Inverse modelling of the Wairakei geothermal field

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1 Introduction

Wairakei is a liquid dominated geothermal field in the middle of the North Island of New Zealand. It has been in production for 40 years and currently produces 157 MWe. The authors have developed several models of Wairakei for Contact Energy Ltd, the field operators. The model currently being used for field management has 1417 blocks. It is more detailed than previous models, particularly around Tauhara. Tauhara is a second geothermal field to the south-west of Wairakei that is connected to Wairakei (see Figure 1). The development of Tauhara is currently being considered and the affect of this on Wairakei and vice versa is being investigated. Inverse modelling using ITOUGH2 [1] was carried out to help calibrate the enlarged model.

In the following section the 1417 block model will be described. The field data used in the inverse model is detailed in the third section. The last section explains how the inverse model was used to help improve the 1417 block model and what was learned about inverse geothermal modelling.

2 Model description

A brief description of the model is given here. A fuller description is given in the accompanying paper [2].

The model has 118 columns. The layout of the columns and their relationship to the field are shown in Figure 1. The large columns in the outer ring are outside the reservoir and are there to maintain time constant pressures and temperatures at the reservoir boundary. The model extends from the top of the reservoir (varies, approximately 400 m above sea level) to 2500 m below sea level and is divided into 12 layers (thicknesses shown in Figure 2). The thicknesses of the blocks in the top layer vary to represent the top of the reservoir which is assumed to approximately follow the topography of the ground surface. There is a single "wet" atmosphere block.

Heat sources are placed in the bottom block of each column to reproduce the background geothermal gradient. Mass sources are placed in the bottom blocks of some columns to represent the upflow zones. During production the rates for these mass sources vary depending on the pressure in the block to account for production induced recharge. Well tables for the 106 production wells were set up using field data.

3 Inverse model description

A large amount of field data has been collected for Wairakei-Tauhara. The following data were included in the inverse model

