

Improving the Conceptual Understanding Through a Recent Injection of 200 GBq of Iodine-125 at the Rotokawa Geothermal Field, New Zealand

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ABSTRACT

The Rotokawa Geothermal Field has been under development since 1997 with the commissioning of the Rotokawa Power Station and the 2010 commissioning of the Nga Awa Purua Power Station. Since the field has been developed six reservoir tracer tests have been conducted. Recent deep reservoir tracer tests (2013 and 2015) have made use of Iodine-125 (I^{125}) due to the high reservoir temperatures ($>320^{\circ}\text{C}$) breaking down naphthalene sulfonates, with injection into RK24 (in 2013) and RK22 (in 2015). Results observed from the 2013 tracer test confirmed what wells observed tracer returns, which was informative alongside well geochemistry observations, however a 12-month tracer test was all that was achievable with the injection of 16.1 GBq of I^{125} . Besides practical learnings around project management and injection methodology, the 2013 tracer test results assisted with improvements in the experimental design for the 2015 test which included increasing the activity of tracer injected (to 200 GBq of I^{125}), increasing count times and having the ability to obtain larger samples. All these options were based around increasing the resolution to enable better identification of the tracer peak and to increase the ability to determine the tracer tail shape. The results to-date from the 2015 tracer test indicate that injection fluids move in a similar pathway to those observed in the 2013 tracer test, albeit with a slower first return, with returns being consistent with the presence of compartments within the reservoir. With injection into RK22 the reservoir tracer test results have given confidence that the risk of cooling from rapid injection returns is very low and it has assisted with conceptual understanding of the field which will be discussed in this paper.

1. INTRODUCTION

The Rotokawa geothermal field is one of approximately 15 known high temperature geothermal systems within the Taupo Volcanic Zone (TVZ), an approximately 60 km wide zone of intense volcanic and geothermal activity which stretches just south of Taupo to White Island. The Rotokawa geothermal system is approximately 10 km NE of Taupo and straddles the Waikato River. The field location in the TVZ is shown in Figure 1 with the field layout as at the start of the 2015 reservoir tracer test shown in Figure 2.

The conceptual model of Rotokawa has been described recently in Sewell *et al.* (2015a) and a review paper by McNamara *et al.* (2016) provides significant information about the field.

In 2010, the total take from the reservoir increased from around 15,000 t/day (which supplied the 34 MWe Rotokawa geothermal power plant) to nearly 65,000 t/day with the commissioning of the 138 MWe Nga Awa Purua (“NAP”) geothermal power plant. This increase revealed the presence of pressure compartments within the production area, with geochemical and thermodynamic trends also providing evidence of these compartments. Pressure contours from 2015 are shown in Figure 3, which also shows conceptually two important faults within the Rotokawa geothermal field, these being the Production Field Fault (“PFF”), the Central Field Fault (“CFF”) and the Injection Field Fault (“IFF”). Cross sections in Figure 4 show further information on the location of these faults in addition to geology of the field.

The western compartment (wells RK18L2, RK17, RK27L2, RK32, RK26 and RK28) had the largest pressure drawdown of the reservoir (up to 42 bar) and a number of the wells (mainly RK28 and RK26), showed early signs of dilution with other wells (RK17 and RK27L2) showing significant signs of chloride increase which was thought to be either due to boiling or injection returns. The rapid initial pressure drawdown resulted in a decrease of the liquid level, creating a steam rich shallow section boosting the flowing enthalpy up to 1700 kJ/kg (from initial 1500kJ/kg). Over time the decrease on the steam cap pressure produced a rise in the liquid level. The large pressure drawdown initiated the recharge of diluted marginal recharge into some of the producers. This process was described and modeled by Clearwater *et al.* (2016) in order to manage the production enthalpy. The tracer test conducted in 2013 did not indicate any signs of injection support to the western compartment, but more testing was required since after 250 days the decay of the I^{125} made the identification of any initial returns difficult due to large error bars, with the test concluding after one year.

The central sector of the field (wells RK5, RK14, RK29 and RK33), contained wells with pressure drawdown between 4 and 20 bar. The enthalpy of these wells has been very stable in the last 5 years, with an initial increase due to the decrease of the liquid level and stable or minor decline over time. These wells also showed higher levels of chloride with time indicating injection support, as Nga Awa Purua makes use of an evaporative cooling tower with condensate and brine injected separately and this brine is subsequently more concentrated than typical reservoir fluids. Northern wells (wells RK25, RK30), have a combination of characteristics of the two other

sectors, given by the variance in vertical distribution of feed zones. Neither the central nor the northern wells have shown to date any indication of downhole cooling.

