

The Mohaka Fault occurs at a distance of c. 700 m from the proposed A7 dam site so it is important to state the seismic hazard that it poses. Slip on the Mohaka Fault is characterised by dominantly right-lateral motion. Where the fault is observed, it has a steep (c. 85° dip) to the northwest (Beanland 1995). Regional estimates of the dextral slip rate range from 4.8 ± 2.4 mm/yr (northern Hawke's Bay; Beanland 1995) to 3-5 mm/yr near Dannevirke and the Big Hill area (Langridge, unpublished data; Litchfield et al., 2011). Raub et al. (1987) present a rate of 3 mm/yr for the Mohaka Fault in the Wakarara area, and 3.5-4 mm/yr to the north along the Mohaka River. Sites which aid in the estimation of single-event displacement (SED) along the Mohaka Fault are sparse. Along the southern part of the Mohaka Fault the smallest displacements measured are c. 5 ± 1 m (Marden 1984). This is comparable to estimates of single-event displacement (4.5 ± 1 m) on the northernmost section of the Wellington Fault (Langridge et al., 2005). Raub et al. (1987) present a single-even displacement estimate of 3.5 m. For this study we use the ranges 4 ± 1 mm/yr and 4.5 ± 1 m for the horizontal slip rate and single-event horizontal displacement, respectively.

Based on these slip rate and SED estimates, the average recurrence interval of faulting is c. 1125 yr (700-1830 yr). There have been several paleo-earthquake trenching studies undertaken along the Mohaka Fault. Raub et al. (1987) describe trenches near Wakarara and at Te Hoe in northern Hawke's Bay. The former site provides evidence for a single surface rupturing event since c. 1165 ± 50 yr before present (BP). The trench at the Te Hoe site provides evidence for 2 surface-rupturing earthquake during the last 1800 yr (i.e. since deposition of the Taupo Pumice). These two observations are consistent with a recurrence interval of c. 1000 yr. There are three other paleoseismic studies that have been undertaken along the Mohaka Fault since 1998, but this data remains largely unpublished (e.g. Hanson 1998). These studies find generally similar results to those listed above. At least along the southern part of the Mohaka Fault, it appears that the most recent faulting event occurred c. 300 yr ago (Hanson 1998; Langridge, unpublished data).

The Mohaka Fault is well-expressed on LiDAR and aerial photographs within 10 km of the A7 dam site (see Fig. 4.3). It is typically expressed by a clear, straight to slightly sinuous fault trace between Alder Road, near the Hinerua Thrust and Mangleton Road within the Gwavas forest. The fault can be mapped crossing hillslopes and alluvial terraces. In detail, the fault is often identified by an uphill-facing scarp that causes ponding to occur along the fault trace. Displaced streams are common along the fault trace. Many of the larger hillslope streams show total dextral displacements of c. 30-40 m (Beanland 1995; Fig. 4.2), indicating that

there have been repeated movements along the fault during the late Pleistocene to Holocene (c. last 20 kyr). During our field reconnaissance we located one site on Rangimarie Station which may indicate repeated dextral displacements of c. 4 m per event (NZMS 260 U22/899544).

Figure 4.2 Uphill-facing scarp of the Mohaka Fault on Rangimarie Station, marked by red arrows. At this locality a ponded basin has formed behind the scarp and the original drainage has been displaced from its source by 27-37 m. Rounded to conical hillocks of greywacke occur on the east (far) side of the fault trace. The dashed line shows an example of profiles that were constructed from the LIDAR DEMs to estimate vertical SED, i.e. the line represents the fall line of the offset ridge.

While the fault has been mapped in a general way for QMap at 1:250,000 scale (Lee et al., in press), the LiDAR DEMs have allowed us to better define the location and complexity of the fault pattern on the ground (see Fig. 4.2; Appendix 1). For example, an important observation in the Wakarara area is that the fault bifurcates to the south of the village near Pebbly Hill No.2 (U22/882499) and steps to the left, creating a stepover of width up to c. 500 m south of Mangataura Stream. This western trace forms a single scarp across most of Rangimarie Station, but bifurcates again in the southern part of the Gwavas Forest. These observations indicate that the faulting is more complex than has been previously mapped and that the zone of deformation may be wider than previously considered.

4.1.2 Vertical slip per event

An estimation of the single-event vertical displacement for a surface rupture on the Mohaka Fault is an important undetermined parameter for the A7 dam site. Such an estimate can be used to assess the effective vertical shift in water in the reservoir during an earthquake displacement event on the Mohaka Fault. Despite the recognition of potential single- (4.5 ± 1 m) and multi-event (c. 30- 40 m) dextral displacements, the single-event vertical displacement for the Mohaka Fault cannot easily be measured in the field.

An estimate of the vertical SED on the Mohaka Fault can be assessed near the dam site on Rangimarie Station (Fig. 4.3), where the strike-slip component of slip is well expressed.

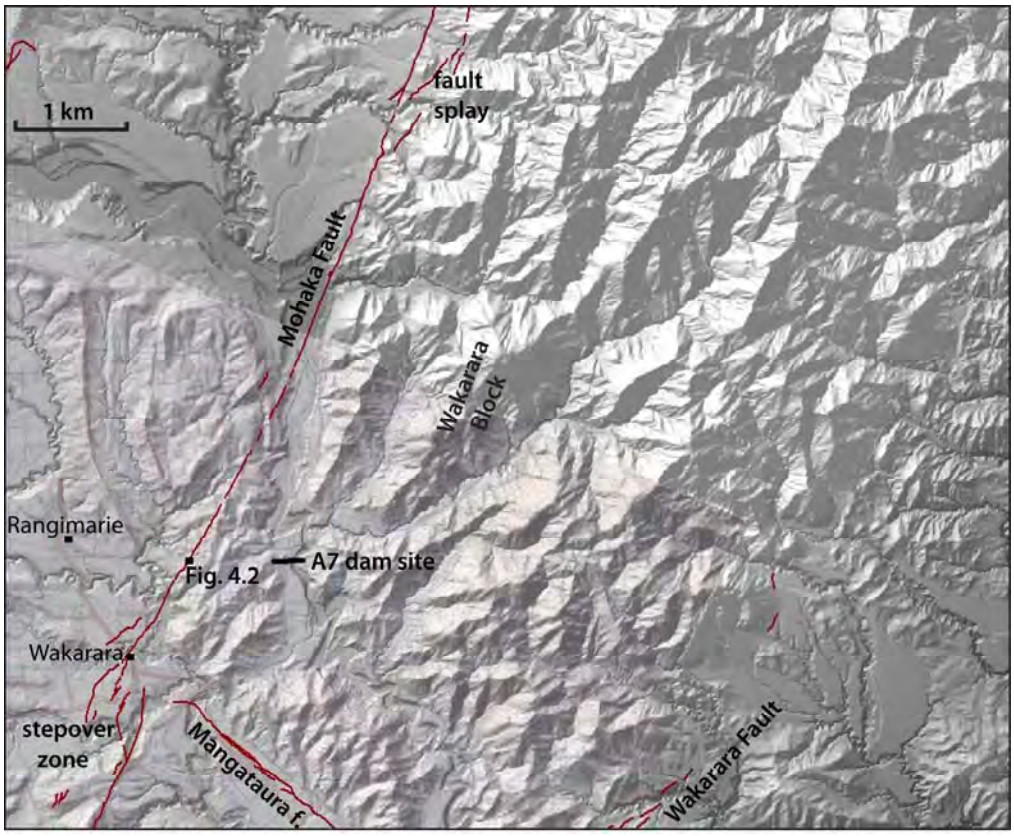


Figure 4.3 LiDAR DEM emphasising the mapped trace of the Mohaka Fault near the A7 dam site, which is typically characterised by a single straight trace. However, fault complexities including a small stepover zone and fault bifurcation (splay) are identified. Profiles used to develop vertical SED estimate occur on Rangimarie Station between Fig. 4.2 and the Makaroro River.

There, it is possible to estimate the vertical SED using the ratio between: (1) the single- and multi-event dextral displacements; and (2) the total vertical height change across the fault related to an equivalent number of dextral displacements. The former can be thought of as the number of distinct earthquake displacements that have led to a large geomorphic displacement in the landscape. The latter is the ratio between the total vertical and horizontal slip for the same time period. From this the H:V (horizontal to vertical slip) ratio can be calculated. The relative single-event vertical displacement can be estimated based on these parameters. Typical H:V ratios for strike-slip faults in New Zealand are up to 10:1 or even »10:1 (e.g., Berryman 1979; Ota et al., 1981).

In this study we have used the LiDAR DEM to create topographic profiles across the Mohaka Fault at a number of places along the fault to estimate the vertical SED. Seven dog-legged profiles were constructed between south of the main Rangimarie farm access road and the Makaroro River in the north. Six of the dog-legged profiles follow ridgelines/spurs perpendicular to the fault, then parallel the fault and finally run perpendicular to the fault along the short axis of shutter ridges, which are the offset equivalents of the spurs. These sites are also good paleoseismic trenching sites (see Fig. 4.2). The other profile traverses a high, faulted alluvial terrace adjacent to the Makaroro River.

Contemporary fault scarps reflect the relative vertical movement across the Mohaka Fault. In each profile we have restored the strike-slip movement on the fault by back-slipping the dextrally offset landscape features using the profiles. This allows us to restore landscape features to their original locations prior to displacement and to assess their actual vertical movement since the contemporary phase of strike-slip movement. The vertical displacement is measured by restoring hillslope (and terrace) surfaces to their expected height/location.

Table 4.1 Horizontal and vertical slip data for the Mohaka Fault on Rangimarie Station

Profile	H_{min} (m)	H_{max} (m)	V_{min} (m)	V_{max} (m)	H:V range
1	38	42	6.5	7.5	5-7
2	26	28	0.75	1.5	17-37
3	28	32	4.8	5.8	5-7
4	46	50	3	3.5	7-13
5	55	61	5.6	9	6-11
6	44	52	12	16	3-5
7	34	36	0.2	0.4	85-180
Average of P1-6	*40*	*44*	*5.4*	*7.2*	*6–8*
Average of P1-7	*39*	*43*	*4.7*	*6.2*	*6-9*
# of events	7-11	8-13			
V SED range (7-13 events)			0.36-0.42	0.89-1.0	0.36 to 1.0 m

Table 4.1 presents the results of these measurements including calculations of H:V ratios. The average estimated dextral offset along this stretch of the fault is 39-44 m. This amount of offset is most likely the result of displacement since the end of the last cold climate period when the landscape was in a colder, wetter climate regime compared to today. Since that time (essentially the Holocene), new streams have become established into the 'reset' hillslope surfaces, and displacement of those streams, and intervening spurs has been able to accumulate. In the previous section we used a range of 3.5-5.5 m for the single-event dextral displacement along the Mohaka Fault. Based on these estimates, we infer that there have been 7-13 earthquake displacement events on the Mohaka Fault since the landscape has been reset.

The total vertical displacement related to this suite of dextral displacements is in the range 4.7-7.2 m. All seven profiles have a west-side-up sense of relative vertical movement on the fault, which is consistent with the steep, west-dipping structure of the Mohaka Fault in this area. The ratio between horizontal and vertical slip (H:V) for the Mohaka Fault based on these measurements is 5.6-9.1. This ratio is low for typical strike-slip faults (H:V »10), but not atypical for strike-slip faults in New Zealand (H:V c. 10), where a component of transpressive behaviour is common. The vertical slip per event based on this H:V ratio and the dextral slip

per event based on 8-11 Holocene displacements is therefore 0.4-1.0 m. This range could encompass the expected vertical displacement per event of the Mohaka Fault to across the floor of the reservoir. Raub et al. (1987) present an H:V ratio of c. 5 and a single-event movement of 3.5 m for the Mohaka Fault, which produces a vertical SED of 0.7 m/event. This is implicitly similar to the central value of our result as it uses mean values.

Profile 7, adjacent to the Makaroro River is the most anomalous of the seven profiles and its H:V ratio. This profile shows a west-side-up height difference across the fault zone of 0.2-0.4 m with respect to the top of the high alluvial terrace there. This measure of vertical movement occurs in association with a dextral offset on the riser cut against this terrace of c. 34-36 m. This produces an H:V ratio of 85-180, and a therefore an estimated vertical single-event displacement range of c. 0.02-0.05 m, i.e. essentially pure strike-slip.

These preliminary results shows that further analysis may be required, as the maximum vertical single-event displacement may be close to 1.0 m, while the minimum possible vertical displacement may be close to zero. It may also be important to consider the effect of strike-slip displacement across the reservoir. In such a case, we estimate a dextral movement of 4.5 ± 1 m across the sidewalls of the reservoir and therefore the water mass in the reservoir. This could have the same or greater effect in terms of creating seiche wave movements within the reservoir.

4.2 Wakarara Fault

4.2.1 Previous work

Based on mapping using the available LiDAR coverage, the previous GNS report by Langridge and Villamor (2011) suggested that the Wakarara Fault is a potentially active fault occurring at the eastern margin of the Wakarara Block, which would dip underneath the Makaroro River dam site. Therefore, an important new component of this report is to undertake field reconnaissance on the Wakarara Fault to assess whether it is active and to assess its activity, style of slip and fault dip. Based on previous work this structure is inferred to be associated with a reverse fault that accommodates shortening at the front of the range. The surface trace of the Wakarara Fault is at least 3.5 km from the A7 dam site.

The Wakarara Fault replaces the name Wakarara Monocline of Raub (1985). The Wakarara Fault is a NNE-striking, range-bounding reverse fault characterised by greywacke to the NW and Tertiary rocks to the SE of the fault. In this report, we have distinguished the Wakarara Fault as being distinct from the Rangefront Fault. The faults are also split for the purposes of creating fault sources for the estimation of acceleration response spectra presented later in this report. Other previous workers have recognised the Wakarara Fault as a structure associated with folding and/or faulting (Kingma 1957; Raub 1985). The Wakarara Fault is defined as a distinct fault from the point where the Wakarara, Rangefront and Mangataura faults meet, i.e. near the eastern end of the Makaroro gorge. On the LIDAR DEMs, the fault trace is discontinuous and displays scarps of up to 1-2 m height in places (Langridge and Villamor 2011).

The fault trace as mapped on the LiDAR hugs the rangefront of the Wakarara Range and it bends upvalley at Poporangi Stream. This indicates that the sense of movement is reverse, characterised by uplift of the Wakarara Range. There are no indications at present that this fault produces a strike-slip component of deformation. The dip of the fault has not been measured directly but is considered to be moderate to shallow (c. 30-45°) to the NW. The Wakarara Fault typically crops out 5 km to the SE of the Mohaka Fault. Models of fault movement that will be discussed later suggest that these faults must therefore converge at shallow crustal depths. As currently defined, the Wakarara Fault is c. 15 km in length.

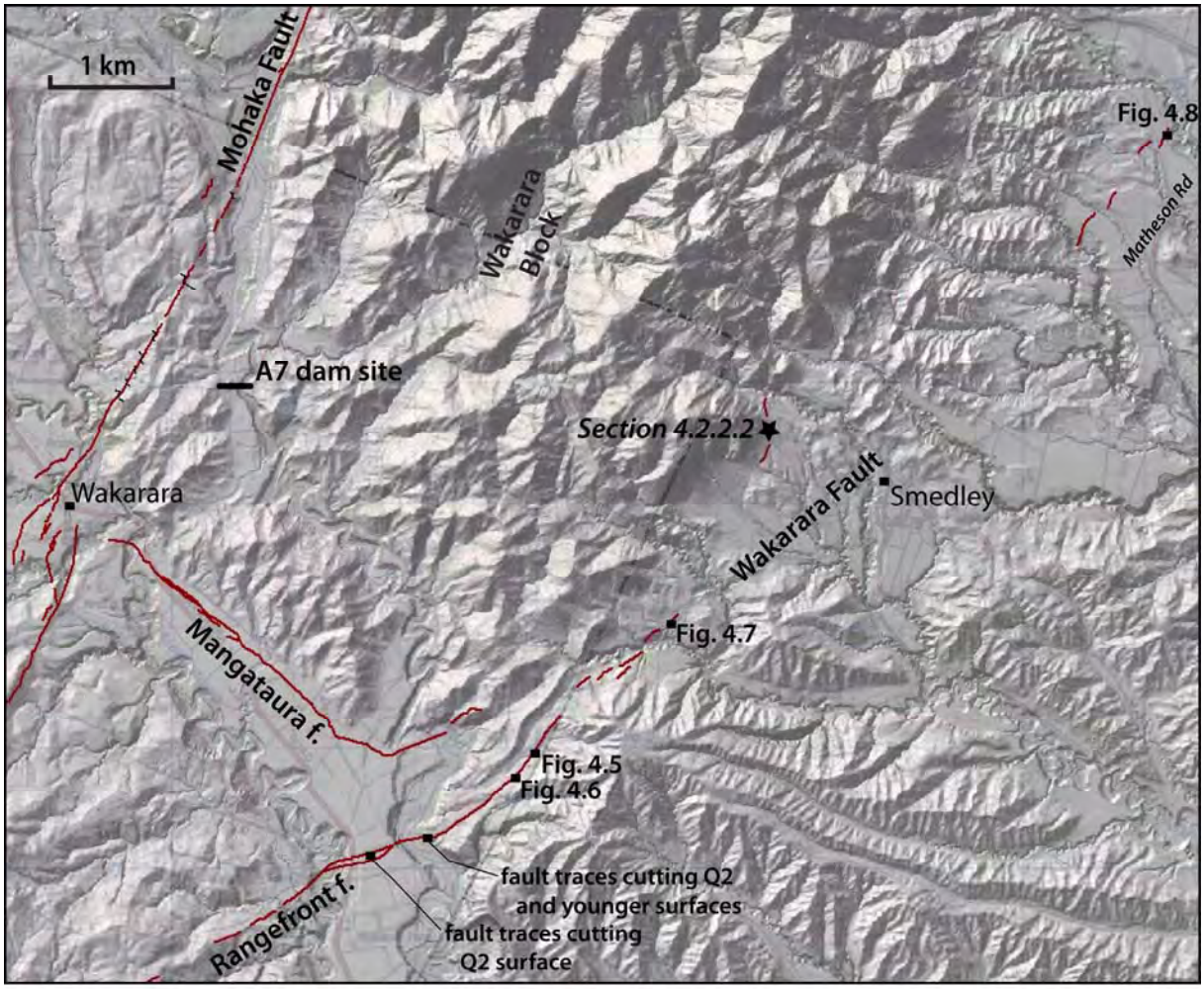


Figure 4.4 LiDAR DEM emphasising mapped traces of the Wakarara Fault visited during this study. Fault traces are not typically continuous along their length.

4.2.2 Field reconnaissance

From GIS mapping onto the LiDAR DEMs, Langridge and Villamor (2011) presented the locations of several possible fault traces along the eastern rangefront of the Wakarara Fault. The purpose of our recent field reconnaissance (20 September, 2011) was to check the validity of these traces on the ground and therefore, determine whether the Wakarara Fault is active. The following sections represent three areas over a length of 9 km along the southern half of the fault where fault traces were investigated.

4.2.2.1 South part of Smedley Station

The first part of our reconnaissance investigated possible fault traces northeast of the fault junction between the Rangefront, Mangataura and Wakarara faults in the southern part of Smedley Station. A semi-continuous trace mapped on the LiDAR was confirmed as an active fault trace in the field (Figs. 4.4, 4.5). At the southern end of Smedley Station this fault trace occurs to the east of folded Tertiary limestones and mudstones (Lee et al., in press) and appears as an uphill-facing scarp against west-facing hillslopes (grid ref. U22/931509). The straight trace pattern is indicative of a steeply-dipping fault plane in this area.

Toward the Makaroro River, this NNE-striking fault trace bends to the SW and crosses two prominent alluvial terraces. On the LiDAR DEM a WSW-striking fault trace cuts a high terrace at c. 390 m a.s.l. and an intermediate (degradation) terrace at c. 369 m a.s.l. The river is at an elevation of c. 345 m a.s.l. here.

Figure 4.5 View to the North of a small, uphill-facing scarp (marked by arrows) at the southern end of the Wakarara Fault on Smedley Station. The fault trace crosses topography without which implies that the fault is steeply-dipping here (See Fig. 4.4. for location; grid ref. U22/931509).

Active fault traces were observed in close proximity to the main Smedley farm road that heads towards the Makaroro River (grid ref. U22/940520). In this area several NE-striking, discontinuous and en echelon fault traces can be mapped parallel to the contact between Tertiary and Quaternary rocks at the edge of the Wakarara rangefront (Fig. 4.5). Tertiary rocks in this area are overlain by older Quaternary fan deposits that are truncated at their southeastern edge. We interpret this truncation as the margin of the zone of active deformation associated with the Wakarara Fault there.

Figure 4.6 View to the north of NNE-striking uphill-facing scarp (marked by arrow) near the southern end of the Wakarara Fault on Smedley Station (See Fig. 4.4. for location; grid ref. U22/931509). This fault trace provides evidence of active faulting on a steeply-dipping fault plane.

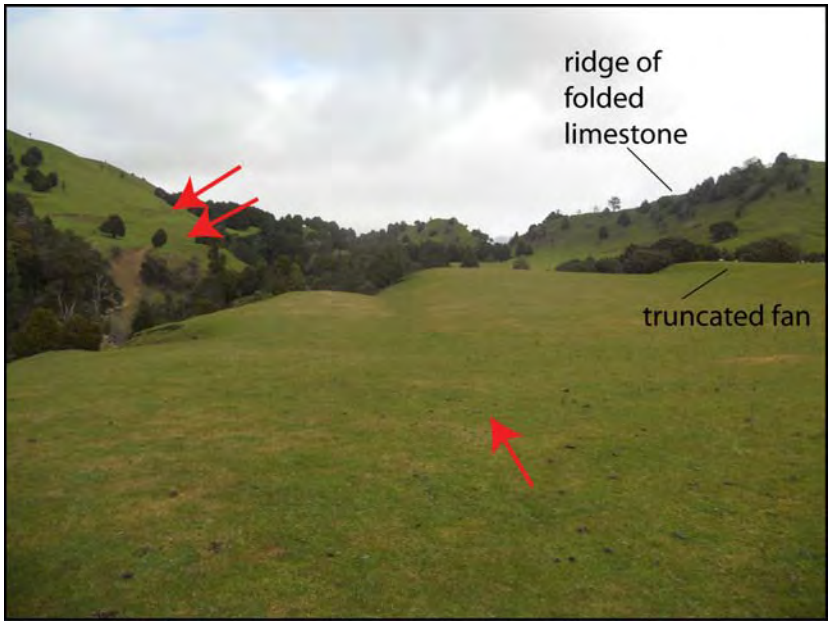


Figure 4.7 View to the south of zone of en echelon active fault traces (marked by arrow) at the southern end of the Wakarara Fault on Smedley Station. These fault trace crop out to the east of the folded ridge of limestone associated with the Wakarara Monocline.

4.2.2.2 West of Smedley Station

We visited two locations immediately west of the Smedley Station homestead area to investigate possible fault traces identified in Langridge and Villamor (2011). Traces at the rangefront near "The Tump" (grid ref. U22/950538) where an unnamed streams exit from the rangefront exhibit weak evidence of fresh, active fault traces. Active faulting may occur along this rangefront as seen from the steep hillfronts. However, these mapped traces are farther west than those described in Sections 4.2.2.1 and 4.2.2.3 and at a different contact within the bedrock geologic sequence (Lee et al., in press). This may indicate that there has not been a recent faulting event (<125,000 yr) along this bedrock geologic contact.

4.2.2.3 West of Matheson Road

We visited a stretch of the Wakarara Fault at the edge of the Wakarara Block, c. 0.5 km northeast of Matheson Road (grid ref. U22/980550) where active fault traces were identified on the LiDAR DEMs in Langridge and Villamor (2011). Several NE-striking, en echelon active fault traces were identified in the field in this area. The most prominent of these traces is NNE-striking and exhibits a c. 1-1.5 m high SE-facing scarps that traverse a high late Quaternary alluvial surface (Fig. 4.6). We interpret this surface to be a Q2 alluvial or fan surface, which has an implied age of c. 15,000 ± 3000 yr. These traces occur to the east of the Torlesse greywacke of the Wakarara Range and approximately at the mapped contact between Tertiary rocks and Quaternary deposits (Lee et al., in press). Based on their morphology, the scarps adjacent to Matheson Road are probably indicative of moderate to low-angle reverse faulting because they face away from the Wakarara Range to their west (Fig. 4.8).

Figure 4.8 View to the north of a fault scarp (marked by arrow) west of Matheson Road (See Fig. 4.4. for location; grid ref. U22/982560). The 1-1.5 m high scarps displace a surface here (green paddock) which is correlated to the Q2 alluvial surface.

4.2.3 Wakarara Fault Summary

Evidence from features identified on LiDAR DEMs and visited during the field reconnaissance confirm that the Wakarara Fault is an active fault. In addition to possible fault traces identified on the LiDAR and confirmed in the field, several new, previously unidentified traces were located in the field south of Smedley Station and have been mapped onto the LiDAR (see Fig. 4.4).

The active fault traces occur near the contact between folded Tertiary rocks near the Torlesse greywacke rangefront of the Wakarara Range, indicating that faulting is focused at the eastern margin of the Wakarara Block and also involves Tertiary bedrock. Fault scarps cut across late Quaternary surfaces indicating the fault has ruptured during the last c. 18,000 yr or less. In the south, the fault appears to have a steep dip, where the fault approaches the junctions with the Rangefront and Mangataura faults. Farther north, where the fault is expressed at Matheson Road, east-facing fault scarps imply a moderate to low fault dip that probably reflects a reverse style of movement. While it is difficult to measure the fault dip, the dip direction of the Wakarara Fault is to the NW. This implies that the fault plane dips underneath the A7 damsite and that the Wakarara Fault would likely merge with the Mohaka Fault at depth.

Based on the height of fault scarps (1-1.5 m), and the assuming that faulted surface near Matheson Road is the Q2 (Ohakean) alluvial aggradation surface (15,000 ± 3000 yr), it is possible to estimate the vertical slip rate of the Wakarara Fault. These sites yield vertical slip rates in the range of between 0.06-0.12 mm/yr for the Wakarara Fault. This indicates that the last fault movement could have been during the last 10,000 yr, which poses the fault as a potential hazard to the A7 dam.

Alternatively, the scarp height may reflect only a single displacement event across the Q2 surface, i.e. only one faulting event since 18,000 yr ago or less. This would mean that the Wakarara Fault is a long recurrence interval fault. In such a case, if the faulted surface is as young as 12,000 yr, then the minimum recurrence interval would be c. 6000 yr.

The discontinuous nature of fault traces along the Wakarara rangefront is consistent with such a long recurrence interval. In addition, the discontinuous expression of active traces may hint at (in-part) blind faulting which causes folding of the bedrock within the Wakarara Range (or Block), east of the Mohaka Fault. The exact nature of the relationship Wakarara Fault compared to the Rangefront fault (discussed below) its active continuation to the south of the Wakarara Block, is not known at this time.

4.3 Rangefront Fault

The Rangefront Fault is an active reverse fault that is the along-strike continuation of the Wakarara Fault, southwest of the Makaroro River. The Rangefront Fault strikes NNE and can be traced for at least 42 km into the Manawatu region as an active reverse fault. Clear active traces of the Rangefront Fault can be mapped on the available LiDAR over a distance of c. 25 km. The scarps shown in Figure 4.9 were mapped as the “Hylton Fault” by Raub (1985). Vertical scarps are clearly associated with the Rangefront Fault between the Makaroro River and the Tukituki River headwaters, including Tukipo Stream. These fault scarps are preserved across likely Q2 (c. 15 ± 3 kyr), younger (Q1 = Holocene; <12 kyr) and older (Q3?;

24-59 kyr) terraces in these areas (Lee et al., in press). There are no indications at present that this fault has a lateral component of movement. The sinuous, multi-trace outcrop pattern of the fault as seen across flat terraces suggests that the Rangefront Fault has a low to moderate dip.

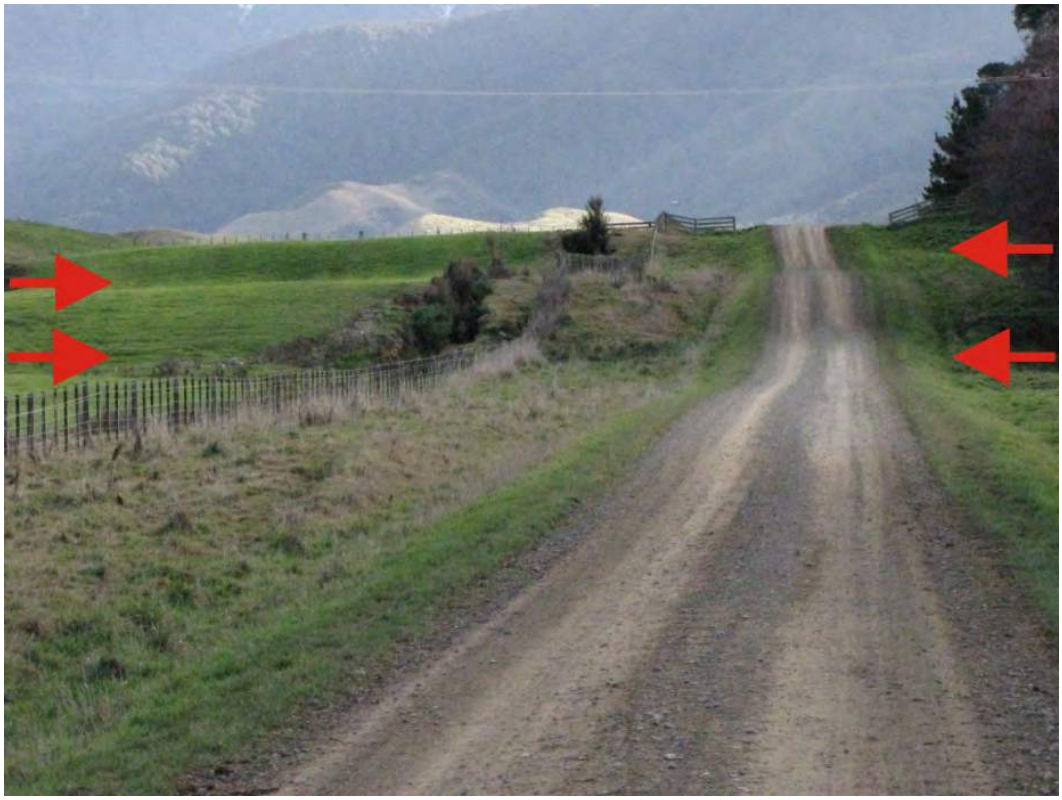


Figure 4.9 Four-metre high scarps of the active Rangefront Fault across Tukituki Road near the Ruahine Ranges (background). Here the fault is expressed as a double scarp across a probable Q2 or Ohakean (c.15 ± 3 kyr old) alluvial terrace. Photo is c. 12 km south of the A7 site.

Based on the height of fault scarps, and the age of the Q2 alluvial aggradation surface (15 ± 3 kyr), it is possible to estimate the vertical slip rate of the Rangefront Fault. At the Tukituki Road site (Fig. 4.9), the Rangefront Fault has a double scarp with an overall height of 4 m (Fig. 4.7). A broad, 2 m high scarp occurs at the Wakarara Road site at the northern end of the Rangefront Fault. These yield vertical slip rates in the range of 0.2-0.3 mm/yr, and 0.1-0.2 mm/yr, respectively for the Rangefront Fault. Scarps of 1-1.5 m in height along the Wakarara Fault are consistent with a lower slip rate compared to the Rangefront Fault.

4.4 Mangataura Fault

The Mangataura Fault was first identified by Kingma (1957) as an active fault that strikes SE from a junction with the Mohaka Fault into the Ruataniwha Depression near Springhill. The fault marks the boundary between greywacke rocks of the Wakarara Range and Tertiary marine rocks, to the south of it (Lee et al. in press). Kingma (1962) shows this fault as having an up-to the-NE sense of displacement. In this study, the Mangataura Fault is defined as a c. 4 km long, SE-striking fault that runs between the active trace of the Mohaka Fault and the Wakarara/Rangefront faults (Fig.4.4). The A7 dam site is at least 1.5 km from the trace of the Mangataura Fault.

From our preliminary field reconnaissance, we suspect that the Mangataura Fault has a sinistral (left-lateral) sense of movement. Geomorphically, the fault is defined by a broad (5-10 m wide and 2-4 m high) linear zone of deformation exhibited across a probable Q2 alluvial surface (Fig. 4.10). Near its southeastern end, the fault crosses younger terraces of the Makaroro River, where the vertical height of the scarp is smaller (c. 1-2 m). The sense of motion on this fault is difficult to assess, but near its southeastern end, we identified a potential left separation in a young terrace riser. In addition, the straight to sinuous bulged trace of this feature appears to indicate a strike-slip sense of motion.

Figure 4.10 View to the southeast along the scarp of the Mangataura Fault from Wakarara Road. The fault is characterised by a series of stepping mound-like surface traces up to 2 m high and 10 m wide (shown by red arrows and highlighted by power pylons) across a probable Q2 surface. Greywacke slopes of the southern edge of the Wakarara Block are just visible at left.

The left lateral sense of movement on the Mangataura Fault is consistent with the right-lateral mode of shear for the Mohaka Fault and sub-parallel faults in the NIDFB, as well as with reverse movement on the Wakarara and Rangefront faults. The dip and dip direction of the plane of the Mangataura Fault are not known at this time, but we suspect is has a steep dip. The fault also represents a boundary between greywacke of the Wakarara Range to the north and Tertiary rocks to the south.

4.5 The Ruahine Fault and faults in the Ruahine Range

The Ruahine Fault is an active dextral strike-slip fault that is located c. 4 km northwest of the

Mohaka Fault and at least 4.7 km from the A7 dam site. These two faults are the main structures in the western strand of the NIDFB. In this area the faults bound a thin block which is filled by Tertiary marine rocks known as the Ohara Depression (Figs. 1.5, 4.1). The Ruahine Fault has a Holocene slip rate of 1-2 mm/yr and an estimated range of dextral single-event displacement of 2-5 m (Beanland and Berryman 1987).

Two other faults are recognised in close proximity (1-2.5 km) to the Ruahine Fault north of the A7 site. These faults have been named the Matapuna and Makaroro faults in the GNS Science Active faults database (http://data.gns.cri.nz/af/). The Matapuna Fault is a 5.3 km long, NNE-striking fault that occurs 1 km to the east of the Ruahine Fault, within the Ohara Depression (Raub 1985). The fault is believed to be active, however, no active fault data (single event displacement, slip rate, earthquake event timings) is available for this fault at this time. The GNS Active Fault database shows a further trace akin to the Ruahine-Matapuna faults occurs another 700 m east of the Matapuna Fault (Figs. 1.5, 4.1).

The Makaroro Fault is a splay of the Ruahine Fault and occurs in the headwaters of the Makaroro River within the Ruahine Ranges (Fig. 4.1). The Makaroro Fault is a NNE-striking fault defined by a c. 9-12 km long zone of left-stepping fault traces that diverge from the Ruahine Fault. The Makaroro Fault is considered to be active, however, no active fault data is available at this time.

4.6 Other faults

In the wider area surrounding the Makaroro River catchment and within 10 km of the A7 dam site, there are several other active faults that have been mapped in previous studies and have been confirmed by Langridge et al. (2010) (see Figs. 1.4, 4.1). These faults are not likely to cause a displacement hazard to the A7 damsite, but are mentioned here as further background regarding active faults that occur near the A7 damsite. An obvious reason to document all of the active faults in the region is to understand whether shorter, probably lower slip rate and longer recurrence interval faults, e.g. Cullens and Pukenui faults that occur within major tectonic blocks such as the Ohara Depression or Wakarara Range can have demonstrable levels of activity. These faults and those described in the preceding paragraphs may be relevant to the A7 dam site if primary fault displacements on these faults cause secondary displacements at, or near, the A7 site.

4.6.1 Cullens Fault

The Cullens Fault is a 4 km long, north-striking fault situated between the Mohaka and Ruahine faults at the southern end of the Ohara Depression (Fig. 4.1) (Raub 1985; Raub et al., 1987). The Cullens Fault has been identified as an active fault in the GNS Active Faults database. The fault may be active, however, there is no data that currently documents this remote fault as having late Quaternary activity (Raub 1985).

4.6.2 Hinerua Thrust and Pukenui Fault

The Hinerua and Pukenui faults occur c. 10 km south of the A7 dam site at the eastern edge of the Ruahine Ranges (Figs. 1.5, 4.1). The Hinerua Thrust was identified by Raub (1985) as an active, NNW-striking fault that bounds the northern end of a narrow tectonic sliver of

greywacke adjacent to the Mohaka Fault near Alder Road (Fig. 4.1). Greywacke of Folgers Hill marks the rangefront of this short (3 km) fault trace. The active trace of the Hinerua Thrust shows down-to-the-south motion (Raub et al. 1987).

The Pukenui Fault was first shown by Kingma (1962) and recognised during reconnaissance mapping reported in Langridge et al. (2010) (Figs. 1.5, 4.1). Raub (1985) refers to this Tukituki Thrust[1]. The Pukenui Fault is an active fault zone between the Mohaka and Rangefront faults in southern Hawke's Bay. The fault extends southward from the eastern end of the Hinerua Thrust. At least two traces observed on LiDAR imagery were confirmed as active faults by Langridge et al. (2010).

The Pukenui Fault is an active fault that is parallel to the tectonic fabric of the western strand of the NIDFB (e.g. Wellington-Mohaka Fault) and occurs between the Mohaka Fault and the Rangefront Fault. In contrast, the Hinerua Thrust strikes oblique to the rangefront and appears to terminate the thin tectonic sliver formed by the Pukenui Fault. This is important as these faults may be indicative of the style and activity of faults and fractures within the Wakarara Block, adjacent to the proposed A7 dam site (Figs. 1.5, 4.1).

Using the LiDAR we have also identified a series of active fault traces that cross Lookout Road between the Hinerua Thrust and the Rangefront Fault. These traces are referred to here as the Lookout Road Fault (Fig. 4.1). The Lookout Road Fault is north-striking and produces west- and uphill-facing across Tertiary hill country. The strike and continuity of fault traces along this trend are similar to the many bedding attitudes measured in Tertiary rocks in this area (Lee et al., in press), i.e. bedding has attitudes that strike north and broadly vary across strike from the Hinerua Thrust to the Rangefront Fault.

4.7 Kinematic fault model of the A7 site area

In this section we present a model of fault motion (kinematic model) to explain possible interactions between the active faults identified in the vicinity of A7. Understanding the geometry and possible interactions of faults provide a basis for considering fault rupture hazards, including possible secondary faulting or other deformation on bedrock defects near the damsite. For this purpose, we have produced a map view of the potential interactions of key faults within 5 km of the A7 damsite (Figs. 4.11, 4.12), and a simple cross section perpendicular to the regional grain and through the location of the site (Fig. 4.13).

The proposed A7 damsite on the Makaroro River is located between three active faults and within the Wakarara Block, which is probably a block which suffers active deformation (Fig. 4.9). The Wakarara Block is a 4-5 km wide area of greywacke bedrock bounded by the Mohaka, Wakarara and Mangataura faults. These faults have right-lateral, reverse and left-lateral sense of movement, respectively.

[1] This name has not been adopted here because it has been used commonly for a fault zone in the lower Tukituki valley near Havelock North.

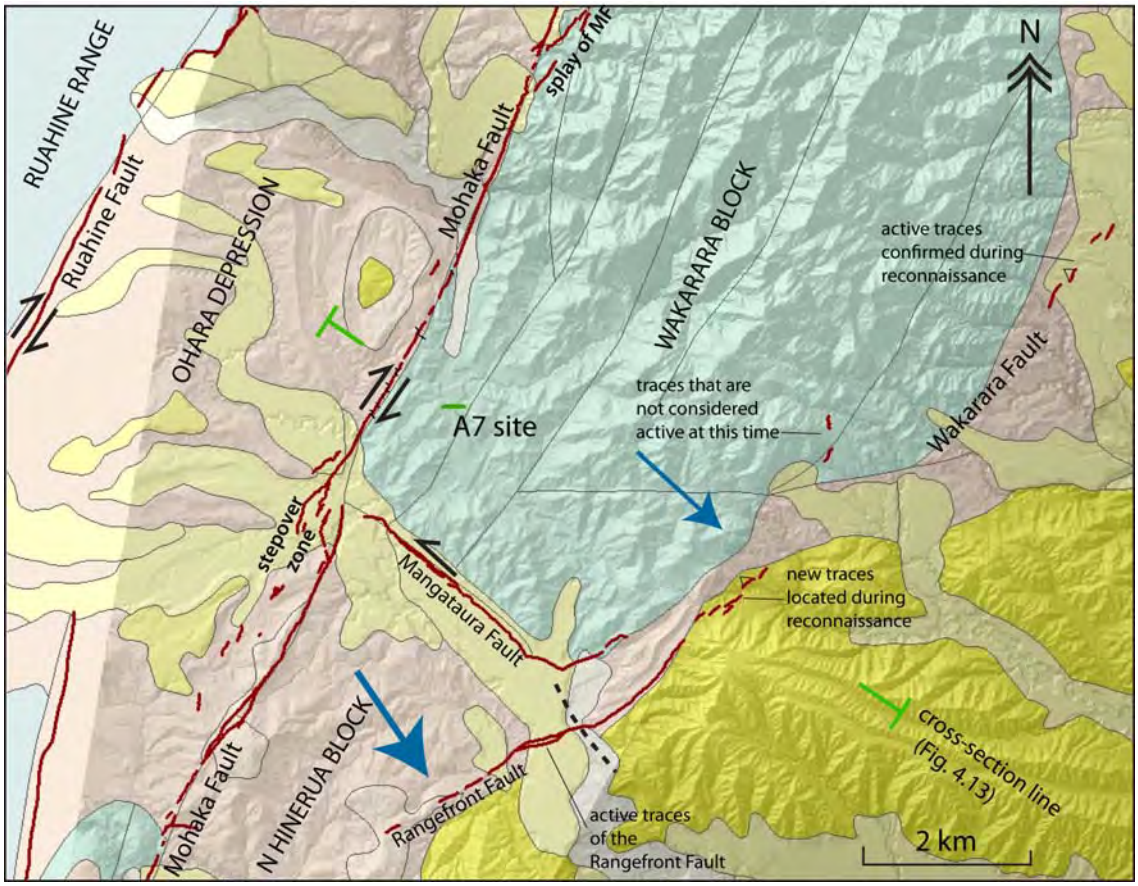


Figure 4.11 Simplified kinematic fault motion model involving the key active faults within 5 km of the proposed dam site. The dextral-slip Mohaka Fault is both the closest and most active fault to the A7 damsite. The Mangataura Fault is interpreted as a left-lateral (sinistral) fault. The sinistral motion (single black arrow) is explained if the reverse-slip Rangefront Fault is more active than the Wakarara Fault, which will cause faster SSE movement of the southern side of the Mangataura Fault compared with movement of the northern side (diagrammatically depicted by relative size of blue arrows). Black dashed line is arbitrary break between the Rangefront and Wakarara faults.

The Rangefront and Wakarara faults are along-strike equivalents of one another. Kinematically, it is apparent from our preliminary studies that the Rangefront and Wakarara faults have a similar strike and displacement style, but the former is probably more active, i.e. has a higher slip rate. This is based on the presence of larger fault scarps preserved across land surfaces that are probably of similar age (i.e. Q2, or Ohakean, aged terraces). The decrease in slip rate to the northeast could be explained by the presence of the Mangataura Fault, which may act as an accommodation zone between the North Hinerua Block and the Wakarara Block (Fig. 4.9). As the North Hinerua Block has a component of southeast motion accommodated through slip on the Rangefront Fault. Because this motion is at a greater rate than the Wakarara Block, then this brings about left-lateral movement on the Mangataura Fault.

A simplified fault and lineament map of the features that make up the complexities near the A7 site is shown in Figure 4.12.

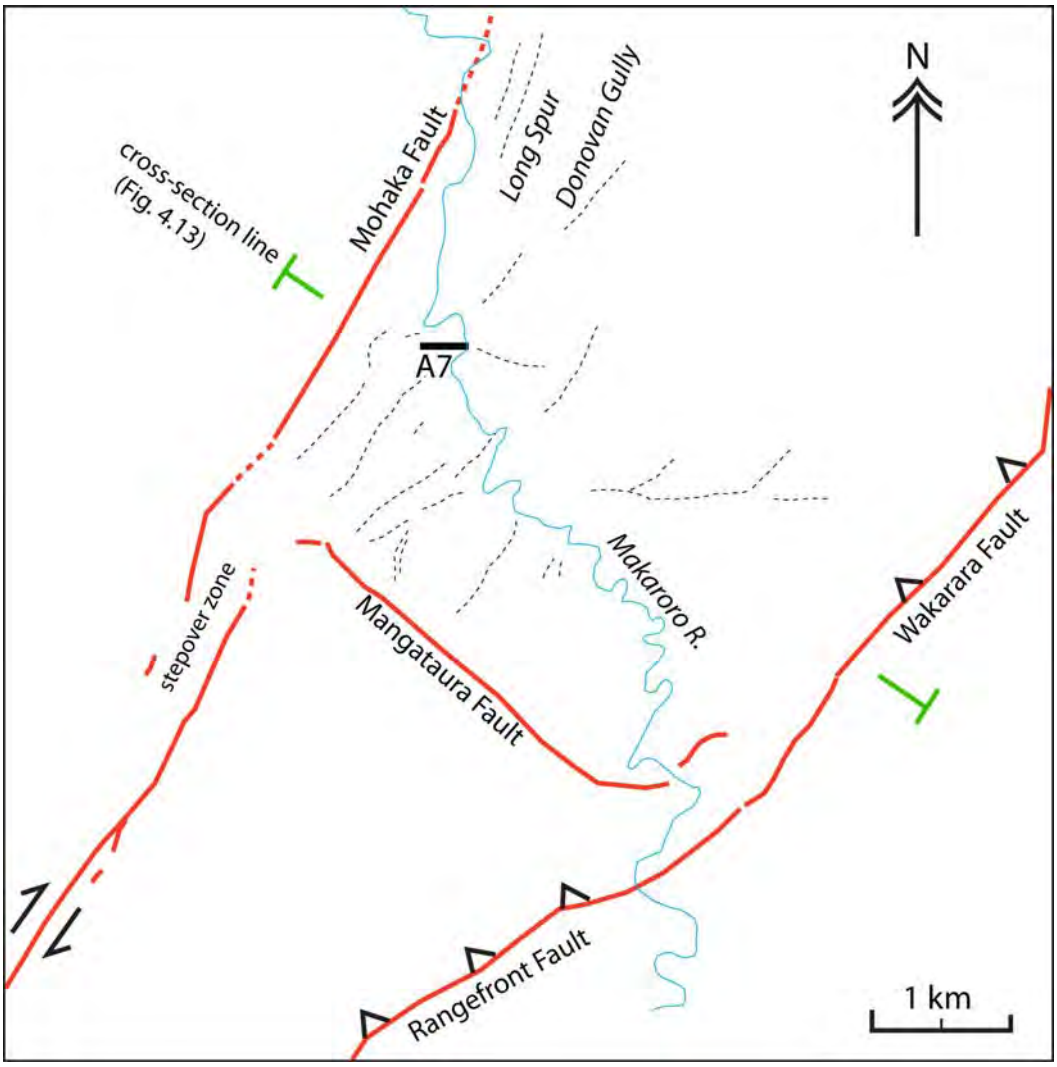


Figure 4.12 Simplified fault map including key active faults and lineaments within 5 km of the proposed A7 dam site.

The preliminary cross-section shown in Figure 4.13 includes the main structural elements. Projections of the linear, valley-forming NNE-trending structural grain in the Wakarara Range have been added to the cross-section, though the activity, dip and extent of these features are not known at this time. The zone of primary deformation associated with the Mohaka Fault is a c. 330 m wide zone of highly sheared rock. This is discussed in greater detail in Section 5 of this report. The Yeoman Syncline is a fold in Tertiary rocks on the west side of the Mohaka Fault (Kingma 1957).

The topography is consistent with continuing activity on the Wakarara Fault, with reverse slip producing uplift and deformation near the rangefront (Figs. 4.7, 4.8). Geomorphically, the Wakarara Range is higher and steeper toward its eastern front with elevations up to 600 m a.s.l. The topography is a little more subdued to the NW flank of the Wakarara Block because strike-slip movement on the steeply-dipping Mohaka Fault does not produce significant relief.

Based on a wide band of uncertainty from field observations and experience, three variations

for the possible dip of the Wakarara Fault have been used to assess the closest distance of the Wakarara Fault to the damsite (Fig. 10). These three angles are shallow (30°), moderate (45°) and steep (60°) for reverse-slip faults. The steeply-dipping option has been added to this report as it reflects the observations of steeply-dipping fault traces at the southern end of Smedley Station (e.g. Figs. 4.5, 4.6). Assuming the fault dip does not change in depth, the Mohaka and Wakarara faults would merge at depths of c. 2.5-3.0 km (shallow dip), c. 4.5-5.0 km (moderate dip), and c. 9 km (steep dip). While there is a large amount of uncertainty concerning the fault dip, from this data we can infer that the Wakarara Fault is at a minimum depth of c. 2.5 km depth beneath the new proposed A7 dam site.

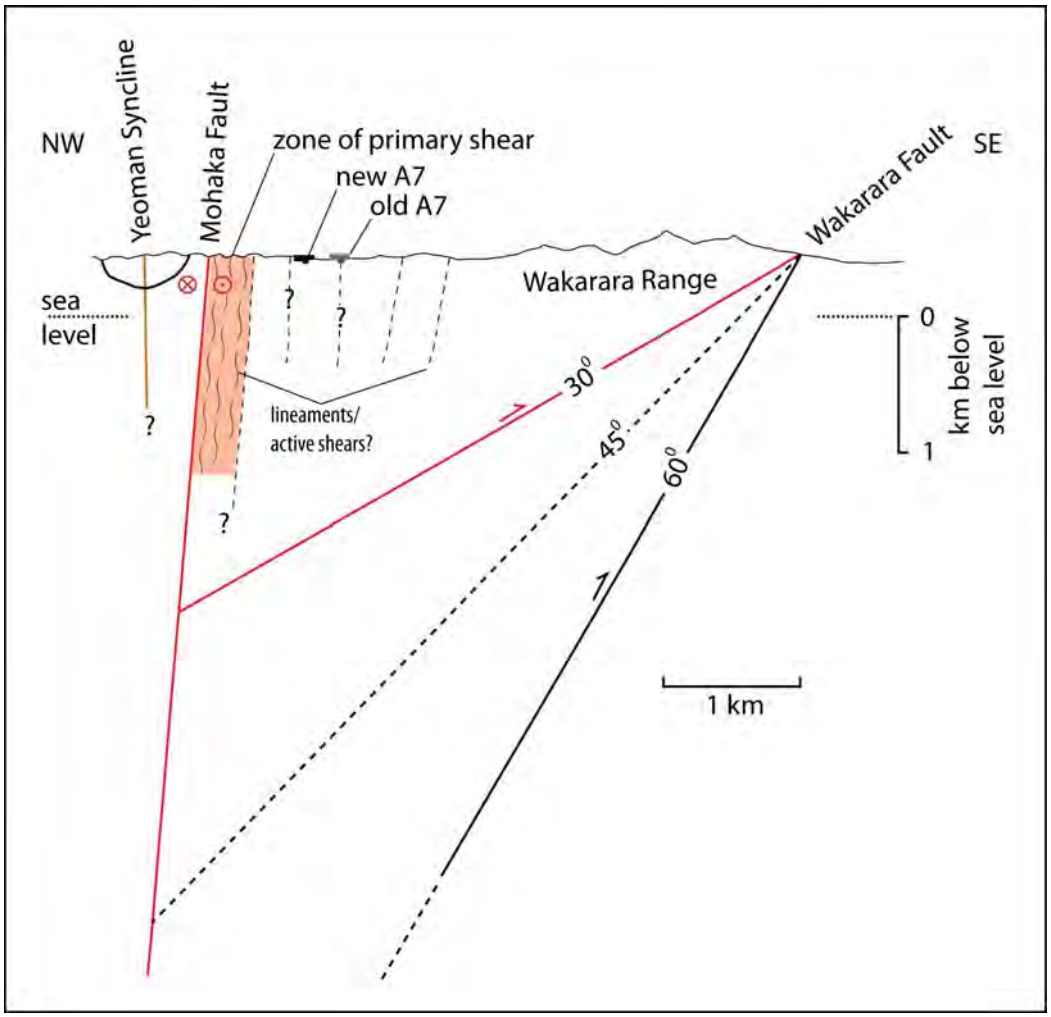


Figure 4.13 Simplified geologic cross-section running NW-SE through the proposed A7 dam site on the Makaroro River. Three models for the dip of the Wakarara Fault are shown. A series of geomorphic lineaments/valleys are marked in the vicinity of the Mohaka Fault and A7 site. Location of cross-section line is shown on Figures 4.11 and 4.12.

4.8 Summary of the location, size and timing of primary surface fault rupture deformation in the study area

Primary surface rupture deformation will take place along the traces of major faults. The closest faults to the A7 damsite are the Mohaka (c. 700 m distant), Wakarara (c. 2.5 km distant in depth based on Figure 4.13) and Mangataura faults (1.5 km distant).

With an average recurrence interval of c. 1000-1300 yr, the Mohaka Fault is the most likely fault to rupture, causing dextral displacements of 4-5 m along its main trace. Because of the presence of lineaments parallel to the Mohaka Fault in close proximity to the fault, it is important to try and constrain the likely width of primary deformation associated with rupture along this fault, to assess if primary rupture could extend toward, or, into the dam site area.

Individual ruptures will probably also occur on the Rangefront and/or Wakarara faults with a recurrence that is unknown at present, but likely to be many thousands of years. The size of co-seismic displacement of the Wakarara Faults is unknown at this time and should be constrained through geologic studies, such as paleoseismic trenching. Because of the possible interaction (merging) of the Mohaka and Wakarara faults at depth one possible rupture scenario for these faults must be that on occasions they could rupture simultaneously, or within a short time of each other.

The recurrence and displacement size of rupture along the Mangataura Fault is unknown. The fault could rupture individually or in association with rupture along the Mohaka and/or the Wakarara and Rangefront faults. This is considered possible because the scarp of the Mangataura Fault is more impressive than either the Wakarara or Rangefront faults. This may suggest that triggered ruptures on these faults could cause internal or block edge deformations near the A7 site.

Primary fault deformation can occur on a number of active faults within 10 km of the A7 damsite. These include the Mohaka, Ruahine, Wakarara, Rangefront, Mangataura, Hinerua (Thrust), Makaroro and Pukenui faults. Each of these faults could slip during a large earthquake sourced on these faults, or from triggered slip from a nearby fault source. The Cullens Fault has not been confirmed as an active fault at this time.

In terms of primary fault deformation the Mohaka Fault is the most important of these faults. The width of the zone of primary deformation associated with the Mohaka Fault (the fault zone) is shown in cross-section in Figure 4.11 (pink band) and described in the next section. The Wakarara Fault has been confirmed as an active fault from this study. Because it dips underneath the A7 damsite, the effects of primary displacement on the Wakarara Fault should also be considered in regards of vertical accelerations, or even through bending deformations within the Wakarara Block. Triggered slip on the Mangataura Fault is also a possible outcome of co-seismic rupture/slip on the Mohaka, Rangefront, and/or Wakarara faults.

5.0 POTENTIAL FAULT DISPLACEMENTS AT THE A7 DAM SITE (PRIMARY AND SECONDARY)

In this section we discuss the potential for primary and/or secondary rupture at the new A7 damsite focusing on new observations and insights from global rupture databases (e.g. Section 2). Firstly, we will present the aspects of the previous mapping undertaken by Langridge and Villamor (2011) on the nearby old A7 damsite (250 m south west of the current site) that are still relevant to the new site. Secondly, we will present the implications on primary and secondary displacements at the new site derived from that mapping, as well as the new mapping at 10 km radius from the site undertaken in this study (Section 4), and the literature review (Section 2). Thirdly, we will describe the reason to acquire new structural data along a transect from the Mohaka Fault towards the damsite along the Makaroro River and the likely implications for secondary faulting from the observations made. Finally we summarise all the results above.

5.1 Observations from Langridge & Villamor (2011) relevant to this study

There are important aspects of the results from our study of the previous location of the A7 damsite that are relevant to this new location. In terms of the potential for primary fault rupture at the site we stated that (Langridge & Villamor 2011, page 17):

> "The width of primary deformation associated with the Mohaka Fault must be considered to be proportional to the width (size) of fault complexities along the fault. In general, we observe a stepover zone SW of the damsite in the Wakarara area that is c. 330-450 m in width (Fig. 9 [on their report]). Four km to the north of the proposed A7 damsite, the Mohaka Fault bifurcates, so that deformation is split onto two sub-parallel traces. The width between these traces is c. 275 m, but this separation between the traces widens to the north to c. 1 km at the northern edge of the LiDAR coverage. Along the western boundary of the Wakarara Block, the Mohaka Fault is characterised by a single trace, adjacent to the proposed A7 site. Primary fault rupture of the Mohaka Fault is not likely to affect the damsite. However, because of the complexity of the fault trace further studies would be required to fully confirm the width of primary rupture."

Figure 5.1 shows those geological structures. The stepover zone to the SW of the dam site (location 1 on Figure 5.1), is in the vicinity of the intersection of the Mohaka Fault with the Mangataura Fault. The bifurcation (splay) in the Mohaka Fault (location 2 of Fig. 5.1), located 4 km north of the damsite, will be called the Mohaka Fault splay hereafter.

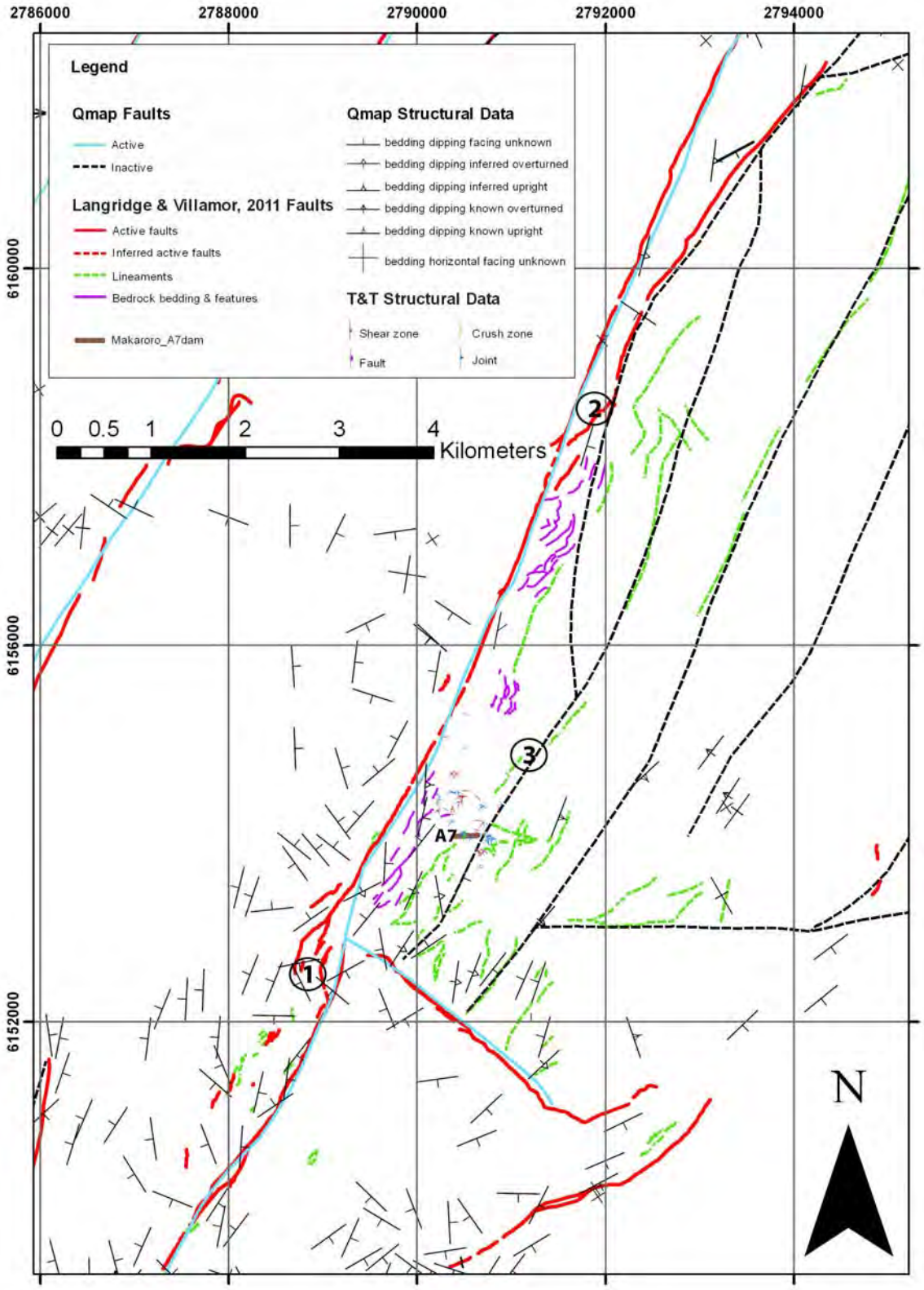


Figure 5.1 Map of active faults, faults, lineaments and bedding attitudes within 4 km of the A7 damsite (at centre). Attitude data comes from GNS Science QMap and Tonkin & Taylor. Numbered sites in circles refer to key deformation features that impact the A7 site, are discussed in the text.

The new site has a similar potential for secondary faulting as the previous location of A7 dam site. Langridge and Villamor (2011., p. 18), concluded that:

> "Primary rupture on the Mohaka and Wakarara faults may result in movement of weak planes in the greywacke rock mass at the damsite through:
>
> (i) Reactivation of old fault zones that are favourably oriented for displacement: These include both NNE to NE and E-W striking fault (shear) zones with strike-slip or reverse displacements, and E-W striking shear zones with strike-slip movement.
>
> (ii) Flexural slip or slip along basement beds: When rocks are folded sometimes brittle deformation (slip) can occur along favourably oriented bedding planes.
>
> (iii) Gravitational collapse: sometimes when tectonic blocks are uplifted, gravitational collapse can occur along favourably oriented weak planes (old fault or bedding planes) in the rock mass, along ranges and hills."

The definitions above (i), (ii) and (iii) can be regarded as secondary or distributed faulting as used in Section 2 of the current report and apply to the new site.

We also stated in that report that (Langridge & Villamor 2011, p. 20):

> "Some of the bedrock features, <1000 m from the active traces of the Mohaka Fault, show signs of possible activity and may require further investigation. For instance, in Donovan Gully (NZMS U22/910545), c. 850 m from the active traces of the Mohaka Fault and <500 m from the damsite, there are definitive NNE-trending linear features including uphill-facing topography that may be the result of recent movement along bedrock faults or bedding. This site was visited during our reconnaissance and the topography appears to be both linear and late Pleistocene to Holocene in age (younger than ~20 kyr). Also, on the true left bank of the Makaroro Station on Smedley Station we observed evidence for possible fault-parallel deformation that could persist close to the A7 damsite (e.g. near NZMS U22/ 909555). In this part of the Makaroro River valley a series of NNE-trending, bedding and river parallel spurs occur in the greywacke within c. 600 m of the Mohaka Fault above the east bank of the river. These observations offer the possibility that secondary deformation associated with the Mohaka Fault could persist out from the most active trace to distances of >0.5 km (the expected width of primary rupture based on observations presented above).
>
> Of significant importance is the fact that one of the NNE-striking geologic faults shown by QMap as being within the Wakarara Block extends right through the foundations of the A7 damsite. This fault is shown as an inactive geologic fault that runs along the length of Donovan Gully, though the site and continues to the SSW until it meets the Mangataura fault. The relevance of this fault is not known at this time. However, it raises the question that a fault has been mapped continuously across the Q2 alluvial terrace and through the site. This will require investigation to either confirm or deny the relevance/activity of this feature."

The new damsite is located 250 m northwest of the previous site that the previous paragraphs refer to. As such, it can also be affected by the same features described above. The damsite is located along the projection of one the lineaments mapped by Langridge & Villamor (2011) south of the damsite, which may continue into Donovan Gully (Location 3 in Fig. 5.1) north of the damsite. The possibility also exists that the QMap inactive fault mentioned above is closer to the site than portrayed on Figure 5.1, given the location accuracy of 250 m for faults mapped in the QMap series. As a reference, we have displayed the active traces of the Mohaka Fault mapped by QMap on Figure 5.1 (blue lines) to show that their locations could be up to 250 m in disagreement from the LiDAR based mapped features. This is because the resolution of their mapping is that of a 1:250,000 scale map.

