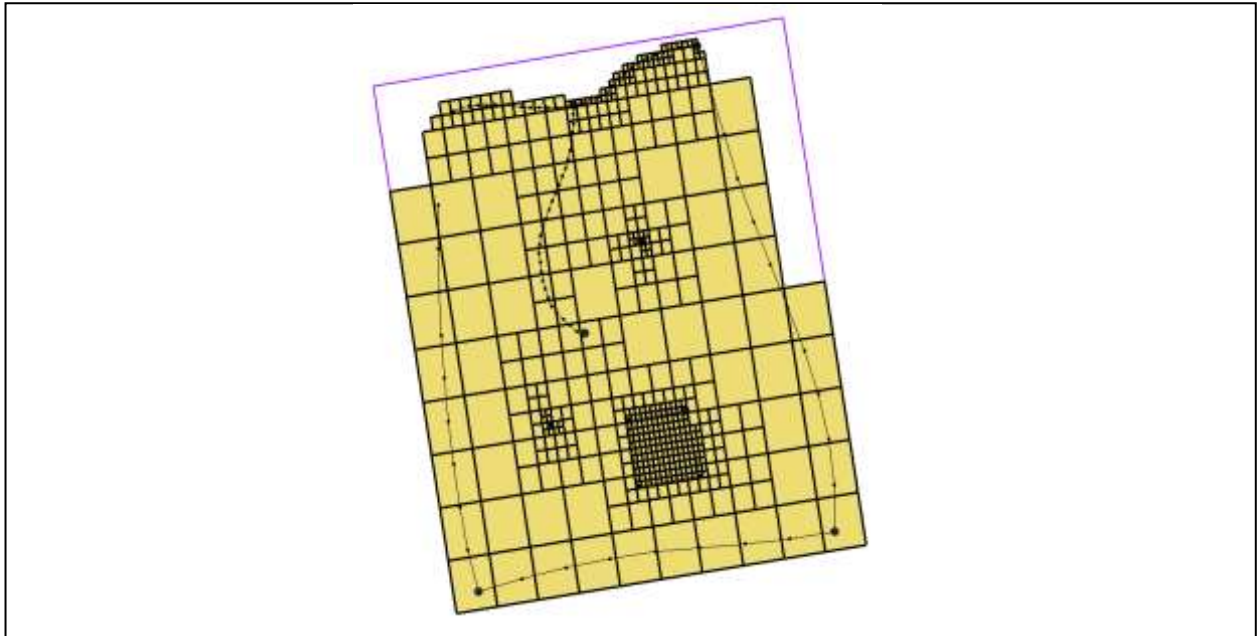


GMS 10.0 Tutorial **UGrid Creation**

Creating unstructured grids (UGrids) in GMS.



Objectives

Learn about unstructured grids, or UGrids, and several methods for creating them in GMS.

Prerequisite Tutorials

- Getting Started

Required Components

- UGrid Module

Time

- 15–30 minutes



1	Introduction	2
1.1	Outline.....	2
2	Getting Started	3
3	Importing	3
3.1	Importing a 3D UGrid.....	3
3.2	Cell Faces.....	4
3.3	Importing a 2D UGrid.....	5
4	New UGrid Commands	6
4.1	3D.....	6
4.2	2D.....	7
4.3	Using a Grid Frame.....	8
5	Conversion from Other Object Types	10
5.1	From 3D Grid.....	10
5.2	From a Shapefile.....	11
6	Map → UGrid	12
6.1	Map → UGrid Dialog.....	13
6.2	Regular (not refined).....	14
6.3	Quadtree: All Layers the Same.....	15
6.4	Refinement Attributes.....	16
6.5	Quadtree/Octree.....	17
6.6	Quadtree on Assigned Layers.....	18
6.7	Voronoi.....	18
6.8	Refining the Polygon Arc.....	19
7	Horizons → UGrid	20
7.1	View the 3D Quadtree UGrid.....	21
8	Conclusion	22

1 Introduction

The newest module in GMS is the UGrid module. “UGrid” is short for “unstructured grid.” A UGrid is similar to the old 3D grids and meshes available in GMS but much more flexible. UGrids can use any type of cell, meaning cells with any number of faces and nodes. This flexibility allows for more realistic modeling of geologic features such as pinchouts. UGrids were added to GMS in order to support MODFLOW-USG which uses the finite volume method.

There are several ways to create UGrids in GMS, as this tutorial demonstrates. The user will start with the simplest methods and move to the more complex.

1.1 Outline

Here are the steps to this tutorial:

1. Import two UGrids.
2. Use the **New UGrid** commands to create UGrids.
3. Create UGrids by converting other data types to UGrids.
4. Create UGrids using the **Map → UGrid** command.

5. Create a UGrid using the **Horizons** → **UGrid** command.

2 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.

3 Importing

The simplest way to get a UGrid into GMS is to import one that has already been created. GMS recognizes the VTK unstructured grid file format.

3.1 Importing a 3D UGrid

The user will import a 3D UGrid that has already been created and saved in a file.

1. Select the **Open**  button.
2. Locate and open the directory entitled *Tutorials\MODFLOW-USG\UGridCreation*.
3. Change the *Files of type* to “All Files (*.*)”
4. Select the file named “ugrid.vtu.”
5. Click **Open**.

A UGrid should appear.

6. Select the **Oblique View**  button.

The user should see a wireframe depiction of the UGrid like that shown in Figure 1.