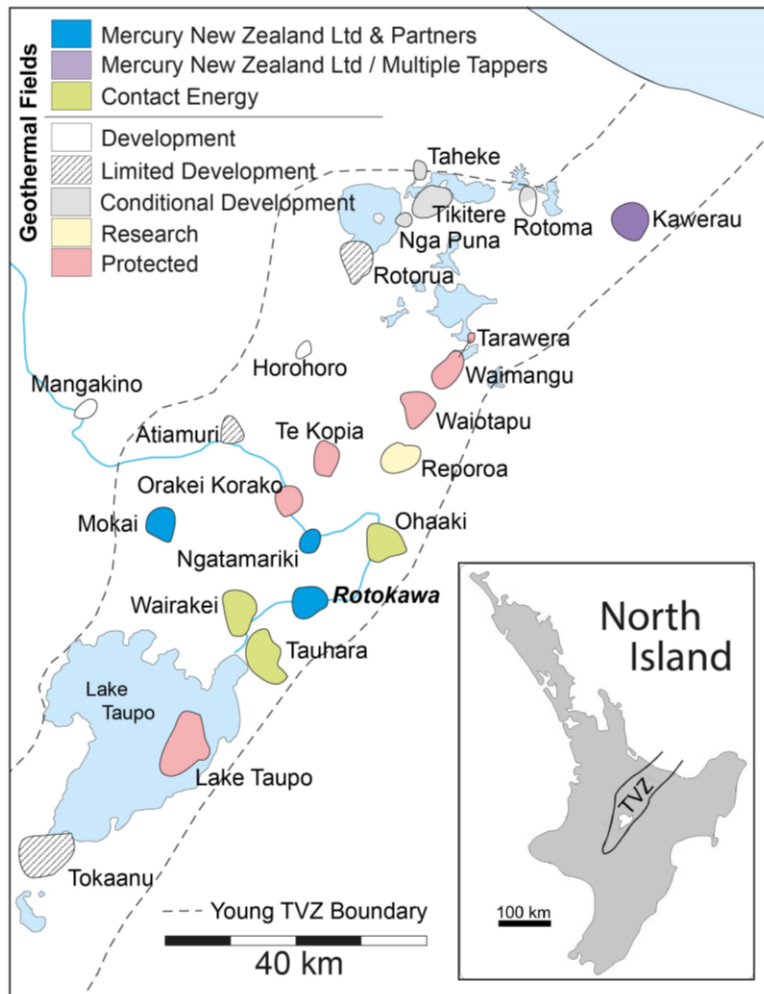


Figure 1: Location of known geothermal fields in the Taupo Volcanic Zone (TVZ) on the North Island of New Zealand as identified by Schlumberger resistivity surveys (Bibby et al., 1995). The Rotokawa field (bold) is approximately 12 km NE of Taupo, 10 km east of Wairakei geothermal field and 10 km south of the Ngatamariki geothermal field.

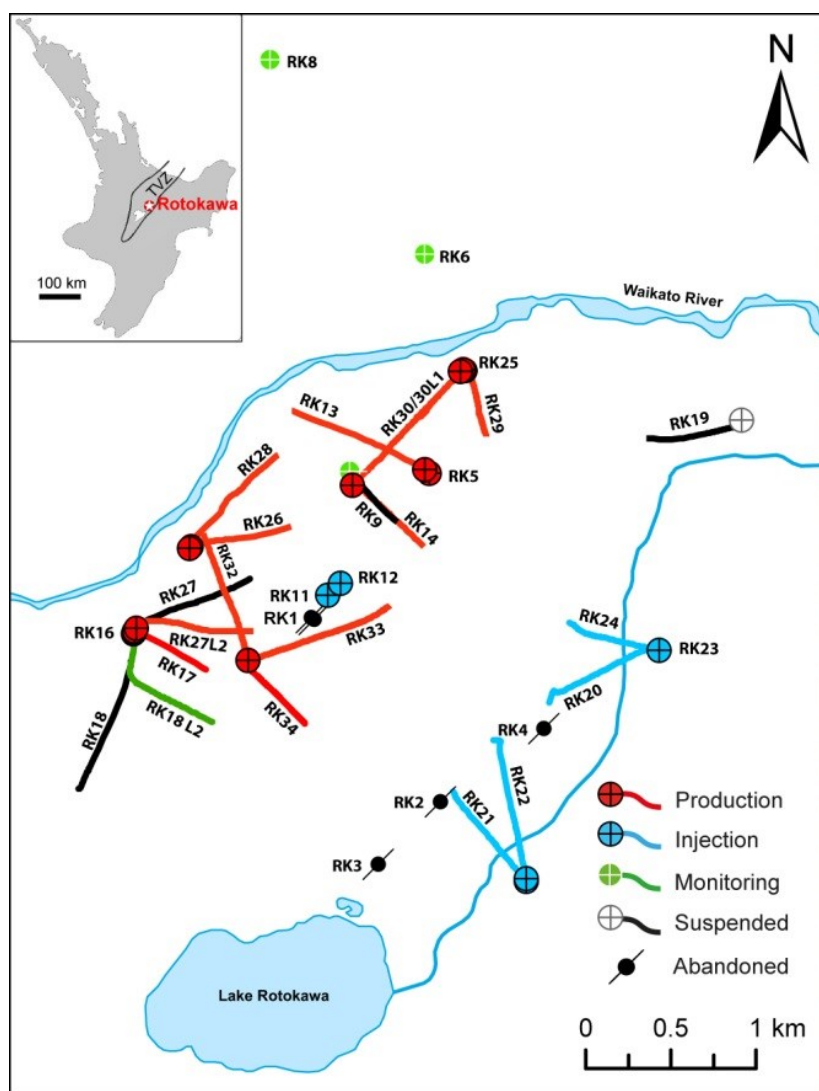


Figure 2: Rotokawa field layout as of the start of the 2015 reservoir tracer test.

Prior to the start-up of Nga Awa Purua, cooling from injection was identified as one of the major risks at Rotokawa. When Nga Awa Purua was commissioned the deep brine injection was initially into both RK21 and RK22 with the intention to use the CFF as a natural barrier. The capacity of these wells increased, likely due to thermal stimulation allowing the full injection of NAP brine in just one well (RK21). A few months after the injection started in RK21, a pressure response was observed in the continuous pressure monitor well RK18L2, which indicated a potential permeable connection between RK21 and the western part of the reservoir. The deep injection (75% of the total injection) was moved to the south east (RK20, RK23 and RK24) in order to minimize the risk of cooling. This has been the configuration between 2011 and 2015.

During the same time period, a monitoring program (including the tracer tests) was put in place to survey the injection returns. As mentioned previously the monitoring results did not indicate any change in downhole liquid temperatures in the central or northern production wells. Any change in enthalpy can be explained by variations of the thermodynamic conditions in the area after the Nga Awa Purua start up. During this period continuous downhole tubing recorded the pressure in RK22. The results and analysis of this data and the transient tests performed were described by Quinao & Azwar (2012). The pressure built up during injection and fell off during plant shutdowns but always returned to the same levels despite the large volumes injected into the nearby wells. Transient tests results indicated that injection fluid was able to dissipate quickly and therefore was able to outflow into a lower pressure compartment. This compartment could be the production sector and therefore more analysis was required to understand the connection between the different pressure compartments. The other possibility was that the CFF acted as a conduit for the injection fluid in the NE-SW direction and therefore prevented the injectate from returning to the production area.

