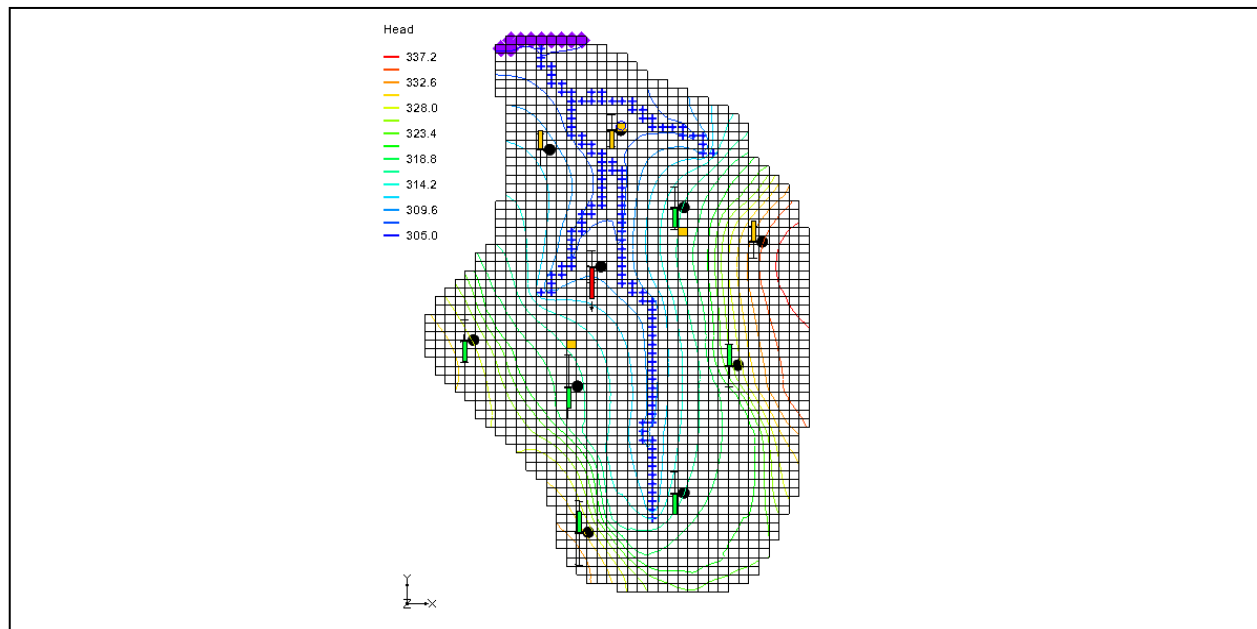


## GMS 10.0 Tutorial

# MODFLOW – Model Calibration

Manually vary input values and use observations to calibrate a MODFLOW model



### Objectives

GMS contains a suite of tools to assist in the model calibration process, including observation points and different types of plots. These tools are described in this tutorial. A MODFLOW model is manually calibrated by adjusting inputs and watching how the computed values compare to the observed values.

#### Prerequisite Tutorials

- MODFLOW – Conceptual Model Approach I

#### Required Components

- Grid Module
- Map Module
- MODFLOW

#### Time

- 25-40 minutes



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# 1 Introduction

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An important part of any groundwater modeling exercise is the model calibration process. In order for a groundwater model to be used in any type of predictive role, it must be demonstrated that the model can successfully simulate observed aquifer behavior. Calibration is a process wherein certain parameters of the model such as recharge and hydraulic conductivity are altered in a systematic fashion and the model is repeatedly run until the computed solution matches field-observed values within an acceptable level of accuracy.

The model calibration exercise in this tutorial is based on the MODFLOW model. Thus, the user may wish to complete the “MODFLOW – Conceptual Model Approach I” tutorial prior to beginning this tutorial. Although this particular exercise is based on MODFLOW, the calibration tools in GMS are designed in a general purpose fashion and can be used with any model.

## 1.1 Outline

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Here are the steps of this tutorial:

1. Open a model.

2. Create observation points and import observation data from a text file.
3. Run MODFLOW under various conditions.
4. Create error plots for each simulation.

