ONEKENEKE STREAM, TAUPO: HISTORICAL CHANGES AND THEIR CAUSES

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ABSTRACT

The hot Onekeneke Stream in Taupo, New Zealand, has changed markedly in flow and chemistry since the 1890s. It once produced a large flow of heavily mineralised water, but now has a much smaller outflow of mixed water. We examine the history of the stream from the 1890s through to 2014 and its changing flows and chemistry, the causes of the changes, and the effects of the changes on the stream's natural environment and cultural uses. Major changes occurred in 1931 and from the 1960s onwards. We conclude that the main causes of the stream's reduced flow are most likely to be due to subsurface hydrology changes caused by the 1931 Napier earthquake, and the effect of urbanization on the local near-surface hydrology.

1. INTRODUCTION

1.1 Background

The Onekeneke geothermal stream flows in the narrow, steep-sided Waipahihi valley towards Lake Taupo (Figure 1). In 1889, the Terrace Hotel was developed above the valley's thermal pools, used as a natural swimming lake. The springs and their extensive black sinter slope became a significant tourist attraction in New Zealand (Allen, 1894). The hotel is now part of the Hilton Lake Taupo.

Exploration of the Tauhara geothermal field started in the 1960s. Tauhara has a shallow steam-heated aquifer that lies beneath the Taupo Township, extending to the east and north. By 1964, 400 shallow wells had been drilled in Tauhara to extract geothermal energy for domestic, commercial and other uses (Sarbutt, 1954).

In the early 1980s, the pressure drawdown in the Tauhara geothermal field was about 14 bars, as a result of production from the hydrologically connected adjacent Wairakei field (Mahon, unpubl. DSIR report, 1984). The deep pressure drawdown has induced ground subsidence at Tauhara of up to 100 mm/year, localised in subsidence bowls in the northern part of Tauhara field (Allis et al., 2001). Contact Energy Ltd. commissioned a new 20 MWth process heat supply to Tenon for kiln drying in 2006 and the new 23 MWe Te Huka binary power plant in 2010, both at Tauhara. In 2010 Taupo Hospital replaced its coal fired boilers with geothermal heating (Febrianto, et al., 2015).

Over time, various factors influenced the geothermal features in the Waipahihi valley, including natural variation in geothermal outflow, the 1931 Napier earthquake, development of the geothermal field and urbanisation.

Field work was conducted on 9 September 2014 to sample water physical data, sinter and outcrops to assess the variations in the Onekeneke stream over time.

1.2: Objectives

The objectives of the study were to: identify new and extinct thermal surface activity along Waipahihi valley; update data of geothermal surface manifestations; investigate decrease of thermal activity in Waipahihi valley; and draw conclusion or hypothesis on the most likely causes of the decline in geothermal activity.

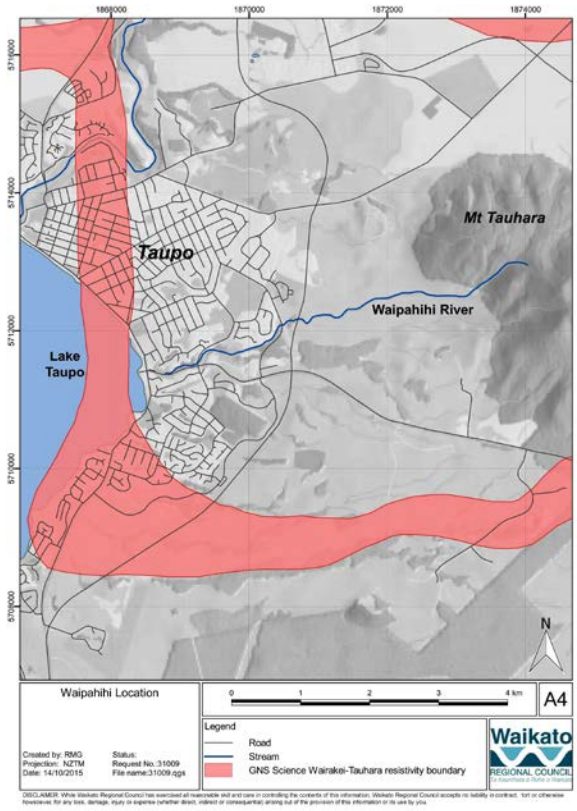

Figure 1: Location of Waipahihi Valley within the resistivity boundary zone of Wairakei-Tauhara. Adapted from Rosenberg et al., (2010).

