COMPUTER MODELLING GROUP LTD.

Introduction to CMG's Workflows

Builder & IMEX Tutorial 2021

cmgl.ca

#FutureOfSimulation

21.CMG.18

Table of Contents

Creating a "Black Oil" Model Using Builder

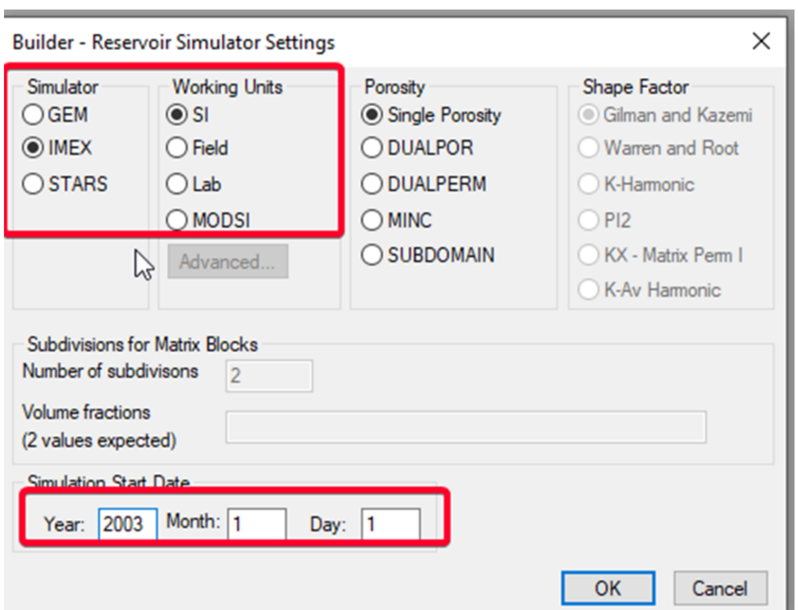
The first exercise will go through the steps of creating a black oil IMEX dataset using builder. In addition to getting familiar with CMG software, this tutorial will also go through the procedure of performing a history match. Once a history match is obtained, a few prediction scenarios will be modelled.

Starting CMG Launcher

1. Start the CMG Launcher by using the icon on your desktop, or by going through the **Start** menu and selecting Programs/CMG/Launcher.

Opening Builder

2. Open Builder by double clicking on the appropriate icon in the Launcher.
3. Select the new file icon .
4. Choose:
    1. **IMEX** Simulator, **SI** Units, **Single Porosity**
    2. Starting date **2003-01-01**
5. Click **OK** twice.



Note: The Simulation Start date cannot be changed in Builder but can be edited in a Text Editor

Figure 1: Reservoir settings in builder

Importing a Rescue File (Structural and Property Data)

6. Click on **File** (on the menu bar, top left), then **Import from another file**… and then **RESCUE/RESQML Model**.
7. Select the RESCUE file from the **Required Data (Rescue)** folder. The RESCUE file is in a binary format and will have a .bin extension, select **RESCUE.bin.**
8. Click **OK** in the dialogue box related to the description of RESCUE model and accept the Grid creation options by default as shown in the following figure.

   A rescue file can be generated with any geological commercial software (E.g., PETREL, GOCAD, etc.). Typically, a rescue file includes the grid, faults and properties (E.g. porosity and permeability).

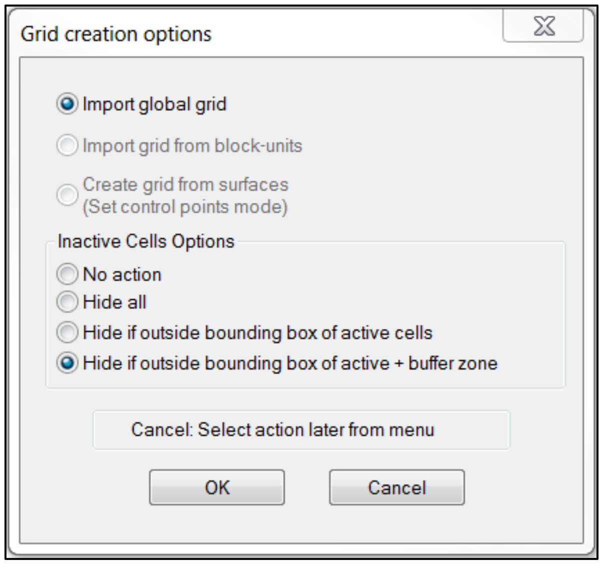


Figure 2: Importing RESCUE grid

9. A new window will appear with the original properties defined in the RESCUE file (left window) and a list of properties to match the CMG software (right window). If the name of the rescue property is the same as name of CMG property, Builder automatically assign the Rescue property to the corresponding CMG property. From the rescue, we have these properties: NULL Blocks, Pinchout Array, Permeability I, Permeability J and Porosity.

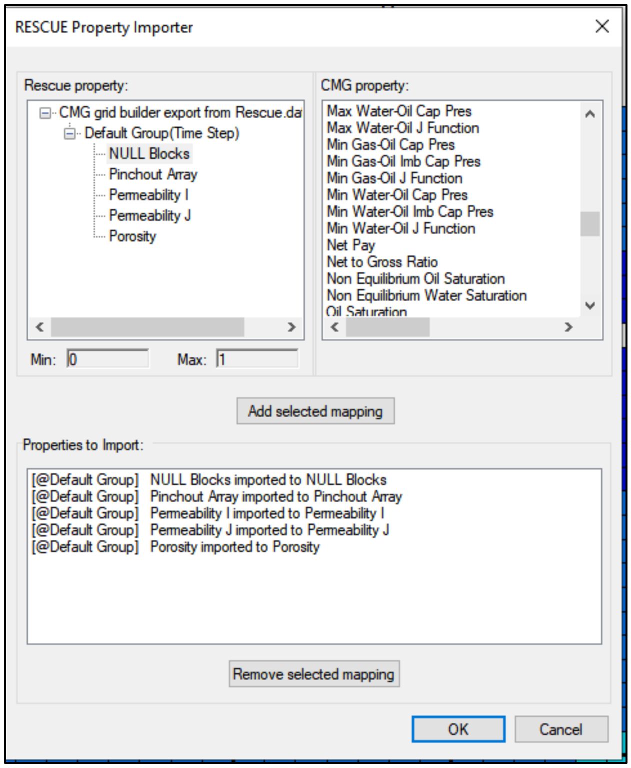


Figure 3: Panel for selection of properties from RESCUE file

For the cases, that name of rescue property is different from CMG property you need to select a property from the RESCUE file and the corresponding CMG property. Then click on the **Add selected mapping** button to add the property from the rescue file into the Builder model.

10. A new grid with properties will be displayed. Change the view from IJ-2D Areal to 3D View in the upper left corner.

11. Click on the Rotate (3D View) button  (from the toolbar) to rotate the display by holding down the left mouse button and using the cursor to move the model. Hold down the **Ctrl key** and the left mouse button and move the mouse toward the bottom of the screen to zoom in or move the mouse to the top of the screen to zoom out. If a mouse has a scroll wheel, this can also be used to zoom in and out by scrolling the wheel forward (zoom out) or backward (zoom in).

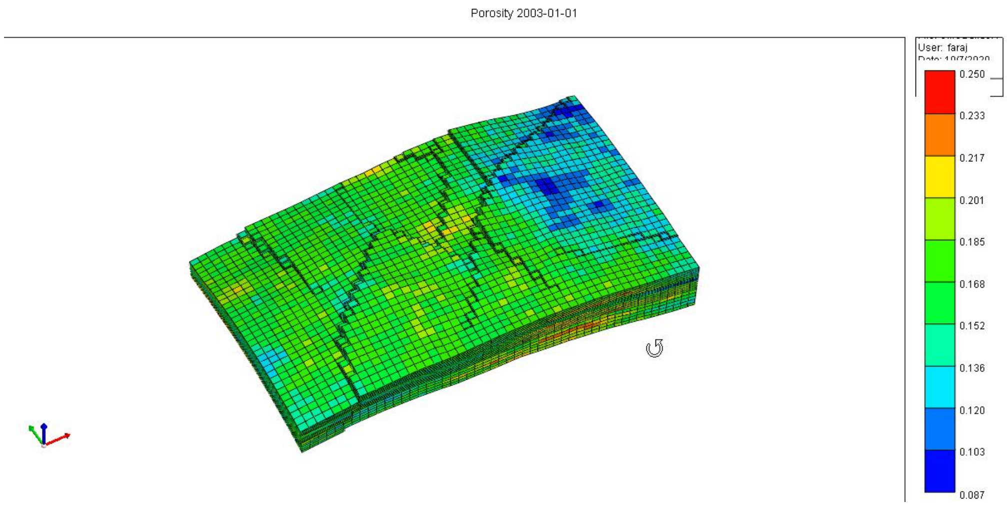
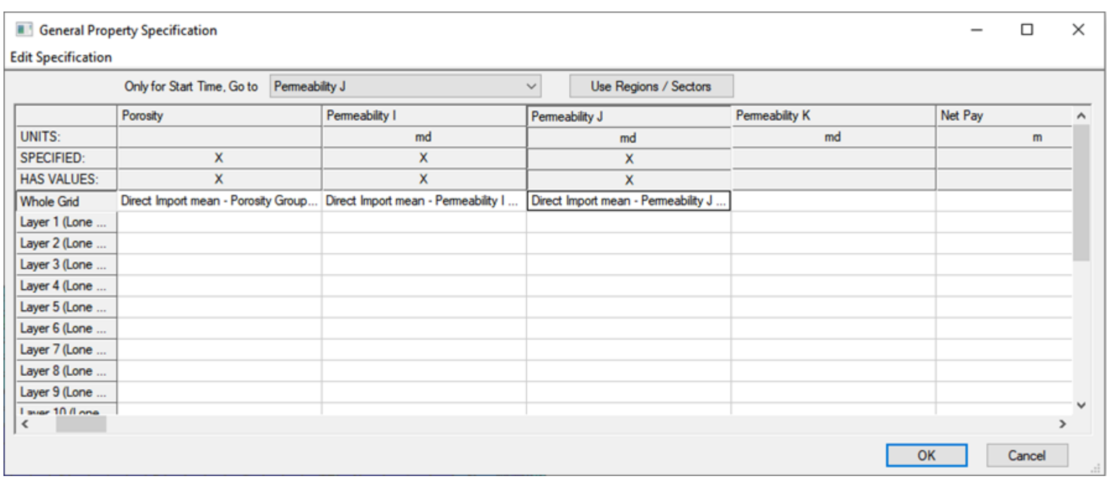


Figure 4: 3D View of the imported grid and distribution of porosity

Note: Depending on the purpose of the simulation and resources available, a full geological model complete with grid and properties may not always be available. Therefore a grid will need to be manually generated, which can be done using Builder. There are several options available when building a grid from simple box models (Cartesian) to complex corner point grids. Frequently, the grid top and thickness data for the reservoir may be given as an aerial contour map. A map can be used to size and properly orient the simulation grid as well as populate the properties in the grid blocks. A sample map file has been provided in the **Required Data** Folder. If time allows, the instructor will demonstrate the steps of how a map file can be used to create and populate a grid.

Assigning Vertical Permeability (K direction) and compressibility to the Model

12. Change display control to Probe mode by clicking on this toolbar button on the top tool bar.
13. Click on the **Specify Property** button (top middle of the screen) to open the General Property Specification spreadsheet as shown below.


General Property Specification
Edit Specification
Only for Start Time, Go to Permeability J
Use Regions / Sectors

	Porosity	Permeability I	Permeability J	Permeability K	Net Pay
UNITS:		md	md	md	m
SPECIFIED:	X	X	X		
HAS VALUES:	X	X	X		
Whole Grid	Direct Import mean - Porosity Group...	Direct Import mean - Permeability I ...	Direct Import mean - Permeability J ...		
Layer 1 (Lone ...					
Layer 2 (Lone ...					
Layer 3 (Lone ...					
Layer 4 (Lone ...					
Layer 5 (Lone ...					
Layer 6 (Lone ...					
Layer 7 (Lone ...					
Layer 8 (Lone ...					
Layer 9 (Lone ...					

OK Cancel

Figure 5: General Property Specification Spreadsheet

14. In the **Specify Property** window, from the **Go to Property** dropdown menu, select **Permeability K.** Right click in the Whole Grid Cell and select **EQUALSI**. In the window that appears select ***** in the **EQUALSI** dropdown. Next enter **0.1** in the second field (this applies a K_v/K_h ratio of 0.1). Press the **OK** button.
15. Press **OK** in the Specify property window. Next the Block / Corner Value Calculation window will pop up. Click OK to populate the grid with these new properties.
16. Double click on **Rock Compressibility** in the tree view menu and input **7.25E-6 1/kPa** in the **Rock Compressibility (CPOR)** box, **20,000 kPa** in the **Reference Pressure (PRPOR)** box and click **OK**. Units will be applied automatically. You should now have the green check mark for Reservoir section.
17. This would be a good point to save the data set you are working on. Click **File,** and then **Save As.** Save the file as **IMEX_TUTORIAL.DAT** under your Student Solution/History Match folder.
18. Analyze different cross sections e.g. IK-2D X-Sec to display the properties distribution, layer thickness and become familiar with the model.
19. To display the dimensions of some grid cells in the models, right click on the main screen and select **Properties.** In the **Properties Window** that appears select **Probe Display** and check the box for **Block Dimensions**. Also, check the box **Other spatial property values at the same time** and highlight **Permeability K** and **Porosity**. Also, check **Use Auto Probe** then Click **OK.**

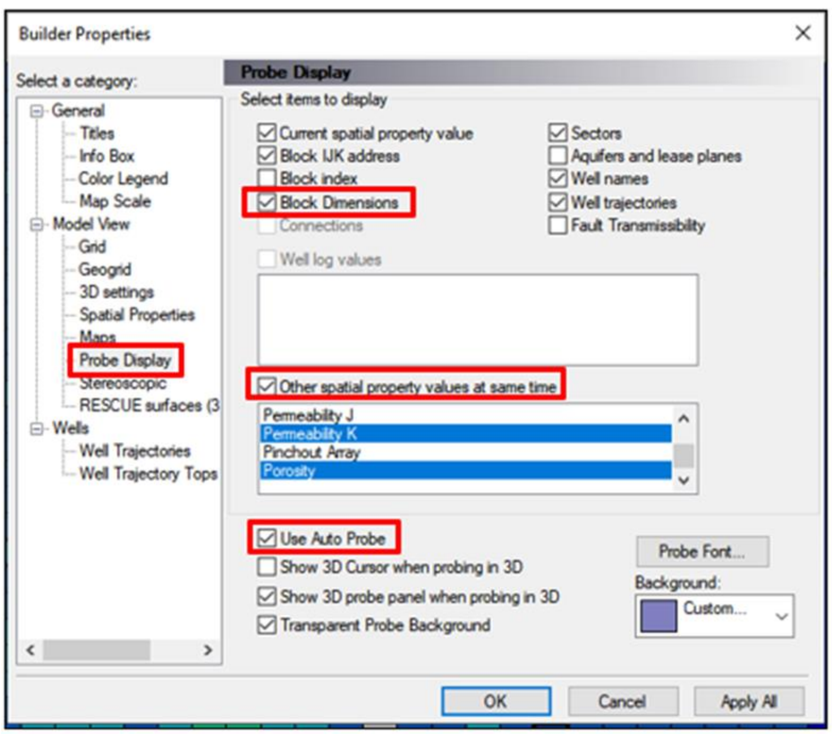


Figure 6: Builder properties (probe display option)

20. Hovering mouse on a grid cell will now display its dimensions. Select the property of **Grid Top** and using the plane slider select different cross sections of the model in 2-D views.

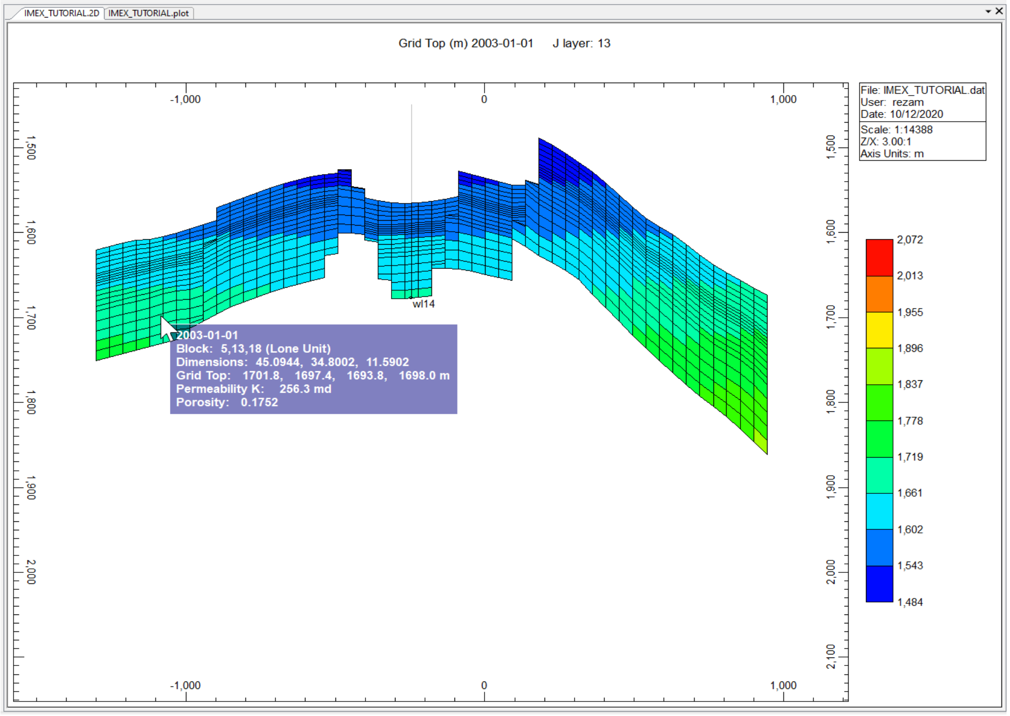


Figure 7: Cross section and block cell properties

Creating PVT Data Using Correlations

21. Click on the **Components** tab in the tree view and double click on **MODEL**.

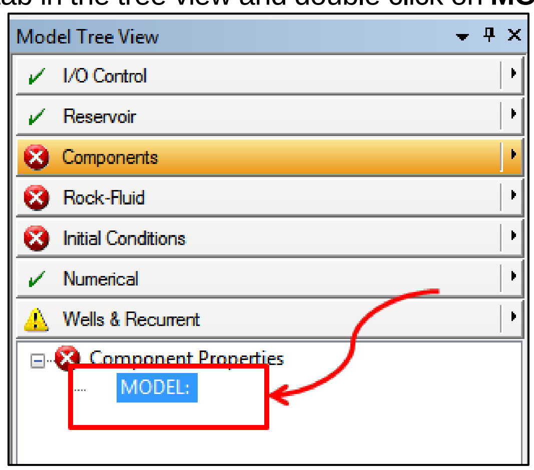


Figure 8: Components tab in the tree view

22. Check on **Launch Dialog to Create a Quick BLACKOIL Model Using Correlations,** and then press the **OK** button.

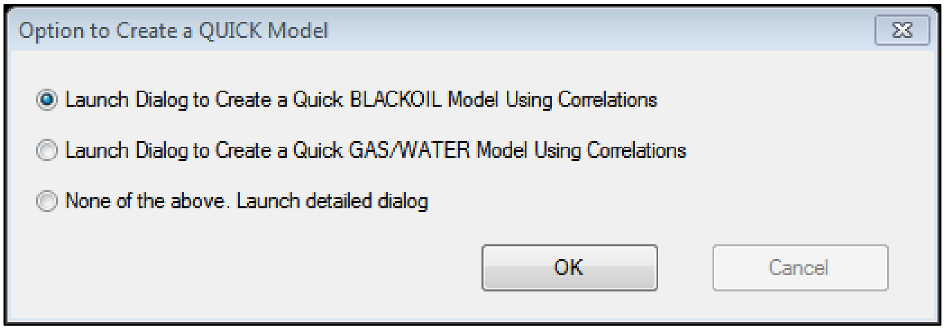


Figure 9: Creating a quick model

23. Enter **50** (°C implied) in the **Reservoir Temperature** box. Generate data up to the maximum pressure of **35,000 kPa**. For **Bubble Point Pressure Calculation**, select the **Value provided** option and enter **9,000 kPa**. For the **Oil Density at STC**, select **Stock tank oil gravity (API)** as the type of gravity value to use and enter **18** in the data entry window. Change the **Gas Density box at STC** to display **Gas Gravity (Air=1)** and type **0.70** in the data entry window. Click **OK**.

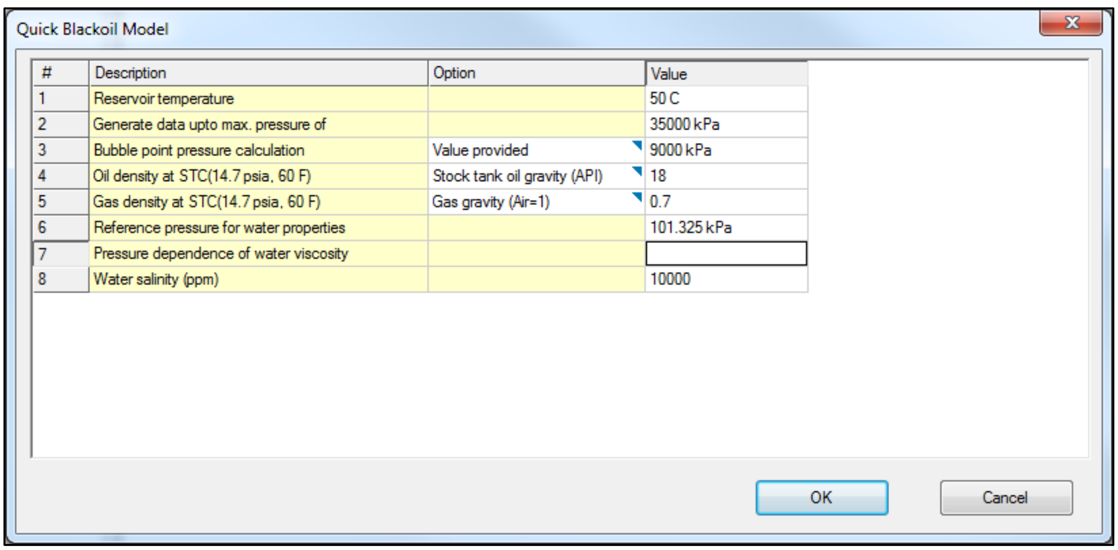


Figure 10: Parameters for a quick black-oil model

24. Double click on **PVT Region: 1** in the tree view and select the **PVT Table** tab to view the BLACKOIL PVT data. For this example, the data shown in this table was generated using the information entered in the **Quick black oil model** window. However, it is also possible to enter directly or edit values in the PVT Table.
These values can also be updated by using your mouse to select points on the plots associated with the PVT Region, and dragging the points to the desired location. Please note that the IMEX PVT Regions window has to be open while using your mouse to change the points on the plot.

25. **Uncheck** the **Include Oil compressibility in PVT table** box to use constant oil compressibility.

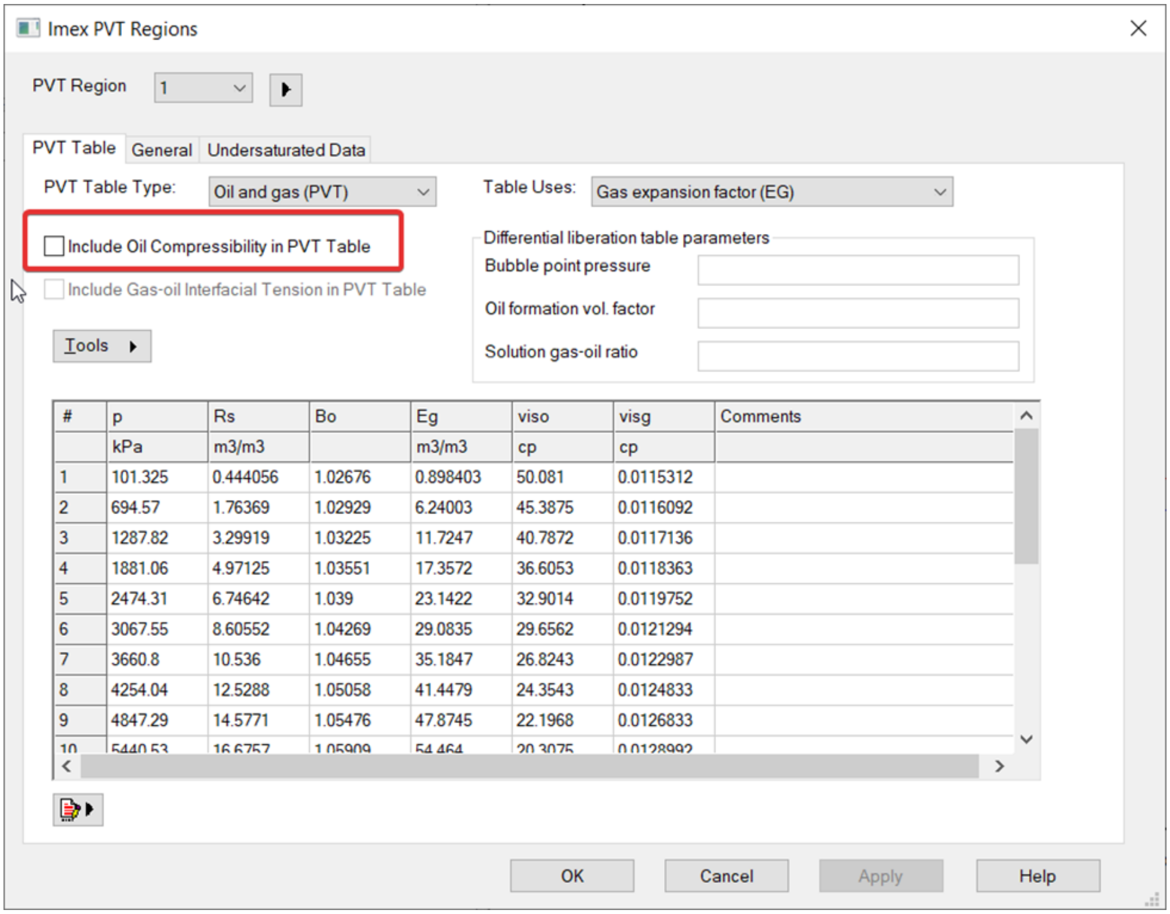


Figure 11: IMEX PVT table with the values generated using the quick black-oil model

26. Go to the **General** tab and input the value of **5e-06 1/kPa** for the **Undersaturated Co (CO)**. Click on **Apply** and **OK**.
27. The **Component** section should have a **green** check mark now.

Creating Relative Permeability Data

28. Click the **Rock-Fluid** button in the left-hand side menu.
29. Double click on **Rock Fluid Types** in the tree view. A window will open. Click on the button and select **New Rock Type**.
30. Press the **Tools** button (on the Relative Permeability Tables tab) and select **Generate Tables Using Correlations**.

31. Enter the following parameters for the analytical relative permeability curves generation. You can also click on Show Equations to view the correlations used by Builder

SWCON	0.2
SWCRIT	0.2
SOIRW	0.4
SORW	0.4
SOIRG	0.2
SORG	0.2
SGCON	0.05
SGCRIT	0.05
KROCW	0.2
KRWIRO	0.8
KRGCL	0.8
KROGCG	0.2
Exponent for Krw	2.0
Exponent for Krow	4.0
Exponent for Krog	4.0
Exponent for Krgcl	4.0

32. Press **Apply** and then **OK**. Press **OK** again to exit the **Rock Types** window. A graph containing the relative permeability curves will appear.
33. The **Rock Fluid** section should have a **green** check mark. **Save** the file at this time. You cannot be in the Rock-Fluid section to save.

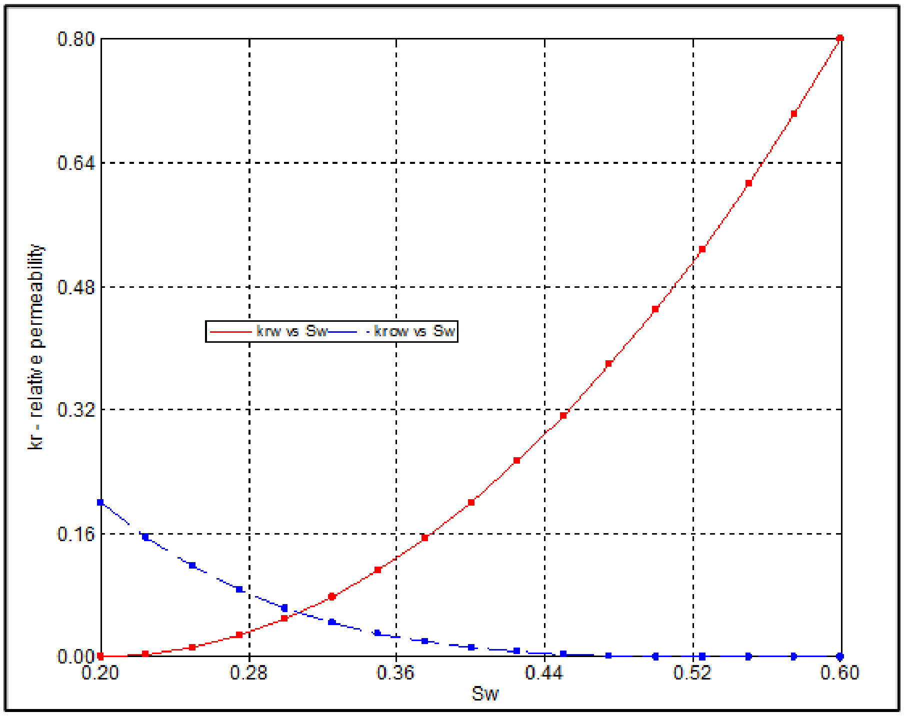


Figure 12: Oil-Water relative permeability plot for Rocktype 1

Creating Initial Conditions

34. Click the **Initial Conditions** button on the tree view of Builder.
35. Double click on **Initial Conditions**.
36. Select **Water, Oil** as the initial fluid in the reservoir to perform a Gravity-Capillary Equilibrium Calculation.
37. Type in the following values in the available fields:

    20,000 (kPa) in the Reference Pressure (REFPRES) box

    1,605 (m) in the Reference Depth (REFDEPTH) box

    1,750 (m) in the Water-Oil Contact (DWOC) box

    9,000 (kPa) in Constant Bubble Point Pressure (PB) box
38. Leave the other boxes blank. Initial Conditions interface should look like this:

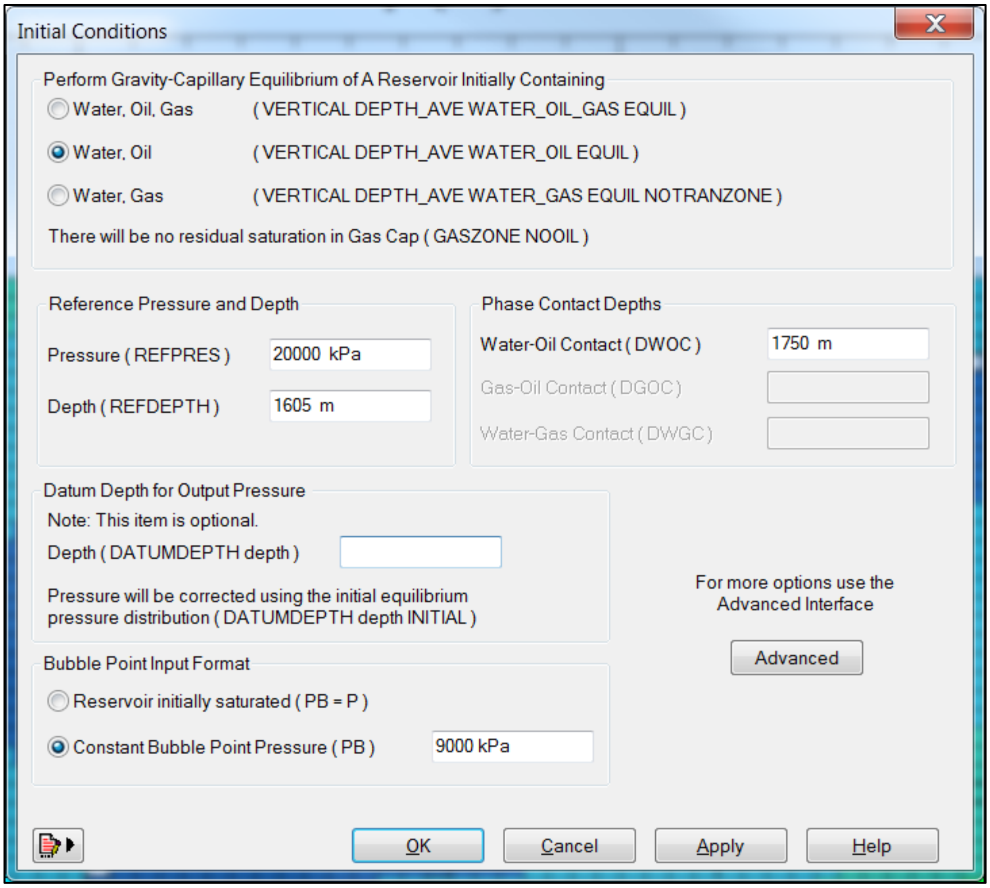


Figure 13: Initial conditions interface

39. Click **Apply,** and then **OK**.
40. You should now be back in the main Builder window with all tabs showing a **green** checkmark in the tree view, except for the Wells & Recurrent tab.
41. At this point, it is advisable to **save** the data again by selecting **File** from the top menu and clicking **Save**.

Adding Well Trajectories and Perforations

Once we have created the static model, we will now incorporate the well trajectory and perforation information into the model.

42. Go to the Builder main menu and select **Well → Well Trajectories → Well Trajectories…**. The **"Import well trajectory wizard. Step 1 of 3"** window (3-step Wizard) will pop up.
43. You need to choose the Trajectory File Type and appropriate Units.
44. Choose **"Table Format"** and **"m"** for X, Y and Z, MD, then browse for the file **"IMEX_TRAJECTORIES.wdb"**. This file can be found in "Required Data" Folder. **Open**, and press **Next** (Step 1 of 3).

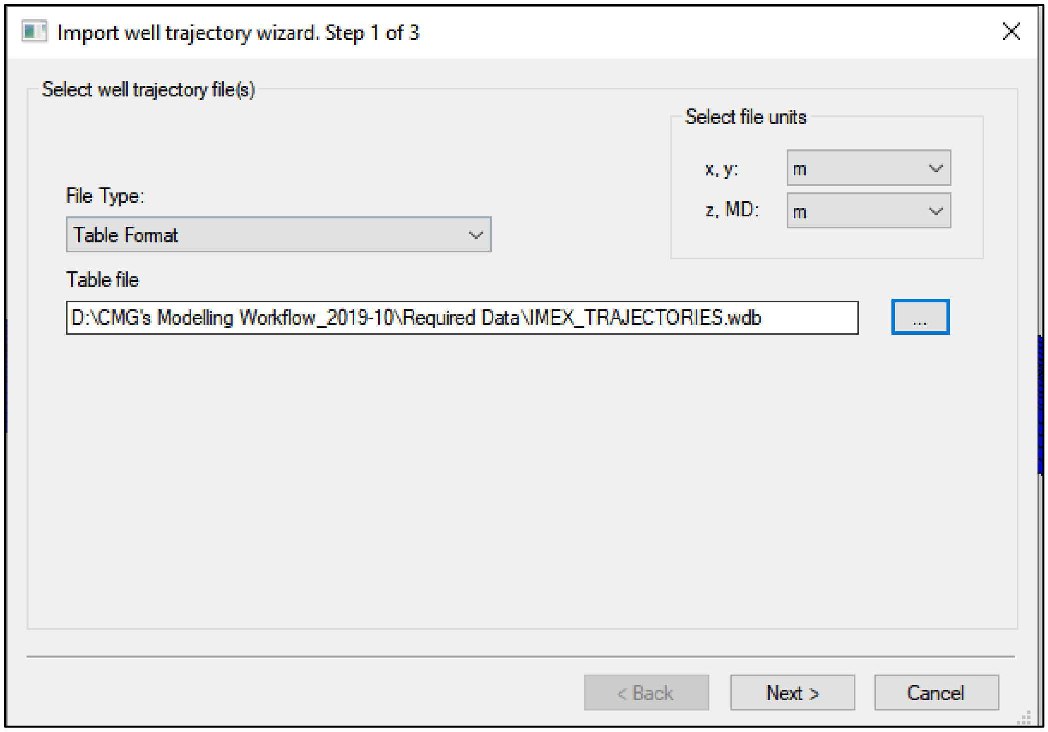


Figure 14: Trajectory properties window, Step 1 of 3

45. The following window will open. Make sure all wells are selected, uncheck **Automatic data point reduction** and check the box **Clear all existing trajectories,** then press **Next** (Step 2 of 3).

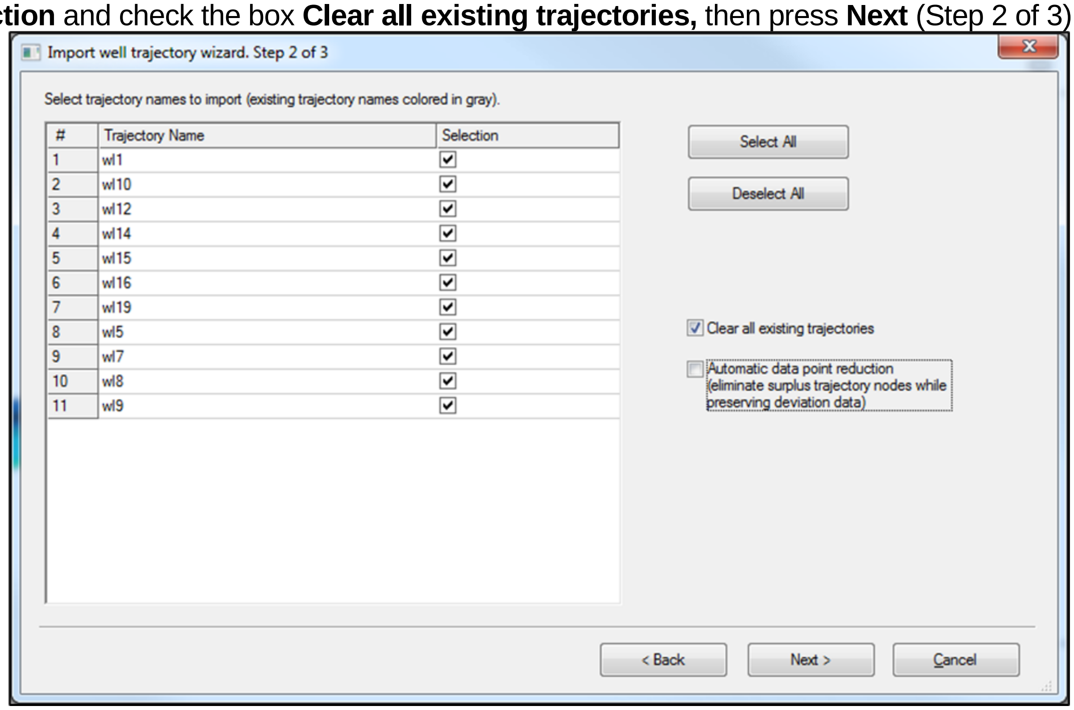


Figure 15: Trajectory properties window, Step 2 of 3

46. Click **Finish** to complete Step 3 of 3.

47. Now go back to the top menu and select **Well**, **Well Trajectories** and click on **Trajectory Perforation Intervals….** A window will open.
48. Click on **Read File** and change the **File unit selection** option to **SI,** and then browse for the **IMEX_PERFORATIONS.perf** located in the Data Required folder. Leave the combine perforation data within 5 days and press **Open**.
49. If this is done correctly, the window will be like the one shown in Figure 16.
50. Press **Apply** and then **OK**. This completes the trajectories and perforation of the wells in the model.