The location of the microseismic events reinforced the idea of the injection fluid flowing across the CFF. According to the analysis published by Sewell *et al.* (2015b), in the period between 2008 and 2012, 70% of these events were related with fluid movements

between the production and the injection area. However, most of these events were in the east area (RK24) and the south-west (RK21 area) was aseismic.

These analyses together with the tracer tests conducted in 2011 and 2013 and described in more detail in section 2, concluded that there is not rapid straight returns of injection fluids from RK20, RK23 and RK24 to the production area and therefore the risk of cooling from these wells was considered very low.

In 2015, as part of the injection management strategy it was decided to use RK22 in order to spread injection and to attempt to move as much injection into the deep geothermal reservoir as possible. There was also the potential benefit of providing some sort of pressure support to the western compartment, but the risk of cooling from this well was not quantified. The strategy was to conduct a tracer test soon after the injection started and the pressure had stabilized in the field, thus testing the direction and quantity of the fluid injected in this well on its path back towards production. Following the final stage of flashing at the Nga Awa Purua, the injection fluid is 130°C. Hence, the higher the flow rate in RK22 the higher the possibilities of detecting positive returns (but also the higher the cooling risk). Therefore it was decided to inject at less than half of its capacity (500-600 t/hr vs 1200t/hr). The field configuration at the time of the reservoir tracer test is discussed in more detail later in this paper.

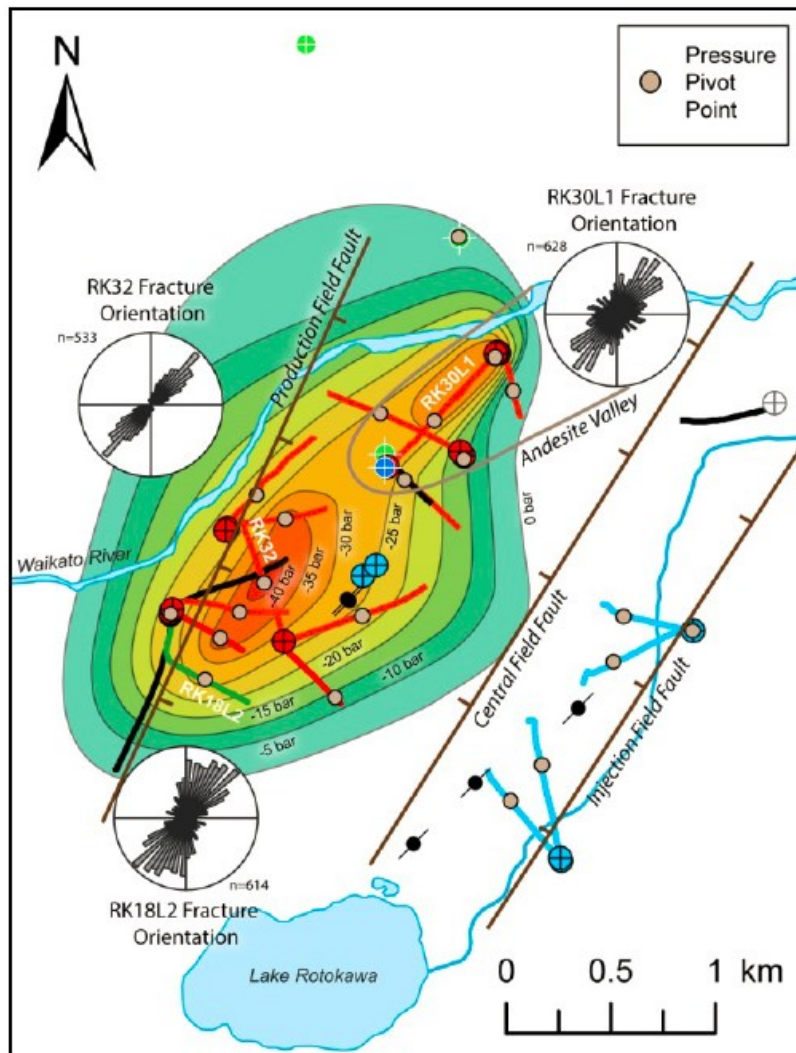


Figure 3: Reservoir pressure in 2015 (contoured colors) overlain by the main geologic structures identified within the field at their projected surface locations. Also shown are the orientation of fractures imaged by well logs in RK18L2, RK32 and RK30L1, of which show a dominant NE-SW fracturing trend.

