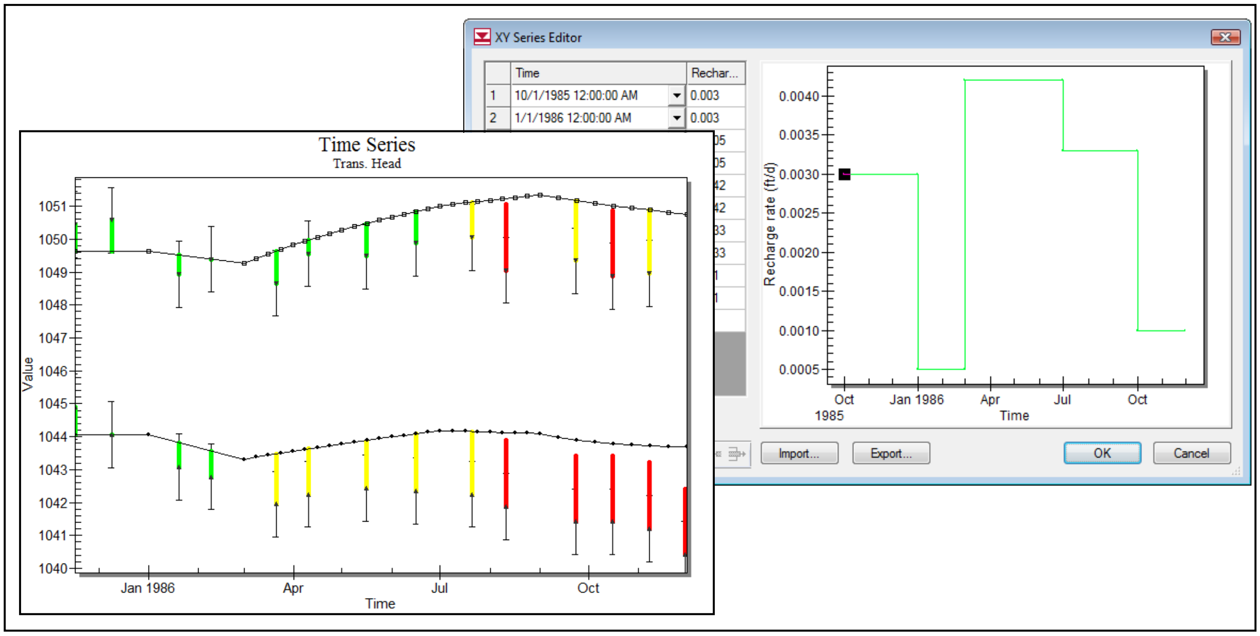
GMS

v. 9.2

GMS 9.2 Tutorial

MODFLOW – PEST Transient Pump Test Calibration

Tools for calibrating transient MODFLOW models



Objectives

Learn how to setup a transient simulation, import transient observation data, and use PEST to calibrate the model.

Prerequisite Tutorials

- MODFLOW - Automated Parameter Estimation
- MODFLOW - PEST Pilot Points

Required Components

- Grid
- Map
- MODFLOW

Time

- 30-60 minutes

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1 Contents

2 Introduction

Pump test data is a common type of transient data available to ground water model developers. In this tutorial we will take an existing steady state MODFLOW model and update the model to simulate a pump test.

2.1 Outline

This is what you will do:

1. Open a MODFLOW model and solution.

2. Set up MODFLOW stress periods.

3. Import transient observation data and create plots.

4. Run PEST to calibrate the transient model.

3 Description of Problem

The model we will be using in this tutorial is the same model used in the **MODFLOW - Generating Data From Solids** tutorial. Figure 1, below, shows our study area in plan view. The production well near the center of the study area was pumping during the pump test. The other two production wells were not pumping during the test and a few head measurements were taken at these wells during the test. One monitoring well was sampled frequently during the pump test. Other monitoring wells had less frequent measurements.

