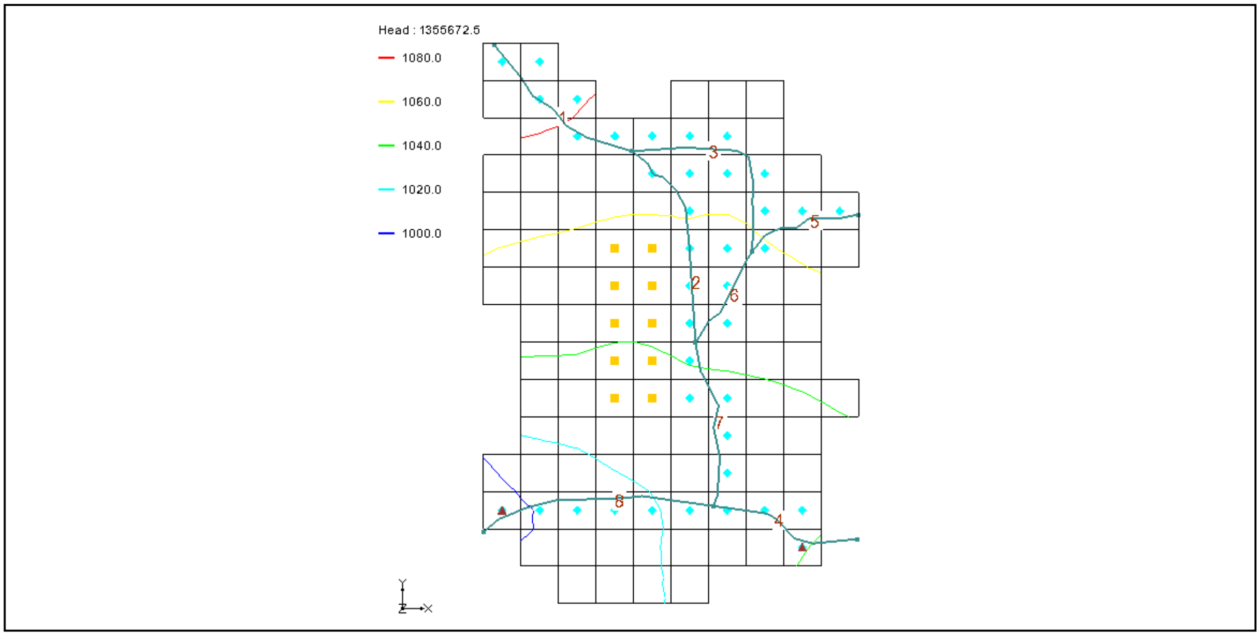
v. 10.0

GMS 10.0 Tutorial

MODFLOW – SFR2 Package

The MODFLOW Streamflow-Routing (SFR2) Package Interface in GMS



Objectives

Learn how to create a model containing SFR1/SFR- type streams. The tutorial is based on the test simulations contained in the SFR1 package documentation. Create a conceptual model of the streams using arcs and orient them from upstream to downstream. Learn about stream segment and reach numbering. Create a parameter for stream conductance.

Prerequisite Tutorials

- MODFLOW – Conceptual Model Approach I

Required Components

- Map Module
- MODFLOW

Time

- 55-65 minutes

1 Introduction

The MODFLOW SFR2 package is used to model streamflow routing and unsaturated flow beneath streams. It is an evolution of the SFR1 package, which was derived from the original MODFLOW stream package, STR1. GMS supports all three stream packages. The SFR2 package is very similar to the SFR1 package with the main difference being support for unsaturated flow beneath streams. The SFR2 package can read files prepared for the SFR1 package.

Because of the grid-independent conceptual model approach that GMS has long supported, GMS is an ideal modeling interface for creating streams. Stream segments and reaches must be listed in a particular order that can be quite tricky to get right if preparing a file by hand. GMS takes care of stream ordering automatically so the user never has to worry about it. The simple point-and-click interface makes it very easy and intuitive to create streams in GMS.

This tutorial illustrates how to create a model containing SFR1/SFR2 type streams. The tutorial is based on the test simulations contained in the "MODFLOW SFR1 Package" documentation.

1.1 Outline

Here are the steps in this tutorial:

1. Open a GMS project.
2. Add stream feature arcs by digitizing a background image.
3. Ensure that the stream arcs are pointing in the right direction.
4. Assign attributes to the stream arcs.
5. Save and run the model.
6. Examine the solution.

2 Stream Package Basics

2.1 Reaches and Segments

The SFR2 package divides streams into reaches and segments.

