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Injection Management in Kawerau Geothermal Field, New Zealand

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ABSTRACT

An adaptive management and injection strategy has been used to ensure that the Kawerau power plant has injection capacity to run at full load and balance pressure support to the field while preventing thermal breakthrough to production areas. A key part of this strategy is understanding injection well interaction. A strategy was developed with active reservoir testing and analyses used to maintain injection capacity.

Injection well capacity was initially measured through standard multi-rate completion tests following drilling. Subsequent monitoring was performed by continuous monitoring of wellhead pressure and injection rate; where no positive wellhead pressure was observed, downhole pressure monitoring tubing (i.e. capillary tubing) was installed to provide a fluid level monitor injectivity increase or decline. Wellbore models were used to estimate the full injectivity curve and its change over time. Tracers and chemical signatures were used to understand injection return to producers.

Various injection well characteristics have been observed over more than five years of operation. Even though the deep injection wells are drilled within a 4km^2 area, behaviors range from steady performance (no stimulation or capacity degradation) to signs of well interference and mineral deposition. Integration of information gathered from injection performance monitoring has resulted in better understanding of injection fluid flow-paths, forecasting of long-term injection capacity, management of chemical dosing of injection fluid and better planning for make-up injection well locations.

1. INTRODUCTION

The Kawerau geothermal field is the most north-easterly of the known major, high temperature geothermal systems in the Taupo Volcanic Zone (TVZ) (Figure 1). The geothermal field is located within the flood plains of the Tarawera River close to the andesitic Putauaki volcano and rhyodacite domes forming the Onepu Hills. The highest measured temperatures, pressures and discharge chloride concentrations at Kawerau occur towards the southern part of the field, in the vicinity of the Putauaki volcano. This is consistent with the current conceptual model of deep upflow and major heat source occurring in this part of the system. The geothermal field has a low resistivity signature extending over an area of up to 35 km^2, whilst most geothermal areas in the TVZ average about 15 km^2.

