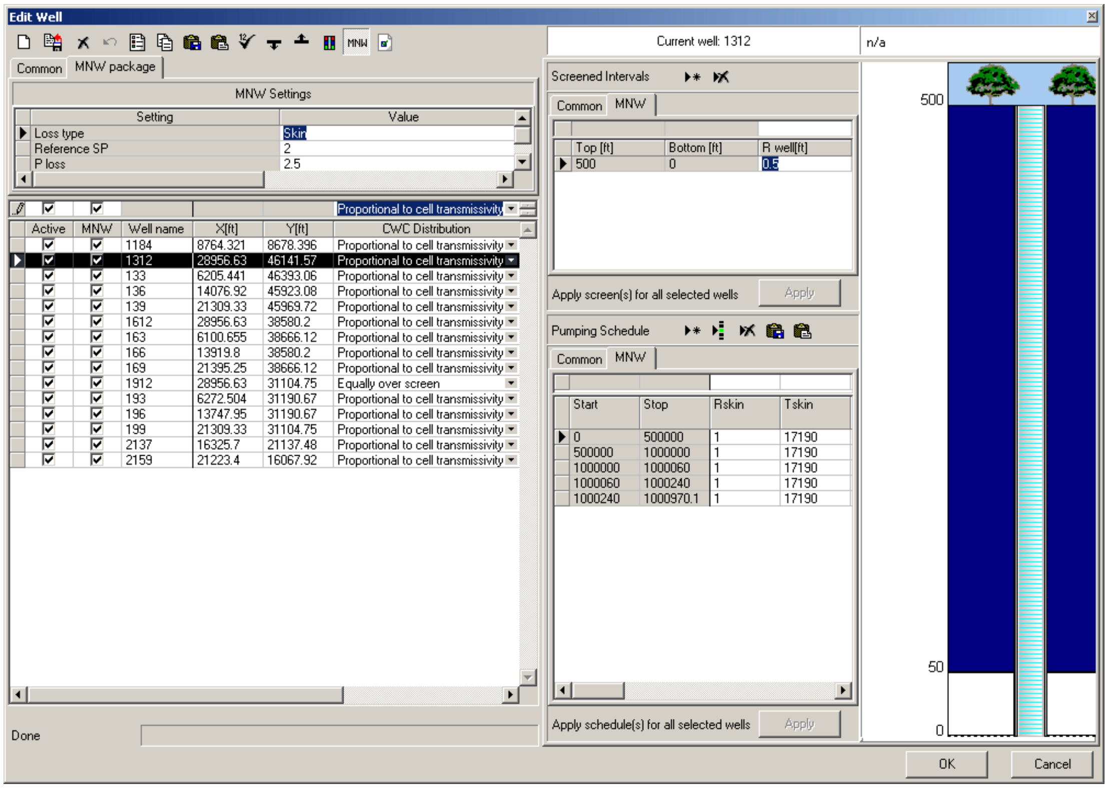
Visual MODFLOW Multi-Node Wells Tutorial



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Introduction

This document contains a step-by-step tutorial to illustrate the capabilities of simulating multi-node wells in Visual MODFLOW. More specifically, this tutorial takes you through a pre-built model that simulates intraborehole flow in wells with screens that span multiple layers, by using the MODFLOW flow engine with the USGS Multiple-Node Well (MNW) package.

In this tutorial, you will:

- View various input data required by the multi-node well package
- View a zone budget configuration designed to calculate intraborehole flow occurring between layers in a multi-node well
- View simulation output using Zone Budget time-step flow charts
- View simulation output using the Mass Balance report

This tutorial assumes that you are already familiar with the Visual MODFLOW interface, and with the process of building a groundwater model. If you are not familiar with Visual MODFLOW, it is recommended that you work through the Visual MODFLOW demo tutorial first.

About the Model

The model used in this tutorial is based on the model published in *User Guide for the Drawdown-Limited, Multi-Node Well (MNW) Package for the U.S Geological Survey's Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, Versions MODFLOW-96 and MODFLOW-2000*, by K.J. Halford and R.T. Hanson.

You will see that the results produced in Visual MODFLOW are very similar to those published in the original USGS document.

Model Overview

The system consists of two aquifers that are separated by a 50-foot-thick confining unit. The upper aquifer is unconfined, has a hydraulic conductivity of 60 ft/d, and has a uniform base of 50 ft above the datum. The lower aquifer is confined and has a transmissivity of 15,000 ft^2/day. The model uses the "quasi three-dimensional" approach in which the confining unit is simply represented by the vertical conductance between layers.

Storage coefficients of 0.05 and 0.0001 were assigned to layers 1 and 2, respectively. The 66-mi^2 area of the model was divided into 21 rows of 14 columns. Uniform square cells measured 2,500 ft on each side were used through out the area. Specified heads and drains are assigned in layer 1 and are maintained at the same elevations for all stress periods.