2. GEOLOGY

2.1 Structural Geology

The Wairakei-Tauhara geothermal system sits in a broad, deep volcano-tectonic depression centered to the northwest of Mt. Tauhara, according to regional gravity and magnetic studies (e.g. Rogan, 1982; Soengkono and Hochstein, 1992, Stagpoole and Bibby, 1999). Rogan (1982) identified a volcanic collapse structure that formed a depression located between Wairakei and Taupo to the southwest.

The geological structure of Waipahihi involves active rifting tectonism of the Taupo Volcanic Zone basin. Compared with Wairakei geothermal field, relatively few faults have been mapped at Tauhara (GNS 2014). Numerous lineaments inferred to be faults have been drawn

from aerial photograph interpretation (for example, lines of craters or straight gully features in the Broadlands Road and Crown Road thermal areas), but most of these have not been confirmed as faults. Those features unequivocally identified as faults are regarded as segments of either the Aratiatia or Rotokawa fault zones (GNS, 2014).

Lineament analysis based on the GNS active fault database 2014, shows a NE-SW lineament lies along the Waipahihi valley at an altitude of about 400 m (Figure 2).

2.2 Surface Geology

Waipahihi is overlain by Taupo Pumice Formation of young pyroclastic falls and non-welded ignimbrite associated with the 1.8 ka Taupo eruption (Wilson, 1993). Rock types are loose to poorly consolidated to sintered, white to pale grey rhyolite ignimbrite with white to pale pumice clasts, fall deposits and alluvium (Figure 3).

In the valley head, the older layers of Oruanui Ignimbrite Formation represent more than 20,000 years of phreatomagmatic deposit, and non-welded and reworked ignimbrite (Wilson, 1993; GNS 2014). Outcrops show sequences of sedimentary deposits. Extensive distribution of alluvial and lacustrine pumiceous pebbly sand is found to the east of Lake Taupo between Taupo and Turangi

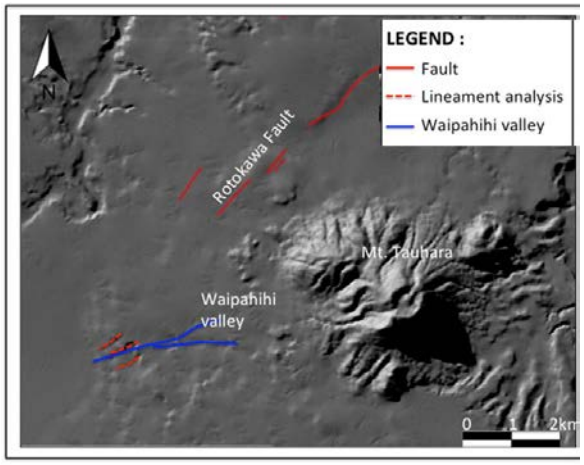

Figure 2: Lineament analysis of Waipahihi valley (GNS Active Database Fault, 2014).

