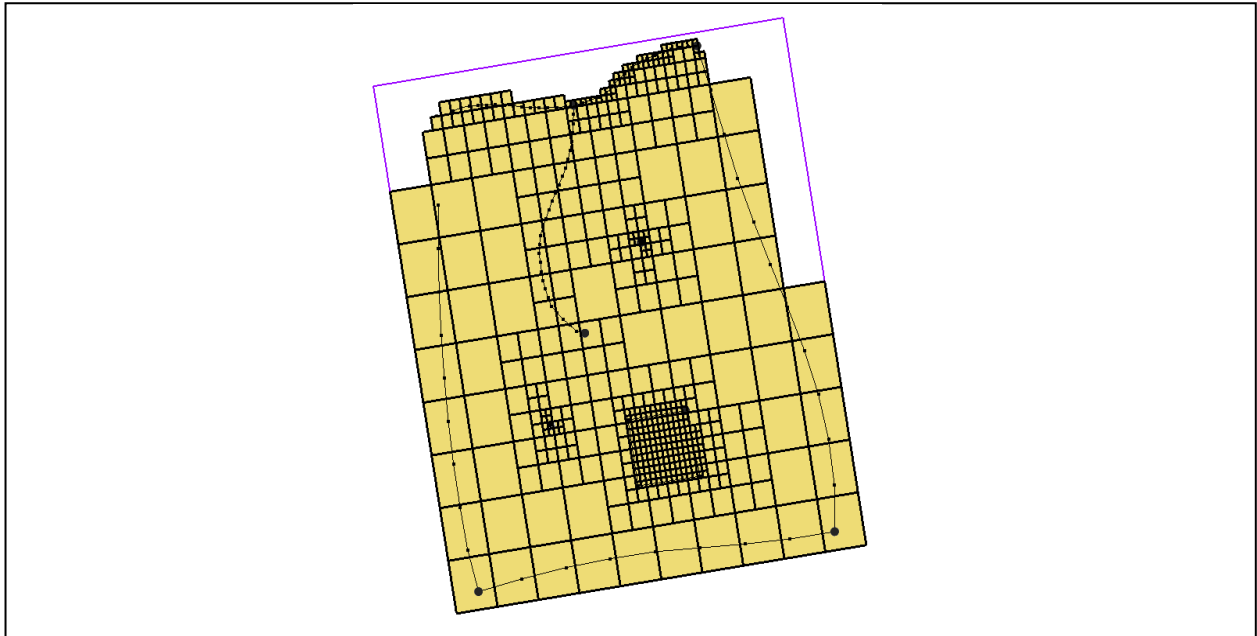


## *GMS 10.2 Tutorial*

### **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

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## 1 Introduction

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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. This tutorial will discuss and demonstrate importing two UGrids and using the **New UGrid** commands to create UGrids. UGrids will be created using multiple methods, including by converting other data types to UGrids, by using the **Map** → **UGrid** command, and by using the **Horizons** → **UGrid** command.

## 2 Getting Started

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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.

## 3 Importing a UGrid

### 3.1 Importing a 3D UGrid

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.

To import a 3D UGrid that has already been created and saved in a file, do the following:

1. Click **Open**  to bring up the *Open* dialog.
2. Select “All Files (\*.\*)” from the *Files of type* drop-down.
3. Browse to the *Tutorials\MODFLOW-USG\UGridCreation* directory and select “ugrid.vtu”.
4. Click **Open** to import the file and exit the *Open* dialog.
5. Switch to **Oblique View** .

A wireframe depiction of the UGrid should appear (  Figure 1).

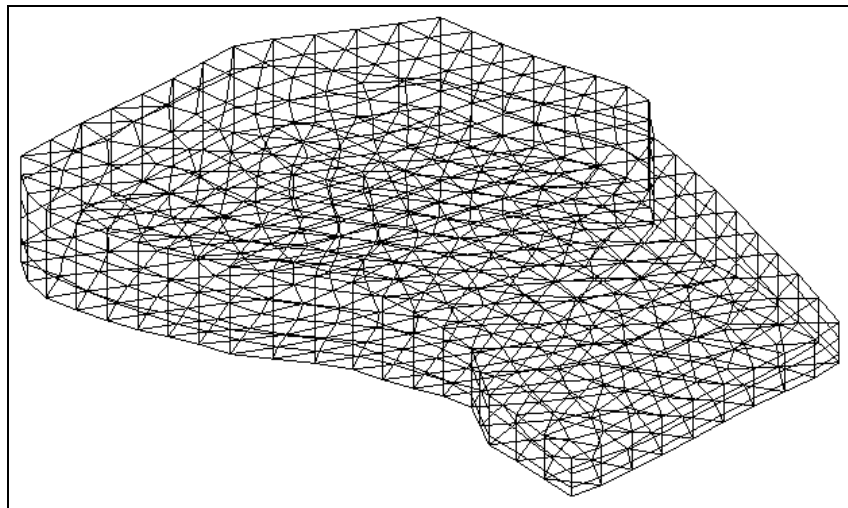



Figure 1 Imported UGrid

### Cell Faces

Now review some of the UGrid display options.

1. Click **Display Options**  to bring up the *Display Options* dialog.
2. Select “UGrid Data” from the list on the left.
3. On the UGrid tab, turn on *Cell faces*.
4. Click **OK** to exit the *Display Options* dialog.

The cell faces should be visible with different colors for different layers (Figure 2). The colors come from the materials assigned to the cells.