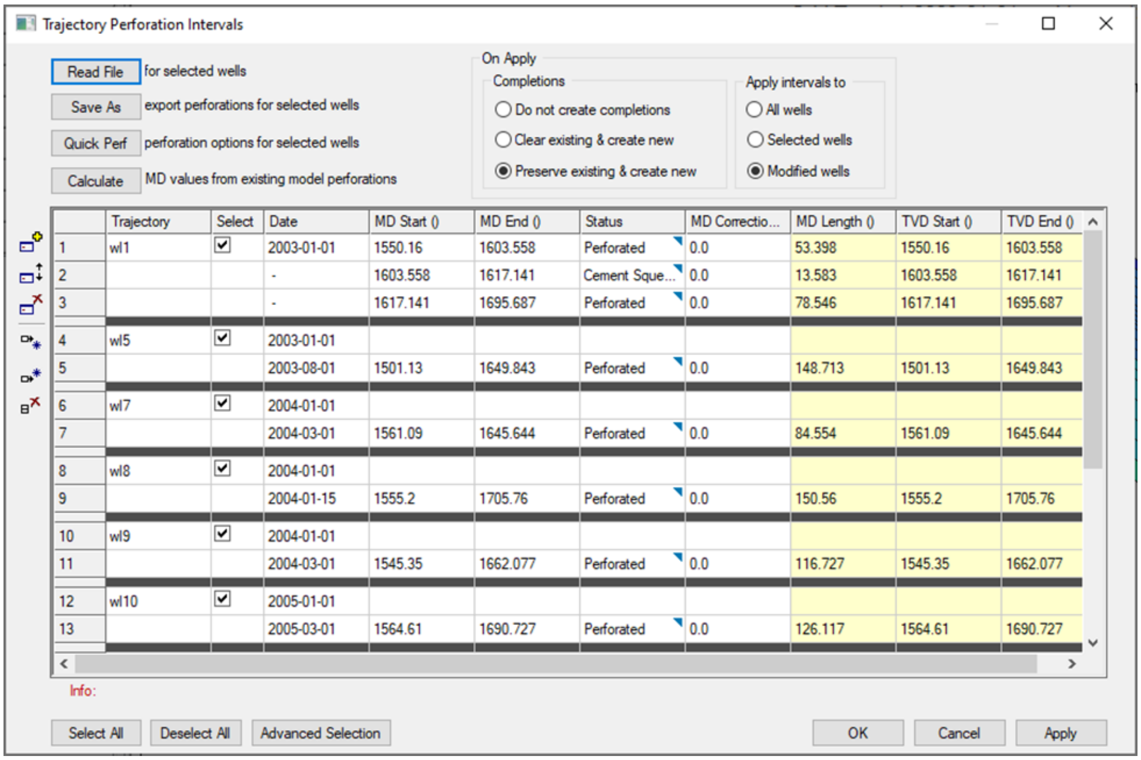


Figure 16: Trajectory perforations window after reading perforation file

Viewing Trajectory and Perforations in 3D

We can view the trajectories and perforations in 3D by increasing the transparency of the grid

51. Change the 2D view to 3D view in the upper left hand corner and click on **Rotate Reservoir** mode.

52. Right-click anywhere on the screen and select **3D settings**. Change transparency setting from 0 to 0.6 and uncheck the **Show Grid** box. Select **Apply All**. The reservoir should now be completely transparent and the well trajectories and perforations should be visible. You will need to choose date of 2006-11-1 in the toolbar (2006-11-01) to view the trajectories and perforations of all wells in this field

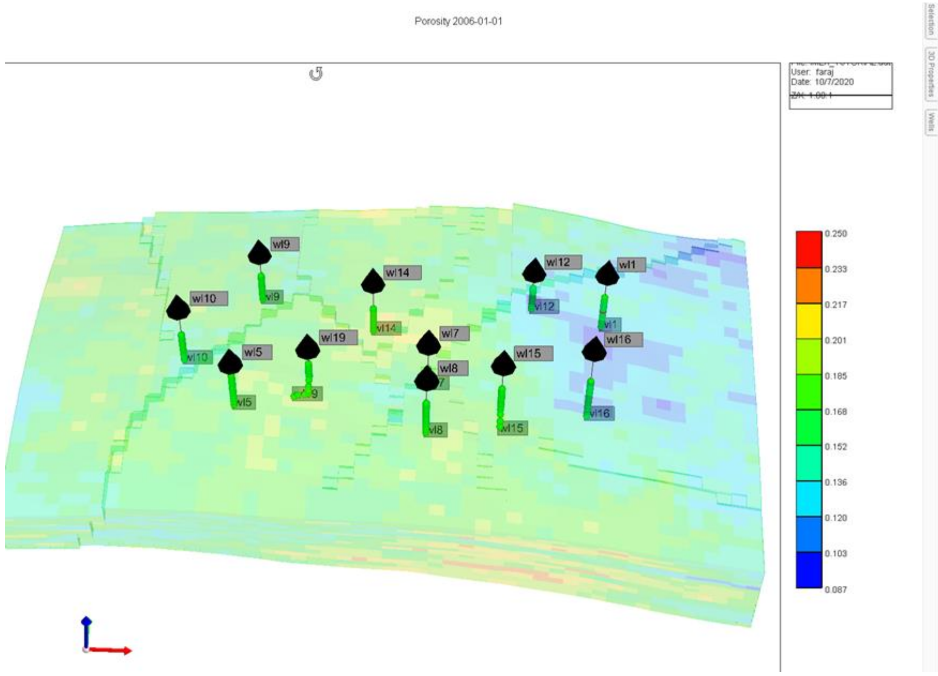


Figure 17: Trajectory and perforations after increasing transparency (Date 2006-11-1)

53. Change the transparency back to 0 in order to see the grid and check the Show Grid box.

Adding Historical Production Data to the Model

The last item we want to do is to add historical rate data so that we can set up a history match run.

54. Go to the main Builder menu and select **Well → Import Production/Injection Data** (this is the wizard used to import production/injection data into the well & recurrent data for the simulator and it defines the status of each well).
55. **STEP 1:** First step of this wizard is to provide the type and name of the production file. In our case, we will use **General** and select the file named **IMEX_PROD_HISTORY.prd** from the Data Required folder. Press the **Next** button.
56. **STEP 2:** Follow the instructions and highlight the first line containing the production data (top window) and well name (lower window) (as shown in the following figure). Press **Next**.

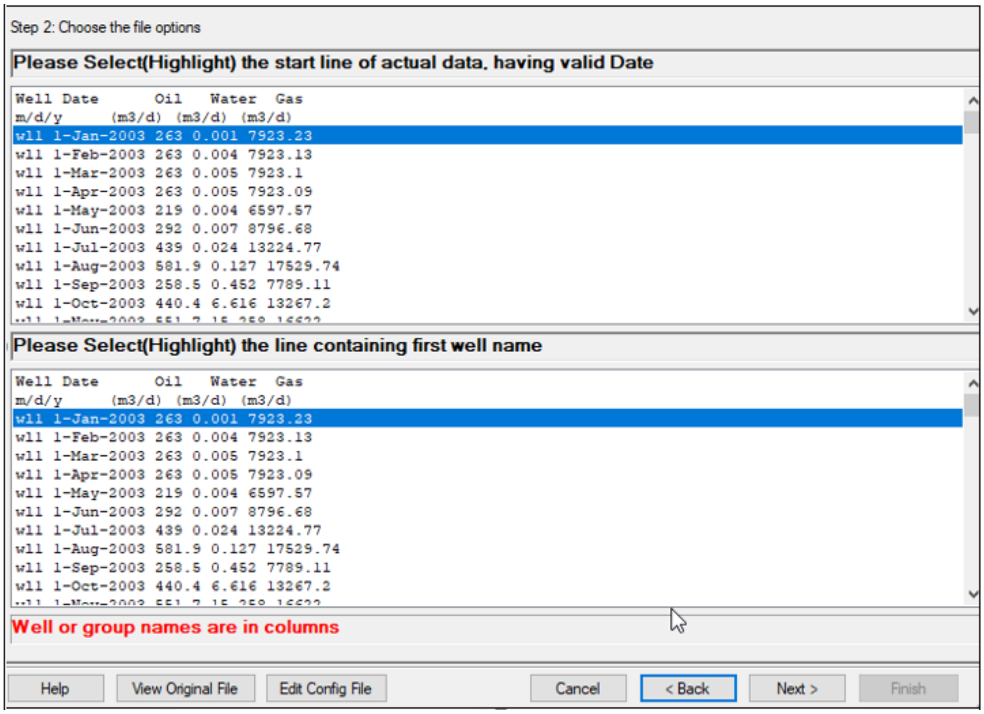


Figure 18: Step 2 of the production data wizard

57. **STEP 3:** If the delimiters look good and separate the columns correctly, click **Next** to go to STEP 4.
58. **STEP 4:** Go through Columns 1 to 5 and in the identifier row, choose **Well/Group name**, **Date/Time, Oil Produced**, **Water Produced** and **Gas Produced** for each column respectively. Leave other cells under each identifier as default as they pop up, and then click **Next** to go to the next step.

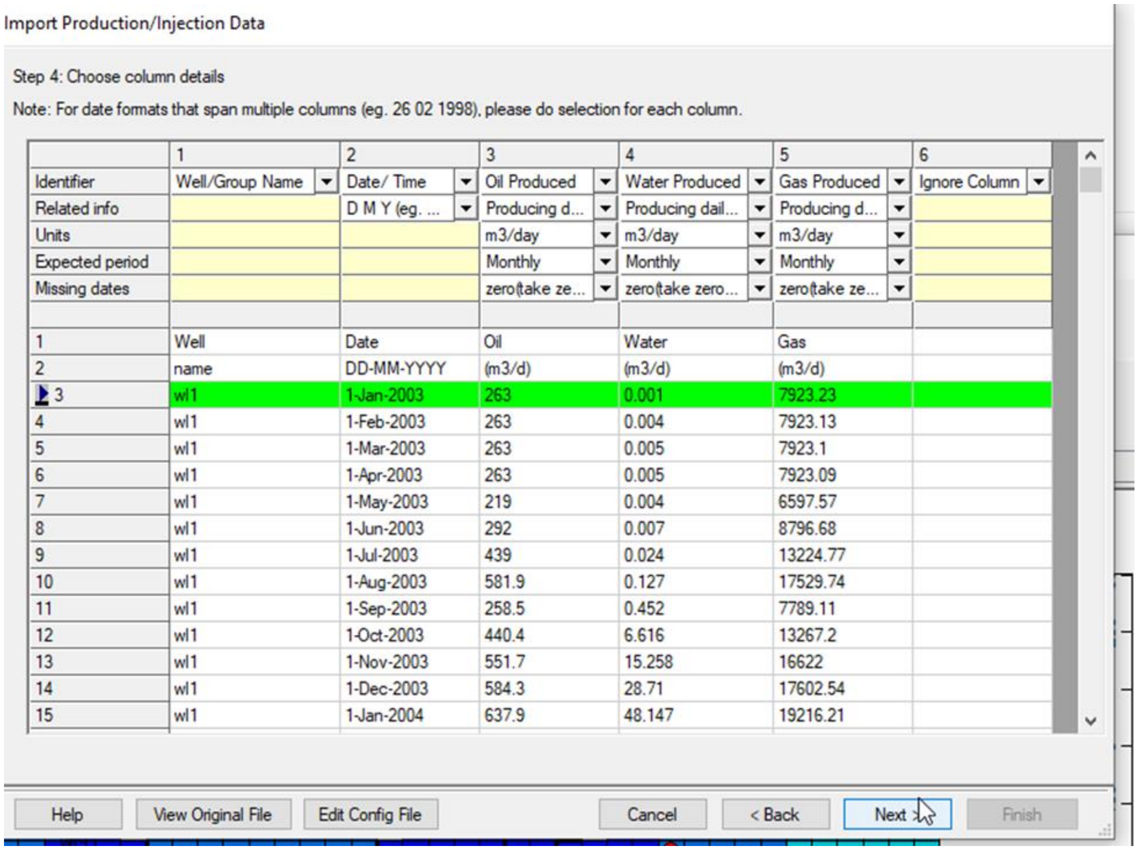


Figure 19: Assigning identifiers to each column

59. **STEP 5:** This step indicates which well production data has been picked up and which one has not. In this section, the primary constraint can be selected for the wells. The primary constraint controls the amount of oil or liquid that will be produced during the simulation based on the production history.
60. Change the primary constraint from oil to liquid by highlighting the list of wells and right click to select the liquid constraint.

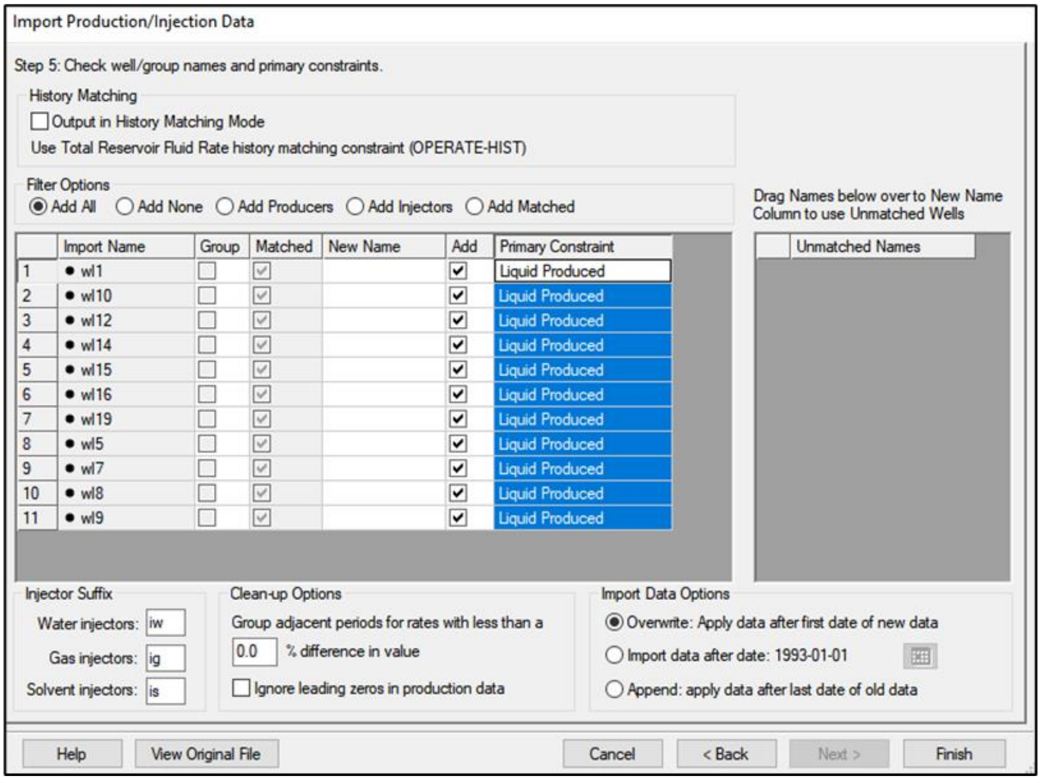


Figure 20: Assigning primary constraint to wells

61. Click **Finish**.
62. In the **Simulation Dates** window that appears set the stop date to be 2020-02-01. Also change the option for grid output limit to **Do not limit grid output.** This is because we want to be able to see grid output every month.

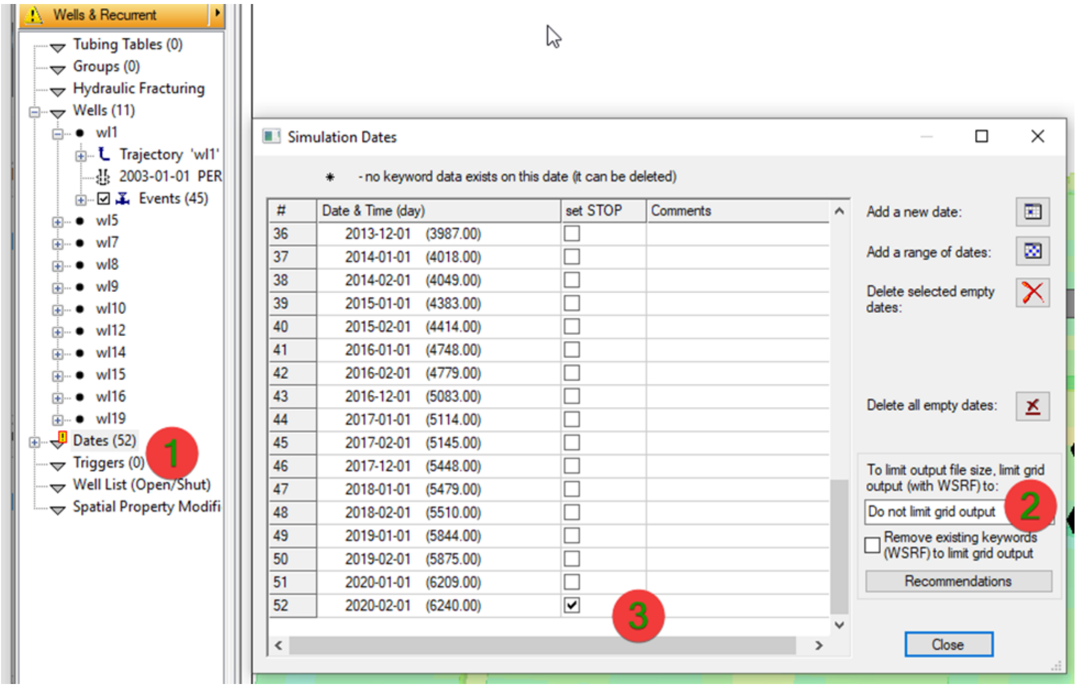


Figure 21: Setting stop date for simulation

Creating Average Monthly Production / Injection Recurrent Well Data

If averaging of production-injection data needs to be done, it can be done as described below. It is not needed for the tutorial as the data is already set on a monthly basis and we want to keep it monthly.

63. On the main Builder menu, select **Well → Average Production/Injection Data.**
64. Next, move your mouse and right click on the x-axis. The pop-up menu will allow you to change the average interval from this point on to **monthly, bi-annually, yearly**, etc.
    For example you can average your production data based on three months and all the Alter keyword will be averaged over three months period.

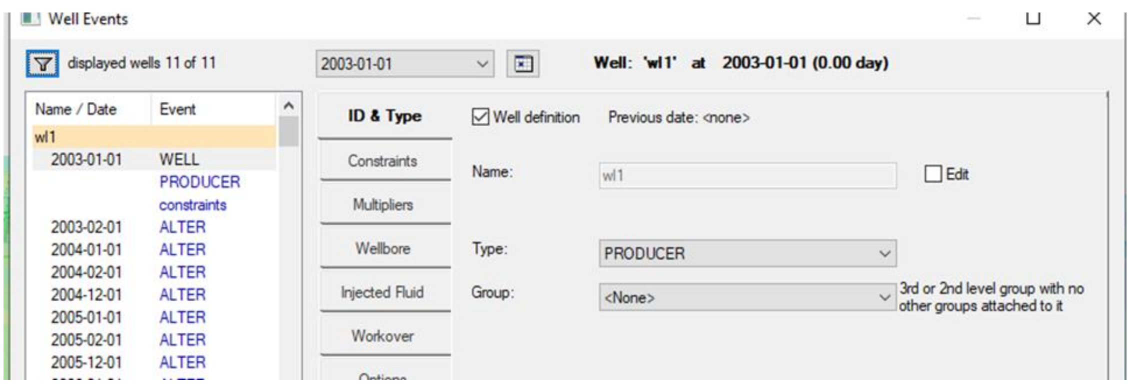


Figure 22: three months period averaging

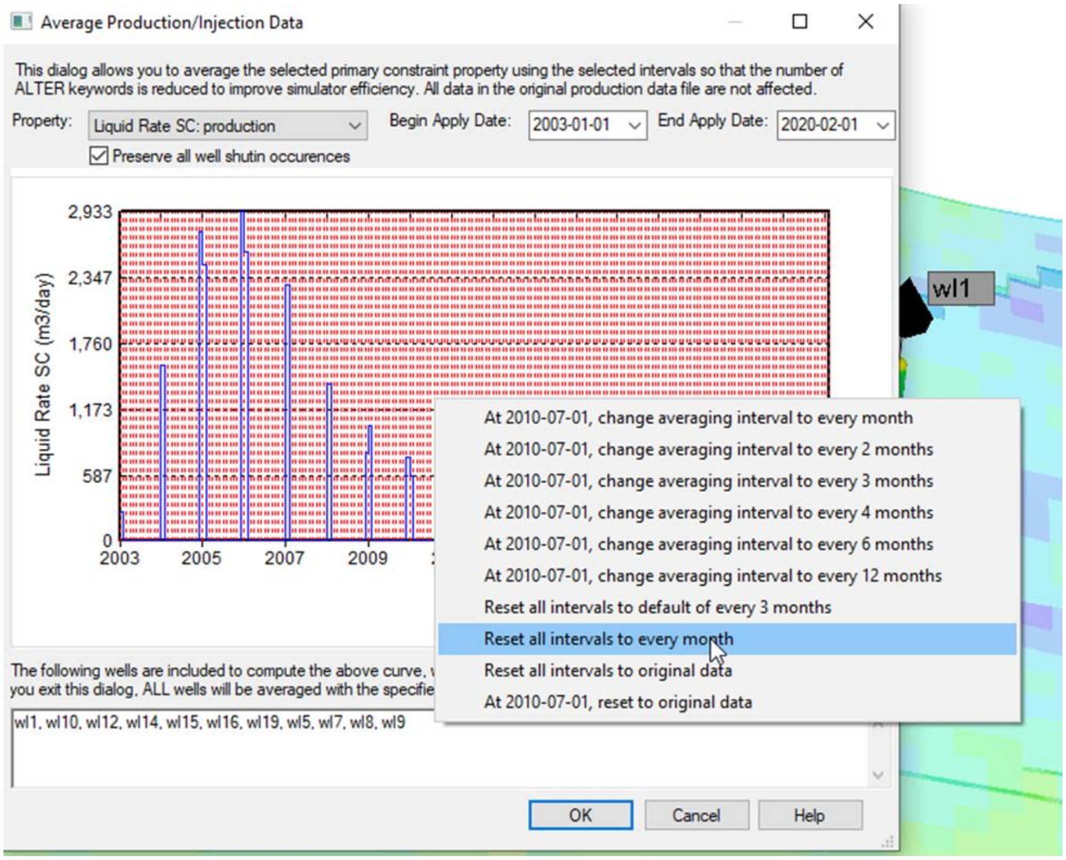


Figure 23: Average production/injection data plot

65. Select **Reset all intervals to every month** and press the **OK** button. Once again, click **Close** on the **Simulations Dates** window that pops up.

Creating Field Production History (*.fhf) for History Match

The next thing we want to do is to create a field history file so that we can make a comparison between the simulation run and the actual field history file.

66. Go to the top menu again and select **Well > Create Field History File…,** then provide a file name (**IMEX_PRODUCTION_HISTORY.fhf**) for the production data. Press **OK**.

Input/Output information

67. If everything is correct, all of the tabs in the tree view should have a **green** checkmark.
68. Go to the **I/O Control** and double click on the **Simulation Results Output**. The Simulation Results File Writing window will open. For a well variable, under OUTSRF table, select **Well values for all layers at reservoir and surface conditions (LAYER ALL DOWNHOLE).**

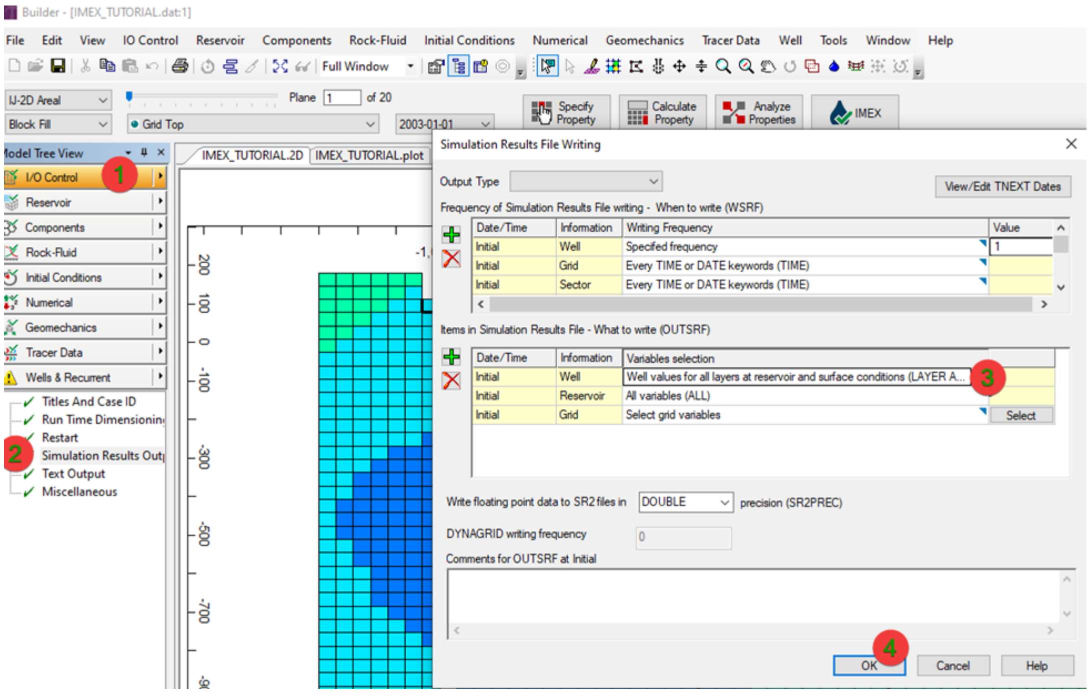


Figure 24: Modifying default well output

69. Please **Save** the file one more time.

Writing Out Restart Information to a Restart File

70. Click on the **I/O Control** tab in the tree view.
71. Double click on **Restart**.
72. Check on **Enable Restart Writing**.
73. Press the button and select the first simulation date, which is 2003-01-01. Press **OK**.
74. Set the **Writing Frequency Option** to **Every TIME or DATE Keywords**.
75. Check the **Maximum number of restart records stored (REWIND)** option and set the value to **3**. This means the restart file contains up to 3 restart records from which the simulation can be restarted from later on.
76. Choose the option to **Combine Graphics and Restart.** The .SR3 file will be larger in size but we will have fewer files created.

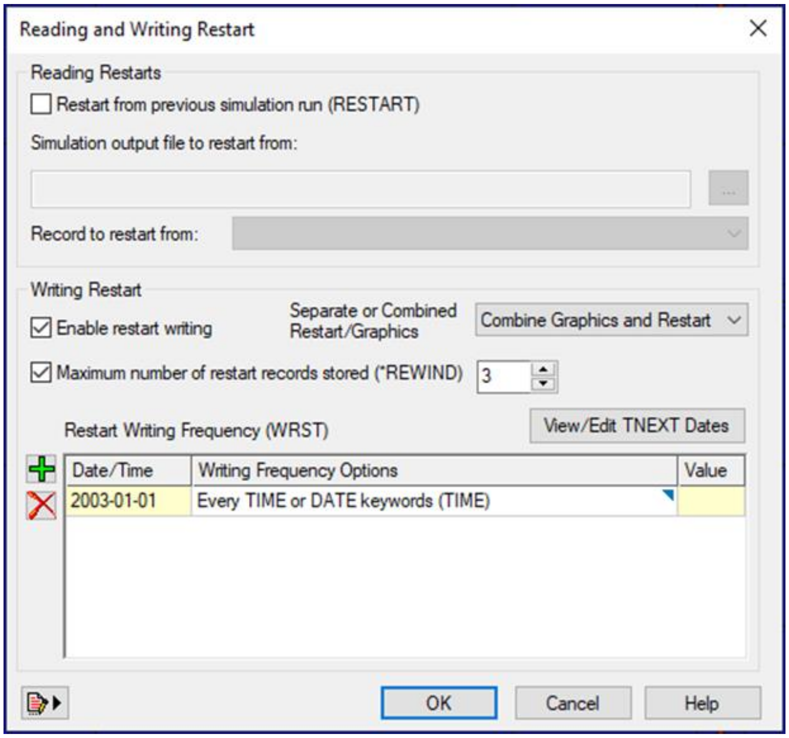


Figure 25: Restart Window

77. Click **OK** to close the window.
78. **Save** the file.

We now have a completed dataset so we can exit Builder and drag and drop the **IMEX_TUTORIAL.DAT** file onto the **IMEX** icon to run it. You will be able to make prediction runs without having to rerun the historical data portion as a result of using the Restart Run feature.

Running the IMEX Dataset and Reviewing the Results

79. If all the steps done before were accurate, you should be able to run the dataset using IMEX. First locate the file **IMEX_TUTORIAL.DAT** in your launcher, then drag and drop into **IMEX** icon and release the mouse. A new window will pop up. Select the option to **Submit to Scheduler** and click OK.

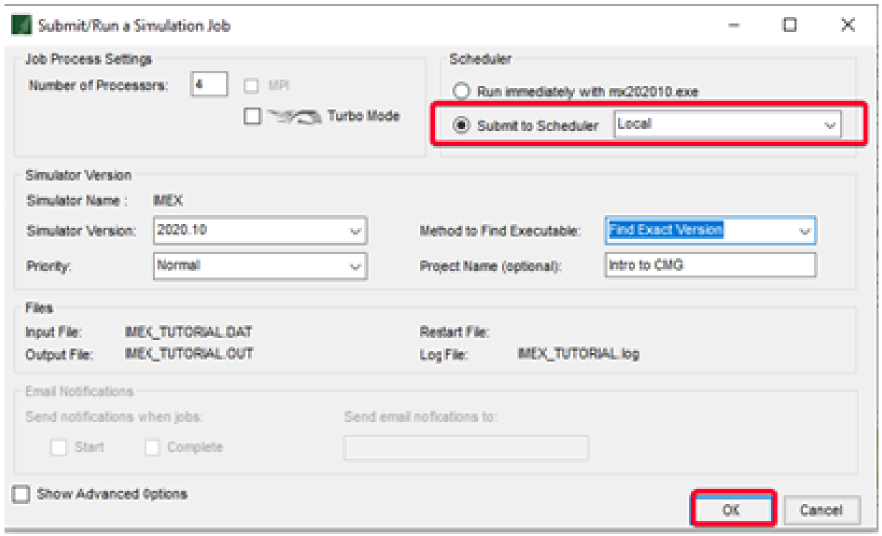


Figure 26: Submit/Run a Siimulation Job Window

80. You can now switch to CMG Launcher to monitor the runs. Once automatically refreshed, Progress bar shows the percentage of the job completed so far. If you right click on the job you can view live IMEX log file.

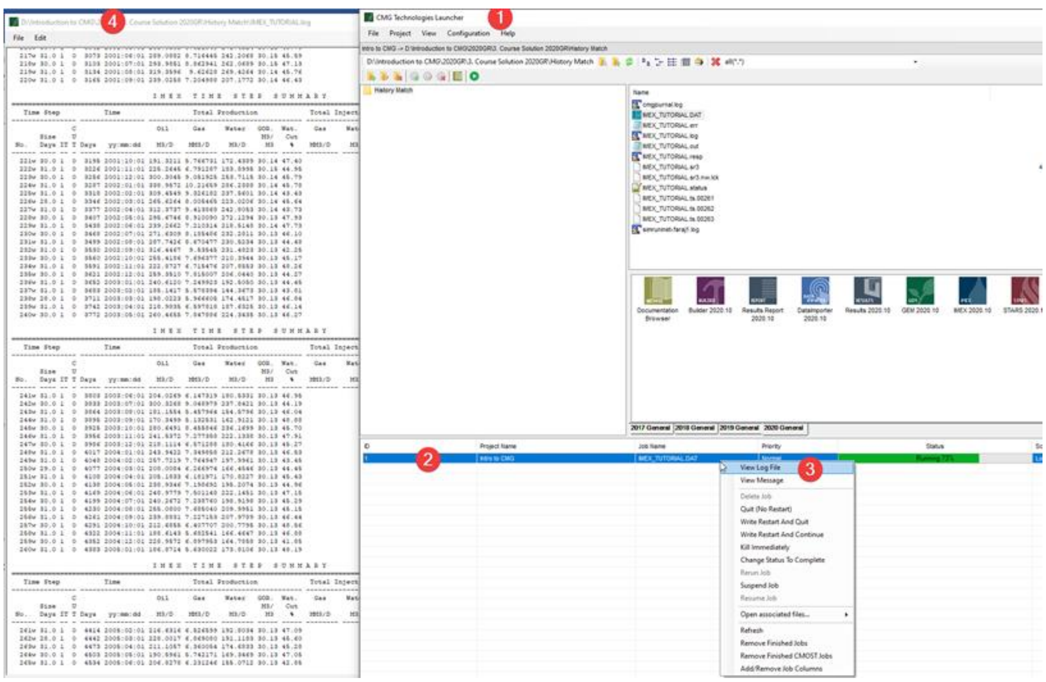


Figure 27: Checking the progress by opening the log file

We can now look at the simulation run and compare it with the historical data and see how the reservoir performs.

Production Data in Results

81. Right Click on the Job name in the Scheduler and then click on **.sr3 in Results 2020.10**.

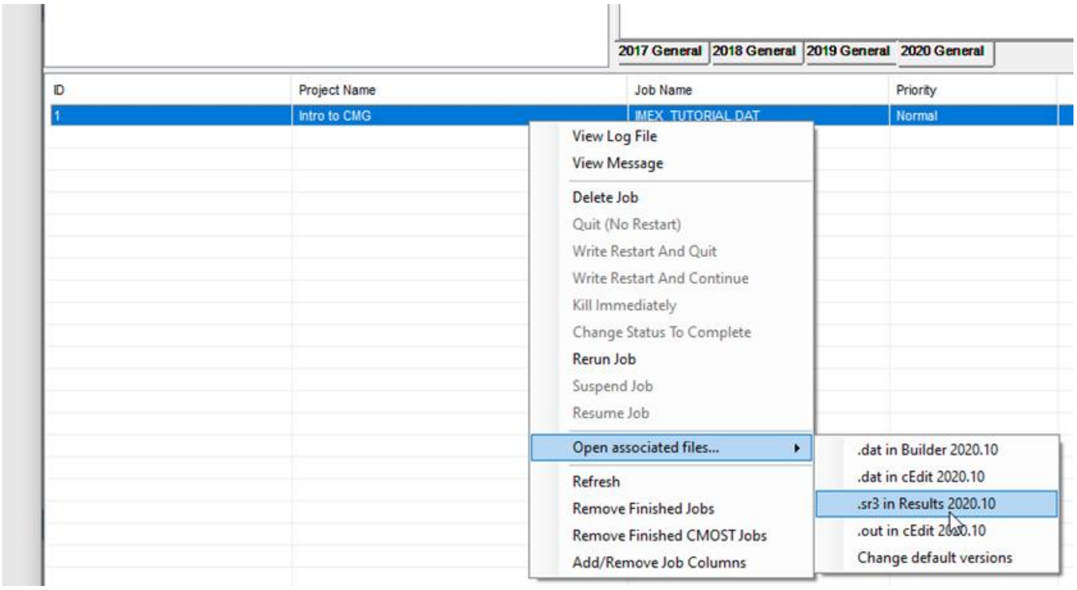


Figure 28: Opening associated files in Launcher

82. In Data Sources section, click on **Add Files;** then open the **IMEX_PROD_HISTORY.fhf** file that we created in the Creating Field Production History section of the tutorial. Click on the **Open** button.
83. Click **Home** in the Ribbon Menu and select to group the plots **By Data.**
84. You should now see the plots grouped by the well name in the **Project Navigation** section. Click on **wl1** to see all the plots for that well:

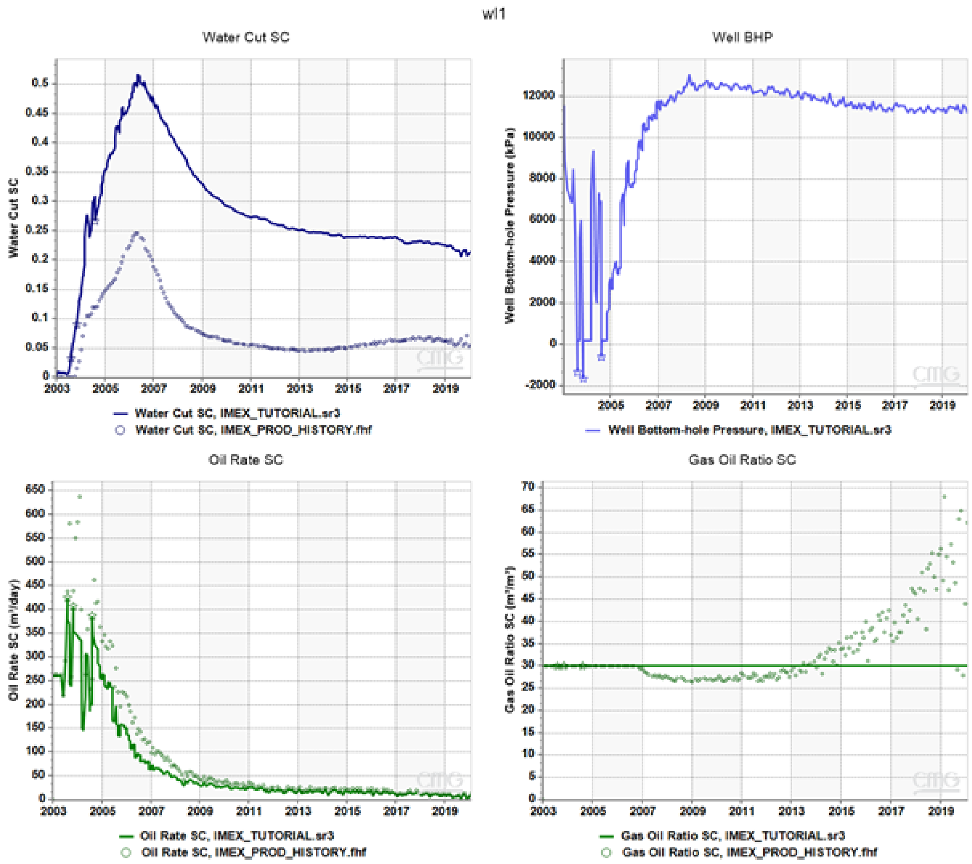


Figure 29: Plot of simulation data versus historical data

85. Click on all the well names in the **Project Navigation** section to compare the simulation results to the historical data

Pressure Data in Results

86. Click on **Data Sources** in the Project Navigation and select **Add Files**. From the **Required Data** folder, select the **IMEX_RESERVOIR_PRESSURE_HISTORY.fhf** file. This file contains the historical data and will be used to compare it with the simulated data.
87. Click on **Time Series** in Project Navigation and in the Curve Selector section; select **Sectors** for the Data Type. Select **Imex_Tutorial.sr3** in the Data Sources section and select the **Ave Pres POVO SCTR** parameter for the Entire Field. Lastly, click **Add to New Plot**:

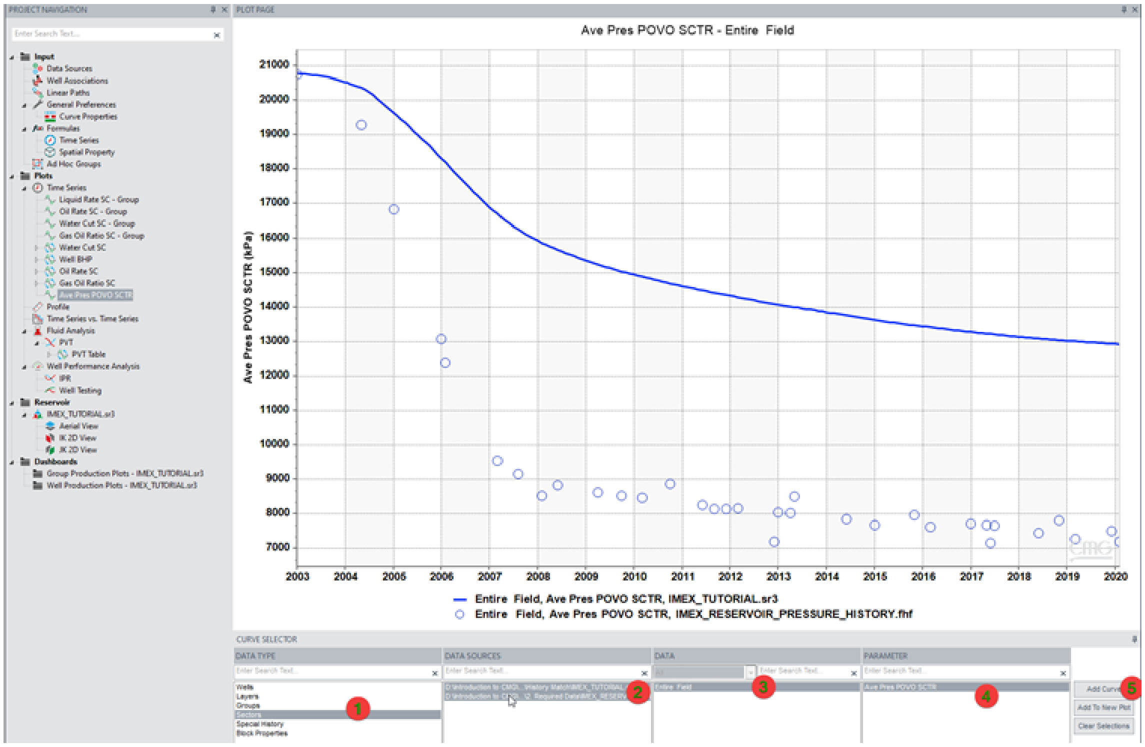


Figure 30: Window in Results to plot simulated reservoir pressure

88. Save the project with the name **IMEX_TUTORIAL_HM.results.**

History Match of Pressure and Production

Changing Rock Compressibility to Match Pressure Behavior

In order to match the reservoir pressure, we can change the rock compressibility, as this is one of the parameters that have an important effect. In the list below there is a selection of values that can be used to approximate the simulation results to the real data values.

