

# Hybrid GFLOW - MODFLOW Modeling Sequential Coupling Only

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## 1 Introduction

Large regional multi-layer MODFLOW models tend to have large cell sizes, in the order of several thousand feet on a side. While perhaps still adequate to describe flow in deeper formations, the cells are often too large to meaningfully represent the complex groundwater flow patterns in shallower formations, which result from detailed surface water and groundwater interactions.

The analytic element method, in contrast, is uniquely suitable for representing surface water and groundwater interactions, even on a large regional scale since it does not employ a computational grid or element network. The idea then is to replace the upper MODFLOW layer or layers in which direct surface water and groundwater interactions take place by the analytic element model GFLOW. In so doing, the coarse MODFLOW grid no longer interferes with an accurate representation of the shallow flow regime, while full advantage can be taken of GFLOW's conjunctive surface water and groundwater flow solutions. The hybrid modeling approach described here is particularly suitable for modeling well-stream interactions, which are difficult to do in a large regional MODFLOW model with cells that are, for instance, a mile on a side.

Below some technical details of the implementation of this coupling are presented.

## 2 Method

We distinguish between two coupling methods:

- Sequential coupling.
- Iterative coupling.

The sequential (non-iterative) coupling provides an approximate, but often satisfactory representation of the groundwater flow regime in the upper layer(s) by

the analytic element model GFLOW. An iterative coupling procedure may offer a refinement on the sequentially coupled models and may be desirable for certain cases, but also significantly increases the computational effort. It has been found, however, that when the transmissivity in the lower MODFLOW layers varies the head interpolation becomes inaccurate and the iterative procedure may fail to produce an improvement. In fact, it is likely to degrade the solution. Consequently, the iterative solution process is not activated in the officially released GFLOW GUI. A more detailed investigation of the performance of these coupling strategies is found in (Abrams et al. 2015; Haitjema et al. 2010).

## 2.1 Sequential coupling summary

1. Produce a (multi-layer) MODFLOW solution for the complete regional flow model.
2. Design a GFLOW model that represents the upper layer(s) of the MODFLOW model.
3. Provide the GFLOW model with a grid of cells that is conform the MODFLOW grid. These cells will be used to transfer recharge at the aquifer top and leakage at the GFLOW aquifer bottom from the MODFLOW model.
4. Solve the GFLOW model with the recharge and leakage values obtained from the previous two steps.

The resulting GFLOW model will include the recharge and leakage distribution from the original MODFLOW model, but more accurately represent surface water and groundwater interactions due to the gridless (analytic) nature of the analytic element method employed by GFLOW. However, when the combined transmissivities of the lower layers (those not included in the GFLOW model) dominate, the leakage values at the bottom of the GFLOW model become relatively large. Since these leakage values are obtained from the original coarse MODFLOW model they are approximate and as they become more significant tend to reduce the accuracy of the GFLOW solution (Haitjema et al. 2010; Abrams et al. 2015).

A more detailed step by step procedure for this sequential coupling using the GFLOW and GW Vistas GUIs is provided in section 4.

## 2.2 Representing leakage

The leakage grid in GFLOW is identical to the MODFLOW grid so that leakage rates can be transferred directly from MODFLOW to GFLOW. While the GFLOW model provides a detailed (analytic) solution to flow in the upper flow domain, which exhibits detailed surface water-groundwater interactions, its leakage representation is still that of the (coarse) MODFLOW grid. Thus there is no detailed leakage distribution near surface waters and wells.

Haitjema et al. (2001) found that MODFLOW cell dimensions should not exceed a “characteristic leakage length”  $\lambda$  [ $L$ ] in order to keep errors in leakage below a few percent. The characteristic leakage length  $\lambda$  for a two aquifer system, separated by an aquitard, is defined as (Hemker 1984; Bruggeman 1999):

$$\lambda = \sqrt{\frac{T_1 T_2 c}{T_1 + T_2}} \quad (1)$$

where  $T_1$  and  $T_2$  are the transmissivities [ $L^2/T$ ] of the two aquifers and where  $c$  [ $T$ ] is the resistance of the separating aquitard:

$$c = \frac{d}{k_v} \quad (2)$$

where  $d$  [ $L$ ] is the thickness of the aquitard and where  $k_v$  [ $L/T$ ] is the vertical hydraulic conductivity of the aquitard. Expression (2) may also be interpreted as the vertical resistance to flow between model layers, like is done in MODFLOW by a “VCONT” parameter, which is the inverse of a resistance. In that case the distance  $d$  is a representative distance for vertical flow, for instance, the distance between the centers of the two model layers. The vertical hydraulic conductivity  $k_v$  is than the vertical hydraulic conductivity in the model layers. Haitjema et al. (2001) studied the flow from a canal to a well in an aquifer underneath a lake or wetland with constant water level. Interpreting the wetland or lake as an adjacent aquifer with an infinite transmissivity reduces (1) to:

$$\lambda = \sqrt{Tc} \quad (3)$$

where  $T$  is the transmissivity of the aquifer and  $c$  the resistance to flow between the aquifer and the overlying lake or wetland. As a general conclusion they found that MODFLOW cell dimensions should not exceed  $\lambda$  in order to limit errors in leakage and thus errors in flow from the canal to the well. In fact, only when the cell dimensions were as small as  $0.1\lambda$  were errors in leakage truly negligible. These observations may also be understood from one-dimensional or two-dimensional radial symmetric solutions to flow in a leaky aquifer (Bruggeman 1999). It appears that 95% of the leakage due to a linear feature( e.g. a long canal) or a well occurs within a distance of  $3\lambda$  or  $4\lambda$  from the canal or well, respectively. Clearly, to represent that leakage fairly an adequate grid resolution is needed at that scale.

### Leakage in multi-aquifer systems

For multi-aquifer settings with more than one aquitard there exist multiple “lambda” ( $\lambda$ ) values. Regretfully, these lambda values cannot be associated with individual aquitards and, therefore, their values cannot be used to assess the leakage distribution though individual aquitards. All that may be said is that the leakage through all aquitards due to a canal or well becomes small beyond 3 or 4 times the *largest* lambda value in the system, respectively.

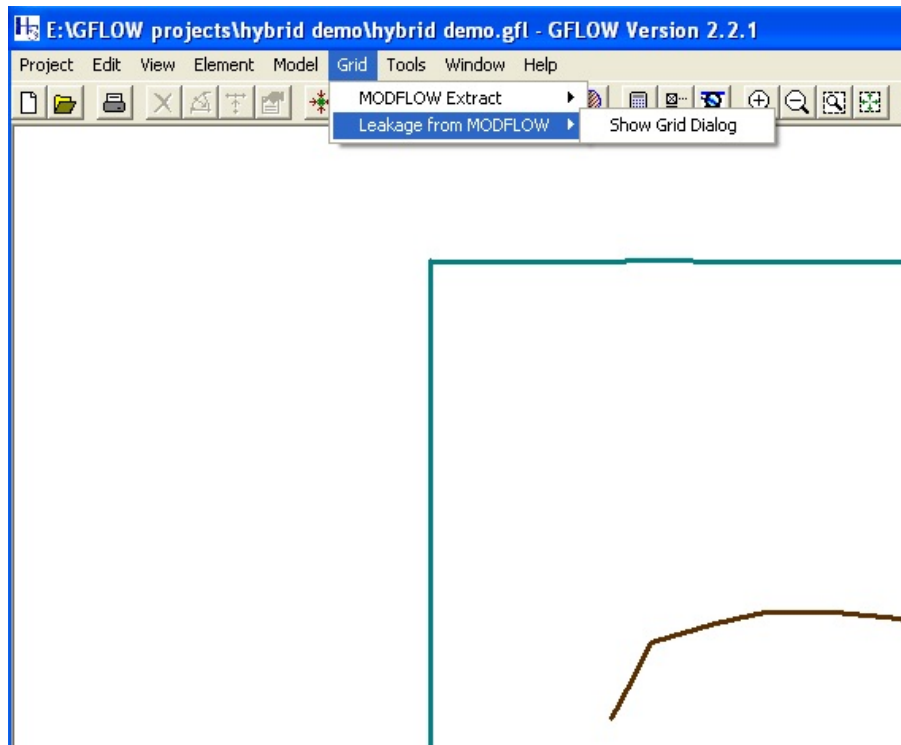


Figure 1: Accessing the “Leakage from MODFLOW” Dialog.

### 3 GUI functions and files from MODFLOW

The sequentially coupled GFLOW - MODFLOW solutions are managed from the GFLOW graphical user interface (GUI). The GUI contains a menu called “Grid” used to manage both the “MODFLOW extract” process and the Hybrid GFLOW - MODFLOW modeling via the “Leakage from MODFLOW” submenu, see Figure 1.

