Monitoring changes in geothermal springs chemistry at Kuirau Park and Ōhinemutu, Rotorua Geothermal System - using field physical measurements as a cost-effective proxy for chemistry changes

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ABSTRACT

Kuirau Park and Ōhinemutu, located in the northwest of the Rotorua Geothermal System (RGS), experienced increased geothermal activity between 1998 and 2002 following the 1986 bore closure programme aimed at restoring the RGS's health. Despite their proximity, the geothermal features of these areas differ in geochemistry and field attributes such as temperature.

A review of geochemical and field measurements, including recent data, shows agreement with previous surveys but highlights changes in two features. Feature RRF3014 (JC Fountain) shows signs of recovery, similar to features at Ōhinemutu, while Feature RRF0715 (Mayor's Mouth) has declined in pH, temperature, and electrical conductivity (EC) since 2017, indicating potential deterioration.

Historical analysis reveals that increased geothermal activity between 1998 and 2002 correlated with rising pH, temperature, and EC in several features. These relationships were used to generate correlations with total dissolved solids (TDS), though dataset constraints limited further analysis. Changes in TDS can indicate adverse effects like groundwater dilution due to pressure decrease within the supporting geothermal aquifer.

Electrical conductivity, pH, and temperature are easily measured in the field, while TDS and geochemistry require significant investment. Developing correlations between these parameters could be a powerful tool for screening the geothermal system and guiding further investigation with targeted chemical sampling. Focused work concentrating on changes and correlations between pH, EC and bicarbonate could be a cost-effective tool to monitor CO_2 reinjection returns to geothermal surface features and monitoring wells.

Future work should focus on improving models and correlations between field parameters and chemistry through more concurrent field measurements and geochemical sampling. Historical data has helped identify changes in pH and conductivity related to increased geothermal activity, which could warn of future activity spikes that pose health and safety risks and potential damage to property and infrastructure.

1. INTRODUCTION

1.1 Background

The Bay of Plenty Regional Council Toi Moana (BOPRC) manages the Rotorua Geothermal System (RGS) under the Resource Management Act (RMA), the Rotorua Geothermal Regional Plan (RGRP; EBOP, 1999) and the recently adopted Rotorua System Management Plan - Ngā Wai Ariki o Rotorua (BOPRC, 2024). Significant geothermal surface features are all located within the Rotorua Sensitive Management Areas (SMAs) (Zuquim, 2022; Alcaraz & Scott, 2022; Zuquim & Box, 2023), thus the BOPRC focus for its environmental monitoring programme is on those areas (Figure 1).

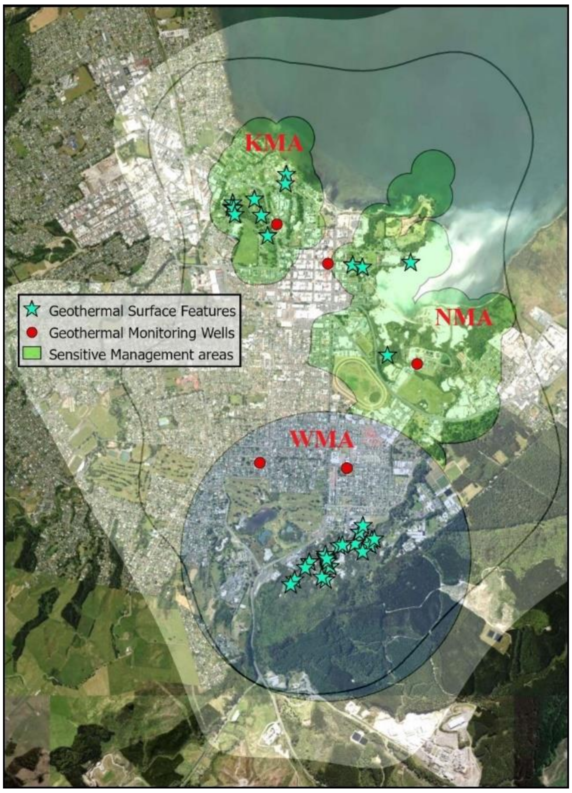


Figure 1: Rotorua Geothermal System extent and the SMAs. Kuirau, Whakarewarewa and Ngapuna (KMA, WMA and NMA, respectively).

Monitoring and reporting of relevant environmental data is central to the management of this resource: it underpins associated policies and rules and is used to assess their effectiveness and helps to inform decisions around resource consenting, ultimately, it helps to ensure the protection of the geothermal taonga for the current community and future generations.

Historically, regular monitoring focused on physical attributes (e.g. water level and flow) and less attention was given to its chemistry changes which was collected through an ad hoc monitoring arrangement. This approach was based on concerns over aquifer pressure declines during the ~1950s–1980s (cause), and its effects at aquifer and feature level (consequence). In contrast, geochemical reporting has been limited due to the costs involved in sampling and analysing the results, and probably the perception that physical attributes suffice, which is probably true in the past but now a different view is taken.

Regular chemistry monitoring of all monitored geothermal surface features began in 2021. The aim of this 'upgrade' is to capture the more nuanced and subtle changes that the RGS is currently experiencing after the quick recovery after the bore closure programme. It also aims to increase our understanding of geothermal features natural variability. This paper reports on some of those initial insights and explores a new area: the understanding of the correlation between field physico-chemical parameters [pH, electrical conductivity (EC) and temperature] and geochemistry for the RGS. While this study is only a first step, it has revealed promising results, with initial correlations being established and modelled, and thus providing a more complete picture of past and present changes in thermal activity within parts of the system.

This work also helps guide BOPRC to interpret the field physico-chemical results after each monitoring round and over longer time-scales. In the future, BOPRC aims to build thresholds for those results, where values above/below certain thresholds (in conjunction with other attributes) would trigger further investigation when those results point towards degradation within the system.

The results are also promising for monitoring bicarbonate-rich injectate returns to geothermal surface features (and even wells). Reinjection of non-condensable gases into reservoirs is becoming 'mainstream' (particularly for binary units) as part of the energy industry efforts to reduce emissions to the atmosphere from geothermal power plants. While this practice is evolving rapidly, monitoring of the fate of the CO_2 is still lagging. Cost-effective techniques, such as monitoring physico-chemical attributes as proxies for chemistry / chemistry changes, are promising monitoring options moving forward.

1.2 The Rotorua conceptual model

The most widely accepted conceptual model is presented in Scott *et al* (2016). This model identifies two main outflow zones: one beneath Ngāpuna and another one beneath Kuirau Park/Ōhinemutu. Geothermal fluids within the RGS are predominantly meteoric (~83%), with a minor arc-type magmatic component. Rainfall significantly influences the shallow aquifer and surface features (Ratouis *et al*., 2017).

Although Ngapuna and Kuirau Park share a deep fluid source, geochemistry diverges due to shallow mixing, particularly in Kuirau Park (Scott *et al*., 2016). This mixing is modulated by rhyolite dome permeability, rainfall and downflows, aquifer pressure support and deep-source fluid feed into this aquifer.

