Geomodelling for Reservoir Engineers

Builder V.2020.10

BUILDER

Tutorial

Geomodelling for Reservoir Engineers

This tutorial will provide steps for building a simple reservoir 3D model using the features available in Builder. It will also show how to use the geostatistical tools for populating the 3D grid with porosity and permeability values. The tutorial aims at making the user more familiar with the options available in Builder for the purpose of building and editing geological models.

A Black-Oil IMEX dataset with metric units well be used for this tutorial. Predefined fluid components and rock-fluid data have been created as a starting point for the model build. For interested users, the steps of loading the Rock Fluid and PVT data can be found in the Introduction to CMGs Modelling Workflows material and will not be repeated in this class.

Loading Basic Dataset in Builder

1. In Launcher drag and drop the **"Tutorial_Start.dat"** file from the *Required Data* folder onto Builder.

Building the Top of the Reservoir

Loading Well Trajectories

The first step in importing the well markers is to load the well trajectories. The tops and the well logs will be loaded at a later step in the tutorial.

1. Click on **Wells & Recurrent | Well Trajectories | Well Trajectories**. This will open the **Import well trajectory wizard**

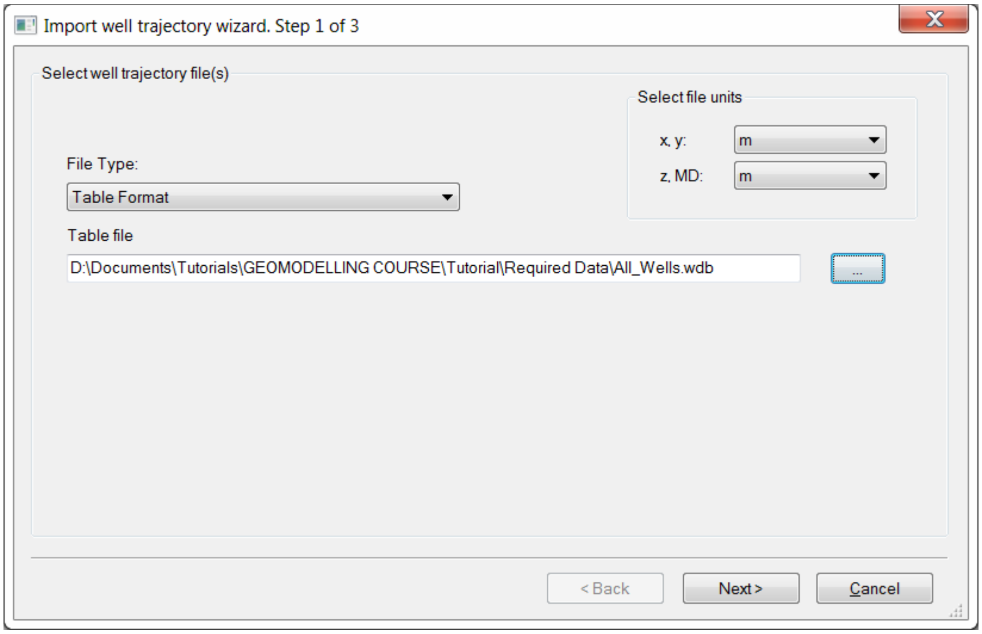


Figure 1: Importing Well Trajectories

2. Select the **Table Format** for the file type and navigate to find "**All_Wells.wdb**". The units will automatically be set to "**m**"

3. Click ***Next*** twice and the ***Finish*** button to close the dialog

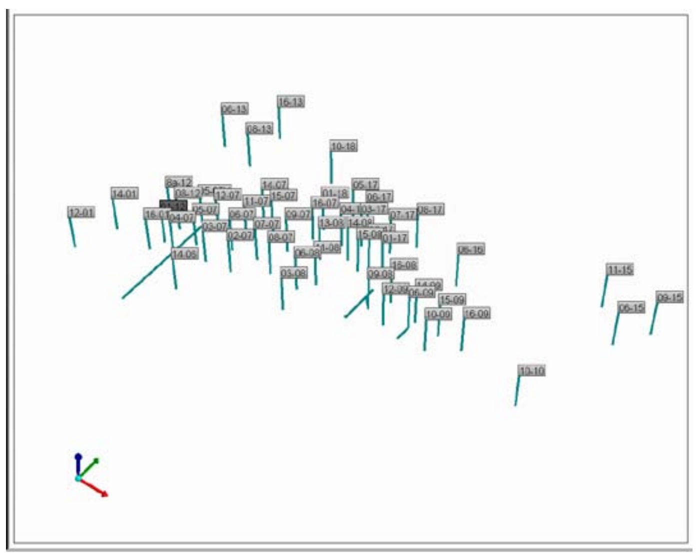


Figure 2: Well Trajectories in 3D view

Importing Top Data

1. Click on **Wells & Recurrent | Well Trajectories | Import Formation Top File**

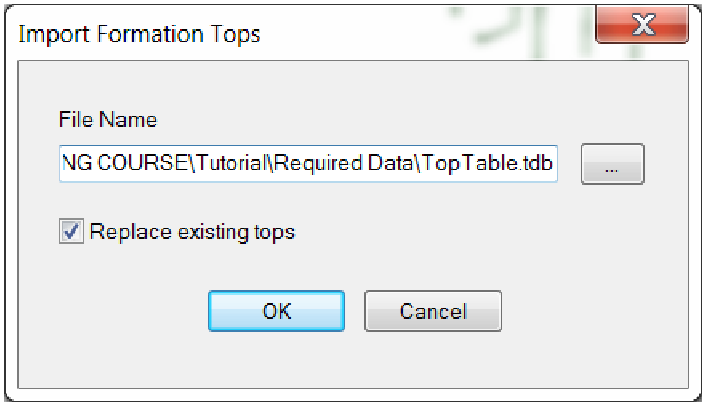


Figure 3: Importing Formation Top Data

2. Select the file "**TopTable.tdb**". Click ***OK*** to close the dialog

   Note: Well tops will automatically be displayed as small red disks on each well. Sometimes the disks are too small for good visualization. The size of the disks can be increased in the Properties menu.

3. Right click and choose **Properties** from the list
4. Navigate to **Wells | Well Trajectory Tops** and adjust the disk size

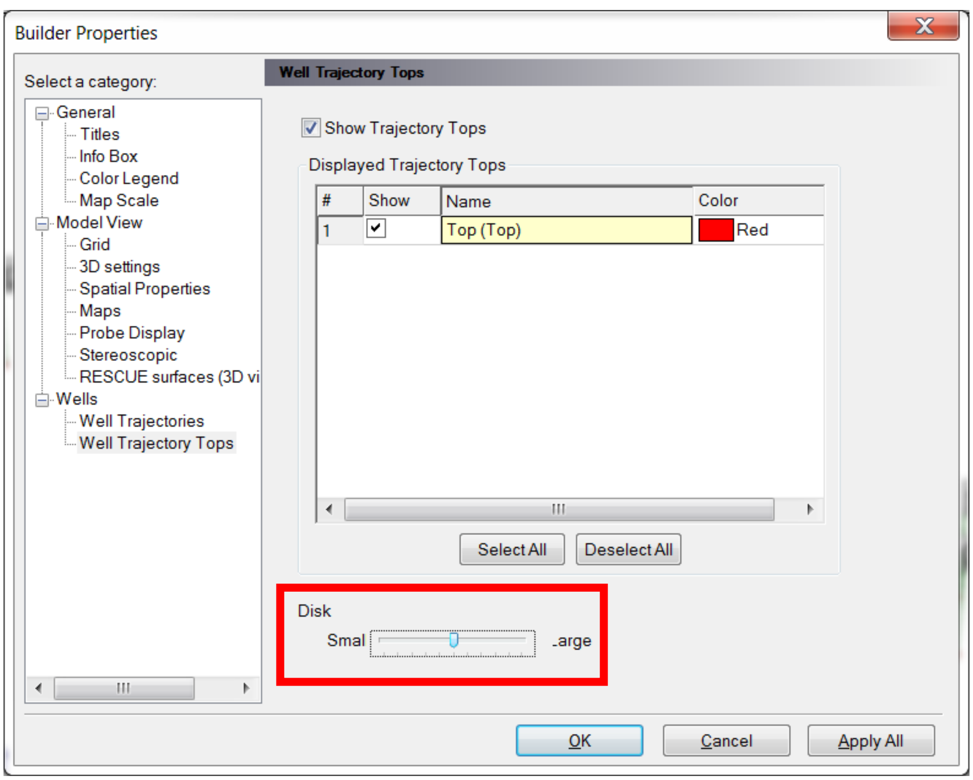


Figure 4: Changing Well Tops Size

5. Click ***OK*** to close the Properties menu. The disks will appear bigger as shown below

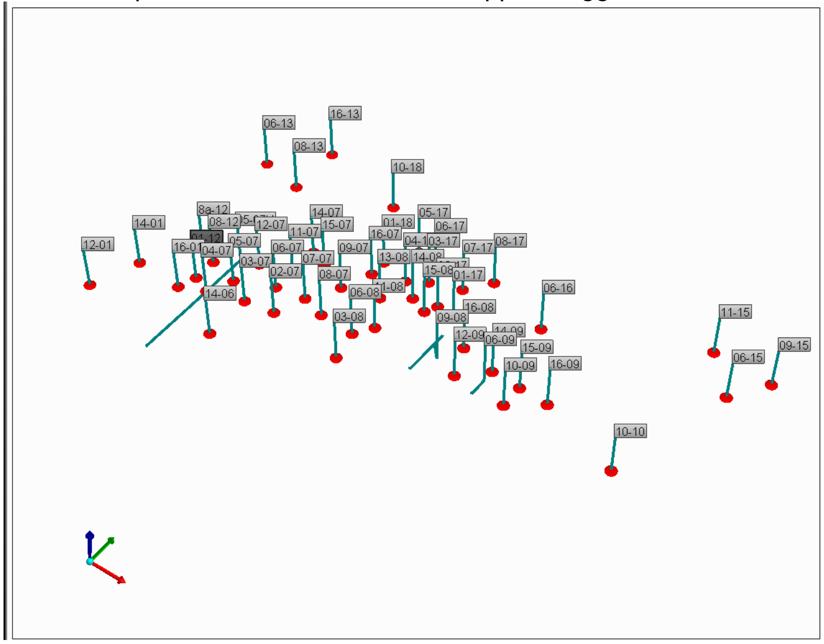


Figure 5: Well Trajectories and Tops in 3D View

Creating a Top Map

1. Navigate to **File | Create Map File** to bring up the **Create Map** dialog

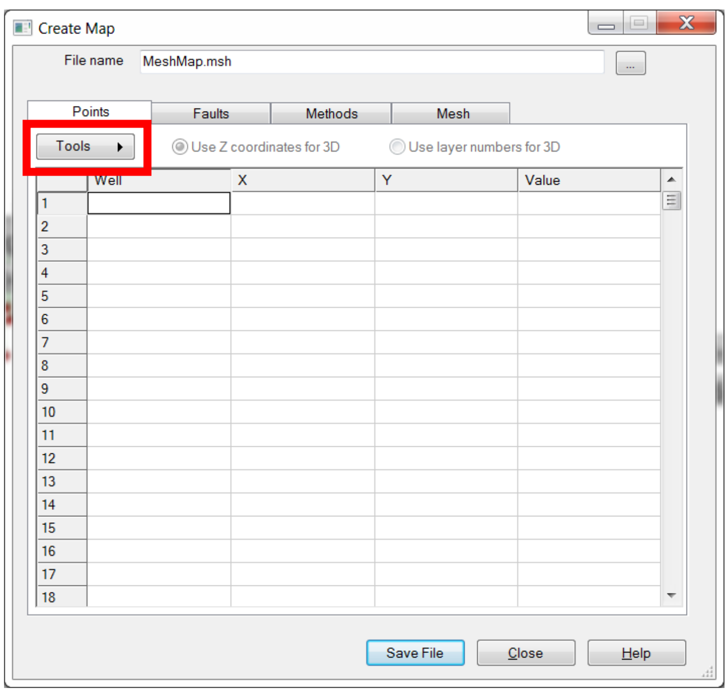


Figure 6: Creating a Top Map

1. Click on **Tools | Import Tops from Trajectories**

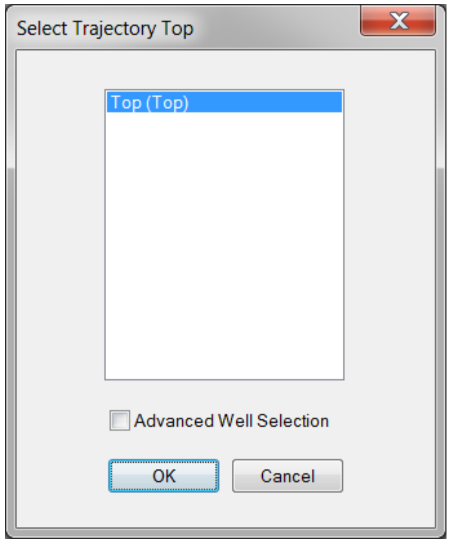
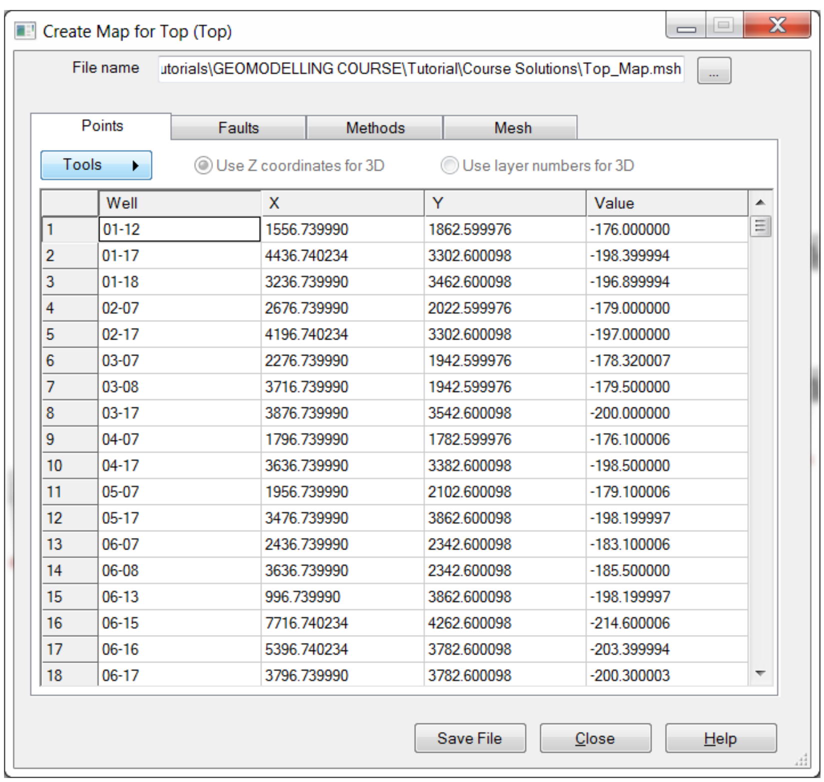


Figure 7: Importing Tops from Trajectories

2. The top file opened previously will already be selected. Click ***OK*** to close the window.
3. Browse to the desired save location using the  button and change the name of the file to **"TOP_Map.msh"**



	Well	X	Y	Value
1	01-12	1556.739990	1862.599976	-176.000000
2	01-17	4436.740234	3302.600098	-198.399994
3	01-18	3236.739990	3462.600098	-196.899994
4	02-07	2676.739990	2022.599976	-179.000000
5	02-17	4196.740234	3302.600098	-197.000000
6	03-07	2276.739990	1942.599976	-178.320007
7	03-08	3716.739990	1942.599976	-179.500000
8	03-17	3876.739990	3542.600098	-200.000000
9	04-07	1796.739990	1782.599976	-176.100006
10	04-17	3636.739990	3382.600098	-198.500000
11	05-07	1956.739990	2102.600098	-179.100006
12	05-17	3476.739990	3862.600098	-198.199997
13	06-07	2436.739990	2342.600098	-183.100006
14	06-08	3636.739990	2342.600098	-185.500000
15	06-13	996.739990	3862.600098	-198.199997
16	06-15	7716.740234	4262.600098	-214.600006
17	06-16	5396.740234	3782.600098	-203.399994
18	06-17	3796.739990	3782.600098	-200.300003

Figure 8: Create Map Dialog with Populated Values

4. Select the **Methods** tab and change the Calculation method to **Ordinary Kriging (OK) Estimation**

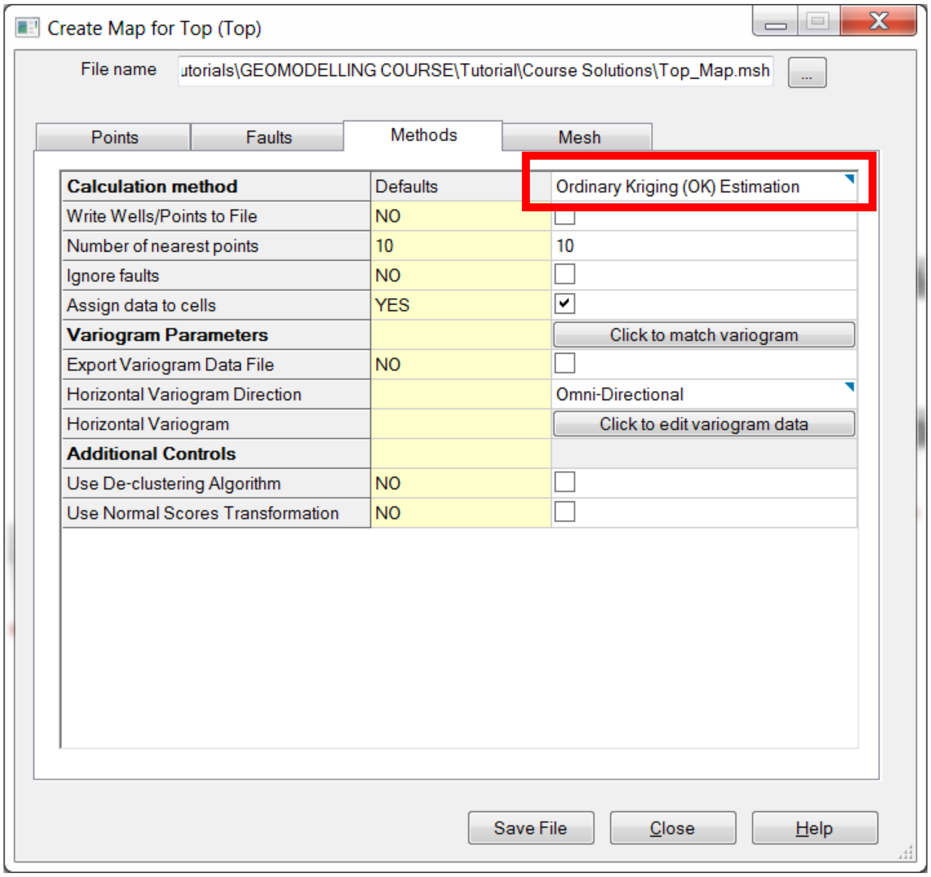


Figure 9: Create Map Dialog with Methods Tab and Ordinary Kriging

5. Make sure the **Assign data to cells** option is checked

Checking for Anisotropies

Note: Variogram calculations are done by pairing data points and looking at the difference between the values. This can be done for a given direction or for all directions lumped together. The latter is called an omni-directional variogram and is used when data points are scarce or when no spatial anisotropy is present. If there is enough data, directional variograms should be computed to explore for possible anisotropies. Computing and modelling variograms in different directions allow us to account for possible anisotropy in the spatial correlation between the data.

When investigating anisotropy a control parameter for the Principal Axis Azimuth Angle and a second control parameter to edit the variogram (in a perpendicular direction) will be added to the options in Builder. The Principal Axis Azimuth Angle is assumed to correspond to the direction of the major axis of the anisotropy ellipse. This is expected to be the direction of maximum continuity (or correlation) in the data.

1. Select the **Bi-Directional** option from the *Horizontal Variogram Direction* pull-down list.

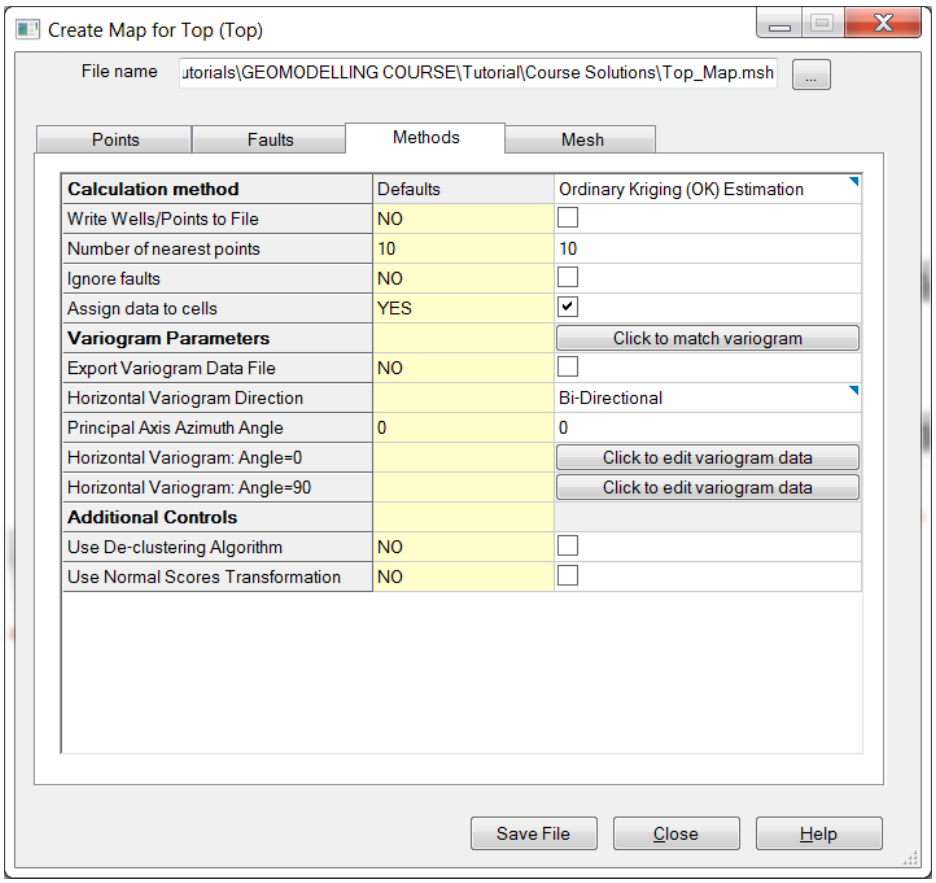


Figure 10: Selecting Bi-Directional Variogram

2. Click on the ***Click to match variogram*** button which will compute the variogram for the given directions and find a best match with the variogram models available in Builder

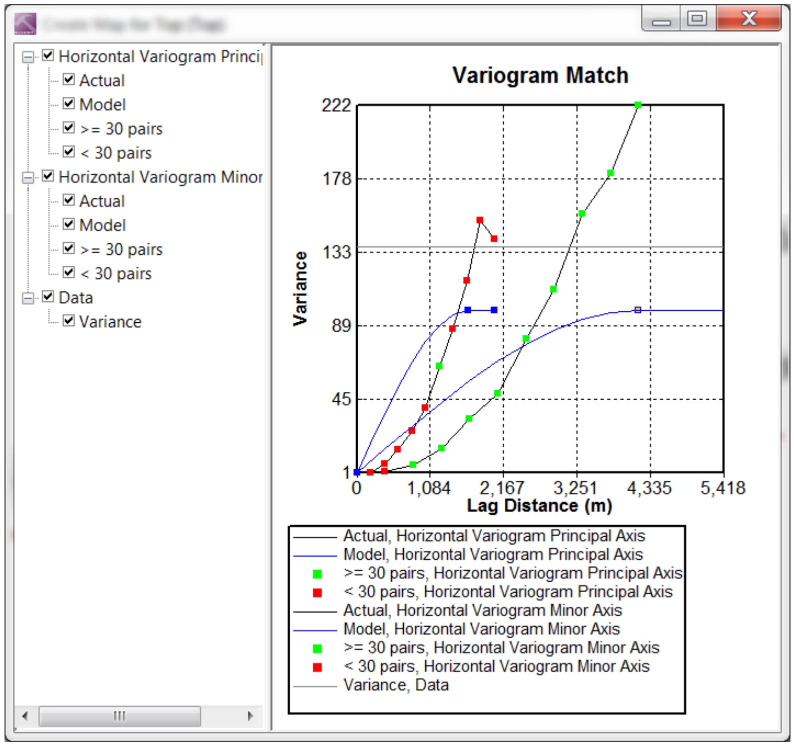


Figure 11: Variogram for Top Map

Note: The plot shows four variogram curves; actual empirical variogram curves computed for each direction (black lines) and the variogram model (blue lines) automatically fitted to the empirical variogram curves. The empirical variogram data points are computed for different lag distances which are marked with green or red small squares. The green data points identify values that were calculated with at least 30 pairs of data points. These data points carry enough statistical mass to be considered as significant. The red points have been computed with less than 30 pairs of data and their variance level (y-axis) may not be less reliable. Attention should be focused on the green points when matching the model curves to the empirical data points.

The horizontal gray line indicates the level of the data variance. In absence of trends in the data, the variograms should level off at (or around) the data variance level. When a trend is present, the variogram will continue increasing above the data variance line. Very strong trends should be removed before the use of interpolation methods. However, trends are usually a matter of scale. Very often, it is correct to consider that there is no trend in the data if we confine the interpolation to a small window around each of the interpolation locations. In such cases, the variogram function needs to be matched only for distances smaller or equal to the search window.

Editing Variogram Data

1. Close the variogram plot window and click on the ***Click to edit variogram data*** button for the *Horizontal Variogram: Angle = 0*.

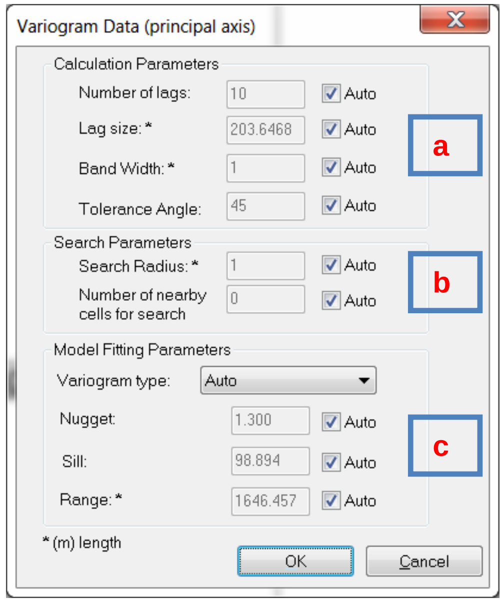


Figure 12: Defining Variogram Data

<u>*Note*</u>: The dialog is divided into three sections

a. Calculation of the empirical variogram data points at various lag distances
b. Search parameters (used only at the interpolation time)
c. Variogram Model fitting.

