

OHAAKI NGAWHA; OHAAKI POOL

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SUMMARY - In its **natural** state, the temperature of the **Chacki** Pool was generally between **85** and **100°C**, and the overflow rate was about **9 l/s**. Historic records show that at least one episode of cessation of flow followed by a temporarily increased flow (**> 23 l/s**) occurred. During test discharges of nearby wells (**1967- 1972**), the flow rate decreased until overflow ceased, then the water level fell by at least **9.5m**. After the test, water level rose but the pool did not overflow again (intermittently) until **1981**. 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 **1970s**. The chloride content remained near constant until **1980**, after which time it varied **as** a result of input of bore water. After commissioning of the **Chacki** Power Station (**1988-1989**), the flow rate again decreased, and the water level fell. Remedial work has been undertaken to restore the flow of hot water to the Te **Chacki** o Ngatoroirangi Marae; **this** includes blocking vents in the base of the pool and flowing separated bore water through the pool.

1. INTRODUCTION

The **Chacki** Pool is an often boiling and overflowing spring, and is the largest **natural** thermal feature in the Broadlands (Ohaaki) field. It is located on the west (true left) bank of the Waikato River in the north-western part of the field: approx. grid reference **2 798 800 mE, 6 293 200 mN** (NZ Map Grid). The rim of the pool is at approx. **295 m** (a.s.l) and about **10 m** above the Waikato River which is about **350 m** distant. The name has been variously spelt **as**: Te Kohaki, Ohake, Ohaki, and **Chacki**. This paper describes the Pool, the impacts that development of the **Chacki** Power Scheme have had on it, and remedial work that has been done to mitigate these impacts. We do not attempt to explain the complex hydrology involved.

2. HISTORY

The first European record of the Pool is given by Hochstetter (**1864**) who notes that *"at Ohake a solfatara Ipu kai himarama and a spring Te Kohaki are mentioned by the natives, but I have not seen them myself"*. Surprisingly, there appears to be no mention of the Pool in Herbert (**1921**) or Vaile (**1939**). The first detailed description of the Pool is given by Grange (**1937**) who reports *"Ohaaki, largest (pool), about 3 chains in diameter has a temperature of 94°C and boils up in two places. It is bordered with petted, white sinter, and its overflow has encrusted a wide area with sinter"*. An account of visits to the pool during a period of increased activity in **1957** is given by Lloyd (**1957**). It is apparent there was little written record of the Pool before investigations for geothermal development in the Broadlands area began in **1965**.

3. CULTURAL SIGNIFICANCE

Geothermal resources are regarded **as** one of the traditional Māori resources referred to in Article 2 of Te Tiriti O Waitangi (Treaty of Waitangi). In traditional Māori terms geothermal springs were not an isolated phenomenon, but were **seen as** the face or eye of the resource. The surface components were **each** given names depending on temperature, overflow and geysering characteristics. The name for large boiling and overflowing pools, such **as** at **Chacki**, was *ngawha*.

The **Chacki** Ngawha was used for centuries by the Ngati Tahu people for cooking **and** bathing, and was an integral part of their daily lives; it is therefore a *taonga* (treasure) to those people.

The principle marae of Ngati Tahu is located adjacent to the Ohaaki Ngawha; on **this** marae is the building 'Te **Chacki** o Ngatoroirangi (the legacy of Ngatoroirangi)' which **was** relocated **from** Orakeikorako. In the **1930s** there were about **30** households around Te O W Marae. The land around the marae was cultivated and produced food for local consumption. No one lives permanently at the marae now (the last house was vacated in the early **1970s**) but **this** does not mean the marae is abandoned; gatherings, *tangihana* (funeral), *hui* (meetings), and social functions are held there.

In the early planning of the O W Power Scheme, it **was** assumed the Crown would obtain ownership of the land: by purchase, or by use of The Public Works Act (**1967**). In **1978**, the Ministry of Works applied to the Māori Land **Court** to purchase the land, but at a meeting of Māori owners called by the **Court** to consider **this** application there **was** a **unanimous** refusal to sell. It

was not expedient to use the Public Works Act to take the land because earlier in the **1970s** there had been political unrest due to the "Māori Land March", the Bastion Point protests and the Raglan Golf Course issue. A representative group from Ngati Tahu was formed to deal with all matters relating to the power scheme.

