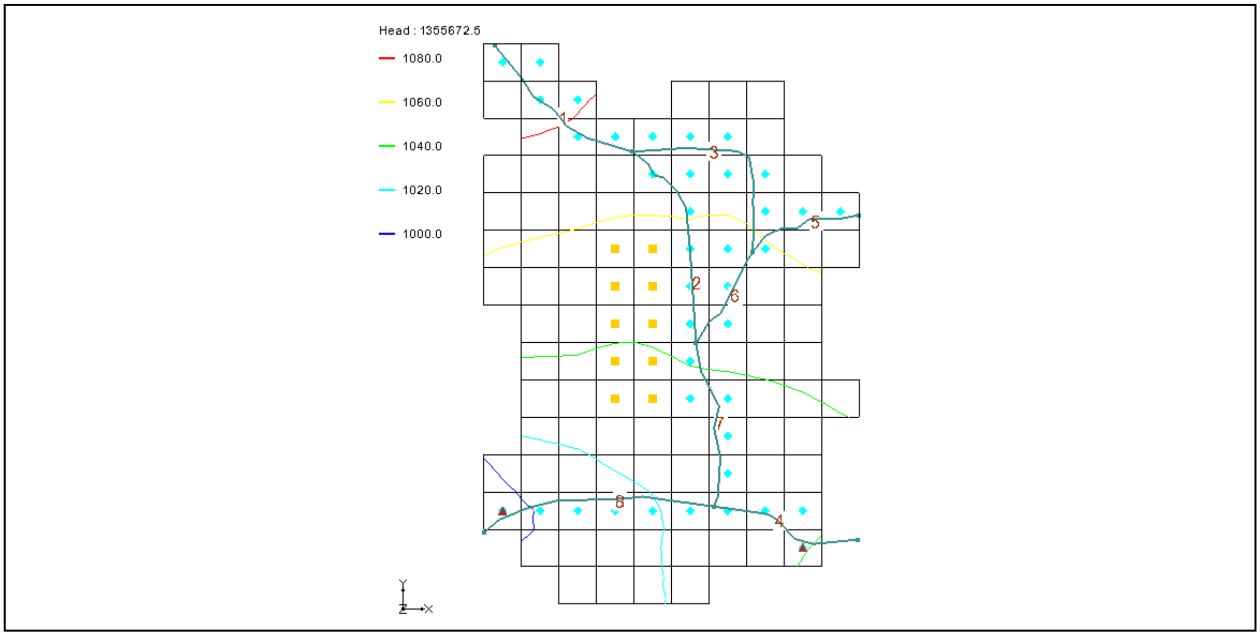
GMS

v. 10.0

GMS 10.0 Tutorial

MODFLOW – STR Package

The MODFLOW Stream (STR) Package Interface in GMS



Objectives

Learn how to create a model containing STR type streams. 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

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1 Contents

2 Introduction

The MODFLOW STR package is used to model the effects of rivers on aquifers while tracking the amount of flow in the river. The STR package also allows rivers to go dry during a given period of the simulation. The STR package is an evolution of the River Package and a precursor to the SFR2 package. However, unlike the River package, flow is routed through the stream. For the STR package, simple channel hydraulics and Manning's equation are used to compute the stage in the stream. GMS supports all three stream packages (SFR2 incorporates all features of the older 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 STR type streams. The tutorial is based on the test simulations contained in the STR 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 and nodes.
5. Save and run the model.
6. Examine the solution.

3 Stream Package Basics

3.1 Reaches and Segments

The STR package divides streams into reaches and segments.

> "Streams superimposed on the aquifer are divided into reaches and segments. A segment is a stream or diversion in which streamflow from surface sources are added at the beginning of the segment or subtracted (in the case of a diversion) at the end of a segment. A reach is the part of a segment that corresponds to an individual cell in the finite-difference grid used to simulate ground-water flow in an aquifer. A segment may consist of one or more reaches."
>
> (Prudic 1989)

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 (STR and SFR) 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.

4 Description of Problem

The model in this tutorial is an STR adaptation 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.

