# Tauranga geothermal system – an overview

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## ABSTRACT

The Tauranga Geothermal System (TGS) is an extensive warm water system with few geothermal surface features. Geothermal-groundwater (GGW) is produced at 30-70 °C from wells mostly 200-600 meters deep. The TGS is available for sustainable use and development, and discharges are managed to minimise the effects on the receiving environment. The main uses are for space and water heating for municipal pools, private domestic space and water heating and mineral pools, and space heating for greenhouses. The use of GGW for irrigation and frost protection is not considered a 'geothermal use' nor a method of discharge. However, it accounts for around 24% of the allocated geothermal water from the TGS. This paper describes the current situation with geothermal takes and discharges from the TGS, aspects of chemistry relevant to the use and discharges to various receiving environments, and the current knowledge of the geothermal energy resource. This is based on published technical reports, historical data stored in the Bay of Plenty Regional Council (BOPRC) archives, and data from resource consent applications and compliance processes. BOPRC is currently building its body of knowledge on this large geothermal system to inform and improve the integrated management of this large geothermal-groundwater resource.

## 1. THE TAURANGA GEOTHERMAL SYSTEM

### 1.1 Introduction

The Bay of Plenty Regional Council (BOPRC) manages the Tauranga Geothermal System under the Resource Management Act 1991 (RMA). The system is managed to provide for extractive uses where the adverse effects of the activity can be avoided, remediated or mitigated. The discharge of geothermal water must be managed to avoid significant adverse effects on freshwater and stormwater (Bay of Plenty Regional Policy Statement).

The Tauranga Geothermal System (TGS) is a low enthalpy warm water system (Zarrouk & McLean, 2019), with a surface extent of around 875 km$^2$. Aquifer temperatures range between 30-70 °C at depths of 200-600 meters [Regional Natural Resources Plan GR P3 (Policy 121)]. The system is available for sustainable use and development. A few warm springs/seeps with temperatures ranging from 23 $^oC$[1] to 47 $^oC$ exist around Woodlands Road and Hot Springs Road (Katikati), Welcome Bay (Tauranga) and Maketū.

The geothermal water consists of groundwater heated by the slightly enhanced thermal gradient in the area, with no input from magmatic volatiles (Simpson & Stewart, 1987). This enhanced thermal gradient is remanent of ancient volcanism in the area around from ca. 2-3 Ma (Leonard *et. al.*, 2010). The main heat transfer mechanism is conduction, possibly with some advection (Pearson-Grant & Burnell, 2018).

So far, heat matters have not been addressed with the same depth of groundwater in regards to allocation, monitoring and assessments of impacts of takes in the system. BOPRC is currently working on building its body of knowledge on this large geothermal system to better inform how to manage the geothermal resource in an integrated way with the freshwater resource. This paper focuses on what we 'learned' over the last two years by reviewing the data stored in our systems.

### 1.2 Uses

Warm water systems are commonly found worldwide (Zarrouk and McLean, 2019) and are predominantly used for direct use for a range of commercial and residential purposes (Lund and Toth, 2020). In the TGS, the main uses are for thermal power for space and water heating and for bathing in geothermal water. Those uses account for 76% of the allocated volume in the TGS. The other 24% is for 'non-geothermal' uses of geothermal water, which is a very peculiar situation in the TGS (see below). The vast majority (>95%) of those 'non-geothermal' takes are for irrigation/frost protection, with a small percentage for dust suppression and bottling. It is important to emphasise that the 'warmth' of the water is not required for irrigation and frost protection purposes.

Altogether, an average of 26,000 tonnes of geothermal water is extracted from the Tauranga Geothermal System per day. A breakdown of the percentage of geothermal water used for 'true' geothermal purposes per economy sector is presented in Figures 1 and 2 (Barns, 2022). The largest 'true geothermal' take is for Baywave in Tauranga, which accounts for 10% of the take from the system. A 40 hectares kiwifruit orchard is the largest geothermal take in the TGS for the sole purpose of irrigation/frost protection and accounts for 1.3% of the total take from the system.

Geothermal water is often tapped 'unintentionally' in horticultural takes for irrigation/frost protection takes. This situation arises when the user wants a coldwater bore but the bore yields warm water. This situation also triggers BOPRC statutory requirements to consent to the activity under the provisions for geothermal takes[1], which is often considered quite 'unfortunate' to the users. This is because tapping into

[1] Geothermal water in the Resource Management Act (1991) is defined as water above 30 $^oC$. This paper adops a science approach and considers springs > 20$^oC$ as warm geothermal springs, given that the upper limit for groundwater springs in the Tauranga area is 19 $^oC$ (Green, 2022*)*.


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the geothermal resource adds complexity to assess and manage potential effects of the activity in the environment. In this case, in addition to the 'suite' of groundwater issues/ potential effects (e.g. saline intrusion, bore interference), the user also has to assess and manage the adverse effects of the activity in the geothermal system. This also adds complexity to the assessment of the discharges of geothermal water to land and freshwater bodies. In the case of take for irrigation/frost protection, an assessment of the potential impacts on soil health is also normally expected due to the slightly higher salinity of the water and potential presence of contaminants like chloride, arsenic and boron, often at levels above the thresholds for drinking water and primary industries (sections 1.7 and 1.8).

