PERFORMANCE OF TAUPO SHALLOW BORES WITH DOWNHOLE HEAT EXCHANGERS

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SUMMARY

A large number of domestic bores tap the hot groundwater aquifers under Taupo township. Experiments are described that investigate the performance of the bores when downhole heat exchangers are used to extract the heat. The tests show that the low temperatures and poor permeability present in the bores are the main factors in limiting the performance of the standard setup. There are possibilities for optimising the installations within these limitations. The useful output of the bores is typically 1-5kW.

1 INTRODUCTION

About half the central area of Taupo township has underlying hot water where the water is 50° or more within 20m of the free water surface (Figure 1). Many shallow domestic bores tap this hot water. Almost all the bores are drilled only into the pumice and ash deposits which overlie the less permeable mudstone. In some parts of the town, a very shallow atmospheric steam resource is present and can be used but this is not discussed in this paper. Curtis (1986) estimates the number of bores at more than 500 but this is thought to be a conservative estimate. Some householders are unaware that there is a bore on their property, while others have denied the existence of a bore because of the prospect of having to pay royalties or inspection levies for it. Most of the bores supply just one house with the heat being used for domestic hot water, spa pools and space heating. Curtis found that almost half the bores used downhole heat exchangers (DHEs) to extract the heat. For the past 5 years very few new bores have been constructed even though a lot of housing has been built on prime sites for exploiting the resource. Houseowners have given the recently introduced regulations and levies as one of the main reasons for not putting in a bore. These rules effectively make the bores uneconomic.

Very little work has been done to assess the potential output of the bores. Pan et al (1984) did some work on the bores of Tauhara College but these were large diameter and were drilled into the underlying mudstone or the breccia below that. Hailer & Dunstall did some modelling and experiments with a simulator rig but there is no published work on the domestic bores known to the author.

2 RESOURCE

The phreatic aquifer consists of rainwater draining from the flanks of Mt Tauhara that has been heated by steam from the underlying geothermal reservoir. Most of the hot water is naturally discharged into Lake Taupo or the upper Waikato River via streams and several kilometres of hot water seeps.

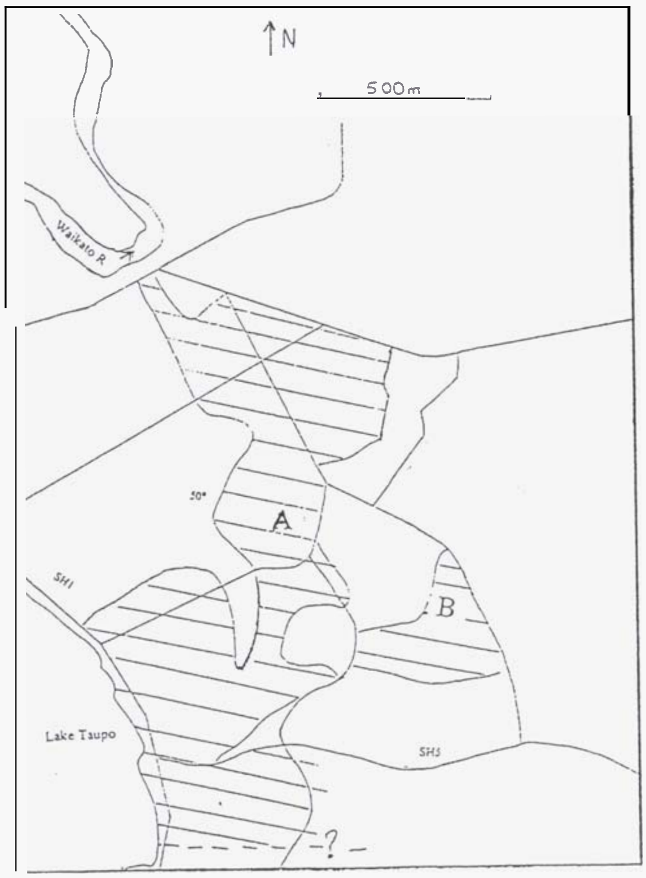


Figure 1 Taupo residential areas with hot groundwater

Exploitation of Wairakei caused the deep reservoir pressures to fall and a steamcap to form. The increased mobility of this steam caused an increase in surface thermal activity. The pressures in the steamcap have continued to decline and the surface activity has decreased. The activity peaked about 1980 (DSIR) and the maximum temperatures

temperatures in many wells have declined considerably since then and it appears that they are continuing to drop.