2. Select **Gaussian** under *Variogram type* and click ***OK*** to close the window
3. Click *the* ***Click to match variogram*** button to redisplay the variogram plot
4. With the new Variogram type, adjust the model by dragging the handles (blue curve) to achieve the best possible match. A match may look similar to the plot below:

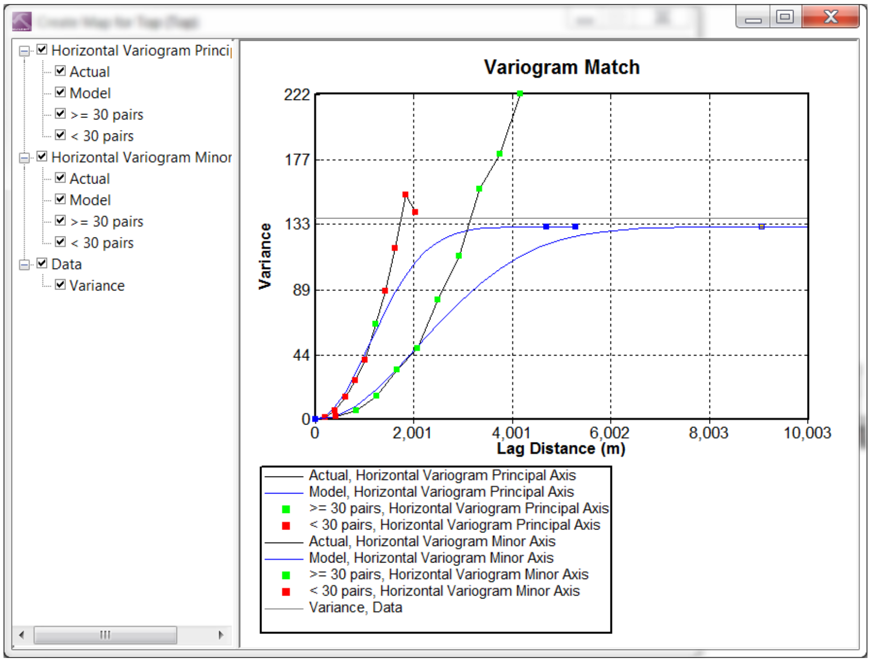


Figure 13: Matching Variogram for Tops

Note: The variogram can be considered matched. Notice the variogram matches the actual curves for a lag distance up to about 2500m. This information will be considered again when defining a search window for the data interpolation.

5. Close the variogram plot.

Defining Search Window

1. Click on the ***Click to edit variogram*** *data* button for the *Horizontal Variogram: Angle=0*
2. Uncheck the **Auto** option for the Search Radius and input a value of **2500**. This is the limit of validity previously observed from our variogram match

Note: No matter how large the search window is defined, the maximum number of data used for calculating an estimated value at any location is actually controlled by the *Number of nearest points* option on the Methods tab

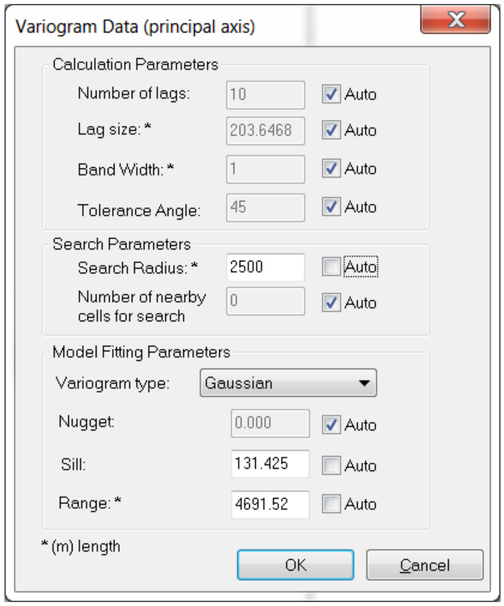


Figure 14: Editing the Horizontal Variogram Data

Note: **WARNING**: Notice that the variogram range (4691 m; values may vary depending on variogram fit) is fairly large in comparison to the distances between the wells. This will likely create issues with the Gaussian variogram type. It is well documented that the Gaussian Variogram model can generate numerical instabilities in such situation. These numerical instabilities will translate as erratic behavior in the contour lines of the interpolated surface. Very often, geostatisticians will add a very small nugget effect to the Gaussian Variogram to avoid numerical instability. In this case, it is suggested to add a nugget effect of 2 which is small enough to not change the variogram fit, yet enough to remove numerical instabilities when solving the kriging equations. It should also be noted that only the Gaussian variogram model requires such attention

3. Change the **Nugget** to **2**
4. Click ***OK*** to close the variogram data dialog and open the *Horizontal Variogram: Angle=90* data window and change the Search Radius for the second horizontal variogram direction to be **2500** m.

Kriging the Top Surface

1. Click the **Save File** button to perform the kriging interpolation and save the results as a mesh file. The kriged map will be displayed similar to the image below:

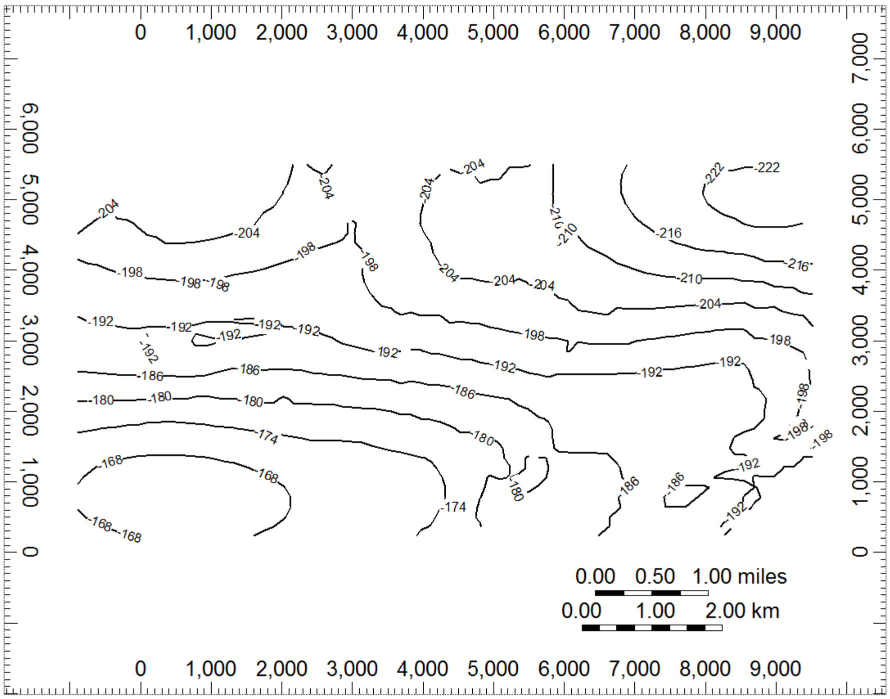


Figure 15: Top Map for Reservoir

Note: The map has been automatically meshed by using the default parameters in the Mesh tab of the Create Map window. These parameters can be changed to refine or coarsen the meshing. The interpolated map should cover the same area as the simulator grid which will be created.

Building the Simulation Grid

Grid Definition

1. If no maps are currently displayed in Builder's main view, navigate to **File | Open Map File** and select the top map created in the previous steps - this helps to correctly position the simulation grid
2. Navigate to **Reservoir | Create Grid | Orthogonal Corner Point** to display the grid creation window
3. Define the grid with the values shown below:

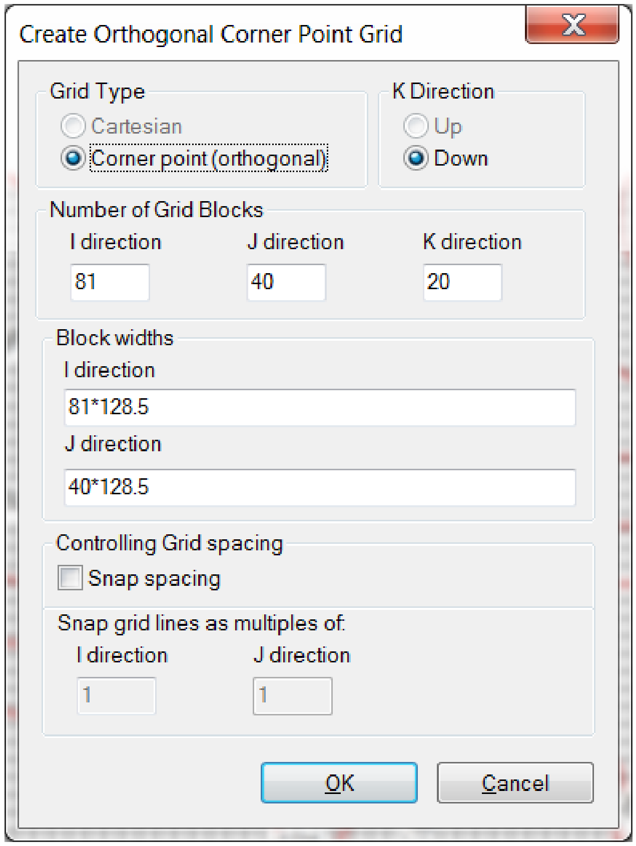


Figure 16: Orthogonal Corner Point Grid Definition

Note: For an exact match with the previous maps, the grid definition can be found in the header of the previously computed mesh maps if viewed in a text editor.

4. Click ***OK*** to construct a grid

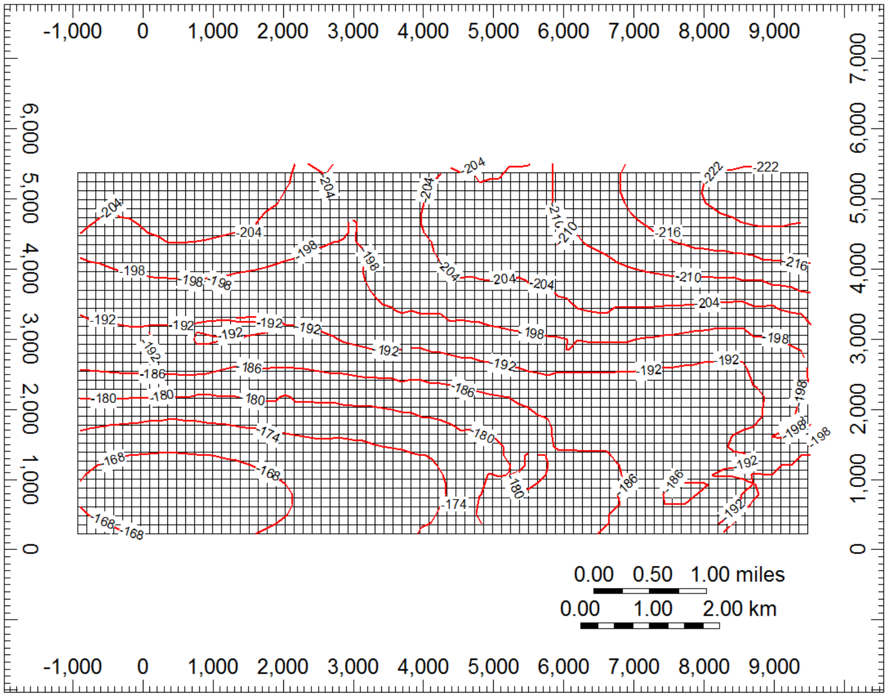


Figure 17: Top Map with Grid Defined

5. *Optional Step*: The grid can be shifted (hold **Shift** + **left** mouse button) or rotated (hold **Ctrl** + **left** mouse button) to align the grid with the displayed map
6. Click on the ***Probe*** button to leave the editing grid mode

Corner Point Calculation

1. Click the Specify Property button on the View Control tool bar
2. In **Layer 1** under the **Grid Top** property, ***right click*** and select **Geological Map** to display the Property Selection window
3. Click the ***Values in file1*** button and navigate and select the "**Top_Map.msh**" file

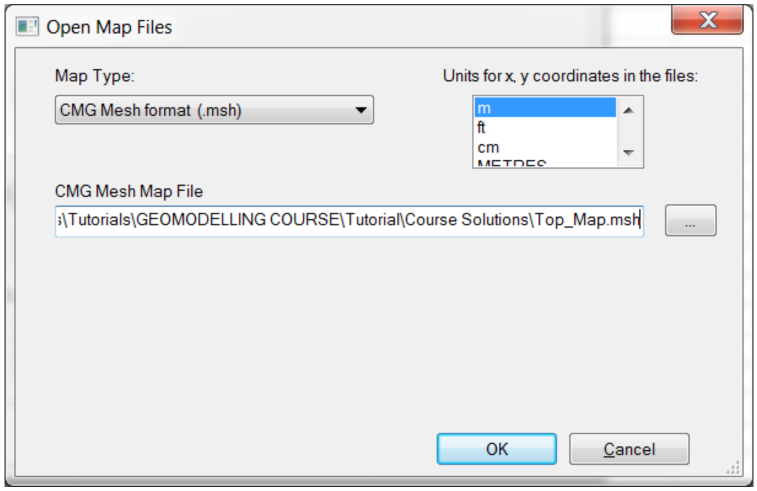
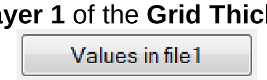


Figure 18: Selecting Map Type and File

4. Click ***OK*** to close the dialog

   Note: A predefined thickness map of the reservoir has been defined. This will be assigned to the grid and subdivided by the number of vertical layers

5. Select **Layer 1** of the **Grid Thickness** property, right click and select **Geological Map**
6. Click the 

 button and navigate to the Required Data folder and select the **Thick_Map.msh**
7. Change the edit box to the right of times from 1 to **0.05**. This is the multiplier used to split the thickness over all the 20 layers, each layer having one twentieth of the total thickness

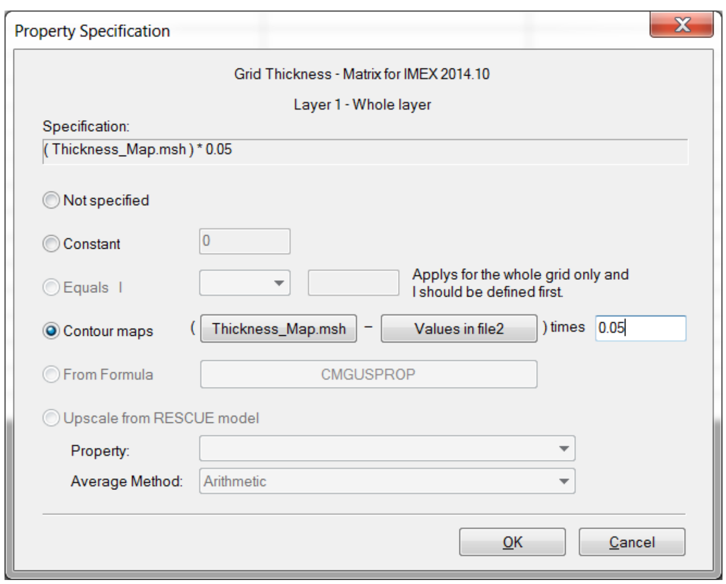


Figure 19: Specifying Map File for Thickness Property

8. Click ***OK*** to close the dialog
9. Copy the **Grid Thickness** specification of row **Layer 1** to all rows from **Layer 2** to **Layer 20** as shown below:

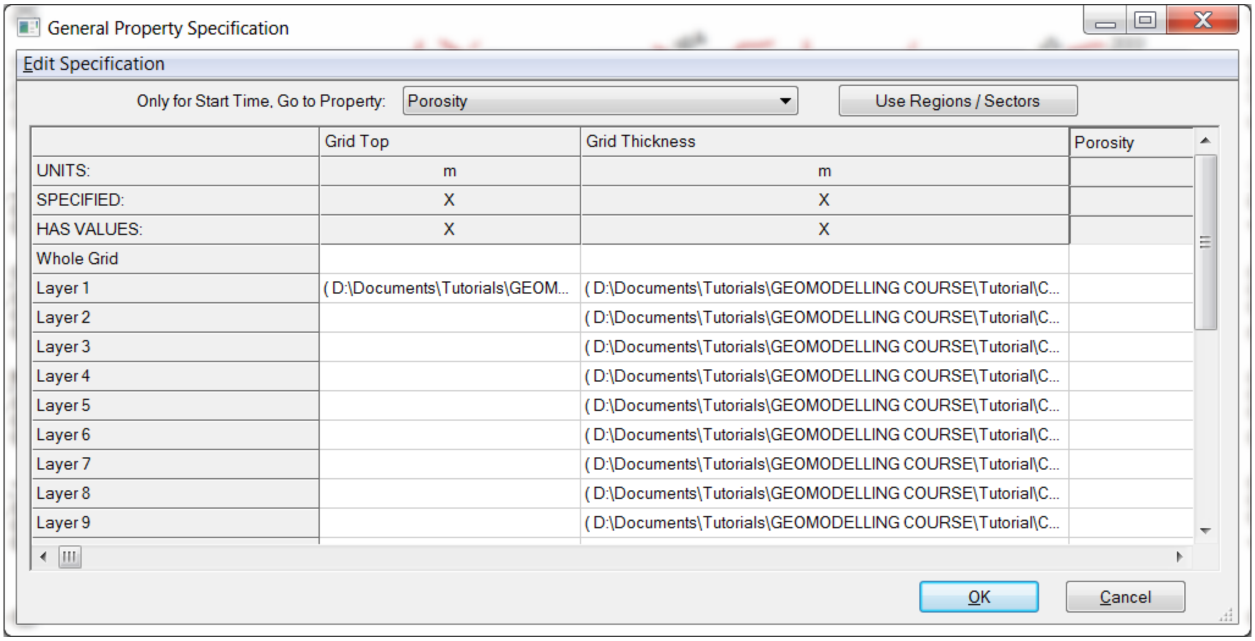


Figure 20: Grid Thickness Definition

10. Click ***OK*** to close the dialog and click ***OK*** to the next dialog to actually compute the corners of the grid

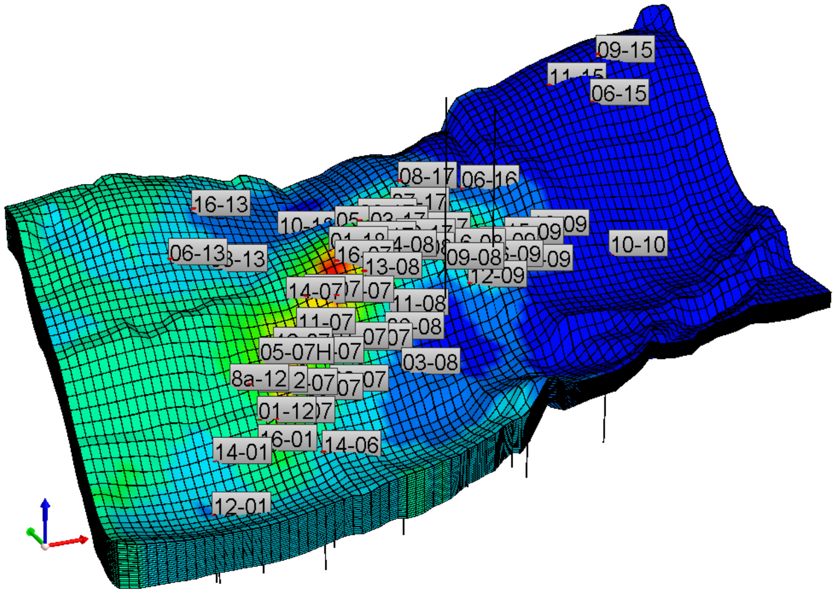


Figure 21: 3D View of the Simulator Grid and Thickness Property

11. Navigate to **File | Save As** and save the dataset as **Geomodel1.dat**

Populating Simulation Grid with Porosity Values

Geostatistical Objects

1. Click on **Reservoir | Geostatistics** to bring up the geostatistics dialog
2. Click the  button select **New (default)**
3. Input the name **PoroSim** for this geostatistical object
4. Click ***OK*** to accept the name
5. Select **Add New Custom Property** in the *Output Property* pull-down list

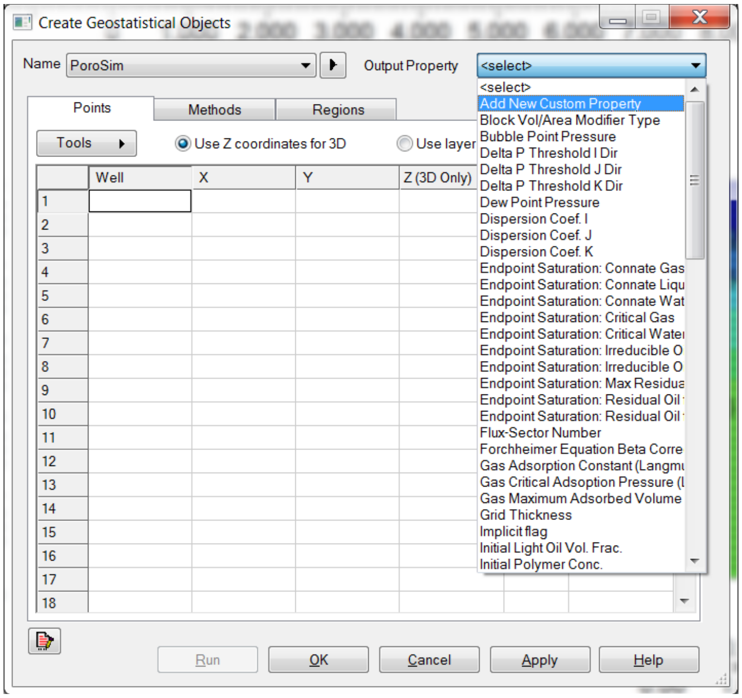


Figure 22: Geostatistics Dialog

6. Add the suffix **PoroSim** for the custom property name

   Note: The porosity values cannot be directly loaded into the Porosity property because the values are percentages instead of fractions. A formula will be used later to adjust the values

7. Click the ***Tools*** button and select **Import logs or tables of measured depth value** option

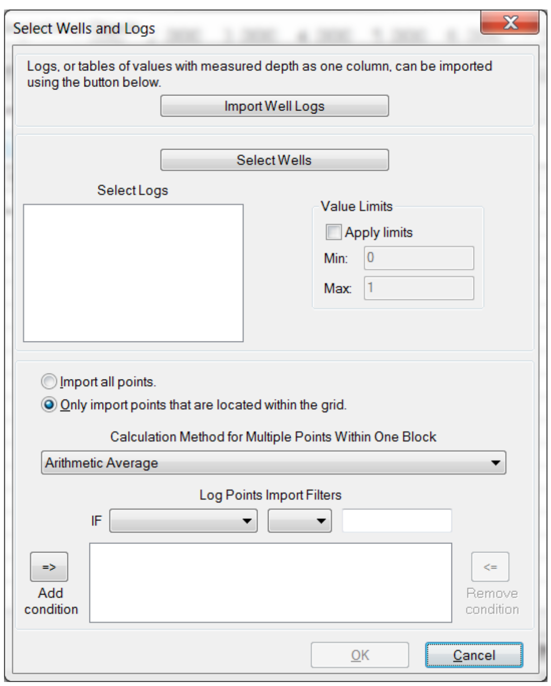


Figure 23: Importing Well and Log Information for Geostatistics

8. Click Import Well Logs to open a new dialog
9. Click Open File(s)... and navigate to the Required Data folder and select all the available LAS files

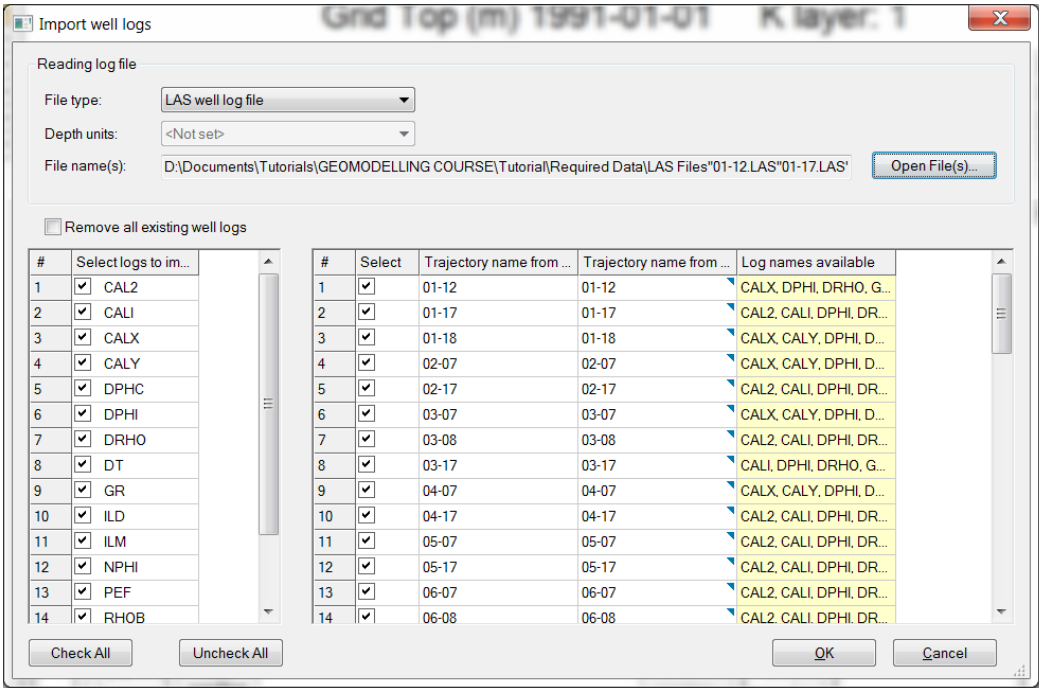


Figure 24: Imported LAS Information

10. Click ***OK*** to import all the logs and back to the Select Wells and Logs dialog
11. Click the Select Wells button
12. Click the >> button to select all wells and ***OK*** to close the dialog

