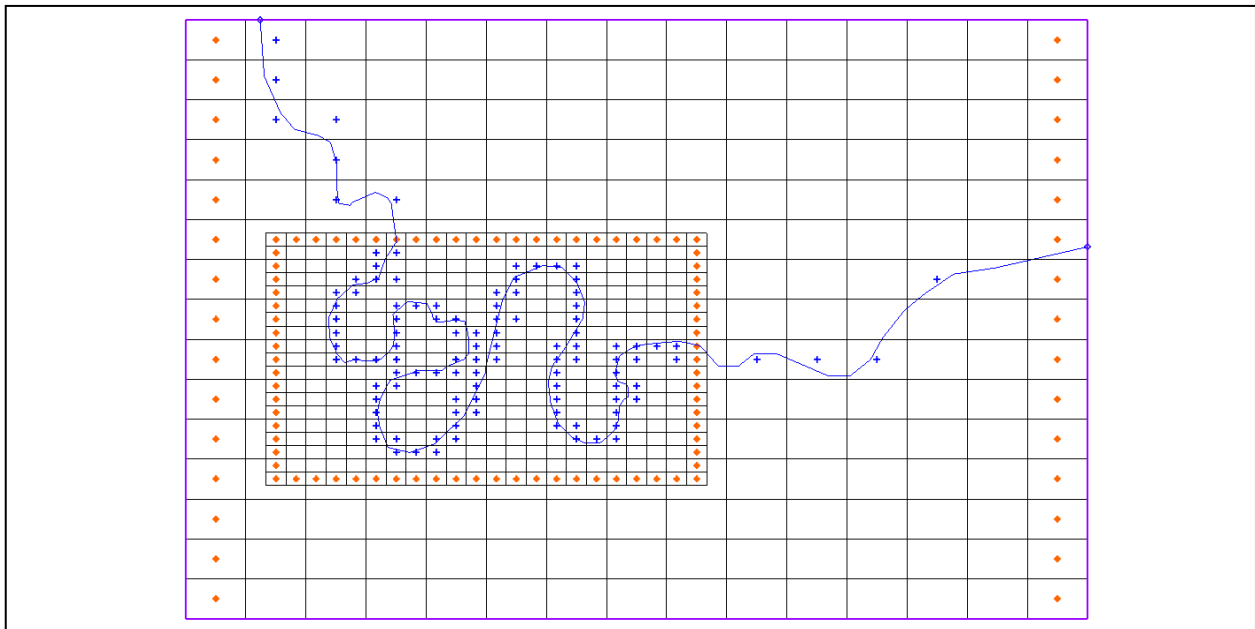


GMS 9.2 Tutorial **MODFLOW-LGR**

Create MODFLOW-LGR models with locally refined grids using GMS



Objectives

GMS supports building MODFLOW-LGR models with nested child grids. This tutorial shows the various parts of the MODFLOW-LGR interface in GMS.

Prerequisite Tutorials

- MODFLOW – Grid Approach
- MODFLOW – Conceptual Model Approach I

Required Components

- Grid
- MODFLOW-LGR

Time

- 30-60 minutes



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2 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.

2.1 Outline

This is what you will do:

1. Read in an existing MODFLOW model.
2. Switch model to MODFLOW-LGR and run.
3. Add a child grid.

4. Map → MODFLOW.
5. Run the parent and child coupled.
6. Save the boundary heads.
7. Turn on the BFH package.
8. Run the child model independently using the boundary heads.

3 Description of Problem

The problem we will be solving in this tutorial is one of the example problems included with MODFLOW-LGR. It consists of a meandering river in a regional model as shown in Figure 1. The area is modeled using MODFLOW-2005 and a three-layer grid with specified head on the left and right and steady state conditions. No-flow boundaries occur on the north and south and flow is generally from west to east. A child grid will be used in the area where the river bends are close together in order to obtain a more accurate solution in this area.

