BAY OF PLENTY REGIONAL COUNCIL TOI MOANA

Annual report to the community on Kawerau Geothermal System

This report was prepared by Bay of Plenty Regional Council with technical input from the Kawerau Peer Review Panel.

Based on 2023 annual technical and compliance reports (reported 2024)

Contents

1 Background

Bay of Plenty Regional Council (BOPRC) manages the Kawerau Geothermal System under the Resource Management Act 1991 through resource consents for the taking of geothermal water and heat, and geothermal discharges. Under the Regional Policy Statement, the system is classified and managed as a Development System. Council is assisted in this role by the Kawerau Geothermal Peer Review Panel, consisting of three independent geothermal technical experts.

There are currently four Consent Holders taking geothermal fluid and energy for both industrial direct heat uses and for electricity generation, including: Mercury (KGL), Ngāti Tūwharetoa Geothermal Assets (NTGA), Geothermal Developments Limited (GDL) and Te Ahi O Māui (TAOM). These consent holders report annually to BOPRC on their consented activities and monitoring of the geothermal system.

As part of its responsibilities for sustainable management of the Kawerau Geothermal System and implementation of the Kawerau System Management Plan (SMP), an update on the overall state of the geothermal system is made available annually to elected members, iwi, stakeholders, and the community.

More information on the Kawerau Geothermal System and its management can be found here.

2 Scope

The content of this report is based upon the consolidation of data and activities for the four Consent Holders for the period 1 January 2023 to 31 December 2023 (presented to Council in the Annual Joint Technical Report in April 2024), and from separate Compliance Reports provided by the four Consent Holders. It covers activities undertaken, changes to the reservoir and well performance, environmental effects of taking geothermal fluid and reservoir model development.

An addendum with background information on monitoring methods and their application is attached. This is for new readers and those unfamiliar with the Kawerau System.

3 Production and injection wells

Figure 1 shows the location of production and injection wells within the Kawerau Geothermal System. In 2023 steam and water were produced from 19 deep production wells which draw fluid from a 230°C to 300°C geothermal reservoir at 1 km to 2 km depth. The fluid produced is used for power generation and industrial direct use, after which most of the spent, cooled, geothermal fluid is reinjected back into the geothermal reservoir, mainly in the outlying areas in the north and northeast, away from the production area.

