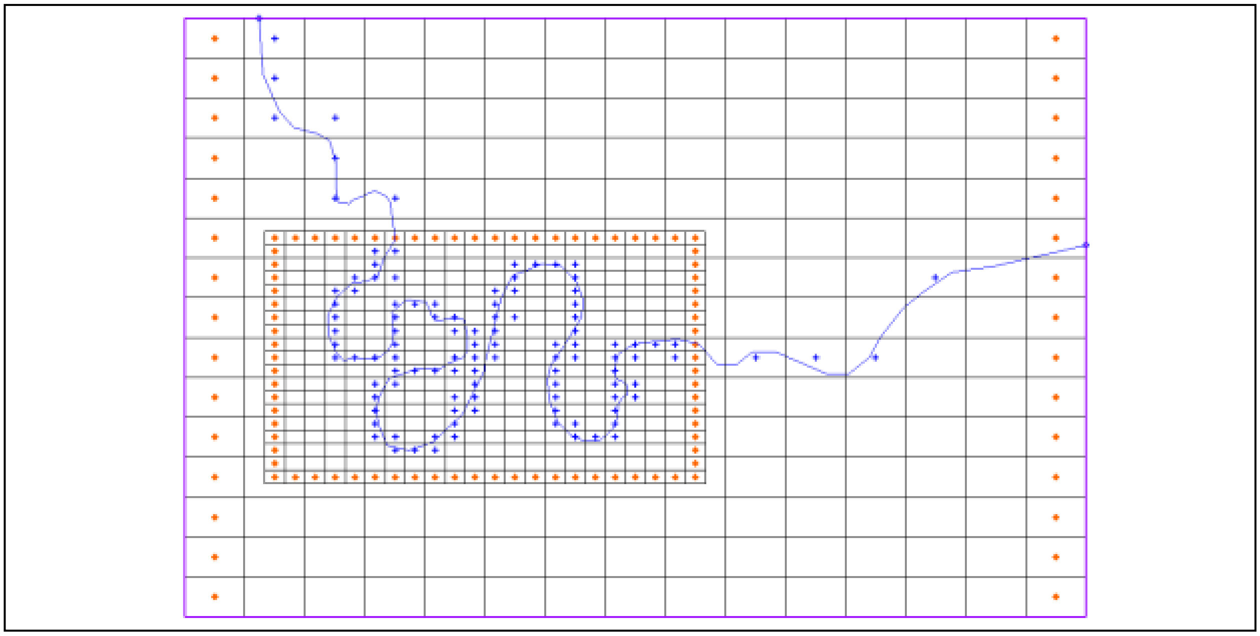
v. 10.5

GMS 10.5 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

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.

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 heads on the left and right with 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.

This tutorial will discuss and demonstrate the following:

- GMS supports MODFLOW-LGR and parent/child models.
- MODFLOW-LGR gives the same results as 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. Only cells in the active grid can be selected.
- 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.

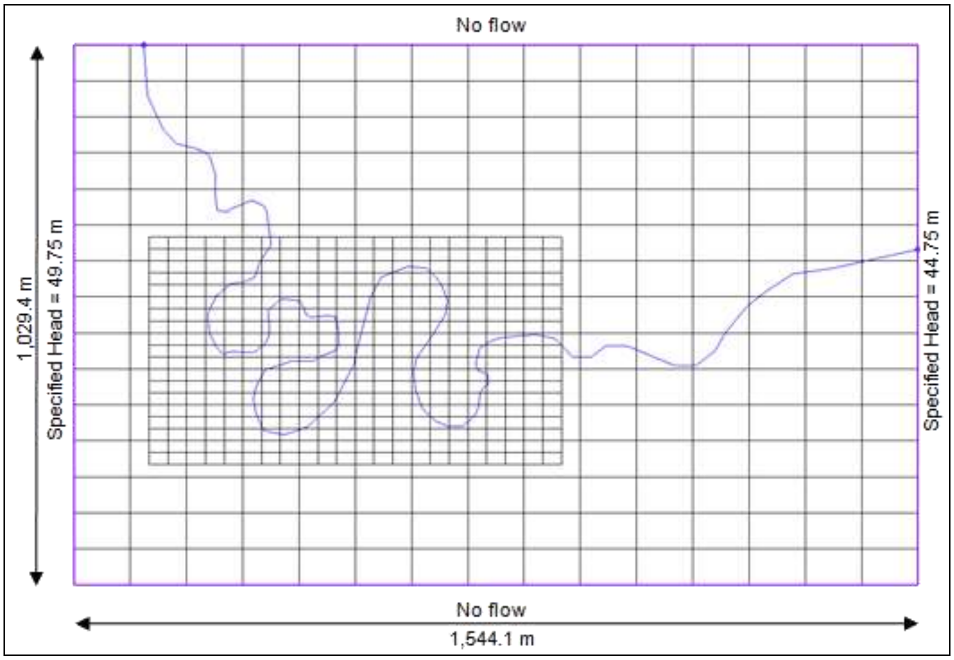


Figure 1 Sample problem to be solved[1]

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.
3. If asked to save changes, click **Don't Save** to close the dialog and restore GMS to a default state.

