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 2021 Annual Reports (and an Appendix), reported in May 2022

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 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 2021 and presented to Council in the Annual Joint Technical Report in May 2022[1]. 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] A separate Compliance report for 2021 was also prepared by each Consent Holder.

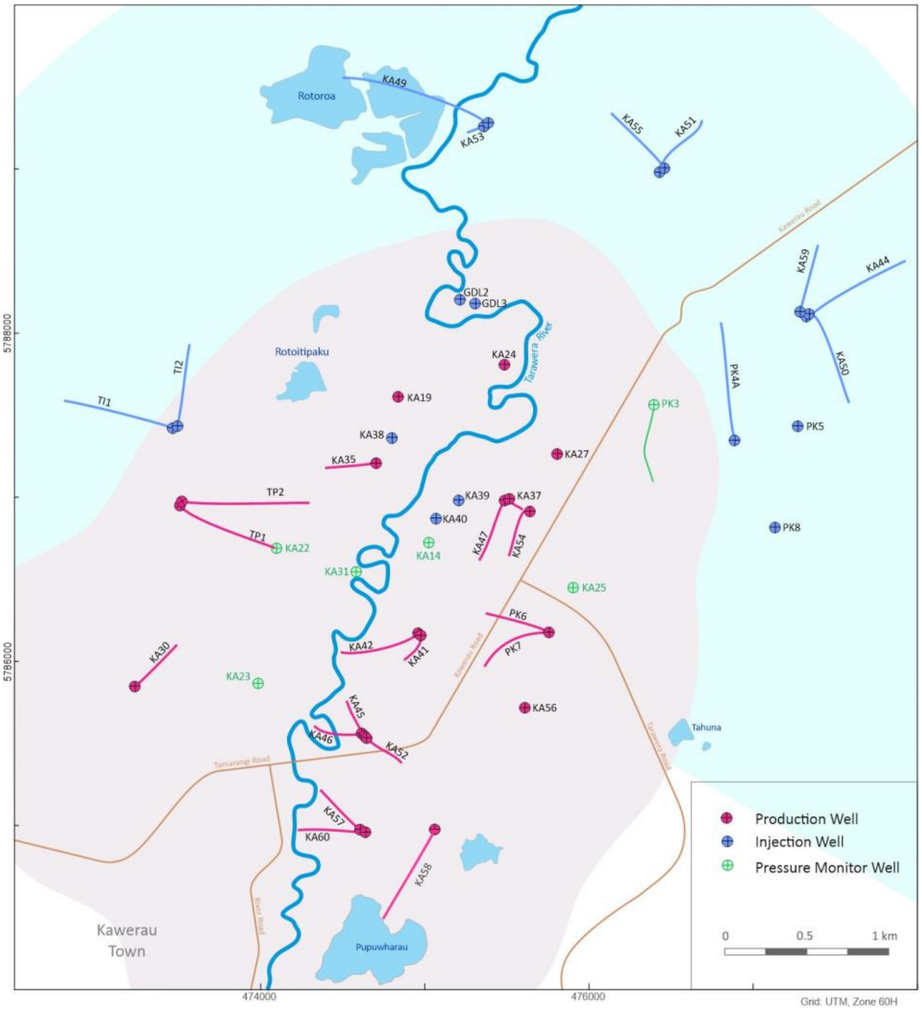

Figure 1 Kawerau geothermal field showing production (pink), injection (blue) and pressure monitor wells (green). The grey and blue areas are the current designated production and injection areas from the SMP.

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 (about 68% of the produced fluid), is reinjected back into the deep formation, mainly in the outlying areas in the north and northeast (Figure 1), away from the production area. Of this amount, some 15% is reinjected shallow in the centre of the field. A further ~10% is discharged to the Tarawera River and the remaining 23% is discharged to the atmosphere as water vapour and gas from cooling towers.

4. Key Operational Highlights in 2021

- New well KA60 was brought into service in the middle of 2021.
- Monitoring for the reservoir tracer test in the TAOM injection wells (TI1 and TI2) continued.

5. Sustainable Management Summary

Reservoir cooling/enthalpy[2] decline remains the key issue for the long-term sustainability of the Kawerau resource. The robust reservoir monitoring programme in place will ensure that reservoir trends are identified and monitored. 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, 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.

