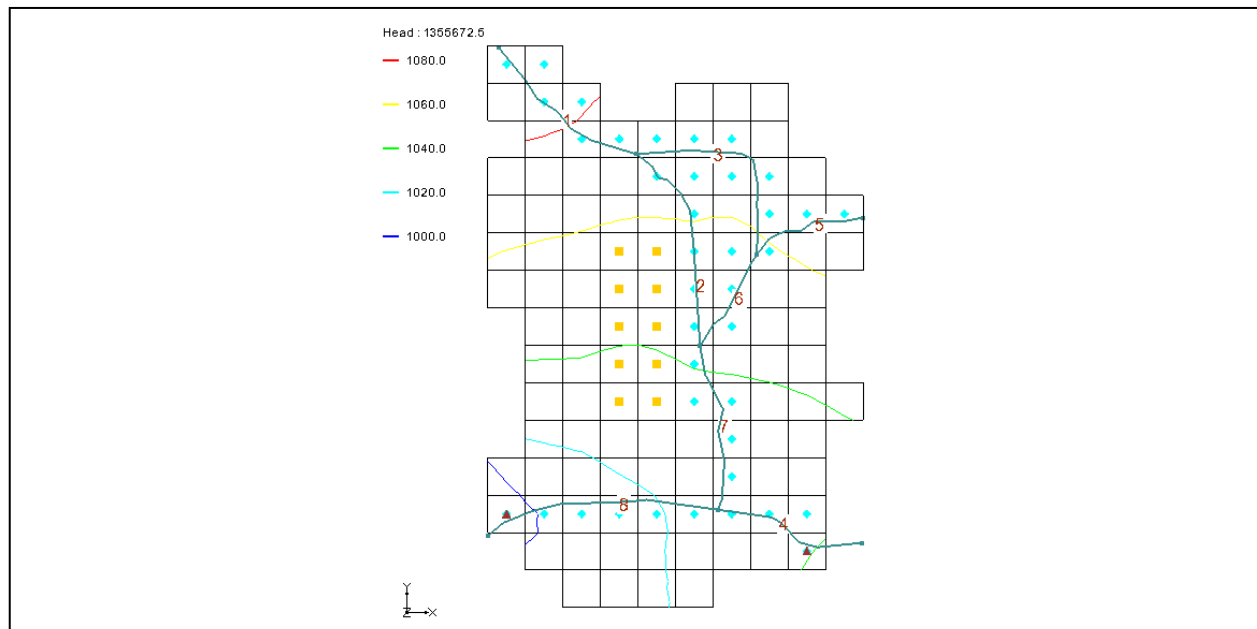


GMS 10.0 Tutorial **MODFLOW – STR Package**

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

- MODFLOW – Conceptual Model Approach I

Required Components

- Map Module
- MODFLOW

Time

- 25-40 minutes



1	Introduction	2
1.1	Outline	3
2	Stream Package Basics	3
2.1	Reaches and Segments	3
2.2	Routing	3
3	Description of Problem	4
4	Getting Started	4
5	Open the Starting Project	5
5.1	Save the Project with a New Name	6
6	Digitize the Stream Arcs	6
6.1	Create a conceptual model	6
6.2	Create a coverage	7
6.3	Create the Arcs	7
7	Correct the Arc Directions	8
8	Stream Reach and Segment Numbering	9
9	Assign Arc Attributes	10
9.1	Arc A	11
9.2	Arc B-H	11
10	Segment IDs	11
11	Assign Node Attributes	12
11.1	Node A	12
12	Map → MODFLOW	13
13	STR Package Dialog	13
14	Save the Project and Run MODFLOW	14
15	Compare the Solutions	15
16	Flow Budget	16
17	Flow from Arcs	17
18	Flow in the Stream Channel	18
19	Conclusion	19

1 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 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 STR type streams. The tutorial is based on the test simulations contained in the STR package documentation.

1.1 Outline

Here are the steps of 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.

2 Stream Package Basics

2.1 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.

2.2 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.

3 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” (Prudic, et al., 2004:13). One grid layer is used.

