MODELLING THE EFFECTS OF DIRECT USE AT THE TAURANGA LOW-TEMPERATURE GEOTHERMAL SYSTEM

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ABSTRACT

Tauranga is underlain by an extensive low-temperature geothermal system covering approximately 40 km by 60 km. Warm springs in the area are between 22ºC and 39°C, and well temperatures have reached 67°C at 750 m depth. The resource has been used for the last 40 years, for heating, cooling, glasshouses, bathing and tropical fisheries. In order to better delineate the system and estimate the effects of current and future withdrawal of warm water, a numerical model of the field has been developed.

A heat and fluid flow model of the area was created using TOUGH2 software. It comprises two layers representing volcanic units and overlying sediments. It was calibrated against temperature depth profiles in 17 wells, and checked against a further 437 mainly single well-temperature measurements. A reasonable fit could be obtained with this simple model, with an R^2 of 0.9. The model suggests that the highest heat flux is centred under Tauranga City. Modelling current estimated usage in the study area shows an initial rapid drop in pressure by up to 25% which then stabilises, while temperature gradually and consistently declines by up to 5% over 400 years. Other scenarios show the effects of higher extraction rates of warm water, providing a tool to help with management of the low-temperature geothermal resource.

1. INTRODUCTION

Tauranga is on the north coast of the North Island of New Zealand (Figure 1), and is the location of an extensive warm water geothermal system (<70°C; White et al., 2009). Over 120,000 people live on this resource, and for the last 40 years it has been used for heating, cooling, bathing, greenhouses and aquaculture. With increased use it is important that the area is studied to determine if the withdrawal of warm water is sustainable.

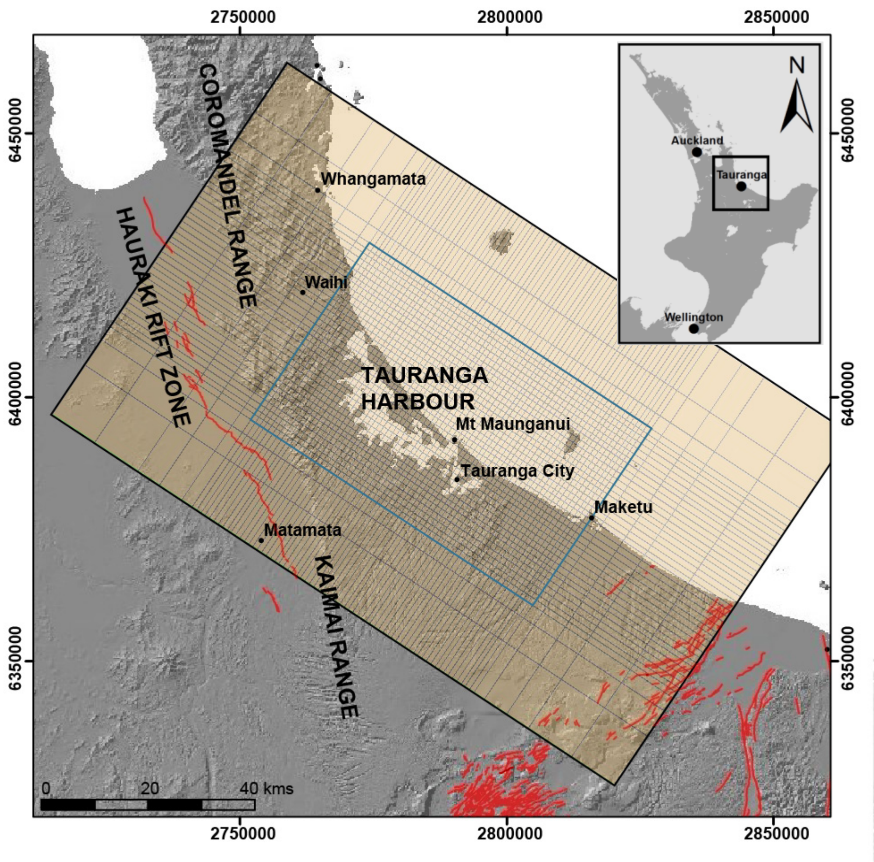

Figure 1. Map of the Tauranga study area. Red lines represent active faults (GNS Science, 2012). The brown grid corresponds to the TOUGH2 model covering 130 km by 70 km. The study area is a 60 km by 40 km area in the centre where warm water springs are found (blue grid).