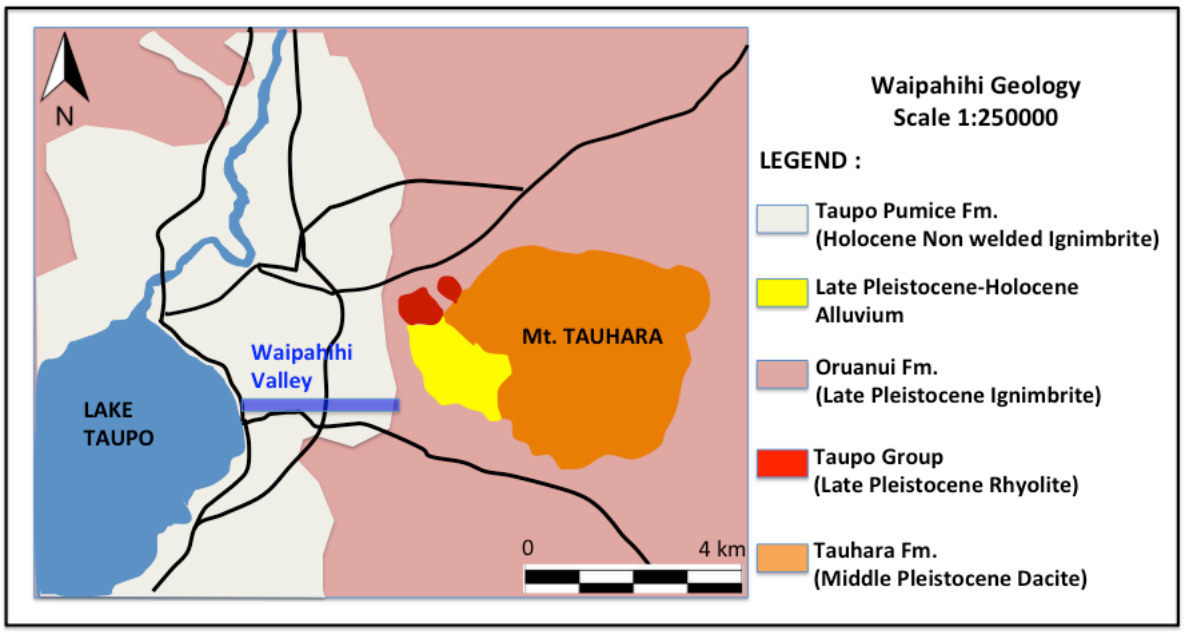

Figure 3: Surface geology of Waipahihi area



Figure 4: Outcrops of Waipahihi area showing the low density white/greyish pumice, non-welded ignimbrite and deposit of reworked gravel-pebble alluvium sand.

(Manville and Wilson, 2004). The quarternary deposit layers in the area are permeable and hold shallow groundwater that supplies domestic hot water bores in Taupo (Febrianto et al., 2015).

Outcrop observation during fieldwork (Figure 4) indicates that the valley is mostly covered by very low density white greyish pumice rocks, non-welded ignimbrite and deposit of reworked gravel-pebble alluvium sand on the road side of Napier-Taupo road. Further down the valley, pyroclastic rock falls and flows are found at the edge of Lake Taupo.

2.3 Stratigraphy

Wairakei-Tauhara outcrops expose young pyroclastic fall and flow units of Taupo Pumice Formation and Post-Oruanui sequence that includes volcanic ash and pumice, intercalated paleosol layer, local basaltic tephra, distal andesitic tephra and aeolian sequences. Local hydrothermal eruption breccia is also deposited at Tauhara (Figure 4).

The Oruanui Formation deposited below the young quartenary deposit consists of pyroclastic flow and fall material from Taupo volcano eruption around 26,500 years ago. The Huka Falls Formation (HFF) (Grindley, 1965) includes all the lacustrine sediments and water-deposited tuffs that lie between the base of the Oruanui Formation and the top of the Waiora Formation play as an aquiclude on the geothermal system.

Below HFF, the Waiora Formation, a thick interlayered sequence of volcanic and sedimentary deposits that includes rhyolite lavas, tuffs and breccias provides the major production aquifers at the Wairakei-Tauhara geothermal field. The basement is formed from Jurassic volcaniclastic sandstones of the Torlesse Terrane (Mortimer, 1994).

3: GEOPHYSICS

3.1: Resistivity

Schlumberger surveys of Wairakei were carried out between 1978 and 1982; the apparent resistivities measured using an array spacing of 500 m. The new surveys gave a better delineation of the field (Risk, 1984; Risk et al., 1984) and showed that the Wairakei Field is part of the much larger Wairakei–Tauhara geothermal system.

3.2: Magnetics

In 1950, airborne magnetic surveys were made over the field at flight heights of 5000 and 2500 ft (1525 and 760 m above sea level (masl), respectively) using a flux-gate magnetometer (Baird, 1951). Gravity data for the period 1961–1985 are confined to only two benchmarks situated in northern Tauhara. These data show large decreases in gravity associated with production induced pressure drawdown at Wairakei (Allis and Hunt, 1986; Hunt and Ikeda, 1994). A contour map of the gravity changes for 1985–1996 shows gravity increased by about 50 gal at benchmarks on Centennial Drive and near the Tenon Mill. The data for 1996–2002 shows a gravity increase of greater than 100 gal in the northern part of the Tauhara field. The gravity changes for the 2002–2006 periods show a large, elongated area of gravity increase in the northern part of the Tauhara field. A map of the gravity changes for the period 1985–2006 compiled by adding grid node values (500 m intervals) for the 1985–1996, 1996–2002 and 2002–2006 periods, shows an elongated area of gravity increase in the northern part of the field, adjacent to Centennial Drive near well TH4, but no significant changes in southern Tauhara. Explanation for the absence of gravity changes in southern Tauhara is that the water lost from this lens has drained downwards and increased the saturation in parts of a deeper, partially-saturated layer underlying the lens (Hunt et al., 2009) (Figure 5).

4: GEOCHEMISTRY

The earliest description of the Onekeneke chemistry reported by Hector (1883) analysed six samples of chloride water from the Waipahihi valley. The result showed significant salt content, the minimum amount being 8.41 g/L and the maximum 23.72 g/L.

