Tauranga Geothermal System: Temperature Distribution

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ABSTRACT

The city of Tauranga in the Bay of Plenty region of New Zealand lies on a warm (30 – 70°C) water geothermal resource classified as Geothermal Management Group 5 by the Bay of Plenty Regional Resources Plan. Despite the widespread use of the resource, mostly for bathing and frost protection and irrigation, this reservoir's temperature distribution and extent is poorly understood.

We constructed subsurface temperature maps in 50 m depth intervals to 300 m below sea level using temperature profiles from 40 wells in the Tauranga and Maketu low-temperature geothermal fields to constrain the resource and localise the hottest zone. These maps "slices" show two temperature anomalies. One, hotter (~50°C) but poorly constrained due to insufficient data, lies southwest of Maketu Peninsula between Maketu and Te Puke. The other is below the city of Tauranga. Both thermal anomalies are confirmed by other evidence. The Maketu anomaly has been subject to interest since the 1960s due to the presence of nearby hot springs and a low resistivity anomaly. The Tauranga anomaly is expected as hundreds of water wells are used mostly for domestic and recreational purposes, with discharge temperatures mostly in the range of 35–45°C.

Additional measurements, especially temperature logs in more wells in the area, as well as thermal conductivity and permeability measurements on samples of representative lithologies (rhyolites, andesites, ignimbrites and sediments of the Tauranga Group), are needed for a deeper understanding of this low-temperature geothermal resource and its potential commercial use.

The Maketu anomaly is supported by geological, geophysical and hydrogeological evidence, so it might be worthy of further exploration.

1. INTRODUCTION

1.1 Tauranga Geothermal System Overview

Tauranga in the Bay of Plenty region of New Zealand lies on a warm (30 – 70°C) water geothermal resource. The area of interest includes the Tauranga/Mount Maunganui (Mauao) and Papamoa/Maketu geothermal fields.

