Modelling of the Wairakei - Tauhara Geothermal System

M.J. O'Sullivan[1]*, D.P. Bullivant*[1]*, S.E. Follows*[2] *and W.I. Mannington*[1]

[1] Department of Engineering Science, University of Auckland and [2] DesignPower Genzl,
Auckland, New Zealand

Introduction

The Wairakei - Tauhara geothermal system is located in the centre of the North Island of New Zealand in a large geothermally active area called the Taupo Volcanic Zone. Electricity generation at Wairakei commenced in 1953. A plant with a maximum capacity of 192MWe was installed but the supply of steam has never been adequate to reach this figure. The maximum output achieved was approximately 185MWe in 1964. Output subsequently declined and has now stabilised at a steady value of 157MWe. This output is achieved from a total mass take of approximately 130,000 t/d giving a flow of separated steam of 29,000 t/d.

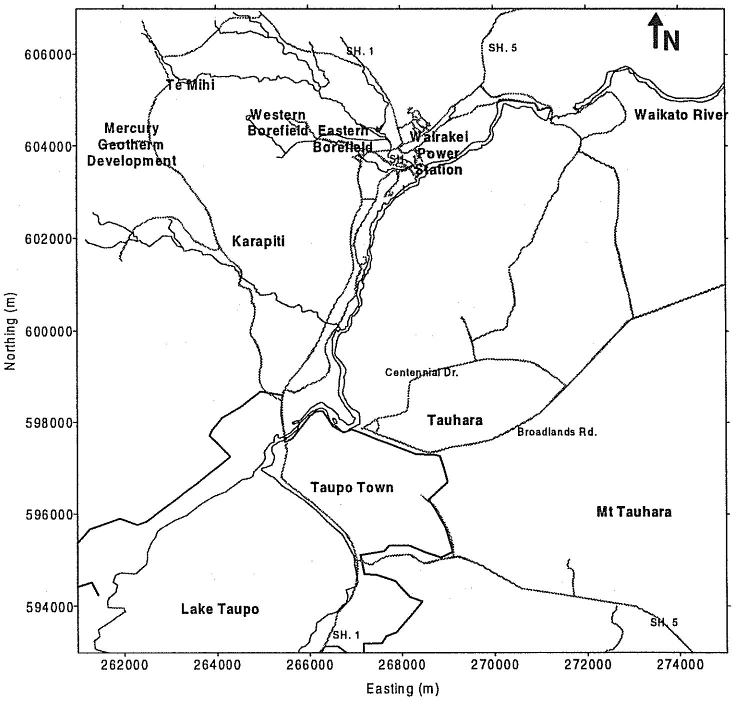

Figure 1 Map of the Wairakei-Tauhara geothermal system

The main hot upflow for Wairakei is in the western part of the field near Te Mihi. In the natural state this hot flow, at 260°C, was diverted horizontally by the low permeability of the Huka Falls formation located between approximately 250 masl and 330 masl (the surface of the Eastern Borefield varies between 380 masl and 420 masl). The capping effect of the Huka Falls formation caused the hot upflow to flow horizontally across the Western Borefield and then to discharge (neutral pH, chloride water) mainly at Geyser Valley in the northwest. There was also some discharge of hot water along the banks of the Waikato River and a small discharge of steam in higher ground at Te Mihi and Karapiti.

Production began in the Eastern Borefield and then spread west into the Western Borefield and Te Mihi. In the natural state almost all of the Wairakei and Tauhara reservoir fluid was hot water but production caused the pressure to drop rapidly (See Fig. 2) and also caused the formation of a steam zone which expanded rapidly vertically and horizontally. This process caused the surface features at Geyser Valley to mostly disappear but in some areas, such as Karapiti, the surface heat flows increased (Allis, 1981).