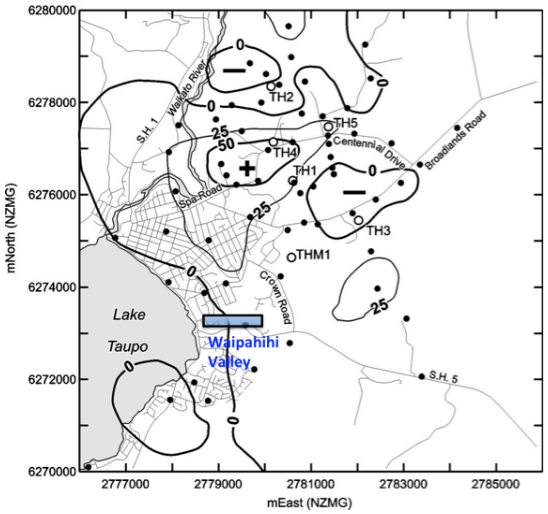

Figure 5: Gravity changes in the northern and central parts of the Tauhara field for the period 1985–2006 (contour interval: 25 gal). (modified from Hunt et al., 2009)

Temperatures ranged from 36.7 to 75.7 ºC. Early comprehensive spring chemistry data is from Magnesia springs reported by MacLaurin (1913). Sarbutt (1964) reported on diluted chloride bicarbonate springs located at Waipahihi terrace (De Brett's) and at the Lake Taupo shore.

Detailed chemistry analysis can be divided into four periods; 1900-1960 (before Tauhara exploration wells were drilled), 1960-1990 (Tauhara pressure drawdown), 1990-2000 (subsidence occurring in north Tauhara) and after 2000 (Crown Park subsidence appears near the valley). Before 1960, chemical data of the area were reported by Herbert (1921), Grange (1937) and Sarbutt (1962). Data from period 1960-1990 were reported by Sarbutt (1962) and Glover (unpublished). Period 1960-2000 data were mostly informed by Glover (1996, 1997, 2005 and 2009). Waikato Regional Council and Contact Energy provided data for the period after 2000.

4.1 Classification and Origin of Geothermal Water

The ternary diagrams show most of the discharge waters plot close to the Cl-apex during the period from 1900-1960 (Figure 7). Terraces stream, Top spring aka Source Spring and Magnesia spring are generally classified as mature waters that are derived from deep reservoir waters. The significant change that occurred in Top spring is the

decrease of chloride content (concentration). This decrease is commonly found in peripheral water in the outflow zone of geothermal systems. The waters are interpreted as dilute chloride-bicarbonate water from mixing geothermal fluid with shallow groundwater.

The ternary plots in Figure 7 support early observations that most waters sampled from Waipahihi valley are immature waters due to high HCO_3 associated with the rock dissolution process followed by deposition of K-rich secondary minerals or mixing with groundwater (Ellis and Mahon, 1977). The waters of Top spring and Magnesia spring in 1921 are partially equilibrated and give subsurface temperatures of 200 ºC and 210 ºC, respectively.

In the period 1960-1980, the waters plot along the Cl-HCO_3 apex, which indicates involvement of shallow groundwater, is significant, for example, Magnesia spring in 1962 plotted in the boundary of peripheral water.

4.2 Geothermometry

The results of chemical analysis from Iron spring (1921) and Magnesia spring (1913) are used to calculate subsurface temperatures. The results of geothermometers from the springs describe the subsurface temperatures before Tauhara exploration wells had been drilled and massive development of Taupo Township. The temperature ranges between 161-227 ºC (Table 1).

5: HYDROLOGY

Waipahihi surface hydrology is controlled by Lake Taupo, which is at a level between 355.85 and 357.25 m above mean sea level (Mighty River Power, 2009). Onekeneke stream flow is about 3-10 l/s near Waipahihi source spring (WRC, 2009), which discharges through the Taupo Pumice and Oruanui Formation (Figure 6).

The Crown Road subsidence bowl, located around 1.5 km northeast of Waipahihi, was identified after the 2001 levelling survey and was assumed to be caused by compaction of a thin lens of highly compressible mudstone, or cavities, in the Post Oruanui Sediments Formation in the Lower Huka Falls. The piezometric level map that reflects the imaginary level to which the water level will rise in wells penetrating the aquifer is constructed from monitoring data of the changes in the subsidence and surrounding area. Piezometric level changes that were developed by Bromley (2009) show no significant change in the Waipahihi valley (0 to -1 m) (Figure 8).

