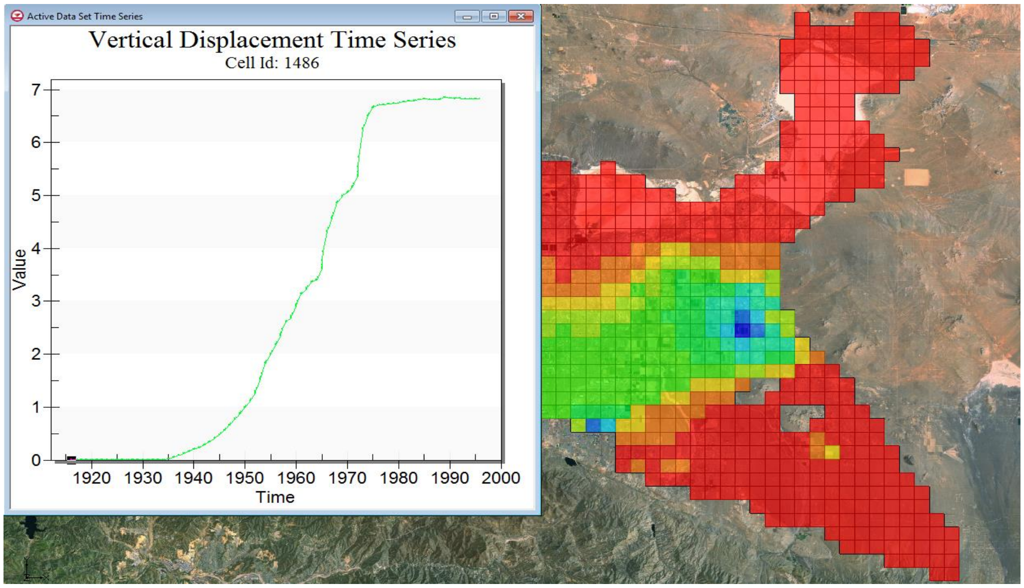
v. 10.0

*GMS 10.0 Tutorial*

# ***MODFLOW – SUB Package***

The MODFLOW SUB Package Interface in GMS




## Objectives

Learn how to use the MODFLOW SUB package interface in GMS.

## Prerequisite Tutorials

- MODFLOW – Conceptual Model Approach I

## Required Components

- Map Module
- Grid Module
- MODFLOW

## Time

- 40-60 minutes

**1 Introduction** ..... **2**
1.1 Outline ..... 2
**2 Description of Problem** ..... **3**
**3 Getting Started** ..... **4**
**4 Reading in the Project** ..... **4**
**5 Adding the SUB Package Using the Grid Approach** ..... **5**
5.1 Save the model with a new name ..... 5
5.2 Enabling the SUB Package ..... 5
5.3 Adding No Delay Interbeds ..... 5
5.4 Adding Delay Interbeds ..... 6
5.5 Enabling Vertical Displacement Output ..... 7
**6 Run MODFLOW** ..... **7**
**7 Examine the Solution** ..... **8**
7.1 Flow Budget ..... 8
7.2 Viewing Vertical Displacement ..... 8
7.3 Creating a Vertical Displacement Plot ..... 8
**8 Building a Conceptual Model** ..... **9**
8.1 Save the model with a new name ..... 9
8.2 Create the Conceptual Model ..... 10
8.3 Create Layer 1 Coverage ..... 10
8.4 Create the Polygon ..... 10
8.5 Set Layer 1 Polygon Properties ..... 11
8.6 Create Layer 2 Coverage ..... 11
8.7 Set Layer 2 Polygon Properties ..... 12
***9 Map → MODFLOW*** ..... **12**
**10 SUB Package Array Values** ..... **12**
**11 Saving and running MODFLOW** ..... **13**
**12 Examine the Solution** ..... **14**
12.1 The Flow Budget ..... 14
**13 Conclusion** ..... **14**
**14 Notes** ..... Error! Bookmark not defined.

# 1 Introduction

The Subsidence and Aquifer-System Compaction (SUB) Package was developed by the USGS to simulate aquifer compaction and land subsidence. The SUB package simulates compaction of interbeds including both elastic (recoverable) and inelastic (not recoverable) compaction. It also includes the ability to simulate interbeds where drainage from the interbed is immediate (no-delay) or delayed.

## 1.1 Outline

Here are the steps of this tutorial:

1. Add the SUB package to an existing simulation using the grid approach.
2. Create a simple conceptual model to illustrate how the SUB package can be modeled conceptually and mapped to MODFLOW.

