# A Graphical Interface to the TOUGH Family of Flow Simulators

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**Abstract**

A graphical interface for the TOUGH family of simulators is presented. The interface allows the user to graphically create or modify a computer model and then to graphically examine the simulation results. The package uses the X Window System, enabling it to be used on many computer platforms.

## 1. Introduction

The development of the MULKOM/TOUGH codes has enabled the modelling of a number of different complex problems involving multi-component, multi-phase flows in a porous medium. Often the models set up involve large complicated three dimensional block structures and it is almost essential to use graphical methods for setting up and checking input data files and for displaying simulation results. These pre-processing and post-processing tasks have received considerable attention from finite element code developers but the software products developed are expensive and mostly customised for one particular modelling package. Some general purpose 3-D graphics packages can be used for assisting with the pre-processing and post-processing of input and output data from codes such as MULKOM/TOUGH (see Kissling,1994, for example) but it is difficult to set them up as general purpose and user friendly modelling tools.

The present paper describes a geothermal modelling graphical interface (called MULGRAPH) developed at the University of Auckland . It can be used to create input files, check and edit input data files and plot results contained in output files. The package was originally based on the low level GKS graphical library but it has recently been modified to use the X Window System enabling it to run on many computer platforms.

A relatively simple 3-D model of the Wairakei geothermal field is used here to demonstrate some of the features of MULGRAPH.

## 2. Model Geometry

The finite volume approach used in the MULKOM/TOUGH codes (Narasimhan and Witherspoon, 1976, Pruess, 1988) allows very general types of grid or block structures to be used. This is one of the many advantages of these codes but it also means that it is difficult to anticipate all the types of block structures which might be used with MULKOM/TOUGH. It was decided by the authors, in the first stage of the development of MULGRAPH, to limit the type of block structures to that commonly used in their models of geothermal fields such as

Wairakei and Broadlands. These models involve a number of horizontal layers, each of constant thickness and with the same block structure in plan view. Some variations of this general system are possible with MULGRAPH and some further modifications are being considered (discussed below).

The geometric data used by MULKOM/TOUGH are the block volumes, the block interface areas and the distance from block interfaces to block centres. These data are all that are required to solve the mass, energy and chemical balances equations which together with Darcy's law are solved numerically by MULKOM/TOUGH. However these data do not allow the reconstruction of the actual geometric shape of the model and an additional geometry file is required for graphical pre-processing and post-processing of MULKOM/TOUGH data.

Therefore the first stage of a new modelling investigation using MULKOM/TOUGH is to set up the geometry file. This can be done manually or by using a separate graphics package (MULGEOM) developed by the authors. MULGEOM allows the user to set up a plan view of the block structures, with each block consisting of nodes or vertices connected by lines. A digitised map of the region of interest can be displayed as background to the grid structure. Extensive editing is possible. For example, nodes and lines can be added, deleted or moved.

Table 1 Data structure for a MULGRAPH geometry file

| **Module name** | **Data** |
|---|---|
| VERTIces | Node number and node coordinates |
| GRID | Block number, number of nodes in the block and their numbers. |
| CONNEctions | Blocks connected together (two for each connection) |
| LAYERs | Elevation of midpoint and bottom of each layer (starting with atmosphere). |
| SURFAce | Elevation of the water level in each block in the top layer |
| WELLS | Coordinates x,y,z for feed zones of each well. |

The geometry file is written in modular form, similar to the style of data for MULKOM/TOUGH. The module names and the data they contain are listed above in Table 1. The purpose of the SURFA module is to allow the top layer on the model to have a variable thickness (in order to represent the estimated elevation of the water table). The WELLS module provides the required information so that the location of the production wells and reinjection wells can be shown on the same plots.