6: THERMAL FEATURES

6.1: Historic Features

Grange (1937) described the Waipahihi valley area as having clear alkaline hot springs, with weakly mineralised springs in the lower valley behind the Terrace Hotel, probably fed by subsurface streams of hot water derived from springs near Tauhara Mountain (Figure 10). In 1955, Grange described the Terraces as moderate chloride springs without gas content. Sarbutt (1964) describes the Waipahihi source springs as being covered by black algae that formed black sinter and suggests that they are probably associated with the Rotokaua fault zone. Now the black sinter has been buried by thick sediment that may correlate with cessation of overflows in the area following the 1931 Napier earthquake (Cody 1993).

6.2: Present Thermal Features

Present-day surface manifestations comprise a hot spring lakelet and stream covered by microbial mats with silica sinter at the edge of the channel. Dark green and orange microbial mats thrive in the Waipahihi source spring and some are partially silicified. Photosynthesis processes of the microbial mats create gas bubbles within the mats and result in a bubblemat texture when it is silicified. Most of the samples that were collected in the stream show bubble-mat textures, indicating mid-temperature hot springs and discharge channels flowing over mid-slope setting (Lynne, 2013) (Figure 10). Conical tufted textures formed in the quiet pool or low-flowing stream are identified by long filament shape.

Silicified plant debris is abundantly found in the stream. The sinter is white and porous, friable and low density that is interpreted as Opal-A sinter that forms in the slow flowing stream/channel. In the downstream springs, near Lake Taupo, sinter is not present.

Chloride concentrations of discharges from Southern Tauhara bores and springs have been relatively stable since 1950 (Bromley 2009) (Figure 12). Rainfall-induced dilution has affected the fluid chemistry and flow of Waipahihi Source Spring. The source water from Terraces Hotel bore in 2004 had a chloride concentration of ca 400 mg/kg.

6.3 Thermal features changes

A detailed plot of Waipahihi flow from several gauges whose locations are shown in Figure 9 shows that flow is relatively stable (Figure 13). An erratic trend at one point is caused by variation of time sampling associated with induced changes from rainfall and shallow borehole activity in Taupo. A declining trend is shown by the Old Waipahihi Marae gauge and SH-1 Taupo gauge that decrease to a flow rate of 1.7 l/s. The data from upper stream Kiddle Culvert is only until 1995. De Bretts weir adjacent to De Bretts resort shows increase in trend from 2010-2013.

The plots show that the Waipahihi valley declined in chloride concentration and temperature from 1960 to 1980, becoming relatively stable after 1980 (Figure 13). Top spring's chloride concentration in 1978 was 413 ppm and 290 ppm in 2013. Maximum temperature decrease was up to15 ºC in Iron spring and Top spring. Waipahihi mouth data show a trend that fluctuated, with a temperature range of 20 -40 ºC and average chloride concentration of 264 ppm.

7. DISCUSSION AND CONCLUSION

Geological data shows Waipahihi located in a structurally complex area overlain by quartenary deposits. The formation hosts an aquifer of hot water for domestic shallow bores in Taupo, including De Bretts Resort and Spa. The gravity map illustrates that there is no significant mass change happen in Waipahihi valley, and this is supported by the piezometric level map showing an absence of changes in the area.

However, Crown Rd subsidence bowl is only 1.5 km from Waipahihi stream.

Ternary diagram plots indicate that the waters have been mixed with shallow groundwater, resulting in dilute chloride-bicarbonate waters. Historically, the spring waters may possibly contain more alkali chloride based on the Cl-SO_4-HCO_3 plot from period 1900-1960. The