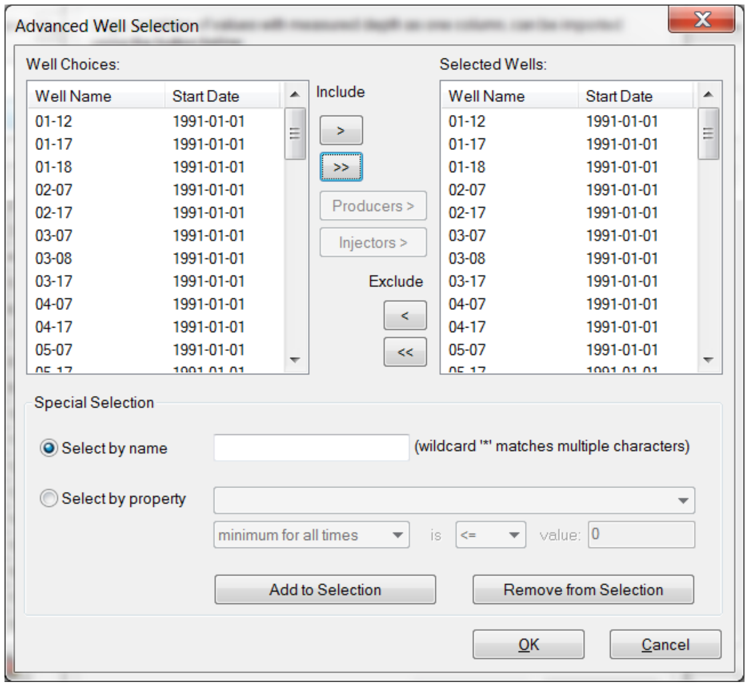


Figure 25: Advanced Well Selection dialog

13. Select the **DPHI** log and click ***OK*** to close the dialog. This will import the well log data and average the values if more than one point is located in the same grid block

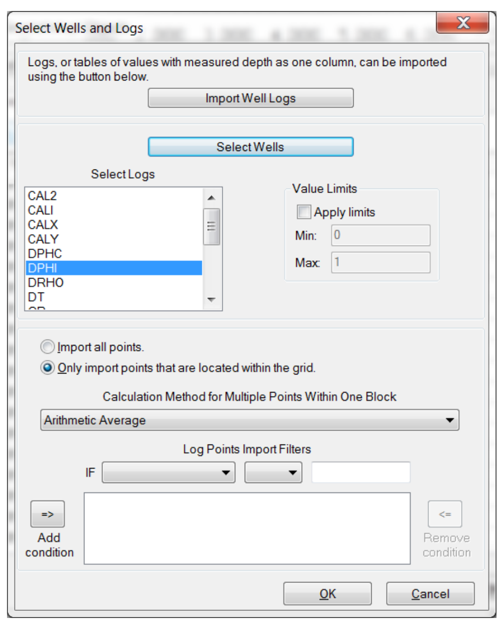


Figure 26: Selecting Specific Log

Geostatistical Method

1. Select the **Methods** tab

2. Change the Calculation Method to **Gaussian Geostatistical Simulation**

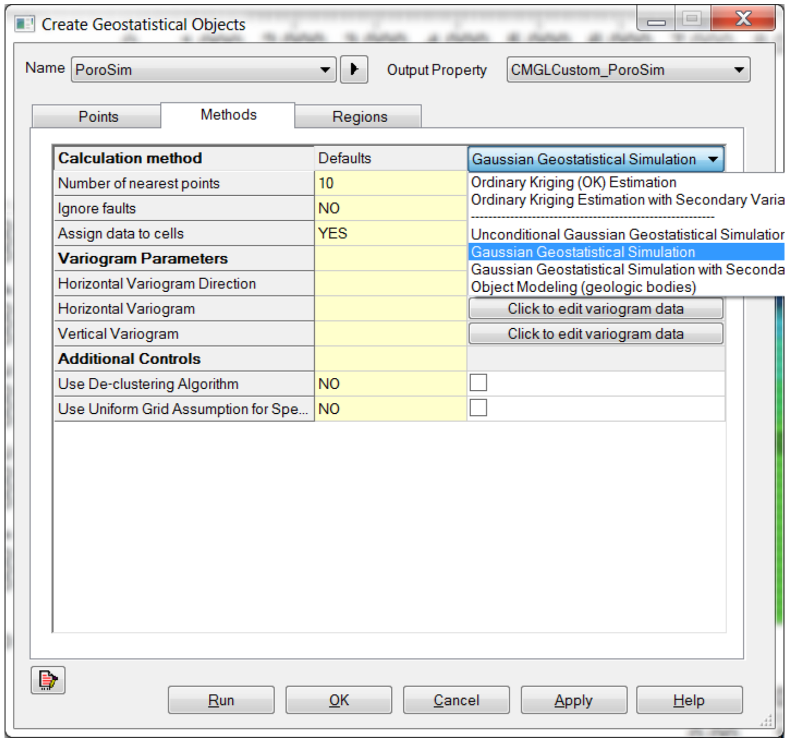


Figure 27: Selecting Gaussian Geostatistical Simulation

Note: Similar to Ordinary Kriging, Gaussian Simulation also computes an estimated value as a weighted average of the neighboring data with the weights based on a variogram model. Contrary to Ordinary Kriging, which only retains the weighted average, Gaussian simulation actually computes an error variance around the weighted average and uses it to simulate a value in the error bracket around the estimated average. Therefore, it is a simulation method as opposed to an estimation method. The simulated values will reproduce the data histogram and the variogram model used. The simulated values will also display a more heterogeneous pattern as oppose to an overly smooth pattern observed with Ordinary Kriging. The pattern obtained with simulation is closer to what is expected for a property such as porosity. Another advantage of simulation is that they can generate multiple versions of the porosity values on the grid. This allows for uncertainty analysis

3D Variogram Analysis

1. To investigate anisotropy, select the ***Bi-Directional*** option from the pull-down list of the Horizontal Variogram Direction
2. Click the ***Click to match variogram*** button

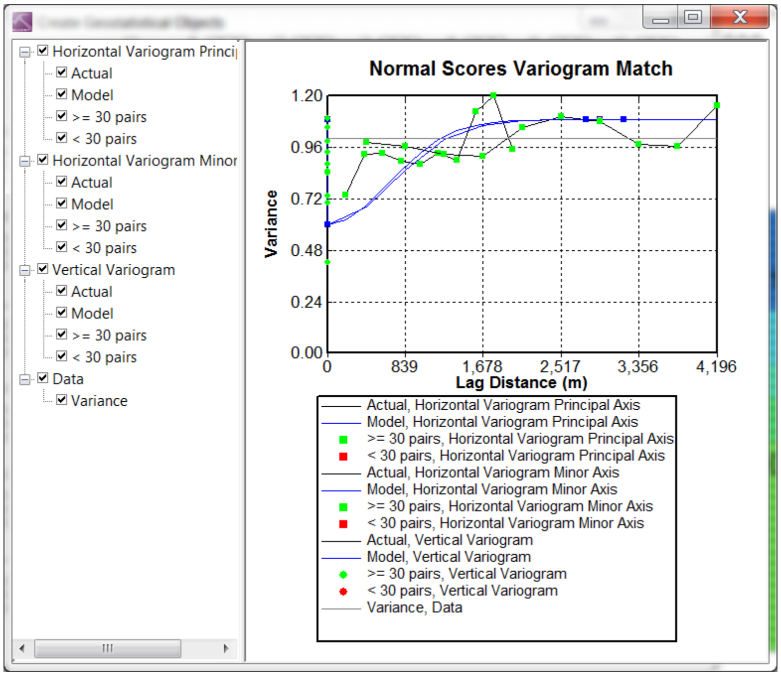


Figure 28: Variogram Plot for 3D Geostatistics Object

Note: The plot shows that the horizontal variogram looks similar in all directions (can verify further by changing the Principal Axis Azimuth Angle). The nugget effect appears to be quite high. Usually, the vertical variogram will give a better estimate of the nugget effect because the data values are closer to each other along the wells than between wells. Currently, the vertical variogram cannot be seen because its scale is much smaller than the horizontal variogram scale.

3. Deselect the horizontal variograms and the Data Variance in the tree view of the window

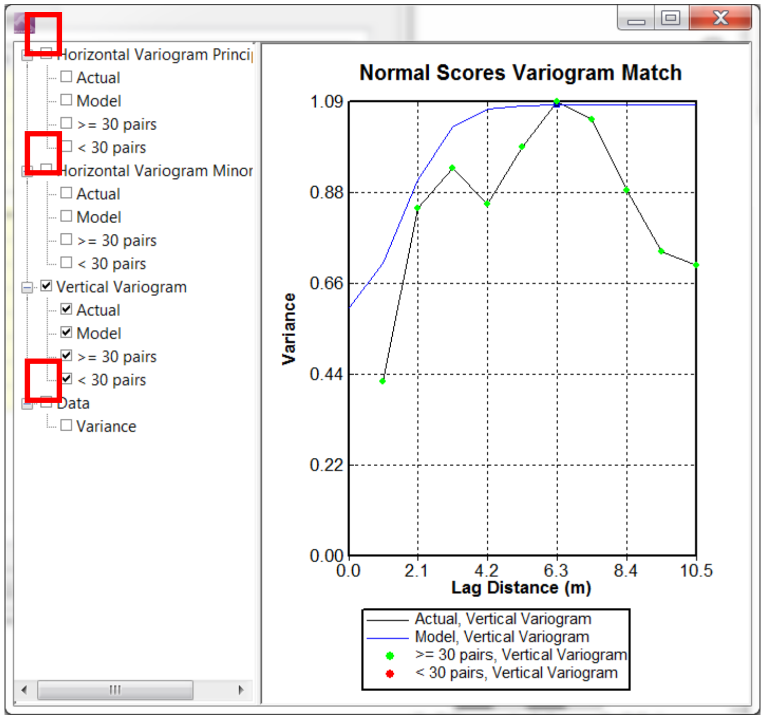


Figure 29: Vertical Variogram Plot

Note: By zooming in on the vertical variogram, it appears the nugget effect should be smaller. To adjust the nugget effect dynamically from the curve, the horizontal variogram needs to be re-selected. In this particular example, the vertical variogram component is very useful to fit the beginning of the variogram. The horizontal component is used to fit the variogram maximum level and possible horizontal anisotropies.

4. Enable the horizontal variograms and adjust the nugget to **0** using the handles on the model

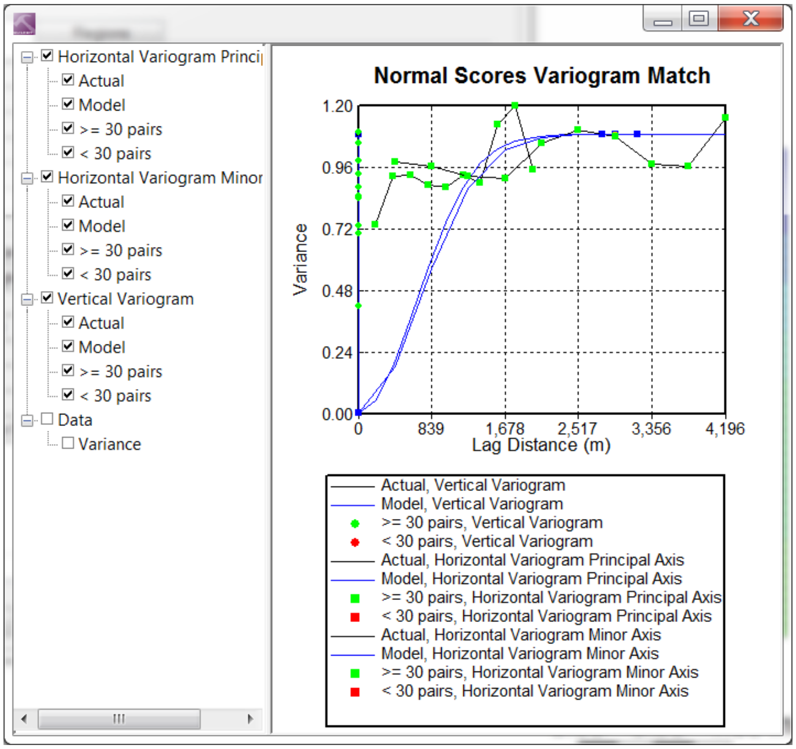


Figure 30: Variogram with Adjusted Nugget

Note: It can be seen that the automated model is most likely Gaussian model is most likely not the best fit for the empirical data. This should be adjusted.

5. Close the variogram window and change the Horizontal Variogram Direction back to **Omni-Direction** as there is no indication of anisotropy
6. Click [Click to edit variogram data]
7. Change the Variogram Type to **Spherical**

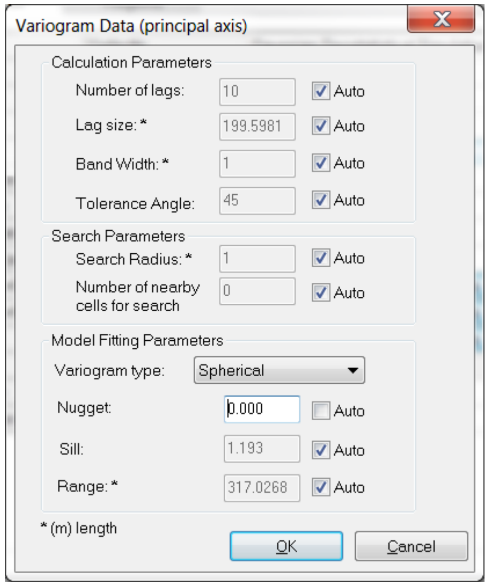
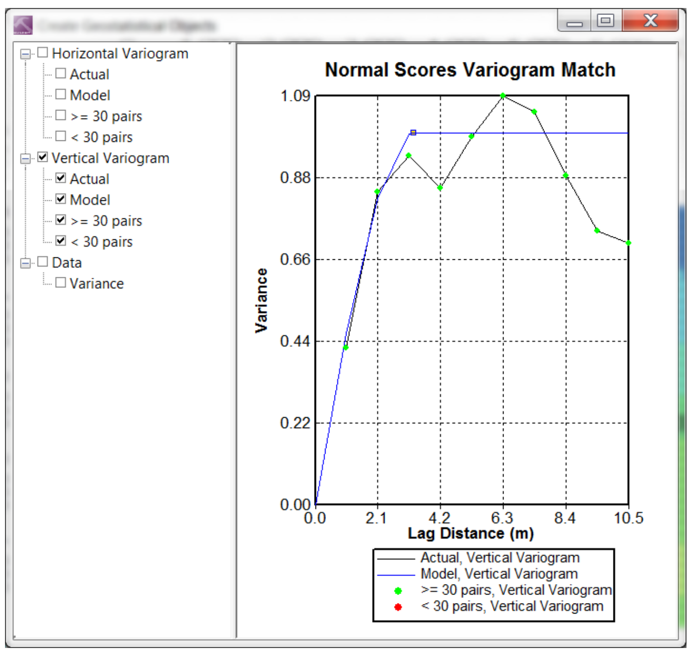


Figure 31: Selecting Spherical Model

8. Return to the Variogram plot and match the Horizontal and Vertical models



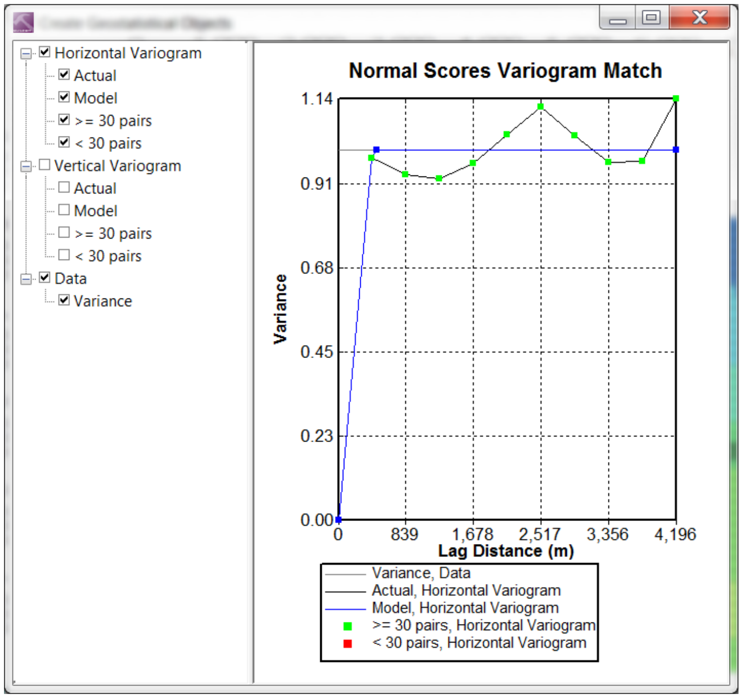


Figure 43: Vertical and Horizontal Variogram Plots

9. Close the Variogram window

Simulating Porosity

10. Click the 

button to actually create the CMGLCustom_PoroSim property. The results will be automatically displayed in Builder's main view when the calculations are finished.

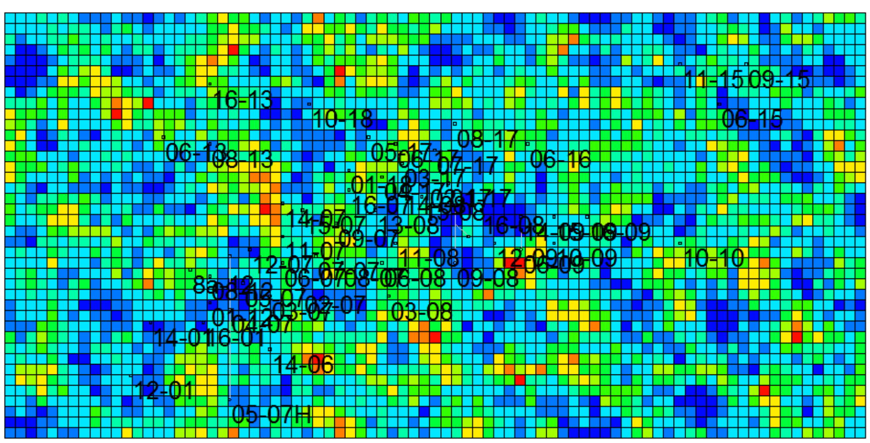


Figure 32: Porosity Property Simulated on the Simulator Grid

11. Click ***OK*** to save the newly created geostatistical object and close the dialog

12. Save the dataset

Creating Porosity Formula

Note: Since the porosity values from well logs are in percent, these will need to be converted to fractions in order to assign the property to the grid. This can be done using the Formula Manager in Builder.

1. Navigate to **Tools | Formula Manager**

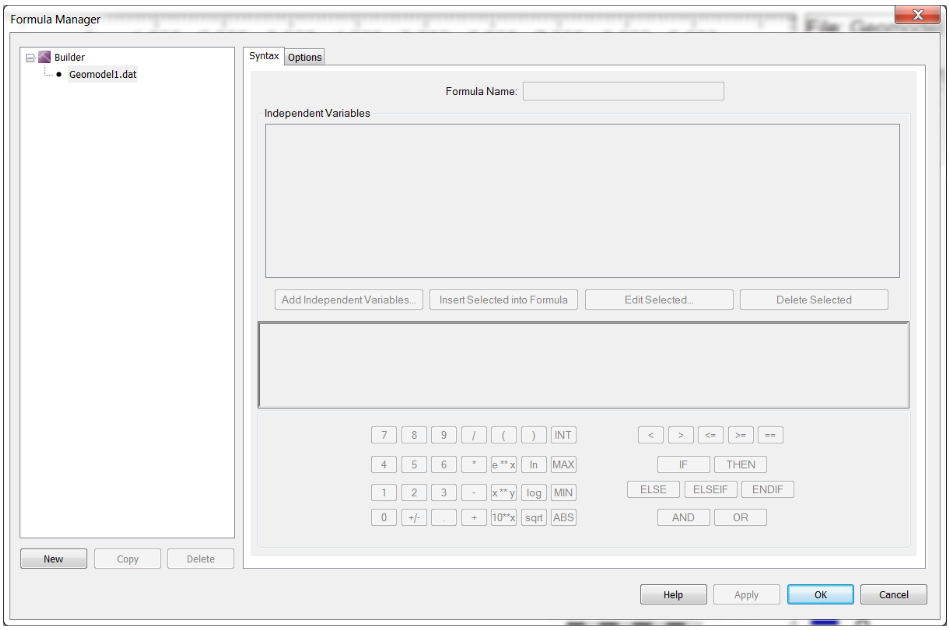


Figure 33: Formula Dialog

2. Click  and change the Formula Name to “**Porosity – Fraction**” under Formula Name
3. Click the ***Add Independent Variables*** button and select the **CMGLCustom_PoroSim** property

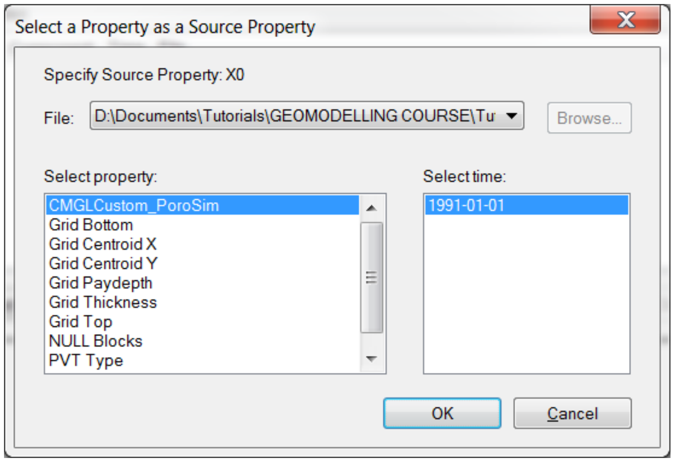


Figure 34: Selecting Source Property for Formula Specification

4. Click ***OK*** to close the window
5. Highlight the **X0** variable under Independent Variables and click the ***Insert Selected into Formula*** *button*
6. Type in the remained of the formula to divide the porosity by a value of 100

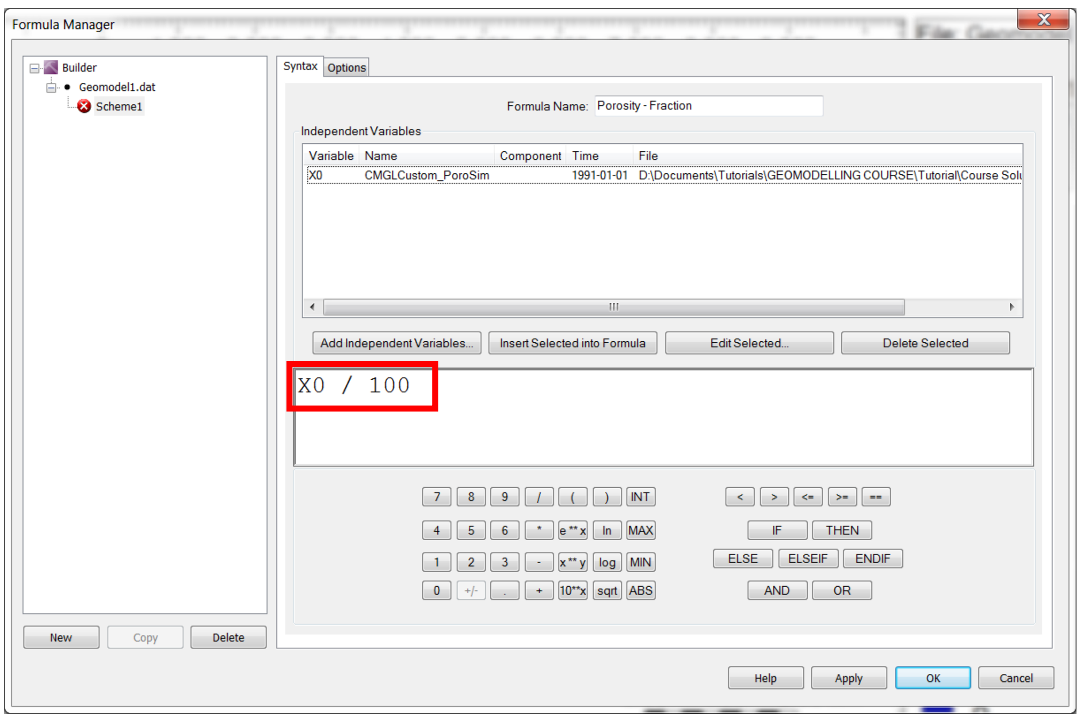


Figure 35: Formula Specification for Porosity

7. Click ***OK*** to exit and click ***YES*** and ***OK*** to the messages that appear

Creating Porosity Property from Formula

Note: If a correlation between Porosity and Permeability is determined, this can also be populated in the model using formulas. However, the Porosity values need to first be assigned to the grid blocks to use the equation for Permeability.

8. Click the ***Specify Property*** button on the view tool bar
9. Navigate to the **Porosity** property and right click on the cell for **Whole Grid** and select **Formula**

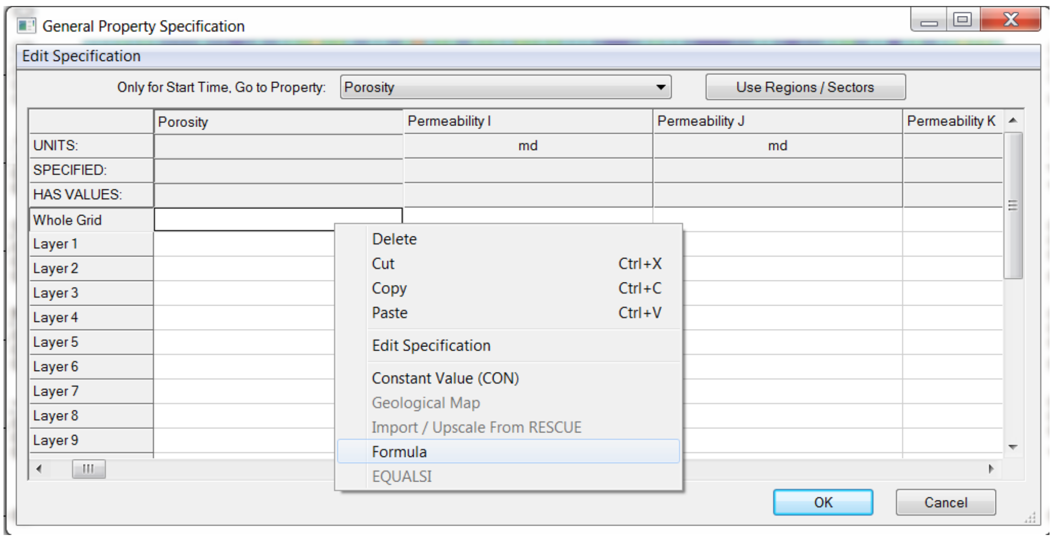


Figure 36: Specifying Porosity Property

10. Click the ***Formula*** button and select **the Porosity – Fraction** formula
11. Click ***OK*** twice to close the Formula Manager and Property Specification windows and to close the dialog.

