A graphical interface for a geothermal reservoir simulator

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Abstract

A graphical interface fur a geothermal reservoir simulator is presented using a model of the Wairakei geothermal field (New Zealand) as an example. The interface allows the user to graphically create or modify a computer model and then to analyse the simulation results. The package uses the **X** Window System, enabling it to be used **an** many computer platforms. The procedure used by the authors to create model?. of geothermal fields is also discussed.

Key words geothermal, modelling, graphics, Wairakei, X-Windows.

1 Introduction

The authors have developed a graphical interface to create the input and **process** the output information for a gcothermal reservoir modelling package. The interface was developed to aid the authors in developing and using large 3-D models *of* geothermal reservoirs such as Wairakei and Broadlands (New Zealand). Kamojang, Dieng and Darajat (Indonesia) and Los Humeros (Mexico).

The interface is built around the philosophy of the authors for model development. It guides the user through the different **steps** in model creation and analysis. It is also used as a tool for research and teaching at the University of Auckland.

The authors use the fallowing **steps** to **develop** a model of a geothermal reservoir :

1. The following reservoir data are gathered :
   - geological and geophysical data (eg. resistivity surveys, gravity surveys, surveys of surface **features** and core studies)
   - geochemical **data**
   - estimates ofthe natural **state** distribution of conductive surface heat flow
   - locations of and estimates of heat and mass flows from surface features
   - well locations
   - temperature **and** pressure profiles in wells
   - the production/injection history **of** mass and hcat flow for each well
2. A conceptual model oithe field is developed. This involves
   - estimating the extent of the reservoir both horizontally **and** vertically
   - estimating the locations and strengths of the inflows of heat and mass at the base of the field and the outflows at the surface
   - estimating the locations **of** the two phase **zoncs** which occur in the natural state and as **a result** of production
   - estimating the permeahility **structure** of the reservoir, including the location and orientation of fault **zones,** and relating it to the temperature distribution and chemistry
3. A computer **modcl** of the lield is developed. This involves
   - identifying the regions of the field where detailed results are required
   - constructing a horizontal discretiration of the field based on the above considerations and the conceptual model. **Extra** discretization may bc needed to represent vertical fault zones
   - setting up **a** numher of layers (all with the same horizontal discretization) with appropriate thicknesses. Extra layers may bc needed to represent high permeahility contact zones
   - assigning permeabilities and othcr rock properties to all blocks in the model. Some blocks may have anisotropic permeability to represent a fault zone
   - assigning inflows of heat and mass at the hare of the model to represent the deep recharge to the held
4. A natural state model is run. This involves
   - running the model to a "steady state" **in** a simulation of the development of the lield over geological time
   - comparing the temperature distribution and the surface heat and mass flows **in** the model with measurcd values
   - repeating steps 1, 2 **and** 3 and adjusting model parameters until a good match is obtained
5. If historical data are available, the permeability distribution developed **in** the natural **state** model **can be** further refined by history matching. This involves
   - allocating the production and injection wells to suitable hlocks in **the model**
   - running a simulation of the past history **of** the field hy inputting the known production **rates.** The **natural** state, calculated previously, **is uscd** as the initial state for the production run
   - comparing the hehaviour **of** the model with **measured** data such as production enthalpies **and** pressure drops
   - adjusting model parameters such **as** permeabilities and porosities and repeating the **process.** The natural state model should also he re-run **to** check its calibration
6. **A** sensitivity **analysis** should be performed. Model parameters. such as rock **properties.** rock **type** distribution, inflow location and inflow strcngth, are perturbed and the resulting simulations compared in order **to** determine which model parameters are **most** important
7. The model is used **to** run possible future scenarios. **A** check should he made that the **"failure** mode" for the model is sensible

This iterative development of the model requires many simulation runs, each ofwhich produces a large output file. Therefore, in order to check the results obtained from the model against measured field data, it is important to have a user-friendly and powerful graphics package.

The interface described in this paper uses the X-windows graphics library which allows it to operate on a wide range of workstations (under UNIX and VMS) and personal computers (under DOS with an X server). Currently it interlaces to the MULKOMITOUGHITOUGHZ family of reservoir simulators developed by Karsten Pruess at Lawrence Berkeley Laboratory [Pruess. 1988], but it could he extended to interface to other simulators.