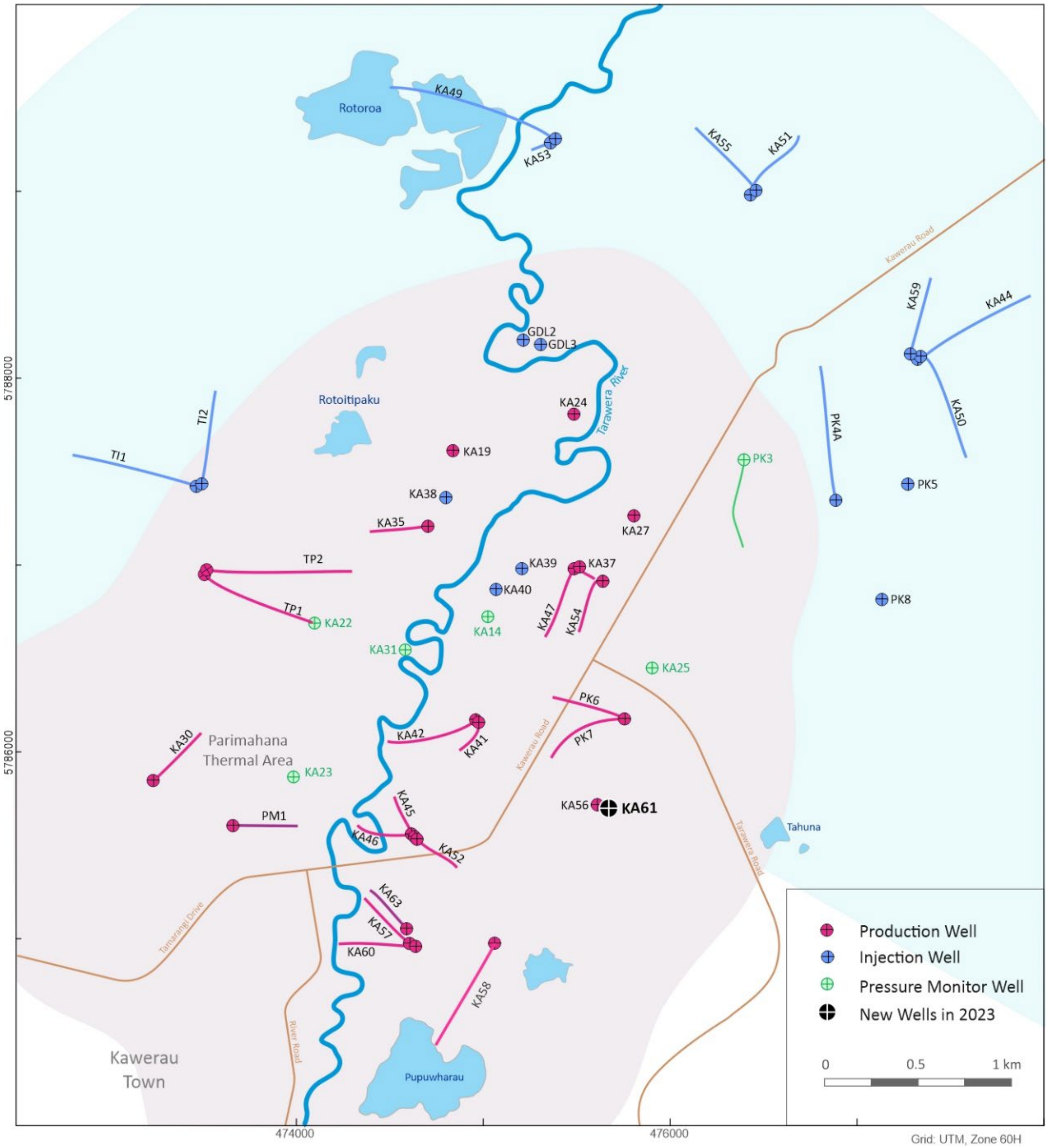

Figure 1 *Kawerau geothermal field showing production, injection, and pressure monitor wells, including deviated (side-ways) well tracks. Also shown is the new well* ***KA61*** *(⊕), with drilling underway in 2023. The pink and blue areas are the current designated production and injection areas from the SMP.*

4 Production and injection rates in 2023

The 2023 average daily production and injection rates for the four Consent Holders are presented in Table 1, together with data for the two previous years. The total 2023 production of 104,420 tonnes/day equates to about 38 million tonnes of geothermal fluid for the year. This is 13% lower than 2022, mainly because of a 2-month shut-down of the KGL power plant, but it continued the downward trend of the past 4 years, due also to the closure of the Norske Skog plant in late 2021 and reduced demand for process steam. The total daily take in 2023 was approximately 60% of the total consented take amount of 174,680 tonnes/day (see Addendum).

Table 1 Production and injection summary, 2021-2023.

Consent Holder	Average production (tonnes/day)			Average injection (tonnes/day)		
	2021	2022	**2023**	2021	2022	**2023**
GDL	6,120	6,100	**5,420**	6,220	5,350	**4,780**
KGL	54,340	58,080	**44,520**	41,950	44,230	**33,770**
NTGA	46,030	40,560	**38,210**	19,460	14,450	**13,820**
TAOM	14,950	15,120	**16,270**	14,950	15,120	**16,270**
Totals	121,440	119,860	**104,420**	82,580	79,150	**68,640**

Of the total produced in 2023, about 66% was returned to the reservoir via injection wells, the same percentage as 2022. The remainder was lost as evaporation from power plants and associated infrastructure or consented discharged to the Tarawera River.

All consent holders complied with their average daily take limits and the maximum daily take specified in their respective consents. This includes commercial agreements that provide additional production and injection allocations to TAOM and GDL using NTGA consents.

5 State of the reservoir

The Kawerau reservoir is considered to be in an overall healthy state. In 2023 reservoir pressure appeared to be stabilising after increasing for the previous three years. The increase in pressure was due, at least in part, to the reduced take. It is expected that any trends will become clearer over the next year, if production remains stable.

Well performance was stable with monitoring showing individual well enthalpy and flow in most of the wells remaining close to the long-term gradual decline rates and modelled predictions.

Fluid chemistry in 2023 indicates that the reservoir continues to be recharged by both reinjection and marginal recharge (groundwater) ingress. Both sources provide reservoir pressure support, with heating from the hot reservoir rock resulting in minimal cooling in the deep production feed zones. Fluid chemistry monitoring provides insight into the balance of reinjection and marginal fluid feeding the reservoir. Chemical tracer tests are carried out on new reinjection wells to understand the timing and magnitude of injectate recharge the reservoir chemical tracer tests.