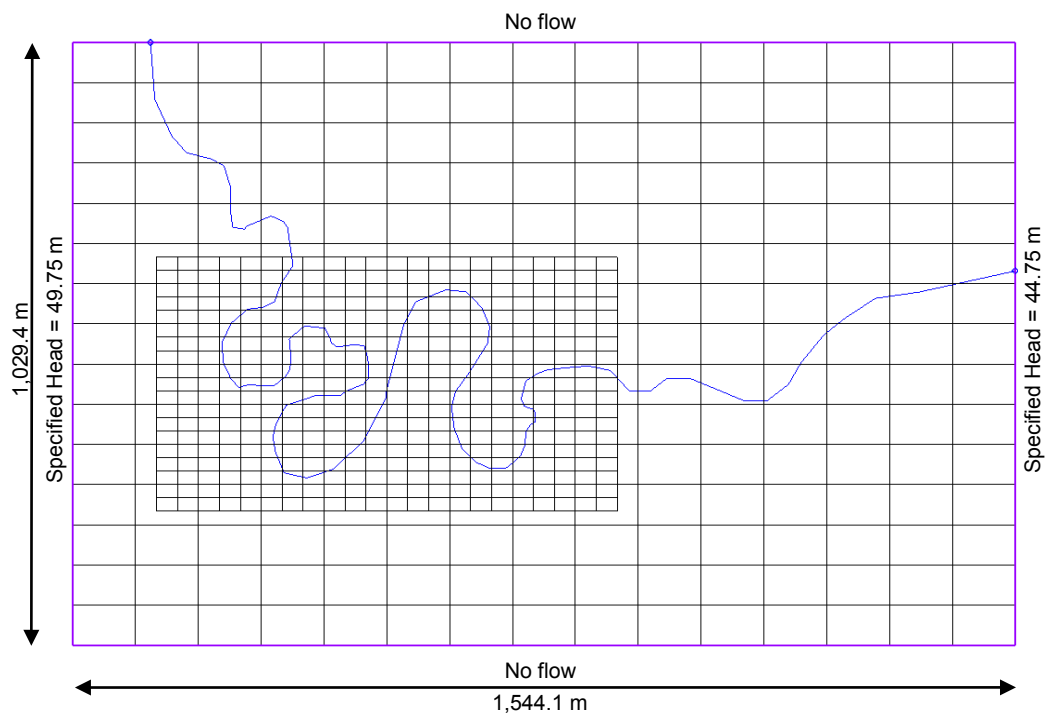


Figure 1. Sample problem to be solved (Mehl and Hill, 2005).


4 Getting Started

Let's get started.

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

5 Open the Non-LGR model

We'll start by opening the non-LGR regional model that has already been created using MODFLOW 2005.

1. Select the *Open* button .
2. Locate and open the directory entitled **Tutorials\MODFLOW\mflgr**.
3. Open the file entitled **start.gpr**.

You should see something like the image below.

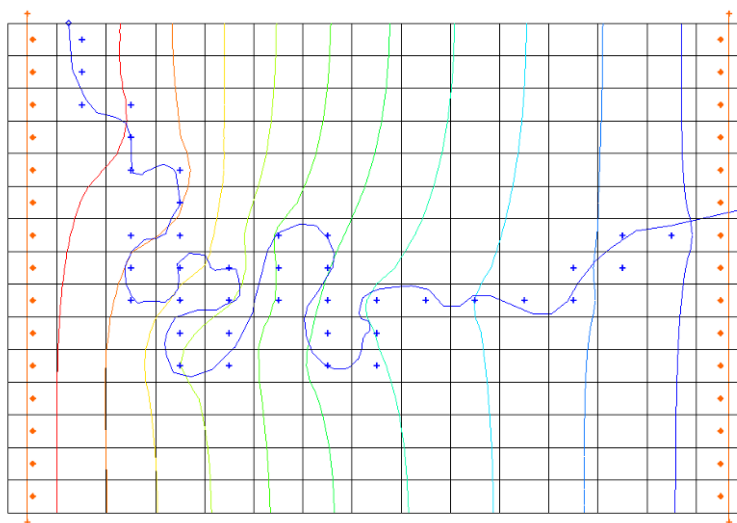



Figure 2. Non-LGR regional model.

6 Save with a different name

Before we make any changes, let's save the project under a new name.

1. Select the *File | Save As* command.
2. Save the project with the name **lgr.gpr**.

Now you can hit the save button  periodically as you develop your model.



7 Switch to MODFLOW-LGR


We need to switch the model from MODFLOW-2005 to MODFLOW-LGR.

1. Select the *MODFLOW | Global Options* command.
2. Change the *MODFLOW version* to **LGR**.
3. Click *OK*.

8 Save and Run MODFLOW



Before we add a child model, let's save what we have and run MODFLOW to make sure MODFLOW-LGR gives us the same results as MODFLOW-2005.