5.2 Inferences on potential primary and secondary fault displacement and deformation at the damsite from the literature review and mapping

In this section we present the main points relevant to the new A7 site from the literature review, the results from the previous study (Langridge & Villamor, 2011) and new mapping undertaken in this study. The main aspects from those studies are:

- Literature review has shown that surface ruptures along strike-slip faults can be very complex (Section 2). Rupture of principal fault traces (primary rupture) can be either concentrated in a narrow simple zone, or be widespread within complex zones. In the complex zones, the main fault consists of parallel or oblique principal traces that can be separated by several kilometres (usually less than 4 km). Stepovers, bends and terminations of faults are typical complex zones (e.g., Fig. 2.5). Displacements along main fault traces during fault rupture are large, ranging from a few centimetres to several meters. Displacements of geomorphic features (e.g., stream channels) along the Mohaka Fault indicate that co-seismic displacements are on the order of c. 4.5 ± 1 m. Displacements associated with fault rupture are related to earthquake magnitude, in that larger earthquakes tend to yield larger displacements.

- In worldwide examples, secondary or distributed faulting with displacements of 0.1-0.5 m can be found up to >2 km away from the principal traces (Fig. 2.6). Distributed faulting tends to occur in traces that splay from principal faults or that are parallel to them. Complex zones are areas of prominent distributed displacements. During fault rupture, triggered displacements of up to 0.35 m and up to 10 km distance (Fig. 2.6) can also occur along sections of mapped faults. Petersen et al. (2011) have developed a regression equation to assess distributed displacements associated with rupture on main faults. The amount of displacement is dependent on the earthquake magnitude associated to the main fault rupture and the distance of the site to the main fault.

- Mapping of the Mohaka Fault (Raub, 1985; Langridge & Villamor 2010; Lee et al., in press) shows that while the Mohaka Fault is a simple structure close to the A7 site. There are also complex areas along the fault that are relatively close. An important area is the stepover 1.6 km south of the damsite (Location 1 on Fig. 5.1) near the intersection with the Mangataura Fault. Furthermore, 4 km north of the damsite the fault branches to the NE (Mohaka Fault splay, Location 2 of Fig. 5.1). The Mohaka splay fault was mapped in the QMap Hawke's Bay sheet (Lee et al. in press) as inactive. However, analysis of the

fault expression on the LiDAR derived DEMs shows a distinct active trace for this splay fault (Langridge and Villamor 2011).

- Mapping of structural features (Raub, 1985; Langridge & Villamor 2010; Lee et al., in press, Tonkin & Taylor data, see below) and other active traces around the Mohaka Fault has shown that there are numerous structures (lineaments, bedding, inactive faults. Fig. 5.1) that are parallel or subparallel to the active Mohaka and Mangataura faults within the Wakarara Block and close to the damsite. The difficulty of assessing if those structures have recent tectonic activity lies in the lack of Quaternary formations to provide age control for the deformation. The Wakarara Block consists of Mesozoic greywacke with small Quaternary terraces that are often not extensive enough to be useful markers. None of these structural features can be proven as active (except for the Mohaka Fault splay mentioned above) without further investigations. However, mapping of active traces south of the intersection between the Mohaka and Mangataura faults on the Tertiary country side (on both sides of the Mohaka Fault) shows numerous discontinuous traces at distances from 100s to 1000s of meters from the Mohaka Fault main traces.

From the points above it is difficult to confidently determine whether or not there will be primary fault displacements at the damsite. One aspect that has become obvious from mapping during this current study is the numerous traces that have been identified in the Tertiary countryside south of the stepover at <2 km distance from the main fault. By comparison, there are less structural features (lineaments, bedding, inactive faults) mapped within the Wakarara Block. This suggests that it is likely that we may be missing information of smaller active traces in the Wakarara Block, due to the lack of younger cover rocks or landscape surfaces in this rugged greywacke hillcountry.

To date, no active fault trace has been mapped through the damsite, only either inactive faults (QMap inactive fault) or lineaments (suspected faults; Langridge and Villamor 2011). The main Mohaka Fault trace at the south-eastern side of the stepover (at Wakarara village, Fig. 4.3) disappears to the northeast. A mapped lineament (Fig. 5.1) projects towards the damsite and into the Donovan Gully lineaments to the north (see Section 5.1). If those lineaments are linked they would have a similar geometry to the Mohaka Fault active splay to the north. The Mohaka Fault active splay branches out from the main simple trace and is located up to 1 km away from the main trace. That trace is a clear active trace on the LiDAR. However, along Donovan Gully, the LIDAR analysis only points to subtle lineaments (Langridge and Villamor 2011), suggesting that if active the activity is less than the splay to the north. For this reason, and without further detailed investigations, our best interpretation is that the Donovan Gully lineaments do not represent primary rupture. However, they could represent a secondary rupture hazard.

The main points presented above suggest that secondary or distributed faulting could occur at the damsite. The complexity of the Mohaka Fault close to the damsite may influence the likelihood of distributed displacements at the site. The new site is now c. 670 m from the Mohaka Fault. From the literature review there are examples that distributed faulting has occurred at similar or greater distances (and up to 2 km; Petersen et al. 2011; Fig. 2.6). In addition, stepovers and terminations of fault ruptures are zones of high fault complexity and prominent distributed faulting. The step-over zone 1.5 km southwest of the damsite at location 1 (Fig. 5.1) along the Mohaka Fault (Raub, 1985; Langridge and Villamor 2011) is

adjacent to the intersection with the Mangataura Fault. This is therefore a zone of high complexity that could lead to nearby secondary faulting within a similar distance and including the A7 site. The presence of lineaments (Fig. 5.1 and descriptions above) close to the site (such as the Donovan Gully lineaments) support the idea that distributed displacements are a distinct possibility at, or in close proximity to, the damsite.

It is also important to assess whether rupture along the Mohaka Fault may terminate at the stepover (location 1 on Fig. 5.1). If it could, then the stress at the rupture termination would most likely stress the crust around the damsite area, enhancing the likelihood for distributed rupture. To date, however, there is not enough knowledge on the length or continuity of Mohaka Fault rupture segments to discern whether fault rupture may stop at the stepover.

We have used a regression equation in Petersen et al. (2011) and the earthquake magnitude of M_w 7.5 assigned to the Mohaka Fault (Stirling et al., in review) to estimate an indicative value for the possible secondary displacement at the site. We obtain a potential average displacement of 14 cm with and uncertainty range from 4.5 to 42 cm for a distance of c. 680 m from the site, i.e., the distance from the damsite to the main trace of the Mohaka Fault. These numbers need to be treated carefully as the data comes from active faults in California and Turkey, and not directly from faults in the New Zealand tectonic setting. In New Zealand we have found that displacements are typically larger for a given fault length, compared to global examples (Stirling et al., 2002). If we were to apply a methodology similar to Petersen et al (2011) for the A7 dam site, we would need to consider faulting in New Zealand conditions. It is also important to highlight that while the earthquake magnitude is a key parameter to assess secondary displacement at a site close to the fault. However, the magnitude used for the Mohaka Fault is in Stirling et al (2011 in review) is derived from data from Marden and Neall (1990) and Raub et al. (1987), but it is not derived from detailed paleoseismic studies close to the site. Therefore, the actual magnitude may have to be revaluated for such a site-specific assessment.

The displacement of 4.5-42 cm for potential distributed faulting at the damsite is a deterministic value and may represent a minimum value if applied to a New Zealand fault study. Petersen at al. (2011) recommend that the regression is incorporated into a probabilistic frame as mentioned above (Section 2) where the uncertainties of the recurrence and earthquake magnitude associated with the Mohaka Fault are incorporated. They also recommend using the specific information of the site area, including careful mapping of fault location and paleoseismic trenching to determine earthquake recurrence and co-seismic displacement size.

5.3 Presence of weak zones between the Mohaka Fault and the damsite from new structural data

To further assess if there are areas that may undergo distributed faulting away from the Mohaka Fault, a structural analysis of bedding attitudes and faults at some outcrops on the banks of the Makaroro River was undertaken by Tonkin & Taylor and is analysed here. The Mohaka Fault is exposed on a side stream to the main river and the style of deformation of bedrock at a main fault trace can be clearly seen. The analysis of exposures of bedrock from the Mohaka Fault towards the dam could disclose other areas of faulting or weak rock that could potentially move in association with the main fault rupture. This exercise assessed how far the influence of main fault rupture can reach away from the main fault trace. The collected structural data on bedrock is shown on Figure 5.2.

The main points from that analysis show:

- The Mohaka Fault plane is a well-developed shear zone with a 330 mm wide gouge zone and an extensive (tens of meters wide) zone of disrupted, crushed rock around it (as also documented by Raub 1985) (Location 1 on Fig. 5.2 and Fig. 5.3a).
- As we move away from the fault (gouge) zone *per se* normal to the fault strike, there is a wider band of c. 330 m width which comprises abundant shear zones that have a general NE trend, (i.e. parallel to the Mohaka Fault). This is the broader shear zone relating to the Mohaka Fault.
- At Location 2 of Figure 5.1, metre (1± m) to decimetre scale displacements on faults and crushed zones parallel or sub-parallel to the Mohaka Fault were documented at distances of c. 380 m from the main trace, each spaced 1-10 m apart (Fig. 5.3b). The age or number of events responsible for these movements is not known.
- At Location 3 at a distance of c. 550 m from the fault (Fig. 5.2) we observed shear and crushed zones with 10 to 200-mm-wide clay gouge. These shear zones do not have the extensive disrupted (tectonised) zone displayed around the Mohaka Fault plane.
- Farther away, in the area around the damsite (c. 700 m away from the Mohaka Fault) there are dispersed shear zones with gouge widths from 1 to 50 mm (Location 4 on Fig 5.2). This is also the area where the NNE-striking QMap inactive fault relating to Donovan Gully projects close to the dam site.

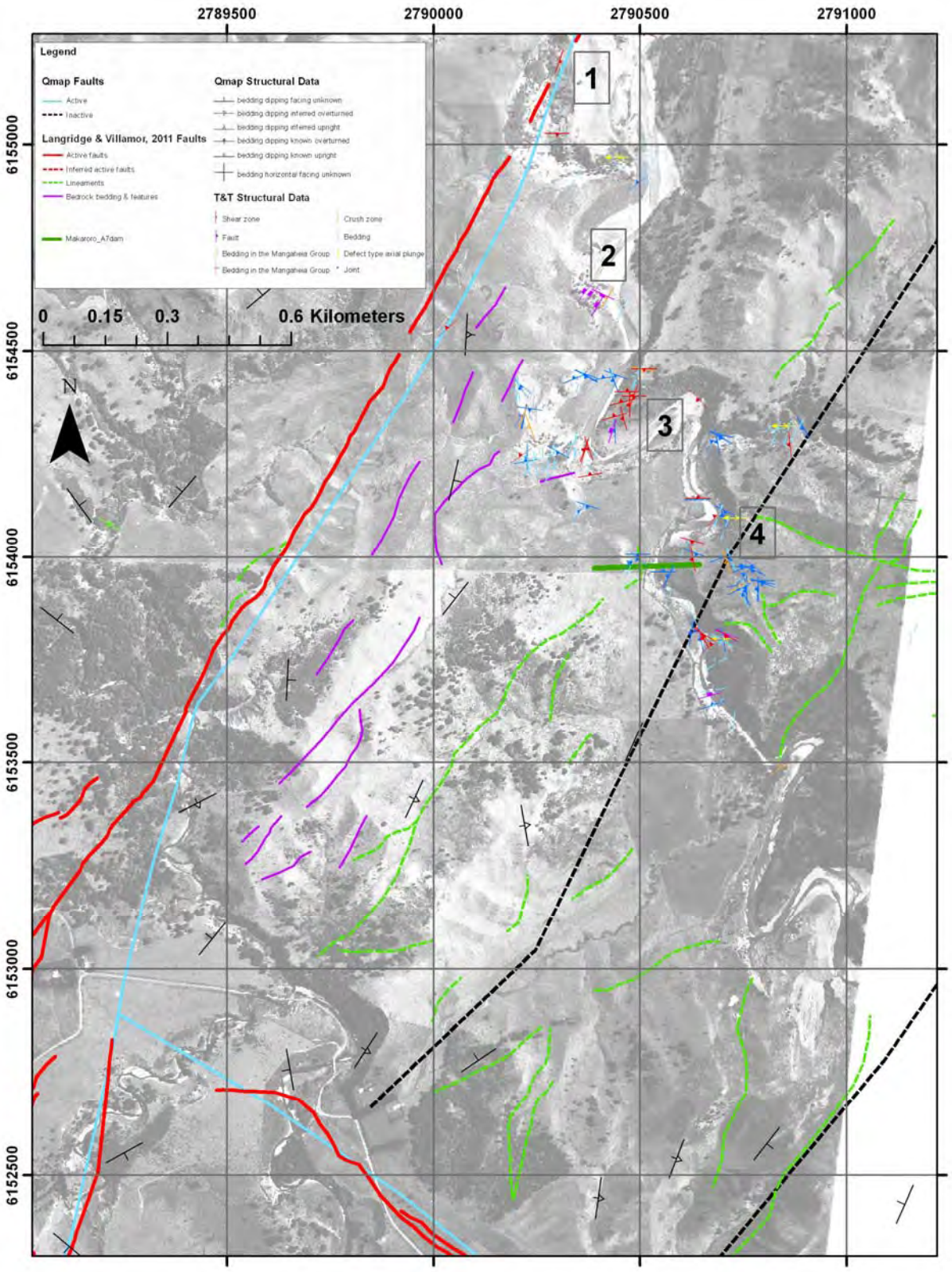


Figure 5.2 Map of active faults, bedrock faults, lineaments and bedding attitudes within 1-2 km of the A7 damsite (next to 4 at centre right). Numbered sites in squares refer to key deformation features referred to in the text.

Figure 5.3 A) Photo of the main plane (red arrow) of the Mohaka Fault showing a 330 mm wide zone of fault gouge (Location 1 in Figure 5.2). B) Photo of faults displacing bedded Mesozoic greywacke at 400 m distance from the main trace of the Mohaka fault (arrowed; Location 2 in Figure 5.2). Displacements are of the order of centimetres to metres. Faults have apparent dip-slip senses of movement. These faults would probably move as secondary rupture displacements.

Mapping and analysis of structural data suggests that where we viewed exposures, we did not find similar features to the shear-crush zone of the Mohaka Fault main fault plane (i.e., Fig. 5.3a). However, clear displacements of sub-parallel faults have been found at a distance of c. 380 m from the main fault, implying that metre-scale secondary rupture could occur at that distance. Several shear and crush zones have been identified at >380 m from the main fault, representing weak planes that can potentially move with secondary/distributed displacements in association with rupture on the main fault (i.e., Fig. 5.3b). Some of these have been found in close proximity to the damsite.

5.4 Summary of the potential for primary and/or secondary displacements at the damsite

With the current information, we interpret that primary faulting is unlikely to occur at the damsite but secondary faulting is a distinct possibility. Despite the fact there are clear topographic lineaments and exposure of shear and crush zone in close proximity to the site (Figs. 5.1 and 5.2), analysis of DEMs derived for LiDAR data have not shown evidence of clear sharp topographic expression of recent faulting along those lineaments typical of primary rupture along the Mohaka Fault. However, evidence from historic surface ruptures of similar (strike-slip) faults, together with the presence of clear lineaments and exposed shear zones close to the damsite, strongly suggests that secondary (or distributed) displacements need to be considered as a possible (and credible) hazard to the future dam.

6.0 ESTIMATION OF ACCELERATION RESPONSE SPECTRA FOR A7 SITE

6.1 Summary of previous results from Langridge et al. (2010)

As part of a region-wide analysis for the Ruataniwha Water Storage scheme, acceleration response spectra were estimated as part of the regional design plan, for a small dam site in the Ruataniwha Depression (B1) and a high dam site in the Ohara Depression (A1), which has now been re-located to site A7 (in Langridge et al., 2010; section 6.0). The following paragraphs summarise the results of that study.

> "The characterisation of the faults in this report in terms of their location, geometry and activity level is sufficient for determination of spectra, but not sufficiently detailed to address fault-avoidance or deformation issues. Maximum Design Earthquake (MDE) motions have been estimated in terms of horizontal-component acceleration response spectra with 5% damping for two client-defined locations that are significant to the proposed Central Hawke's Bay Water Augmentation Scheme.
>
> The spectra were developed using GNS Science's 2010 National Seismic Hazard Model, and secondly by developing an alternative fault model that considers more current knowledge about the active faults in the central Hawke's Bay area. The alternative fault model was based on existing information and a field reconnaissance to perform a reassessment of the active faulting in the central Hawke's Bay area, including defining best-estimate rupture lengths and slip-rates, and hence earthquake magnitudes and recurrence intervals associated with surface rupture of faults in the region.
>
> The results are presented in terms of plots of smoothed 5% damped spectra for return periods ranging from 1000 years to 10,000 years for NZS1170 Class B Rock, and Class C Shallow Soil site conditions. The strongest 50- and 84-percentile spectra were also determined for the various fault-rupture scenarios affecting each location.
>
> For Site A1, we recommend the 84-percentile spectrum of a magnitude M 7.5 scenario earthquake from the Mohaka South fault at a distance of 1.5 km, with 84-percentile near-fault factors, as the MDE spectrum (Figure ES3 and Table ES2).
>
> We presented contour maps for the 10,000-year values of PGA and the 5% damped response spectral acceleration at 1.5 s period for rock and PGA and the response spectral acceleration at 0.75 s for shallow soil conditions. These maps can be used together with the equations in Section 4.2 to generate 10,000-year spectra (excluding near-fault factors) at any location in the region of interest.
>
> The MDE spectra should be capped by the smoothed 84-percentile Mohaka South spectrum at site A1 for the relevant site class; the 10,000-year spectra at some locations will exceed these values. The effect of near-fault factors is not included in the contour maps presented in this report. We recommend that a site specific study be carried out when the final location of the dam sites are determined. Deaggregation results show that the largest hazard contribution is from the Mohaka Fault at the two sites evaluated in the present study."

The fault sources used to develop the two seismic hazard models are shown in Figure 6.1. For this current study, we were tasked with determining spectra for the location of the new A7 damsite, which is c. 4 km south of the original high dam site A1. The new A7 site is situated c. 700 m southeast of the active Mohaka Fault. For this current analysis the same two fault models were employed as were used in the Langridge et al. (2010) study, i.e. the 2010 National Seismic Hazard Model (NSHM) of Stirling et al., (in review), and the NSHM with revisions for the southern Hawke's Bay region with fault sources designed by the authors (RobL model in Fig. 6.3). Methods and tables of fault parameters used in these versions are found in Langridge et al. (2010) and Stirling et al., (in review).

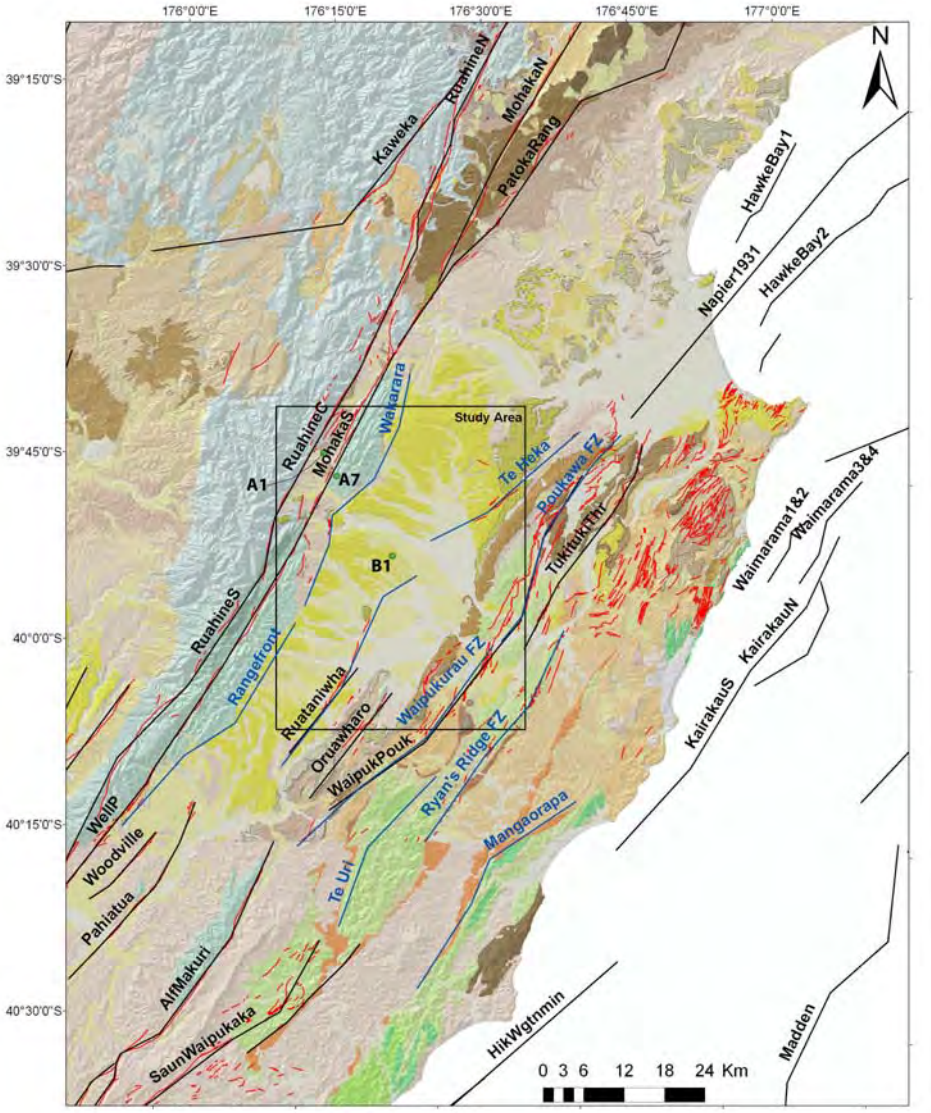


Figure 6.1 Active fault earthquake source model(s) encompassing the Central Hawke's Bay area. The base map comes from QMap geology (e.g. Lee and Begg 2002, Lee et al. in press). The black lines represent the active fault sources as they are in the 2010 version of the NSHM (i.e. Stirling et al., in review; many have abbreviated names). The blue lines are the new and modified seismic shaking sources developed for Langridge et al. (2010). Dam sites A7 and B1 are shown by green dots.

The two models were re-run and acceleration response spectra for site A7 (designated a 'rock' site) were compared with previous estimates for site A1. Site A1 was also a rock site,

which was located c. 1.5 km NE of the Mohaka Fault in the Ohara Depression. The results of these analyses are presented in Figures 6.2 and 6.3.

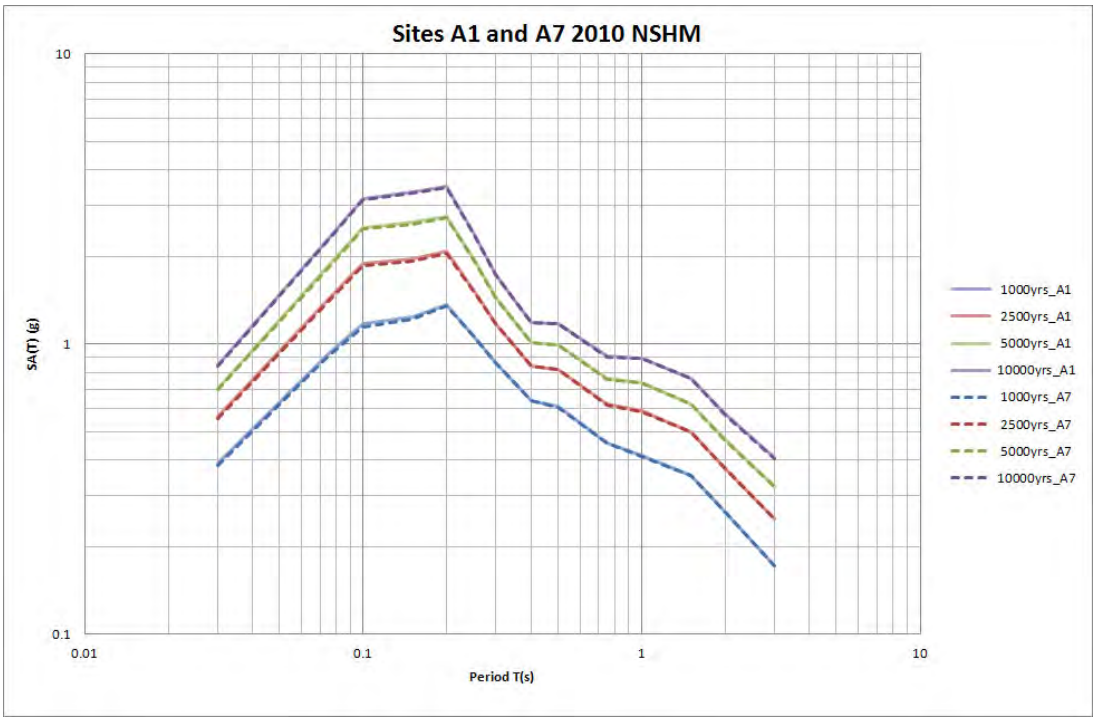


Figure 6.2 Unsmoothed magnitude-weighted rock spectra for site A7 vs. site A1 using the standard NSHM fault model for 1000, 2500, 5000 and 10,000 years. PGA is plotted at 0.03s.

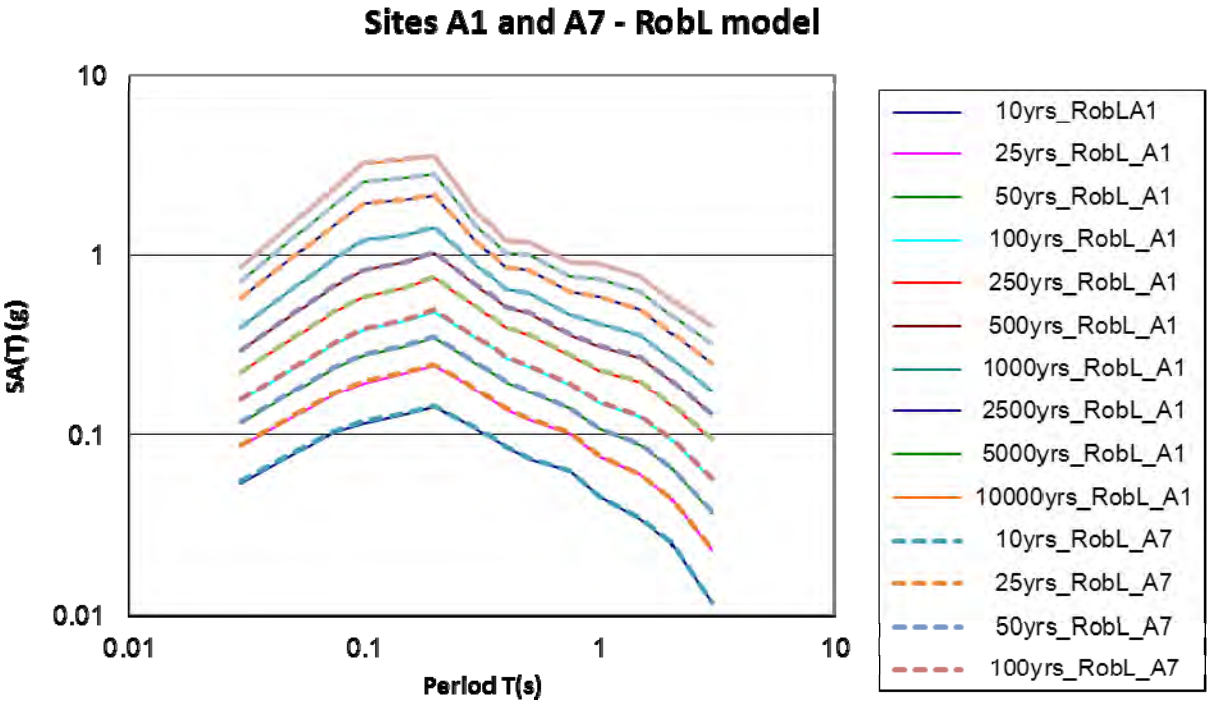


Figure 6.3 Unsmoothed magnitude-weighted rock spectra for site A7 vs. site A1 using the revised Hawke's Bay fault model developed by Langridge et al. (2010) for 1000, 2500, 5000 and 10,000 years. PGA is plotted at 0.03s

The results of acceleration spectral response for the A7 site are essentially indistinguishable (1-2% difference) from site A1 using the standard NSHM model and the modified fault model of Langridge et al. (2010). Spectral analyses using the alternative fault model developed by Langridge et al. (2010) are shown in Figure 6.3. Similarly, there is little difference in the near-fault factors for the A7 and A1 sites which are close to each other.

The most important shaking hazard posed to the A7 dam site is the 'Mohaka South segment' of the Mohaka Fault which has a maximum design earthquake (MDE) of c. M_w 7.5 and a mean recurrence interval of c. 1300 yr in Stirling et al. (in review).

7.0 CONCLUSIONS

- Updated geological mapping has differentiated active fault traces, inferred fault traces, bedding-related features, lineaments, and fold traces within 5 km of the new site. Many of these features have NNE strikes or trends, consistent with the regional tectonic fabric.
- Major active faults have been mapped out to a distance of 10 km from the new A7 dam site. The main active faults in the vicinity of the A7 site are the Mohaka, Wakarara, Rangefront and Mangataura faults.
- Field reconnaissance trips: (i) confirmed the activity of the Wakarara Fault, with probable reverse-slip movement; and (ii) documented deformation in the Makaroro River gorge within the Mesozoic greywacke, and in association with the Mohaka Fault, and the wider Mohaka Fault zone.
- Preliminary single-event vertical displacement (SED) estimated were derived for the Mohaka Fault adjacent to the A7 dam site. These were in the range 0.4-1.0 m, but may cover a wider range from c. 0-1 m.
- A literature review has shown that surface ruptures along strike-slip faults can be very complex. Rupture of principal fault traces (primary rupture) can be either concentrated in a narrow simple zone, or be widespread within complex zones. In the complex zones, the main fault consists of parallel or oblique principal traces that can be separated by several kilometres (usually less than 4 km). Stepovers, bends and terminations of faults are complicated zones, where large earthquake ruptures may be terminated. Displacements along main fault traces during fault rupture are large, ranging from a few centimetres to several meters. Displacements associated with fault rupture are dependent on the earthquake magnitude.
- In worldwide examples, secondary or distributed faulting with displacements of 0.1-0.5 m can be found up to >2 km away from the principal traces. Distributed faulting tends to occur in traces that splay from principal faults or that are parallel to them. Complex zones, such as stepover, and fault termination, are areas of prominent distributed displacements. During fault rupture, secondary displacements of up to 0.35 m and up to 10 km distance can also occur along sections of secondary active faults.
- Based on our mapping in the area and existing information, we interpret that primary faulting is unlikely to occur at the proposed new damsite. Despite the fact there are clear topographic lineaments and exposure of shears and crushed zones in close proximity to the site, analysis of DEMs derived for LiDAR data have not shown evidence of clear

sharp recent faulting along those lineaments typical of primary rupture along the Mohaka Fault. This suggests that there is no primary fault displacement in the vicinity of the A7 dam site.

- The possibility of secondary faulting is a very credible consideration for the A7 site. The presence of clear lineaments and exposed shear zones close to the damsite, strongly suggests that secondary (or distributed) displacements are an important hazard to the future dam. This is in agreement with evidence from our review of historic surface ruptures of similar (strike-slip) faults.
- A re-analysis of the acceleration spectral responses expected at site A7 based on regional models, show that there is no significant difference (1-2 %) between the motions predicted for the A7 dam site compared to the previous analysis for the A1 site.

8.0 RECOMMENDATIONS

We recommend the following studies to improve the characterisation of the possible extent of secondary faulting adjacent to the Mohaka Fault and the potential displacements values at the damsite:

- We strongly recommend that paleoseismic trench excavations are undertaken across the river terrace sequences that blanket the dam foundations to assess the presence and activity of secondary faulting in the bedrock and within late Quaternary materials in the vicinity of the A7 dam site.

- Confirm the origin of (e.g. related to faulting, or another cause) linear geomorphic features such as linear ridges in Donovan Gully, and benched greywacke spurs that run in a NNE direction adjacent to the new proposed A7 damsite. It is important to determine whether these are active surface faulting features; and if they are, when and how often they may have moved; and by how much. If these features are active, use the information on displacement hazard and rupture recurrence observed to contribute to assessment of potential rupture at the site.

- Acquire and analyse structural data on transects across the Mohaka Fault at selected sites to assess the potential distribution of faulting and displacement values at areas of fault complexity compared with areas with a simple fault pattern.

- Undertake paleoseismic (geologic) studies along the Mohaka Fault to confirm earthquake magnitude, co-seismic displacement, earthquake recurrence and fault segmentation (fault termination) to improve shaking analysis and to incorporate those values into assessments of secondary faulting at the damsite, as the primary displacement provides some conditions on the amount and frequency of secondary displacements (see next point).

- Undertake more detailed studies to better characterise the single-event horizontal and vertical displacement for the Mohaka Fault using GPS surveying and trenching. Horizontal displacement of the reservoir sides must be considered as a possible hazard that has not thus far been evaluated.

- Probabilistic assessments of fault displacements are becoming state-of-the-practice for critical facilities. They incorporate global knowledge, as well as, local knowledge, and allow for the treatment of those uncertainties specific to a given site, and those expressed by the global data as well. We strongly recommend that a probabilistic assessment of fault displacements is undertaken for the proposed new A7 damsite. This could only be undertaken at the culmination of the above recommended investigations.

We recommend the following studies to gain further understanding on the extent of faulting on other active faults in the local vicinity of the A7 damsite:

- Undertake further studies along the Wakarara Fault to confirm earthquake magnitude, earthquake recurrence, fault displacements and fault dip to improve shaking analysis and to incorporate those values into assessments of secondary deformation at the damsite. This is because the Wakarara Fault dips beneath the dam site.

- In addition, we recommend paleoseismic studies on the Rangefront Fault and the Mangataura Fault to better understand the kinematic relationship (of active faulting) between these two faults and the Wakarara and Mohaka faults.

These recommendations are further to those described by Langridge and Villamor (2011) as parts of phases 2a, 2b and 3. The timing of this further work should be discussed and agreed between GNS, Tonkin and Taylor and HBRC.

9.0 ACKNOWLEDGEMENTS

GNS Science wishes to thank Tonkin & Taylor for access to the field and field data, and in particular to Bernard Hegan. We also wish to acknowledge the local farmers for access to their properties. We acknowledge the Client for purchasing and providing the LiDAR data which greatly assisted in understanding the local structure. We thank Julie Lee for access to unpublished QMap data. Russ Van Dissen and Stuart Read provided review comments on this report and we thank them for their interest and background knowledge.

10.0 REFERENCES

Aydin, A., Nur, A. 1982. Evolution of pull-apart basins and in their scale independence. *Tectonics,*1: 91-105.

Beanland S. 1995. The North Island Dextral Fault Belt, Hikurangi subduction margin, New Zealand. Unpubl. PhD thesis, Victoria University of Wellington, Wellington, New Zealand.

Beanland, S., Berryman, K.R. 1987: Ruahine Fault reconnaissance. *N.Z. Geological Survey Report EDS* 109. 15 p.

Beanland S., Melhuish A., Nicol A., Ravens J. 1998. Structure and deformational history of the inner forearc region, Hikurangi subduction zone, New Zealand. *New Zealand Journal of Geology & Geophysics* 41: 325-342.

Berryman, K. 1979. Active faulting and derived PHS directions in the South Island, New Zealand. p. 29-34 *In*: Walcott, R.I., Cresswell, M.M. (editors). The Origin of the Southern Alps. *Royal Society of New Zealand Bulletin* 18, 148 pp. Royal Society of New Zealand, Wellington.

Berryman K., Beanland S. 1991. Variation in fault behaviour in different tectonic provinces of *New Zealand. Journal of Structural Geology* 13 (2): 177-189.

Coppersmith, K.J., Youngs, R.R. 2000. Data needs for probabilistic fault displacement hazard analysis, *Journal of Geodynamics* 29, 329-343.

Downes, G.L, 1995. Atlas of isoseismal maps of New Zealand earthquakes. *Institute of Geological & Nuclear Sciences Monograph 11,* 304 p., Lower Hutt, New Zealand. Institute of Geological & Nuclear Sciences Limited.

Downes G.L., Dowrick D. 2011 in prep. Updated atlas of isoseismal maps of New Zealand earthquakes.

Erdman, C.F, and Kelsey, H.M. 1992: Pliocene and Pleistocene stratigraphy and tectonics, Ohara Depression and Wakarara Range, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 35: 177-192.

Gledhill K., Ristau J., Reyners M., Fry, B., Holden C., and the GeoNet Team 2010. The Darfield (Canterbury) earthquake of September 2010: Preliminary Seismological Report. *Bulletin of the New Zealand Society for Earthquake Engineering*, vol. 43 (4): 215-221.

Grouden P. 1966. Early New Zealand earthquakes. Seismological Observatory, Wellington, New Zealand.

Hanson, J.A. 1998.The neotectonics of the Wellington and Ruahine faults between the Manawatu Gorge and Puketitiri, North Island, New Zealand. Unpublished PhD thesis, Victoria University of Wellington, New Zealand.

Kelsey HM, Hull AG, Cashman SM, Berryman KR, Cashman PH, Trexler JH Jr, Begg JG 1998. Paleoseismology of an active reverse fault in a forearc setting: The Poukawa Fault Zone, Hikurangi forearc, New Zealand. Tectonics 110: 1123-1148.

Kingma, JT 1957. Geology of the Wakarara Range, central Hawke's Bay. New Zealand Journal of Geology and Geophysics 1: 76-91.

Kingma, JT 1962: Sheet 11, Dannevirke. Geological Map of New Zealand 1:250,000.

Klos P.Z. 2009. Neotectonic evaluation of seismic hazard along the Ruataniwha Fault, Dannevirke region, New Zealand. B.S thesis, Dept. of Geological Sciences, Colorado College, Colorado Springs, USA.

Langridge, R.M., Villamor, P. 2011. The A7 Makaroro River damsite Phase 1: Initial site evaluation for active deformation. GNS Science Client Report 2011/117. 35 p.

Langridge, R.M., Berryman, K.R., Van Dissen, R.J. 2005. Defining the geometric segmentation and Holocene slip rate of the Wellington Fault, New Zealand: the Pahiatua section. New Zealand Journal of Geology and Geophysics: 48: 591-607.

Langridge RM; Villamor P; Basili R. 2006: Earthquake Fault Trace Survey – Central Hawke's Bay District. GNS Science Client Report 2006/98.

Langridge RM; Zhao, JX, Zajac A, McVerry GH 2010. Spectra and compilation of fault data for Central Hawke's Bay Water Augmentation Scheme. GNS Science Client Report 2010/121.

Langridge RM, Stenner HD, Fumal TE, Christofferson SA, Rockwell TK, Hartleb R, Bachhuber J, Barka AA 2002. Geometry, slip distribution, and kinematics of surface rupture on the Sakarya fault segment during the August 17, 1999 Izmit earthquake. Bulletin of the Seismological Society of America 92: 107-125.

Lee, J., Bland, K., Kamp, P.J.J. (compilers), 2011 in press. Geology of the Hawke's Bay area. Institute of Geological & Nuclear Sciences 1:250,000 geological map 8. 1 sheet + 71 p. Lower Hutt, New Zealand. GNS Science.

Litchfield, N.J.; Nicol, A.; Clark, K.J.; Langridge, R.M.; Reyes, A.G. 2011 IODP Workshop on Using Ocean Drilling to Unlock the Secrets of Slow Slip Events : workshop field trip guide, 4-5 August 2011, Gisborne, New Zealand. Lower Hutt: GNS Science. *GNS Science miscellaneous series 40.* 73 p.

Marden, M. 1984. Geology and the relationship to erosion in the southern Ruahine Range, North Island, New Zealand. Unpublished DPhil thesis, Massey University, Palmerston North, New Zealand.

Marden M, Neall, V.E. 1990. Dated Ohakean terraces offset by the Wellington Fault, near Woodville, New Zealand. N. Z. Journal of Geology and Geophysics 33: 449-453.

McClay, K., Dooley, T. 1995. Analogue models of pull-apart basins. Geology 25:711-714.

McKinstry, H.E. 1953. Shears of the second order. American Journal Science 251: 410-414.

Naylor, M.A., Mandl, G. Sijpesteijn, C.H.K. 1986. Fault geometries in basement-induced wrench faulting under different initial stress states. Journal of Structural. Geology 8: 737-752.

Ota Y, Williams DN, Berryman KR 1981. Part sheets Q27, R27 and R28 - Wellington (1st Edition). Late Quaternary Tectonic Map of New Zealand 1:50000 (with notes). New Zealand Department of Scientific and Industrial Research.

Petersen, M.D., Dawson, T.E., Chen, R., Cao, T., Wils, C.J., Schwartz, D.P., and Frankel, A.D. 2011. Fault displacement hazard for strike-slip faults. Bulletin of the Seismological Society of America 101 (2): 805-825.

Price, N.J., Cosgrove, J.W. 1990. Analysis of geological structures. Cambridge University Press.

Raub, M. L. 1985.The tectonic evolution of the Wakarara area, Southern Hawke's Bay, New Zealand. Unpublished M. Phil. Thesis, University of Auckland, New Zealand.

Raub, M.L., Cutten, H.N.; Hull, A.G. 1987: Seismotectonic hazard analysis of the Mohaka Fault, North Island, New Zealand. In: Proceedings, Pacific Conference on Earthquake Engineering. The New Zealand National Society for Earthquake Engineering, Wellington. Volume 3: 219-230.

Riedel, W. 1929. Zur Mechanik Geologischer Brucherscheinungen. *Zentral-blatt fur Mineralogie, Geologie und Paleontologie*, pp. 354–368.

Schermer ER, Van Dissen R, Berryman KR, Kelsey HM, Cashman SM 2004. Active faults, paleoseismology and historical fault rupture in the northern Wairarapa, North Island, New Zealand. New Zealand Journal of Geology and Geophysics 47: 101-122.

Segall, P., Pollard, D.D. 1980. Mechanics of discontinuous faults. Journal of Geophysical Research 85: (B8): 4337-4350.

Stein, R. S., A. A. Barka, J.H. Dietrich, 1997. Progressive failure on the North Anatolian fault since 1939 by earthquake stress triggering, Geophysical Jour International, 128, 594-604.

Stepp J.C., Wong, I., Whitney, H., Quittmeyer, R., Abrahamson, N., Toro, G., Youngs, R., Coppersmith, K., Savy, J., Sullivan, and Yucca Mountain PSHA Project Members, 2001. Probabilistic Seismic Hazard Analyses for Ground Motions and Fault Displacement at Yucca Mountain, Nevada. Earthquake Spectra, 17 (1),

Stirling, M.W., McVerry, G., Gerstenberger, M., Litchfield, N., Van Dissen, R., Berryman, K., Barnes, P., Wallace, L., Bradley, B., Villamor, P., Langridge, R., Lamarche, G., Nodder, S., Reyners, M., Rhoades, D., Smith, W., Nicol, A., Pettinga, J., Clark, K. and Jacobs., K. in review. National Seismic Hazard Model for New Zealand: 2010 Update. For: Bulletin of the Seismological Society of America.

Stirling, M., Wesnousky, S., Shimazaki, K. 1996. Fault trace complexity, cumulative slip, and the shape of the magnitude-frequency distribution for strike-slip faults: a global survey. Geophysical Journal International 124: 833-868.

Sylvester, A.G. 1988. Strike-slip faults. Geol. Society of America Bulletin 100: 1666-1703.

Tchalenko, J.S. 1970. Similarities between shear zones of different magnitudes. Geological

Society of America Bulletin 81: 1625-1640.

Villamor Perez, M.P. 2002. Cinematica Terceria y cuaternaria de la falla de Alentejo-Plasencia y su influencia en la peligrosidad sismica del interior de la peninsular iberica. Doctoral thesis, Universidad Complutense de Madrid, Madrid, Spain.

Wells, D.L., Coppersmith, K.J. 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. Bulletin of the Seismological Society of America 84: 974-1002.

Wesnousky, S.G. 2006. Predicting the endpoints of earthquake ruptures. Nature 444: 358-360. doi:10.1038.

Wesnousky, S.G. 2008. Displacement and geometrical characteristics of earthquake surface ruptures: Issues and implications for seismic hazard analysis and the process of earthquake rupture. Bulletin of the Seismological Society of America 98: 1609-1632. doi: 10.1785/0120070111

Woodcock, N.H., Fisher, M. 1986. Strike-slip duplexes. J. of Structural Geology 8: 725-735.

APPENDIX 1 GIS LAYERS

ArcMap Shapefiles of features mapped within the vicinity of the A7 Makaroro damsite. (See attached CD).

Appendix E: Borehole Logs and Photographs

TONKIN & TAYLOR LTD.
ENVIRONMENTAL & ENGINEERING CONSULTANTS

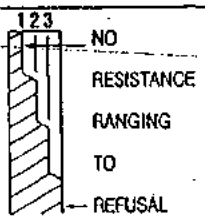
ENGINEERING LOG TERMINOLOGY

DRILLING OR EXCAVATION

WATER

Water level on date shown
Water Inflow
Water Outflow

PENETRATION



CORE RECOVERY

Core recovered expressed as percentage of the length of the core run

METHOD/CASING

Shows drilling method and depth of casing

Common types:
- OB – open barrel
- W – wash
- HQ3 – HQ triple tube coring
- PQ3 – PQ triple tube coring

SAMPLE TYPE

(The length of the sample is indicated by the length of symbol)

- OPEN BARREL
- DOUBLE OR TRIPLE TUBE
- STANDARD PENETRATION TEST
- LARGE DIA. THIN WALLED TUBE
- SMALL DIA. THIN WALLED TUBE
- BULK SAMPLE

GRAPHIC LOG

The graphic log shows soil and rock substances, significant defects, and core loss. Soil and rock substances represented by contrasting symbols consistent for each project.

TYPICAL SYMBOLS:

- ORGANIC MATERIAL
- CLAY
- SILT
- SAND
- GRAVEL
- MUDSTONE
- SILTSTONE
- SANDSTONE
- VOLCANIC ROCK
- NO CORE

TESTS

- N=22 — SPT uncorrected blow count for 300mm
- • 75kPa — Undrained shear strength as measured by field vane
- ⊠ — Pressuremeter Test
- ✱ — Laboratory test(s) carried out:

Common types:
- LV – Laboratory vane
- AL – Atterburg limits
- UU – Undrained trioxial
- PSD – Particle size
- C' Ø' – Effective stress
- CONS – Consolidation
- DS – Direct Shear
- COMP – Compaction
- UN – Unconfined Compression
- IS – Point Load

SOIL DESCRIPTIONS

CLASSIFICATION SYMBOL

Based on USBR Unified Soil Classification System Visual Method for field identification. Classification symbols based on Laboratory Method may differ.

Soil and rock descriptions generally follow the "Guidelines for the field descriptions of Soils and Rocks in Engineering Use" by the NZ Geomechanics Society (1985). Particular in-house abbreviations are given below.

MOISTURE CONTENT

- D – Dry, looks and feels dry
- M – Moist, no free water on hand when remoulding
- W – Wet, free water on hand when remoulding

Moisture content may be compared to the plastic limit (PL) eg M > PL = moist, moisture content greater than the plastic limit

UNDRAINED SHEAR STRENGTH

		Cu (kPa)
VS	Very Soft	<10
S	Soft	10 to 25
F	Firm	25 to 50
St	Stiff	50 to 100
VSt	Very Stiff	100 to 200
H	Hard	>200
Fb	Friable	

RELATIVE DENSITY

		SPT – Uncorrected
VL	Very Loose	0 to 4
L	Loose	4 to 10
MD	Medium Dense	10 to 30
D	Dense	30 to 50
VD	Very Dense	>50

ROCK DESCRIPTIONS

WEATHERING

UW	Unweathered
SW	Slightly Weathered
MW	Moderately Weathered
HW	Highly Weathered
CW	Completely/Extr. Weathered
RW	Residual Soil

FIELD STRENGTH

		UCS (MPa)	Point Load Index (MPa)
R0	Extremely Weak	0.25–1	N/A
R1	Very Weak	1 to 5	N/A
R2	Weak	5 to 25	N/A
R3	Moderately Strong	25 to 50	1–2
R4	Strong	50 to 100	2–4
R5	Very Strong	100 to 250	4–10
R6	Extremely Strong	>250	

P.T.O.

TONKIN & TAYLOR LTD.
ENVIRONMENTAL & ENGINEERING CONSULTANTS

ENGINEERING LOG TERMINOLOGY

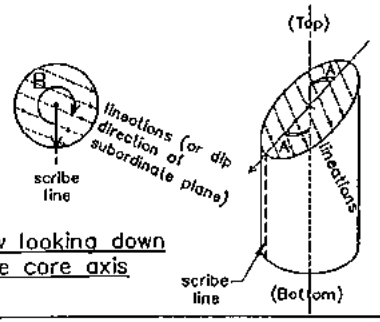
ROCK DESCRIPTIONS

(Continued)

DEFECTS

Significant defects are shown graphically

B	BEDDING
J	JOINT
SZ	SHEARED ZONE
CZ	CRUSHED SEAM/ZONE
IF	INFILLED SEAM/ZONE
XD	EXTREMELY WEATHERED SEAM



View looking down the core axis

CODING

Typical Example:

2J60°, PL, SL, T, CV, stiff green CLAY

- 2 — No. in defect set
- J — Type
- 60° — Angle to core axis
- PL — Shape
- SL — Roughness
- T — Apeture
- CV — Infilling/Coating Type
- stiff green CLAY — Infilling Description (as per Soil Description)

Where possible, the relative angle between the defect and the bedding (B) is given, where B = angle from the dip direction of the bedding, to the dip direction of the defect, in a clockwise direction when looking down the core axis.

SHAPE

TERM	CODE
Planar	PL
Slightly curved	SC
Curved	CV
Irregular	IR
Stepped	ST
Wavy	WV

ROUGHNESS

DESCRIPTION OF JOINT SURFACE	CODE
Slickensided	SL
Smooth	SM
Defined Ridges	DR
Small Steps	ST
Rough	R
Very Rough	VR

After Piteau (1973)

APERTURE

TERM	SYMBOL	DESCRIPTION (Separation)
Very Tight	VT	less than 0.1mm
Tight	T	0.1mm to 1.0mm
Open	O	1.0mm to 10.0mm
Very Open	VO	more than 10mm

After Bienowski (1973)

INFILLINGS AND COATINGS

Clay Gouge	CG	Joints have openings between opposing faces of intact rock substance in excess of 1mm filled with clay gouge. Clay is generally described in terms of soil properties.
Clay Veneers	CV	Joints contain clay coating whose maximum thickness does not exceed 1mm. Note: Describe clay in terms of soil properties.
Penetrative Limonite	PL	Joint traces are marked in terms of well defined zones of slightly to moderately weathered ferruginised rock-substance within the adjacent rock.
Limonite Stained	FeSt	Joint surfaces are stained or coated with limonite, although the rock substance immediately adjacent to the joints is fresh.
Coated	CT SC	Joints exhibit Coatings other than clay or limonite, eg. Carbonate (CT) or silica (SC).
Cemented	CL CS CC	Joints are cemented with limonite (CL), silica (CS), or carbonates (CC).
Clean	CN	Joint surfaces show no trace of clay, limonite, or other coatings.

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 701

PROJECT Ruatamata Water Storage FEATURE Borehole LOCATION A7U

GRID REF 1880315.26, 5592802.3 N CO-ORD NZTM DATUM

ANGLE FROM HORIZONTAL 90° DIRECTION – H.A.D. GROUND H.A.D. COLLAR

DESCRIPTION OF CORE (Weathering, hardness, strength, colour; rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)	DEPTH H.A.D. (m)	ROCK DEFECTS (prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation schistosity; attitude, width, spacing, smoothness) (OR SOIL DESCRIPTION)	R.Q.D.	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s
SILT with trace sand, light brown, moist to wet, low plasticity, insensitive (Brown Ash)	0–0.5			
0.5m SILT with minor gravels, trace sand, light brown, moist, non-plastic (Loess/colluvium)	0.5–1.2			Not tested
MW, MW-H, brown to grey fine SANDSTONE, moderately strong to strong, massive, extremely closely jointed (Greywacke)	1.2	1.2-1.5 broken core 1.5-1.9 broken core	0%	
	2	1.9 4J 20°, PL, R, Fest 4J, 70°, PL, R, Fest 8J, 10°, PL, R, Fest 2.2m 3J 80°, PL, R, Fest 2.4-2.5m broken core 2.5m 2J 70°, PL, R, Fest 1J 10°, PL, R, Fest 2J 40°, PL, R, Fest 2.7m 1J 10°, IE, R, Fest 2.7-3.0m broken core	0%	Not tested
	3	3.0-3.75 broken core 3.75m 3J 40°, SC, R, Fest 1J 90°, SC, R, Fest 1J 50°, ST, R, Fest 2J 30°, PL, R, Fest 1J 70°, PL, R, Fest 4.3-4.4m core broken around vertical joint 4.4m 2J 20°, PL, R, Fest 1J 70°, PL, R, Fest	0%	Not tested
5.0m changes to slightly weathered	4.5	4.5-4.9m core broken around vertical joint 4.8 1J 90°, IC, R, Fest 4.9m 2J 30°, SC, R, Fest 2J 50°, IR, R, Fest 1J 70°, ST, R, Fest 5.0-5.4m shattered core 5.1m 1J 20° IR, R, Fest 5.2m 2J 90°, SC, SM, Fest 1J 20°, IR, R, Fest 4J 50°, PL, R, Fest 5.3-5.4 shattered core 5.4m 3J, 80°, PL, R, Fest 5.6m 3J, 20°, PL, R, Fest 5.8m 2J 20°, PL, R, Fest 5.9-6.0 shattered core	Piezos 1&2 (31/10/11) 0%	Not tested
6.6-7.4m light veining gently to moderate dip	6	6.3 1J 10°, IR, R, silt veneer 6.35 3J 60°, ST, R, cw 1J 45°, PL, R, 1J 90°, SC, R, Fest 6.4 1J 80°, PL, R, silt infill 6.6 1J 85°, SC, SM, silt infill, 3J 15°, PL, R. 3J 20°, IR, R. 6.9 1J 85°, SC, R, silt infill 7.05m 1J 80°, SC, SM, silt infill 7.1m 3J 15°, PL, R, cw	0%	Not tested
SW, MW, black MUDSTONE, massive, very closely jointed, weak	7 – 7.5	7.4 1J 0°, WV, R, cw 1J 80°, PL, R, cw 7.4-7.5 core broken		

DRILLER:	ROCK WEATHERING	ROCK HARDNESS	FRACTURE LOG		
Boart Longyear	UW – Unweathered	VH – Very hard	Spacing of Natural Fractures (cm): 100, 50, 10, 5, 1, 0.1	LOGGED: Damien	PROJECT: 27195.200
STARTED: 06/10/11	SW – Slightly Weathered	H – Hard	Fractures/m of core: 1, 2, 10, 20, 100, 1000	DATE: 09/11/11	HOLE NO: 701
FINISHED: 08/10/11	MW – Moderately Weathered	MH – Moderately hard		TRACED:	LENGTH: 27.0 m
DRILL: Rig 57	HW – Highly Weathered	MS – Moderately soft		CHECKED:	CORE BOXES: 10
	CW – Completely Weathered	S – Soft		ORIGINAL VERTICAL SCALE: 1:25 (at A3)	
		VS – Very Soft		SHEET 1 OF 4	DRG NO.

