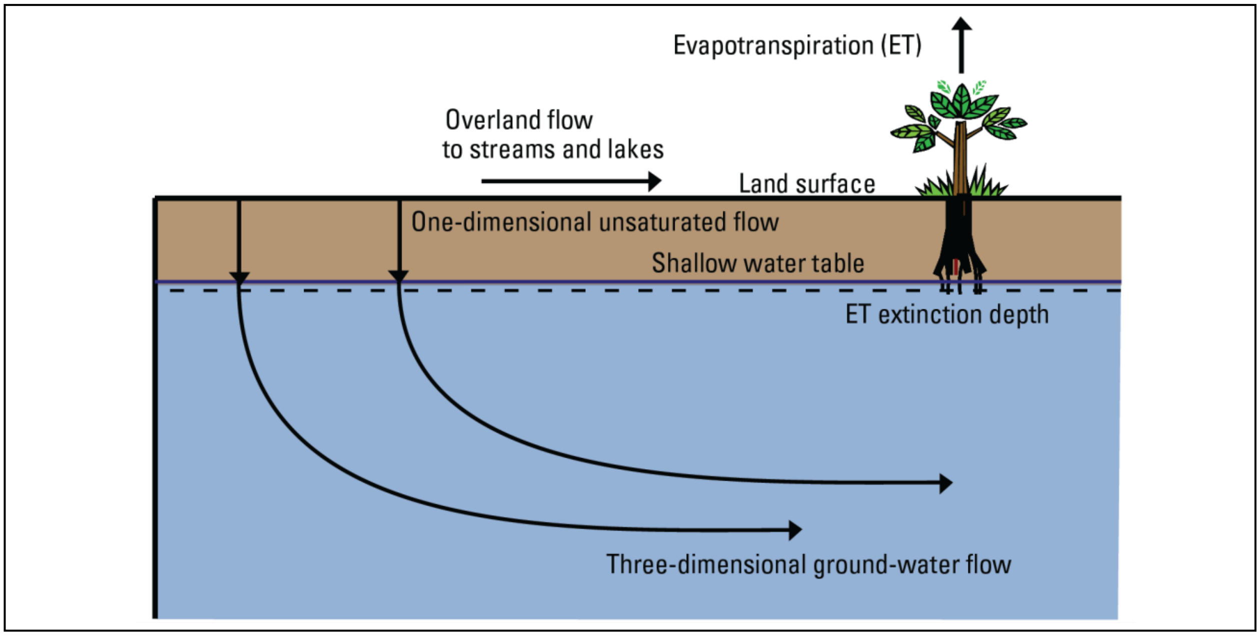
v. 10.0

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

- MODFLOW – Conceptual Model Approach I

Required Components

- Map Module
- Grid Module
- MODFLOW

Time

- 35-50 minutes

1 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.

1.1 Outline

Here are the steps of 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.

2 Description of Problem

The problem 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.
>
> 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

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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.

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.

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.[3]

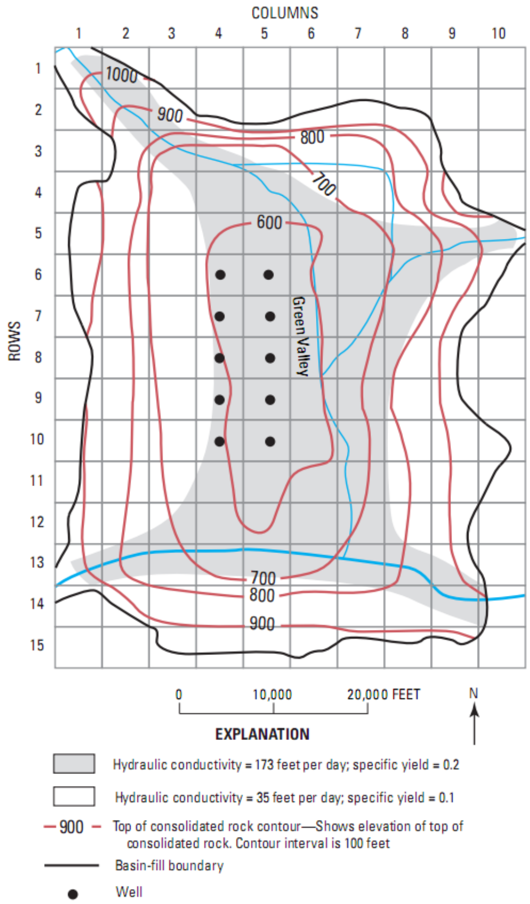

Figure 1 Flow model from UZF documentation[4]

3 Getting Started

Do the following to get started:

1. If necessary, launch GMS.

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3. Niswonger, Prudic, and Regan, 2006, p. 20, 23.

