Problem summary

The Rotorua geothermal system has been exploited by the residents of Rotorua region for free access to hot water for heating and bathing purposes, consequently leaving the Rotorua geothermal system with abundant shallow bores drilled that lead to decreased pressure in the field and Waikite geysers in poor conditions. In hopes to rehabilitate the geothermal system, a borehole closure system was enforced in 1986; the internal pressure of the Waikite geothermal field is slowly recovering thanks to a moratorium imposed by Bay of Plenty Regional Council. Production rates have decreased, reinjection rates have increased, and the internal pressures of the well are stabilizing and even slowly recovering. The problem now is how to manage this recovering natural resource going into the future.

Stakeholders include the Rotorua City Council, who have entered an application to the Bay of Plenty Regional Council detailing their wishes to extend the moratorium as it is. Another is the local iwi (Tūhourangi Ngāti Wāhiao), who wish to see a permanent closure of all boreholes. Lastly, the local Chamber of Commerce, representing local hotels, also opposes the city council's application and wants more boreholes re-opened to install geothermally heated baths.

In short, the three options for resource consent are to

a) maintain the current moratorium
b) stop extracting from all boreholes, or
c) relax the constraints of the moratorium or even remove the moratorium altogether.

Our objective is to formulate an appropriate model of the Waikite geothermal well/s, as subjected to different parameters relative to the three resources consent options. This model will serve as a predictor of future conditions of the well, and ultimately it will help in the decision-making process of the local government, Bay of Plenty Regional Council.

Contribution of modelling study

The council is unsure which of these solutions is the best to proceed with. Using historical data of situations similar to the proposed plans of action, we can model how each different situation would affect the future of the geothermal reservoir, namely the heat, water level and pressure. Using this model with different parameters a decision can be made to ensure the most important stakeholders are satisfied.

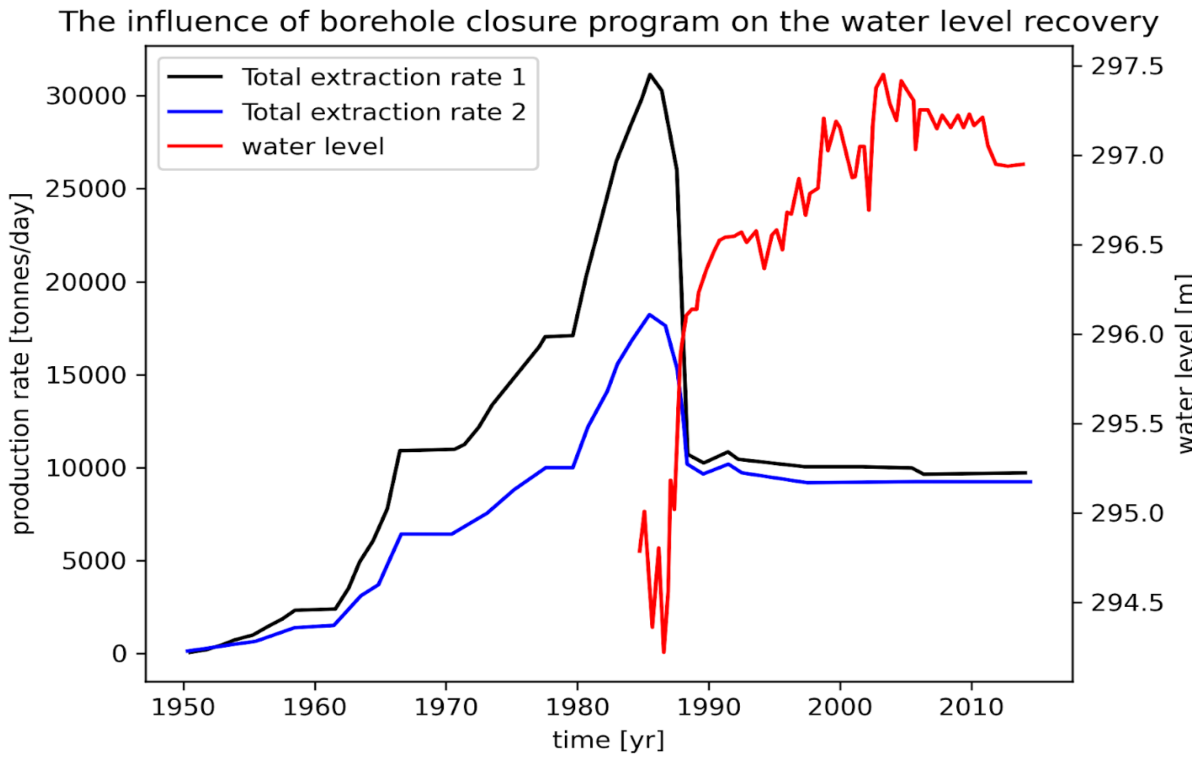
The insight we expect from the models is:

