Ruawai Town Water Supply Bores - Exploratory Drilling, Water Treatment & Aquifer Management

Report Prepared For

ENVIRONMENTAL OPERATIONS LIMITED

On Behalf Of

KAIPARA DISTRICT COUNCIL

- Final
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Executive Summary

Background and Objectives

Sinclair Knight Merz NZ Ltd (SKM) was commissioned by Environmental Operations Limited on behalf of Kaipara District Council to provide specialist groundwater and water treatment engineering advice on the town water supply bores at Ruawai.

The specific objective of the investigation was to assess the aesthetic water quality problems relating to high iron and manganese concentrations in the existing production bores.

Recommendations were made following bore casing condition inspections in SKM (2004) for exploratory work to investigate the potential of an improved water supply within the deeper aquifer underlying the existing bores. This recommendation was based on SKM's conceptual understanding of the district-wide hydrogeology developed for Northland Regional Council in a previous study (SKM, 2003), which suggested the presence of a clean coarse sand and gravel aquifer beneath the deepest existing production bore at around 100 m.

Investigations Carried Out

As part of this phase of study, undertaken during April to August 2005, the following physical works were carried out:

- exploratory drilling using HQtt coring techniques;
- lithological logging;
- monitoring piezometer construction in each aquifer unit identified;
- aquifer hydraulic test pumping;
- groundwater level monitoring; and
- groundwater quality testing.

Findings of Physical Works

The bore drilled encountered limestone basement at approximately 90 m, underlying a coarser sand aquifer as anticipated by SKM. Accurate geological logging enabled the identification of four sand aquifer units, each separated by either clay or finer sand deposits. The existing productions bores are located in the second and third aquifers. The fourth and deepest aquifer unit identified between 75-90 m comprised fine to medium sands, with some coarser materials comprising shell fragments and sandy gravels near the base of the unit. This unit appeared to be the cleanest and most promising from a potable water supply perspective.

Water quality results indicated a trend of decreasing concentration of iron and manganese with depth (i.e., an improvement in iron and manganese concentration between the existing production bores and the piezometer located in the deeper aquifer). However, this positive finding (with respect to the primary project objectives) was tempered slightly by elevated sodium and chloride concentrations relative to the other bores.

Two further rounds of sampling were conducted to verify results for the deeper piezometer and investigate any effects of pumping on water quality. The key results were as follows:

- iron and manganese concentrations remained lower than all existing bores; and
- sodium and chloride ion concentrations remain elevated relative to other bores, indicating either upward leakage of marine-derived salts from the underlying marine sedimentary rocks, or that the deeper bore is possibly closer to the position of saltwater interface than the existing bores.

With respect to the NZDWS 2005, the water quality in the deeper piezometer (BH4d) (80-90 m) meets the aesthetic guideline value (GV) for iron (0.1 mg/L compared to the GV of 0.2 mg/L). While slightly exceeding the GV for manganese (0.065 mg/L compared to the GV of 0.05 mg/L), the manganese concentration is approximately half the concentration of the best existing bore (0.11 mg/L in BH2a). However, at this depth average sodium concentrations are approximately equivalent to the GV of 200 mg/L, while chloride concentrations exceed the GV of 250 mg/L by 80-100 mg/L.

Accordingly, the objectives of this investigation with respect to iron and manganese were achieved in the deeper aquifer between 80-90 m, however the elevated sodium and chloride concentrations provide a minor level of discomfort at this depth.

Recommendations

With respect to the current borefield setup, the following recommendations are made:

- replacement of the existing poor water quality production bore (BH1) with construction of a new larger diameter bore to be screen from 75 to 81 m (refer Recommendations Section for full details);[1]
- retain the best existing bore (BH2a) for full normal duty and as part of mitigation measures to guard against saltwater intrusion (refer Borefield Management section);

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[1] Construction of larger diameter bore (150 mm casing, with 120 mm stainless steel screen) will minimise drawdown and further mitigate potential saline intrusion effects.

- retain BH3a as an emergency backup bore;
- decommission BH1 by i) attempt to remove the bore screen and casing (since the bore casing is not properly grouted in place) and then grout open borehole, or failing this, ii) secure the aquifer at this location through pressurised grouted-sealing of the bore annulus to reduce the risk of vertical leakage or cross contamination of deeper aquifer from poorer surface waters.

Borefield Management

To mitigate any pumping induced saltwater interface issues, a preliminary borefield management plan has been developed. The plan recommends:

- alternate pumping of bores to minimise drawdown and thus saline intrusion potential at any particular location;
- pump continuously at any one bore for no longer than 2-3 hours, to minimise drawdown at any location and enable mixing of the raw water quality to maintain parameters within the GVs;
- bore recovery for at least 2-3 hours (minimum) between duty cycles;
- bore pump rates not to exceed 3 L/s;
- monitoring of saline water quality indicator parameters (electrical conductivity, total dissolved solids) and general field parameters (temperature and pH) on a monthly basis, in all bores;
- monitoring of groundwater levels in all bores on a monthly basis when not pumping (static groundwater levels); and
- continuous metering of groundwater quantity pumped from each bore.

Water Treatment Upgrade

The treatment requirements for the raw water supply was assessed assuming that the existing bore BH2a was to be used in conjunction with a new production bore to be drilled adjacent to BH4d screened from 75 to 81 m.

It was further assumed that the groundwater supplies are secure from surficial influences, which is the most likely scenario for existing bores and certainly the case for the new production bore. This reduces treatment requirements and operational costs significantly.

SKM invited several suppliers to provide budget estimates for the Ruawai treatment plant upgrade. Four suppliers responded with options and budget prices with price ranges for A Grading of $130,000 to $170,000, B Grading - $125,000 to $135,000, and C Grading - $125,000 to $135,000.

SKM recommends that the water treatment plant be upgraded to B grade and that two companies, Contamination Control and Water Systems, be asked to provide detailed cost breakdowns and company attributes (track record, level of service, warranties, etc.) to enable further evaluation of their service and the performance of their respective technologies. Both technologies are considered appropriate for the treatment requirements at Ruawai, but while different, had similar cost estimates of approximately $125,000 and $130,000, respectively.

Summary of Projected Costs

The following table summarises the projected costs to facilitate upgrade of the Ruawai borefield and treatment plant.

Item	Tasks	Cost Estimate (excluding GST)	Sub-Totals
Replacement Production Bore	Drilling & Construction	$40,000	
	Test Pumping	$8,000	
	Design, Analysis & Resource Consenting	$15,000	
			$63,000
Treatment Plant Upgrade	Equipment Suppliers	$130,000	
	Assistance with Selection of Water Treatment Plant Supplier	$5,000	
	Verification of Secure Groundwater in BH2a & BH3	$5,000	**$140,000**
TOTAL			**$203,000**

Contents

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1. Introduction

A bore casing condition assessment and subsequent bore remedial trial was undertaken by Sinclair Knight Merz (SKM) in early 2004 to address water quality concerns, and in particular the elevated iron and manganese, in the town water supply bores at Ruawai. Recommendations were put to Council following this work to further investigate the deeper aquifer based on SKM's conceptual understanding of the district wide hydrogeology, which suggested that better water quality was likely beneath the existing production bores. To this end, an exploratory drilling program was undertaken in mid April 2005.

The specific goals of the investigation included:

- determination of the stratigraphic sequence of soils and sediments with the goal of identifying likely target aquifer zones for potable water supply underlying the existing production bores;
- characterisation of the sediments for optimal production bore design (if deemed successful); and
- analysis of groundwater quality through collection and testing of samples from potential the target aquifer zones.

2. Exploratory Bore Drilling

The exploratory bore was drilled to 95.5 meters below ground level (mBGL) using the wire-line rotary coring method. Drilling was carried out with an HQ size tungsten bit, which produces 63.5 mm diameter cores for detailed geological analysis. HW size casing was placed to 49 m to prevent the borehole walls from collapsing before piezometer installation.

A second borehole was then drilled approximately 3.5 m from the first to a depth of 70 m to accommodate a nest of monitoring piezometers. This was drilled using the HW casing advancer, which produces a hole diameter of 110 mm and has the advantage of rapid penetration rates where geological logging is not required.

A single 50 mm diameter PVC piezometer was installed in the deeper hole to a depth of 90 m (BH4d), with a 9 m machine-slotted PVC screen covered with filter sock to prevent sediment ingress. A 2 mm Walton Park gravel pack was constructed to 1 m above the screen followed by a 500 mm blinding sand layer. The bore annulus was then cement grouted to the surface.

Three 25 mm diameter PVC piezometers were installed in the second hole in a nested configuration to depths of 22.9 m (BH4a), 55.9 m (BH4b) and 70 m (BH4c). Hand-slotted screens ranging from 6 to 9 m in length were constructed and filter sock was used for BH4a and BH4b to prevent sediment ingress. A 2 mm gravel pack was installed to 1 m above the lowest screen, with 300 mm blinding sand followed by a 3 m bentonite plug to isolate the screen interval from interaction with the overlying aquifer profile. A similar procedure was carried out for the two remaining piezometers, except for the use of a mixed sand and gravel pack, before the bore annulus was backfilled to 4 mBGL and capped with a bentonite seal.

Both bores were finished with a heavy-duty 1.5 m long by 200 mm diameter galvanised steel protective monument. The monuments were founded in 0.5 m deep concrete plinths with a radius of 0.4 m.

A summary of the bore drilled depths and piezometer completion details are provided in the borelogs in Appendix A.

Follow completion of the bores, each piezometer was developed using high pressure air and water samples were taken at the end of this procedure from BH4a, BH4c and BH4d on 15 April 2005 for water quality analysis.

Groundwater level monitoring was also undertaken..

2.1 Aquifer Lithology

During drilling, core samples were logged in accordance with the NZ Geotechnical Society field classification scheme for soils and rocks, then photographed prior to disposal. A detailed geological description is provided in borelogs presented in Appendix A and summarised in Table 1, while Appendix B provides photographic reference to the drill core obtained.

- **Table 1. Summary of borehole geology.**

Depth (m)	Thickness (m)	Lithology	Comments
0.0 – 0.5 0.5 – 2.7 2.7 – 3.5 3.5 – 4.0 4.0 – 26.5	0.5 2.2 0.8 0.5 22.5	Fill Clay Sand, fine Sandy silt Sand, fine, minor medium, clean	Fine sand SHALLOW AQUIFER. BH4a piezometer screened between 4 – 22.8 m
26.5 – 27.8 27.8 – 31.7 31.7 – 39.7	1.3 3.9 8	Clay Sand, fine to medium, with shell fragments & silt traces Clay	Interbedded sand and clay.
39.7 – 40.0 40.0 – 46.4 46.4 – 46.6	0.3 6.4 0.2	Sandy silt; Sand, fine Sand, fine, clean Sandy silt	Sandy silt with sand
46.6 – 53.5 53.5 – 54.1 54.1 – 55.4 55.4 – 56.0 56.0 – 59.0	6.9 0.6 1.3 0.6 3	Sand, fine, clean Sand, fine to coarse Gravel, fine to medium Sand, fine, traces of medium Sand, fine, with occasional gravel, fine to medium	Sand and gravel AQUIFER. BH4b piezometer screened between 49 – 56 m. BH1 production bore screened 57-61 m.
59.0 – 59.8	0.8	Organic sand, fine	
59.8 – 61.8 61.8 – 62.9 62.9 – 74.9	2 1.1 12	Sand, fine to medium, occasional coarse Sand, fine to coarse Sand, fine to medium	Fine to coarse sand AQUIFER. BH4c piezometer screened between 60-70 m. BH3 production bore screened 57-61 m. BH2 production bore screened 62-68 m.
74.9 – 77.9 77.9 – 80.9 80.9 – 87.3 87.3 – 89.9 89.9 – 90.3 90.3 – 90.65	3 3 6.4 2.6 0.4 0.35	Sand, fine, minor medium Sand, fine to medium, clean Sand, fine to medium, some coarse Sand, fine to medium, some coarse with shell fragments Sandy gravel with some shell fragments Greywacke boulder, gravel	Fine to coarse sand and gravel PRIMARY AQUIFER. Piezometer D between 80 – 90 m.
90.65 – 95.5	4.85	Sandstone, very weak to weak with minor thin mudstone beds, calcareous between 94.4 and 95.5 m	BEDROCK

As can be seen from the comments column in Table 1, four main aquifer units were encountered. Monitoring piezometers were installed in each. The primary aquifer for water supply purposes based on lithological properties is located between 75 and 90 mBGL. Aquifer lithology in this zone comprises clean fine to coarse sand, some shell fragments and some gravel.

2.2 Groundwater Quality

Three separate sampling phases of the new exploration bore were undertaken. Sampling protocol was based on accepted industry standards for bore sampling (e.g., Ministry of Health and Ministry for Environment, 1997) and all samples were sent to Hill Laboratories in Hamilton for analysis.

Piezometers BH4A, BH4C and BH4D were sampled at the completion of bore development (screen depths of 23, 70 and 90 m respectively)on 15 April 2005. Given the extended period of airlift development, results are expected to be representative of the screened aquifer.

Table 2 presents results of the first sampling phase and also lists the long-term average results for existing town supply bores and parameter limits/guideline values from the Drinking Water Standards for New Zealand (2005) for comparison.

- **Table 2. Water quality results summary for April sampling of Ruawai exploration bores.**

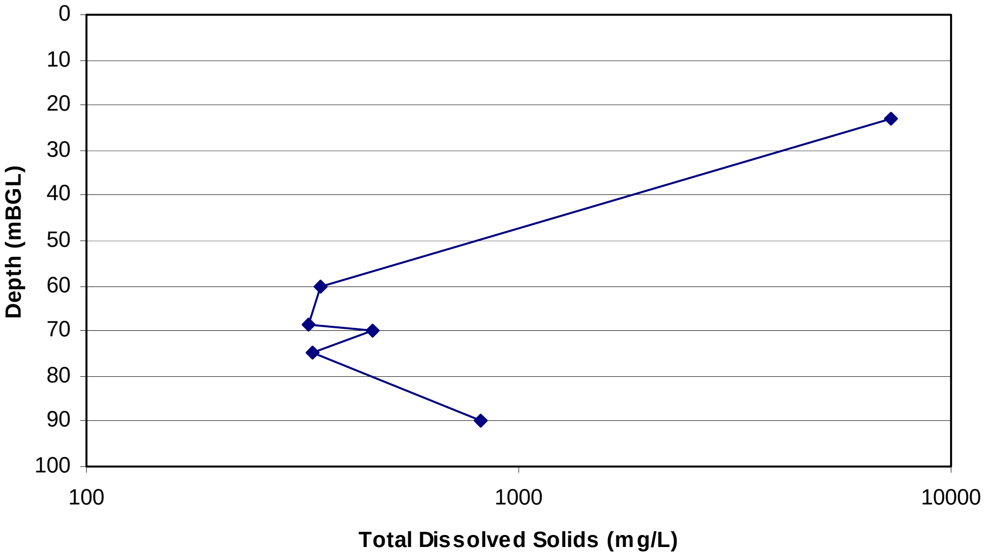
Parameter (mg/L)	Existing Supply Bores (Long-term average results)			Exploration Bore (15 April 2005)			Drinking Water Standards for New Zealand (DWSNZ) (Guideline value)
	BH1 75 m	BH2a 68.5 m	BH3a 60 m	BH4a 22.9 m	BH4c 70 m	BH4d 90 m	
Total Dissolved Solids (TDS)	333^{+}	325^{+}	347^{+}	7,240	458	821	1,000
pH (pH units)	7.2	7.2	7.2	7.5	7.7	7.8	7.0–8.5
Conductivity (mS/m)	539^{+}	556	500	11,500	799	1,400	-
Total Alkalinity	120	117	130	309	120	121	-
Bicarbonate (mg/L at 25ºC)	146^{+}	142^{+}	161^{+}	376	145	147	-
Dissolved Calcium	30.8^{+}	31.2^{+}	40.1^{+}	90.9	43.9	51.9	-
Dissolved Magnesium	5.79^{+}	6.09^{+}	7.00	205	9.24	9.43	-
Total Hardness (mg/L as CaCO3)	118	112	141	1,070	148	169	200
Dissolved Sodium	54.7	61	59.9	2,100	94.1	223	200
Dissolved Potassium	3.30^{+}	3.16^{+}	3.49	77.2	4.71	5.79	-
Nitrate-N	0.013	<0.002	0.021	0.015	0.016	<0.002	50*
Dissolved Chloride	95.6	96.7	101	4,410	172	348	250
Dissolved Sulphate	2.3^{+}	6.6^{+}	6.3	678	3.3	5.5	250
Dissolved Bromide	0.33^{+}	0.33^{+}	0.31	11.9	0.52	1.18	-
Dissolved Iron	<0.02	0.04	0.10	7.1	0.12	0.05	-
Total Iron	5.77	0.21	1.44	10	0.17	0.1	0.2
Manganese	0.253	0.112	0.183^{+}	0.886	0.159	0.0651	0.04
Dissolved Arsenic	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	-

Notes: Figures in red indicate limit exceedances, * MAV (maximum acceptable value), +only a single value available.

Results from the first set of samples indicate that groundwater quality is poorest within the shallow aquifer, probably because of mixing with seawater. Groundwater quality generally improves with depth, except chloride and sodium, which appear to increase in concentration beneath approximately 75 m, as shown in Figure 1 using total dissolved solids as a proxy for chloride and sodium to demonstrate the point.

