Using Temperature Methods to Improve Geyser Monitoring at Rotorua, New Zealand

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ABSTRACT

Geothermal surface features in the Rotorua Geothermal System (RGS) hold significant cultural, economic, and environmental value to Bay of Plenty Regional Council (BOPRC) and local iwi groups. Activity at many of these surface features have been recovering since the bore closure program was instigated in 1986. The recovery has been variable however, and appropriate data to monitor these long-term trends has not always been available. BOPRC therefore partnered with Te Puia, New Zealand Māori Arts and Crafts Institute, and GNS Science to trial a temperature sensor based monitoring system at Geyser Flat, Te Puia in late 2022.

Five thermocouple temperature sensors were deployed around Pohutu and Te Tohu (Prince of Wales Feathers) Geysers, and one at the outlet of Te Horu overflow pool from October 2022 to July 2023. Observational datasets of eruptive activity at the site were also acquired and used to help develop an algorithm to translate the recorded temperature data into a record of eruptive activity.

A clear pattern was immediately evident in the data. Eruptive activity typically began at the Te Tohu Geyser vent, with eruptions at Pohutu following around 15-20 minutes later. Both geysers then continued erupting together for another 30-60 minutes, before ceasing activity simultaneously. This pattern is consistent with historic observations (e.g. Lloyd, 1975) where activity at Te Tohu precedes Pohutu.

While the data could be noisy, the algorithm appeared to work well throughout the trial period, with the flagged start and end of eruptions typically within 6 and 3 minutes of the observed eruption start and end, respectively. Recorded eruptive activity is very consistent, with 17 eruptions occurring each day on average, and more than 50% of each day spent in an eruptive state. Eruptions lasted an average of 37 and 54 minutes at Pohutu and Te Tohu respectively, notably higher than any previously reported values.

1. INTRODUCTION

1.1 Background

Thermal activity at many geothermal surface features in the Rotorua Geothermal System (RGS) have recovered strongly since the "bore closure program" was instigated in 1986 (Scott et al., 2016). Currently, the RGS is broadly in equilibrium with the current level of use and climatic factors, notably rainfall (Scott et al., 2021). Further recovery of surface features in the north of the RGS is not expected, with activity here currently close to historically stable levels. Recovery in Whakarewarewa Valley to the south, has been variable, with some features showing continuing change, including some geysers such as Papakura (Scott et al., 2016). Ongoing recovery is possible, as seen by the increase in activity around east Whakarewarewa.

Geyser Flat in Te Puia, Whakarewarewa Valley, is the most spectacular remaining geyser field in New Zealand, and hosts Pohutu and Te Tohu (Prince of Wales Feathers) geysers, and To Horu Pool, the three features at the centre of this study. Pohutu Geyser is also significant as it is the largest geyser in the Whakarewarewa Valley, with its eruptions regularly ejecting geothermal fluids over 20 m in the air. Te Horu Pool was active as a geyser prior to 1972, and is known to have shallow connections to Pohutu and Te Tohu (Cody and Lumb, 1992). These geysers are of immense significance to local iwi, and are a key tourist attraction in Rotorua. Pohutu Geyser is also significant from a resource management perspective, as it forms the centre-point for the 1.5 km radius of the Rotorua Mass Abstraction Exclusion Zone (Figure 1) (Rotorua Geothermal Regional Plan 1999).

An understanding of the health of the geothermal system is needed to help Bay of Plenty Regional Council (BOPRC), as manager of the RGS (Resource Management Act 1991), understand the effectiveness of their management approach, and guide future management of the system. There is also a high level of interest from local iwi groups, and the wider Rotorua community in current trends of surface feature activity (especially geysers).

While long term monitoring of surface features has been crucial for management of the system, formal recording of geyser activity has been intermittent. To help fill this gap, BOPRC were interested in developing a continuous and automated geyser monitoring system as part of the broader RGS surface features environmental monitoring program.