The interface is used to display quantities such as pressure, temperature. vapour saturation, rock type, well location. mass Row and Hawing enthalpy. There are four types of display used hy the interface :

1. Horizontal slice. This shows how a property varies at the intersection ofthe model with a plane of specified depth.

2. Vertical slice. This shows how a property varies at the intersection ufthe model with a vertical plane that intersects the surface along a specified line.

3. Plot with depth. This shows how a property varies with depth at a specified horizontal location.

4. Time history. This show how a property varies with time.

The following sections illustrate, using a model of the Wairakei geothermal field (New Zealand) as an example, how the graphical interface is used. 'The last section describes developments for the interface which are currently being considered.

2 Development of the reservoir model

The Wairakei geothermal field is located in the centre of the North Island of New Zealand, a few kilometers north ai *Lake* Taupo. It is a hydrothermal system driven by a large scale convective circulation (4-5 km deep) which produces a column of hot rising fluid. In the natural state, some boiling probably occurred towards the top of the column A low permeability formation (the Huka Falls formation) at shallow depth causes the plume to spread laterally. This resulted in a major outflow, before exploitation, to the north-east in Geyser Valley. Some spreading of the plume also occurred towards Lake Taupo producing pre-exploitation thermal features at Karapiti and on the banks of Waikato river. There is a related geothermal system, Tauhara, to the south-east. Production began in 1953 and since then. drilling has moved westwards from the Eastern borefield to the Western borefield and on to Te Mihi. Production first caused the hot plume to hoil more extensively and then to gradually contract in some places as cold recharge replaced the hot water and steam. There is vertical faulting running through the borefield in a predominant SW-NE direction.

The computer model described in thir paper is one in a series of models of increasing complexity. First there were 1-D vertical models [Blakeley, 1986, Blakeley and O'Sullivan, 1981] lhat represented the main upflow region of Wairakei. These models were used to investigate the vertical structure required to give the correct pressure and temperature distribution with depth. The next type of model in the series was a 2-D radially symmetric model [Blakeley, 1986, Blakeley and O'Sullivan, 1982]. The balance between horizontal and vertical flows during production was assessed with the *2-D* radially symmetric models. Finally it was decided that a 3-D model of Wairakei was needed because the lield is not radially symmetric and because recharge is stronger from certain directions.

The model described below is the first 3-D model of Wairakei developed by the authors and co-workers. Larger more detailed models have subsequently been devrloped. The aim with this first 3-D model was to set up a model with as few blocks as possible, but which allowed for the Various parts of the lield lo he represented hy separate hlocks. Since there have been very significant changes in the vertical direction at Wairakei, particularly in vapour saturation as the boiling zone spread. a relatively large number of layers was required.