6. Geothermal Takes from the Kawerau Geothermal System

The four Consent Holders together extracted a total of around 44.3 million tonnes of geothermal fluid from the Kawerau reservoir during 2021, which equates to an average daily take of around 121,400 tonnes. This was significantly less than for 2020 (135,000 tonnes) because of reduced demand for process steam, closure of the Norske Skog plant in late 2021 and maintenance shutdown of the KGL power station for approximately one and a half months in June and July. The total daily take was approximately 69% 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. This includes commercial agreements to provide additional production and injection allocations to TAOM and GDL from NTGA 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 and injection. 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)
- Injection well monitoring (wellhead pressure and mass flow)
- Reservoir pressures from dedicated monitoring wells
- Reservoir tracer tests.

Trends in Reservoir Cooling and Discharge Enthalpy

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[2] 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

The potential sources of cooler recharge that are likely to contribute to enthalpy decline are inflows of cool groundwater at the reservoir margins (i.e., 'marginal recharge'), particularly at its western edge and from shallow aquifers, and injection 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 cases, appears to be approaching a stable state suggesting that the reservoir may be reaching a new thermal equilibrium, consistent with computer-modelled predictions.

Monitoring the impact of cool groundwater and possible injection returns is important for reservoir management. If the 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'). Although both marginal recharge and return of injected fluid have the potential to negatively impact the enthalpy of produced reservoir fluid, having an adaptive injection strategy can mitigate this risk.

To better understand this aspect of reservoir behaviour, the Consent Holders, in their Joint Annual Technical Reports for 2021, grouped the production wells according to the interpreted dominant processes operating in different sectors of the reservoir (Figure 2).

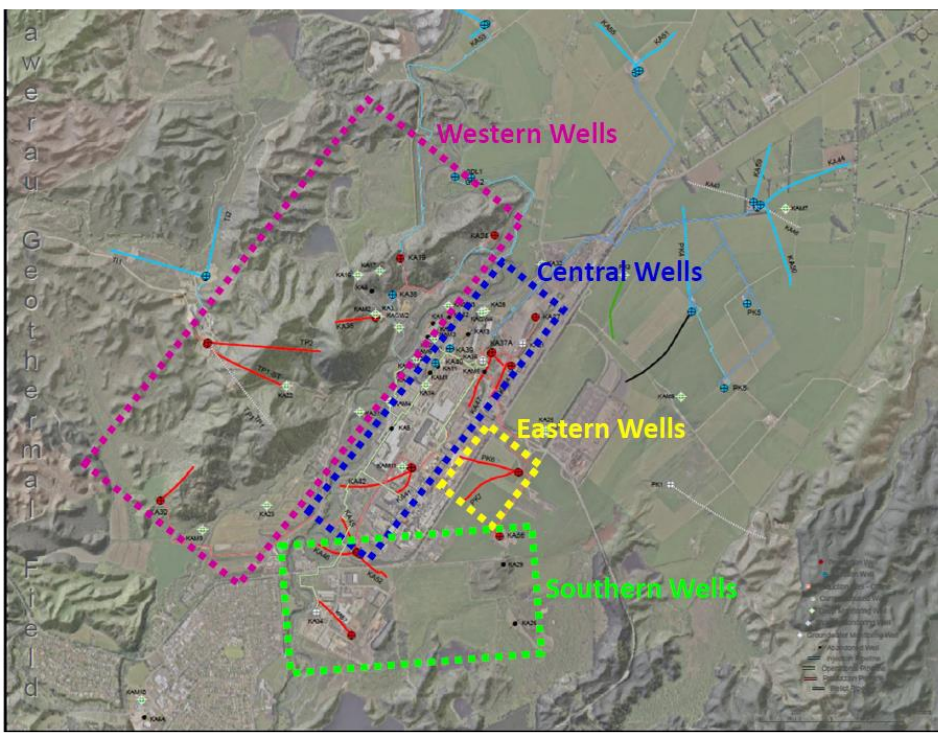

Figure 2: Well groupings Based on Reservoir Processes

<u>Observed Change Due to Cool Groundwater Ingress</u>

Cool groundwater ingress is monitored mainly by well discharge chemistry. Cool groundwater has a lower salinity than the hot reservoir fluid and therefore results in lower salinity in the production well discharge fluid – usually measured as lower 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.