In **1982**, a Memorandum of Heads of Agreement to lease the land was signed by Te **Chaki** Marae and Ngawha Trust members and the Ministry of Energy. The agreement contained provisions intended to protect the marae, *urupa* (burial grounds) and other *waahi tapu* (sacred places) in the area, and to provide steam and hot water to the Marae. Water Rights issued by the Waikato Valley Authority (WVA) were no longer contested by Ngati Tahu and in October **1982**, government approved construction of the **Chaki** Power Scheme.

4. PHYSICAL DESCRIPTION

The **Chaki** Pool is approximately rectangular in shape, about **45 m** long and **15 m** wide, aligned in a NE-SW direction. Surveys made during periods of low water level (Fig. 1) show that the pool has two sections consisting of irregular, funnel-shaped depressions; one in the NE and the other in the SW part, separated by a broad ridge which reaches to within about **1.5 m** of the surface (during overflow). The NE depression contained several pits or vents, the largest about **5 m** diameter and may have been 20 m deep. The SW depression had two vents; the higher of which actively vented when the pool was empty.

In its natural state, the pool was **often** ebullient above the centres of these depressions. Lloyd (**1957**) reported

that in April **1957** "*the Southwestern portion of the spring was extremely active, bubbling up constantly to a height of three feet with occasional surges reaching five feet*", however, this was during a short period of increased activity.

The Pool is surrounded by a gently sloping sinter apron (of unknown thickness), which is bare of vegetation **near** the edge of the pool. Around the edge is a **unique** fretted scroll design sinter lip which often overhangs the pool. The lip is formed of upward expanding, laminated, columnar stromatolites (up to **2 cm** in diameter) consisting of sheets (up to **5 μm** thick) of apparently structureless opaline silica (opal-A). These have been described in detail by Jones *et al.* (**1996**). Locally, the columns are overlain by laminated sinter that is up to **0.5 cm** thick, with individual laminae **<1 mm** thick. The outer surface of the columnar stromatolites is **commonly** coated with calcite crystals which formed **as** a cement. In some areas, the narrow gaps which originally existed between the stromatolite columns are filled with platy calcite crystals which have their long axes perpendicular to the stromatolite surface. Intercalated with the silica sheets are microbial mats, up to **1 mm** thick, formed of loosely interwoven, non-branching, filamentous-sheathed microbes (now dead).

The nature of the connection between the Pool and the geothermal reservoir **has** not been established, but data (described later) show that the Pool responds rapidly to pressure variations in the reservoir. The Pool lies on the alignment of the Ohaaki Fault, one of a number of active, northeast striking, conjugate faults, which pass through the area (Grindley and Browne, **1968**), and which may provide the conduit.

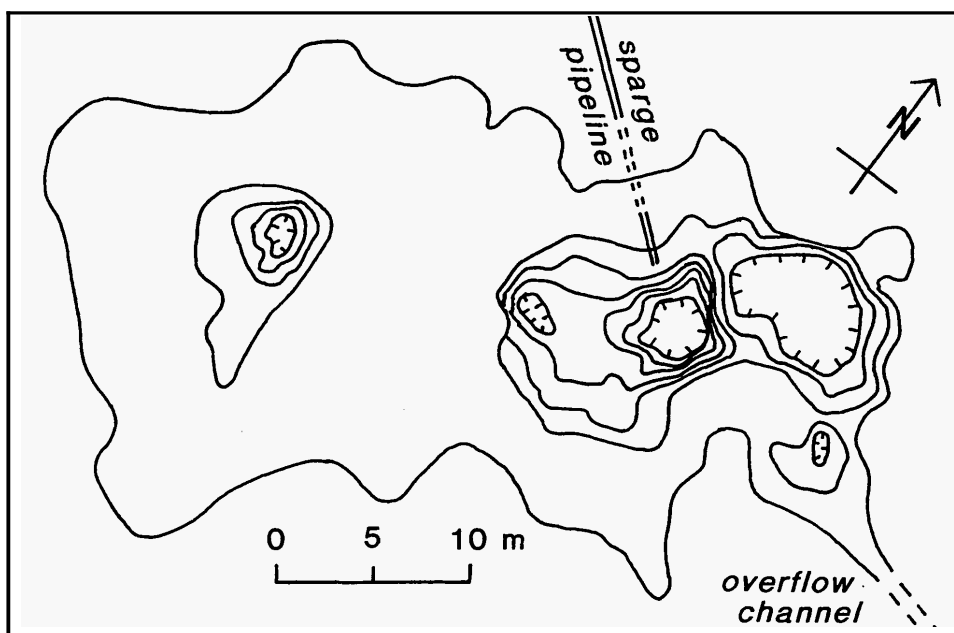


Fig. 1 • Bathymetry of **Chaki** Pool, August **1989**. Contour interval **2 m**.