There have been numerous reports and papers describing conditions and changes in the ground water aquifers. Two of the papers that have a lot of relevance to this paper are Dawson and Thompson **(1981)** and Allis **(1983).** Most of the literature agrees that there are multiple ground water aquifers, at least one of which is perched.

3 BORE AND HEAT EXCHANGER DESIGN

The bores are typically of a very simple standardised construction. **A** 75 or **100mm** ID steel pipe is used as a liner down to just above the fi-ee water surface with open hole for 20 to 40m below that. The liner is installed to prevent hole collapse and stop damage during the installation and removal of the DHE. Because there is no record of any of the wells discharging and most now have a maximum downhole temperature of less than 95°, no headworks or master valves are fitted.

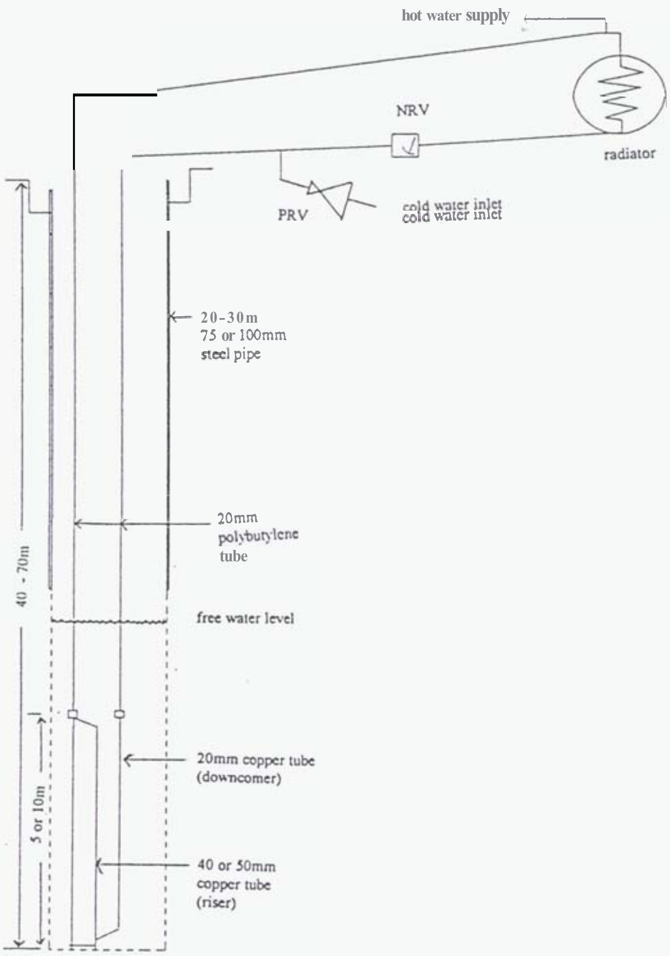


Figure 2 Typical Bore and DHE setup

Most DHEs are made from two unequal diameter copper tubes **5** or 10 metres long, joined at the bottom to form a U bend. The larger leg, the riser, is 40 or 50 mm diameter and the smaller one (downcomer) 20mm. 10m DHEs are assembled by welding the copper lengths as the tubes are lowered into the hole. The DHE usually sits on the bottom of the hole and is connected to the surface with 20mm copper or polybutylene tubing. Some DHEs are designed to be suspended partway down the openhole portion of the bore. The suspension cable is attached to an anchor point in the cellar. Although this set-up is very simple, experience within the Taupo area has shown it can be quite effective. The work of Hailer and Dunstall (**1992)** has shown **that** the performance of these simple set-ups can almost match that of more complicated systems under conditions similar to those experienced in Taupo.

