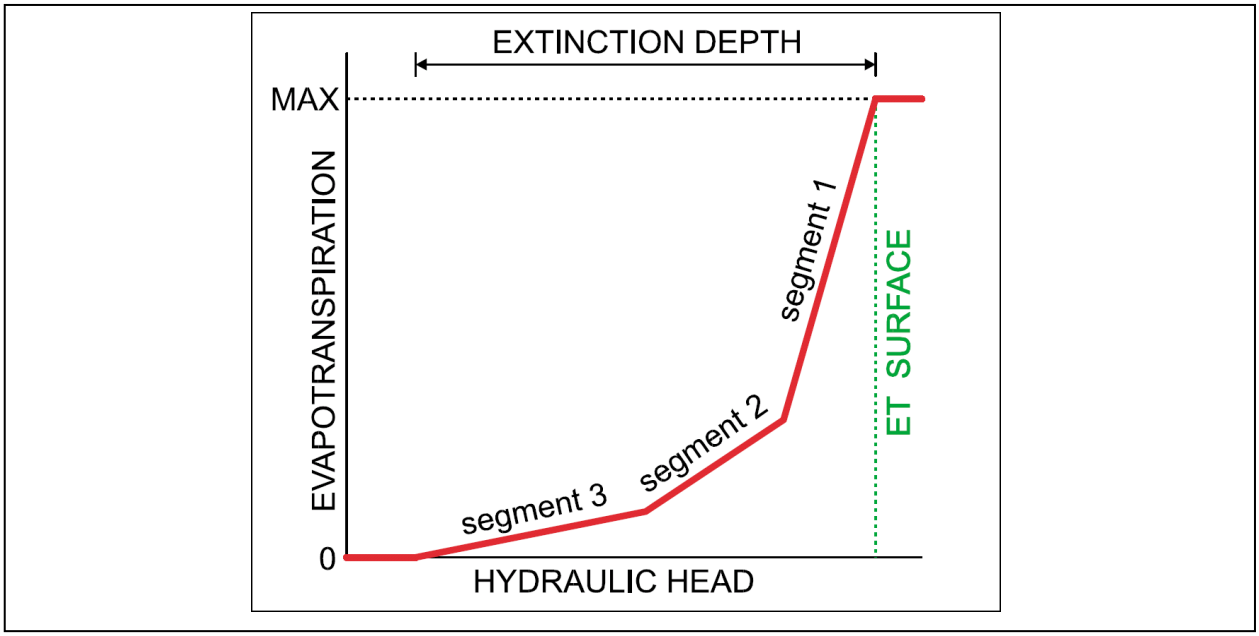
GMS 10.0 Tutorial

MODFLOW – ETS Package

The MODFLOW Evapotranspiration Segments (ETS) package interface in GMS



Objectives

Learn how to use the MODFLOW Evapotranspiration Segments (ETS) package interface in GMS and compare it to the regular MODFLOW Evapotranspiration (EVT) package.

Prerequisite Tutorials

- MODFLOW – Conceptual Model Approach I

Required Components

- Map Module
- Grid Module
- MODFLOW

Time

- 40-60 minutes

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1 Introduction

Evapotranspiration is the moving of water from the ground surface to the atmosphere through evaporation and transpiration. MODFLOW has two standard packages that are used to model evapotranspiration: the EVT package and the ETS package. GMS has long supported the EVT package, and, starting at version 7.0, GMS supports the ETS package.

The EVT package has existed at least since MODFLOW 88. It requires three parameters to determine evapotranspiration: the evapotranspiration (ET) surface elevation, the maximum ET rate, and the extinction depth. When the head in a cell is at or above the ET surface, ET occurs at the maximum ET rate. When the head is below the extinction depth, ET is zero. In between these two points, the ET varies linearly.

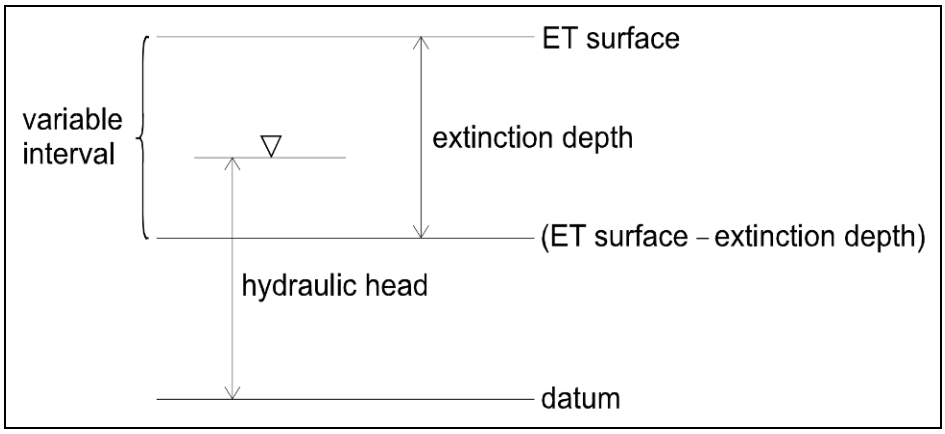

Figure 1 ET model, from Banta, 2000[1]

The ETS package, or Evapotranspiration Segments Package, is very similar to the EVT package but adds the ability to vary the ET nonlinearly between the ET surface and the extinction depth. The ETS package was introduced with MODFLOW 2000.