2 Opening the Non-LGR Model

Start by opening the non-LGR regional model that has already been created using MODFLOW-2005.

1. Click **Open** to bring up the *Open* dialog.
2. Select "Project Files (*.gpr)" from the *Files of type* drop-down.

[1] Mehl, Steffen W. and Hill, Mary C. (2007). "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" in *U.S. Geological Survey Techniques and Methods 6-A12,* p.43. http://pubs.usgs.gov/tm/2006/tm6a12/pdf/TM6-A12.pdf

3. Browse to the *mflgr\mflgr* directory and select “start.gpr”.
4. Click **Open** to import the project and close the *Open* dialog.

The Graphics Window should appear similar to Figure 2.

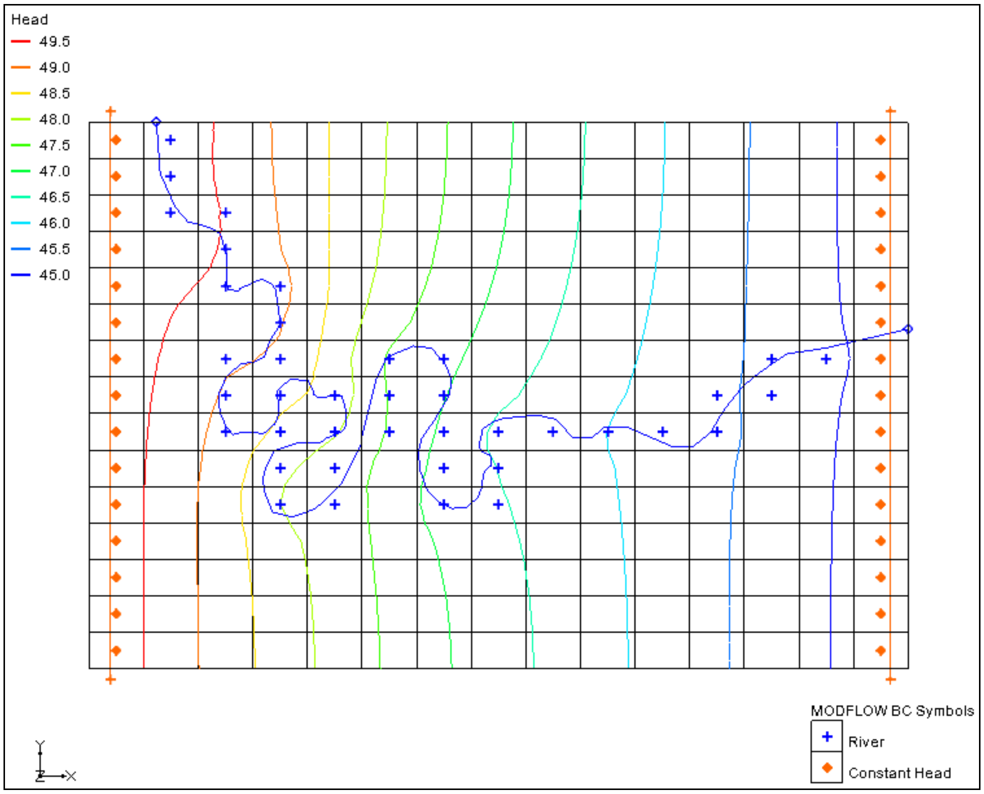


Figure 2 Non-LGR regional model

2.1 Saving with a Different File 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.gpr” as the *File name*.
4. Click **Save** to save the project under the new name and close the *Save As* dialog.

It is recommended to periodically **Save** as the tutorial progresses.

2.2 Switching to MODFLOW-LGR

Now switch the model from MODFLOW-2005 to MODFLOW-LGR.

1. Select *MODFLOW* | **Global Options…** to open the *MODFLOW Global/Basic Package* dialog.
2. In the *MODFLOW version* section, select *LGR*.
3. Click **OK** to close the *MODFLOW Global/Basic Package* dialog.

2.3 Saving and Running MODFLOW

Before adding a child model, save the changes and run MODFLOW to make sure MODFLOW-LGR gives the same results as MODFLOW-2005.

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

Notice there is no difference in the contours—the MODFLOW-LGR solution is the same as the MODFLOW-2005 solution. Expand the " 3D Grid Data" folder and switch between the " start" and " lgr" solutions in the Project Explorer to verify that they are identical.

3 Creating the Child Grid

Now the child grid can be created by selecting a range of cells in the regional model. The area is marked by a rectangle that can be turned on. Start with turning off the contours to make things easier to see.

1. Click **Display Options** to bring up the *Display Options* dialog.
2. Select "3D Grid Data" from the list on the left.
3. On the *3D Grid* tab, in the *Active dataset* section, turn off *Contours*.
4. Click **OK** to close the *Display Options* dialog.
5. In the Project Explorer, turn on the " Annotation Data" folder.

A red rectangle should appear.

6. 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 (Figure 3).

