## Example 10: Hydraulic tomography

This example shows how to set up a hydraulic tomography test with 2 pumping tests.

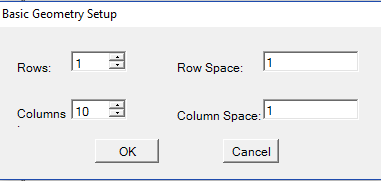
**Part 1: Generating observations well data:**

1. New Project

* Start a new project.
* Select **File** then **New Project**

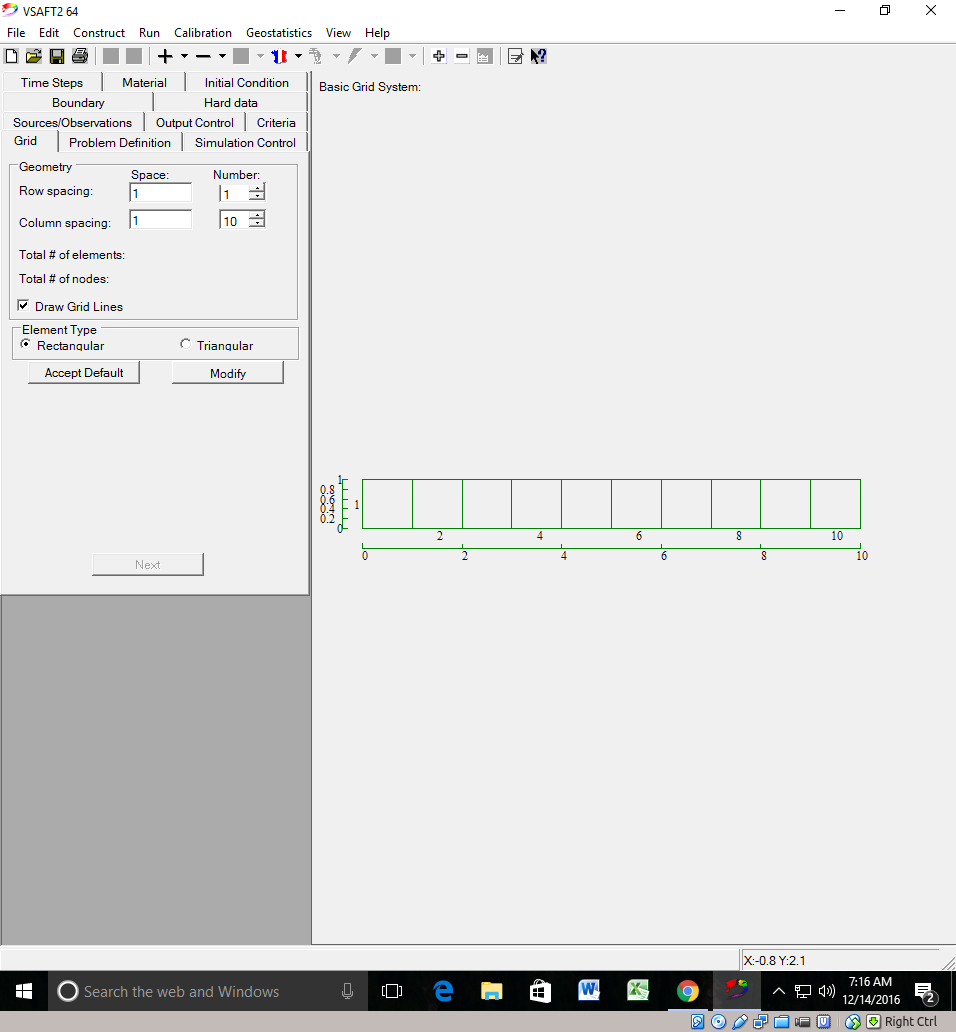
Define the initial grid dimensions (you can edit this later).

* Change the value for the number of rows to **1**
* Change the value for the number of columns to **10**.
* Change the row and column spacing to **1**.
* Select **OK.**



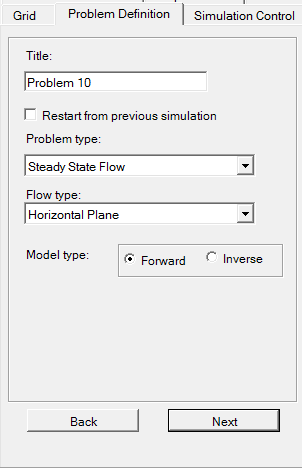
You should have been advanced to the main VSAFT2 window. Your screen should look like the one below.

