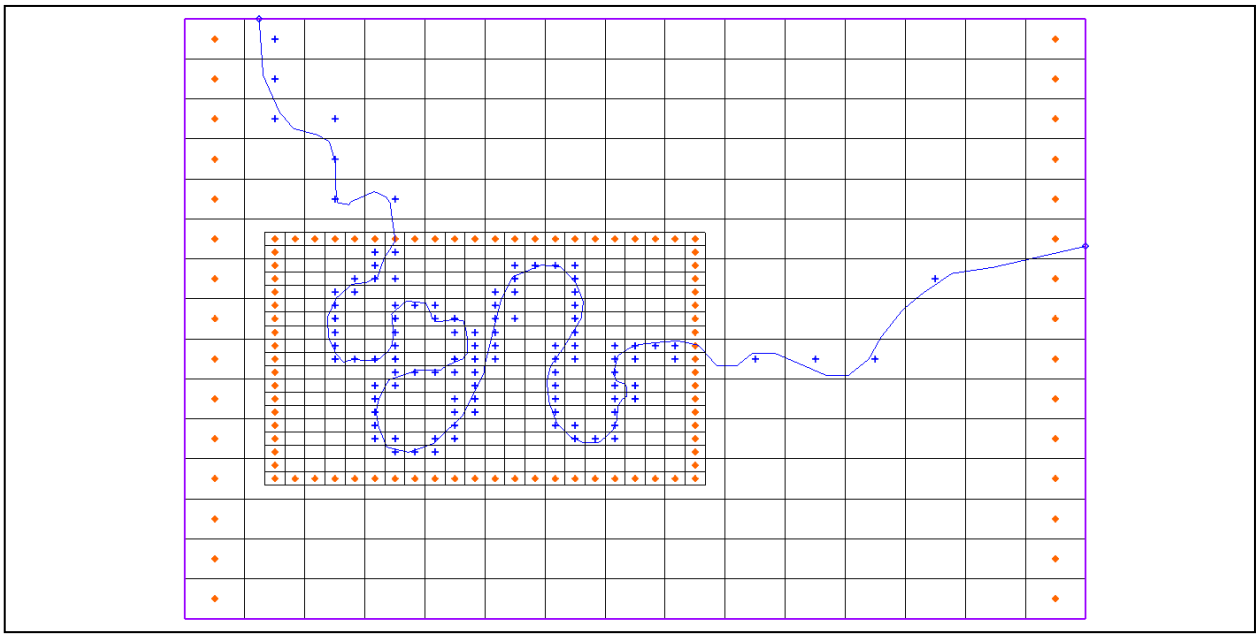
GMS

v. 10.0

GMS 10.0 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 Module
- MODFLOW-LGR

Time

- 30-50 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.

1.1 Outline

Here are the steps of this tutorial:

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.

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2 Description of Problem

The problem 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.

