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INTERPRETATION OF REPEAT SHALLOW TEMPERATURE SURVEYS AT WAIRAKEI AND BROADLANDS FIELDS

R.G. Allis and S. Webber

Geophysics Division, D.S.I.R.,
Wairakei, Private Bag, Taupo

ABSTRACT

Repeat 1 m depth temperature surveys indicate significant cooling in the Wairakei production borefield, and little change at Broadlands field since the late 1960's. In the *area* of decreased temperature at Wairakei, the groundwater level has fallen by >10 m, but the temperature at the water level has *increased* during this time. These changes appear to be due to the movement of water vapour in a 10-20 m thick *zone* above a boiling or near-boiling water surface. *Once* the water surface descends below about 20 m depth, the shallow thermal anomalies become small and may be masked by other perturbing factors such as infiltrating rainwater. In areas with a falling groundwater surface, thermal anomalies may only persist if the groundwater is strongly boiling, and the steam flow is sufficient to reach the surface before significant condensation.

INTRODUCTION

Shallow temperature surveys, mostly at one metre depth, have been used for mapping the extent of thermal ground in the Taupo-Rotorua area since the mid 1950's. However, Allis (1981) pointed out the limitations of such surveys for measuring surface heat flow, or heat flow changes. This is because most of the heat from geothermal fields such as Wairakei or Broadlands is flowing by convection (i.e. steaming ground, hot springs, etc.) rather than by conduction. In areas of convective heat loss, the heat flow is much more sensitive to mass flow than to the temperature at 1 m depth. Also, most of the heat flaw often occurs in relatively small areas, and unless the ground temperature is measured on no more than a 1 m grid spacing, a 1 m depth temperature map gives a very poor indication of the heat flow. Such a high density of measurements is impractical, and 15 cm depth measurements are usually made for heat flow surveys.

Despite these short comings, previous 1 m depth temperature surveys have shown that large areas of both Wairakei and Broadlands fields have a temperature >25°C. The extent of the thermal anomalies is much larger than what could be inferred from vegetation changes or 15 cm depth temperature measurements. At Broadlands field, a 1 km² thermal anomaly coincides with the production borefield on the west side of the Waikato River. Similarly *sited* thermal anomalies exist within the Wairakei production borefield, and at several other parts of Wairakei field. The extent of these anomalies suggests that they may be due to above-normal temperature at the underlying groundwater surface.

Allis (1981) noted that the main area of Wairakei field which had shown a significant heat flow decrease since 1950 was on the northern side of the production borefield (Fig. 1). It was suggested then that the heat flow decrease may have been caused by cold groundwater flowing down into the production borefield along faults which were originally conduits for hot reservoir water flowing to the surface at Geyser Valley. This suggestion raises the possibility that detailed 1 m depth temperature surveys may indicate the area(s) of cold groundwater invasion. It may also be possible to detect an advancing cold groundwater front with repeat surveys. However, an unambiguous interpretation of shallow ground temperature changes would also require knowledge of groundwater depth changes. For example, if the groundwater temperature remained constant, but the groundwater level declined, a decrease in the overlying ground temperature should occur. Clearly, repeat 1 m depth temperature surveys should be accompanied by repeat measurements of water level and, preferably, water temperature in any groundwater wells in the survey area.

This was the rationale behind the measurement programme undertaken at Wairakei and Broadlands fields between November, 1982 and February 1983. At Wairakei, the survey area was restricted to the production borefield, because this area contained the main area of decreased heat flow since 1950 (Fig. 1). The survey area at Broadlands covered the entire field, but most effort was concentrated on defining the thermal anomalies on the Ohaaki (west) side of the Waikato River. There is already some evidence that cold groundwater may have entered the production borefield on that side of the field (Allis, in prep.). A more complete discussion of the measurements and their interpretation will appear as a Geophysics Divieion, D.S.I.R. Report (Allis and Webber, in prep.). In this paper the results are briefly summarized, and the emphasis is on the causes of the changes in 1 m depth temperature found at Wairakei field.