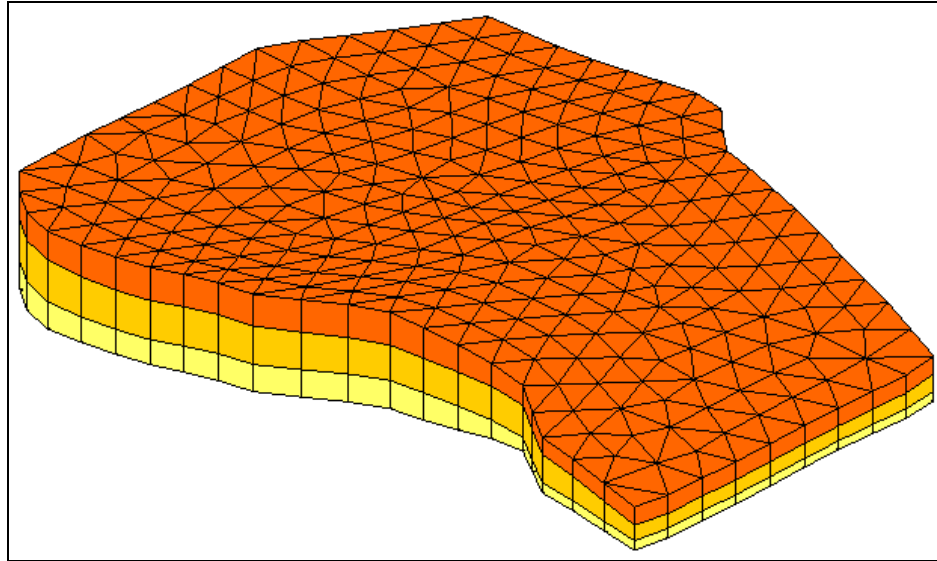



Figure 2 UGrid with cell faces turned on

5. Use the **Rotate**  tool to view the UGrid from different angles.

On examination, 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.

To review the *UGrid Properties* dialog, do the following:

6. In the Project Explorer, right-click on “ ugrid” and select **Properties...** 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** to close the *UGrid Properties* dialog.

## 3.2 Importing a 2D UGrid

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Next, review another example of an imported UGrid.

1. Click **New**  button to start a new project.
2. If asked to save, click **No**.
3. Click **Open**  to bring up the *Open* dialog.
4. Select “All Files (\*.\*)” from the *Files of type* drop-down.
5. Select “cow.vtu” and click **Open** to import the project and exit the *Open* dialog.

A UGrid should appear showing a wireframe cow (Figure 3). This type of unstructured grid is not very useful for groundwater modeling, but it illustrates the flexibility of the UGrid module in GMS.

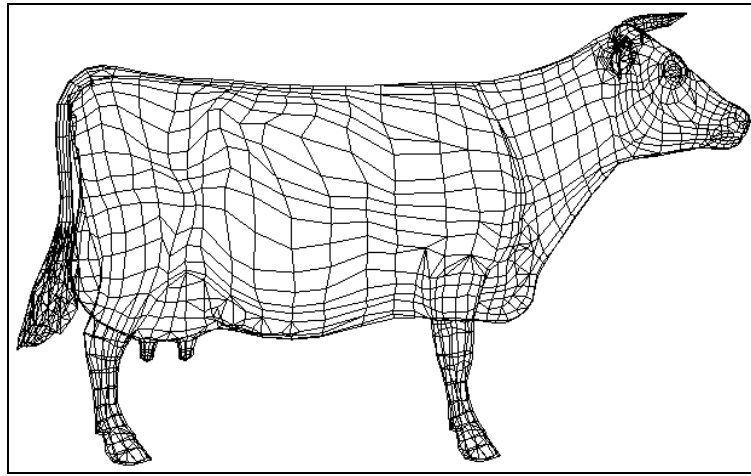




Figure 3 Imported cow unstructured grid

6. Use the  rotate tool to view the UGrid from different angles.
7. In the Project Explorer, right-click on the “ cow” UGrid and select **Properties...** 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 presented later on.

8. Click **Done** to exit the *UGrid Properties* dialog.


## 4 Creating a New UGrid

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Another easy way to create a UGrid in GMS is using the UGrid options in the right-click *New* menus. These commands and their associated dialogs work almost identically to those used to create new 2D and 3D structured grids.

### 4.1 3D UGrid

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1. Click **New**  to start a new project.
2. If asked to save, click **No**.
3. Right-click in either the Project Explorer or the Graphics Window and select *New* | **UGrid 3D...** to bring up the *New UGrid* dialog (Figure 4).

This dialog is almost identical to the dialog used to create structured 3D grids. It allows specifying the origin and length of the grid and the number of cells in *X*, *Y* and *Z* dimensions. Alternatively, the dialog can be used to 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. A better way to do cell biasing will be discussed later in this tutorial.

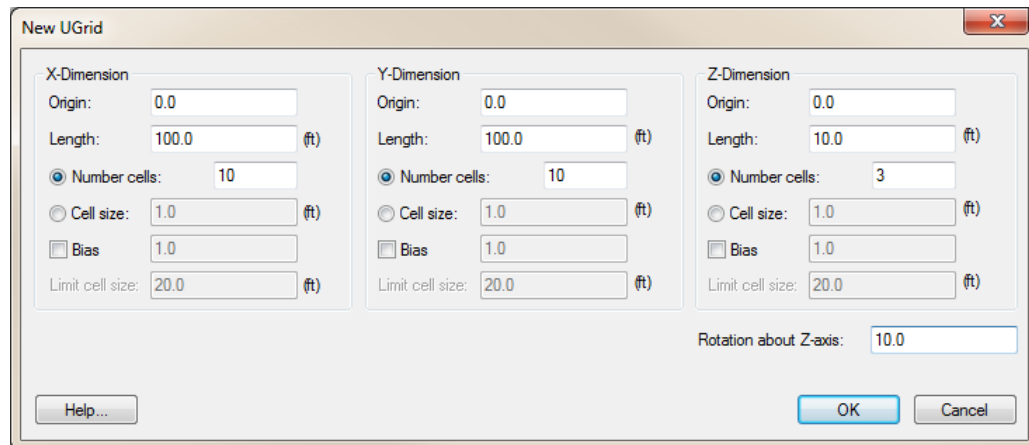



Figure 4 New UGrid dialog

4. Below the *Z-Dimension* section, enter “10.0” as the *Rotation about Z-axis*.
5. Click **OK** to accept the default values and close the *New UGrid* dialog.
6. Switch to **Oblique View** .

