MODELLING OF THE WAIRAKEI - TAUHARA GEOTHERMAL SYSTEM: AN UPDATE

W. I. MANNINGTON[1], M. J. O'SULLIVAN[1], D. P. BULLIVANT[1] & A. W. CLOTWORTHY[2]

[1]Department of Engineering Science, University of Auckland
[2]Contact Energy Ltd, Wairakei

SUMMARY - A large complex three-dimensional computer model of the Wairakei - Tauhara system has been developed over a number of years. Between 1999 and 2001 the model has been updated. The current model consists of 5418 blocks and includes the unsaturated zone. Significant improvements in the representation of the geothermal system have been achieved and the model agrees well with most of the available field data. The model is being used by Contact Energy Limited to assist with resource consent hearings and field management.

1. INTRODUCTION

The Computer Modelling Group of the Department of Engineering Science has developed a succession of models of the Wairakei – Tauhara geothermal system (see O'Sullivan et. al, 1998, and Mannington et al., 2000). The most recent developments will be highlighted in this paper. Contact Energy Limited (Contact) has used previous models in evidence at resource consent hearings, the most recent of which was the 1999 appeal related to the use of Tauhara geothermal field. Contact is using the model presented in this paper in support of their Wairakei Geothermal Field resource consent application. The model was reported in detail in O'Sullivan et al., 2001.

2. MODEL DEVLOPMENT

In the early days of computer modelling Wairakei was used as a test case as there is an extensive database available to validate models. A review of the previous Wairakei – Tauhara models is given in O'Sullivan, et al. (1998). The model presented in this paper is based on an ongoing study of the Wairakei – Tauhara geothermal system that started in the early 1980's (Blakeley and O'Sullivan, 1981, 1982). Throughout this period of time the MULKOM and TOUGH simulators (Pruess, 1991) have been used.

A number of factors have driven the development of the model. These include:

- The advances in the computational speed, memory size and affordability of computers.
- Introduction of fast conjugate gradient solvers into MULKOM (Bullivant et. al., 1991).
- The development of graphical pre- and post-processor tools that make the management of large models much easier (for example: MULGRAPH, O'Sullivan and Bullivant, 1995).
- The availability of more field data to calibrate and validate the model.
- An improved understanding of the Wairakei-Tauhara geothermal system.

2.1 Model Grid

The 2000 model has a more refined grid structure than previous models. Figure 1 shows a plan view of the 1998 model and the 2000 model. The 1998 model has 118 columns divided into 16 layers (a total of 1515 blocks). The 2000 model has 216 columns divided into 32 layers (a total of 5418 blocks). In both cases some of the top blocks were removed to follow the topography of the Wairakei-Tauhara region, and the thickness of the top blocks is also varied for the same reason. The vertical grid structures of the two models are compared in Figure 2.

The re-design of the 2000 grid was based on several criteria. These include:

- Inclusion of the unsaturated zone by allowing the movement of water (or *steam)* and *air* underground.
- A larger total area is used and larger "recharge" blocks are included. Extra blocks have been added to allow for modelling of outfield injection.
- Thinner layers are included to give more resolution in the unsaturated zone and the steam zones which developed at Wairakei and Tauhara.
- The top of the model closely follows the topography of the Wairakei – Tauhara area.
- In the Tauhara and Taupo Township areas smaller blocks are used to give better resolution than in the 1998 model.