Systems usually have a radiator or hot water tank in the circuit so they will thermosiphon naturally, providing a constant heat supply and minimising the delay in delivering hot water. The hot water supply is taken from the **high** point of the system so it can act also as an air purge. When hot water cylinders are installed in the loop, they need to be of a non-standard design to work properly. For a bore as described, total installed cost is $3-8000 depending on configuration. **A** radiator and modifications to the house plumbing would be included in this cost. **A** typical system is shown in Figure 2.

Same bores have two DHEs down the hole, stacked one above the other or even side by side in the larger diameter wells. One DHE might supply domestic hot water while the other heats a pool. Rather than have two DHEs, an alternative is to have an airlift pump to supply water for the pool. The water is too contaminated to use for domestic water. However, most wells are not big enough nor have enough heat capacity or permeability to make more than one DHE viable.

Corrosion of the DHE can be a problem in the wells. The copper often only corrodes below water level which indicates it is not a hydrogen sulphide gas problem. Most houses in Taupo do not have an earth stake for their electrical supply but **an** earth return to the transformer. Earthing through the pipework can cause electrolytic corrosion problems in the DHE. The problem was a lot worse when copper tubing was used instead of the polybutylene. Fitting a sacrificial zinc bar downhole or earthing the liner to the house reduces the problem.

The well is normally set in a small shallow cellar landscaped into the householder's drive or lawn. This minimises the risk of damage to the pipework but still allows easy access. Having the top of the bore below ground level makes it a lot easier to have a naturally thermosiphoning system. If the well is predominately used for space heating, a small pump can be installed in the system to boost the circulation and heat output.

4 TESTING PROBLEMS

The records on the bores are rudimentary at best. In most cases, just the liner depth, total depth, water level and a **5** or 10m interval temperature profile are recorded. There are few formal records of drilling loss zones or pump tests. In personal conversations with the author, the drillers could give information on the conditions encountered that tied into, and expanded on the formal records. Many bores have been deepened or redrilled with a new configuration without the records being altered. Temperature profiles for some of the bores are given in Dawson and Thompson (1981). The data in this report covered a twenty year period during which time the temperatures in the aquifers changed markedly. This means that the information has to be used with caution if used for comparitive purposes. With the temperature drops of 20" to 25" (DSIR) since 1980, this data is now obsolete.

The temperatures below the water table can vary appreciably, which makes baseline temperature profiles very hard to determine. Figure 3 shows a log of the downhole temperature, 5m below the water level in an unused well. On about day 20, a week of rainy weather started and it is thought that infiltration of cold rainwater could be a possible cause of the temperature drop. Similar irregular fluctuations were reported by Thompson (1968) in a study of a Broadlands well. He could find no discernable link to atmospheric conditions and had no explanation for the variations. However, this could have been because he did weekly spot measurements; continuous logging might have given different information.

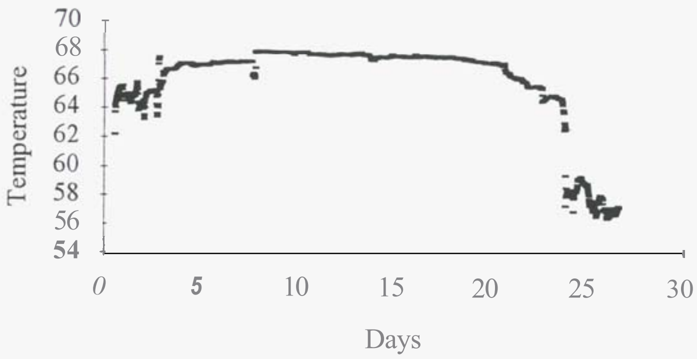


Figure 3 Monitor bore temperatures

Unpublished tests done by the author have indicated that the heat up profiles from ground water wells do not provide as much information as those for deep wells. When water flows out of a top loss zone (or above the free water surface level) during a quench test because of overpressuring, it is not possible to determine the size of the flow continuing down the hole. This makes interpretation more difficult. It is also harder to do tests with tubing and a DHE in the hole because of the limited space to run instruments. It has been suggested by Dunstall and Freeston (1990) that the heat up curves from a large scale quenching might be able to give an estimate of the heatflow but few bore owners would be happy at the prospect of having no hot water for the time of the test. In many cases, they have no alternative supply of hot water heating.