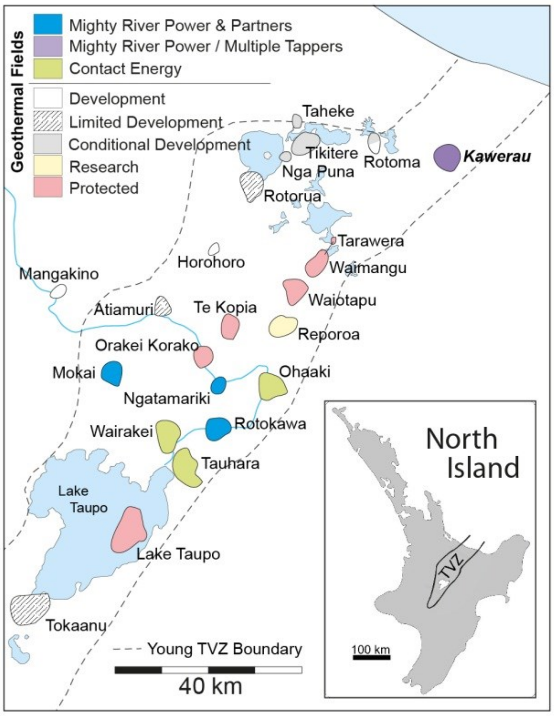
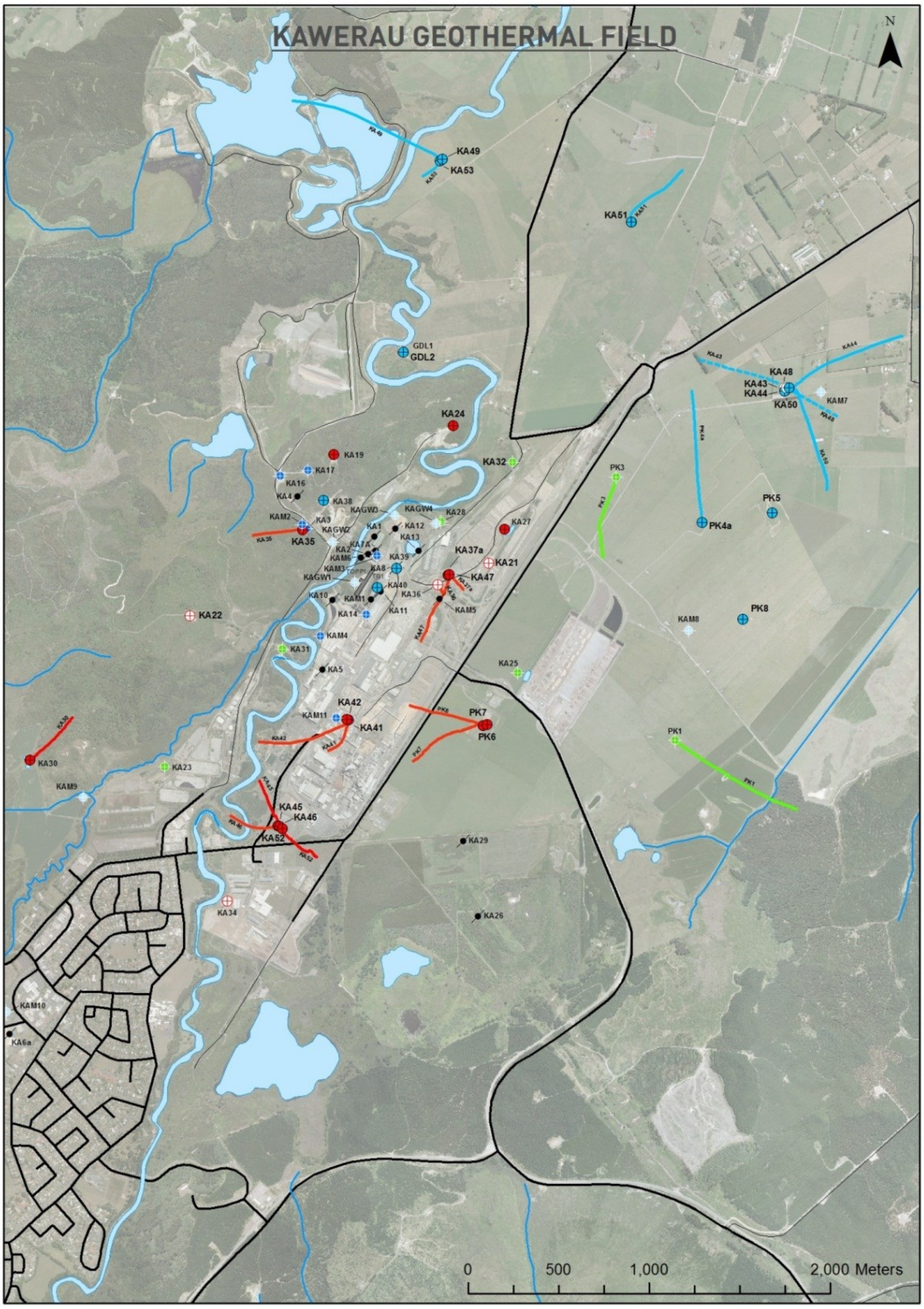


Figure1: Taupo Volcanic Zone, North Island, New Zealand (Geothermal Field resistivity boundaries from Bibby et al., 1995 and Young TVZ Boundary from Wilson et al., 1995).

In 1951/52 the Department of Scientific and Industrial Research and Ministry of Works carried out scientific surveys and shallow drilling to investigate the geothermal potential of the Kawerau area for power production and process heating. One year later, Tasman Pulp and Paper Company decided to site a mill in the vicinity of the field in order to utilise the geothermal energy potential for industrial applications. The drilling of geothermal production wells for Tasman led to the first geothermal steam being supplied for power production and for process heat to the mill in 1957, with the steam supply system fully operational in 1961. A total of 73 wells have been drilled since 1952 (Figure 2).

Shallow injection at Ngati Tuwharetoa Geothermal Assets Ltd (NTGA) injection wells at 150-300m depth began at Kawerau in 1991 and deep injection targeting the basement greywacke to the northeast of the field began in 2008 when Kawerau Geothermal Limited (KGL) power station was commissioned (owned by Mighty River Power). Since start of deep injection various injection well characteristics have been observed. As a result, the injection strategy has been iteratively revised and adaptive management strategy (i.e. adjusting the injection flow rate and stimulating the wells by switching the condensate injection) has been used to ensure that the Kawerau power plant has injection capacity to run at full load and balance between maintaining pressure support to the field and preventing thermal breakthrough to production areas.



