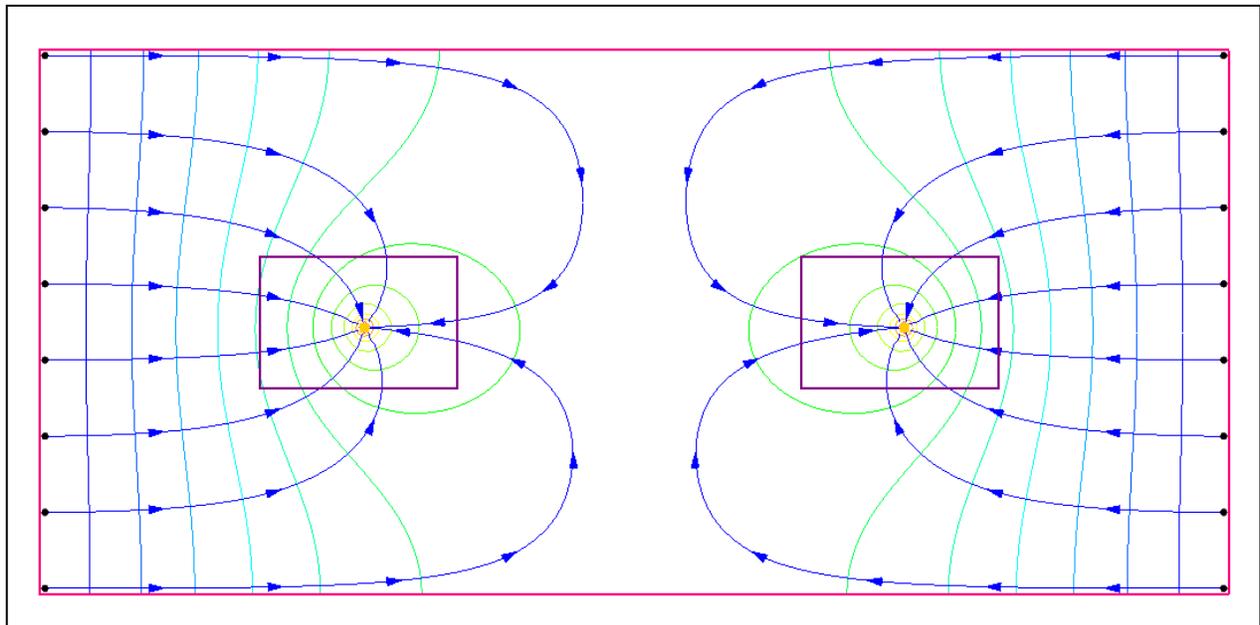


GMS 10.2 Tutorial

MODFLOW-LGR Dual Refinement

Create a MODFLOW-LGR model with two locally refined grids using GMS



Objectives

This tutorial builds on the MODFLOW-LGR tutorial and shows how to create more than one child grid. This tutorial covers parameters, MODPATH, and using the BFH package to check the accuracy of the coupled boundary heads and flows.

Prerequisite Tutorials

- MODFLOW – LGR

Required Components

- Grid Module
- MODFLOW-LGR

Time

- 20-35 minutes



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1 Introduction

MODFLOW-LGR can be used to create MODFLOW models that contain locally refined regions in areas where smaller cell sizes are desired. These refined regions are considered child grids of a parent grid. MODFLOW-LGR solves for the heads and flows of the child and parent grids using an iterative technique while maintaining consistency in the boundary conditions along the borders of the child and parent grids.

MODFLOW-LGR can use multiple child grids. This tutorial builds on the “MODFLOW-LGR” tutorial and demonstrates how to create multiple child grids. It discusses and demonstrates importing an existing MODFLOW-LGR model, examining the MODPATH model, and examining the parameters on the model. It also covers adding a second child grid, using the BFH package to check the accuracy of the coupled boundary heads and flows, and saving and running MODFLOW-LGR.

