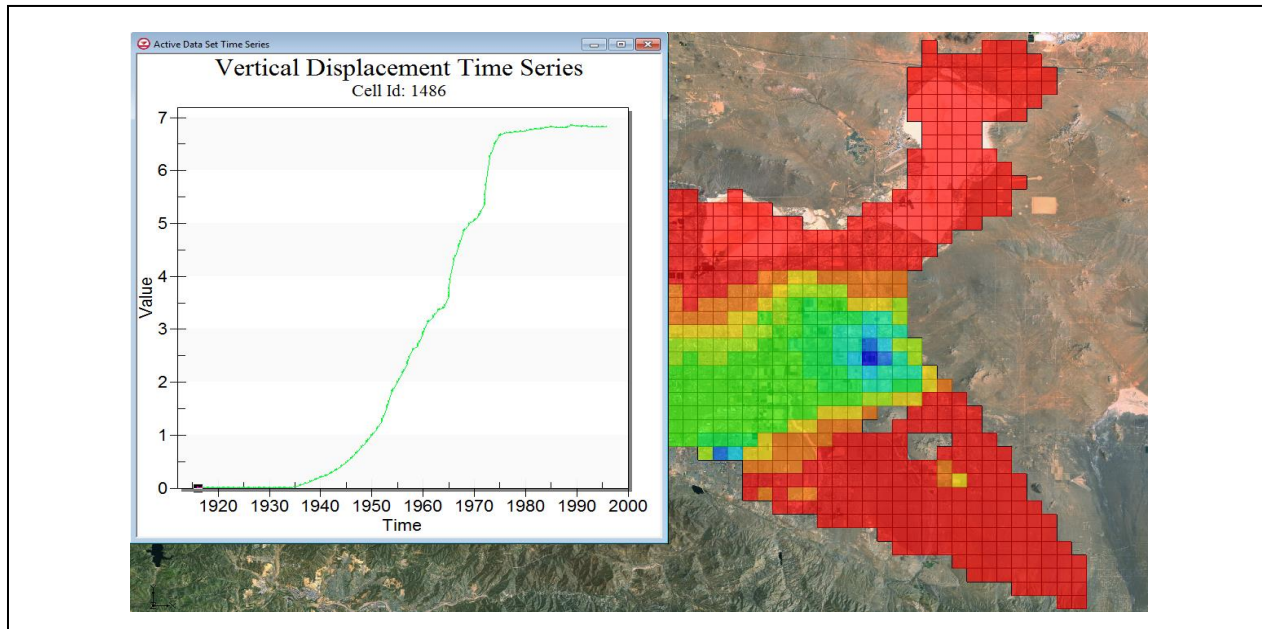## GMS 10.1 Tutorial
MODFLOW – SUB Package
The MODFLOW SUB Package Interface in GMS

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

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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.

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 three 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.
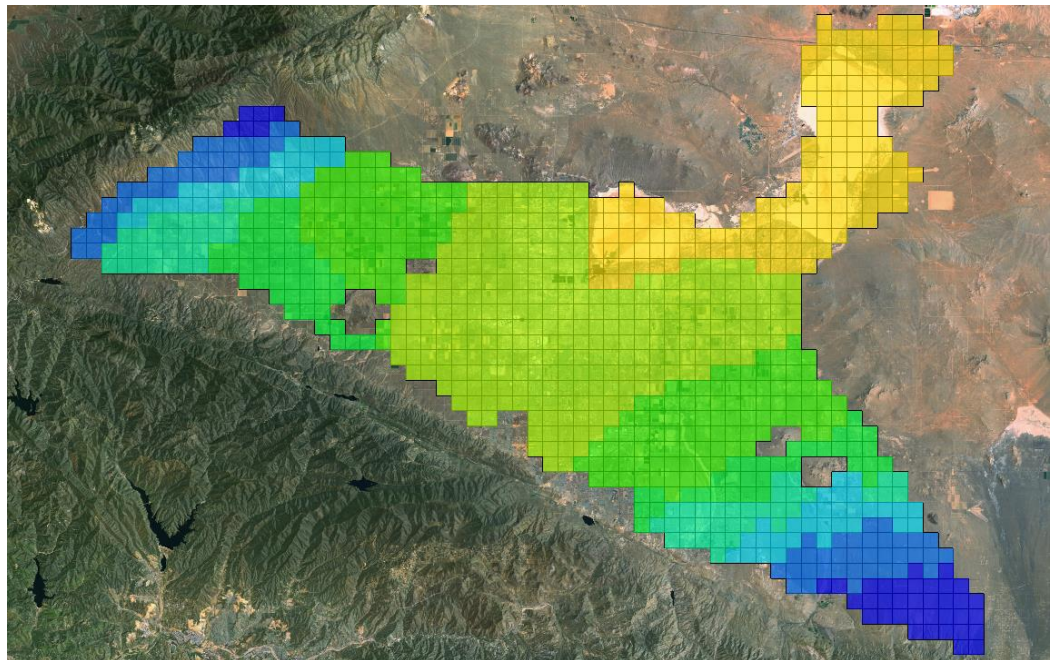