5. FIELD DEVELOPMENT HISTORY

Prior to development, the deep reservoir was liquid-dominated with fluid generally at or near boiling point for depth. Over-lying the reservoir is a zone of cold groundwater, locally heated by fluids escaping upwards to supply **natural** thermal features at the surface.

Exploratory drilling began in **1965**, and by **1971**, **25** deep wells had been drilled, most in the western part of the field, and near the Ohaaki Pool. From the middle of **1967** until late **1971**, test discharges were conducted during which time the **annual** mass withdrawal increased to about **10 Mt/yr** (Fig. 2); during this "Test Discharge Period" all the separated water was discharged into the Waikato River. In the following **16** years, a **further 18** holes were drilled but no extensive testing was done; the average mass discharge was only **1.5 Mt/yr** and did not exceed **3.5 Mt/yr** (Fig. 2). This time is known as the "Recovery Period". Commissioning of the **Ohaaki** Power Station (**116 MWe** installed capacity) began in August **1988** and was completed in November **1989**. **Mass** withdrawal rose to **16.2 Mt** in **1990**, and has remained at similar values since then (Fig. 2). Since commissioning, most of the separated water and condensate has been reinjected, mainly around the periphery of the production areas. Net mass loss is now about **6 Mt/yr**. The reinjection well closest to the Pool is **BR12**, located about **450 m** to the north; the closest production well is **BR3** about **150 m** to the north-west.

During the Test Discharge Period deep-liquid pressures decreased by about **15 bar**, and subsequently recovered by about **10 bar** during the Recovery Period before decreasing again when production began (Fig. 2).

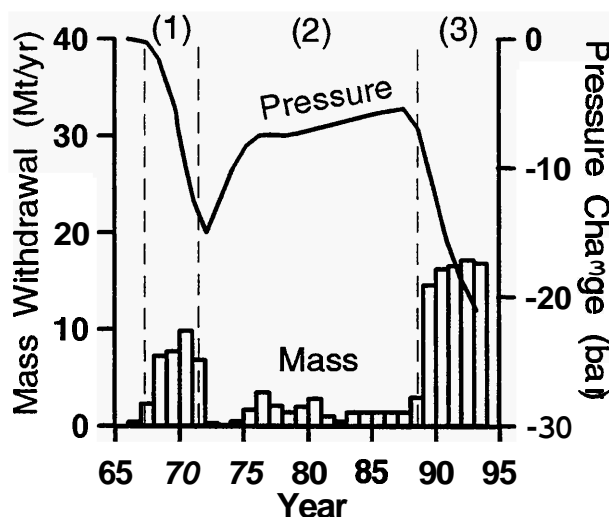


Fig. 2 - Annual mass withdrawal and deep-liquid pressure changes at Broadlands field, during Test Discharge (1), Recovery (2), and Production (3) periods. Data from Environment Waikato and from Clotworthy *et al.* (1995).

6. IMPACTS OF DEVELOPMENT

During the planning stages of the **Ohaaki** Power Scheme, it was recognised that environmental effects might occur, and an Environmental Impact Report (NZED, **1977**) was prepared in which the effects of chemical and gas discharges, noise, and thermal pollution on the climate, **natural** waterways, flora and fauna, and ground movements were assessed, and steps taken to mitigate the impacts. The possible effects of exploitation on **natural** thermal features were not mentioned in the Impact Report, despite the changes which were known to have occurred to such features at Wairakei (Thompson, **1957**; Fisher, **1964**; Dawson and Dickinson, **1970**).