> A stream reach is a section of a stream that is associated with a particular finite-difference cell used to model ground-water flow and transport. A segment is a group of reaches that have (1) uniform rates of overland flow and precipitation to them; (2) uniform rates of evapotranspiration from them; (3) uniform or linearly changing properties (for example; streambed elevation, thickness, and hydraulic conductivity, and stream depth and width); (4) tributary flows or specified inflow or outflow (only in the first reach); and (5) diversions (only from the last reach). (Prudic, et. al., 2004:2)

In GMS, a stream segment corresponds to a single arc. A stream reach doesn’t have a corresponding representation in the conceptual model but exists only on the grid cells after having mapped the conceptual model to the grid.

2.2 Routing

In addition to tracking flow between streams and the underlying aquifer, the MODFLOW stream packages (STR1, SFR1 and SFR2) also route the flow of water through a stream network. The stream network can include tributaries, diversions, and lakes (in conjunction with the Lake package).

Routing is accomplished by determining the inflows for a reach (which are specified for the most upstream reach), adding or subtracting leakage to the aquifer, and allowing any remainder to pass to the next downstream reach as inflow. The process is repeated for the next downstream reach and so forth.

This is different from the MODFLOW River package which only tracks flow between the river and the aquifer. With rivers, once water has entered the river, it is lost to the model, whereas, with the stream packages, that water can travel downstream and possibly reenter the aquifer at another point.

Also unlike the River package, the water depth is not specified in the stream packages but is calculated based on the flow. There are several different options available for calculating water depth, including using Manning's equation or a depth vs. flow table.

3 Description of Problem

The model in this tutorial is from the SFR1 documentation "A New Streamflow-Routing (SFR1) Package to Simulate Stream-Aquifer Interaction With MODFLOW–2000" by David E. Prudic, Leonard F. Konikow, and Edward R. Banta, U.S. Geological Survey Open-File Report 2004-1042. The model is illustrated in Figure 1. The problem is a hypothetical one "developed for an alluvial basin in a semiarid region in which recharge to the aquifer is primarily leakage from streams that enter the basin from mountains on the northwest, northeast, and southeast" (Prudic, et al., 2004:13). One grid layer is used.

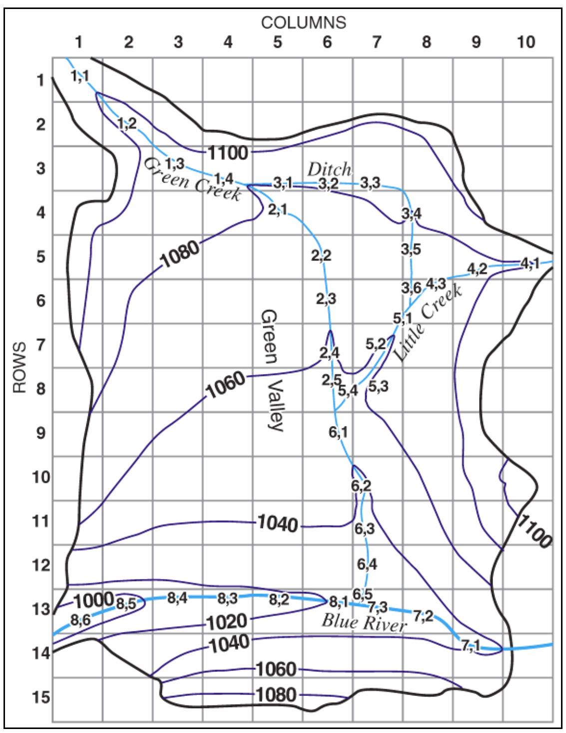


Figure 1 An SFR1 stream network. (Prudic, et al., 2004)

The simulation has two stress periods. In the first stress period, the wells in the middle of the model extract water from the model and draw down the water table. In the second stress period, the wells are turned off and the head recovers from the draw down. The stream data is held constant for both stress periods.

4 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.

5 Open the Starting Project

The point of this tutorial is to illustrate the SFR2 package, so this tutorial won't spend time entering in all the other MODFLOW inputs. The user will just read them in from files that have already been created.

1. Select the **Open** button.
2. Locate and open the *Tutorials\MODFLOW\sfr2* directory.
3. Select the file entitled "start.gpr."
4. Click **Open**.

The user should see a figure showing a grid with some streams and contour lines as shown in Figure 2. This figure comes from the MODFLOW SFR1 documentation.