* For this example we will accept the grid without editing the row or column spacing or adding additional rows or columns.
* Select **Accept Default**
* You will be advanced to the “problem definition” tab.



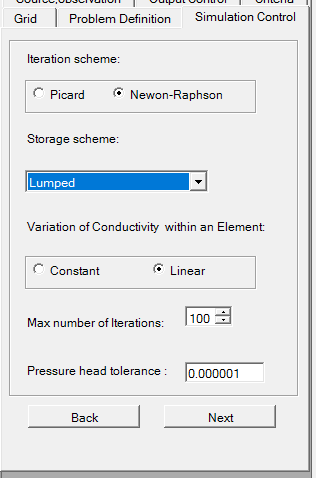
1. Problem Definition.

* Enter a title in the TITLE box such as **Problem 10**. This is for record keeping purposes and to assist in remembering the details of the model. Use a descriptive title.
* Use the Problem type drop down menu to select **Steady State Flow**
* Use the Flow type drop-down menu to select **Horizontal Plane**
* Choose model type **Forward**
* Select **Next** to continue to the simulation control tab.



1. Simulation Control

* Select the **Lumped** storage scheme.
* Select the **Linear** variation of conductivity within an Element.
* Set the **Pressure head tolerance** to **0.000001**
* Select **Next** to continue to the Material tab.



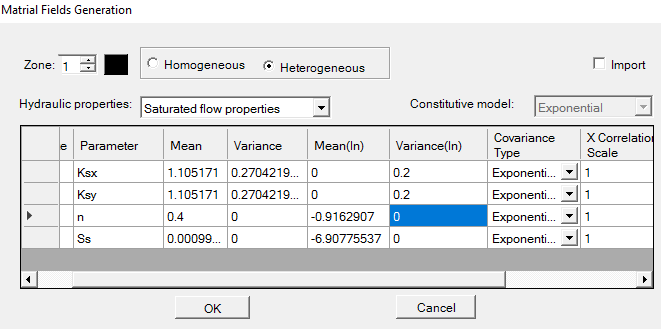
1. Materials

This example uses random materials.

* Click **Define** to enter the material properties
* Choose **Heterogeneous** for representing random material.
* In the Hydraulic properties box select **Saturated Flow properties**.

Enter the X and Y correlation scale and the variance for Ksx, Ksy.

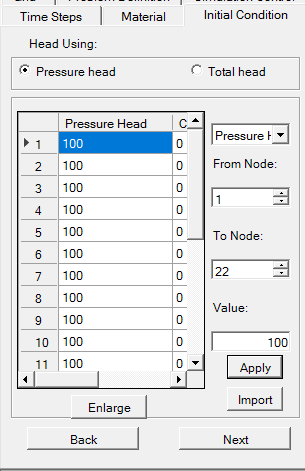
* X correlation scale = **1**
* Y correlation scale = **1**
* Variance (ln) = **0.2**
* Mean (ln) = 0
* Select **OK**
* Select **Next** to continue to the Initial condition tab



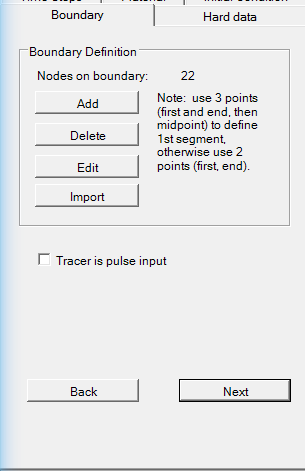
1. Initial conditions

Set the initial hydraulic head

* Select **Pressure Head**
* Enter the initial hydraulic head of **100.0** in the value box.
* Select **Apply.**
* Select **Next** to continue to the Boundary tab.

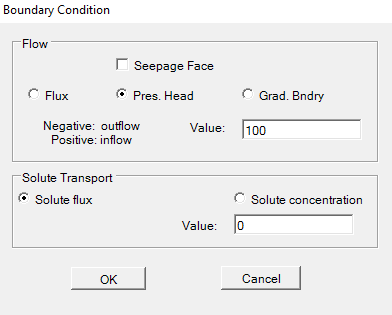


1. Boundary

Here we will set the boundary conditions of both the left and right side as a prescribed **pressure**.