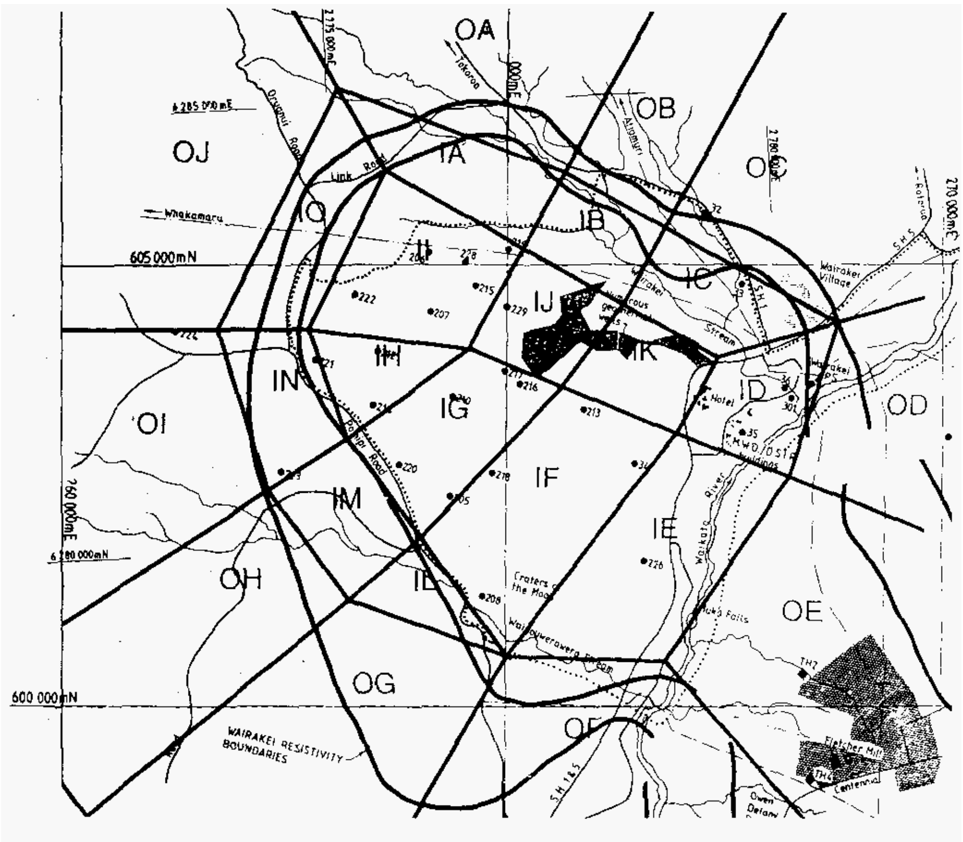


Figure 1: The horizontal discretiration for the Wairakei model

2.1 Horizontal discretization

To create a horizontal discretization with the interface, the **user** draws the block structure with a mouse **on** the computer screen. A digitized map can he read in and the blocks drawn on top of it. Regular rectangular discretizations can be created by specifying the number of blocks in each direction. the block side length in each direction. a base paint and the major direction. A mapping grid with arbitary orientation **can** be drawn to help with setting up the block structure.

Figure 1 shows a map **of** Wairakei with the 2-D horizontal discretization and the **electrical** resistivity boundary [Risk et al., 1984, Allis and Hunt, 1986] overlayed. There arc 15 inner blocks **(IA,** IB, IC. ID. IE, IF, IG, II, IH, IJ. IK, IL, IM, IN and IO) representing the hot part of the geothermal field and 10 **outer** columns **(OA,** OB, OC, OD. OE, OF. OG, OH, OI and OJ) representing the cooler **exterior** which provides horizontal recharge. The boundary between the inner and outer blocks was chosen to approximate the electrical resistivity boundary of the field (regions of hot geothermal fluid or thermally altered rock produce resistivity anomalies). The inner blacks were chosen to represent the areas of interest - **Eastern** borefield (IK), Western borefield (IJ), Te Mihi (II), Karapiti **(IF)** and Geyser **Valley** (IB). The outer hlock. OE. is also of importance because it represents Tauhara, where there is also geothermal activity.

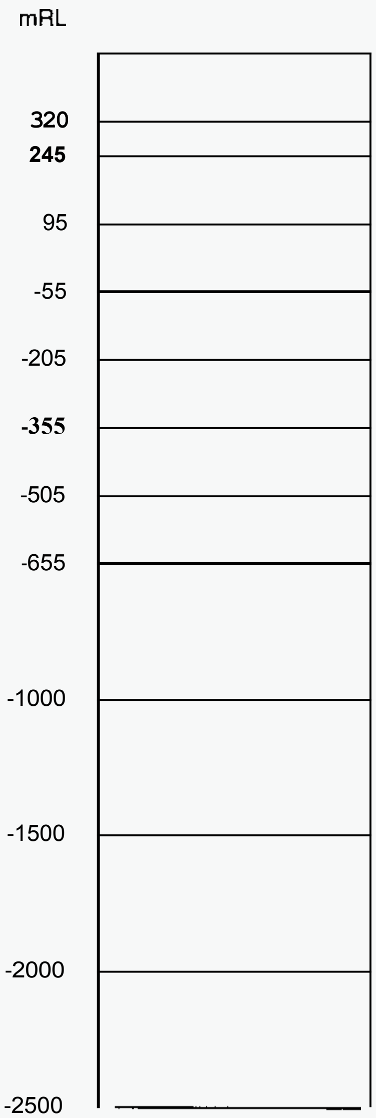


Figure 2: The **vertical** discretization For the Wairakei model

2.2 Vertical discretization

The interface allows the user to stack layers with the same horizontal structure hut different thicknesses on top of each other to form the 3-D model. The thicknesses of the block? in the top layer can be specified individually to follow the surface topography. The vertical discretization for the Wairakei model is shown in Figure 2