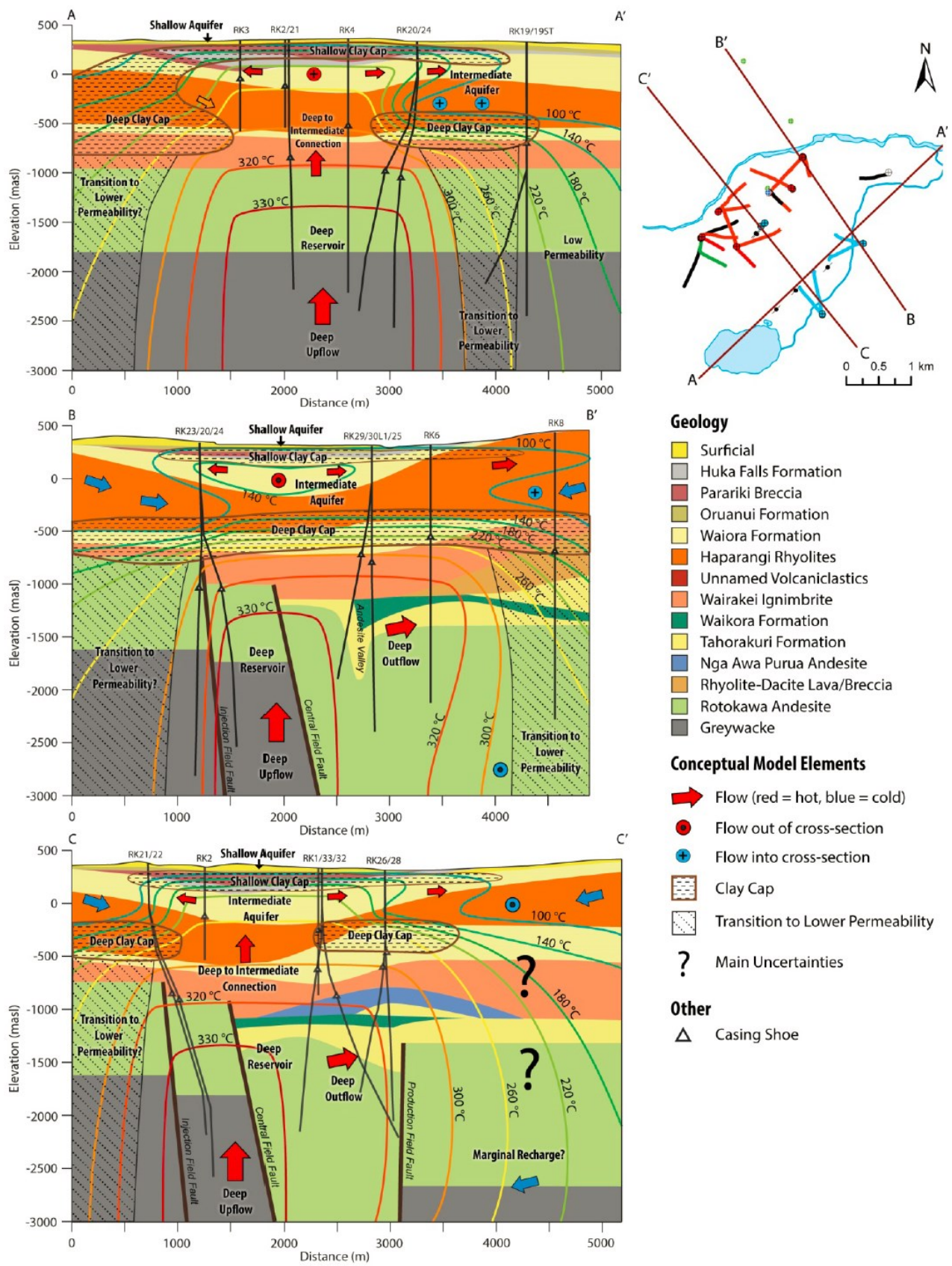


Figure 4: Conceptual model cross-sections showing the main elements of the conceptual model and the geology. The inset shows the location of the cross-sections.

2. PREVIOUS RESERVOIR TRACER TESTS

Five previous tracer tests have been undertaken on the Rotokawa field and these are summarized in Addison *et al.* (2015b) and these are summarized in Table 1. These test have used either a range of naphthalene sulfonates (2006, 2009, 2011), I^{125} (1998) or a combination of naphthalene sulfonate and I^{125} (2013). The 2011 test highlighted issues with the thermal stability of the naphthalene sulfonates in the Rotokawa reservoir, in light of autoclave experiments by Mountain & Winick (2012) and now with further studies looking into other factors controlling the stability of naphthalene sulfonates such as pH, salinity etc. (Sajkowski *et al.*, 2017). In 2013 a coupled tracer test using 2-naphthalene sulfonate and I^{125} was conducted in the Rotokawa reservoir, with this test showing significant differences in the tracer return profile between the 2-naphthalene sulfonate and the I^{125} due to the breakdown in the reservoir of the injected 2-naphthalene sulfonate.

Table 1: Summary of previous tracer tests on the Rotokawa field

Year	Wells tested	Tracer injected
1998	Combined injection line (RK1, RK11, RK12)	I^{125}
2006	RK16, RK18L1	1,5-, 1,6-, 2,6-, 2,7-NDSA
2009	RK20	1,5-NDSA
2011	RK20, RK23, RK24, RK11	1,5-, 1,6-, 2,6-, 2,7-NDSA
2013	RK24	2-NSA, I^{125}

Based on the 2011 naphthalene sulfonate tracer test results, shown in Figure 5, it was expected that the test would be completed within one year as suggested by the recovered profiles of 2-naphthalene sulfonate. 18.5 GBq of I^{125} was procured, which by the time this was imported and then injected equated to 16.1 GBq into the reservoir. At 12 months post injection, whilst returns were generally still increasing, the error margin had increased significantly and it was decided to end the test. These results are shown later in Figure 7 in comparison with the 2015 tracer test results. Based on the return profiles observed in the 2013 test it was decided that for future I^{125} reservoir tracer tests at Rotokawa need to be greater than 12 months, in order to understand the peak concentration and shape of any tracer return profile tail.

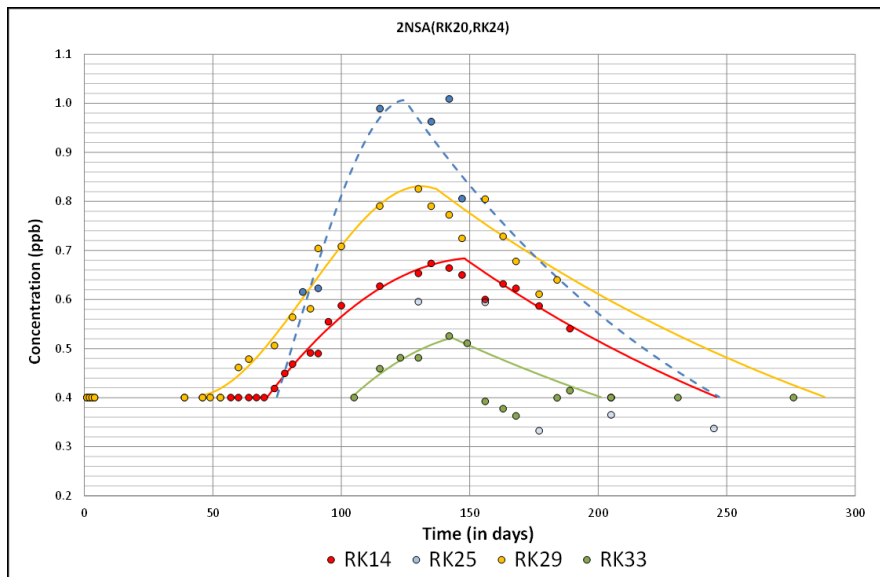


Figure 5: 2-Naphthalene Sulfonate (breakdown product of tracer injected) return profile from 2011 reservoir tracer test

