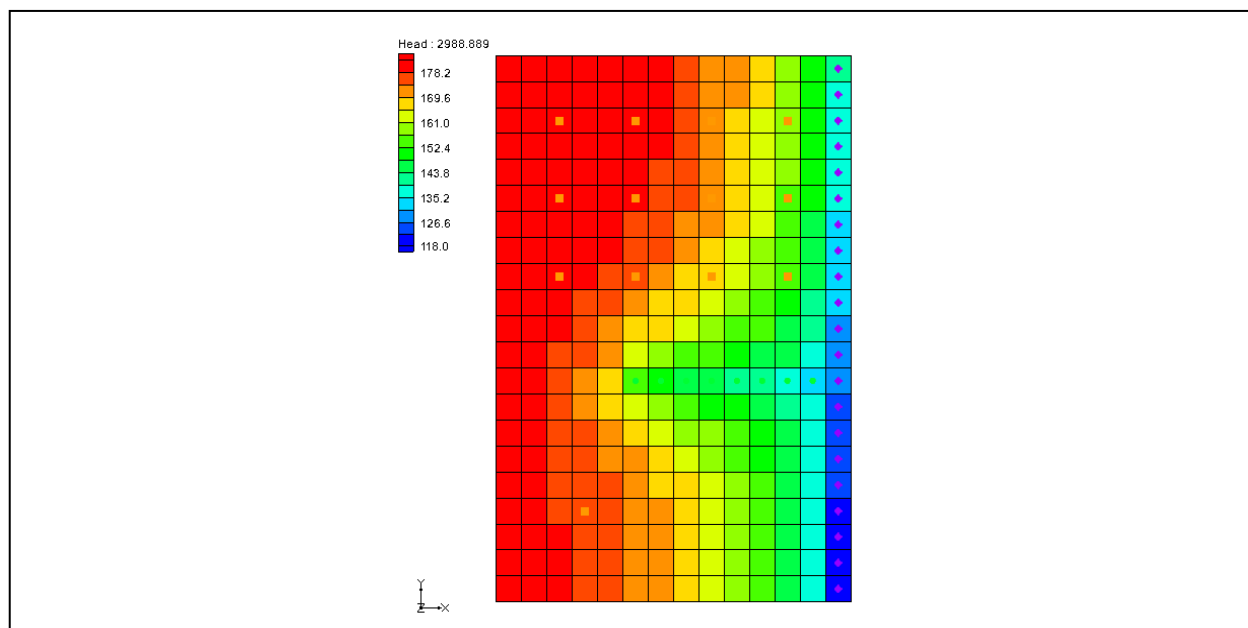


GMS 9.2 Tutorial

MODFLOW – MNW Package

Use the MNW package with the sample problem and a conceptual model



Objectives

Learn how to use the MNW package in GMS and compare it to the WEL package. Both packages can be used at the same time if desired. Examine the sample MNW model that comes with MODFLOW and then examine a different model that uses the conceptual model approach.

Prerequisite Tutorials

- None

Required Components

- Map
- Grid
- MODFLOW

Time

- 30-60 minutes



1 Contents

1	Contents	2
2	Introduction.....	2
2.1	Outline.....	2
3	Description of Problem	3
4	Getting Started	5
5	Importing the existing model.....	5
6	Saving the model with a new name.....	6
7	Viewing the MNW boundary conditions.....	6
7.1	Opening the MNW Package Dialog	6
7.2	Opening the Source/Sinks Dialog.....	7
8	Running MODFLOW.....	8
9	Examining the Solution.....	9
10	Changing the Active Flag for the Multi-node Well.....	10
11	Running MODFLOW and Viewing the Solution	11
12	Drawdown Limited Wells.....	11
13	Running MODFLOW and Viewing the Solution	12
14	Drawdown Limited Multi-Node Wells	13
15	Create a Conceptual Model.....	15
15.1	Open the Existing Conceptual Model.....	15
16	Examining the Existing Solution.....	16
17	Changing the Model to Use MNW.....	16
17.1	Changing the Wells to MNW	16
18	Examine the MNW Package.....	17
19	Saving and running MODFLOW	17
20	Examining the Solution.....	18
21	Changing to a Multi-Node Well	18
22	Examine the MNW Package.....	18
23	Saving and running MODFLOW	19
24	Viewing the Flow in the MNW Boundary Conditions	19
25	Conclusion.....	20
26	Notes.....	20

2 Introduction

The Multi-Node Well (MNW) package was developed to more accurately model wells that are completed in multiple aquifers or in a single heterogeneous aquifer, partially penetrating wells, and horizontal wells that can be affected by the effects of dynamic changes in the distribution of pumping or intraborehole flow that can significantly alter groundwater flow.¹

2.1 Outline

This is what you will do in this tutorial:

1. Import an existing MODFLOW simulation.

2. Run the simulation and examine the results to understand the MNW package options.
3. Modify a conceptual model to use MNW instead of the WEL package.