EXPLANATION: Defect angles from horizontal

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 701

PROJECT Ruataniwha Water Storage FEATURE Borehole LOCATION A7
GRID REF 1880315.2E, 5591230.2 4N CO-ORD NZTM DATUM
ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 474.9 m RL H.A.D. COLLAR

DESCRIPTION OF CORE WEATHERING, HARDNESS, STRENGTH, COLOUR, ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, mineralogy, texture, cement, etc...); STRATIGRAPHIC NAME.	ROCK WEATHERING (SW NW HW)	ROCK HARDNESS (H MH MS S)	POINT LOAD TEST (MPa)	CORE LOSS /LIFT % (5 10 50)	DEPTH H.A.D. (Core size, casing)	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) cm (50 10 5 1)	ROCK DEFECTS PROMINENT JOINTS, BEDDING, SEAMS VEINS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY attitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...	DATE/DEPTH	R.Q.D. %	WATER LEVEL (Date)	DRILL WATER LOSS % (0–100)	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s (0.01 0.1 1 10 100 1000)
UW, H, grey fine SANDSTONE, massive, strong, very to extremely closely jointed 7.5-8.5m, lost core, no recovery 8.6 changes to unweathered, contains numerous mudstone partings UW, H, black MUDSTONE, strong, extremely closely jointed, massive. Prominent veins associated with this unit UW, H, dark grey to grey SANDSTONE, massive, very closely jointed 9.0-10.5m - minor veining 12.6-12.9m light veining follows gently dipping joints				0%	7.5 8 9 10 11 12 13 14 15			8.3m 1380°, SC, SM, CN - mudstone partings along joint 8.8m 1880° - mudstone - deformed 1vein 70°P 8.9m 1360°, SC, SM, CN 9.05m 1355°, PL, SC, CN 9.05-9.15m - core broken 9.15m 2345°, TR, R, CN 1370°, SC, R, CN 9.2m 1350°, SC, SM, zeolite coating 1380°, SC, R, CN } core shattered around these. 9.4 1CZ, 30°, CG 9.5-10.0 - core completely shattered - crushed material in this area suggests crush zone 10.0-10.2m broken core 1380°, SC, R, silt veneer 10.3m 1350°, PL, R, silt veneer 3365°, TR, R, silt veneer 10.4 1 vein 60° 10.5 1340°, SC, R, CN ~10.5m 2340°, SC, R, CN 10.5-10.9m - core broken ~10.7m 1350°, TR, R, CN 1380°, SC, R, CN 1370°, SC, R, CN 10.9m 1370°, WV, R, CT 11.0m 1330°, CU, R, silt veneer 1310°, PL, R, silt veneer 11.0-11.2 core broken around subvertical joints 11.2m 2310°, SC, R, silt veneer 1345°, PL, R, CN, 1vein 30° 11.4m 1350°, WV, R, CT 1370°, PL, R, silt veneer 11.4-11.55 - core broken 11.55-2315°, PL, R, Z/CV 11.6-12.0 core shattered ~11.7m 2370°, ~V, R, silt veneer 2360°, PL, SM, CN 1340°, PL, R, silt veneer 1310°, CU, R, CT 12.1 2340°, SC, R, silt veneer 12.2 2340°, SC, R, silt veneer 12.3m 1CZ 50°, PL, CG 12.4m 2310°, PL, R, silt veneer 12.5 1860° - thin mudstone bed 12.6 2330°, TR, R, silt veneer 12.6-12.7 core shattered around very closely spaced, shallow dipping joints 12.7m 6310°, PL, R, CT 12.9 5325°, PL, R silt veneer 13.1m 1385°, SC, SM, CN 13.3m 1380°, PL, R, CN 13.45m 1360°, SC, SM, CN 1310°, SC, R, CN 13.45-13.5m - broken core. 13.5 to ~14.0m shattered core ~14.0m 1350°, TR, R, CN 14.05m 1340°, TR, R, CN 14.1m 1320°, SM, R, CN 1320°, SM, R, CN 14.1 to 14.8m shattered core 14.8m 1320°, SC, R, CN, zeolite 2370°, SM, R, CN 1385°, PL, R, CT 14.15-15.6 core broken around steep joints		7% 0% 0% 0% 0%			8.25-10.5m Packer pundered and could not be reset

DRILLER: Board Longyear STARTED: 06/10/11 FINISHED: 08/10/11 DRILL: Rig 57	ROCK WEATHERING UW – Unweathered SW – Slightly Weathered MW – Moderately Weathered HW – Highly Weathered CW – Completely Weathered	ROCK HARDNESS VH – Very hard H – Hard MH – Moderately hard MS – Moderately soft S – Soft VS – Very Soft	FRACTURE LOG Spacing of Natural Fractures (100 50 10 5 1 0.1) Fractures/m of core (1 2 10 20 100 1000)	LOGGED: 1 mmm DATE: 09/11/11 TRACED: CHECKED: [illegible] ORIGINAL VERTICAL SCALE: 1:25 (at A3)	PROJECT: 27195.200 HOLE NO: 701 LENGTH: 27nm CORE BOXES: 19

EXPLANATION: Defect angles from horizontal

SHEET 2 OF 4 DRG NO

D:\USERS\ACADDATA\S.DRILLED

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 701

PROJECT Ruataniwha Water Storage FEATURE Bore Lake LOCATION A7
GRID REF 1880315.26, 5592302.6N CO-ORD NZTM DATUM L
ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 474.9mRL H.A.D. COLLAR

DESCRIPTION OF CORE WEATHERING, HARDNESS, STRENGTH, COLOUR, ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, mineralogy, texture, cement, etc...); STRATIGRAPHIC NAME.	ROCK WEATHERING (SW MW HW)	ROCK HARDNESS (H MH MS S)	POINT LOAD TEST (MPa)	CORE LOSS/LIFT % (5 10 50)	DEPTH H.A.D. Core size, casing m	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) cm (50 10 5 1)	ROCK DEFECTS PROMINENT JOINTS, BEDDING, SEAMS VEINS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY altitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...	DATE/DEPTH	R.Q.D. %	WATER LEVEL Date	DRILL WATER LOSS % (0-100)	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s (0.01 0.1 1 10 100 1000)
UW, H, dark grey to grey SANDSTONE, massive, very closely jointed					15			15.0-15.15m shattered core. 15.15-15.30° PL, R, silt veneer 15.65° PL, SM, CN 15.7-15.75° SC, R, CN 15.85-16.5 15.70° PL, R, CV 15.4-15.7 core broken around steep joints 15.8m 18.70° mudstone/argillite 15.9-16.5m shattered core		0%			
					16			16.3-16.4 silty/clayey material suggests crush zone 16.5-16.8m shattered core. 16.6 silty material in shattered core suggests crush zone.					
16.75 to 17.75, numerous, extremely closely space joints					17			11.8m 1CZ 20°, CG 3J 40°, FR, R, CN 1J 40°, FR, R, CN 17.0-17.1 [illegible] 17.1 1CZ 20°, silt infill 17.2 1J 20°, PL, R, CN 17.5 1J 20°, CV, R, silt veneer 17.65m 1J 30°, CV, R, CN 17.7m 1J 5°, OC, SM, CT 17.75m 1CZ 10°, CG Core has shattered around extremely closely spaced joints and shear zones		0%			
					18			17.8-18.2 shattered core 18.0-18.15m shattered core. 18.15m 18.10°, SC, R, silt veneer 8J 50°, PL, R, CN 18.25-18.6 core contains numerous very closely spaced joints 18.4 1CZ 15°, silt infill 18.65m 2J 90° PL 18.7-18.8 - shattered core. 18.8 1J 45°, PL, R, CT 18.9 2J 10°, PL, R, CN 3J 60°, PL, R, CN core broken around these joints 19.2-19.5 shattered core		0%			17.25-19.0m Packer punctured during first stage and could not be reset.
					19			19.5-19.7m shattered core. 19.7m 1J 80°, PL, R, silt veneer 7J 10°, PL, R, silt veneer 19.8-20.1m core shattered due to very close joint spacing 20.1m 2J 60°, SC, R, CN 1J 50°, PL, R, CT 2J 10°, PL, R 20.25m 3J 20°, PL, R, silt veneers 3J 70°, PL, R, CT 20.4 to 20.9m core shattered around steep joints		0%			
					20			20.9m 2J 40°, PL, R, silt veneer 2J 60°, SC, R, CN 1J 10°, FR, R, CN 21.0-21.2m core shattered. 21.2m 3J 70°, PL, R, CG 2J 25°, PL, R, CG 21.3m 1J 10°, PL, R, CN 2J 50°, PL, R, CN 21.4 5J 50°, CV, R, silt veneer 21.7 4J 70°, SC, R, silt veneer 1J 20°, PL, R, CN 2J 10°, PL, R, zeolite coating core broken due to close joint spacing 21.9 4J 40°, PL, R, silt veneer 22.0 1J 70°, PL, R, CT 1J 80°, PL, R, CN 2J 40°, PL, R, CN 22.25-22.5m core shattered		0%			
					21								
					22								
					22.5								

DRILLER: Boart Longyear
STARTED: 05/10/11
FINISHED: 08/10/11
DRILL: Rig 57

ROCK WEATHERING
UW – Unweathered
SW – Slightly Weathered
MW – Moderately Weathered
HW – Highly Weathered
CW – Completely Weathered

ROCK HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very Soft

FRACTURE LOG
Spacing of Natural Fractures 100 50 10 5 1 0.1
Fractures/m of core 1 2 10 20 100 1000

EXPLANATION: Defect angles from horizontal

LOGGED: DMM
DATE: 09/11/11
TRACED:
CHECKED: [signature]
ORIGINAL VERTICAL SCALE: 1:25 (at A3)
SHEET 2 OF 4 DRG NO

PROJECT: 27195.200
HOLE NO: 701
LENGTH: 27m
CORE BOXES: 10

G:\USERS\ACADDATA\S-DRILLOG

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 701

PROJECT: Ruataniwha Water Storage FEATURE: Bore hole LOCATION: A7
GRID REF: 188.0315.26, 5592302.40 CO-ORD DATUM
ANGLE FROM HORIZONTAL: 90° DIRECTION H.A.D. GROUND: 474.9mRL H.A.D. COLLAR

DESCRIPTION OF CORE (weathering, hardness, strength, colour; rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)	DEPTH H.A.D. (m)	ROCK DEFECTS – prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation, schistosity; attitude, width, spacing, smoothness (OR SOIL DESCRIPTION: consistency, compactness, water content, group symbol etc...)	R.Q.D. %
UW, H, dark grey to grey SANDSTONE, massive, very closely jointed	22.5	22.5-22.6m shattered core.	
		22.6m 1CZ 70°, CG 4J 20°, PL, R, CT 2J 70°, PL, R, CN	
22.6-23.8m crush zones have some plasticity		22.7m 1CZ 30°, CG 22.95 1CZ 40°, CG	
	23	23.25m 4J 45° PL, R 3J 70°, CU, R (Core between crush zones is highly fractured)	0%
		23.6 1CZ 45°, CG	
24.0-27.0 minor veining, slightly to steeply dipping		23.7-24m core shattered 23.75 1B 55° - mudstone	
	24	24.0-24.3 broken core around steep joints 24.1m 1J 70°, CU, R, silt veneer 1J 10°, SC, R, CN 1J 45°, PL, SM, CN 1J 10°, CU, SM, CN (on a block of core)	
		24.6m 2J 45°, PL, R, silt veneer 1J 80°, PL, R, CN 24.5 1J 10°, PL, R, CN 5J 45°, WV, R, CN	
		24.7m 2J 80°, PL, R, CN 4J 10°, PL, R, CN 24.815 6J 60° PL, R, CN 5J 30°, PL, R, CN	
	25	25.0 1 vein 30° - zeolite infill 1CZ 20°, CG 1J 60°, ST, R, CN	0%
		25.1 2J 30° PL, R, CN 1J 5°, ST, R, CN 25.4 1CZ 30°, CG 25.4-25.5m core broken	
		25.5m 1J 50°, PL, R, CT 4J 80°, CU, R 4J 20°, PL, R, CN 25.5-25.6m core broken around steep joints	
	26	26.0m 1J 50°, PL, R, CN 26.1-26.2m shattered core 26.2m 1J 30°, PL, R, CN 1J 45°, PL, R, CN 1J 90°, CU, R, CN	10%
26.35-26.65 Mudstone/muddy sandstone bed		26.3m 1CZ 45°, CG 26.45m 1CZ 30°, CG 1B 30°, mudstone	
		26.8m 1J 20°, SC, R, CN - mudstone parting 1J 10°, CU, R, CN 1J 60°, ST, R, CN 1J 5°, SC, R, CN	
End of hole at 27mbgl	27		

Installations:
Piezo 1 - Response zone 13-21mbgl
Piezo 2 - Response zone 21-27mbgl

Column headings (not shown in the table above): Rock Weathering (SW, MW, HW); Rock Hardness (VH, H, MH, MS, S); Point Load Test (MPa); Core Loss/Lift %; Core size, casing; Graphic Log; Fracture Log (spacing of natural fractures, cm); Date/Depth; Water Level; Drill Water Loss % (0–100); Water Pressure Tests – Lugeons or Permeability – 10^{-7} m/s (0.01, 0.1, 1, 10, 100, 1000)

DRILLER: Boart Longyear
STARTED: 06/10/11
FINISHED: 07/10/11
DRILL: Rig 57

ROCK WEATHERING	ROCK HARDNESS
UW – Unweathered	VH – Very hard
SW – Slightly Weathered	H – Hard
MW – Moderately Weathered	MH – Moderately hard
HW – Highly Weathered	MS – Moderately soft
CW – Completely Weathered	S – Soft
	VS – Very Soft

FRACTURE LOG: Spacing of Natural Fractures (cm): 1000, 500, 100, 50, 10, 5, 1 — Fractures/m of core: 1, 2, 10, 20, 100, 200

EXPLANATION: Defect angles from horizontal

LOGGED: Dmmm DATE: 04/11/11
TRACED: CHECKED: SQH
ORIGINAL VERTICAL SCALE: 1:25 (at A3)
SHEET 4 OF 4 DRG NO.
PROJECT: 27195.200 HOLE NO: 701 LENGTH: 27 CORE BOXES: 10

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 702

PROJECT Ruataniwha Water Storage ..... FEATURE Borehole ..... LOCATION A7
GRID REF 1880527.4E, 5592310.0N ..... CO-ORD NZTM ..... DATUM
ANGLE FROM HORIZONTAL 90° ..... DIRECTION ..... H.A.D. GROUND 437m RL ..... H.A.D. COLLAR

DESCRIPTION OF CORE (WEATHERING, HARDNESS, STRENGTH; COLOUR: ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, mineralogy, texture, cement, etc...); STRATIGRAPHIC NAME.)	ROCK WEATHERING (SW MW HW)	ROCK HARDNESS (H MH MS S)	POINT LOAD TEST (MPa)	CORE LOSS /LIFT % (5 10 50)	DEPTH H.A.D. (Core size, casing)	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) cm (50 10 5 1)	ROCK DEFECTS (PROMINENT JOINTS, BEDDING, SEAMS VEINS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY attitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...)	DATE/DEPTH	R.Q.D. %	WATER LEVEL (Date)	DRILL WATER LOSS % (0–100)	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s (0.01 0.1 1 10 100 1000)
Topsoil													
Brown Ash: SILT with trace fine sand, orange brown, firm, low plasticity, insensitive (Brown Ash) 0.46–0.66 contains fine sandstone gravel													
Terrace Gravel: medium to coarse GRAVEL, with some cobbles + boulders, loose to medium dense, poorly graded, dry. Gravel is strong, slight, weathered sandstone (greywacke)					1.0, 2.0, 3.0				Piezo 2 (31/10/11)				Not tested
Waioeka Petrofacies 1 (Pt1): MW/SW, MH, brown to grey fine SANDSTONE, moderately strong to strong, massive, extremely closely jointed; 5.4-thin mudstone bed					4.0, 5.0			3.2m 1J10°, SR, R, Fest; 3.3m 1J30°, PL, R, Fest; 3.4m 1J30°, WV, SM, Fest; 3.45m 1J45°, CV, R, Fest; 3.5m 2J20°, CV, R, Fest; 3.9m 1J20°, CV, R, Fest; 4.05 2J10°, WV, R, Fest; 4.15m 1J50°, PL, R, Fest; 4.17m 1J60°, PL, R, Fest; 4.25m 1J10°, SR, R, Fest; 4.4m 1J20°, CV, R, Fest; 4.45m 2J20°, PL, R, Fest; 4.6m 1J5°, PL, R, Fest; 4.5m 1J05°, SR, R, Fest; 4.58m 2J5°, CV, R, Fest; 4.6m 3J30°, SR, SM, Fest; 4.8m 2J20°, CV, R, Fest; 4.9m 1J80°, PL, R, CT; 5.0m 1J50°, SR, R, Fest; 5.0–5.6m Shattered; 5.4–1.0 unknown dip – mudstone; 5.6–6.0 Shattered		16%			Not tested
Pt2: SW/MW, MH, grey silty fine SANDSTONE with closely spaced joints, weak (Greywacke) interbedded with SW/MW, MH, dark grey to black MUDSTONE with extremely closely spaced fractures					6.0			6.1m 1J50°, SR, CV silt veneer; 6.2m 1J10°, ST, R, PL; 6.35m 1J35°, ST, C, PL; 6.4–6.5m Shattered core; 6.5m 1J60° – mudstone; 6.6–6.7m broken core; 6.7m 1J70°, SC, SM, CW; 6.7m–6.9m – Shattered core		32%			
Pt1: SW, H, grey SANDSTONE, massive, with closely to very closely spaced joints (Greywacke) strong					7.0, 7.5			7.2m 1J30°, ST, R, PL; 7.2–7.3m broken core; 7.31m 1J60°, PL, R, Fest; 7.35m 1J30°, ST, R, PL; 7.35m 1J30°, SC, R, PL; 7.35–7.5 broken core		24%			

DRILLER: Brad Longyear
STARTED: 20/09/11
FINISHED: 29/09/11
DRILL: Rig 57

ROCK WEATHERING
UW – Unweathered
SW – Slightly Weathered
MW – Moderately Weathered
HW – Highly Weathered
CW – Completely Weathered

ROCK HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very Soft

FRACTURE LOG
Spacing of Natural Fractures (100 50 10 5 1 0.1)
Fractures/m of core (1 2 10 20 100 1000)

EXPLANATION: ① Defect angles are all taken from horizontal

LOGGED: Dmann
DATE:
TRACED:
CHECKED: BAH
ORIGINAL VERTICAL SCALE: 1:25 (at A3)

PROJECT: 271 x 200
HOLE NO: 702
LENGTH: 49.5m
CORE BOXES: 20

SHEET 1 OF 7 DRG NO

C:\USERS\ACADDATA\SIDRILLOG

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 702

PROJECT Ruataniwha Water Storage FEATURE Borehole LOCATION A7

GRID REF 1980527.8 E, 5592814 N CO-ORD NZTM DATUM

ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 437mRL H.A.D. COLLAR

DESCRIPTION OF CORE — WEATHERING, HARDNESS, STRENGTH; COLOUR; ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, minerology, texture, cement, etc...); STRATIGRAPHIC NAME.

ROCK WEATHERING (SW MW HW) | ROCK HARDNESS (H MH MS S) | POINT LOAD TEST (MPa) | CORE LOSS /LIFT % (5 10 50) | DEPTH H.A.D. | Core size casing | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) cm (50 10 5 1) | **ROCK DEFECTS** PROMINENT JOINTS, BEDDING, SEAMS VEINS. SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY altitude, width, spacing, smoothness **(OR SOIL DESCRIPTION)** consistency, compactness, water content, group symbol etc... | DATE/DEPTH | R.Q.D. % | WATER LEVEL (Date) | DRILL WATER LOSS % (0–100) | WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s (0.01 0.1 1 10 100 1000)

Description of core

Stratigraphic name (left margin): Waioeka Petrofacies 1 (Pt1)

SW/UW, H, grey SANDSTONE, moderately widely to closely spaced joints, massive (Greywacke)

UW, H, grey SANDSTONE, massive, strong with very closely to extremely closely spaced joints (Greywacke) interbedded with
UW, MW, dark grey to black MUDSTONE, very closely to extremely closely jointed (Argillite)

Stratigraphic name (left margin): Waioeka Petrofacies 2 (Pt2)

10.3 mudstone in core, bedding disrupted
10.6-10.62m mudstone bed
11.4-11.7m broken mudstone bed
12.2-12.21 - mudstone bed
12.2-12.21 - mudstone bed (discontinuous)
12.2 - 13.5 MH inverse
12.7 - 13.1 - mudstone fragments in broken core
13.3-13.5. MH, UW, dark grey MUDSTONE with very closely spaced joints

Stratigraphic name (left margin): Pt1

UW, H, grey SANDSTONE, massive with closely spaced joints

Depth H.A.D.

7.5, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15

Rock defects

7.52 J 80°, PL, R, D, FeSt
7.6 J 10°, PL, Sm, T, CT
7.7m 2J 60°, PL, R,
7.88m 2J 45°, PL, R
7.95m 2J 40°, PL, R
8.0 J 20°, CV, Sm
8.15 J 25°, CV, R, CT
8.2 J 80°, PL, R, FeSt
8.24 J 20°, PL, R, CT
8.5 J 70°, CV, R, FeSt
8.8 J 70°, CV, R, FeSt
9.1 J 50°, PL, R, FeSt
9.11m 1J 10°, ST, R, FeST
9.22m 1J 60°, CV, R
9.25m 1J 60°, PL, R
9.4m-9.5m core broken
9.45m 1J 40°, CV, R, Cl/FeSt
9.6 2J 60°, IR, R, FeSt
9.85m 1J 0°, CC, R, FeSt
9.97m 2J 70°, PL, R, FeSt
9.97m 1J 20°, PL, R, FeSt
10.1m 1J 60°, IR, R
10.15m 1J 60°, CV, R, FeSt
10.15-10.4m core shattered around steep joint & mudstone bed
10.6m 1J 60°
11.0m 1J 60°, PL, R
11.1m 1J 60°, PL, R
11.3m 1J 60° PL R
11.5m 1J, 50°, broken
11.7m 1J 20°, CV, Sm
11.75 2J 50°, CV, R, FeSt
12.0m 1J 70°, PL, R, FeSt
12.2m 1J 60°
12.5-13.4m Core shattered in zone of discontinuous mudstone and around steep joints
12.7m 1J 70°, PL, R, FeSt
12.9m 1J 70°, IR, R, FeSt
13.2m 2J 45°, ST, Sm, FeSt
13.2-13.3m - Core shattered
13.3m 1J 70°, CV, R, FeSt/CT
13.3-13.5m core shattered
13.5m 1J 65°, PL, R, FeSt, CT
13.6m 1J 5°, IR, R, FeSt
13.6m 1J, 60°, CV, R, FeSt/CT
13.7m 1J 45°, PL, R, CT
13.8m 1J 20°, PL, R, FeSt
13.9m 1J 10°, PL, Sm, FeSt
13.95m 1J 20°, ST, R, CT
14.0m 1J 10°, CV, Sm, CT
14.05m 1J 40°, PL, R, CT
14.1-14.2 core broken around very steep joint
14.7m 1J 45°, SV, Sm, CT
14.9m 1J 5°, SV, Sm, CT
14.8 1J 20°, IR, R, CT
14.4-15.0 core broken

R.Q.D.

69%
37%
53%
20%
11%

DRILLER: Bart Longyear STARTED: 20/09/11 FINISHED: 29/09/11 DRILL: Rig 57	ROCK WEATHERING UW – Unweathered SW – Slightly Weathered MW – Moderately Weathered HW – Highly Weathered CW – Completely Weathered	ROCK HARDNESS VH – Very hard H – Hard MH – Moderately hard MS – Moderately soft S – Soft VS – Very Soft	Spacing of Natural Fractures (1000 500 100 50 10 5 1 0.1 cm) Fractures/m of core (1 2 10 20 100 1000) FRACTURE LOG	LOGGED: DMMM DATE: TRACED: CHECKED: [illegible] ORIGINAL VERTICAL SCALE: 1:25 (at A3) SHEET 2 OF 7
	EXPLANATION:			PROJECT: 27115.200 HOLE NO: 702 LENGTH: 49.5m WATER PRESSURE CORE BOXES: 20 DRG NO

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 702

PROJECT: Ruataniwha Water storage FEATURE: Bore hole LOCATION: A7U

GRID REF: 188.0527 4 E, 559.2511.0 N CO-ORD: NZTM DATUM: 437 m RL

ANGLE FROM HORIZONTAL: 90° DIRECTION: .... H.A.D. GROUND: 437 m RL H.A.D. COLLAR: ....

DESCRIPTION OF CORE (weathering, hardness, strength, colour; rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)	DEPTH H.A.D. (m)	ROCK DEFECTS (prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation, schistosity; attitude, width, spacing, smoothness) (OR SOIL DESCRIPTION: consistency, compactness, water content, group symbol etc...)	R.Q.D. %	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s
UW, H, grey SANDSTONE, massive with closely to very closely spaced joints	15	15.0 m 1J 40°, CV, Sm, CT 15.2 m 2J, 70° PL, R, CN 15.3 m 1J, 90°, CV, R, CT 15.4 m 1J 10°, ST, Sm, CN 15.48 m 1J 10° CV, R, CN 15.5–15.9 m core broken around vertical joint	45%	
	16	16.0 m 1J 60°, PL, R, CN 16.1 m 1J 60°, ST, R, CT 16.2 m 1J 70°, ST, R CN		
	17	16.85 1J 10°, CV, Sm, CN 16.85 1J 70°, ST, R, CT 16.95 m 2J, 70°, CV, R, CN 17.3–30 60°, CV, R, CN 17.1–17.4 core broken around steep joints 17.55 1J 45°, ST, R, CN 17.65 m 1J 70°, WS, R, CT 17.7 m 2J, 45°, PL, R, CT 17.85 m 1J 45°, PL, R, CN 17.95 m 2J 45°, PL, R, CN 17.9 m 2J, 50°, SC, Sm, CT 17.9 m 1J, 80°, SR, R, CT	77%	Packer test failed at 243.7 kPa (stage 2), water overflowed casing (15.75–18 m)
	18	18.2 m 1J 45°, ST, R, CN 18.33 m 1J 60°, PL, R, CN 18.4 m 1J, 45°, CV, R, CN 18.6 m 1J, 40°, PL, R, CN 18.68 m 2J, 45°, SC, R, CN 18.72 m 1J, 5°, CV, R, CN 18.68 m 3J, 30°, PL, R, CN 18.8 m 1J, 60°, PL, R, CT 18.85 m 1J, 90°, ST, Sm 18.85–18.95 m core broken around vertical joints 18.95 m 1J 60°, ST, R, CN 19.0 m 1J 50°, PL, R, CT 19.05 m 1J 20°, CV, R, CT 19.1 m 1J, 0°, IR, R, CT 19.1 m 1J, 70°, PL, has silt veneer 19.2–19.4 core broken 19.4 1J 60°, PL, R has silt veneer	29%	Packer test failed at 315.6 kPa (stage 3), water overflowed casing (17.25–19.5 m)
19.1–19.4 core broken & contains crushed material, joints have silt veneer	19	19.5–20.2 core broken		
	20	19.9 m 1J 10°, ST, Sm, CN 19.9 m 1J 80°, PL, R, CT 20.1 m 2J 60° SC, R, CT 20.1 m 1J 10°, ST, Sm, CT 20.3 1J 10°, PL, R, CN 20.2–20.5 m 6J, 60°, PL, R, CT/silt veneers 20.2–20.6 m core broken with silt on joints 20.7 m 1J 70°, PL, R, CT 20.8 m 1J 60°, CV, R, CT 20.8 m 1J 30°, ST, R, CT 20.9 2CZ 30° ..., infilled with SILT/fine SAND, moist, non plastic. Core broken above crush zones	0%	Packer test failed at ... kPa, water overflowed casing
20.9 Crush zones	21	21.1 1J 30°, SC, R, CN 21.1 1J 60°, WV, R, CN 21.2 1J 30°, ST, Sm, CN 21.3 2J 55°, ST, R, CN 21.5 1J 30°, ST, Sm, CT 21.5 1J 60°, PL, R, CT 21.7 1J 30°, ST, R, CT 21.7 1J 70°, PL, R, CT	55%	Packer test failed at 405.6 kPa (stage 3), water overflowed casing
	22	22.1 3J, 90°, PL, R, CT 22.2 1J 60°, PL, R, CT 22.3 1J 90°, CV, R – with silt veneer 22.4 1J 20°, SV, R, CT 22.4 1J 80°, SR, R, CT 22.4 m – 22.5 m core broken		
	22.5			

Stratigraphic name (vertical, left margin): Waioeka Petrofacies I (Pet)

DRILLER: Bountt Longyear	ROCK WEATHERING	ROCK HARDNESS	Spacing of Natural Fractures / Fractures/m of core	FRACTURE LOG	LOGGED: Dmm	PROJECT: 27115.200
STARTED: 20/09/11	UW – Unweathered	VH – Very hard		100 50 10 5 1 0.1	DATE:	HOLE NO: 702
FINISHED: 29/09/11	SW – Slightly Weathered	H – Hard		1 2 10 20 100 1000	TRACED:	LENGTH: 49.5
DRILL: Rig 57	MW – Moderately Weathered	MH – Moderately hard			CHECKED: BH	
	HW – Highly Weathered	MS – Moderately soft			ORIGINAL VERTICAL SCALE: 1:25 (A3)	CORE BOXES: 20
	CW – Completely Weathered	S – Soft			SHEET 3 OF 7	DRG NO ......
		VS – Very Soft				

EXPLANATION:

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 702

PROJECT: Ruataniwha Water Storage FEATURE: Borehole LOCATION: A7U

GRID REF: 1880527.4E 5597318.0N CO-ORD: NZTM DATUM: 437mRL

ANGLE FROM HORIZONTAL: 90° DIRECTION: ...... H.A.D. GROUND: 437mRL H.A.D. COLLAR: ......

DESCRIPTION OF CORE (weathering, hardness, strength, colour, rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)

UW, H, grey SANDSTONE, massive with closely to very closely spaced joints

Waipawa Petrology? (Wpt) [illegible]

Columns: ROCK WEATHERING (SW, MW, HW) | ROCK HARDNESS (H, MH, MS, S) | POINT LOAD TEST (MPa) | CORE LOSS /LIFT % | DEPTH H.A.D. (22.5–30) | Core size, casing | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) cm | ROCK DEFECTS | DATE/DEPTH | R.Q.D. % | WATER LEVEL | DRILL WATER LOSS % | WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s

ROCK DEFECTS — prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation schistosity, attitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...

- 22.5–22.65m broken core.
- 22.7m 2J45°, PL, R, CN
- 22.75m 1J50°, ST, R, CT
- 22.9m 1J90°, WV, R, CT
- 22.9m 1J10°, PL, R, CT
- 22.9m 1J30°, PL, R, CT
- 22.9–23.6m core breaking around vertical joint
- 23.5m 1J20°, PL, R, CT
- 23.6m 1J20°, PL, R, silt veneer.
- 23.9m 1J45°, SC, R, CN
- 23.95m 1J30°, PL, R, CT
- 24.0m 1J70°, PL, R, CT
- 24.13m 1J60°, SC, R, CT
- 24.15m 1J70–90°, CU, VR, CT
- 24.35m 1J20°, SC, R, CT
- 24.5 1J20°, IR, R, CT
- 24.7 1J40°, CU, SM, CT
- 25.0 1J50°, ST, R, CT
- 25.05 1J30°, CU, R, silt veneer CT
- 25.16m 1J40°, SC, R, CT
- 25.3m 1J65°, WV, R, silt infilling (possibly drill wash)
- 25.5m 1J60°, IR, SM, CT
- 25.6m 1J20°, PL, R, CN
- 25.8m 1J20°, IR, R, CN
- 26.0m 1J55°, PL, R, CT
- 26.0–26.2 core shattered
- 26.2m 1J60°, SC, SM, CT
- 26.2m 2J90°, WV, R, CT
- 26.4m 1J20°, WV, SM, CT
- 26.6m 1J20°, SC, SM, CT
- 26.6–26.7m core shattered
- 26.7m 1J20°, SC, SM, CN
- 26.7m 1J60–90°, IR, R, CT
- 26.8m 1J60°, SC, SM, CT
- 26.9m 1J70°, SC, SM silt infill (possibly drill washings)
- 27.2m 1J60°, IR, R, CN
- 27.2m 1J90°, PL, R, CT
- 27.2m 1J90°, IR, R, CT
- 27.6m 1J50°, SC, SM, CT
- 27.8m 1J70°, ST, R, CN
- 27.9m 2J, 40–45°, ST, R, CT
- 28.1m 2J40°, SC, R, CT
- 28.2m 1J70°, IR, R, CN
- 28.4m 3J 80–90°, SC, R, silt veneer (possible drill wash)
- 28.65m 1J60°, ST, SM, CT
- 28.9m 1J35°, CU, R, CN
- 28.9m 1J90°, WV, SM, CT
- 29.1m 1J30°, CU, R, CN
- 29.25m 1J30°, CU, R, CT
- 29.4m 1J30° CU, SM, CT
- 29.4m–29.6m core broken around vertical joint
- 29.6m 2J60°, CU, R, silt veneer (washings)
- 29.8m 1J45°, ST, R, CN
- 29.8m 1J80°, IR, R, CT

R.Q.D.: 23% ; 67% ; 49% ; 61% ; 81%

Water level: Piezo I (31/10/11)

DRILLER: Brett Langran

STARTED: 20/09/11

FINISHED: 29/09/11

DRILL: Rig 57

ROCK WEATHERING	ROCK HARDNESS
UW – Unweathered	VH – Very hard
SW – Slightly Weathered	H – Hard
MW – Moderately Weathered	MH – Moderately hard
HW – Highly Weathered	MS – Moderately soft
CW – Completely Weathered	S – Soft
	VS – Very Soft

FRACTURE LOG: Spacing of Natural Fractures (cm) 100 50 10 5 1 0.1; Fractures/m of core 1 2 10 20 100 1000

EXPLANATION:

LOGGED: DMinn
DATE: ......
TRACED: ......
CHECKED: BAH
ORIGINAL VERTICAL SCALE: 1:25 (at A3)

PROJECT: 27115.100
HOLE NO: 702
LENGTH: 49.5m
CORE BOXES: 20

SHEET 4 OF 7 DRG NO ......

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 702

PROJECT: Ruataniwha Water Storage FEATURE: Bore hole LOCATION: A74
GRID REF: 1889327 mE, 5592318 mN CO-ORD: NZTM DATUM: 457 m RL
ANGLE FROM HORIZONTAL: 90° DIRECTION: H.A.D. GROUND: 457 m RL H.A.D. COLLAR:

Columns: DESCRIPTION OF CORE (weathering, hardness, strength, colour, rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name) | ROCK WEATHERING (UW SW MW HW) | ROCK HARDNESS (VH H MH MS S) | POINT LOAD TEST (MPa) | CORE LOSS /LIFT % | DEPTH H.A.D. m | Core size, casing | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) cm | ROCK DEFECTS: prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation schistosity, attitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc... | DATE/DEPTH | R.Q.D. % | WATER LEVEL | DRILL WATER LOSS % | WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s

Description of core

WAIOEKA PETROFACIES (Pet1)

32.0 – moderately hard

Pet2

Alternating mudstone + sandstone.
mudstone is: UW, MS, black MUDSTONE weak (Argillite)
sandstone is: UW, MW, dark grey, silty fine SANDSTONE, moderately strong, massive (Greywacke)
32.25 – 32.45 mudstone
32.6 – 32.85 mudstone.
33.45 thin mudstone bed
32.6 – 34.6 – UW, MW, dark grey to black MUDSTONE, massive closely to very closely jointed

34.3 changes to hard + strong

34.6 – 35.5 – core disrupted, brecciated

35.5 – mudstone bed w 15 mm thick
35.6 – mudstone bed w 20 mm thick.

WAIOEKA PETROFACIES (Pet2)

35.8 – UW, MS, dark grey to black MUDSTONE weak, massive, closely to very closely jointed (Argillite)

36.65 m – core highly disrupted & brecciated. Contains sandstone clasts

UW, H, grey SANDSTONE, strong, massive

Depth marks
30, 31, 32, 33, 34, 35, 36, 37, 37.5

Rock defects

30.05 m 1J 55°, IR, R, CT
30.15 m 3J 70°, ST, R, CN
30.5 m 1J 50°, SC, R, CT
30.75 1J 35°, SC, R, CT
30.8 m 1J, 45°, SC, R, CT
30.85 m 1J 45°, ST, R, CN
30.95 m 1J 45°, SC, R, CN
31.2 2J 40°, PL, R, CN
31.4 m 1J 40°, ST, R, CN
31.6 m 2J 60°, CU, R, CN
31.7 m 1J 60°, SC, R, CT
31.7 m 1J 70°, ST, R, CN
31.9 – 32.0 m broken core
32.0 m 1J 30°, IR, R, CN
32.4 2J 5°, WV, R, CN
32.2 m 1J 45°, CU, R, CT
32.25 1B 50°
32.25 – 32.45 m core shattered through mudstone bed
32.55 1J 40°, PL, R, CN
32.6 – 32.85 m core shattered through mudstone bed
32.85 m 1B 40° (possible bedding)
32.9 m 1J 60°, IR, R, CN
33.1 1J 60°, PL, R, CT
33.45 m 1 J 60° (thin mudstone bed)
33.5 m 2J 60°, IR, R, CN (follows disrupted mudstone bands)
33.85 1CZ 10°, CC (gouge has pushed into joints/apertures)
34.1 1J 60°, IR, R, CN
34.15 m 1J 30°, IR, R, CN
34.2 1CZ 70°, CC
34.4 broken core
34.5 1CZ, CC core broken, cannot determine attitude
34.5 – 35.6 m broken/brecciated core.
34.8 m 1J 80°, IR, R, CN
34.9 m 1J 50°, SC, R, silt veneer (washings)
35.1 m 1J 50°, ST, R, silt veneer (possibly drill washings)
35.3 1J 30°, ST, R, CN
35.4 1J 70°, ST, R, silt veneer
35.5 3B 70° – mudstone.
36.0 1J 30°, PL, R, CN
36 m 1J, 5°, IR, R, CN
36.1 – 36.25 core shattered around steeply inclined, disrupted mudstone bed
36.3 m 2J 60°, SC, R, CN
36.5 1J 70°, SC, R, silt veneer
36.6 3J 30°, PL, UR, CN
36.8 1J 20°, IR, R, CN
36.9 m 1J 60°, SC, R, CN
37.0 m 1J 60°, R, R, CN
37.2 m 2J 15°, SC, R, CN
? 2B 30° – mudstone
37.3 m 1J 10°, PL, R, CN
37.4 m 1J 70°, IR, R, CN

R.Q.D.
71% · 42.72% · 51% · 71% · 41%

Key

DRILLER: Boart Longyear
STARTED: 20/09/11
FINISHED: 29/09/11
DRILL: Rig 57

ROCK WEATHERING	ROCK HARDNESS
UW – Unweathered	VH – Very hard
SW – Slightly Weathered	H – Hard
MW – Moderately Weathered	MH – Moderately hard
HW – Highly Weathered	MS – Moderately soft
CW – Completely Weathered	S – Soft
	VS – Very Soft

FRACTURE LOG: Spacing of Natural Fractures (cm): 100, 50, 10, 5, 1, 0.1; Fractures/m of core: 1, 2, 10, 20, 100, 1000

EXPLANATION:

LOGGED: DMM
DATE:
TRACED:
CHECKED: RM
ORIGINAL VERTICAL SCALE: 1:25 (at A3)
SHEET 5 OF 7 DRG NO
PROJECT: 27115.200
HOLE NO: 702
LENGTH: 41.5 m
CORE BOXES: 20

C:\USERS\ACADDATA\SCDRILLOG

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 702

PROJECT Ruataniwha Water Storage FEATURE Bore hole LOCATION A7U
GRID REF 1880527.6E, 5592318.0N CO-ORD. NZTM DATUM 437 mRL
ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 437mRL H.A.D. COLLAR

Depth (m)	DESCRIPTION OF CORE (weathering, hardness, strength, colour, rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)
37.5	UW, H, grey, fine SANDSTONE, massive, closely to very closely jointed (Greywacke)
	37.5 - 38.0 - heavily veining
38.5	UW, MS, black MUDSTONE, thinly bedded, weak, very closely jointed (Argillite) with thin beds of UW, H, darkgrey fine SANDSTONE, very closely jointed, strong
39.3	UW, H, grey, SANDSTONE, strong, massive (Greywacke). with thin beds of UW, MS, weak, black MUDSTONE
	39.5 - 40.5m core disrupted & brecciated
	40.8 changes to UW, H, dark grey silty fine SANDSTONE with thin beds of UW, MH/MS, black MUDSTONE (Argillite)
	41.5 - 42.0 UW, H, grey SANDSTONE
41.4	UW, H, grey SANDSTONE massive, strong, moderately widely jointed
42.0	UW, H, black MUDSTONE, weak - moderately strong, closely to very closely jointed, interbedded with UW, H, dark grey, silty fine SANDSTONE massive, closely jointed
	42.6 - 42.75m crush zone is SILT with minor gravel, loose-medium dense, non-plastic.
42.8	UW, H, grey, fine SANDSTONE, strong massive with closely spaced joints (Greywacke).
	42.8 - 43.5 - heavily veined
	44.4m Thin mudstone bed

Stratigraphic name (margin): WAIOEKA PETROFACIES (PET)

Depth scale: 37.5, 38, 39, 40, 41, 42, 43, 44, 45

Point load test (MPa): 1440/1280; 1655/1500; 1438/1500

ROCK DEFECTS (prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation, schistosity; attitude, width, spacing, smoothness)
37.5 - 37.8 - Heavy veining, random orientation
37.7 - 1J 80°, CU, R, CN
37.8 - 1J 20°, PL, Sm, CN, mudstone parting
38.0m 1J 50°, SC, R, silt veneer
38.2m 2J 70°, UN, R, silt veneer
38.4 1J 70°, UN, R, CN
38.5m 1B 60° - mudstone
38.8 - 39.0m - Broken core
39.0m 1B 60° - mudstone
39.1m - Broken core
39.2 - 3B 60-70° - mudstone
39.25m 1J 60°, ST, Sm, CN
39.5 2B 70° - mudstone
40.1 B 60°
40.4m 1B 60° - mudstone
40.45 - 40.5m - broken core
40.7m 1B 30° - mudstone
40.8m 1B 40° - mudstone
40.8m 1J 40°, ST, R, CN
40.9m 1J 20°, IR, R, CN - disrupted mudstone
41.15m 4B 50° mudstone
41.15 - 41.3m core broken around mudstone beds
41.3m 1J 70°, IR, R, CN
41.5m 1J 30°, SC, R, silt veneer (drill induced)
41.6m 2J 20°, SC, R, CN
41.95 1J 60°, CU, R, CN
42.0 - 42.05m broken core
42.05m 1B 60° - mudstone (broken)
42.15 - 42.25m - core broken
42.25 2B 50° - mudstone broken
42.3 1J 70°, ST, R, CN
42.4 2B 55° - mudstone broken
42.5 1B 65° - mudstone
42.6 - 42.75m 1 CZ 60°
42.8 - 43.5 - heavy veining at various dips
42.85m 1J 20°, SC, R, CN
43.0m 1J 50° ST, R, CT
43.1m 2J 20°, CU, R, CN
43.15m 1J 70°, ST, R, CN
43.4m 1J 10°, PL, R, CN
43.5 1J 20°, SC, Sm, silt veneer (slickensiding)
43.6m 1J 50°, SC, Sm, CT
43.65m 1J 20°, PL, Sm, CN
43.7m 1J 10°, CU, Sm, CT
43.9m 2J 10°, ST, R, CN
44.05m 1J 30°, SC, R, CN
44.05m 1J 60°, SC, R, silt gouge
44.1m 1J 25°, CU, R, silt veneer
44.2m 1J 50°, PL, R
44.3m 1J 30°, SC, Sm
44.4m 1B 20°, argillite
44.5m 2J 40°, IR, R, silt veneer
44.5m 1J 20°, SC, R, silt veneer
44.6m 1J 60°, ST, R, silt veneer
44.6m 1J 20°, SC, Sm, CN
44.7m 2J 40°, IR, R,
44.85 1J 10°, SC, Sm, CN

R.Q.D.: 40%; 75%; 42%; 30%; 37%

DRILLER: Boart Longyear	ROCK WEATHERING	ROCK HARDNESS
STARTED: 20/09/11	UW – Unweathered	VH – Very hard
FINISHED: 29/09/11	SW – Slightly Weathered	H – Hard
DRILL: Rig 57	MW – Moderately Weathered	MH – Moderately hard
	HW – Highly Weathered	MS – Moderately soft
	CW – Completely Weathered	S – Soft
		VS – Very Soft

FRACTURE LOG: Spacing of Natural Fractures (cm) 100, 50, 10, 5, 1, 0.1; Fractures/m of core 1, 2, 10, 20, 100, 1000

EXPLANATION:

LOGGED: DMurray	PROJECT: 27195.200
DATE:	HOLE NO: 702
TRACED:	LENGTH: 49.5 m
CHECKED: BDH	
ORIGINAL VERTICAL SCALE: 1:25 (at A3)	CORE BOXES: 20
SHEET 6 OF 7	DRG NO

G:\USERS\ACADDATA\BOREHLOG

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 702

PROJECT Rwatanwha Water Storage FEATURE Bore hole LOCATION A7W
GRID REF 1860527.4E, 5592318.0N CO-ORD NZTM DATUM 437 m RL
ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 437 m RL H.A.D. COLLAR

DESCRIPTION OF CORE (WEATHERING, HARDNESS, STRENGTH, COLOUR, ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, mineralogy, texture, cement, etc...); STRATIGRAPHIC NAME.)	ROCK WEATHERING (SW MW HW)	ROCK HARDNESS (H MH MS S)	POINT LOAD TEST (MPa)	CORE LOSS /LIFT % (5 10 50)	DEPTH H.A.D. (Core size, casing)	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) cm (50 10 5 1)	ROCK DEFECTS (PROMINENT JOINTS, BEDDING, SEAMS, VEINS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY, attitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...)	DATE/DEPTH	R.Q.D. %	WATER LEVEL (Date)	DRILL WATER LOSS % (0-100)	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s (0.01 0.1 1 10 100 1000)
PE1 UW, H, grey fine SANDSTONE, strong, massive with closely spaced joints					45			45.0-45.05m broken 45.15m 1C 250° - around thin deformed mudstone band 45.4m 1J10°, CT, R, silt veneer 45.3m 1J10°, ST, SH, CT 45.3m 1J50°, PL, SH 45.35m 1J20°, ST, R, silt veneer 45.23m 1J10°, PL, R, CT 45.43m 1J70°, WV, R, CT 45.7m 1J60°, ST, R, CT 45.95m 1J40°, PL, SH, CN 46.2m 1J90°, WV, R, CN 46.25m 1J20°, SR, R, CN 46.4m 1J70°, ST, R, CN 46.45m 1B40° - mudstone		64%			
WAIOEKA PETROFACIES 2 (PE2) UW, H, grey fine SANDSTONE, strong, massive with closely spaced joints interbedded with very thin to thin beds of UW, MS/MH, black MUDSTONE, weak,					46			46.6m 1J40°, CV, R, CN 46.6m 1J55°, SR, R, CN 46.65m 1J55°, SR, VR, CN 46.65m 1J20°, CV, SH, CT 46.8m 1B60° - mudstone core broken around mudstone 47.15 1J20°, PL, R, CT 1J40°, PL, R, CT 47.1m 1B60° - mudstone 47.15m 1J40°, PL, R, CN 47.4 1B60° - argillite 47.7-47.8m broken core 47.8m 1B60° - argillite		49%			
48.0 changes to dark grey silty fine SANDSTONE with thin mudstone beds					47			48.05m 1J10°, CV, R, silt veneer 48.05m 1J40°, SC, R, CN 48.15m 1J20°, SC, R, CN 48.25m 1B60° - mudstone } core broken around mudstone and vertical joint 48.3m 1J90°, SR, R, CT 48.4m 1J20°, SR, R, CN 48.5m 1J55°, WV, R, silt veneer 48.6m 1J90°, PL, R, CT 48.8 4B60° - mudstone core broken below mudstone around vertical joint 49.0m 1J80°, WV, R, CT 49.2m 1J50°, PL, R, CT 49.25m 1J70°, SC, R, CN 49.3-49.5m broken core		33%			
					48								
					49								
					49.5								

End of hole at 49.5 mbgl

Installations:

Piezo 1 - response zone 16.5-22.5 mbgl

Piezo 2 - response zone 39.5-49.5 mbgl

DRILLER: Bent Longyear
STARTED: 20/9/11
FINISHED: 29/9/11
DRILL: Rig 57

ROCK WEATHERING
UW – Unweathered
SW – Slightly Weathered
MW – Moderately Weathered
HW – Highly Weathered
CW – Completely Weathered

ROCK HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very Soft

FRACTURE LOG
Spacing of Natural Fractures 100 50 10 5 1 0.1
Fractures/m of core 1 2 10 20 100 1000

EXPLANATION:

LOGGED: Dmmm
DATE:
TRACED:
CHECKED: BDH
ORIGINAL VERTICAL SCALE: 1:25 (at A3)
SHEET 7 OF 7

PROJECT: 27195-200
HOLE NO: 702
LENGTH: 49.5m
CORE BOXES: 20
DRG NO

Q:\USERS\AGADATA\B.DRILLDO

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 703

PROJECT Ruataniwha Water Storage FEATURE Borehole LOCATION A70

GRID REF 1884704mE, 5592815.6mN CO-ORD NZTM DATUM

ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 426 m [illegible] H.A.D. COLLAR

DESCRIPTION OF CORE (Weathering, hardness, strength; colour; rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)	DEPTH H.A.D.	ROCK DEFECTS / (OR SOIL DESCRIPTION)	R.Q.D. %	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s
Topsoil				
SILT with minor gravel & trace sand, brown, wet, some plasticity. Gravel is moderately weathered, fine-medium grained sandstone (greywacke)	1.0		20%	Not tested
1.4m thin bed of f-m gravel				
Inferred boundary	2			
Coarse GRAVEL with cobbles & boulders, poorly graded. Gravel is slightly weathered sandstone (greywacke)			100%	Not tested
UW, H, dark grey to black MUDSTONE massive, moderately widely to very closely jointed, strong. With thin beds of UW, H, grey to dark grey SANDSTONE, massive, strong.	3	3.0m 1CZ 70°, PL, R, CG		
		3.2m 1J 60°, WV, SL, CT; 1J 70° CV, R, CN; 1J 20°, [illegible], R, CN		
		3.3m 1J 65°, UU, SL, CT; 1J, 5°, ST, R; 2J 45°, PL, SL, CT		
		3.4 1B 45°, PL – mudstone		
		3.4–3.6 Broken core.		
		3.6m 3J 40°, PL, R, CN; 3.6m 1J, 5°, BT, SM; 3.6m 1J 90°, [illegible], R	0%	Not tested
	4	3.6–4.5 broken core.		
4.5m crush zone, clayey, gravelly SILT, grey, plastic. Gravel is angular, SW mudstone & sandstone, medium grained		4.4 1CZ 30°		
		4.55m 1J 45°, PL, [illegible]		
		4.7 2B 50°, WV, [illegible] – possibly bedding		
	5	5.1m 1B; 5.1m 4J 10°, CN, R, CN		
		5.2m 2B 70° (mudstone, possible bedding); 5.2m 1CZ 80°; 4J 70°, PL/ST, R, CN	13%	Not tested
		5.7m 1J 80°, [illegible], R, CN		
		5.9m 1J 20°, ST, R, CT; 1J 70°, PL, R, CT		
		5.95m 1J 40°, [illegible], CN; 1J 20°, [illegible], R, CN		
	6	6.0–6.2 broken core		
		6.2–6.25 1B 30° (crushed mudstone, possible bedding)		Not tested
		6.25 1J 40°, PL, [illegible]; 1J 5°, ST, R, CN		
		6.4m 1J 70°, ST, R, CN		
		6.5m 2J, 20°, [illegible], R		
		6.6m 1B 20°, [illegible]; 2J 60°, PL; 1CZ 40°, PL		
		6.7 1B 70°, crushed mudstone, possible bedding		
	7	1J 60°, SC, R, CN; 1J 70°, ST, R, CN	13%	
		7.1m 3J 10°, [illegible], R – mudstone infill		
		7.1m 1J, 90°, PL, R		
		7.25m 1B 30°, mudstone totally crushed, possible bedding		
	7.5	7.45m 1J 40°, ST, R, CN		

DATE/DEPTH: Water subartesian, overflowing piezo (31/10/11) →

Waioeka Petrofacies 2a (PE2a)

DRILLER: Boart Longyear

STARTED: 03/10/11

FINISHED: 12/10/11

DRILL: Rig 25

ROCK WEATHERING: UW – Unweathered; SW – Slightly Weathered; MW – Moderately Weathered; HW – Highly Weathered; CW – Completely Weathered

ROCK HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very Soft

FRACTURE LOG: Spacing of Natural Fractures (100, 50, 10, 5, 1, 0.1) / Fractures/m of core (1, 2, 10, 20, 100, 1000)

EXPLANATION: Defect angles from horizontal

LOGGED: D[illegible] DATE: 04/11/11

TRACED:

CHECKED: BRM

ORIGINAL VERTICAL SCALE: 1:25 (at A3)

PROJECT: 27195.200

HOLE NO: 703

LENGTH: 45m

CORE BOXES: 17

SHEET 1 OF 6 DRG NO

T+T TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 703

PROJECT: Ruataniwha Water Storage ... FEATURE: Borehole ... LOCATION: A7U
GRID REF: 1880704.4E, 5592315.6N ... CO-ORD: NZTM ... DATUM:
ANGLE FROM HORIZONTAL: 90° ... DIRECTION: ... H.A.D. GROUND: 426mRL ... H.A.D. COLLAR:

DESCRIPTION OF CORE (Weathering, hardness, strength; colour, rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)	Depth H.A.D. (m)	ROCK DEFECTS (prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation schistosity; attitude, width, spacing, smoothness) (OR SOIL DESCRIPTION)	R.Q.D. %	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s
UW, H/MH, dark grey to black MUDSTONE, weak to moderately strong, clay, closely jointed, interbedded with thin to moderately thin beds of:	7.5	7.5-7.7m broken core. 7.6m 1J 70°, SC, R; 7.7m 2J 45°, PL, R, CN; 7.8m 2J 60°, PL, R, CT		
UW, H/MH, grey fine SANDSTONE, strong, massive, closely to very closely jointed	8	7.9 1J 70° WV, SM, CN; 8.0 1B 70° (Defined mudstone); 8.1m 1J 60°, PL, R, CN; 8.2m 1J 70°, ST, R; 8.3-8.5 broken; 8.4 1J 90°, ST, R, CN; 8.48m 1J 10°, WV, R; 8.5m 2J 50°, IR, R; 8.6 1J 80°, ST, R, CN	15%	
8.8-9.0 No recovery		8.6-8.8 core broken		
9.0-9.9 Brecciated zone		lost core, likely due to steeply dipping mudstone bed.		
9.4m crush zone with plastic clay gouge.	9	9.0m 90° mudstone veining; 9.0m 1C 60°; 9.2m 2J 45°, SC, R, CN; 1J 70° IR, R; 9.4 1B 70°; 1C 80°; 9.6m 1J 50°, IR, R, CN	41%	
10.4m crush zone with plastic clay gouge.	10	9.75m 1J 40°, CU, R, CN; 9.8m 1J 30°, SC, R, CN; 9.9m 1J 40°, PL, R; 1J 70°, IR, R; 10.0m 1J 70°, CU, R, CT; 10.1m 1J 30°, CU, R, CN; 10.4m 1C 30°, CG; 10.4m 2J 20°, PL, R, CN; 10.5 1C 45°, PL, CG, crushed mudstone; 10.5m 1J 45°, ST, R; 1J 70°, CU, R - polished, crushed mudstone; 1J 70°, SC, R, CN		9.75-12m test failed during first stage
10.9-11.3 light coating of red mineral on joints; 10.9-12.9 massive sandstone	11	10.7 1B 70°, WV mudstone; 10.9-11.05 core broken around steep joint; 10.9m 1J 80°, SC, SM; 1J 80°, ST, R, CN; 11.0 1J 20°, IR, R; 11.2 2J 50°, PL, R; 11.3 1J 60°, ST, R; 11.3m 1J 20°, ST, R, CN; 2J 70°, ST, R, CN; 11.4-11.6m core broken around steep joint	0%	
UW, H, grey SANDSTONE, massive, strong	12	11.7 1J 80°, SC, R; 1J 60°, ST, R; 1J 70°, IR, R; 11.8 2J 10°, IR, R, CT; 11.95 1J 40°, PL, R, silt veneer; 11.9 2J 80°, IR, R; 11.9-12m broken core; 12.0m 1J 10°, IR, R; 12.05m 1J 55°, PL, R, CN; 1J 60°, PL, R, CN; 1J 10°, PL, R, CN; 12.15 2J 45°, R, O, CN; 12.3m 2J 80°, ST, R, CN; 12.40m 1J 45°, SC, R, CN; 1J 10°, PL, SM; 12.4-12.5 broken; 12.6-12.6 broken core; 12.65m 1J 50°, SC, R, CN; 12.75m 1J 15°, ST, R; 1J 80°, WV, R, CN; 12.85m 1J 50°, SC, R, CT; 12.9 1J 85°, IR, R	17%	
UW, H, dark grey to black MUDSTONE massive, strong, extremely closely jointed	13	13.0-13.3 core broken around steep joint; 13.5 1B 70° (mudstone parting) crushed at contact with clay gouge at base + broken core; 13.5m 1J 45°, IR, R, CN; 13.6m 1J 30°, CU, R, CN; 2J 40°, PL, R, CN; 13.6-13.65 broken; 13.65m 1J 75°, SC, SM, CN; 1J 70°, ST, R, CN; 13.7m 2J 10°, IR, R		
13.5-13.7m sandstone bed	14	13.75m 1B 60° (contact with sandstone); 13.75-14.9 broken core; 14.0 clay gouge material	0%	
14.9 100mm thick crush zone with clay gouge	15	14.7m 2J 60°, PL, R, CN; 14.9m 1C 70° CG		

(Margin, written vertically: WAIKEKA PETANE GROUP 2a (LWPE 2a))

DRILLER: Boart Longyear	ROCK WEATHERING	ROCK HARDNESS	FRACTURE LOG	LOGGED: DMMR	PROJECT: 27195.200
STARTED: 3/10/11	UW – Unweathered	VH – Very hard	Spacing of Natural Fractures: 100, 50, 10, 5, 1, 0.1	DATE: 04/11/11	HOLE NO: 703
FINISHED: 12/10/11	SW – Slightly Weathered	H – Hard		TRACED:	LENGTH: 45m
DRILL: Rig 25	MW – Moderately Weathered	MH – Moderately hard	Fractures/m of core: 1, 2, 10, 20, 100, 1000	CHECKED: BDH	CORE BOXES: 17
	HW – Highly Weathered	MS – Moderately soft		ORIGINAL VERTICAL SCALE: 1:25 (at A3)	
	CW – Completely Weathered	S – Soft		SHEET 2 OF 6	DRG NO
		VS – Very Soft			

EXPLANATION: Defect angles from horizontal

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 703

PROJECT Ruataniwha Water Storage FEATURE Borehole LOCATION A7

GRID REF 1380704mE, 5512315.6mN CO-ORD NZTM DATUM

ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 426mRL H.A.D. COLLAR

DESCRIPTION OF CORE
WEATHERING, HARDNESS, STRENGTH, COLOUR, ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, mineralogy, texture, cement, etc...); STRATIGRAPHIC NAME.

ROCK DEFECTS
PROMINENT JOINTS, BEDDING, SEAMS VEINS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY attitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...

Pleistocene

UW, M, dark grey to black MUDSTONE, subvertical foliation, very closely spaced joints

15.6m - UW, VH, grey fine SANDSTONE, very strong, with closely to very closely spaced joints

15.5-16m - deformed and contains numerous elongated mudstone fragments all steeply dipping

18.5-18.75 contains steeply dipping mudstone seams

WAIPAWA PETROGALES 1 (PG1)

15.87-15.2 core broken

15.25m - 18.80° mudstone parting
23/09, PL, R, CN
17/45, CV, R
23/09, PLR

15.35-15.45m broken core

15.45m 162/66, dip could not be obtained

15.9m 23/35°, ST, R, CN
17/65°, CV, SL, CN - mudstone parting

15.95m 15/15°, PL, SM, CW
13/80°, CV, R, CN
16.08m 35°, PL, R, CN
18/20° - mud/silt parting
16.48m 60°, IR, R, CN
16.5m 23/10°, PL, R, CN
13/80°, IR, R, CN
16.6m 16.5 core broken around steep joint
16.6m 85°, MW, R, CN
16.7m 13/40°, PL, R, CN
13/30°, PL, R, CN
16.95m 15/15°, ST, R, CN
13/65°, ST, R, CN
17.05m 13/30°, PL, R, CN
17.1m 13/50°, SC, R, CN
13/70°, PL, R, CN
17.2m 15/5°, ST, R, CN
17.25m 23/25°, SC, R, CT
17.5m 15/5°, ST, SM, CN
17.7m 15/5°, PL, R, CT
17.8m 15/5°, PL, R, CT
13/55°, SC, R, CN
17.9m 15/5°, ST, R, CN
18.05 15/60°, ST, R, CN
18.2 15/50°, SC, R, CN
18.25m 13/10°, SC, R, CN
23/35, SC, R, CN
18.4m 23/10°, PL, R, CN
18.45-18.5 core broken
18.5m 28/40° - mudstone (deformed)
18.6m 18/65° - mudstone (deformed)
18.65m 15/5°, IR, R, CN
18.8 33/20°, ST, R, CN
28/85°, CW, R, CN
19.0m 13/15°, SC, R, CN
19.05 13/90°, W, - mudstone parting
19.1 13/10°, PL, R, CN
13/5°, IR, R, CN
67/50°, PLR, CN
19.2m 13/50°, PL, RM - mudstone parting
13/90°, CV, R, CN
19.37-19.45 core broken around steep joint
19.4 13/60°, W, R, CN
19.45 13/15°, PL, R, CN
20.05 13/10°, PL, R, CN
20.1m 13/20°, ST, R, CN
20.2m 23/25, W, ST, R, CN
20.3-20.35m core broken around steep joint
20.35 23/10°, SC, R, CN
20.45 43, 10°, SC, R, CN
20.45m 13/5°, PL, R, CN
20.6m 13/20°, SC, R, CN
20.8m 13/70°, PL, R, CN
20.95m 13/80°, SC, R, CN
21.0m 13/50°, SC, R, CT
13/90°, W, R, silt veneer
21.05 23/5°, W, R, CN
21.1 13/60°, PL, R - silt veneer
21.2m 13/5°, ST, R, CN
21.5m 13/5°, PL, R, laval/decoating
21.6m 23/20°, ST, R, mud/silt decoating
13/20°, IR, R, CT
21.7m 13/50°, PL, R, CT
21.8m 13/30°, IR, R, CT
13/60°, PL, R, CN
22m 13/50°, PL, R, CN
13/10°, PL, R, CN
22.1 23/5°, SC, R, CN
22.2 23/10°, SC, R, CN
22.3 23/40°, PL, R, CN
13/5°, IR, R, CN.

