IMPROVED VISUALIZATION OF RESERVOIR SIMULATIONS:
GEOLOGICAL AND FLUID FLOW MODELING OF A HIGH-TEMPERATURE
GEOTHERMAL FIELD IN NEW ZEALAND

Sophie C. P. Pearson and Angela Prieto

GNS Science
Wairakei Research Centre, 114 Karetoto Rd
Taupo 3384, New Zealand
e-mail: s.pearson@gns.cri.nz

ABSTRACT

Geothermal energy has been used for electricity production in New Zealand for decades. Our study area, a high-temperature geothermal field in the center of the North Island of New Zealand, has been developed for electricity for over ten years. Previous models have tried to replicate the field, but some unexplained complexity has remained. By creating a Leapfrog Geothermal geological model and incorporating it into a TOUGH2 reservoir model, a detailed simulation of the system can be created that represents more realistic geology. Outputs from the TOUGH2 model can then be read back into Leapfrog Geothermal, facilitating direct comparison between measured and modeled temperatures, and highlighting regions that need to be better modeled.

The geological model of our study area incorporates 20 volcanic units, interpreted from topographic data, surface feature locations, regional and local geological maps, stratigraphic interpretations from geothermal drill hole data, and regional 3D geological models. There are a number of faults trending N, NE, and NW. Although this level of detail cannot be replicated directly in a TOUGH2 model, or is necessary given the sparsity of data, starting from a more realistic geological model will improve the TOUGH2 model and allow future study of the effects of geology, for example including distinct, discrete rhyolitic domes.

INTRODUCTION

Numerical models of geothermal fields in New Zealand are industry standard for assessing energy potential, constraining upflow zones, and satisfying resource consent requirements (O'Sullivan, Pruess and Lippmann 2001). Numerical simulations using specialized software like TOUGH2 (Pruess 1991) provide significant information, but are limited by a lack of good visualization tools that would make the models easier to understand and disseminate to a wider audience. By combining TOUGH2 software with 3D modeling software like Leapfrog Geothermal, inputs can be more easily visualized, and outputs can be compared with both the original model and any other datasets like well temperature, lithology or surface features. This helps to create more accurate models and to vastly improve the way that model results can be visualized and shared.

Geothermal areas are located throughout New Zealand (Figure 1), providing approximately 13% of electricity generation and up to 19% of total primary energy (Statistics New Zealand 2012). Geothermal fields are, therefore, an important energy source for the country. High temperature fields that produce electricity are concentrated in the Taupo Volcanic Zone (TVZ), which runs up the center of the North Island (Figure 1). Eight of these 29 fields, including our study area (Figure 2), are used for energy production.
Our study area is located in the center of the North Island of New Zealand. It was first explored over 20 years ago and has some of the hottest recorded downhole temperatures in the country (New Zealand Geothermal Association 2009). Due to the relatively few scenic areas and the complete lack of unusual, fragile, or unique features, it was deemed fit for development, and a power station has now been operating for several years. There are some complexities to the field that have proved difficult to replicate in numerical models, and geophysical data has also been collected that is not routinely included. In this study, therefore, we create a Leapfrog Geothermal geological model of the field and export this into TOUGH2 to create as accurate a model as possible. We also set up the model so that future work can easily incorporate calibration with traditional data like well temperatures, and other geophysical parameters, like microgravity.