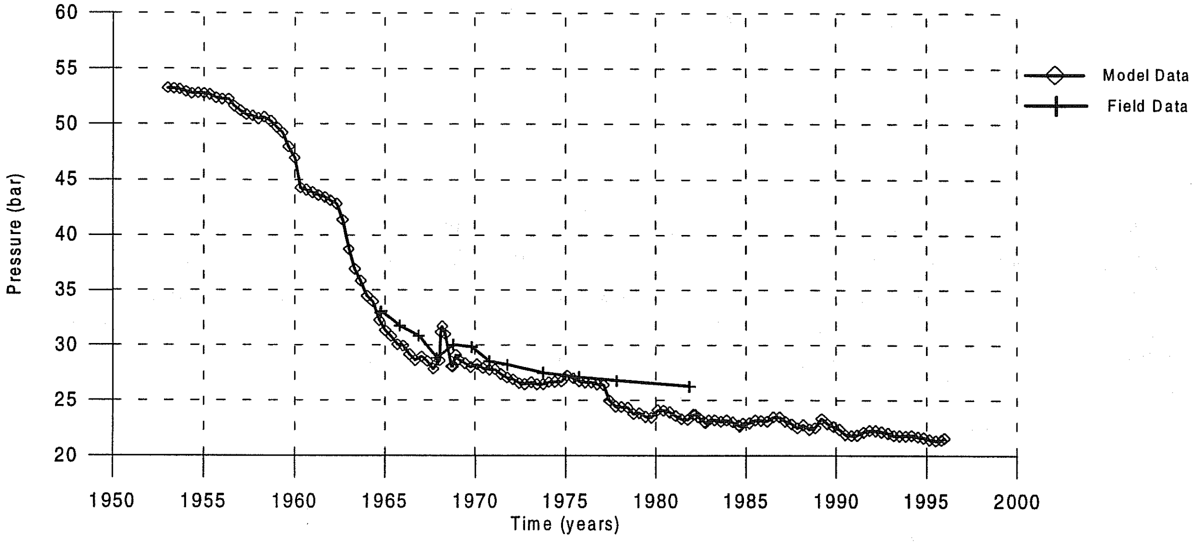

Figure 2. Pressure history for the Western Borefield at Wairakei

Most of the deep wells access liquid water or a wet two-phase zone and in the latter case produce a mixture of steam and water with an enthalpy only a small amount above that for liquid water. The average production enthalpy is shown in Fig. 3. The shallow part of the steam zone has a high steam content and some wells which access it produce dry steam. As Fig. 2 shows the pressure drop slowed down by 1970. This corresponds to the stage when a quasi-equilibrium state had been established at Wairakei - Tauhara with the induced recharge flow matching production.

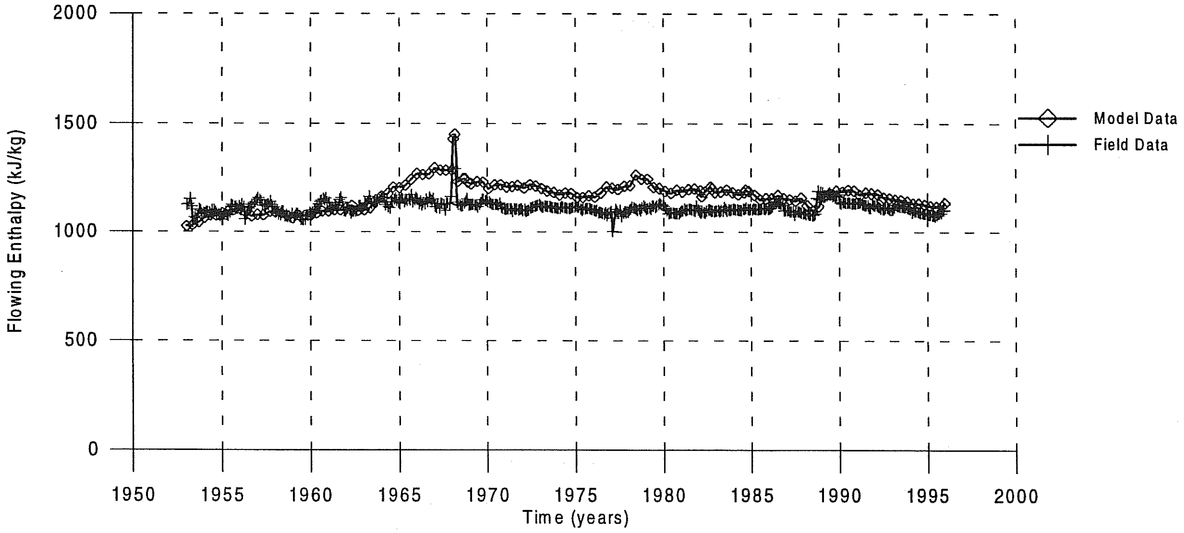

Figure 3. Production enthalpy history for Wairakei

Wairakei - Tauhara is characterised by large permeabilities and the pressure drop extended over a large area with pressures in the Western and Eastern Borefields varying by less than 2 bar. The pressure decline also spread across to the Tauhara part of the system as shown in Fig. 4.