By reducing the value of rock compressibility the reservoir pressure will decrease. Use the values listed in Table 1 to create one data set per value:

Rock Compressibility		Data set
Cr=20e-06 1/psi	(2.9e-06 1/kPa)	IMEX_TUTORIAL_HM_CR1.DAT
Cr=10e-06 1/psi	(1.45e-06 1/kPa)	IMEX_TUTORIAL_HM_CR2.DAT
Cr=5e-06 1/psi	(7.25e-07 1/kPa)	IMEX_TUTORIAL_HM_CR3.DAT

Table 1: Selected Values for History Matching of Reservoir Pressure

1. Open the **IMEX TUTORIAL.DAT** file in cEDIT and search for **CPOR** under Dataset Navigation. Click on the keyword found to jump to the line. Change the rock compressibility (CPOR) value to 2.9e-6 1/kPa. **Save** the file as **IMEX_TUTORIAL_HM_CR1.DAT** under your **HISTORY MATCH** folder.

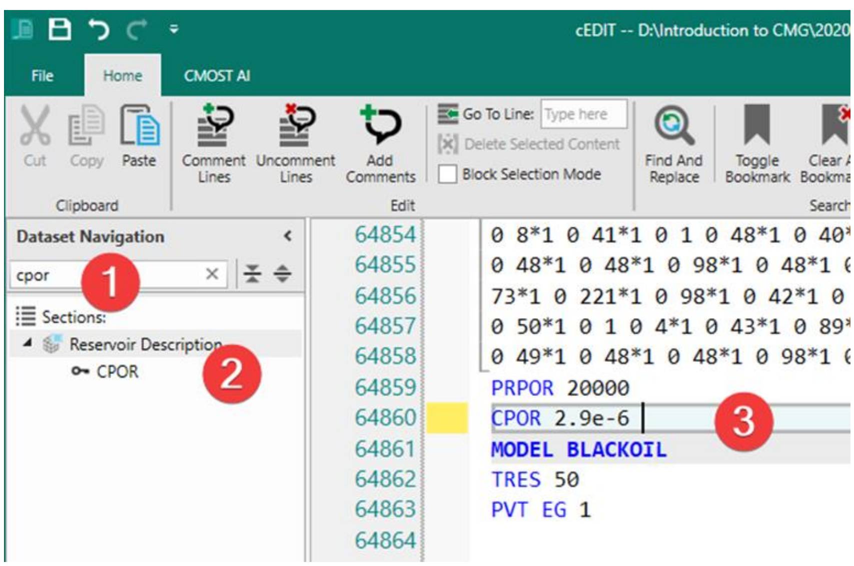


Figure 31: Window in TextPad to modify rock compressibility

2. Repeat the same steps to create the two additional files listed on Table 1.
3. List of the files can be limited to .dat using the drop-down menu.
4. Using the CMG Launcher, submit/run the datasets by dragging and dropping all the *.dat files in one go. This time submit each job using 1 or 4 processor (depending on machine spec).

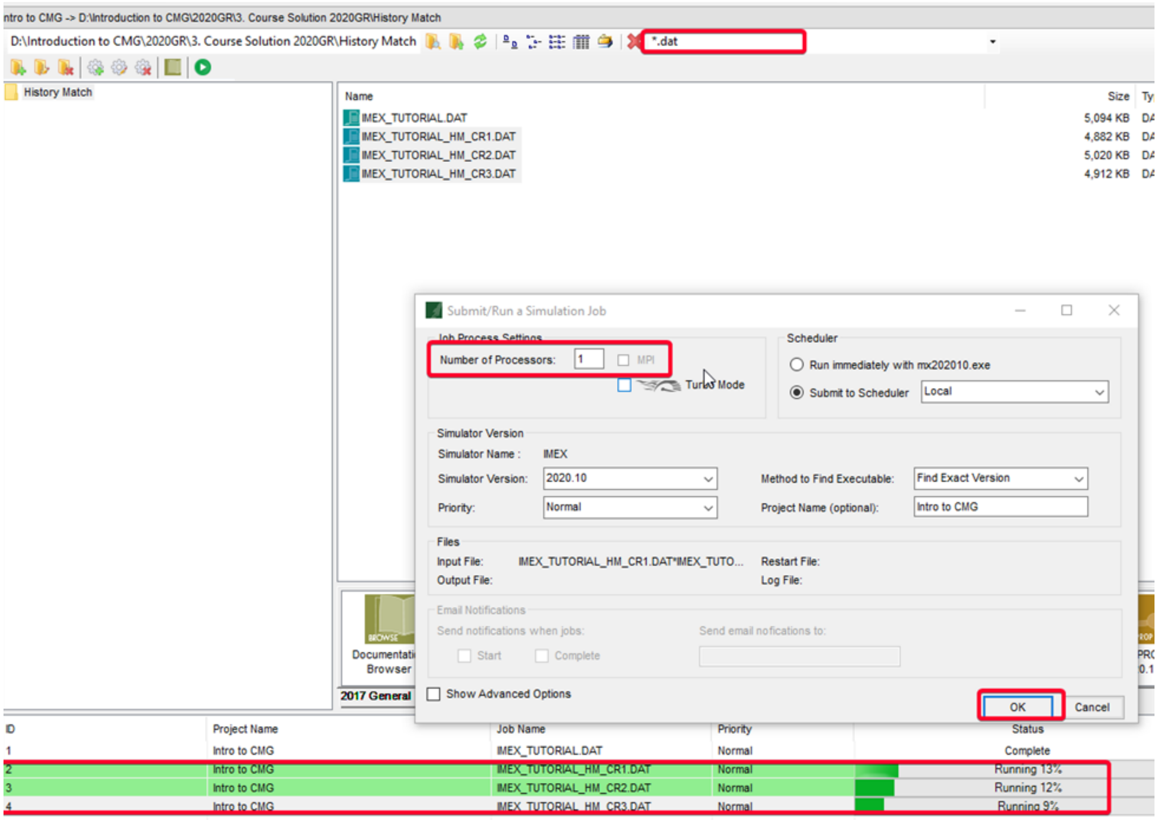


Figure 32: Submitting multiple jobs simultaneously

Reviewing the Simulation Results using Results

5. Open **IMEX_TUTORIAL_HM.results** and click on **Data Sources** and select **Add Files**. Select the three new .sr3 files and click **Open**.
6. In order to differentiate easily between the simulation results from multiple sources please follow steps below to set colours for each sr3/fhf.

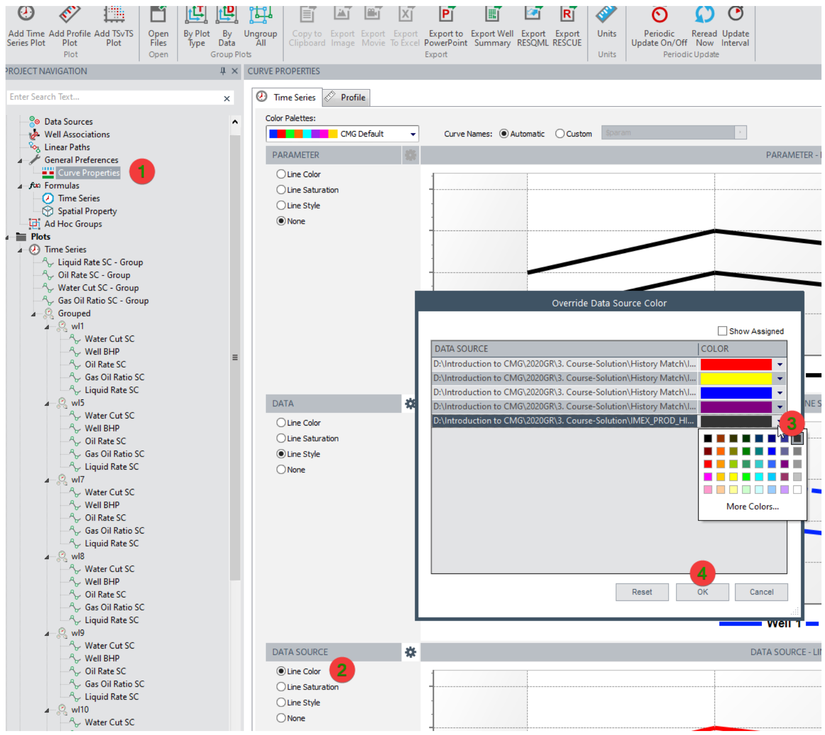


Figure 33: Customize curve properties

7. Click on the pre-created **Ave Pres POVO SCTR** plot in the **Time Series** section of Project Navigation.
8. Using the Curve Selector, add the curve for Ave Pres POVO SCTR for the three .sr3 files that were just imported:

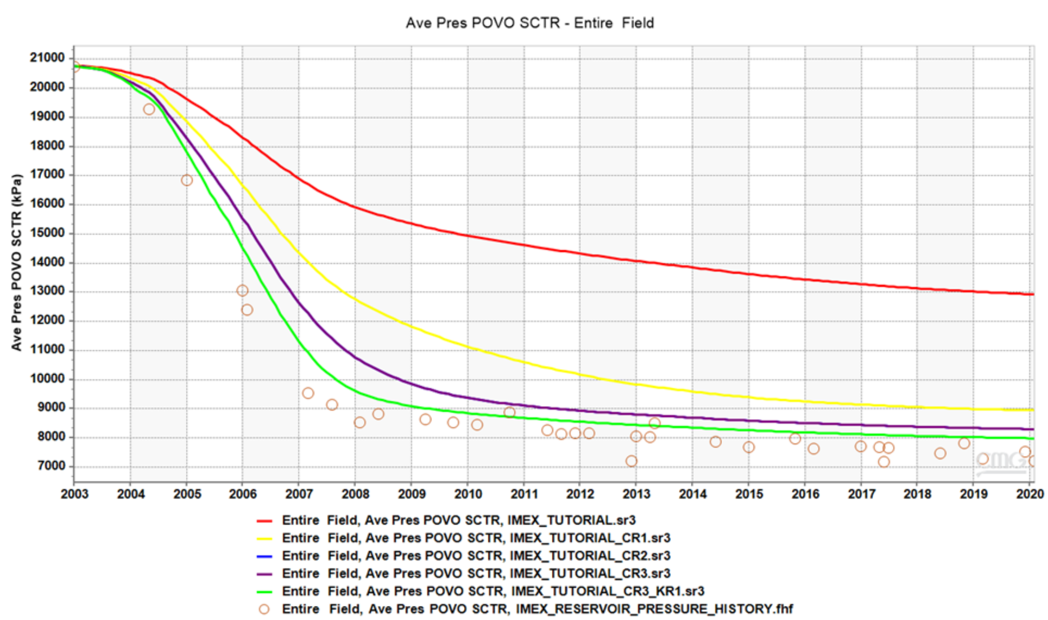


Figure 34: Simulation field pressure versus history

9. Based on the pressure behaviour, case 3 had the best match with the historical data. Therefore, we will use the compressibility value for this case for subsequent simulations.
10. In the same Results file, navigate to the individual well plots in the **Plots** section to view the production rates per well. You should observe a group of plots similar to this:

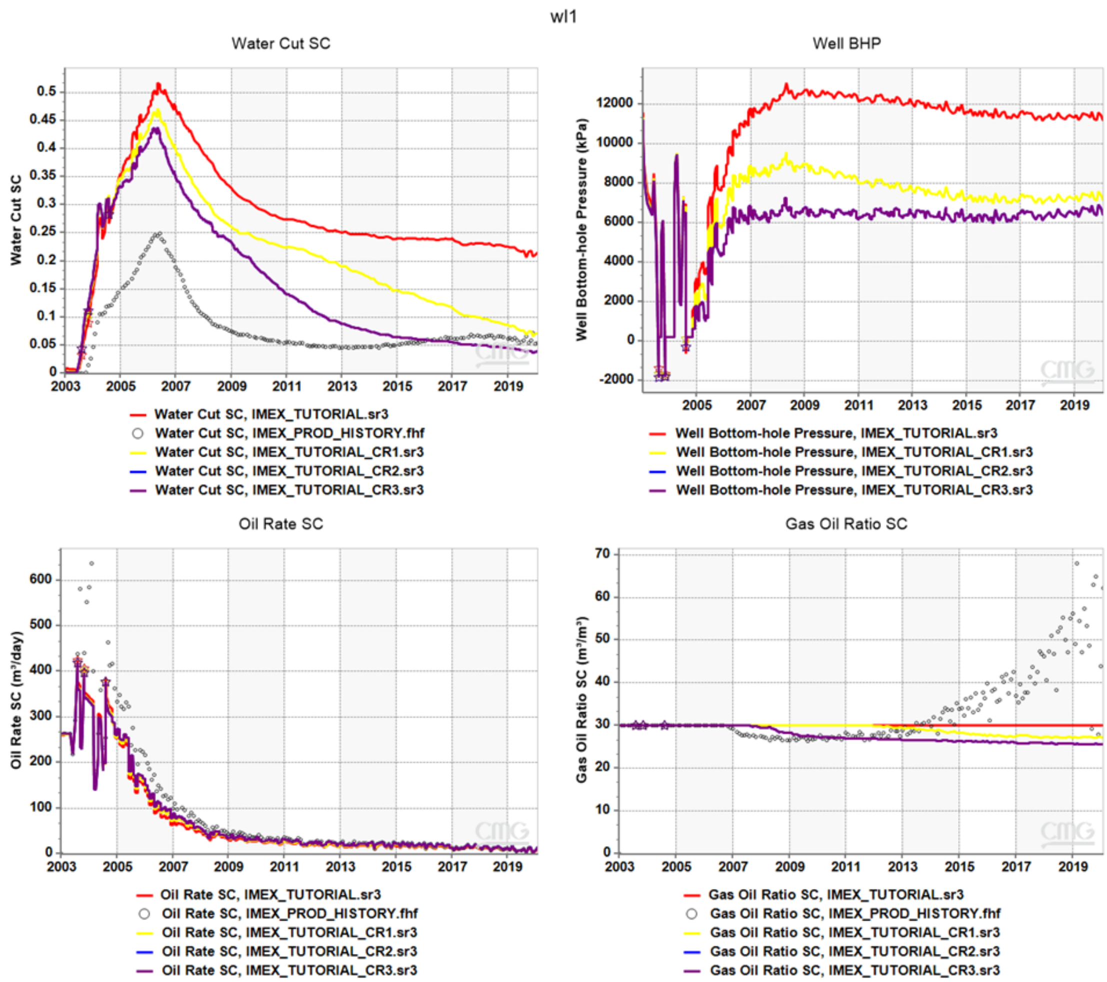


Figure 35: Simulated production vs. real data, best case for reservoir pressure HM

11. As it can be observed, the only parameter that improved in relation to the real data trend was the water cut, but for the rest of parameters the effect was minimal. The next step is to change the relative permeability curves in order to improve the production.

Changing Relative Permeability Curves to Match Production

History Matching is a technique that takes a long time to get a perfect match. It is an iterative process and it is not expected that a perfect match will be obtained in the course. Therefore, the best possible match you will obtain in the limited time will be considered as acceptable. It is advisable to try changing the relative permeability and updating Results in order to observe the difference that was made.

12. Open the **IMEX_TUTORIAL_HM_CR3.DAT** file in Builder and save the file as **IMEX_TUTORIAL_HM_CR3_KR1.DAT.**
13. Go to the **Rock Fluid section** and double click on **Rock Fluid Types**, click on the **Tools** button and select **Generate Tables Using Correlations**. Change the value of the end-point for the Oil curve, KROCW and KROGCG from **0.2 to 0.4**, click on **Apply** button and **OK.**

#	Description	Value
1	SWCON - Endpoint Saturation: Connate Water	0.2
2	SWCRIT - Endpoint Saturation: Critical Water	0.2
3	SOIRW - Endpoint Saturation: Irreducible Oil ...	0.4
4	SORW - Endpoint Saturation: Residual Oil for...	0.4
5	SOIRG - Endpoint Saturation: Irreducible Oil f...	0.2
6	SORG - Endpoint Saturation: Residual Oil for ...	0.2
7	SGCON - Endpoint Saturation: Connate Gas	0.05
8	SGCRIT - Endpoint Saturation: Critical Gas	0.05
9	KROCW - Kro at Connate Water	0.4
10	KRWIRO - Krw at Irreducible Oil	0.8
11	KRGCL - Krg at Connate Liquid	0.8
12	KROGCG - Krog at Connate Gas	0.4
13	Exponent for calculating Krw from KRWIRO	2
14	Exponent for calculating Krow from KROCW	4
15	Exponent for calculating Krog from KROGCG	4
16	Exponent for calculating Krg from KRGCL	4

Figure 36: Modification of the Relative Permeability curves to match production

14. **Save** the file. Close the Builder and go to the CMG launcher to run the model by dragging and dropping the **IMEX_TUTORIAL_HM_CR3_KR1.DAT** file onto the IMEX icon.

Reviewing the Simulation Results

15. In **IMEX_TUTORIAL_HM.results,** go to **Data Sources** and select **Add Files** to open the **IMEX_TUTORIAL_HM_CR3_KR1.sr3.**
16. Click on **wl1** in the Plots section to visualize the improvement in the history match for oil, gas, and water production:

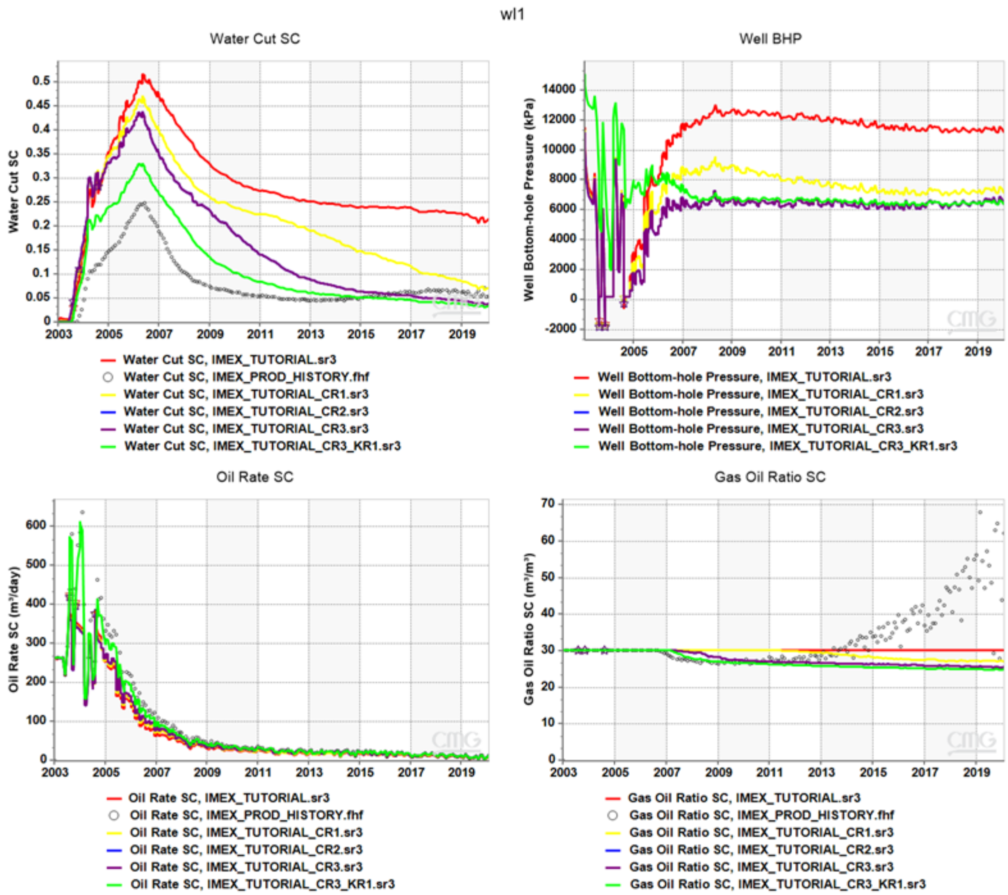


Figure 37: Effect of relative permeability curves on production

17. There is an improvement in the production rates after modification of the relative permeability curve. See the rest of the wells and check the history match; some of them require more work. Try more parameters of the relative permeability curves and see the effect on the history match.
18. Due to limited time, the final history match will be provided by the instructor (**IMEX_TUTORIAL_HM_Matched.DAT**). Run this file in IMEX, plot the simulation results (**IMEX_TUTORIAL_HM_Matched.sr3** in Results and add the historical data (FHF file) for rate and pressure.

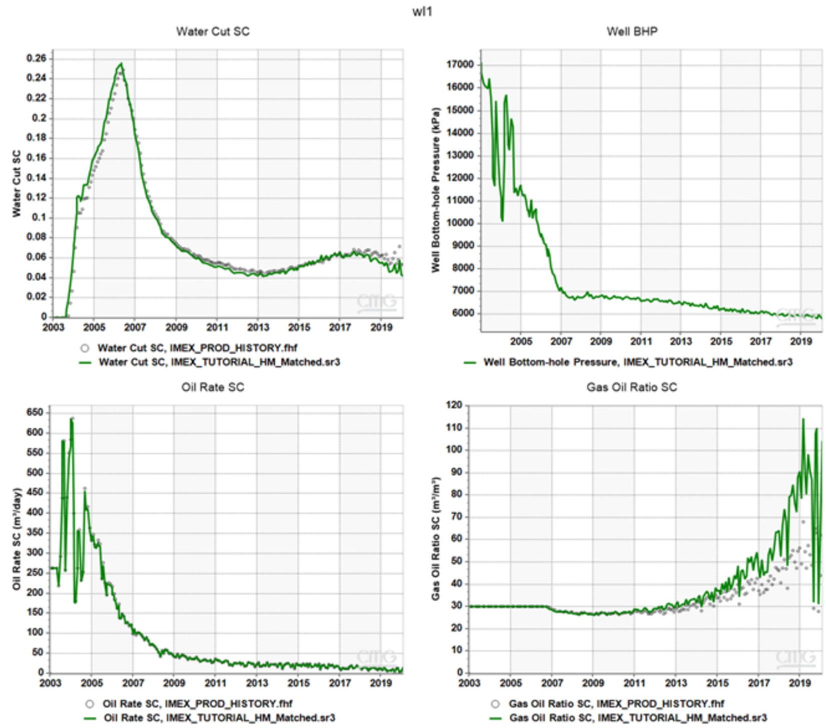


Figure 38: Final History Match for the model (wl 1)

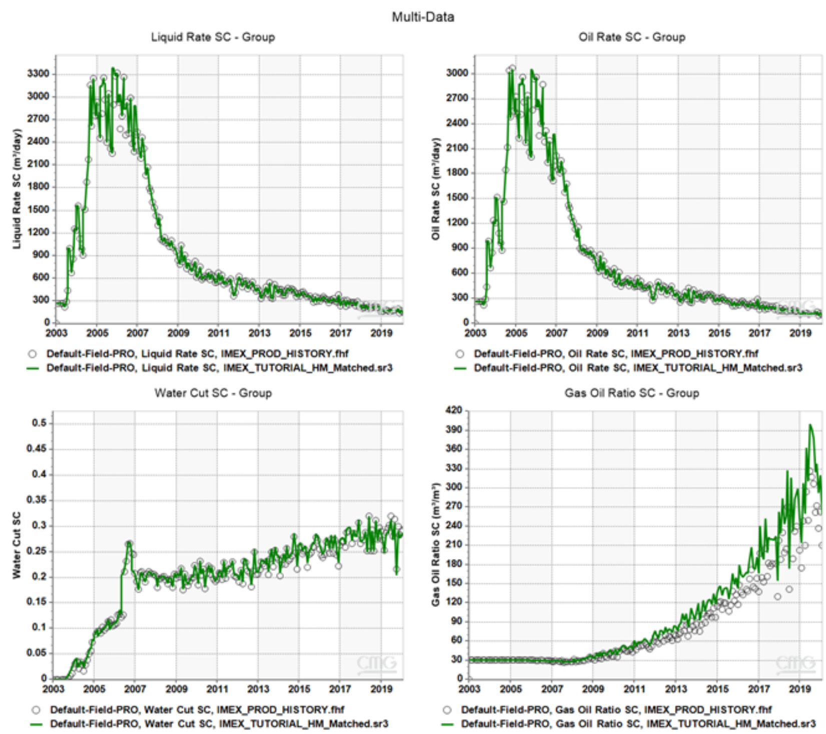


Figure 39: Final History Match for the model (Field)

Visualization of PLT and Petrophysical Log Data in Results

19. In the same result session, load the trajectory file (.wdb) and two log .wlg files containing petrophysical and Production Logging Tool (PLT) data from required data folder.

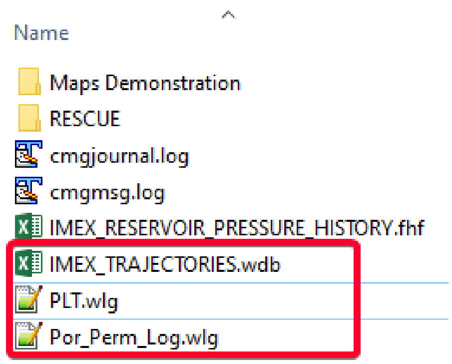


Figure 40: Loading log files and trajectories

20. Click on **Profile** and follow below steps to plot measured PLT data.

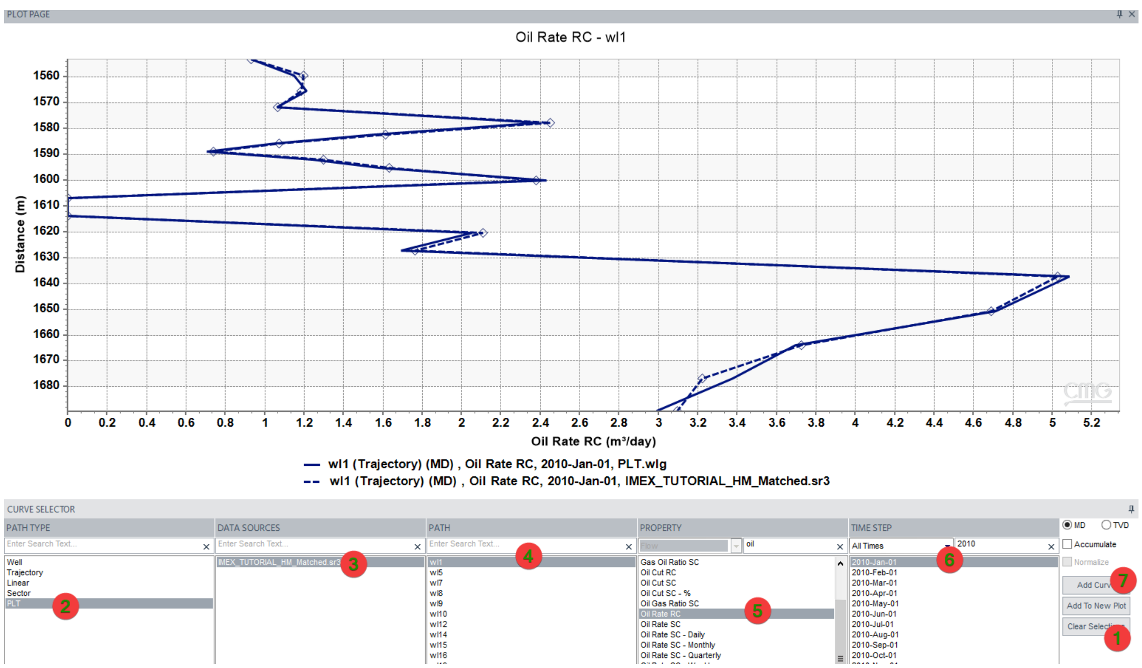


Figure 41: comparison between measured PLT and simulated oil rate

21. Oil Rate (RC) calculated by IMEX for **IMEX_TUTORIAL_HM_Matched.sr3** can be added for comparison purpose. Please follow steps below:

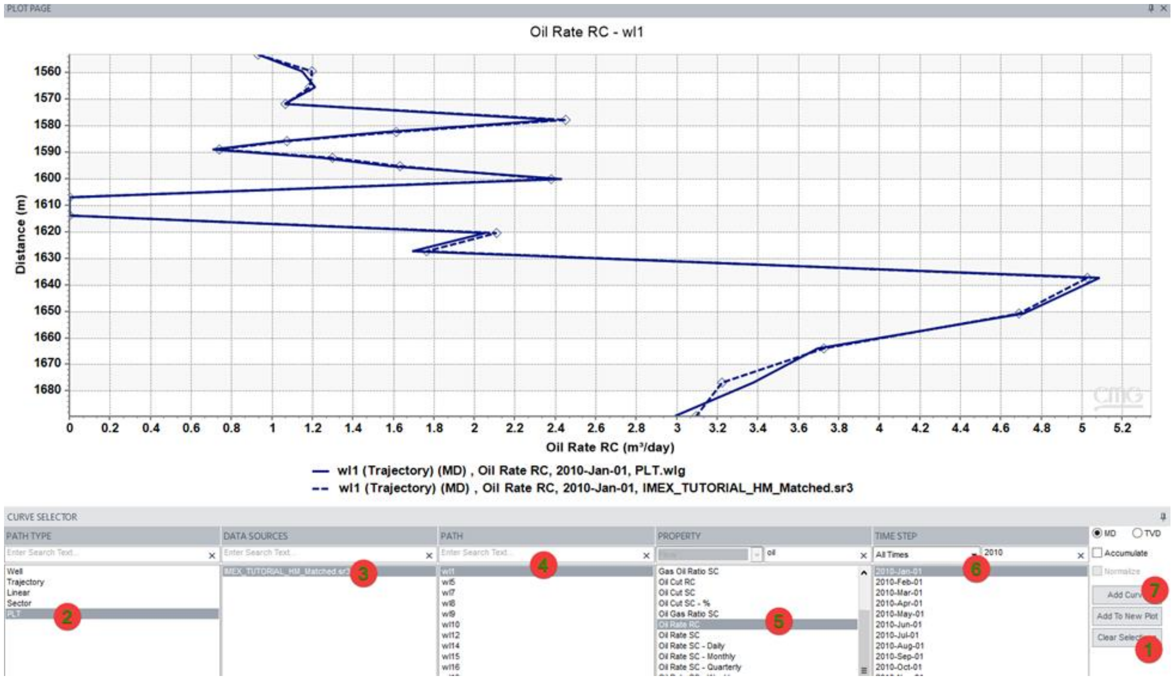


Figure 42: comparison between measured PLT and simulated oil rate

22. We can also create a separate plot showing porosity and permeability measured for the well wl1. Please follow steps below:

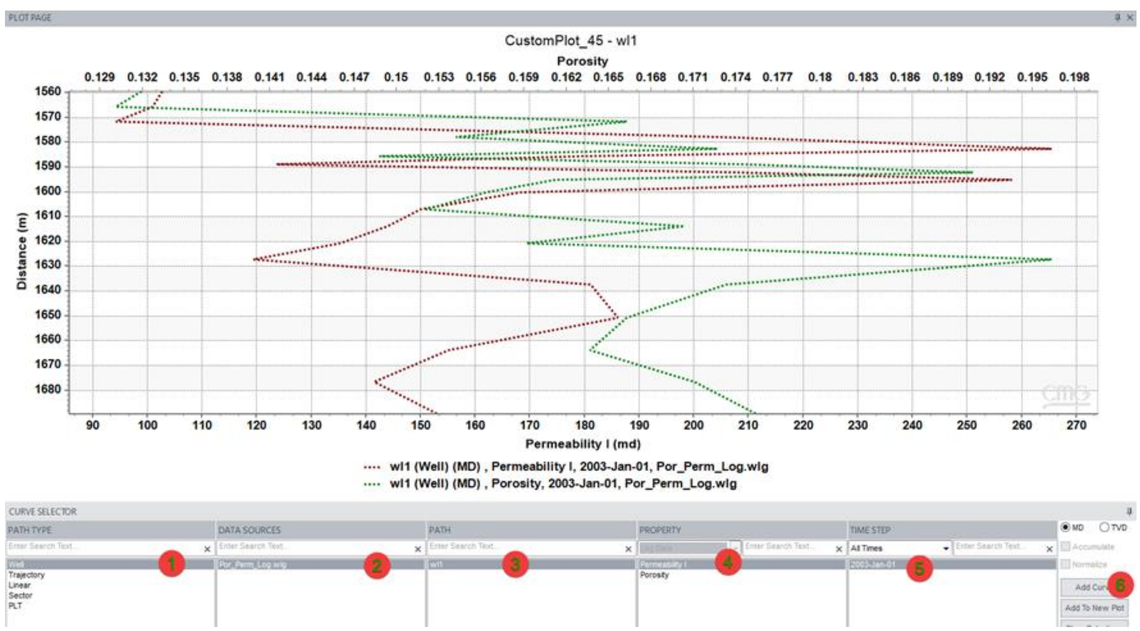


Figure 43: Plotting petrophysical logs

23. Click on Dashboards on the bottom of RESULTS three view and then click on **Create Dashboard.**
24. From the tree view under profile, drag and drop two plots (PLT and petrophysical).
25. This indicates the effects of petrophysical properties on layer productivity.

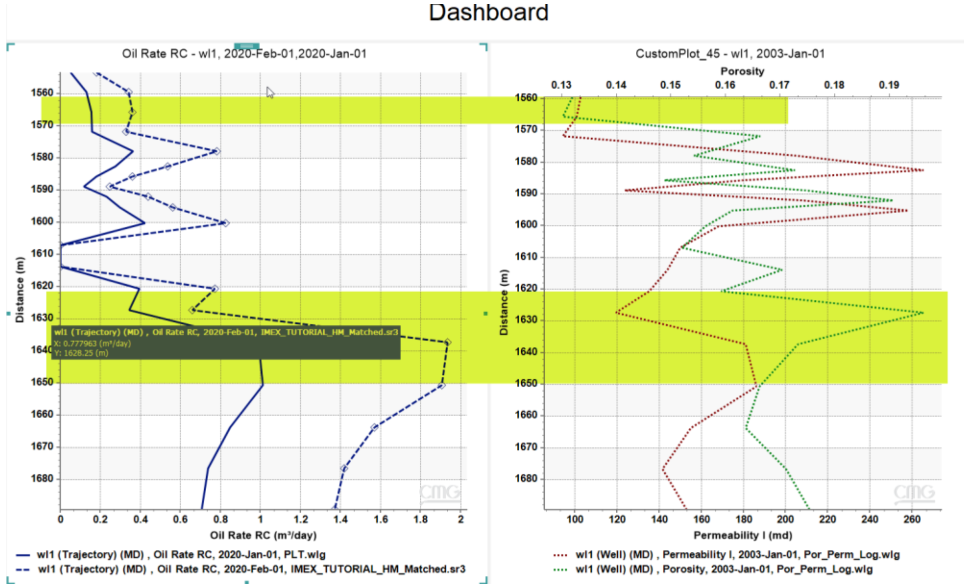


Figure 44: Using Dashboards to Plot PLT/Petrophysical data

Scenarios of Prediction

As previously observed from the historical data, the oil production is declining with time as a result of lack of pressure support in the reservoir.

In order to provide extra support into the reservoir, the injection of fluids will be performed by converting some producer wells into injectors.

For this tutorial, a base case and two different scenarios of injection will be considered: water injection and gas injection. The results will be compared to quantify the benefit in terms of the recovery factor.

Base Case

This scenario considers the prediction under primary depletion with the same number of production wells and constraints based on the stage of history. This scenario will be used as a reference to compare the effect of additional predictions under secondary recovery.

1. In CMG Launcher use CTRL C/V to copy history matched file (**IMEX_TUTORIAL_HM_MATCHED.DAT**) from History Match folder into Prediction folder. Drag and drop the file into IMEX 2020.10 Icon and run the dataset with 4 Processors.
2. Open (**IMEX_TUTORIAL_HM_MATCHED.DAT**) and Save As the file **IMEX_TUTORIAL_PRED_BASE.DAT** in the Prediction folder.

Adding Dates for Prediction

3. Go to the **Wells & Recurrent** section. Double click on **Dates**.
4. Click on the "**Add a Range of Dates"** button. Using the small calendar icon related to "**To**" input the new date related to the end of prediction, 2030/01/01. Click **OK.**
   Remove STOP at 2020-02-01.

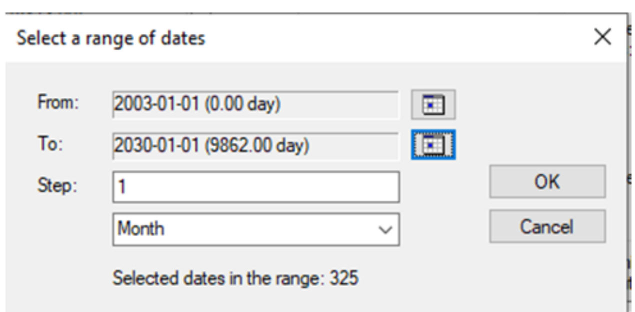


Figure 45: Using Dashboards to Plot PLT/Petrophysical data

Adding New Well Constraints for the Producer Wells

5. Under the **Well & Recurrent** section, expand the **Wells** section and double click on the **wl1** name to display **Well Events**. Click on the **Calendar** button and input the first date of prediction, **2020/02/01** to define new constraints for the prediction.
6. Go to the **constraints tab** and check the **Constraint Definition** box. Remove the first constraint related to the liquid production by using the ✕ button. Leave the Well Bottom Hole Pressure **BHP** as a main constraint **(200 KPa)** and include a **MONITOR** as a second constraint to prevent unnecessary results when the well is producing below the limit of **3 m^3/day** of oil production. Click on the **Apply** button.

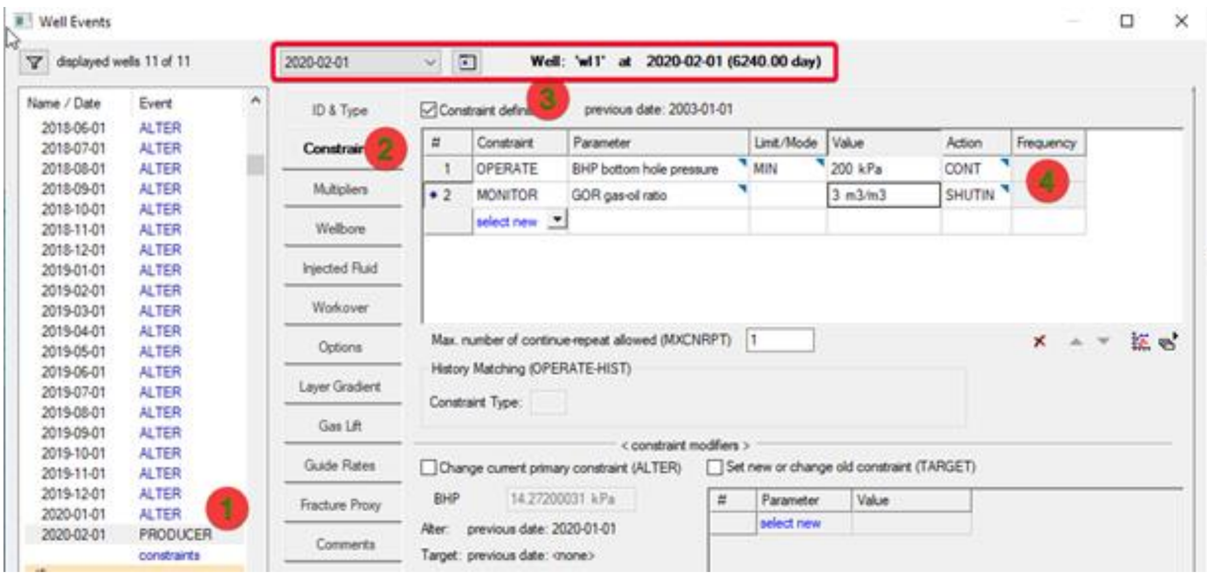


Figure 46: Defining constraints for prediction (wl1)

7. Scroll down to the end of the list of events in the **2020/02/01** well and highlight the events previously generated (PRODUCER and constraints). Right click and select **Copy Events Using Filter** in order to copy the same constraints to the rest of the producer wells.
8. Select all the producer wells.
9. Go to the **Dates** tab, select **2020/02/01** and check the **Create new dates for selected Wells** box. Click on the **Search & Add** button.