A 3D UGrid should be visible (Figure 5). Notice that the cells are all 6-sided 3D objects, or hexahedrons. This method always creates UGrids with hexahedron cells in 3D, and quadrilateral cells in 2D. The creation of more exotic cell types will be covered later in the tutorial.

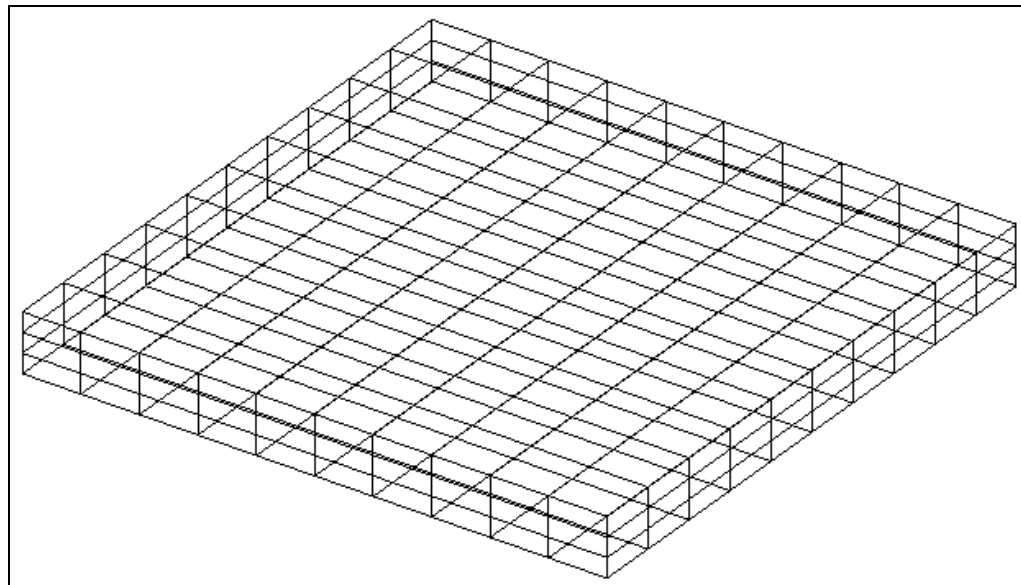


Figure 5 New 3D UGrid

## 4.2 2D UGrid



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The *New | UGrid 2D...* command works the same but instead creates a UGrid with only 2D cells. The dialog is the same except that only the option to specify cells in the Z dimension is available. Feel free to experiment with this command.

## 4.3 Using a Grid Frame

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Although using the *New UGrid* dialog is a quick and easy way to create a UGrid, it requires knowing the origin and lengths of the grid in each dimension. To create a grid that surrounds existing data, an easier way is to create a grid frame. This allows for orienting the grid graphically before using the *New UGrid* dialog.

1. Click **New**  to start a new project.
2. If asked to save, click **No**.
3. Click **Open**  to bring up the *Open* dialog.
4. Select “Project Files (\*.gpr)” from the *Files of type* drop-down.
5. Select “biscayne.gpr” and click **Open** to import the project and exit the *Open* dialog.

A conceptual model should be visible including well points and arcs representing rivers and canals.


6. Right-click in either the Project Explorer or the Graphics Window and select *New | Grid Frame* to create a new grid frame.

Now it is necessary to fit it around the data.

7. Right-click on “ Grid Frame” in the Project Explorer and select **Fit To Active Coverage**.

### Moving and Resizing the Grid Frame

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

1. Using 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 and drag on the circle in the lower right corner to rotate the grid frame.

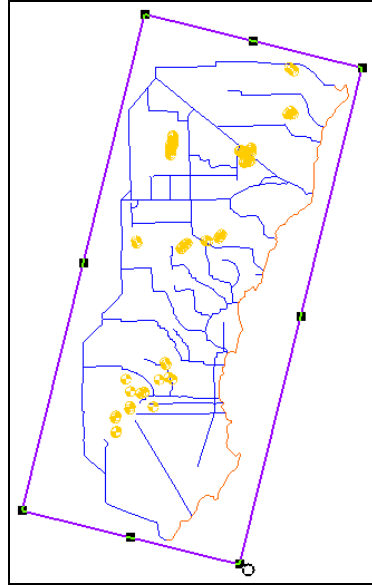



Figure 6 Grid frame surrounding a conceptual model

2. When finished positioning the grid frame, right-click in the Graphics Window and select *New | UGrid 3D...* to bring up the *New UGrid* dialog.

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

3. Click **OK** to accept the defaults and close the *New UGrid* dialog.

GMS creates the UGrid inside the boundary of the grid frame (Figure 7). If this were a real model, more cells might need to be created.

4. Turn off the “ ugrid” in the Project Explorer.

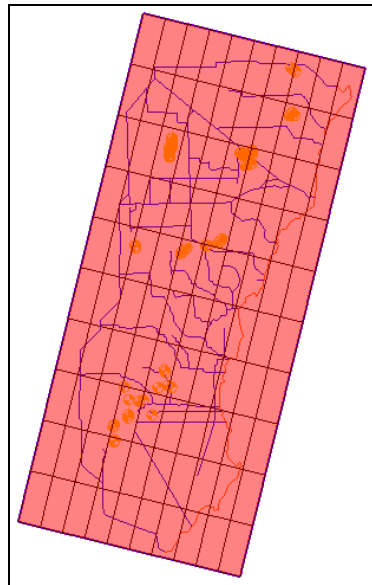


Figure 7 The UGrid created inside the grid frame





## 5 Converting from Other Object Types




UGrids can be created from several other types of objects in GMS, including TINs, 2D and 3D grids and meshes, polygons in a coverage, and polygon shapefiles in the GIS module. Two example conversions are demonstrated here.