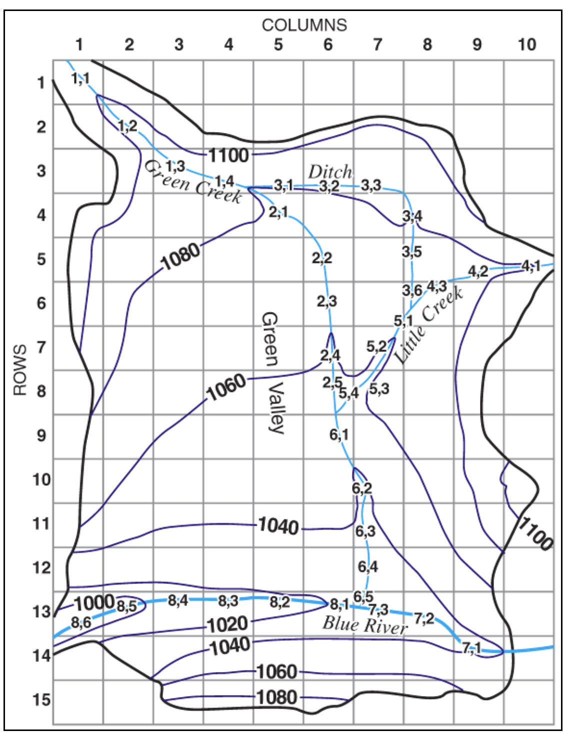


Figure 1. The stream network (Prudic et. al. 2004).

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 STR 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\str** 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. While this figure comes from the MODFLOW SFR1 documentation, we will use this scenario with the STR package.

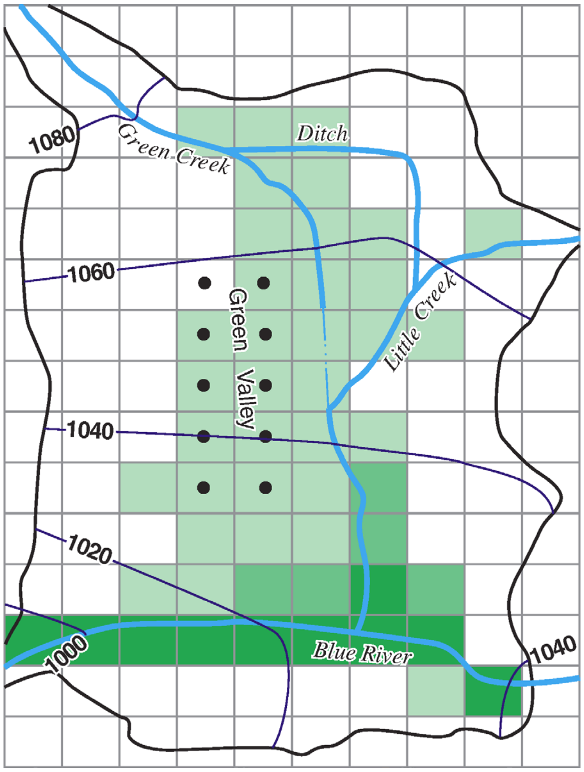


Figure 2. *Background image in GMS, taken from the MODFLOW SFR1 documentation.*

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).

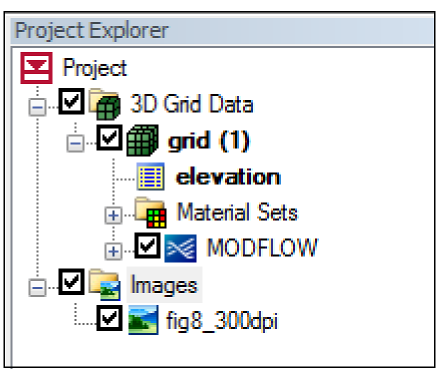


Figure 3. *Project Explorer contents for the starting project.*

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 **STR_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* 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. Click on the **Streams** coverage you just created to switch to the Map module.

2. Select the *Create Arc* tool.

3. 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.

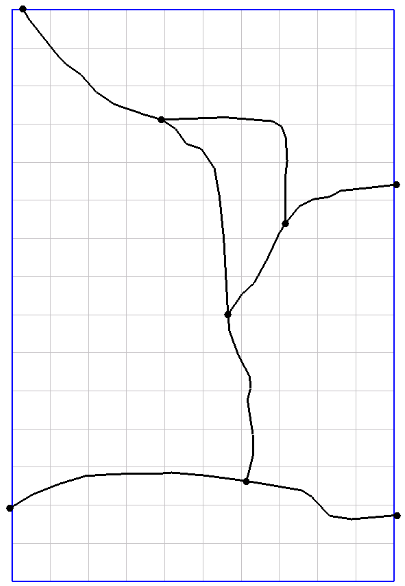


Figure 4. Location of stream arcs after digitizing.

