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M. P. Hochstein, J. Brotheridge and S.F. Simmons

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RESULTS OF REPEAT TRACER TESTS AT OHAAKI, NZ

W.J. McCABE¹, A.W. CLOTWORTHY² AND C MORRIS²

¹ Nuclear Sciences Group, IGNS, Lower Hutt, NZ

² ECNZ, Geothermal Group, Wairakei, NZ

SUMMARY.

During 20 years of tracer testing at Ohaaki a number of wells have been used more than once as tracer injection sites. In studying the various responses obtained it has been necessary to consider variations in the experimental test conditions before making comparisons which relate to field conditions. Some very significant changes have occurred in the field hydrology in recent years and water flow speeds as high as those encountered at Wairakei have been demonstrated.

1. INTRODUCTION.

The use of tracers, both chemical and radioactive, in hydrology has been well established for many years. The first use of a radioactive tracer in a geothermal field dates from 1971. This test at Ahuachapan in El Salvador was reported by Einarson (1975). Our experience in the use of these tracers in geothermal systems dates from June 1974 when a number of tests were begun at Ohaaki, (McCabe et al.1983). The tracer work at Wairakei started in 1978. Tracer tests have been made in geothermal fields in the United States, Mexico, El Salvador, Costa Rica, Iceland, Greece, The Philippines, Indonesia, Kenya and Japan. References to most of these are given in the review paper (McCabe,1991).

A tracer test programme has been running in New Zealand since 1974 supported by DSIR, NZED, MWD, the Ministry of Energy and in recent years ECNZ, Geothermal Group. This work was originally started to provide a new source of scientific information to assist in the better understanding of fluid movement in geothermal systems in general and at Ohaaki and Wairakei in particular. Despite extensive enquiries at the time of starting this tracer work, no information could be found on the natural or induced fluid velocities that existed in the fields. From such an on going tracer test programme, a picture of the flow patterns in a geothermal field, or parts of the field, can be built up and applied to field management and development.

Overseas experience has shown that making a choice of reinjection wells without tracer testing has led to premature cool water intrusion into production areas with the subsequent need to close down the reinjection wells to avoid declining production as a result of cooling.

In its simplest form, tracer testing is done by putting the tracer in one well and then testing the fluid from other wells (observation wells) for signs of the tracer. More information

can be obtained by measuring the variation of the tracer concentration with time, in the fluids from these wells. Knowing the well locations this information can be used to determine:

- the existence of a flow path;
- the direction of flow, including the flow from observation well to observation well;
- the speed of flow.

Using the measured tracer concentration data together with individual well production flows and initial tracer quantity, it is possible to calculate or infer:

- the percentage of tracer recovered at individual observation wells;
- the total percentage of tracer recovered from all observation wells;
- the total tracer likely to be produced. This includes tracer recovered from observation wells and tracer likely to have been recovered by wells which are producing but which were not sampled. This judgment can be based on the pattern of tracer recoveries in the sample wells together with other information, including other tracer tests;
- the nature of the flow path between the point of tracer injection and the observation wells.

As a conservative tracer moves in the same way as the water in which it is dissolved, it is therefore possible to calculate not only the tracer movement as described above but also the movement of the water.

The order in which wells respond, the concentrations measured and the locations of nonresponding wells are all relevant factors to be considered in the interpretation of test data.

A nil return of tracer at an observation well has a number of possible reasons:

- there was no flow between the injection well and the observation well under the conditions of the test;
- the flow was so slow that the tracer had not arrived by the time the test was stopped;
- the tracer was undetectable due to dilution or decay;
- the tracer flowed to the observation well but at a depth different from that from which it was feeding or being sampled;
- an unsuitable tracer was being used.

Consequently, while a positive return indicates fluid movement, a nil return does not mean that there has been no fluid movement.

In the 20 years since tracer testing began at Ohaaki, 27 radio-tracer and several rhodamine dye tests have been made. Tracer injection wells include 5 on the eastern side of the river and 13 on the western side. The locations are shown on the Ohaaki map, fig.1. The seven wells which have been tested more than once are listed in table 1.

Fig. 1. Map of the Ohaaki geothermal field.

Table 1. REPEATED OHAOKI TESTS

Inj Well	Date	Tracer	Responding Wells	Non Responding Wells
BR7	11.06.81	¹³¹ I	-	10, 16, 27, 29, 36
BR7	07.09.89	¹³¹ I	-	10, 14, 24, 25, 27, 35, 36, 42, 43, 44, 45
BR7	06.06.91	¹²⁵ I	10, 25, 27, 29, 36, 42, 44	13, 14, 24, 35*, 43*, 45*
BR11	04.10.74	¹³¹ I	8	2, 4, 17, 18
BR33	21.05.77	¹³¹ I	8, 11	
BR11	28.06.94	¹³¹ I	2, 8, 17	3, 9, 13, 18, 19, 20, 21, 22, 31, 35, 43
BR16	13.02.90	¹³¹ I	-	13, 14, 25, 27, 35, 36, 42, 43, 44, 45.
BR16	19.08.92	¹²⁵ I	42	10*, 13, 14, 24, 25, 27, 29, 31, 35*, 36*, 43, 44*, 45
BR30	06.03.81	¹³¹ I	-	25, 27, 28, 35
BR30	01.11.89	¹³¹ I	-	24, 25, 27, 28, 35, 36, 42, 43, 44, 45
BR30	19.07.93	¹²⁵ I	27, 36, 42	10, 25, 27, 28, 29, 35, 43, 44, 45
BR40	14.02.90	¹³¹ I	-	2, 8, 11, 13, 18, 19, 20, 21, 22, 25, 31, 35, 45
BR40	03.03.92	¹²⁵ I	M9	2, 8, 13, 17, 19, 20, 21, 22, 25, 28, 31, 35, 45

