EFFECTS OF BORE CLOSURE AT ROTORUA, NEW ZEALAND

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Abstract

The waning of natural surface activity, in particular the geysers and hot springs at Whakarewarewa, in the late 1970s and early 1980s, prompted a fear that Pohutu and other geysers would soon be lost. Geothermal and hydroelectric development has destroyed most of New Zealand's geysers. Public concerns led to the establishment of a government funded monitoring programme in 1982, resulting in the government-funded enforced closure of many Rotorua wells in 1987.

Pressures rose sharply during the bore closure programme in 1987-88 and subsequently have continued to rise gradually. The bore closure programme reduced withdrawal by about 60%. During the period of high geothermal fluid withdrawal the level of natural hydrothermal activity at surface features declined by about 50% and several geysers ceased erupting. Since the enforced closure of bores, some surface features have shown signs of recovery and eruptions have resumed from one geyser. Other features have shown no signs of recovery.

Introduction

The Rotorua Geothermal Field of New Zealand is recognised internationally for its setting within the Taupo Volcanic Zone (TVZ) and in particular for its local geothermal manifestations which include the Whakarewarewa hot springs and geysers. Geysers are a relatively rare natural phenomenon Worldwide and Pohutu is New Zealand's largest surviving example. The extraction of subsurface fluid (~120 Ktd^{-1}) for geothermal power led to the demise of geyser activity at Wairakei, while many geysers at Orakei Korako were flooded after the construction of a hydroelectric scheme (Lloyd, 1972). Although there are over 20 geothermal fields within the TVZ, only four have been noted for their geyser activity: Wairakei, Orakei Korako, Rotomahana and Rotorua.

Public sensitivity to the intrinsic and tourism values of New Zealand's few remaining geysers increased during the 1980s as geyser and hot spring features failed due to the subsurface extraction of geothermal fluid. These concerns, along with a realisation that there was no quantified estimate of the actual volume of fluid extracted, or adequate records of the changes in the surface activity, led to the establishment of the Rotorua Geothermal Monitoring Programme in 1982. This programme soon established the winter daily mass discharge from wells was around 31 000 tonnes (td^{-1}) and represented about 40% of the natural deep upflow of the Rotorua system (Ministry of Energy, 1985).

In the early 1960s and again in the mid-1970s, mass flows via wells increased as additional wells were drilled (Allis and Lumb, 1992). During this time the level of natural hydrothermal activity declined to reach an all time recorded low in the mid-1980s (Cody and Lumb, 1992). In 1986 the Government initiated a bore closure programme and a charging regime for remaining well discharges. Subsequently fluid pressure in the Rotorua system, represented by the water level in the monitor bores, showed strong recovery. Several hot springs and some, but not all geyser activity have shown signs of rejuvenation.

Geological-Geophysical Setting

The Rotorua system, as defined by surface activity and shallow drillholes, covers about 12 km^2 and is associated with the margin of the Rotorua Caldera (Fig. 1). Thompson (1974) described the regional geology, and Crafer (1974) commented on drillhole geology of Rotorua. Wood (1985) developed a geological model of the Rotorua aquifers, revising it in Wood (1992).

The principal production aquifers are the caldera forming Mamaku Ignimbrites and younger rhyolite domes under the city. Poorly permeable lacustrine siltstones interbedded with sands, gravels and tephra cap the aquifers and form an aquitard. The Whakarewarewa hot springs feed from fractured ignimbrite inside an embayment of the caldera's southern boundary (Wood, 1992). Rotorua City rhyolite lava domes comprise a buried N-S ridge under the city containing mostly sub-boiling water (up to 190°C), which flows laterally through the outer fractured and permeable carapace. Surface activity in the Kuirau-Ohinemutu area is related to structural controls (Kuirau Fault) along the west flank of the northern dome.