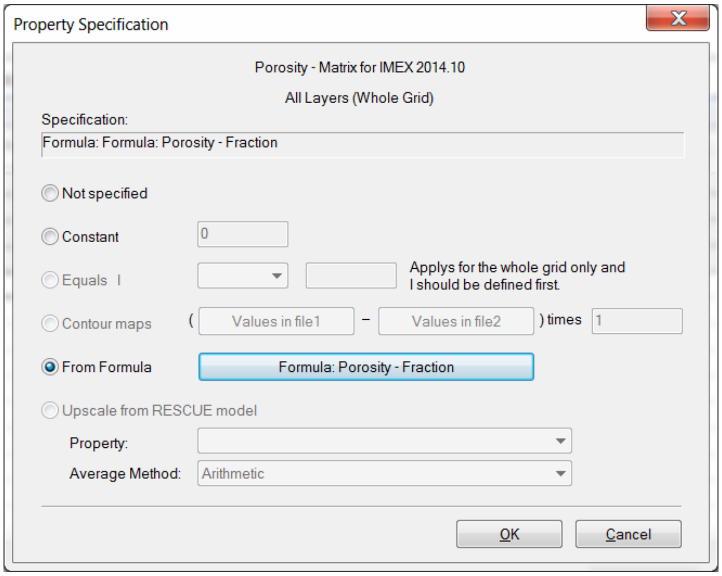


Figure 37: Selecting Formula for Porosity

12. Click ***OK*** again to close the General Property and one more time to calculate the Porosity property as a rescaled version of CMGLCustom_PoroSim property

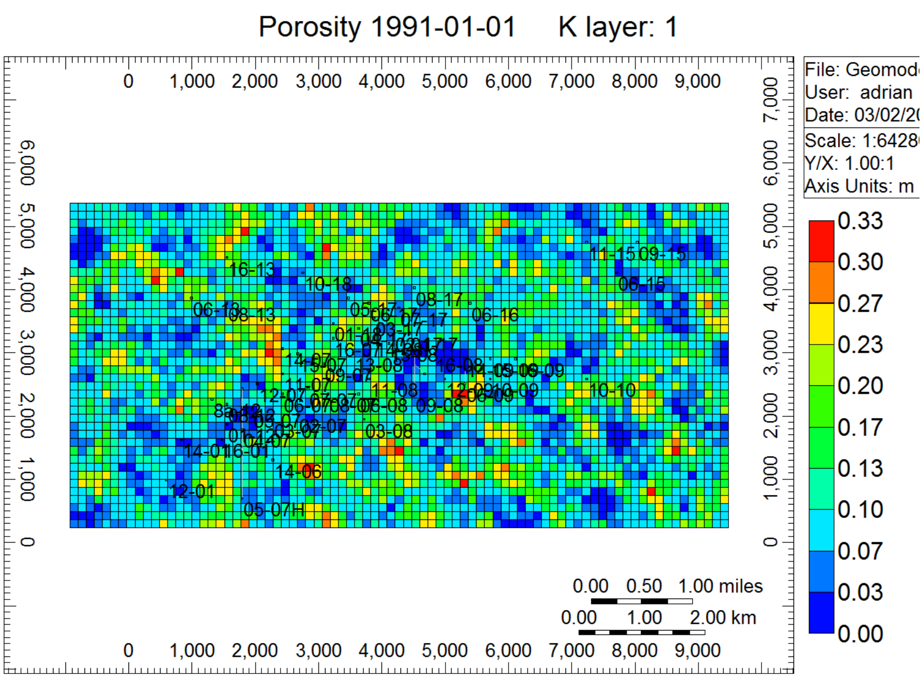


Figure 38: Porosity Fraction in 2D Reservoir View

Note: With this dataset, the permeability values can be estimated in combining two different sources of information; the regression equation from a Permeability-Porosity cross-plot from cores and the well test data for a limited number of wells. Cross-plot equation will be added in the following steps to estimate permeability. In the Bonus section of this tutorial incorporation of well test data to the estimated permeability for the cross-plot will be discussed.

13. Save the dataset

Creating Permeability Formula

1. Navigate to **Tools | Formula Manager** and click the **New** button to create a new formula
2. Name the formula as **PermFromPoro**
3. Add **Porosity** as the independent variable and assign the following equation:
    a. **3000 * (X0+0.1)**3 / ((1-X0)**2)**
    b. Where X0 represents the Porosity property

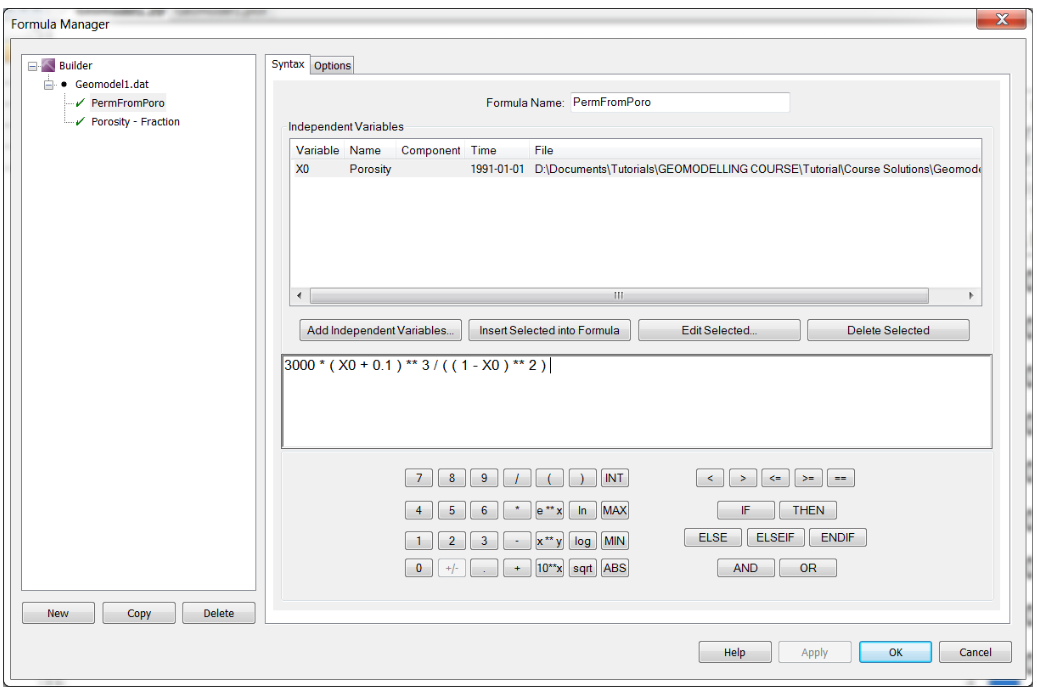


Figure 39: Creating Formula for Permeability I

4. Click ***OK*** and exit the Formula Manager

Note: The formula created will be applied to the Permeability property of the reservoir. If the plan is to complete the dataset using the steps outlined in the Bonus section, please create a custom property (CMGLCustom_PermFromPor) at this point and assign the Permeability formula. The following steps assume the well test data for permeability will not be incorporated.

5. Click on ***Specify Property*** and navigate to the **Permeability I**
6. Under **Whole Grid** right click and select **Formula**
7. Click the ***Formula*** button and select **PermFromPoro**
8. Click ***OK*** twice to return to the Specify Property window
9. Right click on **Whole Grid** for **Permeability J** and select **EQUALSI**
10. Click ***OK*** to set Permeability J to the same values as the I direction
11. Repeat the procedure for **Permeability K**, except change the option from “equal” to “*****” and input a value of **0.1**

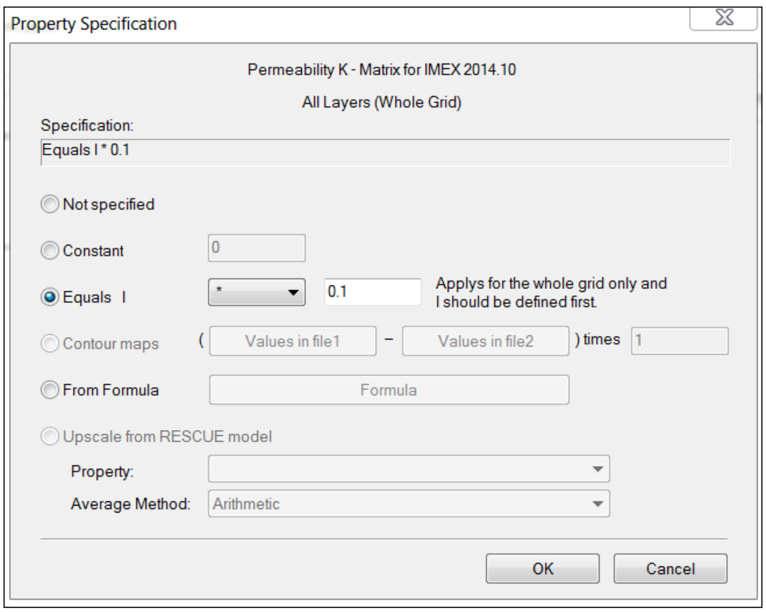


Figure 40: Permeability K Specification

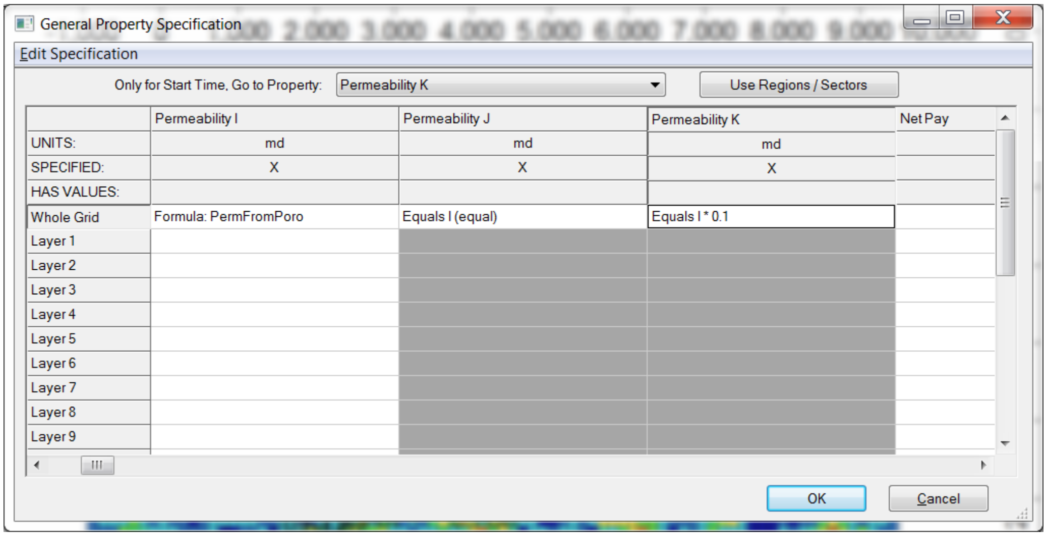


Figure 41: Permeability Property Specifications

12. Click ***OK*** twice to assign the Permeability in all directions to the grid

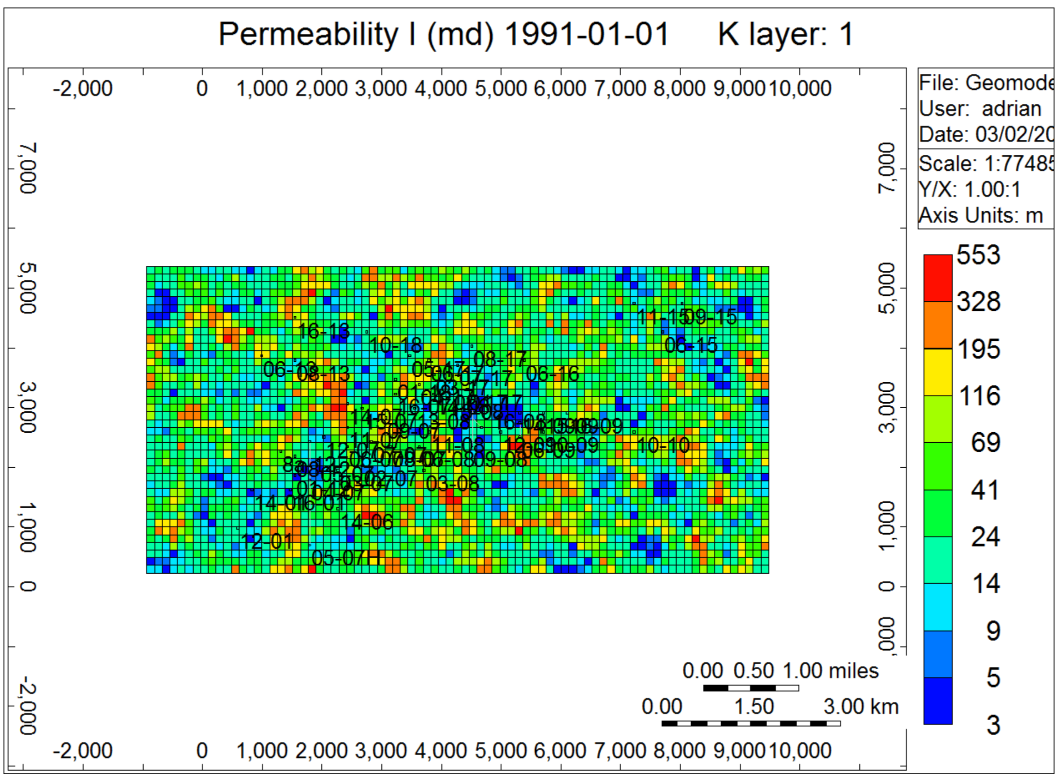


Figure 42: Calculated Permeability I Displayed on Log Scale

13. Save the dataset

Grid Up-Layering

<u>*Note*</u>: If the plan is work through the Bonus material, it is recommended to skip the following Up-Layering section and continuing with the bonus material. Once the dataset has been completed, the up- layering steps can be followed.

<u>*Note*</u>: One of Builder's features is up-layering that allows combining the grid layers in K-direction with automatic averaging of the grid properties and updating well completions. The model should be able to run faster as there are fewer number of grid blocks; however, some vertical resolution will be lost. In the current exercise the number of K layers will be reduced from 20 to 10. It is <u>always</u> good practice to compare the original and up-layered model results.

1. Click the ***Edit Grid***  button on the modes tool bar and ***OK*** to the message
2. Navigate to **Reservoir | Edit Grid | Combine Layers**
3. In the drop down menu select **PERMK/POROSITY** as the Guide Property for Grouping

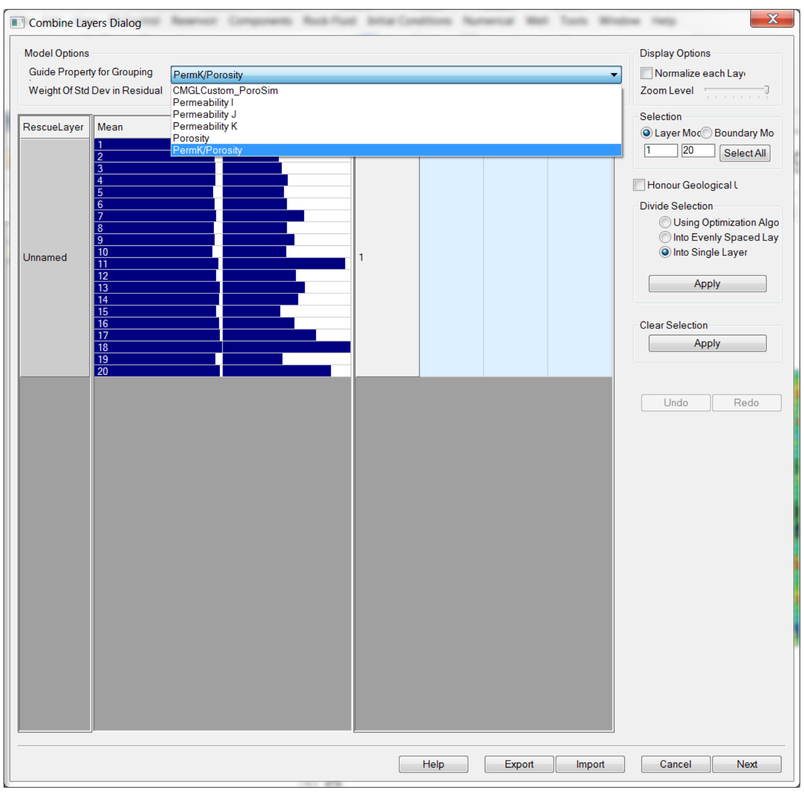


Figure 43: Combining Layers Window

4. In the Divide Selection select **Into Evenly Spaced Layers** and click the ***Apply*** button

5. In the Combine Layers Dialog change the **Lone Unit** drop down from 3 to **10**

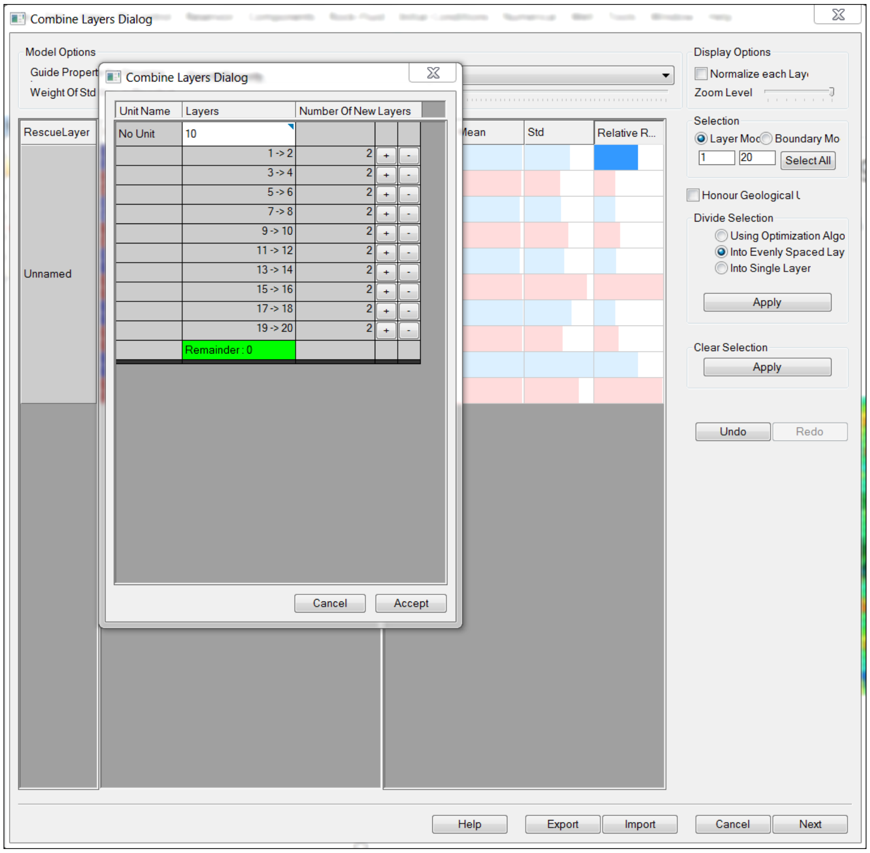


Figure 44: Divided Evenly Dialog

6. Click ***Accept*** and observe the Mean, Std, and Relative Residual for the current combination
7. In the Divide Selection select **Using Optimization Algorithm** and click the ***Apply*** button
8. Highlight down to **Layers 10** and click ***Accept*** and observe the combined layers and Residual

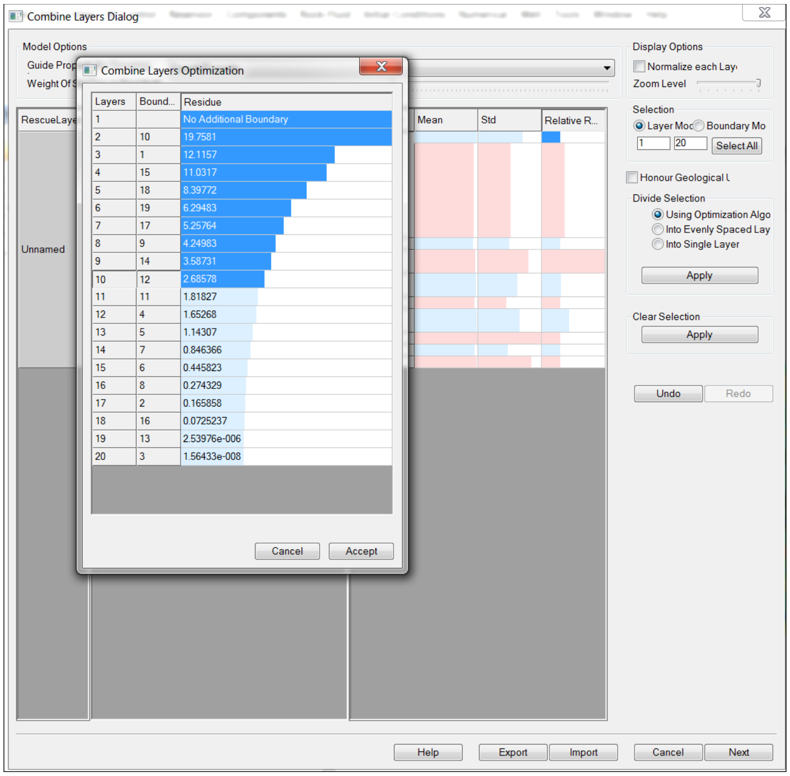


Figure 45: Optimization Algorithm Dialog

9. Choose the combination preferred and click ***Next***

   Note: For the purpose of this tutorial the Optimized Algorithm was used. Both scenarios could be tested and the resulting models should be run and compared to the fine scale model for validation.

10. Notice the default averaging routines for different grid properties and ensure that **Arithmetic** is selected as the Average Type for **CMGLCustom_PoroSim** (will transfer to Porosity through the formula)

11. Click ***Finish*** to up-layer the model

12. A message may appear relating small porosity values in certain blocks. These blocks should be investigated as they may impact simulation run time. Input a valid pore volume cut-off should alleviate the issue. Click ***OK*** on the message

13. Save the dataset as "**Geomodel2_Uplayering.dat**"

Note: Well trajectories in this dataset should be updated for intersection with grid blocks anytime there is a grid change (refinements, splitting combining layers, and submodel extraction).

14. Navigate to **Well | Well Trajectories | Recalculate Intersections with Grid** which will recalculate block entries and exits for all trajectories.
15. Save the dataset

Note: It is always good practice to compare results before and after upscaling. Histograms of property distributions could be compared before and after upscaling to verify the upscaled model. If the dataset is complete, both models could be run in a flow simulator to compare results and again verify the upscale method.

