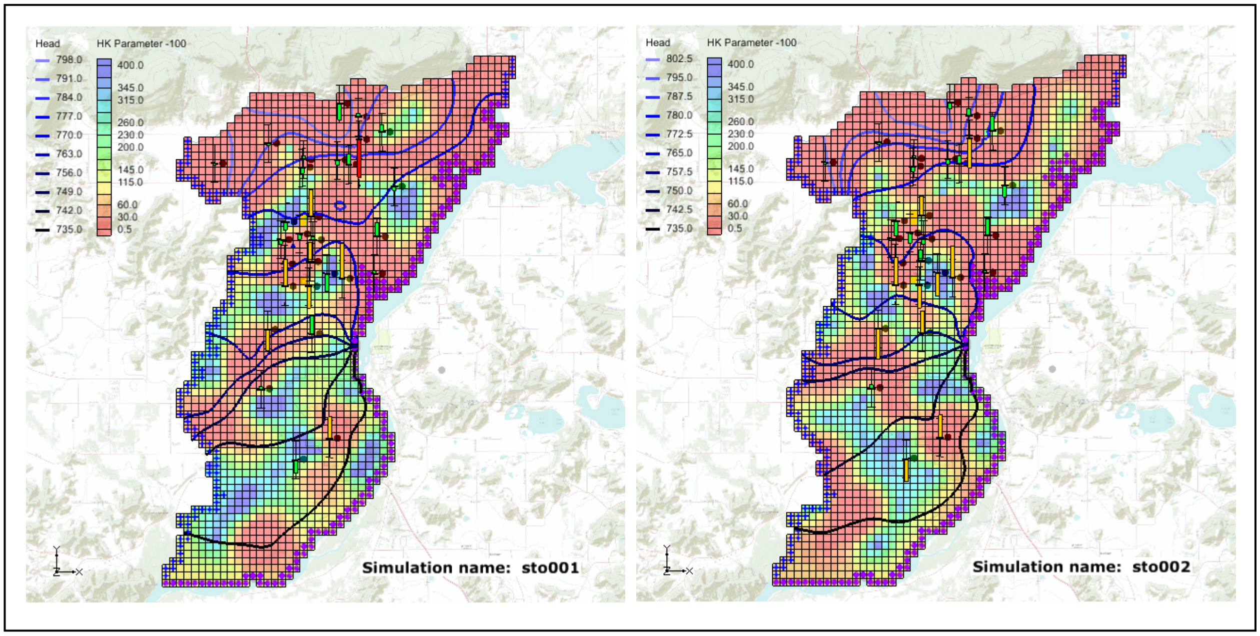
v. 9.2

GMS 9.2 Tutorial

MODFLOW – Stochastic Modeling, PEST Null Space Monte Carlo II

Use results from PEST NSMC to evaluate the probability of a prediction



Objectives

Learn how to use the results from a PEST Null Space Monte Carlo (NSMC) simulation to set up a new stochastic simulation with MODFLOW.

Prerequisite Tutorials

- MODFLOW – Stochastic Modeling, PEST Null Space Monte Carlo I

Required Components

- Grid
- Map
- MODFLOW
- PEST
- Stochastic Modeling

Time

- 30-60 minutes

1 Contents

2 Introduction

GMS supports the following three methods for performing stochastic simulations:

- Parameter randomization
- Indicator simulations (T-PROGS)
- PEST Null Space Monte Carlo (NSMC)

The first two approaches are described in separate tutorials. This tutorial will explain features of GMS associated with the PEST NSMC method. If you have not done so already it is highly recommended that you finish the *MODFLOW – Stochastic Modeling, PEST Null Space Monte Carlo I* tutorial prior to doing this tutorial.

In the PEST NSMC I tutorial we discussed how the NSMC method is used to create multiple calibrated MODFLOW models. This exercise is useful for exploring the uncertainty associated with the calibrated model. However, a groundwater model is normally used to help make some kind of future prediction. The usual process for using a model to make a prediction is: first, use historical data to create a calibrated groundwater model; then, modify the calibrated model to account for some future scenario and evaluate the prediction.

For example, perhaps we want to know how much drawdown a well would cause if an area was in a drought for a prolonged period of time. First, we would create a calibrated groundwater model using historical information on water levels, pumping rates at wells, and rainfall. Then, we would take the calibrated model as a starting point, modify the inputs so as to simulate a drought, and then run the model. We could then view the model outputs and make a prediction on the amount of drawdown caused by a well in such a scenario.

We would never say that we were 100% confident in our prediction because we know that there is uncertainty associated with various inputs to the groundwater model (hydraulic conductivity, recharge, water levels, etc. all have error associated with their input values). More often than not, the model is better than a scientific guess since in building the model we have analyzed the study area and accounted for the different processes that affect groundwater. Further, we have used historical data to make sure that our model can match what has been measured in the past. So while the model is not perfect it is better than a less sophisticated approach.