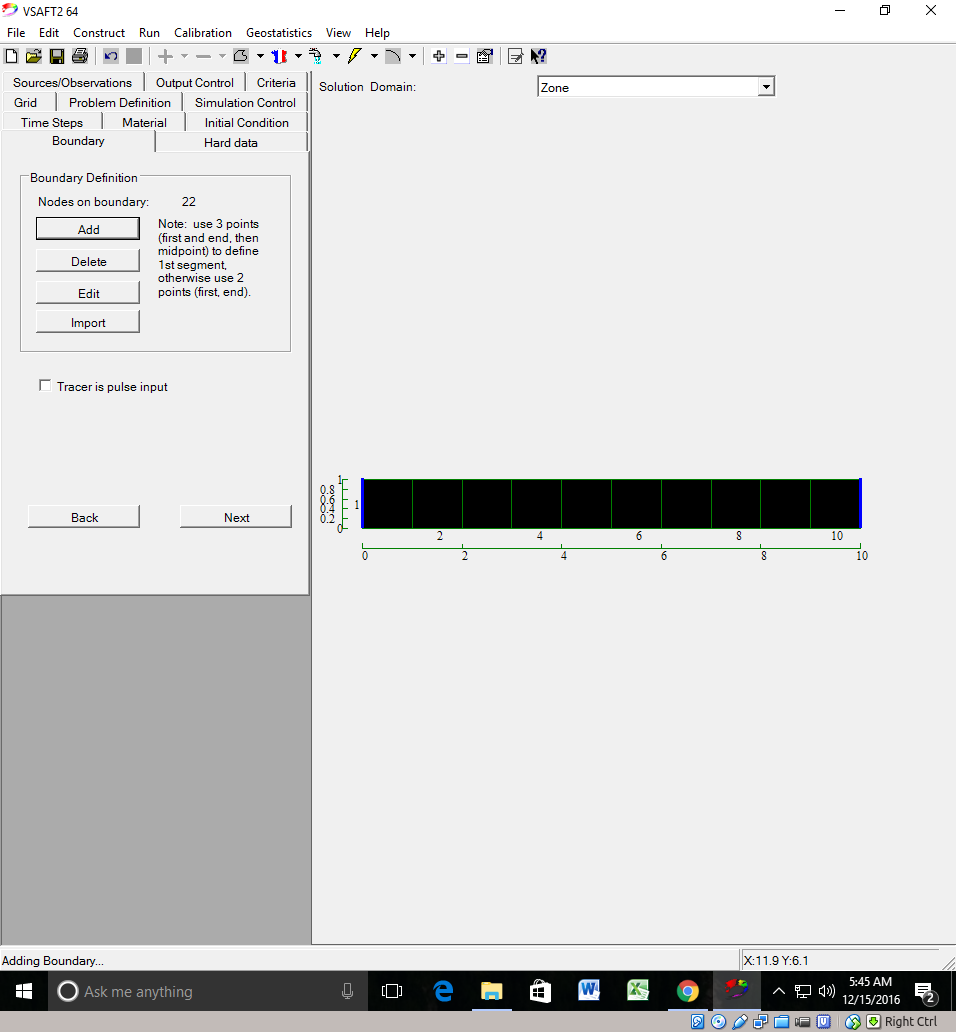
* Click **Add** in the Boundary Definition area.
* With the mouse select the beginning and the end of the boundary to the left of the column.
* Also select the midpoint on the boundary so that VSAFT2 knows which direction along the boundary you wish to define. This step is only required for the first boundary.

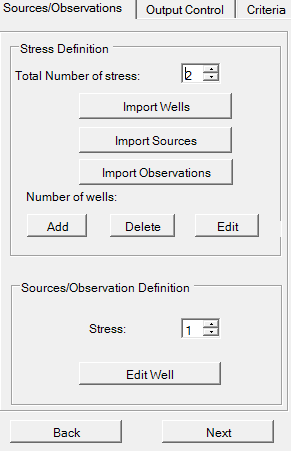
Once the boundary is defined a pop-up window will appear for entering the boundary values.

* Select **Pres. Head** and enter the value of **100.**
* Select **OK**

Add another boundary condition to the right side of the domain.

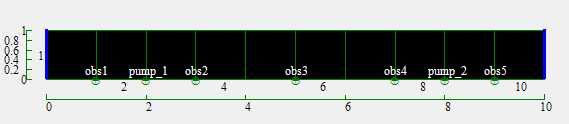
* Select **Add** from the boundary definition window and define the right prescribed head boundary.
* With the mouse select the beginning and the end of the boundary on the right.
* Once the boundary is defined a pop-up window will appear for entering the boundary values.
* Select **Pres. Head** and enter the value of **100**.
* Select **OK**
* Select **Next** to continue to the Source/observation tab.



