THE NGATAMAFUKI GEOTHERMAL FIELD, NZ: SURFACE MANIFESTATIONS - PAST AND PRESENT

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SUMMARY - The Ngatamariki geothermal field, located 7 km south of Orakeikorako, discharges dilute chloride-bicarbonate waters of almost neutral pH from springs mostly on the margins of the field. Rhyolite tuffs in the northwestern part of the field are weakly silicified, probably due to their having reacted with heated groundwaters. Sinter deposits are common at Ngatamariki but are mostly relict from former activity. In 1994, the natural heat loss from the field was 30±5 $MW_{thermal}$. There has been a shift of thermal activity southward over the past 60 years; the changes were recognised by comparing air photographs taken in 1941 and 1991. In 1948, a hydrothermal eruption deposited breccia around its crater, which is now occupied by a pool at 52.5°C. Another pool at 88°C, first noticed in 1993, deposits a mixture of silica and calcite.

INTRODUCTION

The Ngatamariki geothermal field lies approximately 8km outside the southeastern margin of the Maroa Volcanic Centre, about 7km southeast of the Orakeikorako field (Figure 1). The field covers an area of 7km² as delineated by -resistivity measurements (Bennie, 1983) (Figure 2). The Waikato River marks the northern boundary of the field, whilst the Orakonui Stream forms its western boundary, and it is here where most thermal features are located (Figure 2).

Grange (1937) was the first to provide information about the area. It was studied in more detail by Bennie (1983) who undertook geophysical investigations and described the surface features and spring chemistry. Four wells were drilled in the mid-1980's to depths of 2400m.

Our study had the following aims: to compare information obtained by this *study* with previously published data; to assess the thermal history of the field; to characterise the mineralogy and hydrothermal alteration of the d a c e rocks and interpret them; to map all surface manifestations and analyse their thermal fluids, and to measure the mass flux from the field.

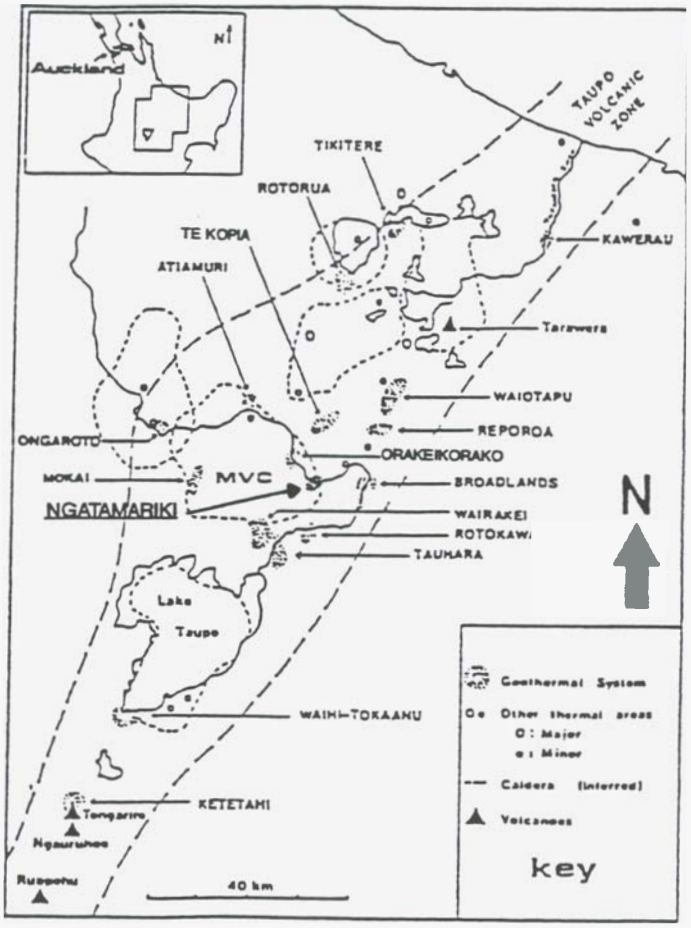


Figure 1: Location of the Ngatamariki Geothermal Field, Taupo Volcanic Zone, New Zealand. MVC= Maroa Volcanic Zone (modified from Bignall, 1991)

SURFACE MANIFESTATIONS

Most of the thermal features are located in two areas on the Orakonui Stream (Figure 2), which are named here North Orakonui and South Orakonui. There are also a few springs located in the Waikato River but these are often flooded.

