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Low enthalpy geothermal resources - Miranda-Kaiaua area

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Abstract

A survey was carried out in the Miranda-Kaiaua area to find out whether the low enthalpy geothermal resource is one, linked or two separate resources altogether.

As part of the survey, water samples from four sites in Kaiaua were analysed for their chemical properties.

The hydrology, geophysical and geochemical data presented indicate that Kaiaua and Miranda are the same geothermal resource. Miranda is the upflow of the system where the fluid is flowing laterally in a north direction from the greywacke basement to the Waitemata sediments reaching Kaiaua area.

With limited data on both areas, it is difficult to provide the extent of the resource. However, from the Miranda data provided, stored heat was estimated at 2.169 MWe.

Recommendation on the sustainable use of this low enthalpy geothermal resource is dependent on the rate of heat and mass withdrawal, pressure drawdown in the reservoir and recharge supplied to the system. A reinjection program will need to be established in order to prevent pressure drawdown if future use is to be extensive.

1 Introduction

This report encompasses the western portion of the Hauraki Depression namely from the Miranda Hot Springs to the Kaiaua area.

The purpose of the survey was to assess the geothermal resources of the Miranda-Kaiaua area and see if there is a link between the two areas, one resource or whether they are separate.

The field survey was conducted on 11 October 2010, measuring water temperatures of the hot spring and water bores along the Miranda-Kaiaua stretch. Water samples of thermal waters were also taken. The preliminary geochemical analyses are looked at, identifying the chemical components of the sampled waters in the area.

It should be stressed that not much information on previous work was gathered on the Kaiaua area and only field observations are discussed. Much of the report covers the Miranda hot springs.

The sustainability of the resource is also discussed.

2 Previous work - Miranda-Kaiaua area

Much background information on past work has been carried out in the Miranda hot springs as partly the result of consent applications for extension or upgrade of the Miranda thermal baths complex as well as better knowledge of the Hauraki Depression.

Geology

Geological observations by Johnstone (1979) in the Miranda hot springs are described further in the geology part of the report. Gregg (1978) also made carried out a geological survey with the objective of establishing continuity of the supply of thermal water in the area.

Geophysics

Geophysical surveys carried out by Hochstein and Nixon (1979) on the Hauraki Depression showed that the whole depression is an active rift giving way to the horst and graben features controlled by parallel faults. They were also able to show the hydrology of the depression with a connection between the deeper circulation and shallow regime.

Sudarman later in 1981 did a D.C resistivity and magnetic survey of the Miranda hot springs area as part of his Geothermal Diploma paper. He concluded that the magnetic survey showed no concealed intrusion underlying the area and the low resistivity area are at a depth of about 85 m, correlating with the occurrence of the hot springs. Also, the low resistivity shows a lateral flow of waters to the north, within the Waitemata sediments.

Bennie and Graham (2001) from GNS conducted further geophysical surveys as part of an assessment of the thermal resource at Miranda hot springs. Further to Surdarman’s work and recommendations, the techniques used for the survey were a vertical electrical sounding (VES) and resistivity gradient array to better define the resistivity in the area and to verify the possible outflow structure.

Geochemistry

Geochemical surveys done by Petty in 1972 and Hochstein in 1978 give an outlook of the water type of Miranda hot springs. Also, the report by Gregg (1978) for Rice Resource Limited show records of water analyses from 4 springs and bores with high borate concentrations and described further on. Johnstone's (1979) work showed the significance of the gas (H_2S) discharge in the area. Jenkinson (1994) did a Masters paper with the Geology Department of The University of Auckland on the study on thermal waters and wells in the Hauraki Depression to find out the chemical composition of these waters. He commented on the alkalinity of Miranda waters as well as the geothermometers. This is discussed in the geochemistry section.

Later on in 2007, Webster-Brown and Brown assessed data for Waikato Regional Council from 2005/06 of geothermal features in the Waikato region. Their interpretations on the Miranda and Kaiaua areas are further discussed.

Resource Assessment

Freeston and Lund's (1998) work was based on previous reports done by Hochstein and Nixon (1979) and Sudarman (1981).

Tourism

Rockel (1986) made a record of all spas in New Zealand.

Other

Other work in proximity to Miranda-Kaiaua was done by Nicholson et. al (1989), Wei and Nicholson (1990) looked at the soil surveys and how useful they are in the exploration of low enthalpy resources, and show similarities in terms of the geology and chemical properties.

During the course of this study, it has become evident that there is very little information on the geothermal resources on the Kaiaua area.

3 Miranda Hot Springs

3.1 Location

The Miranda-Kaiaua thermal area lies on the western head of the Firth of Thames and at the western portion of the Hauraki Depression. It lies on a flat area of about one meter above sea level and 700 m inland from the sea edge and 3 km south from the old site of the Miranda township (Figure 1).

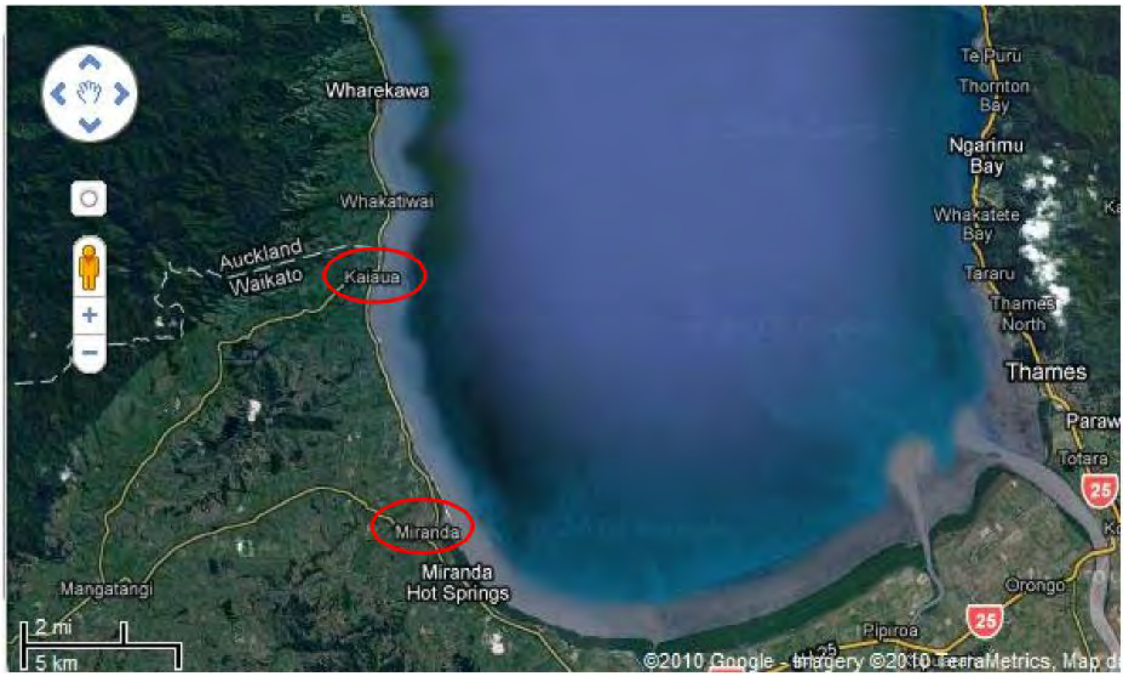


Figure 1: Location of Miranda-Kaiaua thermal area circled in red. (from Google Maps)

3.2 History of Miranda Springs

The Miranda hot springs were once known as the Hauraki Hot Springs and later changed to its current name taking it from a Naval gun board which was dispatched during the Maori wars (Gregg, 1978).

Rockel (1986) stated that some 100 hot springs were located over an area of 40 hectares. The springs remained undeveloped longer than other smaller springs due to the lack of road access until the mid 19th century. One of the first owners of the springs J.Pond carried out early water analyses throughout the country and was rather disappointed that the government refused to purchase the springs in 1903 and 1913.

In pre-European times, the springs were used by the locals to cook food and for swimming as a result of the knowledge of the healing properties of the water.

In the 1950s, swamps were drained and the land cleared making way for an Olympic-sized pool, which is still in use today.

3.3 Present development

The pool complex in Figure 2 consists of a 1.14 million litre pool, public sauna pool, children's pool and 4 private spa tubs. The flow rate into the pool is 30,000 litres per hour.

3 springs (Figure 3) are used to heat the spa pools with a big bore used to heat up the main pool. These springs are also used for space heating and bathing.

According to Freeston and Lund (1998), the pools were minimally developed until the late 1950s when concrete walls and tiered steps were introduced. The bottom of the pool was then sealed with concrete allowing for the collection and distribution of percolating water in a 3000 mm layer of coarse scoria to 380 mm concrete pipes. This was done without water pressure build up. It is the largest geothermal bath in the country with a maintained temperature of the main pool at 35-37^{0}C to 40-41^{0}C of the sauna pools.

Figure 2: Main pool of the Miranda pool complex. The shelter straight ahead is the sauna pool

Figure 3: One of the 3 springs used for pool, space heating and bathing.

The hot mineral waters are generally mineralized, alkaline, saline waters with a high concentration of borax. The chemical properties are pH of 8.9, 146 ppm chloride, 18 ppm silica, 43 ppm borax and 430 ppm of total solid contents (Freeston and Lund, 1998).

3.4 Land use

The Lands and Survey soil maps show that the land is mostly covered by Hauraki clay, the parent material of the estuarine mud. Therefore, the Miranda-Kaiaua area is suited for grazing purposes and is generally farmland consisting of mainly cattle farms with limited horticultural potential (high water table) (Gregg, 1978).

The western side of Firth of Thames is utilized for holidaying purposes. In addition, the establishment of a RAMSAR-listed bird reserve on the shores of the Miranda-Kaiaua stretch with an information centre attracts locals and tourists alike.