3 Description of Problem

The problem we will be solving in this tutorial is the same as the model used in the MNW documentation.

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 ft²/d. Storage coefficients of 0.05 and 0.0001 were assigned to layers 1 and 2, respectively. The 66-mi² area of the test problem was divided into 21 rows of 14 columns. Uniform, square cells that measured 2,500 ft on a side were used throughout the simulated area. Specified heads and drains are assigned in layer 1 and are maintained at the same elevations for all stress periods.¹

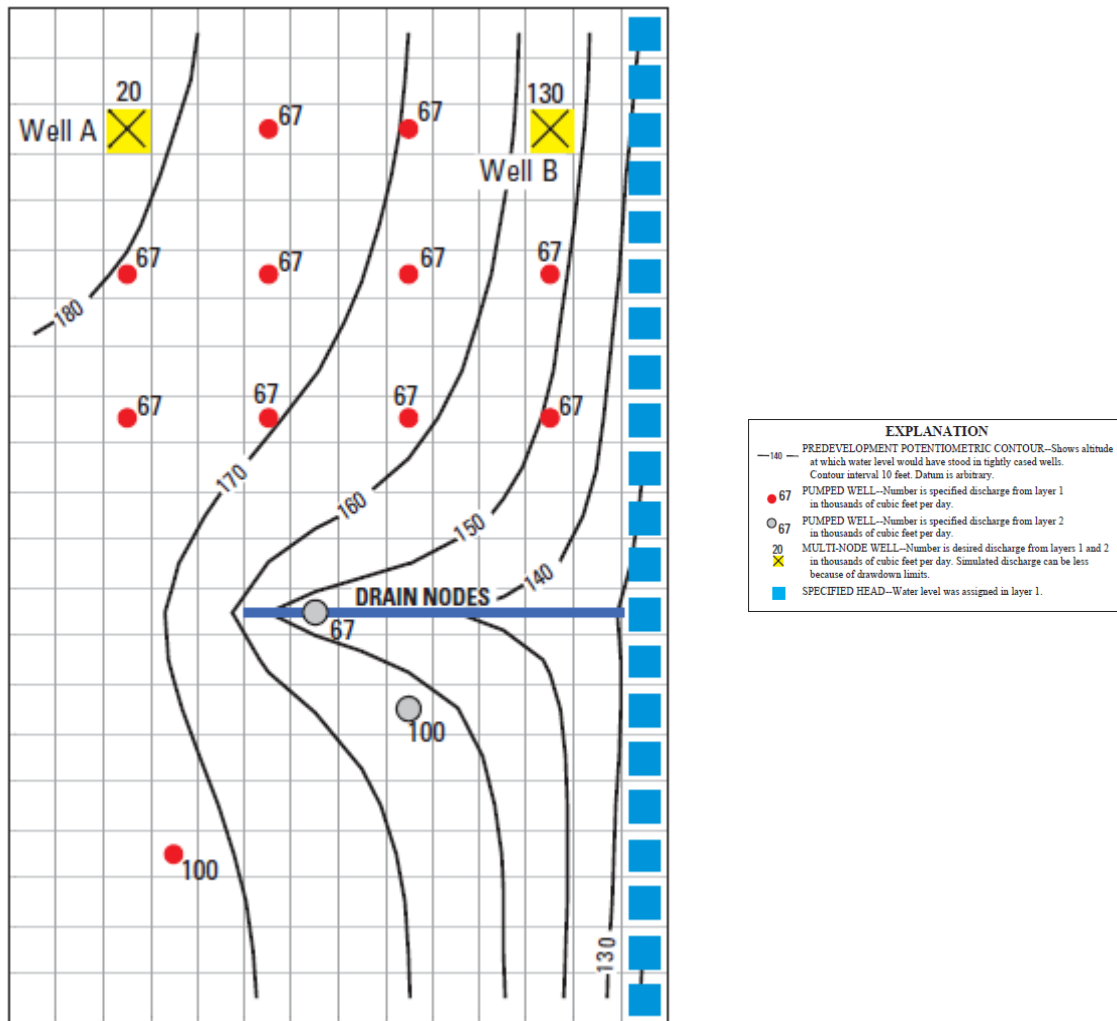


Figure 1. Flow model from MNW documentation.¹

A period of 1,000,970 days was simulated with 5 stress periods. The first two stress periods simulated steady-state conditions, which were achieved by having each stress period be 500,000 days long. Recharge during stress periods 1 and 2 was a uniform 7 inches per year (in./yr). No pumpage was extracted during stress period 1 but multi-node wells were simulated. About 950,000 ft³/d of pumpage was extracted during stress period 2; this is about 35 percent of the total volumetric budget. Transient conditions were simulated during stress periods 3, 4, and 5, which were periods of 60, 180, and 730 days, respectively. Uniform recharge rates of 2, 0, and 12 in./yr, respectively, were applied during stress periods 3, 4, and 5. In addition to the simulation of two multi-node wells (wells A and B), there are 15 other single-node wells that have a combined discharge of 935,350 ft³/d for stress periods 2 through 5.¹


4 Getting Started

Let's get started.

1. If necessary, launch GMS. If GMS is already running, select the *File | New* command to ensure that the program settings are restored to their default state.

5 Importing the existing model

We will start with a MODFLOW model that has already been created.

1. Select the  *Open* button (or the *File | Open* menu command).
2. Browse to the `\Tutorials\MODFLOW\mnw\` folder.
