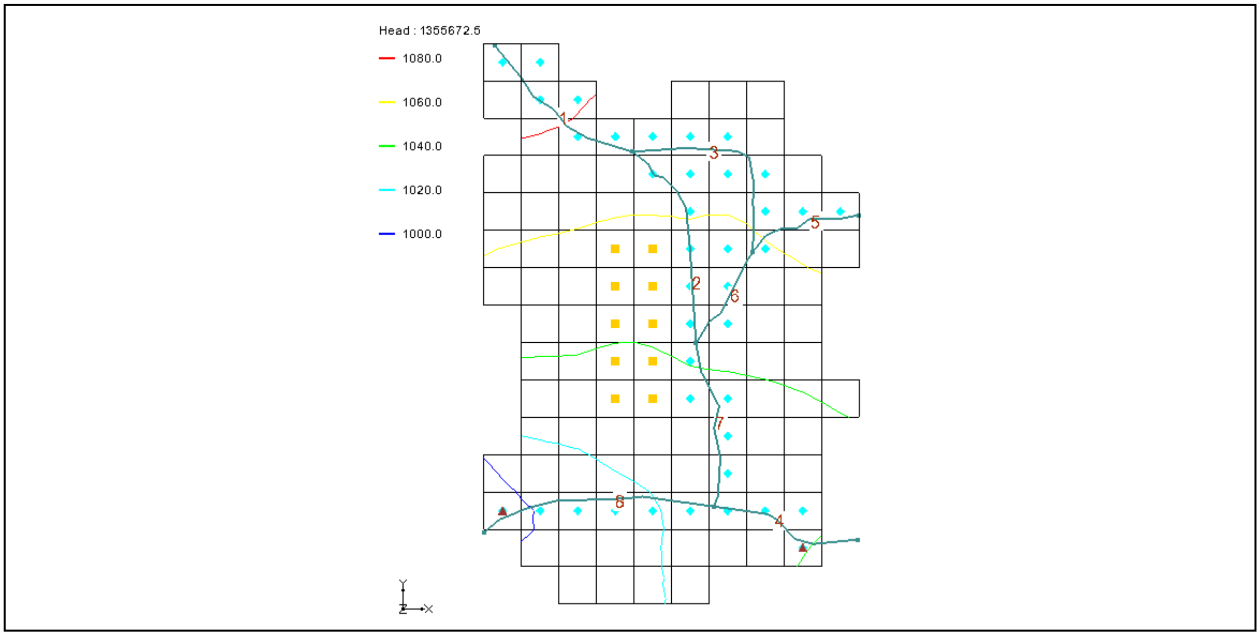
v. 10.0

*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/SFR2 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

- Feature Objects
- MODFLOW - Conceptual Model Approach

## Required Components

- Map
- MODFLOW

## Time

- 30-60 minutes

# 1 Contents



# 2 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 which 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 you never have 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 SFR1 package documentation.

### 2.1 Outline

Here's what you'll do 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.

## 3 Stream Package Basics

### 3.1 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)

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.

### 3.2 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.

# 4 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." One grid layer is used.

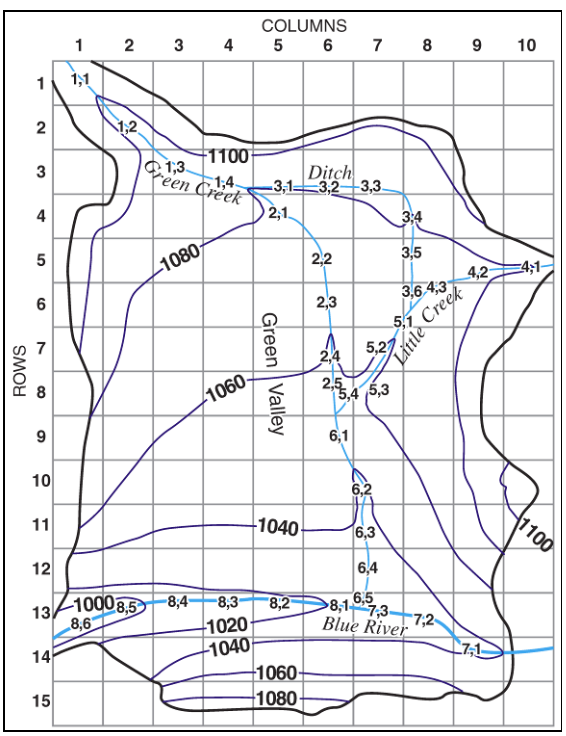



*Figure 1. An SFR1 stream network. (Prudic et. al. 2004).*

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.