### 5.1 Converting from a 3D Grid

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

1. Fully expand the “ 3D Grid Data” folder in the Project Explorer.
2. Turn on “ grid”, then right-click and select *Convert To | UGrid*.
3. Select **Yes** at the prompt to only convert active cells used by MODFLOW.

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

4. Turn off “ grid” so that the UGrid is visible.
5. Click **Display Options**  to bring up the *Display Options* dialog.
6. Select “ UGrid Data” from the list on the left.
7. On the *UGrid* tab, turn on *Cell faces*.
8. Click **OK** to close the *Display Options* dialog.

The UGrid should now look just like the 3D Grid it came from (  Figure 8).

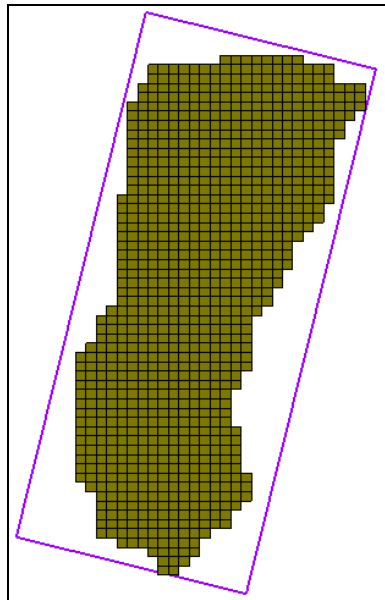





Figure 8 UGrid created from the 3D grid

## 5.2 Converting from a Shapefile

A UGrid can be created by conversion from a shapefile.

1. Turn off “ UGrid Data” and “ Map Data” in the Project Explorer.
2. Turn on “ GIS Layers”.

A shapefile should appear in the form of a quadtree grid (Figure 9). Quadtree UGrids can be created in GMS or imported and then converted to UGrids as shown here.

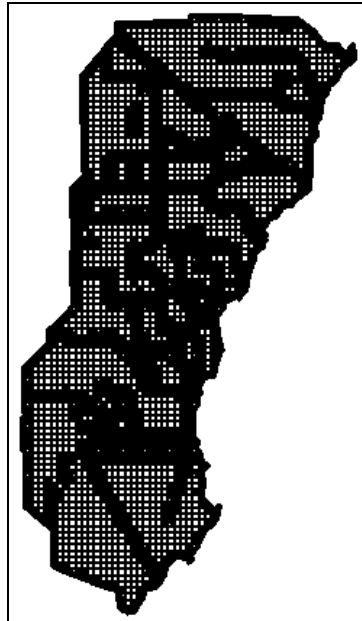











Figure 9 Shapefile showing a quadtree grid

3. **Zoom**  in on the shapefile to better see the quadtree refinement.
4. When done examining the grid refinement, **Frame**  the project.
5. Expand “ GIS Layers”, then right-click on “ biscayne.shp” and select *Convert To / UGrid* to create a new UGrid with cells matching the shapefile polygons.
6. Turn off “ biscayne.shp”.
7. **Zoom**  in to see that the quadtree refinement matches the shapefile.

### Extruding a 2D UGrid to a 3D UGrid

Now the UGrid consists of 2D cells. If wanting to create a MODFLOW model with the grid, a 3D UGrid is needed. To extrude the 2D UGrid into a 3D UGrid, do the following:

1. Switch to **Oblique View** .

2. **Zoom**  on one of the edges of the grid to see that the cells have no depth.
3. Right-click on “ biscayne.shp” and select **Extrude Down to 3D UGrid** to bring up the *Thickness* dialog.
4. Click **Insert Row**  to add a row to the spreadsheet.
5. Enter “100.0” on row 1 in the *Thickness* column.
6. Click **OK** to close the *Thickness* dialog.





The new UGrid is now 3D and therefore has depth (Figure 10).



Figure 10 2D UGrid extruded to a 3D UGrid

## 6 Using the Map to UGrid Dialog

The next way to create UGrids is by using the Map → UGrid dialog. This dialog provides tools that are more powerful than the methods seen so far because it creates quadtree, octree, and Voronoi UGrids using a conceptual model. The UGrid boundaries can be made to match the conceptual model boundaries.

1. Click **New**  button to start a new project.
2. If asked to save, click **No**.
3. Click **Open**  to bring up the *Open* dialog.
4. Select “Project Files (\*.gpr)” from the *Files of type* drop-down.
5. Select “mapToUGrid.gpr” and click **Open** to import the project and exit the *Open* dialog.
6. Fully expand “ Map Data” and turn on “ Grid Frame” in the Project Explorer.

This opens a grid frame and conceptual model with two coverages (Figure 11).

