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SOME ENVIRONMENTAL CHANGES RESULTING FROM DEVELOPMENT OF OHAAKI GEOTHERMAL FIELD, NEW ZEALAND

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ABSTRACT

Ohaaki field underwent large-scale discharge testing (1967-1972), followed by a long period of recovery (1972-1987). Production began in 1988, and continues at about 16 Mt/yr (6 Mt/yr net mass loss). During testing the deep reservoir pressures were drawn down by 1.5 MPa, subsequently recovered by 1.0 MPa, and have declined a further 2.0 MPa since production started.

After testing began, the overflow rate from the Ohaaki Pool declined from a natural value of 9 l/s and ceased in early 1968. As testing continued, the water level fell by 9.5 m but slowly recovered when testing ceased. Since 1980, addition of separated bore water and sealing of the base of the pool have maintained overflow. No changes to the chemistry of the pool water occurred until introduction of the bore water. After production began, many smaller hot pools dried up and have been invaded by vegetation, but upflows of steam to most surface features still occur. New steam vents have occurred where subsidence has created tension cracks up to 5 cm wide at the ground surface.

Over most of the field, shallow (1m depth) ground temperatures have not changed. However, temperatures have increased by up to 75 ^{o}C near the tension cracks, and decreased by up to 45 ^{o}C at the edges of some areas of previously thermal ground which are now at ambient temperature.

Shallow groundwater levels have been unaffected by testing or production except in local areas near thermal features, where several metres of water level decline has occurred. Groundwater temperatures have not been affected by the drawdown, except near cold downflows through previously active thermal vents. Most changes to groundwater chemistry appear to be associated with leakage of separated bore water from holding ponds or temporary surface discharges.

1. INTRODUCTION

The Resource Management Act requires all geothermal developers in New Zealand to safeguard the environment, and avoid, remedy or mitigate any adverse effects on the environment. Until recently the only information available about possible environmental impacts of large scale development of a liquid-dominated field was that from Wairakei (NZ), where there were serious impacts on the natural thermal features, localised ground subsidence, and groundwater level changes (Hunt & Glover, 1996).

2. DEVELOPMENT HISTORY

Prior to development, the Ohaaki reservoir was liquid-dominated with fluid at or near boiling point for depth, and overlain by cold groundwater which in places was locally heated by fluids escaping upwards to feed natural thermal features at the surface.

Exploratory drilling at Ohaaki (Broadlands) began in 1965 and, from mid 1967 to late 1971, large-scale test discharges were made in the north-western part of the field. This period is called the Test Discharge Period, and during this time annual mass withdrawal increased to about 10 Mt/yr (Fig 1); there was no reinjection. For the next 16 years only minor testing was done, and the annual mass withdrawal was less than 3.5 Mt/yr. The Ohaaki Power Station was commissioned between August 1988 and November 1989, and most of the separated water and condensate has been reinjected, mainly around the periphery of the field. Mass withdrawal increased to 16.2 Mt in 1990 and has remained at similar values since then; net mass loss is about 6 Mt/yr (mainly to the atmosphere). Operation of the power station and management of the field is by Contact Energy Ltd, which was formerly part of Electricity Corporation of NZ.

During the Test Discharge Period, deep-liquid pressures decreased by about 1.5 MPa (15 bar), but after the testing recovered by about 1.0 MPa during the Recovery Period, before decreasing again after production began (Fig. 1) (Clotworthy *et al*, 1995).

3. GROUND MOVEMENTS

Regular levelling surveys have shown that subsidence has occurred in the north-western part of the field during the Test Discharge and Production periods and is continuing. The subsidence is caused by drainage of a highly compressible mudstone unit above the reservoir as a result of pressure drawdown in the geothermal reservoir (Allis *et al*, 1997).