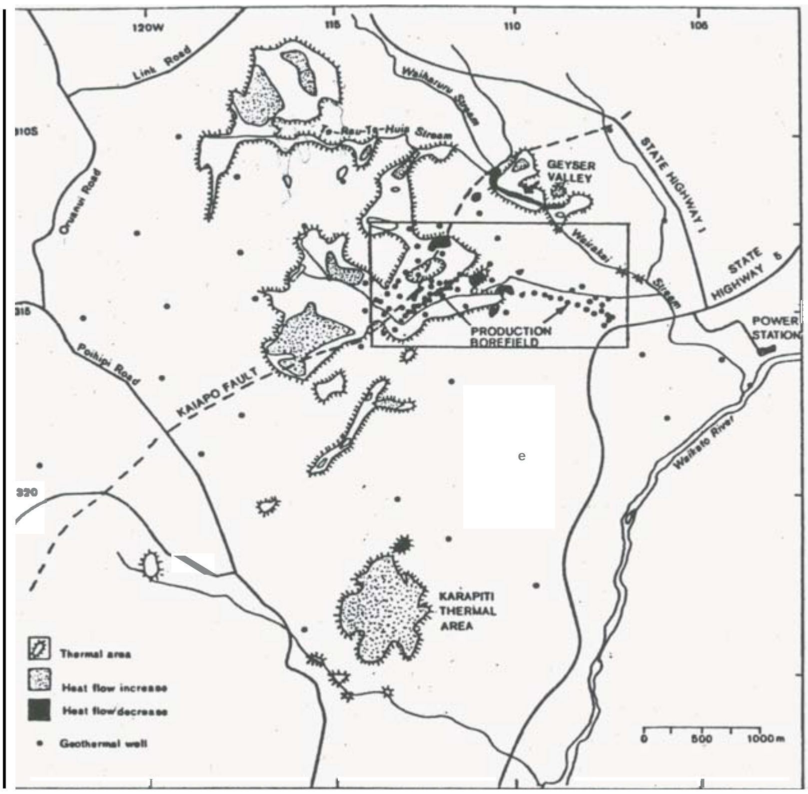

Fig. 1: Location of 1 m depth temperature survey area at Wairakei field. Stippled and dark areas on map are thermal areas where significant heat flow changes have occurred since 1950. Grid coordinates are in 1000 feet west and south of Uaketu datum.

RESULTS

Space limitations in this paper do not permit a map of the actual temperature measurements at Wairakei to be shown. However, a summary Figure showing the changes in 1 m depth temperature contours in the production borefield between 1958, 1962-1966 and 1982-1983 is given in Fig. 2. Although the contours on the 1958 map are less precise than those on subsequent maps, gross differences between the 3 maps probably reflect real changes in ground temperature. In particular, the area of ground at >50°C is much smaller in the 1982/83 *survey* than in both the earlier surveys. The area of ground above 25°C (20°C in 1958) increased between 1958 and 1962–1966, but has significantly decreased subsequently. The largest changes appear to have occurred near the centre of the production borefield where the thermal anomaly between wells 52 and 14 has almost disappeared. This anomaly contained over 10^4 m^2 of ground with a temperature >50°C in 1962-1866. A quantitative summary of these changes is given in Table 1.

The changes in areas of the thermal anomalies shown in Fig. 2 are similar to the heat flow trend for all of Wairakei field since exploitation began in 1950 (Allis, 1981). Heat flow increased during the late 1950's and early 1960's, reaching a peak around 1963 and 1964. Since then, there has been a gradual decrease in heat flow. Based on this comparison, it is tempting to suggest that the decrease in the extent of thermal ground in the production borefield is due to a decline in heat flaw from depth. That is, a decreased steam flow from the production zone has caused the ground-water to cool off. *An* alternative suggestion in Allis (1981) is that there has been additional cooling in this area of the field due to cold groundwater invasion. A study of the ground-water level and temperature changes in this area indicates that both these suggestions are incorrect. This topic is discussed in the next section.

The 1 m depth temperature map of Broadlands field is shown in Fig. 3. This map provides more detail of the thermal anomalies west of the Waikato River than do the earlier thermal maps of Thompson (1968) or Dickinson (1968). Detailed comparison with these earlier maps is not possible, so the *maps* have not been reproduced here. The approximate area and location of the thermal anomalies on the earlier maps and the present one are similar, suggesting that no major changes in the shallow thermal regime have occurred as a result of the drawdown and subsequent