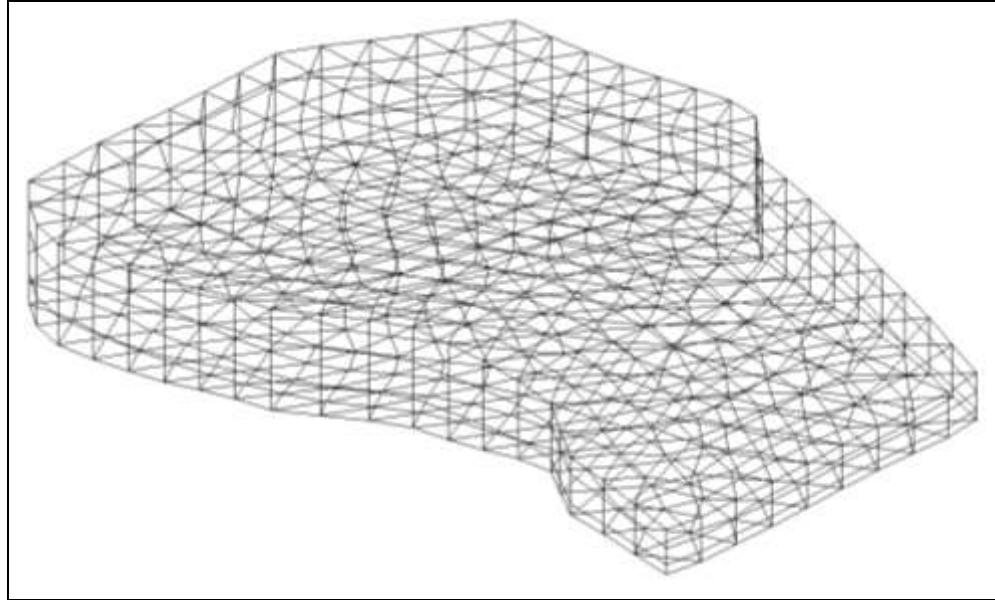




Figure 1 Imported UGrid

3.2 Cell Faces

The user will now look at some of the UGrid display options.


1. Click the **Display Options**  button.
2. Turn on *Cell faces*.
3. Click **OK**.

The user should see the cell faces with different colors for different layers. The colors come from the materials assigned to the cells.

4. Use the  rotate tool and click and drag on the *Graphics Window* to view the UGrid from different angles.

On examination, the user can see that this UGrid is composed of prismatic, wedge elements. It has an irregular boundary, and it appears to be made of three layers. Remember, however, that a UGrid is unstructured and need not have continuous layers, or any layers at all.

The cells of this grid are 3D cells. Now look at the *UGrid Properties* dialog:

5. In the Project Explorer, right-click on the “ugrid” .
6. Select the **Properties** command to open the *UGrid Properties* dialog.

Notice the number of 2D and 3D cells. This UGrid is composed of only 3D cells.

7. Click **Done**.

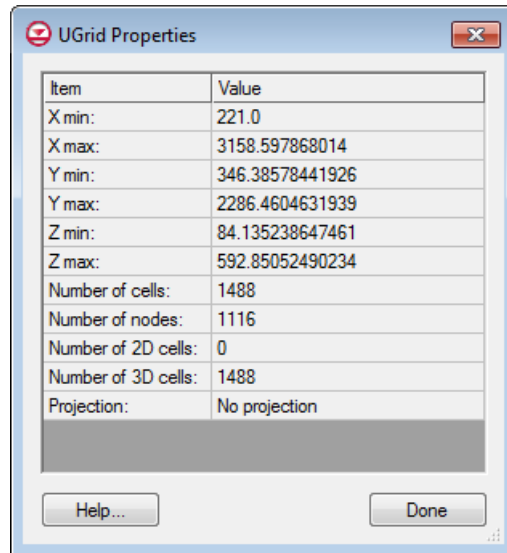




Figure 2 UGrid Properties dialog

3.3 Importing a 2D UGrid

Now take a look at another example of an imported UGrid.

1. Select the **New**  button to start a new project.
2. If asked to save, click **No**.
3. Select the **Open**  button.
4. Select the file named "cow.vtu."
5. Click **Open**.

A UGrid should appear showing a wireframe cow. This type of unstructured grid is not very useful for groundwater modeling, but it illustrates the flexibility of the UGrid module in GMS.

