Rotorua Geothermal Surface Feature Monitoring Data: An innovative approach to a unique database

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ABSTRACT

The Bay of Plenty Regional Council (BOPRC) manages the Rotorua Geothermal System (RGS) to support its sustainable use, while protecting its valuable natural and intrinsic qualities. Regional councils have obligations under the Resource Management Act (RMA) to collect information on the state of the environment and ensure the integrity and public access of information (including data) in a transparent way and to foster public participation.

The BOPRC Geothermal Surface Features Monitoring Programme continues to generate vast datasets that require careful management to ensure accuracy, reliability, availability and meaningful interpretation. Geothermal surface feature data has been collected once every two months for over ~20 years, with some datasets going back to the 1980s, with isolated datapoints from the 1940s. These historical datasets are an invaluable source of information on what the Rotorua Geothermal System 'looked like' in a nearly undisturbed state, at its environmental bottom-line and at its current much improved state.

BOPRC migrated data from a previous ineffective data storage system, bringing data out to the community in an effective, transparent, meaningful way. Several systems already adopted by BOPRC were used, including AQUARIUS Time-series (AQTS) and AQUARIUS WebPortal (AQWP). BOPRC now have all the data import process automated using language codes R and python. Developing these codes was a key part of this project.

The project successfully imported all historical data and photographs into AQTS, establishing 38 new locations, each with ~13 geochemistry and ~10 field observation time series. Qualitative data was introduced into AQTS for the first time, necessitating the creation of new data legends for three parameters (water colour, visual clarity and odour).

End users can now access and interact with comprehensive information on geothermal surface features, fostering greater engagement and understanding of this specific type of environmental data. This is a significant improvement on data management workflow, supporting BOPRC in delivering key functions under the RMA and other statutory or non-statutory requirements.

This paper describes the steps taken to develop this bespoke database, from data automation, storage, presentation, and opportunities for meaningful use of similar datasets – especially those containing qualitative information. Similar processes could enable storage and display of other types of knowledge information beyond modern science, for example, from Mātauranga Māori monitoring, which are strongly based on sensorial tohu.

1. INTRODUCTION

The Bay of Plenty Regional Council (BOPRC) manages the Rotorua Geothermal System (RGS) under the RMA (various sections), the Rotorua Geothermal Regional Plan (RGRP; Environmental Bay of Plenty, 1999), and the recently adopted Rotorua System Management Plan - Ngā Wai Ariki o Rotorua (BOPRC, 2024) (Figure 1).

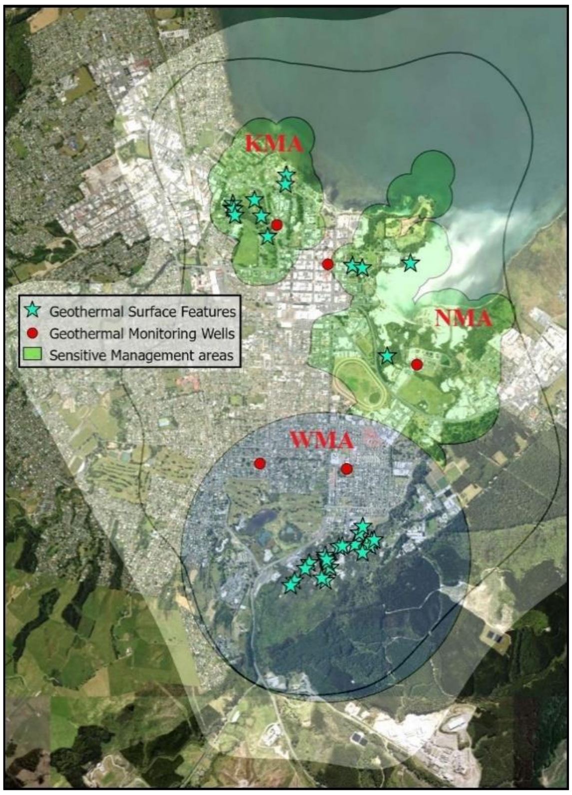

Figure 1: Rotorua Geothermal System extent and sensitive management areas: Kuirau (KMA), Ngāpuna (NMA) and Whakarewarewa (WMA) (Rotorua SMP).

Regional councils (like BOPRC) have obligations under the RMA to collect information on the state of the environment and ensure the integrity and public access of information (including data) in a transparent way. Among other drivers, those requirements ensure or at least foster public participation and accountability for Councils.

Previously, geothermal data was not available in an accessible way, nor had it been through tight QA/QC processes across all historic datasets. Up until 2024, data was stored in-kind within the Geothermal Groundwater database (GGW) hosted at GNS Website (https://www.gns.cri.nz/data-and-resources/gns-geothermal-and-groundwater-ggw-database/). The GGW was designed to be a repository of temporal and spatial measurement data, with some functionality for data retrieval, but in a way that was extremely hard to navigate even for data-systems professionals. Therefore, when directing the public to the GGW database upon request, there was a perception that BOPRC was creating barriers to access data, rather than facilitating access, understandably.