Chemical analyses show that the eastern RGS is dominated by hot alkali chloride fluids, while southern zones exhibit elevated bicarbonate levels due to groundwater dilution (Scott *et al*., 2021; Mroczek *et al*., 2002). In contrast, the northern outflow at Kuirau Park/Ōhinemutu display bicarbonate-enriched chloride waters, attributed to deeper cooling and CO_2-rock interaction (Mroczek *et al*., 2002). A decreasing Cl/B ratio from SSE to NNW further evidence compositional shifts occur during fluid ascent.

1.3 The BOPRC monitoring programme

The BOPRC geothermal monitoring programme consists of monitoring of 38 geothermal surface features bimonthly, 4 geothermal monitoring wells of intermediate depth (~100 m) (M-series wells) and 4 shallow warm bores (G-series bores). Data collected by BOPRC, both raw and processed, is freely available for all users at the BOPRC data portal - Data - Bay of Plenty Regional Council WebPortal.

The geothermal features are usually of diluted alkali-chloride composition. Table 1 and Figure 2 shows the details of the monitored features in Kuirau-Ōhinemutu, which is the focus area of this paper.

1.3.1 Geochemical monitoring

Data from scientific surveys of the RGS date back to 1945 through to present. The most significant period for Rotorua monitoring was the 1980s, when the New Zealand Government funded a comprehensive monitoring programme to investigate the decline in thermal activity which, among other severe adverse effects, led to the demise of several geysers particularly in the WMA. Significant attention has been historically given to index-features like RRF0601 (Kuirau Lake) and RRF3014 (JC Fountain) due to their high-chloride content and reliability as aquifer indicators, yielding longer time-series records compared to several other features currently monitored.

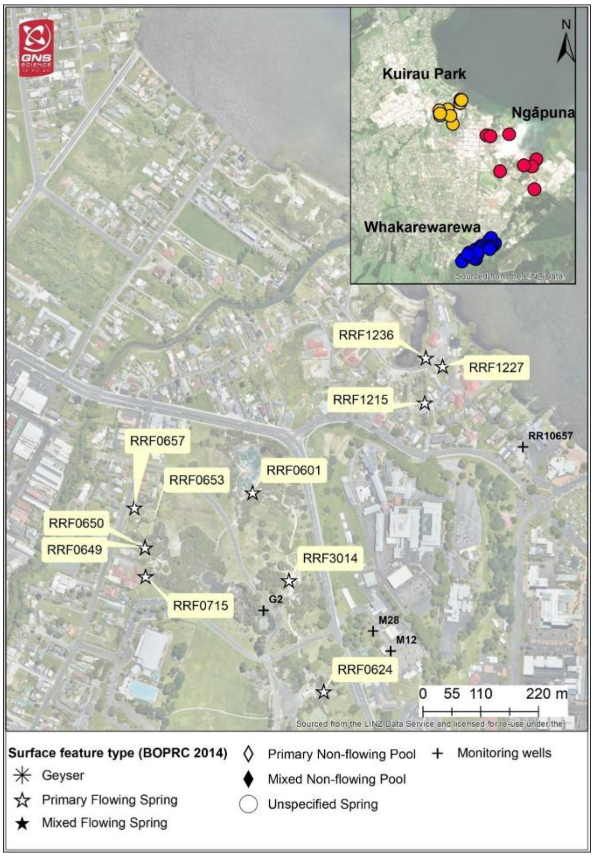


Figure 2: Surface features monitored in the Kuirau Park-Ōhinemutu area. After Scott *et. al.* (2021).

The pH, temperature and electrical conductivity are measured for all features highlighted in Table 1 and Figure 2. This is a valuable long-term dataset which requires further analysis – to date it has only been used as a support dataset to chemical analysis, rather than a standalone dataset and thus is currently under utilised. In contrast, geochemical sampling has been more sporadic, often tied to specific scientific or hazard-related investigations rather than regular routine environmental monitoring. This paper presents systematic data from the surveys of 2002, 2008, 2021 and 2022, as well as additional ad hoc data from the late 1980s. The analytes used are the standard geothermal suite of solutes such as chloride, bicarbonate, sulphate, sodium and potassium.

Table 1: ID, name, location, and activity trend classification of the monitored surface features at Kuirau Park and Ōhinemutu. Sp. = Spring.

ID	Name	Location	Classification - State
RRF0601	Kuirau Lake	Kuirau	Cyclic
RRF0624	Soda Sp.	Kuirau	Cyclic
RRF0649/50	Tarewa Group	Kuirau	Cyclic
RRF0653	Tarewa Sp.	Kuirau	Cyclic
RRF0657	Waiariki Parekaumoana	Kuirau	Cyclic
RRF0715	Mayors Mouth	Kuirau	Cyclic
RRF1215	Little Waikite	Ōhinemutu	Increasing
RRF1227	Porahi	Ōhinemutu	Cyclic
RRF1236	Deer Head Sp.	Ōhinemutu	Steady
RRF3014	JC Fountain	Kuirau	Steady

2. GEOCHEMICAL ANALYSIS

2.1 Ternary plots

Selected ternary plots exploring key chemical changes driven by processes at subsurface relevant to Rotorua (mixing of different fluids, equilibration) are presented in Figures 3 and 4, respectively. Refer to Appendix 1 for labels in Figure 4. Raine (2025) provides a full report with all plots and graphs. The focus of this paper is on new information not previously reported in previous system-wide studies, therefore only plots that revealed new information are presented.

Figure 3 presents data for two recent geochemical surveys of the area (from 2021 and 2022). This dataset is used to explore and present the recent changes in spring composition observed in the study area, with springs showing a markedly change in its visual attributes reflecting a change in fluid composition. Many features recently become hotter, reaching ebullition point, and the water became clearer and the colour transitioning to brownish colours to colourless. This change is clearly seen in changes in geochemical signature, with a significant drop in sulphur concentration for all features is observed in factors ranging from tens to thousands (Tables 4 and 5, Appendix 1). The largest changes are in central Kuirau Park, while the smallest changes are located on the eastern side of the park, and also for all features in Ōhinemutu.

As shown in Figure 3, all features moved away from the SO_4 apex in all ternary diagrams that include SO_4 (Raine, 2025). This could suggest that a greater proportion of the deeper alkaline chloride fluids are present in the shallow/intermediate geothermal aquifer, which is supported and accompanied by the general SiO_2 increase for those features as well (see Section 2.3). Minimal changes in the Na-K-Mg ternary diagram were observed between 2021-2022, indicating a relative stability of the deep(er) source fluid, which is currently untapped. Features in Kuirau Park consistently exhibit higher SO_4 concentrations than those at Ōhinemutu or JC Fountain (RRF3014).