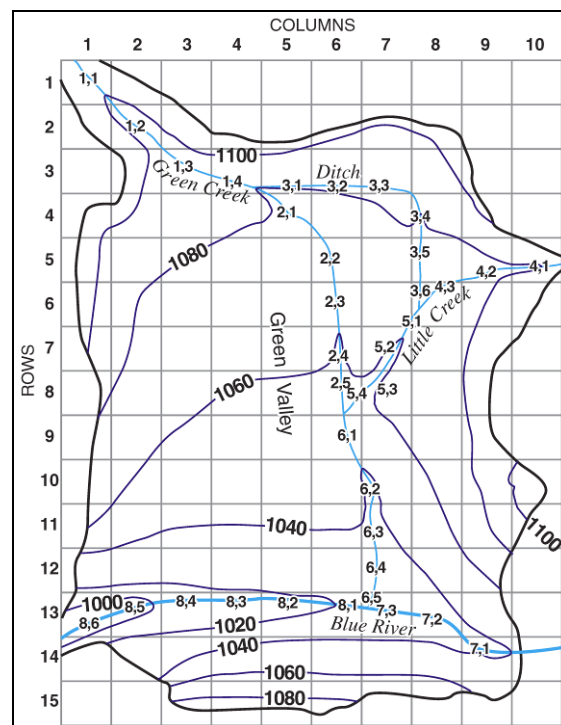


Figure 1 The stream network (Prudic, et al., 2004:14)

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 STR 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\str* directory.
3. Open the file entitled “start.gpr.”

The user 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, this scenario will be used with the STR package.

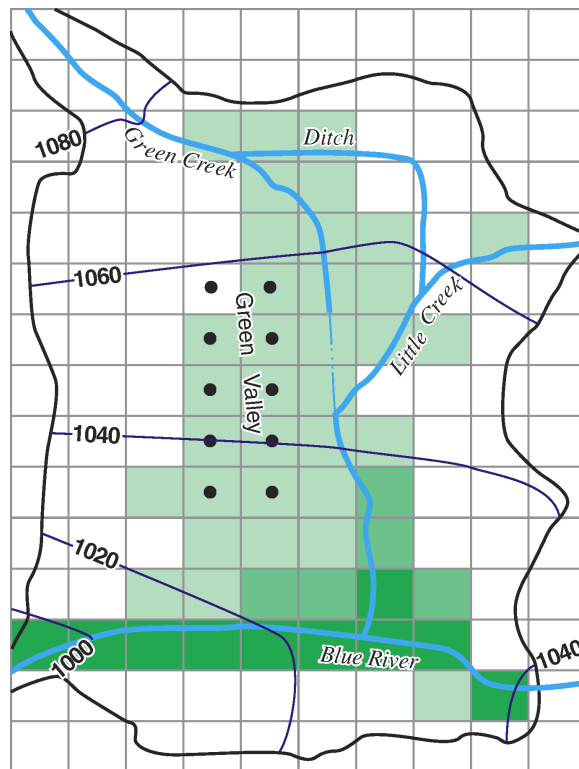


Figure 2 Background image in GMS (Prudic et al., 2004:16)

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).

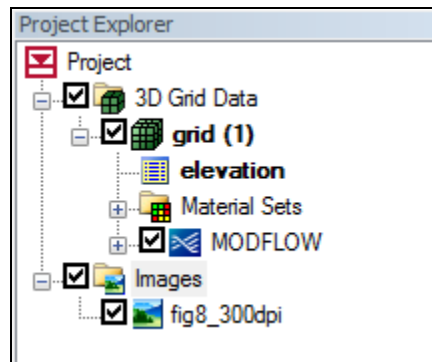



Figure 3 Project Explorer contents for the starting project

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 “STR_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, the user can only create streams by using the conceptual model approach. That is, the user must use feature objects and map them to the grid. It is not possible to 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, 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.”
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* option.
4. Change the *Default elevation* to “1500” so our coverage will be above the grid.
5. Click **OK**.

6.3 Create the Arcs

Now the user will create the arcs.

1. Click on the newly created “Streams”  coverage 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.” The arcs should be located approximately as shown in Figure 4.

