Bay of Plenty Regional Council

Annual Overview on the Sustainable Management of the Kawerau Geothermal System

Prepared by BOPRC with technical input from the Kawerau Peer Review Panel
Based on 2020 Annual Reports (reported in July 2021)

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.[1]

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. Each Consent Holder also prepares its own community liaison group report.

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

Detailed information on the Kawerau Geothermal System and its management, as well as previous Community Reports, can be found on Council's website https://www.boprc.govt.nz.

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 to 31 December 2020 and presented to Council in the Annual Joint Technical Report in July 2021[2]. It covers activities undertaken by the Consent Holders, changes to the reservoir, environmental effects of taking geothermal fluid and reservoir model development.

3. Field Description

Figure 1 shows the location of production and injection wells and areas within the Kawerau geothermal field, which covers an area of >20km^2. Steam and water are produced from 18 deep production wells which draw fluid from a 230 to 300°C liquid water reservoir at 1 to 2km depth. The reservoir water is slightly saline (moderate sodium and chloride content) with some dissolved gas (mainly carbon dioxide and hydrogen sulphide). The source of this reservoir water is believed to be a deep up flow of ~300°C water, in the vicinity of Putauaki.

[1] For the 2020 reporting year review, the Panel comprised three technical experts, after the addition of one new member in 2021.
[2] A separate Compliance report for 2020 was prepared by each Consent Holder.

The steam and water produced by the deep wells is used for power generation and industrial direct use, after which the spent, cooled, geothermal water (67% of the produced fluid), is injected back into the deep formation, mainly in the outlying areas in the north and northeast (Figure 1), away from the production are. The remainder is discharged to shallow injection, to the Tarawera River or is discharged to the atmosphere as water vapour and gas from cooling towers.