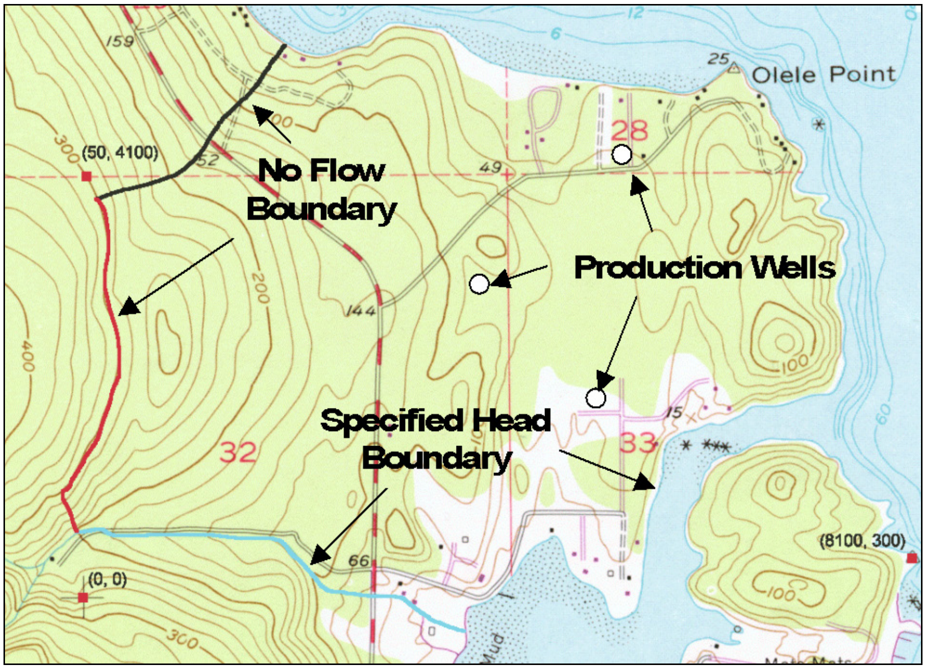

Figure 1. Study area for ground water model

The figure below shows a cross section through the study area. There are two main aquifers in the area. The lower-confined aquifer (red) is overlain by an upper unconfined aquifer (green). The lower aquifer is where our pumping well and main observation well are located. In some areas, there is an aquitard (yellow) that overlays portions of the lower aquifer.

Figure 2. Cross section through the study area

We will import transient observation data at multiple observation wells. The model has already been parameterized into different zones of hydraulic conductivity (HK), specific yield (SY), and specific storage (SS) for the upper and lower aquifers; there is also a parameter for estimating recharge. We will run the model with the current parameter values to see how well the model matches the pump test. Then we will have PEST optimize the parameter values. Finally, we will use pilot points with the parameters to see if we can improve the match between the simulated and field observed values.

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 the project:

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

You should see a MODFLOW model with a solution and a set of map coverages similar to the next figure.

