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HYDROLOGIC CHANGES AT TAUHARA FIELD DUE TO EXPLOITATION OF WAIRAKEI FIELD

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ABSTRACT

The major thermal areas of Tauhara field are situated around the town of Taupo, about 8 km from the Wairakei production borefield. Within Taupo, over 400 wells have been drilled to between 30 and 150 m depth, tapping the near-surface hot water of Tauhara field for domestic heating. Analysis of many measurements made since the 1950's in both domestic wells and the hot springs of Tauhara field has failed to find evidence of a widespread decline in water level or near-surface aquifer pressure. However, a significant increase in both temperature of the near-surface aquifer, and heat flow from thermal areas of Tauhara field has occurred since the mid-1960's. This has resulted in a spread of steaming ground and 3 hydrothermal eruptions on the outskirts of Taupo.

A study of pressure changes in deep wells of Tauhara field suggests a decline of around 18 bars has occured at >400 m depth, due to exploitation at Wairakei. The deep reservoir pressure of Tauhara field is now about 7 bars higher than that of Wairakei field, and significant flow towards Wairakei production borefield is probably occurring. The lack of a significant pressure drop in the surface aquifer of Tauhara field is due to the presence of low permeability lacustrine mud-stone layers covering most of the field between 100 and 400 m depth. Deep drawdown of the field has caused a steam zone to form beneath the mudstone layers, and this in turn has caused the increase in steam-heating of the surface aquifer.

INTRODUCTION

Tauhara geothermal field is situated at the base of Mt Tauhara, a rhyo-dacite volcano near Lake Taupo, New Zealand. Apparent resistivity mapping indicates that the field has a 20 km^2 area, and that it merges with Wairakei field in the vicinity of the Waikato River (Fig. 1). The main thermal areas of Tauhara field are about 8 km from the centre of Wairakei production borefield. Prior to 1950, the surface thermal activity of Tauhara field could be divided into 3 areas. At Spa Sights on the Waikato River, there was an outflow of hot chloride water (approx. 1500 ppm Cl) in the form of geysers and springs; in the Waipahihi-Terraces area, dilute chloride (<500 ppm Cl) seeps and springs occurred; and at higher elevation (towards Mt Tauhara) steam heated thermal activity was present. Domestic wells tapping the shallow groundwater at that time confirmed that hot water was restricted to the eastern half of Taupo town, and that where encountered, it varied from a dilute chloride water to sulphate and bicarbonate waters (Thompson, B.N., 1951; Sarbutt, 1964).

The first recorded changes in the thermal activity of Tauhara field occurred in the early 1950's when hydro-electric developments on the Waikato River caused the river level at Spa Sights to fall, and geyser activity became intermittent. Although exploitation of Wairakei field began in 1952, and changes in surface activity of Wairakei field were evident by 1954, similar changes in Tauhara field were not observed until the mid-late 1960's (Fisher, 1965; Dickinson, 1968; Allis, 1981). Existing steam-heated thermal areas expanded in size and increased in intensity, and 3 hydrothermal eruptions have occured since 1974. The magnitude of the increase in heat flow is controversial (Dickinson, 1976; Allis, 1979), but it has clearly been at least 100 MW.

The relatively constant chemistry of springs and well waters in the Waipahihi-Terraces area indicates few changes have occurred to the near-surface water in this part of Tauhara field (Henley and Stewart, 1982). However elsewhere a decline in chloride concentrations, increasing sulphate and silica values, and enrichment of oxygen and deuterium isotopes have occurred. These changes reflect both an increase in steam-heating of the near-surface waters, and also increased steam loss from these waters (Henley and Stewart, 1982).

This paper summarizes the hydrologic changes that have occurred in Tauhara field. A more detailed presentation and discussion of the data is given in Allis (1982a). Additional data on water levels and temperature in domestic wells, and shallow resistivity sounding results have appeared in Dawson and Thompson, (1981). Wooding (1981,1982) has mathematically modelled the pressure response of deep Tauhara wells, and Donaldson (1982) has recently reviewed all of the above papers.