1. Click the *Save*  button.
2. Click the *Run MODFLOW*  button.
3. When the model finishes, click *Close*.


GMS reads the solution and updates the contours. Notice there is no difference in the contours – the MODFLOW-LGR solution is the same as the MODFLOW-2005 solution. You may want to switch between the **start** and **lgr** solutions  in the *Project Explorer* to prove to yourself that they are identical.

9 Creating the Child Grid

Now we'll create the child grid by selecting a range of cells in the regional model. The area is marked by a rectangle which we'll turn on. We'll also turn off the contours to make things easier to see.

1. Click the *Display Options*  button.
2. Turn **off** *Contours* and click *OK*.
3. In the *Project Explorer*, turn **on**  *Annotation Data*.

A red rectangle should appear.

4. Using the *Select Cells*  tool, drag a box to select the cells in the red rectangle. Be sure to get all the cells touched by the rectangle. The region of selected cells should be 8 wide by 7 high.
5. Right-click anywhere in the selected area and select the *Create Child Grid* command.

This opens the *Create Child Grid* dialog as shown below.

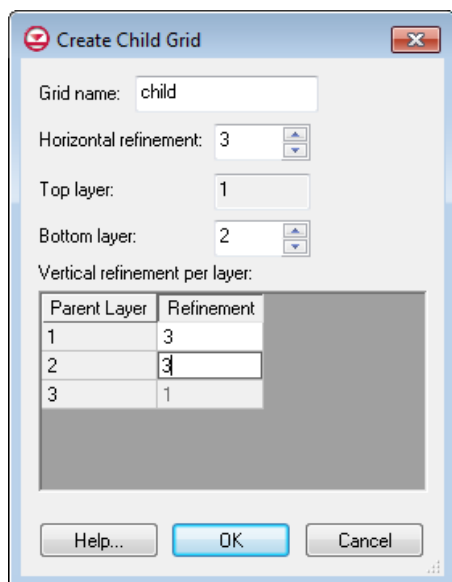



Figure 3. *Create Child Grid* dialog.

6. Set the options as shown in Figure 3. Set the *Bottom layer* to 2 and the *Vertical refinement per layer* to 3 for parent layers 1 and 2.
7. Click *OK*.
8. In the *Project Explorer*, turn **off**  *Annotation Data* to hide the red rectangle.

You now have a nested child grid. Your model should look like Figure 4.

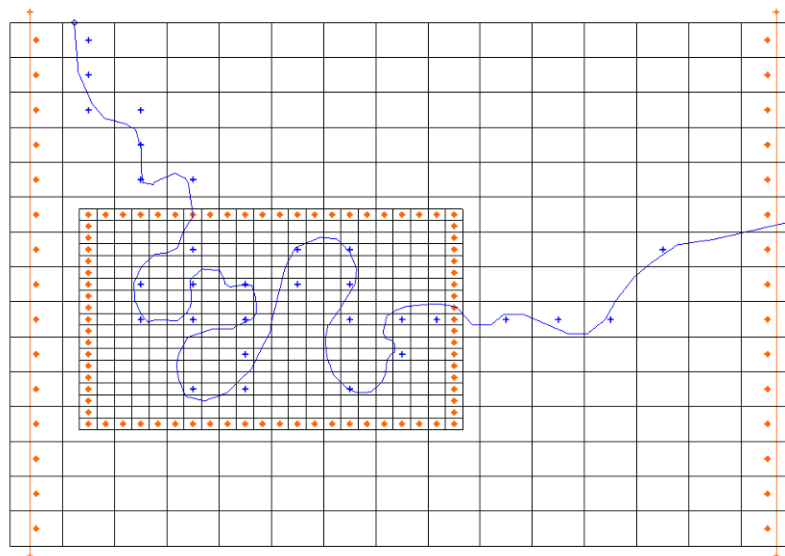






Figure 4. *Model with child grid*.

10 Examine the Child Grid

Notice that the cells on the outside boundary of the child grid have constant head boundary conditions. In MODFLOW-LGR terminology, these child cells on the sides are 1/2 cells and on the corners they are 1/4 cells. Note that GMS always draws the entire cell even though only 1/2 or 1/4 of the cell actually exists as far as MODFLOW is concerned. Where the child cell center coincides with a parent cell center it is a shared node. Head and flows are iteratively computed along this boundary and shared between the parent and child models.