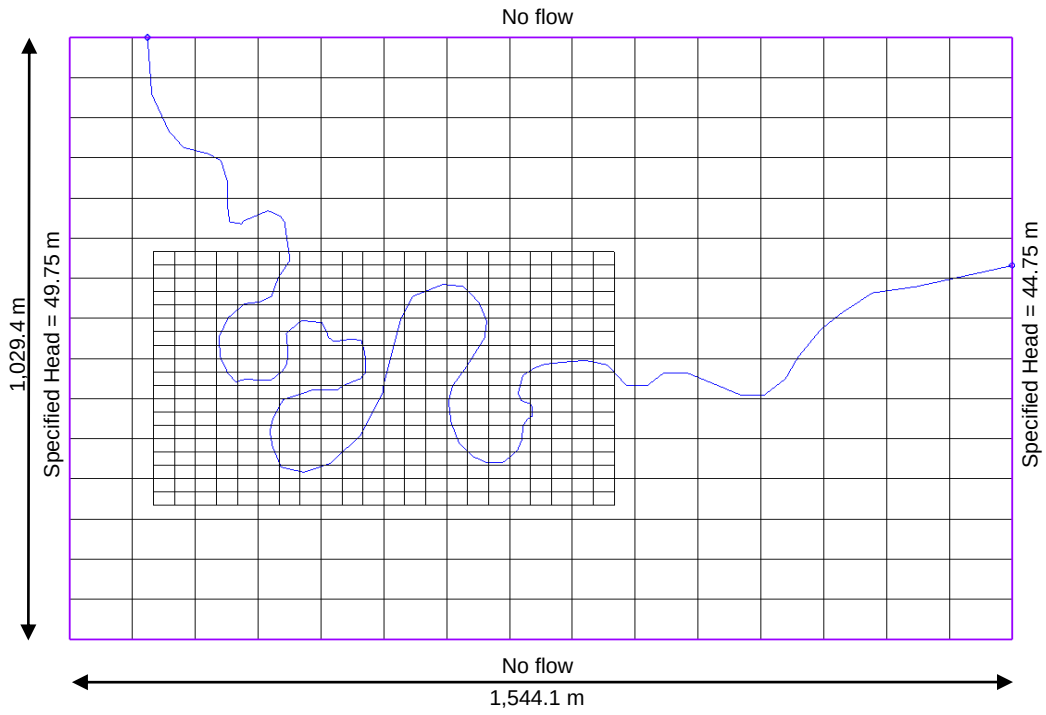

Figure 1 Sample problem to be solved[1]

3 Getting Started

Do the following to get started:

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

1 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, p. 43.

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4 Open the Non-LGR model

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. Select the file entitled "start.gpr."
4. Click the **Open** button.

The user should see something like the image below.

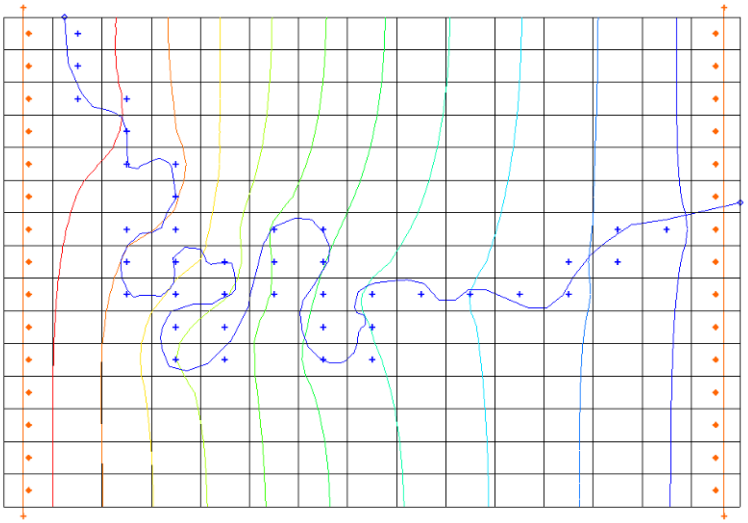

Figure 2 Non-LGR regional model

5 Save with a different name

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

1. Select the *File* | **Save As** command.
2. Change the project name to "lgr.gpr."
3. Click the **Save** button.

Now select the save button periodically as the model is developed.

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6 Switch to MODFLOW-LGR

It is now necessary to switch the model from MODFLOW-2005 to MODFLOW-LGR.

1. Select the *MODFLOW* | **Global Options** command to open the *MODFLOW Global/Basic Package* dialog.
2. Change the *MODFLOW version* to *LGR*.
3. Click **OK**.

7 Save and Run MODFLOW

Before adding a child model, save the changes 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. The user may want to expand the "3D Grid Data" folder and switch between the "start" and "lgr" solutions in the Project Explorer to prove that they are identical.

8 Creating the Child Grid

Now it is possible create the child grid by selecting a range of cells in the regional model. The area is marked by a rectangle that the user will turn on. The user will 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 the "Annotation Data" folder.

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.

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

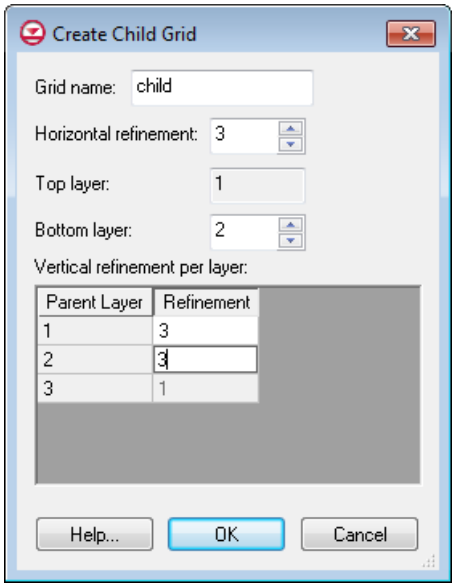

Figure 3 Create Child Grid dialog

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

The user should now have a nested child grid. The model should look like Figure 4.