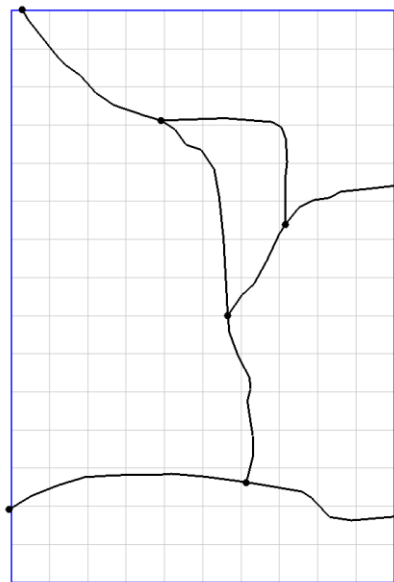


Figure 4 Location of stream arcs after digitizing



Now that the arcs have been digitized, the background image is no longer needed.

4. 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 arc is first created. 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 will 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. It is necessary for the arrows to 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 that point the wrong direction.

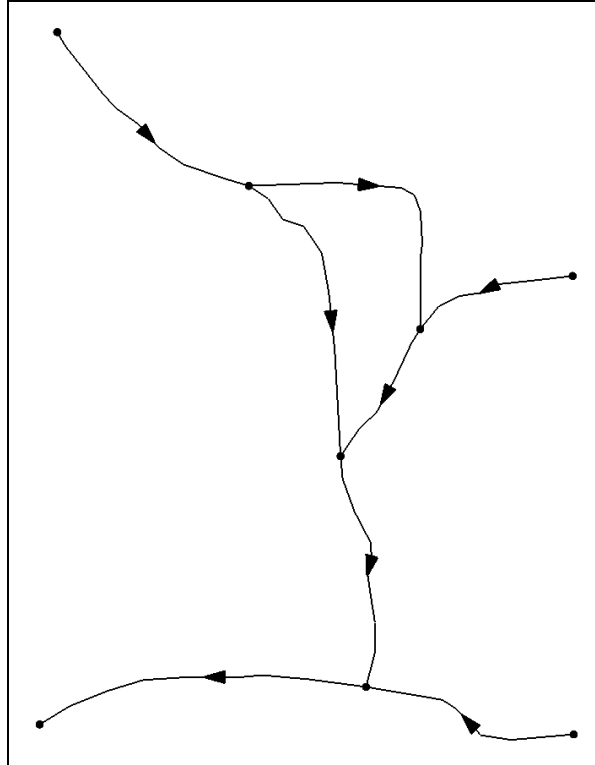




Figure 5. Arc directions.

All the arcs should now be pointing the correct direction and the direction arrows should match Figure 5. Now 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 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: 3). Figure 6 illustrates stream and segment numbering.

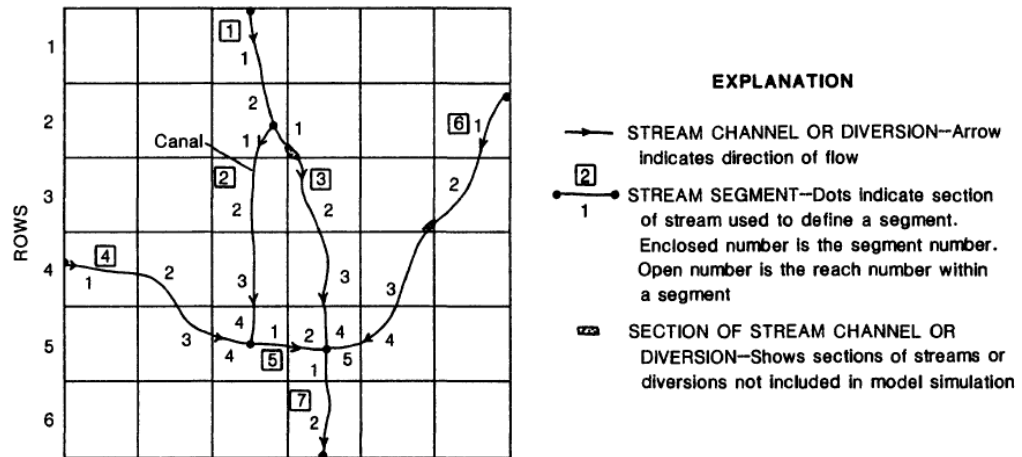


Figure 6. Illustration of stream segment and reach numbering. (Prudic, 1989:4)

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.