3. Change the *Files of type* popup menu to *All Files*.
4. Select the *mnw1.nam* file and click *Open*.

A dialog should alert you that the model needs to be translated into GMS format.

5. Click *OK* to translate the model.

Now the MODFLOW Translator runs and ends with a message saying MODFLOW 2000 terminated successfully.

6. Press *Done*.

This imports the model. You should see a grid with symbols representing wells, drains, and specified head boundary conditions similar to the figure below.

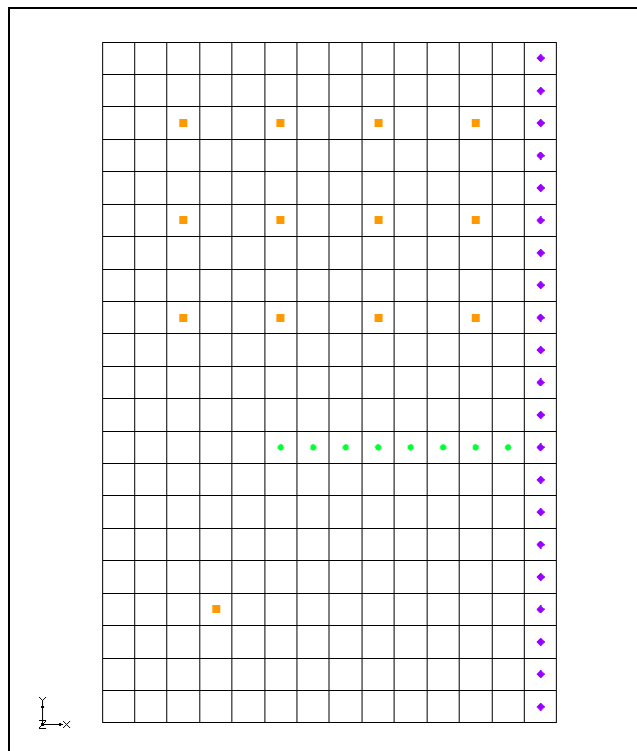


Figure 2. Imported MODFLOW model.

6 Saving the model with a new name

We're ready to start making changes. Let's save the model with a new name.

1. Select the *File | Save As* menu command.
2. Change the project name to **MNW**.
3. Save the project by clicking the *Save* button.

7 Viewing the MNW boundary conditions

Before running the simulation we'll view the MNW boundary conditions.

7.1 Opening the MNW Package Dialog

1. Select the *MODFLOW | Optional Packages | MNWI - Multi-Node Well* command to open the MNW Package dialog.

This dialog is used to edit existing MNW boundary conditions and to change options associated with the MNW package. The options located near the top of the dialog apply to the MNW package while the spreadsheet allows the user to edit individual MNW boundary conditions. Instead of repeating all of the MNW documentation here, it is

recommended that the user review the MNW documentation for more information on each input option. MNW documentation can be found at the following URL: <http://water.usgs.gov/nrp/gwsoftware/modflow2000/MFDOC/mnw.htm>.

Now we will examine the MNW boundary conditions. You should see 17 MNW wells listed in the spreadsheet. Most of these are single node wells. However, the wells named “Well-A” and “Well-B” are multi-node wells. Notice that for each of the wells labeled “Well-A” the Well ID is 1 and for each of the wells labeled “Well-B” the Well ID is 4.