The little townships of Miranda and Kaiaua comprises of small shops, district schools and other essential services.

4 Miranda-Kaiaua geoscience

4.1 Geology

Miranda thermal area is located on an old fault line bounding the western part of the Hauraki graben.

Natural thermal features are few in the Miranda-Kaiaua area and are only found in and near the Miranda hot springs. These are associated with the swimming pool complex and a small area several metres north of it (Johnstone, 1979), localized in a 240 m x 90 m area. Other natural discharge features are located about 20m south east of the pool but were not all observed during fieldwork. These are recorded in Johnstone's (1979) work where 7 other hot pools were described.

There are no hydrothermal altered rocks, nor is there any silica sinters or deposition (Sudarman, 1981, Freeston, 1998).

Geological observations by Johnstone (1979) of the Miranda hot springs area were detailed. The oldest rocks exposed were pale cream to grey sandstone with rare 20-30 m thick siltstone beds. These are said to be correlated with the Tertiary Waitemata Group of the Auckland Region. The rocks dip steeply to the northwest and are cut by joints and veins with multiple orientation.

Overlying the Waitemata Group with an unconformable, possibly faulted contact are two units, having a horizontal conformable contact. Brown sandy siltstone with carbonaceous material forms the lower units and increase in abundance towards the upper contact of the unit. Although no bedding planes were observed, the orientation of the carbonaceous material indicates some sort of sub-horizontal bedding. The age of the unit is unknown but is considered to be younger than the Waitemata Group.

The upper unit is more than 40m thick containing white pumice. Near the base of the pumice is a 20m thick bed of accretionary lapilli indicative of airfall origin.

Several small faults with displacements of 1 -2 cm were observed on farm cuttings. These cut both the pumice and carbonaceous siltstone with little alteration to the surrounding rock.

Also observed are the 20 cm thick deposits of bivalve shells material. This is considered to be an intertidal shell bed extending laterally for a considerable distance with uniform thickness. Several shells with both valves intact in their life positions were also found.

The shell bed is a recent deposit which was either uplifted during faulting or formed when sea level was higher than the present.

The basement rocks are the Mesozoic greywacke forming the whole Hauraki rift area (Hochstein and Nixon, 1979). In addition, Hochstein and Nixon (1979), and contained in Reyes and Jongens (2003), reiterate the discharging of thermal waters in Hauraki region are heated groundwater where the water flowing from shallow areas may contain saline pore waters. Thermal activity is also said not to be directly associated with the Quaternary volcanism but by a hot mantle swell.

According to Gregg (1978), the geological features have determined the occurrence of the thermal waters and are important in determining the continuous supply of the spring water.

It has been concluded by Hochstein and Nixon (1979) that the Hauraki depression is an active rift giving rise to the horst and graben structures controlled by three parallel faults.

The faults are also said to control the appearance of hot springs at the margins and centre of the depression.

The faults are also said to control the appearance of hot springs at the margins and centre of the depression

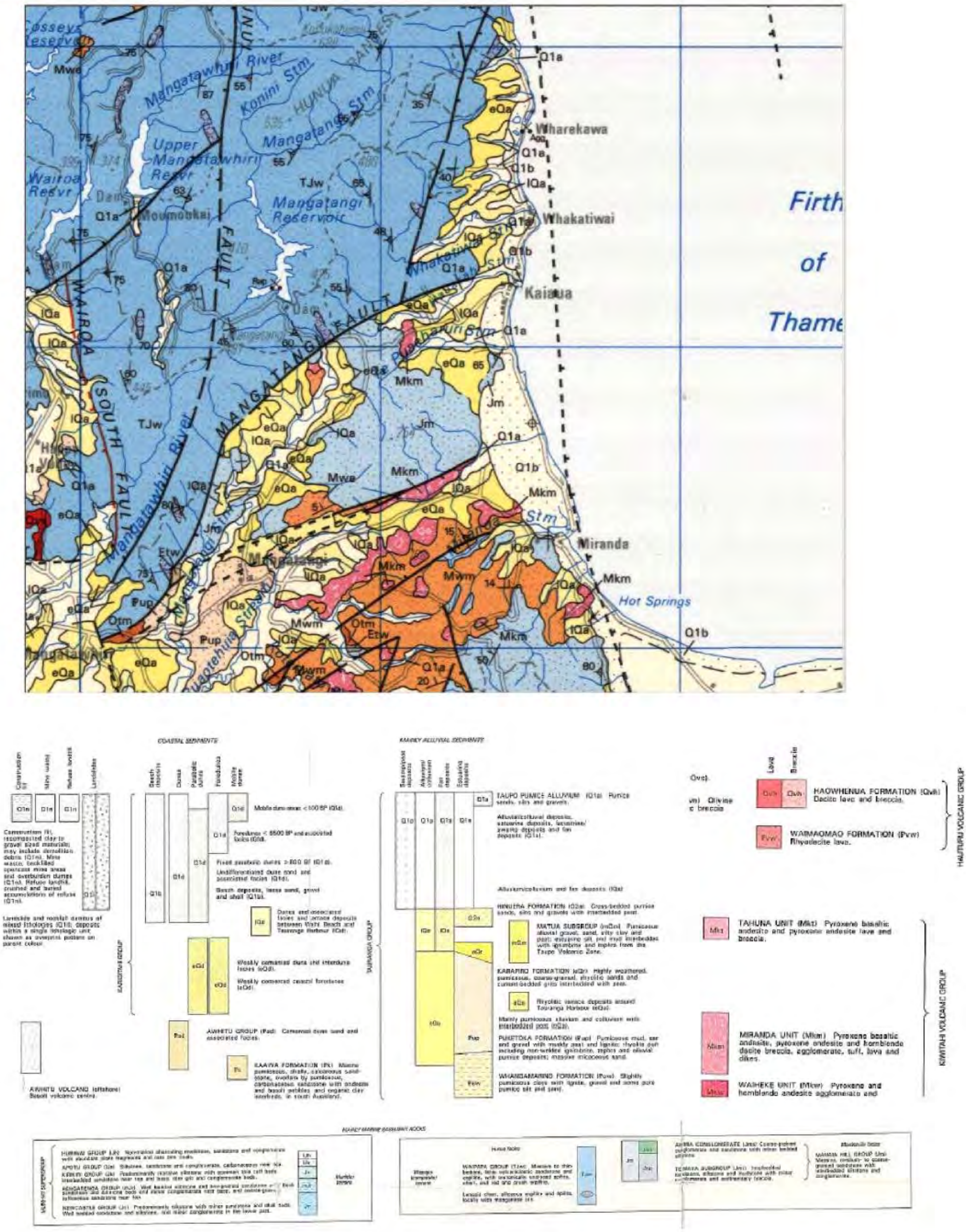


Figure 4: 1:250,000 Geology of Miranda-Kaiaua area (Geological Map of NZ: Geology of the Auckland Area, GNS 2003)

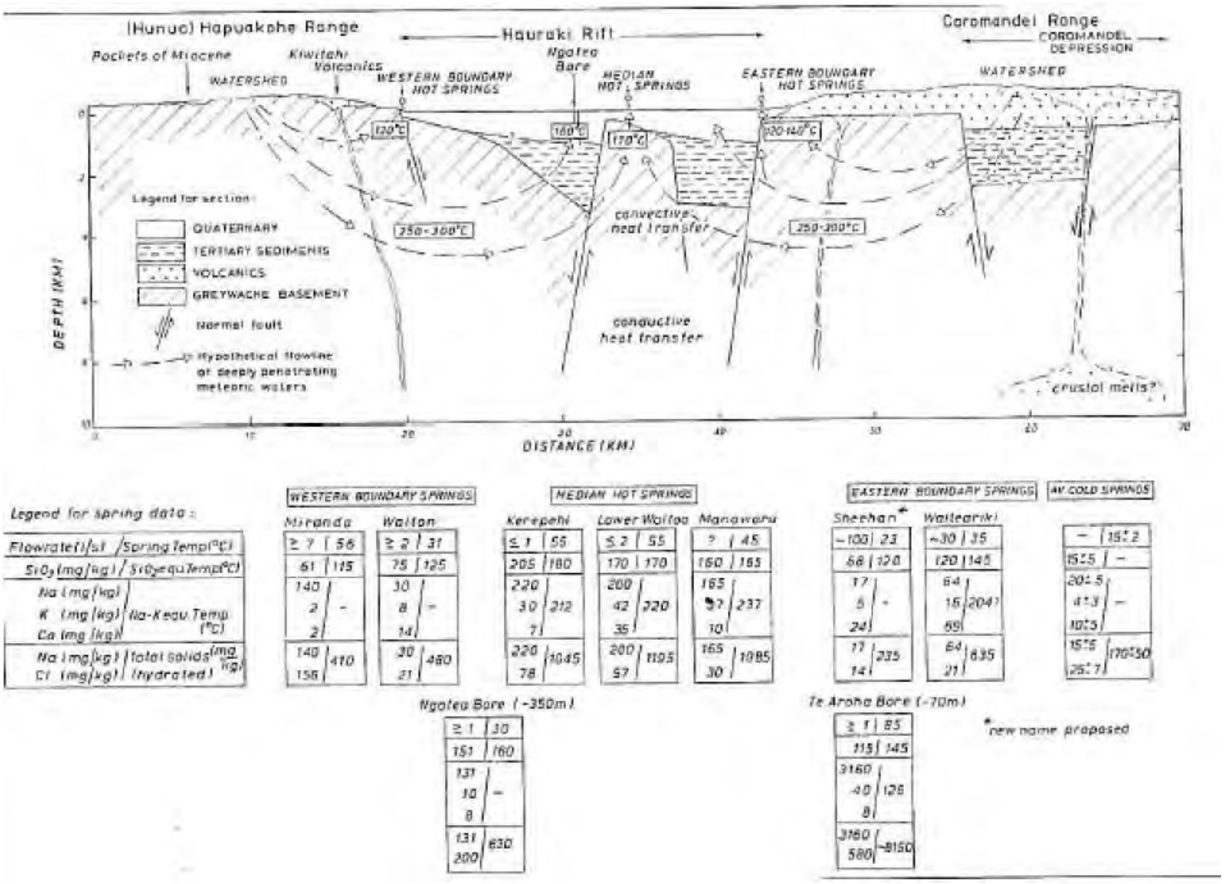
4.2 Hydrogeology

There are two patterns of water circulation existing in the Hauraki depression, a shallow one in the volcanic (Kiwitahi volcanic at the western part and Coromandel at the eastern) and a deeper one in the fractured greywacke basement representing a confined aquifer underlying an almost impermeable layer of the tertiary sediments (Waitemata) (Sudarman, 1981).