6.1 Changes in flow rate and water level

The presence of an extensive sinter apron around the pool indicates that it has overflowed for a long time. In recent times, a narrow channel was made in the **rim** and from it a shallow **canal** (ditch) dug in the sinter to convey the overflowing water to an open **air** bath near the marae (Lloyd, **1957**). Measurements made in this **canal** prior to the Test Discharge Period (Fig. 3a) suggest that normally the flow rate was about **9 l/s**, however, it is known that sudden changes in flow rate and water level have occurred. Lloyd (**1957**) reports that on **25 March 1957** the pool ceased to overflow, and on **2 April 1957** the water level was about **0.73 m** below the overflow channel. He describes that *"it appeared that the water supply to the spring had been completely cut-off, and the comparatively high surface temperature of 94°C was being maintained by the steam/gas supply . . . it does seem certain that Ohaaki has receded previously, but had never been known to go down so far, and [then] only for a matter of hours or days at a time. Certainly not for weeks. It appears that the water level went down overnight . . ."* He continues that *"On Thursday 18 April 1957, Ohaaki was reported to be overflowing again and I visited the area on 24 April. Not only was the discharge flowing down the dug ditch, but there was water spilling over the lip all round and flowing away over the terrace. It was quite impossible to make an accurate measurement of the overflow, but a minimum figure of 23 l/s was obtained, showing a substantial increase over previous measurements of 9 l/s. The south-western portion of the spring was extremely active, bubbling up constantly to a height of three feet with occasional surges reaching five feet. The temperature in the active portion was 98.7°C."* Lloyd (**1957**) also reports that at this time there was increased activity (including geysering) in other nearby springs. The increased flow slowly declined, but by **5 June 1957** was still greater than normal. He considered that *"the unusual recession was due to mechanical causes; probably the feeding channels becoming blocked by earth movements, and later clearing themselves as pressure increased below the blockage. The fact that springs some distance from the main pool behaved in*

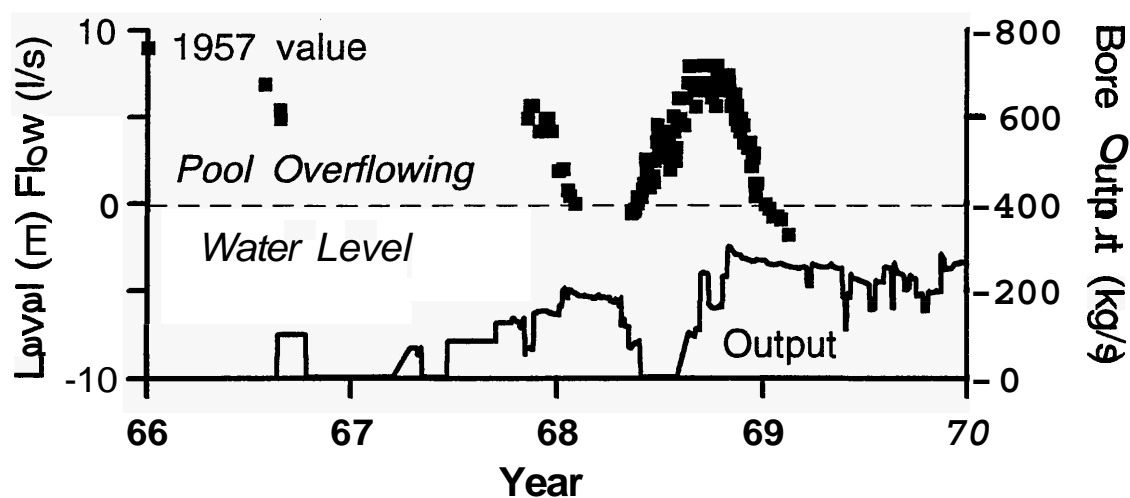


Fig. 3 - Changes in flow rate from Ohaaki Pool during part of the Test Discharge Period. Note the decrease in flow rate when nearby bores were open and discharging, and the increase when these bores were shut. Scatter in the flow rate data is caused mainly by atmospheric pressure variations.

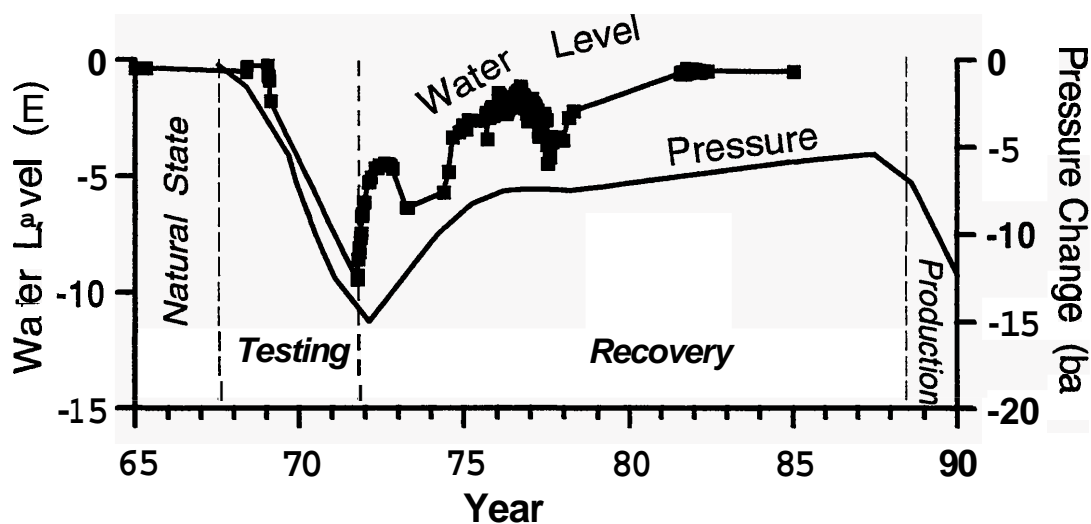


Fig. 4 - Changes in water level in Ohaaki Pool.

