WAIRAKEI-TAUHARA PRESSURE REGIME UPDATE

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ABSTRACT

Information from wells drilled over the last five years at Wairakei and Tauhara, together with continuous pressure monitoring has provided new insights into the pressure regimes and interconnections between Wairakei and Tauhara. Continuous pressure monitoring using capillary tubing has allowed simultaneous observations of pressure responses in several wells. This information has significantly improved the understanding of both fields.

This new information confirms the long-term pressure trends observed in both systems, with the Tauhara pressure regime approximately 5 bars higher than Wairakei. The new data was also used to develop isobar contours across both systems, which together with the information from the continuous pressure monitoring, indicates that the Tauhara pressure regime extends northwest as far as Karapiti. Wells that were once considered to be part of the Wairakei system can now be considered part of Tauhara based on their pressure regime. The results also suggest a connection between Karapiti South and Tauhara, and challenge the "traditional" concept of the two systems being separated by the Waikato River.

1. INTRODUCTION

The Wairakei-Tauhara Geothermal System is situated north of Taupo and straddles the Waikato River (Figure 1).

Over the last 60 years more than 200 wells have been drilled in the Wairakei-Tauhara Geothermal System. These range in depth from 300m to over 3000m, and include both infield and outfield areas. With this many wells comes many opportunities to monitor how the reservoir is changing over time with response to fluid extraction and injection.

Historically, periodic downhole pressure-temperature logs were used to monitor reservoir pressure trends in the deep liquid zone. Although this method is adequate to define the overall liquid pressure trends across both fields, the lack of continuity prevented any delineation of short term pressure trends.

Nitrogen filled capillary tubing was first installed in 1988 and with time the number of monitored wells has gradually increased. Today there are 10 "permanent" monitor wells, plus several "temporary" short-term systems in place across the Wairakei-Tauhara fields. This has provided sufficient data to characterise short term reservoir pressure responses to changes to production or injection.

2. PRODUCTION AND INJECTION HISTORY

The Wairakei power plant was commissioned in 1958 and for the first 20 years of operation the majority of production fluid was extracted from relatively shallow wells (<700m)

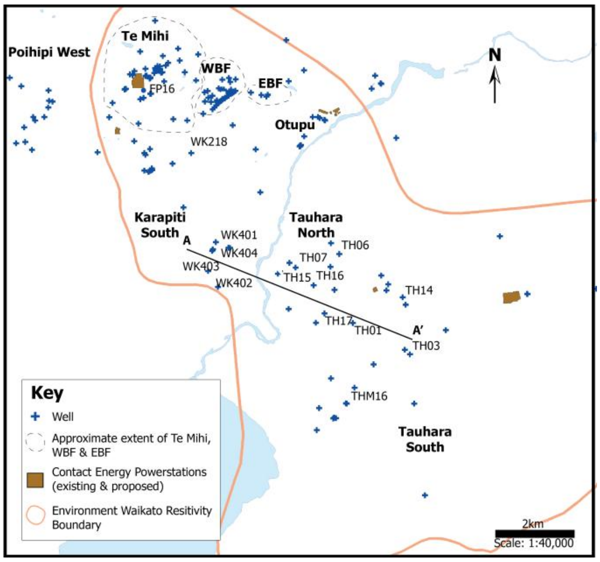

Figure 1: Map of the Wairakei-Tauhara geothermal system highlighting the wells discussed in this paper. Abreviations: EW - Environment Waikato; WBF - Western Borefield; EBF - Eastern Borefield.

in the Eastern Borefield (EBF) and Western Borefield (WBF) (Figure 1). As production in both borefields declined, make up wells from Te Mihi were connected in the 1980s.

After an initial enthalpy increase in the EBF wells resulting from field wide boiling, a declining enthalpy trend followed due to cold groundwater encroachment. This caused the total production in the EBF to decline starting from the early 1980s (Bixley et. al., 2009). Since 1990, there has been minimal production from the EBF with the bulk of production fluid obtained from the WBF and Te Mihi.