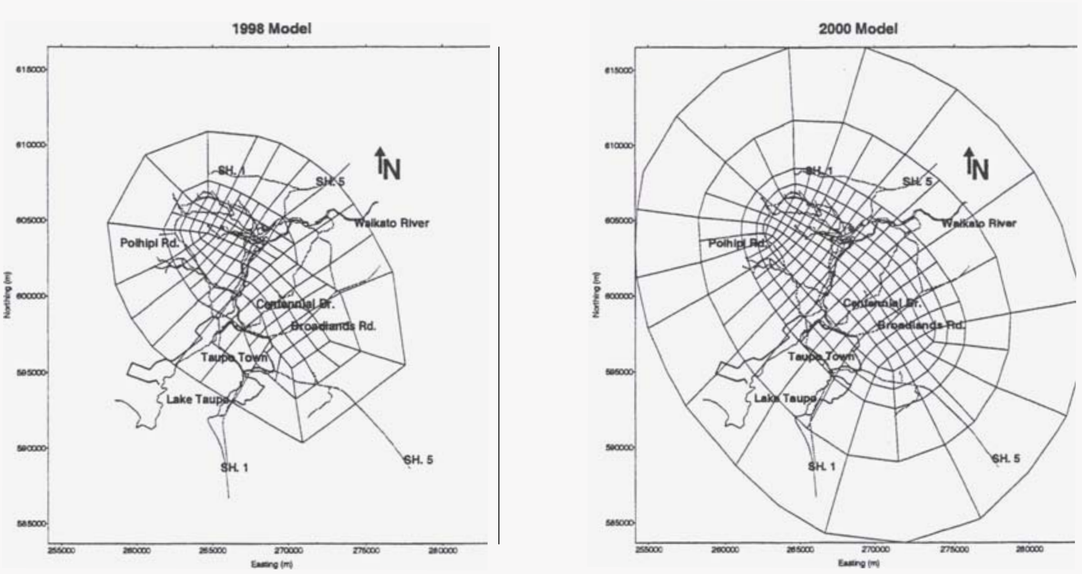
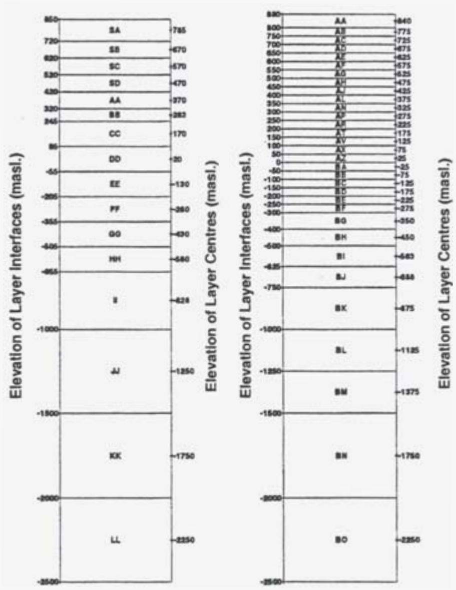


Figure 1 - Plan View of 1998 and 2000 Model Grids



98 Model 2000 Model

Figure 2 - Vertical Structure of 1998 and 2000 Models

Refining the grid structure has the benefits of reducing the discretisation error and allowing for a greater complexity in the geological structure. There is a trade off between accuracy and computation time associated with these changes. For every extra block that is added the time that the model takes to run and the memory requirements both increase. Therefore grid refinement was focused in areas where the thermodynamic properties of the geothermal fluid are changing more quickly, such as areas where a steam zone is likely to expand or contract.

2.2 Boundary Conditions

At the top surface of the model atmospheric conditions are maintained. This allows water and air to flow out of the top of the model into the atmosphere. The infiltration of rain at the surface of the model is represented by the injection of cold water into the top blocks in the model. A constant value of 1.58×10^{-6} kg/s.m^2 was used. This corresponds to an average rainfall of 1000 mm/yr and an infiltration fraction of 0.05.

For the natural state model the vertical sides are treated as no-flow boundaries. This means that the whole of the large convective system at Wairakei-Tauhara, with up-flow of hot water and down-flow of cold water, is assumed to be within the model volume. In the history matching simulations and future scenario simulations the boundary conditions on the sides are relaxed and the vertical sides of the model are treated as recharge boundaries, which means that water can flow in and out through these boundaries. The magnitude of the flow is in proportion of the pressure increase or decrease from the natural state. The constant of proportionality (recharge coefficient) is chosen to represent a permeable connection to the surrounding groundwater.