## 2 Description of Problem

The problem for this tutorial is illustrated in Figure 1. The model is based on a U.S. Geological Survey (USGS) model which is described as follows:

> Antelope Valley, California, is a topographically closed basin in the western part of the Mojave Desert, about 50 miles northeast of Los Angeles. The Antelope Valley ground-water basin is about 940 square miles and is separated from the northern part of Antelope Valley by faults and low-lying hills. Prior to 1972, ground water provided more than 90 percent of the total water supply in the valley; since 1972, it has provided between 50 and 90 percent. Most ground-water pumping in the valley occurs in the Antelope Valley ground-water basin, which includes the rapidly growing cities of Lancaster and Palmdale. …
>
> The ground-water flow system consists of three aquifers: the upper, middle, and lower aquifers. The aquifers, which were identified on the basis of the hydrologic properties, age, and depth of the unconsolidated deposits, consist of gravel, sand, silt, and clay alluvial deposits and clay and silty clay lacustrine deposits. Prior to ground-water development in the valley, recharge was primarily the infiltration of runoff from the surrounding mountains. Ground water flowed from the recharge areas to the playas where it discharged either from the aquifer system as evapotranspiration or from springs. Partial barriers to horizontal ground-water flow, such as faults, have been identified in the ground-water basin. Water-level declines owing to ground-water development have eliminated the natural sources of discharge, and pumping for agricultural and urban uses have become the primary source of discharge from the ground-water system. Infiltration of return flows from agricultural irrigation has become an important source of recharge to the aquifer system.[1]

The model has been discretized into a grid that consists of 43 rows, 60 columns, and 3 layers. Each layer corresponds to the three aquifers. The simulation covers an 80 year period from 1915 through 1995 with the first year being steady state.

1. Leighton, David A.; Phillips, Steven P. (2003). Simulation of ground-water flow and land subsidence in the Antelope Valley ground-water basin, California. Water-Resources Investigations Report 03-4016. U.S. Geological Survey, p. 1.

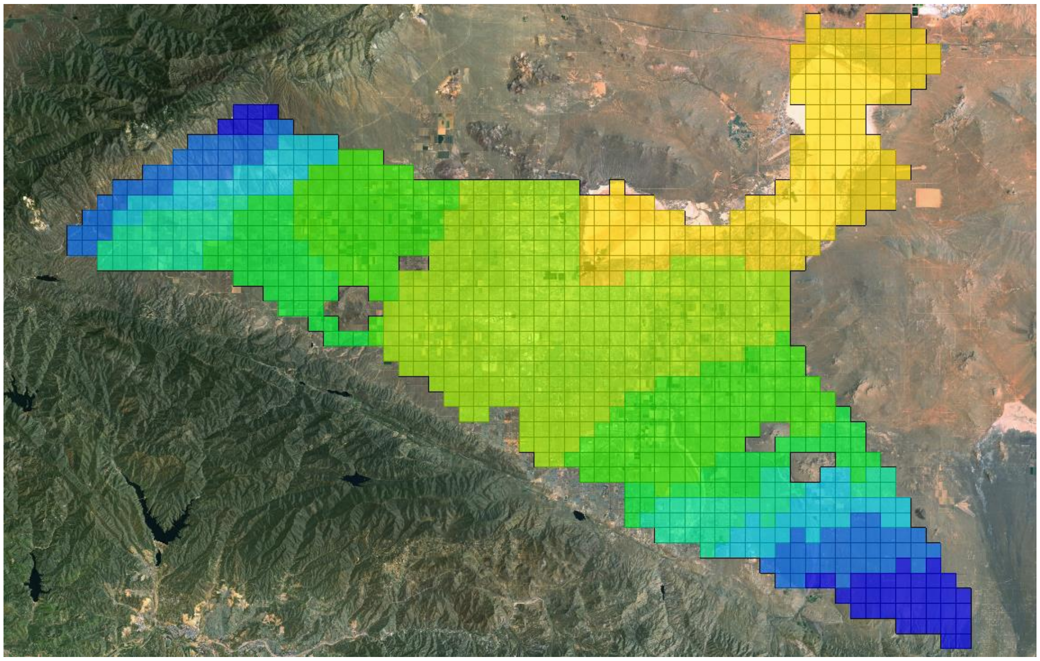


*Figure 1 MODFLOW model for Antelope Valley*

## 3 Getting Started

Do the following to get started:

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

## 4 Reading in the Project

First, read in the project:

1. Select the ***Open*** button (or the *File* | **Open** menu command).
2. Browse to *the \Tutorials\MODFLOW\sub* folder.
3. Select the file entitled “start.gpr.”
4. Click **Open.**

The user should see a MODFLOW model as shown in Figure 1.