There was also some redistribution of the KGL injection load to the north to lower the amount of injectate from KA59 reaching KA27 (see following section). The flexibility for KGL to further spread injection load, should it be necessary, will likely increase with the drilling of well KA65 (at the KA51/55 pad, Figure 1).

6 Reservoir trends

6.1 Marginal recharge and reservoir cooling

Cool groundwater is an important source of recharge to the Kawerau reservoir. That said, it needs to be managed to minimise the risk of excessive cooling in the reservoir. Monitoring has shown that the western production wells, notably KA30, are more vulnerable to cooling by ingress of groundwater and marginal recharge but have reached some stability in the last few years since KA30 was shut.

Conversely, geochemical data collected during the year indicated that the amount of marginal recharge affecting some production wells in the central part of the field has reduced, indicating a reduced risk of excessive cooling with reheated brine from the north/north-east deep injection wells providing pressure support.

6.2 Injection returns

Most of the brine[1] injected at Kawerau has high chloride and sulphate relative to production fluid. Movement of this brine into the production area is clearly seen as increasing chloride and sulphate trends in the production chemistry, particularly in the central and eastern sectors.

Reservoir tracer tests conducted over the past 20 years have shown that brine injected into the northern injection wells moves slowly south into the production area. This brine is reheated by the time it reaches the production area (typically after several months) and thus provides beneficial recharge and pressure support. The most recent tracer injection test was conducted using KA59 in the north-east and KA55 in the north (see Figure 1). Tracer from KA59 showed much greater returns than from KA55, with tracer detected in 11 of the 17 production wells that were monitored.

In contrast to KA59, tracer returns from neighbouring KA55 were detected in only two of the monitored production wells and the return times were much longer in duration and only minimal tracer was recovered, indicating slow, dispersed movement of injectate back to the main production reservoir from the more northerly injection well.

The reservoir tracer results revealed the contrasting patterns of fluid movement through the reservoir and the role of faulting in controlling fluid movement. The relatively long return times and lower levels of tracer recovery is expected to reduce the risk of cooling from injection returns. Groundwater Monitoring

[1] Geothermal reservoir water is generally saline and so is commonly referred to as ‘brine’.

About 12 shallow groundwater wells are monitored regularly for water level, temperature and chemistry. Rainfall fluctuations are the main reason for the minor variations in groundwater level reported over the past few years but there also appears to be a weak longer-term trend following the deep reservoir pressure change. This would point to an indirect hydrological link between the deep and shallow reservoirs.

Over the past few years chloride and temperature have increased in three groundwater wells, which are geothermally influenced. This follows a trend of increasing temperatures in river seeps and vegetation plots in the GDL lease area, revealed in surveys carried out in 2023 (see below).

7 Monitoring of surface thermal features and thermal vegetation

7.1 Surface thermal features

A photographic survey of surface thermal activity was conducted in 2023 (the previous one was in 2018). The results provide a useful update of thermal feature activity, including most of the original 28 locations designated for monitoring. The 2023 survey showed broader temperature decline in the Parimahāna thermal area (Figure 1) with a further five sites declining to near ambient temperature. The township thermal area near the aquatic centre has also cooled off, in line with slowly declining temperatures in a nearby shallow bore (KAM10).

In contrast, some Tarawera River springs to the north of Parimahāna showed increasing temperatures and rising chloride. The reasons for this are unclear but could include the recent rise in groundwater levels or the effects of shallow injection. This is still being assessed.

The range and frequency of surface feature surveying remains a topic of importance for all parties. It is probable that the surface feature temperature decline in the Parimahāna area is due, in part at least, to production-induced ingress of groundwater into this part of the field. Accordingly, a detailed analysis of the surface monitoring data, shallow hydrology and localised downflows will be done as part of the scheduled update of the conceptual model - and on a regular basis alongside the reservoir monitoring.

A review of surface monitoring is being carried out by consent holders and will be incorporated into of the current update of the Kawerau System Management Plan.

7.2 Vegetation surveys

In 2023 surveys of geothermal vegetation were carried out at Parimahāna, TAOM and the GDL lease area (Addendum Figure 3).

Within the Parimahāna area the survey confirmed that temperatures in the two monitoring plots had declined to near-ambient temperature. Although the coverage of geothermal vegetation in 2023 was stable compared to previous surveys, the invasion of non-geothermal vegetation is expected.

Within the GDL lease area, two monitoring plots (GDL2 and GDL3) showed large increases in mean temperature of 31°C and 38°C respectively. Major changes in vegetation are not yet evident but may be expected in the next survey. The temperature increases are in line with increased temperatures of Tarawera River seeps and some nearby shallow bores.