1. Source/observation

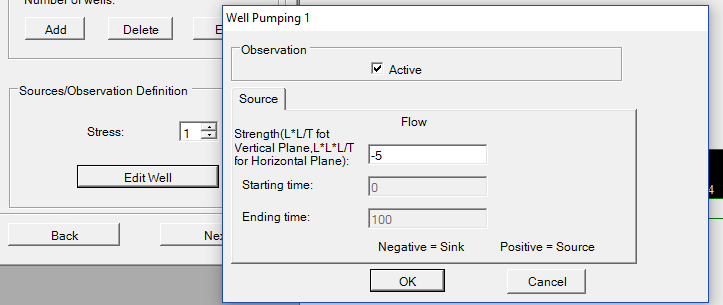
We will use two pumping test to conduct a tomographic survey.

* Change number of Stress into **2** in the Sources/Observation section.
* To add wells, click **Add** under the Number of Wells text in the Stress Definition area.
* Add 7 wells to the domain with the following names
  + **Obs1**
  + **Pumping\_1**
  + **Obs2**
  + **Obs3**
  + **Obs4**
  + **Pumping\_2**
  + **Obs 5**
* Once finished your domain should look something like the picture below.

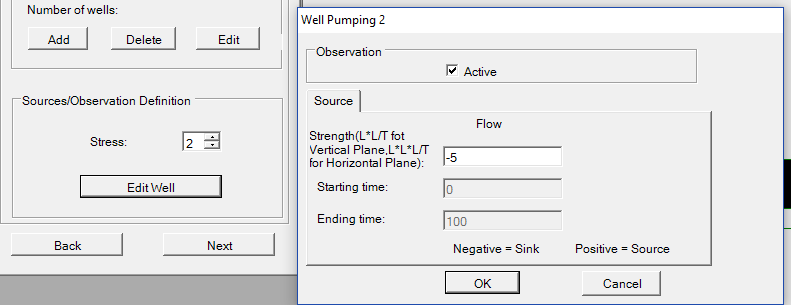


Now we need to define the fluxes out of the two pumping wells.

* Under the “Source/Observation Definition” area, select **1** in the Stress number box.
* Click **Edit Wells** button in the Source/Observation Definition area.
* Select **Pumping 1** well.
* The Well Pumping\_1 dialogue box will be displayed. In the Flow section of the Source tab set the pumping Strength to **-5**.
* Select **OK**.



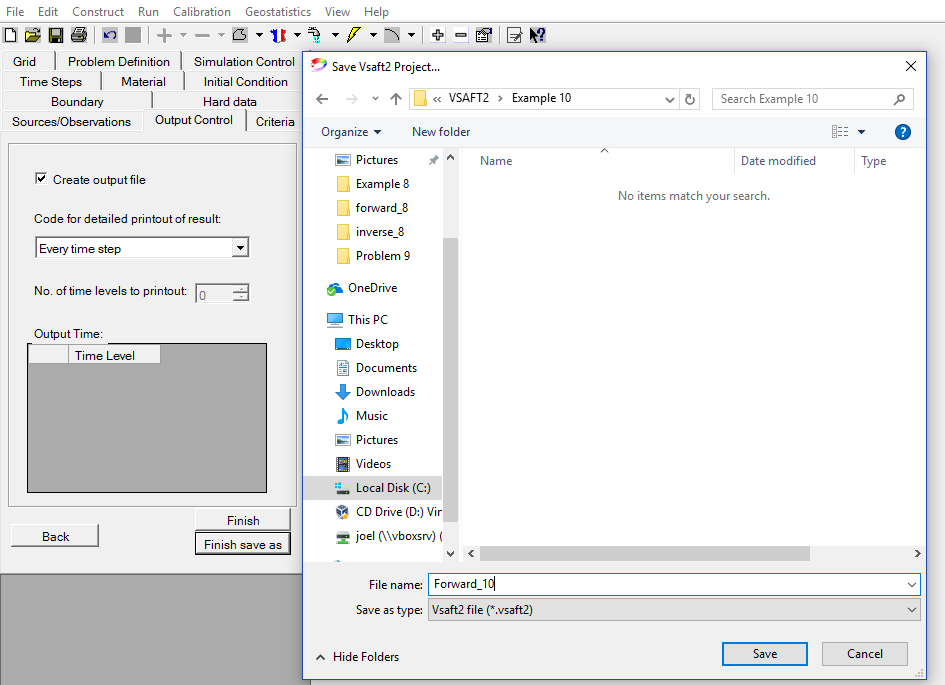
* Next, in the Source/Observation Definition area change the stress number to **2**.
* In the same area select **Edit Well**.
* Locate a pumping\_2 well on the right side of the domain and select it.
* When the Well Pumping\_2 dialogue box is loaded, define the pumping strength as **-5**, under the Flow section of the Source tab.
* Then select **OK**.