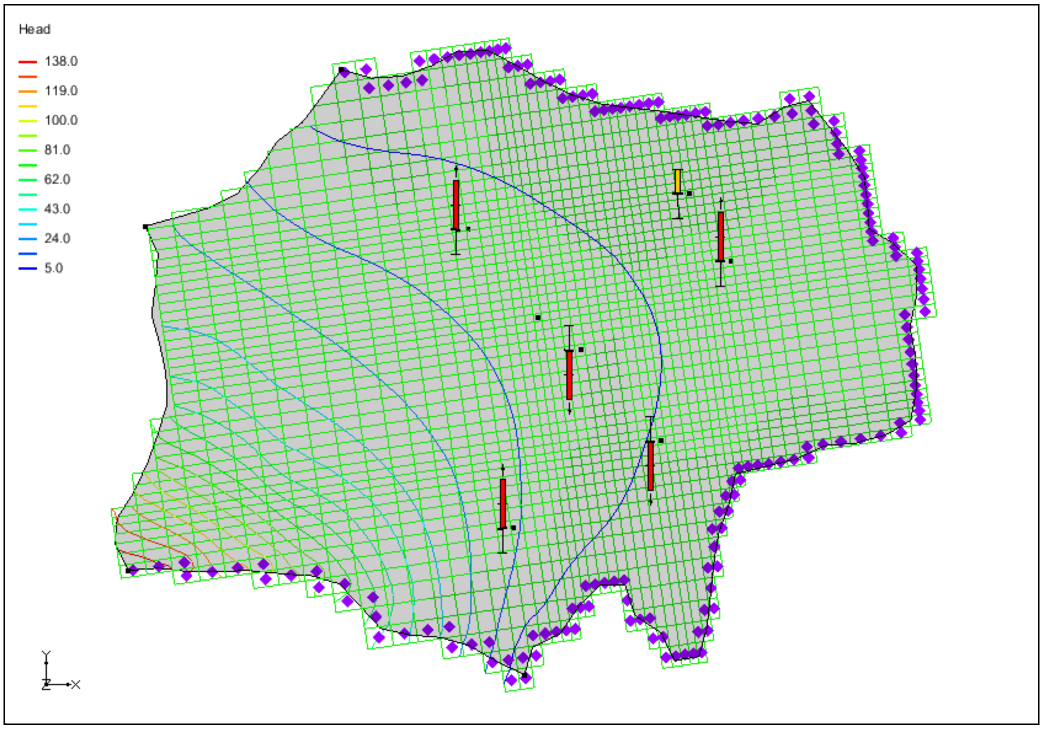

Figure 3. Steady state MODFLOW model

6 Save the Project With a New Name

Before we continue, let's save the project with a new name.

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

It's a good idea to save your work periodically as you proceed.

7 Setting up the Transient MODFLOW Model

First, we are going to set up our transient MODFLOW model. Our pump test occurred over a two week period. Data was collected at the main observation well during the first three days while the well was pumping and then more sporadically over the next ten days while the well was off. We will want to set up our MODFLOW model to have at least two stress periods: one stress period with the well on for 3 days and one stress period with the well off for 10 days.

1. Select the *MODFLOW* | *Global Options* command.
2. On the right side of the dialog, change the *Model type* to **Transient**.
3. Click on the *Stress Periods* button.

7.1 Entering MODFLOW Stress Period Data

This brings up the *Stress Periods* dialog. Here we can set the number of stress periods, how long each period will be and the number of time steps in each period.

1. Increase the *Number of stress periods* to 3.
2. Change the *Start* of the second stress period to **0.0** in the spreadsheet. The *Length* of the first stress period will be updated to **0.0**.
3. Change the *Start* of the third stress period to **3.0**. The *Length* of the second stress period will be updated to **3.0**.
4. Change the *End* of the third stress period to **13.0**. The *Length* of the third stress period will be updated to **10.0**.
5. Make sure that the *Num. Time Steps* is **10** for stress periods *2* and *3*.
6. Set the *Multiplier* to **1.5** for stress periods *2* and *3*. This increases the number of time steps at the beginning of the stress period so that we can see the effect of the change in stresses more accurately.

When you are finished the dialog should look like the figure below.

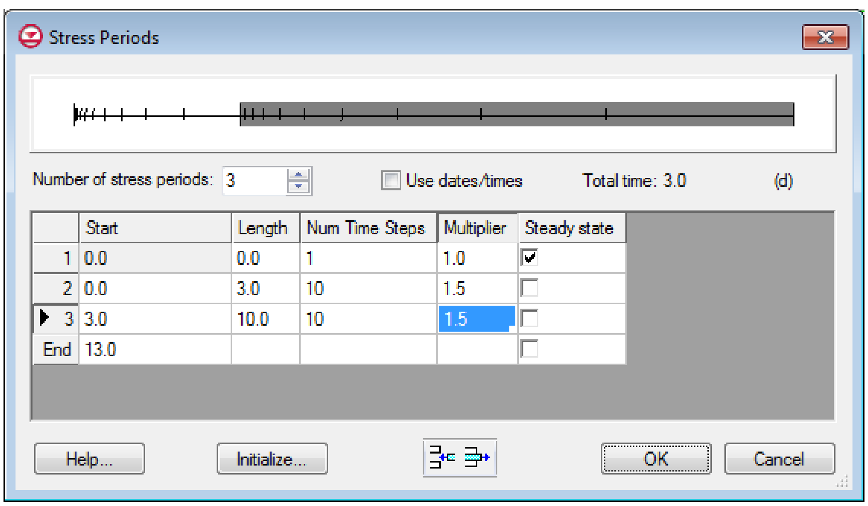

Figure 4. Stress periods dialog

7. Select *OK* to exit the dialog.
8. Select *OK* at the prompt. We want the first stress period to have a length of zero because it is a steady state stress period.

