Geothermal Resources Council TRANSACTIONS, Vol. 16, October 1992

REINJECTION AT THE WAIRAKEI GEOTHERMAL FIELD

P.F. Bixley[(1)], B.S. Carey[(2)], and K.H. Harwood[(2)].

[(1)] PO Box 1414, Taupo, New Zealand
[(2)] Electricity Corporation of New Zealand, Private Bag, Taupo, New Zealand.

ABSTRACT

A scheme to reinject an average flow of 2500 t/h of separated geothermal water derived from production operations at Wairakei is now under construction. Reinjection wells are to be located near the north-eastern margin of the field. This permanent reinjection scheme is the culmination of more than 10 years of investigation and testing in the field. It is the first stage of an environmental enhancement programme being carried out by Electricity Corporation of New Zealand relating to disposal of separated geothermal water at Wairakei.

INTRODUCTION

When development of the Wairakei geothermal resource was conceived in the 1950's, there was little or no awareness of the potential impacts of discharging the separated geothermal water into the Waikato River. In 1967, when legislation was introduced in New Zealand to control the quality of surface waters, the discharge from the Wairakei field was licensed as an existing operation. From the early 1970's there has been increasing awareness of environmental issues, and the need to maintain or improve the quality of surface waters. The primary objective of reinjection at Wairakei is to improve the quality of the Waikato River waters by reducing the thermal and chemical inputs into the river that result from the operation of the Wairakei geothermal field. The Electricity Corporation of New Zealand is pursuing this work as part of its environmental policy as it relates to the Wairakei facility.

Reinjection at Wairakei poses some unusual issues not found in most other geothermal projects. The field was developed and has operated for 30 years with no reinjection. While pressures in the deep liquid have been reduced by about 26 bar below the pre-development values, over the last 10 years pressure changes have been relatively small, less than 0.5 bar. Prior to field development, the natural fluid flow through the Wairakei system to the surface was assessed to be about 1400 t/h. As a result of pressure drawdown, the natural hot recharge has been stimulated and is estimated to have increased by about four times to approximately match the production rate of about 5000 t/h (Allis, 1981). This large recharge of hot fluid into the field warrants special attention when considering reinjection.

The high horizontal permeability and good communication between wells across the field has been appreciated from early in the field's development (Bolton, 1970), and the probability of rapid movement of cool injected fluid along preferred flow paths has remained a major concern. Because of the potential adverse impacts of the cool reinjected water on the sustainability of the resource as a whole, the approach to large scale injection has been cautious, with emphasis on understanding the fluid flow paths within the geothermal field and gaining a practical appreciation of the longer term effects before fixing the design layout for a permanent reinjection scheme.

The average enthalpy of the fluid withdrawn from the Wairakei field is lower than in other developments of comparable size, thus the quantity of water that remains after separating the steam is correspondingly larger than in other similar installations (table 1). Excluding the wells producing only steam, the average discharge fluid enthalpy is about 1000 kJ/kg. At the present time with the power station operating at a load of 140 MWe, the total fluid withdrawn from the field is typically 5000 t/h, and after separation of steam, about 4000 t/h of separated water is available for disposal. The average flow of the Waikato River, into which the separated water has been discharged to date, is about 500,000 t/h.

Field	Average Generation (MWe)	Total Production (t/h)	Separated Water (t/h)
Wairakei (1988)	140	5000	4000
Bulalo (1988) (Benavidez et al, 1988)	250	4000	2000
Tongonan (1985) (Sarmiento, 1986)	40-50	900	400
Ahuachapan (1984) (Campos, 1985)	70	2000	1500

Table 1: Approximate flows for total production fluid and separated water for some liquid-dominated geothermal fields.

In 1991, new legislation (the Resource Management Act) was introduced in New Zealand, which places geothermal fields into a sustainable resource category. Under this legislation all "existing use" authorisations, such as those for production at Wairakei, made under the 1967 legislation will cease in year 2001 and must be replaced before that date by authorisations under the new Act. How the application of this Act will affect large scale geothermal developments in New Zealand has yet to be determined.

Investigations into reinjection of geothermal fluids began in New Zealand in 1974. At this time the investigations were carried out jointly by three government departments; DSIR, Ministry of Works and Electricity Division of Ministry of Energy. This work included basic research into fluid chemistry, response of the geothermal field to reinjection and obtaining operational experience with small scale reinjection equipment. At Wairakei, investigations into the feasibility of reinjecting the separated geothermal water commenced in 1978 with some small scale field trials and tracer tests. This work lead into pumping trials, tracer tests, geophysical surveys, a 13 month trial where about 600 t/h of separated water was injected, and drilling new wells.