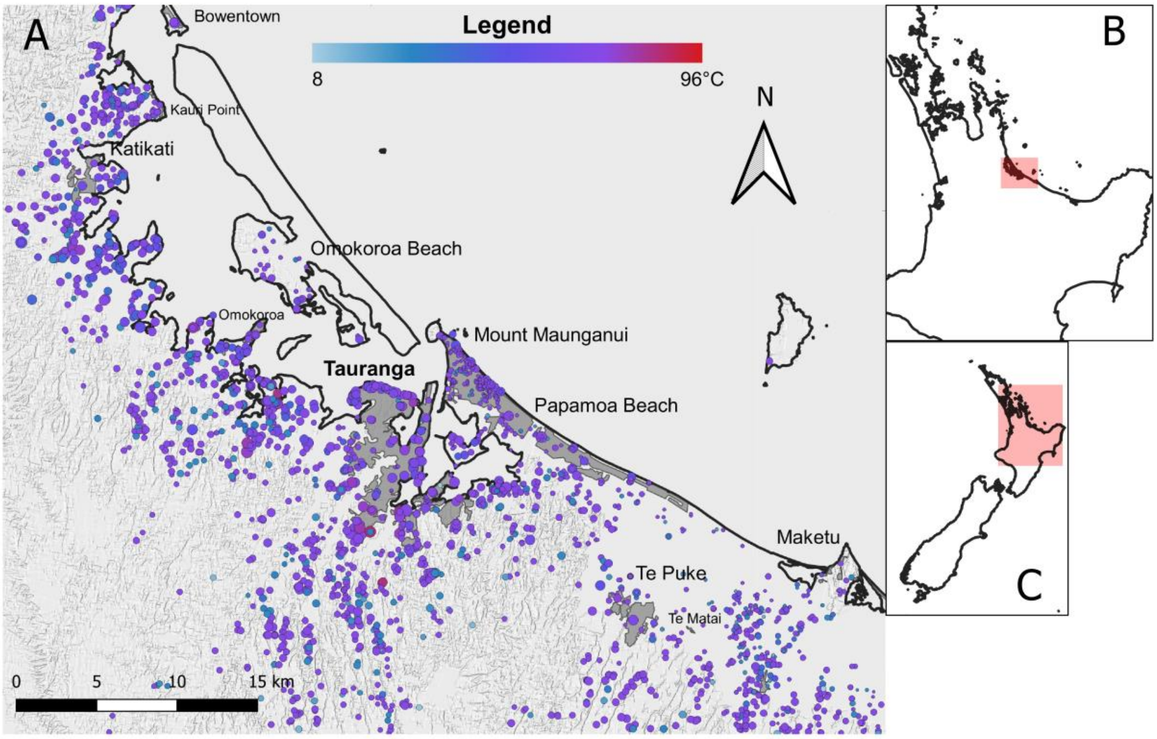

Figure 1: Boreholes with temperature data (either discharge temperature or downhole logs) in the Tauranga/Mount Maunganui (Mauao) and Papamoa/Maketu geothermal systems. Temperatures are symbolised by colour, from 8°C in blues to over 90°C in reds. The depth of boreholes is represented by the symbol size (greater depth corresponds to a larger symbol).

Over 1000 geothermal wells have been drilled in the Bay of Plenty. Of these, 106 warm water wells, in addition to cold groundwater wells, are in Tauranga (Figure 1) and are used mostly for irrigation, domestic purposes, swimming and bathing. Although temperature data are not available for all wells, it is assumed that wells without temperature data are cold water wells.

Despite the large number of wells, extensive use of the resource, and a reservoir model (Pearson-Grant and Burnell 2016; Pearson and Alcaraz 2013), the subsurface temperature distribution in the geothermal field is poorly understood.

The aim of this study is to summarise the existing information on temperatures, hydrogeology and geology of the area and estimate the thermal structure of the system.

1.2 Geology of Western Bay of Plenty

The area of interest lies on the northwest coast of the Bay of Plenty and is wedged between the Taupo Volcanic Zone (TVZ) and Coromandel Volcanic Zone (CVZ). It covers the Coastal Lowlands and a part of the Kaimai Range and Mamaku Plateau, as defined by Leonard et al. (2010). Kaimai Ranges are the south-eastern tip of the Coromandel Volcanic Zone (CVZ), comprising mostly Middle Pliocene to Pleistocene (18 – 1.9 Ma) andesite stratovolcanoes and some younger rhyolite domes (Booden et al. 2012; Leonard, Begg, and Wilson 2010). The Mamaku Plateau consists predominantly of ignimbrites (Booden et al. 2012; Leonard et al. 2010). In the Coastal Lowlands area, marine and alluvial sediments cover most of the late Pliocene volcanics (ignimbrites and rhyolite lavas) of Whitianga Group, with some rhyolite domes of the Tauranga Volcanic Centre (active until 1.95 Ma) such as Mt Maunganui forming unsedimented topographic elevations (Booden et al. 2012; Leonard et al. 2010).

Maketu peninsula is a horst consisting of fluvial and aeolian deposits and a lahar dated to 0.25 Ma with redeposited boulders of the Mamaku Plateau ignimbrite, bounded by NE-striking normal faults (Briggs et al. 2006). The youngest deposits are Quaternary and recent tephra, including ash from the Mt Tarawera eruption 1886 AD (Briggs et al. 2006). Although the faults do not crop out, they may play a role as conduits for geothermal fluids.

The lowlands are formed by fluvial terraces (mostly silts and some coarser clastic sediments) with some loess and tephra layers (Briggs et al. 2006; Simpson 1987; White et al. 2009).

1.3 Previous studies and temperature data

A thorough groundwater survey was carried out by White et al. (2009) for the area between Waihi and Maketu, including Tauranga city. White et al. (2009) investigated hundreds of wells, of which 56 had groundwater level monitoring, 171 had chemistry data, 346 had a geological log, and 68 wells had some temperature data (17 of these had full temperature profiles, and we are using these in our study). Tests performed in some of these wells (White et al., 2009) provided estimates of hydraulic conductivity in andesites (4×10^{-7} to 4×10^{-6} m/s), ignimbrites ($1–5\times10^{-6}$ m/s) and sediments (10^{-5} m/s). Some aquifers are in the sediments, and most warm water wells source the fluid from ignimbrites or rhyolitic host rock, confined by the sediments of the Tauranga Formation (White et al., 2009). This is consistent with the findings of Simpson (1987), who concluded that the silts of Tauranga Formation form the caprock of the warm water reservoir hosted by ignimbrites and rhyolites with high fracture permeability.