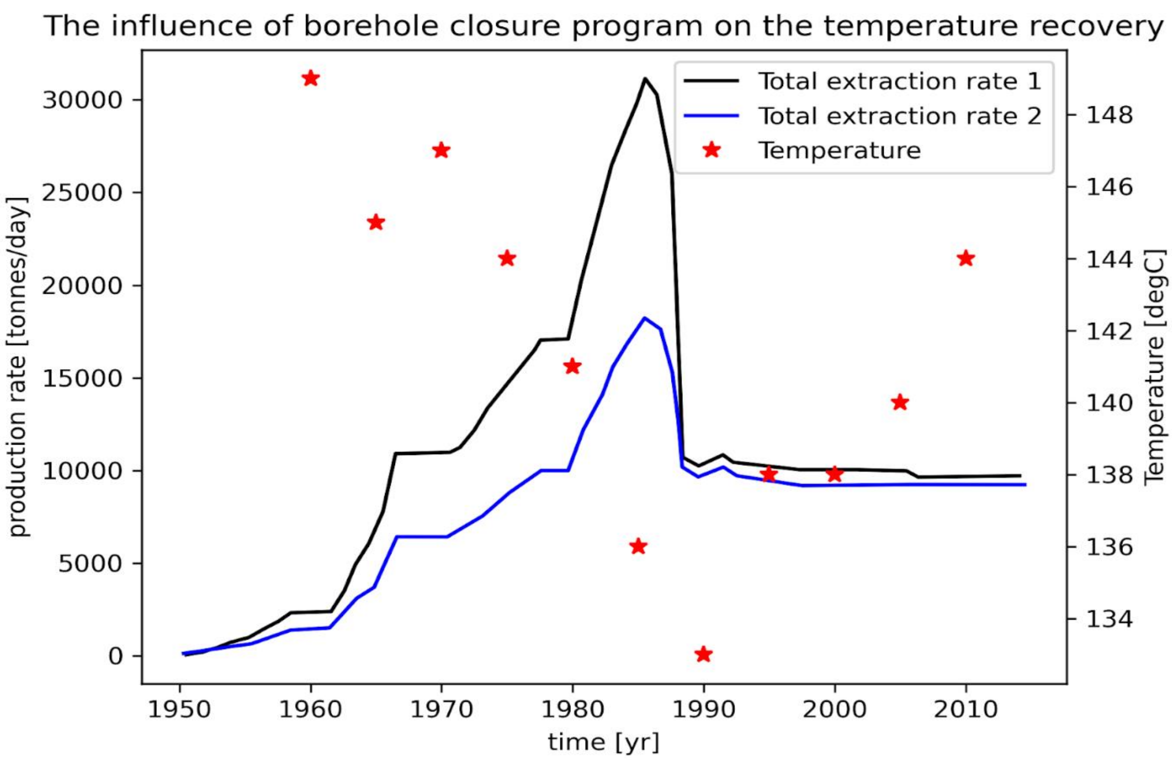
- How the system will react to the addition/removal of borewells
- How the system will respond to different rates of production (extraction)
- How the system will respond to different rates of re-injection of cold water
- How the system will recover if left in its current state

Relevant parameters:

Initial Conditions (from 1990):	Boundary conditions:	Control Volume:	Physical quantities:
Production rate ~ 10,000 t/d	Reinjection water temperature ~ 30°C	Model with reservoir, water level, in Whakarewarewa region	Conversation of mass
Water Level ~ 295m			Conversation of energy
Temperature ~ 134°C			Darcy's law (Darcy's law defines how water and steam move underground)
Reinjection rate ~ 1500t/d			

Data visualization





Data description

We have been given .txt files of data recording:

a. Temperature of reservoir from 1960-2010
b. Production rate from 1950-2014 from two different boreholes
c. Water level of reservoir 1984-2014

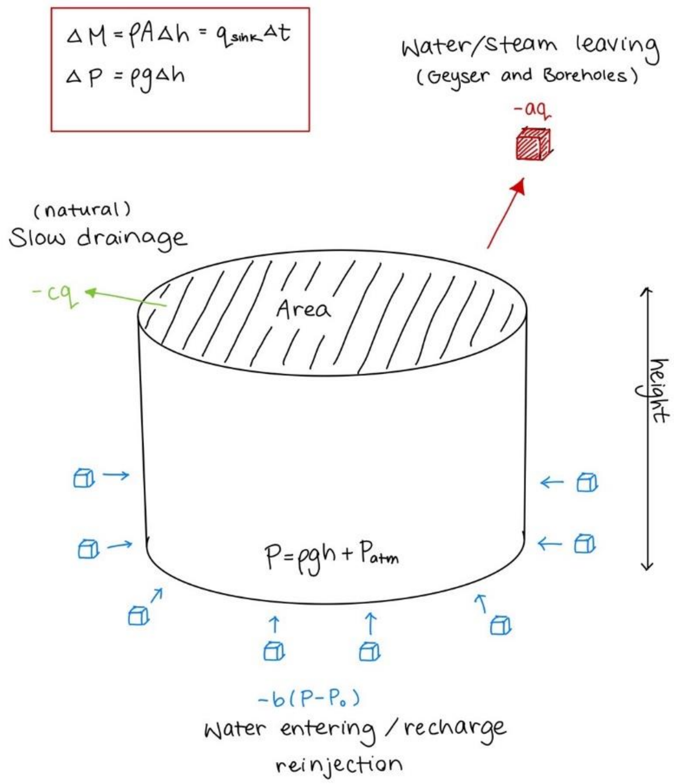
The data shows that the reservoir production rate decreased due to the Borehole Closure Program; there was a rapid decline in production rate from 1986, when the borehole closure program began, to 1990. This led to an increase in reservoir water levels (and thus, pressure). Temperature in the reservoir also increased as a result of reinjection and the decreased extraction rate. To summarise, temperature of the reservoir was inversely proportional to production rate before the borehole closure program in 1986, and the pressure and temperature increased after production rate remained constant from 1990.