Although mass flows have stabilised temperature declines are continuing as colder recharge fluid moves into the reservoir from the sides and top. Some wells have been "quenched" by this process.

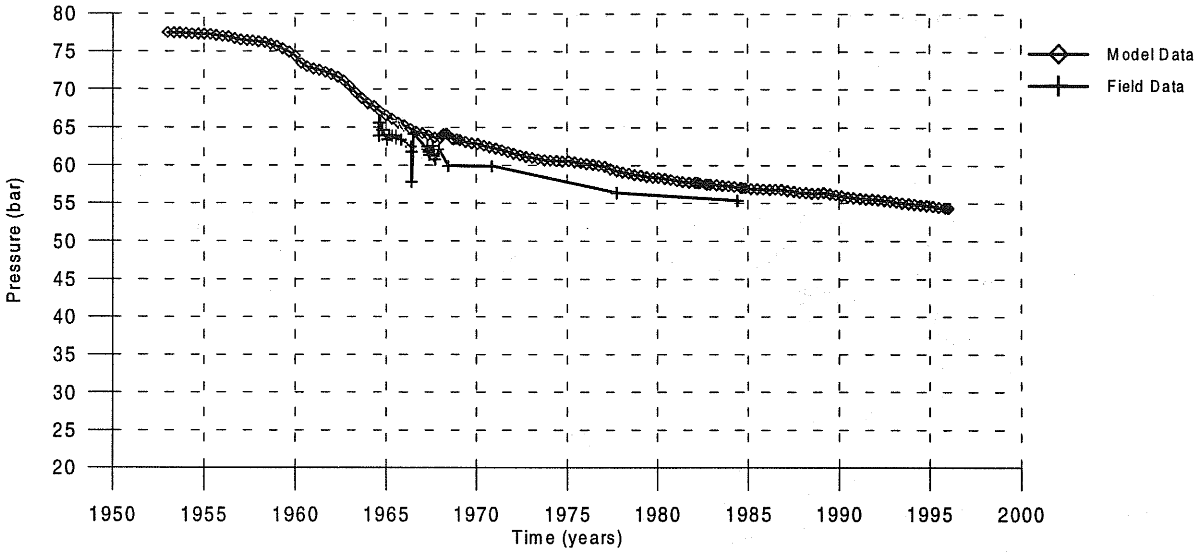

Figure 4. Pressure History for the Tauhara Region

Data

There is a very extensive database for Wairakei. Temperature vs depth profiles are available for many wells although the first available data for some wells is considerably after the start of production in 1953. Maps of pre-exploitation surface features are available although the information is qualitative rather than quantitative. Estimates of the total natural through-flow for Wairakei vary but the generally accepted figures are 400kg/s for mass and 450MW$_{th}$ for energy (Allis, 1981). For Tauhara the heat flow figure is approximately 100MW$_{th}$. Comparison of these figures with the present take of approximately 1650MW$_{th}$ shows that Wairakei is being "mined" for heat.

Measurements on individual wells have been made regularly and records of mass flow, production enthalpy, pressures and temperatures are available. Records of changes for chemicals such as chloride are available and various geophysical surveys have been carried out. Because of the ready availability of data Wairakei was used as a test case in several early computer modelling studies (Mercer and Faust, 1979; Pritchett et al., 1980) and in discussions of methods for geothermal resource assessment (Donaldson and Grant, 1979). A few lumped parameter models were also investigated (Whiting and Ramey, 1969; Fradkin et al., 1981).

The database for the Tauhara region is not as extensive. Only four deep wells have been drilled and monitored.

Model Design and Calibration

Our computer modelling study of Wairakei - Tauhara has been proceeding for many years (Blakeley and O'Sullivan, 1981, 1982) and our models have grown in complexity, partly as our knowledge of Wairakei - Tauhara has improved, but mainly as software and hardware have improved. Our introduction of conjugate gradient solvers into MULKOM greatly increased the number of blocks we could use in our model of Wairakei - Tauhara and also increased the computational speed (Bullivant et al., 1991). The development of very fast, cheap, workstations has also greatly increased computational speed. We currently run our models of Wairakei-Tauhara on DEC Alpha and Silicon Graphics workstations.

The grid for one of our most recent models of Wairakei-Tauhara is shown in Fig. 5. There are 118 blocks per layer and 12 layers giving a total of 1417 blocks (including one for the atmosphere).

