

**Industrial Research Limited Report**

**Rotorua Geothermal Reservoir  
Modelling 2006  
Heat Exchanger Scenarios  
Preliminary Report**

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## 1. Executive Summary

In 2005 the computational reservoir model for the Rotorua geothermal field was updated and a series of usage scenarios was run using the model to test the effects on natural features of the field. In this report the Rotorua Geothermal Reservoir Model was used to assess the impact of 12 further scenarios on geothermal surface activity. The scenarios were designed to test if there is capacity for increased heat exchanger use across the field outside the 1.5 exclusion zone whilst protecting surface features. Half the scenarios also included a 5% increase in production in the 1.5km exclusion zone.

The scenarios were prepared by Environment Bay of Plenty Staff and were implemented in the 2004 version of the Rotorua Geothermal Reservoir Model. The scenarios were run for 30 years from 2007 and the results showed that:

Estimates were made of the possible uptake of downhole heat exchangers and used as a “realistic use” scenario. This increased use of downhole heat exchangers in the field results in an increase in total heat extracted from the field by 10%. To test a range of scenarios, high and low use scenarios were also constructed. Impacts on the field from the increased use in these scenarios included:

- The “realistic use” scenarios equates to an increase of about 148 heat exchanger systems in the northern area of the field.
- The “low use” scenarios indicated an impact on the outflow at Kuirau Park, of about 10% and the “realistic use” scenarios had an impact between 14 and 25%.
- The impact on Whakarewarewa was found to be negligible for all scenarios tested
- Downhole heat exchangers abstracting heat from deeper (120 m) into the Rhyolite aquifer were found to have a greater impact on the Kuirau Park outflow than heat exchangers that penetrate the aquifer from shallower depths (50 m)
- The impact of deeper downhole heat exchanger use is between 10 – 15 % more than taking from the shallower parts of the aquifer.

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## 2. Introduction

This report follows two reports in 2005 that described the results of computational modelling of the Rotorua Geothermal System. All three reports were commissioned by Environment Bay of Plenty to support the review of the Rotorua geothermal management plan. The first report describes the computational model of the Rotorua geothermal field. The second report considers the effects of 19 scenarios for possible future production from the Rotorua geothermal field. This latest report considers further scenarios for future production, concentrating on the use of downhole heat exchangers.

The 12 scenarios considered in this report were prepared in consultation with Environment Bay of Plenty Staff. They involve the use of downhole heat exchangers in three categories: “realistic use”, “low use” and “high use”. After some discussion it was decided that:

- “Realistic use” would mean downhole heat exchanger use from 1 in 10 buildings where shallow heat exchangers can be used, and from 1 in 20 buildings where deeper heat exchangers are required.
- “Low use” would mean half “realistic use”.
- “High use” would mean twice “realistic use”.
- Typical domestic use would extract 20 kW of heat from the downhole heat exchanger.

In the scenario modelling, “new” downhole heat exchanges were added in proportion to the number of buildings in various areas outside of the 1.5 km Exclusion Zone. In areas where motels, hotels or other commercial premises were present that proportion was doubled.

A further variation used in the scenarios was to consider increased downhole exchanger use in conjunction with a 5% increase in existing take added to the region inside the 1.5 km Exclusion Zone. This increase of 5% of existing take was identified in the scenario modelling report, **Burnell** (2005), as only having a minor impact on the surface features. The increase take was included in a zone between 1km and 1.5 km from Pohutu geyser.

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## 3. Usage 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 with Environment Bay of Plenty staff to test if there is an opportunity to provide for increased use of heat and/or mass from the field whilst protecting the field’s surface features. The scenarios can be broken into 4 groups, the scenario numbers start at 10 to distinguish them from the 5 scenario groups previously reported in **Burnell** (2005).