The first in-field injection system was commissioned in 1998 in the Otupu area (Figure 1), followed by the commissioning of new re-injection wells at Karapiti South in late 2011.

At Tauhara, commercial production (approximately 250t/h) began in 2008 with the commissioning of an industrial heat supply for wood drying at the Tenon plant, which requires 13MWth. This development was followed by the commissioning of the 26MWe Te Huka binary plant in March 2010. Production for both Tenon and Te Huka is obtained from the Waiora Formation with 100% re-injection back to the Middle Huka Falls Formation (Mid HFF) and the Waiora Formation. Stratigraphy and production/re-injection depths for this part of the Wairakei-Tauhara geothermal system is shown in Figure 6.

3. HISTORY OF PRESSURE CHANGE

There has been a uniform pressure response in the deep liquid at Te Mihi and WBF with pressures measured from different wells being within ±0.5bar of each other. As is typical of a liquid dominated reservoir, the largest drawdown was during the first few years of production. When Wairakei reached peak production in 1963, there was a maximum pressure decline of 3 bar/yr. By 1967 this had dropped to 1 bar/yr, and from 1975, pressure drops had stabilised at 23-25 bars, until infield re-injection began in 1998. Since then, pressures have increased by more than 4 bars (Bixley et al., 2009).

Historically, pressure response at Tauhara, around 10 km to the southeast from Wairakei, follows changes at Wairakei with an offset of approximately 5 bars (Figure 2). It is noteworthy that the Rotokawa Geothermal System, located 10km to the northeast of Wairakei, has not responded to these pressure changes (Bixley et al., 2009).

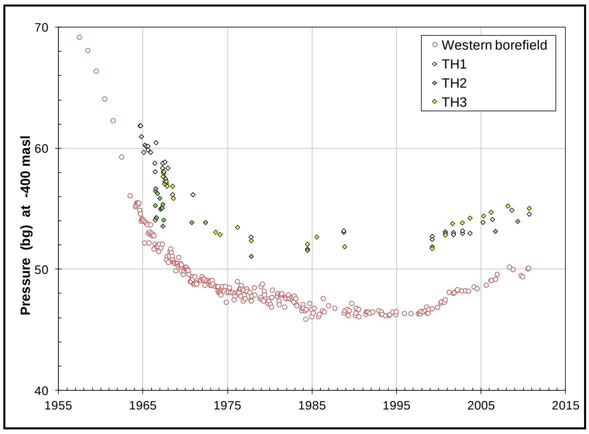

Figure 2: Wairakei-Tauhara liquid pressure history

4. WAIRAKEI-TAUHARA PRESSURE REGIMES

There are several different liquid pressure regimes throughout the Wairakei-Tauhara Geothermal System. In the deep reservoir the main two are the Wairakei Production regime (shown in dark blue, Figure 3) which includes Te Mihi and WBF wells, and the Tauhara regime (green circles, Figure 3). Both pressure regimes have almost the same gradient which is surprising as the temperatures at Tauhara are generally higher than at Wairakei by 30-40°C. As shown on Figure 2, the pressures continue to track each other with time, with Tauhara sitting 5 bars higher than Wairakei.

In addition to these two main regimes, there is also the Karapiti South regime (red crosses, Figure 3), which falls on, or very close to the Tauhara regime. The outfield wells (orange crosses, Figure 3) are about 15 bars higher than Tauhara pressures.

5. WAIRAKEI-TAUHARA PRESSURE ISOBARS

Pressure isobars were created using available 'shut-in' pressures from production, injection and monitoring wells in the Wairakei-Tauhara Geothermal System between 2008 and 2010, before the Te Huka binary plant went online. Futhermore, pressures from outfield wells unaffected by Te Huka, up to 2012, have also been used as these show minimal change with time. All pressures were normalised to -400masl using the common pressure gradient found at both Wairakei and Tauhara (Figure 3), to reflect deep liquid pressures in the Waiora Formation.