The main reasons behind those 'accidental' geothermal takes are the following:

- Horticultural uses typically require a substantial volume of water (a magnitude of hundreds of tonnes per day). Therefore, to yield the necessary volume of water to the end use, and to minimise the impacts on surface water bodies connected to the shallow aquifer, the users typically construct deeper wells. Those deeper wells will tap into the deeper confined aquifer associated with the older volcanic units (WAI1, WAI2 and WAI3), that underlay the shallow unconfined aquifer typically correlated to the Tauranga Group sediments.
- Most of the uses for horticultural purposes are also already in relatively warm areas, like Te Puke in the South and Katikati to north (figures 4 and 8).

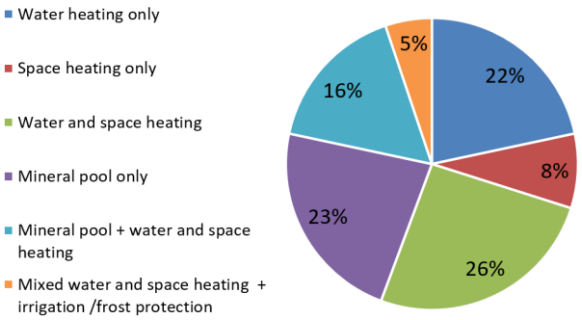


**Figure 1: End use of the allocated geothermal water (% of volume) for 'true geothermal' takes.**

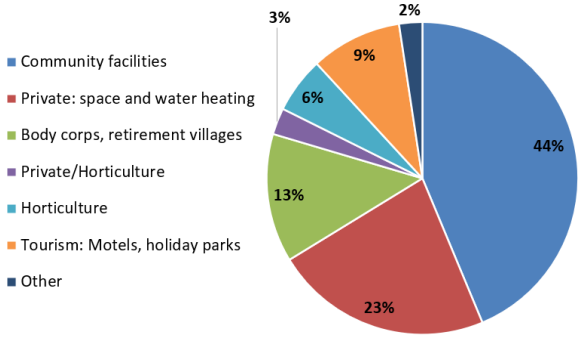


**Figure 2: Allocated geothermal water (% of volume) for geothermal takes for geothermal purposes (i.e. excluding irrigation, frost protection and dust control) per economic sector.**

### 1.3 Drilled depths and temperature

There are around 320 geothermal wells in the TGS. Their basic statistics for depths and temperature are presented in Table 1. The deepest well in the system is located in Hairini (Tauranga), and it is drilled to an impressive depth of 916m, to reach only 47 ºC. Nonetheless, the average will in the TGS is ~300 meters deep, with a mean temperature of 40 ºC. The hottest well so far (68 ºC) was drilled in 2012 in Pyes Pa (Tauranga). This well is 707 meters deep and cased to 385m.

It is interesting to note that there is no strong correlation between increased drilled depth and temperature (Figure 3). This shows that the users will go only as deep as necessary to reach the temperature for the end use, which is normally around 30 ºC to 60 ºC for the uses in the TGS (Table 2). This 'targeted temperature approach' without a large temperature buffer is reasonable considering the wells' current drilling costs of ~$1,300 per meter. It also highlights the importance of the careful management of this geothermal system as (i) the users are already going to significant depths for reasonably little temperatures, and (ii) a small temperature decline might impact the suitability of the heat available for its end use (table 2).

**Table 1 – Depth and temperature basic stats for the wells in the TGS.**

| | Drilled depth (m) | Temperature after drilling (ºC) |
|---|---|---|
| Mean | 304.8 | 40 |
| Maximum | 916.8 | 68 |
| Minimum | 15.2 | 30 |

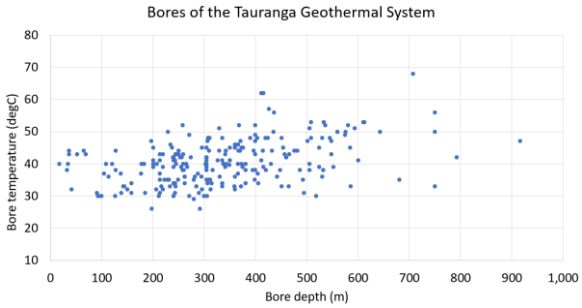


**Figure 3: Temperature and drilled depth for the ~320 wells in the TGS.**

**Table 2: Temperature requirements for the main heat uses in the TGS (from Peng & Moore, 2021):**

| End-use | Temperature requirement |
|---|---|
| Hot domestic water heating | 60°C |
| Space heating forced convection | 50°C |
| Spa pools heating | 40°C |
| Underfloor heating | 35°C |
| Leisure/swimming pools heating | 30°C |


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### 1.4 Temperature gradient distribution

Zones of enhanced thermal gradient in relation to the local background were delineated using data from temperature profiles collected over time (Figure 4). This data was compiled by Pearson-Grant & Burnell (2018), and recent data obtained by BOPRC was added to the database. This analysis assumes a linear vertical gradient, which is not strictly correct, but it is a good approximation for the majority of the temperature profiles in the TGS. Changes in temperature gradient that coincides with changes in stratigraphy are often observed, but no temperature inversions have been observed in the data so far. Therefore, the map can be considered an average thermal gradient for the area.

The results showed a good variability of the thermal gradient across the system, highlighting the Tauranga city anomaly, another smaller anomaly in Katikati, and the Maketu anomaly. It is important to note that there is limited data in the south and the west (Janků-Čápová *et al.*, 2022). More data in the area would help to better constrain particularly the southern Maketu anomaly. The temperatures to the west are probably cooler, given the effects of rainfall in the Kaimai Range to the west (Simpson, 1987).