Other significant issues included the sparse (annual) schedule for data upload into GGW, which failed to provide prompt access to the latest information. Data was publicly available, however, the nature of the GGW as an inventory made access to the data challenging for the community.

In 2023 the BOPRC Environmental Information Services (EIS) and Science teams started a significant joint project to transition geothermal monitoring data stored in GGW, to BOPRC data storage and sharing systems, the same systems used to store and share all other environmental monitoring datasets (e.g. freshwater, air, flood management). The challenge here was to create innovative ways to accommodate the unique and bespoke nature of geothermal surface features data and make it meaningful for our communities.

The purpose of this work was therefore two-fold: (i) to ensure that BOPRC meets its statutory requirements to store and make data available in a transparent and viable way to our communities, and (ii) to enable greater levels of community engagement by fostering and encouraging people to explore geothermal monitoring data and foster kaitiakitanga for Māori, which are hau kāinga in most monitoring sites.

1.1 Geothermal data users

The primary users of environmental data across all disciplines, are both internal and external to BOPRC. Users include iwi/hapū groups, consent holders / applicants or consultants working on their behalf, territorial authorities (e.g. Rotorua Lakes Council - RLC), and primary and secondary schools. The tertiary education/research sector (e.g. the Geothermal Institute at the University of Auckland) and public research organisations, such as Earth Sciences New Zealand (formerly GNS Science and NIWA) are also key users. Finally, BOPRC's staff particularly with environmental reporting functions (e.g. scientists, land management officers), are key internal users.

Geothermal activity (waiariki, the chiefly waters) in Rotorua and across Te Ahi Tupua (the Taupō Volcanic Zone) is of special significance for Māori. Te waiariki (geothermal) is a taonga (treasure) to Māori. The health of waiariki is strongly linked with the physical and metaphysical wellbeing of Māori, and their connection transcends time and dimensions (Conroy & Te Ahi Kaa Roopu, 2022). Māori holds strong Mātauranga (Māori knowledge and ways of knowing) based on hundreds of years living in thermally active areas in Rotorua. Mainstream scientific data is considered as being very important to Māori as well and is often requested to complement their Mātauranga.

Resource consents from BOPRC are required to take and discharge geothermal water and heat in Rotorua (in fact, in any geothermal system). Monitoring data is frequently used to inform those regulatory processes and for their assessment of the environmental effects.

The Rotorua Lakes Council is required to manage geothermal hazards to protect people, property and lifelines. Data on surface feature activity is a key source of information for RLC to understand changes to thermal activity and the exposure to geothermal hazards.

Local schools often request BOPRC data to help support their kaiako (teachers) and ākonga (students) to get scientific perspectives, with many of the ākonga growing amongst it. A user-friendly interface is key for their success. The same is valid for the tertiary education sector, with students from multiple locations (e.g. Japan, USA, Europe and the many pacific nations) often requesting data from Rotorua for their projects. This is driven by its international significance and popularity, relative abundance of data, length of datasets and data accessibility, given that data from geothermal developments is mostly inaccessible due to their commercial sensitivity, whether real or perceived. The public (and private) research organisations, as well as university researchers often choose Rotorua as case studies for the same reason as tertiary education. Rotorua is also a 'natural lab', with ideal conditions to test new ideas and methods, as well as having a long history of monitoring data collection.

Finally, BOPRC holds functions under the RMA to report on the state of environment (SOE). SOE reporting is key to understand the state and trend of our natural systems, to inform policies and plans, and to provide information on whether the natural environment is meeting the vision and aspirations of our communities or not. This guides BOPRC on what monitoring is required to ensure that we are delivering on this. Therefore, there is an expectation from our community to access and scrutinise this monitoring data themselves.

In summary, monitoring data for Rotorua needs to be available to all customers, internal and external to BOPRC, in various formats to meet a variety of clients' needs.

1.2 The BOPRC geothermal monitoring programme

The backbone of the BOPRC Rotorua geothermal monitoring programme is the monitoring of 38 geothermal surface features, the 4 geothermal monitoring wells of intermediate depth (M-series) and the 4 shallow warm bores (G-series). Geothermal surface features (GSFs) are visited bimonthly to collect data on visual and physical attributes of a quantitative and qualitative nature (e.g.: water temperature, water colour). For the M-series wells, water level / pressure readings are recorded at 15-minute intervals and temperature profiles are carried out on an annual basis. Spot water level and temperature readings, taken at the bottom of hole ~8m depth. are recorded fortnightly for the G-series bores.