Numerical models of high-temperature geothermal fields are routinely carried out to assess energy potential, identify upflow zones for drilling targets, and satisfy resource consent requirements (O'Sullivan et al., 2001). Numerical simulations of low-enthalpy geothermal fields are less common, but are beginning to be used both to assess a field and to determine its potential usage (Molière, 2010; Pearson, 2012). In this study we created a TOUGH2 model of the Tauranga area and calibrated it against well temperature data. We used this model to determine the effects of withdrawing warm water by modelling extraction and reinjection at currently allocated rates over a 400 year period.

2. STUDY AREA

Our study area extends from Waihi to the northwest to Maketu to the southeast (Figure 1). It covers an area of 40 km by 60 km which contains more than 450 warm water wells. Spring temperatures are between 22°C and 39°C, and the largest concentration of wells are around Tauranga City. However, the hottest well (67°C at 750 m) is located at the northwest edge of Tauranga Harbour (White et al., 2009).

The lithology in the Tauranga area is primarily volcanic, comprising ignimbrite, tuff, breccia and lava (White et al., 2009). At the coast there is an overlying layer of sediments several hundred metres thick that pinches out to the west and to the south (Figure 2; Davis and Healy, 1993; Simpson and Stewart, 1987). There are active faults to the south and west of the study area, but none identified within it (Figure 1; Briggs et al., 2005; Edbrooke, 2001; Leonard et al., 2010).

3. RESERVOIR MODEL

A TOUGH2 numerical model was created to study how heat and fluid flow through the Tauranga geothermal system.

3.1 TOUGH2 model

The model represents two simplified lithological layers in the area: volcanic units and sedimentary cover (White et al., 2009). The model domain encompasses an area of 70 km by 130 km extending to 2 km depth (Figure 2). The grid has a finer spacing within the central 40 km by 60 km area in which warm water wells are found. The model extends beyond this only to ensure that calculations in the warm water area of interest are not influenced by the model boundary conditions. Similarly, the maximum depth of 2 km is set to be significantly deeper than the deepest well.

Boundaries of the model were simplifications based on the literature (Hodges, 1994; Reyes, 2008; Simpson, 1987; Studt and Simpson, 1969). Cells at the top boundary were fixed at atmospheric temperature and either atmospheric pressure with 100% air to represent the land, or hydrostatic pressure with 100% water to represent the ocean as appropriate. Recharge into the system due to rainfall was simulated into surface cells representing dry land at atmospheric temperature of 13°C (NIWA, 2011). Vertical boundaries of the model were fixed as no-flow far from the area of interest. For the bottom boundary condition, a heat source was placed along the base of the model as geochemical investigations suggest that there is minimal flow of geothermal fluids from depth (Hodges, 1994; Reyes, 2008). The heat flux was initially assumed to be homogeneous, based on average values for the area (Reyes, 2008; Simpson, 1987; Studt and Thompson, 1969), but was varied to refine the fit of the model temperatures to measured data.

The interior of the model was initially at atmospheric temperature and pressure but was allowed to vary during calculations. Chemical analyses show that the Tauranga geothermal region consists of mainly heated groundwater, with minor seawater in the north and minor magmatic volatiles in the south (Hodges, 1994; Reyes, 2008). The model was therefore fully saturated with fresh water. Some rock properties have been measured in or near the study area (Heu, 1985; Harding et al., 2010; Petch and Marshall, 1988; Schofield, 1972; Simpson, 1987), and these were used to populate the model initially. Density, porosity and specific heat capacity were fixed because experimentation showed that the model was relatively insensitive to them. Permeability and thermal conductivity were varied during model calibration to identify their likely values.

