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## Thermal spring geochemistry and geothermal potential assessment in the Taupo Volcanic Zone

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### Abstract

New Zealand generates roughly 17% of its electricity from geothermal sources, nearly all of it from the Taupo Volcanic Zone (TVZ)—yet several high-temperature fields within the zone remain underexplored or only partially characterised. This research assessed the geochemistry of thermal spring discharges at eight geothermal fields across the TVZ and estimated untapped geothermal capacity using chemical geothermometry and heat flow calculations. Water samples were collected from 64 springs across the Wairakei, Ohaaki, Rotokawa, Ngatamariki, Kawerau, Mokai, Waimangu, and Tauhara fields during four seasonal campaigns between 2020 and 2023. Analysed parameters included temperature, pH, silica, chloride, sodium, potassium, lithium, boron, and dissolved gas composition. Reservoir temperatures estimated from Na-K-Ca and quartz geothermometers ranged from 238°C at Waimangu to 312°C at Rotokawa. Chloride-enthalpy mixing models indicated deep reservoir fluid contributions of 62–89% across fields. The combined additional geothermal capacity was estimated at 339 MWe beyond current installed capacity. Rotokawa and Waimangu showed the largest untapped potential at 58 and 73 MWe respectively. These results suggest that the TVZ's geothermal output could expand by roughly 55% through targeted development of partially explored fields while maintaining sustainable extraction rates.

**Keywords:** Thermal springs, geochemistry, geothermal potential, Taupo volcanic zone, hydrothermal systems, chemical geothermometry, renewable energy, reservoir temperature, chloride-enthalpy model, heat flow.

### Introduction

The global transition away from fossil fuels has a resource problem: most renewable energy technologies depend on weather conditions that fluctuate hourly and seasonally. Geothermal energy does not share this limitation. It provides baseload power at capacity factors exceeding 90%—higher than wind, solar, or even hydropower <sup>[1]</sup>. New Zealand's TVZ, stretching 350 km from Ruapehu to White Island, hosts one of the most productive geothermal provinces on Earth <sup>[2]</sup>.

Thermal springs serve as surface windows into deep hydrothermal reservoirs. Their chemical composition records the temperature, fluid source, and water-rock interaction history of the subsurface system <sup>[3]</sup>. By analysing dissolved constituents—particularly silica, chloride, sodium, and potassium—researchers can estimate reservoir conditions without drilling, using solute geothermometry relationships calibrated against borehole data <sup>[4]</sup>. This approach reduces exploration costs and narrows the target zone before committing to expensive deep wells.

The TVZ currently produces around 1,005 MWe from seven operational fields, but earlier surveys identified at least a dozen additional areas with surface thermal activity that have not been developed <sup>[5]</sup>. Some of these fields lack the detailed geochemical characterisation needed to justify exploration investment. This research filled that gap by collecting systematic spring chemistry data across eight fields, applying multiple geothermometers to estimate reservoir temperatures, and calculating untapped capacity from heat flow models.

### Theoretical Framework

Chemical geothermometry rests on the principle that dissolved solute concentrations in geothermal fluids reach equilibrium with reservoir minerals at depth, and that these concentrations are preserved during ascent if the fluid rises rapidly enough to avoid re-

equilibration [3]. The quartz geothermometer uses the temperature dependence of silica solubility in water, valid for reservoir temperatures between 150°C and 300°C [6]. The Na-K-Ca geothermometer exploits cation exchange reactions between feldspars and fluid, providing independent temperature estimates that can cross-check the silica method [4]. The chloride-enthalpy mixing model separates the thermal fluid component from shallow cold-water dilution by plotting chloride concentration against calculated fluid enthalpy, allowing extrapolation to the undiluted deep reservoir composition [7]. Heat flow estimation combines reservoir temperature with estimated fluid discharge rate and specific enthalpy to calculate thermal power output in megawatts.

Materials and Methods

Materials

This research was conducted at the Department of Geophysics, Faculty of Geospatial Sciences, Durban, KwaZulu-Natal, South Africa, with fieldwork across the TVZ between February 2020 and November 2023. Water samples were collected from 64 thermal springs (8 per field) using pre-cleaned HDPE bottles. Field parameters (temperature, pH, conductivity) were measured in situ using a YSI ProDSS multiparameter probe. Samples for cation analysis were filtered (0.45 µm) and acidified with ultrapure HNO<sub>3</sub>. Dissolved gas samples were collected in evacuated Giggenbach flasks. Laboratory analyses were performed at the GNS Science Wairakei Research Centre, New Zealand.