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

4. 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.

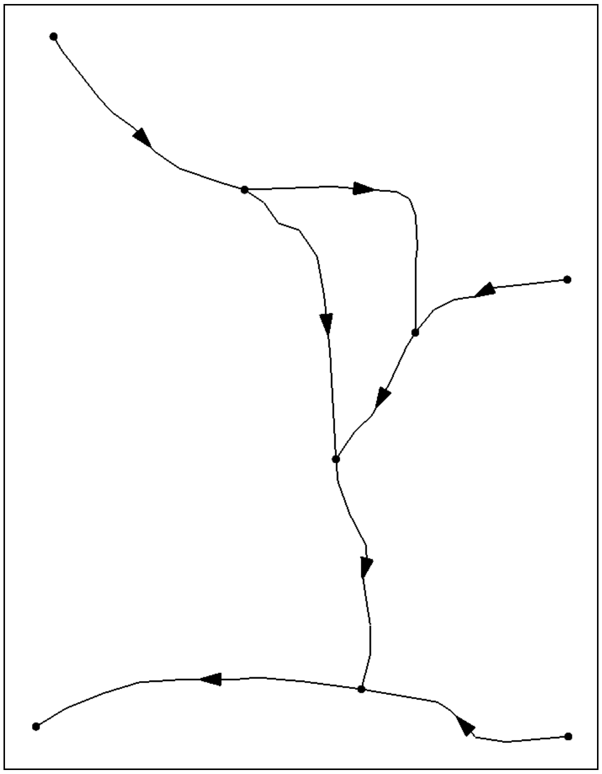


Figure 5. Arc directions.

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 STR package dialog which is covered later in this tutorial.

According to the STR package documentation, "Segments are numbered sequentially from the farthest upstream segment to the last downstream segment as are reaches within each segment." (Prudic 1989). Figure 6 illustrates stream and segment numbering.

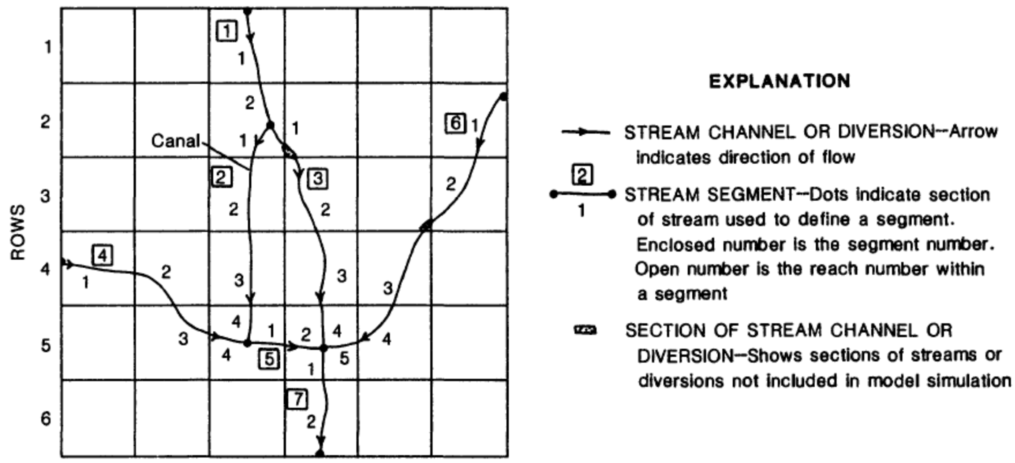


Figure 6. Illustration of stream segment and reach numbering. (Prudic 1989)

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. Do not confuse arc ID numbers with stream segment numbers.