Monitoring over the past 10 years shows that the western production wells have been progressively cooled by ingress of cool groundwater that likely originates from aquifers on the western side of the production area. However, in the last few years the rate of reservoir temperature decline for the western wells (as shown by discharge enthalpy decline) has slowed to the point where it now appears to be reaching a new thermal equilibrium. This was the case in 2021 and is consistent with the relative stabilization of the chemistry of the produced reservoir fluid. Wells located in the other well groupings have also shown stabilization in enthalpy and new production wells drilled in the Southern area have encountered very high reservoir temperatures, indicating that no cooling has occurred in this area.

Observed Change Due to Injection Returns

Most of the spent, cooled brine from the power plants is reinjected in the N and NE, 1 to 2km away from the production area (Figure 1). Reservoir tracer tests are used to check the connection between injection 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. Therefore, the brine is reheated before it reaches the production area. The injection returns are currently providing hot recharge and pressure support to the geothermal system. Injection returns have not, so far, caused measurable decline in reservoir temperature, but this needs to be closely monitored.

A reservoir tracer test in TAOM injection wells (TI-1 and TI-2), located in the west (Figure 1) is ongoing with returns to the two nearest production wells (TP-1 and KA-35) peaking after 250 days. Returns have yet to peak in two other wells where tracer is present. Again, the results show reassuringly slow returns to nearby western production wells and no significant returns to the other areas. Hence, TAOM injection is also unlikely to cause thermal breakthrough.

Trends in Pressure Change

When fluid is extracted from a geothermal reservoir pressure can fall. Reservoir pressure 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 and this trend continued in 2021. Given that only about 67% of the produced fluid is returned to the reservoir by injection, it is likely that the inflow of cool groundwater from above and from the edge of the production area is providing much of this pressure support. In 2021 the reservoir pressure recovery continued and was probably also influenced by the reduced production take. A noteworthy feature of the Kawerau monitoring are rapid pressure and chemistry responses to short-term changes in production (e.g., plant shut-downs) which indicate good hydrological connectivity through the deep reservoir.

Recent Trends

Reservoir monitoring in 2021 showed little change in reservoir conditions; individual well enthalpy and mass flow declines in most of the wells remained close to the long-term gradual decline rates. However, the relatively stable conditions may have been partly due to the reduced take.

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 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 monitored 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.

Recent trends

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 measured in most groundwater wells have been stable over the past few years, an exception being KAGW1 (10m depth, close to KA40 injection well), which has shown a small but steady increase in chloride and temperature, but unfortunately was not tested in 2021.

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 along the riverbanks, mudpools, sinter sheets, steaming and heated ground and thermotolerant vegetation.

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. (Figure 3). 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).