In the TAOM area the average soil temperature of a small thermal area has fallen from about 42°C in 2019 to 25°C in 2023, but there has been little reported change in the extent or composition of vegetation.

8 Subsidence

The report for the September 2023 subsidence survey was received in 2024. This survey was of limited extent focusing on a 4 km^2 area in the western and central production areas, between the Tarawera River and Kawerau Road. Importantly, it showed a broad increase in subsidence rate across the survey area, attributed to an earthquake swarm of magnitude 4.9 which occurred on March 18, 2023. The average subsidence was -56 mm/yr, with higher values on the western side of the survey area (>-100 mm), thus showing increased tilt in that direction.

Precise levelling surveys are conducted annually to assess ground subsidence (and tilt) changes that might be related to production or injection. Gradual subsidence has been occurring at Kawerau since at least the 1970s, at rates ranging from <5 mm/yr to 20 mm/yr. After 2008, many benchmarks showed an increase in subsidence rate, ranging up to 40 mm/yr but since 2018, there has been a general reduction in subsidence rates. The exception has been Area E located in the SE (near KA30, Figure 1) which showed a continuation of large and increasing subsidence rates since it was first recognised in 2016. The highest subsidence rate for the 2023 survey (-151 mm/yr) was recorded in this area. The maximum subsidence rate for Area ‘E’ is about three times higher than that reported for the previous levelling survey of the same area and higher than the increased rate reported for other surveyed benchmarks for the same period, attributed to the March 2023 earthquake swarm.

Overall, subsidence rates to date, including tilt within the vicinity of sensitive machinery and structures, are relatively modest and are not of concern. A full levelling survey will be carried out in 2024 to establish a new baseline.

9 Field development

KGL commenced drilling KA61, a production well located next to KA56 in the southeastern part of the field (Figure 1). Drilling continued at the end of 2023 reporting year.

10 Numerical reservoir modelling

Mercury maintains a numerical reservoir model of the Kawerau geothermal field on behalf of the Consent Holders. The official version of the fieldwide numerical model is KRMv5, which was adopted by the BOPRC, after receiving the Peer Review Panel’s recommendation in November 2019.

No changes were made to the numerical model in 2023 apart from updates to the production and injection rates to the end of 2023. The model has been able to provide reasonable matches to observed data, including pressure increases during operational changes over the past three years (e.g. station shuts). This provides confidence that it can be used to make useful long-term projections of reservoir change.

11 Future work

11.1 Review of discharge strategy

The discharge strategy for the Kawerau Geothermal System (i.e., injection and discharges of geothermal fluid to land or water) is a key consideration for its sustainable management. The current strategy was reviewed in 2020 by the Consent Holders and BOPRC with support from the Peer Review Panel, with a view to optimising the discharge strategy, particularly with respect to the potential for ongoing groundwater ingress and associated cooling effects. The Consent Holders recommended changes to the current strategy that included provision for shallower injection (but still within the reservoir) and trials of targeted infield injection. Changes approved by BOPRC will need to be reflected in the update of the System Management Plan currently in progress.

11.2 Review of Kawerau System Management Plan

The current Kawerau System Management Plan was approved by the Council in 2018. In 2022 a detailed review of the Plan was begun, considering changes in best practice management of the system, including adaptive management processes and modelling. As noted above, any approved changes to the discharge strategy and the monitoring programmes will be reflected in the System Management Plan. Bay of Plenty Regional Council are working with Consent Holders to continue reviewing the plan in 2024.

11.3 TOPP2 development

Eastland and NTGA, in conjunction with Ormat, are in the process of developing the TOPP2 49MW geothermal binary power plant. Wells PM1, KA57, KA60 and KA63 will provide geothermal fluid to the power plant, while injection wells (PM4, 5 and 6) are planned to be drilled starting in July 2024.

11.4 TAOM injection wells

Eastland are planning to drill new injection wells from a pad located further to the west of the existing injection wells, TI1 and TI2 (Figure 1). Wells TI1 and TI2 will then be converted to provide production fluid to the TAOM power plant.

ADDENDUM/FACT SHEET

Management of the Kawerau Geothermal System
Reservoir processes and monitoring

Background

Bay of Plenty Regional Council (BOPRC) manages the Kawerau Geothermal System under the Resource Management Act 1991 through resource consents for the taking of geothermal water and heat, and geothermal discharges. Under the Regional Policy Statement, the system is classified and managed as a Development System. Council is assisted in this role by the Kawerau Geothermal Peer Review Panel, consisting of three independent geothermal technical experts. A System Management Plan has also been developed for the System.

