Industrial Research Limited Report

Rotorua Geothermal Reservoir Modelling Part 2: Scenario Modelling

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1. Executive Summary

The Rotorua Geothermal Reservoir Model was used to assess the impact of 19 scenarios on surface activity. The scenarios were designed to test:

- Whether increases in production can occur whilst protecting field surface features;
- If there is an ability for a limited increase in fluid abstraction in the 1.5 km mass abstraction exclusion zone whilst maintaining the protection of surface features;
- If there is an ability for increases in heat exchanger use within the 1.5 km zone whilst protecting surface features.

The scenarios were prepared by Environment Bay of Plenty Staff and were implemented in the 2004 version of the Rotorua Geothermal Reservoir Model. All new production added to the model was accompanied by reinjection. The scenarios were run for 30 years from 2005 and the results showed that:

- Increased production in the Central Business District and along Fenton St adversely impacted the outflow at Kuirau Park.
- New production and reinjection within 1 km of Pohutu Geyser showed an adverse impact on the amount of steam under Whakarewarewa.
- New production and reinjection of about 500 tonnes/day can be added to a zone between 1 km and 1.5 km from Pohutu Geyser with an impact on surface outflow of less than 1% of the recovery between 1986 and 1990.
- Increased use of downhole heat exchangers by up to 1,280 kW within the 1.5 km zone has a negligible impact on surface features.

2. Introduction

This report is the second of two reports that describe the results of recent computational modelling of the Rotorua Geothermal System. This work was commissioned by Environment Bay of Plenty to support their review of the Regional Management Plan. The first report describes the computational model of the Rotorua Geothermal System. This report considers the effects of 19 scenarios for possible future production from the Rotorua Geothermal System.

The 19 scenarios, prepared by Environment Bay of Plenty Staff, are:

1 An increase in taking fluid evenly across the field of; 5%, 10% and 20% of the current total abstraction with the 1.5 km exclusion zone in place and there is full reinjection of the increase.
2 An increase in taking fluid of 5%, 10% and 20% of the current total abstraction with the increased abstraction located evenly in the CBD and Fenton Street. The 1.5 km exclusion zone is in place and there is full reinjection of the increased take.
3 Increase total extraction until the model indicates a decline in temperature in the thermal outflow areas. The 1.5 km exclusion zone is in place and full reinjection of the increased take.
4 An increase in taking fluid of 5%, 10% and 20% within the 1.5 km exclusion zone and this zone reduced to 1.0 km, 0.5 km and 0 km. The increase in abstraction shall be located evenly along Fenton Street and Sophia Street. There shall be full reinjection of the increased take. This is designed to evaluate the effect of reducing the 1.5 km zone and the effect of new uses moving into the newly available areas.
5 Increase rate of heat extraction by downhole heat exchangers within the 1.5 km zone by 50%, 100% and 200%. Designed to evaluate large-scale increase in downhole heat exchangers within the 1.5 km zone.

3. The Scenarios

The scenarios were constructed by adding new production and reinjection to the computational model of the Rotorua Geothermal System described in the report by **Burnell and Kissling** (2005). This model provides a good match to the changes seen in the geothermal system since the Bore Closure Programme of 1986-7. Details of the model and the match to the data are given in that report.

3.1 Scenario Details

The scenarios considered here were developed by EBOP staff to test whether changes can be made to the Rotorua Geothermal Plan whilst protecting the field's surface features. The 19 scenarios can be broken into 5 groups.

Scenario	Description
Scenario 1 Group	Increase existing production evenly across the field.
Scenario 2 Group	Increase production in the CBD and along Fenton St.
Scenario 3 Group	Increase existing production evenly across the field.

Scenario 4 Group	Adds new production within the 1.5 km Exclusion Zone
Scenario 5 Group	Increase the use of downhole heat exchangers within the 1.5 km Exclusion Zone

Within each group there are a number of sub-scenarios which increase the total amount of production by 5%, 10% and 20%. The details of all 19 scenarios are:

Scenario 1a Increase existing production evenly across the field by 5%. This is an increase of 500 tonnes/day. The 1.5 km exclusion zone remains in place and there is full reinjection of the increased production.

Scenario 1b Increase existing production evenly across the field by 10%. This is an increase of 1000 tonnes/day. The 1.5 km exclusion zone remains in place and there is full reinjection of the increased production.

Scenario 1c Increase existing production evenly across the field by 20%. This is an increase of 2000 tonnes/day. The 1.5 km exclusion zone remains in place and there is full reinjection of the increased production.

Scenario 2a Add new production evenly in the CBD and Fenton Street of 5% of the current total. This is an increase of 500 tonnes/day. The 1.5 km exclusion zone remains in place and there is full reinjection of the increased production.

Scenario 2b Add new production evenly in the CBD and Fenton Street of 10% of the current total. This is an increase of 1000 tonnes/day. The 1.5 km exclusion zone remains in place and there is full reinjection of the increased production.

Scenario 2c Add new production evenly in the CBD and Fenton Street of 20% of the current total. This is an increase of 2000 tonnes/day. The 1.5 km exclusion zone remains in place and there is full reinjection of the increased production.

