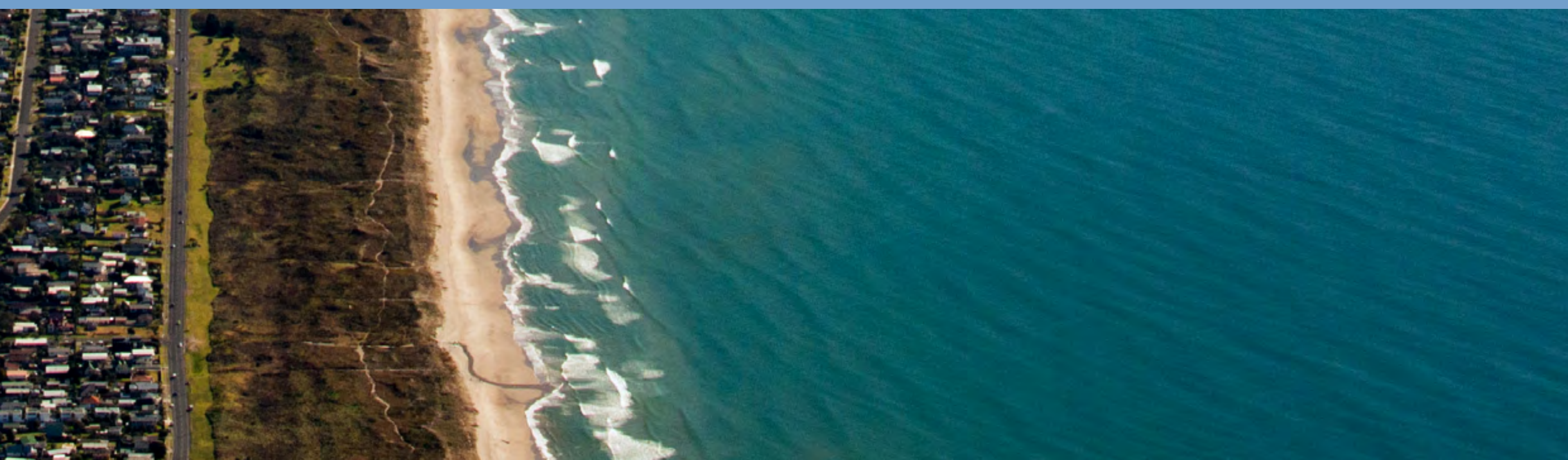
BAY OF PLENTY REGIONAL COUNCIL TOI MOANA

Te Rīpoata Whakarāpopoto Pūtaiao o Te Waiariki ki Tauranga Moana

Tauranga Geothermal System Science summary report



Environmental Summary Report
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We acknowledge the mahi of all scientists and professionals that contributed to building the understanding and management of this unique geothermal system.

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Part 1
Description of the resource

Overview

The Tauranga Geothermal System (TGS) is a large low-temperature geothermal system located in the Bay of Plenty region. The TGS extends from Waihi Beach in the north to Te Puke-Maketu in the south (Figure 1), with a surface extent of around 875 km^2.

The Bay of Plenty Regional Council (BOPRC) manages the Tauranga Geothermal System under the Resource Management Act (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 the receiving environment, such as a freshwater body (Bay of Plenty Regional Policy Statement).

Unlike other high-temperature systems, such as Rotorua, that have at least three separate geothermal aquifers, the Tauranga Geothermal System has only one main geothermal-groundwater aquifer hosted mostly by a deeper volcanic unit. The Tauranga geothermal aquifer is effectively cold groundwater naturally heated by warm rocks from the ancient volcanism that occurred in the area around 2-3 million years ago (Leonard *et. al.,* 2010). Aquifer temperatures range between 30-70 °C at depths of 200-600 m [Regional Natural Resources Plan GR P3 (Policy 121)].

While volcanic activity does not exist anymore, and the area is cooling down over geological timescales (thousands of years), there is still some residual heat within the rocks at depth that heats the circulating groundwaters. A few warm springs/seeps with temperatures ranging from 23 °C to 50 °C are known to exist or have existed in some areas. Those seeps/springs are the surface expression of the geothermal system.

The mineral content in the thermal waters of the Tauranga Geothermal System is much lower than in high-temperature systems, such as Rotorua or Kawerau. The chemistry of the water is similar to cold groundwater. The water quality makes it suitable for irrigation, stock water and frost protection uses in most cases, although in some locations it can have slightly elevated levels of potentially toxic minerals, such as arsenic and boron.

The geothermal water and energy is widely exploited for direct use, including for bathing, and space and water heating. A significant amount of geothermal water is used for irrigation and frost protection. In this situation, the heat value of this water is not used, just the water value as groundwater. Discharge methods vary widely; the main ones being to land and reinjection.

Regional Geology Setting

The Tauranga Geothermal System is a by-product of the volcanic activity in the Coromandel Volcanic Zone (CVZ), which is now extinct. This volcanism is associated with the evolution of the Australian-Pacific plate convergence at the Hikurangi Subduction Margin (Reyners, 2013). The CVZ is only a small onshore segment of a ~1300 km-long volcanic arc, the Lau-Colville Ridge-CVZ arc (Timm *et. al.,* 2019), the majority of which is submerged offshore.

The Coromandel Volcanic Zone was active between 18 million and 2 million years ago (Ma). Tectonic changes in the Hikurangi Subduction Zone around 2 Ma years ago led to a quick transition in location of volcanic arc from the CVZ to the Taupō Volcanic Zone (TVZ), which is currently active. Remnant volcanic landforms in the Tauranga area associated with the CVZ can be seen today, with distinctive volcanic features in the Kaimai Range, Pāpāmoa Hills and Mt. Maunganui.

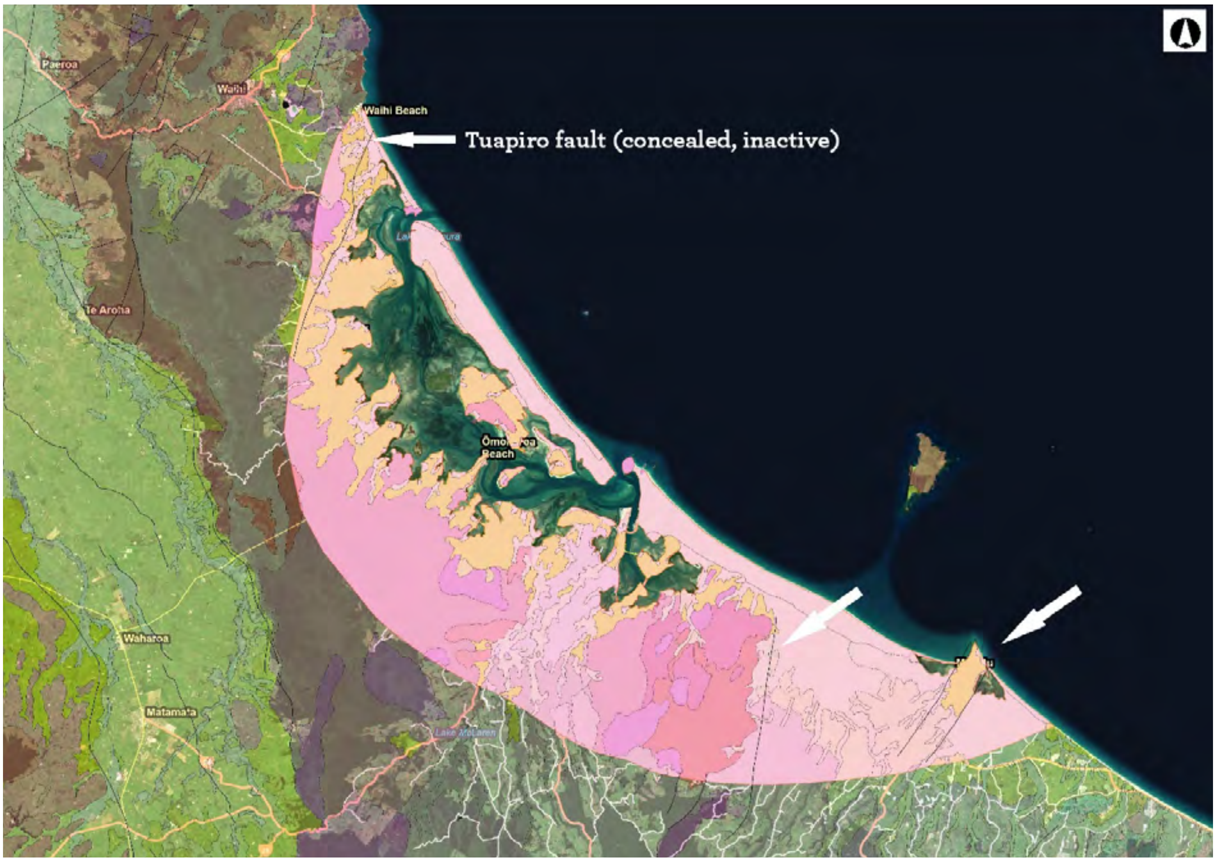


Figure 1: *Geological map and the approximate spatial extent of the TGS. The map shows the various volcanic units in pink with the younger rocks of the Tauranga Group sediments in orange. The black lines are the mapped inactive faults (from the QMap series – GNS Science).*

The volcanic rocks that host the Tauranga Geothermal System warm aquifer are of Late Pliocene age (1.8 to 3.6 Ma). Those rocks are overlain by the alluvial, beach, and volcaniclastic sediment of the Tauranga Group (<~7 thousand years old) (Davis & Healy, 1993). The Tauranga Group sediments are generally thin and pinch off to the west, while reaching about 300 m thickness to the east, towards the coast (Figures 2 and 3).

There are no active faults mapped in the Tauranga area; only inactive, concealed faults (white arrows in Figure 1). Both the northern Tuapiro Fault and the set of two unnamed parallel faults to the southeast around Maketū are significant faults in the sense that they hold some form of physiographic expression (Briggs *et. al.,* 2006). This pair of northeast-striking faults that shape the Maketū Peninsula are what is called in geology a horst-graben type fault system or structure. This means that the peninsula is like a geological 'ridge' with the blocks to the southeast and northwest downfaulted in relation to this geological 'ridge'.