At the base of the model a low background input of heat is applied. At selected locations in the base of the model hot water is injected to simulate the hot deep up-flow. During production modelling hot recharge is added at the base of the model in proportion to the deep pressure decline.

2.3 Model Calibration

Model calibration involves iteratively adjusting the model parameters to improve the fit of the model behaviour to the field data. The process is time consuming and often gives conflicting results. A parameter change may improve the match to some of field data but make the match worse in another area.

Some use of inverse modelling using iTOUGH2 (Finsterle et al., 1997) has been made to assist the manual calibration process. The iTOUGH2 simulator systematically changes the values of a small set of parameters and uses mathematical optimisation techniques to improve the match to the field data. The process still requires user intervention to choose the parameter to adjust and to decide on the level of importance of each piece of field data (i.e. to construct the objective function).

A large number of iterations through the calibration process have significantly improved the match of the model to field data.

3. RESULTS

3.1 Natural State Model

This involves running a model to simulate the development of the geothermal system over geological time. The results of this simulation are compared with pre-production measurements within the field. The quantities examined include reservoir temperatures, location of surface outflows, and vapour saturations. The parameters adjusted are the permeabilities and the deep inflows.

Temperature v Depth

The 2000 model provides a good overall match to reservoir temperatures. Figures **3-8** show some representative results for various locations. The quality of the agreement is good. In a few areas, particularly near the Waikato River, the model results are not quite so good (Figure 8). It should be noted that the field data shown here are interpreted well temperature measurements and some profiles (eg, Te Mihi and Tauhara wells) were measured after production had occurred at Wairakei.