Scenario 3 Increase total extraction until the model indicates a decline in temperature in the thermal outflow areas. The 1.5 km exclusion zone remains in place and there is full reinjection of the increased production.

Scenario 4a Add new production within the 1.5 km exclusion zone of 5% of the current total. This is an increase of 500 tonnes/day. The increased production shall be located evenly along Fenton Street and Sophia Street between zones of 1 and 1.5 km centred at Pohutu Geyser. There is full reinjection of the increased production.

Scenario 4b Add new production within the 1.5 km exclusion zone of 5% of the current total. This is an increase of 500 tonnes/day. The increased production shall be located evenly along Fenton Street and Sophia Street between zones of 500 m and 1.5 km centred at Pohutu Geyser. There is full reinjection of the increased production.

Scenario 4c Add new production within the 1.5 km exclusion zone of 5% of the current total. This is an increase of 500 tonnes/day. The increased production shall be located throughout the 1.5 km exclusion zone. There is full reinjection of the increased production.

Scenario 4d Add new production within the 1.5 km exclusion zone of 10% of the current total. This is an increase of 1000 tonnes/day. The increased production shall be located evenly along Fenton Street and Sophia Street between zones of 1 and 1.5 km centred at Pohutu Geyser. There is full reinjection of the increased production.

Scenario 4e Add new production within the 1.5 km exclusion zone of 10% of the current total. This is an increase of 1000 tonnes/day. The increased production shall be located evenly along Fenton Street and Sophia Street between zones of 500 m and 1.5 km centred at Pohutu Geyser. There is full reinjection of the increased production.

Scenario 4f Add new production within the 1.5 km exclusion zone of 10% of the current total. This is an increase of 1000 tonnes/day. The increased production shall be located throughout the 1.5 km exclusion zone. There is full reinjection of the increased production.

Scenario 4g Add new production within the 1.5 km exclusion zone of 20% of the current total. This is an increase of 2000 tonnes/day. The increased production shall be located evenly along Fenton Street and Sophia Street between zones of 1 and 1.5 km centred at Pohutu Geyser. There is full reinjection of the increased production.

Scenario 4h Add new production within the 1.5 km exclusion zone of 20% of the current total. This is an increase of 2000 tonnes/day. The increased production shall be located evenly along Fenton Street and Sophia Street between zones of 500 m and 1.5 km centred at Pohutu Geyser. There is full reinjection of the increased production.

Scenario 4i Add new production within the 1.5 km exclusion zone of 20% of the current total. This is an increase of 2000 tonnes/day. The increased production shall be located throughout the 1.5 km exclusion zone. There is full reinjection of the increased production.

Scenario 5a Increase the rate of heat extraction by downhole heat exchangers within the 1.5 km zone by 50%.

Scenario 5b Increase the rate of heat extraction by downhole heat exchangers within the 1.5 km zone by 100%.

Scenario 5c Increase the rate of heat extraction by downhole heat exchangers within the 1.5 km zone by 200%.

3.2 Implementation in the Model

The grid used for the computational model is shown in Figure 1, and the scenarios were constructed by adding new production and reinjection wells onto that grid in appropriate locations. The locations of these new production and reinjection wells are shown in Figure 2 to Figure 7.

In Scenarios 1-4 reinjection wells were located in neighbouring grid blocks to the production wells. This was done to represent the situation where a number of properties share a production well, and the reinjection well is located in a different property.

The purpose of this work is to assess the impact on the surface features. To do this the mass outflows predicted by the model were compared with a base case with no increase in production. In the model, the mass flowrate depends on the pressure and the fraction of water present in the fluid. However, since colder fluid is being reinjected into the system, thermal effects could also impact on the surface features. For example, some of the scenarios showed that cooling at Whakarewarewa had the effect of quenching the steam underlying Whakarewarewa. So in addition to mass flowrates and pressures, temperatures and the mass of steam were also monitored.