This tutorial explains how to use the ETS package and compares it to the EVT package. Both packages can be used at the same time if desired.

1.1 Outline

Here are the steps of this tutorial:

1. Read in an existing MODFLOW simulation.
2. Add ET to the model using the EVT package.
3. Add ET to the model using the ETS package, mimicking the EVT package.
4. Define a nonlinear curve for the ETS package.
5. Create a simple conceptual model to illustrate how ETS can be modeled conceptually and mapped to MODFLOW.

1. Banta, Edward R. (2000), MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model-Documentation of Packages for Simulating Evapotranspiration with a Segmented Function (ETS1) and Drains with Return Flow (DRT1). Open-File Report 00-466, Denver, Colorado.

2 Description of Problem

The problem in this tutorial is the same as the problem in the "MODFLOW – Grid Approach" tutorial. It is shown in Figure 2. This problem is a modified version of the sample problem described near the end of the *MODFLOW 88 Reference Manual*. Refer to the "MODFLOW – Grid Approach" tutorial for a complete description of the problem. In brief, it is a grid-based model (no conceptual model) with three layers, some wells, some drains, recharge, and constant head cells.

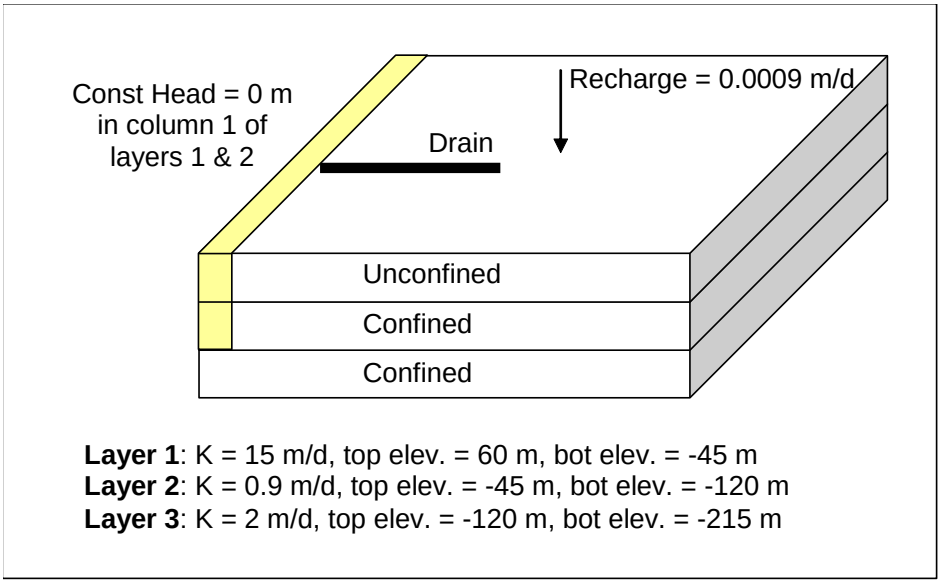

Figure 2 Sample problem to be solved

3 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.

4 Opening the Existing Model

The first step is to start with a MODFLOW model that has already been created.

1. Select the **Open** button (or the *File* | **Open** menu command).
2. Browse to the *Tutorials/MODFLOW/et* folder.
3. Select the "modfgrid.gpr" file.

4. Click the **Open** button.

This opens the model. The user should see a grid with color-filled contours and symbols representing wells, drains and other boundary conditions.

5 Saving the Model with a New Name

Now it is possible to start making changes. First, the user will save the model with a new name.

1. Select the *File* | **Save As** menu command.
2. Change the project name to "evt."
3. Save the project by clicking the **Save** button.

6 Adding ET via the EVT package

The first change the user will make is to add ET to the model via the EVT package.

6.1 Turning on the EVT package

It is necessary to turn on the EVT package.

1. Select the *MODFLOW* | **Global Options** menu command.
2. In the *MODFLOW Global/Basic Package* dialog select the **Packages** button.
3. Under *Optional Packages* in the *MODFLOW Packages* dialog, turn on the *Evapotranspiration (EVT1)* package.
4. Click **OK** to exit the *MODFLOW Packages* dialog.
5. Click **OK** to exit the *MODFLOW Global/Basic Package* dialog.