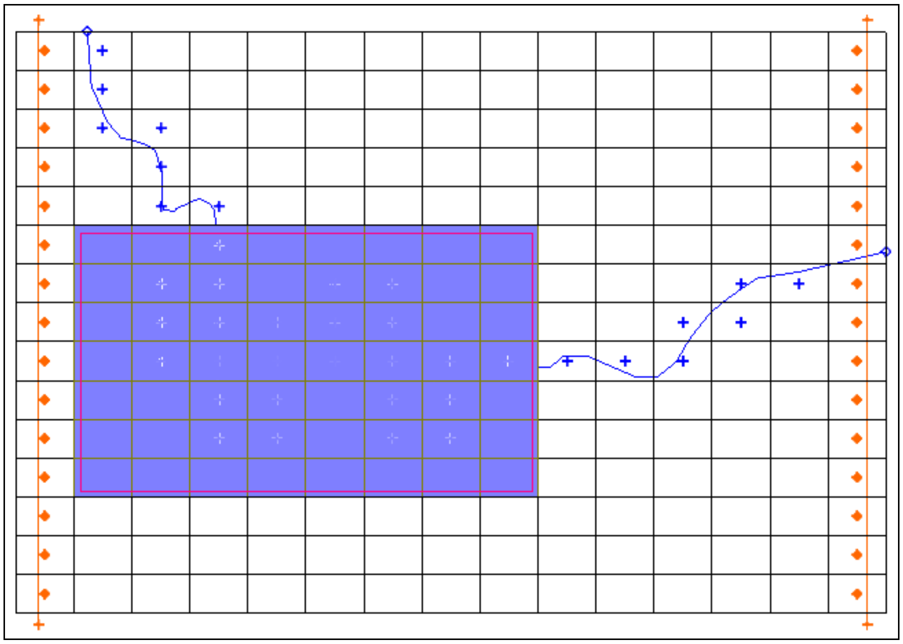


Figure 3 The selected cells for the child grid

7. Right-click in the selected area and select **Create Child Grid…** to bring up the *Create Child Grid* dialog (Figure 4).

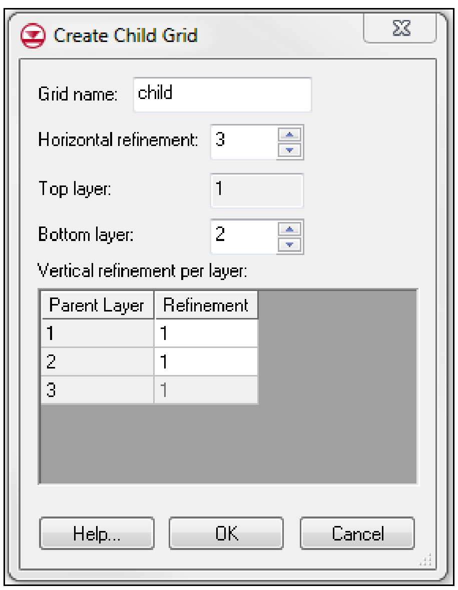


Figure 4 Create Child Grid dialog

8. Enter “2” for the *Bottom layer*.
9. In the *Vertical refinement per layer* section, enter “3” in the *Refinement* column for parent layers 1 and 2.
10. Click **OK** to close the *Create Child Grid* dialog.

11. In the Project Explorer, turn off the " Annotation Data" folder to hide the red rectangle.

A nested child grid should now be visible within the cells that were previously selected (Figure 5).

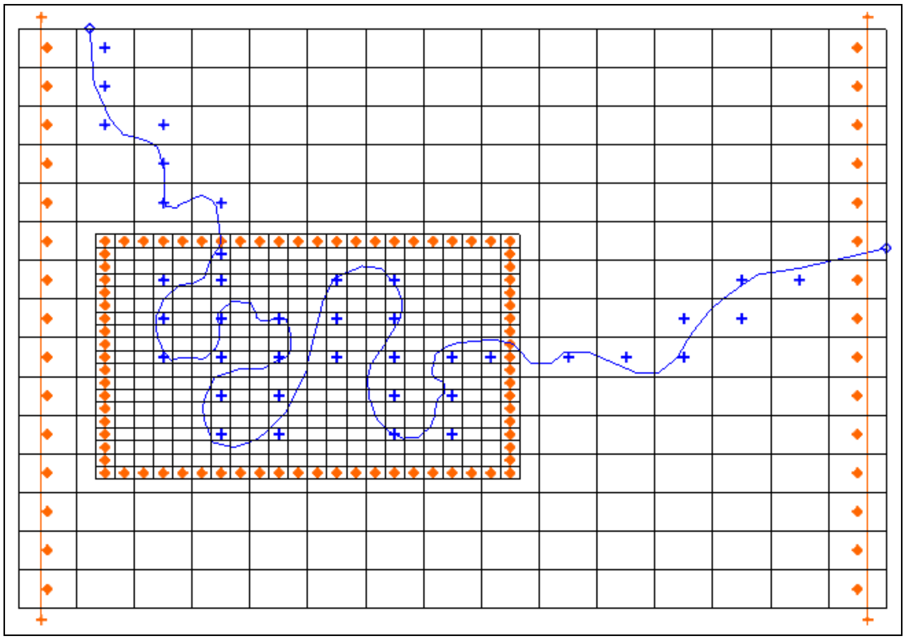


Figure 5 Model with child grid

3.1 Examining 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 called " child" has been added to the " 3D Grid Data" folder. 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. Only cells in the active grid can be selected. 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.