3. 2015 RESERVOIR TRACER TEST

3.1 Field Configuration

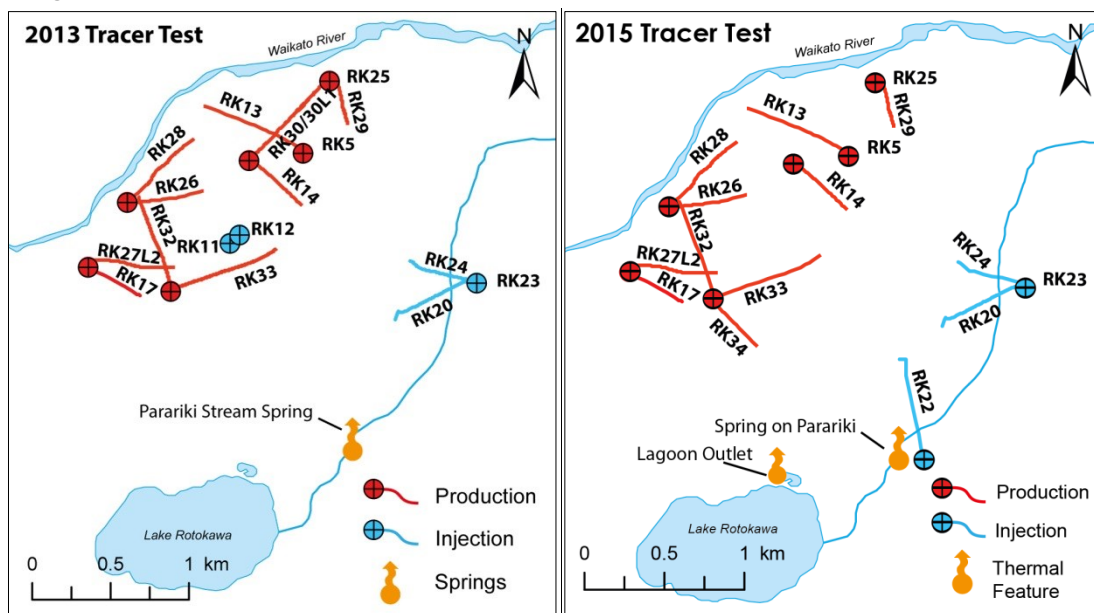


Figure 6: Field configuration for the 2013 and 2015 reservoir tracer tests. Not all wells drilled in the field at the time are shown, only those active during the reservoir tracer test.

Production well operation was relatively consistent between the 2013 and 2015 tracer tests, as shown in Figure 6. One new production well was drilled between 2013 and 2015, this being RK34. Due to a casing integrity issue RK30 was shut in throughout the 2015 tracer test and was abandoned, with this well having previously had a small connection in the 2013 tracer test with RK24. RK28 in both tests was generally not operated unless the well was required to cover for outages of other wells, therefore it was not able to be sampled for the 2015 tracer test.

The most significant change between the tests was a change in the injection setup in the field. The field has three different injectate chemistries (Addison *et al.*, 2015a) and these therefore are injected separately from one another. Rotokawa injectate continued to be injected into RK20. Nga Awa Purua brine was previously injected into RK24 and RK23. This was changed to RK24 and RK22 so that Nga Awa Purua condensate could be injected deep into RK23. These changes were made three months before the planned reservoir tracer test, providing enough time for fluid pathways to be established within the reservoir.

Nga Awa Purua brine was injected into RK24 and RK22 at ~600 t/hr and ~500 t/hr respectively. Condensate from Nga Awa Purua was injected exclusively into RK23 at ~280 t/hr. RK20 continued to accept the all the fluid from the Rotokawa power plant.

3.2 Test Details

A number of alternative tracers to I^{125} were considered. However, none were deemed suitable, due to their possible reactivity within the reservoir or, to their unsuitable half-life duration i.e. by being either too long (e.g. tritium), or too short (e.g. iodine-131). If the tracer half-life is too long it will result in residual tracer within the reservoir which will reduce the ability to conduct additional tests, whereas if a tracer half-life is too short it will result in the inability to conduct a meaningful test. With a half-life of just under 60 days, I^{125} was determined to be the most appropriate. Increasing the quantity injected to 200 GBq would extend the test by just over 3 half-lives, or about 7 months extra in duration. Increasing both the sample size and the count time in the scintillometer, would provide a greater resolution towards the end of the test. Both of these were planned for in the second year of the tracer test, to reduce errors, rather than in the first year where errors were reduced solely from the injection of a larger quantity of I^{125} . This balanced the additional costs of larger samples and count times with the necessary resolution. By increasing the sample size and the counting time this is expected to further increase the possible test duration by a few months.

Due to the increase in the quantity of I^{125} injected, a consideration is the maximum quantity that suppliers will produce per vial with this generally between 30 – 120 GBq. This means that for the injection of 200 GBq more than one vial was to be utilized. In addition to the quantity of I^{125} per vial, there are relatively limited numbers of suppliers around the world, and chemical production windows need to be factored into project planning. The order was booked significantly ahead of time with confirmation made around 6 weeks before the planned injection date, with two vials of 100 GBq ordered. These had a volume of 2.5-3 mL each.

Previously in 2013 the injection method that was utilized made use of an evacuated stainless steel vessel which was surrounded by protective lead, where through a small needle-like piece of apparatus the I^{125} was sucked into the vessel through the septum of the vial before then being chased by pumped water through to the injection line. This method relied upon a reliable vacuum within the shielded

vessel. Through project planning it was considered that this method would not be appropriate for more than one vial of I^{125} and that we should consider alternatives to see if a safer and more reliable method could be established. This is discussed further in the next section.