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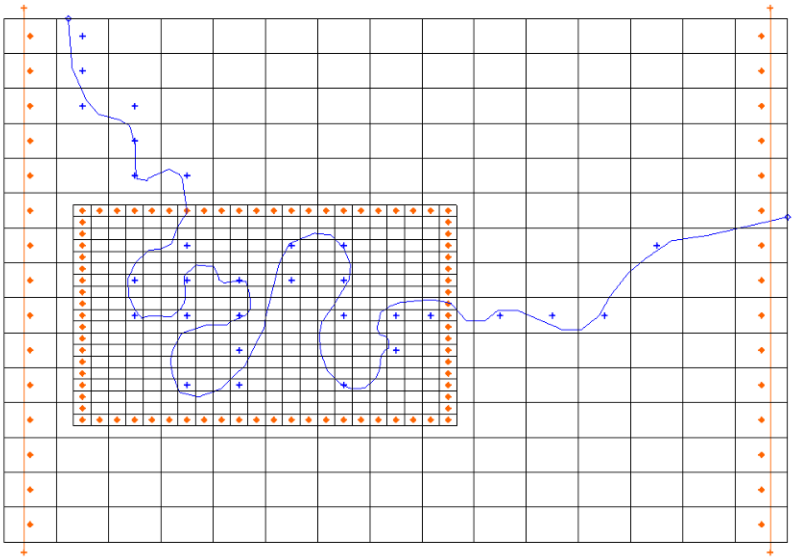

Figure 4 Model with child grid

9 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 one-half cells and on the corners they are one-quarter cells. Note that GMS always draws the entire cell even though only a half or quarter 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. The user can only select cells in the active grid. To activate a 3D grid, simply click on its icon.
- A "MODFLOW" model has appeared 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.

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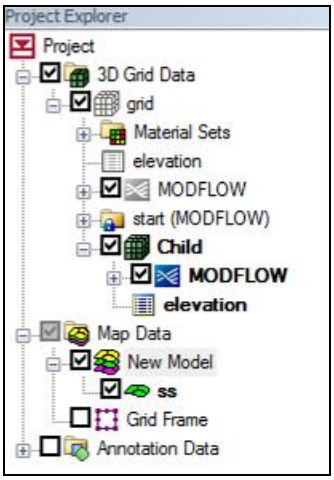

Figure 5 Project Explorer with child grid

Now examine grid activity and the child grid.

1. With the **Select Cells** tool, try to select a cell in the parent grid. This isn't possible because it is inactive.
2. Now try to select cells in the child grid. This is possible 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 the user clicks in the area of the child grid, the user is actually selecting cells in the parent grid.
5. Click on the **Front View** button.

The display should look something like this:

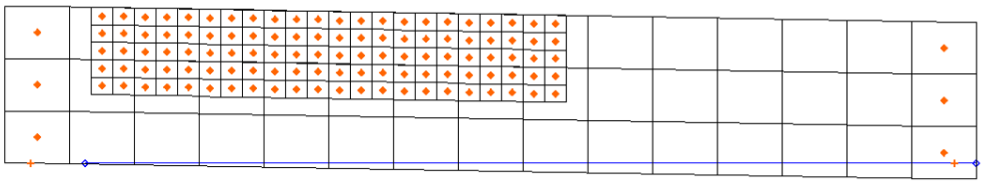

Figure 6 Front view

6. Change the row being viewed by using the up and down arrows on the *Ortho Grid Toolbar*. 

Notice that both the parent and child grids change while viewing 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.

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

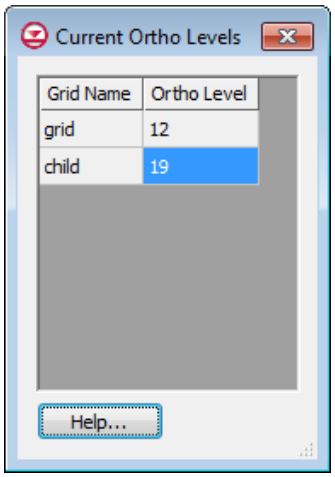

Figure 7 Current Ortho Levels dialog

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

8. 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 the user doesn't want to have GMS synch the ortho levels, the user can turn this off via the *Synch ortho levels with all grids* option in the 3D Grid *Display Options* dialog. Then the user can set the levels on each grid independently.

