TEMPERATURE, RESISTIVITY AND SELF' POTENTIAL INVESTIGATIONS OF KUIRAU PARK , ROTORUA GEOTHERMAL FIELD, NEW ZEALAND

S. SOENGKONO, E. SUHANTO, C. TEECE, A. H. A TUAH,
C. E. MEJIA DIAZ & K. TANSUPO

Geothermal Institute, University of Auckland

SUMARY – Temperature, resistivity and self potential (SP) surveys were carried out across Kuirau Park, Rotorua geothermal field, in September 2000 and August 2001. The temperature survey showed that the total amount of heat discharged at Kuirau Park was about 30 MW (September 2000). The result also suggests a possible relationship between ground temperatures and near future hydrothermal eruptions. The resistivity survey delineated the extent of shallow hydrothermal alteration which affected the upper part of the buried Rotorua rhyolite dome. Our preliminary interpretation of self potential (SP) data suggests the existence of some source regions of electric potential that may be associated with geothermal activity at 100 to 300 m depths. There is indication of a possible relationship between production of geothermal fluids from the Rotorua sytem and temperature variations at Kuirau Park.

1.0 INTRODUCTION

Kuirau Park in Rotorua City is one of the main discharge areas of the Rotorua geothermal system (Fig. 1). The park contains a mixture of various types of thermal manifestations, such as alkaline chloride and bicarbonate springs and pools, mud ponds, hot and warm lakes and turbid acid sulfate pools, some of which have been partially landscaped in keeping with its function as a city park.

Kuirau Park is situated near the northwestern boundary of the Rotorua field delineated by Schlumberger resistivity mapping (Bibby et al., 1992). This area is underlain by Rotorua rhyolite domes which are buried beneath a variable thickness of pumice and silt layers. A concealed, possibly active fault trending NNW-SSE (the Kuirau fault) has been iderred to be associated with the thermal activity at Kuirau Park (Wood, 1992). Geochemical studies suggest that the chloride-bicarbonate waters discharged by the thermal manifestations represent a secondary upflow zone of the Rotorua system (Stewart et al., 1992).

There is some evidence that thermal activity at Kuirau park change over time. For example, many of the pools, including some of those which currently discharge acid sulfate waters, are surrounded by relict sinter deposits. Also, new thermal activity occurs intermittently, even in recent years. The most spectacular example of this is two hydrothermal eruptions that occurred in the early 2000 and early 2001. New thermal pools formed at the craters created by these eruptions.

The primary objective of this study was to measure the amount of heat discharged by surface manifestations and to delineate the extent of thermally altered ground at shallow depths. In addition, we also wanted to investigate any other geophysical signatures of the thermal activity at Kuirau Park.

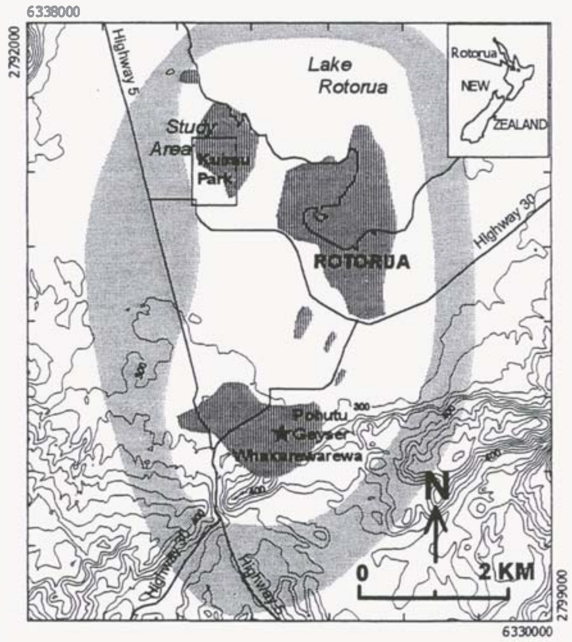

Figure 1. Location of the Kuirau Park in the Rotorua geothermal field, North Island, NZ. The boundary of the field, delineated from Schlumberger resistivity mapping (Bibby et al., 1992), is shown by light *shading.* **Dark shades represent areas of surface thermal manifestations.**