Because the bores are small diameter and have at least two tubes inside, it is very hard to run instruments down the hole. Thermocouple or thermistor probes can be used but it can be difficult to get the probe down to the bottom of the well without it tangling in the pipework. The DHE is sometimes partially buried in silt and it is not always possible to run a probe to the bottom of the hole. With a small lightweight probe, it can be difficult to determine when one has actually reached the bottom, especially if the hole is near isothermal. A calibrated thermocouple probe on a graduated 100m cable was used to measure the downhole temperature profiles for this paper.

Details of the dimensions of the DHEs actually installed are generally non-existent. It is a relatively simple if strenuous job to lift one for inspection or a baseline temperature survey. However the law treats removal or replacement of heat exchangers in wells over 70° as drilling work for which a permit is needed. This, and the risk of damaging the tubes mean that heat exchangers are usually only lifted when there is a leak.

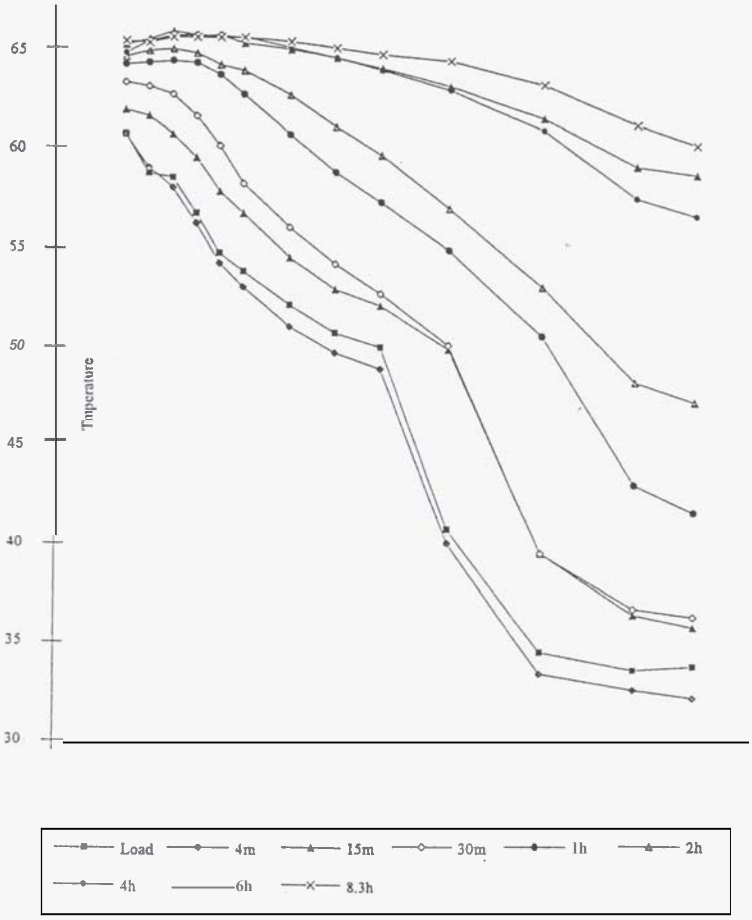
5 TEST PROGRAMME

Two wells were selected for testing. The first of these, "Bore **A**" was chosen because the dimensions were known and there was a reasonable record over the last five years of downhole conditions. The surface pipework and cellar were modified to give good access to the wellhead. The polybutylene tubes were tensioned so that a temperature probe could be lowered to the bottom of the hole more easily. When the DHE was replaced in 1992, it had a cable fitted so the DHE could be suspended above the bottom of the bore. An isolation valve was fitted to stop thennosiphoning so that shut surveys could be done. Surface pipework was properly lagged to minimise heat losses. Thermistor probes were fitted under the lagging on the inlet and outlet pipes so that secondary circuit temperatures could be continuously monitored. The maximum temperature of the bore was under **70'** so the Geothermal Energy Regulations do not apply. The location of the bore is shown as the **A** in Figure 1.