At this stage the interface **creates** a geometry **file** which is stored separately from the input and output **files** for the geothermal simulator. The geometry file can **be** used **on its** own, with the interface, to **view** the hasic grid structure. Once the geometry of the grid is satisfactory. the interface can he used to create an input tile forthc geothermal simulator. The interface can also he used to graphically edit an existing input file. The steps involved in creating a new input tile **are** described in the following sub-sections.

The style of model discussed here, which consists of **a** number of layers cach with the same block structure. is not universally used and MULKOM/TOUGH/TOUGH2 are capable of handling more general 3-D models. The authors **have** not often found this layered approach to be too restricative. In a few cases, where there was an irregular vertical structure, the "layering" was turned **an** its side, That is the model was **set up** with a number of vertical **slices,** each with the same **block** structure (see (Chen. 1993], for example).

2.3 Rock properties

The assignment of rock propertics is carried out layer by layer and uses the concept of rock **types.** Figure 3 shows the interface window part way through assigning **rock** types to **one** of the layers in the Wairakei model. **On** the right is a palette of **rock types.** The **rock** types with names have been assigned propertics. If the user selects an unnamed box from the palette, corresponding to **an** unassigned rock type. they will he prompted for a name and rock properties (permeabilities, porosity and thermal conductivity). The current rock type (last selected) **is** highlighted and if the user selects one of the blocks in the layer, that **block** will bc given the **current** ruck type. The user can make a layer all of one rock type **or** have the same **rock** type structure as another layer. Editing is possible **after** one of these options has been selected.

2.4 Wells

There are various types of wells which are **available** with MULKOM/TOUGH/TOUGH2. Some **extra** well **types** have **been** added to the University of Auckland version. **As** well as production and injection wells. representing actual wells, inflow from depth and recharge from the **side** of the model are represented by special types of wells. The interface allows the **user** to choose the type of **well. its** location in the model and parameters such **as flow rate.** productivity index and injection enthalpy.

3 Viewing the simulation results

While calibrating a natural **state** model, carrying out a history match **or** running future scenario simulations. the user needs to display simulation **results** and to compare simulation results with field measurements and possibly the results from other simulations. This section gives **examples, based** on the Wairakei model, of ways this can be done

3.1 Vertical slice

Figure 4 shows a **vertical** slice drawn through the natural slate model of Wairakei along a north-south line through Geyser Valley. the Western borefield and Karapiti. The slice has been "coloured according to the temperatures of the blocks using the **Scale on** the right. The mushroom shaped hot plume can be clearly **seen.** This **agrees** with the conceptual model developed by the authors.