Features at Kuirau Park, excluding RRF3014 (JC Fountain), all lie within the partial equilibrium area of the plot (Figure 4), with the predicted temperatures within the 200°C to 240°C range. While no feature generally appears to be reaching equilibrium, all features excluding RRF0601 were closest to the equilibrium curve in 2002 ('r' being the closest followed by 'j', 'x', and 's'). Data from 2021-2022 show movement of all features away from the equilibrium curve, suggesting a change in the system causing the features to move further away from equilibrium (points 'a', 'b', 'c', 'd', 'g', 'h', 'm', 'n', 'o', 'p', 't', 'u'). Refer to Tables 4 and 5 (Appendix 1) for labels.

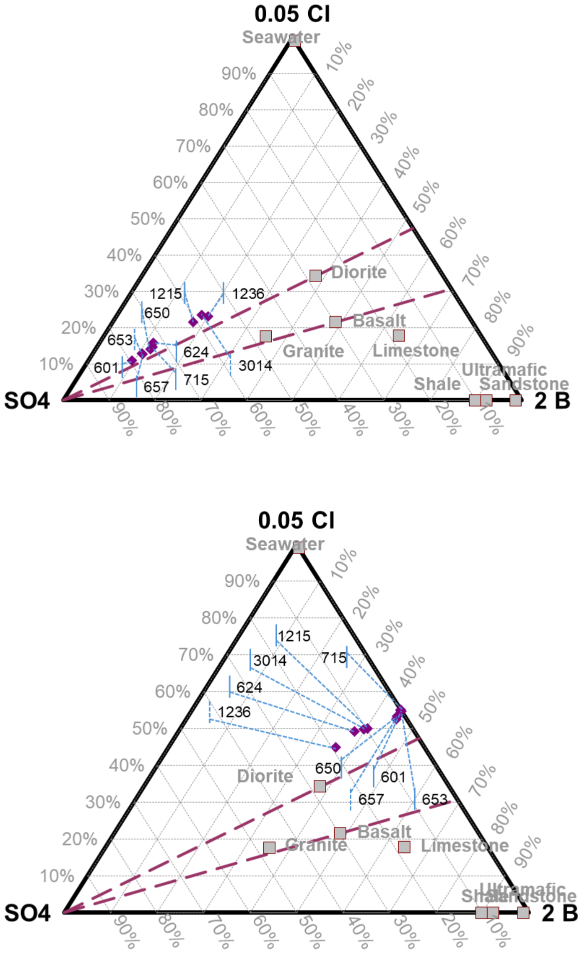


Figure 3: Ternary plots of the Kuirau Park/Ōhinemutu features in 21/02/21 (top) and 15/02/22 (bottom). After Raine (2025). See Tables 4 and 5 (Appendix 1) for labels.

Features such as RRF0653 (Tarewa Spring) have shown consistent movement away from this curve (points 'g', 'h', 'i', 'j', 'k' and 'l'), with the most recent geochemical samples (2022 and 2021; points 'g' and 'h') suggesting that the fluid at RRF0653 has become less equilibrated than it was in 1979 (point ‘l’).

Feature RRF0624 (Soda Spring) has shown a similar movement in the data points between 1997 (point ‘s’) and 2022 (point ‘o’). This feature also shows cooler temperatures predicted based on the ternary plot compared to other features in the area throughout all samples.

Feature RRF0601 (Kuirau Lake) has only shown marginal movement in the data points, with the predicted equilibrium moving minimally between the equilibrium curve and the immature curve. Feature RRF0601 is predicted to be at its least equilibrated state (points ‘w’ and ‘v’) between 2002 and 2008 while its most equilibrated state (points ‘x’ and ‘y’) was between 1993 and 1997. In conjunction, the results suggest broader changes coinciding with the increased thermal activity in Kuirau area around the late 1990s-early 2000s.

Ōhinemutu features and RRF3014 (JC Fountain) appear more geochemically mature, trending towards equilibrium. RRF3014 shows historical movement away from equilibrium during 2002–2009 (e.g. points ‘d’, ‘f’, ‘g’, ‘i’), before returning closer to equilibrium from 2012 onwards (points ‘a’, ‘b’, ‘c’). Similarly, RRF1215 (Little Waikite) deviated from equilibrium between 2009–2014 but has since trended back towards equilibrium. RRF1236 shows only one partially equilibrated sample (‘o’), with anomalously low HCO_3.

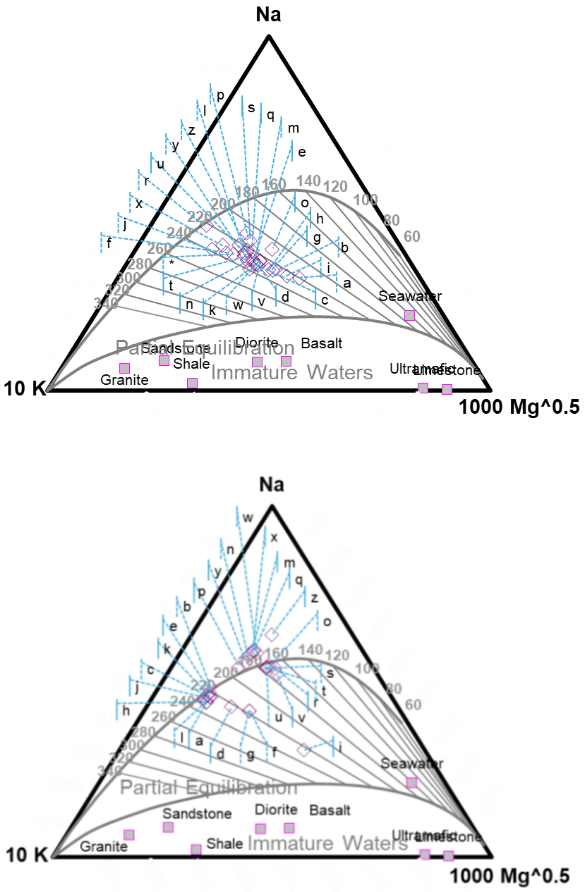


Figure 4: Na-Mg-K ternary diagrams of the Kuirau Park (top) and Ōhinemutu + JC Fountain (bottom). All sample results available. Some samples date back to 1992. After Raine (2025). See Tables 4 and 5 (Appendix 1) for labels.

2.2 Geothermometry

Cation and silica geothermometers are used to estimate the temperature for alkali-chloride type water from shallow to deeper reservoir levels. When utilising geothermometers, five assumptions are made (Nicholson, 1993):

- The concentration of elements or species is controlled by temperature-dependant fluid-mineral reaction.
- There is an abundance of mineral and/or dissolved species in the fluid system for the reaction to occur readily.
- Fluid-rock has attained equilibrium at depth.
- Water ascends quickly so this deep equilibrium is retained. There is rapid flow to surface and no re-equilibration occurs during its ascent.
- No mixing or dilution occurs during this ascent.