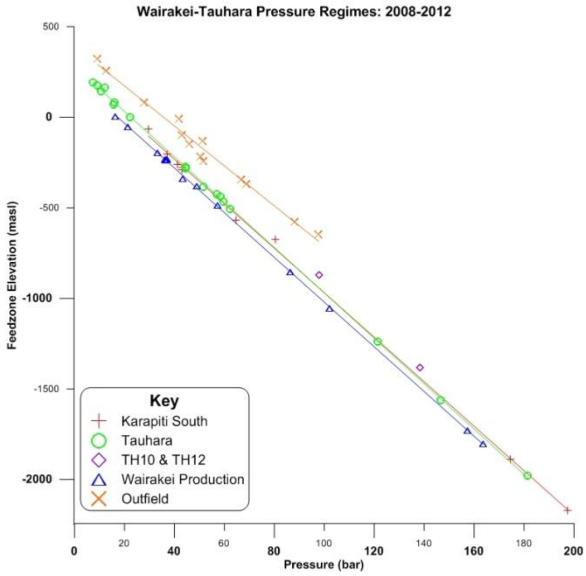

Figure 3: The varying pressure regimes over the Wairakei Tauhara Geothermal System.

The general shape of the infield low pressure zone mirrors the shape of the Wairakei-Tauhara resistivity boundary (red, Figure 4). There are clear divisions between the Wairakei and Tauhara fields, and the infield and outfield areas, as well as the different production and injection areas which have a difference of several bar (Bixley, 1986). These variations reflect the differences in pressure regime over the different parts of the field.

6. PRESSURE TUBING AND INTERFERENCE

This section focuses on selected monitor wells which provide a more detailed insight into the deep hydrological structure; TH01 and TH03 are deep liquid (Waiora Formation) monitors in Central Tauhara, THM16 monitors deep liquid (Waiora Formation) pressures near the Taupo township, THM17 and TH07 measures Mid HFF pressures in Central Tauhara, WK402 measures deep liquid pressures at Karapiti South and WK218 measures deep liquid

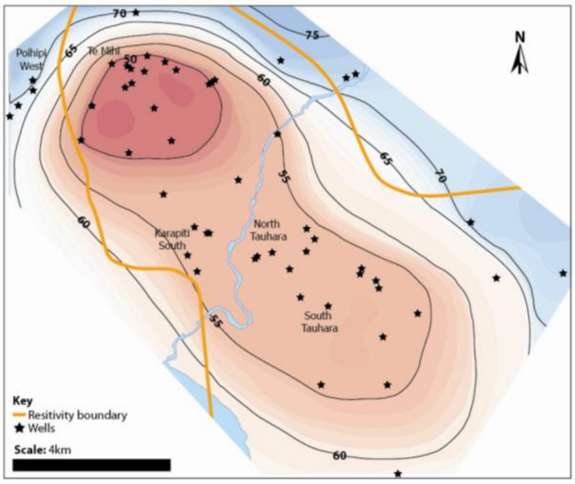

Figure 4: Wairakei-Tauhara map with pressure isobars normalised to -400masl. Red indicates lower pressures and blue indicates higher pressures. Resistivity boundary is from Environment Waikato.

pressures at Wairakei. Location of these wells are shown in Figure 1.

The period between March 2010 and January 2012 provided an excellent opportunity to monitor pressure changes with large changes in production and re-injection flows associated with the commissioning of several new production and re-injection wells. In March 2010, the Te Huka binary plant (at Tauhara) came online. Production came from the deep Waiora Formation with 100% re-injection into the Mid HFF and Waiora Formation, (Figure 6). Then, in August 2011, several new production wells connected to a new separation plant, Flash Plant 16 (FP16), were commissioned in Te Mihi, with the separated water being reinjected at Karapiti South.

