CHEMISTRY OF THE ROTORUA GEOTHERMAL FIELD – UPDATE OF SPRING AND WELL COMPOSITIONS

Ed Mroczek[1], Duncan Graham[1] and Brad Scott[1]

[1]Wairakei Research Centre, GNS Science, PB 2000, Taupo 3352, New Zealand

e.mroczek@gns.cri.nz

Keywords: *Rotorua, geochemistry, wells, springs, Kuirau, Whakarewarewa, Ngapuna, Ohinemutu, Government Gardens, Rotorua Geothermal*

ABSTRACT

The chemical monitoring undertaken over the last decade and comparison with historical data suggests that, with only a few exceptions, the compositional spring changes appear within natural variability.

Many springs reached stable composition after the bore closure programme in 1986. However there is no explanation as to why the Whakarewarewa springs, which became acid features prior to the bore close programme, have not reactivated. Also difficult to explain is the decrease, after an initial increase in activity and discharge, especially around Lake Roto-a-Tamaheke but also elsewhere at Whakarewarewa.

The well compositions in the Western and Government Garden areas appear to be slowly changing, most containing less SO_4 and more HCO_3. This is what would be expected given an increase in fluid pressures but there has been little increase in the fraction of deep reservoir higher chloride fluids. The only Kuirau well sampled (RR913) shows no change in composition since 2003.

The geothermal reservoir in the Government Garden and Kuirau areas could be within the normal range expected relative to the current use of the geothermal resource.

1. INTRODUCTION

The scientific and cultural history of the Rotorua Geothermal Field (RGF) spans many decades. Rotorua is a resort city built on a large geothermal resource which has been exploited by significant shallow drilling since the 1950s. The use has resulted in a decline in the surface discharge and ultimately was considered to be endangering the famous Whakarewarewa geysers. Government intervention in the mid 1980s, which reduced the number of bores from 370 to 140, has led to increasing geothermal aquifer pressures (water level rise) as measured in monitor bores. However the recovery has been uneven across Rotorua and increasing groundwater levels and pressures have not resulted in the reactivation of many Whakarewarewa surface features including some geysers. The management of the RGF presents challenges where increasing demand from industrial, tourism and domestic use is balanced against surface feature intrinsic values.

The RGF is a case study to better understand the recovery of a geothermal field.

2. PREVIOUS WORK

The scientific monitoring which was undertaken prior to the bore closure programme in 1986 was published in a Geothermics special issue (Allis and Lumb, 1992). Of direct relevance were the papers by Giggenbach and Glover (1992) on the chemistry of the discharges and Stewart et al. (1992) on the isotopic data. The more recent response of the RGF and surface features is reviewed by Scott and Cody (2000) and Scott et al. (2005). An update of the spring and well compositions was undertaken by GNS Science in 2002 & 2003 (Mroczek et al., 2004). This work was in support of a Field Management Review of the field undertaken by the Bay of Plenty Regional Council in 2005 (Gordon et al., 2005). A summary of the chemical and isotopic data and the field hydrology was published as Chapter 5 in that review (Mroczek et al., 2005).

The three main conclusions from the chemistry of the discharges in the 2002-2003 study were that:

- The fluids discharged in the northern area of the field at Kuirau Park matched those discharging in the early 1960s and it is probable that this part of the field is near full recovery.

- The Whakarewarewa recovery has been mixed. Many features showed increases in aquifer (geothermometer) temperatures with a greater proportion of deep geothermal fluid being present but variably discharged.

- The shallow aquifer feeding the wells showed relatively minor changes in reservoir chloride and small increases in geothermometer temperatures (~16°C). This indicates stability and that no deleterious processes were affecting the deeper RGF.

3. SAMPLING PROGRAMME

3.1 Springs

The 34 features we sampled for this study in 2008 were based on those sampled in 2002 (Mroczek et al., 2005). They were originally chosen to give a good geographical coverage over the three main areas of surface discharge. Since 2005 samples from four of the sampled springs have been collected yearly as part of the GeoNet volcano monitoring programme for the Rotorua caldera. These provide a valuable dataset for assessing longer and shorter term compositional trends.