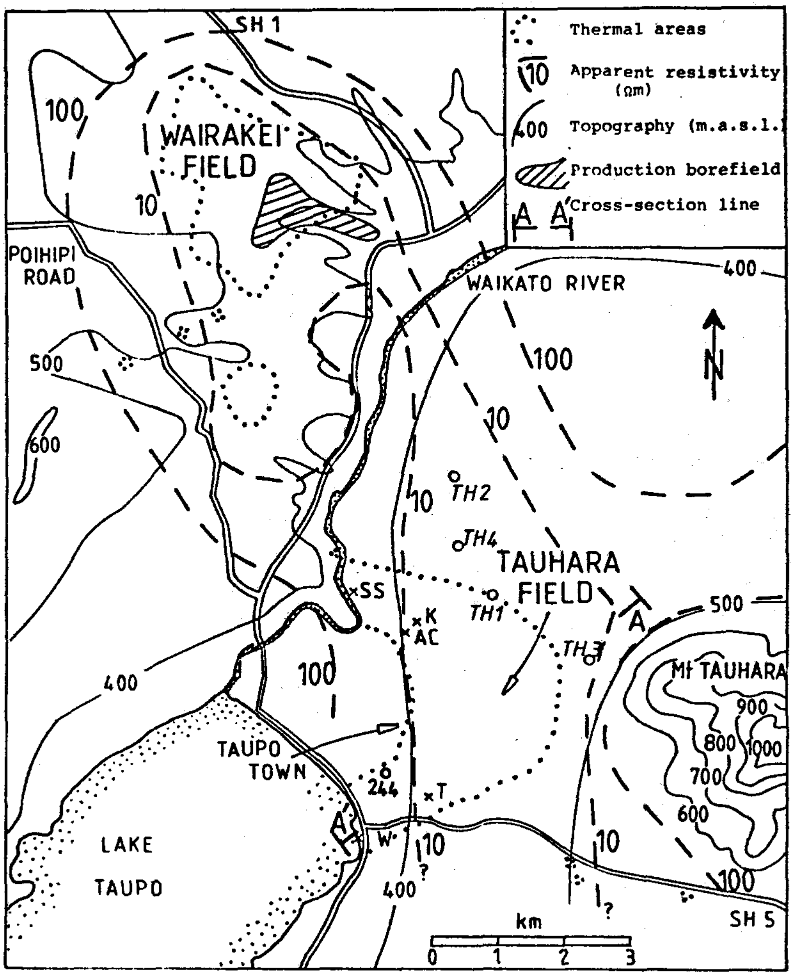

Fig. 1: Map of Tauhara and Wairakei fields. Crosses mark thermal areas of Tauhara field referred to in text: SS = Spa Sights; K = Kathleen Spring; A.C. = A.C. Spring; T = Terraces Springs; W = Waipahihi Springs. o are wells mentioned in text.

SHALLOW HYDROLOGIC CHANGES

Springs Probably the best indicators of hydrologic change at shallow depth are springs. Small changes in aquifer pressure can cause large fluctuations in flow, and changes in heat flow from depth can be precisely monitored by measuring temperature as well. A summary of the thermal changes at several Tauhara springs is shown in Fig. 2. A.C. and Kathleen Springs tap relatively low chloride water in the central part of Tauhara field; Iron Bath and the source of the Waipahihi Stream are dilute chloride springs in the Terraces area near the southern side of the field. Measurements of flow have only been made on the A.C. and Kathleen springs, and these were in 1951, 1963, 1967 and 1982. The A.C. spring flow has remained constant at 10-11 l/s, while the flow of Kathleen spring has remained constant at 22-23 l/s since 1963 at least (V-notch measurements). The 1951 flow measurement of Kathleen spring was 30 l/s, but the accuracy of this measurement is unknown.

Iron Bath spring is now pumped for a nearby baths complex, and its water level has fallen to about 1 m below ground level. There has been no obvious change in flow of the source of the Waipahihi stream since 1951.

The apparently constant mass flow of all springs since at least the early 1960's implies there has been little change in water level or shallow aquifer pressure during this time.