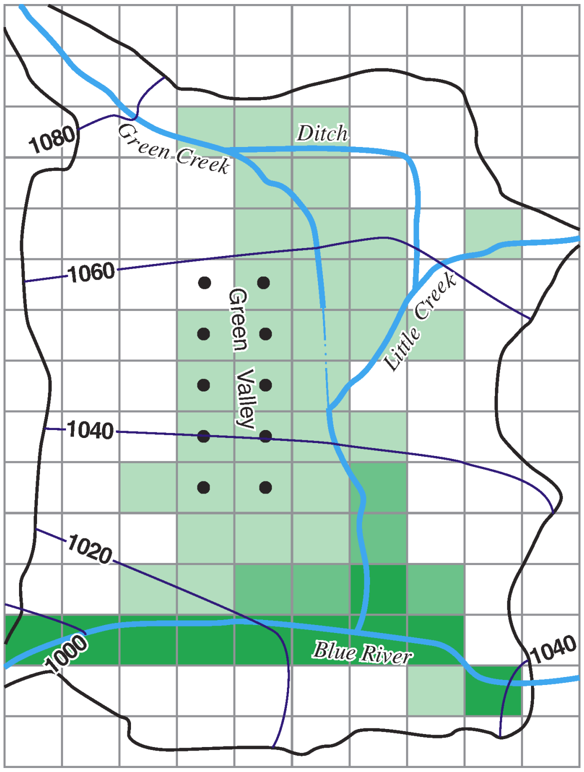


Figure 2 Background image in GMS, taken from the MODFLOW SFR2 documentation

Notice the Project Explorer includes a 3D grid and a MODFLOW simulation (the user may need to expand items in the Project Explorer to see the MODFLOW simulation).

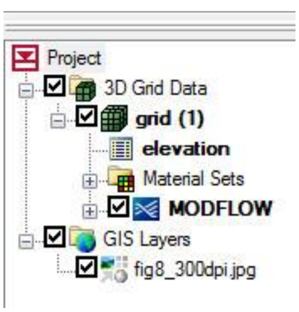


Figure 3 Project Explorer contents for the beginning project

5.1 Save the Project with a New Name

Now save the project with a new name.

1. Select the *File* | **Save As** menu command.
2. Change the *File name* to "SFR2_GMS."
3. Click **Save**.

The user may wish to select the **Save** button occasionally to save the work as the user continues with the tutorial.

6 Digitize the Stream Arcs

In GMS, it is only possible to create streams by using the conceptual model approach. That is, the user must use feature objects and map them to the grid. The user cannot create streams directly on the grid.

The user will create the stream arcs by digitizing the background image.

6.1 Create a conceptual model

First, it is necessary to create a MODFLOW conceptual model.

1. In the Project Explorer, right-click somewhere in a blank area and select the *New* | **Conceptual Model** command from the pop-up menu.

2. In the *Conceptual Model Properties* dialog, change the *Name* to "Test 1."

3. Click **OK**.

6.2 Create a coverage

1. Right-click on the "Test 1" conceptual model and select the **New Coverage** menu command from the pop-up menu.

2. In the *Coverage Setup* dialog, change the *Coverage name* to "Streams."

3. In the list of *Sources/Sinks/BCs* on the left, turn on the *Stream (SFR2)* option.

4. Change the *Default elevation* to "1500" so the coverage will be above the grid.

5. Click **OK**.

6.3 Create the Arcs

Now the user will create the arcs.

1. Select the **Create Arc** tool.

2. Create arcs by clicking on and following the blue lines in the figure. These are labeled “Green Creek,” “Ditch,” “Little Creek,” and “Blue River.” The arcs should be located approximately as shown in Figure 4.

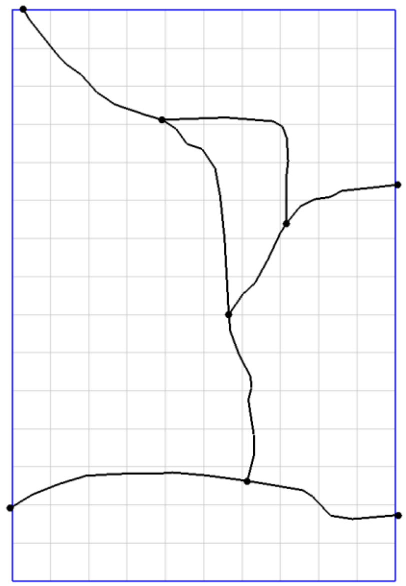


Figure 4 Location of stream arcs after digitizing

Now that the arcs have been digitized, the user no longer needs the background image.

3. In the Project Explorer, turn off the “GIS Layers” folder.

7 Correct the Arc Directions

Arcs have a direction associated with them. The direction is from the starting node to the ending node and is defined when the user first creates the arc. Usually the direction doesn’t matter, but with streams it does. It is necessary to make sure that the arcs go from upstream to downstream. The direction can be displayed and reversed if needed.

The user must now check the arc direction and make sure all the arcs are pointing from upstream to downstream.

1. Click the **Display Options** button.
2. In the *Display Options* dialog, make sure *Map Data* is selected in the list on the left.
3. Turn on the *Arc direction arrows* option.
4. Click **OK**.

The user should now see arrows on the arcs. The arrows should be pointing as shown in Figure 5. If any of the arcs are pointing in the wrong direction, do the following:

5. Switch to the **Select Arcs** tool.

6. Right-click on an arc that is pointing the wrong way (if there are any) and select the *Reverse Arc Direction* command from the pop-up menu. Repeat for all arcs which point the wrong direction.

