LOW ENTHALPY GEOTHERMAL RESOURCES – MIRANDA-KAIAUA, NEW ZEALAND

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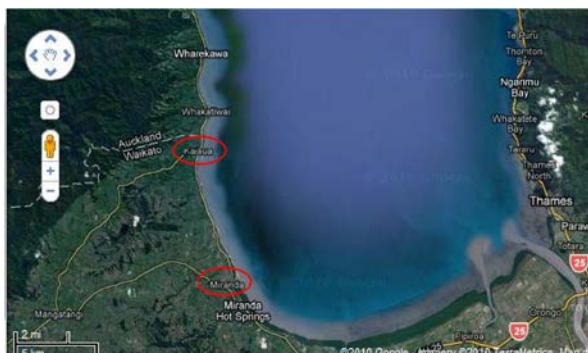
ABSTRACT

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

As part of the survey, water samples from four sites in Kaiaua were analyzed 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 from the greywacke basement reaches the overlying Waitemata sediments. It then flows laterally in a north direction through the Waitemata sediments reaching Kaiaua area.

1. INTRODUCTION

This report encompasses the western portion of the Hauraki Depression from the Miranda Hot Springs to the Kaiaua area (See Figure 1).

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

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 geochemical analyses are reported and interpreted.

This paper uses previous work, and the most recent survey, to establish a conceptual model of the Miranda-Kaiaua system.

2. MIRANDA HOT SPRINGS

2.1 Location and history

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 metre above sea level and 700 m inland from the sea edge and 3 km south from the old site of the Miranda township.

The Miranda hot springs were once known as the Hauraki Hot Springs and later changed to their current name, taking it from a Naval gun boat that was dispatched during the Maori wars (Gregg, 1978). Approximately 100 hot springs were located over an area of 40 hectares (Rockel, 1986).

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.

The springs remained undeveloped due to the lack of road access until the mid-19th century. One of the early European land owners, J. Pond, carried out early water analyses throughout the country and was disappointed that the government refused to purchase the springs in 1903 and 1913.

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

2.2 Present development

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

Three springs are used to heat the spa pools (See Figure 3) with a large 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 main pool temperature of 35-37 ^{0}C and 40-41 ^{0}C in 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 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).

2.3 Soils and 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. Because of this, and a high water table, the Miranda-Kaiaua area is suited for grazing purposes and is generally farmland consisting of mainly cattle farms with limited horticultural potential (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 small townships of Miranda and Kaiaua comprise small shops, district schools and other essential services.

2.4 Sustainability of geothermal use

In the 1950s the first substantial use of the geothermal resource at Miranda commenced with the building of the swimming pool over the springs area. The first shallow geothermal well was drilled some time after that. Current consented take from wells for the baths complex and a separate motor camp is 907 cubic metres per day. This is in addition to the water that upwells directly into the main swimming pool. All of the wells are artesian. To date there has been no evidence that the resource is being depleted. Analysis of flows over time and any changes in geochemistry would be early indicators of stress on the resource. Intrusion by water from the cold mineralized aquifer or seawater are a possibility. There are also may wells in the area accessing the cold groundwater for farming and horticulture, so the reverse problem of breakthrough of the hot resource into the warm ground water is also a possibility. Although to date there has been no evidence of communication between aquifers, any further applications for take from the resource should provide evidence of the resource's sustainability, and where possible, given the mixed uses of the water, reinjection of the used water should be considered.

3. MIRANDA-KAIAUA GEOSCIENCE

3.1 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 20 m southeast 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 hydrothermally altered rocks, silica sinters or deposition (Sudarman, 1981, Freeston, 1998).

The basement rocks are the Mesozoic greywacke forming the whole Hauraki rift area (Hochstein and Nixon, 1979).

The oldest rocks exposed are pale cream to grey sandstone with rare 20-30 m thick siltstone beds. These are 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, with an horizontal conformable contact. Brown sandy siltstone with carbonaceous material forms the lower units. 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 40 m thick containing white pumice. Near the base of the pumice is a 20 m thick bed of accretionary lapilli indicative of airfall origin.

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

Also exposed are 20 cm thick deposits of bivalve shells material. This is an intertidal shell bed extending laterally for a considerable distance with uniform thickness. 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 Hauraki depression is an NNE trending active rift giving rise to the horst and graben structures (Hochstein and Nixon, 1979). Basement faults control the appearance of hot springs at the margins of the rift.

3.2 Hydrogeology

There are two aquifers in the Hauraki depression, a shallow one in the volcanic rocks (Kiwitahi volcanics) 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 Waitemata sediments (Sudarman, 1981).

The shallow aquifer of 30 m is associated with cold water while the 100 m deep aquifer is warmer.