10 Assign Arc Attributes

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

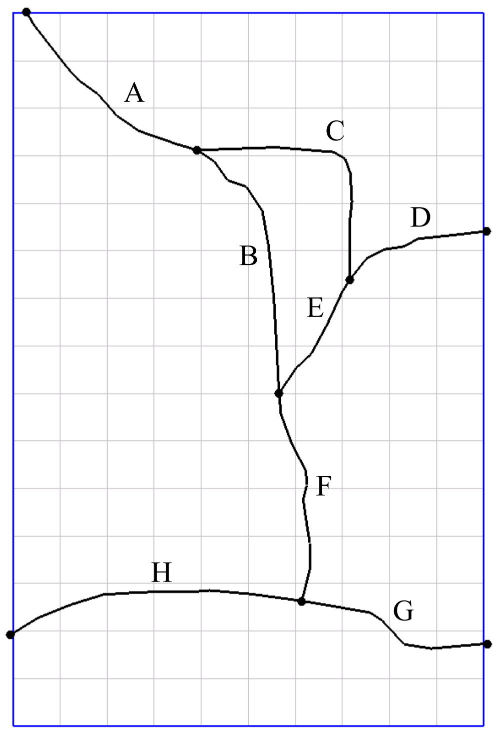


Figure 7. Arcs with letters to distinguish them.

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**.

3. Enter the remaining values as given in the following table (only the columns where you change something are shown):

Cond.	Width	Sinuosity	Roughness	Inc. flow
0.0003	20	1.0	0.03	25

You may need to scroll to the right to see everything. You can also stretch the dialog to make it bigger.

4. 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 below.

ARC Letter from Figure 7	Cond.	Width	Sinuosity	Roughness	Diversion	Inc. flow
A	0.0003	20	1.0	0.03		25
B	0.0003	20	1.0	0.03		-1.0
C	0.0003	5	1.0	0.03	Checked	10
D	0.0003	12	1.0	0.03		10
E	0.0003	15	1.0	0.03		-1.0
F	0.0003	27	1.1	0.03		-1.0
G	0.0003	45	1.0	0.025		150
H	0.0003	52	1.0	0.025		-1.0

Table 1 Stream arc attributes.

The default -1.0 in the Inc. flow column denotes that the incoming flow is the sum of the immediately upstream tributary segments.

11 Segment IDs

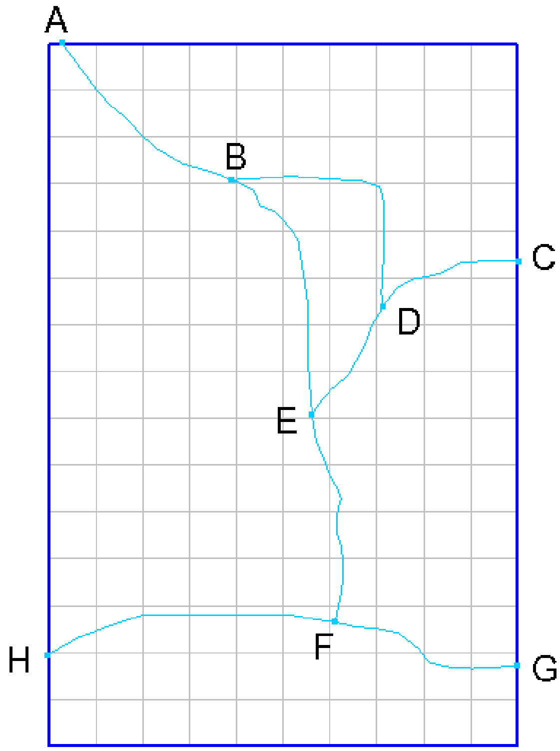
GMS can display the stream segment ID numbers. Let's turn them on.

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 Assign Node Attributes

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



	Top elev.	Bot. elev.
A	1095	1092
B	1075	1072
C	1080	1078
D	1060	1056
E	1045	1040
F	1025	1020
G	1040	1036
H	990	984

Figure 8. Nodes with letters to distinguish them.

12.1 Node A

1. Click the *Select Nodes* tool still active and then double-click on arc A as given in Figure 8. This brings up the *Properties* dialog.

2. Enter the values as given for node A in the table above next to Figure 8 (only the columns where you change something are shown):

Notice that we are not entering a value for **Head/Stage** values for the stream nodes. This is because the stage will be calculated when MODFLOW runs.

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

4. Repeat the above procedure to assign the appropriate values to nodes B through H in Figure 8.

13 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.

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.