9 Assign Arc Attributes

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

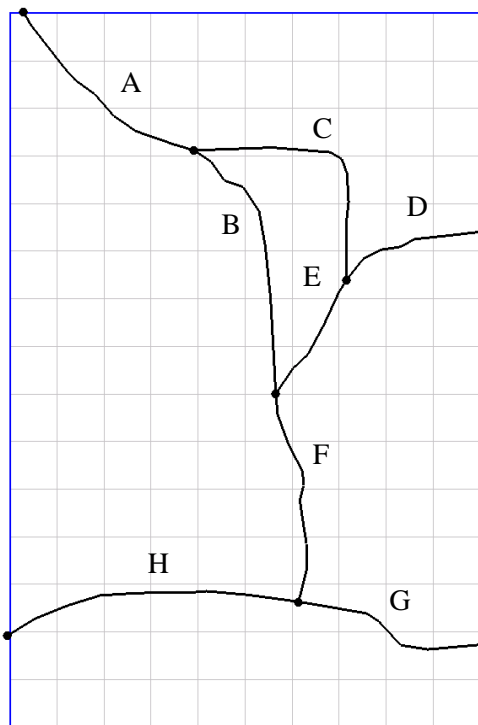



Figure 7 Arcs with letters to distinguish them

9.1 Arc A

1. With the **Select Arcs**  tool active, double-click on arc A as given in Figure 7. This brings up the *Attribute Table* dialog.
2. Change the *Type* to “stream.”
3. Enter the remaining values as given in the following table (only the columns with changes are shown):

Cond.	Width	Roughness	Inc. flow
0.0003	20	0.03	25

The user may need to scroll to the right to see everything. It is also possible to stretch the dialog to make it bigger.

4. 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 below.

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

10 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 of the *Display Options dialog*, 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 **Map → MODFLOW** is performed, the stream segment numbers will follow the rule of upstream to downstream.