Consideration was made as to how best to run the tracer test. Mercury makes use of the Project Management Institute project methodology and this was utilized for this project. It was concluded early on that a commercial partnership approach was the best way to develop a new injection methodology. GNS Science owned all the intellectual property and were willing to invest in developing the methodology. This would mean the method and equipment developed could be used for other clients than just Mercury, therefore providing the service to the whole geothermal industry. GNS Science would also train and accredit their staff to allow for importation and handling of unsealed sources of radiation. The 2013 tracer test was conducted on a time and materials basis which enabled a more accurate determination of costs for various aspects of these tracer tests and one key procurement agreement was that Mercury and GNS Science would work towards set prices for the injection, analysis and processing of results. This pricing methodology has significantly reduced the administration to both parties for the 2015 tracer test to around 10% of the administration levels of the 2013 tracer test.

3.3 Tracer Injection

A number of different injection methods were screened. These included injection with above-ground systems or through the use of downhole tools. Relatively early on it was concluded that the best method would be through the use of an above-ground system, as running a tool introduced significant complexity and cost, in addition to potential risk of close proximity of staff loading the tool and uncertainty if the tool injected the iodine successfully. Vial designs are generally glass surrounded by a polycarbonate outer surface, which are shipped within lead shielding inside a sealed can. Early-stage testing of whether or not crushing the vials quickly concluded that this method was not the preferred pathway as crushing resulted in significant force needing to be applied and the vial breakage was highly variable in terms of sizes of pieces. Therefore there were concerns about whether or not all iodine would be flushed and the risk of blockage from the polycarbonate pieces. Focus therefore was applied to non-crush options. ...

The New Zealand Office of Radiation Safety (“ORS”) sits within the Ministry of Health. The ORS is responsible for approving licenses for the importation and use of radioactive substances. For this test it was necessary for us to have someone qualified in the use of radioactive unsealed sources. The license holder wrote the radiation safety assessment which provided details of how the test would be conducted, calculations on the levels of radioactivity to the injection staff and general public, whilst detailing how to minimise any potential exposure, and, details on contingency plans.

To inject 200 GBq of I^{125} required the use of at least two vials, therefore duplicate injectors were manufactured and the set-up was to be able to inject these almost simultaneously. The design was put through a hazard and operability (“HAZOP”) study which included both Mercury technical and site staff, in addition to GNS Science staff. This HAZOP study identified some minor design changes and some operational procedure notes to be included in the method. Once the injection equipment was manufactured significant testing at GNS Science Wairakei was conducted, using other non-radioactive tracers to establish flush times and effectiveness. All tracer analyses were undertaken at the the GNS Wairakei laboratory (NZ Geothermal Analytical Laboratory). Once the testing at GNS Wairakei was completed the equipment was also tested on the operational well using colored low temperature dyes, working under the Mercury work controls system.

Supply chain management is a very important consideration for these tracer tests due to the natural half-life decay of the product, whereby with every day tracer activity decreases rapidly. Therefore “just in time” delivery principles needed to be worked towards, with sufficient contingency to allow for any delays in production, transportation or import. GNS Science at its Wairakei facility has a compliant radiation storage shed and therefore it was planned to have the I^{125} come into New Zealand and be transported and stored at this facility for up to about one week before injection.

Injection was planned to occur over the weekend to reduce potential concerns by workers who may have been undertaking other works on the site. On injection day, the I^{125} was brought onto site in an appropriately labeled vehicle via a pre-agreed travel route, with remote sign-in to site provided. To prevent public access to the site multi-stages of warning signage was established, the outer signage noted dangerous testing being conducted (with contact details of the control room) and it was deliberate not to have radiation signage on this outer sign to prevent public concern. The inner signage, upon entry to the wellpad, had official radiation hazard signage with the contact details of the radiation license holder as was this was a requirement in accordance with NZ law. The radiation license holder had to be present on site and directly supervise activities.

Various call points were made in the process and the injection was monitored from the control room through the use of a closed-circuit camera system. Following successful injection all injection equipment was removed from site back to GNS Science Wairakei and the staff involved were remotely signed-out from site.

3.4 Sampling and Analysis

Prior to injection background samples were collected from all locations to be sampled during the reservoir tracer test. Sampling was commenced from all Rotokawa production wells, subject to their operational availability. Sampling events followed an expanded tracer sampling schedule, whereby higher frequency sampling was conducted immediately following tracer injection to ensure the capture of more rapid returns. Based on previous tracer tests on the field, a frequency of weekly initially was deemed appropriate for this purpose due to significant confidence that there were no returns within days. Sampling frequency reducing to every two weeks after approximately three months and then to every three weeks after approximately nine months.

Sampling of production wells involved condensing two-phase production fluids through simple cooling coils attached to the production well branch lines. The sampling ports on these branch lines are located at 135° from vertical and are 1" in diameter. The sampling line is purged sufficiently to ensure fresh sample. The sample was collected into a bulk container then split to an I¹²⁵ sample and an aliquot for sodium analysis, which can later be used for correction purposes such as adjusting for variable steam portion due to two-phase sampling. In the 2013 tracer test, the sample was also analysed in the field for pH and conductivity, but this requirement was removed for the 2015 test as this increased sampling time without any significant benefit.

Sampling and flow measurements of selected discharging surface features, the Lagoon Outlet and the Parariki Stream Spring, was conducted monthly for one year post injection.

For the first year 2L samples were collected, with these then increasing to 4L in the second year. For planning purposes all samples should be planned to be processed and analyzed as soon as practicable. After one year the analysis count time was increased from 200 minutes to 400 minutes, with the ability to increase the count time further subject to instrument availability.

In order to determine the background I¹²⁵ counts, samples were collected from the relevant production wells and natural features five days before the tracer injection. These were processed using the standard methods (McCabe *et al.*, 1998) to extract the background iodine concentration. Samples taken after tracer injection are spiked with 5 – 10 mg of non-radioactive iodine to confirm efficient recovery. Final results are expressed as the concentration of radioactive iodine, corrected for radioactive decay, in 1 kg of fluid normalized to the original injected activity (200 GBq). This is multiplied by 10¹² to obtain values in the 0 – 100 range (Figure 7).