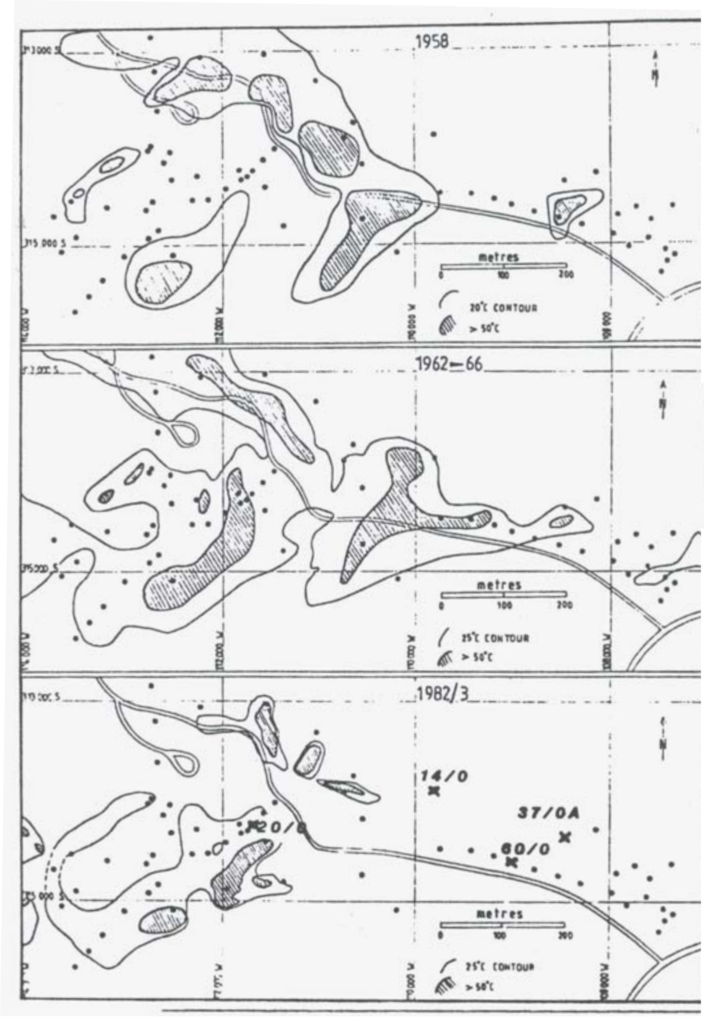

Fig. 2: Comparison of thermal anomalies in the Wairakei production borefield, in 1958, 1962-66 and 1982-83. Four groundwater wells discussed in text are shown on the 1982-83 map.

Survey Date	Area of ground with temperature >50°C	Area of ground with temperature >25°C*
1958	0.1 km^2	0.4 km^2
1962-66	0.1	0.6
1982/83	0.05	0.2

* >20°C in 1958

Table 1: Comparison of the areas of thermal ground shown in the three maps of Fig. 2.

recovery of the production zone. On the west side of the Waikato River, the maps show cooler temperatures between the main production borefield area, and the thermal area around BR6, in the south of the field. A previously unmapped thermal area was found 200 m north of BR5. Inspection of 1968 air photographs shows that it was present then, and therefore it is unlikely to be a new feature. The seeps identified by Dickinson (1968) along the west bank of the Waikato River adjacent to BR22, and on both banks adjacent to BR6 were confirmed during the 1983 survey.

EFFECT OF WATER LEVEL CHANGES

There have been large groundwater level changes beneath much of the Wairakei production borefield and it is possible these have significantly affected 1 m depth temperatures. A compilation of all the groundwater data from wells having both water level and temperature measurements is contained in Allis and Webber (in prep.), and a summary of the data was given in Allis (1982).

In this paper, the groundwater changes in Wairakei wells 14/0, 20/0, 37/0A and 60/0 are considered in detail, because of their proximity to the area of cooled ground in the centre of the production borefield (Fig. 2). In addition to the water temperature measurements usually made in the wells, measurements were also made in the overlying air column of these four wells. The accuracy of the air measurements is probably ±2°C.

Fig. 4 shows that the water levels in wells 14/0, 37/0A and 60/0 have fallen by over 10 m, but the temperature at the water level has *increased* since the mid 1950's. In wells 37/0A and 60/0, the temperature increase has been around 20°C, and in well 14/0 the increase has been >50°C. The water level in the well 20/0 has fallen by only 5 m, and the temperature increase at its water level has been 10°C. However, it is possible that the temperature at the present depth of the water level in 20/0 has not changed greatly with time.

In this area, therefore, one metre depth temperatures have decreased with time, despite an increase in the underlying groundwater surface temperature. If the heat transfer between the groundwater surface and the ground surface is purely conductive, and the temperature at the surface is assumed *to be* constant at 15°C (approximate mean annual ground temperature), then the mean annual temperature at 1 m depth should have risen by about 3°C *around* the 14/0, and there should have been less than 1°C change in the other 3 wells, according to the changes shown in Fig. 4.