Applying geothermometers accurately is challenging and key to yield reliable results. While RRF3014 and some Ōhinemutu features now reflect equilibrium conditions suitable for reservoir temperature estimation, Kuirau Park features remain in partial equilibrium. Therefore, geothermometric comparisons in Kuirau Park are less reliable, further limited by cation/anion imbalances exceeding 5% (Appendix 1). As such, temperature predictions should be treated with caution. Nevertheless, results are consistent with previous findings (Mroczek *et al.,* 2003).

Previous surveys (e.g. Mroczek *et. al.,* 2003) utilised the K-Mg and the Na/K (Giggenbach; Giggenbach & Glover*,* 1992) geothermometers to investigate the estimate subsurface temperatures under different settings. The K-Mg geothermometer is a commonly used geothermometer based on the mineral reactions that respond faster than the Na/K geothermometer. Where the Na/K geothermometer indicates the temperature at which the deep source fluids are equilibrated at, the K-Mg indicates the most recent temperatures of the equilibrated fluid within the shallow aquifer. The Na/K (Giggenbach) geothermometer is most often accurate at temperatures above 150°C (Kharaka *et al*, 2006). This paper also applied the Na/K (Arnórsson; Arnórsson, 2000) which also shows suitability at predicting temperatures up to 250°C. Also, as noted by Mroczek *et. al.* (2011), a greater range in cation geothermometers reflects disequilibrium rather than a range of equilibrium temperatures, as is observed in many sites within Kuirau Park.

Silica geothermometers can be used to characterise the local temperature feeding springs (Mroczek *et. al.*, 2011). Historical analysis comparing silica geothermometers (quartz, chalcedony, and the alpha-cristobalite) assumed that alpha-cristobalite controls the silica concentration for all springs as is the case for wells. Due to the focus of this paper compared to previous studies, chalcedony and alpha-cristobalite are re-examined here.

A comparison of the Na/K (Giggenbach and Arnórsson) and Mg-K geothermometers for Kuirau Park and Ōhinemutu is presented in Figure 5. The agreement between the fast-reacting K-Mg geothermometer and slow reacting Na/K geothermometer for features in Ōhinemutu (and JC Fountain) suggests that all fluids have been at similar temperatures for long periods of time (Mroczek *et. al.* 2003), while the lack of agreement for features in Kuirau Park suggests temperature fluctuations leading to disequilibrium.

Among the geothermometers applied, the alpha-cristobalite and the Na/K (Giggenbach) geothermometers show the most agreement for Ōhinemutu, while the Na/K (Arnórsson) geothermometer shows the most agreement for features at Kuirau Park (Figure 5). The JC Fountain shows somewhat agreement between both types and further highlights its distinctness to features in the Kuirau Park / Ōhinemutu area. This feature displays both the equilibrium observed in Ōhinemutu and the higher temperatures in Kuirau Park.

Estimated temperatures align with earlier findings that Ōhinemutu is a cooler outflow of the Kuirau Park area but still part of the same shallow upflow. All geothermometers indicate that the geothermal fluids in Kuirau are up to 50°C hotter than those at Ōhinemutu (Figure 5). Charge imbalance appears to have minimal impact on temperature estimates, with balanced and imbalanced data producing similar results - likely due to meteoric mixing but limited cation exchange affecting fluid-rock interaction.

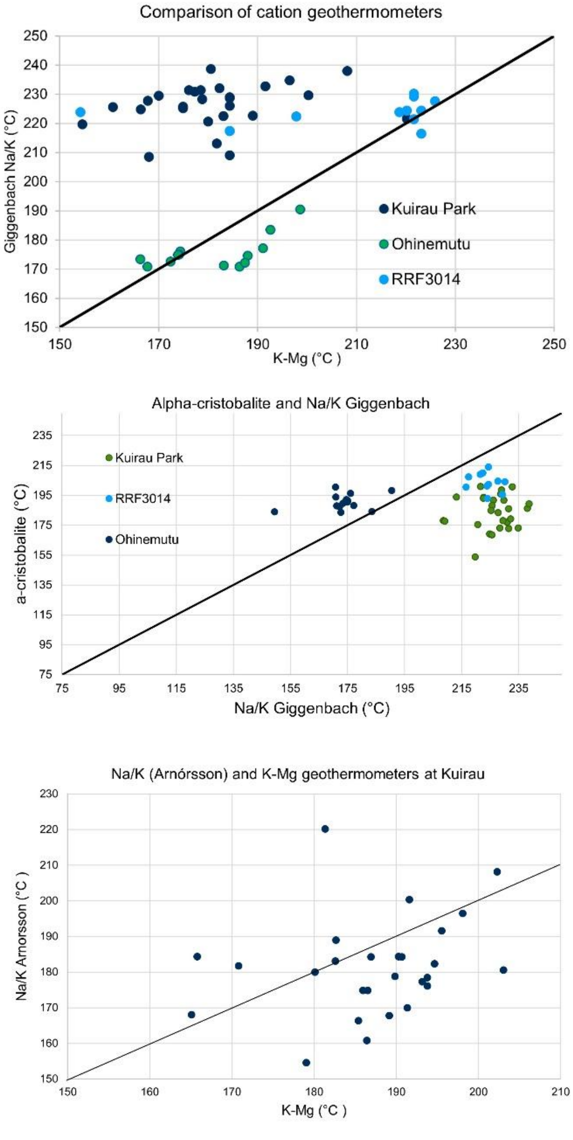


Figure 5: Geothermometry results - Na/K (Giggenbach) vs K-Mg (top) and alpha-cristobalite vs Na/K (Giggenbach) (middle) for Ōhinemutu, Kuirau Park and RRF3014 (JC Fountain). Na/K (Arnórsson) vs K-Mg for Kuirau Park (bottom). After Raine (2025).

Interestingly, RRF3014 (JC Fountain) shows temperatures up to 50°C higher than both Kuirau Park and Ōhinemutu, suggesting it may follow a more direct subsurface flow path to surface. The clear relationship between chloride concentration and water levels (Figure 6) further supports the notion that JC Fountain is fed more directly from the underlying deeper reservoir and is less subjected to mixing and cooling. This correlation between altitude of the water level and temperature across multiple features is related to a lower density of the hotter fluids along the spring feeder fractures.

2.3 Temperature vs chemistry

Surface feature temperatures are a reliable first order proxy for the temperature and level of input of deeper thermal waters into the shallower geothermal aquifer(s). However, because the measured temperature is in fact the result of multiple overlapping complex processes happening at subsurface at the various aquifers and their interaction, temperature results must be treated with caution. A temperature decline, for example, might not indicate cooling, just dilution by rainwater infiltration causing a short-term, transient temperature drop, as often is the case specially for features in Kuirau Park (Scott *et al*, 2021). However, unlike geochemical analysis, field temperature measurements offer immediate, cost-effective data, therefore a standard attribute in geothermal monitoring particularly useful to observe and define long-term trends. Field temperature vs chemistry data is presented in Figure 7.