The problem in this tutorial is one of the example problems included with MODFLOW-LGR.¹ It is a simple, one layer, confined, steady state model containing two extraction wells as shown in Figure 1. No-flow boundaries occur on the north and south, and specified head boundaries are defined on the east and west. Flow is generally to the

¹ Mehl, Steffan W. and Hill, Mary C. (2007). “MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model—Documentation of the Multiple-Refined-Areas Capability of Local Grid Refinement (LGR) and the Boundary Flow and Head (BFH) Package” in *U.S. Geological Survey Techniques and Methods 6-A21*, p.6.
http://pubs.usgs.gov/tm/2007/06A21/pdf/TM6-A21_508.pdf .

wells. For this tutorial, a child grid has been created around the area of the well on the left. Another child grid will be created around the well on the right.

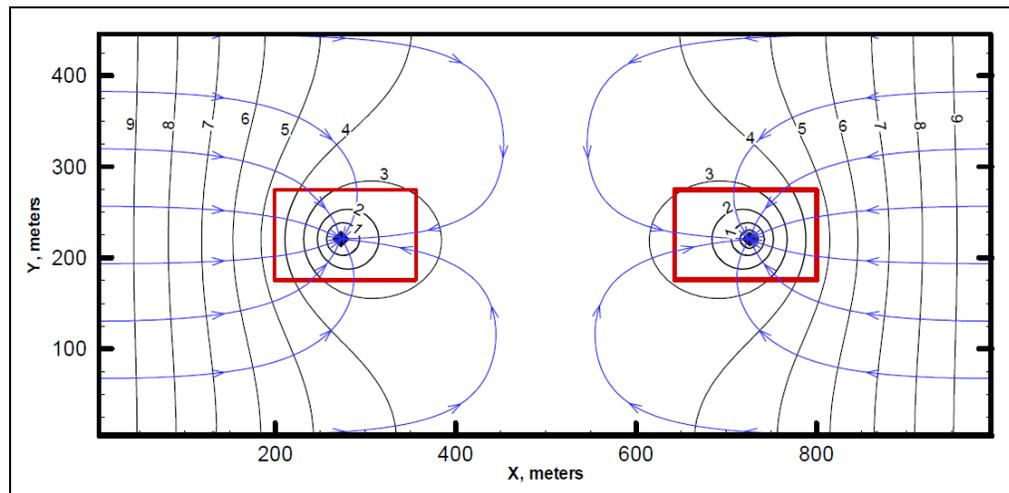


Figure 1 Sample problem to be solved²

1.1 Getting Started

Do the following to get started:

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

2 Open the Starting Model

Start by opening the existing model.

1. Click **Open**  to bring up the *Open* dialog.
2. Browse to the *Tutorials\MODFLOW\mflgr-dual* directory and select “start.gpr”.
3. Click **Open** to import the project and close the *Open* dialog.

The Main Graphics Window should appear similar to Figure 2.

² Mehl (2007).

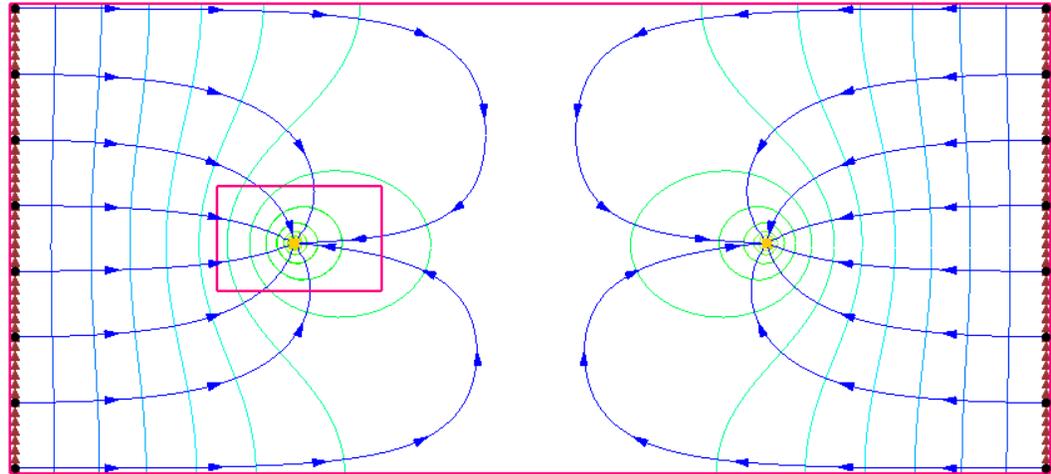


Figure 2 Starting model

2.1 MODPATH

This model includes a child grid around the well on the left side (grid cell edges are turned off but the grid shell is visible). It also includes pathlines generated by MODPATH. The pathlines are on the parent grid and are generated from a solution that was created by running MODFLOW-LGR independently on the parent model. MODPATH does not handle pathlines crossing grid boundaries. In GMS, MODPATH particles can be created and MODPATH solutions can be generated on the parent model.