Simpson (1987) also provided measurements of thermal conductivity of the volcanic rocks ranging from 0.97—1.11 W/(m K) in ignimbrites and 1.67—1.77 W/(m K) in rhyolites, and measured downhole temperatures to determine heat flux in the area, averaging at 88±16 mW/m^2. White et al. (2009) model predicts a high-temperature zone of 45 – 55°C in ignimbrites between 160 and 340 m depth below Tauranga Harbour. A TOUGH2 geothermal model of the system (Pearson and Alcaraz 2013) predicts the highest heat flow below Tauranga city produced by inferred local faults increasing the vertical permeability of the reservoir rocks. As pointed out by Pearson-Grant & Burnell (2016), the model predicts unrealistic pressure and temperature decline that has not been observed in practice. This suggests that the thermal regime below Tauranga is convective rather than conductive.

A surface resistivity survey of the TVZ by Stagpoole & Bibby (1998) did not include Tauranga/Mt Maunganui field, but it reached the Maketu field. A zone of low resistivity was identified between Maketu and Te Puke (Figure 2).

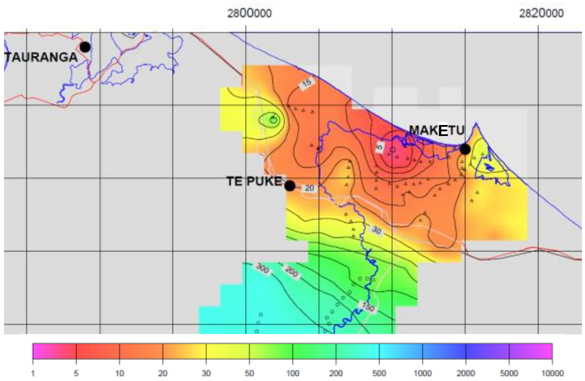

Figure 2: Resistivity (in Ωm) map of the area of interest (adapted after Stagpoole and Bibby (1998)) measured by Wenner array of equally spaced electrodes by 550 m.

2. DATA AND METHODS

2.1 Measured temperatures

Borehole measurements used in this study were acquired from the internal databases of the Bay of Plenty Regional Council, GNS Science, and from White et al. (2009). The locations, as well as the measured profiles, are shown in Figure 3 and Figure 4. The temperature profile in Bay of Plenty monitoring well 2504 shows anomalously high temperatures below 150 m depth. The measurement in this well was repeated in December 2021, showing a temperature of 44°C at 178 m depth, confirming the anomalously high downhole temperature.

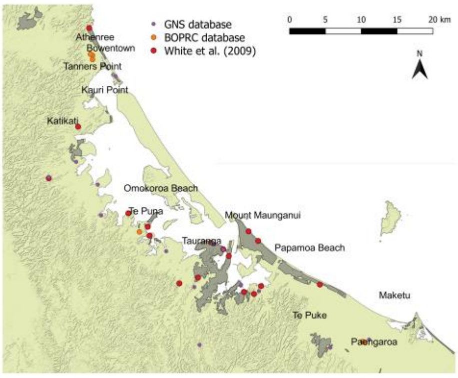

Figure 3: Borehole locations (colour-coded based on their source).