There are currently four Consent Holders taking geothermal fluid and energy for industrial direct heat uses and for electricity generation, including: Mercury (KGL), Ngāti Tūwharetoa Geothermal Assets (NTGA), Geothermal Developments Limited (GDL) and Te Ahi O Māui (TAOM). These consent holders report annually to BOPRC on their consented activities and monitoring of the geothermal system.

This factsheet provides some background information on how the system is managed, with a focus on monitoring.

Geothermal takes from the Kawerau Geothermal System

There are four major Consent Holders producing from the Kawerau System and each has resource consents for taking and discharge (injection) of geothermal water, heat and energy (Table 2). There are agreements in place that allow GDL and TAOM to use some of the consented take of NTGA.

Table 2 Kawerau discharge (take) and injection consent limits.

Consent Holder	Consent No.	Take (tonnes/day)	Injection (tonnes/day)	Limit Basis
Mercury	63295	45,000	45,000	annualised average daily
	67335	20,000	20,000	daily maximum
NTGA	24598	44,400	24,000	annualised average daily
	66862	45,000	45,000	daily maximum
TAOM	67340	15,000	15,000	annualised average daily
GDL	67161	5,280	5,280	annualised average daily

Field sectors

Monitoring of the Kawerau production wells has shown that their behaviour is dependent to some degree on their location in the field. To better understand this behaviour, the Consent Holders, in their Joint Annual Technical Reports since 2019, have grouped the production wells into four sectors according to the interpreted dominant processes operating in the different sectors of the reservoir (Figure 2). The features that distinguished these sectors over time are as follows, although some wells have now deviated from their original group characteristics, which in itself, is informative.

Western (KA19, 30, 35, 24, TP1) More affected by marginal recharge as shown by a general decline in chloride over the years since 2008.

Central (KA27, 37A, 47, 54, 41, 42, 45) affected by both injection returns (high chloride) and marginal recharge (low chloride), but in varying proportions over time.

East (PK06, PK07) Increasing sulphate and cycling chloride.

Southern (KA46, 52, 56, 57, 58, 60). These wells are higher-temperature producers located closer to the hot upflow. Chemistry generally more stable and less affected by injection and marginal recharge