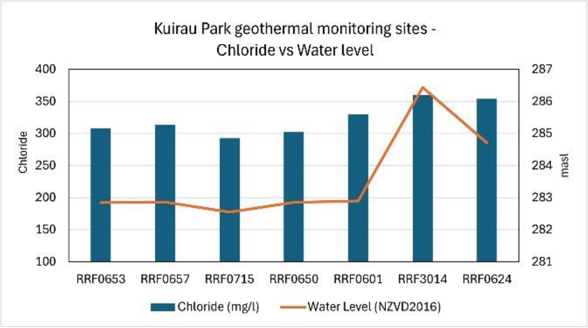


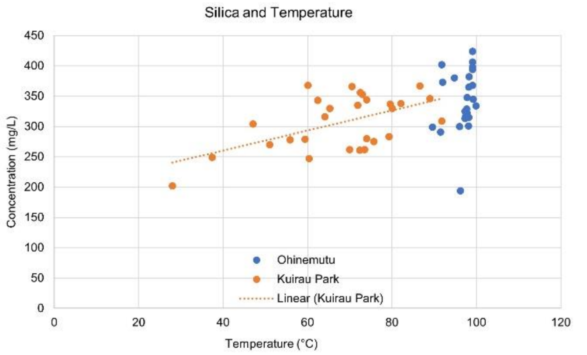
Figure 6: Water level vs chloride concentration for features in Kuirau Park.

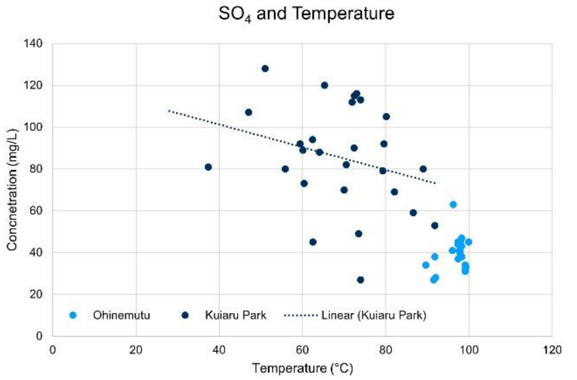
Temperature and ion concentration for SiO_2, SO_4, HCO_3 were compared to assess qualitative relationships across features in Kuirau Park and Ōhinemutu (Figure 7). The positive relationship between SiO_2 and temperature is expected and indicates a greater proportion of deeper primary geothermal fluid in the make-up of the spring water, while the negative relationship between SO_4 and HCO_3 with temperature indicates dilution by cooler meteoric or shallow groundwater. Features in Ōhinemutu overall have higher silica and lower sulphate and bicarbonate content compared to the features in Kuirau Park. The different linear relationship between silica vs temperature between Kuirau and Ōhinemutu features are likely a result of greater dilution and mixing for features in Kuirau Park, except for JC Fountain (Raine, 2025).

2.4 pH

The surface features in the Kuirau Park / Ōhinemutu area show variation in pH values, but the patterns of change differ in those areas. The basic understanding of pH vs shallow processes in the geothermal aquifer is that features with lower pH (more acidic) have a higher degree of mixing with meteoric water compared to more alkaline features. The key findings of the pH analysis are presented below:

- In general, all features display a similar pattern of change in pH, the main difference being the timing at which certain features show changes in pH compared to others. The difference is likely due to the short-term effect of the infiltration of meteoric water and mixing with the deep-sourced fluids.
- Features in the southwest are more acidic than the features to the northeast.
- Features in the southwest tend to drop in pH more readily after rainfall compared to northeastern features.
- pH varies between five and eight (absolute), typical of peripheral and steam-heated acidic waters.





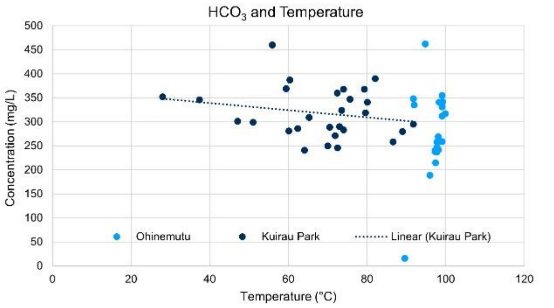


Figure 7: Selected analytes concentration and temperature for Kuirau Park and Ōhinemutu. After Raine (2025).

Correlation analysis between monthly precipitation and pH suggests varying sensitivity to mixing (Table 2). Ōhinemutu features exhibit more stable pH (lower gradients), while Kuirau Park features show greater variability, indicating a higher degree of meteoric mixing in the latter. Nonetheless, overall, pH variations fall within natural variability, consistent with system stabilization and are not considered to be driven by anthropogenic factors. Note that pH data is quite limited and a higher resolution sampling programme would be required to increase confidence on the results. The fact that JC Fountain and Soda Spring rate of change is in the higher end is not consistent with previous findings, for example. Nonetheless, the approach to explore the effects of rainfall (Figure 8) on pH is quite unique and promising.

Table 2: Rate of change in pH per surface feature.

Feature	Feature name	Rate of change in pH
RRF0650	*unknown	-0.0046
RRF0715	Mayor’s Mouth	-0.0037
RRF3014	JC Fountain	-0.0021
RRF0624	Soda Spring	-0.0016
RRF0653	Tarewa Spring	-0.0015
RRF0601	Kuirau Lake	-0.0013
RRF0657	Waiariki Parek.	-0.0007
RRF1236	Deer Head Spring	-0.0005
RRF1215	Little Waikite	-0.0005

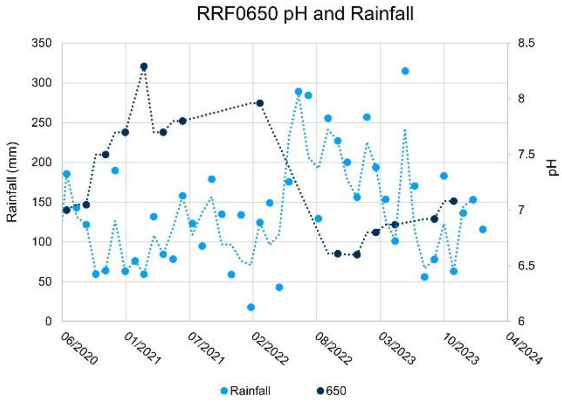


Figure 8: Monthly moving averages of pH and rainfall for the Kuirau Park/Ōhinemutu area. In general, heavy precipitation seems to result in a decline in pH for all features after a period of two to four months. After Raine (2025).

2.5 Electrical conductivity

Electrical conductivity (EC) has been monitored in the Kuirau Park / Ōhinemutu sporadically since 1991, with bi-monthly field measurements becoming common from 2020 onwards. Conductivity serves as a proxy for total dissolved solids (TDS). An initial analysis indicated a weak positive relation ($R^2 = 0.26$) between those parameters (Equation 1; Figure 9).

$$\textbf{Equation 1: } y = 0.25x + 1014.9$$

Where y = TDS (mg/L) and x = conductivity (µS/cm).

