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 2022 annual reports (reported 2023)

Bay of Plenty Regional Council

Annual Report to the Community on the Sustainable Management
of the Kawerau Geothermal System

Prepared by BOPRC with technical input from the Kawerau Peer Review Panel.
Based on 2022 Annual Technical Report and Compliance Reports, reported in 2023

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 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 to 31 December 2022 (presented to Council in the Annual Joint Technical Report in May 2023), and from separate Compliance Reports provided by the four Consent Holders. It covers activities undertaken by the Consent Holders, 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. Steam and water are produced from 18 deep production wells which draw fluid from a 230 to 300°C geothermal reservoir at 1 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 deep formation, mainly in the outlying areas in the north and northeast, away from the production area.

In 2022, two new deep production wells were drilled in the southern part of the field by NTGA. The locations of these wells, PM1 and KA63, are shown in Figure 1.

- Well KA63 was completed August 4, 2022 to a measured depth of 1980 m
- Well PM1 was completed October 7, 2022, to a measured depth of about 2205 m

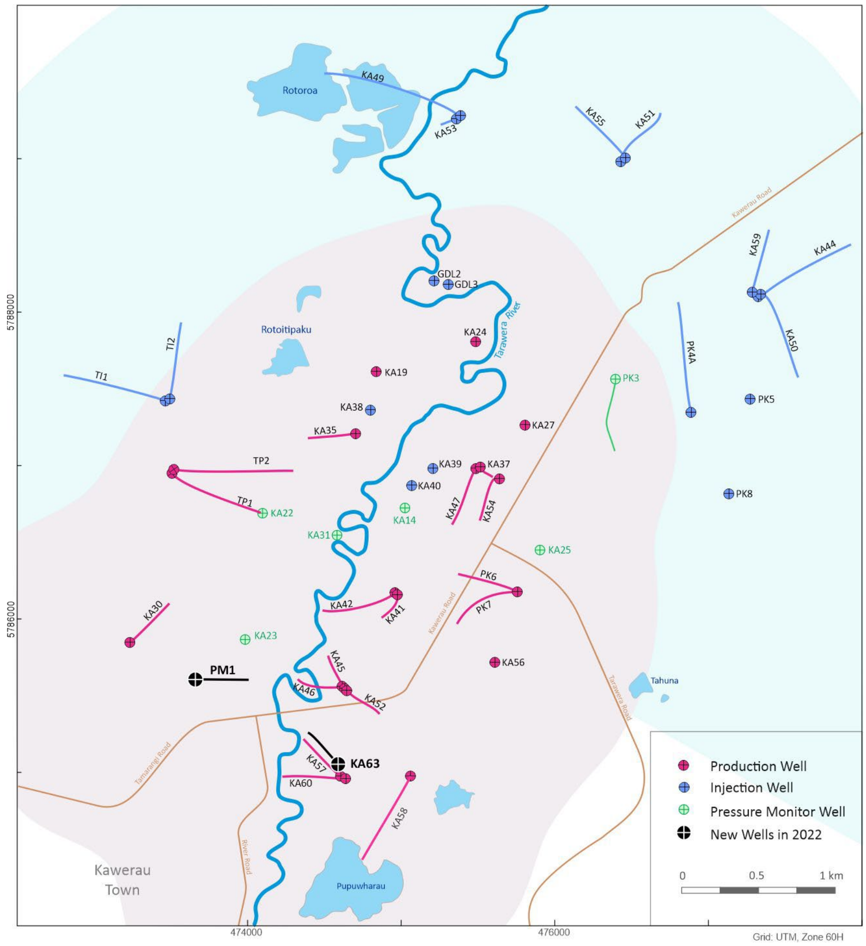

Figure 1 Kawerau geothermal field showing production, injection and pressure monitor wells, including deviated (side-ways) well tracks. Also shown are the two new wells drilled in 2022 (⊕). The pink and blue areas are the current designated production and injection areas from the SMP.