The “Show Grid Dialog” option in Figure 1 opens the dialog “Leakage from MODFLOW” shown in Figure 2. The “File” menu offers the options “Open Grid” and “Remove Grid” (not shown in Figure 2). When clicking on “Open Grid” the “Open MODFLOW Grid” dialog is shown. If present in your working directory, the file “*basename.del*” will be shown. “*basename*” is the DOS file name used for communications between the GUI and the Solver and is set on the *Project>Project Settings* dialog. In the example used in this document the *basename* is “hybrid.” The *basename.del* file is a MODFLOW file that defines the MODFLOW grid to be used in GFLOW. The *basename.del* file does generally not contain georeferencing information, but you can supply that on the “General” tab of the “Leakage from MODFLOW” dialog, see Figure 2. However, it is better to edit the file *basename.del* (e.g. using Notepad) and add the

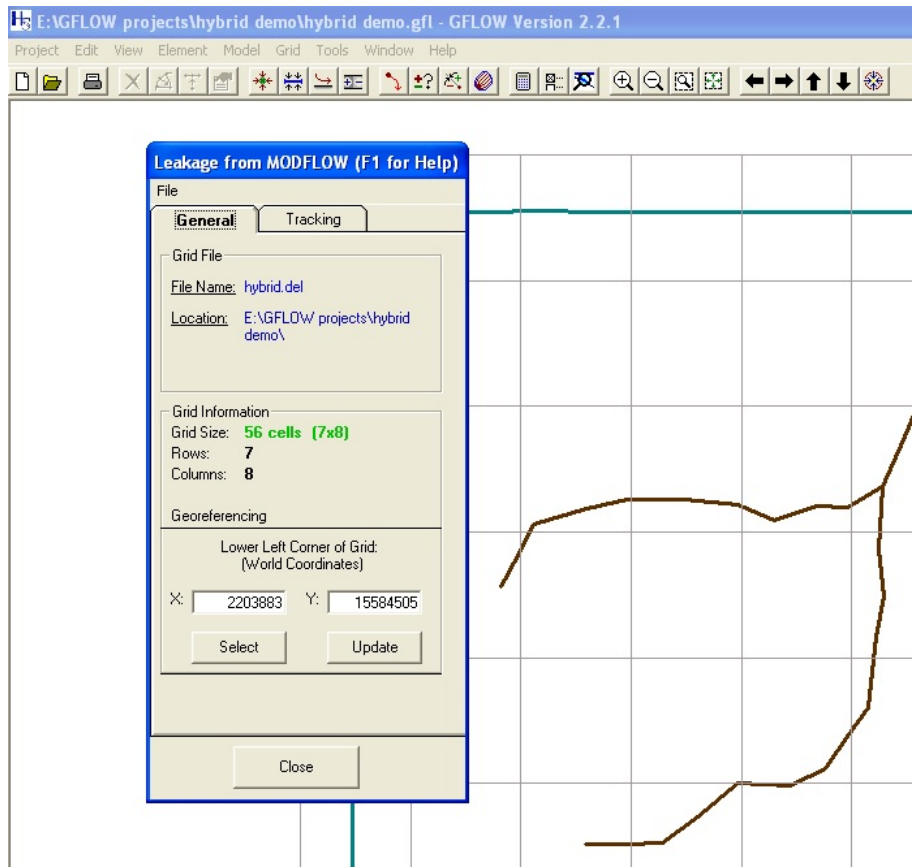


Figure 2: The “General” tab of the “Leakage from MODFLOW” dialog.

x and y coordinates of the lower left corner of the grid to the bottom of the file, see the file format for *hybrid.del* in the Appendix.

The coupling process requires the following files to be present in the working directory, which is the folder where the GFLOW project file (\*.gfl) resides:

- *basename.del* contains the grid design parameters. This file is read by GUI and Solver.
- *basename.vlk* contains an array of leakage values from the lowest MODFLOW layer that is represented in GFLOW to the MODFLOW layer below it. Thus now from the GFLOW model layer into the underlying MODFLOW layer. This file is read by GUI and Solver.
- *basename.rta* contains an array of recharge values applied to the top of Layer 1 in the MODFLOW model. It will also be applied to the top of the GFLOW model. Note: If not present the Solver will assume no recharge input from MODFLOW, but any recharge defined in the GFLOW GUI by use of inhomogeneity domains will still apply. This file is read by the Solver only.