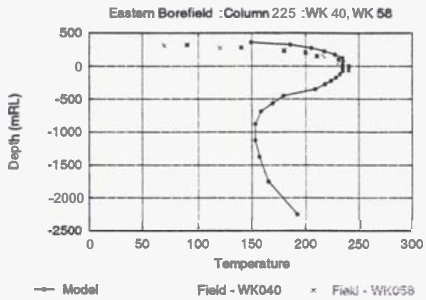


Figure **3** – Re-Production Temperature **for an** Eastern Borefield Well

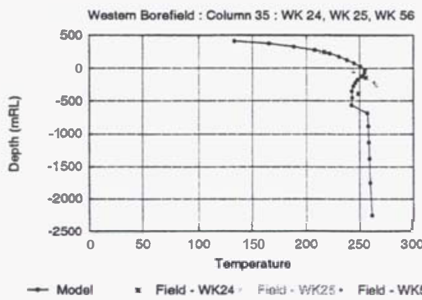


Figure **4** – Re-Production Temperature for a Western Borefield Well

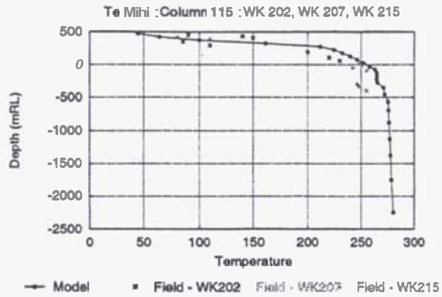


Figure **5** – Re-Production Temperature for a Te Mihi Well

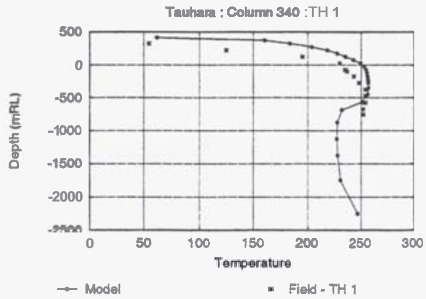


Figure *6* – Pre-Production Temperature for a Tauhara Well

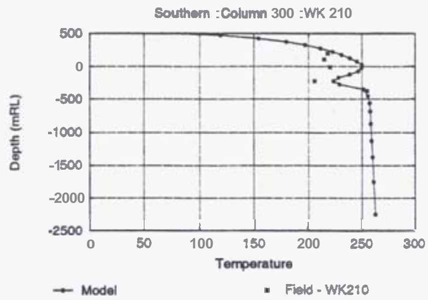


Figure **7** – Re-Production Temperature for a Southern Wairakei Well

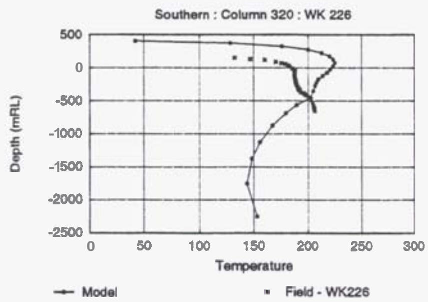


Figure 8 – Pre-Production Temperature for a Well near the Waikato River

Surface flows

Another goal of the natural state model is **to** qualitatively match the surface heat flow. **A** reasonable match was obtained (not shown). For example, in the model large surface heat flows were obtained in the Geyser Valley and Spa Sights areas.

32 Production Model – History Matching

The production model simulates the effect of Wairakei production since 1953 on the geothermal system. The initial conditions for the production model are taken from the natural state model. The goal of the production model is to try and match the pressures, production enthalpies, surface heat flows, temperatures and vapour saturations

Liquid Pressure Drawdown

Some representative results are shown below. Figures 9-13 shows the pressure drawdowns at a number of locations. The match to available data is good, although the early drawdown should be more rapid and the Western Borefield (Figure 10) pressures are 2-3 bars lower than the field data.