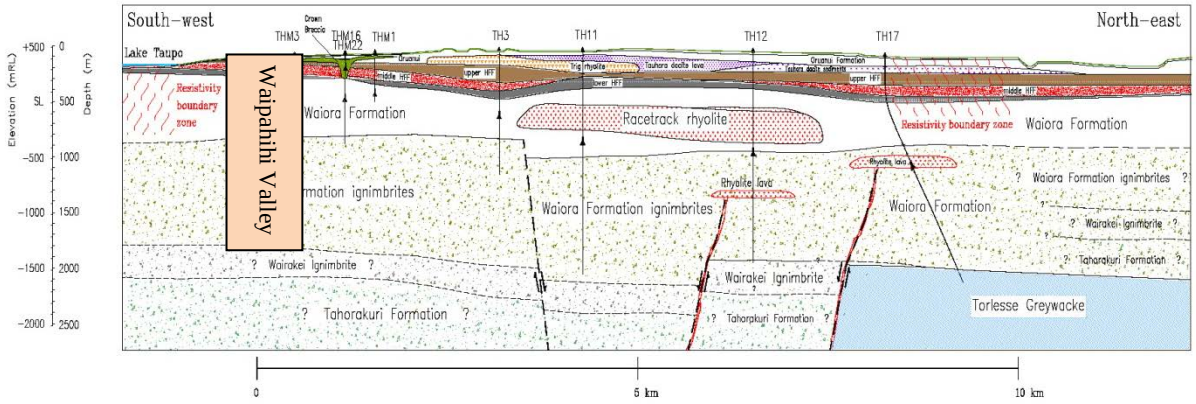

Figure 6: Southwest-Northeast interpretative geological cross section through Wairakei-Tauhara geothermal field, Waipahihi stratigraphy is the highlighted box (adapted from Rosenberg et al., 2010).

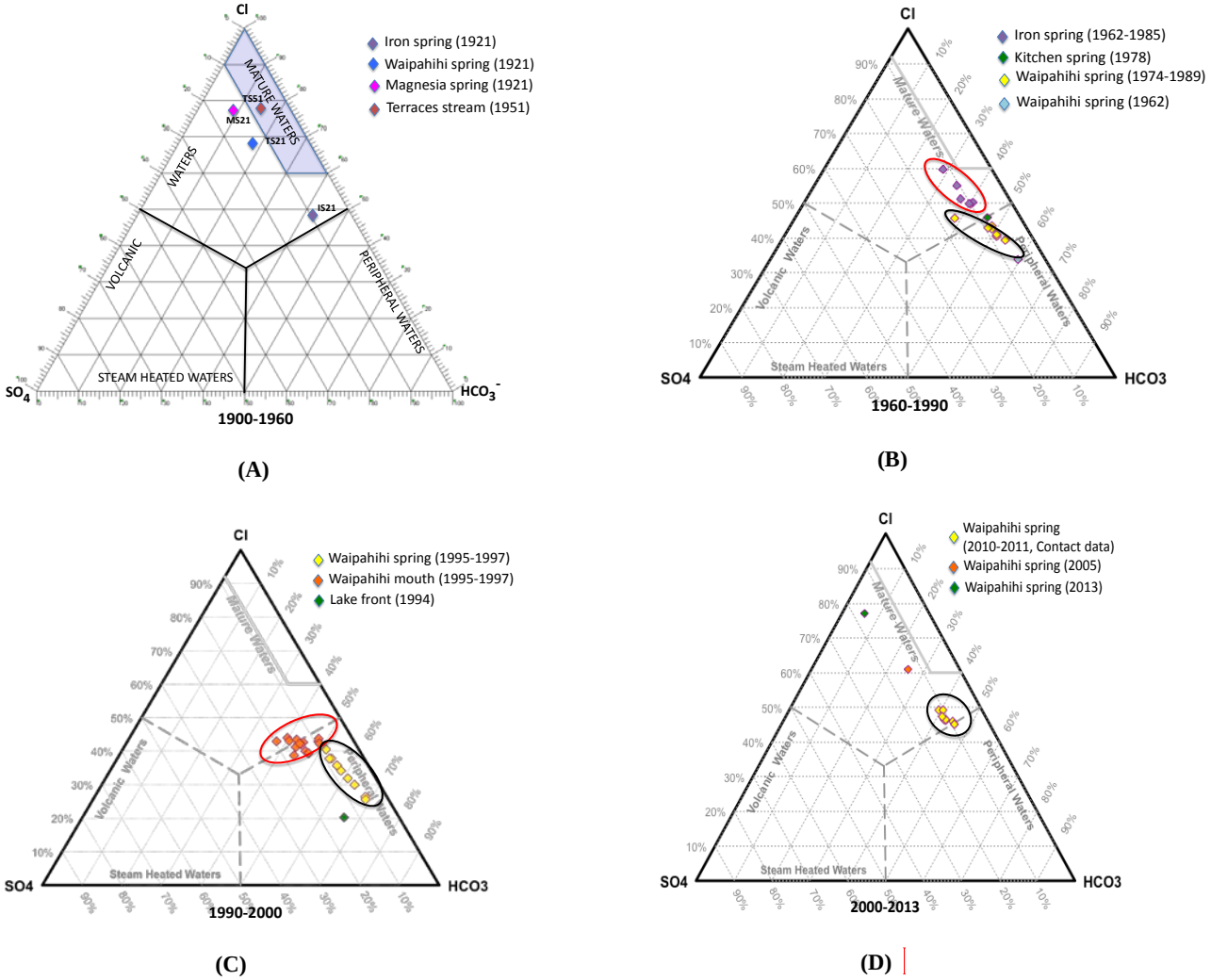

Figure 7: Cl-SO_4-HCO_3 ternary plot from various samples in Waipahihi Valley (1900 – 2013).