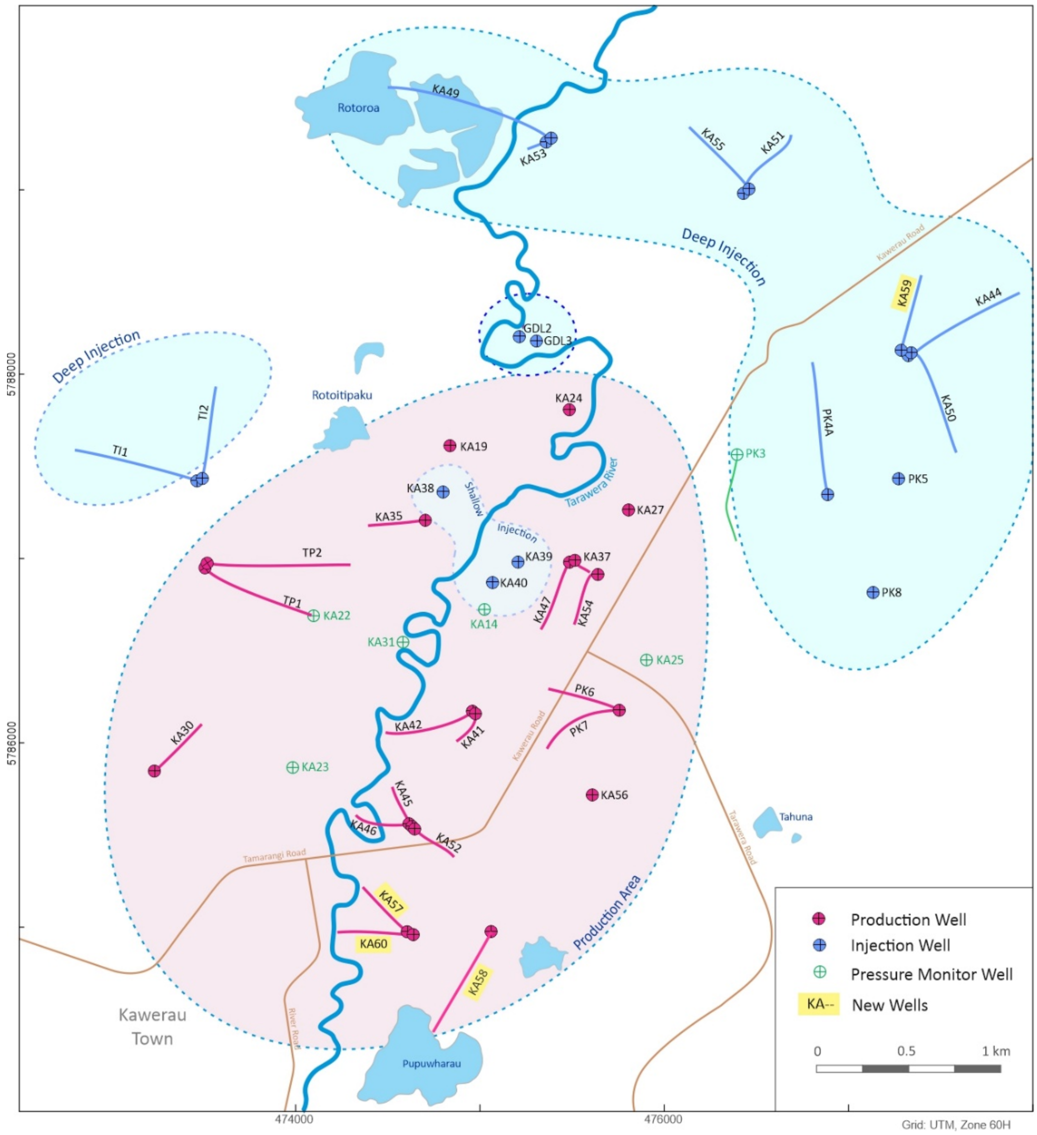

Figure 1 Kawerau geothermal field showing production wells (pink), injection wells (light blue) and pressure monitor wells (green)

4. Key Operational Highlights in 2020

- TAOM commenced a reservoir tracer test in both their reinjection wells (TI1 and TI2). Returns are being monitored in 10 production wells and three groundwater wells.
- The completion of three new wells; two production and one injection, in 2020 and start of production from one new well drilled in 2019 (see Figure 1).

5. Sustainable Management Summary

Reservoir cooling/enthalpy[3] decline remains the key issue for the long-term sustainability of the Kawerau resource. The robust monitoring programme in place ensures that reservoir trends continue to be monitored closely. Those observed to date are as expected and consistent with modelled forecasts.

Monitoring of the potential effects of taking geothermal fluid on the surface environment, particularly surface geothermal features and associated thermotolerant vegetation, will continue. Analysis of changes to surface features over time is ongoing to ensure monitoring is effective and efficient and inform management.

6. Geothermal Takes from the Kawerau Geothermal System

The four Consent Holders together extracted a total of around 49.23 million tonnes of geothermal fluid from the Kawerau reservoir during 2020, which equates to an average daily take of around 135,000 tonnes, slightly higher than for 2019. The increase was due to additional fluid abstraction for the TAOM and GDL power stations, with the additional fluid provided under NTGA consents. The total daily take was approximately 77% of the total consented take amount of 174,680 tonnes per day.

All Consent Holders have complied with their average daily take limits and the maximum daily take specified in their respective consents.

7. Summary of Reservoir Trends

Overview

The following sections of this report summarise trends in key physical parameters (discharge enthalpy and reservoir pressure) and geochemical trends.

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

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

Trends in Reservoir Cooling and Discharge Enthalpy

The potential sources of cooler recharge that are likely to be contributing to enthalpy decline are inflows of meteoric water[4] at the reservoir margins, particularly at its western edge and from shallow aquifers, and reinjection of geothermal fluid at reduced temperatures (50 to 130°C) into the reservoir. That said, the rate of enthalpy decline for many of the production wells has decreased in recent years and in some

[3] Enthalpy is the sum of internal energy and work done by applied pressure. For Kawerau, the reservoir enthalpy is also directly related to reservoir temperature. In a constant pressure system, it can be viewed as 'heat content'. Work performed by a turbine, for example, equates to the change in fluid enthalpy

[4] Referred to as 'meteoric water' as it is derived from rainfall

cases, appears to be approaching a stable state suggesting that the reservoir may be reaching a new thermal equilibrium, consistent with modelled predictions.