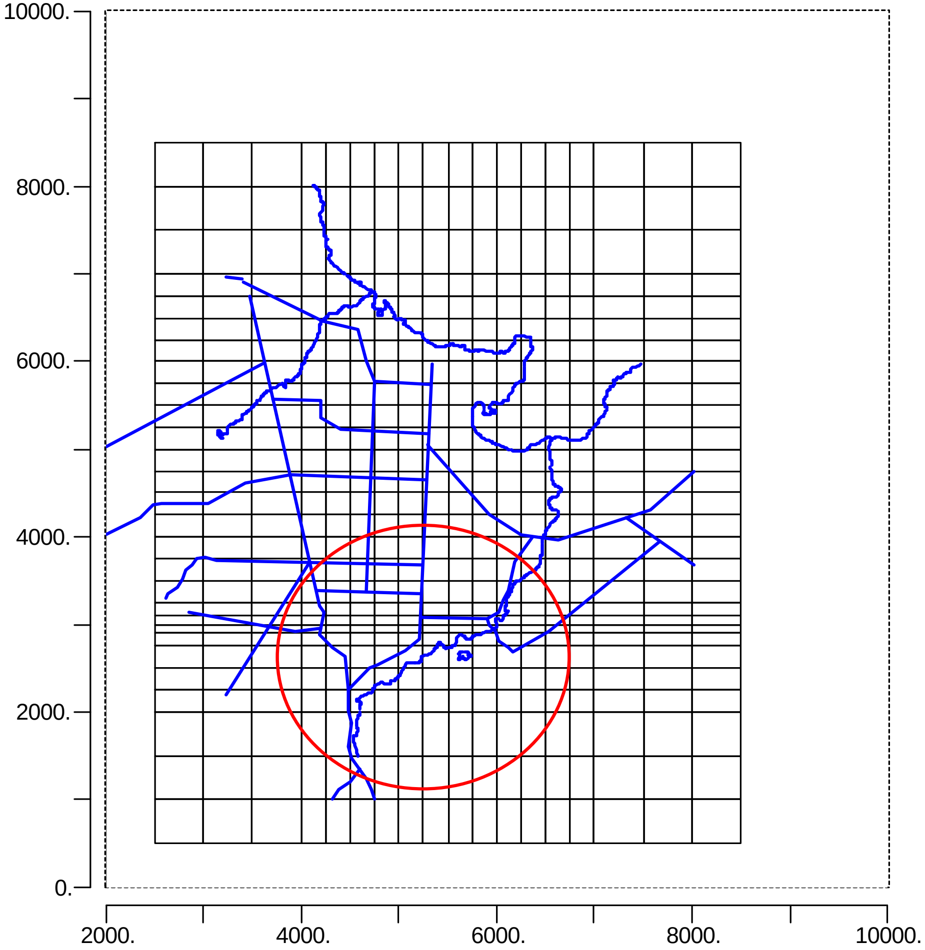

Figure 1: Grid used for the computational model. The coordinates refer to map coordinates with (2,000, 0) on the diagram corresponding to (2790,000N, 6332,000E) in map coordinates. The blue lines are local roads, streams and the lakefront, and the red line approximately shows the 1.5km exclusion zone.

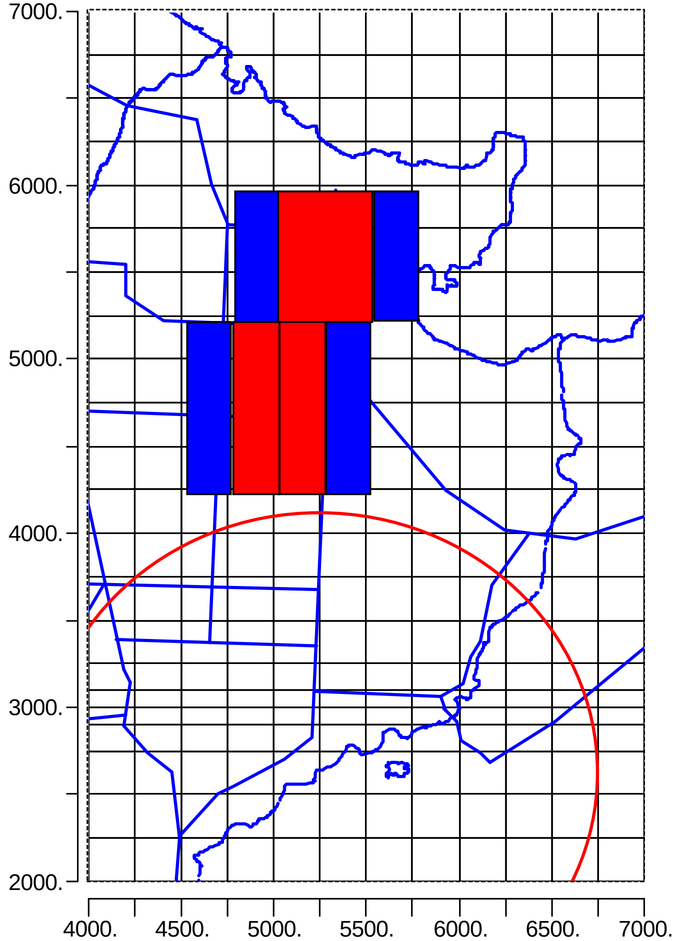

Figure 2: Locations of new wells used for Scenarios 1a, 1b, 1c and 3. Production wells are shown in red and reinjection wells are shown in blue.