The well has a 75mm ID liner to 30m. **A** 10m copper DHE with a 40mm diameter riser and 20mm downcomer sat on the well bottom at a depth of about 57m. The well was originally drilled to 75m. The DHE is connected to the surface with 20mm polybutylene tubing. The volume of water in circulation when thermosiphoning is about **60** litres, of which only a third is in the heat exchanger. The free water surface has varied over the past five years between 31.5 and 32.7m. Over the five year period, temperature profiles done while the DHE has been thennosiphoninghave shown a consistent shape though the actual temperatures varied by up to 6°. The maximum outlet temperature when thermosiphoning varied over a 3°range. The heat output while thermosiphoning was less than 0.5kW. Exact output was not able to be determined as the flow could not be measured.

The baseline temperature profile of the well with the heat exchanger removed showed isothermal conditions. In 1975 it was **84°,** in 1992 it was 62'. Many other wells in the area have experienced a similar temperature decline. Allis (1983) discusses two wells within 100m of Bore **A** and showed that the isothermal conditions were due to a downflow from a perched hot water aquifer. Curtis (1988) conducted pumping tests and showed that wells in the area had very poor permeability.

A series of surveys after the isolation valve was shut showed the peak temperature rose several degrees over a four hour period. The top 10m heated up considerably faster than the bottom portion of the bore. The temperature profiles indicated that a downflow slowly descended the bore. The 24 hour heating profile was an isothermal 62" but this was nearly 2" lower than peaks measured at earlier stages of the heating. Heat up profiles fiom a heavy load showed similar results (Figure 4). For a maximum downhole temperature of 64°, the transient peak temperature out of the DHE was 54°. Under these conditions, the temperature out while thermosiphoning was about 51°, 5° hotter than the inlet temperature.



The well's output was tested by logging the temperature and measuring the water flow out of the hot tap. Figure 5 shows the log of one test. To minimise the variations due to naturally fluctuating bore temperatures, all the tests were done when the thermosiphoning outlet temperature just before the tests was 51'. The domestic cold water inlet temperature was between 11.8 and 13.3" for the tests. Downhole surveys were done during some of these tests. Figure 6 shows the temperature profile of the bore while thermosiphoning and under a load of 7.5kW and output temperature of 25.9'. The stable output of the bore at a variety of flow rates is shown in Figure 7. Tests on nearby bores indicated their output was comparable to Bore **A.**

The heat exchanger in Bore A was then raised 12m so the top was about 35m to determine the characteristics of the upper zone of the well. The tests were repeated. Figure 7 also the shows heat input from the bore in the modified state. There was no discernable difference in output. Temperature profiles of the bore while thermosiphoning and under a load are shown in Figure 8. The load was 7.4kW and an outlet temperature of 23.4".