3.5 Results

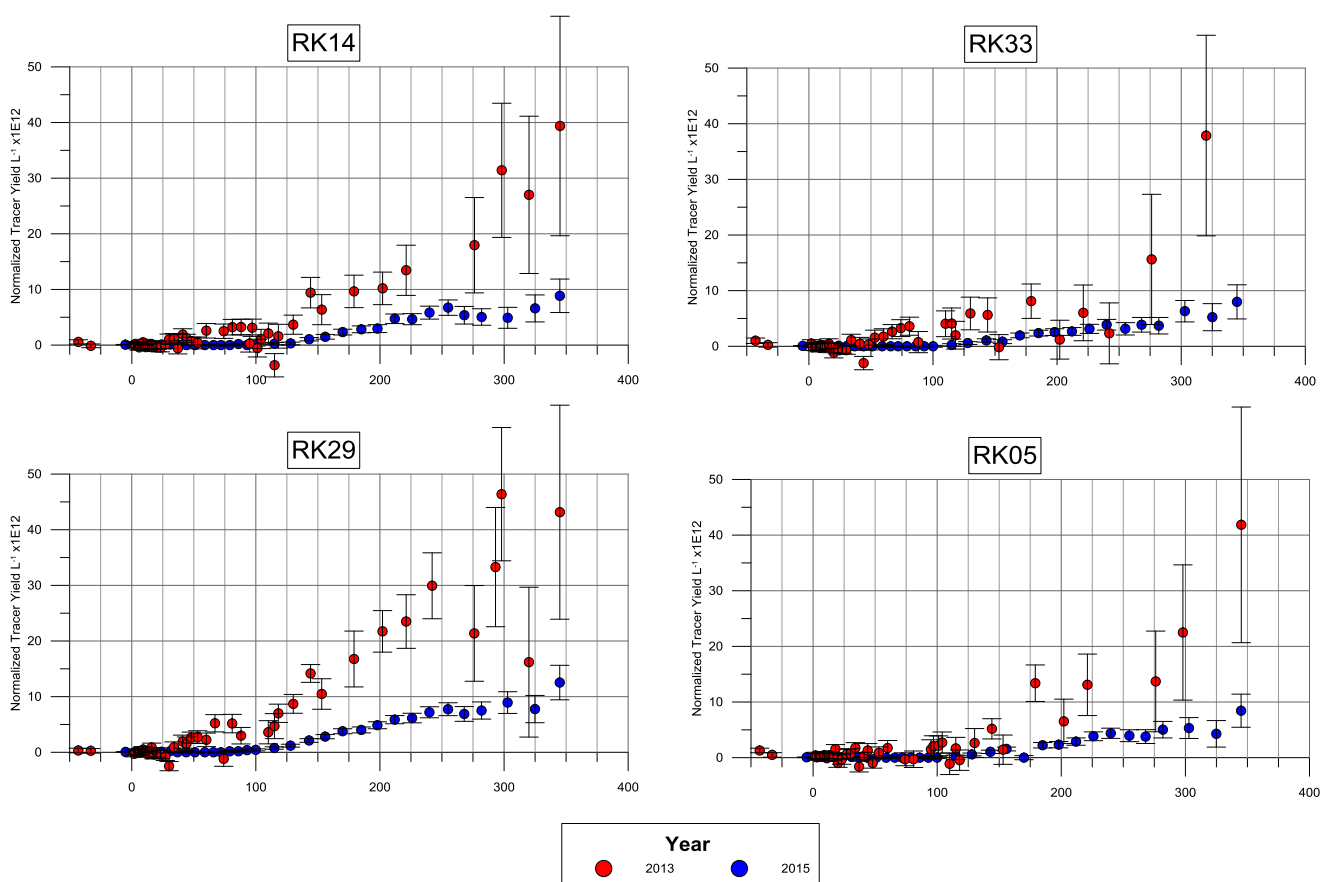


Figure 7: Raw uncorrected tracer return profiles for wells RK14, RK33, RK29 and RK5 for reservoir tracer tests in 2013 (from RK24) and in 2015 (from RK22) with calculated error bars shown

Within one year only four wells have observed confirmed returns, these being wells RK29, RK5, RK14 and RK33, with no apparent returns detected for the thermal features monitored. A direct comparison of normalized tracer concentrations between the 2013 RK24 tracer test and the 2015 RK22 tracer test is shown in Figure 7. These results shown do not account for station shuts, which as Nga Awa Purua equates to around 80% of field flow is significant enough to need to be corrected for final tracer return curves. Note that as the injection flow rate of RK22 during the tracer test was approximately half than that of RK24 (during the 2013 test), it is expected to have lower normalized tracer concentrations for a similar level of connection with production wells.

Upon completion of the tracer test sampling and analysis program full return calculations will be made and therefore will not be discussed within this paper. In addition it will be interesting in time to conduct a more detailed review of microseismic activity in the field since the introduction of RK22 to see if any correlations can be made with the reservoir tracer test results.

4. UNDERSTANDING RESULTS FROM 2015 TRACER TEST

The 2013 and 2015 tracer tests have played an important role in improving and confirming the understanding the flow paths and permeability structure within the Rotokawa reservoir. The data obtained by the tracer tests have driven updates to the conceptual model, updates to the numerical model and subsequent changes to the field management strategy. From a reservoir management perspective the key insights gained by the tracer tests were that:

- 1) It supports the conceptual model of cooling in the Western Compartment which is mainly due to marginal recharge and not injection returns.
- 2) Injection returns contribute to the low pressure drawdown in the central wells (especially in RK29) compared to the rest of the field.

In recent years wells in the Western Compartment at Rotokawa have shown signs of enthalpy reduction and cooling (Hernandez *et al.*, 2015). The cause of this cooling was not clear and injection returns were a potential cause of the declining enthalpy. The tracer test data showed no returns to the Western Compartment, ruling out injection returns as a possible source of cooling. This understanding strongly indicated marginal recharge as the mechanism underlying the enthalpy decline and drove the decision to reduce take from the Western Compartment as described in Clearwater *et al.* (2016) through the use of process modeling and a subsequent update to the full field numerical model.