The top and bottom elevations are such that the model slopes down from left to right. The user 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 8.

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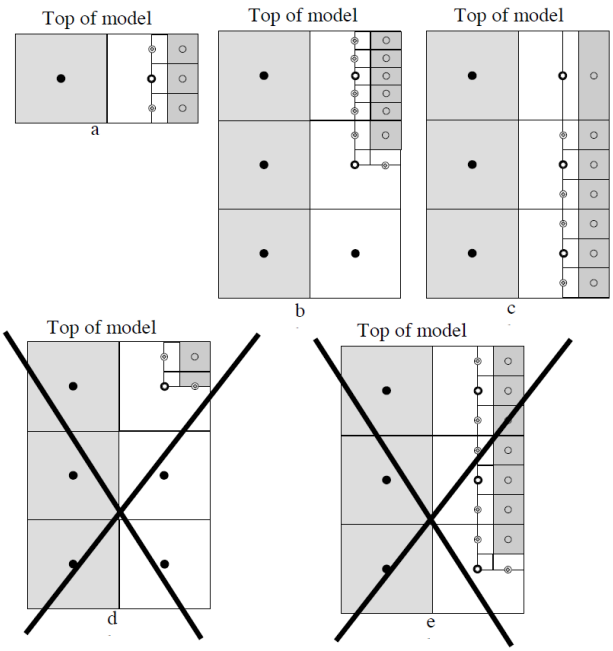

Figure 5. Cross-sectional schematic of vertical refinement interface of (a) a one-layer parent model refined to a three-layer child model, (b) a multi-layer parent model where the child refinement varies vertically and terminates at the shared node of the second parent layer, (c) a multi-layer parent model where the child refinement varies vertically and extends to the bottom of the parent model, (d) a multi-layer parent model where the child refinement terminates at the first shared node of the parent, which is not possible, and (e) a multilayer parent model where the child refinement terminates at the bottommost shared node, which is not possible.

Figure 8 Vertical refinement rules[2]

9. Switch back to the *Plan View* button.
10. Exit the *Current Ortho Levels* dialog.

10 LGR Options

Now look at the *LGR Options* dialog.

1. Make sure the parent grid is active by clicking on it in the Project Explorer.
2. Select the *MODFLOW* | **Global Options** command to open the *MODFLOW Global/Basic Package – Parent* dialog.

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. The user 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 the parent grid is renamed.

2 Ibid, p. 13.

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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 the user makes 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. The user 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 9. The items in this dialog correspond to the LGR Control File. This file is what the user passes to MODFLOW-LGR when running a parent/child coupled simulation; this file also 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. The user cannot edit the dimensions or refinement of the child grids in this dialog, but the user 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** to exit the *LGR Options* dialog.

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

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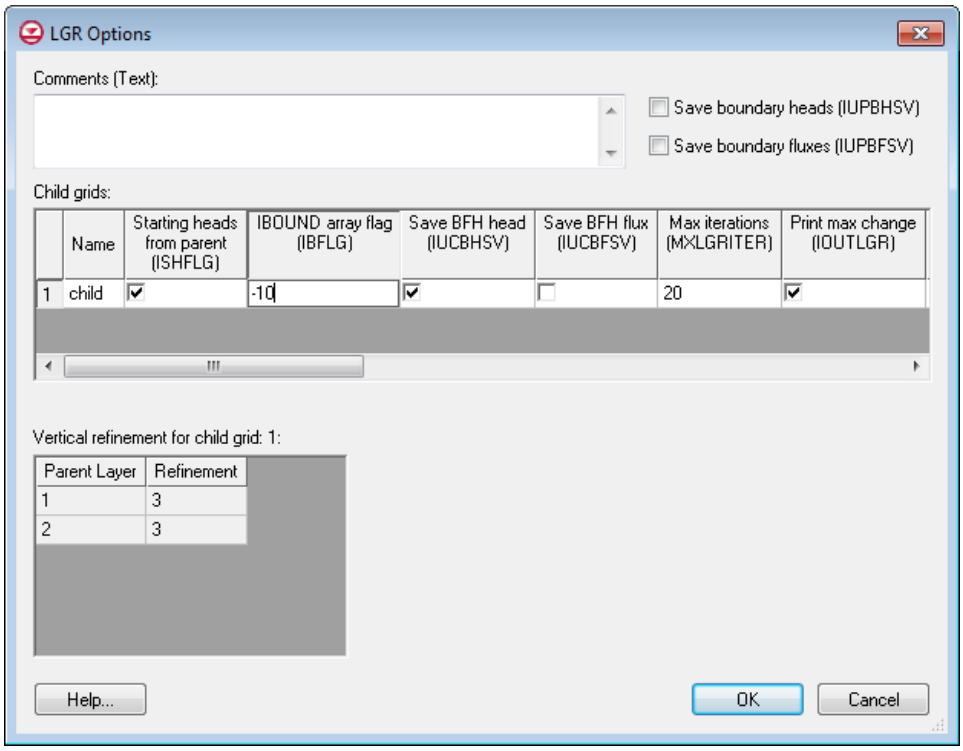