## 3. Creation of Input data

Once the geometry file has been constructed, either manually or by using MULGEOM, the modelling interface MULGRAPH can be used to create an input file for MULKOM/TOUGH. The main menu in MULGRAPH presents the user with several choices. Usually the "check grid" option is selected first and either layers or vertical slices through the model can be displayed (and printed out if desired). Once the geometry file is satisfactory the "create grid" option can be selected and the user is taken through the procedure for setting up a MULKOM/TOUGH input file. All the tedious calculations of volumes, areas and distances are carried out by MULGRAPH. One of the most time consuming parts of the data creation task is the assignment of rock types to blocks. This is done graphically by pointing and clicking with the mouse. The modification of rock types is probably the most commonly used part of the "edit file" option (discussed in more later). Some parts of setting up a MULKOM/TOUGH file are still more conveniently carried out with an ordinary file editor and usually the authors do not use all the features available in MULGRAPH. For example in MULGRAPH it is possible to set up a complete set of initial data for a modelling run with a different pressure and temperature specified in every block, but this is seldom done. Instead very approximate initial conditions are set up and a natural state is calculated from these. This natural state is then used as the initial data for production runs. Similarly a complex table of production rates and times required for a simulation of production from a geothermal field could be set up using MULGRAPH but usually some alternative procedure is used.

## 4. Checking an input file

To make use of this option in MULGRAPH a geometry file and a MULKOM/TOUGH input file are required. The geometric data are checked (volumes, areas and distances) and various views of the model can be displayed to check that the desired rock-type structure has been set up. MULGRAPH also checks for missing blocks and connections. The authors have sometimes found such checks of MULKOM/TOUGH input files, previously prepared by hand for large complex models, rather embarrassing.

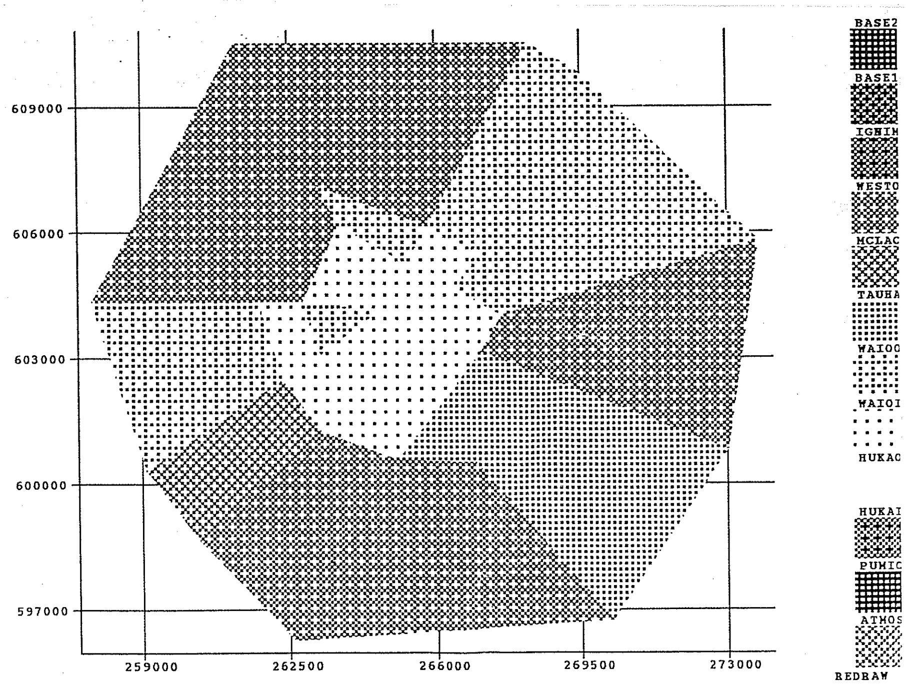


Figure 1. The MULGRAPH window while editing the rock-type assignment

## 5. Editing an input file

As mentioned above, the most common use of this option is for graphical editing of the rock-type distribution in a model. Other parameters can also be changed but often it is just as convenient to do so with a file editor. For example the authors would not normally use MULGRAPH to change permeability values within the ROCKS module of a MULKOM/TOUGH input file. A typical plot, for the Wairakei model, showing the shaded plot of rock-types and a legend is shown in Fig. 1.

## 6. Plotting Results

Once a MULKOM/TOUGH input file has been set up and a simulation run carried out the "plot results" option in the main menu of MULGRAPH can be selected. For this option MULGRAPH requires three files: the geometry file, a MULKOM/TOUGH input file and a MULKOM/TOUGH output file. A variety of plots of block parameters (pressure, temperature, saturation, etc.) can be produced. Two dimensional plots can be produced on layers or vertical slices, either showing numerical values or appropriately shaded. A typical example is shown in Fig. 2.