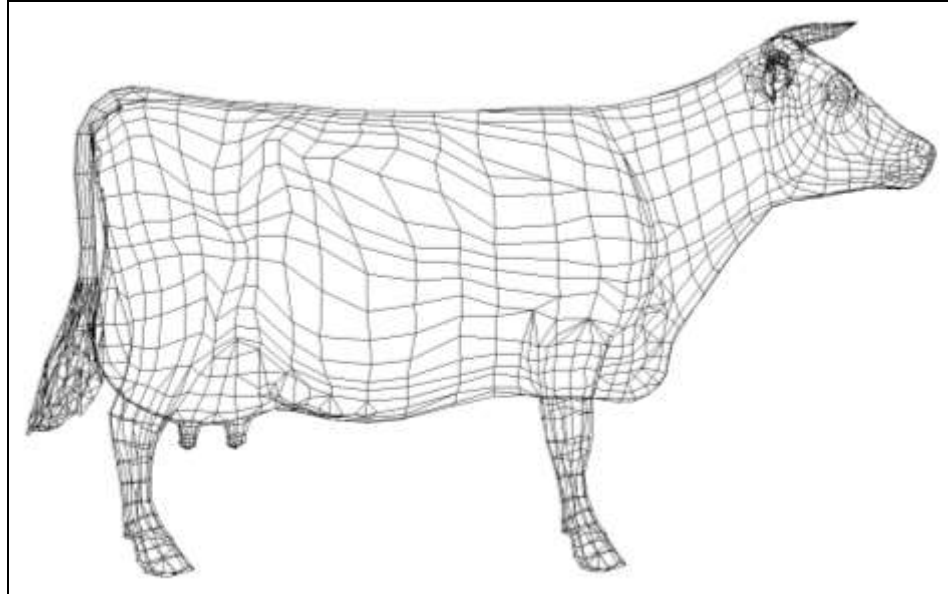




Figure 3 Imported cow unstructured grid

6. Use the  rotate tool and click and drag on the *Graphics Window* to view the UGrid from different angles.
7. In the Project Explorer, right-click on the “cow”  UGrid.
8. Select the **Properties** command to open the *UGrid Properties* dialog.


Again notice the number of 2D and 3D cells. This UGrid is a hollow shell composed of 2D cells. Although this UGrid is not particularly useful for groundwater modeling, 2D UGrids are used in GMS as projection grids to create 3D UGrids, as the user will see later on.

9. Click the **Done** button to exit the dialog.

4 New UGrid Commands

Besides importing, another easy way to create a UGrid in GMS is using the **New UGrid 2D** or **New UGrid 3D** commands. These commands and their associated dialogs work almost identical to the old **New 2D Grid** and **New 3D Grid** commands that are used to create structured grids. Now the user will see how these commands work.

4.1 3D

1. Select the **New**  button to start a new project.
2. If asked to save, click **No**.
3. Right-click in either the Project Explorer or the Graphics Window.

4. Select the **New → UGrid 3D** command.

This opens the *New UGrid* dialog. This dialog is almost identical to the dialog used to create structured 3D grids, so if the user is familiar with that dialog, this will be nothing new.

This dialog allows users to specify the origin and length of the grid and the number of cells in X, Y and Z dimensions. Alternatively users can specify the cell sizes and even define a bias causing cell sizes to increase or decrease from one side of the grid to the other (although this tutorial will look at a better way to do cell biasing later).

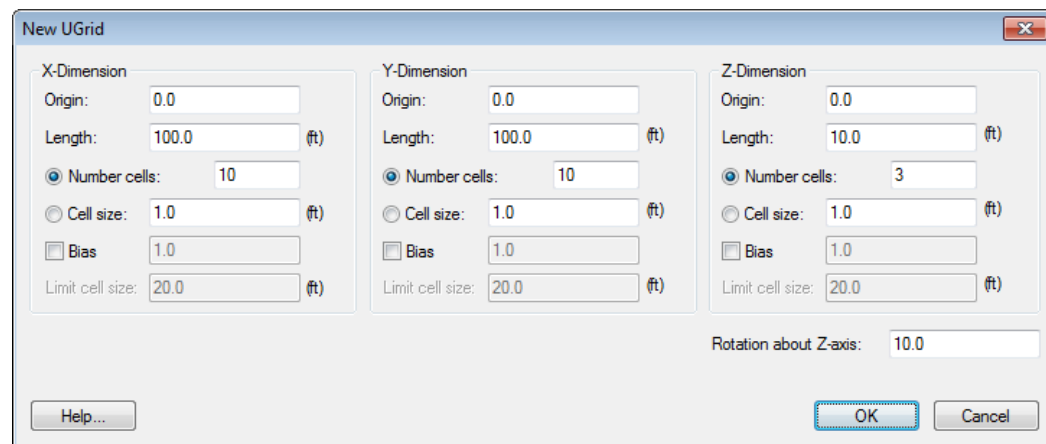



Figure 4 New UGrid dialog

5. Change the *Rotation about Z-axis* to “10.”
6. Click **OK** to accept the default values.
7. Select the **Oblique View**  button.

The user should see a 3D UGrid like the one depicted in Figure 5. Notice that the cells are all hexahedrons (6 sided). The **New UGrid** commands always create UGrids with hexahedron cells in 3D, and quadrilateral cells in 2D. The user will find out how to create more exotic cell types later.

4.2 2D

The **New UGrid 2D** command works the same but creates a UGrid with only 2D cells. The dialog is the same except that the options to specify cells in the Z dimension are not available. Feel free to experiment with the **New UGrid 2D** command.

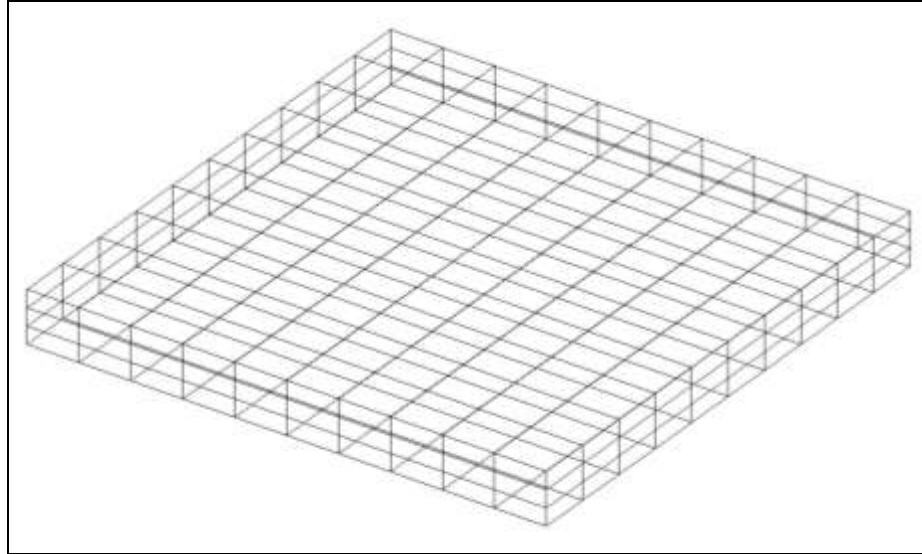




Figure 5 3D UGrid created using the New UGrid dialog

4.3 Using a Grid Frame

Although using the *New UGrid* dialog is a quick and easy way to create a UGrid, it forces users to specify, and therefore to know, the origin and lengths of the grid in each dimension. If the user wants to create a grid that surrounds existing data, an easier way is to create a Grid Frame. This allows users to orient the grid graphically before using the **New UGrid** command.