The key results are as follows:

- iron and manganese concentrations are significantly lower for the deeper piezometer (BH4d) in comparison to the long-term averages for existing supply bores (BH1 and BH3a) and the other newly constructed piezometers (BH4a, BH4c);
- concentrations of major ions, particularly sodium and chloride are elevated in BH4c (70 m) and BH4d (90 m) relative to the BH1 long-term average. This may be due to increased groundwater interaction with the aquifer sediments at depth due to age, influence of groundwater upwelling from underlying sedimentary bedrock, or proximity to the freshwater/sea water interface.



- Figure 1. Distribution of total dissolved solids with depth.

Two further rounds of sampling occurred on 14 June and 13 July 2005, primarily to confirm the iron and manganese concentrations, but also to verify that parameter concentrations are stable.

Both sampling rounds involved the use of a Grundfos MP1 submersible pump for purging of BH4d.

Table 3 presents results of the June/July 2005 sampling rounds and includes results for BH4d (April) and BH2a (long term average) for comparison.

For the June sampling, BH4d was pumped for 2 hours and 20 minutes at a rate of 0.36 L/s and sampled at the beginning and end of pumping. BH2a was also sampled. Key results can be summarised as follows:

- Total iron and dissolved manganese concentrations in both BH4a and BH2 increased from the April sampling round. Manganese remained below the long term average for BH2A, however iron levels exceeded the BH2A average. These concentrations are still significantly lower than existing supply bores BH1 and BH3A
- Major ion concentrations remained relatively consistent with the April results
- The high nitrate value recorded for both samples is difficult to explain and inconsistent with previous and subsequent results suggesting field or laboratory contamination

The July sampling event was undertaken to investigate effects of longer term pumping on water quality and assess the extent of connectivity between the different aquifer units, if any. BH4D was pumped for 10 hrs at a rate of 0.39 L/s and sampled at the start, middle and end of pumping. Results are shown in Table 3 and are summarised as follows:

- Iron and manganese levels improved with pumping, finishing with concentrations at or below the April values. Final iron concentrations are half the DWSNZ guideline value, while manganese exceeds the respective guideline slightly, but remains at half the level present in the current best water quality water supply bore (BH2A).
- Major ion concentrations remained consistent with previous analyses.
- The high nitrates level recorded in June is no longer present suggesting as indicated above, that the June results may be due to erroneous sampling or laboratory procedures.

Figure 2 is a chemical characterisation diagram comparing water quality from the existing supply bores, the new exploration bore, and seawater. The ratios of major anions and cations offers information on the geochemical evolution of water, enabling conclusions to be drawn regarding factors such as the geology of aquifers, rock/groundwater interaction and residence times, potential flow paths and water sources (i.e. marine- versus rainfall-derived).

- **Table 3. Results of June and July sampling rounds**

Parameter (mg/L)	BH2a results		BH4d results						Drinking Water Standards for New Zealand (DWSNZ) (Guideline value)
	Long term average	June 2005	April 2005	June 2005 Start of pumping	June 2005 End of pumping	July 2005 Start of pumping	July 2005 Middle of pumping	July 2005 End of pumping	
TDS	325^+	337	821	866	867	851	849	848	1,000
pH (pH units)	7.2	7.9	7.8	7.6	7.6	8	8.1	8.1	7.0–8.5
Conductivity (µS/cm)	556	543	1,400	1,420	1,420	1,310	1,280	1,280	-
Total Alkalinity	117	112	121	125	123	130	125	123	-
Bicarbonate (mg/L at 25ºC)	142^+	136	147	152	150	157	150	148	-
Dissolved Calcium	31.2^+	35.1	51.9	58.1	57.7	48.3	48.9	50.5	-
Dissolved Magnesium	6.09^+	6.68	9.43	8.55	8.8	8.17	7.41	7.39	-
Total Hardness (mg/L as CaCO3)	112	115	169	180	180	154	153	157	200
Dissolved Sodium	61	65.6	223	200	204	195	183	190	200
Dissolved Potassium	3.16^+	3.53	5.79	6.38	6.3	5.13	4.65	4.75	-
Nitrate-N	<0.002	< 0.002	<0.002	1.15	0.203	< 0.002	0.016	< 0.002	50*
Dissolved Chloride	96.7	95.1	348	353	357	327	329	327	250
Dissolved Sulphate	6.6^+	5.7	5.5	6.3	5.4	< 0.5	0.8	0.6	250
Dissolved Bromide	0.33^+	0.29	1.18	1.12	1.13	1.09	1.11	1.06	-
Dissolved Iron	0.04	0.03	0.05	0.04	0.04	0.19	0.08	0.07	-
Total Iron	0.21	0.23	0.1	0.3	0.39	0.22	0.1	0.1	0.2
Manganese	0.112	0.123	0.0651	0.0863	0.0952	0.123	0.0647	0.063	0.04
Dissolved Arsenic	<0.001	< 0.001	<0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	-

Notes: Figures in red indicate limit exceedances, * MAV (maximum acceptable value), +only a single value available.

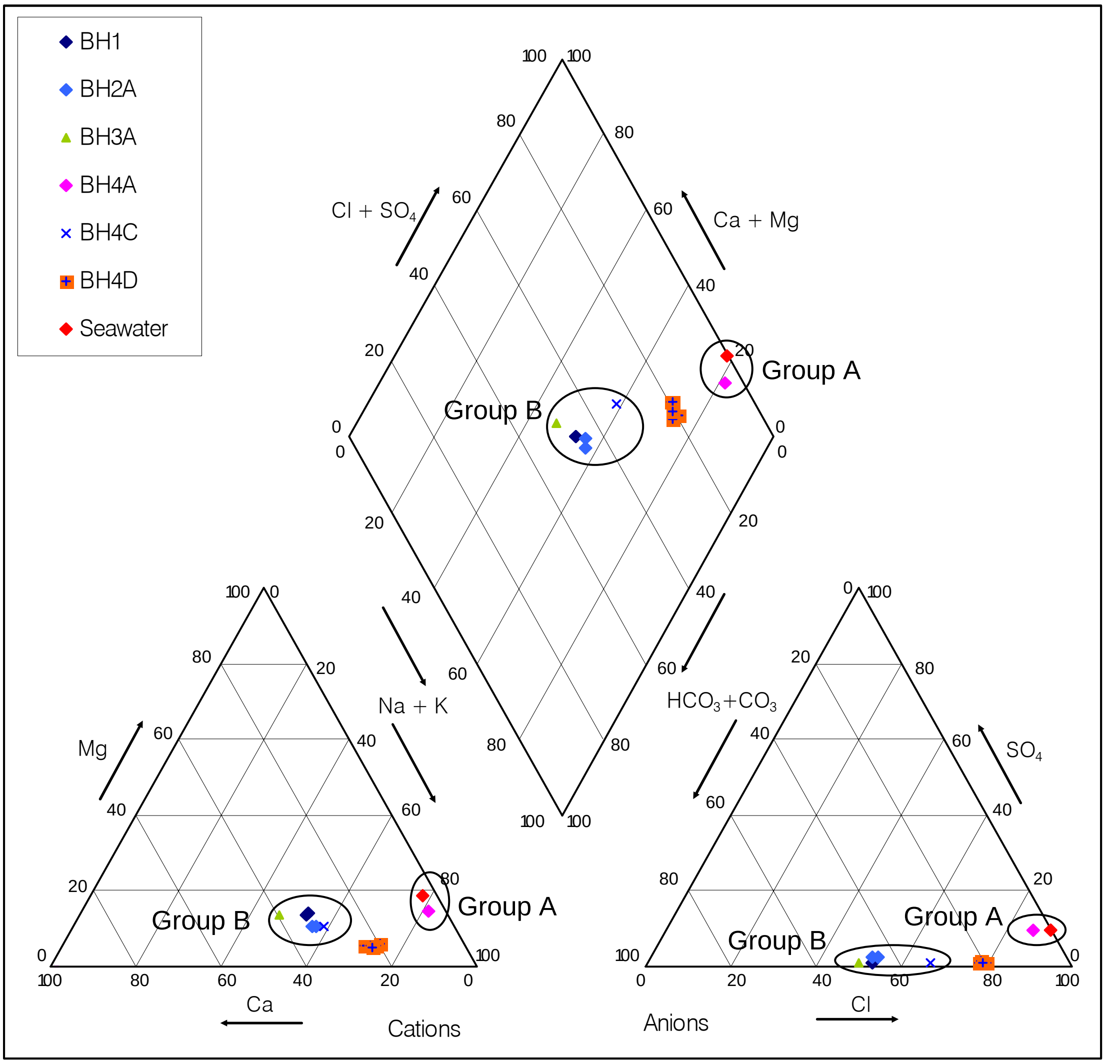


Figure 2. Groundwater Chemical Characterisation Diagram (Piper Plot).

Group A includes the BH4a and seawater samples, indicating that the shallow waters are likely to be highly influenced by mixing with marine waters. Group B comprises samples from depths of 60 to 75 mBGL (i.e. the existing supply bores and BH4c) and reflects decreasing influence of surface marine waters with depth.

The position of the BH4d samples is related to slightly elevated major ion concentrations previously discussed and is likely to reflect the presence of groundwaters entering the aquifer from underlying marine derived sedimentary rocks and/or proximity to the deep freshwater/saltwater interface and significant flushing or lateral throughflow of fresh groundwaters.

Higher ionic concentrations indicate greater mineral dissolution of common rock mineral constituents suggesting that the water is significantly older than that of Group B, previously age-dated at >100 years by the Institute of Geological and Nuclear Sciences.

The corrosive tendencies of water can be assessed using the Ryznar Stability Index, which predicts the reaction of metal objects in saturated subsurface environments based on the total dissolved solids, pH, alkalinity and calcium concentrations. Water is corrosive if the Ryznar Stability Index is greater than 7 and incrusting if the Ryznar Stability Index is less than 7. Using coefficient factors and graphs in Driscoll (1986), the Ryznar Stability Index for BH4a is 6.9, indicating near neutral conditions with neither incrusting nor corrosive tendencies. BH4c and BH4d have values of 8.0 and 7.9 respectively, indicating slightly corrosive potential.

Overall implications of water quality results are that the samples taken from BH4d have significantly reduced iron and manganese concentrations relative to existing water supply bores BH1 and BH3a. The samples from BH4d also have slightly lower iron and manganese concentrations than BH2a, but are higher in major ion concentrations (dissolved minerals and salts), particularly sodium and chloride.

The concentrations of other major ion species such as calcium and magnesium are not considered to be of concern as any potential effects are likely to be aesthetic (taste) only.

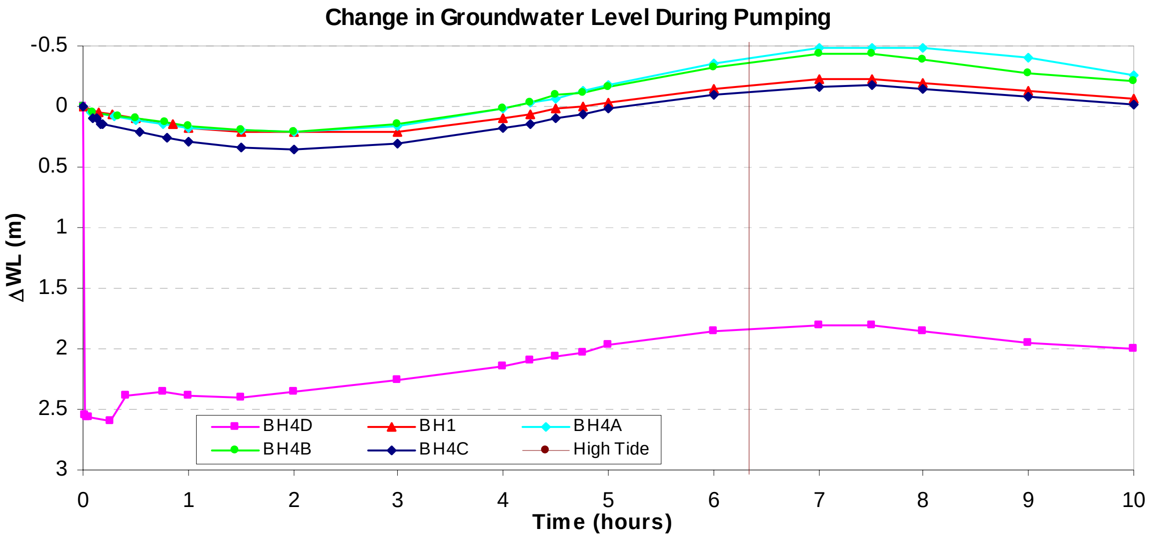
Potential sources of elevated major ion concentrations are as follows:

- The exploration bore penetrated 5 m into the underlying marine sedimentary bedrock and was backfilled with gravel rather than grout, hence minor leakage of poorer quality water from the underlying rock may be a factor. A properly targeted and constructed production bore will avoid this issue, and potentially provide even better water quality than currently obtained from BH4d.
- However, the most likely explanation for elevated ions is proximity to the deep freshwater/seawater interface which occurs in most coastal areas. This factor has important implications for water supply as aquifer depressurisation through over pumping can raise the

interface or in a worst case scenario lead to saltwater intrusion. Mitigation of this issue may be achieved through a carefully designed borefield management plan, or possibly through targeting a slightly shallower level of the deeper aquifer.

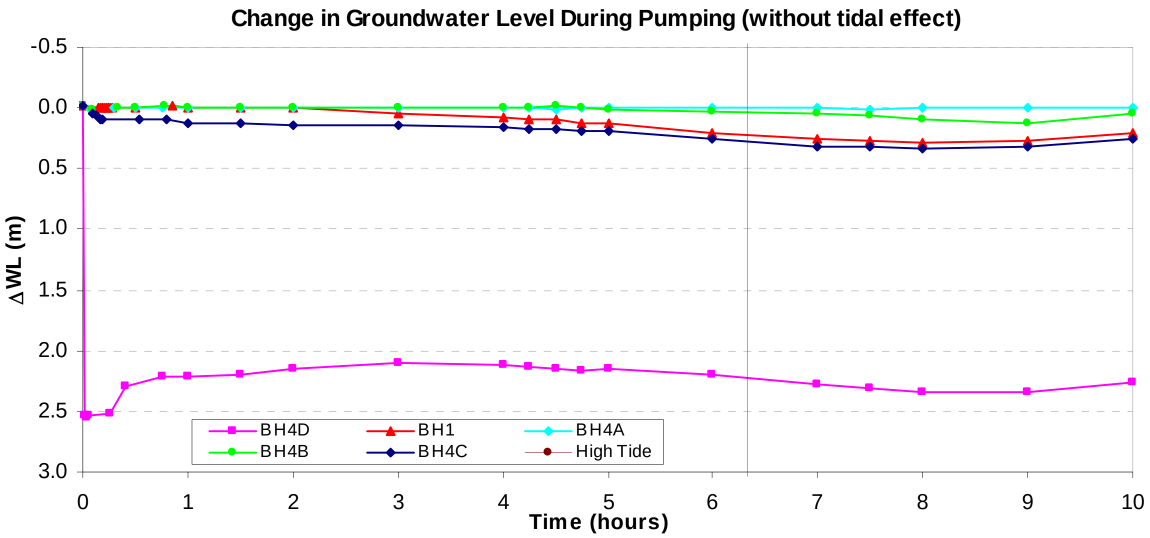
2.3 Drawdown Analysis

During the July sampling, water levels were recorded in bores BH1, BH4A, BH4B and BH4C to monitor any drawdown resulting from the pumping of BH4D. Water level changes within adjacent bores screened through different aquifer units is likely to indicate the degree of aquifer connectivity. It should be noted that that the pumping rate used for this test (0.36 L/s) is significantly less than that of the existing production bores. Raw data drawdown results from the test are presented in Figure 3.



- **Figure 3. Change in Groundwater Level During Pumping**

Analysis of Figure 3 clearly indicates the effects of tidal fluctuation as groundwater levels increase with the incoming tide. (Note: high tide data for the Kaipara Harbour is indicated on the graph). The approximately one hour delay shown between the official Kaipara Harbour high tide measured at Pouto Point and the Ruawai high which is a result of the tidal 'bore' within the Wairoa River. To delineate any pumping effects, the data must be normalised to account for the tidal influence. Figure 4 presents the pumping results without tidal effect.



- **Figure 4. Change in Groundwater Level (without tidal effect)**

Analysis of Figure 4 shows the following key features:

- A drawdown of 2 to 2.5 m was observed for pumping well BH4D
- BH4A (screened from 13.5 – 22.5 m) was not effected
- BH4C (screened from 61 – 70 m) was impacted immediately and exhibited a maximum drawdown of 0.34 m
- BH1 (screened from 57 – 61 m) was impacted after 2 hours with a drawdown of 0.29 m
- BH4B (screened from 50 – 56 m) was impacted after 5 hours with a drawdown of 0.13 m.

The drawdown observations suggest that the screened aquifers are part of a leaky aquifer system, which has important implications for any new production bore. Given that the pumping rate was much less than that which is likely for a new supply, the pumping schedule will need to be carefully designed to ensure that poorer quality water is not drawn down from shallower units and that saline intrusion is not induced from beneath.

2.4 Summary

Information gained through this investigation indicates that groundwater quality in the aquifer at 80 to 90 m (BH4d), while improved in respect to iron and manganese contains elevated sodium and chloride concentrations. This may indicate closer proximity to the underlying saltwater interface at this depth than in other shallower investigation and production bores. Therefore, any new production bore should be screened at depths between BH2 (62-68 m) and no deeper than approximately 81 m. However, it is recommended that measures be included to mitigate against potential seawater intrusion issues as detailed in Section 3.