DATE/DEPTH: 10% 34% 31% 39% 15%

WATER LEVEL: R.O.D. % Date

DRILL WATER LOSS %: 0-100

WATER PRESSURE TESTS - Lugeons or PERMEABILITY - 10^{-7} m/s: 0.01 0.1 1 10 100 1000

CORE LOSS /LIFT %: 5 10 50

POINT LOAD TEST (MPa)

ROCK HARDNESS: H VH MH MS S VS

ROCK WEATHERING: SW MW HW CW

GRAPHIC LOG

FRACTURE LOG (Spacing of natural fractures): 50 10 5 1 cm

DEPTH H.A.D. m: 16 17 18 19 20 21 22 22.5

Core size, casing

ROCK WEATHERING
UW - Unweathered
SW - Slightly Weathered
MW - Moderately Weathered
HW - Highly Weathered
CW - Completely Weathered

ROCK HARDNESS
VH - Very hard
H - Hard
MH - Moderately hard
MS - Moderately soft
S - Soft
VS - Very Soft

FRACTURE LOG
Spacing of Natural Fractures
Fractures/m of core

EXPLANATION: Defect angles from horizontal

DRILLER: Brent Langyear
STARTED: 3/10/11
FINISHED: 12/10/11
DRILL: Rig 25

LOGGED: DMM
DATE: 04/11/11
TRACED:
CHECKED: BAH
ORIGINAL VERTICAL SCALE: 1:25 (at A3)

PROJECT: 27193.200
HOLE NO: 703
LENGTH: 4.5m
CORE BOXES: 17

SHEET 3 OF 6
DRO NO

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 703

PROJECT Rosterwhe Water Storage FEATURE Borehole LOCATION A7

GRID REF 1880704.46 5542815.6N CO-ORD NZTM DATUM

ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 466 mRL H.A.D. COLLAR

DESCRIPTION OF CORE WEATHERING, HARDNESS, STRENGTH, COLOUR, ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, mineralogy, texture, cement, etc...); STRATIGRAPHIC NAME.	ROCK WEATHERING SW NW HW	ROCK HARDNESS H MH MS S	POINT LOAD TEST (MPa) 5 10 50	CORE LOSS /LIFT %	DEPTH H.A.D. Core size, casing m	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) 50 10 5 1 cm	ROCK DEFECTS PROMINENT JOINTS, BEDDING, SEAMS VEINS. SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY attitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...	DATE/DEPTH R.C.O. % Date	WATER LEVEL	DRILL WATER LOSS % 0–100	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s 0.01 0.1 1 10 100 1000
UW, H, grey, fine SANDSTONE, very strong, massive with closely to very closely spaced joints					24 25			22.8m 15 50°, CV, R, CN 23.4m 13 20°, SC, R, ST 23.75m 15m 20°, R, CN 23.85 55 10°, R, R, CN 23.05m 35 20°, SC, R, CN 23.2-23.5 5°, SC, R, CN 23.35m 15 20°, SR, R, CN 23.3m 20 70°, SR, R. 23.3-23.45 – core broken around steep joint 23.5-23.55°, SC, R, ST 23.65m 15 20°, PL, R, CN 15 40°, SC, R, CN 23.8 15 70°, SC, R, ST 23.8 25 10°, PL, R, ST 23.95 35°, CN, R – malachite coating 23.95-24 – broken core 24.0-24.3 15 40°, SC, R, CN } core broken around these joints 40 30°, SC, R, ST 15 60°, ST, R, CN 24.2m 15 15°, SC, R, CN 15 70°, CV, R, ST 15 30° PL, R, silt veneer 24.35-24.55 broken around steep joint 24.55 25 35° PL, R, ST 15 40°, SR, R, CN 24.9 25 10°, SC, R, CN 25.1 15 70°, CN, R, silt veneer 25.2-25.5 core broken around steeply dipping joint	0%			
UW, H, dark grey to black, MUDSTONE, massive, strong with closely to extremely closely spaced joints (Argillite). Deformed + steeply dipping					26			25.5m 15 50° PL, R, CN 25 75°, PL, R, CN 25.7-25.75m mud/bedparting 25.85 15 65°, SR, R 25.85 15 10°, SC, R, CN 25.85-25.95 CN – broken 25.95 15 35°, SR, R, CN 26.05 15 30°, SR, R, CN 26.1 15 15°, SR, R, CN 26.2 15 15°, SR, R, CN 26.3 15 10°, SR, R, silt veneer 26.5-26.7 broken core 26.5 – likely crushed mudstone contains concretionary material 26.7-26.8 80°, W, Sm mud/bedparting	22%			
26.6m severely crushed + broken core												
UW, H, grey SANDSTONE, massive + strong with closely to very closely spaced joints					27			26.85-27 core broken 27.0-27.15 35° W, R, CN 15 80° – mudstone parting 27.2m 25 30° SR, R, CN 27.3m 15 90°, PR, R, CN 27.2-27.35 CN – broken core 27.4 15 40°, PL, R, CN 15 80°, CV, R, CN				
27.2-27.3 – Sandstone is brecciated down the mud down					28			27.9 25 65° SC, R, CN 15 10°, SR, R, CN 28.0-28.3 90°, CV, R, CN 28.2m core broken around steep joints 28.3m 15 30° SR, R, CN 28.4m 25 60°, CV, R, CN 28.4-28.5 broken core.	33%			
					29			28.5m 15 40°, PL, R, silt veneer 28.6m 15 55°, PL, R, CN 15 85° CV, R, SR. 28.9-29.05 35° PL, R, CN 15 60° PL, R, 35/CT 15 75° PL, R, 35/CT 29.1m 15 20° SC, R, laminated coating 29.1m 15 50° W, R, CN 15 80° PL, R, 35/CT 29.2m 15 30° PL, R, CN 15 60° SC, R, CN 15 70° PL, R, ST 25 20° PL, R, CN 15 40° R, R, CN 29.4m 15 35° R, R, CN 29.5-29.7m 30° SR, CN – core broken around these	0%			
					30			29.7m 15 85° CV, R, ST 25 30° SC, R, CN 15 30° SR, R, CN 35 10° PL, R, CN 29.9m 15 10° SR, R, CN				

DRILLER: Boart Longyear
STARTED: 3/10/11
FINISHED: 12/10/11
DRILL: Rig 25

ROCK WEATHERING
UW – Unweathered
SW – Slightly Weathered
MW – Moderately Weathered
HW – Highly Weathered
CW – Completely Weathered

ROCK HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very Soft

FRACTURE LOG
Spacing of Natural Fractures
Fractures/m of core

EXPLANATION: Dashed angles from horizontal

LOGGED: Bmunn
DATE: 04/11/11
TRACED:
CHECKED: BM
ORIGINAL VERTICAL SCALE: 1:25 (at A3)

PROJECT: 27195.200
HOLE NO: 703
LENGTH: 45 m
CORE BOXES: 13

SHEET 4 OF 6 DRG NO

G:\WORKS\HEADDATA\S.PRI.LOG

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 703

PROJECT Ruataniwha Water Storage FEATURE Borehole LOCATION A7

GRID REF. 1880704.4E, 5592815.6N CO-ORD. NZTM DATUM

ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 426mRL H.A.D. COLLAR

DESCRIPTION OF CORE (WEATHERING, HARDNESS, STRENGTH; COLOUR; ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, minerology, texture, cement, etc...); STRATIGRAPHIC NAME.)	DEPTH H.A.D.	ROCK DEFECTS (PROMINENT JOINTS, BEDDING, SEAMS VEINS. SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY altitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...)	R.Q.D. %	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s
UW, H, grey fine SANDSTONE, very strong, massive with closely to very closely spaced joints.	30	30.4m 1J 40°, CU, R, CT		
		30.18m 1J 50°, PL, R, silt veneer.		
		30.4 1J 45°, PL, R, CN		
		30.5m 1J 45°, PL, R, CT / 1J 40°, SC, R, CT		
		30.55m 1J 5°, ST, R, CN		
		30.65m 1J 35°, SC, R, CN		
30.85m steeply dipping mudstone (argillite parting) ~ 10mm thick.		30.75m 1J 60° SC, R, CT	37%	
30.9–31m – sandstone is brecciated and core broken below mudstone.		30.8m 3J 30°, CV, R, CN / 1J 75°, PL, R, CL		
	31	30.85 1J 70° – argillite parting		
		30.9–31m – core brecciated + broken below argillite		
		31.2 1J 10°, CU, R, CN / 3J 05°, SC, R, silt veneer		
		31.25 1J 10°, PL, R, CN		30.75 – 33.0m L = 0
		31.7m 1J 70° WV, R, silt veneer		
		31.9 1J 60°, WV, R, CN / 1J 45°, K, R, CN		
32.2–32.6m – heavily veined and moderately hard, strong	32	31.95 1J 85°, CN, R, CT / 1J 30°, ST, R, silt veneer / 1J 65°, SE, R, silt veneer } core broken around these.		
		32.1m 1J 45°, ST, R, SC / 1J 60°, PL, R, CN		
		32.3 1J 50° WV, R, silt veneer / 1J 5° ST, CN	51%	
		32.4 2J 45°, CU, R, CN		
		32.6 1J 10° WV, R, CN / 1J 70° CV, R, CN		
		32.75 1J 45°, ST, R, CN		
		32.9 1J 10°, PL, R silt veneer / 1J 40°, SC, SM, silt veneer		
	33	33m 1J 10°, ST, R, silt veneer / 1J 60°, WV, R, CT		
		33.1m 1J 10°, SE, R, CT / 1J 60°, SC, R, CT/SC		
		33.25 1J 10°, PL, R, SC/CT		
		Check photos		
		33.75m 1J 70°, CV, R, CT		
		33.8m 2J 10°, ST, SM, SC/CT / 1J 45°, PL, R, SC/CT		
	34	33.9 1J 55°, SE, R, CN	27%	
		34.0m 2J, 40°, SE, R, CN		
		34.05m 1J 15°, PL, R, silt veneer / 2J 70° SC, R, CN		
		34.25m 1J 15°, PL, R, CN / 1J 60°, CV, R, silt veneer.		
		34.4–34.5m broken core.		
		34.6m 1J 75°, WV, R, SC/CT		
		34.75m 1J 20°, SC, R, CN		
		34.8m 1J 15°, ST/W, R, CN		
	35	34.9m 1J 50°, ST, R, CT / 1J 80°, PL, R – silt veneer		
		35m 1J 20°, ST, R, CN		
		35.1m 1J 10°, ST, R, CN		
		35.2 1J 85° PL, R, CT/SC		
		35.2–35.5m – core broken around steep joints	28%	
		35.5 2J 5°, SC, R, CN		
		35.6 1J 80°, SW, R, silt veneer / 1J 45° SC, R, SC/CT		
		35.5 1J 60° SC, R, SC/CT		
	36	35.9 1J 10°, PL, R, SC / 1J 40°, SC, R, silt veneer / 1J 60°, PL, R		
		36.0 3J 80°, SC, R, CN / 3J 90°, CN, R, CN		
		36.2 3J 70°, PL, R, silt veneer / 36.3 1J 70°, PL, R, CN } core broken around these.		
		36.50 2J 85°, SE, R, CN		
		36.6 1J 10°, CU, R, CT / 1J 45°, CN, R, silt veneer		
		36.7 1J 90°, WV, R, SC/CT / 1J 70°, PL, R, SC, CT		
		36.7–37.2m core broken around vertical joint	7%	
	37	37.15m 1J 65°, SC, R, CN		
		37.2m 1J 90°, CV, R, CN		
		37.3m 1J 10° SC, R, CN		
	37.5	37.45m 1J 40°, WV, R, CT/SC / 36.5–37.5m – broken		

WAIOEKA PETROFACIES (Tw)

DRILLER:	ROCK WEATHERING	ROCK HARDNESS	FRACTURE LOG		
Boart Longyear	UW – Unweathered	VH – Very hard	Spacing of Natural Fractures: 1000, 50, 10, 5, 1, 0.1	LOGGED: Dmm	PROJECT: 27195.200
STARTED: 3/10/11	SW – Slightly Weathered	H – Hard		DATE: 04/11/11	HOLE NO: 703
	MW – Moderately Weathered	MH – Moderately hard	Fractures/m of core: 1, 2, 10, 20, 100, 1000	TRACED:	LENGTH: 45m
FINISHED: 12/10/11	HW – Highly Weathered	MS – Moderately soft		CHECKED: BAH	
	CW – Completely Weathered	S – Soft			
		VS – Very Soft			
DRILL: Rig 25	EXPLANATION: Defect angles from horizontal			ORIGINAL VERTICAL SCALE: 1:25 (approx)	CORE BOXES: 17
				SHEET 5 OF 6	DRG NO

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 703

PROJECT: Ruataniwha Water Storage — FEATURE: Bore hole — LOCATION: A7

GRID REF: 1880704.4E, 5597315.6N — CO-ORD: NZTM — DATUM:

ANGLE FROM HORIZONTAL: 90° — DIRECTION: — H.A.D. GROUND: 426mRL — H.A.D. COLLAR:

DESCRIPTION OF CORE (WEATHERING, HARDNESS, STRENGTH; COLOUR; ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, mineralogy, texture, cement, etc...); STRATIGRAPHIC NAME.)	DEPTH H.A.D.	ROCK DEFECTS (PROMINENT JOINTS, BEDDING, SEAMS VEINS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY attitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...)	R.Q.D. %
UW, H, grey, fine SANDSTONE, very strong, massive with closely to very closely spaced joints with steeply dipping very thin mudstone beds		37.5m 2J65°, CV, R, silt veneer 37.65-37.8 - core broken around steep joint 37.9m 1J90°, ST, R, CN; 1J40°, ST, R, CN 37.9m 1J80°, WV, R/SE/CN	
	38	38.2 1J90°, CV, R, CN; 1J30°, WV, R, CN 38.3, 45 1J?, PL, R, CN 38.5, 1J75°, SC, R, SE/CS; 1J 20°, SE, R, CN	54%
38.8 core contains mudstone fragments		38.9m 1J60°, ST, R, CN	
	39	39.0m 1J/B95° mudstone parting 39.0-39.3m core broken around mudstone parting 39.3m 1J60°, ST, R silt veneer 39.4m 1J20°, ST, R 39.835 80°, ST/CV, R, SC, CT	
	40	40.0m 1J5°, SR, R, CN 40.1-40.3 core broken around mudstone parting 40.4m 2J70°, WV, R SE/CT 40.43 1J/B 60°, WV, R - mudstone parting	10%
40.75-41m - Mudstone "tears" on side of core		40.8 1J50°, CV, mudstone parting 40.9 2J70°, SR, R, CV; 1J50°, SR, R - core broken around these joints	
	41	41.5m 2J65°, PL, R, CN; 1J60° ST, R, SE/CT 41.6 2J60° WV, R, CN; 1J 70°, CV, R; 1J 10°, PL, R 41.9m 1J90°, CV, R, CN	54%
42.1m UW, H, black MUDSTONE; strong with very closely to extremely closely spaced joints heavily deformed with subvertical partings	42	42.0m 1J30°, PL, R, SE/CT 42.2 1J/B85, WV mudstone parting 42.1 1J30°, ST, R, CN; 1J/B85° mudstone parting 42.22 2J85°, WV mudstone parting 42.4 1J/B65° WV mudstone parting	
	43	43.1 1J70°, CV, SM - mudstone coating	13%
UW, H, grey, fine SANDSTONE, very strong, massive with closely to very closely spaced joints heavily deformed, brecciated & re-healed with subvertical mudstone partings & beds		43.4 1J50°, WV, SM, mudstone parting 43.6-43.9m broken 43.4m 1J85°, CV, mudstone parting 43.7m 2J 70°, CV, R, CN 43.75 1J70° CV - mudstone 43.9m 1J 70°, WV, R, CN	
End of hole at 45mbgl Installations Piezo 1 - response zone 13 to 20mbgl Piezo 2 - response zone 37 to 45mbgl	44	44.3m 2J 85°, WV, R, CN 44.4-44.5m core broken 44.5m 2J/B 85°, mudstone partings 44.8m 1J 15° PL, R, CN	8%
	45		

Stratigraphic name (left margin): WAIOEKA PETROFACIES 1 (PZ1); WAIOEKA PETROFACIES 3a (PZ2a)

DRILLER: Bart Longspar	ROCK WEATHERING	ROCK HARDNESS	FRACTURE LOG	LOGGED: D. Wiman	PROJECT: 27195.200
STARTED: 3/10/11	UW – Unweathered	VH – Very hard	Spacing of Natural Fractures (cm): 100, 50, 10, 5, 1, 0.1	DATE: 04/11/11	HOLE NO: 45m
FINISHED: 12/10/11	SW – Slightly Weathered	H – Hard		TRACED:	LENGTH:
DRILL: Rig 25	MW – Moderately Weathered	MH – Moderately hard	Fractures/m of core: 1, 2, 10, 20, 100, 1000	CHECKED:	
	HW – Highly Weathered	MS – Moderately soft		ORIGINAL VERTICAL SCALE: 1:25 (at A3)	CORE BOXES: 17
	CW – Completely Weathered	S – Soft VS – Very Soft		SHEET 6 OF 6	DRG NO /

EXPLANATION: Defect angles from horizontal

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 704

PROJECT Ruataniwha Water Storage FEATURE Borehole LOCATION A7
GRID REF 1880777.06, 5592311.0N CO-ORD NZTM DATUM
ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 457.4 mRL H.A.D. COLLAR

DESCRIPTION OF CORE (WEATHERING, HARDNESS, STRENGTH, COLOUR: ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, mineralogy, texture, cement, etc...); STRATIGRAPHIC NAME.)	ROCK WEATHERING (SW MW HW)	ROCK HARDNESS (H MH MS S)	POINT LOAD TEST (MPa)	CORE LOSS /LIFT % (5 10 50)	DEPTH H.A.D. (Core size, casing)	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) cm (50 10 5 1)	ROCK DEFECTS (PROMINENT JOINTS, BEDDING, SEAMS VEINS. SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY attitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...)	DATE/DEPTH	R.C.D. %	WATER LEVEL (Date)	DRILL WATER LOSS % (0–100)	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s (0.01 0.1 1 10 100 1000)
SILT, with trace sand minor gravel, light brown, firm, low plasticity, Gravel is fine, angular sandstone (Completely weathered greywacke)													
HW, MS, greyish brown SANDSTONE, moderately weak (Greywacke)													Not tested
MW, H, dark grey to orange brown MUDSTONE, moderately strong, closely to extremely closely jointed					1					0			
1.0-1.5m No recovery								1.6m 1B20°, PL, R, Fast; 1J20° PL, R, Fast; 1.9m 5J20°, SC, R, Slit weather (weathering)					
MW, H, grey to orange brown SANDSTONE moderately strong, closely to extremely closely jointed (Greywacke)					2			2.1 2J65°, PL, R, Fast; 2.1-2.4 Shattered core; 2.3 1J40°, PL, R, Fast; 2.35 1J35°, SC, R, Fast; 2.4m 1J20°, PL, Sm, Fast; 1J30°, PL, Sm, Fast; 2.5m 1J0°, WV, R, Fast; 2.65m 1J20°, CV, R, Fast, 1B40°; 1J0°, FR, R, Fast; 2.8m 1CZ20°, CG		13%			Not tested
MW, H, dark grey to orange brown MUDSTONE, moderately strong, closely to extremely closely jointed								2.9m 1CZ20°					
SW, H, grey SANDSTONE, massive, strong with closely to widely spaced joints interbedded with SW, H, dark grey to black MUDSTONE, strong, thinly to moderately thinly bedded with closely to widely spaced joints					3			3.0m 1J25°, PL, R, Fast; 3.1m 1J5°, IR, R, Fast; 1J20°, PL, R, Fast; 3.15m 1J60°, SC, R, Fast; 3.25m 1J45°, PL, R, Fast; 3.45 1CZ20°; 3.6 1B30° - mudstone parting					Not tested
SW, H, dark grey to black MUDSTONE, strong (Argillite)					4			4.0m 1CZ30°, CG; 4.1m 2J60°, SC, R, Fast; 2J65°, PL, Polished, clear; 4.2m 1CZ, 55°, CG; 4.3 2J60°, PL, R, Fast; 4.3-4.5m Shattered core (probable crush zone); 4.5-4.6m shattered core; 4.6m 1CZ30°, CG; 4.8 2J20°, mudstone; 4.7m 3J55° PL, R, Fast; 4.85m 4J20° PL, R, Fast		57%			
SW, H, grey SANDSTONE, strong, massive with very closely spaced joints (Greywacke)					5			5.1m 1CZ20°, CG; 5.4m 1 vein 45°; 5.5m 2J 60°, PL, R, Fast; 2J 85°, IR, R, CN; 5.7m 1 vein 60°		19%			Not tested
6.2 changes to silty fine SANDSTONE, dark grey					6			6.0m 1J20°, PL, R, Fast; 1J60°, PL, R, Fast; 6.0m 1J45°, IR, R, Fast; 6.5m 2J65°, PL, R, Fast; 6.1m 3J 50°, PL, Sm, Fast; 1J 70°, PL, R, Fast; 6.2m 1 vein 70°; 6.4m 2J60°, IR, C, CN; 1J25°, PL, R, CN; 6.5m 3J25°, SC, R, Fast; 1J5°, CV, R, Fast; 6.6m 2J40°, PL, R, Fast; 2J70°, PL, R, Slit weather; 6.8 - 6.85 broken core; 6.9 1J60°, PL, R, CT/C - vein; 6.75m 1J15°, PL, Sm, Fast; 10J45°, SC, R, } core broken around these joints; 7.0m 3J 60°, PL, R, Fast }		17%			Not tested
					7			7.3-7.5m - core broken					
					7.5								

WAIKEKA PETROFACIES 2 (PK2)

WAIKEKA PETROFACIES 1 (PK1)

DRILLER: Boart Longyear	ROCK WEATHERING	ROCK HARDNESS	FRACTURE LOG	LOGGED: Dimmin	PROJECT: 27195200
STARTED: 9/10/11	UW – Unweathered; SW – Slightly Weathered; MW – Moderately Weathered; HW – Highly Weathered; CW – Completely Weathered	VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very Soft	Spacing of Natural Fractures (100 50 10 5 1 0.1); Fractures/m of core (1 2 10 20 100 1000)	DATE: 10/11/11	HOLE NO: 704
FINISHED: 12/10/11				TRACED:	LENGTH: 16.5
DRILL: Rig 57				CHECKED: BAH	
	EXPLANATION: Defect angles from horizontal			ORIGINAL VERTICAL SCALE: 1:25 (4 AB)	CORE BOXES: 7
				SHEET 1 OF 3	DRG NO

G:\USERS\ACADMATA\SCORELOG

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 704

PROJECT: Rudanmutna Wate Storage … FEATURE: Bore hole … LOCATION: A7

GRID REF: 1880777.0 E 5592311.0 N … CO-ORD: NZTM … DATUM:

ANGLE FROM HORIZONTAL: 90° … DIRECTION: … H.A.D. GROUND: 457.4m … H.A.D. COLLAR:

DESCRIPTION OF CORE (weathering, hardness, strength, colour; rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)	DEPTH H.A.D.
SW, H, dark grey, silty fine SANDSTONE, massive, strong with very closely to extremely closely spaced joints (Greywacke)	7.5
8.4m changes to unweathered	8.4
8.6 – 4mm mudstone beds dip at 20°	8.6
10.3 moderate veining, veins dip 30° to 70°	10.3
10.7 changes to grey, fine SANDSTONE	10.7
11.7–12.0m moderate veining (steeply dipping)	11.7
12.6m moderate veining	12.6
13.9 changes to dark grey silty fine SANDSTONE	13.9
14.1–14.5m moderate veining	14.1

Stratigraphic name (vertical, left margin): WAIROEKA PETROFACIES (RCL)

ROCK DEFECTS – prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation, schistosity; altitude, width, spacing, smoothness (OR SOIL DESCRIPTION) consistency, compactness, water content, group symbol etc...

- 7.5–7.8m core shattered
- 7.8m 1J 60°, CU, R, FeSt; 1J 70°, IR, R, FeSt; 1J 25°, CU, R, FeSt – core broken around these joints
- 8.0 1J 85°, WV, FeSt; 1 vein, 85°
- 8.4m 1J 35°, IR, R, silt infill, 2mm spacing
- 8.45m 1J 10°, ST, R, FeSt; 1J 50°, PL, R, FeSt; 1J 60°, SL, R, FeSt
- 8.6 2B 20° – mudstone
- 8.7m 1J 65°, SL, R, FeSt; 1J 40°, WV, R, FeSt; 1J 70°, SL, R, CN – core broken around these joints
- 8.9 2J 40°, SL, R, FeSt
- 8.9 – crushed zone
- 9.0–9.3m broken core
- 9.3m 4J 55°, PL/ST, R, CN; 1J 30°, PL, R, silt infill – core fractured around these joints
- 9.6m 2J 40°, PL, R, CN
- 9.65m 2J 85°, SL, R, CN – core fractured around these joints
- 9.75–9.9m – core crushed – mudstone
- 9.9m 1J 65°, WV, R, FeSt, lined; 1C 80°, CG; 1J 20°, PL, SM, CN
- 10.1 2J 10°, PL, R, FeSt
- 9.4–10.1m core broken due to steep joint & CZ
- 10.3 CB cuts across core
- 10.4–10.6 broken core
- 10.6m 6J 70°, PL, R, CN; 2J 30°, SL, R, CN; 1J 80°, PL, R, FeSt – core fractured around these joints
- 10.9m 1 vein 70°
- 11.0m 3J 75°, CU, R, CN; 1J 70°, CU, R, CN; 4J 20°, PL, R, CN – core broken around these joints
- 11.3m 1 vein 70°
- 11.4–11.5m – core broken
- 11.5m 3J 30–40°, WV, R, CN
- 11.7–12.0m – moderate veining, steeply dipping (70°)
- 11.45m 1J 85°, WV, R, CN
- 12.1m 1J 85°, WV, SM (polished), CN; 1J 70°, SL, R, CN
- 12.2m 2J 25°, PL, R, CN
- 12.3 1J 85°, CU, R, CN; 2J 20–30°, WV, R, CN
- 12.5 1CZ 50°, CG
- 12.6 moderate veining 30°
- 12.7m 1J 30°, PL, SM, CN; 2J 50°, WV, R, CN
- 12.9m 1J 65°, CU, R, CN
- 13.2 1CZ 35°, CG; 4J 55°, CU, R, silt veneer; 1J 10°, PL, R, CN; 2J 40°, WV, R, CN
- 13.4 …
- 13.55m 1J 55°, R, silt infill; 13.6m 2J 10°, WV, R, CN; 2J 75°, R, CN
- 13.9 3J 45°; 2J 30–75°
- 14.0m 2J 35°, R, CT/zeolite
- 14.1m 2J 60°, PL, CT/zeolite
- 14.1m veining 70–80°
- 14.3–14.9m – core broken around steep joints
- 14.5–15.0 core broken around steep joints
- 14.6m 1CZ 80°, polished (mudstone parting)
- 14.7 2J 80°, SL, R, CN; 1J 80°, SL, R, CN
- 14.95–15.0 core shattered, possible crush zone

DATE/DEPTH	R.Q.D. %
	0%
	0%
31/10/11 (water level)	0%
	13%
	0%
	0%

WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s
- Not tested
- 9.75–12.0m L=0
- 11.25–13.5m L=0
- 12.75–15m L=0

DRILLER: Bord Longyear	ROCK WEATHERING	ROCK HARDNESS	FRACTURE LOG	
STARTED: 09/10/11	UW – Unweathered	VH – Very hard	Spacing of Natural Fractures (100, 50, 10, 5, 1, 0.1)	LOGGED: [illegible]
FINISHED: 12/10/11	SW – Slightly Weathered	H – Hard	Fractures/m of core (1, 2, 10, 20, 100, 1000)	DATE: 19/11/11
DRILL: Rig 57	MW – Moderately Weathered	MH – Moderately hard		TRACED:
	HW – Highly Weathered	MS – Moderately soft		CHECKED: [illegible]
	CW – Completely Weathered	S – Soft		ORIGINAL VERTICAL SCALE: 1:25 (at A3)
		VS – Very Soft		SHEET 2 OF 3

EXPLANATION: Defect angles from horizontal

PROJECT: 27195.200 · HOLE NO: 704 · LENGTH: 16.5m · CORE BOXES: 7 · DRG NO:

G:\...\SCRIPT\DRILLOG

TONKIN & TAYLOR LTD CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 704

PROJECT Ruataniwha Water Storage FEATURE Bore hole LOCATION A7
GRID REF 1889777.06, 5592311.01 CO-ORD NZTM DATUM
ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND 457.4mRL H.A.D. COLLAR

DESCRIPTION OF CORE (Weathering, hardness, strength; colour; rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)	DEPTH H.A.D. (m)	ROCK DEFECTS (prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation schistosity; attitude, width, spacing, smoothness) (OR SOIL DESCRIPTION)	R.Q.D. %
UW, H, grey fine SANDSTONE, strong, massive with very closely spaced joints (Greywacke) 15.1-16.8m moderate veining, gently to steeply dipping 16.2-16.5 moderate to heavy veining	15.0 – 16.5	15.05-15.1 1B 20° - mudstone rear & broken 15.1m 1J 80°, Sc, R, silt veneer; 2J 60°, U, Ca, CN 15.15 1J 45° - polished - mudstone parting; 1B 20° - polished, mudstone parting 15.4m 1J 05° CU, R, CN 15.5m 1J 20°, PL, R, CN; 1 vein 55° 15.6m 1J 20°, UV, R, CN; 1J 80°, PL, R, CN 15.8-15 65°, UV, R, silt veneer 15.9-1J 85°, UV, R, CN; 1J 70°, PL, R, CS; Vein 5°, IR 16.2-1J 70°, PL, R, CN; 1J 20°, IR, R, CN; 1J 45°, PL, R; 1J 85°, UV, R; 1J 25°, IR, R	45%

Core box: 1 of 1 (15.0–16.5 m)

End of hole at 16.5mbgl

Installation:

Piezo 1 - Response zone 9.0-16.5mbgl

DRILLER:	ROCK WEATHERING	ROCK HARDNESS	FRACTURE LOG		
Boart Longyear	UW – Unweathered	VH – Very hard	Spacing of Natural Fractures: 100 50 10 5 1 0.1	LOGGED: D...	PROJECT: 2719520.00
STARTED: 9/10/11	SW – Slightly Weathered	H – Hard	Fractures/m of core: 1 2 10 20 100 1000	DATE: 10/11/11	HOLE NO: 704
FINISHED: 12/10/11	MW – Moderately Weathered	MH – Moderately hard		TRACED:	LENGTH: 16.5m
DRILL: Rig 37	HW – Highly Weathered	MS – Moderately soft		CHECKED: GH	CORE BOXES: 7
	CW – Completely Weathered	S – Soft		ORIGINAL VERTICAL SCALE: 1:25 (at A3)	
		VS – Very Soft		SHEET 3 OF 3	DRG NO

EXPLANATION: Defect angles from horizontal

C:\WSORS\ICADDATA\SIDRILLOG

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 705

PROJECT: Ruataniwha Water storage FEATURE: Borehole LOCATION: A7

GRID REF: 1880717.8 E, 5592227.9 N CO-ORD: NZTM DATUM:

ANGLE FROM HORIZONTAL: 90° DIRECTION: H.A.D. GROUND: 439.84 H.A.D. COLLAR:

Column headings: DESCRIPTION OF CORE (weathering, hardness, strength, colour; rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name) | ROCK WEATHERING (SW MW HW) | ROCK HARDNESS (H MH MS S) | POINT LOAD TEST (MPa) | CORE LOSS /LIFT % | DEPTH H.A.D. | Core size, casing | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) cm | ROCK DEFECTS (prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation, schistosity, attitude, width, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc...) | DATE/DEPTH | R.Q.D. % | WATER LEVEL | DRILL WATER LOSS % (0–100) | WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s (0.01, 0.1, 1, 10, 100, 1000)

Description of core

0 to 1.5 mbgl · No recovery

1.5m MW, H, grey to brown, fine SANDSTONE, strong closely to very closely jointed (Greywacke)

3.0m becomes slightly weathered

4.6m becomes unweathered, grey

UW, H, grey, fine SANDSTONE massive, strong with closely to very closely spaced joints (Greywacke)

interbedded with

UW, H/MH, dark grey to black MUDSTONE massive, strong with closely spaced joints (Argillite)

Stratigraphic name (margin): Waipapa Petrofacies (Pe1)

PE29

Depth H.A.D.

1, 2, 3, 4, 5, 6, 7, 7.5

Rock defects

1.55 1535°, ST, R, Fast
1545°, PL, R, Fast
1.7m 1545°, SR, R, Fast
1560°, IR, R, Fast
1.8m 1575°, WV, R, Fast
1545°, CU, R, Fast
1.8–3m core shattered

~2.7m 1590°, IR, R, Fast
1580°, CU, R, Fast
1570°, SC, R, Fast
3.0 – 3.4 lost core
3.4 4 J 560°, CU, R, Fast
1 J 10°, PL, R, SK/CT
2 J 70°, PL, R, Fast } core shattered around these joints

3.9 2 J 40°, PL, R, Fast
2 J 90°, WV, R, Fast
3.8–4.2 core shattered around vertical joints
4.3m 1 B 40° – mudstone parting
1 J 30°, SR, R, Fast
4.4m 1 J 10°, PL, R, Fast
4.5 – core shattered around steep joints
4.5 – 5.8 core broken.
4.7m minor veining ~60°
4.7m 1 J 80°, CU, R, ?
4.85m 1 J 70°, ST, R, mudstone coating
1 J 20°, ST, R, CN
1 J 25°, PL, R, CN
5.0 – 5.05 – heavy veining
5.15m 1 J 5°, 1 B 25° – mudstone parting
1 J 85°, ST, R, CN
1 J 55°, ST, SM, CN
1 J 90°, WV, R, CN
5.55m 1 CZ 25°, PL – crushed mudstone
5.6m 1 J 15°, ST, SM, CN
1 B 30° – crushed mudstone
1 J 60°, PL, R, CN
5.75m 1 B 35°, PL, SM – crushed mudstone
1 J 5°, IR, R, CN
5.8m 1 J 85°, IR, R
5.9m 1 J 30°, SR, R
light veining 60°
1 J 60°, SC, R, CN
6.0m 1 J 90°, ST, R, CN
1 J 70°, CU, R, CN
6.2m 3 J 60°, CU, R, CN
6.3 – 1 J 60°, PL, R, SC – vein
6.3–6.5 – shattered core.
6.5 1 J 45°, ST, SM, CN
1 J 40°, PL, R, silt veneer
6.7 2 J 25°, SC, R, CN
6.8m 1 B 55°, SC – crushed mudstone
6.9m 2 J 40°, PL, SM, CN
1 J 55°, PL, R, CN
7.1 3 J 30°, CU, R, CN
2 J 30°, SC, SM, CN
1 B 55°, R – crushed mudstone
7.3 3 J 40°, SK/CT, R, CN
7.4 1 J 40°, PL, R, CN
1 J 45°, PL, R, CN

Date/Depth, R.Q.D., water

31/10/11 (both pieces) — water level marker

R.Q.D.: 0%, 0%, 0%, 0%, 20%

Water pressure tests: Not tested; Not tested; Not tested; Not tested; Not tested

Footer

DRILLER: Boart Longyear

STARTED: 13/10/11

FINISHED: 26/10/11

DRILL: Rig 25

ROCK WEATHERING	ROCK HARDNESS
UW – Unweathered	VH – Very hard
SW – Slightly Weathered	H – Hard
MW – Moderately Weathered	MH – Moderately hard
HW – Highly Weathered	MS – Moderately soft
CW – Completely Weathered	S – Soft
	VS – Very Soft

FRACTURE LOG: Spacing of Natural Fractures (cm): 100, 50, 10, 5, 1, 0.1; Fractures/m of core: 1, 2, 10, 20, 50, 1000

EXPLANATION: Defect angles are from horizontal

LOGGED: [illegible] DATE: 08/11/11 TRACED: CHECKED: BOH

ORIGINAL VERTICAL SCALE: 1:25 (at A3)

PROJECT: 27195.200 HOLE NO: 705 LENGTH: 27m CORE BOXES: 10

SHEET 1 OF 4 DRG NO.

G:\USERS\ACADDATA\SIGGLEG

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 705

PROJECT: Rowtaniwha Water Storage ...... FEATURE: Borehole ...... LOCATION: A7

GRID REF: 1880717.8E 5547327.8N ...... CO-ORD: NZTM ...... DATUM: ......

ANGLE FROM HORIZONTAL: 90° ...... DIRECTION: ...... H.A.D. GROUND: 429.8m ...... H.A.D. COLLAR: ......

DESCRIPTION OF CORE (Weathering, hardness, strength; colour; rock or soil type, defect spacing, lithological features (bedding, foliation, mineralogy, texture, cement, etc...); stratigraphic name)	Depth (m)	ROCK DEFECTS (prominent joints, bedding, seams, veins, shatter, shear & crush zones, foliation, schistosity; attitude, width, spacing, smoothness) (OR SOIL DESCRIPTION)	R.Q.D.
UW, H, grey, fine SANDSTONE, massive, strong with closely to very closely spaced joints (Greywacke) interbedded with very thin to moderately thick UW, H/MH, dark grey to black MUDSTONE, massive, strong, with closely spaced joints	7.5–8	7.5m 1J35°, PL, R, (+) 1J50°, UN, Sm, CN; 7.6 1J70°, PL, R, CN 1J50°, PL, R, Silt veneer; 7.7 2J20°, IR, R, CN; 7.8 1CZ, 60°, mudstone parting 1J40°, UN, SL, CN 1J20°, SL, CN; 7.9 2CZ 30° 2CZ 65°; 8.1m 3J 60°, UN, R, CN; 8.3m 3J 45°, PL, R, CN – core broken around these; 8.5m 3J 60°, UN, R, CN 1J 50°, PL, R, brecciated coating 1J 70°, UN, R, CN; 8.6 1B 50° – argillite – core shattered	0%
8.3–8.6 – contains mudstone (argillite) partings; 8.6 – 9.0 – MUDSTONE bed, UW, MH, strong, dark grey	9	8.7 2B 40° – 4mm mudstone bands; 9.0m 1J 40°, CV, R, CN 1J 70°, CN, R, CN; 9.0–9.1m – core broken; 9.1m 4J 60°, SC, R, SC; 9.15–9.2 – core broken; 9.6 1B 30° – thick mudstone 1J 60°, CV, R, CN; 9.5m 3B 40°, SC, R – very thin mudstone; 9.7m 1J 70°, SC, R	
9.7–10.0m – moderate veining	10	9.7 – veins dip 40°; 10.0m 1J 35°, SC, R	23%
UW, H, dark grey to black MUDSTONE, strong (Argillite) with thin to moderately thick beds of UW, H, grey SANDSTONE, massive, strong (Greywacke); 10.2–10.4 – sandstone bed; 10.5–11.0m – light veining	10–11	10.1 1B 40°, CV, R – mudstone; 10.2 1J 70°, SC, R, CN 3J 60°, PL, R, CN – core broken; 10.4m 1J 50°, ST, R; 10.5m 1J 20°, PL, Sm 1J 70°, UN, R 1J 30°, SC, R; 10.6m 2J 45°, PL, R, CN; 10.8m 1J 55°, PL, slicken 1J 60°, ST, R, CN 1J 35°, PL, R – mudstone parting; 10.9m 1B 40° – mudstone; 10.9 1B 35° – mudstone; 10.8–11.2m broken/shattered core; 11.2 1B 40° – mudstone parting	
11.8 to 11.5 core contains rehealed crush zones	11–12	11.6m 1J 45°, CV, R, CN; 11.7 1B 35°, mudstone parting	51%
12.4 – mudstone has brecciated & rehealed; 12.6–13.0m – light veining	12–13	12.0m 1J 45°, SC, R, CN; 12.1m 1J 70°, UN, R, CN 1J 45°, ST, R; 12.3m 1J 40°, IR, R, CN 1J 45°, PL, R, CN; 12.4 1B 50° [illegible]; 12.6 1J 70°, SC, R, silt veneer; 12.9m 1J 50°, IR, R – zeolite coating 1J 60°, IR, R, CN; 13.0 1CZ 30° – rehealed, core shattered in this zone; 13.1m 1J 55°, ST, R, silt veneer; 13.2 1J 15°, IR, R mudstone parting	47%
UW, H, grey fine SANDSTONE, massive, strong with closely spaced joints	13–13.7	13.45m 1J 60°, ST, R, CN; 13.5m 1J 90°, UN, R, zeolite coating; 13.7m 1J 45° ST, R, CN	
UW, H, dark grey to black MUDSTONE, massive, strong with closely to moderately widely spaced joints	14–15	13.9m 2J 45°, SC, Sm, CN 1B 40°; 13.9m 2J 30°, SC, R, silt veneer 1J 45°, IR, R, CN; 14.1m 1J 60°, CV, Sm, silt veneer; 14.5 2J 45°, ST, R, CN 1B 45°; 14.6m 1J 40°, CV, R, CN	61%
14.6–14.7m – sandstone bed	15	14.7m 1B 40°, mudstone; 15.0m 1J 20°, IR, R	

Stratigraphic name (margin): WAIOEKA PETROFACIES (Pk2a)

DRILLER: Boart Longyear	ROCK WEATHERING	ROCK HARDNESS	FRACTURE LOG	LOGGED: Dimm	PROJECT: 27145.200
STARTED: 13/10/11	UW – Unweathered	VH – Very hard	Spacing of Natural Fractures (cm): 100, 50, 10, 5, 1, 0.1	DATE: 08/11/11	HOLE NO: 705
FINISHED: 24/10/11	SW – Slightly Weathered	H – Hard	Fractures/m of core: 1, 2, 10, 20, 100, 1000	TRACED:	LENGTH: 27 m
DRILL: Rig 25	MW – Moderately Weathered	MH – Moderately hard		CHECKED: ZoH	
	HW – Highly Weathered	MS – Moderately soft		ORIGINAL VERTICAL SCALE: 1:25 (A3)	CORE BOXES: 10
	CW – Completely Weathered	S – Soft		SHEET 2 OF 4	DRG NO:
		VS – Very Soft			

EXPLANATION: Defect angles from horizontal

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 705

PROJECT Ruatanwha Water Storage FEATURE Bore Lake LOCATION A7
GRID REF 1860717.6E, 5592327.8N CO-ORD NZTM DATUM
ANGLE FROM HORIZONTAL 90° DIRECTION H.A.D. GROUND [illegible] H.A.D. COLLAR

DESCRIPTION OF CORE (WEATHERING, HARDNESS, STRENGTH, COLOUR, ROCK OR SOIL TYPE, DEFECT SPACING, LITHOLOGICAL FEATURES (bedding, foliation, mineralogy, texture, cement, etc...); STRATIGRAPHIC NAME.)	ROCK WEATHERING (SW MW HW)	ROCK HARDNESS (H MH MS S)	POINT LOAD TEST (MPa)	CORE LOSS /LIFT % (5 10 50)	DEPTH H.A.D. (Core size, casing)	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) cm (50 10 5 1)	ROCK DEFECTS (PROMINENT JOINTS, BEDDING, SEAMS, VEINS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION SCHISTOSITY, attitude, width, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc...)	DATE/DEPTH	R.Q.D. %	WATER LEVEL (Date)	DRILL WATER LOSS % (0–100)	WATER PRESSURE TESTS – Lugeons or PERMEABILITY – 10^{-7} m/s (0.01 0.1 1 10 100 1000)
Rock is highly disrupted and brecciated and contains a mixture of UW, H, grey, fine SANDSTONE, massive, strong and UW, H, dark grey to black MUDSTONE, massive, strong. 15.4 to 17.0m - moderate to heavy veining, steeply dipping				0%	15			15.15 J15°, JR, R, silt veneer; 15.30° - mudstone; 15.5m J30° PL, R, CN; 15.10° CV, R, CN; 15.70° ST, R, CN; 15.60° - mudstone; 15.4 1B90° mudstone - heavily deformed		85%			
UW, H, grey fine SANDSTONE, massive, very closely jointed, strong (greywacke) interbedded with UW, H, dark grey to black MUDSTONE, massive, strong (Argillite)					16			15.75m J60° PL, R, CN; 15.30° JR, R, CN; 15.9m J90° JR, R, CN; 16.15m J20° JR, R, CN; 16.25m J25° JR, R; 16.25m J70° PL, R; 16.2m 2385° WV, R, CN; 1575° WV, R, CN; 1510° CV, R, CN; 1B15° - mudstone parting; 16.6 1B60° - mudstone parting; 16.5m J50° JR, R, CN; 16.6m 1560° PL, R, zeolite coating; 16.75-16.85m broken core; 16.15 J30° JR, R, CN; 1580° ST, R, CN; 1580.90° - mudstone parting; 17.1 1CZ35°, CG		86%			
					17			17.5m 1325° JR, R, CN; 3860° - sandstone; 17.8 1B40° WV, SM, CN; 1550° PL, R, zeolite coating; 18.0 1B45° WV - mudstone					
18.0-19.5 light veining gently to steeply dipping					18			18.3m J10° JR, R, CN; 18.4m 1565° SC, R, CN; 1555° JR, R, CN; 18.6 1CZ30°, SC, R, CG; 18.75m 1550° SC, R, CN; 1560° PL, R, CN; 18.9m 1B50° - mudstone, but truncated by joint, becomes vertical; 19.1m 1565° PL, R, CN; 1560° SC, R, silt veneer		84%			
UW, H, dark grey to black MUDSTONE, massive, strong (Argillite)					19								
19.5-21m - moderate veining - core is disrupted & brecciated					20			19.95m 1560° WV - mudstone, deformed; 20.1-20.5 4B60-70° - mudstone partings (deformed); 20.23m 1590° WV, SM, CN; 1555° ST, R, CN; 20.5m 2570° PL, R, CN; 20.5-20.55m core broken around steep joints; 20.6m 1530° ST, R, CN; 20.65 2B50° - mudstone; 20.85-21.4 - core broken; 21.4 1530° JR, R, CN; 21.10m 1560° SC, R; 1525° JR, R; 1570° JR, R, CN; 1580° WV, R, CN; 1840°; 21.25m 1510° JR, R, CN; 1595° ST, R, CN; zeolite coating; 1550° PL, R, CN; 21.4 1CZ85°, CG		77%			
21.2-21.6m heavy veining, gently to steeply dipping					21			21.7 1B70° mudstone - truncated on shear zone; 21.9 1560° WV, R, silt veneer; 1590° ST, R; 22.0m 2515° SC, R, CN; 22.2m 1CZ45°, CG; 22.3 1B30° - mudstone; 22.4 1B60° PL, R, CN; 22.45 1B30°		22%			
22.4-22.5 moderate veining					22.5								

WAIOEKA PEDESTRIES 24 (PEZ)

DRILLER: Boart Longyear
STARTED: 13/10/11
FINISHED: 26/10/11
DRILL: Rig 25

ROCK WEATHERING: UW – Unweathered; SW – Slightly Weathered; MW – Moderately Weathered; HW – Highly Weathered; CW – Completely Weathered

ROCK HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very Soft

FRACTURE LOG: Spacing of Natural Fractures (100 50 10 5 1 0.1); Fractures/m of core (1 2 10 20 100 1000)

EXPLANATION: Defect angles from horizontal

LOGGED: Dmmm
DATE: 08/11/11
TRACED:
CHECKED: BOll
ORIGINAL VERTICAL SCALE: 1:25 (at A3)

PROJECT: 27195.200
HOLE NO: 705
LENGTH: 27m
CORE BOXES: 10

SHEET 3 OF 4 DRG NO

G:\WSGIS\ACADDATA\S.DRILLOG

TONKIN & TAYLOR LTD
CONSULTING ENGINEERS

DRILL HOLE LOG

HOLE No. 705

PROJECT: Ruataniwha Water Storage — FEATURE: Bore hole — LOCATION: A7
GRID REF: 1882717.8 E, 5593327.8 N — CO-ORD: NZTM — DATUM:
ANGLE FROM HORIZONTAL: 90° — DIRECTION: — H.A.D. GROUND: 383.8m — H.A.D. COLLAR:

Depth (m)	Description of core	R.Q.D.	Point load test	Rock defects	Water pressure tests
22.5–24.0	UW, H/MH, black MUDSTONE, massive, strong (Argillite) interbedded with UW, H, grey SANDSTONE, massive, strong. 22.55–22.8 - sandstone bed. 22.8 to 22.9m - Rehealed crush zone	59%	0%	22.55 1B20° - sandstone; 22.7 1B 35°, 1B 45° } mudstone partings; 22.8 - 10 B 45°, JC, R, CN; 23.1 1S 70°, CV, R, CN; 2S 20°, IR, R, CN; 23.2 1 B 65° - mudstone; 23.5 1 CZ - Rehealed; 23.5–23.75m - broken core; 23.8 1 B 75° - thin mudstone bed; 23.9–24.0m - shattered core	22.5–23.25m Gap in testing
24.0–25.8	UW, H, light grey fine SANDSTONE, very strong, massive, very closely jointed	11%	1400/1500	24.0–24.3m - shattered core; 24.3m 1CZ 65°, IR, (Possible joint); 1S 80°, UN, R, CN; 5J 15°, PL, R, CN; 2J 20°, IR, R, CN; 24.5 - 2J 20°, PL, R, CN; 24.6m 1S 45° PL, SM, silt infill; 1S 10° ST, R, CN; 24.8m 1 BS 5°, UN, R, CN; 24.9–25.05m - shattered core; 25.1 5J 70°, SL, R - silt veneers; 25.4–25.5 shattered core; 25.5–25.6m - shattered core; 25.6m - 1J 65°, UN, R, CN; 2J 95°, SL, R, CN	
25.8–26.5	UW, H, dark grey MUDSTONE, massive, strong, very closely jointed	0%	1410/1500	25.8–26.1m - shattered core; 26.1m 5J 60°, CV, R, CN; 7J 85°, UN, R, CN; 1J 50°, CV, R, CN; 26.3–26.6 shattered core	
26.5–27.0	UW, H, light grey fine SANDSTONE, very strong, massive, very closely jointed			26.6m 1S 10°, PL, R, CN; 1S 55°, SL, R, silt veneer; 1S 60°, ST, R, silt veneer; 26.75m 1S 75°, PL, R, CN; 4J 5°, IR, R, CN	

Stratigraphic names (margin): PEZh; WHIOEKA PETROFACIES (UPEh?)

End of hole at 27mbgl

Piezo 1 - Response zone 6–12.5mbgl

Piezo 2 - Response zone 19–27mbgl

Depth scale: 22.5, 23, 24, 25, 26, 27, 28

DRILLER: Boart Longyear
STARTED: 13/10/11
FINISHED: 26/10/11
DRILL: Rig 25

ROCK WEATHERING: UW – Unweathered; SW – Slightly Weathered; MW – Moderately Weathered; HW – Highly Weathered; CW – Completely Weathered

ROCK HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very Soft

FRACTURE LOG: Spacing of Natural Fractures; Fractures/m of core

EXPLANATION: Defect angles from horizontal

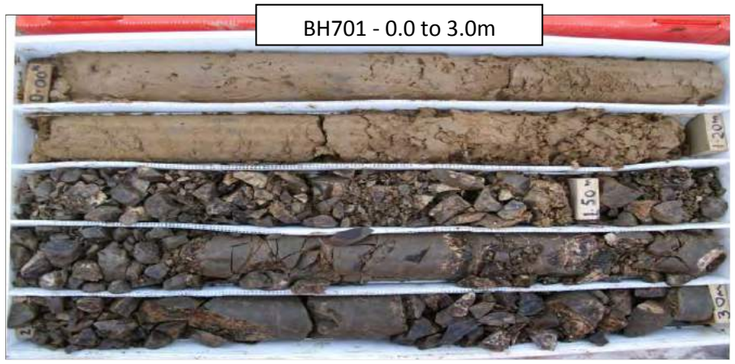
LOGGED: [illegible] — DATE: 08/11/11 — TRACED: — CHECKED: BOM

ORIGINAL VERTICAL SCALE: 1:25 (at A3)

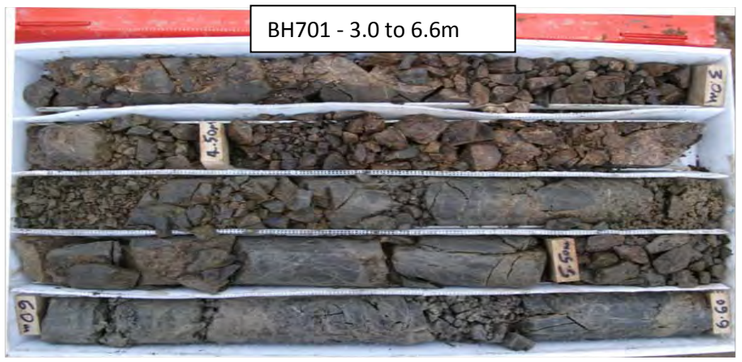
PROJECT: 27145200 — HOLE NO: 705 — LENGTH: 27m — CORE BOXES: 10