Look at the *Project Explorer* and take note of the following:

- A new  3D grid item has been added and it is called “child”. It is under the original, parent grid.
- The original  3D grid icon is now grey indicating that it is no longer active. There is only one active grid at a time. You can only select cells in the active grid. To activate a 3D grid, simply click on its icon.
- A  MODFLOW model appears under the new child grid.
- The original  MODFLOW icon under the parent grid is now grey indicating it is inactive. Similar to 3D grids, there is only one MODFLOW model active at a time. To activate a MODFLOW model, simply click on its icon or on the icon of its parent grid. Activating a MODFLOW model also activates its grid.

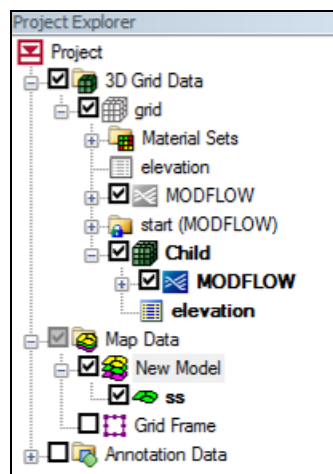





Figure 5. *Project Explorer with Child grid.*

Let's examine grid activity and the child grid.

1. With the *Select Cells*  tool, try to select a cell in the parent grid. You cannot because it is inactive.
2. Now try to select cells in the child grid. You can, because it is active.

3. In the *Project Explorer*, click on the parent  grid to activate it.
4. Now try to select cells in the parent grid and the child grid. When you click in the area of the child grid, you are actually selecting cells in the parent grid.
5. Switch to  *Front View*.

The display should look something like this:

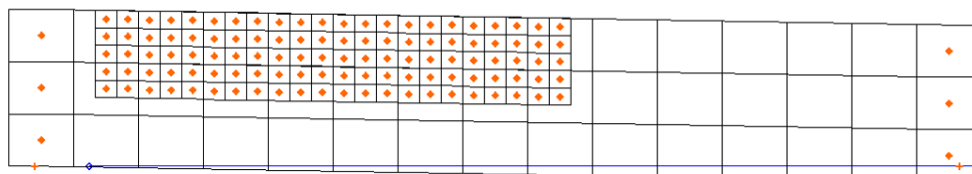



Figure 6. Front view.

6. Change the row that you are looking at by using the up and down arrows on the *Ortho Grid* toolbar. 

Notice that both the parent and child grids change as you view different rows. The *Ortho Grid* toolbar acts on the active grid but the child grid row is kept in synch with the parent grid row.

7. On the *Ortho Grid* toolbar, turn **on** the *Multiple grids* toggle.

This opens the *Current Ortho Levels* dialog which shows which row is currently being displayed on all grids.

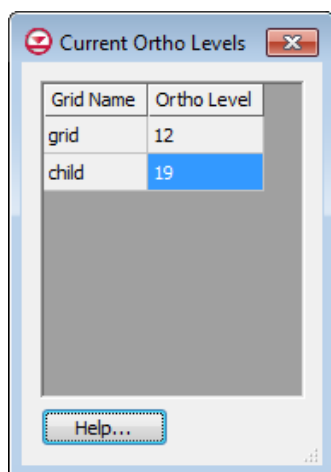


Figure 7. Current Ortho Levels dialog.

This dialog is modeless, meaning you can continue to use the GMS interface while it is being displayed.

- Continue to change the grid row up and down and watch the values change in the *Current Ortho Levels* dialog.

The child grid rows change by three as the parent grid row changes by one. GMS is finding and displaying the child row that corresponds with the current parent row.

If you want to not have GMS synch the ortho levels you can turn this off via the *Synch ortho levels with all grids* option in the *3D Grid Display Options* dialog. Then you can set the levels on each grid independently.

The top and bottom elevations are such that the model slopes down from left to right. You can see that the child grid extends down to the middle of the second layer. This follows the LGR rules for vertical refinement as shown in Figure 7.