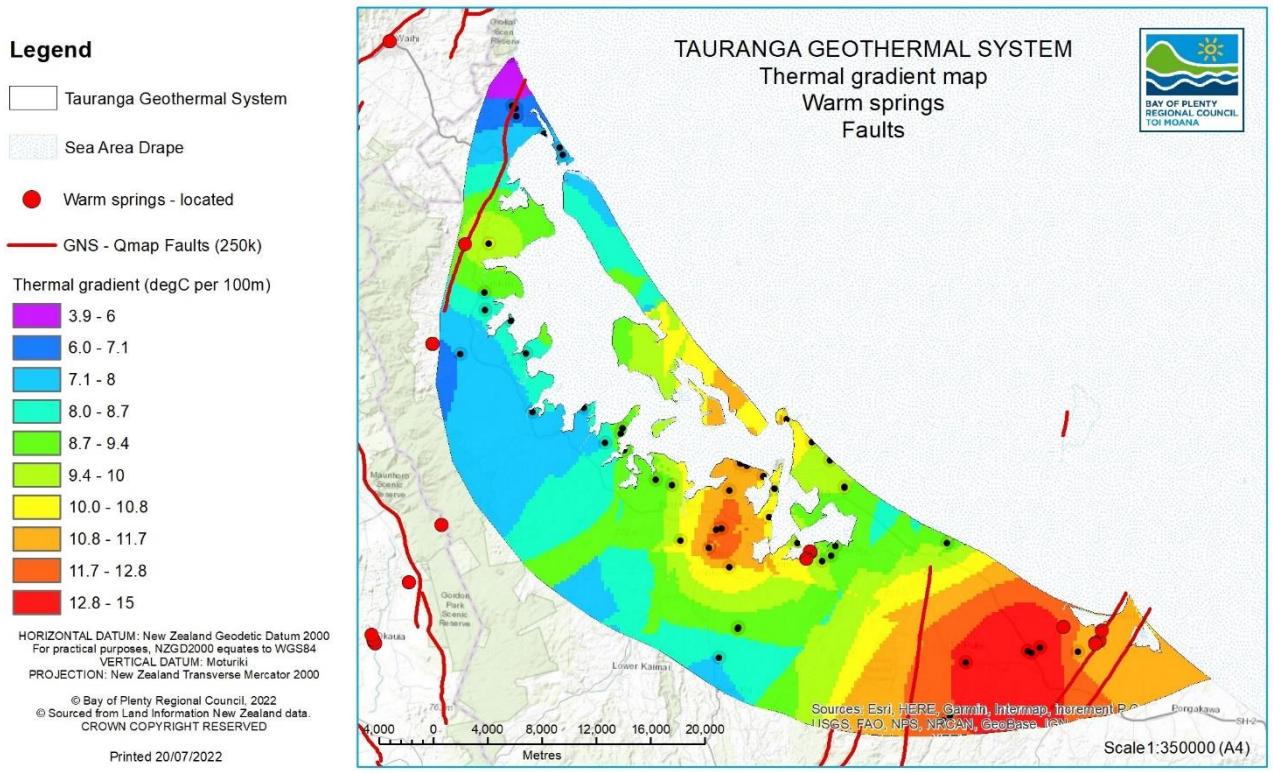


**Figure 4: Thermal gradient distribution and location of the warm springs in the TGS. The black dots are the data points for contouring the thermal gradient. The faultline offshore marks the western limit of the Motiti Island.**

### 1.5 The Te Puke-Maketū thermal anomaly

The Te Puke-Maketū thermal anomaly was analysed in more detail based on the available data and information for the area. Janků-Čápová *et al.* (2022) processed the resistivity data from Stagpole & Bibby (1998) for the Maketū area. Stagpole & Bibby (1998) interprets that the low-resistivity zone in Maketū reflects the presence of highly conductive sea water at shallow depths. However, this is not necessarily substantiated by the chemistry data of Simpson & Stewart (1987), as well as data from resource consent applications in the area and chemistry data from the BOPRC NERMN monitoring well BN-1018.

Based on the evidence below, it is currently considered that the resistivity anomaly in the Maketū area is possibly reflecting a heat anomaly in the area, but further work is needed to confirm that:

- The resistivity lines terminate against the coastline perpendicularly.
- The relatively wide spacing of electrodes used in the Werner array will measure the resistivity at depths likely deeper than the saline intrusion/brackish water.
- Chemical results are not consistent with salt water intrusion.
- Previous resistivity survey by DSIR (1974) also utilised the Werner array and, comparing the results with their geochemical sampling survey, concluded that the geochemical results are incompatible with the predicted water resistivity, possibly due to high temperatures with depth.


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- The resistivity is probably reflecting some enhanced clay alteration related to this heat anomaly (Simpson and Stewart, 1987).

- Records of warm thermal springs/seeps.