Figure 1: A map of Wairakei-Tauhara showing the column layout

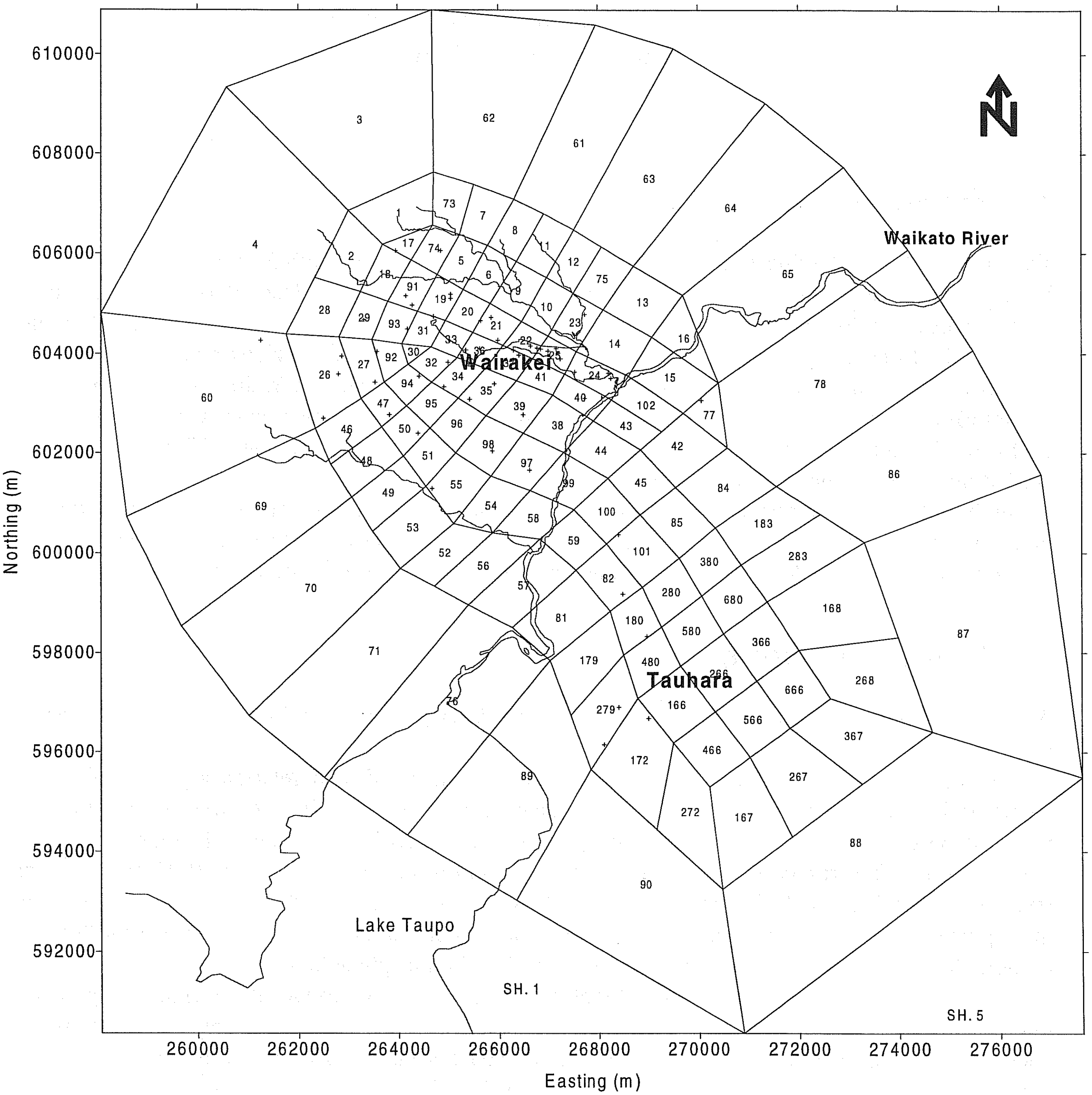
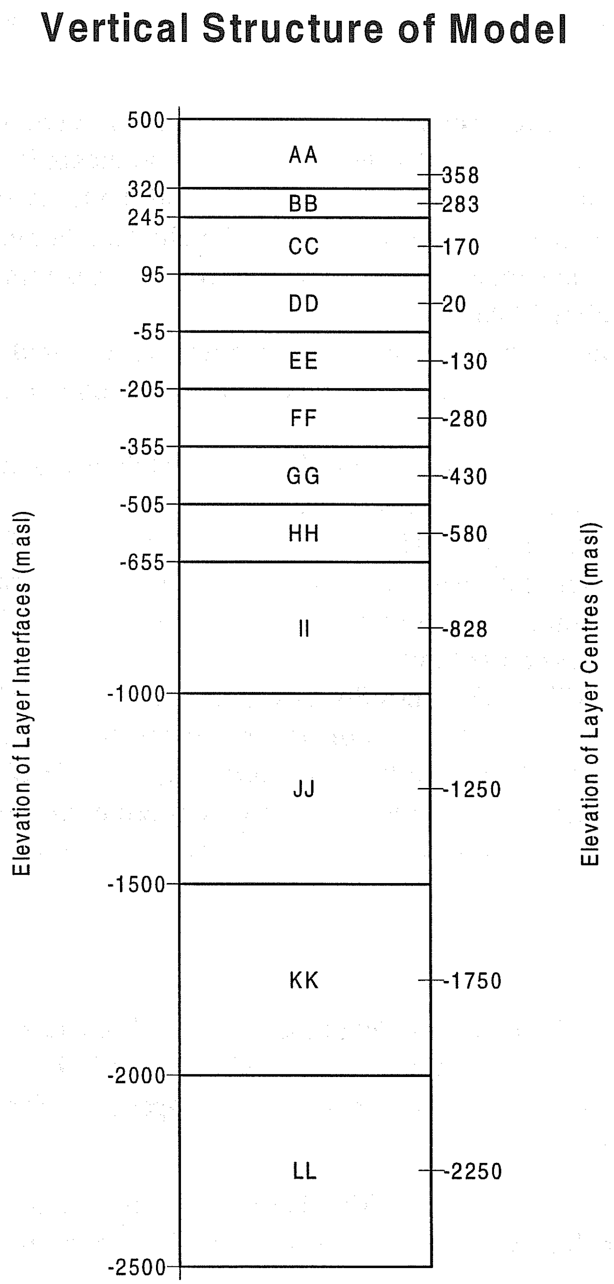


Figure 2: The model layers



- Well temperature profiles. These were available at different times for different wells. They were assigned to the column containing the well and linearly interpolated to give values at layer centres.

- Well pressure time histories. These were assigned to the block containing the well feed zone and adjusted, assuming a hydrostatic pressure gradient, to the block centre.

- Well flowing enthalpy time histories. These were assigned to the block containing the well feed zone.

The calibration of the Wairakei model by hand has proceeded in two stages - natural state modelling and history matching. In the natural state matching, the permeability structure and the deep hot inflow (location and magnitude) in the model are adjusted and the temperature distribution and surface outflows (location and magnitude) are compared with field data. For history matching, the model permeabilities and porosities are adjusted and pressure declines, temperature changes and production enthalpies are compared with field data.

Both processes are iterative. In fact a cycle of iterations is followed, with several iterations of the natural state followed by iterations of history matching and then a return is made to recheck the natural state.

ITOUGH2 allows both stages (natural state and history matching) to be used in one evaluation of the goodness of fit measure and this feature was used.