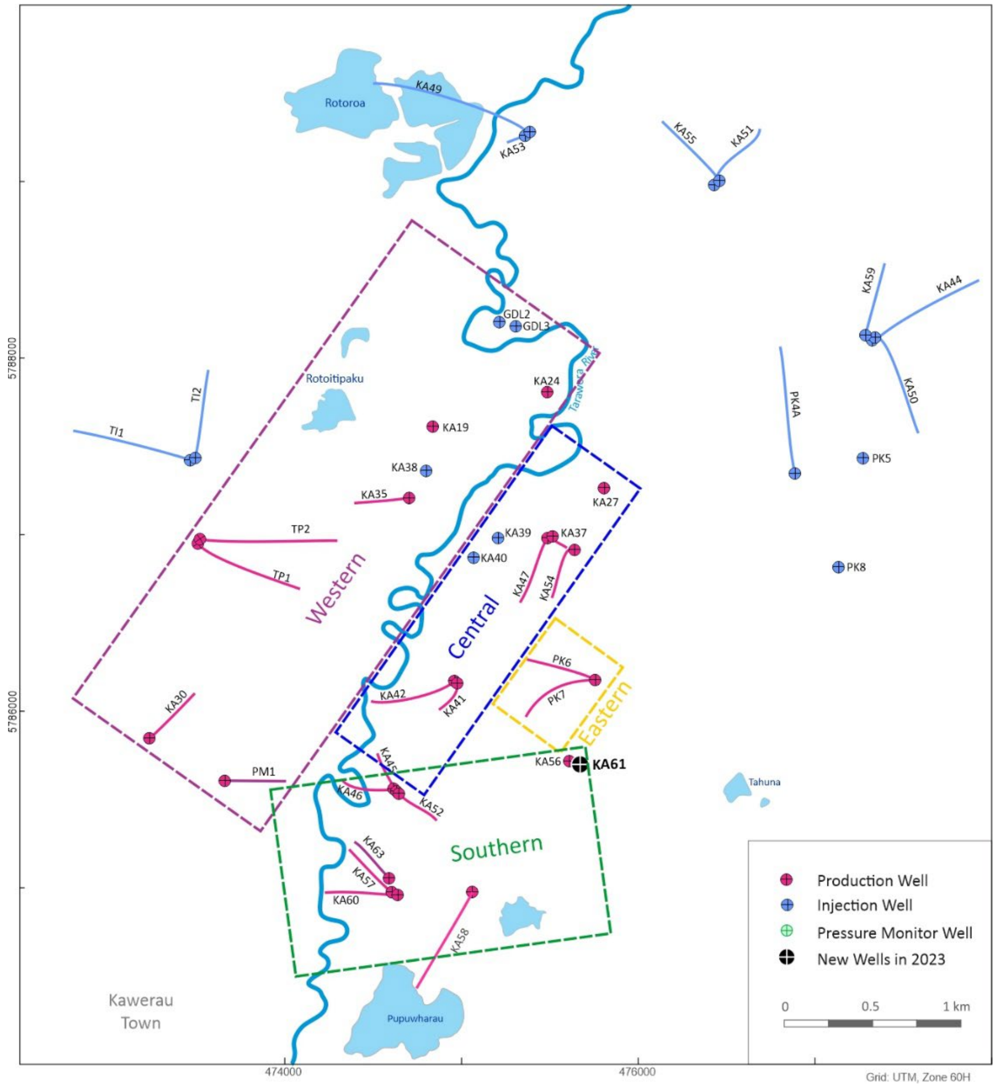

Figure 2 Four well groups based on reservoir processes.

Reservoir monitoring methods

What is monitored and why?

Monitored reservoir conditions (physical and chemical) provide insights into reservoir processes and the impact of production and injection. This informs operational decisions to optimise sustainable production. Reservoir monitoring includes the following:

- Downhole well measurements (temperature, pressure and flow).
- Production well discharge measurements (wellhead pressure, mass flow and enthalpy).
- Production well discharge chemistry (water, steam and gas).
- Injection well monitoring (wellhead pressure and mass flow).
- Reservoir pressures from dedicated monitoring wells.
- Reservoir tracer tests.

Key reservoir processes

Reservoir cooling

Reservoir temperature is monitored closely with downhole temperature surveys, measured discharge enthalpy (controlled by temperature) and discharge chemistry. The potential sources of cooler recharge are:(1) ingress of cool groundwater at the reservoir margins (termed ‘marginal recharge’), particularly at its western edge and from shallow aquifers; (2) injection of geothermal fluid at reduced temperatures (50°C to 130°C) into the reservoir. However, the geothermal heat resource is predominantly hot rock which heats cooler waters recharging the system as they flow towards to the production area.

If the cool water ingress is gradual and the cool water has time to be heated as it passes through hot rock, then this will provide both pressure support and hot recharge for the reservoir, so is beneficial. On the other hand, if the cool water ingress is rapid and/or large it may cause adverse cooling (so-called ‘thermal breakthrough’). Both groundwater ingress and return of injected fluid therefore have the potential to negatively impact the enthalpy of produced reservoir fluid.

- Observed change due to cool groundwater ingress: Cool groundwater ingress is monitored mainly by well discharge chemistry. Ingress of groundwater is usually seen as a fall in chloride concentration because groundwater is relatively un-mineralised with low chloride. Where this results in cooling, this will be seen as falling discharge enthalpy or more directly by lower fluid temperatures measured within the well. Temperature decline can also be tracked by ‘geothermometers’ which are chemical species (e.g. silica) or chemical ratios (e.g. sodium/potassium) in the brine that are controlled by temperature.
- Observed change due to injection returns: ‘Injection returns’ refers to spent brine that is injected back into the reservoir and ‘returns’ to the production area. Most of the spent, cooled brine from the power plants and industrial users is reinjected in the N and NE, 1 km to 2 km away from the production area (Figure 1). The chemistry of produced brine is used to monitor for injection returns, since the injected brine has characteristically high chloride and sulphate concentrations. As of year-end 2023, there had not been any observed reservoir cooling that can be clearly linked to injection returns. It can therefore be considered beneficial in terms of providing hot recharge and pressure support to the system.
- Chemical tracers can also be added to the injected brine to track its movement between injection and production wells. Tracer tests conducted to date have confirmed that this injected brine moves slowly south into the production area, reaching most of the production wells after five to eight months.