SHEET 4 OF 4 — DRG NO

BH701 - 0.0 to 3.0m



BH701 - 3.0 to 6.6m



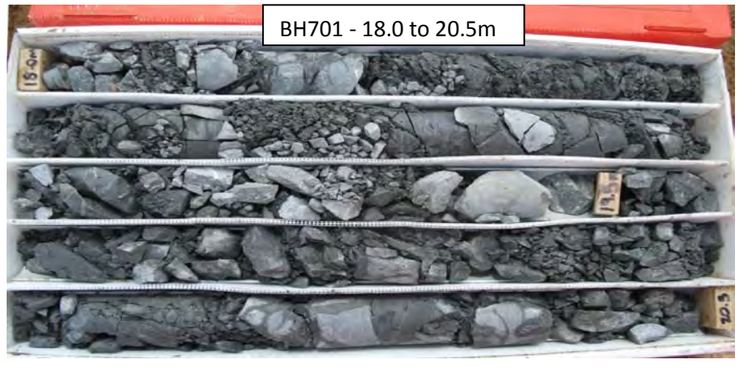
BH701 - 6.6 to 10.5m

BH701 - 10.5 to 13.1m

BH701 - 13.1 to 15.2m

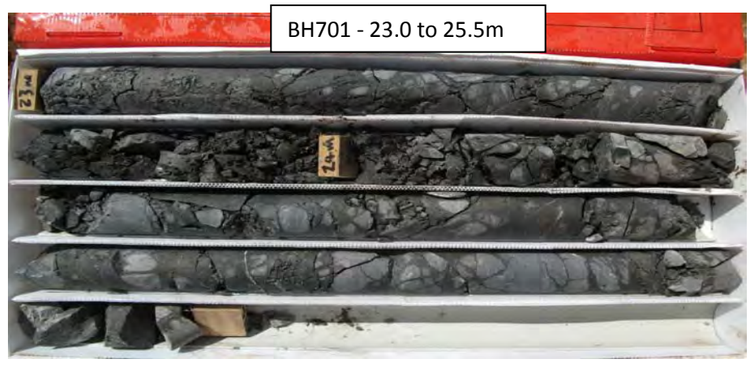
BH701 - 15.2 to 18.0m

BH701 - 18.0 to 20.5m

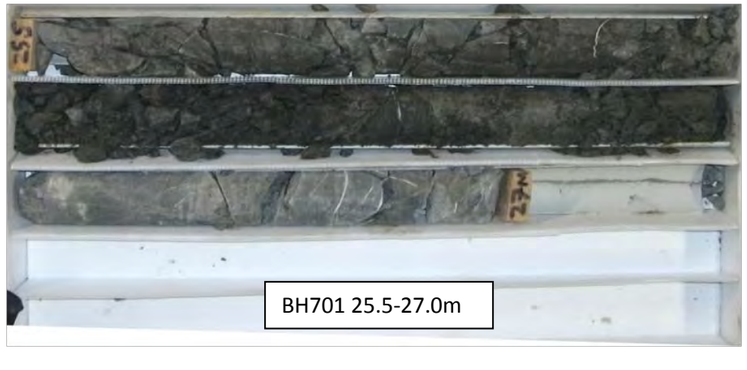


BH701 - 20.5 to 23.0m

BH701 - 23.0 to 25.5m



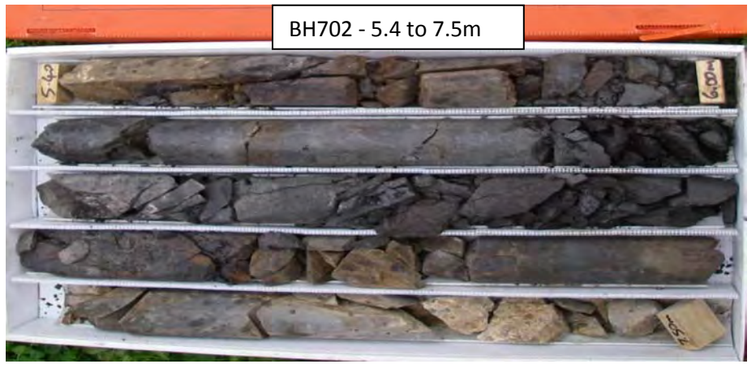
BH701 25.5-27.0m



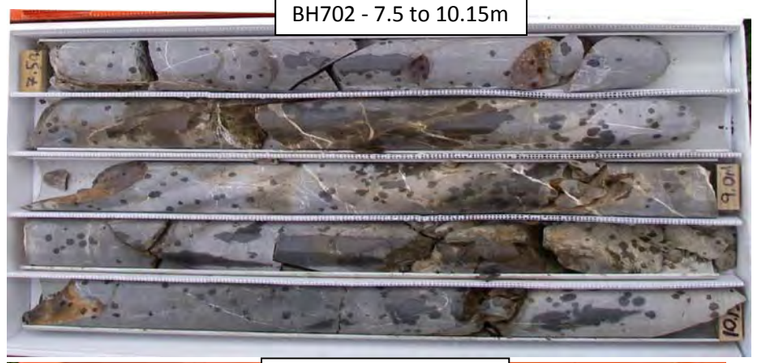
BH702 – 0 to 3.0m

BH702 - 3.0 to 5.4m

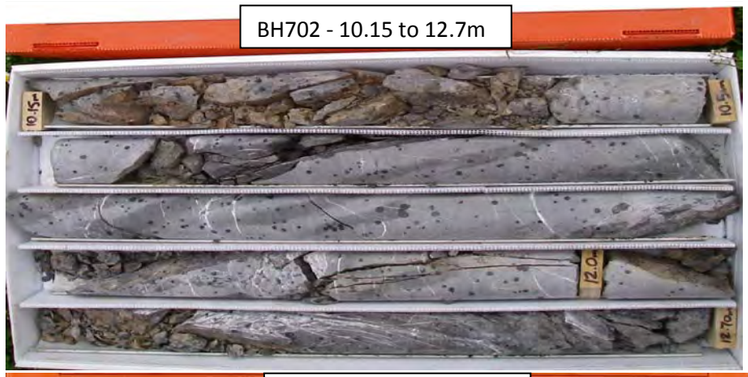
BH702 - 5.4 to 7.5m



BH702 - 7.5 to 10.15m

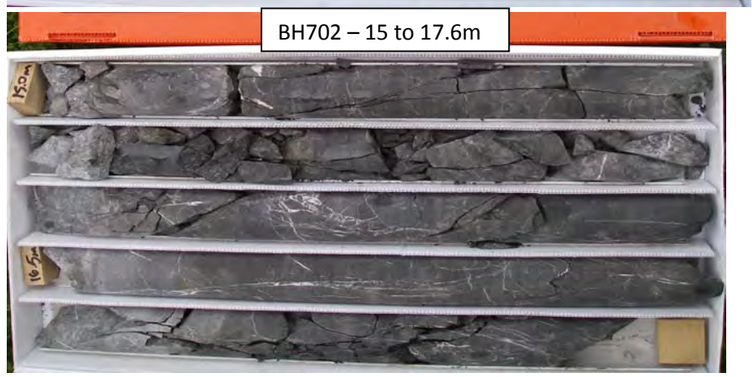


BH702 - 10.15 to 12.7m



BH702 - 12.7 to 15.0m

BH702 – 15 to 17.6m

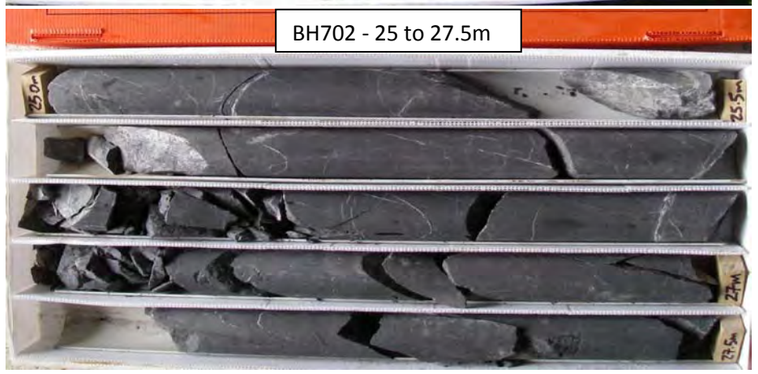


BH702 - 17.6 to 20.2m

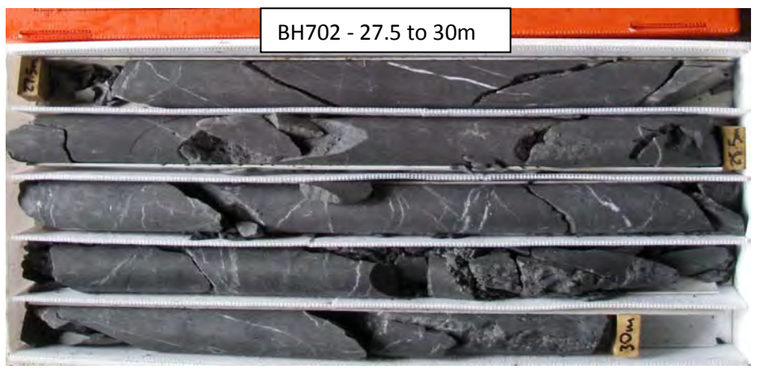
BH702 - 20.2 to 22.5m

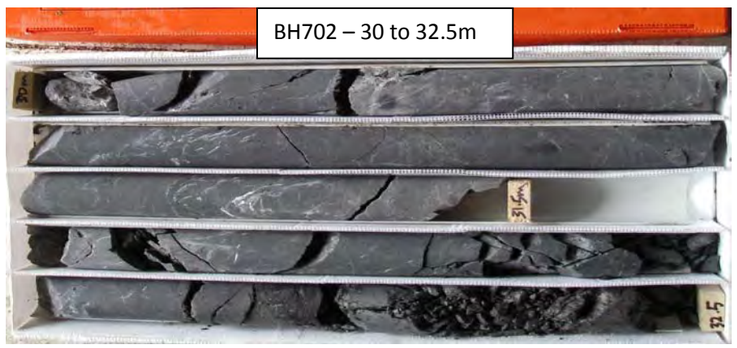
BH702 - 22.5 to 25m

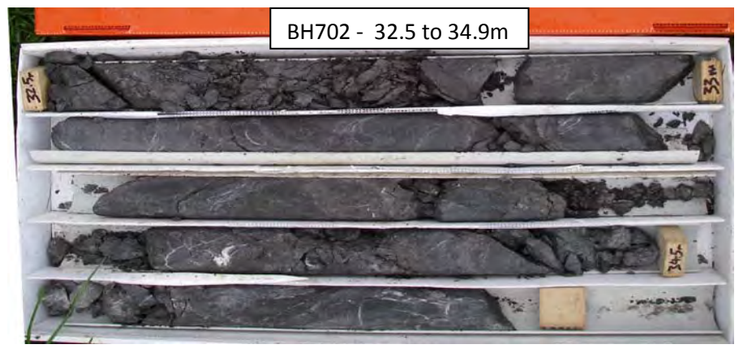
BH702 - 25 to 27.5m



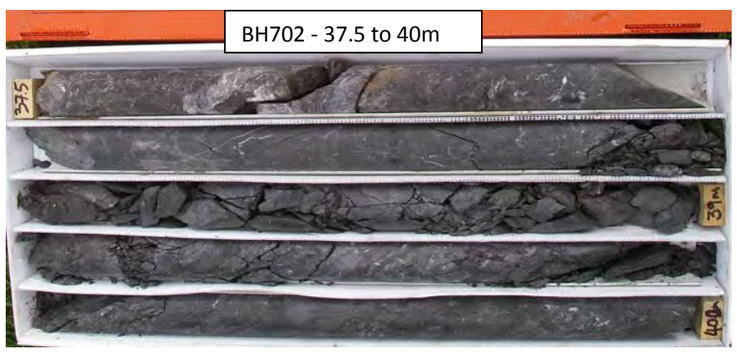
BH702 - 27.5 to 30m

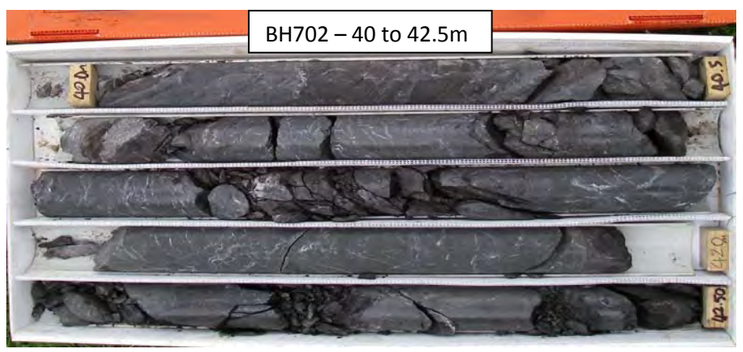



BH702 – 30 to 32.5m

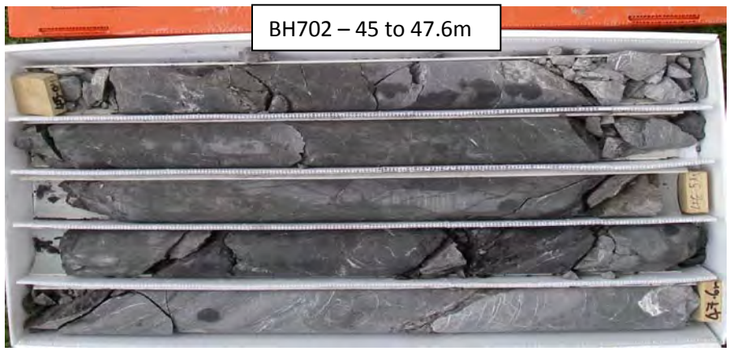

BH702 - 32.5 to 34.9m

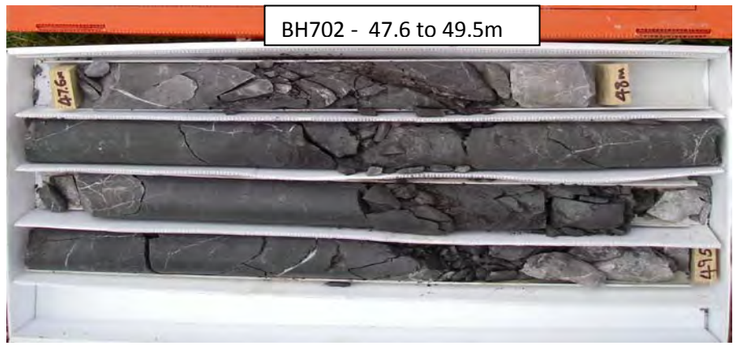
BH702 - 34.9 to 37.5m

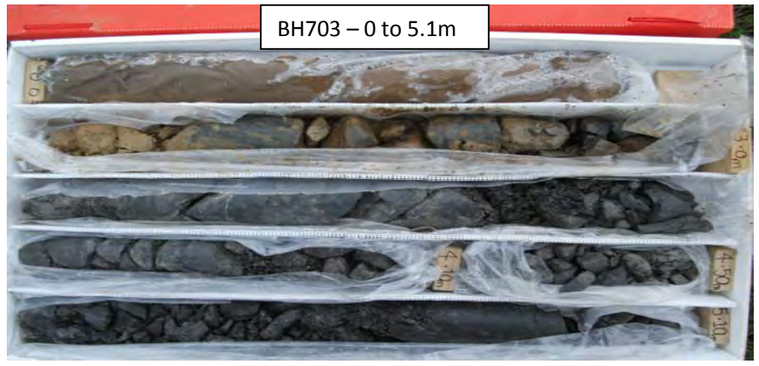

BH702 - 37.5 to 40m


BH702 – 40 to 42.5m

BH702 - 42.5 to 45m


BH702 – 45 to 47.6m

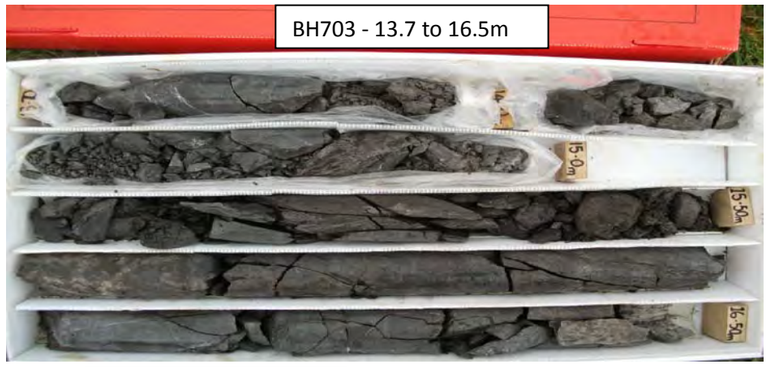

BH702 - 47.6 to 49.5m

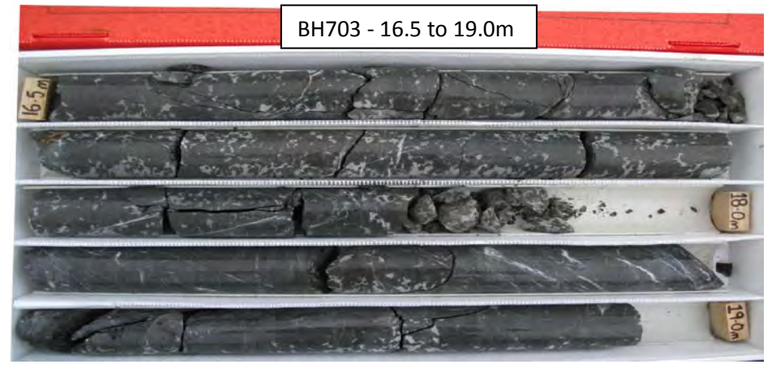

BH703 – 0 to 5.1m

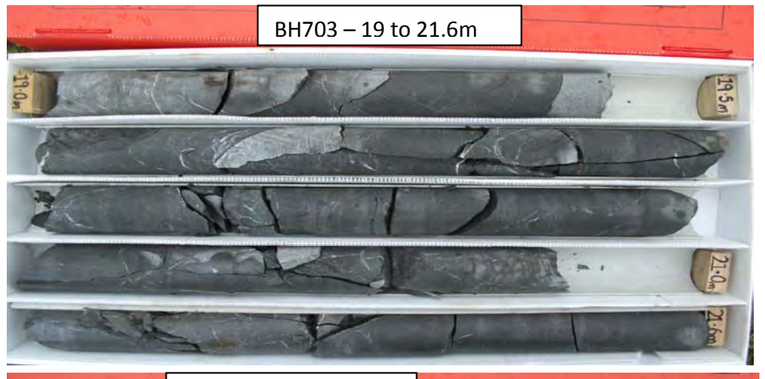
BH703 - 5.1 to 8.1m

BH703 - 8.1 to 11.2m

BH703 - 11.2 to 13.7m

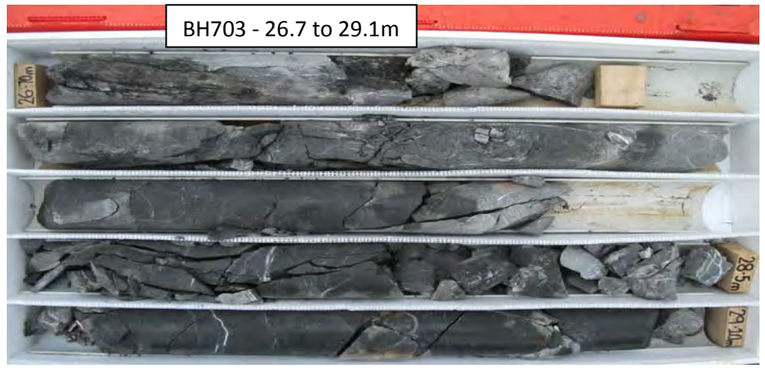

BH703 - 13.7 to 16.5m

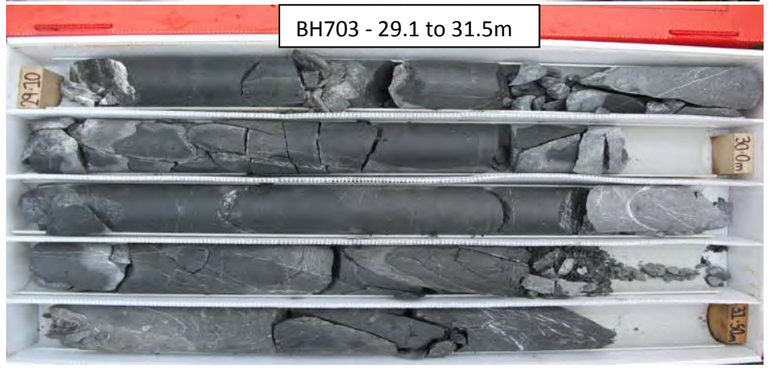

BH703 - 16.5 to 19.0m


BH703 – 19 to 21.6m

BH703 - 21.6 to 24.2m

BH703 - 24.2 to 26.7m


BH703 - 26.7 to 29.1m

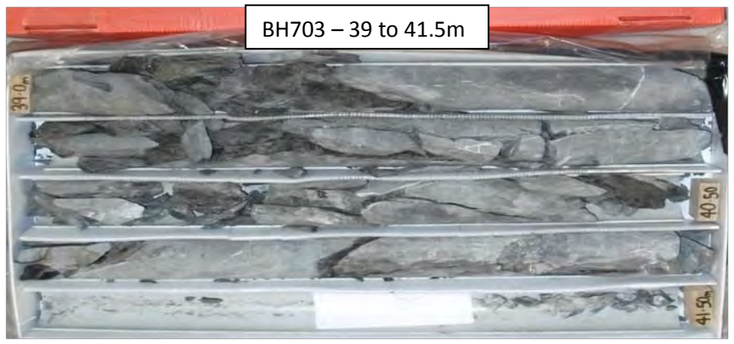

BH703 - 29.1 to 31.5m

BH703 - 31.5 to 34.1m

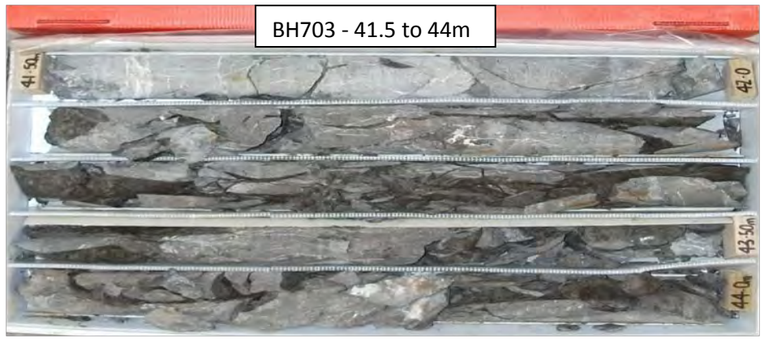
BH703 - 34.1 to 36.6m

BH703 - 36.6 to 39m

BH703 – 39 to 41.5m



BH703 - 41.5 to 44m



BH703 – 44 to 45m

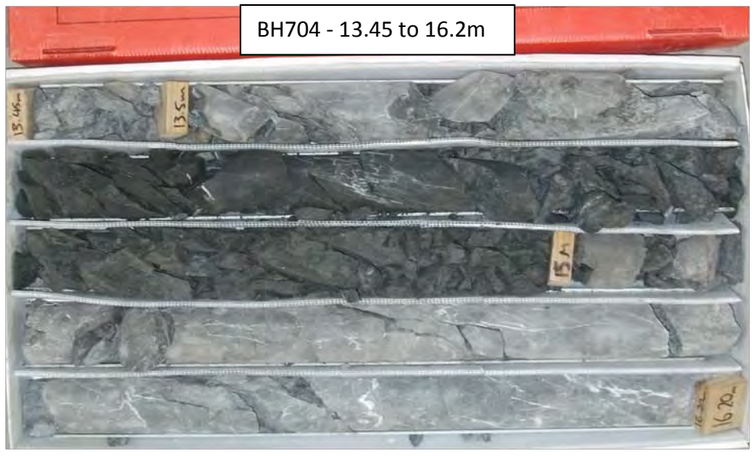
BH704 – 0 to 3m

BH704 – 3 to 5.8m

BH704 - 5.8 to 8.4m

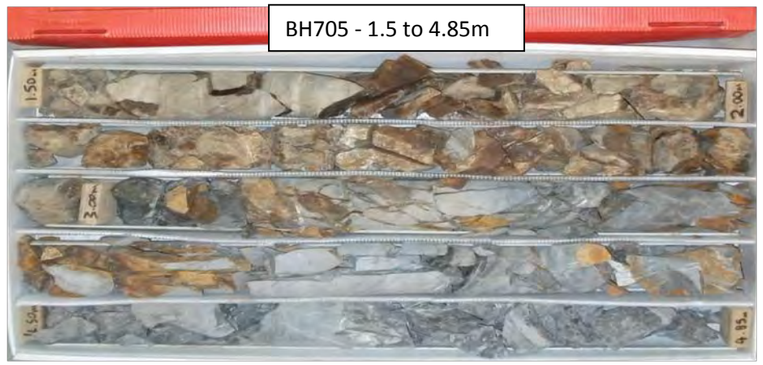
BH704 - 8.4 to 10.9m

BH704 - 10.9 to 13.45m


BH704 - 13.45 to 16.2m

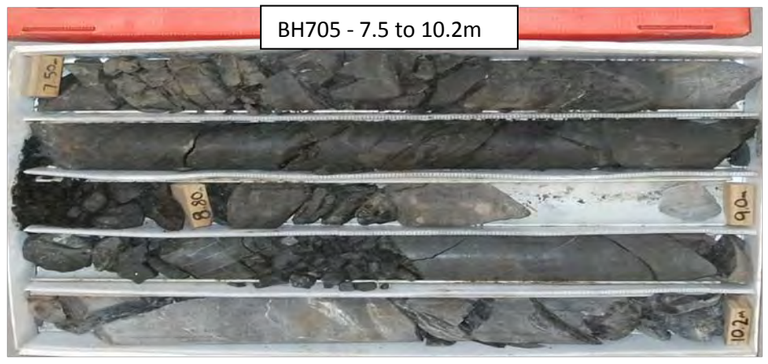
BH704 - 16.2 to 16.5m

BH705 - 1.5 to 4.85m



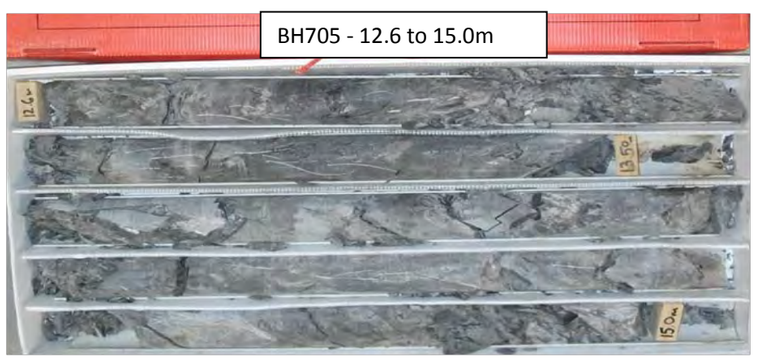
BH705 - 4.85 to 7.5m

BH705 - 7.5 to 10.2m

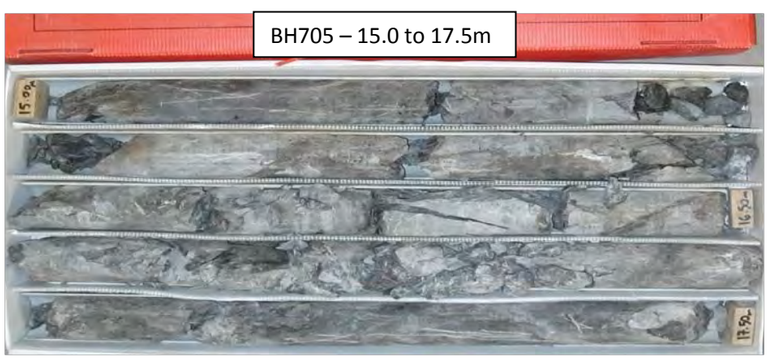


BH705 - 10.2 to 12.6m

BH705 - 12.6 to 15.0m

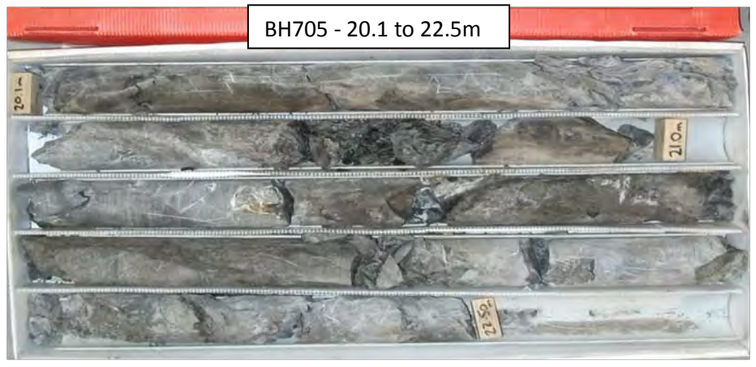


BH705 – 15.0 to 17.5m



BH705 – 17.5 to 20.1m

BH705 - 20.1 to 22.5m



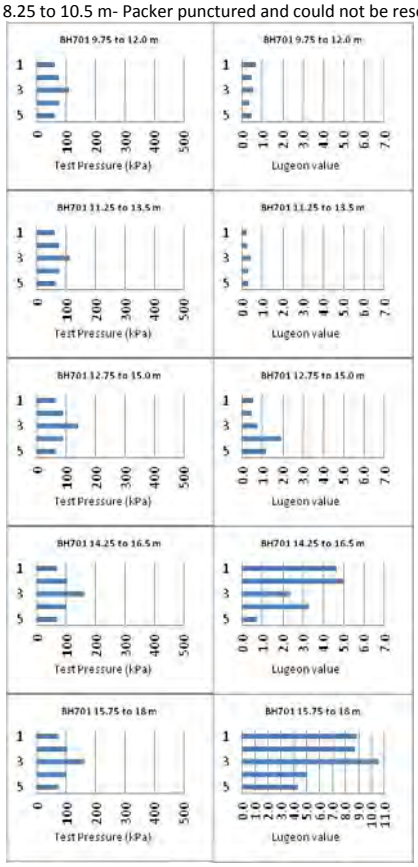
BH705 - 22.5 to 25m

BH705 – 25 to 27m

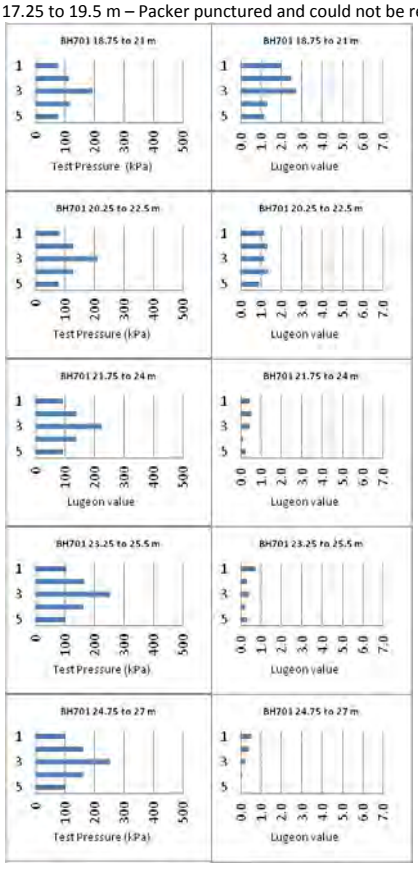
Appendix F: Rock Permeability Test Results

Borehole 701 – Lugeon data

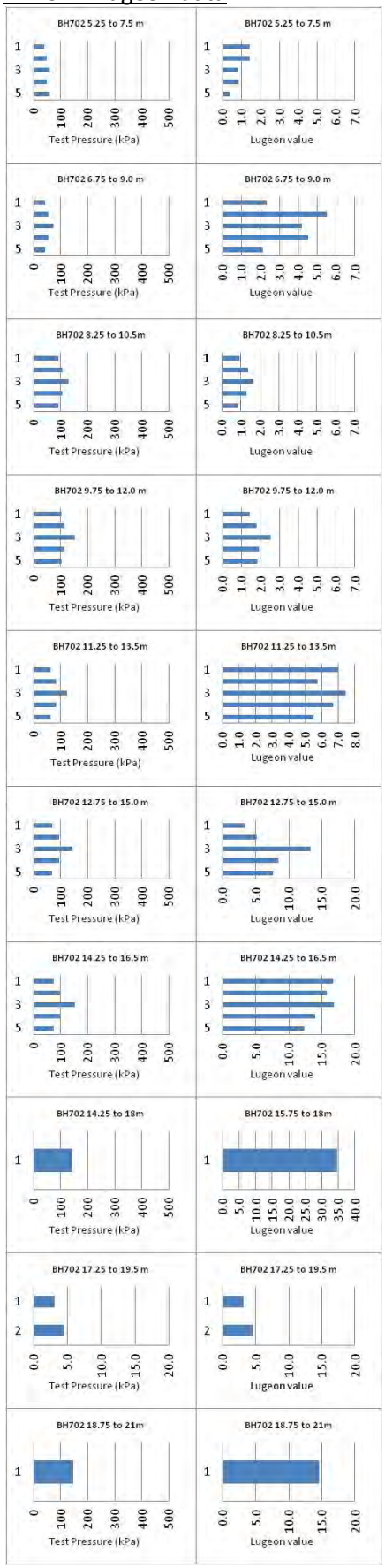
8.25 to 10.5 m- Packer punctured and could not be reset

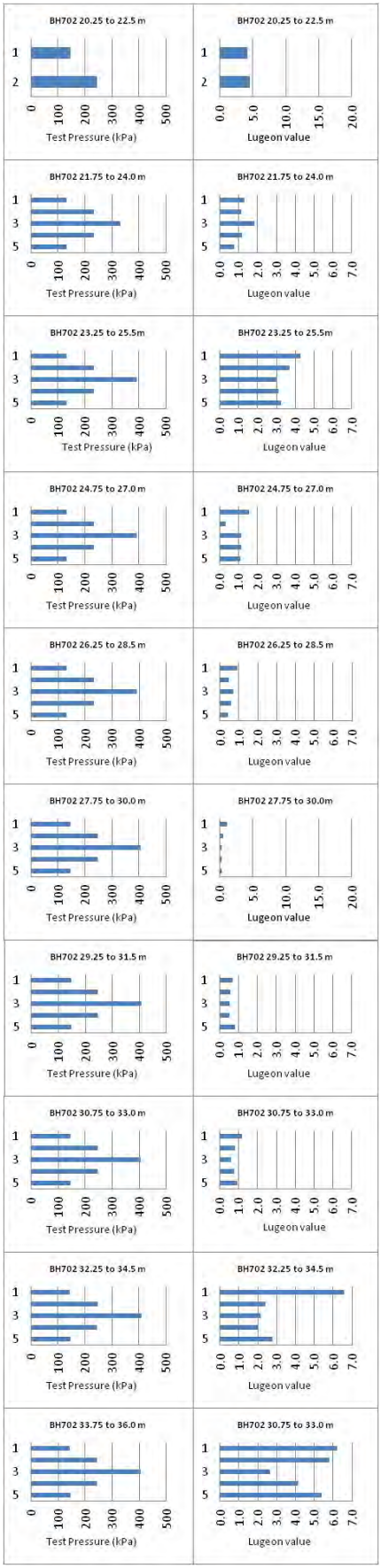


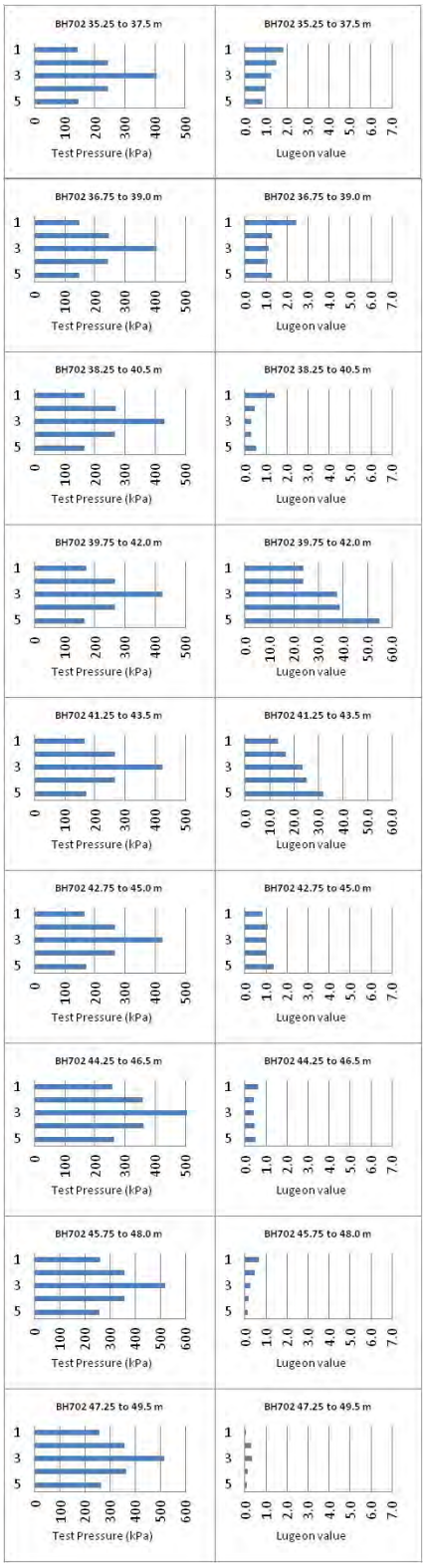
17.25 to 19.5 m – Packer punctured and could not be reset



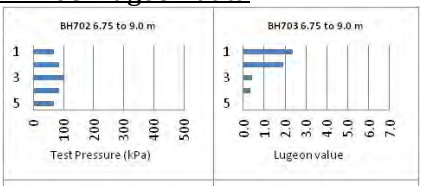
BH702 – Lugeon data

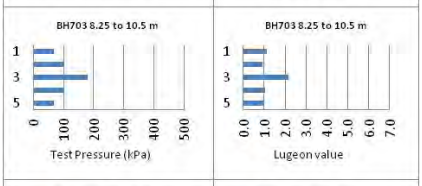


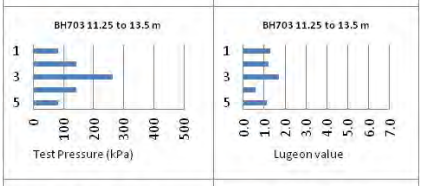


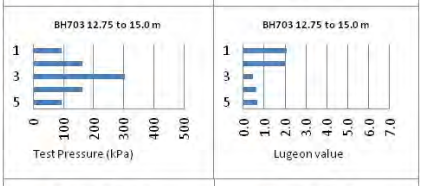

BH702 35.25 to 37.5 m
1
3
5
0
100
200
300
400
500
Test Pressure (kPa)
BH702 35.25 to 37.5 m
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Lugeon value
BH702 36.75 to 39.0 m
BH702 36.75 to 39.0 m
BH702 38.25 to 40.5 m
BH702 38.25 to 40.5 m
BH702 39.75 to 42.0 m
10.0
20.0
30.0
40.0
50.0
60.0
BH702 41.25 to 43.5 m
BH702 42.75 to 45.0 m
BH702 44.25 to 46.5 m
BH702 45.75 to 48.0 m
600
BH702 47.25 to 49.5 m

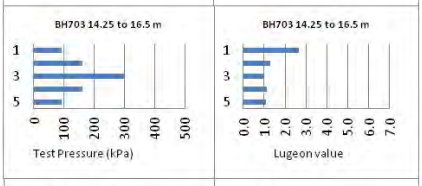
BH703-Lugeon data

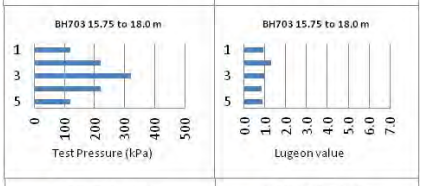


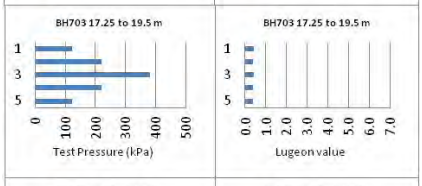


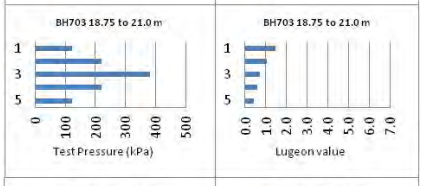


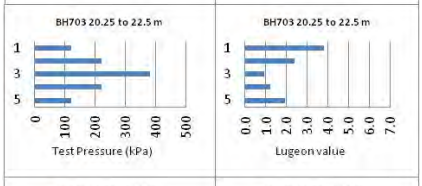


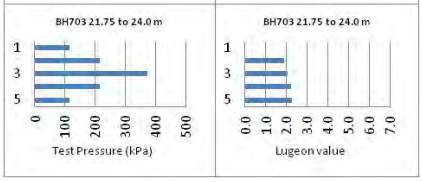


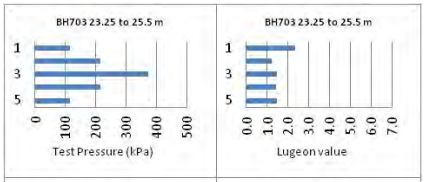


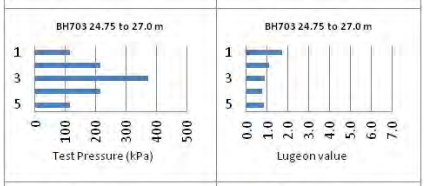


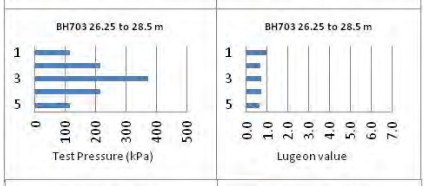


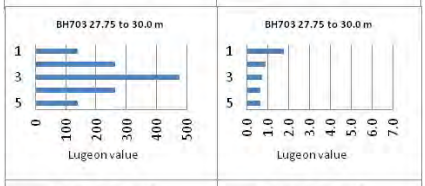


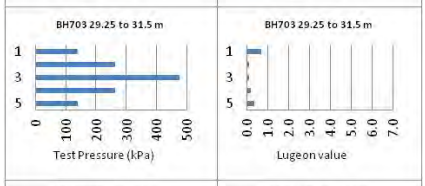


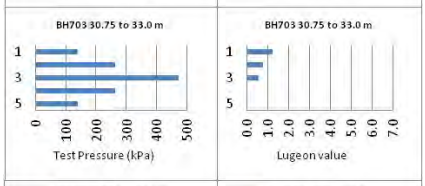


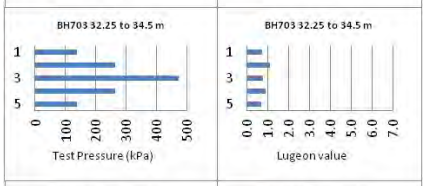


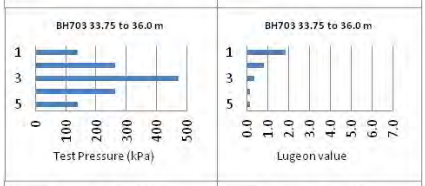


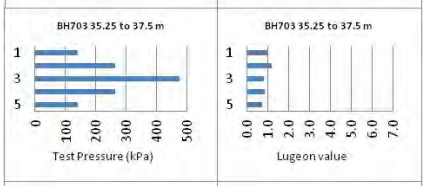


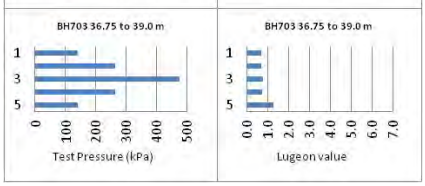


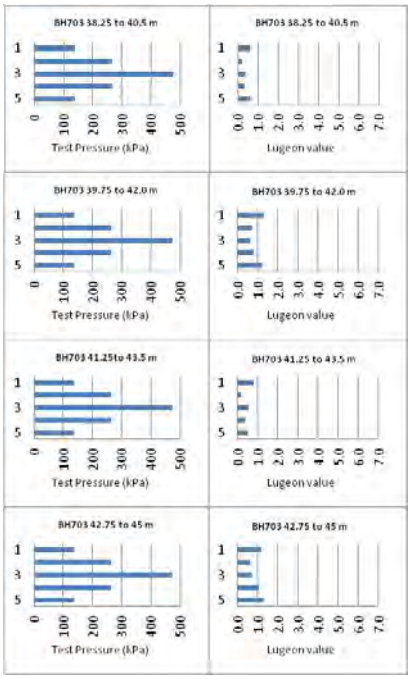




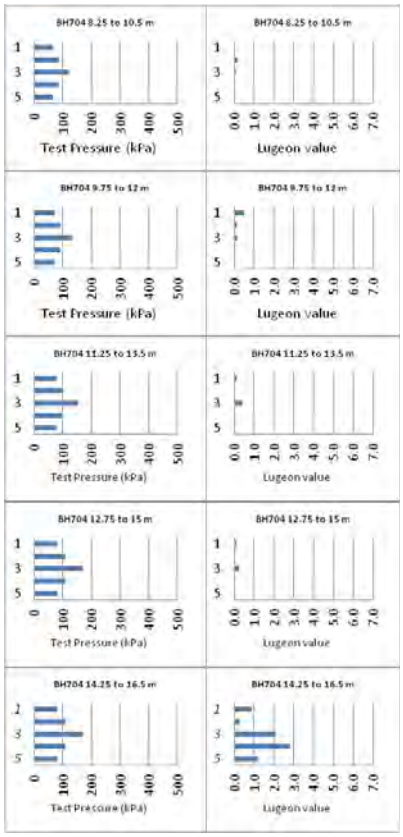




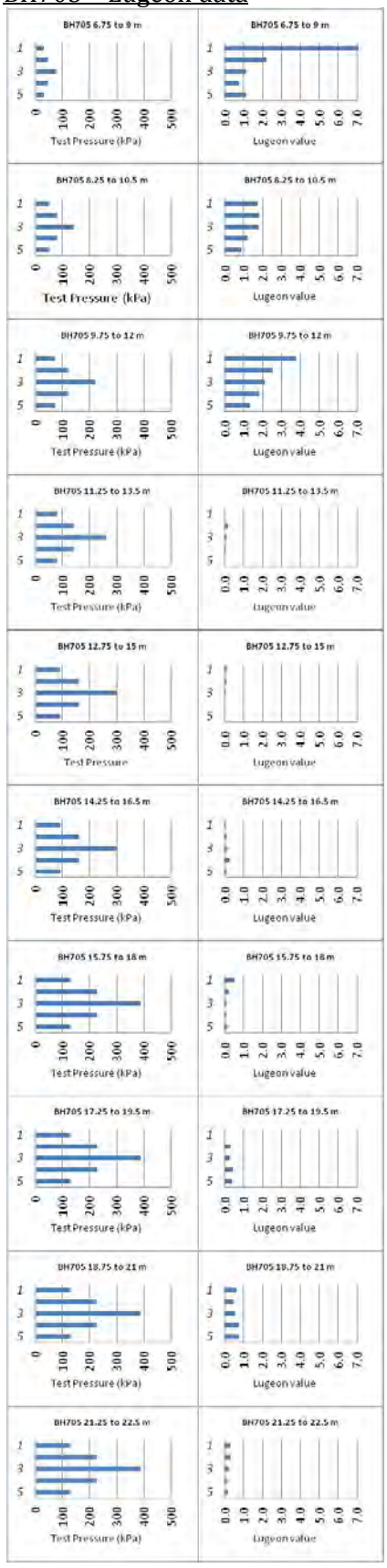


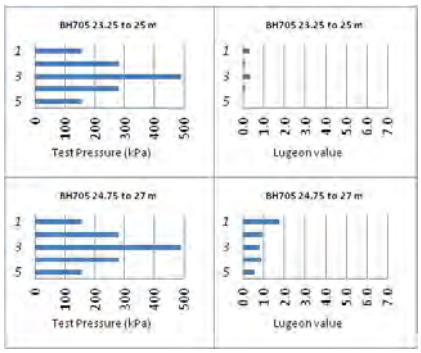


BH704 – Lugeon data



BH705 – Lugeon data





Appendix G: Piezometer Construction Details

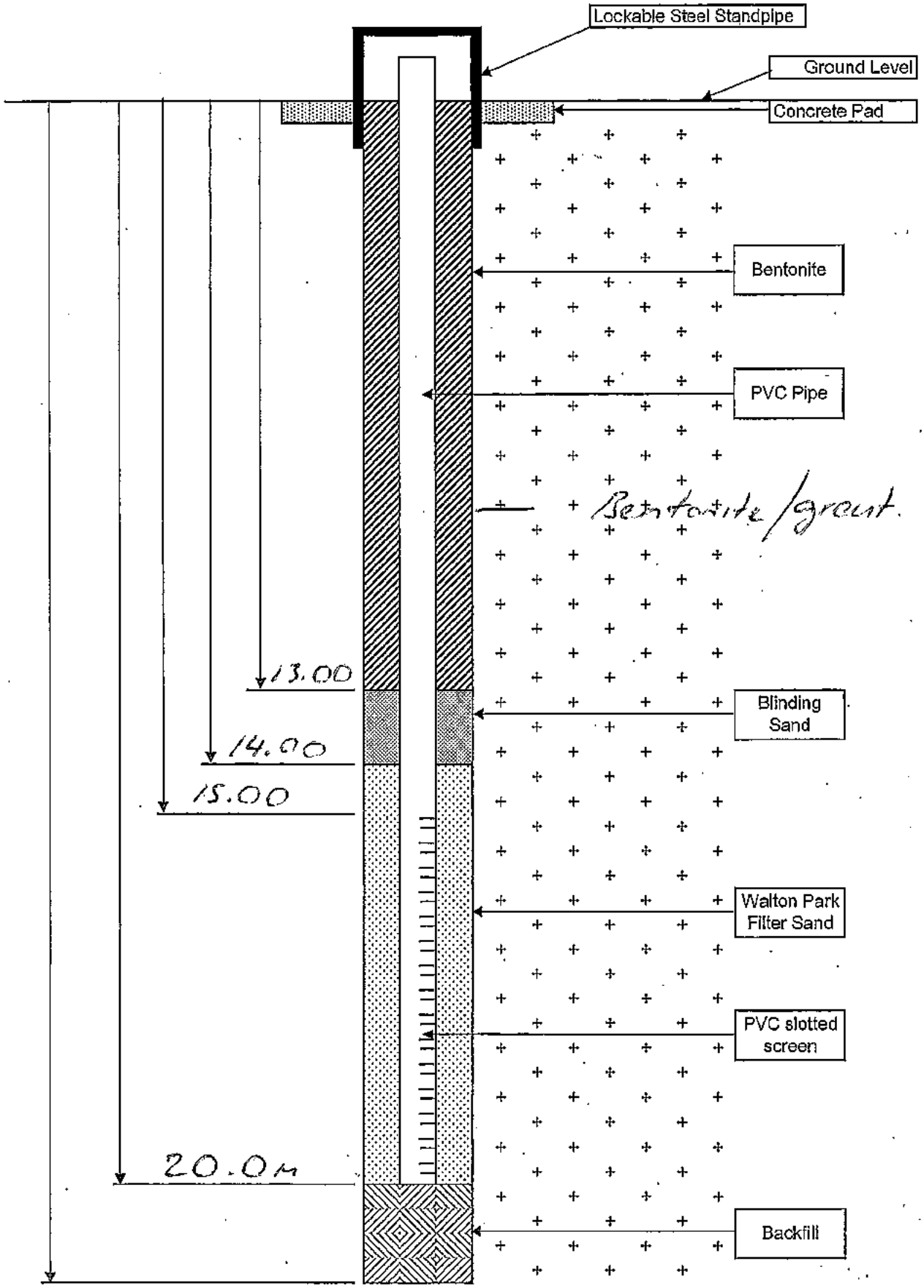
BOART LONGYEAR

Daily Log Sheet(General) Log No. 0912697

1°client T&T | Job Ref No. BC (Comp) 11 (Year) CG (Div) 074 (#) | Day SAT

2° client | Permit No. | Date 8 (day) 10 (mth) 11 (yr)

Location Waipukurau (street address or locality) | Bore Hole No. 701 | Bore Size HQ



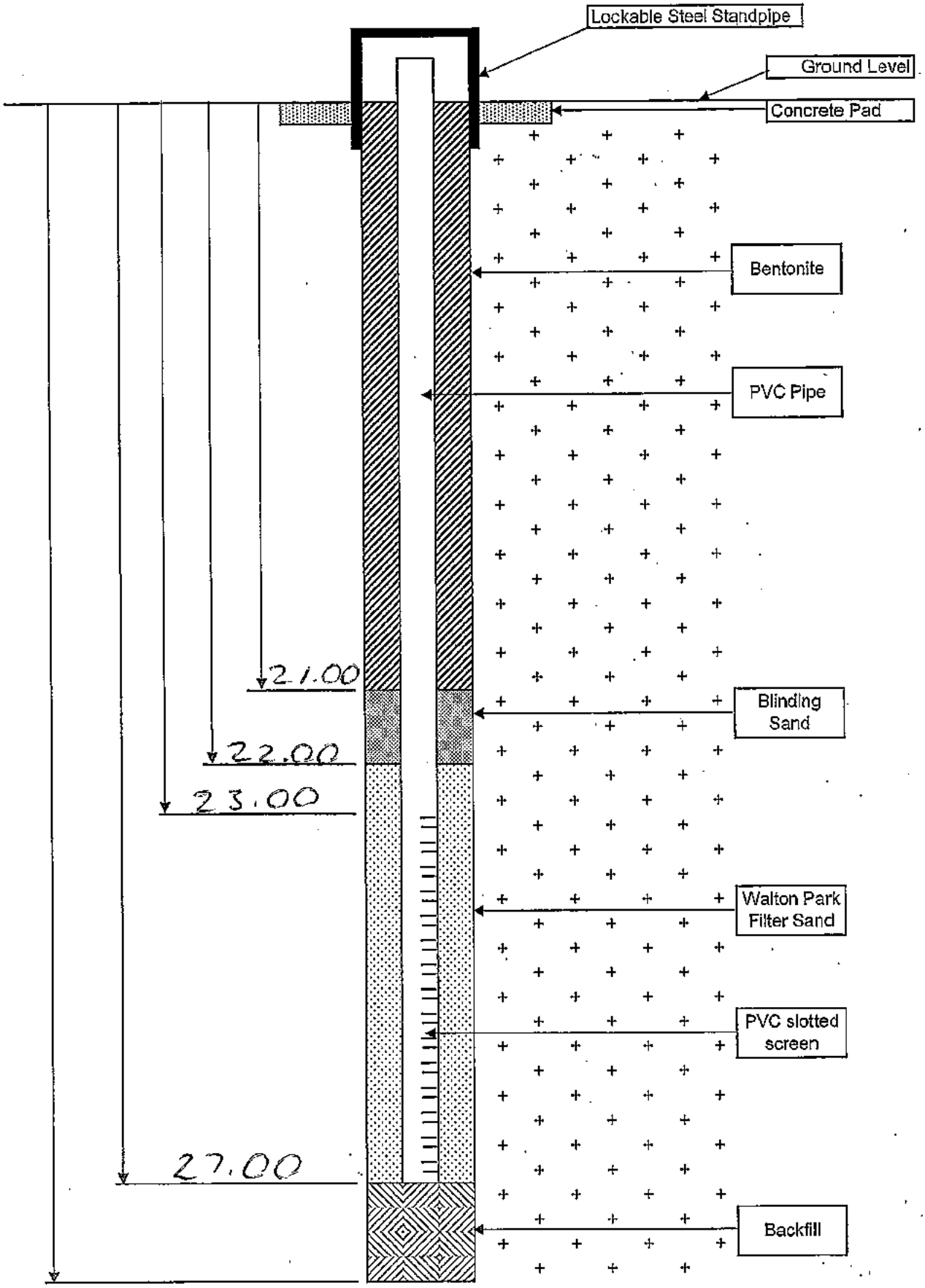
BOART LONGYEAR

Daily Log Sheet(General) Log No. 0912697

1°client TRT | Job Ref No. (Comp) IX (Year) 11 (Div) CC (#) 074 | Day Sat

2° client | Permit No. | Date (day) 8 (mth) 10 (yr) 11

Location Wajuhunga (street address or locality) | Bore Hole No. 701 | Bore Size HQ



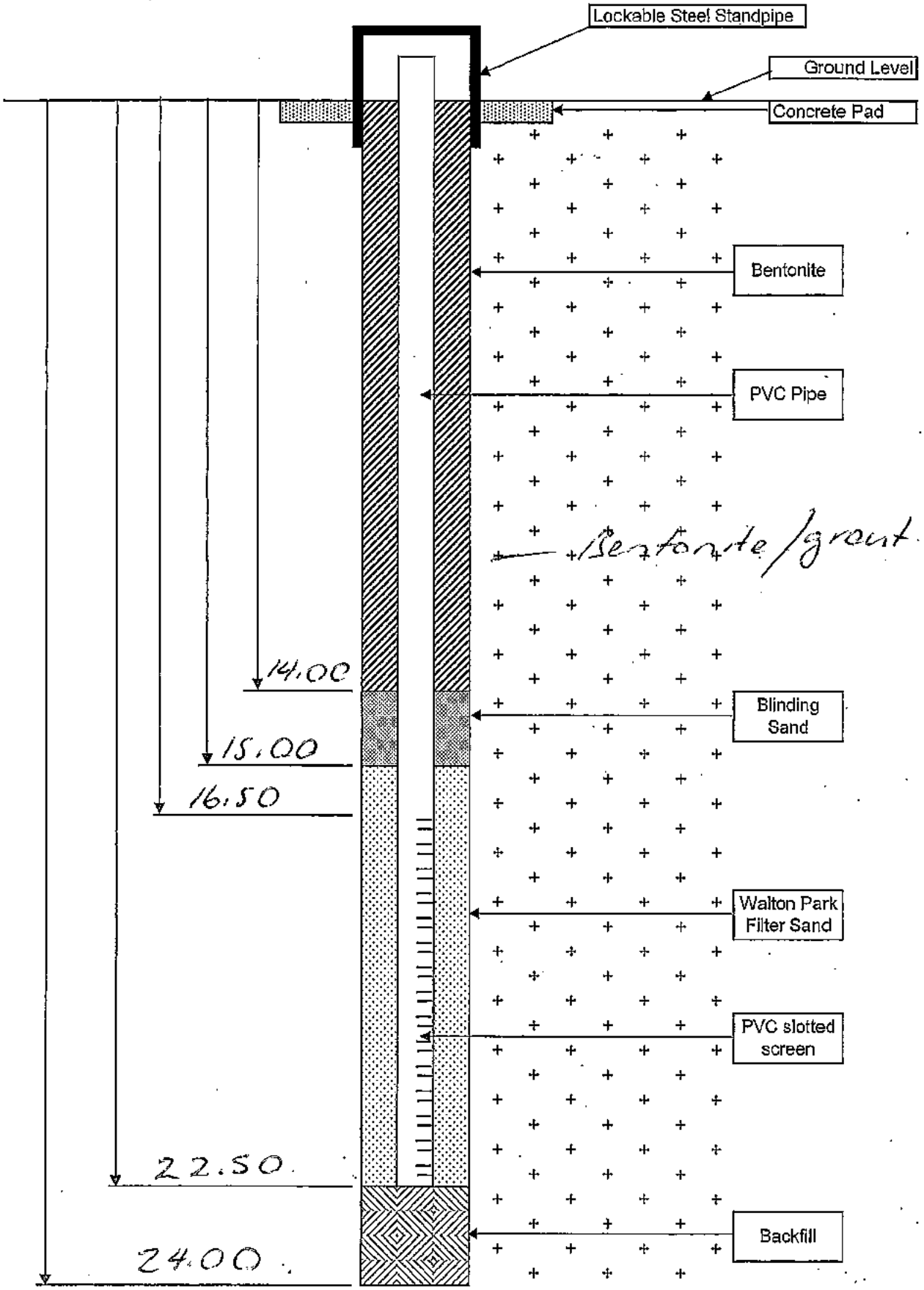
BOART LONGYEAR

Daily Log Sheet(General) Log No. 0912687

1° client T&T | Job Ref No. BC 11 CC 074 (Comp Year Div #) | Day FRI

2° client | Permit No. | Date 30 9 11 (day mth yr)

Location Waipuhurau (street address or locality) | Bore Hole No. 702 | Bore Size HQ



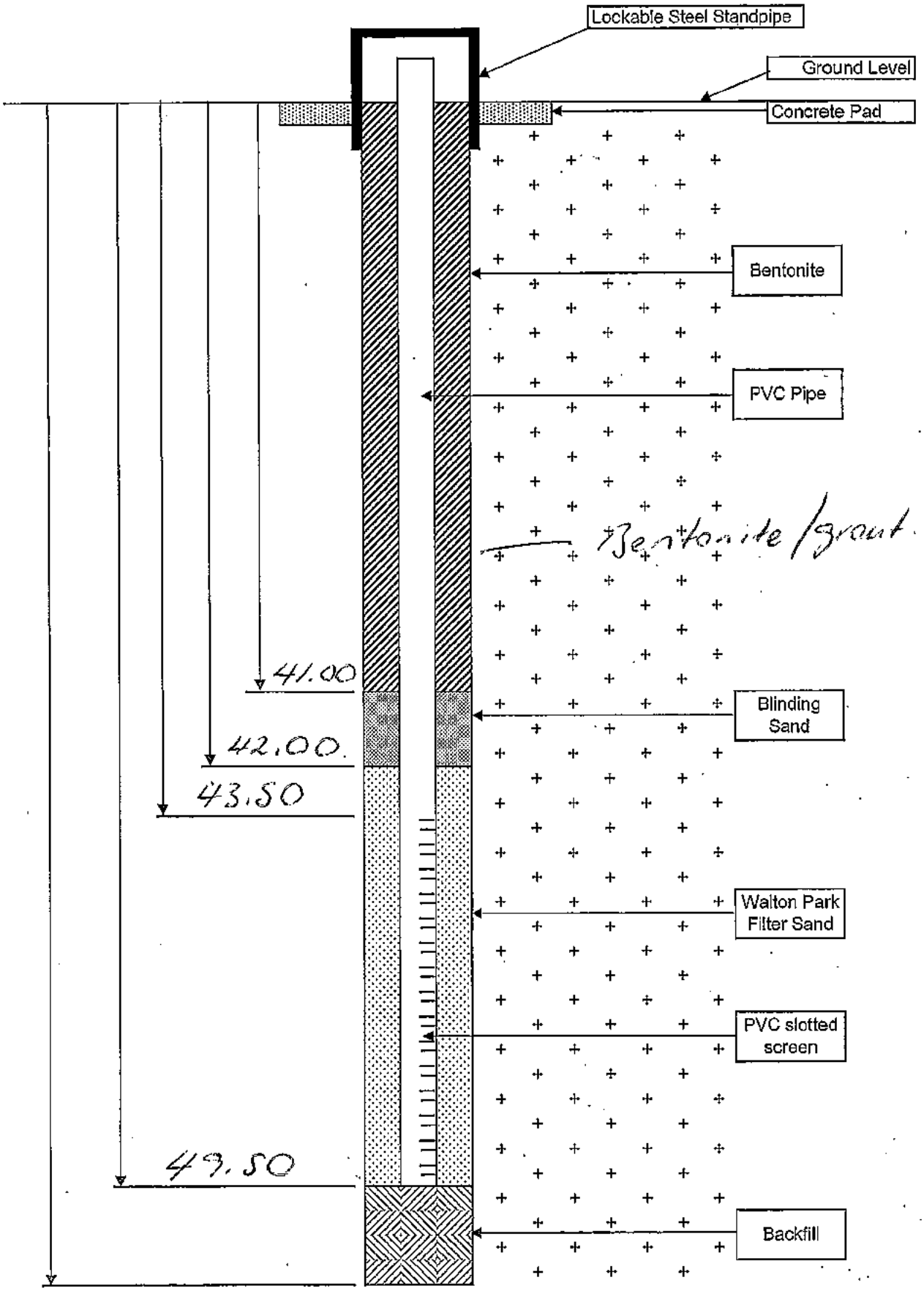
BOART LONGYEAR

Daily Log Sheet(General) Log No. 09/2686

1⁰client TRT | Job Ref No. BC (Comp) 10 (Year) CC. (Div) 074 (#) | Day THUR

2⁰ client | Permit No. | Date 29 (day) 9 (mth) 11 (yr)

Location Waipukurau (street address or locality) | Bore Hole No. 702 | Bore Size HQ



BOART LONGYEAR

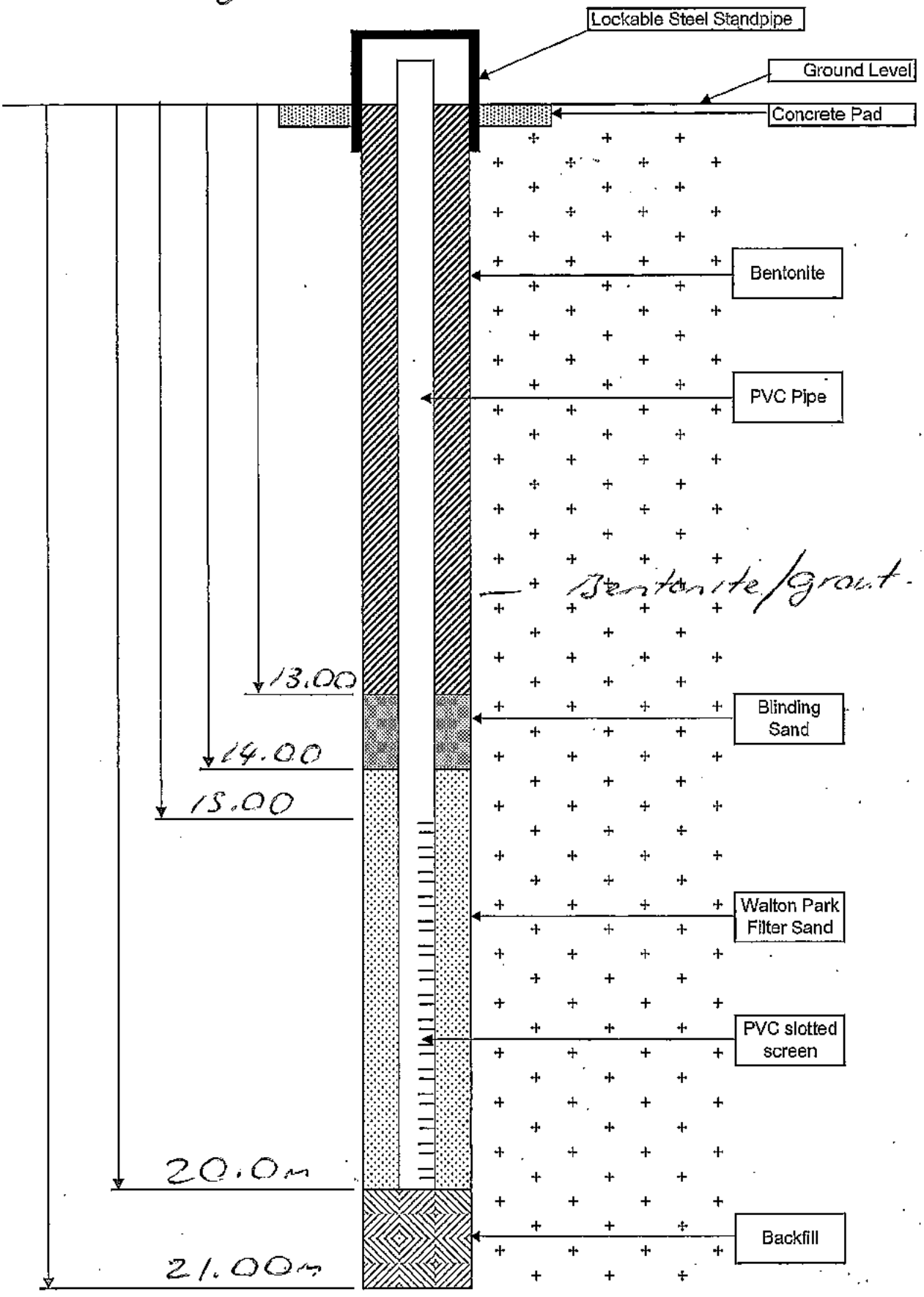
Daily Log Sheet(General) Log No. 0909218

1⁰client TLT

Job Ref No. BC (Comp) 11 (Year) CA (Div) 074 (#) Day WED

2⁰ client ____ Permit No. ____ Date 12 (day) 10 (mth) 11 (yr)

Location Smeatley Station (street address or locality) Bore Hole No. 703 Bore Size HQ



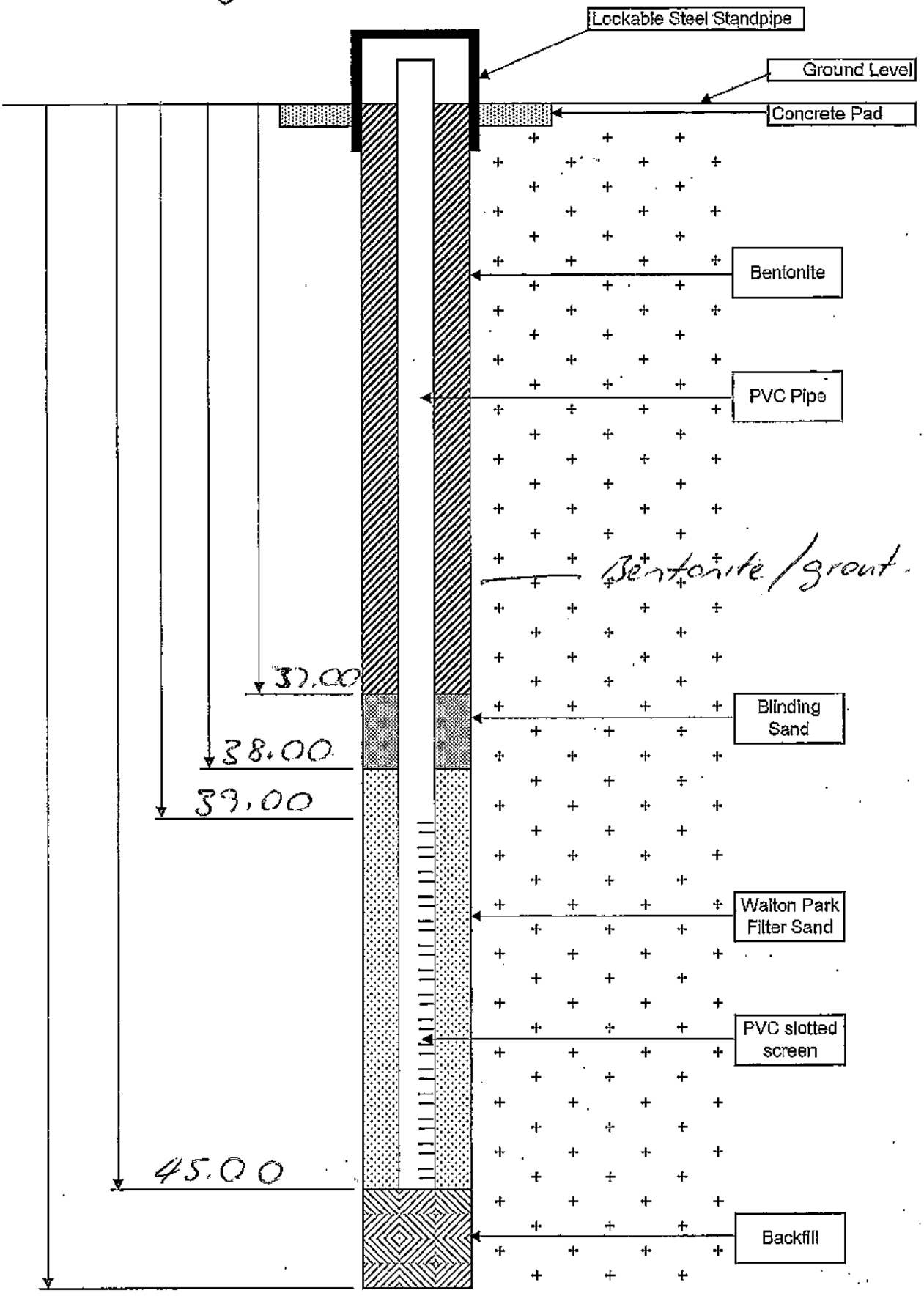
BOART LONGYEAR

Daily Log Sheet(General) Log No. 0909218

1°client TLT | Job Ref No. BL (Comp) 11 (Year) CA (Div) 074 (#) | Day WED

2° client | Permit No. | Date 12 (day) 10 (mth) 11 (yr)

Location Smedley Station (street address or locality) | Bore Hole No. 703 | Bore Size HQ



BOART LONGYEAR

Daily Log Sheet(General) Log No.

1° client: TRT

Job Ref No.: BL 11 CC 074 (Comp Year Div #)

Day:

2° client:

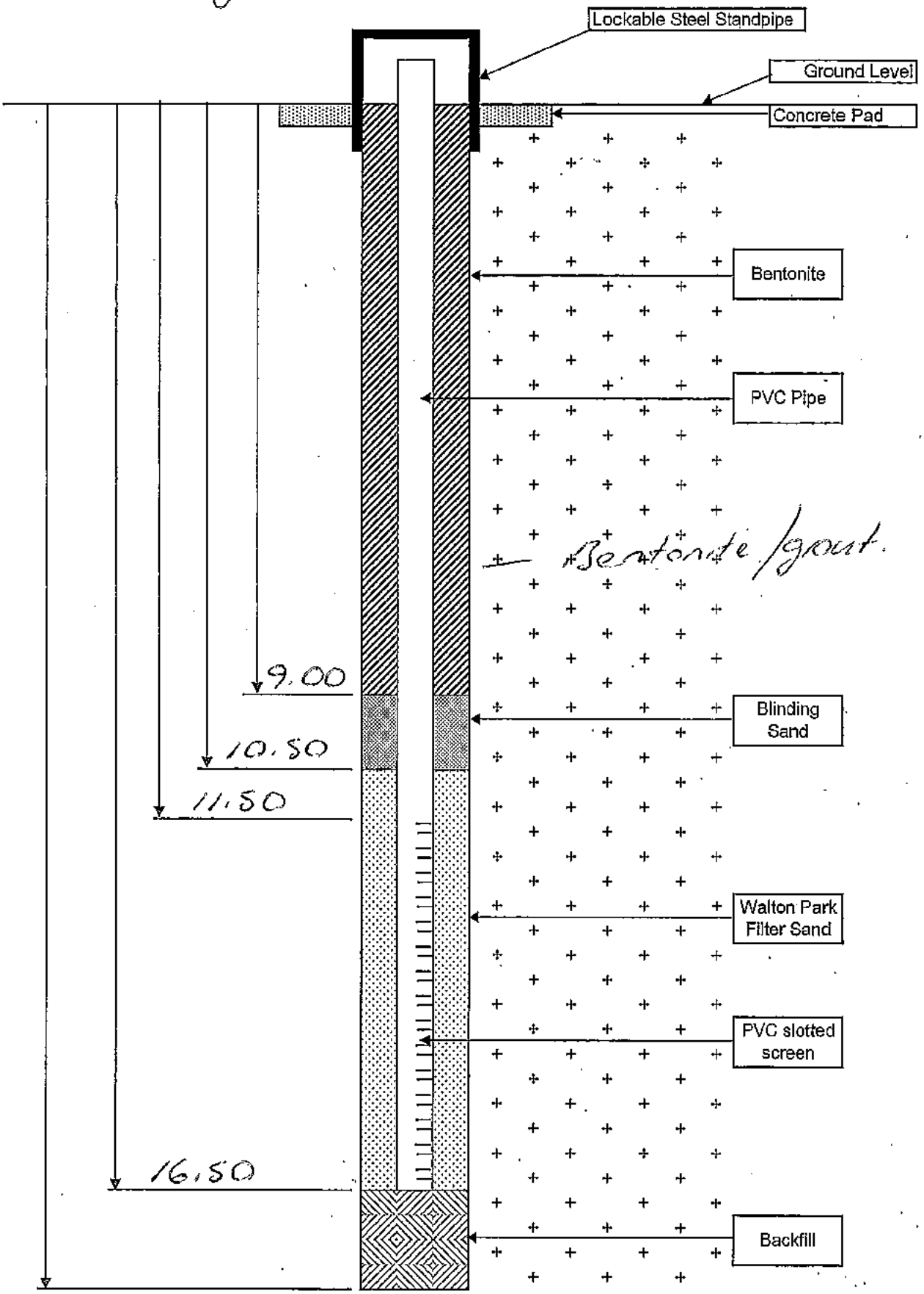
Permit No.:

Date: (day mth yr)

Location: Smedley Station (street address or locality)

Bore Hole No.: 704

Bore Size: HQ



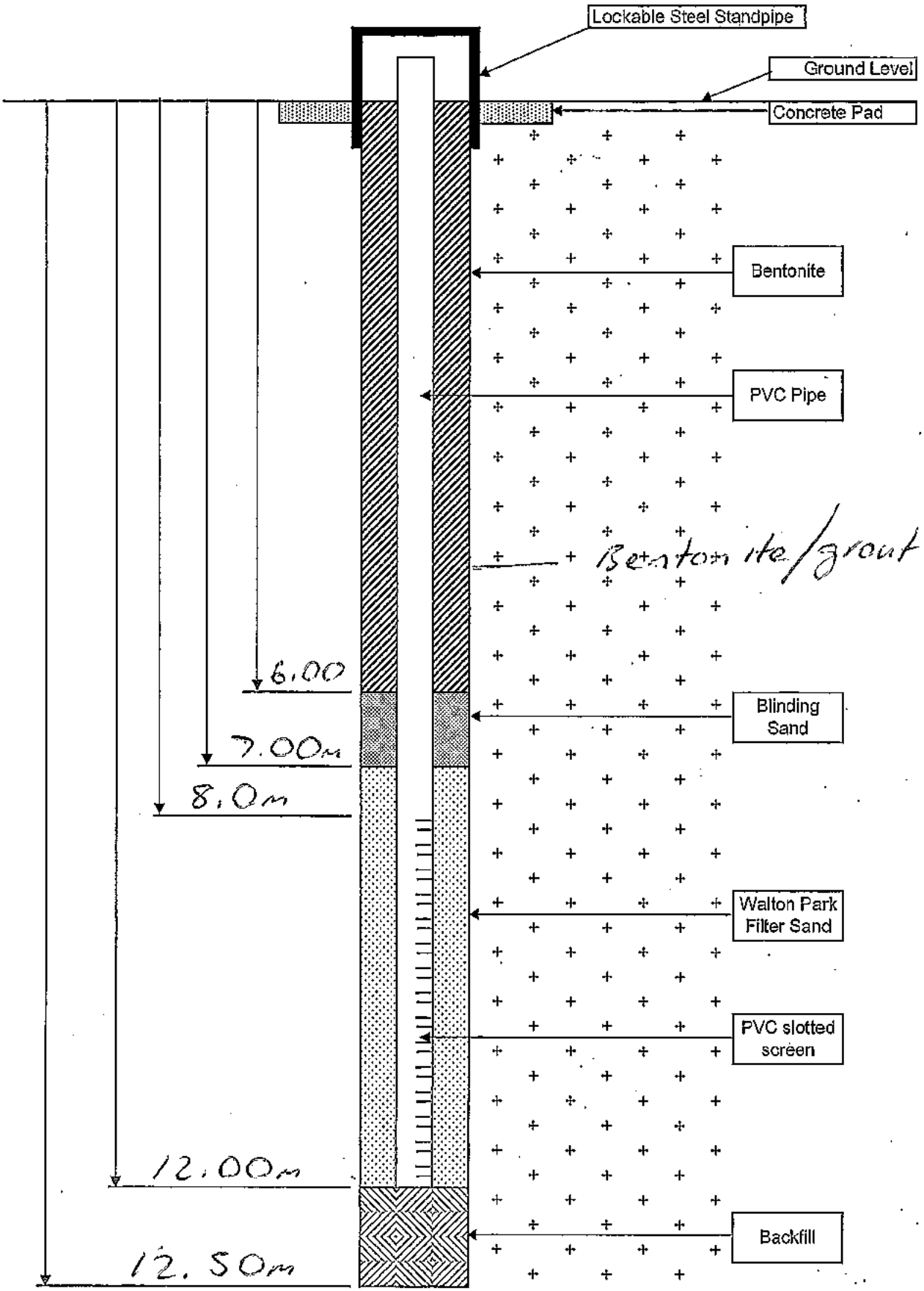
BOART LONGYEAR

Daily Log Sheet(General) Log No. 0913477

1° client T & T | Job Ref No. BC 11 CG 074 (Comp Year Div #) | Day WED

2° client | Permit No. | Date 26 10 11 (day mth yr)

Location Smedley Station (street address or locality) | Bore Hole No. 705 | Bore Size HQ



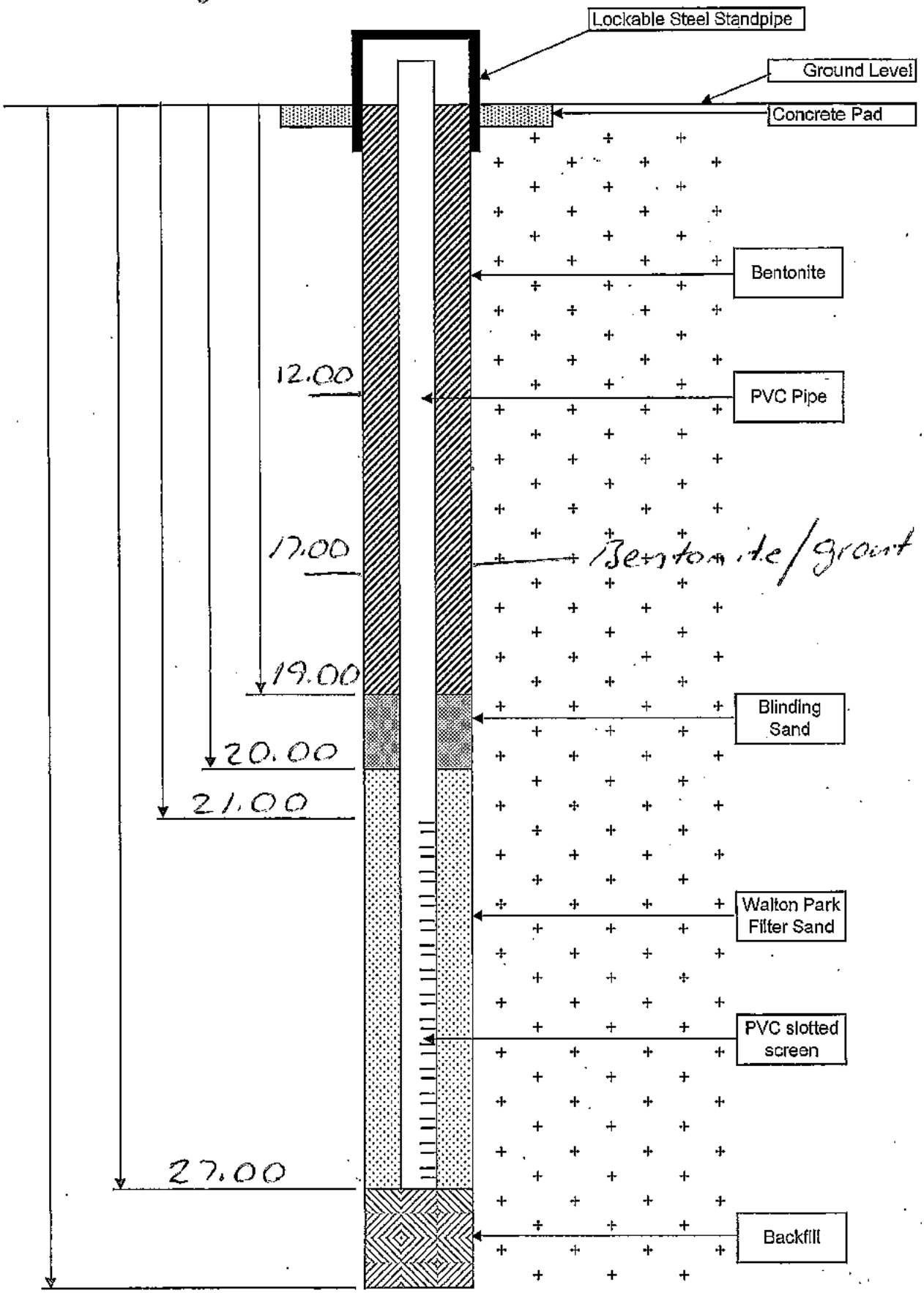
BOART LONGYEAR

Daily Log Sheet(General) Log No. 0913477

1°client TLT | Job Ref No. BL (Comp) | 41 (Year) | CC (Div) | 074 (#) | Day WED

2° client Piezo 1 | Permit No. | Date 26 (day) 10 (mth) 11 (yr)

Location Smedley Station (street address or locality) | Bore Hole No. 705 | Bore Size HQ