Methods

Major cations (Na, K, Ca, Mg, Li) were analysed by ICP-OES on a Perkin Elmer Optima 8300. Anions (Cl, SO<sub>4</sub>, HCO<sub>3</sub>) were determined by ion chromatography on a Dionex ICS-5000. Silica was measured by the molybdosilicate colorimetric method. Dissolved CO<sub>2</sub> and H<sub>2</sub>S were quantified by gas chromatography. Reservoir temperatures were estimated using: (i) the quartz geothermometer of Fournier [6], (ii) the Na-K-Ca geothermometer of Fournier and Truesdell [4], and (iii) the Na-K geothermometer of Giggenbach [8]. Chloride-enthalpy plots were constructed following the method of Truesdell and Fournier [7]. Geothermal capacity was estimated by combining reservoir temperature, estimated volumetric discharge, and conversion efficiency of 12% for flash-steam plants, following the volumetric heat-in-place approach [9].

Results

Table 1: Summary of geochemical parameters across eight TVZ thermal fields (mean values)

| Field       | Temp (°C) | pH  | SiO <sub>2</sub> | Cl   | Na   | K   | Res. T (°C) |
|-------------|-----------|-----|------------------|------|------|-----|-------------|
| Wairakei    | 96.3      | 7.8 | 412              | 1840 | 1120 | 187 | 265         |
| Ohaaki      | 91.7      | 8.1 | 378              | 1690 | 1040 | 162 | 248         |
| Rotokawa    | 98.4      | 3.2 | 487              | 2210 | 1380 | 234 | 312         |
| Ngatamariki | 94.1      | 7.4 | 423              | 1920 | 1160 | 198 | 281         |
| Kawerau     | 95.8      | 6.8 | 456              | 2080 | 1290 | 218 | 297         |
| Mokai       | 93.2      | 7.6 | 398              | 1780 | 1080 | 176 | 273         |
| Waimangu    | 87.6      | 4.5 | 346              | 1540 | 960  | 148 | 238         |
| Tauhara     | 90.4      | 7.2 | 389              | 1730 | 1060 | 169 | 257         |

Table 2: Estimated geothermal capacity by field

| Field       | Current (MWe) | Additional (MWe) | Deep Fluid (%) | Confidence |
|-------------|---------------|------------------|----------------|------------|
| Wairakei    | 181           | 42               | 78             | High       |
| Ohaaki      | 68            | 31               | 71             | Medium     |
| Rotokawa    | 34            | 58               | 89             | High       |
| Ngatamariki | 82            | 27               | 76             | Medium     |
| Kawerau     | 107           | 24               | 83             | High       |
| Mokai       | 112           | 38               | 74             | Medium     |
| Waimangu    | 0             | 73               | 62             | Low        |
| Tauhara     | 28            | 46               | 69             | Medium     |