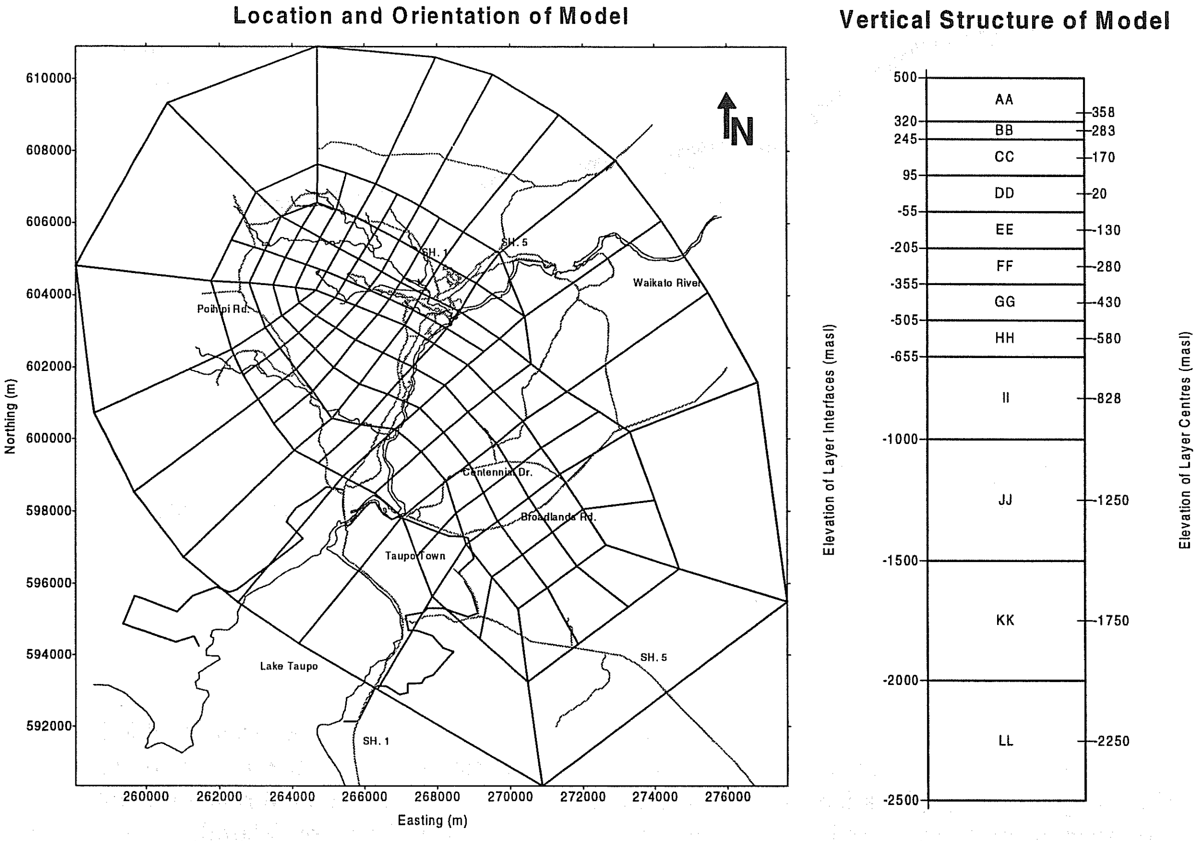

Figure 5. Grid layout for the Wairakei-Tauhara model

The design of this grid was based on several criteria:

(i) The blocks near the Wairakei Borefields are aligned approximately SW-NE along the direction of faults and fractures.
(ii) The adjoining Taupo-Tauhara area is included.
(iii) The boundary of the small blocks in the model corresponds to the resistivity boundary.
(iv) Large "recharge" blocks are included.

It is assumed that the model is sufficiently large so that all recharge at the outer lateral boundaries of the model is negligible and they are treated as closed. At the surface of the model, corresponding to the water table, the temperature and pressure are fixed at atmospheric values. At the base hot water at 260°C is injected over part of the model and a background low heat flow is applied over the rest. During production runs some extra hot inflow at the base is allowed by adding recharge proportional to the pressure drop.

The model is calibrated in two stages, firstly by matching the natural state behaviour and secondly by matching the historical performance (O'Sullivan, 1985). For natural state matching the permeability structure and deep inflows (location and magnitude) are adjusted and the model results are compared with measured temperature profiles and surface outflows (location and magnitude). Some typical results for the calibrated natural state model are shown in Fig. 6.