4. Production and Injection Rates in 2022

The 2022 average daily production and injection rates for the four Consent Holders are presented in Table 1, together with data for 2021. The total 2022 production of 119,860 t/d equates to about 44 million tonnes of geothermal fluid for the year. This is similar to 2021 but about 10% down on 2020 (134,930 t/d) due to closure of the Norske Skog plant in late 2021 and reduced demand for process steam. The total daily take in 2022 was approximately 69% of the total consented take amount of 174,680 tonnes/day.

Table 1 2021 and 2022 Production and Injection Summary

Consent Holder	Average Production (tonnes/day)		Average Injection (tonnes/day)	
	2021	**2022**	**2021**	**2022**
GDL	6,120	6,100	6,220	5,350
KGL	54,340	58,080	41,950	44,230
NTGA	46,030	40,560	19,460	14,450
TAOM	14,950	15,120	14,950	15,120
Totals	**121,440**	**119,860**	**82,580**	**79,150**

Of the total produced in 2022, about 66% was returned to the reservoir via injection wells. The remainder was lost as evaporation from the power plants or 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

In 2022 the reservoir and well performance were generally stable. Monitoring showed little change in reservoir conditions since 2021: individual well enthalpy and flow in most of the wells remained close to the long-term gradual decline rates and modelled predictions, although there were some local changes.

Reservoir pressure continued to increase slowly. This is attributed to a larger proportion of the total production reinjected, in addition to hot natural recharge marginal groundwater recharge. It could also be due to the reduced annual production over the last two years.

The reservoir in considered an overall healthy state. Recharge from injection and groundwater ingress have provided reservoir pressure support, with heating from the hot reservoir rock resulting in minimal cooling in the deep production feed zones. While the injectate recharge can be tracked with chemical tracer tests, the nature of groundwater ingress is less clear, but will hopefully become more apparent with ongoing monitoring. The recharge balance is of ongoing interest.

6. Reservoir Trends

Marginal Recharge & Reservoir Cooling

While most production wells were stable output in 2022 there were a few localised changes. A downhole survey of well TP01, on the western side of the field, showed a 7 to 10°C decline in the feed zones since the previous survey in 2019. The chemistry suggests that much of this cooling probably occurred before 2021. A follow up downhole pressure-temperature-flow survey will hopefully provide more information on the reasons for this change.

Monitoring has shown that the western production wells are more vulnerable to cooling by ingress of groundwater but have reached some stability in the last few years. KA30, located on the SW edge of the field was the most affected by groundwater ingress, with a decline of 68°C at the main feed zone between 2008 and 2019 (it was closed in 2020). It is hoped that ongoing monitoring of this well, even while shut, will improve understanding of groundwater ingress in this area.

In the central sector, wells KA42 and KA47 have shown declining chloride and temperature over the past five years, departing from the trends of neighbouring wells and indicating some localised groundwater ingress. In 2022 there was some stabilisation in these trends. For other wells, the chemistry in 2022 was either stable or showed slightly increasing chloride, indicating relatively more recharge from injection.

Injection Returns

Brine[1] has relatively high chloride and sulphate, and movement of the re-injected 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. In 2022 chloride and sulphate continued to increase in the central and eastern wells (KA42 and KA47 excepted) indicating that injection returns are prevailing over marginal recharge - at present. As of year-end 2022, there had not been any observed reservoir cooling that can be clearly linked to injection returns.

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

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. In July 2022, tracer was introduced into KA55 and KA59 injection wells (see location in Figure 1) and tracked in nine production wells to build understanding how injectate moves through the reservoir.

Monitoring of the previous tracer test, conducted in 2020/21 in TAOM injection wells (TI1 and TI2) showed slow returns to nearby western production wells (TP1, KA19, 24 and 35) and no significant returns to the other areas.

Trends in Pressure

Between 2008 and 2015 deep reservoir pressure declined by about 5 bars and then stabilised. Since 2019 the pressure has been steadily increasing and this recovery continued in 2022. The pressure now appears to be stabilising at values similar to those in 2009. The recovery is believed to be due mainly to proportionally more rejection and continuing hot natural recharge and groundwater ingress.