<b>Scenario</b>	<b>Description</b>
<i>Scenario 10 Group</i>	New shallow heat exchangers outside the 1.5km Exclusion Zone.
<i>Scenario 11 Group</i>	New deeper heat exchangers feeding from the rhyolite or ignimbrite outside the 1.5km Exclusion Zone.
<i>Scenario 12 Group</i>	New shallow heat exchangers outside the 1.5km Exclusion Zone with a 5% increase of the existing production added to the 1.5km Exclusion Zone.
<i>Scenario 13 Group</i>	New deeper heat exchangers outside the 1.5km Exclusion Zone with a 5% increase of the existing production added to the 1.5km Exclusion Zone.

Within each group there are a three of sub-scenarios with realistic, low and high heat exchanger use. The details of all 19 scenarios are:

<i>Scenario 10a (Realistic use)</i>	Add new heat exchangers totalling 2,966 kW from 148 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 50m. Existing rates of production and reinjection were assumed from the field.
<i>Scenario 10b Low use</i>	Add new heat exchangers totalling 1,483 kW from 74 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 50m. Existing rates of production and reinjection were assumed from the field.
<i>Scenario 10c High use</i>	Add new heat exchangers totalling 5,933 kW from 296 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 50m. Existing rates of production and reinjection were assumed from the field.
<i>Scenario 11a (Realistic use)</i>	Add new heat exchangers totalling 2,571 kW from 128 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 125m. Existing rates of production and reinjection were assumed from the field.
<i>Scenario 11b Low use</i>	Add new heat exchangers totalling 1,285 kW from 64 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 125m. Existing rates of production and reinjection were assumed from the field.
<i>Scenario 11c High use</i>	Add new heat exchangers totalling 5,143 kW from 256 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 125m. Existing rates of production and reinjection were assumed from the field.
<i>Scenario 12a (Realistic use)</i>	Add new heat exchangers totalling 2,966 kW from 148 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 50m. An increase of 5% in existing rates of production and reinjection was included in the 1.5km Exclusion Zone.
<i>Scenario 12b Low use</i>	Add new heat exchangers totalling 1,483 kW from 74 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 50m. An increase of 5% in existing rates of production and reinjection was included in the 1.5km Exclusion Zone.
<i>Scenario 12c High use</i>	Add new heat exchangers totalling 5,933 kW from 296 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 50m. An increase of 5% in existing rates of production and reinjection was included in the 1.5km Exclusion Zone.
<i>Scenario 13a</i>	Add new heat exchangers totalling 2,571 kW from 128 buildings to the field

- (Realistic use)* area outside of the 1.5 km Exclusion Zone at depths of 125m. An increase of 5% in existing rates of production and reinjection was included in the 1.5km Exclusion Zone.
- Scenario 13b Low use* Add new heat exchangers totalling 1,285 kW from 64 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 125m. An increase of 5% in existing rates of production and reinjection was included in the 1.5km Exclusion Zone.
- Scenario 13c High use* Add new heat exchangers totalling 5,143 kW from 256 buildings to the field area outside of the 1.5 km Exclusion Zone at depths of 125m. An increase of 5% in existing rates of production and reinjection was included in the 1.5km Exclusion Zone.

### 3.2 Implementation in the Model

The computational model used for this work was reported in the report **Burnell and Kissling** (2005), and the grid is shown in Figure 1. The downhole heat exchangers were simulated as wells producing heat only, so there was no mass take from these wells. The downhole heat exchanger wells used for these scenarios were added to the model in the locations shown in Figure 2 and Figure 3. Figure 4 shows the location of the new production within the 1.5km Exclusion Zone used in Scenarios 11 and 12.