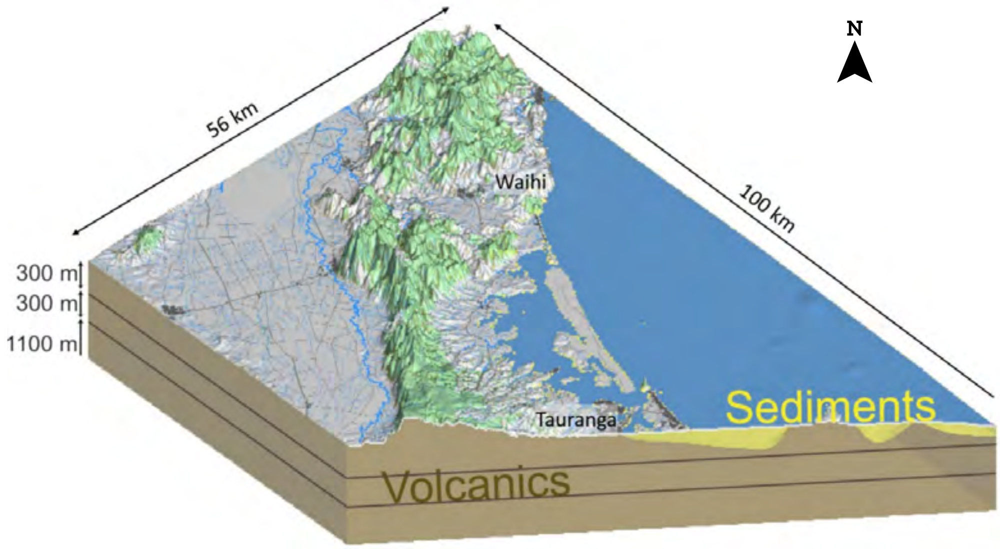


Figure 2: *Block diagram showing the topography and main geological units of the Tauranga Geothermal System, which are the underlying volcanics covered by the Tauranga Group sediments. This broad structure is reproduced in the Tauranga numerical model used to simulate heat and mass flow of the geothermal aquifer at depth (from Pearson-Grant & Burnell, 2018).*

The Tauranga Geothermal System

As described before, the Tauranga Geothermal System is a by-product of the now extinct Coromandel Volcanic Zone (CVZ). As such, there is no magmatic body at depth acting as a heat source to cause vigorous fluid flow, such as in Rotorua (Table 1). Instead, there is only some residual heat at the rocks associated with the now inactive CVZ.

This residual heat slightly heats up the groundwater system to form the geothermal aquifer that users tap into. This heat transfer occurs through a process called conduction and, potentially, some convection and advection (Pearson-Grant & Burnell, 2018). The conductive heat transfer mechanism is like heating your hands with a cup of tea – the heat from the cup is transferred to your hands through touch.

Some areas of the Tauranga Geothermal System are 'warmer' than others. Those warmer areas are mainly located around Tauranga City and Te Puke-Maketū (Zuquim *et. al.,* 2022), and secondarily around Aongatete. Those areas have an enhanced thermal gradient, which means that, on average, the temperatures increase faster with depth compared to other areas (Figure 4). It also means that, generally, higher temperatures are encountered closer to surface.

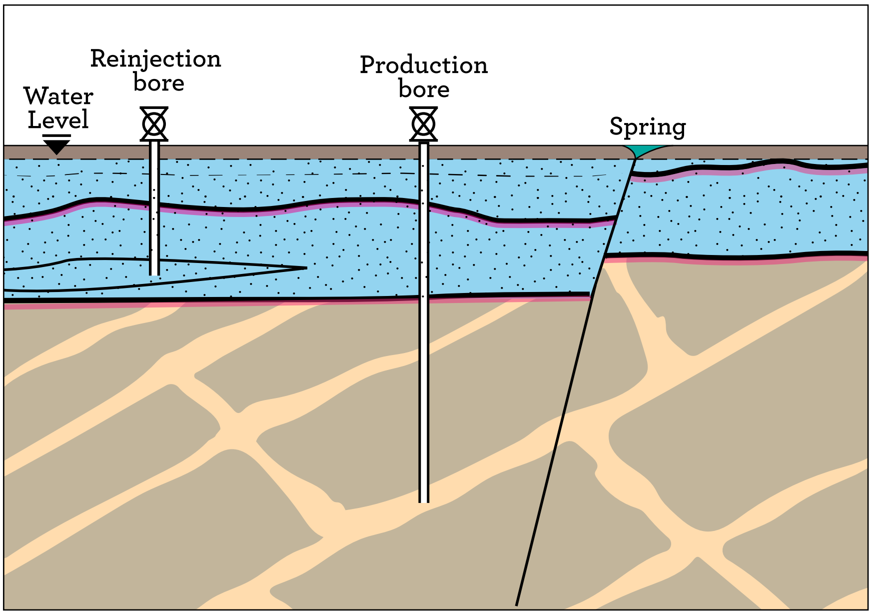


Figure 3: Schematic diagram showing fractured, undifferentiated volcanic rocks overlain by volcanoclastic sediments of the Tauranga Group sediments. Tectonic warm to hot springs occur associated with concealed inactive faults. Production bores tap into the geothermal aquifer hosted mostly in natural fractures of the volcanic rocks. Reinjection occurs mostly to the overlain Tauranga Group sediments.

The broad groundwater movement of the Tauranga geothermal-groundwater aquifer is from west and southwest (Kaimai Range, Pāpāmoa Ranges, and Mamaku Plateau) to east (Tauranga Harbour). The high elevation mountainous areas are the main rainfall recharge zones of the Tauranga geothermal-groundwater system, with discharge occurring regionally along the Tauranga Harbour estuary and locally at streams and springs. Groundwater flows through the region very slowly (taking hundreds, if not thousands, of years to reach the coast). This slow-moving water heats up as it flows through heated rocks, becoming more or less hot depending on the residual temperature of the rocks along the flow pathway.

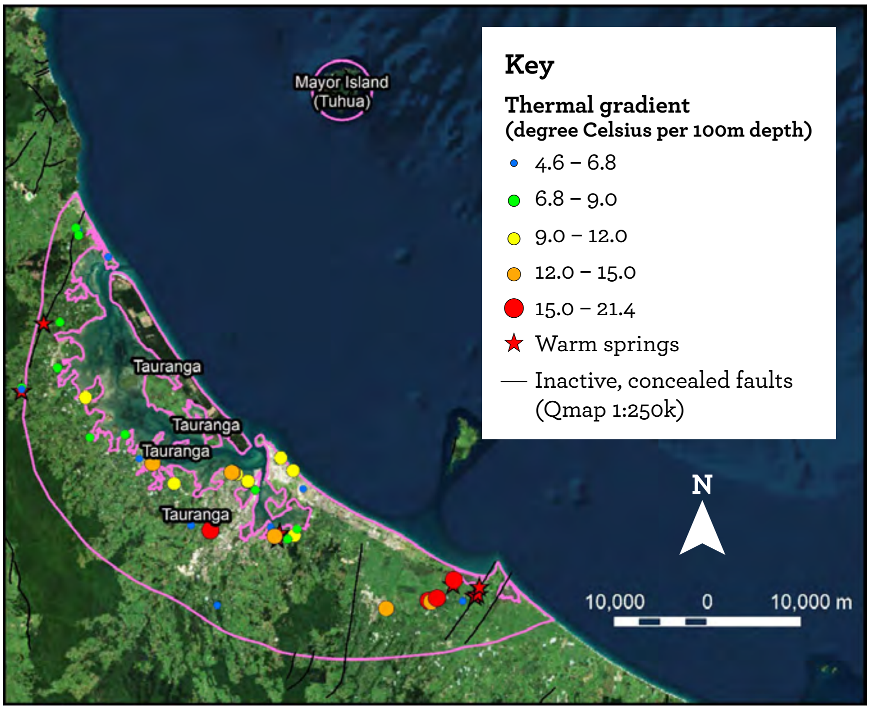


Figure 4: Thermal gradient distribution and location of the warm springs in the TGS. The higher the thermal gradient, the quicker the temperature increases with depth.

Chemistry

The mineral concentration of the Tauranga geothermal waters is very close to cold groundwater and broadly mirrors the aquifer rock composition. The long residence time (hundred to thousand years) allows for the slow-moving water to incorporate the chemical footprint of the rocks that they flow through (Simpson & Stewart, 1987). Overall, older, deep circulating water chemistry shows an andesitic host rock signature, while younger, shallow circulating waters show a dacitic or rhyolitic character (Simpson & Stewart, 1987).

The waters associated with the volcanic units are mostly sodium-chloride to sodium-bicarbonate waters, with waters richer in bicarbonate normally hosted by the shallower Tauranga Group sediments. Sea water can also locally affect the water chemistry, with higher chloride waters closer to the coast, such as in the Mount Maunganui area. As a result, there is a large variability of the geothermal water composition across the TGS. An important point is that the geothermal heat at depth will heat whatever type of water is stored in the aquifer, even saltwater. This is noticeable with some warm takes around the Mount Maunganui.

The TGS geothermal warm water can have slightly enhanced levels of arsenic, boron and chloride and, around coastal areas, chloride can be quite high due to saltwater influence. It is important to note that the concentration levels are not of similar magnitude to the concentration encountered in fluids from medium or high-enthalpy geothermal systems such as Rotorua (Mroczek *et. al.,* 2003), but can reach levels above the threshold for drinking water standards and primary industries (e.g. for horticultural use).

Differently from Rotorua, where most of the water is reinjected to a deeper aquifer after use, most of the discharge from the TGS is to surface, causing its own environmental issues that need to be managed according to the policy provisions of the region. Finally, unlike Rotorua, there are no magmatic gases like (such as H2S) dissolved in the geothermal water because there is no magma body at depth (Table 1).