# 5 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.

# 6 Open the Starting Project

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

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

You 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.

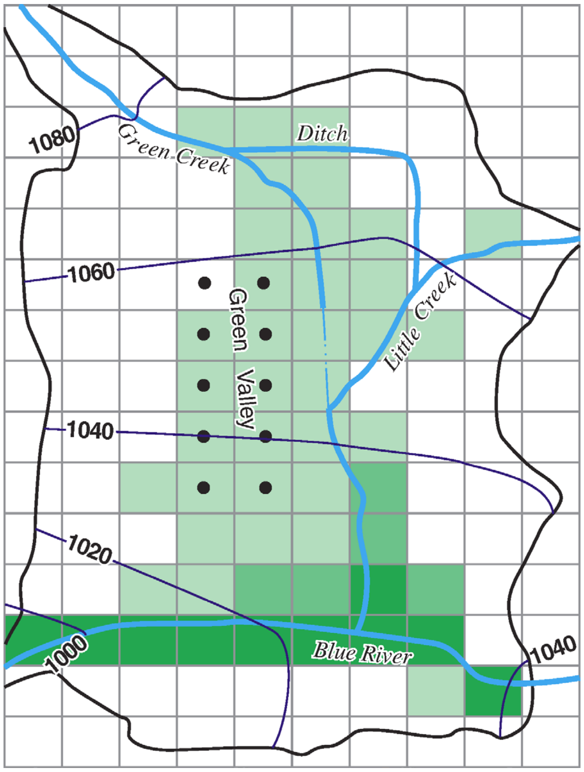



*Figure 2.* *Background image in GMS, taken from the MODFLOW SFR2 documentation.*

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

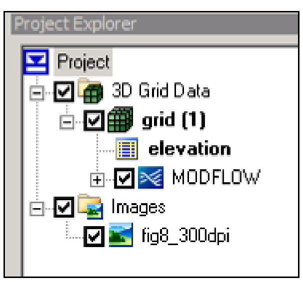



*Figure 3.* *Project Explorer contents for the starting project.*

## 6.1 Save the Project with a New Name

We'll save the project with a new name.

1. Select the *File|Save As* menu command.
2. Change the *File name* to **SFR2_GMS** and click *Save*.

You may wish to select the *Save* button occasionally to save your work as you continue with the tutorial.

# 7 Digitize the Stream Arcs

In GMS, you can only create streams by using the conceptual model approach. That is, you must use feature objects and map them to the grid. You cannot create streams directly on the grid.

We'll create the stream arcs by digitizing the background image.

## 7.1 Create a conceptual model

First we need 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. Change the *Name* to **Test 1** and click *OK*.

## 7.2 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. 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 our coverage will be above the grid.

5. Click *OK*.

## 7.3 Create the Arcs

Now we'll 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". Your arcs should be located approximately as shown in Figure 4.

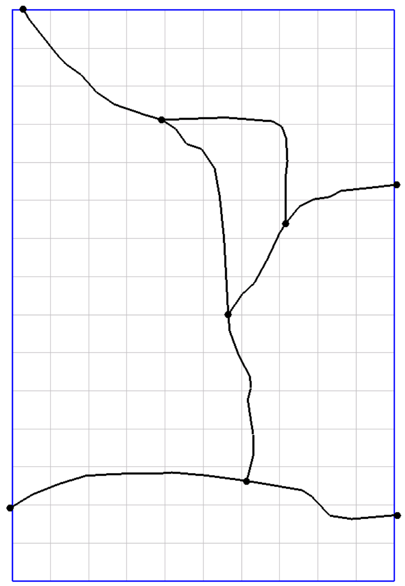


*Figure 4. Location of stream arcs after digitizing.*

Now that the arcs have been digitized we no longer need the background image.

