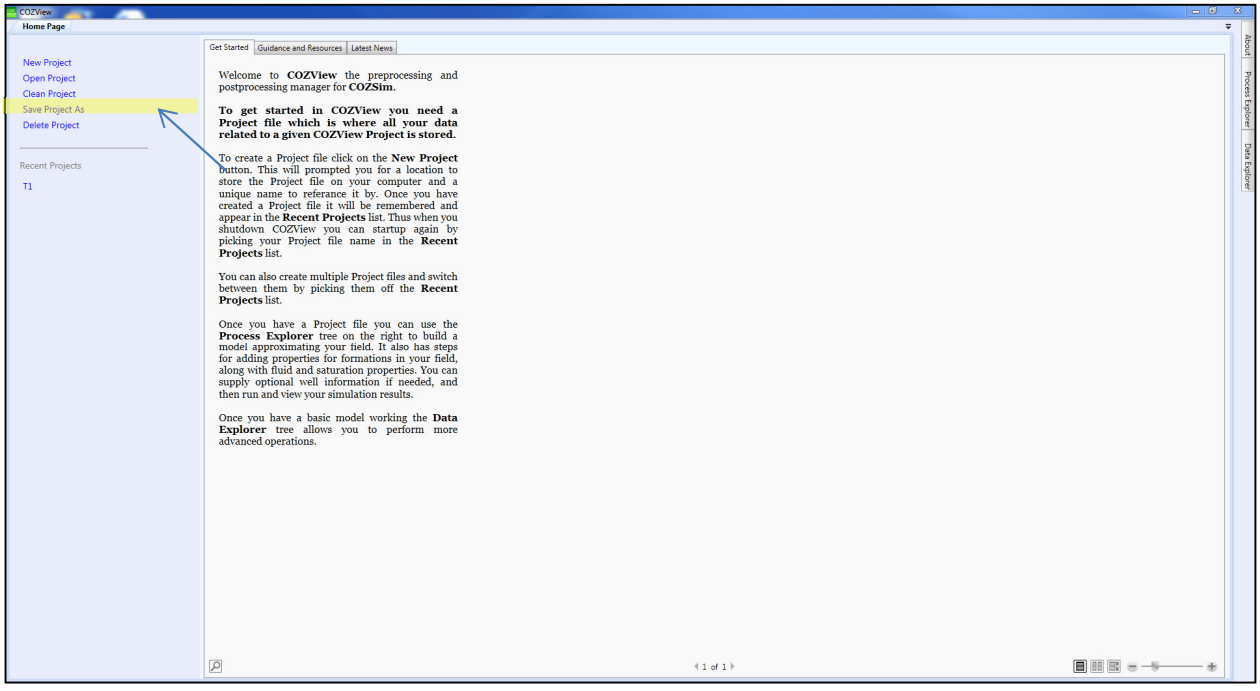
TUTORIAL #1-2

This tutorial is a minor modification of the model developed in Tutorial 1. This example shows a general procedure for adjusting the model to current day OIP and saturation levels when historical operations have included water flooding.