Hochstein and Nixon (1979) came up with a simplified hydrogeological section. 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. The open fractured Mesozoic greywacke along the fault allows for deep seated groundwater circulation, therefore, resulting in the rapid return to the surface of the thermal waters.

By comparison (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 up-thrown on the Whitford Fault. Drill holes in the area produce large quantities of warm water.

3.3 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. Hot water has accumulated in a porous sedimentary formation which is found above the greywacke basement at a depth of about 85 m (for comparison, resistivities in other areas in the region, average to 30 to 40 ohm-metres in the sediments and 100 ohm-metres in the greywacke basement).

Sudarman's resistivity map 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.

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 inferred to be the Waitemata sediments that contain 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. It is suggested that near surface lateral flow may direct some of the hot water to discharge on the sea floor or mix with cold groundwater in the area.

Resistivity pattern in the gradient measurements also show same horizontal layering in the sounding. Similar results were also shown by Sudarman who suggested that the area of shallow hot water is 0.3 km^2.

3.4 Geochemistry

Petty (1972) and Hochstein (1978) show that the thermal fluids in the Miranda thermal area are very dilute alkali chloride water with total dissolved constituents less than 600 ppm (mainly Na, Cl and SiO$_2$). The isotopic compositions give an indication that the thermal fluids are heated groundwater and that the source is meteoric (Jenkinson, 1994).

The Miranda waters also have very low Mg concentrations and high total sulphur concentrations (in sulphide form) Jenkinson, 1994).

The relatively low total dissolved solid contents may reflect the origin of the fluids is deep circulation on fault planes without coming into contact with volcanic fluids or magma. The high boron concentration in the water is due to the passage of heated groundwaters through the greywacke basement to other marine sediments. (Gregg, 1978).

Johnstone's (1979) work also reports significant gas discharge in the Miranda area. A thermal feature near the area gave off intermittent H$_2$S, and H$_2$S odour was evident in the swimming pool area. However, gas analysis from Petty (1972) did not mention the presence of H$_2$S with only N$_2$, and CH$_4$ with small amounts of CO$_2$.

Water analyses were conducted in 1918 and 1966 for Miranda Hot Springs and are contained in Petty (ibid) and Gregg (1978). However there is no data on sample location or name. Further water analyses for the 4 springs and bores were taken in 1972 by TJ Sprott and Associates for the then owners of the pool complex (Mr and Mrs Wilson).

Maximum spring temperatures have been recorded at about 63.8 $^\circ$C in 1978. Temperatures were observed to increase in the springs (1918 – 54.5 $^\circ$C, 1966 – 57 $^\circ$C and 1978 – 63.8 $^\circ$C) over this period.

There is no historical data on the flow rates but Gregg (1978) estimated that the flow rate appeared to be reasonably constant at approximately 36,000 litres/hour.

3.5 Spring chemistry

This section discusses all information on thermal water chemistry including the sampling results from this 2010 study. All the data is given in Table 2.

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 available from the Waikato Regional Council website. 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.
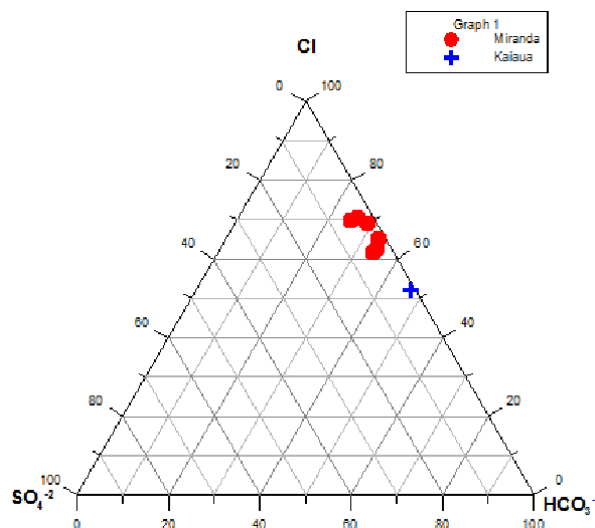
A triangular diagram of the water types for the Miranda and Kaiaua area shows that the Miranda waters are of alkali chloride composition and the sole Kaiaua sample by Webster-Brown and Brown (2007) represents a mixing of chloride and bicarbonate waters (See Figure 4).

3.6 Boron and chloride content

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.

Webster-Brown and Brown (2007) suggest the B/Cl ratio of Miranda springs show that they are all 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 dilution as the hot water flows through the sediments.

Figure 4: Water chemistry of Miranda and Kaiaua samples from previous work.

3.7 Temperature

Figure 5 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.

3.8 Magnesium (Mg) content, Salinity (NaCl), and Bicarbonate (HCO3)

The magnesium content of Miranda and Kaiaua samples are given in Table 2. Miranda has a very low magnesium concentration, while Kaiaua has a slightly higher concentration, suggesting that Kaiaua fluid is diluted by groundwater.