DSIR commissioned exploratory works in the 1970s to confirm the existence of a heat resource in Maketū following a preliminary resistivity survey. A 440 ft (134m) deep well was drilled and surveyed for temperature with depth in 20m intervals. The temperature at the bottom of the hole was 41.7 ºC, giving a thermal gradient of 18.1 ºC/100 m depth – consistent with other wells in the area. The well was artesian from 150 ft depth (45m), with discharge (flowing) temperatures of 39 ºC. Geochemical samples were taken at 100 ft (30m) intervals and other wells were sampled in the vicinity. The results showed that the composition of the water from the exploratory well and wells in the vicinity showed composition similar to other tectonic springs in New Zealand, but with a lower degree of mineralisaton than the tectonic springs in the East Cape. In a short letter dated back to 1974, the DSIR superintendent Dr. Hochstein concludes that the resistivity anomaly is likely related to a low temperature geothermal resource in the area. This is consistent with Janků-Čápová *et al.* (2022) conclusion that there is sufficient hydrological and geophysical evidence to support the existence of a thermal anomaly in the Maketū area.

### 1.6 BOPRC monitoring results – warm wells

BOPRC has recorded discharging temperatures for seven geothermal-groundwater monitoring sites across the Tauranga Geothermal System and logged temperatures at the casing shoe depth for one site. No evidence of cooling was observed in any of the sites other than for the Sharp Road site (well BN-2303) located 2.5 km southeast of Katikati (Figure 5). The Sharp Road site shows a consistent and gradual temperature decline of the discharging water over time.

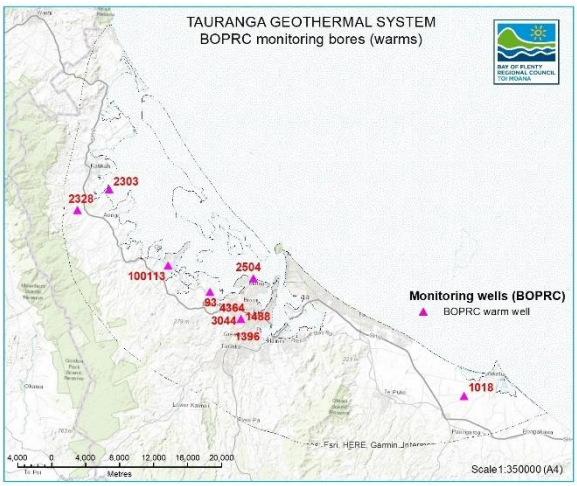


**Figure 5: Location of BOPRC warm monitoring wells.**

The discharge temperature of well BN-2303 declined from 37 ºC in 1991 to 29 ºC in 2021, a decrease of 8 ºC over 30 years, or a rate of 0.27 ºC per year. The decline has been sharp from 2018-2019 (Figure 6). Well BN-2303 is a tidal well, thus influenced by the seawater. A sampling at the site always occurs at low tide, minimising the effects of seawater on the discharge temperature and water chemistry of the samples collected. The chloride concentration of the discharged water did not increase over time and had a negative correlation with the temperature only in 2005 (Figure 6). Therefore, there is good confidence in this dataset, as there is no evidence that saline / brackish water was drawn during sampling/discharge for most of the time series.

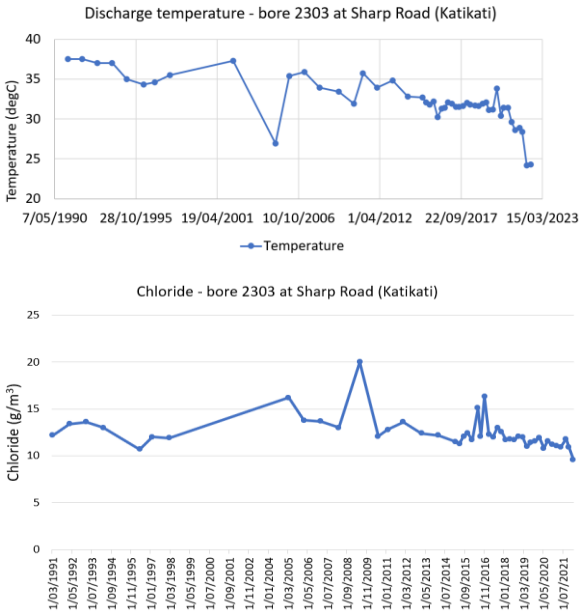


**Figure 6: Temperature trend for well BN-2303 (top) vs chloride concentration (bottom).**

This temperature decline could be due to unsustainable rates of takes that would be drawing cold groundwater into the warm GGW aquifer in the area, natural cooling, or something else. There are no reinjection wells in the area that could cause thermal breakthrough – another plausible hypothesis. A more thorough assessment would be required to determine with more certainty the reasons for the temperature decline of well BN-2303.

### 1.7 Discharges

The main methods of discharge for the geothermal water in the TGS are to land (24.6%), reinjection to the aquifer (16.4%), to the stormwater system (13.6%), and to surface water (11.7%) (Figure 7). Irrigation, frost protection and dust suppression are considered types of use and not discharge methods.

