GEOTHERMAL ENERGY RESOURCES CAN ALSO BE TOURIST RESOURCES: LESSONS FROM WAIRAKEI AND ROTORUA-WHAKAREWAREWA, NEW ZEALAND

Ian G. Donaldson,* Physics & Engineering Laboratory, D.S.I.R., New Zealand

INTRODUCTION

To date we have tended to dedicate our geothermal systems to a single use; i.e. either as an energy source, as is the case with The Geysers field in California, or as a tourist reserve, as with Yellowstone National Park. With increased energy demand on a local scale we may wish to extract some energy in some areas but at the same time retain the tourist attractions that these areas have. This is already the case in the Whakarewarewa-Rotorua area in New Zealand. The questions currently being asked of us with regard to that area are:

"Is such combined use possible?"
"How much energy will be available (or what are the energy costs of the retention of the tourist features)?" and
"What are the costs in terms of the tourist features of various levels of energy extraction?"

As these questions are almost certain to be asked elsewhere in the future it is relevant to introduce and discuss them here. In this attempt at some answers, I will look first at our experience in the Wairakei, New Zealand, area and then discuss the Whakarewarewa-Rotorua case.

WAIRAKEI, NEW ZEALAND

A general map of Wairakei, showing locations of early drillholes and the hydrothermal areas as they were prior to exploitation, is shown in Fig. 1. This drilling commenced in 1950 and the wells illustrated are those that were drilled by the end of 1956. 18 of these wells were discharged before the end of 1954, the total discharge by that time being 12.5×10^9 kg of fluid (a mean discharge of about 200 kg s^{-1} over a two-year period). By 1968 there were 125 wells drilled into the Wairakei reservoir. The discharge peaked at about 2500 kg s^{-1} at the end of 1964.

Before production commenced there were several areas of natural activity in and around Wairakei. The most prominent of these were the water-based features of Geyser Valley (to the north) and the steam-based features of Waiora Valley (to the west) and Karapiti (to the south). There was also activity in and around Taupo, but this, being some distance from Wairakei, was not thought to be connected with the borefield at that time.

*Manager, Stanford Geothermal Program, 1980/81.