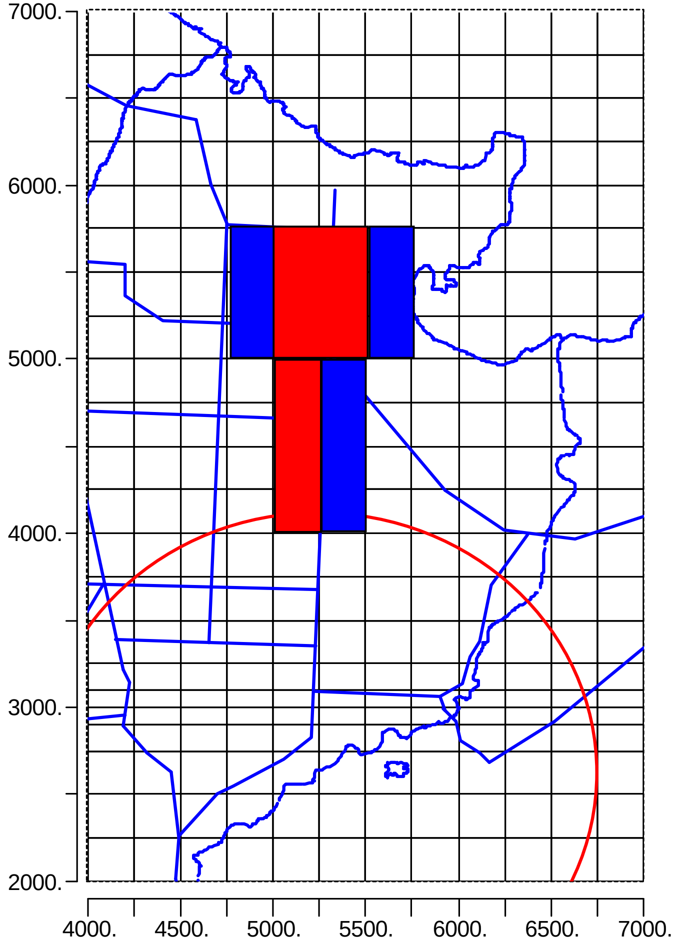

Figure 3: Locations of new wells used for Scenarios 2a, 2b and 2c. Production wells are shown in red and reinjection wells are shown in blue.

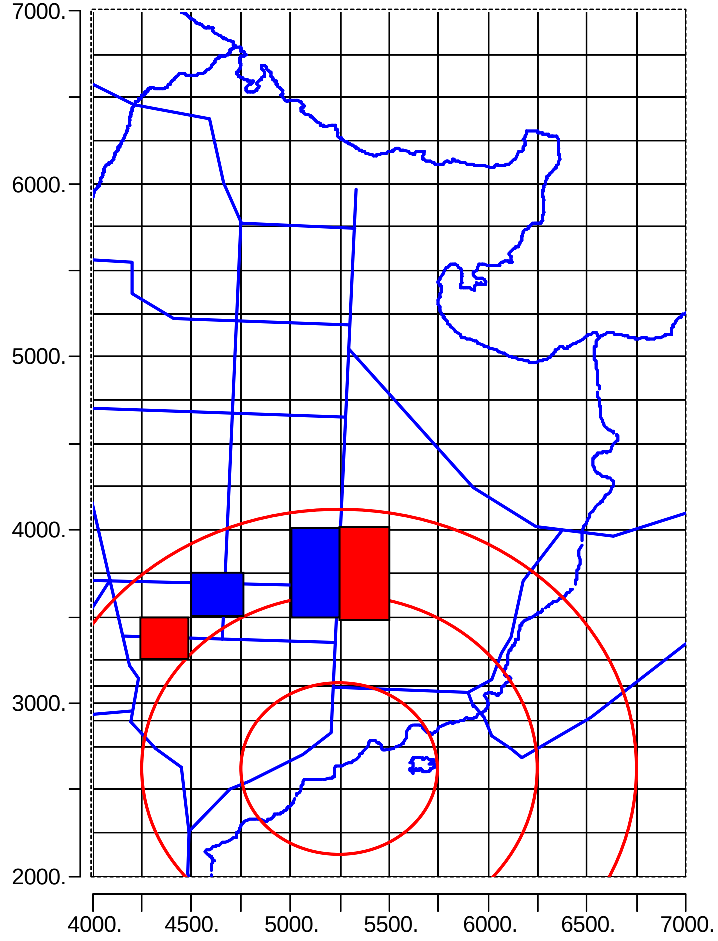

Figure 4: Locations of new wells used for Scenarios 4a, 4d and 4g. Production wells are shown in red and reinjection wells are shown in blue.

