# MODFLOW – Generating Data From Solids

Complex stratigraphy can be difficult to simulate in MODFLOW models. MODFLOW uses a structured grid that requires that each grid layer be continuous throughout the model domain. This makes it difficult to explicitly represent common features such as pinchouts and embedded seams in a MODFLOW model.

Solid models can be used to represent arbitrarily complex stratigraphy. Figure 2.1 shows a cross section through a solid model where different stratigraphic units pinchout. Designing a MODFLOW compatible grid for this type of stratigraphy is very difficult.

*Figure 2.1 Cross-section through a Solid Model*

In this tutorial we will cover the steps necessary to convert solid models, like the one in Figure 2.1, to MODFLOW data. The elevations associated with the finite-difference grid will be adjusted to match the elevations defined by the solid models. Also, the material

assigned to each grid cell will be inherited from the solid that encompasses the cell. Figure 2.2 shows a MODFLOW compatible grid of the cross section shown in Figure 2.1.

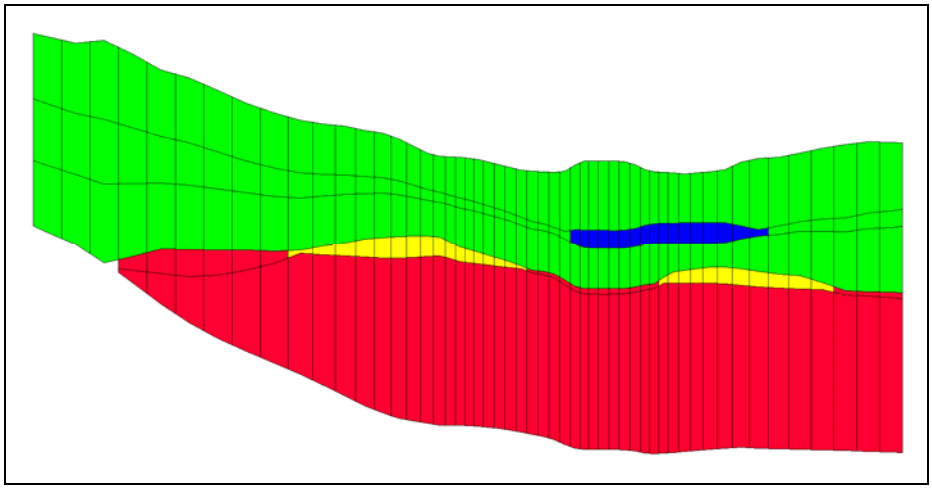

*Figure 2.2 Finite Difference Grid with Elevations and Materials Inherited from Solid Model*

One of the main benefits of using solid models to define stratigraphy for MODFLOW models is that it provides a grid-independent definition of the layer elevations that can be used to immediately re-create the MODFLOW grid geometry after any change to the grid resolution.

Solid models of stratigraphy can easily be created in GMS using the "horizons approach." The tutorial entitled *Stratigraphy Modeling – Horizons and Solids* explains how to create solid models using GMS.

Although not required, it may be useful to complete the *MODFLOW – Conceptual Model Approach* tutorial before doing this tutorial.

## 1.1 Outline

This is what you will do:

1. Open a file containing solids data.
2. Assign grid layers to the solids and convert solids to MODFLOW.
3. Fix problems associated with thin cells.
4. Convert the conceptual model to MODFLOW and run MODFLOW.
5. Convert the solids to HUF data.
6. Convert the conceptual model again and run MODFLOW.

### 1.2 Required Modules/Interfaces

You will need the following components enabled to complete this tutorial:

- Sub-surface characterization
- Grid
- Map

You can see if these components are enabled by selecting the *File* | *Register* menu command.

## 2 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.

## 3 Reading in the Solids

First, we will read in a file containing a set of solids for the site we are modeling.

1. Select the *Open* button  .
2. Locate and open the directory entitled **tutfiles\MODFLOW\sol2mf**.
3. Open the file named **start.gpr**.

You should see cross-sections in the main GMS window that show the stratigraphy for this site.