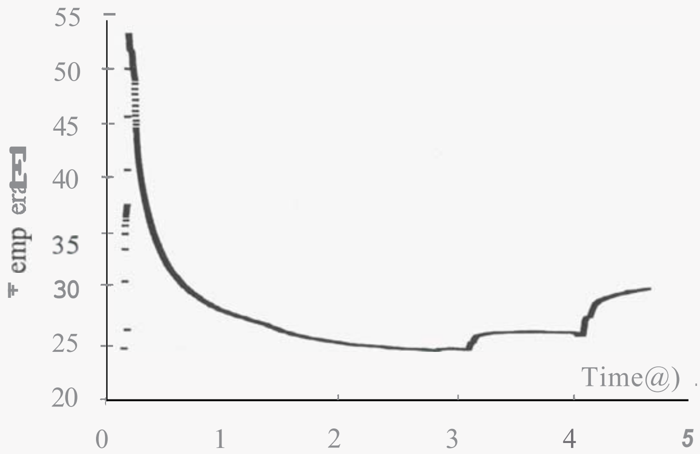


Figure 5 Temperature log of output test

The second well tested, "Bore B", is in the Invergarry Rd area (location shown in Figure 1). The well has a 100mm liner set at 20m and the water level is about 29m. When the well was drilled, the bit dropped 300mm at about 33m depth. A recent pump test with a downhole pump set at 48m gave a steady output of 5t/h at a discharge temperature of 70°. The water level during pumping was not known. There is now installed in the bore a 6m long 50mm OD annular copper DHE which is suspended and has its bottom at about 37m. The downcomer is 25mm diameter, centralised and coppper. There is a venturi jet at the top of the internal downcomer to allow the DHE to internally thermosiphon. It is connected to the surface with 20mm polybutylene tubing. The temperature profiles of the well when fully heated, thermosiphoning and providing 16 kW at an outlet temperature of 31° is shown in Figure 9. It was not possible to do repeat surveys below 45m as the well had silted up 4m in two years.

6 DISCUSSION

The temperature variations in the phreatic aquifers means it can be difficult to do reproducable tests unless they are done over a short period. A small change in the downhole temperatures can have a large effect on temperature differentials. Boreowners notice this. The fluctuations often mean that shower settings have to be adjusted every day. Many boreowners have also noted that the performance of their bore declines considerably during bad weather or over the winter. This is the period when the heat fiom the bore is needed most. Some owners now just use their bore for space heating over the winter as the water from the bore is not hot enough to use for domestic hot water because of the general temperature decline.

The temperature profiles of the bores under load confirm the work of Allis (1983) and Curtis (1988) and show that there are several discrete aquifers, each with different characteristics. Inversions in the temperature profiles while the wells in the area around Bore A are thermosiphoning are quite common, yet the fully heated profiles invariably show isothermal conditions. It can be seen from Figures 8 & 9 that for Bore A there is very little heat entering the bore below 40m and for Bore B, between 38 & 43m. These areas may be the aquicludes between the aquifers.

Even though Bore A is hotter and has better permeability in the top section of the hole, it is possibly more effective to put the existing DHE at the bottom. This allows more of the primary fluid's heat to be extracted, increases the storage capacity and thermosiphoning head but relies on an internal downflow of fresh fluid for maximum output. Sitting the DHE on the bottom makes the wellhead less cluttered and also limits the possibilities for premature pipe failures. It is possible that raising the DHE to the crossflow zone with the top at 33m would improve the output significantly. This may be done at the next service as the suspension method also needs improvement.

If bore A was 100mm rather than 75mm diameter, this would nearly double the storage capacity of the bore. It would also allow for a larger diameter heat exchanger to be installed. A longer copper heat exchanger is not really feasible as the tubes have to be assembled and welded as it is inserted into the bore. Putting a longer heat exchanger in Bore B would probably not improve it's performance appreciably though one of a larger diameter would provide an increased surface area in the permeable zone.

The downhole profiles in the unmodified bore A when under load show that an appreciable portion of the heat is absorbed through the polybutylene tubing. At the higher flows, this could amount to 40-50% of the total heat. This would indicate that the modelling work of Hailer and Dunstall (1992) where they suggested that an all plastic heat exchanger might be just as effective as a copper one was justified.

Bore B's temperature profile shows that there is a very narrow band of hot water flowing above the colder water. The velocity of the water appears to be very fast, possibly metres per hour. Curtis determined that the overall permeability of bores in this area several orders of magnitude better than for bores near Bore A. The profile of bore B also indicates that the heat supply for the hot water must be some distance away and that the upper layer of water has a different source to the water below it.

There is little incentive to improve the performance of bore B. The house couldn't use much more space heating or hot water It would be possible to install an airlift pump and use the hot water for a spa pool or the like. The pump test indicates that this would probably have little effect on the output of the DHE.

For domestic bores, the water needs to be hotter than 40° to be useful. It is preferable that the water is at least 50°. That means the continuous useful output of Bore A would be less than 1kW. The comparable figure for bore B is about 5kW. The reason why they can be economic is because of the storage capacity, both in the circulating water and the primary fluid inside the bore, which allows much higher loads to be extracted for short periods.