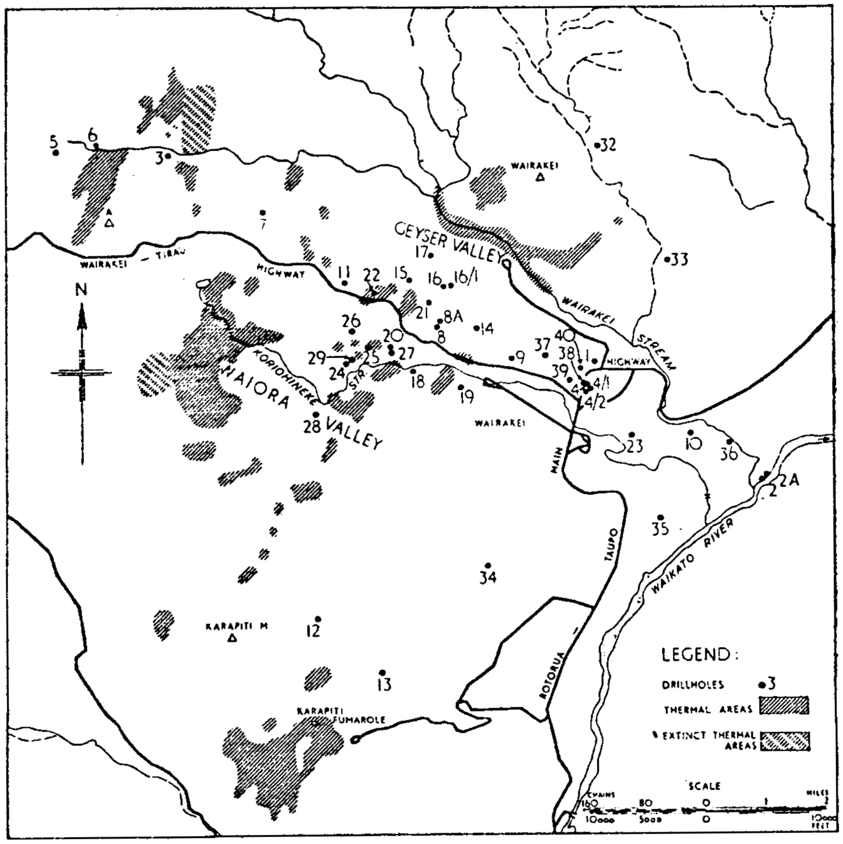

FIG. 1: GENERAL MAP OF WAIRAKEI, SHOWING LOCATIONS OF DRILLHOLES AND HYDROTHERMAL AREAS (Studt, 1957)

Effects of Exploitation

As early as 1954 the activity in Geyser Valley was showing signs of deterioration due to the withdrawals from the Wairakei reservoir, even though these withdrawals were only on the order of half the natural discharge (c. 400 kg s^{-1}). The overall deterioration of the features in this area was quite fast, although the tourist reserve was not finally closed until 1972.

In contrast, the steam-based sections showed no such early decay. Grindley (1974) suggested, in fact, that the total natural heat flow had increased from about 450 to about 750 megawatts over the first 20 or so years of lifetime of the exploited field. With the decay of the water-based features, this would require an increase in the steam heating. Since Grindley's report there has been a marked dying off of these features and zones of activity.

Although the activity within and around Taupo showed a slower response, that response has been similar to that for similar features known to be directly linked with the Wairakei reservoir. Steam-heated features in Taupo, for example, appeared to increase in both size and intensity in the early- to mid-1970's.

Lessons from the Wairakei Experience

This Wairakei discussion unfortunately leaves a lot of questions unanswered. Wairakei is, for example, still exploited heavily, at about 3-4 times the natural discharge rate, and hence we have no direct measure of the likely effects of lower rates of exploitation. Nonetheless, the early effect on Geyser Valley does suggest that we must take care.

Wairakei is also exploited much more deeply than we may need to exploit for local use. This could be either a gain or a loss as far as the tourist features are concerned. We are also continually removing mass from the reservoir, so that we are restricting the availability of liquid water and making no effort to maintain pressure.

Finally, in spite of our observations of the features in Geyser Valley, we still have little knowledge of their sensitivity to drawdown and water supply.

Nonetheless, the effects are much as we might expect from an analysis of fluid removal from a liquid-dominated geothermal reservoir. Removal of mass (fluid) from the reservoir results in a local drop in pressure. This may act to reduce the flow to the surface. This pressure drop will, however, also induce additional boiling and this, in turn, can modify relative permeability factors and hence affect the flow still further. For the water phase it is the change in vertical pressure gradient that is critical. This vertical pressure gradient is usually only slightly above hydrostatic for the fluid temperatures involved. A small change may thus have a significant effect. The pressure change and the decrease in relative permeability will thus act conjunctively to markedly decrease the water discharge.

For steam the pressure effect is relatively insignificant and the greater relative permeability may well act to increase the flow. Ultimately, with significant drawdown and little additional boiling, this balance may no longer be maintained. The discharge will then go down.

It is interesting to note that in spite of the demise of the natural tourist features in the area, Wairakei has maintained its tourist image. The development itself is still sufficiently unique to attract the interest. It is, however, most unlikely that this state of affairs would apply in any future New Zealand situation.

WHAKAREWAREWA-ROTORUA, NEW ZEALAND

The Whakarewarewa thermal area is New Zealand's primary geothermal tourist reserve and obviously there is a lot of pressure to maintain this status. The immediately adjacent city, Rotorua, however, extracts heat from a shallow hot water aquifer that is now known to be connected to the Whakarewarewa system and some energy is also extracted from the system itself, just outside the reserve boundaries. As, with time, the evidence of interaction between the withdrawals and the tourist features is increasing, there is an associated increase in demand for control of the exploitation and the protection of the Whakarewarewa field.