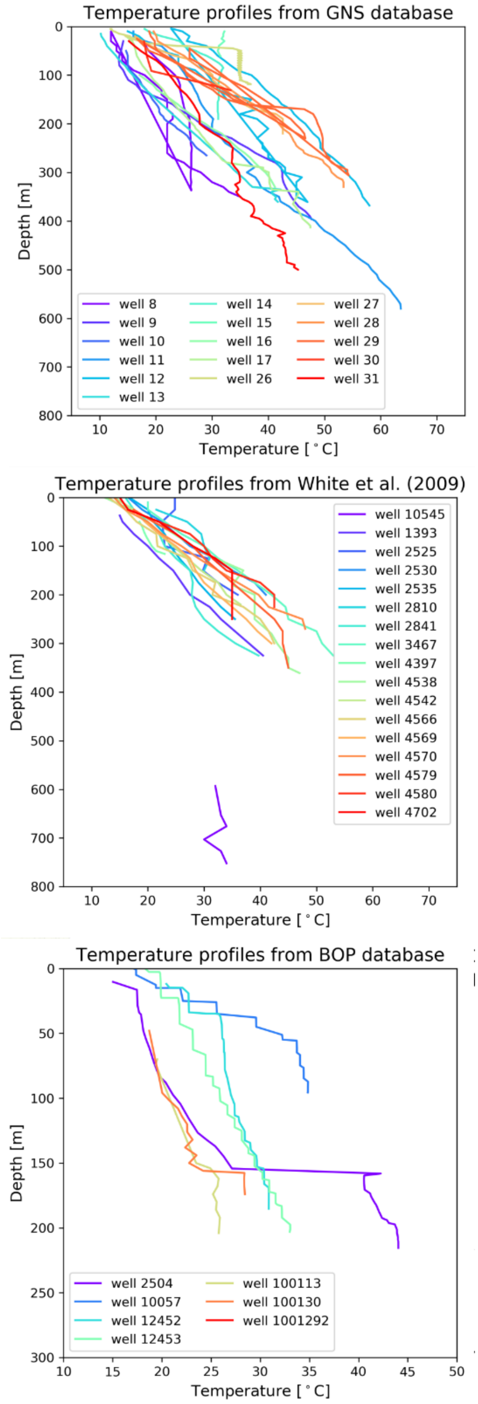

Figure 4: Measured temperature profiles from the GNS database (upper graph), White et al. (2009) (middle graph) and BOPRC database (lower graph).

2.2 Interpolation method

With only sparse point data available for each depth, temperatures within the area need to be interpolated between them. Kriging was specifically developed for exploration geology and is one of the most widely used interpolation methods in geosciences, as it is particularly well suited for irregularly spaced data (Golden Software 2002),

3. RESULTS

To assess the temperature distribution at depth in the area of interest, existing temperature profiles from 39 boreholes were used to produce temperature maps at several depth intervals “slices”.

Given the drilled depths and the location of these wells, we chose to produce slices relative to sea level (a.s.l. meaning “above sea level”, b.s.l. meaning “below sea level”): 50 m a.s.l., at sea level (0 m a.s.l.), 50 m b.s.l., 100 m b.s.l., 150 m b.s.l., 200 m b.s.l., 250 m b.s.l. and 300 m b.s.l. as shown in Figure 5 — Figure 12.

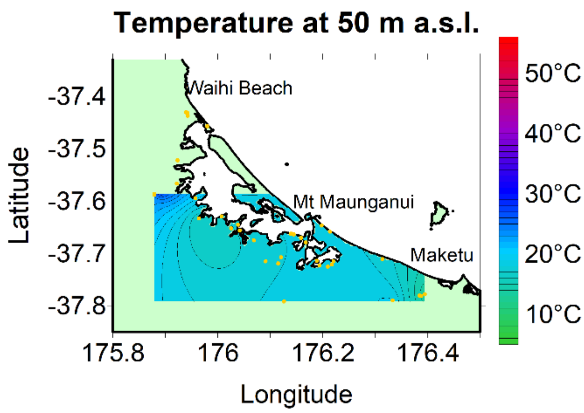

Figure 5: Temperature slice at 50 m a.s.l. across Tauranga and (partly) Maketu Geothermal areas interpolated by Kriging. The latitude-longitude coordinates are in the NZGD2000 system.

