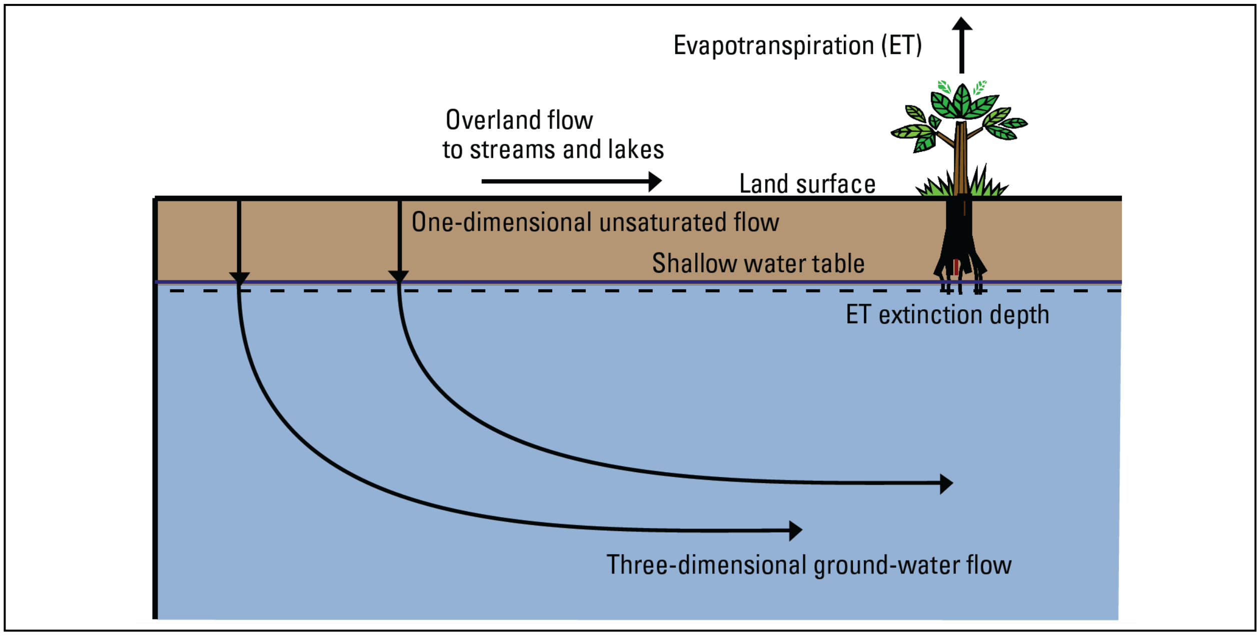
v. 10.0

GMS 10.0 Tutorial

MODFLOW – UZF Package

The MODFLOW Unsaturated-Zone Flow (UZF) Package Interface in GMS



Objectives

This tutorial explains how to use the MODFLOW Unsaturated-Zone Flow (UZF) package and compares it to the RCH and EVT packages.

Prerequisite Tutorials

- Feature Objects
- MODFLOW - Conceptual Model Approach

Required Components

- Map
- Grid
- MODFLOW

Time

- 30-60 minutes

1 Contents

2 Introduction

The Unsaturated-Zone Flow (UZF) package was developed by the USGS to more accurately model recharge of groundwater through an unsaturated zone. The package models percolation of precipitation through the unsaturated zone and can include storage in the unsaturated zone, groundwater recharge, evapotranspiration, and surface discharge. The surface discharge can be routed to streams or lakes, or, if a lake or stream is not specified the discharge is removed from the model. The package was designed to be substituted for the EVT and RCH packages although they can all be used at the same time. The UZF package is only available in MODFLOW-2005.

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2.1 Outline

This is what you will do in this tutorial:

1. Import an existing MODFLOW simulation.
2. Run the simulation and examine the results to understand the UZF package options.
3. Modify a conceptual model to use UZF instead of the RCH and EVT packages.