Figur2: Kawerau Geothermal Field.

2. INJECTION CHALLENGES IN KAWERAU GEOTHERMAL FIELD

The brine and condensate produced at KGL power station are injected into five deep brine injectors (KA44, KA51, PK4A, PK5 and PK8) and one deep condensate injector (KA50). Even though these wells have been drilled within about a 4km^2 area, their behaviors range from steady performance (no stimulation or capacity degradation) to signs of well interference and mineral depositions.

2.1 Mineral Deposition

All of the KGL injection wells have been used to inject brine (including current condensate injector KA50) since plant commissioning in August 2008. Silica precipitation at Kawerau has been a concern since the design phase due to silica saturation index (SSI) of approximately 2.0-2.2 at injection temperature and further reduced solubility at lower temperature. Since plant commissioning, routine monitoring of the wells identified decline in some of the wells' capacity. An investigation carried out in 2009 confirmed that the injectivity indices of some of the wells (i.e. KA44 and PK4A) had declined to approximately half of the pre-utilisation levels (Lim et al 2011). This decline in injectivity was in contrast with injection well stimulation elsewhere. In the absence of mineral deposition, the injectivity should increase with time as the injectate cools the rock and stimulates the well (Grant 2009). Further investigation on the injectate chemistry also suggested that the most likely cause of the decline is colloidal silica scaling.

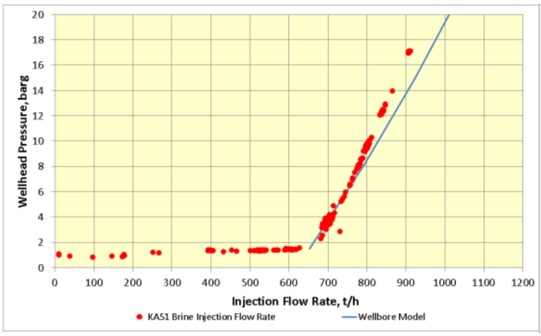
As the decline in injectivity constrained KGL plant operation, it was decided to acidize wells KA44 and PK4A as a remedial action. Acidizing had been proven in Philippine and Indonesian geothermal fields. The acidizing campaign was carried out in 2010 using a traditional 10% hydrochloric (HCL) and 5% hydrofluoric (HF) mud acid along with corrosion inhibitors, iron chelating and gelling agents. The post acidizing test results suggested improvement of injectivity to almost twice as high as the injectivity prior acidizing (Lim et al 2011), however it was short-lived and the wells quickly reverted to pre-acidizing injection rates.

The acidizing operation was deemed uneconomic, so it still remains a challenge to optimize the injection wells in Kawerau. Currently silica scaling is controlled by PH modification using sulfuric acid. The purpose of acid dosing is to delay the silica polymerization process by extending the "induction period" during which no formation of silica colloids takes place. This allows sufficient time for injection brine to be injected into the formation with little temperature loss prior to scaling pipe and well bores.

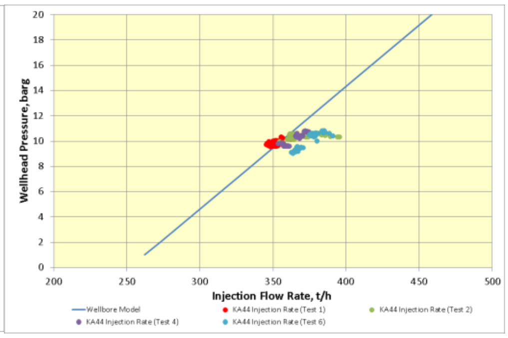
2.2 Interference With Nearby Wells and Access to Fracture Network

As KGL deep injection wells have been drilled in a relatively small area, interference with nearby wells and their access to fracture networks have also been a challenge in managing the injection well performance. In order to determine the level of interference among these wells and also infer the capacity of the fracture network in the reservoir to which the wells are connected, a series of interference tests were carried out on KGL deep injection wells (KA44, KA51, PK4A and PK8) in February 2014. Significantly different responses to the interference test were observed (plotted in figure 3). In summary:

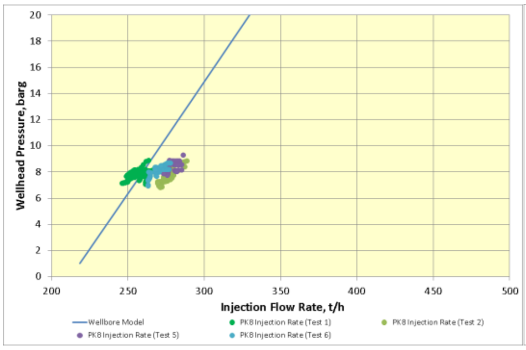
1) Among the tested wells, PK8 was most impacted by interference followed by KA44. KA51 and PK4A showed minor effects of interference.
2) PK5 and KA50 were both shut in at the time of testing, so there could also be some interference between PK8 and PK5 and/or KA50.
3) The north-eastern region of the field where KA44, KA50 and PK8 are located seems to have a finite conductive fracture network; the transmissivity of this type of fracture network tends to reduce from over-injection and/or mineral deposition in the formation. More detailed pressure transient analysis needs to be to done in order to characterize the fracture network in this part of the field.
4) PK8 in particular seems to be close to a boundary of sufficient and good permeability in the reservoir; combining the findings from PK8 with data from nearby non-commercial PK1 suggests that a boundary is likely to be between these two wells.
5) Much better permeability with considerable access to a wider fracture network is indicated by the two most western KGL injectors KA51 and PK4A.



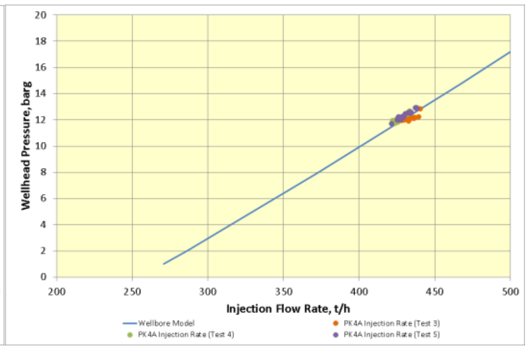
KA51 capacity test



KA44 injectivity curve vs. flow rates



PK8 injectivity curve vs. flow rates



PK4A injectivity curve vs. flow rates

Figure 3: Plot of injectivity curve vs. flow rate for each of the tested wells in the February 2014 interference test trial.

Overall the results suggest that the north-eastern part of the field where KA44, KA50 and PK8 are located is unfavorable for locating future injection wells. The more western KGL injection area (KA51 and PK4A) has much better permeability and access to a wider fracture network. This indicates the area to explore for potential future make-up injection wells. To mitigate potential cooling from rapid injection returns, the area in the vicinity of KA51 may provide the best location for future injection wells. To mitigate potential interference, adequate separation and a limited number of wells per drilling pad also need to be considered.

2.3 Injection Returns

Shallow tracer tests conducted in October 2009 at KA38, KA39 and KA40 (NTGA shallow injection wells) and deep tracer tests performed in December 2010 (KGL wells PK4A, PK8, KA44 and KA50) provided information about the extent, rate and magnitude of injection returns to the Kawerau shallow and deep production wells. Tracer from KA38 was most widely spread and was detected in KA24, KA35, KA37, KA38, KAGW1, KAGW4 and KAM4. The tracers injected at KA39 and KA40 were less widely spread and were only confirmed in wells west of the Tarawera River (KA19, KA24 and KA35). No tracer returns from shallow injection were confirmed for the KGL deeper production wells. On the other hand, KGL production wells PK6, PK7, KA41, KA42, KA45 and NTGA production wells KA27, KA37A, KA47 were positive for tracer returns from all KGL deep injection wells, with 10-20% combined injection returns and close to 30% in PK6. The tracer first-arrival-times in these wells with high tracer returns were in the range of 50-100 days with the exception of KA27 at 27 days. The influence of injection returns was further confirmed by the elevated chloride, sulfate and silica in well fluid chemistry, and depressed noncondensible gas in total flow.