7. Groundwater Monitoring

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 a hydrological link between the deep and shallow reservoirs.

Temperatures and chloride measured in most groundwater wells have been stable over the past few years, the exception being KAGW1.

8. Monitoring of Surface Thermal Features and Thermal Vegetation

Monitoring data reported to 2020 indicated that there had been a general decline in surface activity within and near the Parimahāna Reserve (located in the SW of the production area), which warranted close ongoing monitoring. However, due to access issues, there has been no monitoring of surface thermal features or vegetation over the past two years. These issues have now been resolved and the full suite of surface surveys has been programmed for 2023.

The range and frequency of surface feature surveying is of concern to the different parties and is a topic of ongoing discussion, including the potential to apply new technologies (e.g., drone thermal infrared). Of particular concern is the challenge of attributing surface change to reservoir production and/or naturally occurring waning of the shallow geothermal system. The review of surface monitoring will be part of the current update of the System Management Plan.

9. Subsidence

Precision 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, 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 but since 2014, there has been a general reduction in subsidence rates. The exception has been Area E located in the SE (near KA30) which showed a continuation of large and increasing subsidence rates since it was first recognized in 2016. Comparison of data for the November 2020 survey with that of the previous survey, showed a small decrease in the Area E subsidence rate, possibly indicating the first signs of a stabilisation of subsidence rate in this area and a further decrease was indicated by the November 2021 survey. Overall, subsidence rates to date, including tilt, are relatively modest and are not of concern. A levelling survey was conducted in 2022 but the contractor’s report had not been completed by the end of the year.

10. Field Development

The main field development work conducted in 2022 was the drilling of the two new NTGA production wells (PM1 and KA63), as discussed above.

11. 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 2022 apart from updates to the production and injection rates to the end of 2022. The model has been able to provide reasonable matches to observed pressure increases during operational changes over the past three years (e.g. station shuts).

12. Future Work

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 planned update of the System Management Plan and resource consents.

Review of Kawerau System Management Plan

The current Kawerau System Management Plan was approved by 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. BOPRC are working with Consent Holders to review the plan in 2023.

ADDENDUM/FACT SHEET

Management of the Kawerau Geothermal System

Reservoir processes and monitoring

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. 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.