There are five different solids in this project file. There are two main units labeled upper_aquifer (green) and lower_aquifer (red). Inside of upper_aquifer there are two silty-clay (blue) units, and between upper_aquifer and lower_aquifer there is a clay (yellow) unit.

## 4 Assigning Grid Layers to Solids

The first step in converting solids to MODFLOW data is to assign grid layers to the solids. In this model we will use a five-layer grid.

 

## 4.1 Layer Ranges

Before we can convert the solids to MODFLOW data we must assign a layer range to each of the solids. The layer range represents the consecutive sequence of layer numbers in the MODFLOW grid that are to coincide with the solid model. A sample set of layer range assignments is shown in Figure 4.1(a). The example in Figure 4.1 is a case where each solid is continuous through the model domain and there are no pinchouts. Each of the solids is given a layer range defined by a beginning and ending grid layer number. The resulting MODFLOW grid is shown in Figure 4.1(b).

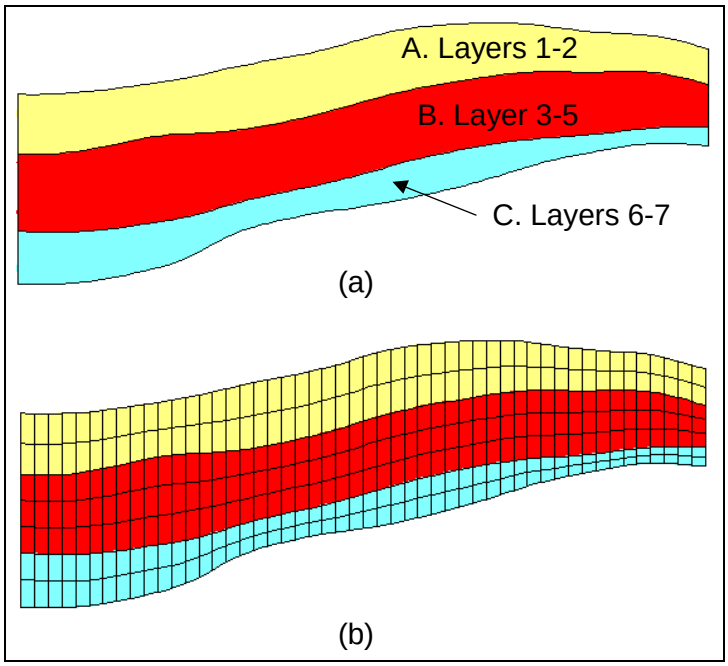


*Figure 4.1 (a) A Set of Simple Solids with Grid Layer Assignments (b) The MODFLOW Grid Resulting From the Layer Assignments.*

A more complex case with pinchouts is illustrated in Figure 4.2(a). Solid A is given the layer range 1-4, and the enclosed pinchout (solid B) is given the layer range 2-2. The set of grid layers within the defined range that are actually overlapped by the model may change from location to location. The layer range represents the set of grid layers potentially overlapped by the solid anywhere in the model domain. For example, on the left side of the problem shown in Figure 4.2(a), solid A covers grid layers 1, 2, 3 and 4. On the right side of the model, solid A is associated with grid layers 1, 3 and 4 since the enclosed solid (solid B) is associated with layer 2. Likewise, Solid C is associated with grid layers 5 and 6 on the left side of the model but only with layer 6 on the right side of the model where solid D is associated with layer 5. The resulting MODFLOW grid is shown in Figure 4.2(b).