A period of 1,000,970 days was simulated with 5 stress periods (see table below):

Stress Period	From (days)	To (days)	Conditions
1	0	500,000	Steady State
2	500,000	1,000,000	Steady State
3	1,000,000	1,000,060	Transient
4	1,000,060	1,000,240	Transient

5	1,000,240	1,000,970	Transient

Recharge during stress periods 1 and 2 was 7 inches per year. No pumpage was extracted during stress period 1 but two multi-node wells were simulated. About 950,000 ft^3/d of pumpage was extracted during stress period 2; this is about 35% of the total volumetric budget. Uniform recharge rates of 2, 0, and 12 in/year were applied during stress periods 3, 4, and 5, respectivley. In addition to the simulation of two multi-node wells, there are 13 other single-node wells that have a combined discharge of 935,350 ft^3/d for stress periods 2 through 5.

Reference: *User Guide for the Drawdown-Limited, Multi-Node Well (MNW) Package for the U.S Geological Survey's Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, Versions MODFLOW-96 and MODFLOW-2000* by K.J. Halford and R.T. Hanson..

Terms and Notations

For the purposes of this tutorial, the following terms and notations will be used:

Type:- type in the given word or value

Select:- click the left mouse button where indicated

⇔ - press the **<Tab>** key

☞ - **Click** the left mouse button where indicated

☞☞ - double-click the left mouse button where indicated

[...] - denotes a button to click on, either in a window, or in the menu bars.

The **bold faced type** indicates menu or window items to click on, or values to type in.

Getting Started

To start this tutorial:

☞☞  (the Visual MODFLOW program icon) to start the Visual MODFLOW program

☞ **File > Open** from the Main Menu

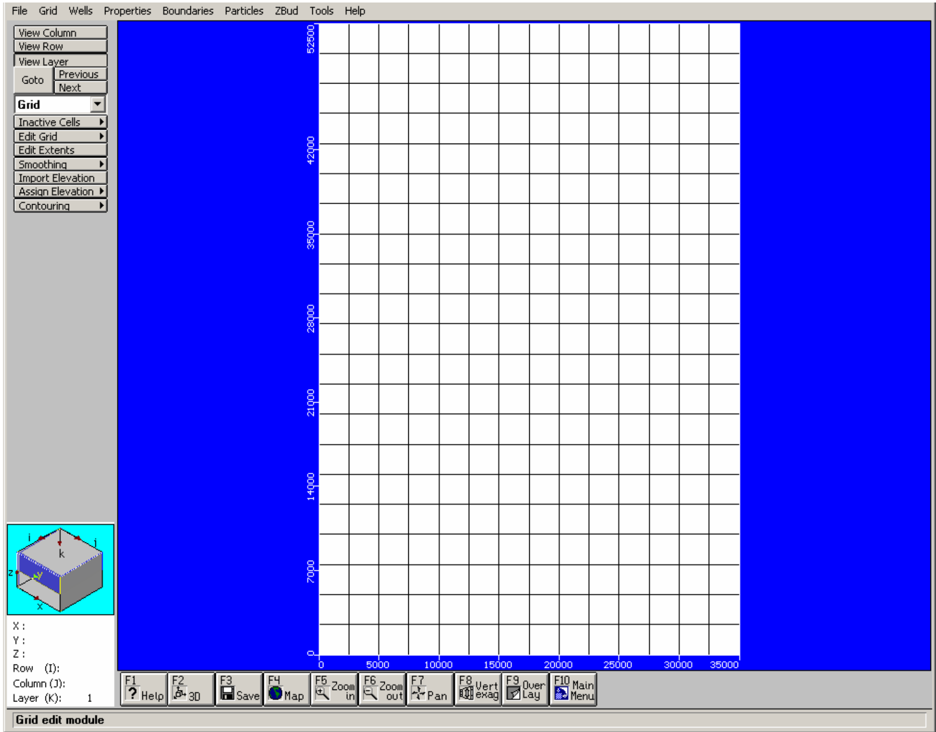
Browse to the location of the tutorial files. From this folder, open the MNW folder, select the MNWVmod.vmf file, and