6.2 Specifying ET

Now it is necessary to specify the ET parameters.

1. Select the *MODFLOW* | *Optional Packages* | **EVT - Evapotranspiration** menu command.

This brings up the *MODFLOW EVT Package* dialog. The user will set the ET surface elevation to be 59 meters, just 1 meter below the ground surface. The user will set the max ET rate to be 0.01 meters per day, and the extinction depth at 6 meters below the ground surface.

Max ET Rate

1. Make sure the *View/Edit* combo box is set at "EVTR. Max ET rate."
2. Select the **Constant → Array** button.
3. In the *Grid Value* dialog, enter a value of "0.01," and click **OK**.

ET Surface

1. Switch the *View/Edit* combo box to "SURF. Elevation of ET surface."
2. Select the **Constant → Array** button.
3. In the *Grid Value* dialog, enter a value of "59," and click **OK**.

Extinction depth

1. Switch the *View/Edit* combo box to "EXDP. ET extinction depth."
2. Select the **Constant → Array** button.
3. In the *Grid Value* dialog, enter a value of "6," and click **OK**.

No more changes will be made. The user may have noticed the *ET option* combo box. This will not be changed because the default will apply ET only to the top layer of cells.

4. Click **OK** to exit the *MODFLOW EVT Package* dialog.

7 Saving and Running MODFLOW

The next steps are to save our changes and run MODFLOW.

1. Select the **Save** button (or the *File* | **Save** menu command).
2. Select the *MODFLOW* | **Run MODFLOW** menu command.
3. When MODFLOW finishes, select the **Close** button.

The user should notice some changes in the new solution.

4. Expand the "3D Grid Data" folder.
5. Compare the new and old solutions by alternately selecting the "modfgrid (MODFLOW)" and the "evt (MODFLOW)" items in the Project Explorer.

Notice the head is lower in the new "evt" solution. The addition of evapotranspiration has caused more water to leave the model, thus lowering the head.

6. Select the ***Save*** button to save the project with the new solution.

8 Examining the Flow Budget

This tutorial will now take a look at how much water is leaving the system due to evapotranspiration.

1. Make sure the "evt (MODFLOW)" solution is selected in the Project Explorer.
2. Select the *MODFLOW* | **Flow Budget** menu command.
3. Notice under *Sources/Sinks*, for *ET*, there is zero flow in but some flow out. Also, notice there is no flow at all for the ETS package.
4. Select **OK** to exit the dialog.

9 Saving the Model with a New Name

Before changing the model to use the ETS package, save the model with a new name.

1. Select the *File* | **Save As** menu command.
2. Change the project name to "ets1."
3. Save the project by clicking the **Save** button.

10 Adding ET via the ETS package

The next step is to switch to the ETS package to model evapotranspiration. At first, the user will not define any curve segments so that the ETS package will work just like the EVT package. Later, the user will add segments.

10.1 Turning Off the EVT Package and Turning On the ETS Package

First, it is necessary to turn on the ETS package.

1. Select the *MODFLOW* | **Global Options** menu command.
2. In the *MODFLOW Global/Basic Package* dialog, select the **Packages** button.
3. In the *MODFLOW Packages* dialog, turn off the *Evapotranspiration (EVT1)* package.
4. Turn on the *Evapotranspiration (ETS1)* package.
5. Click **OK** to exit the *MODFLOW Packages* dialog.
6. Click **OK** to exit the *MODFLOW Global/Basic Package* dialog.

10.2 Specifying ET

Now it is necessary to specify the ET parameters.

1. Select the *MODFLOW* | *Optional Packages* | **ETS - Evapotranspiration Segments** menu command.

This brings up the *MODFLOW ETS Package* dialog. It's very similar to the *MODLFOW EVT Package* dialog. The ET parameters will be set to the same values that were used for the EVT package.

2. In the *MODFLOW ETS Package* dialog, repeat the steps that were completed in the EVT package dialog to set the ET surface elevation to be "59" m, the max ET rate to be "0.01" m/d, and the extinction depth at "6" m. (Refer to Section 6.2 to brush up on the process.)

3. Click **OK** when finished to exit the *MODFLOW ETS Package* dialog.

Notice that the tutorial left *NETSEG* at 1. This means there is one curve segment, which means the curve is linear. Therefore, the ETS package will behave just like the EVT package.

10.3 Switching LMT Package to Extended Header

When GMS saves a MODFLOW simulation, by default, it includes the linkage files needed by MT3D to run a transport simulation, even if no MT3D model is currently defined. If the ETS package is in use, a setting for the MT3D linkage files must be changed.

1. Select the *MODFLOW* | **OC - Output Control** menu command.

2. In the *MODFLOW Output Control* dialog, find the *Other output* section

3. Then, under the **.hff file for transport* item, switch the setting to *Extended header format*.

4. Click **OK**.

Alternatively, the user could have just turned off the **.hff file for transport* item since it will not be using MT3D with this model.