2.0 TEMPERATURE SURVEY

We conducted a temperahue survey at Kuirau Park in September 2000. Temperature measurements were made at springs and pools, together with estimation of their flow rates and surface areas for heat loss calculation. In addition, we measured ground temperatures (0.5 and 1 m depths) along a few traverses across the park

Fig. 2 shows the localities of surface manifestations. Based on their distribution, we separated the thermal manifestations into 4 groups, i.e. Group 1 (Soda Springs), Group 2 (J. Cs. Fountain and Waiparuparu), Group 3 (Kuirau Lake area), and Group 4 (Tawera Springs).

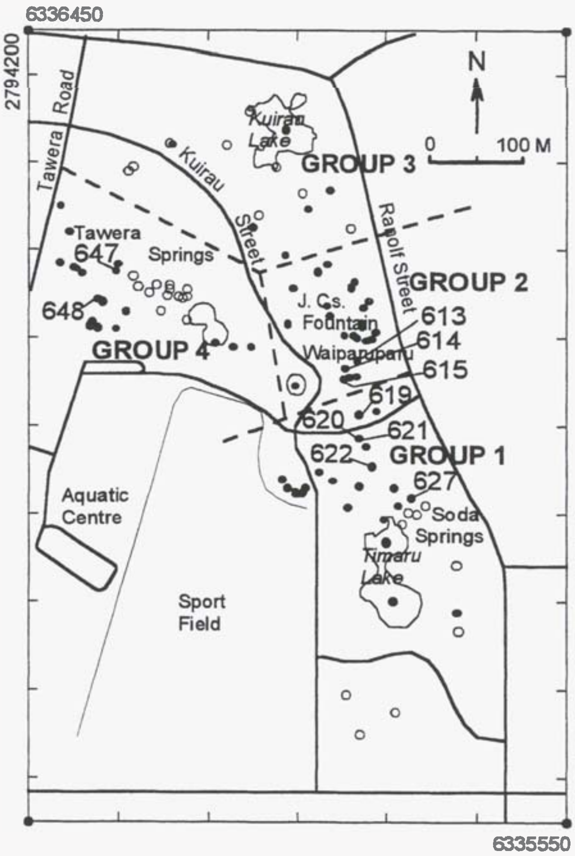

Figure 2. Surface thermal manifestations at Kuirau park. Solid circles indicate manifestations where heat loss measurements were carried out m September 2000. For the other manifestations shown by open circles, the heat loss was estimated using the measurements of *similar* features.

21 Heat loss estimation

A *summary* of convective heat loss from springs (Q-flow) and fi-om evaporation of pools (Q-evaporative) is presented in Table 1 (ambient temperature = 12.5°C). Details of their calculations are documented by Suhanto (2000). Conductive heat loss was estimated fi-om the ground temperature measurements. Temperatures at 0.5 and 1 m depths, after a correction for annual temperature variations, were used to determine anomalous near surface temperature gradients. By assuming an average soil thermal conductivity of 1 W/m°C, we found the total conductive heat loss was about 0.8 MW. Hence, the total heat discharged by surface thermal manifestations at Kuirau Park in September 2000 was about 30 MW.

Group	Q-flow (MW)	Q-evaporative (MW)	Sub-total (MW)
1	1.5	5.1	6.6
2	0.5	2.2	2.7
3	7.2	6.9	14.1
4	2.7	3.2	5.9
TOTAL	11.9	17.4	29.3.

22 Distribution of ground temperature

A contour map of ground temperatures at 1 m depth is shown in Fig 3. The distribution of ground temperatures correlates with the thermal manifestation groups shown in Fig, 2. There are four areas of thermal ground (T≥25°C) indicated in Fig. 3, which occur in the vicinity of Soda Springs and Timaru Lake (*Group* 1), near J. Cs. Fountain-Waiparuparu (Group 2), to the NW of Kuirau Lake (Group 3) and east of Tawera Springs (Group 4).