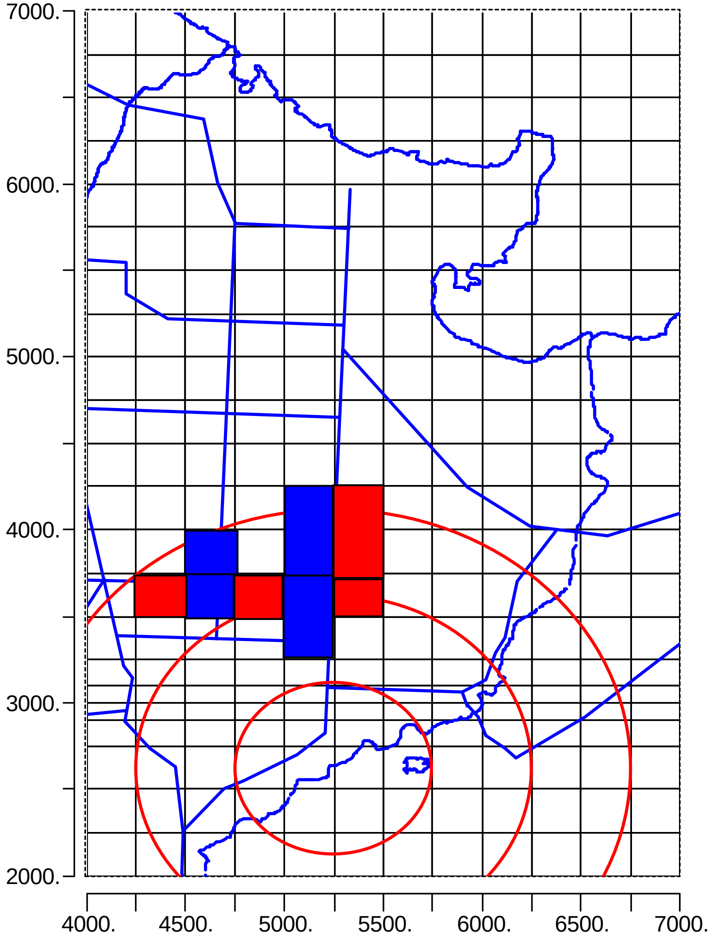

Figure 5: Locations of new wells used for Scenarios 4b, 4e and 4h. Production wells are shown in red and reinjection wells are shown in blue

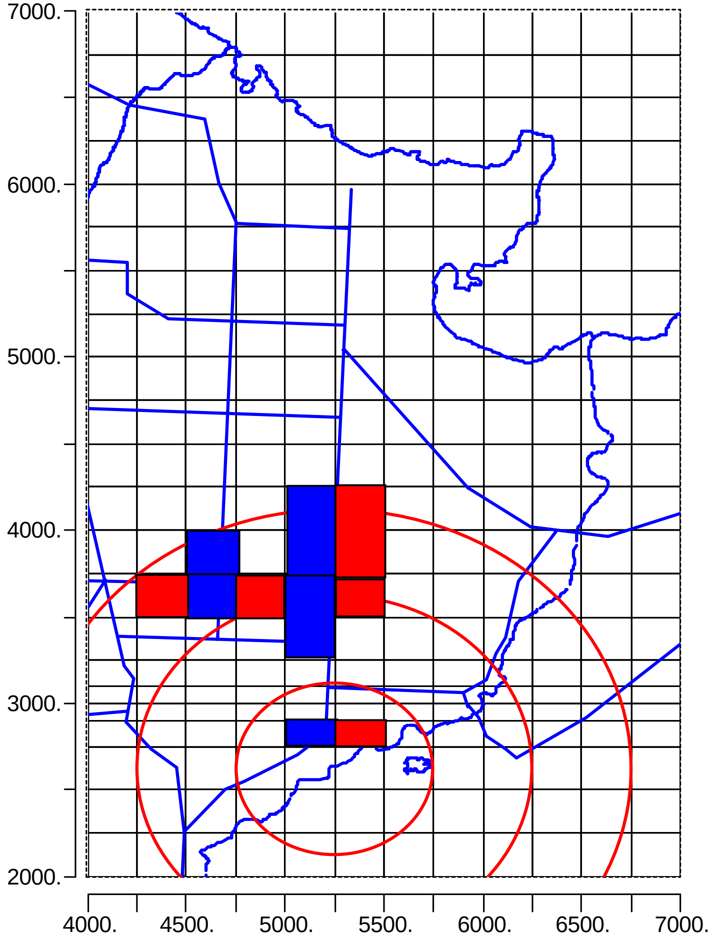

Figure 6: Locations of new wells used for Scenarios 4c, 4f and 4i. Production wells are shown in red and reinjection wells are shown in blue