11 Saving and Running MODFLOW

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

1. Select the **Save** button (or the *File* | **Save** menu command).

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

3. When MODFLOW finishes, select the **Close** button.

The new solution is identical to the "evt" solution.

4. Compare all three solutions by alternately selecting the "modfgrid (MODFLOW)", the "evt (MODFLOW)", and the "ets1 (MODFLOW)" items in the Project Explorer.

Notice the head is the same for the "evt" and "ets" solutions.

5. Select the **Save** button to save the project with the new solution.

12 Examining the Flow Budget

This tutorial will now take a look at how much water is leaving the system due to evapotranspiration.

1. Make sure the "ets1 (MODFLOW)" solution is selected in the Project Explorer
2. Select the *MODFLOW* | **Flow Budget** menu command.
3. Notice under *Sources/Sinks*, for *ET Segments (ETS)* there is zero flow in but some flow out. The flow out is the same amount that was reported for the EVT package previously.
4. Select **OK** to exit the dialog.

13 Saving the Model with a New Name

Before changing the model to use a nonlinear curve for ETS, save the model with a new name.

1. Select the *File* | **Save As** menu command.
2. Change the project name to "ets2."
3. Save the project by clicking the **Save** button.

14 Adding ETS Curve Segments

The next step will actually take advantage of the extra functionality in the ETS package by specifying a nonlinear curve. The user will create a curve that looks like this:

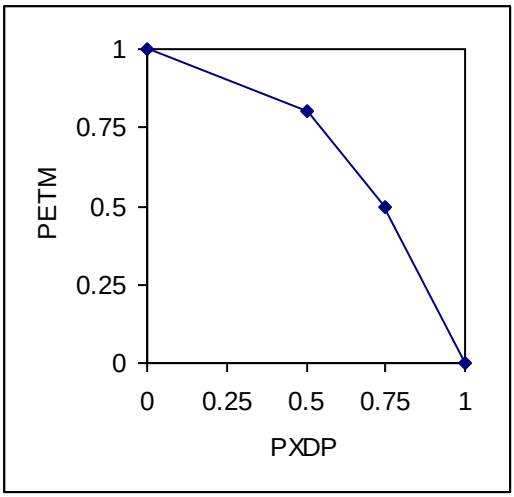

Figure 3 Nonlinear ET curve with two segments

This curve requires some explanation. PXDP and PETM are MODFLOW variables. The ETS1 package documentation describes them as follows:

> In the ETS1 Package, the functional relation of evapotranspiration rate to head is conceptualized as a segmented line in the variable interval. The segments that determine the shape of the function in the variable interval are defined by intermediate points where adjacent segments join. The ends of the segments at the top and bottom of the variable interval are defined by the ET surface, the maximum evapotranspiration rate, and the extinction depth. The number of intermediate points that must be defined is one less than the number of segments in the variable interval. For each intermediate point, two values, PXDP and PETM, are entered to define the point. PXDP is a proportion (between zero and one) of the extinction depth, and PETM is a proportion of the maximum evapotranspiration rate. PXDP is 0.0 at the ET surface and is 1.0 at the bottom of the variable interval. PETM is 1.0 at the ET surface and is 0.0 at the bottom of the variable interval.[2]

The curve in Figure 3 is nonlinear and is defined such that the ET rate drops gradually as the head drops below the ET surface, but then it drops more rapidly as the head approaches the extinction depth. The values for PXDP and PETM in this case are as follows:

2. Banta, Edward R. (2000), MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model-Documentation of Packages for Simulating Evapotranspiration with a Segmented Function (ETS1) and Drains with Return Flow (DRT1). Open-File Report 00-466, Denver, Colorado.

PXDP	PETM
0	1
0.5	0.8
0.75	0.5
1	0

To use the curve in Figure 3 for the ETS package, the user needs to change the number of segments (NETSEG) to 3 and define the points where the segments meet. Since there are three segments, two points of intersection need to be defined. It is not necessary to define the first and last points on the curve since they are always at 1.0 and 0.0. It is only necessary to define the two interior points on the curve.