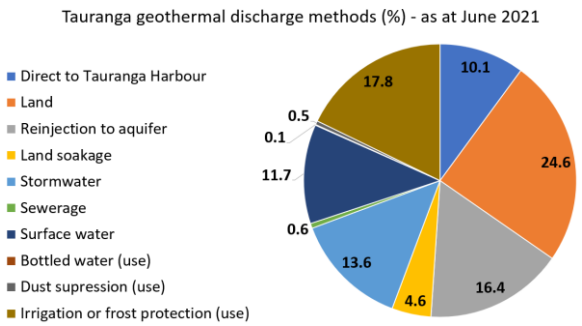


**Figure 7: Methods of discharge in the TGS.**


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**Table 3 – Advantages and disadvantages of the different methods of disposal for the TGS.**

| | Advantages | Disadvantages |
|---|---|---|
| **Reinjection, overall** | • Avoids thermal, chemical and ecological impacts associated with other methods of discharge | • Disruptions due to drilling operations in densely occupied, urban area<br>• Costs |
| **Reinjection into the shallower aquifer**, normally into the Tauranga sediments | • Avoids cooling of the producing aquifer<br>• Avoids thermal pollution of the receiving aquifer<br>• More cost-effective than deeper drilling<br>• Smaller drilling operations disruptions compared to drilling deeper | • Chemical and thermal pollution of the shallow aquifer, particularly for areas with takes for drinking and stock water<br>• Returns to surface water bodies |
| **Reinjection into the deeper aquifer**, normally into the undifferentiated volcanics | • Avoids chemical effects of reinjection into a shallow aquifer<br>• Pressure support for the producing aquifer<br>• No water wastage | • Potential localised cooling effects<br>Return of cooled reinjection water into other users (well interference), particularly in areas with a high density of takes |
| **Land soakage** | • Safe option if done at an appropriate rate.<br>• Potential shallow aquifer contamination (chemical, thermal) | • Issues with land stability |
| **Sewer** | • Water is treated before is returned to the environment<br>• More cost-effective than reinjection<br>• Solution for urbanised areas | • Pressures on the sewerage system2 |
| **Stormwater** | • More cost-effective than reinjection<br>• Solution for urbanised areas | • Possible breaches of discharge limits in resource consents held for those stormwater outlets (O'Shaughnessy, 1998) |
| Surface water – Tauranga **harbour/estuary** | • Little thermal impact compared to freshwater water bodies | • Pathogens contamination2<br>• Some chemical contamination<br>• Resource consent is required to build the infrastructure, which is not encouraged |
| Surface water – **freshwater** | • Cost-effective for the user | • Potentially significant thermal, chemical and ecological impacts |

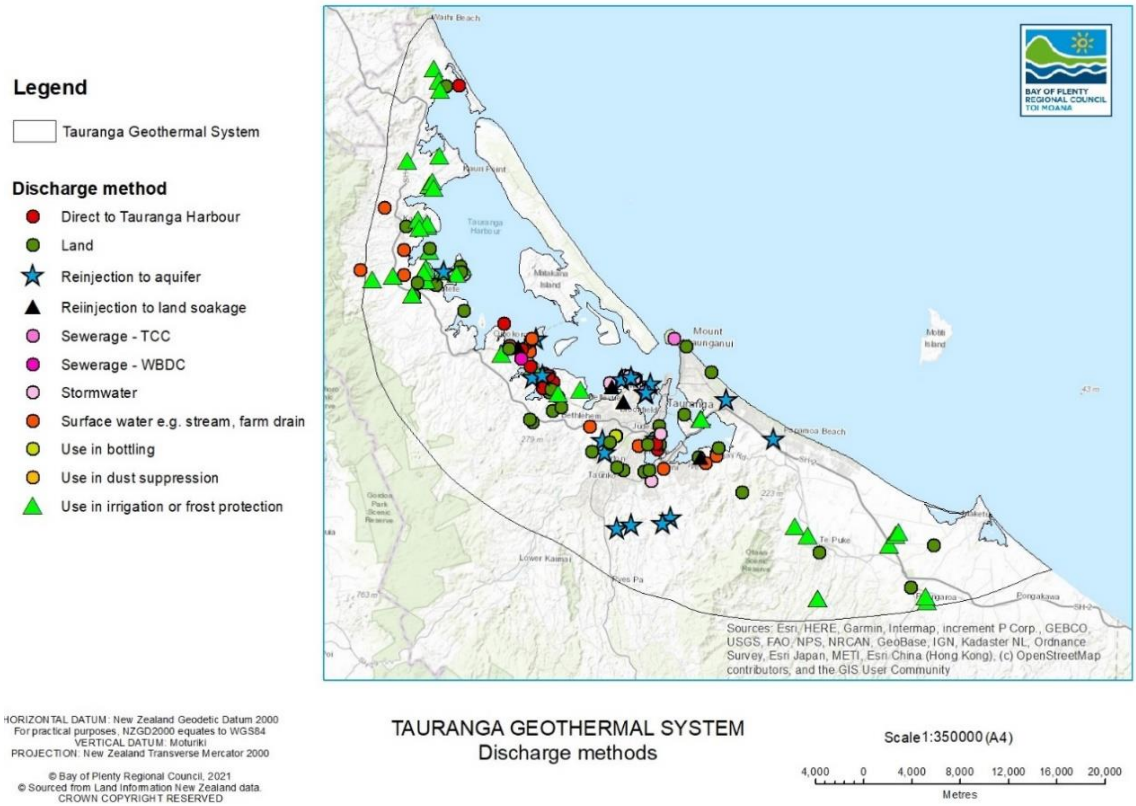


**Figure 8: Methods of discharge – Tauranga Geothermal System.**


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The geographical distribution for the different methods of discharges is presented in Figure 8, and it is noted that:

- The majority of the use for irrigation and frost protection occurs in the northwest and southeast zones of the system (Figure 8).
- Reinjection occurs mostly in the urban areas (Tauranga / Mt Maunganui central and Pāpāmoa) and towards Pyes Pā.
- Shallow soakage is limited to Tauranga City.
- Discharge to land occurs across the entire system.
- Discharge to storm/wastewater occurs in urban areas only, for obvious reasons.