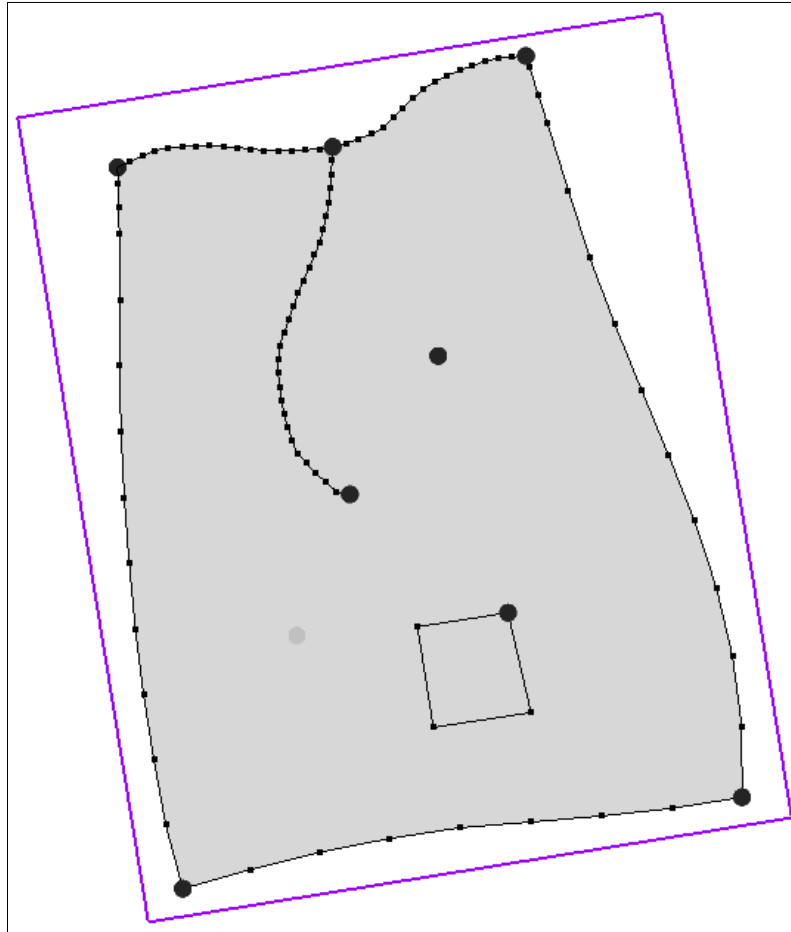



Figure 11 Conceptual model and grid frame

The conceptual model represents an area of interest a groundwater model will be created. 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 right part of the model where greater refinement is desired.

Now map the feature objects to create a new UGrid and look at the options.

7. Click **Map** → **UGrid**  to bring up the *Map* → *UGrid* dialog (Figure 12).

The first drop-down is *Dimension*, which is either “2D” or “3D”. The next is *UGrid type*, which has four choices: “Regular (not refined),” “Quadtree / Octree,” “Nested Grid”, and “Voronoi”. The nested grid option is not discussed in this tutorial.<sup>1</sup> The best way to explain the other three is to demonstrate them.

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<sup>1</sup> The nested grid option creates a grid with rectangular cells that are refined like the quadtree option, but the surrounding cells are not smoothed.

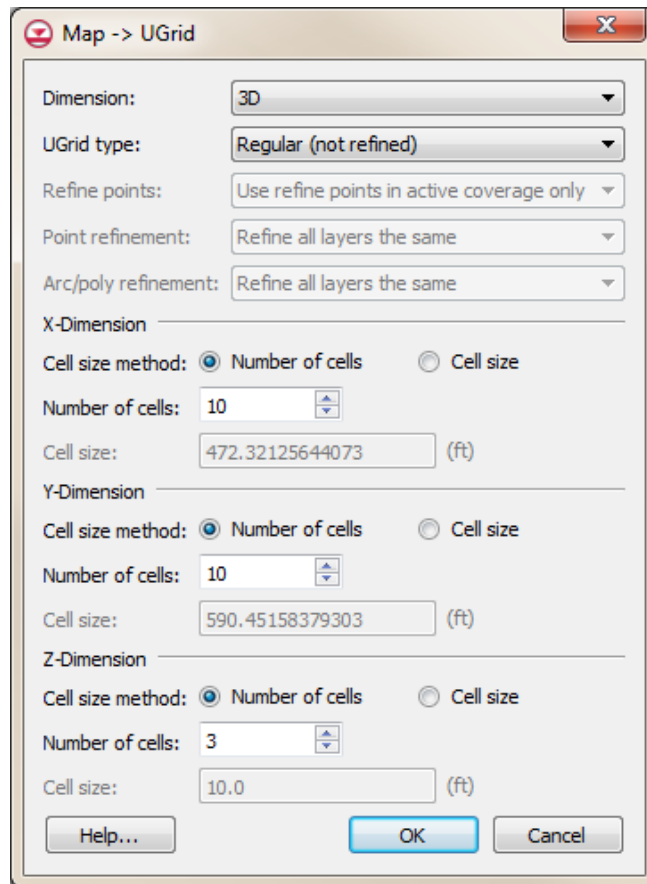


Figure 12 Map → UGrid dialog

## 6.1 Regular (not refined)

Notice that the grid will have 10 cells in the  $X$  and  $Y$  dimensions and three 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. Either specify the number of cells like this, or 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 partial cells don't appear along the edges.

8. Click **OK** to accept the defaults and close the *Map → UGrid* dialog.

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 (the grid frame) are not included in the UGrid. They are not inactive—they simply don't exist.

9. Switch to **Oblique View** .

The UGrid is 3D with three layers, and its dimensions fit the grid frame. The  $X$  and  $Y$  dimensions are 10 by 10 cells (Figure 13).

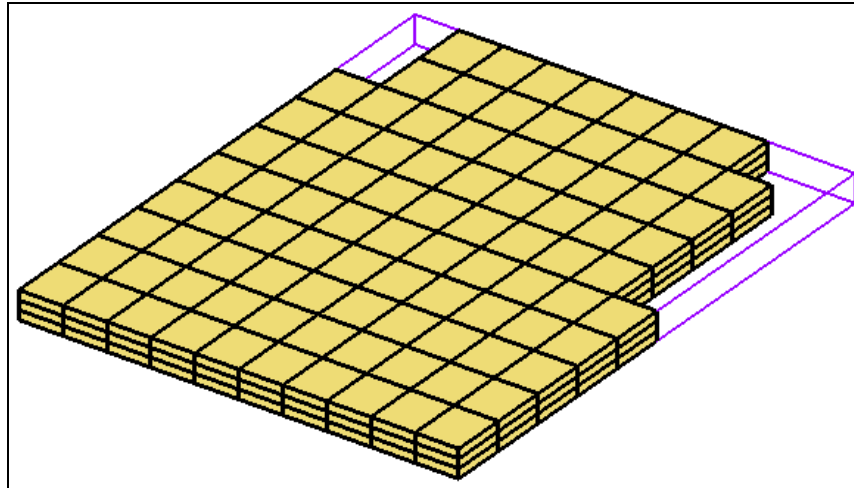





Figure 13 Regular (not refined) appearance

## 6.2 Quadtree / Octree


### Quadtree: All Layers the Same

Now see what the Quadtree option produces:

1. Switch to **Plan View**  and turn off the new “ ugrid”.
2. Click **Map** → **UGrid**  button to open the *Map* → *UGrid* dialog.
3. Select “Quadtree/Octree” from the *UGrid type* drop-down.
4. Select “Use refine points in active coverage only” from the *Refine points* drop-down.
5. Select “Refine all layers the same” from both the *Point refinement* and *Arc/poly refinement* drop-downs.
6. Click **OK** to close the *Map* → *UGrid* dialog.