North Orakonui

North Orakonui (Figure 3) is characterised by silica sinters, which typically slope over 6-10m into the Orakonui *Stream* Valley. This area is largely overgrown and only a few springs are now actively depositing sinter.

Temperatures of the springs are approximately 70°C although one (AreaC) located 1m from the *stream* 94°C was measured

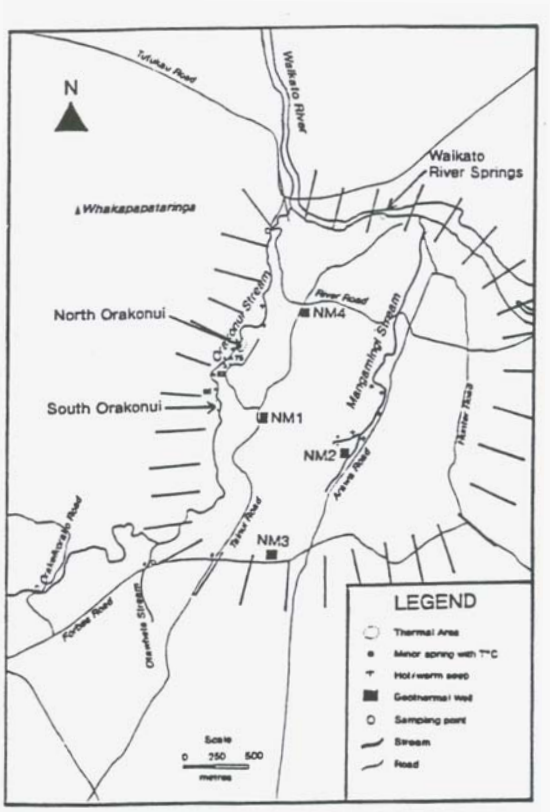


Figure 2: Map of the Ngatamariki Geothermal field showing the thermal areas, well sites and resistivity boundary (Bennie, 1983).

South Orakonui

There are four hot pools located at South Orakonui (Figure 4). The largest, Pool 1, is about 40x20m and occupies a hydrothermal eruption crater. Pool 1 has a bottom temperature of 52.5°C and is 2m deep. It has an outflow of ~ 4.5 l/s (Bennie, 1983), discharging into the Orakonui Stream.

Pool 2 is located 10m north of Pool 1 and may also occupy a hydrothermal eruption crater. It is approximately 20m long and 10m wide, and is 8m deep at its deepest point. It has a bottom temperature of 78°C. There is no surface outflow but subsurface seepage is estimated to be > 1l/s.

Pool 3, which is located 20m north of Pool 2, was first noted in 1993. It is a vigorously bubbling spring of 88°C which is depositing a 'marshmallow'looking mixture of calcite and silica 'sinter'. The deposit is extremely delicate and finely layered. The calcite forms spicules whilst the silica is formless and smooth on the surface. The calcite comprises approximately 10-15wt% of the total deposit. Pool 3 has an outflow of 1 l/s into the Orakonui Stream.

Pool 4, the southem-most feature, is located 50m south of Pool 1. There is a vigorously bubbling spring at the centre of the pool measuring 78°C. The pool is approximately 15m long and 8m wide. There is no outflow, but subsurface seepage is estimated to be > 1 l/s.