Using the NSMC method we now have a method for quantifying the amount of uncertainty associated with our prediction. Instead of creating a single calibrated model, we can use PEST NSMC to create multiple calibrated models. We can modify our model to account for future conditions and then run multiple models using the different parameter values that PEST calculated. Then we can view a distribution of results for our prediction. Using the previously mentioned drawdown example, we can present a mean drawdown with a standard deviation instead of presenting a single value. In this way we can feel much more confident in our prediction and we have quantified the amount of uncertainty associated with the prediction. If the amount of uncertainty is unacceptably high then more work may be required such as collecting more field data or better calibrating the original model.

2.1 Outline

This is what you will do:

1. Open a project with multiple calibrated MODFLOW solutions that were calibrated using PEST NSMC.
2. Modify the MODFLOW simulation.
3. Set up a stochastic run using the results from PEST NSMC.
4. Run MODFLOW in stochastic mode.

3 Description of Problem

A groundwater model for an unconfined alluvial aquifer in Wisconsin, USA is shown in Figure 1. The alluvium is highly variable in terms of hydraulic conductivity. In some areas it is composed of high conductivity well sorted gravels, while in other areas it is composed of low conductivity sandy silts. While the location and description of the model area are accurate, the observation wells used in this exercise are not field measured values.

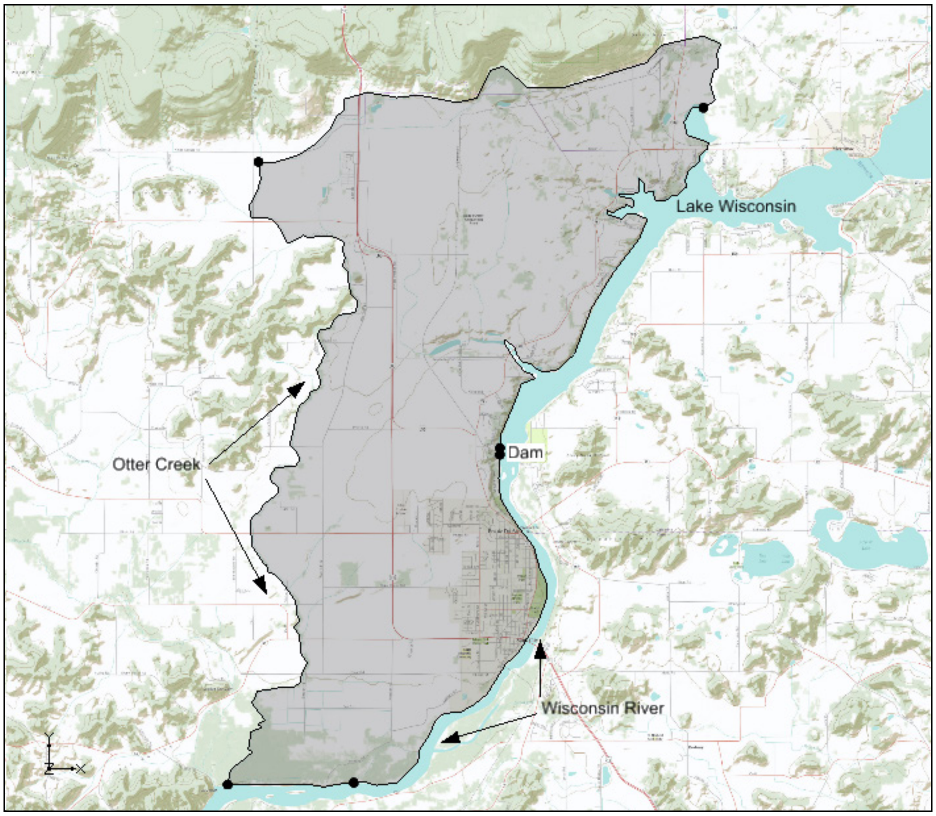


Figure 1. Study area.

The model is bounded on the east by Lake Wisconsin and on the south by the Wisconsin River. A stream (Otter Creek) is used as the western boundary. Based on observed heads it is assumed that there is a significant amount of recharge occurring along the northern boundary. The aquifer becomes very thin as you approach the northern and western boundaries.

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 Reading in the Project

First, we will read in a project containing the MODFLOW solution:

1. Select the *Open* button.
2. Locate and open the **Tutorials\MODFLOW\sto_pest_nsmc_II** directory.

3. Open the file entitled **nsmcII.gpr**.

You should see a one layer MODFLOW model and observation wells similar to the figure below.