1. Select the **New**  button to start a new project.
2. If asked to save, click **No**.
3. Select the **Open**  button.
4. Select the file named “biscayne.gpr.”
5. Click **Open**.

The user should see a conceptual model including well points and arcs representing rivers and canals.


6. Right-click in either the Project Explorer or the Graphics Window and select the **New → Grid Frame** command.

A grid frame appears. Now it is necessary to fit it around the data.

7. Right-click on the  Grid Frame in the Project Explorer.
8. Select the **Fit To Active Coverage** command.

Moving and Resizing the Grid Frame

Although the **Fit To Active Coverage** command is convenient, the user might want to rotate the grid frame or resize it to better fit the data.

1. With the **Select Grid Frame**  tool, rotate, resize, and reposition the grid frame to more or less match the image shown in Figure 6.
 - Drag the corners or sides of the grid frame to resize it.
 - Click anywhere inside the grid frame, or on an edge but not on an anchor point to drag and move the entire grid frame.
 - Click on the circle in the lower right corner to rotate the grid frame.

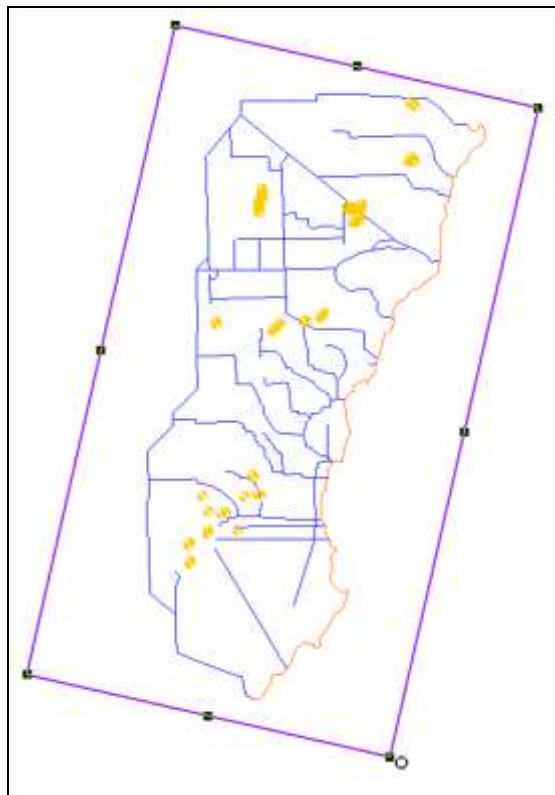


Figure 6 Grid frame surrounding a conceptual model

2. When finished positioning the grid frame, right-click in the window.
3. Select the *New* | **UGrid 3D** command.

Notice that the origin, lengths, and rotation are defaulted to values that come from the grid frame.

4. Click **OK**.

The UGrid gets created inside the boundary of the grid frame. The user would probably want to create more cells if this were a real model but it's not necessary to worry about that now.

5. Uncheck the “ugrid”  UGrid to hide the item.

5 Conversion from Other Object Types




UGrids can be created from several other types of objects in GMS. The objects that can be converted to UGrids are:

- TINs
- 2D Grids
- 3D Grids
- 2D Mesh
- 3D Mesh
- Polygons in a coverage
- Polygon shape files in the GIS Module




This tutorial will look at just two examples.

5.1 From 3D Grid

The current project includes a 3D Grid that is turned off. The user will convert it to a UGrid.

1. Turn on the “grid”  item under “3D Grid Data”  folder.
2. Right-click on the “grid”  item.
3. Select *Convert To | UGrid*.
4. Select **Yes** at the prompt to only convert active cells used by MODFLOW.



There are inactive cells in the 3D grid that the user can't see because they are set to 0 in the MODFLOW IBOUND array. By selecting yes, the user is telling GMS not to include those cells in the UGrid.

5. Turn off the “grid”  so that the UGrid is visible.
6. Click the **Display Options**  button.
7. Select “UGrid Data”  from the list on the left.
8. Turn on *Cell faces*.
9. Click **OK**.

The UGrid should now look just like the 3D Grid it came from.

5.2 From a Shapefile

The user will look at one more example of creating a UGrid by conversion from some other data type, this time from a shapefile. There is one included in the project that is turned off.

1. Turn off the “UGrid Data”  folder.
2. Turn on the “GIS Layers”  folder.

The user should see a shapefile in the form of a quadtree grid as shown in Figure 7. Quadtree UGrids can be created in GMS as the user will see later. But if the user has a way to create quadtree shapefiles outside of GMS, this shows how to convert them to UGrids.