After discussions with Te Puia, BOPRC partnered with GNS Science to trial a temperature sensor-based monitoring system at Geyser Flat, to monitor eruptive activity at Te Tohu (Prince of Wales Feathers) and Pohutu Geysers. In particular, they were interested in obtaining an objective record of:

- The length of each eruption (minutes per cycle).
- The frequency of eruptions (cycles per day).
- The percentage of each day spent in an eruptive state (% per day).

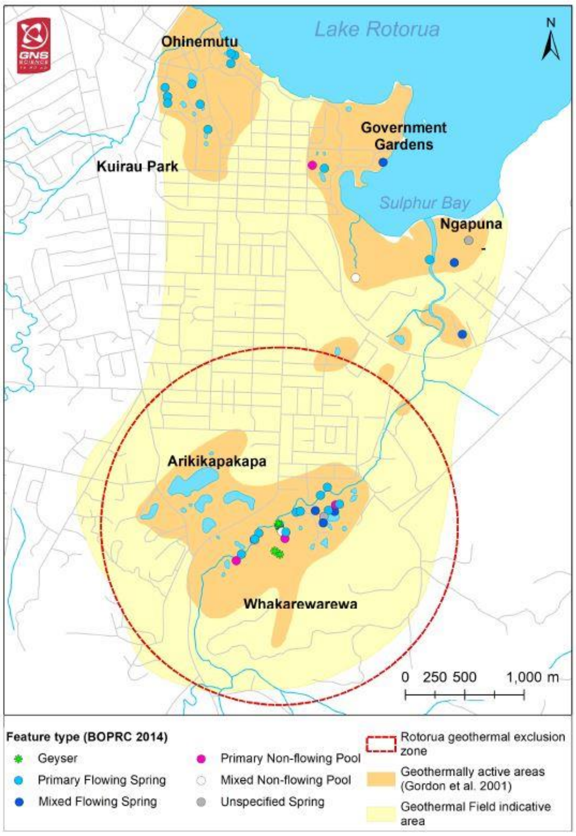

Figure 1: The Rotorua Geothermal System showing monitored surface features. Pohutu and Te Tohu Geysers are in Whakarewarewa, at the centre of the geothermal exclusion zone. Figure from Scott et al. 2021.

1.2 Geyser monitoring trial

1.2.1 Design of the monitoring network

The monitoring network was designed to have low visual impact, with lessons from past monitoring experiments in mind, and so that the data acquired could be compared with historic datasets (e.g., Cody and Lumb, 1992).

Sensor locations were selected around Te Tohu and Pohutu geyser vents, so that hot water ejected during geyser eruptions would make contact with the temperature probes, resulting an increase in the recorded temperature relative to periods of inactivity. The underlying assumption being that fluids ejected from the geyser vents during eruptions are hotter than ambient temperatures, and the resulting temperature time series can be used as a proxy for eruptive activity.

Consideration was given to both submerged (underwater when the geyser is inactive) and ambient (exposed to the air when the geyser is inactive) sensor locations. The former was expected to provide a more stable record of temperature, but respond to the onset and cessation of eruptive activity more slowly. The latter was expected to provide a noisier record due the random nature of splashing activity and wind direction, but respond to changes in eruptive states more quickly.

1.2.2 Deployment of monitoring network

Six T16 thermocouple temperature probes from Servotech, connected by wire to a CR1000x datalogger from Campbell Scientific in a rugged pelican case were installed at Geyser Flat, on 5-6th October 2022.

Three probes were installed around Te Tohu Geyser vent, one submerged and one ambient by the standing pool, and one ambient probe at its northern outflow. Two probes were installed at the standing pool by Pohutu Geyser, one submerged and one ambient. A submerged sensor was also deployed at the outflow of Te Horu Pool. Overflows at Te Horu Pool tend to occur during eruptive activity at Pohutu, due to both a rise in water flows from its internal plumbing, and erupted fluids from Pohutu landing in the pool catchment. This probe was therefore expected to provide an additional record of eruptive activity at Pohutu. This deployment configuration is shown in Figure 2.