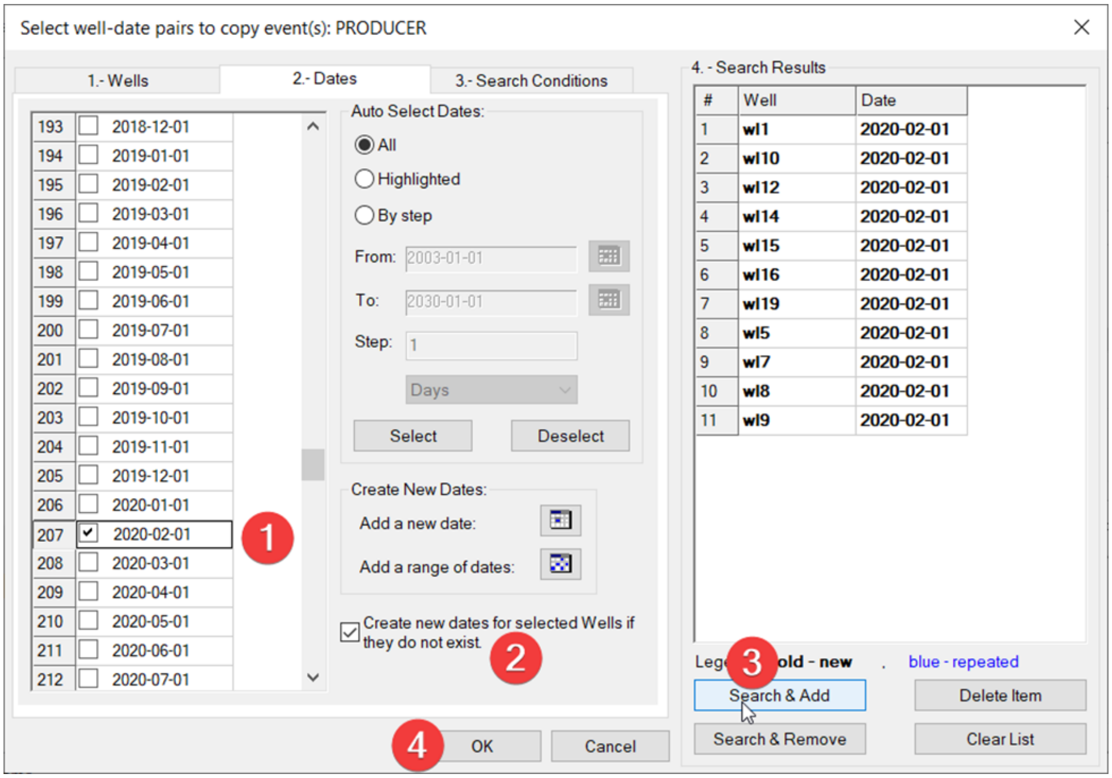


Figure 47: Copying constraints for all the producer wells

10. Review the producer wells and make sure all of these are using the same constraints for the prediction, 2020/02/01. Click **OK** to close the Well Events window and **Save** your file.
11. In order to generate realistic predictions for the wells, it will be required to use the Well Bottom Hole Pressure values (BHP) calculated by the simulator at the end of the history.
12. Go to the CMG launcher and open the **IMEX_TUTORIAL_HM_MATCHED.sr3** by dragging and dropping the file onto the Results Graph icon. Plot the property of **Well Bottom-hole Pressure** for all the wells.

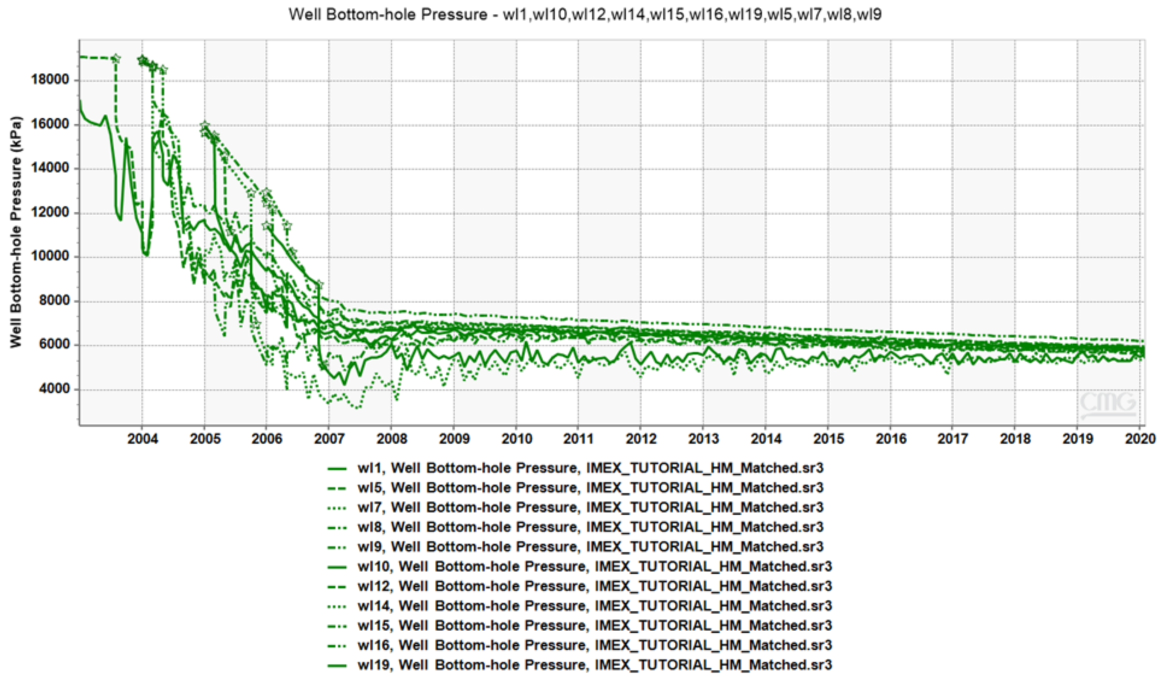


Figure 48: Plot of simulated values of BHP at the end of history for all producers

13. Right-Click on the plot and select **Export To Excel**.
14. From the generated Excel file **Copy** the last value of **Well Bottom Hole Pressure** for well **wl1** which is related to the conditions of production at the end of the stage of history. **Save** the Excel file. You can also make a filter in Excel and filter it for last time/date (2020-Feb-01)

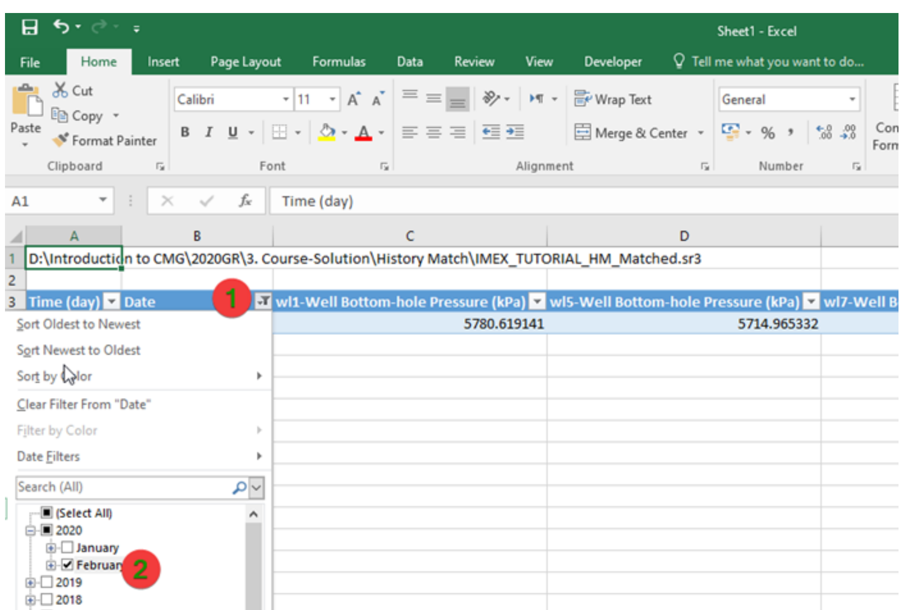


Figure 49: Tabulated values of production well's BHP in Excel at the end of history

	BHP @ end of History:2020-02-01
wl1-Well Bottom-hole Pressure (kPa)	5781
wl5-Well Bottom-hole Pressure (kPa)	5715
wl7-Well Bottom-hole Pressure (kPa)	5772
wl8-Well Bottom-hole Pressure (kPa)	5880
wl9-Well Bottom-hole Pressure (kPa)	5707
wl10-Well Bottom-hole Pressure (kPa)	5912
wl12-Well Bottom-hole Pressure (kPa)	5797
wl14-Well Bottom-hole Pressure (kPa)	5498
wl15-Well Bottom-hole Pressure (kPa)	5981
wl16-Well Bottom-hole Pressure (kPa)	6229
wl19-Well Bottom-hole Pressure (kPa)	5624

Figure 50: Values of wells BHP required to update constraints

15. In Builder expand the **Wells section** under **Wells & Recurrent** and double click on the **wl1** name to open the **Well Events** section, scroll down to find the constraints for 2010/02/01 and paste the value of BHP obtained from the Excel file for well **wl1**.

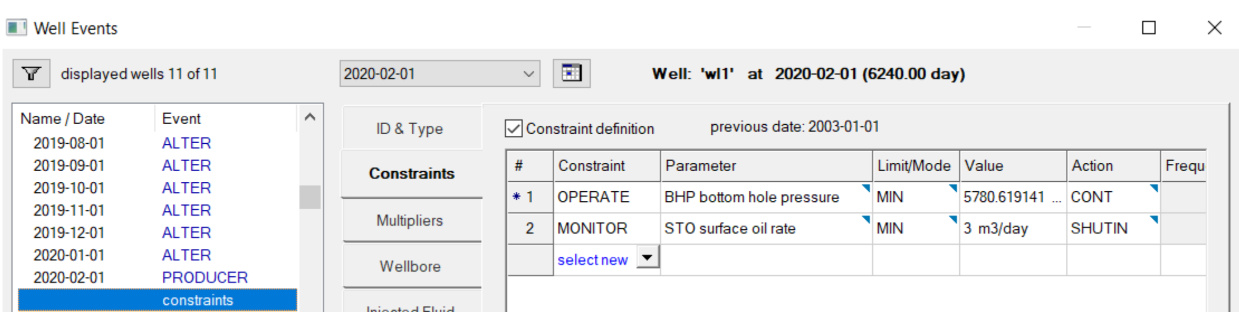


Figure 51: Assigning calculated values of BHP from the stage of history

16. In order to copy the value of Bottom Hole Pressure for the rest of the wells, we can sort them by date. Use the **Filter** in Excel to jump to **Time = 6240** for all the wells. Paste the values of BHP from Excel to Builder for each of the wells.

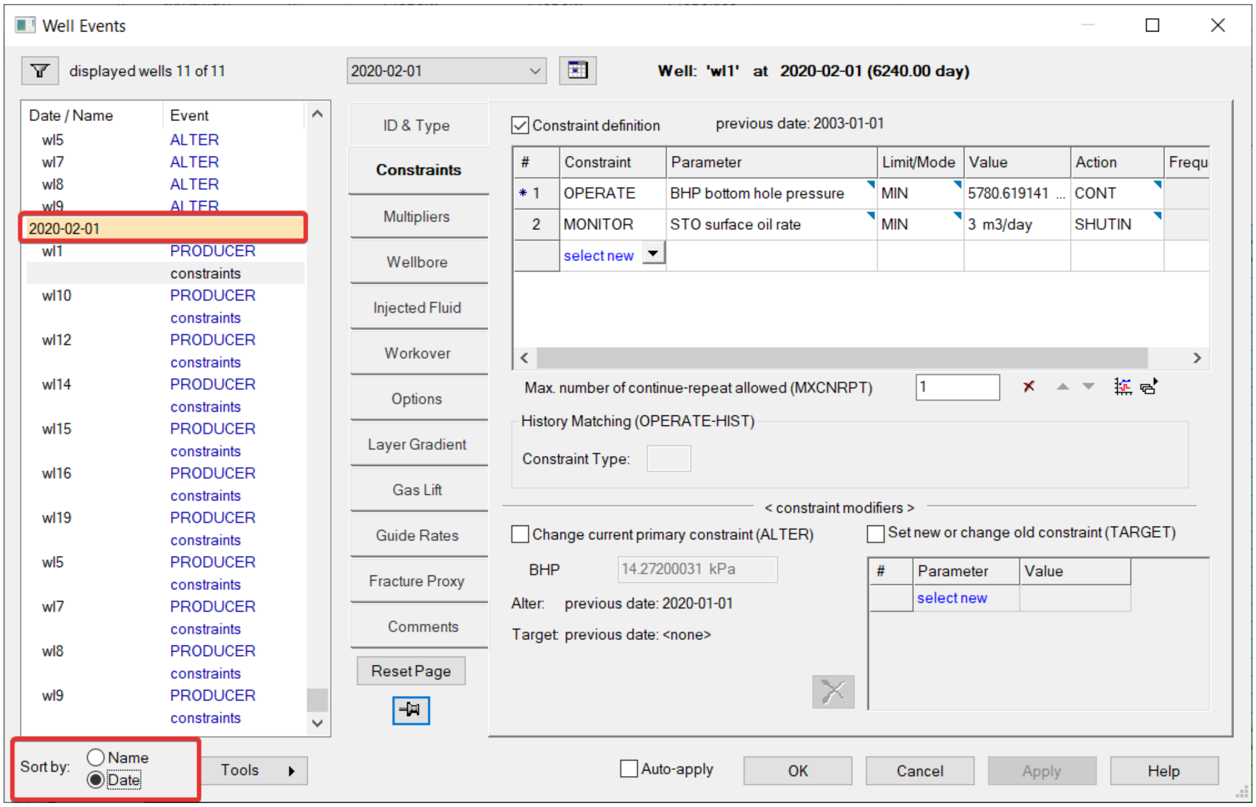


Figure 52: Well constraints sorted by date

Using a Restart File

17. Click on the **I/O Control** and double click on **Restart.** Check the **Restart from…** box.
18. Browse for the restart file generated during the stage of history match. We copied the .sr3 (**IMEX_TUTORIAL_HM_MATCHED.sr3**). Select **2020/01/01** from the restart date options.
19. Uncheck the **Enable Restart Writing** box.

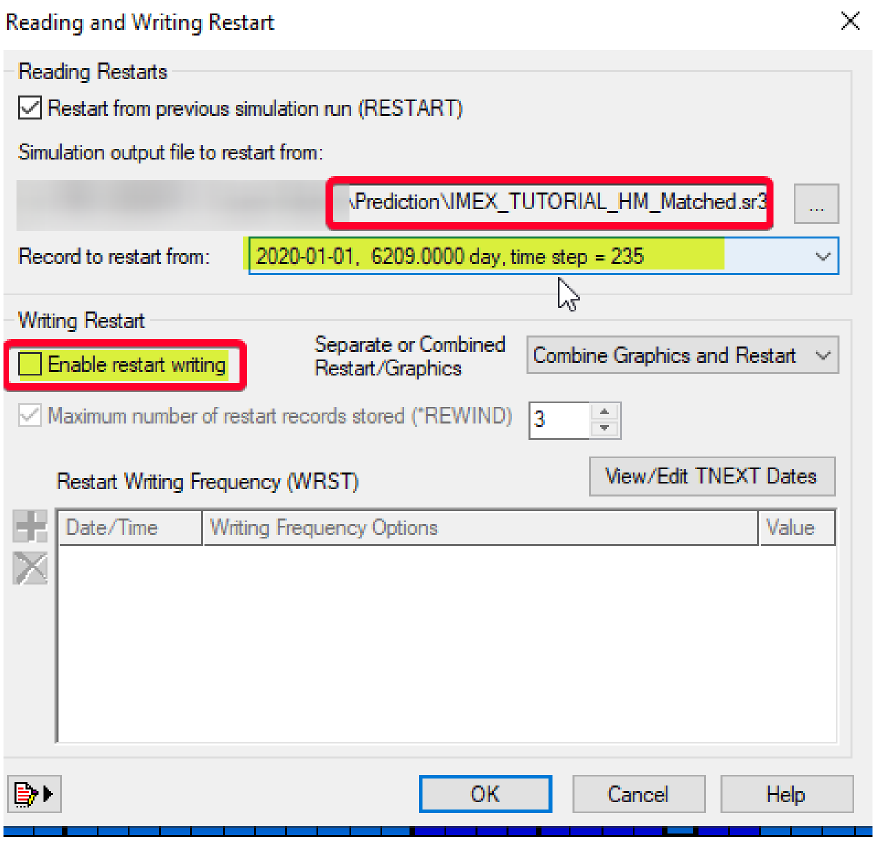


Figure 53: Restart file and time step selection

20. **Save** the file **IMEX_TUTORIAL_PRED_BASE.DAT** one more time.

Running the File in IMEX

21. In the CMG launcher right click on **IMEX_TUTORIAL_PRED_BASE.DAT** and select **Run Simulation**. Please select 4 processors in the pop-up menu.

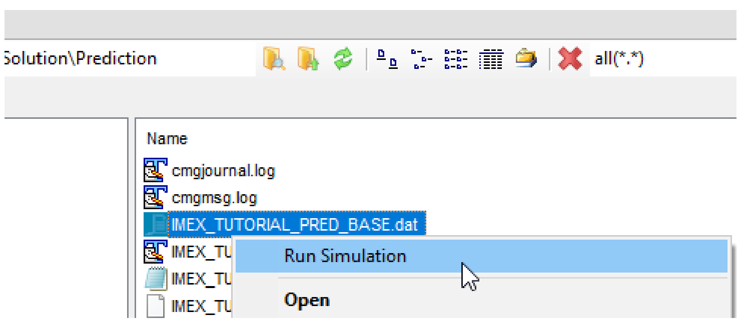


Figure 54: Submitting the job window

Analysis of Results

22. In the Scheduler section you will see the simulation progress. Right Click on the job and select option below to open the results **(IMEX_TUTORIAL_PRED_BASE.sr3)** in **Results.**

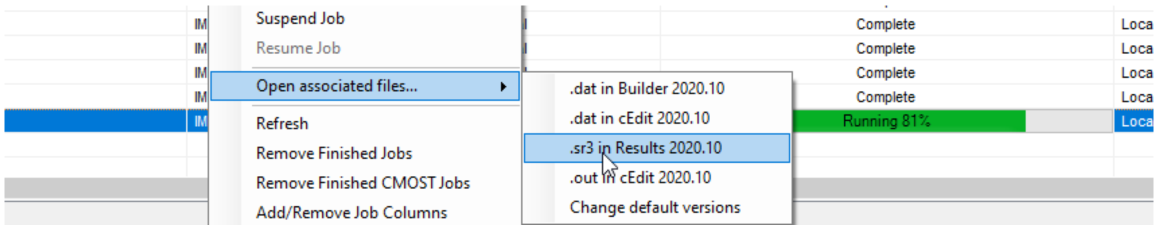


Figure 55: Instructions to open associated files of a simulation job

23. Click on **Add Files;** then open the **IMEX_PROD_HISTORY .fhf** file that we created in the Creating Field Production History section of the tutorial. Click on the **Open** button.
24. Click **Home** in the Ribbon Menu and select to group the plots **By Data**
25. You should now see the plots grouped by the well name in the **Project Navigation** section. Click on **wl1** to see all the plots for that well:

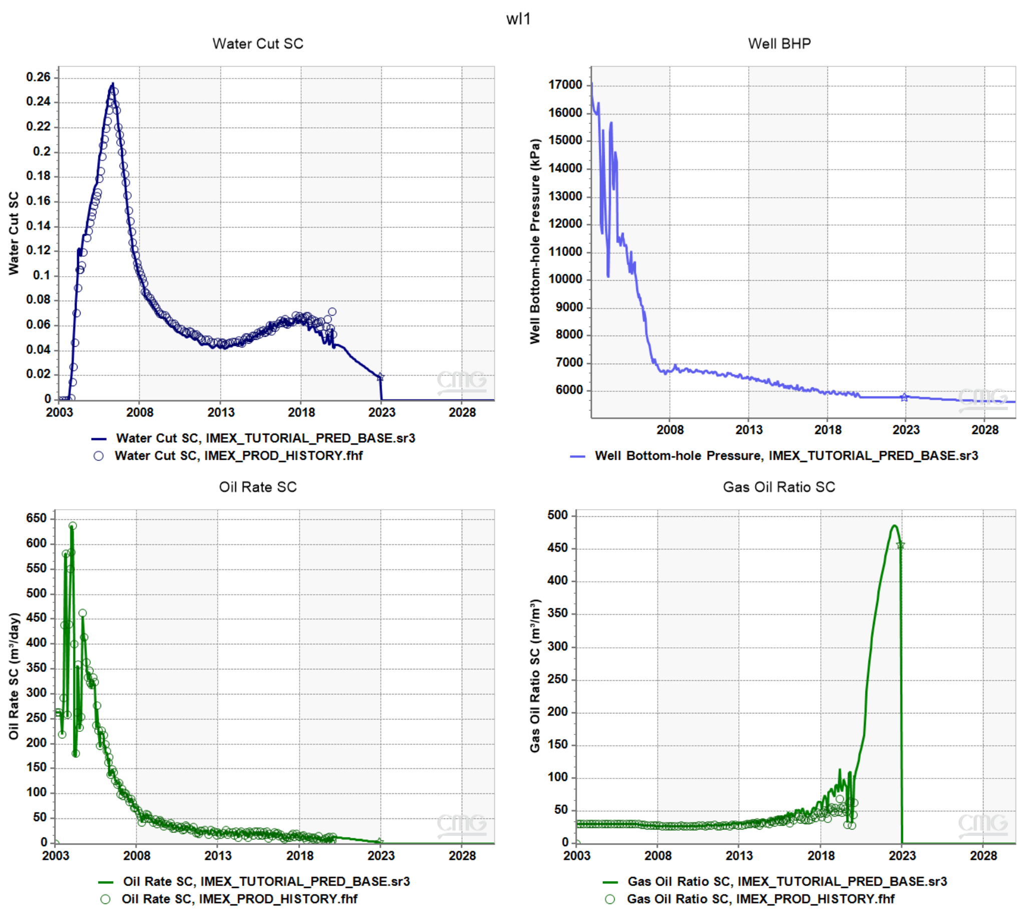


Figure 56: Basecase Prediction Results – wl1

26. Analyze the behavior of all the wells and make sure the prediction rates look reasonable.
27. Add two independent plots to the session: the first one displaying the Oil Rate SC (Sector) and Oil Recovery factor (Sector) and the second one indicating Average Pressure for the entire field (Sector).

Plot 1: Oil Rate SC and Recovery Factor

- Curve 1 and 2: Data Type (**SECTOR**), Data Sources (**IMEX_TUTORIAL_PRED_BASE.sr3**), Data (**Entire Field**), Parameter (**Oil Prod Rate SCTR, Oil Recovery Factor SCTR**), **Add To New Plot**
- Curve 3: Data Type (GROUP), Data Sources **(IMEX_PRODUCTION_HISTORY.fhf)**, Data (**Default-Field-PRO**), Parameter (**Oil Rate SC**), **Add Curve**
- Click on the title at the top of the plot and change it to **Oil Rate & RF**

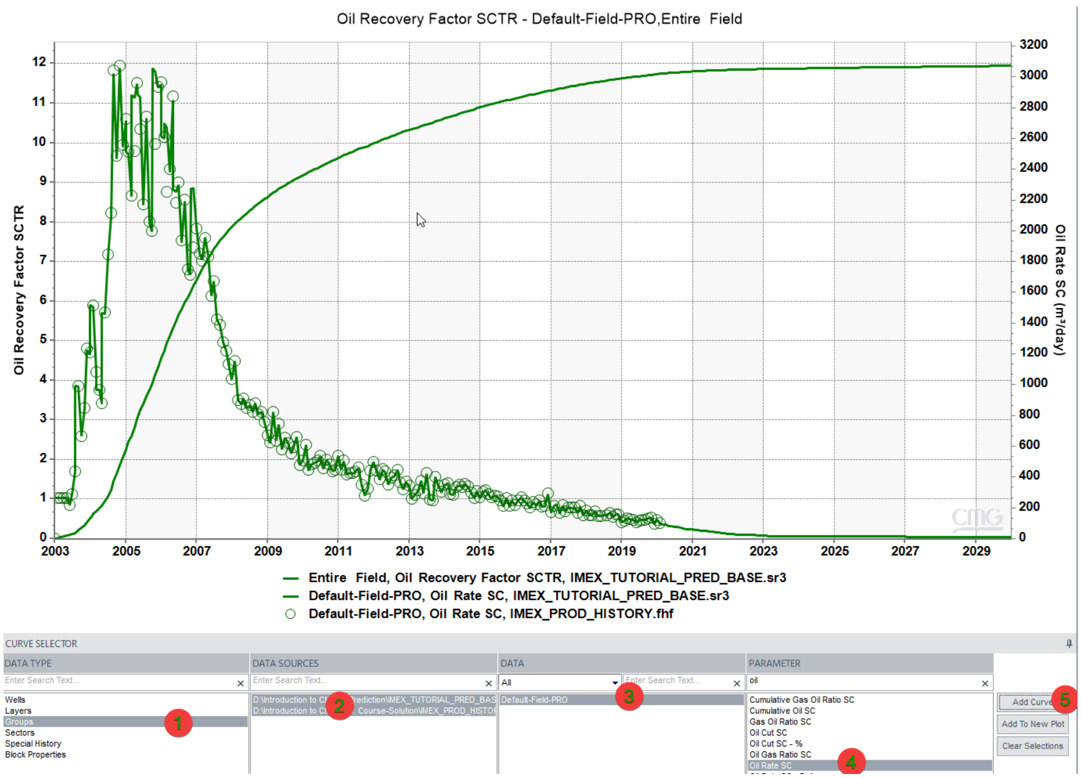


Figure 57: Field production results for the base case

Plot 2: Average Pressure in the Reservoir

- Curve 1: Data Type (**SECTOR**), Data Sources **(IMEX_TUTORIAL_PRED_BASE.sr3)**, Data (**Entire Field**), Parameter (**Ave Pres POVO SCTR**), **Add To New Plot**
- Curve 2: Data Type (**SECTOR**), Data Sources (**IMEX_RESERVOIR_PRESSURE_HISTORY.fhf),** Data (**Field**), Parameter (**Ave Pres POVO SCTR**), **Add Curve**

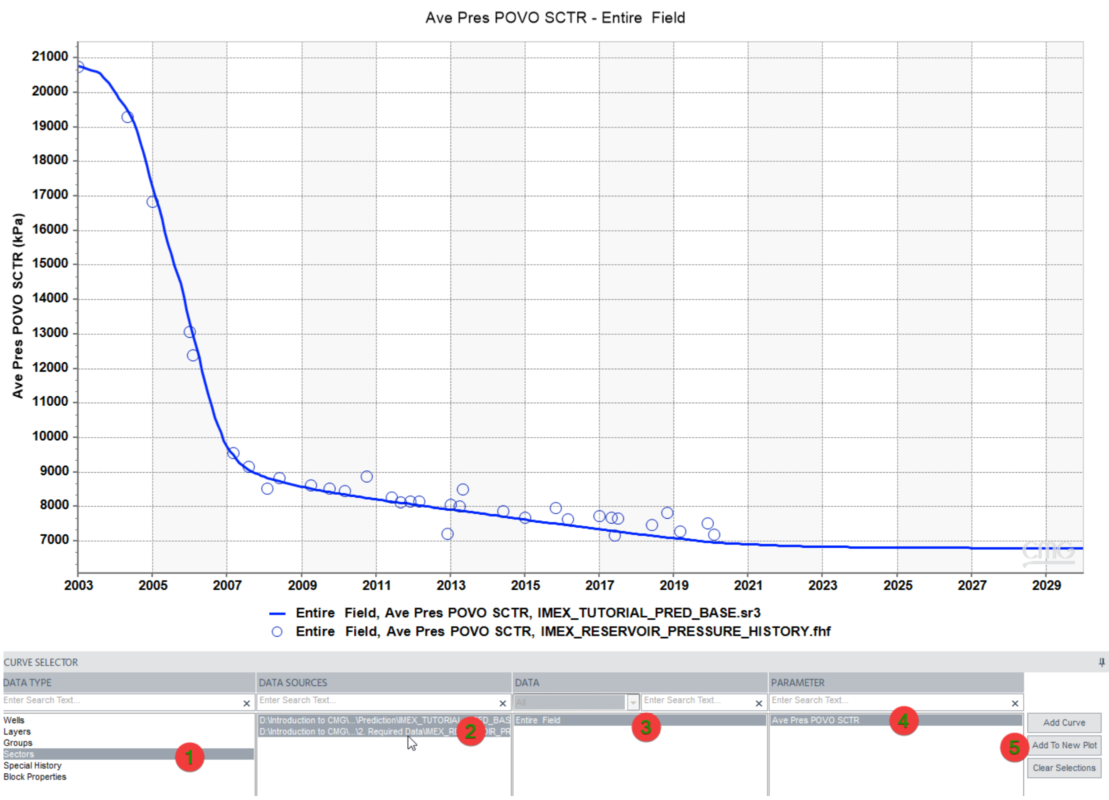


Figure 58: Reservoir pressure results for the base Prediction case

28. Save the project as **IMEX_Tutorial_Predictions.results**

Water Injection

Observations of the pressure behavior within the time period show evidence that this parameter declines by more than 60% of its original value. Since pressure represents the main source of energy for production wells, the decline of pressure and oil production reduction are related. Therefore, we need to provide extra support in the reservoir in order to increase the reservoir pressure and hence oil production in the wells.

Analysis in Results

We can use the Results to display different properties that can be useful to take decisions for the stage of prediction.

1. Open the **IMEX_Tutorial_Predictions.results** file in **Results.**
2. Under the **Reservoir** section in Project Navigation, select the **3D View**.
3. In the Ribbon Menu, click on the **Display** tab and select the **Water Saturation** property.
4. In the Ribbon Menu, click on the **Display** tab to the last date of historical data, **2020-Feb-01**.

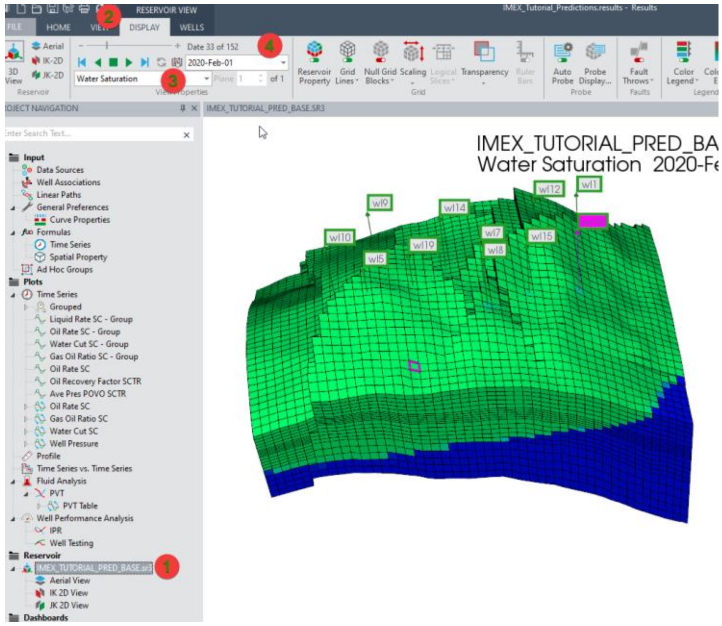


Figure 59: Water saturation at the start of forecast

5. On the grid view, click on the top block intersecting **wl16.** Once the block is selected, it becomes purple block. Now right click on the block and select **Locate Cell (39,20,1) in JK View**

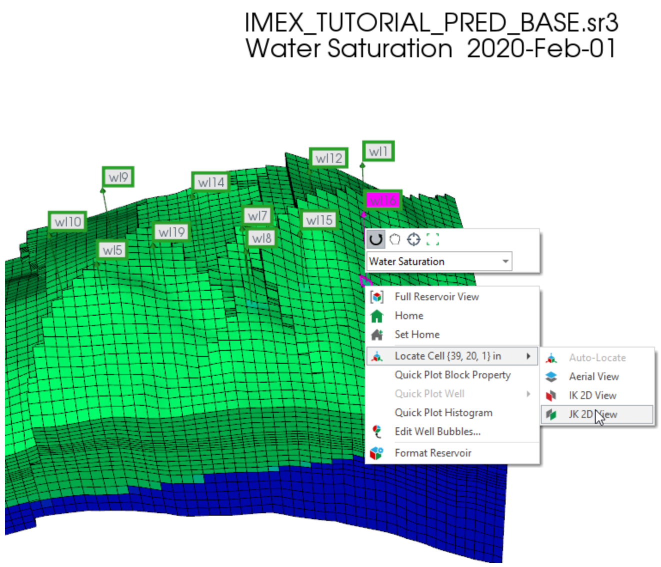


Figure 60: Creating JK cross section using Locate Cell

6. Results now show the water saturation around wl16. Change date as required.

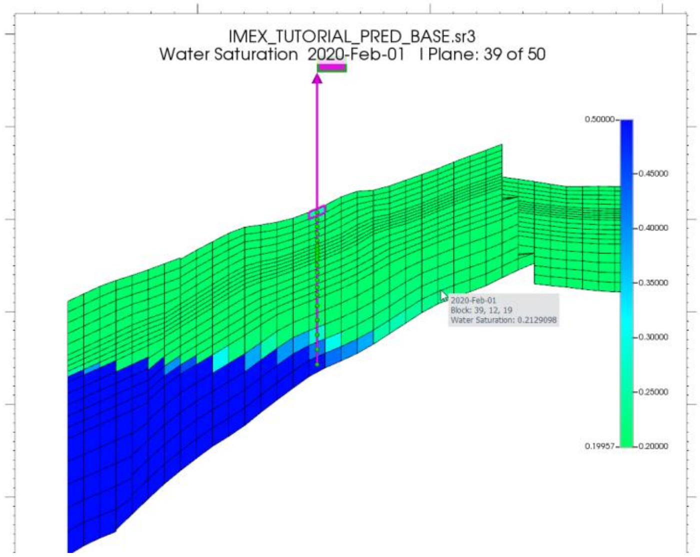


Figure 61: Water saturation at the end of history, w16 cross section

7. Go back to 3D view and click on wl16 name tag to select the well itself this time. Right click on the tag and select **Quick Well Plot: Oil Producer.**

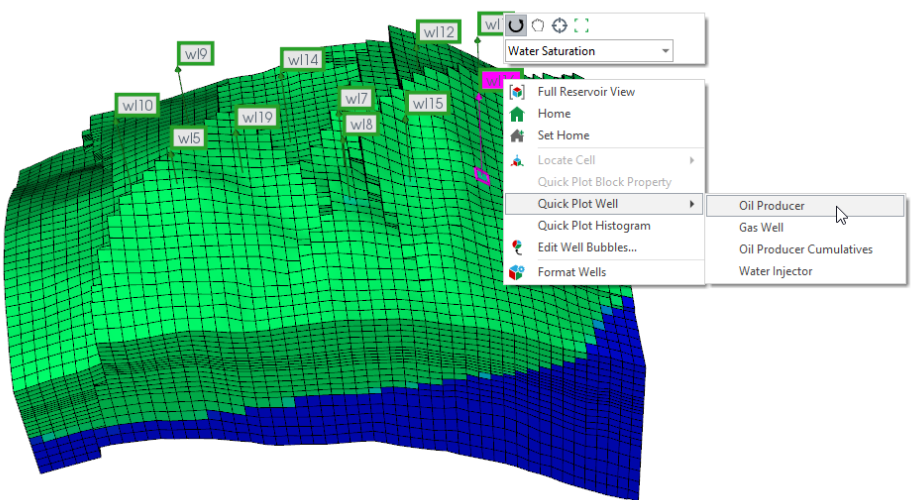


Figure 62: Quick Plot Well

8. In the newly created Dashboard, you can see all the relevant plots. Few weeks after the forecast, this well is going to be closed as oil rate production drops below minimum of 3 m^3/d. Also, the well water cut is near 80% at this point.

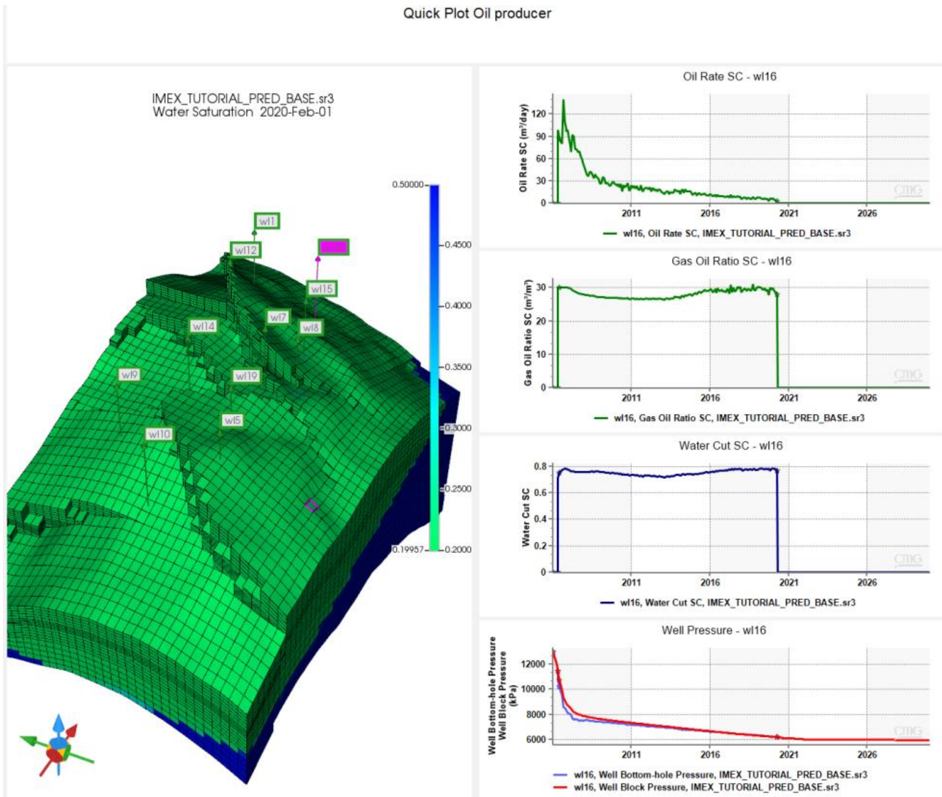


Figure 63: wl16 production dashboard

9. The criteria for the second candidate for injection will be based on those with less oil production rates and location. Production Dashboard will automatically update plots for the other wells if you click on the other well names. The base case results indicate that one of the wells with less oil production is **wl5**; additionally, this well is located on the other side of the reservoir, which can be an advantage from the pressure distribution perspective.

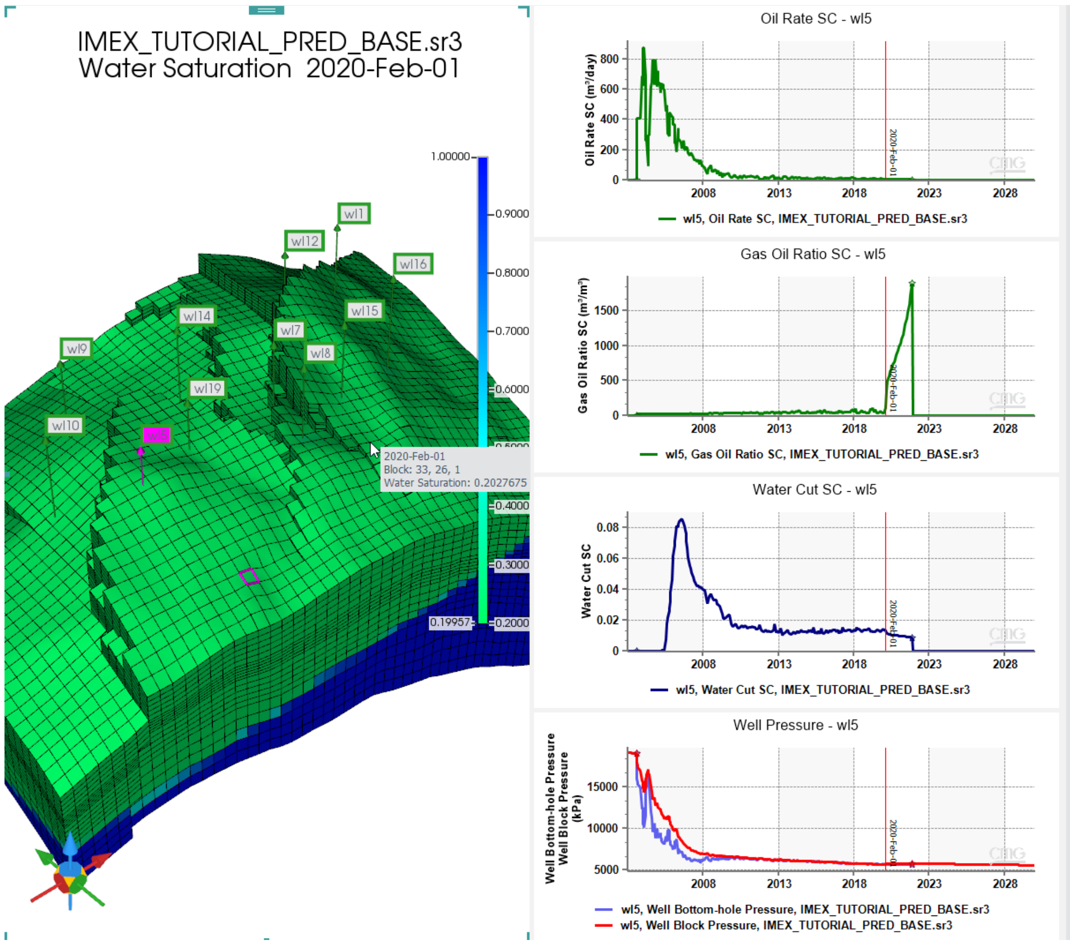


Figure 64: Location of wl5 compared to wl16 and its production dashboard

Conversion of Producer Wells into Water Injectors

We are unable to switch the same well from production to injection and vice versa In a simulation. However, in order to mimic this change, we need to create a new well in the same location with the same trajectory, perforations and characteristics but with the opposite functionality. In other words, if the original well is a producer the new well should be an injector.