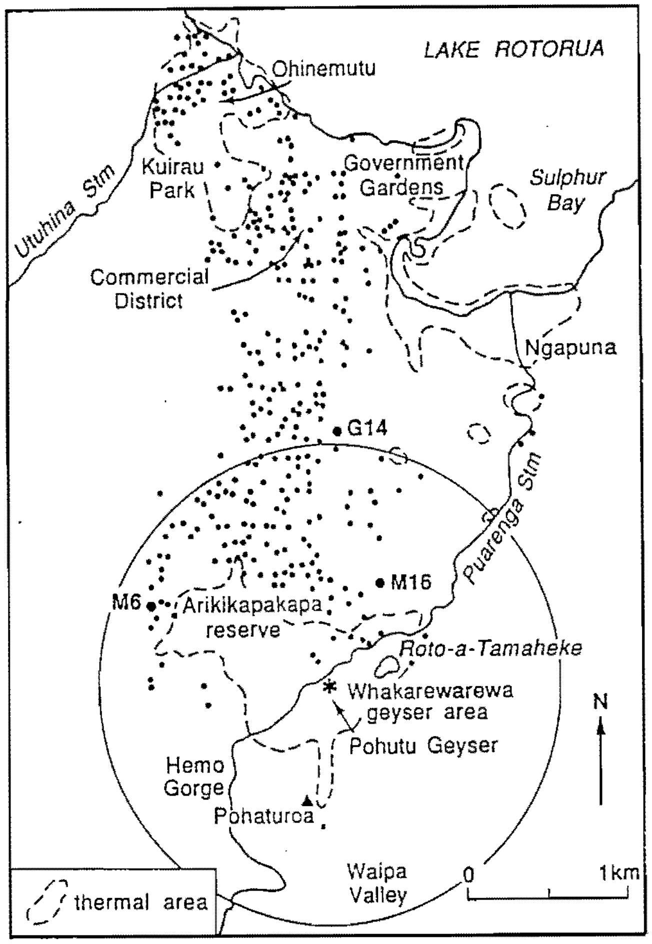

Figure 1: Map showing distribution of wells in 1985, monitor wells and main surface hot spring areas. The circle denotes the area in which all wells were closed.

Geophysical and geochemical studies indicate the field has an area of 18 - 28 km^2 at about 500 m depth and a natural heat flux of 430 ± 30 MW. About a third of its area and over half its heat and mass flux occur beneath southern Lake Rotorua (Allis and Lumb, 1992; Glover, 1992).

Exploitation History

Many of Rotorua's residents have taken advantage of the geothermal waters by drilling wells to extract the hot fluids. These fluids were used for both domestic and commercial heating, with some of the largest commercial users being Government Department offices, hospitals and major tourist hotels (Ministry of Energy, 1985). The first geothermal wells in Rotorua were drilled during the 1920s, with close to 750 wells having been drilled since then. Some of these were replacement or standby wells and some wells were not replaced after casing failures or blockages, so the actual number of wells in use reached a maximum of around 500 in 1985. At that time, the total well discharge was estimated to be 25 000 tonnes day^{-1} (td^{-1}) (290 kg s^{-1}) during summer months, rising to 31 000 td^{-1} (360 kg s^{-1}) during winter months. Only an estimated 5% of the discharge fluids were reinjected to production depths (typically 100 - 200 m). Most of the waste liquid was put into shallow soak holes (<20 m depth) and, contravening a local by-law, into storm water drains. Approximately half the fluid extracted was for residential use and half for commercial use. However, because many wells in the residential sector were shared by several households, 1500 of the total 1840 geothermal users were residential. The dominant commercial sector user in 1985 was tourist accommodation which used 20% of the total discharge (Ministry of Energy, 1985).

The effect of the bore closure programme, when 106 wells within 1.5 km of Pohutu geyser were cemented up (most during 1987), and a charging regime for remaining well discharges was implemented, was a reduction of the total well discharge to about 30% of 1985 levels by 1989 (Timpany, 1990). The average summer drawoff in 1990 was estimated to be 10 280 td^{-1} (118 kg s^{-1}) increasing in winter by 1040 td^{-1} (12 kg s^{-1}). The commercial sector now accounts for 68% of the total discharge, and the reinjected mass has risen to 31% of the discharge (Timpany, 1990). The net mass withdrawal from the field in 1990 had decreased to close to 20% of the 1985 level. By late 1992, only 141 wells were producing 9500 td^{-1}, with 5100 td^{-1} being reinjected (Grant-Taylor & O'Shaughnessy, 1992).

Rotorua Geothermal Field Pressures and Water Levels

A network of geothermal monitor (M) wells was established in 1982, with up to 24 of these located throughout Rotorua city, typically 80 - 180 metres deep. They either stand open to atmosphere or where under-pressure are shut in so that no discharge can occur. Since 1987, total numbers of producing wells has fallen and total withdrawal mass has also been dramatically reduced. By 1995 about 200 wells produced a total of ~11 500 td^{-1}, of which ~7 000 td^{-1} was being reinjected, leaving a net fluid loss of ~4 500 td^{-1} to shallow groundwaters. Within a few more years nearly all this net loss should stop, as reinjection is a mandatory requirement of any water right permit renewal.