In the years following the startup of the Nga Awa Purua plant an interesting feature of the reservoir was the very low pressure drawdown in the central wells RK5, RK14, RK29 and RK33. RK29 is the Rotokawa larger producer with over 700 t/hr at an enthalpy of around 1500 kJ/kg. The drawdown in response to field development at RK29 has been less than 5 bar. A neighboring well RK25 produces only around 100 t/hr yet the pressure drawdown measured at RK25 is over 35 bar. The difference in magnitude of pressure drawdown at these neighboring wells was puzzling until the tracer data confirmed that some reinjection fluid travels across the Central Field Fault to provide pressure support to RK29. Despite providing some pressure support, the low total returns of tracer from injection is not enough to explain the significant pressure support in RK29. This indicates the potential of a larger permeable area, east of RK29 than initially thought in the conceptual model. Alternatively it may be that the tracer return tails are significantly larger and therefore have larger returns than conservatively calculated from the 2013 tracer test, with various scenarios calculated in Addison *et al.* (2015a) using chloride mass balances.

Previously the Central Field Fault was considered a feature with very low across-strike permeability, which the 2015 reservoir tracer test confirmed; however, the data from the tracer tests confirmed a connection across the Central Field Fault in the vicinity of RK29. The conceptual model of the reservoir has been updated to reflect this understanding and the TOUGH2 numerical model used in field management has also been updated and able to better match the pressure changes in the injection area around RK24 and in the production area around RK29. Improvements in the pressure match give more reliable forecasts of future reservoir behavior. The update of the match by the numerical model for wells RK29 and RK24 is shown in Figure 8A and Figure 8B. This significant improvement of the pressure match was achieved without affecting the temperature and pressure match to the natural state condition.

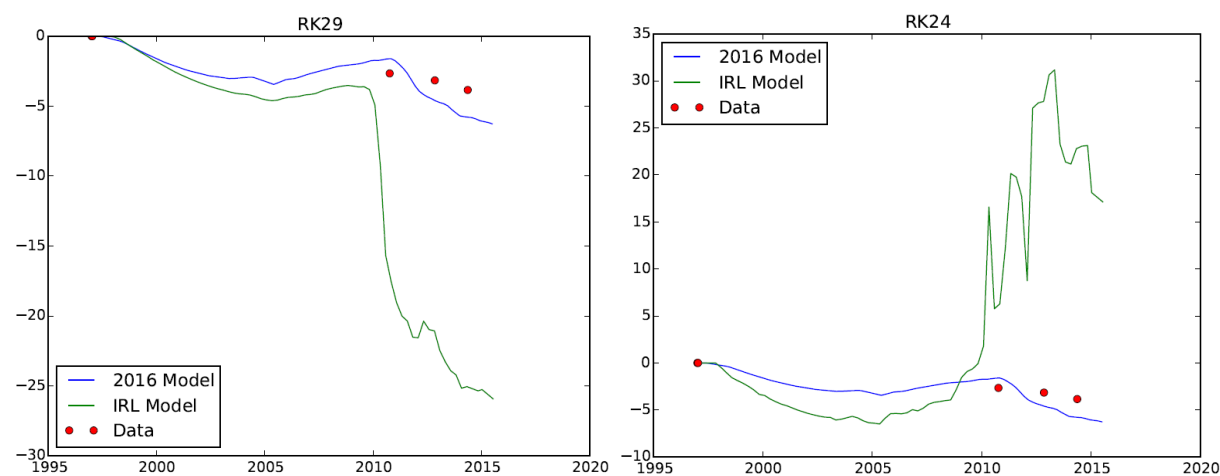


Figure 8A and 8B: Modeling matches of RK29 and RK24 respectively before (IRL Model) and after (2016 Model) modifications to the central field fault connection in the vicinity of RK29. Pressures indicated are shown in bar relative to natural state pressures.

After the start of the injection in RK22, the reservoir pressure was measured in the production area but there was not any significant variance that could indicate fast return into the production wells. In the injection area, the pressure in RK22 built up but soon after this

stabilized. Whilst the full return calculations have not been reported here, the relatively low percentage recovered in the production wells reinforces the idea initiated by Quinao & Azwar (2012) of a potential sink or outflow south west of RK22.

The results obtained in the most recent tracer test have also had a major impact in the operation and development strategy of the Rotokawa field and as further results progress over the next year this information will further provide greater information around tracer returns. The risk of cooling from a potential future injection in RK21 is now slightly lower, and therefore it opens the possibility to a future expansion of injection in RK21 with lower risk. Whilst RK22 does not show evidence from this tracer test of direct pressure support to the western compartment, it is possible that RK21 could provide this once this well is repaired and begins operation again, however to prove this a further tracer tests will be required.

The confidence in the most recent tracer test results from 2013 and 2015, combined with the pressure and temperature monitoring, have been fundamental in the selection of the location of future production areas. For example, the low total recovery, the time of arrival and the lack of cooling between RK33 and RK5 minimizes significantly the risk of future drilling in this area.

CONCLUSION

The results of the tracer test are consistent with the hydrodynamic observations of the 2013 reservoir tracer test that was conducted into RK24. Wells that have observed confirmed returns are RK29, RK14, RK5 and RK33, which are all wells that see also geochemical trends associated with injection returns. The use of 200 GBq of I^{125} in 2015 for RK22 (compared to 16.1 GBq in 2013 for RK24) has been beneficial for reducing errors and uncertainty in the results and this increase in the tracer quantity along with increasing sample sizes and count times have been fruitful for providing a greater test duration. The injection of over ten-times more I^{125} was able to be conducted safely with newly designed equipment from GNS Science in New Zealand.

The results from the tracer test have assisted with improving the conceptual model understanding of the field. In particular the lack of any observed connection to the Western Compartment (mainly production wells RK17, RK27L2) within one year of tracer results is consistent with expected permeability barriers between RK22 and that part of the reservoir. In addition, with injection support from RK22 to the same area as the RK24 tracer test, this assists in partially explaining the generally low pressure drawdown observed in RK29 compared to other parts of the Rotokawa reservoir.

The increased conceptual understanding from both the 2013 and 2015 reservoir tracer tests have assisted in providing updates to the numerical model for the field that result in better matches of pressure in both the production and injection areas.

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Addison et al.

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