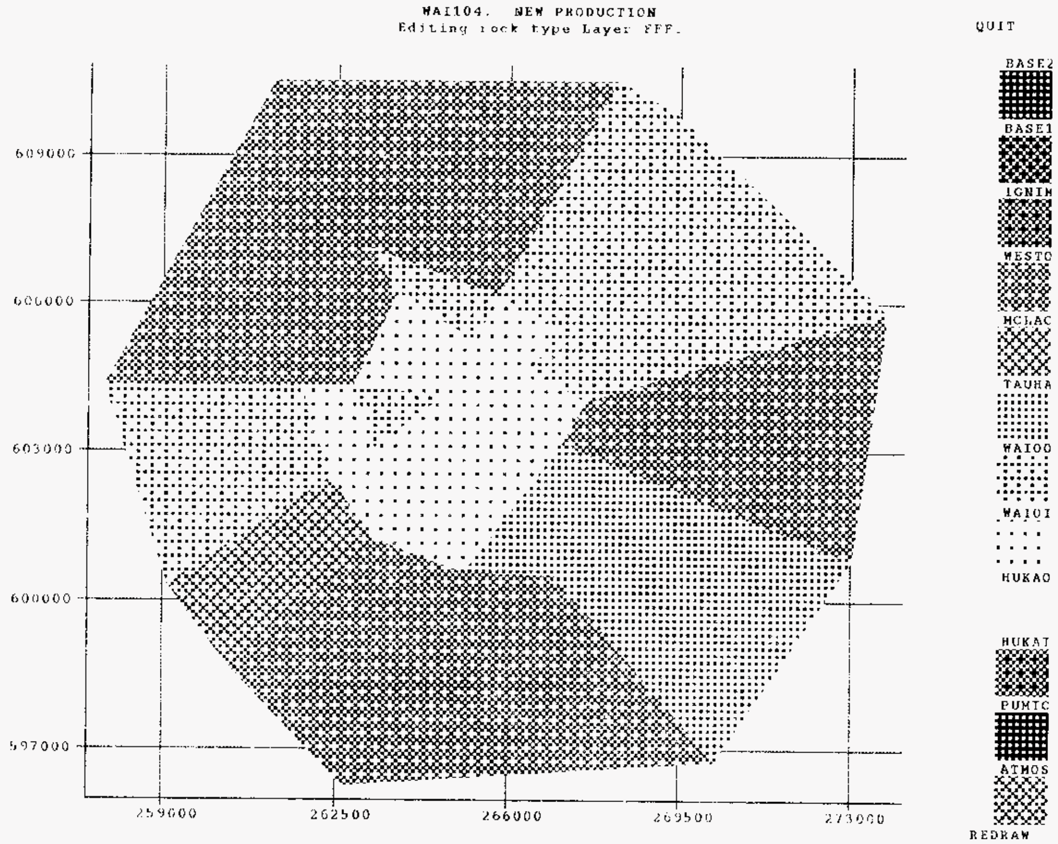


Figure 3: The interface window while editing the rock properties for a layer in the Wairakei model

