MONITORING AT NGAWHA SPRINGS BEFORE AND AFTER COMMISSIONING OF THE POWER STATION

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SUMMARY - Pre-commissioning monitoring of surface features at Ngawha from 1996 to 1998 generally supports the findings of Sheppard and Johnston (1984) in terms of temperature, mass flow rates of chemical species in solution, and gas species discharged. Although the behaviour of Universal Bath remained relatively constant a significant decrease in the chloride content was found compared to historical data. Over the two years of power generation (1998 to 2000) the variability of the above parameters and the total deep reservoir fluid discharged at the surface of the Ngawha Springs locality are similar to baseline values.

1. INTRODUCTION

Ngawha geothermal field is located approximately 250 km north-north-west of Auckland and about 5 km east of Kaikohe. Ngawha is the only high temperature geothermal system in the north of New Zealand. Surface manifestations are sparse (Mongillo, 1985). The geothermal reservoir is regarded by Maori as 'Taniwha'. Local people think of Lake Omapere as the heart, and Ngawha Springs as the head and the eye. The system is seen as a living being, commanding respect and awe.

The Ngawha springs are in an old lake basin. What is unusual about this area is a deposit of cinnabar or mercuric sulphide. For many years claims were made about the curative properties of the mercuric Ngawha mud, principally for the treatment of syphilis. Written accounts of bathing in Ngawha's hot waters and muds go back to the missionary William Wade (1842), who noted "The springs at this place are much resorted to by diseased natives from the Bay of Islands, who bring baskets of provisions with them, and remain on the spot to use the sulphur warm-bath till a cure is effected." Herbert (1921) referred to "a remarkable group of hot springs at Ohaeawai... in the midst of old workings of a mercury mine, itself desolate in a setting of old *gum* fields." He wrote of the hot mud containing globules of cinnabar, being used as a parasiticide by Maori people of the area. In the past Ngawha was known as Ohaeawai.

The baths are also valued for treatment of arthritis, skin diseases such as eczema and ringworm, and some people *drink* small quantities of the water as a 'pick-me-up' and even as a cure for cancer. Serious geothermal investigations were started by the DSIR in the early sixties and the scientific work carried out during the next twenty years were published in the DSIR Geothermal Report #7, (Browne et al. 1981).

2. RESERVOIR CHARACTERISTICS

2.1 Subsurface geology

Three discrete units of allochthonous Cretaceous and Tertiary sedimentary rocks are recognised, and presumed to be separated by low angle thrust faults, (Petty' 1985). The upper slide unit comprises mainly a grey non-calcareous siltstone called the Ngatuturi Claystone. It was encountered down to a maximum depth of 243m below the surface.

A middle 'melange' unit follows. This is a distinctive unit of sheared, mixed and brecciated multi-coloured shales of various ages. Drill cuttings of this unit are distinctive in that they are "puggy" and have mixed lithologies. This has been found up to 220m thick (NG 16).

A lower slide unit is a very mixed group lithologically but rather than being a brecciated melange, variable size 'blocks' made up of different lithologies occur in sheared relationships to each other. In some holes only one rock type was drilled in this interval e.g. argillaceous limestone. Other rock types encountered are calcareous brecciated shales, glauconitic sandstone, calcareous sandstone and interbedded fine sandstone and siltstone.

In some holes, there exists a thin unit of argillaceous sandstone with subsidiary glauconitic sandstone.

The Waipapa Group basement of mainly argillite with lesser amounts of fine greywacke sandstone is the geothermal reservoir (aquifer) for the field.

2.2 Permeability

The reservoir in the Waipapa Group basement is overlain by poorly permeable units. The reservoir extends to a depth of 1.5 km below sea level. It contains liquid water at 210 to 230°C, 1250 mg/t chloride and about 1 to 2 wt% gas. Below the reservoir zone temperatures rise to over 300°C but permeability is proven to be poor. The gases discharged with the well waters and via the baths have equilibrated at higher temperatures (up to 400°C).