7.2 Initial Conditions

With a transient model it is important to have an initial condition that is consistent with the model inputs. If the initial condition is not consistent with model parameters then the model response in the early time steps will reflect not only the model stresses but also the adjustment of computed head values to offset the lack of correspondence between the model inputs and the initial head values.[1] In our case we have set the first stress period to be steady state. This will prevent any lack of correspondence between model inputs and the initial heads for the transient stress periods. This is important when calibrating a transient model. When we allow a tool like PEST to change the model inputs we want to make sure that the initial heads correspond to the new inputs that PEST has chosen. The easiest way to do this is to have the first stress period of the model be steady state.

1. Select *OK* again to exit the *Global Options* dialog.

8 Entering Pumping Data

We now need to update our well data so that our well will have the appropriate pumping rate for the first stress period and 0.0 for the second stress period. We will edit the well data in the WEL Package.

1. Select the *MODFLOW | Optional Packages | WEL - Well* menu command.

This dialog contains a spreadsheet listing all of the pumping wells in the model. Currently, all of the wells have a flow rate of 0.0. We are going to change the second well, named w-15, to have a flow rate of -130,000.0 during the second stress period.

2. Near the top of the dialog change the *Stress period* to **2**.
3. Uncheck the *Use previous* check box next to the *Stress period* field.
4. Enter **-130000.0** for the *Q (flow)* for the second well listed in the spreadsheet.
5. Near the top of the dialog change the *Stress period* to **3**.
6. Uncheck the *Use previous* check box next to the *Stress periods* field and make sure the *Q (flow)* is **0.0** for the second well.
7. Select *OK* to exit the dialog.

9 Importing Transient Observation Data

Now we will import the transient field-measured head values. This type of data can be imported using the *Text Import Wizard*. The *Text Import Wizard* can import transient data in multiple formats, including date/time. In our example problem, we are not using date/time formatted transient data, we are using relative time where the beginning of our simulation is time 0.0 and we are using units of days. Below we can see the format for this kind of data.

[1] Anderson and Woessner, Applied Ground Water Modeling

```
Name            Time        Head
mw - 3          0.0         10.25
mw - 3          0.5         10.3
w-38            15.0        4.6
…
```

9.1 Adjusting the Coverage Set Up

Before importing the transient observation data we need to make sure that our coverage with our observation points is set up correctly.

1. Expand the **MODFLOW** conceptual model under **Map Data** and double-click on the **Obs** coverage in the *Project Explorer*.
2. On the right side of the dialog under *Observation Points*, select the check box next to **Trans. Head**.
3. Select *OK* to exit the dialog.

9.2 Importing Transient Data Text File

We are now ready to import the transient observation data.

1. Select the *Open* button.
2. In the *Open* dialog, change the *Files of type* selection to **Text Files (*.txt)**.
3. Select the file named **obs_wells_trans.csv** and click *Open*.

You should now see the *Text Import Wizard*. It should look similar to the next figure. This wizard is used to import text data into a GMS project.

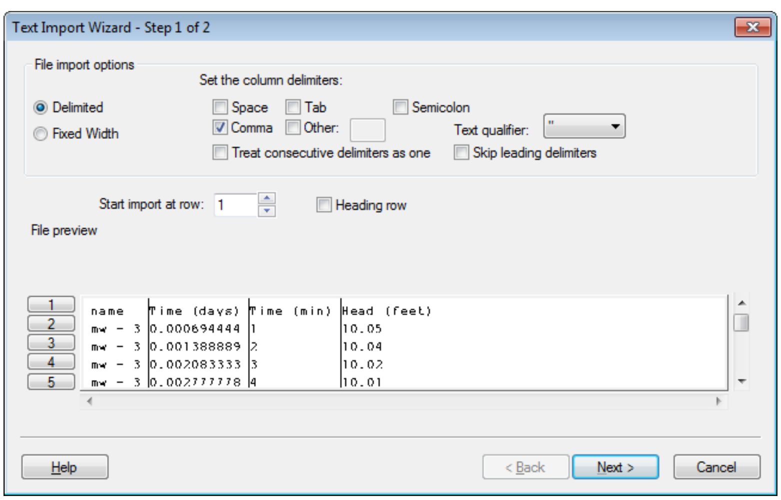

Figure 5. Text Import Wizard

4. Turn on the *Heading row* check box and click the *Next* button.

5. Near the top of the dialog, change the *GMS data type* to **Transient Observation data**. The dialog should look like the next figure.