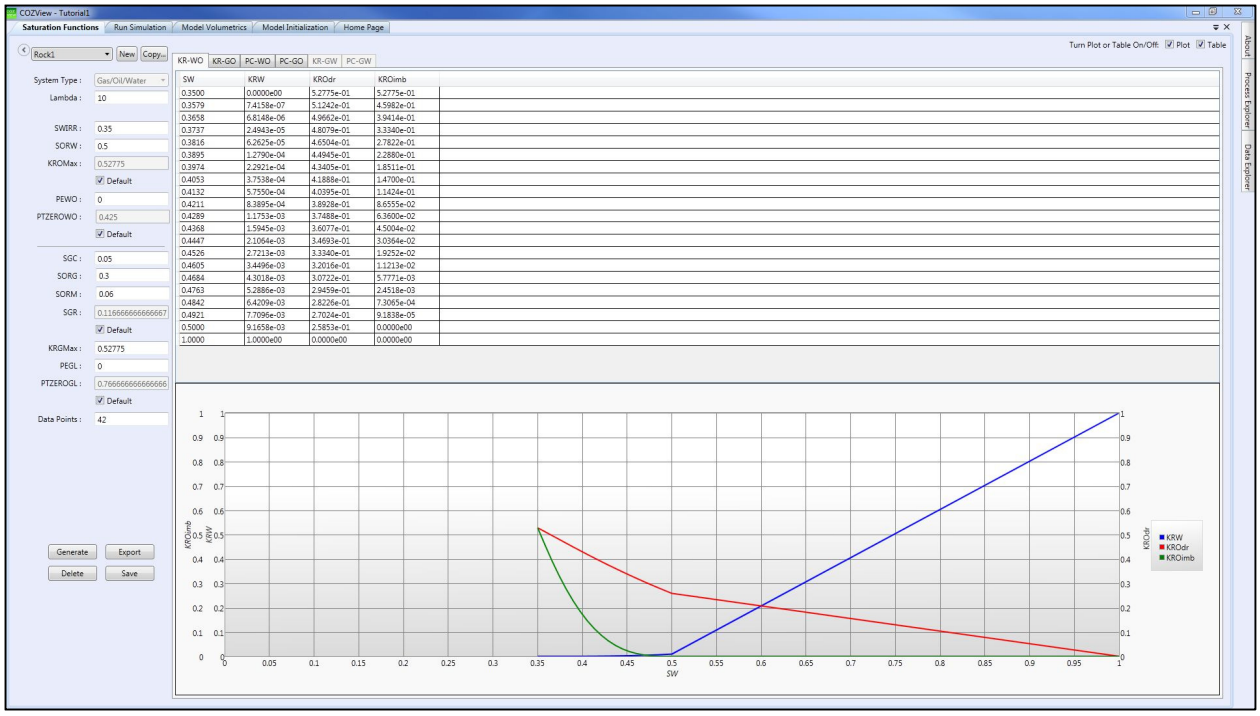
This example shows how to initialize the model at the original conditions and at current conditions and initiate CO2 injection. Oil production results for this example are much different than for Tutorials 1 or 1-1 due to the difference in the saturations conditions at the start of CO2 injection. Tutorial 1-1 initiated CO2 injection with oil saturations throughout the reservoir at So = 0.50. The oil was assumed to be immobile at this saturation. This case initiates CO2 injection with oil saturations in excess of Sorw and but less than Soi. Oil in excess of Sorw = 0.35 is assumed to be mobile.

The initial OOIP was 2.79 MMSTB. The reservoir is depleted from 1/1/1990 to 1/1/2012 under primary recovery and water flood operations. The cumulative oil production over the life of the reservoir is 1.08 MMSTB. This suggests an OIP at 1/1/2012 of 1.71 MMSTB. The reservoir pressures are 2500 psia at -4500 ft ss on 1/1/1990 and 1500 psia at -4500 ft ss on 1/1/2012.

The base case in this tutorial is Tutorial 1. From the *Recent projects* section in COZView Homepage, load the project file for Tutorial 1. It is recommended to save the project under a different name using **Save Project As** in the **Home Page** as we will make minor changes to the original project data.



Please note that the PVT properties are the same as in Tutorial 1. Select **Saturation Functions** from the **Fluid and Saturation properties** menu area. Select **Rock1 as** defined in Tutorial 1.