3.2 Wells

The wells, which are not limited to areas of natural discharge, were chosen to provide a good geographical coverage. However wells only exist outside of the Pohutu exclusion zone. The location map for the wells sampled is shown in Figure 1. Nearby similar, "proxy" wells have also been included in the dataset due to the paucity of previous data from some of the wells sampled. M25 (replacement for RR889) at Ngapuna at a depth of 245m could not be sampled and was last sampled in 2003. This well is the

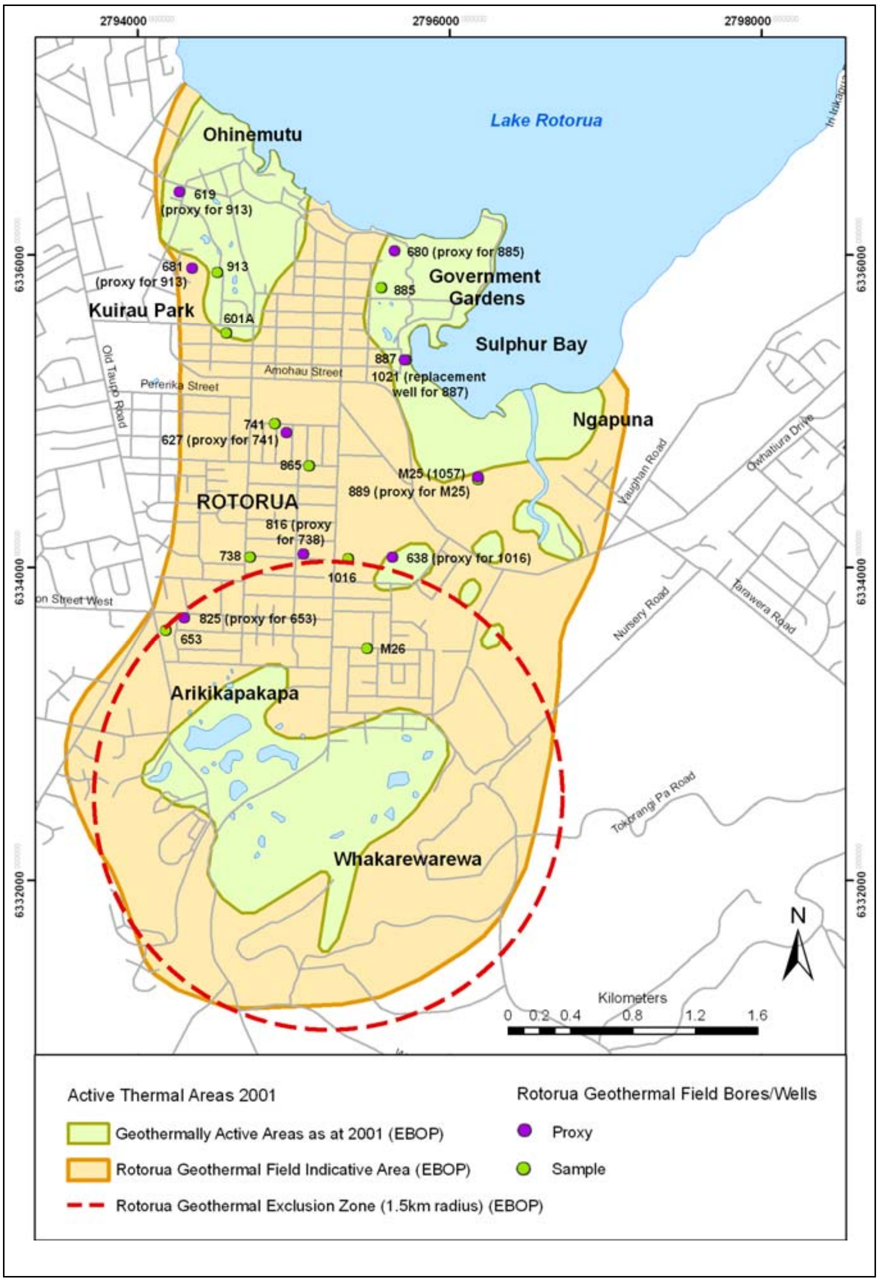

Figure 1: Location map for sampled and proxy wells.

hottest (maximum temperature of 216°C) with high reservoir chloride ~ 1300 mg/L and is diluted least with shallow fluids high in HCO_3 and SO_4.

GeoNet annually samples two wells, which as for the springs, provides a valuable dataset for assessing longer and shorter term compositional trends.

