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OPERATIONAL HISTORY OF THE OHAAKI GEOTHERMAL FIELD, NEW ZEALAND

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ABSTRACT

The 116 MW Ohaaki geothermal field has completed about ten years of commercial production. Reservoir changes since commissioning have been dominated by enthalpy decline caused by the ingress of shallow groundwater from the overlying Ohaaki Rhyolite Formation. This has been most pronounced in shallow cased wells that are open to this formation. A consequence of cold water ingress has been an increase in calcite scaling which has required the installation of antiscalant dosing systems. Separated water injected on the margins of the field has returned to a number of the production wells – movement of the fluid appears to be along structurally controlled routes. Three wells have shown major returns. A deep exploration programme was undertaken in 1995. Three deep wells were drilled to cross the regional structural trend, seeking to locate permeable fractures and zones within the greywacke below the volcanic formations. The wells were drilled with nominal drilled depths of 2.5km and deviation angles of 45° from vertical. Feed zones in the volcanic formations above the greywacke encountered temperatures up to 300°C. This paper reviews the changes in the reservoir over the period of commercial operation and describes the future production expectations from the Ohaaki geothermal field.

1. INTRODUCTION

1.1 Background

Field exploration and development at Ohaaki occurred over a period of 20 to 30 years, and was influenced by government policy, uncertainty in the resource potential, and uncertainty of the potential effects of reinjection. The DSIR undertook scientific work commencing in the 1960's. The first well was drilled in late 1965. The Ohaaki power station was commissioned in 1988 / 1989 and was officially opened on 31st October 1989.

1.2 Geology

The geology at Ohaaki represents about 750,000 years of volcanic and sedimentary accumulation in a subsiding basin at the eastern margin of the Taupo Volcanic Zone. A generalised stratigraphic sequence is shown in Figure 1.

The basement beneath productive strata comprises mainly greywacke sandstones of the Mesozoic Torlesse Terrane (down to the depths currently explored, about 2.5km). Above the basement, the Waikora Formation greywacke conglomerates are interbedded with undifferentiated Ohakuri Group volcanics, forming a wedge of rocks of poorly known production potential. The 330,000 year old Rangitaiki Ignimbrite forms a thick, field-wide marker horizon, above which are 800 – 1000 m of variable deposits which include lacustrine sediments (Lower Siltstone, Huka Falls Formation), lava domes (East Broadlands Rhyolite, Broadlands Dacite, Broadlands Rhyolite, Ohaaki Rhyolite), and bedded volcanics (Rautawiri Breccia, Waiora Formation).

The thick, ubiquitous pumiceous tuffs of the Rautawiri Breccia and the more restricted Waiora Formation are generally permeable and productive.

The Broadlands Rhyolite has good fracture permeability, and occurs only near the western margin of the field where it is used for reinjection.

Ohaaki Rhyolite is present in the western and central parts of the field. It has fracture permeability where it is thickest, west of the Waikato River, and prior to field development acted as a mixing aquifer for cooler shallow waters and hot geothermal fluids originating from depth. Unlike the two large rhyolite domes (Ohaaki and Broadlands Rhyolites), the similar-sized Broadlands Dacite dome in the south-eastern part of the field has low permeability.

No active faults are evident at the surface crossing the field, though aligned thermal features on the west bank suggest shallow-rooted fissures occur above the Ohaaki Rhyolite domes. At least four faults displace the greywacke basement, which falls from SE to NW at an average gradient of 570 m/km, these faults do not affect formations shallower than Rangitaiki Ignimbrite.

2. Development and construction

2.1 Background

Using the experience from Wairakei and the generally high production rates found in the successful Ohaaki wells, original estimates of the field potential for electricity generation ranged between 30 and 200 MWe, with a final assessment of 80 MWe. In 1982 the government committed to the 114 MWe power station development. At that time sufficient production wells were available to provide steam for the proposed station.

To take advantage of excess well capacity that would be available for the first few years operation, higher pressure turbines (decomissioned from the Wairakei station) were to be installed to provide an extra 22 MWe capacity. It was anticipated that these turbines would function for about 10 years. This arrangement required a two pressure steam supply system capable of delivering 520 t/h steam at 14.5 bg, and 190 t/h steam at 4.0 bg. At the time of commissioning the production wells could supply a total of about 900 t/h HP and 380 t/h IP steam.