Table 1. Geothermometers result from Iron spring (1921) and Magnesia spring (1913)

Sample Name	Na-K-Ca	Na-K-Ca Mg corr	Na/K Fournier 1979	Na/K Giggenbach 1988
Iron Spring	data not complete	data not complete	161	179
Magnesia Spr	197	142	211	227

geothermometers indicate that the initial subsurface temperatures range from 161 ºC to 227 ºC and are declining over time, based on temperature plots.

Reported decline of surface feature activity in Waipahihi valley following the 1931 Napier earthquake (Cody 1993) has been followed by possible effects of Taupo urbanisation. Chanelling stormwater into the valley has increased the rate of sedimentation. The shallow bores drilled into shallow aquifer in 1964 led to a decrease of chloride concentration and temperature. The dilute chloride-bicarbonate waters continued to discharge by support from rainfall that recharged geothermally heated groundwater aquifer. This aquifer continues to be supplied by a deep upflow of boiling two-phase fluids driving some chloride waters mixed with steam into the aquifer. Allis et al. (1989) discussed the possibility of a separate brine upflow from deep beneath the southern slopes of Mt. Tauhara that is hydrologically unaffected by pressure drawdown in the north because of a low-permeability barrier. The hypothesis of separate geothermal systems explains the absence of mass changes and piezometric level but decrease in temperature and chloride content (Figure 14).

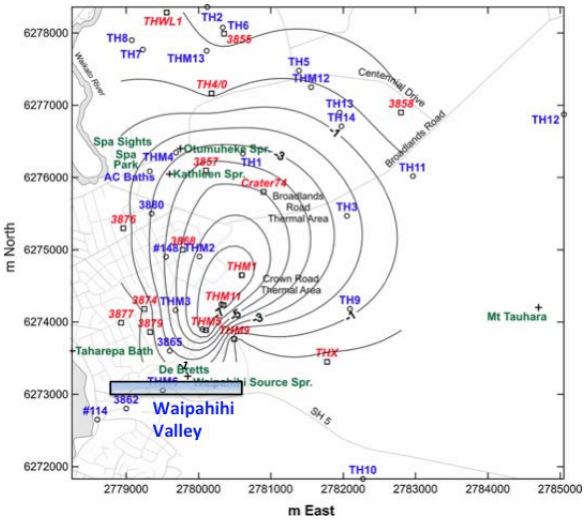

Figure 8. Map of the Tauhara Field piezometric level changes in the Upper Aquifer between 1995 and 2006 (from Bromley, 2009)

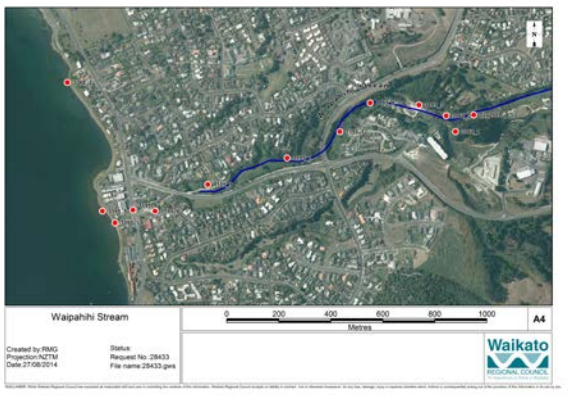

Figure 9. Map of Waipahihi thermal features showing WRC monitoring sites (red dots).



Figure 10. Picture of black terrace, Waipahihi valley on mid-late 1890 (© Rotorua Bathhouse Museum)

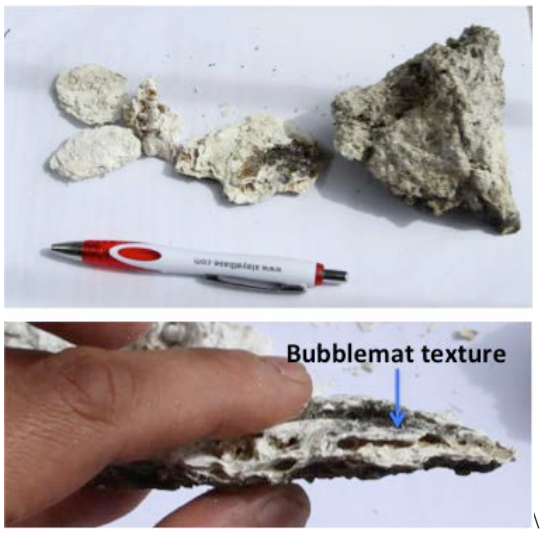

Figure 11. Waipahihi spring silica sinter samples.

