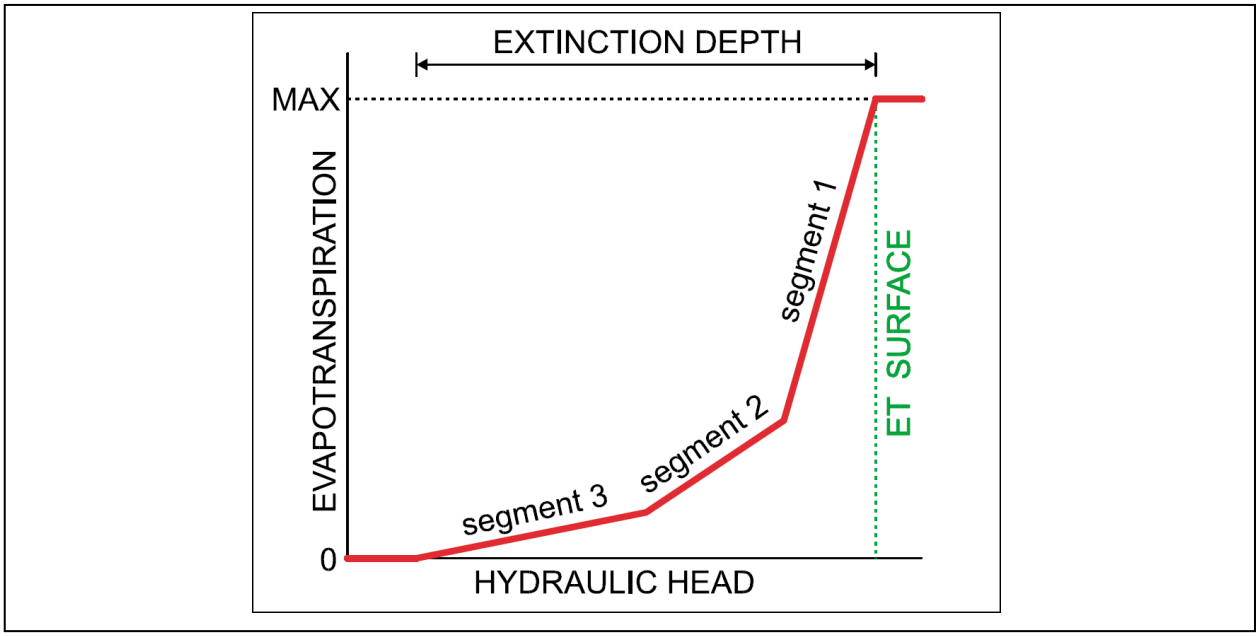
GMS 9.2 Tutorial

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

- None

Required Components

- Map
- Grid
- MODFLOW

Time

- 30-60 minutes

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1 Contents

2 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 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.

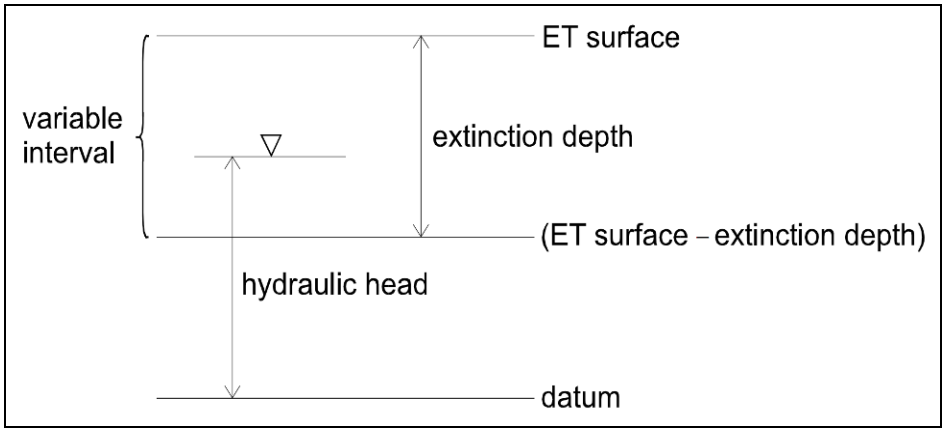

Figure 1. ET model, from Banta, 2000.[1]

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.