14.1 Changing NETSEG

To change the number of segments:

1. Select the *MODFLOW* | *Optional Packages* | **ETS - Evapotranspiration Segments** menu command.

2. In the *MODFLOW ETS Package* dialog, change *NETSEG* to "3."

14.2 Defining the PXDP Data

This tutorial will define the PXDP values for both points. The user will apply the same curve to all the cells in the grid, although it is possible to have different curves for each cell. The order that the user enters the values for PXDP and PETM is important, as explained in the package documentation:

> PXDP is a proportion of the extinction depth (dimensionless), measured downward from the ET surface, which, with PETM, defines the shape of the relation between the evapotranspiration rate and head. The value of PXDP must be between 0.0 and 1.0, inclusive. Repetitions of PXDP and PETM are read in sequence such that the first occurrence represents the bottom of the first segment, and subsequent repetitions represent the bottom of successively lower segments. *Accordingly, PXDP values for later repetitions (representing lower segments) should be greater than PXDP values for earlier repetitions.* PETM is a proportion of the maximum evapotranspiration rate (dimensionless) which, with PXDP, defines the shape of the relation between the evapotranspiration rate and head. The value of PETM should be between 0.0 and 1.0, inclusive. Repetitions of PXDP and PETM are read in sequence such that the first occurrence represents the bottom of the first segment, and subsequent repetitions represent the bottoms of successively lower segments. *Accordingly, PETM values for later repetitions (representing lower*

segments) generally would be less than PETM values for earlier repetitions.[3] (emphasis added)

1. Change the *View/Edit* combo box to "PXDP. Curve segments."
2. Make sure the *Segment array* is set to "1." This means the user is viewing/editing data for the first point.
3. Select the **Constant → Array** button.
4. In the *Grid Value* dialog, enter a value of "0.5," and click **OK**.
5. Change the *Segment array* to "2" in order to view the second segment.
6. Select the **Constant → Array** button.
7. In the *Grid Value* dialog, enter a value of "0.75," and click **OK**.

14.3 Defining the PETM Data

The next step is to define the PETM data for both points. Again, the user will make the same curve apply to all the cells in the grid.

1. Change the *View/Edit* combo box to "PETM. Curve segments."
2. Set the *Segment array* to "1."
3. Select the **Constant → Array** button.
4. In the *Grid Value* dialog, enter a value of "0.8," and click **OK**.
5. Set the *Segment array* to "2."
6. Select the **Constant → Array** button.
7. In the *Grid Value* dialog, enter a value of "0.5," and click **OK**.
8. Click **OK** to exit the *MODFLOW ETS Package* dialog.

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3. Banta, Edward R. (2000), MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model-Documentation of Packages for Simulating Evapotranspiration with a Segmented Function (ETS1) and Drains with Return Flow (DRT1). Open-File Report 00-466, Denver, Colorado.

15 Saving and Running MODFLOW

The next steps are to save these changes and run MODFLOW.

1. Select the **Save** button (or the *File* | **Save** menu command).
2. Select the *MODFLOW* | **Run MODFLOW** menu command.
3. When MODFLOW finishes, select the **Close** button.

The user should notice some slight changes in the new solution.

4. Compare all four solutions by alternately selecting the "modfgrid (MODFLOW)", the "evt (MODFLOW)", the "ets1 (MODFLOW)", and the "ets2 (MODFLOW)" items in the Project Explorer.
5. Select the **Save** button to save the project with the new solution.

16 Saving the Model with a New Name

Before changing the model to use a conceptual model, save the model with a new name.

1. Select the *File* | **Save As** menu command.
2. Change the project name to "ets3."
3. Save the project by clicking the **Save** button.

17 Building a Conceptual Model

The next step is to examine how to use a conceptual model with ETS data.

17.1 Creating the Conceptual Model

1. Right-click in the Project Explorer and select the *New* | **Conceptual Model** command from the pop-up menu.
2. In the *Conceptual Model Properties* dialog, change the *Name* to "modfgrid."
3. Click **OK**.

17.2 Creating a Coverage

1. Right-click on the **modfgrid** conceptual model the user just created in the Project Explorer.

2. Select the **New Coverage** command from the pop-up menu.
3. In the *Coverage Setup* dialog, change the *Coverage Name* to "ets."
4. In the list of *Areal Properties*, turn on the following options:
   - *Max ETS rate*
   - *ETS elev.*
   - *ETS Extinction depth*
   - *ETS Segmented curve*
5. Click **OK** to exit the *Coverage Setup* dialog.

17.3 Creating the Polygon

1. Select the **Create Arc** tool.
2. Create an arc that surrounds the grid. End the arc on the starting point by double-clicking in order to form a closed polygon, as shown in Figure 4.
3. Select the *Feature Objects* | **Build Polygons** menu command.