 

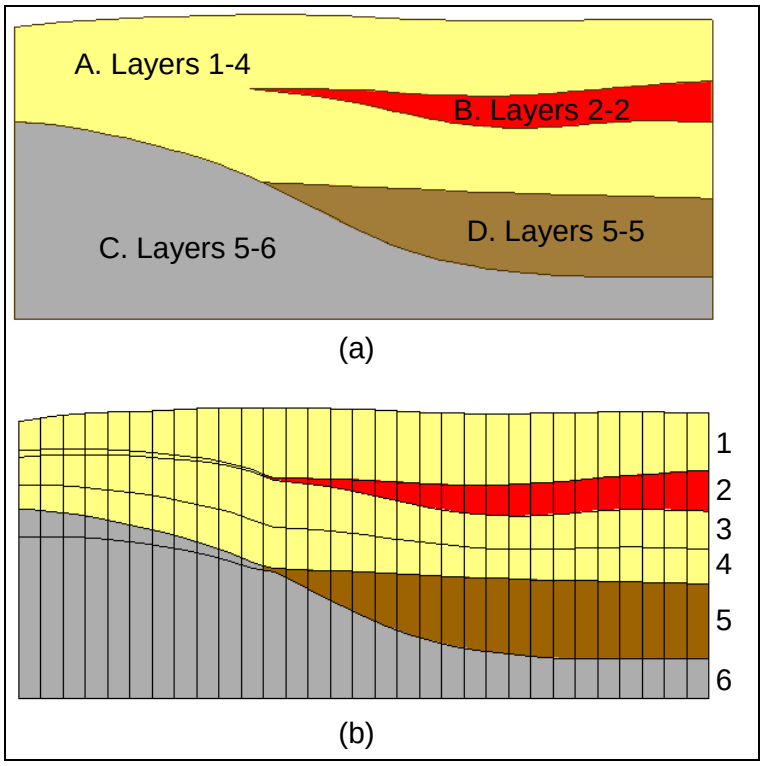


*Figure 4.2 (a) Grid Layer Assignments for a Set of Solids with Pinchouts (b) The MODFLOW Grid Resulting From the Layer Assignments.*

When assigning layer ranges to solids, care must be taken to define associations that are topologically sound. For example, since solid B in Figure 4.2(a) is enclosed by solid A, solid B could not be assigned a layer range that is outside the layer range of solid A.

## 4.2 Assigning Layers to Solids

Now we are ready to assign the grid layers to the solids.

The figure below is a cross section through our site. Notice that we must have a minimum of five grid layers in order to represent all of the layers present in this cross-section. In this case the upper_aquifer (green) will be assigned to layers 1-3. The silty-clay (blue) will be assigned to layer 2. The clay (yellow) will be assigned to layer 4, and the lower_aquifer (red) will be assigned layers 4-5.

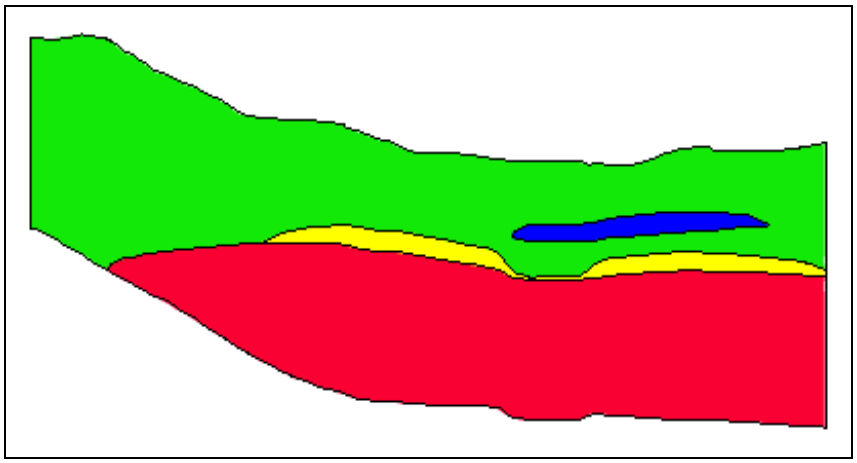

*Figure 4.3 Cross-section through Model Domain*

1. Double click on **upper_aquifer 1** solid in the *Project Explorer*. For the *Begin layer*, enter **1** and for the *End layer*, enter **3**. Click *OK*.