2.1 Outline

This is what you will do in 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.

3 Description of Problem

The problem we will be solving in this tutorial is the same as the problem in the *MODFLOW – Grid Approach* tutorial, and 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) that has three layers, some wells, some drains, recharge, and constant head cells.

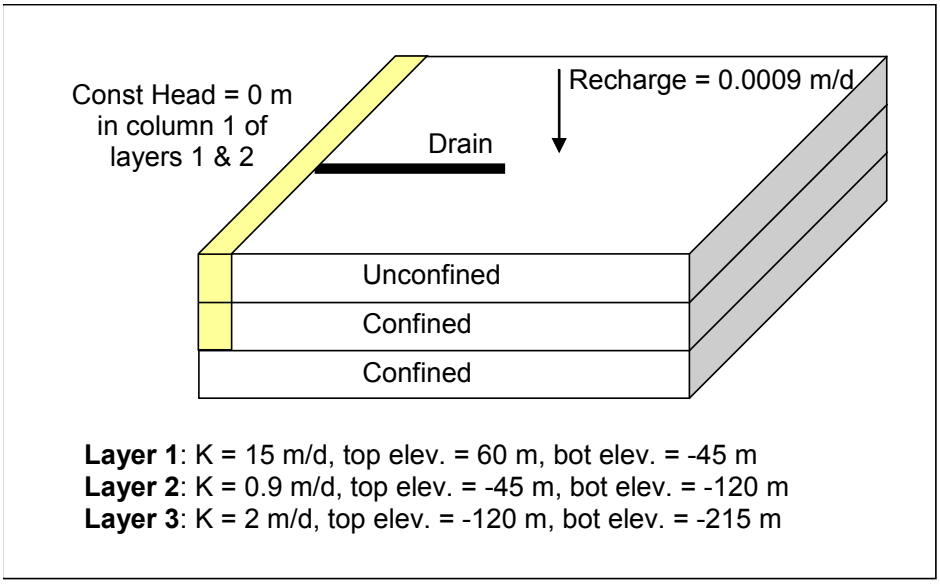

Figure 2. Sample problem to be solved.

4 Getting Started

Let's get started.

1. If necessary, launch GMS. If GMS is already running, select the *File* | *New* command to ensure that the program settings are restored to their default state.

5 Open the existing model

We will 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. Open the **modfgrid.gpr** file.

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

6 Save the model with a new name

We're ready to start making changes. Let's 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.

7 Add ET via the EVT package

The first change we'll make is to add ET to the model via the EVT package.

7.1 Turn on the EVT package

We need to turn on the EVT package.

4. Select the *MODFLOW* | *Global Options* menu command.
5. Select the *Packages* button.
6. Turn **on** the *Evapotranspiration (EVT1)* package.
7. Click *OK* twice to exit the *Packages* dialog and the *Global Options* dialog.

7.2 Specify ET

Now we need to specify the ET parameters.

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

This brings up the EVT package dialog. We'll set the ET surface elevation to be 59 meters, just 1 meter below the ground surface. We'll 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 **Max ET rate**.
2. Select the *Constant* → *Array* button.
3. Enter a value of **.01** and click *OK*.

ET Surface

1. Switch the *View/Edit* combo box to **Elevation**.
2. Select the *Constant* → *Array* button.
3. Enter a value of **59** and click *OK*.

Extinction depth

1. Switch the *View/Edit* combo box to **ET extinction depth**.
2. Select the *Constant* → *Array* button.
3. Enter a value of **6** and click *OK*.