TRACER TESTS

Since 1978 extensive tracer tests have been undertaken to better understand the fluid flow paths within the Wairakei field. For most tests radioactive tracers ^{131}I and ^{125}I have been used. The first tracer tests were made in wells located within the Western Borefield (figure 1) which had natural internal flows as great as 180 t/h (McCabe, 1983). These tests showed that the tracers moved rapidly between some wells along preferred flow channels, then became well mixed in the deep liquid, appearing at lower concentrations in most wells in the Western Borefield.

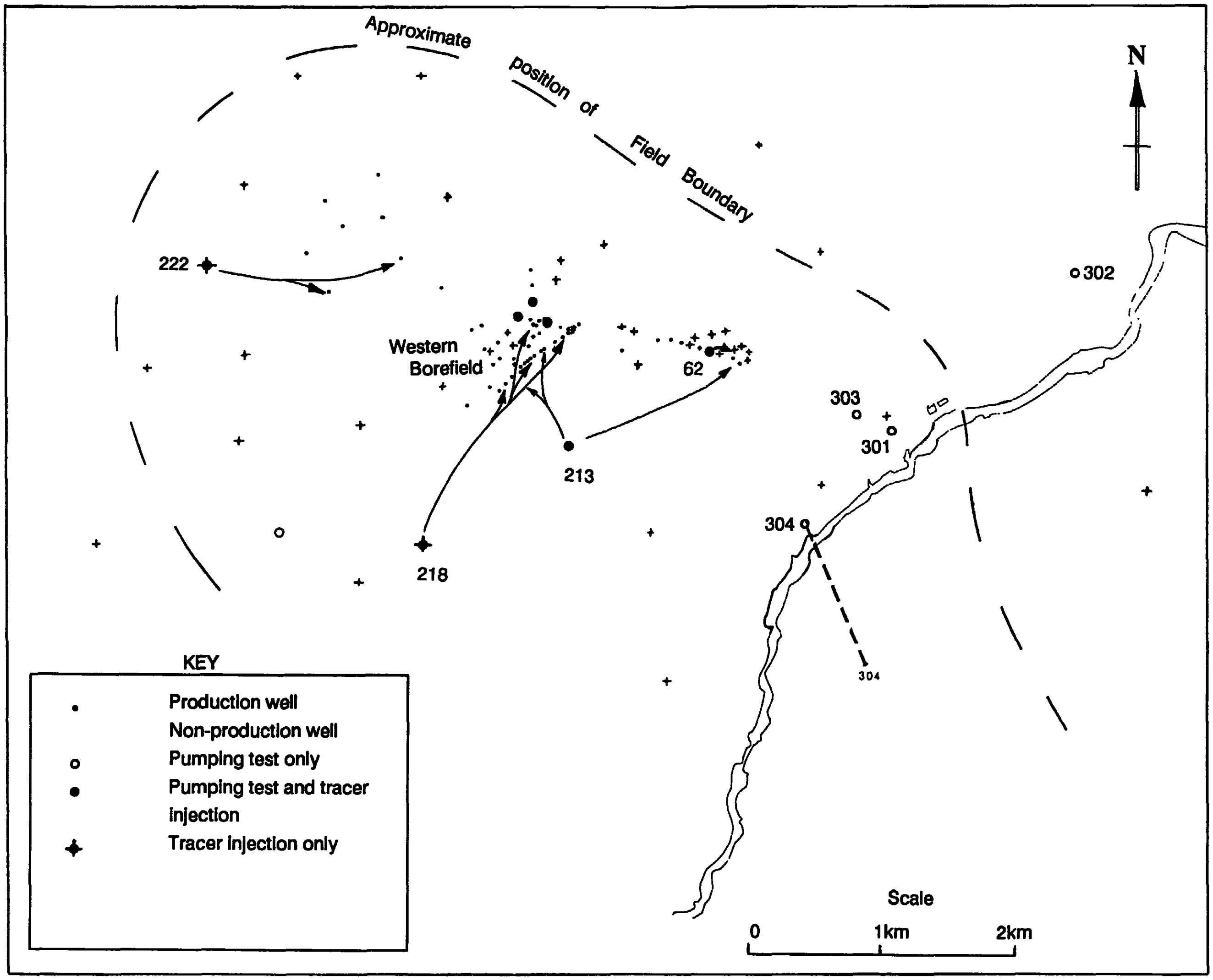

Figure 1: Wairakei geothermal field showing tracer return patterns, locations of existing reinjection wells and of pumping tests done as part of the investigations into reinjection.