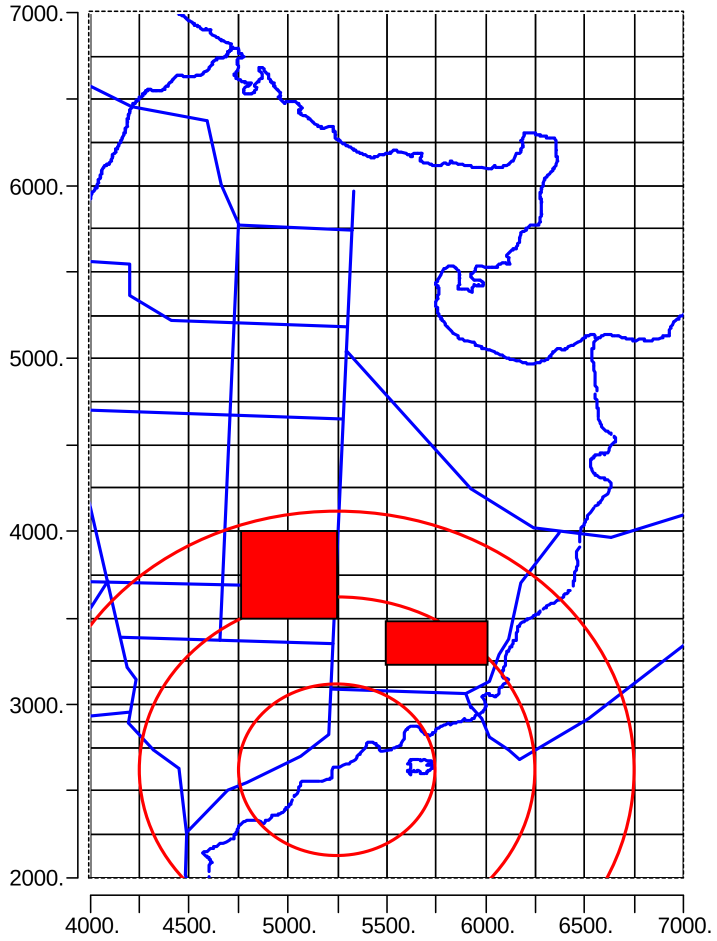

Figure 7: Locations of downhole exchangers used for Scenarios 5a, 5b and 5c

The new production in the scenarios was allocated according to the scenario details, which are summarised in Table 1. The scenarios were run for 30 years, beginning in 2005.

Table 1: Scenario summaries

Scenario	Extra Production	Location	1.5 km Zone Intact
1a	500 tonnes/day	Existing locations	Yes
1b	1000 tonnes/day	Existing locations	Yes
1c	2000 tonnes/day	Existing locations	Yes
2a	500 tonnes/day	CBD and Fenton St	Yes
2b	1000 tonnes/day	CBD and Fenton St	Yes
2c	2000 tonnes/day	CBD and Fenton St	Yes
3	250 tonnes/day	Existing Locations	Yes
4a	500 tonnes/day	Within 1.5 km zone between 1 and 1.5 km	No
4b	500 tonnes/day	Within 1.5 km zone between 500m and 1.5 km	No
4c	500 tonnes/day	Within 1.5 km zone	No
4d	1000 tonnes/day	Within 1.5 km zone between 1 and 1.5 km	No

4e	1000 tonnes/day	Within 1.5 km zone between 500m and 1.5 km	No
4f	1000 tonnes/day	Within 1.5 km zone	No
4g	2000 tonnes/day	Within 1.5 km zone between 1 and 1.5 km	No
4h	2000 tonnes/day	Within 1.5 km zone between 500m and 1.5 km	No
4i	2000 tonnes/day	Within 1.5 km zone	No
5a	320 kW	Within 1.5 km zone	N/A
5b	640 kW	Within 1.5 km zone	N/A
5c	1,280 kW	Within 1.5 km zone	N/A

4. Results

The modelled scenarios were run for 30 years from 2005 until 2035. A base case was firstly run using the existing production rates out to 2035. For each scenario, the results in 2035 were compared to the base case. In particular, comparisons were made with:

- The mass flowrate at Whakarewarewa;
- The mass flowrate at Kuirau Park;
- The amount of steam under Whakarewarewa between elevations 210 and 250 m.a.s.l.;
- Temperatures at Whakarewarewa and Kuirau Park.

Because the reinjected fluid is colder than the produced fluid, there is the potential for significant cooling to occur. This is why the amount of steam under Whakarewarewa and temperatures were also considered.

For the base case in 2035, the mass flowrate at Whakarewarewa is 29,460 tonnes/day and 1,530 tonnes/day at Kuirau Park. The amount steam under Whakarewarewa between 210 and 250 m.a.s.l. is 4,369 tonnes. Temperatures are around 170ºC at Whakarewarewa and 120ºC at Kuirau Park.

The results of the scenarios are summarised in Table 2, and Figure 8 and Figure 9.

4.1 Discussion

It is important to realise that the results presented here are indicative only. They only show the response to the particular pattern of production and reinjection used in the model. Different patterns may produce different results. But the results do show the magnitude of the impact that can be expected from the various scenarios.

To assist in the assessment of the impact of these scenarios it is helpful to consider a benchmark provided by the response to the Bore Closure Programme. Any scenario that has an impact that is a significant fraction of that response is likely to be unacceptable. Relevant aspects of the response from 1986 to 1990 as calculated from the model are:

- The mass flowrate at Whakarewarewa increased by 7,780 tonnes/day;
- The mass flowrate at Kuirau Park increased by 1,380 tonnes/day.
- The amount of steam under Whakarewarewa increased by 100 tonnes.

Table 2: Scenario results. The results show the amount reduction in outflow from the base case at Whakarewarewa, Kuirau Park, and the reduction in the mass of steam under Whakarewarewa from the base case. A positive number means that the scenario had a reduced value compared to the base case, a negative means that the scenario value was higher than the base case.