4. Ibid, p. 21.

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

4 Import the Existing Model

The user 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. Select the "UZFtest2.nam" file.
5. Click **Open**.

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

6. Click **OK** to translate the model.

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

7. Press **Done**.

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

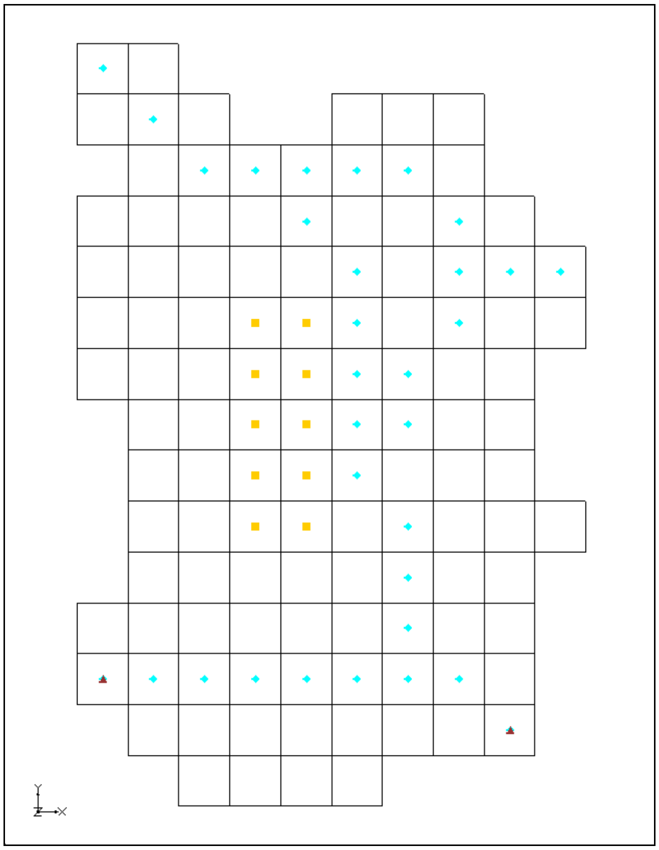

Figure 2 Imported MODFLOW model

5 Save the Model with a New Name

Now it is possible to start making changes. Let's save the model with a new name.

1. Select the *File* | **Save As** menu command.
2. Be sure to remain in the *\Tutorials\MODFLOW\UZF* folder.
3. Change the project name to "UZF.gpr."
4. Save the project by clicking the **Save** button.

6 View the UZF Boundary Conditions

Before running the simulation, view the UZF boundary conditions in the UZF Package dialog.

6.1 The UZF Package Dialog

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

2. Ensure that “Infiltration Rate” is selected in the *View/Edit* popup menu.

3. Change the *Multiplier* to 1.0e-09.

4. 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. The user 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.

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

6.2 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 users 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.

7 Run MODFLOW

Before running MODFLOW, it is necessary to change the output options to make it easier to see the results.

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

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 it is possible to save the 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:

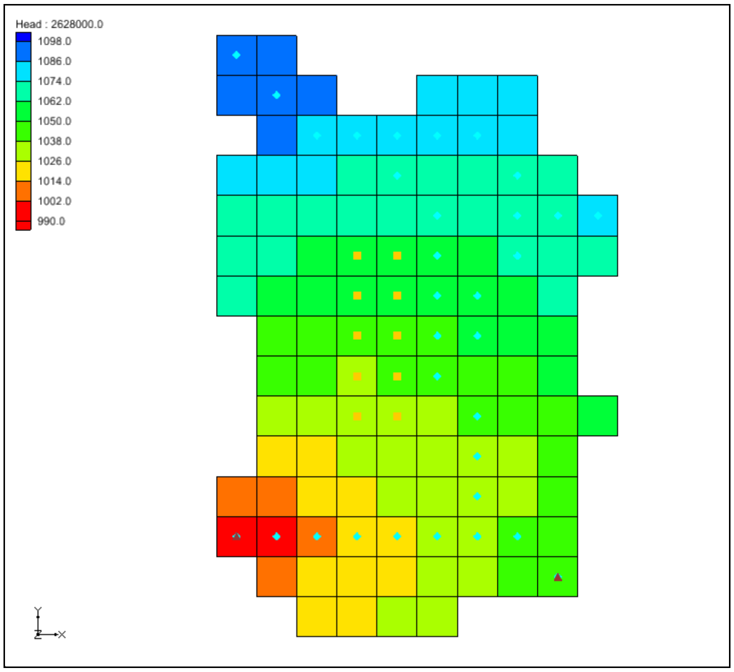

Figure 3 MODFLOW solution

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

8 Examine the Solution

Now it is necessary to 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.

8.1 The Flow Budget Dialog

Let’s examine the flow budget for this simulation.

1. In the Project Explorer, expand the “3D Grid Data” folder and the “grid” item if necessary.
2. Click on the “Head” dataset.

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

3. 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 GW ET. is -20.4 (out of the model). At the end of the first stress period, there is no *UZF Surface Leakage*.

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

5. Toggle on *Use all timesteps*.

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

6. 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.

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

8.2 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 a program 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 the user finds 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.

9 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 "FINF. Infiltration Rate."

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

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

10 Run MODFLOW

The user will run MODFLOW again to generate a new solution.

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

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

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

11 Examine the Solution

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

11.1 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.

11.2 CCF Datasets

Now the user will investigate to see where the surface leakage is occurring.

1. Right-click on the “CCF” item in the project explorer and select the **CCF → Datasets** command.

2. Select the dataset named “Surface Leakage.”

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

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

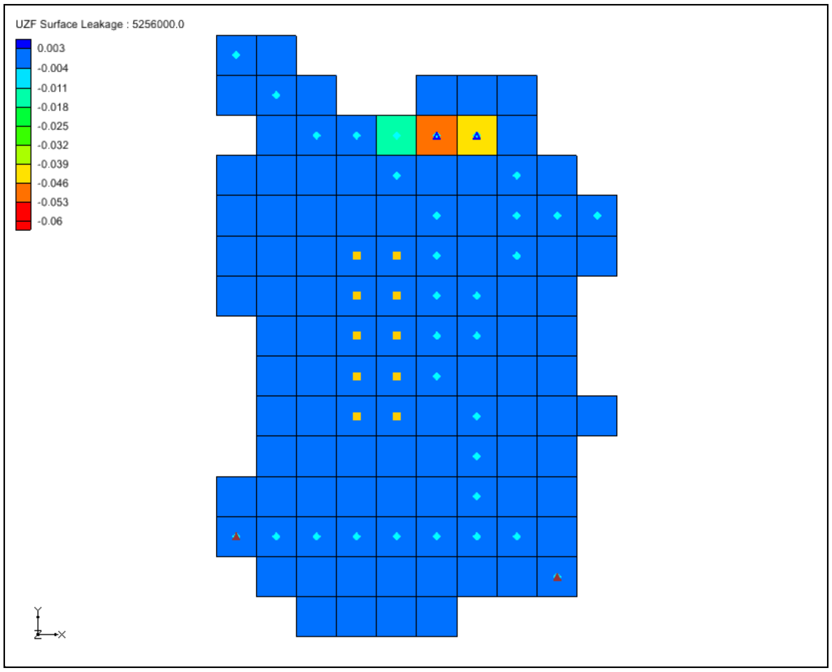

Figure 4. Surface leakage cells.

12 Create a Conceptual Model

Now the user will examine how to use a conceptual model with UZF data. The user will 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.

12.1 Open the Existing Conceptual Model

1. Before opening the conceptual model the user 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. Change the *Files of Type* to "All Files (*.*)."
6. Select the file entitled "SFRmap.gpr."
7. Click **Open.**

Before making any changes, save the project under a new name.

8. Select the *File* | **Save As** command.

9. Change the project name to "UZFmap.gpr."

10. Click the **Save** button.

13 Examine the Existing Solution

Before changing to the UZF package, 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.

14 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 to bring up the *MODFLOW Global/Basic Packages* dialog.

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 **OK** to exit the *MODFLOW Packages* dialog.