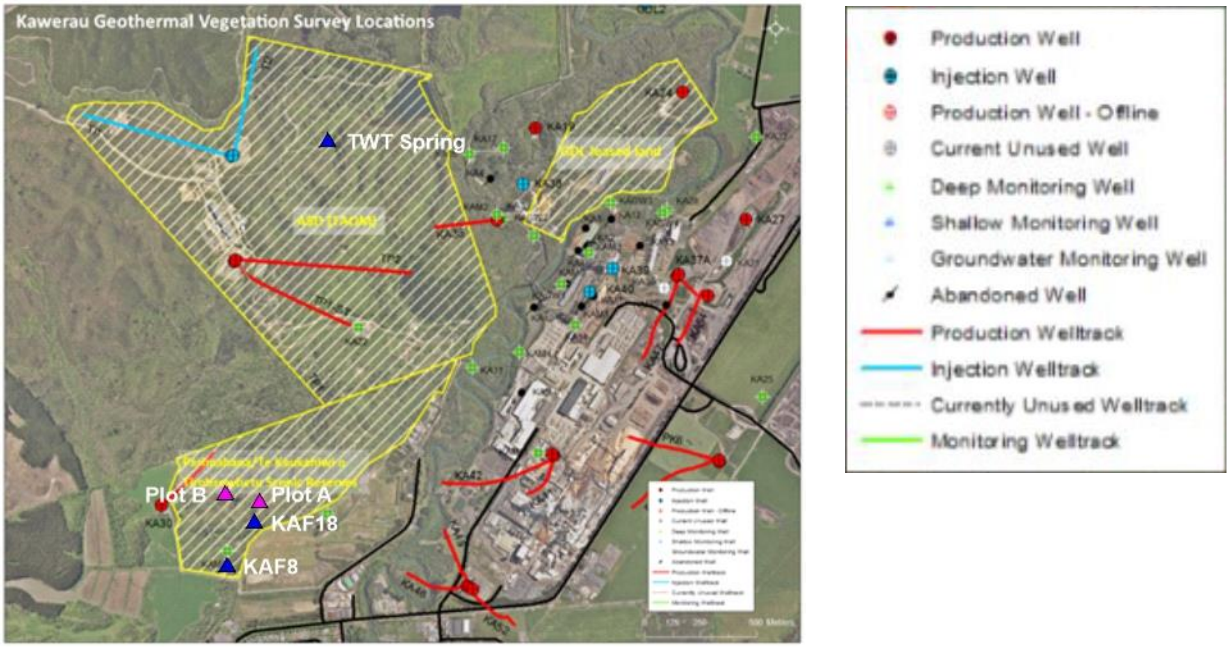

Figure 3: Surface Thermal Features and Vegetation Survey Areas

<u>Recent trends</u>

Over the past few years there has been a general decline in activity within and near the Parimahāna Reserve, located in the SW of the production area (see Figure 3). This includes a decline in temperature and cessation of flow from the two designated monitoring springs (KAF8 & KAF18) and cooling within the nearby area of hot ground (Plot A) and in a shallow groundwater well (KAM9). Several monitored riverbank springs have also disappeared since 2018. The nature of this cooling is not yet understood but it is notable that cooling has also occurred in the nearby KA30 production well where it is clearly due to ingress of cool groundwater. There has been little consistent change in thermotolerant vegetation cover and there was no surface thermal feature monitoring in 2021.

Resource consent holders have previously raised a concern about the range and frequency of surface feature surveying, the challenge of attributing surface change to reservoir production and/or naturally occurring waning of the shallow geothermal system, and the potential to apply new technologies (e.g., drone thermal infrared). The Kawerau Steam Tappers Management Committee (STMC) completed an initial review of the surface monitoring programme in December 2021, and this was discussed at the 2021 Annual Technical Review meeting.

10. Subsidence

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

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, 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 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 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 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 be largely responsible for 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 but since 2014, there has been a general reduction in subsidence rates. 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 large and increasing subsidence rates since it was first recognized in 2016. In the 2020 survey, there is 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. 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.

Injection wells may also be drilled to reduce the risk of potential cooling issues related to 'short circuiting' of injected fluid with the production sector of the reservoir.

No new wells were drilled in 2021.

12. Numerical Reservoir Modelling

Computer modelling is an advanced tool used for 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 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 2021 apart from updates to the production and injection histories to the end of 2021. In 2021 the model was able to provide good matches to the pressure increase observed during the KGL station shut.

13. 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 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. The consent holders recommended changes to the current strategy including 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.

Review of Surface Monitoring

As noted in Section 9 of this report, the STMC completed a review of the surface monitoring programme in 2021 and this was discussed at the 2022 Annual Technical Review meeting. It was agreed that ongoing investigations are needed, and several initiatives were presented. The Tappers proposed that they could collaborate on a trial with drone thermal infrared surveying looking at the benefits of targeted surveys (e.g., along the river course) and low-elevation flights for high-resolution. The consent holders also agreed to meet with an ecological consultant with geothermal expertise to discuss changes to the frequency of thermal vegetation surveying, then report to BOPRC.

Review of Kawerau System Management Plan

The Kawerau System Management Plan was approved by Council in 2018. However, it now needs to be reviewed to reflect changes in best practice management on the system, including adaptive management processes and modelling. As noted above, any approved changes to the discharge strategy and the monitoring programmes also need to be reflected in the System Management Plan. A review was begun in 2020 but put on hold. BOPRC will work with Consent Holders to progress this in 2022-23.