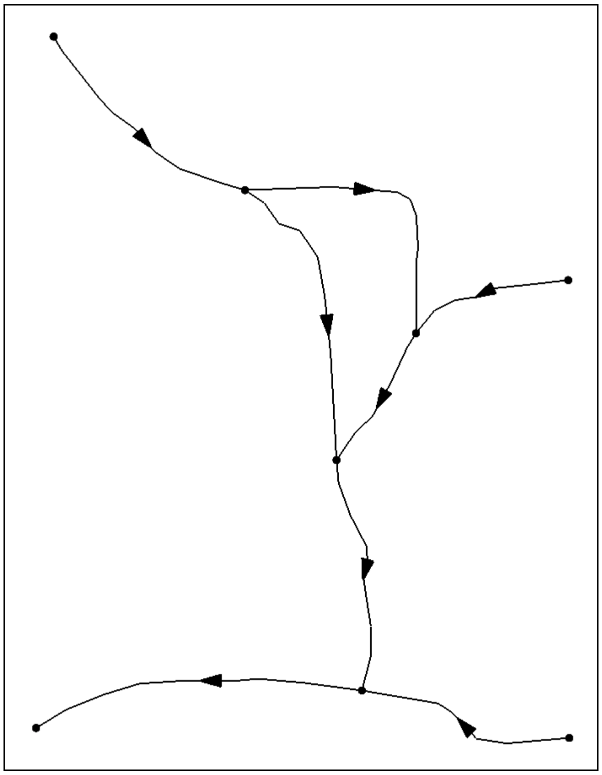


Figure 5 Arc directions

All the arcs should now be pointing the correct direction, matching Figure 5. Now it is necessary to turn the arrows back off.

7. Click the **Display Options** button.
8. In the *Display Options* dialog, make sure *Map Data* is selected in the list on the left.
9. Turn off the *Arc direction arrows* option.
10. Click **OK**.

8 Stream Reach and Segment Numbering

With GMS, the user generally won't need to worry about stream segment and reach numbering because GMS figures it all out automatically. However, it is a concept the user should be aware of; moreover, the user will see the numbering in the SFR2 package dialog, which is covered later in this tutorial.

According to the SFR1 package documentation, "The numbering of segments and reaches is important. Segments are numbered sequentially from the farthest upstream segment to the last downstream segment … Reaches within a segment must be numbered sequentially from the farthest upstream reach in a segment to the last downstream reach" (Prudic, et al., 2004:3). Figure 6 illustrates stream and segment numbering.

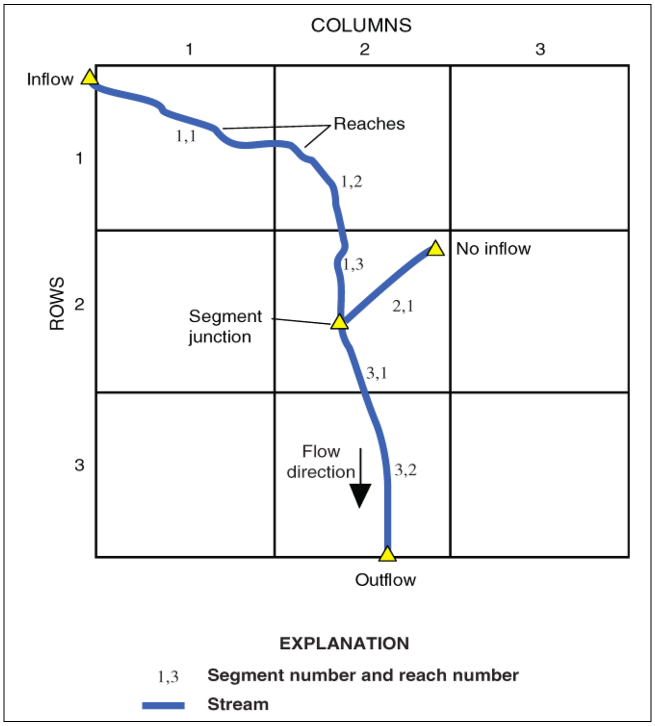


Figure 6 Illustration of stream segment and reach numbering. (Prudic, et al., 2004)

GMS assigns an integer ID number to each arc automatically as it is created. This ID number is NOT the stream segment number. Stream segment and reach numbers are only determined when the **Map →MODFLOW** command is executed. The user should be careful not to confuse arc ID numbers with stream segment numbers.

9 Assign Arc Attributes

Now the user will assign the stream attributes to the arcs.