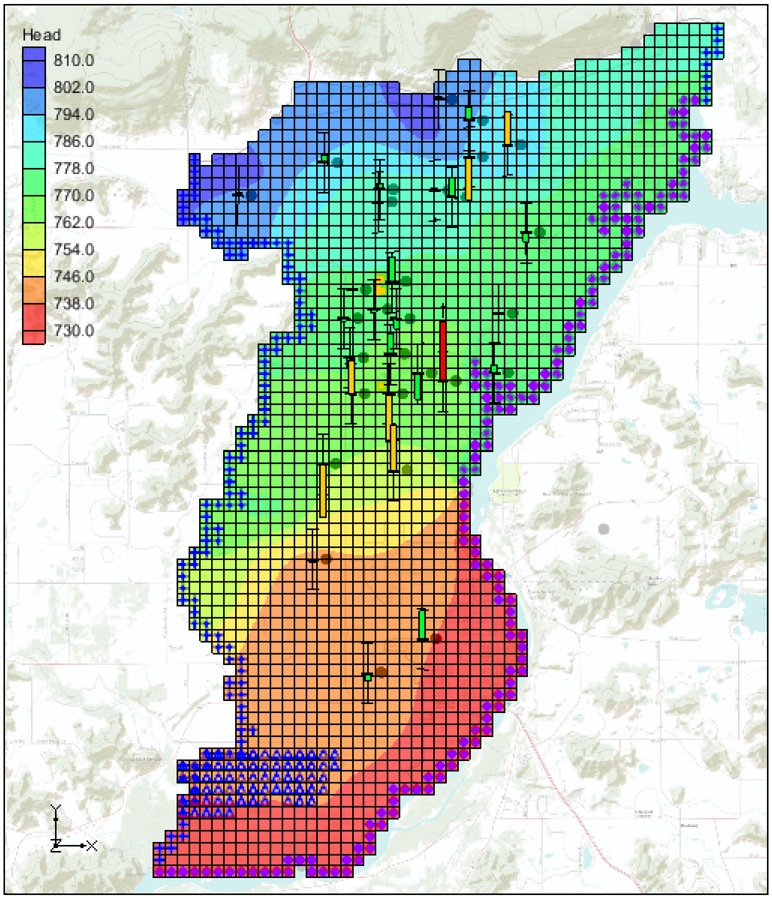


Figure 2. Calibrated MODFLOW model.

4. Expand the following items in the *Project Explorer*: *3D Grid Data* folder, *grid*, the *nsmcII (MODFLOW)(STO)* folder.

These are the results from a PEST Null Space Monte Carlo run. The current set of heads are part of the nsmcII001 (MODFLOW) solution. You may wish to select different solutions to see the variability in the computed heads.

5. Double-click on the nsmcII.mfo text item in the *Project Explorer*.

This will open this file in a text editor. You should see something similar to the figure below.

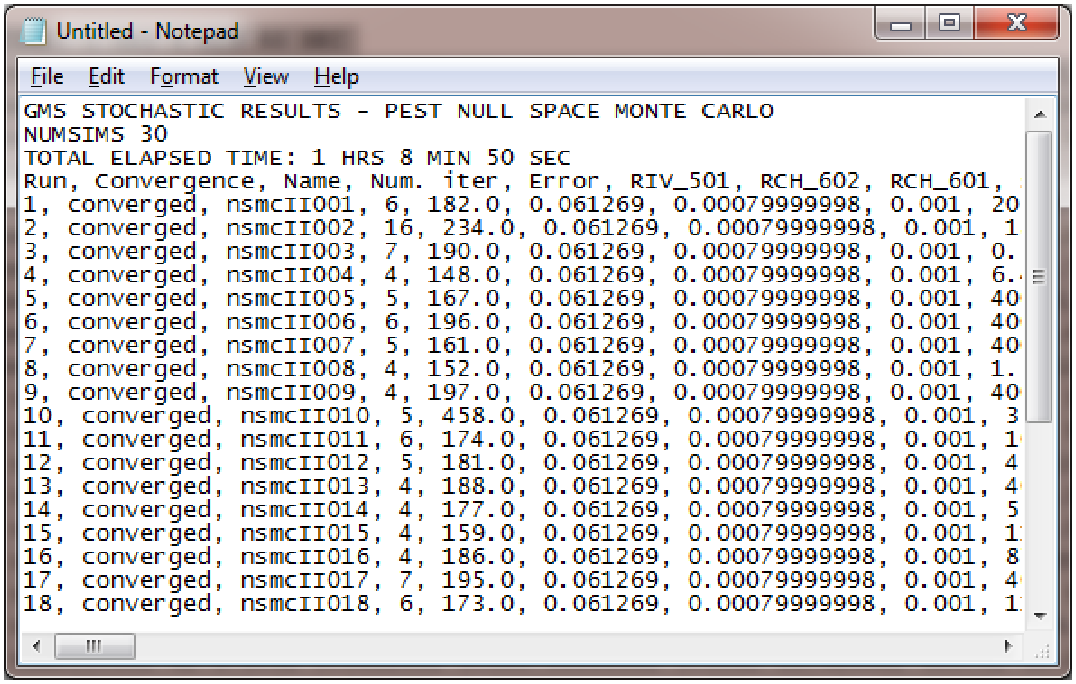


Figure 3. Stochastic output file (nsmcII.mfo) displayed in Notepad.