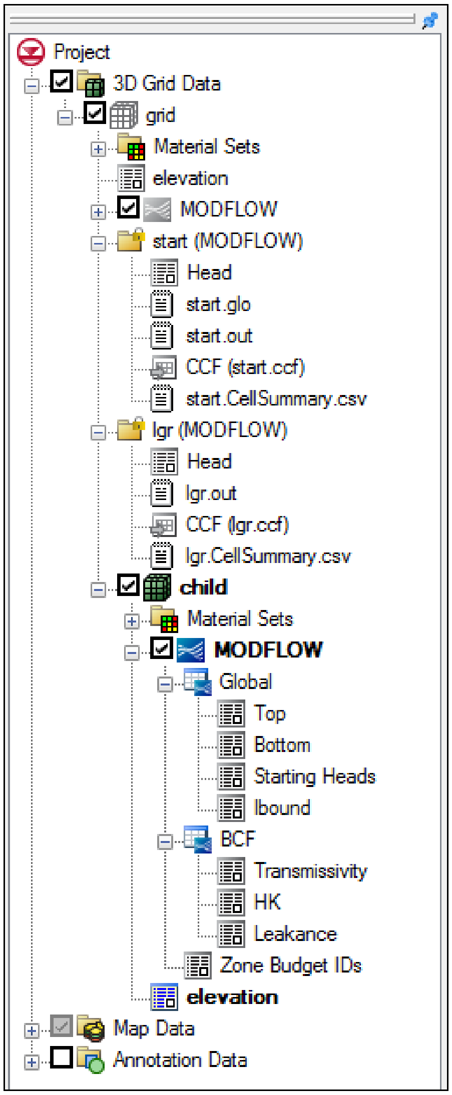


Figure 6 Project Explorer with child grid

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 make it activate.
4. Now try to select cells in the parent grid and the child grid. When clicking in the area of the child grid, cells in the parent grid are being selected.
5. Switch to **Front View** .

The display should show a grid sloping slightly to the right (Figure 7).

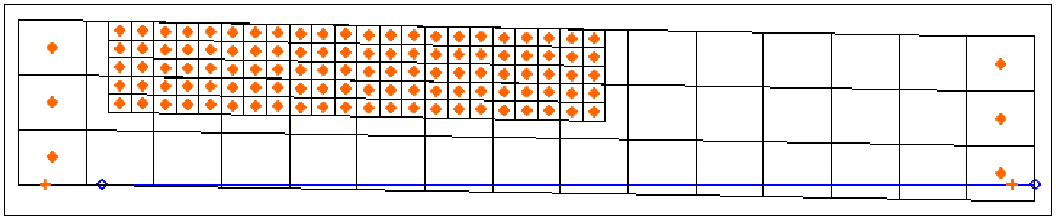
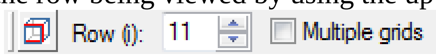


Figure 7 Front view, row 6

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

Notice that both the parent and child grids change while viewing different rows. The *Mini Grid Toolbar* acts on the active grid but the child grid row is kept in synch with the parent grid row.

7. On the Mini Grid Toolbar, turn on *Multiple grids* to bring up the *Current Ortho Levels* dialog (Figure 8).

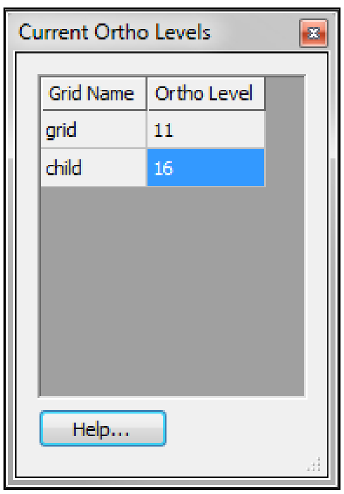


Figure 8 Current Ortho Levels dialog

This dialog shows which row is currently being displayed on all grids. This dialog is modeless, so the GMS interface can continue being used while it is being displayed. Feel free to move the dialog to a convenient location on the screen.

8. Change the grid row up and down.

Notice that the values change in the *Current Ortho Levels* dialog. The parent grid rows changes once for every three child grid rows. GMS is finding and displaying the child row that corresponds with the current parent row. Now disable synching of the ortho levels.

9. Click **Display Options**  to bring up the *Display Options* dialog.

10. Select "3D Grid Data" from the list on the left.

11. On the *3D Grid* tab, in the top section, turn off *Synch ortho levels with all grids*.

12. Click **OK** to close the *Display Options* dialog.

The top and bottom elevations are such that the model slopes down from left to right. Notice 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 9.

