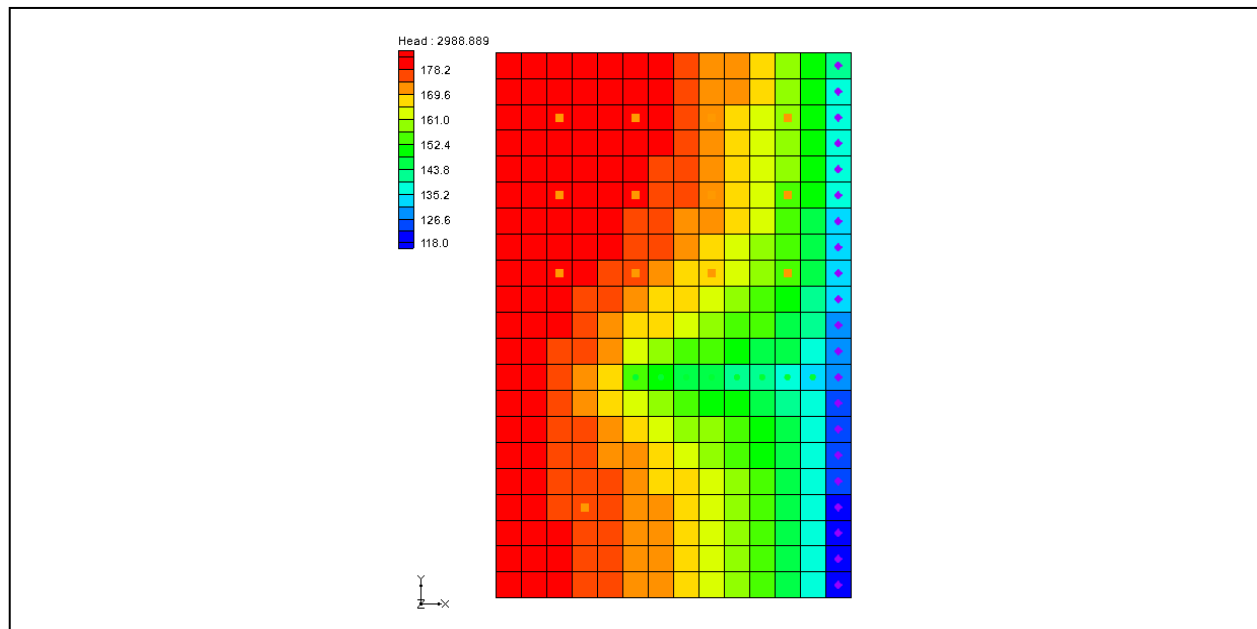*GMS 10.0 Tutorial*

MODFLOW – MNW Package

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

Objectives

Learn how to use the Multi-Node Well (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
- MODFLOW – Conceptual Model Approach I

Required Components
- Map Module
- Grid Module
- MODFLOW

Time
- 30-45 minutes

1   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, wells that are partially penetrating wells, and wells that are 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]

1.1   Outline

Here are the steps of this tutorial:

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

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.

2   Description of Problem

The problem 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 ft^2/d. Storage coefficients of 0.05 and 0.0001 were assigned to layers 1 and 2, respectively. The 66-mi^2 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.