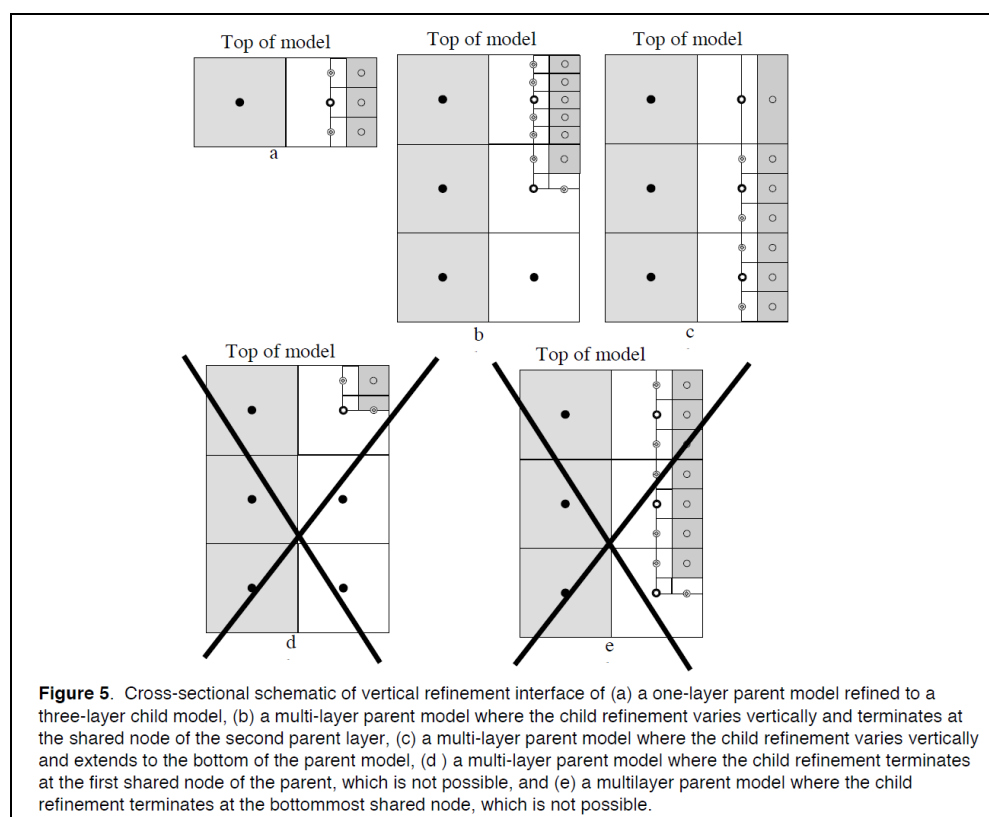




Figure 8. Vertical refinement rules (Mehl and Hill, 2005).

- Switch back to  *Plan View*.

11 LGR Options


Let's look at the *LGR Options* dialog.

- Make sure the parent  grid is active by clicking on it in the *Project Explorer*.

2. Select the *MODFLOW | Global Options* command.

Notice the name of the dialog ends in “ – Parent”. When LGR is in use, the MODFLOW dialogs will end in “– Parent” or “– child” depending on which MODFLOW simulation is currently active. You can rename grids and, for the child grids, the new grid name will be displayed in the MODFLOW dialogs. For the parent grid, the MODFLOW dialogs will always say “– Parent” no matter what you rename the parent grid.

The main MODFLOW menu depends on which MODFLOW simulation is active. Since the parent simulation is currently active, all the main MODFLOW menu commands will act on it. If we make the child model active, the main MODFLOW menu commands will act on the child model.

The same menu commands can also be found by right-clicking on the  MODFLOW item in the *Project Explorer*. You may prefer to use the *Project Explorer* to avoid having to remember which model the main menu is acting on.

3. Click the *LGR Options* button.

This opens the LGR Options dialog as shown in Figure 8. The items in this dialog correspond to the LGR Control File. This file is what you pass to MODFLOW-LGR when running a parent/child coupled simulation and contains information on the parent and child models.

The top spreadsheet lists all the child grids. The lower spreadsheet displays the layer-by-layer vertical refinement of whichever child grid is selected in the top spreadsheet. You cannot edit the dimensions or refinement of the child grids in this dialog, but you can see the corresponding values that will be written to the LGR Control File (NPLBEG, NPLEND etc.).

4. Click anywhere in the first row of the upper spreadsheet. The vertical refinement table is activated.
5. Click *Cancel* twice to exit all dialogs.