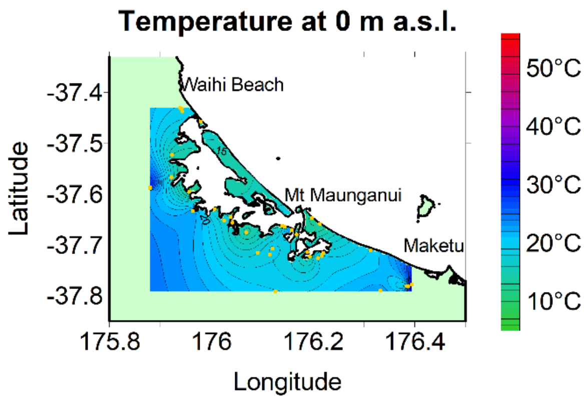

Figure 6: Temperature slice at sea level across Tauranga and (partly) Maketu Geothermal areas interpolated by Kriging. The latitude-longitude coordinates are in the NZGD2000 system.

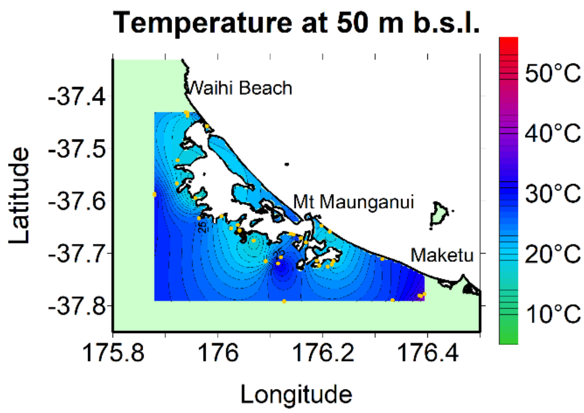

Figure 7: Temperature slice at 50 m b.s.l. across Tauranga and (partly) Maketu Geothermal areas interpolated by Kriging. The latitude-longitude coordinates are in the NZGD2000 system.

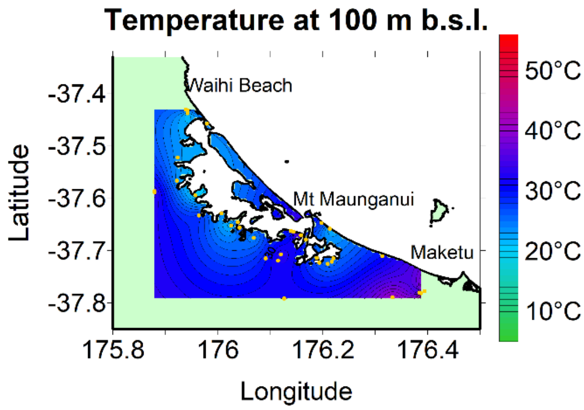

Figure 8: Temperature slice at 100 m b.s.l. across Tauranga and (partly) Maketu Geothermal areas interpolated by Kriging. The latitude-longitude coordinates are in the NZGD2000 system.

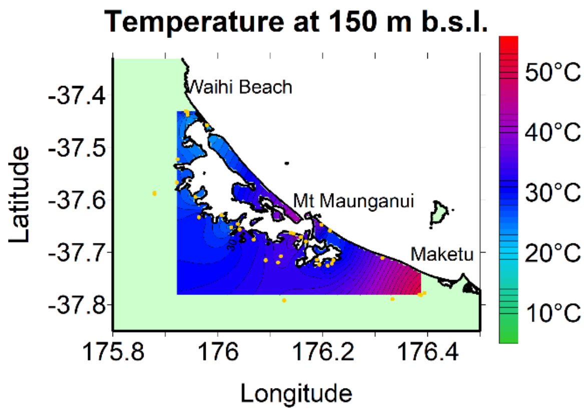

Figure 9: Temperature slice at 150 m b.s.l. across Tauranga and (partly) Maketu Geothermal areas interpolated by Kriging. The latitude-longitude coordinates are in the NZGD2000 system.