## 2 Description of Problem

A groundwater model for a medium-sized basin is shown in Figure 1. The basin encompasses 72.5 square kilometers. It is in a semi-arid climate, with average annual precipitation of 0.381 m/yr. Most of this precipitation is lost through evapotranspiration. The recharge that reaches the aquifer eventually drains into a small stream at the center of the basin. This stream drains to the north and eventually empties into a lake with elevation 304.8 m. Three wells in the basin also extract water from the aquifer. The perimeter of the basin is bounded by low permeability crystalline rock. There are ten observation wells in the basin. There is also a stream flow gauge at the bottom end of the stream.

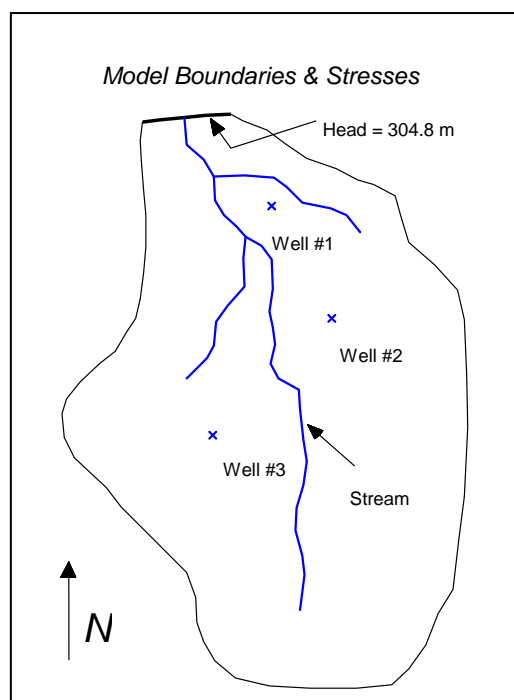


Figure 1 Sample model used in calibration exercise

The assumed recharge and hydraulic conductivity zones for the model are shown in Figure 2. The model region encompasses fractured and weathered bedrock as well as alluvial material, grading from hydraulically tighter materials in the south to more permeable materials in the north. Furthermore, the materials around the stream tend to be coarser, cleaner, and thus more permeable. The topmost region of the model near the lake has a high level of phreatophytic plant life.

The first task of this exercise will be to import a single layer, unconfined MODFLOW model that has been constructed for the site. This model contains an initial estimate of hydraulic conductivities and recharge. A solution computed with this initial model will then be imported and the error in the initial solution will be analyzed. New values for hydraulic conductivity and/or recharge will then be entered, a new solution will be generated, and a new error estimate will be computed. These steps should be repeated until the error is reasonably small.

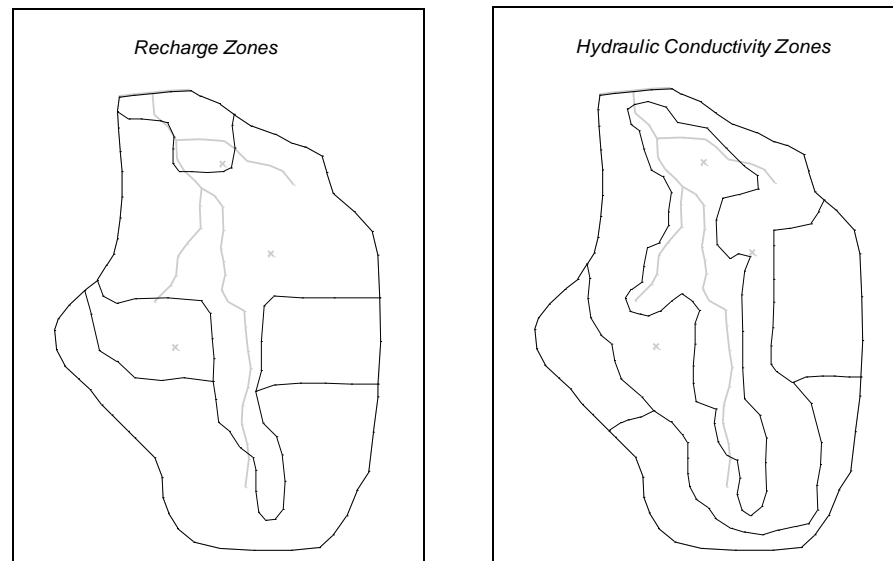


Figure 2 Recharge and hydraulic conductivity zones

### 3 Getting Started

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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.