The temperature rise of both Kathleen and A.C. springs has been over 30°C. The start of the increasing temperature trend is known to be 1966, because A.C. Baths management noted increased supply temperature at this time. The small rise in Kathleen spring since 1975 is due to the spring temperature reaching the boiling point of water. A further increase in heat flow of this spring probably occurred through increased steam loss from the groundwater. Enriched oxygen and deuterium concentrations compared to A.C. springs are

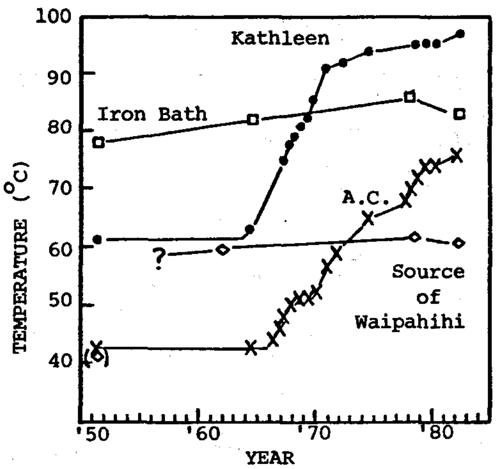

Fig. 2: Temperature changes at some Tauhara Springs.

consistent with such steam loss. Combining temperature with mass flow shows that the heat flow of Kathleen spring has risen from between 4-6 MW prior to 1970, to about 8 MW in 1982 (relative to 15°C). A.C. spring heat flow has risen from just over 1 MW to nearly 3 MW.

Shallow Wells In 1950 there were close to 50 domestic wells in Taupo. Since the sharp rise in the cost of home heating during the early 1970's, the number of wells has increased greatly. Today (1982) the number of wells is probably around 500. The wells are normally between 30 and 150 m deep and tap groundwater up to 120°C. Most water pumped from the ground is returned to shallow (<10 m deep) soak holes after use.

A careful study of repeat water level measurements, and water levels from nearby wells, has failed to find a consistent pattern of water level changes since the first measurements in 1950 (Allis, 1982a). Most water levels (irrespective of date) can be contoured as one water table which reflects the topographic gradient from Mt Tauhara towards Lake Taupo and the Waikato River. However the water table does not have a uniform gradient. Near the western edge of Tauhara field (and roughly parallel to it) there is a 30-40 m step, occurring over less than 100 m of horizontal distance in places. On the low side of the step, water levels range from lake level to about 10 m above lake level. On the high side of the step water levels are typically 40-50 m above Lake Taupo. Wells drilled close to this step, and on the high water level side, often have downflows with water level being dependent on well depth. It will be shown below that the step is due to two near-surface aquifers separated by a mudstone aquiclude. The upper aquifer (in Wairakei pumice breccia) becomes progressively perched as water flows westwards. In addition the mudstone wedges out to the west, with the sudden change in water level marking the western edge of the mudstone aquiclude. Below this aquiclude is the Huka pumice breccia aquifer.

In general, shallow well temperatures have increased with time. Most of the increase occurred during the late 1960's and early 1970's. A good example of this is well 244 located near the Waipahihi seeps (Fig. 3). The greatest temperature increase has occurred near the water level, causing a negative temperature gradient to develop in the well. This indicates that the heat source for the groundwater is not beneath well 244, but must be further east, towards the steam-heated, central area of Tauhara field.

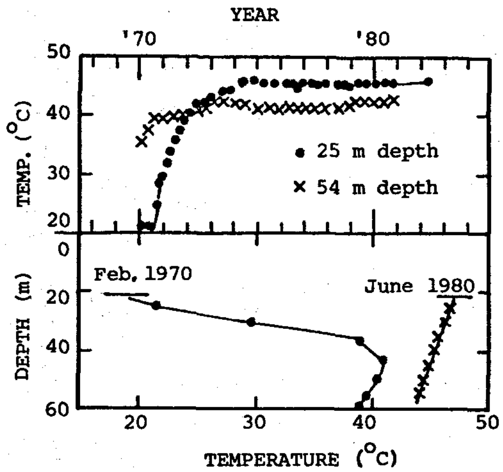

Fig. 3: Temperature changes in well 244, about 500 m north of Waipahihi springs as marked on Figure 1.