2.2 Parameters

Both the parent and child models use parameters and clusters to define hydraulic conductivity.

1. Select *MODFLOW* | **Parameters...** to open the *Parameters* dialog.
2. Notice that there are 5 parameters defined, then click **Cancel** to close the *Parameters* dialog.
3. Select *MODFLOW* / **LPF – Layer Property Flow** to bring up the *LPF Package – Parent* dialog.
4. Notice the warning note at the bottom about LPF parameters.
5. In the *Layer data* section, notice that the *Layer type* is set to *Confined*.
6. Click **Cancel** to close the *LPF Package – Parent* dialog.

It is perfectly acceptable to use parameters to define MODFLOW inputs with MODFLOW-LGR. View the parameters for the CHILD1 model, or look at the zone array used with the parameter clusters.

2.3 Save with a Different Name

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

1. Select *File* / **Save As** to bring up the *Save As* dialog.
2. Select “Project Files (*.gpr)” from the *Save as type* drop-down.
3. Enter “lgr-dual.gpr” as the *File name*.
4. Click **Save** to save the project under the new file name and close the *Save As* dialog.

Use **Save**  periodically as the model is developed.

3 Create a Second Child Grid

Create another child grid around the well on the right.

1. Turn on the “ Annotation Data” folder in the Project Explorer. A purple rectangle should appear around the well on the right.
2. Using the **Select Cells**  tool, drag a box to select the cells within the purple rectangle.
3. Right-click in the selected area and select **Create Child Grid...** to bring up the *Create Child Grid* dialog.
4. Enter “CHILD2” as the *Grid name*.
5. Enter “9” as the *Horizontal refinement*.

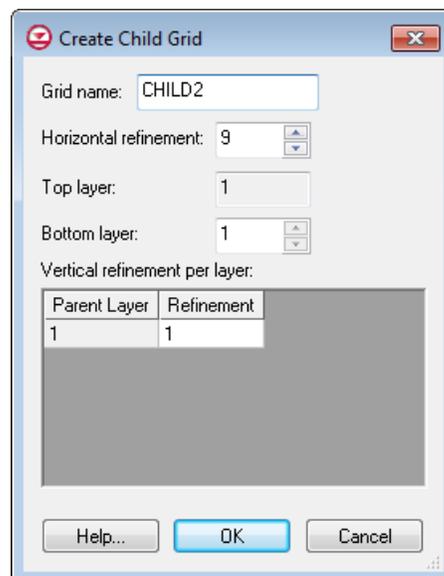


Figure 3 Create Child Grid dialog

6. Click **OK** to close the *Create Child Grid* dialog.
7. Turn off “ Annotation Data” in the Project Explorer.

There are now two child grids (Figure 4).