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 ft^3/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 ft^3/d for stress periods 2 through 5.[2]
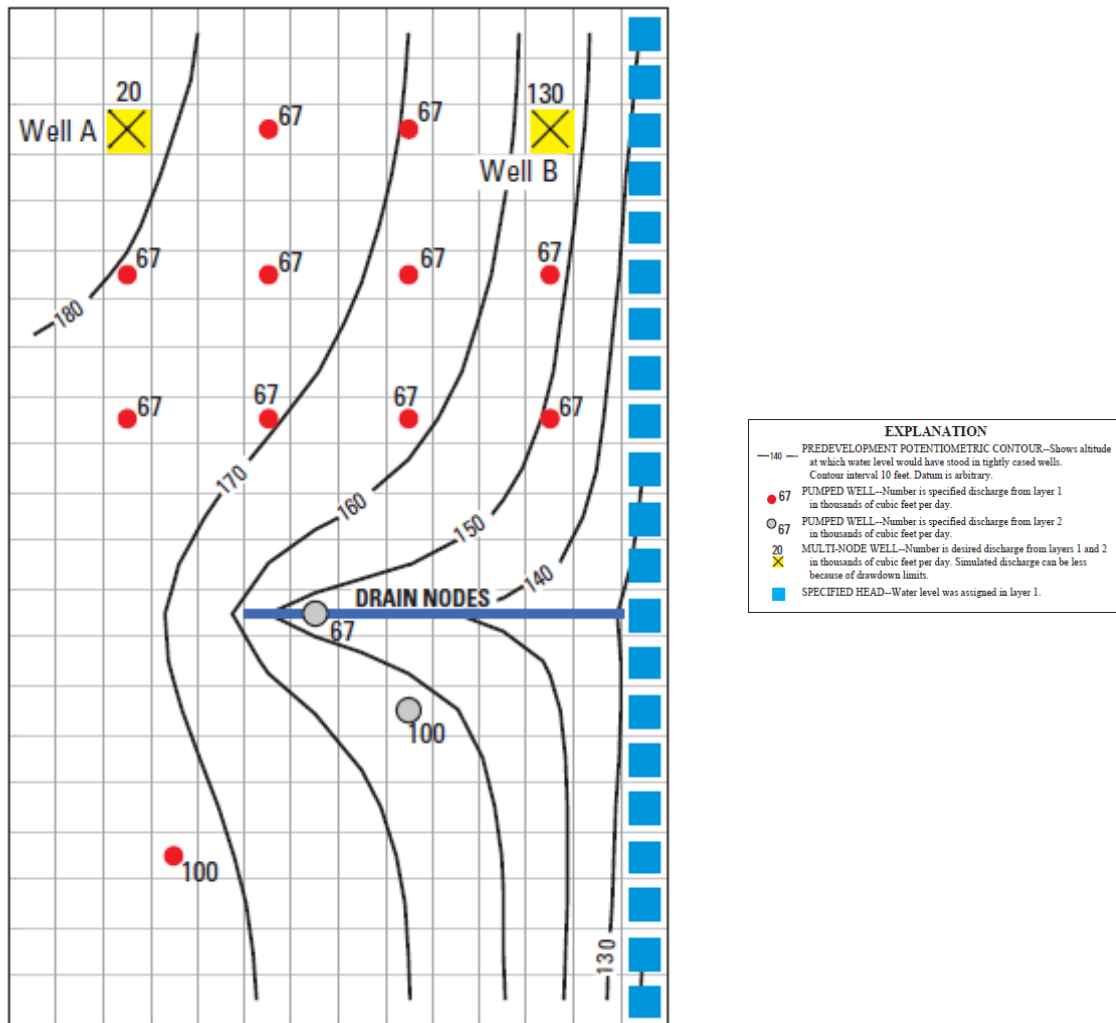
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2. Ibid.

Figure 1   Flow model from MNW documentation[3]

3 Getting Started

Do the following to get started:

1. If necessary, launch GMS.

2. If GMS is already running, select the *File* / **New** command to ensure that the program settings are restored to their default state.

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3. Ibid.

4   Importing the existing model

The user 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* pop-up menu to "All Files."

4.   Select the "mnw1.nam" file, and click **Open**.

A dialog should alert the user 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. The user should see a grid with symbols representing wells, drains, and specified head boundary conditions similar to the figure below.
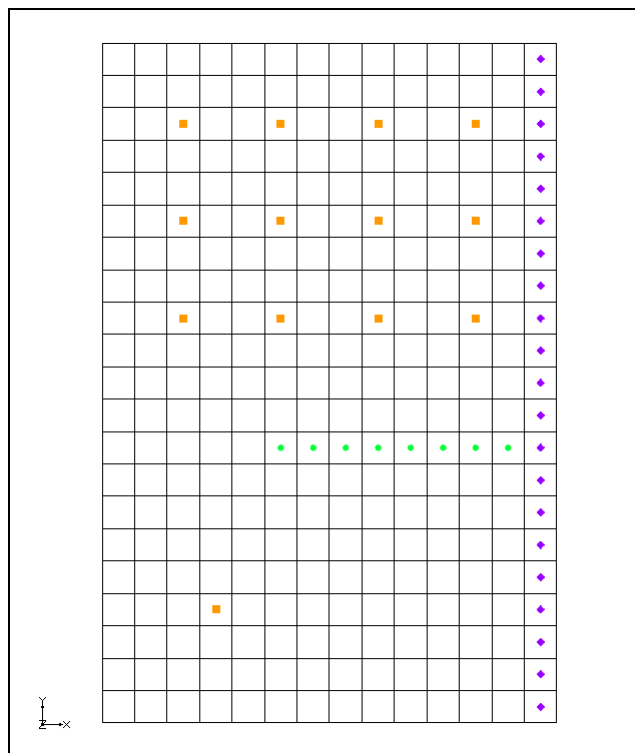

Figure 2   Imported MODFLOW model

5   Saving the model with a new name

Before making changes, 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.