7. Press **OK** to exit the *MODFLOW Global/Basic Packages* dialog.

14.1 Changing to UZF

1. Expand the "Green Valley" conceptual model in the Project Explorer below "Map Data" folder.

2. Right-click on the **"**Recharge & ET" coverage.

3. Select **Coverage Setup** command to open the *Coverage Setup* dialog.

4. In the *Areal Properties* section of the dialog, turn on the following toggles:

- *UZF FINF (Infiltration Rate)*
- *UZF PET (ET Demand Rate)*
- *UZF EXTDP (ET Extinct. Depth)*

5. Click **OK** to exit the dialog.
6. Right-click on the "Recharge & ET" coverage.
7. Select the **Attribute Table** command to open the *Attribute Table* dialog.
8. Change the *Feature type* combo box to "Polygons."
9. Change the *UZF FINF (Infiltration Rate)* to "5.0e-8."
10. Change the *UZF PET (ET Demand Rate)* to "8.5e-8."
11. Change the *UZF EXTDP (ET Extinct. Depth)* to "15."

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

12. Press the **OK** button to exit the *Attribute Table* dialog.
13. Right-click on the **"**Recharge & ET" coverage.
14. Select the **Coverage Setup** command to open the *Coverage Setup* dialog.
15. In the *Areal Properties* section, turn off the following toggles:
    - *Recharge rate*
    - *Max ET rate*
    - *ET Extinction depth* toggles.
16. Press the **OK** button to exit the *Coverage Setup* dialog.

The conceptual model is set up so now it can be mapped to the MODFLOW grid.

17. Select the **Map → MODFLOW** button.
18. Click **OK** at the prompt.

15 Examine and Configure the UZF Package

Now 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.

The user 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 *Simulate ET (IETFLG.)* toggle.

3. Click **OK** to exit the dialog.

16 Save and run MODFLOW

The next step is to save the changes and run MODFLOW.

1. Select the **Run MODFLOW** button.

2. Select **Yes** at the prompt to save the changes.

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

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

17 Examine the Solution

Now 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 GW ET* is now -55.0 (out of the model). The *UZF Surface Leakage* flow is -8.97. Since the routing to streams isn't turned on, this amount is leaving the model.

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

18 Add Routing to Streams

Now the user 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 "GIS Layers" 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.

5. Select the **Coverage Setup** command to open the *Coverage Setup* dialog.

6. In the *Areal Properties* section, toggle on *UZF IRUNBND.*

7. Press **OK** to close the *Coverage Setup* dialog.

8. Right-click on the "UZF Stream" coverage.

9. Select the **Attribute Table** command to open the *Attribute Table* dialog.

10. If necessary, change the *Feature type* to **Polygons**.

11. In the *UZF IRUNBND* column, change each value of UZF IRUNBND to match the polygon number.

12. Select **OK** to exit the dialog.

The conceptual model is now setup so now it can be mapped to the MODFLOW grid.

13. Select the **Map→ MODFLOW** button.

14. Click **OK** at the prompt.

19 Configure the UZF Package

Now 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 "IRUNBND. Stream Segments/Lakes."

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

3. Toggle on the *Route surface discharge to streams/lakes (IRUNFLG)* check box to enable routing.

4. Click **OK** to exit the dialog.

20 Save and Run MODFLOW

The next step is to save the changes and run MODFLOW.

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

21 View the Changes

Now it is possible to view the changes to the output caused by turning on stream routing.

1. Expand the “3D Grid Data” folder.
2. Right-click on the “CCF” dataset under the “UZFmap2 (MODFLOW)” solution.
3. Select the **CCF → Datasets** command.
4. Select the newly created “Surface Leakage” dataset.
5. Select the **Contours** button to open the *Dataset Contour Options – 3D Grid – SURFACE LEAKAGE* dialog.
6. In the *Contour method* section of the dialog, change the method to “Block Fill.”
7. Select **OK** to exit the dialog.

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

8. Select the two cells with surface leakage by clicking on one and then shift-clicking on the other.
9. 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.

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

11. If necessary, expand the "UZFmap (MODFLOW)" solution in the Project Explorer.

12. Underneath that solution, select the "Head" dataset.

13. 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.

22 Conclusion

This concludes the tutorial. Here are the key concepts 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.