4. WELL RESULTS

4.1 Reservoir Cl, temperature and O^{18} correlations

Figure 2 shows the chloride-enthalpy diagram for all the wells. The chloride Cl(res) is the reservoir concentration at reservoir enthalpy H which was calculated from the cristobalite temperature (T(cris)). With the most recent data the dilution trends are essentially unchanged since 2003.

Including all wells, Glover and Mroczek (1998) showed that the main reservoir process is dilution with a zero chloride end-member near 150°C for wells above 150°C and in equilibrium with quartz and a 15°C zero chloride cold diluting component for fluids with temperatures below 150°C.

The Cl-δO^{18} trend in Figure 3 also supports dilution as the principle reservoir mechanism with dilution to a groundwater isotopic signature.

On their own the Government Garden wells lie along a dilution line of constant enthalpy of ~ 650 kJ/kg (153°C) while the cooler and more dilute Western wells now appear to better extrapolate to a zero-chloride end member with enthalpy 475 kJ/kg (113°C) rather than to 15°C.

Perhaps of more interest for monitoring are the changes over time. In this respect it is unfortunate that not all wells sampled in 2002 could be resampled. For most Government Garden and Western wells reservoir temperatures, as inferred from the T(cris), have decreased by about 5-10°C. The Cl(res) for Government Garden wells appear to have decreased between 1989 and 2003 by about 100 mg/L but now appear to be increasing whereas in the Western wells the Cl(res) is still declining except for well 741. These changes are however not large.

At Kuirau only one well, RR913 has been regularly sampled and both Cl(res) and T(cris) are now higher than when first sampled in 1985 and the values have been stable since 2003.

4.2 Relative concentrations of B, Cl, SO_4 and HCO_3

A significant chemical characteristic of the RGF fluids is the decrease in Cl from Ngapuna (East) to Kuirau (West) and higher HCO_3 concentrations between the two, centred broadly around the Government Gardens area and also centred on Kuirau (Stewart et al., 1992). The Cl and B are from the deeper sourced primary geothermal fluid while HCO_3 arises from water-rock interaction at shallower depth in the geothermal system. Condensation of steam and oxidation by groundwater results in elevated SO_4 and acidic fluids at very shallow levels.

The change in relative concentrations between these anions gives important information on the hydrological changes such as the change in proportion of the deep geothermal fluid mixing with acidic high SO_4 surficial fluids.

The Government Garden wells RR885 and RR1021 show a stable composition while RR887 increased in Cl(res) from 384 mg/L to 455 mg/L between 2003 and 2005 and HCO_3 dropped over this same time period from 600 to 356 mg/L. The field in this area may now be near equilibrium with respect to production and natural recharge. In the Western wells the change in the relative concentrations of the anions does not show any consistent pattern. For example between 2003 and 2009 in well RR1016 the HCO_3 and SO_4 decreased while in RR865 both increased and in RR738 there was no change. The biggest change was in RR741 where the SO_4 halved from 228 to 110 mg/L while the HCO_3 doubled from 170 to 302 mg/L. Stewart et al. (1992) identified the highest SO_4 area to be near the saddle between the buried rhyolite domes so the large reduction in SO_4 in RR741 is significant. Figure 4 shows the relative proportions HCO_3-Cl-SO_4 for the Western wells and the composition of these anions is on a mixing line between high SO_4-low Cl and low SO_4-high Cl end-members.

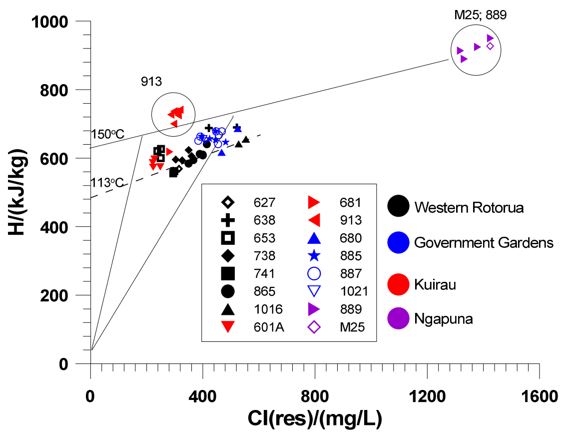

Figure 2: Chloride-enthalpy diagram for all sampled and proxy wells; Cl(res) is at the reservoir concentration at T(cris); M25 & RR889 at T(qtz)