Description of the System

Although the data are limited, the analyses and tests that have been carried out have led to a model of the combined system that appears both consistent and meaningful (Donaldson, 1980; Grant & Donaldson, 1980). This model of the system is illustrated in Fig. 2. In this model the Whakarewarewa features are the main water-based discharge features for the reservoir. Just to the north of these we have some steam-heated features, while further to the north we have a mixed geothermal fluid/groundwater flow out through a horizontal aquifer, or series of flow channels. This is the hot water flow that is tapped by most of the Rotorua wells. To the northeast, and not illustrated in this N-S section, we appear to have other fracture zones or flow paths running out from the main geothermal reservoir. When tapped, these give hotter, higher pressure fluid than is found in the hot water aquifer. This, coupled with their high discharge characteristics, suggests some direct connection with either the deeper water or the two-phase zone adjacent to Whakarewarewa. In either case these flow channels may be considered simply as an extension of that two-phase reservoir.

Effects Attributed to the Withdrawals to Date

The major effects of the withdrawal of heat and fluid from this system that we need to consider are the changes that have taken place in the Whakarewarewa surface discharge features and the changes that we can identify in the reservoir itself. Although there has been a marked decay in surface activity within the Rotorua City area, at the moment this is being taken as an acceptable cost of exploitation. We thus do not consider this directly here.

Changes within the boundaries of the Whakarewarewa Thermal Reserve have been occurring throughout the lifetime of the system. Hence we must expect some natural modification of some features. Several recent changes have, however, occurred during particularly high rainfall (and high groundwater) periods--the highest this century, and hence it is difficult to associate these with the main natural cause, a slow drop in the overall groundwater level.

The main changes that have occurred, both historically and recently, have been the reduction of outflow from hot springs and the cessation of activity of various geysers. Most of these changes have been discussed in some detail by Lloyd (1975). Of particular interest is the more recent cessation of activity of Papakura Geyser. This geyser has only been recorded at stopping once before, for 3 months in 1924, at the end of the driest period (and lowest groundwater levels) this century. The recent cessation of Papakura Geyser was monitored and studied by Grant & Lloyd (1980) and a brief return to activity after an initial cessation has been attributed by them to a 10 millibar change in atmospheric pressure. This shows the sensitivity of such features near their critical point. The water level in this geyser is now down more than a metre from its pre-dormant level.

The most important change in the reservoir itself is the marked pressure drop, estimated by Donaldson (1980) at about 0.5 bar, over the period 1955-75. This drop appears to be relatively uniform throughout the hot water section of the reservoir. As there are no historic data available for the Whakarewarewa area, we cannot get a direct measure of the drawdown there. It is unlikely that in the section of reservoir underlying the tourist features the drawdown would be less than half the hot water zone figure. The drawdown, which might be translated as 2.5-5 metres of water head, must therefore be considered "significant." For management and protection of the tourist features it would obviously be preferable for it not to be increased. To allow for full maintenance of the present features during future dry periods, it may, in fact, need to be decreased.

Controlling the Pressure Drawdown

If we assume that we must reduce the pressure drawdown, we have three potential management alternatives available:

(1) we may reduce the rate of withdrawal and restrict any future expansion;
(2) we may reinject all the extracted fluid or extract heat alone; or
(3) we may resite the withdrawal and injection wells.

As the first of these is likely to be both socially and politically unacceptable it is currently being considered the approach of last resort. Nonetheless, more care and efficiency in usage of the energy could be a big gain.

In considering reinjection we must treat the two sections of the reservoir independently. Within the water section of the reservoir either withdrawal of heat alone or total reinjection of the extracted water should maintain the aquifer pressures. Currently such reinjection is written into the permits. The general drawdown, which could only be established by some distributed withdrawal of fluid from this section, suggests, however, that this reinjected water is not all getting back to the aquifer from which it was taken. It appears that greater care may be necessary in the future.