☞ **[Open]**

MNW Input

First we will take a look at the model input. To view the input screen,

☞ **Input** from the main menu

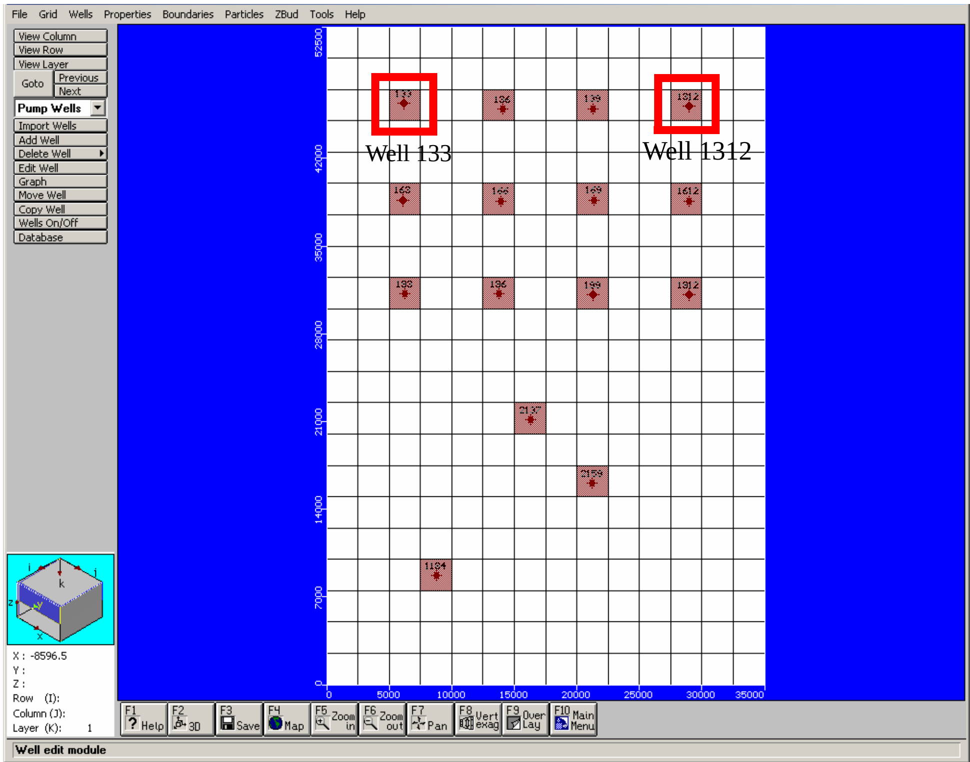


This image displays the grid of the model; as you can see, the model domain is 21 rows by 14 columns, by 2 layers. Cell size is 2,500 x 2,500 feet. Total area is 66 mi^2.

The property values and boundary conditions described in the model overview have already been defined for you. Before proceeding, take a minute and view the different input data for properties and boundary conditions, i.e. constant head, conductivity, drain etc, by using the combo box in the side menu.

Next, we will view the input for pumping wells. To do so,

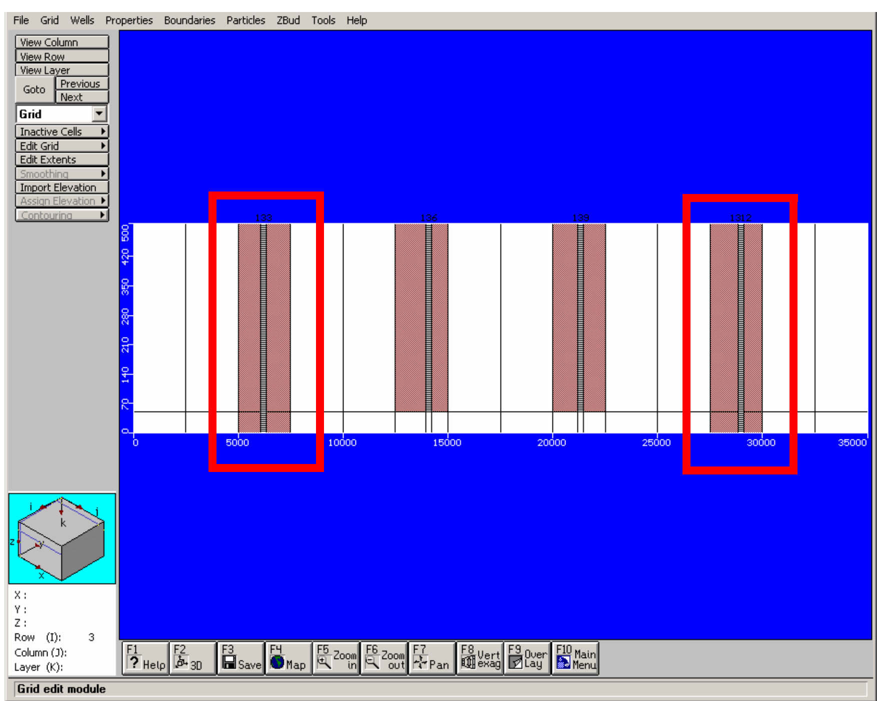
☞ **Wells / Pumping Wells** from the main menu



The two multi-node wells are indicated in the image above. Both MNW wells are screened across both the top and bottom aquifer. This can be seen by viewing a cross section of this row. To do so,