* Now select **next** to continue to the Output Control tab.

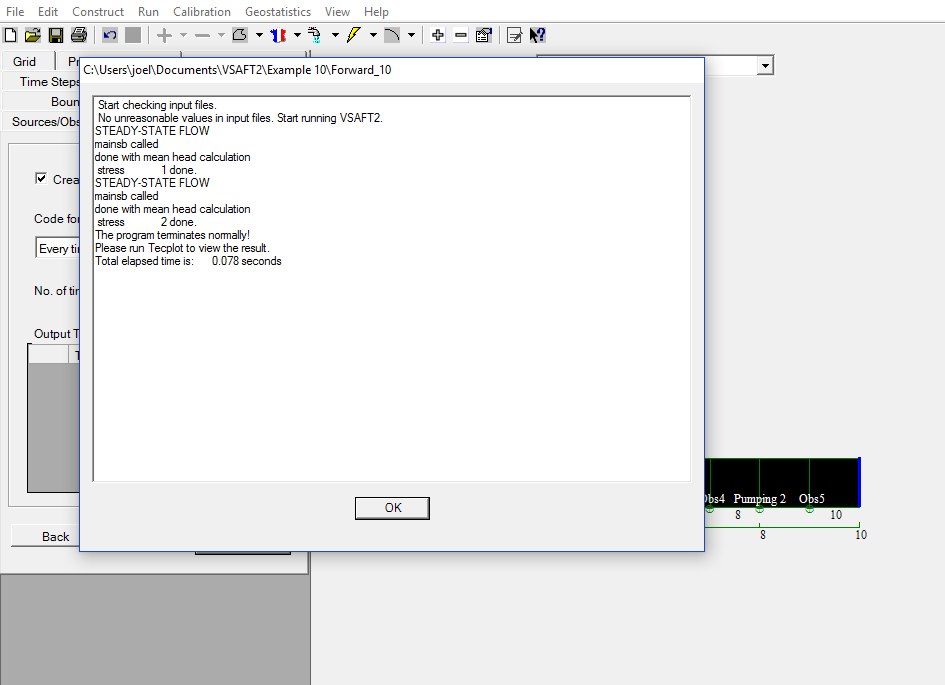
1. Output Control

* Keep all default
* Choose **finish save as** to save the project as **forward\_10**.



1. Running VASFT**2**

* Select **RUN** and then **VSAFT2**
* When finished the screen should look like the picture on the next page.

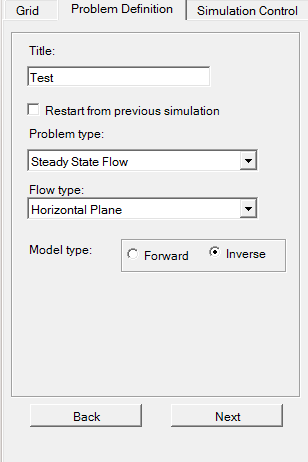


**Part 2: Using well data from part one in an inverse model:**

1. Problem Definition

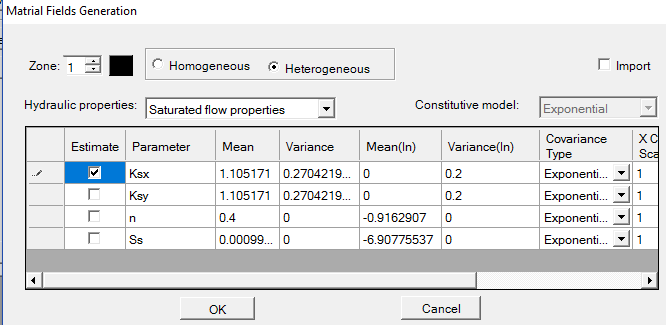
After running part one, keep the project loaded.

* Select tab **Problem Definition**.
* Check **Inverse** in the model type.
* Then select the **Materials** tab.