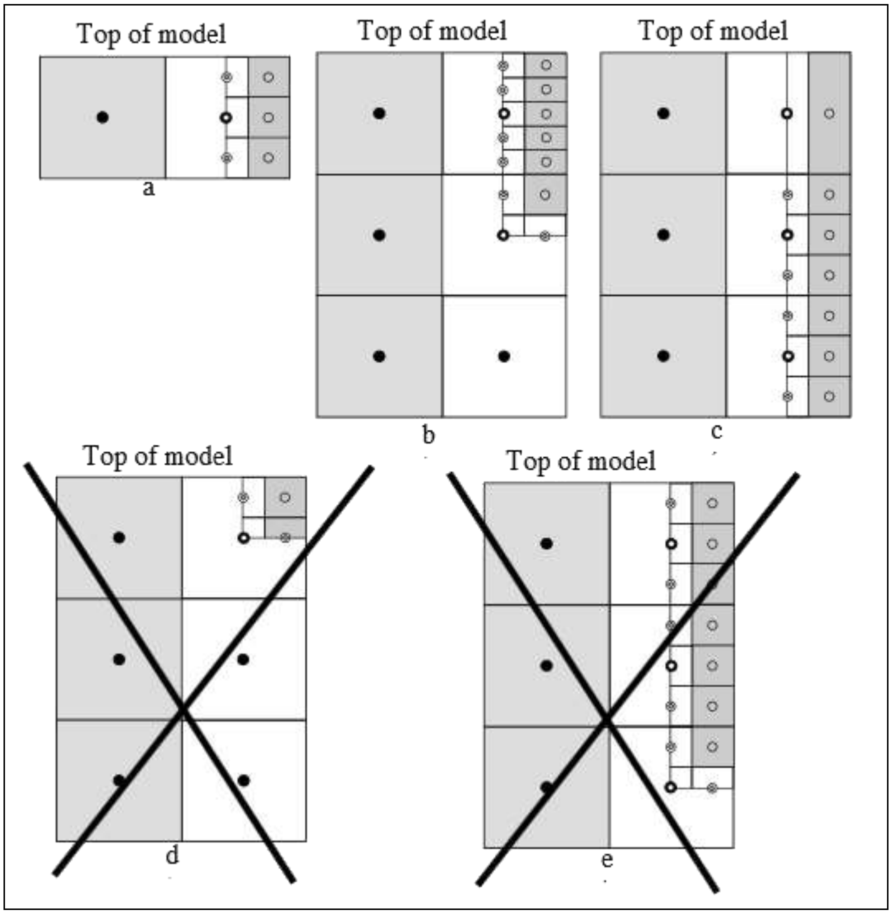


Figure 9 Vertical refinement rules[2]

Referring to Figure 9:

> 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.[3]

[2] Mehl, p.13. http://pubs.usgs.gov/tm/2006/tm6a12/pdf/TM6-A12.pdf

[3] Ibid.

13. Switch to **Plan View**.
14. **Close** the *Current Ortho Levels* dialog.

3.2 LGR Options

Now look at the *LGR Options* dialog.

1. Select the parent "grid" in the Project Explorer to make it active.
2. Select *MODFLOW* | **Global Options…** 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 grids can be renamed, and the new grid name will be displayed in the MODFLOW dialogs for the child grids. For the parent grid, the MODFLOW dialogs will always say "– Parent" no matter what the parent grid is renamed.

The effects of the options in the main *MODFLOW* menu depend 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 child model is made 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 Project Explorer may be used to avoid having to remember which model the main menu is acting on.

3. Click **LGR Options…** to bring up the *LGR Options* dialog (Figure 10).

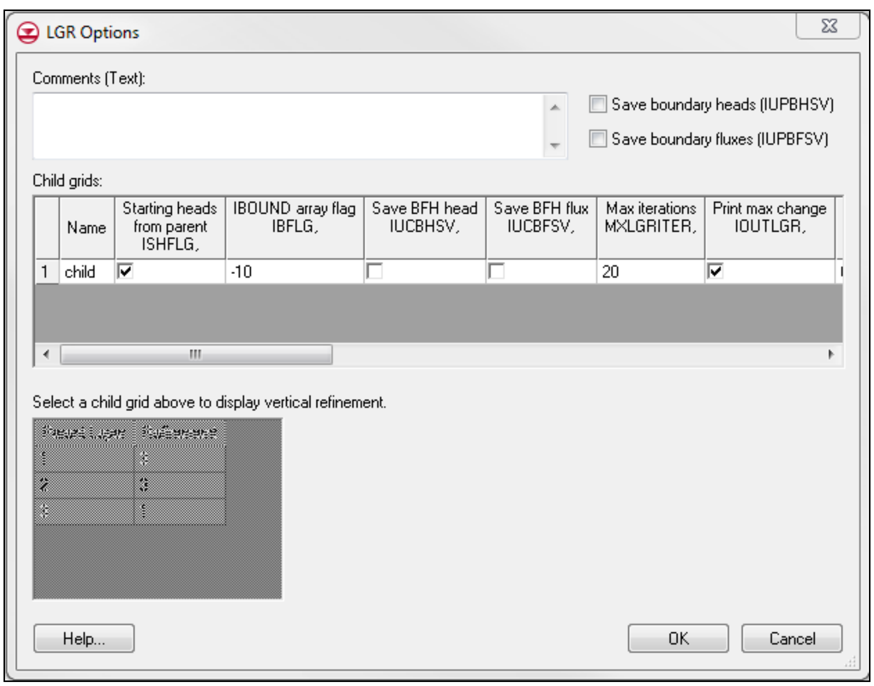


Figure 10 LGR Options dialog

The items in this dialog correspond to the LGR control file. This file is passed to MODFLOW-LGR when running a parent/child paired simulation. The file also contains information on the parent and child models.