The file formats are presented in the Appendix for files with the basename “hybrid.”

The “Tracking” tab of the “Leakage from MODFLOW” dialog is shown in Figure 3. By moving the mouse over the MODFLOW grid, cell-specific data are shown on the “Tracking” tab fields. The “X Position” and “Y Position” (under “Grid”) are relative to the lower left corner of the MODFLOW grid, while the coordinates displayed above it are the “world coordinates,” see Figure 3.

**Important:** The cell-by-cell MODFLOW recharge rate (in the *basename.rta* file) is added by the Solver to whatever recharge rate is already defined in the GFLOW model by the GUI. Thus for the recharge rate at the aquifer top to be the same in the MODFLOW and GFLOW models no other recharge should be defined in the GFLOW GUI!

## 4 Step by Step Sequential Coupling Procedure

1. Produce a MODFLOW solution for the complete regional flow model. The grid must be aligned with the horizontal and vertical coordinates of a cartesian world coordinate system. e.g. UTM or State Plane. It works best to zone the aquifer properties in MODFLOW in a manner that can easily be duplicated in GFLOW. To the degree possible, include all surface water features that will also be included in the GFLOW representation of the upper model.
2. Design a GFLOW model that represents the upper layer(s) of the MODFLOW model. Make sure that all layers in MODFLOW that are in direct contact with surface waters are represented in the GFLOW model. If this

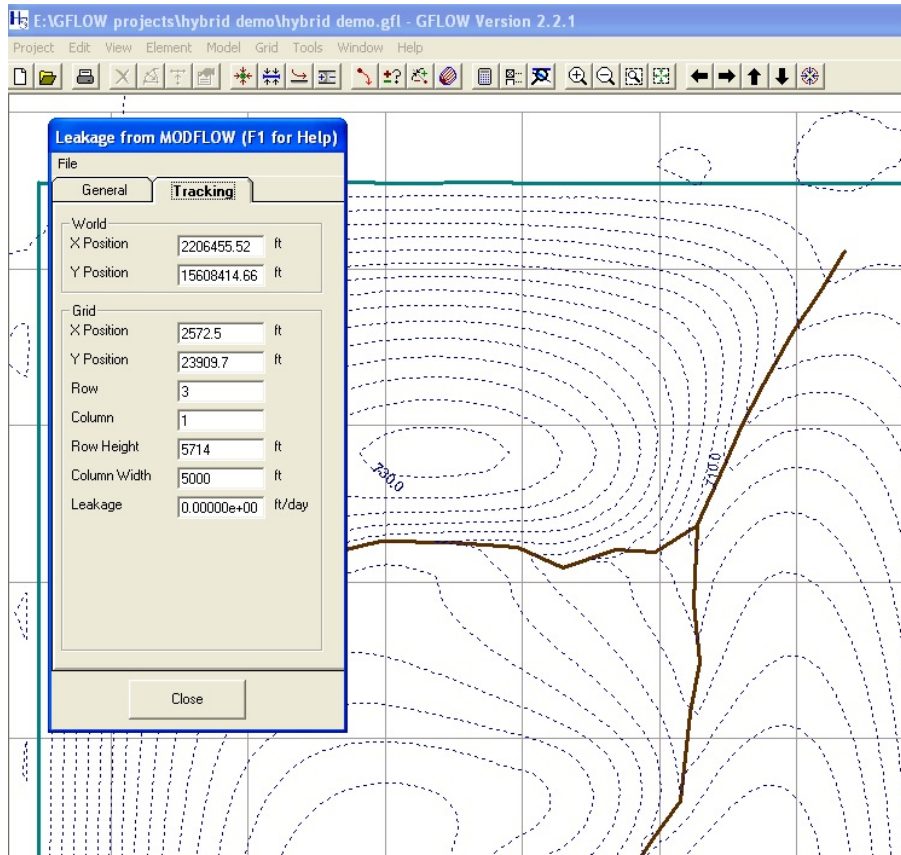


Figure 3: The “Tracking” tab of the “Leakage from MODFLOW” dialog.

is indeed more than one MODFLOW model layer, they will be represented as a single Dupuit-Forchheimer aquifer in GFLOW. Hence, these MODFLOW layers should be well connected to each other without significant resistance to vertical flow. Note: If there is substantial vertical resistance to flow, for instance due to aquitards, calculate  $\lambda$  values for these upper layers (see section 2.2) and make sure that they are, in general, at least an order of magnitude smaller than the distance between the surface waters. Alternatively, one can also verify that the head differences between the MODFLOW layers to be included in GFLOW are small. If not, the GFLOW model will generate heads that are a weighted average of the heads in the various (upper) layers; weighted according to the transmissivities of these layers.