3 Description of Problem

The problem we will be solving in this tutorial is the same as the model used in the UZF documentation.[1] The model was first described in the SFR documentation.[2]

> The hypothetical stream-aquifer interaction problem used in this test simulation was developed for an alluvial basin in a semiarid region. The principal aquifer comprises unconsolidated deposits of mostly sand and gravel. Recharge to the aquifer primarily is leakage from the streams that enter the basin from the mountains on the northwest, northeast, and southwest. The main stream in the southern part of the valley is perennial, whereas all other streams in the valley are intermittent with small drainage areas. Streamflow entering the model domain and diversions from streams were the same as that used by Prudic and others (2004) and remained the same for all stress periods. Different methods were used to represent the relations between width, depth and flow in the streams. Infiltration rates in the UZF1 Package file and pumping rates in the Well Package file were varied during 12 stress periods but the distribution of infiltration and pumping among grid cells did not change. The ET demand was specified as constant over the entire modeled area equal to 1.6 ft/yr to a maximum depth of 15 ft below land surface. The LPF Package was used to specify hydraulic properties for the aquifer. The hydraulic conductivity and specific yield were 173 ft/d and 0.2, respectively, in the vicinity of the stream channels and the hydraulic conductivity and specific yield were 35 ft/d and 0.1, respectively, elsewhere in the alluvial basin.

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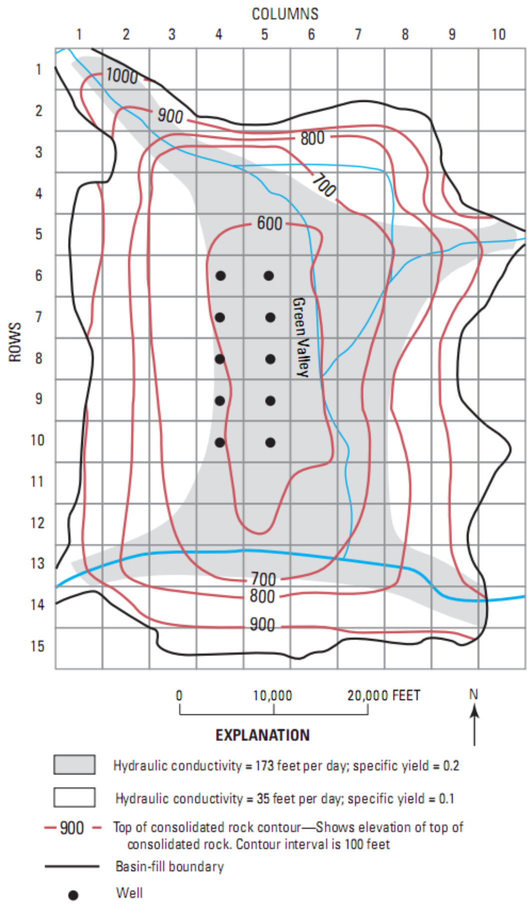

Figure 1. Flow model from UZF documentation.[1]

The model grid was divided into uniformly spaced cells 5,000 ft on each side. The strongly implicit procedure (SIP) was used to solve the flow equation for test simulation 2. The head-closure criterion was 0.0002. The option to add overland runoff to stream segments was specified in the UZF1 Package; however, no ground-water seepage to land surface was simulated in the test. The number of stress periods in the Discretization file was 12. Each stress period was 2.628×106 seconds or 30.42 days. The first stress period was steady state and had one time step. This allowed for the calculation of initial water contents for the unsaturated zone on the basis of the steady-state infiltration rate. The remaining 11 stress periods were transient and were divided into 15 time steps that increased sequentially by a factor of 1.1.[1]

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.

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5 Import 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\uzf** folder.
3. Change the *Files of type* selection box to *MODFLOW Name Files*.
4. Open the *UZFtest2.nam* file.

A dialog should alert you that the model needs to be translated into GMS format.

5. Click *OK* to translate the model.

Now the MODFLOW Translator runs and ends with a message saying MODFLOW 2005 terminated successfully.

6. Press *Done*.

This imports the model. You should see a grid with symbols representing wells, streams, and general head boundary conditions similar to the figure below.