Later tests were performed using wells outside the production area. The well locations and flow paths identified by these tests is shown on figure 1. As with the tests within the production area, the tracers moved rapidly along preferred flow paths between the injection points and the pressure sinks where production was occurring. The most significant test was carried out at WK218 where more than 60% of the tracer injected at WK218 was recovered in the production area 2 km to the east.

Tracer Injection Well	Tracer Return Well	Distance (metres)	Tracer Velocity (m/day)
213	39	1330	85
213(I)	39	1330	130
218	66	1870	200
218	55	1940	200
218	70	1660	200
222	207	890	70
222	215	1390	100
62	40	250	>700
62	55	960	6

Table 2: Comparison of tracer returns from different tests. Tracer injection well locations are shown on figure 1. For WK213 two tracer tests were made. The first without continuous injection (213 above) and the second with injection at 200 t/h (213(I) above).

The flow paths discovered by the tracer tests, and the relatively rapid movement of tracer, highlight the risks of designing a reinjection system for Wairakei. Overall, tracer tests have been useful in developing strategies with which the risks associated with reinjection of cooled geothermal water within the geothermal field may be reduced. Some of these strategies include: Location of reinjection wells away from preferred flow paths that link with production areas and location of reinjection and production areas across rather than parallel to the local fault trend pattern. When the permanent reinjection scheme is completed, tracer tests will be performed on wells soon after they are commissioned to provide advance warning of likely cooling in production areas or of the existence of preferred flow paths from particular wells, to allow time for remedial action to be undertaken.

REINJECTION TRIALS

In the period from 1980 to 1984 six trial injection tests were made to look at changes in injection well performance and together with tracer tests to examine the movement of water injected within the field (figure 1). Tests were done using cold fresh water and separated geothermal water at 80-95°C, for periods of up to two months.

The reinjection tests culminated in a long term reinjection trial, injecting 580 t/h of 130°C water into well WK62 in the Eastern Borefield for 13 months during 1988-89 (Hunt et al 1990). Continuous monitoring over a period extending three months either side of the test was provided for several key parameters. These included production flows and chemistry from selected wells, pressures in the deep liquid and microseismic activity. No effects on production flows or reservoir pressures were observed in the production areas to the west of the reinjection well. All measured effects were concentrated in the immediate vicinity and to the east of WK62, where pressure, and tracer/production chemistry changes were observed. Low levels of tracer were observed in the Western Borefield toward the end of the tracer test using ^{125}I. Pressures were continuously monitored in two monitor wells about 100m either side of the injection well. Throughout the test pressure continued to buildup in an almost linear manner, with a total increase of about 3 bar. This pressure fell away to a net 1 bar increase two months after the test was terminated. A gravity anomaly was also located around the injection well following the test. No microseismic events that could be associated with the reinjection were observed.

In general the tests showed that while reinjection of geothermal water was feasible from a surface engineering point of view, there was significant potential for damage to the underground resource and to production well fluids.

GEOPHYSICAL SURVEYS

To assist with definition of potential reinjection well targets and to better define the eastern boundary of the field, a series of new geophysical surveys were performed in 1988-89. These included seismic reflection, aeromagnetic, gravity and resistivity. This information was brought together with new geological information, obtained from reappraisal of old cores and cutting samples, to build up a more reliable picture of the subsurface conditions near the eastern margin of the field and was used to select locations and designs for three reinjection wells.

DRILLING

New wells have been drilled to investigate the geological structure and reinjection potential along the eastern margin of the field (figure 1). The first of these wells, WK301, was drilled in 1984. This well failed to encounter good permeability and will accept only limited quantities of reinjection water. In 1990 WK301 was deepened from 1450 to 1980m to assist in resolution of the deep geological structure along the eastern margin of the field. While the new geological information was useful in understanding the local structure, the well permeability was not improved by the deepening.

Using information from new seismic reflection and resistivity surveys, WK302 was located to investigate the structure and reinjection capacity outside the field boundary zone, to the northeast of the Power Station. The well intercepted a series of highly permeable formations at depths of 200-600m. Pressures in this well were artesian and temperatures were 12-24°C.

WK303 was drilled into the Huka Falls Formation breccias and the underlying Waiora Formation in the outflow zone near the field boundary. Permeability was found in both targeted formations.

After evaluating the results of WK301, 302 and 303, together with new geophysical and geological work, WK304 was designed as a high angle deviated well, located within the field boundary to the south of WK301. This well was completed to 1470m measured depth, with a vertical depth of 740m and a throw of 1100m. Well testing indicates that the well will accept more than 400 t/h of separated water.