2. Change the current *Stress period* to 2.

Notice that nearly all of the wells have a specified pumping rate in this stress period except for “Well-A” and “Well-B”. Only one of the boundary conditions associated with each of the multi-node wells has a desired pumping rate specified. The MNW package will determine how much of the desired flow should come from each of the nodes associated with a multi-node well.

The user is referred to the MNW documentation for a full explanation of each of the inputs to the MNW boundary conditions. In GMS we have added the Name, Active, and Well ID fields. Name is a label used to identify a boundary condition. Active is a flag used to determine if the boundary condition is used during a particular stress period. The Well ID field is used to identify multi-node wells.

3. Close the dialog by pressing the *OK* button.

7.2 Opening the Source/Sinks Dialog

1. Switch to the 3D Grid module by selecting the  *3D Grid Data* item in the *Project Explorer*.
2. Select the 3D grid cell with the MNW well in it as shown in the figure below.

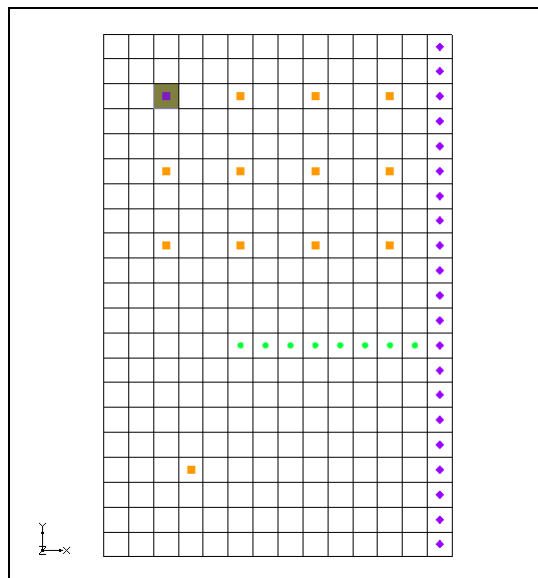


Figure 3. Selected MNW well cell.

3. Open the *MODFLOW Source/Sinks* dialog by right clicking on the selected cell and selecting the *Sources/Sinks* command.

This dialog allows the user to edit the properties of a selected boundary condition as well as add additional boundary conditions in the selected cells. Note that some of the properties available for MNW boundary conditions do **NOT** allow the user to enter a time series (such as Well ID). As such, the value entered in this dialog for these properties will be assigned to the boundary condition for all stress periods.


4. Select *OK* to exit the dialog.

8 Running MODFLOW

Before running MODFLOW we need to change the output options to make it easier to see the results.

1. Select the *MODFLOW | OC - Output Control* menu command.
2. From the *Output interval* section, select the *Output at last time step of each stress period* radio button.
3. Check the *Save cell by cell flow terms to *.cdf file* toggle.
4. Press the *OK* button to exit the *MODFLOW Output Control* dialog.

Now we are ready to save our changes and run MODFLOW.

5. Select the  *Save* button (or the *File | Save* menu command).
6. Select the *MODFLOW | Run MODFLOW* menu command.

- When MODFLOW finishes, select the *Close* button.

Contours should appear on the grid similar to those shown in the following figure:

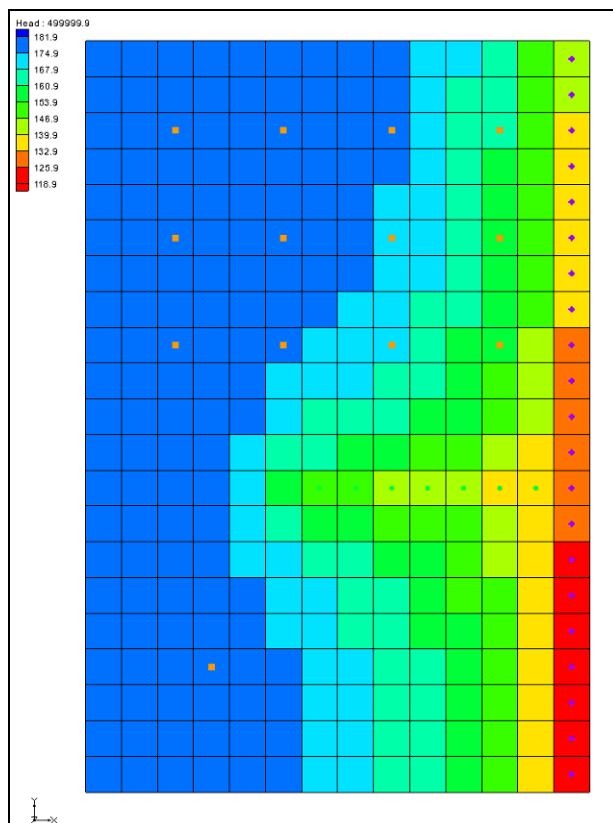





Figure 4. MODFLOW solution.