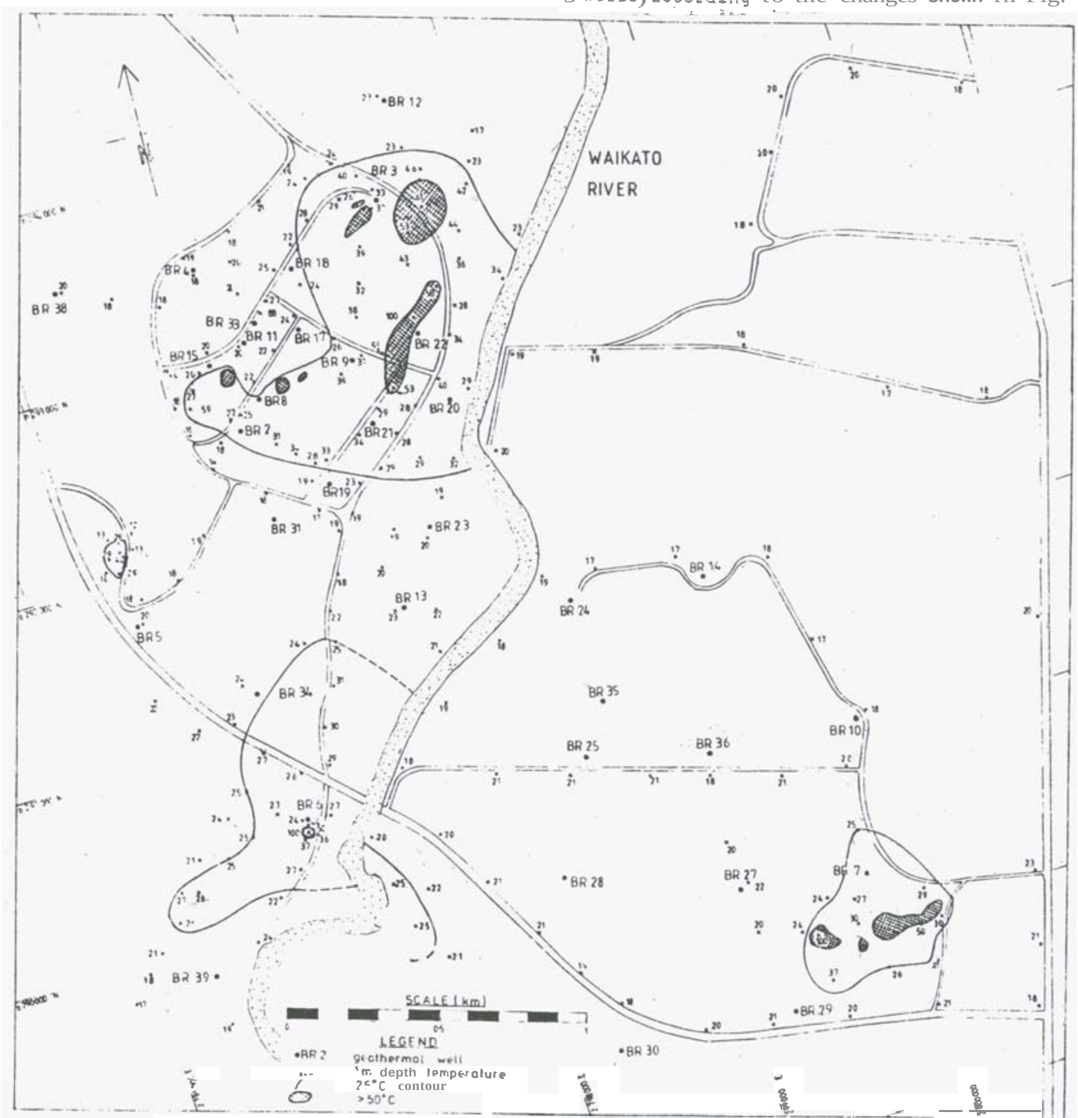

Fig. 3: 1 m depth temperatures at Broadlands field. Measurements were made between January-February 1983.

Since much larger changes have occurred, it would appear that convective processes have been dominant. Two convective processes may be operative. Near the ground surface, infiltrating rain water may reduce the temperature gradient, and conductive temperature changes would be attenuated or masked. It is also possible that above a hot groundwater surface, upward movement of water vapour may be dominant. This would also reduce the soil temperature gradient where convection is dominant, and the ground temperature would be closer to the water level temperature than that expected from a conductive temperature gradient.

There is some evidence of these two convective processes in the temperature profiles of wells 20/0, 37/0A and 60/0. In wells 37/0A and 60/0, the temperature profiles are concave upwards between the ground surface and about 20 m depth. The shape of the profiles cannot be due to the annual temperature wave propagating into the soil. This wave is attenuated to around ±1°C at about 5 m depth. Assuming the temperature of the air-filled portions of these wells is close to the actual soil temperature outside the well, the concave curvature of the profile could be caused by infiltrating rainwater. The lack of similar curvature in the temperature profile of well 14/0 is puzzling. Possibly its location beneath pine trees has decreased the amount of infiltrating rainwater. In well 20/0, the boiling water surface is presumably close enough to the ground surface so that the movement of water vapour dominates all other effects.

