Cover Page - Example

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INTERFERENCE TESTING AT KAWERAU 2006-2007

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SUMMARY – Recent drilling by Mighty River Power at Kawerau has proven high permeability and good production at depths of 1400-2000m in greywacke. Interference tests among these wells and between them and the existing production wellfield shows very high and horizontally isotropic permeability communicating over several kilometres laterally and a kilometre vertically.

1. INTRODUCTION

Figure 1 shows well locations in Kawerau field, and Figure 2 a cross section.

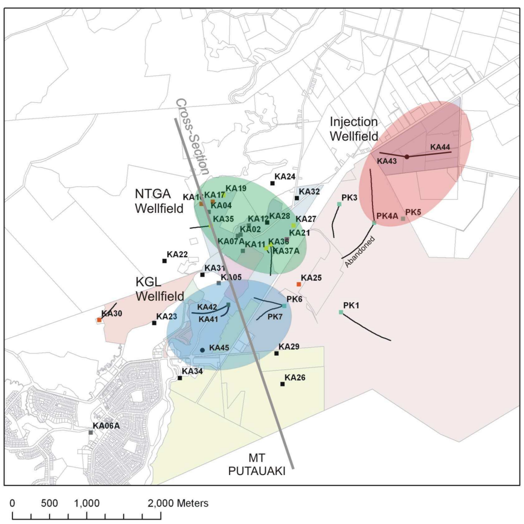

Figure 1. Location map

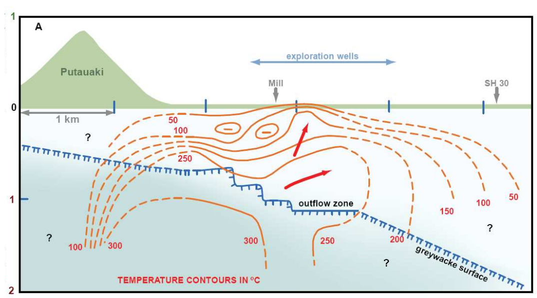

Figure 2. Cross section

The upflow for Kawerau originates under Putauaki and outflows to the north. The first drilling was on the outflow. Over the years drilling has gone deeper.

The wellfield has two developers: NTGA (Ngati Tuwharetoa Geothemal Assets), who own the old Crown development and supply steam for process heat, and KGL (Kawerau Geothermal Ltd.), Mighty River Power's development for a 90MW power station to be commissioned in 2008. MRP is also the operator for NTGA.

2. NEW WELLS

Mighty River has drilled deeper than previous developments, and further to the south of the field where temperatures are higher and any reversal lies deeper. Most wells have found very high permeability within the greywacke.

Table 1. New wells

Well	Depth	Permeable zone
PK4A	1715	1460
PK6	1995	1770-1995
PK7	2005	1925-2005
KA41	1910	1360-1375
KA42	2050	1470-1540

Note: depths are TVD.

Various of the wells have been instrumented, for a period, with pressure tubing to observe the response to well discharges. On occasion a response has also been observed to changes in the NTGA production well field.

3. OBSERVATIONS

Figure 3 below shows some typical monitoring data. The pressure in PK6 was monitored over several months, with PK4A being added at the end also. There have been instruments on KA25, KA17 and KA3 for some time.

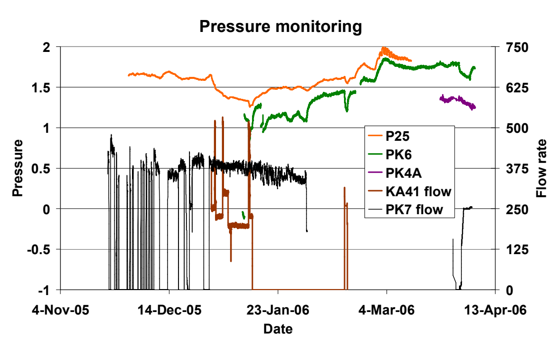

Figure 3. Monitoring data in KA25, PK6 & PK4A

There was extensive test discharge of KA41 and PK7. PK6 shows responses to both wells. Figure 4 and Figure 5 show two of these responses in expanded scale.

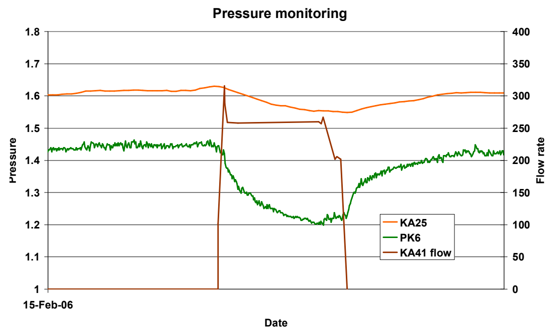

Figure 4. Response of PK6 and KA25 to KA41

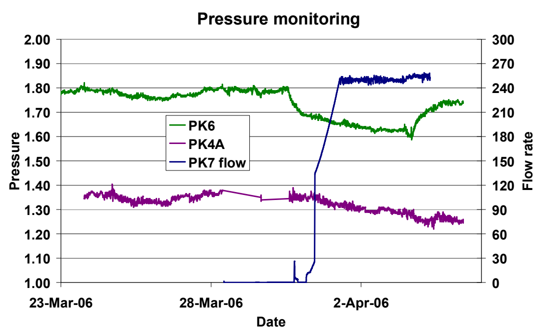

Figure 5. Responses to PK7

Figure 6 below shows an earlier response of PK6 to KA31, and Figure 7 a semilog plot of the response together with a fit.