Although these data suggest widespread and substantial injection returns into the production area of both NTGA and KGL (Figure 4), these returns have not significantly impacted the enthalpies of the production wells. The actual flow path is yet to be understood, but with tracer-first-arrival time >50 days in most wells (the mean residence time >200 days), it is expected that there is sufficient time for the injection fluids to be reheated before reaching the production areas.

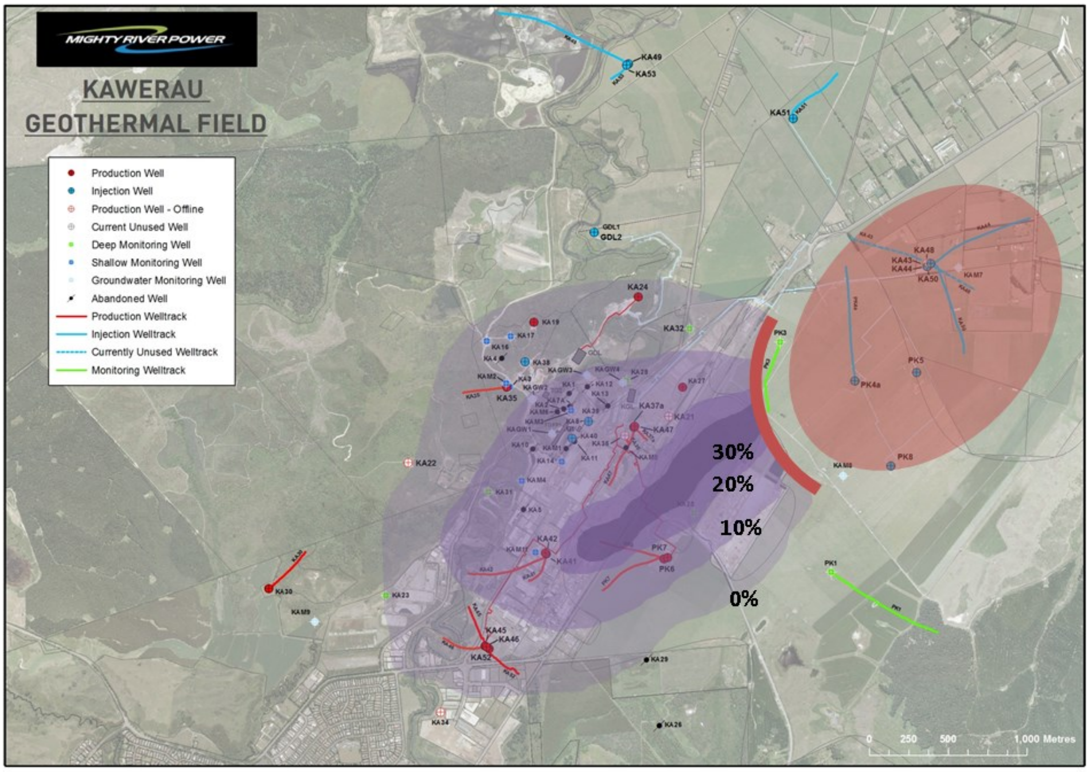


Figure 4: Contour map of combined tracer returns to production area from deep KGL injection wells.

Continued geochemical monitoring of all production, injection and monitoring wells with a deep injection tracer test in new injection wells (NTGA KA49 and KA53 and KGL KA51) should further a better understanding of injection return and its mechanism.

3. INJECTION STRATEGY

The injection strategy stands as component in management of field pressure support and protection of production enthalpy in Kawerau geothermal field. This strategy has been in place since early 2010 and has resulted in finding the best layout of injection well locations. With the results of tracer tests and more than five years of injection experience, the strategy has been recently reassessed and reinforced with some refinement to its implementation.

The current injection strategy considers an overall holistic reservoir view that includes numerous factors in determining suitable locations for sustainable fluid injection. These include:

1) Reasonable stand-off from producing wells
2) Results of geophysical resistivity surveys
3) The area of land available
4) The risk associated with the level of data known
5) The need to spread injection out and position wells off suspected fluid pathways
6) Land access.