The steam supply (converted to MWe potential) had been observed to decline at a rate of 14% per annum during the late 1960's and early 1970's field testing. Decline rates greater than 14% were therefore expected when the power plant was at full production.

2.2 Injection

At the time of commitment to the Ohaaki development in the early 1980's there was limited experience with injection of separated water in the NZ geothermal industry. There was uncertainty in the anticipated performance of injection wells and the effect of injection on production. A programme of testing injection of hot geothermal water inside the field boundary zone and investigating the potential for injection at the field margins and outside the field was carried out. The design injection scheme was a combination of injection inside the field, near the field margins, and outside the field. It was recognised that some of the injection wells may have effects on production, and changes may have to be made once the subsurface fluid flow patterns and interconnection between wells became evident.

2.3 Other tests

To assist with selection of injection locations and prediction of injection effects, a series of interference tests and tracer tests were carried out to identify sub-surface interconnections in the reservoir before the flow pattern was disturbed by larger scale production. As a result of these tests a body of permeable rhyolite, somewhat isolated from the hot resource, was identified near the southwest and western field boundaries.

3. Production/Injection 1988-1998

Monitoring of the Ohaaki reservoir began prior to the commissioning of the power station and has continued to the present. Output tests, fluid chemistry and non-condensable gas data have been obtained from well flow tests. These tests were conducted at approximately 3-month intervals over the first 5 years of production by taking wells off the production system and testing them using the lip pressure and weir method. The tests are currently undertaken on an annual basis. Changes in reservoir characteristics are monitored from downhole temperature and/or pressure profiles in representative wells and a permanent system in BR34.

3.1 Production history

Fig 2 shows the annual field production, injection and generation from the Ohaaki plant from 1988 to 1998.

3.2 Operational strategy

Up to 1993, full production was maintained using the surplus capacity in the available production wells. Since that time, station energy production has been declining. The output has been optimised by reducing the HP pressure, derating some of the HP wells to IP, and connecting new wells.

Well cleanout operations to remove calcite scale and workovers seeking performance improvements have also been undertaken.

3.3 Pressure change

3.3.1 Deep reservoir pressures

Deep liquid pressure measured (Clotworthy et al., 1995) in production wells declined by up to 15 bars during the test discharge between 1968 to 1971. Since production began in 1988 the pressure has declined by an average of 15-20 bar in the production areas. Figure 3 shows the pressure history since 1988, for selected deep wells. The pressure is plotted as the difference from the original trend of pressure with depth using data at the main feed point of each well.

Wells outside the main production areas show reduced or negligible pressure drawdown, depending upon location.

3.3.2 Intermediate depth wells

There are 12 monitor wells drilled to depths of a few hundred metres, both inside and outside the production area. These wells generally have permeability in the shallow rhyolites. Wells BR4, BR33, BRM10 & BRM11 show a total drawdown of about 10 bars for the inner rhyolite.

Some wells have shown a response to reinjection. With the wells showing a response, there has generally been an increase in pressure of about 1 bar.

3.3.3 Steam zone pressure

At the end of the 1968-71 testing, a steam zone had formed on the west bank. After production recommenced in 1988, a coherent steam zone did not develop on the West Bank, due to cold water invasion. Some West Bank shallow wells returned to high enthalpy by 1996-97. On the East Bank there was for a period, a zone where steam was tending to form. The shallow-producing wells drew from it. Pressures in this steam zone were about 60 bar in 1988, declining to 40 bar by 1995.

3.4 Reservoir temperature changes

In general, temperatures in the reservoir have fallen with pressures. Nearly all the production zone is at boiling point and as pressure decreases the temperature also decreases.

Notable exceptions to this are the development of some inversions associated with the entry of colder waters into shallow producing zones. In some wells localised inversions have appeared at shallow feedzones. For example in BR2, where a downflow from 520 m appeared when the well is shut. Water at around 190°C enters at this depth. In addition increased cooling with time was observed at 510-570 m in BR15 behind the casing prior to the well being redrilled and being used for production from 1996.

3.5 Chemistry

3.5.1 Dilution and cooling

In almost all shallow-cased wells on the West Bank, the high temperature (250-260°C) reservoir waters have become diluted (with respect to chloride) and cooled by the influx of cooler water from the overlying Ohaaki Rhyolite.