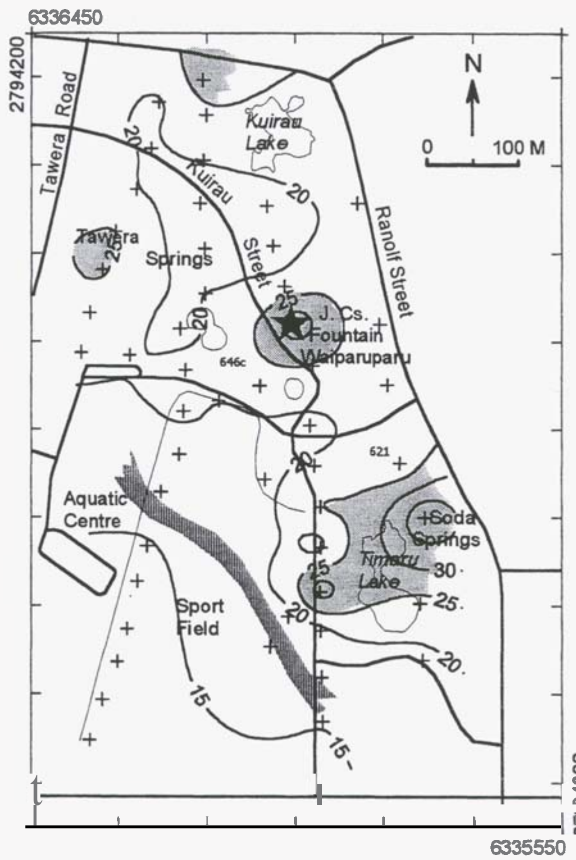

Figure 3. Ground temperatures (°C) at 1 m depth, Kuirau Park, September 2000. Measurement *sites* are shown by crosses. Thermal ground areas with T≥25°C are indicated by a light shaded pattern. The solid *star* represents the location of the 26th Feb. 2001 hydrothermal eruption. The *darker* shaded pattern across the sport field is the boundary of shallow hydrothermal alteration inferred from results of Schlumberger resistivity mapping presented m Fig. 5.

2 3 Changes of temperature over time

Previous temperature measurements at Kuirau Park which dated back to 1878 (Kuirau Lake) were reported by Donaldson (1985). No temperature measurements were documented after 1982 until we conducted our survey in September 2000. In Fig 4, we plotted the temperature variations at Kuirau Lake (T max.) and at some springs located within groups 1, 2 and 4.

Fig. 4 shows that between late 1940s and early 1980s the temperature was decreasing from 60-80°C to 40-50°C at Springs 614 and 615 (Group 2), from about 40°C to 30°C at Spring 613 (Group 2), from about 65°C to 50°C at Kuirau Lake (Group 3), and from about 75°C to 35°C at Spring 627 (Group 1). With the exception of Spring 627, the decrease did not continue into the 1980s. The temperature at Kuirau lake was probably already back to its late 1940s value as early as 1982. For Springs 613, 614 and 615,