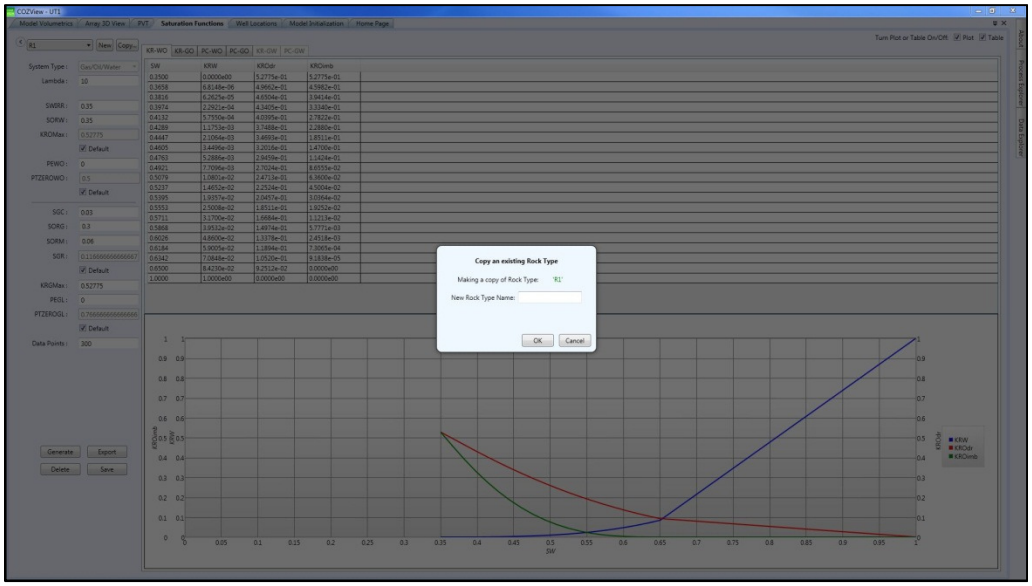


Click **Generate** to update the relative permeability tables and then **Save** the rock properties.

Please note that the saturation function used in Tutorial 1 has no capillary pressure. The Water-oil contact used in the tutorial (-5000 ft ss) is below the reservoir model to assure that the water saturation is at Swirr (0.35) throughout the reservoir at initial conditions.

The user is required to create a new saturation function to incorporate capillary pressure in the model.

Click **Copy** to create a copy of the current saturation functions



Name the new rock type (**R2**) and click OK to continue.

$$OIP = Rock\ Volume \times \emptyset \times (1 - Sw) \times \left(\frac{1}{Bo}\right)$$

The Rock Volume, porosity (Ø) are constant throughout the simulation. The formation volume factor (Bo) is a function of reservoir pressure, temperature and fluid composition. The unknown in this equation is water saturation. This saturation is controlled by the capillary pressure curve. The drainage curve controls the saturation in the reservoir at the original time (and any point in the reservoir above the current day WOC) and the imbibition curve controls the saturations in the reservoir at current time at any point below the implied current WOC. (The original WOC and the implied current WOC will be different.)

The user should follow the procedure applied in this example for matching current day OIP.

- Calculate capillary pressure value at the midpoint of reservoir

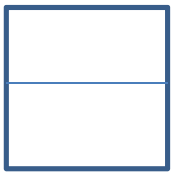
$$Pcow = (\rho_w - \rho_o)gh$$

$$Pcow \sim 0.1 \times (Zmidpoint - WOC)$$

ρ_w, ρ_o are water and oil densities, h is the height above (or below) the WOC, WOC is the water-oil contact at the initialization time.

$Pcow$ can be positive or negative based on the location of WOC

For this example



TOP = -4537.8

Midpoint = -4585.35

Bottom = -4632.9

Maximum and Minimum Elevation values can be found in the Model Initialization screen.

Original conditions (at 1/1/1900)