- Select the  *Save* button to save the project with the new solution.

9 Examining the Solution

Now we will look closely at the computed solution.

- If necessary re-select the grid cell shown in Figure 3, the one containing the top-left well (in Cell ID 31).
- Click on the *Front View* button .
- Select the *Display Options*  button and set the *Z magnification* to **20**.
- Select the *OK* button.

From this view, you can see the water table and the head contours. Notice that on the left side of the view the head is greater in the top layer of the model. In contrast, the head on the right side of the view, where the specified head boundary condition is located, is less

in layer 1 than in layer 2 of the model. Notice that the head in the selected cell is about 179.7.

5. Select the cell in the second layer (Cell Id 325) just below the currently selected cell.

Notice that the head in the cell in the second layer is about 175.8. So there is a potential for flow from layer 1 to layer 2 at these particular cells. Now we will see what effect the MNW multi-node well has on these grid cells.

6. Right click on the *CCF* item in the *Project Explorer* and select the *CCF → Data Sets* command.
7. Select the data set named *Multi-Node Wells*.
8. Click anywhere off the grid to unselect the grid cell.

Notice that flow is occurring between the multi-node well boundary conditions at these cells. This is an example of intraborehole flow that can occur when a well is completed in more than one aquifer. We can see the effect of the multi-node wells by looking at the *Flow Budget* dialog.

9. Select the two wells on the left of the grid by clicking on one cell and then shift clicking on the other.
10. Select the *MODFLOW | Flow Budget* menu.

Notice that the *Flow In* and the *Flow Out* are equal and opposite just as we would expect. A flow of about -16088 leaves the model cell in layer one and enters the model cell in layer 2

11. Select the *OK* button to exit the *Flow Budget* dialog.

10 Changing the Active Flag for the Multi-node Well

Now we will see the effect of turning off the active flag for the multi-node well. Let's assume that "Well-A" was not constructed until after the first stress period in our model. Therefore, we would not want to model the intraborehole flow or any pumping until after the first stress period. This can be accomplished by turning off the active flag for the boundary condition.


1. Select the *MODFLOW | Optional Packages | MNWI - Multi-Node Well* command to open the *MNW Package* dialog.
2. Turn **off** the *Active* toggle box for both "Well-A" boundary conditions in the spreadsheet.
3. Change the value of the stress period to **2**.

Notice that “Well-A” is active in stress period 2.

4. Select *OK* to exit the dialog.

11 Running MODFLOW and Viewing the Solution

Now we will run MODFLOW to see how our solution has changed.

1. Select the *Run MODFLOW* button .
2. Select *Yes* at the prompt to save your changes.
3. When MODFLOW finishes, select the *Close* button.
4. Right click on the **CCF** item in the *Project Explorer* and select the *CCF → Data Sets* command.
5. Select the data set named **Multi-Node Wells**.


Notice that there is no intraborehole flow now at “Well-A” during the first stress period.

12 Drawdown Limited Wells

The MNW package also allows for wells to be limited by the drawdown in the cell containing the well. This feature allows a well to stop pumping when the head in the cells drops below a specified elevation. We will now change the drawdown for one of the wells and see the effect on the solution. However, first we will change the active flag back to its original state for “Well-A”.

1. Select the *MODFLOW | Optional Packages | MNW1 - Multi-Node Well* command to open the *MNW Package* dialog.
2. Turn **on** the *Active* toggle box for both “Well-A” boundary conditions in the spreadsheet.
3. Select *OK* to exit the dialog.

Now we will edit one of the MNW wells to illustrate the drawdown-limited feature.

4. Switch to plan view by clicking the *Plan View*  button.
5. Select and right-click the cell shown in the figure below.