Some experimentation was required with the weighting factors used for combining the different types of field data into the overall measure of goodness of fit in order to make ITOUGH2 work well. The L1 error estimator (maximum absolute error) was used instead of the L2 error estimator (sum of squared errors) because it is less biased towards outliers.

ITOUGH2 was run on a Silicon Graphics Power Challenge with 16 R10000 processors and 2 GB of memory. This machine was used because of its large memory and not because of the multiple processors (only one was used). As part of its post-processing, ITOUGH2, calculates the correlation matrices which are very large for this problem. The memory requirements could be reduced by not using some of the post-processing. It is intended to investigate ways of parallelizing ITOUGH2.

4 Results

Most of the work with ITOUGH2 on the model of the Wairakei-Tauhara system was carried out when a coarse grid model (301 blocks) was refined overall and particularly in the Tauhara area, to produce a model with 1417 blocks (described in the accompanying paper [2]). The aims for the recalibration of the 1417 block model were

- To maintain or improve the fit to the Wairakei data. In particular the matches to production enthalpy and pressure drawdown for the Western Borefield (columns 20, 21, 33 and 36).

- To include the Tauhara field data.

- To experiment with conceptual models of the connection between Wairakei and Tauhara.

Some preliminary runs with ITOUGH2 showed up a problem with the location of the feed zones of some wells in the model. The difficulty was highlighted by an apparent failure of ITOUGH2 to improve the match of model results for production enthalpy from some wells to field data. This was because the initial placement (based on estimates of feed elevation) had wells with vastly different boiling characteristics (if and when they boiled) in the same block. The practical solution to this problem was to move the offending wells up or down a layer.

ITOUGH2 was then used to vary the following groups of parameters (each group was included in a separate ITOUGH2 run)

- The rates and enthalpies for the wells that represent the deep upflow at Wairakei.
- The permeabilities in the Wairakei production zone (layers DD, EE and FF).
- The recharge coefficients for the deep upflow (these control how much a change in pressure during production changes the recharge rate).

At Tauhara, there is much less field data available than at Wairakei. The data used for calibration was

- Temperature profiles from 4 deep wells. These were included in the ITOUGH2 input file.
- Locations of surface outflows. This is qualitative data and was not included in the ITOUGH2 input file.

The conceptual model of Tauhara includes high permeability, due to faulting, which runs south-west to north-east. This was included in the model and the permeabilities for the rock types representing this faulting was one of the groups of parameters varied using ITOUGH2. The other group was the flow rates and enthalpies for the wells representing the Tauhara upflow zone.

The conceptual model for the Wairakei-Tauhara connection has the connection leaving Tauhara at a fairly shallow elevation and then taking a step down into Wairakei near Karapiti (columns 55 and 98). There are a few wells between Tauhara and Wairakei and these were used for calibration. The parameters varied were the permeabilities of the connection rock types. To obtain a satisfactory match the connection had to be moved deeper.

The general mode of operation for ITOUGH2 was as follows:

- To include all the field data in the ITOUGH2 input file.
- To vary a small group of parameters (not more than 20 and usually less 10) related to a particular feature of the model.
- To look in general at how much the goodness of fit measure changed and to look in detail at the change in how the model fitted the feature of interest.

The number of parameters varied in an ITOUGH2 run is restricted partly because of the computation time, but mainly because if too many parameters or insignificant parameters are included the minimization procedure "flops" around and does not make progress. Another important component of the inverse modelling is the choice of weights for the field data. If this is incorrect then the match to one part of the data may be improved, but the match to another part may become unacceptable.

In the calibration of the 1417 block model both "hand" calibration and ITOUGH2 were used. This combined process proved to be very effective. Human interaction was necessary to choose groups of parameters and weighting factors for groups of data, while ITOUGH2 quickly sorted out the optimal choices for parameter values. Human intuition and commonsense is still required to sort out strategies for model improvement which require more than parameter adjustment, for example the relocation of feed zones that was discussed above.

In the combined process of manual calibration and computerised calibration, the sensitivity data provided by ITOUGH2 proved to be a useful aid in decision making. The sensitivity data was used to decide which parameters to discard so that others could be included in the limited size parameter set for a new ITOUGH2 run.

The current version of the 1417 block model of the Wairakei-Tauhara system matches the data for both Wairakei and Tauhara well.

References

[1] Stefan Finsterle. ITOUGH2 User's Guide, Version 2.2. Technical Report LBL-34581, Earth Sciences Division, Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, CA94720, 1993.

[2] M.J. O'Sullivan, D.P. Bullivant, S.E. Follows, and W.I. Mannington. Modelling of the Wairakei-Tauhara geothermal system. TOUGH Workshop '98.