DEEP HYDROLOGIC CHANGES

Pressure changes at >400 m depth in Tauhara field are known only from 4, 1-km-deep wells (TH1-4, locations shown on Fig. 1). The first deep well was drilled in 1964, so deep pressure changes before this time have not been measured. Assuming the deep pressure trend measured in TH1 to be typical of that for the whole field, the pressure drop since late 1964 has been 9 bars. This compares with a pressure drop of 7 bars at Wairakei field during this time (Fig. 4; pressure at -152 m R.L.). The pressure drop in both fields since 1970 has been 2 bars. This suggests that deep Tauhara field pressures have followed the Wairakei pressure trend closely, and that any time delay is unlikely to be more than about 2 years.

The only way of estimating the initial pressure of Tauhara field is from the height to which chloride water (from the deep reservoir) rose within the field. Chloride - bearing springs range in elevation from 360-410 m R.L. (metres above sea level). However because of the lateral pressure gradient away from Mt Tauhara, shallow wells east of the springs contain chloride water at a higher elevation. The highest measured chloride water level is at 430 m R.L. Extrapolating downwards from this

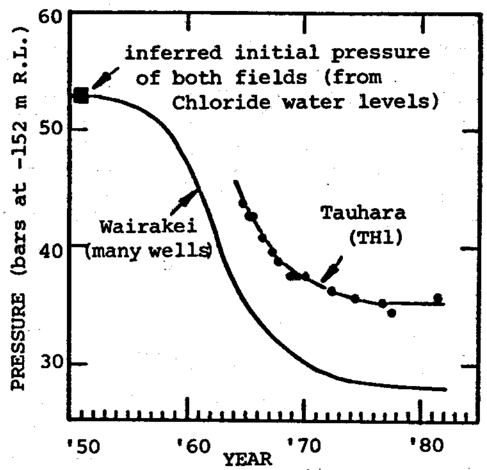

Fig. 4: Comparison of pressure changes in Tauhara field and Wairakei field. Pressure trends are at -152 m R.L., or about 550 m depth.

elevation, assuming a hydrostatic pressure gradient for boiling point conditions, gives a pressure of 48 bars at -152 m R.L. When allowance is made for the initial gradient being about 10% above hydrostatic (to drive the chloride water to the surface; Grant, 1979), the initial pressure must have been close to that at Wairakei before exploitation (i.e. 53 bars at -152 m R.L., Fig. 4). By comparison, chloride springs at Wairakei field ranged in elevation from 370-390 m R.L. in Geyser Valley, to 440 m R.L. in the upper Waiora Valley (Gregg and Laing, 1951). The similarity in the maximum height of chloride water at Wairakei and Tauhara field confirms their initial pressure profiles were also probably similar.

The deep drawdown of Tauhara field has therefore been around 18 bars, compared to about 25 bars at Wairakei. This means there is now a horizontal pressure gradient from Tauhara to Wairakei field, and some of the recharge to Wairakei is probably from Tauhara field.

VERTICAL PRESSURE PROFILE - 1982

To examine the hydrological relationship between shallow domestic wells and springs, and deep wells, a composite pressure-depth plot was compiled by Allis (1982a)(Fig. 5.) This involves plotting aquifer pressure at the pressure-controlling point for each well. Some of the data points from shallow wells date back to the late 1960's. However others in the same depth range suggest little pressure change, so most points are though to be within 1-2 bars of 1982 pressures. The date of measurement is shown with the deep well measurements because of the much larger pressure changes that have occurred at depth. The presence of single phase (liquid) or 2-phase conditions is also shown on Fig. 5.

Tauhara field now seems to have 3 distinct pressure lines, or aquifers. The upper two

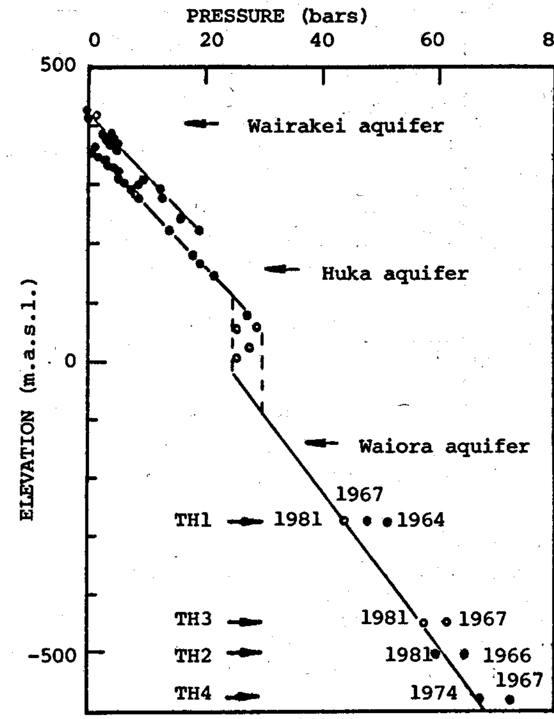

Fig. 5: Vertical pressure trends in Tauhara field (1982).