### 4 Reading in the Model

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First, read in the model:

1. Select the **Open**  button.
2. Locate and open the *Tutorials\MODFLOW\calib* directory.
3. Select the file entitled “bigval.gpr.”
4. Click the **Open** button.

The user should see both a grid and a conceptual model appear. The conceptual model was used to construct the MODFLOW model and consists of three coverages. The currently active coverage contains the model boundary, the specified head boundary, the stream, and the wells. There is also a coverage of recharge zones and a coverage of hydraulic conductivity zones. For the initial simulation, a single value of hydraulic conductivity (2.4 m/day) and a single value of recharge ( $7.62e-5$  m/day) have been assigned. The polygonal zones of hydraulic conductivity and recharge will be edited as the tutorial progresses to reduce the model error.

## 5 Observation Data

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The tutorial will be using two types of observation data in the calibration process: water table elevations from observation wells and observed flow rates in the stream. Since the model is in a fairly arid region, the user will assume that most of the flow to the stream is from groundwater flow.

## 6 Entering Observation Points


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First, it is necessary to enter a set of observation points representing the observed head in the ten observation wells in the region. Observation points are created in the Map module.

### 6.1 Creating a Coverage with Observation Properties

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Before entering observation points, the user must first create a coverage with observation properties.

1. Expand the “Map Data” folder in the Project Explorer.
2. In the Project Explorer, right-click on the “BigVal”  conceptual model.
3. Select the **New Coverage** command from the pop-up menu.
4. In the *Coverage Setup* dialog, name the new coverage “Observation Wells.”
5. In the list of *Observation Points* properties, turn on *Head*.
6. Change the *3D grid layer option for obs. pts* option to “By layer number.”
7. Select the **OK** button to exit the *Coverage Setup* dialog.

### 6.2 Creating an Observation Point



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It is now possible to create an observation point. The first point the user will be creating has the following values:


x [m]	y [m]	Head [m]	Interval [m]	Confidence [%]
4770	9965	305	1.5	95

The interval represents the estimated error ( $\pm$ ) in the observed value. The confidence value represents the confidence in the error estimate. The interval can be used as a calibration target. Calibration is achieved when the error is within the estimated error interval ( $\pm 1.5$  m in this case) of the observed value. In other words, if the computed head falls between 303.5 to 306.5, the calibration target is reached for this observation well.

To create the point, do the following:

1. Select the “Observation wells”  coverage in the Project Explorer to assure it is the active coverage.
2. Select the **Create Point**  tool.
3. Click once anywhere on the model.
4. With the point selected, change the *X* and *Y* values in the *Edit Window* to *X*: “4770” and *Y*: “9965.”



To assign the properties to the point:

5. With the point still selected, select the **Properties**  button.
6. In the *Attribute Table* dialog, change the name of the point to “Point #1.”
7. Change the *Type* to “obs. pt.”
8. Enter “305” for the *Obs. Head*.
9. Enter “1.5” for the *Obs. Head Interval*.
10. Enter “95” for the *Obs Head conf(%)*.
11. Select the **OK** button.

### 6.3 Calibration Target

At this point, a calibration target like the one shown in Figure 3 typically shows up next to the observation point. In this case, however, the observation measurement model is MODFLOW, and with MODFLOW, things are a bit different. With MODFLOW, the user must run the simulation and read in the solution before the calibration targets appear. This is because the computed values are output by MODFLOW and are not calculated internally by GMS. So, it is now time to run MODFLOW and read in the solution.

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

2. Change the project name to “run2.gpr.”
3. Select the **Save** button.
4. Select the “3D Grid Data”  folder in the Project Explorer.
5. Select the **Run MODFLOW**  button.
6. When MODFLOW is finished running, select the **Close** button.

Note that a calibration target is now drawn next to the point. The components of a calibration target are illustrated in Figure 3. The center of the target corresponds to the observed value. The top of the target corresponds to the observed value plus the interval and the bottom corresponds to the observed value minus the interval. The colored bar represents the error. If the bar lies entirely within the target, the color bar is drawn in green. If the bar is outside the target but the error is less than 200%, the bar is drawn in yellow. If the error is greater than 200%, the bar is drawn in red.