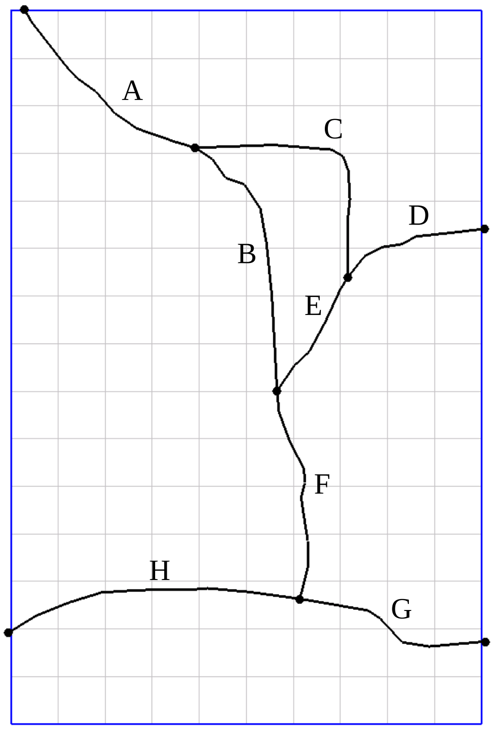


Figure 7 Arcs with letters to distinguish them

9.1 Arc A

1. With the **Select Arcs** tool still active, double-click on arc A as given in Figure 7. This brings up the *Attribute Table* dialog.

2. Change the *Type* to "stream (SFR2)."

3. Enter the remaining values as given in the following table (only the columns with changes are shown):

ICALC	FLOW	HCOND1	THICKM1	ELEVUP	HCOND2	THICKM2	ELEVDN
table (4)	25	.00003	3	1095	.00003	3	1075

There are a lot of columns in the dialog so the user will need to scroll to the right to see everything. The user can also stretch the dialog to make it bigger.

4. Scroll to the far right and click on the … button in the *Flow Table* column.

5. In the *Stream Flow Table* dialog, enter the following table of information:

Flow	Depth	Width
.5	.25	3
1	.4	3.5
2	.55	4.2
4	.7	5.3
7	.8	7
10	.9	8.5
20	1.1	12
30	1.25	14
50	1.4	17
75	1.7	20
100	2.6	22

6. When the data has been entered, click **OK** to close the *Stream Flow Table* dialog.

7. Click **OK** to close the *Attribute Table* dialog.

9.2 Arc B-H

1. Repeat the above procedure to assign the appropriate values to arcs B through H in Figure 7. Refer to the values shown in Table 1 and Table 2 below.

ARC Letter from Figure 7	Type	ICALC	Diversion	FLOW	ROUGHCH	ROUGHBK	CDPTH	FDPTH	AWDPTH	BWDTH
A	Stream (SFR2)	table (4)		25						
B	Stream (SFR2)	wide channel (1)			.03					
C	Stream (SFR2)	specified (0)	✓	10						
D	Stream (SFR2)	wide channel (1)		10	.03					
E	Stream (SFR2)	power function (3)					0.3	0.35	3.8	0.6
F	Stream (SFR2)	wide channel (1)			.03					
G	Stream (SFR2)	cross section (2)		150	.025	.045				
H	Stream (SFR2)	cross section (2)			.025	.045				

Table 1 Stream arc attributes

ARC Letter from Figure 7	HCOND1	THICKM1	ELEVUP	WIDTH1	DEPTH1	HCOND2	THICKM2	ELEVDN	WIDTH2	DEPTH2
A	.00003	3	1095			.00003	3	1075		
B	.00003	3	1075	12		.00003	3	1050	12	
C	.00003	2	1075	10	2	.00003	2	1060	6	1
D	.00003	3	1080	10		.00003	3	1060	10	
E	.00003	3	1060			.00003	3	1045		
F	.00003	3	1045	12		.00003	3	1025	12	
G	.00006	3	1040			.00006	3	1025		
H	.00006	3	1025			.00006	3	990		

Table 2 Stream arc attributes continued

9.3 Channel Cross Sections

Arcs G and H use a cross section to determine the stream depth. The user needs to enter the cross section points.

1. Double-click on arc G as given in Figure 7.
2. In the *Attribute Table* dialog, scroll to the right to view the *Channel Cross Section* column.
3. Click on the … button in the *Channel Cross Section* column.
4. Enter the following values in the *XY Series Editor*:

Distance	Elevation
0	20
10	13
80	10
100	2
150	0
170	10
240	13
250	20

5. Click **OK** to exit the *XY Series Editor* dialog.
6. Click **OK** to exit the *Attribute Table* dialog.
7. Repeat the procedure (steps 1-6) to assign the following cross section to arc H:

Distance	Elevation
0	25
10	17
80	13
100	4
150	0
170	10
240	16
250	20

10 Segment IDs

GMS can display the stream segment ID numbers. Now turn them on.

1. Click the **Display Options** button.
2. In the lower right corner, turn on the *Segment ID* option.

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

The user should notice some numbers displayed in the middle of each arc. They are all 0. That is because the user has not yet mapped the conceptual model to the grid using the **Map → MODFLOW** command. Until this is done, GMS does not know how the stream segments should be numbered. After the **Map → MODFLOW** is done, the stream segment numbers will follow the rule of upstream to downstream.