3. In the *Project Explorer*, turn **off** the *Images* folder.

## 8 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 you first create the arc. Usually the direction doesn't matter, but with streams it does. We have to make sure that the arcs go from upstream to downstream. The direction can be displayed and reversed if needed.

We'll check the arc direction and make sure all the arcs are pointing from upstream to downstream.

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

You should now see arrows on your arcs. We want the arrows to be pointing as shown in Figure 5. If any of the arcs are pointing in the wrong direction…

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.

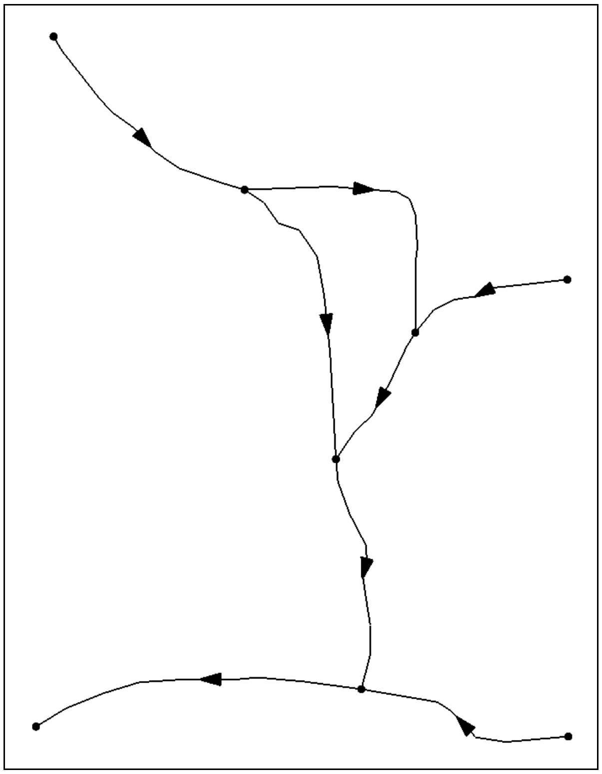


*Figure 5. Arc directions.*

All the arcs should now be pointing the correct direction and the direction arrows should match Figure 5. We'll turn the arrows back off.

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

# 9 Stream Reach and Segment Numbering

With GMS you generally won't need to worry about stream segment and reach numbering because GMS figures it all out automatically. However, it is a concept you should be aware of and you 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). Figure 6 illustrates stream and segment numbering.

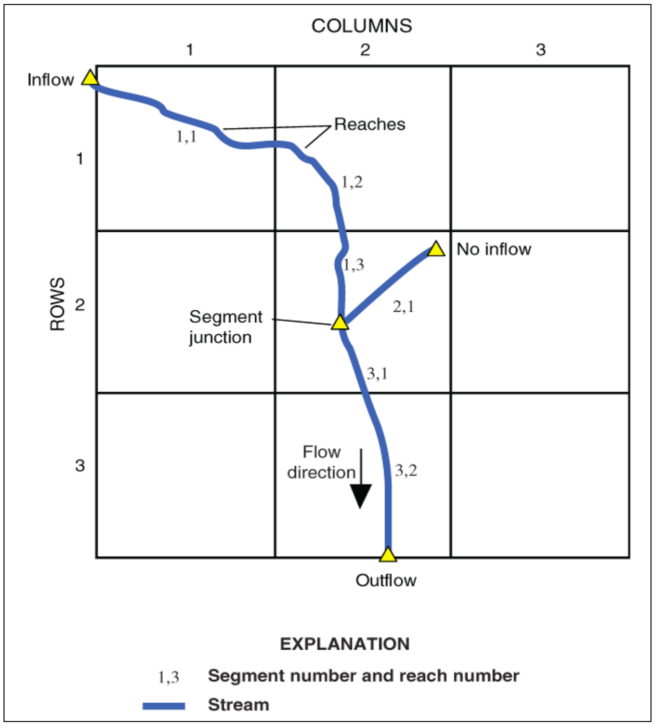



*Figure 6. Illustration of stream segment and reach numbering. (Prudic et. al. 2004)*

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. You should be careful not to confuse arc ID numbers with stream segment numbers.