M-well responses

All M-wells showed a sudden water level or pressure rise during late 1987 of ~2m, with continual ongoing gradual recoveries to date. M-16 is typical of wells into ignimbrite aquifers and M-6 rhyolite aquifers (Fig. 2). The same general trends are present in all M-wells, although cool waters entering the ignimbrite from the west and proximity to Lake Rotorua at the north cause some wells to show additional short term responses.

Bore Field Management Today

The primary geothermal source aquifer is Mamaku ignimbrite, with outflows from this into the fractured outer layers of buried rhyolite domes and into shallow permeable sediments. Since forced closures of many wells in 1986-87, remaining wells have been progressively modified to reinject waste waters (typically ~80°C) back to source aquifers via disused or specially drilled deep disposal wells.

All water rights to use geothermal wells are short term (~3-5 years) and further renewal of these permits is conditional upon deep reinjection of all waste waters. The intention is that within a few years time nearly all well waste waters will be reinjected back to source aquifers, with the aim of maintaining fluid mass. The Geothermal Institute (Auckland University) has made studies of 30 reinjection wells using production and reinjection pairs (called doublets); to date no adverse effects of reinjection have been identified.

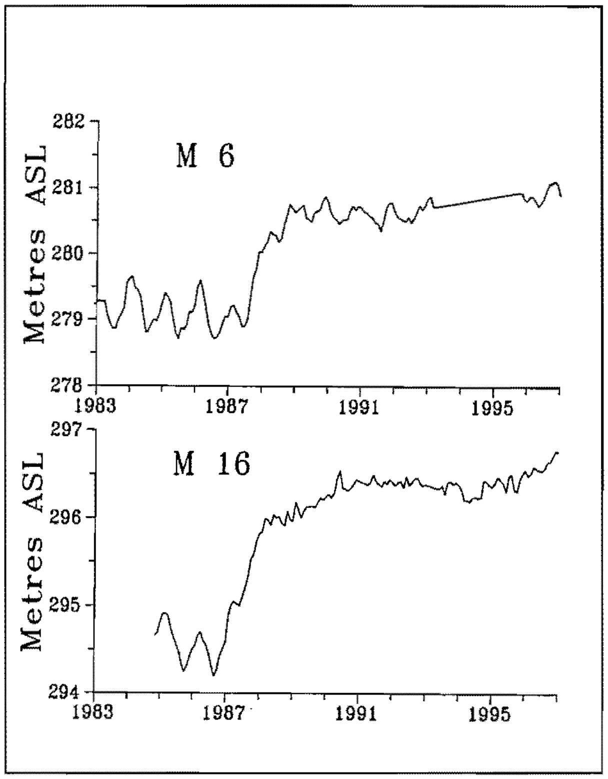

Figure 2: Time series plot of the water level in monitor wells M-6 and M-16.

Prior to forced well closures in 1986-87, some 500 wells were in production producing up to 31 000 td^{-1} in winter months, falling to ~25 000 td^{-1} in summer. Nearly all this produced water mass was then discarded into shallow groundwaters, or illegally into surface drains.

Surface Features

Surface features are generally alkaline, high chloride - low sulphate waters typical of deep waters found in neighbouring wells. Many of Rotorua's geysers and flowing hot springs have shown responses to the sudden reduction of well drawoff in 1987. Although no precise early measurements of total natural outflow are available, estimates are that all hot springs and geysers produced ~17 500 td^{-1} in 1960s, ~13 500 td^{-1} in 1986 and ~20 000 td^{-1} in 1992. This change in outflow of hot springs follows expected trends and is consistent with more geothermal fluids now being available for natural spring outflows. Some areas of natural springs showing significant recovery are mixtures of groundwaters and increased upflows of deep geothermal fluids, but these are given less attention due to the complication of the groundwater availability.

Many springs and geysers have up to c.150 years of intermittent recorded information, but only a few large springs and geysers have substantial quantitative data spanning many decades; today geyser activity is confined to Whakarewarewa. On Geyser Flat there are seven intimately connected and interactive geysers, such that data from any single one of these is itself not indicative of total trends there.