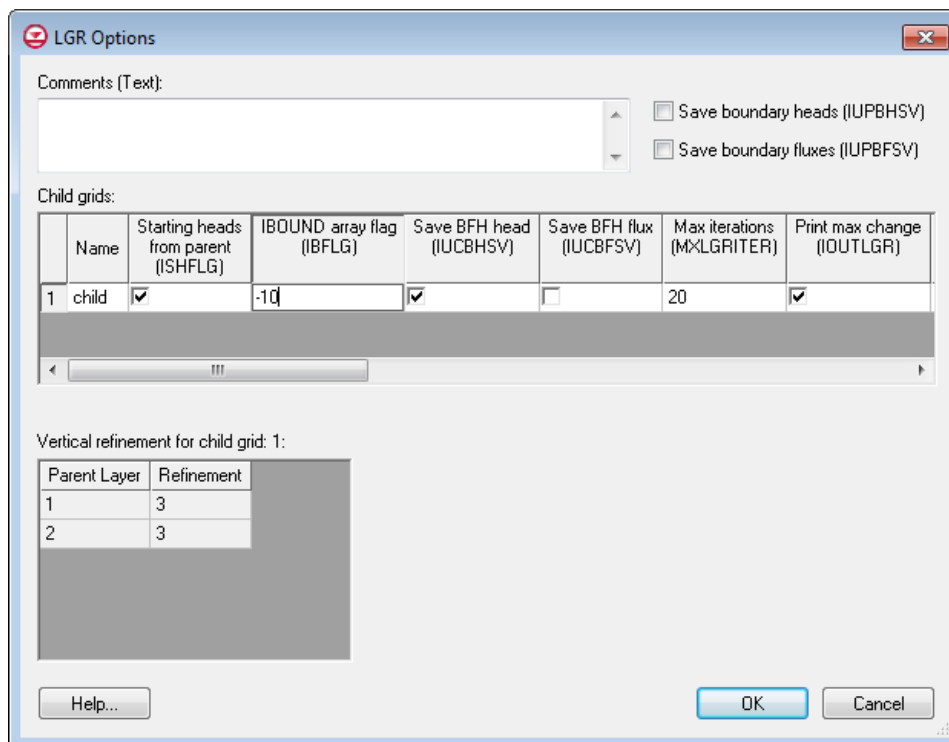




Figure 9. LGR Options dialog.

12 Map → MODFLOW

Now that we've created a child grid, we need to map our conceptual model to it so that the river is represented in the child model.

1. Make the child  grid active by clicking on it in the *Project Explorer*.
2. Change the k layer to 1 in the *Ortho Grid* toolbar.
3. Click the *Map → MODFLOW*  button.
4. Accept the default values in the dialog and click *OK*.

Your model should look like Figure 9. You should now see that river boundary conditions have been added to all the cells in the child grid under the river arc.

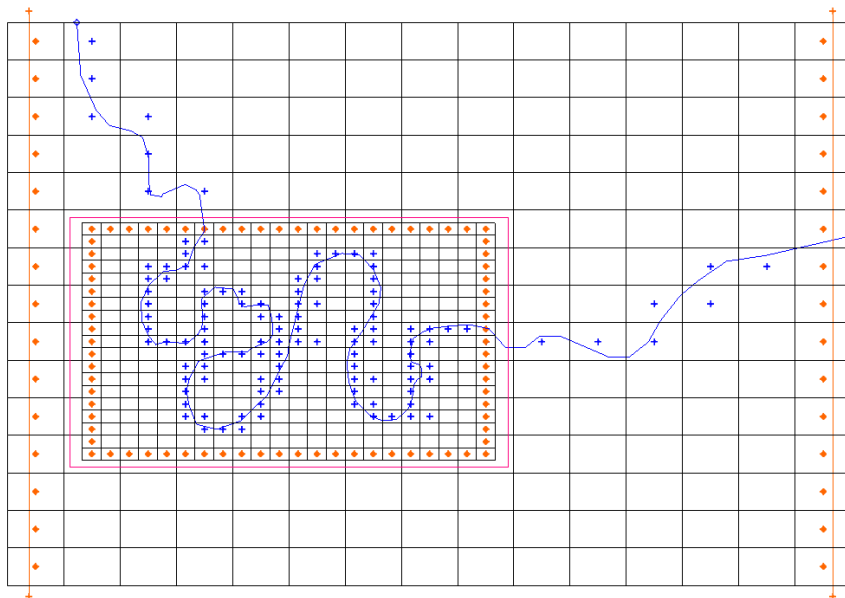


Figure 10. After Map → MODFLOW with child model.

13 Checking the Simulation

Before we run MODFLOW, let's run the *Model Checker* to see if there is anything amiss.



1. Select the *MODFLOW | Check Simulation* command.
2. Click the *Run Check* button. There should be no warnings or errors detected.

Notice that the model checker checked both the parent and the child models. It doesn't matter which grid/model is active, the model checker will always look at all MODFLOW models.

3. Click the *Done* button.

14 Save and Run MODFLOW


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

1. Click the *Save*  button.
2. Click the *Run MODFLOW*  button.
3. When the model finishes, click *Close*.

GMS reads the solutions and updates the contours. There are two solutions, one for the parent and one for the child.