Notice that the grid has been refined in a quadtree fashion around the arcs, points, and polygons (Figure 14). 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 specified 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.

7. Turn on the *Single layer* option in the UGrid Viewing Mode

 toolbar and change the layer to “2,” then “3”.

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

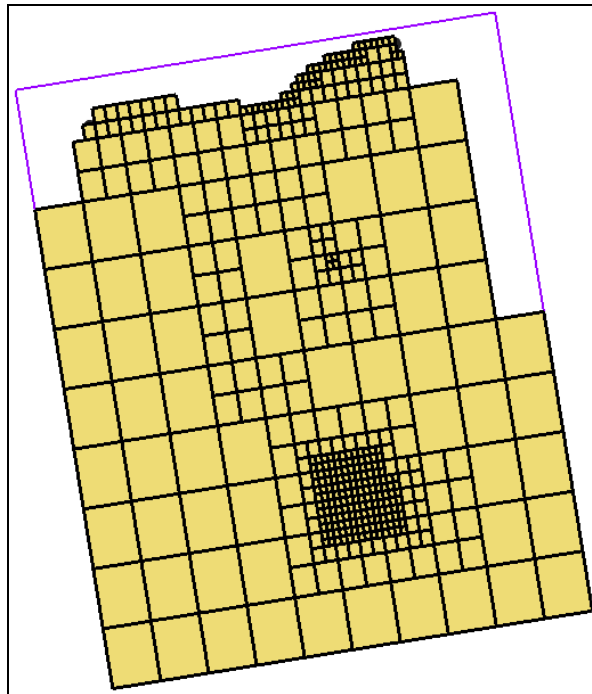







Figure 14 Quadtree UGrid

## Refinement Attributes

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


1. Turn off the new “ ugrid (2)” in the Project Explorer.
2. Select “ Map Data” to switch to the **Map**  module dynamic tools.
3. Using the **Select Arc**  tool, double-click one of the arcs along the top of the coverage to bring up the *Attribute Table* dialog.

Notice that the *Refine* attribute is on and the *Base size (ft)* is set to “100.0” or “200.0” (depending on which arc is clicked on). UGrid cells along this arc will therefore be about 100 (or 200) feet in size.

4. Click **Cancel** to close the *Attribute Table* dialog.
5. Using the **Select**  tool, double-click on the well point in the upper right area to bring up the *Attribute Table* dialog.

Notice that the *Refine* attribute is on and the *Base size (ft)* is set to “75.0”. The UGrid cell at this location will therefore be 75 feet in size. The *Bias* and *Max size* options are ignored when creating quadtree UGrids. These options are only used when creating structured 3D grids.


6. Click **Cancel** to close the *Attribute Table* dialog.

- Using the **Select**  tool, double-click on the rectangular polygon in the lower area to bring up the *Attribute Table* dialog.

Refinement is on and *Base size (ft)* is set at “100.0”, so all cells in this area of the UGrid will be about 100 feet in size.

- Click **Cancel** to close the *Attribute Table* dialog.
- Double-click somewhere in the main polygonal area to bring up the *Attribute Table* dialog.

Notice that refinement is off. Cells in this area will be allowed to grow to the maximum allowed size.



- Click **Cancel** to close the *Attribute Table* dialog.
- Double-click on the “ M1” coverage in the Project Explorer to bring up the *Coverage Setup* dialog.

Notice the *Refinement* attribute is on in the list of *Sources/Sinks/BCs*. This must be on in order to have the *Refine* attribute available for points, arcs, and polygons.

- Click **Cancel** to close the *Coverage Setup* dialog.

## Quadtree/Octree

Now review the *Octree* option for points.


- Click **Map** → **UGrid**  to bring up the *Map* → *UGrid* dialog.
- Select “Octree” from the *Point refinement* drop-down.
- Enter “3” in both the *From layer* and *To layer* columns.
- Click **OK** to accept the defaults and close the *Map* → *UGrid* dialog.
- Use the UGrid Viewing Mode  toolbar to view layers 2 and 3.

Notice that each layer has a different refinement, 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.

## Quadtree on Assigned Layers

Now look at the Quadtree on assigned layers option.

- Turn off the new “ ugrid (3)”.



2. Click **Map** → **UGrid**  to bring up the *Map* → *UGrid* dialog.
3. Select “Quadtree on assigned layers” from the *Arc/poly refinement* drop-down.
4. Click **OK** to close the *Map* → *UGrid* dialog.
5. Use the UGrid Viewing Mode  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 2 to layer 3 is therefore more abrupt and not smoothed like it would be if using the *Octree* option.



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, the “MODFLOW-USG – Quadtree” also discusses and demonstrates quadtree creation.


### 6.3 Voronoi

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

1. Turn off “ ugrid (4)” in the Project Explorer.
2. Click **Map** → **UGrid**  to bring up the *Map* → *UGrid* dialog.
3. Select “Voronoi” from the *UGrid type* drop-down.

Notice that almost all the other options become unavailable. This is because Voronoi UGrids are very different than the other types presented so far. The number of cells in the *X* and *Y* dimension cannot be specified 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** to accept the defaults and close the *Map* → *UGrid* dialog.
5. Switch to **Plan View** .

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 (Figure 15). This increases computational accuracy when using the finite volume method.