Chemistry data has been obtained annually over the last 3 years for all GSFs but was previously collected *ad hoc*. Most monitored GSFs are of primary nature to monitor effects to the intermediate geothermal aquifer that feeds the primary springs. Those springs have the highest value under the BOPRC Regional Policy Statement (RPS) (BOPRC, 2014), thus requiring a high level of protection.

While health, safety and accessibility constraints restrict some monitoring options, they do not present significant issues to the overall programme. BOPRC maintains good relationships with its community, both directly and indirectly through contractors. These contractors are fronting monitoring on behalf of the BOPRC. Thanks to these good relationships, there is a good level of geographic coverage of the monitoring programme, the only significant gap being Ngāpuna due to the iwi/hapū's own aspirations for environmental monitoring.

2. ENVIRONMENTAL DATA MANAGEMENT SYSTEMS AND PUBLIC / INTERNAL INTERFACES

The systems listed below are central to BOPRC's ability to store, manage and disseminate data and information to internal and external end users:

- HydroTel®: Used for storing telemetry data and managing alarms for when the geothermal aquifer reaches critically low levels, posing significant risk to the GSFs.

- AQUARIUS Time-Series (AQTS): System for internal access only. AQTS is used to store and carry out specialist QA/QC on environmental data and metadata, including photographic records, site visit records for validation/calibration, location and access information, to apply offsets and merge data across different sites when monitoring locations change over time. Very importantly, the AQTS system enables 'backdoor' access for large data import and/or export through coding (e.g. R, Python) and application programming interfaces (APIs). The AQTS environment controls what data is published externally to the Council's Environmental Data Portal.

- AQUARIUS WebPortal (AQWP): Known as the Environmental Data Portal (EDP), is the public interface to AQTS and provides access to a range of current and historical environmental monitoring datasets. The EDP hosts multiple dashboards and has a map-based interface (not available in AQTS). It enables the development of colour-coding / state bands, to better communicate what the data means to the public. For example, areas affected by draught, as defined in the Standard Precipitation Index scheme adopted by BOPRC.

- Geoview: Internal Geospatial system used to store geospatial data. Relevant to this work is the creation of monitoring locations through this system. It also has the metadata that enables cross-referencing with AQTS through the monitoring location name, tags, and other metadata.

- Objective ECM: A retired document management system (BOPRC has since adopted SharePoint). Data (photographs in particular) that was historically stored in Objective, has since been imported into AQTS via automated APIs, as Objective was not designed to be a data-storage or management system.

3. DATA PROCESSING AND PREPARATION

A significant and time-consuming challenge of this project was consolidating data in one place and carrying out strict QA/QC processes, to ensure confidence in the data. Data was spread across multiple systems, the main ones being:

- GGW database: Main source of field attribute results, some chemistry and some observational metadata. Over 80 years of monitoring data was/is stored there.
- Report attachments: Data stored as attachments for technical reports from consultants commissioned by BOPRC, such as chemistry data.
- Level surveys: Conducted by BOPRC in 2023-2024 (Zuquim, 2024). The results were used to geolocate the monitoring sites and to reconcile levels of past and current datums.
- Objective ECM: Photographs, as well as some qualitative field attributes missing from GGW, were stored in multiple locations within Objective.

Data preparation required the following steps:

- Data export from GGW.
- Data quality review – carried out by BOPRC and ESNZ staff jointly.
- Extensive level surveying.
- Compilation and formatting of data files for automated import into AQTS: Field photographs, chemistry data, field observation attributes.
- Creation of monitoring locations in BOPRC's geospatial systems.
- Standardisation of qualitative attributes through defining bands and converting data accordingly.
- Developing and running scripts in R and Python languages for bulk data import into AQTS.
- Data post-processing in AQTS: Application of all water level datum offsets, combining data where a monitoring site's location changed over time, aligning attribute nomenclature and standardisation of units with other Council areas.
- Design of qualitative attributes display on the AQWP/EDP.
- Publishing of data to AQWP/EDP by setting appropriate metadata required for publication in AQTS.

4. CURRENT DATA WORKFLOWS

Once all data was imported into the BOPRC systems, small adjustments with field contractors were made to ensure that data collection and delivery was standardised to meet BOPRC requirements. This collaboration was key to ensure the smooth automation of data import using the newly developed scripts. As a result, data import has become a seamless process. Firstly, data QA/QC is carried out by ESNZ on behalf of BOPRC, and a final check is then conducted by the BOPRC Science team. Finally, data is imported and published by the BOPRC EIS team. It is by nature a bespoke system where field data is handled by multiple people with much care from collection to publishing, with QA/QC occurring at multiple levels prior to being shared with the public.