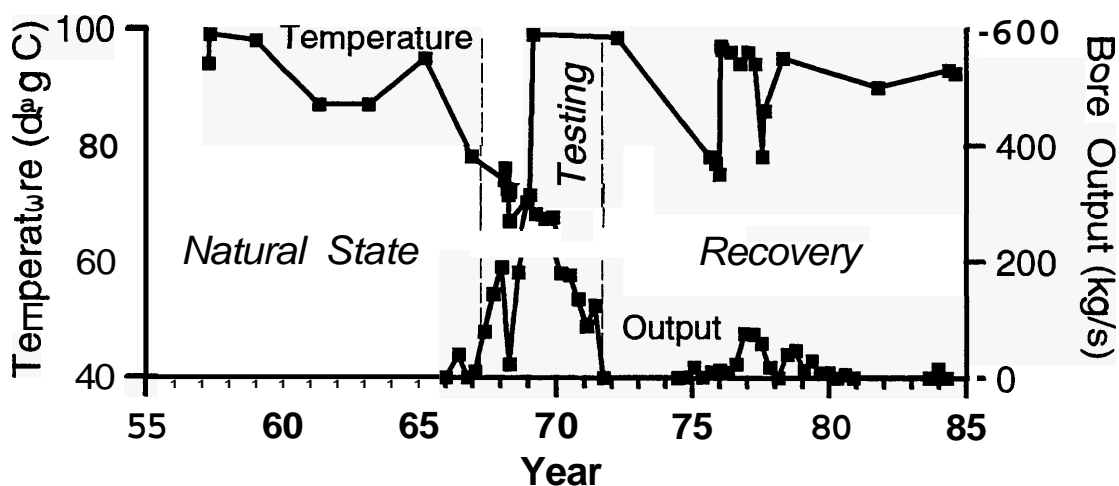


Fig. 5 - Changes in temperature in Ohaaki Pool from 1957 to 1985.

sympathy with Ohaaki indicates that the blockage occurred at a considerable depth."

Measurements have shown that the flow rate is strongly influenced by the operation of nearby bores (Fig. 3). During the Test Discharge Period, when nearby bores (BR2, 3, 4, 8, 9, 11, 17, 19, 22) were discharged the flow rate decreased until overflow ceased, and then the water level receded. When discharge decreased and was temporarily stopped in 1968, the water level rose, the pool began to overflow, and the flow rate increased to about 8 l/s. Soon after the discharges recommenced, the flow rate stabilised then again decreased rapidly until the pool ceased to overflow. The water level then fell, reaching a level of 1.8 m below the channel on 14 February 1969 (Fig. 3). About this time it was noticed that some parts of the overhanging edge had collapsed, possibly due to loss of buoyancy support by the water and/or thermally-induced fracturing associated with exposure to the air. No further water level data were collected until 1 October 1971, when the water level was 9.5 m below overflow (Fig. 4). During the remainder of 1971 the water level rose reaching a (temporary) maximum of 4.5 m in July 1972, before again declining to 6.4 m in April 1973. There was another gap in the data from then until May 1974 when the water level was at 5.7 m, after which time the level quickly rose to 3.1 m by November 1974, and then more slowly until the middle of 1976 (Fig. 4). The reason for the temporary drop in level between July 1972 and November 1974 is not known; there was little discharge from nearby bores during this period. During the remainder of the Recovery Period a number of discharge and interference tests were conducted which resulted in perturbations (up to 4 m) to the water level in the pool, which were noted by Grant (1982). The data suggest that, except for these perturbations, the water level generally rose and the pool began intermittently overflowing in October 1981 due to injection of separated water from BR22. From then until August 1988 (start of the Production Period) the pool overflowed intermittently at rates of up to 2 l/s. During the Production Period, the water level in the pool has generally been sufficient to result in overflow.