3. Provide the GFLOW model with a grid of cells that is conform the MODFLOW grid. These cells will be used to model recharge at the aquifer top and leakage at the aquifer bottom. In the GFLOW GUI use the

*Project*>*Project Settings* to define a unique “Base Filename (DOS)” which from here on will be referred to as the “*basename*.” Create a *basename.del* file that defines the MODFLOW grid to be included in GFLOW, see the Appendix for the file format. Make sure this (one layer) grid is identical to the grid layers in your MODFLOW model (same horizontal cell sizes).

Note: It is possible to only represent a sub-grid of the regional MODFLOW model in GFLOW. In that case the cell-by-cell leakage rates and recharge rates referred to below must belong to that same sub-grid.

4. Create a file *basename.rta* that contains the cell-by-cell recharge values used for the top MODFLOW layer. This file may be created using the GW Vistas GUI by selecting the *View as Matrix* option on the *Plot* menu after having selected these recharge rates as the boundary condition to be displayed on the *Plot* menu. In this matrix view, select an appropriate formatting and copy the matrix to a spreadsheet or to an editor (e.g. Notepad). Remove the header of column numbers and the first column with row numbers. Write the matrix of recharge rates to an ASCII file with the name *basename.rta*. Note: If no *basename.rta* file exists in the working directory then the Solver will assume zero recharge rates in the MODFLOW model. Of course, any recharge defined in GFLOW inhomogeneities will still be included in the calculations.
5. Follow this same procedure for exporting the leakages between the upper layer(s) to be represented in GFLOW and the layer immediately below it by selecting in the *Plot* menu the vertical flows to be displayed. Make sure in the *View as Matrix* menu to select the proper layer to get the flows into the layer(s) that will be represented by GFLOW. Save the matrix of leakage values to the file *basename.vlk* which may be done using the same steps as outlined above for the recharge rates (step 4).
6. Make sure that the above created files are in the GFLOW working directory for your project. This is the folder where the project file \*.gfl resides (in this example: *hybrid demo.gfl*). In the GFLOW GUI go to *Grid*>*Leakage from MODFLOW*>*Show Grid Dialog*. On the “Leakage from MODFLOW” dialog click on *File*>*Open Grid*. You should see the file *basename.del* in the file dialog box. Open the file. If you included the x and y coordinates of the lower left corner of the grid at the bottom of the *basename.del* file (see the *hybrid.del* file in the Appendix) you will see these displayed on the “General” tab of the “Leakage from MODFLOW” dialog (see Fig. 2). If not, type in these coordinates and click “Update.” Click on the “Tracking” tab and by moving the cursor over the cells check that all properties are there.
7. Assuming that all other GFLOW data are correctly entered, click on the calculator icon to schedule the GFLOW Solver (will run in a DOS box). The resulting solution will include the recharge and the leakage obtained from the MODFLOW model.



Note: The grid of recharge rates from MODFLOW, *basename.rta*, is only read by the Solver, not by the GUI. Hence, you can only inspect the recharge rates in GFLOW after a solution has been generated (step 7 above) and by placing the cursor on the location where you seek the recharge rate and then perform a *shift left-click* to bring up the “Model Results” message box. The recharge rate is listed near the middle of the data list. The recharge reported here is the sum of any recharge that may have been introduced in the GUI via an inhomogeneity domain and the recharge rate in the MODFLOW cell in which the cursor was placed. In general, for consistency with the MODFLOW model, no recharge rates other than in the MODFLOW grid cells should be specified. Thus none of the inhomogeneities in GFLOW should have the box “Change recharge rate from default” checked!

The GFLOW solution obtained in this manner will be approximate since the leakage rates of the (coarse regional) MODFLOW model are approximate. The approximation has been found to be quite acceptable in most cases except perhaps under circumstances where the lower MODFLOW layers, those not represented by GFLOW, have a combined transmissivity that is significantly higher (by several factors) than the combined transmissivity of the layers represented by GFLOW. More details on the performance of the hybrid model are found in (Abrams 2015).