Monitoring the impact of meteoric waters and possible reinjection returns is important for reservoir management, including understanding their effect on the enthalpy of produced reservoir fluid.

Observed Change Due to Meteoric Water Ingress

Meteoric water ingress is monitored mainly by well discharge chemistry, as meteoric water has a lower salinity than the hot reservoir fluid. Any cooling will be seen as falling discharge enthalpy or by lower fluid temperatures measured within a well.

Monitoring over the past 10 years shows that production wells in the west have been progressively cooled by meteoric water. However, in the last few years the rate of reservoir temperature decline for western wells has slowed to the point where it now appears to be reaching a new thermal equilibrium. Wells located in other areas have also shown stabilisation in enthalpy and new production wells drilled in the South have encountered very high reservoir temperatures, indicating that no cooling has occurred in this area.

Observed Change Due to Reinjection Returns

Most of the spent, cooled brine from the power plants is reinjected in the N and NE of the reservoir, 1 to 2km away from the production area (Figure 1). Reservoir tracer tests are used to check the connection between reinjection and production wells and the tests conducted to date have confirmed that this injected brine moves slowly south into the production area reaching most of the production wells after 150 to 250 days. Because of the slow ingress and reheating that occurs before it reaches the production area, reinjection returns have not, so far, caused measurable decline in reservoir temperature. This continues to be monitored. The reinjection returns are currently providing hot recharge and pressure support to the geothermal system and so are beneficial.

In 2020 there was no discernible temperature decline that could be linked to injection returns. A reservoir tracer test in TAOM reinjection wells, TI-1 and TI-2, located in the west is ongoing and early results also showed reassuringly slow returns to nearby western production wells and no significant returns to the other areas. Hence, TAOM reinjection is also unlikely to cause thermal breakthrough.

Trends in Pressure Change

When fluid is extracted from a geothermal reservoir, changes including pressure occur. Reservoir pressure at Kawerau is measured continuously in six deep and one intermediate depth well. These pressure monitoring wells are at different locations around the field (Figure 1) to provide 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 and this trend continued in 2020. Given that only about 67% of the produced fluid is returned to the reservoir by reinjection, it is likely that the inflow of meteoric water from above and from the edge of the production area is providing much of this pressure support.

Recent Trends

In early 2020, during a period of reduced production, small pressure spikes were recorded simultaneously in a number of wells in the southern and central sectors of the bore field. This seemed to coincide with spikes in chloride concentration also seen across a large number of production wells. This will continue to be monitored to better understand the process.

8. 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 reinjection 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 thirteen shallow groundwater monitoring wells at Kawerau, ranging in depth from 10 to 798m, of which 11 are currently monitored regularly, Chemical analysis is also carried out to determine whether the geothermal component (which has high chloride) is changing. About half the wells are cold to warm and the other half are hot and close to boiling point conditions. Most of 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 reinjection.

Recent trends

Rainfall fluctuations are the main reason for the minor variations in groundwater level reported during 2020. Temperatures measured in most wells were stable (with one exception which has shown a small but steady increase in chloride and temperature over the past few years).

9. Monitoring of Surface Thermal Features and Thermal Vegetation

What is monitored and why?

The surface thermal features of the Kawerau geothermal field occupy an area of some 13km^2. They include warm springs and seeps at different locations, mud pools, sinter sheets, steaming and heated ground and thermotolerant vegetation.

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

The Consent Holders monitor selected surface thermal features of the Kawerau field, within the Parimahāna Reserve, Te Taukahiwi o Tirotirowhetu Scenic Reserve, the A8D block and the Eastland Generation lease area.

The monitoring includes temperature measurements and chemistry for two hot springs, photographic surveys of 28 surface thermal features, ground temperature measurements at 1m depth within areas of heated ground, surveys of rare and often significant thermotolerant vegetation (vegetation that tolerates elevated ground temperature) and thermal infrared imagery of the field.