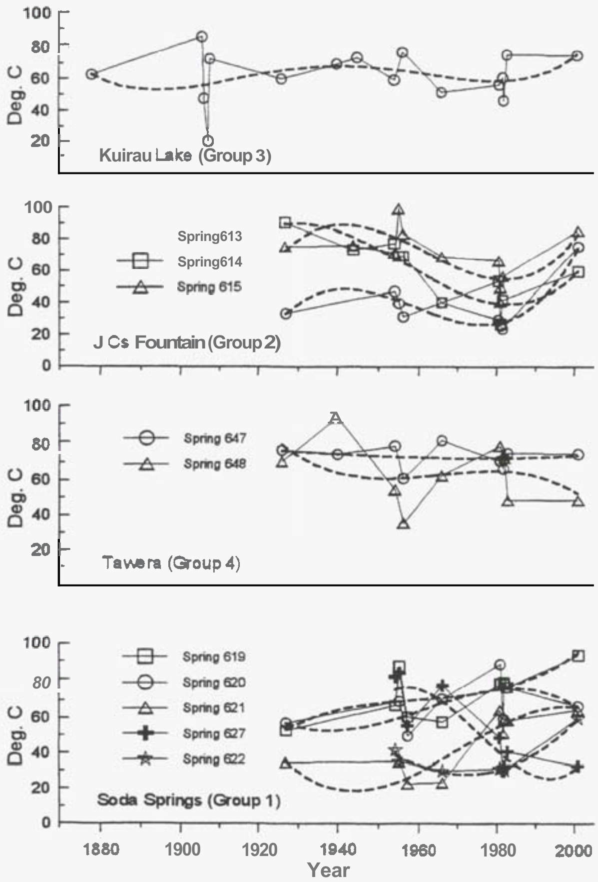

Figure 4. Temperature variations at Kuirau Lake and some springs at the Kuirau Park. Broken lines represent a polynomial fitting for temperature data at each manifestation (third order for the springs; fourth order for Kuirau Lake which has a longer history of measurements). See Fig. 2 for the locality of springs.

the reversal to a temperature increase probably occurred around mid- to late- 1980s. By September 2000, the temperature had recovered to its 1940's values at Springs 614 and 615; at Spring 613 the temperature was higher than it was in late 1940s.

In contrast, Springs 619, 620, 621 and 622 (Group 1) showed an increase of temperature between 1940s and early 1980s. With the exception of Spring 620, the increase continued into the year 2000. Springs 647 and 648 (Group 4) did not show any clear pattern of variation.

3.0 RESISTIVITY SURVEY

The main purpose of this survey was to delineate the extent of shallow hydrothermal alteration which would be indicated by a low electrical resistivity of the ground.

3.1 Schlumberger resistivity mapping

We carried out a resistivity mapping across Kuirau Park in September 2000, using the Schlumberger array with AB/2 spacing of 50 and 100 m. The patterns of apparent resistivity measured using both values of AB/2 are very similar across the Kuirau Park. Only the contour map of apparent resistivity for AB/2 = 100 m is shown in Fig 5.

The result in Fig. 5 shows that the Tawera Springs and J Cs. Fountain – Waiparuparu are located within an area with a very low apparent resistivity (≤4 ohm-m) indicating intense hydrothermal alteration at shallow (<100 m) depths. We can only delineate the SW boundary of the shallow hydrothermal alteration, shown in Fig. 5 across the Kuirau Sport Field

3.2. Schlumberger vertical electrical sounding (VES)

During the September 2000 and August 2001 field works we carried out VES measurements at 5 sites; see Fig. 5. The VES curves and their interpretations are shown in Fig. 6.

All VES curves indicate a 4-layer resistivity structure. The resistivity of the first layer (down to 1-1.8 m depths) is the highest. It has a value ranging from about 120 to 180 ohm-m at VES 1, 2 and 3, which probably represents the resistivity of a top soil containing only a small amount of hydrothermal alteration products. At VES 4, the first layer has a resistivity of about 45 ohm-m suggesting a higher content of hydrothermal alteration clays. A highly resistive first layer (615 ohm-m) at VES 5 is probably part of the road foundation of Ranolf street.