The top *Child grids* spreadsheet lists all the child grids. The lower *Vertical refinement for child grid* spreadsheet displays the layer-by-layer vertical refinement for the selected child grid. The dimensions and refinement of the child grids cannot be edited here, but the values to be written to the LGR Control File (NPLBEG, NPLEND, etc.) can be seen.

4. Select the child grid by clicking in any field in the first row of the *Child grids* spreadsheet. This activates the *Vertical refinement for child grid* section at the bottom of the dialog.
5. Click **Cancel** to exit the *LGR Options* dialog.
6. Click **Cancel** to exit the *MODFLOW Global/Basic Package – Parent* dialog.

3.3 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. Select the " child" grid in the Project Explorer to make it active.
2. Enter "1" in the *Lay (k)* field of the Mini Grid Toolbar.
3. Click **Map → MODFLOW** to bring up the *Map → Model* dialog.
4. Click **OK** to accept the defaults and close the *Map → Model* dialog.

The river boundary conditions have now been added to all the cells in the child grid under the river arc (Figure 11).

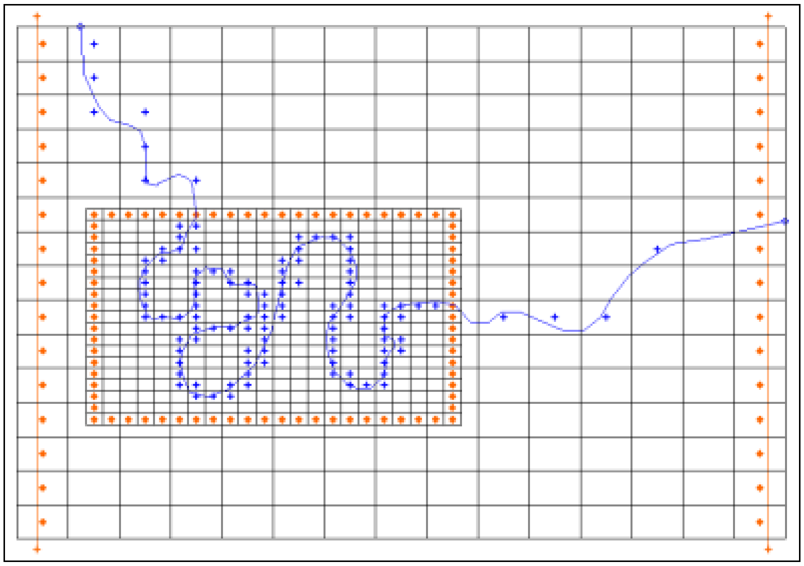


Figure 11 After Map → MODFLOW with child model

3.4 Checking the Simulation

It is recommended to always run the *Model Checker* prior to running MODFLOW.

1. Select *MODFLOW* | **Check Simulation…** to open the *Model Checker* dialog.
2. Click **Run Check**. There should be no warnings or errors detected.

Notice that the model checker checked both the parent and the child models. Regardless of which grid/model is active, the model checker will always look at all MODFLOW models.

3. Click **Done** to close the *Model Checker* dialog.

3.5 Saving and Running MODFLOW

Now save the work 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 and exit the *MODFLOW* model wrapper dialog.

There are two solutions: one for the parent and one for the child.

4 Viewing the Solution

Contours are displayed for both the parent and child grids. Notice there is some overlap around the edges. 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. This can be verified by examining the parent IBOUND array.

2. Turn on the " child" grid.

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

4.1 Flow Budget

Now examine the flow budget.

1. Select the parent “ grid” to make it active.
2. Under “ lgr (MODFLOW)”, double-click on the “ lgr.out” file to bring up the *View Data File* dialog.

This dialog will not appear if *Never ask this again* was previously turned on in this dialog. If this is the case, skip to step 4.

3. Select the desired text editor from the *Open with* drop-down and click **OK** to open the data file and close the *View Data File* dialog.
4. Locate the “PARENT FLUX B.C.” items in the budget summary near the bottom of the file (red stars in Figure 12).