6   Viewing the MNW boundary conditions

Before running the simulation, the user will view the MNW boundary conditions.

6.1   Opening the MNW Package Dialog

1. Select the *MODFLOW* / *Optional Packages* / **MNW1 - 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 near the bottom 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 it is possible to examine the MNW boundary conditions. The user 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. If necessary, 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. GMS now has 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.

6.2   Opening the Source/Sinks Dialog

1. Switch to the 3D Grid module by selecting the "3D Grid Data" 🗃 item in the Project Explorer.

2. Using the **Select Cells** tool, select the 3D grid cell with the MNW well in it as shown in the figure below.
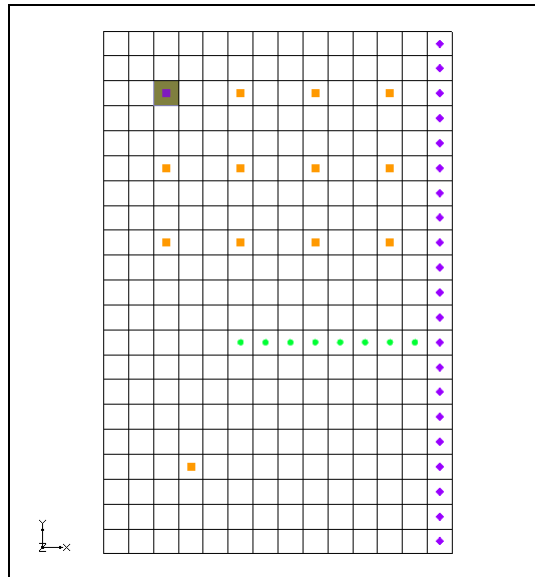

Figure 3   Selected MNW well cell

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.

7   Running MODFLOW

Before running MODFLOW, it is necessary to change the output options to make it easier to see the results.

1. Select the *MODFLOW* / **OC - Output Control** menu command.

2. In the *MODFLOW Output Control* dialog, 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 *.ccf file* toggle.

4. Press the **OK** button to exit the *MODFLOW Output Control* dialog.

Now save these changes and run MODFLOW.

5. Select the **Save** 🖫 button (or the *File* | **Save** menu command).

6. Select the *MODFLOW* | **Run MODFLOW** menu command.

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

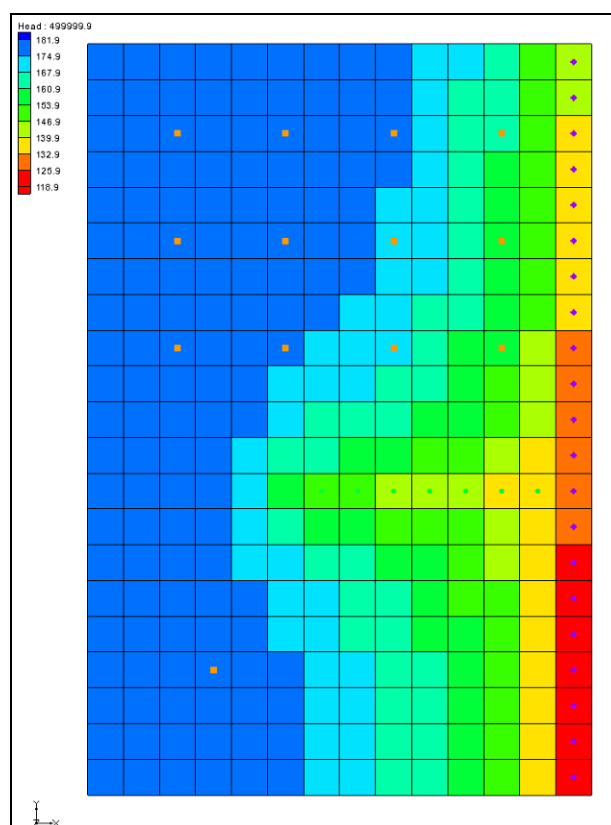Contours should appear on the grid similar to those shown in the following figure:

Figure 4   *MODFLOW solution*

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

8   Examining the Solution

Now look closely at the computed solution:

1. If necessary, re-select the grid cell shown in Figure 3, the one containing the top-left well (in Cell ID 31).

2. Click on the **Front View** button.

3. Select the **Display Options** button and set the *Z magnification* to "20."

4. Select the **OK** button.

From this view, it is possible to 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 just below the currently selected cell (Cell ID 325).

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, it is possible to 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 dataset named "MNW."

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. The user 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 expected. 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.

9   Changing the Active Flag for the Multi-node Well

Now it is possible to see the effect of turning off the active flag for the multi-node well. The user will assume that "Well-A" was not constructed until after the first stress period in the model. Therefore, the user 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 |* **MNW1 - 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.

10   Running MODFLOW and Viewing the Solution

Now it is possible to run MODFLOW to see how the solution has changed.

1. Select the **Run MODFLOW** button.

2. Select **Yes** at the prompt to save the changes.

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

4. Right-click on the **CCF** item in the Project Explorer.

5. Select the **CCF → Data Sets** command.

6. Select the dataset named "MNW."

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

11   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. The user will now change the drawdown for one of the wells and see the effect on the solution. However, first the user 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 the user will edit one of the MNW wells to illustrate the drawdown-limited feature.

4. Switch to plan view by clicking the **Plan View** button.

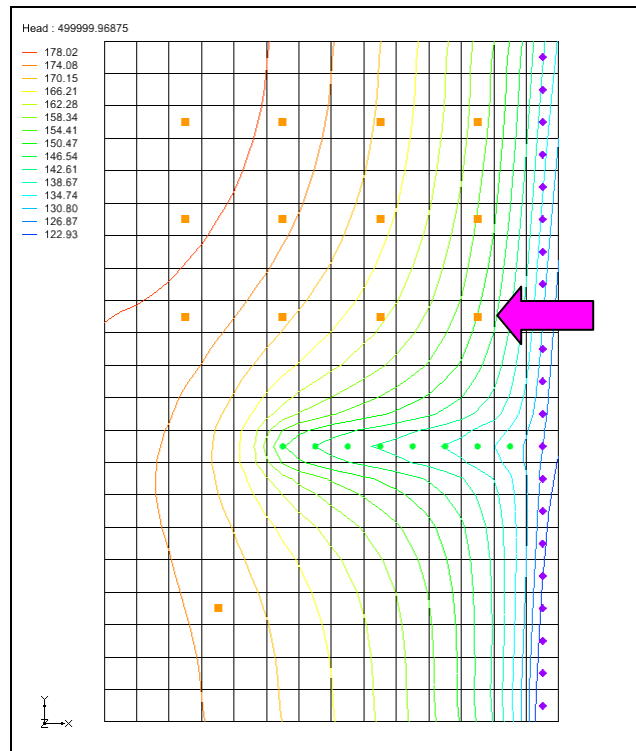5. Select and right-click the cell shown in the figure below (Cell ID 124).

Figure 5   MNW boundary condition cell

6. Select the **Sources/Sinks** command from the pop-up menu to open the *MODFLOW Sources/Sinks* dialog.

7. If necessary scroll over in the spreadsheet to the *Hlim* column and select the lower button to edit the value of Hlim for the boundary condition.

8. In the the *XY Series Editor* dialog, enter a value of "142.0" in each of the spreadsheet cells that currently have a value of 115.

9. Select **OK** to exit the *XY Series Editor* dialog.

10. Select **OK** to exit the *MODFLOW Sources/Sinks* dialog.

12   Running MODFLOW and Viewing the Solution

Now run MODFLOW to see how the solution has changed:

1. Select the **Run MODFLOW** button.

2. Select **Yes** at the prompt to save the changes.

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

4. Right-click on the "CCF" item in the Project Explorer.

5. Select the **CCF → Data Sets** command.

6. Select the dataset named "MNW" 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 was edited is about -5754.

7. Select the "Head" dataset. Notice that the head in this cell is about 143.29.

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 it is possible to look at the head at the next output time.