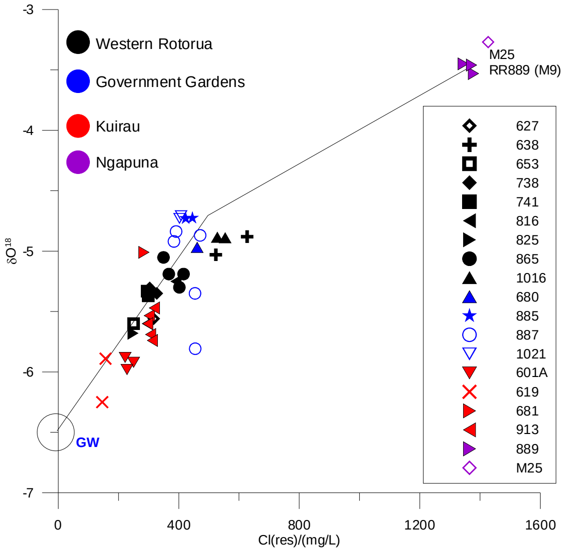

Figure 3: δO^{18} versus Cl(res) for all sampled and proxy wells.

Except for RR741 the absolute changes are not large and the chemical trends suggest the shallow infiltration of cooler groundwater is not increasing and may even be reversing. However the irregular sampling periods and the small number of wells sampled means that the true variability is not known nor whether Western wells are now varying around a uniform mean. RR913 is the only Kuirau well which has been sampled since 2003. The anion composition has been stable with only small changes in Cl(res) and HCO_3.

4.3 Summary

The changes in the individual well compositions suggest in general an increasing contribution from deeper fluids with most wells producing fluid lower in SO_4 and higher in Cl.