10. Go to the CMG launcher and open in Builder the dataset related to the base case option (**IMEX_TUTORIAL_PRED_BASE.DAT**).
11. Save the file as **IMEX_TUTORIAL_PRED_WATER.DAT** under the Prediction folder.
12. Go to the **Wells and recurrent** section, and choose the **Copy Well** option.
13. From the list of producers, select **wl16 and wl5**. Click on next button.

14. Accept the options by **default** for **step 2** (Copy all perforation dates) and check the boxes to **Copy Geometry** and **Copy Trajectory** in **steps 3 and 4.** In step 5 under New Well Date select **2020/03/01.**
15. Two new wells have been created to switch from production to injection.

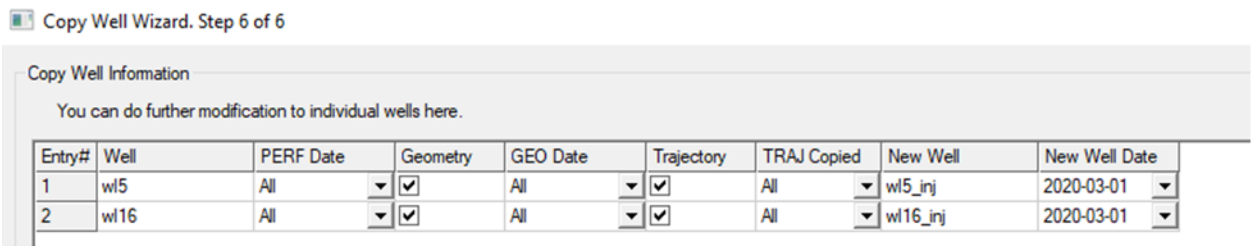


Figure 65: Producers 5 and 16 will be converted to injectors

Well Constraints, Water Injector

16. Under **Wells & Recurrent** double click on the well name **wl16_inj** to open the well **Events** section.
17. Under **Type**, define **INJECTOR MOBWEIGHT**, and then click on the **Apply** button.
18. Go to the **Constraints** tab, check the **Constraint** definition box. From the options available input: OPERATE, BHP MAX=20000Kpa, CONT REPEAT

Figure 66: Constraints for the w16 injector

19. Go to the **Injected Fluid** tab and select **WATER**. Click on **Yes** to **Apply the Changes**.
20. Now we need to **copy** the specified events for well **wl5_inj**. To do this, select the events (INJECTOR, constraints, injected fluid), right click and select the option **Copy Events Using Filter….**
21. In the window that will pop-up, select **wl5_inj** under the **Wells** tab. Under **Dates**, select 2010-03-01. Click on **Search & Add**. Click **OK** and **OK** again to close the **Well Event** window.

Shut-in the Converted Wells (wl16 and wl5)

22. It will be required to **shut-in** wells **wl5** and **wl16** during the prediction as these wells have been already converted into injectors. To do this, double click on the well name **wl16** and go to the last event, **2020/02/01**.

23. Select the **Options** tab, check the **Status** box and select **SHUTIN** from the drop-down menu. Click on **Apply** and **OK**. Repeat the previous steps to shut-in the wl5 well.

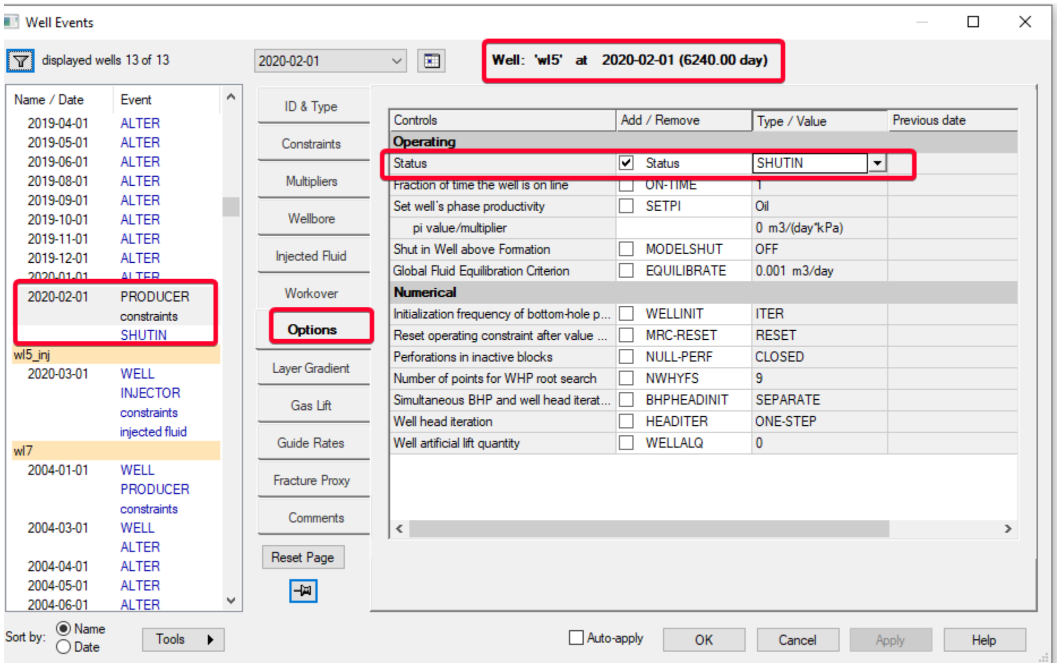


Figure 67: Shut-in the converted well w16

24. In order to make sure the status of the wells have been applied Well time line view can be used. Go to **Wells** tab and select **Open Time-Line View** and check the wells status on February 2020.

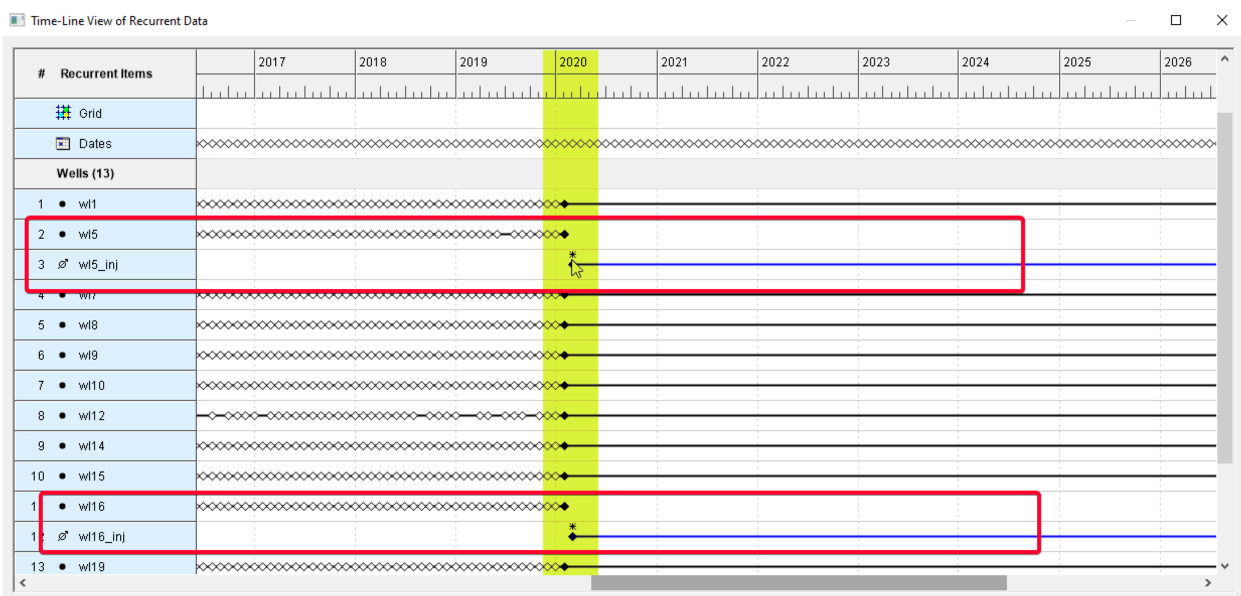


Figure 68: Time line view

25. In order to perform injection using different wells in the reservoir, we need to attach the injector wells to a group. In the Wells & Recurrent tree view, right click on the **Groups (0)** and select **New**.
26. The **Create New Group** dialog window pops up. In the **Definition** tab, name the group "**FIELD**" as the top-level group. Click on the **Calendar** button and input the date **2020-03-01**. The window must look like in the following figure.

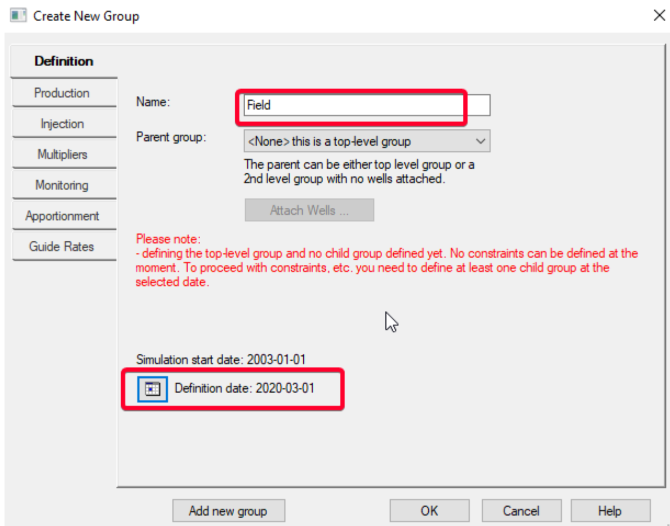


Figure 69: Creation of a parent group

27. Click on the **Add New Group** button and create a new group with the name "**G_INJ**". Make sure **FIELD** is the parent group as shown in the following figure. Click **OK**.

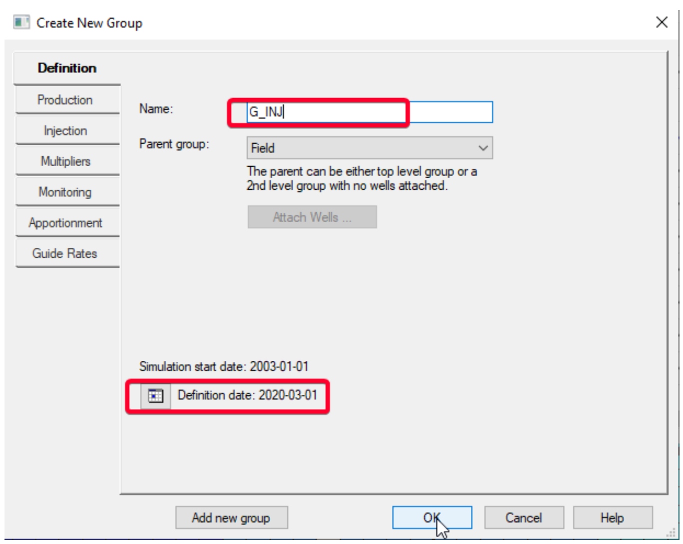


Figure 70: Creation of group of injection

28. In the Wells & Recurrent tree view, expand the groups attached to **FIELD**, and double click on the **G_INJ** to open the **Group Events** dialog window. Then click on the **Attach Wells…** button to open the **Well-Group Attachment** dialog. Select **"wl5_inj"** and **"wl16_inj"** and click **OK**.

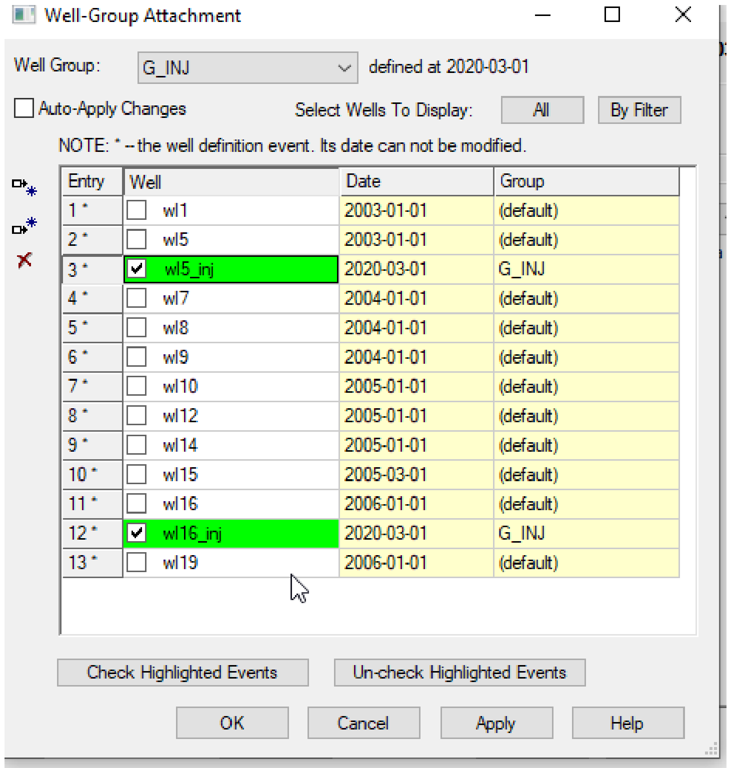


Figure 71: Attaching injector wells into the group

29. Go to the **Injection** tab, check the **GCONI** group injection box and select **GTARGET** (Under type) from the available options and a water constant rate (STW surface water rate) of **4000 m3/day**. This option will be used to inject a maximum water rate per group; this option is useful especially when a fixed amount of water is available for the entire reservoir. Press **Apply.**

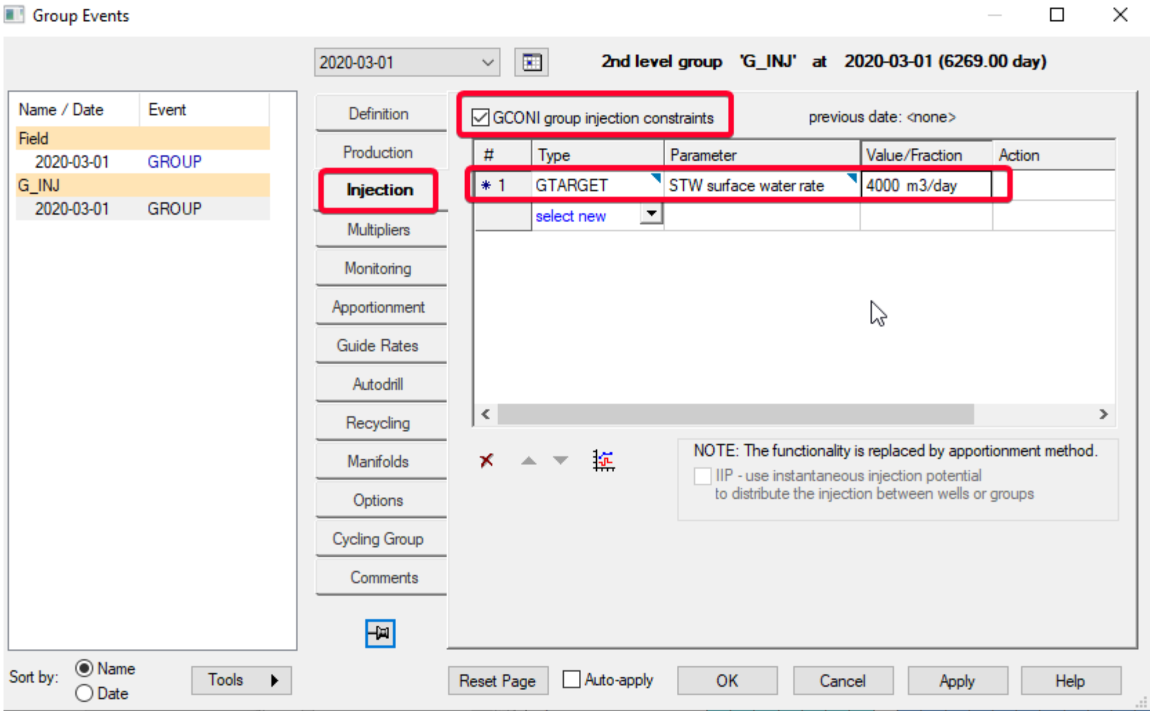


Figure 72: Group constraints definition

30. In the **Apportionment** tab, check the box for **water injection**. Leave the default apportionment method as **Instantaneous Potential.** This will distribute the injection between the wells based on the potential for each well.

Running the Model

31. **Save** the model and close Builder.
32. In the CMG launcher, run the model by dragging and dropping the **IMEX_TUTORIAL_PRED_WATER.DAT** file onto the IMEX icon. Submit the job to the **Local** scheduler.

Analysis of Results

33. Open **IMEX_Tutorial_Predictions.results**
34. Go to **Data Sources** → Open CMG simulation results to open the results for the water injection case (**IMEX_TUTORIAL_PRED_WATER.sr3**).

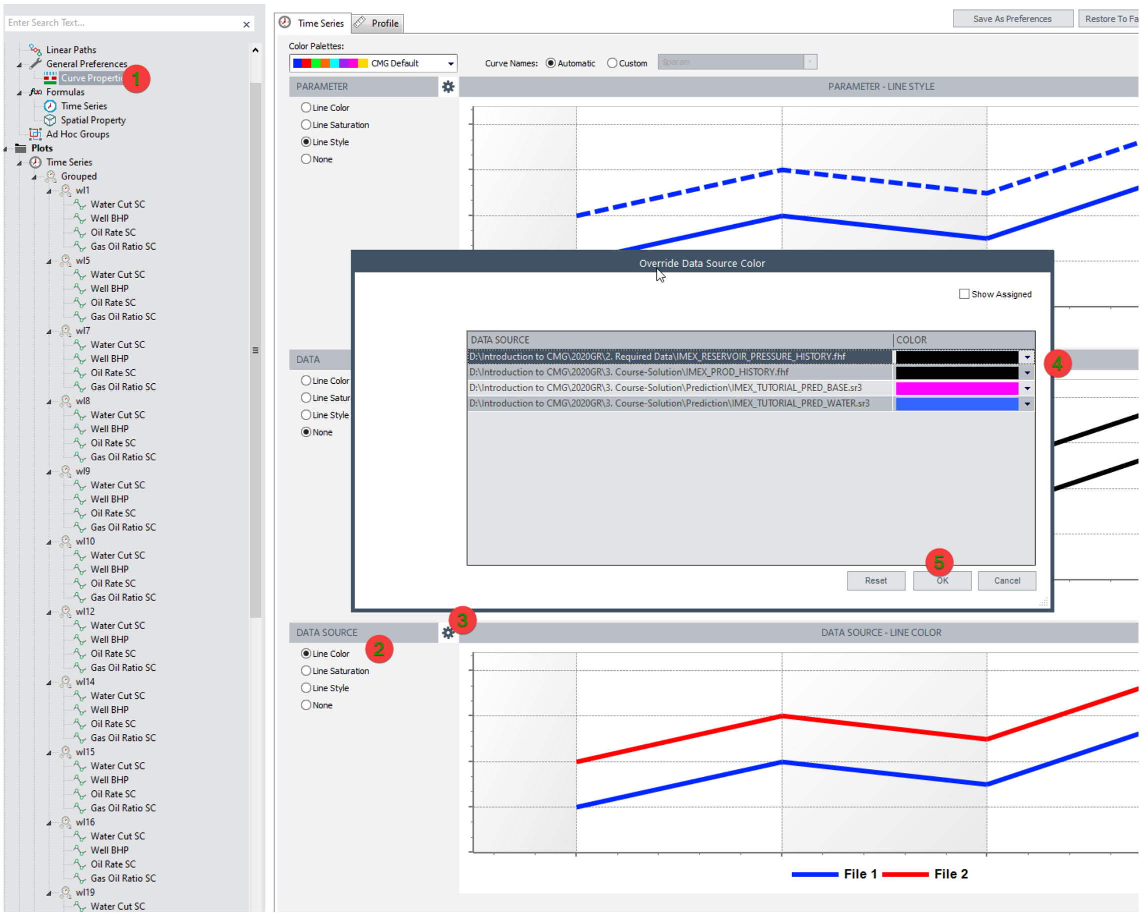


Figure 73: Setting curve properties

35. Go to the Plots section in Project Navigation and click on the individual wells to see the increase in oil production.

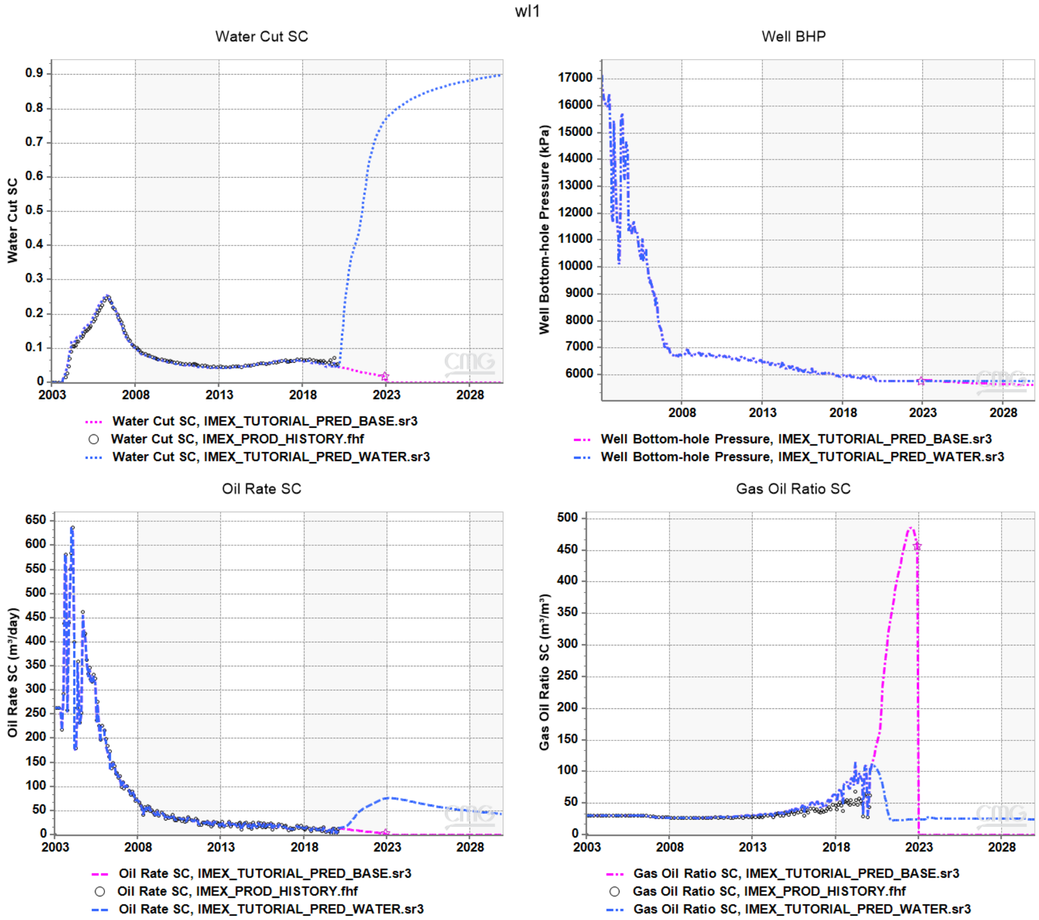


Figure 74: Comparison between base and water injection cases

36. Click on the Oil Rate & Oil Recover Factor plot that was created for the base case and add the following curves for the **IMEX_TUTORIAL_PRED_WATER.sr3** case:

    For Oil Rate, select:

    Data Type (**Group**), Data Sources (**IMEX_TUTORIAL_PRED_WATER.sr3**), Data (**Field-PRO**), Parameter **(Oil Rate SC)**, add curve

    For Recovery Factor, select:

    Data Type (**Sector**), Data Sources (**IMEX_TUTORIAL_PRED_WATER.sr3**), Data (**Entire Field**), Parameter (**Oil Recovery Factor SCTR)**

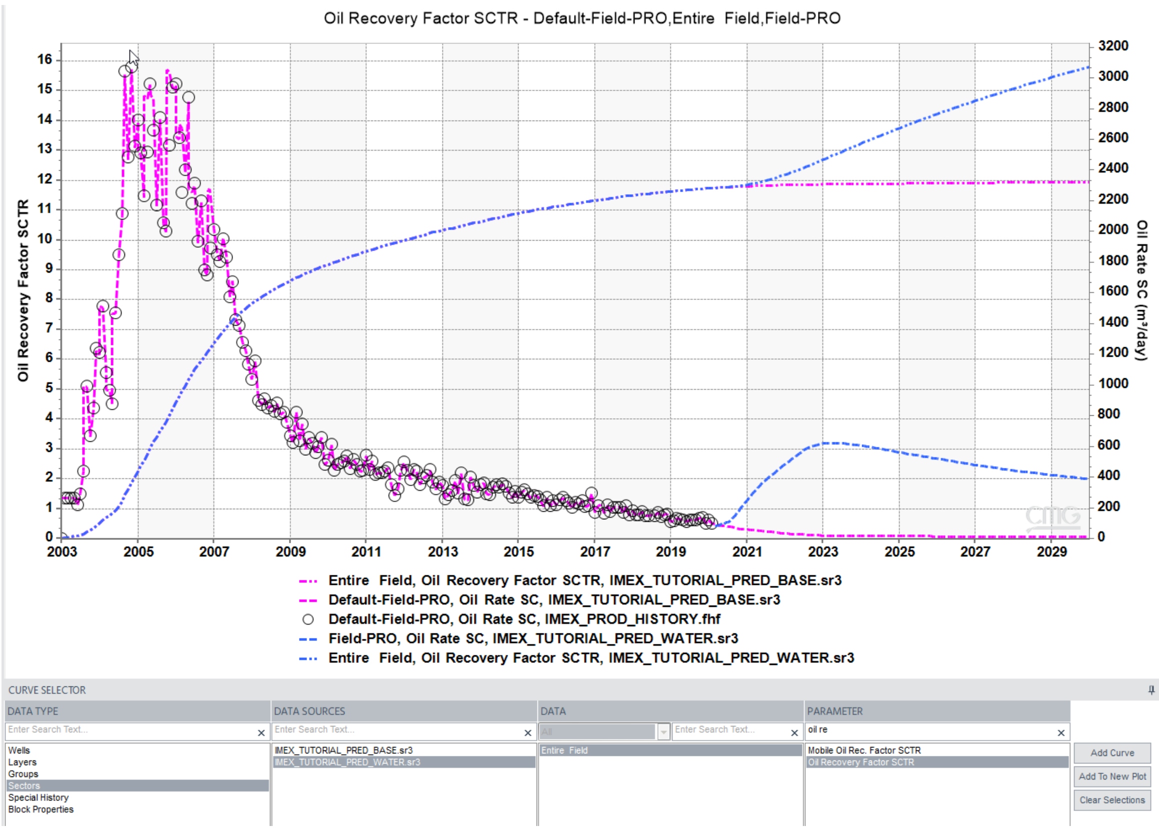


Figure 75: Comparison between base and water injection cases (Oil Rate and Oil RF)

37. Click on the **Ave Pres POVO SCTR** plot that was created for the base case and add the following curves for the **IMEX_TUTORIAL_PRED_WATER.sr3** case:

For Reservoir Pressure, select:

Data Type (**SECTOR**), Data Sources **(IMEX_TUTORIAL_PRED_WATER.sr3)**, Data (**Entire Field**), Parameter (**Ave Pres POVO SCTR**), Add Curve

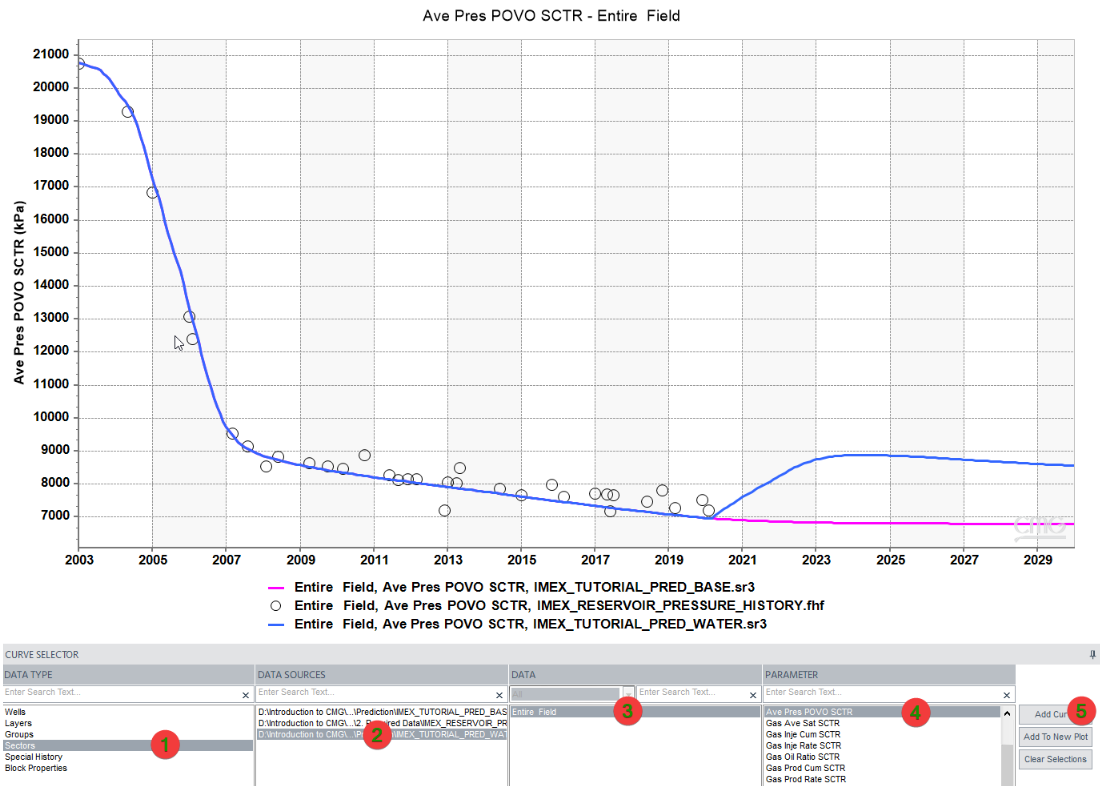


Figure 76: Comparison between base and water injection cases, average field pressure

Gas Injection

Another possibility to increase the reservoir pressure is by injecting gas instead of water. As the saturation pressure was reached during the historical period, we can tentatively inject gas in the gas cap in order to increase the pressure.

Analysis in Results

We can use Results to display different properties that can be useful to take decisions for the stage of prediction.

1. Open **IMEX_Tutorial_Predictions.results**
2. In the **Reservoir** section of Project Navigation, select the **Aerial View** for **IMEX_TUTORIAL_PRED_BASE.sr3**
3. Display the property of **Gas Saturation** at the end of the stage of history, **2020-02-01**.
4. In 3D view, add **Well Slab Filter**. We can observe a region of gas at the top of the reservoir structure. Some well locations have been covered by this gas, **wl12 and wl19**.

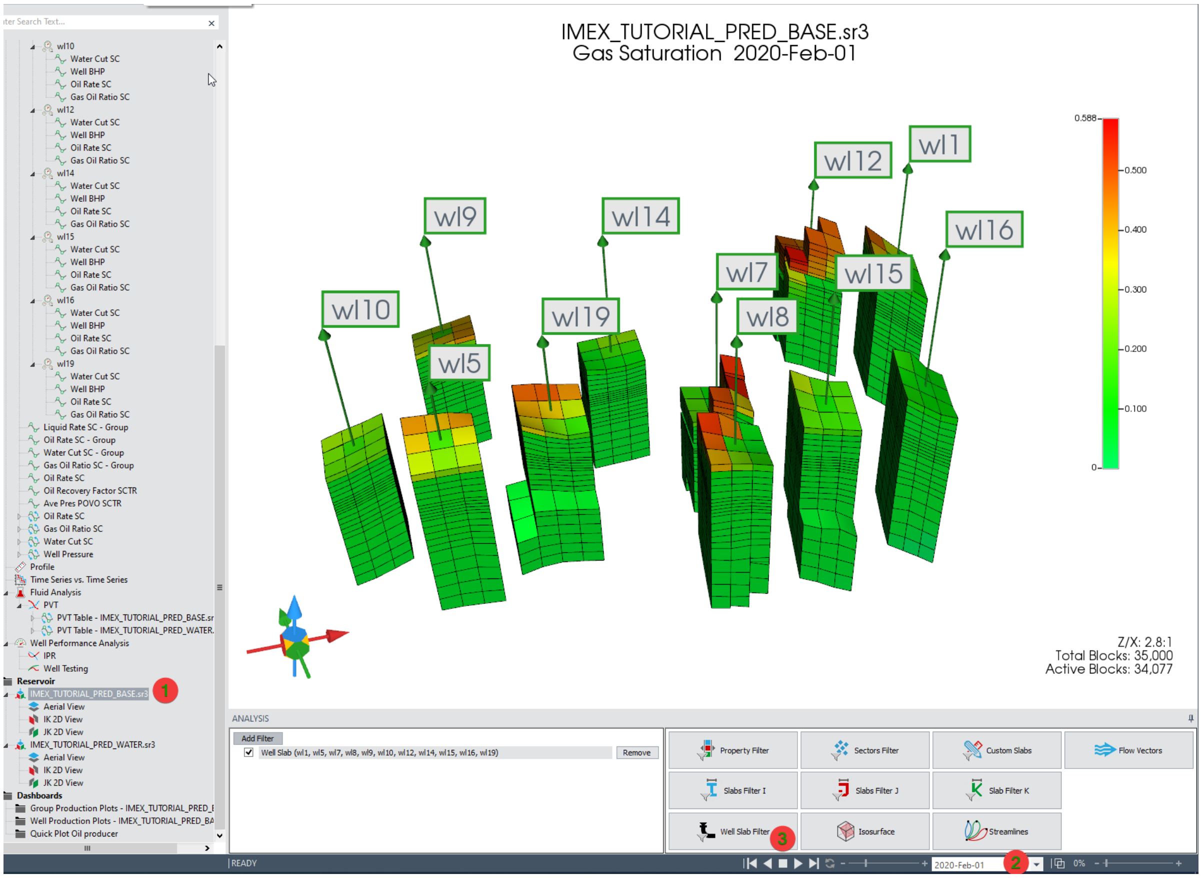


Figure 77: Gas saturation in 3D and using well slab filter

5. You can click on **wl12** and then right click and select **Quick Plot Well: Oil Producer** to create dashboard below:

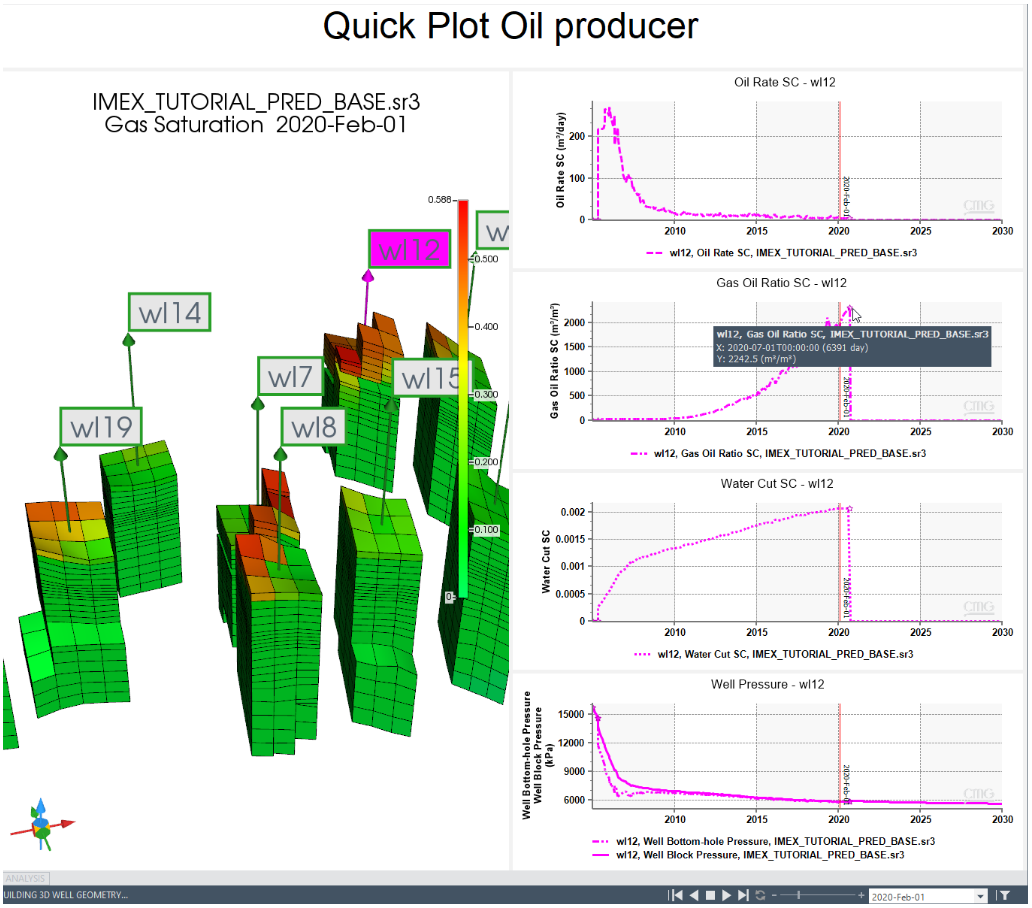


Figure 78: Production results for wl12

6. From these plots, it can be concluded that wl12 can be a suitable well candidate to be converted into a gas injector.

Conversion of Producer Wells into Gas Injector

7. Go to the CMG launcher and open in Builder the dataset related to the base case option (**IMEX_TUTORIAL_PRED_BASE.DAT**).
8. Save the file **IMEX_TUTORIAL_PRED_GAS.DAT.**
9. Go to the **Wells** and recurrent section and click **Copy Well.**
10. From the list of producers, select **wl12**. Click on the **Next** button.
11. Accept the options by **default** for **step 2** and check the boxes to **Copy Geometry** and **Trajectory** in **steps 3 and 4.** In step 5 under **New Well Date,** select **2020/03/01.**
12. A new well has been created to switch from production to gas injection.

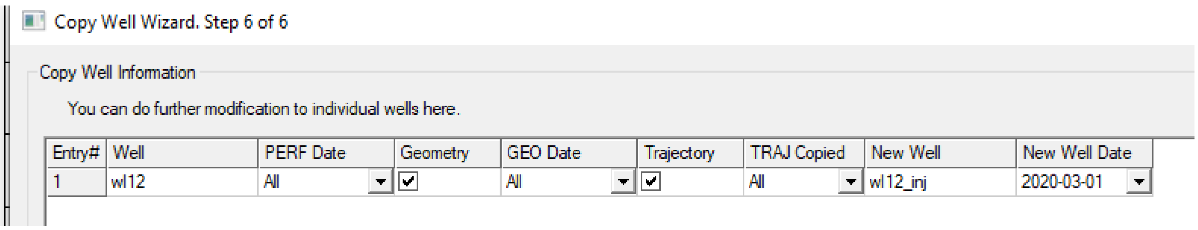


Figure 79: Conversion of wl12 from producer to injector

Well constraints, GAS INJECTOR

13. Under Wells & Recurrent, double click on the well **wl12_inj** to open the well **Events** section.
14. Under **Type**, define **INJECTOR MOBWEIGHT**, and then click on the **Apply** button.
15. Go to the **Constraints** tab, check the **Constraint Definition** box. From the options available select for the first constraint:

    OPERATE, **BHP MAX=20,000 KPa**, CONT REPEAT

    For the second constraint:

    OPERATE, **STG** surface gas rate=**400,000 m^3/day**, CONT REPEAT

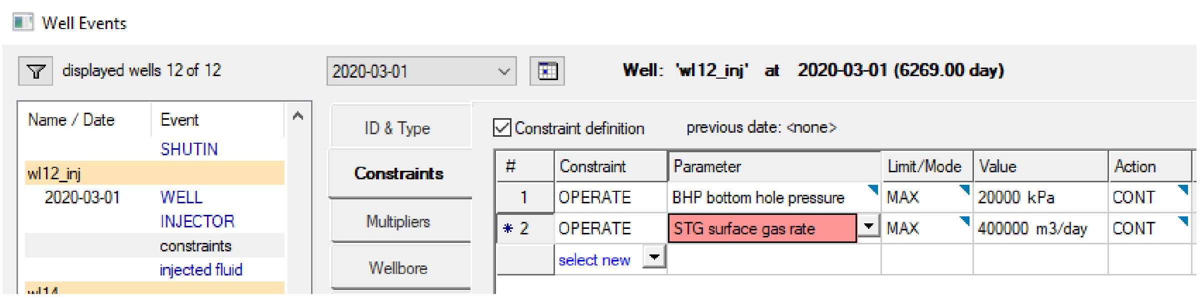


Figure 80: Well constraints for the new converted well, wl12

16. Go to the **Injected Fluids** tab and change injected fluid from WATER to **GAS**. Click **APPLY** then **OK** (this removes the Pink color on STG, since default injected fluid is water).