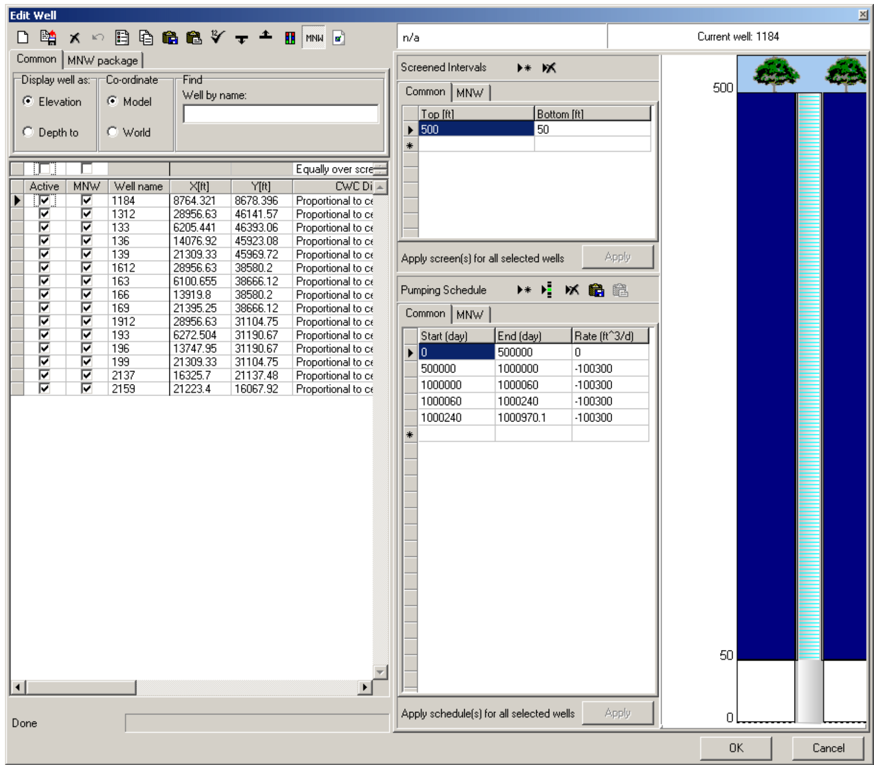
☞ **View Row** button from side menu

☞ **Row 3** from the grid



Next, we will take a look at the different well parameters required by the MNW package. MNW data input is facilitated through the newly improved **Edit/Add** well window. To load this window,

☞ **Database** button from side menu to open the **Edit Well** window.



The MNW options can be shown by selecting the MNW button from the main toolbar.

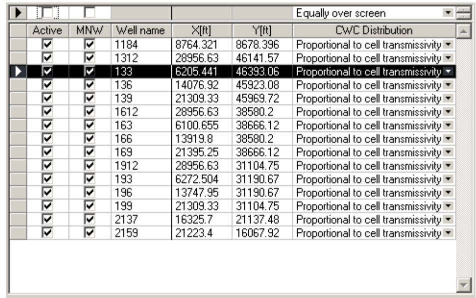
This button has already been enabled for you and all MNW parameters have been defined.

When this button is selected, additional options become available in the well table, screen interval table and pumping schedule table. In addition, global MNW options become available.

These options are described briefly in the following sections of this tutorial.

Viewing the Well Table

All the pumping wells in the model are stored in the well table. When a well (row) is selected, its screen interval and pumping schedule data is shown in the adjacent Screen Intervals and Pumping Schedule tables.



The **MNW** column allows you to include/exclude the well in/from the MNW package by selecting/deselecting the corresponding checkbox.

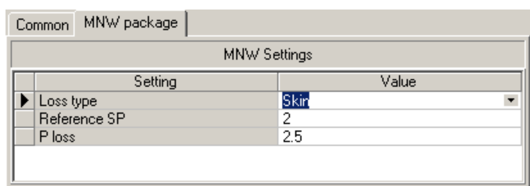
In this tutorial, all wells will be simulated using the MNW package.

The **CWC Distribution** column allows you to select the method in which Cell-to-Well Conductance is distributed along the length of the screen. In this example, we will use the **Proportional to Cell Transmissivity** option.

Viewing MNW Global Options

To view the MNW global options (applies to all wells included in MNW package),

☞ **MNW Package** tab located beside the Common tab, beneath the main toolbar



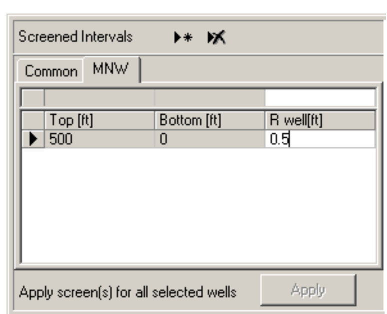
Here you can specify the well loss options for all wells selected as MNW. Choose between **Skin**, **Linear** and **Nonlinear** from the **Loss Type** combobox.

This tutorial will use the simple skin coefficient **(Skin)** for well losses.

Viewing MNW Screen Options

To view the MNW screen options,

☞ **MNW** tab located beside the **Common** tab, in the screened intervals frame



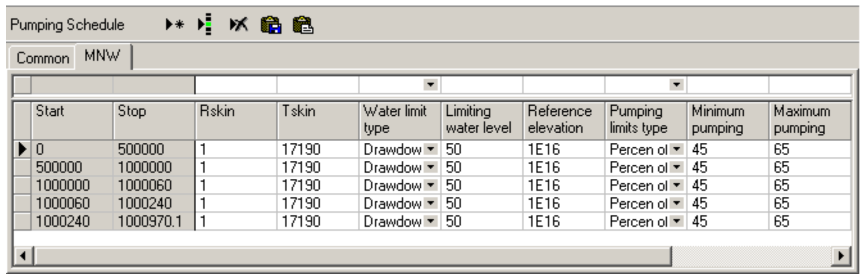
The **Screened Intervals** table displays the screen interval of the selected well. The screen is also shown graphically in the adjacent well diagram. The multi-node well package requires that each well has only one screen interval. Moreover, the well radius (**R Well**) for this interval must be specified.