The most appropriate discharge method for each user will depend on a variety of local factors beyond what is 'best' for the geothermal system. The main advantages and advantages of the available methods are outlined in Table 3. Ultimately the selected method will depend on the technical and economic viability of each method, and potential adverse effects on the environment (section 1.2).

### 1.7.1 Reinjection

Typical reinjection strategy (worldwide) for warm water systems with large scale, centralised production (e.g. electricity generation with binary units or direct use for district heating system) is in-field, at the same production depth and not far from the production area, to minimise pressure drawdown (Kamila *et al.*, 2021; Zarrouk & McLean, 2019). However, there is a trade-off between providing pressure support and avoiding cooling through the reinjection of cooled fluids. The situation in the TGS is incommensurable with the situation aforementioned, with a large number of relatively small users sharing a geothermal-groundwater resource for multiple purposes, and only a small proportion of the takes effectively reinjecting the water after use (~16%).

The majority of the takes with reinjection n the TGS are located in urban areas. This is due to the following factors:

- The unwillingness of the local authority to accept geothermal water discharges into the wastewater or stormwater systems.
- Issues with land stability for shallow soakage.
- A limited number of users with riparian rights to discharge to the harbour.
- The Bay of Plenty RNRP (GR P5 (Policy 123)) effectively promotes reinjection as the preferred method of discharge for geothermal takes.

Reinjection occurs in general into shallower units than the production zone (Figure 9). Production of geothermal water is mostly from undifferentiated intermediate volcanic units (Pearson and Burnell, 2018), which are inferred to have moderate permeability. Reinjection is mostly to the overlaying Tauranga Group sediments and, less commonly, to undifferentiated shallow and intermediate volcanics. Both the top and bottom units are inferred to have moderate to high permeability (Pearson and Burnell, 2018), which should ensure good injectivity.

For those takes with reinjection, the temperature range of the produced water is from 53 °C to 35 °C, with an average of 44 °C. Reinjection temperatures range from 41 °C to 10 °C, with an average of 31 °C. The temperature difference between the produced and reinjected water ranges from 19 °C to as little as 4 °C, with an average difference of 13 °C.

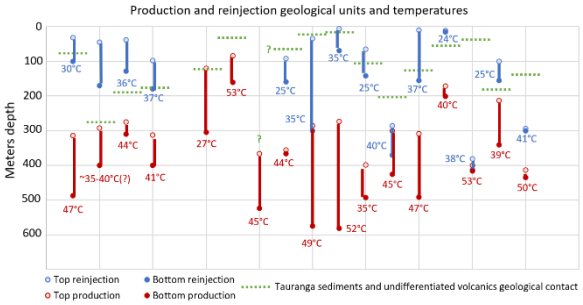


**Figure 9 – Production and reinjection depth range and respective geologic units, and fluid temperature. The green dashed line shows the approximate contact between the Tauranga Group sediments (above) and the undifferentiated intermediate volcanic units (below).**

### 1.8 Geochemistry

Geochemistry data collected for consent and compliance processes were compiled and analysed to identify areas where potentially toxic elements are present in greater concentration in the geothermal aquifer and to understand potential controls on those patterns.[2]

As discussed by Simpson and Stewart (1987), the geochemistry of the TGS broadly mirrors the aquifer rock composition. The long residence time (hundred to thousand years) allows for the slow-moving water and the aquifer rock to reach physic-chemical equilibrium (Simpson and Stewart, 1987). Overall, older, deep circulating water chemistry shows an andesitic host rock signature [small (Na + K / (Ca + Mg) ratio], while younger, shallow circulating waters show a dacitic or rhyolitic character (Simpson and Stewart, 1987). Waters with relatively high bicarbonate concentration occur associated with the shallow Tauranga Group sediments (Simpson and Stewart, 1987). Sea water can also locally affect the water geochemistry through mixing processes, with higher chloride concentrations closer to the coast, like in the Mount Maunganui peninsula area (Simpson and Stewart, 1987). As a result, there is a large variability of fluid composition across the TGS.

Geothermal water (not influenced by saltwater) in the TGS can have a slightly higher concentration of arsenic, boron and chloride than the background groundwater. While the levels of concentration encountered are not of similar magnitude to the fluids from convective geothermal systems like Rotorua (e.g. Mroczek *et al.*, 2003), it can reach levels above the

[2] The presented values are total values for the sample and not dissolved in the water. Dissolved values could be significantly lower than the values presented. Therefore, the results presented are intended to bradly characterise the spatial variation of the analytes.


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thresholds for the New Zealand drinking water standard (Ministry of Health, 2018) and the ANZECC Guideline for primary industries. Therefore, the natural geochemical signature is taken into consideration when assessing the potential effects of the discharge into the environment, and conditions are built into consents to manage discharges when necessary.

Higher arsenic concentrations are found in takes by the Tauranga Harbour shore (Figure 10). Takes further inland, to west, show lower levels of arsenic in the geothermal water. No correlation between areas of thermal anomaly and higher arsenic concentration was found. Stewart *et al.* (2018) measured the concentration of 226Ra, among other Radium isotopes, to investigate submarine groundwater discharges in the Tauranga Harbour. The 226Ra isotope has a long half-life of 1600 years, so is appropriate to determine the age of older groundwater. The location of the sample with higher arsenic concentration (0.06g/m3) matches with the estuarine area with higher 226Ra concentrations in Stewart *et al.* (2018) (Figure 10).