3. Borefield Management

3.1 Water Demand

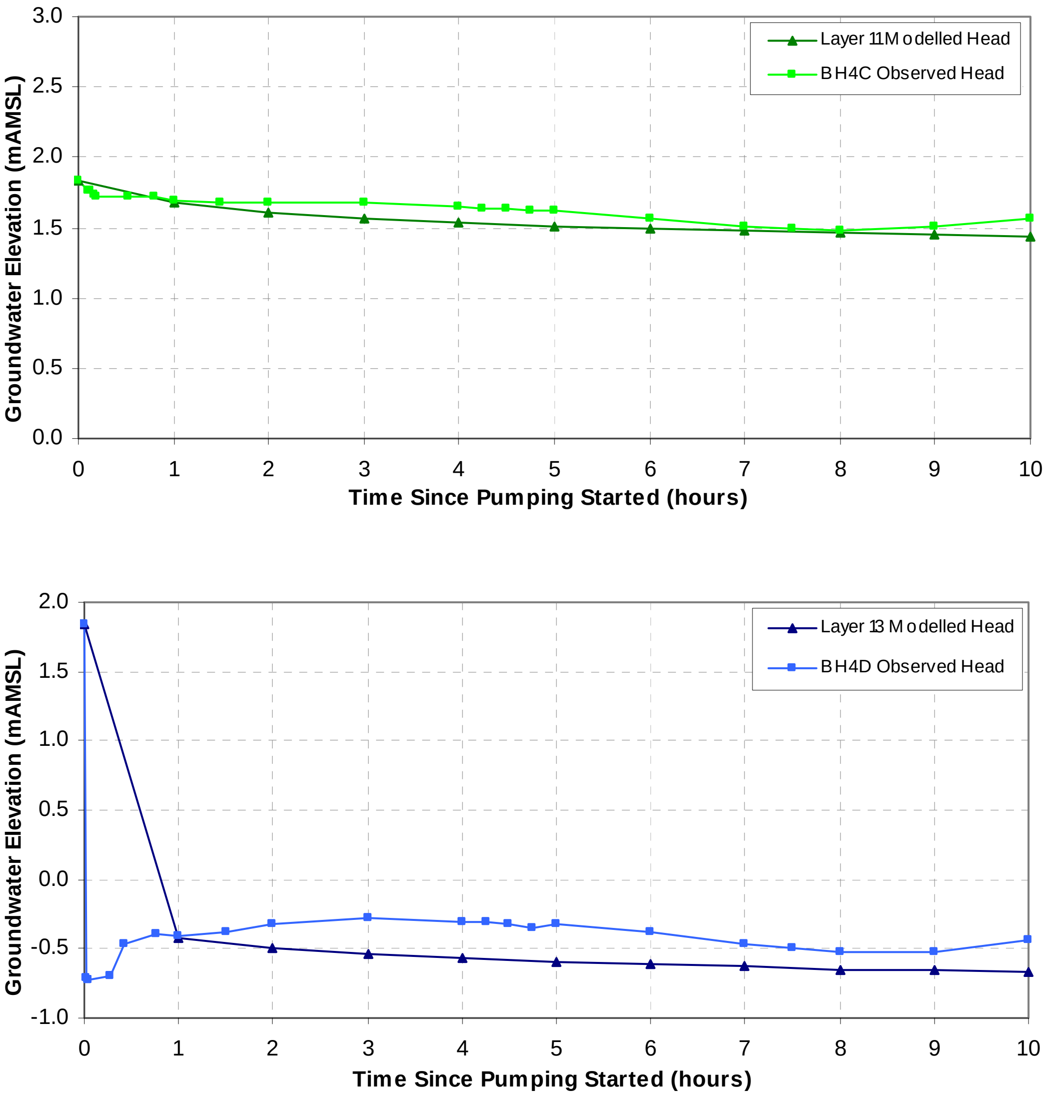
An understanding of water demand is fundamental to the development of a Borefield Management Plan.

Data supplied by Environmental Operations Limited (pers. comm. Waldron, 2006) indicated that the peak metered consumption for Ruawai is 123 m^3/day. Applying a factor of 1.23 to account for wastage and illegal usage, it is assumed that peak demand is approximately 162 m^3/day. This equates to a peak average discharge rate of 1.9 L/s.

3.2 Bore Performance Analysis

The groundwater model developed in SKM (2004) was modified and recalibrated to the test pumping data shown in Figure 4 to assess bore performance at normal operating duties and to assist with development of an appropriate aquifer management regime.

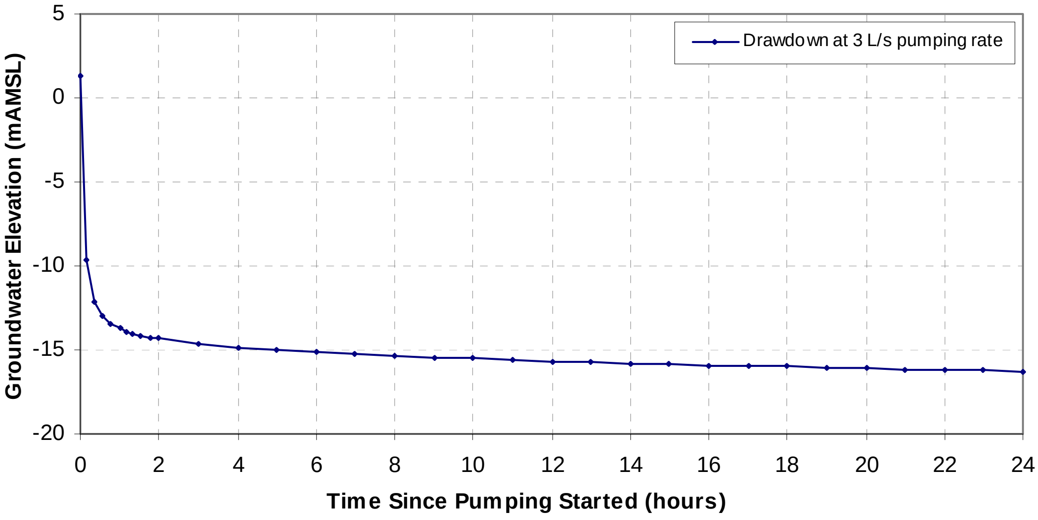
Figure 5 shows the model calibration hydrographs for the two deeper monitoring piezometers, which are located within the zone of existing and potential water supply production. The model pumping stress was 0.4 L/s (1.6 m^3/hr), equivalent to that discharged with the Grundfos MP1 pump during testing.



- **Figure 5. Calibration hydrographs for BH4C (60-70 m) and BH4D (80-90 m).**

Simulation of the calibrated model under the maximum pumping scenario for each bore of approximately 3.0 L/s (10.75 m^3/hr) enabled accurate prediction of maximum drawdown and timing of drawdown.

From steady state simulation the maximum drawdown at this rate is likely to be approximately 20.1 m. Given the static groundwater level at 1 to 2 mAMSL, clearly this level of pumping at one single bore location is not sustainable continuously and would induce saline intrusion. However, from Figure 6 it can be seen that drawdown becomes relatively stable within 2 to 3 hours from the outset of pumping at -14 mAMSL (~ 16 m drawdown), reducing only steadily after that point. This indicates that the aquifer is relatively permeable and hence it follows that recovery would be just as quick.

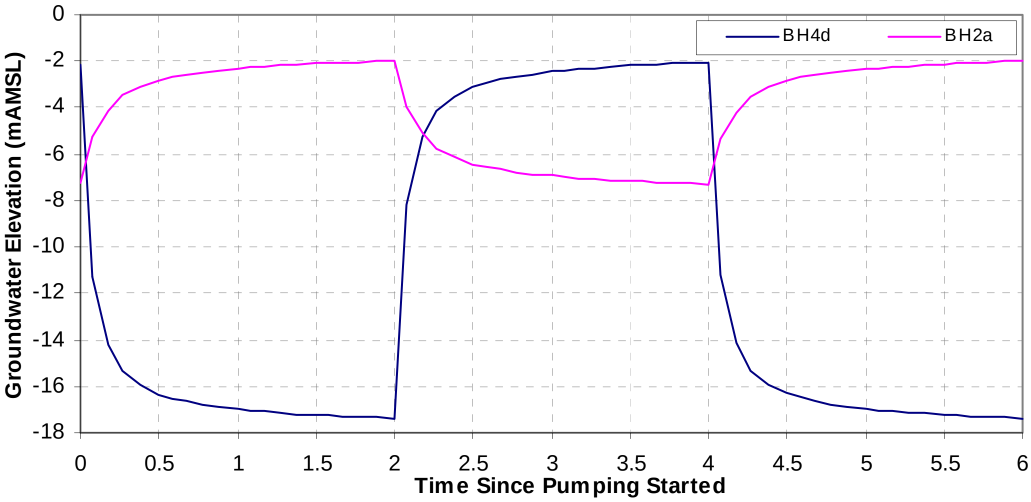


- **Figure 6. Simulated drawdown response with 3 L/s yield.**

In this regard, a 2 hour on, 2 hour off cycle (minimum off time to be sure) would provide a full recovery in the pumping bore.

Figure 7 shows the simulated drawdown and recovery cycle based on the above pumping regime at 3 L/s (with pumping alternating between bores) and demonstrates clearly the above hypothesis – that full recover of the aquifer occurs. Given the average peak discharge requirement if pumping occurs over a 24 hour period is only 1.9 L/s, this shows that the proposed aquifer management regime is sustainable.

Note: The varying degree of drawdown between the two bores is due to the difference in hydraulic properties at the screen interval of each bore and in a vertical sense between the bores.



- **Figure 7. Simulated drawdown and recovery response with two bores pumping at 3 L/s.**

4. Water Treatment Requirements

In accordance with SKM's proposal of 6 October 2005, this section reports on the treatment requirements for the proposed raw water sources for the Ruawai water supply, assuming that existing bore BH2a be used in conjunction with a new production bore to be drilled adjacent to BH4d to a depth of 82 m, with a screen located between 75 to 81 m, and that bore BH3a be retained only as an emergency backup.

4.1 Raw Water Quality

Groundwater quality results for parameters of particular importance for potable consumption from bore BH2a and the exploratory piezometer BH4d are presented in Table 4. The parameters for BH2a are long term average values and those for BH4a are values measured at the end of pumping in July 2005. The guideline value (GV) and maximum acceptable value (MAV) from the DWSNZ 2005 are also summarised in Table 4. Values shown in red exceed the DWSNZ 2005 GV. No parameters exceed the MAV.

Other comments of note are as follows:

- Clause 4.1 of the report of Duffill Watts and King Limited dated May 2003 states that the turbidity of raw water from BH2 is 5.8 NTU. Turbidity was not measured at bore BH4d.
- Clause 4.1 also notes that no *E. coli* was detected in any of the existing bores.
- Bromide is also present in the raw water (0.33 mg/L in BH2a, 1.06 mg/L in BH4d). Though bromide is not listed in the DWSNZ 2005 as having health significance by itself, it can react with disinfectants to form trihalomethanes (THMs), a disinfection byproduct. MAVs are provided in the DWSNZ 2005 for these THMs.

- **Table 4. Raw water quality parameters.**

Parameter	Bores		DWSNZ 2005	
	BH2a	BH4d	MAV	GV
Total dissolved solids (mg/L)	325	848	-	1,000
Turbidity (NTU)	5.8	-	-	$2.5^{\#}$
pH	7.2	8.1	-	7.0 – 8.5
Hardness (as $CaCO_3$) (mg/L)	112	157	-	200
Sodium (mg/L)	61	190	-	200
Nitrate (mg/L)	<0.01*	<0.01*	50	-
Chloride (mg/L)	96.7	**327**	-	250
Sulphate (mg/L)	6.6^{+}	0.6	-	250
Iron (total) (mg/L)	**0.21**	0.1^{++}	-	0.2
Manganese (mg/L)	**0.112**	**0.063**	0.4	0.04
Arsenic (mg/L)	<0.001	<0.001	0.01	-
E.coli (cfu/100 mL)	0	0	<1	-
Bromide (mg/L)	0.33	1.06	-	-

Notes: $^{\#}$ for appearance only, * Nitrate-N <0.002 mg/L, + only a single value available, ++ higher value at start of pumping test (0.22 mg/L).

4.2 Treatment Standard

The treated water delivered into supply is required to comply with the Drinking Water Standards of New Zealand (DWSNZ) 2005. The DWSNZ provides two levels of treatment requirements for groundwater depending on whether the groundwater is considered secure from surficial influences or non-secure. Groundwater is considered secure when it can be demonstrated that contamination by pathogenic organisms is unlikely because the groundwater is not directly affected by surface or climatic influences and it is abstracted from a borehead that provides satisfactory sanitary protection.

Test pumping work on BH4d indicates that the aquifer at this depth is secure (i.e., 90 m). Bores BH2a and BH3a, while slightly shallower is also likely to be secure because:

- the water quality results in these bores indicate significant differences from that of the shallow exploratory piezometer BH4a that is known to have surficial influences;
- the groundwater chemistry results are stable relative to that expected for groundwater with surficial influences; and
- groundwater age is approximately 160 years, with the young fraction of water (water with age less than one year) less than 0.005%, which satisfies NZDWS criteria for secure groundwater (SKM, 2004).

4.3 Treatment Requirements

In order to comply with the DWSNZ, the treated water must not exceed the MAVs for microbial and chemical determinants of public health significance. In addition, compliance criteria must be met and procedures followed to verify this. The DWSNZ 2005 also list GVs for aesthetic determinants to avoid complaints from the water users. Aesthetic determinants affect appearance, taste and odour and, while not obligatory, it is preferable that GVs are not exceeded.

The Ministry of Health provides a grading for each community drinking-water supply in order "to provide a public statement of the extent to which a community drinking-water supply achieves and can ensure a consistently safe and wholesome product" (Public Health Grading of Community Drinking-Water Supplies 2003, Ministry of Health).

For a community the size of Ruawai, the minimum grading that should be achieved for the source and treatment is C. It is understood that the Kaipara District Council wishes to achieve a B grading or better for the Ruawai supply. It is SKM's recommendation that a B grading be obtained with any treatment plant upgrade for this rural community.

The Ministry of Health's Drinking Water for New Zealand website indicates that the source and existing treatment plant is currently not graded.

The definitions for A, B and C gradings are as follows:

- ***Grade A*** Completely satisfactory, extremely low level of risk.
- ***Grade B*** Satisfactory, very low level of risk when the water leaves the treatment plant.
- ***Grade C*** Marginally satisfactory, low level of microbiological risk when the water leaves the treatment plant, but may not be satisfactory chemically.

A higher grading of A1 is available but requires that all criteria for aesthetic determinants are met and that the supply meets the requirements of ISO 9001:2000 series or equivalent.

The treatment requirements for A, B and C gradings, and secure and non-secure groundwater sources are summarised in Table 5.

Table 5. Treatment requirements for A, B and C gradings

Criteria	A Grading		B Grading		C Grading	
	Secure source	Non-secure source	Secure source	Non-secure source	Secure source	Non-secure source
Priority 2 monitoring compliance	Y	Y	Y	Y	Y	Y
Adequate record keeping	Y	Y	Y	Y	Y	Y
E. coli compliance	Y	Y	Y	Y	Y	Y
Protozoan compliance	N/A	Y	N/A	Y	N/A	Y
Appropriate supervision	Y	Y	Y	Y		
Compliance with chemical MAVs	Y	Y	Y	Y		
Continuous quality control		Y				
Disinfection with residual	Y	Y				
Turbidity compliance	Y*	Y		Y		Y
pH compliance	Y*	Y		Y		Y

Sources: DWSNZ 2005, Public Health Grading of Community Drinking Water Supplies 2003, Ministry of Health

Notes: Priority 2 determinants are those of public health significance that are present at concentrations that exceed 50% of the MAV

Y	Meets criterion
N/A	Not applicable
Blank	May or may not meet criterion
*	Turbidity and pH measurement required for disinfection residual requirements

The additional requirement for an A grading over a B grading is the requirement to provide disinfection giving a residual in the distribution zone whether the source is secure groundwater or not. For a non-secure source, protozoan compliance is necessary for all three gradings and for an A grading continuous quality control must also be provided. Turbidity and pH requirements must also be met for bacterial and protozoan compliance for a non-secure groundwater source.

The DWSNZ defines protozoan compliance by the ability of the treatment process to remove or inactivate *Cryptosporidium*, the most difficult protozoan to deal with. If the treatment process can remove or inactivate *Cryptosporidium*, then it will also remove or inactivate other protozoa. If less than 0.01 *Cryptosporidium* oocysts/10 L are present in the raw water, a treatment process providing a log credit of 2 will be required. A log 2 credit represents 99% removal of *Cryptosporidium*. For greater numbers of oocysts, treatment processes providing additional log credits would be necessary. In order to obtain an A grading for a non-secure groundwater source, the Ministry of Health requires that the treatment process must be more than direct filtration. This is to ensure that no protozoa/bacteria are present in the treated water.

For a non-secure source, turbidity must be measured and comply with the requirements of the DWSNZ 2005. Though these standards provide a GV for turbidity of 2.5 NTU, this relates to appearance only. The standards state, however, that the turbidity shall not exceed 1.0 NTU for more than 5% of the compliance monitoring period and shall not exceed 2.0 NTU for the duration of any 3-minute period. The DWSNZ exclude the requirement to measure turbidity for a secure groundwater source. However, to achieve effective terminal disinfection for an A grading, the median turbidity must be less than 1 NTU with no single sample greater than 5 NTU (Public Health Grading of Community Drinking-Water Supplies 2003, Ministry of Health).

