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# AN ASSESSMENT OF HEAT FLOW AT WHAKAREWAREWA

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## ABSTRACT

The Thermal Reserve at Whakarewarewa on the southern boundary of Rotorua Geothermal Field is believed to have been under stress for a number of years. Artificial exploitation of the hydrothermal resource appears to be a significant contributor to the observed decline in natural activity. Although the decline has been described in detail it has been difficult to quantify the changes.

Recently all the natural features at Whakarewarewa were resurveyed, the only preceding survey having been made in 1967-69. A total heat flux at Whakarewarewa of 158 MW is estimated on the basis of heat loss from springs due to evaporation, radiation and discharge, and allowing for ground surface heat flow and losses into the Puarenga Stream.

The 1984 resurvey of 285 springs shows a reduction in heat flux of 31% over the 15 year period, while the heat flux through the ground surface has decreased by 23%.

## INTRODUCTION

The Rotorua geothermal aquifer supplies fluid to the natural features at Whakarewarewa Thermal Reserve on the southern boundary of Rotorua City. It is also the source of fluid for many boreholes used for space and process heating. Development at Wairakei in the 1950s proved that large scale exploitation of a geothermal resource is incompatible with preservation of natural surface activity such as geysers and chloride springs. For some years there has been growing concern that artificial exploitation of geothermal fluid in Rotorua is affecting the natural activity. A preliminary analysis of heat flow results (this paper) leaves little doubt that activity at Whakarewarewa is declining.

In the 1960s E F Lloyd had the foresight to see that Whakarewarewa's hot springs might be jeopardised by the growing demand for geothermal energy (unpublished results). Accordingly over the period 1967-69 he conducted a detailed survey (referred to here as Survey A) of the natural features. He mapped the Reserve, gave detailed descriptions of 538 features including chloride springs, geysers, turbid pools, mudholes, fumaroles and collapse pits, and surveyed ground temperatures at 150 mm penetration. His persistence and enthusiasm have resulted in an outstanding database with which all subsequent work at Whakarewarewa can be compared. In the 1984-85 resurvey over 800 features were described, many of which had been overlooked in Survey A because of inaccessibility or small size. A detailed qualitative comparison of Surveys A and B shows that there has been significant cooling and a decline in chloride spring activity (Cody, 1984).

## HEAT FLOW FROM SPRINGS

The rate of heat loss from hot springs is determined using techniques described by Dawson (1964). Annual mean atmospheric conditions for Rotorua have been used in the evaporation equation. Since spring descriptions rarely include any comment on height of ebullition, this factor has been ignored in the calculations which, therefore, provide minimum estimates. Radiative heat loss from hot springs has been assessed using the Stefan-Boltzmann Law of black body radiation modified for the emissivity of a water surface. Relative to evaporative and radiative losses the effects of conduction and diffusion are negligible and have not been included. Surface discharge, where it exists, is a significant means of heat loss and has been evaluated relative to the annual mean ambient temperature of 12°C.

Each feature description from both Survey A and Survey B has been examined and, where appropriate, heat loss due to evaporation, radiation and surface discharge has been calculated. In some cases the descriptions are insufficiently quantitative to allow calculation, while in many others the described features are dry, or contain viscous bubbling mud, or are steaming fumaroles. Dawson's equations are not appropriate in these circumstances, but wherever possible these features have been included in the hot ground survey (see below). Large errors in the heat flow estimates arise because of uncertainties in the pool areas, the mean surface temperature (usually only one spot reading has been taken), and the quantity of discharge. However, since the same techniques have been used in analysing both surveys, comparisons between them should be meaningful.

Despite the large number of features described, only 285 could be identified and quantified in both Surveys A and B (Table 1).

Table 1: Heat loss due to evaporation, radiation and surface discharge from 285 springs at Whakarewarewa.

| | Evaporation & Radiation | Discharge | Total |
|---|---|---|---|
| Survey A | 108 MW | 27 MW | 135 MW |
| Survey B | 76 MW | 17 MW | 93 MW |

On the basis of this 285 spring comparison there has been a 31% decline in heat loss from springs with the biggest change attributable to decreased mass discharge. This is consistent with Cody's (1984) qualitative comparison of the two surveys in which cooling is expressed by a 40% reduction in the number of boiling chloride springs and a 15% reduction in the number of discharging springs.

If all springs in Survey B for which heat loss can be calculated are summed, this results in a flux of 100 MW, which can be taken as a minimum estimate of the current total natural heat loss from springs at Whakarewarewa.

Geysers have not been included in the above analysis, because of the practical difficulties in assessing their discharge. No estimates are available from Survey A, but Cody (pers. comm.) has recently assessed an order of magnitude discharge for four geysers on the basis of average eruption time, column height and cross sectional area of the vent. Heat flow is then calculated relative to ambient temperature assuming the enthalpy of boiling water (Table 2).