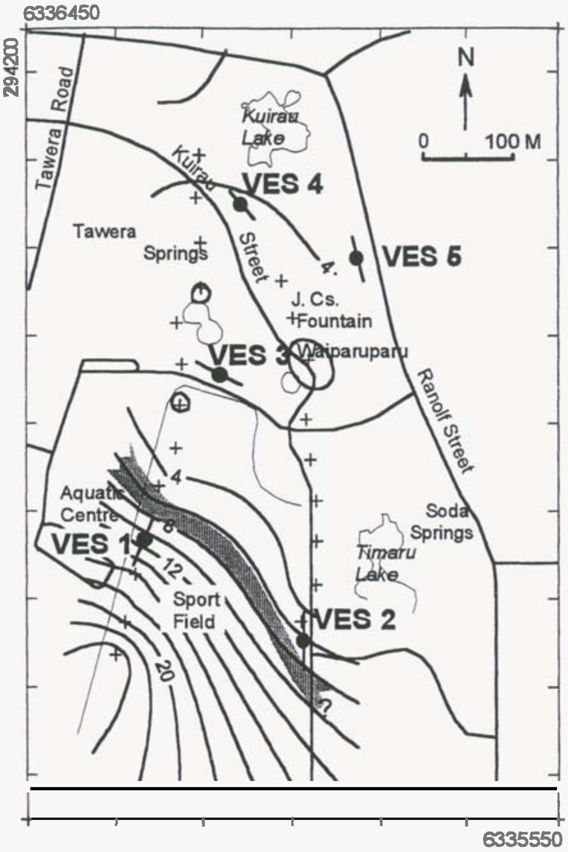

Figure 5. Contour *map* of Schlumberger apparent resistivity measured using AB/2 = 100m, Kuirau Park. Measurement sites are shown (cross symbols) together with localities of VES 1-5. Contour values are in ohm-m. The shaded zone across the Sport Field indicates the boundary of intense hydrothermal alteration at shallow depths inferred from the resistivity mapping, VES 1 and VES 2.

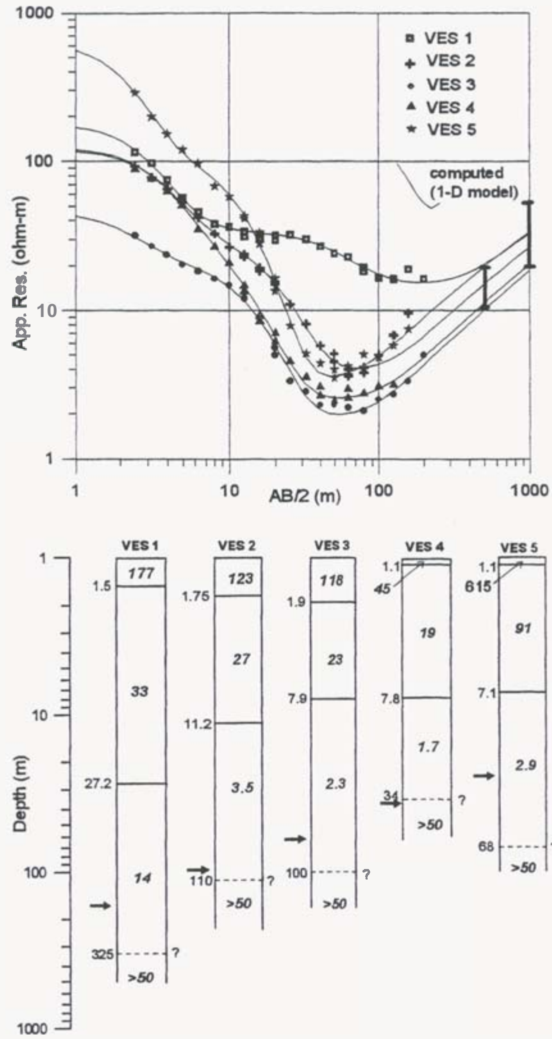

Figure 6. Schlumberger vertical electrical sounding (VES) curves and their interpretations, Kuirau Park. Apparent resistivity values for AB/2 spacing of 500 and 1000 m are interpolations from resistivity maps by Bibby et al. (1992). The 1-D models (lower figures) show true resistivity values in ohm-m. Solid arrows indicate the top of Rotorua rhyolite dome interpolated from drillhole data. Measurement sites are shown in Fig. 5.

The second layers at VES 2, 3 and 5, which lie between 1-2 m depths at the top and 8-11 m depths at the bottom, have similar resistivity values (19 to 27 ohm-m). They are probably the same layer representing the upper part of shallow hydrothermal alteration at Kuirau Park. This upper hydrothermal alteration zone does not extend to VES 1 and to VES 5 where the resistivity of the second layer is higher, i.e. 33 and 91 ohm-m, respectively.