11 Assign Node Attributes

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

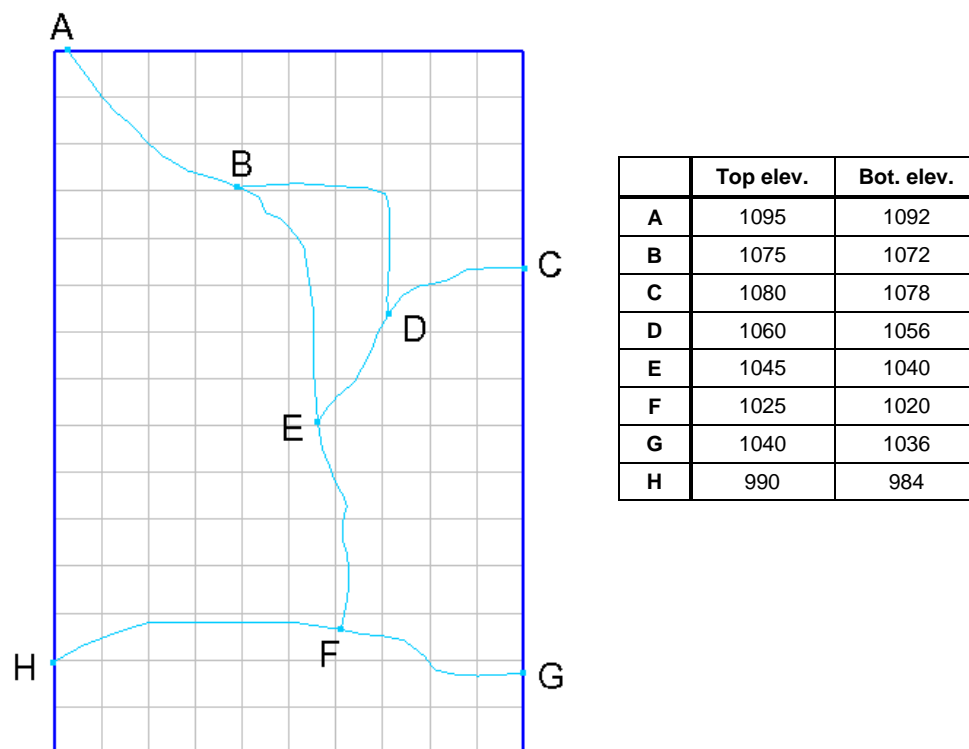



Figure 8 Nodes with letters to distinguish them

11.1 Node A

1. Click the *Select Nodes*  tool and then double-click on arc A as given in Figure 8. This brings up the *Attribute Table* dialog.
2. Enter the values as given for node A in the table above next to Figure 8 (only the columns with changes are shown):

Notice that the user is 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 *Attribute Table* dialog.
4. Repeat the above procedure to assign the appropriate values to nodes B through H according to Figure 8.

12 Map → MODFLOW


Everything has been entered, so it is now possible to 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.

13 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.

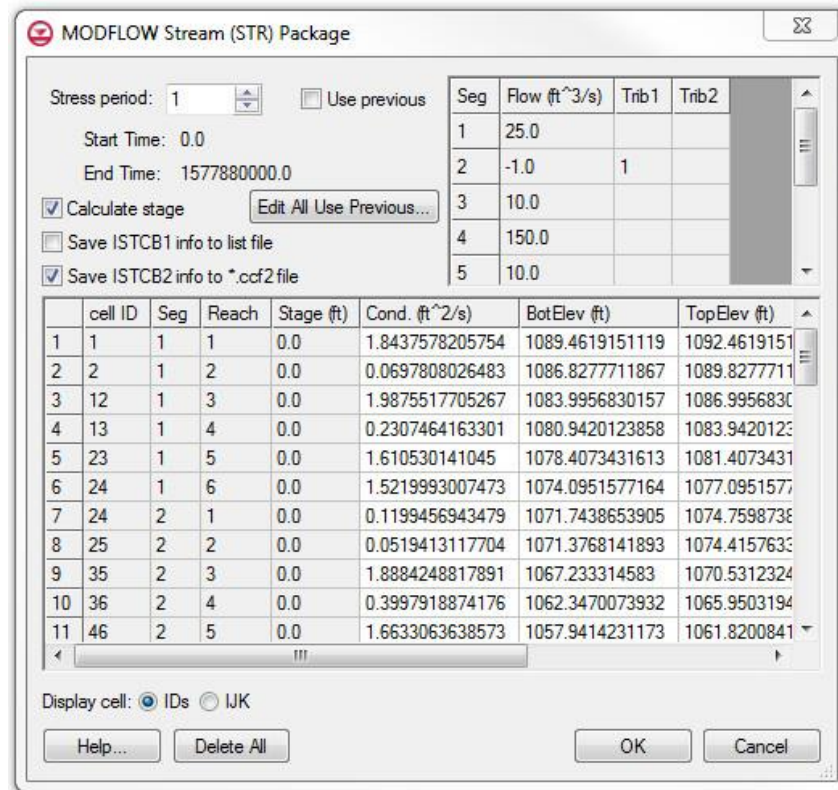


Figure 9 MODFLOW Stream (STR) Package dialog

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 the user can edit most things, but it isn't possible to edit the segment numbers or the cells that the reaches are in (cell ID). Nor is it possible to add segments or reaches. 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 STR data, it will populate the stream package dialog even if the user doesn'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. The user will view the information written to this file after running MODFLOW.

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

14 Save the Project and Run MODFLOW

Now save the project and run MODFLOW.


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

Now compare this solution with the original one from the USGS.

1. Select the **Contour Options**  button.
2. In the *Dataset Color Options – 3D – Head* dialog, change the *Contour Interval* to *Specified Values*.
3. Change the *Specified Values* value to “5.”
4. Then change the other options to match the figure below.