Figure 1   MODFLOW model for Antelope Valley

This tutorial will discuss and demonstrate adding the SUB package to an existing simulation using the grid approach, and creating a simple conceptual model to illustrate how the SUB package can be modeled conceptually and mapped to MODFLOW.

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[1] Leighton, David A.; Phillips, Steven P. (2003). *Simulation of Ground-Water Flow and Land Subsidence, Antelope Valley Ground-Water Basin, California*. Water-Resources Investigations Report 03-4016. U.S. Geological Survey, p.1.
http://pubs.usgs.gov/wri/wrir034016/wrir034016.book.pdf

2   Getting Started

Do the following to get started:

1. If necessary, launch GMS.

2. If GMS is already running, select *File* / **New** to ensure that the program settings are restored to their default state.

2.1   Importing the Project

First, import the project:

1. Click **Open** 📂 to bring up the *Open* dialog.

2. Select "Project Files (*.gpr)" from the *Files of type* drop-down

3. Browse to *the \Tutorials\MODFLOW\sub* folder and select "start.gpr".

4. Click **Open** to import the project and exit the *Open* dialog.

A MODFLOW model similar to that in Figure 1 should appear.

2.2   Saving the Model with a New Name

Before making changes, save the model with a new name.

1. Select *File* / **Save As…** to bring up the *Save As* dialog.

2. Select "Project Files (*.gpr)" from the *Save as type* drop-down.

3. Enter "avgrid.gpr" as the *File name*.

4. Click **Save** to save the project under the new name and close the *Save As* dialog.

3   Adding the SUB Package Using the Grid Approach

Begin by adding the SUB package using the grid approach.

3.1   Enabling the SUB Package

The first step is to turn on the SUB package by doing the following:

1. Select the *MODFLOW* / **Global Options…** to open the *MODFLOW Global/Basic Package* dialog.

2. Click **Packages…** to open the *MODFLOW Packages / Processes* dialog.

3. In the Optional packages / processes section, turn on *SUB - Subsidence*.

4. Click **OK** to exit the *MODFLOW Packages / Processes* dialog.

5. Click **OK** to exit the *MODFLOW Global/Basic Package* dialog.

3.2   Adding No Delay Interbeds

Next, add no-delay interbeds for the first and second model layers.

1. Select *MODFLOW | Optional Packages |* **SUB – Subsidence…** 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. On the *No Delay Interbeds* tab, click **Insert Row** ⊒⁺ᴄ twice to create two new interbed systems in the *No-delay interbed layers (LN)* spreadsheet.

3. Enter "1" in the *Layer* column on row *1*.

4. Enter "2" in the *Layer* column on row *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. Select row *1* in the *No-delay interbed layers (LN)* spreadsheet to show its values in the *HC for system* array editor on the right.

6. Click **2D Dataset → Array** to bring up the *Select Dataset* dialog.

7. In the *Solution* section, select the "Preconsolidated Head" dataset and click **OK** to exit the *Select Dataset* dialog.

8. Select "(Sfe) Elastic skeletal storage coeff" from the *View/Edit* drop-down.

9. Click **Constant → Array** to bring up the *Grid Value* dialog.

10. Enter "1.5e-4" as the *Constant value for grid* and click **OK** to exit the *Grid Value* dialog.

11. Select "(Sfv) Inelastic skeletal storage coef" from the *View/Edit* drop-down.

12. Click **Constant → Array** to bring up the *Grid Value* dialog.

13. Enter "8.0e-3" as the *Constant value for grid* and click **OK** to exit the *Grid Value* dialog.

14. Select row *2* in the *No-delay interbed layers (LN)* spreadsheet.

15. Select "(HC) Preconsolidated head or stress (ft)" from the *View/Edit* drop-down.

16. Click **2D Dataset → Array** to bring up the *Select Dataset* dialog.

17. Repeat steps 7-13, entering "9.0e-5" for the "(Sfe) Elastic skeletal storage coef" and "5.0e-3" for the "(Sfv) Inelastic skeletal storage coef".