Shut-in the Converted Well (wl12)

17. It will be required to shut-in the producer well **wl12** during the prediction as this well has been already converted into gas injector. To do this, double click on the well **wl12** and go to the last event, 2020/02/01.
18. Select the **Options** tab, check the **Status** box and change the condition from OPEN to SHUTIN. Click **Apply** and **OK.**

Running the Model

19. **Save** the model and close Builder.

20. In the CMG launcher, run the model by dragging and dropping the **IMEX_TUTORIAL_PRED_GAS.DAT** file into the IMEX icon.

Analysis of Results

21. Open **IMEX_Tutorial_Predictions.results**
22. Go to **Data Sources** → Open CMG simulation results to open the results for the gas injection case (**IMEX_TUTORIAL_PRED_GAS.sr3**).
23. Go to Curve Properties and select red color for **IMEX_TUTORIAL_PRED_GAS.sr3.**
24. Go to the Plots section in Project Navigation and click on the individual wells to see the increase in oil production.

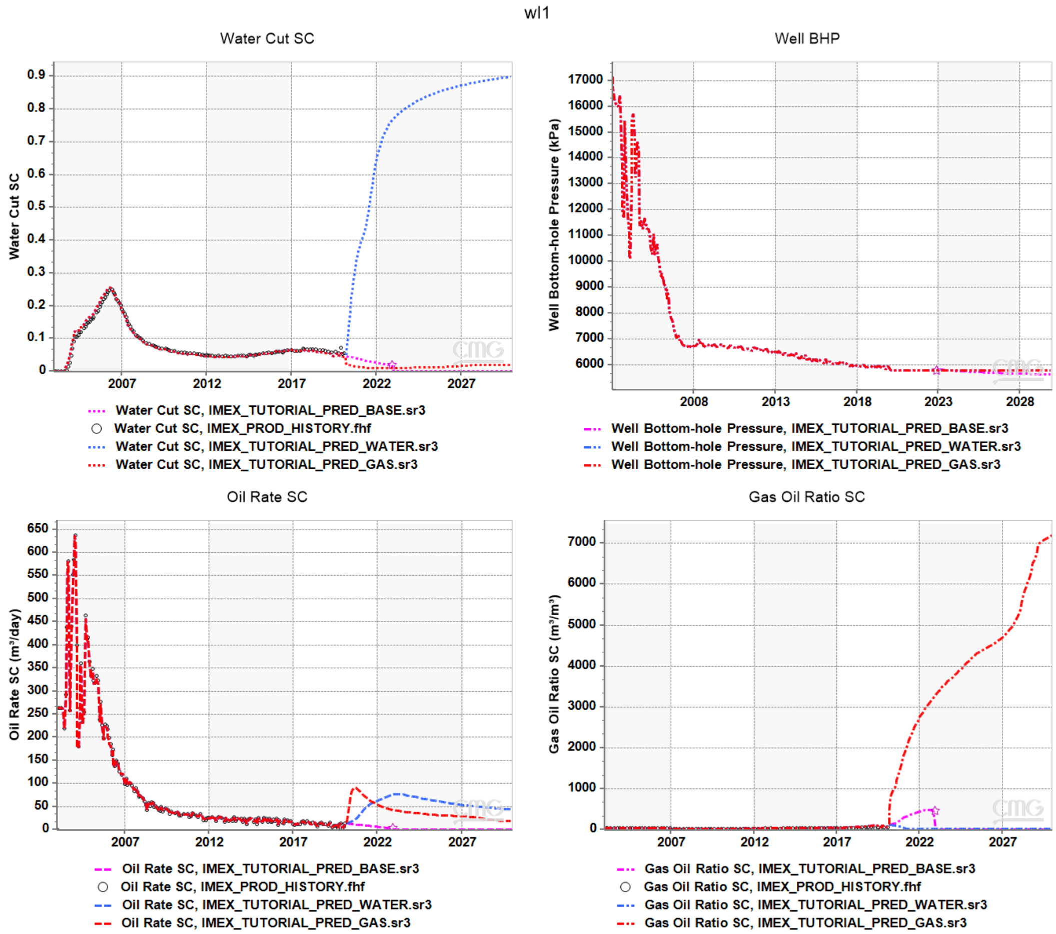


Figure 81: Comparison between base case, water injection, and gas injection cases

25. Similarly compare the results per field, oil production, oil recovery factor and reservoir pressure.

26. Click on the Oil Rate & RC plot that was created for the base case and add the following curves for the **IMEX_TUTORIAL_PRED_GAS.sr3** case:

For Oil Rate, select:

Data Type (**Group**), Data Sources (**IMEX_TUTORIAL_PRED_GAS.sr3**), Data (**Default-Field-PRO**), Parameter **(Oil Rate SC)**, add curve

For Recovery Factor, select:

Data Type (Sector), Data Sources (IMEX_TUTORIAL_PRED_GAS.sr3), Data (Entire Field), Parameter (Oil Recovery Factor SCTR)

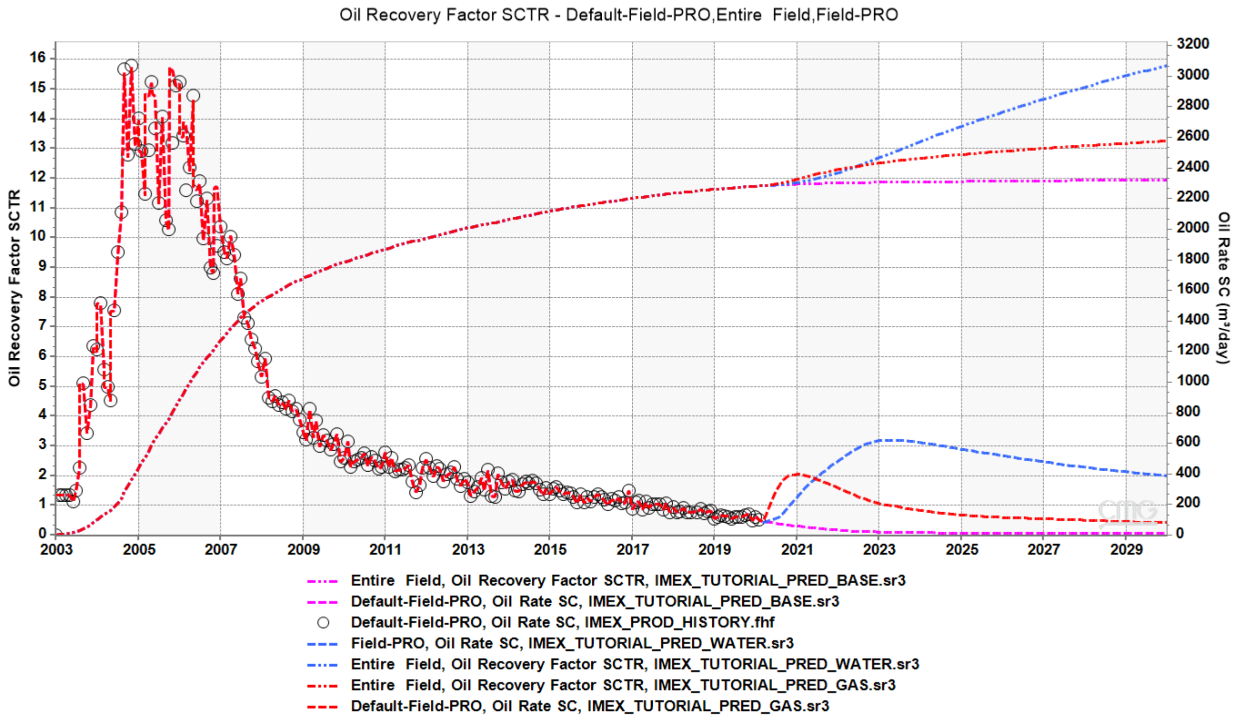


Figure 82: Comparison of the three different scenarios of prediction

For Reservoir Pressure, click on the **Ave Pres POVO SCTR** plot and select:

Data Type (**SECTOR**), Data Sources **(IMEX_TUTORIAL_PRED_GAS.sr3)**, Data (**Entire Field**), Parameter (**Ave Pres POVO SCTR**), **Add Curve**

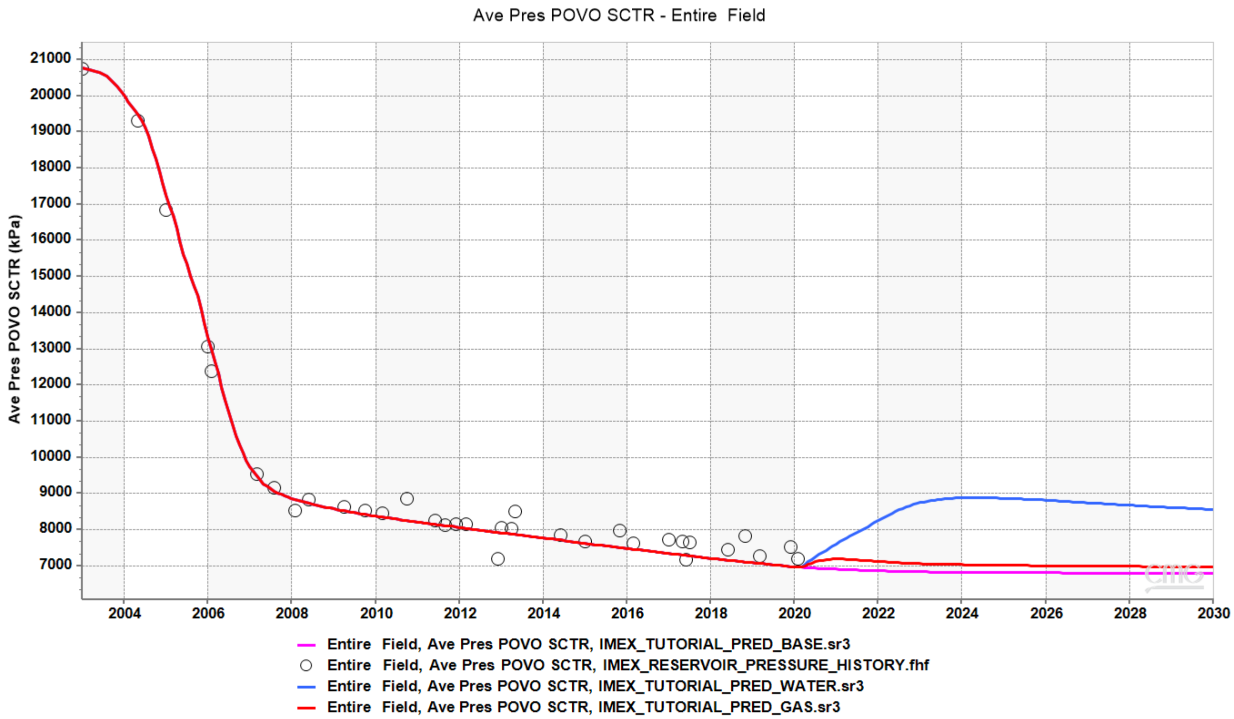


Figure 83: Comparison of the three different scenarios of prediction, average field pressure

27. Based on the previous outcomes, the scenario with water injection generates better results in terms of recovery factor, now the question is why. In order to understand the results, we are going to analyze parameters such as saturations at the end of the prediction.
28. In the **Reservoir** section of Project Navigation, click on **IMEX_TUTORIAL_PRED_GAS.sr3** to get access to the 3D view of the reservoir
29. Change the **Property** being shown to **Gas Saturation** and start animation from 2020-Feb-01.

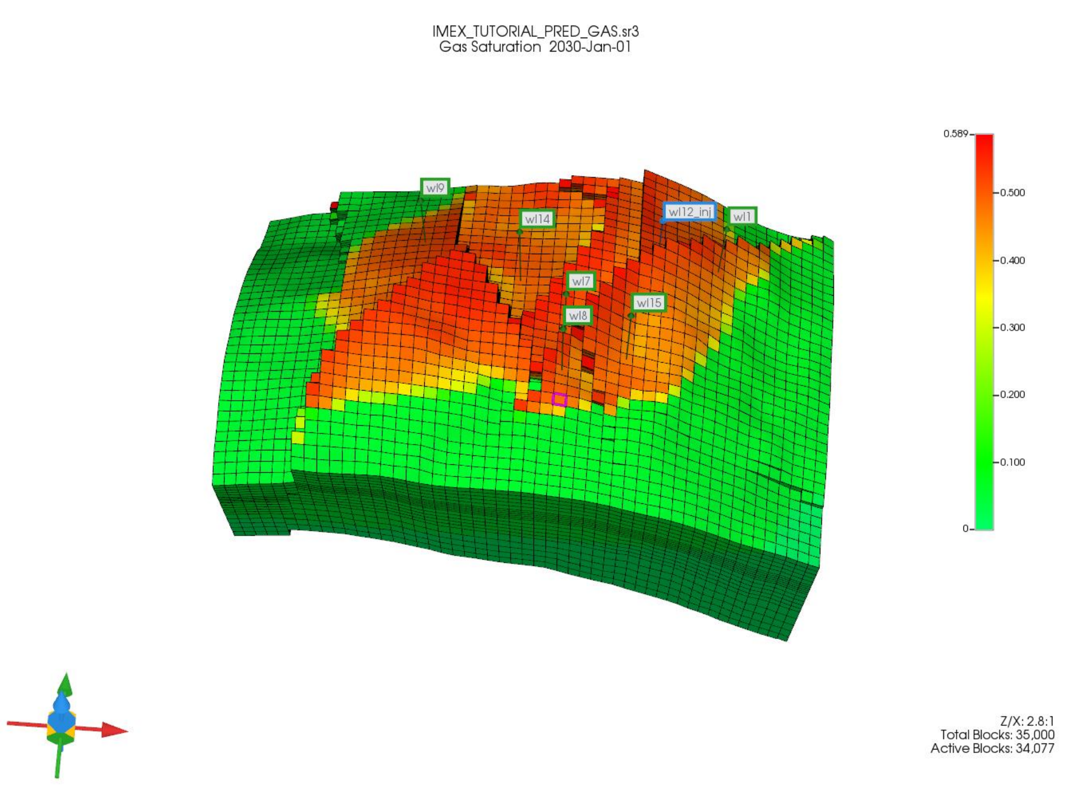


Figure 84: Gas Saturation distribution for gas injection scenario

30. It can be observed that the gas injection scenario generates an extended gas cap in the reservoir. As a consequence, the gas production increases and most of the injected gas is produced by the wells (Fig.85), reducing the effect of pressure support (see the reservoir pressure comparison in Results Graph). This scenario is due to the flat condition in the structure and open production intervals in the top layers.
31. Click on **Time Series** in the **Plots** section of Project Navigation and add two curves **(Sector – Gas Inje Rate SCTR & Sector – Gas Prod Rate SCTR)**

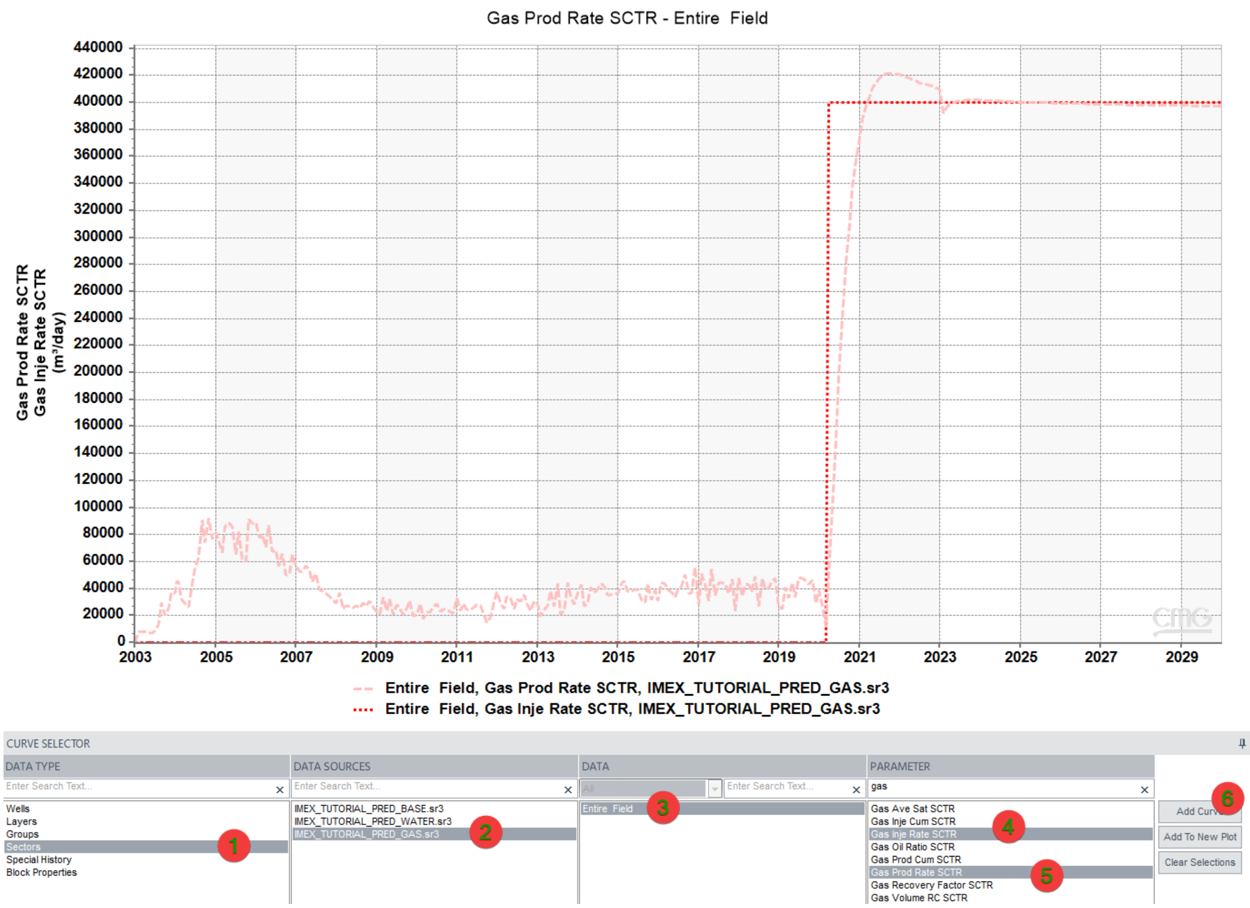


Figure 85: Comparison between gas injected vs. gas produced

Horizontal Wells

Based on the above results, it was concluded that the water injection option is more attractive from the point of view of oil recovery factor. Now we will analyze the possibility of developing the field by adding new wells, in order to maximize the recovery factor.

Definition of New Locations Using Results

*Our goal is to determine new well locations. Open the water injection scenario in results by dragging and dropping the **IMEX_TUTORIAL_PRED_WATER.sr3** on Results. We will select a high oil saturation zone with good porosity and permeability for the new well location. This zone should also be away from high water saturation areas.*

1. In the **Reservoir** section of Project Navigation, click on **3D View** and set the date to 01-Feb-2020.
2. **Select** Property Filter from the options below
3. Apply four filters to identify the most productive sections of the model:

Property Filter (Porosity):	Min value: 0.17
Property Filter (Permeability I):	Min value: 200 mD
Property Filter (Oil Saturation):	Min value: 0.7
Property Filter (Oil Per Unit Area-Layer):	Min value: 1

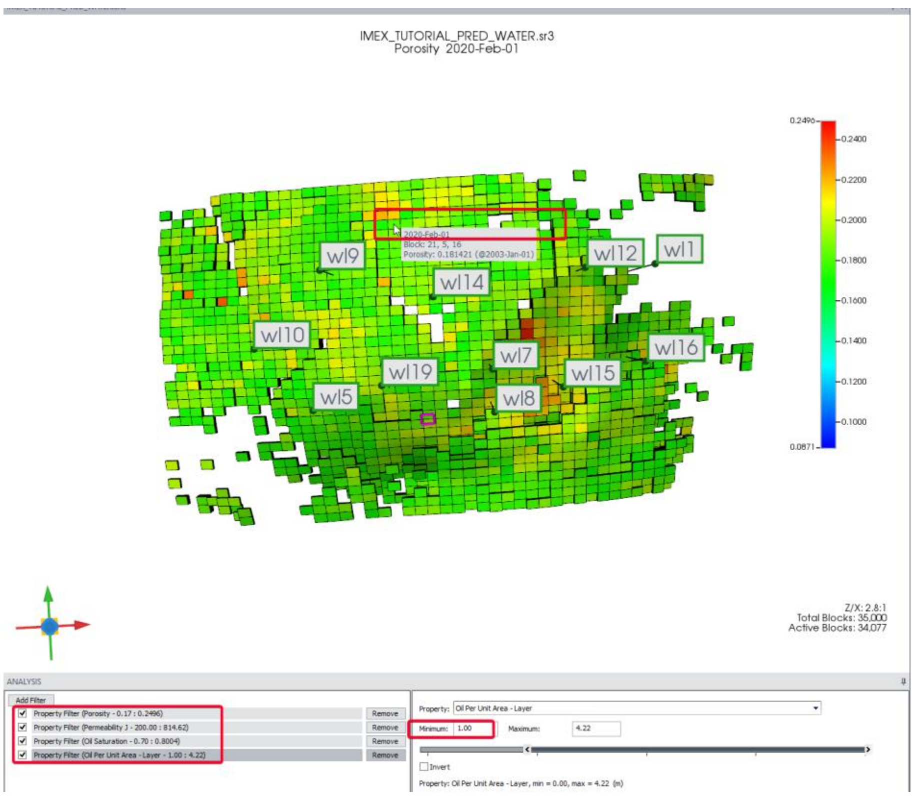


Figure 86: Definition of new locations based on Sw, So, Permeability I, and Porosity

Based on this plot, it is decided to drill new horizontal well in J direction from block 21 5 17 to 28 5 17.

Adding a New Horizontal Well in Builder

4. Open **IMEX_TUTORIAL_PRED_WATER.DAT** in Builder and start by **saving** the file as **IMEX_TUTORIAL_PRED_WATER_ADD_WELLS.DAT** under the Prediction folder. In the Wells & Recurrent tree view, right click on **Wells (13)** and click on **New…** to create a new well.
5. The **Create New Well** window pops up. In this window, **Name** the well **wl20** and select the **Type** as **PRODUCER**. Change the **Definition date** to **2020-03-01**. The window should look like the following figure.

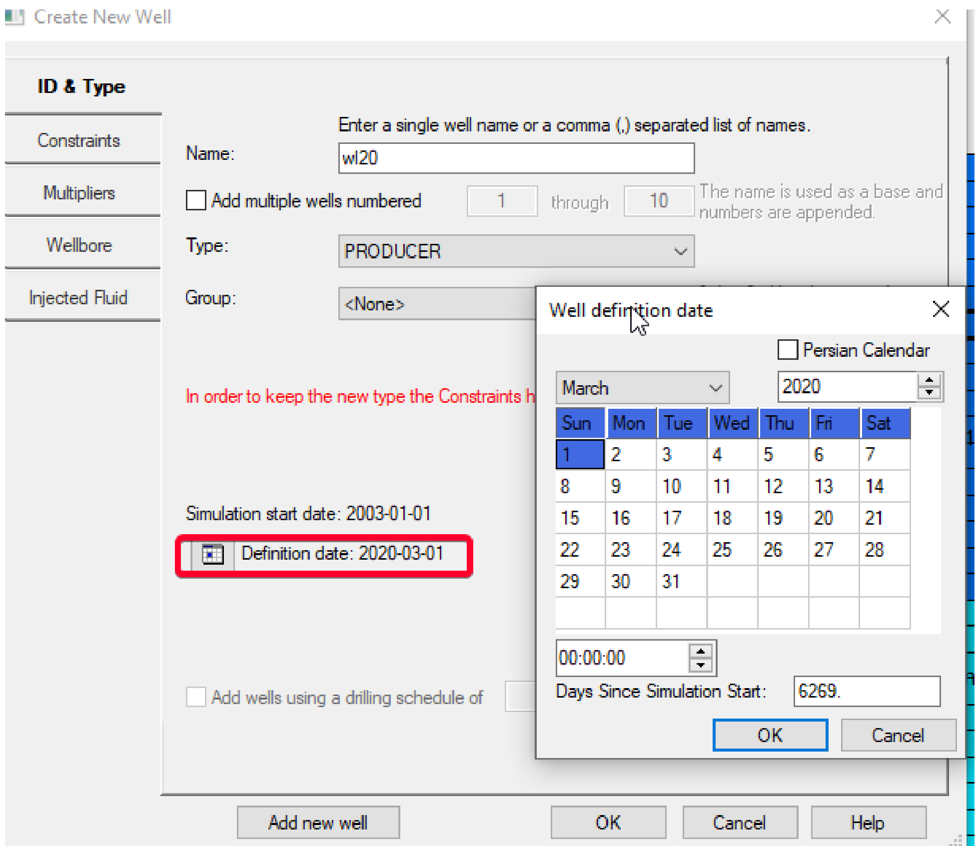


Figure 87: Definition of new well in Builder

6. In order to assign an appropriate group of constraints for the new well, we need to look at other producer wells located in the same area. As can be observed in Figure 88, **Wl9 is located in the same area** of the new proposed well, so we will use the same Bottom Hole Pressure values for prediction, **BHP=5707 kPa.**

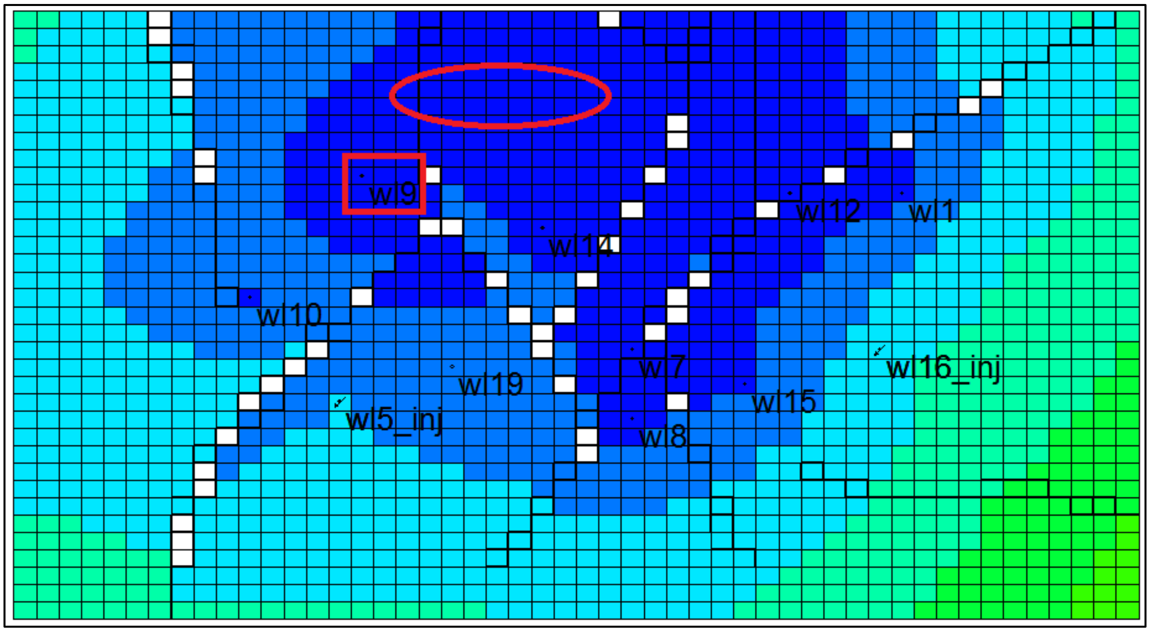


Figure 88: Location of neighbor wells

7. In Builder, in the **Constraints tab**, check the **Constraint Definition** box. Select the **OPERATE BHP Bottom Hole Pressure** as the primary constraint: **MIN: 5707 kPa; CONT REPEAT**. Also, enter a MONITOR constraint of STO surface oil rate **of MIN 3 m^3/day** and select **SHUTIN** as the action.
8. Click **OK** to exit from the **Create New Well** panel.
9. Well **wl20** should appear on the **Wells & Recurrent** tree view. There should be a **red dot** next to this well indicating that there is a data problem.

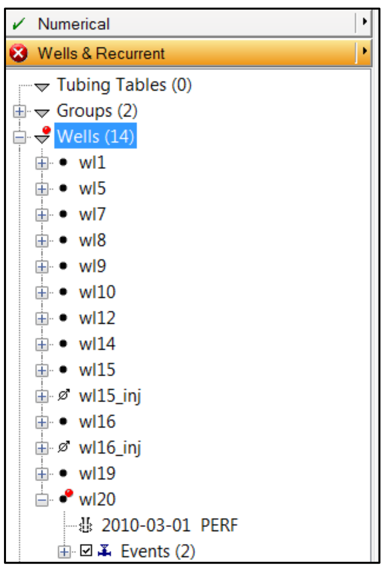


Figure 89: Validation of the new well

10. Right click on this well and select **Validate** to display any errors or warning messages. The message should indicate that there are no valid perforations defined for this well. Click **OK** to close the window.
11. Using the plane slider display layer K=17 and change the property display to Permeability I.

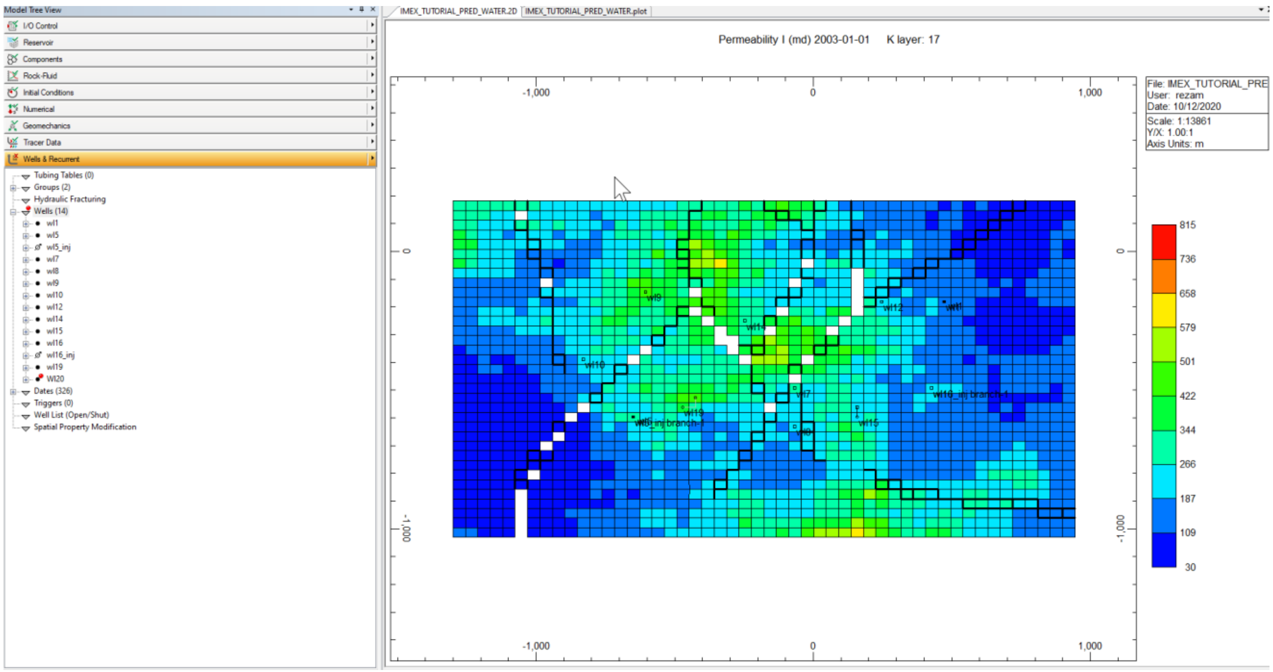


Figure 90: Areal view used for the location of the new well

12. Click on the **+** sign next to **wl20** and double click on **2020-03-01 PERF** to open the **Well Completion Data (PERF)** window.
13. Click on the **Perforations** tab and click the **Begin** button to add perforations with the mouse. Then click on the tool button for **Advanced** options to select **perforate all intermediate blocks** between mouse clicks.

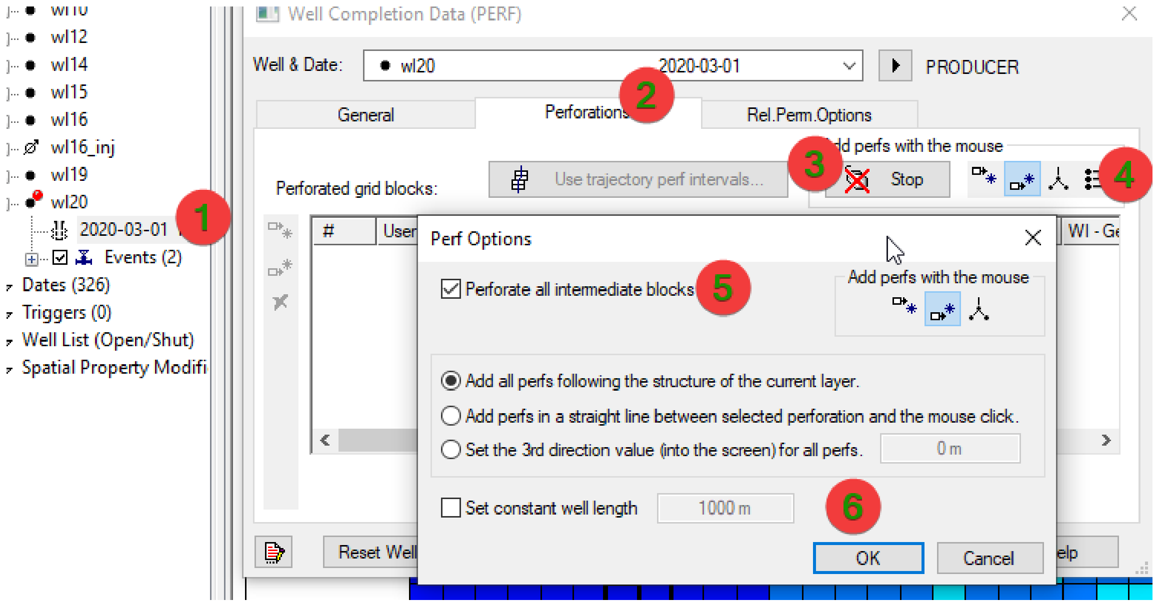


Figure 91: Advanced options for horizontal wells

14. Check the **Perforate All Intermediate Blocks** box. Click **OK**.
15. Move the **Well Completion Data (PERF)** panel to the side so that the model grid can be viewed.
16. Move to **K Plane 17**. Click on grid blocks **21 5 17** and **28 5 17** to create horizontal perforations.

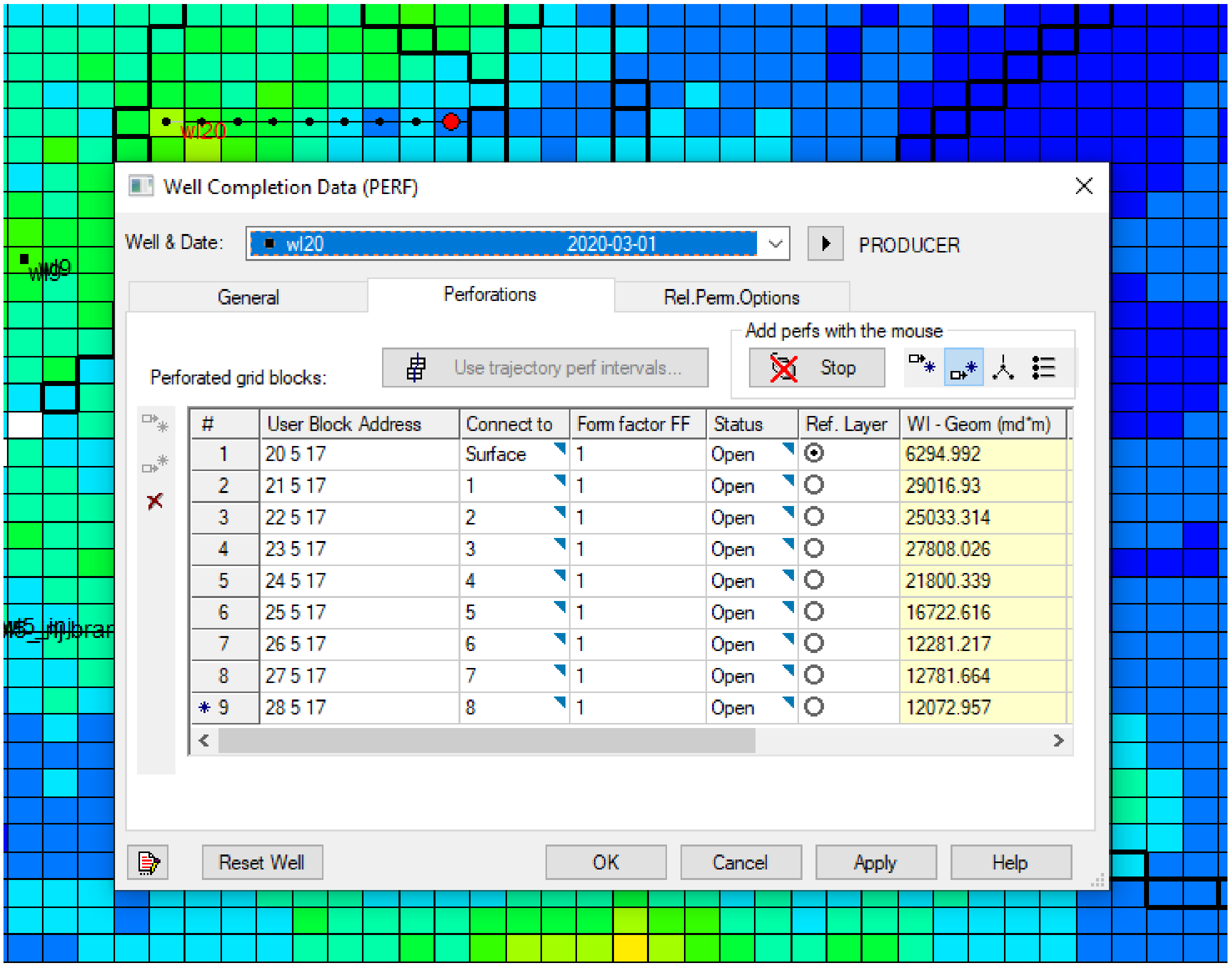


Figure 92: Creating a horizontal trajectory in Builder

17. Click **Stop** to end the perforations. Go to the general tab and change the well direction to **I axis.** Click **Apply** and **OK** to exit. Change from areal view to IK-2D cross section and click on the perforation date **2020-03-01** of well **wl20** to display the horizontal section.
18. The vertical cross section can be enhanced if you increase **Z/X Aspect Ratio** using the option in **View.**

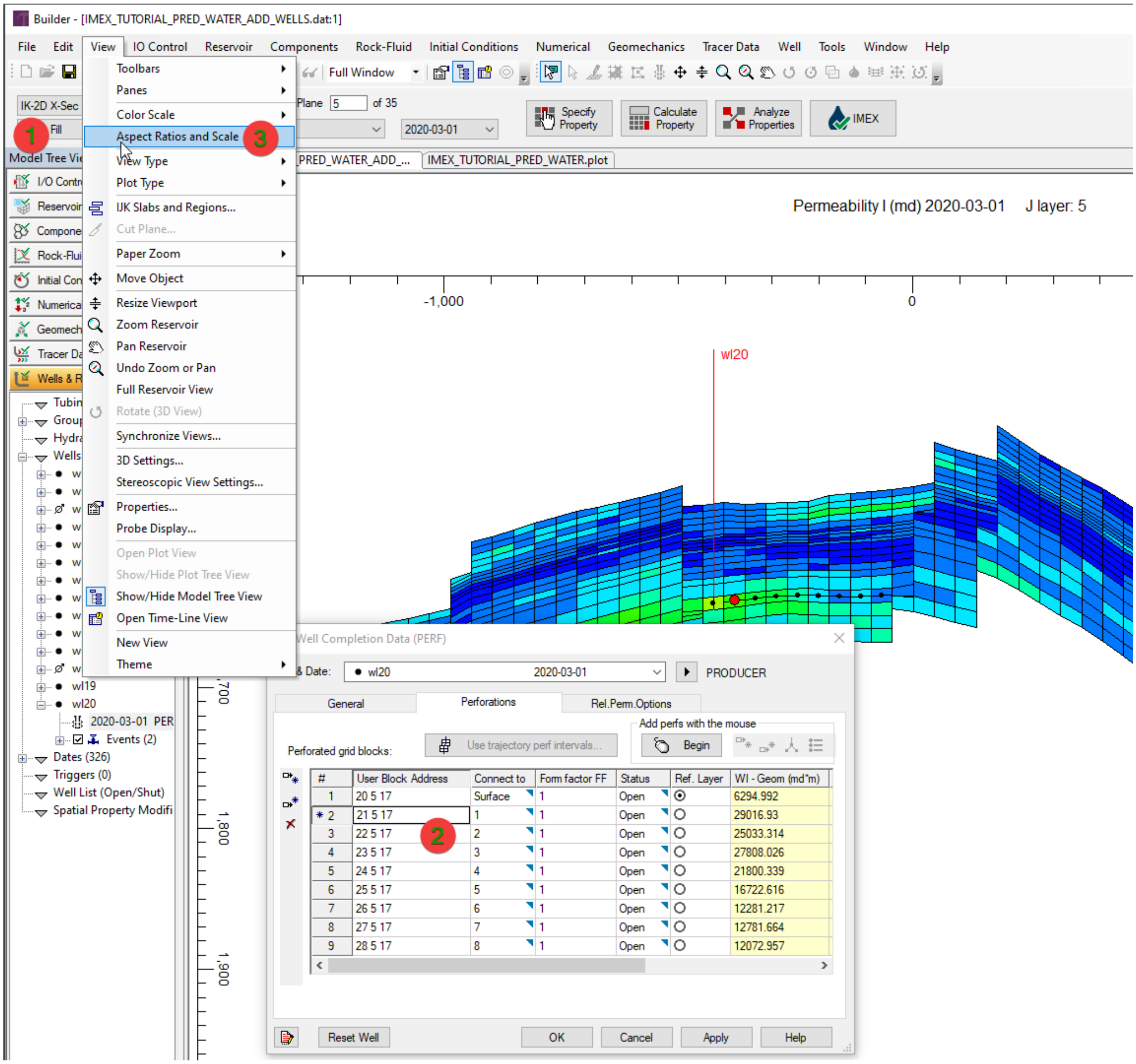


Figure 93: Cross section view, horizontal well perforation for wl20

19. In the same section, click on Select grid variables and from the list activate Flux outputs. Press **OK** on the both windows open.