6.1 Pressure tubing response

When the Te Huka binary plant came online in March 2010, there was a response in pressure from most of monitor wells noted above, apart from WK218 (Figure 5). TH01, TH03, THM16 showed pressure declines (Figure 5), which were expected given these wells are in the same area as the Te Huka production wells and have feedzones in the Waiora Formation. THM17 (Mid HFF monitor) also saw decline, though to a smaller magnitude, suggesting there is some hydrological link between the Mid HFF and deeper Waiora Formation aquifers.

WK402, located in the Karapiti South area, also showed a response initially declining at the same rate as other Waiora monitors at Tauhara, before showing a stabilising trend. WK218, located approximately 1km South East of the WBF, showed no observable short term response to changes at Tauhara during this period. TH07 (Mid HFF monitor) on the other hand, located adjacent to the shallow injection well at Te Huka, showed a pressure build-up, most likely responding to Mid HFF injection.

With the commissioning of FP16 and associated production wells and re-injection starting at Karapiti South, WK402 showed an immediate response to Karapiti injection, and WK218 exhibited a pressure decline in line with the increased production from Te Mihi. Unfortunately, given the simultaneous commissioning of FP16 production and Karapiti South injection, it was not possible to confirm if there was a response from WK218 to Karapiti injection or a response from WK402 to production from FP16 wells.

Additionally, re-injection at Karapiti South reversed the previously declining trends in TH01, TH03 and THM16 that had been observed since commissioning the Te Huka plant, confirming a good hydrological link between Karapiti South and Tauhara (Figure 3). In the Mid HFF monitor wells, TH07 also showed a subdued response to Karapiti South injection with pressures increasing above the previous levels with no change in shallow Tauhara injection. THM17 however, showed no immediate response to Karapiti South injection.

6.2 Interference Calculations

The pressure responses described above were analysed quantitatively to obtain values for transmissivity (kh) and storativity (φch). For all calculations, production was assumed to be constant, and data effected by shuts or tubing leaks was ignored. These are summarised in Table 1.

Interference calculations on WK218 to FP16 production show excellent permeability in the Te Mihi area (Table 1), confirming previous studies that the Te Mihi and WBF are permeable and well connected (Grant & Bixley, 2011). Average storativity was too high for a confined liquid aquifer and reflects the presence of the extensive segregated steam zones, which are present across much of the Te Mihi area.

The response from TH01, TH03, THM16 and WK402 to Te Huka production showed similar transmissivities (Table 1). This demonstrates that there is excellent isotropic permeability in the Tauhara area that extends several kilometres northwest to Karapiti South. Storativities obtained varies with high values from TH01 and TH03 and moderate values from WK402 and THM16. These values suggest two-phase conditions within North and Central Tauhara, but this diminishes towards Karapiti South where shallow conditions are generally cooler.

The response of TH07 to Mid HFF injection suggests poor permeability within the Mid HFF. Storativity was high reflecting the presence of two-phase fluids and segregated steam zones that are observed in this formation.