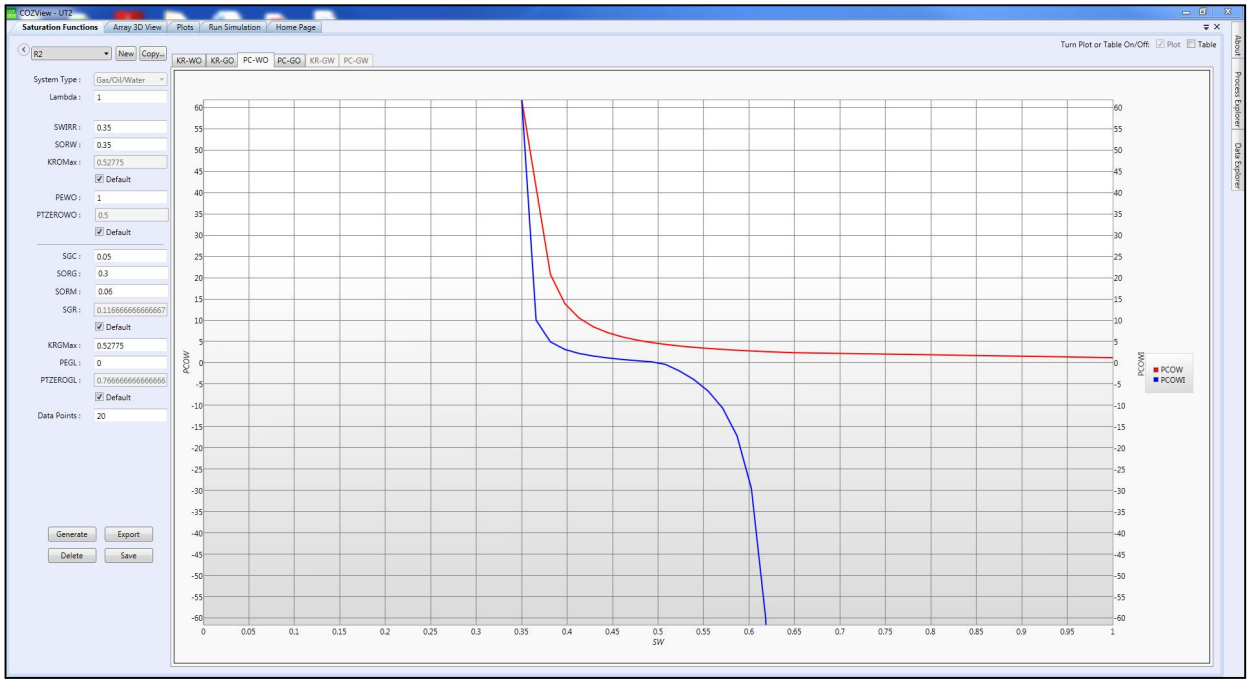
Pcow at Zmidpoint ~ 0.1*(-4585.35-(-5000)) = 41.45 psi; WOC is -5000 ft ss

Current condition (at 1/1/2012)

Pcow at Zmidpoint ~ 0.1*(-4585.35-(-4500)) = -8.5 psi; implied WOC is -4500 ft ss

- Generating capillary pressure curves in COZView

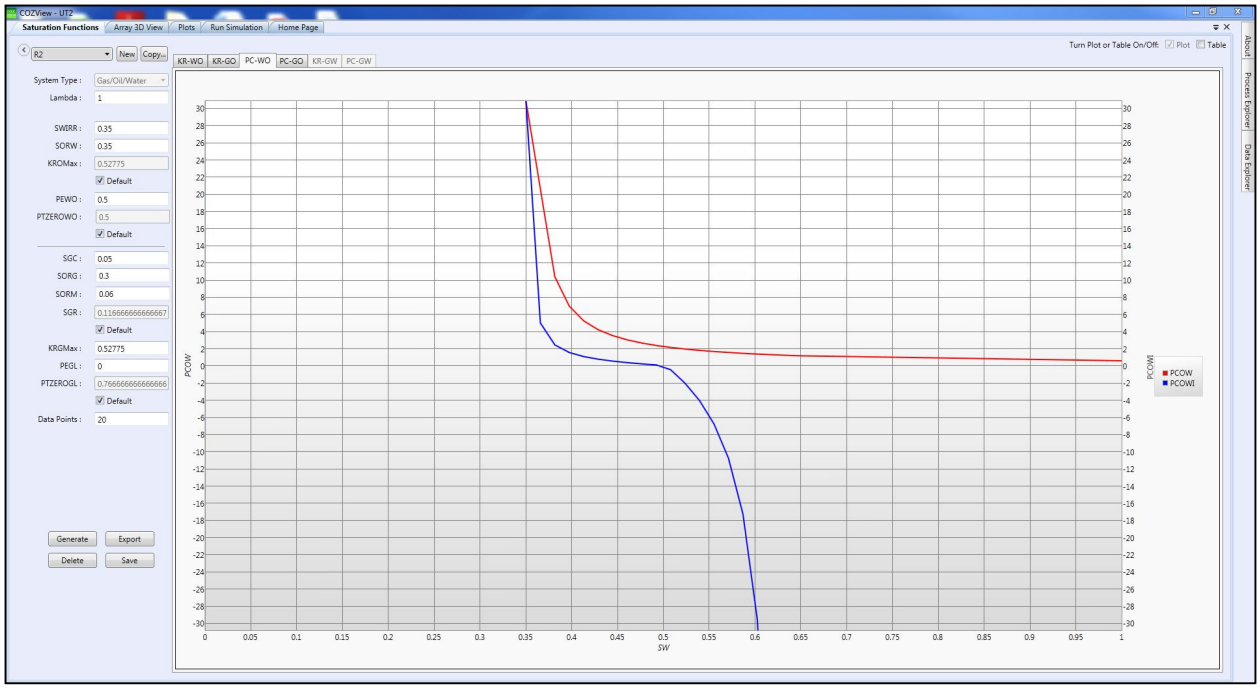
Set Lambda value to 1.0 (Default) and PEWO to 1 and select **Generate.** Click on PC-WO to view Oil-water capillary pressure curves. (PEWO must be greater than zero for a capillary pressure curve to be generated.)