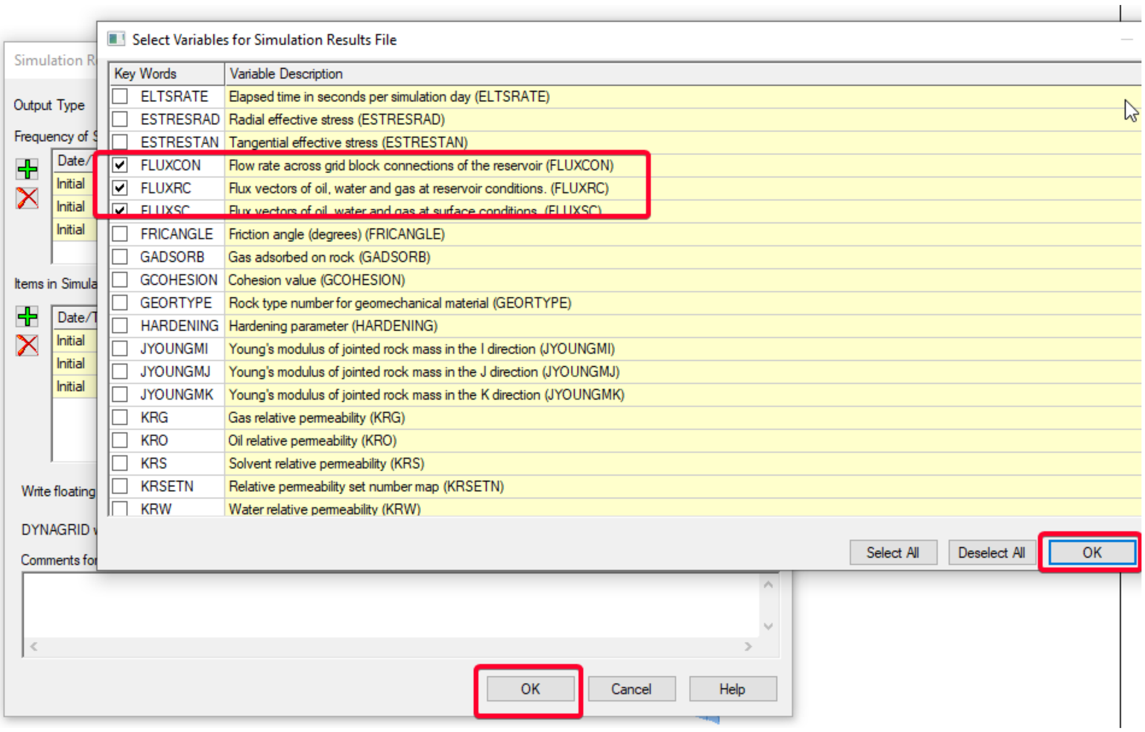


Figure 94: Modifying defaults grid output list

20. **Save** the file one more time. Run the file with IMEX.

Analysis of Results

21. Open **IMEX_Tutorial_Predictions.results**

22. Go to **Data Sources** → Open CMG simulation results to open the results for the infill horizontal well case study (**IMEX_TUTORIAL_PRED_WATER_ADD_WELLS.sr3**).

23. Click on the Oil Rate & RC plot that was created for the base case and add the following curves for the **IMEX_TUTORIAL_PRED_WATER_ADD_WELLS.sr3** case:

    For Oil Rate, select:

    Data Type (Group), Data Sources (**IMEX_TUTORIAL_PRED_WATER_ADD_WELLS.sr3**), Data (**Field-PRO**), Parameter **(Oil Rate SC)**, add curve

    For Recovery Factor, select:

    Data Type (**Sector**), Data Sources (**IMEX_TUTORIAL_PRED_WATER_ADD_WELLS.sr3**), Data (**Entire Field**), Parameter (**Oil Recovery Factor SCTR)**

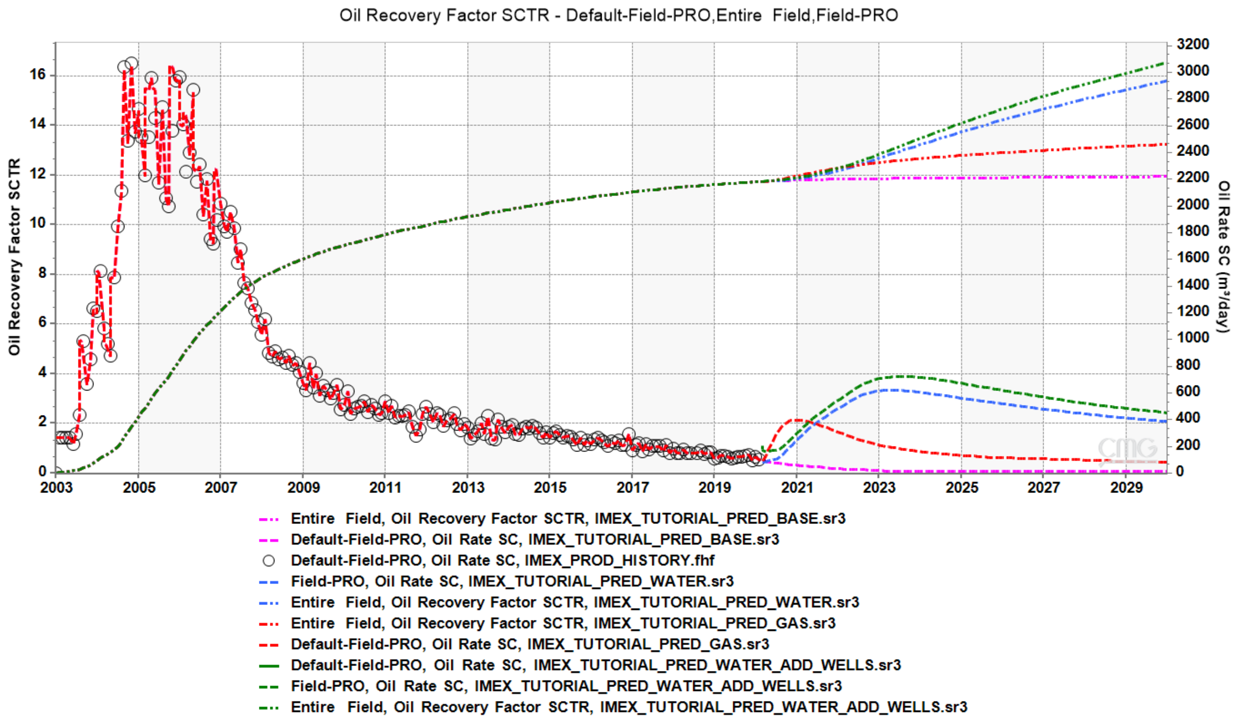


Figure 95: Comparison of different production scenarios including adding horizontal well

24. Click on 3D view. Choose Streamlines and use below settings to visualize the distribution of injected water between the producers at the last simulation date.

Figure 96: Viewing streamlines in Results

Use of Triggers

If we have a limitation in our facilities to handle a maximum of 2,500 m^3/day of produced water then we need, in our simulations, a way to monitor this maximum production. Since most of this water comes from the injector wells, we also need to monitor reservoir pressure in order to avoid a reduction in pressure below 7,500 kPa.

We are going to use the Trigger feature to shut-in the injector wells (16 and 5) when the water production increases above 2,500 m3/day and open the same injector wells if the reservoir pressure decreases below 7,500 kPa.

1. Open "**IMEX_TUTORIAL_PRED_WATER_ADD_WELLS.dat** " model using Builder
2. Click File in the main Builder menu and select Save As. Name this file "**IMEX_TUTORIAL_PRED_WATER_ADD_WELLS_TRIGGER.dat**" and save this file in student solution in Additional Exercises subfolder.
3. Click on the **Wells & Recurrent** section in the tree view and double-click on the **Triggers (0)** option.
4. Select the Date **2020-03-01** for the trigger definition date.
5. Input the following Trigger Name: **WATER_RATE**
6. Select **Field** under **Apply On** dropdown menu.
7. Select **STW-RP: Stock Tank Water – Rate of Production** under **When** dropdown menu and define the trigger value higher than **> 2,500 m3/day**
8. Under **Options** input a value of **10** for the **Maximum number of times that the actions specified with the trigger can be taken.**
9. Type the following inside **Actions** box:

   SHUTIN 'wl5_inj'

   SHUTIN 'wl16_inj'
10. The well management Trigger interface should include the following information.

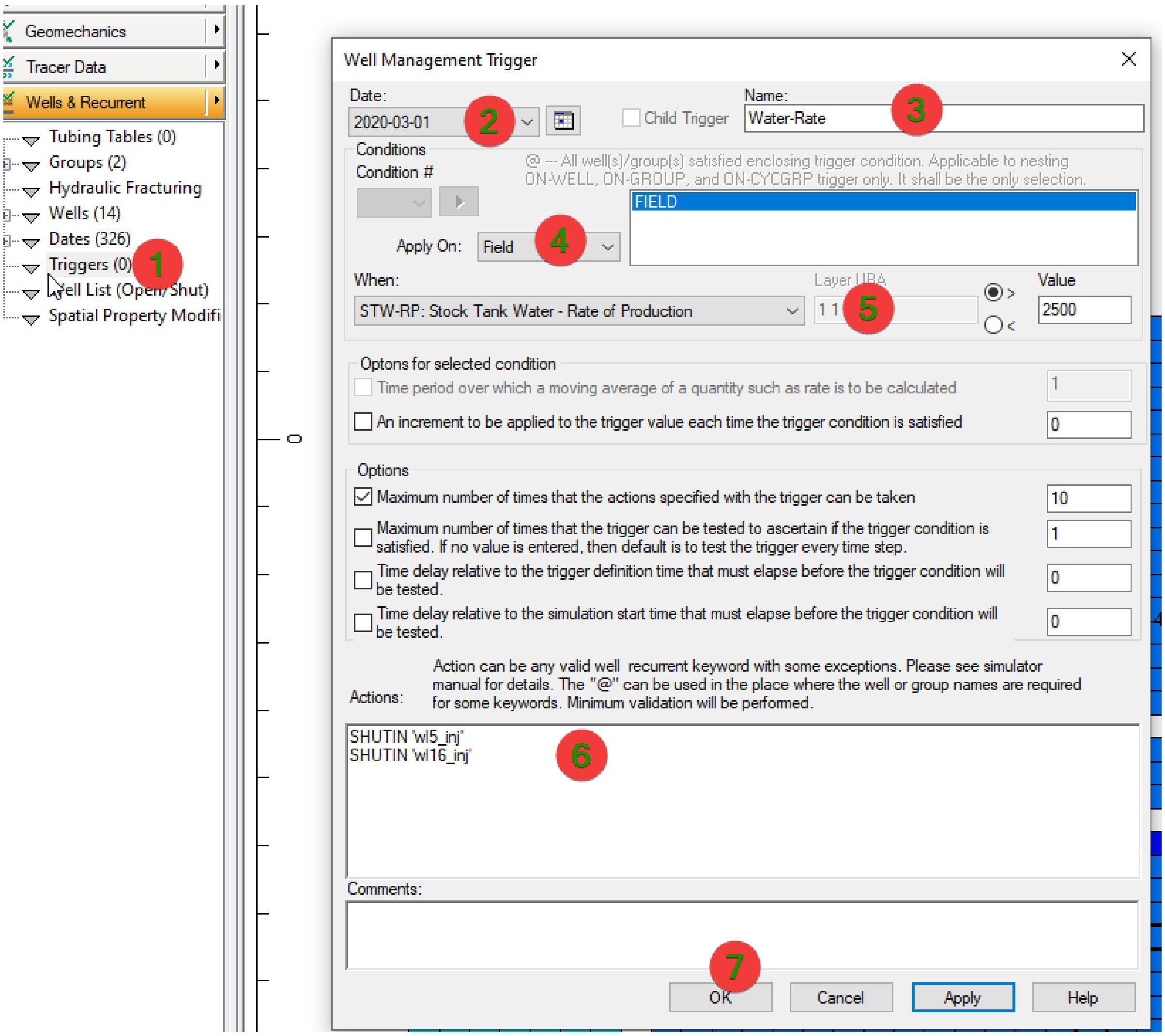


Figure 97: Well management for triggers (Water Rate)

11. Click on **Apply** and **OK.**
12. The second part of the trigger is related with the reservoir pressure. To do this, a nested trigger will be used. Under Triggers, right click on the trigger date and select **New Child**.
13. The Management Trigger window will pop up again and Under Trigger Name input: **RESERVOIR_PRESSURE.**
14. Select **Sector** under **Apply On** dropdown menu.
15. Select **PAVE: Pore-volume Weighted Pressure** under **When** dropdown menu and define the trigger value less than **< 7,500 kPa**.
16. Under Options input a value of **10** for the **Maximum number of times that the actions specified with the trigger can be taken.**

17. Type the following inside Actions box:
    OPEN 'wl5_inj'
    OPEN 'wl16_inj'
18. The well management Trigger interface should include the following information.

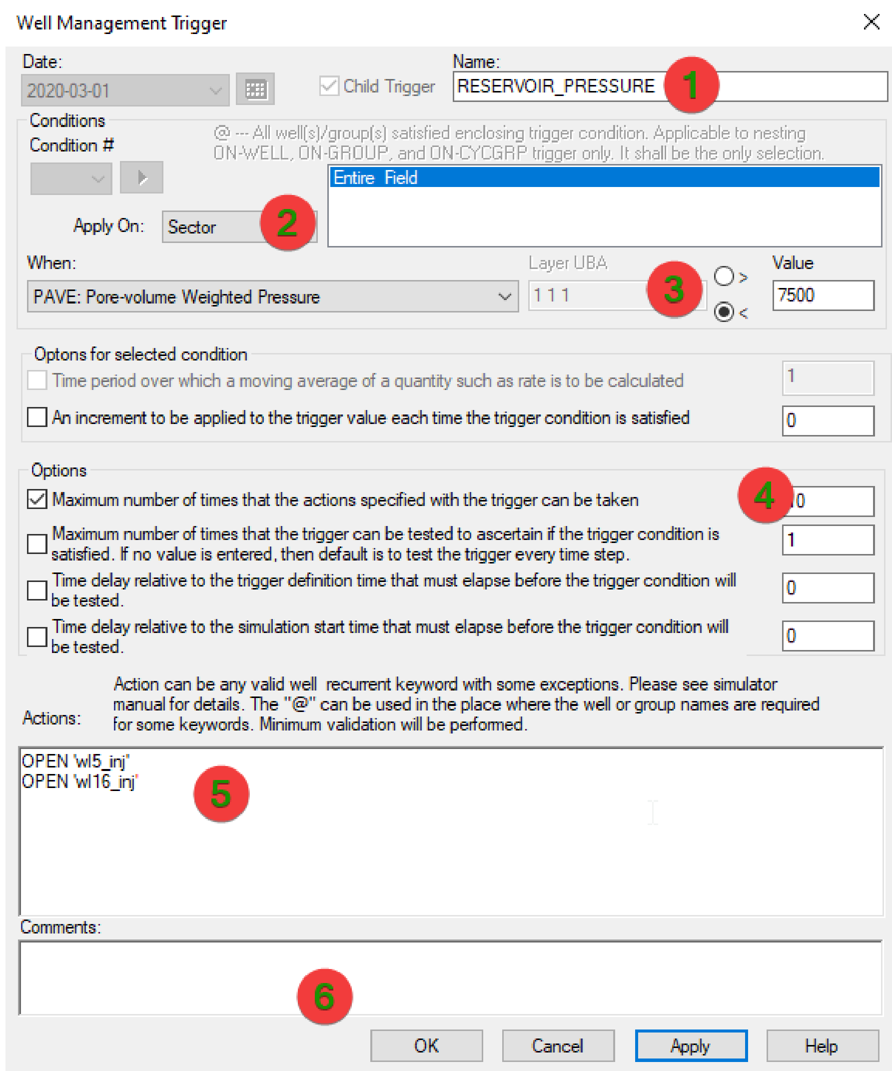


Figure 98: Well management for triggers (Pressure)

19. Click on Apply and OK. Save and run the file in IMEX.
20. Open the .sr3 file in Results
21. Click on the **Time Series** in Project Navigation and add the following curves: (Sector --- Water Prod Rate SCTR --- Entire Field) and (Sector – Ave Pres POVO SCTR – Entire Field) to see the effect of the trigger.

22. A similar plot should be observed. Please note the automatic annotations RESULTS adds to identify when the triggers kick in.

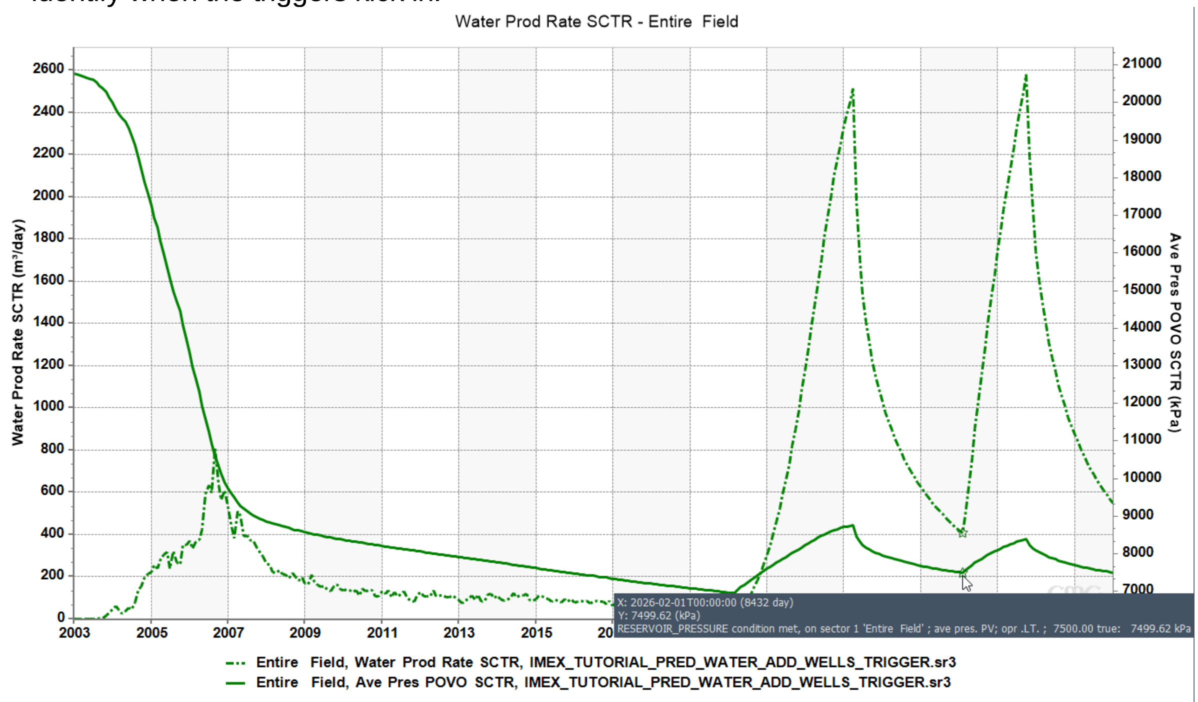


Figure 99: Combined effect of two triggers in simulation results

Coning Effect in a Well Model

In some reservoirs it is required to model local effects such as water or gas coning. These studies require the construction of radial well models or the extraction of some sub-models, which can include refinements around the well.

Extracting a Sub model

*In this section, we will extract a sub-model around **wl18** well in order to study the effect of water coning.*

1. Open **IMEX_TUTORIAL_PRED_BASE.DAT** in Builder. While in the IJ-2D Areal view, right click on the model and select **Edit Grid…**. You can also access this from the icon in the top menu.
2. **Grid Editing Options** will pop up. Leave the editing option as default and click **OK.**
3. Using the mouse, select couple of grid blocks around well **wl18** as shown in the figure below:

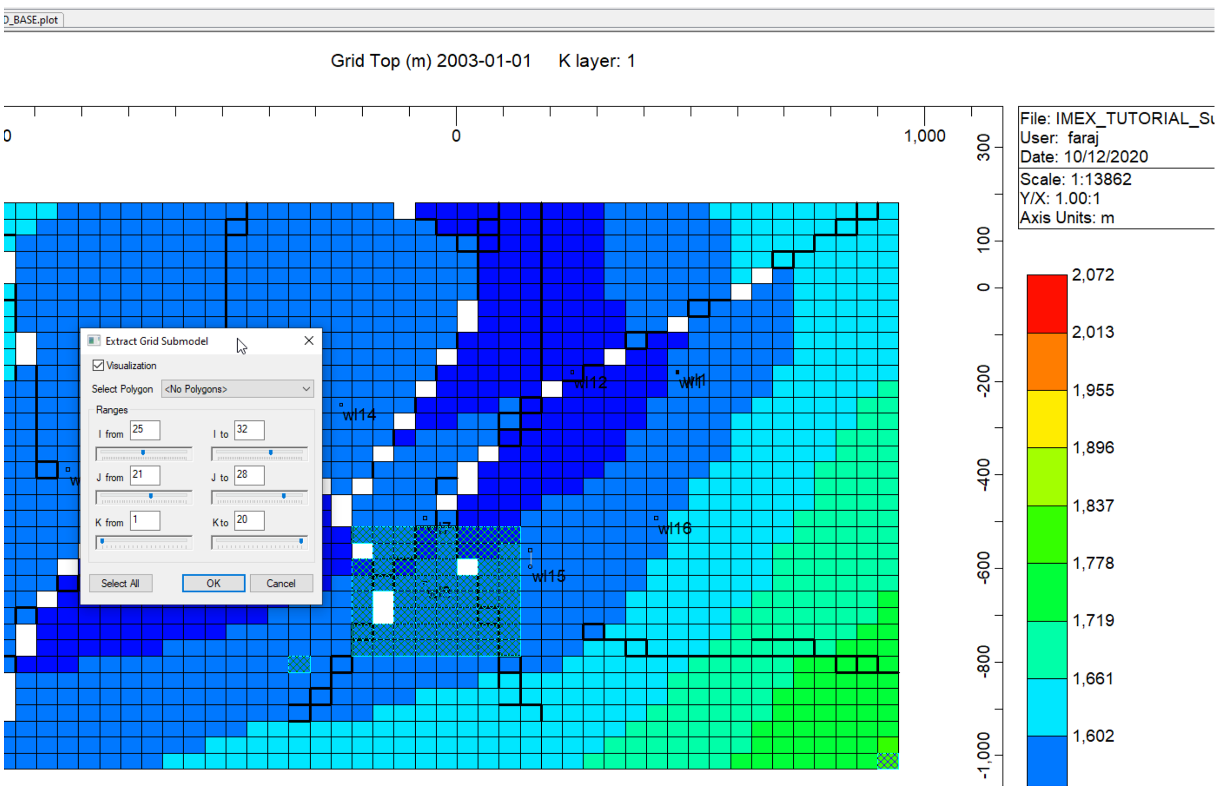


Figure 100: Selection of cells around well wl8 to extract a sub-model

4. In order to extract a sub-model, go to **Reservoir,** then **Edit grid** and **Extract Sub-model…** Click **OK** to accept the selection (I=25 to I=32), (J=21 to J=28) and (K=1 to K=20). In the pop-up window click **OK** and then **OK** on No new Trajectories.... and **YES** to recalculate tolerances. Delete all the wells <u>except wl16</u>.
5. Save the file as **IMEX_TUTORIAL_SUBMODEL.DAT** in Additional Exercise folder.

6. In order to reproduce the effect of water coning, you will be required to change the position of the water oil contact and perforations.
7. Under **Wells & Recurrent**, expand the **Wells** section and double click on the **perforation date** for **wl8**, 2004-01-01. Go to the **Perforations** tab and remove perforations in layers 1 to 6 and 8 to 20 by using the button . **Leave perforations in layer 7.** Click on **Apply** and **OK**.

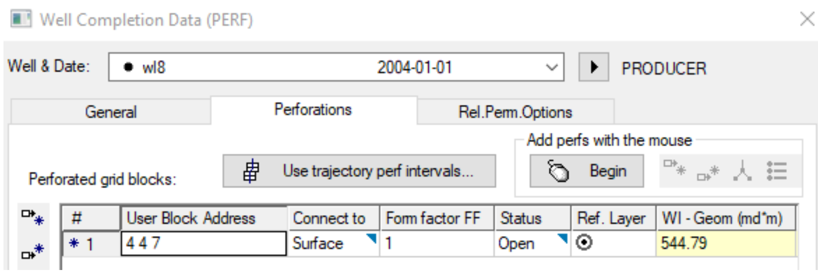
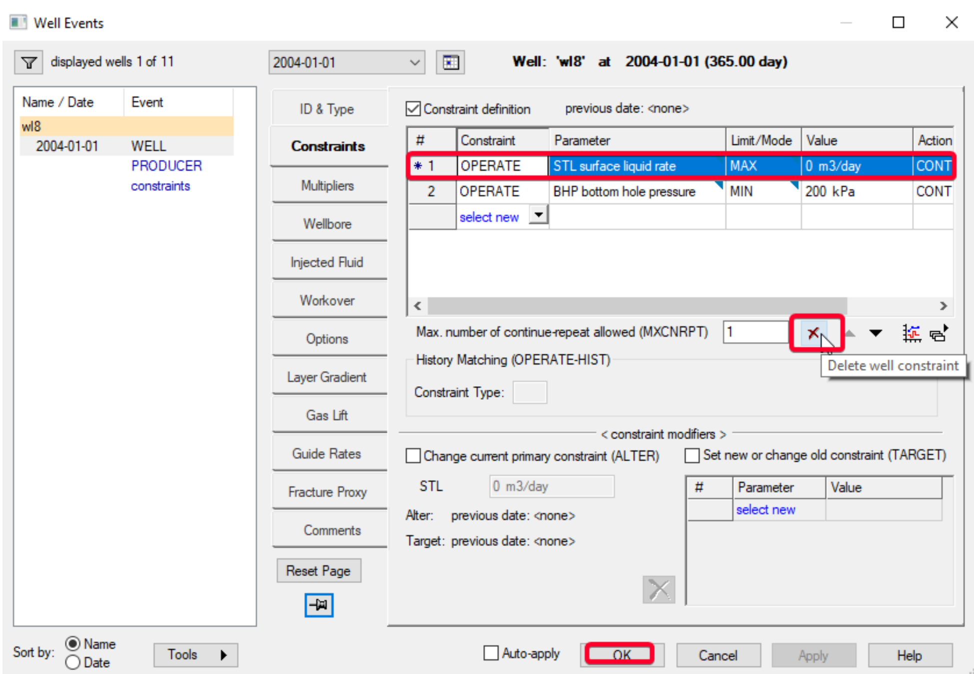


Figure 101: Removing perforations in the well

8. Double click on the well name **wl8** to open the **Well Events** window. Remove the events from **2004-03-01 to 2020-02-01**. To do this, highlight the events (To do this, click on 2004-03-01 event, then while pressing Shift Key, click on 202-02-01event), right click and select **Delete Events Selected in the List** and click **Yes** to apply the changes**.**
9. Click on **Constraints** and remove the STL using , leaving min BHP=200 kPa as the only active constraint.



10. Go to the **I/O** control and remove the restart file by unchecking the **Restart** box. Click **OK**.

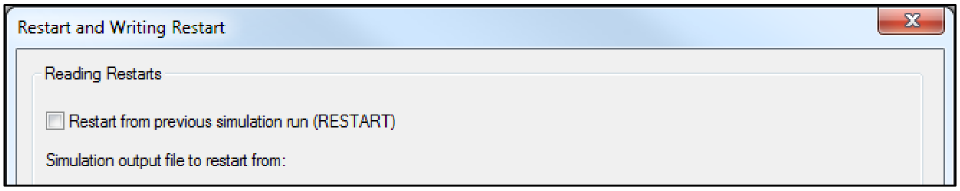


Figure 102: Removing perforations in the well

11. **Save** the model and **close** Builder.
12. Once BUILDER is closed open the **IMEX_TUTORIAL_SUBMODEL.DAT** in **cEDIT.**

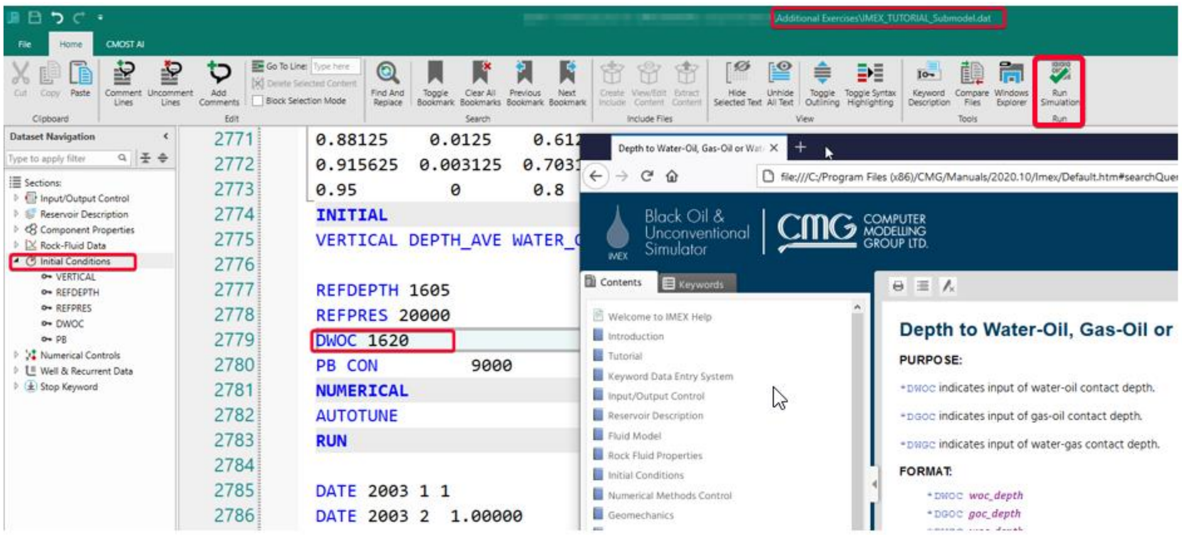


Figure 103: Use cEDIT to modify the keyword and access IMEX manual

13. **Open** Initial Conditions section and click on **DWOC**.
14. Click on DWOC keyword on the dataset and use **F1 key** to get access to the relevant help manual. Change DWOC to **1620.**
15. Use **Run Simulation**  button and then **Submit to the Launcher**  to initiate the IMEX run.
16. As soon as IMEX starts, the log file will be shown in this window. Whenever IMEX crashes, it issues descriptive error messages.

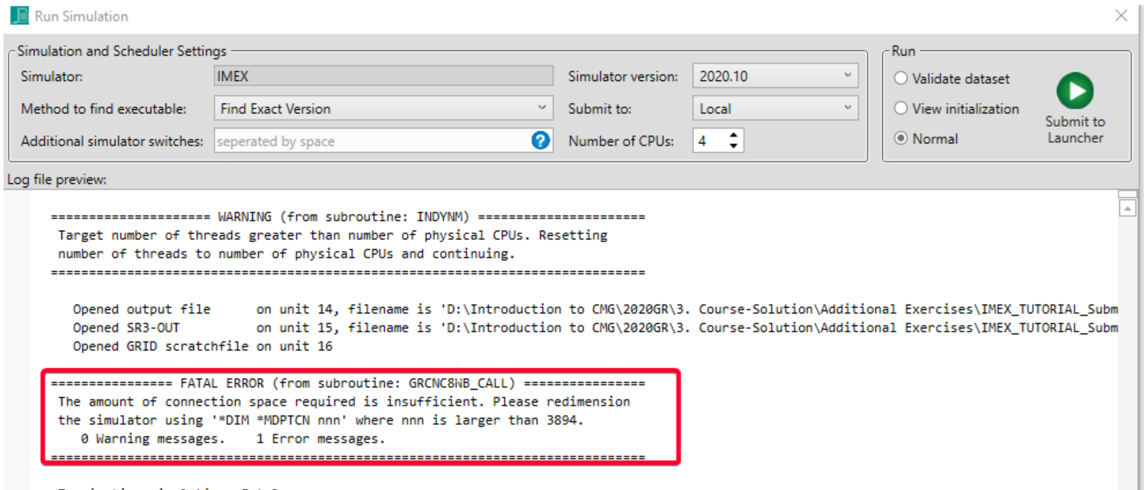


Figure 104: Viewing Log file in cEDIT

17. If you received the above error message, close this window and go back to edit mode in cEDIT. On the very top of the .dat file, type in:

```
DIM MDPTCN 50000
```

This overrides internal IMEX dimensioning:

```
RESULTS SIMULATOR IMEX 202010

DIM MDPTCN 50000
SRFORMAT SR3
```

..

18. Save the dataset and run the dataset.
19. **Close cEDIT.**

Refinement around the Well

20. Open in Builder the file IMEX_TUTORIAL_SUBMODEL.DAT and save it as **IMEX_TUTORIAL_SUBMODEL_REF.DAT.**
21. Click on the icon in the top menu.
22. **Grid Editing Options** will pop up. Leave the editing option as default and click **OK.**
23. Using the mouse, select the one grid block around the **wl8** well as shown in the figure below.

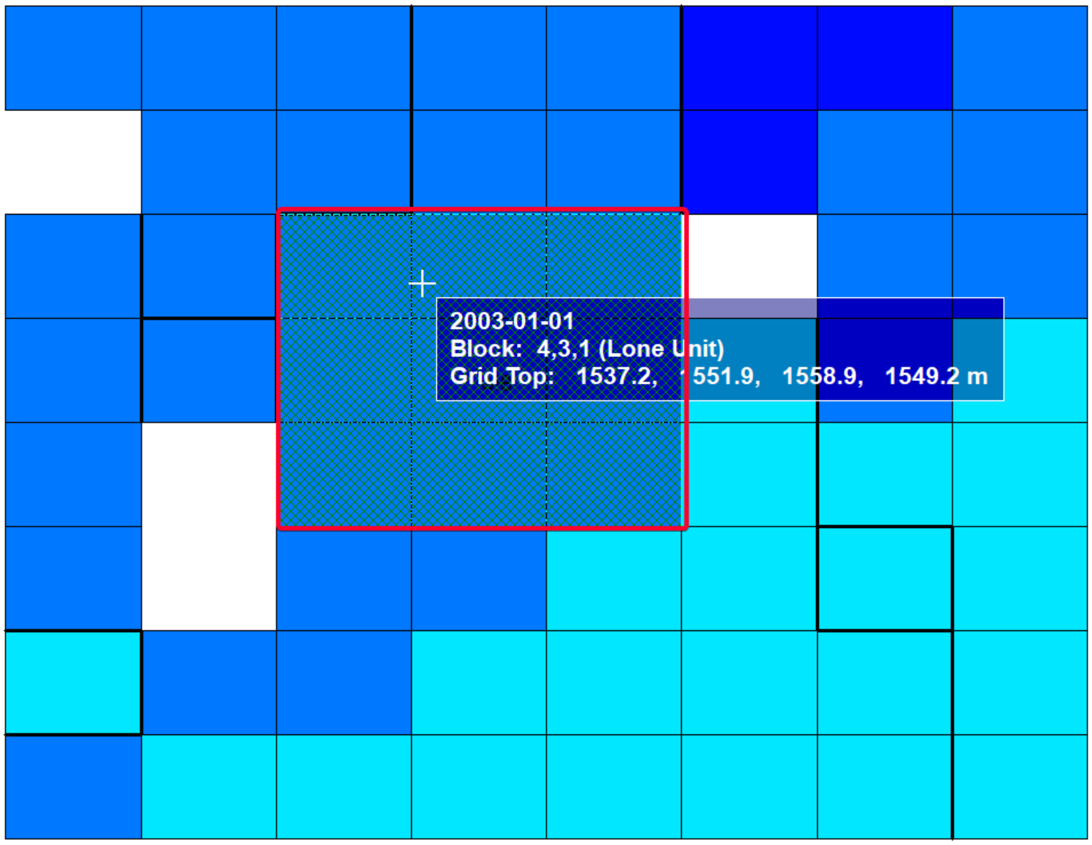


Figure 105: Selection of cells around the well to perform refinement

24. To access the option to refine cells, go to **Reservoir→Edit grid→Refine Blocks.**
25. In **Refinement Wizard** select **A Range of Fundamental Layers** and input K=7 to K=12. Click **Next**.

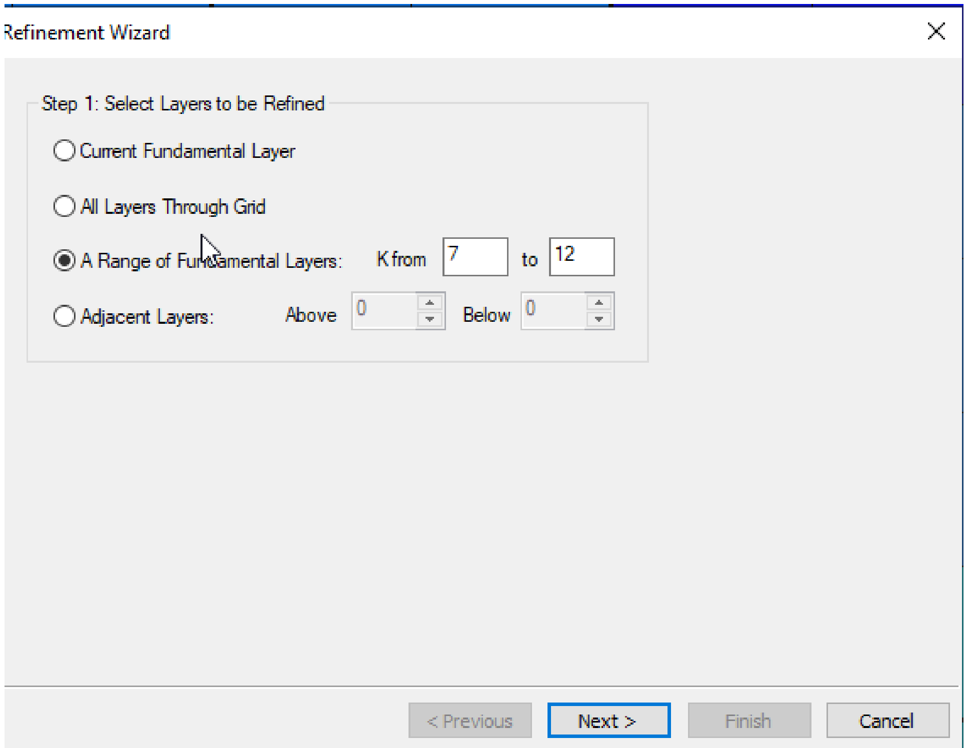


Figure 106: Selection of number of layers to refine

26. Then select **Cartesian** as the **Type of Refinement** and click **Next. Specify the number of block divisions in each direction** as the following figure.