It is seen that the shallow aquifer of 30 m is associated with cold and poor quality water while the 100 m deep aquifer is warmer.
Hochstein and Nixon (1979) came up with a simplified hydrogeological section shown in Figure 5. The deeper circulation is connected with the shallow regime through absorption areas on the edges of the depression.

Freeston (1998) states that the genesis of the hot springs is a result of the deep-seated circulation of groundwater. It is the open fractured Mesozoic greywacke along the fault which allows for deep seated groundwater circulation, therefore, resulting in the rapid return to the surface of the thermal waters.

In comparison with studies from Simpson and Tearney (1987), boron-rich warm waters of Whitford, East Auckland, rise rapidly through a zone of high vertical permeability that is associated with intense fractured rocks at the intersection of point of two faults. As the water rises, it meets an impermeable layer (Waitemata sediments – cap rock) and is diverted laterally. The route taken for the lateral flow is the fractures of the basement rock that is downthrown by the Polo Lane Fault and upthrown on the Whitford Fault. Drillholes were conducted in the area showing large quantities of warm water.



Legend for spring data	Miranda	Walton	Kerepehi	Lower Waitoa	Manawaru	Ngatea Bore (-350m)	Sheehan*	Waitearik!	Te Aroha Bore (-70m)	AV COLD SPRINGS
Flowrate (l/s) / Spring Temp (°C)	≥ 7 / 56	≥ 2 / 31	≤ 1 / 55	≤ 2 / 55	? / 45	≥ 1 / 30	~100 / 23	~30 / 35	≥ 1 / 85	– / 15±2
SiO_2 (mg/kg) / SiO_2 equ Temp (°C)	61 / 115	75 / 125	205 / 180	170 / 170	160 / 165	151 / 160	68 / 120	120 / 145	115 / 145	15±5 / –
Na (mg/kg) K (mg/kg) Ca (mg/kg) / Na-K equ Temp (°C)	140 2 2 / –	30 8 14 / –	220 30 7 / 212	200 42 35 / 220	165 37 10 / 237	131 10 8 / –	17 5 24 / –	64 15 69 / 204?	3160 40 8 / 126	20±5 4±3 10±5 / –
Na (mg/kg) Cl (mg/kg) / total solids (mg/kg) (hydrated)	140 156 / 410	30 21 / 460	220 78 / 1045	200 57 / 1195	165 30 / 1085	131 200 / 630	17 14 / 235	64 21 / 635	3160 580 / ~9150	15±5 25±7 / 170±50

Figure 5: **Simplified geological section across the Hauraki Depression, which shows the inferred hydrological setting of the hot springs. Analyses of major constituents, together with flow rate, temperature of springs, SiO_2 and Na-K-Ca equilibrium are shown in the lower part of the figure. (from Hochstein and Nixon, 1979)**

4.3 Geophysics

A small scale resistivity survey by Sudarman (1981) in the Miranda Hot Springs area show that a small area of 0.3 km^2 of low resistivity (up to 20 ohm-metres) to depths of about 85 m correlated with hot spring occurrences.

There is contrast in the resistivities with those from other areas in the region, averaging to 30 to 40 ohm-metres in the sediments and 100 ohm-metres in the greywacke basement.

According to Sudarman (1981), hot water accumulated in the porous sedimentary formation is found above the greywacke basement at a depth of about 85 m.

A resistivity map of Sudarman's work is illustrated in Figure 6. It shows that the low resistivity demonstrated by the 20 ohm-metre contour has a distinct lobe to the north, suggesting that the fluid may be flowing laterally in the north direction, within the Waitemata sediments. This is discussed by Bennie and Graham (2001) that the near surface lateral flow may cause the hot water to reach the surface on the sea floor or mix with cold groundwater in the area.

Recently, further studies were conducted in the Miranda hot springs area by Bennie and Graham (2001) to assess the thermal resource and determine the best option to better utilize the existing resource.

Two measurement techniques were used, vertical electrical sounding (use of expanding array of measuring electrodes) and resistivity gradient array survey (use of fixed current electrodes).

Results from the sounding survey show that sediments with low resistivity (17 ohm-metres) are found at depths of 17 to 96 m, which is the layer concluded to be the Waitemata sediments saturated with hot geothermal water.
Soundings also show increasing resistivity with depth and a high resistivity at about 96 m. This may indicate that the thermal fluid passes through narrow fracture channels in the basement and accumulates in the sediments above.

Resistivity pattern in the gradient measurements also show same horizontal layering in the sounding. Same results were also shown by Sudarman who suggested that the area of shallow hot water accumulates at 0.3 km^2, therefore indicating a substantial volume of hot water in Miranda. This is illustrated in Figure 7.

Figure 8 shows a simple conceptual model of the geophysics data provided. There is no information on the Kaiaua area in any of the previous reports.

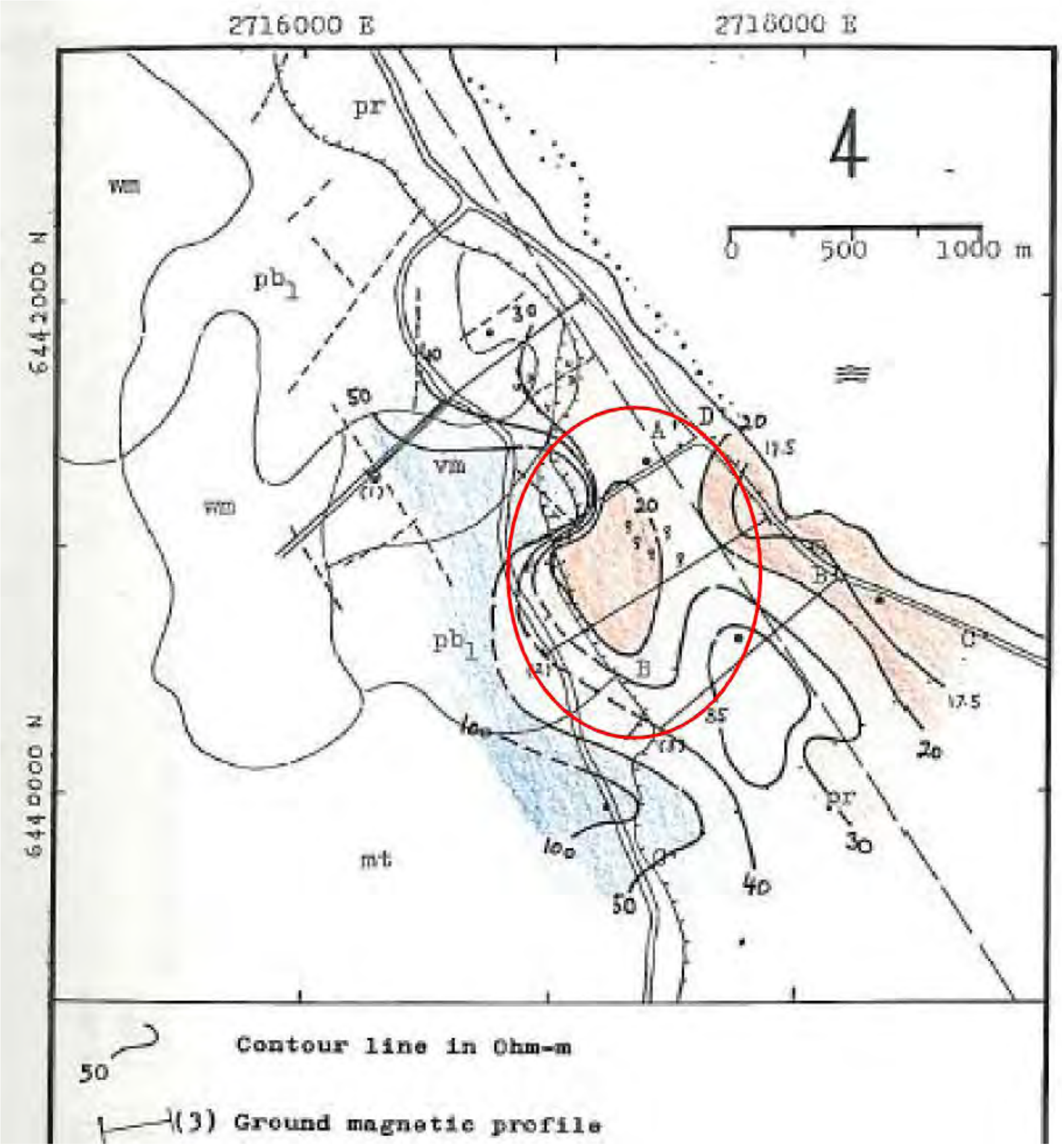


Figure 6: Map showing the lateral distribution of apparent resistivities from Schlumberger array at the Miranda thermal area. (from Sudarman, 1981) The red circle represents an approximate area of the geophysical survey carried out by Bennie and Graham (2001).