1. Material

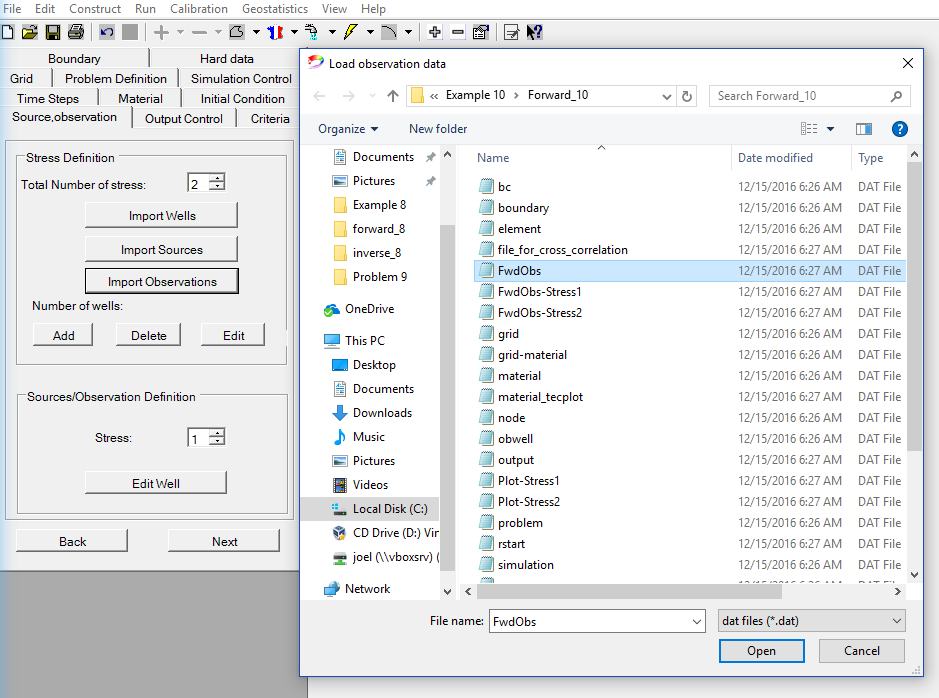
* Select the **Material** tab.
* Click **Define,** located in the Zone material properties section. A window, like the one shown below, will open.
* Under the Estimate section, select the checkbox next to Ksx. Since we are modeling a steady state saturated flow problem, we can only estimate Ksx.
* Make sure the parameters not being estimated from the part 1 are the same (they should be).
* Select **OK.**
* Now select the **Source.observation** tab.



1. Source, observation

Now we can import the observed head generated by the synthetic test.

* Click **import** **Observations** in the Stress Definition area.
* Find the location of the file **FwdObs.dat** located in the Forward\_10 folder generated from part 1.
* Select **Open**, to import the data.

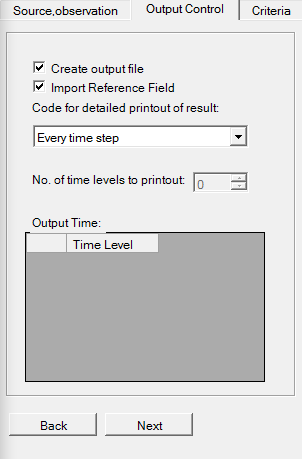


You can check whether the data is correct or not by the following procedure:

* Select **Edit Well** under the Sources/Observation Definition section and then click any of the observation well.
* A new window will open. Select the **Observation** tab and notice the fields are now populated with observational data from the forward model in Part 1.
* Select **Ok.**
* Next change the Stress in the Sources/Observation Definition section to **2**.
* Select **Edit Well** under the Sources/Observation Definition section and then click the same observation well you selected before.
* A new window will open. Select the **Observation** tab. You will notice that for stress 2 the observation fields have changed based off of measurements calculated from running pumping well 2 as opposed to pumping well 1.
* Select **Next** to continue to Output Control tab.