We're done making our changes. You may have noticed the *ET option* combo box. We will not change it because we want to leave it at the default, which is to apply ET only to the top layer of cells.

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

8 Save and run MODFLOW

We're ready 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.

You should notice some changes in the new solution.

4. 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.

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

9 Examine the flow budget

We'll 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 *Evapotranspiration* 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.

10 Save the model with a new name

We are about to change the model to use the ETS package, so let's 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.

11 Add ET via the ETS package

Now we'll switch to the ETS package to model evapotranspiration. At first we will not define any curve segments so that the ETS package will work just like the EVT package. Later we will add segments.

11.1 Turn off the EVT package and turn on the ETS package

We need to turn on the ETS package.

1. Select the *MODFLOW* | *Global Options* menu command.
2. Select the *Packages* button.
3. Turn **off** the *Evapotranspiration (EVT1)* package and turn **on** the *Evapotranspiration (ETS1)* package.
4. Click *OK* twice to exit the *Packages* dialog and the *Global Options* dialog.

11.2 Specify ET

Now we need to specify the ET parameters.

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

This brings up the ETS package dialog. It's very similar to the EVT package dialog. We'll set the ET parameters to the same values that we did for the EVT package.

2. Repeat the steps you 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.
3. Click *OK* when you are finished to exit the *MODFLOW ETS Package* dialog.

Notice that we 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.

11.3 Switch 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 *Other output* section, under the **.hff file for transport* item, switch the setting to **Extended header format**.
3. Click *OK*.

Alternatively we could have just turned off the **.hff file for transport* item since we are not going to use MT3D with this model.

12 Save and run MODFLOW

We're ready 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.

13 Examine the flow budget

We'll 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 *Evapotranspiration (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. Also notice that now there is no flow at all for the EVT package (listed as simply "Evapotranspiration" in the dialog).

4. Select *OK* to exit the dialog.

14 Saving the model with a new name

We are about to change the model to use a nonlinear curve for ETS, so let's 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.

15 Adding ETS curve segments

Now we'll actually take advantage of the extra functionality in the ETS package by specifying a nonlinear curve. We'll create a curve that looks like this:

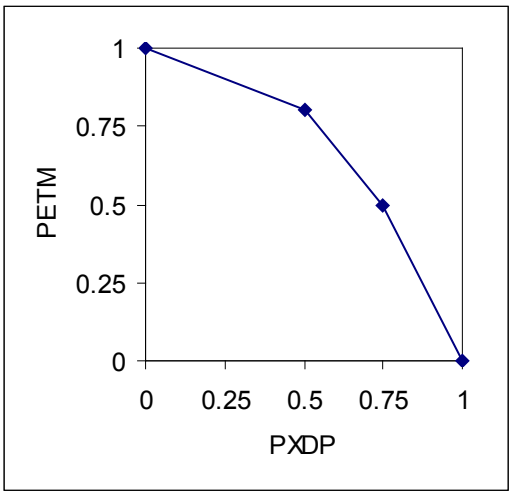

Figure 3. Nonlinear ET curve with two segments.

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.[1]

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 drops more rapidly as the head approaches the extinction depth. The values for PXDP and PETM in this case are:

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, we need to change the number of segments (NETSEG) to 3, and define the points where the segments meet. Since there are three segments, there are two points of intersection that 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. We only need to define the two interior points on the curve.

15.1 Change NETSEG

To change the number of segments:

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

2. Change *NETSEG* to **3**.

15.2 Define the PXDP data

We'll define the PXDP values for both points. We'll 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 we enter 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.*[1] (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 we are viewing/editing data for the first point.
3. Select the *Constant* → *Array* button.
4. 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. Enter a value of **0.75** and click *OK*.

15.3 Define the PETM data

Now we'll define the PETM data for both points. Again, we'll 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. Enter a value of **0.8** and click *OK*.
5. Set the *Segment array* to **2**.
6. Select the *Constant* → *Array* button.
7. Enter a value of **0.5** and click *OK*.
8. Click *OK* to exit the *MODFLOW ETS Package* dialog.