Horizontal ground movement has accompanied the subsidence. In the central part of the subsidence area there is compressional strain, manifested by *en echelon* ridges in the sinter apron surrounding the Ohaaki Pool, and buckling of steam pipelines. Around the periphery of the subsidence area there is tensional strain manifested by cracks in the ground up to 5cm wide, and displacement of pipeline supports.

4. CHANGES TO OHAAKI POOL

The Ohaaki Pool is the largest (750 m^2) and most significant thermal feature in the field. In its natural state, the temperature of the pool was generally between 85 °C and 100 °C, and the overflow rate was about 9 l/s. During test discharges of nearby wells, the flow rate decreased until overflow ceased, then the water level fell by at least 9.5 m. After the test, the water level rose but the pool did not overflow again until 1981, and then only intermittently. Temperatures fell to about 70 °C during the early part of the testing but later recovered to about 100 °C, which was maintained except during brief discharge tests in the late 1970's. The chloride content was near constant at about 1060 mg/kg until 1980, after which time it varied as a result of input of bore water (Fig. 2). After commissioning of the power station, the flow rate again decreased, and the water level fell. Remedial work was undertaken in 1989 to restore the flow of hot water; this included blocking vents in the base of the pool and flowing separated bore water (160 °C) through the pool. Further details are given by Glover *et al* (1996)

5. CHANGES TO OTHER THERMAL FEATURES

Before development began, more than 20 thermal features of lesser significance were present at Ohaaki (Fig 3, Table 1). These included: boiling mud pools (up to 12 x 6 m), warm pools (up to 80 x 40 m), and thermal ground. Photographic and thermal infra-red (TIR) surveys of these features were made in 1988 (before production), and repeated in 1997.

The surveys showed that in the north-eastern part of the field many of the warm pools and mud pools had dried up and become weakly steaming from vents in the base (Table 1), and for the remainder there were temperature decreases of up to 38 °C. Some patches of thermal ground decreased in area, but others were unaffected (especially in the south-eastern part of the field).

6. GROUND TEMPERATURE CHANGES

Ground temperature measurements are used to establish the extent, nature and magnitude of any temperature changes. These data are of use in helping to understand the response of the geothermal system to exploitation, as well as the environment. Areas of increased ground temperature may be associated with areas in which there is an increased upflow of steam from the reservoir resulting from the formation and extension of 2-phase conditions and/or increased shallow permeability due to fracturing. Areas of decreased ground temperature may show the positions of cold downflow where previously upflowing hot fluids have been replaced by cold groundwater flowing down conduits from the surface to the reservoir. However, ground temperatures at 1-m depth may be influenced by changes in air temperature and pressure, and by the temperature and level of groundwater (Allis, 1981).

Shallow (1 m depth) ground temperature measurements made in 1967 (prior to well testing), showed that temperatures exceeding 10 °C above ambient occurred over most of the north-western part of the field. Additional measurements made in 1983 (Recovery Period) indicated the approximate area and location of the thermal anomalies was similar to that in 1967. In Dec. 1988, during the commissioning of the power station, a set of 1 m ground temperature monitoring points was established at 25 m intervals along 3 lines across the thermal anomalies (Fig.3). The measurements were repeated in April 1996, and the data corrected for seasonal temperature changes.

Comparison of data from the 1988 and 1996 surveys shows that there were no significant temperature differences on Line 1 through the south-eastern thermal anomaly (Fig. 4). On Line 2, there were temperature ***decreases*** (10-45 °C) over distances of about 200 m; at these places the ground temperatures in 1988 had been 40-70 °C above ambient. There was an ***increase*** of up to 75 °C near BR17; and ground temperatures are now in excess of 90 °C here. However, additional measurements suggest these high temperatures are very localised. The area near BR17 lies in a zone of tensional strain associated with ground subsidence and there are numerous cracks in the ground surface. It is probable that the high ground temperatures measured are associated with localised heating of the ground by steam rising through these cracks. Evidence for this is that, on cold mornings during the 1996 survey, steam could be seen rising from the cracks, and grass on the edges of the cracks was observed to be dying. On Line 3, there have been no significant changes, except at three point (Fig. 4) where ground temperatures have ***decreased*** by 10-20 °C (from 44-48 in 1988, to 27-36 °C in 1996).