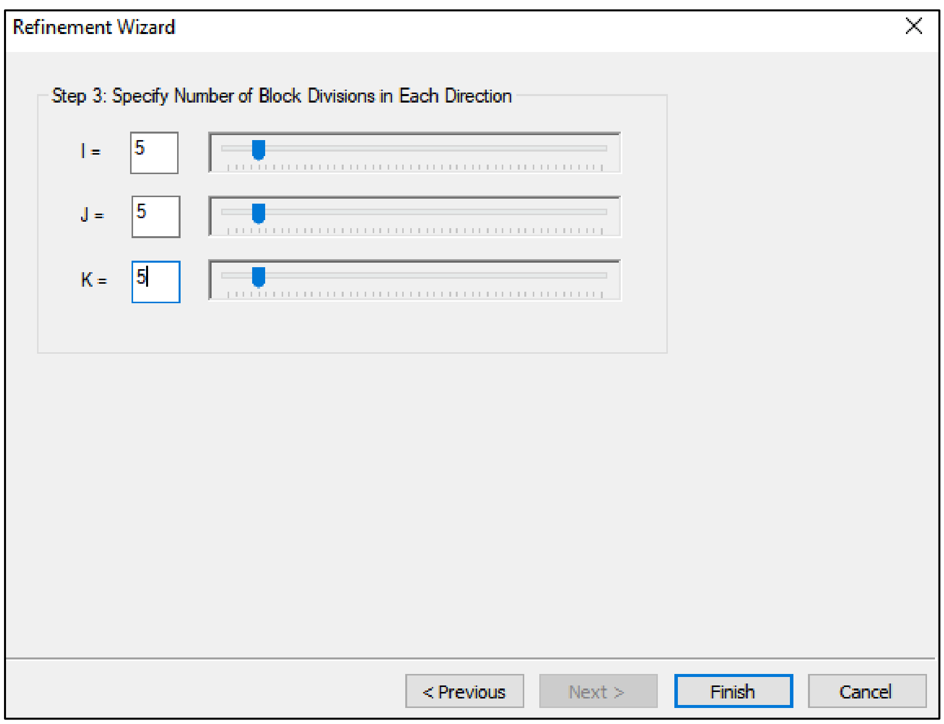


Figure 107: Definition of number of refinements in horizontal and vertical directions

27. Click **Finish**. Select the **Probe Mode to exit the Edit Grid mode**. **Save** the file one more time.
28. Run the file using the scheduler and with 4 processors.
29. Drag and drop the corresponding .sr3 file onto Results. Also, open **IMEX_TUTORIAL_SUBMODEL.sr3** in Results by clicking on **Add Files – Open**…
30. From the **Reservoir** section in Project Navigation, drag and drop both **IK 2D views** onto the same **dashboard window** to be able to compare results side-by-side.
31. In the **Dashboard** section of the ribbon menu, change the **layout to a 1 by 2 grid** to be able to visualize the models properly.
32. In the **Display** section of the ribbon menu, change the **slider to Plane 4**. Then select the property **Water Saturation** and compare two models for distribution of water saturation around the wl18 well (Jan-01-2030). Make the changes for both views individually.
33. Right click on the Water Saturation scale and select **Color Scale Editor**. Change max to 0.5 to exaggerate the saturation changes due to the coning.

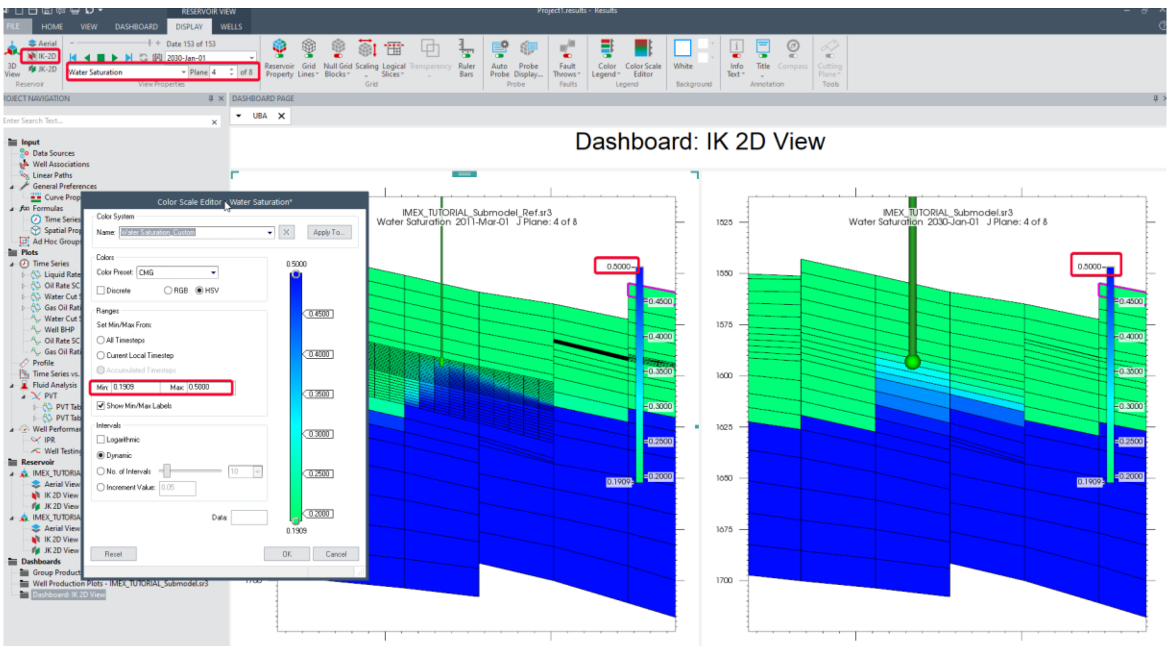


Figure 108: Coning effect using a refined model

Hydraulic Fractures

We want to see how much production could be achieved if the reservoir was much tighter. To see this comparison, we will reduce the porosity of the reservoir by a factor of 10. Permeability is also recalculated by user defined formula. We will also examine the effect of adding a hydraulic fracture to a well in the tight reservoir.

To have an accurate comparison between the differing permeability cases, we will remove the production rate constraints and operate the wells with a constant bottom-hole pressure. This is commonly done when predicting performance in new fields where no production has yet occurred.

1. Open the **IMEX_TUTORIAL.dat** file in Builder.
2. Save this file as **IMEX_TUTORIAL_CONS_BHP.DAT** in the HF folder.
3. Click on **Wells & Recurrent** then double click on **Wells (11).**
4. In the Well events section, click on the **ALTER** event on 2003-02-01 for wl1.
5. Click on **Tools > Delete Events using filter.** In the **1.-Wells** tab, select all the wells in the list.

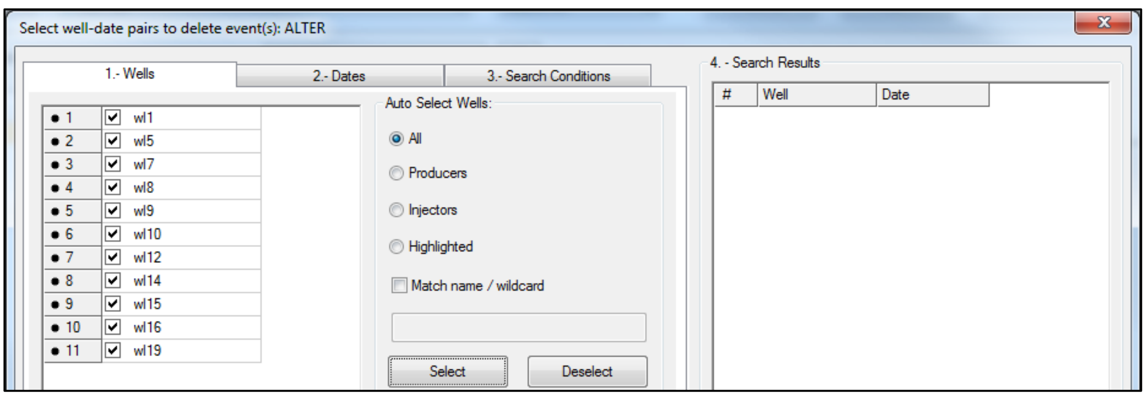


Figure 109: Selection of wells to delete using events filter

6. In the **2. –Dates** tab **select All.** In the **3.- Search** conditions select **ALTER** and click on **Search & Add button**. Click OK

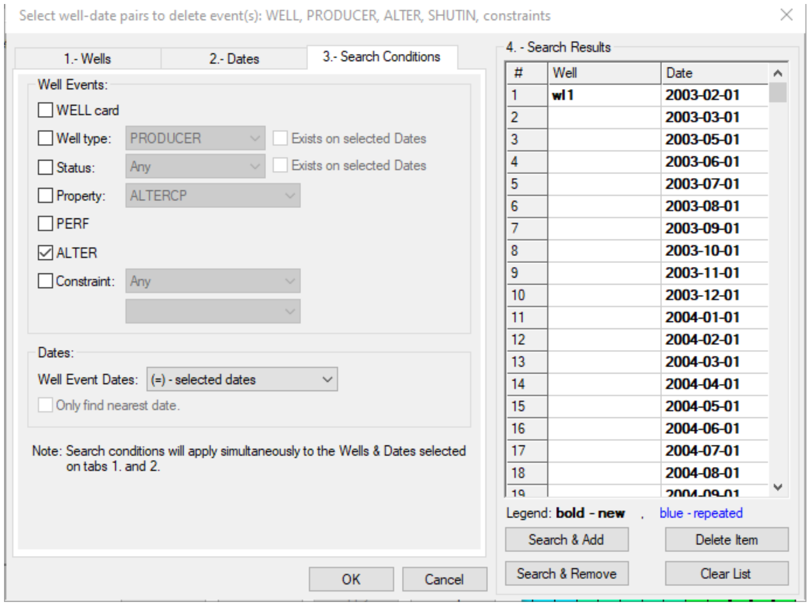


Figure 110: Selection of wells to delete Alter CONSTRAINTS using events filter

7. In the new window that will appear, click on constraints for the well, **wl1, 2003-01-01**. Change the value of the first constraint (STL) to be **150 m3/day** and for the second one (BHP) change the value to **1000 kPa**. Set the **Action** to be **CONT REPEAT** for both constraints. Use BHP as the first and STL as secondary constraint by clicking on Move Well constraint up and down button:

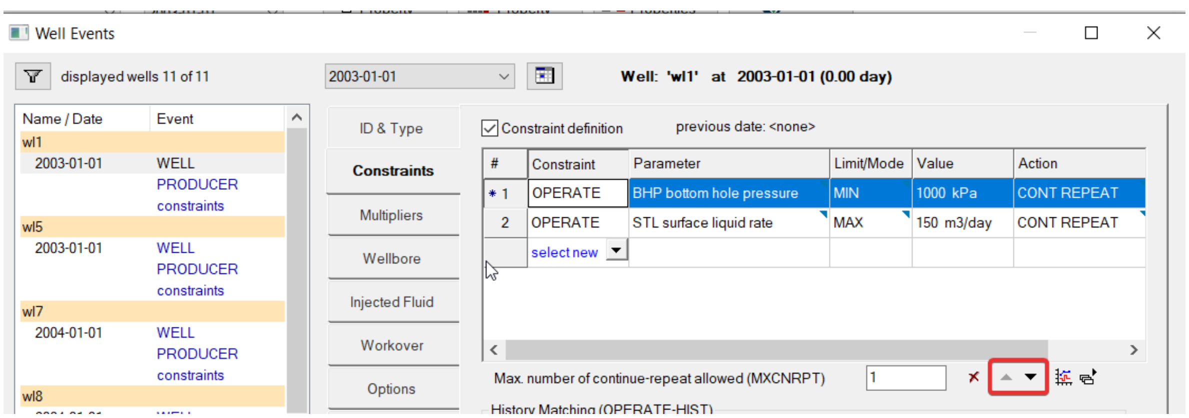
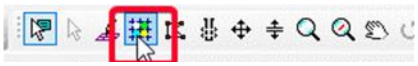


Figure 111: Definition of new constraints for tight reservoir

8. Copy these two constraints for the rest of producer wells by using the button **Tools > Copy Events** using filter. In the **1.- Wells** tab, (In case it is needed, remove the previous selection by using the Clear List button) select all wells.
9. On the **2.- Dates** tab (select all dates except first date 2003-01-01), **click on Search & Add button**. Click on OK. Make sure the well constraints are the same in the rest of the wells.
10. Save and run this model.

Modify Reservoir Properties

11. Load **IMEX_TUTORIAL_CONS_BHP.DAT** into Builder.
12. Save the file as **IMEX_TUTORIAL_CONS_BHP_TIGHT.DAT**
13. Change viewing property to **Porosity**
14. Change BUILDER mode to **Edit Reservoir Property**



15. **Drag the mouse to select all the blocks.**
16. n the pop-up window, assign 0.1 multiplier to the original porosity

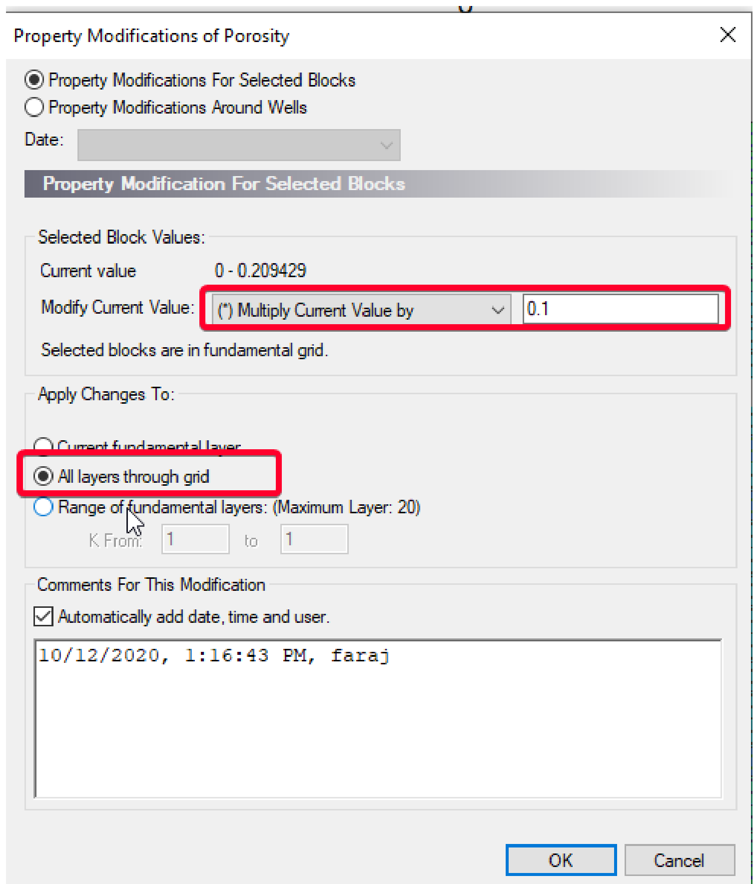


Figure 112: Multiplying original porosity by factor of 0.1

17. Click on **Tools** menu and select the **Formula Manager** option. In the new window that will appear Click on the **New** button to create a new formula.

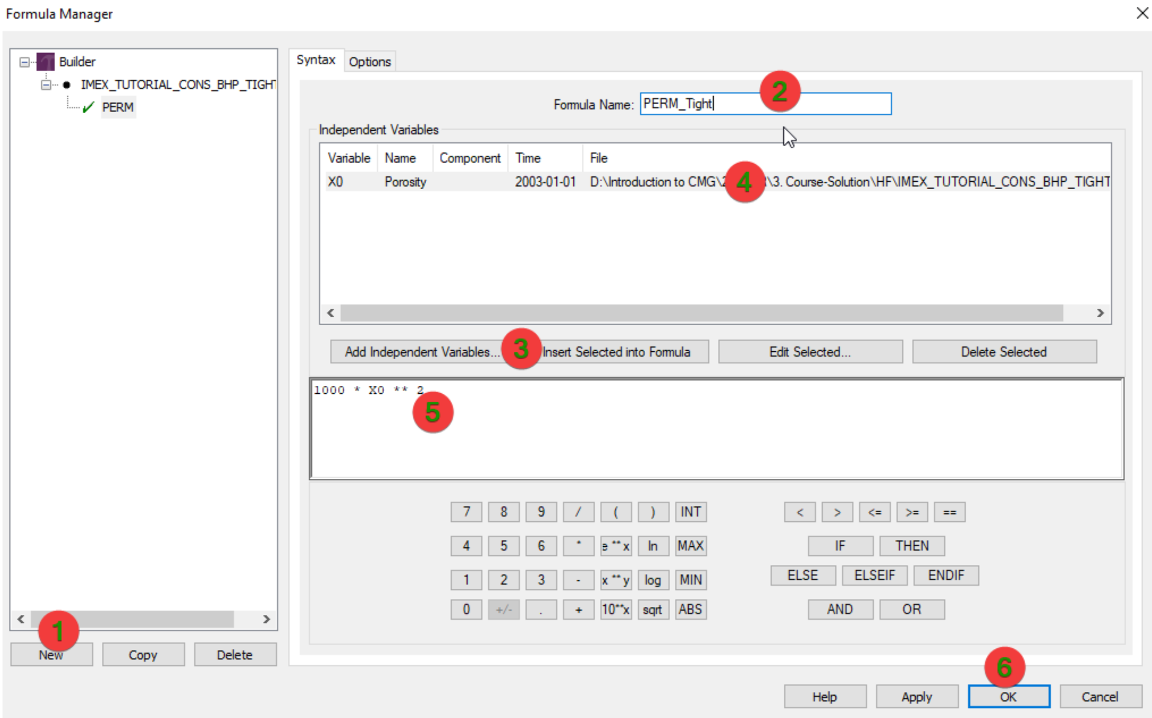


Figure 113: Use formula manager to define porosity/permeability equation

18. Click on Specify Property to assign the new permeability to be used as Permeability I in the simulation.

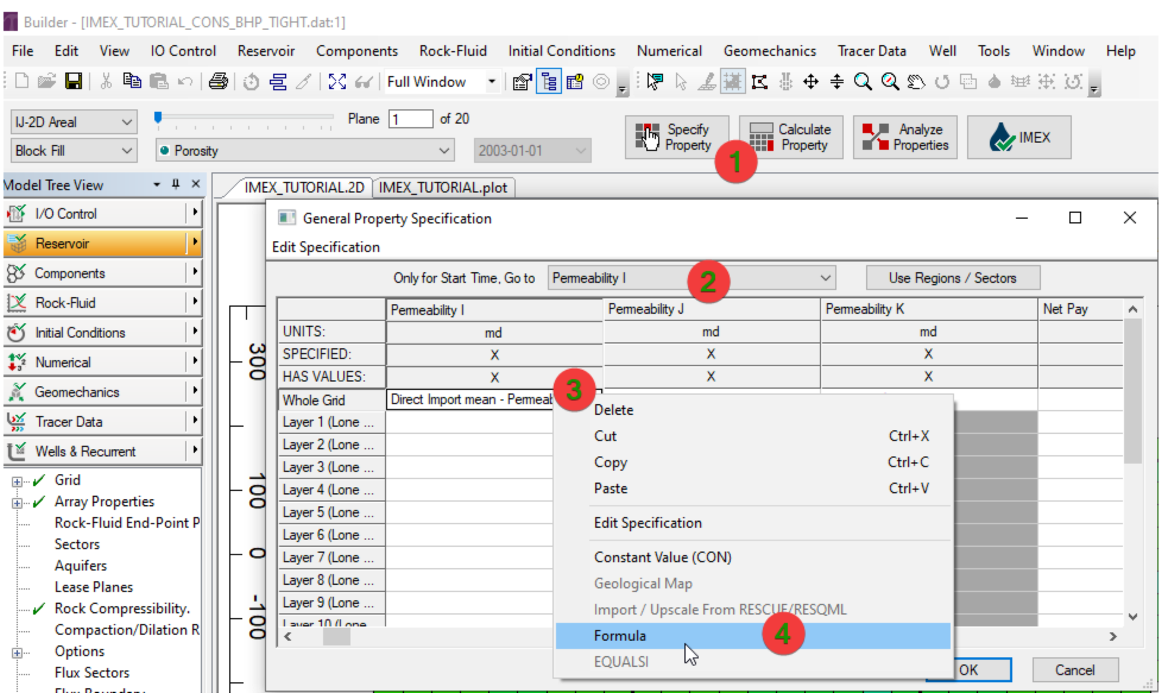


Figure 114: Assigning the formula to Permeability I

19. On the prop up window click on Perm_Tight and click on the subsequent pop ups.
20. Repeat the same steps to assign the formula to Permeability J.
21. Save the model, go to the Launcher and run the file using IMEX**.**
22. Plot the oil production rates per well. It can be observed that the production per well is low as typically happens in tight reservoirs.
23. You can compare oil production rate or cum between **IMEX_TUTORIAL_CONS_BHP** and **IMEX_TUTORIAL_CONS_BHP_TIGHT** cases.

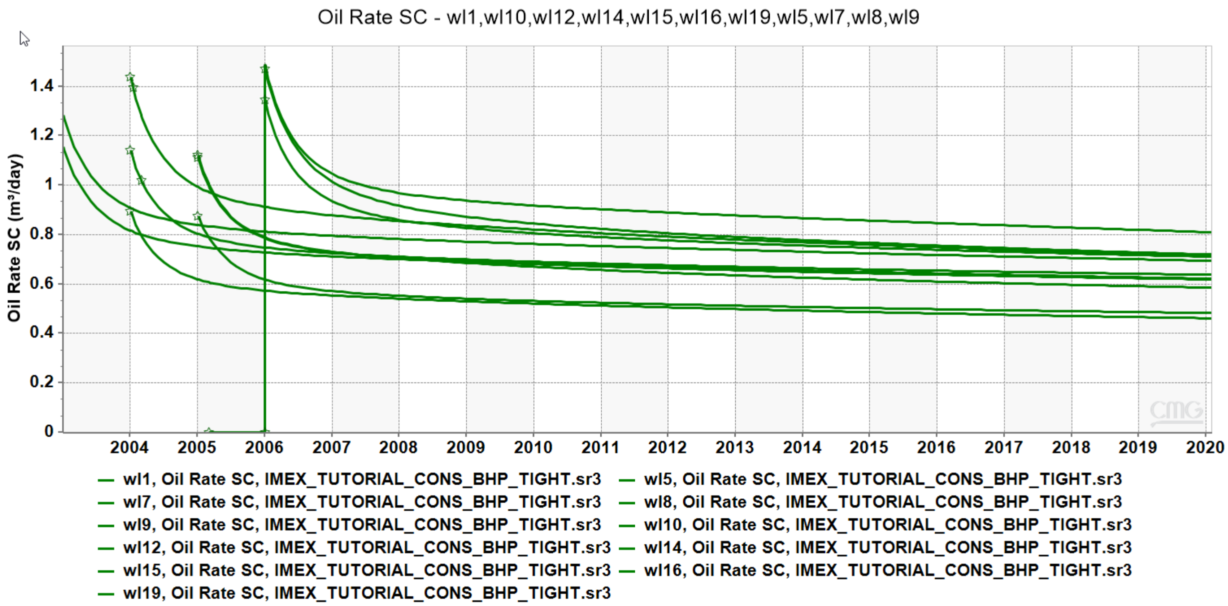


Figure 115: Production profile per well for tight reservoir

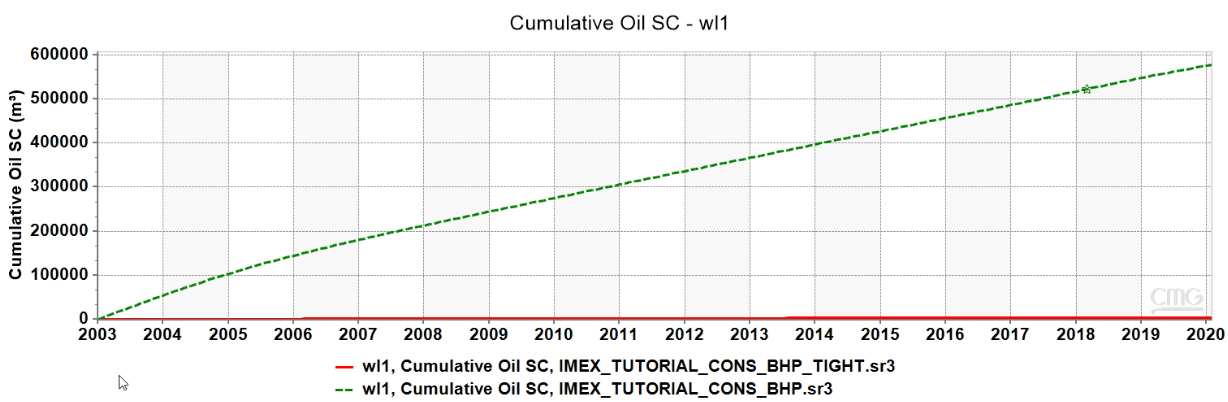


Figure 116: Cum oil production comparison between tight and conventional case

Addition of Hydraulic Fracture

We will examine how much of an increase in production rates can be seen if a well is hydraulically fractured. The Hydraulically Fractured Wells wizard performs Local Grid Refinement to bring the grid-block size close to the actual fracture width, to model the fracture more explicitly than using something like skin factor.

The low production rate in the hypothetical reservoir of lower permeability can be remedied by implementing hydraulic fractures in some wells.

24. Open the dataset **IMEX_TUTORIAL_CONS_BHP_TIGHT.dat** in Builder.
25. Save the file as **IMEX_TUTORIAL_CONS_BHP_TIGHT_HF.dat**
26. Under Wells & Recurrent select the option **Hydraulic Fracturing.**

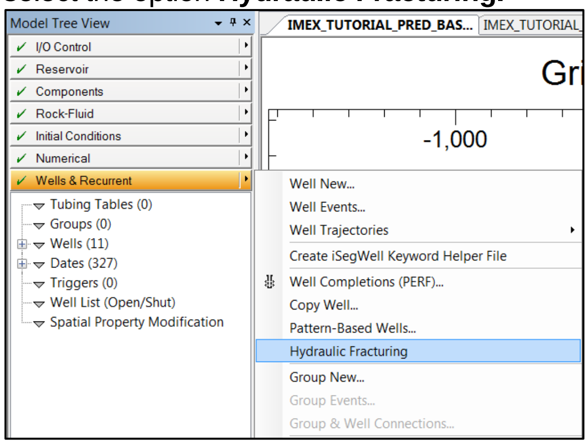


Figure 117: Hydraulic Fractures wizard

27. In the new window that will appear, click on the **Non-Darcy Option** tab at the top of the wizard. In the Non-Darcy Flow Options, select **General Correlation** as the Non-Darcy Flow Option. The following values will be applied for each phase:
    - Alpha: 1.485e9
    - N1: 1.021
    - N2: 0
    - Forch_max: 10,000
    - Forchheimer Number Weighting Factor: 0.5

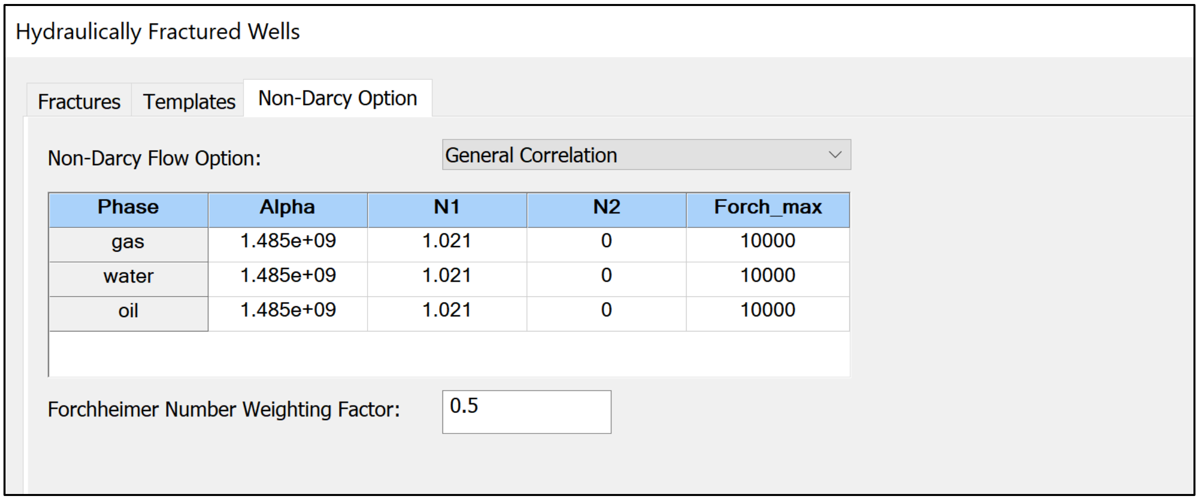
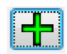


Figure 118: Non-Darcy flow options for hydraulically fractured wells

28. Click on the **Templates tab** and select  to create a new template. Enter in the following Properties:
    - **Fracture width:** 0.005m
    - **Intrinsic Permeability:** 100000 mD
    - **Orientation:** J –Direction
    - **Number of refinements in the I direction:** 5
    - **Number of refinements in the J direction:** 5
    - **Number of refinements in the K direction:** 1
    - **Half Length:** 300m
    - **Number of layers above perforation:** 0
    - **Number of layers below perforation:** 0

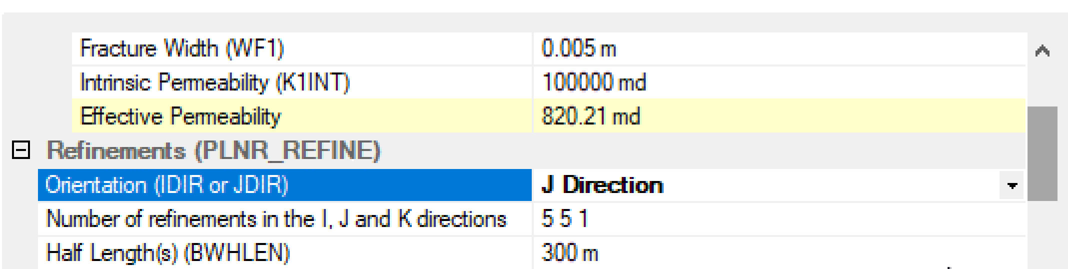


Figure 119: Creating a new fracture Template

29. Click the **Apply** button and navigate to the **Fractures** tab.
30. Select the date **2003-01-01** for well '**wl5**' and then select **New Planar Fracture Stage.**

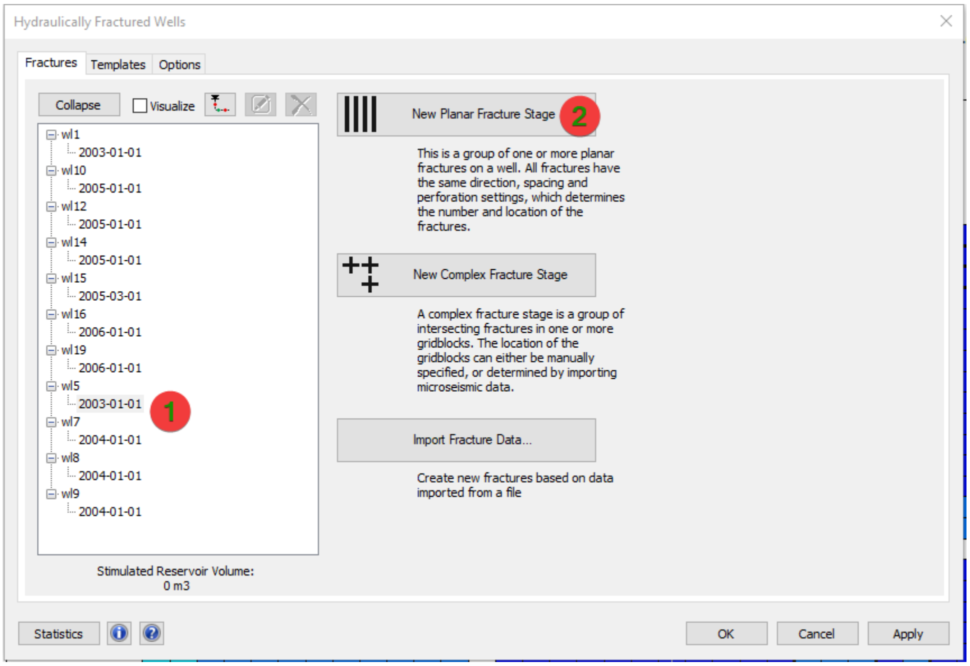


Figure 120: Adding a new planar stage

31. Select **Planar Template** for the **Fracture Template**. Click **Apply** and then close the "Hydraulically Fractured Wells" window.

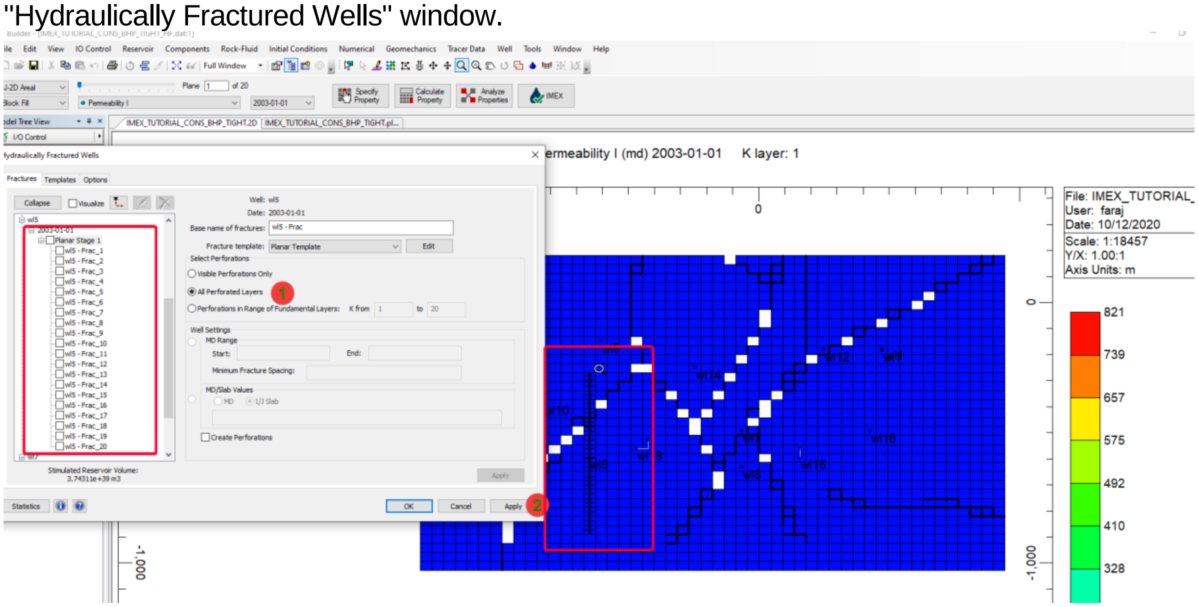


Figure 121: Create Hydraulic fractures around perforations in Wl5

32. You can zoom in to see the refinement for the fracture and how the **Permeability I** has been modified for the grid blocks corresponding to the fracture (make sure date is 2003-01-01).

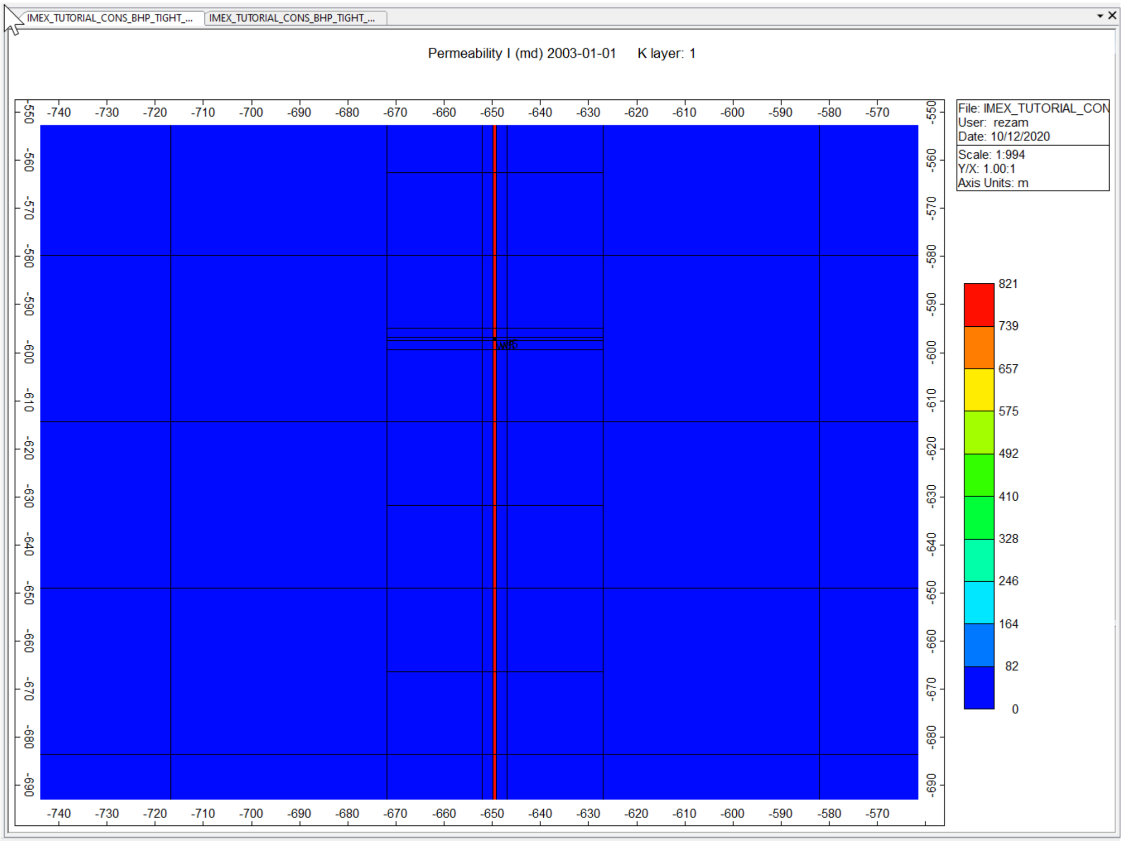


Figure 122: Properties associated to the new fracture in Builder

33. Save the model and run the file in IMEX.
34. Compare in Results, oil production rate for the well wl5 with the case with no hydraulic fractures.

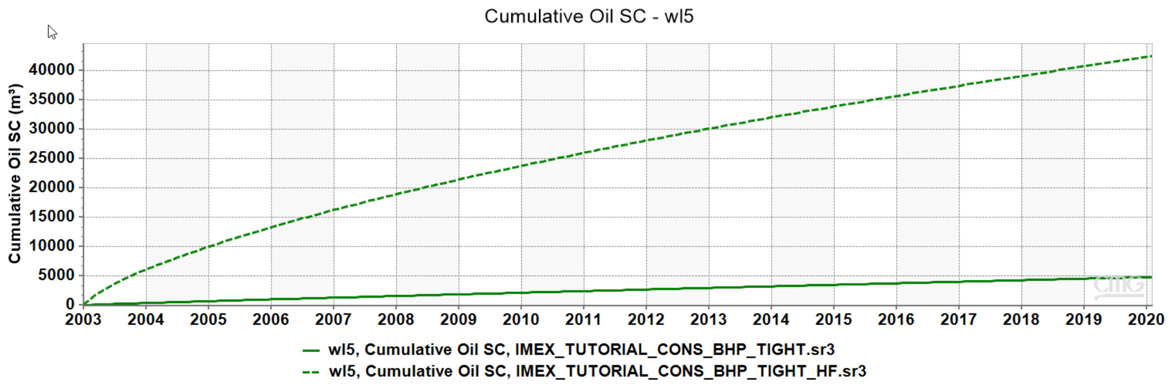


Figure 123: Effect of hydraulic fractures in well wl5

Extra Exercise

1. Using the Horizontal Wells case as a base case, implement a development plan for the reservoir.
2. Extend the prediction period until 2037-01-01.
3. Convert one or two wells from producers to injectors in 2020-03-01.
4. Use groups to control the injection rate. Try different injection rates.
5. Drill new horizontal wells and define an estimate of the maximum number of new wells for this reservoir.
6. Compare your scenarios per well and per field in terms of the oil recovery factor.
7. Create conclusions of your different scenarios of prediction.