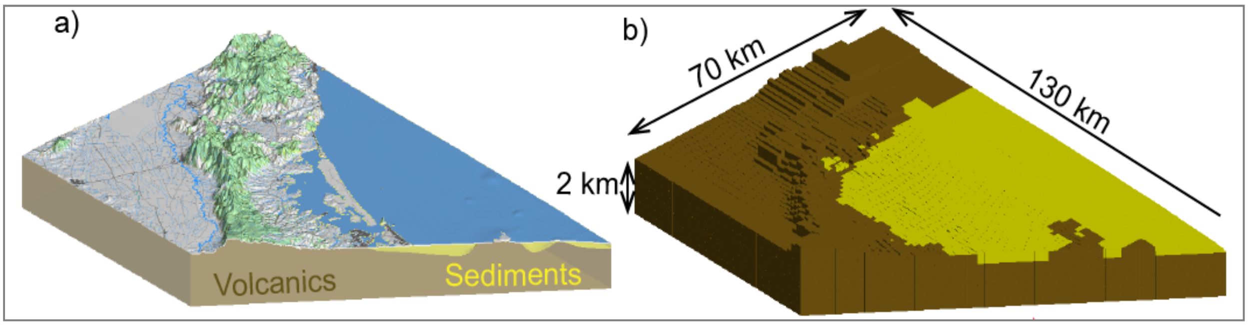

Figure 2. Models of the study area with ten times vertical exaggeration. a) Geological model adapted from White et al. (2009). b) TOUGH2 model showing grid blocks.

3.2 Calibration with well temperatures

The Tauranga area has been drilled extensively for groundwater, providing temperature information down to several hundred metres below the surface (White et al., 2009). For this study, temperature data from 454 wells were used, sourced from Bay of Plenty Regional Council database (March 2012), a groundwater report by White et al. (2009), Waikato Regional Council database (June 2012), and the GNS Science archives (GNS Science, 1987). In total there were 1338 individual temperature measurements, 417 of which were single measurements in one well, and the other 921 were depth profiles in 37 wells. Measurements were recorded from the surface to a maximum depth of 752 m. Temperatures varied between 8°C and 67°C, with the majority of observation between 10ºC and 40°C (Figure 3). Of the 37 wells with temperature depth profiles, 17 were used to calibrate the model (Figure 3). The remaining 20 well records were only found later and were much older. They also had less detail regarding depth and location and were therefore less reliable for model calibration. All data not used to calibrate the model was used to validate it afterwards.

The calibrated model showed that a simplified system of two homogeneous rock layers could result in an acceptable fit to all observed well temperatures (Figure 4). The average error was -1°C, the standard deviation was 9°C and the R^2 value was 0.9. The model corresponds to a basal heat flux at 2 km depth forming 6 zones, with the highest heat flux below Tauranga City (Figure 5). Horizontal permeability of 2.5 x 10^{-14} m^2 in the Tauranga Group Sediments (5 x 10^{-15} m^2 vertically) and 1 x 10^{-16} m^2 in the volcanic units (assumed to be isotropic) was found to maintain the primarily conductive regime. Thermal conductivities in the best-fit model were 1.25 W/m°C in the sediments and 1.8 W/m°C in the volcanic units.