The main zone of shallow hydrothermal alteration is represented by the third layers at VES 2, 3, 4 and 5, which have resistivity values between 1.7 and 3.5 ohm-m. It does not extend to VES 1 where the third layer's resistivity is 14 ohm-m. Hence, the resistivity boundary indicated in Fig 5 across the Kuirau Sport Field represents the SW limit of the main zone of shallow hydrothermal alteration. The third layer at VES 1 may represent either a bed of non-hydrothermal clay and silts, or a zone of less intense hydrothermal alteration.

The depths to the base of the main alteration zone cannot be determined without ambiguity (the so-called equivalence problem). However, the interpretation in Fig. 6 suggests that the zone extends deeper than the top of Rotorua rhyolite dome, which means the upper part of the dome have been intensely altered by hydrothermal activity. This result is consistent with thermal fluid flowing through the outer shell of the rhyolite dome suggested by Wood (1992).

All VES curves indicate the existence of a resistive fourth layer (the sub-stratum), which is also suggested by the data interpolated from resistivity maps of Bibby et al. (1992). This resistive sub-stratum, whose upper level cannot be delineated from our data without ambiguity, probably represents rhyolite lava that is massive and only weakly fractured (Wood, 1992).

4.0 SELF POTENTIAL (SP) SURVEY

The self potential (SP) measurements. were conducted in August 2001. The purpose of this survey was to investigate any SP anomalies associated with thermal activity at Kuirau Park. Static electrical potentials of the ground were measured with respect to a base station located in the southwestern comer of the Kuirau Sport Field, outside the thermal area indicated by results of the ground temperature measurements and the Schlumberger resistivity mapping.

We used an array of non-polarised electrodes ($Cu/CuSO_4$ porous pots) placed at five measurement sites along the SP traverse. The electrodes were connected to a high impedance voltmeter near the centre of the array by using four lengths of double core cable. By appropriate switching, electrical potential difference can be measured between any combination of two electrodes. Such a measurement technique allows up to ten overlapping SP measurements for each site, and effectively reduces the "tie-in" errors caused by an unstable electrode.

A contour map of the SP anomalies across Kuirau Park is presented in Fig 7. The main features of the result in Fig, 7 are the positive anomaly (>+25 mV) south of J Cs. Fountain-Waiparuparu and the negative anomaly (<-20 mV) southeast of Tawera Springs. There are some shorter wavelength variations shown in Fig. 7 that are probably caused by superficial sources of electrical potential that may or may not be of geothermal origin.

Fig,. 8 shows our preliminary interpretation of the main positive and negative SP anomalies. The computation was made using the method of Fitterman (1984). Three vertical source planes (S1, S2 and S3) indicated in Fig. 8, each representing a region of 150 mV electrical potential discontinuity (the source intensity, F_o=150mV), can generate theoretical anomalies similar to the main positive and negative anomalies shown in Fig 7. Similar SP modelings conducted over other thermal areas, such as the East Mesa prospect in the USA (Fitterman, 1984), some geothermal prospects in Greece (Apostolopoulos et al., 1997) and the Ulubelu prospect in Sumatra (Soengkono et al., 2000), have shown that such source planes may represent zones of flowing fluid, heat and ions associated with the elevated temperature and fluid convection inside a geothermal system.