4.1 Qualitative attributes

Quantitative analysis is intrinsic for scientific method in mainstream science, although long recognized as tohu (indicators) by Māori. With the BOPRC database being strongly rooted to fulfill 'modern science' / methods, a process to store and make available qualitative data did not previously exist.

However, several of the field attributes in geothermal data are of qualitative nature rather than absolute measures, obtained through senses (i.e.: sight and smell). These qualitative attributes are water colour, odour and visual clarity (which is an absolute measurement in freshwater, hence 'visual clarity' in 'our' geothermal database). While a lot of information can be drawn from these simple attributes, they were previously overlooked due to the challenges of using this type of data for quantitative analysis, rather than the acknowledgement of their significance. The strategy to deal with this type of data is presented in steps below and an example shown in Figure 2 (Appendix):

- Review all historic data and create fixed options for field observation records. This is key in both constraining the number of options, and to ensure consistent grammar is used for seamless data import using the developed scripts. The challenge was to ensure that decades of data for all 38 sites, could be reclassified into a limited and well-defined number of options without losing resolution and its richness.

• Convert qualitative data to numbers by assigning values to each of the fixed field result options (Table 1).

• Upload data into AQTS as numbers but display results in AQWP/EDP as coloured bands and meaningful legends.

Table 1: Qualitative attributes and their assigned values used for automated data import and data display.

Odour			
Base Value		**Secondary Value**	
0	No Odour	.1	Mild Odour
1	H2S Gas Odour Detected	.2	Moderate Odour
		.3	Strong Odour
Visual Clarity			
Base Value			
0	Clear		
1	Moderately Turbid / Cloudy		
2	Turbid / Milky		
Water Colour			
Base Value		**Secondary Value**	
0	Colourless	.1	Dark
1	Blue	.2	Light
2	Green	.3	Green
3	Yellow	.4	Blue
4	Orange	.5	Yellow
5	Red	.6	Grey
6	White	.7	Milky
7	Grey		
8	Black		
9	Brown		
10	Purple		
11	Violet		
12	Magenta		
13	Pink		
14	Cyan		

5. EXAMPLES – Results for individual and spatially varied features

This section shows how the AQWP public interface was designed to suit all users, from curious individuals to data specialists. Experts can quickly preview results before deciding whether to download and analyse the data further, which is often enough. An ākonga might be fascinated by how chemistry differs between geothermal and nearby freshwater in Rotorua, sparking dreams of becoming a geothermal scientist (Figure 5, Appendix). For a Regional Council, data goes beyond legal obligations, we serve every person and community.

Two examples are provided below on how one could use the AQWB/EDP to explore the state of a GSF or a thermal area. Note that an in-depth data analysis or interpretation and is beyond the scope of this paper.

• Papakura Geyser: To illustrate how the one can explore the results for multiple attributes for a single location / GSF.

• Whakarewarewa Valley: To illustrate how one can explore the results of each attribute across multiple sites. This is a key functionality in Rotorua, where there is large spatial variability and patterns are not obvious.

5.1 Papakura Geyser

The Papakura Geyser is a highly dynamic feature that has experienced multiple states / stages over time, due to both natural variability and anthropogenic adverse effects. These changes have been captured through monitoring over time. Combining recent detailed datasets and the sparser historic data, with some data from as far back as 1945, both step and gradual changes can be observed in some of the quantitative attributes. By adding results of qualitative attributes into the analysis, a more comprehensive, holistic and robust understanding of the state and changes (trends) of the surface features is achieved.

The Papakura Geyser, on the southern banks of Puarenga Stream (Whakarewarewa), was historically a flowing spring with frequent episodes of geysering up until the 1980s (Pearson-Grant *et al*, 2015). The 1970s to 1980s have seen the demise of many features, including Papakura, which succumbed to overuse. With its collapse it became a cold to warm pool, with water levels below its feeding zone. Around the year 2012, Papakura became a lot more active and even occasionally erupted, defining a new state for this feature which is still more or less sustained.

5.1.1 Results

Timeseries for selected attributes are presented in figures 3 and 4 (Appendix). By viewing and comparing data side-by-side, one can quickly identify patterns, trends and changes.

Changes in water colour were observed at similar timings as changes in pH (a scientist might read this as an indication of changes in the source fluid, with changes in the amount or proportion of primary vs steam heated / condensate water). Grey-brownish colours occurred between ~ 2000-2005, more or less concomitantly with lower pH values (more acidic water), although the water colour dataset is limited between 2005-2010. Near neutral pH results (~ 7 pH units) are observed after ~ 2005, with accompanying changes in colour from the colourful brownish tones to colourless and blueish-greenish tones. One interesting observation made was that this change in proxies for chemistry (water colour and pH), did not accompany a marked change in sulphate (in fact, neither in chloride), potentially identifying a limitation of the dataset.