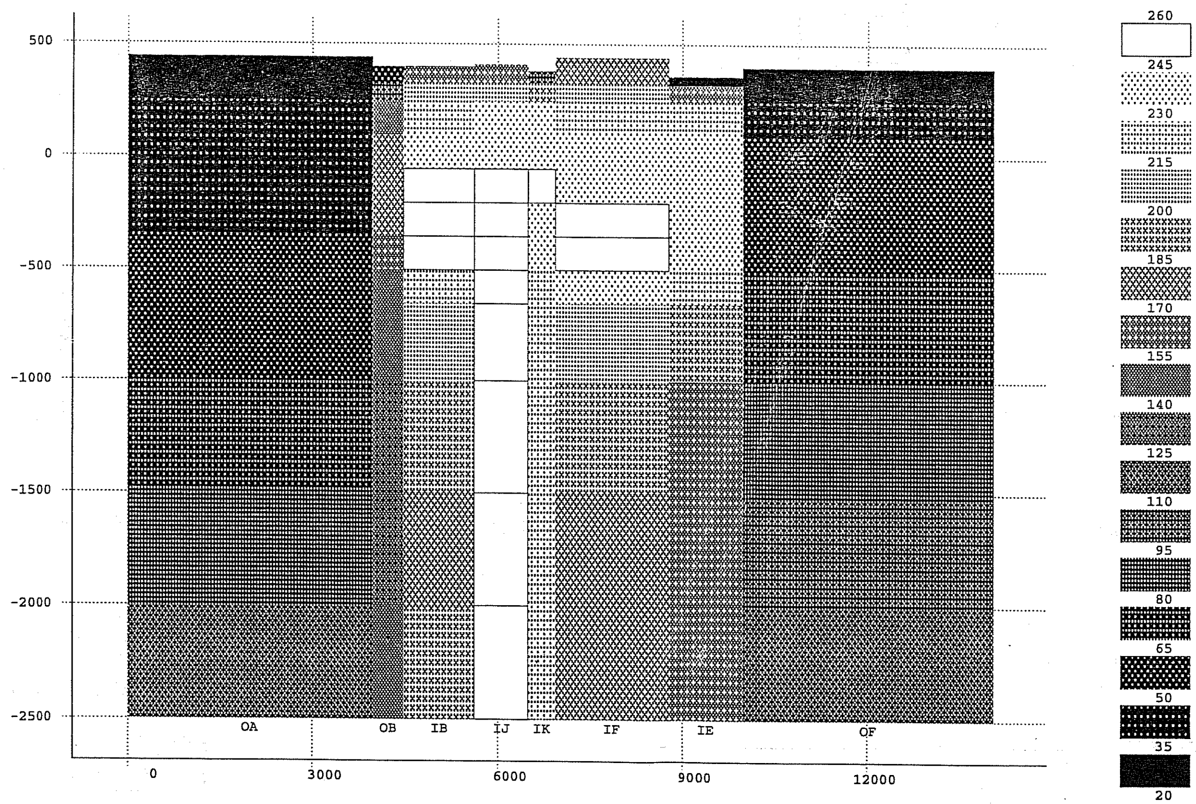


Figure 2. A vertical slice showing the temperature distribution for the Wairakei model.

Two-dimensional plots of flows across connections show arrows, proportional in size to the magnitude of the flows, located at the centre of the connections. Plots of flows through the tops of layers show the numerical values of the flows.

One dimensional plots showing variation of block parameters with depth can also be produced. Field data can be superimposed as shown in Fig. 3.