15 Viewing the Solution

Contours are displayed for both the parent and child grids. You'll notice some overlap around the edges. This is because although the parent cells around the parent/child interface are 1/2 cells and 3/4 cells, GMS draws, and contours, the entire cell.

1. Turn **off** the  *child* grid.




Notice that the parent cells in the region of the child grid are inactive and not displayed. The cell activity is a property of the head solution data set. The IBOUND array still has them marked as active, as it should. You may want to verify this by examining the parent IBOUND array.

2. Turn **on** the  *child* grid.



Notice the contours of the child and parent seem to match pretty well.

15.1 Flow Budget

Let's examine the flow budget.

1. Make the parent  grid the active grid (by clicking on it in the *Project Explorer*).
2. Double-click on the  *lgr.out* file in the  *lgr (MODFLOW)* solution under the parent grid. If prompted to choose a text editor, pick one.
3. Scroll to the bottom and locate the *PARENT FLUX B.C.* items in the budget summary.

This represents the flow between the parent and child models. There should be about 24 m³ in and 120 m³ out. That means 24 m³ flows from the child to the parent and 120 m³ flows from the parent to the child.

4. In GMS, double-click on the  *lgr_child.out* file in the  *lgr_child (MODFLOW)* solution under the *parent* grid.
5. Scroll to the bottom and locate the section called FLUX ACROSS PARENT-CHILD INTERFACE.

Notice the flow in to the child and flow out to the parent are the same as what we just saw in the *lgr_child.out* file. Also notice the *PARENT FLUX B.C.* items are not listed in the budget summary.

6. In GMS, select the *MODFLOW | Flow Budget* command.

Notice that the Flow Budget does **not** include the PARENT FLUX B.C. item that's included in the .out file. Unfortunately MODFLOW does not write this information to

the CCF file for either the parent or the child. GMS gets the flow budget numbers from the CCF file, not the .out file.

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

16 BFH package

The BFH package was created to allow parent and child models to be run independently using the coupling flux and head boundary conditions produced by LGR. To do this, the model is first run coupled using LGR to calculate and save the coupling boundary conditions. Then the parent or child model is run independently by turning on the BFH package and using the coupling boundary conditions saved in the first step. To demonstrate we'll first run the child model independently, then run the parent model independently.

16.1 Run the Child Model Independently

Save the boundary heads and fluxes

Since we are planning to run the child model independently, we'll turn on the option to save the coupling heads (IUCBHSV). If we were planning on running the parent model independently, we would turn on the option to save the complimentary fluxes (IUPBFSV). Actually, we want to run the parent independently in a minute so we'll turn on both options.

1. With the **parent** model active, select the *MODFLOW | Global Options* command.
2. Click the *LGR Options* button.
3. At the top right of the dialog, turn **on** the *Save boundary fluxes (IUPBFSV)* option.
4. In the top spreadsheet, turn **on** the *Save BFH head (IUCBHSV)* option for the child grid.
5. Click *OK* twice to exit both dialogs.

We'll save the project with a new name so we can compare the solutions.

6. Select the *File | Save As* command.
7. Save the project with the name **lgr2.gpr**.


This causes the following line to be written to the name file of the child model:

DATA	1787	"lgr2_child.bfh_hed"
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When the model is run, the boundary heads will be saved to this *lgr2_child.bfh_hed* file. We haven't changed anything else so the solution will not change.


Run MODFLOW

We need to run MODFLOW in coupled mode.


1. Click the *Run MODFLOW*  button.
2. When the model finishes, select the *Close* button.

Turn on BFH package

Now we'll use the boundary heads that were just saved in the *lgr2_child.bfh_hed* file to run the child model independently. These heads are applied around the boundary of the child model.

1. In the *Project Explorer*, right-click on the **child**  MODFLOW model and select the *Global Options* command.
2. Click the *Packages* button.
3. Turn **on** the *BFH – Boundary Flow and Head* package.
4. Click *OK* twice to exit both dialogs.

Now that we've turned it on, let's look at the options in the BFH Package.

5. In the *Project Explorer*, right-click on the **child**  MODFLOW model and select the *Optional Packages | BFH – Boundary Flow and Head* command.

The dialog should look like Figure 10 (the path to the head file will depend on where you saved your project).