Figure 9 LGR Options dialog

11 Map → MODFLOW

Now that a child grid has been created, the conceptual model must be mapped 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 by clicking **OK**.

The model should look like Figure 10. The user should now see that river boundary conditions have been added to all the cells in the child grid under the river arc.

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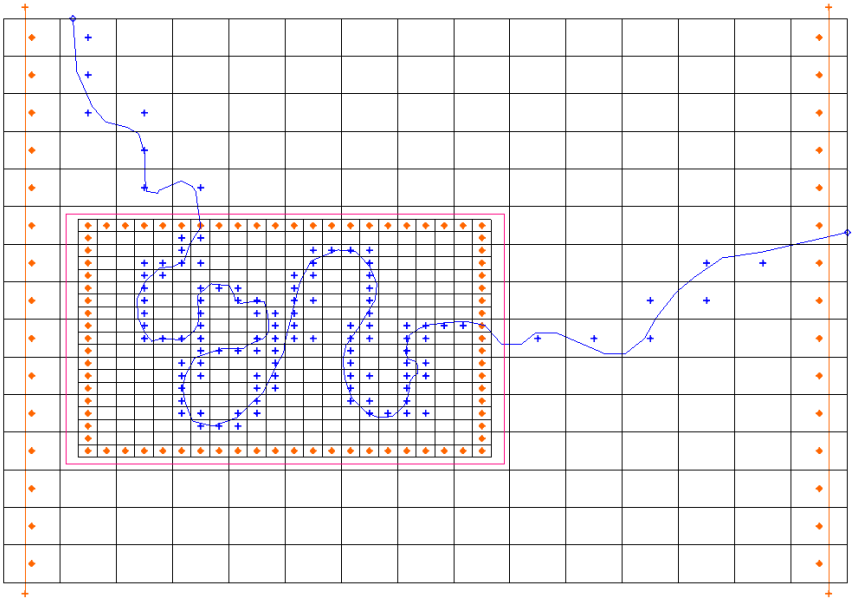

Figure 10 After Map → MODFLOW with child model

12 Checking the Simulation

Before running MODFLOW, 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.

13 Save and Run MODFLOW

Now save the 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.

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14 Viewing the Solution

Contours are displayed for both the parent and child grids. The user will notice some overlap around the edges. This is because although the parent cells around the parent/child interface are half cells and three-quarter 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 dataset. The IBOUND array still has them marked as active, as it should. The user 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.

14.1 Flow Budget

Now 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 m^3 in and 120 m^3 out. That means 24 m^3 flows from the child to the parent and 120 m^3 flows from the parent to the child.

4. Close the "lgr.out" file.
5. In GMS, double-click on the "lgr_child.out" file in the "lgr_child (MODFLOW)" solution under the "child" grid.
6. 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 was just seen in the "lgr.out" file. Also notice the *PARENT FLUX B.C.* items are not listed in the budget summary.

7. Close the "lgr_child.out" file.
8. In GMS, select the *MODFLOW* | **Flow Budget** command.

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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.

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

15 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, the user will first run the child model independently and will then run the parent model independently.

15.1 Run the Child Model Independently

Save the boundary heads and fluxes

Since the plan is to run the child model independently, it is necessary to turn on the option to save the coupling heads (IUCBHSV). If the user were planning on running the parent model independently, it would be necessary to turn on the option to save the complimentary fluxes (IUPBFSV). Actually, the plan is to run the parent independently in a minute, so it is necessary to turn on both options.

1. With the parent model active, select the *MODFLOW* | **Global Options** command to open the *MODFLOW Global/Basic Package – Parent* dialog.