All screen intervals and R Well values have already been defined for you.

Viewing MNW Pumping Schedule Options

To view the MNW Pumping Schedule options,

- ☞ **MNW** tab located beside the Common tab, in the Pumping Schedule frame



Start	Stop	Rskin	Tskin	Water limit type	Limiting water level	Reference elevation	Pumping limits type	Minimum pumping	Maximum pumping
0	500000	1	17190	Drawdow	50	1E16	Percen ol	45	65
500000	1000000	1	17190	Drawdow	50	1E16	Percen ol	45	65
1000000	1000060	1	17190	Drawdow	50	1E16	Percen ol	45	65
1000060	1000240	1	17190	Drawdow	50	1E16	Percen ol	45	65
1000240	1000970.1	1	17190	Drawdow	50	1E16	Percen ol	45	65

The pumping schedule grid will exand to allow for input of **Rskin** and **Tskin** values, draw down constraints, pumping constraints and water quality options, for each step in the pumping schedule.

All these values have already been defined for you. For more information on these options, please refer to the USGS User Guide for the Drawdown-Limited, Multi-Node Well (MNW) Package or the Visual MODFLOW User's Manual.

At this point, feel free to explore the different MNW settings for each well in the well table.

To close the **Edit Well** window,

- ☞ **[Ok]** button

Before continuing, change the input view from row view (cross section view) back to **Layer View** (planar view):

- ☞ **View Layer** button from the side menu
- ☞ **Top Layer** in the model grid

Applying Zones Using ZoneBudget

ZoneBudget will be used in this simulation to determine the intraborehole flow in multi-node **Well 133**, during the first time step when there is no pumpage.

Two zones have been defined for the cells that represent Well 133: Zone 2 was assigned to Layer 1 and Zone 3 was assigned to Layer 2.

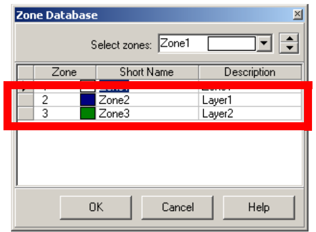
First we will turn off the Wells layer,

- ☞ **[F9 Overlay]** button
- ☞ Deselect **BC(F) - Wells**
- ☞ **[Ok]** button.

To view the ZoneBudget configuration,

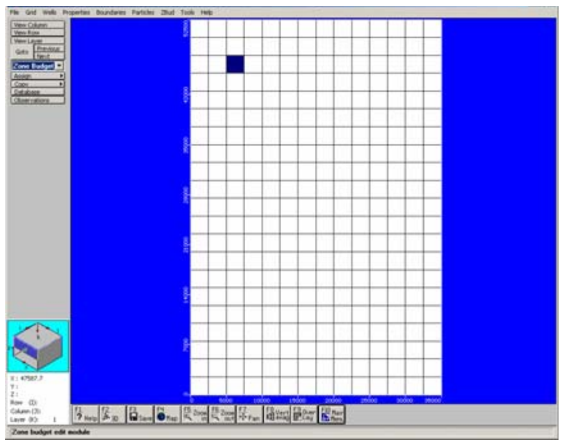
- ☞ **ZBud** from the main menu.
- ☞ **Database** from the side menu.

The **Zone Database** dialog will display. Two zones were created to represent **Layer 1** (blue) and **Layer 2** (green) of Well 133.



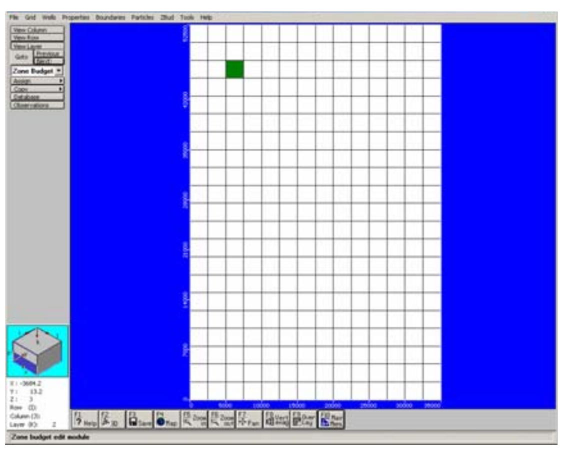
☞ **[Ok]** to close the dialog.

When viewing Layer 1 of the grid, you will notice that the cell containing Well 133 (MNW) was assigned Zone 2 (blue).