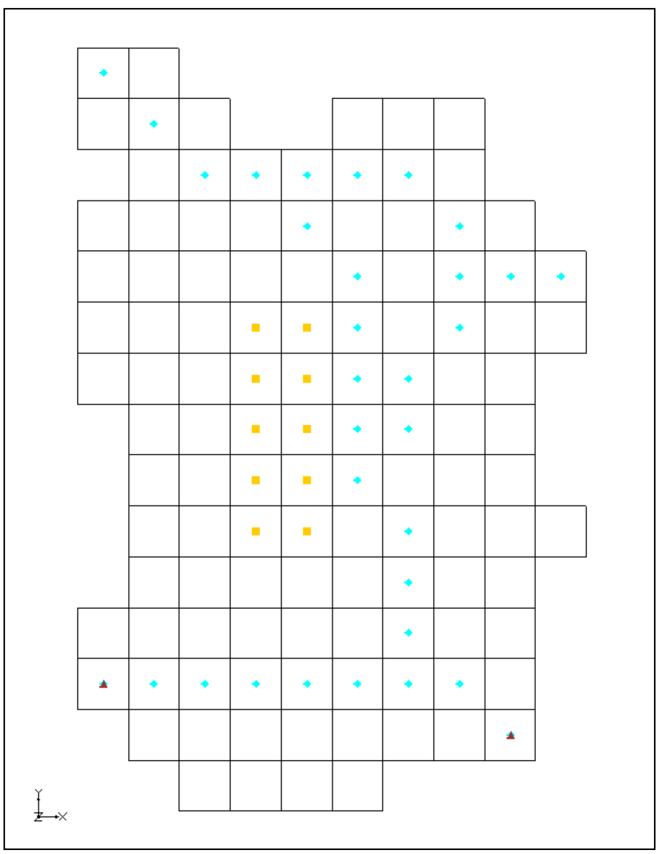

Figure 2. Imported MODFLOW model.

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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. Make sure you are still in the **Tutorials\MODFLOW\UZF** folder.
3. Change the project name to **UZF.gpr**.
4. Save the project by clicking the *Save* button.

7 View the UZF boundary conditions

Before running the simulation we'll view the UZF boundary conditions in the UZF Package dialog.

7.1 The UZF Package Dialog

1. Select the *MODFLOW* | *Optional Packages* | *UZF - Unsaturated Zone Flow* command to open the *UZF Package* dialog.

This dialog is used to edit existing UZF boundary conditions and to change options associated with the UZF package. The options located on the left of the dialog apply to the UZF package while the spreadsheet on the right allows the user to edit individual UZF boundary conditions. Instead of repeating all of the UZF documentation here, it is recommended that the user review the UZF documentation for more information on each input option. UZF documentation can be found at the following URL: http://water.usgs.gov/nrp/gwsoftware/modflow2000/MFDOC/uzf___unsaturated_zone_flow_pa_3.htm.

Now we will examine the UZF boundary conditions. The boundary conditions for the UZF package can be edited in the spreadsheet on the right with the different boundary condition arrays selectable using the *View/Edit* combo box. The first four arrays listed in the combo box can vary per stress period including *Infiltration Rate*, *ET Demand Rate*, *ET Extinction Depth*, and *ET Water Content*. Ensure that *Infiltration Rate* is selected in the *View/Edit* popup menu, notice that the *Multiplier* is set to **1.0e-09**.

2. Change the current *Stress period* to **2**.

Notice that the *Multiplier* field is now set to **8.0e-09**. For this simulation the infiltration rate changes via the *Multiplier* field through most of the remaining stress periods. You may wish to view the other arrays for additional UZF boundary conditions. Refer to the UZF documentation for a full explanation of each of the inputs to the UZF boundary conditions.

3. Close the dialog by pressing the *OK* button.

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7.2 The Sources/Sinks Dialog

1. Switch to the 3D Grid module by selecting the 3D Grid Data item in the *Project Explorer*.

2. Select all of the cells in the 3D grid by selecting *Edit* | *Select All* command.

3. Open the *MODFLOW Source/Sinks* dialog by right clicking on one of the selected cells and selecting the *Sources/Sinks* command.

4. From the list at the left of the *Sources/Sinks* dialog select UZF.

This dialog allows you to edit the properties of a selected boundary condition as well as add additional source/sink boundary conditions in the selected cells. For the areal boundary conditions such as EVT, RCH, and UZF the package has to be turned on before it becomes available. For UZF boundary conditions the values associated with stress periods can be entered as a constant value for all stress periods or as a time-varying XY series.