Appendix H: Trial Pit Logs and Photographs

TONKIN & TAYLOR LTD

EXCAVATION LOG

BOREHOLE No: TP 1
Location: A 7
SHEET 1 OF 1

PROJECT: Ruataniwha Water Storage Scheme | LOCATION: A 7M | JOB No: 27195200

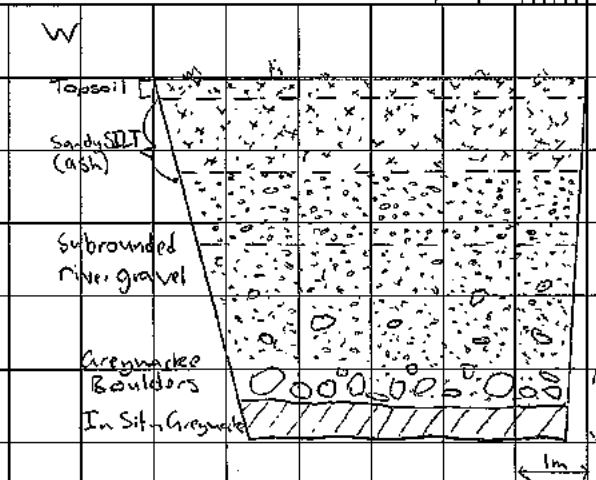
CO-ORDINATES: mN 5591970.4 mE 1980640.0
R.L. 433 m
DATUM NZTM-10

EXPOSURE TYPE: Test Pit
EQUIPMENT: 20t Volvo Excavator
OPERATOR: Cair Contracting
DIMENSIONS: 2.5 x 6 x 5m

EXCAV. STARTED: 11/10/11
EXCAV FINISHED: 11/10/11
LOGGED BY: CWM
CHECKED BY: DMMM

EXCAVATION TESTS						ENGINEERING DESCRIPTION						GEOLOGICAL	
PENETRATION 1 2 3	SUPPORT	WATER	SAMPLES, TESTS	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	SOIL NAME, PLASTICITY OR PARTICLE SIZE CHARACTERISTICS, COLOUR, SECONDARY AND MINOR COMPONENTS	MOISTURE CONDITION / WEATHERING	STRENGTH / DENSITY CLASSIFICATION	ESTIMATED SHEAR STRENGTH (kPa) 10 100 200	ORIGIN TYPE, MINERAL COMPOSITION, DEFECTS, STRUCTURE	UNIT
					0		MS	Dark brown sandy SILT with many Rootlets	M				Topsoil
					1		MS	Orange brown sandy SILT, moist, non plastic, firm	M	F			Volcanic Ash
					2		GS	Sandy fine to coarse GRAVEL with some silt and cobbles, grey, moist, Tightly packed. Gravel is subrounded, slightly weathered, poorly graded greywacke	M	TP			River Gravel
					3		GS	Sandy fine to coarse GRAVEL with some cobbles and boulders, grey, moist, Tightly packed. Gravel is subrounded, Slightly weathered, poorly Graded greywacke. Cobbles and boulders are rounded. Boulders become larger with depth 0.5m diameter maximum at base of pit	M	TP			
					4								
					5			Grey SANDSTONE, HW; Weak (difficult to excavate, used pick on edge) Greywacke with some mudstone (argillite)	HW	R1		In Situ Greywacke	Waipaoa Terrane
								EOH @ 5m UTP No collapse; no water inflow					

SKETCH



Log Scale 1:50

EXCAVLOG TP.GPJ 27/9/07

TONKIN & TAYLOR LTD

EXCAVATION LOG

BOREHOLE No: TP 2
Location: A 7

SHEET 1 OF 1

PROJECT: Ruataniwha Water Storage Scheme — LOCATION: A7U — JOB No: 27195.200

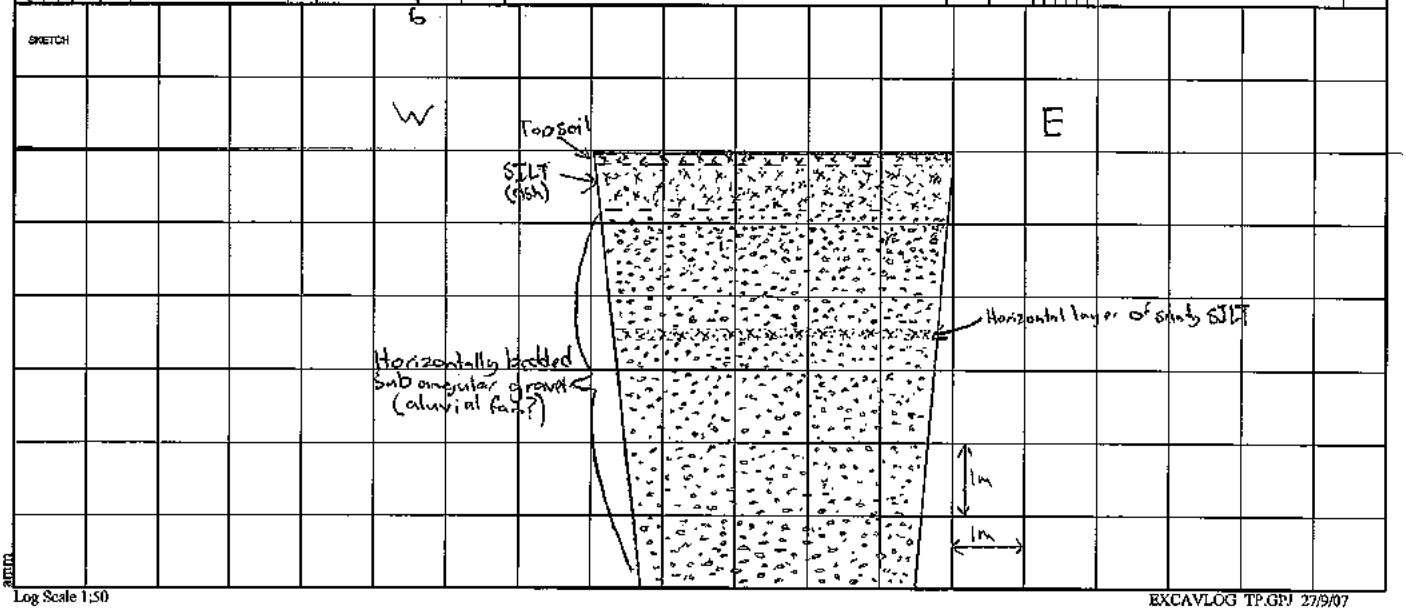
CO-ORDINATES: mN 5591969.8, mE 1880497.8
R.L. 440 m
DATUM NZTM-10

EXPOSURE TYPE: Test Pit
EQUIPMENT: 20t Volvo Excavator
OPERATOR: Cain Contracting
DIMENSIONS: 2.5 x 5 x 6m

EXCAV. STARTED: 4/10/11
EXCAV FINISHED: 4/10/11
LOGGED BY: CVM
CHECKED BY: Duncan

EXCAVATION TESTS						ENGINEERING DESCRIPTION						GEOLOGICAL	
PENETRATION 1 2 3	SUPPORT	WATER	SAMPLES, TESTS	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	SOIL NAME, PLASTICITY OR PARTICLE SIZE CHARACTERISTICS, COLOUR, SECONDARY AND MINOR COMPONENTS	MOISTURE CONDITION / WEATHERING	STRENGTH / DENSITY CLASSIFICATION	ESTIMATED SHEAR STRENGTH (kPa) 50 100 150 200	ORIGIN TYPE, MINERAL COMPOSITION, DEFECTS, STRUCTURE	UNIT
					0			Dark brown sandy SILT with many Rootlets					Topsoil
							MS	Orange brown sandy SILT with minor rootlets, friable	M	F			Volcanic Ash
					1		GS	Sandy fine to coarse GRAVEL, light brown, tightly packed, moist. Gravel is subangular, slightly weathered greywacke	M	TP			Alluvial fan gravel
								Thin continuous horizontal beds of well graded gravel					
					2		MS	Horizontal layer of sandy SILT 100mm thick, orange brown	M	TP		overbank deposit	
			Sample TP2		3		GS	Horizontally bedded GRAVEL as above	M	TP			Alluvial fan gravel
					4								
					5			EOH @ 6m Pit walls show no sign of collapse, no water inflow					
					6								

SKETCH



Log Scale 1:50

EXCAVLOG TP.GPJ 27/9/07

TONKIN & TAYLOR LTD

EXCAVATION LOG

BOREHOLE No: TP3
Location: A7
SHEET 1 OF 1

PROJECT: Ruataniwha Water Storage Scheme | LOCATION: A7U | JOB No: 27195.200

CO-ORDINATES: mN 5592111.5 mE 1880508.1
R.L. 436 m
DATUM NZTM-10m

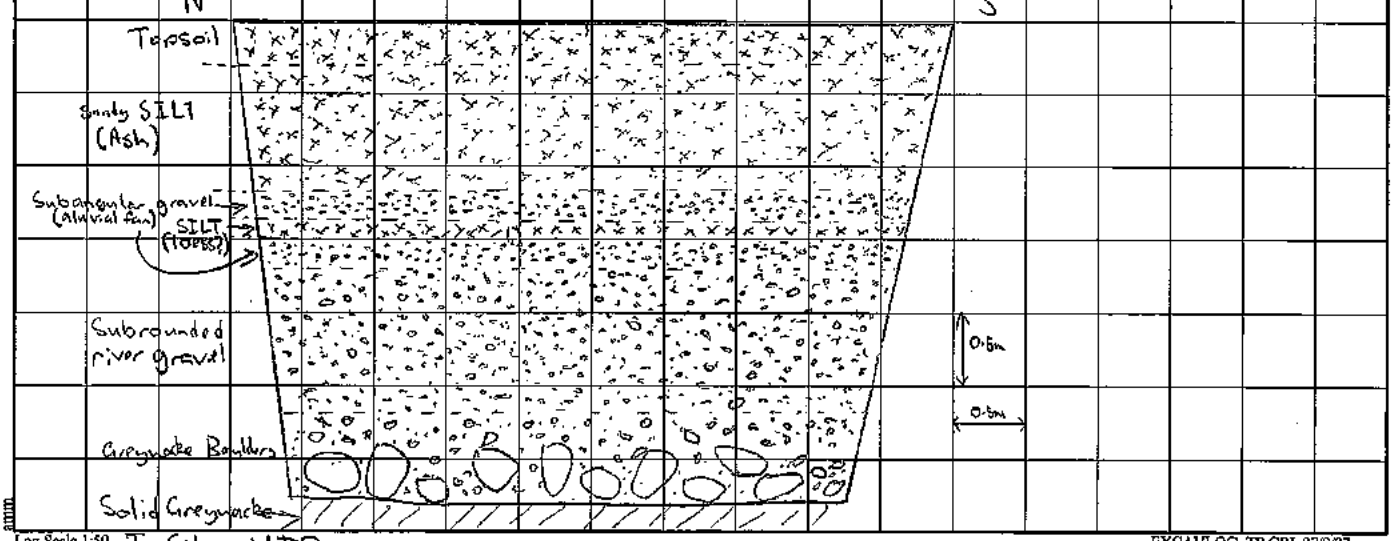
EXPOSURE TYPE: Test Pit
EQUIPMENT: 20t Volvo Excavator
OPERATOR: Gair Contracting
DIMENSIONS: 2.5 X 5 X 3.2m

EXCAV. STARTED: 11/10/11
EXCAV FINISHED: 11/10/11
LOGGED BY: CWM
CHECKED BY: Dmmm

EXCAVATION TESTS | ENGINEERING DESCRIPTION | GEOLOGICAL

PENETRATION	SUPPORT	WATER	SAMPLES, TESTS	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	SOIL NAME, PLASTICITY OR PARTICLE SIZE CHARACTERISTICS, COLOUR, SECONDARY AND MINOR COMPONENTS	MOISTURE CONDITION / WEATHERING	STRENGTH / DENSITY CLASSIFICATION	ESTIMATED SHEAR STRENGTH (kPa)	ORIGIN TYPE, MINERAL COMPOSITION, DEFECTS, STRUCTURE	UNIT
								Dark brown sandy SILT with many Rootlets					Ts
					1		MS	Orange brown sandy SILT, stiff, moist, non plastic	M	St			Volcanic ash
			Sample TP3				GS	Sandy, fine to coarse GRAVEL, light grey, subangular	M	TP		Alluvial fan? with interbedded loess?	
							MS	Sandy SILT, light brown, horizontally bedded					
							GS	Sandy GRAVEL, light grey as above					
					2		GS	Sandy GRAVEL with some cobbles, light brown, subrounded, Tightly packed, Thin horizontal continuous beds	M	TP			River gravel
					3		GS	Sandy GRAVEL with some cobbles and boulders, brown, subrounded, fine to coarse 0.4m maximum boulder diameter	M	TP			
					4			EOH @ 3.2m UTP Hard rock (Sandstone greywacke)				In Situ Greywacke Rock	Waioeka Terrane
					5								

SKETCH



Log Scale 1:50

EXCAVLOG TP.GPJ 27/9/07

TONKIN & TAYLOR LTD

EXCAVATION LOG

BOREHOLE No: TP 4
Location: A7
SHEET 1 OF 1

PROJECT: Ruataniwha Water storage Scheme | LOCATION: A7U | JOB No: 27195.200

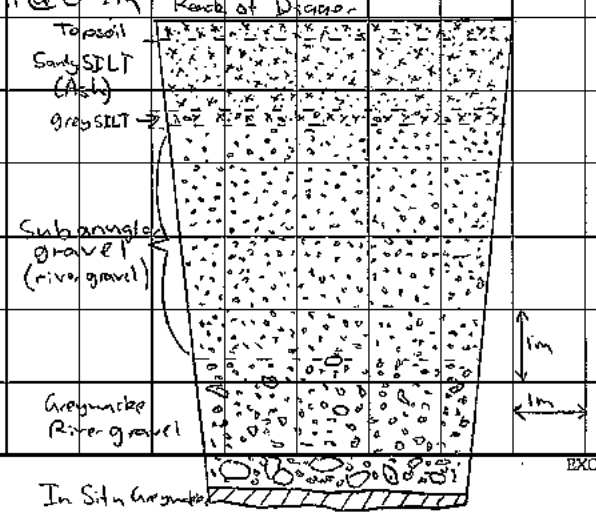
CO-ORDINATES: mN 5592179.9 mE 1880484.0
R.L. 438 m
DATUM NZTM-10

EXPOSURE TYPE: Test Pit
EQUIPMENT: 20 t Volvo Excavator
OPERATOR: Gair Contracting
DIMENSIONS: 2.5 x 5 x 6.7m

EXCAV. STARTED: 11/10/11
EXCAV FINISHED: 11/10/11
LOGGED BY: CWM
CHECKED BY: DMMM

EXCAVATION TESTS | ENGINEERING DESCRIPTION | GEOLOGICAL

PENETRATION	SUPPORT	WATER	SAMPLES, TESTS	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	SOIL NAME, PLASTICITY OR PARTICLE SIZE CHARACTERISTICS, COLOUR, SECONDARY AND MINOR COMPONENTS	MOISTURE CONDITION / WEATHERING	STRENGTH / DENSITY CLASSIFICATION	ESTIMATED SHEAR STRENGTH (kPa)	ORIGIN TYPE, MINERAL COMPOSITION, DEFECTS, STRUCTURE	UNIT
								Dark brown sandy SILT with many Rootlets					Topsoil
					1		MS	Orange brown Sandy SILT, Stiff, moist, non plastic	M	St			Volcanic Ash
							MG	light grey gravelly (subangular) SILT with some sand	M	T.P.			
			Sample TP4		2, 3, 4		GS	Sandy, fine to coarse GRAVEL, light brown sub angular Horizontal, thin, well graded greywacke gravel beds	M	T.P.			River Gravel
			water inflow at 5m		5			GRAVEL with some cobbles and boulders, minor sand and clay, wet, subrounded, grey, fine to coarse Cobbles and boulders increase in size with depth with maximum diameter of 0.4m Gravel, cobbles and boulders are CW Sandstone	W	T.P.			River Gravel
SKETCH					6								
								Weathered SANDSTONE (Greywacke)				In Situ Greywacke (Waioeka Terrace)	
					7			EOH @ 6.7m					



Log Scale 1:50

EXCAVLOG TP.GPJ 27/9/07

TONKIN & TAYLOR LTD

EXCAVATION LOG

BOREHOLE No: TP5
Location: A7

SHEET 1 OF 1

PROJECT: Ruataniwha water Storage Scheme | LOCATION: A7U | JOB No: 27195.200

CO-ORDINATES: mN 5592248.4 mE 1890433.1 | EXPOSURE TYPE: Test Pit | EXCAV. STARTED: 11/10/11

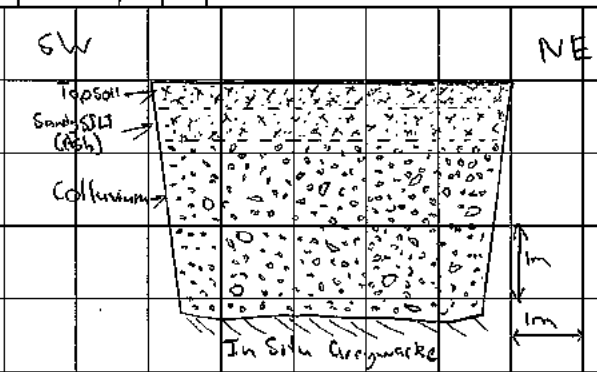
EQUIPMENT: 20t Volvo Excavator | EXCAV FINISHED: 11/10/11

R.L. 445 m | OPERATOR: Cain Contracting | LOGGED BY: Cwm

DATUM NZTM -10. | DIMENSIONS: 2.5 x 5 x 3.2m | CHECKED BY: Dmmm

EXCAVATION TESTS					ENGINEERING DESCRIPTION						GEOLOGICAL	
PENETRATION 1 2 3	SUPPORT	WATER	SAMPLES, TESTS	R.L. (m) / DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	SOIL NAME, PLASTICITY OR PARTICLE SIZE CHARACTERISTICS, COLOUR, SECONDARY AND MINOR COMPONENTS	MOISTURE CONDITION / WEATHERING	STRENGTH / DENSITY CLASSIFICATION	EST. MATED SHEAR STRENGTH (kPa) 10 25 100 200	ORIGIN TYPE, MINERAL COMPOSITION, DEFECTS, STRUCTURE	UNIT
				0			Dark brown sandy SILT with many rootlets					Topsoil
				0.5		MS	Orange brown sandy SILT, firm, moist, non plastic	M	T.P		Volcanic Ash	
			Sample TP5	1		GS	Sandy fine to Coarse GRAVEL with some subrounded cobbles and boulders. Gravel is light brown, slightly weathered, Sub angular greywacke	M	T.P.			Colluvium
				3.2			EOH @ 3.2m Solid Rock UTP SW. weak. SANDSTONE (Greywacke)				In Situ Greywacke Rock	Waioeka Terrane

SKETCH



Log Scale 1:50

EXCAVLOG TP.GPJ 27/9/07

TONKIN & TAYLOR LTD

EXCAVATION LOG

BOREHOLE No: TP 6
Location: A7
SHEET 1 OF 1

PROJECT: Ruataniwha Water Storage Scheme | LOCATION: A74 | JOB No: 27195.200

CO-ORDINATES: mN5592299.3 mE1880428.3 | EXPOSURE TYPE: Test Pit | EXCAV. STARTED: 11/10/11

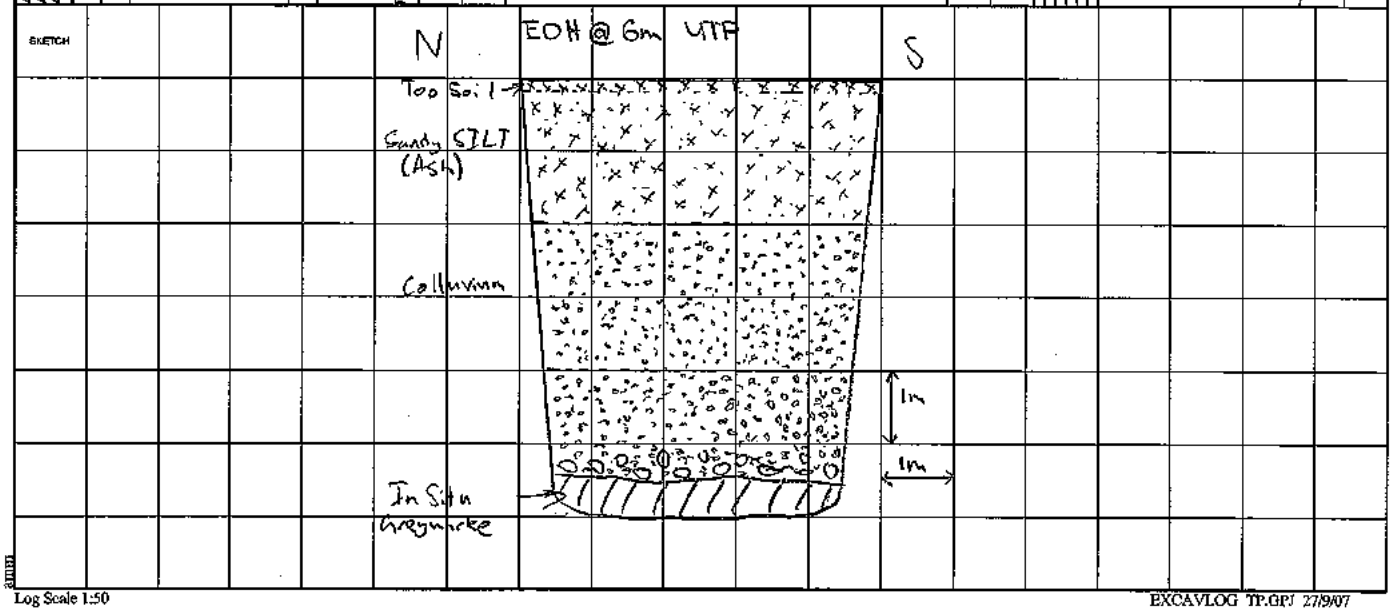
R.L. 445 m | EQUIPMENT: 20t Volvo Excavator | EXCAV FINISHED: 11/10/11

DATUM NZTM-1D | OPERATOR: Geir Contracting | LOGGED BY: CWM

DIMENSIONS: 2.5 x 5 x 6m | CHECKED BY: Dmunn

EXCAVATION TESTS						ENGINEERING DESCRIPTION					GEOLOGICAL	
PENETRATION 1 2 3	SUPPORT	WATER	SAMPLES, TESTS	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	SOIL NAME, PLASTICITY OR PARTICLE SIZE CHARACTERISTICS, COLOUR, SECONDARY AND MINOR COMPONENTS	MOISTURE CONDITION / WEATHERING	STRENGTH / DENSITY CLASSIFICATION	ESTIMATED SHEAR STRENGTH (kPa) 50 100 200	ORIGIN TYPE, MINERAL COMPOSITION, DEFECTS, STRUCTURE	UNIT
					0			Dark brown sandy SILT with many rootlets					Topsoil
			Sample TP6		1		MS	Orange brown sandy SILT with some clay becoming light brown at 1m, non plastic, firm	M	TP			Volcanic Ash
					2		GS	Sandy, fine to medium GRAVEL with minor clay, light brown, subangular, tightly packed, well graded. Gravel is SW greywacke Sandstone	M	TP			River gravel
					3			gravel becomes coarse					
					4		GS	Sandy, fine to coarse GRAVEL, light brown, subangular, tightly packed, moist. gravel is SW greywacke sandstone	M	TP			
					5			light brown sandy GRAVEL with some cobbles and boulders (reworked)					
					6			SW SANDSTONE, weak, blue grey (greywacke)	SW	RI		In Situ Greywacke (Waioeka Terrane)	

SKETCH



Log Scale 1:50

EXCAVLOG TP.GPJ 27/9/07

TONKIN & TAYLOR LTD

EXCAVATION LOG

BOREHOLE No: TP 7
Location: A7
SHEET 1 OF 1

PROJECT:
LOCATION: A7u
JOB No: 27195.200

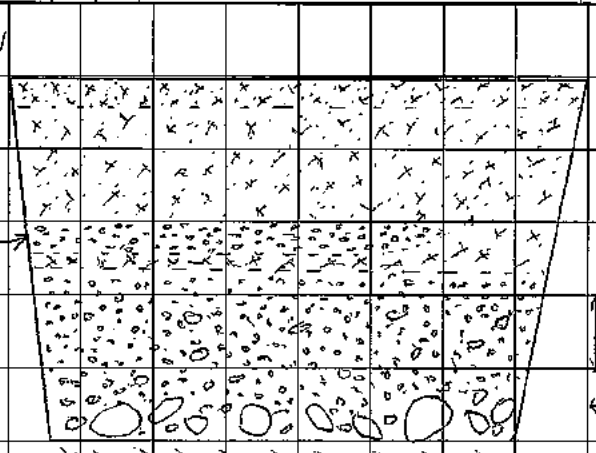
CO-ORDINATES: mN 5892435.2
mE 1880449.9
R.L. 438 m
DATUM NZTM-10

EXPOSURE TYPE: Test Pit
EQUIPMENT: 20 t Volvo Excavator
OPERATOR: Gair Contracting
DIMENSIONS: 2.5 x 4 x 2.5m

EXCAV. STARTED: 11/10/11
EXCAV FINISHED: 11/10/11
LOGGED BY: CWM
CHECKED BY: Drummond

EXCAVATION TESTS						ENGINEERING DESCRIPTION						GEOLOGICAL	
PENETRATION 1 2 3	SUPPORT	WATER	SAMPLES, TESTS	R.L. (m)	DEPTH (m)	GRAPHIC LOG	CLASSIFICATION SYMBOL	SOIL NAME, PLASTICITY OR PARTICLE SIZE CHARACTERISTICS, COLOUR, SECONDARY AND MINOR COMPONENTS	MOISTURE CONDITION / WEATHERING	STRENGTH / DENSITY CLASSIFICATION	ESTIMATED SHEAR STRENGTH (kPa) 10 100 200	ORIGIN TYPE, MINERAL COMPOSITION, DEFECTS, STRUCTURE	UNIT
		water inflow @ 2.2m	Sample TP7		0			Dark brown Sandy SILT with many rootlets					Topsoil
					1		MS	Orange-brown Sandy SILT with some clay, non plastic, Stiff	M	St			Volcanic Ash
							SA	Dark grey gravelly SAND (Subrounded gravel) discontinuous bed	M	TP		River gravel	
							MS	Sandy SILT with some Clay, Stiff, non plastic.	M	St			
							GS	Sandy GRAVEL, fine to coarse, subrounded with some cobbles, poorly graded, moist, Tightly packed	M	TP			River Gravel
					2		GS	Sandy GRAVEL with some cobbles and boulders. (0.6m max diameter), brown, Subrounded, moist Tightly packed, poorly graded horizontally bedded Gravel + Boulders are Sw greywacke Sandstone	M / W	TP			
					3			EOH @ 2.5m UTP (Slightly weathered greywacke rock)				In Situ Greywacke Rock	Waipapa Terrane
					4								
					5								

SKETCH



Log Scale 1:50

RXCAVLOG TP.GPJ 27/9/07

Trial Pit 1

Trial Pit 1

Trial Pit 2

Trial Pit 2

Trial Pit 3

Trial Pit 3

Trial Pit 4

Trial Pit 4

Trial Pit 5

Trial Pit 5

Trial Pit 6

Trial Pit 6

Trial Pit 7

Trial Pit 7

Trial Pit 8 (Trench, see Drawing 27690.200-07 for log) – Looking east before extending the pit.

Trial Pit 8 (Trench, see Drawing 27690.200-07 for log) – Western end of trench.

Trial Pit 8 (Trench, see Drawing 27690.200-07 for log) – Middle of trench.

Trial Pit 8(Trench, see Drawing 27690.200-07 for log) – Eastern end of trench.

Trial Pit 8 (Trench, see Drawing 27690.200-07 for log) – Eastern end of trench.

Trial Pit 8 (Trench, see Drawing 27690.200-07 for log) – Eastern end of trench showing extension and shear zone within (marked by the arrow). Note that the units above the shear zone have not been displaced.

Appendix I: Laboratory Test Results

WET SIEVE ANALYSIS
TEST REPORT

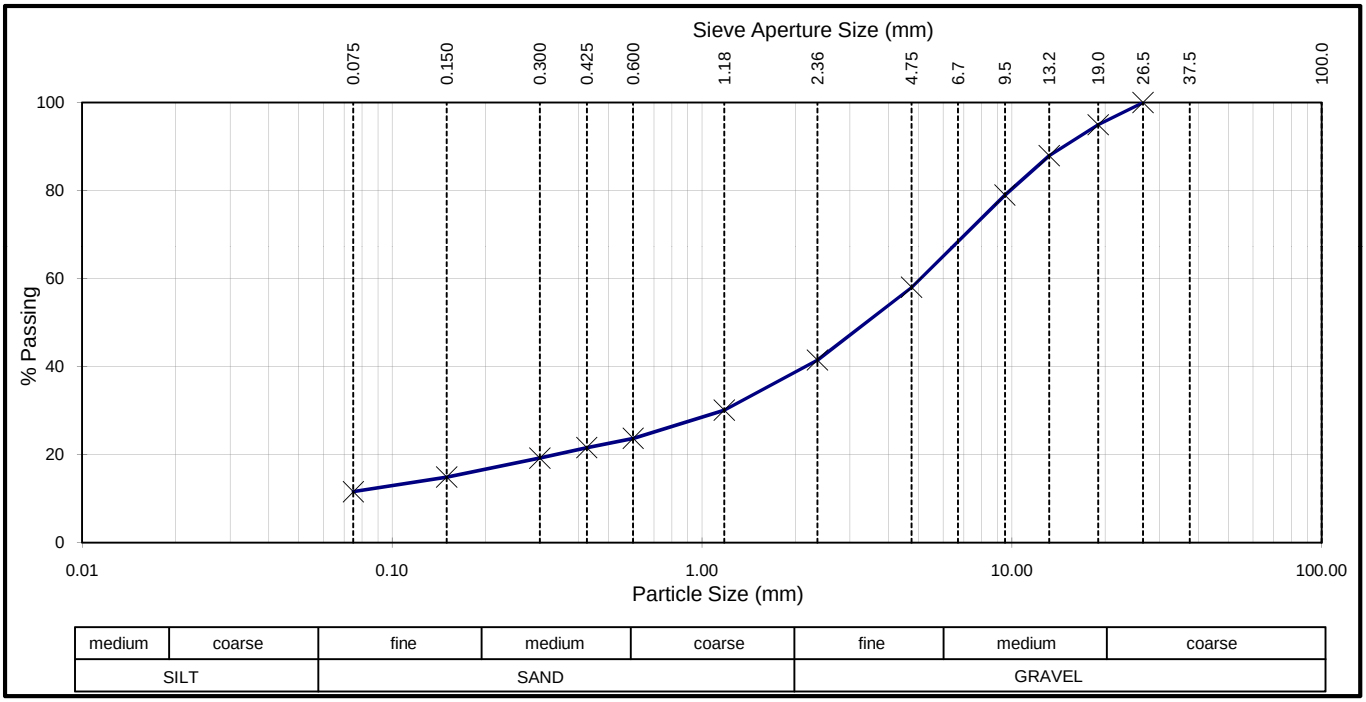
Project :	**Ruataniwha Water Storage System**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, Private Bag 6006, Napier**
Contractor :	**Tonkin & Taylor (Auckland)**
Sampled by :	**Tim Fisher**
Date sampled :	**October 2011**
Sampling method :	**Digger Pit**
Sample description :	**Sandy Gravel**

Site: **TP. 2**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11.759 C**
Client Ref No :	

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
63.00	-	19.00	**95**	4.75	**58**	0.425	**22**
53.00	-	13.20	**88**	2.36	**42**	0.300	**19**
37.50	-	9.50	**79**	1.18	**30**	0.150	**15**
26.50	**100**	6.70	**-**	0.600	**24**	0.075	**12**



Test Method	Notes
NZS 4407 : 1991 Test 3.8.1	History : Fraction tested : Whole Sample Dispersant Used : Nil ***Fraction passing finest sieve is by difference.***

Date tested : 3/11/2011
Date reported : 3/11/2011

This report may only be reproduced in full

Approved **A.Ching**

Designation : ***Laboratory Manager***
Date : 3/11/2011

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

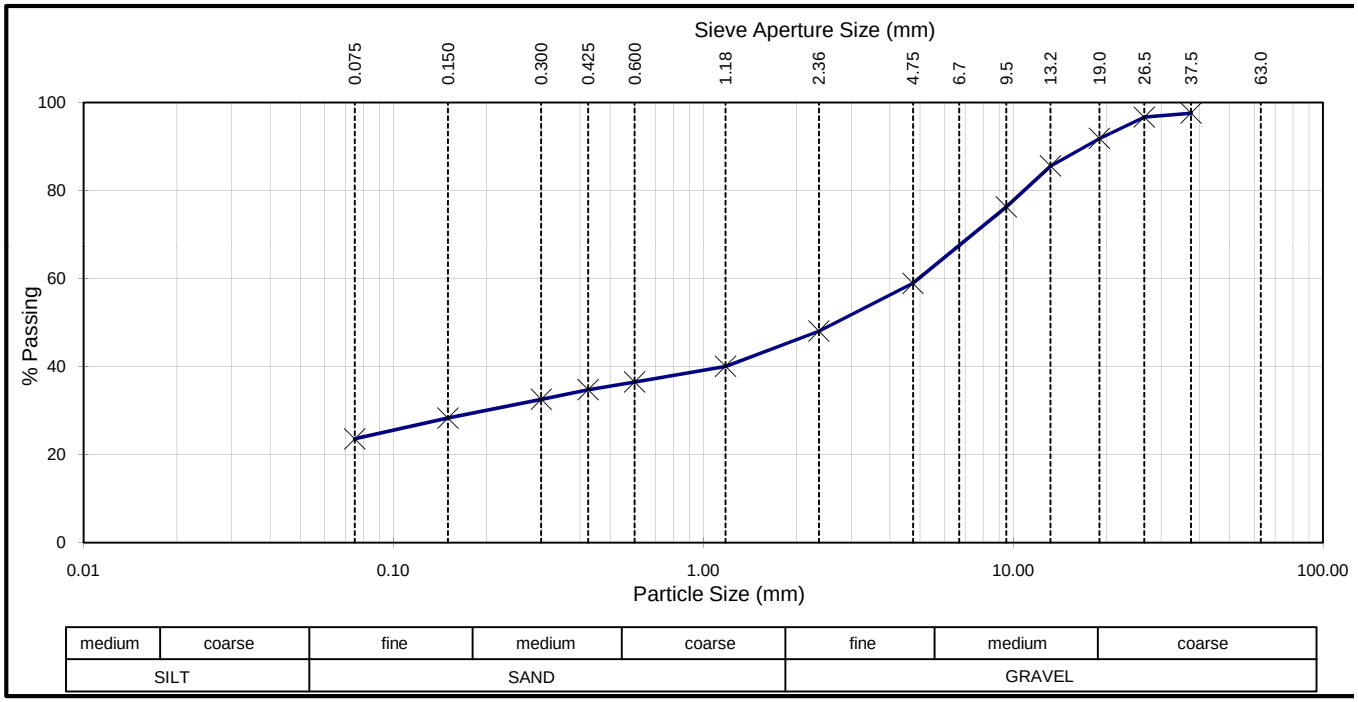
WET SIEVE ANALYSIS
TEST REPORT

Project :	**Ruataniwha Water Storage System**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, Private Bag 6006, Napier**
Contractor :	**Tonkin & Taylor (Auckland)**
Sampled by :	**David Milner**
Date sampled :	**October 2011**
Sampling method :	**Digger Pit**
Sample description :	**Silty/Sandy Gravel**

Site: **TP. 3**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11.759 E**
Client Ref No :	

Sieve Analysis							
Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
63.00	-	19.00	**92**	4.75	**59**	0.425	**35**
53.00	**100**	13.20	**86**	2.36	**48**	0.300	**33**
37.50	**98**	9.50	**76**	1.18	**40**	0.150	**28**
26.50	**97**	6.70	-	0.600	**37**	0.075	**24**



Test Method	Notes
NZS 4407 : 1991 Test 3.8.1	History : Fraction tested : Whole Sample Dispersant Used : Nil ***Fraction passing finest sieve is by difference.***

Date tested : 3/11/2011
Date reported : 3/11/2011

This report may only be reproduced in full

Approved **A.Ching**

Designation : ***Laboratory Manager***
Date : 3/11/2011

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

WET SIEVE ANALYSIS
TEST REPORT

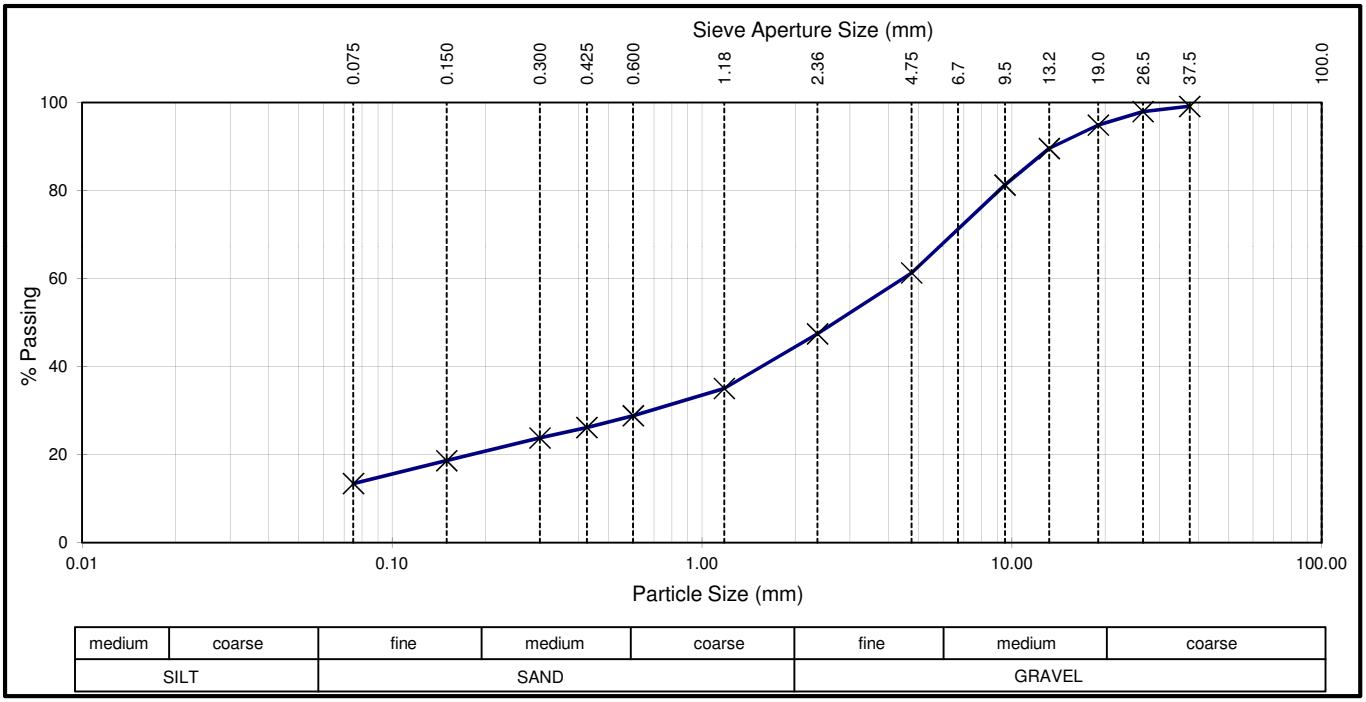
Project :	**Ruataniwha Water Storage System**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, Private Bag 6006, Napier**
Contractor :	**Tonkin & Taylor (Auckland)**
Sampled by :	**Tim Fisher**
Date sampled :	**October 2011**
Sampling method :	**Digger Pit**
Sample description :	**Sandy Gravel-minor Silt**

Site: **TP. 4**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11.759 D**
Client Ref No :	

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
100.00	**-**	19.00	**95**	4.75	**61**	0.425	**26**
53.00	**100**	13.20	**90**	2.36	**47**	0.300	**24**
37.50	**99**	9.50	**81**	1.18	**35**	0.150	**19**
26.50	**98**	6.70	**-**	0.600	**29**	0.075	**13**



Test Method	Notes
NZS 4407 : 1991 Test 3.8.1	History : Fraction tested : Whole Sample Dispersant Used : Nil *Fraction passing finest sieve is by difference.*

Date tested : 03/11/11
Date reported : 03/11/11

This report may only be reproduced in full

Approved **A.Ching**

Designation : *Laboratory Manager*
Date : 03/11/11

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

WET SIEVE ANALYSIS
TEST REPORT

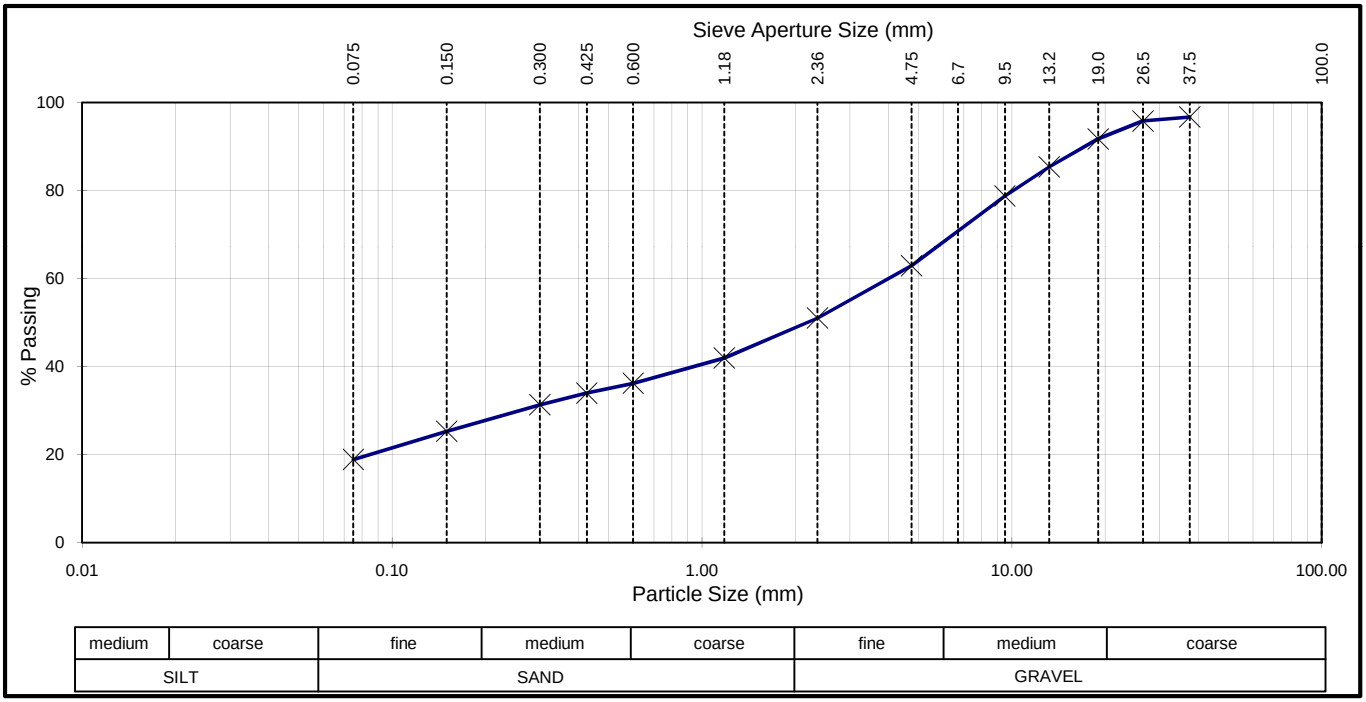
Project :	**Ruataniwha Water Storage System**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, Private Bag 6006, Napier**
Contractor :	**Tonkin & Taylor (Auckland)**
Sampled by :	**Tim Fisher**
Date sampled :	**October 2011**
Sampling method :	**Digger Pit**
Sample description :	**Silty/Sandy Gravel**

Site: **TP. 5**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11.759 B**
Client Ref No :	

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
100.00	-	19.00	**92**	4.75	**63**	0.425	**34**
53.00	**100**	13.20	**85**	2.36	**51**	0.300	**31**
37.50	**97**	9.50	**79**	1.18	**42**	0.150	**25**
26.50	**96**	6.70	-	0.600	**36**	0.075	**19**



Test Method	Notes
NZS 4407 : 1991 Test 3.8.1	History : Fraction tested : Whole Sample Dispersant Used : Nil ***Fraction passing finest sieve is by difference.***

Date tested : 3/11/2011
Date reported : 3/11/2011

This report may only be reproduced in full

Approved **A.Ching**

Designation : ***Laboratory Manager***
Date : 3/11/2011

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

WET SIEVE ANALYSIS
TEST REPORT

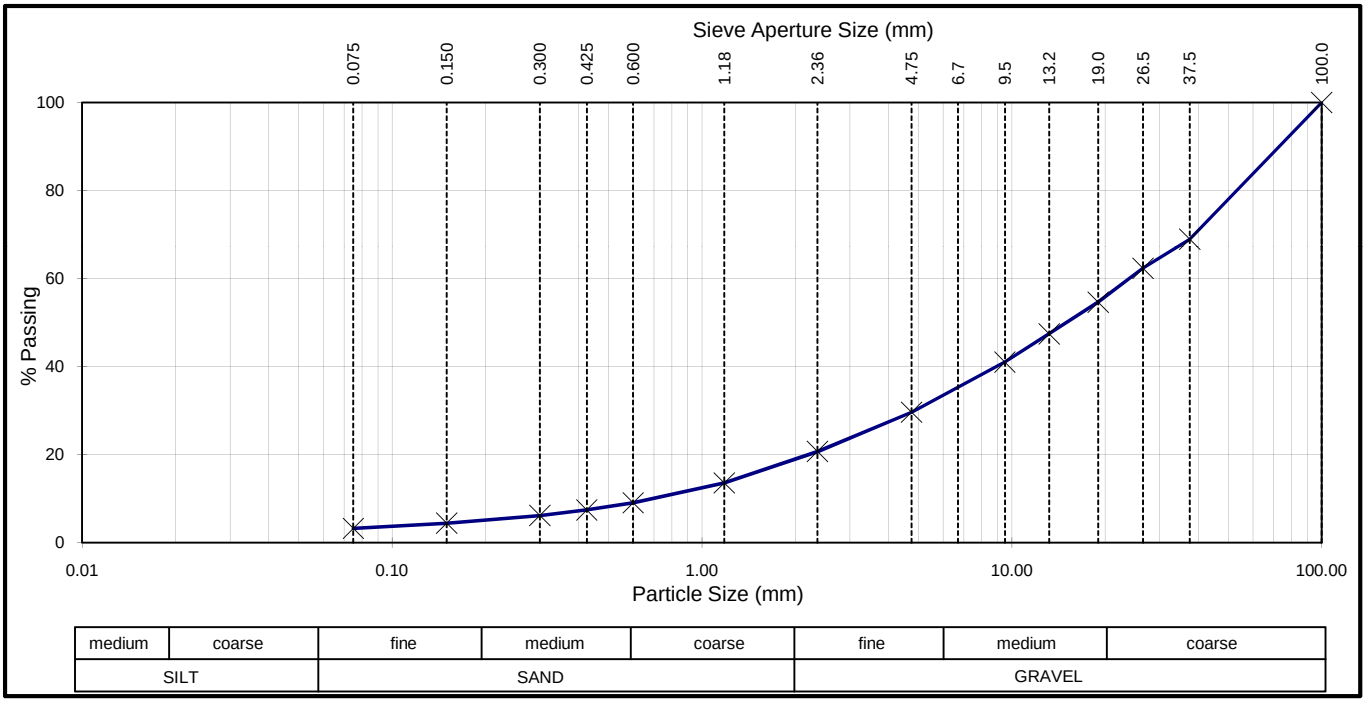
Project :	**Ruataniwha Water Storage System**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, Private Bag 6006, Napier**
Contractor :	**Tonkin & Taylor (Auckland)**
Sampled by :	**Tim Fisher**
Date sampled :	**October 2011**
Sampling method :	**Digger Pit**
Sample description :	**Gravel - minor Cobbles & Sand**

Site: **TP. 7**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11.759 A**
Client Ref No :	

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
100.00	**100**	19.00	**55**	4.75	**30**	0.425	**7**
75.00	**86**	13.20	**47**	2.36	**21**	0.300	**6**
37.50	**69**	9.50	**41**	1.18	**14**	0.150	**4**
26.50	**62**	6.70	**-**	0.600	**9**	0.075	**3**



Test Method	Notes
NZS 4407 : 1991 Test 3.8.1	History : Fraction tested : Whole Sample Dispersant Used : Nil ***Fraction passing finest sieve is by difference.***

Date tested : 3/11/2011
Date reported : 3/11/2011

This report may only be reproduced in full

Approved **A.Ching**

Designation : ***Laboratory Manager***
Date : 3/11/2011

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

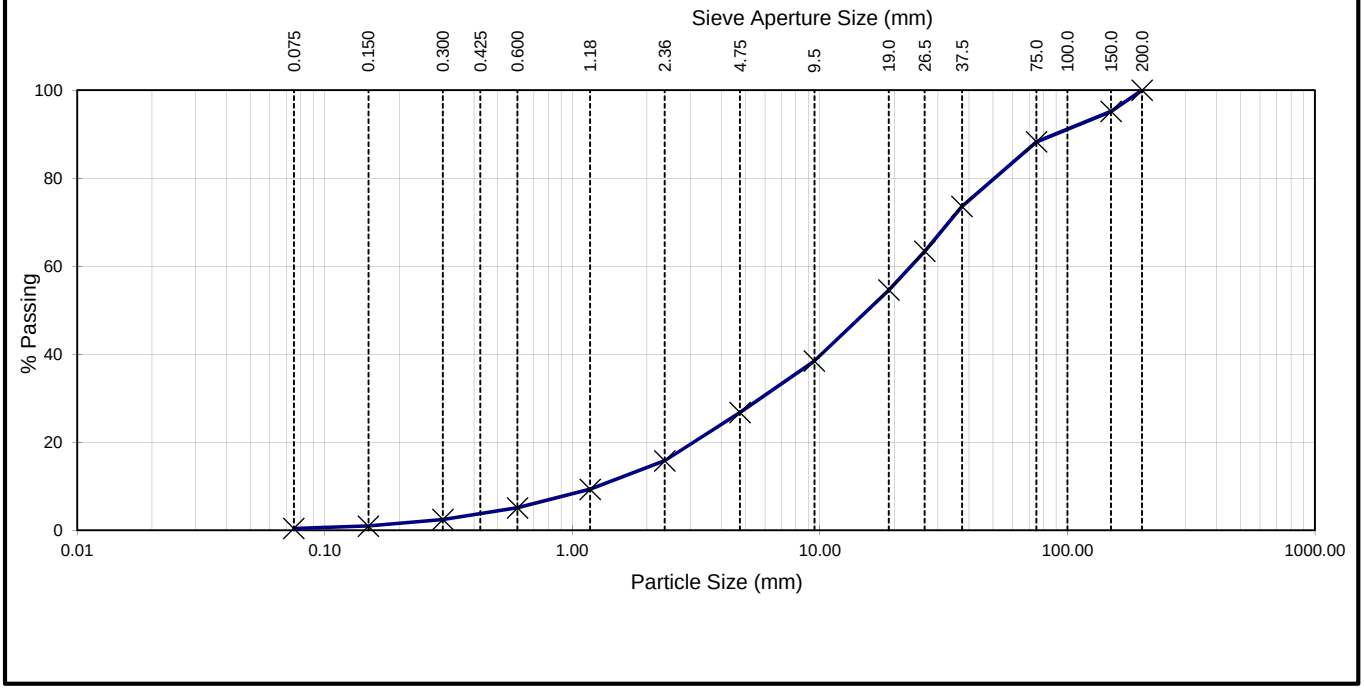
DRY SIEVE ANALYSIS
TEST REPORT

Project :	**Ruataniwha Water Storage Scheme**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, P.Bag 6006, Napier**
Consultant :	**Tonkin & Taylor - Auckland**
Sampled by :	**Tim Fisher**
Date sampled :	**26/10/11**
Sampling method :	**Digger Pits**
Sample description :	**Gravel**
Sample condition	**Wet**
Test Pit no :	**RG. 1**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11. 760 / 1**
Client Ref No :	**Sample RG. 1**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
200.00	**100**	37.50	**74**	4.75	**27**	0.425	**-**
150.00	**95**	26.50	**63**	2.36	**16**	0.300	**2**
100.00	**-**	19.00	**55**	1.18	**9**	0.150	**1**
75.00	**88**	9.50	**38**	0.600	**5**	0.075	**0**



Test Method	**Notes**	
NZS 4407 : 1991 Test 3.8.2	History:	River bed material
	Fraction tested:	Whole sample
	Dispersant Used:	Nil

Date tested : 4/11/2011

Date reported : 7/11/2011

Sampling is not covered by IANZ Accreditation. Results apply only to sample tested.

This report may only be reproduced in full

IANZ Approved Signatory

A.Ching

Designation : ***Laboratory Manager***

Date : 7/11/2011

Tests indicated as not accredited are outside the scope of the laboratory's accreditation

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

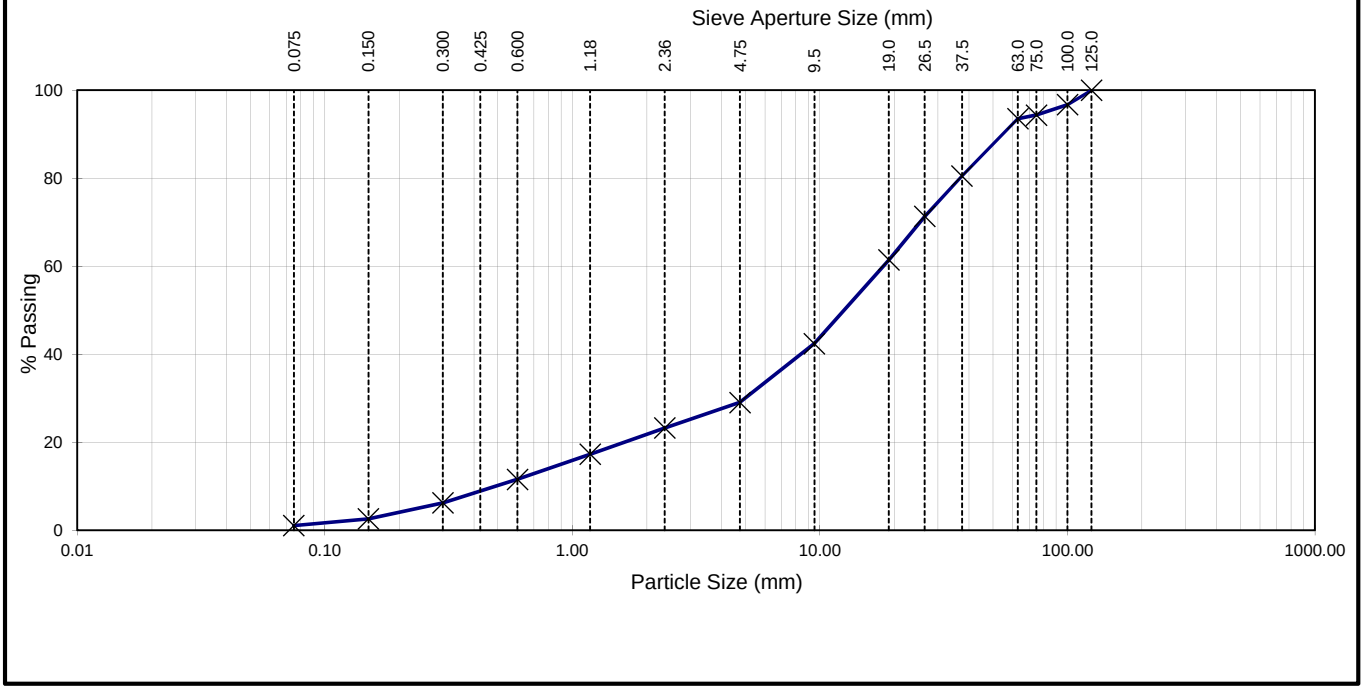
DRY SIEVE ANALYSIS
TEST REPORT

Project :	**Ruataniwha Water Storage Scheme**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, P.Bag 6006, Napier**
Consultant :	**Tonkin & Taylor - Auckland**
Sampled by :	**Tim Fisher**
Date sampled :	**26/10/11**
Sampling method :	**Digger Pits**
Sample description :	**Gravel**
Sample condition	**Wet**
Test Pit no :	**RG. 2**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11. 760 / 2**
Client Ref No :	**Sample RG. 2**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
125.00	**100**	37.50	**81**	4.75	**29**	0.425	**-**
100.00	**97**	26.50	**71**	2.36	**23**	0.300	**6**
75.00	**94**	19.00	**61**	1.18	**17**	0.150	**3**
63.00	**93**	9.50	**42**	0.600	**12**	0.075	**1**



Test Method	Notes	
NZS 4407 : 1991 Test 3.8.2	History:	River bed material
	Fraction tested:	Whole sample
	Dispersant Used:	Nil

Date tested : 7/11/2011

Date reported : 7/11/2011

Sampling is not covered by IANZ Accreditation. Results apply only to sample tested.

This report may only be reproduced in full

IANZ Approved Signatory

A.Ching

Designation : ***Laboratory Manager***

Date : 7/11/2011

Tests indicated as not accredited are outside the scope of the laboratory's accreditation

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

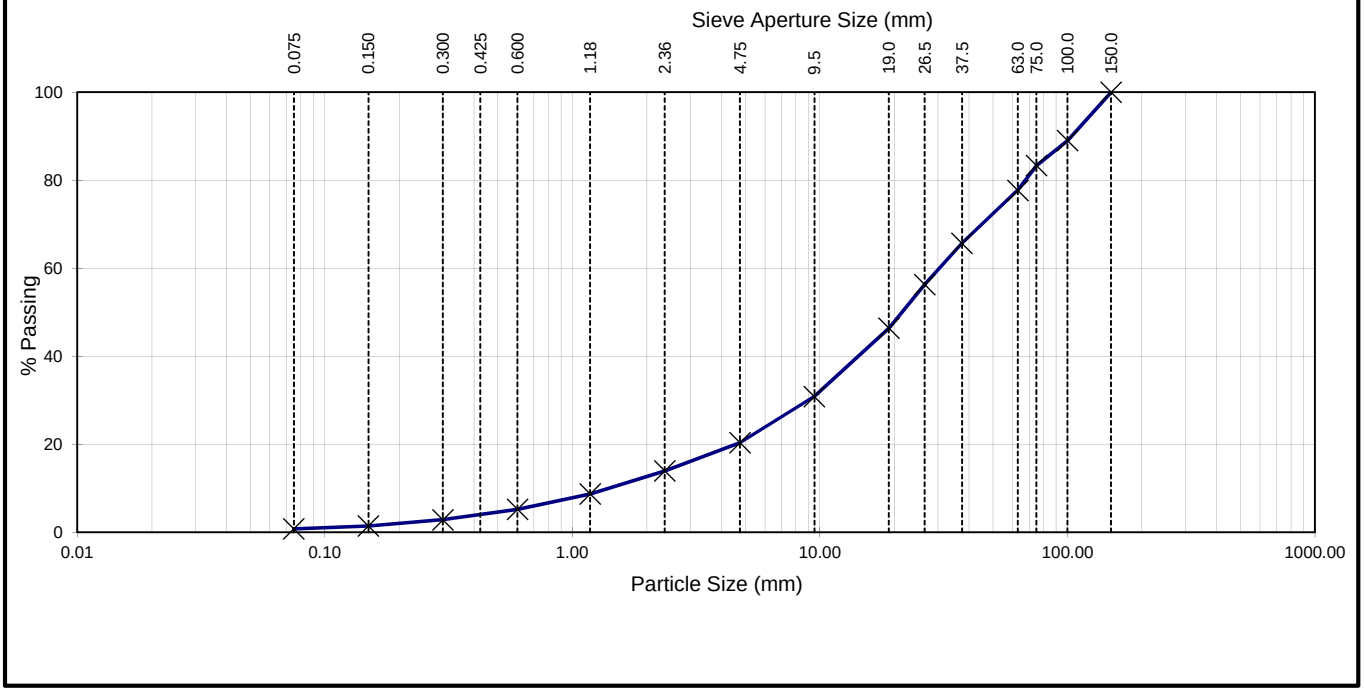
DRY SIEVE ANALYSIS
TEST REPORT

Project :	**Ruataniwha Water Storage Scheme**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, P.Bag 6006, Napier**
Consultant :	**Tonkin & Taylor - Auckland**
Sampled by :	**Tim Fisher**
Date sampled :	**26/10/11**
Sampling method :	**Digger Pits**
Sample description :	**Gravel**
Sample condition	**Wet**
Test Pit no :	**RG. 3**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11. 760 / 3**
Client Ref No :	**Sample RG. 3**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
150.00	**100**	37.50	**66**	4.75	**20**	0.425	-
100.00	**89**	26.50	**56**	2.36	**14**	0.300	**3**
75.00	**83**	19.00	**46**	1.18	**9**	0.150	**1**
63.00	**78**	9.50	**31**	0.600	**5**	0.075	**1**



Test Method	**Notes**	
NZS 4407 : 1991 Test 3.8.2	History:	River bed material
	Fraction tested:	Whole sample
	Dispersant Used:	Nil

Date tested : 4/11/2011

Date reported : 7/11/2011

Sampling is not covered by IANZ Accreditation. Results apply only to sample tested.

This report may only be reproduced in full

IANZ Approved Signatory

A.Ching

Designation : ***Laboratory Manager***

Date : 7/11/2011

Tests indicated as not accredited are outside the scope of the laboratory's accreditation

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

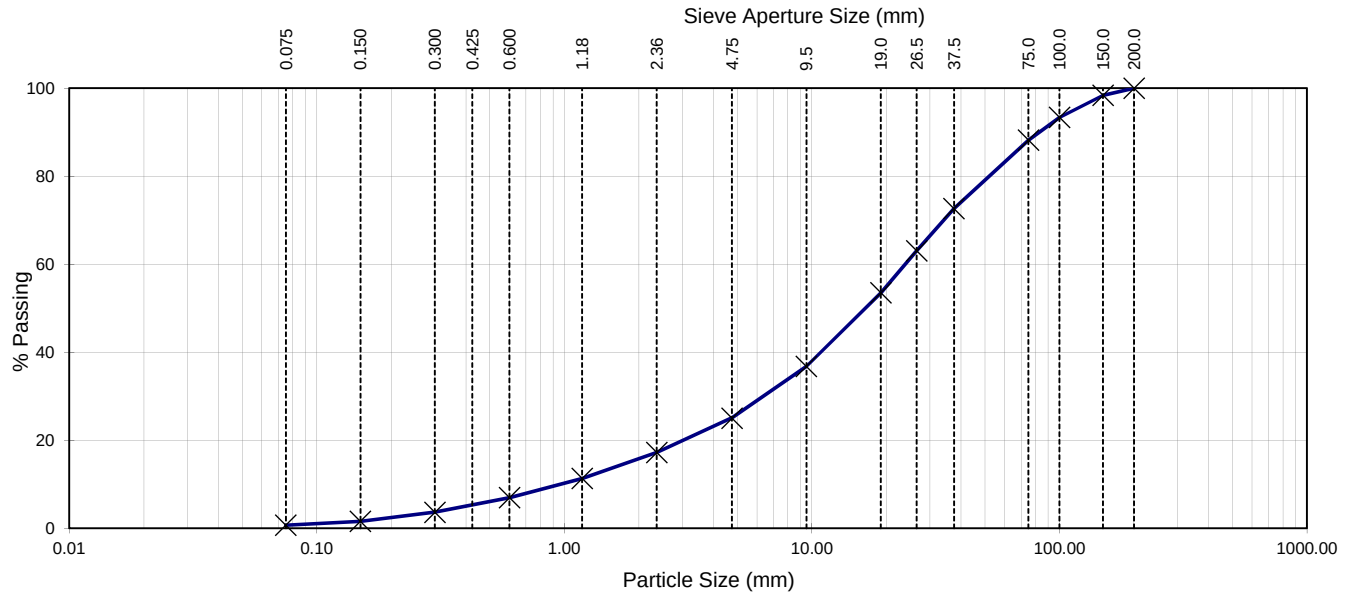
DRY SIEVE ANALYSIS
TEST REPORT

Project :	**Ruataniwha Water Storage Scheme**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, P.Bag 6006, Napier**
Consultant :	**Tonkin & Taylor - Auckland**
Sampled by :	**Tim Fisher**
Date sampled :	**26/10/11**
Sampling method :	**Digger Pits**
Sample description :	**Gravel**
Sample condition	**Wet**
Test Pit no :	**RG. 1, 2 and 3**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11. 760 / 1 - 3**
Client Ref No :	**Combined Sample**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
200.00	**100**	37.50	**73**	4.75	**25**	0.425	-
150.00	**98**	26.50	**63**	2.36	**17**	0.300	**4**
100.00	**93**	19.00	**54**	1.18	**11**	0.150	**2**
75.00	**88**	9.50	**37**	0.600	**7**	0.075	**1**



Test Method	**Notes**	
NZS 4407 : 1991 Test 3.8.2	History:	River bed material
	Fraction tested:	Whole sample
	Dispersant Used:	Nil

Date tested : 4/11/2011

Date reported : 7/11/2011

Sampling is not covered by IANZ Accreditation. Results apply only to sample tested.