In addition, the salinity of Miranda is higher than Kaiaua's suggesting that Kaiaua is the diluted outflow. This is shown in Table 2.

Kaiaua has a higher bicarbonate content than the Miranda samples (Table 2). The HCO$_3$ concentrations ranging from 78-141 g/m^3 or mg/l and are an indication of mixing of thermal waters with groundwater.
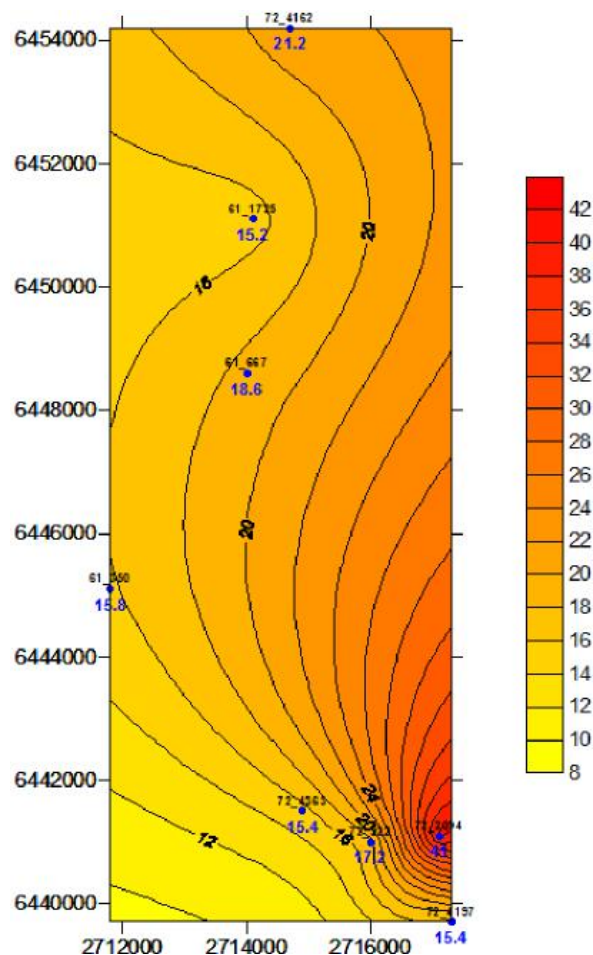
3.9 Soil chemistry

There are similarities between the Miranda-Kaiaua area geochemical soil surveys and those conducted in nearby low enthalpy geothermal resources of Naike by Nicholson *et.al*

(1989). The results of survey illustrated a pattern of anomalies parallel to known faults, meaning the hydrology is dominated by fractures.

3.10 Geothermometers

The Miranda-Kaiaua waters do not approach boiling temperatures or deposit silica at the surface the assumption is made that these waters cool conductively, and that the application of the adiabatic (no-steam loss) quartz geothermometer is appropriate for these waters.

Figure 5: **Contour map of survey points by bore ID and their respective measured temperatures.**

The cation geothermometers of Na-K-Ca were used by Jenkinson (1994) to evaluate the deep subsurface equilibrium temperature of the Hauraki Depression. However the Na-K-Ca geothermometer is sensitive to CO$_2$ in the waters, therefore, the Na-K geothermometer is applied to the Miranda waters.

The silica and cation geothermometers show a consistent result with equilibrium temperatures of about 80-100 $^\circ$C. This is close to the observed surface temperature of nearly 60 $^\circ$C, showing that equilibrium compositions are obtained at relatively shallow depths.

Quartz geothermometer of the Kaiaua area ranges from 71-123 $^\circ$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.

Table 1: Kaiaua geothermometer 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

3.10 Stored heat calculation

The area of the main Miranda resource was calculated by Sudarman (1981) to be 0.3 km^2, and the depth of the greywacke basement, where the hot water is accumulated, to be 85 m. Using a porosity for the Waitemata sediments of 10%, which takes into account the presence of clay minerals, and a spring temperature of 64 degrees C, the stored heat calculation yields a stored heat of 0.2 MWe (Peter, 2011). However, this system is unlikely to be used for electricity generation. Direct use of the geothermal water, or heat, is generally a more suitable option for small, low enthalpy systems. The full details of the calculation can be found in a fuller report published on the Waikato Regional Council website.

4. CONCEPTUAL MODEL

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 (Figure 6).

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 of Miranda with groundwater.

Miranda has a higher boron concentration than Kaiaua. High boron concentrations are associated with heated water from the greywacke basement to the sedimentary layer and are also experienced in Whitford and Naike.

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.