Table 1: *Comparison table between Rotorua and Tauranga*

Characteristic	Rotorua – High-temperature	Tauranga – Low-temperature
Temperature of the geothermal aquifer	Geothermal aquifer close to or at boiling point at depth, >100 °C	Lower-temperatures, 30-70 °C
Heat source	Deep intrusive heat source (magma body)	Slightly elevated temperature gradient from remnant volcanic activity
Chemistry	Rich in magmatic gases, mostly CO_2 and H_2S, but no SO_2 like in an active volcano	No magmatic chemical input or gases
Surface features	Vast majority of the suite of geothermal features present (such as geysers, mud pools and hot springs)	Some warm springs. Temperature range from 23 °C to 50 °C

Figure 5 shows the spatial distribution of potential water contaminants in the Tauranga geothermal waters compared to the trigger values for the drinking water (NZDWS) and primary industry (ANZECC) guidelines. High chloride, arsenic and boron concentrations indicate areas where the use and discharge of geothermal water from the TGS might be an issue.

Overall, what can be observed is that:

- Chloride and Boron:
  - Areas with higher chloride and boron are closer to the coast, but also matches with the areas of enhanced thermal gradient in the Tauranga City and Aongatete.
- Boron:
  - In about 25% of the sites the water is not suitable for drinking but still suitable for stock water.
  - For less than 10% of the sites the water is not suitable even for stock water.
- Chloride:
  - Chloride levels vary greatly across the TGS, but are mostly below 200-300 g/m^3.
  - In some coastal areas chloride concentrations can reach up to 22,000 g/m^3 due to different levels of mixing with saltwater.
  - In about 30% of the sites the water is so ‘salty’ that it is not suitable even for stock water.
- Arsenic:
  - Higher arsenic occurs close to the estuary, from the Tauranga City area to the north, but there is limited data to the south and further inland.
  - There is no strong correlation between areas with higher concentration of arsenic and temperature.
  - In about 60% of the sites the arsenic concentration would make the water unsuitable for drinking but water is still within thresholds for stock water use.
  - In none of the sites the concentration of arsenic in the water makes it unsuitable for irrigation and frost protection.

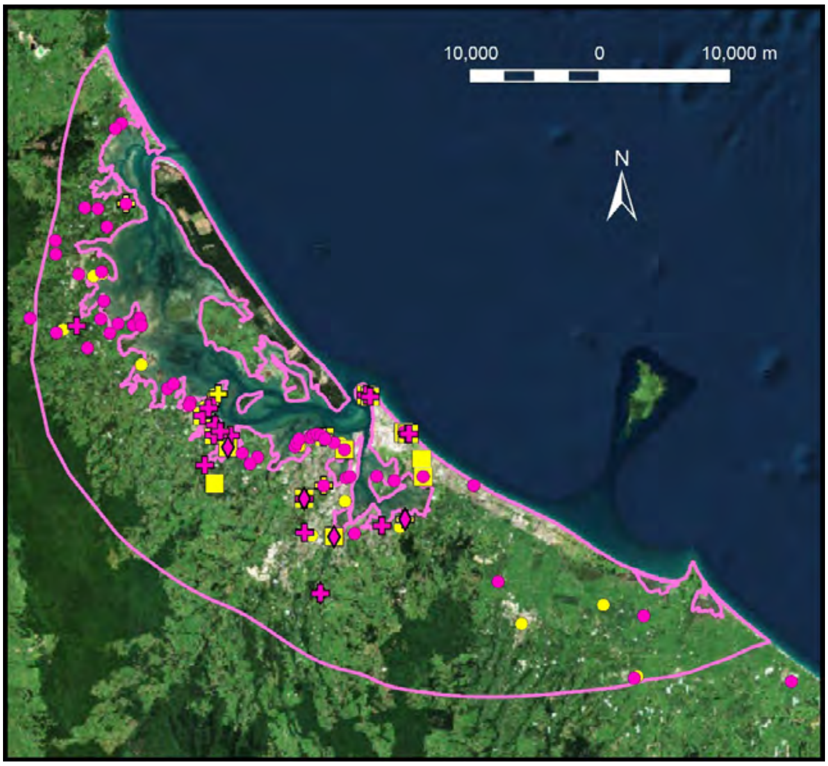
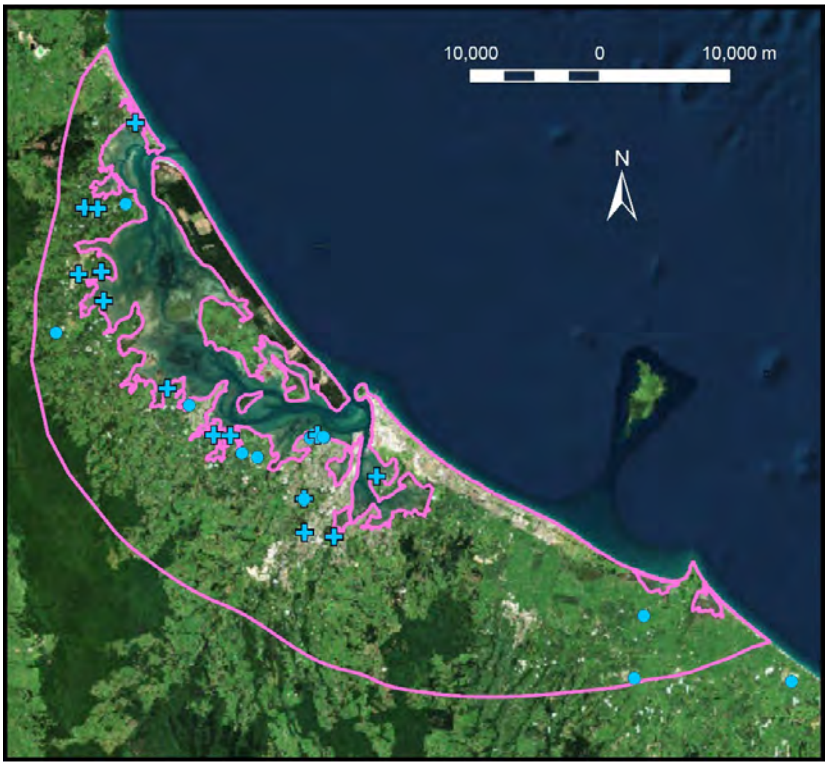


***Figure 5:** Spatial distribution of potential water contaminants relevant drinking water and primary industry typically elevated in Tauranga geothermal waters.*



Legend

Tauranga Geothermal System (indicative extension)

Arsenic (g/m³)
- 0.00 - 0.01
- 0.01 - 0.50
- 0.50 - 2.00

Boron (g/m³)
- 0.01 - 1.4
- 1.4 - 5.0
- > 5.0

Chloride (g/m³)
- 8 - 175
- 175 - 250
- 250 - 350
- > 350

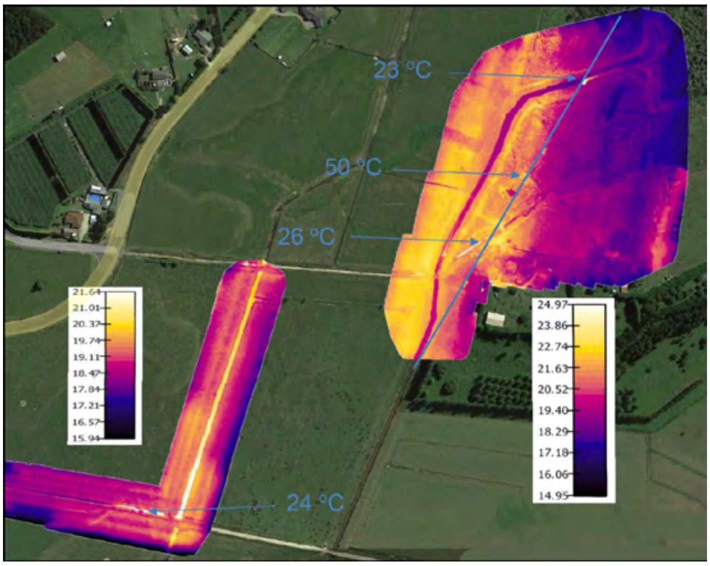
Potential contaminant	Drinking water standard	Primary Industry ANZECC Guideline
Arsenic	0.01 g/m³	0.5 g/m³ (stock water) 2.0 g/m³ (irrigation)
Boron	1.4 g/m³	5 g/m³ (stock water)
Chloride	250 g/m³	<175 g/m³ spray irrigation of sensitive crops >350 g/m³ increasing risk of cadmium uptake

Warm springs

While the Tauranga system does not have much thermal activity at the surface, warm seeps are present in the Katikati, Tauranga City and Maketū areas. Those springs are usually associated with mapped, concealed, inactive faults with regional significance (Figure 1), the only exception being one spring in Welcome Bay (Tauranga City). This spring is likely associated with an unmapped, secondary structure like a fracture zone.

This close association between the warm springs and faults is not surprising and is well known to exist in most of the geothermal systems, as faults provide a vertical pathway, or conduit, for the thermal waters at depth to ascend to the surface.

The TGS seeps have very low flow (< 0.1 liters per second) and temperatures range from 23 °C (geothermally influenced) to 50 °C (geothermal warm). All the spring waters are odourless and colourless, but can look murky due to some clay/mud content. In terms of chemistry, only the Maketū spring has been sampled and shows a sodium-bicarbonate composition, consistent with previous sampling by Simpson & Stewart (1987).



Top left: *Thermal infrared drone image and spot water temperature readings.*

Top right: *Small warm seep in the Welcome Bay (Tauranga Harbour) estuary. Geothermally influenced (temperature above groundwater but below regulatory thresholds for geothermal water strictu sensu).*

Bottom: *Woodlands warm spring and temperature reading.*

Part 2
Management, use and challenges

Management

New Zealand's geothermal systems are managed under the provisions of the Resource Management Act (RMA). Under the RMA water over 30 °C is considered geothermal water. Under Section 30 of the RMA, the Regional Council is responsible for managing the take and use of geothermal water, heat and energy and geothermal discharges to land, air, and water. There are several relevant regional planning documents that guide management of the geothermal resource, including the Bay of Plenty Regional Policy Statement (RPS) and the Regional Natural Resources Plan (RNRP).

The Tauranga Geothermal System is classified under the RPS and RNRP as a low-temperature system (Group 5), in which the primary objective for system management is the sustainable use of the geothermal resource and management of geothermal discharges to the environment.