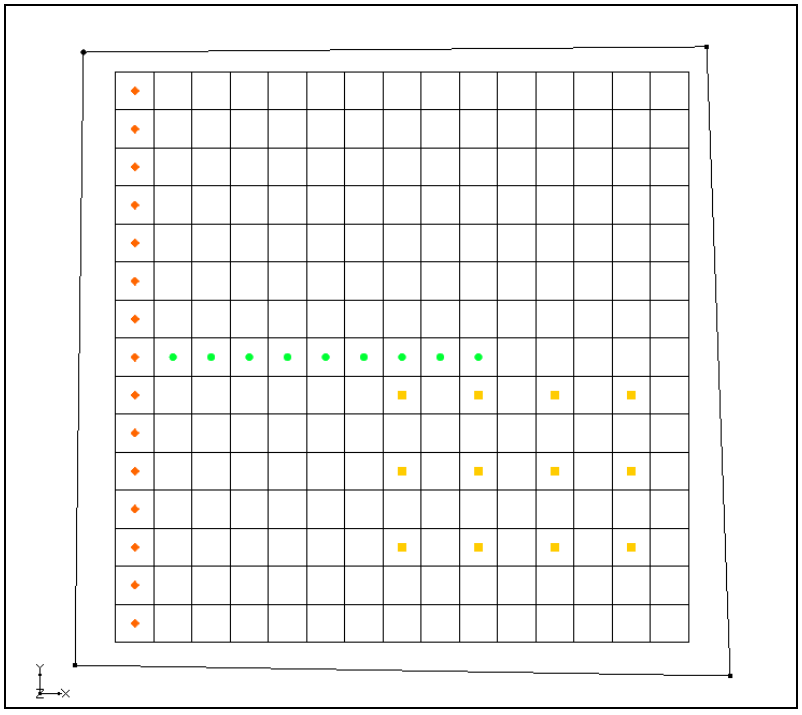

Figure 4 Creating a polygon that encompasses the model grid

17.4 Setting the Polygon Properties

1. Switch to the **Select** tool.
2. Double-click anywhere inside the polygon that was just created.
3. In the *Attribute Table* dialog, set the values to be as shown in Figure 5.

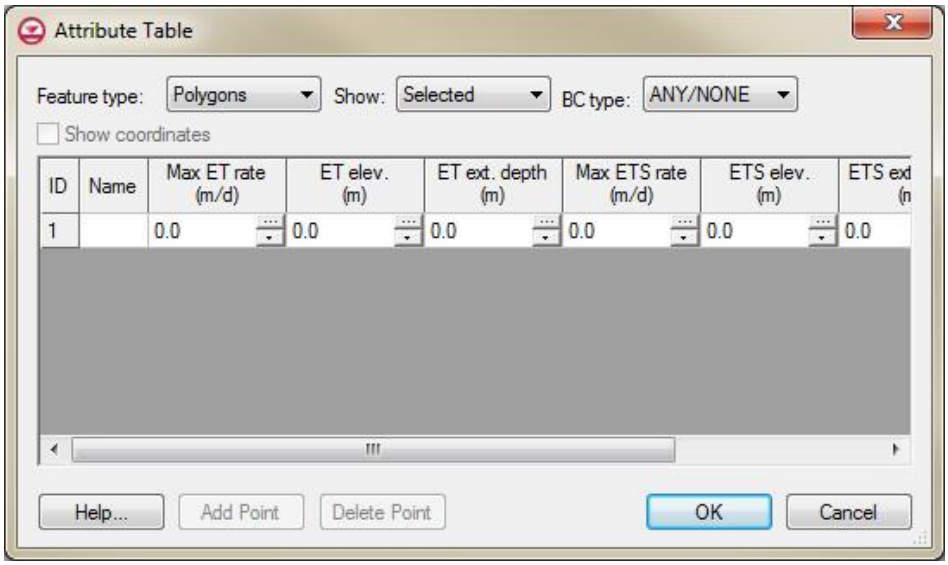

Figure 5 Coverage Properties dialog showing the polygon

The value in the *ETS segmented curve* column is the number of an XY series. The curves are defined using the XY Series Editor, and each XY series has a unique number. A value of -1 indicates that no XY series has been specified yet.

4. Click on the button in the *ETS segmented curve* column.

This brings up the *XY Series Editor*.

5. Enter the following values in the *XY Series Editor*.

PXDP	PETM
0	1
0.4	0.9
0.8	0.6
1	0

Note that these are different values than were used previously. Also, note that, in this case, the user will include the first and last values on the curve.

6. Click **OK** to exit the *XY Series Editor*.

Notice the value in the *ETS segmented curve* column has changed.

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

18 Map → MODFLOW

The conceptual model is set up so now it is possible to map it to the MODFLOW grid.

1. Select the *Feature Objects* | **Map → MODFLOW** menu command.
2. When the *Map → Model* dialog appears, click **OK**.

19 Examining the ETS Package

The next step is to take a look at the data in MODFLOW that was mapped from the conceptual model.

1. Select the *MODFLOW* | *Optional Packages* | **ETS - Evapotranspiration Segments** menu command.
2. In the *MODFLOW ETS Package* dialog, switch the *View/Edit* combo box between the various selections and check that the *Elevation* is "59," the *Max ET rate* is "0.01," and the *ET extinction depth* is "6."
3. Switch the *View/Edit* combo box to "PXDP, Curve segments."
4. Check that the *Segment array* for "1" are all "0.4"
5. Check that the *Segment array* for "2" are all "0.8."
6. Switch the *View/Edit* combo box to "PETM. Curve segments."
7. Check that the *Segment array* for "1" are all "0.9."
8. Check that the *Segment array* for "2" are all "0.6" for segment array 2.
9. Click **OK**.