Scenario	Reduction in Outflow at Whakarewarewa (tonnes/day)	Reduction in Outflow at Kuirau Park (tonnes/day)	Reduction in Steam under Whakarewrewa (tonnes)
1a	28	380	0.2
1b	103	684	0.8
1c	295	1,432	1.7
2a	30	477	0.3
2b	94	869	1
2c	452	1,987	3.9
3	7	235	0
4a	29	7	0.8
4b	10	7	1.7
4c	-8	10	26
4d	65	18	2.2
4e	41	18	4
4f	-20	23	36
4g	143	38	4.7
4h	90	39	9.3
4i	-50	59	309
5a	1	0	0.2
5b	0	1	0.5
5c	7	4	0.8

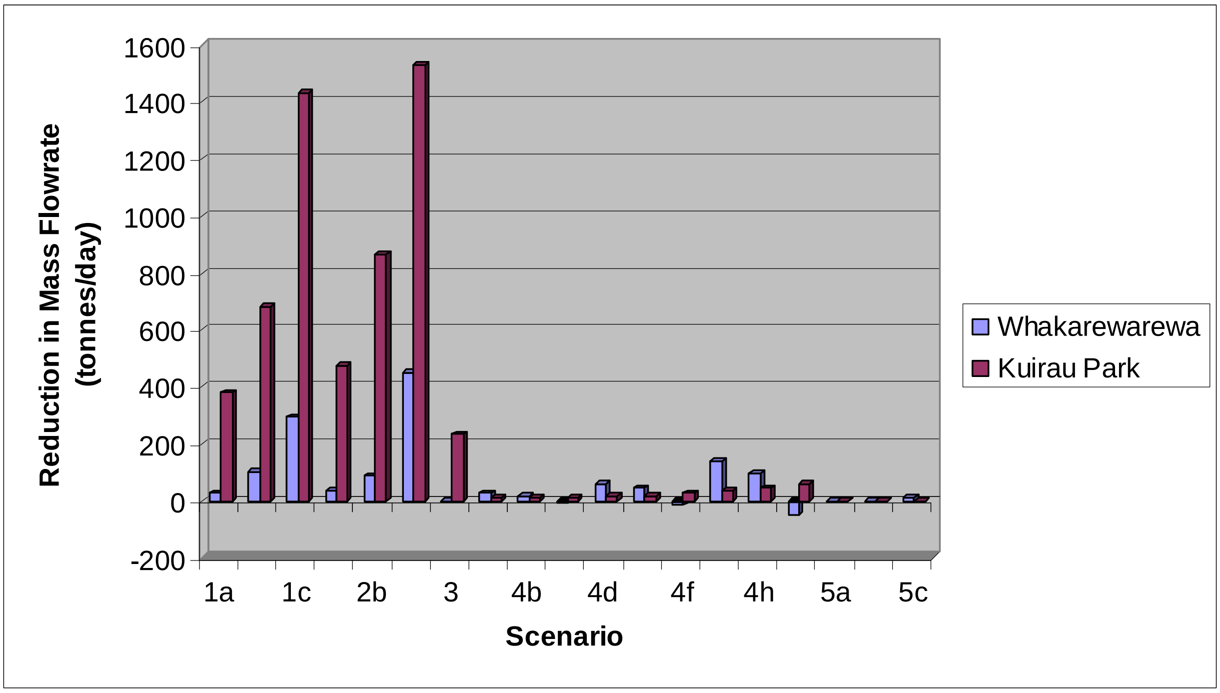

Figure 8: Reduction in outflow at Whakarewarewa and at Kuirau Park for all the scenarios

