

ModelMuse Version 4: A Graphical User Interface for MODFLOW 6

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By Richard B. Winston

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Abbreviations

3D	three dimensional
CFP	Conduit Flow Process
CSV	comma-separated values
DIS	structured grid discretization
DISU	unstructured grid discretization
DISV	discretization by vertices
GNC	Ghost-Node Correction
HFB	Horizontal Flow Barrier
LGR	Local Grid Refinement
MAW	Multi-Aquifer Well
MVR	Water Mover
NPF	Node Property Flow
NWT	Newton-Raphson Formulation
OBS	Observation Process
q	quadtree refinement level
SFAC	scale factor
SFR	Streamflow Routing
STR	Stream
SUTRA	Saturated-Unsaturated Transport model
USG	Unstructured Grid
USGS	U.S. Geological Survey
UZF	Unsaturated Zone Flow

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Abstract

ModelMuse, a graphical user interface for groundwater-modeling software, was modified to support MODFLOW 6. ModelMuse works with two types of spatial discretization in MODFLOW 6: structured grids (DIS) and discretization by vertices (DISV). Quadtree refinement is used to generate a DISV model from a structured-grid model. The locations and weights for ghost nodes used to improve DISV model accuracy are computed automatically by ModelMuse using a new algorithm. ModelMuse does not support other types of DISV grids and unstructured grids. ModelMuse supports options in MODFLOW 6 that designate individual cells as confined or convertible and remove inactive cells associated with discontinuous layers, thereby reducing the computational burden. ModelMuse can specify fully three-dimensional (3D), spatially variable anisotropy in hydraulic conductivity. Although MODFLOW 6 does not support the parameters supported by MODFLOW-2005, ModelMuse provides backward compatibility by allowing ModelMuse parameters to specify scale-factor variables in MODFLOW 6 time-series files within packages that support time-series files. ModelMuse can automatically convert the data for many of the packages from other MODFLOW models to the new data for these packages in MODFLOW 6. Some packages, such as the Streamflow Routing (SFR) package, changed significantly enough that only a partial conversion is possible. Head and flow observations in older models are also converted to observation locations in the MODFLOW 6 Observation Utility. ModelMuse accommodates the ability of MODFLOW 6 to store specific discharge components by allowing the user to visualize the components of a specific discharge on the model grid. ModelMuse supports the versions of MODPATH and ZONEBUDGET compatible with MODFLOW 6.

Introduction

Previous versions of ModelMuse (Winston, 2009, 2014; Winston and Goode, 2017) supported MODFLOW-2005 (Harbaugh, 2005) and several of the variations based on it: MODFLOW-NWT (Niswonger and others, 2011),

MODFLOW-OWHM (Hanson and others, 2014), MODFLOW-CFP (Shoemaker and others, 2007), and MODFLOW-LGR (Mehl and Hill, 2005, 2007, 2013). ModelMuse version 4 adds support for MODFLOW 6 (Langevin and others, 2017). This report documents the changes in ModelMuse needed to support MODFLOW 6. Previous reports (Winston, 2009, 2014; Winston and Goode, 2017) document other features of ModelMuse. Users can refer to these reports for additional information about ModelMuse (U.S. Geological Survey, 2018, 2019).

There are many differences between MODFLOW-2005 and MODFLOW 6, including the replacement of all the groundwater-flow and solver packages with new packages, the elimination of parameters, changes in how observations are specified and recorded, and a revised input format. New MODFLOW 6 capabilities include fully three-dimensional (3D) anisotropy in hydraulic conductivity and the ability to assign the outflow from one boundary condition as the inflow to another. Arguably, the most important difference is greater flexibility in spatial discretization.

In MODFLOW-2005 and the U.S. Geological Survey (USGS) modeling programs based on it, the only spatial discretization allowed is a structured grid in which the 3D spatial domain is divided into columns, rows, and layers. Although the layers can have a varying thickness, each column and row has a uniform width. Each cell in the model is a rectangle in “plan view,” and the connections among cells are inferred from the column, row, and layer numbers.

In addition to structured discretization grids (DIS), MODFLOW 6 supports two additional types of spatial discretization: discretization by vertices (DISV) and unstructured discretization grids (DISU). The latter was introduced in MODFLOW-USG (Panday and others, 2013). This version of ModelMuse is compatible only with DIS and DISV spatial discretizations. The cells in DISV grids are organized into layers as in structured grids, but instead of rectangles, cells in the “plan view” can be convex polygons with any number of sides. In plan view, a cell number is used for each polygon. Thus, each cell in a 3D grid is identified by its cell number, specifying the plan view location and its layer number. The “across layer” connections among cells in different layers are inferred from their shared cell number, but the modeler must

specify the “within layer” connections among cells in the same layer.

Working with Discretization by Vertices (DISV) Grids

ModelMuse version 4 supports only one type of DISV, namely a quadtree-refined grid. A quadtree-refined grid is a structured grid that has selected cells subdivided, (or “refined,”) in plan view, into four equal, rectangular cells. Those cells can be further subdivided (fig. 1) such that adjacent cells change by only one level of refinement. The same refinement is applied for all layers of the DISV grid. MODPATH version 7 (Pollock, 2016) is compatible with quadtree-refined DISV grids with no grid rotation and with structured grids.

The user can generate a quadtree-refined grid in ModelMuse in the following way: (1) set the Model type to MODFLOW 6; (2) if not already created, generate the structured grid, (3) specify the quadtree refinement level (optional), and (4) switch from a structured grid to a DISV grid, or refresh the DISV grid.