* Possible small return

Changes in the responses have occurred with time. There are several reasons for this not all relating to changing field conditions:

- change of measuring methods;
- tracers with different properties;
- changed well operating conditions;
- changed field conditions.

Changes of Measuring Methods.

Until 1984 the ¹³¹I tracer concentrations were measured in the field with a well-head continuous monitoring system. After that date a system of sampling followed by laboratory processing and counting was used. This enabled the introduction of ¹²⁵I which could not be detected in the field. The sampling method is much more sensitive for both tracers so it is possible that in pre 1984 tests, tracer was not detected

in wells where it would have been detectable post 1984. The sampling method also allowed a much more flexible and extensive sampling programme. The disadvantage is that fast responses may be missed or inadequately covered.

Tracers with different properties

Using ^{131}I tracer ($T_{1/2} = 8$ days), decay and dilution limit the duration of tests to 5 to 6 weeks. Using ^{125}I ($T_{1/2} = 60$ days), the limit is about a year, and the movement of tracer can be followed over much greater distances or at much slower speeds.

Changed well operating conditions.

A nil response from a well may not mean that there is no tracer in its vicinity. It may be due to the well being fed with water from a *depth* where no tracer exists. Several instances of this have been observed, for example BR2, BR3, and BR42, where changing the well operating pressures have resulted in changes in the tracer concentrations in the discharge from strong positive to zero values. Fig. 2 shows the tracer response at BR3 during the BR12 test. The well was throttled up partway through the test. Temperature/pressure surveys on the flowing well showed that the feed points changed as the wellhead pressure changed.

Fig. 2. BR12 test September 1990. Showing the effect of WHP on the response at BR3.

Change in Field Conditions.

When the tests started at Ohaaki in 1974 the field had been shut in for three years following production testing which had peaked in 1970. Discharges began increasing in late 1974, when a new series of output tests started. Since then withdrawal has increased with full production and peripheral reinjection of separated water implemented. Clotworthy et al (1995) discuss these changes in their forthcoming paper. The changes could be expected to affect the fluid flow in the geothermal aquifer.

2. REPEAT TRACER TESTS AT OHAAKI.

Of the 27 tests run 17 were repeat tests in 7 wells. Two of the wells, BR13 and BR34, should be removed from

consideration because the conditions or objectives of the tests were so different that to do so in this context would be misleading.

The 1980 test on BR13 was done during a long term reinjection test into BR13 with water from BR19. The 1981 test was made with approximately 66 tonnes (2 well volumes) of cold river water. There is some doubt about the validity of tests made using cold river water. Generally considerable efforts are made to maintain the hydrological characteristics of the system by injecting the tracer with hot geothermal fluid when making these tests.

The second BR34 test was made to measure the response of two monitor wells drilled close to BR34 and only those wells were monitored.

The remaining wells are shown in table 1. A quick look at the table shows that in each case the most recent test has shown more wells in which returning tracer has been detected.

Consideration will now be given to the tests in each of the five wells to see whether changes in *experimental conditions* or *field conditions* can account for the observed changes in results. If experimental changes can be eliminated as causes, can the changes in the wells responding, the flow speeds and directions and the concentrations and amounts of tracer recovered be interpreted in terms of the geological structure of the field or changes in the field due to management activities?

Well BR11. In 1974 the tracer was released into a shut-in well. Measurements were done with a very inefficient detecting system and the 1.2% tracer return was obtained from a high concentration, low volume discharge (<1 tonne/h). All the monitored wells were on bleeding discharge. Fig.3 shows the only response obtained in 53 days of monitoring of the 1974 test. Tracer appeared in BR8 5 days after injection, peaking at about 25 days. No tracer was detected in wells BR2 or BR17.

Fig. 3. BR8 response from BR11 test 1974.

Fig.4 shows the responses to an injection starting 21 May 1977, in BR33. This is a shallow reinjection well near BR11. The difference in the first arrival times at BR11 and BR8, the only wells monitored, is again about 5 days. Operating

conditions could not have been more different. In the first test all the wells in the field were either closed or on a light bleed. In the second test all wells in the vicinity were on full discharge and yet the travel time for the tracer between BR11 and BR8 were virtually unchanged.

In the 1994 test tracer was injected into a downflow in BR11 and started to show at BR2 and BR8 on day 6 and at BR17

Fig. 4. Responses from BR8 and BR11 from BR33 test.

on day 16 (fig.5.). The tracer returns were 0.5%, 1.6% and 0.2% respectively.