**GEOLOGY**

**Geologic Setting**

The Taupo Volcanic Zone (TVZ) is uniquely situated above the oblique subduction of the Pacific plate beneath the Australian plate (Cole and Spinks 2009). Because of the obliquity, the TVZ is extending at about 8 mm/yr to the NW-SE (Darby, Hodgkinson and Blick 2000), with a thin, rifted crust, and is the most active rhyolitic system on Earth (Houghton, et al. 1995). Our field comprises more than 20 volcanic units overlain by some sparse sediments (Figure 3). The volcanic units are primarily Pleistocene and Holocene volcanoclastic rocks. The area is quite strongly faulted, with three dominant trends to the NE, N and NW (Soengkono 2011).
Leapfrog Geothermal
Leapfrog Geothermal is a 3D modeling and visualization software package developed by ARANZ Geo (Christchurch, New Zealand), with input from GNS Science (Wairakei, New Zealand), University of Auckland (Auckland, New Zealand), and Contact Energy Ltd (Wairakei, New Zealand). It is an integrated interface that allows the development of conceptual and quantitative geological models (Alcaraz, et al. 2012). It incorporates lithology, structure, faulting and well data, as well as allowing geophysical and other information to be saved within the well data information.

As well as creating detailed geological models, it allows surfaces to be exported in a number of formats, including x,y,z, so that they can be imported into other software for further calculations like heat and fluid flow models. As data can also be imported directly from TOUGH2 (Newson, et al. 2012) or as x,y,z,T (for example), TOUGH2 model outputs can then be plotted against the geological model, allowing measured well temperatures, isotherms interpreted from the well temperatures, and isotherms from the reservoir model to be compared directly. This not only makes the outputs easier for a non-modeler to understand, but allows much easier and more direct comparisons for improving the fluid flow models.

Geological Model
The 3D geological model of our study area was built incorporating topographic data, surface feature locations, regional and local geological maps, stratigraphic interpretations from geothermal drill-hole data, and regional 3D geological models. It extends to 2600 m depth, the depth of the deepest well. It comprises a number of layers, with thick sections of ignimbrites filling the active basin to the SE, intercalated with rhyolite domes and lavas (Figure 4). There is no local evidence of the deep greywacke basement found in other geothermal fields of the region. The model includes a number of high-angle normal faults dipping to the SE that correspond to the western side of the Taupo Rift (Figure 5).
effects of extracting energy. The Leapfrog Geothermal software and TOUGH2 will be used to create a numerical model of this system.

**TOUGH2-Leapfrog Interface**

The most recent update to Leapfrog Geothermal interfaces with TOUGH2 files directly to facilitate visualizing inputs and results of the model. It works with traditional TOUGH2 from Lawrence Berkeley National Lab (Pruess 1991) or with AUTOUGH2 from University of Auckland, New Zealand (O’Sullivan 2000). It can also be used to create and populate the grid, and the resulting model is exported to run with

TOUGH2. The TOUGH2 output file can then be imported back into Leapfrog to view results and compare them with input data and any relevant local measurements. Leapfrog enables easy visualization of model temperatures or pressures—for example, allowing isotherms to be modeled, cross sections or slices of data to be plotted, and viewing angles to be changed easily (Figure 6). Future discussion may also include time-varying plots.

![Figure 6. Example of a Leapfrog Geothermal plot of TOUGH2 output temperatures (solid isotherms) compared to measured well temperature data (solid squares) from the Tauranga geothermal field, New Zealand.](image-url)
FUTURE WORK
Future work will be to create the complete TOUGH2 model from the Leapfrog Geothermal geological model, and to populate it with relevant parameters. The model will be run and calibrated against measured data like well temperatures (both with depth and time). The goal is to use iTOUGH2 to find the best-fit model, and then to further refine it based on microgravity data collected in the region over the last several years.

CONCLUSIONS
Combining Leapfrog Geothermal with a TOUGH2-Petrasim model facilitates the creation of a more realistic model, visualization of model outputs, and comparison of model outputs directly with well data. This not only makes the modeling process easier, but also helps when disseminating TOUGH2 models to a non-specialist audience. Our study area provides a perfect case study, as there are a number of wells with temperature measurements down to kilometers depth collected over a period of years. Microgravity data in the area also provides an ideal opportunity to further calibrate the model, hopefully creating a model that can replicate the available data and provide a realistic simulation of the geothermal field, so that the field can be used sustainably and optimally for the foreseeable future.

REFERENCES