This model is based on a limited dataset thus while limited levels of confidence exist to apply the model, it is a first step to guide future refinement and increased confidence on the results.

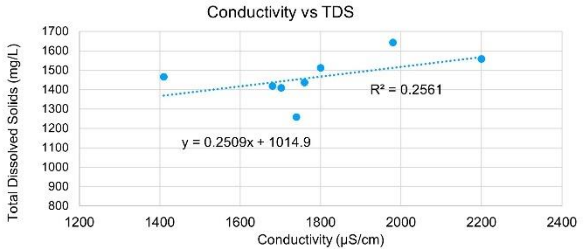


Figure 9: Conductivity vs total dissolved solids. After Raine (2025).

2.5.1 Conductivity and major ions

Qualitative analysis suggests that EC correlates most strongly with Na^+, Cl^-, HCO_3^-, with SiO_2. SO_4^{2-} showing a weaker and more inconsistent relationship. The limited spatial and temporal distribution of geochemical samples constrains the interpretation for some features like RRF1236 (Deer Head Spring). Features RRF3014 (JC Fountain) and RRF1215 (Little Waikite) are better represented, thus the relationship results are more reliable for features with larger sample sizes.

Figure 10 shows varied conductivity–temperature relationships across features, with RRF1236, RRF0715, RRF657, RRF0653, and RRF0650 exhibiting clear positive correlations, while RRF3014, RRF1215, RRF0624, and RRF0601 showing no correlation (i.e large conductivity differences despite similar temperatures). Most of the elevated conductivity readings occurred between July 1998 and December 2001 (highlighted in red), with RRF0624 and RRF0601 also showing spikes between 1989 and 1992 (highlighted in yellow). Notably, RRF0715 currently shows both low conductivity and temperature. Isotopes data from this feature and the shallow bore G2 nearby supports the interpretation that this feature has been 'flooded' by the shallow warm geothermal aquifer, currently having minimal input from deeper fluids (Figure 11).

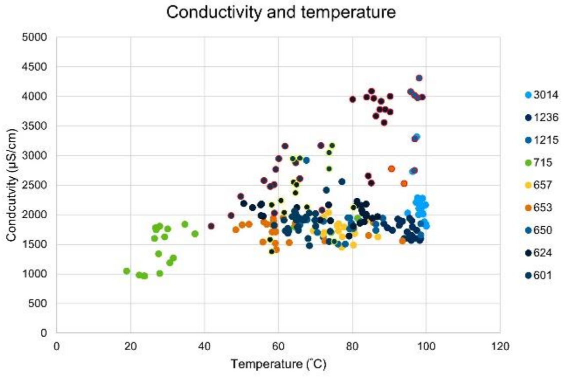


Figure 10: Conductivity vs temperature for all features at Kuriau Park / Ōhinemutu. Red ring indicates measurements between 1998 and 2001, yellow ring indicates measurements between 1989 and 1992. After Raine (2025).

Temporal comparisons show that features sampled prior to 2002 exhibited stronger co-variation between pH, EC, and temperature than those sampled after (Figure 12). This suggests a change in system dynamics, possibly reflecting a rather fast step change in the state of the Rotorua Geothermal System. Post-2002, conductivity appears more stable across a range of pH and temperature values, indicating less sensitivity to surface-driven changes or greater subsurface buffering.

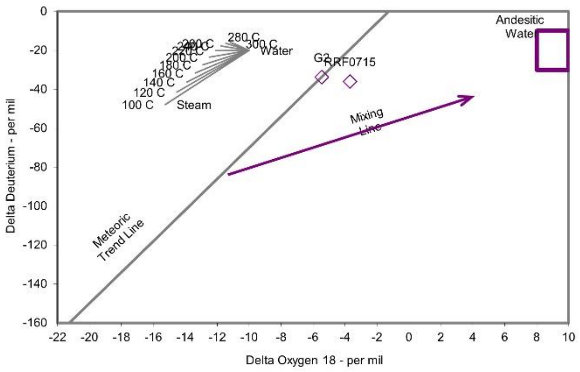


Figure 11: $\delta^{18}O$ – δD stable isotope plot for RRF0715 and G2, a shallow warm monitoring bore nearby. After Raine (2025).

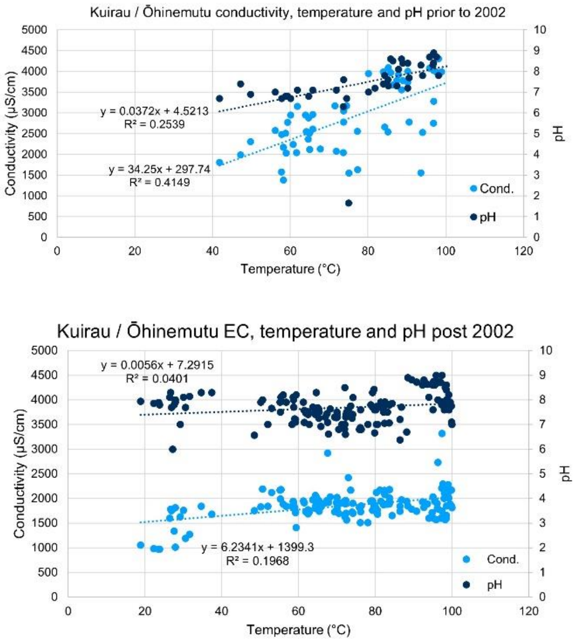


Figure 12: Electrical conductivity (EC), temperature and pH for the surface features in Kuirau Park / Ōhinemutu – data prior to and post 2002 (above, and below, respectively). After Raine (2025).

The behaviour of RRF0715 (Mayor's Mouth) provides an example of system complexity. Recent field data show lower temperatures (< 30°C) with an increase in pH—an apparent contradiction suggesting reduced input from hot alkali chloride fluids and possible flooding by shallow groundwater.

Overall, conductivity—especially when considered alongside temperature and pH—offers a valuable, real-time indicator of geothermal fluid composition and subsurface changes. It is less delayed and more cost-effective than full geochemical analyses and can enhance early detection of system shifts when used in conjunction with other monitoring parameters.

2.5.1 Conductivity as an indicator of increased surface feature activity.

Large increase in conductivity could indicate increases in geothermal fluid input. As shown in Table 3, conductivity for features in Ōhinemutu are within a range of 1700–2200 µS/cm and 1500–2000 µS/cm for Kuirau Park features.

Historical data shows conductivity spikes—exceeding two standard deviations from the mean—often coincide with geothermal resurgence. When combined with pH data, this may support early identification of increasing geothermal activity (Raine, 2025).