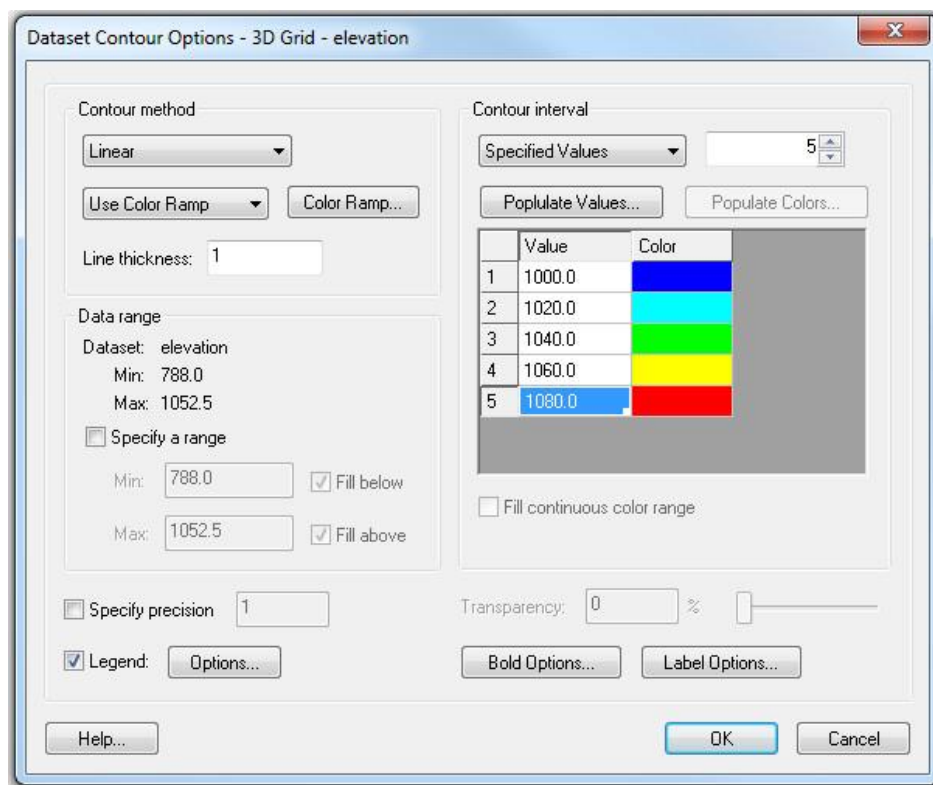




Figure 10 Contour Options dialog

5. Click **OK** to exit the dialog.
6. Click **Yes** if a dialog asks to turn contours on.

7. 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.




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

16 Flow Budget

Now 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 the MODFLOW solution is visible. Expand the  solution too.

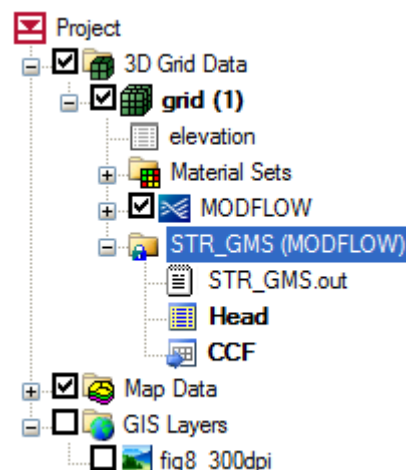




Figure 11 Project Explorer showing the MODFLOW solution

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 12 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.