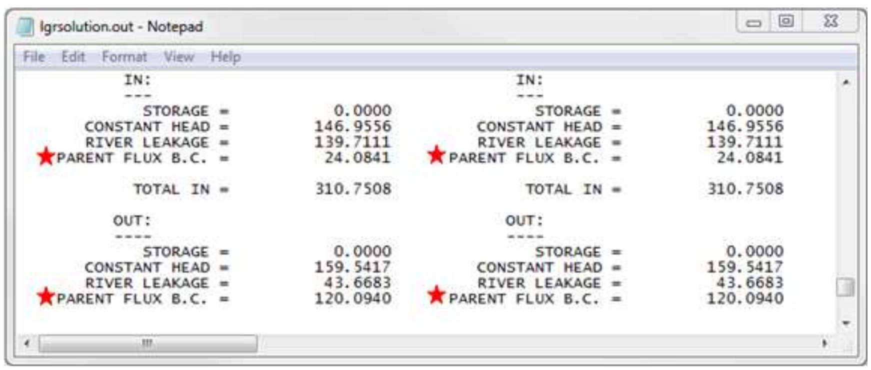
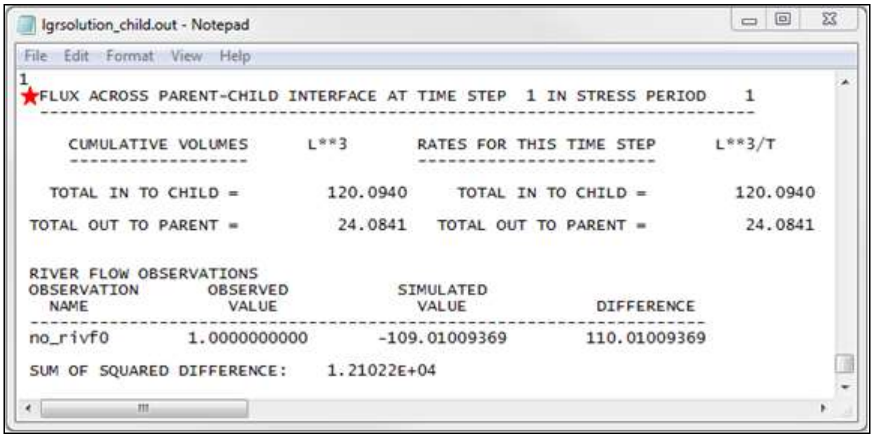


Figure 12 Flow between parent and child grids

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.

5. Close the “lgr.out” file and return to GMS.
6. Under “ lgr_child (MODFLOW)”, double-click on the “ lgr_child.out” file to bring up the *View Data File* dialog. As before, this dialog may not appear. If this is the case, skip to step 8.
7. Select the desired text editor from the *Open with* drop-down and click **OK** to open the data file and close the *View Data File* dialog.
8. Locate the “FLUX ACROSS PARENT-CHILD INTERFACE” section near the bottom of the file (red star in Figure 13).




```
1
FLUX ACROSS PARENT-CHILD INTERFACE AT TIME STEP  1 IN STRESS PERIOD    1
---------------------------------------------------------------------------

    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

  TOTAL IN TO CHILD =         120.0940    TOTAL IN TO CHILD =         120.0940

TOTAL OUT TO PARENT =          24.0841  TOTAL OUT TO PARENT =          24.0841

RIVER FLOW OBSERVATIONS
OBSERVATION        OBSERVED            SIMULATED
  NAME               VALUE               VALUE              DIFFERENCE
---------------------------------------------------------------------------
no_rivf0       1.0000000000       -109.01009369        110.01009369

SUM OF SQUARED DIFFERENCE:    1.21022E+04
```

Figure 13   Flux across parent-child interface

Notice the flow into 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.” entries are not listed in the budget summary in this file.

9. Close the “lgr_child.out” file and return to GMS.
10. Select *MODFLOW* | **Flow Budget…** to bring up the *Flow Budget – Parent* dialog.

On the *Cells* tab, notice that the flow budget does not include the “PARENT FLUX B.C.” item included in the OUT file. 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.

11. Click **OK** to exit the *Flow Budget – Parent* dialog.

5 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 practice this, first run the child model independently and then run the parent model independently.

5.1 Running the Child Model Independently

Saving the Boundary Heads and Fluxes

In order to run the child model independently, it is necessary to turn on the option to save the coupling heads (IUCBHSV). If running the parent model independently, it is necessary to turn on the option to save the complimentary fluxes (IUPBFSV). In this case, the plan is to run the parent independently, so it is necessary to turn on both options.

1. Select the parent " grid" to make it active.
2. Select *MODFLOW* | **Global Options…** to open the *MODFLOW Global/Basic Package – Parent* dialog.
3. Click **LGR Options…** to open the *LGR Options* dialog.
4. Turn on *Save boundary fluxes (IUPBFSV)* at the top right.
5. In the *Child grids* spreadsheet, turn on *Save BFH head (IUCBHSV).*
6. Click **OK** to exit the *LGR Options* dialog.
7. 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.

8. Select *File* | **Save As…** to bring up the *Save As* dialog.
9. Select "Project Files (*.gpr)" from the *Save as type* drop-down.
10. Enter "lgr2.gpr" as the *File name*.
11. Click **Save** to save the project under the new name and close the *Save As* dialog.

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. As nothing has been changed, the solution will not change.

Running MODFLOW

Now it is necessary to run MODFLOW in coupled mode.

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

Turning 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. Under the “child” grid in the Project Explorer, right-click on “MODFLOW” and select **Global Options…** to open the *MODFLOW Global/Basic Package – child* dialog.
2. Click **Packages…** to open the *MODFLOW Packages/Processes – child* dialog.
3. In the *Optional packages/processes* section, turn on *BFH – Boundary Flow and Head*.
4. Click **OK** to exit the *MODFLOW Packages/Processes – child* dialog.
5. Click **OK** to exit the *MODFLOW Global/Basic Package – child* dialog.