Appropriate supervision is a requirement to achieve an A or B grading. The Ministry of Health publication, *Public Health Grading of Community Drinking-Water Supplies 2003*, defines the qualification for a treatment plant serving an aggregate population of 500-5,000 for management or supervision as the “National Certificate in Water Treatment (Site Operator) plus additional unit standards from the National Diploma in Drinking-water strand Water Treatment (Site Technician) as specified by the Water ITO”. This is equivalent to the old Water Treatment C Grade Certificate.

The aesthetic determinants that are present in the raw water for which treatment preferably should be provided are summarised in Table 6.

- **Table 6. Aesthetic determinants for which treatment is recommended**

A Grading		B Grading		C Grading	
Secure source	Non-secure source	Secure source	Non-secure source	Secure source	Non-secure source
Iron	Iron	Iron	Iron	Iron	Iron
Manganese	Manganese	Manganese	Manganese	Manganese	Manganese
Chloride*	Chloride*	Chloride*	Chloride*	Chloride*	Chloride*

Note: * Treatment required if use new production bore only. Can reduce concentration by mixing with water from BH2a.

The effects of these determinants are as follows:

Iron	Staining of laundry and sanitary ware
Manganese	Staining of laundry and taste (MAV 0.4 mg/L)
Chloride	Taste and corrosion.

The chloride level measured in exploratory bore BH4d screen between 80 to 90 m exceeds the DWSNZ GV value of 250 mg/L. Any new bore (with suggested depth of 75 to 81 m) used in conjunction with bore BH2a under a carefully designed borefield management plan would be to mitigate potential saltwater intrusion and reduce chloride concentrations.

The iron level in bore BH2a is 0.21 mg/L, marginally greater than the GV of 0.2 mg/L. The iron level in bore BH4d is only 0.1 mg/L. By mixing the raw waters from bores BH2a and the new production bore, the level of iron can be reduced to acceptable levels.

4.4 Treatment Options

SKM have approached several suppliers of water treatment systems to obtain treatment options and budget prices for the Ruawai water supply. Four suppliers have responded including Filtec, Contamination Control, Water Systems Treatment Specialists and Veolia Water Systems.

Recognising the elevated levels of chloride and sodium in BH4d (see Table 4), suppliers were advised that the water from the proposed production bore would be mixed with water from BH2a in accordance with a borefield management plan. Therefore, the suppliers have not been specifically invited to provide treatment for moderate salinity. It has also been assumed that the water received at the treatment plant is from a secure source. This would be the case if it can be shown that water from both production bores is secure.

The treatment options given below generally provide for water that would meet either an A or B grading. The major differences for an A grade non-secure source over a B grade non-secure source are the requirements to have a disinfection residual and have continuous quality control.

The treatment options offered by the suppliers are as follows:

4.4.1 Filtration Technology (Filtec)

Filtec offered two treatment processes in 2003 that were reported in the Duffill Watts and King Limited report, *Kaipara District Council Ruawai Water Treatment Plant Upgrade*, of May 2003. Filtec is again offering the same processes.

Their primary offer is for aeration and chlorination prior to retention time in a contact tank. The water then would pass through a *Kinetico* ceramic media filter (*Macrolite*® 70/80 mesh). An alternative to this offer is to replace the Kinetico media with sand.

The secondary offer utilises the existing softener vessel as a contact tank for chlorine. No aeration is provided. The water would again pass through a *Kinetico* or sand media filter. pH adjustment would be required for removal of manganese. The option does not provide for any flexibility or expandability and is therefore not recommended.

For a non-secure source, UV treatment has been offered for protozoan compliance.

4.4.2 Contamination Control

Contamination Control also proposed a process for the Ruawai supply in 2003. They again offer the process offered then, that being a *Kinetico Macrolite*® filter with pre-treatment with MIOX. The MIOX cell generates a mixed-oxidant solution which is mainly hypochlorous acid. This is a stronger oxidant than chlorine alone. The oxidant is generated from brine. The process oxidises the raw water to assist in removal of manganese and iron and it provides chlorine residual, a requirement for A grading.

For a non-secure source, UV treatment has been offered for protozoan compliance.

Contamination Control note that oxidation with air did not appear to be effective in trials they undertook in 2003.

4.4.3 Water Systems Treatment Specialists

This supplier has presented two proposals from their supplier, Culligan International Italy. Each offer includes supply of 2 steel filter tanks complete with filter media, microprocessor based controller, pipework and valves. During backwash, one tank is backwashed at a time.

The first option is for a Culligan *FILTR-CLEER HI-FLO 9 UFP 48* multimedia filter. This is a triple-media filter of anthracite based mineral, catalytic mineral and silica sand. The filter is designed for turbidity reduction and iron and manganese removal. Continuous pre-filter chlorine dosing is required to reactivate the catalytic mineral. The chlorine dose can be adjusted to provide a disinfection residual in the reticulation.

The second option is for a Culligan *FILTR-CLEER HI-FLO 9 UR 48* carbon filter. This is a double-media filter using activated carbon and silica sand. The filter is designed for turbidity reduction with taste, odour colour and organics removal.

4.4.4 Veolia Water Systems

Veolia Water Systems have offered a microfiltration plant based on Memcor *Axia 32S10V*. The plant is very expensive compared to alternatives offered by other suppliers and is therefore not recommended.

4.4.5 Biological Filtration

An option that has not been offered by the treatment suppliers but that may be suitable for this installation is biological filtration. It has been adopted by the Waimakariri District Council for its Woodend Treatment Plant and is successfully reducing manganese and iron levels. This process uses no chemicals for the removal of manganese and iron but relies on the establishment of a biomass on the filter media.

Review of the raw water parameters indicates that the supply may be suitable for this process. The effectiveness of the process is also dependent on the redox potential of the raw water.

We note that the existing treatment process includes a sand filter. It may be possible to convert this for use as a biological filter.

Pilot trials would be necessary to establish whether such a treatment system would be appropriate for this supply

4.5 Budget Estimates

The estimates obtained from the four suppliers are indicative budget estimates only and are accurate to ±50%. More detailed analysis of existing treatment performance and pilot testing would be required to provide estimates of higher accuracy.

The budget estimate from Veolia Water Systems is a rough order of cost at $750,000. It is not considered further. More detailed budget estimates have been provided by Filtec, Contamination Control and Water Systems.

Operating costs have not been included in the estimates. Estimates for plant modifications have been taken from the Duffill Watts and King Ltd report of May 2003.

The estimates are summarised as follows.

4.5.1 Filtec

Item	A Grading	B Grading	C Grading
Plant and equipment	$50,000	$50,000	$50,000
Installation	$15,000	$15,000	$15,000
Modifications to existing plant and building	$30,000	$30,000	$30,000
Continuous quality control			
Protozoan compliance	N/A	N/A	N/A
Turbidity compliance	N/A	N/A	N/A
Disinfection with residual	$6,000	N/A	N/A
pH compliance	$12,000	N/A	N/A
	$7,000	N/A	N/A
Subtotal	$120,000	$95,000	$95,000
Engineering (20%)	$24,000	$19,000	$19,000
Contingency (20%)	$24,000	$19,000	$19,000
Total (rounded)	**$170,000**	**$135,000**	**$135,000**

Notes: N/A Not applicable

4.5.2 Contamination Control

Item	A Grading	B Grading	C Grading
Plant and equipment	$42,000	$42,000	$42,000
Installation	$15,000	$15,000	$15,000
Modifications to existing plant and building	$30,000	$30,000	$30,000
Continuous quality control			
Protozoan compliance	N/A	N/A	N/A
Turbidity compliance	N/A	N/A	N/A
Disinfection with residual	included	included	included
pH compliance	$8,000	N/A	N/A
	included	N/A	N/A
Subtotal	$95,000	$87,000	$87,000
Engineering (20%)	$19,000	$17,400	$17,400
Contingency (20%)	$19,000	$17,400	$17,400
Total (rounded)	**$135,000**	**$125,000**	**$125,000**

Notes: N/A Not applicable

4.5.3 Water Systems Treatment Specialists

Item	A Grading	B Grading	C Grading
Plant and equipment	$45,500	$45,500	$45,000
Installation	$15,000	$15,000	$15,000
Modifications to existing plant and building	$30,000	$30,000	$30,000
Continuous quality control			
Protozoan compliance	N/A	N/A	N/A
Turbidity compliance	N/A	N/A	N/A
Disinfection with residual	included	included	included
pH compliance	included	N/A	N/A
	included	N/A	N/A
Subtotal	$90,500	$90,500	$90,500
Engineering (20%)	$18,100	$18,100	$18,100
Contingency (20%)	$18,100	$18,100	$18,100
Total (rounded)	**$130,000**	**$130,000**	**$130,000**

Notes: N/A Not applicable; priced on multi-media option.

Comment

The above estimates indicate that there are no cost differences between B and C gradings. However, to achieve a B grading over a C grading, chemical MAV compliance and appropriate supervision are required. Chemical MAV compliance is included in all treatment options proposed. Supervision costs need to be added to the estimates for A and B grading.

The Ministry of Health publication, *Public Health Grading of Community Drinking-Water Supplies 2003*, defines the qualification for a treatment plant serving an aggregate population of 500-5,000 for management or supervision as the “National Certificate in Water Treatment (Site Operator) plus additional unit standards from the National Diploma in Drinking-water strand Water Treatment (Site Technician) as specified by the Water ITO”. This is equivalent to the old Water Treatment C Grade Certificate.

The offer from Filtec would require use of sodium hypochlorite as an oxidising agent. Chlorine would also need to be used for disinfection residual.

The offer from Contamination Control requires the use of salt for preparation of a brine solution.

The offers from Water Systems require chlorine for disinfection residual and for reactivation of the multi-media filter option.

4.5.4 Biological Filtration

It is estimated that the capital cost for biological filtration would generally be of the same order of cost as those from Filtec, Contamination Control and Water Systems. However, there is no chemical required for treatment for iron and manganese. Chlorine would be required for disinfection residual and UV for protozoan compliance if the source was found to be non-secure.

4.6 Summary of Estimates

In summary, the estimates for a secure source of supply are as follows:

A Grading	B Grading	C Grading
$130,000 - $170,000 (plus supervision)	$125,000 - $135,000 (plus supervision)	$125,000 - $135,000

4.7 Summary and Recommendations

The current water supply bores are not currently certified as secure groundwater sources, although water quality data indicates that BH2a and BH3 are likely to be secure (note: BH1 is definitely not secure). Work will be required to demonstrate this at a later date for water treatment grading purposes.

The proposed production bore will be used in conjunction with bore BH2a to provide water for the supply to Ruawai with bore BH3a used as a back-up. Mixing of the water from the proposed production bore with that from BH2a will reduce iron and manganese concentrations and manage chloride and sodium concentrations.

Treatment requirements differ for achievement of A, B or C gradings for the source and treatment facilities of the water supply system. They also are dependent on whether the groundwater source is certified as secure or not.

The minimum treatment required will be to reduce the manganese concentration in the treated water so that it does not exceed the GV defined in the DWSNZ. In addition, treatment for turbidity reduction will be required if an A grading for the supply is preferred.

SKM recommends that Kaipara District Council:

- adopt a strategy to achieve B grading at Ruawai; and
- commission the lowest risk, most well know technology, and the supplier company with the best track record and reputation in the marketplace. It would appear that Contamination Control and Water Systems are the two companies that propose the most favourable solutions, with similar costs at $125,000 and $130,000, respectively.

5. Conclusions

The quality of drinking water produced by the present Ruawai town supply bores is currently satisfactory in two bores (BH2a and BH3a) and very poor in one bore (BH1). The objective of this study was to explore the presence of a deeper aquifer beneath the existing supply bores and determine whether the water quality is improved relative to the existing boreholes. This objective was achieved through the drilling of exploratory bore BH4, followed by water quality analysis and hydraulic testing of installed piezometers (BH4a, BH4b, BH4c and BH4d), and additional sampling of existing supply bore BH2a.

Results of the investigation have confirmed the presence of a deeper aquifer and repeat sampling of piezometer BH4d screened within the deeper aquifer confirms an improved groundwater quality compared to the existing bores. There are some remaining minor concerns regarding manganese and sodium and chloride concentrations, which exceed aesthetic guideline values for taste only. These values are not a human health concern and are significantly improved with respect to manganese, or only slightly poorer with respect to sodium and chloride, than the current supply water quality.

Given the information available, it is considered that construction of a new production bore at a depth of 75-81 m will provide sufficiently improved water quality compared to existing bores BH1 and BH3A. However, the pumping regime will need to be carefully managed to mitigate any potential saltwater interface issues due to depressurisation (over-pumping).

Groundwater is currently extracted from alternating combinations of the three existing town supply bores at an average daily rate of 1.9 L/s, and with peak rates of up to 3 L/s for individual bores. It is estimated that with the proposed bore specifications, the drawdown from a new production bore pumping at maximum rates of 3 L/s would be approximately 20 m. This level of drawdown if maintained indefinitely has the potential to induce saline intrusion at that particular location. To mitigate against this, it is recommended that the new bore is never pumped at these rates for extended periods and that pumping should be alternated with one of the existing supply bores (BH2A) to allow adequate recovery. A third bore could serve as a back-up or emergency supply (BH3A) and the remaining installation may then be decommissioned and grout-sealed to prevent leakage.

An analysis was undertaken of the key water quality parameters with respect to treatment requirements and companies were invited to provide appropriate treatment systems and cost estimates to upgrade the treatment plant. Four suppliers responded with cost estimates to achieve C to A grading. SKM recommend that B grading be sought at Ruawai.

Two suppliers have been short listed (Contamination Control Ltd and Water Systems Ltd) based on the appropriateness of their technology and costs. Following construction of a new bore and water quality testing, it is recommended that Council invites these companies to prepare detailed cost estimates and a list of company attributes such as track record, level of service, and warranties, so that the preferred company can be selected and finalised.

6. Recommendations

6.1 New Production Bore

Based on the results of this study, SKM recommends that a production bore be constructed adjacent to BH4 to the specifications outlined in Table 7.

- **Table 7. Production Bore Specifications.**

Item	Specification
Bore depth	82 m
Drillhole diameter	200 mm
Casing diameter	150 mm
Casing depth	0 to 74 m
Casing material	Primed steel (screwed and socketed)
Header pipe depth	74 to 75 m (1 m)
Screen diameter	120 mm
Screen depth	75 to 81 m (with 1 m allowance for header and sump pipes each end).
Screen length	6 m
Screen slot size	0.3 mm (based on 60% passing of sediment)
Screen material	TS stainless steel
Sump pipe depth	81 to 82 m (1 m)
Construction details	Full cement grout outside annulus of casing to protect against corrosion and increase bore longevity from surface to 81 m. 1 m sump pipe, 1 m header pipe, neoprene packer and 120 mm screen recovery coupling.
Development	High pressure air induction or submersible pumping until fines cleared (coarser aquifer material becomes packed against outside annulus of the screen)
Pump depth	Set pump base at around 30 m, but confirm following development
Pump types	To confirm following bore development and prelim testing.

Note: For naturally developed wells, it is common practice to select a screen slot width that retains about 40% of the sediment (60% is passed) in the formation adjacent to the screen.

Costs have been obtained from two reputable drilling companies for the construction of the above bore specifications, as summarised below:

Drillwell Exploration Limited	$36,600 excluding GST
Barham United Welldrillers Limited	$38,000 excluding GST

Both these quotes allow for 8 hours bore development and any additional time over and above this to accomplish satisfactory result would be charged at an hourly rate of approximately $250/hr.

In addition to the drilling and development, production bore test pumping is required. This would involve step testing the bore on the first day followed by constant rate discharge testing on the following 2 days. Barham United provide an all inclusive cost estimate for both the drilling and test pumping of $44,000 to $48,000 excluding GST.

Consultants fees for analysis of the test pumping data, obtaining resource consent for the new production bore, production of borefield management plan and completion report would be approximately $15,000 excluding GST. It is also suggested that a Senior Hydrogeologist attends site during screen placement to verify that the engineer designed depth settings and screen slot size have been adhered too. Costs for this are approximately $2,000 excluding GST.

Therefore, total costs for the procurement of a production bore are estimated at $52,000 to $57,000 excluding GST[2].

6.2 Borefield Management Plan

To mitigate any pumping induced saltwater interface issues, a preliminary borefield management plan has been developed. The plan recommends:

- alternate pumping of bores to minimise drawdown and thus saline intrusion potential at any particular location;
- pump continuously at any one bore for no longer than 2-3 hours, to minimise drawdown at any location and mix the raw water quality to maintain parameters within the GVs;
- bore recovery for at least 2-3 hourly between duty cycles;
- bore pump rates not to exceed 3 L/s;
- monitoring of saline water quality indicator parameters (electrical conductivity, total dissolved solids) and general field parameters (temperature and pH) on a monthly basis, in all bores;
- monitoring of groundwater levels in all bores on a monthly basis when not pumping (static groundwater levels).
- continuous metering of groundwater quantity pumped from each bore.

6.3 Treatment Plant Upgrade

SKM recommends that the water treatment plant be upgraded to B grade and that two companies, Contamination Control and Water Systems, be asked to provide detailed cost breakdowns and track

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[2] Excluding cost of new pump and reticulation, which will be confirmed following performance testing.

record to enable further evaluation of their service and system performance. Both systems, while different, had similar cost estimates of approximately $125,000 and $130,000, respectively.