2. Repeat this process on the remaining solids, entering the values shown in the following table.

| | upper_aquifer 1 | lower_aquifer 2 | clay 3 | silty-clay 4 | silty-clay 5 |
|---|---|---|---|---|---|
| *Begin layer* | **1** | **4** | **4** | **2** | **2** |
| *End layer* | **3** | **5** | **4** | **2** | **2** |

# 5 Solids → MODFLOW

We are now ready to convert the solids to MODFLOW data. When the *Solids → MODFLOW* command is executed the grid will inherit the elevations as well as the material from each of the solids.

## 5.1 Displaying the 3D Grid

The grid was read in as part of the project, but the display of the grid cells was turned off. Let's turn on the display of the grid.

1. In the *Project Explorer* turn on the *3D Grid Data* folder.

2. Select the *Ortho Mode* button.

You should now see the 3D grid.

## 5.2 Initializing MODFLOW

We must initialize MODFLOW before we can execute the *Solids → MODFLOW* menu command.

 

1. In the *Project Explorer* right-click on the *3D Grid Data* folder and select the *New MODFLOW* command.

Now we will also set up the starting heads for MODFLOW. We will assign a constant value as the starting head.

2. Select the *Starting Heads* button.
3. Select the *Constant* → *Grid* button.
4. Enter a value of **250.0** and select *OK* to exit the dialog.
5. Select *OK* twice to exit both dialogs.

### 5.3 Activating Cells

We need to inactivate the cells outside our model domain.

1. In the *Project Explorer* select the *Map Data* folder.
2. Select the *Feature Objects* | *Activate Cells in Coverage(s)* menu command.

### 5.4 Solids→MODFLOW

1. In the *Project Explorer* select the *Solid Data* folder.
2. Select the *Solids* | *Solids* → *MODFLOW* menu command.
3. Make sure that the *Boundary Matching* option is selected and select *OK* to execute the *Solids* → *MODFLOW* menu command.

The *Solids* → *MODFLOW* command may take less than a minute to a few minutes to complete depending on the speed of your computer.

## 6 Viewing the Grid

Now, we will see how our grid has changed. First, we will hide the solid cross sections so that the display is not so cluttered.

1. Select the *Select Cross Section* tool.
2. Select the *Edit* | *Select All* menu command.
3. Select the *Hide* button.
4. In the *Project Explorer* select the *3D Grid Data* folder.
5. Select the *Display Options* button.

6. Turn on the *Cell faces* option and select **Material** for the *Color*.

7. Select *OK* to exit the dialog.

The cells on the 3D grid should now be colored according to the material assigned to the grid cells. Layer 1 of the grid is all green because all of the cells were assigned the material from the upper_aquifer solid.

8. In the mini-grid display, select the down arrow ⬇ to view the second layer.

Notice that the second layer has both silty-clay (blue) and upper_aquifer (green) materials assigned to it. Cycle through the other layers to see how the materials were assigned.

9. Select the *Select Cells* tool  .

10. Select a cell somewhere near the middle of the grid.

11. Select the *Front View* button  .

12. Use the arrow buttons ↙ ↗ to view the grid along different rows.

13. Select the *Side View* button  .

14. Use the arrow buttons ⬅ ➡ in the *Mini-Grid Display* to view the grid along different columns.

# 7 Thin Cells

The purpose of the *Boundary Matching* option for the *Solids → MODFLOW* command is to ensure that each upper and lower boundary defined by the solid model is precisely matched by a layer boundary in the MODFLOW grid. As a result of this approach thin cells often occur where solids pinchout. If you want to limit the effect of the thin cells in your model grid you can set a target minimum thickness for each of the solids.