The result of incursion of shallow, cooler waters on the West Bank has been declining discharge enthalpies, calcite scaling and in some cases increases in gas content in separated steam, the gas becoming increasingly concentrated in the diminishing steam fraction.

Incursion of cool waters has been less evident in the East Bank production wells. BR25, 35 and BR45 have shown decline in chloride, but here the decline in the silica geothermometer temperature has been moderate.

3.5.2 Calcite Scaling

Calcite ($CaCO_3$) scaling has been found in some production wells on both banks. This scale typically occurs in the wellbore above the flash-point, and in some cases in two-phase surface pipelines. Downhole scaling has been controlled in most of the affected wells by downhole injection of antiscalant chemicals through capillary tubing.

Recent analysis of well chemistry, including some of the deeper wells, provides indication of deposition of calcite in the reservoir formations near the wellbore. Some wells have declined in flow by more than can be explained by falls in reservoir pressure and temperature, and this is considered to be related to deposition in the formation.

3.5.3 Trends in Chemistry of Deep Fluids

Dilution and cooling trends have been evident in West Bank wells which produce from shallow depths (450-700 m). West Bank wells with deeper feed zones (eg: BR9, BR20) have shown little change in discharge chemistry since commissioning.

On the East Bank most wells increased in enthalpy during the first three years of production. This trend was accompanied by increasing chloride and gas content. More recently there has been a reversal of this trend in some shallow feeding wells (eg: BR25, 35 and 45) with discharge enthalpies declining toward single-phase conditions. Other, deeper feeding, wells have continued producing excess enthalpy (BR36, 42).

3.6 Reinjection including tracer tests

The reinjection system designed for the Ohaaki development included reinjection wells located near the field margin, but within the field, and other wells in areas considered to be hydrologically more isolated from the hot resource.

Production wells were monitored for returns of reinjected fluid by tracer testing and chemical monitoring. Returns of reinjected water to production zones from most of the infield injection wells were identified within two years of commissioning. Long term tracer tests on the outfield injection wells indicated that there were little or no returns of fluid to production wells. To minimise potential damage to the resource and production, new outfield reinjection wells in the rhyolite formations to the west of the field were drilled and / or commissioned (BR38, 41 and 46), and infield injection wells identified as the source of fluid returns were shut or disconnected from the injection system (BR7, 12, 29 and 30).

3.7 Surface environment

Pressure drawdown, as a result of the 1968-71 discharge testing caused the flow from Ohaaki Pool to decrease, then cease, and the water level to fall (Glover and Hunt, 1996 NZGW). Since 1989, the Pool has been supplied with separated geothermal water from the reinjection system. The base of the Pool has been sealed to reduce and control the amount of water leaking through it.

3.8 Surface deformation

3.8.1 Observed and projected deformation

Small rates of subsidence have been measured over most of the geothermal field. Subsidence at rates of up to 100 mm/y occurs over about 1 km^2 of the steamfield (Allis et al., 1997 NZGW). Figure 4 shows the subsidence from 1988 to 1998.

3.8.2 Geological control of subsidence

The mechanism controlling the localised subsidence is considered to be the compaction in the Huka Falls Formation, as a consequence of dewatering of this formation. The maximum subsidence is centred on BR22. The rate of subsidence is expected to reduce with time as has been observed at Wairakei.

4. Deep drilling and resource review 1995-96

4.1 Background

After 5 years field operation, the production wells were not able to produce sufficient steam to maintain the station at full load.

Temperatures and fluid chemistry in the deep-feeding production wells showed little change and other deep exploration wells showed that there were considerable heat reserves at greater depths.

In 1993 a scientific evaluation of options for development of the deeper heat reserves at Ohaaki was initiated, and in 1995 a deep drilling programme was undertaken.

4.2 Results of the 1995 deeper drilling programme.

Three new wells were drilled and two existing wells were plugged and redrilled to new locations (well tracks are shown on Fig 5). High temperatures (generally 290-300°C) were found in permeable zones in the volcanic formations below the existing production depths and near the greywacke surface (1200-2000 m depth).

Three of the deep wells are successfully producing into the steam production system.