When we come to the two-phase section of the reservoir the picture is somewhat different. Here, withdrawal of either fluid or <u>heat</u> will instigate a pressure drop. Reinjection of the cool fluid will, in most cases, <u>increase</u> the pressure drop rather than reduce it (Grant, 1980). The options for this section of the reservoir are thus <u>no</u> withdrawal or some pressure drawdown.

By juggling with the siting of withdrawal and injection wells we both increase our options and complicate the problem. The alternatives will depend primarily on our overall approach. We might for example decide on some controlled drawdown of the system to stimulate more heat and fluid flow into the hot water zone. We would then need to balance our withdrawal and reinjection to achieve the state desired. Alternatively, we may wish to mine some of the stored heat from one area. The siting and operation of the wells in that area would then depend on this new requirement.

Within the hot water zone there is little problem foreseen unless we approach an over-production situation. That is something that we will have to work to prevent. In the two-phase areas we do, however, have problems. Here no well is likely to be "far enough away" to be able to be used without some drawdown propagating through to the feature zone. Thus here we have little option but to accept resiting or some drawdown.

Heat Considerations

Total control of the drawdown, at any specific level, must result in the limitation of the heat withdrawal. If, for example, we permit no drawdown, i.e. insist that the field be returned as closely as possible to its original pressure condition, we can permit no withdrawal at all from the two-phase areas, and only a limited amount from the hot water zone. This latter would be controlled by the amount of heat naturally entering that zone, the recoverability factor of the system (which could depend on the well layout and extraction rates as well as the structural composition of the withdrawal and injection zones), and such management decisions as whether to mine some of the stored heat or not.

If, alternatively, some drawdown were permitted, there may be different but still limited amounts of heat available depending on whether we induce that drawdown by withdrawals from the hot water zone or some section of the two-phase one.

Protecting the Tourist Features

Clearly the greater the drawdown the greater the risk for the tourist features. Thus the drawdown limit in the feature zone is the "critical" parameter of this exercise.

At the two extremes are the argument that the current drawdown is a satisfactory limit and the counter-argument that there should be no drawdown at all. The former of these is presumably based on the assumption that if we don't change anything we won't do any more damage. This, however, does not take natural effects into account, and unfortunately, we have little or no idea of just how much a long dry spell may contribute in the future.

The argument for the return to the pre-exploitation condition is presumably based to some extent on the idea that such a return will result in the re-awakening of features that have become dormant over more recent years. Unfortunately, even the full recovery of pressures may be of little benefit to some such features. Reversed flows, cooling, erosion and deposition of silica, etc. from the cooler water means that some features may never recover and others may need much greater pressures than those that existed 30 years ago to restart. We note, for example, that the water in Papakura Geyser has dropped about 1 metre in level in a year since it became dormant. There has been no similar drop in pressures in the reservoir with which we can relate that decay.

Hopefully, there will be a balance at which we should aim. More and better data will, however, be needed before we can even guess where.

CONCLUSIONS

To the "tourist-environmentalist," New Zealand's excursions into geothermal energy extraction at Wairakei and Rotorua may appear to be disasters. We have, however, learned a lot from our experiences and, while we must now recognise Wairakei as an alternative man-made feature to the natural ones that existed prior to exploitation, we feel that there is still time to protect Whakarewarewa and that it is technically possible to do so. Our current theoretical considerations indicate that, with care and good management, utilisation of geothermal energy from this field should be compatible with the retention of the surface thermal features in the tourist reserve.

Limits of withdrawal will depend on the limits on drawdown that can be tolerated by these features and on the location of the withdrawal and reinjection. For the Rotorua-Whakarewarewa system, under the tightest restraints and the most conservative assumptions, it has been estimated that we could still extract about 13 megawatts of heat energy (above 20^{o}C) on a continuous basis (using a recovery factor of 50%). Hopefully, with the optimal management plan we will be able to extract several times that figure.