Recent trends

The thermal features in the Parimahāna Reserve, located in the SW of the production area Figure 2) were visited in February 2020 and it was found that the two springs located close to the Tarawera River (KAF8 & KAF18) remained dry, having ceased flow in 2018 and 2016, respectively. Therefore, no water samples could be collected. Also, no water samples were collected from the Te Wai U o Tūwharetoa (TWT) Spring during 2020 but the spring has historically shown a dilute chemistry with minor, if any geothermal influence.

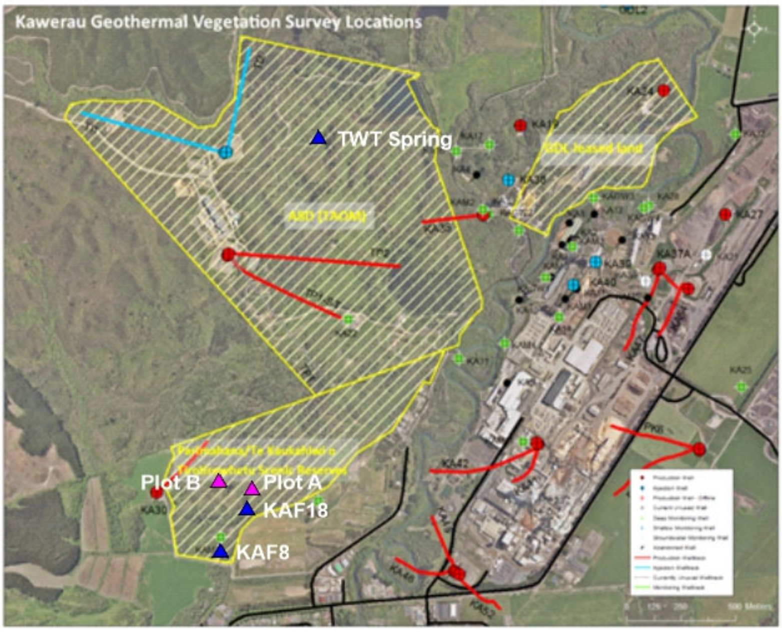

Figure 2: Vegetation Survey Areas

Ground temperature measurements in the Parimahāna Reserve were obtained at the two permanent monitoring plots (known as 'A' and 'B') in February 2020. Temperatures at Plot 'A' at a depth of 1 m ranged from 20 to 30°C, which is slightly higher than measured in 2019 but is still a significant decline since 2014 and earlier when temperatures ranged from 80 to 90°C. This decline suggests that meteoric water infiltration has replaced the geothermal influx in this area of the field. In contrast, Plot 'B', which is located on higher ground east of KA30 (currently shut in and not producing), has maintained relatively stable, near-boiling temperatures (85 to 98°C), probably because it is fed by steam rather than hot water. No ground temperature measurements were taken within A8D block in 2020; in 2019 they reportedly ranged from 28 to 100°C at both 0.4 m and 1.0 m depths.

No vegetation surveys were conducted in the 2020 reporting period due to issues with land access, but in the most recent surveys (2016 and 2018) changes in ground temperature and thermotolerant vegetation were reportedly modest. In Plot 'A', the occurrence and cover of most taxa[5] and ground cover variables remained largely unchanged between 2016 and 2018, except for a large increase in the occurrence of

[5] A taxon is a group of one or more populations, in this case, plant populations, considered to form a unit

geothermal kānuka in higher height tiers, which may correlate with the cooler soil temperatures observed in 2018.

It is clear from results reported for recent monitoring that changes to at least some Kawerau surface thermal features have occurred. The principal change has been cooling of heated ground and the 'drying up' of some warm/hot springs. The Peer Review Panel, in their review of the 2019 Annual Joint Technical Report, recommended to BOPRC that historical data be reviewed to better understand medium term changes and their causes. At the 2020 Annual Meeting the Tappers recommended that some of the surface monitoring be less frequent or ceased, based on the historical trends. The Panel saw merit in some of the recommended changes but is of the view they should be based upon a full review of all the data collected over the years as recommended in 2019.