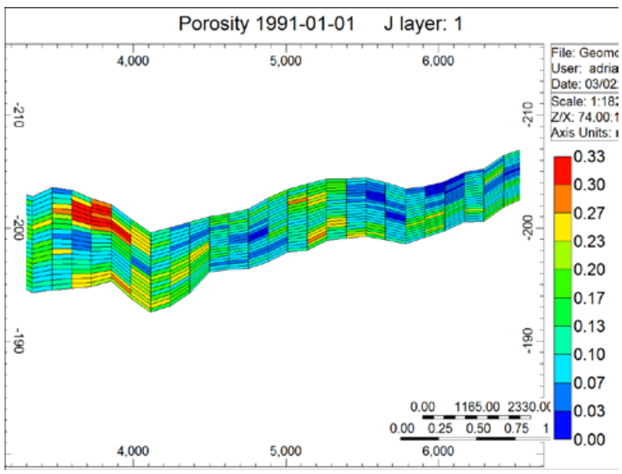


Figure 46: Original Porosity Distribution IK-2D X-Section

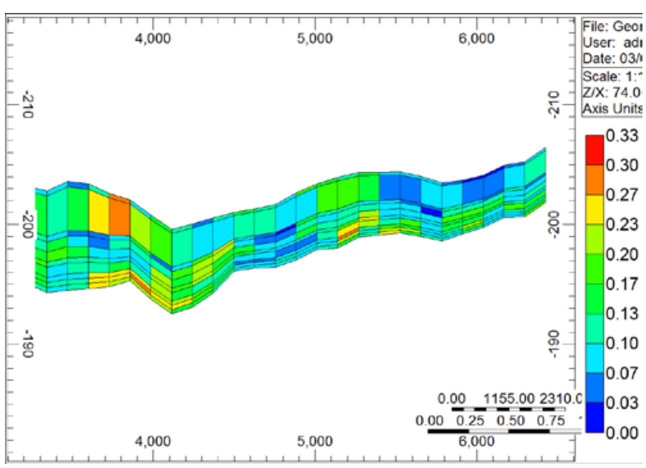


Figure 47: Upscaled Porosity Distribution IK-2D X-Section

Bonus Exercise: Completing the Dataset

Defining Well Perforations

1. Navigate to **Wells & Recurrent | Well Trajectories | Trajectories Perforations Intervals**

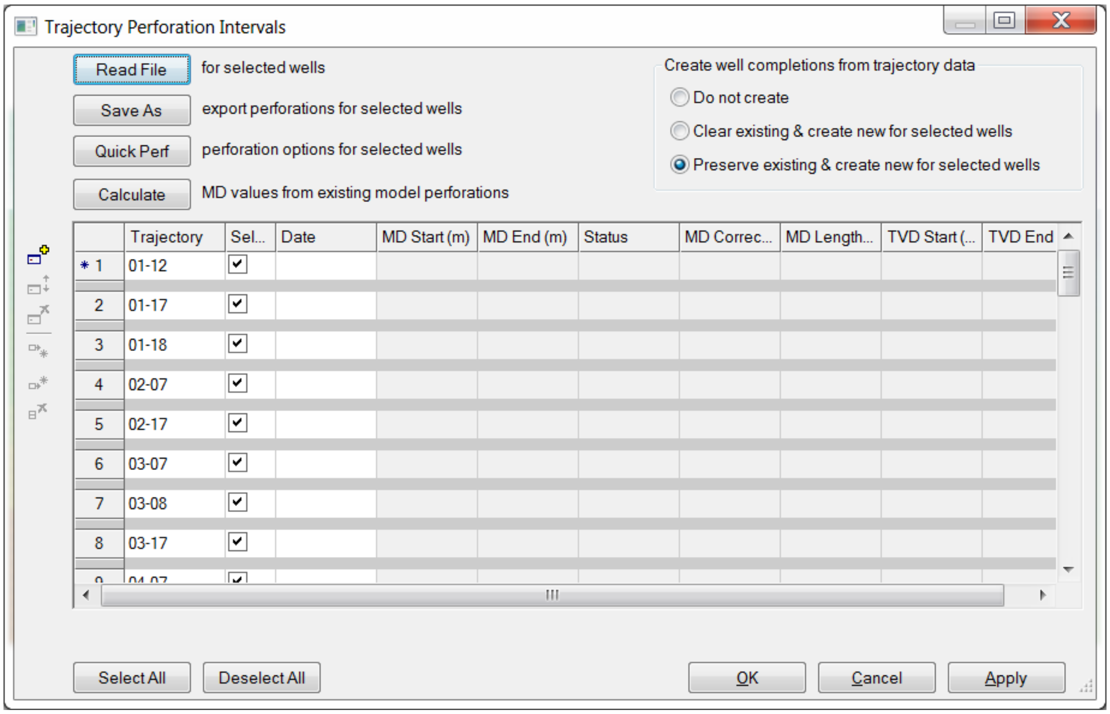


Figure 48: Trajectory Perforation Intervals Dialog

2. Click the ***Quick Perf*** button

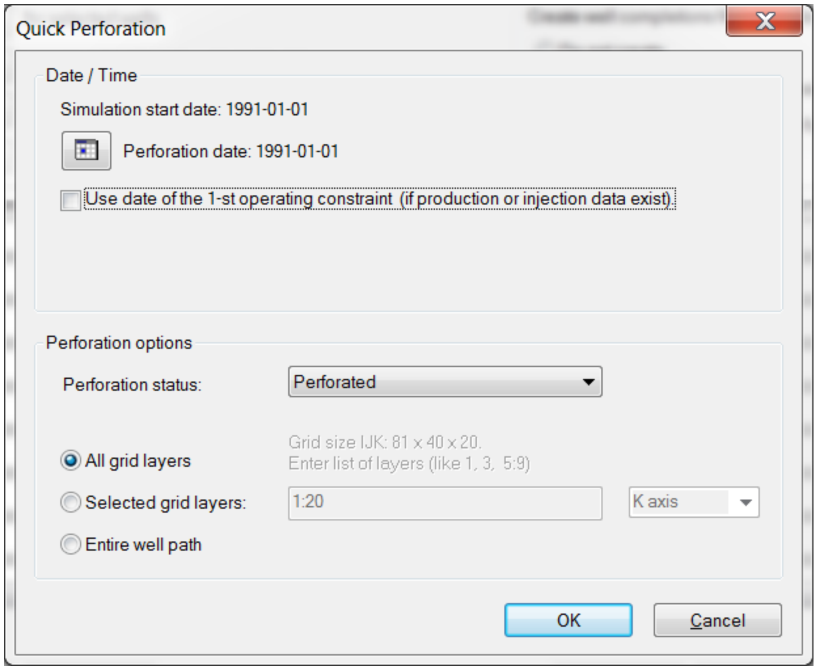


Figure 49: Quick Perforation Dialog

3. Click ***OK*** to close and accept the defaults. All grid layers will be perforated for all wells.

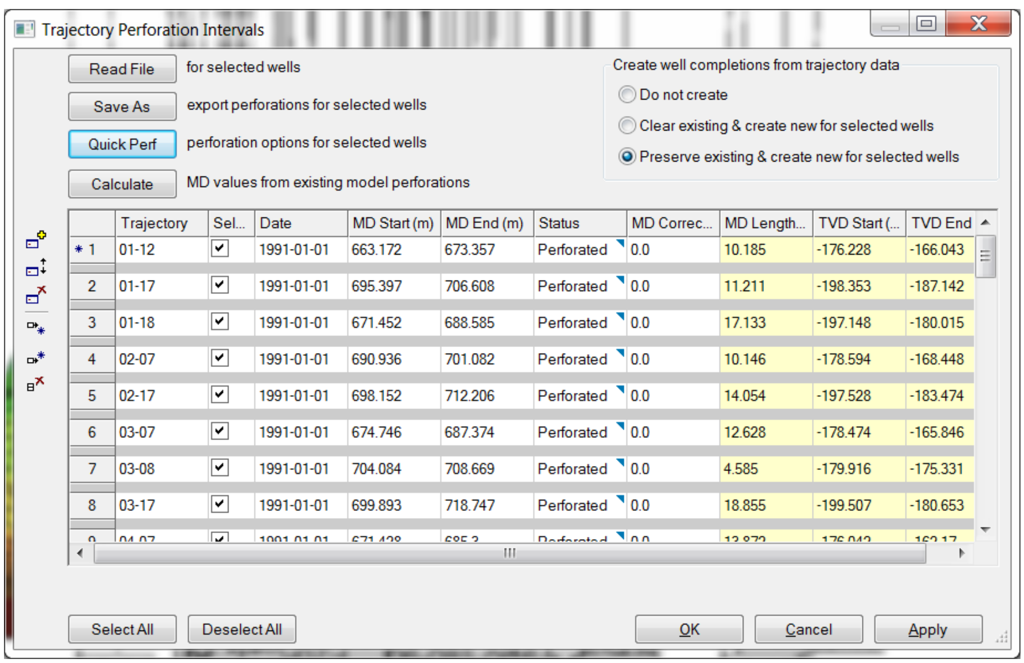


Figure 50: Perforation Intervals Defined

4. Click ***OK*** to close the Trajectory Perforation Intervals dialog. The wells are perforated over the entire reservoir thickness. The trajectories should be displayed in the view.

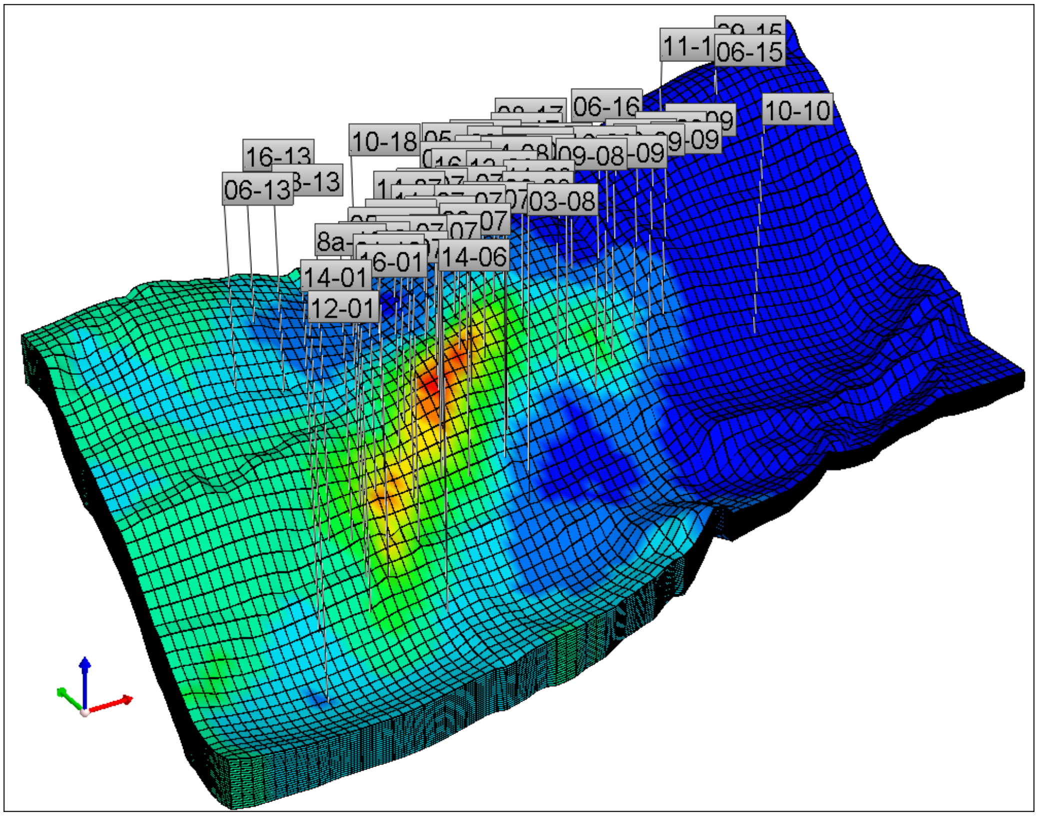


Figure 51: 3D View of Trajectories after Perforations

<u>Note</u>: At this step it is possible to associate log data such as porosity with the wells. This would be a good time to save the dataset. The Permeability in I,J,K directions will be assigned in Builder from well test data and CMGLCustom_PermFromPor.

Populating Simulation Grid with Permeability Values

Geostatistical Objects

5. Open the Excel document **WellTest.xls**
6. Navigate to **Reservoir | Geostatistics** to display up the Create Geostatistical Objects dialog
7. Click the  and select New (default)
8. Input a meaningful name such as **WellTestSim** and click ***OK*** to accept the name
9. Select **Permeability I** in the Output Property pull-down list

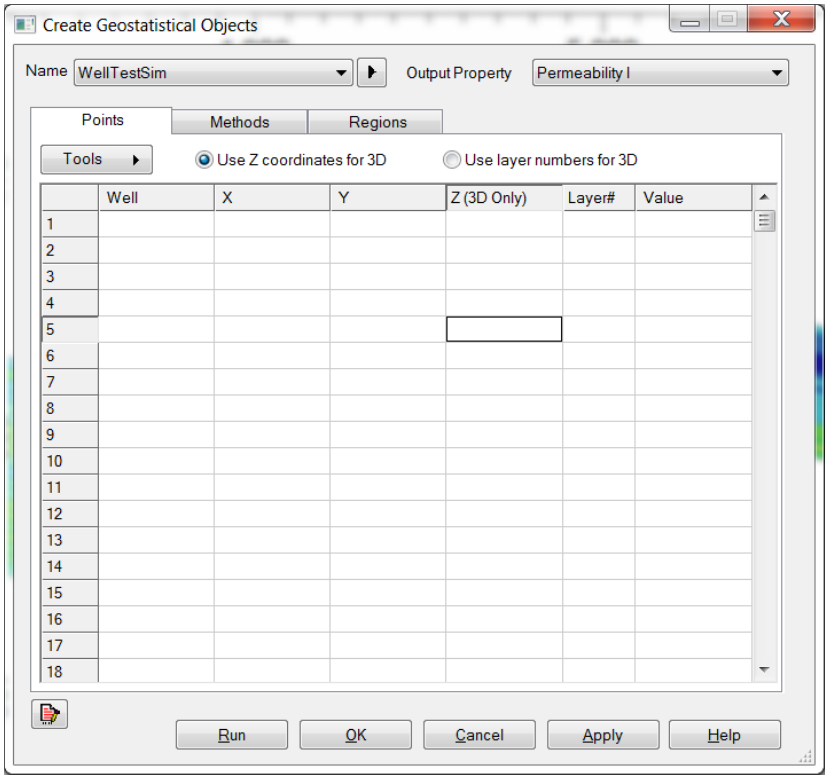
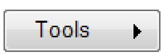


Figure 52: Geostatistics Dialog

Importing Well Test Data

1. Click the 

button and select **Import well test permeabilities**
2. Copy and paste the well test data from the Excel spreadsheet into the window and select **CMGLCustom_PermFromPor** as Property for individual layer weighting values:

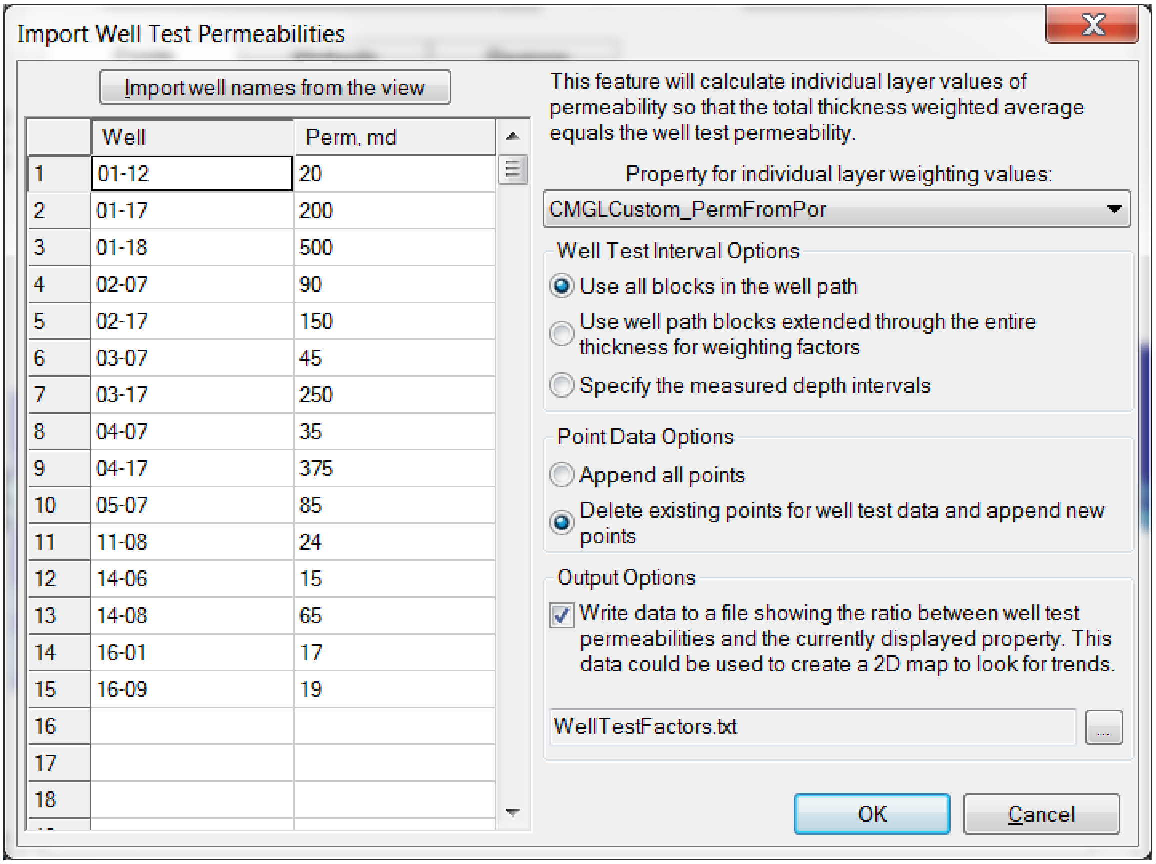


Figure 53: Importing Well Test Information for Geostatistical Object

3. Click ***OK*** to close the dialog

<u>*Note*</u>: This will import the well test data. For each well test, the values will be distributed on each grid layer (at the well location) according to the spatial distribution of permeability values from CMGLCustom_PermFromPor.

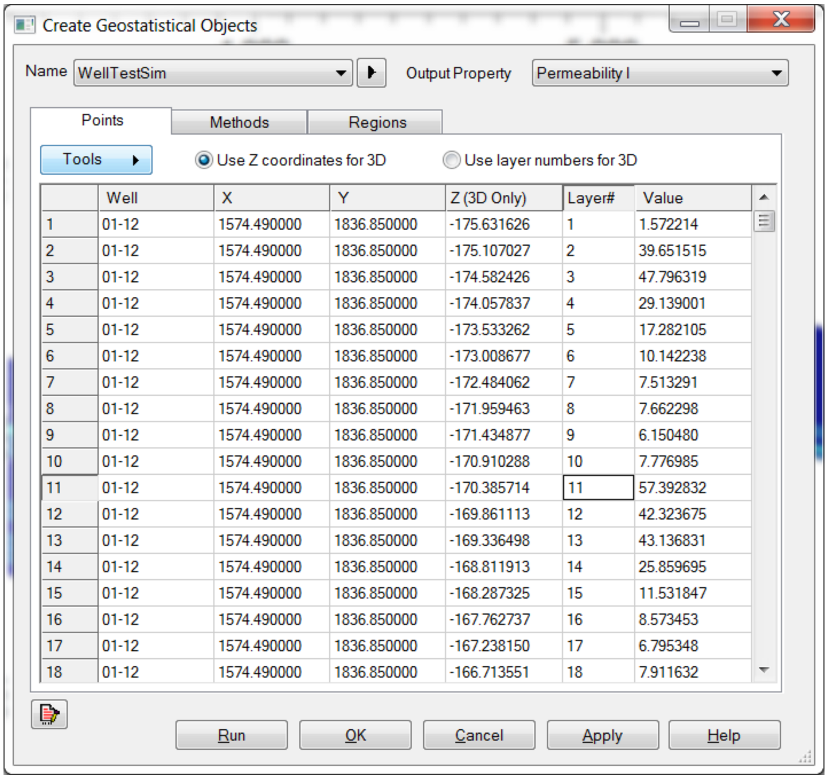


Figure 54: Geostatistics Dialog Defined for Permeability I

.

Geostatistical Method

1. Go to the **Methods** tab
2. Change the Calculation Method to **Gaussian Geostatistical Simulation**

3D Variogram Analysis

Note: As seen in previous examples the presence of anisotropy in the data can be explored by selecting Bi-Directional in the Horizontal Variogram Direction. This case does not seem to have anisotropy and the omni-direction will be selected.

3. Click the ***Click to match variogram*** button to display the variogram plot window

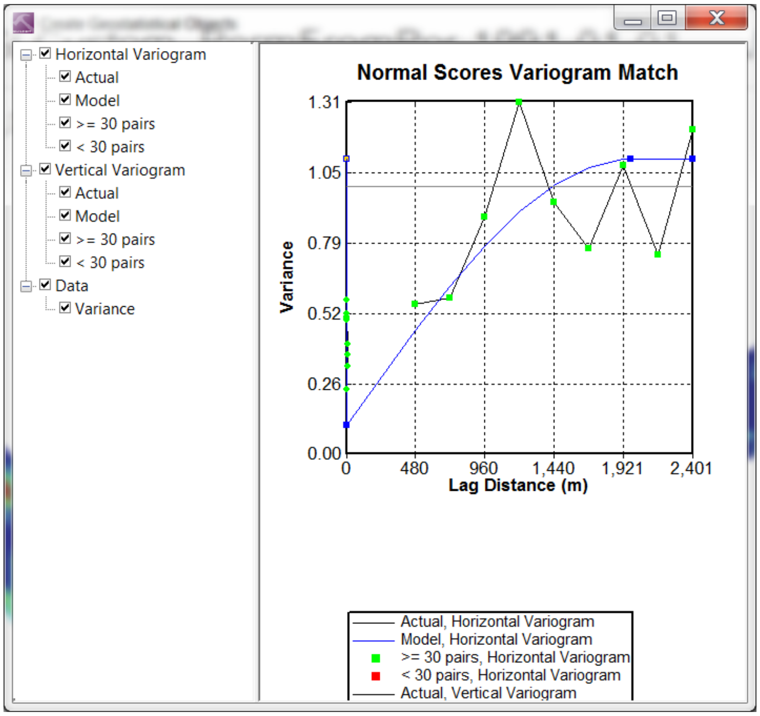


Figure 58: Variogram Plot for Calibrated Well Test Data

<u>Note</u>: The nugget effect appears to be quite high. Usually, the vertical variogram will give a better estimate of the nugget effect because the data values are closer to each other along the wells than between wells. The Nugget value should be adjusted.

4. Match both the vertical and horizontal curve

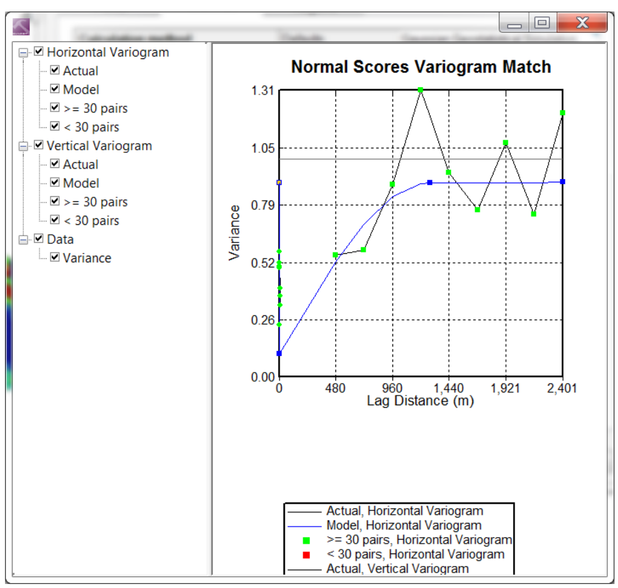


Figure 60: Omnidirectional Variogram Plot for Calibrated Well Test Data

Simulating Permeability

1. Click the ***Run*** button to actually create the Permeability I property. The results will be automatically displayed in Builder's main view when the calculations are finished. Set the color scale to **Logarithmic**

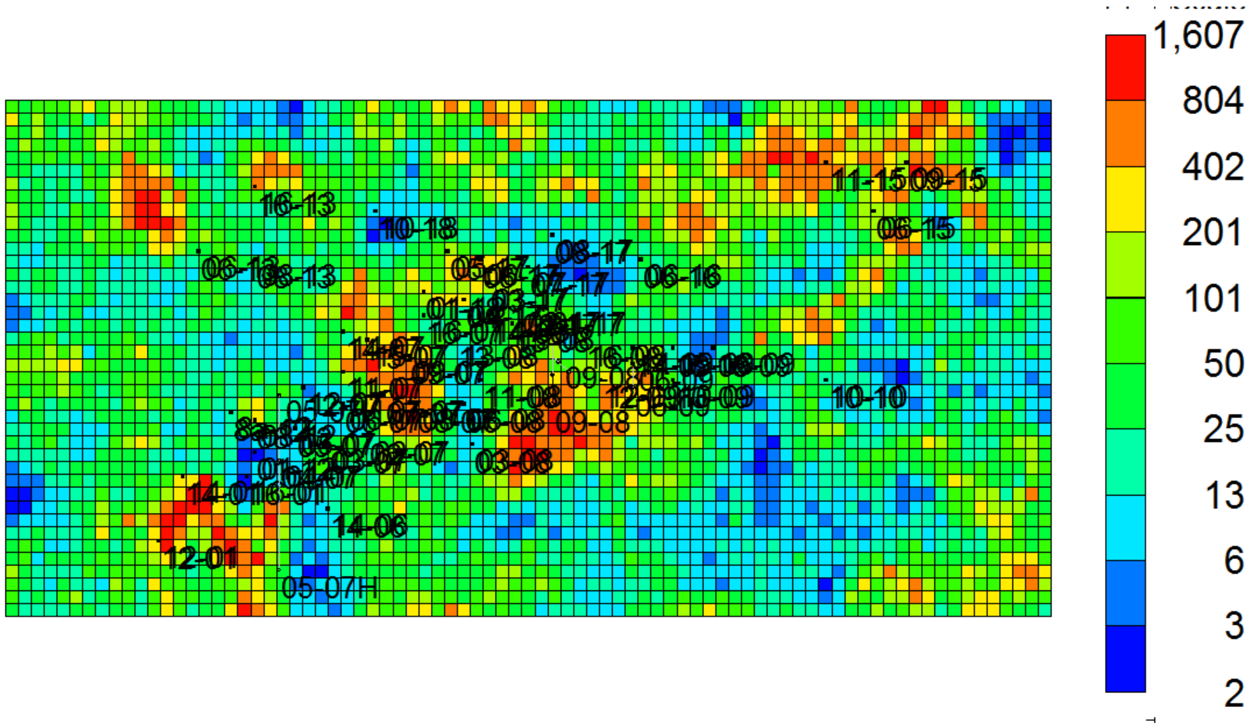


Figure 55: Permeability Property Simulated on the Simulator Grid

2. Click ***OK*** to save the newly created geostatistical object and close the dialog

   Note. This Gaussian Simulation geostatistical object will be used again in an automatic workflow. You can save the dataset to keep a permanent copy of the geostatistical object within it. Permeability J and Permeability K properties can easily be defined by specifications relative to Permeability I.

3. Click the ***Specify Property*** button on the view tool bar
4. Under **Whole Grid** and **Permeability J** right click and select **EQUALSI** from the context menu
5. Click ***OK*** to accept the default and create Permeability J as equal to Permeability I.
6. Repeat the process for Permeability K, but this time change "equal" to "*" and assign a value of 0.1
7. Click ***OK*** to close the dialog and set Permeability K as one tenth of Permeability I

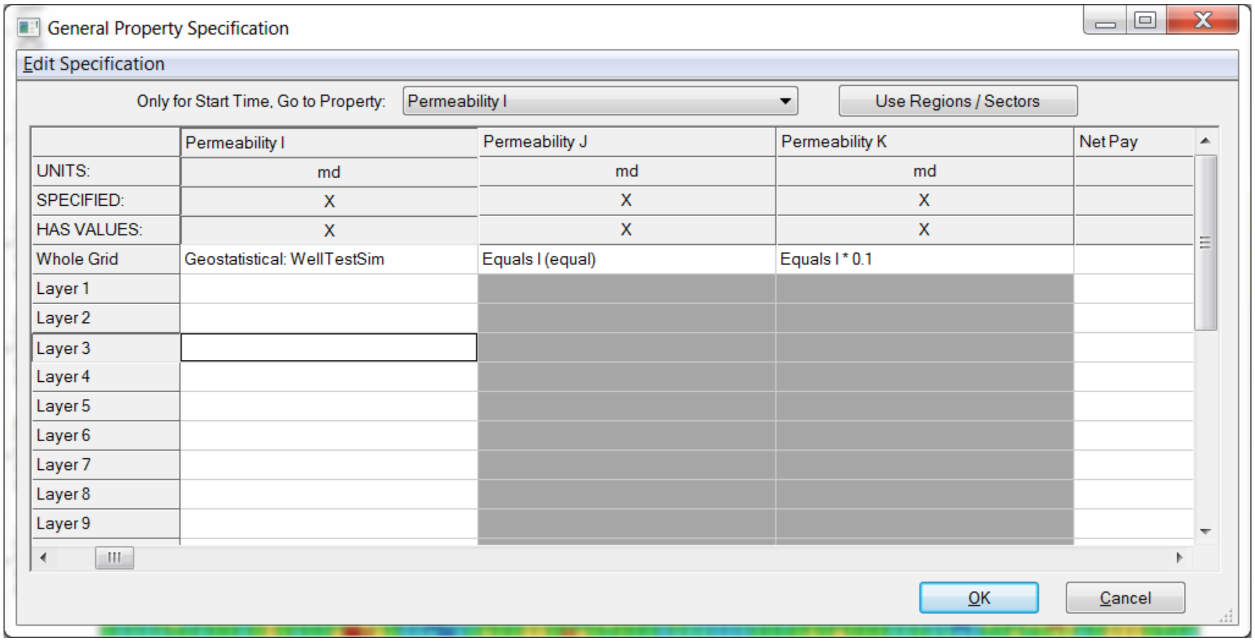


Figure 56: General Property Specification Dialog with Permeability Specified

8. Click ***OK*** twice to calculate the Permeability J and Permeability K properties

Initial Conditions and Well Constraints

<u>*Note*</u>: In this section of the tutorial, we are going to set the simulator initial conditions and well operating constraints. This will allow us to initialize the dataset for initial oil in place. To have a simulator ready dataset, we still need to add more engineering data.