8. Select the third time step listed in the *Time Step Window*. Notice that the head at the cell is about 142.36.

9. Change to the "MNW" dataset 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. The user can find out why by examining the well's settings in the *MNW Package* dialog.

10. Select the *MODFLOW | Optional Packages | **MNW1 - Multi-Node Well** command to open the *MNW Package* dialog.

11. Change the stress period to stress period 2 and notice the settings for Cell ID 124 at the bottom of the spreadsheet.

12. 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, the user 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.

13. Select **OK** to exit the dialog.

13   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. Select the *MODFLOW | Optional Packages | **MNW1 - Multi-Node Well** command to open the *MNW Package* dialog.

2. Change back to stress period 2.

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

3. 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, the user will adjust the Qdes values for Well-A.

4. Scroll back to the left and enter "-1.0" in the Qdes column for the first Well-A cell

5. Enter "-19999.0" for the second Well-A cell. The combined value of Qdes for Well-A remains -20000.

6. Select **OK** to exit the dialog.

Before running MODFLOW with these changes, it is necessary to check head and multi-node well values in the first cell to verify that they will remain the same.

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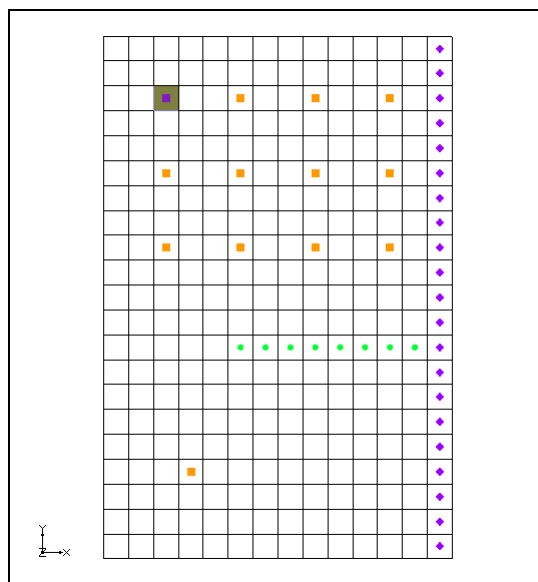

Figure 6   Selected MNW well cell

8. Select the Head dataset in the Project Explorer. Notice that the head value is 164.60.

9. Select the **Run MODFLOW** button.

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10. Select **Yes** at the prompt to save the changes.

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

12. Select the "Head" dataset 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.

13. Right-click on the **CCF** item in the Project Explorer.

14. Select the **CCF → Data Sets** command.

15. Select the dataset named "MNW" 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 the user will adjust the Qdes values so that the sum remains the same but the sign of the Qdes for the first cell is positive.

16. Select the *MODFLOW | Optional Packages |* **MNW1 - Multi-Node Well** command to open the *MNW Package* dialog.

17. Enter "1.0" in the Qdes column for the first Well-A cell.

18. Enter "-20001.0" for the second Well-A cell.

19. Click **OK** to exit the dialog.

20. Select the **Run MODFLOW** button.

21. Select **Yes** at the prompt to save the changes.

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

23. Select the "Head" dataset and change to stress period 2 in the *Time Step Window*. Notice that the head in this cell has changed to 165.60.

24. Right-click on the **CCF** item in the Project Explorer.

25. Select the **CCF → Data Sets** command.

26. Select the dataset named "MNW" 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.

14   Create a Conceptual Model

The next step is to 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.

14.1   Open the Existing Conceptual Model

1. Before opening the conceptual model, the user may wish to save the grid-based MNW model by selecting the **Save** ![save icon] button.

2. Select the **New** ![new icon] button.

3. Select the **Open** ![open icon] button.

4. Locate and open the directory entitled *Tutorials\MODFLOW\modfmap\sample2*.

5. Select the file entitled "modfmap2.gpr."

6. Click the **Open** button.

Before making any changes, save the project under a new name.

7. Select the *File | **Save As*** command.

8. Browse back to the *Tutorials\MODFLOW\mnw* folder.

9. Save the project with the name "MNWmap.**"**

15   Examining the Existing Solution

Before changing to the MNW package, 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 -2344.60 (out of the model).