A point of interest is that shallow soakholes near bore B discharge atmospheric steam. The bore's temperature profile shows that the surface stem does not come from the boiling of the groundwater aquifer directly below it. There does not seem to be a simple model that can explain this phenomenon.

7 CONCLUSIONS

1. Temperatures in the groundwater aquifer are quite variable. This variability can affect the performance of the bores.
2. In some bores, DHE placement and the circulating system can be optimised to improve the output of the bore.
3. Even with optimised equipment, the maximum output of the bores is very low and the limiting factors are the low temperatures and permeability.

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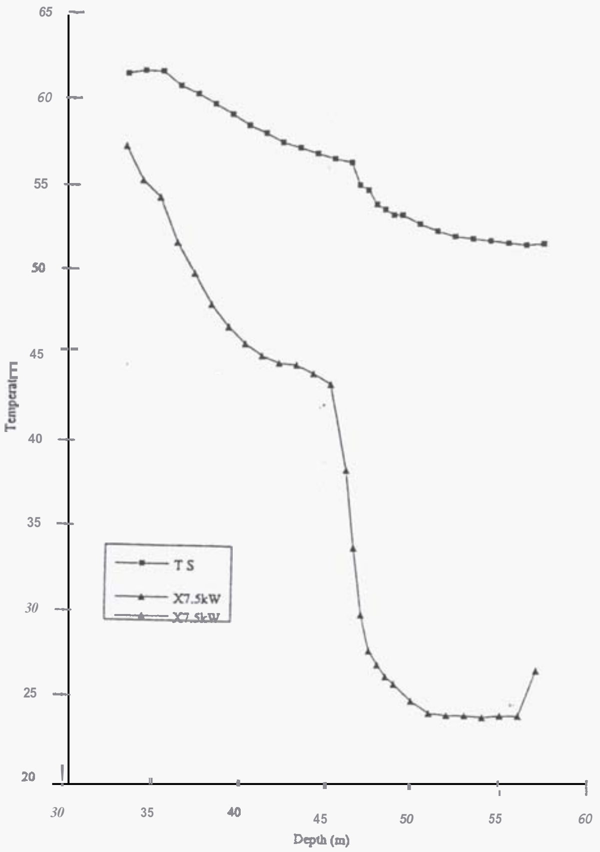