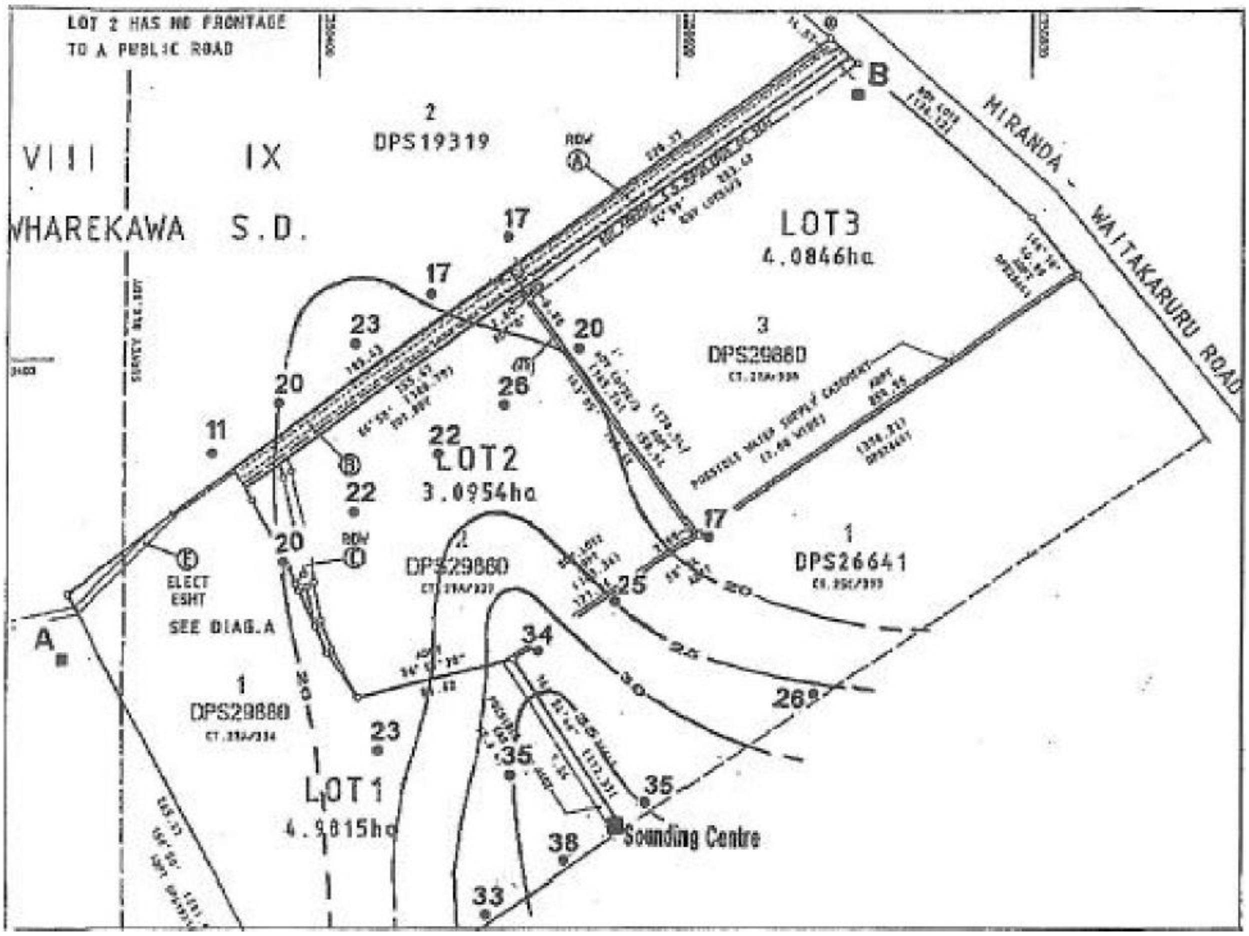


Figure 7: Map showing gradient array apparent resistivities current electrodes are at A and B. (from Bennie and Graham, 2001

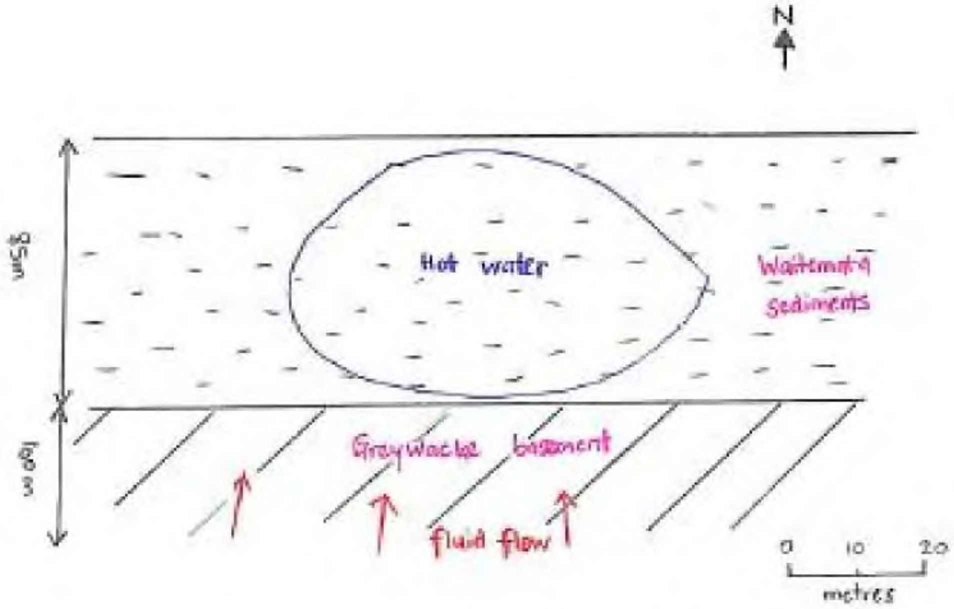


Figure 8: Conceptual model of the system from the provided Geophysics data

4.4 Geochemistry

Previous studies by Petty (1972) and Hochstein (1978) and contained in Johnstone (1979) on the fluid chemistry of Miranda thermal area show that the thermal fluids are very dilute alkali chloride water with total dissolved constituents less than 600 ppm (mainly Na, Cl and SiO_2 (63 ppm). According to Hochstein (1978), the isotopic compositions give an indication that the thermal fluids are heated groundwater. It also indicates that the source is meteoric (Jenkinson, 1994).

Jenkinson (1994) commented that the Miranda waters are of an alkaline sodium chloride composition with very low Mg concentrations and high total sulphur concentrations (in sulphide form).

The relatively low total dissolved solid contents may reflect the origin of deep burial, rather than volcanic contact (Gregg, 1978).

Also of interest is the high borate concentration in the water. This is due to the passage of heated groundwaters through the greywacke basement to other marine sediments. Thermal waters of volcanogenic origin are normally low in borates. SiO_2 content tends to follow the same conclusion (Gregg, 1978).

Johnstone's (1979) work also showed that the gas discharge of the whole area is significant. A thermal feature near the area gave off intermittent H_2S and also odour of H_2S in the swimming pool area. However, gas analysis from Petty (1972) did not mention the presence of H_2S with only N_2, and CH_4 with little amounts of CO_2.
Water analyses conducted in 1918 and 1966 for Miranda Hot Springs and contained in Petty (ibid) and Gregg (1978) are shown in Table 1. There is no data on which springs were sampled as well as their locations.

Table 1: Miranda Spring Chemistry for a918 and 1966 (from Gregg, 1978)

Year	All concentrations (ppm)	Concentration
1966	NaCl	217
	Total dissolved solids	449
1918	$NaHCO_3$	179
	NaCl	281
	SiO_2	29
	$Na_2B_4O_7.10H_2O$ (crystallized borax)	70
	Total solids Traces of Fe, Al, lime and magnesia	559

Later work show similar results. The maximum spring temperatures have been recorded at about 63.8 ^{0}C in 1978. There has been an observation of temperature increase in the springs (1918 – 54.5 ^{0}C, 1966 – 57 ^{0}C and 1978 – 63.8 ^{0}C) and it can be inferred that the temperatures has not decreased over the last few decades. This may also be an indication that the supply of hot water is continuous (Gregg, 1978).

There is no historical data on the flow rates but documentation by Gregg (1978) states that the flow rate has remained constant over the years at approximately 36,000 litres/hour.

Further water analyses for the 4 springs and bores taken in 1972 by TJ Sprott and Associates for the then owners of the pool complex (Mr and Mrs Wilson) are in Table 2.

Table 2: Miranda Spring Chemistry for 1972 (from Gregg, 1978).

Elements	Spring by South trees	Old bore	Stainless steel well	Domestic bore
All results in parts per million				
Hydrogen ion concentration	pH 8.9	pH 8.9	pH 8.9	pH 8.9
Free and saline ammonia	0.444	0.386	0.314	0.042
Albumenoid ammonia	0.093	0.02	0.178	0.04
Oxygen absorbed	6.4	5.3	4.6	1.5
Nitrogen as nitrate	Nil	Nil	Nil	Nil
Free CO2	Nil	Nil	Nil	20
Total alkalinity	95	95	90	95
Chlorides (Cl)	146	212	157	36
Silica (SiO2)	18	38	27	9
Total hardness	10	10	10	60
Calcium hardness	7	9	9	38
Magnesium hardness	3	1	1	22
Carbonate hardness	10	10	10	60
Non carbonate hardness	Nil	Nil	Nil	Nil
Total iron	Nil	0.15	0.7	6.5
Borates (B2O3)	15	12	16	Nil
Equivalent to borax (Na2B4O7)	43	34	46	Nil
Total solids on evaporation	430	335	446	296

4.5 Spring chemistry

This section discusses all information on thermal water chemistry including the sampling results from this 2010 study.