Finally, the marked increase in water temperature happened at a much later date (not until ~ 2014), with a clear increase in reactive silica (despite the limited data points) and a stabilisation of low turbidity (clear water) field results. Prior to ~ 2014 water clarity results were highly variable.

5.2 Whakarewarewa Valley

The Whakarewarewa Valley is part of the southern shallow upflow of the RGS and is part of the WMA (Figure 1). It hosts the Geyser Flat in Te Puia, home of the renowned Pohutu and Te Tohu (Prince of Wales Feathers) geysers, as well as several other smaller geysers and phenomenal hot springs. Previous scientific analysis (Scott *et al*, 2021 and references therein) struggled to identify trends with great levels of confidence, apart from eastern Whakarewarewa, around Roto-a-Tamaheke. Perhaps one reason is because it fell short of exploring the richness of the full monitoring database by limiting itself to ‘modern science attributes’ (e.g.: water level, flow, temperature and *ad hoc* chemistry), an intrinsic limitation of the scientific method approach to data.

This example shows some initial but clear patterns and demonstrates the potential for the use of qualitative attributes for spatial analysis to extract maximum value from the BOPRC's extensive and rich database.

5.2.1 Results

Selected attribute results for the Whakarewarewa Valley are presented in figures 6 to 9 (Appendix). Immediately, one can observe that (i) Chloride values increase broadly to the northeast (the main deep upflow in Rotorua is a few km further to the northeast, around Ngāpuna / Sulphur Point – Scott *et al*, 2016); (ii) that there are still plenty of 'murky' mixed-water / high chloride features to the northeast, and that those are slightly more acidic than the clear features, and (iii) these slightly acidic features have higher sulphate concentrations. Significantly more information can be derived from these types of maps for other attributes, this example merely illustrates the insights that can be obtained within two or three clicks.

6. CONCLUSIONS

Monitoring data for Rotorua needs to be available to all customers, internal and external to BOPRC, in various formats to meet a variety of users' needs. This project has enabled BOPRC, in its role as a data custodian, to continue to look at ways to improve methods to store and share data and information. Perhaps most importantly, we are demonstrating commitment to everyone and every community to make data transparent and accessible.

With creative bespoke solutions for the uniqueness and richness of geothermal monitoring data and its qualitative attributes, no additional software was required to process and make available such information. This leverages the use of Council's resources that are already widely used and supported, such as AQTS and the Environmental Data Portal (AQWP). This demonstrates efficiency and commitment to appropriate use of public resources.

Geothermal data now sits alongside all other environmental data held by Council, unlocking the power of seeing geothermal data in a holistic and more integrated way – as part of the suite and cycles of natural 'waters', which also aligns with Te Ao Māori for waiariki.

For the first time, a system was created to enable qualitative attributes to be displayed and analysed alongside quantitative attributes, such as flow or chemistry data. This shows that 'mainstream' scientific databases can be modified, and limitations removed to enable readily accessible qualitative attributes. Integrating qualitative datasets into the wider database unlocked the potential of these highly underutilised datasets. These datasets can stand on their own or be used in conjunction with other quantitative attributes in analysis. Previously, qualitative data was only used for *ad hoc* 'checks' and to make sense of quantitative results, often when data was difficult to interpret.

BOPRC is now well positioned to manage many geothermal indigenous datasets (tohu) in the future, if required or requested. We believe that the integration between different knowledge systems could be transformative for Rotorua if realised.

This paper offers only a preliminary glimpse into the capabilities of the BOPRC's geothermal database. This valuable resource is publicly accessible and available for all to explore. We encourage you to engage with it, experiment boldly, challenge conventional approaches, and most importantly, share your discoveries with us. Curiosity drives innovation, let it guide your journey.