Those regional plans also set out the rules for use, for example, a resource consent (or permit to use) is required from the Regional Council to:

- Build a new geothermal well.
- Take geothermal water and energy.
- Take the energy only (i.e., no water abstraction).
- Discharge geothermal water by reinjection or to the surface environment.

As part of any consent application, the effects of the use on the environment must be assessed.

Additionally, systems with a high level of use, such as the Tauranga Geothermal System, are required by the RPS to have a System Management Plan (SMP), which outlines objectives for its overall management and strategies to achieve the objectives.

Uses

About 9.5 million m³ of geothermal water is consented to be extracted from the Tauranga Geothermal System per year, both for 'geothermal uses' and for 'non-geothermal uses'. For the purpose of this report:

- **'Geothermal uses'** are those in which the value of using the resource is intrinsically linked to the geothermal energy (heat) and/or wellbeing associated with bathing in pure geothermal water (e.g. balneology/mineral pools).
- **'Non-geothermal'** uses are those in which the produced water is relatively warm (> 30 °C) however the end use does not require the geothermal energy or the mineral proprieties of the geothermal water for the end use (e.g. irrigation/frost protection).

Overall, production from the TGS consists of several, relatively small users sharing the geothermal-groundwater resource for multiple purposes. About 80% of the takes are between 450 - 75,000 m³ per year, another 10% are slightly larger (75,000-150,000 m³ per year) and the last 10%, or 16 takes, are larger than 150,000 m³ per year.

- The largest geothermal warm consent accounts for 10% of the all the water extracted from the system.
- The five largest takes accounts for 30% of all the water extracted.
- The 12 largest accounts for 50% of the water taken.
- The remaining 50% is extracted by 130 consent holders.

At this stage, there isn't sufficient data to understand changes in use over time given the age of some resource consents and the fact that many consents have not yet been reviewed.

'Geothermal uses' account for 76% of the allocated geothermal water of the TGS. The thermal energy is mostly used for space and water heating, either for residential, public, or commercial purposes (Figure 6).

'Non-geothermal uses' account for 24% of the take from the system. Around 95% of the water allocated for 'non-geothermal uses' is for irrigation and frost protection, with the remaining 5% for dust protection and water bottling.

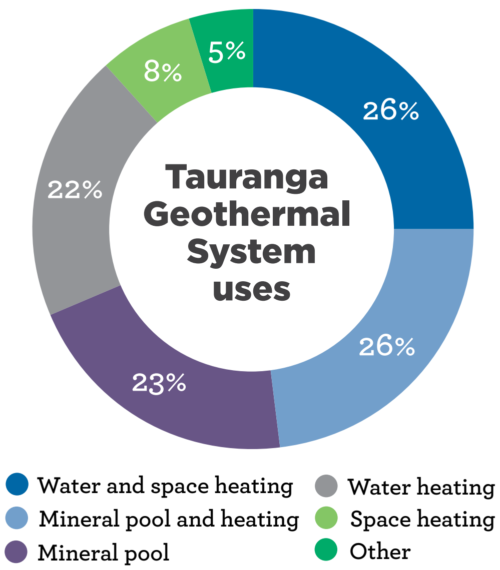


Figure 6 (Right): *End use of geothermal takes from the TGS, for 'geothermal uses' only.*

Public swimming pools and other community facilities (e.g., schools) account for 44% of the consented volume for direct use (Barns, 2022). About 29% is allocated to businesses (commercial use), including retirement villages (e.g., space and water heating), horticulture (e.g., heating greenhouses) and tourism (space and water heating, including mineral pools). About 23% is allocated to private, non-commercial uses, such as heating homes, private swimming pools and spa pools (Figure 7).

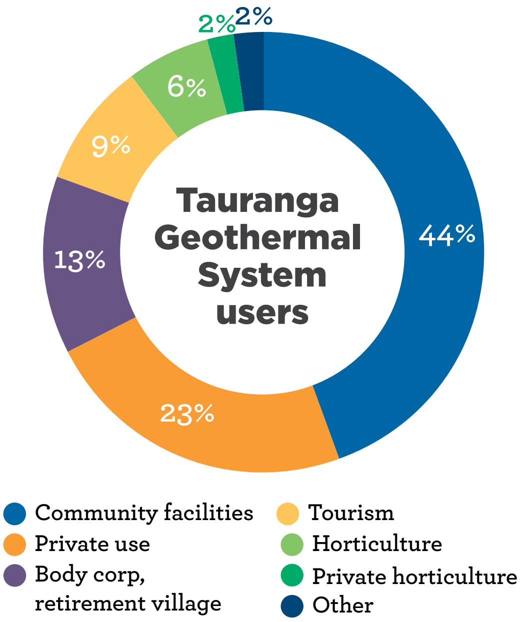


Figure 7 (Right): Type of users for 'geothermal uses' of the Tauranga Geothermal System.

Consented uses and number of geothermal wells

Approximately 320 geothermal wells have been historically drilled in the TGS (Table 2). About 150 wells are estimated to be in use, associated with about 140 currently active consents. About 80 of these consents are for 'true geothermal' use, with the rest being for 'non-geothermal' uses (see section on Uses). In contrast, there are more than 2,500 cold groundwater wells (i.e., with temperature < 30 °C) in the Tauranga-Kaituna-Waihi area (i.e. the freshwater management units which contain the TGS) and 618 of these currently have consents. The distribution of the consented takes is shown in Figure 8.

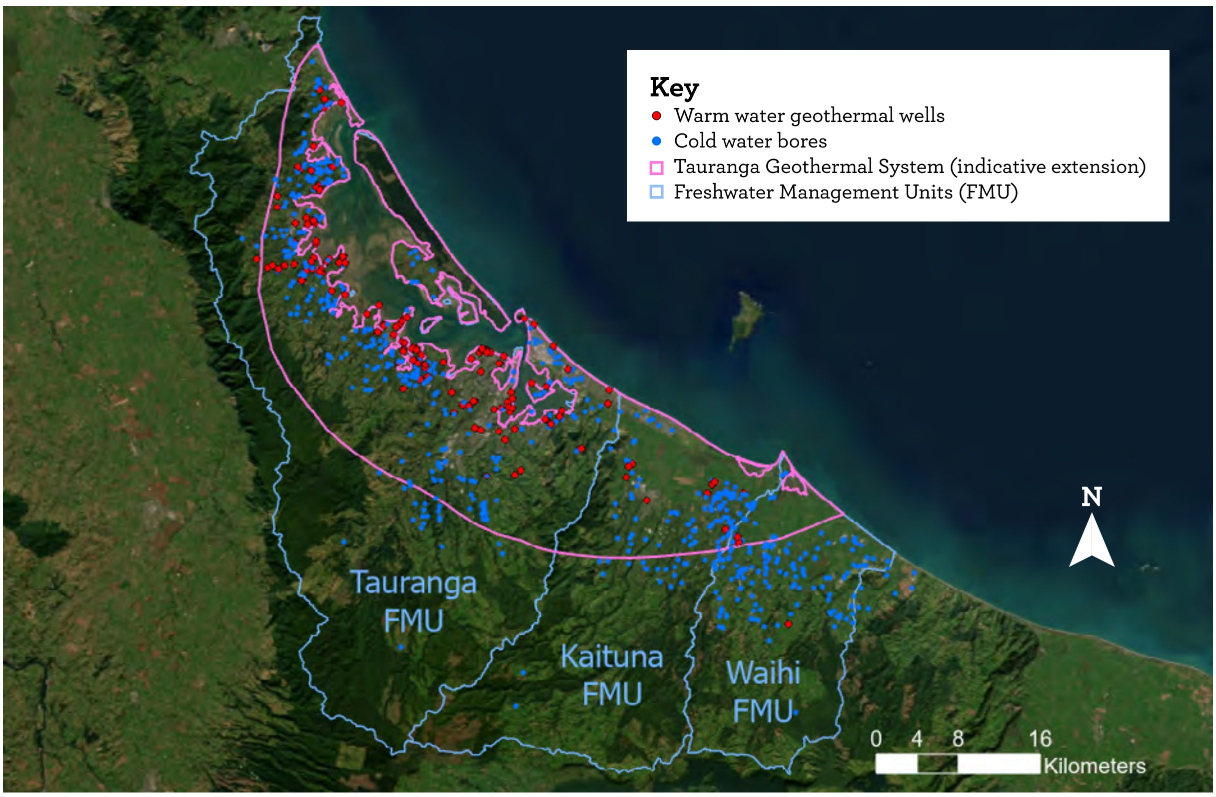


Figure 8: Distribution of the 'cold' and 'warm' wells associated with the active geothermal-groundwater takes around TGS.

Table 2 shows that the total consented take of the cold groundwater in the Tauranga-Kaituna-Waihi area is 53 million m^3 per year, approximately 5.5 times greater than the geothermal take volume consented for use. Since these takes are both part of the same groundwater system, they are combined to calculate how much of the water available for allocation has been used. Within the Kaituna-Tauranga-Waihi freshwater management units 37.8% of the total available water for use has been allocated.

Table 2: *Basic stats of the wells and takes from the Tauranga-Kaituna-Waihī freshwater management units (FMUs) and from the Tauranga Geothermal System at the time of publication (2023).*

Type of groundwater (as per RMA)	**Warm geothermal**[1]	**Cold groundwater**
Total number of wells historically drilled (approximate)	320	2,530
Total number of active wells (approximate)	150	701
Number of active consents	140 ('geothermal' + 'non-geothermal' uses)	603
Consented take volume (m^3 per year)	9.5 million ('geothermal' + 'non-geothermal' uses)	53 million
Water available for allocation[1] (m^3 per year)	165.5 million	
% allocated	37.8%	

Table 3 provides a summary of the difference between the 'cold' and 'warm' wells in the Tauranga-Kaituna-Waihi area. Warm wells in the TGS have an average temperature of 40 °C, with the hottest well at 68 °C. There is a wide range of bore depths, with wells drilled from ~ 20 m though to ~ 900 m depth, with an average of 300 m. On the other hand, cold groundwater wells range in temperature from 8 °C to 26 °C, with an average of 20 °C. The bore depth ranges from 3 m to 670 m with an average of ~ 120 m.