# 5 Adding the SUB Package Using the Grid Approach

The user will begin by adding the SUB package using the grid approach.

## 5.1 Save the model with a new name

Now it is possible to start making changes. First, save the model with a new name.

1. Select the *File* | **Save As** menu command.
2. Remain in the *\Tutorials\MODFLOW\sub* folder.
3. Change the project name to "avgrid.gpr."
4. Save the project by clicking the **Save** button.

## 5.2 Enabling the SUB Package

Now it is necessary to turn on the SUB package.

1. Select the *MODFLOW* | **Global Options** command to open the *MODFLOW Global/Basic Package* dialog.
2. Select the **Packages** button to open the *MODFLOW Packages* dialog.
3. Toggle on the *SUB* - *Subsidence* package under *Optional packages*.
4. Select **OK** to exit the *MODFLOW Packages* dialog.
5. Select **OK** to exit the *MODFLOW Global/Basic Package* dialog.

## 5.3 Adding No Delay Interbeds

First the user will add no-delay interbeds for the first and second model layers.

1. Select the *MODFLOW* | *Optional Packages* **| SUB - Subsidence** command to open the *MODFLOW SUB Package* dialog.

The *Options* tab of the dialog contains general package values on the left, and delay interbed material zone values on the right. The *No-Delay Interbeds* and *Delay Interbeds* tabs are used for creating interbeds and setting the interbed array values.

2. Select the *No Delay Interbeds* tab.
3. Insert two new interbed systems by selecting the insert row button twice at the bottom of the *No-delay interbed layers* spreadsheet.
4. Set the layer value for the first interbed to "1," and the second interbed to "2."

The array values for a particular interbed system are shown by selecting an item in the desired system in the interbed layer spreadsheet.

5. Click on the spreadsheet row for interbed system 1 to show its values in the array editor.
6. Select the **2D Dataset → Array** button to set the preconsolidated head.
7. In the *Select Dataset* dialog, select the “Preconsolidated Head” dataset.
8. Select the **OK** button to exit the dialog.
9. Select “(Sfe) Elastic skeletal storage coeff” from the *View/Edit* popup menu.
10. Select the **Constant → Array** button and set the array value to “1.5e-4.”
11. Select “(Sfv) Inelastic skeletal storage coef” from the *View/Edit* popup menu.
12. Select the **Constant → Array** button and set the array value to “8.0e-3.”
13. Click on the spreadsheet row for interbed system 2 to show its values in the array editor.
14. Select the **2D Dataset → Array** button.
15. In the *Select Dataset* dialog, select the “Preconsolidated Head” dataset.
16. Set the “(Sfe) Elastic skeletal storage coef” value to “9.0e-5.”
17. Set the “(Sfv) Inelastic skeletal storage coef” value to “5.0e-3.”

## 5.4 Adding Delay Interbeds

Next, the user will add delay interbeds for the first and second layers.

1. Select the *Delay Interbeds* tab.
2. Insert two new interbed systems by selecting the insert row button twice at the bottom of the *Delay interbed layers* spreadsheet.
3. Using the **Constant → Array** button, enter the array values from the following table for the *View/Edit* value.

| System | Layer | RNB | DZ | NZ |
|---|---|---|---|---|
| 1 | 1 | 1.0 | 5.5 | 1 |
| 2 | 2 | 1.0 | 4.7 | 2 |

4. For the Dstart and DHC arrays in the *View/Edit* drop-down menu, enter the values below using the **2D Dataset → Array** button.

| System | Layer | Dstart | DHC |
|---|---|---|---|
| 1 | 1 | Starting Head 1 | Preconsolidated Head |
| 2 | 2 | Starting Head 2 | Preconsolidated Head |

5. Select the *Options* tab at the top of the dialog.
6. Change the *Number of Material Zones (NMZ)* to "2."
7. Set the material zone values as shown in the table below:

| ID | Vertical K | Elastic spec. storage | Inelastic spec. storage |
|---|---|---|---|
| 1 | 1.0e-6 | 5.0e-6 | 6.0e-4 |
| 2 | 0.5e-6 | 5.0e-6 | 6.0e-4 |

## 5.5 Enabling Vertical Displacement Output

Next the user will turn on the generation of vertical displacement data, which for layer 1 is the same as subsidence. The vertical displacement will be shown as a dataset in the MODFLOW solution.