ACKNOWLEDGEMENTS

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Appendix – Figures

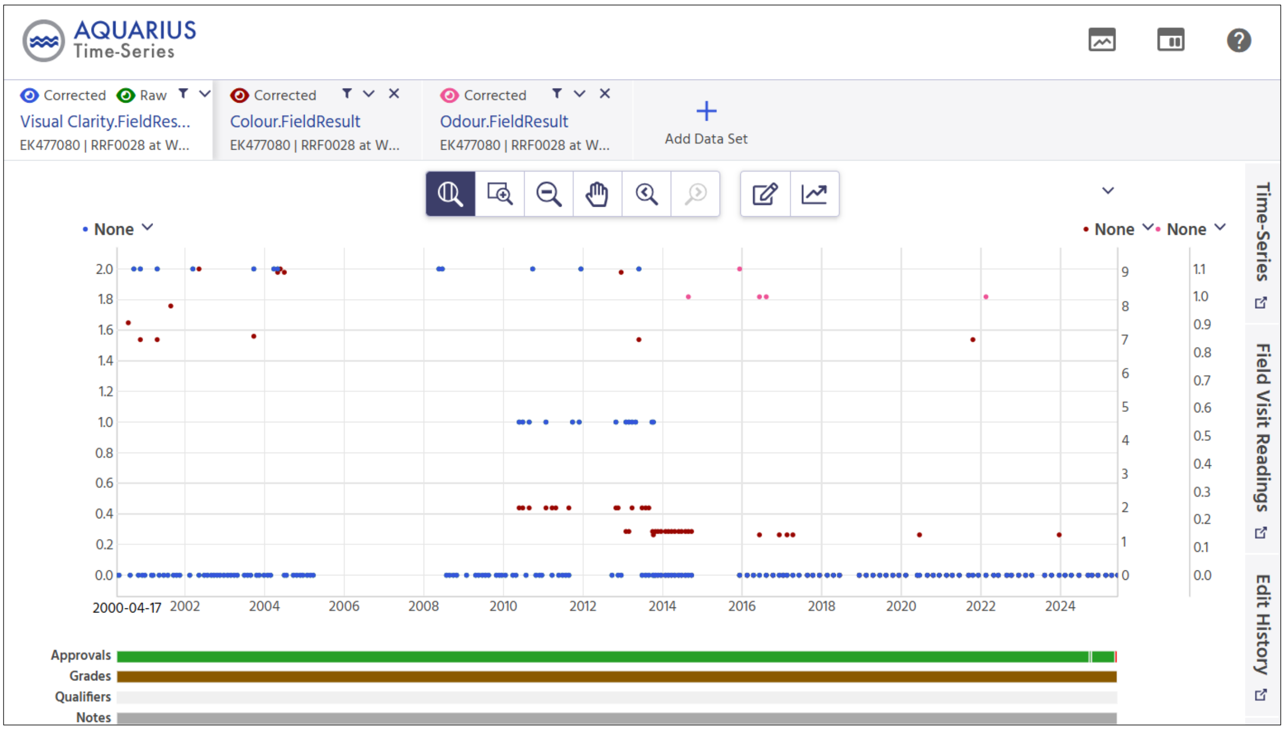

Figure 2: Example of how qualitative attributes are displayed in AQTS for Papakura. Adding colour bands to qualitative attributes in AQWP/EDP is key to facilitate a more meaningful user experience.

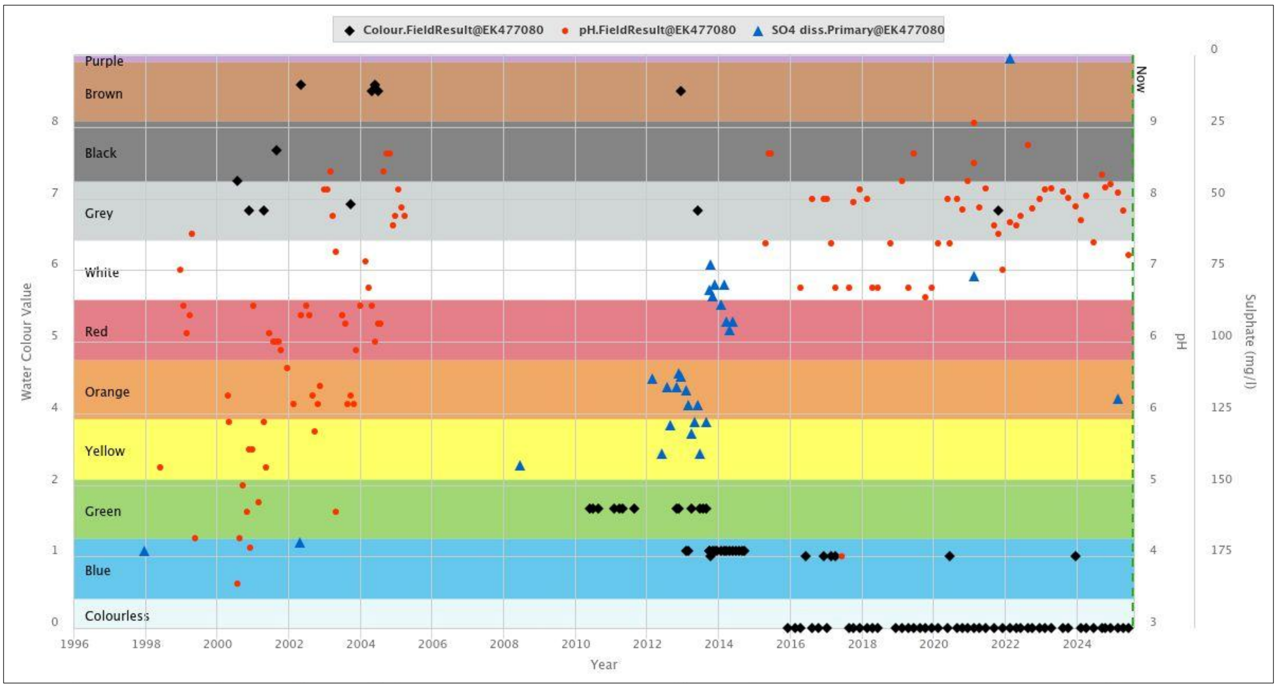

Figure 3: Chart view of water colour, pH and sulphate for Papakura in AQWP/EDP, 1996 to present.