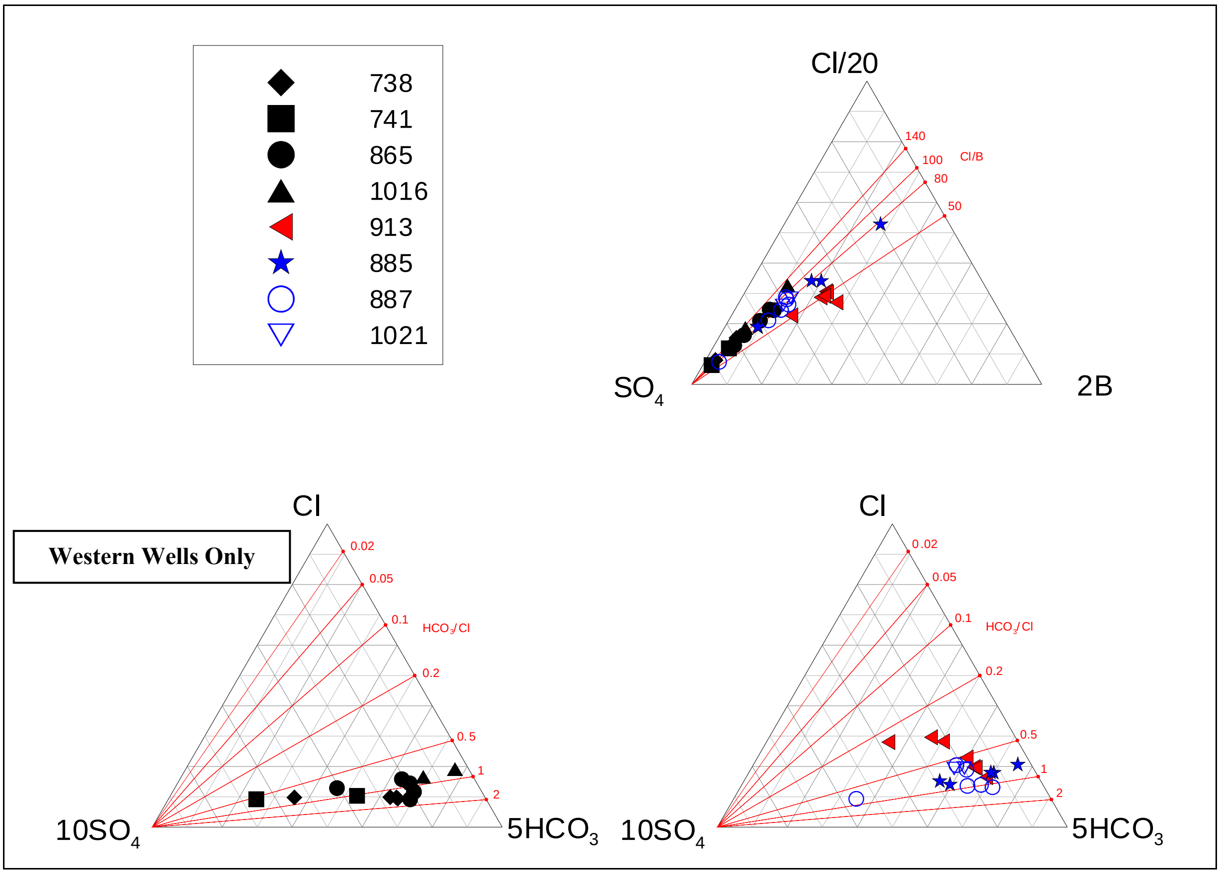

Figure 4: Relative concentrations (by weight) HCO_3-Cl-SO_4 & B –Cl-SO_4 for wells.

5. SPRINGS

5.1 Spring Compositions

The compositional relationships for spring samples collected after 2002 are presented in Figures 5 to 7. The springs are grouped by location except in the δO^{18} vs. Cl plot in Figure 8 where the springs are individually identified. In this plot, data prior to 2002 is also used but not all springs are included.

The B-Cl-SO_4 plot in Figure 5 shows the Ngapuna features highly enriched with respect to chloride. Similarly THC Blowout spring (S952) is also relatively lower in HCO_3 (Figure 6). This spring intercepts deep fluid which ultimately discharges at Whakarewarewa after mixing with more bicarbonate water and steam heated waters at shallower depths. The isotopic signature of S952 also stands well apart (Figure 8) from the other Whakarewarewa springs at more enriched δO^{18} values.

Figure 6 (HCO_3-Cl-SO_4) shows the Government Gardens and Kuirau features highly enriched in bicarbonate compared to the Ngapuna features with the Whakarewarewa features lying between the two. The higher bicarbonate reflects the long residence time of the fluids in the West of the field where the CO_2 is converted to HCO_3 by water rock interaction.

Figure 7 shows the Mg-Na-K correlation with the T(Na/K) and T(K-Mg) geothermometer temperatures (Giggenbach's correlations) shown on two axes. Points falling on the upper full equilibrium line, such as Pohutu, Korotiotio, Parekohoru and THC Blowout (S952), suggest fully equilibrated fluids while points plotting toward the Mg apex, such as the Kuirau Park features, suggests lower temperature partially equilibrated fluids. All the Geyser Flat features fall on the T(Na/K) 250°C line including other Whakarewarewa springs such as Ngararatuatara and Puapua but many trend to higher Mg indicating greater mixing with shallow fluids and re-equilibration to cooler conditions given by the T(K-Mg) geothermometer.

Figure 8 is a plot of $\delta^{18}O$ vs. Cl and both these constituents are considered to be conservative. The overall trend between the springs is for dilution with decreasing Cl and depletion to more negative $\delta^{18}O$. Two other trends are of interest. The trend for the Ngapuna Stopbank Spring (S1100) is perpendicular to the groundwater dilution trend. In this case the fluids are diluted (more or less) with highly evaporated water so that as the Cl decreases the $\delta^{18}O$ becomes more enriched, not more depleted as occurs with groundwater dilution. The latest results for Ngapuna Springs S940 show a significantly decreased chloride and more depleted $\delta^{18}O$ implying increased groundwater dilution. The other trend in many of the springs is an increase to more positive $\delta^{18}O$ at essentially constant Cl, for example Rachel spring, Soda Spring and Tarewa Spring, which implies steam heating.