1. Select the **SUB Output Options** button to open the *MODFLOW SUB Package Output Options* dialog.
2. Select the **Populate Time Steps** button.
3. Change the popup menu to "Specified output last time step each stress period."
4. Select **OK** to close the dialog.
5. In the spreadsheet, scroll to the right and turn on the *Save vert. disp (Ifl8)* toggle for all rows.
6. Select **OK** to exit the *MODFLOW SUB Package Output Options* dialog.
7. Select **OK** to exit the *MODFLOW SUB Package* dialog.

# 6 Run MODFLOW

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

1. Select the ***Save*** button (or the *File* | **Save** menu command).
2. Select the **Run Modflow** button (or the *MODFLOW* | **Run Modflow** menu command).
3. When MODFLOW finishes, select the **Close** button.

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

# 7 Examine the Solution

Now the user will look more closely at the computed solution. First the user will look at the flow budget entries for the SUB package.

## 7.1 Flow Budget

1. Expand the "3D Grid Data" folder.

2. Select the "Head" dataset in the Project Explorer. Then, select the last time step in the *Time Step Window*.

3. Select the *MODFLOW* | **Flow Budget** command to display the *Flow Budget* dialog.

The flow budget values for the SUB package include the INST. IB STORAGE and DELAY IB STORAGE. The values are approximately as shown in the table below. The user will use these values to compare against later in the tutorial when the user builds the same model using the conceptual approach.

| Type | Flow In | Flow Out |
|---|---:|---:|
| INST. IB STORAGE | 209,368 | -6, 347 |
| DELAY IB STORAGE | 150,000 | -1,210 |

4. Select **OK** to close the *Flow Budget* dialog.

## 7.2 Viewing Vertical Displacement

1. In the Project Explorer, click on the "VerticalDisplacement" dataset in the "avgrid (MODFLOW)" solution.

2. If necessary, scroll through the *Time Step* window and click on the last time step.

The vertical displacement in the model varies from near zero to as high as about 6.8 ft in cell ID 1486.

3. In the Project Explorer, change back and forth between the "VerticalDisplacement" and "DrawDown" datasets and notice the similarities between the grid contours of the two datasets.

## 7.3 Creating a Vertical Displacement Plot

Next the user will generate a plot that shows the vertical displacement for a single cell.

1. Make sure that the "VerticalDisplacement" dataset is selected in the Project Explorer.

2. Select the *Grid* | **Find Cell** menu command and enter "1486" for the *Cell ID*.

3. Select **OK** to exit the dialog, which will select the cell in the *Graphics Window*.

4. Select the **Plot Wizard** macro from the tool bar at the top of GMS (or select the *Display* | **Plot Wizard**… menu item).

5. In the *Plot Type* list, select "Active Dataset Time Series."

6. Click on the **Finish** button.

The generated plot is shown in Figure 2. Again, switching back and forth between the VerticalDisplacement and DrawDown datasets in the Project Explorer shows there is a relationship between the two.

7. Select the **Save** button to save the project.

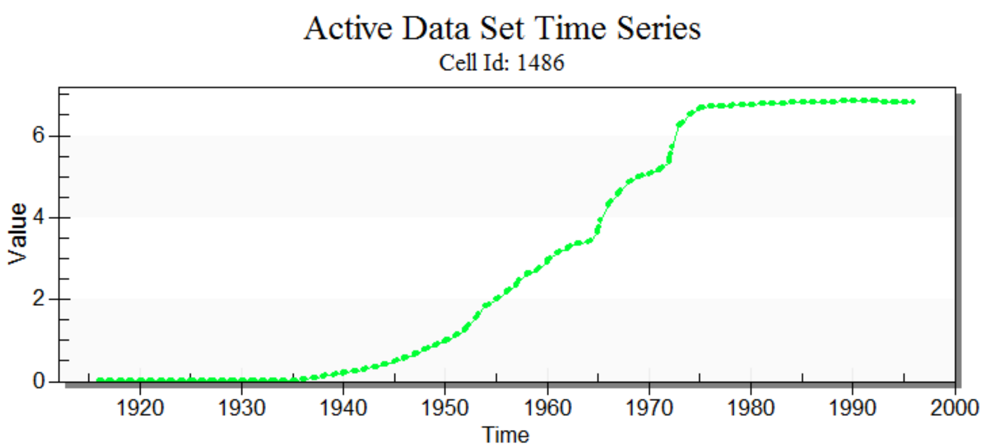



*Figure 2 Vertical displacement plot for cell ID 1486*

# 8 Building a Conceptual Model

Next the user will use the conceptual model approach to add the same interbeds to the initial model.