Now that it has been turned on, look at the options in the BFH Package.

6. Select the “child” grid in the Project Explorer to make it active
7. Under the “child” grid, right-click on “MODFLOW” and select *Optional Packages* | **BFH – Boundary Flow and Head** to open the *BFH Package* dialog (Figure 14).

The *Head file* path will vary depending on the location where the project was saved.

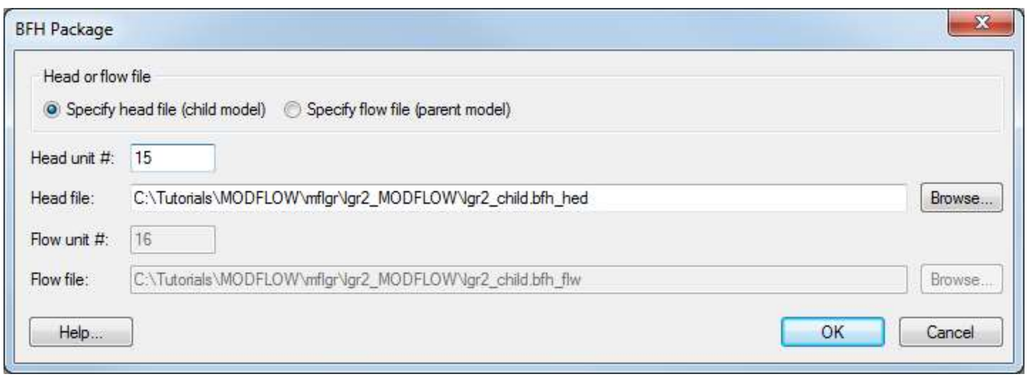


Figure 14 BFH Package dialog

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.

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

Saving and Running MODFLOW

Now it is possible to run the child model independently.

1. **Save** the project.

2. Under "child" in the Project Explorer, right-click on " MODFLOW" and select **Run MODFLOW Uncoupled On Just This Model** to bring up the *MODFLOW – child* model wrapper dialog.

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 the model has finished, turn on *Read solution on exit* and *Turn on contours (if not on already)*.
4. Click **Close** to import the solution and exit the *MODFLOW – child* model wrapper dialog.

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 the BFH package in the child model would need to be turned off in order to rerun it.

5.2 Running the Parent Independently

This tutorial will now demonstrate how the BFH package can be used to run the parent independently. The option to save the complimentary fluxes (IUPBFSV) has already been turned on, so just turn on the BFH package in the parent model.

Turning on BFH Package

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. Under "grid" in the Project Explorer, right-click on the parent " MODFLOW" model and select **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.

At this point, the BFH Package dialog for the parent model would be opened to look at the options. However, GMS has defaulted everything to what is desirable, so just run the parent independently.

Save and Run MODFLOW

Now it is possible to run the parent model independently.

1. **Save** the project.

2. Under "grid", 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.

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 is 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 (Figure 15).

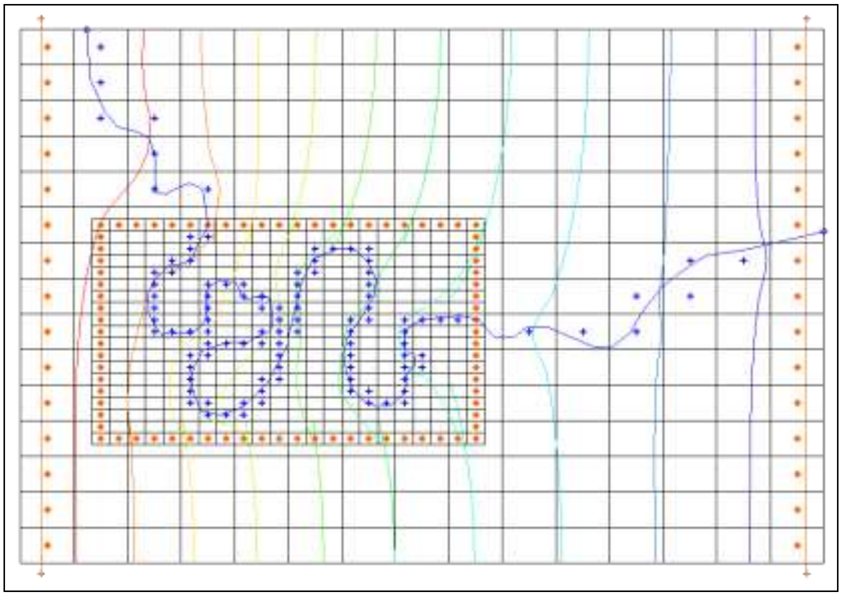


Figure 15 Final view after parent run independently

6 Conclusion

This concludes the "MODFLOW – LGR" tutorial. This tutorial demonstrated and discussed:

- Importing an existing MODFLOW model.
- Switching the model to MODFLOW-LGR and running it.
- Adding a child grid.
- Running the parent and child coupled.
- Saving the boundary heads.
- Turning on the BFH package.
- Running the child model independently using the boundary heads.