This file describes the PEST NSMC run. If we scroll through the file we will see that this stochastic simulation comprised 30 different models. Each line in the file describes a model run. Notice that the name of the simulation, the number of PEST iterations, the model error, and the parameter values are given on each line.

The original calibrated model had a total model error of 197.5. During the NSMC run, PEST would run each model until the total model error was less than 200.0. (The value specified for the PEST input parameter PSTOPTHRESH.) Model runs 2, 10, and 21 had model error above the 200.0 and so they were removed from the stochastic folder in the project explorer. Model run 29 encountered some kind of problem so it was reported as a failed run.

6. Close the text file and return to GMS.

6 The MODFLOW Run Options

Now we will modify our MODFLOW run to analyze the capture zone of a proposed well. Then we will run MODFLOW in stochastic mode using the results from the PEST NSMC run.

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

2. Under the *Run options* section of the dialog, select the *Stochastic* option.

3. Select the *Stochastic Options* button.

This dialog is used to change the stochastic options. We are still going to use the PEST NSMC option, but we need to select the PEST NSMC stochastic solution that we are going to use as input for our new stochastic simulation.

4. In the drop down box next to the *PEST NSMC* option, select the **nscmII (MODFLOW)(STO)** item.

5. Select OK twice to exit the dialogs and return to the main GMS window.

7 Creating the new well

We are now ready to add the proposed well and run MODFLOW.

1. Select the Zoom tool .

2. Zoom in on the area shown in the figure below by dragging a box with the Zoom tool.

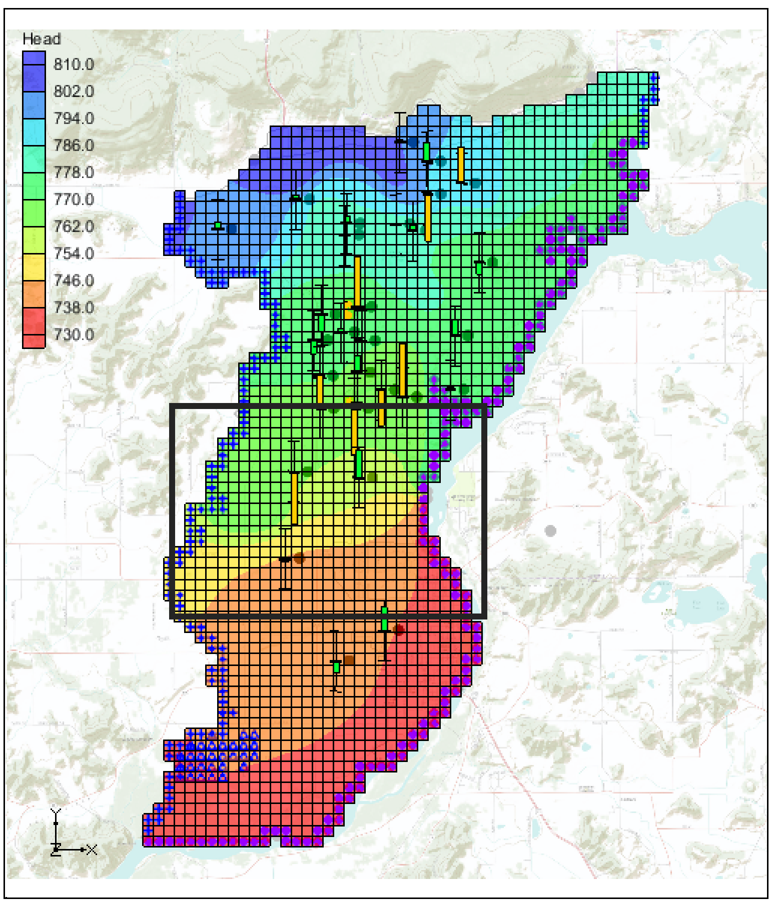


Figure 4. Area in model where new well will be created.