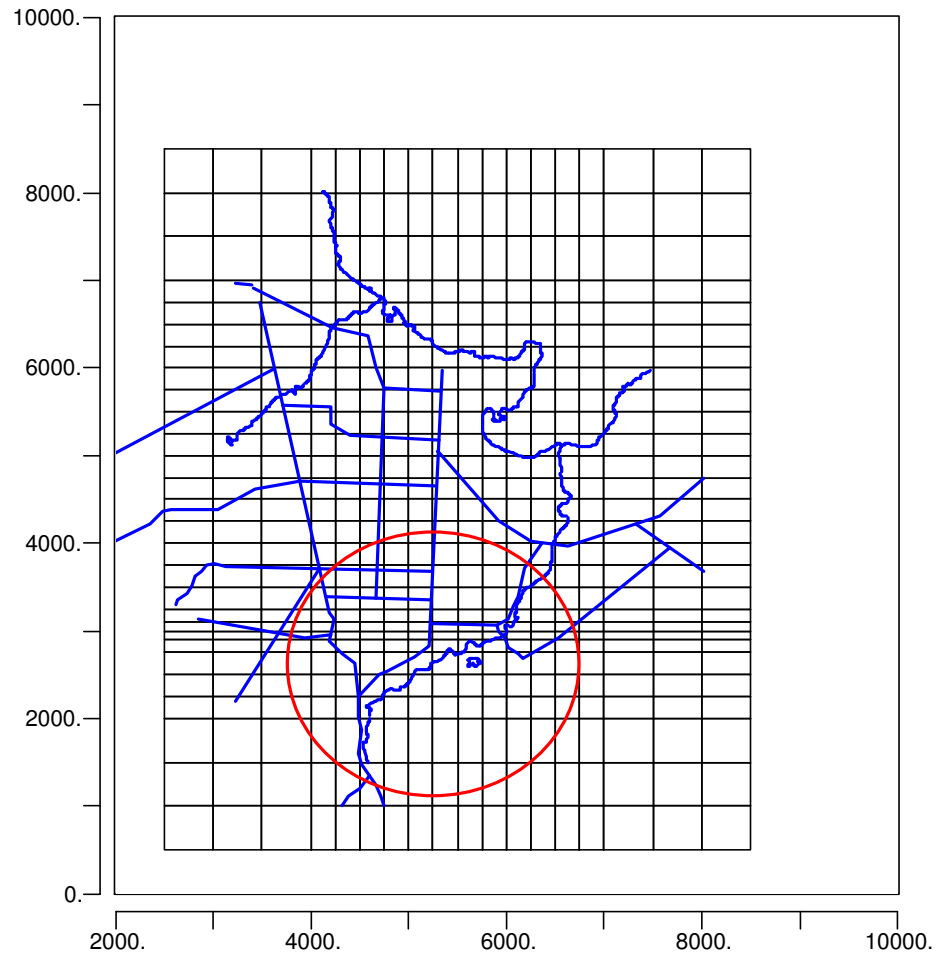
The purpose of this work is to assess the impact on the surface features across the field. To do this the mass outflows predicted by the model were compared with a base case with no increase in production. In the model, the mass flowrate from surface features depends on the pressure and the fraction of water present in the fluid. However, since heat is being mined from the system, thermal effects could also impact on surface features. For example, some of the scenarios reported in **Burnell** (2005) showed that cooling had the effect of quenching some of the steam underlying Whakarewarewa. So in addition to mass flowrates of surface features, pressures, temperatures and the mass of steam were also monitored during model runs.

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 2007.