5. Select *OK* to exit the dialog.

6. Click outside of the grid to unselect the cells.

8 Run MODFLOW

Before running MODFLOW we need to change the output options to make it easier to see the results.

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

2. From the *Output interval* section, select the *Output at last time step of each stress period* radio button.

3. Turn **on** the *Save cell by cell flow terms to *.ccf file* toggle.

4. Press the *OK* button to exit the *MODFLOW Output Control* dialog.

Now we are ready to save our changes and run MODFLOW.

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

6. Select the *Run Modflow* button (or the *MODFLOW* | *Run MODFLOW* menu command).

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

Block-fill contours should appear on the grid similar to those shown in the following figure:

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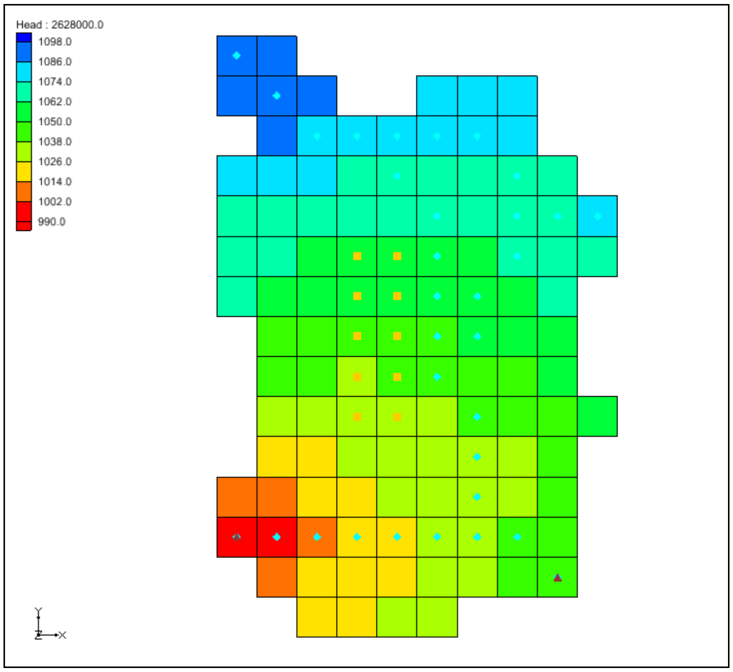

Figure 3. MODFLOW solution.

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

9 Examine the Solution

Now we will look more closely at the computed solution. The solution contours show that the potential for flow for this model is from the top left down toward the bottom left.

9.1 The Flow Budget Dialog

Let's examine the flow budget for this simulation.

1. In the *Project Explorer* click on the **Head** dataset.

The *Time Step* window appears at the bottom of the *Project Explorer*, and the first stress period is selected.

2. If necessary click outside the grid to make sure none of the cells are selected and select the *MODFLOW | Flow Budget…* menu item.

The flow budget for all cells for the time step at the end of the first stress period is shown. Note that the flow for *UZF Recharge* is **8.4** (into the model) and the flow for *UZF Groundwater ET.* is **-20.4** (out of the model). At the end of the first stress period there is no *UZF Surface Leakage*.

3. Select the *Zones* tab at the top of the *Flow Budget* dialog.

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4. Toggle on *Use all timesteps*.

The generated spreadsheet shows the flow budget for the last time step of each stress period.

5. Scroll down through each time step noticing the flow budget values for the UZF package.

Notice the UZF surface leakage is 0.0 in all stress periods.

6. Select the *OK* button to exit the *Flow Budget* dialog.

9.2 The .out file

MODFLOW also generates a flow budget for the unsaturated zone that's available in the MODFLOW list output file. Let's look at the flow budget for the unsaturated zone.

1. Double click on UZF.out in the *Project Explorer*. (If prompted with the *View Data File* dialog, select the program to use to view the text file and click *OK*.)

2. Scroll to the bottom of the document that appears and then up a few pages until you find the unsaturated zone budget.

3. Close the UZF.out document.

A UZF flow budget is printed to the out file at the end of each time step just like the volumetric flow budget for the entire model.