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

16   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 to open the *MODFLOW Global/Basic Package* dialog.

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 **OK** to exit the *MODFLOW Packages* dialog.

5.   Press **OK** to exit the *MODFLOW Global/Basic Package* dialog.

16.1   Changing the Wells to MNW

1.   Expand the "Map Data" folder.

2.   Expand the "East Texas" 🐢 conceptual model in the Project Explorer.

3.   Select the "Sources & Sinks" coverage.

4.   Right-click on the **"**Sources & Sinks" coverage.

5.   Select **Coverage Setup**.

6.   Turn on the *Wells (MNW)* toggle in the *Sources/Sinks/BCs* section of the dialog.

7.   Press the **OK** button to exit the *Coverage Setup* dialog.

8.   Right-click on the "Sources & Sinks" coverage.

9.   Select **Attribute Table** to open the *Attribute Table* dialog.

10. In the *All* row, change the type to *well (MNW)*.

11. Change the *Qdes* of well1, the first well, to "–50.0." The user may need to scroll to the right to see these fields.

12. Change the *Qdes* of well2, the second well, to "–300.0."

13. Press the **OK** button to exit the *Attribute Table* dialog.

The conceptual model is set up so now it can be mapped to the MODFLOW grid.

14. Select the **Map → MODFLOW** 🔧 button.

15. Click **OK**.

17   Examine the MNW Package

The next step is to take a look at the data in MODFLOW that was mapped from the conceptual model.

1. Select the *MODFLOW | Optional Packages |* **MNW1 - Multi-Node Well** menu command.

Review the two MNW boundary conditions that were created.

2. Click **OK** to exit the *MODFLOW Multi-Node Well Package* dialog.

18   Saving and Running MODFLOW

Now it is almost possible to save the changes and run MODFLOW. First, the user needs to adjust the Output Control.

1. Select the *MODFLOW |* **OC - Output Control** menu command.

2. In the *MODFLOW Output Control* dialog, 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 the changes.

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

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

19   Examining the Solution

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 -2344.0 (out of the model).

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

20   Changing to a Multi-Node Well

Now the user will create a multi-node well from the map data.

1. Right-click on the "Sources & Sinks" coverage.

2. Select the **Attribute Table** command.

3. Change the *From layer* value to "1" for well1 in the table.

4. Select **OK** to exit the dialog.

The conceptual model is set up so now it can be mapped to the MODFLOW grid.

5. Select the **Map→ MODFLOW** button.

6. Click **OK**.

21   Examine the MNW Package

Now it's possible to take a look at the data in MODFLOW that was mapped from the conceptual model.

1. Select the *MODFLOW | Optional Packages | **MNW1 - Multi-Node Well*** menu command.

Review the various MNW boundary conditions that were created. Notice that well2 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 well1 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.

22   Saving and running MODFLOW

Now it is possible to save the changes and run MODFLOW. Before doing so, the user will need to adjust the parameters associated with the solver.

1. Select the *MODFLOW | **PCG2 - Pre. Conj.-Gradient Solver*** command.

2. In the *MODFLOW PCG2 Package* dialog, change *Maximum number of outer iterations (MXITER)* to "100."

3. Change the *Relaxation parameter (RELAX)* to "0.5."

4. Click **OK** to exit the dialog.

5. Select the *File | **Save As*** menu command.

6. Change the project name to "MNWmap2."

7. Select **Save.**

8. Select the **Run MODFLOW** button.

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

23   Viewing the Flow in the MNW Boundary Conditions

Now the user will view the computed flow out of each of the MNW boundary conditions associated with well2.

1. Click on the "3D Grid Data" folder to make it active.

2. Select the **Zoom** tool and zoom in around the well on the right side of the model.

3. Select the cell containing the well using the **Select Cell** tool.

4. Select the *MODFLOW* / **Flow Budget** command.

Notice that the flow out of the well in the top layer is about -170.08. Now the user will view the flow out of the well in the second layer.

5. Select **OK** to exit the dialog.

6. Change to view layer 2 of the grid by clicking the up arrow in the *Mini Grid Toolbar*.

7. Select the cell containing the well using the **Select Cell** tool.

8. Select the *MODFLOW* / **Flow Budget** command.

Notice that the flow rate for this well is about -129.93.

24   Conclusion

This concludes the tutorial. Here are the main concepts from 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.