The repeat TIR imagery also showed the development of numerous narrow, linear thermal anomalies in the north-eastern part of the field, particularly in the vicinity of BR 9 (Fig. 5). These anomalies are coincident with the tension cracks associated with ground subsidence

The data indicate that over most of the field, shallow (1m depth) ground temperatures have not changed since production began in 1988.

7. GROUNDWATER LEVEL CHANGES

Groundwater levels have been monitored regularly by Contact Energy since 1967; at present there are 35 shallow (<50m deep) wells (#/0 holes) adjacent to the deep wells and 10 deep (250 m) monitor wells. The data indicate that groundwater levels have generally been unaffected by discharge testing or production, except in local areas near thermal features (Bromley *et al*., 1993). Here the groundwater levels have declined by several metres (Fig. 6). Some very shallow wells indicate the presence of localised pockets of steam- and rainwater-recharged water, which are perched above the principal groundwater aquifer. The water levels in such perched aquifers are more variable.

8. GROUNDWATER TEMPERATURE CHANGES

The temperatures at, or near the water surface, in 46 shallow groundwater monitor holes. have been measured by Contact Energy. In 13 holes, the measurements extend back in time to the Test Discharge Period (1967-72), but no temperature measurements were made prior to investigation of the field; at that time the possibility of changes in groundwater temperatures was not considered likely to occur - only changes in groundwater level. Subsequently, as more monitor holes have been drilled, data collected, and knowledge of the geothermal system increased, more measurements have been made.

The data obtained show that over most of the field the groundwater is cold (ambient temperature 10-25 °C). In two areas the groundwater temperature is warm (25-75 °C) or hot (75-100 °C):

a) A banana-shaped area of about 2 km^2 extending from BR3 in a southwest direction to BR6 (western bank);

b) An area of about 0.5 km^2 in the vicinity of the thermal area near BR7 (eastern bank).

Both of these areas of anomalous groundwater temperature surround known areas of thermal ground.

Generally, the test discharges had no effect on shallow groundwater temperatures, either hot (e.g. BR3/0,BR6/0; Fig. 6) or cold (e.g. BR10/0; Fig. 6). One clear exception, however, was in BR4/0: between August 1967 and February 1970, the groundwater was near boiling (90-100°C), but between then and August 1974 the temperature decreased by about 60 °C and has remained at 20-25 °C since June 1979 (Fig. 6). This decrease in water temperature may reflect the onset of a localised cold downflow associated with the pressure drop that occurred during the Test Discharge Period. As the hot water drained downwards it was replaced by cold groundwater which moved in laterally. Another possible exception is BR2/0; at the beginning of the Test Discharge Period the temperature in this monitor hole was 60 °C but it quickly decreased to about 40 °C (Fig. 6).

There were no significant changes in groundwater temperature during the Recovery Period. A possible exception was in BR19/0 where the temperature decreased by about 20 °C (from 50 °C+ to 32 °C, between 1970 and 1980) but it subsequently increased to previous values; such changes were not associated with any observed changes in groundwater level (Fig. 6).

Production from the field does not appear to have resulted in widespread changes in groundwater temperature. Water in holes that was hot or boiling at the start of the Production Period has remained hot, or decreased in temperature by less than 20 °C (eg. BR3/0; Fig. 6). Similarly, water in holes that were cold, has remained cold (e.g. BR10/0; Fig. 6).