14 STR Package Dialog

Now the streams in the conceptual model have been mapped to the grid. The *MODFLOW Stream (STR) 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 | STR - Stream* menu command.

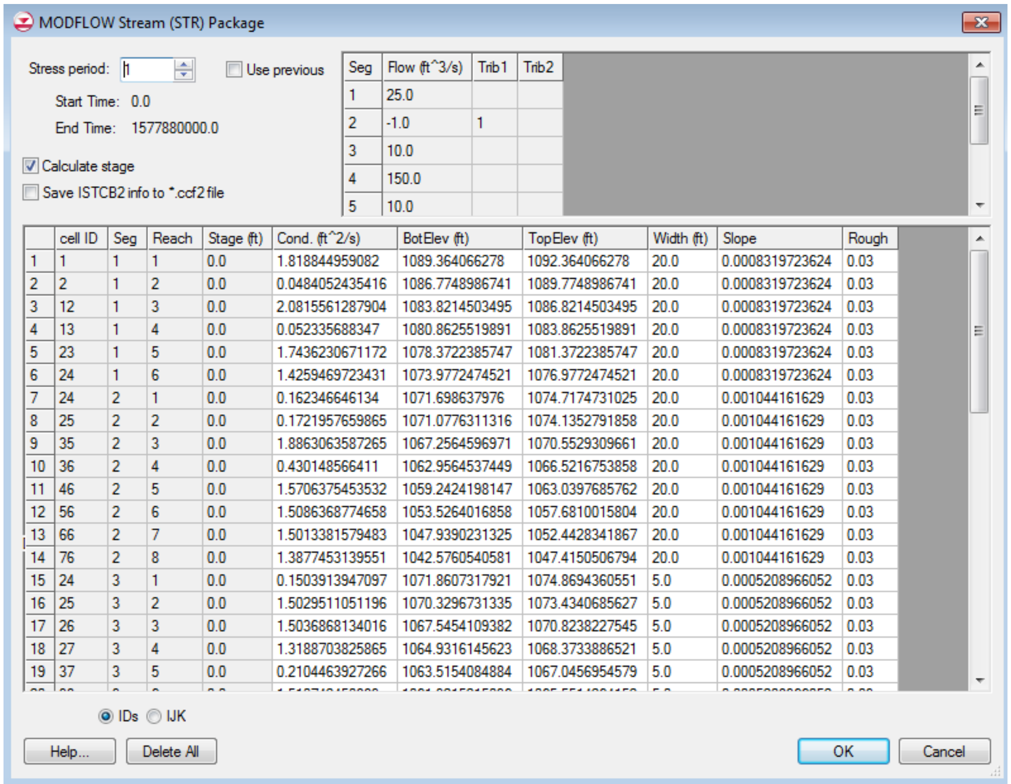


Figure 9. *MODFLOW Stream (STR) Package dialog.*

The stream segments are listed in the top spreadsheet and the reaches in the bottom spreadsheet. GMS calculated the conductance during the *Map -> MODFLOW* process.

Notice that in this dialog you can edit most things, but you cannot edit the segment numbers or the cells that the reaches are in (cell ID). 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 STR data, it will populate the stream package dialog even if you don't have a conceptual model.

3. Turn on the *Save ISTCB2 info to *.ccf2 file* option.

This will write stream flow in each stream reach to a ccf2 file. We will view the information written to this file after we run MODFLOW.

4. Click *OK* to exit the dialog.

15 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.

16 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.