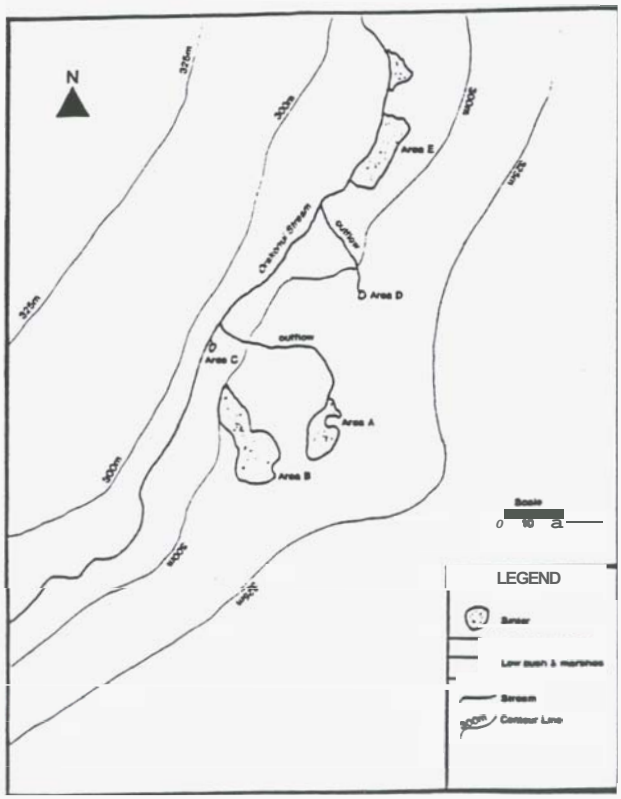


Figure 3: Map of North Orakonui showing distribution of thermal features and extent of silica sinter.

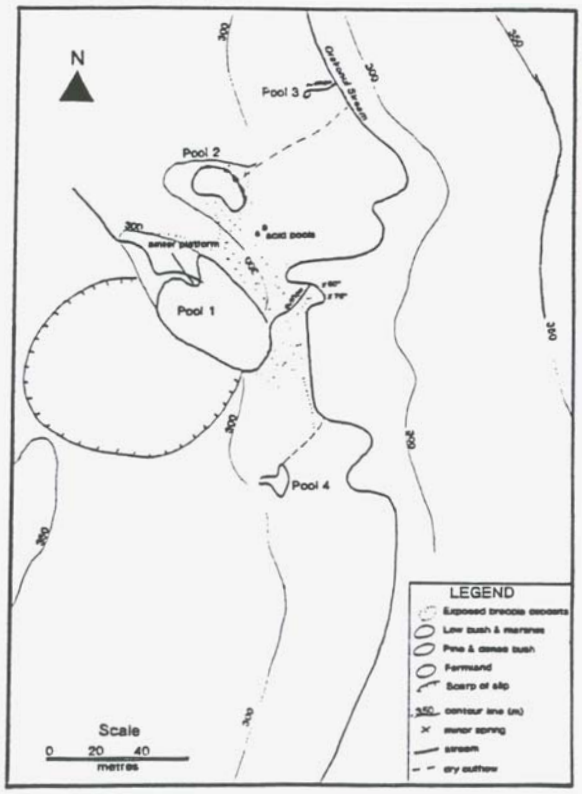


Figure 4: Map of South Orakonui showing the distribution of thermal features and hydrothermal eruption breccia deposits.

Between South and North Orakonui there are numerous small springs and seeps in the Orakonui Stream. The average temperature is ~ 70°C.

Waikato River Springs

There are many small springs located in the marshy area on the south banks of the Waikato River, on the northern margin of the field. One spring has deposited a sinter fan of 200 m^2 and has a temperature of ~ 70°C.

SPRING WATER CHEMISTRY

Most d a c e waters at Ngatamariki have a near neutral pH. Chloride concentrations (–600 mgkg) are lower than those at Wairakei, Broadlands and Waiotapu, but they are similar to concentrations of most dilute springs at Orakeikorako, Waikite and Mokai. There are a few acid pools between Pool 1 and Pool 2 at South Orakonui, but they are cool and stagnant.