2.3 Surface flow

Mass flow of deep chloride water to the surface can be deduced fkom the chloride flux in the run off waters. The flows fiom the main thermal baths and Spa areas flow into the Mangamutu stream. This flows, together with flow fkom Lake Tuwhakino and spring discharges, into the Ngawha stream. The Mangamutu stream discharges a chloride flux of 0.82 and 2.8 g/s (mean and maximum respectively). For a deep water chloride concentration of 1250 g/t the chloride fluxes equate to 0.66 and 2.2 L/sec of water at 230°C. The total flow from all the thermal discharges is measured at the Ngawha Weir. The total mean chloride flux (excluding flood values) is 2.3 g/s equivalent to 1.8 L/sec water. This compares with 250 g/s chloride and ca.150 L/sec of water at 265°C in Geyser Valley, Wairakei, prior to development. In Rotorua the chloride flow, including subsurface flow in Lake Rotorua is ca. 540 g/s and 390 L/sec of water at-250°C.

The mean heat flux calculated fiom the chloride flux in the Mangamutu stream is 590 kilowatt thermal. For an air temperature of 12°C and a wind speed of 1 m/sec this would maintain a water temperature of 40°C over a surface area of ca. $40 m^2$. The maximum flow calculated fkom chloride flux in the Mangamutu stream could sustain 40°C over ca. $130 m^2$.

Table 1: Surface flows

	Measured		Calculated		Calculated	
	Chloride	Chloride	230 C water		CO2	Heat
	mean	maximum	mean	maximum		flow
	g/s	g/s	L/sec	L/sec	g/s	KWt
Mangamutu	0.82	2.8	0.66	2.2	7.9 to 110	590
Ngawha Weir	2.3		1.8			
Geyser Valley	250		150		75	
Rotorua	540		390			

The minimum CO_2 fluxes can be calculated fkom the chloride flux and the CO_2/Cl in the deep fluid. For the Spa and baths area this is 7.9 g/s. *Tiger* Bath discharges 0.21 g/s at its monitoring point. There is evidence fkom NG 1 that the gas/water ratio increases near the surface. For this shallow well the *gas* in total fluid mixture in the well is ca. 16 wt%. If we use this figure then the CO_2 flux is ca. 110 g/s. For Wairakei, the CO_2 flux was about 75 g/s.

2.4 Deep and shallow fluid

The *deep* component is characterised by high chloride (1250 mg/kg) and boron (900 mg/kg). The water will be saturated with silica (about 390 mg/kg) at depth. Due to the low vertical permeability, as evidenced by the low flows at the surface, the water rises very slowly and this allows the silica to equilibrate to the lower near surface temperatures and thus the bath waters are not over saturated with silica. *Jubilee* Bath, which has the highest chloride, 1250 mg/kg, has a silica content of 156 mg/kg. The Cl/SiO_2 wt ratio = 8.0, compared to the ratio in the deep water of 3.0. The normal silica terraces found in most thermal areas are thus absent at Ngawha. Steam and gases separate fkom the rising water and heat the near surface waters. Condensation of steam also allows cool gas to discharge. Oxidation of hydrogen sulphide to sulphuric acid, either close to the surface, or in near stagnant baths, produces the low pH waters found in *Tiger* Bath and *Centre* Bath, both of which have a particularly high gas flow.

The shallow reservoir, at 145°C, is characterised by low (<70mg/kg) chloride and high calcium-magnesium and bicarbonate concentrations. This water is formed by absorption of steam and carbon dioxide released from the higher temperature waters below, forming aggressive solutions preferentially leaching calcium and magnesium fiom the country rock. When mixed with the deep water, the latter is diluted and its originally low magnesium is increased so that the Mg/Cl ratio increases. This is illustrated by a plot of log Mg/Cl versus chloride concentration in Figure 1. Three sets of data are shown. 1) 1980-1981 data (Sheppard and Johnston, 1984), 2) Baseline data fkom 1996 to 1998, which have a linear regression line through them, and 3) recent production-phase data. Data from Sheppard and Johnston (1984) for the five baths sampled in both surveys are also shown and show significant changes over the past 15 years. Immediate *rainfall* is the final component that can be discerned in the baths that would dilute all components in the bath water with little change to the ratios.

Evaporation, overflow fkom one bath to another, and human activities can also affect the baths. In *Tiger* Bath some of the lower temperatures correspond to periods of low rainfall and elevated chloride suggesting evaporation and possibly steam loss. On the other hand dry weather is not associated with elevated chloride or pool temperatures in *Universal,* which is much less ebullient than *Tiger.* Human activities include emptying the baths and mixing bath waters to achieve the desired temperature (e.g. *Jubilee* in the 1980's), urination, septic tank seepage, skin lotions and body salts especially when baths are pumped infrequently. Bather's actions such as stirring up the mud will affect the appearance of the bath but will have minimal effect on the water composition.