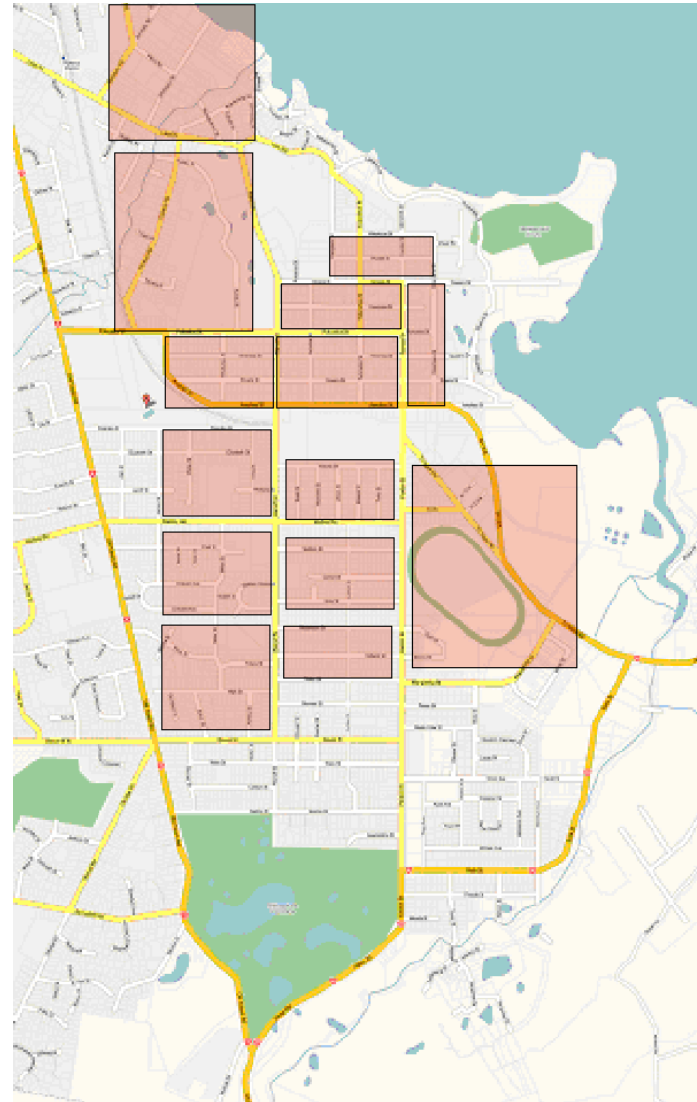
**Table 1: Scenario summaries**

Scenario	Extra DHX Production	Number of Extra DHX	Depth	1.5 km Zone Intact
10a	2,966 kW	148	50m	Yes
10b	1,483 kW	74	50m	Yes
10c	5,933 kW	296	50m	Yes
11a	2,571 kW	128	125m	Yes
11b	1,285 kW	64	125m	Yes
11c	5,143 kW	256	125m	Yes
12a	2,966 kW	148	50m	No, 5% of total production added
12b	1,483 kW	74	50m	No, 5% of total production added

12c	5,933 kW	296	50m	No, 5% of total production added
13a	2,571 kW	128	125m	No, 5% of total production added
13b	1,285 kW	64	125m	No, 5% of total production added
13c	5,143 kW	256	125m	No, 5% of total production added