● Ohinemutu
● Kiurau
● Govt. Gardens
● Ngapuna
◆ Geyser Flat - Te Puia
◆ Other - Te Puia
● Korotiotio Parekohoru
● Whaka Village & Oki
● THC Blowout

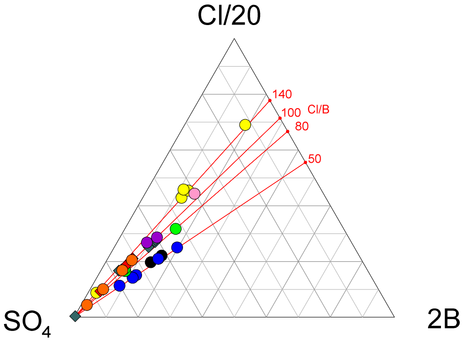

Figure 5: Spring B-Cl-SO_4 relative concentrations.

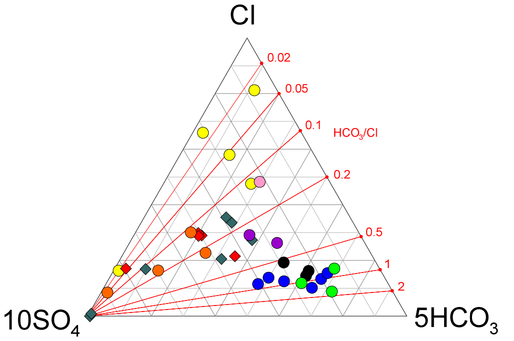

Figure 6: Spring HCO3-Cl-SO4 relative concentrations.

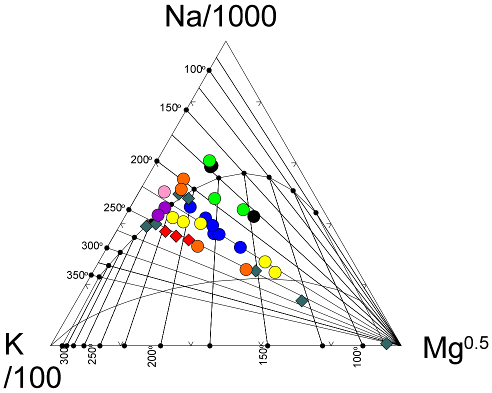

Figure 7: Spring Mg-Na-K relative concentrations

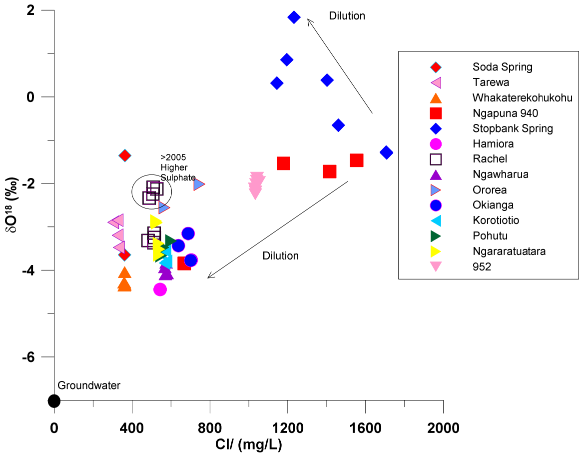

Figure 8: δO^{18} (‰) vs. Cl/(mg/L).

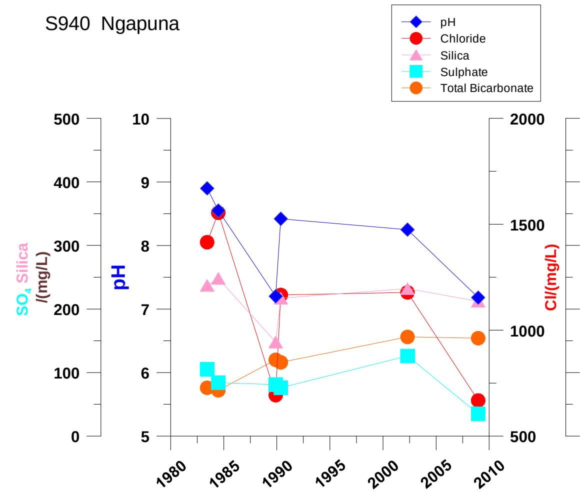

Figure 9: Ngapuna Springs S940, temporal compositional trends.