This report may only be reproduced in full

IANZ Approved Signatory

A.Ching

Designation : ***Laboratory Manager***

Date : 7/11/2011

Tests indicated as not accredited are outside the scope of the laboratory's accreditation

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

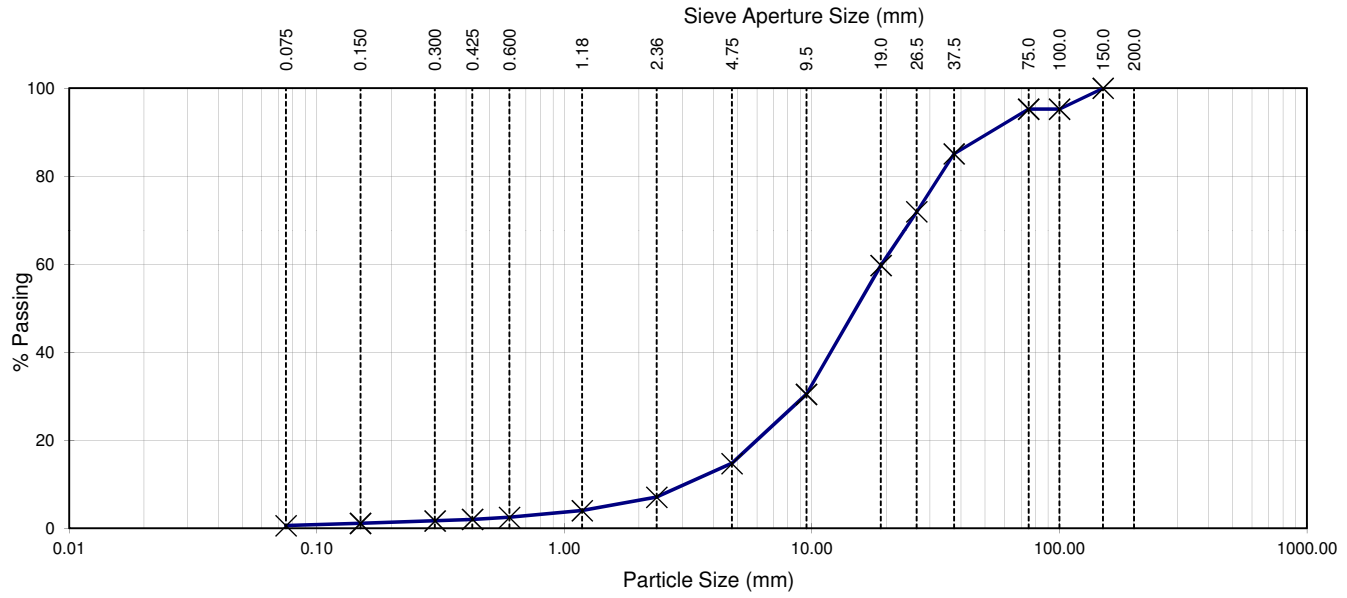
WET SIEVE ANALYSIS
TEST REPORT

Project :	**Ruataniwha Water Storage Scheme**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, P.Bag 6006, Napier**
Consultant :	**Tonkin & Taylor - Auckland**
Sampled by :	**David Milner**
Date sampled :	**10/03/2011**
Sampling method :	**Digger Pits**
Sample description :	**Rotten Rock**
Sample condition	**Damp**
Test Pit no :	**A7/5**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11. 808 / A**
Client Ref No :	**Sample A7/5**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
200.00	**-**	37.50	**85**	4.75	**15**	0.425	**2.1**
150.00	**100**	26.50	**72**	2.36	**7**	0.300	**1.7**
100.00	**95**	19.00	**60**	1.18	**4**	0.150	**1.2**
75.00	**95**	9.50	**30**	0.600	**3**	0.075	**0.6**



Test Method	Notes	
NZS 4407 : 1991 Test 3.8.1	History:	Rangimarie Farm
	Fraction tested:	Whole sample
	Dispersant Used:	Nil
		Fraction passing finest sieve is by difference.

Date tested : 21/11/11

Date reported : 21/11/11

Sampling is not covered by IANZ Accreditation. Results apply only to sample tested.

This report may only be reproduced in full

IANZ Approved Signatory

A.Ching

Designation : *Laboratory Manager*

Date : 21/11/11

Tests indicated as not accredited are outside the scope of the laboratory's accreditation

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

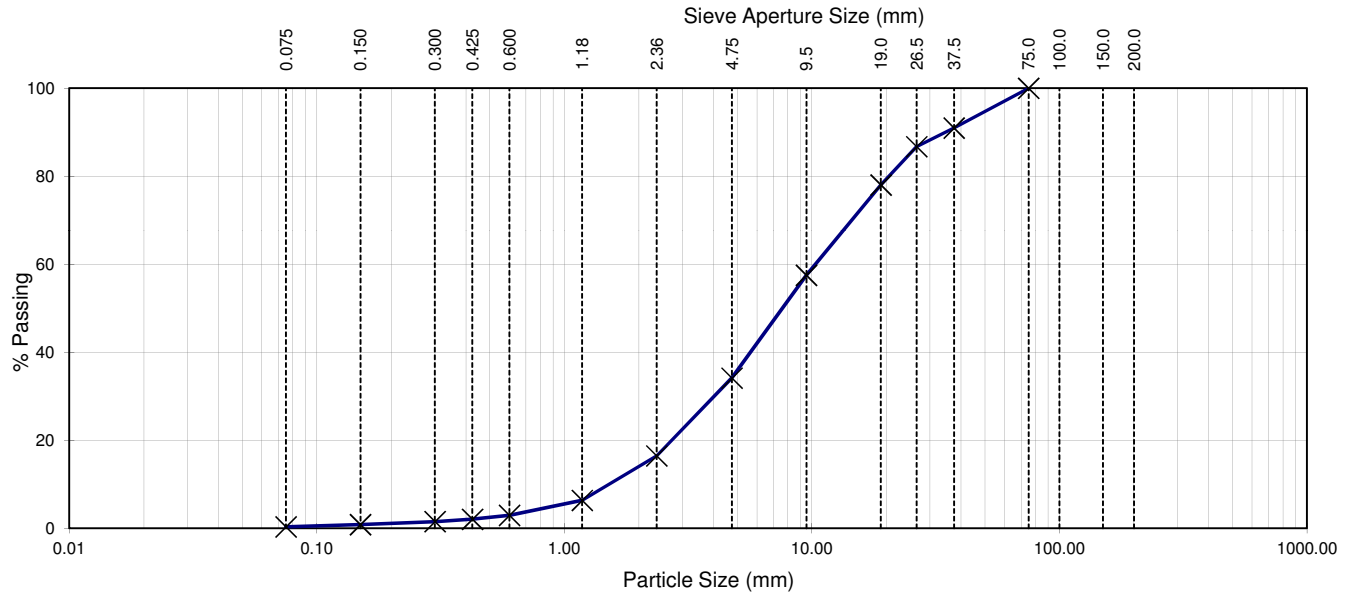
WET SIEVE ANALYSIS
TEST REPORT

Project :	**Ruataniwha Water Storage Scheme**
Location :	**Central Hawkes Bay**
Client :	**HB Regional Council, P.Bag 6006, Napier**
Consultant :	**Tonkin & Taylor - Auckland**
Sampled by :	**David Milner**
Date sampled :	**10/03/2011**
Sampling method :	**Digger Pits**
Sample description :	**Argillite**
Sample condition	**Damp**
Test Pit no :	**A7/6**

Project No :	**2-L0054.09 - 001NL**
Lab Ref No :	**N11. 808 / B**
Client Ref No :	**Sample A7/6**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
200.00	-	37.50	**91**	4.75	**34**	0.425	**2.1**
150.00	-	26.50	**87**	2.36	**16**	0.300	**1.6**
100.00	-	19.00	**78**	1.18	**6**	0.150	**0.9**
75.00	**100**	9.50	**58**	0.600	**3**	0.075	**0.4**



Test Method	Notes	
NZS 4407 : 1991 Test 3.8.1	History:	Rangimarie Farm
	Fraction tested:	Whole sample
	Dispersant Used:	Nil
		Fraction passing finest sieve is by difference.

Date tested : 21/11/11

Date reported : 21/11/11

Sampling is not covered by IANZ Accreditation. Results apply only to sample tested.

This report may only be reproduced in full

IANZ Approved Signatory

A.Ching

Designation : *Laboratory Manager*

Date : 21/11/11

Tests indicated as not accredited are outside the scope of the laboratory's accreditation

Opus International Consultants Limited
Napier Laboratory
Quality Management Systems Certified to ISO 9001

90 Prebensen Drive
Private Bag 6019, HB Mail Centre,
Napier 4142, New Zealand

Telephone +64 6 833 5590
Facsimile +64 6 835 3892
Website www.opus.co.nz

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No : S2
Form Date: January 2004

Plate No.: Page of **Your Job No.: 27195.200**

Site : A7 Ruataniwha **Our Job No.: 615677.000**

Test Method Used: NZS 4402:1986 **Test 2.1 Determination of the Water Content**

Test 2.2 Determination of the Liquid Limit

Test 2.3 Determination of the Plastic Limit

Test 2.4 Determination of the Plasticity Index

TEST RESULTS

Atterberg Limits Test Results Summary

Test Pit No.:	TP6
Water Content (%)	24.2
Liquid Limit	38
Plastic Limit	21
Plasticity Index	17

Description:

TP6: sandy SILT with minor clay, soft to firm, brown, medium plasticity, dilatant.

Remarks : Atterberg limits performed on material passing 0.425mm test sieve.

Sample description is not IANZ endorsed.

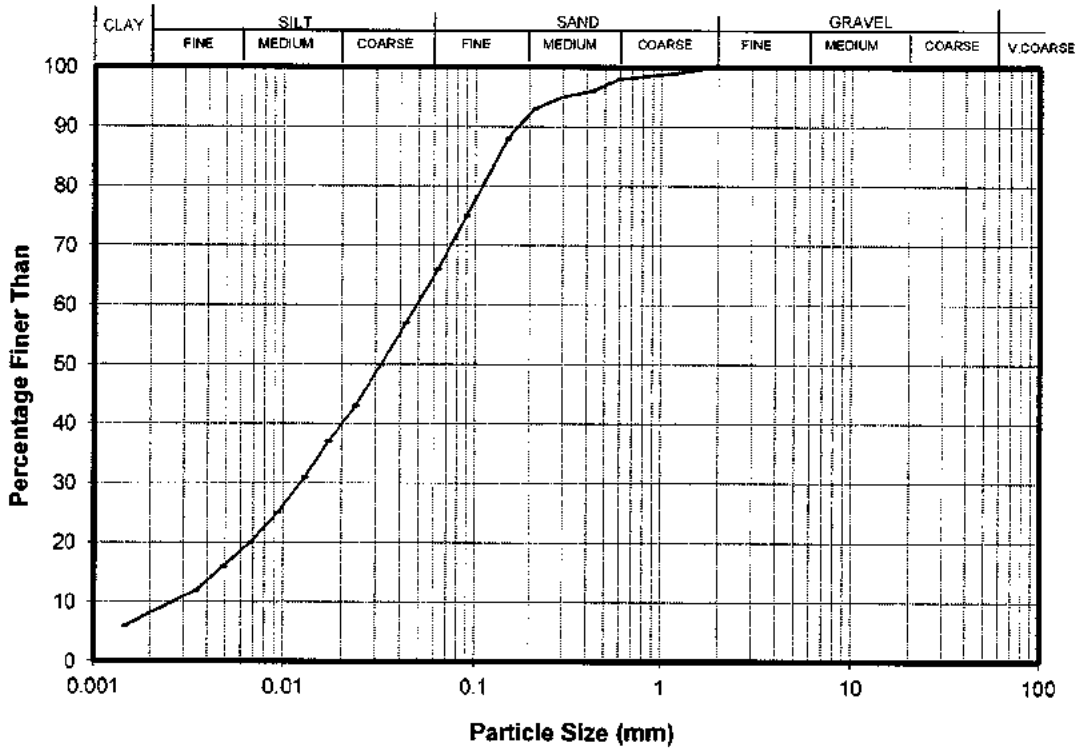
Tested by: ST Date: 7/11/11 Checked by: SJA Date: 7/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.: P6
Form Date: January 2004
File: F:\615677.000\Working Material\TP6_Wet Sieve+Hydro.xlsx

Plate No.: Page of Your Job No.: **27195.200**
Site : **A7 Ruataniwha** Our Job No.: **615677.000**
TP No.: **6** Sample No.: --- Depth (m): ---
Test Method Used : NZS 4402:1986 Test 2.8.1 Wet Sieve Test 2.8.4 Hydrometer

PARTICLE SIZE ANALYSIS



Sieve (mm)	Total % Passing	Sieve (mm)	Total % Passing
26.5	---	0.425	96
19.0	---	0.300	95
13.2	---	0.212	93
9.50	---	0.150	88
6.70	---	0.090	75
4.75	---	0.063	66
3.35	---		
2.00	100		
1.18	99		
0.600	98		

Equivalent Particle Diameter D (mm)	% of Particles Finer than D
0.0431	57
0.0320	50
0.0235	43
0.0171	37
0.0129	31
0.0094	25
0.0068	20
0.0049	16
0.0035	12
0.0015	6

Sample history : As received.
Solid Density (assumed) : 2.68 t/m^3
Description : sandy SILT with minor clay, soft to firm, brown, medium plasticity, dilatant.

Remarks : Two representative sub samples were split from the original sample for wet sieve and hydrometer analysis. The wet sieve sample was washed over 0.063mm test sieve, until the individual particles were clean. The material retained on 0.063mm test sieve was oven dried and dry sieved. The hydrometer sample was oven dried at the end of the test to determine the mass passing 0.063mm for hydrometer calculations.
The sieve data was combined with the hydrometer analysis to give a continuous curve.
Suspension pH 8.0
The classification of sand-silt-clay components are described on the basis of particle size analysis.
Sample description is not IANZ endorsed.

Entered by : ST Date : 7/11/11 Checked by : MWRA Date : 7/11/11

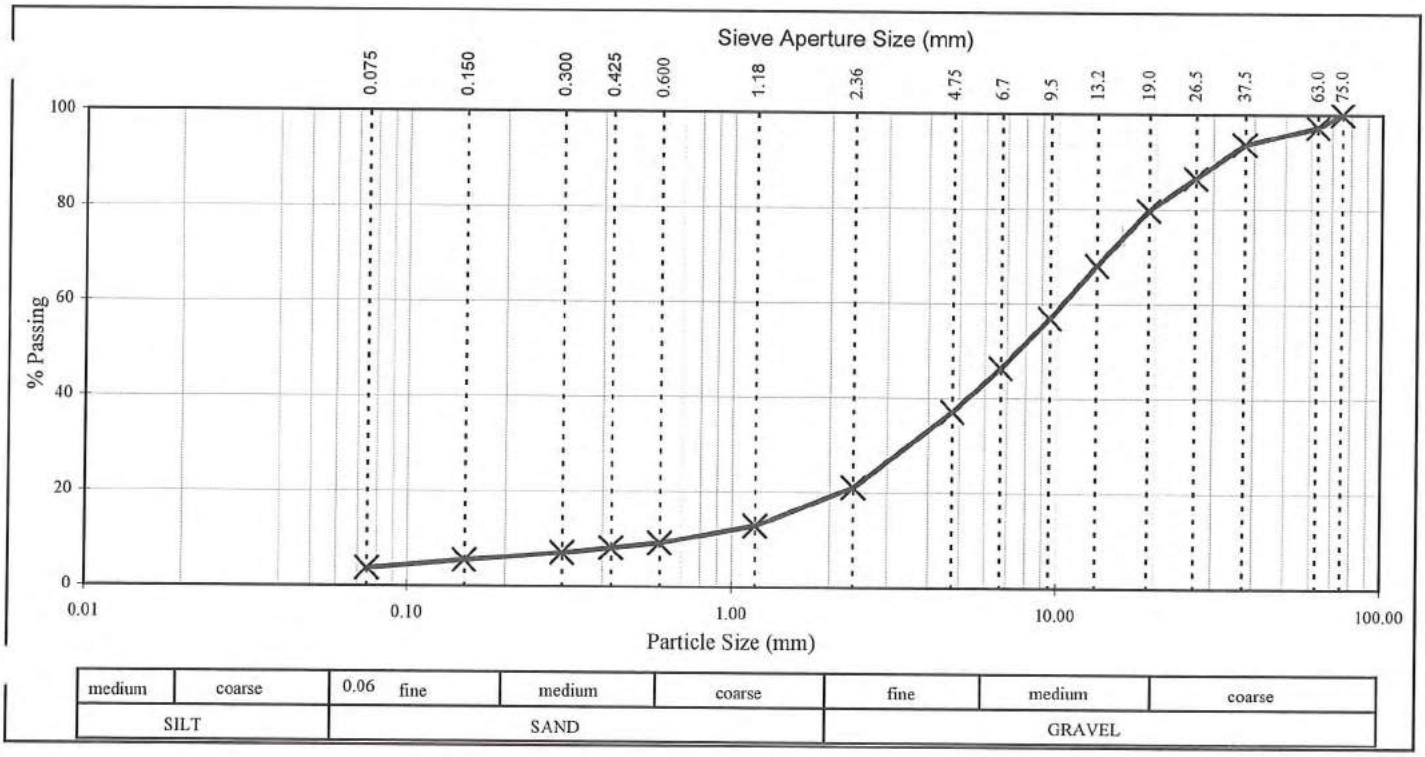
WET SIEVE ANALYSIS
TEST REPORT

Project :	**Dam Site**
Location :	**Wakarara Rd**
Client :	**Tonkin & Taylor Ltd**
	P.O Box 5271, Auckland
Sampled by :	**A.Pomfret / B.Hegan**
Date sampled :	**8/08/2006**
Sampling method #:	**Not stated**
Sample description :	**Red Metal**
Sample condition	**Wet**

Project No :	**2-S173G.1L**
Lab Ref No :	**N06.634**
Client Ref No :	**23783**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
75.00	**100**	19.00	**80**	4.75	**37**	0.425	**8**
63.00	**97**	13.20	**68**	2.36	**21**	0.300	**7**
37.50	**94**	9.50	**57**	1.18	**13**	0.150	**5**
26.50	**87**	6.70	**46**	0.600	**9**	0.075	**4**



medium	coarse	0.06 fine	medium	coarse	fine	medium	coarse
SILT		SAND			GRAVEL		

Test Method	**Notes**
NZS 4407 : 1991 Test 3.8.1	History : On site borrow Fraction tested : Whole sample Water Content % 27.7 *Fraction passing finest sieve is by difference.*

Date tested : 11/08/06
Date reported : 14/08/06

Testing is covered by IANZ Accreditation
This report may only be reproduced in full

IANZ Approved Signatory
A. Ching
Designation : *Laboratory Manager*
Date : 25/08/06

Tests indicated as # not accredited are outside the scope of the laboratory's accreditation

Opus International Consultants Ltd
Napier Laboratory
Quality Management Systems Certified to ISO 9001
90 Prebensen Drive
Private Bag 6019
Napier
Telephone +64 6 833 5590
Facsimile + 64 6 835 3892
Website www.opus.co.nz

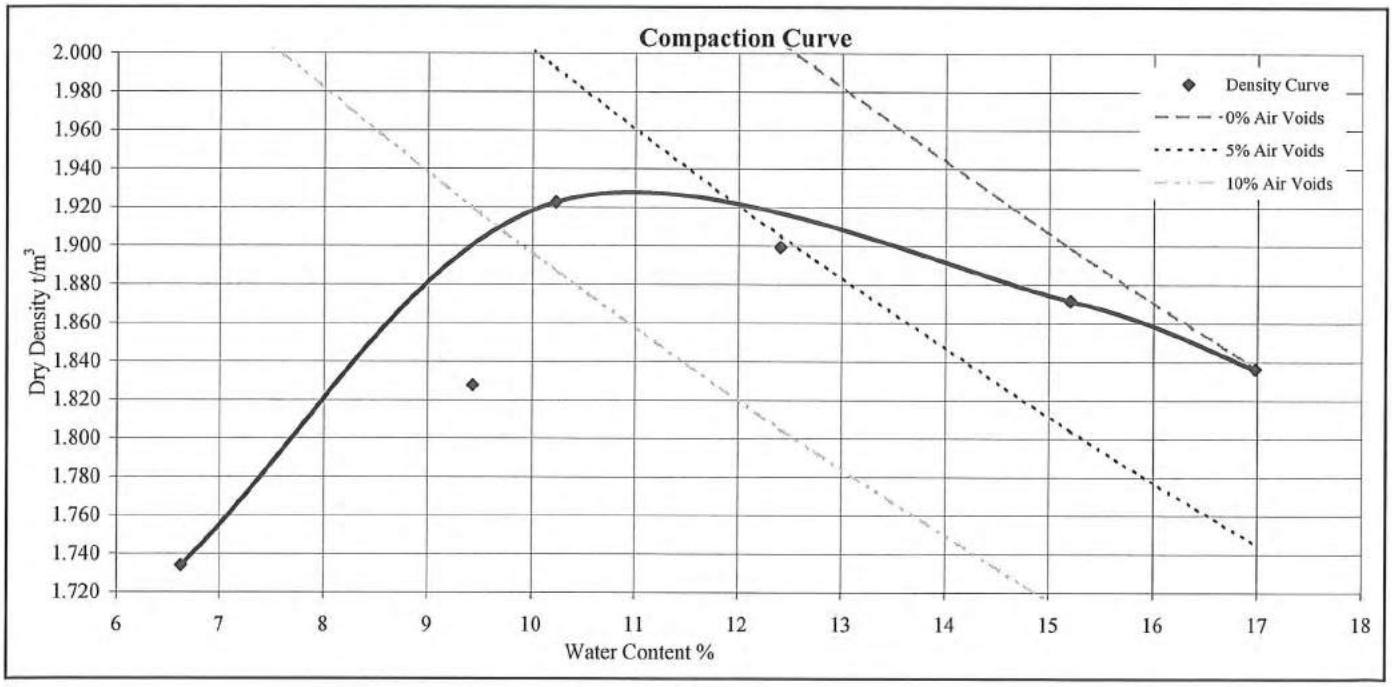
DRY DENSITY / WATER CONTENT RELATIONSHIP
COMPACTION

Project :	**Dam Site**
Location :	**Wakarara Road**
Client :	**Tonkin & Taylor, P.O Box 5271, Auckland**
Sampled by :	**A.Pomfret / B.Hegan**
Date sampled :	**08/08/06**
Sampling method :#	**Client Sampled**
Sample description :	**Red Metal**
Sample condition :	**Wet**
Solid density :#	**2.67 t/m³ (Assumed)**
Source :	**On site borrow**

Project No :	**2-S173G.1L**
Lab Ref No :	**N06.634**
Client Ref No :	**Job No. 23783**

Test Results

Maximum dry density		**1.92**	t/m³	Natural water content		-	%
Optimum water content		**11.0**	%	Fraction tested		Passing 19mm	
Sample ID						0	
Bulk density	t/m³	1.849	2.000	2.119	2.135	2.156	2.148
Water content	%	6.6	9.4	10.2	12.4	15.2	17.0
Dry density	t/m³	1.734	1.828	1.923	1.899	1.872	1.836
Sample condition		Dry Dense	Moist Dense	Moist Dense	Moist Dense	Wet Hard	Saturated Dense



Test Methods		Notes
Compaction	NZS 4402 : 1986 Test 4.1.1 (Standard)	

Date tested : 14/08/2006
Date reported : 25/08/06

Testing is covered by IANZ Accreditation
This report may only be reproduced in full

IANZ Approved Signatory
A.Ching
Designation : *Laboratory Manager*
Date : 25/08/06

Tests indicated as # not accredited are outside the scope of the laboratory's accreditation

Opus International Consultants Ltd
Napier Laboratory
Quality Management Systems Certified to ISO 9001
90 Prebensen Drive
Private Bag 6019
Napier
Telephone +64 6 833 5590
Facsimile + 64 6 835 3892
Website www.opus.co.nz

SOIL PERMEABILITY TEST REPORT

Mr. A. Pomfret
Tonkin & Taylor Ltd
P.O Box 5271
Wellesley St
Auckland

Project :	**Dam Site**
Location :	**Wakarara Road - Central HB**
Client :	**Tonkin & Taylor Ltd**
Sampled by :	**A.Pomfret / B.Hegan**
Date sampled :	**8/08/06**
Sampling method :	**Not stated**
Sample description :	**Red Metal**
Sample condition :	**Wet**

Project No :	**2 - S173G.1L**
Lab Ref No :	**N06. 634**
Client Ref No :	**Job No. 23783**

Test Results

Test No.	1	2
Material type:	Gravel (Red Metal)	
Sample location:	On site borrow	
Proposed use:	Lining material	
Water Content (as compacted) %:	**8.7**	**10.2**
Compacted Dry Density t/m^3:	**1.82**	**1.92**
Permeability (k) cm/sec:	**1.67×10^{-2}**	**2.72×10^{-4}**

Test method:	Notes:
Lab Permeability Test (Falling Head method) TW Lambe - Soils Testing	Test 1 compacted to approx 95% of max dry density

Date tested : 14/8/06 to 24/8/06
Date reported : 25/08/06

This report may only be reproduced in full

Approved

A. Ching

Designation : *Laboratory Manager*

Date : 25/08/06

GEOTECHNICS

LAB REF: 551/11
JOB NO: 650605.000

TONTRUATANIWHALAB	
LABORATORY TEST RESULTS	
LOCATION: Ruataniwha, Waipawa	JOB NO: 27195.200

Determination of Liquid & Plastic Limit, Plasticity Index – *NZS 4402: 1986 Tests 2.2, 2.3 & 2.4*

Determination of Water Content – *NZS 4402: 1986 Test 2.1*

SAMPLE NO	TEST RESULTS			
	WATER CONTENT %	Liquid Limit	Plastic Limit	Plasticity Index
A7/20	20.0	47	25	22
A7/21	16.7	-	-	-
A7/22	11.2	33	21	12
A7/23	16.3	-	-	-

The materials used for testing were natural, whole soils.

CHECKED:	
DATE:	30/09/11

GEOTECHNICS LTD Cnr Elizabeth & Durham Streets
Tauranga 3110. PO Box 317, Tauranga 3140, New Zealand
p. +64 7 571 0280
f. +64 7 571 0282
e. tauranga@geotechnics.co.nz
w. www.geotechnics.co.nz

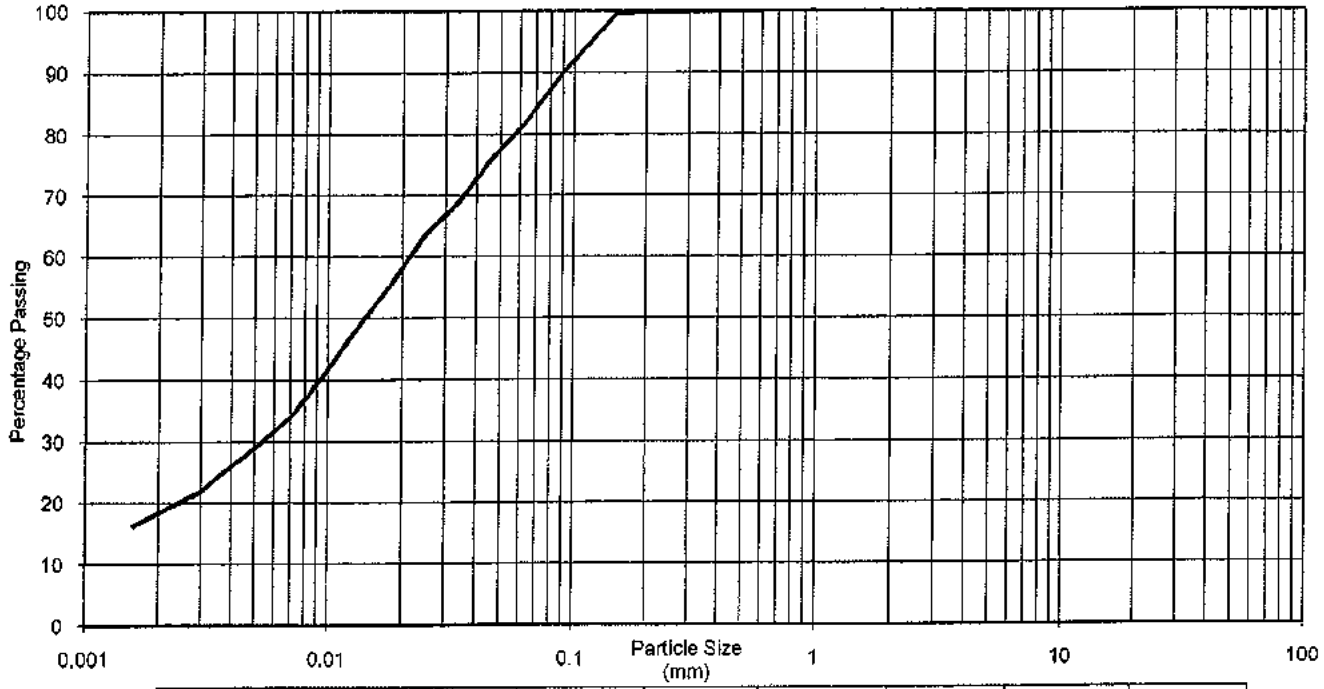
PARTICLE SIZE DISTRIBUTION

HYDROMETER NZS 4402:1986 TEST 2.8.4

Tests / comments indicated * are outside the scope of the laboratory's accreditation

B.E. Coker Approved Signatory

JOB NO	INFOTAUC80470AA
PROJECT	Ruataniwha
CLIENT	Geotechnics Ltd
LAB REF	551/11
SAMPLE NO	A7/20 26.09.11
LAB SAMPLE ID	TAUC11S-00503



	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE
CLAY	SILT			SAND			GRAVEL		

Tested from 'As received natural' state without pretreatment pH 9.0 Solid Density 2.6 Assumed

'As received' natural water content 18.6 % Percentage passing obtained by difference

SIZE	FRACTION	RANGE mm	%	*Size parameters diam % passing	mm
COBBLES		> 60		d_{85}	0.073
GRAVEL	Coarse	60 - 20		d_{60}	0.022
	Medium	20 - 6		d_{50}	0.014
	Fine	6 - 2		d_{30}	0.0054
SAND	Coarse	2 - 0.6		d_{15}	-
	Medium	0.6 - 0.2		d_{10}	-
	Fine	0.2 - 0.06	19	d_5	-
SILT	Coarse	0.06-0.02	23	*Uniformity Coefficient	
	Medium	0.02-0.006	27	C_u	-
	Fine	0.006-0.002	13	*Curvature Coefficient	
CLAY		<0.002	18	C_c	-

coffey information
SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS
141 Cameron Road
Tauranga 3110
www.coffey.com

DATE 29.09.11

CHECKED

GEOTECHNICS
Cnr Elizabeth & Durham Streets, Tauranga
New Zealand
p. +64 7 571 0280
f. +64 7 571 0282
w. www.geotechnics.co.nz

LAB. REF.: 551/11

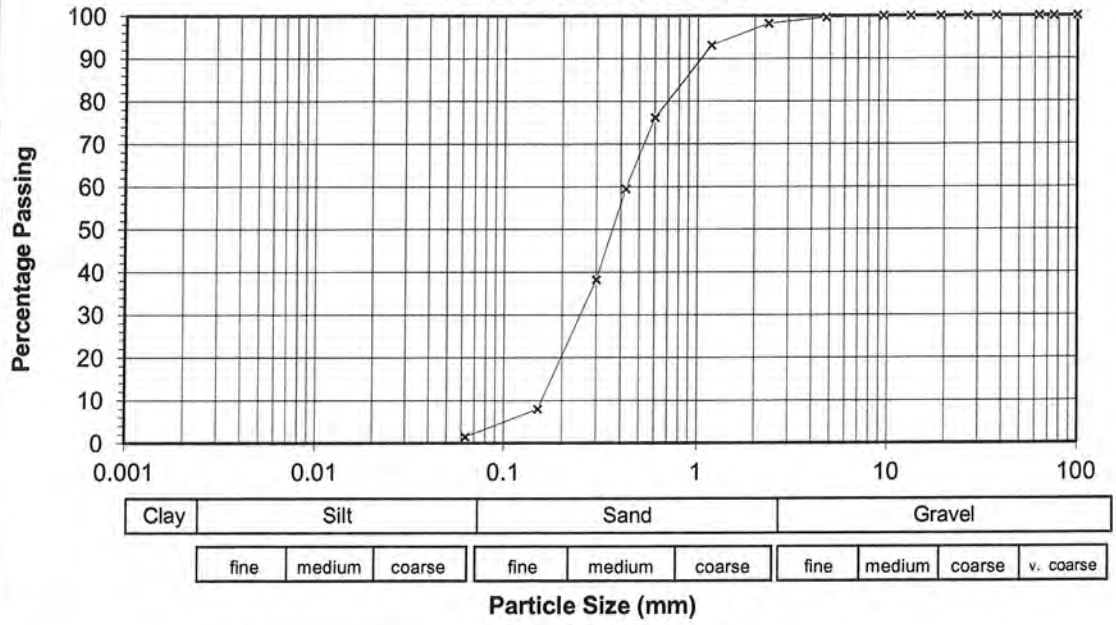
FILE: 650605.000

Sheet 1of 1

Location:	Ruataniwha, Waipawa	Sample: A7 / 23	Job Name: TonTRuataniwhaLab
Material:	fine to coarse SAND, trace fine gravel, dark grey, moist		Job Number: 27195.200
Sample Number:	Ruataniwha/260911/PSD A7 / 23		Depth: -

Sample History: **Natural**/~~Air-dried/Oven Dried/Unknown.~~ **Whole Soil**/~~Fraction passing.....mm sieve~~

PARTICLE SIZE DISTRIBUTION
NZS 4402:1986 TEST 2.8.1 ~~& 2.8.2~~



Sieve Aperture (mm)	Cumulative % Passing
200.0	100
150.0	100
100.0	100
75.0	100
63.0	100
37.5	100
26.5	100
19.0	100
13.2	100

Sieve Aperture (mm)	Cumulative % Passing
9.5	100
4.75	100
2.36	98
1.18	93
0.60	76
0.425	60
0.30	38
0.15	8
0.063	1

SPECIFICATION: None Issued

Note: For Wet Sieve, the percentage passing the < 0.063mm was obtained by Difference / ~~Weight.~~

Tested:	KHC	Date:	28/9/11
Calculated:	RTH	Date:	28/9/11
Checked:	KM	Date:	28/9/11

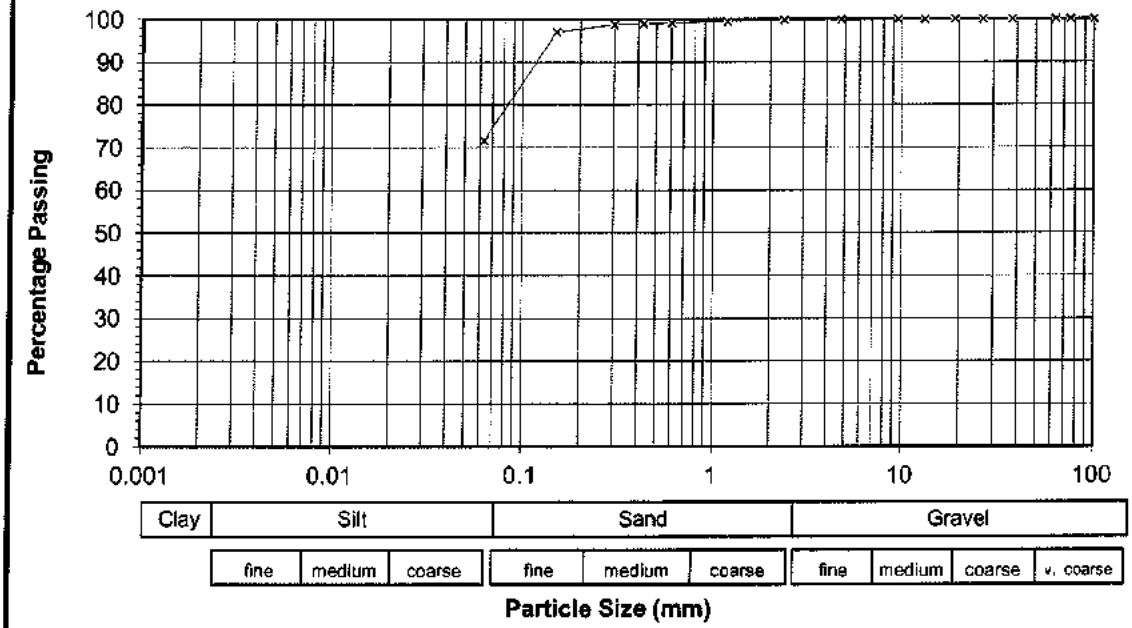
GEOTECHNICS
Cnr Elizabeth & Durham Streets, Tauranga
New Zealand
p. +64 7 571 0280
f. +64 7 571 0282
w. www.geotechnics.co.nz

LAB. REF.: 551/11
FILE: 650605.000
Sheet 1of 1

Location:	Ruataniwha, Waipawa	Sample: A7 / 21	Job Name: TonTRuataniwhaLab
Material:	SILT with some fine sand, grey, dry to moist		Job Number: 27195.200
Sample Number:	Ruataniwha/260911/PSD A7 / 21		Depth: -

Sample History: **Natural**/~~Air dried/Oven Dried/Unknown.~~ **Whole Soil**/~~Fraction passing.....mm sieve~~

PARTICLE SIZE DISTRIBUTION
NZS 4402:1986 TEST 2.8.1 ~~& 2.8.2~~



Sieve Aperture (mm)	Cumulative % Passing
200.0	100
150.0	100
100.0	100
75.0	100
63.0	100
37.5	100
26.5	100
19.0	100
13.2	100

Sieve Aperture (mm)	Cumulative % Passing
9.5	100
4.75	100
2.36	100
1.18	100
0.60	99
0.425	99
0.30	99
0.15	97
0.063	72

SPECIFICATION: None Issued

Note: For Wet Sieve, the percentage passing the < 0.063mm was obtained by Difference / ~~Weight.~~

Tested:	KHC	Date:	28/9/11
Calculated:	RTH	Date:	28/9/11
Checked:	RH	Date:	29/09/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH702_4.8m_UCS.xlsx

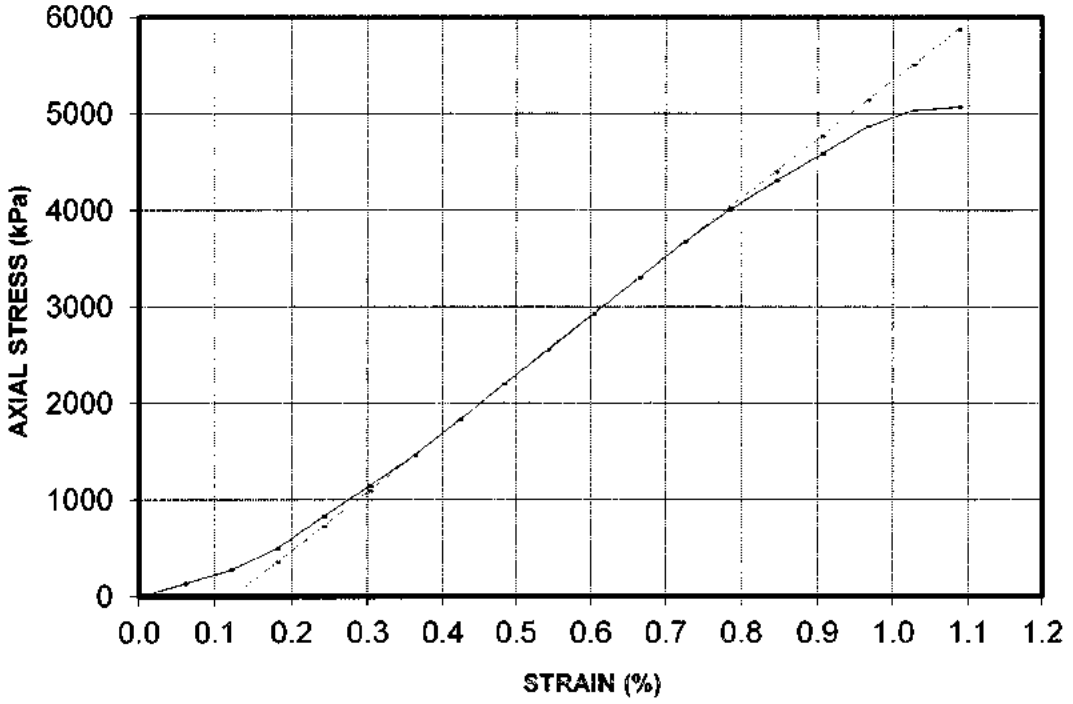
Plate No.: Page of **Your Job No.: 27195.200**

Site: **A7 Ruataniwha** **Our Job No.: 615677.000**

BH No.: **702** Sample No.: **---** Depth (m): **4.8**

Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	82.87	mm	Bulk Density:	2.39	t/m³
Sample Diameter:	61.08	mm	Dry Density:	2.31	t/m³
Test Height:	82.87	mm	Water Content:	3.8	%
Test H/D Ratio:	1.36				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
1.09	5071	0.15	610

Mode of Failure: Shear

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, weak, SW Greywacke Sandstone with iron staining.
Failure occurred along defects (iron-staining).

Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing.
Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description, UCS and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 12/10/11 Checked by: SJA Date: 12/10/11

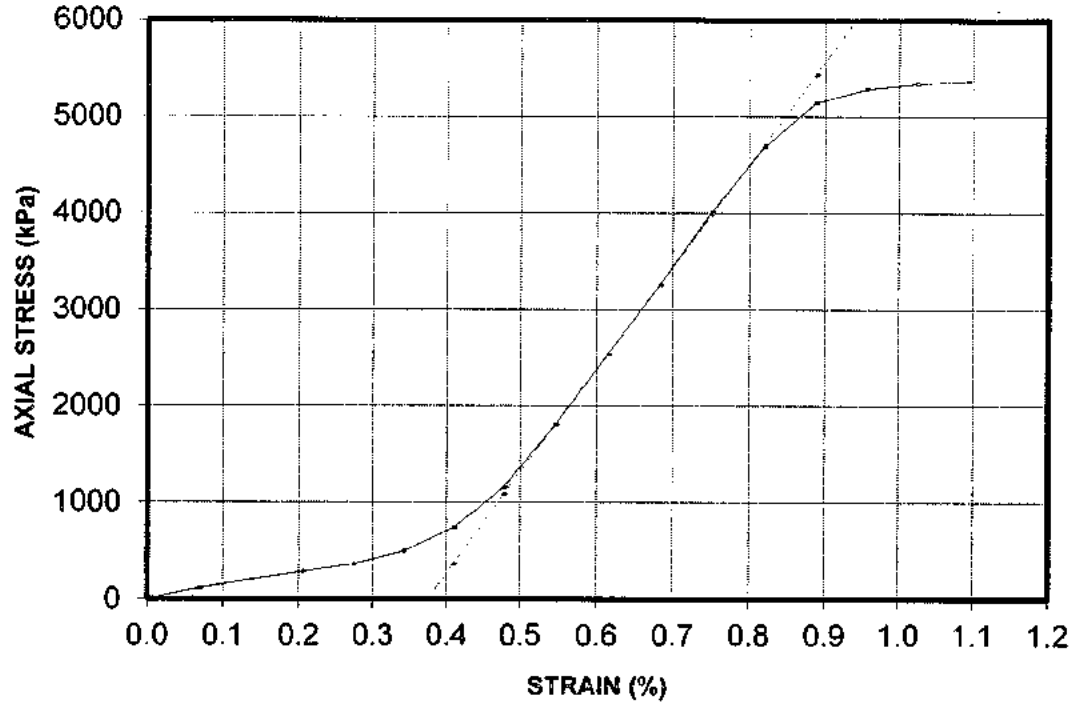
GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH702_12.3m_UCS.xlsx

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **702** Sample No.: **---** Depth (m): **12.3**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	73.30	mm	Bulk Density:	2.44	t/m³
Sample Diameter:	61.35	mm	Dry Density:	2.40	t/m³
Test Height:	73.30	mm	Water Content:	2.0	%
Test H/D Ratio:	1.19				

Failure Value:

Axial Strain	Unconf. Compressive	Rate of Compression	Modulus of Elasticity
%	Strength qu (kPa)	(mm/min)	(MPa)
1.09	5370	0.13	1062

Mode of Failure: Shear
Sample History: Undisturbed core trimmed at natural water content.
Description: Grey, weak, Greywacke Sandstone with vertical argillite partings, quartz veins. Failure occurred along argillite partings.
Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing. Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only. Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only. Sample description, UCS and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 11/10/11 Checked by: SJA Date: 12/10/11

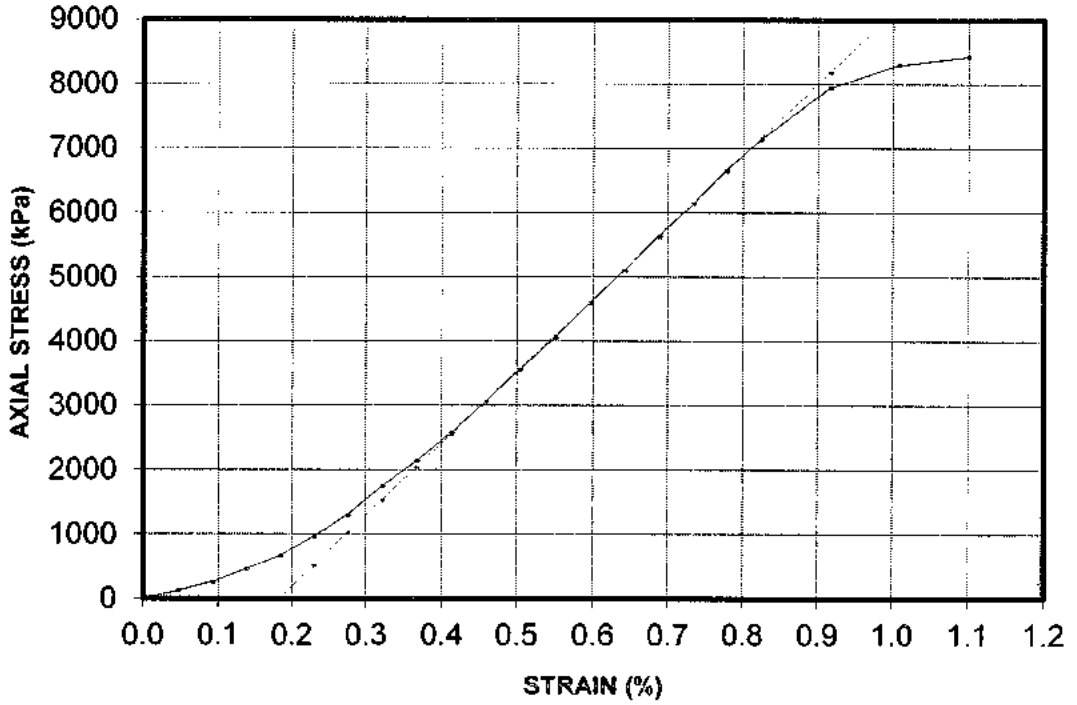
GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\@-1702_29.6m_UCS.xsv

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **702** Sample No.: **---** Depth (m): **29.6**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	109.33	mm	Bulk Density:	2.53	t/m³
Sample Diameter:	61.10	mm	Dry Density:	2.48	t/m³
Test Height:	109.33	mm	Water Content:	2.1	%
Test H/D Ratio:	1.79				

Failure Value:

Axial Strain	Unconf. Compressive	Rate of Compression	Modulus of Elasticity
%	Strength qu (kPa)	(mm/min)	(MPa)
1.10	8426	0.18	1118

Mode of Failure: Shear
Sample History: Undisturbed core trimmed at natural water content.
Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.
Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing.
Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description, UCS and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 12/10/11 Checked by: SJD Date: 12/10/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH702_11.30m_UCS.xls

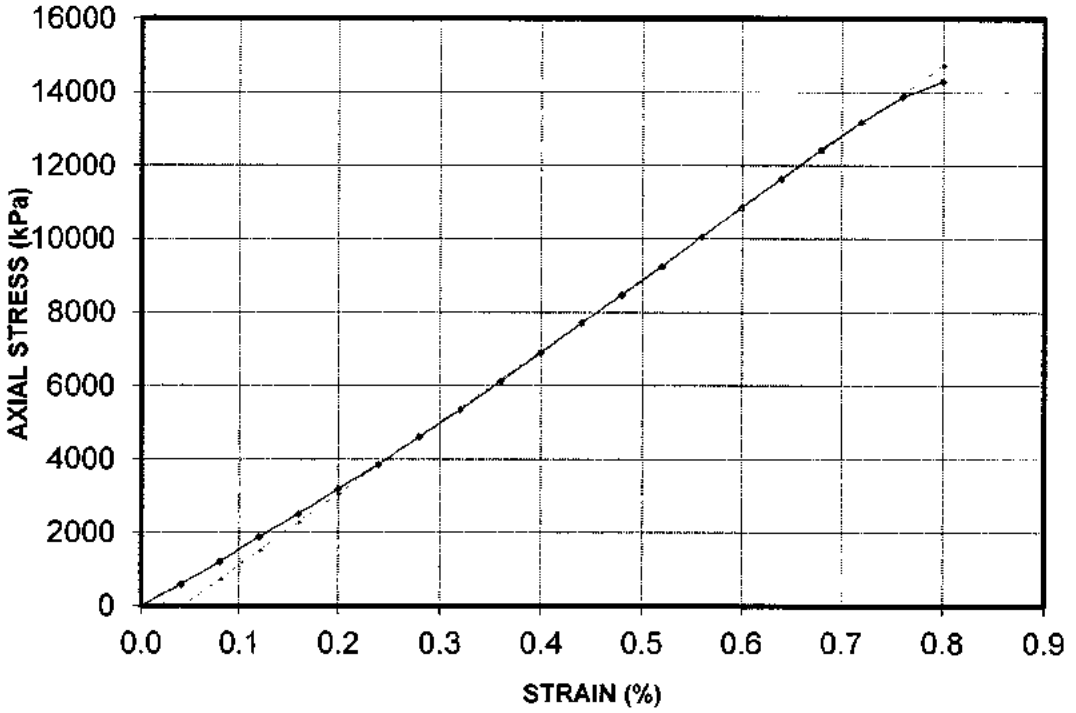
Plate No.: Page of **Your Job No.: 27195.200**

Site: **A7 Ruataniwha** **Our Job No.: 615677.000**

BH No.: **702** Sample No.: --- Depth (m): **11.3**

Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	125.16	mm	Bulk Density:	2.61	t/m³
Sample Diameter:	61.14	mm	Dry Density:	2.57	t/m³
Test Height:	125.16	mm	Water Content:	1.6	%
Test H/D Ratio:	2.05				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
0.80	14283	0.14	1947

Mode of Failure: Shear

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.

Test Remarks: Unconfined Compressive Strength reported to the nearest 1 kPa
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 2/11/11 Checked by: AJFC Date: 2/11/11

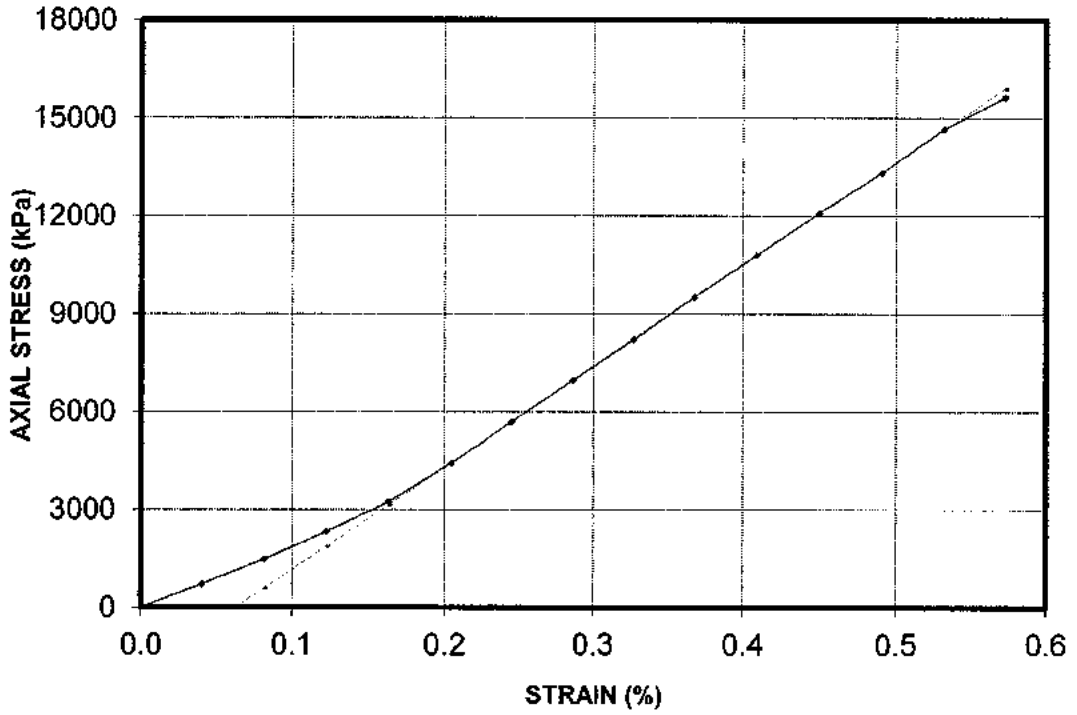
GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH702_16.5m_UC.S.xlsx

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **702** Sample No.: --- Depth (m): **16.5**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	122.31	mm	Bulk Density:	2.59	t/m³
Sample Diameter:	61.06	mm	Dry Density:	2.55	t/m³
Test Height:	122.31	mm	Water Content:	1.6	%
Test H/D Ratio:	2.00				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
0.57	15629	0.10	3122

Mode of Failure: Shear
Sample History: Undisturbed core trimmed at natural water content.
Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.
Test Remarks: Unconfined Compressive Strength reported to the nearest 1 kPa
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 2/11/11 Checked by: ADFC Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04
File: P:\615677\Working Material\BH702_24.45m_UCS.xlsx	

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No. **702** Sample No.: **---** Depth: **24.45 (m)**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST

Sample Parameters:

Sample Height:	76.02	mm	Bulk Density:	2.60	t/m³
Sample Diameter:	61.24	mm	Dry Density:	2.57	t/m³
Test Height:	76.02	mm	Water Content:	1.1	%
Test H/D Ratio:	1.24				

Failure Value:

Unconf. Compressive Strength qu (kPa)
85730

Mode of Failure: Axial

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, strong, Greywacke Sandstone with numerous quartz veins.

Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing.
The sample was tested in a concrete machine because of high strength, therefore strain could not be measured. The test results are not IANZ endorsed.
Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.

Entered by: ST Date: 2/11/11 Checked by: AJFC Date: 2/11/11

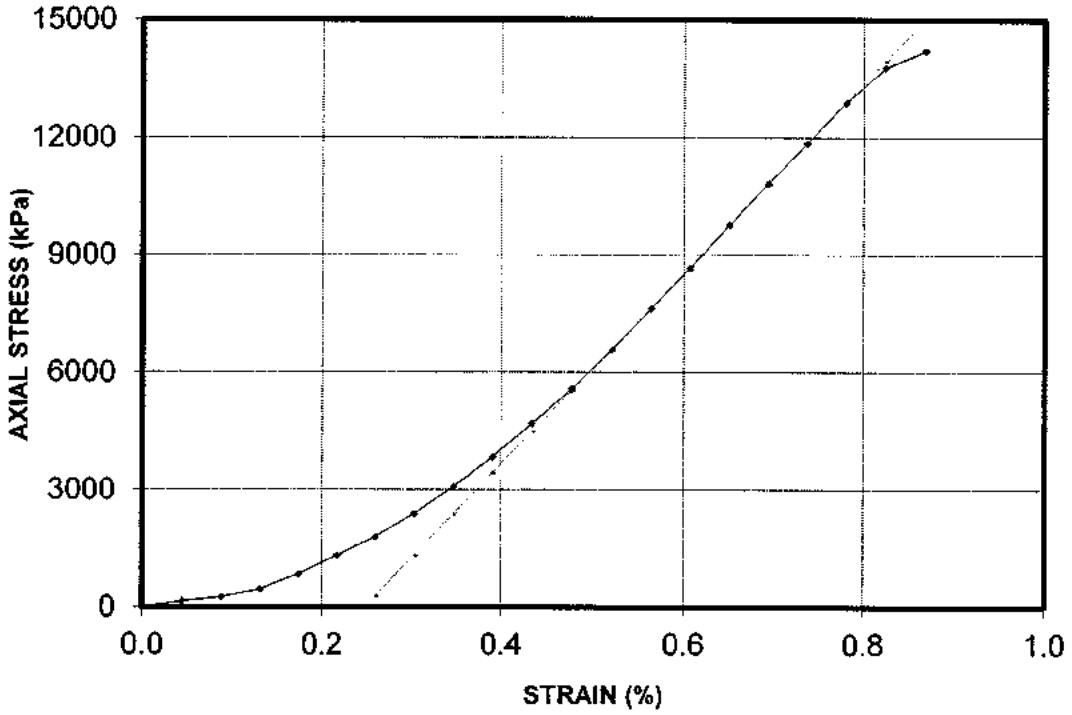
GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH702_25.0m_UCS.xls

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **702** Sample No.: **---** Depth (m): **25.0**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	115.30	mm	Bulk Density:	2.60	t/m³
Sample Diameter:	61.11	mm	Dry Density:	2.56	t/m³
Test Height:	115.30	mm	Water Content:	1.8	%
Test H/D Ratio:	1.89				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
0.87	14212	0.15	2430

Mode of Failure: Shear
Sample History: Undisturbed core trimmed at natural water content.
Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.
Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing.
Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description, UCS and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 2/11/11 Checked by: AJFC Date: 2/11/11

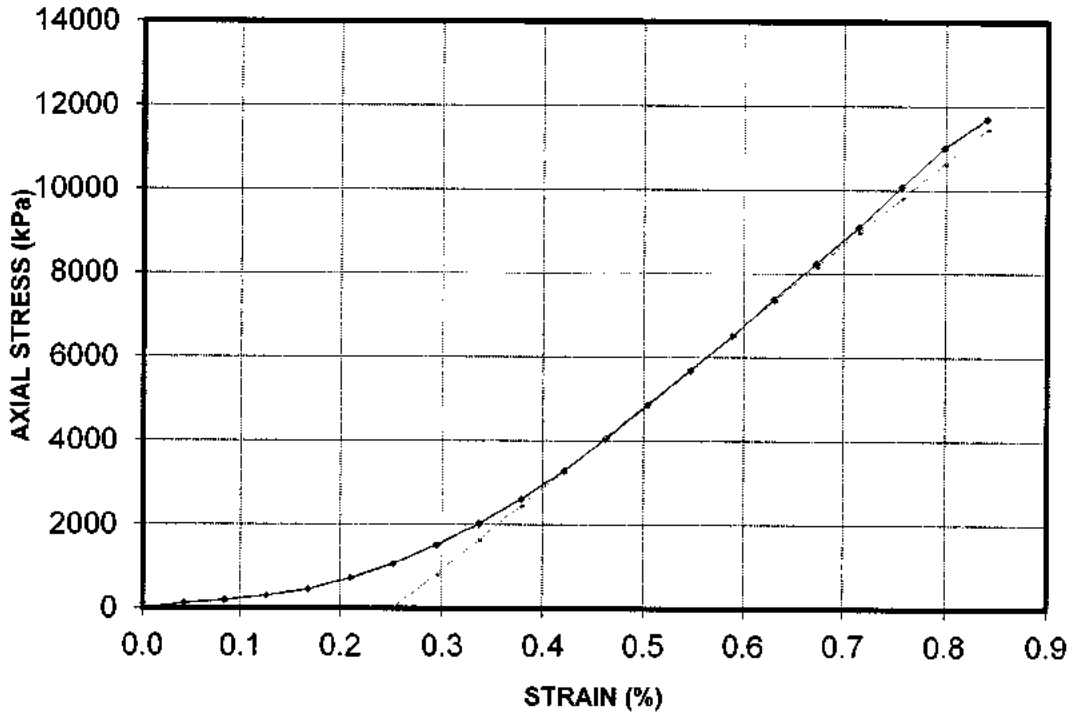
GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File P:\615677.000\Working Material\BH702_25.16m_UCS.xlsx

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **702** Sample No.: --- Depth (m): **25.16**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	118.97	mm	Bulk Density:	2.55	t/m³
Sample Diameter:	61.23	mm	Dry Density:	2.51	t/m³
Test Height:	118.97	mm	Water Content:	1.8	%
Test H/D Ratio:	1.94				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
0.84	11693	0.16	1943

Mode of Failure: Shear

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.

Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing.
Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description, UCS and modulus of elasticity value reported are not IANZ endorsed.

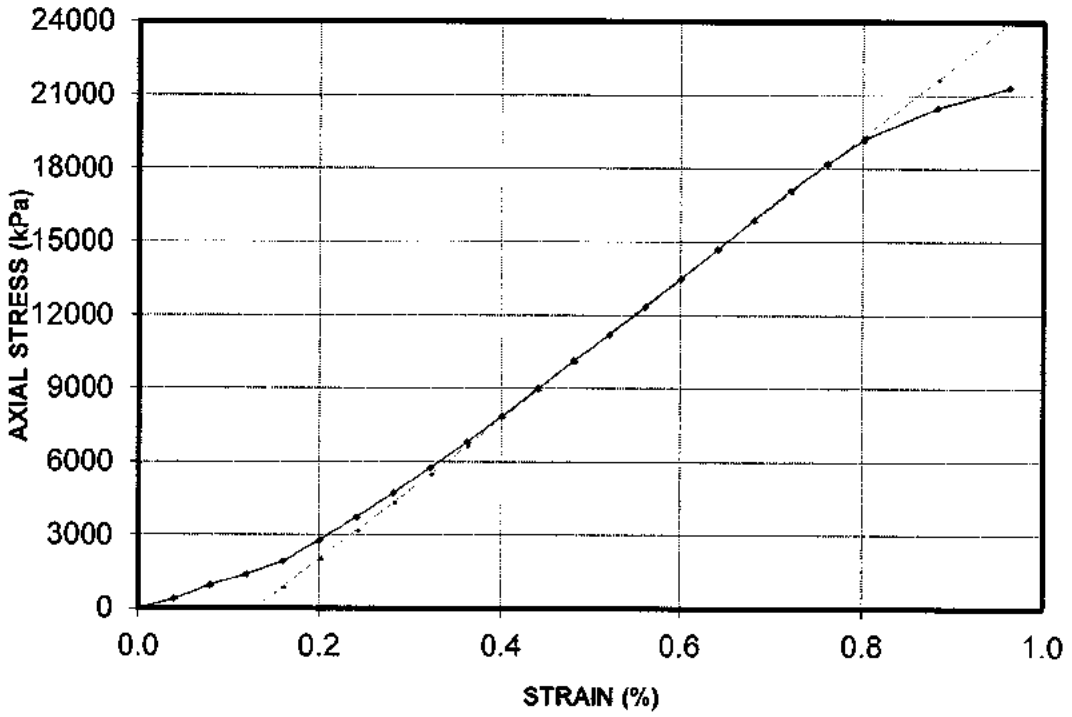
Entered by: ST Date: 2/11/11 Checked by: AJFC Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04
File: P:\615677.000\Working Material\BH702_25.55m_UCS.xlsx	

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **702** Sample No.: **---** Depth (m): **25.55**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	124.77	mm	Bulk Density:	2.57	t/m³
Sample Diameter:	61.35	mm	Dry Density:	2.53	t/m³
Test Height:	124.77	mm	Water Content:	1.6	%
Test H/D Ratio:	2.03				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
0.96	21311	0.19	2879

Mode of Failure: Shear
Sample History: Undisturbed core trimmed at natural water content.
Description: Grey, moderately strong, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.
Test Remarks: Unconfined Compressive Strength reported to the nearest 1 kPa
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 2/11/11 Checked by: ASFG Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677\Working Material\BH702_31.1m_UCS.xlsx

Plate No.: Page of **Your Job No.: 27195.200**

Site: **Ruataniwha** **Our Job No.: 615677.000**

BH No. **702** Sample No.: **---** Depth: **31.1(m)**

Test Method Used: **NZS 4402 :1986 TEST 6.3.1** Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST

Sample Parameters:

Sample Height:	124.30	mm	Bulk Density:	2.58	t/m³
Sample Diameter:	61.21	mm	Dry Density:	2.53	t/m³
Test Height:	124.30	mm	Water Content:	1.8	%
Test H/D Ratio:	2.03				

Failure Value:

Unconf. Compressive Strength qu (kPa)
35880

Mode of Failure: Axial

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, moderately strong, Greywacke Sandstone with numerous quartz veins.