3.3   Adding Delay Interbeds

Now add delay interbeds for the first and second layers.

1. On the *Delay Interbeds* tab, click **Insert Row** ⌐ twice to create two new interbed systems in the *Delay interbed layers (LDN)* spreadsheet.

2. Enter "1" in the *Layer* column on row *1* and "2" in the *Layer* column on row *2*.

3. Select row 1 in the *Delay interbed layers (LDN)* spreadsheet.

4. Select "(RNB) nequiv and areal extent" from the *View/Edit* drop-down.

5. Click **Constant → Array** to bring up the *Grid Value* dialog.

6. Enter "1.0" as the *Constant value for grid* and click **OK** to close the *Grid Value* dialog.

7. Select "(DZ) bequiv equivalent thickness (ft)" from the *View/Edit* drop-down.

8. Click **Constant → Array** to bring up the *Grid Value* dialog.

9. Enter "5.5" as the *Constant value for grid* and click **OK** to close the *Grid Value* dialog.

10. Select "(NZ) Material zone numbers" from the *View/Edit* drop-down.

11. Click **Constant → Array** to bring up the *Grid Value* dialog.

12. Enter "1" as the *Constant value for grid* and click **OK** to close the *Grid Value* dialog.

13. Select "(Dstart) Starting head in interbeds (ft)" from the *View/Edit* drop-down.

14. Click **2D Dataset → Array** to bring up the *Select Dataset* dialog.

15. Select "Starting Head 1" from the *Solution* section and click **OK** to close the *Select Dataset* dialog.

16. Select "(DHC) Starting preconsolidated head (ft)" from the *View/Edit* drop-down.

17. Click **2D Dataset → Array** to bring up the *Select Dataset* dialog.

18. Select "Preconsolidated Head" from the *Solution* section and click **OK** to close the *Select Dataset* dialog.

19. Select row *2* in the *Delay interbed layers (LDN)* spreadsheet and repeat steps 5-19 using the values from the following table:

System	Layer	RNB	DZ	NZ	Dstart	DHC
2	2	1.0	4.7	2	Starting Head 2	Preconsolidated Head

3.4   Additional Options

1. On the *Options* tab, enter "2" in the *Number of Material Zones (NMZ)* field.

2. In the *Delay interbed material zone properties (DP)* spreadsheet, enter the following values:

ID	Vertical K (ft/d)	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

3.5   Enabling Vertical Displacement Output

Next, 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. Click **SUB Output Options…** to open the *MODFLOW SUB Package Output Options* dialog.

2. Click **Populate Time Steps…** to bring up the *Populate Time Steps* dialog.

3. Select "Specified output last time step each stress period" from the drop-down and click **OK** to close the *Populate Time Steps* dialog.

4. In the *All* row, scroll to the right in the spreadsheet and check the box in the *Save vert. disp (Ifl8)* column.

5. Click **OK** to exit the *MODFLOW SUB Package Output Options* dialog.

6. Click **OK** to exit the *MODFLOW SUB Package* dialog.

3.6   Saving and Running MODFLOW

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

1. **Save** the project.

2. Click **Run Modflow** to bring up the *MODFLOW* model wrapper dialog.

3. When MODFLOW finishes, turn on *Read solution on exit* and *Turn on contours (if not on already)*.

4. Click **Close** to import the solution and close the *MODFLOW* model wrapper dialog.

5. **Save** the project with the new solution.

3.7   Examining the Solution

Look more closely at the computed solution. First, look at the flow budget entries for the SUB package.

Flow Budget

1.   Expand the "⬛ 3D Grid Data" folder, select the "📑 Head" dataset under the "🔷 avgrid (MODFLOW)" solution, and select the final time step in the Time Step window.

2.   Select *MODFLOW* / **Flow Budget…** 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. These values will be used to compare against later in the tutorial when building the same model using the conceptual approach.

Type	Flow In	Flow Out
INST. IB STORAGE	298,086	-6,406
DELAY IB STORAGE	149,747	-1,210

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

Viewing Vertical Displacement

1.   Select "📑 VerticalDisplacement" under "🔷 avgrid (MODFLOW)".

2.   If necessary, scroll to the bottom of the Time Step window and select the last time step.

The vertical displacement in the model varies from near zero to as high as about 6.9 ft in cell ID 1486.

3.   Switch between the "📑 VerticalDisplacement" and "📑 DrawDown" datasets and notice the similarities between the grid contours of the two datasets.