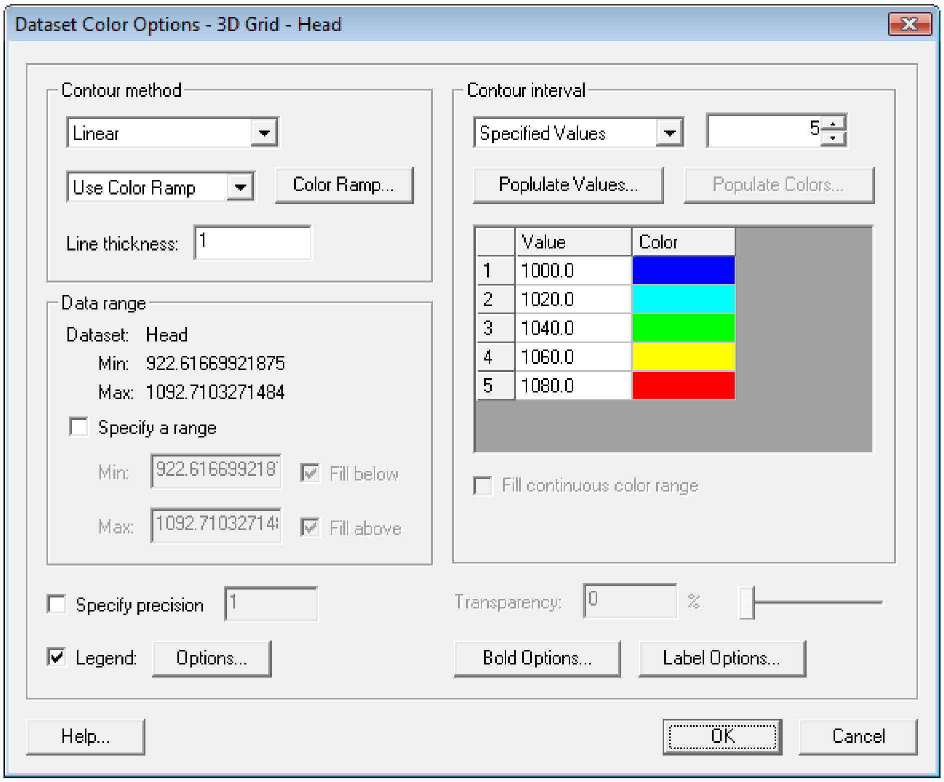


Figure 10. Contour Options dialog.

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.

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 *STREAM LEAKAGE* item. There is more flow in than out. Thus the streams are mostly losing streams – water is flowing from the streams into the aquifer in most places. But there is some flow out from the aquifer to the streams.

2. Click *OK*.

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.

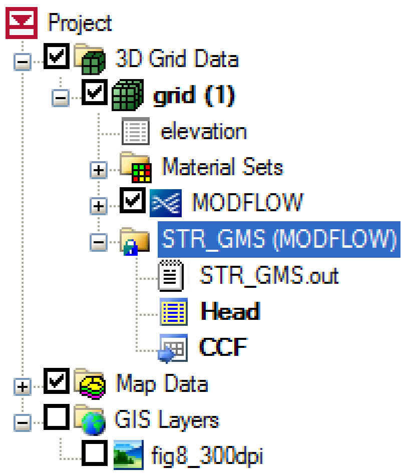


Figure 11. Project Explorer showing the MODFLOW solution.

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

6. Select the *Streams* 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 12 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.