Test Remarks: The sample was tested in a concrete machine because of high strength, therefore strain could not be measured. The test results are not IANZ endorsed.
The UCS results are reported to the nearest 1 kPa

Entered by: CT Date: 2/11/11 Checked by: AJFC Date: 2/11/11

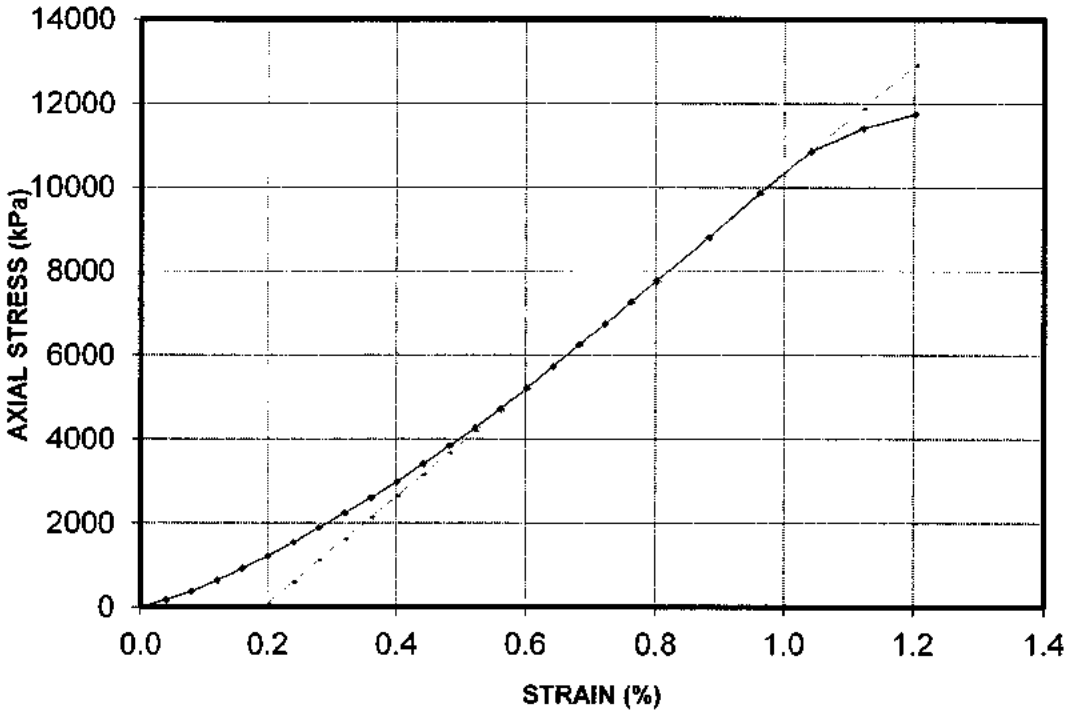
GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH702_34.6m_UCS.xlsx

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **702** Sample No.: **---** Depth (m): **34.9**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	124.74	mm	Bulk Density:	2.45	t/m³
Sample Diameter:	61.55	mm	Dry Density:	2.39	t/m³
Test Height:	124.74	mm	Water Content:	2.8	%
Test H/D Ratio:	2.03				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
1.20	11747	0.22	1280

Mode of Failure: Shear
Sample History: Undisturbed core trimmed at natural water content.
Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.
Test Remarks: Unconfined Compressive Strength reported to the nearest 1 kPa
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description and modulus of elasticity value reported are not IANZ endorsed.

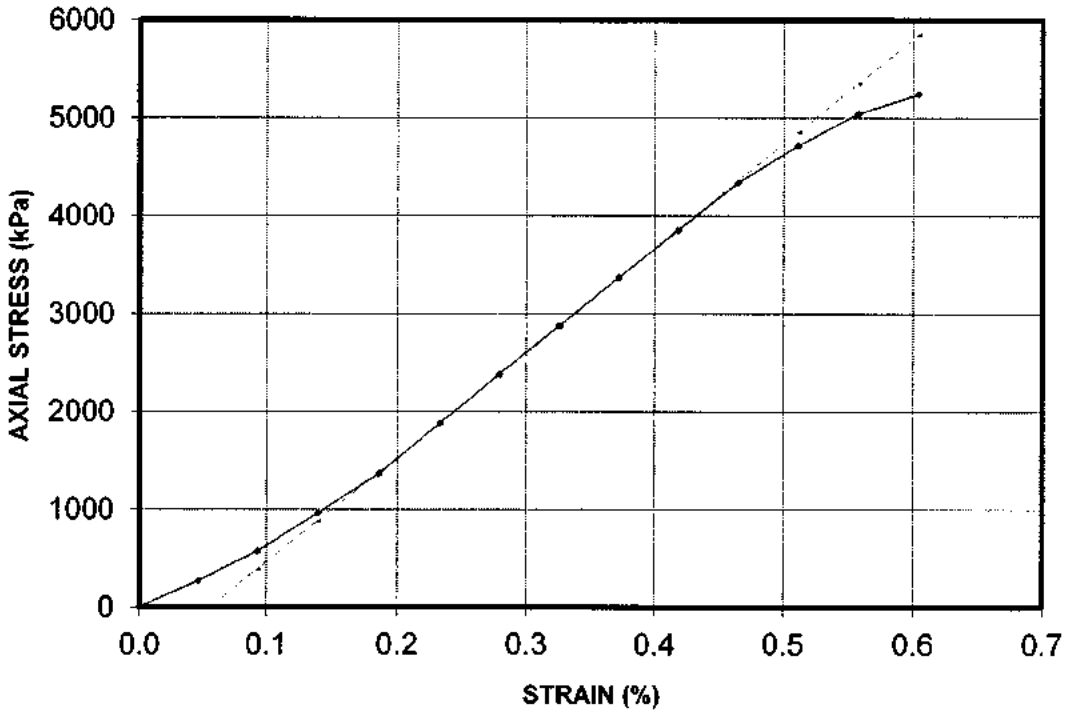
Entered by: ST Date: 2/11/11 Checked by: AJFG Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04
File: P:\615677.000\Working Material\BH702_46.0m_UCS.xlsx	

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **702** Sample No.: --- Depth (m): **46.0**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	107.57	mm	Bulk Density:	2.54	t/m³
Sample Diameter:	61.19	mm	Dry Density:	2.49	t/m³
Test Height:	107.57	mm	Water Content:	2.3	%
Test H/D Ratio:	1.76				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
0.60	5246	0.10	1069

Mode of Failure: Shear
Sample History: Undisturbed core trimmed at natural water content.
Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.
Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing.
Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description, UCS and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 2/11/11 Checked by: ASFC Date: 2/11/11

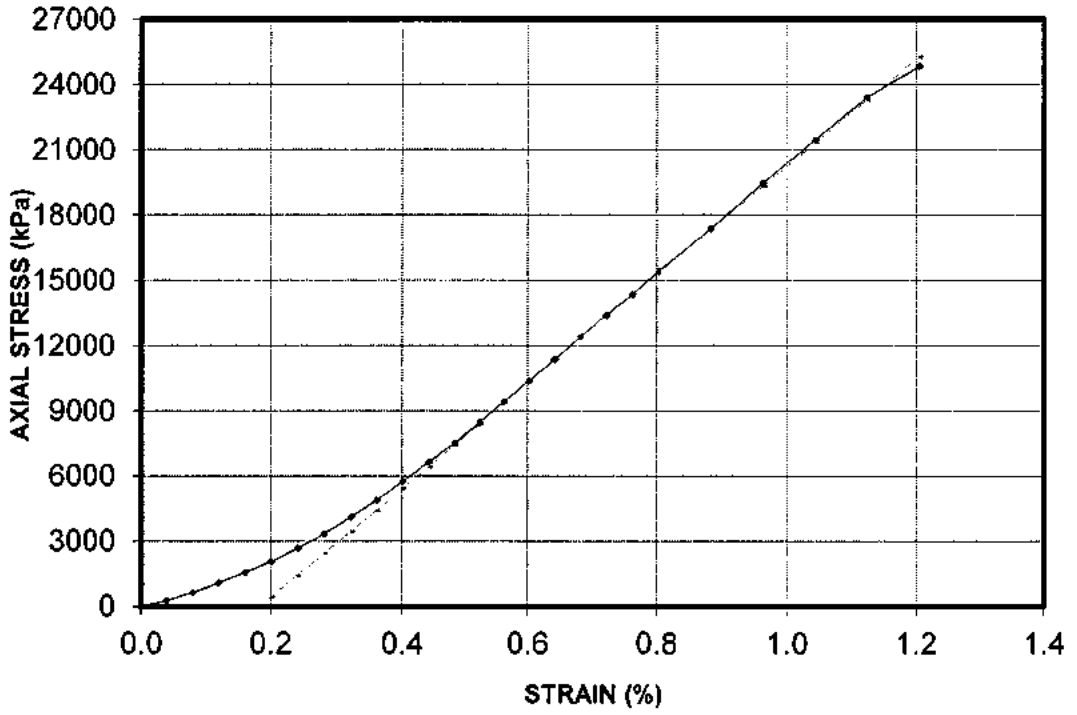
GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH702_47.15m_UCS.dat

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **702** Sample No.: **---** Depth (m): **47.15**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	124.57	mm	Bulk Density:	2.55	t/m³
Sample Diameter:	61.21	mm	Dry Density:	2.50	t/m³
Test Height:	124.57	mm	Water Content:	2.1	%
Test H/D Ratio:	2.04				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
1.20	24841	0.22	2477

Mode of Failure: Shear
Sample History: Undisturbed core trimmed at natural water content.
Description: Grey, moderately strong, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.
Test Remarks: Unconfined Compressive Strength reported to the nearest 1 kPa
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 2/11/11 Checked by: AJFC Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04
File: P:\615677\Working Material\BH703_17.2m_UCS.xlsx	

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No. **703** Sample No.: **---** Depth: **17.2 (m)**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST

Sample Parameters:

Sample Height:	91.23	mm	Bulk Density:	2.56	t/m³
Sample Diameter:	60.97	mm	Dry Density:	2.52	t/m³
Test Height:	91.23	mm	Water Content:	1.6	%
Test H/D Ratio:	1.50				

Failure Value:

Unconf. Compressive Strength qu (kPa)
41380

Mode of Failure: Axial

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, moderately strong, Greywacke Sandstone with numerous quartz veins.

Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing. The sample was tested in a concrete machine because of high strength, therefore strain could not be measured. The test results are not IANZ endorsed. Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.

Entered by: ST Date: 2/11/11 Checked by: ASFC Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04
File: P:\615677\Working Material\BH703_17.55m_LCS.xls	

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No. **703** Sample No.: **---** Depth: **17.55(m)**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST

Sample Parameters:

Sample Height:	105.82	mm	Bulk Density:	2.57	t/m³
Sample Diameter:	61.26	mm	Dry Density:	2.53	t/m³
Test Height:	105.82	mm	Water Content:	1.6	%
Test H/D Ratio:	1.73				

Failure Value:

Unconf. Compressive Strength qu (kPa)
40710

Mode of Failure: Axial

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, moderately strong, Greywacke Sandstone with numerous quartz veins.

Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing. The sample was tested in a concrete machine because of high strength, therefore strain could not be measured. The test results are not IANZ endorsed. Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.

Entered by: ST Date: 2/11/11 Checked by: AJFC Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04
File: P:\615677\Working Material\BH703_30.18m_UCS.xlsx	

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No. **703** Sample No.: **---** Depth: **30.18(m)**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST

Sample Parameters:

Sample Height:	109.42	mm	Bulk Density:	2.62	t/m³
Sample Diameter:	61.35	mm	Dry Density:	2.59	t/m³
Test Height:	109.42	mm	Water Content:	1.3	%
Test H/D Ratio:	1.78				

Failure Value:

Unconf. Compressive Strength qu (kPa)
84810

Mode of Failure: Axial

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, strong, Greywacke Sandstone with numerous quartz veins.

Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing.
The sample was tested in a concrete machine because of high strength, therefore strain could not be measured. The test results are not IANZ endorsed.
Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.

Entered by: ST Date: 2/11/11 Checked by: ASFC Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH703_31.5m_UCS.xlsx

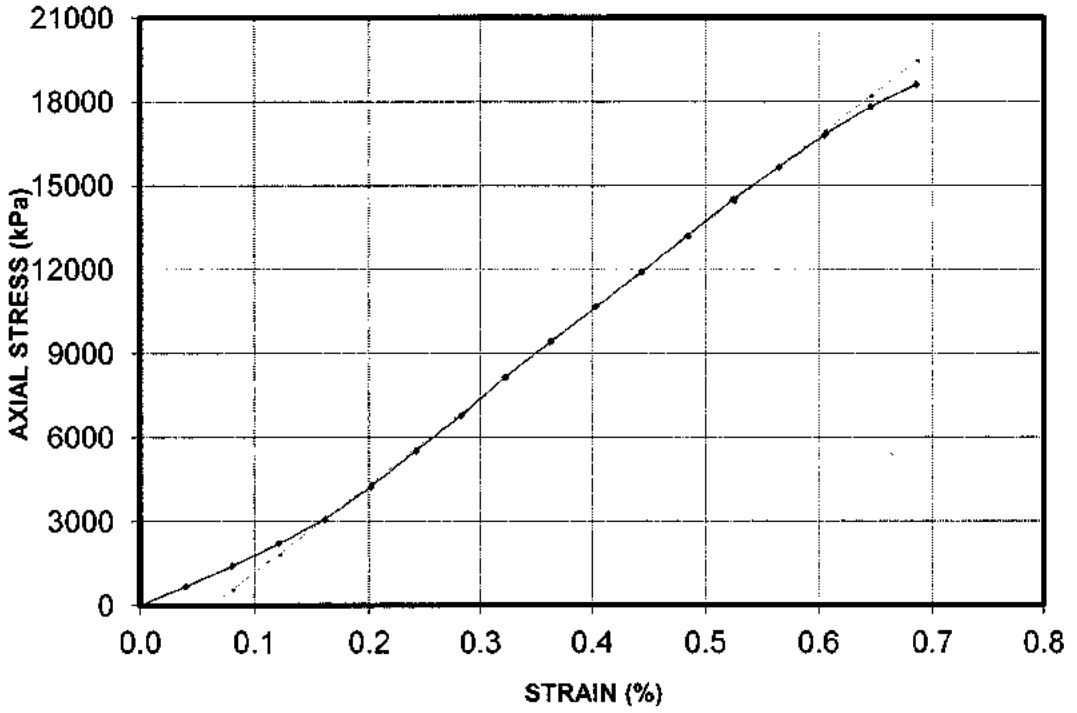
Plate No.: Page of **Your Job No.: 27195.200**

Site: **A7 Ruataniwha** **Our Job No.: 615677.000**

BH No.: **703** Sample No.: --- Depth (m): **31.5**

Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	123.89	mm	Bulk Density:	2.50	t/m³
Sample Diameter:	61.30	mm	Dry Density:	2.45	t/m³
Test Height:	123.89	mm	Water Content:	1.8	%
Test H/D Ratio:	2.02				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
0.69	18609	0.13	3122

Mode of Failure: Shear

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.

Test Remarks: Unconfined Compressive Strength reported to the nearest 1 kPa.
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 2/11/11 Checked by: AJFC Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04
File: P:\615677\Working Material\BH703_33.28m_UCS.xls	

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No. **703** Sample No.: — Depth: **33.28 (m)**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST

Sample Parameters:

Sample Height:	123.76	mm	Bulk Density:	2.62	t/m³
Sample Diameter:	61.09	mm	Dry Density:	2.61	t/m³
Test Height:	123.76	mm	Water Content:	0.3	%
Test H/D Ratio:	2.03				

Failure Value:

Unconf. Compressive Strength qu (kPa)
71900

Mode of Failure: Axial

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, strong, Greywacke Sandstone with numerous quartz veins.

Test Remarks: The sample was tested in a concrete machine because of high strength, therefore strain could not be measured. The test results are not IANZ endorsed.
Unconfined Compressive Strength reported to the nearest 1 kPa.

Entered by: SJ Date: 2/11/11 Checked by: AJFC Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677\Working Material\BH703_33.5m_UCS.xlsx

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No. **703** Sample No.: **---** Depth: **33.5 (m)**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST

Sample Parameters:

Sample Height:	83.65	mm	Bulk Density:	2.62	t/m³
Sample Diameter:	61.09	mm	Dry Density:	2.59	t/m³
Test Height:	83.65	mm	Water Content:	1.3	%
Test H/D Ratio:	1.37				

Failure Value:

Unconf. Compressive Strength qu (kPa)
55310

Mode of Failure: Axial

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, strong, Greywacke Sandstone with numerous quartz veins.

Test Remarks: The sample height to diameter ratio is less than the required 2. The strength may be lower, due to the h/d ratio. We advised the engineer and it was decided to continue with the testing.
The sample was tested in a concrete machine because of high strength, therefore strain could not be measured. The test results are not IANZ endorsed.
Unconfined Compressive Strength reported to the nearest 1 kPa and provided as indicative only.

Entered by: ST Date: 2/11/11 Checked by: AJFC Date: 2/11/11

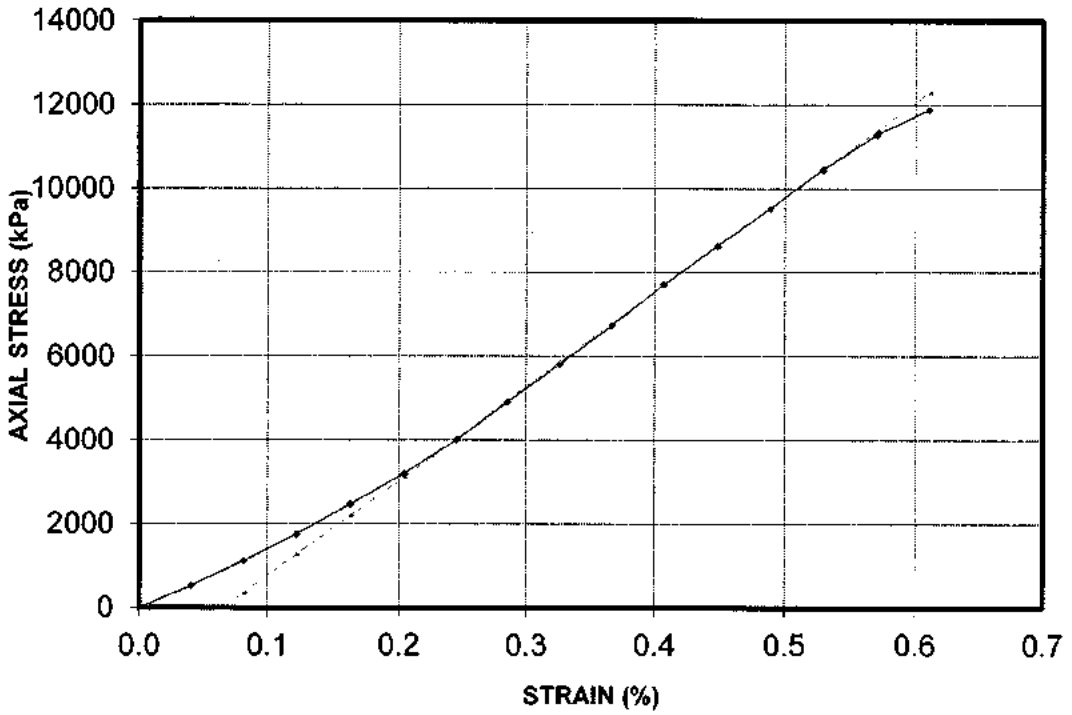
GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH703_38.5m_UCS.xlsx

Plate No.: Page of **Your Job No.: 27195.200**
Site: **A7 Ruataniwha** **Our Job No.: 615677.000**
BH No.: **703** Sample No.: **---** Depth (m): **38.5**
Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	122.81	mm	Bulk Density:	2.53	t/m³
Sample Diameter:	61.28	mm	Dry Density:	2.48	t/m³
Test Height:	122.81	mm	Water Content:	2.0	%
Test H/D Ratio:	2.00				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
0.61	11881	0.11	2257

Mode of Failure: Shear
Sample History: Undisturbed core trimmed at natural water content.
Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.
Test Remarks: Unconfined Compressive Strength reported to the nearest 1 kPa.
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 2/11/11 Checked by: AJFC Date: 2/11/11

GEOTECHNICS
23 Morgan Street, Newmarket
Auckland 1023, New Zealand
p. +64 9 356 3510
w. www.geotechnics.co.nz

Form No.:	S17a
Form Date:	Jan-04

File: P:\615677.000\Working Material\BH703_41.02m_UCS.xls

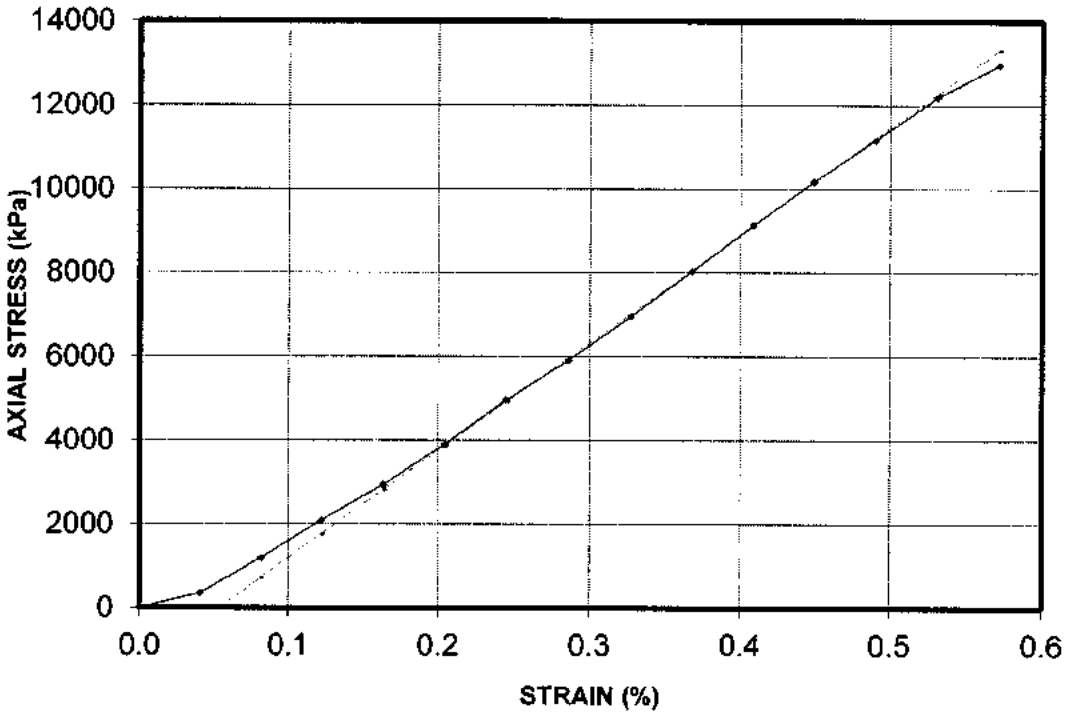
Plate No.: Page of **Your Job No.: 27195.200**

Site: **A7 Ruataniwha** **Our Job No.: 615677.000**

BH No.: **703** Sample No.: --- Depth (m): **41.02**

Test Method Used: NZS 4402 :1986 TEST 6.3.1 Determination of the unconfined compressive strength of cohesive soil

UNCONFINED COMPRESSIVE STRENGTH TEST
AXIAL STRESS VS STRAIN



Sample Parameters:

Sample Height:	122.43	mm	Bulk Density:	2.53	t/m³
Sample Diameter:	61.14	mm	Dry Density:	2.49	t/m³
Test Height:	122.43	mm	Water Content:	1.6	%
Test H/D Ratio:	2.00				

Failure Value:

Axial Strain %	Unconf. Compressive Strength qu (kPa)	Rate of Compression (mm/min)	Modulus of Elasticity (MPa)
0.57	12960	0.11	2570

Mode of Failure: Shear

Sample History: Undisturbed core trimmed at natural water content.

Description: Grey, weak, Greywacke Sandstone with numerous quartz veins.
Failure occurred along existing fractures.

Test Remarks: Unconfined Compressive Strength reported to the nearest 1 kPa.
Modulus of Elasticity value reported based upon straight line portion of the curve and provided as indicative only.
Sample description and modulus of elasticity value reported are not IANZ endorsed.

Entered by: ST Date: 2/11/11 Checked by: ADFC Date: 2/11/11

Appendix J: Results of Zeolite Analyses

RUATANIWHA PROJECT

REPORT ON PETROGRAPHY OF SEDIMENTS (CORE SAMPLES AND RIVER GRAVELS) For Tonkin and Taylor Ltd. (Job code: A7 27195.200)

1. SAMPLES PROVIDED

The following samples were provided :

1. Core samples of the local Waioeka petrofacies (Waioeka terrane of the Torlesse "Super-terrane").
2. Two sacks of river gravels from different localities in the Makaroro River.

Information about the core samples, the gravel samples, and the nature of the investigations of each sample are given in the Appendix attached (page 12).

2. BRIEF

The brief given was to:

1. Examine the core material for the presence of zeolites; identify the zeolites; and estimate the amount of zeolites in the sediments.
2. Comment on the use of the core material for fill.
3. Examine the gravels and assess the amount of zeolite-bearing material in them.
4. Assess the gravels for use as concrete aggregate.

3. SUMMARY OF RESULTS AND RECOMENDATIONS

The Waioeka petrofacies rocks are volcaniclastic sandstones and mudstones. Laumontite and calcite are common as veins cutting the sandstone. Laumontite, when it occurs in the rock itself, is a very minor component (estimated less than 5 wt %) of the matrix of the sediments. The more siliceous and hydrous calcium-rich zeolite, heulandite, has also been observed in some samples as a vein mineral and in the sediment matrix.

Rakaia terrane arkosic sandstones and argillites, from the headwaters of the Makaroro River, are the dominant component of the gravels. Both sacks of gravels contained small amounts of Waioeka and ?Pahau terrane sediments that contained some vein (and presumably also matrix) laumontite. One sack of the gravels contained very minor amounts of shell material and fragments of Pliocene sediments (mudstone and sandstone) that outcrop locally.

The Rakaia terrane rocks are notably much larger and tougher / harder than the local Waioeka and Pahau sandstones. The Rakaia terrane cobbles could be separated from the other sediments by screening and crushed to provide a good quality fine and coarse-grade concrete aggregate.

It is recommended that, since the Waioeka petrofacies rocks contain two minerals with expansive properties (smectite and laumontite), the durability of these sediments and their potential for use as fill be further investigated by determining their Weathering Quality Index and Clay Index values (NZS 4407: 1991 Tests 3.11 and 3.5 respectively).

4. GEOLOGICAL BACKGROUND

All the sediments examined belonged to the Torlesse "Super-terrane" which is subdivided into a number of terranes.[1] In the part of the North Island that is of interest to this project there are three Torlesse terranes. These are from west (also oldest) to east (youngest): Rakaia, Pahau and Waioeka. The Waioeka terrane is divided into two petrofacies but only one of these (the Waioeka petrofacies) is exposed in the Ruataniwha area.

There are petrographic differences between the three terranes. Rakaia terrane sandstones are felsic arkosic. The Pahau terrane contains notably more lithic debris but is still classified as arkosic.[2] The Waioeka petrofacies sandstone characteristically contain volcanoclastic lithic debris. The Pahau terrane and the Waioeka petrofacies rocks have been "metamorphosed" (i.e. diagenetically altered) to zeolite facies. The older (western) Rakaia terrane, which outcrops in the headwaters of the Makaroro River, has been metamorphosed to the higher temperature prehnite - pumpellyite facies.

5. METHODOLOGY

Portions of all the samples listed in the Appendix were hand-crushed then packed into aluminium holders for bulk sample X-Ray diffraction analysis.

An oriented sample was made of some of the samples to provide X-ray diffractograms that enhanced the basal spacings of clay minerals and zeolites, thus facilitating their identification.

Material that was unveined was selected for thin-sectioning. The thin-sections were examined with a polarising microscope and microphotographs taken of petrographic features that were characteristic of the rock type.

The sacks of gravel were individually tipped out and the contents examined to determine the nature of the material in the cobbles and to select those cobbles that had features such as veining and/or either looked or behaved (when crushed) differently from the majority of the cobbles. Representatives were then crushed for X-Ray diffraction examination.

6. ZEOLITES

Natural zeolites have low-density, micro-porous framework structures composed of aluminosilicate tetrahedra arranged in rings and/or cages of various dimensions. The rings / cages are linked to form chains or layers with interconnecting cavities that allow ions and

[1] Terminology from N.Mortimer (1995) 'Origin of the Torlesse Terrane and coeval rocks, North Island New Zealand', *International Geology Review*, 36, 891-910. Also Axel Leverenz (1999) *Aspects of the Sedimentology and Petrology of "Torlesse" Rocks, northeastern North Island, New Zealand*. PhD Thesis, University of Auckland.

[2] Karein Bassett and Richard Orlowski (2004) 'Pahau Terrane type locality: fan delta in an accretionary prism trench slope basin.' *NZ Journal of Geology and Geophysics* 47, 603-623.

molecules to freely migrate through the structure. Zeolites are commonly described as molecular sieves.

The aluminosilicate famework of all zeolites has a charge imbalance that is compensated / neutralized by the presence of alkali ions and water molecules that are loosely held in the cavities within the tetrahedral framework. All zeolites have the ability to "boil-off" all the water held in their structures and to fully rehydrate on cooling.

7. LAUMONTITE

Laumontite is a hydrated calcium aluminosilicate that is common in low-temperature altered volcaniclastic sediments containing glassy tuffaceous debris and volcanic rocks. In a normal water-saturated sedimentary environment, laumontite is fully hydrated and has the formula Ca_4 [Si_{16} Al_8 O_{48}] .18H_2O. However, when exposed to the atmosphere under ambient (room temperature) and low (< 50-60%) humidity conditions, laumontite dehydrates to a stable partially-hydrated form with only 14 water molecules per formula unit ie Ca_4 [Si_{16} Al_8 O_{48}] . 14H_2O.[3]

The dehydration from the 18H_2O to the 14H_2O form of laumontite is accompanied by an approximately 2.5% volume decrease.[4] The fully hydrated form of laumontite has a molar volume of 1384Å^3 , while the partly hydrated form has a molar volume of 1351Å^3. [5]

The laumontite structure contains four distinct sites for holding water. In two of these sites the water molecules surround and neutralise the calcium ions. In the other two sites the water molecules are hydrogen-bonded to the aluminosilicate framework. Water that is hydrogen-bonded is more easily driven off than water that is associated with the calcium ions. The dehydration from the 18- to 14- molecule form of laumontite involves water loss from only one of the two hydrogen bonded sites. As the mineral is subject to increasing temperature water loss is stepped as water is boiled off from each of the other three sites.

In the Waioeka petrofacies sediments laumontite is common as a vein mineral (often in association with calcite) and also occurs in small amounts in the matrix of the sediments usually in tension gashes or replacing plagioclase feldspar.

A second calcium zeolite, heulandite - Ca [Si_7Al_3] O_{18} .6H_2O – which is more siliceous and water-rich than laumontite - has also been observed as veins and in the matrix of Waioeka petrofacies sediments (samples 4 and 6 on appended list).

[3] This partly dehydrated mineral has been called leonhardite, but is now considered to be a variety of laumontite.

[4] One Angstrom (Å) is 10^{-10} meters or 0.0001microns.

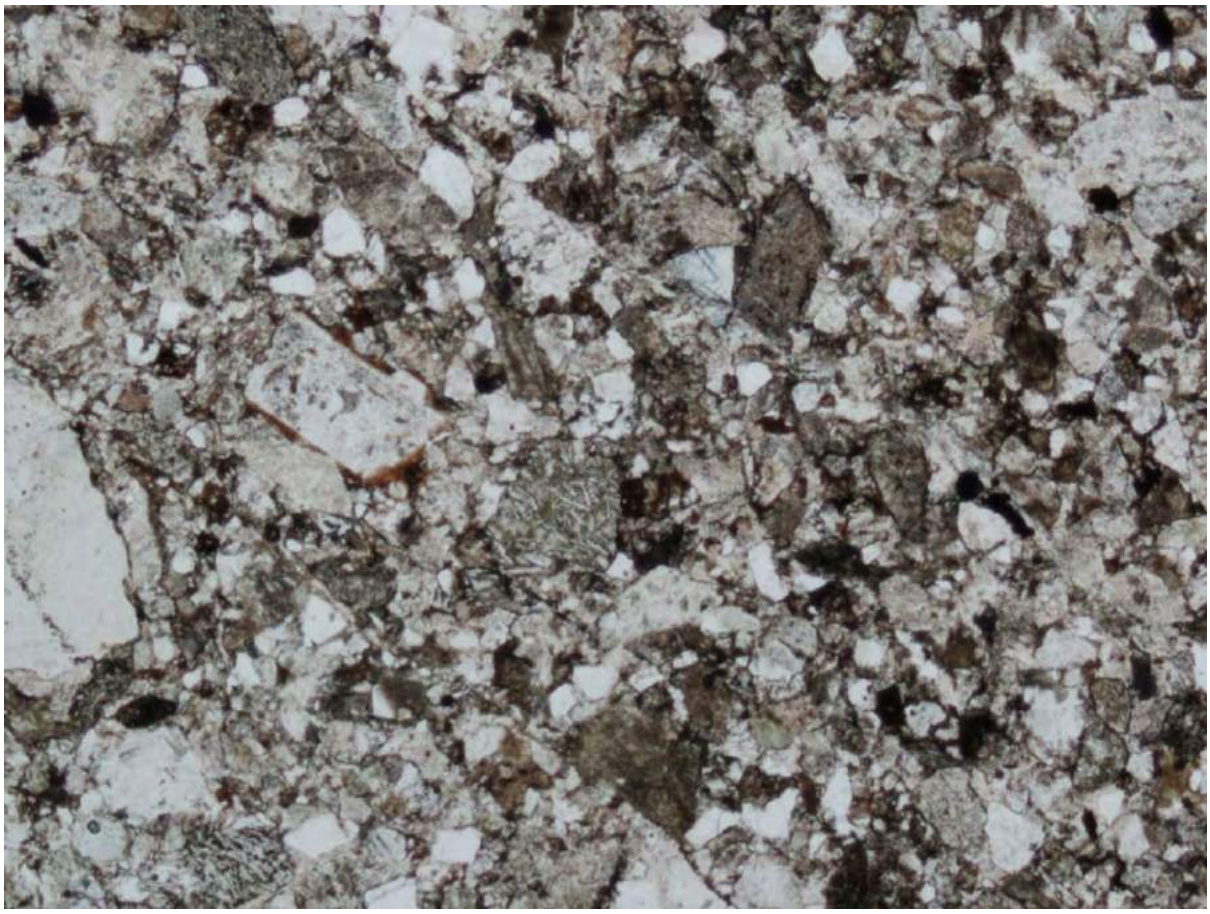
[5] Neuhoff, P.S. and Bird, D.K. (2001) 'Partial dehydration of laumontite: thermodynamic constraints and petrogenetic implications.' *Mineralogical Magazine* 65 (1) 59-70. Also: Fridriksson, T., Bish, D.L. and Bird, D.K. (2003) 'Hydrogen-bonded water in laumontite 1: X-ray powder diffraction study of water site occupancy and structural changes in laumontite during room-temperature isothermal hydration/dehydration.' *American Mineralogist* 88, 2277-287.

8. PETROGRAPHY OF SAMPLES

8.1 Waioeka Petrofacies

Six samples of core material from the local Waioeka petrofacies were thin-sectioned (samples 5, 7, and 9 to 12 on the appended list). In selecting the portion of the core for sectioning, wherever possible areas that contained veins were avoided; but in some cases the veining was so close that inclusion of veins was unavoidable. A portion of the thin-sectioned core material was also crushed to provide a bulk XRD diffractogram; this provided a check on the clay minerals in the sample and also the presence of zeolite. In taking material to crush for a bulk XRD I also avoided any material that contained veins. [6]

A general view of a typical portion of Waioeka petrofacies rock is shown below:



Microphoto 1 : (plane polarised light) sample 5 (BH703 at 31.4-31.5m); (field of view is 3.5 x 5mm). Note that the sandstones are grain-supported (ie low matrix), poorly sorted, and the clastic grains are very angular.

[6] In hand-crushing the material I noted that the Waioeka petrofacies rocks (and also material in the gravels that I presume to be Pahau Terrane in origin) had considerably less strength than the older Rakaia material.

The detrital material in the sandstones is very variable in origin. Some of the larger (>1mm) lithic fragments observed in thin-sections included fragments of siltstone, and arkosic sandstone (which clearly originated from erosion of Rakaia terrane). Chloritised igneous material is also very common (see Microphotos 2 - 6). Small angular fragments of felsic volcanic rock (centre of Microphoto 1) occur but they are not abundant. No volcanic glass shards (i.e. tuffaceous debris) was observed in any of the Waioeka petrofacies rocks that I had thin-sectioned. Heavy minerals observed were: epidote, biotite, zircon and pyroxenes.

8.1.1 Points to note :

- Most of the igneous material in the sandstones has clearly been altered (chloritised) before being eroded and included in the sediment.
- The matrix of the Waioeka petrofacies rocks is dominated by the clay minerals chlorite and smectite with some illite/mica (this category will include detrital biotite). Smectite occurs as individual minerals and also interlayered with chlorite and illite.
- Laumontite is a common vein mineral but the matrix of the sediments was largely free of laumontite. Where I did observe laumontite it appeared to be concentrated on extension gashes and in lenses rather than in the matrix of the rock.
- Calcite is common in veins and also locally as cement in sandstone.

8.1.2 Comment :

The Waioeka petrofacies sandstones do contain some laumontite but in very small amounts. The X-ray diffraction method that I used accentuates the basal spacings of minerals and when the laumontite peak appears in the diffractogram of the rock the basal (in this case the cleavage plane spacing) is very low intensity. I would estimate that laumontite, when it is present in the matrix, occurs in amounts that do not exceed 5 weight %. Laumontite is most common in late veins.

The laumontite is concentrated in veins. Contraction of vein laumontite when it dries / dehydrates will be a defining factor in controlling the size of breakdown particles formed (on the scale of several cm). I do not think there is sufficient laumontite in the matrix of the Waioeka petrofacies sediments to create significant contraction of the sediment as a whole but it would be wise to test the durability of these sediments.

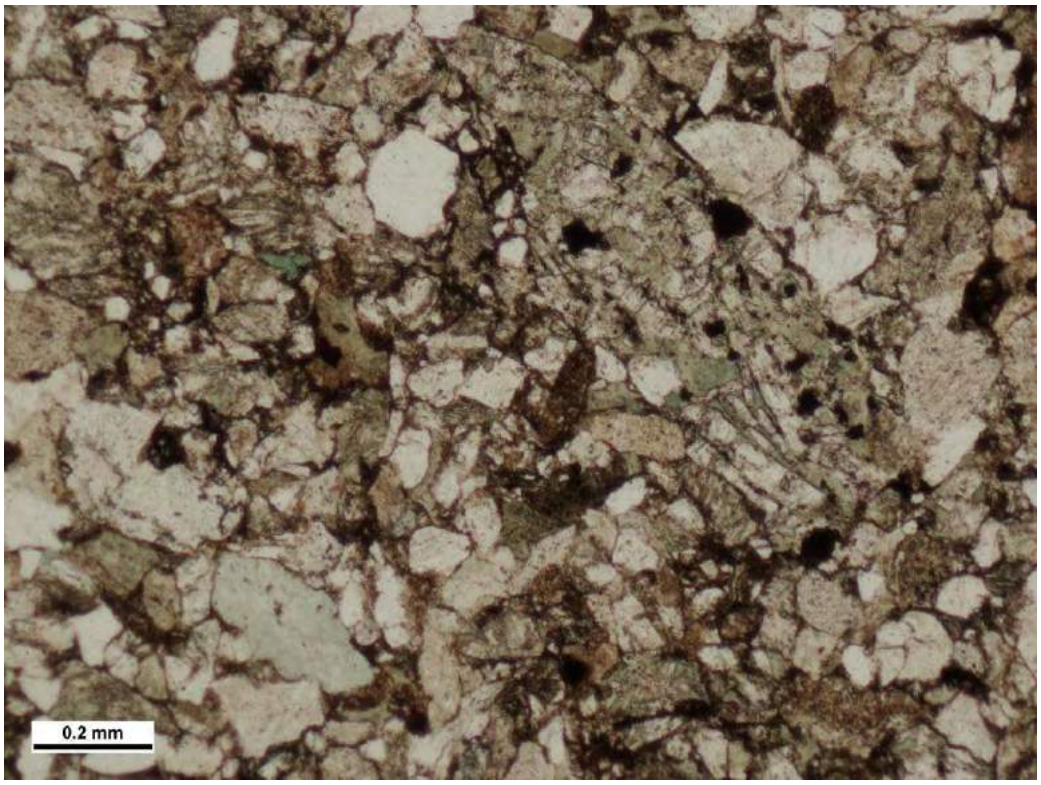
8.1.3 Recommendation :

Since the Waioeka petrofacies rocks, which contain two expanding minerals (smectite and laumontite), have been proposed for use as fill, I recommend that an additional set of tests be carried out. The tests are :

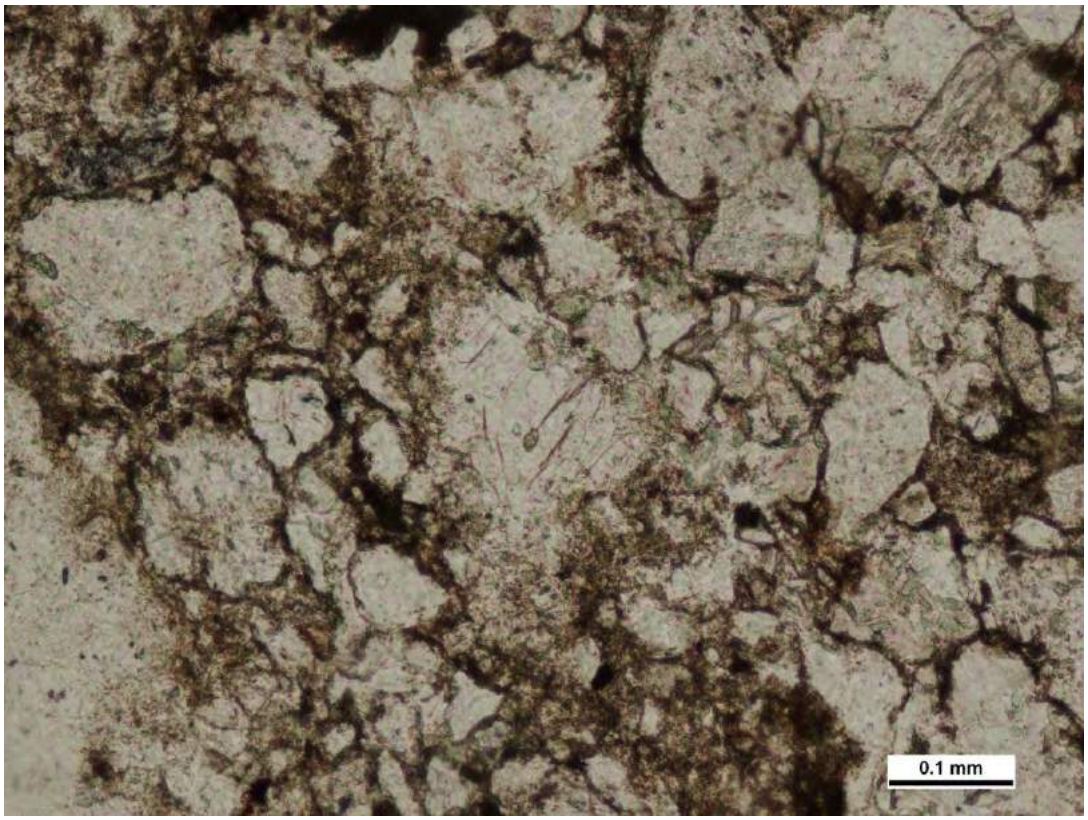
(1) Weathering Quality Index (NZS 4407: 1991 Test 3.11) – a test that repeatedly wets and dries the sample and measures the resulting physical breakdown of the rock.

(2) Clay Index (the methylene blue absorption test) NZS 4407 : 1991, Test 3.5) which is actually providing a measure of surface area. Smectite clays and zeolites both have very high surface areas and both will be counted in the Clay Index value. This data will provide another estimate of the swelling capacity of the material. Since smectite occurs in several "forms" in the sediment, and interlayered smectite is difficult to determine by X-ray diffraction, the Clay Index will provide an independent estimate of its relative abundance.

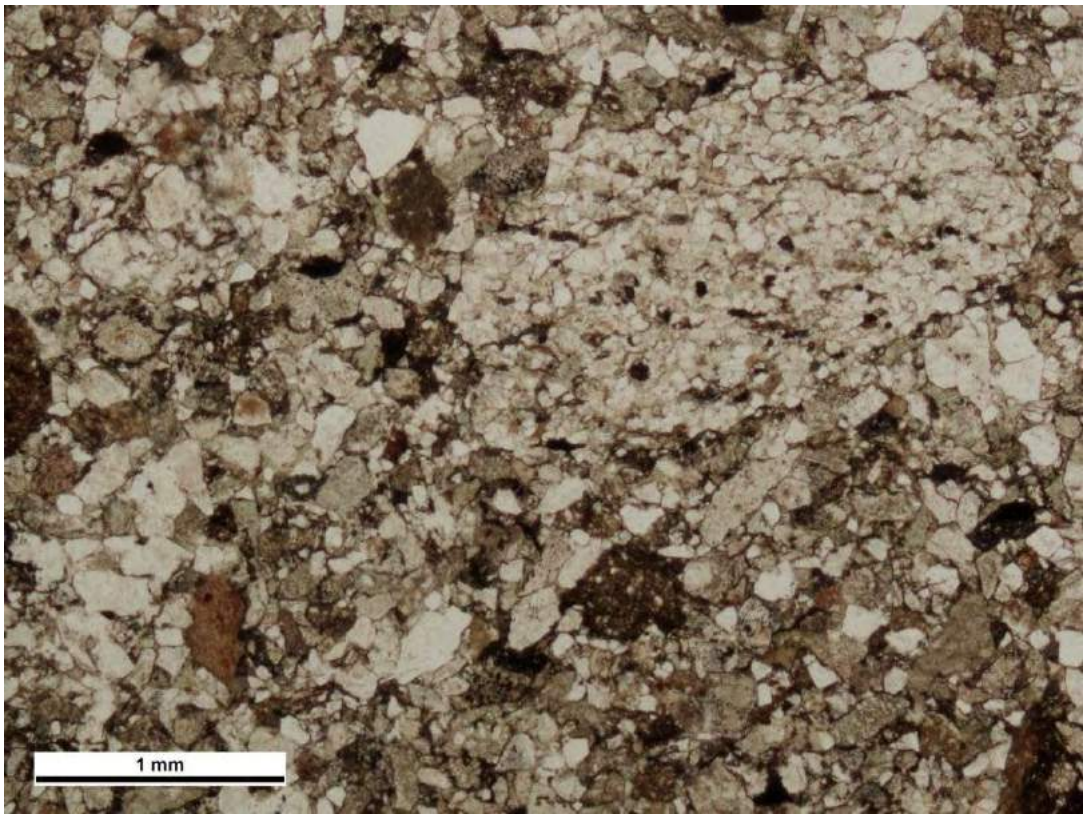
Microphoto 2 : sample 12 BH703 21.5- 21.6m. Plane polarised light. Waioeka petrofacies sandstone. Reddish heulandite in small elongated lens and replacing material (possibly feldspar).



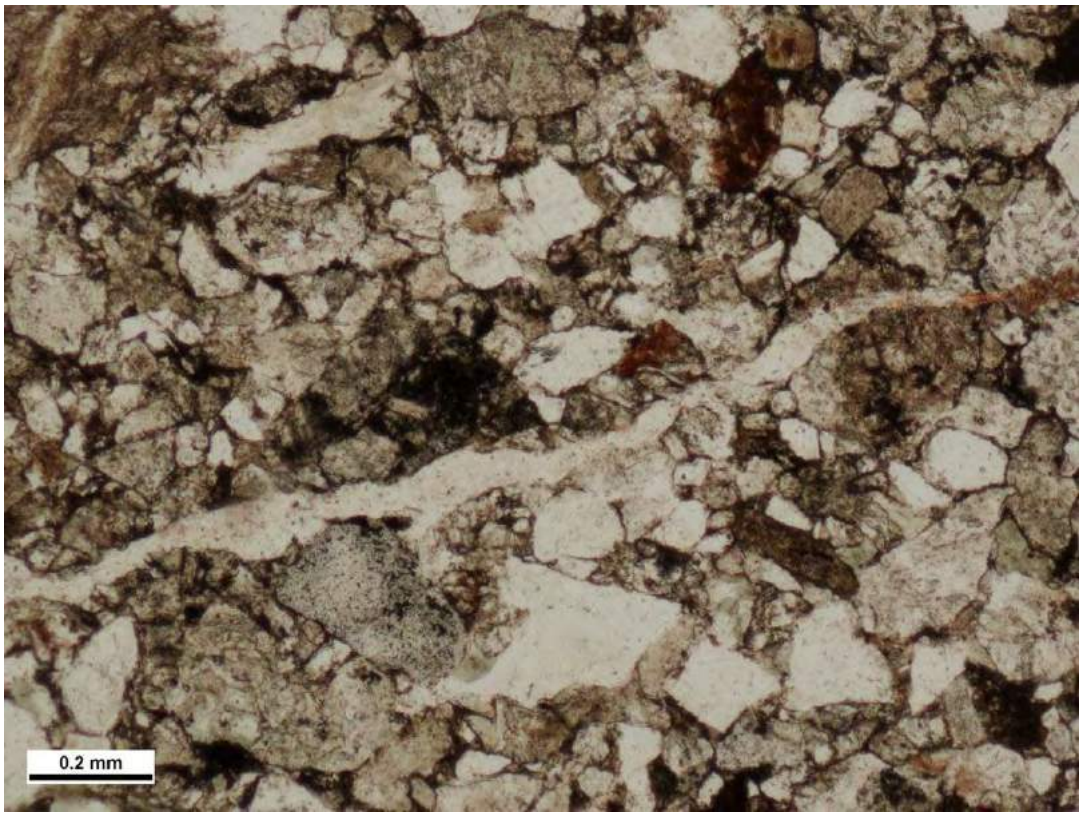
Microphoto 3: sample 11 BH 703 at 23.4-23.5 Plane polarised light. Waioeka petrofacies sandstone. Showing large lensoid –shaped clast of igneous rock (above right).



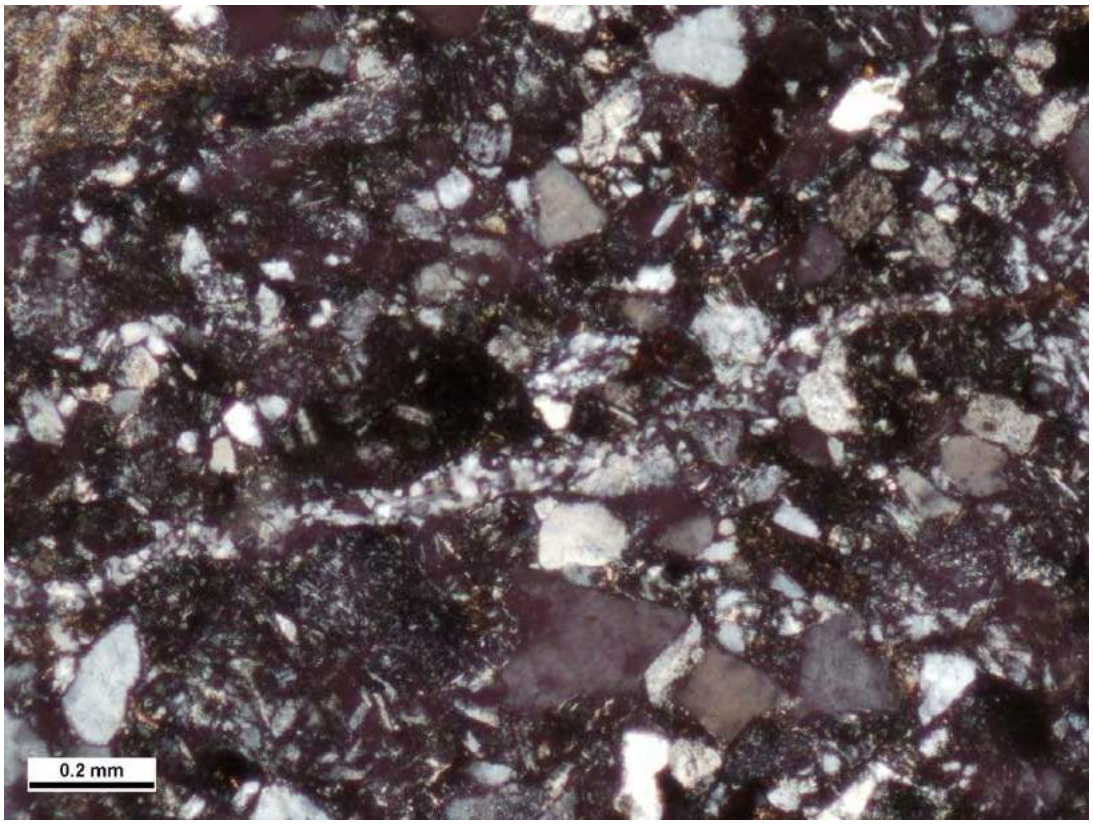
Microphoto 4: sample 7 BH 702 at 12.4m Plane polarised light. Waioeka petrofacies sandstone. Showing zeolitised material centre and bottom left.



Microphoto 5: sample 12 BH 703 at 21.5-21.6m. Plane polarised light. Waioeka petrofacies sandstone. Showing large well-rounded clast of Torlesse-type arkosic rock (above right).



Microphoto 6 A – plane polarised light (above) and 6B – crossed polars (below): sample 9 BH 702 at 19.9m Waioeka petrofacies sandstone. Showing vein of laumontite (centre) and some evidence of zeolitisation in the matrix. Brownish area in top left corner is calcite veining.



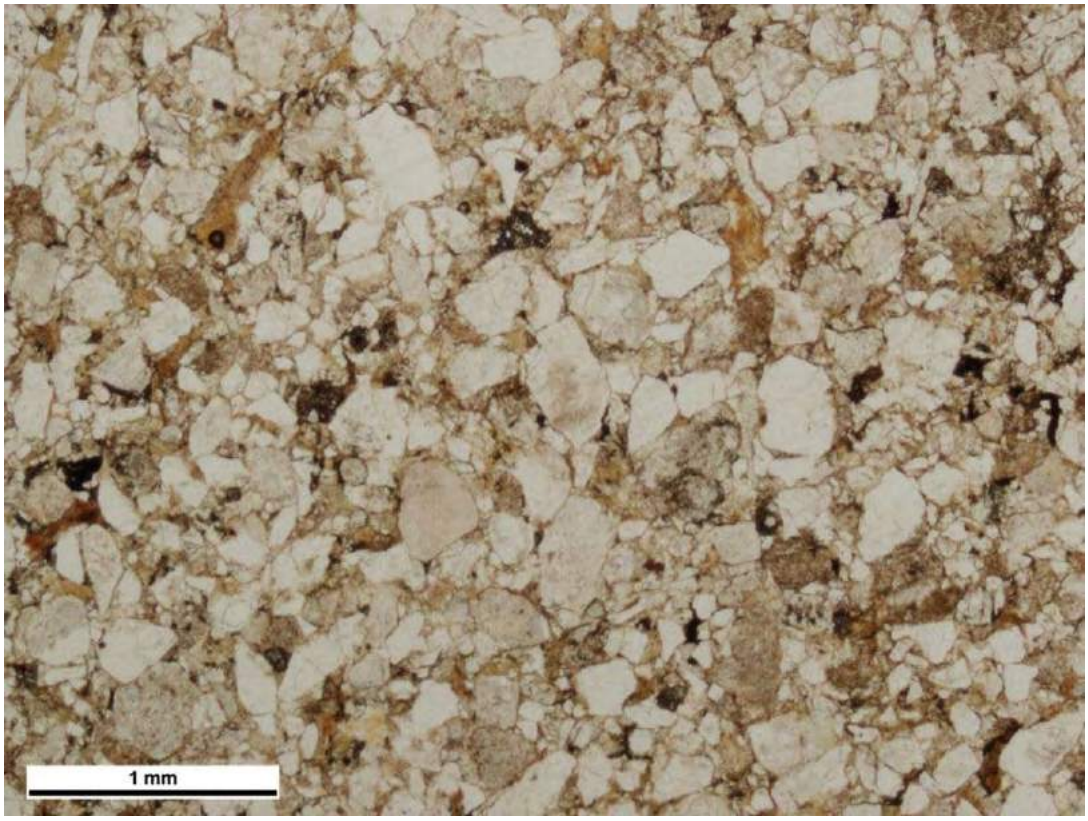
8.2 Rakaia Terrane (Torlesse-type) Greywacke.

From my examination of the pebbles in the sacks the quartz and feldspar-rich Rakaia terrane (called Kaweka in old geological maps) greywacke pebbles dominate.

Thin section microphotos below show the typical features of this type of greywacke (illustrated in the Microphotos 7 and 8 below). Typically these greywackes are moderately well sorted, clast supported arkosic sandstones. The clastic grains in the rock are very angular. The dominant sand grains being quartz (individual crystals, polycrystalline aggregates and strained crystals) and alkali feldspars. Brownish biotite, in various stages of alteration, is a common detrital mineral.

8.2.1 Points to Note :

- These greywackes are high strength and free from zeolites or swelling clays.
- The matrix of these sandstones is very quartzose and the clay mineralogy is dominated by chlorite and illite.
- Some sutured quartz may be a slight issue but since Rakaia-type Torlesse greywackes are commonly used as concrete aggregate in the South and the southern North Island there should be no problems with using them for concrete aggregate.



Microphoto 7. Plane polarised light. Rakaia Terrane sandstone cobble (sample 13) in gravels (sack A7/3).

Microphotos 8A and 8B – Rakaia terrane sandstone cobble (sample13) in sack A7/3. Plane polarised light (above – 8A) and same field of view with crossed polars (below - 8B). Note twinning in feldspar grains; polycrystalline quartz grains, and some strained quartz.

9. RIVER GRAVELS

Two sacks of gravel labeled A7/3 and A7/8 were provided. I understand that these gravels were sourced from two localities 2km apart in the Makaroro River.

Sack A7/3 contained small amounts of shell material (up to 1.5cm in length) and some fragments of soft mud and sandstone. I presume that this material was derived from the fossiliferous Pliocene sediments that outcrop near the sample-collection area.

Sack A7/8 did not contain either the shell material or the soft mudstone flakes found in sack A 7/3.

Both sacks contained small fragments of sediment containing veins of laumontite and/or calcite and pieces of brownish slightly weathered sandstone. This material could be either Waioeka or Pahau. Without a thin-section I cannot really distinguish them, but in either case the sediments will contain small amounts of laumontite. This material was a very minor component of the gravels.

9.2 Comment:

The major component of both gravel samples appeared to me to be the old Rakaia terrane arkosic sandstones and argillites that are in the headwaters of the Makaroro River. The Rakaia terrane sandstone cobbles are notably much larger and tougher / harder than the sandstones. Screening could easily separate the Rakaia terrane cobbles from the smaller Pahau and Waoieka terrane cobbles (which do not normally exceed 3cm in short diameter.)

The Rakaia terrane cobbles are very similar to those that are harvested from rivers and terraces to supply the concrete industry in the Wellington and Christchurch areas.

I would expect that they will crush to provide good quality fine and coarse aggregate suitable for use in concrete.

Philippa Black
December 10, 2011

Appendix : RUATANIWHA PROJECT : Samples studied.

Core and Gravel Samples (ex David Milner, Mark Taylor and Bernard Hegan)
Tonkin and Taylor Job code: A7 27195.200

Core samples Waioeka petrofacies [My lab numbers 1 – 12]

Samples 5, 7, 9, 10 and 11 were thinsectioned. All samples were checked by XRD for zeolites and/or clay mineral content.

1. **BH703 at 29.1m** white vein ... vein laumontite
2. **BH703 at 9.2m** white vein ... quartz + some laumontite
3. **BH703 at 18.5m** white vein is laumontite
4. **BH703 at 11.2m** Bernard Hegan's red vein mineral is the zeolite heulandite
5. **BH703 at 31.4-31.5m** vein laumontite also calcite
6. **BH703 at 9.4m -** clay in pug zone. Material was dispersed and then sedimented on a glass side to provide an oriented sample from which XRDs were run on untreated sample which was then glycolated to test for swelling clays : good identification of smectite (swelling clay), chlorite and illite in roughly equal amounts.
7. **BH702 at 12.4m –** soft very black material – seems to be just a zone of pulverised rock as it contained quartz, feldspar, chlorite illite, some small amount of smectite and laumontite. An XRD of the light coloured rock in sharp contact with the black material showed quartz, feldspar, chlorite and small amount of smectite and laumontite.
8. **BH702 at 36.6 – 36.65m** vein is laumontite
9. **BH702 at 19.9-21.0m** coarse sandstone; no obvious veining
10. **BH702 at 30.9 -31.0m** coarse sandstone; many thin crosscutting veins spaced about 1cm apart
11. **BH 703 at 23.4-23.5** coarse sandstone; some grains up to 2mm in long dimension (usually argillite). Thin (<1mm wide) veins spaced at about 5cm apart.
12. **BH703 at 21.5- 21.6m** coarse sandstone; some grains up to 2mm in long dimension (usually argillite). Thin (<1mm wide) veins spaced at about 5cm apart. Pinkish red mineral in some veins – probably heulandite.

River Gravels in sacks

Sack A7/3

13. **cobble** coarse unveined sandstone that looked similar to local Waioeka petrofacies but was very much stronger (thin-section and XRD) – Rakaia terrane
14. **cobble** coarse dark-grey unveined sandstone (XRD only) – Rakaia terrane.

Pieces of white veined material in small rock chips.

- **RuaCS1** white vein in small (<1cm) pebble ... dominantly calcite with trace of quartz.
- **RuaCS2** small pebble with white veining .... vein is laumontite
- **RuaCS3** small pebble with lots of white veins - whole rock sample (includes vein) : quartz, feldspar, chlorite, illite and small amount of laumontite; vein laumontite
- **RuaCS4** pale-coloured rock chip (no vein) : quartz, feldspar and a clear laumontite pattern

Pebbles of sediment that was notably different to the Waioeka and other Torlesse-type rocks.

- **RuaA7/31b** soft mudstone clast – probably Pliocene sediment
- **RuaA7/3 2b** small sandstone clast –probably Pahau terrane - laumontite

Sack A7/8

Pebbles of sediment that were notably different to the Waioeka and Rakaia terrane rocks.

- **Rua A7/8 1b** sandstone clast – probably Pahau terrane: chlorite and illite-mica (XRD only)
- **Rua A7/8 2b** white veined clast – laumonite vein (XRD only)
- **Rua A7/8 3b** sandstone possibly Pahau terrane; chlorite and illite-mica (XRD only).

www.tonkin.co.nz

ENVIRONMENTAL AND ENGINEERING CONSULTANTS