6.2 Changes in temperature

Temperature data are not as detailed as for flow and water level, but show that they were influenced by operation of nearby bores. Measurements made prior to well testing (Fig. 5) suggest that water in the pool was not always boiling, but surface temperatures were in excess of 75°C. During the initial part of the Test Discharge Period, temperatures decreased to about 65–75°C, but later recovered, and in the Recovery Period were generally greater than 90°C, except when discharges were made from bores in the Western Steamfield at which time they decreased to about 75°C. The reason for the decrease (to 75°C) in late 1975 is not known.

6.3 Changes in chemistry

Chloride has been determined for 114 samples, but reliable calcium and magnesium analyses are available for only 10 samples (Table 1). The samples are divided into four groups. The first group of 8 samples were collected between 1929 and March 1965, before drilling began. The second and largest group of samples (65) were collected between February 1968 and October 1979, and includes the Test Discharge Period and some of the Recovery Period. The third group of 33 samples were collected between May 1980 and May 1987, a time when the chloride concentration increased almost step-wise by over 150 mg/kg and when waste water from BR22 was, at times, flowing into the pool. The fourth group of 8 samples, collected between July 1988 and July 1995, cover the Production Period when large scale discharge of bore water was made into the Ohaaki Pool and remedial work was carried out to provide an overflow. All chloride data, together with mean concentrations for each group are shown in Fig. 6.

The values for mean chloride concentration (1081 and 1048 mg/kg) in the first two groups of data indicates the water in the pool was a mixture of a deep parent fluid which had undergone boiling and dilution with a steam heated, 140°C, water (Glover and Hedenquist, 1989). The calcium and magnesium concentrations were 5 and 10 times higher in the pool water than in the deep drillhole waters; this supports the inference that a shallow cooler component had mixed with the deep parent fluid.

Table 1: Ohaaki Pool water chemistry - concentrations expressed as mg/kg.

Start Date	1929	Feb-68	May-80	Jul-88
End Date	1965	Oct-79	May-87	Jul-95
Chloride				-
Samples	8	65	33	8
Min	1049	1021	1103	1075
Max	11321	1074	1402	2175
Mean	1081	1048	1205	1391
SDev	31	13	56	665
Calcium				
Samples	2	5	2	1
Min	8.5	3.8	7.9	
Max	12	11.6	12.1	
Mean	10.25	8.2	10	3.2
Magnesium				
Samples	2	4	3	1
Min	0.2	0.2	0.4	
Max	0.5	0.72	0.5	
Mean	0.35	0.47	0.44	0.04

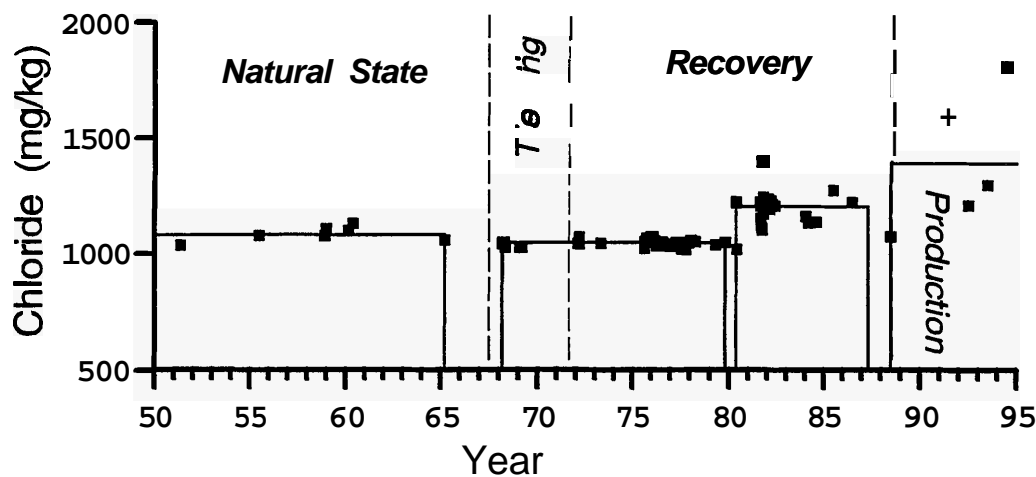


Fig. 6 - Chloride concentrations in Ohaki Pool from 1951 to 1995. Bar graphs show mean values for the four groups in Table 1.