Reservoir Pressures and GOW Contacts

1. Select "Initialization Settings…" from the Initial Conditions menu. The Initial Conditions dialog will appear. Keep the default Water-Oil-Gas system and enter 27600 kPa for Pressure, -190m for Depth, -185m for Water-Oil contact and -220m for Gas-Oil contact.

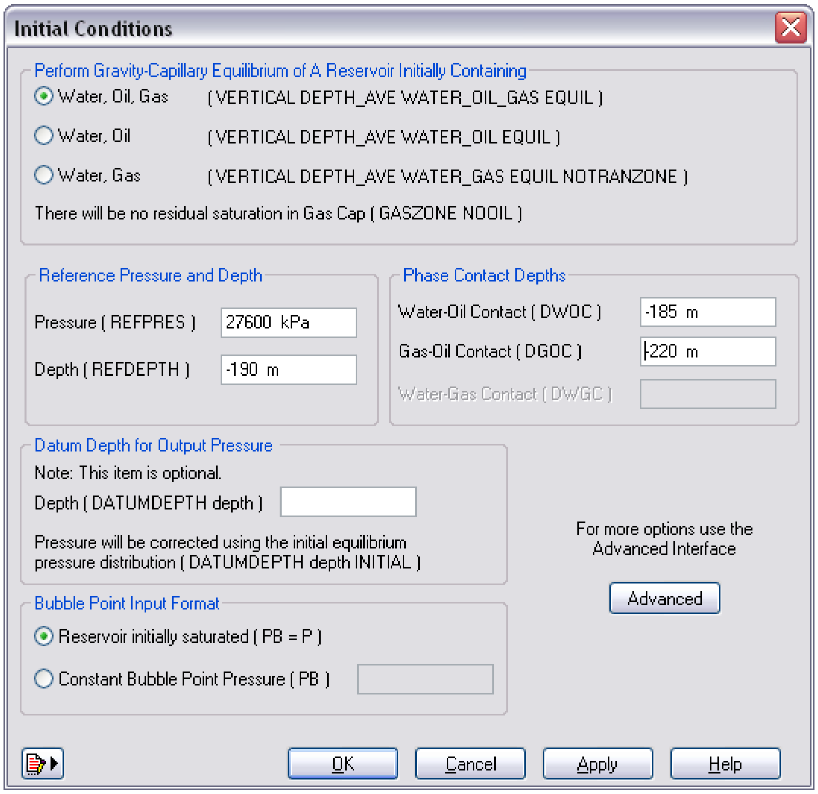


Figure 57: Initial Conditions Settings

This will complete the Initial Conditions section.

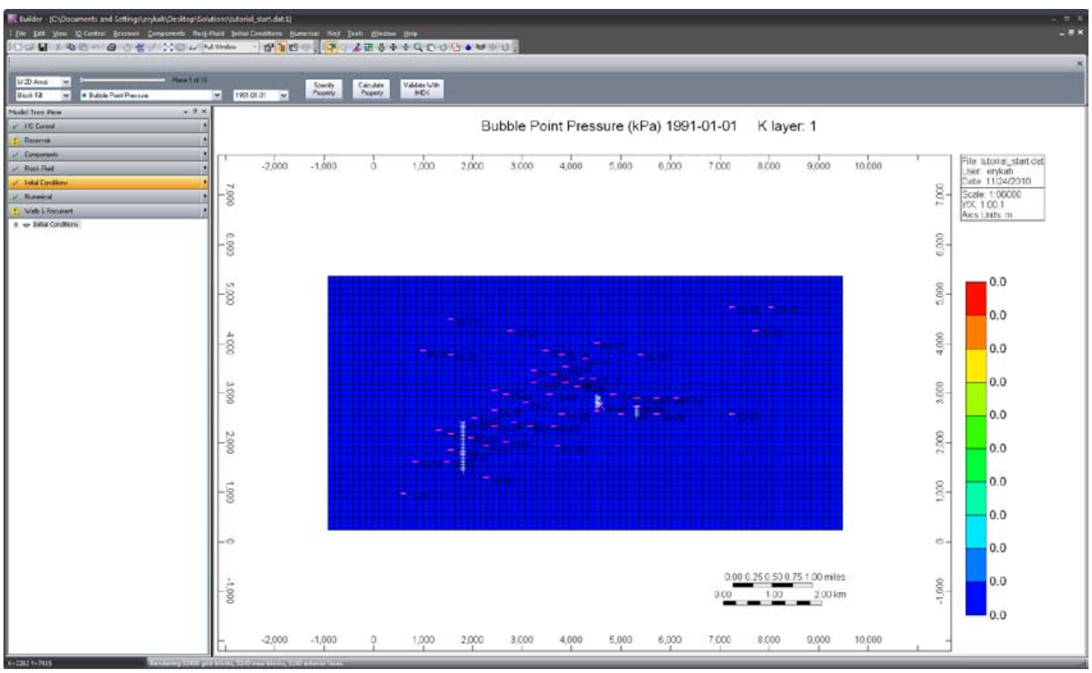


Figure 58: Reservoir View after Initial Conditions Specified

Well Constraints

Wells now need to be defined as producers and bottom hole pressure constraints needs to be added.

1. Select “Well Events…” from the Well menu. The Well Events dialog will appear. Select Producer for the type in the “ID & Type” tab for well 01-12.

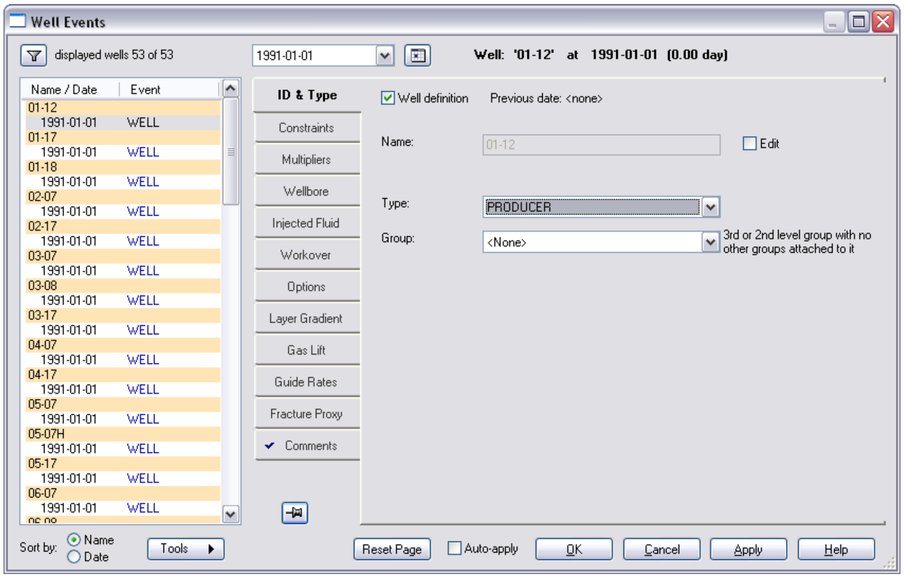


Figure 59: Well Events Dialog with Little Information Defined

2. Select the Constraints tab. If asked to apply changes, say YES to save the previous change.
3. On the Constraint tab, check off the Constraint definition check box at the top of the tab. Select the Constraint pull down list and select OPERATE, give it a value of 5000 kPa (as shown below).

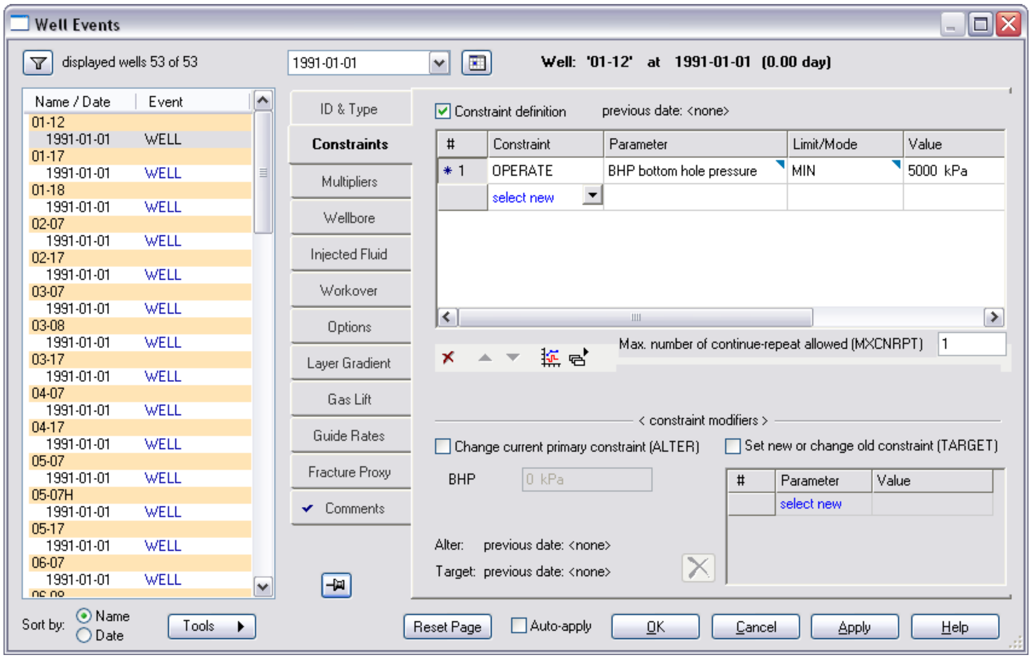


Figure 60: Defining Well Constraint Information

4. Click on the well 01-12 in the list of wells on the left of the dialog, say YES to save the changes. This will expand the events for this well as shown below. (If prompted, say yes to save the previous change.)

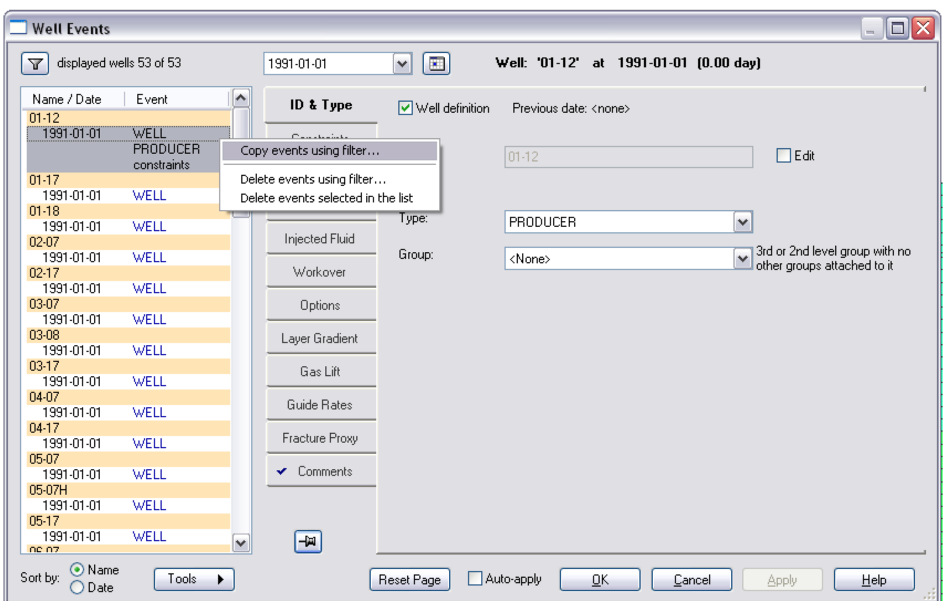


Figure 70: Well Events Tree View copy events using filter

5. Select the Producer and constraint event and right click WELL event for well 01-12 and select Copy events using filters… from the context menu. The 'Select well-date pairs to copy event(s): WELL' dialog will appear.

6. Click the Select button to select all the wells.

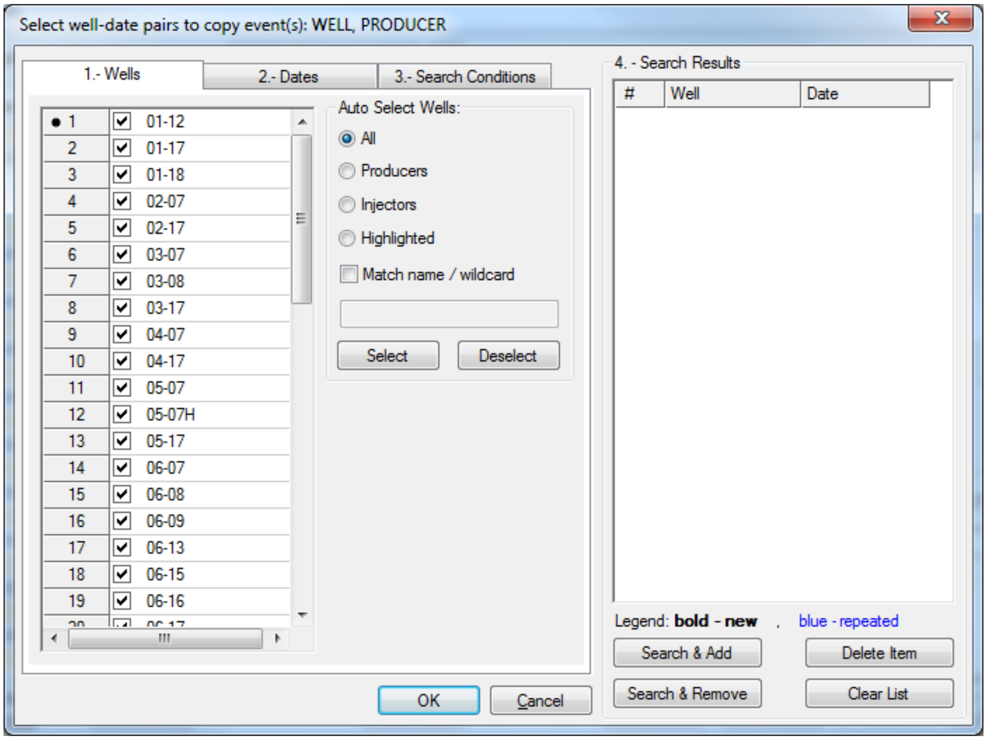


Figure 61: Selecting Wells for Copying WELL Keyword

7. Select the 2.- Dates tab and click the Select button to select all dates

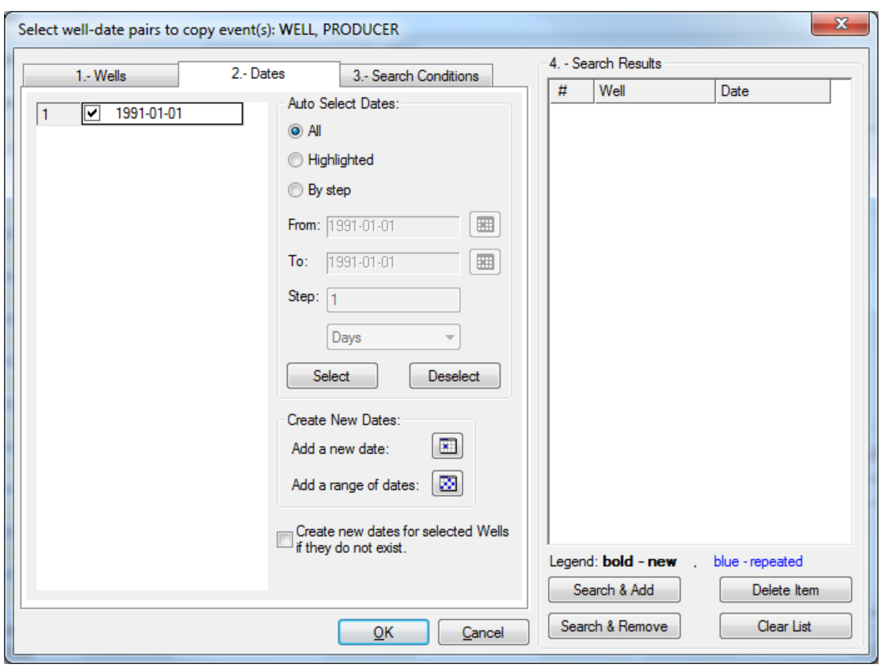


Figure 62: Selecting Date for Copying WELL Keyword

8. Click the Search & Add button to fill the right hand side of the dialog with wells.

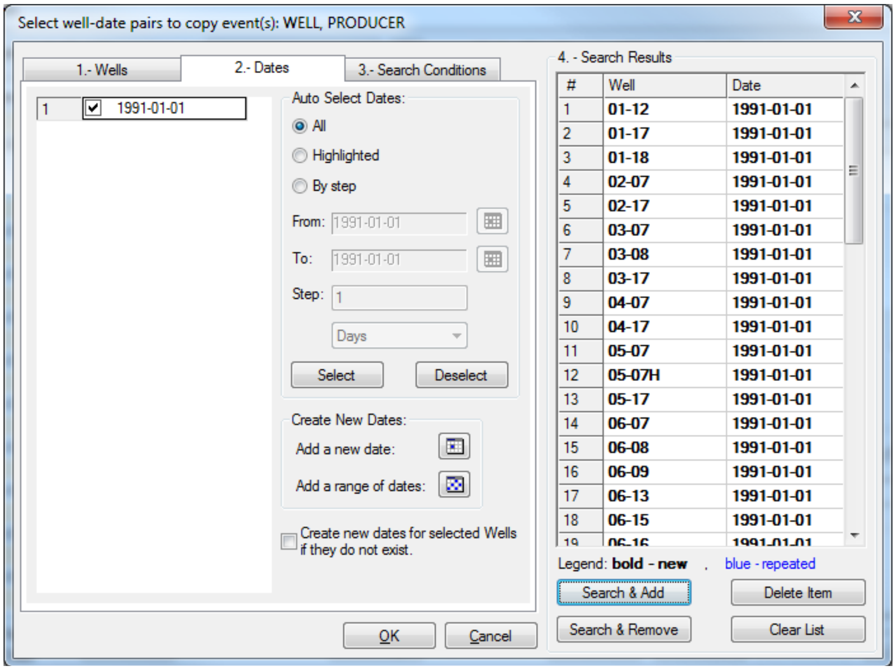


Figure 63: Wells and Dates Selected for Copying Information To

9. Click OK to close the dialog and go back to the Well Events dialog.. All the wells will have the same constraints as shown below.

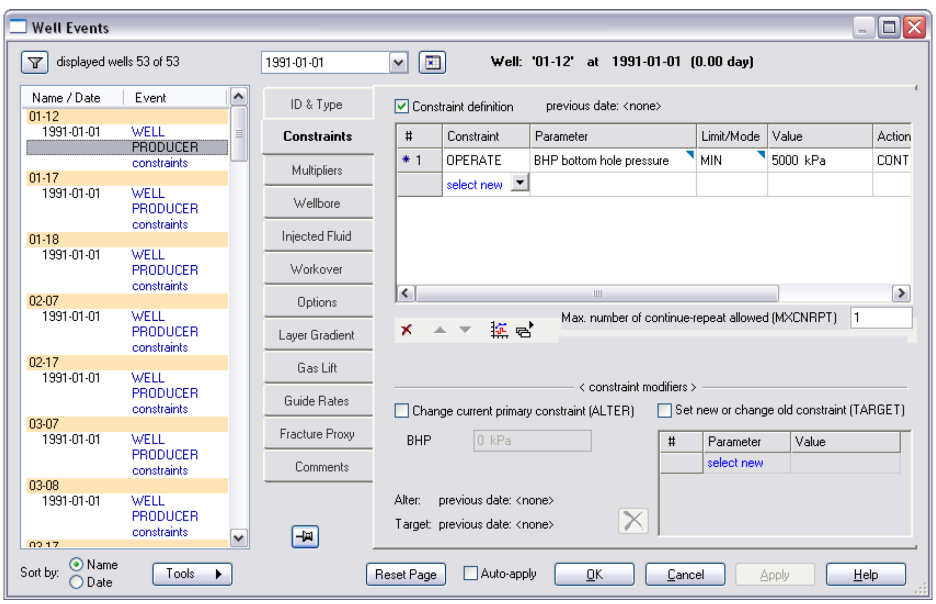


Figure 74: Updated Well Events Dialog after Information is copied

10. Click OK to close the dialog.
11. So far we have only one date for the wells. We need to add at least one more date if we want initialize the reservoir for the static properties. Select "Dates…" from the Well menu. The Simulation Dates dialog will appear:

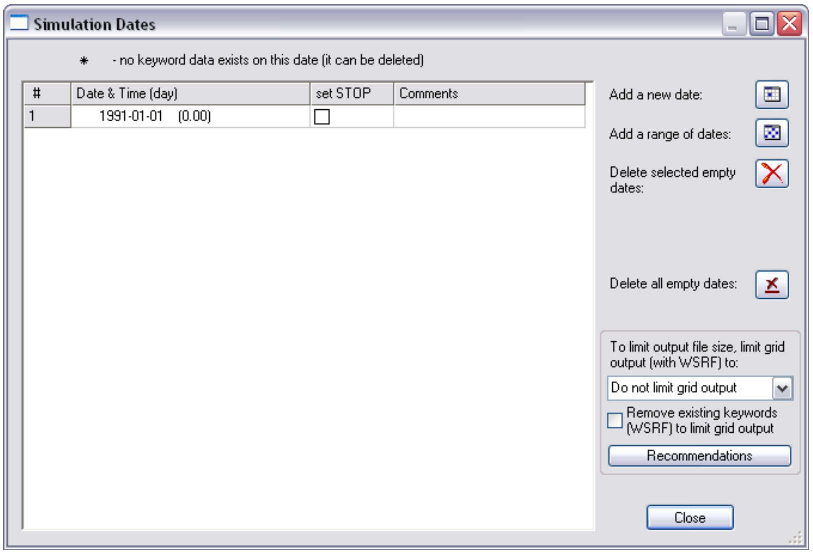


Figure 75: Adding More Dates in Simulation Dates Dialog

Click the "Add a new date" icon to add a date. The date value is not very important for the purpose of this tutorial, one day (1991-01-02) will be correct for initialization. Select the last date as the STOP and click close to close the dialog. This will complete the Wells & Recurrent section.

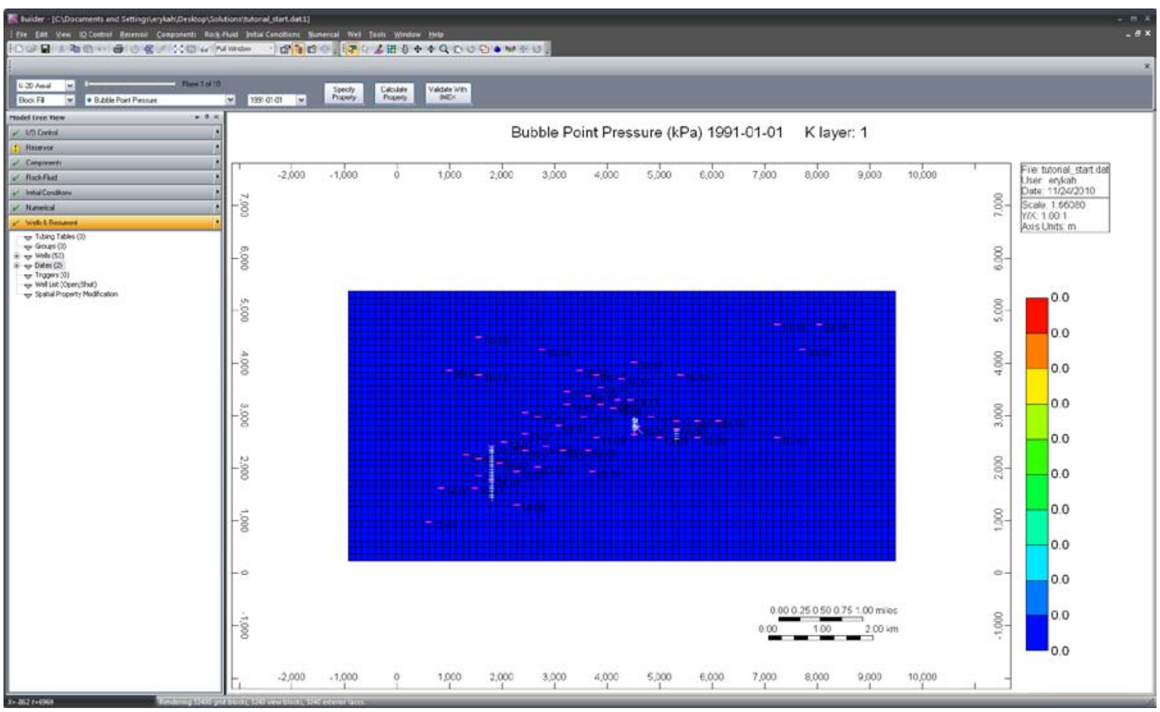


Figure 64: Dataset after All Main Information has been defined

Note: We are still having a warning in the reservoir section due to the use of the defaults for Rock compressibility. This will not prevent us from running, but if desired double click in Rock Compressibility under the Reservoir section and use the following values in the window:

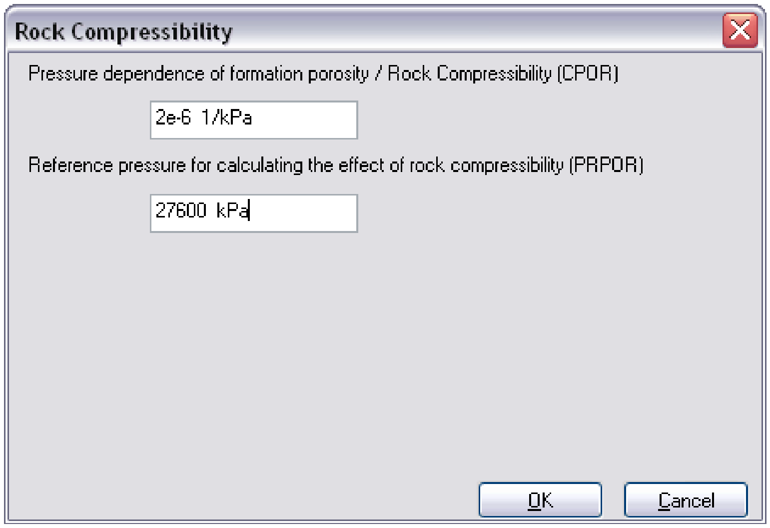


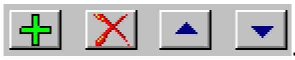
Figure 77: Defining Rock Compressibility

Note: We now have a simulator ready dataset which can be used for iterative or automated workflows. You can save it to disk if you want. The dataset has now reached a state where it can be sent to the flow simulator. It is important to remember that the porosity and permeability values have been simulated by geostatistical methods and therefore represent just one possibility among an infinite number of porosity and permeability models for the reservoir. Uncertainty about these properties can be explored by running the geostatistical methods multiple times. We are now going to create a script that will help us to automate this process

Creating Workflows with Script

Note: Scripts are used for automatic execution of basic Builder's actions. The sequence in which the actions are performed defines the workflow. The ordering of the actions in the script is important as some actions may depend on the results generated or updated by previous actions. At the time of writing this tutorial, the available basic actions are: *Repeat* for looping, *Geostatistical Calculation* for estimation or simulation of any Builder's property, *Calculation from Specification* for general calculation of Builder's properties with formulas, *Save Dataset* for saving the current states of Builder's properties involved in the script, and *Simulator Initialization* for retrieving initialization reservoir values in using the current state of the dataset. Altogether, these actions provide for very general and flexible workflows. They can be used to automatically generate many different datasets useful for uncertainty analysis or for testing various scenarios.