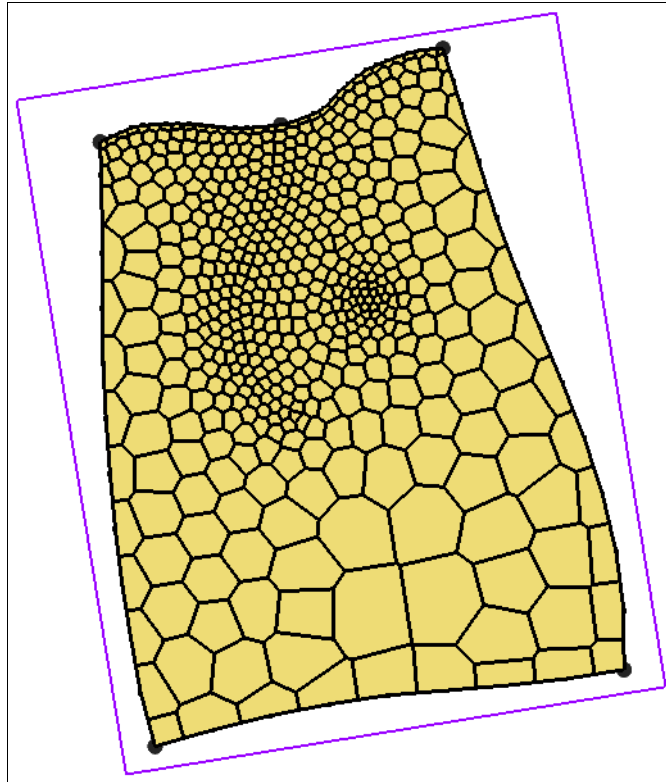






Figure 15 Voronoi UGrid on layer 1

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, it is necessary to redistribute vertices along arcs. In this case, redistribute vertices more densely along the arc defining the rectangular polygon in the lower right to obtain smaller cells sizes in this area.

### Refining the Polygon Arc

1. Turn off “ ugrid (5)” in the Project Explorer.
2. Select “ MI” to make it active.
3. Using the **Select Arcs**  tool, right-click the arc forming the rectangular polygon in the lower right area of the larger polygon and select **Redistribute Vertices...** to open the *Redistribute Vertices* dialog.
4. Enter “100.0” for the *Average spacing*.
5. Click **OK** to close the *Redistribute Vertices* dialog.
6. Click **Map** → **UGrid**  to bring up the *Map* → *UGrid* dialog.
7. Click **OK** to accept the defaults and close the *Map* → *UGrid* dialog.

Now the cells in the area of the polygon are much smaller (Figure 16).

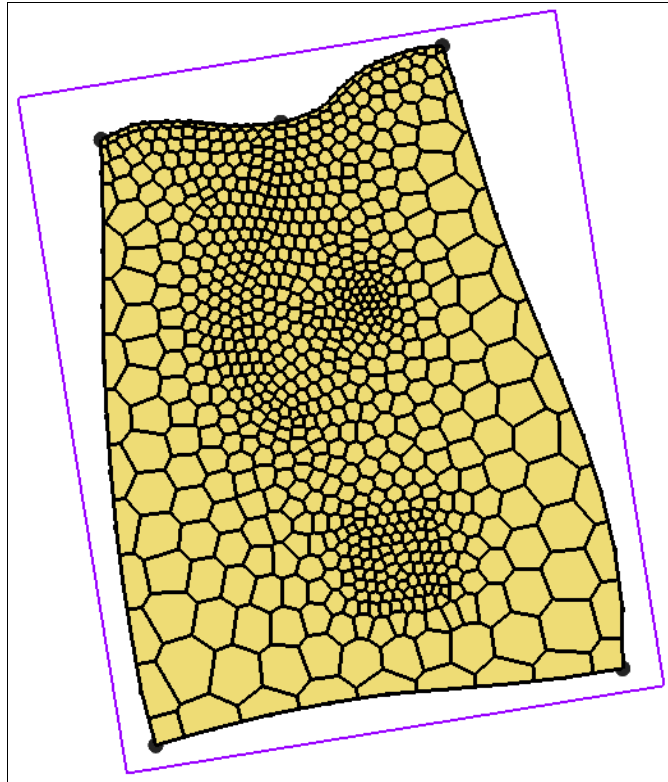




Figure 16 The area of the rectangular polygon is more refined

## 7 Horizons to UGrid

So far, the methods used to generate UGrids either create 2D UGrids or 3D UGrids that have layers that are continuous and flat in the Z dimension. Elevation information for the layer boundaries can be used 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.

Another way to generate UGrids allows for creating layers that are not flat and that may even pinch out. This method uses the **Horizons** → **UGrid** command. This method has its own tutorial—“MODFLOW-USG –Complex Stratigraphy”—to explain it in detail.

To briefly look at this method, do the following:

1. Click **New**  to start a new project.
2. If asked to save, click **No**.
3. Click **Open**  to bring up the *Open* dialog.
4. Select “Project Files (\*.gpr)” from the *Files of type* drop-down.
5. Select “horizons.gpr” and click **Open** to import the project and exit the *Open* dialog.

A project containing a lot of data—including boreholes, cross sections, and TINs- will appear (Figure 17). All of this data is used in the converting from a horizons conceptual model to UGrid.