7. References

Driscoll, F.G., 1986. Groundwater and Wells. Second Edition. Johnson Filtration Systems Inc., Minnesota, USA.

DWK, 2003. Ruawai Water Treatment Plant Upgrade. Report prepared for Kaipara District Council (File No.: 287/3/1).

Freeze, R.A., and Cherry, J., 1979. Groundwater. Prentice Hall.

SKM, 2003. Ruawai Aquifer Management Zone Bore Survey & Preliminary Hydrogeological Study. Report prepared for Northland Regional Council.

SKM, 2004. Ruawai Town Water Supply Bores - Hydrogeology and Bore Security Assessment. Report prepared for Environmental Operations Limited on behalf of Kaipara District Council.

Appendix A Geological Borelogs

Sinclair Knight Merz
25 Teed Street, Newmarket
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Borehole Logging Record

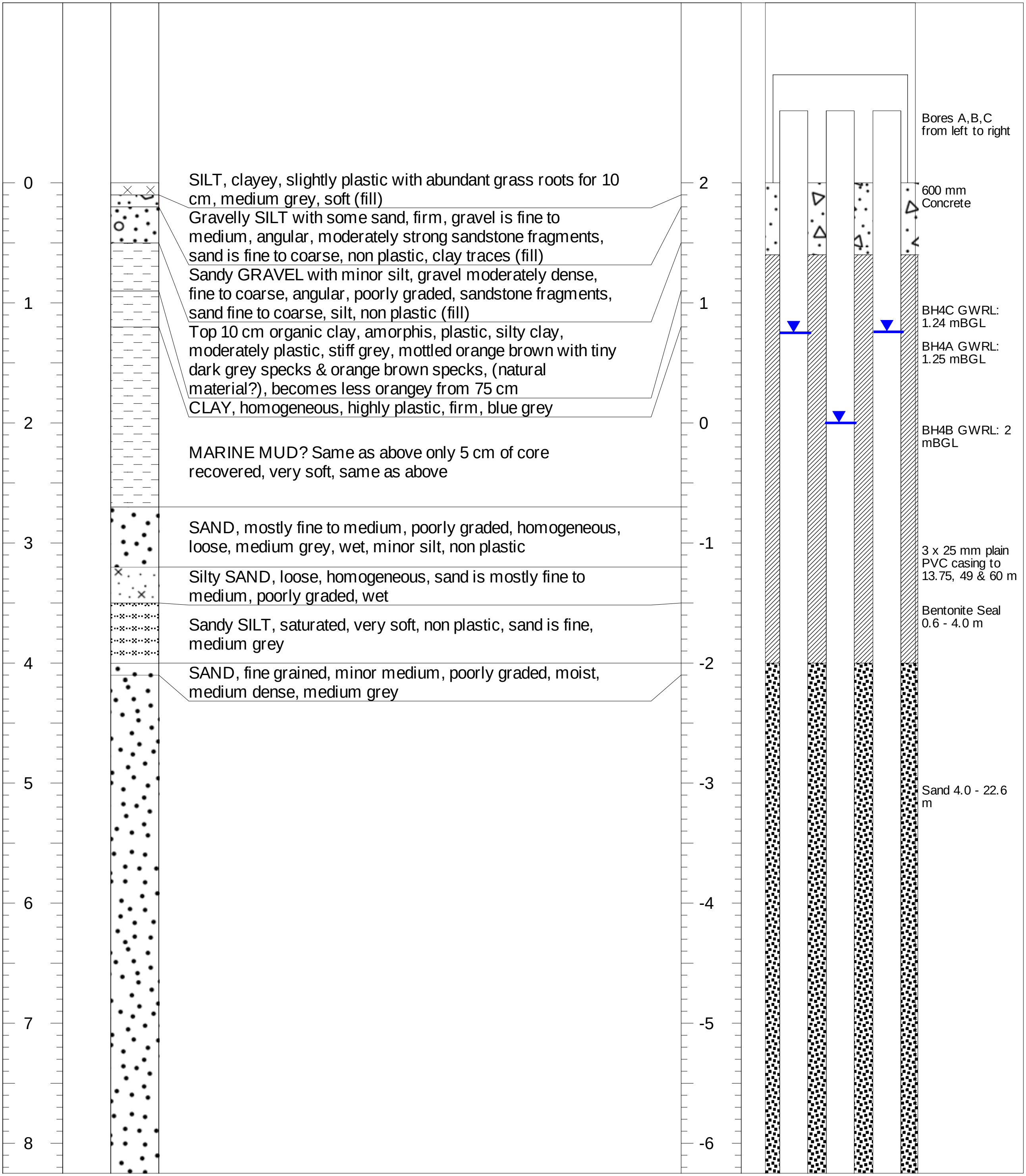
Bore: Borehole 4 (A-C)

Project Name: Ruawai Exploration Bore
Location: Ruawai
Project Number: AE02170.02
Geologist: T. Adhikary

DRILLING DETAILS

Drilling Company: Drillwell Exploration
Drilling Method: Wash drilling
Drilling Date: 14-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 70 (mBGL)
Bore Diameter: 120 mm
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels



SILT, clayey, slightly plastic with abundant grass roots for 10 cm, medium grey, soft (fill)

Gravelly SILT with some sand, firm, gravel is fine to medium, angular, moderately strong sandstone fragments, sand is fine to coarse, non plastic, clay traces (fill)

Sandy GRAVEL with minor silt, gravel moderately dense, fine to coarse, angular, poorly graded, sandstone fragments, sand fine to coarse, silt, non plastic (fill)

Top 10 cm organic clay, amorphis, plastic, silty clay, moderately plastic, stiff grey, mottled orange brown with tiny dark grey specks & orange brown specks, (natural material?), becomes less orangey from 75 cm

CLAY, homogeneous, highly plastic, firm, blue grey

MARINE MUD? Same as above only 5 cm of core recovered, very soft, same as above

SAND, mostly fine to medium, poorly graded, homogeneous, loose, medium grey, wet, minor silt, non plastic

Silty SAND, loose, homogeneous, sand is mostly fine to medium, poorly graded, wet

Sandy SILT, saturated, very soft, non plastic, sand is fine, medium grey

SAND, fine grained, minor medium, poorly graded, moist, medium dense, medium grey

Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
200	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	

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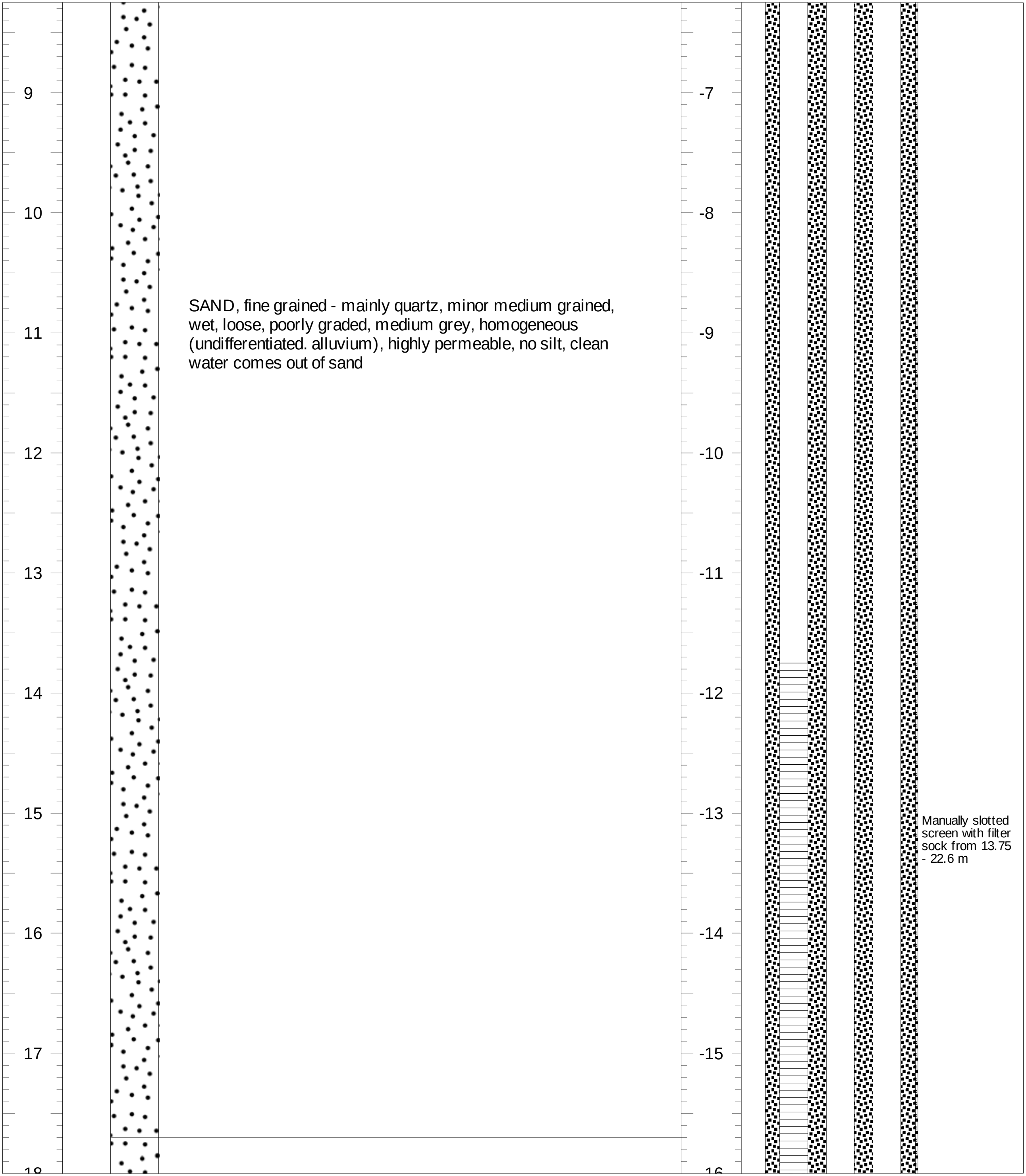
Borehole Logging Record

Bore: Borehole 4 (A-C)

Project Name: Ruawai Exploration Bore
Location: Ruawai
Project Number: AE02170.02
Geologist: T. Adhikary

DRILLING DETAILS
Drilling Company: Drillwell Exploration
Drilling Method: Wash drilling
Drilling Date: 14-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 70 (mBGL)
Bore Diameter: 120 mm
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels



SAND, fine grained - mainly quartz, minor medium grained, wet, loose, poorly graded, medium grey, homogeneous (undifferentiated. alluvium), highly permeable, no silt, clean water comes out of sand

Manually slotted screen with filter sock from 13.75 - 22.6 m

Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
200	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	

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Borehole Logging Record

Bore: Borehole 4 (A-C)

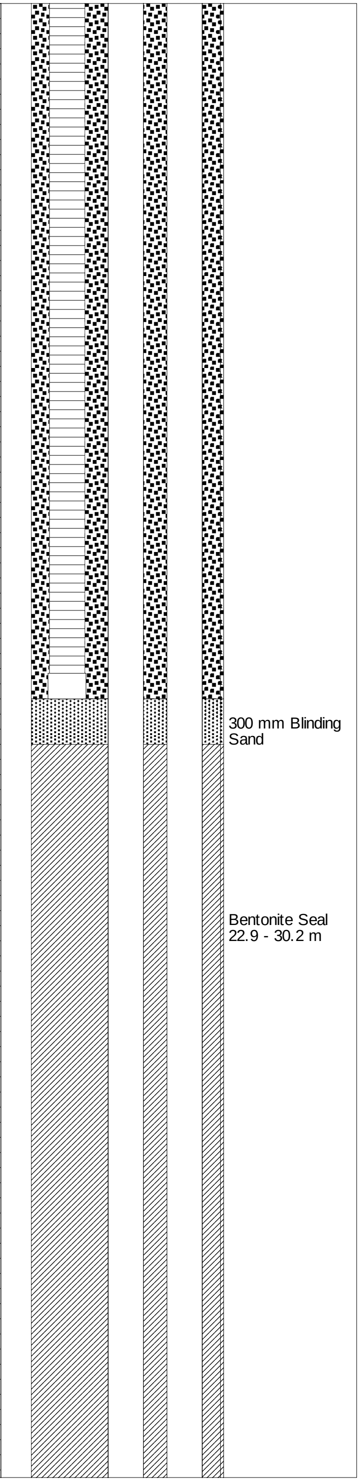
Project Name: Ruawai Exploration Bore
Location: Ruawai
Project Number: AE02170.02
Geologist: T. Adhikary

DRILLING DETAILS

Drilling Company: Drillwell Exploration
Drilling Method: Wash drilling
Drilling Date: 14-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 70 (mBGL)
Bore Diameter: 120 mm
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)
18				-16
			Same as above with traces of silt (1-2%)	
19				-17
20				-18
21				-19
22				-20
			Same as above	
23				-21
24				-22
25				-23
			CLAY, silty, moderately plastic, soft, moist, medium grey (marine mud?) alternating with 5-10 cm thick fine sand layers & clay layers (7 cm x 3)	
26				-24
			Same as above with a fine sand layer 5 cm at the lower part	
27			SAND, fine grained, loose, wet, poorly graded, mainly quartz grains with a clay layer 12 cm at the upper part, clay is sticky, highly to moderately plastic, moist, soft	-25

Piezometer Construction Details And Groundwater Levels



Grainsize Classification (mm):

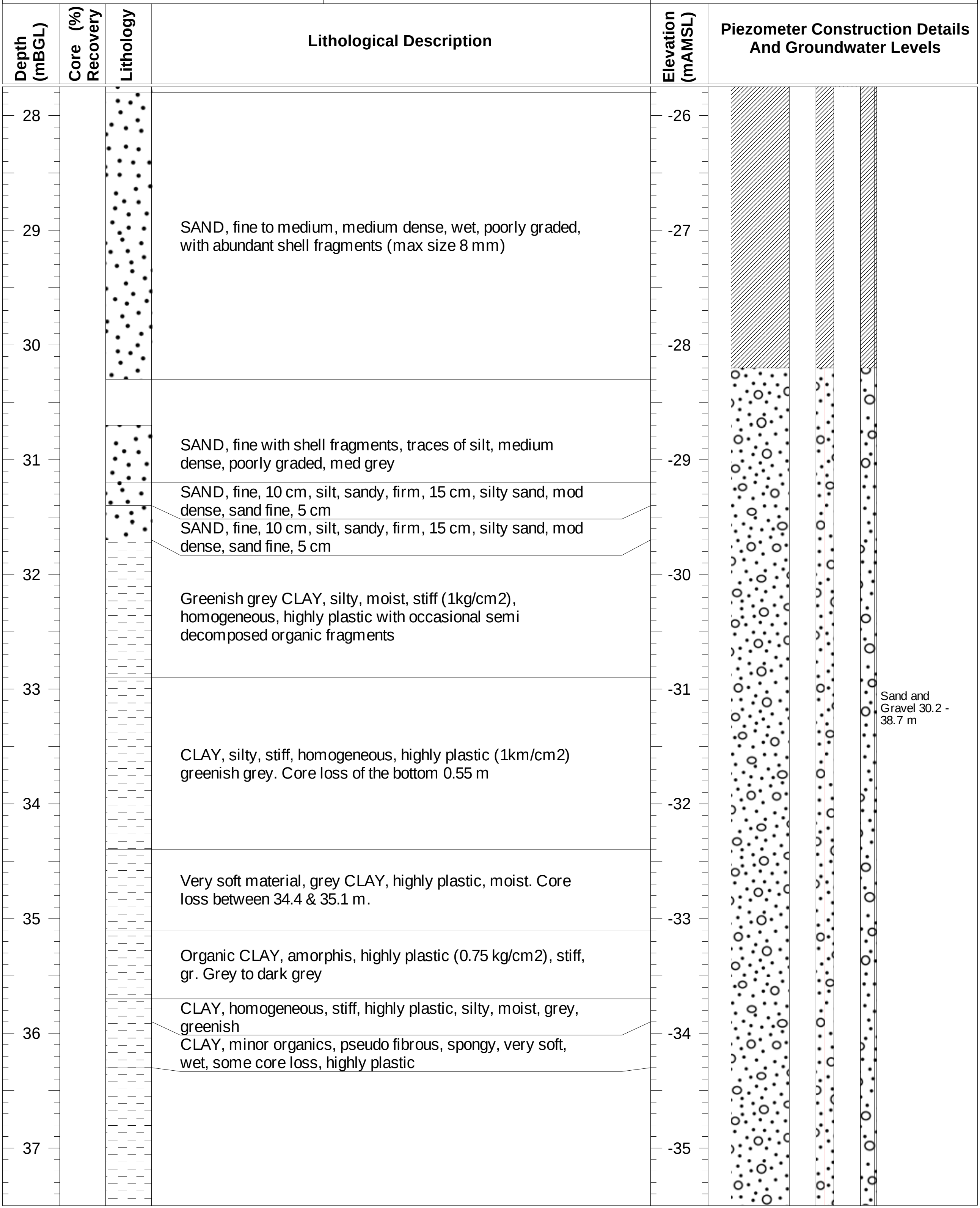
Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

Borehole Logging Record **Bore:** Borehole 4 (A-C)

Project Name: Ruawai Exploration Bore **Location:** Ruawai
Project Number: AE02170.02 **Geologist:** T. Adhikary

DRILLING DETAILS		**Drilling Date:**	14-Apr-05	**Drilled Depth:**	70 (mBGL)
Drilling Company:	Drillwell Exploration			**Bore Diameter:**	120 mm
Drilling Method:	Wash drilling	**Elevation:**	~2 (mAMSL)	**Top of Casing Elev:**	0.9 (mAGL)



SAND, fine to medium, medium dense, wet, poorly graded, with abundant shell fragments (max size 8 mm)

SAND, fine with shell fragments, traces of silt, medium dense, poorly graded, med grey

SAND, fine, 10 cm, silt, sandy, firm, 15 cm, silty sand, mod dense, sand fine, 5 cm

SAND, fine, 10 cm, silt, sandy, firm, 15 cm, silty sand, mod dense, sand fine, 5 cm

Greenish grey CLAY, silty, moist, stiff (1kg/cm2), homogeneous, highly plastic with occasional semi decomposed organic fragments

CLAY, silty, stiff, homogeneous, highly plastic (1km/cm2) greenish grey. Core loss of the bottom 0.55 m

Very soft material, grey CLAY, highly plastic, moist. Core loss between 34.4 & 35.1 m.