PERMANENT REINJECTION

The conceptual understanding of the resource that has evolved for Wairakei is that substantial reinjection anywhere within the productive part of the field will rapidly interfere with production temperatures. Reinjection in the Wairakei field is accepted as a method for disposing of the separated geothermal water rather than as a tool for better management or enhancement of the resource, or for improving heat recovery from the reservoir. The first concern in designing the reinjection system layout has been to minimise the potential for reinjected water to return to production wells and to avoid damage to other potentially productive parts of the field.

In the longer term the objective is to increase the horizontal separation between production and injection sites. Since 1982 new production wells have been located further toward the northwestern side of the field. The first stage of the permanent reinjection scheme allows for the bulk of injection within the field, toward the eastern margin, with some injection outside the field boundary. In future, a greater proportion of reinjection is envisaged outside the boundary zone.

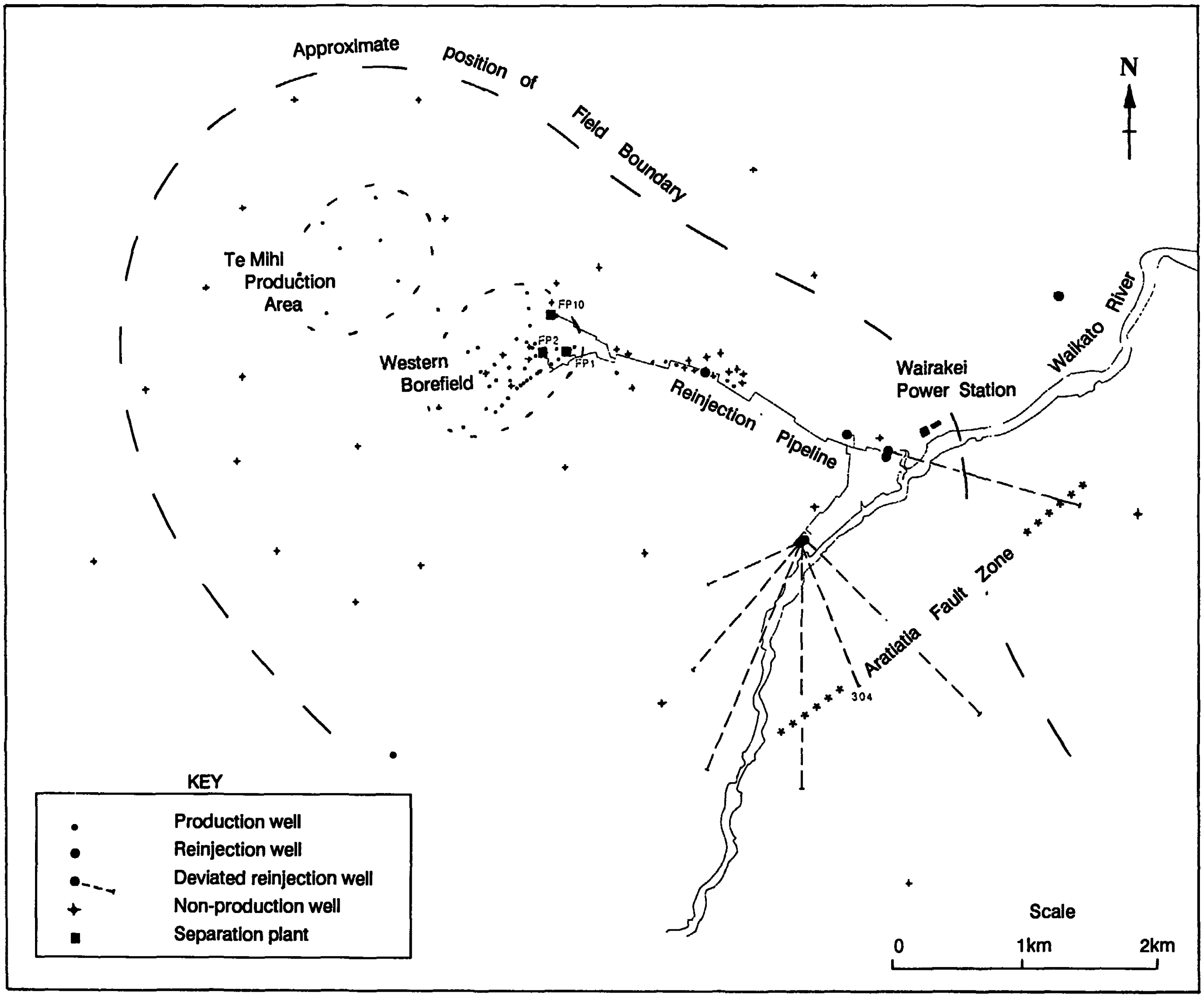

Figure 2: Wairakei geothermal field showing layout of the first stage of the permanent reinjection scheme, existing and proposed reinjection wells.