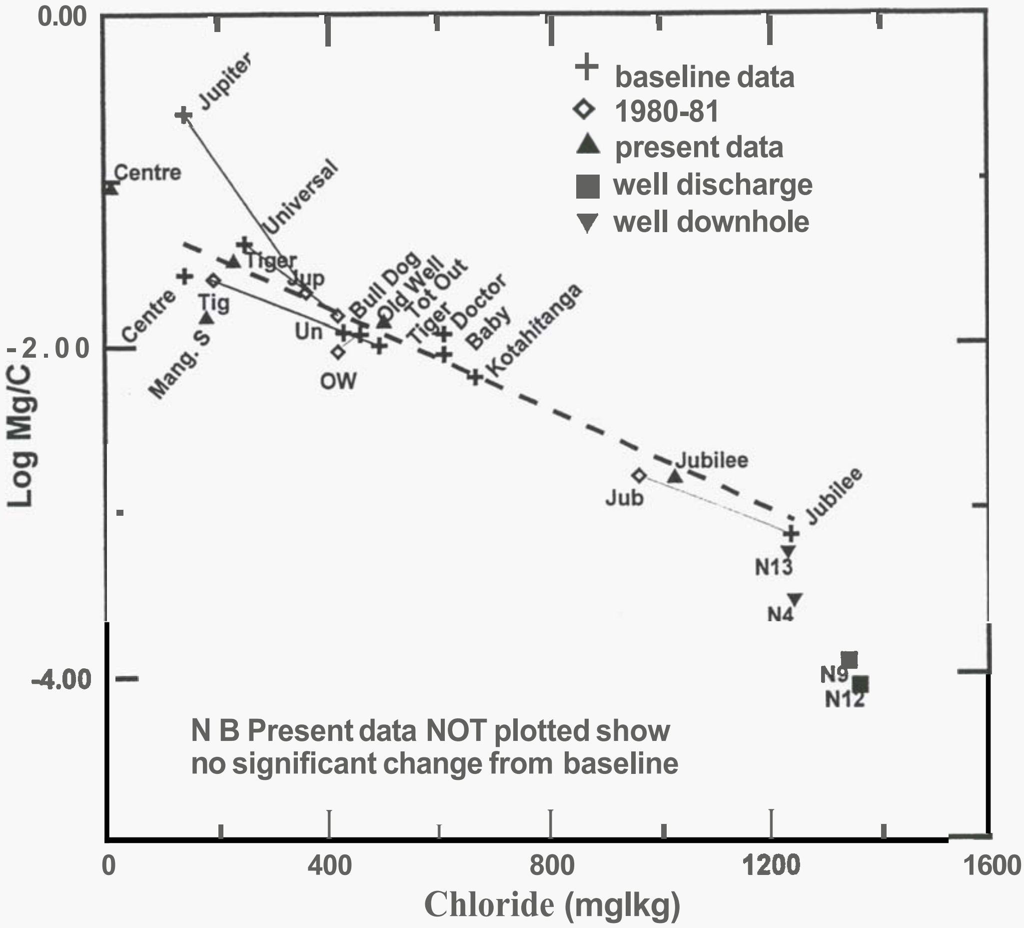

Fig 1: Chloride versus Log Mg/Cl for Ngawha waters. Solid lines link 1980-81 and baseline data. Dashed line is regression line for baseline data.

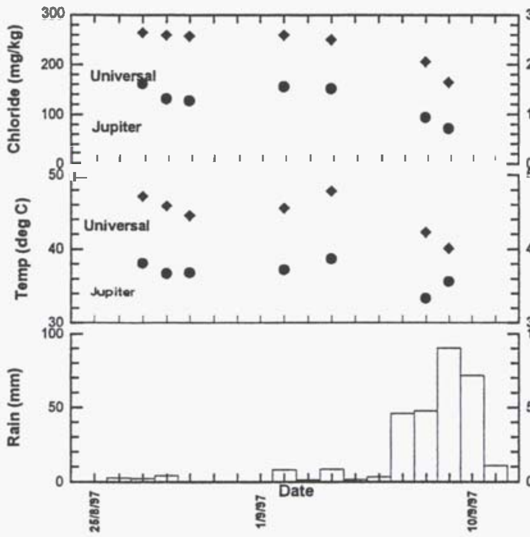

Fig 2: Rain, Temperature, and Chloride versus time for *Universal* and *Jupiter,* August and September 1997