Initially, the user switches to a MODFLOW 6 model (“Model|MODFLOW 6”) and then creates or edits an object and specifies the level of quadtree refinement (fig. 2). Cells enclosed or intersected by the object have quadtree-refinement applied. Applying the quadtree refinement along the edge but not the interior of a polygon, in plan view, requires setting the number of z formulas to zero.

For a polygon with two z formulas, “intersected” applies to cells that intersect the shell of the object defined by the vertical edges and the horizontal top and bottom surfaces but

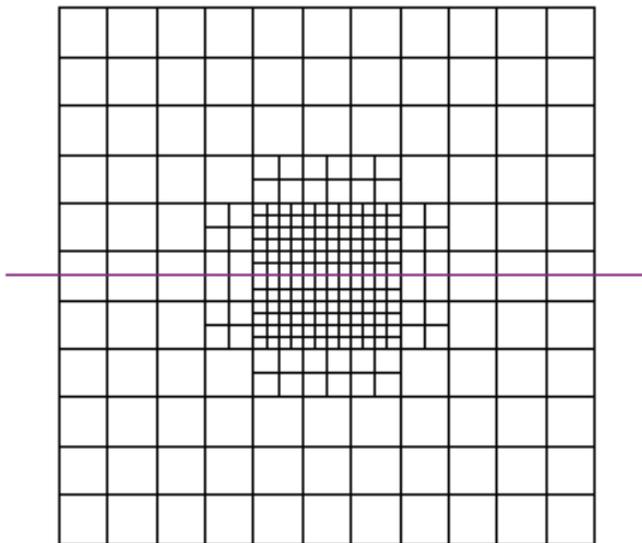


Figure 1. Screen capture illustrating a quadtree-refined discretization by vertices (DISV) grid in “plan view.”

not the cells that are completely inside the shell. For a polygon with zero z formulas, “intersected” applies to cells that intersect the edge of the polygon but not cells completely inside the polygon. By definition, if the quadtree-refinement applies to any layer, then it applies to all layers.

When the DISV grid is generated, the edge of each cell in the structured grid is split into 2^q cells, where “ q ” is the quadtree-refinement level. For example, if $q = 0$, the cell is not split because $2^0 = 1$. If $q = 2$, the edge of the cell is split into four equal parts for a total of 16 cells. In ModelMuse, 6 is the maximum allowed quadtree-refinement level. Testing with higher refinement levels has resulted in excessive computation time for DISV grid generation.

The process of generating a DISV grid starts with a structured grid. The process of creating a structured grid is unchanged from the previous version of ModelMuse (Winston, 2009). Generating the DISV grid requires the user to select “Grid|Switch to DISV,” and the structured grid is converted into a DISV grid. When switching to a DISV grid, the Grid menu item and toolbar are replaced by a DISV menu item and toolbar (fig. 3). To change the areas of quadtree refinement, the user can add, remove, or edit objects that specify the quadtree-refinement level and then select either “DISV|Refresh quadtree

refinement” or click the “Refresh DISV grid” button  on the DISV toolbar. It is possible to switch back to a structured grid by selecting “DISV|Switch to Structured Grid” to edit the structured grid. If objects were used to specify the location of the structured grid, another option is to select “DISV|Generate Grid” or to click the “Generate grid” button . This selection creates a new structured grid and converts it into a DISV grid.

In addition to the grid cells in the DISV grid, the top view of the model has a purple line, which is the cross-section line (fig. 1). The cells intersected by the cross-section line are displayed in the front and 3D views of the model, as described in Winston (2014) for SUTRA models.

There are two additional buttons on the DISV toolbar:

- The “Move cross-section” button  allows the user to drag the cross section to a new position by clicking and dragging with the mouse. Each end of the cross section can be dragged separately, or the whole cross section can be moved by clicking and dragging the middle of the cross section. Another way to move the cross section is by clicking on the model cube.
- The “Rotate cross-section” button  allows the user to rotate the cross section around the vertical axis by dragging with the mouse.

The actions of these buttons can also be accessed through the DISV menu. The DISV menu also allows the user to set the cross section to a specific angle or position or restore it to its default position.