10 Increase the infiltration rate

Now let's try increasing the infiltration rate and see what affect it has on the model.

1. Select the *MODFLOW | Optional Packages | UZF - Unsaturated Zone Flow* command to open the *UZF Package* dialog.

2. Change the current *Stress period* to **2**.

3. Make sure the *View/Edit* combo box is set to *Infiltration Rate (FINF)*.

4. Change the *Multiplier* from 8.0e-009 to **8.0e-008**.

5. Close the dialog by pressing the *OK* button.

11 Run MODFLOW

We'll run MODFLOW again to generate a new solution.

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1. Select the *Run Modflow* button (or the *MODFLOW | Run MODFLOW* menu command).

2. When prompted to save your changes, select *Yes*.

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

12 Examine the Solution

Let's look at the solution to find out if increasing the infiltration rate caused any UZF surface leakage.

12.1 The Flow Budget Dialog

1. In the *Project Explorer* click on the **Head** dataset.

The *Time Step* window appears at the bottom of the *Project Explorer*, and the first stress period is selected.

2. In the *Time Step* window, click on time step number **2**.

3. Select the *MODFLOW | Flow Budget* menu item.

The flow budget for all cells for the current time step is shown. Note that *UZF Surface Leakage* is **-0.128** (out of the model).

4. Select the *OK* button to exit the *Flow Budget* dialog.

12.2 CCF Data Sets

Let's see where the surface leakage is occurring.

1. Right click on the *CCF* item in the project explorer and select the *CCF → Data Sets* command.

2. Select the data set named **UZF Surface Leakage**.

3. In the *Time Step* window, click on time step number **2**.

You should see an image similar to the figure below. Most of the grid should have a value of zero for the data set. A few cells have negative values indicating surface leakage.

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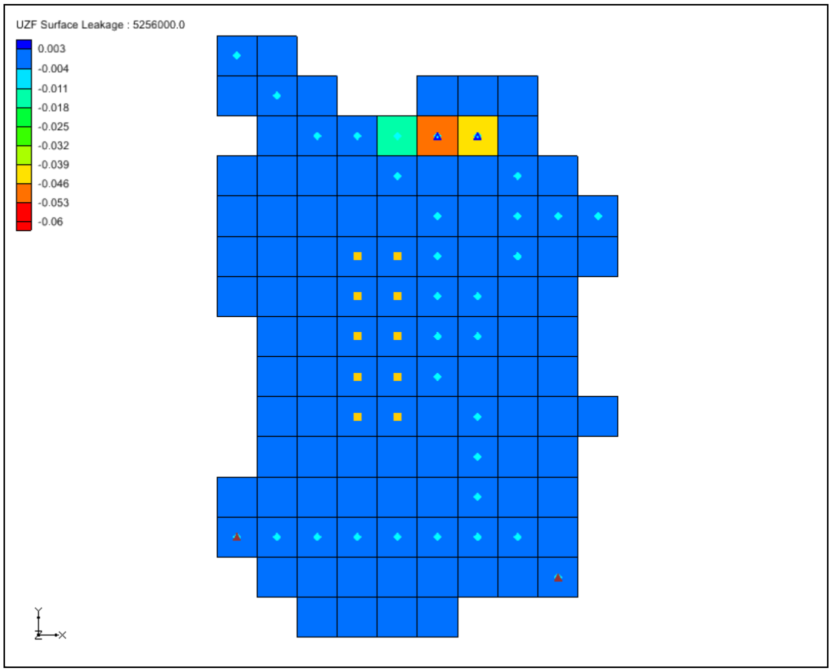

Figure 4. Surface leakage cells.

13 Create a Conceptual Model

Now we'll examine how to use a conceptual model with UZF data. We'll do this by taking a modified version of the finished model for the MODFLOW – SFR package tutorial and changing it to use the UZF package.

13.1 Open the Existing Conceptual Model

1. Before opening the conceptual model you may wish to save the grid based UZF model by selecting the *Save* button.
2. Select the *New* button.
3. Select the *Open* button.
4. Locate and open the directory entitled **Tutorials\MODFLOW\uzf**.
5. Open the file entitled **SFRmap.gpr**.