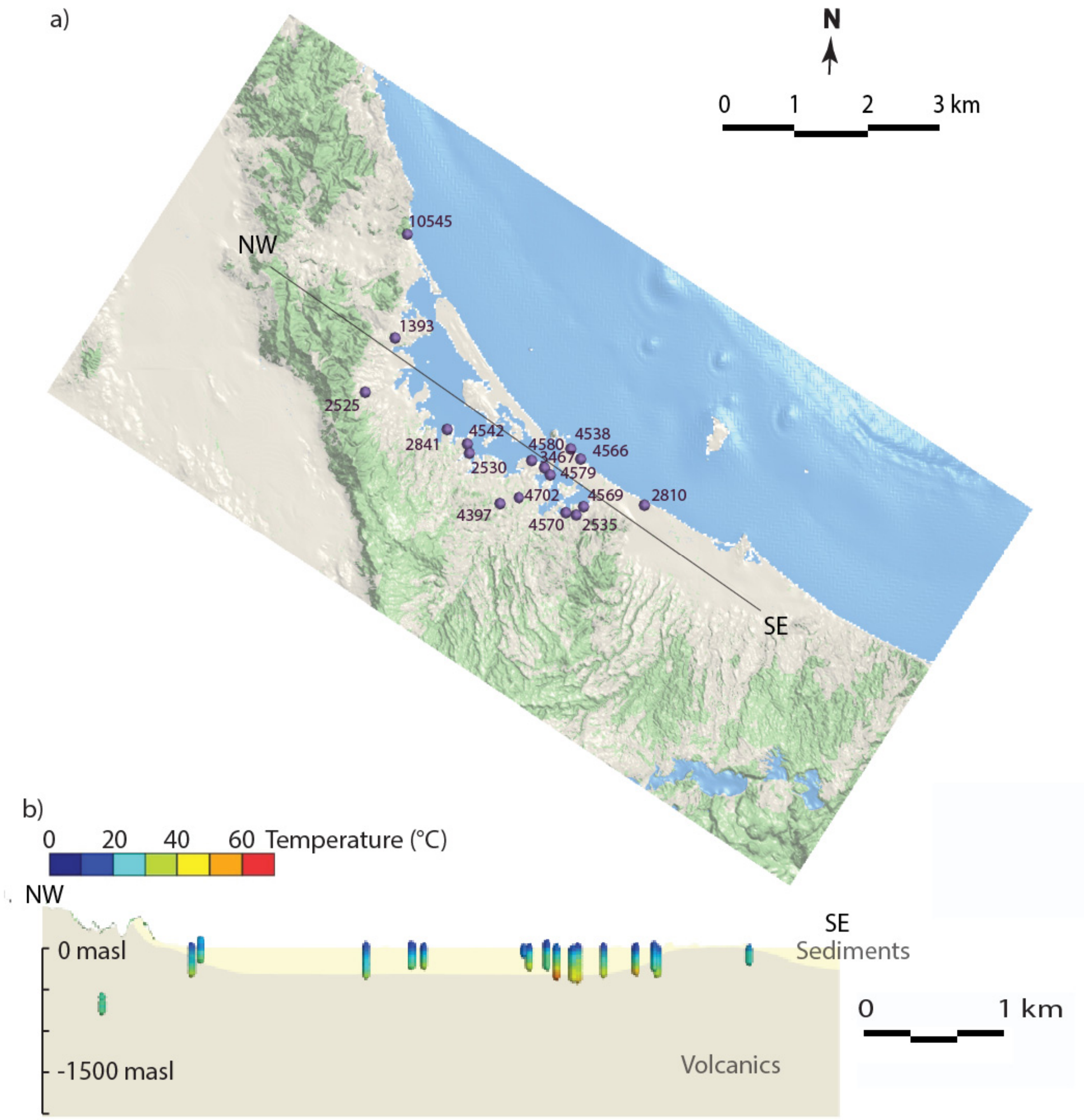

Figure 3. a) Wells used to calibrate the TOUGH2 model. Numbers represent the well names. Black line shows the location of the cross-section in (b). b) Temperature profiles measured in the 17 wells.