One key aspect of injection is injecting the fluid deep to prevent overloading of the shallow aquifer, take advantage of the higher density injection fluid's propensity to sink and contact hotter rock, but provide pressure support to the reservoir. Pressure support must be at a distance and depth that prevents cooler injection fluid returning too soon to the production area. It is important to spread injection over a large area around the periphery of the field in case injection wells are too connected to the production reservoir and to avoid having large amounts of injection fluid concentrated in one place. Either of these can lead to faster injection returns and rapid cooling of production wells. Long term management of injection fluid for KGL, NTGA and other geothermal developers should include targeting wells in northern outflow areas of the field at distances of greater than 1000m from the nearest production well (refer to Figure 5 between the 1km and 3km red lines).

MRP resource consents for Kawerau stipulates that injection wells shall generally be cased into the greywacke basement. At Kawerau the greywacke basement deepens towards the north and of the current wells was encountered at the greatest depth in KA49 at about 1500 m. Tracer testing and reservoir analyses have shown that vector distance (total distance in a straight line between feedzones) is the main factor controlling fluid return times in the greywacke. This indicates that there is little additional benefit drilling deeper so long as the vector distance is sufficient. Tracer returns from wells cased down to 2000mVD have shown returns to the nearest shallow wells despite the depth.

The upper greywacke and overlying volcanic/sedimentary cover are capable of rapid, channelized injection returns. A significant amount of the NTGA and GDL (Geothermal Development Limited) production feed zones are located at or near this interface between the greywacke and the volcanic/sedimentary cover (Figure 6). Casing into the greywacke confines injection below this interface and greatly mitigates the risk of injection returns causing cooling in the NTGA/GDL production zone.

Therefore it is appropriate to case into the greywacke while exploration drilling in new injection sectors of the field. This will be a valid strategy as long as vector distance is maintained by spreading injection around the margins of the field and maintaining the standoff buffer from production of more than 1km.