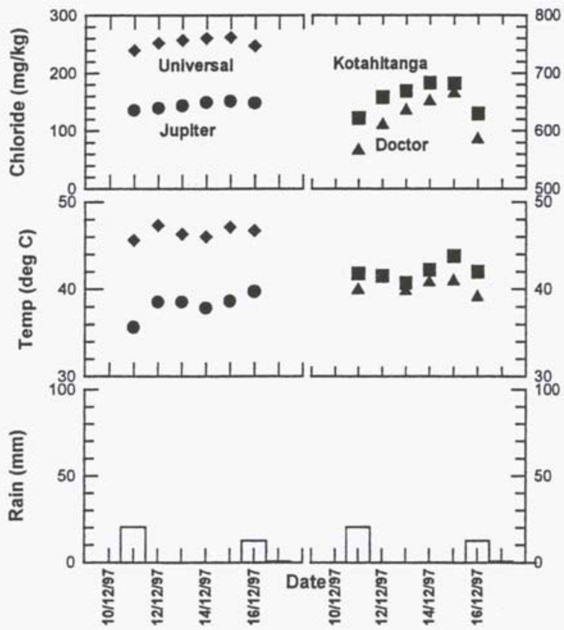

Fig 3: Rain, Temperature, and Chloride versus Time for *Universal,Jupiter, Kotahitanga* and *Doctor* Baths, December 1997

The components and processes affecting the temperature and chemical composition of the baths can thus be summarised.

Components:

1) Deep geothermal water from a reservoir at 230°C. Chloride = 1250 mg/kg, Boron = 900 mg/kg.
2) A shallow reservoir at 145°C. Low chloride, high magnesium and bicarbonate.
3) Steam and gas flowing with or separated fiom the deep water.
4) Immediate rainfall.

Processes:

1) The proportions of the components entering each bath.
2) Evaporation.
3) Pool management, i.e. pumping out of the water, mixing of bath waters.
4) Bather's activities.

3. SHORT TERM VARIATIONS

Two sets of samples were collected to observe short-term variations. The first (Fig 2) were taken from the ***Jupiter*** and ***Universal*** baths on 27th, 28th, and 29* August and on 4th, 8th, and 9th September 1997. These samples showed that dilution and decrease in temperature occurred following rainfall. The higher rainfall on the 7th 8th and 9th September (184 mm) had a much greater impact than the lower rainfall of August 26th, 27* and 28th (10.6 mm).

The second set, (Fig 3), were collected from ***Universal, Jupiter, Kotahitanga*** and ***Doctor*** following 39.6 mm and 11.4 mm rain on 4th and 11th December 1997. The baths could have been affected by both rainfall events when sampling commenced on 11* December. The aim was to determine the time taken for the baths to recover from rainfall. The dilution appeared to be removed after 4 or 5 days. However, a further 20.4mm rainfall on 16th December interfered with the recovery and sampling ceased.

The earlier rainfall of September was about 15 times that of 11th December. Thus it is expected that the baths could take well over a week to recover from more than 100mm rainfall. This in contrast to "normal" thermal springs when rainfall only affects the springs that mix with surface water. Most geothermal springs have sufficient flow to prevent contamination with rain (Klyen, 1993).

These samples illustrate that the baths are affected by rainfall.

4. FACTORS WHICH HAVE CHANGED SINCE 1983

The number of baths in the Domain has increased from 6 to 7, and in the Maori Baths has increased from 6 to 8. Today the Domain and Maori Baths are collectively referred to as the Waiariki Baths comprising 15 baths compared to only 12 when Davey and van Moort (1986), studied the area in the mid 1970's.

Jubilee Bath is no longer cooled with water fkom ***Tranquility*** but continues to be pumped every morning.

Stream flows are measured volumetrically at Lake Tuwhakino Outlet, and by V-notched weirs at Mangamutu Stream, (located downstream of Lake Tuwhakino Outlet and including the Tuwhakino Stream) and at the Ngawha Stream.

Comprehensive weather data collected in the village is utilised for time series plots and interpretation.

Management of the baths has been inconsistent. At the time, Sheppard and Johnson were monitoring the Domain Baths were pumped out nightly. During pre-commissioning monitoring, to obtain the baseline data, baths were regularly pumped but over the last eighteen months baths have at times been left for four to six weeks at a time without pumping.