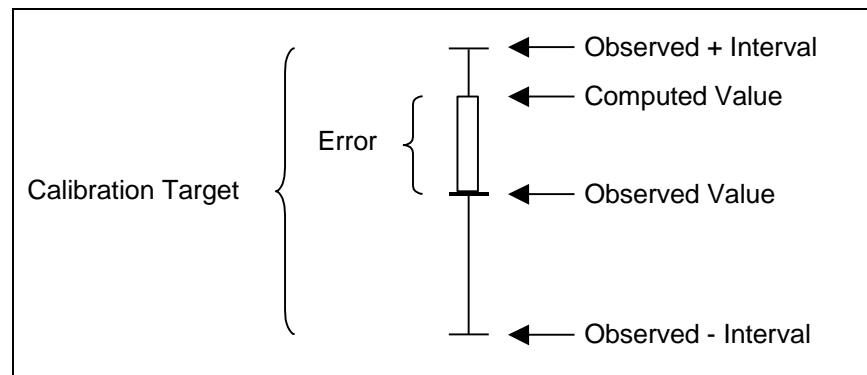




Figure 3 Calibration target

## 6.4 Point Statistics

The user can view more detailed statistics concerning the error at the point by selecting the point.

1. Select the “Map Data”  folder in the Project Explorer.
2. Select the **Select Points/Nodes**  tool.
3. Click on the observation point.

Notice that a set of statistics related to the point is displayed in the *Status Bar* at the bottom of the GMS screen.

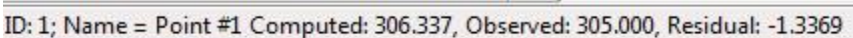


Figure 4 Status bar showing information on the selected observation point

## 7 Reading in a Set of Observation Points


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Using the steps defined above, the user could proceed to enter the remaining nine observation points. However, in the interest of time, the user will simply read in a previously prepared map file containing all ten points.

### 7.1 Deleting the Observation Point

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Before reading in the observation points, the user will first delete the point that was created in the *Observation Wells* coverage.

1. Select the **Select Points/Nodes**  tool.
2. Right-click on the point that was created earlier.
3. Select the **Delete** command.

### 7.2 Importing the Points

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Now read in a file containing several observation points.

1. Select the **Open**  button.
2. Locate and open the *Tutorials\MODFLOW\calib* directory.
3. Change the *Files of Type* to “\*.txt.”
4. Select the file entitled “obswells.txt.”
5. Select the **Open** button.

### 7.3 Text Import Wizard

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Opening a \*.txt file in GMS will bring up the *Text Import Wizard*. In the first step of the wizard, it is necessary to identify the delimiters that separate the data into columns. In the second step of the wizard, the user maps the columns to fields that GMS recognizes.

1. Turn on the *Heading row* toggle.
2. Select the *Next* button.
3. In the *GMS data type* combo box select “Observation data.”

Notice in the file preview section of the dialog that GMS has mapped the different columns of data in the file into fields recognized by GMS.

4. Select the **Finish** button.






## 8 Entering the Observed Stream Flow


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Now that the observation points are defined, the user will enter the observed flow in the stream. Observed flows are assigned directly to arcs and polygons in the local source/sink coverage of the conceptual model. The user will assign an observed flow to the river arcs. MODFLOW determines the computed flow from the aquifer to the stream. This flow value will be compared to the observed flow.

GMS provides two methods for assigning observed flow: to individual arcs or to a group of arcs. The stream flow that was measured at the site represents the total flow from the aquifer to the stream at the stream outlet at the top of the model. This flow represents the flow from the aquifer to the stream for the entire stream network. Thus, the user needs to assign the observed flow to a group of arcs. When reading a solution, GMS will then automatically sum the computed flow for all arcs in the group. Before assigning the observed flow, the user must first create an arc group:


1. In the Project Explorer, right-click on the “Sources & Sinks”  coverage.
2. Select the *Coverage Setup* command to open the *Coverage Setup* dialog.
3. In the list of *Sources/Sinks/BCs*, toggle on the *Observed Flow* row.
4. Select **OK** to exit the dialog.
5. In the Project Explorer, select the “Sources & Sinks”  coverage to assure it is active.
6. Select the **Select Arcs**  tool.
7. While holding down the *Shift* key, click on each of the river arcs.
8. Select the *Feature Object* / **Create Arc Group** command.