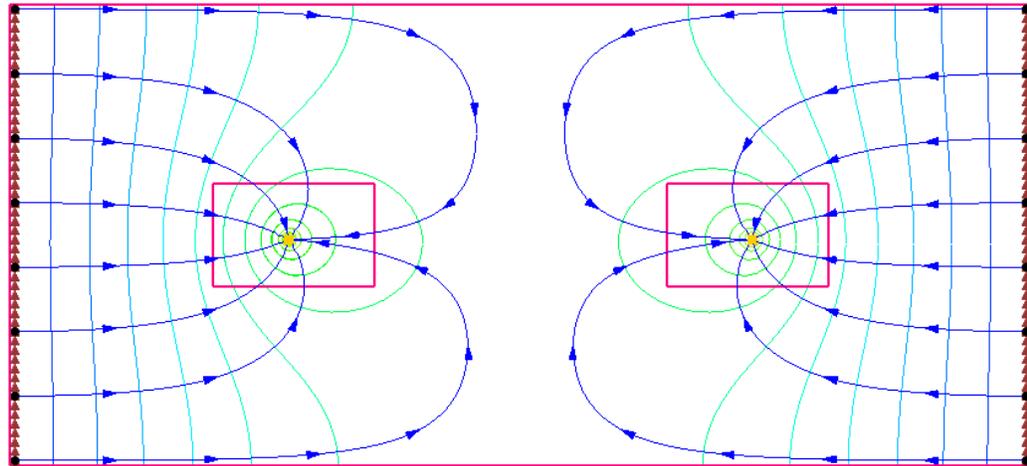


Figure 4 Two child grids visible

4 LPF Package

Some things in the LPF package need to be changed. Although the parent and CHILDD1 models use parameters to define hydraulic conductivity, in the interest of time, none will be specified for CHILDD2.

1. Select *MODFLOW | LPF – Layer Property Flow* to open the *LPF Package – CHILDD2* dialog.
2. In the *Layer data* section, select *Confined* as the *Layer type*.
3. Click **Horizontal Hydraulic Conductivity...** to bring up the *Horizontal Hydraulic Conductivity* dialog.
4. Click **Constant** → **Grid...** to bring up the *Grid Value* dialog.
5. Enter “0.0005” as the *Constant value for grid* and click **OK** to close the *Grid Value* dialog.
6. Click **OK** to exit the *Horizontal Hydraulic Conductivity* dialog.
7. Click **OK** to exit the *LPF Package – CHILDD2* dialog.

5 Save and Run MODFLOW

Now it is possible to save and run MODFLOW.

1. Save  the project.
2. Click **Run MODFLOW**  to bring up the *MODFLOW* model wrapper dialog.
3. When the model finishes, turn on *Read solution on exit* and *Turn on contours (if not on already)*.
4. Click **Close** to import the solution, turn on contours, and close the *MODFLOW* model wrapper dialog.

Note that the pathlines have changed and they no longer go all the way to the wells (Figure 5). This is because the parent model ends where the child models start and MODPATH does not track pathlines across parent/child model boundaries. To see the original pathlines, simply change the solution back to the “start (MODFLOW)” solution.

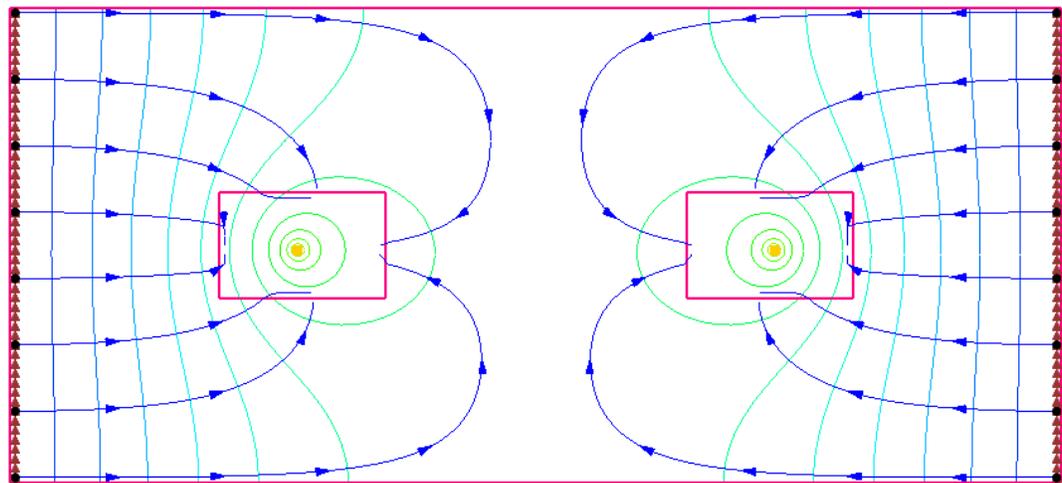


Figure 5 MODPATH pathlines do not continue to wells

6 Examining Accuracy Using BFH Package

The BFH – Boundary Head and Flow package can be used to run parent or child models independently using coupling head and flow data generated from a previous coupled run of MODFLOW-LGR. This was demonstrated in the “MODFLOW-LGR” tutorial. The BFH package can also be used to examine the accuracy of the parent/child model coupling. This section of the tutorial will demonstrate how.