## 8.1 Save the Original Model with a New Name

1. Select the *File* | **New** command to close the grid based model.

2. Select the **Open** button (or the *File* | **Open** menu command).

3. Browse to the *\Tutorials\MODFLOW\sub* folder.

4. Select the file entitled "start.gpr" file.

5. Click the **Open** button.
6. Select the *File* | **Save As** menu command.
7. Remain in the *\Tutorials\MODFLOW\sub* folder.
8. Change the project name to “avconc.gpr.”
9. Save the project by clicking the **Save** button.

## 8.2 Create the Conceptual Model

1. Right-click in the Project Explorer and select the *New* | **Conceptual Model** command from the pop-up menu.
2. In the *Conceptual Model Properties* dialog, change the *Name* to “Anetelope Valley.”
3. Change the *Flow Package* to “BCF.”
4. Click **OK**.

## 8.3 Create Layer 1 Coverage

1. Right-click on the **Antelope Valley** conceptual model that was just created in the Project Explorer.
2. Select the **New Coverage** command from the popup menu.
3. In the *Coverage Setup* dialog, change the *Coverage Name* to “layer 1.”
4. In the list of *Areal Properties*, turn on the following:
   - *SUB Delay Interbed*
   - *SUB Non-delay Interbed*
5. Click **OK** to exit the *Coverage Setup* dialog.

## 8.4 Create the Polygon

1. Select the “layer 1” coverage to make it the active coverage.
2. Select the **Create Arc** tool.
3. Create an arc that surrounds the grid. End the arc on the beginning point to form a closed polygon, as shown in Figure 3.
4. Select the *Feature Objects* | **Build Polygons** menu command.

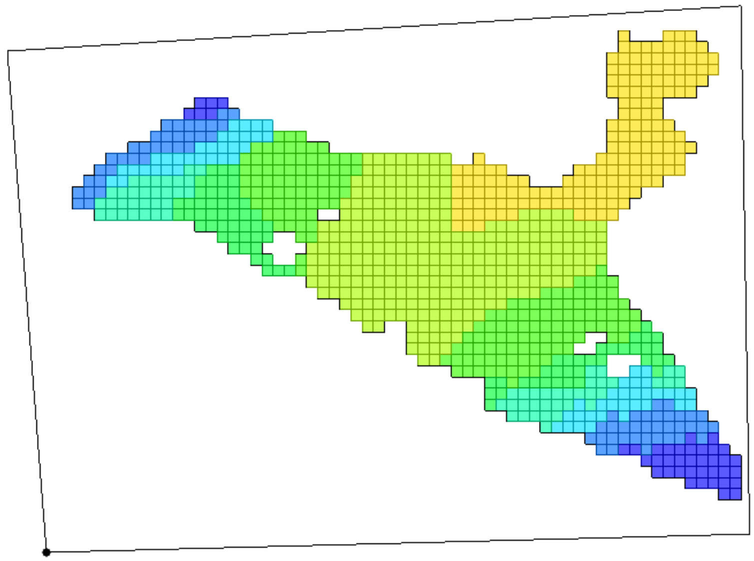


*Figure 3 Creating a polygon that encompasses the model grid*

## 8.5 Set Layer 1 Polygon Properties

1. Switch to the **Select** tool.
2. Double-click anywhere inside the newly created polygon.
3. In the *Attribute Table* dialog, set the values as shown in the table below. Leave all other properties at the default values.

| | |
|---|---|
| **SUB Sfe (elast. skel. st. coef, ND)** | 0.00015 |
| **SUB Sfv (inelast. skel. st. coef, ND)** | 0.008 |
| **SUB RNB (nequiv, D)** | 1.0 |
| **SUB DZ (bequiv equiv. thick., D)** | 5.5 |
| **SUB Vertical k (D)** | 1.0e-006 |
| **SUB Elastic spec. storage (D)** | 5.0e-006 |
| **SUB Inelastic spec. storage (D)** | 0.0006 |

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

## 8.6 Create Layer 2 Coverage

1. Right-click on the “layer 1” coverage in the Project Explorer.
2. Select **Duplicate** from the popup menu.
3. Right-click on the newly created coverage “Copy of layer 1” and select **Coverage Setup** from the popup menu.
4. Change the *Coverage name* to “layer 2.”