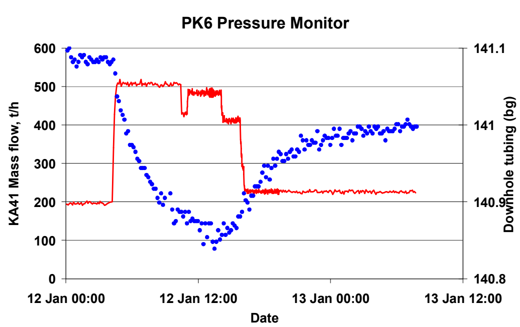

Figure 6. PK6 response to KA41

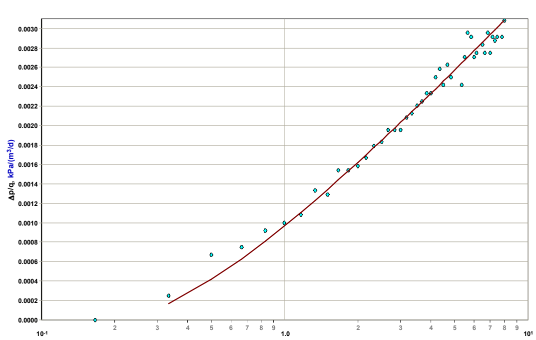

Figure 7. Analysis of PK6 response to KA41

PK6 also showed a response when production was reduced in the NTGA wellfield. The start time of the shut was picked from the pressure record, and a semilog plot is shown in Figure 8, together with a transient fit made using the FAST package.

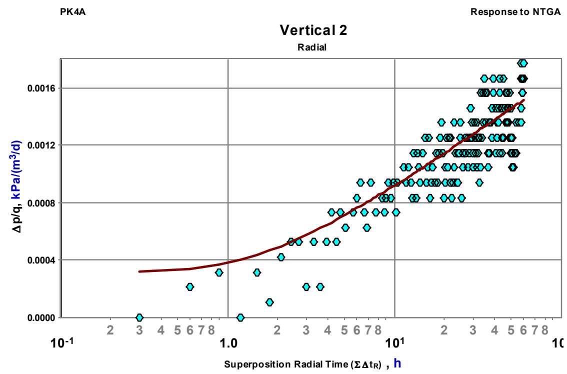

Figure 8. Analysis of PK6 response to NTGA

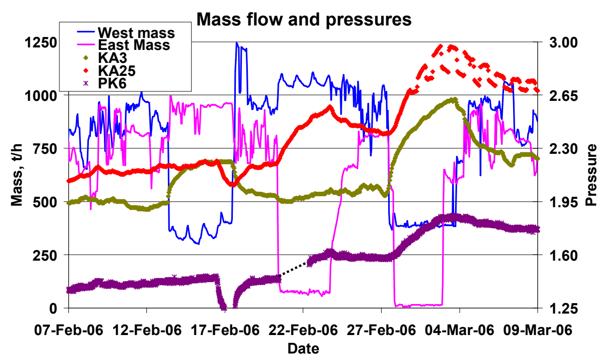

Figure 9. Responses to partial closure of NTGA wellfield.

Figure 9 shows the observations in early 2006. There were three times when the NTGA production was partly shut. The well field is conveniently divided in to eastern and western producers, and there were different changes at the different shuts. This allows desuperposition to compute the response to each source.

Another set of observations were made in early 2007. Three wells, KA19, KA27 and KA35 were each partly shut during three periods, with different flow changes. This again gave the unit response functions. Figure 10 shows the unit response functions for KA41.

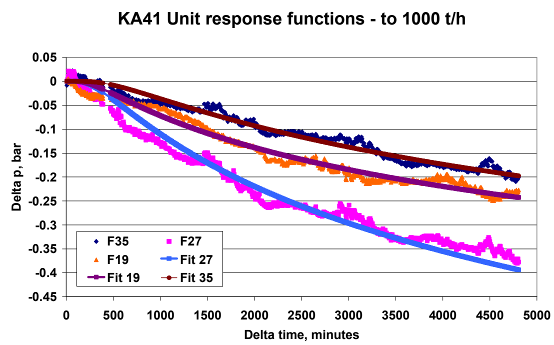

Figure 10. Unit response functions and fits for KA41

4. RESULTS

Table 1 below lists the parameter values found from these interference tests, together with earlier tests in 1985, reported by McGuinness (1985) and Burnell & McGuinness (1985). They used a more complex aquifer model, with boundaries, from which only the *kh* and *φh* values have been repeated.