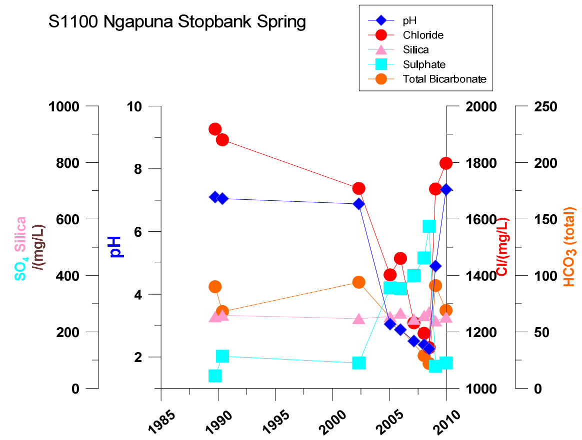

Figure 10: Stopbank Spring S1100, temporal compositional trends.

Three springs have shown significant changes in composition; at Ngapuna Springs S940 the concentration of Cl has halved (Figure 9) and the slow decline in Cl and pH in Stopbank Spring (S1100) has reversed (Figure 10); at Te Puia the Wairoa Geyser (S79) Cl has increased from 108 mg/L to 438 mg/L, similar to the average concentration observed between 1982 -1997 (Figure 11). Papakura geyser (S28), historically always active until March 1979 when boiling and geysering stopped, continues to decline in Cl and measured temperature.

5.2 Summary

Spring compositions naturally change across the Rotorua geothermal field. In the Ngapuna area the Cl/HCO_3 ratio is <0.05 while in the Government Gardens-Ohinemutu-Kuirau areas the Cl/HCO_3 ratio is ~ 1 while in the Whakarewarewa area the ratio is between 0.1 and 0.5. However any group of springs in close proximity can also be variably diluted with shallow groundwater and/or steam heated high sulphate acid water which can give rise to a wide range of compositions by mixing with the same deeper geothermal parent water. The repeat sampling undertaken over the last decade and comparison with historical data suggests that, with only a few exceptions, the compositional changes appear within natural variability. The change after the bore closure programme is exemplified by THC Blowout spring (S 952) as well the Kuirau Park Tarewa Springs (S649 to S653). THC Blowout spring reached a stable composition by 1990 (see Figure 12) and the Tarewa Springs which in 1984 were dry sinter lined craters and recommenced overflowing in 1998. However there is no explanation as to why the Whakarewarewa springs, which became acid features prior to the bore close programme, have not reactivated. Also difficult to explain is the initial increase in activity and discharge, especially around Lake Roto-a-Tamaheke but also elsewhere at Whakarewarewa. After the bore closure programme water levels (pressures) rapidly recovered in the monitor bores. Timing suggests the latter decease in activity may be due to other causes.

6. CONCLUSIONS

Most spring compositions are within the variability range except for Ngapuna Springs S940 and Stopbank Spring S1100 which have become more and less dilute respectively. At Whakarewarewa Wairoa Geyser and Papakura springs show recovery and continuing decline respectively.

The well compositions in the Western and Government Garden areas are still changing, most containing less SO_4 and more HCO_3. This is what would be expected given an increase in fluid pressures but there has been little increase in the fraction of deep reservoir higher chloride fluids. There is sufficient data to show that the Western wells are related to each other along a dilution mixing trend of cooler fluid, inferred by Stewart et al. (1992) to be high SO_4 surface water penetrating down into the reservoir. The influence of the shallow fluid is much less for the Government Garden area wells and the changes here are typically an increase or decrease in the HCO_3 fraction with little change in enthalpy. The only Kuirau well sampled, RR913, shows no change in composition since 2003. No wells in the Ngapuna area were sampled. Few of the Rotorua wells have been sampled and most only irregularly. In this regard the annual sampling by GEONET of two wells (Kuirau and Government Gardens) as well as four springs (Ngapuna, Government Gardens, Ohinemutu and Kuirau) is of value in assigning significance to the changes observed in the Government Garden and Kuirau areas. The results to date suggest the geothermal reservoir in these areas could be within the normal range expected relative to the current use of the geothermal resource.