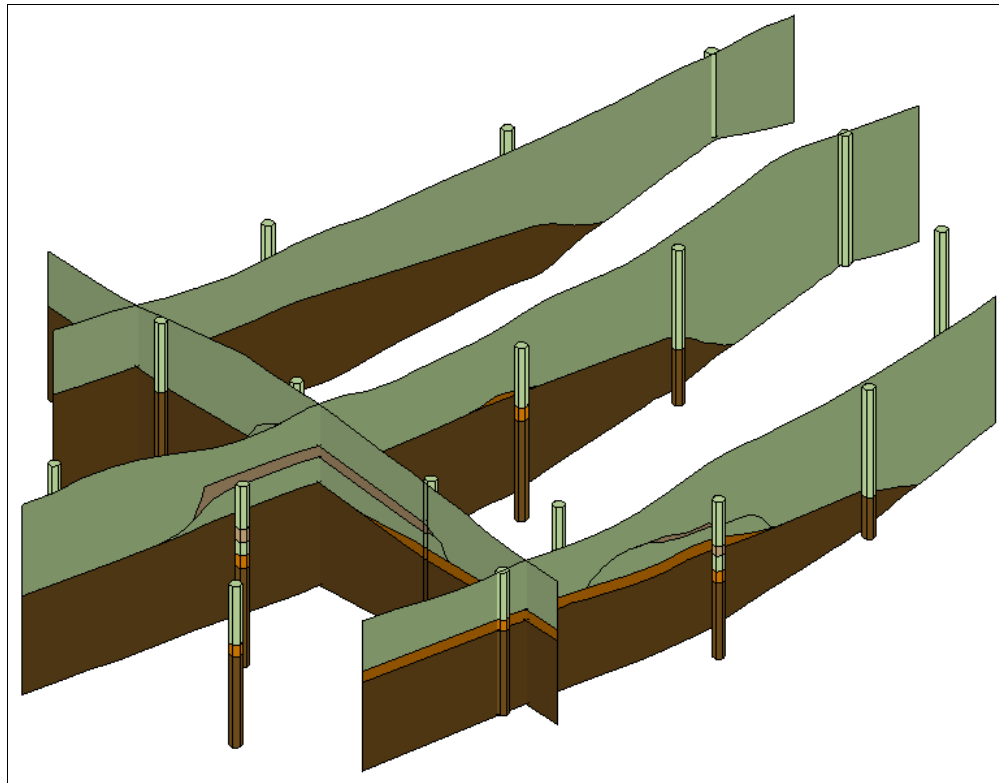



Figure 17 The horizons conceptual model

6. Select “ TIN Data” in the Project Explorer to make it active.
7. Select *TINs / Horizons* → **UGrid...** to bring up the *Horizon Elevations* page of the *Horizons to UGrid* dialog.
8. In the *Conceptual model* section, turn on *Use horizons conceptual model*.
9. Click **Next** to go to the *Top and Bottom Elevations* page of the *Horizons to UGrid* dialog.
10. In the *Primary UGrid* section, select “voronoi”.
11. In the *Top elevation* section, select *TIN elevations*.
12. Click **Next** to go to the *Build UGrid* page of the *Horizons to UGrid* dialog.
13. In the *Meshing options* section, turn on *Minimum element thickness* and enter “2.0” in the field below that.
14. Click **Finish** to create the 3D UGrid and close the *Horizons to UGrid* dialog.

## 7.1 Viewing the 3D Quadtree UGrid

The 3D UGrid generation should complete after a few moments, depending on the speed of the computer used. It is best practice to rename the new UGrid to a more descriptive name. For the purposes of this tutorial, it will not be renamed.

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

A 3D UGrid should appear, similar to Figure 18.

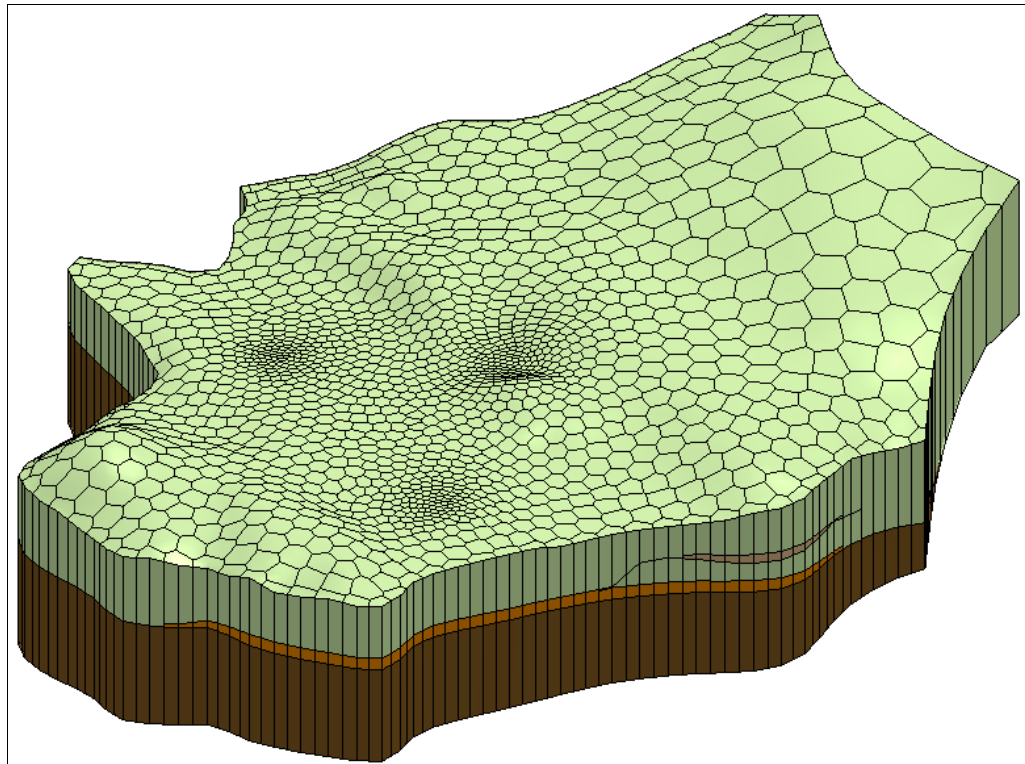




Figure 18 3D Voronoi UGrid made using the Horizons → UGrid command

2. On the UGrid Viewing Mode  Layer: 1   Single layer toolbar, turn on *Single layer*.
3. Review layers 1-5 to using the toolbar.

Notice that this UGrid has some layers that are discontinuous (or that “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

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This concludes the “UGrid Creation” tutorial. The following key concepts were discussed and demonstrated 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 can create the following types of UGrids:
  - Regular (not refined)
  - Quadtree/Octree
  - Voronoi
- The **Horizons** → **UGrid** command can create complex UGrids with layers that pinch out.