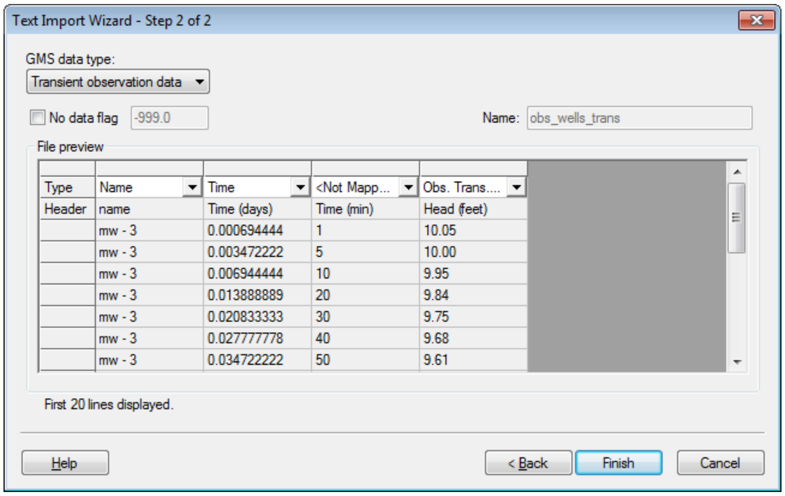

Figure 6. *Step 2 of the Text Import Wizard*

Notice that the Name, Time, and Head columns were automatically recognized by GMS. There are two time columns, one in units of days and one in units of minutes. We want to use the one in units of days and ignore the other one. The dialog is already set up the way we want it.

6. Click on the *Finish* button.

You can see the imported time series data by double-clicking on any of the observation wells and selecting the button under the **Obs. Trans Head** column. The next figure shows the time series curve for observation well **mw - 3**. This observation well is near the center of the model.

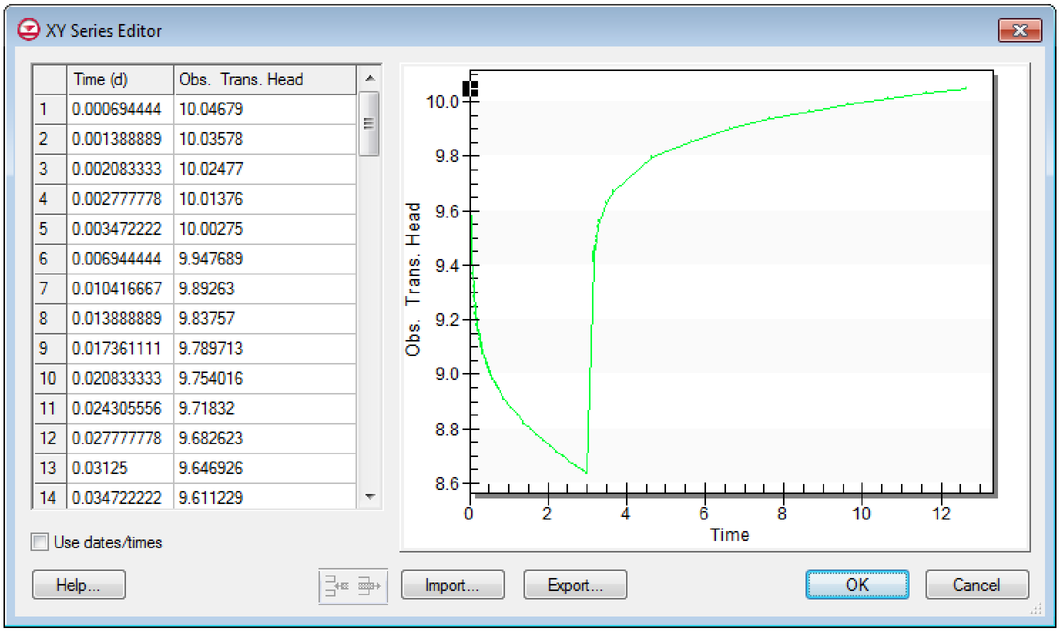

Figure 7. Time series data for well mw - 3.