Layer 1

☞ **[Next]** button from the side menu to display Layer 2 of the grid.



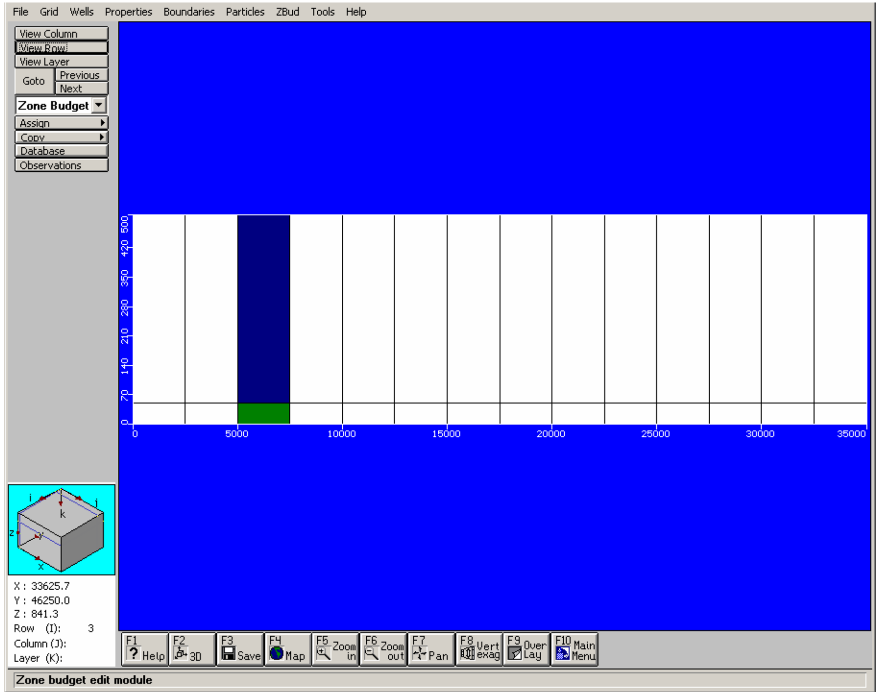
Layer 2

You will notice that the cell containing Well 133 (MNW) was assigned Zone 3 (green).

You can view this configuration in a cross section view. To do so,

☞ **View Row** from the side menu.

☞ **Row 3** from the grid



In cross section view, you can see that Zone 2 was assigned to the cell in the upper layer, and Zone 3 was assigned to the cell in the lower layer

Next we will run the model using the MODFLOW-2000 flow engine and ZoneBudget, and then view the output results.

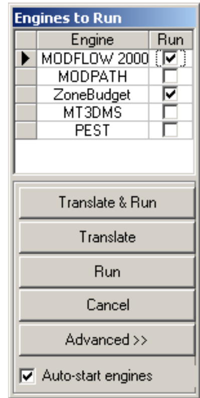
Before continuing, change the input view from row view (cross section view) back to **Layer View** (planar view):

- ☞ **View Layer** button from the side menu
- ☞ **Top Layer** in the model grid

Running the Model

To Run the model,

- ☞ **[F10 Main Menu]** button
- ☞ **[Yes]** button from the warning message to save the project
- ☞ **[Run]** from the main menu
- ☞ **[Run]** from the top menu



In the **Engines to Run** dialog, select the following options:

- ☞ **MODFLOW-2000** (if not already selected)
- ☞ **ZoneBudget** (if not already selected)
- ☞ **[Translate & Run]**

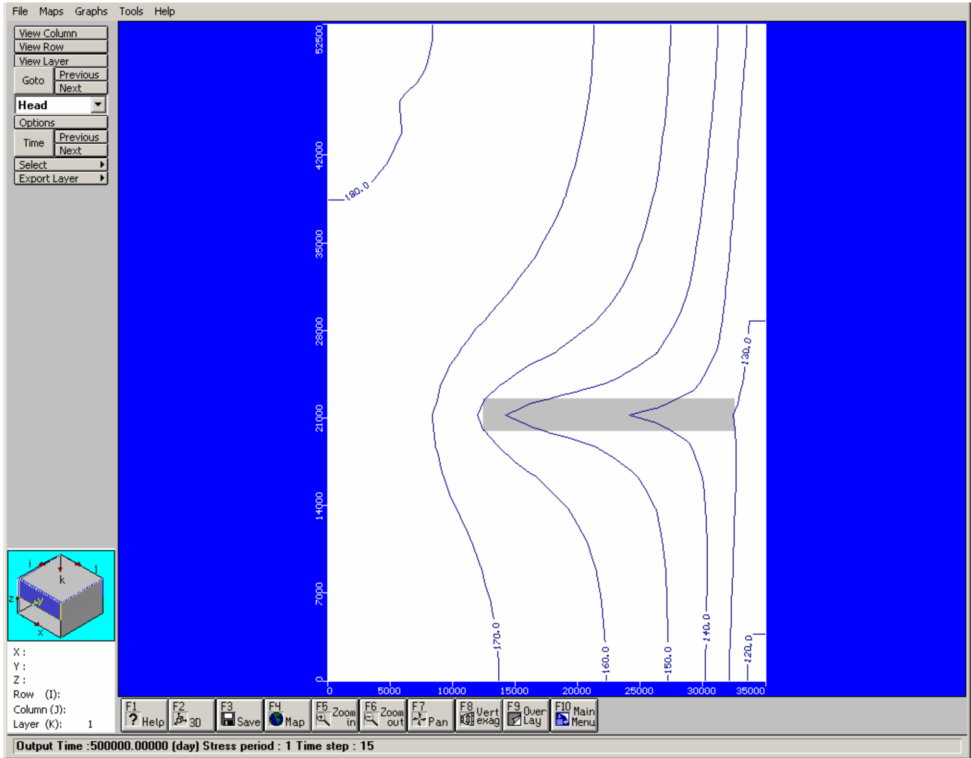
Visual MODFLOW will then **Translate** the Visual MODFLOW data set into the standard data input files required for the selected Numeric Engines, and then Run the simulations in a seperate window labelled **VMEngines**.