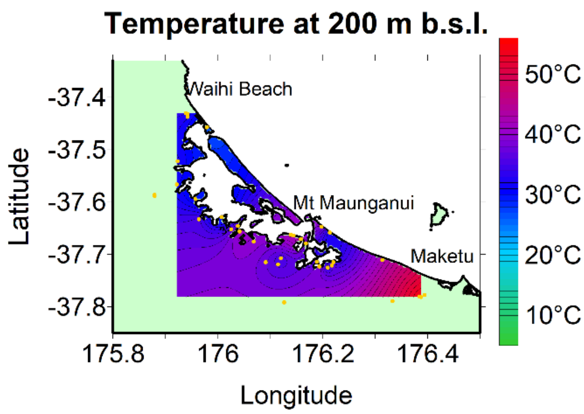

Figure 10: Temperature slice at 200 m b.s.l. across Tauranga and (partly) Maketu Geothermal areas interpolated by Kriging. The latitude-longitude coordinates are in the NZGD2000 system.

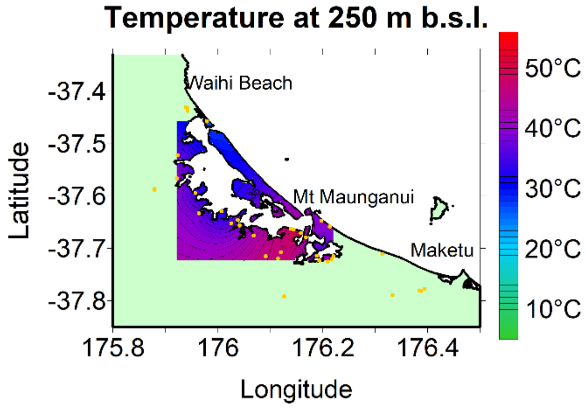

Figure 11: Temperature slice at 250 m b.s.l. across Tauranga and (partly) Maketu Geothermal areas interpolated by Kriging. The latitude-longitude coordinates are in the NZGD2000 system.

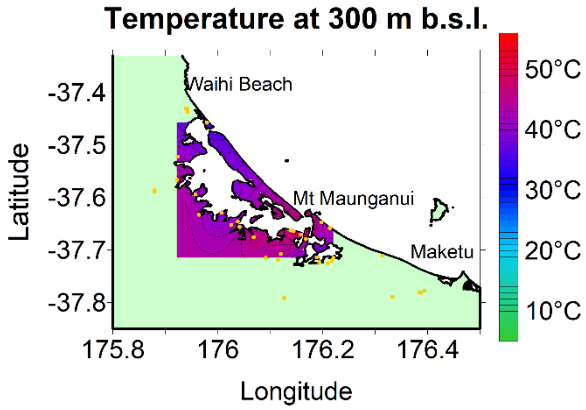

Figure 12: Temperature slice at 300 m b.s.l. across Tauranga and (partly) Maketu Geothermal areas interpolated by Kriging. The latitude-longitude coordinates are in the NZGD2000 system.

As the greatest amount of data was available for the depth of 50 m b.s.l. (37 data points) and slightly less for 0 m a.s.l., 100 m b.s.l. and 150 m b.s.l.(29–34 data points). These slices provide more detail and are more reliable than the deeper slices where fewer data points are available, many of which are located near the coast and the wells are likely affected by seawater. The deepest slices are concentrated on the Tauranga Harbour but still show temperatures of around or over 40°C at 200–300 m depth.

4. DISCUSSION AND CONCLUSION

4.1 Data acquisition and reliability

Especially for greater depths, temperature data are limited. Although there are hundreds of boreholes within the Tauranga geothermal field, only 40 temperature profiles have been obtained. The rest of the boreholes can only provide the temperature of the production fluid if any. Hand-held infrared thermometers often measure this temperature, so the accuracy of the measurement is questionable. Temperature data loggers placed at the wellhead would provide more reliable information on the production temperature. This temperature then needs to be corrected for any heat losses during the ascent to the surface. Determination of the depth of the reservoir fluid is also complicated because the majority of these wells only provide the information on the drilled depth and the depth of the casing shoe, and thus, there is the whole open-hole interval that may be considered a production zone, although this assumption may be wrong and only a single fracture within the open hole interval may provide all the produced fluid.