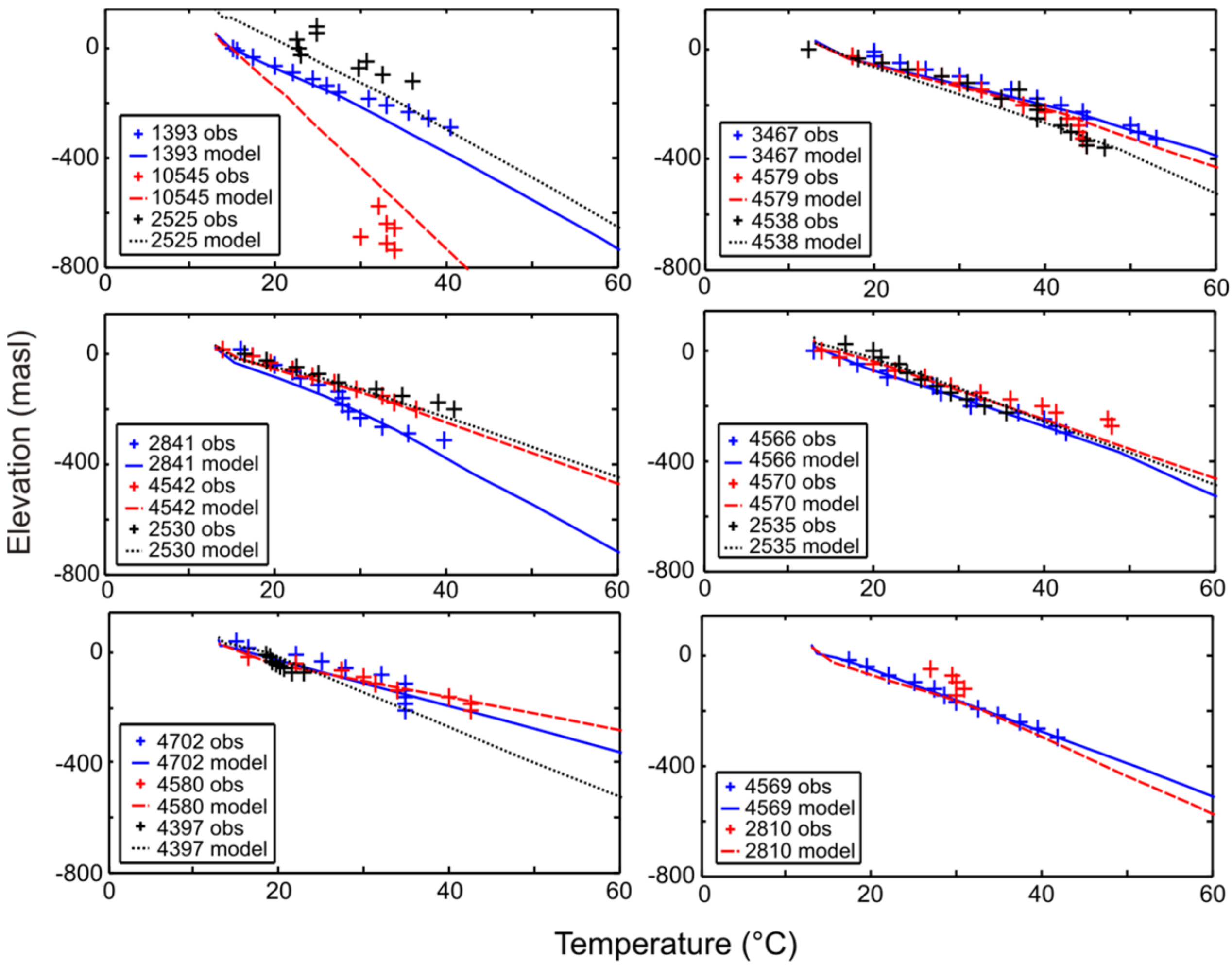

Figure 4. Comparison of observed temperatures (symbols) and modelled temperatures (lines) in the 17 wells used to calibrate the models. Colours correspond to different well locations as shown in Figure 3.