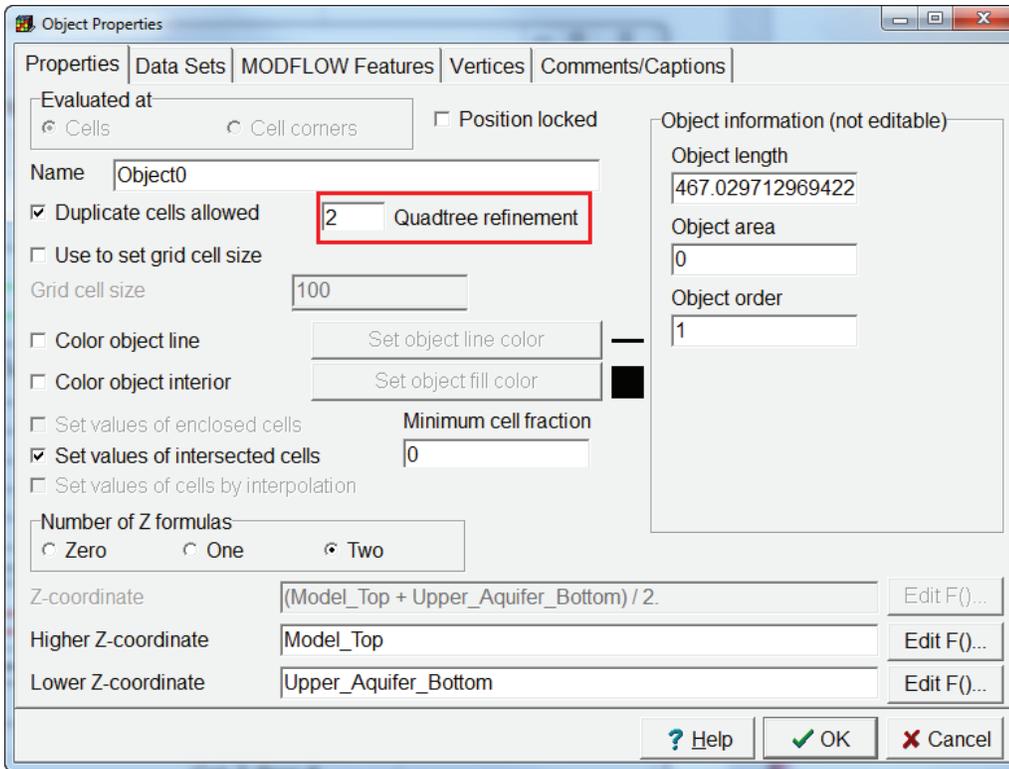


Figure 2. Screen capture illustrating how to specify quadtree-refinement level (outlined in red).

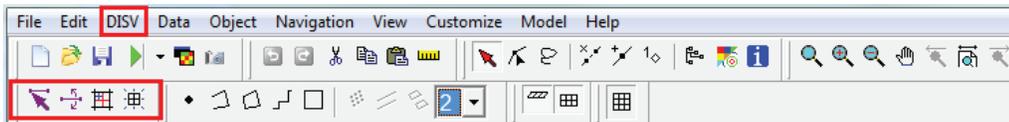


Figure 3. Screen capture illustrating the discretization by vertices (DISV) menu and toolbar, which are outlined in red.

Specification of Data With Objects

When an object is drawn on the top view of the model, it can be used to specify data in the same way as previous versions of ModelMuse. The user specifies a number of z formulas to use (zero, one, or two), whether to set data for intersected and (or) enclosed cells or by interpolation, and specifies formulas for datasets or the properties of model features. For objects on the cross-sectional view, the same procedure is applied, except in a direction perpendicular to the plane of the cross section. With objects drawn on the cross-sectional view, objects are only visible if the angle associated with the object is the same as the current angle of the cross section. If the user selects an object (for example, using the “Show or Hide Objects” dialog box) associated with a different cross-section angle than the current cross section, the cross section is rotated to the same angle as the object, such that the object becomes visible.

Ghost-Node Correction Package

The Ghost-Node Correction (GNC) package is used to partially compensate for violations of the control-volume,

finite-difference assumptions used in calculating groundwater flow in MODFLOW 6 and thus improves accuracy. One such assumption is that the line passing from one cell to a connected cell passes through the center of the interface between the cells, and it does so at a right angle to the interface.

By default, the GNC package is turned on for DISV grids in ModelMuse. The specification of ghost nodes is automatic in ModelMuse; it uses an algorithm similar, but not identical to, the algorithm used by GRIDGEN (Lien and others, 2015). The difference occurs in cases like the one illustrated in figure 4. In GRIDGEN, the position of the ghost node is not always on the line that connects the centers of the cells contributing to the ghost-node head. In ModelMuse, contributions from additional cells are included to correct for displacement. The process is illustrated in figure 5. Node 1 is not directly across from node 2, therefore ghost-node 3 is required. The ideal location to interpolate with node 1 is found at location 4, but node 5 is displaced from location 4. The head at location 4 could be estimated by interpolating between node 5 and location 6. In this instance, location 6 is not at the center of a cell either, but its head can be estimated by interpolating between nodes 7 and 8. Ultimately, nodes 1, 5, 7, and 8 all contribute to the head for ghost-node 3. Locations 4 and 6 are never included in the input for MODFLOW, but they are used to calculate the contributions of nodes 5, 7, and 8. The

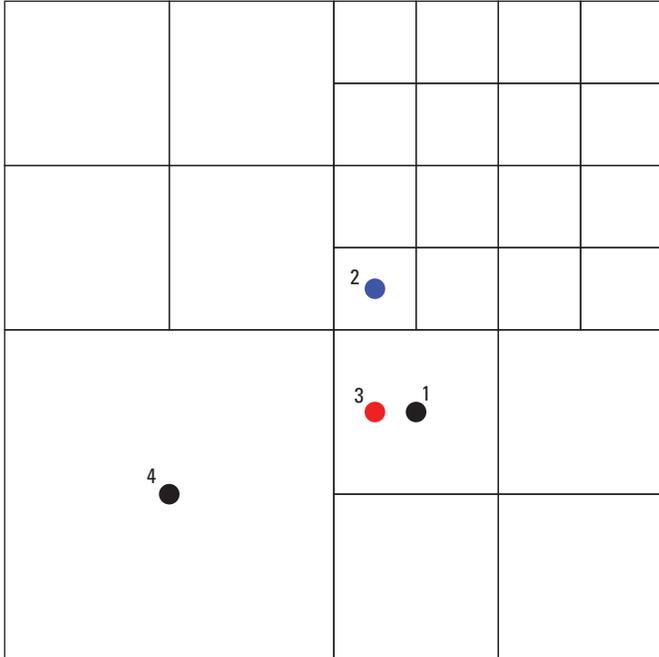


Figure 4. Illustration of ghost nodes generated by GRIDGEN. The red dot (3) is a ghost node connected to the cell with the blue dot (2). The two black dots (1 and 4) are the nodes in cells that contribute to the head in the ghost-node head.