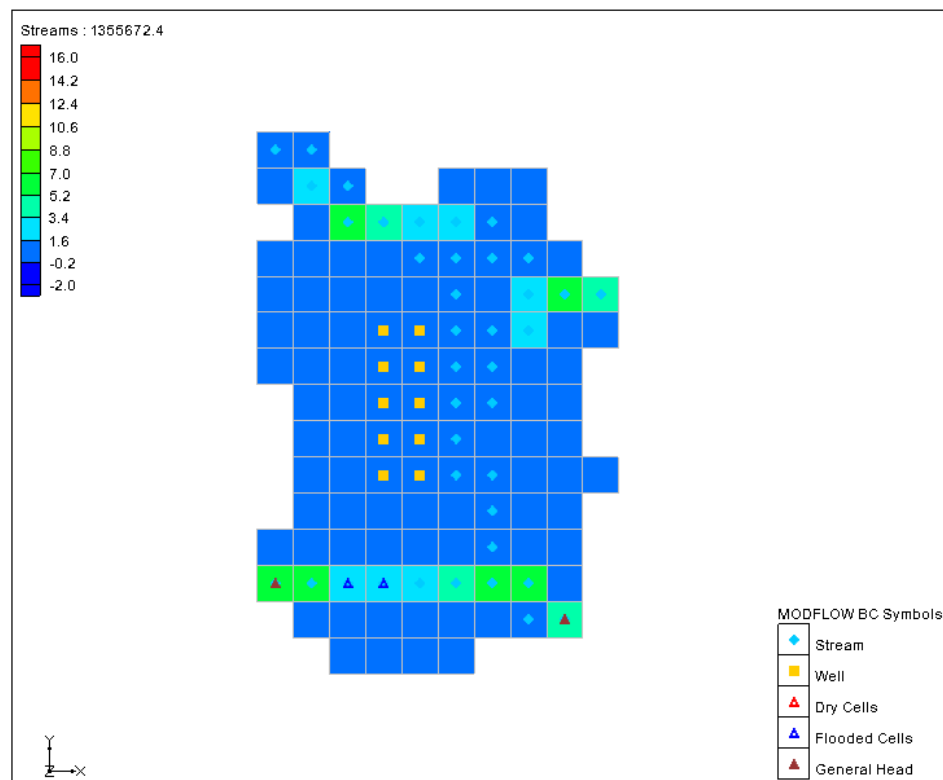



Figure 12 Block Fill showing stream in/out flow

17 Flow from Arcs

Since the user created the streams using the conceptual model, the user 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 the user should see information on the selected arc. *COMPUTED FLOW* will be one of the items listed. The user should see a value around 14.5 (depending on the exact geometry of the arc).


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

18 Flow in the Stream Channel

In the Stream Package dialog, the user turned on the *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.
2. Select **CCF → Datasets** from the pop-up menu.

The user now has a dataset that shows the stream reach flow at each cell. The dataset is called “STREAM FLOW OUT.”

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

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

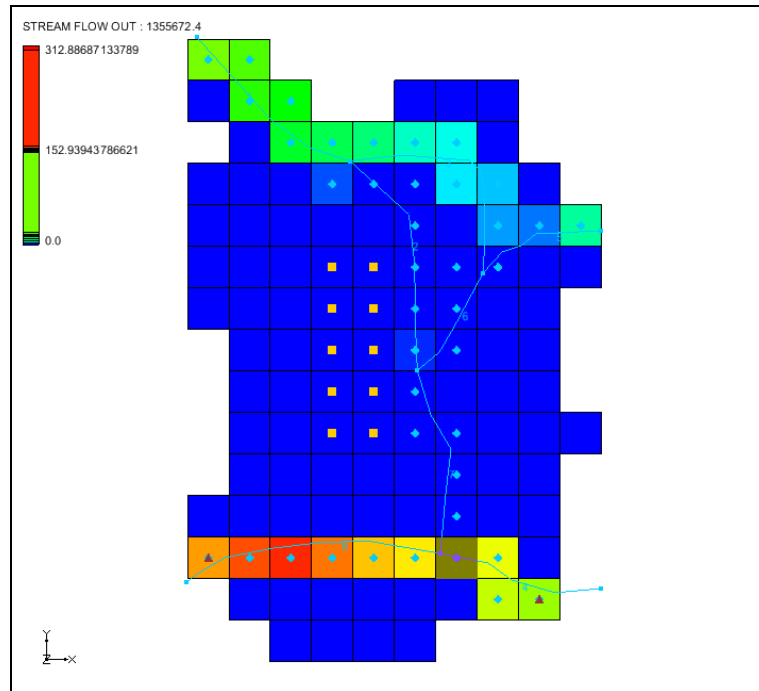


Figure 13 Stream Reach Flow

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 STR and SFR type streams.
- Streams must be created in the Map module using Feature Objects and cannot be created directly on the grid.
- The user must make sure 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 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.
- It is possible to click on feature objects and see the flow in or out of that object.
- It is possible to view the computed flow out of each stream reach using the CCF2 file.