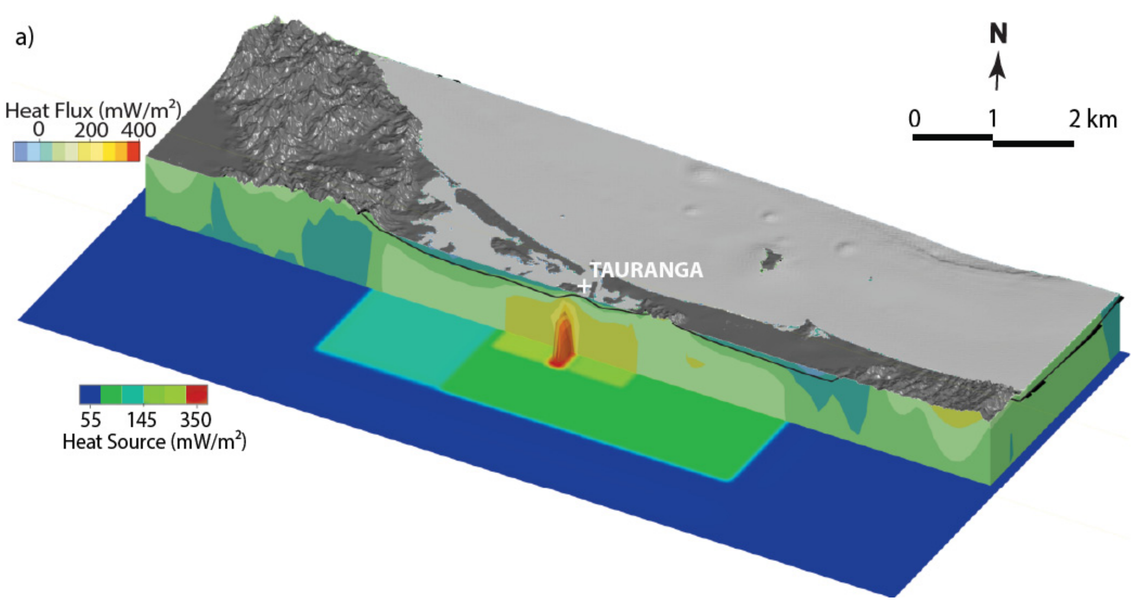

Figure 5. Heat flux in the study area with ten times vertical exaggeration. Heat flux at the source at depth (bottom layer) and resulting heat flux are highest under Tauranga City (red).

3.3 Extraction and withdrawal

Current resource consents have been given by Bay of Plenty Regional Council for the extraction of warm groundwater in a total of 106 wells in and around Tauranga City (Figure 6). None of these were wells with temperature information that were used in the calibration of the model. In 18 of the extraction wells, reinjection of waste water is also required. In the remainder, excess water is discharged to the ground surface or to the storm-water system. There are three types of use for these wells; commercial, irrigation and residential, assumed to be 365, 155 and 90 days per year respectively. Actual usage data is not available, but is thought to be less than half of allocated volumes (Barber, March 2012). The natural-state model developed above was used to estimate the effects of this extraction and reinjection by adding sources and sinks as appropriate. Allocated use was modelled, as were 50%, 20% and 10% of allocated use.

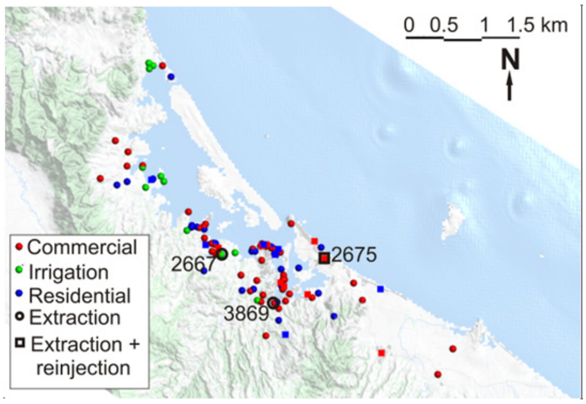

Figure 6. Locations of wells with allocated extraction, or extraction and reinjection. Numbers correspond to the well names used in the text.