11 Map → MODFLOW

Everything that was needed has been entered to in the conceptual model and can now be mapped to the grid.

1. Select the *Feature Objects* | **Map → MODFLOW** menu command.

2. Click **OK.**

Notice the stream segment numbers are no longer all 0s. The stream segments have been numbered so that downstream numbers are always greater than upstream numbers.

12 SFR2 Package Dialog

Now the streams in the conceptual model have been mapped to the grid. The *MODFLOW Stream (SFR2) Package* dialog shows all of the stream segments and reaches on the grid.

1. In the Project Explorer, click on the "3D Grid Data"  item.

2. Select the *MODFLOW* | *Optional Packages* | **Stream (SFR2) Package** menu command.

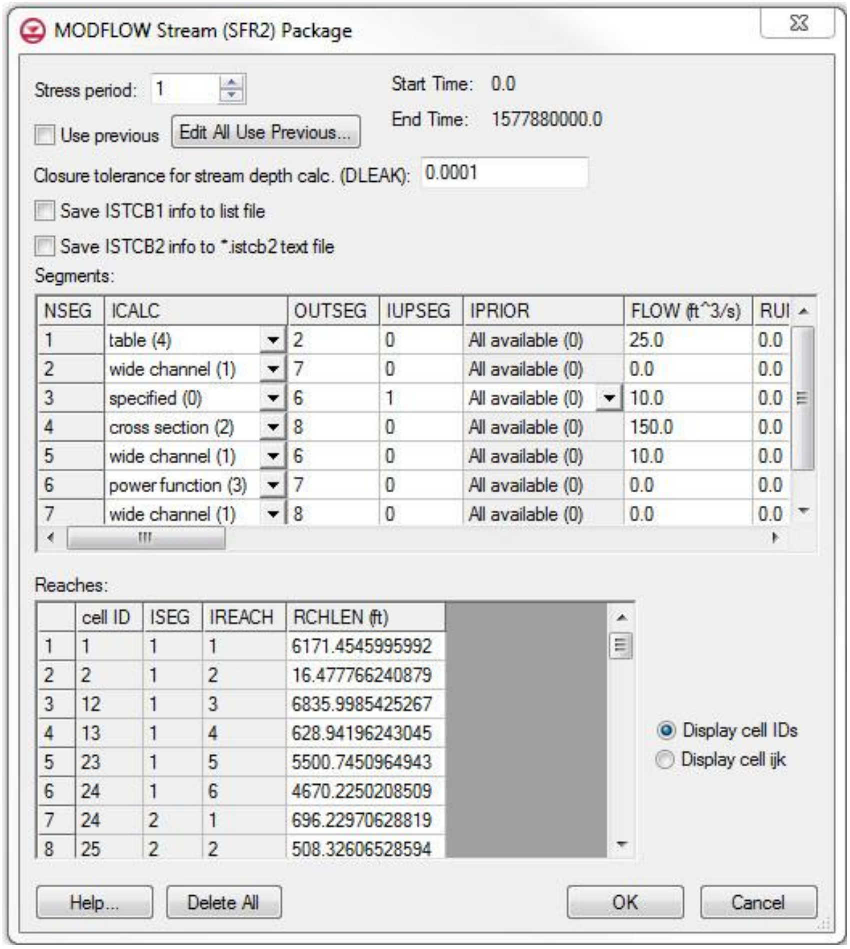


Figure 8 MODFLOW Stream (SFR2) Package dialog

The stream segments are listed in the top spreadsheet and the reaches in the bottom spreadsheet. GMS calculated the reach lengths (RCHLEN) during the **Map → MODFLOW** process.

Notice that, in this dialog, the user can edit most things but not the segment numbers (NSEG), the cells that the reaches are in (cell ID), or the ISEG or IREACH numbers. Nor can segments or reaches be added. Thus, the user can only create stream data by mapping to MODFLOW from a conceptual model. If the user reads in a MODFLOW simulation with SFR2 data, it will populate the stream package dialog even if the user doesn't have a conceptual model.

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

13 Save the Project and Run MODFLOW

The next step is to save the project.

1. Select the *Save* button.

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

3. After the model finishes, select the **Close** button.

The solution is imported and displayed as contours.

14 Compare the Solutions

Compare the new solution with the original one from the USGS.