MNW Output

Once the model has converged, you may **[Close]** the **VMEngines**.

- ☞ **Output** from the top menu bar of the **Main Menu**

Upon entering the **Output** section, Visual MODFLOW will automatically load the available Output files for Head (.HDS) for all output times. Once these data files are loaded, the **Output** screen will appear.



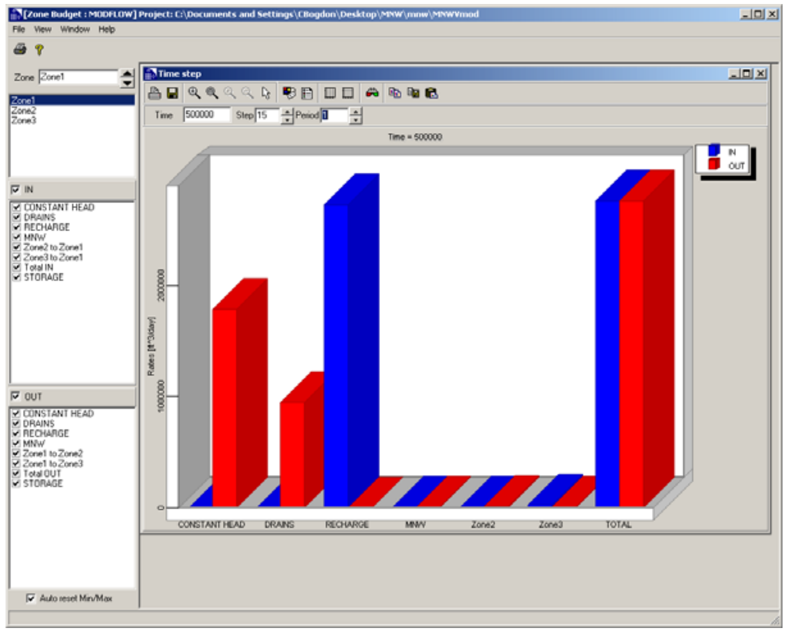
Viewing Zone Budget Flow Graph

To view the flow zone budget graph,

☞ **Graphs \ Zone Budget \ Flow** from the main menu

The **[Zone Budget: MODFLOW]** window will open displaying a series of graphs. **Close** the following graphs so that only the **Time Step** graph is displayed: **Percent Discrepancy**, **IN-OUT**, **Time Series**.

Your screen should look similar to the screen shown in the figure below:

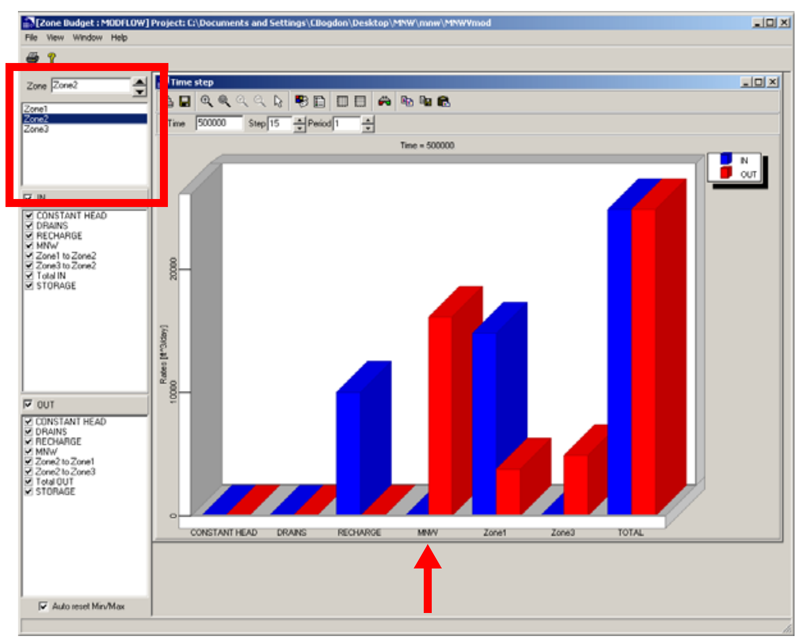


This graph plots a bar chart of the flow IN and OUT of the system of the selected zone through the individual sources and sinks (flow boundary conditions and storage) for selected output times.