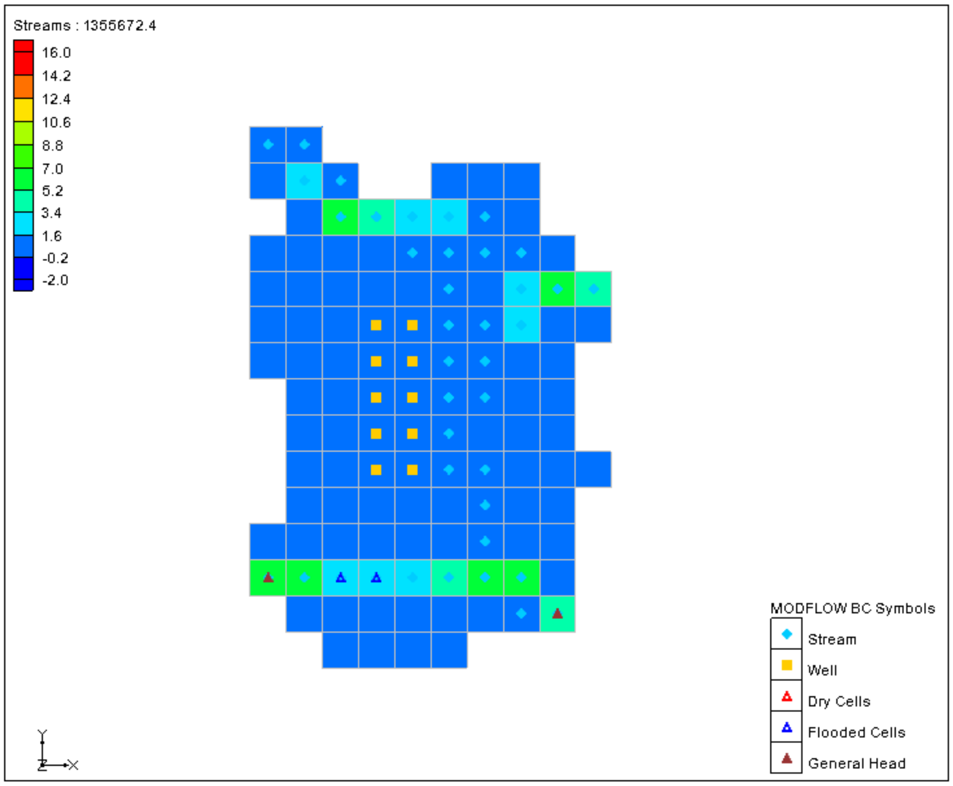


Figure 12. Block Fill showing stream in/out flow.

18 Flow from Arcs

Since we created the streams using the conceptual model, we can view the computed flow into or out of the aquifer by selecting the arcs.

1. Select the **Streams** coverage in the Project Explorer.
2. Choose the *Select Arcs* tool.
3. Select the arc in the northwest portion of the model.
4. Look at the status bar at the bottom of the GMS window and you should see information on the selected arc. *COMPUTED FLOW* will be one of the items listed. You should see a value around 14.5 (depending on the exact geometry of your arc).

You may wish to select other arcs and see the computed flow.

19 Flow in the Stream Channel

In the Stream Package dialog we turned on *Save ISTCB2 info to *.ccf2 file* option. This file contains information about the calculated flow out of each stream reach.

1. Right-click on the CCF2 file listed below the STR_GMS (MODFLOW) solution and select *CCF -> Data Sets* from the pop-up menu.

We now have a data set that shows the stream reach flow at each cell. The data set is call STREAM FLOW OUT.

2. Make sure the STREAM FLOW OUT data set is active.
3. Select the *Contour Options* button.
4. Under the *Contour interval* select the **Unique Values** option.
5. Click *OK* to exit the dialog.

You should see something similar to the figure below. You may wish to select different time steps to see how the data changes with time.

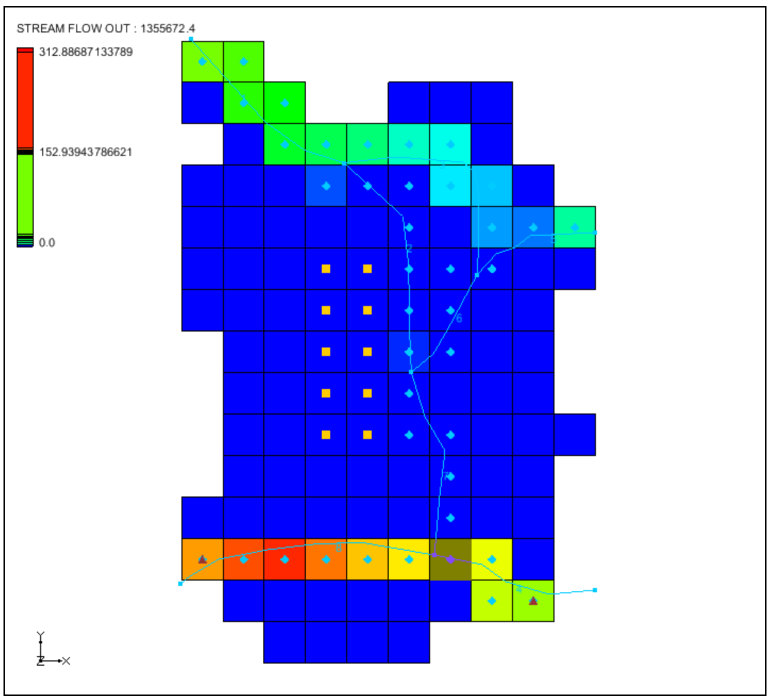


Figure 13 Stream Reach Flow

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 STR and SFR 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 stream arcs and nodes. 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.
- You can click on feature objects and see the flow in or out of that object.
- You can view the computed flow out of each stream reach using the CCF2 file.