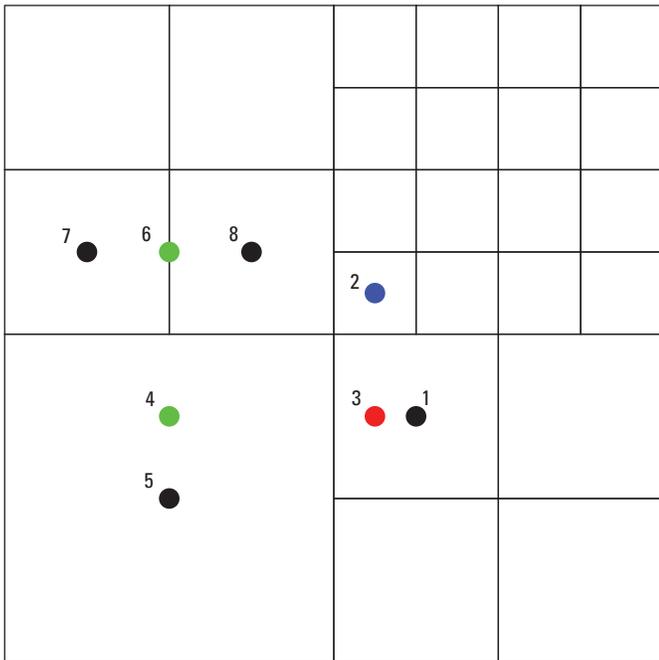


Figure 5. Illustration of ghost nodes generated by ModelMuse. The red dot (3) is a ghost node connected to the cell with the blue dot (2). The black dots (1, 5, 7, and 8) are the nodes in the cells that contribute to the head in the ghost-node head.

transmissivity of each cell is included in the calculation of weights assigned to the contributing cells.

A test case was constructed to verify that the revised algorithm improves on the one used in GRIDGEN. In the test case, a structured grid, made of 30 rows, 30 columns, one layer, and uniform properties, and specified heads in two diagonally opposite corners, was used. This grid was refined along several diagonals, and ghost nodes were generated based on either the GRIDGEN algorithm or the ModelMuse algorithm (fig. 6A). The heads generated by the two models were compared with heads generated by a structured grid model in which every row and column was subdivided into four rows or columns (fig. 6B). The absolute errors ranged from -0.12 to $+0.12$ for the ModelMuse algorithm and from -0.44 to $+0.28$ for the GRIDGEN algorithm. The absolute error was more significant with GRIDGEN: 2,783 for GRIDGEN versus 11 for ModelMuse. In all models, the discrepancy in the overall budget was less than 0.01 percent.

If the “Grid or Mesh Values” dialog box is visible and the mouse pointer is over a cell containing a ghost node on the top view of the DISV grid, a tab on the dialog box displays the cell numbers of the cell that contains the ghost node, the cell number of the cell to which the ghost node is connected, and the cell numbers and weights of all cells that contribute to the estimated head at the ghost node.

The ghost-node correction only operates in the horizontal plane; no adjustments are made to account for the varied layer thicknesses between adjacent cells, corresponding offsets in the z coordinate of the cell centers, and how those impact the control-volume, finite-difference solution of the 3D groundwater-flow equation.

XT3D Option

The XT3D option (Provost and others, 2017) in the Node Property Flow (NPF) package has two main functions: (1) it can be used to incorporate the full 3D hydraulic-conductivity tensor for anisotropic flow and (2) as an alternative to ghost-node correction to partially compensate for violations of the control-volume, finite-difference assumptions used to calculate groundwater flow in MODFLOW 6. The GNC package and the XT3D option cannot be used together.

When the XT3D option is used, the modeler must supply six datasets for every cell in the grid: three datasets for the hydraulic conductivities in three orthogonal directions and three datasets for angles that specify the orientation of the hydraulic-conductivity tensor with respect to the model coordinates (x,y,z) . In ModelMuse, when all the angles are zero, the component of hydraulic conductivity oriented parallel to the x -axis is designated K_x , the component of hydraulic conductivity oriented parallel to the y -axis is designated K_y , and the component of hydraulic-conductivity oriented parallel to the z -axis is designated K_z . A 3D visualization of the magnitude of hydraulic conductivity is an ellipsoid, and it is