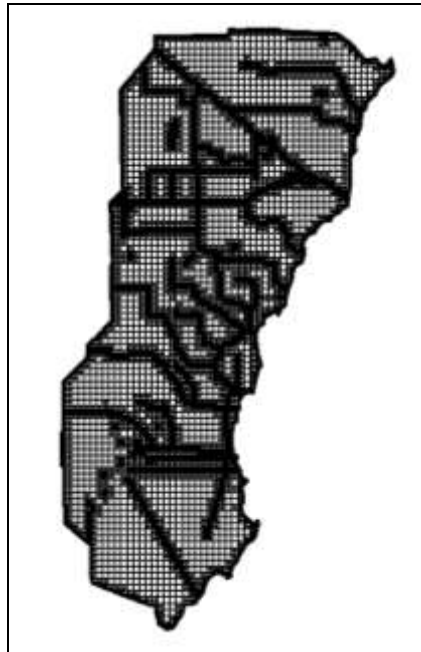






Figure 7 Shapefile showing a quadtree grid

3. Using the mouse wheel or the **Zoom**  tool, zoom in on the shapefile to see the quadtree refinement better.
4. When done examining the grid refinement, use the **Frame**  tool on the image.
5. Expand the “GIS Layers” folder.
6. Right-click on the “biscayne.shp”  shapefile.
7. Select *Convert To / UGrid*.




This creates a new UGrid with cells that match the shapefile polygons.

8. Turn off the shapefile .

At this point, the user may wish to zoom in to see that the quadtree refinement matches the shapefile.

Extrude 2D UGrid to 3D UGrid



Now the UGrid consists of 2D cells. If the user wants to create a MODFLOW model with the grid, the user needs a 3D UGrid. The user can extrude the 2D UGrid into a 3D UGrid.

9. Select the **Oblique View**  button.
10. Zoom in on some edge of the grid to see that the cells have no depth.
11. Right-click on the “biscayne.shp”  UGrid.
12. Select **Extrude Down to 3D UGrid**.
13. Select the **Insert Row**  button.
14. Change the value to “100.”
15. Click **OK**.

The user should now see that the new UGrid is 3D and therefore has depth.

6 Map → UGrid

The next way to create UGrids is by using the **Map → UGrid** command. This command is more powerful than the methods seen so far because it lets users create quadtree, octree, and voronoi UGrids using a conceptual model. The UGrid boundaries can be made to match the conceptual model boundaries.

1. Select the **New**  button to start a new project.
2. If asked to save, click **No**.
3. Select the **Open**  button.
4. Click on the file called “mapToUGrid.gpr.”
5. Click **Open**.

This opens a project containing a grid frame and conceptual model with two coverages as shown in Figure 9.

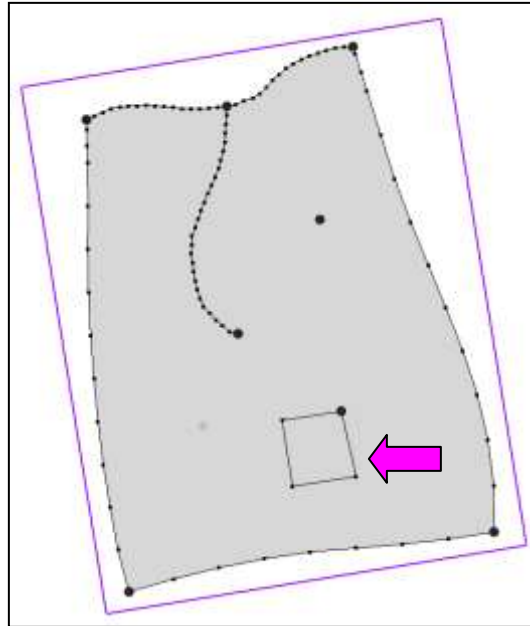



Figure 8 Area of greater refinement marked

The conceptual model represents an area of interest where the user wants to create a groundwater model. The top arc will be a constant head boundary and the other boundary arcs will be no flow boundaries. The arc in the middle represents a stream. There are two well points, one in a separate coverage. There is also a rectangular area in the lower part of the model where the user will desire greater refinement.

6.1 Map → UGrid Dialog

The user will now run the **Map → UGrid** command and look at the options.

1. Select the **Map → UGrid**  button (the same command can also be found in the *Feature Objects* menu or by right-clicking on a coverage in the *Project Explorer*).