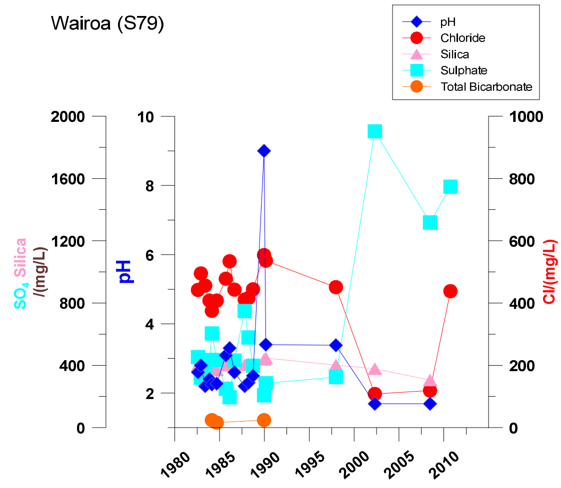

Figure 11: Wairoa Geyser (S79), temporal compositional trends.

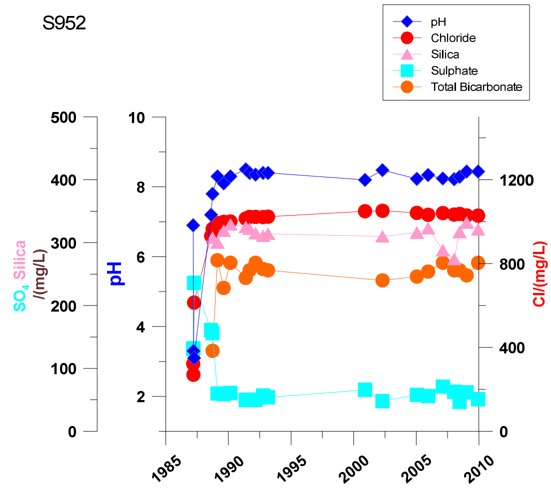

Figure 12: THC Blowout (S952), temporal compositional trends.

ACKNOWLEDGEMENTS

This project is the part of a research study within the Geothermal Research Programme funded by the Foundation for Research, Science and Technology on “Long Term Geothermal Utilisation Strategies”.

Co-funding and support from the Environment Bay of Plenty is important to the success of the project.

The interest and permission for access to features and bores by Te Puia Maori Arts and Crafts Institute, Whakarewarewa Thermal Village, Hurunga Te Rangi Trust and many domestic and industrial bore owners is gratefully acknowledged.

We also acknowledge the New Zealand GeoNet project and its sponsors EQC for providing some of the data used in this study.

REFERENCES

Allis, R.G. and Lumb, J.T., 1992. The Rotorua geothermal field, New Zealand: its physical setting, hydrology, and response to exploitation, Geothermics, 21, 1-2, 7-24.

Giggenbach, W.F., Glover, R.B., 1992. Tectonic regime and major processes governing the chemistry of water and gas discharges from the Rotorua Geothermal Field, New Zealand. Geothermics, 21(1/2): 121-140.

Glover, R.B., Mroczek, E.K., 1998. Changes in silica chemistry and hydrology across the Rotorua geothermal field, New Zealand. Geothermics, 27(2): 183-196.

Gordon, D.A., Scott, B.J., Mroczek, E.K., (comps), 2005. Rotorua geothermal field management monitoring update: 2005. Whakatane: Environment Bay of Plenty. Environmental publication / Environment Bay of Plenty 2005/12. 152 p.

Mroczek, E.K., Stewart, M.K., Scott, B.J., 2004. Chemistry of the Rotorua Geothermal Field Part 3: Hydrology. Institute of Geological & Nuclear Sciences client report 2004/178. 71 p.

Mroczek, E.K., Stewart, M.K., Scott, B.J., 2005. Chemistry of the Rotorua Geothermal Field. p. 71-91 IN: Gordon, D.A.; Scott, B.J.; Mroczek, E.K. (comps) Rotorua geothermal field management monitoring update: 2005. Whakatane: Environment Bay of Plenty. Environmental publication / Environment Bay of Plenty 2005/12.

Scott, B.J., Cody, A.D., 2000. Response of the Rotorua geothermal system to exploitation and varying management regimes, Geothermics, Volume 29(4-5), 573-592.

Scott, B.J., Gordon, D.A., Cody, A.D., 2005. Recovery of Rotorua geothermal field, New Zealand: Progress, issues and consequences, Geothermics, 34,159-183.

Stewart, M.K., Lyon, G.L., Robinson, B.W., Glover, R.B., 1992. Fluid flow in the Rotorua geothermal field derived from isotopic and chemical data. Geothermics, 21(1/2): 141-163.