5. Change the *Default layer range* from 1 to 1 to values of “2” to “2.”

6. Click **OK** to exit the *Coverage Setup* dialog.

### 8.7 Set Layer 2 Polygon Properties

1. Make sure the “layer 2” coverage is selected as the active coverage in the Project Explorer.

2. Switch to the **Select** tool if necessary.

3. Double-click anywhere inside the newly created polygon.

4. In the *Attribute Table* dialog, set the values to be as shown in the table below.

| | |
|---|---|
| **SUB Sfe (elast. skel. st. coef, ND)** | 0.00009 |
| **SUB Sfv (inelast. skel. st. coef, ND)** | 0.005 |
| **SUB RNB (nequiv, D)** | 1.0 |
| **SUB DZ (bequiv equiv. thick., D)** | 4.7 |
| **SUB Vertical k (D)** | 5.0e-007 |
| **SUB Elastic spec. storage (D)** | 5.0e-006 |
| **SUB Inelastic spec. storage (D)** | 0.0006 |

5. Click **OK** to exit the *Attribute Table* dialog.

## 9 Map → MODFLOW

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

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

2. Click **OK**.

## 10 SUB Package Array Values

Now it is possible to take a look at the data in MODFLOW that was mapped to the SUB package from the conceptual model.

1. Select the *MODFLOW* | *Optional Packages* | **SUB - Subsidence** menu command to open the *MODFLOW SUB Package* dialog.

Note that two materials have been created in the *Delay interbed material zone properties (DP)* spreadsheet.

2. Switch to the *No Delay Interbeds* tab at the top of the dialog.

3. Switch between the different arrays using the *View/Edit* combo box and the layer spreadsheet.

Note that the "(Sfe) Elastic skeletal storage coef" and "(Sfv) Inelastic skeletal storage" coef values have been properly mapped, and the "(HC) Preconsolidation head or stress" values were mapped to the default value (0.0).

4. Switch the *View/Edit* combo box to "(HC) Preconsolidation head or stress."
5. Select the spreadsheet row for interbed layer 1.
6. Select the **2D Dataset → Array** button and set the array values to the "Preconsolidated Head" dataset.
7. Click **OK.**
8. Switch to interbed layer 2 by selecting its spreadsheet row.
9. Set the array values to the "Preconsolidated Head" dataset using the **2D Dataset → Array** button.
10. Click **OK.**
11. Select the *Delay Interbeds* tab at the top of the dialog.
12. Using the **2D Dataset → Array** button, set the Dstart and DHC array values for the delay interbeds to the 2D grid datasets shown in the table below.

| System | Layer | Dstart | DHC |
|---|---|---|---|
| 1 | 1 | Starting Head 1 | Preconsolidated Head |
| 2 | 2 | Starting Head 2 | Preconsolidated Head |

13. Select the **OK** button to exit the *MODFLOW SUB Package* dialog.

# 11 Saving and running MODFLOW

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

1. Select the **Save** button (or the *File* | **Save** menu command).
2. Select the *MODFLOW* | **Run MODFLOW** menu command.
3. When MODFLOW finishes, select the **Close** button.
4. Select the **Save** button to save the project with the new solution.

# 12 Examine the Solution

Now the user will look more closely at the computed solution.

## 12.1 The Flow Budget

1. Select the "Head" dataset in the "avconc (MODFLOW)" solution in the Project Explorer.
2. Then select the last time step in the *Time Step Window*.
3. Select the *MODFLOW* | **Flow Budget** command to display the *Flow Budget* dialog.

The flow budget should match the values previously observed when adding the SUB package using the grid method. The approximate values are shown in the table below.

| Type | Flow In | Flow Out |
|---|---:|---:|
| INST. IB STORAGE | 298,000 | -6,400 |
| DELAY IB STORAGE | 150,000 | -1,210 |

# 13 Conclusion

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

- GMS supports the MODFLOW SUB package.
- SUB data can be entered and viewed in the *SUB Package* dialog.
- SUB data can be entered in a conceptual model and then mapped to a MODFLOW model.