2. 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

3. 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

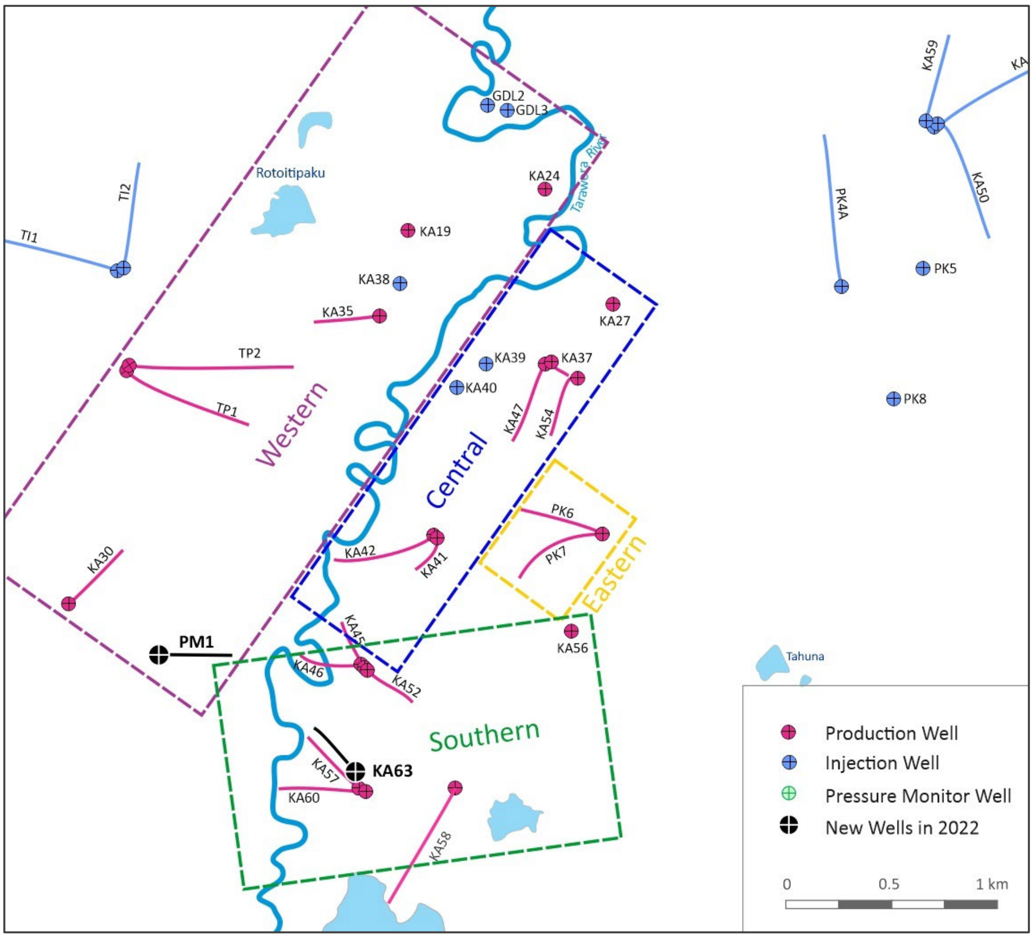

Figure 2: Four Well Groups Based on Reservoir Processes

4. 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.

5. 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 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 to 2km 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 2022, 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 5 to 8 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.

6. 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 to 798m, 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.

7. 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).

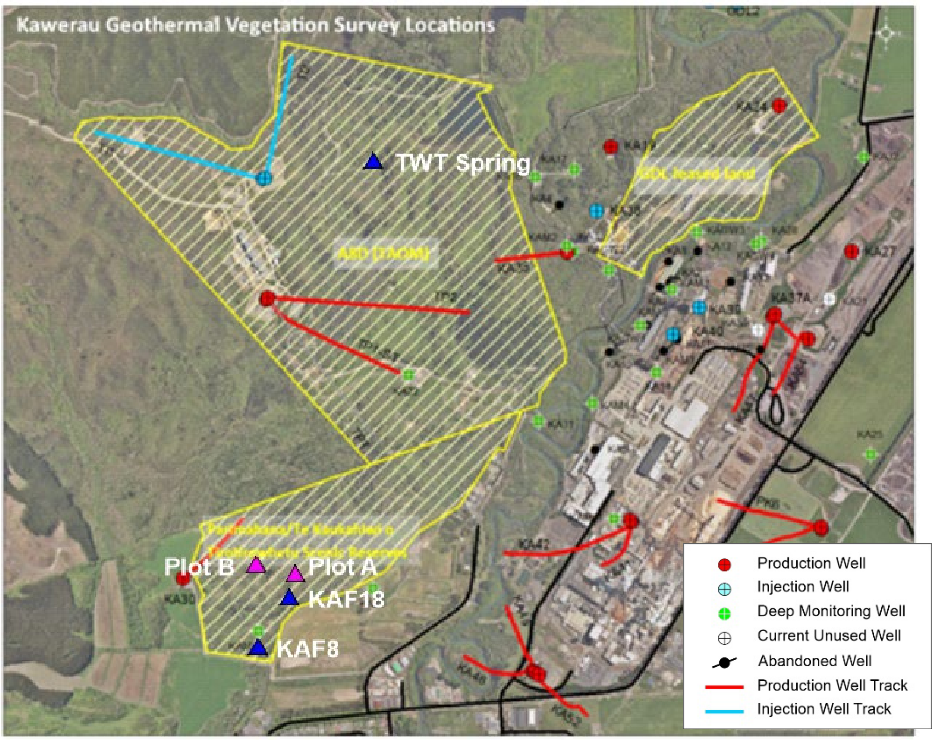

Figure 3: Surface Thermal Features and Vegetation Survey Areas

8. Subsidence

<u>What is it and how is it measured?</u>

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.

9. 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.

10. 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 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.

11. 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.