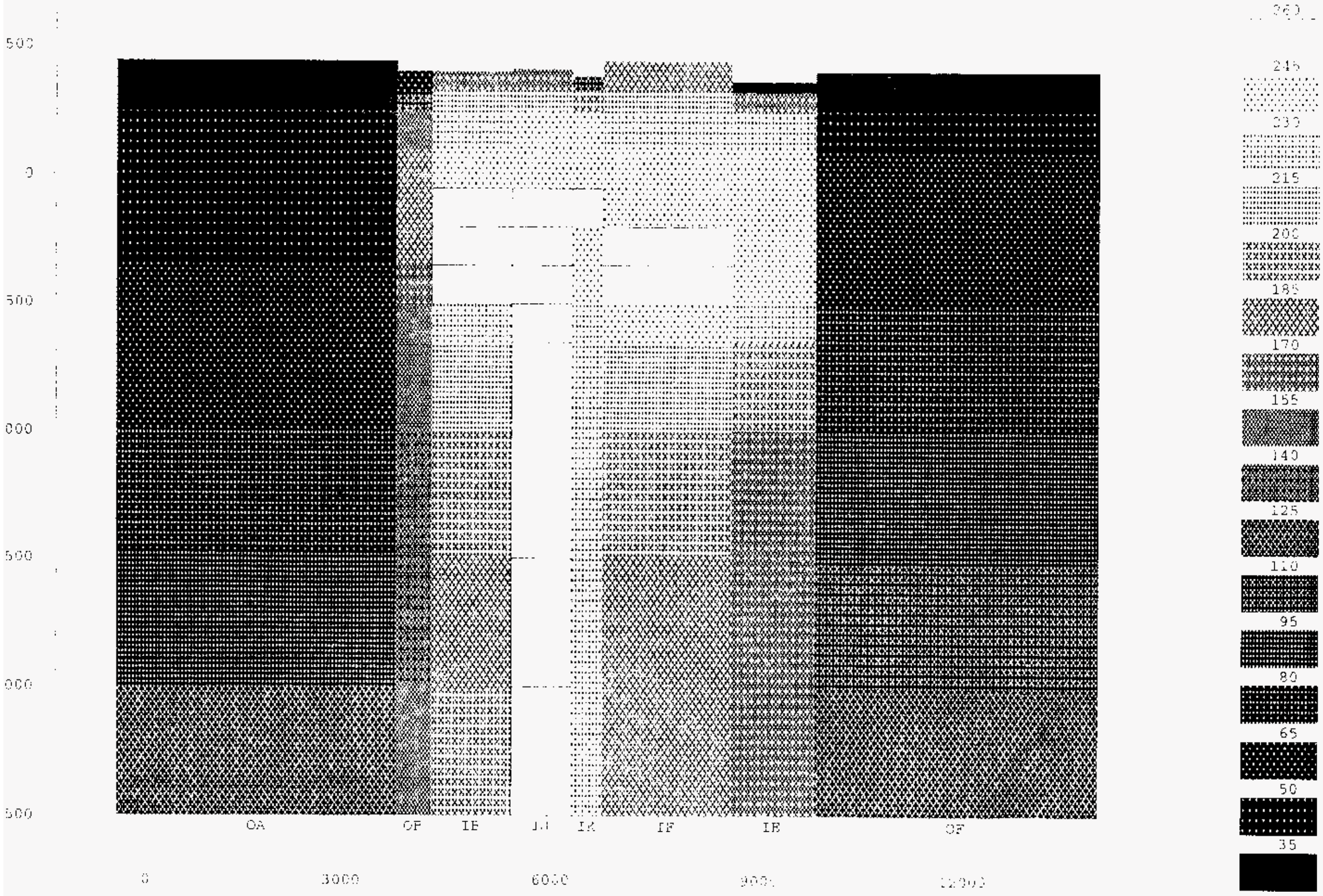


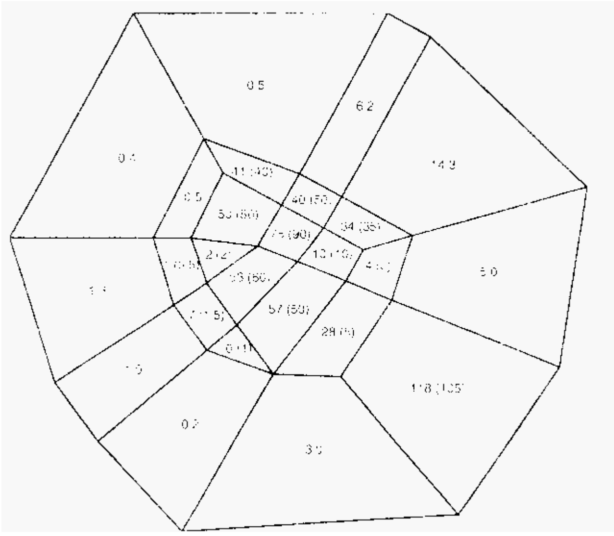
Figure 4: A vertical slice showing the temperature distribution for the natural state of the Wairakei model

Other properties such as pressure, vapour saturation and rock type can be displayed on a vertical slice. The interface gives the alternative, to colouring, of writing numerical values in each block on the vertical slice.

3.2 Horizontal slice

The interface is also able to select horizontal slices through a model. There are two ways of specifying the horizontal slice. The first is by selecting a layer and the second is by specifying an elevation. These differ when the model layers are sloping.

In addition to the properties that can be displayed on a vertical slice, flows (heat, mass, steam and water) through the top of a layer can be displayed on a horizontal slice. It is also possible, for comparison, to draw several different slices on the same plot. Figure 5 compares the distribution of surface heat flow between the natural state of the Wairakei model and field estimates (in brackets).