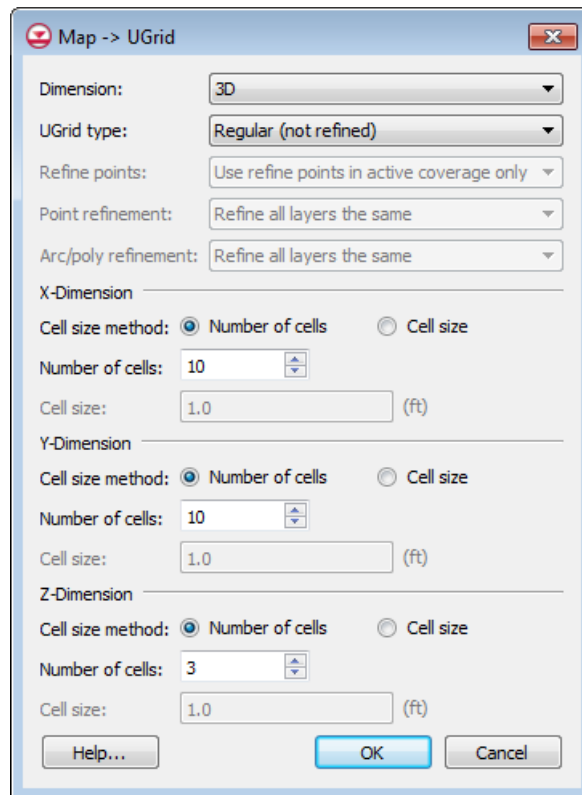


Figure 9 Map → UGrid dialog

The *Map* → *UGrid* dialog will appear. The first option is *Dimension* which is either 2D or 3D. The next option is *UGrid type* which has three choices: “Regular (not refined),” “Quadtree/Octree,” and “Voronoi.” The best way to explain these is simply to create them and look at them. Before doing that, notice that the grid will have 10 cells in the X and Y dimensions and 3 cells in the Z dimension. GMS uses the grid frame to determine the size of the grid and the number of cells to determine the cell size. The user can either specify the number of cells like this, or the user can specify the cell size and let GMS determine how many cells will fit in each dimension. In that case, the cell size specification is only a target size because the size will almost always need to be adjusted so that the user doesn’t get partial cells along the edges.

6.2 Regular (not refined)

1. Accept the default options as shown in **Error! Reference source not found.**
2. Click **OK**.




Notice the rectangular cells. This is what is meant by the “Regular (not refined)” option. Also notice that the cells outside the outer polygon boundary are not included in the UGrid. They are not inactive—they simply don’t exist.

3. Select the **Oblique View**  button.

The user can see that the UGrid is 3D with three layers, and its dimensions fit the grid frame. The user can also see there are 10 cells in the X and Y dimensions.

6.3 Quadtree: All Layers the Same

Now the user will see what the Quadtree option produces.

1. Select the **Plan View**  button.
2. Turn off the “ugrid”  that was just created.
3. Select the **Map → UGrid**  button to open the *Map → UGrid* dialog.
4. Change *Ugrid type* to “Quadtree/Octree.”
5. The dialog options should match those shown in Figure 10.
6. Click **OK**.

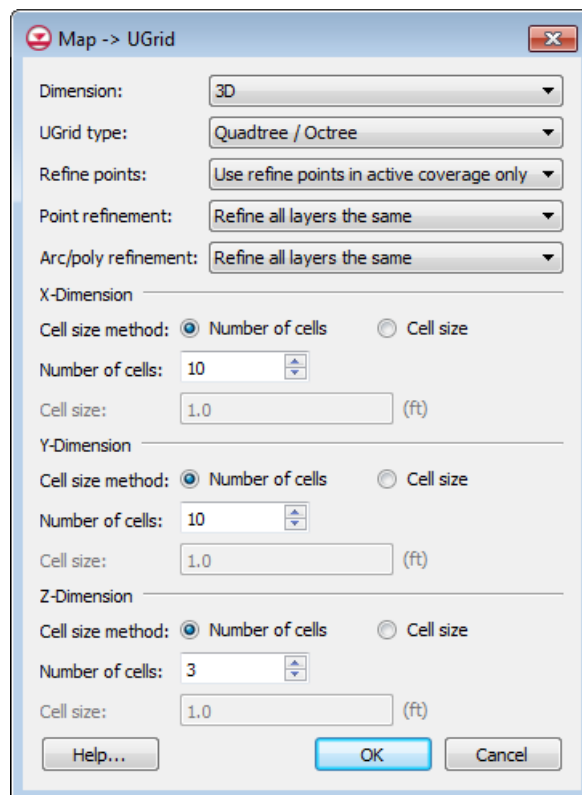


Figure 10 *Map → UGrid* dialog showing Quadtree options

Notice that the grid has been refined in a quadtree fashion around the arcs, points, and polygons. With a quadtree grid, each cell has, at most, two neighboring cells to the side. The largest cells are the same size as in the regular grid. This means that the number of cells the user specifies in the *Map → UGrid* dialog for the X, Y and Z dimensions refers

to the unrefined number of cells or the number of cells that would exist if there was no refinement.

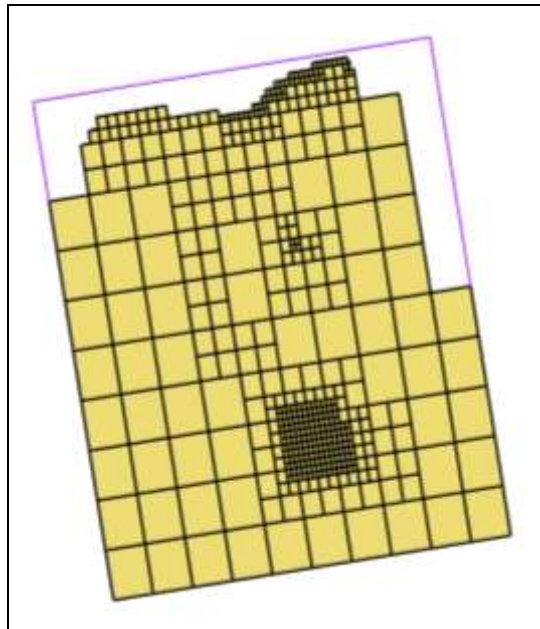


Figure 11 Quadtree UGrid




7. Turn on the *Single layer* option in the toolbars and change the layer to “2,” then “3.”




The *Single layer* option allows the user to see one layer of the UGrid at a time. The user will see that all layers are refined the same. This tutorial will now cover how to define the refinement in the conceptual model.

6.4 Refinement Attributes

Refinement is specified as attributes on feature objects in the conceptual model.

1. Turn off the “ugrid”  that was just created.
2. Click on the “Map Data”  folder to switch the dynamic tools to the Map module.
3. Change to the **Select Arc**  tool.
4. Double-click one of the arcs along the top of the coverage.