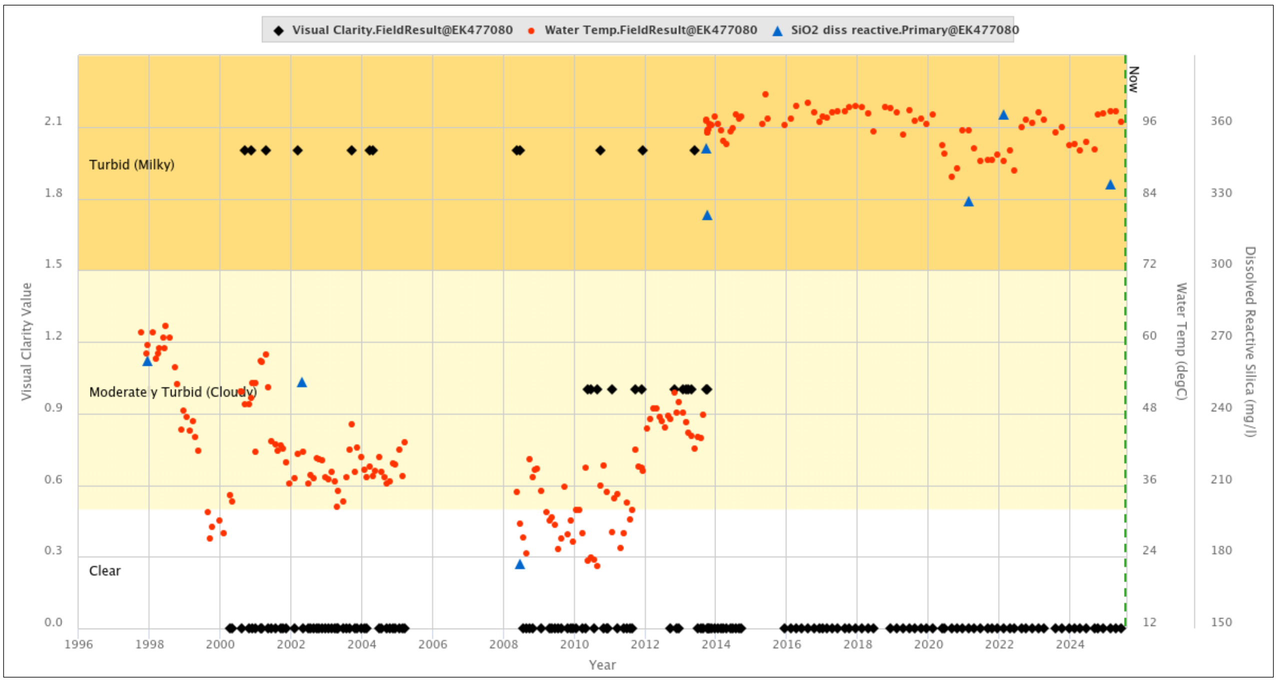

Figure 4: Visual clarity, water temperature and dissolved reactive silica for Papakura from AQWP/EDP, 1996 to present.

Figure 5: Spatial distribution of chloride (mg/L) in waters of natural origin. Blue ellipse shows broad RGS extent.

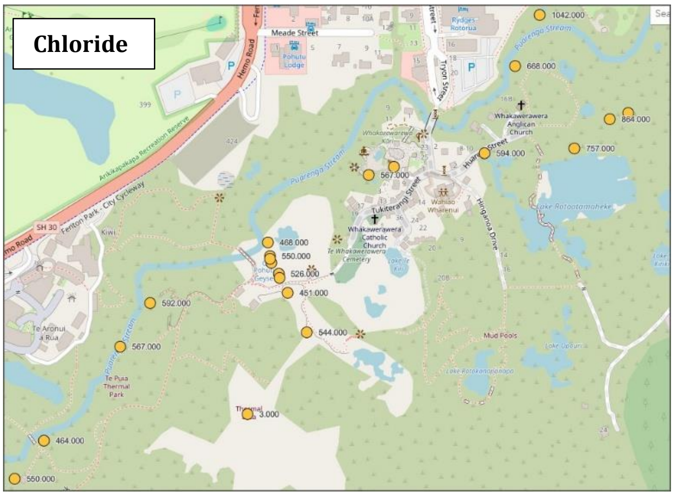

Figure 6: Spatial distribution of monitoring results in Whakarewarewa Valley – Chloride (mg/L).