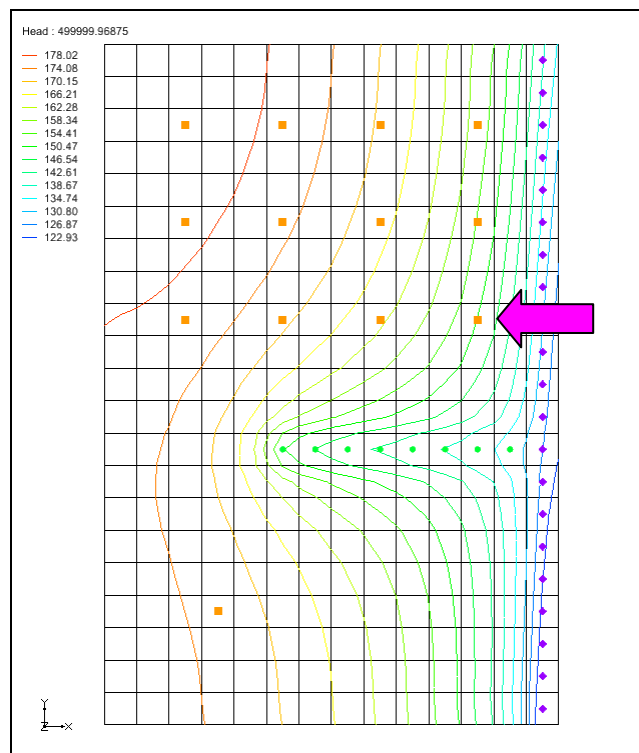




Figure 5. MNW boundary condition cell.

6. Select the *Sources/Sinks* command from the pop-up menu.
7. If necessary scroll over in the spreadsheet to the *Hlim* column and select the  button in the cell in the second row to edit the value of Hlim for the boundary condition.
8. Enter a value of **142.0** in each of the spreadsheet cells that currently have a value of 115.
9. Select *OK* twice to exit both dialogs.

13 Running MODFLOW and Viewing the Solution

Now we will run MODFLOW to see how our solution has changed.

1. Select the *Run MODFLOW*  button.
2. Select *Yes* at the prompt to save your changes.
3. When MODFLOW finishes, select the *Close* button.
4. Right click on the *CCF* item in the *Project Explorer* and select the *CCF → Data Sets* command.

5. Select the data set named **Multi-Node Wells** and change the active time step to the second time step listed in the *Time Step Window* below the *Project Explorer*. Notice that the flow at the cell that we edited is about -5754.
6. Select the **Head** data set. Notice that the head in this cell is about 143.29.

If you will remember, the desired flow rate (Qdes) that was specified for the well was 66850.0. Nevertheless, the computed flow for this drawdown limited well was only 6130. Now we will look at the head at the next output time.

7. Select the third time step listed in the *Time Step Window*. Notice that the head at the cell is about 142.36.
8. Change to the **Multi-Node Wells** data set and notice that the flow in this time step is 0.0.

Even though the head value is high enough the well has been deactivated during this stress period. We can find out why by examining the well's settings in the *MNW Package* dialog.

9. Select the *Optional Packages | MNW1 - Multi-Node Well* command to open the *MNW Package* dialog.
10. Change the stress period to stress period 2 and notice the settings for cell id 124 at the bottom of the spreadsheet.
11. Change to the next stress period.

Notice that for this stress period the QCUT value has been set to Percent with a Qfrcmn value of 45 pct. The Qfrcmn value is the minimum pumping rate required for the well to remain active. With a desired flow rate (Qdes) of -66850.0 we would need a flow rate of -30082.5 for the well to remain active. For the previous stress period QCUT was set to None allowing the well to be active.

12. Select *OK* to exit the dialog.

14 Drawdown Limited Multi-Node Wells

For multi-node wells the limiting water level needs to be specified for the first multi-node cell listed in the *MNW Package* dialog.

1. Change back to stress period 2.

Notice that for this stress period the row for Well-A has a flow rate of -20000.

2. If necessary, scroll over in the spreadsheet to show the *Hlim* and *DD* columns.

Notice that the *Hlim* value is set to 50 and the *DD* is set to relative. When using relative drawdown, the *Hlim* value used by MODFLOW is calculated by either adding or

subtracting Hlim from Href. When the Qdes value is greater than zero Hlim is added to Href, and when the Qdes value is less than zero Hlim is subtracted from Href. To demonstrate how the sign of the Qdes value can affect the model we will adjust the Qdes values for Well-A.

3. Scroll back to the left and enter **-1.0** in the Qdes column for the first Well-A cell, and enter **-19999.0** for the second Well-A cell. The combined value of Qdes for Well-A remains -20000.
4. Select *OK* to exit the dialog.

Before running MODFLOW with these changes we'll check head and multi-node well values in the first cell to verify they remain the same.

5. Select the top Well-A cell as shown in the figure below. Notice that the Multi-Node well value for the cell is -20120.