Table 3: Mean conductivity (measured) and estimated conductivity based on +/- 1 and +/- 2 standard deviations (µS/cm). Increasing geothermal activity has been observed when conductivity is above mean +2 STD for the feature.

Feature (RRF)	+2 STD	+1 STD	Mean	-1 STD	-2 STD
3014	2900	2600	2200	1800	1500
1236	2000	1800	1700	1600	1400
1215	2000	1900	1800	1700	1600
715	2200	1800	1500	1200	800
657	2000	1800	1700	1600	1400
653	2100	2000	1800	1600	1500
650	2400	2200	1900	1600	1400

3. DISCUSSIONS

The findings of this paper broadly align with previous assessments of Kuirau Park and Ōhinemutu that identified that features at Kuirau Park are more acidic / steam-heated while Ōhinemutu features are more bicarbonate-dominated, and that all of them fall in the peripheral waters class (Scott *et al.*, 2016; 2021; Mroczek *et al.*, 2004). However, this paper focused on doing a 'deep dive' into the data, establishing a clear geochemical affinity between RRF3014 (JC Fountain) and features in Ōhinemutu despite its geographical location in Kuirau area.

Ōhinemutu features have consistently approached the equilibrium curve, while Kuirau Park features generally do not, indicating less equilibrated fluids. Between 2002 and 2008, RRF0653 (Tarewa Spring) showed the most pronounced shift toward immature fluid, a trend also seen—though to a lesser extent—in other Kuirau Park features, excluding RRF3014. This trend is not seen in Ōhinemutu.

Between 1997 and 2002, features such as RRF0653, RRF0624 and RRF0601 were closest to equilibrium, suggesting more mature fluid compositions at the time. These shifts may reflect changing meteoric water infiltration, pressure conditions or varying contributions of alkali-chloride fluids. Recent data show a slight return towards equilibrium for RRF0601 and RRF0624, aligning with earlier conditions.

Temperature estimates consistently place Ōhinemutu as cooler than Kuirau Park, consistent with previous studies (Scott *et al.*, 2021). However, comparisons are qualitative due to widespread charge imbalances and partial equilibrium at Kuirau Park.

Recent System Changes

In 2022 a marked drop in SO_4 concentrations was observed across most features compared to the previous years. While within historical ranges for RRF0715 and RRF0624, the reduction elsewhere exceeds typical natural variability and may indicate broader system changes. Potential drivers include changes in permeability, aquifer pressure or analytical uncertainty.

Historically, pressure loss due to over-exploitation (1950s–1980s) led to increased acid-sulphate water in surface features (Mroczek *et al.*, 2004). The observed 2021–2022 SO_4 decline suggests a widespread reduction in shallow groundwater input, potentially accompanied by shifts in pH or temperature, supporting the notion that the system is still changing and potentially recovering from overexploitation.

pH and fluid composition

The pH analysis confirms that Ōhinemutu features are generally hotter and more basic than features in Kuirau Park. A pH decrease typically follows high rainfall events by 2–4 months. This finding helps to guide the understanding on the differences in patterns in changes in pH due to natural mixing from downflows vs from anthropogenic factors.

Conductivity, temperature and fluid composition

Systematic analysis of the conductivity data provided insights into surface features at Kuirau Park and Ōhinemutu for the first time. A linear correlation between conductivity and TDS was determined, allowing for a simple predictive model, though its confidence is reasonably limited by dataset size. In theory, conductivity can also act as a proxy for major ion concentrations and overall water chemistry, but more data is required to develop more robust correlations and models.

Conductivity also correlates positively with temperature, driven by two key factors: (1) higher temperatures increase ion mobility, enhancing conductivity, and (2) hotter fluids dissolve more minerals, raising total dissolved solids. These mechanisms reinforce one another, creating a positive feedback loop between temperature and conductivity. For example, an original fluid at 20 °C and at 100 °C would likely have a higher conductivity at 100 C both because of increased ion mobility at higher temperature and because in reality it will likely have a higher TDS due to increased rock-fluid interaction.

4. CONCLUSION

Given the distinct geochemical profiles of each area, the models and analysis presented in this paper treated Kuirau Park and Ōhinemutu separately, with RRF3014 grouped with Ōhinemutu due to its chemistry affinity with the latter.

Ōhinemutu remains consistently hotter and more alkaline than Kuirau Park. From 1998 to 2002, pH and conductivity rose by one to two standard deviations, despite stable temperatures, potentially indicating increased geothermal activity. Such changes, if observed consistently across multiple features, could signal broader aquifer changes.

Rainfall appears to affect pH, with reductions observed two to four months post-rainfall likely due to the infiltration of meteoric water and the oxidation of H_2S into SO_4. This lag provides insight into natural vs. anthropogenic factors. Those results are preliminary and warrant further investigation in the future.

Na/K (Giggenbach) and alpha-cristobalite geothermometers give the best temperature agreement for Ōhinemutu, while the Na/K (Arnórsson) remains most reliable for Kuirau Park. Chalcedony consistently overestimates temperatures, likely due to cristobalite dominance.

The relationship between conductivity, temperature, pH and major ions was explored and the correlation between conductivity and TDS modelled as a starting point. Several modelled equations are presented in Raine (2025), some with tighter fitting and some requiring a significantly larger dataset for refinement and increased confidence. The results are promising and provide greater understanding of the correlation between physical parameters and chemistry within the context of the study area. Further work will help to increase confidence in these relationships.

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APPENDIX 1 - SUPPLEMENTARY TABLES TO FIGURES 3 AND 4 - CHEMISTRY RESULTS AND LABELS FOR THE PLOTS. CONCENTRATIONS ARE IN MG/L, TEMPERATURE IS IN CELSIUS. RED INDICATES A CHARGE BALANCE GREATER THAN OR EQUAL TO ±5%.

Table 4 – Features in Kuirau Park area.