4.2 Geothermal models and permeability

Not having temperature profiles in the majority of production wells (including cold water wells) introduces a positive bias leading to the assumption of a larger, hotter reservoir that may be present below Tauranga and Maketu areas. The geothermal model by Pearson and Alcaraz (2013) is simplified to provide some constraints on the extent of the reservoir and the location of the upflow zone(s). Additional measurements of thermal conductivity and permeability of all the major lithologies would help constrain the model to provide more realistic outputs (as suggested by Pearson-Grant and Burnell (2016) who already provide some limits on permeability between 8.2×10^{-19} m^2 and 2.4×10^{-10} m^2 and warn that the permeability of sediments is greater than the permeability of ignimbrites). Simpson (1987) noted that some temperature profiles appear conductive in the sediments and convective in the volcanics beneath. It is not uncommon for geothermal reservoirs to be confined in a single permeable fracture zone within otherwise impermeable rock, so all the discussed permeability estimates are only relevant when referred to on an appropriate scale (e.g. as little as 10^{-19} m^2 for the volcanic basement with the exception of a fracture zone with a permeability of 10^{-10} m^2, or 10^{-12} m^2 for the sediments with the exception of a silty bed with a permeability of 10^{-15} m^2 that serves as the caprock for the fractured volcanics-hosted geothermal reservoir). In the author's opinion, the main weakness of the Tauranga geothermal model (Pearson and Alcaraz, 2013) is not in wrongly assigned values, as suggested by Pearson-Grant and Burnell (2016), but instead in low resolution with only two lithological units. Suppose a revision of the current model was able to clearly distinguish between the permeability of fractured volcanics and intact volcanics, and aquifers and aquitards within the sedimentary sequence. In that case, its accuracy would improve without the need to create a radically different model.

4.3 Conclusions and recommendations

In this study, we provide the first rough estimate of temperature distribution with depth in the Tauranga geothermal field and propose actions that need to be taken in order to improve our understanding of the system.

Our results show the highest temperatures at depth (near 50°C at 300 m depth) in the corner of the study area near Pungarehu SW of Maketu. Although the borehole data are sparse and some are of questionable quality, a temperature anomaly is feasible due to the presence of a fault, which is not active, but its damage zone may still serve as a conduit for hot fluid from beneath. There is also a low resistivity anomaly confirmed by two surveys (Geophysics Division DSIR 1970; Stagpoole and Bibby 1998) coinciding with the increased temperature, although given the proximity of the sea and the tidal river estuary, the shallow aquifers may be affected by seawater intrusion that would reduce resistivity. Results based on the sparse downhole temperatures and old resistivity surveys need to be verified. Hot springs were reported by residents in the 1960s, although they have since then been strongly modified by the flood protection drainage system (Whyte 2021). The extent of this thermal anomaly cannot be constrained due to the lack of temperature profiles in the wells S and SW of Maketu.

Another anomaly (>40°C at 300 m depth), consistent with the geothermal model (Pearson & Alcaraz, 2013), is under Tauranga city, where also the hottest wells are located (Well 3467 reached 53°C at 325 m depth).

These results, however, carry a substantial amount of uncertainty due to insufficient data. There are hundreds of wells in the area, but only 40 have full temperature profiles. Temperature profiles along the coast of Athenree, Tauranga, Mt Maunganui and Omokoroa beach are clearly affected by the close proximity of the sea which is confirmed by the high groundwater conductivity reported by White et al. (2009). Temperature logs in more wells, particularly between Maketu and Te Puke, as well as further inland from Tauranga Harbour, would greatly improve our understanding of the temperature distribution at depth and constrain the temperature anomalies to locate upflow zones of the geothermal fluids. As some of the temperature logs in Figure 8 show, and what has been confirmed by previous studies (Simpson 1987; White et al. 2009), some wells may have convective profiles. Additional temperature logs in holes intersecting these potential convective horizons would determine flow paths and rates in the warm aquifer. This would help track the source of the geothermal fluid and hence assess the potential of this warm water resource.

By more comprehensive subsurface temperature mapping focusing on the Maketu anomaly, its extent can be determined, and reservoir temperature estimates can be improved. Given the supporting geological, geophysical and hydrogeological evidence, it is likely that this anomaly is not an artefact and is, in fact, potentially worthy of further exploration.

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