The fluid compositions may be represented on a Cl-SO_4-HCO_3 ternary diagram (Figure 5). The fluids of Ngatamariki are predominantly of mixed chloride-bicarbonate type with little sulfate. The composition of these springs are thus characterised by fluids that have a chloride component of approximately 60%, a bicarbonate component of 35% and a sulfate component of <5%.

The springs are located at the field margins. as delineated by resistivity measurements (Figure 2) reported by Bennie (1983); a shallow zone of steam-heated groundwater is probably providing the bicarbonate component to the springs.

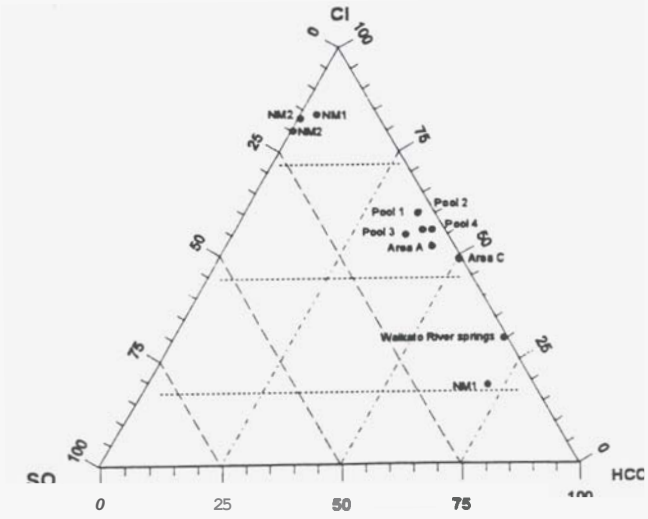


Figure 5: Cl-SO_4-HCO_3 ternary diagram showing water compositions.

The conductive quartz geothermometer gives values ranging from 140°C to 190°C for the spring waters.

'Reservoir' equilibration temperatures have been determined assuming that quartz saturation controls the silica contents of the fluids sampled. The results from the springs, clearly define a dilution trend, with the diluent having a temperature of ~ 140°C at zero chloride concentration. This is similar to the diluent noted at Broadlands-Ohaaki of 150°C (Hedenquist and Stewart, 1985), the Waiotapu diluent of ~ 160°C (Hedenquist and Browne, 1989) and the Orakeikorako diluent of 105°C (Sheppard and Lyon, 1984). The characteristics of the diluent at Ngatamariki indicates that it is steam-heated water.

The maximum calculated temperature using standard chemical geothermometers is 300°C. From the enthalpy-chloride diagram (Figure 6) for 'reservoir' compositions, the chloride concentrations at 300°C will be approximately 1000 to 1200mg/kg. This is identical to Broadlands-Ohaaki, but much lower than at Mokai (as high as 2000mg/kg at 300°C) and at Wairakei. The chemistry of the Orakeikorako water, as deduced from spring and well samples, are very low in chloride (~320mg/kg) for their 220°-250°C temperatures and quite distinct from Ngatamariki fluids (Sheppard and Lyon, 1984).

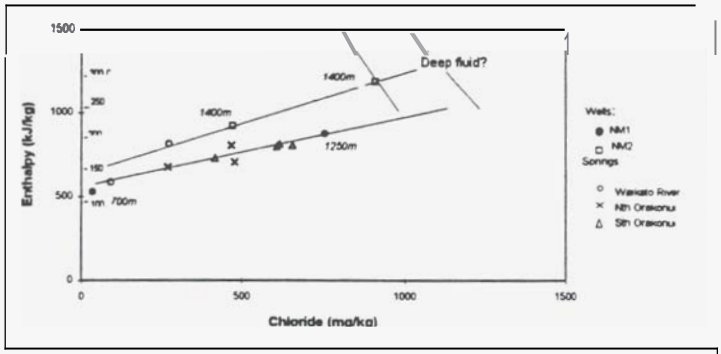


Figure 6: Enthalpy-chloride mixing diagram for compositions of waters from surface features and Wells NM1 and NM2 at Ngatamariki (modified from Hedenquist, 1986).