This brings up the *Attribute Table* dialog. Notice that the *Refine* attribute is on and the *Base size* is set to 100 or 200 ft (depending on which arc the user clicked on). UGrid cells along this arc will therefore be about 100 (or 200) ft in size.

5. Click **Cancel**.
6. Switch to the **Select**  tool.
7. Double-click on the well point in the upper right area.


This opens the *Attribute Table* dialog. Notice that the *Refine* attribute is on and the *Base size* is set to 75 ft. The UGrid cell at this location will therefore be 75 ft in size. The *Bias* and *Max size* options are ignored when creating quadtree UGrids. These options are only used when creating structured 3D grids.

8. Click **Cancel**.
9. Double-click on the rectangular polygon in the lower area.

This opens the *Attribute Table* dialog. Refinement is on and set at 100 ft. All cells in this area of the UGrid will be about 100 ft in size.

10. Click **Cancel** to close the dialog.
11. Double-click somewhere in the main polygonal area.

This opens the *Attribute Table* dialog. Notice the refinement is off. Thus cells in this area will be allowed to grow to the maximum allowed size.



12. Click **Cancel** to close the dialog.
13. Expand the “Map Data” folder and the “Modflow” item.
14. Double-click on the “M1”  coverage in the Project Explorer.

In the *Coverage Setup* dialog, notice the *Refinement* attribute is on in the list of *Sources/Sinks/BCs*. This must be on in order for the *Refine* attribute that just showed up for points, arcs, and polygons.

15. Click **Cancel** to close the dialog.

6.5 Quadtree/Octree

Now the user will see what the *Octree* option for points does.



1. Select the **Map**  **UGrid**  button.
2. Change the *Point refinement* option to “Octree.”
3. Click **OK**.
4. Use the *Single layer* toolbar to view layers 2 and 3.

Notice that each layer is different now and that layer 3, where the point is located, is the most highly refined. The octree option thus refines vertically as well as horizontally. Every cell has at most two neighboring cells to the side, and four neighboring cells above or below. This option does not subdivide the layers into smaller cells. There are still only three layers of cells throughout the UGrid.

The octree option is also available for arcs and polygons and works similarly.

6.6 Quadtree on Assigned Layers

Now the user will look at the *Quadtree on assigned layers* option.



1. Turn off the “ugrid”  that was just created.
2. Select the **Map** → **UGrid**  button.
3. Change the *Arc/poly refinement* option to “Quadtree on assigned layers.”
4. Click **OK**.
5. Use the *Single layer* toolbar to view layers 2 and 3.

Notice that quadtree refinement around arcs and polygons only occurs in layer 1. The *Quadtree on assigned layers* option only refines cells in the layer that the arcs or polygons are assigned to. The arcs and polygons are all assigned to layer 1 by using the *Layer range* attribute in the *Coverage Setup* dialog and, for each arc or polygon, by specifying 1 in the *From layer* and *To layer* attributes. The transition from layer 1 to layer 2 is therefore more abrupt and not smoothed like it would be if using the *Octree* option. Thus the *Quadtree on assigned layers* option results in fewer cells which will decrease the time required to get a solution at the tradeoff of computational accuracy. If groundwater flow is primarily horizontal, this might be a good tradeoff.

For more practice creating quadtree UGrids, there is another tutorial that includes quadtree creation called “MODFLOW-USG – Quadtree.”

6.7 Voronoi

The last option the user will look at in the *Map* → *UGrid* dialog is the Voronoi option.

1. Turn off the “ugrid”  that was created.
2. Select the **Map** → **UGrid**  button.
3. Change the *UGrid type* to “Voronoi.”

Notice that almost all the other options become unavailable. This is because Voronoi UGrids are very different than the other types the user has seen so far. The user cannot specify the number of cells in the X and Y dimension with Voronoi UGrids. The cells

are created with a meshing and triangulation algorithm that depends solely on the geometry of the points, arcs, and polygons in the active coverage.

4. Click **OK**.

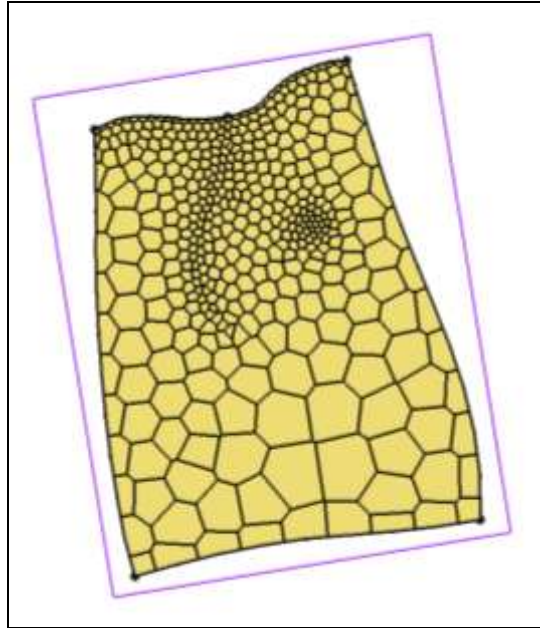




Figure 12 Voronoi UGrid

A Voronoi UGrid has a very different type of cell. The cells are designed such that the boundary conditions are located at the cell center and the faces between adjacent cells are perpendicular to a line connecting the cell centers. This increases computational accuracy when using the finite volume method.