6.1 Turn on IUPBFSV and IUCBHSV

1. Expand the “3D Grid Data” folder in the Project Explorer.
2. Make the parent model active by clicking on its “ MODFLOW” model or its “ grid”.
3. Select *MODFLOW | Global Options...* to bring up the *MODFLOW Global/Basic Package – Parent* dialog.

4. Click **LGR Options...** to bring up the *LGR Options* dialog.

Notice the *Save boundary fluxes (IUPBFSV)* option in the top right is on and the *IUCBHSV* option is on for CHILD1 in the spreadsheet. This indicates that the coupling flow and head files were created when MODFLOW-LGR was last run coupled on the parent and child models. If these options were not on, they would need to be turned on and MODFLOW-LGR would need to be run again in coupled mode to create these files.

5. Click **Cancel** to exit the *LGR Options* dialog.
6. Click **Cancel** to exit the *MODFLOW Global/Basic Package – Parent* dialog.

6.2 Turn on BFH Package

Now it is necessary to activate the BFH package.

1. Make the “CHILD1” model active in the Project Explorer by clicking on its “ MODFLOW” model or on “ CHILD1”.
2. Select *MODFLOW / Global Options...* to open the *MODFLOW Global/Basic Package – CHILD1* dialog.
3. Click **Packages...** to open the *MODFLOW Packages/Processes – CHILD1* dialog.
4. In the *Optional packages/processes* section, turn on *BFH – Boundary Flow and Head*.
5. Click **OK** to exit the *MODFLOW Packages/Processes – CHILD1* dialog.
6. Click **OK** to exit the *MODFLOW Global/Basic Package – CHILD1* dialog.

The file names specified in the BFH package could be reviewed at this time. The default name is based on the project file names in this case, however, so it is not necessary.

6.3 Save and Run CHILD1

Now save and run MODFLOW on just the CHILD1 model.

1. **Save**  the project.
2. Under “ CHILD1”, right-click on “ MODFLOW” and select **Run MODFLOW Uncoupled On Just This Model** to bring up the *MODFLOW – CHILD1* model wrapper dialog.
3. When the model finishes, turn on *Read solution on exit* and *Turn on contours (if not on already)*.
4. Click **Close** to import the solution, turn on contours, and close the *MODFLOW – CHILD1* model wrapper dialog.

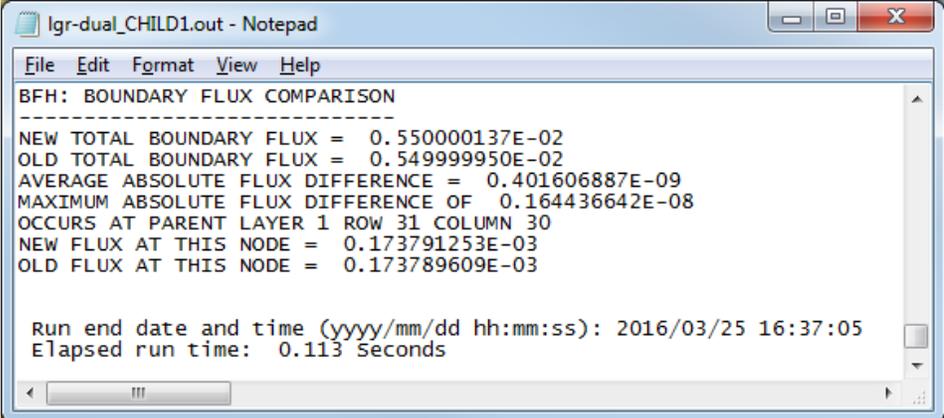
6.4 Examine the Accuracy

Now look at the accuracy of the parent/child coupling.

1. Expand the “ lgr-dual_CHILD1 (MODFLOW)” solution in the Project Explorer and double-click on “lgr-dual_CHILD1.out” to bring up the *View Data File* dialog.

If *Never ask this again* has previously been turned on, this dialog will not appear. If this is the case, skip to step 3.