1. Output Control

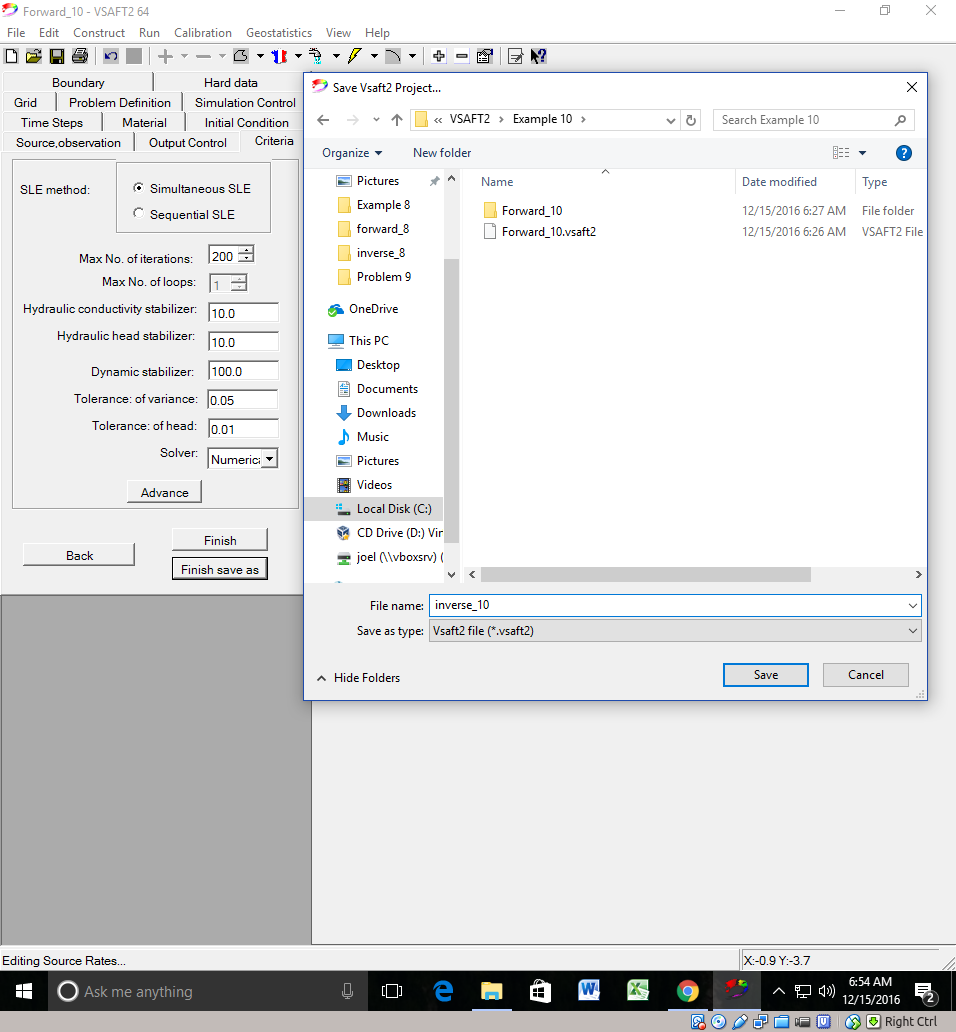
* Make sure the **Create output file** box is checked.
* Select **Import Reference Field** and a popup box will be displayed.
* Find the location of the file, **material.dat** located in the “Forward\_10” folder generated from part 1.
* Select **Open** to import the data. This will allow us to compare data from the forward problem to the results generated in the inverse problem.
* leave the other defaults
* Click **Next** to continue to the “Criteria” tab.



1. Criteria

The Criteria tab is used to define the parameters used for the parameter estimation.

* For this example, we will keep all the parameters as default.
* Choose **Finish** **Save as**.
* Save the file as **Inverse\_8**



1. Running VASFT2

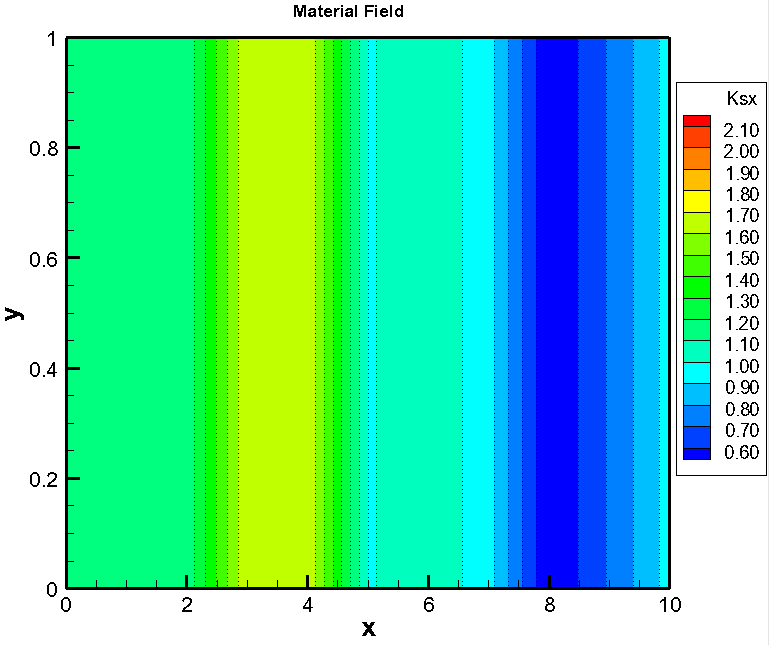
* Select **RUN** and then **VSAFT2**

The program will run SSLE to estimate the unknown Ks values.