Sample Name	Date	Sample Label	Temp	pH	Na	K	Ca	Mg	SiO_2	B	Cl	SO_4	HCO_3	sum cations	sum anions	Charge Balance
715 '22	16-Feb-22	a	28	8.47	329	28	.2	0.18	202	6	284	0	352	15.20	13.78	5%
715 '21	25-Feb-21	b	37.4	8.3	374	34	2.7	0.14	249	7	325	81	346	17.28	16.53	2%
657' 22	15-Feb-22	c	75.7	7.3	346	34	1.9	0.08	275	7	302	1	347	16.02	14.22	6%
657 '21	25-Feb-21	d	72.4	8.27	354	35	1.8	0.09	261	7	300	90	360	16.39	16.24	0%
657 '08	18-Jun-08	e	73.5	8.52	347	33	1.5	0.07	262	6	326	49	324	16.02	15.53	2%
657 '02	23-Apr-02	f	8.24	70	320	33	1.2	0.03	262	6	326	70	250	14.83	14.75	0%
653 '22	15-Feb-22	g	56	8.2	360	34	2.2	0.13	298	6	309	0	379	16.65	14.93	5%
653 '21	25-Feb-21	h	59.4	8.2	373	36	2.0	0.13	279	7	308	92	369	17.26	16.65	2%
653 '08	18-Jun-08	i	8.5	8.5	381	35	2.0	0.20	247	6	303	73	387	17.58	16.41	3%
653 '02	23-Apr-02	j	91.8	8.49	326	35	0.9	0.02	309	6	332	53	295	15.12	15.30	-1%
653 '84	19-Dec-97	k	n/a	8.2	319	35	1.2	0.07	320	6	301	62	366	14.82	15.78	-3%
653 '79	04-May-79	l	89	8.75	335	32	1.3	0.05	346	6	305	80	280	15.46	14.86	2%
650'22	15-Feb-22	m	n/a	7.96	354	35	1.9	0.08	308	6	304	1	379	16.40	14.80	5%
650 '21	25-Feb-21	n	79.3	8.29	361	36	1.6	0.07	283	6	301	79	368	16.71	16.17	2%
624 '22	15-Feb-22	o	n/a	8.06	410	30	2.0	0.10	279	7	342	5	464	18.71	17.35	4%
624 '21	25-Feb-21	p	55.9	8.2	434	32	1.7	0.05	278	7	350	80	460	19.79	19.08	2%
624 '08	18-Jun-08	q	51	8.23	395	34	3.3	0.07	270	7	363	128	299	18.22	17.81	1%
624 '02	23-Apr-02	r	86.6	9.11	367	32	1.0	0.01	367	7	361	59	258	16.83	15.64	4%
624 '97	19-Dec-97	s	82.1	7.5	385	30	1.8	0.05	338	7	341	69	390	17.61	17.45	0%
601 '22	15-Feb-22	t	n/a	8.2	365	35	1.5	0.06	357	7	347	0	298	16.85	14.67	7%
601 '21	25-Feb-21	u	65.3	7.25	379	35	1.5	0.06	330	7	331	120	309	17.46	16.90	2%
601 '08	18-Jun-08	v	64.1	8.29	348	32	2.0	0.08	316	6.6	335	88	241	16.06	15.23	3%
601 '02	24-Apr-02	w	47.1	7.57	350	32	2.4	0.08	304	7	352	107	301	16.17	17.09	-3%
601 '97	19-Dec-97	x	80.1	7.56	372	36	0.9	0.03	330	6	330	105	341	17.15	17.08	0%
601 '93	02-Mar-93	y	79.6	7.65	362	32	1.2	0.04	337	6	332	92	319	16.63	16.51	0%
601 '92	07-Oct-92	z	71.9	7.8	351	31	1.4	0.05	335	6	324	112	271	16.14	15.91	1%
601 '90	27-Feb-90	*	70.5	7.3	338	34	1.0	0.04	366	7	325	82	289	15.63	15.61	0%

Table 5 – Features in Ōhinemutu area + JC Fountain in Kuirau Park. Red indicates a charge balance greater than or equal to ±5%.

Sample Name	Date	Sample Label	Temp	pH	Na	K	Ca	Mg	SiO_2	B	Cl	SO_4	HCO_3	Sum cations	Sum anions	Charge Balance
3014 '22	15-Feb-22	a	94.8	8.73	339	33	1.9	0.01	380	7	332	4	462	15.69	17.01	-4%
3014 '21	28-Feb-21	b	n/a	n/a	417	34	1.9	0.01	365	7	340	42	449	19.10	17.82	3%
3014 '13	10-Jan-13	c	99.1	8.56	376	34	2.0	0.01	424	7	363	34	312	17.33	16.06	4%
3014 '12	21-Feb-12	d	99.1	8.63	386	34	2.1	0.03	406	7	360	31	331	17.77	16.23	5%
3014 '10	29-Oct-10	e	91.8	8.4	379	33	2.1	0.01	402	8	375	38	348	17.44	17.07	1%
3014 '09/12	09-Dec-09	f	99.1	8.91	388	32	2.2	0.05	394	7	363	31	355	17.81	16.70	3%
3014 '09/01	09-Jan-09	g	99.1	8.74	388	32	2.2	0.05	394	7	363	31	355	17.81	16.70	3%
3014 '08	09-Jan-08	h	99.2	8.31	343	33	2.2	0.01	345	7	359	33	342	15.87	16.42	-2%
3014 '07	15-Feb-07	i	99.9	8.64	356	32	2.5	0.24	334	7	362	45	317	16.45	16.34	0%
3014 '05/12	13-Dec-05	j	98.3	8.43	382	36	2.4	0.01	382	7	360	38	341	17.66	16.54	3%
3014 '05/01	17-Jan-05	k	92	8.6	354	32	2.8	0.01	373	7	363	28	335	16.36	16.31	0%
3014 '02	23-Apr-02	l	99.1	9	345	31	2.4	0.01	368	7	364	32	259	15.92	15.18	2%
1236 '22	18-Feb-22	m	n/a	9.62	353	16	0.7	0.01	331	6	318	7	203	15.79	12.44	**12%**
1236 '21	22-Feb-21	n	97.4	9	365	17	0.7	0.01	316	7	301	37	215	16.34	12.79	**12%**
1236 '89	04-Oct-89	o	89.6	n/a	350	15	0.7	0.02	299	6	313	34	0.16	15.65	9.54	**24%**
1215 '22	18-Feb-22	p	n/a	n/a	354	20	1.0	0.01	356	6	317	3	237	15.96	12.89	**11%**
1215 '21	28-Jan-21	q	n/a	n/a	360	15	1.0	0.01	338	7	318	45	246	16.09	13.94	**7%**
1215 '14	06-Mar-14	r	98.2	n/a	392	16	1.1	0.03	365	7	318	47	260	17.53	14.21	**10%**
1215 '13	10-Jan-13	s	97.8	n/a	349	16	0.9	0.02	348	6	319	40	258	15.63	14.06	**5%**
1215 '12	21-Feb-12	t	97.7	n/a	353	16	1.0	0.02	329	6	321	41	237	15.81	13.79	**7%**
1215 '10	29-Oct-10	u	97.3	n/a	351	16	1.0	0.02	325	6	343	45	240	15.72	14.55	4%
1215 '09/12	09-Dec-09	v	97.8	n/a	362	16	1.1	0.03	322	6	324	40	247	16.21	14.02	**7%**
1215 '09/01	09-Jan-09	w	98.2	n/a	332	14	1.1	0.01	315	6	317	43	242	14.85	13.80	4%
1215 '08	01-Jul-08	x	97.3	n/a	362	15	1.2	0.01	313	6	317	44	238	16.20	13.76	**8%**
1215 '02	23-Apr-02	y	98.1	n/a	342	17	0.8	0.01	301	6	310	46	269	15.36	14.11	4%
1215 '89	01-Jul-89	z	96	n/a	346	10	1.1	0.01	300	6	330	41	189	15.36	13.26	**7%**