1. Select the **Contour Options** button.

2. Change the options to match the figure below.

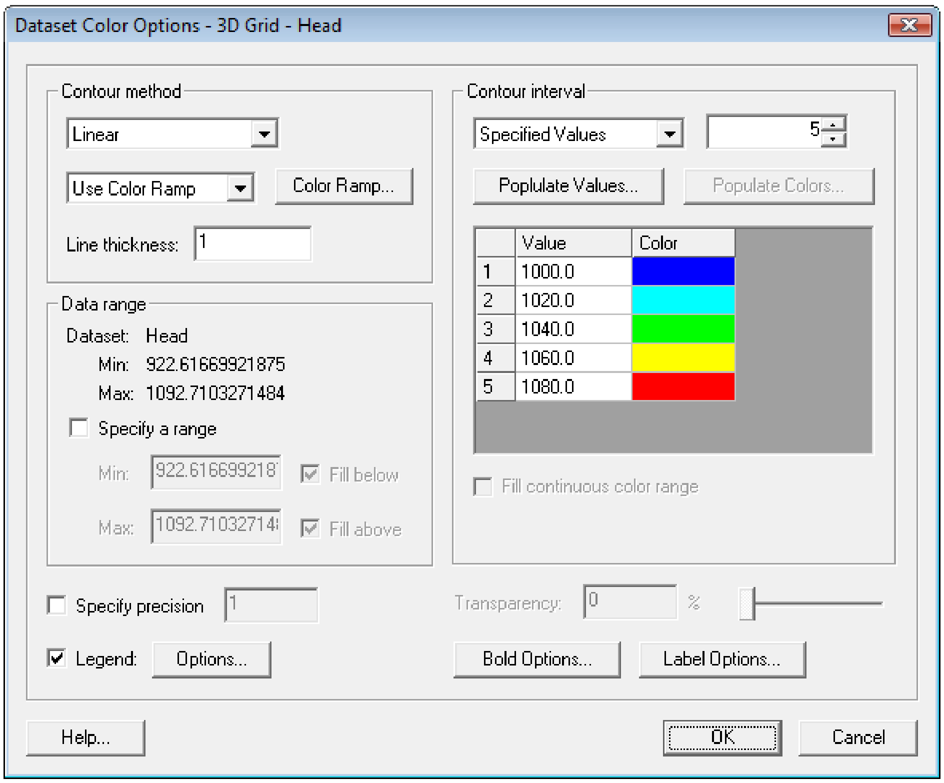


Figure 9 Contour Options dialog

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

4. In the Project Explorer, turn on the" GIS Layers" folder.

Notice how the GMS contours match the contours on the background image pretty closely. The match isn't perfect for a couple of reasons. First, the stream input generated by GMS differs some from the original USGS input. In particular, the reach lengths are different. The original USGS files, which were built by hand, contain rough estimates for the length of the stream channel within each model cell. GMS, on the other hand, calculates this value by intersecting the stream arcs with the grid cells.

The second reason why the contour lines differ is due to the different methods used by the USGS and GMS to interpolate and generate contour lines from gridded data.

5. In the Project Explorer, turn off the "GIS Layers" folder.

15 Animation

Since this model is transient, a good way to examine the results is to use an animation. The user will animate color filled contours.

1. Select the *Contour Options* button.
2. In the *Dataset Contour Options – 3D Grid – Head* dialog, switch the *Contour method* to "Color Fill."
3. Click **OK**.
4. Select the *Display* | **Animate** menu command.
5. Accept the defaults and click **Next**.
6. Again accept the defaults and click **Finish**.

It will take a minute to generate the animation. After it is finished generating it will play automatically. The animation clearly shows how the wells draw down the head in the first stress period and how the head recovers in the second stress period.

7. Feel free to play around with the controls on the animation window.
8. When finished, close the animation window.

16 Flow Budget

Now look at the flow budget for streams.

1. Select the *MODFLO W*| **Flow Budget** menu command.

This brings up the *Flow Budget* dialog. Notice the *Streams (SFR2)* item. There is more flow in than out. Thus the streams are mostly losing water—water is flowing from the streams in to the aquifer in most places. But there is some flow out from the aquifer to the streams.

2. Click **OK**.

With other MODFLOW packages, the user can click on a feature object in the map module and see the flow associated with that object. GMS does this by using the MODFLOW OBS process. Streams, however, don't participate in the OBS process, so this is not available. However, the user can look at the flow on a cell-by-cell basis.

3. In the Project Explorer, click on the "3D Grid Data" item.

4. Expand the items under the "3D Grid Data" item in the Project Explorer until the user can see the MODFLOW solution. Expand the solution too.