Organic CLAY, amorphis, highly plastic (0.75 kg/cm2), stiff, gr. Grey to dark grey

CLAY, homogeneous, stiff, highly plastic, silty, moist, grey, greenish

CLAY, minor organics, pseudo fibrous, spongy, very soft, wet, some core loss, highly plastic

Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

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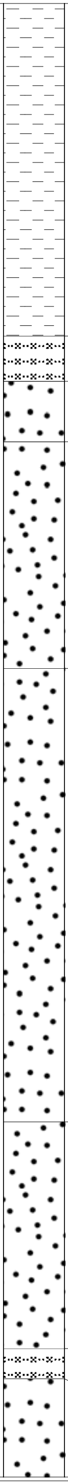
Borehole Logging Record

Bore: Borehole 4 (A-C)

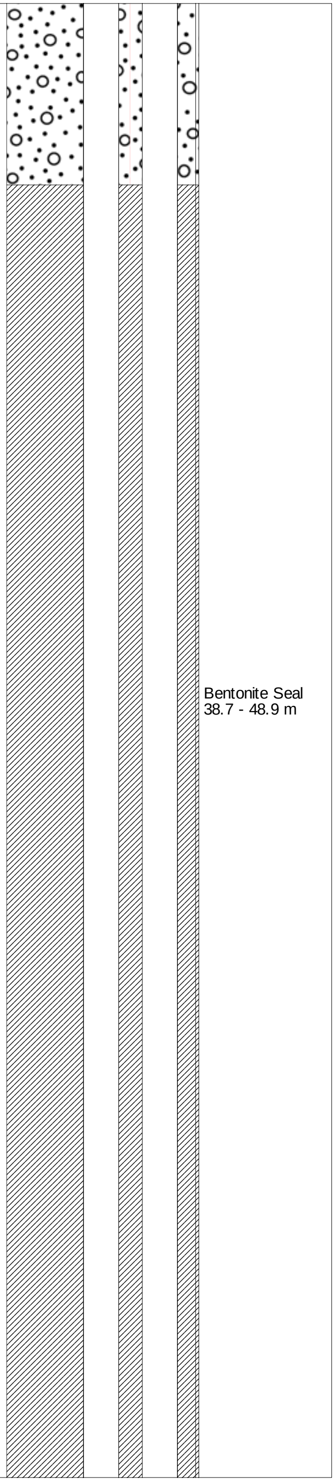
Project Name: Ruawai Exploration Bore
Project Number: AE02170.02
Location: Ruawai
Geologist: T. Adhikary

DRILLING DETAILS
Drilling Company: Drillwell Exploration
Drilling Method: Wash drilling
Drilling Date: 14-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 70 (mBGL)
Bore Diameter: 120 mm
Top of Casing Elev: 0.9 (mAGL)



Depth (mBGL)	Lithological Description	Elevation (mAMSL)
38	CLAY, homogeneous, moist, highly plastic, silty (1.74kg/cm2), very stiff (undifferentiated alluvium), greenish grey	-36
39		-37
	Sandy silt, stiff, moist, non plastic, homogeneous	
40		-38
	SAND, fine, poorly graded, moist, dense	
41	SAND, fine grained, no fines, silty, minor dense, moist to wet, greenish grey, homogeneous	-39
42		-40
43		-41
	SAND, fine grained, non plastic, dense, wet, greenish grey, homogeneous, silt, minor	
44		-42
45		-43
	SAND, with a layer of sandy silt, sand is fine, dense, moist, homogeneous. Silt is very stiff, moist, silt non plastic, it is between 45.3 and 45.9	
46		-44
	Sandy SILT, moist, stiff, non plastic, greenish grey, sand is fine	
	SAND, clean, dense, wet, homogeneous, poorly graded, fine grained, greenish grey	
47		-45

Piezometer Construction Details And Groundwater Levels



Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

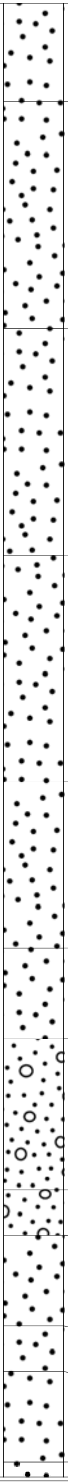
Borehole Logging Record **Bore:** Borehole 4 (A-C)

Project Name: Ruawai Exploration Bore **Location:** Ruawai
Project Number: AE02170.02 **Geologist:** T. Adhikary

DRILLING DETAILS
Drilling Company: Drillwell Exploration
Drilling Method: Wash drilling
Drilling Date: 14-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 70 (mBGL)
Bore Diameter: 120 mm
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Elevation (mAMSL)
48	-46
49	-47
50	-48
51	-49
52	-50
53	-51
54	-52
55	-53
56	-54

Core (%) Recovery | **Lithology**



Lithological Description

SAND, very dense, fine, traces of medium, silty between 48.5 and 48.7 m, homogeneous, wet, poorly graded

SAND, fine with traces of medium, traces of silt, homogeneous, wet to saturated, loose to medium dense, medium grey silty sand between 49.4 & 49.55 m, silty, non plastic, sand is fine

SAND, fine, poorly graded, traces of medium, silty between 51.7 & 51.9 m, dense to very dense, homogeneous, medium grey

SAND, fine, clean, poorly graded, dense, homogeneous, grey, med

SAND, fine to medium progressing into fine to coarse, moderately graded, med dense, saturated, grains mainly quartz

Sandy GRAVEL, gravel, fine to medium, loose, saturated, sand is fine to coarse, rock fragments, hard moderately strong to weak angular to sub-rounded, poorly graded, max size 20 mm, med grey

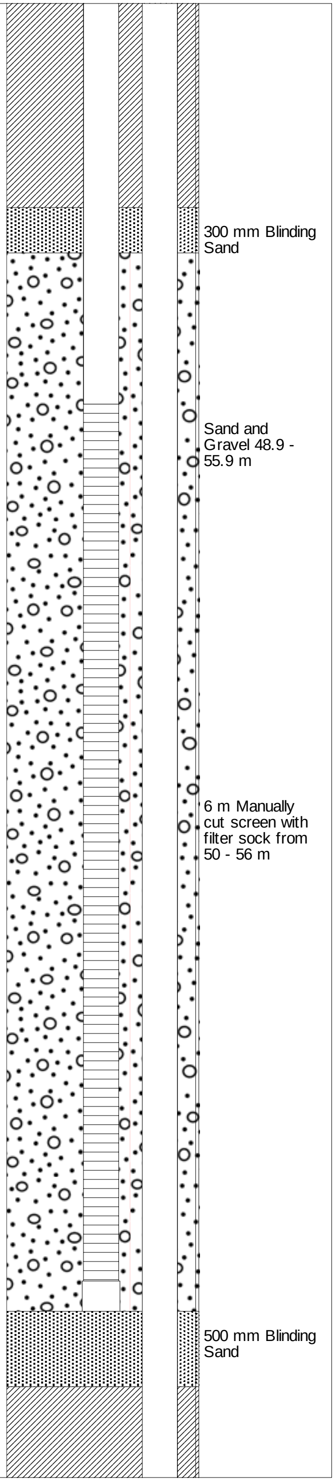
Sandy GRAVEL as above, occasionally coarse, max size 28 mm

SAND, fine, traces of medium, med dense to dense, grey, homogeneous, pockets of organic, homogeneous fragments, pseudo-fibrous, 10 mm to max 30 mm thick between 55.8 & 56.0 m

Same as above, SAND, with traces of silt, fine, grey, med dense with occasional fine gravel, angular, hard

SAND, fine grained, loose to medium dense, saturated, homogeneous, grey, occasional fine gravel (3 mm), hard, quartz

Piezometer Construction Details And Groundwater Levels



Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

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Borehole Logging Record

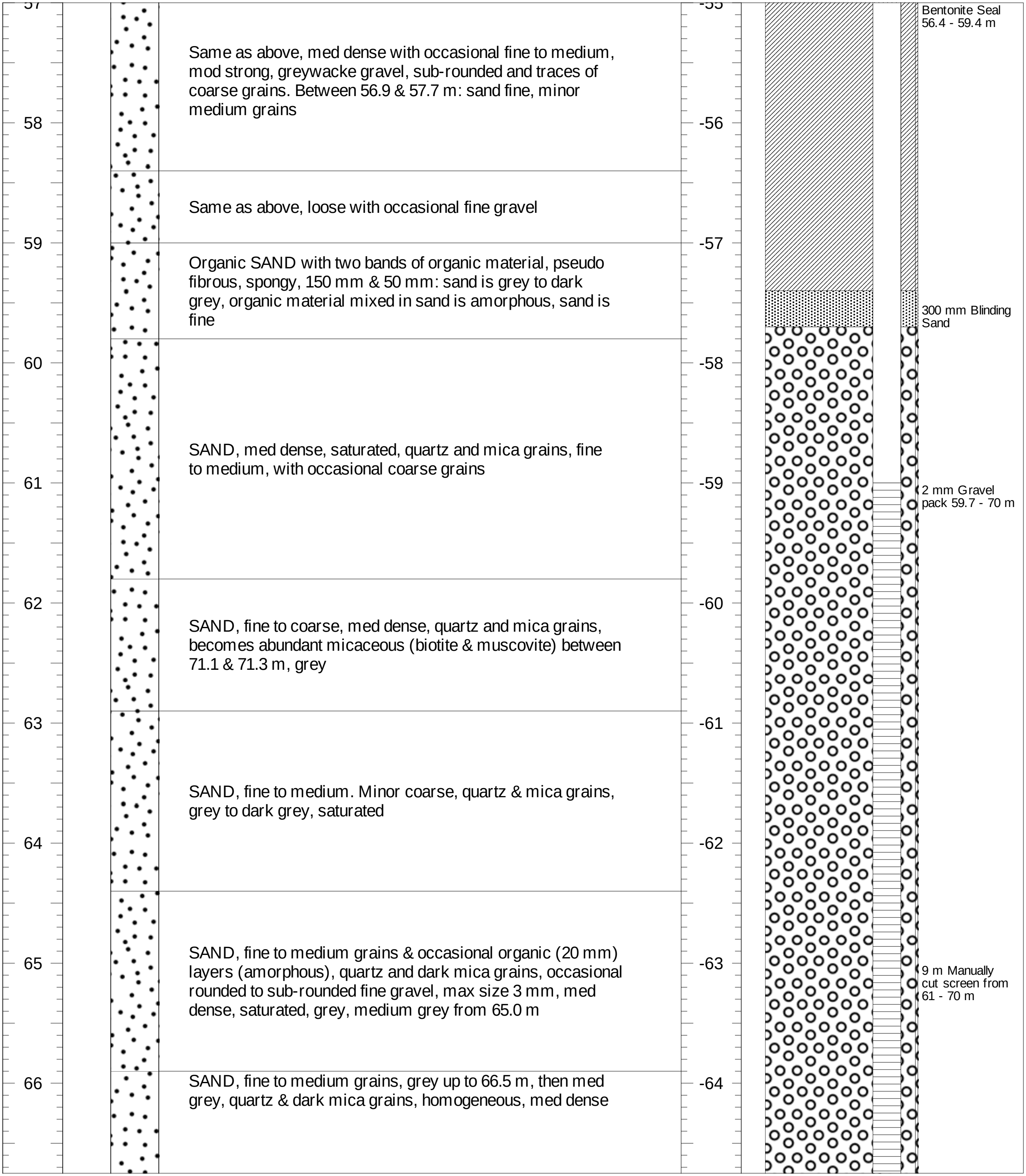
Bore: Borehole 4 (A-C)

Project Name: Ruawai Exploration Bore
Location: Ruawai
Project Number: AE02170.02
Geologist: T. Adhikary

DRILLING DETAILS

Drilling Company: Drillwell Exploration
Drilling Method: Wash drilling
Drilling Date: 14-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 70 (mBGL)
Bore Diameter: 120 mm
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels



Same as above, med dense with occasional fine to medium, mod strong, greywacke gravel, sub-rounded and traces of coarse grains. Between 56.9 & 57.7 m: sand fine, minor medium grains

Same as above, loose with occasional fine gravel

Organic SAND with two bands of organic material, pseudo fibrous, spongy, 150 mm & 50 mm: sand is grey to dark grey, organic material mixed in sand is amorphous, sand is fine

SAND, med dense, saturated, quartz and mica grains, fine to medium, with occasional coarse grains

SAND, fine to coarse, med dense, quartz and mica grains, becomes abundant micaceous (biotite & muscovite) between 71.1 & 71.3 m, grey

SAND, fine to medium. Minor coarse, quartz & mica grains, grey to dark grey, saturated

SAND, fine to medium grains & occasional organic (20 mm) layers (amorphous), quartz and dark mica grains, occasional rounded to sub-rounded fine gravel, max size 3 mm, med dense, saturated, grey, medium grey from 65.0 m

SAND, fine to medium grains, grey up to 66.5 m, then med grey, quartz & dark mica grains, homogeneous, med dense

Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
200	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	

Borehole Logging Record

Bore: Borehole 4 (A-C)

Project Name: Ruawai Exploration Bore
Location: Ruawai
Project Number: AE02170.02
Geologist: T. Adhikary

DRILLING DETAILS
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Drilling Method: Wash drilling
Drilling Date: 14-Apr-05
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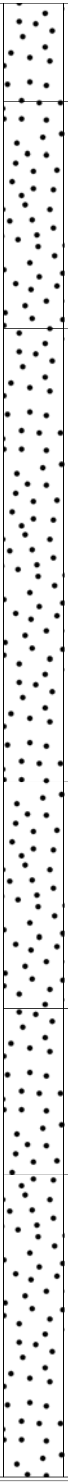
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels



Depth (mBGL)	Elevation (mAMSL)
67	-65
68	-66
69	-67
70	-68
71	-69
72	-70
73	-71
74	-72
75	-73
76	-74

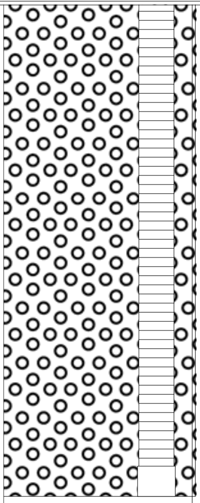
SAND, fine to medium, traces of coarse, homogeneous, quartz & mica (dark & light), strongly micaceous (up to 10 mm at 68.5 m), grey, saturated, med dense

Same as above, strongly (20 mm) micaceous sand at 71.5 m, grey

Same as above, fine to med, traces of coarse, no organics, grey, fine to coarse micaceous (20 mm at 72.7 m), traces of silt, wet, med dense

SAND, fine to medium, homogenous, med dense, wet, quartz & mica grains

SAND, fine, some medium, homogeneous, clean, saturated, med dense, micaceous, poorly graded, grey



Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
200	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	

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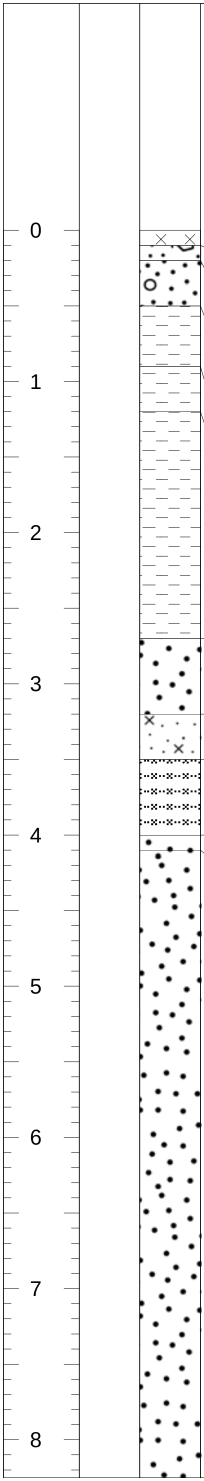
Borehole Logging Record

Bore: Borehole 4 (D)

Project Name: Ruawai Exploration Bore
Location: Ruawai
Project Number: AE02170.02
Geologist: T. Adhikary

DRILLING DETAILS
Drilling Company: Drillwell Exploration
Drilling Method: HQ rotary coring
Drilling Date: 12-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 95.5 (mBGL)
Bore Diameter: 96 mm
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels



SILT, clayey, slightly plastic with abundant grass roots for 10 cm, medium grey, soft (fill)

Gravelly SILT with some sand, firm, gravel is fine to medium, angular, moderately strong sandstone fragments, sand is fine to coarse, non plastic, clay traces (fill)