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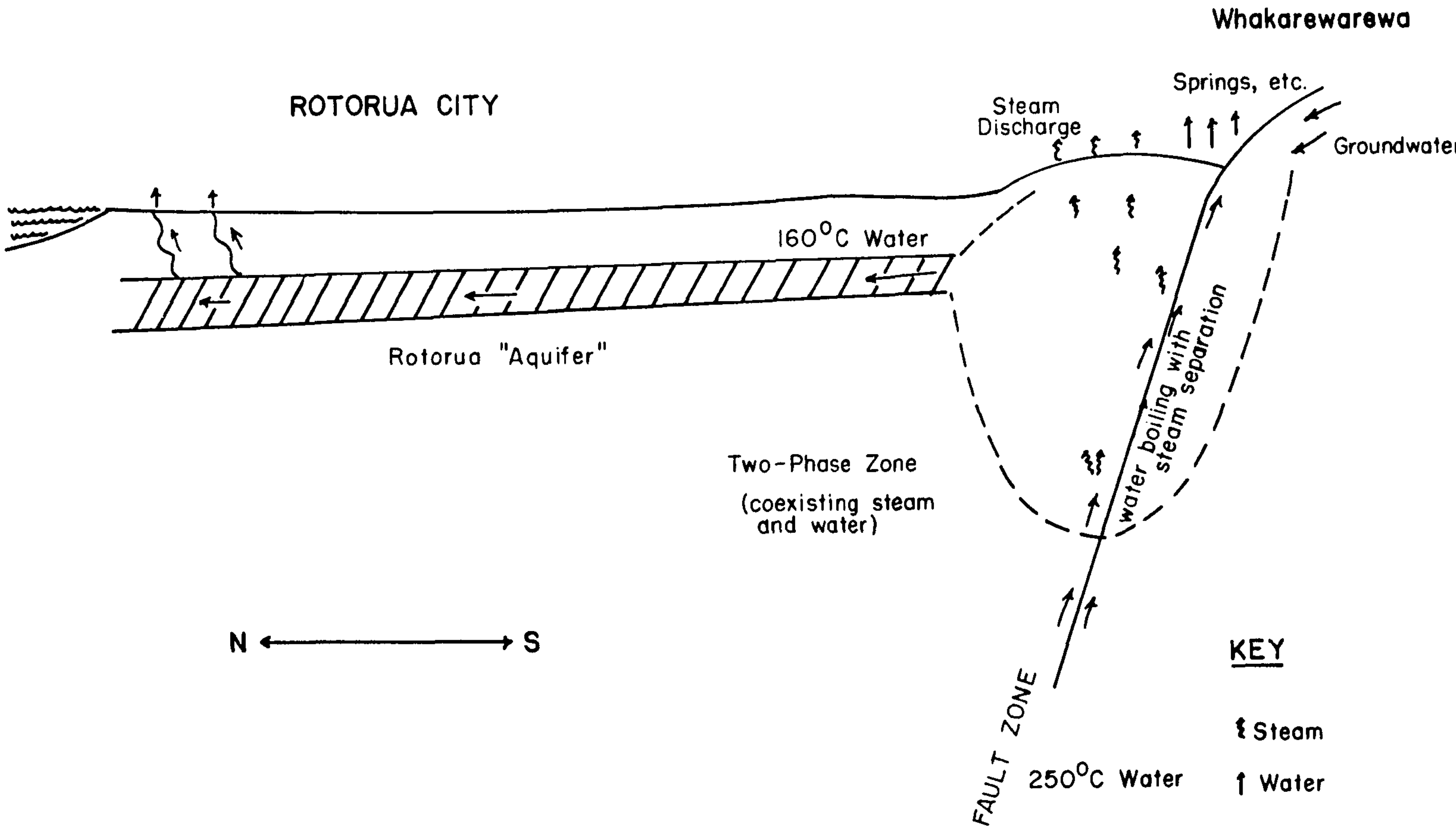

FIG. 2: A NORTH-SOUTH SECTION THROUGH THE UPPER LAYERS OF THE WHAKAREWAREWA-ROTORUA GEOTHERMAL RESERVOIR TO ILLUSTRATE THE LIKELY HYDROLOGICAL CONNECTIONS (Grant and Donaldson, 1980)