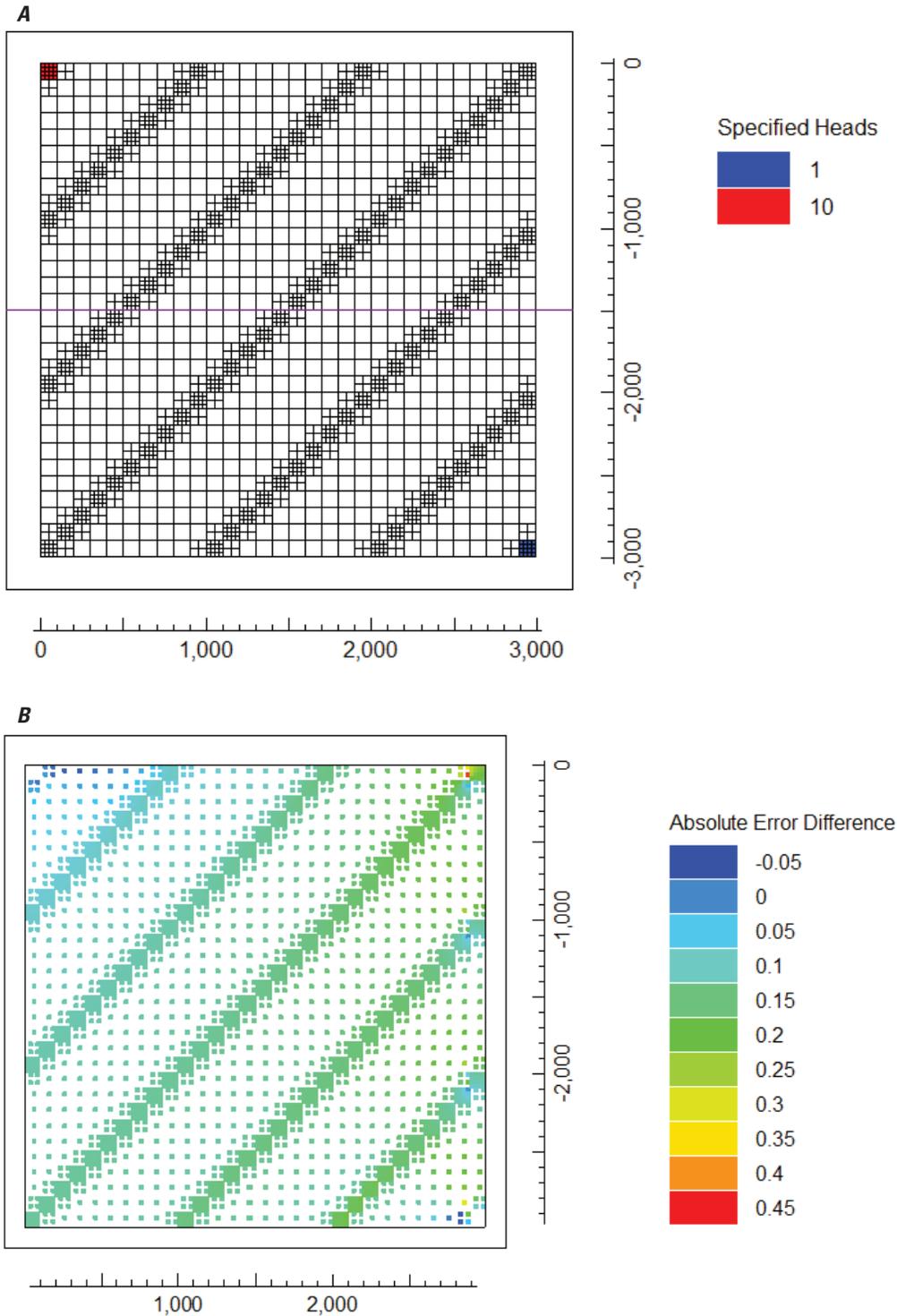


Figure 6. Illustration of the effects of the algorithm used to generate ghost nodes. (A) DISV grid and locations of specified head cells. (B) Difference in absolute errors between heads computed using the GRIDGEN and ModelMuse algorithms for specifying the ghost nodes. Values greater than zero represent cases where the absolute error was smaller when using the ModelMuse algorithm.

illustrated—for a case with $K_x > K_y > K_z$ and all angles = 0—in figure 7A. Angle 1 rotates the direction of K_x ; counterclockwise around the z -axis when viewed from above (fig. 7B). The positive value of angle 2 rotates the positive end of the direction of K_x above the xy plane (fig. 7C). The positive value of angle 3 rotates the ellipsoid in a clockwise direction around the K_x axis when viewed from any point on the positive K_x axis and looking toward the center of the ellipsoid (fig. 7D).

All angles are measured in degrees. An example of all three angles set at 20° is shown in figure 7E.

If the “Grid or Mesh Values” dialog box is visible, the XT3D option is active, and the mouse pointer is over a cell, a tab on the dialog box displays the values of K_x , K_y , and K_z , along with the three XT3D angles. If any of these datasets is out of date, a question mark is displayed. The “Update” button on the tab is used to refresh the values for datasets if they are out of date.