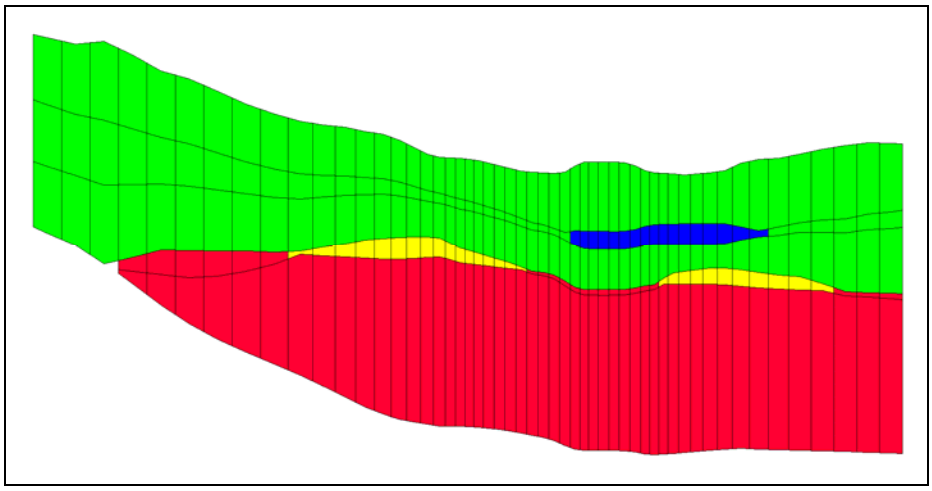

*Figure 7.1 Row 30 of Model Grid After Executing Solids → MODFLOW*

Figure 7.1 shows a row of the model grid after running *Solids → MODFLOW*. Notice the thin cells that you get on the edges of the clay (yellow) and silty-clay (blue) solids.

1. Select the *Front View* button .
2. Use the arrow buttons ↙ ↗ to move the current grid row to **30**.

The grid should look similar to Figure 7.1.

## 7.1 Assigning Minimum Thickness

Now we will use the *Target minimum thickness* to limit the thin cells in our model.

1. Double click on the **upper aquifer 1** solid in the *Project Explorer*.
2. Change the *Target min. cell thickness* to **20** and select *OK* to exit the dialog.
3. Repeat these steps for all of the remaining solids.

## 7.2 Top Cell Bias

Another problem that may be encountered using the *Boundary Matching* option is that the cells in the top layer of the grid may also be too thin and subject to wetting and drying. To ensure that the top layer of your grid is sufficiently thick you can use the *Top cell bias* option.

1. Double-click on the **upper_aquifer 1** solid in the *Project Explorer*.
2. Change the option next to *Use top cell bias* to **Yes** and select *OK* to exit the dialog.
3. Select the *Solids* | *Solids → MODFLOW* menu command.

 

4. Select *OK* to execute the *Solids* → *MODFLOW* menu command.

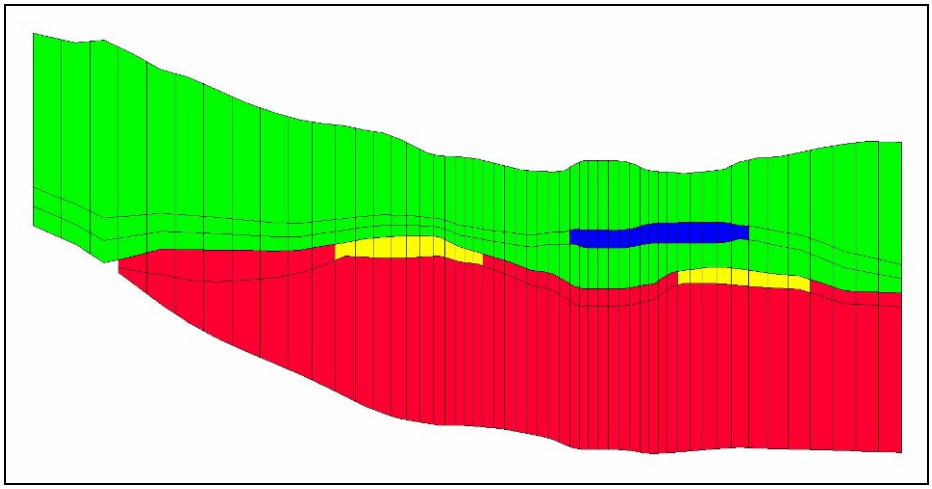

*Figure 7.2 Row 30 of Model Grid Using Target Minimum Thickness and Top Cell Bias*

Your grid should now look similar to Figure 7.2.