We are interested in the flow IN and OUT of Layer 1 (Zone 2) and Layer 2 (Zone 3) for Multi-Node Wells during time step 1 (no pumpage).

To plot the flow for Zone 2,

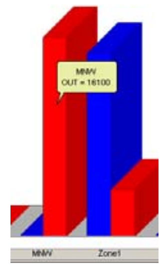
☞ **Zone 2** from the zones frame, indicated in the image below



In the bar chart above, you will see an OUT bar for MNW.

Although the OUT value can be estimated by reading the Y-axis, you can easily display the total OUT value by clicking on the bar.

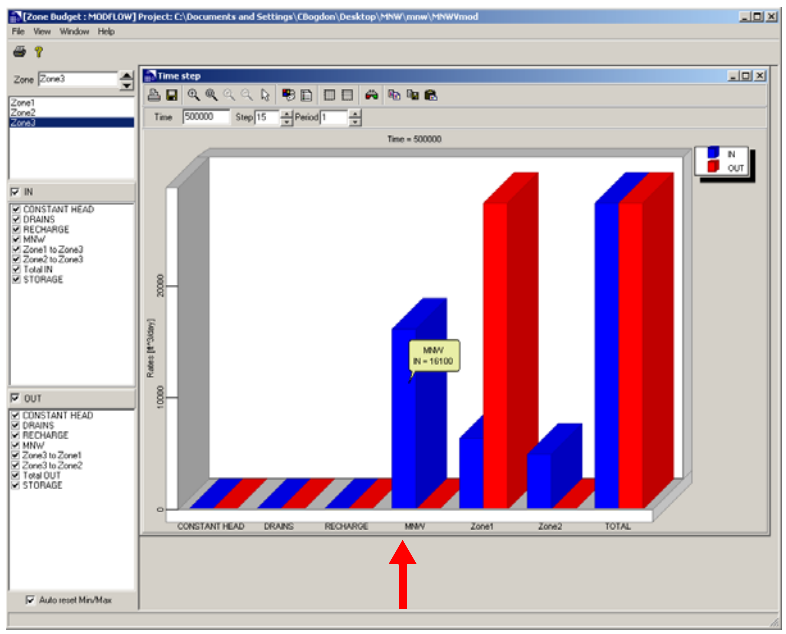
☞ on **Red MNW bar**



As indicated in the call-out box, about 16,100 ft^3/day moved out of Zone 2 (Layer 1).

Next we will plot the flow for Zone 3 (Layer 2),

☞ **Zone 3** from the zones frame



In the bar chart above, you will see an IN bar for MNW. By clicking on the bar, you will see that approximately 16,100 ft^3/day moved into Zone 3 (Layer 2).

By comparing the flow for both zones we can infer that 16,100 ft^3/day moved through the well as intraborehole flow from the upper aquifer (Layer 1) to the lower aquifer (Layer 2), during the non-pumping time step.

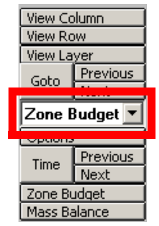
To close the **Zone Budget:MODFLOW** window,

☞ **File / Exit** from the main menu

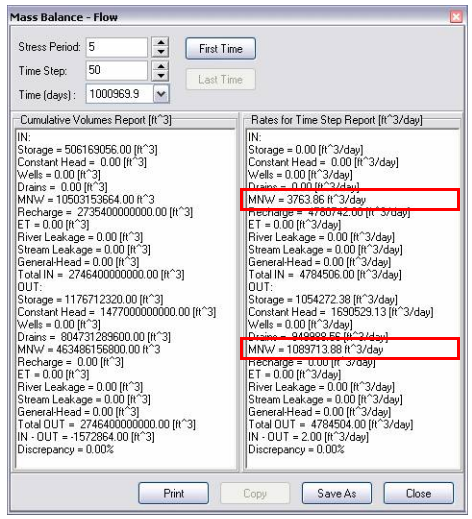
Viewing Mass Balance Report

To view the Mass Balance report,

☞ **Zone Budget** from the side menu combobox



- **Mass Balance** from side menu
- **[Last Time]** button to view the rates for the last time step



Multi-node wells appear in the mass balance as the “MNW” term. Mutli-node wells occur in both the inflow and the outflow portions of the mass balance. The total rate of outflow from multi-node wells was 1,089,713.88 ft^3/day and a total inflow was about 3,786.86 ft^3/day, which yields a net discharge rate of 1,085,950.02 ft^3/day.

This demonstrates how there can still be net discharge with intraborehole flow ocurring between selected model layers in multi-node wells.

This concludes the MNW tutorial.