4.3 Reservoir temperatures

There has been no change in the temperatures in the deep wells since they were drilled and since they have been put into production. The deep temperatures are similar for all these wells, and the temperatures of the major feed zones are also similar, at about 280 – 290’C.

5. Conclusion

There have been changes in the Ohaaki geothermal field as a result of the discharge tests undertaken between 1968 to 1971 and since production commenced from the reservoir in 1988. This is particularly so in the shallower parts of the resource.

Even with the field changes that have been experienced the Ohaaki Power Plant has performed well achieving high availability, high output factors and consistent levels of generation from 1989 to 1993.

Since mid-1993, generation has been constrained by the ability of the steam field to produce steam and consequently the annual energy generation from the plant has declined.

The deeper production potential of the Ohaaki resource was identified as a good prospect in 1993. This was proven with a deeper well drilling programme undertaken in 1995. Some wells drilled as part of that programme have subsequently been used to supply the power station.

Additional deep drilling will enable more electrical energy generation from the Ohaaki power station better utilising the installed plant capacity.

6. Acknowledgements

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7. References

Allis, R.G., Carey, B., Darby, D., Read, S.A.L., Rosenberg, M. and Wood, C.P. (1997) Subsidence at Ohaaki field, NZ. Proc 19th NZ Geothermal Workshop, pp 9-15.

Clotworthy, A.W. (1987) Selection and testing of reinjection wells for the Ohaaki geothermal field. *Proc.11th NZ Geothermal Workshop,* pp.67-72.

Clotworthy, A.W., Lovelock B. and Carey B. (1995) Operational History of The Ohaaki Geothermal Field. *Proc. World Geothermal Congress 1995,* pp.1797-1802.

Glover, R.B., Hunt, T.M. and Severne, C.M. (1996) Ohaaki Ngawha;Ohaaki pool, *proc 18th NZ Geothermal Workshop*, pp 77-84.

Grant, M.A. (1982) A heat balance on the Ohaaki reservoir, *Geothermal Circular MAG33*, DSIR, Wellington, NZ.

Hedenquist, J.W. (1983) Characteristics of the Broadlands-Ohaaki water chemistry and changes subsequent to initial production. *Proc. 5th N.Z. Geothermal Workshop*, pp. 151-156.

Hedenquist, J.W. (1990) The thermal and geochemical structure of the Broadlands-Ohaaki geothermal system, New Zealand. *Geothermics*. Vol.9,No 2 pp 155-185.

Hedenquist, J.W. and Stewart, M.K. (1985) Natural CO_2 –rich steam-heated waters in the Broadlands-Ohaaki geothermal system, New Zealand: their chemistry distribution and corrosive nature. *Geothermal Resources Council, Transactions*, Vol.9, Part II, pp 245-250.

Hitchcock, G.W. and Bixley, P.F. (1975) Observations of the effect of a three-year shutdown at Broadlands geothermal field, New Zealand, *2nd U.N. Symposium on Geothermal Energy Development*

Hunt, T.M. (1987) Recharge at Broadlands geothermal field 1967-1983 determined from repeat gravity measurements, *Report No. 216*, Geophysics Division, DSIR, Wellington, NZ.

Mahon, W.A.J. (1969) Recent chemical results from Broadlands drillholes. Internal N.Z. D.S.I.R. Chemistry Division Circular CD 118/12/WAJM/55

Mahon, W.A.J. and Finlayson, J.B. (1972) The chemistry of the Broadlands geothermal area, New Zealand. Am J. Sci. Vol 272, pp 48-68

Mahon, W.A.J. and Finlayson, J.B. (1976) Geothermal survey Broadlands. Sept-Nov, 1976. Preliminary report Unpublished N.Z. D.S.I.R. Chemistry Division Report 118/12/WAJM/57

McGuinness, M.J. (1984) Recent interference tests at Ngawha and Ohaaki, *Proc.6th NZ Geothermal Workshop*, pp. 169-174.

Risk, G.F., Groth,M.J., Rayner, H.H., Dawson, G.G., Bibby, H.M. Macdonald, W.J.P. and Hewson, C.A.Y. (1977) The resistivity boundary of the Broadlands geothermal field. *Report No 123*, Geophysics Division, D.S.I.R. Wellington, N.Z.