Table 2. Recorded interference observations at Kawerau

Obs well	Source	*kh, dm*	*φh, m*
KAM1	KAM3	575	100
KAM2	KAM3	392	265
KAM4	KAM3	511	62
KA11	KAM3	1600	135
KA14, 17,31	KAM3	No response	
KA17	KA27	15±10	90
KA17	KA35	585	42
	KA21	48	
KA14	KA35		460
	KA21	390	
KA31	KA35	679	35
	KA21	95	
KAM1,M2, M4,11	KA21, 35	No response	
PK6	KA41	100 ± 16	200 ± 50
PK6	KA41	98	
PK6	PK7	136 ± 3	68 ± 7
PK6	NTGA	210	150
PK4A	NTGA	400	
PK4A	PK7/PK3	100	
KA17	E	290 ± 53	100 ± 20
KA25	E	215 ± 45	240 ± 40
KA17	W	120 ± 30	200 ± 100
KA3	W	127 ± 12	240 ± 35
KA25	W	80 ± 35	110 ± 10
KA25	PK7/PK3	70 ± 8	180 ± 20
KA25	KA41 PFO	68 ± 17	95 */ 3.3
	KA41 PBU	85 ± 3	85 ± 25
KA25	KA27	360	290
KA25	KA19	475	110
KA25	KA35	400	270
KA41	KA27	117	30
KA41	KA19	200	43
KA41	KA35	170	113
PK4A	KA27	230	11
PK4A	KA19/35	240	20

Note: First set of results above divider from 1985.

All current analyses assume that the reservoir fluid is 290°C liquid water. Some analyses are done by a welltest package (FAST), some by fitting the liner source solution. Some confidence limits are also given as generated by FAST. It should be noted that the fitting routine is nonlinear and does not generate a unique optimum fit. Often a re-trial will find another, similar fit with parameters reasonably similar to other trials; but experience with such repeats has shown that parameters may often reasonably range outside the stated confidence limits. The different methods may give different results on noisy data.

Also it is notable that there are some tests which are effective repeats, and different results are obtained as shown in the responses of KA25 to western wells in Table 3 below. This demonstrates the very considerable range of error in the results.

Table 3. KA25 response to western wells

KA25	W	80 ± 35	110 ± 10
KA25	KA19	475	110
KA25	KA35	400	270

The most striking feature of the new results is their similarity. Both transmissivity and storativity mostly lie within a range of a factor of four, which is pretty tight for such data. There is some tendency toward lower storativity in the greywacke wells. It demonstrates that all these wells communicate through the same reservoir, the properties of which are fairly uniform. The communication extends from PK4A in the north down to KA41 in the south, and from the production zones of the NTGA wells to the deep zones of the new MRP wells..

The storativity is generally a little bit too high for a compressed liquid aquifer. Reasonable values would be 70m or less (1000m x 7% porosity). This indicates communication with a relatively small amount of two-phase fluid, or an area of free surface. If there were patches of two-phase fluid, the boundary between them and the underlying liquid would act like a free surface. The amounts of such two-phase or free surface needed is quite small, as the storativity is only a bit too high. There were originally two-phase conditions in shallower parts of the Kawerau reservoir, and it is quite reasonable that some patches of these may remain, by-passed by cooler recharge waters.

PK4A, KA41 and PK6 both respond to the NTGA wells, demonstrating communication with this shallower production level. The previous 1985 tests show communication among these wells including KA14 and KA17, showing that communication extends up to 800m depth. There is thus connection over a depth interval of a kilometre, from 800 to 1800m.

If the medium were anisotropic, with permeability greater in one direction, the *kh* value found in the tests would always be the same ($\bar{k}h = \sqrt{k_{max}k_{min}}\ h$), but the storativity (or porosity-thickness) would vary with direction, being greatest in the direction of least permeability. There is not apparent any marked variation of storativity with direction. The lowest storativity values, at KA41 and PK4A, are for responses along the field axis (KA41-KA27) and across it (PK4A-KA19/35).

SUMMARY

Interference testing has shown that the production reservoir at Kawerau is extensive, covering a lateral distance of 3km, and a thickness of at least a kilometre. This permeability lies in the greywacke basement and in the overlying volcanics, and on the large scale is horizontally isotropic.

ACKNOWLEDGEMENTS

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McGuinness, M.J., 1985 “Interference between KA17 and KA27” report KA-1985-MJM-1, Applied Mathematics Division, DSIR

Burnell, J.G., & McGuinness, M.J., 1987 “Interference tests at Kawerau, New Zealand” *12th Workshop on Geothermal Reservoir Engineering,* Stanford University, pp173-179