Table 3: *Basic stats of the wells in the TGS:*

		Drilled depth (m)	**Temperature (°C)**
Warm geothermal wells	Mean	304.8	40
	Maximum	916.8	68
	Minimum	15.2	≥ 30 (set by the RMA)
Cold groundwater wells	Mean	122	20
	Maximum	670	26
	Minimum	3	8

1 There are no downhole heat exchangers in the Tauranga system to produce geothermal energy. This differs from Rotorua Geothermal System.

One interesting fact is that there is only a weak correlation between increased drilled depth and higher temperatures (Figure 9). This shows that the wells are only drilled deep enough to reach the temperature or the water needed for the end use, which is normally around 30 °C to 60 °C for the uses from the TGS (Table 4). Going only as deep as needed is justifiable, given the high capital costs involved to construct a well and set up the geothermal-groundwater production system. Long term, this initial high capital cost is offset by lower power bills (i.e. no cost for thermal energy/fuel), which makes geothermal energy highly attractive, particularly for larger users with an interest in space and water heating (such as municipal pools).

Table 4: Temperature requirements for the main heat uses in the TGS (adapted from Peng & Moore, 2021):

End-use	Temperature requirement (approximate)
Spa pools	40 °C
Underfloor heating	35 °C
Leisure/swimming pools	30 °C

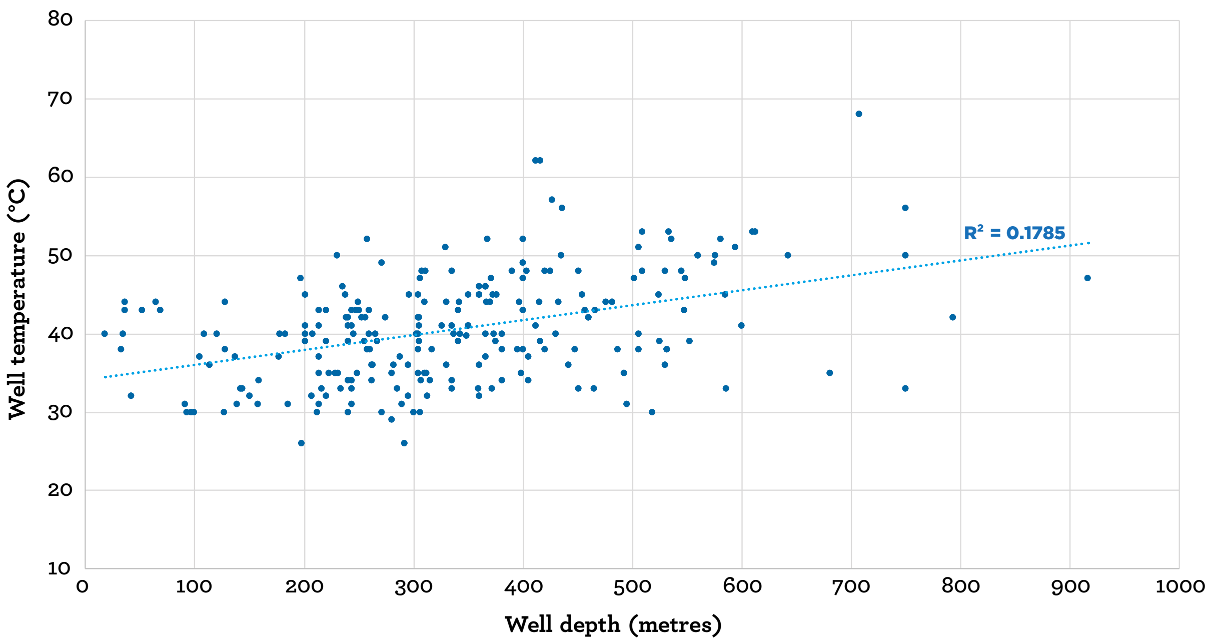


Figure 9: Temperature vs. drilled depth for ~320 wells in the TGS.

Geothermal discharges

Geothermal discharges are managed for the best outcome of the receiving environment, whether that be the geothermal or cold aquifers, surface water bodies, Tauranga Harbour or to land. 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 10). Irrigation, frost protection and dust suppression are considered types of use and not discharge methods.

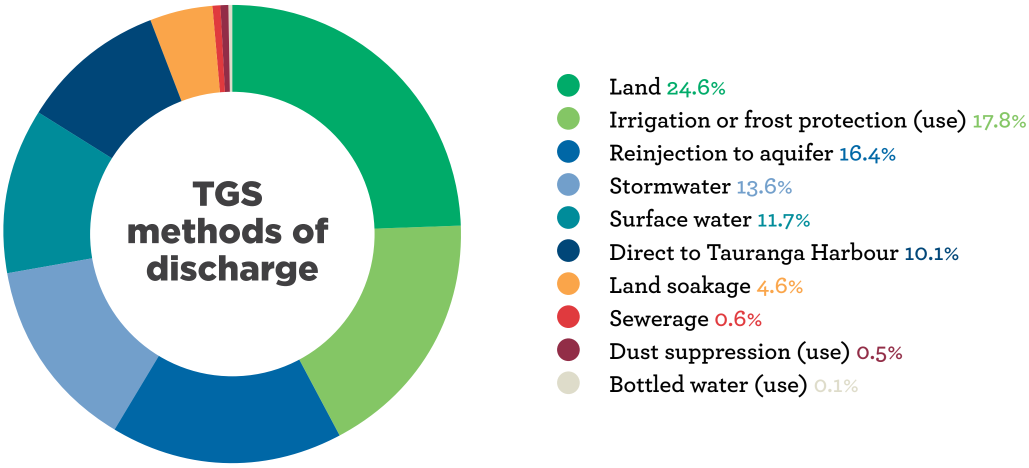


Figure 10: Methods of discharge in the TGS.

Some spatial patterns on geothermal discharge and use are observed in Figure 11, with the key facts outlined below. Those patterns are generally a consequence of how the heat is taken, used or disposed mostly due to practical reasons:

- Most of the use for irrigation and frost protection occurs in the northwest and southeast. There is extensive horticultural land use on those areas (e.g. kiwifruit orchards in Te Puke).
- Reinjection occurs mostly in the urban areas (Tauranga / Mount Maunganui central and Pāpāmoa) and towards Pyes Pā. This is mostly because of a lack of other suitable options for discharge. Local councils, in general, are not willing to accept geothermal water in their stormwater or sewerage systems.
- Discharge to land occurs across the entire system.
- Discharge to local councils' stormwater or sewerage systems occur in urban areas only, as this is where the infrastructure is present.

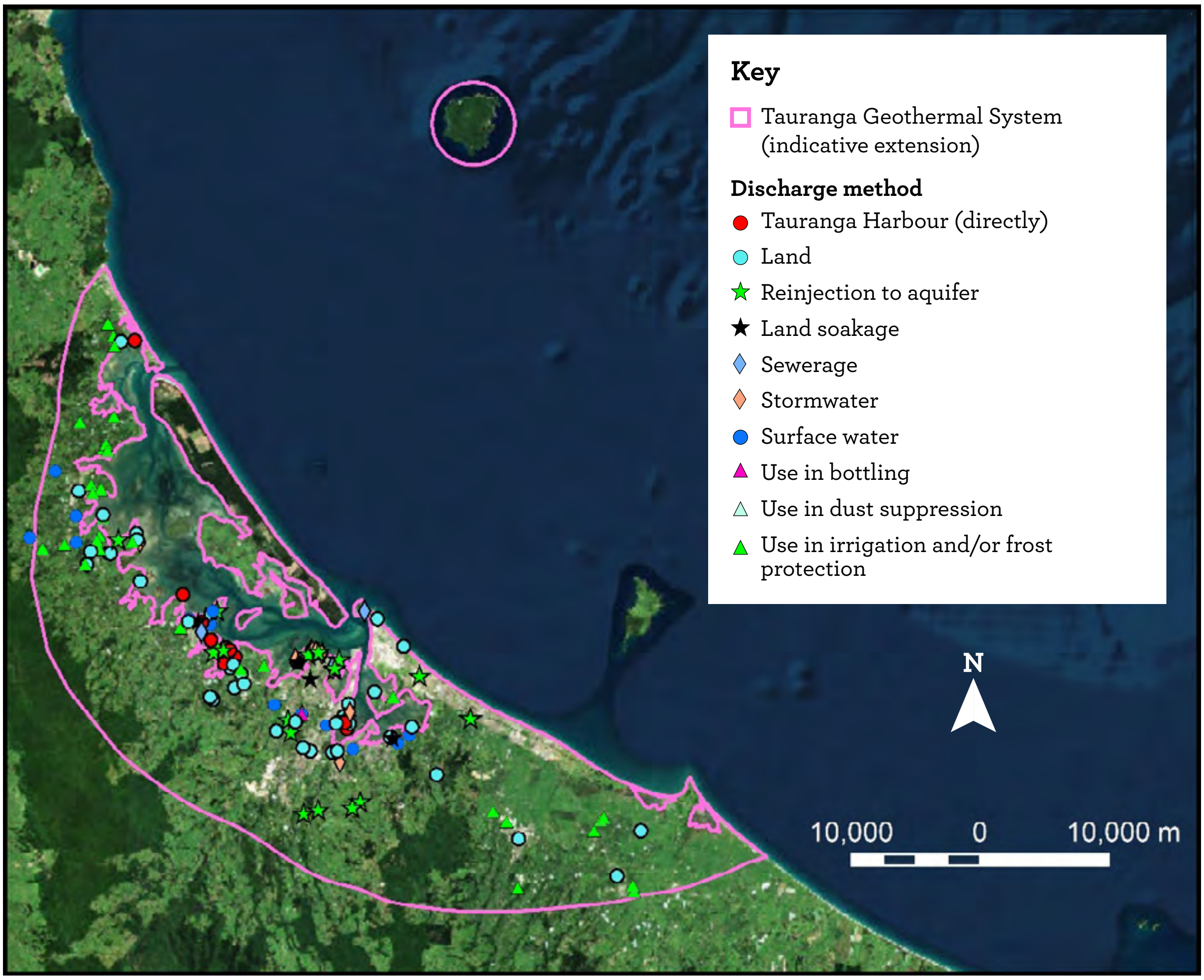


Figure 11: Methods of discharge – Tauranga Geothermal System.