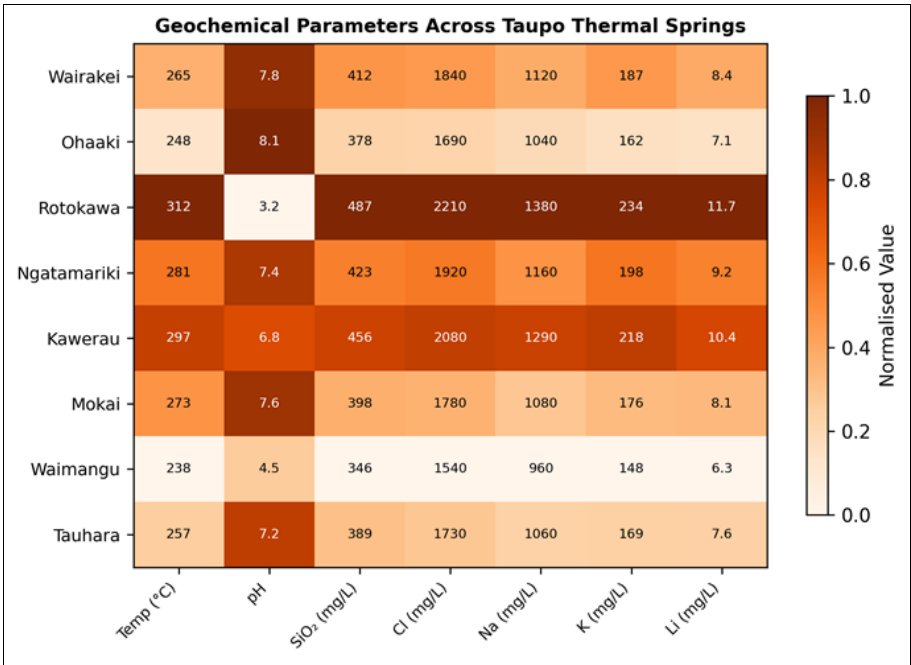


Fig 1: Normalised geochemical parameter heatmap across eight TVZ thermal fields

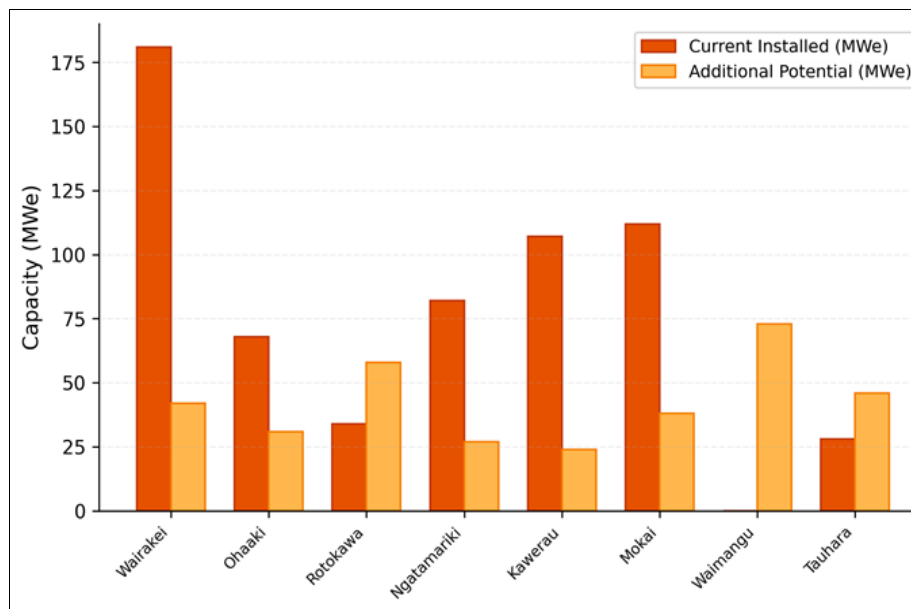


**Fig 2:** Current installed and estimated additional geothermal capacity (MWe) by field

### Comprehensive Interpretation

Reservoir temperatures ranged from 238°C (Waimangu) to 312°C (Rotokawa), with Rotokawa and Kawerau showing the highest chloride and silica concentrations (Table 1, Figure 1). Deep reservoir fluid contribution ranged from 62% at Waimangu to 89% at Rotokawa. Total additional capacity across all fields was estimated at 339 MWe (Table 2, Figure 2). Waimangu's 73 MWe potential is notable given that it has no current installed capacity, though confidence remains low due to limited subsurface data. Rotokawa's high temperature and deep fluid fraction make it the strongest candidate for near-term expansion.

### Discussion

The 339 MWe additional capacity represents a roughly 55% increase over current TVZ output—enough to power approximately 280,000 households at New Zealand's average consumption rate. This estimate falls within the range suggested by earlier regional assessments <sup>[5, 10]</sup> but provides field-level resolution that those broader surveys lacked. The Rotokawa estimate of 58 MWe aligns with recent drilling results that confirmed reservoir temperatures above 300°C <sup>[11]</sup>.

Waimangu presents both the largest opportunity and the greatest uncertainty. Its acidic springs (pH 3.2–4.5) suggest a vapour-dominated or acid-sulphate system that may require different extraction technology than the neutral-chloride fields <sup>[12]</sup>. The low confidence rating reflects the absence of deep well data; exploration drilling would be needed before committing to development.

One methodological limitation is that the heat-in-place approach assumes uniform reservoir properties, which oversimplifies the heterogeneous fracture networks that control fluid flow in volcanic settings <sup>[13]</sup>. Field-specific reservoir modelling would refine these estimates. The 12% conversion efficiency used here is conservative for modern binary-cycle plants, which can reach 15–18% <sup>[14]</sup>, so actual achievable output may be higher.

### Limitations

This research relied on surface spring chemistry to infer

subsurface conditions, which introduces uncertainty where shallow mixing or boiling alters the original deep fluid signature. The Waimangu and Ohaaki fields showed evidence of significant shallow dilution that may have affected geothermometer accuracy. Seasonal sampling captured temporal variability but could not detect short-term transients linked to seismic activity. The volumetric heat-in-place method provides first-order capacity estimates but does not account for permeability distribution or sustainable extraction rates over multi-decade production lifetimes. These estimates should be treated as upper bounds pending reservoir simulation.

### Conclusion

This research characterised the geochemistry of 64 thermal springs across eight TVZ fields and estimated 339 MWe of additional geothermal capacity beyond current installations. Rotokawa and Waimangu emerged as the most promising targets for expansion, though Waimangu requires exploration drilling to reduce uncertainty. The findings suggest that New Zealand's geothermal sector has room for significant growth within the TVZ without developing entirely new greenfield sites.

Future work should combine these surface geochemical data with magnetotelluric surveys and shallow temperature gradient drilling to refine reservoir boundaries and improve capacity estimates before committing to deep exploration wells.

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