# 8 Converting the Conceptual Model

We are now ready to convert our conceptual model and run MODFLOW. In the interest of time, the conceptual model has already been built and was read in when we read in the project file. For more information on conceptual models, refer to the *MODFLOW – Conceptual Model Approach* tutorial.

1. In the *Project Explorer* select the *Map Data* folder .
2. Select the *Plan View* button .
3. Select the *Feature Objects* | *Map* → *MODFLOW* menu command.
4. Ensure the *All applicable coverages* option is selected and select *OK*.

## 8.1 Using Materials to Define Hydraulic conductivity

Now we need to set the option for MODFLOW to use the material assigned to the grid cell to define the hydraulic conductivity for the cell.

1. In the *Project Explorer* select the *3D Grid Data* folder .
2. Select the *MODFLOW* | *LPF Package* menu command.
3. Select the *Use Material IDs* option in the *Layer property entry method* section of the dialog.

 

4. Select the *Material Properties* button in the *Layer data* section of the dialog.

5. Select each material in the list and enter the values for the properties shown in the table below.

| | Horizontal k | Horizontal anisotropy | Vertical anisotropy (Kh / Kv) |
|---|---|---|---|
| *upper_aqufier* | **15.0** | **1.0** | **3.0** |
| *lower_aquifer* | **30.0** | **1.0** | **3.0** |
| *clay* | **0.5** | **1.0** | **3.0** |
| *silty-clay* | **1.0** | **1.0** | **3.0** |

6. Select *OK* twice to exit both dialogs.

## 9 Running MODFLOW

We are now ready to run MODFLOW. First, we must save our MODFLOW simulation.

1. Select the *File* | *Save As* menu command.

2. Save the project with the name **run1_lpf.gpr**.

3. Select the *MODFLOW* | *Run MODFLOW* menu command.

4. When MODFLOW has finished running, select the *Close* button. The MODFLOW solution will automatically be read in.

5. Select the *Display Options* button  .

6. Turn off the *Cell faces* option and select *OK* to exit the dialog.

You should now see the head contours on the grid. Cycle through the layers to see how the head contours change within the different layers. You can also switch into side view to see the contours on the rows or columns.

## 10 Solids → HUF

Now we will use the HUF package in MODFLOW instead of the LPF package to define the hydraulic properties of the grid cells. The Hydrogeologic Unit Flow (HUF) package is new in MODFLOW 2000. This package is designed to represent complex stratigraphic relationships in a grid independent fashion.

The hydro-stratigraphy is represented using a set of hydrogeologic units. Each unit is defined by two arrays, one for the top elevation and one for the thickness. The thickness values can be set to zero in regions of the model where the unit is not present. When MODFLOW is executed, each cell is compared to the corresponding unit elevation arrays and equivalent hydraulic properties are assigned to the cell. The figure below shows an example of HUF units on a MODFLOW grid.

 

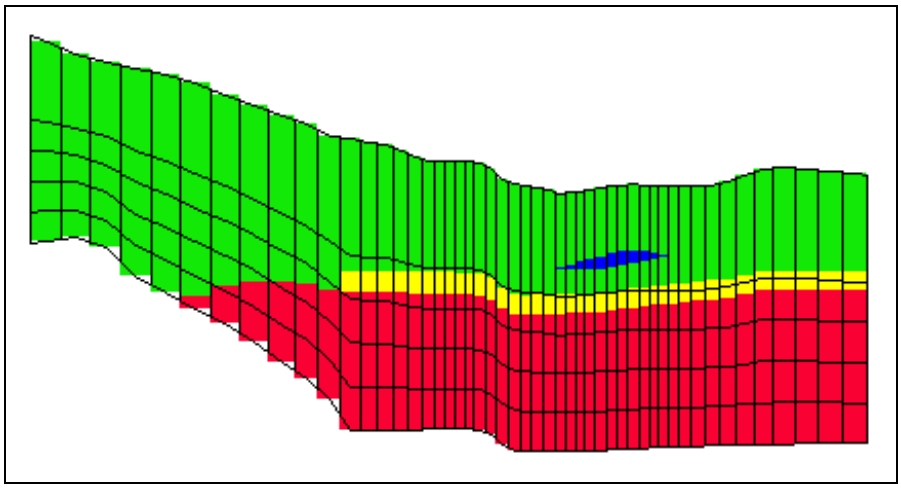

*Figure 10.1 HUF Data*

## 10.1 Selecting the HUF Package

First, we need to select the HUF package as our flow package.