Figure 6 Bore **A** - Unmodified well, temperature profiles

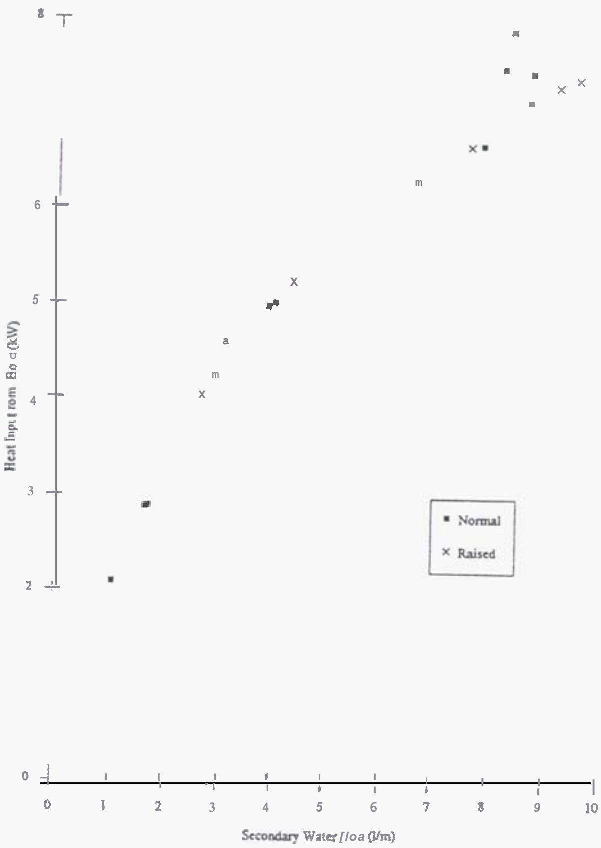

Figure 7 Bore **A** - Well output graph

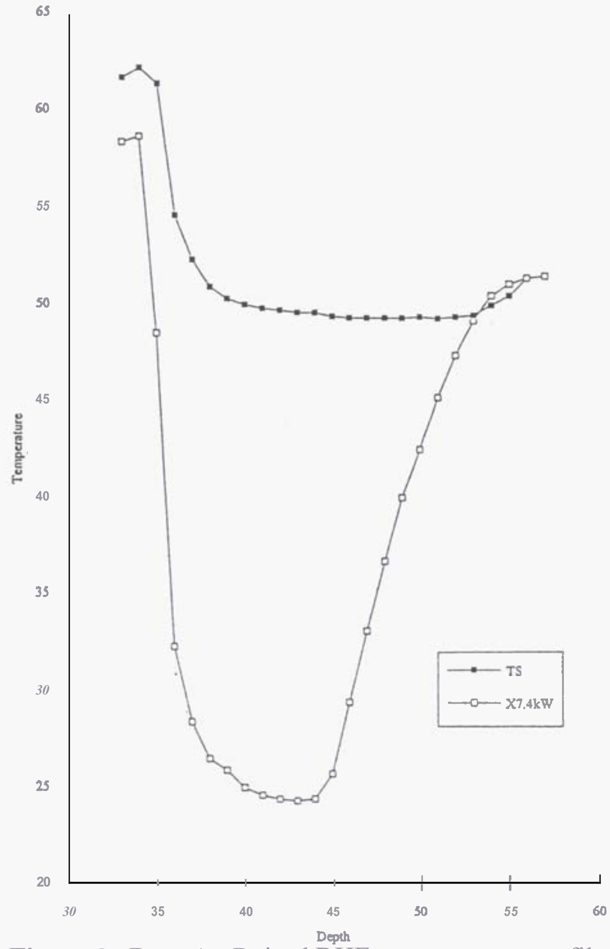

Figure 8 Bore **A** - Raised DHE, temperature profiles

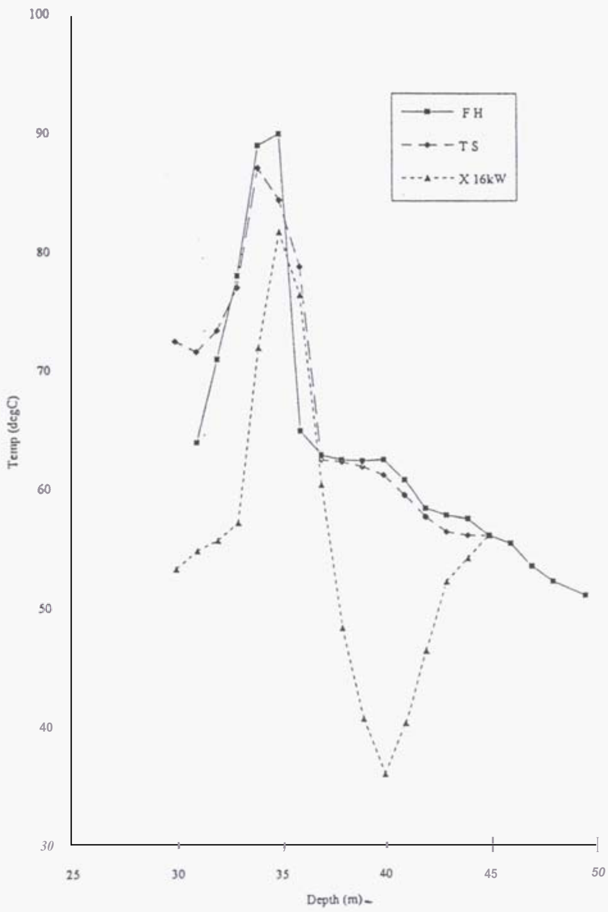

Figure 9 Bore B - Temperature profiles