A new monitoring point, Total Outflow, has been added which is taken at the outflow to the stream, (after the holding tanks), from the Waiariki Baths.

5. GAS SPECIES DISCHARGED

Constituents in the gas species discharged at the surface are in different proportions to those at depth. Hydrogen sulphide, which is very chemically reactive is removed in the shallow waters so that the CO_2/H_2S in the production wells (100 to 110) increases to 140 to 200 in the gas discharging in the baths. Sheppard and Johnson (1984) inferred that the waters in contact with the gas stream are saturated with respect to the gases and therefore the thermal system has reached a stable state.

The ratio of CO_2/H_2S in the features is approximately 60% higher than that of the production wells (140 to 200 compared with 100 to 110). The highest values were found in the most ebullient baths ***(Tiger, Centre, Jupiter,*** and ***Jubilee)*** all of which are whitish-grey in colour. This probably indicates that some of the hydrogen sulphide had been oxidised to sulphur. The lowest value was seen in ***Universal*** which has a very low gas discharge and is greenish-black in colour.

The ammonia is also removed fiom the gas as it bubbles through the bath water. The CO_2/NH_3 ratio in the production wells (150 to 250) rises to between 17,000 and 80,000 in the gases discharged in the baths. The ratio of CO_2/H_2 in *Centre* Bath, located between the Old *Well* and the Maori Baths, and formerly know as the Maori Well, is closest to the production wells yet the water temperature and chloride content of this bath is low at 29.7°C and 138 mgkg respectively. *Centre* Bath is also characterised by very high N_2/Ar and He/Ar ratios. In contrast, *Tiger* Bath has a CO_2/H_2 ratio of 1064, approximately 2.5 times that of the production wells. Unlike *Centre* Bath, *Tiger* bath has a mean baseline temperature of 46.9°C and a chloride content of 496 mg/kg. Ratios of N_2/Ar were most similar to the wells in *Jubilee, Jupiter* and *Universal* Baths. *Jubilee* and *Jupiter* are similar in appearance and gas flow but quite different in chloride content, 1250 mg/kg and 148 mg/kg respectively, and location, with *Jubilee* on the edge of Lake Tuwhakino and *Jupiter* in the Domain area. The similarities between *Universal* and *Jupiter* are limited to temperature, proximity and chloride content 257 mgkg and 148 mgkg respectively.

6. INDIVIDUAL BATH CHARACTERISTICS

Jubilee bath is distinct from all the other features in that it has the highest contribution of deep water component. Although the composition has varied (Figure 3), the baseline value is closest to the downhole samples from NG4 and NG13. The chemical concentrations in the waters and proportions of individual gases in the gas collected fiom the bath are similar to those in the wells. Thus this bath has the most direct contact with the deep reservoir. Sheppard and Johnson (1984) noted it was cooled by water fiom *Tranquility,* confirming the high temperature of the *Jubilee* bath water. The high $Ca\text{-}Mg\text{-}HCO_3$ water fiom the shallower reservoir is present in *Tranquility* bath, adjacent to *Jubilee,* and other baths in the Spa area. The flow of the deep water to *Jubilee* appears to be sufficient to prevent the access of the water fiom the shallower reservoir.

Kotahitanga bath has the next highest chloride of the baths monitored for the baseline data, 669 mg/kg, and contains about 40 to 50% of the Ca-Mg bicarbonate water. It has a moderate gas flow.

Centre bath lies on the edge of the Tuwhakino stream. *Centre* bath is different again to all the baths monitored in that it is dominated by a supply of gas. This is evident by the gas composition, (highest H2/Ar temperature = 500°C), and the high ebullience of the gas flow. The gas flow is similar to *Tiger* bath. The amount of deep fluid is comparatively small and although the gas comes ficm a high pressure and temperature zone the bath temperature is very cool. The cooling suggests that this location has the greatest sub-surface permeability and the greatest proportion of meteoric and $Ca\text{-}Mg\text{-}HCO_3$ reservoir water. *Centre* is the most acid bath, with low Cl/SO_4 (= 0.25). This is likely due to sulphate produced fiom oxidation of H2S and the low chloride. The chloride content was highly variable during baseline monitoring (9 to 250mg/kg). More recent samples have no deep water component (see Fig 3) and the temperature is being maintained by the shallow reservoir and gas.