Creating a Script

1. Load the last saved dataset if not already open in Builder.
2. Select the *Scripting …* option under the *File* menu. The Property Calculation Scripting dialog will appear. It has a spreadsheet where each row corresponds to a script action. Rows can be added as more actions are needed. They can also be removed or moved up and down in using these buttons .

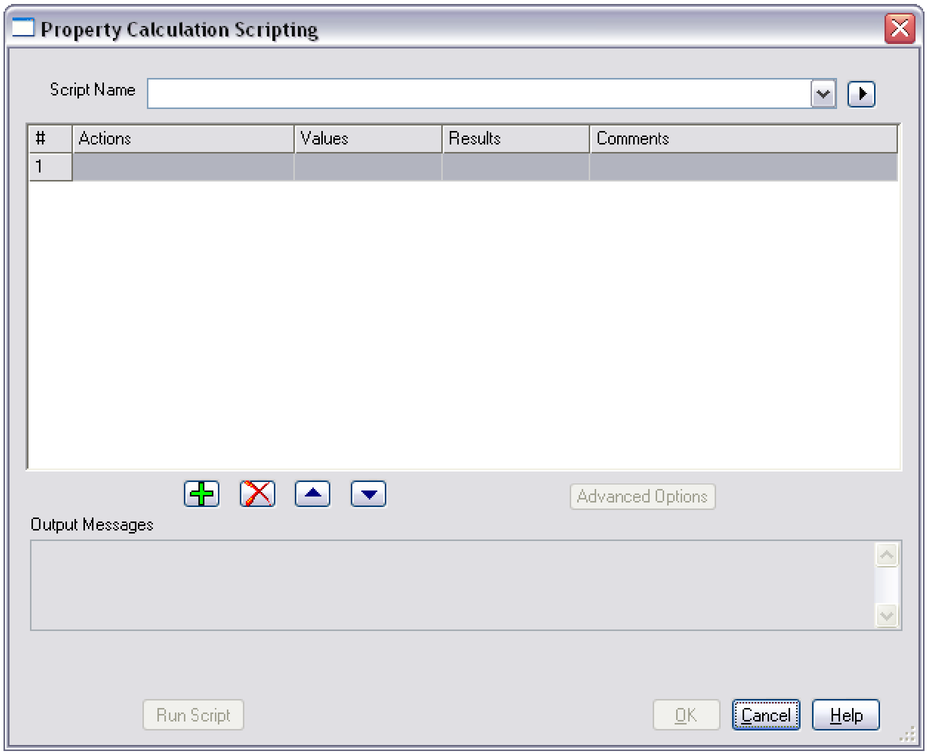


Figure 65: Empty Scripting Dialog

3. Click the right pointed arrow button and select new, to create a new script. Give it a meaningful name such as PorSim. The purpose of the script is to generate multiple datasets by changing the porosity values, and the permeability values, using geostatistical simulations. We also want to initialize each dataset with the simulator.
4.

<u>*Note*</u>: Now the dialog becomes active for the input of actions into the newly created empty script. We want to create a loop and for each iteration we will simulate the percent porosity values using our previously created geostatistical object PoroSim, we will rescale the porosity values between 0-1 and simulate the I permeabilities, we will calculate the J,K permeability values using EQUALSI assignment, we will save the dataset, and finally run the simulator for initialization. (It might be a good idea to write the steps down on paper before actually creating the script.)

5. Select (right click) the first empty row of the Scripting dialog and select *Repeat Action (loop)* from the context menu (right mouse button). This will create a Repeat block of actions in the script. The block is initially empty.
6. Change the Values cell for the Repeat action from 1 to 3. This will create a loop with 3 iterations.

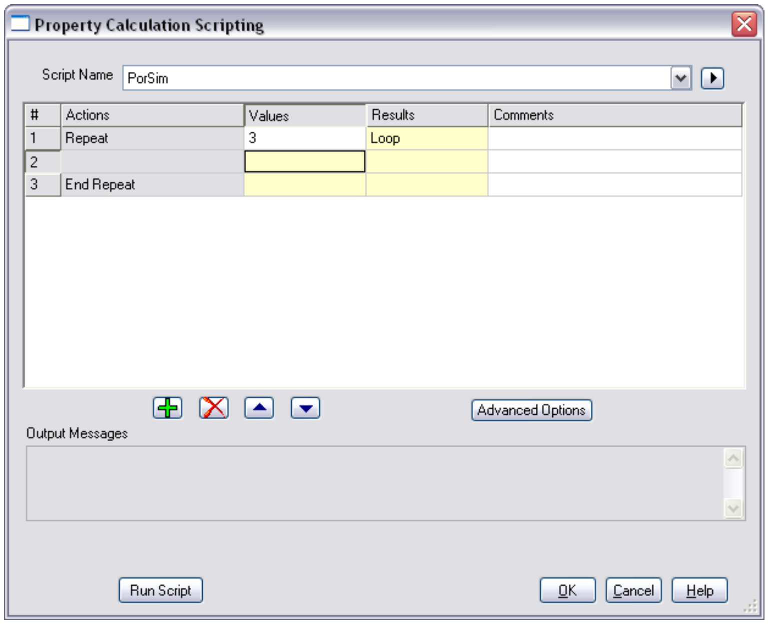


Figure 66: Script with Repeat Action

7. Select row 2 and select Geostatistical Calculation from the context menu. A pull down list of geostatistical objects will be created in the Values cell of the geostatistical action. Select the PoroSim geostatistical object from the pull down list (remember that this PoroSim object was created earlier in this tutorial). The CMGLCustom_PoroSim property name will be displayed in the Results cell of the geostatistical action to indicate that this action creates or updates that property.
8.

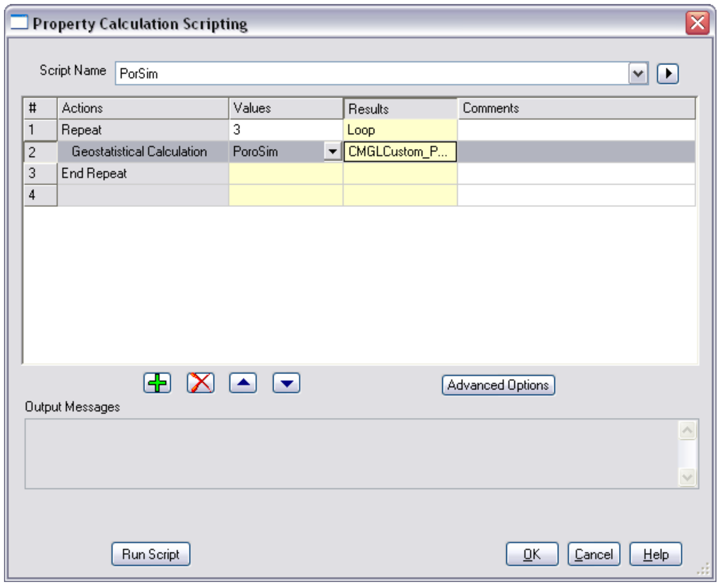


Figure 80: Script with Repeat Action and Geostatistical Calculation

9. We need to add more rows in the Repeat block before we can add more actions to it. You can do that by selecting the last action of the Repeat block and using the button a number of times. We need 1 more row for rescaling the porosity values, 1 more row for the permeability from porosity calculation, 1 more row for adding the well test permeability, 1 more row for saving the dataset, and 1 last row to initialize the dataset with the simulator for initial volume estimation at the end of the loop.

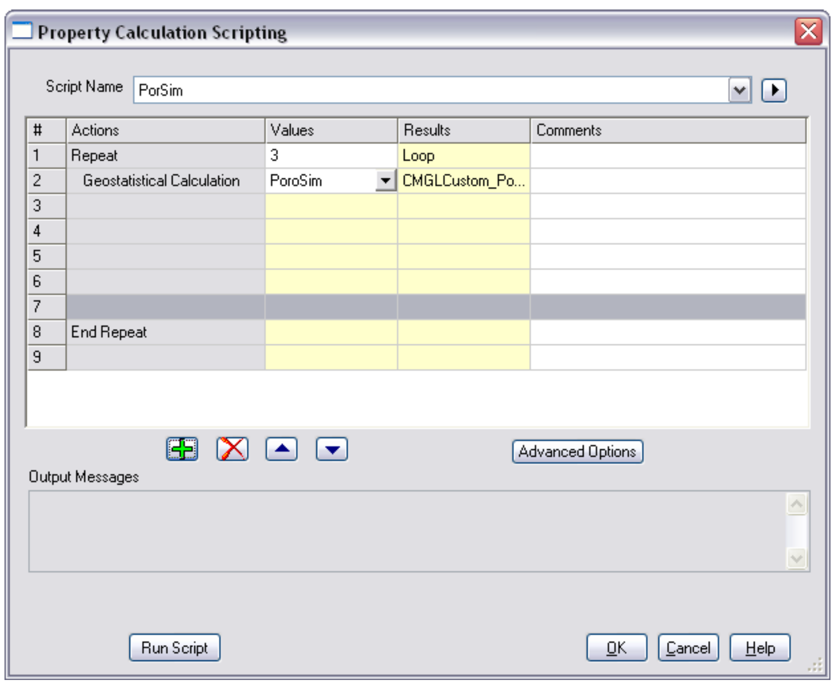


Figure 81: Script with Extra Rows Added

10. Select row 3 and select the *Calculation from Specification* action from the context menu. The Block/Corner Value Calculation dialog will appear. Check off the Porosity property only and click OK to close the dialog. You may have to uncheck CMGLCustom_PermFromPor and click OK few times to close a message dialog about the dependency of CMGLCustom_PermFromPor on Porosity.

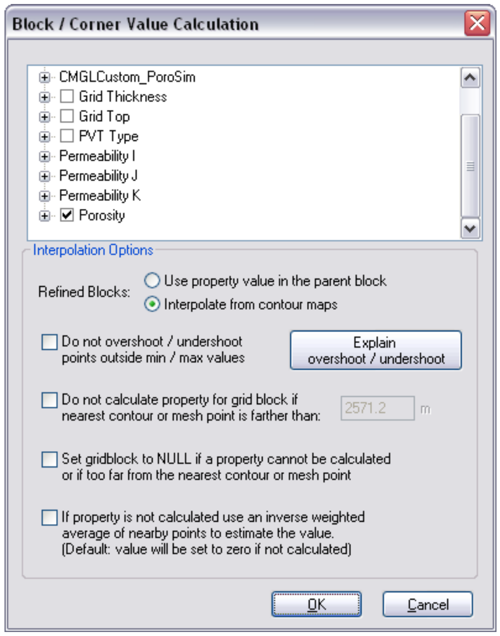


Figure 82: Specifying Porosity Calculation for Script

Note: This will add the Porosity calculation which is defined as a Formula using the CMGLCustom_PoroSim property. Porosity will appear in the Results cell of the Calculation from Specification action indicating that the Porosity property will be created or updated by this action.

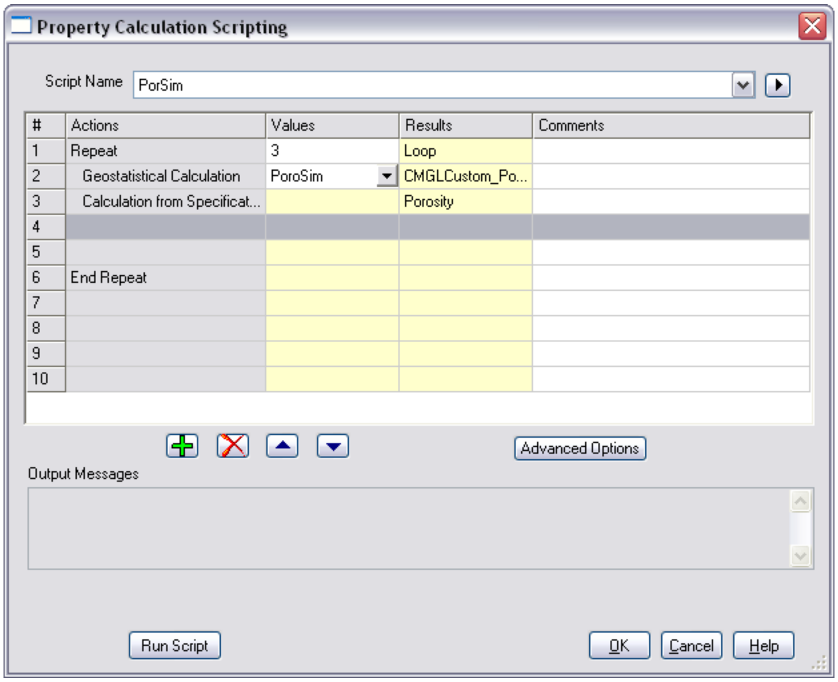


Figure 83: Script with Porosity Calculation

After the porosity, we need to add the calculations for the permeability values.

11. Select row 4 and select the *Calculation from Specification* action from the context menu. The Block/Corner Value Calculation dialog will appear. Check off the CMGLCustom_PermFromPor property only and click OK to close the dialog. You may have to uncheck Porosity and click OK few times to close a message dialog about the dependency of Porosity.

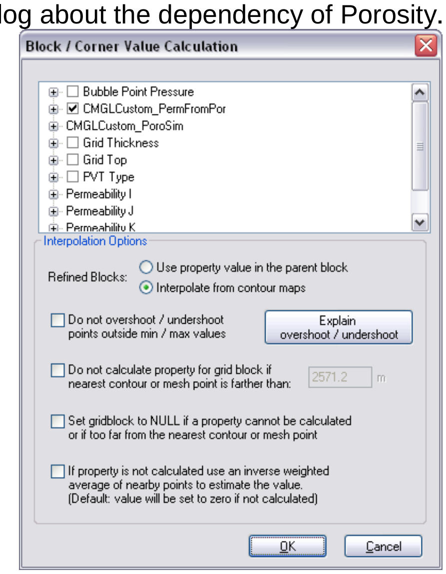


Figure 84: Specifying Permeability Calculation from Porosity

<u>*Note*</u>: This will add the CMGLCustom_PermFromPor calculation which is defined as a Formula using the Porosity property. CMGLCustom_PermFromPor will appear in the Results cell of

the Calculation from Specification action indicating that the CMGLCustom_PermFromPor property will be created or updated by this action.

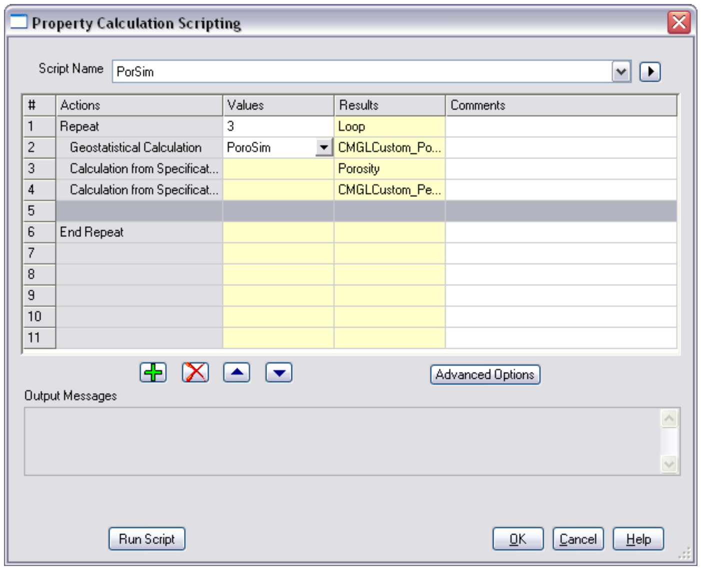


Figure 85: Script with CMGLCustom_PermFromPor Calculation

Now we need to add the Perm I. Perm J and Perm K which both depend on Perm I are not calculated in Builder. Instead, their EQUALSI specifications are directly passed on to the simulator. Therefore, we don't need to include them in the script.

12. Select row 5 and select the *Geostatistical Calculation* action from the context menu. A pull down list of geostatistical objects will be created in the Values cell of the geostatistical action. Select the WellTestSim geostatistical object from the pull down list (remember that this WellTestSim object was created earlier in this tutorial). The Permeability I property name will be displayed in the Results cell of the geostatistical action to indicate that this action creates or updates that property.

This will add the Permeability I calculation previously defined as a geostatistical object using the calibrated well test data.

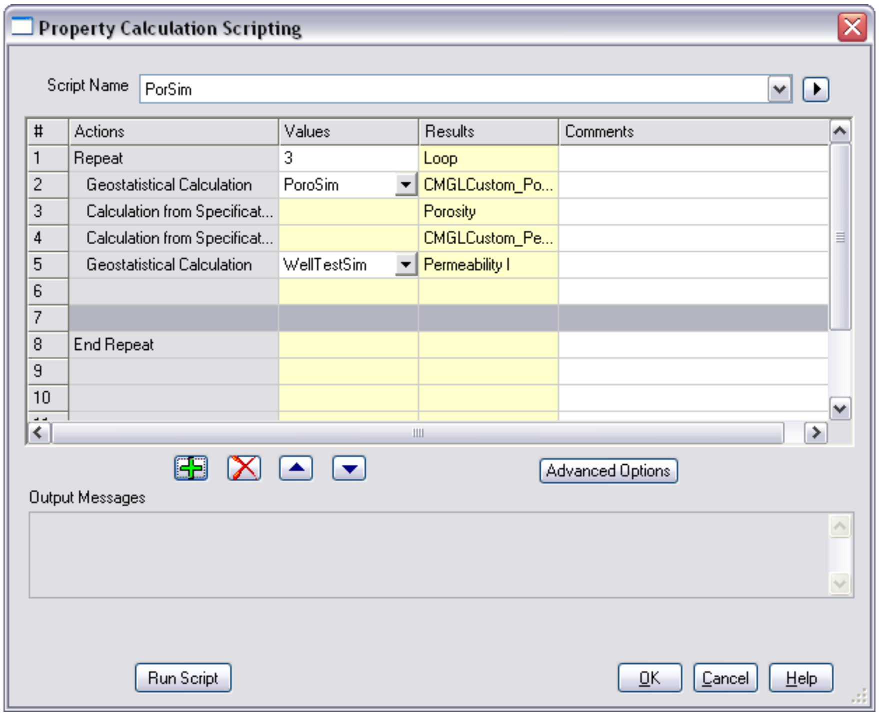


Figure 67: Script with Porosity and Permeability Calculations Specified

The next action of the loop is to save the current state of the dataset, which will have been updated for the Porosity and the Permeability values by the precedent actions.

13. Select row 6 and select the *Save As Dataset* option from the context menu. The Save As action dialog will appear.

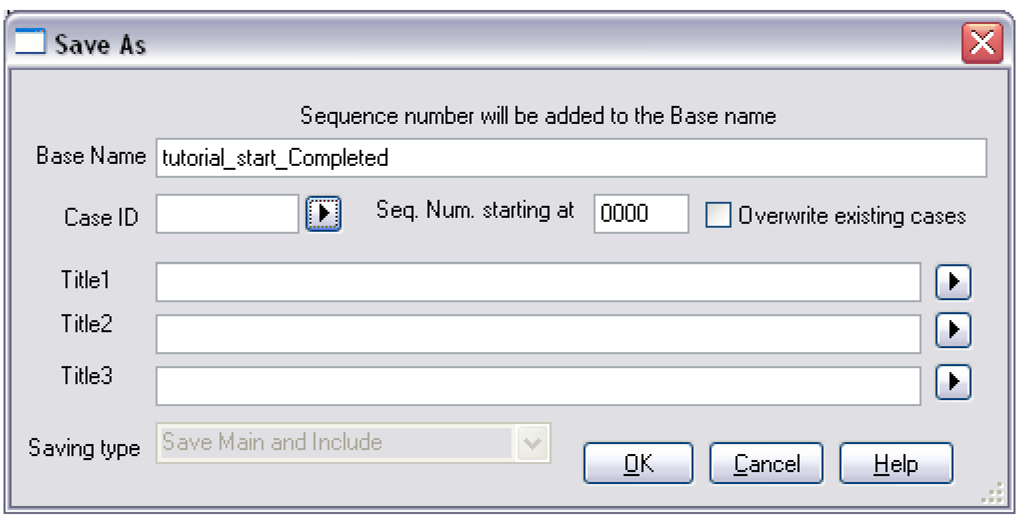


Figure 68: Saving Option in Scripting Dialog

<u>*Note*</u>: This dialog is used to define the names along with titles for the datasets that will be generated by the script. Macros are used to insert sequence number, script name, date, and dataset filename in any of the Title1, Title2, or Title3 in the dataset. The macros are accessible by clicking the right pointed arrow buttons at the right of the Title's edit field.

Click OK to close the dialog. This will create a series of datasets with the same base name; each appended with a sequence number starting with 0. From the above picture, the first dataset generated will be tutorial_0000.dat, the second will be tutorial_0001.dat and so on.

Finally, the last action of the script is used to send the current dataset to the flow simulator for initialization and initial volume estimations.

14. Select row 7 and select the *Simulator Initialization* option from the context menu. The Simulator Initialization dialog will appear.

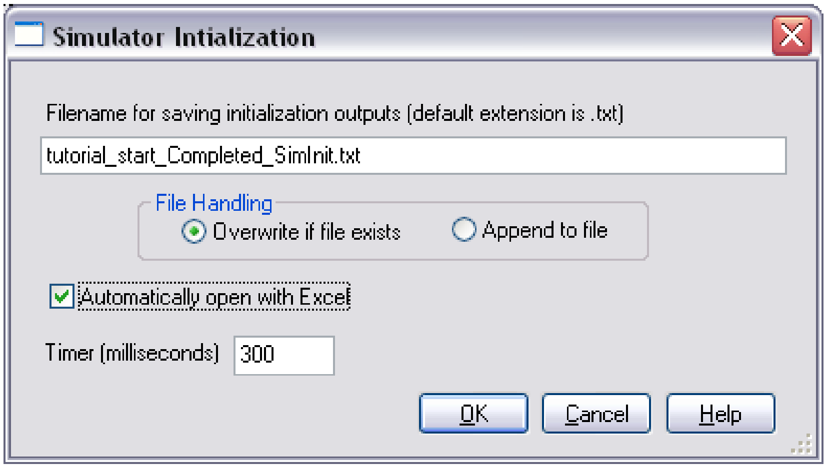


Figure 69: Simulator Initialization Dialog for Script

Note: This dialog is used to create an ASCII file with initial pore volume estimates for each datasets generated by the script. The file can be automatically opened in Excel when the script is finished executing. The Timer option is used to set a number of milliseconds for cycle time when trying to read the simulator outputs. Click OK to close, the Results value of the Simulator Initialization action (script row 7) indicates where the Excel compatible file will be saved.

The script is now complete. The scripting dialog should look like this:

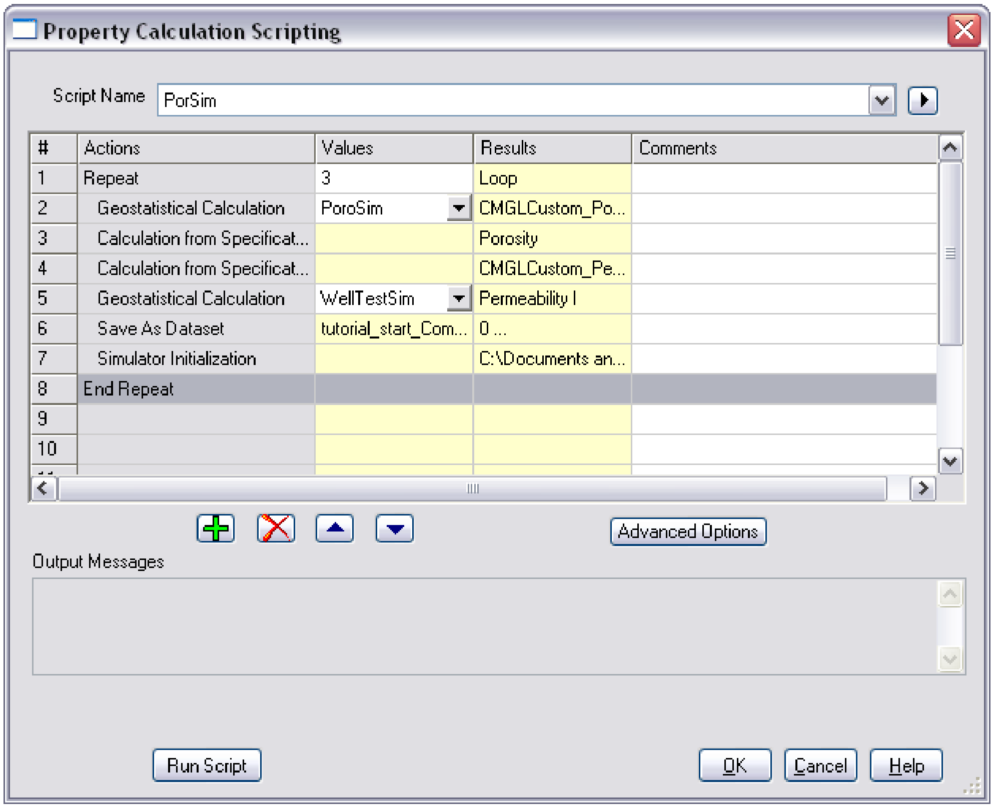


Figure 70: Final Script

15. You can run the script by clicking the Run Script button. You can also save it by clicking the OK button. This script will be saved with the dataset on a Save or a Save As selection from the File menu.