# 10 Assign Arc Attributes

Now we'll assign the stream attributes to the arcs.

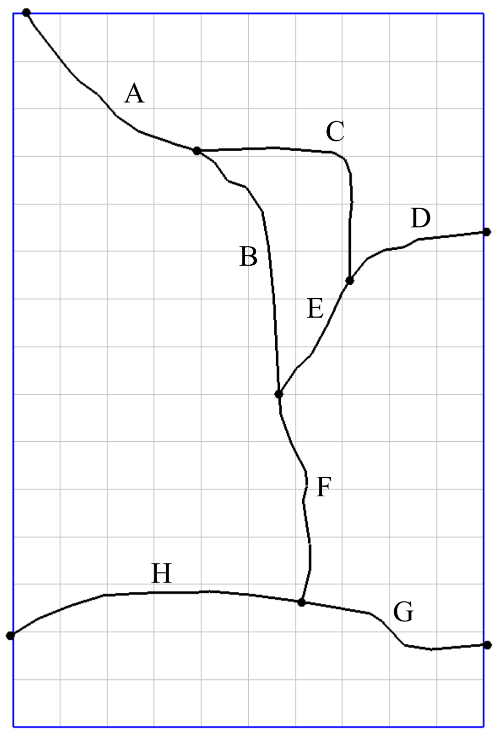



*Figure 7. Arcs with letters to distinguish them.*

## 10.1 Arc A

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

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

3. Enter the remaining values as given in the following table (only the columns where you change something 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 you will need to scroll to the right to see everything. You 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. 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 you have entered the data, click *OK* to close the *Stream Flow Table* dialog.

7. Click *OK* to close the *Properties* dialog.

## 10.2 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 | ICALC | Diversion | FLOW | ROUGHCH | ROUGHBK | CDPTH | FDPTH | AWDPTH | BWDTH |
|---|---|---|---|---|---|---|---|---|---|
| **A** | table (4) | | 25 | | | | | | |
| **B** | wide channel (1) | | | .03 | | | | | |
| **C** | specified (0) | true | 10 | | | | | | |
| **D** | wide channel (1) | | 10 | .03 | | | | | |
| **E** | power function (3) | | | | | 0.3 | 0.35 | 3.8 | 0.6 |
| **F** | wide channel (1) | | | .03 | | | | | |
| **G** | cross section (2) | | 150 | .025 | .045 | | | | |
| **H** | 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.*

## 10.3 Channel Cross Sections

Arcs G and H use a cross section to determine the stream depth. We need to enter the cross section points.

1. Double-click on arc G as given in Figure 7.
2. In the *Properties* 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* twice to exit both dialogs.
6. Repeat the procedure 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 |

# 11 Segment IDs

GMS can display the stream segment ID numbers. Let’s 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.

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

## 12 Map → MODFLOW

We've entered everything we need to in the conceptual model and can now map it to the grid.

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

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.