Simpson & Stewart (1987) interpreted that the recharge zone of the Tauranga system is towards west, and deep, slow-moving groundwater flows to east, which is consistent with Stewart *et al.* (2018) study. Considering the (i) location of higher arsenic concentrations close to the groundwater discharge zone in the Tauranga Harbour, (ii) the correlation with the age of the water, (iii) arsenic being a conservative element (Smedley and Kinniburgh, 2002; Stewart *et al.*, 2018), and (iv) the lack of correlation with temperature distribution, it is interpreted that the metalloid enrichment in takes closer to the mid-region of the Tauranga Harbour, closer to shore, is controlled by the higher residency time of the geothermal groundwater in that area.

Chloride levels vary greatly across the TGS, but are mostly below 200-300 g/m3. In some coastal areas, chloride concentrations can reach up to ~22,000 g/m3 due to different levels of mixing with saltwater (Simpson and Stewart, 1987). The exception is Fernland Spa, where dissolved chloride concentrations are ≈ 800 g/m$^3$. Relatively high boron values are also found in the Fernland Spa site, as well as between Te Puna and Welcome Bay in the Tauranga area. Those are all areas with subsurface temperatures relatively higher than the local background (Figure 11).

Boron is also a conservative element, and igneous rocks can be a source of boron and chloride (Simpson and Stewart, 1987). The low chloride to boron ratio for the Fernland Spa site (Cl/B = 28) and the molar ratio of cations ((Na+K)/(Ca+Mg) = 27.7) indicate no influence of seawater / brackish water. It is interpreted that the higher concentration of boron and chloride in Fernland Spa is due to the reaction between the slow-moving aquifer waters and the volcanic rocks enhanced by the thermal anomaly present in the area. A similar pattern is observed across the whole area between Te Puna and Welcome Bay in Tauranga. A very high Cl/B ratio is limited to the coastal zones, reflecting the zones of mixing with seawater/brackish water (Figure 11).

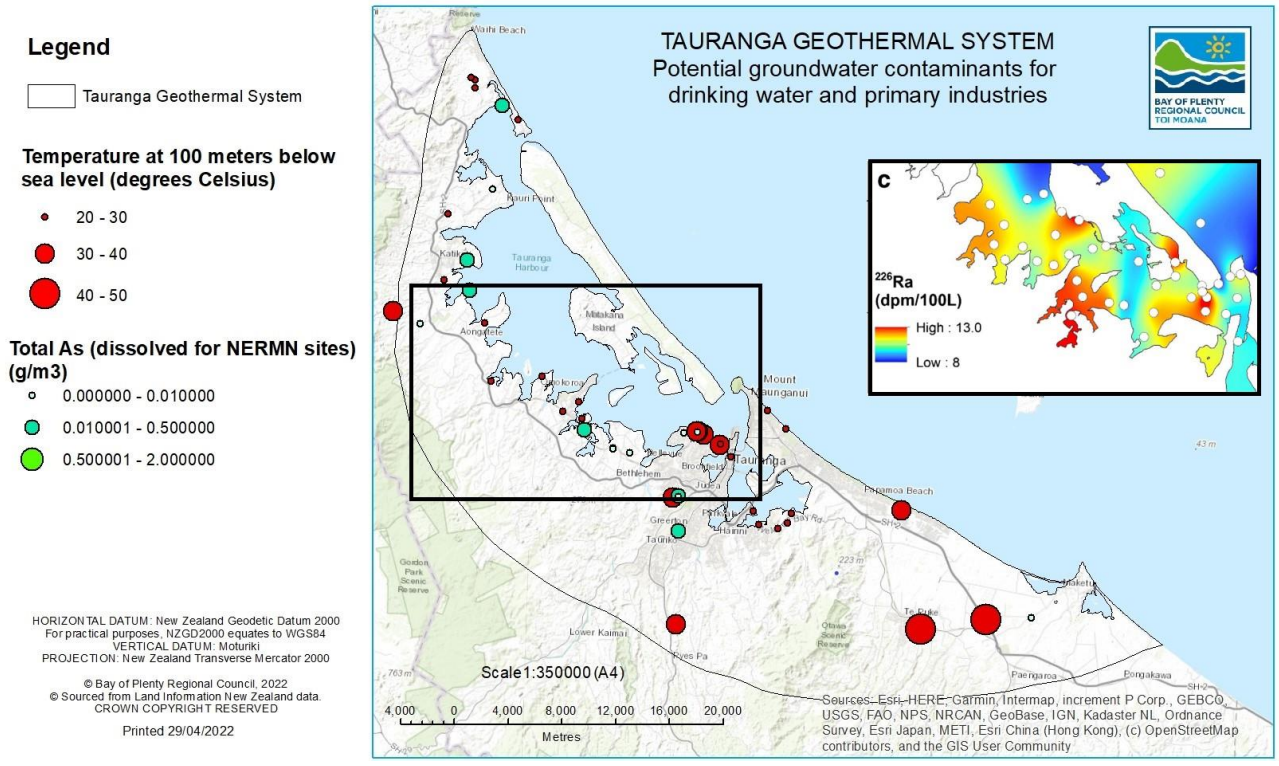


**Figure 10 – Geographical distribution of arsenic in warm wells (>30 °C) for the TGS. 226Ra concentration map (inset) of Stewart *et al.* (2018).**