4. RESULTS

Modelling shows that with current consented extraction rates, the temperature in the well with the highest rate (well 2675) will drop to less than 5°C after 38 years of extraction (Figure 7a). Pressure decreases rapidly for about three months but then stabilizes (Figure 7b). If the usage rate is 50% of that allocated, the temperature cools completely after 175 years of extraction (Figure 7a, red line), while the pressure response is similar to that of the higher extraction rate (Figure 7b, red line). For 20% and 10% of allocated use, the model runs for the full 400 years and although there is a decrease in temperature and pressure, it is by less than 10% of original temperature and 60% of original pressure (Figures 7a and 7b).

With wells that have smaller extraction rates, for example, wells 2667 and 3869, the pressure still drops significantly but the temperature is only affected by 1ºC or 2°C (Figure 7c-f). The pressure always appears to decrease rapidly over the first three months and then remain stable, while the temperature response is much slower and more consistent.

For larger wells like 2675, there appears to be a distinct pattern in the temperature decline (Figure 7a). Initially the temperature decreases gradually, but then it drops dramatically over the space of a few years and the model halts prematurely, showing that allocated usage rates are not sustainable. Therefore temperature is a better indicator of failure in a well than pressure, which restabilises over time but at a lower value. With the currently estimated 10% of consented use, this threshold for failure is never reached and usage appears to be sustainable.