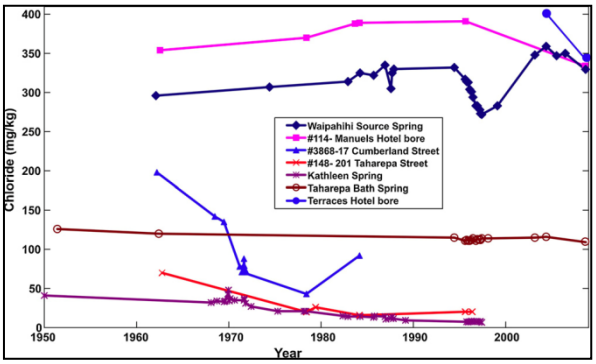

Figure 12. Changes in flow rates in Waipahihi springs and stream (from Bromley 2009).

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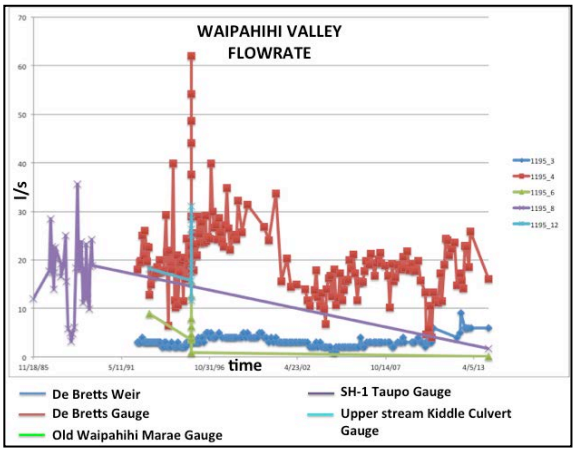

Figure 13. Changes in flow rates in Waipahihi springs and stream (WRC data).

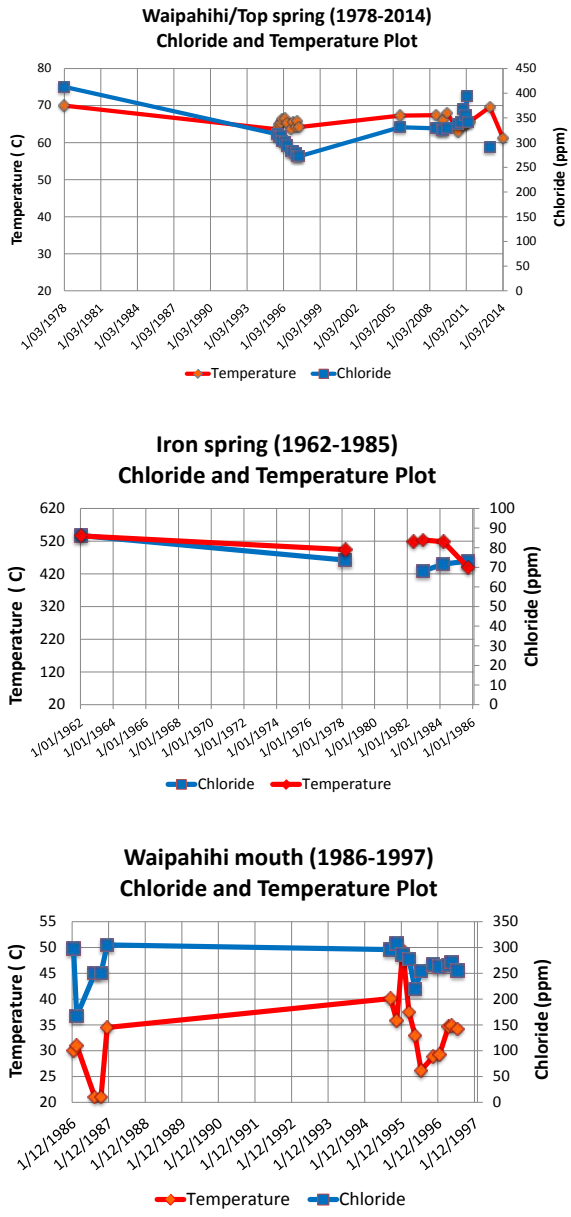

Figure 14. Changes in chloride and temperature in Waipahihi springs and stream.

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