10 Saving and Running MODFLOW

We are now ready to save the model and launch MODFLOW.

1. Select the *Save* button.
2. Select the *Run MODFLOW* button.
3. Once MODFLOW has finished, select the *Close* button to close the window and return to GMS.

The contours should change. We are currently looking at the top layer of the grid. The pumping well and some of the observation wells are in layer 5.

4. Use the *Mini-grid* Lay (k): 1 near the top of the GMS window to change the current layer to layer **5**.
5. Expand the *pumptest (MODFLOW)* item in the *Project Explorer* and select the *Head* data set.
6. Use the *Time Step* window to cycle through the different time steps of the solution to see the effect of the pump test.

11 Creating a Time Series Plot

One of the useful tools for working with transient calibration data is the time series plot. This plot allows us to see how well our simulated heads match our field measurements.

1. Select the *Plot Wizard* button.
2. Change the plot type to *Time Series*.
3. Select the *Next* button.
4. Select the check box next to point **mw - 3**.
5. Also, turn on the *Calibration Target* and *Observed Values* check boxes.
6. Select the *Finish* button.

You should see a plot similar to the next figure. Currently, our model simulated heads are a little low at this particular well. We will now use PEST to help calibrate the transient model. You can also see other observation wells in the model by right-clicking on the plot and selecting the Plot Data command and selecting a different well in the dialog.

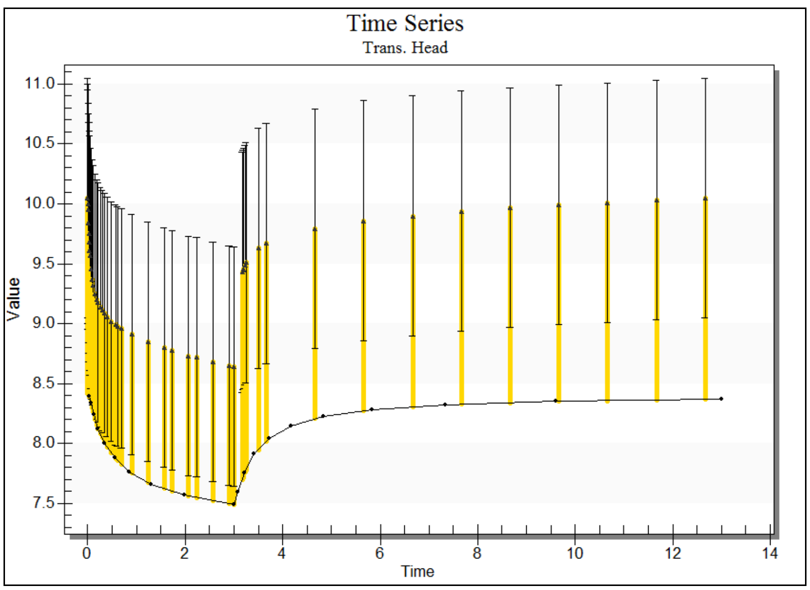

Figure 8. Time series plot

12 Running PEST

We will change our MODFLOW simulation so that we are using PEST to estimate the values of HK (hydraulic conductivity), SY (specific yield), and SS (specific storage) of our upper and lower aquifer. We will also allow PEST to estimate the value of recharge (RCH).