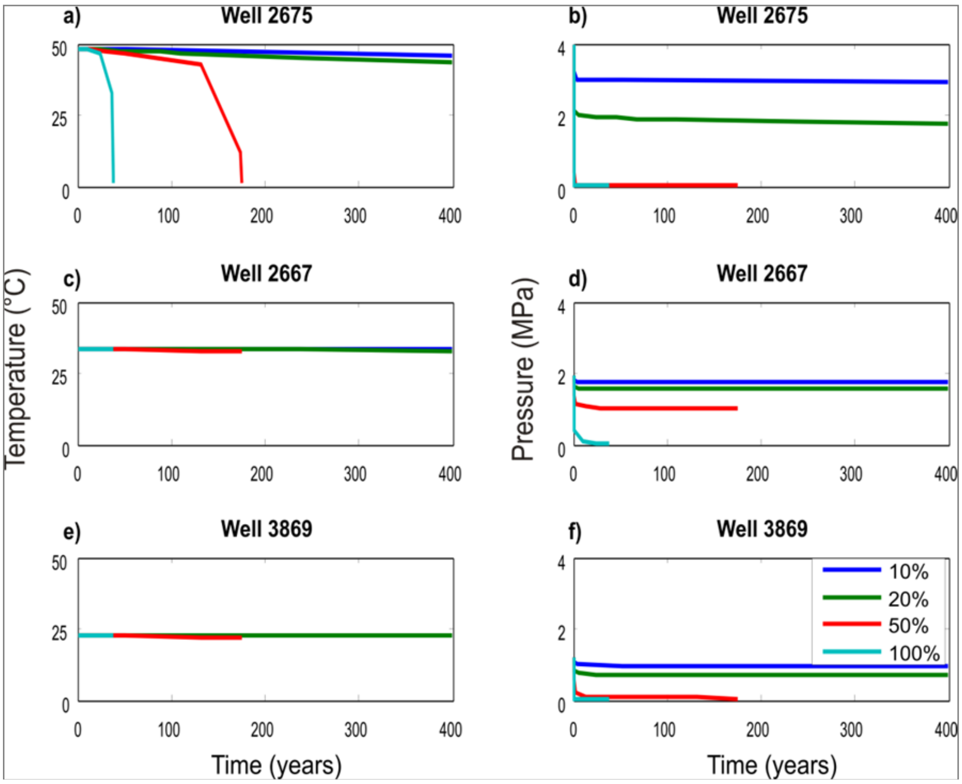

Figure 7. Effects of withdrawing warm water on temperature (left) and pressure (right) in the cell where water is extracted. Results from three wells (Figure 6), with allocated extraction rates of 31 kg/s (well 2675) and 3.5 kg/s (wells 2667 and 3869). Different colours correspond to the different percentages of allocated use modelled (see legend bottom right).

5. DISCUSSION

Modelling suggests that with current consented rates, wells would be cooling down and losing pressure to unsustainable values after 38 years. However, some wells in the area have been extracting fluid for 40 years and therefore actual use is likely to be less than consented use. If actual use is 100% or 50% of allocated use, temperatures and pressures will reach unsustainable levels on decade to century timescales. However, if allocated rates are decreased to 20% or 10% (the estimated actual use), at least 40% of the original pressure and 90% of the original temperature are retained over the 400 years as modelled.

As the Tauranga geothermal system is primarily conductive, the effects of extraction appear to be quite localised. The model shows that the temperatures and pressures will drop in the 1 km^2 area surrounding the well and will only be slightly affected beyond that. Although pressure decreases more rapidly and by greater amounts than temperature, it appears to restabilise and the system can continue at a lower pressure. Pumping and/or reinjection can mitigate the decrease in pressure also, and therefore temperature is the most effective indicator of stress in an area.

Results are based on the calibrated natural-state model described above. This has some uncertainty associated with it, for example the top boundary condition assumes constant air temperature and rainfall over the time that the natural-state model was run. Changing the air temperature by a few degrees shifted all of the modelled temperatures in the relevant direction but did not affect the temperature gradients which were primarily used to calibrate the model. There was an obvious range of air temperatures that were feasible, and 13°C was found to give the best fit. In contrast, the effects of rainfall can permeate to some depth and therefore change the temperature gradient and overall model calibration. Increasing the rainfall from 1220 mm/yr to 2000 mm/yr, which is still typical of some parts of the study area (White et al., 2009), changes the R^2 value by only 0.2%. Therefore the effects of varying rainfall were assumed to be negligible in this study.

Assuming only two homogeneous rock types is a large simplification. Most of the temperature profiles are approximately linear with depth, corresponding to a conductive profile, but some have small changes in gradient suggesting the onset of convection (Figure 4), which may be related to a change in rock properties or in heat flux as modelled. Modelling a more complex rock property distribution is not justified with the current dataset, but future work could include collecting more temperature profiles at key areas to allow the model to be refined.

6. SUMMARY AND CONCLUSIONS

A TOUGH2 model was created to study heat and fluid flow through the Tauranga geothermal system. The model focuses on a 60 km by 40 km area and was calibrated against temperature profiles from 17 wells. Another 20 wells with profiles and 417 wells with spot downhole measurements were used to validate the model. It shows that the system is primarily conduction-dominated, with higher heat flux under Tauranga City. The calibrated model shows a good agreement between measured and modelled temperatures, with an average misfit of 1°C, a standard deviation of 9°C, and an R^2 value of 0.9.

The Tauranga geothermal system provides energy that has been used for over 40 years and continues to be used for commercial, irrigation and residential uses. Modelling the consented extraction and reinjection rates in 106 wells suggests that with estimated use of 10% of consented use, pressures will drop by less than 25%, and temperature by less than 5%. Pressures appear to drop rapidly over a few months and then restabilise at a lower value, while temperatures decline slowly and consistently over time. However, modelling allocated use reveals that the temperature in the well with the highest extraction rate decreases completely in as little as 38 years. Effects appear to be localized, but severe. Therefore it is important that areas with higher allocated usage are studied and monitored in more detail.

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