16 Saving and running MODFLOW

We're ready 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.

You 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.

17 Saving the model with a new name

We are about to change the model to use a conceptual model, so let's 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.

18 Building a Conceptual Model

Now we'll examine how to use a conceptual model with ETS data.

18.1 Create 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*.

18.2 Create a Coverage

1. Right-click on the **modfgrid** conceptual model you just created in the *Project Explorer* and select the *New Coverage* command from the pop-up menu.

2. In the *Coverage Setup* dialog, change the *Coverage Name* to **ets**.
3. In the list of *Areal Properties*, turn **on** the following:
   - *Max ETS rate*
   - *ETS elev.*
   - *ETS Extinction depth*
   - *ETS Segmented curve*
4. Click *OK* to exit the *Coverage Setup* dialog.

18.3 Create the polygon

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

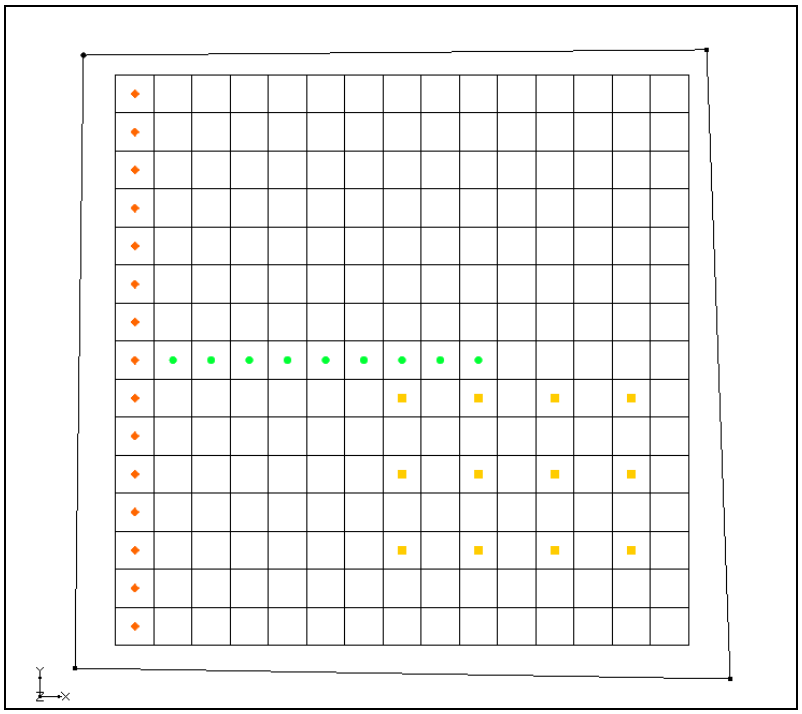

Figure 4. Creating a polygon that encompasses the model grid.

18.4 Set the Polygon Properties

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

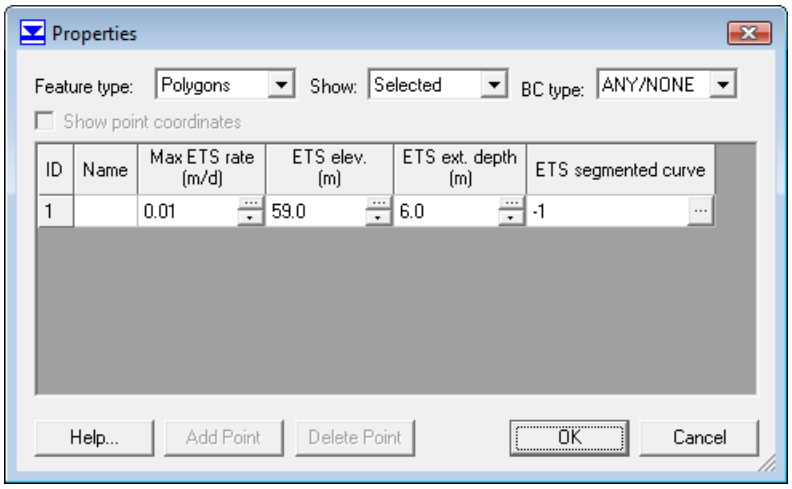

Figure 5. Coverage Properties dialog showing the polygon.