This creates a new object out of the selected objects. It is now possible to assign an observed flow to the arc group.

9. Select the **Select Arc Groups**  tool.
10. Double-click on any of the river arcs to open the *Attribute Table* dialog.
11. Turn on the *Obs.flow* option.
12. In the *Obs. flow rate* field, enter a value of “-4644.”
13. Enter a value of “210” for the *Obs. Flow interval*.

The entered values indicate that, to achieve calibration, the computed flow should be between -4434 and -4854 m<sup>3</sup>/day (4644 +/- 210).

14. Select the **OK** button to exit the dialog.

15. Click outside the arc group to unselect it.
16. Select the **Save**  button.
17. Select the *MODFLOW* | **Run MODFLOW** command.
18. When the model finishes running, select the **Close** button.

At this point, the user should see a calibration target appear for the observed flow on the arc group.

## 9 Viewing the Solution




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The contours currently shown on the 3D grid are the heads from the MODFLOW run with the optimum parameter values.

### 9.1 Error Summary

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The user will now look at the observation targets in the map model and the error associated with this model run.

1. Select the “Sources & Sinks”  coverage from the Project Explorer.
2. Select the **Select Arc Group**  tool.
3. Select the arc group by clicking on the river arc. Notice in the edit strip at the bottom of the graphics window the computed and observed flow is reported.
4. Right-click on the “run2 (MODFLOW)”  solution in the Project Explorer.
5. Select the **Properties** command to open the *Properties* dialog.


This command brings up a spreadsheet showing the error from this model run. The spreadsheet shows the error from the head observations, the flow observations, and the combined weighted observations.

6. When finished viewing the properties, select **Done**.

### 9.2 Computed vs. Observed Data Plot

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Next, the user will generate some plots related to the calibration error. The user will create two plots related to the error at the observation points.

1. Select the **Plot Wizard**  button to open the *Plot Wizard* dialog.
2. Select the *Computed vs. Observed Data* plot from the list on the left.


3. Select the **Next** button.
4. Select the **Finish** button.

In the first plot, a symbol is drawn for each of the observation points. A point that plots on or near the diagonal line indicates a low error. Points far from the diagonal have a larger error.



## 10 Editing the Hydraulic Conductivity

The next step in the calibration exercise is to change the model parameters and re-run the model. Note, if the user switches to the observation coverage, the errors are mostly red and negative. This indicates that the observed value is much larger than the current computed value. The user will begin by changing the hydraulic conductivity in these zones. The hydraulic conductivity will be edited by changing the hydraulic conductivity assigned to the polygonal zones in the conceptual model.

Before editing the hydraulic conductivity values, the user will first make the hydraulic conductivity zone coverage the active coverage.

1. In the Project Explorer, select the “Hydraulic Conductivity”  coverage.

To edit the hydraulic conductivity values:

2. Select the **Select Polygons**  tool.
3. While holding the *Shift* key, select polygons 1 and 2 shown in Figure 5.
4. Select the **Properties**  button to open the *Attribute Table* dialog.
5. Enter a value of “0.6” for the *Horizontal K* for each polygon.
6. Select the **OK** button.
7. Double-click on polygon 3 shown in Figure 5 to open the *Attribute Table* dialog.
8. Enter a value of “0.15” for the *Horizontal K*.
9. Select the **OK** button.
10. Click outside the model to unselect the polygon.

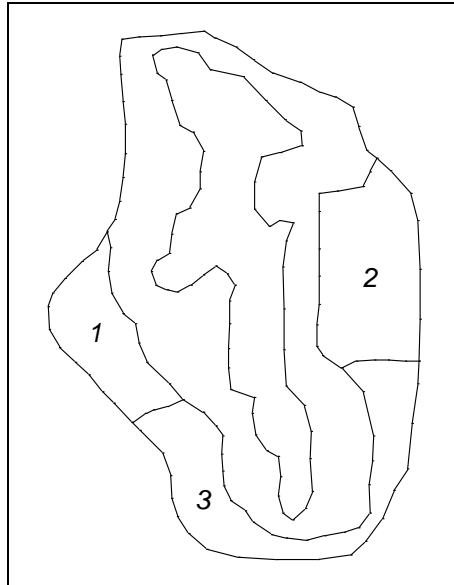


Figure 5. Polygons to be selected.