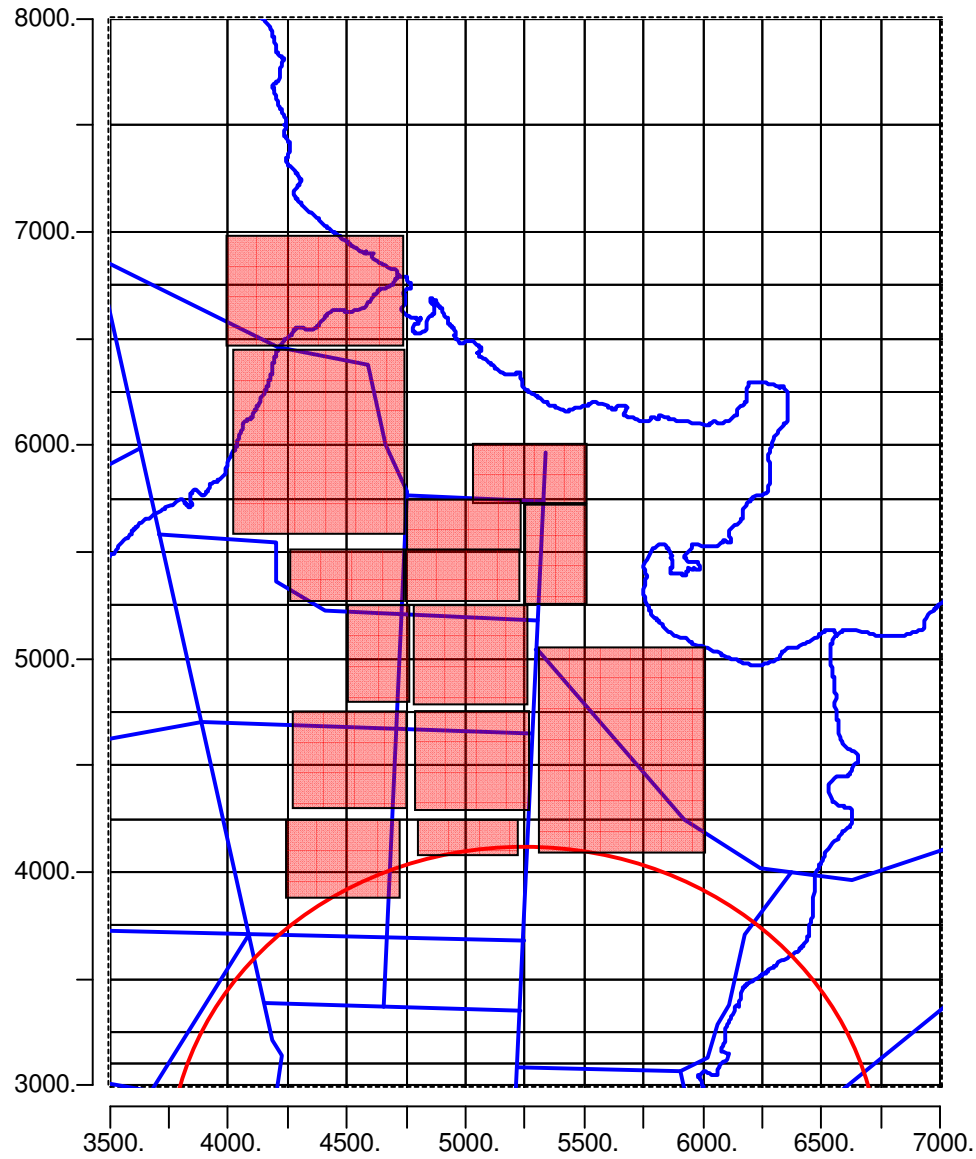


**Figure 1: Grid used for the computational model. The coordinates refer to map coordinates with (2,000, 0) on the diagram corresponding to (2790,000N, 6332,000E) in map coordinates. The blue lines are local roads, streams and the lakefront, and the red line approximately shows the 1.5km exclusion zone.**