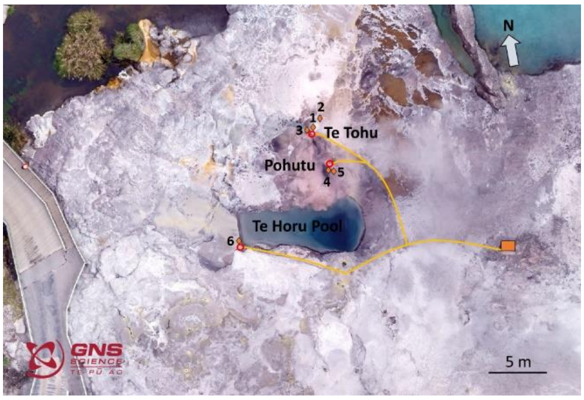

Figure 2: Layout of the temperature sensor network. Orange diamonds mark approximate sensor locations, yellow lines the location of the connecting wires, and the orange rectangle the location of the case containing the datalogger and batteries.

2. DATA AND ANALYSIS

2.1 Data

2.1.1 Temperature data

Data from the six thermocouples was recorded to a Unicode text file. The data record included a NZST timestamp, record number and the temperature value from each probe (in °C). The temperature data were smoothed at the outset by logging a reading every 5 seconds and recording the average of the previous six readings every 30 seconds.

Technical issues meant that a continuous dataset was not available for the duration of the study. An initial 2 weeks of data was recorded from the 6-20th of October 2022. The next 4 weeks of data was lost due to an issue with the data download. Data was again reliably recorded from the 17th of November to the 14th of December 2022. Issues with the timestamps were noted at the next data download on the 13th of January 2023, and the datalogger was removed for inspection. This showed that extended exposure to hot geothermal steam had damaged the datalogger electronics. A replacement datalogger was ordered and reinstalled at the site (with significantly improved insulation and moisture protection), and a final data series obtained from the 23rd of May to the 11th of July 2023 without further issues.

2.1.2 Observational data

Two observational datasets were acquired to provide a formal record of eruptive activity at the site during the trial period. The first was acquired during the initial phases of the deployment, with observed eruptive activity logged on the 7th, 9th, and 10th of October 2022. The second was acquired on the 29th of June 2023, towards the end of the deployment.

These confirmed that recorded increases in temperature on the deployed thermocouple probes were closely correlated with observed eruptive activity at both Te Tohu and Pohutu Geysers.

These observations broke down eruptive activity into three categories: "pre-play", referring initial phase of eruptive activity when only minor amounts of fluids are ejected; "eruption", referring to the onset of more persistent eruptive activity with larger volumes of fluid are being consistently ejected; and "full-column", referring to the most active phase of the eruptive cycle where fluids are ejected up to 20 m in the air in a steady stream.

These observational datasets were used to develop and calibrate the eruption algorithm described in the following section.

2.2 Geyser eruption algorithm

A key part of this project was the development of an algorithm to interpret the acquired temperature data and automatically flag the start and end of geyser eruptions in the data record. From this, a series of secondary statistics, such as the duration of each eruption, the number of eruptions per day, and the percentage of each day spent in eruption, could be derived that would provide an objective record of eruptive activity at both Te Tohu and Pohutu Geysers.

To determine whether a geyser is transitioning from an inactive to an active (i.e., eruptive) state from the temperature data, we consider two aspects of the data: The recorded temperature (T, in °C), and the change in temperature relative to the previous reading (ΔT, in °C). If both T rises above a threshold value, and ΔT is also positive and above a threshold value, an eruption is likely to have started. Conversely, if T falls below a threshold value, and ΔT is also negative and below a threshold value, the eruption is likely to have ended (see Figure 3). The thresholds for each sensor were set to be between the background and eruptive temperatures, and were determined through trial and error by comparing the performance of the algorithm during the observational periods to observed eruptive activity.