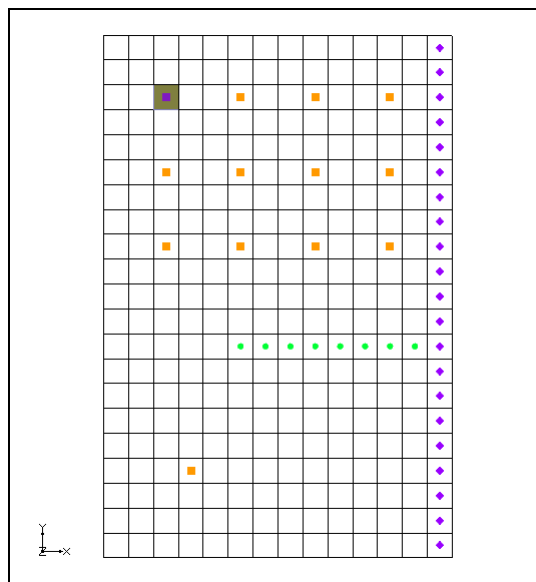




Figure 6. Selected MNW well cell.

6. Select the Head dataset in the Project Explorer. Notice that the head value is 164.60.
7. Select the *Run MODFLOW*  button.
8. Select *Yes* at the prompt to save your changes.
9. When MODFLOW finishes, select the *Close* button.
10. Select the **Head** data set and change the active time step to the second time step listed in the *Time Step Window* below the *Project Explorer*. Notice that the head in this cell remains at 164.60.

11. Right click on the **CCF** item in the *Project Explorer* and select the *CCF → Data Sets* command.
12. Select the data set named **Multi-Node Wells** and change the active time step to the second time step listed in the *Time Step Window* below the *Project Explorer*. Notice that the flow remains at -20120.

Now we will adjust the Qdes values so that the sum remains the same but the sign of the Qdes for the first cell is positive.



13. Select the *MODFLOW | Optional Packages | MNWI - Multi-Node Well* command to open the *MNW Package* dialog.
14. Enter **1.0** in the Qdes column for the first Well-A cell, and enter **-20001.0** for the second Well-A cell.
15. Select the *Run MODFLOW*  button.
16. Select *Yes* at the prompt to save your changes.
17. When MODFLOW finishes, select the *Close* button.
18. Select the **Head** data set and change to stress period 2. Notice that the head in this cell has changed to 165.61.
19. Right click on the **CCF** item in the *Project Explorer* and select the *CCF → Data Sets* command.
20. Select the data set named **Multi-Node Wells** and change the active time step to the second time step listed in the *Time Step Window* below the *Project Explorer*.


Notice that the flow has changed to -13809. This change has been caused by a higher Hlim value which was in turn brought about by changing the sign of the Qdes value in the first Well-A cell. Less flow could be taken from the model by the well to maintain a higher head value.

15 Create a Conceptual Model

Now we'll examine how to use a conceptual model with MNW data. We'll do this by taking the finished model for the *MODFLOW – Conceptual Model Approach* tutorial and changing it to use the MNW package.

15.1 Open the Existing Conceptual Model

1. Before opening the conceptual model you may wish to save the grid based MNW model by selecting the *Save*  button.
2. Select the *New*  button.

3. Select the *Open*  button.
4. Locate and open the directory entitled **Tutorials\MODFLOW\modfmap1\sample**.
5. Open the file entitled **modfmap.gpr**.

Before we make any changes, lets save the project under a new name.

6. Select the *File | Save As* command.
7. Browse back to the **Tutorials\MODFLOW\mnw** folder.
8. Save the project with the name **MNWmap**.

16 Examining the Existing Solution

Before changing to the MNW package lets look at the flow budget for the existing solution.

1. Select the *MODFLOW | Flow Budget* command.

Notice the flow budget for the Well package has a flow rate of -3510.0 (out of the model).


2. Press the *OK* button the exit the *Flow Budget* dialog.

17 Changing the Model to Use MNW

To change to the MNW package first the WEL package needs to be removed from MODFLOW.


1. Select the *MODFLOW | Global Options* command.
2. Press the *Packages* button to bring up the *MODFLOW Packages* dialog.
3. Turn **off** the *Well (WEL1)* toggle to disable the WEL package.
4. Press the *OK* button twice to exit both dialogs.

17.1 Changing the Wells to MNW

1. Expand the  **East Texas** conceptual model in the *Project Explorer* and select the **Sources & Sinks** coverage.
2. Right click on the **Sources & Sinks** coverage and select *Coverage Setup*.