Note that the scale of PCOW (y-axis) is -60 to 60. The capillary pressure calculated at the midpoint of the reservoir is 41 and -8 psi respectively for original and current conditions. PCOW at Midpoint at 1/1/1990 should always be much greater than the highest value on the PCOW scale to assure that the Sw = Swirr. (This PC-WO curve (scale) would suggest a Sw value of approximately 0.37 at the midpoint of the reservoir which is greater than Swirr.)

Modify the PEWO value to make the scale more appropriate. A higher PEWO value will increase the scale and a lower PEWO will decrease the scale.

A PEWO value of 0.5 is used in this example. The capillary pressure scale is now set to -30 to 30. The PCOW at the Midpoint (41 psi) at original conditions is now above the max scale value shown.



Go to Model Initialization from the **Verify Model** menu area. The user must input two Initialization times and the associated data for 1/1/1990 (original conditions) and 1/1/2012 (current conditions). Use **PVT1** and saturation function R2 for this initialization.

Initialization Date	**1/1/1990**
Model Type	2 phase
Pressure @Ref	2500
Reference Elevation	-4500
Elevation @ WOC	-5000 (is below the model)
PSATHCG	800

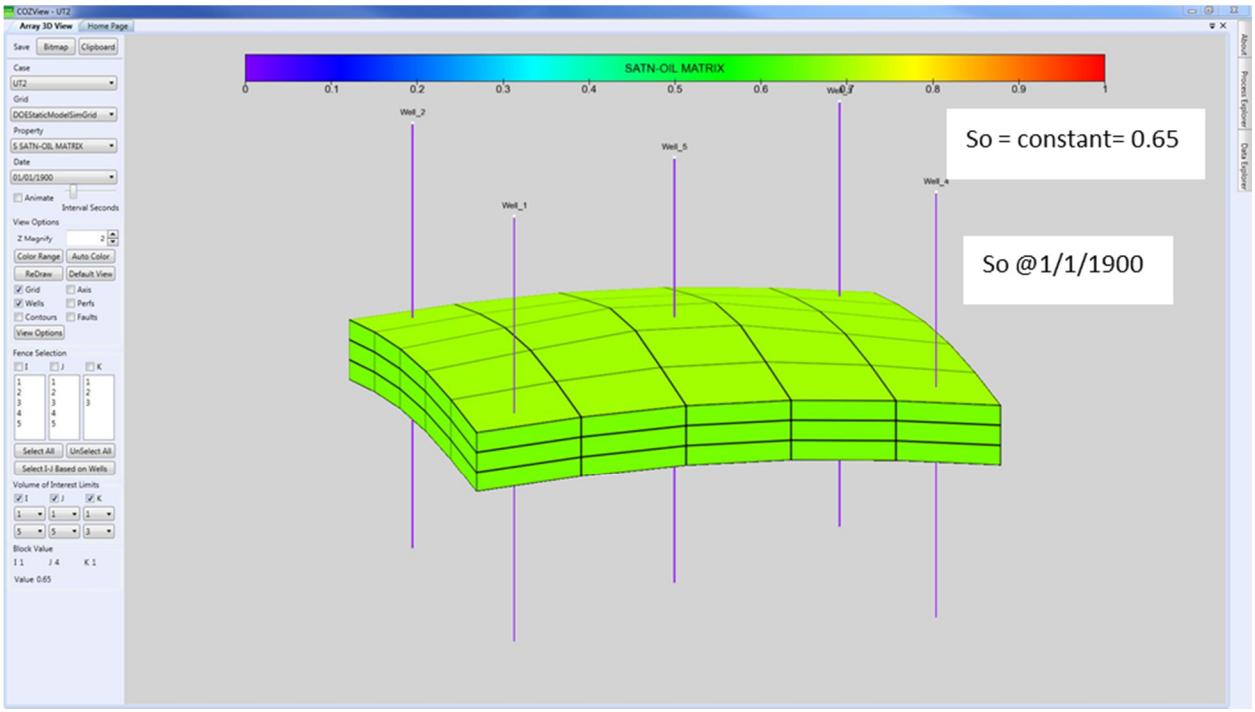
Initialization Date	**1/1/2012**
Model Type	2 phase
Pressure @Ref	1500
Reference Elevation	-4500
Elevation @ WOC	-4500 (is above the model)
PSATHCG	800