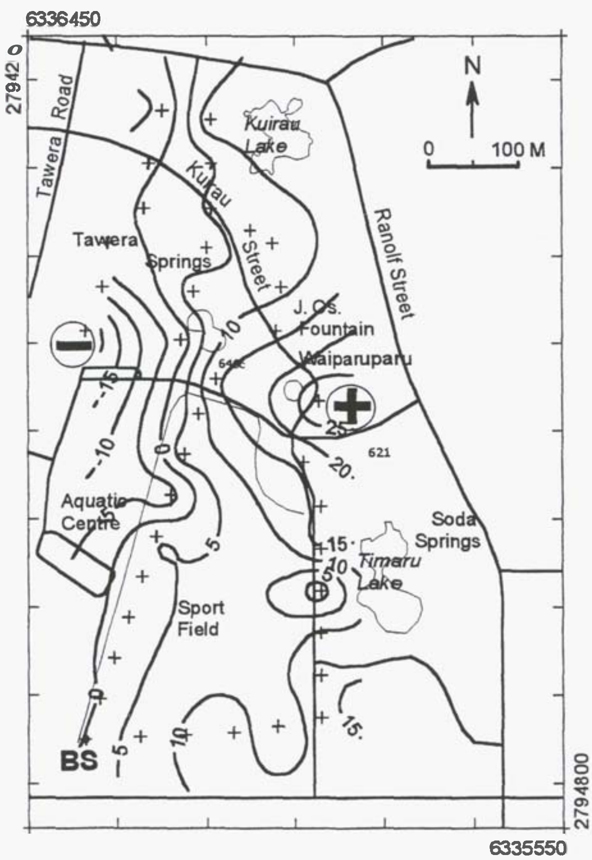

Figure 7. Contour map of SP anomalies, Kuirau Park Contour values are in mV. Measurement sites are shown by crosses. All SP values are relative to the base station (BS)

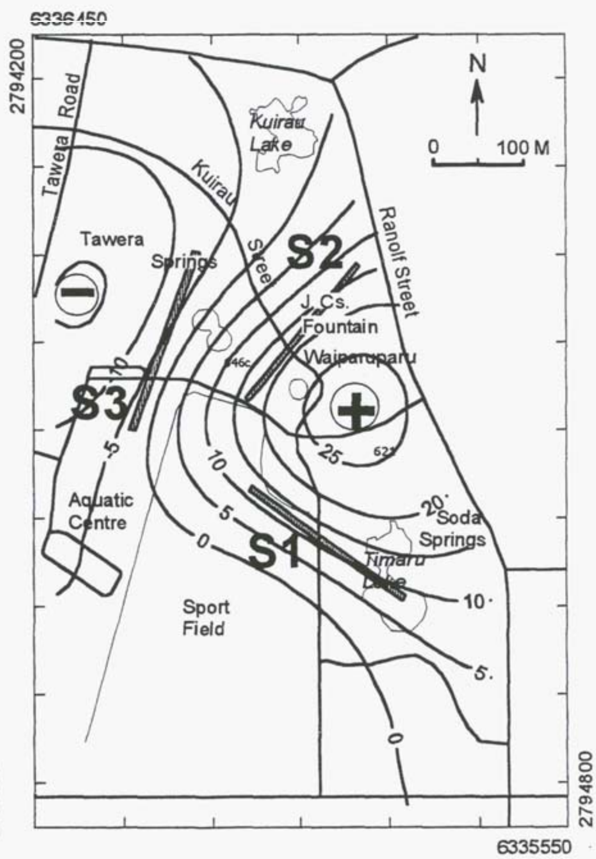

Figure 8. Preliminary interpretation of SP anomalies at Kuirau Park. The contour lines are theoretical SP anomalies (in mV) generated by the vertical source planes S1, S2 and S3. The top of the vertical planes is at 100 m depth, their base lies at 300 m depth. The source intensity (F_o) of each plane is 150 mV.

5.0 DISCUSSION

5.1 Thermal ground and hydrothermal eruption

On the 26th of February 2001, a hydrothermal eruption occurred to the east of J. Cs. Fountain, which destroyed a few mature trees and created a crater about 10 m across. The location of this hydrothermal eruption is shown in Fig 3, coinciding with the centre of Group 2 thermal ground delineated by our measurements in September 2000, about 5 months prior to the eruption. This thermal ground was not located close to any springs or pools, and therefore it may represent deep thermal water that moved close to the surface. There is no conclusive evidence that this particular thermal ground was a precursor of the hydrothermal eruption However, this result suggests that a regular monitoring of ground temperature may be useful to identify areas of hydrothermal eruption risk at Kuirau Park.