Data from 1990s for Miranda hot springs with only one set of data on Kaiaua (East Coast Road) by Webster-Brown and Brown (2007) were collated and their chemistry interpreted.

Preliminary results of the sites surveyed in 2010 are in Appendix 1. The samples were analysed for various elements to determine generally the chemical properties of the water and the water type, whether it is meteoric, thermal or groundwater.

Figure 9 shows the Giggenbach diagram of the water type of the Miranda and Kaiaua area. With the limited data from previous studies, it can be concluded that the Miranda waters are of alkali chloride composition and the sole Kaiaua sample by Webster-Brown and Brown (2007) represents a mixing of chloride and bicarbonate waters.

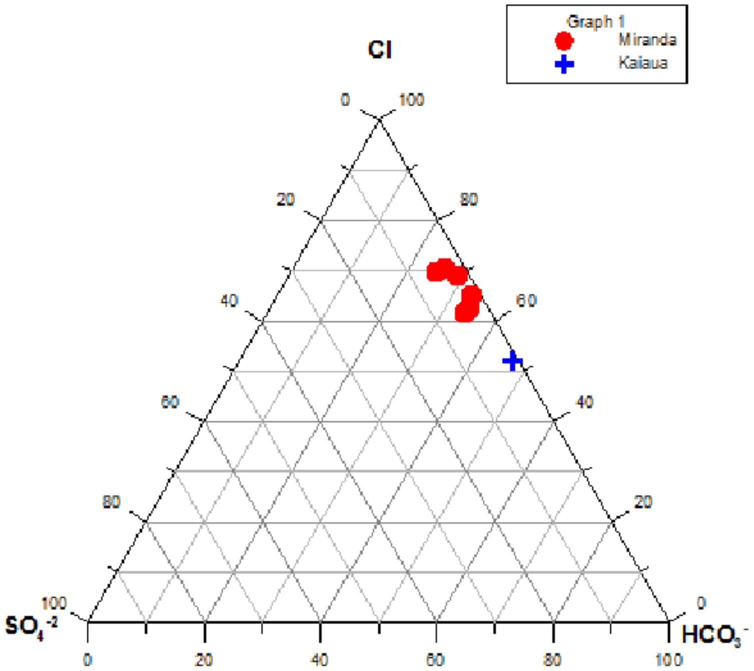


Figure 9: **Water chemistry of Miranda and Kaiaua samples from previous work.**

4.6 Boron and chloride content

Webster-Brown and Brown (2007) suggest the B/Cl ratio of Miranda are from the same source with high boron concentration suggesting a link with the greywacke basement. The Kaiaua result has a lower boron concentration which is interpreted as a connection with the sediments.

Results from the sites surveyed in October 2010 together with Webster-Brown and Brown's (2007) work has rather extreme concentration ranges of chloride and boron. It is seen that there is a very small concentration of boron with high concentration of chloride resulting in variation in the B/Cl ratio.

In comparison, Miranda has a higher boron concentration than Kaiaua as a probable result of it being transported in water phase. High boron concentrations are associated with heated water from the greywacke basement to the sedimentary layer and are also experienced in Whitford and Naike. There is more rock dissolution in Miranda resulting in the high boron concentration. This can be seen in Table 3.

Table 3; **Boron and Chloride concentrations and B/Cl ratio of Miranda and Kaiaua sites.**

References	Site	Cl (mg/l)	B (mg/l)	Cl (Molar)	B (Molar)	Cl/B ratio
Gregg, 1978	Miranda 1916	170	1.98	0.0047955	0.000183	26.18142
Gregg, 1978	Miranda 1966	132	-	0.0037236	-	-
Gregg, 1978	Miranda 1972 (spring by south trees)	146	4.64	0.0041185	0.000429	9.594986
Gregg, 1978	Miranda 1972 (old bore)	212	3.69	0.0059803	0.000341	17.51939
Gregg, 1978	Miranda 1972 (stainless steel well)	157	5	0.0044288	0.000463	9.575007
Gregg, 1978	Miranda 1972 (domestic bore)	36	-	0.0010155	-	-
Hill Laboratories, 1985 (from WRC)	Miranda 1985 (spring stainless steel)	154	5.2	0.0043441	0.000481	9.03
Hill Laboratories, 1985 (from WRC)	Miranda (bore) 1985	155	5	0.0043724	0.000463	9.45

References	Site	Cl (mg/l)	B (mg/l)	Cl (Molar)	B (Molar)	Cl/B ratio
Jenkinson, 1994	Miranda 1 1994	162.8	4.32	0.0045924	0.0004	11.49
Jenkinson, 1994	Miranda 2 1994	190.2	4.5	0.0053653	0.000416	12.89
Hill Laboratories, 2000 (from WRC)	Miranda 2000	158	4.72	0.004457	0.000437	10.21
Hill Laboratories, 2001(from WRC)	Miranda 2001	155	4.54	0.0043724	0.00042	10.41
Hill Laboratories, 2002 (from WRC)	Miranda 2002	193	4.5	0.0054443	0.000416	13.08
Webster-Brown & Brown, 2007	Miranda hot spring	151	<5	0.0042595	-	-
Webster-Brown & Brown, 2007	kaiaua east coast rd (2007)	49	0.666	0.0013822	6.16E-05	22.4
Present study	72_5158	21	0.179	0.0005924	1.66E-05	35.77468
	72_5154	44	0.48	0.0012412	4.44E-05	27.95252
	72_4162	35	0.75	0.0009873	6.94E-05	14.23037
	61_667	61	0.31	0.0017207	2.87E-05	60.00364

4.7 Water temperature

Figure 11 shows the contour map of the locations and temperatures of the sites surveyed for this report. As the temperature increases, the colour changes from yellow to red as shown on the scale. The highest temperature recorded was 41 ^{0}C (Miranda Hot Springs). The rest were either ambient (15 ^{0}C – 17 ^{0}C) or above ambient temperatures (180 ^{0}C+) indicating thermal waters. Two sites from Kaiaua are not plotted as their bore locations were not available at the time of writing, however, their bore water was sampled as temperatures were higher than ambient.

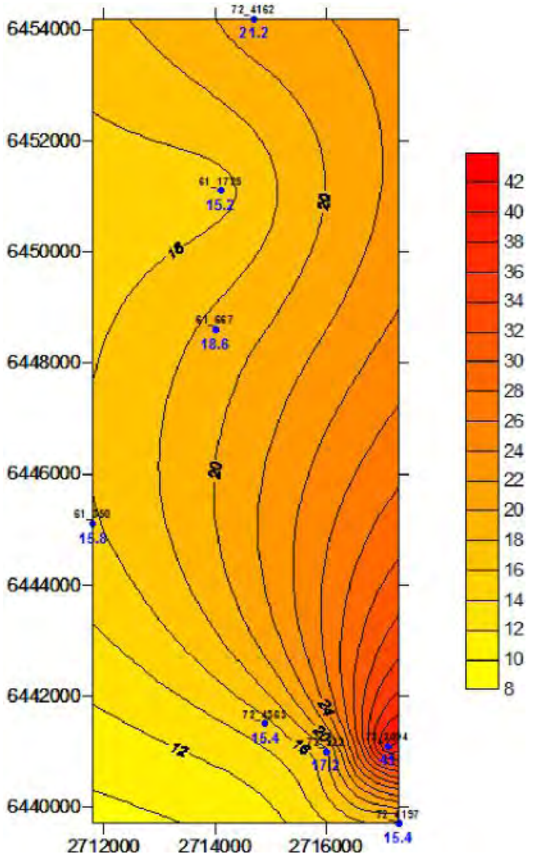


Figure 10: **Contour map of survey points by bore ID and their respective measured temperatures.**

4.8 Bicarbonate (HCO_3), Salinity (NaCl) and Magnesium (Mg) content

With the results at hand, the water type of the samples cannot be confirmed. It can be assumed however that Kaiaua is bicarbonate water from the 3 samples that have been analysed. They show high concentrations ranging from 78-141 g/m^3 or mg/l and are evident of mixing of thermal waters with groundwater. This can be seen in Table 4 together with data from previous work.

Table 4: Bicarbonate (HCO_3) concentrations for Miranda and Kaiaua

References	Site	HCO3 (mg/l)
Hill Laboratories, 1985 (from WRC)	Miranda 1985 (spring stainless steel)	85
Hill Laboratories, 1985 (from WRC)	Miranda (bore) 1985	85
Jenkinson, 1994	Miranda 1 1994	80
Jenkinson, 1994	Miranda 2 1994	79
Hill Laboratories, 2000 (from WRC)	Miranda 2000	-
Hill Laboratories, 2001(from WRC)	Miranda 2001	-
Hill Laboratories, 2002(from WRC)	Miranda 2002	-
Webster-Brown & Brown, 2007	Miranda bath source	54
Webster-Brown & Brown, 2007	Miranda bath source	56
Webster-Brown & Brown, 2007	Miranda hot spring	-
Webster-Brown & Brown, 2007	Kaiaua East Coast Rd (2007)	44
Present Study	Site (2010) Kaiaua	
	72_5158	141
	72_5154	78
	72_4162	in progress
	61_667	102

In addition, the salinity of Miranda is higher than Kaiaua's suggesting that Kaiaua is the diluted outflow. This is shown in Table 5.