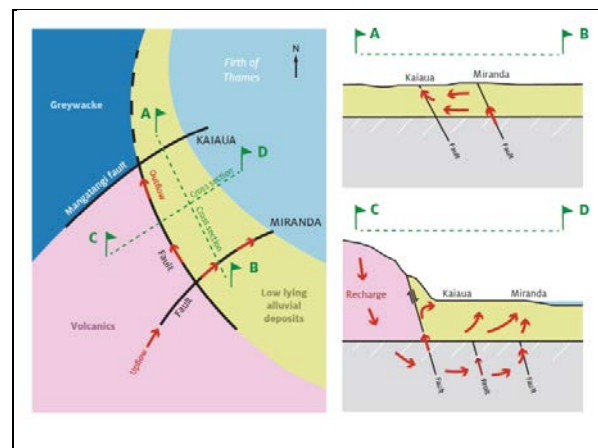Due to the limited data available and inconsistency in sample collection and records, it is difficult to estimate the extent of the Miranda-Kaiaua resource, however, it is likely to be a rather small resource.

5. CONCLUSION

Recent and past geophysical and geochemical surveys indicate that Miranda and Kaiaua groundwater resources are hydrologically linked.

The system is fault-driven, allowing for the flow of water from the basement to the sediment layer then finally emerging as springs or percolating horizontally through the sedimentary layer with some mixing occurring.

Geophysics surveys indicate low resistivity at shallow depths which may be explained by fluid flow in a lateral direction towards the north, towards Kaiaua within the Waitemata sediments. As the fluid flows through the sediments, it mixes with groundwater.

Figure 6. Conceptual model and cross section of Miranda-Kaiaua area.

Kaiaua is considered to be the outflow of the system as a result of the low boron concentration, low salinity, and higher CO_2.

Currently, the resource is utilized for bathing and heating at the Miranda swimming pool and motor camp complexes. 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. As development proceeds, a reinjection program may be needed to be established in order to prevent pressure drawdown.

ACKNOWLEDGEMENTS

Table 2: Geochemical Analyses of the Miranda-Kaiaua area

References	Site	Cl (mg/l)	B (mg/l)	Cl (Molar)	B (Molar)	Cl/B ratio	HCO3 (mg/l)	NaCl (mg/l)	Na (mg/l)	Mg (mg/l)
Gregg, 1978	Miranda 1916	170	1.98	4.7955	0. 183	26.1814		281		
Gregg, 1978	Miranda 1966	132	-	3.7236	-	-		217		
Gregg, 1978	Miranda 1972 (spring	146	4.64	4.1185	0.429	9.59498			146	
Gregg, 1978	Miranda 1972 (old bore)	212	3.69	5.9803	0.341	17.5193			212	
Gregg, 1978	Miranda 1972 (stainless	157	5	4.4288	0.463	9.57500			157	
Gregg, 1978	Miranda 1972 (domestic	36	-	1.0155	-	-			36	
Hill Laboratories, 1985 (from EW)	Miranda 1985 (spring stainless steel)	154	5.2	4.3441	0.481	9.03	85		117	<0.2
Hill Laboratories, 1985 (from EW)	Miranda (bore) 1985	155	5	4.3724	0.463	9.45	85		112	<0.2
Jenkinson, 1994	Miranda 1 1994	162.8	4.32	4.5924	0. 4	11.49	80		137	0.046
Jenkinson, 1994	Miranda 2 1994	190.2	4.5	5.3653	0. 416	12.89	79		152	0.036
Hill Laboratories, 2000 (from EW)	Miranda 2000	158	4.72	4.457	0.437	10.21	-		123	0.02
Hill Laboratories, 2001(from EW)	Miranda 2001	155	4.54	4.3724	0. 42	10.41	-		132	-
Hill Laboratories, 2002 (from EW)	Miranda 2002	193	4.5	5.4443	0. 416	13.08	-		122	0.009
Webster-Brown & Brown, 2007	Miranda bath source	151	4.9	4.2595	0.453	9.40	54		133	0.02
Webster-Brown & Brown, 2007	Miranda bath source	150	5.1	4.2313	0.472	8.97	56		127	0.01
Webster-Brown & Brown, 2007	Miranda hot spring	151	<5	4.2595	-	-	-		80	<0.02
Webster-Brown & Brown, 2007	Kaiaua East Coast Rd	49	0.666	1.3822	0.0616	22.4	44		62.8	0.03
Present Study	72_5158	21	0.179	0. 5924	0.0166	35.7746	141		46	1.48
	72_5154	44	0.48	1.2412	0.0444	27.9525	78		46	1.57
	72_4162	35	0.75	0. 9873	0.0694	14.2303	-		56	0.84
	61_667	61	0.31	1.7207	0.0287	60.0036	102		67	1

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