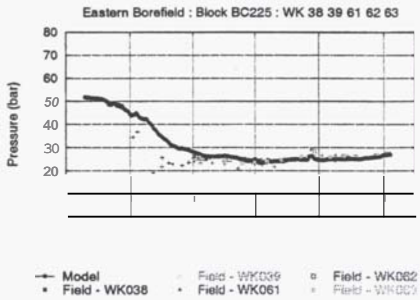


Figure 9 – Pressure Drawdown in the Eastern Borefield

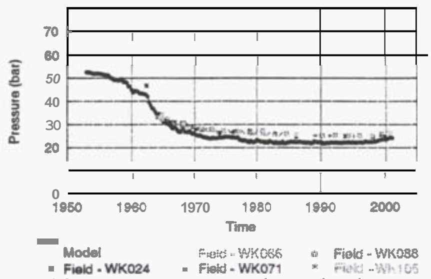


Figure 10 – Pressure Drawdown in the Western Borefield

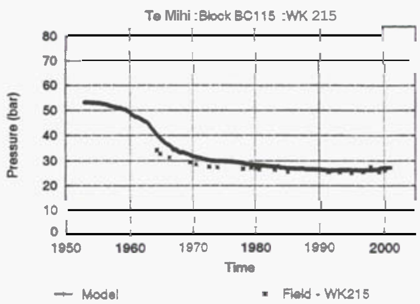


Figure 11 - Pressure Drawdown for Te Mihi

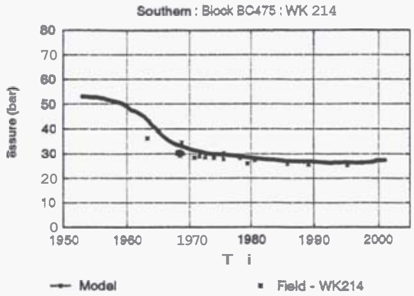


Figure 12 - Pressure Drawdown for Southern Wairakei

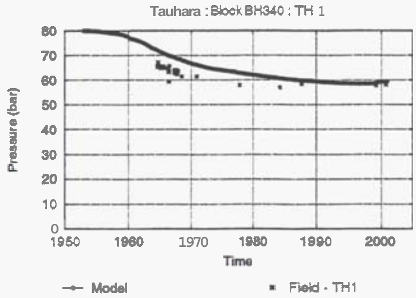


Figure 13 - Pressure Drawdown for Tauhara

Vapour Pressure

One of the main focus areas of the 2000 model was to obtain an improved match to vapour zone pressures. Figure 14 shows vapour pressures in the Te Mihi steam zone, Figure 15 shows the Southern steam zone pressures, and Figure 16 shows Mid-Huka aquifer pressures over the Eastern Borefield

The field data used here are uncorrected well head pressure measurements, but they are adequate to show the trend of the data. These results are good and have improved significantly form the 1998 model. We are currently working on improving the fit to the pressure change in the Southern steam zone pressure (Figure 15), which results from production at steam wells supplying the Poihipi Road power station.

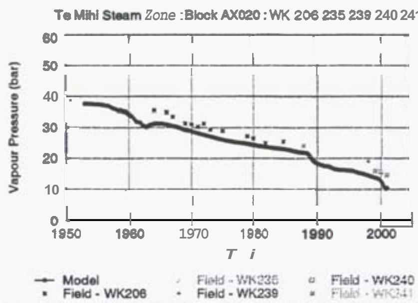


Figure 14 – Vapour Pressure Drawdown in the Te Mihi Steam Zone

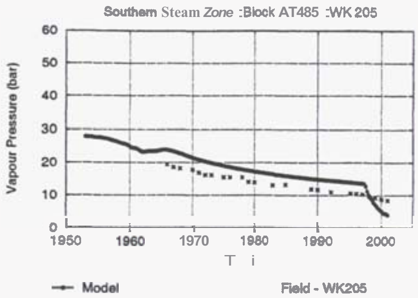


Figure 15 - Vapour Pressure Drawdown in the Southern Steam Zone

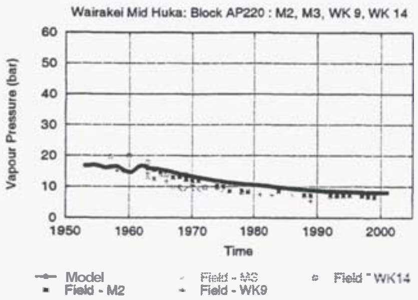


Figure 16 - Vapour Pressure Drawdown in the Wairakei Mid Huka Aquifer

Steam Zones

Figure 17 shows the extent of the steam zone at an elevation of 175 masl in 2001. It can be seen that a large steam zone develops under Wairakei, with a smaller one at Tauhara. This matches observations, although the Wairakei steam zone probably extends too far south in the model.

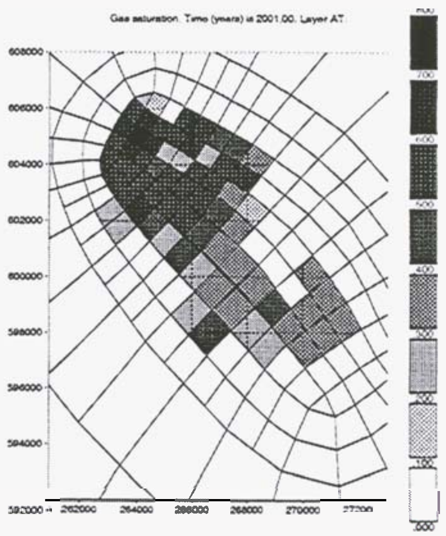


Figure 27 - Gas Saturation on layer 'AT' (175masl.) (Change to B+W)

Production Enthalpies

Another good measure of model calibration is the production enthalpies. Figures 18-21 show the average enthalpies for the main borefields and the whole field. The match here is very good. The enthalpies of individual wells (not shown) are mostly matched well.