1. Select the *MODFLOW* | *Global Options* menu command.
2. Select the *Packages* button.
3. In the *Flow Package* section of the MODFLOW Packages dialog change the flow package to **Hydrogeologic Unit Flow (HUF)**.
4. Select *OK* twice to exit both dialogs.

## 10.2 Converting the Solids to HUF Data

We are now ready to convert the solids to HUF data. However, when we ran the *Solids* → *MODFLOW* command some of the cells were inactivated in layers 4 and 5. We want those cells to be active for this new model.

1. In the *Project Explorer* select the *Map Data* folder .
2. Select the *Feature Objects* | *Activate Cells in Coverage(s)* menu command.
3. In the *Project Explorer* select the *Solid Data* folder .
4. Select the *Solids* | *Solids* → *HUF* menu command.
5. Turn on the *Adjust grid cell elevations* toggle.

   This toggle results in the grid elevations matching the topology of the solids. The MODFLOW top elevation array of the top layer and the bottom elevation array of the bottom layer are adjusted to match the union of all the solids. The interior top

 

and bottom elevation arrays are assigned based on the proportions entered in the *Elevation bias* spreadsheet. The entire grid depth for each grid column is distributed according to the entries in the spreadsheet for each layer.

1. In the *Elevation bias* spreadsheet, change the value for layer 1 to **0.4**.
2. Select *OK* to execute the *Solids* → *HUF* menu command.

## 10.3 Viewing the HUF Data

To view the HUF data:

1. In the *Project Explorer* select the *3D Grid Data* folder.
2. Select the *Display Options* button.
3. Switch to the *MODFLOW* tab.
4. Turn on the *Display hydrogeologic units* toggle.
5. Select *OK* to exit the dialog.
6. Select the *Select Cells* tool.
7. Select a cell somewhere near the middle of the grid.
8. Select the *Front View* button.
9. Use the arrow buttons ↙ ↗ to view the grid along different rows.

## 10.4 Converting the Conceptual Model

We need to convert the conceptual model again to ensure that any cells that were inactive will have the correct boundary conditions.

1. In the *Project Explorer* select the *Map Data* folder.
2. Switch to plan view by selecting the *Plan View* button.
3. In the *Project Explorer* right-click on the *MODFLOW* conceptual model and select *Properties* from the menu.
4. Change the flow package to HUF and select *OK* to exit the dialog.
5. Select the *Feature Objects* | *Map* → *MODFLOW* menu command.
6. Ensure the *All applicable coverages* option is selected and select *OK*.

### 10.5 Running MODFLOW

We're now ready to save the project and run MODFLOW.

1. In the *Project Explorer* select the *3D Grid Data* folder  .
2. Select the *File* | *Save As* menu command.
3. Save the project with the name **run1_huf**.
4. Select the *MODFLOW* | *Run MODFLOW* menu command.
5. When MODFLOW has finished running, select the *Close* button. The MODFLOW solution will automatically be read in.

You should now see the head contours on the grid. You may see some red triangles on certain grid cells. These cells have gone dry (the water table is below the bottom of the cell) in this simulation. Cycle through the layers to see how the head contours change within the different layers. You can also switch into side view to see the contours on the rows or columns.

## 11 Conclusion

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

- Solids can be used to define the MODFLOW layer elevations. They can also be used to create MODFLOW HUF data.
- You must assign layer ranges to the solids before using them to create a layered grid.
- You can use a minimum thickness to avoid thin cells. You can also specify a top cell bias to make the top grid layer thicker.
- If you are using solids to define your MODFLOW layer data, you probably want to use the Material IDs approach to define the hydraulic properties of grid cells based on their material.