Sherburn, S., Clotworthy, A. and Hunt, T. (1993) No induced seismic activity at Ohaaki geothermal field. *Proc 15th NZ Geothermal Workshop*, pp. 201-205

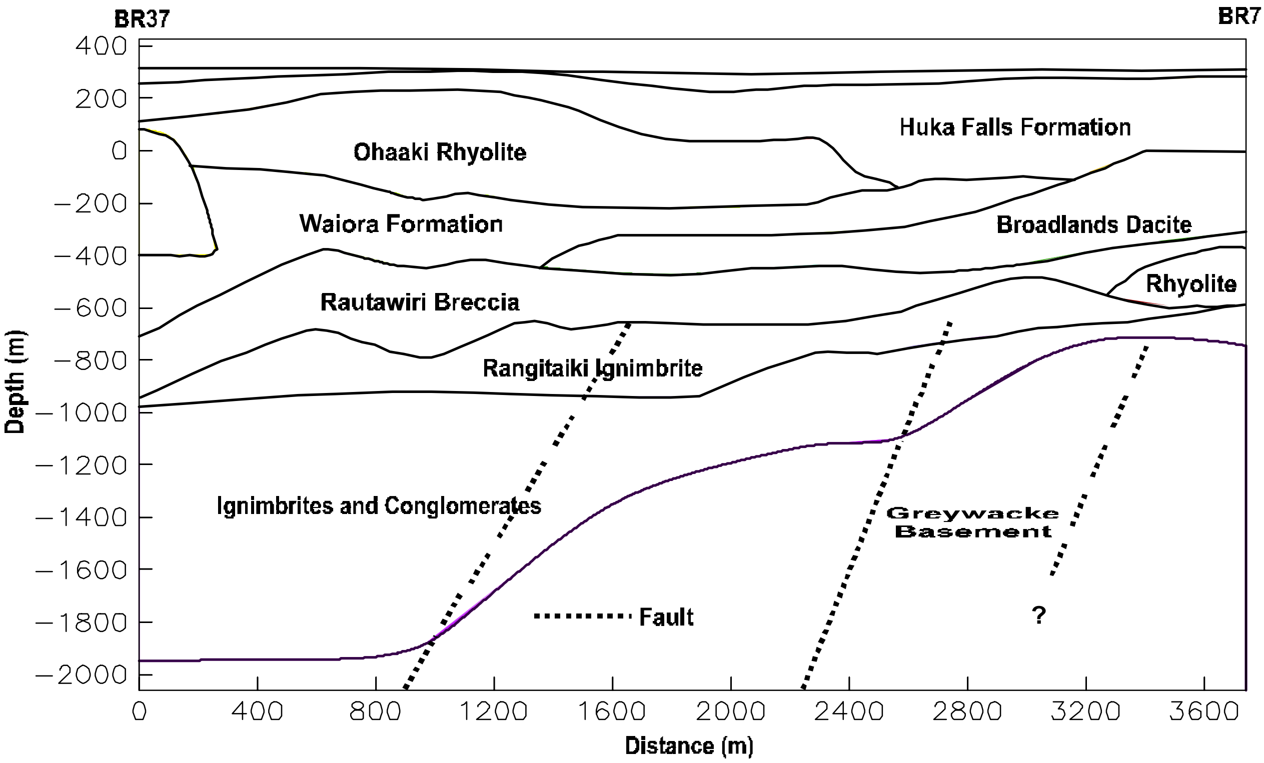