Table 2: Heat flow due to geyser discharge

| Geyser | Mass discharge ($m^3$/day) | Heat loss (kW) |
|---|---|---|
| Prince of Wales' Feathers | 325 | 1386 |
| Pohutu | 1600 | 6826 |
| Waikorohihi | 415 | 1770 |
| Mahanga | 13 | 55 |

## HOT GROUND SURVEY

Survey A included the measurement of over 1150 ground temperatures, 150 mm deep, covering a total area of about 400 000 $m^2$. These measurements were all made during October-November 1968. The repeat survey, conducted in January-February 1985, involved over 1500 measurement sites. A check for consistency was made during Survey B by reoccupying a series of sites. In general, data points were reproducible to within 5°C. Different seasonal conditions prevailed for the two surveys, but Allis (1979) shows that error bars of ± 5°C may be applied in comparing 150 mm temperature readings in spring and summer.

All data points for each survey were plotted on a map and contours were evaluated at 20°C, 40°C, 60°C and 80°C. Although the errors in individual data points are not large, contouring involves assumption and interpolation, which may lead to large errors. Since the same analysis technique has been used for both surveys, comparisons should still be reliable. Ground surface heat flow has been determined using Dawson's (1964) empirical equation based on the areas defined by map contours (Table 3).

Table 3: Comparison of ground surface heat flow defined by temperature contours 150 mm deep

| Contour | Heat flow Survey A | Heat flow Survey B |
|---|---|---|
| $20^{\circ}C \leqslant T \leqslant 40^{\circ}C$ | 1233 kW | 1144 kW |
| $40^{\circ}C \leqslant T \leqslant 60^{\circ}C$ | 1912 kW | 2314 kW |
| $60^{\circ}C \leqslant T \leqslant 80^{\circ}C$ | 2891 kW | 2521 kW |
| $80^{\circ}C \leqslant T$ | 4242 kW | 1904 kW |
| Total | 10278 kW | 7883 kW |

This represents a total decline in ground surface heat flow of 23% which is broadly consistent with the decline observed in the springs. Temperatures less than about 40°C are less reliable because of diurnal and seasonal variations in air temperature. Not surprisingly, the largest change between Surveys A and B has occurred at temperatures greater than 80°C. An increase in heat flow in the 40-60°C range is most apparent at higher elevations further from the geothermal source area at Whakarewarewa. These observations are consistent with increased steam heating due to decreasing pressures in the geothermal aquifer.

## SEEPAGE INTO THE PUARENGA STREAM

Bradford and Glover (1984) have estimated the heat gain of the Puarenga Stream as it drains through Whakarewarewa Thermal Reserve. Their estimate of approximately 40 MW is based on chemical, temperature and flow data collected both upstream and downstream of the Reserve. Many springs, both on the streambed and its banks, contribute to this discharge. Because of lack of definition and susceptibility to flooding by the stream the majority of these springs were not included in the evaporative, radiative and surface discharge heat loss assessment. Some springs which were included in these calculations also discharge into the stream, resulting in errors which are likely to be insignificant relative to the errors in calculation of heat flow from springs.

The absence of equivalent data from the Puarenga Stream for earlier years makes it impossible to investigate changes over a period of time.

## DISCUSSION

A significant and dramatic decrease in heat flow, amounting to about 30%, has occurred at Whakarewarewa between Surveys A and B. The change observed is consistent with a pressure decline resulting from increased artificial extraction of fluid from the geothermal aquifer. In particular there has been a large decrease in the surface discharge of chloride springs, and ground temperature results suggest increased steam heating of shallow groundwater.

Heat flow at Wairakei measured in 1951-52 and 1958 (Fisher, 1964), during which time artificial discharge from the field increased by a factor of 14, showed a 25% reduction in heat loss by evaporation from springs in Wairakei Geyser Valley and a 43% reduction in heat discharge into the Wairakei Stream. Over the same period hot spring and geyser activity at Wairakei Geyser Valley declined steadily.

The results presented here not only quantify the changes at Whakarewarewa since Survey A, but also allow an estimate of the total natural heat flow under current conditions. The major heat losses occur by evaporation, radiation and surface discharge from hot springs, for which Survey B gives a minimum value of 100 MW, plus another 10 MW for geyser discharge. Seepage into the Puarenga Stream accounts for 40 MW, while ground surface heat flux adds about 8 MW. Summing these components gives a total of 158 MW. Taking the artificial drawoff as 32 000 tonnes/day at an average discharge enthalpy of 650 kJ/kg gives a total artificial heat flux of about 220 MW relative to ambient temperature.

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