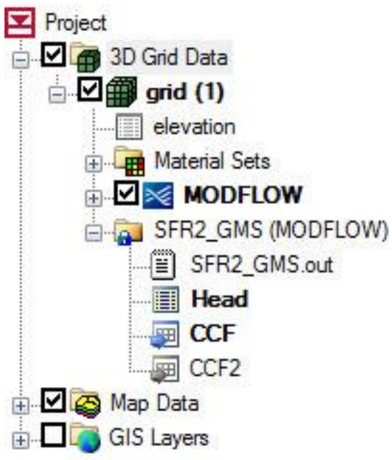


Figure 10 Project Explorer showing the MODFLOW solution

5. Right-click on the *CCF* item and select ***CCF* → *Datasets*** from the pop-up menu.

6. Select the "Stream Leakage" dataset to make it active.

7. Select the **Contour Options** button.

8. Switch the *Contour method* to "Block Fill."

9. Change the *Contour interval* to "Number of Contours," and set the number to **10**.

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

The user should see something like Figure 11 below. With the **Select Cells** tool, the user can move the mouse over the grid cells and watch the status bar at the bottom of the graphics window and see what the stream flow is throughout the grid.

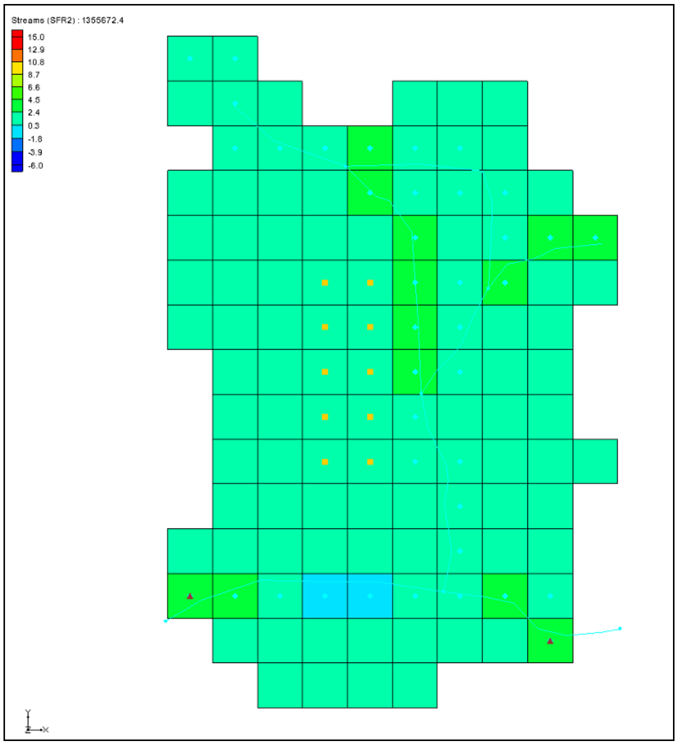


Figure 11 Block Fill showing stream in/out flow

17 Creating an SFR Parameter

Now the tutorial will illustrate the creation of an SFR parameter. The user will change the conductance on the first SFR segment at the top-left of the model to use a parameter instead of specifying the conductance value.

1. Select the "Map Data" folder in the Project Explorer.
2. With the **Select Arcs** tool, double-click on the top-left arc to open the *Attribute Table* dialog.
3. Change the value in the **HCOND1** and **HCOND2** fields to **-10.0**.
4. Click **OK** to exit the dialog.
5. Select the *Feature Objects* | ***Map*** **→ MODFLOW** menu command.
6. Click **OK**.
7. Select the *MODFLOW* | **Parameters** command to bring up the *Parameters* dialog.
8. Click the **Initialize from Model** button. Notice that a new parameter has been created. Change the *Value* to "0.00003."

9. Click **OK** to exit the *Parameters* dialog.

10. Select the *MODFLOW* | *Optional Packages* | **Stream (SFR2) Package** menu command.

This brings up the *MODFLOW Stream (SFR2) Package* dialog. Notice that the Segments table now shows *Hc1fact* and *Hc2fact* columns at the far right. The values listed in these columns are multiplied by the parameter value to give the final conductance values for the SFR boundary condition.

11. Click **OK** to exit the *MODFLOW Stream (SFR2) Package* dialog.

18 Saving and Running MODFLOW

Now it is possible to save our changes and run MODFLOW.

1. Select the *File* | **Save As** menu command.
2. Change the project name to “SFR2_GMS2.”
3. Select the *MODFLOW* | **Run MODFLOW** menu command.
4. After the model finishes, select the **Close** button.

The user should notice that the new solution is the same as the previous run.

19 Conclusion

This concludes the tutorial. Here are some of the key concepts in this tutorial:

- It is possible to use GMS to create MODFLOW models with STR1, SFR1, and SFR2 type streams.
- Streams must be created in the Map module using Feature Objects and cannot be created directly on the grid.
- It is necessary to make sure that the stream arcs are oriented from upstream to downstream correctly.
- The conceptual model does not have to include all aspects of the model. In this case, the conceptual model contained only the streams and the other boundary conditions were already part of the grid.
- GMS automatically determines the proper ordering of the stream data for input to MODFLOW based on the orientation and topology of the stream arcs.
- Unlike with other MODFLOW packages, with streams, the user cannot click on feature objects and see the flow in or out of that object.

- GMS supports SFR parameters.