5.2 Expansion of thermal activity

The result of our ground temperature measurements (Fig. 3) shows that warm ground with a temperature >15°C extends beyond the SW boundary of the shallow hydrothermal alteration across the Kuirau Sport field This result may indicate an expansion of the Kuirau thermal activity in the SW direction.

5 3 Possible relationship with fluid production from the Rotorua system

We have discussed in 2.3 that the temperatures at Springs 613, 614 and 615 (Group 2) were decreasing between late 1940s and early 1980s, but sometime after 1982 the trend was reversed. This pattern is consistent with the drawoff of geothermal fluids from the Rotorua system that started in 1950s and continued to 1980s before compulsory closure of most wells close to Whakarewarewa (Fig 1) resulted in 80% reduction of hot water production by late 1989 (Allis and Lumb, 1990). Hence, there appears to be a relationship between temperature changes at Kuirau and fluid production from the Rotorua system. However, it is also possible that the temperature variations may simply represent the natural cycle of each surface manifestation as suggested by the polynomial fitting of each data set shown in Fig 4.

6.0 CONCLUSIONS

1. The total rate of heat loss from Kuirau Park was about 30 MW in September 2000. The largest heat loss was by evaporation from pools and lakes (17.4MW), followed by heat loss from springs (12.9MW). Conductive heat loss through thermal ground amounted to only about 0.8 MW.

2. Our resistivity survey delineated the extent of shallow hydrothermal alteration which affects the upper part of the buried Rotorua rhyolite dome.

3. There is indication that thermal activity may be expanding to the SW across the Sport Field

4. The results of our temperature survey suggest that a regular monitoring of ground temperature (say, every 6 months) may be useful to identify areas of hydrothermal eruption risk at Kuirau park.

5. The thermal activity at Kuirau Park is associated with a positive and a negative SP anomaly that can be explained by a simple model of some planar, vertical source regions which may represent some geothermal activity between 100 and 300 m depths.

6. There is indication of a possible relationship between production of geothermal fluids from the Rotorua system and temperature variations at Kuirau Park.

7.0 REFERENCES

Allis, R G. and Lumb, T. (1990). Preservation of the Rotorua Geysers: Conflicts and issues. Geothermal Resources Council Transactions 14, p. 581.

Apostolopoulos, G., Louis, I. and Lagios, E (1997). Case history: The self-potential method m the geothermal exploration m Greece. Geophysics 62, 1715-1723.

Bibby, H.M., Dawson, G.B., Rayner, H.H, Bennie, S.L and Bromley, C. J. (1992). Electrical resistivity and magnetic investigations of the geothermal systems m Rotorua area, New Zealand. Geothermics 21, 1/2, 43-64.

Corwin, R. F., Hoover, D. B. (1979). The self-potential method m geothermal exploration. Geophysics 44, 226-245.

Donaldson, I. G. (1985). Long term changes m thexmal activity m Rotorua-Whakarewarewa area. In: Technical Report of the Rotorua Geothermal Monitoring Programme, NZ Ministry of energy, 83-225.

Fitterman, D.V. (1984). Thermoelectric self-potential anomalies and their relationships to the solid angle subtended by the source region. Geophysivs 49, 165-170.

Soengkono, S., Daud, Y, Suhamo and Sudarman, S. (2000). Interpretation of self-potential anomalies over the Ulubelu geothermal prospect, South Sumatra, Indonesia. Proc. 22nd NZ Geothermal Workshop, 127-131.

Stewart, M. K. and Lyon, G. L. (1992). Fluid flow m the Rotorua geothermal field derived fkom isotopic and chemical data. Geothermics 21, 1/2, 141-163.

Suhanto, E (2000). Temperature survey and alteration study of Kuirau Park, Rotorua. Geothermal Diploma Project Report 2000.22, Geothermal Institute, The University of Auckland, 54 p.

Wood, C.P. (1992). Geology of the Rotorua geothermal system. Geothermics 21,112,2541.