20 Saving and Running MODFLOW

The next steps are to save our changes and run MODFLOW.

1. Select the **Save** button (or the *File* | **Save** menu command).
2. Select the *MODFLOW* | **Run MODFLOW** menu command.
3. When MODFLOW finishes, select the **Close** button.

The user should notice some slight changes in the new solution.

4. Compare all five solutions by alternately selecting the "modfgrid (MODFLOW)", the "evt (MODFLOW)", the "ets1 (MODFLOW)", the "ets2

(MODFLOW)" , and the "ets3 (MODFLOW)" items in the Project Explorer.

5. Select the **Save** button to save the project with the new solution.

21 Saving the Model with a New Name

Next the user will examine how parameters work with the EVT and ETS packages, so the user should save the model with a new name.

1. Select the *File* | **Save As** menu command.
2. Change the project name to "ets4."
3. Save the project by clicking the **Save** button.

22 Parameters

It is possible to use parameters with the EVT and ETS packages. This tutorial will use parameters to assign one ET rate to the left side of the model and a different rate to the right side.

22.1 Parameterizing the Model

1. Turn off the "Map Data" item in the Project Explorer.
2. Click on the "3D Grid Data" item in the Project Explorer to switch to the 3D grid module.
3. Select the **Select Cells** tool.
4. Drag a box around the right side of the model to select those cells as shown in the figure below.

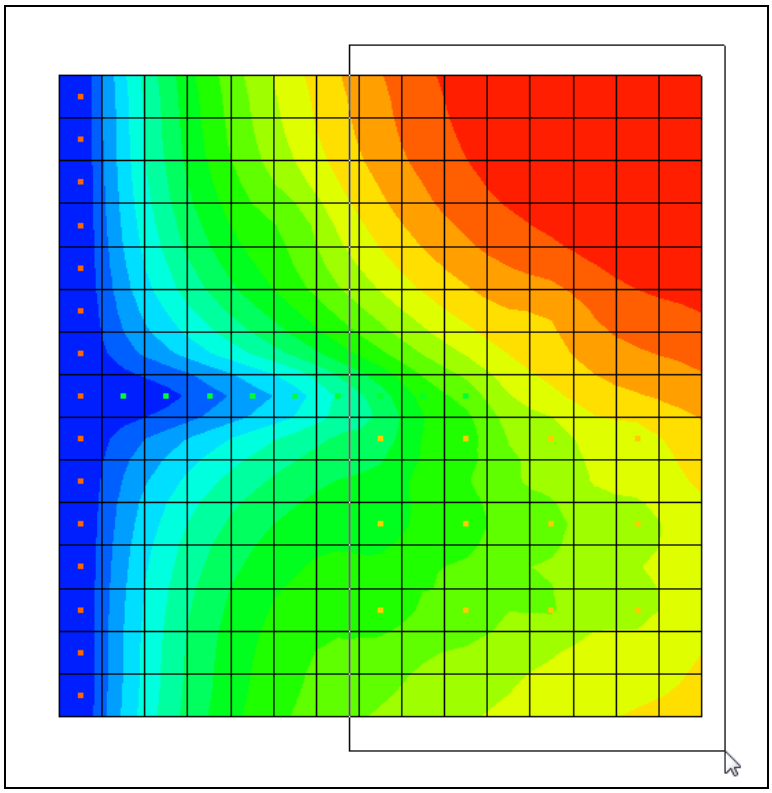

Figure 6 Dragging a box around the right side of the model

5. Right-click somewhere in the selected portion of the grid and select the **Sources/Sinks** command from the pop-up menu.