HYDROTHERMAL ERUPTION BRECCIAS

The hydrothermal eruption history at Ngatamariki has not been previously described. The only account of such activity comes from Prof. RF. Keam. He, together with E.F. Lloyd visited the area in the late 1950's before the flooding of Orakeikorako (1961).

Prof. Keam (*pers. comm.*, 1994) remembers that in 1948 residents at Orakeikorako heard a loud explosion and recall that the Waikato River became discoloured for two days. The water was not discoloured at the Te Mihi bridge (upstream from Ngatamariki) so it was assumed that the source for the discoloured water came from Ngatamariki. Prof. Keam also remembers the large pool (Pool 1) being approximately 30m across and bubbling; it may have then had an outflow. The area surrounding the pool was unvegetated and breccia deposits could be clearly

seen. He believes that the breccia deposits exposed near the pool are a product of the 1948 eruption. Apart from the large pool he does not remember any other activity apart from a few small individual springs.

The most exposed area of the breccias lies on the eastern side of Pool 1 (Figure 3), adjacent to the Orakonui Stream. The outlet of Pool 1 cuts through the southern end of the exposure and the northern area is vegetated. The breccia deposits are poorly sorted, matrix supported, and contain angular to subrounded polylithologic clasts, predominantly tuffs. Bedding features are absent. The clasts have been subjected to silicification and weathering. The matrix is comprised mainly of unconsolidated, sandy to silty ash containing clays.

Progressively further away from the source (over 20m), the clast to matrix ratio is: 10-15%, 8-10%, 15%, 20%, 8-10%, 8-10%. This is not a uniform decrease as may be expected. Average clast size away from the source is 15mm, 10mm, 5-6mm, 10mm, 5mm, 3-5mm, and there is an increase in clast size corresponding to the increase in clast to matrix ratio near the stream. The thickness of the breccia varies, but in general it decreases away from the eruption source. Breccia thickness is uncertain; the quality of the exposures and erosion implies that values obtained are minimum values.

Mineralogical and textural relationships indicate that the hydrothermal eruption breccias at Ngatamariki have been subject to two hydrothermal regimes. An alunogen-sulfur-jarosite-cristobalite alteration assemblage (acid-sulfate style) developed after an earlier-formed quartz silicification-calcite-zeolite-smectite assemblage (neutral pH chloride style).

Clasts of calcite 'sinter' are present in the breccia deposits at Pool 1 and Grange (1937) reports deposits of 'snow-white sinter' in this area. The 1941 aerial photos reveal a large 'white' area at the present location of Pool 1. We suggest that this area, prior to the eruption, was covered by an impermeable layer of silica or calcite 'sinter'. Shallow groundwater seeped into hot rocks at deeper levels causing the water to flash and a hydrothermal eruption to occur. The eruption surface descended until there was no more water available to form steam; fallback material might have smothered the eruption or the system was flooded by stream water.

SURFACE ALTERATION

Crystal, lithic and vitric tuff dominate the rock types in the western region of Ngatamariki with minor pumice and tuff breccia also. Only the pumice breccias are in situ, the rest occur as large, subrounded boulders scattered over the farmland and gullies. These deposits exhibit only low intensity alteration. The tuff deposits are mostly fresh except for weak silicification and minor clay (smectite) alteration. This type of alteration is probably produced by interaction of heated groundwaters with rhyolitic glass.

One sample of tuff breccia is cut by white and orange opal veins. This opalisation indicates low temperature (<100°C) hydrothermal alteration occurred in this area as it is typically produced by reaction of rocks with shallow neutral pH chloride waters (Henneberger 1983). In this instance, opalisation may have resulted from hot or warm water discharging from an isolated spring or warm seep.