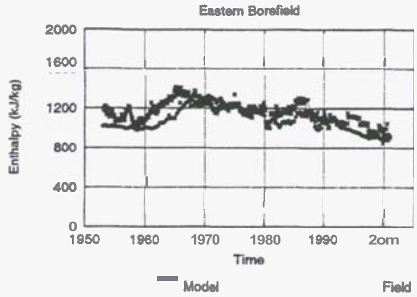
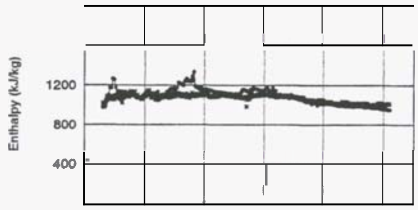


Figure 18 – Average Production Enthalpy for Eastern Borefield Wells



Western Borefield Wells

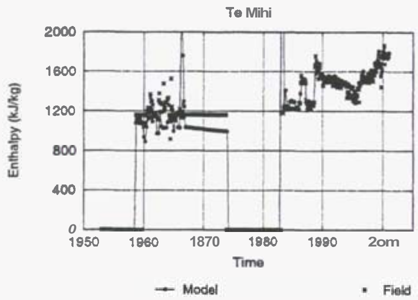


Figure 20 – Average Production Enthalpy for Te Mihi Wells

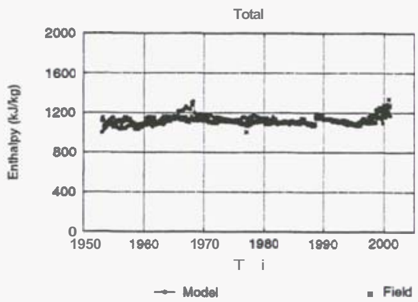


Figure 21 – Average Production Enthalpy for all Wairakei Wells

Surface Flows

A large reduction in surface heat flow occurs in the model. This is consistent with what has been observed in the field.

Where more information on the surface heat flow is available a detailed comparison can be made, for example Figure 22 shows the heat flow for the Karapiti area and Figure 23 for Tauhara. The measurement of heat flows is difficult and this is reflected in the large error bars on the field data. The match at Karapiti could be improved further, especially the behaviour fiom 1970 onwards. The match at Tauhara is reasonable.

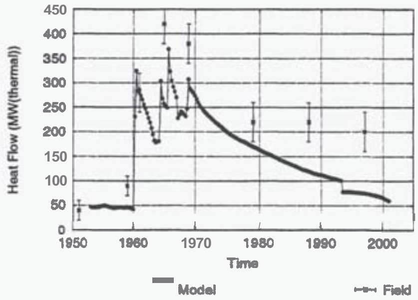


Figure 22 - Surface Heat Flow at Karapiti

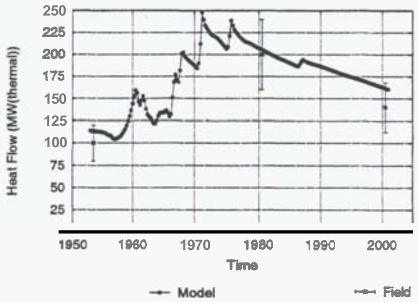


Figure 23 - Surface Heat Flow for the Tauhara Region

4. DISCUSSION

The 2000 model is an improvement over the 1998 model and the model provides a good match to most available field data. Work is continuing on further calibration and model development, as there is still some room for improvement. The model has been used by Contact Energy to investigate the future behaviour of the system for various scenarios.

5. ACKNOWLEDGEMENTS

Apart from the authors several others have contributed significantly to the development of our computer model of the Wairakei - Tauhara system. In particular Brian Carey from Contact Energy Limited, Paul Bixley formally from Contact Energy Limited, Chris Bromley and Peter Wood from the Institute of Geological and Nuclear Sciences and Rick Allis formally from IGNS, now from Utah Geological Survey have offered useful advice.

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