Fig 1: Ohaaki geological cross section BR37 – BR07

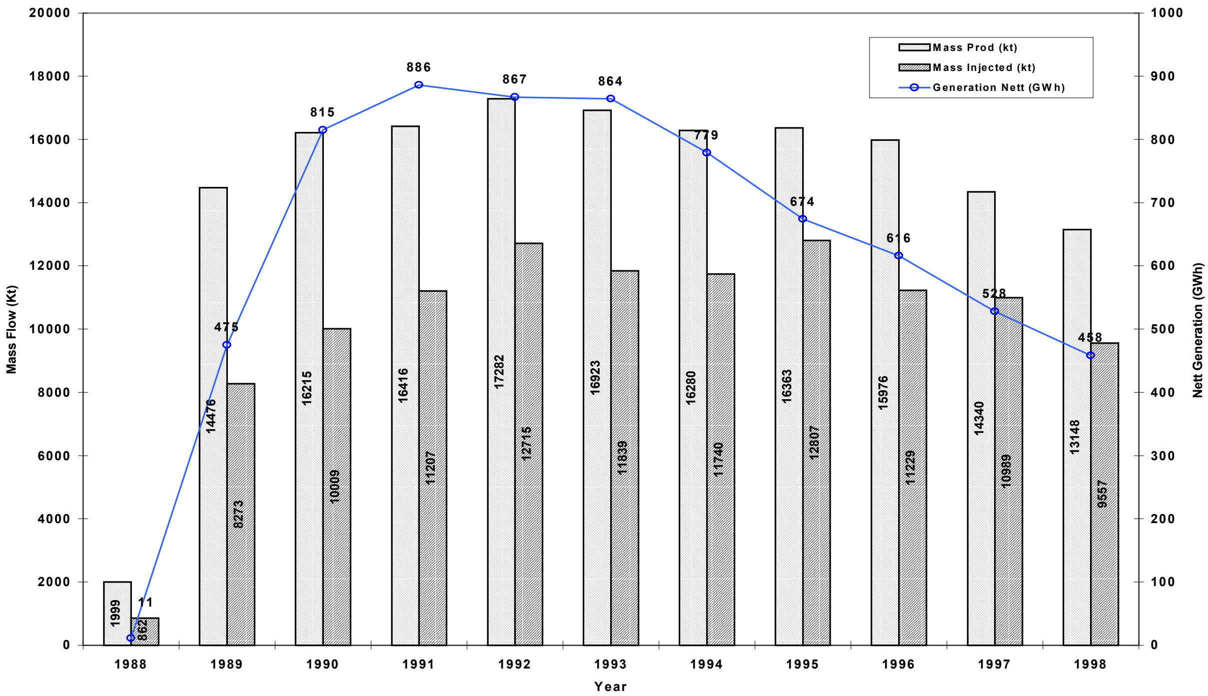

Fig 2: Ohaaki Generation, Production and Injection

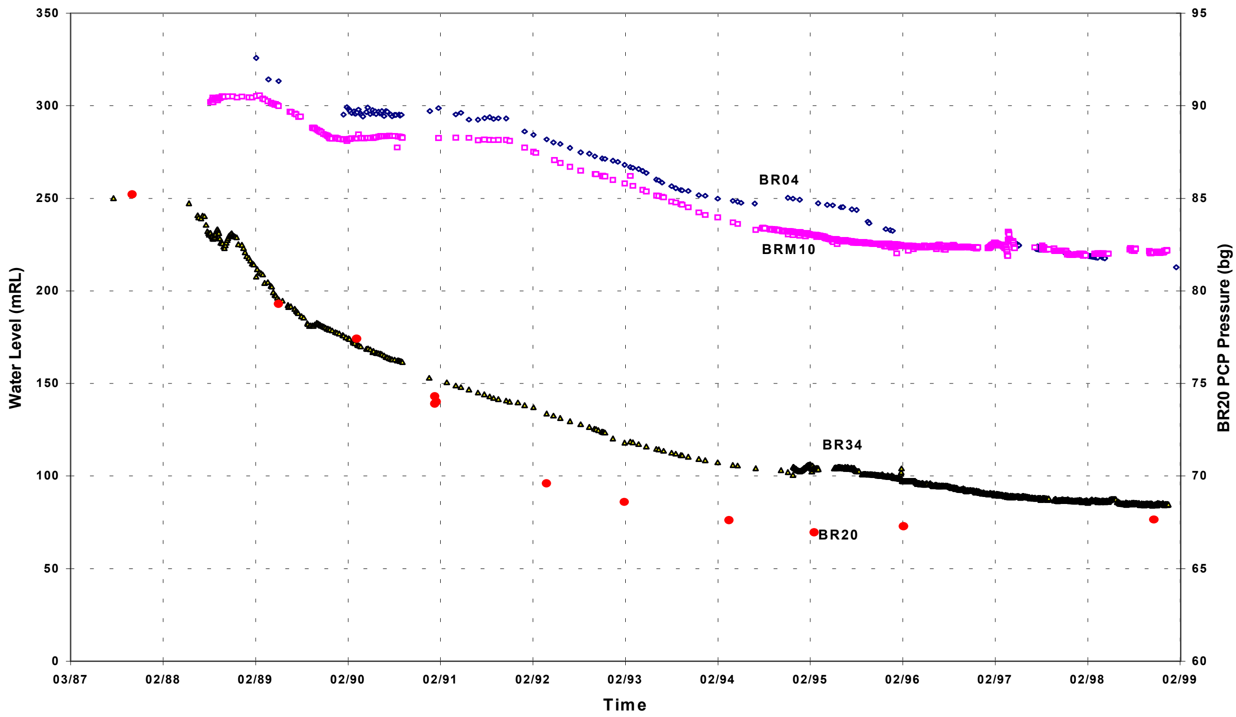