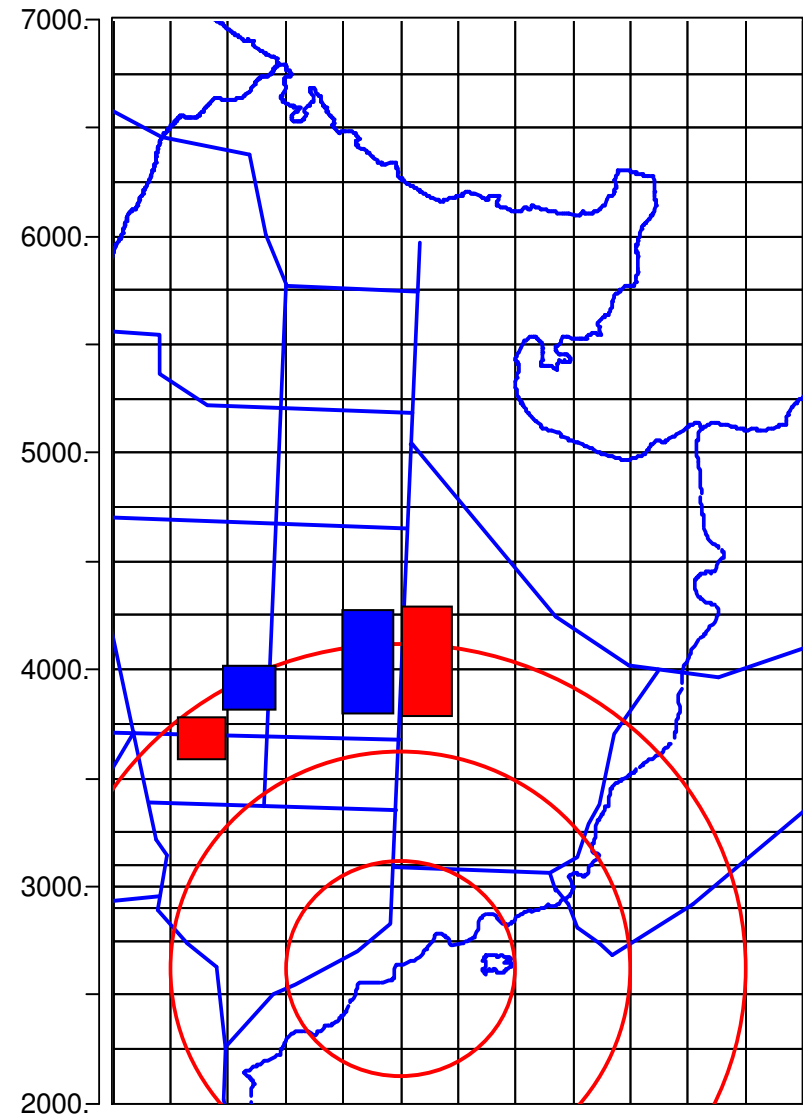


**Figure 2: Regions where downhole heat exchangers were added to the model**





**Figure 3: Locations of wells used to simulate the downhole heat exchangers on the model grid.**



**Figure 4: Location of new production within the 1.5km Exclusion Zone used in Scenarios 12 and 13.**

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## 4. Results

The modelled scenarios were run for 30 years from 2007 until 2037. A base case was firstly run using the existing production rates out to 2037. For each scenario, the results in 2037 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 downhole heat exchangers are mining heat from the system, 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 2037, the mass flowrate at Whakarewarewa is 29,526 tonnes/day and 1,563 tonnes/day at Kuirau Park. The amount steam under Whakarewarewa between 210 and 250 m.a.s.l. is 4,380 tonnes. Temperatures are around 170°C at Whakarewarewa and 120°C at Kuirau Park.

The results of the scenarios are summarised in Table 2, and Figure 5 and Figure 6.

### 4.1 Discussion

It is important to appreciate that the results presented here are only indicative of the possible field response. The results only show the response to the particular pattern of heat production used in the model. Different patterns of production may produce different results. However the results do show the magnitude of the impact that can be expected from the various scenarios.

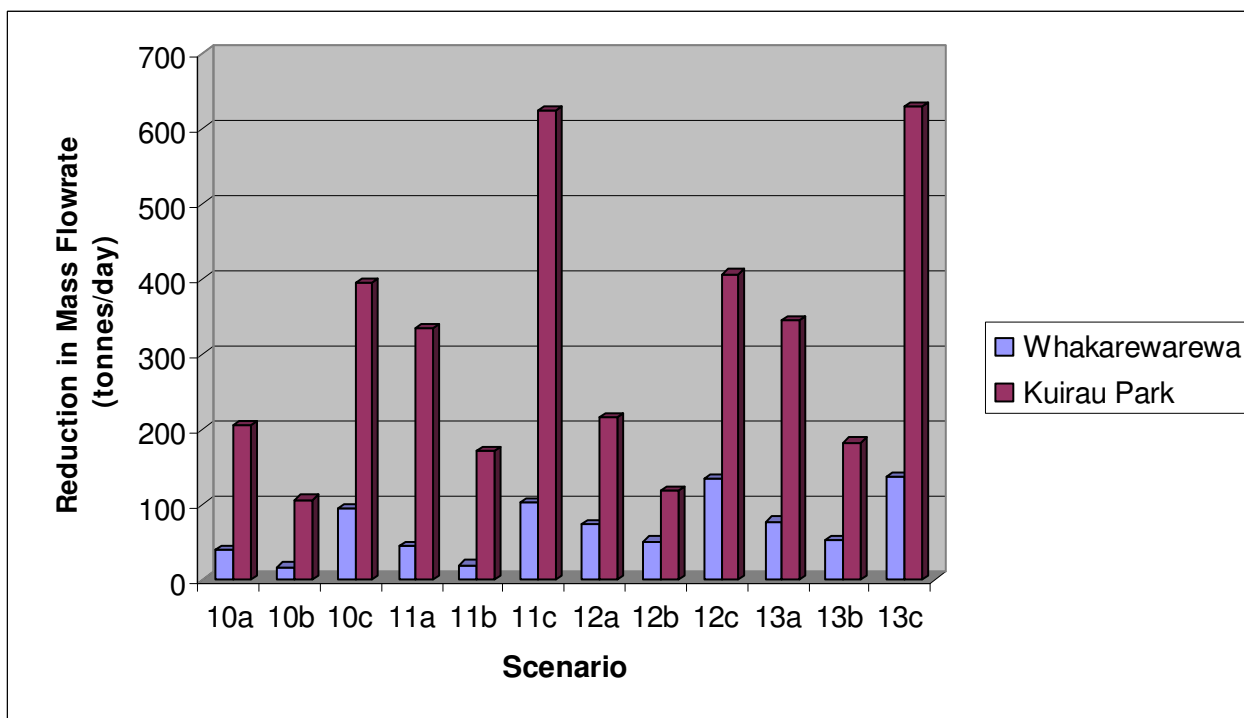
To assist in the assessment of the impact of these scenarios it is helpful to consider a benchmark provided by the response to the Bore Closure Programme. Any scenario that has an impact that is a significant fraction of that response is likely to be unacceptable. Relevant aspects of the response to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