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 we used previously. Also note that in this case we do 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 *Properties* dialog.

19 Map → MODFLOW

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

1. Select the *Feature Objects* | *Map → MODFLOW* menu command.
2. Click *OK*.

20 Examine the ETS Package

Let's 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. 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. Switch the *Segment array* between **1** and **2** and verify that the PXDP values are all **0.4** for segment array 1 and **0.8** for segment array 2.
5. Switch the *View/Edit* combo box to **PETM curve segments**.
6. Switch the *Segment array* between **1** and **2** and verify that the PETM values are all **0.9** for segment array 1 and **0.6** for segment array 2.
7. Click *OK*.

21 Saving and running MODFLOW

We're ready 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.

You 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.

22 Saving the model with a new name

Next we'll examine how parameters work with the EVT and ETS packages, so let's 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.

23 Parameters

You can use parameters with the EVT and ETS packages. We'll use parameters to assign one ET rate to the left side of the model and a different rate to the right side.

23.1 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 show in the figure below.

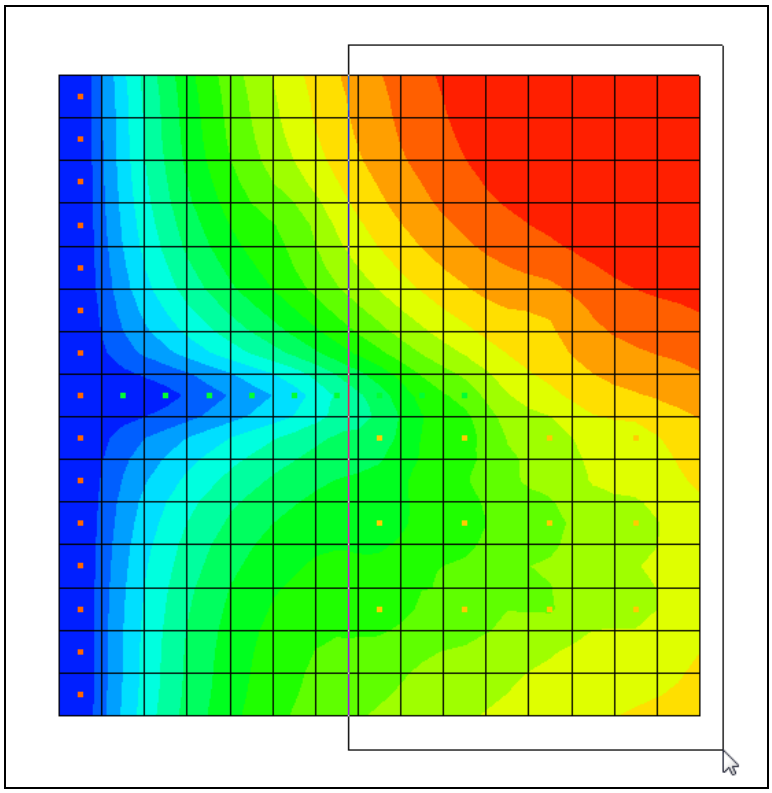

Figure 6. Dragging a box around the right side of the model.

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

6. 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.*.