The two hottest wells in Fig. 4, 20/0 and 60/0 show upward convex curvature of the temperature profile over at least a 10 m interval immediately above the water level. In both these wells the temperature at the water level is within 2°C of the boiling point. The convex curvature is undoubtedly due to steam rising from the water surface. Well 20/0 has a high temperature gradient up to the ground surface, which is consistent with the anomalous 1 m depth ground temperatures measured near this well (the three measurements within 50 m of the well were 29, 37 and 43°C). In contrast to well 20/0, well 60/0 has a relatively low temperature gradient between the ground surface and 5 m depth. The water level in 60/0 is 12 m deeper than in 20/0, so the water vapour movement is apparently insufficient to rise the additional distance to the surface. The results from these two wells suggest that the upward movement of steam or water vapour above a hot groundwater surface can significantly perturb the ground temperature within 10–15 m of the water level. If the groundwater is actually boiling (i.e. steam bubbles are rising through the water) then the movement of steam and water vapour will probably have a greater effect on ground temperatures above the water level. In such areas steam may flow up to the surface even if the boiling water surface is >20–30 m below the ground surface.

The comparison of air temperature profiles in wells 20/0 and 60/0 highlights the problems of using 1 m depth temperature changes to infer groundwater temperature changes. A drop in water level of around 10 m, as has occurred in 60/0, is sufficient to cause a 20–30°C drop in the temperature at 1 m depth. This temperature drop may be enhanced by infiltrating rain water, as has also apparently occurred in 60/0. The water level drop has completely masked the 20°C temperature increase which occurred at the water level while the water level in 60/0 was falling. These results imply that 1 m depth temperature monitoring is a very poor indicator of the underlying groundwater temperature changes.

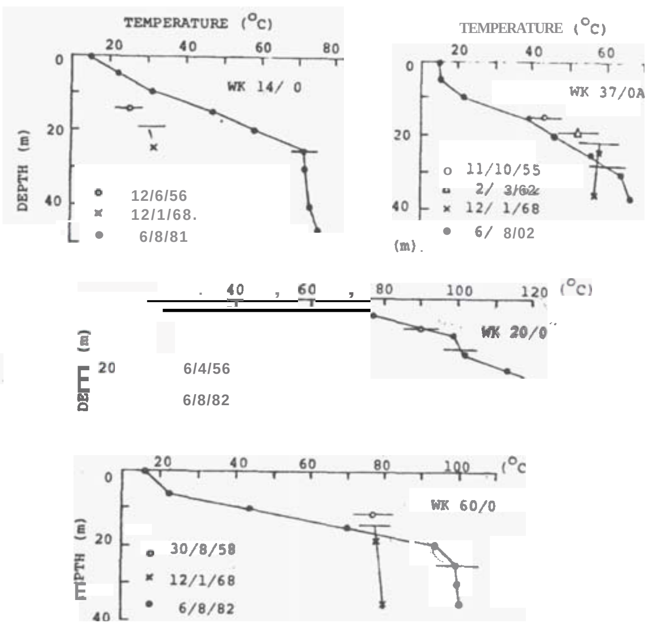

Fig. 4: Temperature-depth profiles in four groundwater wells in the Wairakei borefield (located in Fig. 2). Horizontal bars on profiles indicate the water level at the time of measurement.

CONCLUSIONS

The results of this study indicate that declining surface thermal activity in exploited geothermal fields must be interpreted cautiously. A correct interpretation depends on groundwater wells being present in the area where the changes have occurred, and furthe these wells must have been monitored regular for both temperature and water level changes. If the depth to the groundwater surface does not change with time, then the monitoring of 1 m depth temperatures may be a useful indicator of groundwater temperature changes. However, the use of such surveys at Wairakei and Broadlands fields will be limited because both production borefields are in areas where the groundwater surface has been drawn down by withdrawal of fluid from greater depth. The conclusion in Allis (1981) that the surface heat flow decrease on the northern side of the Wairakei production borefield was due to cold water invasion from the Geyser Valley area may be incorrect. This study has shown that groundwater temperatures have generally increased, and the decreased thermal activity is probably due to the decline in groundwater level in this area of the field. Although there is no shallow temperature evidence of a cold groundwater invasion, groundwater is probably flowing down to the production depths in this area of the field. The evidence for this is the drawdown of the groundwater in this area, and the most likely sink is the underlying production zone.

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