While we initially hoped to develop a single algorithm to apply to all six temperature records, it quickly became apparent that such an approach would not work. The background temperatures at the submerged sensors differed notably from each other, and the temperatures at the ambient sensors were more erratic than expected, dropping down to inactive levels before eruptive activity had properly ceased (very little fluids may land on the sensor during a full column eruption for example). We therefore selected a primary sensor to interpret for each geyser vent, with the other sensors providing a backup and reference data record in case the primary sensor failed.

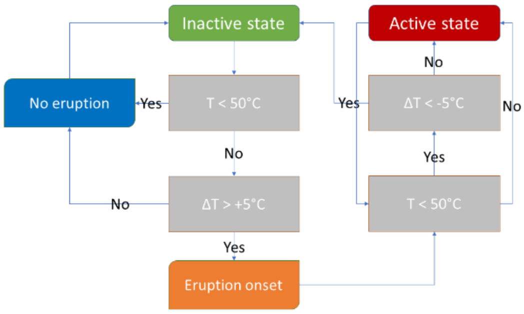

Figure 3: Flowchart showing the logical framework for deriving the start and end of an eruption from temperature data. We assume the geyser is initially inactive, so the flowchart starts from "Inactive state".

2.2.1 Te Tohu (Prince of Wales Feathers) algorithm

At Te Tohu, we selected the submerged sensor (PWF_1_Avg) as our primary sensor, as the ambient sensors did not maintain a consistently high temperature during eruptions.

The algorithm developed for this sensor consisted of a symmetric temperature threshold of 55°C, with three consecutive readings above (or below) this threshold to register the start (or end) of an eruption. The first of these readings was also required to have ΔT above 1°C to change from inactive to active, and -0.5°C to change from active to inactive.

That is:

- To switch from inactive to active: T_i, T_{i+1}, $T_{i+2} > 55$ and $\Delta T_i - \Delta T_{i-1} > 1$
- To switch from active to inactive: T_i, T_{i+1}, $T_{i+2} < 55$ and $\Delta T_i - \Delta T_{i-1} < -0.5$

2.2.2 Pohutu algorithm

At Pohutu, we selected the ambient sensor (Pohutu_5_Avg) as our primary sensor, as the submerged sensor took too long to return to background temperature levels after an eruption. The pool of water the submerged sensor was placed in at Pohutu was larger than for the submerged sensor at Te Tohu, which likely accounts for the longer lag in returning to ambient temperatures here.

The algorithm developed for this sensor consisted of an asymmetric temperature threshold, with three consecutive readings above 48°C and ΔT above 5°C to register the start of an eruption. To switch back to an inactive state we required 4 consecutive readings below 42°C, with a ΔT below -1°C on the first readings.

That is:

- To switch from inactive to active: T_i, T_{i+1}, $T_{i+2} > 48$ and $\Delta T_i - \Delta T_{i-1} > 5$
- To switch from active to inactive: T_i, T_{i+1}, T_{i+2}, $T_{i+3} < 42$ and $\Delta T_i - \Delta T_{i-1} < -1$

3. RESULTS

An early inspection of the temperature data, and comparison with the observational dataset confirmed the monitoring network was working as intended, with recorded

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temperatures notably increasing during periods of observed eruptive activity on all thermocouple probes.

3.1 Typical eruption pattern

Eruptions at Geyser Flat typically follow a set pattern. Eruptive activity begins with minor “pre-play” activity at Te Tohu. More sustained eruptive activity then follows, and activity then also commences at Pohutu. The eruption will then transition to its most intense “full-column” phase for a period, before coming to an end at both vents more or less simultaneously. A short (typically around 30 minutes) period of dormancy follows, and the eruptive cycle begins again.

This eruptive pattern was also evident in our temperature dataset, with the data record for a typical eruption shown in Figure 4.