3. Select the *Select 3D Grid Cells* tool .

4. Select the cell shown in the next figure. The cell id should be 2356 shown at the bottom of the GMS window: Cell ID:2356…

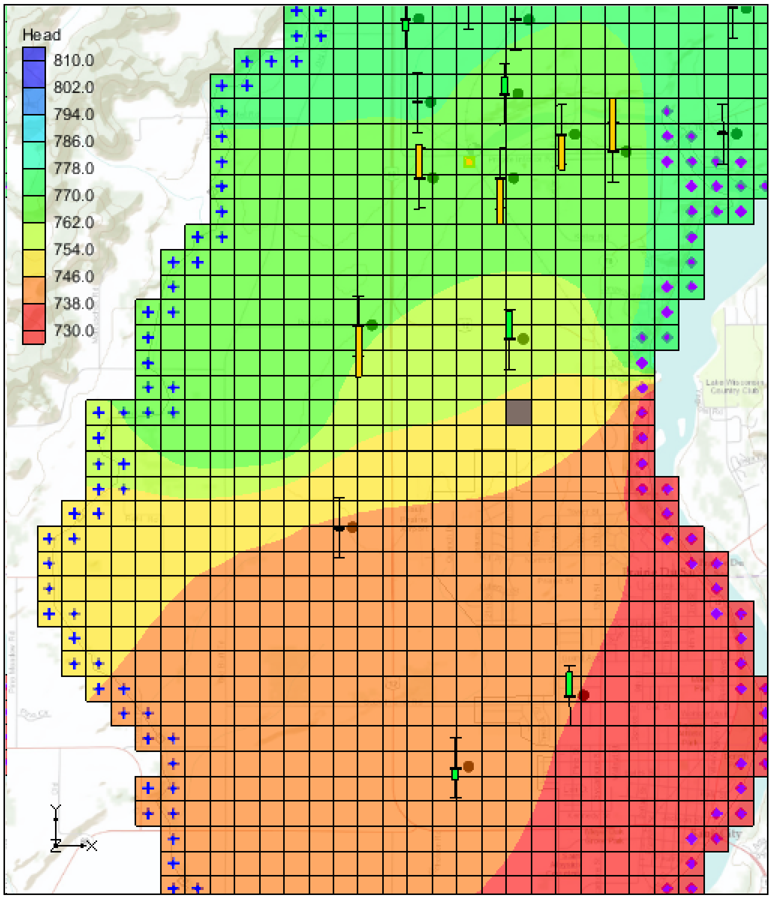


Figure 5. Location of new well.

5. Right click on the cell and select the *Sources/Sinks* command.

6. Select **Wells** from the list box on the left side of the dialog.

7. Click on the *Add BC* button at the bottom of the dialog to create a new well.

8. Enter **Well 4A** for the name and **-65000.0** for the flow rate. (See the next figure)

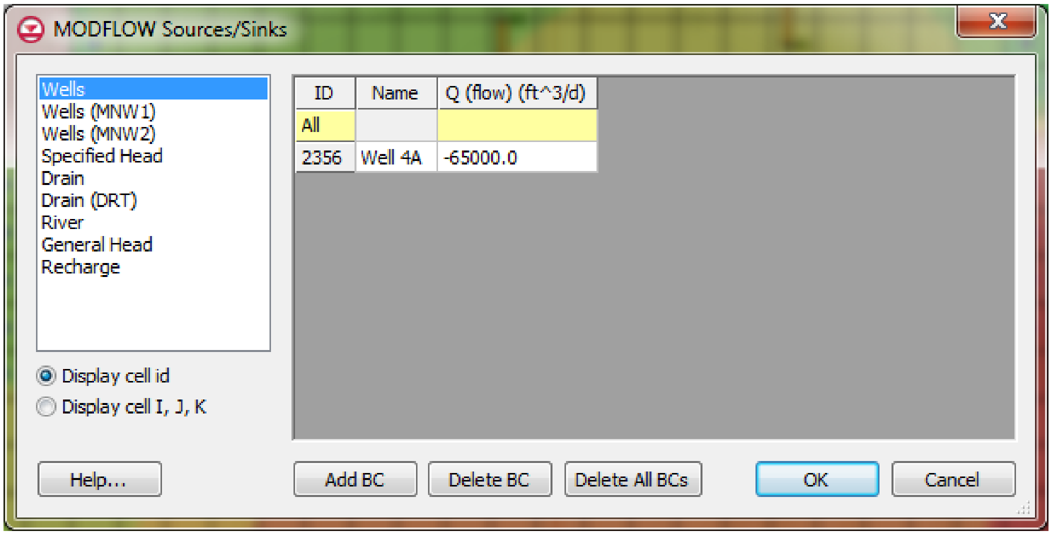


Figure 6. Sources/Sinks dialog creating a new well.

9. Select *OK* to exit the dialog.

10. Select the *Frame* macro .

8 Removing the observations

We will now remove the head observations since we are now running a model scenario that is inconsistent with these head measurements.