Based on data in the article of Scott (2005) and Mroczek (2015), we have assumed that water level data is from the M16 well, and that production rate data are from wells M12 and M16. Based on the GNS Science Consultancy Report titled “Rotorua Geothermal Bore Water Level Assessment - 2014”, we have concluded that M12 well is at Rotorua Hospital, and M16 well is at the Alpin Motel on Sala Street (Kissling, 2014).

We’re missing data on the water level of the reservoir before the closure program began. This is important as we need a reference point of the pressure before overproduction occurred. The “Recovery of Rotorua geothermal field, New Zealand: Progress, issues and consequences” article has graphs of M16 well and two other wells, M12 and M6, where water level data extends back to 1983 (Scott, 2005). The water level in M12 and M6 was sinusoidal before the recovery project in 1986, and then pressure significantly increased once reservoir recovery began.

The ‘Recovery of Rotorua geothermal field, New Zealand: Progress, issues and consequences’ article lists 4 re-injection rates in 1985, 1992, 2001 and 2005, forming a step function of re-injection rates (Scott, 2005). It is important to find a correlation between reinjection rate and the pressure of the field in order to recommend a model (this data is not specific to a particular borehole, whereas other data are).

Conceptual model sketch



Conceptual model justification

To simplify our model, there are a few assumptions to be made. This would allow us to visualise the ODEs needed specifically for our problem.

The physical processes that are used in our model are the Conservation of Mass and the Conservation of Energy. These conservation laws are used to portray the ODEs on pressure and temperature respectively for the Rotorua Reservoir. These laws are necessary for our model as we wish to find the change in the pressure considering both the temperature and the water level.

The Conservation of Solute will be ignored for our model as our main focus is on the change in pressure and temperature rather than the concentration of water in the reservoir.
To further simplify our model, we will assume that there is only one inflow to the control volume. This would consider both the natural recharge of water and the reinjection of water by human.

Conceptual model formulation

Conservation of Mass LPM ODE (with drawdown, recharge, slow drainage effect)

$$\frac{dP}{dt} = \underbrace{-a_P q_{sink}}_{\text{forcing term}} \underbrace{- b_P(P - P_0)}_{\text{restoring term}} \underbrace{- c_P \frac{dq_{sink}}{dt}}_{\text{slow drainage}}$$

$constants: \quad a_P, b_P, c_P, P_0 (initial\ pressure)$

$q_{sink}: extracting\ mass\ rate$

$p: \ pressure$

$t: time$

$\left(a_p = \frac{g}{A\phi},\ where\ g\ is\ acceleration\ due\ to\ gravity, A\ the\ area, \phi\ is\ volume\ fraction\right)$

$\left(b_p = \frac{gk\rho A_{rech}}{A\phi\mu L},\ where\ g\ is\ acceleration\ due\ to\ gravity, k\ is\ permeability, \rho\ is\ density, A_{rech}\ and\ A\ are\ areas, \phi\ is\ volume\ fraction, \mu\ is\ dynamic\ vicosity, L\ is\ length\right)$

Conservation of Energy LPM ODE

$$\frac{dT}{dt} = \underbrace{\frac{T}{M} q_{sink}}_{\text{flow out}} \underbrace{- \frac{b_p}{Ma_p}(P - P_0)T}_{\text{pressure flow}} \underbrace{- b_T(\mathrm{T} - T_0)}_{\text{conduction}}$$

$constants: \quad a_P, b_P, b_T, M, T_0\ (initial\ temperature), P_0\ (initial\ pressure)$

$q_{sink}: extracting\ mass\ rate$

$T: \ temperature$

$p: \ pressure$

$t: time$

$\left(b_T = \frac{\Upsilon}{\rho c V},\ where\ \Upsilon\ is\ heat\ transfer\ cofficient, \rho\ is\ density, c\ is\ specific\ heat\ capacity, V\ is\ volume\ of\ water\right)$

References

Scott, B.J. et al.(2005). Recovery of Rotorua geothermal field, New Zealand: Progress, issues and consequences. ScienceDirect. https://www.sciencedirect.com/science/article/pii/S0375650505000143

Mroczek, E.K. et al.(2015). The Rotorua Geothermal Field: An experiment in environmental management. ScienceDirect. https://www.sciencedirect.com/science/article/pii/S0375650515001145

Kissling, W.(2014). Rotorua Geothermal Bore Water Level Assessment – 2014. GNS Science Consultancy Report. https://cdn.boprc.govt.nz/media/395573/rotorua-geothermal-bore-water-level-assessment-2014.pdf