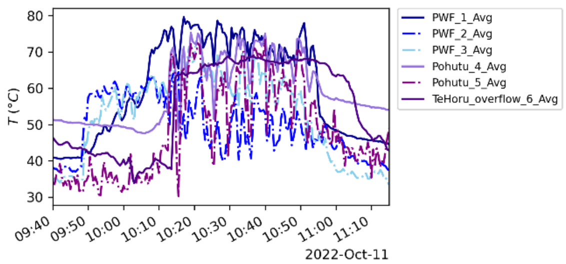

Figure 4: A typical eruption at Te Tohu and Pohutu Geysers. Note that temperature spike at Te Tohu first (PWF sensors), before following at Pohutu. Submerged sensors are represented as solid lines, and ambient sensors as dashed lines.

3.2 Algorithm performance

The algorithmically flagged start and end of eruptive activity generally matched the observed start and end of eruption closely, with almost no erroneous switching of states (particularly at Te Tohu). The algorithm also appeared to remain effective for the duration of the study, with the exception of a 5-day period from the 17-22nd of November 2022 where the recorded temperatures decreased so that the threshold temperature values were rarely met. This may have been an early indication of hardware issues with the datalogger.

3.2.1 Te Tohu

The temperature data from sensors around Te Tohu had background (inactive) temperatures of around 30°C, with spikes up to 60-80°C during observed eruptions. The ambient sensors were notably more erratic than the submerged one (which was selected as the primary sensor here for this reason).

Observations of eruption activity at Te Tohu showed that activity normally began with a 5-10 minutes of pre-play, before launching into a more sustained eruption for around 50 minutes, the majority of which was in full-column levels of activity.

A typical series of eruptive events at Te Tohu is shown in Figure 5, with the algorithmic thresholds and observed eruptive activity overlain.

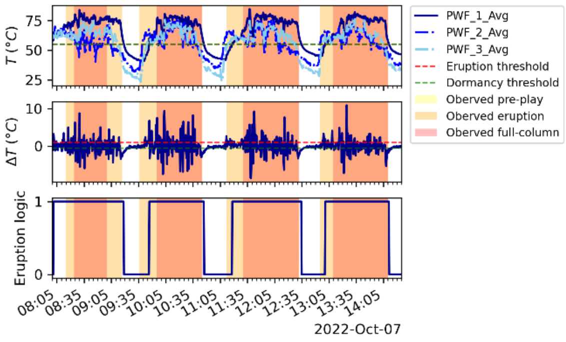

Figure 5: Temperature record from Te Tohu sensors during an observation period on the 7th of October 2022.

3.2.2 Pohutu

At Pohutu the recorded temperature data had background values of around 25°C, spiking to around 70°C during observed eruptions. The submerged sensor here was slow to return to background temperature values eruptions ended, so the ambient sensor was selected as the primary sensor here.

Observations of eruptive activity at Pohutu showed that activity typically commenced around 10 minutes after Te Tohu with a pre-play phase lasting around 20 minutes. It then launched into a more sustained eruption for around 40 minutes, with short bursts of full-column activity.

A typical series of eruptive events at Pohutu is shown in Figure 6, with the algorithmic thresholds and observed eruptive activity overlain.

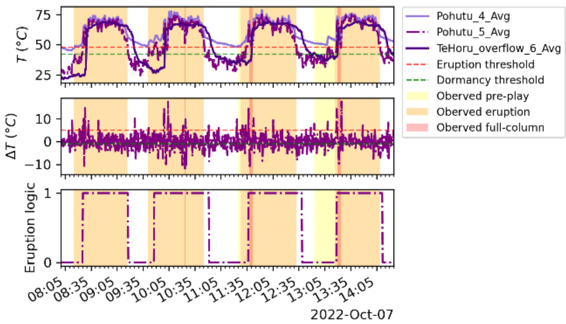

Figure 6: Temperature record from Pohutu sensors during an observation period on the 7th of October 2022.