All the scenarios are mining heat from the system so will result in some cooling. However the amount of heat being produced in most scenarios is only a fraction of the total heat being extracted from the system from existing production and reinjection wells. It is difficult to estimate exactly how much heat is being extracted as production and reinjection temperatures are not very well known. We can obtain an estimate from the model which suggests that 25 MW of heat is being extracted from production in 2005. In comparison, the “High Use” Scenario 10c produces another 6 MW.

**Table 2: Scenario results.** The results show the amount of 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. The positive values mean that the scenarios had reduced values compared to the base case. Figures in parentheses show the percentage reduction compared to the response to the Bore Closure Programme – see previous page.

Scenario	Reduction in Outflow at Whakarewarewa (tonnes/day)		Reduction in Outflow at Kuirau Park (tonnes/day)		Reduction in Steam under Whakarewarewa (tonnes)	
10a – Realistic	40	(0.5%)	205	(14%)	0.24	(0.2%)
10b – Low	18	(0.2%)	107	(8%)	0.12	(0.1%)
10c - High	94	(1.2%)	394	(29%)	0.61	(0.6%)
11a – Realistic	45	(0.6%)	334	(24%)	0.33	(0.3%)
11b – Low	20	(0.3%)	171	(12%)	0.16	(0.2%)
11c – High	104	(1.3%)	624	(45%)	0.75	(0.8%)
12a – Realistic	74	(1%)	216	(16%)	1.8	(1.8%)
12b – Low	51	(0.7%)	119	(9%)	1.69	(1.7%)
12c – High	135	(1.7%)	407	(30%)	2.21	(2.2%)
13a – Realistic	78	(1%)	345	(25%)	1.89	(1.9%)
13b – Low	53	(0.7%)	183	(13%)	1.71	(1.7%)
13c – High	137	(1.8%)	629	(46%)	2.33	(2.3%)