Trends in pressure

The pressure in the geothermal reservoir at Kawerau is measured continuously using special tubing inserted in six deep and one intermediate depth wells. These pressure monitoring wells are at different locations around the field (Figure 1) to measure representative responses from the reservoir. Historically, the measured pressure decline, particularly after the commissioning of the KGL power plant in 2008, has been relatively modest (<6 bars) compared to other developed NZ fields. Moreover, since about 2016 pressure has slowly recovered. Given that only about 67% of the produced fluid is returned to the reservoir by injection, the ingress of cool groundwater from above and from the edge of the production area, as indicated by the changes in production well chemistry, and also possibly deep, hot recharge, are providing additional pressure support.

Groundwater monitoring

What is monitored and why?

The shallow groundwater system, which overlies the Kawerau production area is mixed to varying degrees with geothermal reservoir fluid, some of which discharges into the Tarawera River as seeps.

In addition to natural mixing, it is possible that reinjected fluid, particularly from shallow injection wells, will leak into the groundwater over time, changing its chemistry (e.g., increased concentrations of chloride). The hydrology and chemistry of the shallow groundwater is important to understand because it seeps into surface waters and outflows into the regional groundwater system. It is also influenced by change in the deeper geothermal reservoir and so monitoring is useful for reservoir management.

There are twelve shallow groundwater monitoring wells at Kawerau, ranging in depth from 10 m to 798 m, of which 11 are currently tested regularly for water level and chemistry. Most of the wells are cold to warm but three are hot and close to boiling. The hot wells have high chloride (>100 ppm), which confirms the presence of a geothermal component from deep up-flowing reservoir water and possibly shallow injection.

Monitoring of surface thermal features and thermal vegetation

What is monitored and why?

The surface thermal features of the Kawerau geothermal system occupy an area of some 13 km^2. They include warm springs and seeps along the riverbanks, mud pools, sinter sheets, steaming and heated ground and thermotolerant vegetation. Areas that are regularly surveyed are shown in Figure 3.

In addition to natural influences, changes in surface thermal activity often reflect changes in the reservoir due to production (e.g., pressure decline, cooling and reduced or increased flow to surface). Monitoring informs decisions about managing both the resource and the surface features themselves.

The Consent Holders monitor selected surface thermal features within the Parimahāna Reserve, Te Taukahiwi o Tirotirowhetu Scenic Reserve, the A8D block and the Eastland Generation lease area. The monitoring includes temperature measurements, spring chemistry, photographic surveys, ground temperature measurements, thermal infrared imagery and surveys of rare and often significant thermotolerant vegetation (vegetation that tolerates elevated ground temperature).