2. Select the desired text editor from the *Open with* drop-down and click **OK** to open “lgr-dual_CHIDL1.out” and close the *View Data File* dialog.
3. Scroll to the bottom of the file and find the “BFH: BOUNDARY FLUX COMPARISON” section (Figure 6)



```

lgr-dual_CHILD1.out - Notepad
File Edit Format View Help
-----
BFH: BOUNDARY FLUX COMPARISON
-----
NEW TOTAL BOUNDARY FLUX = 0.550000137E-02
OLD TOTAL BOUNDARY FLUX = 0.549999950E-02
AVERAGE ABSOLUTE FLUX DIFFERENCE = 0.401606887E-09
MAXIMUM ABSOLUTE FLUX DIFFERENCE OF 0.164436642E-08
OCCURS AT PARENT LAYER 1 ROW 31 COLUMN 30
NEW FLUX AT THIS NODE = 0.173791253E-03
OLD FLUX AT THIS NODE = 0.173789609E-03

Run end date and time (yyyy/mm/dd hh:mm:ss): 2016/03/25 16:37:05
Elapsed run time: 0.113 Seconds
  
```

Figure 6 BFH Comparison data

The information shows the difference in flux across the boundary between running the models coupled and running them uncoupled. Notice there is a difference but it is very small. This information can help determine if the boundary heads and flows are still valid when running and modifying a child model independently.

7 Add Well To Child

Now add another well to CHILD1 and see how it impacts the boundary flows.

1. Using the **Select Cells**  tool, right-click somewhere in the upper right area of CHILD1 (the exact location is not important, see Figure 7 for approximate location) and select **Sources/Sinks...** to open the *MODFLOW Sources/Sinks – CHILD1* dialog.
2. Select “Wells” from the list on the left.
3. Click **Add BC**. A new entry will appear in the spreadsheet section above the button.

4. Enter “-0.0055” in the Q (flow) (ft^3/s) column (replacing the “0.0”). This is the same rate as the first well.
5. Click **OK** to close the *MODFLOW Sources/Sinks – CHILD1* dialog.

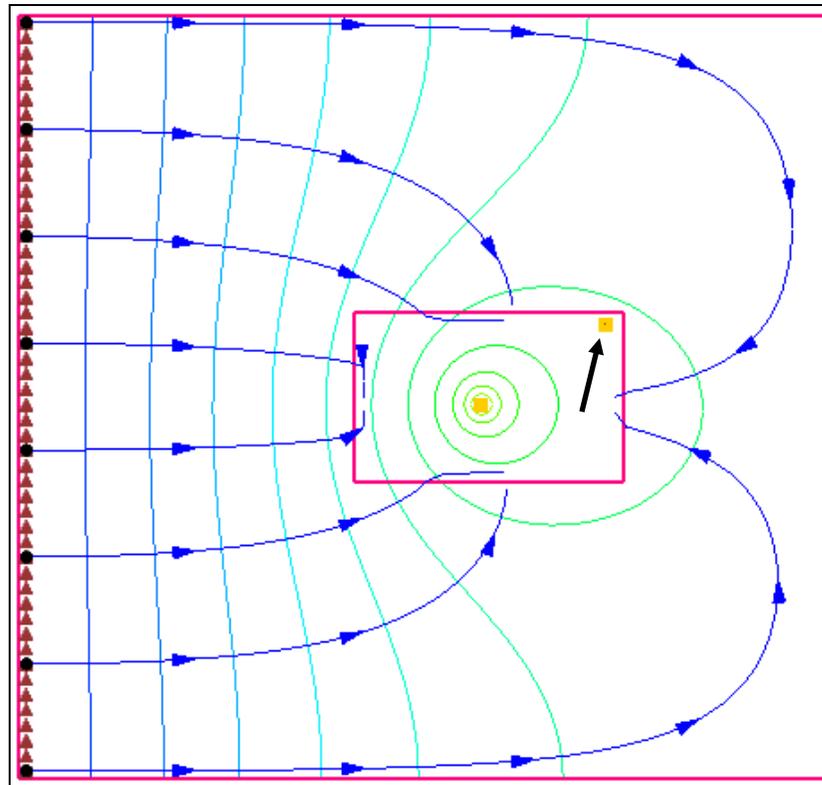


Figure 7 Creating a second well (indicated by arrow) in CHIL1

7.1 Save and Run CHIL1

Now save and run MODFLOW on just the CHIL1 model.