To reduce the risks associated with return of cool separated water, a variety of options for the location of reinjection wells were chosen for this first stage. These included reinjection outside the field, reinjection at different elevations and into different formations, and reinjection into different structures.

The first stage of permanent reinjection is for a maximum flow of 2700 tonnes per hour of separated geothermal water. This will allow reinjection of approximately 60% of the total separated geothermal water that is currently produced from the field. Most of this water will be injected within the field boundary. Separated water will be collected from flashplants 1, 2, and 10 and piped to the reinjection wells where it will be injected, without pumping, at depths generally between 190 and 1000m below ground level. The scheme will involve constructing approximately 6 km of new pipelines.

Figure 2 shows the well tracks for proposed reinjection wells. For the wells within the boundary, the formation temperatures are expected to be 150 to 200°C. Two of the proposed reinjection wells will be shallower and deviated to the southwest from the WK304 site to target the flank of the Karapiti Rhyolite dome. The is a large, oval-shaped dome centred about wells WK218 and WK208 in the south of the field (Figure 2).

Deeper wells (deviated at about 70° from vertical) to the south and southeast from the WK304 site are proposed to target permeability associated with the Aratiatia Fault Zone and formation permeability in the quadrant south from this site. One deep deviated well from the WK301 site is proposed to pass through the field boundary zone and intercept permeability in the Aratiatia Fault Zone outside the field.

In addition to the proposed wells outlined above, existing wells WK301, 303 and 304 will be connected into the scheme. Any additional future reinjection wells drilled from the WK304 site will also be deviated, targeting geologic structures most likely to provide good capacity for water disposal and having minimal connections with producing areas of the field.

For standby or emergency reinjection it is proposed to use existing wells near WK62 in the Eastern Borefield. The use of these standby wells would allow servicing of the main reinjection wells without reducing production.

Construction of the surface facilities for reinjection is now under way. An application for discharge permits for permanent reinjection of 2700 t/h of separated water was made in January 1992 under the Resource Management Act. The Application is currently being processed.

CONCLUSION

This is the first stage of a programme to improve the quality of the Waikato River waters by reducing the thermal and chemical inputs into the river that result from the operation of the Wairakei geothermal field. The Wairakei field poses some special problems when addressing reinjection, in particular the large natural influx of hot fluid and the quantity of separated water available. A cautious approach to reinjection has been adopted, with several different options for location of the injected water. The response of the field to the first stage of reinjection will be monitored in order that detrimental effect of reinjection are minimised. The Electricity Corporation of New Zealand is pursuing this work as part of its overall environmental policy as this relates to geothermal development.

ACKNOWLEDGMENTS

Permission of Electricity Corporation of New Zealand to present this paper is acknowledged.

REFERENCES

Allis, R.G., 1981. Changes in heat flow associated with exploitation of the Wairakei geothermal field, New Zealand. New Zealand Journal of Geology and Geophysics, Vol 24: pp 1-19.

Benavidez, P. J., Mosby, M. D., Leong, J. K., Navarro, V. C., 1988. Development and Performance of the Bulalo Geothermal Field. Proc 10th New Zealand Geothermal Workshop. pp 55-60

Bolton, R.S., 1970. The behaviour of the Wairakei Geothermal Field during exploitation. United Nations symposium on the development and utilization of geothermal resources, Pisa, Geothermics special issue 2: pp 1426-1439.

Campos, T., 1985. Ten years of commercial exploitation at the Ahuachapan Geothermal Field. Proc 7th New Zealand Geothermal Workshop. pp 15-20

Hunt, T.M., Bixley, P.F., Carey, B.S., Young, R.M., 1990. Results of a 13-month reinjection test at Wairakei Geothermal Field, New Zealand, Geothermal Resources Council Transactions, Vol 14, Part II, pp 1193-1200.

McCabe, W.J., Barry, B.J., Manning, M.R., 1983. Radioactive tracers in geothermal underground water flow studies. Geothermics, 12, 2/3, pp 83-110.

Sarmiento, Z. F., 1986. Waste water reinjection at Tongonan Geothermal Field: results and implications. Geothermics, Vol 15/3, pp 295-308.