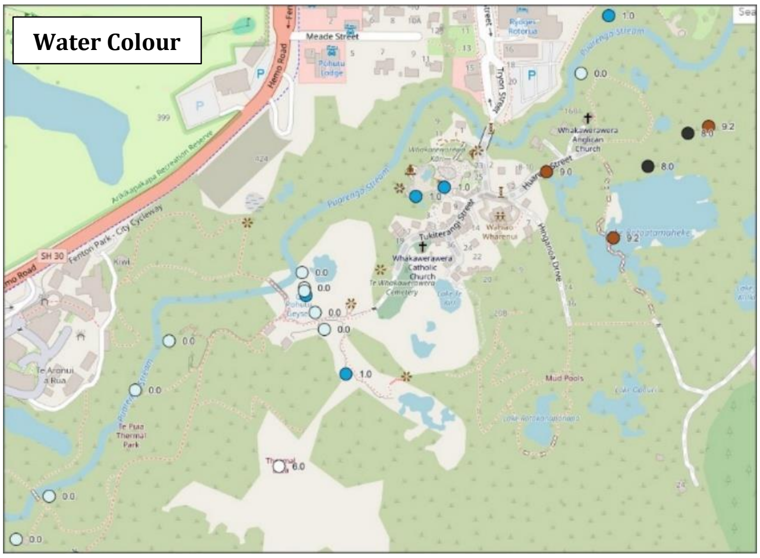

Figure 7: Spatial distribution of monitoring results in Whakarewarewa Valley – Water colour.

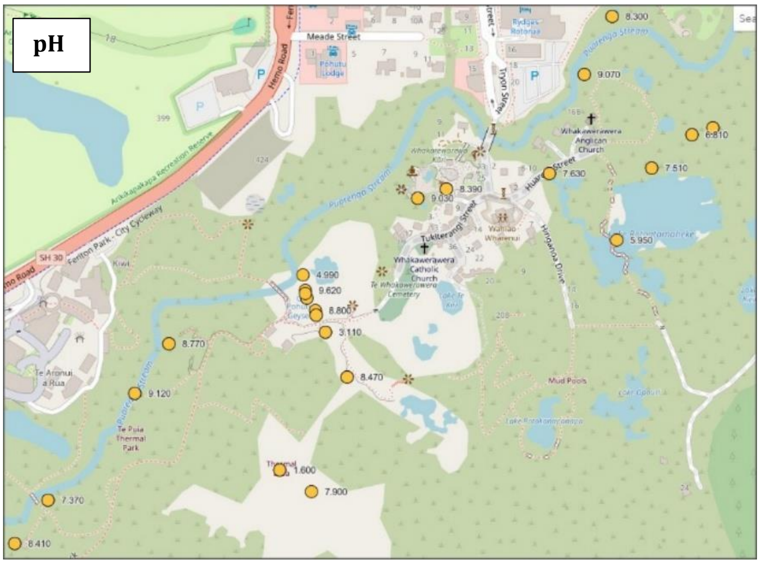

Figure 8: Spatial distribution of monitoring results in Whakarewarewa Valley – pH.

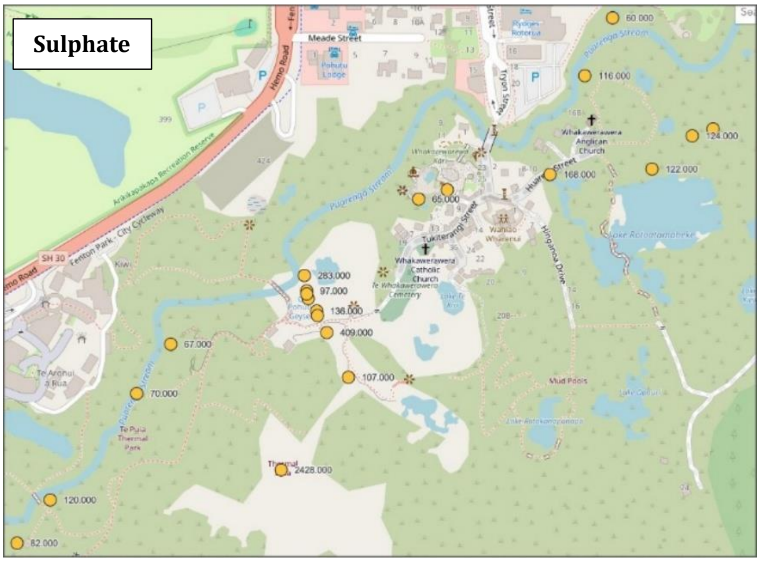

Figure 9: Spatial distribution of monitoring results in Whakarewarewa Valley – Sulphate (mg/L).