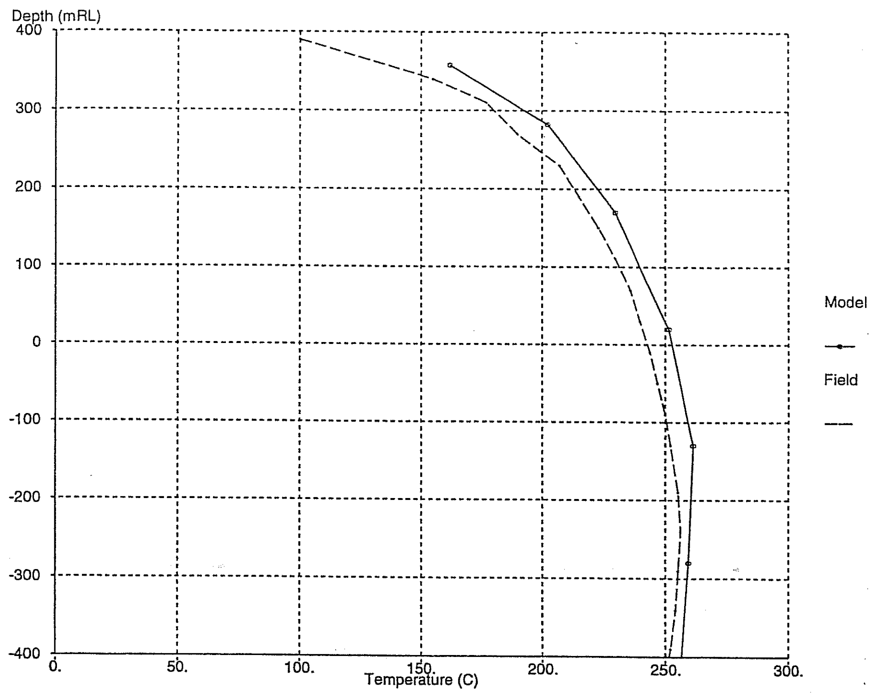


Figure 3. Comparison of natural state temperature profiles in the Wairakei model.

Plots of various quantities as functions of time can be produced. A typical example from the Wairakei model is shown in Fig. 4. In order to be able to produce these time plots some modification of the standard MULKOM/TOUGH output was required. In the standard version of MULKOM/TOUGH two levels of output are possible: either a complete output for all blocks or output for one block. We have set up an intermediate option where output for a few selected blocks, connections and wells can be included in the output file. An extra module with the heading SHORT is added to the input file. It lists the selected blocks, connections and wells.


Figure 4. Average production enthalpy from the Wairakei model

## 7. Graphics

The interface uses simple graphical techniques for output (line, point, filled area and text) and input (string, locate and menu). Initially, these were provided by the Graphical Kernel System (GKS) library. To make the interface available on a wider array of computer platforms, the calls to GKS were separated into a set of graphics routines within the interface and these internal graphics routines were implemented using the X Window System and Motif. The interface could be ported to a computer with a graphics system different from GKS or X, by rewriting the internal graphics routines using the new graphics system. An alternative would be to install an X server (available for personal computers) and use the X version of the interface.

## 8. General Comments

(i) The MULGRAPH package has been designed to interface to the MULKOM/TOUGH code, but could easily be adapted to read input and output files for other 3-D modelling packages.

(ii) The particular style of model on which MULGRAPH is based, with the layered structure, does limit its usefulness. However it is possible to have a complex vertical structure by arranging the "layers" to be vertical. MULGRAPH allows the orientation of the layers relative to the vertical direction to be selected. We are currently working on an option to allow some local subdivision of blocks.

(iii) Other plotting options such as contours on 2-D plots, 3-D plots and animation are being investigated.

(iv) MULGRAPH does not provide a complete graphical output capability. More sophisticated packages are required to provide genuine 3-D plots with zooming and rotation as options. However MULGRAPH does provide most graphical options which are required for modelling projects. The authors have found MULGRAPH to be an essential tool for geothermal modelling.

(v) MULGRAPH has been extensively used by graduate students and students attending short courses on reservoir engineering at the University of Auckland. It seems to be user friendly and relatively easy to learn to use.

## References


Kissling, W., Visualisation of geothermal reservoir models, presented at the 16th New Zealand Geothermal Workshop, University of Auckland (1994).

Narasimhan, T.N. and Witherspoon, P.A., An integrated finite difference method for analyzing fluid flow in porous media, *Water Resour. Res.*, **12**, 57-64 ( 1976).

Pruess, K., SHAFT, MULKOM, TOUGH: a set of numerical simulators for multiphase fluid and heat flow, *Geotermia, Rev. Mex. Geoenergia*, **4**(1), 185-202 (1988).