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

2. Under the *Run options* select the **Parameter Estimation** option.

3. Select *OK* to exit the dialog.

At this point you would normally need to parameterize your model. Model parameterization is explained in the *MODFLOW - Automated Parameter Estimation* tutorial. Our model has already been parameterized so we are ready to run PEST. (This model uses material zones to assign properties to the aquifers. The HK, SY, and SS parameter key values have been entered in the *Material Properties* dialog. If you are interested in seeing the materials properties select the *Edit | Material Properties* command.) We are going to use Parallel PEST to optimize this model.[2]

4. Select the *MODFLOW | Parameter Estimation* command.

5. Make sure that the **Use Parallel PEST** and **Use SVD** options are checked.

6. Select *OK* to exit the dialog.

We are now ready to run Parallel PEST.

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

8. Save the project with the name **pumptest_pest.gpr**.

9. Select the *Run MODFLOW*  button.

Depending on the speed of your computer Parallel PEST will take about 2 to 10 minutes to run this problem. When finished, you should see that PEST completed **2** iterations and had a final model error of about **697**.

10. Select the *Close* button.

Your contours and time series plot should update. Your time series curve for the observation well should look like the next figure. We have made a minor improvement in our match with the field-observed values.

[2] This next step can be completed without Parallel PEST but it will take significantly longer to complete.

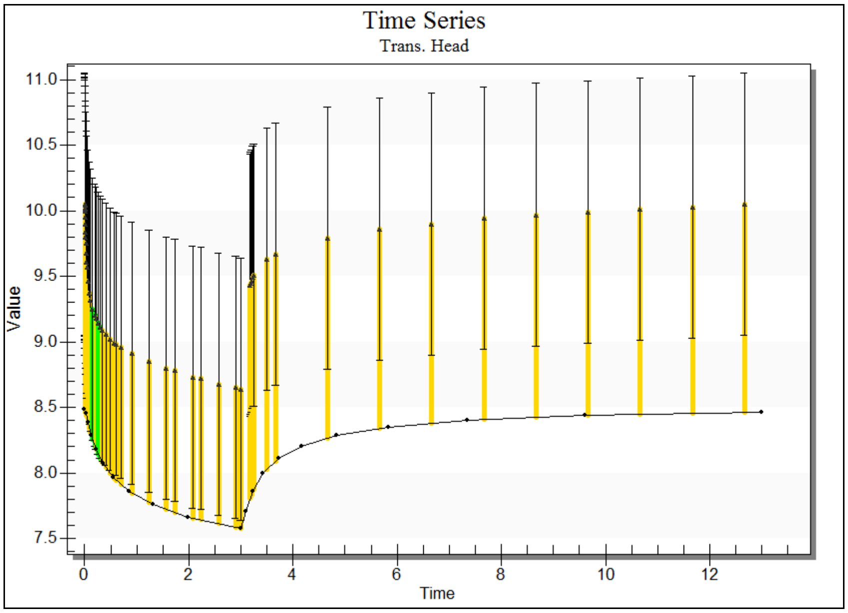

Figure 9. Time series plot after PEST run

We would like to improve the fit between the simulated and the observed heads. We could adjust some of the PEST input parameters to allow PEST to run more with this model or we could try using pilot points with our parameters. We will use pilot points to try to get a better fit at all of the wells.

13 Pilot Points

Now we will import pilot point data. For more information on pilot points you can see the *MODFLOW - Pest Pilot Points* tutorial.

1. Select the *Open* button .

2. In the *Open* dialog, change the *Files of type* selection to **Text Files (*.txt)**.

3. Select the file named **pp.txt** and click *Open*.

The *Text Import Wizard* will open showing the contents of the file.

4. Turn on the *Heading row* check box and click the *Next* button.

Pilot points are 2D scatter points which is the default option. GMS has everything already set up just how we want.

5. Click the *Finish* button on the second page of the wizard.

13.1 Using Pilot Points with the Parameters

We need to change our MODFLOW parameters so that they will use the pilot points that we just imported.

1. Select the *MODFLOW | Parameters* command.
2. Turn on the *Pilot Points* option for parameter **HK_15** by selecting the drop down arrow in the *Value* column. Then select **<Pilot points>** from the drop down list.

The interpolation options associated with the pilot points can be changed by clicking on the small button above the drop down arrow in the *Value* column.

3. Click on the button above the drop down arrow in the *Value* column for parameter **HK_15**.

This brings up the *2D Interpolation Options* dialog. Here you can select the scatter point set and data set used with your parameter as well as the interpolation scheme.