Table 5: Salinity (NaCl) concentrations for Miranda and Kaiaua

References	Site	Cl (mg/l)	Na (mg/l)
Gregg, 1978	Miranda 1916	281	
Gregg, 1978	Miranda 1966	217	
Gregg, 1978	Miranda 1972 (spring by south trees)	146	-
Gregg, 1978	Miranda 1972 (old bore)	212	-
Gregg, 1978	Miranda 1972 (stainless steel well)	157	-
Gregg, 1978	Miranda 1972 (domestic bore)	36	-
Hill Laboratories, 1985(from WRC)	Miranda 1985 (spring stainless steel)	154	117
Hill Laboratories, 1985(from WRC)	Miranda (bore) 1985	155	112
Jenkinson, 1994	Miranda 1 1994	162.8	137
Jenkinson, 1994	Miranda 2 1994	190.2	152
Hill Laboratories, 2000(from WRC)	Miranda 2000	158	123
Hill Laboratories, 2001(from WRC)	Miranda 2001	155	132
Hill Laboratories, 2002(from WRC)	Miranda 2002	193	122
Webster-Brown & Brown, 2007	Miranda bath source	151	133
Webster-Brown & Brown, 2007	Miranda bath source	150	127
Webster-Brown & Brown, 2007	Miranda hot spring	151	80
Webster-Brown & Brown, 2007	Kaiaua East Coast Rd (2007)	49	62.8
Present Study	Site (2010) Kaiaua		
	72_5158	21	46
	72_5154	44	46
	72_4162	35	56
	61_667	61	67

Differences in the magnesium content of Miranda and Kaiaua samples are provided in Table 6. Magnesium indicates the presence of groundwater. It is seen that Miranda has a very low magnesium concentration, while Kaiaua has a slightly higher concentration, suggesting that Miranda is alkali chloride water.

Table 6: Magnesium (Mg) concentration for Miranda-Kaiaua area

References	Site	Mg (mg/l)
Hill Laboratories, 1985(from WRC)	Miranda 1985 (spring stainless steel)	<0.2
Hill Laboratories, 1985(from WRC)	Miranda (bore) 1985	<0.2
Jenkinson, 1994	Miranda 1 1994	0.046
Jenkinson, 1994	Miranda 2 1994	0.036
Hill Laboratories, 2000(from WRC)	Miranda 2000	0.02
Hill Laboratories, 2001(from WRC)	Miranda 2001	-
Hill Laboratories, 2002(from WRC)	Miranda 2002	0.009
Webster-Brown & Brown, 2007	Miranda bath source	0.02
Webster-Brown & Brown, 2007	Miranda bath source	0.01
Webster-Brown & Brown, 2007	Miranda hot spring	<0.02
Webster-Brown & Brown, 2007	Kaiaua East Coast Rd (2007)	0.03

References	Site	Mg (mg/l)
Present Study	Site (2010) Kaiaua	
	72_5158	1.48
	72_5154	1.57
	72_4162	0.84
	61_667	1

4.9 Soil chemistry

Interesting to note with similarities to the Miranda-Kaiaua area is the geochemical soil surveys that have been conducted in nearby low enthalpy geothermal resources of Naike by Nicholson *et.al* (1989). The survey showed that not only are the soil surveys an effective tool in exploration of the resources, but also that the results illustrated a pattern of anomalies parallel to known faults, meaning the hydrology is dominated by fractures. Furthermore, the use of ammonia was seen to be a reliable pathfinder species defining areas of thermal activity and fluid flow.

Figure 11 shows the location of study area of soil surveys in Naike and Whitford are in proximity to Miranda, hence some similarities in the geochemistry.

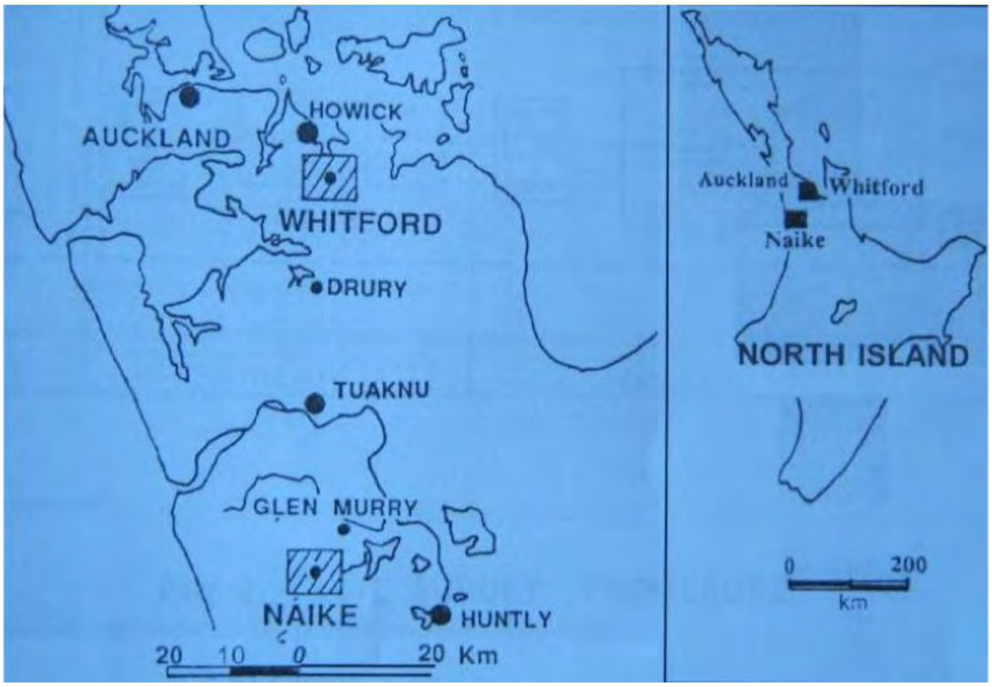


Figure 11: Location of Naike and Whitford, Auckland. (from Wei and Nicholson, 1990)

4.10 Geothermometers

Since the waters do not approach boiling temperatures or deposit silica at the surface, the main factors limiting the silica geothermometers application are that:

1. Silica precipitates at the subsurface
2. Dilution or mixing with shallower waters (Jenkinson, 1994).

Quartz is the most stable SiO_2 species controlling the dissolved silica content in fluid temperatures of > 180 ^{0}C and also at lower temperatures if fluids descend slowly enough. The slow ascending fluids are seen to cool conductively (Jenkinson, 1994).

Jenkinson (1994) comments that Miranda waters are low in SiO_2 so the application of the quartz geothermometer is more suited for these waters.

The cation geothermometers of Na-K-Ca were applied to the study by Jenkinson (1994) on evaluating the deep subsurface equilibrium temperature of the Hauraki Depression. However, such geothermometers can only be applied to near neutral pH chloride waters. The sensitivity of the Na-K-Ca geothermometer to variations in the amount of CO_2 in the waters as well as the Na-K geothermometer is applied only to low calcium-concentration waters. Therefore, the Na-K-Ca and K-Mg geothermometers were applied to the Miranda waters out of the rest in the Hauraki Plains.

Further mentioned in Jenkinson's report on the study of thermal waters and wells in the Hauraki Depression, is that Miranda waters has a different composition form the rest of the Hauraki Plains in that it is alkali sodium-chloride. The very low magnesium concentration and apparent equilibrium composition indicate that these are unmixed thermal waters.

The silica and cation geothermometers in Table 7 show a consistent result with equilibrium temperatures of about 80-100 ^{0}C and is close to the observed surface temperature of nearly 60 ^{0}C, showing that equilibrium compositions are obtained at shallow depths.

Table 7: Summary of geothermometer of Miranda Springs (from Jenkinson, 1994)

References	**Site**	**Cond. qtz**	**Chalcedony**	**Am. SiO2**	**Observed**	**K-Mg**	**Na-KCa**
		Temp °C	Temp °C	Temp °C	Temp °C	Temp °C	Temp °C
Jenkinson, 1994	Miranda 1	105	75	-12	56	92	88
Jenkinson, 1994	Miranda 2	101	71	-15	57	91	83

Applicable geothermometer temperatures highlighted in bold.

Quartz geothermometer of the Kaiaua area is seen to range from 70-122 ^{0}C. This in comparison to Miranda geothermometers, where they are within the 101-105 ^{0}C range according to data by Webster-Brown and Brown (2007) and geochemical analyses from Waikato Regional Council. They reach equilibrium at a later stage.

Table 8: Kaiaua geothermeter from Webster-Brown and Brown and present study

References	**Sample Name**	**Quartz**	**Na-K**
Webster-Brown & Brown, 2007	Kaiaua	64.23386	94.85646
	72_5158	78.5226	163.2884
	72_5154	122.6263	235.7248
	72_4162	79.92428	195.3826
Present Study	61_667	70.84374	116.0146

Limited data and consistency of data collection in these two areas provides difficulty in mapping out the extent of the resource, therefore assumptions are made.

4.11 Stored Heat

Below is the calculation on the estimated stored heat for Miranda. The volume was obtained from Sudarman's (1981) work where he surveyed an area of 0.3 km^2. This study showed that the greywacke basement is at depth of 85 m which is the area of hot water accumulation.

Porosity of the rock (Waitemata sediments) is assumed to be 10% as a result of some clay minerals present. Density and the rock heat specific are standard numbers. The temperature of the reservoir is about 64 ^{0}C which was the last measured temperature for the spring in 1978 (Gregg, 1978).