Creating a Vertical Displacement Plot

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

1.   Select the "📑 VerticalDisplacement" dataset in the Project Explorer.

2.   Select *Grid* / **Find Cell…** to bring up the *Find Grid Cell* dialog.

3.   Enter "1486" as the *Cell ID* and click **OK** to exit the *Find Grid Cell* dialog.

Cell 1486 will be selected in the Graphics Window.

4.   Click **Plot Wizard** 📊 to bring up the *Step 1 of 2* page of the *Plot Wizard* dialog.

5. In the *Plot Type* section, select "Active Dataset Time Series" from the list on the left.

6. Click **Finish** to close the *Plot Wizard* dialog.

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.
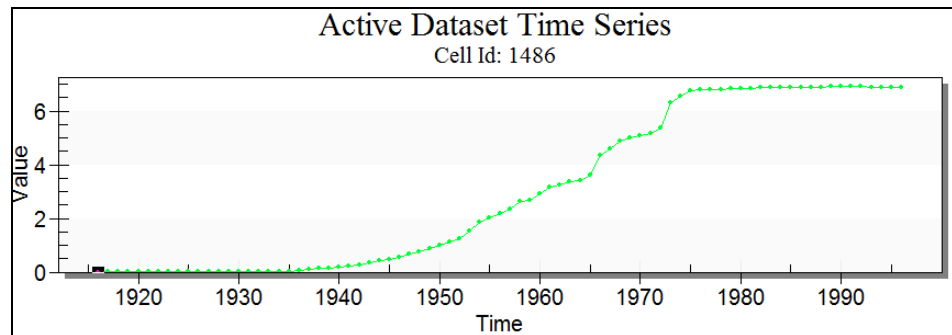
7. **Save** 💾 the project.

Figure 2   *Vertical displacement plot for cell ID 1486*

4   Building a Conceptual Model

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

4.1   Importing and Renaming the Original Model

1. Select *File* / **New** to close the grid based model and reset to defaults

2. Select **Open** 📂 to bring up the *Open* dialog.

3. Select "Project Files (*.gpr)" from the *Files of type* drop-down.

4. Browse to the *Tutorials\MODFLOW\sub* folder and select "start.gpr".

5. Click **Open** to import the project and exit the *Open* dialog.

6. Select *File* / **Save As…** to bring up the *Save As* dialog.

7. Select "Project Files (*.gpr)" from the *Save as type* drop-down.

8. Enter "avconc.gpr" as the *File name*.

9. Click **Save** to save the project under the new name and close the *Save As* dialog.

4.2   Creating the Conceptual Model

1. Right-click in a blank spot in the Project Explorer and select *New* / **Conceptual Model…** to bring up the *Conceptual Model Properties* dialog.

2. Enter "Antelope Valley" as the *Name*.

3. Select "BCF" from the *Flow Package* drop-down.

4. Click **OK** to close the *Conceptual Model Properties* dialog.

4.3   Creating Layer 1 Coverage

1. Right-click on the "🐢 Antelope Valley" conceptual model and select **New Coverage…** to bring up the *Coverage Setup* dialog.

2. Enter "layer 1" as the *Coverage Name*.

3. In the *Areal Properties* column, turn on *SUB Delay Interbed* and *SUB Non-delay Interbed.*

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

4.4   Creating the Polygon

1. Select the "🐢 layer 1" coverage to make it active.

2. Turn off "🌐 GIS Layers" in the Project Explorer.

3. Using the **Create Arc** 🖊 tool, create a quadrilateral arc surrounding the grid. End the arc on the beginning point to form a closed polygon (see Figure 3).

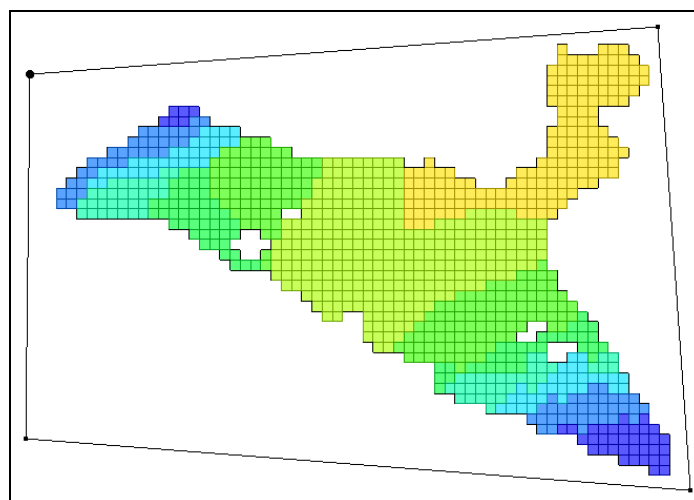4. Select *Feature Objects* / **Build Polygons** to turn it into a polygon.