3.2.3 Uncertainty analysis

The algorithms developed to characterize the temperature data into eruptive activity generally worked well. However, they will inevitably throw up some spurious results, and there will be some errors in the algorithmically flagged start and end of each eruption. We attempt to quantify these errors by comparing the algorithmically flagged and observed eruption start and end times.

The start of an eruption is typically much harder to identify than the end, as they usually begin with some minor “pre-play” activity and can transition into a full fledged eruption gradually as well as suddenly. For this analysis we have ignored the observed pre-play phase and considered the “eruption start” as the start of activity.

We found that at both Te Tohu and Pohutu the algorithmically flagged eruption start was an around 6 minutes after the observed start, though the variation was lower at Pohutu. Eruptions typically end more abruptly than they start so the end of an eruption proved easier to identify in the temperature record than the start. At Te Tohu the algorithmically flagged end was usually within 1 minute of the observed end, while at Pohutu it was typically 3 minutes beforehand.

4. DISCUSSION

Observations of eruptive activity at Geyser Flat, Te Puia go back a long way with the first records of eruptive activity dating back to the late 1800's, with early records by Hochstetter (1859) and Malfroy (1891). Monitoring methods became more reliable from the 1960's, with records from Lloyd (1975), Cody and Simpson (1985), Cody and Lumb (1992), and Scott et al. (2005).

Pohutu has had a variable eruption history, with early activity being very infrequent. After the 1886 Tarawera eruption its activity was noted to increase slightly (Cody and Lumb, 1992). From the 1900's to 1940's it was active around 5-8% of the day, though long periods of inactivity were also common. By the 1970's activity had increased to be around 30% of the day. From the 1970's onward a shift in its eruptive pattern was noted, with eruptions becoming shorter and more frequent, and full-column activity becoming rare until after the bore closure program in 1986. From March 2000 to April 2001 Pohutu played continuously, and since then has settled into a regular pattern of longer and more frequent full-column eruptions, with dormant periods in-between (Gordon et al., 2001).

Te Tohu Geyser was formed after the 1886 Tarawera eruption, and was initially known as "the indicator", as it always commenced activity before Pohutu. From the 1950's to 1970's it spent 25-35% of each day in eruption, always accompanying activity at Pohutu. In 1992 it began erupting almost continuously, with 95% of the day spent in an eruptive state. From 2001 onwards it has developed a cyclic pattern of eruptive activity similar to Pohutu, with active periods interspersed with periods of dormancy (Gordon et al., 2001).

Figure 7 shows a time series of the eruption statistics derived during this study. It shows that the number of eruptions recorded at Te Tohu and Pohutu is very similar throughout the study period, averaging around 17 per day. The duration of eruptions is consistently longer at Te Tohu, with eruptions here lasting 54 minutes on average compared to 37 at Pohutu. The percentage of the day in eruption is also consistently higher at Te Tohu, with 64% of the day spent in eruption compared to 45% at Pohutu.

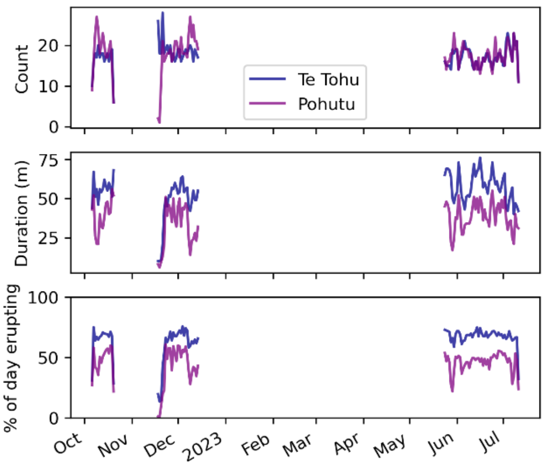

Figure 7: Eruption statistics derived from this study. Count refers to the number of eruptions per day, duration the average length of eruptions each day (in minutes), and the percentage of the day in eruption.