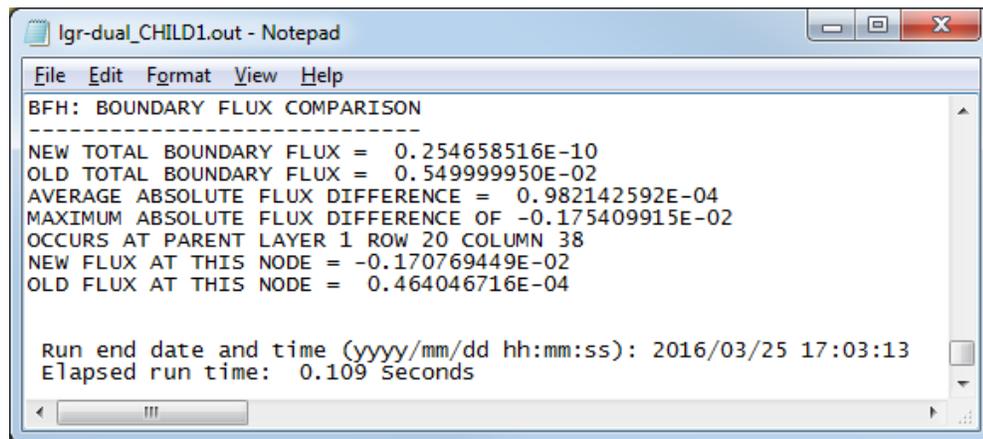
1. **Save**  the project.
2. Under “ CHILD1”, right-click “ MODFLOW” and select **Run MODFLOW Uncoupled On Just This Model** to bring up the *MODFLOW – CHIL1* model wrapper dialog.
3. When the model finishes, turn on *Read solution on exit* and *Turn on contours (if not on already)*.
4. Click **Close** to import the solution, turn on contours, and close the *MODFLOW – CHIL1* model wrapper dialog.

7.2 Examine the Accuracy

Now review the accuracy of the parent/child coupling.

1. Expand “ Igr-dual_CHILD1 (MODFLOW)” in the Project Explorer.
2. Double-click on “Igr-dual_CHILD1.out” to bring up the *View Data File* dialog. As before, this dialog may not appear. Skip to step 4 if it does not appear.
3. Select the desired text editor from the *Open with* drop-down and click **OK** to open “Igr-dual_CHILD1.out” and close the *View Data File* dialog.
4. Scroll to the bottom of the file and find the BFH: BOUNDARY FLUX COMPARISON section (Figure 8).

Notice the differences from the previous results (Figure 6) and determine if the difference is acceptable.



```

Igr-dual_CHILD1.out - Notepad
File Edit Format View Help
BFH: BOUNDARY FLUX COMPARISON
-----
NEW TOTAL BOUNDARY FLUX = 0.254658516E-10
OLD TOTAL BOUNDARY FLUX = 0.549999950E-02
AVERAGE ABSOLUTE FLUX DIFFERENCE = 0.982142592E-04
MAXIMUM ABSOLUTE FLUX DIFFERENCE OF -0.175409915E-02
OCCURS AT PARENT LAYER 1 ROW 20 COLUMN 38
NEW FLUX AT THIS NODE = -0.170769449E-02
OLD FLUX AT THIS NODE = 0.464046716E-04

Run end date and time (yyyy/mm/dd hh:mm:ss): 2016/03/25 17:03:13
Elapsed run time: 0.109 seconds

```

Figure 8 BFH comparison data with two wells in CHILD1

8 Add Well To Parent

Now add a well to the parent and see how it affects the boundary heads.

1. Select the parent “ grid” in the Project Explorer to make it active.
2. Using the **Select Cells**  tool, right-click somewhere between the two child grids (the exact location is not important as long as it is not within one of the child grids) and select **Sources/Sinks...** to open the *MODFLOW Sources/Sinks – Parent* dialog.
3. Select “Wells” from the list on the left.
4. Click **Add BC** to create a new entry in the spreadsheet above the button.
5. Enter “-0.0055” in the *Q (flow) (ft³/s)* column (replacing the “0.0”). This is the same rate as the other wells.
6. Click **OK** to create the new well and close the *MODFLOW Sources/Sinks – Parent* dialog.