### **Modeling well-stream interactions**

To model the impact of wells on streams, say to assess the magnitude and extent of streamflow reduction, it is necessary to create a hybrid model of the aquifer system without and with the well present. Thus two sets of cell-by-cell leakages must be transferred from MODFLOW to GFLOW, one whereby the well is absent and one set whereby the well is present in MODFLOW. These leakages must then be used in two different GFLOW models whereby the well is also absent and present, respectively. The two different GFLOW models can then be used to inspect streamflow differences and plot drawdowns.

## Appendix: File Formats

Below are example files to illustrate their file format. In some cases repetitive lines are replaced by "...". The files are for a test case of a well at the center of a 40 by 40 cell MODFLOW grid, but this case is not provided with the program. All text between parentheses are explanations that are not included in the files themselves.

### file: hybrid.dat (Solver input file generated by the GUI)

```
* Written by GFLOW for Windows 2.2.1
error error.log
yes
message message.log
yes
echo echo.log
yes
picture off
quit

bfname hybrid
modelorigin 2206233.41 15586965.1 2
title hybrid
aquifer
base 4.00000E+02
permeability 2.0000000E+01
thickness 2.0000000E+02
porosity 1.0000000E-01
reference 2.6477658E+05 2.6478237E+05 7.0116129E+02
quit
layout
window -26894.28 -16361.92 74575.92 52970.03
quit
linesink
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
6.620000E+00 3.497833E+04 0.000000E+00 3.028509E+04 7.00000E+02 LS_000727_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
0.000000E+00 3.026523E+04 0.000000E+00 2.530308E+04 7.00000E+02 LS_000728_0101
head
```

```

resistance 0
width 0.000000E+00 1
depth 0.000000E+00
0.000000E+00 2.528984E+04 0.000000E+00 2.026915E+04 7.00000E+02 LS_000729_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
0.000000E+00 2.024929E+04 6.620000E+00 1.528817E+04 7.00000E+02 LS_000730_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
6.620000E+00 1.527494E+04 6.620000E+00 1.027410E+04 7.00000E+02 LS_000731_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
6.620000E+00 1.025217E+04 1.324000E+01 4.795630E+03 7.00000E+02 LS_000732_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
1.986000E+01 4.762530E+03 0.000000E+00 1.030000E+00 7.00000E+02 LS_000733_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
1.324000E+01 0.000000E+00 4.752810E+03 1.324000E+01 7.00000E+02 LS_000734_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
4.792530E+03 6.620000E+00 9.746400E+03 6.620000E+00 7.00000E+02 LS_000735_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
9.759640E+03 0.000000E+00 1.509497E+04 2.648000E+01 7.00000E+02 LS_000736_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
1.513578E+04 2.529000E+01 1.976612E+04 2.529000E+01 7.00000E+02 LS_000737_0101
head
resistance 0

```

```

width 0.000000E+00 1
depth 0.000000E+00
1.981054E+04 1.324000E+01 2.490095E+04 1.324000E+01 7.00000E+02 LS_000738_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
2.494770E+04 2.529000E+01 3.012705E+04 1.986000E+01 7.00000E+02 LS_000739_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
3.018440E+04 2.529000E+01 3.494027E+04 1.324000E+01 7.00000E+02 LS_000740_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
2.896000E+01 3.496323E+04 4.761080E+03 3.496323E+04 7.00000E+02 LS_000741_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
4.814040E+03 3.496323E+04 9.757990E+03 3.497647E+04 7.00000E+02 LS_000742_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
9.791080E+03 3.496985E+04 1.474744E+04 3.496323E+04 7.00000E+02 LS_000743_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
1.480702E+04 3.496985E+04 1.975180E+04 3.496323E+04 7.00000E+02 LS_000744_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
1.979813E+04 3.496323E+04 2.496632E+04 3.496323E+04 7.00000E+02 LS_000745_0101
head
resistance 0
width 0.000000E+00 1
depth 0.000000E+00
2.500603E+04 3.496323E+04 2.994915E+04 3.496323E+04 7.00000E+02 LS_000746_0101
head
resistance 0
width 0.000000E+00 1