All samples in the second group were taken when the pool had no visible outflow, i.e. no overflow. The fact that evaporation from the surface did not cause increased concentrations suggests that subsurface outflow was occurring. This phenomenon was demonstrated to occur in Champagne Cauldron, Wairakei in October 1965 at a time when overflow had ceased (Glover, 1965). At Ohaki, it was first noted by Lloyd (1957) when the pool was overflowing. He used heat and mass flow measurements (made by Gregg in 1952) to calculate a steam flow of 9.9, an overflow of 9.4, and a subsurface outflow of 16.7 kg/s, i.e. a total liquid flow of 26.1 kg/s and total mass flow of 36.0 kg/s. This was based on an enthalpy of 200 cal/g (837 J/g) equivalent to a temperature of 197°C. Hochstein and Henrys (1988) calculated mass flows for a time when the pool had no visible outflow. Using the algorithm of Ryan *et al.* (1974) to estimate heat loss from the evaporating surface, they calculated a steam flow of 6.7 kg/s and a subsurface flow of 30 to 41 kg/s, i.e. a total mass flow of 37 to 48 kg/s.

Sometime between October 1979 and May 1980, the mean chloride concentration increased to 1205 mg/kg. During this time, BR22 was being used for corrosion, pilot plant and silica removal experiments and had an output of approximately 17 kg/s (P Taylor, pers. comm.). The increase of chloride concentration was probably due to bore fluid from BR22 entering the pool. The large variations in chloride, over short time periods, between May 1980 and May 1987, are likely to have been caused by changes in bore water inflow.

In 1988, ECNZ obtained a water right to inject up to 300 t/h (83 kg/s) into the pool to provide overflow. The high average chloride concentration in the pool (1391 mg/kg) between July 1988 and July 1995 is due to a larger flow of bore water (chloride at atmospheric pressure approximately 1620 mg/kg) compared to period 3. The low value of 1075 mg/kg indicates no inflow of

bore water and the high of 2175 mg/kg is probably due to evaporation at a time when leakage and overflow was minimal. The high standard deviation in the chloride concentration reflects the large variation in inflow and varied conditions in the permeability of the base of the pool (see Section 7).

Calcium and magnesium values decrease with the increase in drillhole fluid entering the pool in period 4. The effect of BR22 water in period 3 is not obvious, probably due to the paucity of samples analysed for calcium and magnesium together with the smaller proportion of bore water in the pool compared with about 100% at times during period 4 (Cl = 1596 mg/kg in the sample analysed for Ca and Mg).

In mid 1957, a red-orange flocculent precipitate was carried in the pool and being deposited (Ritchie, 1961). Spectrographic analysis of a sample of this precipitate (collected in early 1959) showed the presence of about 10% antimony, and that gold, mercury, thallium and arsenic were also present. Weissberg (1969) described the material as mainly metastibnite (amorphous antimony sulphide). The precipitate was not present in January 1963 and its reoccurrence has not been reported since. A similar precipitate (8% antimony) was deposited in 1966 (Weissberg, 1969) on the concrete run off apron from well BR2, 1000 m southwest of Ohaki Pool. Episodic appearances of similar precipitates have also occurred in Champagne Pool, Waiotapu (K L Brown, pers. comm.). We suggest that the occurrence of the precipitate at Ohaki was related to the physical events that caused the pool to cease to flow and then discharge with an increased flow rate in March 1957 (Lloyd, 1957). Admixture of a shallow acid sulphate water or injection of gas from a gas cap, could cause the pH of the fluid to drop; this has a major influence on stibnite solubility below 150°C (Krupp, 1988) causing metastibnite to precipitate. On flowing to the surface, steam and gas loss would cause the pH to rise

again and thus little evidence of the low pH fluid would be observed. The precipitate would be slow to dissolve even when the pH rose so would remain in the pool water.

6.4 Ground movements

Pressure drawdown in the reservoir during the Test Discharge Period and since Production began has led to compaction within a rock unit above the reservoir, resulting in deformation of the ground surface over a crescent-shaped area in the northwestern part of the field (Clotworthy *et al.* 1995).

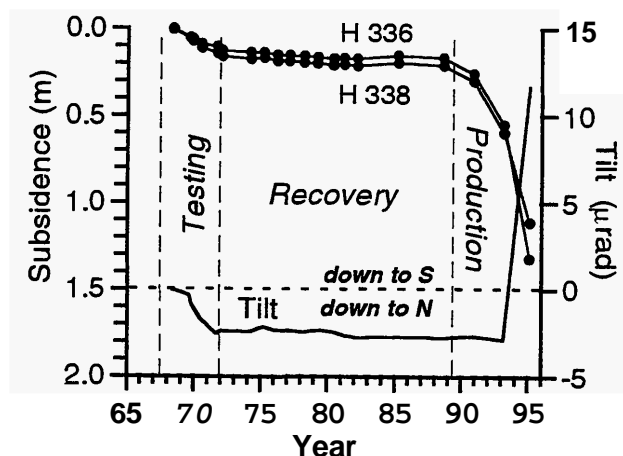


Fig. 7 - Subsidence at benchmarks, near Ohaaki Pool and tilt along the line joining them.