With Voronoi grids, the refinement attributes on the feature objects are ignored and only the geometry of the feature objects matters. This means that in order to have a more refined grid, the user will need to redistribute vertices along arcs. In this case, the user would want to redistribute vertices more densely along the arc defining the rectangular polygon in the lower right because the user would want smaller cells sizes in this area. This tutorial will now demonstrate this.

6.8 Refining the Polygon Arc

1. Turn off the “ugrid”  that was just created.
2. Right-click the arc forming the rectangular polygon in the lower area (see the arrow in Figure 9).
3. Select the **Redistribute Vertices** command to open the *Redistribute Vertices* dialog.
4. Change the *Average spacing* to “100.”



5. Click **OK**.
6. Select the **Map → UGrid**  button.
7. Click **OK**.

Now the cells in the area of the polygon are much smaller.


7 Horizons → UGrid

So far, the methods the user has seen to generate UGrids either create 2D UGrids or 3D UGrids that have layers that are continuous and flat in the Z dimension. If the user has elevation information for the layer boundaries, the user can use it to interpolate to the MODFLOW layer arrays and thus warp the UGrid after it has been created. This is the same procedure used with structured 3D grids and is described in the “MODFLOW – Interpolating Layer Data” tutorial.

There is yet another way to generate UGrids that allows users to create layers that are not flat and that may even pinch out. This method is the **Horizons → UGrid** command. This method has its own tutorial to explain it in detail. That tutorial is “MODFLOW-USG – Complex Stratigraphy.” The user will take a look at this method briefly now.

1. Select the **New**  button to start a new project.
2. If asked to save, click **No**.
3. Select the **Open**  button.
4. Select the file called “horizons.gpr.”
5. Click **Open**.

This project contains a lot of data, including boreholes, cross sections, and TINs. All of this data is used in the **Horizons → UGrid** command.

6. Click on the “TIN Data”  folder in the Project Explorer.
7. Select the *TINs* / **Horizons → UGrid** command.
8. Under the *Conceptual model* section turn on *Use horizons conceptual model*.
9. Click **Next**.
10. Under *Primary UGrid*, select the “voronoi” UGrid.
11. Under the *Top elevation* section select the *TIN elevations* option.
12. Click **Next**.

13. Under the *Meshing options* section, turn on the *Minimum element thickness* and enter a value of “2.0.”
14. Click on the **Finish** button to create the 3D UGrid.

7.1 View the 3D Quadtree UGrid

The 3D UGrid generation should complete quickly. The user will now rename the new UGrid and view it in 3D.

1. Turn off the “Borehole Data”  folder in the Project Explorer.
2. Turn off the “Solid Data”  folder in the Project Explorer.

The user should see a 3D UGrid similar to the figure below.

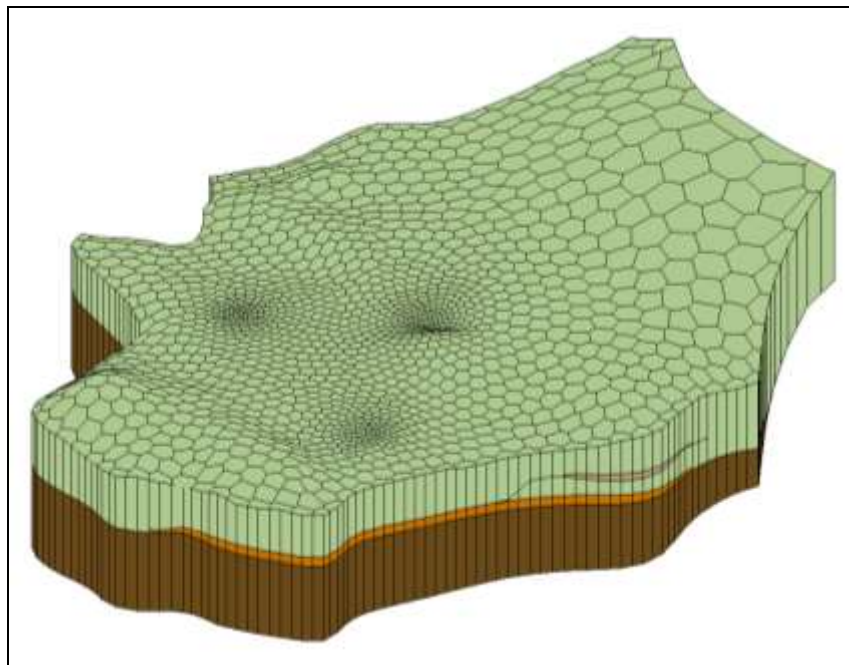



Figure 13 3D Voronoi UGrid made using Horizons → UGrid command

Now the user will look at each layer.

3. Turn on the check box next to *Single layer*  on the tool bar.
4. Change the *Layer* value to “2,” then “3” and on down to “5” to examine each layer.

The user can see that this UGrid has some layers that are discontinuous (pinch out). The top and bottom elevations of each layer are irregular and match the solid, borehole and cross section data.

The **Horizons → UGrid** command is very powerful. Feel free to experiment with it. For further practice, refer to the “MODFLOW-USG – Complex Stratigraphy” tutorial.

8 Conclusion

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

- UGrids can be created in GMS in the following ways:
 - Importing
 - New UGrid commands
 - Conversion from other objects
 - **Map → UGrid** command
 - **Horizons → UGrid** command.
- The **Map → UGrid** command allows users create the following types of UGrids:
 - Regular (not refined)
 - Quadtree/Octree
 - Voronoi
- The **Horizons → UGrid** command allows users to create complex UGrids with layers that pinch out.