Before we make any changes, lets save the project under a new name.

6. Select the *File* | *Save As* command.
7. Save the project with the name **UZFmap.gpr.**

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14 Examine the Existing Solution

Before changing to the UZF package lets look at the Flow Budget for the existing solution.

1. Select the *MODFLOW | Flow Budget* command.

Notice the flow budget for the Recharge package has a flow rate of **145.0** (into the model), and the Evapotranspiration package has a flow rate of **-46.09** (out of the model).

2. Press the *OK* button the exit the *Flow Budget* dialog.

15 Change the Model to Use UZF

To change to the UZF package, first the RCH and EVT packages need to be removed from MODFLOW.

1. Select the *MODFLOW | Global Options* command.
2. Change the MODFLOW version to *2005*.
3. Press the *Packages* button to bring up the *MODFLOW Packages* dialog.
4. Unselect the *Recharge (RCH1*) toggle to disable the RCH package.
5. Unselect the *Evapotranspiration (EVT1*) toggle to disable the EVT package.
6. Press the *OK* button twice to exit both dialogs.

15.1 Changing to UZF

1. Expand the **Green Valley** conceptual model in the *Project Explorer* below **Map Data** and select the **Recharge & ET** coverage.
2. Right click on the **Recharge & ET** coverage and select *Coverage Setup*.
3. Turn **on** the *UZF FINF (Infiltration Rate), UZF PET (ET Demand Rate), and UZF EXTDP (ET Extinct. Depth)* toggles in the *Areal Properties* section of the dialog.
4. Press the *OK* button to exit the *Coverage Setup* dialog.
5. Right-click on the **Recharge & ET** coverage and select *Attribute Table*.
6. Change the *Feature type* combo box to **Polygons**.
7. Change the *UZF FINF (Infiltration Rate)* to **5.0e-8**, the *UZF PET (ET Demand Rate)* to **8.5e-8**, and the *UZF EXTDP (ET Extinct. Depth)* to **15**.

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Notice that these values match the values for the recharge and evapotranspiration packages.

8. Press the *OK* button to exit the *Properties* dialog.
9. Right click on the **Recharge & ET** coverage and select *Coverage Setup*.
10. Turn **off** the *Recharge rate*, *Max ET rate*, and *ET Extinction depth* toggles.
11. Press the *OK* button to exit the *Coverage Setup* dialog.

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

12. Select the *Map →MODFLOW* button.
13. Click *OK* at the prompt.

16 Examine and Configure the UZF Package

Let's take a look at the data in MODFLOW that was mapped from the conceptual model.

1. Select the *MODFLOW | Optional Packages | UZF - Unsaturated Zone Flow* menu command and review the UZF boundary conditions that were created.

You can look at the UZF data on the right side of the dialog and verify that the *Infiltration Rate*, *ET Demand Rate*, and *ET Extinction Depth* have the values entered in the conceptual model. The default settings for the UZF package have evapotranspiration disabled. Evapotranspiration must be turned on in the UZF package dialog.

2. Turn on the *IETFLG. Simulate ET* toggle.
3. Click *OK* to exit the dialog.

17 Save and run MODFLOW

We're ready to save our changes and run MODFLOW.

1. Select the *Run MODFLOW* button.
2. Select *Yes* at the prompt to save your changes.
3. When MODFLOW finishes, select the *Close* button.
4. Select the *Save* button to save the project with the new solution.

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18 Examine the Solution

Let's look at the flow budget for the new solution.

1. Select the *MODFLOW | Flow Budget* command.

Notice the flow budget has changed. For recharge the UZF package gives nearly the same flow rate as the RCH package with a flow rate of **144.7** (into the model), and the flow budget *UZF Groundwater ET* is now **-55.0** (out of the model). The *UZF Surface Leakage* flow is **-8.97**. Since we don't have routing to streams turned on, this amount is leaving the model.

2. Press the *OK* button the exit the *Flow Budget* dialog.

19 Add Routing to Streams

Now we will add routing from the unsaturated zone to surface streams.