CHANGES IN THERMAL ACTIVITY AT NGATAMARIKI OVER THE LAST 60 YEARS

From the accounts of Grange (1937), Gregg (1951, 1958), Healy (1974), Bennie (1983), Hedenquist (1986) and R F Keam (pers. comm. 1994) it appears that the geothennal activity at Ngatamariki has been changing during the last 60 years. A comparison between aerial photographs taken in 1941 and 1993 (summarised in Table 1), shows there has been a reduction in thermal activity at North Orakonui. There also appears to have been a decr activity at the Waikato River Springs area but difficult to ascertain as the river levels have change 1961. The South Orakonui features have also ch with a hydrothermal eruption (Pool 1), a new feature (Pool 3) depositing calcite and silica 'sinter', and a significant decrease in activity at Pool 2.

Feature	1941	1993
Sth Orakonui	large, white area of ~ 4500m^2; no evidence of pools; bare ground, stunted bush	Pools 1,2,3 & 4 and eruption breccias visible, evidence of slope failure; dense bush and pines
Nth Orakonui	extensive sinters areas; Areas A and B are one large sinter deposit of ~1300m^2; Area E is distinctive area of sinter of ~ 1350m^2; stunted bush and bare ground	Area A is ~ 200m^2 and Area B is ~180m^2, both are isolated sinter deposits; Area E is ~80m^2 and is faintly discernible, densely vegetated with bush and pines
Waikato River springs	River narrower; 50x10m strip of bare ground trending NE	River wider due to Ohakuri dam; springs not discernible

Table 1: Summary of features on 1941 and 1993 aerial photographs.

The changes in thermal activity may have resulted from a modification to the near-surface permeability caused by tectonic activity or hydrothermal alteration. hydrothermal eruption which occurred in 1948 mu resulted from changes to the plumbing below the Pool 1.

The decrease in thermal activity at the Waikato River Springs may be a result of cold water inflowing from the river. This was probably initiated by the dam at Ohakuri which filled in 1961. Relicts of hydrothermal alteration in the north-western region of the field and increased thermal activity at South Orakonui support the theory of a southward shift in the focus of the thermal activity.

OUTPUT OF HEAT FROM THE NGATAMARIKI SYSTEM

The natural heat output from the Ngatamariki geothermal field was estimated at 42MW in 1952 by Gregg (1958) and 37.6MW in 1981 by Bennie (1983) relative to 12°C. Most (~80%) of this heat was derived from springs and pools discharging along the Orakonui Stream and 10% each from thermal springs along the Mangamingi Stream and the Waikato River (Figure 2).

The anomalous heat loss from hot springs and pools consists principally of the heat discharged directly by hot water with some minor heat lost by evaporating *steam* (Gregg 1958). The heat carried downstream by hot water was assessed by:

1. Estimating the total liquid discharges and evaporation of individual springs and pools.

2. Measuring the increase in heat content of the Orakonui Stream into which the springs discharge. allowing for evaporation from springs and pools (ie. a calorimetric method).

However, thermal water is often carried away with groundwater and *can* enter the bottom of a *stream* as diluted, cooler fluid. If diluted thermal fluids enter a draining *stream* outside the margin of the system, the heat transferred *can* still be estimated from the concentrations of chloride in the *stream.* The heat transferred by liquid discharges from hot springs, subsurface flows etc, entering a stream from a geothermal area *can* thus be assessed from any 'anomalous' chloride flux. This was estimated by:

(a) Measuring the increase in the chloride content of the Orakonui Stream into which the thermal springs discharge after allowing for evaporation.

(b) Estimating the heat transferred separately by liquid and vapour from the reservoir after boiling takes place and using the Cl contents of the liquid fraction to estimate both heat components and allowing for mixing.

Heat loss estimates are 26.5 and 34 MW based on the methods of 'anomalous' chloride flux and surface heat discharge respectively (Table 2). Both estimates include heat loss fkom the Waikato River Springs, evaporation, and from the Mangamingi Stream.