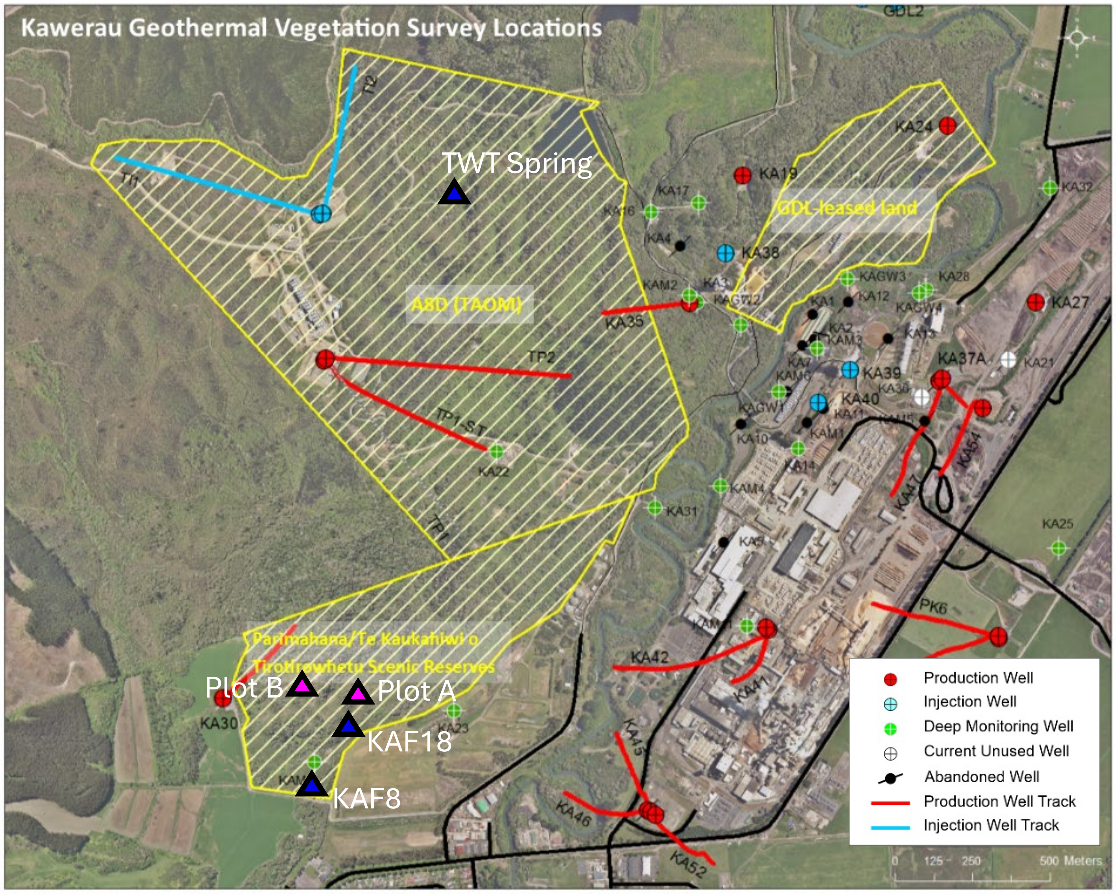

Figure 3 Surface thermal features and vegetation survey areas.

Subsidence

What is it and how is it measured?

The production of fluid from New Zealand geothermal systems usually results in downward movement of the ground surface above the reservoir (subsidence). This is a result of pressure decline and draining of water from shallow, compressible formations and is in addition to naturally occurring regional subsidence. At Kawerau, historic subsidence rates have been relatively modest, but land above the reservoir hosts industrial machinery some of which is particularly sensitive to non-uniform subsidence (known as tilt). Subsidence at Kawerau is monitored by means of annual repeat precise-levelling surveys. Some of these surveys utilise most or all the several hundred benchmarks installed across the field. These are known as full surveys. Others utilise a lesser number of benchmarks and are focussed upon areas where sensitive industrial machinery is present. These are known as partial surveys.

The benchmark network is linked to a ‘stable’ benchmark which is located outside the field and therefore not susceptible to geothermal influence. Subsidence within the geothermal field is determined in relation to this benchmark.

Past surveys at Kawerau have shown a relatively large bowl of slowly subsiding ground above the reservoir which is consistent with the abstraction of geothermal fluid from the field. Within this bowl are localised areas where the ground is subsiding at higher yet still relatively modest rates. Shallow processes unrelated to the production of geothermal fluid are thought to be largely responsible for these localised areas, also known as bowls.

Field development

There are several reasons why new production and injection wells need to be drilled from time to time. It may be due to increased demand for fluid, or due to declining performance of some wells. Production wells are sometimes 'worked over' (physically or chemically) to remove mineral scale that has deposited in the well bore, reducing flow at the wellhead significantly. Injection wells may also be worked over to restore some or all the lost capacity while new wells are drilled as needed to maintain the required injection capacity.

New injection wells may also be drilled, located and designed to reduce the risk of potential cooling issues related to 'short circuiting' of injected fluid with the production sector of the reservoir.

Numerical reservoir modelling

Computer modelling is an advanced tool used to assist in the management of the reservoir. Numerical reservoir models, calibrated using key reservoir data, are used to gain an understanding as to how the reservoir has responded to historical production and injection and to forecast how the reservoir might respond to different production/injection strategies in the future, including investigating and evaluating options for adaptive management in the event of a reservoir issue.

Mercury maintains a numerical reservoir model of the Kawerau geothermal field on behalf of the Consent Holders. The current official version of the fieldwide numerical model is KRMv5, which was adopted by the BOPRC, after receiving the Peer Review Panel's recommendation in November 2019.

As part of the ongoing improvement of the model, it is planned to attempt to incorporate matching of chloride concentration changes into the model in the next update, scheduled for ca. 2025. Chloride is a key parameter used for interpreting the degree of recharge from injection returns, deep hot fluid, and groundwater ingress. Matching this data will therefore provide additional insights into the interaction of the various recharge components in the field.

Sustainable management summary

Reservoir cooling and temperature decline remains the key issue for the long-term sustainability of the Kawerau resource. The robust reservoir monitoring programme in place helps ensure that reservoir trends are identified as quickly as possible. Those observed to date are as expected and consistent with computer-modelled forecasts.

Monitoring of the potential effects of taking geothermal fluid on the surface environment, particularly surface geothermal features and associated thermotolerant vegetation, is an important and on-going part of the sustainable management strategy. Analysis of changes to surface features over time, and a review of the surface feature monitoring programme is needed to ensure effective and efficient monitoring, and to better inform any future remediation or mitigation strategies.