Centre and *Tiger* baths share the same deep gas supply as indicated both by the size and ebullience of the bubbling and by various gas components. They share similarly high CO_2/NH_3 values, high N2/Ar ratios. The high N2 value indicates a genetic relationship with magmatic fluids (Sheppard and Lyon, 1981) and N_2 also is unlikely to be affected by rock interaction processes. *Tiger* has the highest CO_2/H_2 values, even higher than the wells. This may be due to the low pH water releasing the bicarbonate from the $Ca\text{-}Mg\text{-}HCO_3$ water as CO_2.

Tiger bath differs from *Centre* in temperature and water chemistry. This appears to be due to a supply of high chloride water from the deep 230 °C water below 500m. The baseline fluid appears to be diluted to about 30% of the "production well" fluid composition. Because the water is so much less diluted than *Centre* bath, the high gas (and probably steam) flow maintains the bath at a higher mean temperature. Because of its relatively high elevation it is most likely to be supplied by steam. It is also likely to show changes in the proportions of the different fluids reaching it. This is seen in the difference between the 1980s, baseline and present data in Fig 3. The high chloride in the baseline data could also be due to the few samples in the baseline data set for *Tiger.* The high gas flow and temperature causes the high concentrations of mercury in the vicinity. *Tiger* has a high sediment load of a brownish colour, this could be meta-cinnabar (black) and cinnabar (red). Davey and van Moort (1986) reported 900 mg/kg mercury in stream sediments in the *Tiger* bath area. Mercury concentrations in the *Tiger* bath water were 14.5 mgkg. Although this could be in part due to contamination with sediment, it reinforces the above suggestion.

Tiger, Bull *Dog and Old Well* have some common features. They are similar in temperature and Mg/Cl ratios and all appear to comprise approximately 30% well fluid chemical constituents. Bull *Dog* and *Old Well* differ from *Tiger* in their low gas flow and suggesting that the deep water component supplying these two baths has lost gas before reaching the baths.

The chemical variability in *Old Well,* noted by Sheppard and Johnson (1984), is most likely to be due to near-surface water as *Old* Well is situated on the flood zone of the Tuwhakino Stream.

Jupiter and ***Universal*** baths are very interesting in that they are adjacent and have some close similarities and yet appear very differently. Most obviously ***Jupiter*** is whitish and ***Universal*** is greenish in colour. Historically the baths were similar. In the last three and a half years of monitoring (pre- and post-commissioning) a decrease in the chloride content has occurred in both ***Jupiter*** and ***Universal,*** when compared to the historical data. Physically the baths appear to be the same (no name change) although a connection in the wall between Cinderella and ***Universal*** baths exists, which may not have been present historically. Apart ftom this, the other variable is the number of baths. The mean chloride concentrations for the historic (up to **1983)** and recent (baseline to present) are **425** and **257** mgkg for ***Universal*** and **360** and **148** mg/kg for ***Jupiter.*** Both baths are supplied with a low flow, about half that of ***Old Well*** and ***Bull Dog,*** of high chloride fluid from the 230°C zone and this is the dominant chemical feature. However ***Jupiter*** has the highest Mg/Cl ratio suggesting a significant input ftom the high Ca-Mg-HCO_3 reservoir. The gas in ***Jupiter*** appears to have lost most of its ammonia by solution in the bath or earlier as it has the highest CO2/NH3 ratio in the bath gases analysed. The CO2/H2S ratio is high, (194), similar to ***Tiger*** and ***Centre,*** and all three baths contain sulphur.

7. CONCLUSIONS

- Variations in temperature are similar to historical variations. ***Tiger*** and ***Universal*** are slightly hotter and ***Jubilee*** slightly lower.
- Rainfall is a cause of low temperatures and low chloride contents in the baths.
- Mass flow rates of chloride ftom the Ngawha Springs and baths locality is ca. **0.82** g/sec.
- Total deep reservoir fluid discharged at the surface in the Ngawha Springs and baths locality is ca. **0.66** L/sec.
- Gas species discharged are similar to that in the deep water. H_2S is partly oxidised to sulphate and sulphur. The acid sulphate water reacts with local limestones and/or shallow bicarbonate water to add CO_2 to the gas discharge.
- A significant decrease in the chloride content of the water in ***Universal*** and ***Jupiter*** baths, compared with historical values, has occurred prior to commissioning. Other features show similar concentrations to historical values.
- Changes will best be detected during rain free periods and under a controlled baths management regime.

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