aquifers represent water tapped by domestic wells. The uppermost aquifer has a zero-pressure intercept of around 410 m R.L., which is close to the elevation of the Terraces, Kathleen and A.C. springs. The intermediate depth aquifer has an intercept at around 360 m R.L., which is a few metres above the level of Lake Taupo and Spa Sights. The overlap of these two lines between 360 and 220 m R.L. is caused by geographic separation and the presence of a lateral pressure gradient away from Mt Tauhara.

Beneath the two shallow aquifers is a region with a very low, subhydrostatic gradient. The points in this zone are 2-phase with both the shut-in fluid state, and the discharge enthalpy of the wells showing strong evidence of steam-zone. Fig. 5 indicates that the steam zone is at least 100 m thick, and that it is at 25-30 bars pressure (230°C approximately). Its elevation coincides with the base of the lower Huka mudstones, and the upper Waiora pumice breccia. This is the same as the initial location of the steam zone at Wairakei (Allis, 1982b). It appears to be a consequence of the relatively low permeability of the lacustrine mudstone compared to the underlying pumice breccia. The mudstone layers in and above the Huka formation have prevented the pressure decline propagating to shallow depth, and have also caused the two shallow aquifers to be present beneath Taupo. This is clearly illustrated in the cross-section shown in Fig. 6. This extends southwest from well TH3 on the northwest flank of Mt Tauhara, to Lake

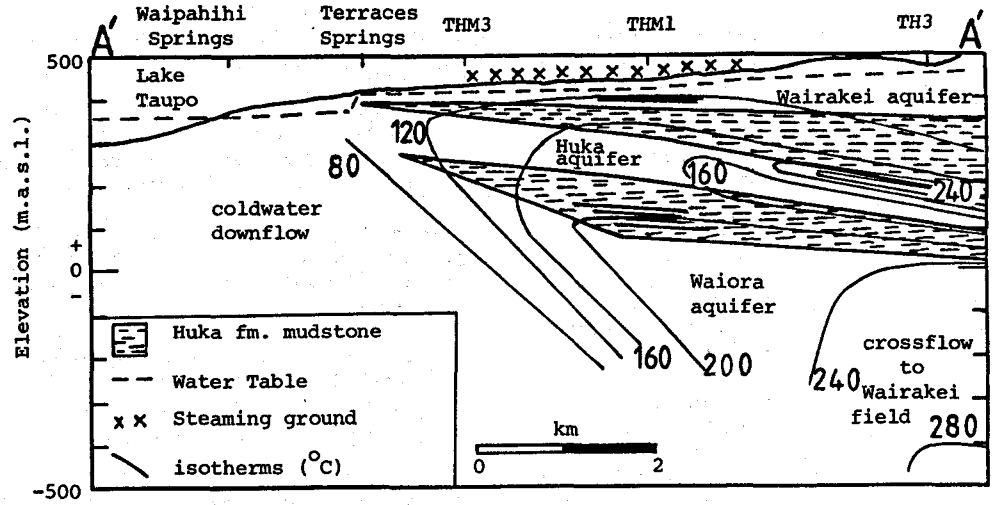

Fig. 6: NE-SW cross-section of Tauhara field showing locations of the 3 aquifers and intervening mudstone aquicludes.

Taupo. TH3 is the hottest well in Tauhara field (temperature >280°C) and it may be close to the field's deep upflow region.

Prior to drawdown, chloride water rose into the shallow aquifers and mixed with cold water flowing westwards. With drawdown, a steam zone has formed beneath the lower mudstone layer, and now steam is flowing up into the shallow aquifers instead of chloride water. A small steam zone may have also formed in the top of the intermediate depth Huka aquifer in the vicinity of TH3. The change to steam-heating has caused increased temperature of the groundwater, and increased heat flow from thermal areas. It has probably also triggered the hydrothermal eruptions. The location of the upflowing steam into the shallow aquifers is uncertain. It could be through faults in the mudstone near TH3, or it could be further east beneath Mt Tauhara where volcanism has disrupted the mudstone layer.