1. Select the *MODFLOW* | *Observations* command.

2. Uncheck the toggle next to the **wells** coverage on the right side of the dialog.

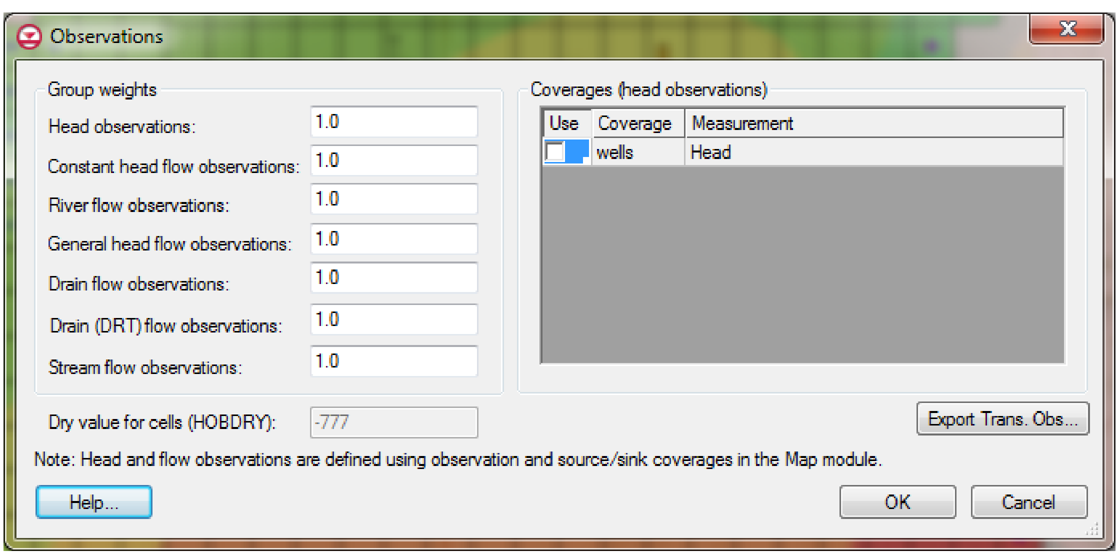


Figure 7. Observations dialog.

3. Select OK to exit the dialog.

9 Saving the Project and Running MODFLOW

We are now ready to save the project and run PEST in stochastic mode.

1. Select the *File* | *Save As* command.
2. Save the project with the name **nsmcII_forward.gpr**.
3. Select the *MODFLOW* | *Run MODFLOW* command.

MODFLOW is now running in stochastic mode as shown in the next figure. Depending on the speed of your computer this process may take up to 15 minutes. On a fairly fast computer the model should finish running in a couple of minutes.

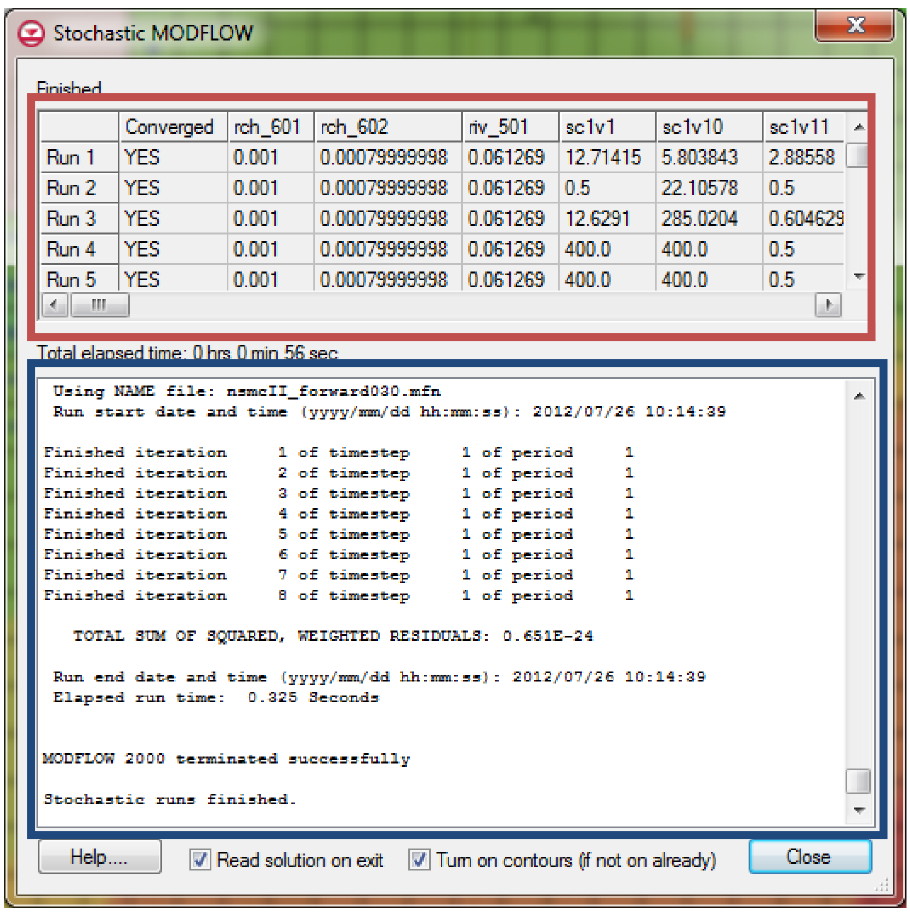


Figure 8. PEST Model Wrapper.