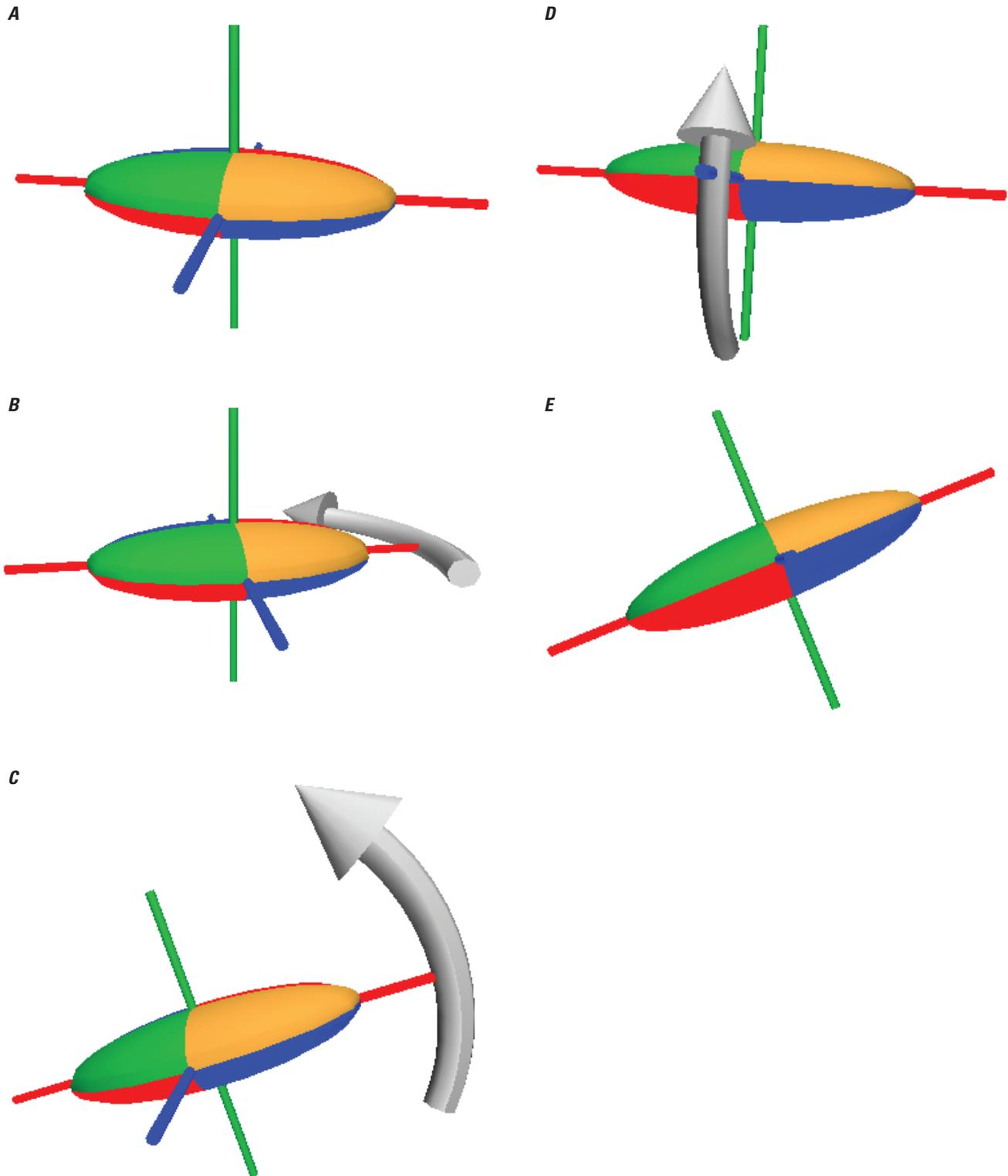


Figure 7. Illustration of angles used with the XT3D option. Viewpoint is approximately 18° above and 10° to the right of the y-axis. x-axis is red; y-axis is blue; z-axis is green. (A) The default is all angles = 0°. (B) Only angle 1 changed to +20°. (C) Only angle 2 changed to +20°. (D) Only angle 3 changed to +20°. (E) All three angles changed to +20°. K_x (relative max permeability = 2) > K_y (relative mid permeability-1) > K_z (relative min permeability = 0.3).

Convertible Cells in MODFLOW 6

In MODFLOW 6, the user no longer designates layers as confined or convertible. Instead, individual cells are designated using the ICONVERT dataset in the Storage package. This dataset corresponds to the Convertible dataset in ModelMuse. When Convertible is set to “True,” a cell can convert between confined and unconfined. When it is “False,” the cell is always confined. A related MODFLOW 6 dataset is “ICELLTYPE” in the NPF package. ICELLTYPE corresponds to the Cell_Type dataset in ModelMuse. The following values should be specified in the Cell_Type dataset to specify how the cell thickness is evaluated by MODFLOW 6:

- 0: constant cell thickness,
- > 0: calculated cell thickness,
- < 0: constant or calculated cell thickness depending on the THICKSTRT option in the NPF package.

If the THICKSTRT option is active, cells having a negative Cell_Type are confined. However, their cell thicknesses for conductance calculations are based on the saturated thicknesses at the beginning of the simulation rather than the cell height. When converting a model from an earlier version of MODFLOW to MODFLOW 6, ModelMuse sets the default formula for the Cell_Type dataset so that the method for evaluating thickness is specified properly. The default formula for the convertible dataset is “Cell_Type > 0”. If users activate the THICKSTRT option, a more appropriate default formula would be “Cell_Type < 0,” but users must set this default formula themselves if they wish to use it. ModelMuse prompts users to make this change when activating or deactivating the THICKSTRT option.

Simulating Discontinuous Layers

In MODFLOW 6, a new method for simulating layers that pinch out is introduced. In models that use DIS and DISV, cells can be designated “vertical pass-through cells” (Langevin and others, 2017). Such cells are excluded from the simulation, and yet, if these cells are overlain and underlain by active cells, a direct connection is established between the overlying and underlying cells. Vertical pass-through cells are identified by specifying a negative value in the IDOMAIN array; IDOMAIN is set to zero for inactive cells and to positive values for active cells.

In ModelMuse, there is an IDOMAIN integer dataset. The default formula for an IDOMAIN integer dataset is “IfI(Active, IfI((LayerHeight > 0.), 1, -1), 0).” Through this formula, any cell for which the Active dataset is True, when the layer height is less than or equal to zero, receives a value of -1, which makes it a vertical pass-through cell. Normally, the user does not need to subsequently override the value assigned using the default formula. If desired, the user could

modify the formula so that cells with a minimal thickness become vertical pass-through cells. An example of such a formula is “IfI(Active, IfI((LayerHeight > 0.001), 1, -1), 0).”