CONCLUSIONS

Drawdown of Tauhara field due to exploitation of Wairakei field has caused a steam zone to form beneath the Huka formation. The pressure of the steam zone has probably not changed greatly since it was first formed in the late 1950's or early 1960's, and it therefore marks the upper limit of significant drawdown in Tauhara field.

This contrasts with the situation beneath the Wairakei production borefield where a steady pressure decline has occurred in the steam zone (due to production), causing the top of the steam zone to migrate to shallower depth. (Fig. 7). In addition, drawdown has propagated into the surface aquifer in this area of the field, and water levels in shallow wells have declined by more than 10 m (Allis, 1982b). West of the production borefield the steam zone pressure rises to about 25 bars. Changes in the surface thermal activity were apparent at Wairakei by the mid-1950's (Thompson, G.E.K., 1960; Allis, 1980). Similar changes in the thermal activity of Tauhara field were not noted until the mid-1960's.

These differences are not attributable to a delay in the pressure drop reaching Tauhara field. The delay, if any, is unlikely to have been more than a few years. The main reason for the differences is the presence of relatively thick (>200 m), presumably competent lacustrine mudstone layers over most of Tauhara field causing highly anisotropic permeability.

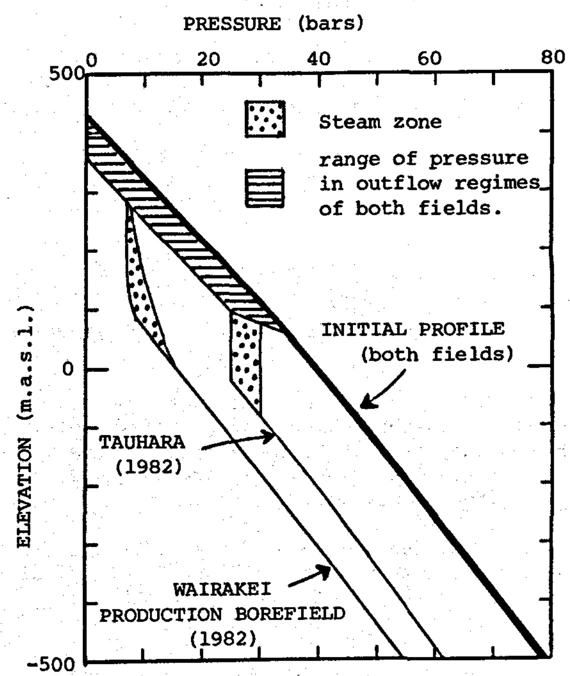

Fig. 7: Comparison of the 1982 pressure-depth trends beneath Tauhara field and the Wariakei production borefield, as a result of exploitation of Wairakei field.

In contrast, across the central portion of Wairakei field, from Geyser Valley in the north to Karapiti thermal area in the south, the thickness of the Huka formation is less than 60 m (Grindley, 1965). The mudstone layers at Wairakei are also severely faulted by the Taupo Fault Belt. These faults control the locations of many of the thermal areas, and because of this the thermal areas of Wairakei field have responded rapidly to changes at depth.

Most of the heat and mass flow from thermal areas of Tauhara field has reached the surface after considerable lateral flow though permeable layers within and above the Huka formation. Since the source region is inferred to be beneath northern Mt Tauhara, the length of the subhorizontal flow path may be at least 2 km. With drawdown of the deep Tauhara aquifer beginning during the 1950's, the mode of heat transport in the source region changed from upflowing chloride water to a steam flux. The temperature of the upflowing fluid may not have changed greatly however. This change in the heat and mass flow into the surface aquifers did not become immediately apparent in the thermal areas and domestic wells of Taupo because of both the length of the outflow path and, to a lesser extent, initial buffering due to storage effects of the rock. These factors are also responsible for the very slow chloride depletion observed in the surface aquifers, and the 50-100 year residence time deduced from tritium analyses (Henley and Stewart, 1982; Allis, 1982a).

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