1. Hide the 3D grid by turning off the check box next to the *3D Grid Data* folder in the *Project Explorer*.
2. Hide the image by turning off the *Images* folder in the project explorer.
3. Click on the **UZF Stream** coverage in the project explorer.

The coverage will become visible in the graphics view. The coverage is made up of polygons that have been labeled beginning with **Polygon 1** and ending at **Polygon 8**. Each polygon matches to a stream segment in the Streams coverage. Once set up, any UZF surface leakage in a given polygon will be routed to its associated stream segment.

4. Right click on the **UZF Stream** coverage and select *Coverage Setup*.
5. In the *Areal Properties* section, toggle **on** *UZF IRUNBND*.
6. Press *OK* to close the *Coverage Setup* dialog.
7. Right click on the **UZF Stream** coverage and select the *Attribute Table* command.
8. If necessary, change the *Feature type* to **Polygons**.
9. In the *UZF IRUNBND* column change each value of UZF IRUNBND to match the polygon number.
10. Select *OK* to exit the dialog.

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

11. Select the *Map → MODFLOW* button.

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12. Click *OK* at the prompt.

20 Configure the UZF Package

Let's take a look at the data in MODFLOW that was mapped from the conceptual model.

1. Select the *MODFLOW | Optional Packages | UZF - Unsaturated Zone Flow* menu command.
2. Change the *View/Edit* combo box to **Stream Segments/Lakes (IRUNBND)**.

The values in the spreadsheet now match the values we mapped from the conceptual model. One change still needed is to enable the routing of surface discharge to the streams.

3. Toggle **on** the *IRUNFLG* check box to enable routing.
4. Click *OK* to exit the dialog.

21 Save and Run MODFLOW

We're ready to save our changes and run MODFLOW.

1. Turn on the 3D Grid Data folder in the Project Explorer so we can view the results.
2. Select the *File | Save As* menu command.
3. Change the project name to **UZFmap2** and click *Save*.
4. Select the *Run MODFLOW* button.
5. When MODFLOW finishes, select the *Close* button.

22 View the Changes

Now we will view the changes to the output caused by turning on stream routing.

1. Right click on the **CCF** data set under the *UZFmap2 (MODFLOW)* solution and select the *CCF → Data Sets* command.
2. Select the newly created **UZF Surface Leakage** data set.
3. Select the *Contours* button.
4. In the *Contour method* section of the dialog, change the method to **Block Fill**.

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5. Select OK to exit the dialog.

Notice that two of the cells toward the bottom left of the model show surface leakage.

6. Select the two cells with surface leakage by clicking on one and then shift-clicking on the other.

7. Select the *MODFLOW | Flow Budget* menu command.

Notice that the flow rates for the *Streams (SFR2)* and the *UZF Surface Leakage* are **-1.95** and **-10.66** respectively.

8. Click *OK* to exit the *Flow Budget* dialog.

9. If necessary, expand the *UZFmap (MODFLOW)* solution in the *Project Explorer*, and underneath it select the **Head** dataset.

10. With the same two cells still selected, select the *MODFLOW | Flow Budget* menu command.

Notice that the flow rates for the *Streams (SFR2)* and the *UZF Surface Leakage* are **-3.36** and **-8.97** respectively. For this model turning on stream routing caused a small change to the model in these cells.

23 Conclusion

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

- GMS supports the UZF package with MODFLOW-2005.
- The UZF package is meant to replace the RCH and EVT packages and provides additional functionality.
- UZF data can be viewed and edited in the *UZF Package* dialog.
- UZF data can be entered in a conceptual model and then mapped to MODFLOW.
- The settings in the UZF package may need to be adjusted to match the UZF properties selected in the Map module.

24 Notes

1. Niswonger, R.G., Prudic, D.E., and Regan, R.S., 2006, Documentation of the Unsaturated-Zone Flow (UZF1) Package for modeling unsaturated flow between the land surface and the water table with MODFLOW-2005: U.S. Geological Techniques and Methods Book 6, Chapter A19.

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2. Prudic, D.E., Konikow, L.F., and Banta, E.R., 2004, A new stream-flow routing (SFR1) package to simulate stream-aquifer interaction with MODFLOW-2000: U.S. Geological Survey Open-File Report 2004-1042.

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