Where the extracted geothermal water ends up in the environment is very important from an environmental management perspective and helps inform the development of policy provisions for the system management. The effects of geothermal uses and discharges are varied, depending on the water quality, rate of take, and the sensitivity of the receiving environment.

Constraints or factors, such as costs (e.g., drilling of a reinjection well), proximity to other users, property size, riparian rights, or connection to storm/wastewater system are key considerations when choosing the most suitable method of discharge for and by the user. The discharge method and strategy for each user will be assessed at the time of consenting in a pragmatic way and according to the regional policy framework.

It is important to note that the health of the Tauranga Geothermal System does not heavily rely on providing pressure support for the producing aquifer. This differs from the Rotorua Geothermal System.

Reinjection

There are about 25 takes with reinjection in the TGS, and those are located mostly in urban areas. Reinjection occurs mostly to the shallower Tauranga Group sediments, while production is mostly from undifferentiated intermediate volcanic units (Figures 3 and 12). This reinjection strategy has the benefit of avoiding localised cooling through reinjection of cooler fluid into the warm geothermal aquifer.

Pressure support through effective reinjection is mostly applicable for high-temperature geothermal systems, such as Rotorua or Kawerau. For the Tauranga Geothermal System, the concept of pressure support is not strictly applicable. Sustained water levels at regional scale are managed effectively through groundwater allocation and monitoring. From a localised perspective, this is managed through consenting, where users are required to perform specific testing to avoid excessive drawdown and significant well interference.

For those takes with reinjection, the temperature range of the produced water is from 35 °C to 53 °C, with an average of 44 °C. Reinjection temperatures range from 41 °C to 24 °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.

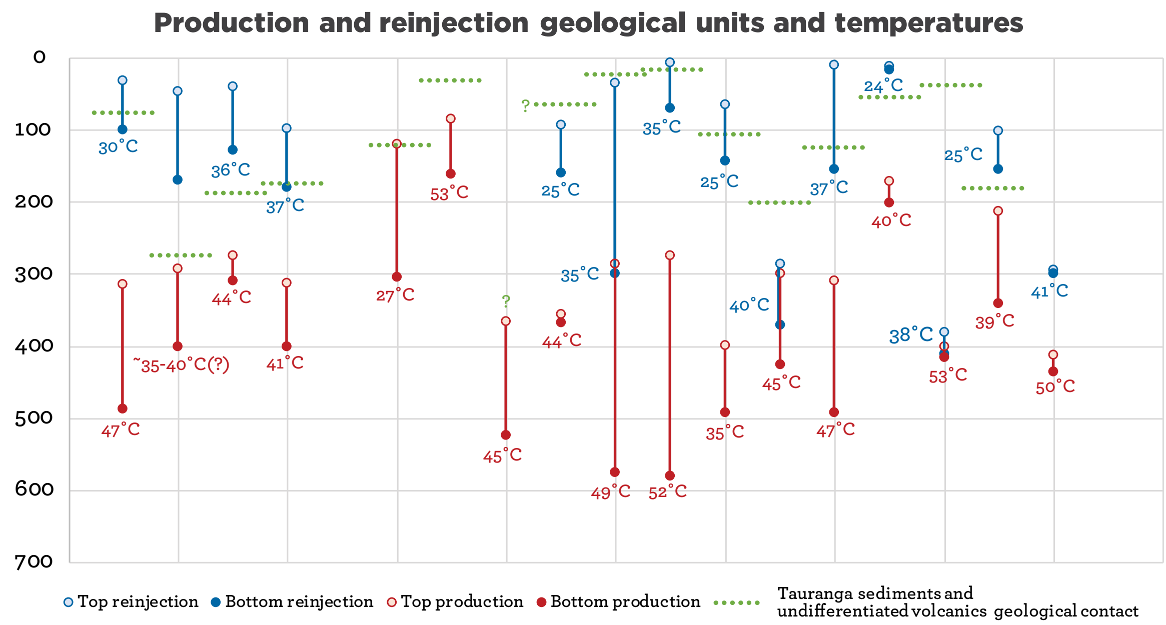


Figure 12: Production and reinjection depth range and respective geologic units, and fluid temperature for selected takes with reinjection. The green dashed line shows the approximate contact between the Tauranga Group sediments (above) and the undifferentiated intermediate volcanic units (below).

Competing uses and pressures on the natural resources

There are competing demands for the geothermal-groundwater resource in Tauranga, with the same allocation limits applying to both warm and cold groundwater takes. Figure 13 shows the percentage by volume for each type of consented use.

Most of the water extraction is for water use for municipal supply and irrigation, with only a relatively small amount of water being extracted specifically for 'geothermal uses' (refer to Table 2 where we outline the % of water allocated under cold and warm consents).

Therefore, most of the use from the wider geothermal-groundwater system is for water values or use. Some of the groundwater management units are already heavily or over-allocated[2] (Figure 14), which means there is no water available for any use (water and/or heat, cold or warm).

Groundwater extraction and aquifer drawdown has the potential to cause localised or system-wide cooling. However, the latest modelling indicates that, by limiting groundwater use within sustainable allocation limits, that the geothermal heat at depth will be protected by default.

The inefficient use of the heat resource is also a consideration. Areas of extensive horticultural land use (e.g., kiwifruit orchards) overlap with warm areas of the TGS, such as Te Puke and around Katikati. The high volumes of water required for irrigation and/or frost protection are usually only found in the deeper aquifers, which coincides with the geothermally heated volcanic units. In these cases, the effects of extraction on the geothermal resource are considered through the resource consent process.

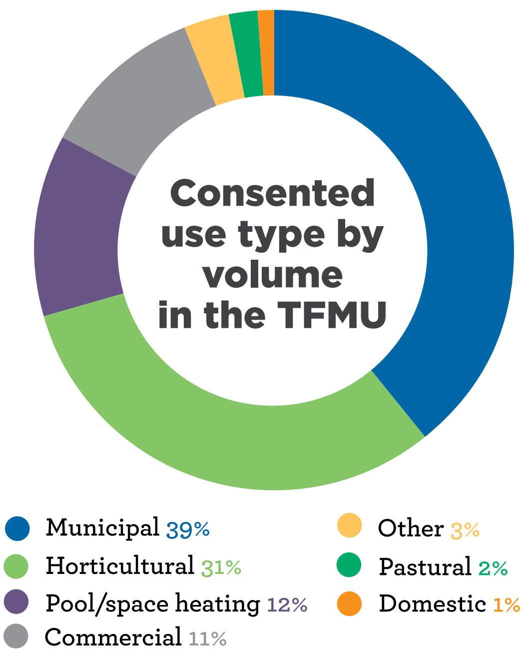


Figure 13: The percentage by volume for each type of consented use in the Tauranga Freshwater Management Unit.

2 Note that allocation limits are currently being reviewed under the NPS-FM (National Policy Statement for freshwater), so the allocation status for the groundwater management units within Tauranga may change within the next couple of years.

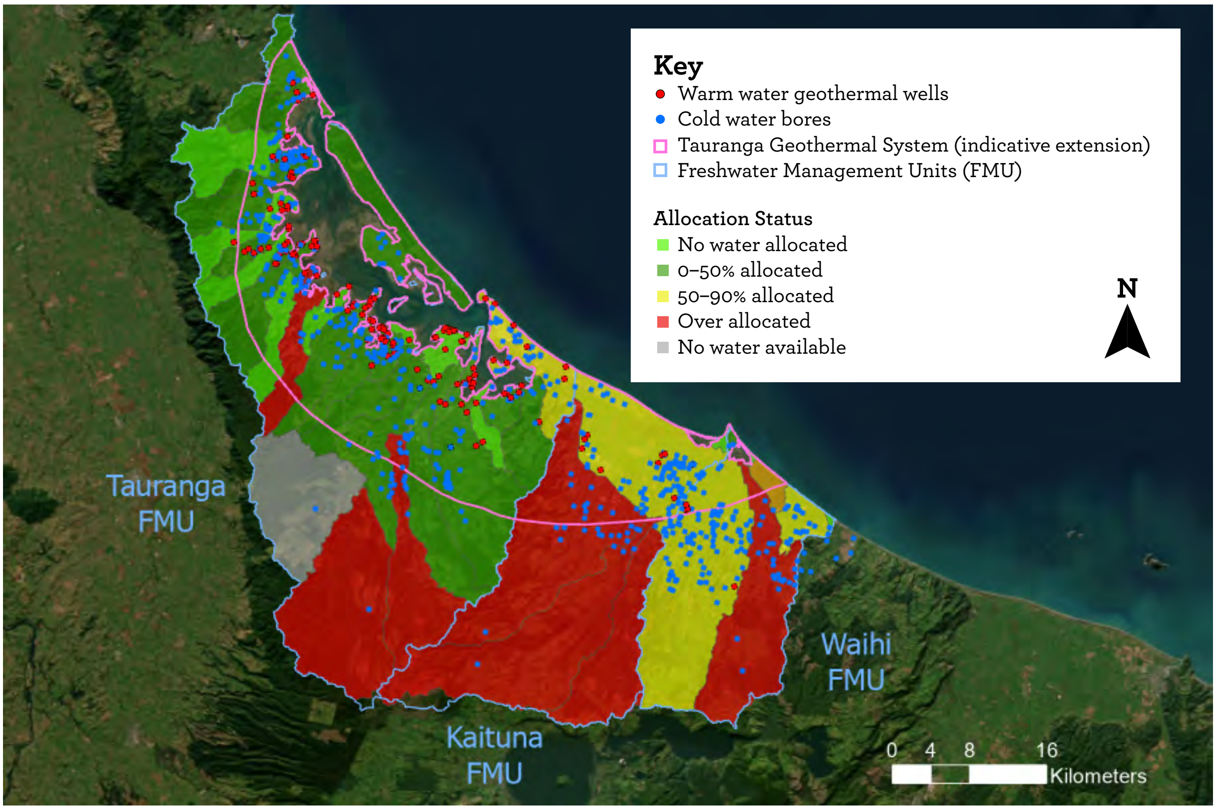


Figure 14: The current allocation status for the Tauranga, Kaituna and Waihī Freshwater Management Units.