Histograms of eruption durations for Te Tohu and Pohutu are shown in Figures 8 and 9 respectively. For Te Tohu they show a strong clustering around the hour mark, though with a non-negligible proportion lasting less than 40 minutes, and a small number extending to almost 2 hours. At Pohutu the most common duration is around 45 minutes, though a similar structure to Te Tohu is observed with a significant number lasting less than 30 minutes and few out to longer than 80 minutes.

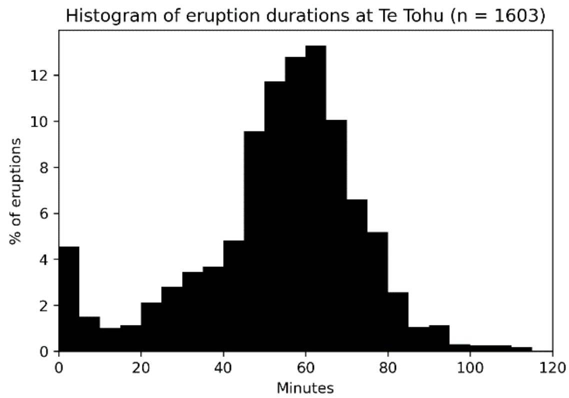

Figure 8: Histogram of the duration of eruptive activity at Te Tohu during this study.

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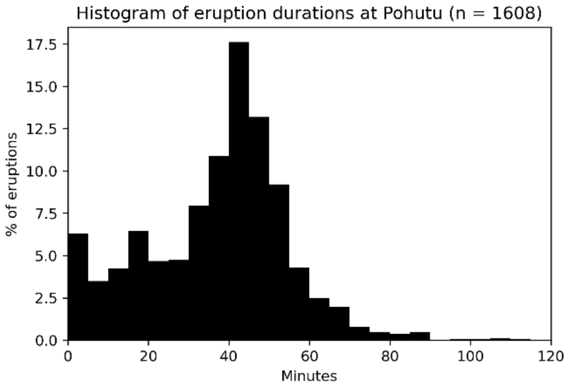

Figure 9: Histogram of the duration of eruptive activity at Pohutu during this study.

Analysis of the dormancy period between eruptions showed a similar pattern to eruptive activity, and were consistent throughout the study period. At Te Tohu the average dormancy period between eruptions was around 30 minutes, with a non-negligible proportion in the 2-20 minute range. Dormancies lasting longer than 60 minutes were rare.

The gaps in the dataset, along with its short duration, limit our ability to comment on the effects of rainfall, air pressure, or seasonal variability in geysering activity. However, little difference in eruptive patterns was observed between the start and end of the study period.

5. CONCLUSIONS

Continuous automated monitoring of the geysers in Whakarewarewa Valley could make an important contribution to understanding the health of the Rotorua Geothermal System.

The temperature sensor based geyser monitoring trial at Geyser Flat, Te Puia, showed that it could be a promising proxy for geyser activity here, with recorded temperatures rapidly responding to the onset and cessation of eruptive activity at both Te Tohu and Pohutu Geyser vents.

The processing algorithm developed to process the temperature data and extract eruption statistics worked well, with all observed eruptions correctly flagged, acceptable errors in picking their start and end point, and minimal erroneous switching of states.

Eruptive activity at Geyser Flat, Te Puia remained very consistent throughout our 9-month study period, with no seasonal variation observed, and an average of 17 eruptions observed each day at both Te Tohu and Pohutu Geysers. Eruptions generally last 15-20 minutes longer at Te Tohu than Pohutu, with an average duration of 54 minutes compared to 37 at Pohutu. Dormancy periods between eruptions also remained consistent with, a gap between eruptions of ~30 minutes at Te Tohu. Both geysers were also very active, with Te Tohu spending an average of 64% of the day in an eruptive state, and Pohutu 45%. These values (duration and percentage of the day spent in eruption) are both higher than any previously recorded values at these geysers (see Gordon et al., 2001), though activity in Whakarewa more broadly is below its historical levels.

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