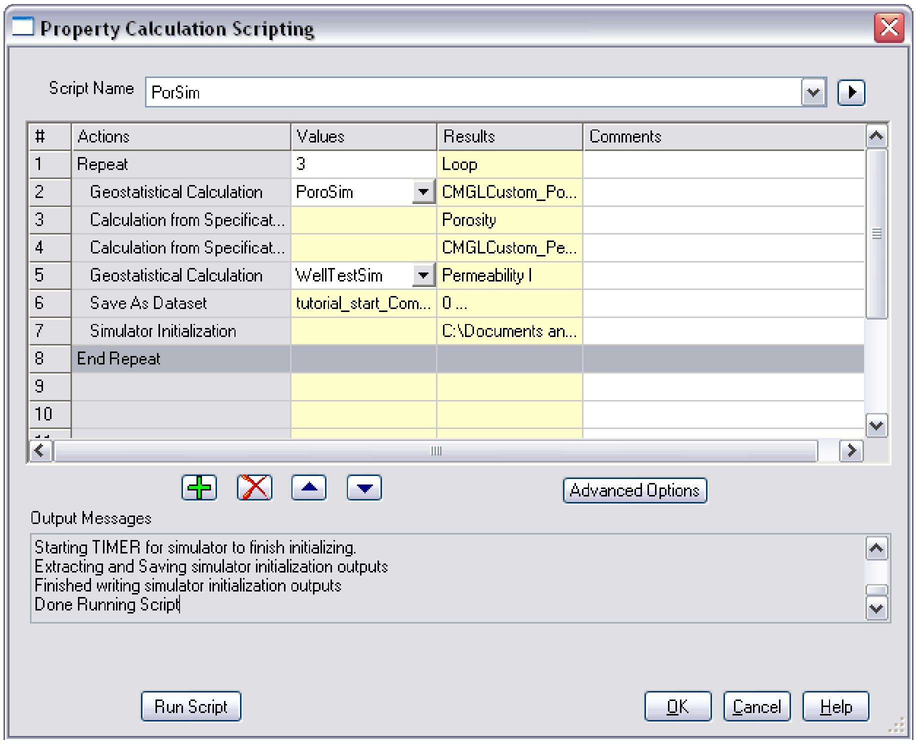


Figure 90: Script with Output Messages from being Run

Note: Running the script generates 3 versions of the dataset. The last dataset created by the script will become the Builder's current dataset showing the last property that was calculated by the script.

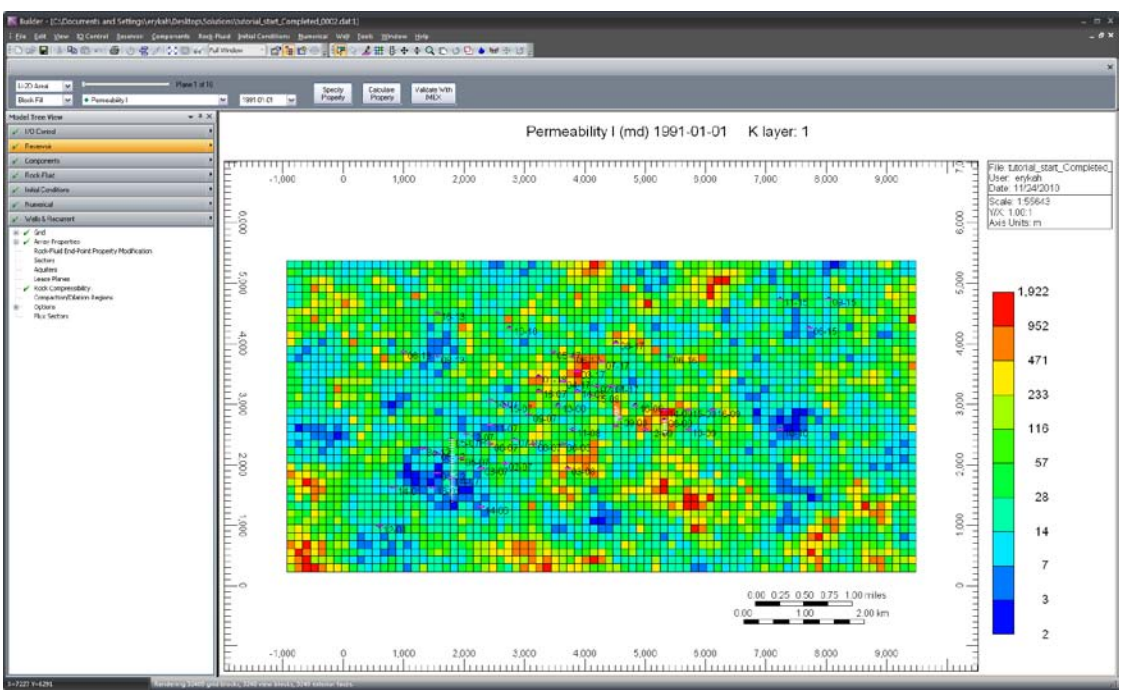
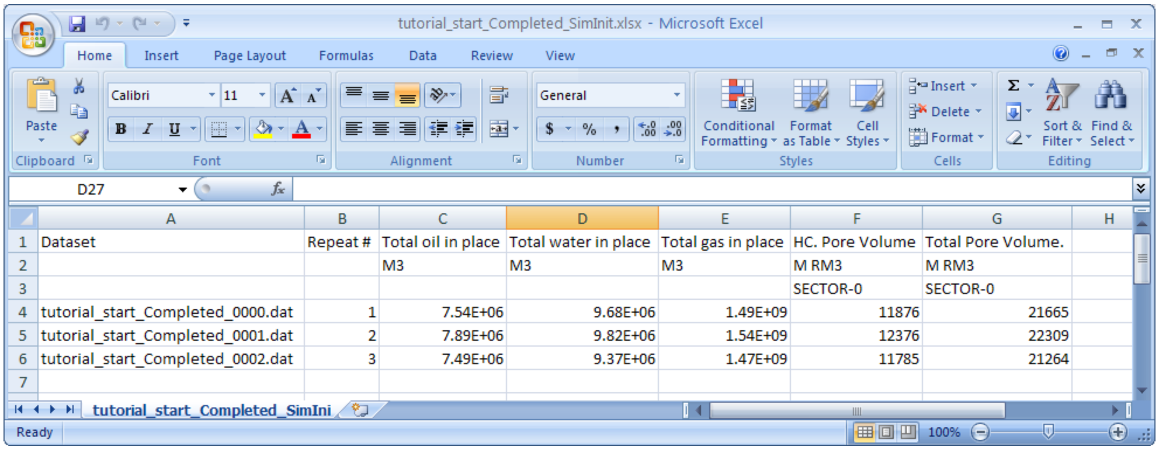


Figure 91: Reservoir View for Script Generated Dataset

The Excel compatible file will be automatically opened showing the initial volumes as estimated by the simulator.



	A	B	C	D	E	F	G	H
1	Dataset	Repeat #	Total oil in place	Total water in place	Total gas in place	HC. Pore Volume	Total Pore Volume.	
2			M3	M3	M3	M RM3	M RM3	
3						SECTOR-0	SECTOR-0	
4	tutorial_start_Completed_0000.dat	1	7.54E+06	9.68E+06	1.49E+09	11876	21665	
5	tutorial_start_Completed_0001.dat	2	7.89E+06	9.82E+06	1.54E+09	12376	22309	
6	tutorial_start_Completed_0002.dat	3	7.49E+06	9.37E+06	1.47E+09	11785	21264	
7								

Figure 92: Excel Worksheet Created by Script

Bonus Exercise: How the Thickness Map was Determined

Building the Reservoir Thickness

Note: To complete the reservoir geometry, we need to estimate its thickness below the top surface. Similarly to the reservoir top, the thickness too can be estimated by kriging. We need to import the thickness data into Builder. The next few steps are very similar to those we went through for estimating the reservoir top. At this point, you may find useful to save the dataset, close it, and reopen it. This will clear the variogram data values retained from the previous reservoir top data.

Data Importing

1. Open the Create Map dialog by selecting the Create Map File option from the File menu if not already open.
2. Change the File Name at the top of the Create Map dialog. You can type the new name directly in or navigate the folders by clicking the ellipses button [...]. Give a name like ThickMap.msh and an appropriate path where to save it. We are going to create a mesh file (extension ".msh") for the reservoir thickness.
3. Clear the spreadsheet of the Create Map dialog if it is not already empty. You can do it by clicking the gray cell at the very top left corner of the spreadsheet. This will select all the cells which can then be cleared by depressing the Delete key on the keyboard.
4. Open the file Thicknesses.xls in Excel if not already open. The file has 57 records with the well name, well (x,y) coordinates, and reservoir thickness for each record. We are going to paste that data into the Create Map dialog.

   Select the range of data values in Excel and copy (rows 2 to 58 and columns A to D).
5. Paste the data into the Create Map dialog with Ctrl-v (on the keyboard). Alternatively, you could have selected rows 1 to 59 of the Create Map dialog Points tab and selected the Paste option of the context menu (right mouse button).

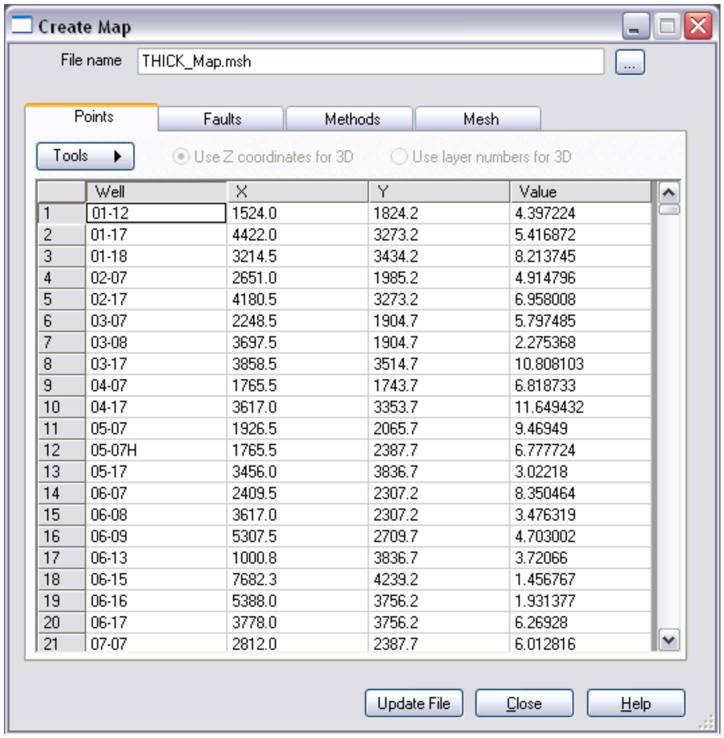


Figure 71: Inputting values for thickness map

Kriging Method and Variogram Modelling

6. Select the *Methods* tab, all the selections used to build the Top Map should be selected.
7. Keep the *Ordinary Kriging (OK) Estimation* option selected.
8. Change the horizontal Variogram direction to Omni-Directional
9. Click on "Click to edit variogram data and reset all the variogram parameters to Auto.
10. Click on the *Click to match variogram* button. The following variogram plot will appear (assuming all variogram parameters were reset to Auto):

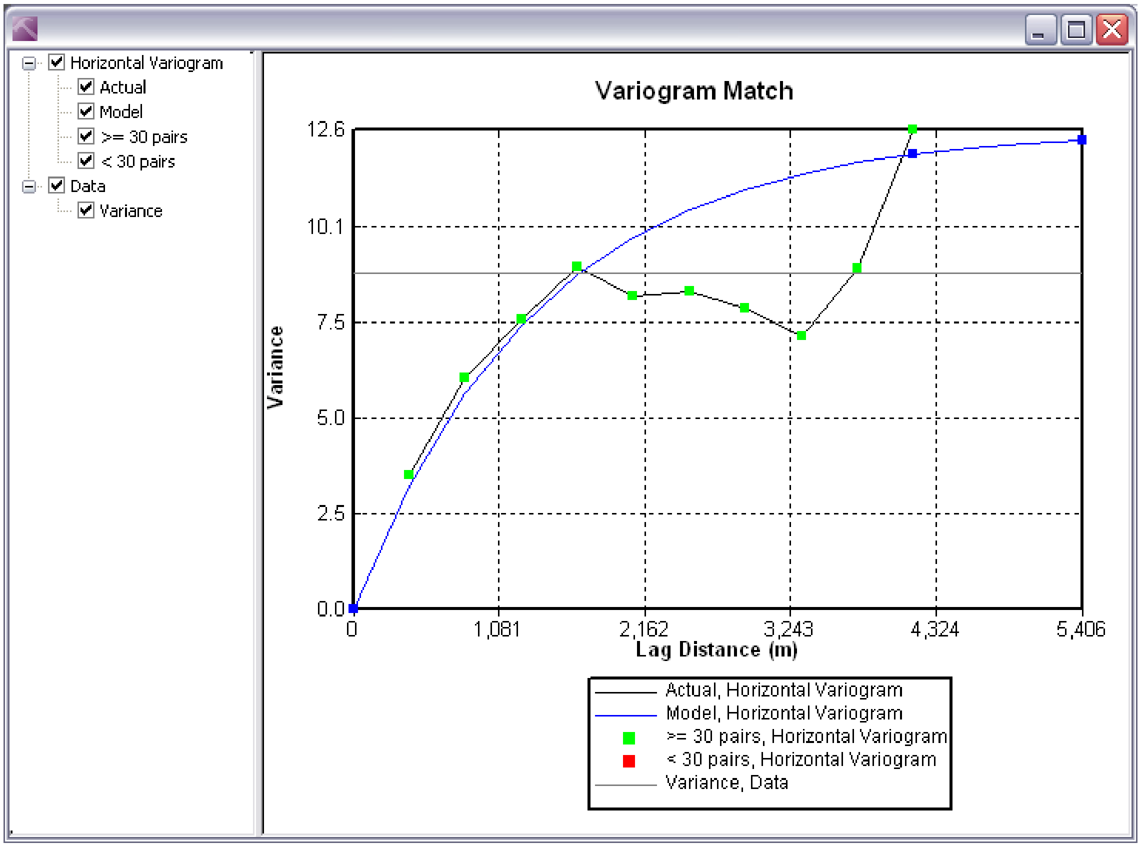


Figure 72: Variogram Plot for grid thickness

Note: Although the variogram fit looks good, it does need adjustment. Remember that we are dealing with a thickness attribute. The thickness is not likely to change abruptly over a very short distance. The actual variogram fit (blue curve) is not zero at the origin (zero lag distance). It has a small nugget effect which indicates that the model is compatible with abrupt thickness variations within very short distances. The nugget effect needs to be removed if this is not a plausible situation. A too high nugget effect is very often observed on variograms. This is explained by the usual lack of samples with very short separation distances. In this case, we should try to recompute the variogram for smaller lag distances.

Variogram Calculations

11. Close the variogram plot and use the *Click to edit variogram* data button to change the variogram calculation parameters with a number of lags of 20 (instead of 10) and a smaller lag size of 200 m as shown below. You will need to uncheck the Auto check box before you can change these values. These changes will allow for smaller lag distances (e.g. 200 m instead of the current value 415 m) and yet will cover a similar total separation distance than before (as an example 4000m = 20 X 200m = 10 X 400 m).

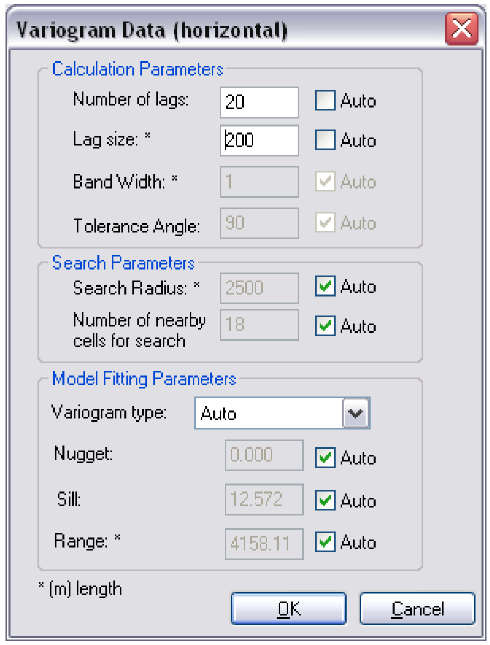


Figure 73: Editing Horizontal Variogram Data for Thickness Map

12. Click OK to close the variogram data dialog and click the *Click to match variogram* button to redisplay the variogram plot.
13. Hover the mouse on the blue rectangle at the origin of the variogram model and drag it down to zero. This will reset the nugget effect to zero.
14. Make other adjustments to the curve until the fit is deemed acceptable like in the picture below:

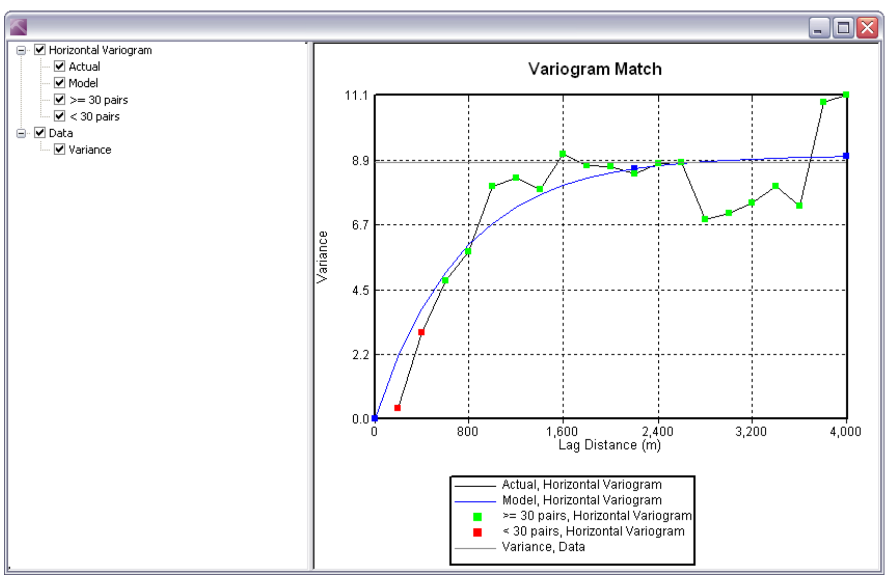


Figure 74: Variogram Plot for Thickness Data

Note: The first variogram point is almost at zero variance but now has been computed with less than 30 data pairs (red square mark). Although the point is marked to not carry enough statistical mass, it does suggest that the nugget effect could be smaller than first observed. We can now consider that we have a good variogram match. Notice that the variogram model matches the actual curve for a lag distance up to about 3300 m. For distances larger than 3300 m, the actual variogram does continue to increase which indicates that a deterministic trend actually creates more important variations than variations associated with the spatial correlation between the data. This suggests that we should apply kriging in a limited search window.

15. Close the variogram plot window and click the *Click to edit variogram data* button. Uncheck the *Auto* option for the search radius and set the search to 3300m as shown below.

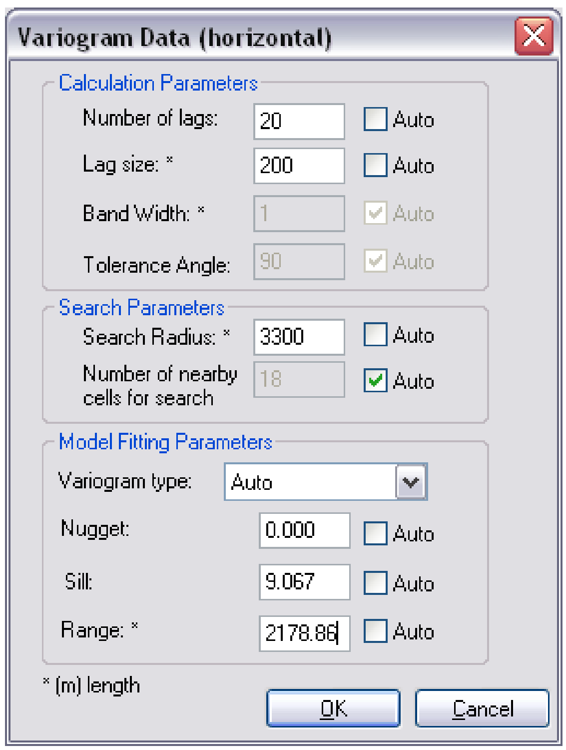


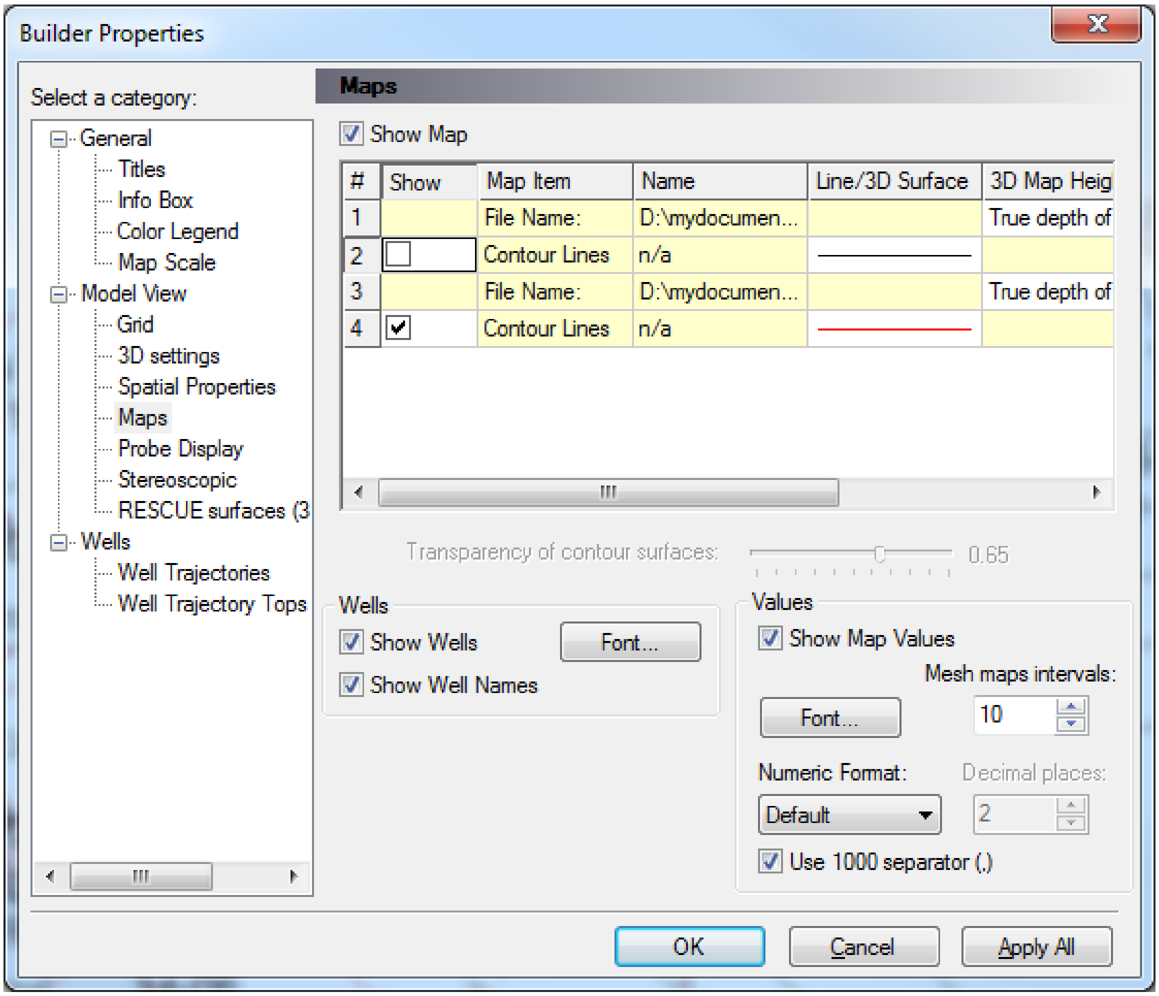
Figure 75: Editing search radius for thickness map

16. Click the OK button to close the Variogram Data dialog. We are now ready to compute the thickness map.

Kriging the Thickness Surface

17. Click the Save File (or Update File) button to actually perform the interpolation with kriging and save the results as a mesh file. After the calculations, the kriged map will show up in the Builder main view. However you also will see the Top map in the view, so close the top map by going to the properties

window (click on the top icon  Set/modify properties), select the maps option and uncheck the top map. Click OK



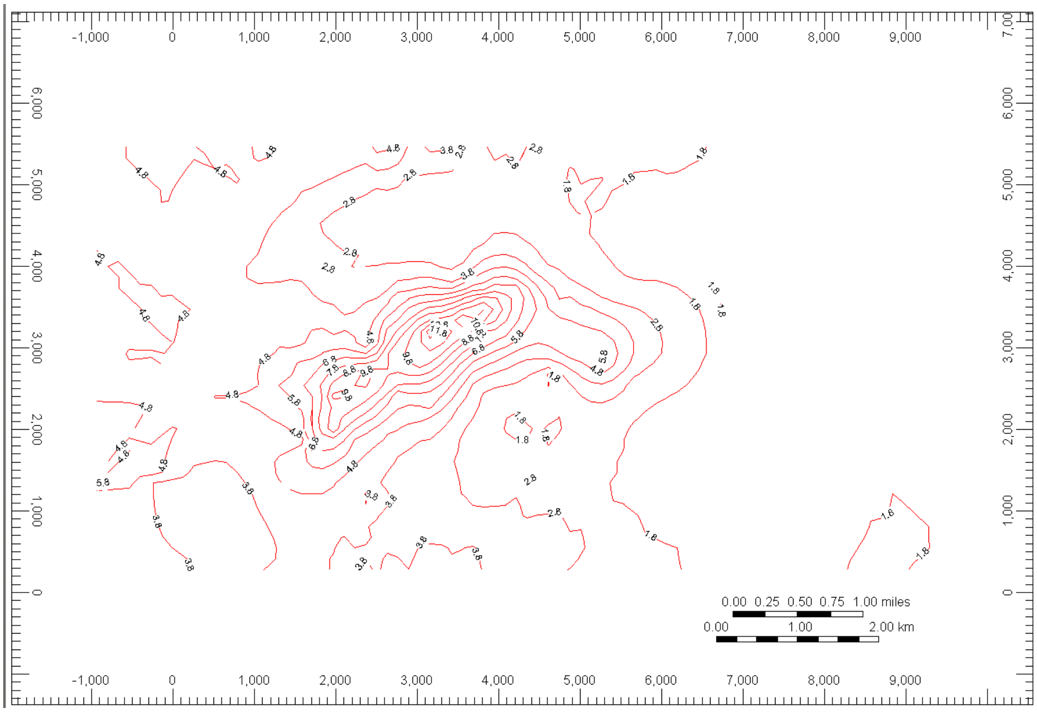


Figure 76: Map for Reservoir Thickness

18. You can now close the Create Map dialog since we have completed all the maps.