Part 3
Monitoring and modelling

Monitoring

As part of the Bay of Plenty Regional Council state of the environment monitoring programme (NERMN), Regional Council measures temperatures for seven geothermal groundwater monitoring sites across the Tauranga Geothermal System and monitors one warm spring in Maketū (Table 5). Private wells are not monitored by Regional Council at the moment, but some temperature and chemistry data are collected *ad hoc* as part of consenting and compliance processes.

Even though monitoring is limited, these monitoring wells are located around the key warmer areas, therefore they are reasonably suitable to monitor induced cooling in those key areas.

It is important to note that, unlike high-temperature systems (Rotorua), water chemistry changes are not considered a good indicator of adverse processes on the thermal resource. Chemistry is a good indicator of other adverse effects to the groundwater system though, such as saltwater intrusion, but such effects are beyond the scope of this snapshot report.

Table 5: *Regional Council monitoring programme summary – types of monitoring and monitored attributes.*

	Warm wells (BOPRC NERMN)	Warm springs	Private wells
Water level	●		
Metering			● (some takes)
Temperature	●	●	● (ad hoc)
Chemistry	●	●	● (ad hoc)
Visual changes		●	

Based on the monitoring results so far, no evidence of cooling has been observed in any of the monitored sites, except for one well at Sharp Road (well BN-2303), located 2.5 km southeast of Katikati (Figure 15).

The Sharp Road site shows a consistent gradual temperature decline over time (Figure 16). The discharge temperature of the well 2303 declined from 37 °C in 1991 to 29 °C in 2021, a decrease of 8 °C over 30 years. A rapid decline occurred between 2018-2019, but started to recover since then. Over time it will be clearer whether temperatures will come back to previous levels.

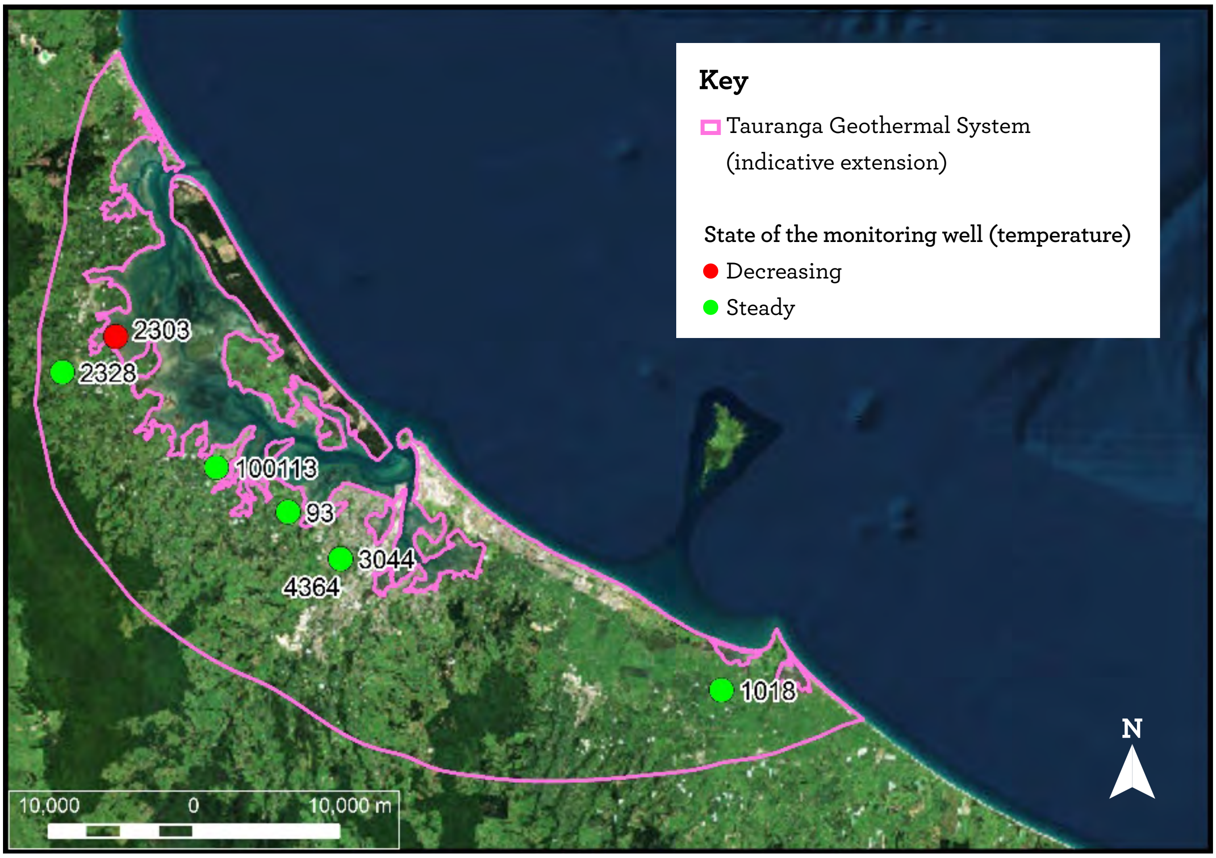


Figure 15: State of the geothermal aquifer for Regional Council warm monitoring wells.

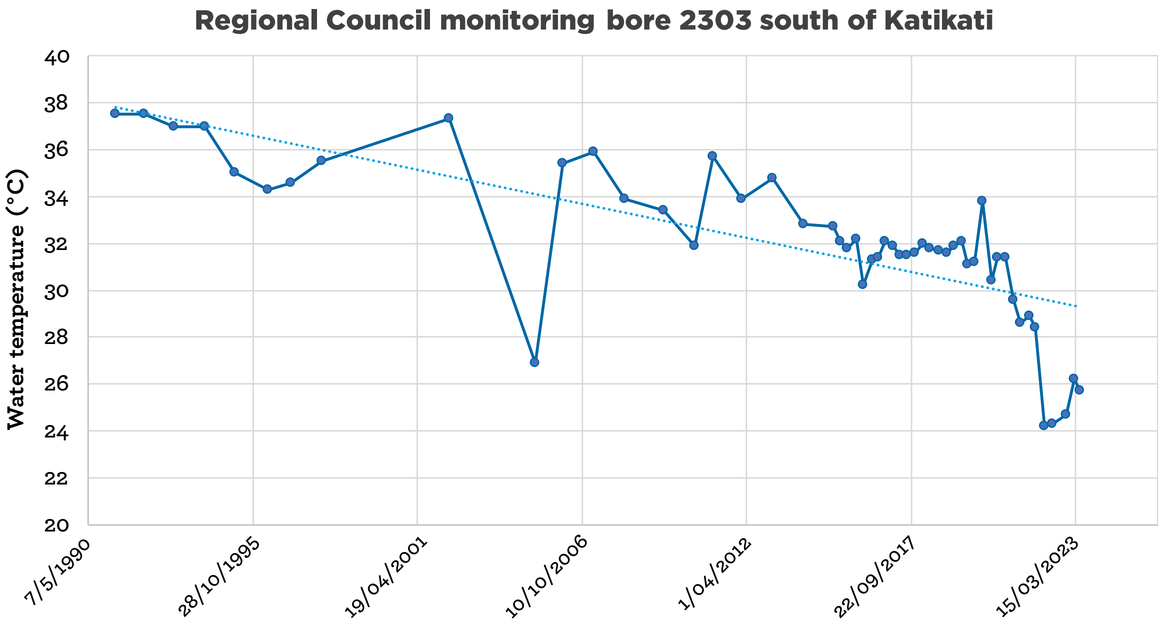


Figure 16: Temperature trend for well BN-2303.

This temperature decline could be due to unsustainable rates of takes that would be drawing cold groundwater into the warm aquifer in the area, natural cooling, or something else. Considering the high levels of horticultural use in the area, the system might be locally stressed. Regional Council may consider options for improved monitoring in the area to inform future management options of the geothermal-groundwater resource.

Finally, there are no thresholds or triggers associated to groundwater levels, as there is in Rotorua. The water level data collected as part of the NERMN monitoring network is used to develop and calibrate the state and trends of the geothermal-groundwater system and for other purposes, such as to inform numerical models. This is a different setting of Rotorua, which has 'hard-wired' minimum geothermal aquifer water levels requirements under the Rotorua geothermal Regional Plan to protect the precious geothermal surface features there.

Resource consent monitoring

Warm takes from the Tauranga system require telemetry (recording at 15 minute intervals and reporting daily) for uses that require large volumes, such as for irrigation and frost protection. Takes that are for relatively small amounts, including for space and pool heating, are not required to telemeter, but they are required to meter, record volumes monthly and report those annually. Tauranga warm takes are classed as 'Geothermal' water takes, so the Metering Regulations do not apply to them.

For temperature monitoring, there is no default monitoring condition, but some users are required to undertake frequent temperature monitoring (e.g. once a year). Some monitoring is also done by Regional Council compliance every three years, but not as frequent as the monitoring done through resource consent.