The spreadsheet (outlined in red above) shows the parameter values for each model run and whether or not the model converged. Below the graph is a text window (outlined in blue above) that shows the output that MODFLOW would print to the screen if you were running MODFLOW from the command line.

For each model run GMS reads the parameter values calculated by PEST in the previous NSMC run and saves those parameter values to the SEN package file for MODFLOW 2000 or to the PVAL package file for MODFLOW 2005 and NWT. Then MODFLOW executes that model run.

10 Reading in and Viewing the MODFLOW Solutions

Once all the MODFLOW runs are completed, you can read in the solutions.

1. Make sure the *Read solution on exit* toggle is checked and select the *Close* button.

2. Select *OK* at the prompt to read in all converged solutions.

You should see a new folder named **nsmcII_forward (MODFLOW)(STO)** appear in the *Project Explorer*. Expand this folder and view the individual solutions.

11 Risk Analysis

Now we will use the nsmcII_forward set of stochastic solutions to examine the capture zone for the new well.

1. Right click on the **nsmcII_forward (MODFLOW)(STO)** folder in the *Project Explorer* and select the *Risk Analysis* command.

2. Select the *Probabilistic capture zone analysis* option and then click the *Next* button.

3. Under the *Particle termination at cells with weak sinks* section select the *Stop in cells with weak sinks* option.

4. Select the *Finish* button.

GMS is now running MODPATH on each of the MODFLOW solutions. A particle is placed on the water table surface at each cell in the model grid and then the particle is tracked forward in time to determine the cell where the particle terminates. When the model finishes running you should see something similar to the figure below.

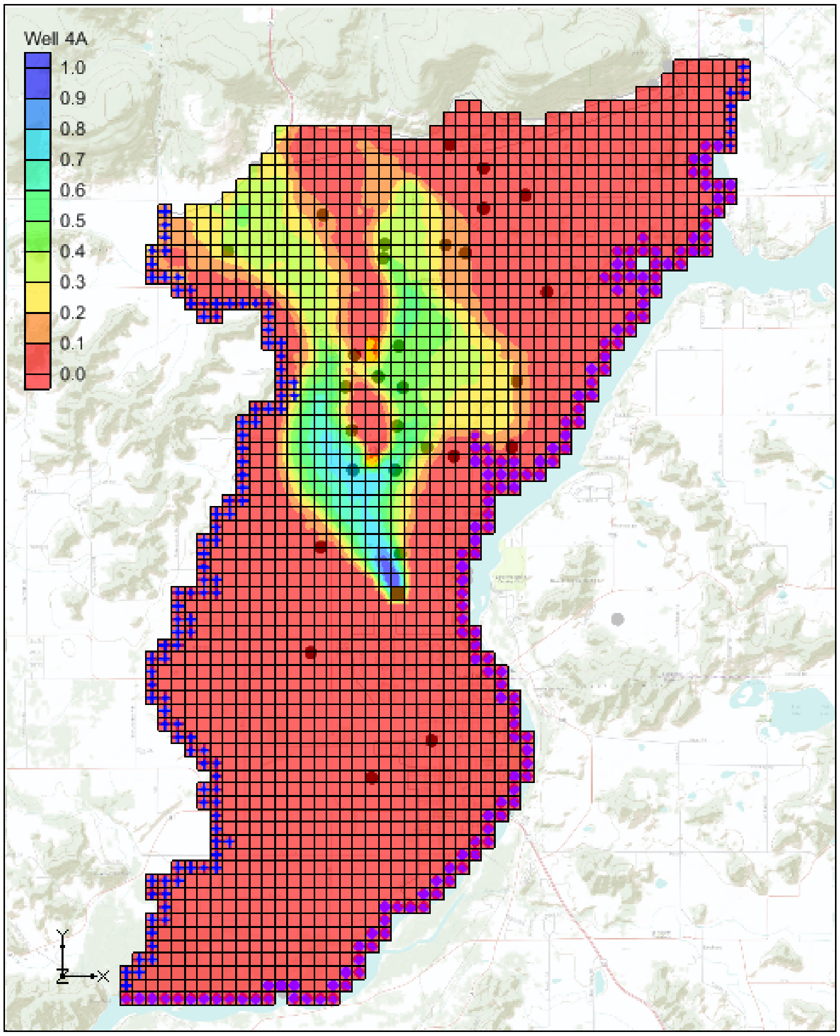


Figure 9. Probabilistic capture zone for proposed well.