Model Features

The names of many boundary condition packages and model features in MODFLOW 6 are the same as in MODFLOW-2005, but in all cases there are important differences. In this section, differences in how model features are handled in MODFLOW-2005 and MODFLOW 6 are listed, and the treatments of differences in ModelMuse are described. A table listing the packages and features of MODFLOW 6 supported by ModelMuse is distributed with the ModelMuse software.

Parameters

In MODFLOW-2005, the Parameters setting can be used to help define properties of the Time-Variant Specified Head, Drain, River, Streamflow Routing, General-Head Boundary, Well, Recharge, and Evapotranspiration packages. MODFLOW 6 does not include parameters in any package. ModelMuse retains the parameters for the aforementioned packages in MODFLOW 6 models and uses them to define time-series files with the parameter value used to define the scale factor (SFAC) value in the time series.

Parameters can be used with the Horizontal Flow Barrier (HFB) package in MODFLOW-2005, but the HFB package in MODFLOW 6 does not support parameters or time-series files, and only a single HFB input file can be used per groundwater model. If any parameters are defined for the HFB package in a MODFLOW 6 model, ModelMuse generates an input file in which the hydraulic characteristic has been multiplied by the parameter value associated with the flow barrier. Parameters defined for the Layer Property Flow, Upstream Weighting, Hydrogeologic-Unit Flow, Stream, and Streamflow Routing packages are not used with MODFLOW 6 models in ModelMuse.

Streamflow Routing Package

The Streamflow Routing package (SFR) in MODFLOW-2005 organizes stream reaches into stream segments. Connections between reaches in the same segment are identified automatically whereas the modeler must specify connections among stream segments. In the SFR package for MODFLOW 6, only reaches are defined, and the modeler must specify all connections among reaches. In ModelMuse, the connections among stream reaches specified by the same object are identified automatically. The modeler must assign a segment number to each object that defines stream reaches, and these are used to identify connections among stream

reaches specified using different objects. This segment number is not part of the input to SFR but instead is used as a way of simplifying the input for the ModelMuse user.

In MODFLOW–2005, the stage in a stream reach can either be specified by the modeler or calculated from the flow in the stream in one of four different ways. Only one of these four ways of calculating the head is retained in SFR. Because of this and other changes, SFR in MODFLOW 6 is treated as a different package from the SFR package in MODFLOW–2005.

If the user changes a MODFLOW–2005 model or another, earlier model version to a MODFLOW 6 model, ModelMuse can convert the MODFLOW–2005 streams in either the SFR or Stream (STR) packages to SFR streams. The user is then prompted to make the conversion if the STR or SFR packages in MODFLOW–2005 are active, but the SFR package in MODFLOW 6 is not active. In some cases, data required for SFR streams are not part of the input for MODFLOW–2005 streams. For example, in MODFLOW–2005, if the stream uses a rating table to specify the relationship between stage and flow in the stream, the stream width is not included in the input for the SFR package. In MODFLOW 6, the stage can only be calculated by assuming the stream channel has a rectangular cross section for which a width must be specified. In such cases, default values are supplied for missing data. The user must then provide appropriate formulas for such data. ModelMuse does not notify the user when default values are used. The default formulas used when converting from the MODFLOW–2005 SFR package are as follows: streambed thickness—1; streambed elevation—0; streambed hydraulic conductivity— Kx ; stream width—10; stream depth—1. The default formulas when converting from the STR package are streambed thickness—1; streambed hydraulic conductivity—STR conductance; stream width—1; stream depth—1.

Lake Package

The Lake package in MODFLOW 6 is sufficiently different from the Lake package in MODFLOW–2005; it is treated as a new package in ModelMuse. A user can specify lakes by using objects. Unless a user specifies that a lake is embedded in a single cell, lake cells are converted to inactive cells. Active cells adjacent to lake cells are the lake-connection cells specified in the Lake package input file.

Multi-Aquifer Well Package

The Multi-Aquifer Well (MAW) package in MODFLOW 6 is similar to the two Multinode Well packages in MODFLOW–2005, but there are differences. In ModelMuse, multi-aquifer wells are defined by point objects, where the number of z formulas is set to zero, and the parts of the well that exchange flow with the aquifer are specified by the altitudes of the tops and bottoms of well screens. ModelMuse makes no

attempt to convert multinode wells from MODFLOW–2005 to multi-aquifer wells in MODFLOW 6.

Horizontal Flow Barrier Package

A new feature of MODFLOW 6 treats the properties of horizontal flow barriers in the Horizontal Flow Barrier (HFB) package as optionally different for each stress period. For MODFLOW 6 models, the user must define not only the hydraulic conductivity and thickness of the barrier but also the starting and ending times of the barrier. When converting from earlier versions of MODFLOW to MODFLOW 6, ModelMuse can convert existing horizontal flow barriers by setting the starting and ending times of the barrier to the starting and ending times of the model. If the HFB package is active and horizontal flow barriers were specified but starting and ending times were not specified for any of the horizontal flow barriers, the user is prompted to convert the HFB package so that the starting and ending times are added.