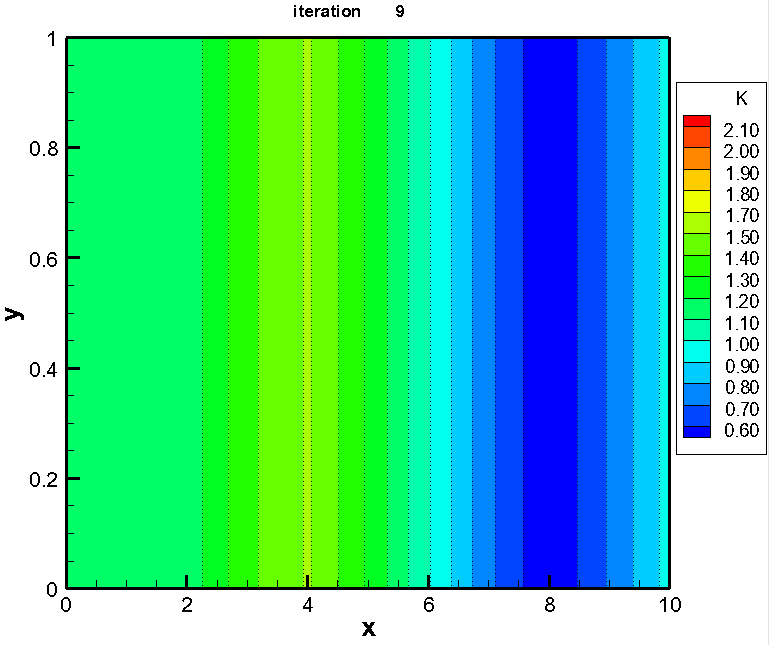
1. View results

* You can compare the results in the same procedure outlined in example 8 and 9.

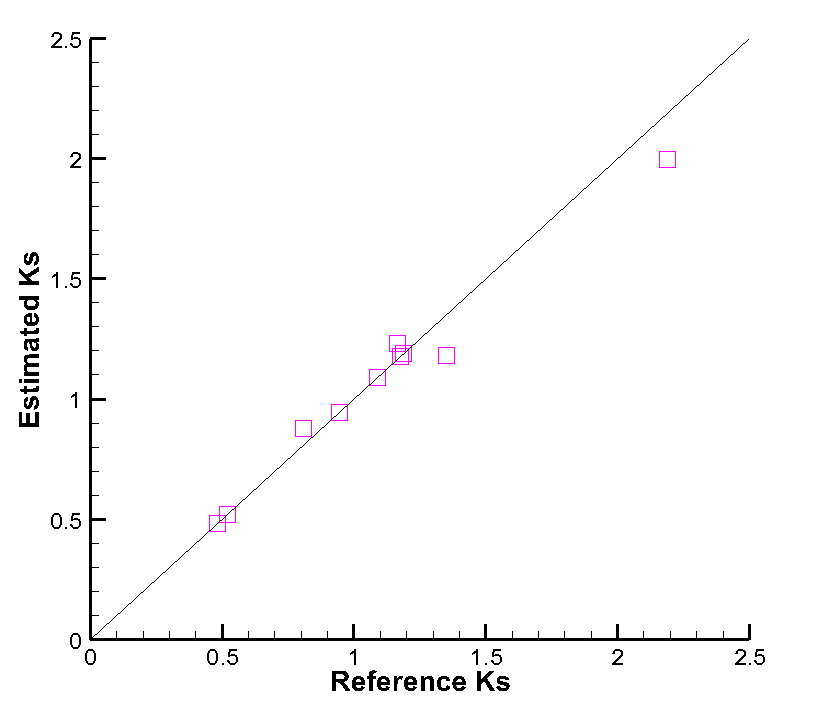
This is the Hydraulic conductivity contour diagram from part one:



With the tomographic test, the estimated result is better than the Ill-Posed one dimensional test in Example 9.



Following the procedure described in “Example\_8”, we can produce an X-Y plot comparing the hydraulic conductivity at each observation well calculated by the inverse solver and the actual hydraulic conductivity generated by the forward problem.



Like the two hydraulic conductivity field maps produced above; there are some small variations between the estimated hydraulic conductivity and the reference hydraulic conductivity. With the additional information provided by the two pumping tests, the inverse solver was able to calculate a better estimation of hydraulic conductivity then in the ill-posed problem of example 9.