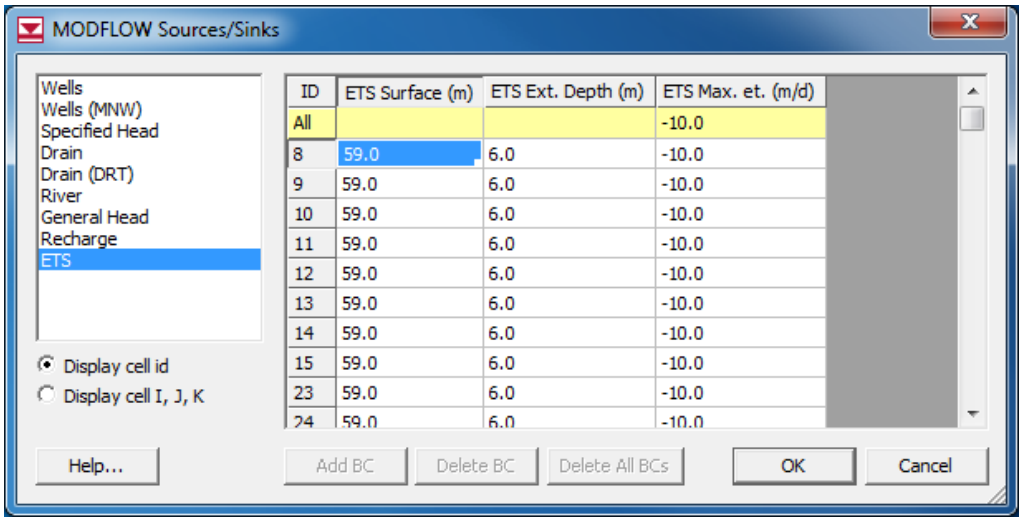

Figure 7. Changing the ET rate to a key value of -10.

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/Sink* 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. Change the value of the parameter to **0.1**.

The dialog should appear as shown below.

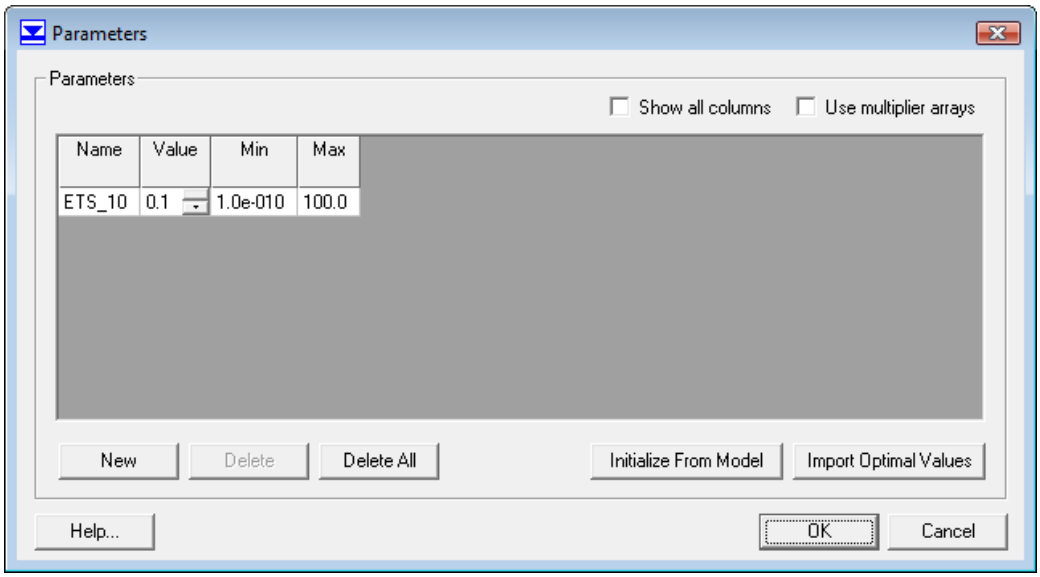

Figure 8. MODFLOW Parameters dialog.

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

24 Saving and running MODFLOW

We're ready 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.

You 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.

25 Conclusion

This concludes the tutorial. Here are the things that you should have learned in 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 that 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.

26 Notes

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.