Subsidence monitoring, at benchmarks, near the pool, shows that during the Test Discharge Period the area subsided by 0.15 - 0.20 m. There was little subsidence during the Recovery Period, but it restarted at the beginning of the Production Period and has now exceeded 1 m. The subsidence has not been uniform, resulting in tilting. Examination of the relative changes in level (with time) between BM H336 (north of the Pool) and BM H338 (south) shows that the tilt, along a line between the two benchmarks, was down to the north by at least 2 microradians during the Test Discharge Period (Fig. 7). During the Recovery and initial part of the Production periods there was no tilting. However, between 1993 and 1995 the tilting, along this line, reversed direction and was more than 10 microradians. This has, in part, caused water in the pool (when full) to overflow from the southwestern part of the pool.

Compressional strain has occurred near the pool, and is manifested in the form of buckling of the sinter apron south of the pool. Here, the sinter has been upthrust about 20 cm along several A-shaped, sub-parallel ridges extending for up to 100 m. These ridges were first

noticed in 1994. It is possible that the compressional strain has been responsible for fracturing of the base of the pool, allowing fluid in the pool to drain away.

7. REMEDIAL WORK

The Ngati Tahu people were alarmed at the physical damage to the pool due to the changes in water level during the Test Discharge Period. The expectation of the marae Trustees was that the pool would be returned to a similar condition as that before the field was investigated, and they agreed the water level in the pool could be maintained by using waste geothermal fluid. To this end, Water Right 1408 was issued by the WVA to allow discharge into the pool of up to 300 t/hr and a maximum overflow rate of 36 t/hr (approx. 10.4 l/s at 100°C). However, the acceptance of the pool was so great that overflow could not be achieved. Action was therefore planned to seal off some of the vents in the base of the pool.

It was agreed that all the NE and part of the SW sections would be completely sealed, but the higher vent in the SW section left unsealed to reduce the risk of an uncontrolled hydrothermal eruption. Sealing began in September 1989. Craters were filled with large boulders and rock, gradually reducing in size to gravels (a total of 600 m³), to produce a stable working surface. On top of this surface, a layer of 30 MPa concrete (reinforced with light mesh) was poured and bonded with the sides of the pool. A temporary bund was built between the two sections to restrict flow from the NE into the SW section so that seepage time through the NE section could be assessed.

The pool was kept full for some time by addition of bore water, conveyed through an open drain. This allowed the bore water to cool before it reached the pool, so that the pool was often cool enough to bathe in. However, an unpleasant sludge of grey amorphous silica formed in the pool. The Ngati Tahu people were not happy with the state of the pool, and in November 1993 (after reported seismic activity) the pool was again empty. Gas discharges from vents in the pool could be smelled at the Marae, causing further concern. To overcome these problems it was proposed to discharge hot separated water (160°C) into the pool, which would also aid sealing of fissures with silica precipitated by cooling.

In June 1994, a subsurface pipeline was constructed to deliver separated water from Separator Plant 1 to the base of the pool. A sparge was attached to the end of this pipeline to reduce outlet erosion. Mechanical failure, due to vibrations, led to the sparge being modified in December 1994.

In March 1996, a new vent (3 x 0.5 m) developed in the NE section of the pool which resulted in that part draining. Initial attempts to fill the vent with concrete

failed because of a large gas discharge. The vent was filled only after installation of a vertical vent pipe to control the gas discharge. The supply to the sparge was staged so that the pool filled gradually over the following 3 months and the gas vent pipe was extended in 3 stages. At times water would flow down the vent pipe, and at other times it displayed geyser-like activity.

In September 1996 the pool had been overflowing for 3 months. Contact Energy Ltd and Ngati Tahu are aware that base of the pool will probably fail again; both parties, however, are working towards a solution satisfactory to both.

8. CONCLUSIONS

Historically, changes have occurred in the water level, overflow rate, and temperature of Ōhaaki Pool. However, more recent changes in flow rate, water level, temperature, chemistry and ground movement, are linked to development of the Ōhaaki Power Scheme. Remedial measures have been taken to ensure a flow of hot water from the pool to the marae.

9. ACKNOWLEDGEMENTS

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