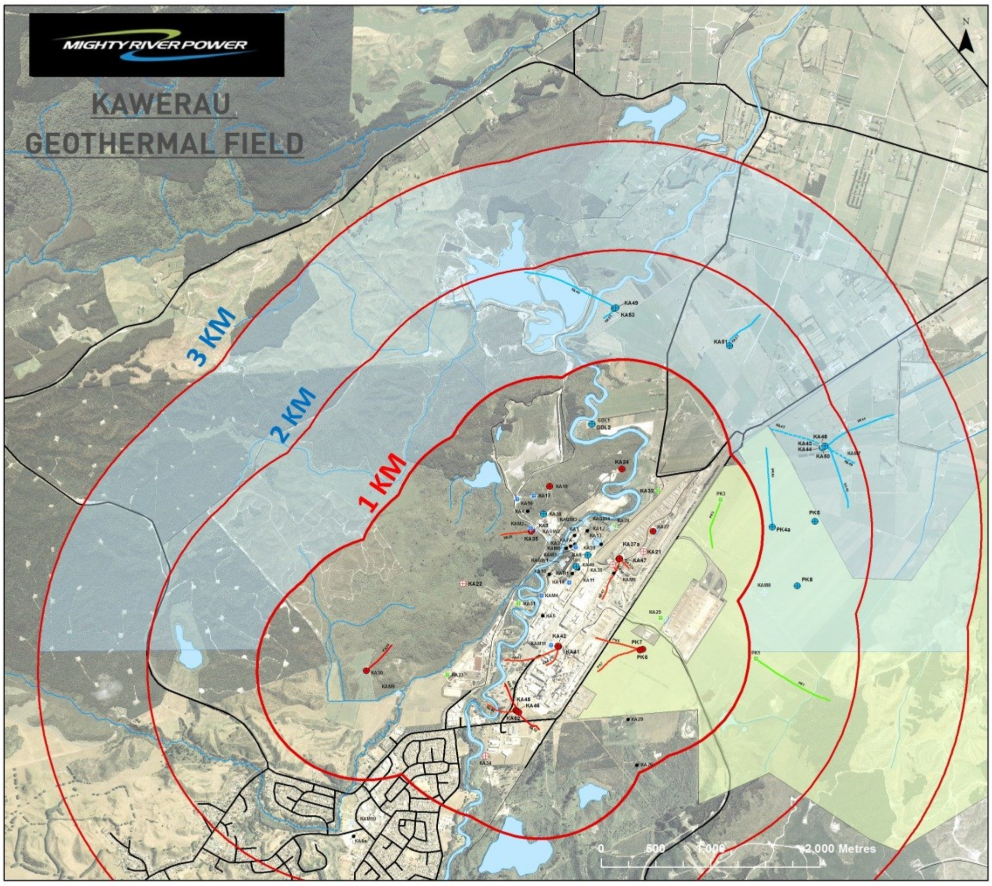


Figure 5: Kawerau 1 km production stand-off and injection target zones (shown by the blue shading) for sustainable geothermal operations.

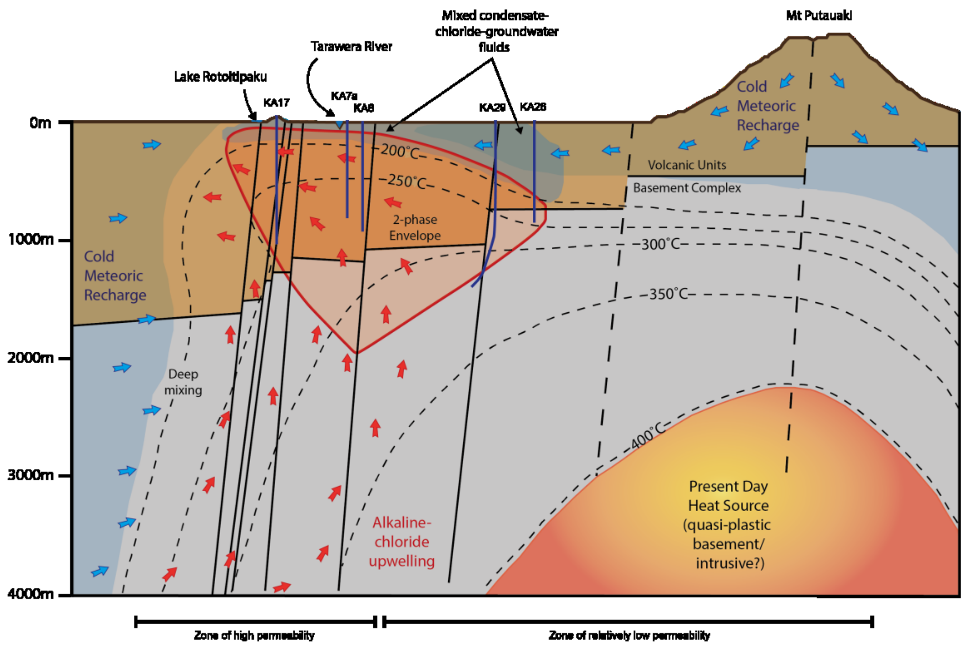


Figure 6: Conceptual model of the Kawerau Geothermal Field adapted from Bignall and Harvey (2005).

4. CONCLUSIONS

The data obtained from the Kawerau geothermal field suggest that the injection strategy that has been used since commissioning of KGL power plant in 2008 has effectively helped in full utilization of the power plant as well as long term sustainability of the reservoir. However, adaptive management implies that this strategy should be continuously reviewed, assessed and modified (if needed) as more data are acquired. The tracer tests which will be carried out in KA51, KA49 and KA53 will significantly test the concept of spreading and deeper injection since existing injection and new injection fluid will be partially directed to these wells. Tracer returns from these new injectors at the northernmost production wells of >200 days, similar to PK8, KA44 and KA50 results, will be further evidence to support and maintain the current strategy.

Evidence of chloride dilution by cooler side-recharge fluids at the producers, additional MT resistivity surveys and the review of structural geology will help contribute to the review of the Kawerau conceptual model. Together with use of the numerical model to match these trends, these data will help refine the future management of the field and provide a solid basis to verify or modify the injection strategy. Numerical model scenarios developed by the Kawerau team as a result of these trends will test the location of future injection wells to balance pressure support with heat recovery for long term sustainability and preferred injection management.

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