```

depth 0.000000E+00  
 2.999549E+04 3.496323E+04 3.491379E+04 3.496323E+04 7.00000E+02 LS\_000747\_0101  
 head  
 resistance 0  
 width 0.000000E+00 1  
 depth 0.000000E+00  
 3.494689E+04 3.496985E+04 3.494689E+04 3.026544E+04 7.00000E+02 LS\_000748\_0101  
 head  
 resistance 0  
 width 0.000000E+00 1  
 depth 0.000000E+00  
 3.495351E+04 3.021249E+04 3.494689E+04 2.520793E+04 7.00000E+02 LS\_000749\_0101  
 head  
 resistance 0  
 width 0.000000E+00 1  
 depth 0.000000E+00  
 3.496013E+04 2.516159E+04 3.496013E+04 2.025198E+04 7.00000E+02 LS\_000750\_0101  
 head  
 resistance 0  
 width 0.000000E+00 1  
 depth 0.000000E+00  
 3.496675E+04 2.022550E+04 3.496013E+04 1.522095E+04 7.00000E+02 LS\_000751\_0101  
 head  
 resistance 0  
 width 0.000000E+00 1  
 depth 0.000000E+00  
 3.496675E+04 1.518123E+04 3.494689E+04 1.064893E+04 7.00000E+02 LS\_000752\_0101  
 head  
 resistance 0  
 width 0.000000E+00 1  
 depth 0.000000E+00  
 3.495351E+04 1.062907E+04 3.495351E+04 5.247200E+03 7.00000E+02 LS\_000753\_0101  
 head  
 resistance 0  
 width 0.000000E+00 1  
 depth 0.000000E+00  
 3.496675E+04 5.220720E+03 3.496013E+04 3.971000E+01 7.00000E+02 LS\_000754\_0101  
 head  
 resistance 1.763917E+00  
 width 1.500000E+01 1  
 depth 1.000000E+01  
 6.757060E+03 1.794031E+04 7.483310E+03 1.935203E+04 7.19597E+02 LS\_000755\_0051  
 7.483310E+03 1.935203E+04 8.232700E+03 2.075553E+04 7.18791E+02 LS\_000755\_0101  
 8.232700E+03 2.075553E+04 1.064324E+04 2.144063E+04 7.17751E+02 LS\_000755\_0151  
 1.064324E+04 2.144063E+04 1.248426E+04 2.190376E+04 7.16634E+02 LS\_000755\_0201  
 1.248426E+04 2.190376E+04 1.508065E+04 2.185406E+04 7.15493E+02 LS\_000755\_0251

```

1.508065E+04 2.185406E+04 1.748598E+04 2.166198E+04 7.14222E+02 LS_000755_0301
1.748598E+04 2.166198E+04 1.915977E+04 2.091696E+04 7.13145E+02 LS_000755_0326
1.915977E+04 2.091696E+04 2.103395E+04 2.157844E+04 7.12176E+02 LS_000755_0351
2.103395E+04 2.157844E+04 2.248319E+04 2.151011E+04 7.11304E+02 LS_000755_0376
2.248319E+04 2.151011E+04 2.404944E+04 2.248329E+04 7.10468E+02 LS_000755_0401
head
resistance 1.763917E+00
width 1.500000E+01 1
depth 1.000000E+01
1.056055E+04 6.199080E+03 1.248986E+04 6.199080E+03 7.21548E+02 LS_000756_0051
1.248986E+04 6.199080E+03 1.408844E+04 6.254200E+03 7.20721E+02 LS_000756_0101
1.408844E+04 6.254200E+03 1.568701E+04 7.466910E+03 7.19876E+02 LS_000756_0201
1.568701E+04 7.466910E+03 1.750607E+04 9.010360E+03 7.18847E+02 LS_000756_0226
1.750607E+04 9.010360E+03 1.987637E+04 8.844990E+03 7.17731E+02 LS_000756_0251
1.987637E+04 8.844990E+03 2.147494E+04 9.616720E+03 7.16758E+02 LS_000756_0276
2.147494E+04 9.616720E+03 2.246566E+04 1.108882E+04 7.15926E+02 LS_000756_0301
2.246566E+04 1.108882E+04 2.340425E+04 1.242800E+04 7.15127E+02 LS_000756_0351
2.340425E+04 1.242800E+04 2.379011E+04 1.562514E+04 7.13990E+02 LS_000756_0401
2.379011E+04 1.562514E+04 2.411925E+04 1.748776E+04 7.12792E+02 LS_000756_0501
2.411925E+04 1.748776E+04 2.390036E+04 1.964913E+04 7.11839E+02 LS_000756_0601
2.390036E+04 1.964913E+04 2.405744E+04 2.248329E+04 7.10665E+02 LS_000756_0701
head
resistance 1.763917E+00
width 4.700000E+01 1
depth 1.000000E+01
2.405629E+04 2.249586E+04 2.500282E+04 2.461021E+04 7.08980E+02 LS_000757_0101
2.500282E+04 2.461021E+04 2.560918E+04 2.604342E+04 7.07275E+02 LS_000757_0301
2.560918E+04 2.604342E+04 2.638090E+04 2.747662E+04 7.05873E+02 LS_000757_0401
2.638090E+04 2.747662E+04 2.753849E+04 2.951617E+04 7.04123E+02 LS_000757_0501
2.753849E+04 2.951617E+04 2.853070E+04 3.100450E+04 7.02303E+02 LS_000757_0601
2.853070E+04 3.100450E+04 2.940914E+04 3.248390E+04 7.00758E+02 LS_000757_0701
quit
leakage (This command makes the Solver include the Leakage from MODFLOW)
origin -2350.41000000015 -2460.09999999963
quit
layout
window -26894.28 -16361.92 74575.92 52970.03
quit
time 0
solve 30 3 1 1

save hybrid
y
time 0
extract
file hybrid