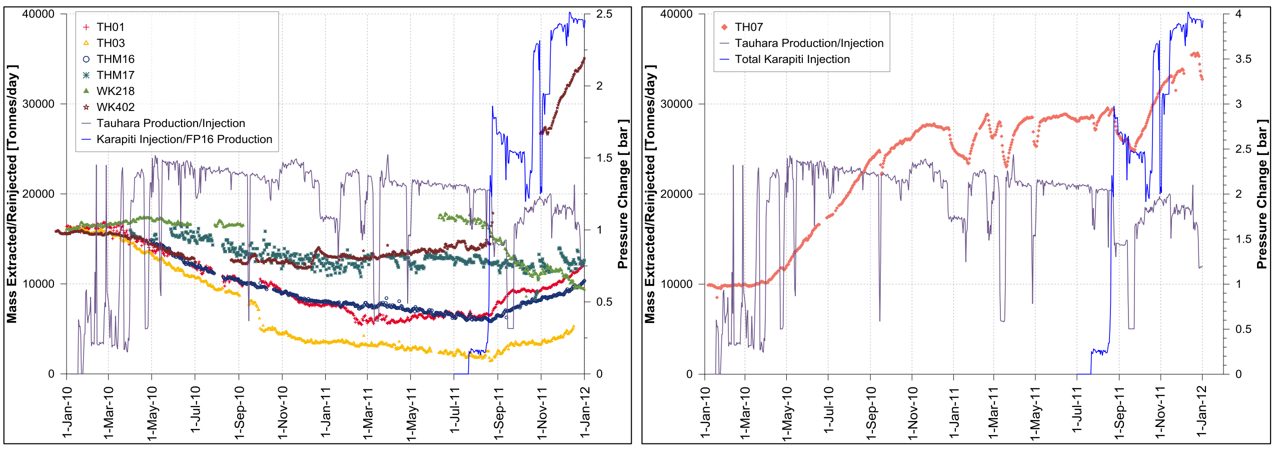

Figure 5: Pressure response of wells with capillary tubing installed

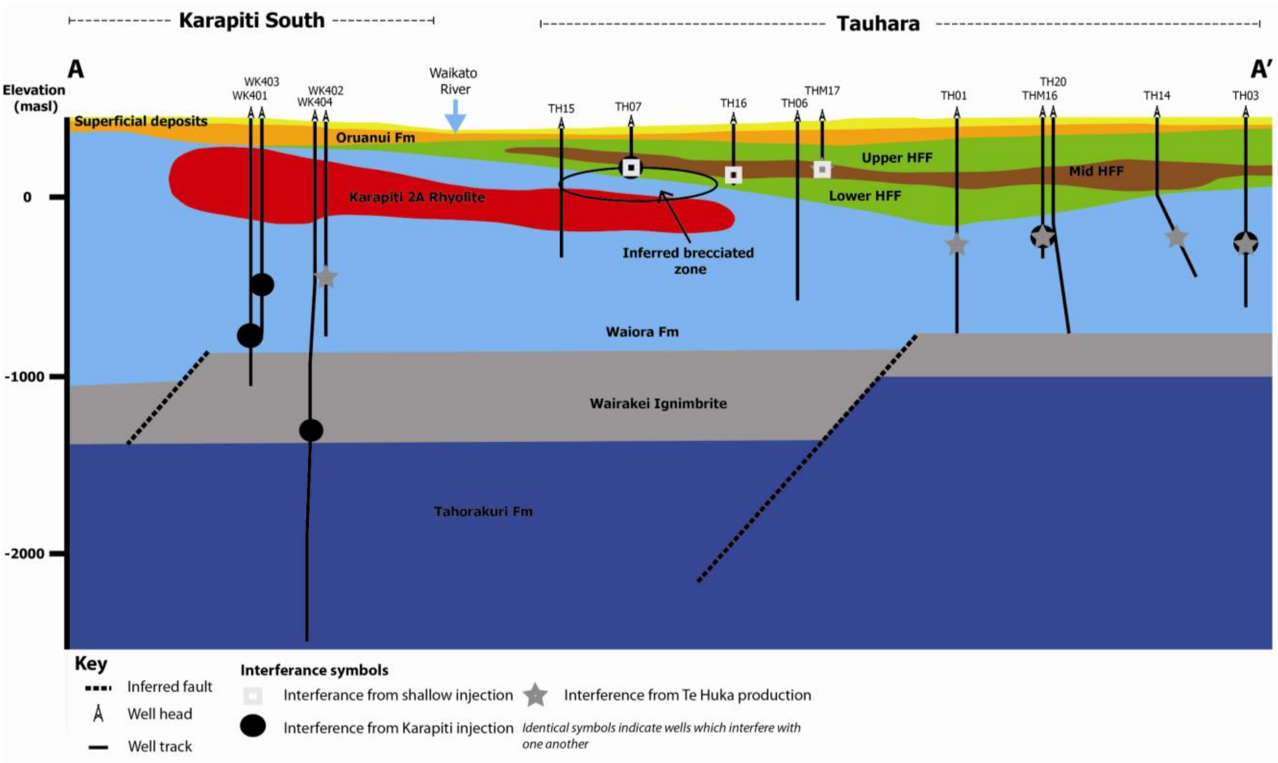

Figure 6: Cross-section showing wells interference, as well as the conceptual geology between Karapiti South and Tauhara. Refer to Figure 1 for cross-section trace.

Table 1: Transmissivity and storativity summary

Source Well(s)	Monitor Well(s)	kh [d-m]	φch [m/bar]
FP16 Wells	WK218	126	0.13
TH14	WK402	115	0.07
	TH01	101	0.44
	TH03	97	0.87
	THM16	92	0.12
Karapiti South Injection Wells	TH03	89	0.03
	THM16	50	0.02
TH16	TH07	6	0.13

Pressure responses to Karapiti South injection showed high transmissivity at TH03, but reduced transmissivity at THM16 suggesting either a less direct or less permeable connection between THM16 and Karapiti South. Storativities calculated were low, which suggests that the link between Karapiti South to TH03 and THM16 occurs through a liquid aquifer.

Overall, the transmissivities calculated are consistent with previous tests conducted at Wairakei over a number of years (Grant & Bixley, 2011).

A summary of hydrological connections at Karapiti South and Tauhara is demonstrated in Figure 6.

7. DISCUSSION & CONCLUSION

The distinction between Wairakei and Tauhara is evident from the pressure isobars (Figure 4), the pressure vs. elevation plot (Figure 3), and the different pressure responses seen in the interference monitoring (Figure 5). Taking all these observations into consideration, this shows that the “Tauhara” field is larger than previously thought and extends to the Karapiti South injection area on the western side of the Waikato River.

The interference results presented here indicate that there is excellent permeability between Tauhara and Karapiti South. This is likely to be related to the Karapiti 2A Rhyolite, which is a common target for injection wells and extends from the southern part of Wairakei to Tauhara (Figure 6). Well testing and drilling experiences indicate that this rhyolite is highly brecciated and permeable zones are found both near