Regarding horizontal flow barriers, another difference between MODFLOW 6 and earlier versions of MODFLOW is that in MODFLOW 6, a negative value for the hydraulic characteristic causes the absolute value of the hydraulic characteristic to be treated as a multiplier of the conductance between the two cells that contain the barrier. In earlier versions of MODFLOW, a negative value for the hydraulic characteristic was treated as an error. The hydraulic characteristic is the barrier hydraulic conductivity divided by the barrier thickness—to make the hydraulic characteristic negative, the user makes one or the other a negative value.

Unsaturated Zone Flow Package

In MODFLOW 6, the input for the Unsaturated Zone Flow (UZF) package is specified as a list of UZF cells rather than arrays of values over the upper surface of the model, as is the case in previous versions of MODFLOW. MODFLOW 6 also allows more than one UZF boundary in a single groundwater-flow cell. Many of the options previously present in the UZF package were eliminated. In ModelMuse, the UZF package in MODFLOW 6 is treated as a new package. ModelMuse does not convert the UZF package from previous versions of MODFLOW to the UZF package in MODFLOW 6. ModelMuse does not support defining more than one UZF boundary in a single groundwater-flow cell, although two or more UZF cells can lie above one another in different layers. In ModelMuse, UZF is treated as a head-dependent flow package.

Water Mover Package

The Water Mover (MVR) package is new in MODFLOW 6. This package transfers water from one boundary condition to another. In ModelMuse, it is treated as a head-dependent flow-boundary condition. The user specifies the link in an

object that defines the boundary condition that acts as the source of the water transfer and selects one or more other objects that define boundary conditions that act as receivers of the water transfer. For each receiver, the user specifies the starting and ending times at which water is transferred, the type of transfer to make, and a value that determines amount of water to transfer. The type of transfer can be any of the four choices described in the MODFLOW 6 documentation: FACTOR, EXCESS, THRESHOLD, or UPTO (Langevin and others, 2017).

Observations

MODFLOW–2005 has packages for specifying observed values of head and flow for comparison with simulated values. In MODFLOW 6, this package was replaced by an observation utility implemented in several different packages. The utility allows users to specify cells for head, flow, and other sorts of observations. Simulated values at these locations are generated at each time step. Any comparison with observed values is made outside of MODFLOW 6. In ModelMuse, the user can activate the Observation Utility (OBS) in the “MODFLOW Packages and Programs” dialog box. Then the user can use objects to specify the cells used for observations. Observations are specified on the Observation Utility pane on the MODFLOW Features tab of the Object Properties dialog box. For each observation location, the user must specify an observation name. For each observation type, the user checks the appropriate checkboxes on the Observation Utility pane. For observations of flow between most boundary conditions and groundwater, the user can define the observation using either an object that also defines the related boundary or one that does not. If the object also defines the boundary, the boundary name (derived from the object name) is used to identify the appropriate cells in the input file for the observation utility. If the object does not define the boundary, any boundary cells of the appropriate package that are among the cells selected by the object defining the observation are subsequently included in the input for the Observation Utility. These boundary cells are then identified by their cell identifier rather than the boundary name. For observations of the SFR, MAW, and Lake packages, only objects that also define a stream, well, or lake in those packages can be used to define an observation of the stream, well, or lake. When converting to MODFLOW 6 from an earlier version of MODFLOW, head observations and observations of flow at specified heads, drains, general head boundaries, and rivers are converted to MODFLOW 6 observation locations.

Specific Discharge

The NPF package has an option to save the x,y,z components of specific discharge to the cell-by-cell flow file. These components can be imported from the cell-by-cell flow file in

the same way as other data, except that the individual components of flow are not displayed in the list of datasets to import. Instead, only “Data-spdis” is listed. If selected, all three components are imported, and the last of the components (qz) can be contoured or used to color the grid upon import. The other two components of specific discharge, qx and qy, can be visualized by selecting those datasets in the Data Visualization window from Data Sets/Optional/Model Results/3D Data after import.

Postprocessors

ModelMuse supports versions of MODPATH and ZONEBUDGET that are compatible with MODFLOW 6. MODPATH version 7 (Pollock, 2016) is compatible with structured and quadtree-refined DISV model grids—the latter with some restrictions—and is distributed separately from MODFLOW 6. The version of ZONEBUDGET compatible with MODFLOW 6 is distributed with MODFLOW 6. In previous versions of ZONEBUDGET, the user had the option to define composite zones and generate zero, one, or two comma-separated value (CSV) files of the output. In the version for MODFLOW 6, composite zones are not supported, and a single CSV file is always generated. Because of these changes, the related ZONBEBUDGET options are disabled in ModelMuse for MODFLOW 6 models.

Summary

ModelMuse version 4 is a pre- and post-processor for MODFLOW 6 as well as MODPATH version 7 and ZONEBUDGET for MODFLOW 6. The user can generate structured-grid and quadtree-refined DISV models, run them, and plot the results. For DISV models, the MODFLOW 6 GNC package is automatically activated, and the weights associated with all ghost nodes are specified automatically using an improved algorithm. Full 3D anisotropy in hydraulic conductivity is available with the XT3D option for MODFLOW 6, which also provides an alternative to ghost-node correction. Because of the extent of changes between MODFLOW 6 and earlier versions of MODFLOW, converting an existing MODFLOW model to MODFLOW 6 may be imperfect. Some packages in earlier versions of MODFLOW were eliminated, and others were changed or replaced. ModelMuse can be used to completely convert some existing models. However, models that use features that were removed or substantially altered may be difficult or impossible to convert with complete fidelity.

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