6. In the *MODFLOW Sources/Sinks* dialog, select on the *ETS* item in the list box on the left side of the dialog.

7. Enter "-10.0" in the All row for *ETS Max. et.*

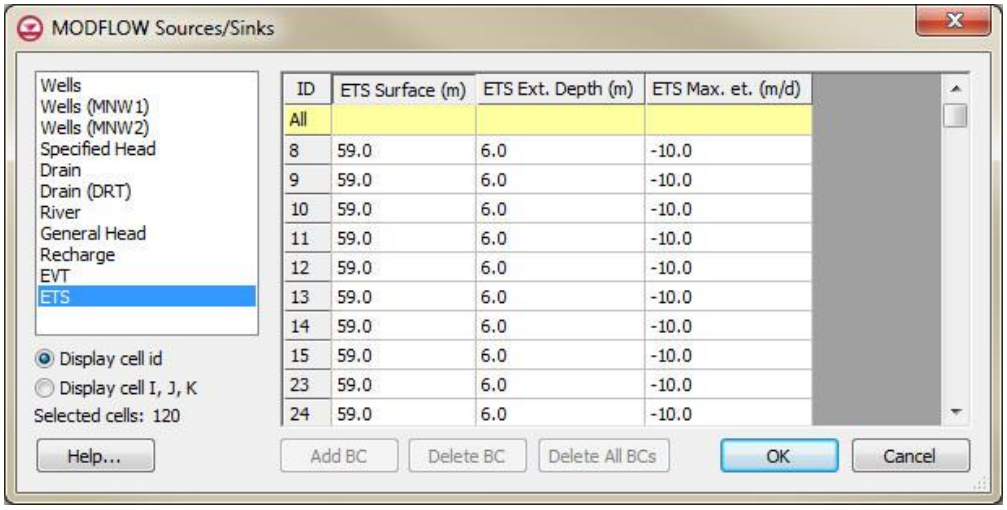

Figure 7 Changing the ETS rate to a key value of -10

Note that -10 is not a valid ET rate, but is a key value that indicates these cells will be associated with a parameter. The number can be any negative number.

8. Click **OK** to exit the *MODFLOW Source/Sinks* dialog.

9. Select the *MODFLOW* | **Parameters** menu command.

This brings up the *Parameters* dialog.

10. Select the **Initialize From Model** button.

This results in GMS looking through the model inputs for negative numbers and creating a parameter whenever one is found. In this case, GMS creates one parameter for the -10 values it encountered in the ETS package.

11. Make sure the *Value* of the parameter is "0.1."

The dialog should appear as shown below.

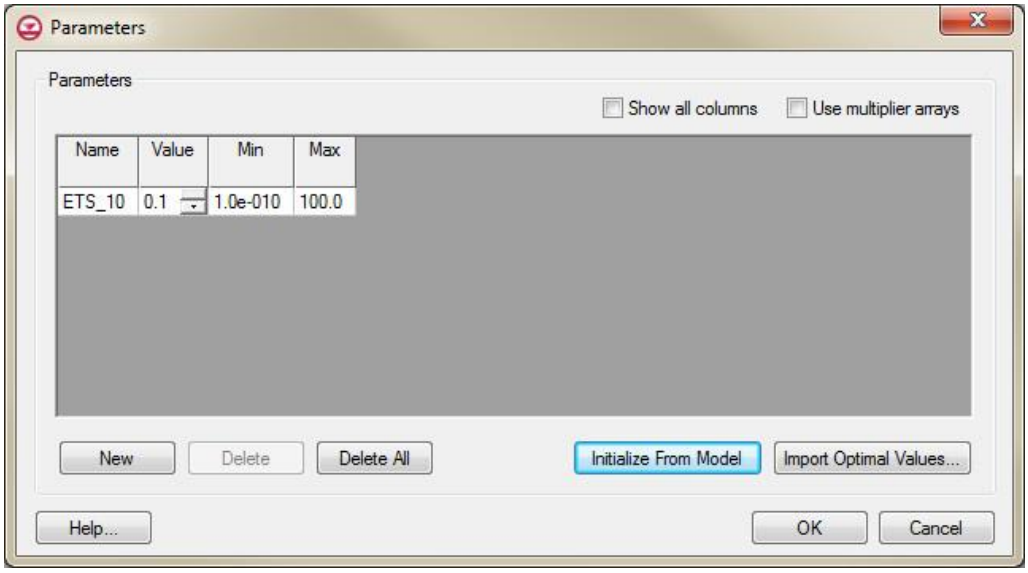

Figure 8 MODFLOW Parameters dialog

12. Click **OK** to exit the *Parameters* dialog.

23 Saving and running MODFLOW

The next steps are to save our changes and run MODFLOW.

1. Select the **Save** button (or the *File* | **Save** menu command).

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

3. When MODFLOW finishes, select the **Close** button.

The user should notice some slight changes in the new solution.

4. Compare all five solutions by alternately selecting the "modfgrid (MODFLOW)" , the "evt (MODFLOW)" , the "ets1 (MODFLOW)" , the "ets2 (MODFLOW)" , the "ets3 (MODFLOW)" , and the "ets4 (MODFLOW)" items in the Project Explorer.

5. Select the **Save** button to save the project with the new solution.

24 Conclusion

This concludes the tutorial. Here are the key concepts from this tutorial:

- GMS supports both the EVT and ETS packages. Both packages can be used at the same time if desired.
- The ETS package produces the same results as the EVT package if only one curve segment is defined.
- ETS data can be viewed and edited in the ETS Package dialog.
- The order in which the PXDP and PETM data is entered is important. PXDP values should be in increasing order and PETM values should be in decreasing order.
- ETS data can be defined on polygons in a conceptual model.