The figures below show capture zones from individual solutions computed by MODFLOW. Notice the difference in the shape and location of the various capture zones. This is due to the uncertainty associated with this model. Even though the model has been calibrated to field measured water level data, using PEST NSMC we can create multiple calibrated models that show significant differences in the capture zone for our well. Thus, it is more reasonable to discuss modeling results in terms of uncertainty and probability than in terms of the results from a single model.

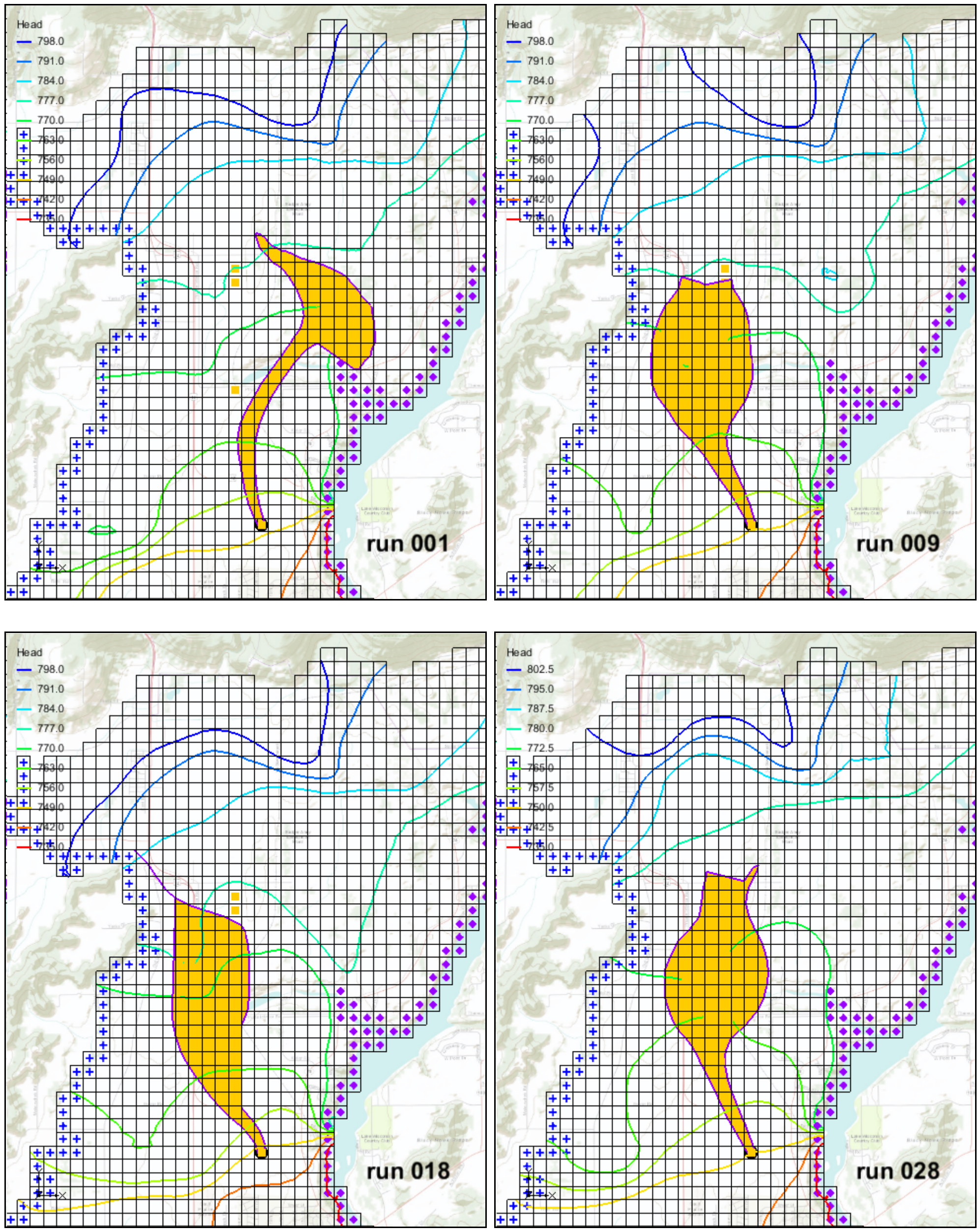


Figure 10. Capture zones from individual runs.

12 Conclusion

This concludes the *Stochastic Modeling – PEST Null Space Monte Carlo II* tutorial. Here are the things that you should have learned in this tutorial:

- You can create a new stochastic solution using the results of a completed PEST Null Space Monte Carlo run.
- The Risk Analysis tools in GMS allow you to create probabilistic capture zones.