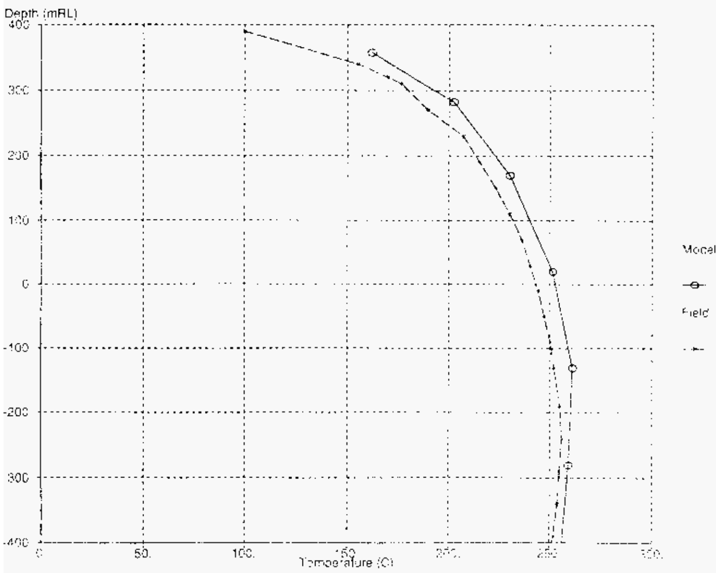


Figure 6: Comparison of natural state temperature profile in the Western borefield between the model and field estimates

3.3 Plots with depth

Often field data includes temperature profiles in wells or estimates of the variation of temperature and pressure with depth in different parts of the field. The interface can draw plots of pressure, temperature or vapour saturation versus depth. Figure 6 compares the natural state temperature profile in the Western borefield for the model with a field estimate from [Allis and Hunt, 1986].

3.4 Time history

A comparison of the variation over time in total flowing enthlapy for the production wells between the model and field measurements is shown in Figure 7. The interface is able to draw time histories for block properties (pressure, temperature and vapour saturation), flows between blocks (mass, heat, steam and liquid) and well flows (mass, heat, steam, liquid and flowing enthalpy).

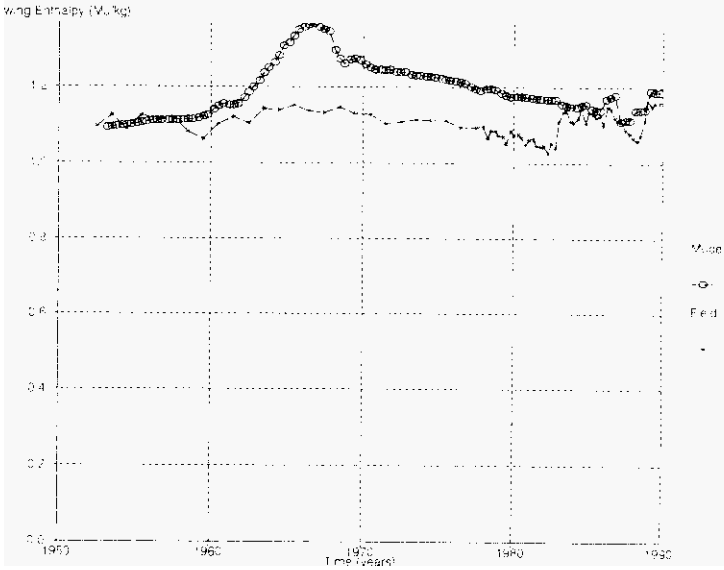


Figure 7: Comparison of total flowing enthalpy between the model and field measurements

4 Summary and discussion of future developments

The geothermal interface provides a very useful tool for setting up and using computer models of geothermal reservoirs. The types of plots available are designed to allow the modeller to quickly and easily interpret results. In the experience of the authors, it is an essential tool for developing and using large complex models of real geothermal systems.

The quality of the plots is adequate for presentation, but some further improvements are possible. At present, when layer plots or vertical section plots are coloured (or shaded) according to a parameter, such as temperature, the same colour (shade) is used for the whole block. Work is proceeding on the development of a general interpolation and contouring algorithm to allow contour lines and continuous variation of colour (shade).

In some cases, the restriction of having the same block structure in every layer is inconvenient (and not necessary for MULKOM). The possibility of allowing different structures in some layers is being investigated. For example a finer discretization in the production zone in some layers may be desirable.

Work is also directed towards 3-D displays and animation, so that a complete video of the possible future behaviour of a geothermal system can be presented. The 3-D displays will include surfaces of constant pressure, temperature and vapour saturation with the option of including superimposed flow vectors or streamlines

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