However, there have been exceptions. In BR21/0, at the start of the Production Period the water temperature was 66 °C, but in March and September 1990 the temperature had risen to 97.5 and 101°C respectively (Fig. 6). By August 1992, the temperature had returned to 61 °C, and all subsequent measurements have shown a steady decline in temperature from that value to about 50 °C in late 1994. Except for the two measurements in 1990, the groundwater temperature in this hole has decreased steadily from about 90 °C in the early 1970's to about 50 °C in 1995. A similar temperature peak, but of smaller magnitude, also occurred in nearby BR19/0 followed by a decrease of about 30 °C in the early 1990's (Fig. 6). Both these holes are in the vicinity of thermal features and the rapid pressure drawdown in the reservoir may have temporarily induced an increased flow of steam to the surface along conduits feeding these features, which in turn may have heated groundwater in the vicinity.

Reinjection at BR12, up to 1994, did not cause any changes in groundwater level or temperature (Fig. 6).

9. SEISMIC ACTIVITY

Continuous seismic monitoring was carried in 1987-1992. Seismic activity was low in and around the field prior to commissioning of the power plant. During the first 3 yrs of production no induced seismicity was detected, even though injection pumping pressures temporarily reached 4 MPa (Sherburn et al., 1993)

10. ADDITIONAL INFORMATION

This paper is a only a summary of the physical changes that have occurred. More extensive environmental data are presented in the application submitted by Contact Energy to obtain renewal of the Resource Consent for operation of the Ohaaki Power Plant (Contact Energy, 1998).

11. CONCLUSIONS

Production-induced pressure drawdown in the reservoir has resulted in some changes to the environment at Ohaaki, including:

- Ground subsidence and strain manifestations have occurred in the north-eastern part of the field;
- Some warm and boiling pools in the north-western part of the field have dried up; and
- New areas of steaming ground have developed where tension cracks have formed around the subsidence area in the north-western part of the field.

However, there have been no significant changes to shallow ground temperatures, except for local areas where temperatures have increased in some places but decreased in others. Groundwater levels and temperatures have generally been unaffected, except in local areas near thermal features. There has been no injection-induced seismicity.

12. ACKNOWLEDGEMENTS

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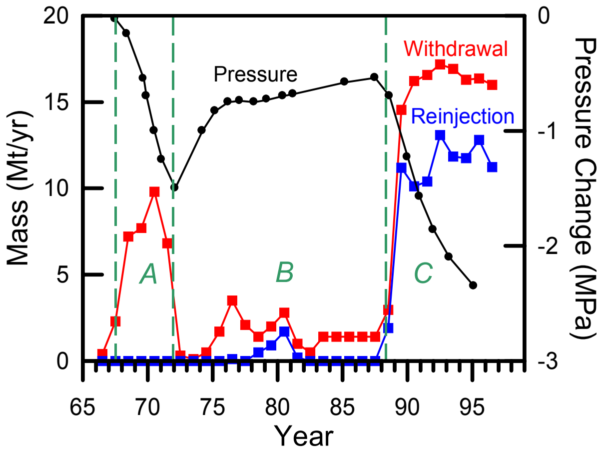

Fig.1. Mass withdrawal and pressure changes at Ohaaki Geothermal Field. (A) is the Test Discharge Period, (B) the Recovery Period, and (C) the Production Period. Pressure changes are for the deep liquid zone.

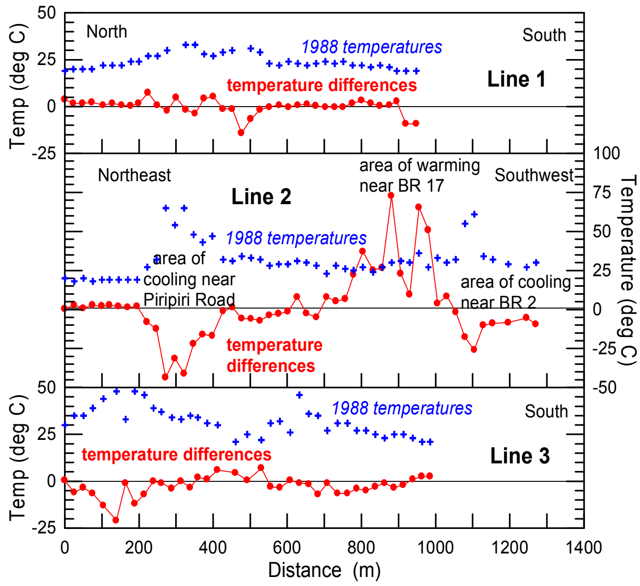

Fig. 4. Shallow ground temperature differences between 1988 and 1996, along profile lines through areas of thermal ground at Ohaaki. Locations of lines are shown in Fig. 3.