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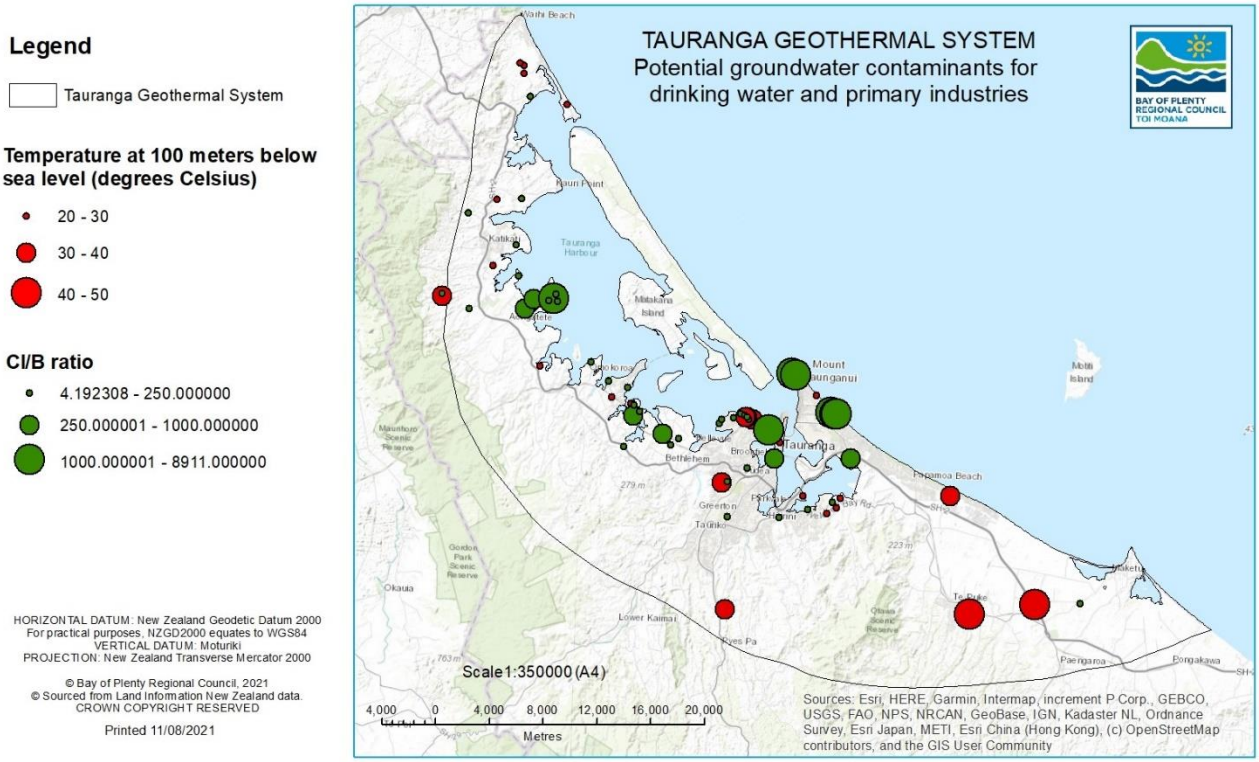


**Figure 11 – Geographical distribution of chloride/boron ratio in warm wells (>30 °C) for the TGS.**

## 2. CONCLUSION

- The Tauranga Geothermal System is an extensive warm water system in the Bay of Plenty that provides warm water for various direct uses. However, about 25% of the geothermal water is used for 'non-geothermal' uses like irrigation/frost protection, which is not ideal in terms of waste of heat and additional potential adverse effects to the receiving environment.

- To tap into the geothermal aquifer, users drill an average of 300 meters in depth to reach relatively low temperatures, around 40 ºC. However, the temperature gradient is not homogeneous across the TGS. There are 'pockets' of enhanced thermal gradient in Tauranga, Katikati and Te Puke-Maketū, and the location of warm springs broadly reflects those warmer zones. In those zones, higher temperatures can be achieved at shallower depths.

- No evidence of cooling was observed in any of the BOPRC monitoring sites, other than one area 2.5 km south of Katikati. More work is needed to confirm this temperature decline and, if confirmed, determine whether it is a result of anthropogenic activities or a natural process.

- The method of discharge for geothermal takes varies widely across the system and is controlled mainly by regulatory requirements from local and regional authorities (TCC/WBOP and BOPRC), and technical and economic constraints. Reinjection plays a small but key role in the discharge strategy as the only suitable method of discharge for users in urban areas like Tauranga.

- For production-reinjection takes, reinjection occurs predominantly into the shallow unconfined aquifer, and production is mostly from the deeper confined aquifer.

- Areas of high natural concentration for some chemical species relevant to drinking water and primary industry standards were identified. However, the data quality and spatial resolution of the data are not sufficient for spatial planning purposes. Those boundaries/areas could be a useful spatial planning tool to inform the system management, but it is considered unlikely to be developed medium-term. This is mostly due to the size and complexity of the TGS, and the impeditive level of investment required to develop the tool with the robustness required for planning and consents processes.

- Some correlation between the age of the water and arsenic concentrations appear to exist and is speculated. The temperature of the water shows some good correlation with higher levels of chloride and boron. Nonetheless, further work is required to gather more data to improve the robustness of the analysis, and develop more in-depth studies would help to improve the understand the processes controlling the geochemistry of the TGS.

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