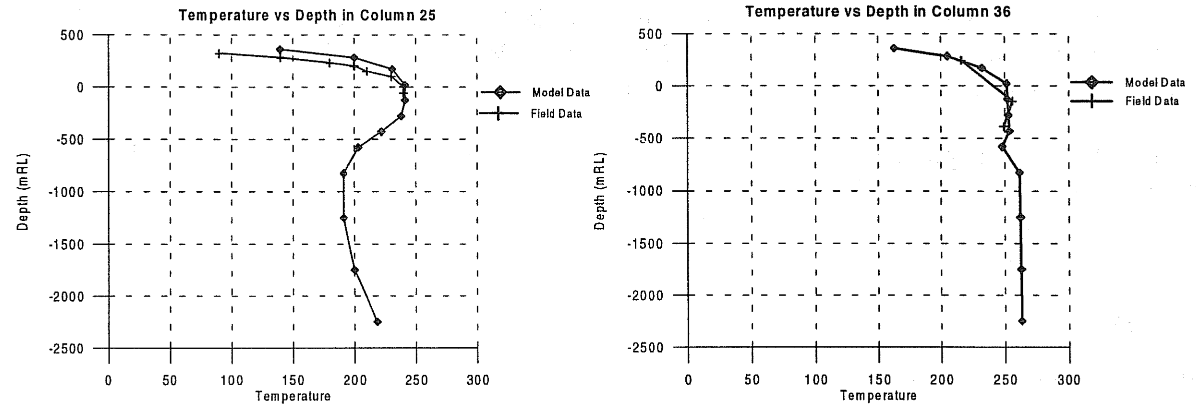

Figure 6. Temperature vs depth in the Western Borefield

For history matching further adjustments are made to the permeability structure and also porosities are adjusted. Model results are then compared with measured pressure declines, enthalpy transients and temperature changes. Typical results are shown in Figs. 2 - 4.

This calibration process required many iterations at each stage (natural state and past history) and between the two stages. Most of the calibration process was carried out by "hand", that is with one of the authors deciding which parameters should be adjusted. Recently we have experimented with computerised calibration (Finsterle et al., 1997) with some success.

The model of Wairakei - Tauhara described here is working well in terms of its match to natural state and historical data. It has reached the state that it produces good results for some data which were not included in the original calibration. For example well-by-well enthalpy data were not included in the calibration process; only the average enthalpies for the Western or Eastern Borefields were used. However the calibrated model gives a good match to the well performance for both its deep (liquid) and shallow (steam) wells in Te Mihi. Our model of Wairakei - Tauhara was used as a test for the chemical transport version of TOUGH2 developed at IRL (White, 1995). A good match between model results and field data was obtained for chloride concentrations at Wairakei (Kissling et al., 1996).

A few aspects of the model need improvement, for example the average field enthalpy in the period 1965 - 1985 is too high in the model. We are currently reviewing the feed-zone data for the Eastern Borefield wells and may adjust our feed-zone depths. However it may be impossible to improve the model greatly without further grid refinement (more thinner layers). Most of the wells concerned are no longer significant producers and therefore this aspect of the model is no longer important.

Some of the model temperature in the zone between Wairakei and Tauhara are too high. This aspect of the model is not particularly important in terms of the model performance but it is being reviewed.

Discussion

Our computer model of Wairakei - Tauhara is working well and is being used by Contact Energy Ltd to assist with field management and planning; for example to study the impact of major reinjection and to investigate the interaction between Wairakei and Tauhara (Contact Energy Ltd was previously part of the Electricity Corporation of New Zealand (ECNZ) which in turn was set up by corporatising the New Zealand Electricity Department (NZED)). Contact's support of our work is gratefully acknowledged.

We have found MULKOM/TOUGH2 to be a very effective tool for geothermal reservoir modelling, both for Wairakei - Tauhara and several other fields. The flexible block structure is very useful and apart from introducing fast solvers (which are now available with the standard version of TOUGH2) we have had to modify MULKOM/TOUGH2 very little. We have introduced extra options for the operation of wells to allow the actual field procedures to be closely modelled.

Perhaps the most important feature we have added to MULKOM/TOUGH2 is the tightly coupled graphical interface MULGRAPH (O'Sullivan and Bullivant, 1995). This enables us to graphically edit the geometry and permeability structure of our model and to very quickly view the results and compare them with field data.

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