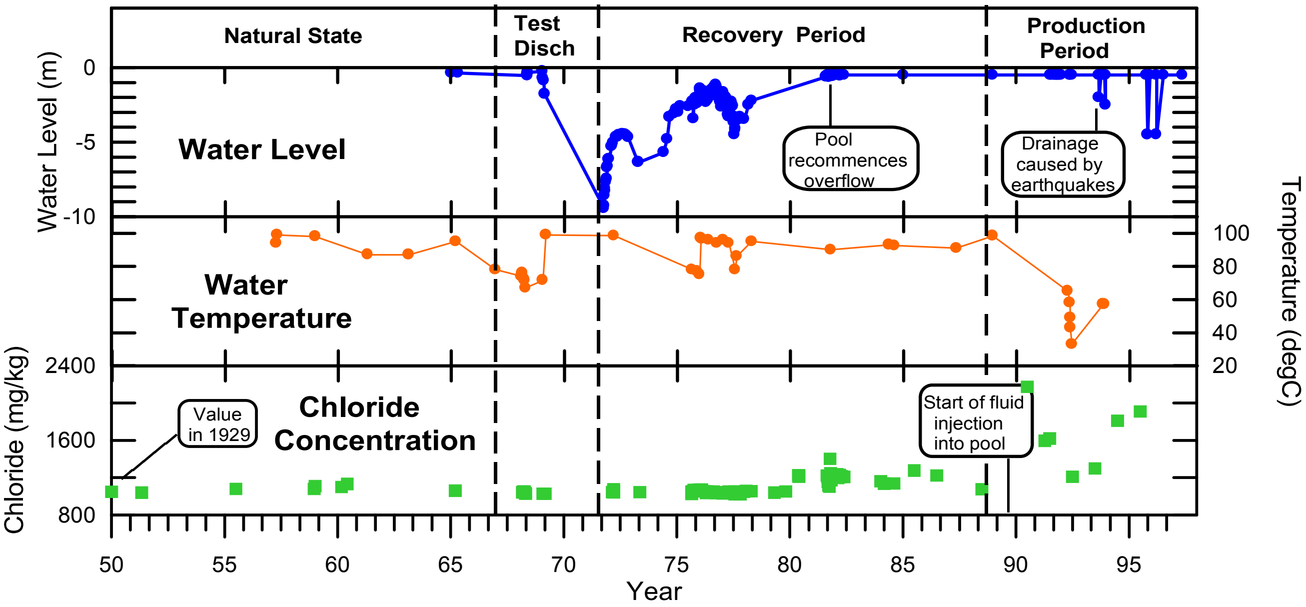

Fig. 2. Changes in water level, temperature, and chemistry in Ohaaki Pool.