## 11 Converting the Model

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Now that the values have been edited, the next step is to convert the conceptual model to the grid-based numerical model:

1. Select the **Map → MODFLOW**  command.
2. At the prompt, make sure the *All applicable coverages* option is selected and click **OK**.

## 12 Computing a Solution

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The next step is to save the MODFLOW model with the new values and compute a new solution.

### 12.1 Saving the Simulation

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To save the simulation:


1. Select the *File / Save As* command.
2. Change the project name to “run3.gpr.”
3. Click the **Save** button.

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## 12.2 Running MODFLOW

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Do the following to run MODFLOW:

1. Select the **Run MODFLOW**  button.
2. When the MODFLOW simulation is completed, select the **Close** button. The solution is read in automatically.

Note that the plot in the *Plot Window* has been updated. Up to this point, the tutorial has not paid much attention to the flow target on the arc group. In the next section, the user will create a plot that shows how well the flow target is being met.


Note that, although the error improved for the observation wells, the head is still too low on the left and right sides of the model.

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## 13 Error vs. Simulation Plot

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When performing trial and error calibration, it is important to keep track of the trend in the error as new solutions are repeatedly computed. GMS provides a special calibration plot to simplify this task.

1. Select the **Plot Wizard**  button.
2. Select the *Error vs. Simulation* plot.
3. Select the **Next** button.
4. Select the **Finish** button.

The change in each of the three error norms from one solution to the next is clearly visible in the new plot. The plot is updated as each new solution is read in. Ideally, as the user makes changes to the model, the error should gradually become smaller and smaller. If a bad choice is made in changing the model, the error may temporarily increase. In most cases, it is a good idea to keep a log of the changes made and the resulting errors.

5. When finished viewing the plot, close the window.
6. Maximize the graphic window again.

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## 14 Continuing the Trial and Error Calibration

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At this point, the user is free to continue with the trial-and-error calibration process using the steps outlined above. The user may wish to change both the recharge and the hydraulic conductivity values. Before editing the recharge values, be sure to make the coverage visible by selecting it in the Project Explorer.

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## 14.1 Changing Values vs. Changing Zones

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For this tutorial, the user should be able to get a good match between the computed and observed values simply by changing the hydraulic conductivity and recharge values assigned to the polygonal zones. In a real application, however, the user may also need to change the size and distribution of the zones in addition to the values assigned to the zones.

## 14.2 Viewing the Answer


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If the user wishes to view the “answer,” a map file can be imported that contains a set of parameter values that result in a solution that satisfies the calibration target for each of the ten observation wells.

Before reading in the new conceptual model, the user must first delete the “BigVal” conceptual model:

1. In the Project Explorer, highlight the “BigVal”  conceptual model.
2. Right-click on the model, and select **Delete**.

To read in the new conceptual model:

3. Select the **Open**  button.
4. Make sure to turn on the *Import into current project* toggle.
5. If necessary change the *Files of Type* to \*.gpr.
6. Select the file titled “answer.gpr.”
7. Select the **Open** button.

The user can now convert this model to the grid and compute a new solution using the steps described above.

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## 15 Conclusion

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

- Observation points will display a target next to them that shows how well the computed values match the observed values.
- With MODFLOW, the computed values at the observation points come from MODFLOW and not GMS. Thus, if the user creates an observation point, the user will have to run MODFLOW before seeing a target.

- If the user wants to specify a flow observation that applies to a network of streams, the user can create an arc group.
- A number of different plots are available when doing model calibration.
- It is possible to import data from another GMS project by turning on the *Import into current project* toggle in the *Open* dialog.
- Whenever changes are made to the conceptual model, the user must use the *Feature Objects / Map* → **MODFLOW** command and save the project before running MODFLOW.