Figure 3   Creating a polygon that encompasses the model grid

4.5   Setting Layer 1 Polygon Properties

1. Using the **Select Objects** tool, double-click anywhere inside the newly created polygon to bring up the *Attribute Table* dialog.

2. Enter the values from right column in the table below into the fields indicated in the left column of the table. 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

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

4.6   Creating Layer 2 Coverage

1. Right-click on the "▨ layer 1" coverage in the Project Explorer and select **Duplicate…** to create a "▨ Copy of layer 1" coverage..

2. Right-click on "▨ Copy of layer 1" and select **Coverage Setup…** to bring up the *Coverage Setup* dialog.

3. Enter "layer 2" as the *Coverage name*.

4. Change the *Default layer range* to "2" to "2".

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

4.7   Setting Layer 2 Polygon Properties

1. Select "▨ layer 2" to make it active.

2. Using the **Select Objects** tool, double-click anywhere inside the polygon to bring up the *Attribute Table* dialog.

3. Enter the values from right column in the table below into the fields indicated in the left column of the table. Leave all other properties at the default values.

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

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

5   Mapping to MODFLOW

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

1. Select *Feature Objects* / **Map → MODFLOW** to bring up the *Map → Model* dialog.

2. Click **OK** to accept the defaults and close the *Map → Model* dialog.

5.1   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 *MODFLOW* / *Optional Packages* / **SUB – Subsidence…** to open the *MODFLOW SUB Package* dialog.

On the *Options* tab, note that two materials have been created in the *Delay interbed material zone properties (DP)* spreadsheet.

2. On the *No Delay Interbeds* tab, 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).

3. Select "(HC) Preconsolidation head or stress" from the *View/Edit* drop-down.

4. Select row *1* in the *No-delay interbed layers (LN)* spreadsheet.

5. Click **2D Dataset → Array** to bring up the *Select Dataset* dialog.

6. Select "Preconsolidated Head" and click **OK** to exit the *Select Dataset* dialog.

7. Select row *2* in the *No-delay interbed layers (LN)* spreadsheet.

8. Click **2D Dataset → Array** to bring up the *Select Dataset* dialog.

9. Select "Preconsolidated Head" and click **OK** to exit the *Select Dataset* dialog.

10. On the *Delay Interbeds* tab, select "(Dstart) Starting head in interbeds (ft)" from the *View/Edit* drop-down.

11. Select row *1* in the *Delay interbed layers (LDN)* spreadsheet.

12. Click **2D Dataset → Array** to bring up the *Select Dataset* dialog.

13. Select "Starting Head 1" and click **OK** to close the *Select Dataset* dialog.

14. Select row *2* in the *Delay interbed layers (LDN)* spreadsheet.

15. Click **2D Dataset → Array** to bring up the *Select Dataset* dialog.

16. Select "Starting Head 2" and click **OK** to close the *Select Dataset* dialog.

17. Select "(DHC) Starting preconsolidated head (ft)" from the *View/Edit* drop-down.

18. Select row *1* in the *Delay interbed layers (LDN)* spreadsheet.

19. Click **2D Dataset → Array** to bring up the *Select Dataset* dialog.

20. Select "Preconsolidated Head" and click **OK** to close the *Select Dataset* dialog.

21. Select row *2* under *Delay interbed layers (LDN)* and repeat steps 19-20.

22. Click **OK** to exit the *MODFLOW SUB Package* dialog.

5.2   Saving and Running MODFLOW

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

1. **Save** the project.

2. Select *MODFLOW* | **Run MODFLOW** to bring up the *MODFLOW* model wrapper dialog.

3. When MODFLOW finishes, turn on *Read solution on exit* and *Turn on contours (if not on already)*.

4. Click **Close** to close the *MODFLOW* model wrapper dialog.

5. **Save** save the project with the new solution.

5.3   Examine the Flow Budget

Now, review the computed solution more closely.

1. Expand the " 3D Grid Data" folder, then select the " Head" dataset in the " avconc (MODFLOW)" solution in the Project Explorer.

2. Select the last time step in the Time Step window.

3. Select *MODFLOW* | **Flow Budget…** 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

6   Conclusion

This concludes the "MODFLOW – SUB Package" tutorial. The following key concepts were discussed and demonstrated:

- 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.