Fig 3: Pressure Trend for Deep West bank Wells and Shallow wells

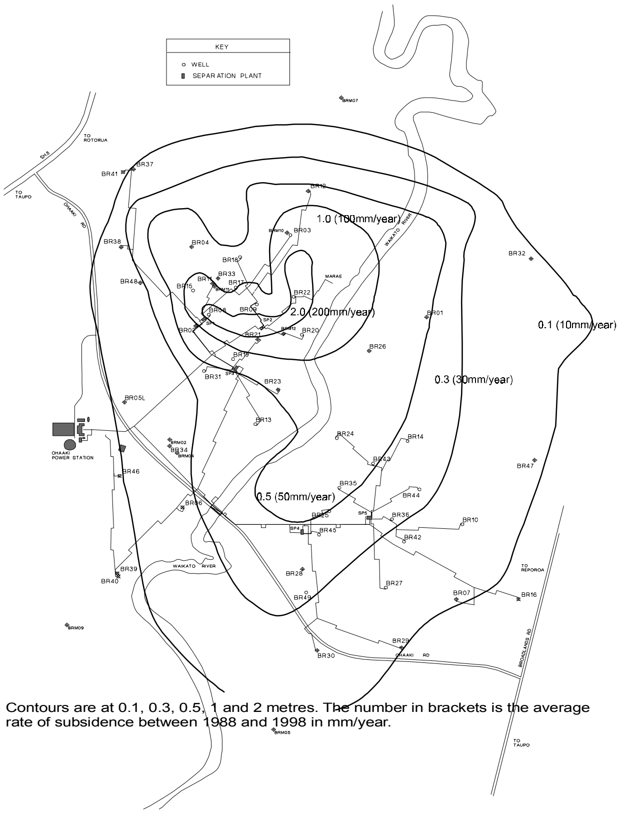

Fig 4: Ohaaki Subsidence from 1988 to 1998.

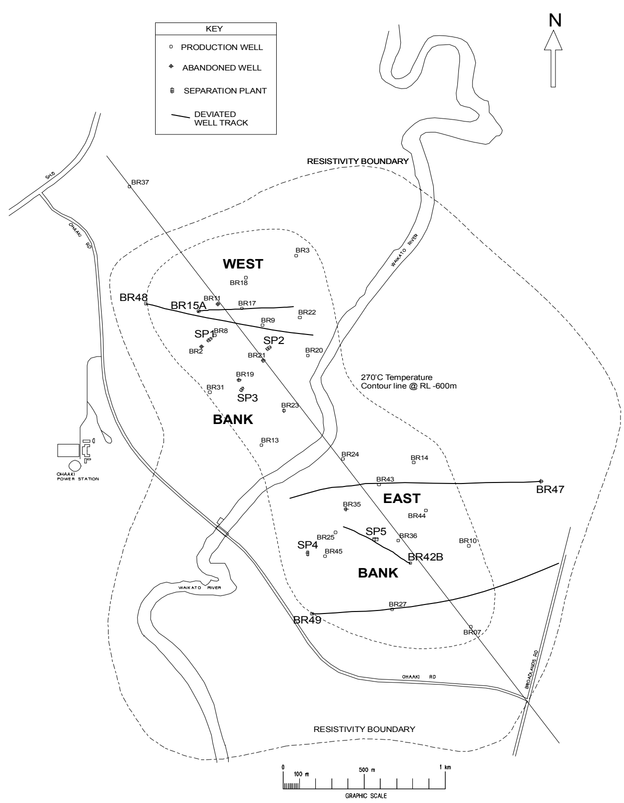

Fig 5: Map of the Ohaaki Geothermal Field