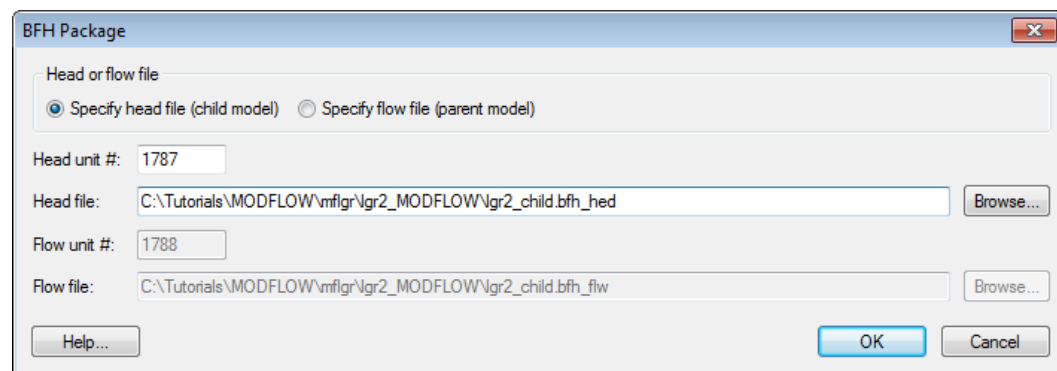


Figure 11. BFH – Boundary Flow and Head package dialog.




By default, the *lgr2_child.bfh_hed* file that MODFLOW just created is listed in the *Head file* field. This file and the *Head unit #* will be written in the MODFLOW name file. When MODFLOW runs, it will read the heads from this file and apply them to the

boundary of the child model. We don't need to change anything because GMS has defaulted the options the way we want them.

6. Click *OK* to exit the *BFH Package* dialog.

Save and Run MODFLOW

Now we're ready to run the child model independently.

1. Click the *Save* button .
2. In the *Project Explorer*, right-click on the **child**  *MODFLOW* model and select the  *Run MODFLOW Uncoupled On Just This Model* command.

This command causes GMS to launch MODFLOW on just the child model. MODFLOW-LGR is still used, but not in a coupled fashion.

3. When it's finished, click *Close*.

GMS reads the solution and displays the contours. Notice that the contours are the same as when the models were run coupled.


The BFH package cannot be used when running MODFLOW-LGR in coupled mode, so if we wanted to do that again we would need to turn off the BFH package in the child model.

16.2 Run the Parent Independently

Now let's see how the BFH package can be used to run the parent independently. We already turned on the option to save the complimentary fluxes (IUPBFSV) so we just need to turn on the BFH package in the parent model.

Turn on BFH package




Now we'll use the boundary flows that were saved in the *lgr2.bfh_flw* file to run the parent model independently. These flows are applied to the boundary of the parent model around the child model.

1. In the *Project Explorer*, right-click on the **parent**  *MODFLOW* model and select the *Global Options* command.
2. Click the *Packages* button.
3. Turn **on** the *BFH – Boundary Flow and Head* package.
4. Click *OK* twice to exit both dialogs.

At this point you might want to open the BFH Package dialog for the parent model and look at the options. However, GMS has defaulted everything to what we want so we can go ahead and run the parent independently.

Save and Run MODFLOW

Now we're ready to run the parent model independently.

1. Click the *Save* button .
2. In the *Project Explorer*, right-click on the **parent**  *MODFLOW* model and select the  *Run MODFLOW Uncoupled On Just This Model* command.

This command causes GMS to launch MODFLOW on just the parent model. MODFLOW-LGR is still used, but not in a coupled fashion.

3. When it's finished, click *Close*.

GMS reads the solution and displays the contours. Notice there is a small difference in the contours compared to the coupled solution.

17 Conclusion

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

- GMS supports MODFLOW-LGR and parent/child models.
- MODFLOW-LGR gives the same results as MODFLOW-2005 and MODFLOW-2005 if there are no child grids present.
- Child grids appear in the *Project Explorer* under the parent grid.
- Only one grid and MODFLOW simulation is active at a time. You can only select cells in the active grid.
- The *LGR Options* dialog shows the child grids and the information that will go in the LGR Control file.
- The BFH package can be used to run the parent or child model independently.

18 References

- Mehl, S.W. and Hill, M.C., 2005, MODFLOW-2005, the U.S. Geological Survey modular ground-water model -- documentation of shared node local grid refinement (LGR) and the Boundary Flow and Head (BFH) Package: U.S. Geological Survey Techniques and Methods 6-A12.