	Volume V (300000 x 85) m**3	2.55000E+07
Rock properties	Porosity POR	0.1
	Rock density RHOR (kg/m**3)	2500
	Rock specific heat CR (J/kg K)	1000
Thermodynamic quantities	Temperature T (deg C)	64
	Pressure P (bar) - from Steam Tables	0.23942
	Liquid saturation SL	0.9
	Vapour saturation SV=1-SL	0.1
	Density of water RHOL (kg/m**3) - from Steam Tables	981.07
	Density of steam RHOV (kg/m**3) - from Steam Tables	0.1548
	Enthalpy of water HL (kJ/kg) - from Steam Tables	267.9
	Enthalpy of steam HV (kJ/kg) - from Steam Tables	2615.8
	Internal energy of water UL (J/kg) =HL-P/RHOL	2.67876E+05
	Internal energy of steam UV (J/kg) =HV-P/RHOV	2.46114E+06
Heat calculations	Heat in rock AER (J/m**3) = (1-POR)*RHOR*CR*T	1.44000E+08
	Heat in water AEL (J/m**3) = POR*RHOL*UL*SL	2.36524E+07
	Heat in steam AEV (J/m**3) = POR*RHOV*UV*SV	3.80984E+03
	Heat in fluid AEF (J/m**3) = AEL+AEV	2.36562E+07
	Heat in reservoir AE (J/m**3) = AER+AEF	1.67656E+08
Total	Total heat in reservoir J =AE*VOL	4.27523E+15
	Total heat in reservoir MJ	4.27523E+09
	H theoretical	4.27523E+09
	Recovery	0.4
	Hdesign, MJ	1.71009E+09
	Time,years	25
	Time,sec	788400000
	Efficiency of Conversion	0.1
	Stored heat in Mwe	2.16907E-01

5 Discussion

From the data gathered, it can be assumed that Miranda-Kaiaua is somewhat a linked resource. The geology is uniform throughout the two areas even though they have separate hydrological systems.

Miranda has a shallow aquifer and Kaiaua a deeper one, where the deeper circulation is connected with the shallow regime through absorption areas on the edges of the depression as stated by Hochstein and Nixon (1979).

The Hauraki depression is an active rift giving rise to the horst and graben structures controlled by three parallel faults (Hochstein and Nixon, 1979). Similar situations in the Whitford and Naike fields also show that warm waters rise rapidly through the high permeability associated with fractures at the fault sand are diverted laterally to the up-thrown part of the fault line. This can be the same scenario for Miranda-Kaiaua area, as the warm waters flow in a lateral direction towards Kaiaua to the North, parallel with the NE trending fault at Miranda.

Geophysics surveys by Sudarman (1981) also show low resistivity at shallow depths, which may allow for fluid flow in a lateral direction towards the north within the sedimentary layer (Waitemata). This suggests that fluid flows towards the Kaiaua area mixing with groundwater.

The geochemistry also suggests the linkage between the two areas. The bicarbonate waters of Kaiaua indicate mixing of deep thermal waters with groundwater from the shallow chloride rich waters of Miranda.

Miranda has a higher boron concentration than Kaiaua, probably as a result of it being transported in water phase. High boron concentrations are associated with heated water from the greywacke basement to the sedimentary layer and are also experienced in Whitford and Naike. There is more rock dissolution in Miranda resulting in the high boron concentration.

In addition, the salinity of Miranda is higher than for Kaiaua. This suggests that Kaiaua is the diluted outflow of Miranda. The magnesium concentration also indicates that Miranda is the upflow of the resource as it has very low concentrations and is associated with heated groundwater.

Due to the limited data available and inconsistency in sample collection and records, it is difficult to estimate the extent of the Miranda-Kaiaua resource, however, the stored heat calculated for the Miranda area is 2.169 MWe, a rather small resource.

6 Recommendations

New Zealand has a wide range of geothermal resources, one being low enthalpy in nature. According to Carey (2010), there are plans for further development of geothermal resources under the New Zealand Energy Strategy to 2050, to increase the use of renewable energy by the nation. Part of this strategy is the potential increase in low enthalpy geothermal resources.

However, the lack of data is the weakness in having a better understanding of these systems therefore, more research is needed on identifying and recording them and better utilizing them sustainably. According to Carey (2010) this will be undertaken as part of a 3 year program covering aspects of technological development, economics, social understanding, and national and regional policy framework.

Currently, the resource is utilized for the heating of the Miranda swimming pool complex. It is important to ensure that further development of the thermal water resource of the Miranda-Kaiaua area be sustainable in that it does not deplete the reservoir in future. This is dependent on the rate of heat and mass withdrawal, pressure drawdown in the reservoir, as well as the recharge supplied to the resource. As development proceeds with extensive use, it will be vital to have a reinjection program in place in order to support the pressure in the reservoir.

7 Conclusion

Miranda-Kaiaua is somewhat a linked resource as the evidence of the geophysics and geochemical surveys that have been carried out in the past and recently.

The aquifer systems are separate but they are connected through the absorption of the depression. The system is a fault-driven one allowing for the flow of water from the basement to the sediment layer then finally emerging as springs or percolating through the sedimentary layer with some mixing occurring.

Geophysics surveys show low resistivity at shallow depths which may allow for fluid flow in a lateral direction towards the north within the Waitemata sediments, suggesting that the fluid flows towards the Kaiaua area, mixing with groundwater.

The B/Cl ratio of Miranda and Kaiaua distinguishes the two areas and is noticed that Miranda contains higher boron concentration than Kaiaua, suggesting heated groundwater from the greywacke basement is dissolving minerals and entering the sediment layer. It has very low magnesium concentrations, which is associated with alkali chloride water. Therefore, Miranda is the upflow of the system.

Kaiaua is seen to be the outflow of the system as a result of the low boron concentration and low salinity.

Preventing damaging effects to the resource in terms of pressure drawdown, with heat and mass flow depletion is vital to ensure that the future use is sustainable in order for the resource to continue providing geothermal heat.

References

Bennie SL, Graham DJ 2001. Geophysical assessment of the geothermal resource at Miranda Hot Springs. GNS Report 2001/26. [Lower Hutt]. Geological & Nuclear Sciences Ltd (GNS Science).

Carey B 2010. Low Enthalpy Geothermal Research – New Zealand. World Geothermal Congress 2010. Bali, Indonesia, International Geothermal Association.

Dewhurst RH 1982. Warm ground water and its potential uses in the Thames Valley. Te Aroha, Hauraki Catchment board.

Freeston DH, Lund John W 1998. Miranda hot springs. Quarterly Bulletin Oregon Institute of Technology. Geo Heat Center 19(3): 35-36.

Hochstein MP 1978. Geothermal systems in the Hauraki rift zone (New Zealand) - an example for geothermal systems over an inferred Upper Mantle Swell. Alternative Energy Sources: an International Computer Edition. Veziroglu, Washington, Hemisphere Publishing Corporation: 2599-2610.

Hochstein MP, Nixon IM 1979. Geophysical study of the Hauraki depression, North Island, New Zealand. New Zealand Journal of Geology and Geophysics 22: 1-19.

Jenkinson DG 1994. Studies of Thermal Waters and Thermal Wells in the Hauraki Depression. Unpublished thesis, University of Auckland, Auckland.

Johnstone RD 1979. Miranda thermal area. In: Horne RN ed. Proceedings of the New Zealand Geothermal Workshop 1979 (Part 2): 355-362.

Nicholson K, Franklyn AK, Aredes SD 1989. Geochemical soil surveys: an exploration technique for low-enthalpy geothermal resources. In: Browne PRL, Nicholson K ed. Proceedings of the 11th New Zealand Geothermal Workshop 1989: 189-193.

Petty DR 1972. Springs of the Auckland region. New Zealand Geological Survey Report 57.Wellington, Department of Scientific and Industrial Research.

Reyes AG, R. J 2003. Tectonic setting of low enthalpy geothermal systems in New Zealand : a review. 25th New Zealand Geothermal Workshop. Auckland, University of Auckland.

RC G 1978. Geological Site Report. In Miranda Hot Springs – Pool Complex Consents Application.

Rockel I 1986. Taking the waters : early spas in New Zealand. Wellington, New Zealand, Government Printing Office.

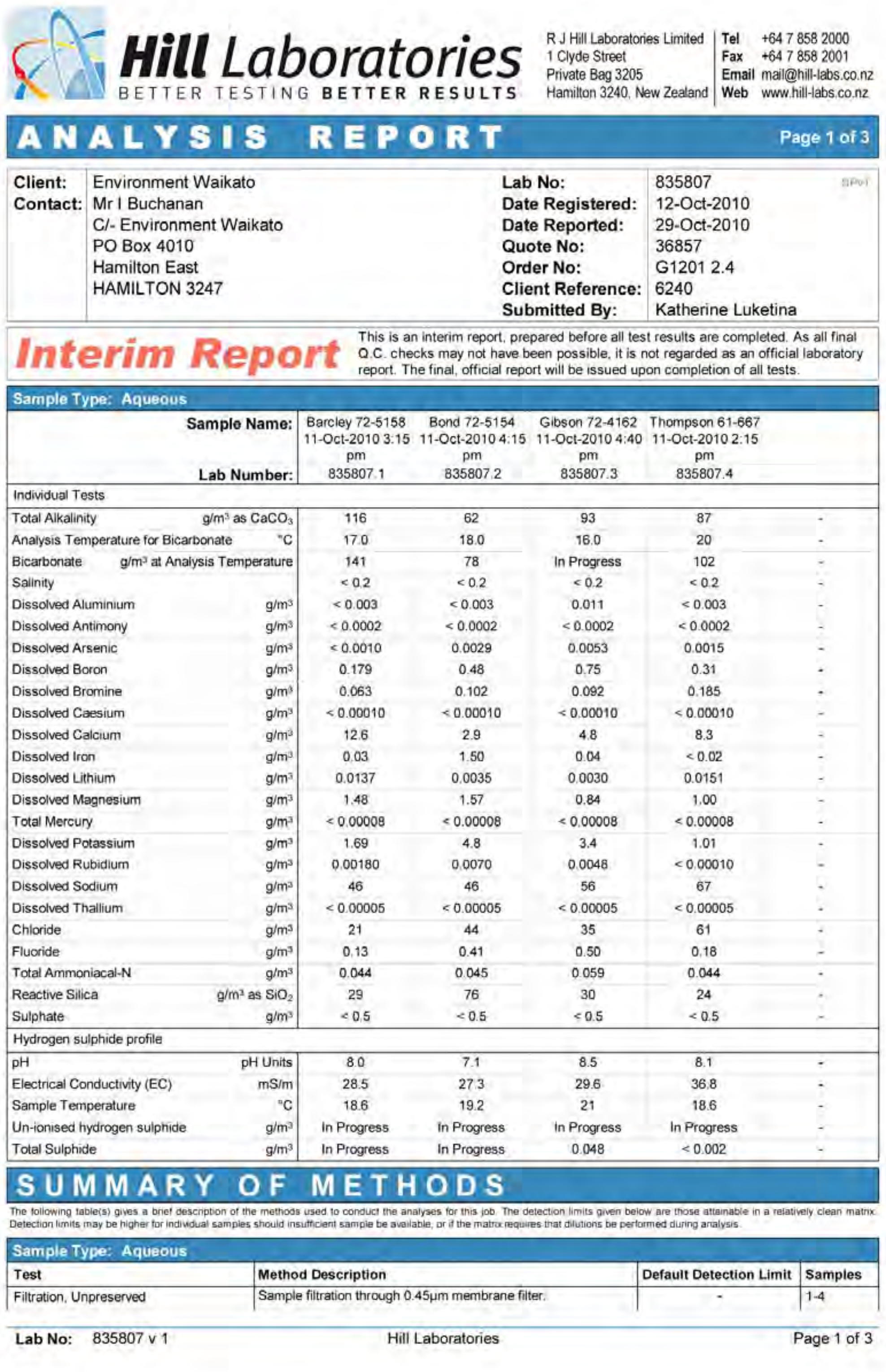
Simpson B, Tearney K 1987. Development of a low enthalpy water resource at Whitford, East Auckland. 9th New Zealand Geothermal Workshop. Auckland, University of Auckland.