8.1 Turn on BFH Package in the Parent Model

To run the parent model independently, the BFH package must first be turned on.

1. Select *MODFLOW* | **Global Options...** to open the *MODFLOW Global/Basic Package – Parent* dialog.
2. Click **Packages...** to open the *MODFLOW Packages/Processes – Parent* dialog.
3. In the *Optional packages/processes* section, turn on *BFH – Boundary Flow and Head*.
4. Click **OK** to exit the *MODFLOW Packages/Processes – Parent* dialog.
5. Click **OK** to exit the *MODFLOW Global/Basic Package – Parent* dialog.

8.2 Save and Run the Parent

Now save and run MODFLOW on just the parent model.

1. **Save**  the project.
2. Right-click on the parent “ MODFLOW” model and select **Run MODFLOW Uncoupled On Just This Model** to bring up the *MODFLOW – Parent* model wrapper dialog.
3. When the model finishes, turn on *Read solution on exit* and *Turn on contours (if not on already)*.
4. Click **Close** to import the solution, turn on contours, and close the *MODFLOW – Parent* model wrapper dialog.

The Graphics Window should appear similar to Figure 9.

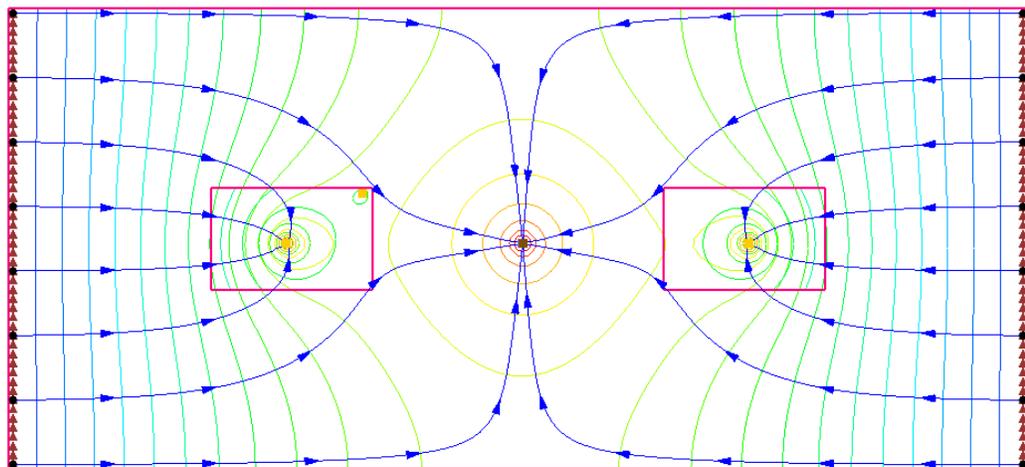


Figure 9 The new well is visible in the parent grid

8.3 Examine the Accuracy

Again, look at the accuracy of the parent/child coupling.

1. Expand the “ lgr-dual (MODFLOW)” solution in the Project Explorer.
2. Double-click on “lgr-dual.out” to bring up the *View Data File* dialog. As before, this dialog may not appear. If it does not appear, skip to step 4.
3. Select the desired text editor from the *Open with* drop-down and click **OK** to open “lgr-dual.out” and close the *View Data File* dialog.
4. Scroll to the bottom of the file and find the BFH: BOUNDARY HEAD COMPARISON section.

Notice that now this section shows boundary heads, not fluxes. Notice how big the head difference is from the coupled model and determine if the difference is acceptable.

9 Conclusion

This concludes the “MODFLOW – LGR Dual Refinement” tutorial. The following concepts were discussed and demonstrated:

- GMS supports MODFLOW-LGR and models with multiple children.
- MODPATH can be used with MODFLOW-LGR, but pathlines do not cross parent/child borders.
- In GMS, MODPATH can only be used on the parent model.
- Parameters can be used with MODFLOW-LGR.
- The BFH package can be used to examine the accuracy of the parent/child coupling and the impact that modifications in uncoupled models have on the boundary heads and flows.