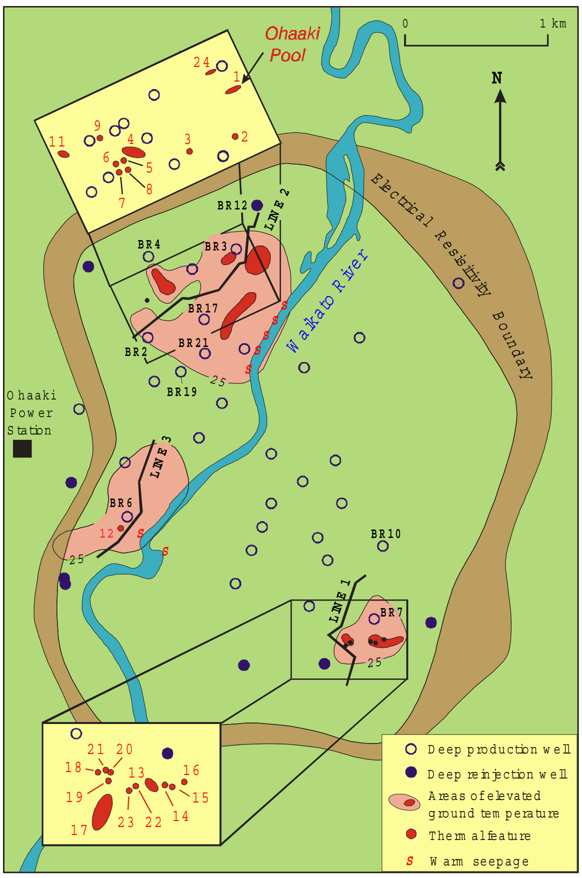

Fig. 3. Map of Ohaaki showing areas of thermal ground, natural thermal features (insets) and ground temperature survey lines. Contours show areas of thermal ground that are 0-25, and 25-50 °C above ambient temperature. Numbers refer to the thermal features listed in Table 1.

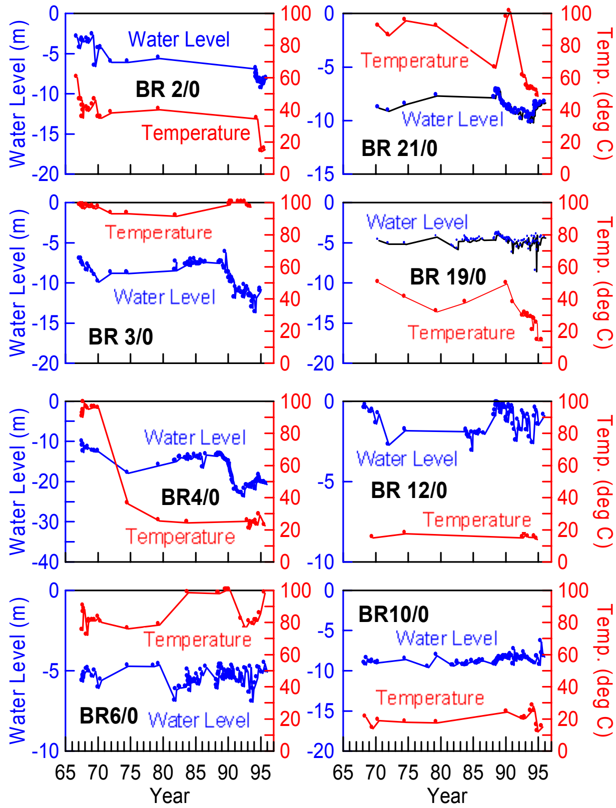

Fig. 6. Changes in groundwater level and temperature in shallow monitor wells at Ohaaki. The wells are situated adjacent to deep wells, locations of which are shown in Fig. 3.