Sudarman S 1981. A DC resistivity and magnetic survey of the Miranda hot springs area. Unpublished Diploma thesis, University of Auckland, Auckland.

Webster-Brown JG, Brown KL 2008. Interpretation of Geochemical Data (REGEMP II) and Recommendations for Further Monitoring. Waikato Regional Council Technical Report 2008/01.

Wei L, Nicholson K 1990. Boron in soil over Naike and Whitford low-enthalpy geothermal fields, New Zealand. In: Freeston DH, Browne PRL, Scott GL ed. Proceedings of the 12th New Zealand Geothermal Workshop 1990: 177-182.

Appendix 1 – Analysis Report of water samples from Kaiaua, 2010



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ANALYSIS REPORT

Page 1 of 3

Client:	Environment Waikato	**Lab No:**	835807
Contact:	Mr I Buchanan C/- Environment Waikato PO Box 4010 Hamilton East HAMILTON 3247	**Date Registered:**	12-Oct-2010
		Date Reported:	29-Oct-2010
		Quote No:	36857
		Order No:	G1201 2.4
		Client Reference:	6240
		Submitted By:	Katherine Luketina

Interim Report

This is an interim report, prepared before all test results are completed. As all final Q.C. checks may not have been possible, it is not regarded as an official laboratory report. The final, official report will be issued upon completion of all tests.

Sample Type: Aqueous

Sample Name:		Barcley 72-5158 11-Oct-2010 3:15 pm	Bond 72-5154 11-Oct-2010 4:15 pm	Gibson 72-4162 11-Oct-2010 4:40 pm	Thompson 61-667 11-Oct-2010 2:15 pm	
Lab Number:		835807.1	835807.2	835807.3	835807.4	
Individual Tests						
Total Alkalinity	g/m^3 as $CaCO_3$	116	62	93	87	-
Analysis Temperature for Bicarbonate	°C	17.0	18.0	16.0	20	-
Bicarbonate	g/m^3 at Analysis Temperature	141	78	In Progress	102	-
Salinity		< 0.2	< 0.2	< 0.2	< 0.2	-
Dissolved Aluminium	g/m^3	< 0.003	< 0.003	0.011	< 0.003	-
Dissolved Antimony	g/m^3	< 0.0002	< 0.0002	< 0.0002	< 0.0002	-
Dissolved Arsenic	g/m^3	< 0.0010	0.0029	0.0053	0.0015	-
Dissolved Boron	g/m^3	0.179	0.48	0.75	0.31	-
Dissolved Bromine	g/m^3	0.063	0.102	0.092	0.185	-
Dissolved Caesium	g/m^3	< 0.00010	< 0.00010	< 0.00010	< 0.00010	-
Dissolved Calcium	g/m^3	12.6	2.9	4.8	8.3	-
Dissolved Iron	g/m^3	0.03	1.50	0.04	< 0.02	-
Dissolved Lithium	g/m^3	0.0137	0.0035	0.0030	0.0151	-
Dissolved Magnesium	g/m^3	1.48	1.57	0.84	1.00	-
Total Mercury	g/m^3	< 0.00008	< 0.00008	< 0.00008	< 0.00008	-
Dissolved Potassium	g/m^3	1.69	4.8	3.4	1.01	-
Dissolved Rubidium	g/m^3	0.00180	0.0070	0.0048	< 0.00010	-
Dissolved Sodium	g/m^3	46	46	56	67	-
Dissolved Thallium	g/m^3	< 0.00005	< 0.00005	< 0.00005	< 0.00005	-
Chloride	g/m^3	21	44	35	61	-
Fluoride	g/m^3	0.13	0.41	0.50	0.18	-
Total Ammoniacal-N	g/m^3	0.044	0.045	0.059	0.044	-
Reactive Silica	g/m^3 as SiO_2	29	76	30	24	-
Sulphate	g/m^3	< 0.5	< 0.5	< 0.5	< 0.5	-
Hydrogen sulphide profile						
pH	pH Units	8.0	7.1	8.5	8.1	-
Electrical Conductivity (EC)	mS/m	28.5	27.3	29.6	36.8	-
Sample Temperature	°C	18.6	19.2	21	18.6	-
Un-ionised hydrogen sulphide	g/m^3	In Progress	In Progress	In Progress	In Progress	-
Total Sulphide	g/m^3	In Progress	In Progress	0.048	< 0.002	-

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Samples
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter.	-	1-4

Lab No: 835807 v 1 Hill Laboratories Page 1 of 3

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Samples
pH	pH meter. APHA 4500-H^+ B 21st ed. 2005.	0.1 pH Units	1-4
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (Modified for alk <20) 21st ed. 2005.	1.0 g/m^3 as $CaCO_3$	1-4
Analysis Temperature for Bicarbonate	Temperature at which Bicarbonate titration was conducted as reported by Geological & Nuclear Sciences, Wairakei.	1.0 °C	1-4
Bicarbonate	Bicarbonate (HCO3) Titration Method conducted at reported temperature. Subcontracted to Geological & Nuclear Sciences, Wairakei. ASTM Standards D513-82 Vol.11.01 of 1988.	20 g/m^3 at Analysis	1-4
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B 21st ed. 2005.	0.1 mS/m	1-4
Salinity	Meter, no temp. compensation. APHA 2520 B 21st ed. 2005.	0.2	1-4
Sample Temperature	Supplied by customer, otherwise 20°C.	0.10 °C	1-4
Filtration for dissolved metals analysis	Sample filtration through 0.45µm membrane filter and preservation with nitric acid. APHA 3030 B 21st ed. 2005.	-	1-4
Dissolved Aluminium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.003 g/m^3	1-4
Dissolved Antimony	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.0002 g/m^3	1-4
Dissolved Arsenic	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.0010 g/m^3	1-4
Dissolved Boron	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.005 g/m^3	1-4
Dissolved Bromine	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.005 g/m^3	1-4
Dissolved Caesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.00010 g/m^3	1-4
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.05 g/m^3	1-4
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.02 g/m^3	1-4
Dissolved Lithium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.0002 g/m^3	1-4
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.02 g/m^3	1-4
Total Mercury	Bromine Oxidation followed by Atomic Fluorescence. US EPA Method 245.7, Feb 2005.	0.00008 g/m^3	1-4
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.05 g/m^3	1-4
Dissolved Rubidium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.00010 g/m^3	1-4
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.02 g/m^3	1-4
Dissolved Thallium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.00005 g/m^3	1-4
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500 Cl^- E (modified from continuous flow analysis) 21st ed. 2005.	0.5 g/m^3	1-4
Fluoride	Direct measurement, ion selective electrode. APHA 4500-F^- C (modified from manual analysis) 21st ed. 2005.	0.05 g/m^3	1-4
Total Ammoniacal-N	Filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH_4-N = NH_4+-N + NH_3-N). APHA 4500-NH_3 F (modified from manual analysis) 21st ed. 2005.	0.010 g/m^3	1-4
Reactive Silica	Filtered sample. Heteropoly blue colorimetry. Discrete analyser. APHA 4500-SiO_2 F (modified from flow injection analysis) 21st ed. 2005.	0.10 g/m^3 as SiO_2	1-4
Un-ionised hydrogen sulphide	Calculation from total sulphide, EC, pH and temperature. APHA 4500-S^{2-} H 21st ed. 2005.	0.002 g/m^3	1-4
Sulphide Microdistillation	Acid distillation of sample into alkaline trapping solution using Lachat MICRO DIST system. APHA 4500-S^{2-} I 21st ed. 2005.	-	1-4
Total Sulphide	Sulphide microdistillation. Automated methylene blue colorimetry, flow injection analyser. APHA 4500-S^{2-} I 21st ed. 2005.	0.002 g/m^3	1-4
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B 21st ed. 2005.	0.5 g/m^3	1-4

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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Ara Heron BSc (Tech)
Client Services Manager - Environmental Division