```

```
y
well discharge
well head
ppwell discharge
ppwell head
Theis well
linesink discharge
linesink head
inhomogeneity
quit
grid
window -26894.28 -16361.92 74575.92 52970.03
dotmap off
horizontalpoints 80
plot heads
go
save hybrid
y
surfer hybrid
y
quit
trace
picture off
file hybrid
y
time 3650
step 491.579030023864
go
quit
stop
```

**file: hybrid.del**

```
7 ...(number of rows)
5714 ..(height of the cells in row 1)
5714 ..(height of the cells in row 2)
5714 ..(height of the cells in row 3)
5714 ..(height of the cells in row 4)
5714 ..(height of the cells in row 5)
5714 ..(height of the cells in row 6)
5714 ..(height of the cells in row 7)
8 ...(number of columns)
5000 ..(width of the cells in column 1)
5000 ..(width of the cells in column 2)
5000 ..(width of the cells in column 3)
5000 ..(width of the cells in column 4)
```

5000 ..(width of the cells in column 5)  
5000 ..(width of the cells in column 6)  
5000 ..(width of the cells in column 7)  
5000 ..(width of the cells in column 8)  
2203883 ...(X-coordinate of the lower-left corner of the grid in world coordinates)  
15584505 ...(Y-coordinate of the lower-left corner of the grid in world coordinates)

**file hybrid.vlk (containing cell-by-cell leakages)**

0.000000000000000E+00 0.000000000000000E+00 0.000000000000000E+00  
0.000000000000000E+00 0.000000000000000E+00 0.000000000000000E+00  
0.000000000000000E+00 0.000000000000000E+00 ...(row 1)  
0.000000000000000E+00 2.507515440976488E-03 2.660565789135689E-03  
2.720754589488521E-03 2.716079297600277E-03 4.918693188006090E-04  
3.097917282885222E-03 0.000000000000000E+00 ...(row 2)  
0.000000000000000E+00 2.421764901068415E-03 -2.100747776078358E-03  
-3.896573220271630E-03 -3.163913686349994E-03 1.179318435661254E-03  
2.573168306622857E-03 0.000000000000000E+00 ...(row 3)  
0.000000000000000E+00 2.075526482809555E-03 4.750195929213012E-03  
5.772680122509183E-03 5.620805593552664E-03 2.816617820536916E-03  
2.070578530495633E-03 0.000000000000000E+00 ...(row 4)  
0.000000000000000E+00 2.430273522934196E-03 2.919889229907431E-03  
2.377718403029333E-03 -1.167561686142696E-03 1.489259056565748E-03  
1.881474961749453E-03 0.000000000000000E+00 ...(row 5)  
0.000000000000000E+00 1.040659992248662E-04 -2.737262264488966E-03  
-6.136200699793848E-03 6.303836810405135E-04 1.573031551952371E-03  
-9.823841780295809E-05 0.000000000000000E+00 ...(row 6)  
0.000000000000000E+00 0.000000000000000E+00 0.000000000000000E+00  
0.000000000000000E+00 0.000000000000000E+00 0.000000000000000E+00  
0.000000000000000E+00 0.000000000000000E+00 ...(row 7)

**file hybrid.rta (containing cell-by-cell recharge values)**

0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00  
0.00E+00 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 0.00E+00  
0.00E+00 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 0.00E+00  
0.00E+00 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 0.00E+00  
0.00E+00 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 0.00E+00  
0.00E+00 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 5.00E-03 0.00E+00  
0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00



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