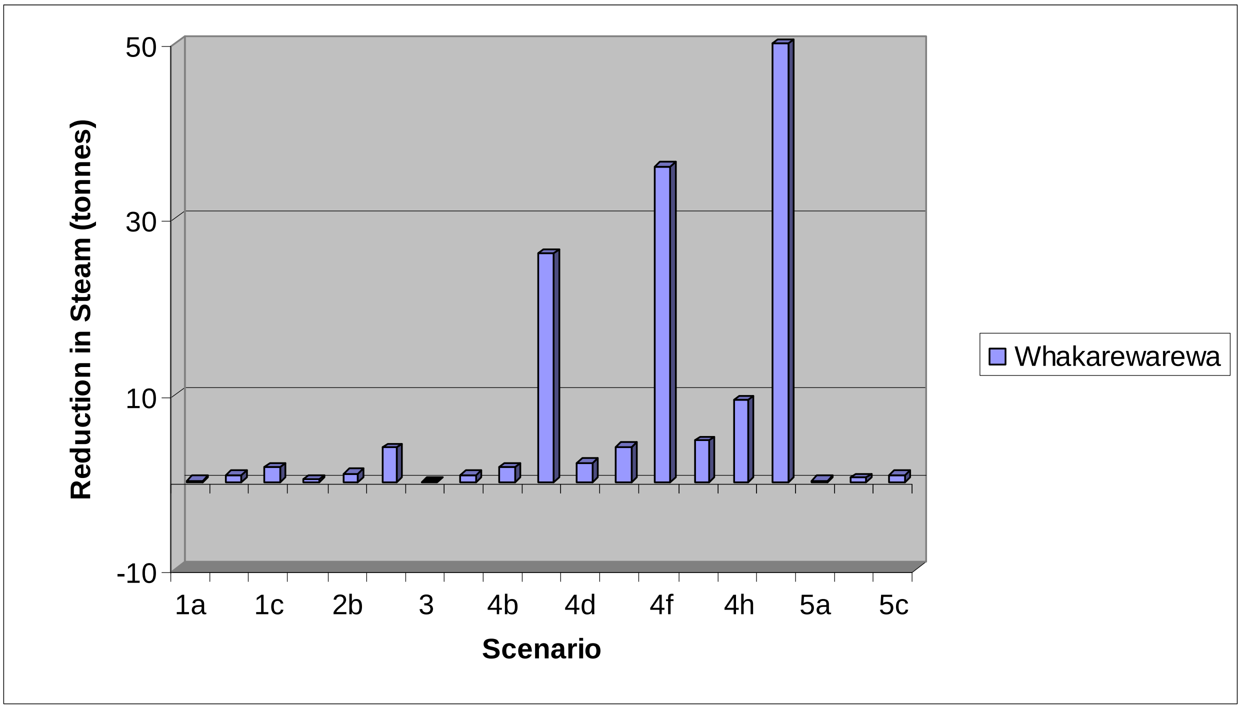

Figure 9: Reduction in steam under Whakarewarewa for all the scenarios.

Scenarios 1 and 2 show a significant impact on the mass flowrate at Kuirau Park. In these scenarios the production is sited in the Rotorua Rhyolite. Because this formation is highly permeable, pressures travel rapidly through the formation to the Kuirau Park area. For Scenario 1, the impact is approximately 70%, that is every 100 tonnes/day of production reduces the outflow at Kuirau Park by approximately 70 tonnes/day. The impact for Scenario 2 is even higher.

On the other hand, the impact of Scenarios 1 and 2 on Whakarewarewa is negligible, except for Scenarios 1c and 2c where the increase in total production is 20%. Scenario 2c reduces the outflow at Whakarewarewa by 452 tonnes/day and the amount of steam under Whakarewarewa by 3.9 tonnes. This impact is nearly 5% of the recovery after 1986.

Scenario 3 shows that even a modest increase in production of 2.5% can have a noticeable impact at Kuirau Park.

The results of Scenario 4 are a little more complicated. Scenarios 4a, 4b and 4d have only a minor impact on the surface activity. The other scenarios in the Scenario 4 series have an impact on the amount of steam under Whakarewarewa.

In Scenarios 4a and 4d new production is added to a zone between 1 km and 1.5 km from Pohutu Geyser. The new production is sufficiently distance from Whakarewarewa and Kuirau Park that reinjection lessens any possible pressure drop, consequently the impact on the mass flowrates is small.

In Scenarios 4b, 4e and 4h production is also added to zone between 500m and 1 km from Pohutu Geyser. These scenarios show a slightly smaller impact on the outflow at Whakarewarewa than the corresponding Scenarios 4a, 4d and 4g. The reason for this is that thermal effects are starting to become important. The reinjected fluid is about 25ºC colder than the reservoir fluid, so cooling starts to occur and the steam starts to condense. With less steam present, liquid is able to travel more easily and this counters the reduction in outflow from increased production.

A similar phenomenon is observed with scenarios 4c, 4f and 4i. In these scenarios, reinjection occurs very close to Whakarewarewa and consequently has a significant impact on the steam under Whakarewarewa. In Scenario 4i, 120 tonnes/day of 145ºC is reinjected next to Whakarewarewa, and temperatures fall by 2.5ºC and the amount of steam is reduced by 309 tonnes.

The results show that many of the Scenario 4 series impact on the amount of steam under Whakarewarewa. Exactly what this means for the surface features is unclear at this stage. Many of the features at Whakarewarewa are not steam features, so reducing the amount of steam will not directly affect these features. However, a change in the amount of steam under Whakarewarewa shows that the character of the fluid is changing and if the change is large enough the impact on the surface features could be significant.

The final scenarios, 5a, 5b and 5c, show a negligible impact on the surface features. These scenarios increase the use of downhole heat exchangers by up to 1.28 MW. By contrast the amount of heat extracted for Scenario 4i is approximately 7 MW.

5. Conclusions

1. 19 scenarios were simulated using the Rotorua Geothermal Reservoir Model. The results of these simulations were used to assess the impact on the surface features at Rotorua.

2. The impact was assessed by considering mass flows at Whakarewarewa and Kuirau Park and the amount of steam under Whakarewarewa.

3. Scenarios with production outside the 1.5 km Exclusion Zone showed an impact on the outflow at Kuirau Park of more than 15% of the recovery from 1986 to 1990.

4. Scenarios with production and reinjection within 1 km of Pohutu Geyser showed an adverse impact on the amount of steam under Whakarewarewa.

5. Adding new production and reinjection at a level of 5% of the existing total production to a zone between 1 km and 1.5 km from Pohutu Geyser has only an impact on surface activity of less than 1% of the recovery from 1986 to 1990.

6. Increasing the use of downhole heat exchangers by up to 200% within the 1.5 km exclusion zone has a negligible impact on surface features.

7. The scenarios considered here provide an indication of the likely response to increased production in various parts of the field. If changes to the Rotorua Geothermal Plan are envisaged then a more detailed set of scenarios should be developed and simulated to fully test the consequences of the anticipated change in the production pattern.

6. References

Burnell and Kissling (2005) Burnell, J. and Kissling, W. *Rotorua Geothermal Reservoir Modelling Part 1: Model Update 2004*, Report to Bay of Plenty Regional Council