At Geyser Flat, historical qualitative data presents a clear picture of significant decline in outflows and geyser activity during 1950s - 1980s and a pronounced recovery since 1987 to present day. The geysers are fed from the ignimbrite aquifer. These changes are briefly summarised as follows:

Te Horu Geyser: Through historical times up until 1972, this geyser used to erupt 2-7 metres (m) high with about 100 litres per second (lps) outflows, which occurred 10-15 times day. Since 1972 eruptions have ceased and not resumed to present day (February 1997).

Kereru Geyser: Eruptions 10 - 15 m high several times a week until 1972, from when no eruptions are known until they resumed in January 1988. Since then these have occurred every few days and occasionally up to seven per day have been observed in daylight hours.

Waikite Geyser: This last erupted in March 1967 and its vent remained dry and weakly steaming until June 1996, when its previously 8.5 m deep dry vent suddenly filled with boiling waters to within 2.5 m of overflow. It is the highest elevation of any historically active geyser or hot spring at 315 m asl, compared with 302 m asl for Pohutu geyser and 280 m asl for Lake Rotorua. Waikite water levels remain high and boiling. It didn't respond to soap in January 1997.

Pohutu Geyser: Pohutu geyser erupts ~21 m high, 25 - 60 times each day, spending a total of ~35 - 60% of any day in eruption. Its eruptions have not shown any changes conclusively related to well closures of 1986-87. During 1950s - 1980s, Pohutu showed a pronounced shift to more frequent but shorter duration eruptions, possibly consistent with reduced aquifer pressures. However, it is intimately connected with six other nearby geysers and the total mass and heat flows from Geyser Flat have not been quantified. To date it continues to have numerous short eruptions (2-5 mins).

Wairoa Geyser: This last erupted naturally in December 1940, but was soaped into huge eruptions (up to ~50 m high) in late 1950s on many occasions. Since then its water level fell to >4.5 m below overflow and became acidic (low chloride - high sulphate). In early 1996 its water level rose to 3.2 m below overflow boiling powerfully; it remains so.

Okianga Geyser: During late 1970s and early 1980s no eruptions were observed. However, since c.1992 it has been reliably erupting every 25 - 35 minutes to ~7 m high.

Papakura Geyser: This geyser stopped erupting in March 1979 after a very long period (c. 90 yrs) during which it was known to have faltered very briefly only 3 times. It was the cessation of Papakura's eruptions which was directly responsible for the initiation of the monitoring programme. This feature has not recovered.

Parekohoru Spring: In 1985-6 this spring ceased outflowing for several days each winter. Since 1988 there have been no further cessation and boiling surges have recommenced, similar to reports earlier this century.

Outside of Whakarewarewa to the north, near the southern shores of Lake Rotorua, two large springs fed from the rhyolite aquifer have undergone significant changes consistent with well closures and higher water levels as measured in M-wells (Fig. 2).

***Rachel Spring*:** This is the sole remaining boiling, flowing alkaline spring in the Government Gardens. Prior to 1987, its last overflow and boiling episode was in 1967, but since then until 1987 its water level had remained at 1.2 - 1.7 m below overflow (70 - 80°C). Since late 1988 it has been continually flowing 7 - 12 lps, boiling and high chloride waters. It still has brief cessation of overflow, but these last only a few days and water level has never fallen more than 0.1 m below overflow since 1988.

***Kuirau Lake*:** From late 1940s - 1987 this large hot spring (~5 000 m^2) was only warm (~45 - 50°C), acidic, low chloride and without any overflows. Since 1988 it has been consistently overflowing ~50 - 60 lps at ~80°C, high chloride alkaline waters.

The consistently high water levels and large overflows of Rachel Spring and Kuirau Lake are the most visible of all spring recoveries following well closures in 1986-87. Geysers require prolonged observation to witness eruptions and so the general public are less familiar with geyser activity changes, although quantitative instrumental records confirm that most geysers have shown a significant improvement in activity since well drawoff was forcibly reduced in 1986-87.

Summary

Forced closures by central Government was a matter of great animosity and resistance. Subsequent water level recoveries measured in M-wells, resumed overflows of hot springs and resumed eruptions from several geysers is consistent with reduced well drawoff returning more geothermal waters to natural surface spring outlets (i.e. hot springs and geysers). Fluid pressure beneath Rotorua has recovered about half the inferred drawdown caused by a combination of exploitation and a long-term decrease in rainfall prior to the mid 1980s (Bradford, 1992). Geyser activity and hot springs have subsequently been rejuvenated, with some springs overflowing for the first time in over 30 years (Cody and Lumb, 1992).

Acknowledgements

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