**Figure 5: Reduction in outflow at Whakarewarewa and at Kuirau Park for all the scenarios**

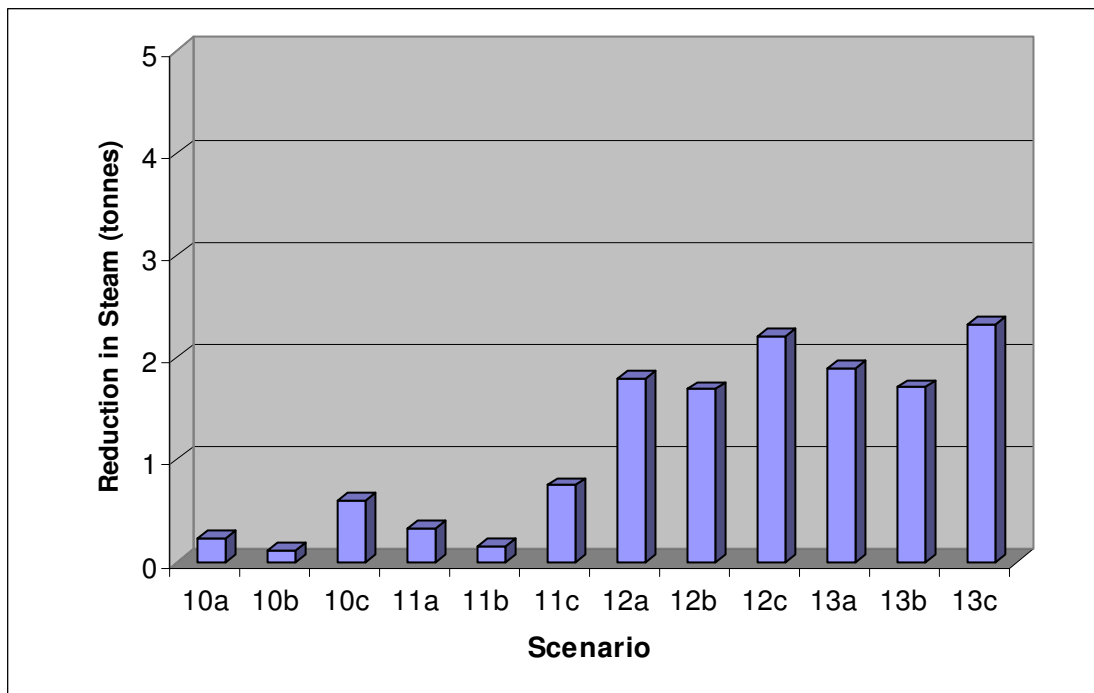


Figure 6: Reduction in steam under Whakarewarewa for all the scenarios.

All the scenarios reduce the mass flowrate at Kuirau Park. This is due to the cooling of the system, which results in slightly lower pressures around the Kuirau Park area. The “Low Use” B scenarios result in a reductions of flow at Kuirau Park of between 8 and 13%. The “Realistic Use” A scenarios reduce the Kuirau Park flow by between 14 and 25%, and the “High Use” C scenarios by between 29 and 46%.

Scenario groups 11 and 13 had a greater impact on the flow at Kuirau Park. These scenarios include the use of deeper heat exchangers. The model indicates that these appears to be a cooling effect if new heat exchanger use is added in the main deeper Rhyolite aquifer. It is this aquifer that contains the feeds for the Kuirau Park flows.

On the other hand, the impact of all the scenarios on Whakarewarewa is negligible, with largest impact on the flow from Whakarewarewa being nearly 1% of the recovery after 1986. None of the scenarios have a noticeable impact on the temperatures at Whakarewarewa or amount of steam present under Whakarewarewa.

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## 5. Conclusions

1. 12 scenarios considering downhole heat exchanger use 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. The impact was assessed by considering mass flows at Whakarewarewa and Kuirau Park and the amount of steam under Whakarewarewa. The scenarios considered in this report provide an indication of the likely response to increased use of downhole heat exchangers in various parts of the field outside the 1.5 km exclusion zone

2. All scenarios showed some impact on the outflow at Kuirau Park. Impacts ranged from 8 to 45% of the recovery from 1986 to 1990. The high use “C” scenarios were found to have the highest reduction in geothermal outflow at Kuirau Park
  3. “Realistic use” scenarios showed a reduction of between 14 and 25% of the geothermal outflow at Kuirau Park. The realistic use scenario equates to an increase of about 148 heat exchanger systems in the northern area of the field.
  4. Downhole heat exchangers drawing heat from deeper depths were found to have a higher impact on Kuirau Park outflow than scenarios drawing from shallower depths (50 m) The impact of deeper downhole heat exchanger use is between 10 – 15 % more than those taking from the shallower aquifer.
  5. The impact of all scenarios on Whakarewarewa was found to be negligible.
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## 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
- Burnell** (2005) Burnell, J. *Rotorua Geothermal Reservoir Modelling Part 2: Scenario Modelling*, Report to Bay of Plenty Regional Council