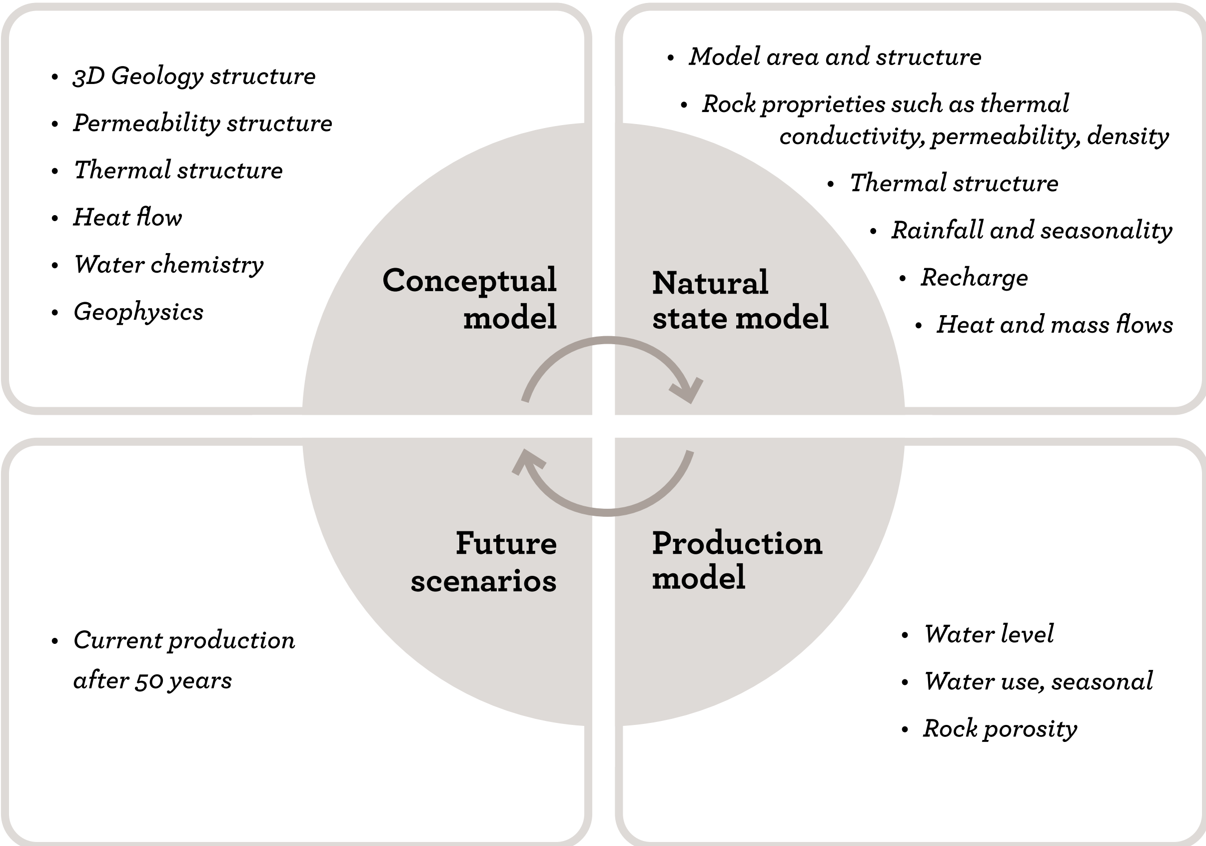
Some consent holders are also required to monitor the temperature and chemistry of the discharge if the receiving environment is sensitive to those effects, such as surface water. However, this only applies to a small portion of the consents, therefore discharge monitoring is generally minimal.

Modelling

A geothermal numerical model was developed for the Tauranga Geothermal System using a powerful computer simulator called ToughII (Pearson-Grant & Burnell, 2018). ToughII is the state-of-art geothermal modelling tool used to simulate heat and fluid flow through rock pores and cracks at depth.

The goal of developing a numerical model is to assist on determining the sustainable levels of use long term, and understand how different levels and patterns of use affect the geothermal system system-wide. It can also be used to simulate changes in the geothermal-groundwater system due to natural factors, for example climate change. The outcomes of those studies help inform the policy provisions for the management of the natural resources.

The ToughII numerical model draws on all the geoscientific data available to replicate the geothermal system at its natural state and in response to production. This includes but are not limited to geology, water chemistry and aquifer rock proprieties such as thermal conductivity, porosity, and permeability. Water meter data from consent holders, temperature profiles and water level from wells, and rainfall data are also used to calibrate the numerical production model and then test the response of the geothermal system to various production scenarios.



In the Tauranga case, two initial scenarios were modelled:

- What happens in 30 years' time if the current level of use is maintained as is?
- What happens if the users increase their takes to their maximum allowed by consent conditions?

The numerical model simulation concluded that induced cooling is not an issue across any specific area or the wider geothermal system at the current levels of use. However, at maximum water yield capacity, some wells are predicted to experience large drawdowns. In those cases, the well 'dries out' and well interference becomes an issue. These localised adverse effects are currently managed on a consents-by-consents basis through assessment of the environmental effects.

A groundwater model using MODFLOW (a three-dimensional numerical groundwater flow modelling code) is currently being developed to investigate sustainable limits for groundwater in the region. Those limits will be used as a proxy for protecting the heat resource, as it is broadly assumed that a significant water level drop would be observed before any cooling. This is because the pressure changes in the aquifer happens faster than temperature changes.

The sustainable limits for groundwater will also protect the springs and base flow for surface water. Likewise, as a proxy, it is assumed that geothermal springs will be protected from overuse with this same measure. Changes in limits for allocation developed using MODFLOW might need to be tested on ToughII to understand the implications of potential future changes in groundwater allocation limits on the geothermal system.

It is also possible that users could be causing localised cooling mostly due to reinjection practices, affecting their own geothermal takes and/or those of their neighbours. When this is a potential issue, the consent holders are generally required to monitor the produced water temperature (see section on Resource consent monitoring). This information also helps Regional Council refine its numerical model and provide for greater certainty on how we manage the Tauranga Geothermal System.

Part 4
Gaps and future work

To manage the Tauranga Geothermal System sustainably, some potential future areas of monitoring and research include:

- Improve temperature monitoring for the Regional Council monitoring wells by increasing the network of monitoring wells and upgrading to continuous downhole monitoring at targeted depths.
- Work with consent holders to improve temperature monitoring via consenting processes and build understanding of trends in use.
- Define areas of high heat value and increase monitoring in those areas, potentially building new monitoring wells and setting allocation limits more specifically designed to protect the thermal resource.
- Consider options for improved monitoring and management of the geothermal groundwater resource around Katikati, where some induced cooling might be happening.
- Strengthen integration with the management of the cold groundwater system to set sustainable use limits through allocation.
- Investigate climate change-related issues that can have an effect on the geothermal and groundwater resources due to changes in the aquifer and patterns of use.
- Continue, and potentially improve, monitoring of the warm springs.
- Regular reporting of the state of the geothermal system, use and discharges.
- Understand the long-term effects on the soil health due to use of geothermal water for irrigation.

Summary

State of the resource	• Current levels of use are considered sustainable system-wide and should not induce excessive levels of cooling. • The Tauranga City and Te Puke-Maketu are the warmest areas. • The geothermal aquifer is mostly hosted by the deep volcanic units, which is a highly productive unit. • Aquifer temperatures are stable system-wide, with potential localised cooling south of Katikati.
Production and uses	• About 9.5 million m^3 per year of geothermal water is consented for extraction from the Tauranga Geothermal System. Those takes are both for 'geothermal use' and for 'non-geothermal use'. This compares with about 53 million m^3 per year of cold groundwater. • Geothermal and cold groundwater take size distribution are very similar. Most of the consents are for relatively small volumes. • For geothermal takes about 80% of the consents are for between 450 - 75,000 m^3 per year. • The largest geothermal warm consent accounts for 10% of all warm water extracted from the system. This take is for a community heated pool complex, highly valued by the community. • The 12 largest warm water consents account for 50% of the water taken, with the remaining 50% extracted by 130 consent holders. • For cold groundwater takes, 80% or 494 consents are for less than 70,000 m^3 per year. • For the cold groundwater takes, only 7 consents (i.e., ~ 1% of the total consents) account for nearly 40% of the total volume of cold groundwater being extracted per year. Those takes are all for the municipal supply, an essential service for our region. • Approximately 25% of the geothermal water is used for 'non-geothermal' uses like irrigation. • Trends of levels of use are unknown.
Discharges	• Geothermal discharges are highly varied: to land, stormwater, sewer, surface water and reinjection. • No standard discharge practice occurs across the system mostly due to practical reasons.
Reinjection	• Around 15% of the geothermal water extracted is reinjected, mostly to a shallower unit than it is produced from (to the Tauranga Group sediments). This avoids localised cooling of the geothermal aquifer. • Reinjection is not necessary for pressure support as it is in Rotorua, but has the benefit of providing for efficiency in water use.
Geothermal surface features	• There is only a few geothermal surface features in the TGS, mostly warm seeps with temperatures between 23 - 50 °C . • Those warm seeps are localted around Tauranga City, Te Puke-Maketu and Katikati.

Glossary

Discharge	To emit, deposit, and allow to escape. For the Tauranga Geothermal System this relates to discharge of geothermal water to any receiving environment but does not include uses like for irrigation.
Efficiency	For the purposes of measuring efficiency of geothermal resource use (Section 7 RMA) efficiency has several dimensions. Efficiency includes the comparison of the overall benefit to society (economic efficiency) of competing uses (allocative efficiency), productive efficiency, and the ability of productive efficiency to increase over time through technology improvements and better understanding of the resource (dynamic or innovative efficiency) (from RPS).
Geothermal aquifer	Permeable geological formation, group of formations, or part of a formation, beneath the ground, capable of receiving, storing, transmitting and yielding geothermal water (from NPS2019; cf. groundwater aquifer). In this document the geothermal and groundwater share the same aquifer, the only difference being the nature of the water stored and produced.
Geothermal energy	Energy derived or derivable from and produced within the earth by natural heat phenomena; and includes all geothermal water.
Geothermal system	A system defined by scientific investigation comprising geothermal energy stored as geothermal water or steam and the rocks confining them and associated water, steam and gas emissions and the geothermal surface features resulting from these emissions and is believed to have no hydrological connection to another system (from RPS).
Geothermal well	A geothermal bore (hole) drilled into the geothermal system, intended to take or reinject geothermal water, steam and/or energy, or to investigate or monitor the geothermal resource. When used in the context of 'bore' the meaning remains the same.
Geothermal water	Water heated within the earth by natural phenomena to a temperature of 30 °C or more; and includes all steam, water and water vapour, and every mixture of all or any of them that has been heated by natural phenomena (from RMA).
Groundwater	Means water occupying openings, cavities, or spaces in soils or rocks beneath the surface of the ground (from NPS 2019).
Groundwater aquifer	Permeable geological formation, group of formations, or part of a formation, beneath the ground, capable of receiving, storing, transmitting and yielding geothermal water (from NPS2019; cf. groundwater aquifer). In this document the geothermal and groundwater share the same aquifer, the only difference being the nature of the water stored and produced.
Pressure	The force exerted by the column of water at any point and is temperature-dependant.
Reinjection	The return of geothermal water into the geothermal aquifer from which it was taken (from the RPS).

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