## 13 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|Source/Sink Packages|Stream (SFR2) Package* menu command.

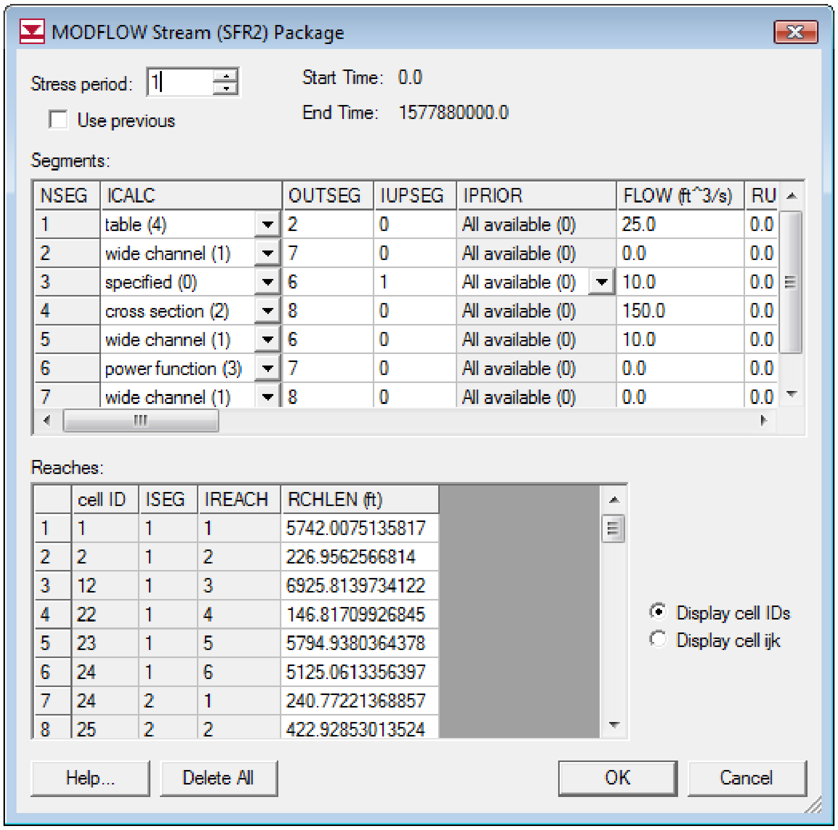



*Figure 8. MODFLOW Stream (SFR2) Package dialog.*

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

3. Click *OK* to exit the dialog.

## 14 Save the Project and Run MODFLOW

We're ready 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.

# 15 Compare the Solutions

Let's compare our solution with the original one from the USGS.

1. Select the *Contour Options* button.
2. Change the options to match the figure below.

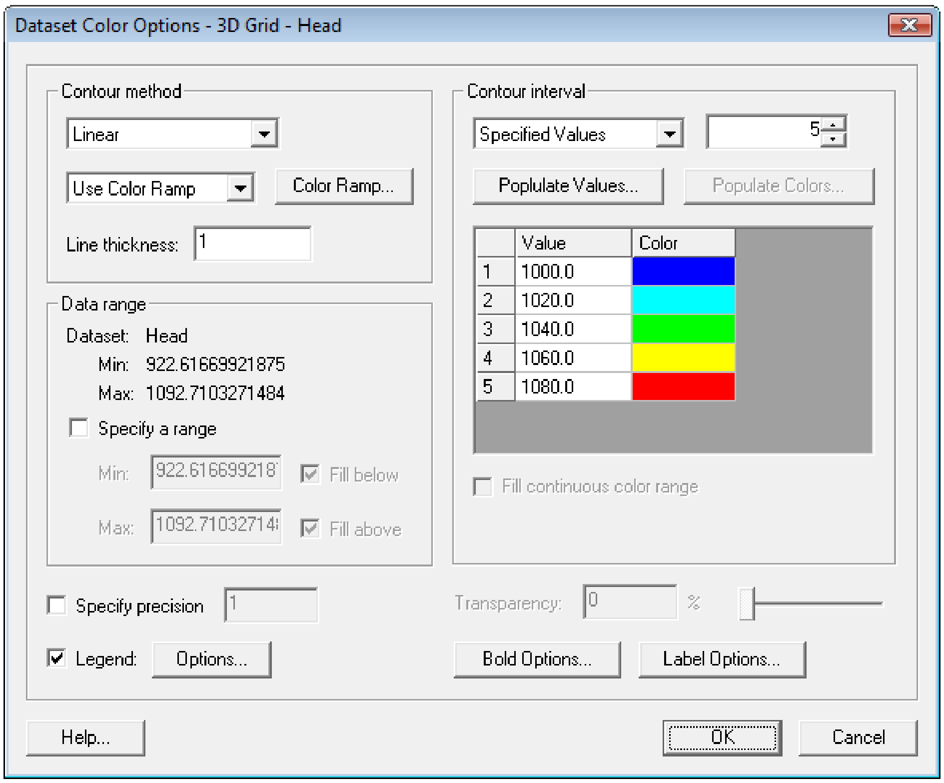



*Figure 9. Contour Options dialog.*

3. Click *OK* to exit the dialog.
4. In the *Project Explorer*, turn **on** the *Images* 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 *Images* folder.