the contacts and within this formation. This rhyolite is believed to provide a connection between Karapiti South and Tauhara at elevations around +100 to -200 masl (~300-600m depth) via these brecciated zones (Figure 6). Results from several deep injection wells indicate there is also likely to be a connection below 2000m depth.

Results from the continuous pressure monitoring undertaken over the last few years confirm the previous hydrological understanding that the Wairakei and Tauhara fields have very high and well interconnected permeability. This is demonstrated by the uniformity of the pressure isobars throughout each field (Figure 4) and is reflected in the high transmissivities calculated from the interference study. The results also suggest that the hydrological ‘boundary’ between the Wairakei and Tauhara fields is not along the Waikato River, as previously thought, but in fact lies in the southwest, between Te Mihi and Karapiti South. These results also indicate that permeability is not contained within certain formations, but that it includes intra-formational permeability. This means that there is not only a high degree of primary permeability, but also secondary permeability from faulting and brecciation.

Further evidence of varying types of permeability throughout the Wairakei-Tauhara system is discussed using results from acoustic formation imaging technology (AFIT) logs in McLean & McNamara (2011). Results from the AFIT logs show that permeability is dominated by primary, formational permeability to a depth of 1500-2000m, but at deeper depths, permeability is structurally controlled (pers comm.. Katie McLean, 2012).

Online pressure monitoring with the capillary tubing and the pressure response calculations have demonstrated that the re-injection programme is effective in reversing previously declining pressure trends. Pressure monitoring will continue so that we can closely track these changes, and learn more about how production and injection affects the reservoir.

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