Sandy GRAVEL with minor silt, gravel moderately dense, fine to coarse, angular, poorly graded, sandstone fragments, sand fine to coarse, silt, non plastic (fill)

Top 10 cm organic clay, amorphous, plastic. Silty CLAY, moderately plastic, stiff grey, mottled orange brown with tiny dark grey specks & orange brown specks, (natural material?), becomes less orangey from 75 cm

CLAY, homogeneous, highly plastic, firm, blue grey

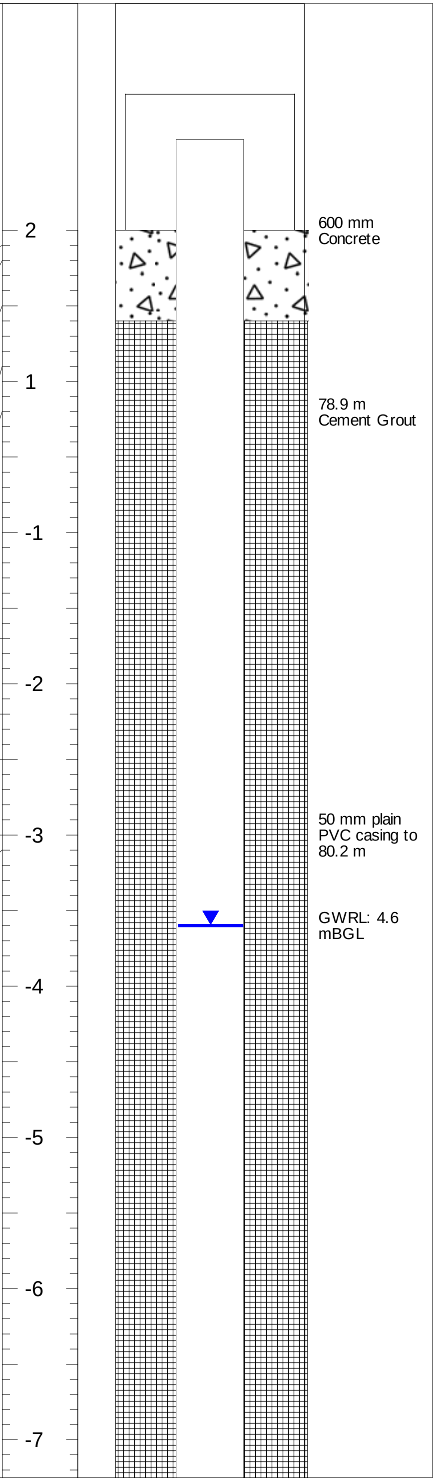
MARINE MUD? Same as above only 5 cm of core recovered, very soft

SAND, mostly fine to medium, poorly graded, homogeneous, loose, medium grey, wet, minor silt, non plastic

Silty SAND, loose, homogeneous, sand is mostly fine to medium, poorly graded, wet

Sandy SILT, saturated, very soft, non plastic, sand is fine, medium grey

SAND, fine grained, minor medium, poorly graded, moist, medium dense, medium grey



Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

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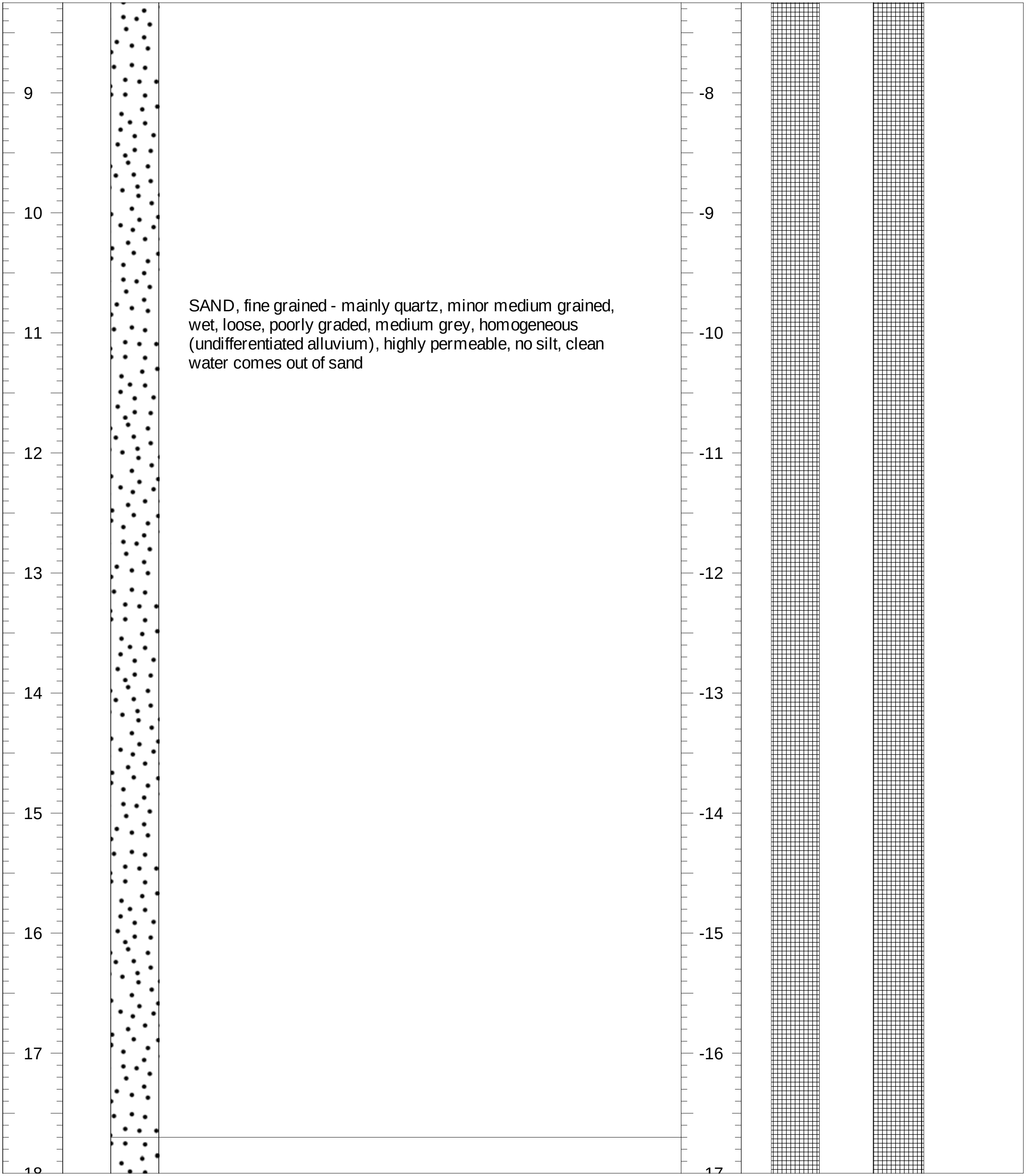
Borehole Logging Record   Bore: Borehole 4 (D)

Project Name: Ruawai Exploration Bore   **Location:** Ruawai
Project Number: AE02170.02   **Geologist:** T. Adhikary

DRILLING DETAILS   **Drilling Date:** 12-Apr-05   **Drilled Depth:** 95.5 (mBGL)
Drilling Company: Drillwell Exploration   **Bore Diameter:** 96 mm
Drilling Method: HQ rotary coring   **Elevation:** ~2 (mAMSL)   **Top of Casing Elev:** 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels



SAND, fine grained - mainly quartz, minor medium grained, wet, loose, poorly graded, medium grey, homogeneous (undifferentiated alluvium), highly permeable, no silt, clean water comes out of sand

Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

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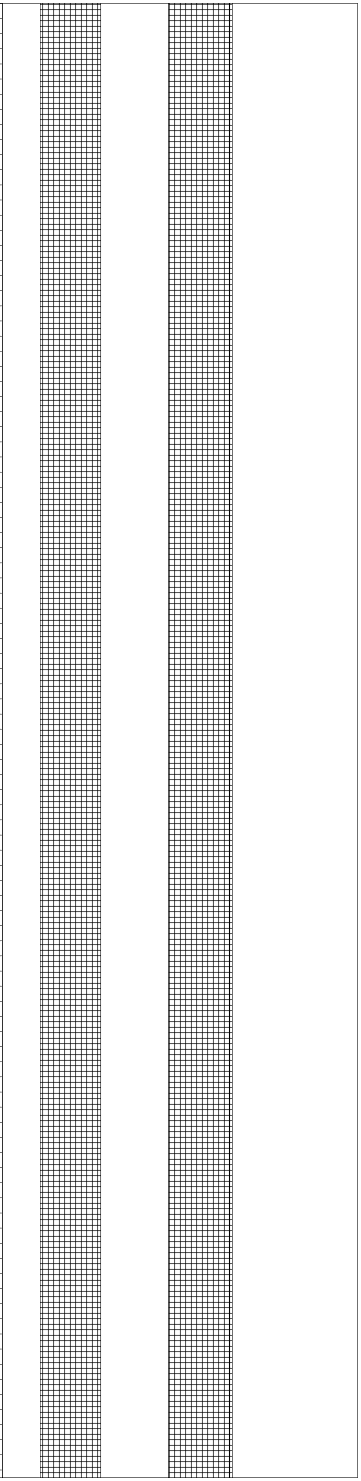
Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)
18				-17
			Same as above with traces of silt (1-2%)	
19				-18
20				-19
21				-20
22				-21
			Same as above	
23				-22
24				-23
25				-24
			CLAY, silty, moderately plastic, soft, moist, medium grey (marine mud?) alternating with 5-10 cm thick fine sand layers & clay layers (7 cm x 3)	
26				-25
			Same as above with a fine sand layer 5 cm at the lower part	
27			SAND, fine grained, loose, wet, poorly graded, mainly quartz grains with a clay layer 12 cm at the upper part, clay is sticky, highly to moderately plastic, moist, soft	-26

Piezometer Construction Details And Groundwater Levels



Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

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Borehole Logging Record

Bore: Borehole 4 (D)

Project Name: Ruawai Exploration Bore
Project Number: AE02170.02
Location: Ruawai
Geologist: T. Adhikary

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Drilling Company: Drillwell Exploration
Drilling Method: HQ rotary coring
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Drilled Depth: 95.5 (mBGL)
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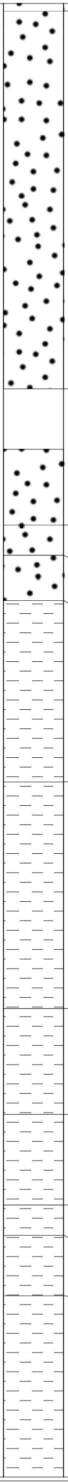
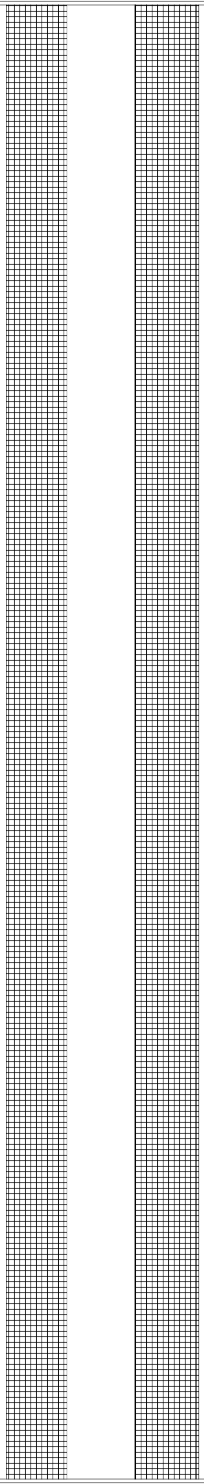
Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels
28				-27	
29			SAND, fine to medium, medium dense, wet, poorly graded, with abundant shell fragments (max size 8 mm)	-28	
30				-29	
31			SAND, fine with shell fragments, traces of silt, medium dense, poorly graded, med grey	-30	
			SAND, fine, 10 cm, silt, sandy, firm, 15 cm, silty sand, moderately dense, sand fine, 5 cm		
			SAND, fine, 10 cm, silt, sandy, firm, 15 cm, silty sand, moderately dense, sand fine, 5 cm		
32			Greenish grey CLAY, silty, moist, stiff (1kg/cm2), homogeneous, highly plastic with occasional semi decomposed organic fragments	-31	
33			CLAY, silty, stiff, homogeneous, highly plastic (1km/cm2) greenish grey. Core loss of the bottom 0.55 m	-32	
34				-33	
35			Very soft material, grey CLAY, highly plastic, moist. Core loss between 34.4 & 35.1 m.	-34	
			Organic CLAY, amorphis, highly plastic (0.75 kg/cm2), stiff, gr. Grey to dark grey		
36			CLAY, homogeneous, stiff, highly plastic, silty, moist, grey, greenish	-35	
			CLAY, minor organics, pseudo fibrous, spongy, very soft, wet, some core loss, highly plastic		
37				-36	





Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
200	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	

Borehole Logging Record

Bore: Borehole 4 (D)

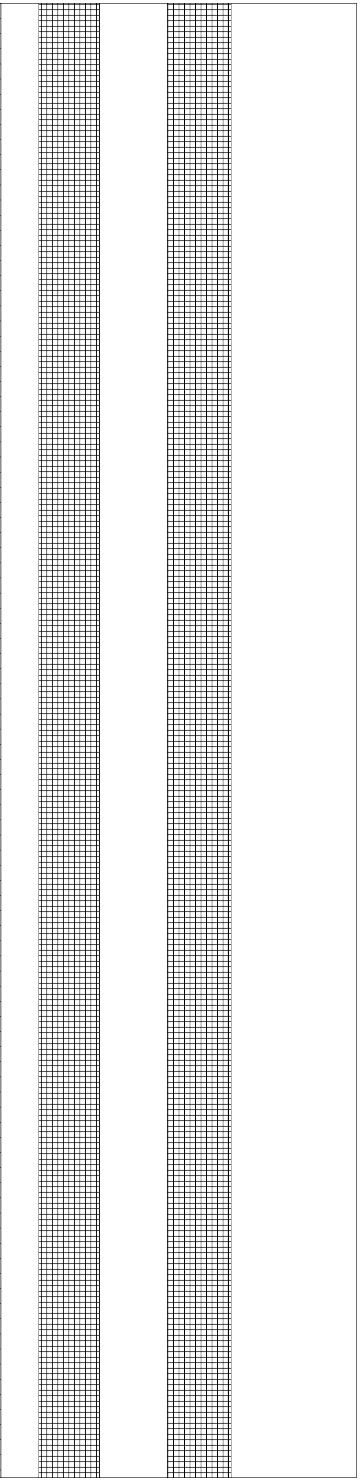
Project Name: Ruawai Exploration Bore
Project Number: AE02170.02
Location: Ruawai
Geologist: T. Adhikary

DRILLING DETAILS

Drilling Company:	Drillwell Exploration	**Drilling Date:**	12-Apr-05	**Drilled Depth:**	95.5	(mBGL)
				Bore Diameter:	96	mm
Drilling Method:	HQ rotary coring	**Elevation:**	~2 (mAMSL)	**Top of Casing Elev:**	0.9	(mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)
38			CLAY, homogeneous, moist, highly plastic, silty (1.74kg/cm²), very stiff (undifferentiated alluvium), greenish grey	-37
39				-38
			Sandy silt, stiff, moist, non plastic, homogeneous	
40			SAND, fine, poorly graded, moist, dense	-39
41			SAND, fine grained, no fines, silty, minor dense, moist to wet, greenish grey, homogeneous	-40
42				-41
43			SAND, fine grained, non plastic, dense, wet, greenish grey, homogeneous, silt, minor	-42
44				-43
45			SAND, with a layer of sandy silt, sand is fine, dense, moist, homogeneous. Silt is very stiff, moist, silt non plastic, it is between 45.3 and 45.9	-44
46				-45
			Sandy SILT, moist, stiff, non plastic, greenish grey, sand is fine	
47			SAND, clean, dense, wet, homogeneous, poorly graded, fine grained, greenish grey	-46

Piezometer Construction Details And Groundwater Levels



Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
200	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	

Borehole Logging Record

Bore: Borehole 4 (D)

Project Name: Ruawai Exploration Bore
Location: Ruawai
Project Number: AE02170.02
Geologist: T. Adhikary

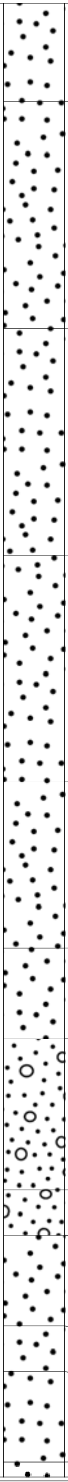
DRILLING DETAILS

Drilling Company:	Drillwell Exploration	**Drilling Date:**	12-Apr-05	**Drilled Depth:**	95.5	(mBGL)
				Bore Diameter:	96	mm
Drilling Method:	HQ rotary coring	**Elevation:**	~2 (mAMSL)	**Top of Casing Elev:**	0.9	(mAGL)

Depth (mBGL)	Elevation (mAMSL)
48	-47
49	-48
50	-49
51	-50
52	-51
53	-52
54	-53
55	-54
56	-55

Core (%) Recovery

Lithology



Lithological Description

SAND, very dense, fine, traces of medium, silty between 48.5 and 48.7 m, homogeneous, wet, poorly graded

SAND, fine with traces of medium, traces of silt, homogeneous, wet to saturated, loose to medium dense, medium grey silty sand between 49.4 & 49.55 m, silty, non plastic, sand is fine