## 16 Animation

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

1. Select the *Contour Options* button.
2. 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 you are finished, close the animation window.

## 17 Flow Budget

Let's look at the flow budget for streams.

1. Select the *MODFLOW|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 streams – 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 you 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 we 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 you can see the MODFLOW solution. Expand the solution too.

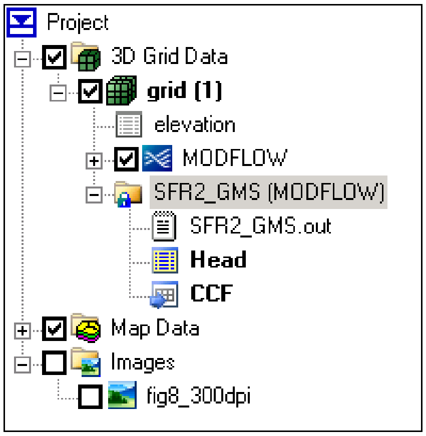



*Figure 10. Project Explorer showing the MODFLOW solution.*

5. Right-click on the *CCF* item and select *CCF -> Data Sets* from the pop-up menu.

6. Select the *Streams (SFR2)* data set to make it the active data set.

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.

You should see something like Figure 11 below. If you use the *Select Cells* tool you 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.

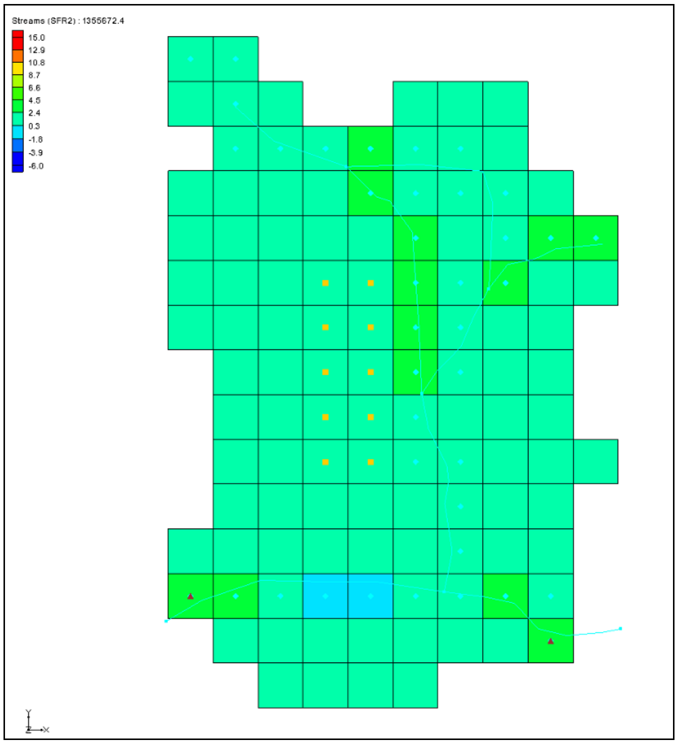



*Figure 11. Block Fill showing stream in/out flow.*

## 18 Creating an SFR Parameter

Now we will illustrate the creation of an SFR parameter. We 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 *Properties* 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.
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|Source/Sink Packages|Stream (SFR2) Package* menu command.

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 *Stream (SFR2) Package* dialog.

## 19 Saving and Running MODFLOW

We're ready 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.

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

## 20 Conclusion

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

- You can 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.
- You must make sure your stream arcs are oriented from upstream to downstream correctly.
- Your conceptual model does not have to include all aspects of your 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 you cannot click on feature objects and see the flow in or out of that object.
- GMS supports SFR parameters.