2. Click the **LGR Options** button to open the *LGR Options* dialog.

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** to exit the *LGR Options* dialog.

6. Click **OK** to exit the *MODFLOW Global/Basic Package – Parent* dialog.

Now save the project with a new name so the solutions can be compared.

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

8. Change the project name to "lgr2.gpr."

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9. Click the **Save** button.

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

```
DATA          1787 "lgr2_child.bfh_hed"
```

When the model is run, the boundary heads will be saved to this "lgr2_child.bfh_hed" file. The user hasn't changed anything else so the solution will not change.

Run MODFLOW

Now it is necessary 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 it is necessary to 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.
2. Select the **Global Options** command to open the *MODFLOW Global/Basic Package – Child* dialog.
3. Click the **Packages** button to open the *MODFLOW Packages – Child* dialog.
4. Turn on the *BFH – Boundary Flow and Head* package.
5. Click **OK** to exit the *MODFLOW Packages – Child* dialog.
6. Click **OK** to exit the *MODFLOW Global/Basic Package – Child* dialog.

Now that the user has turned it on, take a look at the options in the BFH Package.

7. In the Project Explorer, right-click on the "child" MODFLOW model.
8. Select the *Optional Packages* | **BFH – Boundary Flow and Head** command to open the *BFH Package* dialog.

The dialog should look like Figure 11 (the path to the head file will depend on where the project was saved).

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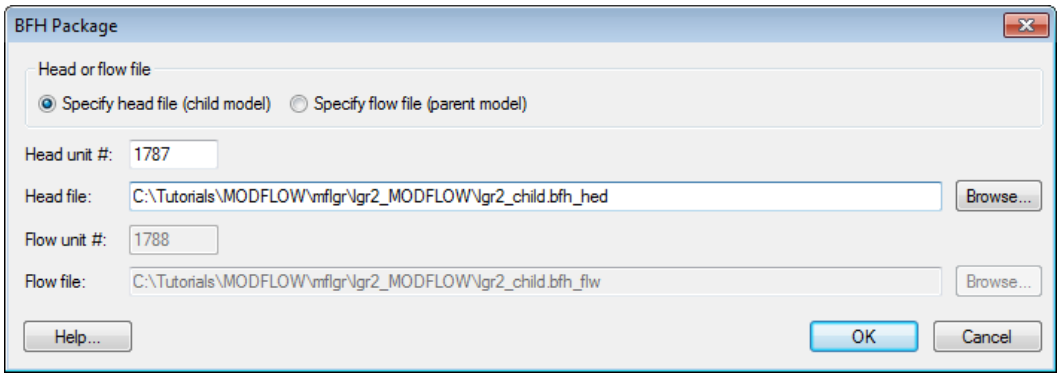

Figure 11 BFH – Boundary Flow and Head package dialog

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. Nothing else needs to change because GMS has defaulted the options in the desired way.

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

Save and Run MODFLOW

Now it is possible to run the child model independently.

1. Click the **Save** button.
2. In the Project Explorer, right-click on the "child" MODFLOW model.
3. 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.

4. 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 the user wanted to do that again, the user would need to turn off the BFH package in the child model.

15.2 Run the Parent Independently

Now look to see how the BFH package can be used to run the parent independently. The user already turned on the option to save the complimentary fluxes (IUPBFSV), so the user just needs to turn on the BFH package in the parent model.

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Turn on BFH package

Now it is necessary to 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.
2. Select the **Global Options** command to open the *MODFLOW Global/Basic Package – Parent* dialog.
3. Click the **Packages** button to open the *MODFLOW Packages – Parent* dialog.
4. Turn on the *BFH – Boundary Flow and Head* package.
5. Click **OK** to exit the *MODFLOW Packages – Parent* dialog.
6. Click **OK** to exit the *MODFLOW Global/Basic Package – Parent* dialog.

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

Save and Run MODFLOW

Now it is possible to run the parent model independently.

1. Click the **Save** button.
2. In the Project Explorer, right-click on the parent MODFLOW model.
3. 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.

4. 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.

16 Conclusion

This concludes the tutorial. Here are the key concepts in this tutorial:

- GMS supports MODFLOW-LGR and parent/child models.
- MODFLOW-LGR gives the same results as MODFLOW-2005 if there are no child grids present.

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- Child grids appear in the Project Explorer under the parent grid.
- Only one grid and MODFLOW simulation is active at a time. The user 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.

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