3. Turn **on** the *Wells (MNW)* toggle in the *Sources/Sinks/BCs* section of the dialog.
4. Press the *OK* button to exit the *Coverage Setup* dialog.
5. Right-click on the **Sources & Sinks** coverage and select *Attribute Table*.
6. In the *All* row change the type to *well (MNW)*.
7. Change the *Qdes* of point_95, the first well, to **-680.0**. You may need to scroll to the right to see these fields.
8. Change the *Qdes* of point_96, the second well, to **-2830.0**.
9. Press the *OK* button to exit the *Properties* dialog.

The conceptual model is set up so now we can map it to the MODFLOW grid.

10. Select the *Map → MODFLOW*  button.
11. Click *OK*.

18 Examine the MNW Package

Let's take a look at the data in MODFLOW that was mapped from the conceptual model.


1. Select the *MODFLOW | Optional Packages | MNWI - Multi-Node Well* menu command.


Review the two MNW boundary conditions that were created.

2. Click *OK* to exit the dialog.

19 Saving and running MODFLOW

We're ready to save our changes and run MODFLOW. First we need to adjust the Output Control.

1. Select the *MODFLOW | OC - Output Control* menu command.
2. Turn off the **.hff file for transport* option.
3. Select *OK* to exit the dialog.
4. Select the *Run MODFLOW*  button.
5. Select *Yes* at the prompt to save your changes.
6. When MODFLOW finishes, select the *Close* button.

7. Select the  *Save* button to save the project with the new solution.

20 Examining the Solution

Let's look at the flow budget for the new solution.

1. Select the *MODFLOW | Flow Budget* command.

Notice the flow budget for the MNW package has the same flow rate of -3510.0 (out of the model).


2. Press the *OK* button to exit the *Flow Budget* dialog.

21 Changing to a Multi-Node Well

Now we will create a multi-node well from our map data.

1. Right-click on the **Sources & Sinks** coverage and select the *Attribute Table* command.
2. Change the *From layer* value to **1** for point_96 in the table.
3. Select *OK* to exit the dialog.

The conceptual model is set up so now we can map it to the MODFLOW grid.

4. Select the *Map → MODFLOW*  button.
5. Click *OK*.

22 Examine the MNW Package

Let's take a look at the data in MODFLOW that was mapped from the conceptual model.


1. Select the *MODFLOW | Optional Packages | MNWI - Multi-Node Well* menu command.

Review the various MNW boundary conditions that were created. Notice that point_96 is associated with 2 MNW boundary conditions and that the Well ID is 1 for each of the boundary conditions. Notice also that the Qdes has only been assigned to one of the point_96 boundary conditions. The MNW package will calculate the amount of flow that each of the wells will take from the aquifer.

2. Click *OK* to exit the dialog.



23 Saving and running MODFLOW

We're ready to save our changes and run MODFLOW. Before doing so we will need to adjust the parameters associated with our solver.


1. Select the MODFLOW | PCG2 - Pre. Conj.-Gradient Solver command.
2. Change *MXITER. Maximum number of outer iterations* to **100** and *RELAX. Relaxation parameter* to **0.5**.
3. Click *OK* to exit the dialog.
4. Select the *File | Save As* menu command.
5. Change the project name to **MNWmap2**.
6. Select the *Run MODFLOW*  button.
7. When MODFLOW finishes, select the *Close* button.

24 Viewing the Flow in the MNW Boundary Conditions

Now we will view the computed flow out of each of the MNW boundary conditions associated with point_96.

1. Select the *Zoom* tool  and zoom in around the well on the right side of the model.
2. Select the cell containing the well using the *Select Cell* tool .
3. Select the MODFLOW | *Flow Budget* command.

Notice that the flow out of the well in the top layer is about -1628.5. Now we will view the flow out of the well in the second layer.

4. Select *OK* to exit the dialog.
5. Change to view layer 2 of the grid by clicking the up arrow in the *Mini Grid* toolbar.
6. Select the cell containing the well using the *Select Cell* tool .
7. Select the MODFLOW | *Flow Budget* command.

Notice that the flow rate for this well is about -1201.4.

25 Conclusion

This concludes the tutorial. Here are the things that you should have learned in this tutorial:

- GMS supports both the WEL and MNW packages. Both packages can be used at the same time if desired.
- The MNW package produces the same results as the WEL when there are no multi-node wells.
- MNW data can be viewed and edited in the MNW Package dialog.

26 Notes

1. 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. K.J. Halford and R.T. Hanson. Open-File Report 02-293. 2002.