Although the value of 34 MW found in this *study* is of the same order as that estimated by Bennie (1983) of 37.6MW and Gregg's (1958) estimate of 42 MW relative to 12°C, the latter is based only on heat loss into the Orakonui *Stream* (30 MW) and evaporation from springs and pools (12 MW). No upstream flowrates or thermal discharge from springs and pools were measured.

	MW	MW	MW
Heat loss from Orakonui Stream calculated from calorimetric method	15 6		
Heat loss by evaporation from pools and Orakonui Stream	8.5		8.5
H u t loss by shallow h u t transfer from 140-100°C	5.3		5.2
H a t loss from chloride flux m discharging pools and springs		-	7.8
H u t loss from $\Delta H(T_{200°C} - T_{12°C})$ plus 0.4MW/kg deep fluid		14.8 7.4	
Heat loss and evaporation from Waikato River Springs	0.75	0.75	0.75
H a t loss from Mangamingi Stream calculated from calorimeter method (Bennie, 1983)	3.6	3.6	3.6
SURFACE HEAT DISCHARGE TOTAL	34		
HEAT LOSS FROM a TRANSFER IN RESERVOIR		26.5	
CHLORIDE FLUX FROM POOLS AND SPRINGS. EVAPORATION AND OTHER FEATURES TOTAL			26

Table 2: Summary of heat loss (MW) estimated from

Heat loss estimates for our study, using the same methods (i.e. mass flowrate × temperature increase of Orakonui Stream), give values of 15.6 MW for the Orakonui *Stream* and 8.5 MW for evaporation (Table 1). Both values are almost half those of Gregg's (1958) whose *stream* flow estimates ($1.7 m^3/s$) were made by measuring the d a c e velocity of the stream This method is less reliable than using *stream* gauging as employed in our study.

Bennie's 1982 estimate of heat discharged into the Orakonui Stream, based on temperature increases, was 26MW and again the flowrate measured for the *stream* was ~ 60% higher than that measured between 1986 and 1995 (~$0.8 m^3/s$). There has been a decrease in discharge into the Orakonui Stream, mainly from Pool 2 at South Orakonui and also from the springs at North Orakonui. Pool 2 had a flow rate of 14 l/s at 68°C in 1952; this had dropped to 8.5 l/s in 1981 but the temperature had increased to 88°C. However, such changes in flowrate of thermal water would have had only a small effect on the *stream* flow values obtained for 1952 and 1982. The Waikato River Springs, as measured in this *study,* also give lower values (0.75 MW) than those estimated by Bennie (1983) at 3.5 MW. Accurate assessment of these springs was difficult due to their location in the river bank.

The heat transfer estimate of 14.8 MW (3rd column in Table 2) is based on the likely change in enthalpy of ascending deep fluids as a result of boiling and mixing in the reservoir, and is a minimum value. It includes only the 'anomalous' chloride discharged into the Orakonui Stream catchment. Another 7.4 MW is probably discharged by vapour and condensates which do not surface within the boundaries of the Ngatamariki field.

The output values cited are thus conservative; their uncertainty is large, probably ~ ±5 MW for the total of 30 MW.

CONCLUSIONS

The Ngatamariki Geothermal field is quite small compared with the nearby Orakeikorako, Te Kopia and Broadlands-Ohaaki fields. The resistivity boundary encloses an area of 7km^2 (Bennie, 1983) and is centred on a zone of warm springs along the Mangamingi *Stream,* 1.5km east of the Orakonui Stream where the main thermal features are located. This *study* describes the thermal features and surface alteration of the field and relates them to its thermal evolution since the early 1940's.

The *study* has shown that thermal activity at Ngatamariki has undergone significant changes within only 50 years, although heat loss has probably remained the same. Petrographic, photogeologic, geochemical and direct field observations indicate that thermal changes have occurred as a result of the southward migration of activity. Thermal features have been mapped, so a baseline is available for future surveys to monitor natural or induced changes in surface thermal activity.

ACKNOWLEDGMENTS

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