10. Land Subsidence

What is it and how is it measured?

Taking 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. That said, 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 repeat precise levelling surveys of several hundred benchmarks installed across the field. This 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 broad bowl of slowly subsiding ground above the reservoir. Within this bowl are localised areas, within which the ground is subsiding at higher yet still relatively modest rates. Shallow processes that are unrelated to the taking of geothermal fluid are thought to influence these localised areas, also known as bowls.

Recent Trends

Gradual subsidence has been occurring at Kawerau since at least the 1970s, with more or less linear declines ranging from <5 to 20 mm/yr. After 2008, many benchmarks showed an increase in subsidence rate, ranging up to 40 mm/yr.

The full 2019 survey, covering an area of approximately 50km^2, showed an overall decrease in subsidence rates across the field compared to the 2014 and 2018 results, including in four of the localised subsidence bowls. The exception was Area E, located in the SE (near KA30), which showed a continuation of increasing subsidence rates since it was first recognized in 2016. In the 2020 survey, there was a small decrease in the Area E subsidence rate, possibly indicating the first signs of a stabilisation of subsidence rate in this area.

The subsidence pattern across the mill areas has been fairly regular, with the 2020 survey showing a decrease since 2019. Tilt gradients are also generally low.

While most ground level change has been subsidence, it is not unusual for there to be areas where the ground level has risen relative to the reference benchmark. This is known as inflation. An area of inflation at the western edge of the field was reported for the 2018-2019 reporting period.

In summary, subsidence rates to date, including tilt, are relatively modest and are not of concern.

11. 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' to remove mineral scale that has deposited in the well bore reducing flow at the wellhead significantly.

The capacity of injection wells to accept geothermal fluid may also decline due to mineral deposition. Injection wells may 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 wells

Four new wells (refer Figure 1) were either commissioned or drilled at Kawerau during 2020:

- February 2020: KGL completed a new deviated production well (KA58) to a depth of 2.8km.
- February 2020: KGL commissioned a new deviated reinjection well (KA59) in the NE injection sector that had been drilled in November 2019 to a depth of 2.1km .
- August 2020: NTGA commissioned production well KA57, which had been drilled in 2019 to a total depth of 2km in the southern sector of the field.
- November 2020: NGTA completed a new deviated production well (KA60) to a depth of 2.2km.

12. Numerical Reservoir Modelling

Computer modelling is the most advanced tool currently available for 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 official version of the field wide numerical model was adopted by the BOPRC, after receiving the Peer Review Panel's recommendation in November 2019.

The updated version of the numerical model was used by the Kawerau Steam Tappers Management Committee (STMC) to simulate various injection scenarios, for review by the BOPRC and the PRP in 2020.

No changes were made to the numerical model in 2020 except to update the production and injection histories to the end of 2020. The model provided good matches to the stable downhole temperature profiles in the three newly drilled wells, although some adjustments will made to improve calibration.

13. Future Work

Review of Discharge Strategy

The discharge strategy for the Kawerau Geothermal System (i.e., reinjection and discharges of geothermal fluid to land or water) is a key consideration for its sustainable management. The current strategy is being reviewed by resource 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 marginal recharge and associated cooling effects.

Review of Surface Monitoring

As outlined above, the Panel in their review of the 2019 and 2020 Annual Reports recommended a review of monitoring data. This was to determine what, if any, changes in near-surface ground temperatures and surface thermal features have occurred over the monitored period and whether any such changes might be related to the taking and injection of geothermal fluid. Note that at the time of writing this report, the review is underway, as is a wider review of the surface feature monitoring programme.

Review of Kawerau System Management Plan

The Kawerau System Management Plan was approved by Council in 2018. However, it now needs to be reviewed by BOPRC and consent holders to reflect changes in best practice management on the system, including adaptive management processes and modelling. Any changes to the discharge strategy and monitoring programmes also need to be reflected in the System Management Plan.