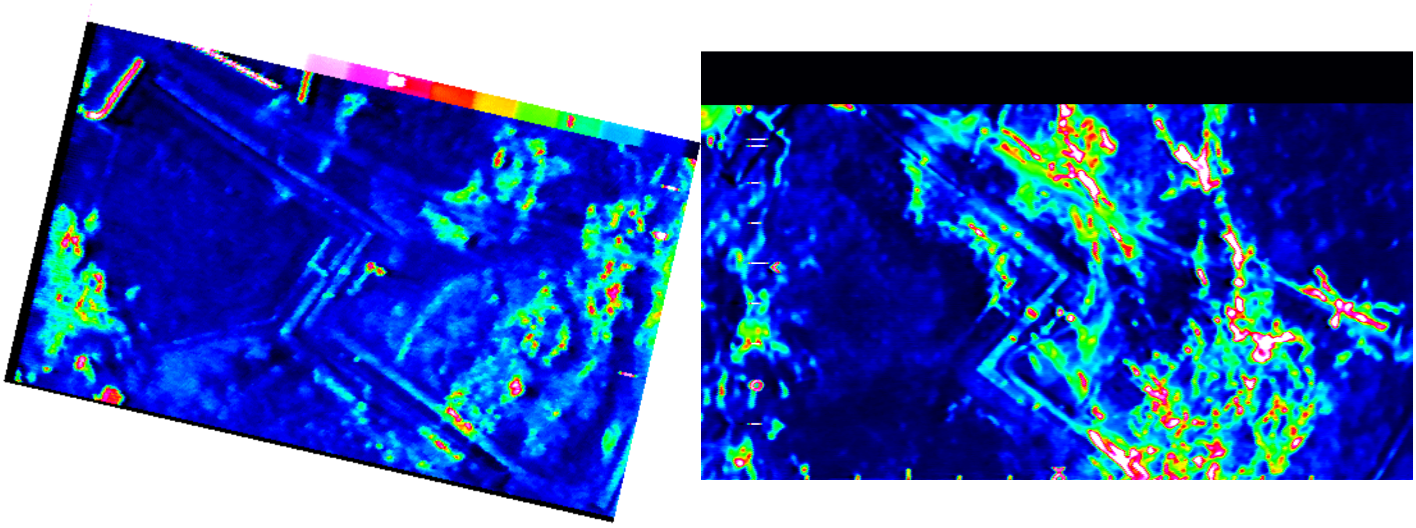

Fig. 5. Thermal infrared imagery of an area near BR 9 (centre of images), showing increases in surface thermal activity between 13 April 1989 (left) and April 27 February 1998 (right). Colours indicate surface temperature, ranging from 10 °C (black) to >33 °C (white). Each image covers a ground area of about 300 x 200 m.

Table 1: Changes to thermal features at Ohaaki Geothermal Field. For feature locations refer to Fig. 3

Feature Number	Description (in 1988)	Temp (°C) Dec 1988	Temp (°C) Dec 1997	Changes since production began
1	Large hot pool (Ohaaki Ngawha)	98	67	(see fuller description in text above)
2	Silica pan with small pools	88-92	*	Pools dried up
3	Boiling mud pool (12 x 6 m)	99	ambient	Cooled and area re-vegetating
4	Warm pool (80 x 40 m)	40	*	Dried up, vegetation now growing in bottom
5	Warm pool (16 m diam.)	34	*	Dried up
6	Warm pool (14 m diam.)	44	*	Dried up, weak steam vent appeared
7	Warm pool	53	*	Dried up
8	Channel between features 6 & 7	78	*	Dried up
9	Warm pool	35	*	Dried up, weak steam vents appeared
10	Warm pool (6 x 3 m), 30 m.S.E. of #9	58	*	Dried up
11	Clay pan and vent	77 (vent)	*	Covered by new road and plantation forest
12	Pits	99	*	Weakly steaming
13	Warm pool (55 x 40 m)	31	*	Water level fallen
14	Warm pool (28 x 15 m)	42	39	Slight decrease in temperature
15	Warm ground, sulphur mounds and pits	99 (pit)	97	Area flooded
16	Mud pot (0.4 m diam.)	99	61	Became warm pool
17	Warm altered ground, steam vents	95	97	No significant change
18	Thermal ground, steam vent	*	*	Little change, some new vegetation at margins
19	Hot bank; steam vents at base	97	*	Vegetation regrowth
20	Warm ground, steam vent	94 (vent)	*	Vent reduced to weakly steaming
21	Warm ground	No data	No data	
22	Warm pool (55 x 35 m)	33	34	Water level lower, recent flooding
23	Warm pool	36	31	Water level lower, recent flooding
24	Group of small hot pools	72-82	*	Pools empty, bottoms now weakly steaming