SAND, fine, poorly graded, traces of medium, silty between 51.7 & 51.9 m, dense to very dense, homogeneous, medium grey

SAND, fine, clean, poorly graded, dense, homogeneous, grey, med

SAND, fine to medium progressing into fine to coarse, moderately graded, med dense, saturated, grains mainly quartz

Sandy GRAVEL, gravel, fine to medium, loose, saturated, sand is fine to coarse, rock fragments, hard moderately strong to weak angular to sub-rounded, poorly graded, max size 20 mm, med grey

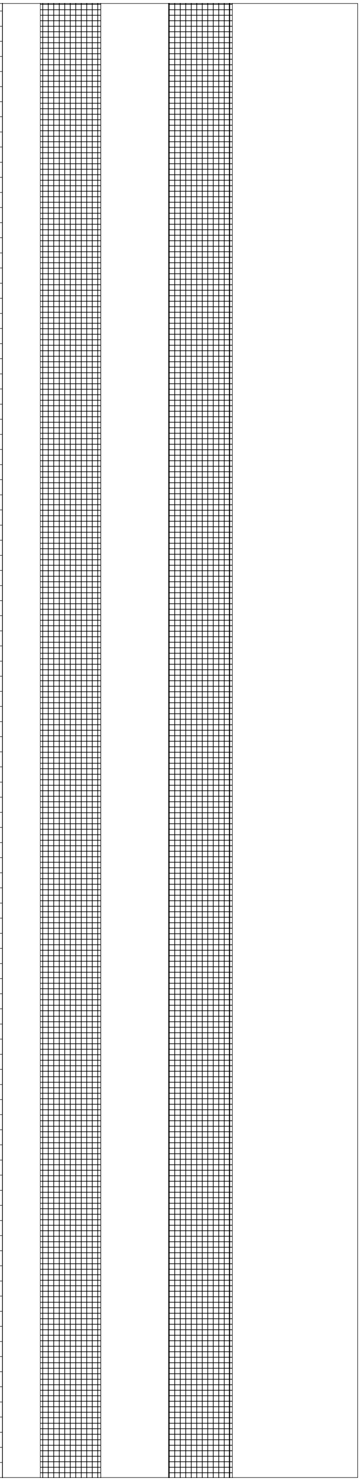
Sandy GRAVEL as above, occasionally coarse, max size 28 mm

SAND, fine, traces of medium, med dense to dense, grey, homogeneous, pockets of organic, homogeneous fragments, pseudo-fibrous, 10 mm to max 30 mm thick between 55.8 & 56.0 m

Same as above, SAND, with traces of silt, fine, grey, med dense with occasional fine gravel, angular, hard

SAND, fine grained, loose to medium dense, saturated, homogeneous, grey, occasional fine gravel (3 mm), hard, quartz

Piezometer Construction Details And Groundwater Levels



Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

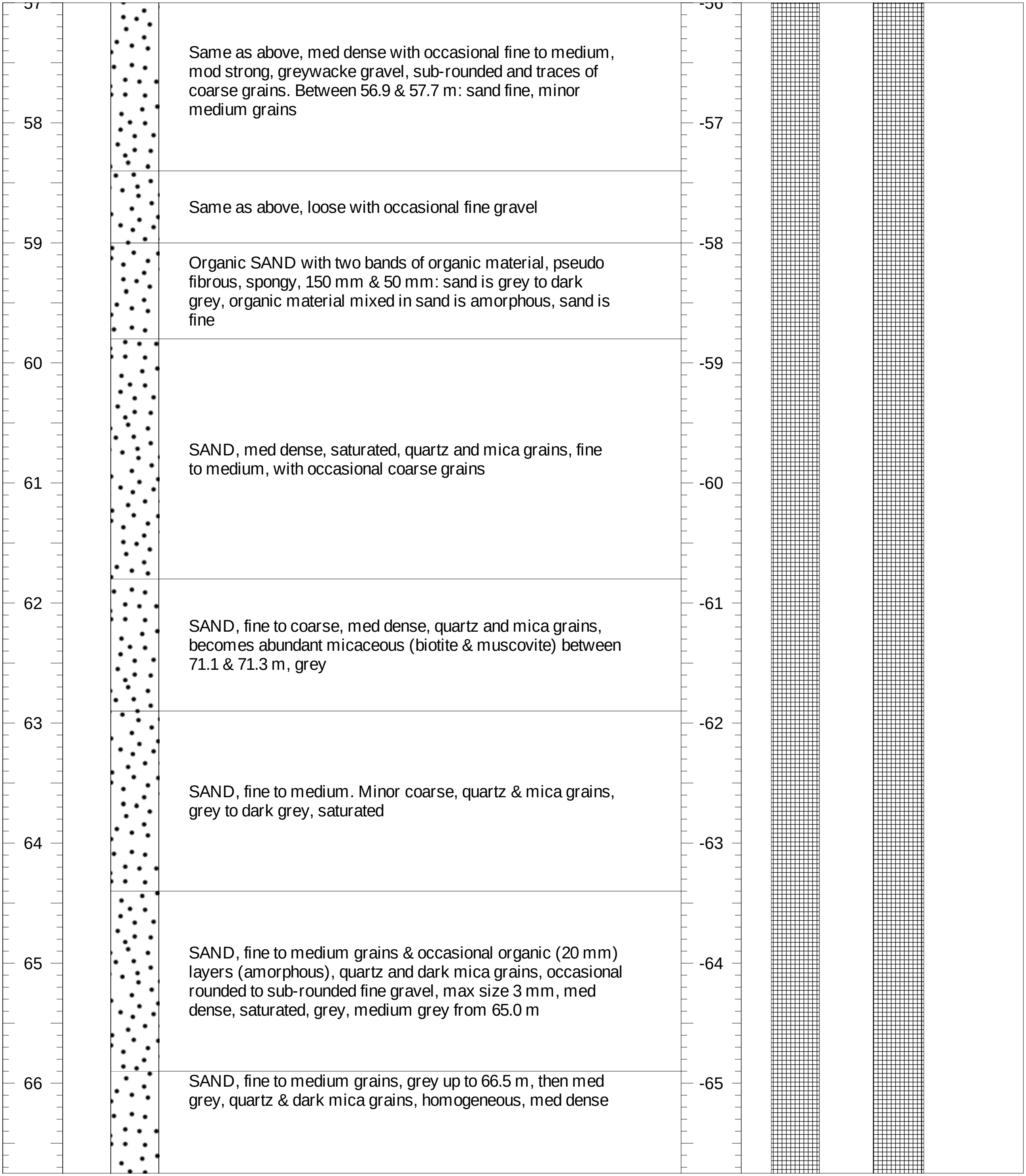
200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

Borehole Logging Record **Bore:** Borehole 4 (D)

Project Name: Ruawai Exploration Bore **Location:** Ruawai
Project Number: AE02170.02 **Geologist:** T. Adhikary

DRILLING DETAILS
Drilling Company: Drillwell Exploration
Drilling Method: HQ rotary coring
Drilling Date: 12-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 95.5 (mBGL)
Bore Diameter: 96 mm
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels



Same as above, med dense with occasional fine to medium, mod strong, greywacke gravel, sub-rounded and traces of coarse grains. Between 56.9 & 57.7 m: sand fine, minor medium grains

Same as above, loose with occasional fine gravel

Organic SAND with two bands of organic material, pseudo fibrous, spongy, 150 mm & 50 mm: sand is grey to dark grey, organic material mixed in sand is amorphous, sand is fine

SAND, med dense, saturated, quartz and mica grains, fine to medium, with occasional coarse grains

SAND, fine to coarse, med dense, quartz and mica grains, becomes abundant micaceous (biotite & muscovite) between 71.1 & 71.3 m, grey

SAND, fine to medium. Minor coarse, quartz & mica grains, grey to dark grey, saturated

SAND, fine to medium grains & occasional organic (20 mm) layers (amorphous), quartz and dark mica grains, occasional rounded to sub-rounded fine gravel, max size 3 mm, med dense, saturated, grey, medium grey from 65.0 m

SAND, fine to medium grains, grey up to 66.5 m, then med grey, quartz & dark mica grains, homogeneous, med dense

Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

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Borehole Logging Record

Bore: Borehole 4 (D)

Project Name: Ruawai Exploration Bore
Project Number: AE02170.02
Location: Ruawai
Geologist: T. Adhikary

DRILLING DETAILS
Drilling Company: Drillwell Exploration
Drilling Method: HQ rotary coring
Drilling Date: 12-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 95.5 (mBGL)
Bore Diameter: 96 mm
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels
67				-66	
68			SAND, fine to medium, traces of coarse, homogeneous, quartz & mica (dark & light), strongly micaceous (up to 10 mm at 68.5 m), grey, saturated, med dense	-67	
69				-68	
70			Same as above, strongly (20 mm) micaceous sand at 71.5 m, grey	-69	
71				-70	
72			Same as above, fine to med, traces of coarse, no organics, grey, fine to coarse micaceous (20 mm at 72.7 m), traces of silt, wet, med dense	-71	
73				-72	
74			SAND, fine to medium, homogenous, med dense, wet, quartz & mica grains	-73	
75				-74	
76			SAND, fine, some medium, homogeneous, clean, saturated, med dense, micaceous, poorly graded, grey	-75	

Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
200	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	

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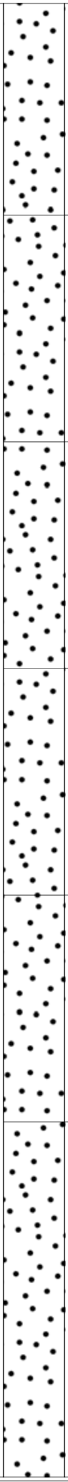
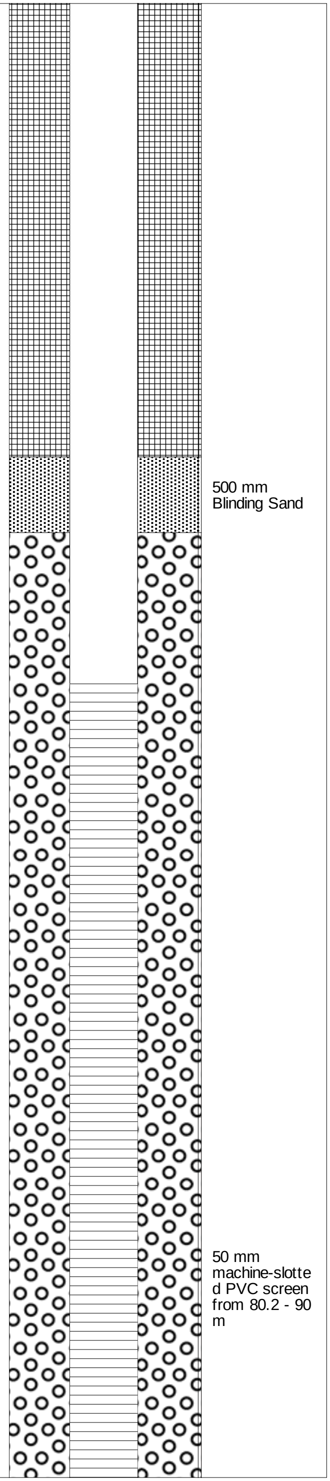
Location: Ruawai
Project Number: AE02170.02
Geologist: T. Adhikary

DRILLING DETAILS
Drilling Company: Drillwell Exploration
Drilling Method: HQ rotary coring
Drilling Date: 12-Apr-05
Elevation: ~2 (mAMSL)
Drilled Depth: 95.5 (mBGL)
Bore Diameter: 96 mm
Top of Casing Elev: 0.9 (mAGL)

Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)
77				-76
78				-77
			SAND, fine to medium, homogeneous, micaceous, med dense, saturated, clean, traces of coarse grains	
79				-78
80			Same as above, minor coarse grains, grey	-79
81				-80
			SAND, fine to medium, loose to medium dense, saturated, clean, some coarse grains, homogeneous, poorly graded, no fines, grey	
82				-81
83			Same as above with traces of silt	-82
84				-83
85				-84
			SAND, fine to medium, med dense, wet, traces of silt, some coarse grains, homogeneous, poorly graded, med grey, dark and light micas	
86				-85



Piezometer Construction Details And Groundwater Levels



Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	
200	60	20	6	2	0.6	0.2	0.06	0.02	0.006	0.002	

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Borehole Logging Record **Bore:** Borehole 4 (D)

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Project Number: AE02170.02 **Geologist:** T. Adhikary

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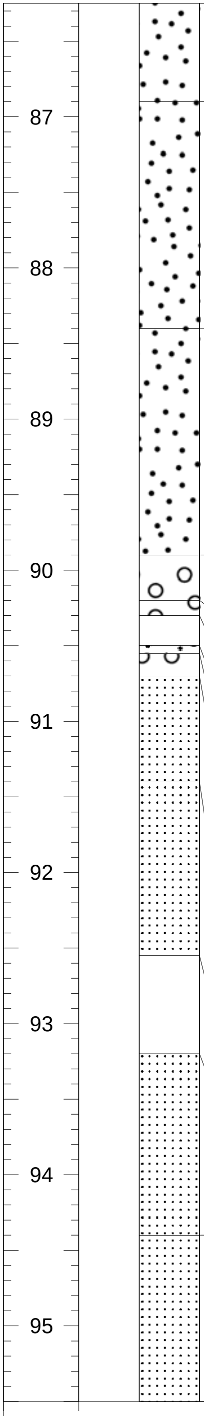
Depth (mBGL)	Core (%) Recovery	Lithology	Lithological Description	Elevation (mAMSL)	Piezometer Construction Details And Groundwater Levels



SAND, fine to med, med dense, some coarse grains, poorly graded quartz & mica grains (dark and light colour), no fines, with minor shell fragments below 87.3, coarse sand to med gravel size, saturated

Same as above with some shell fragments, coarse sand to med gravel size

Sandy GRAVEL with some shell fragments, gravel poorly graded, angular, fine to coarse, very loose, max size 28 mm, sand corse some fine to med, grey to light grey

Coarse GRAVEL, greywacke 45 mm, sub-rounded to angular loose, poorly graded; med strong, slightly weathered rock fragments, dark grey

Greywacke BOULDER, slightly weathered, strong, massive, size 40 mm, 50 mm & 110 mm

Sandy GRAVEL with fine to med gravel size shell fragments, angular graywacke fine to med gravel, weak rock fragments, sand fine to coarse, poorly graded, max gravel size 20 mm

Coarse greywacke GRAVEL, sub-rounded, max size 50 mm with some fine to coarse sand, loose. 20 mm of Shelley sand, fine to coarse, loose at the bottom

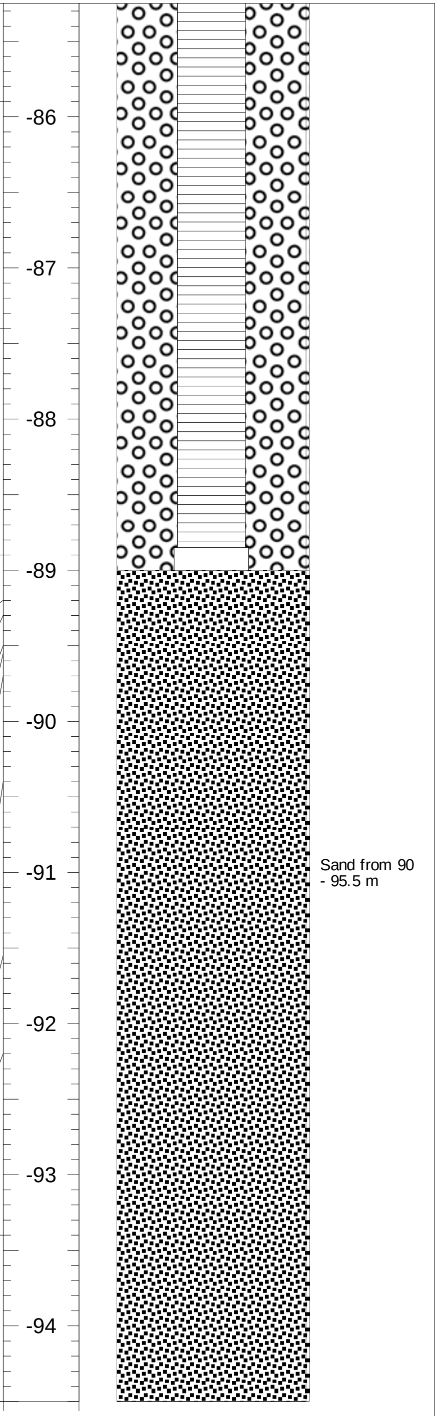
SANDSTONE, fine grained, slightly weathered, extremely weak up to 91.25 m, below 91.25 m: sandstone, very weak with bands of siltstone, fracture with quartz infilling 45º-30º to core axis, 2-3 mm, rough, planar at 91.35 & 91.9 m. Siltstone bands 20 mm to 70 mm, calcareous sandstone between 91.65 & 91.75 m, grey, can be scraped with knife

SANDSTONE, fine, unweathered, very weak, can be easily scraped with knife, thinly bedded with thin 20 mm - 70 mm layers of siltstone

SILTSTONE, homogeneous, very weak with a few very thin (5-10 mm) layers of sandstone

SANDSTONE, fine grained, massive, homogeneous, very weak, can be scraped with knife. Calcareous from 94.2 and below

Calcareous SANDSTONE, grey, massive, weak, scrapes with knife with difficulty, homogeneous, bedding inc at 45º to core axis, 35 mm dark grey sandstone layer



Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
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