The test results are summarized in table 2. If field conditions had been the same in 1974 as in 1994 there should have been no difficulty in detecting responses at BR2 and BR17 if they had occurred.

Fig. 5. Well responses in the BR11, June 1994 test.

Table 2. Summary of BR11 Tests

Date	Maximum Concentration L ⁻¹ BR2	Maximum Concentration L ⁻¹ BR8	Maximum Concentration L ⁻¹ BR17	% Tracer Return BR2	% Tracer Return BR8	% Tracer Return BR17	BR8 Dis-charge T/h
04.10.74	-	15000	-	-	1.2	-	0.6
21.08.77	*	350	*	*	2.5	*	106
28.06.94	25	110	350	0.5	1.6	0.3	150

* not monitored.

Fig. 6. Cross section of the Ohaaki field, BR5 to BR12, showing well feed zones.

In the 1974 test, the injection was into the shallow feed of BR11 while BR2 and BR8 were bleeding from their

shallow feeds, fig.6. In 1977, the injection at BR33 was shallow and BR11 and BR8 were both discharging from only their shallow feeds. For the 1994 test, the injection was into the deep feed of BR11 while a small portion of the discharge from both BR2 and BR8 came from the deep feeds. BR17 has always drawn only from the feed in the Rautawhiri Breccia. Thus a change in operating conditions would appear to have changed the formation being observed from the Ohaaki Rhyolite to the Rautawhiri Breccia. The surprising thing is that the permeabilities, as reflected in the tracer speed and recovery, are so similar.

Well BR7. The first test on 11.06.81 was run for 39 days and gave no sign of tracer return. The second one starting 07.09.89, ran for 41 days and again showed no returns. The third on 06.06.91 however gave early responses in BR27 (fig.7) and BR10 and probably BR29, and eventually spread to most of the wells in the eastern side of the river. BR27 returned 4% of the tracer. If field conditions had been the same, the 1989 test should have shown strong returns long before the test concluded.

Fig. 7. Tracer discharge at BR27 showing the time when reinjection at BR7 was stopped.

Well BR16. The test of 13.02.90 was run for 35 days and showed no responses. The test of 19.08.92 did not start to return measurable amounts of tracer at BR42 until almost 80 days into the test. (fig.8). There is no inconsistency here and the very minor return and the long time involved would indicate that this is a good reinjection site. The speed of the tracer front at BR42 was about 10 m/d (0.4 m/h) with a mean velocity much slower than that. Such speeds may allow for an acceptable degree of heat exchange between rock and water when managing a reinjection programme.

Fig. 8. BR16 test showing the response at BR42

Well BR40. Tests in BR40 on 14.02.90 and 03.03.92 which ran for 38 and 101 days respectively produced no positive returns. However it was suggested in the report on the second of these tests that occasional sampling of wells in the vicinity, (BRM9, BR13, BR31, BR28), should be made through until the next year.

In fact in the course of extensive, field wide sampling for the next test, in BR16, significant activity was found at BRM9 only three weeks after the injection. The first arrival time of the tracer probably coincided with the injection time at BR16, fig.9. All samples collected from BRM9 in the period 200 to 400 days after the 03.03.92 test showed significant tracer returns. This implies a (radial) flow away from the production

area. However, lack of close observation wells on the production field side of BR40, prevented any determination of flow in that direction.

Fig. 9. Showing the response at BRM9 from the March 1992 test at BR40 and the start time of the BR16 test of August 1992.

Well 30. The original test on 06.03.81 was made during a long term reinjection trial into BR30 with water from BR35. No responses were observed during the 36 days of the test. Neither was there any response from the test of 01.11.89 during the 41 days for which it ran. However within 24 hours of injecting tracer on 19.07.93, it was starting to appear at BR27, 620 metres away, (fig.10). This indicates fluid velocities greater than those recorded along the Kaiapo fault at Wairakei. 30% of the tracer was returned during this test.

Fig. 10. Showing the response at BR27 to reinjection BR30.

Major changes occurred to the feed of BR27 during 1991 due to calciting off of the deep feed and what was a minor feed at 550 m becoming the main one. The enthalpy changed from 1600 to 1000 kJ/kg. Reinjection ceased three months after the start of this test and BR30 was disconnected from the reinjection system. An unplanned change of operating condition has brought to light a very high permeability path for which no other evidence exists. The curve in fig.10 does suggest at least one other, much slower, response starting around day 50 which could not have been observed in the earlier tests because they finished too soon.

3. CONCLUSIONS.

- Tests at Ohaaki confirm the experience obtained at Wairakei that repeated tests run years apart can produce very similar results. However, when field conditions are changing tracer test results are likely to change too.
- The potential exists for obtaining significantly more information from tracer tests if well operating conditions are varied at sampling time to induce changes in the feed points. While doing this may be a practical problem in an operating field, the linking of the reinjection and tracer data to specific formations could lead to a much better understanding of the field hydrology and hence better field management.
- Tests have shown very significant changes in the responses obtained from some wells. Some of the changes can be related to known alterations in well conditions but others remain unexplained at this time.

4. REFERENCES.

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