4. Make sure the *Data set* is set to **HK_15**.
5. Select *OK* to exit the *2D Interpolation Options* dialog.
6. Turn on the *Pilot Points* option for parameters **HK_30** and **RCH_300** by following the same steps listed above.
7. Make sure the appropriate data sets are selected in the *2D Interpolation Options* dialog for **HK_30** and **RCH_300** as we did for **HK_15**.
8. When you are finished select *OK* to exit the *Parameters* dialog.

14 Running PEST

Now we will run Parallel PEST again. However, this time we will use the SVD-Assist option. Currently we have 24 pilot points for each parameter. This means that for each PEST iteration, PEST will run MODFLOW once for each pilot point that we have. For this model that would be a total of 72 MODFLOW runs in addition to runs for the other 3 parameters. Using SVD-Assist PEST can decrease the number of necessary MODFLOW runs for each PEST iteration.[3]

1. Select the *MODFLOW | Parameter Estimation* command.
2. Select the check box next to *Use SVD-Assist*.
3. Select *OK* to exit the dialog.

[3] You will **NOT** want to complete this portion of the tutorial if you are not running Parallel PEST.

4. Select the *File* | *Save As* menu command.

5. Save the project with the name **pumptest_pest_pp.gpr**.

6. Select the *Run MODFLOW* button.

Depending on the speed of your computer Parallel PEST will take about 5 to 20 minutes to run this problem. When finished, you should see that PEST completed **5** iterations and had a final model error of about **19.6**.

7. Select the *Close* button.

Your contours and time series plot should update. Your time series curve for the observation well should look like the next figure. We have significantly improved the match between our field values and our model simulated values.

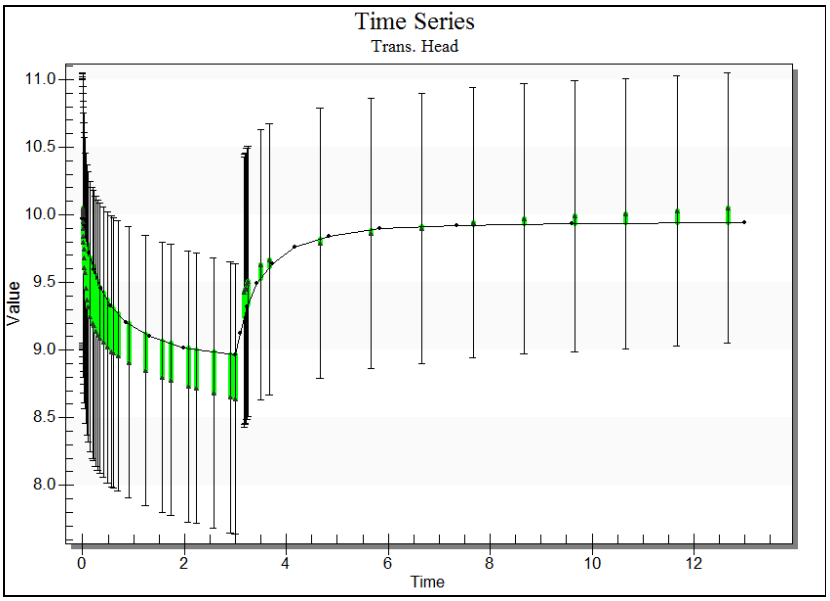

Figure 10. Time series Plot after PEST Calibration

If we want to see the final hydraulic conductivity and recharge arrays we can look under the **pumptest_pest_pp (MODFLOW)** solution item in the *Project Explorer*. We will find a folder called *Parameters* and inside that folder a data set named **HK Parameter -30, -15**. Selecting this data set you can see the final hydraulic conductivity array computed from the pilot points. The recharge is also available.

15 Conclusion

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

- You can import transient observation data with the text import wizard.

- You can use PEST to calibrate transient MODFLOW models.
- It is important to have your first stress period as steady state when calibrating a transient model so that the computed heads for the first transient stress period are consistent with the model input parameters.
- You can view the final array values from parameters that use pilot points by selecting the data set under the MODFLOW solution.