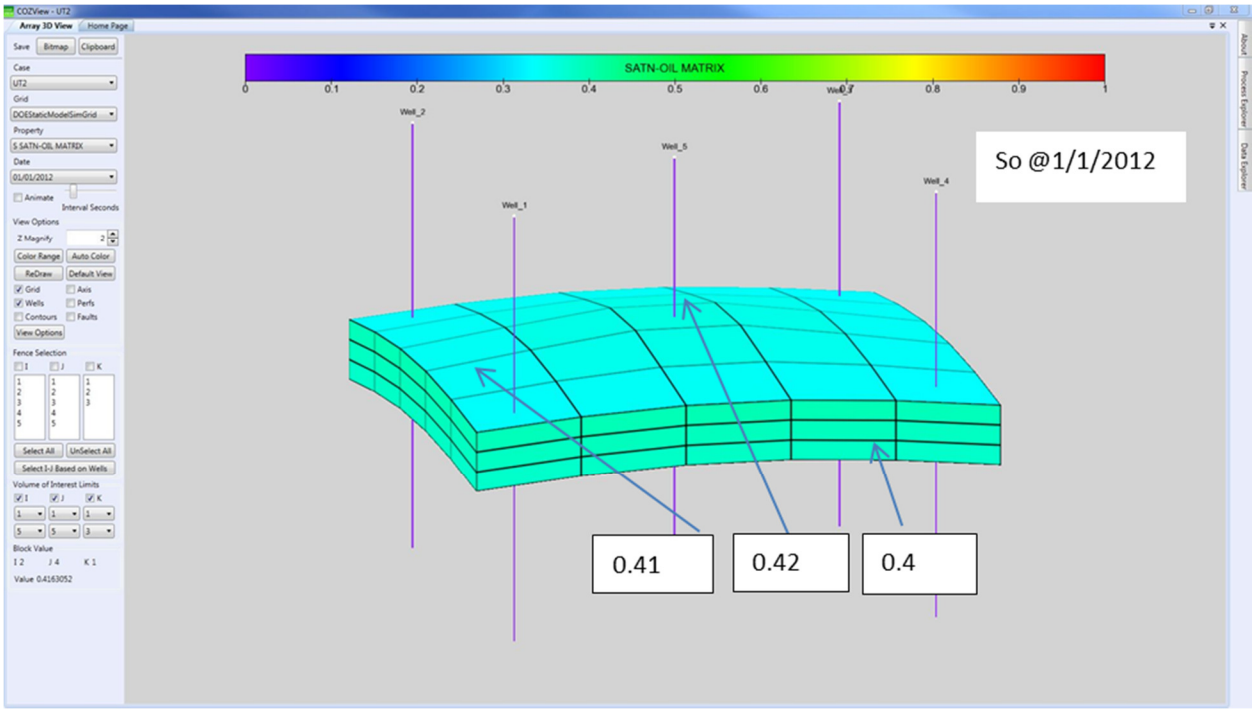
Selection of **Initialize Model** will provide the results of the volumetric calculation on the **View Model Volumetrics** screen. A brief view of the **Simulator Runner** window will appear before the volumetrics are reported. An OOIP of approximately 2.79 MMSTB should be reported subject to differences in the user defined model and this example for the initialization date 1/1/1990. The water saturation in the reservoir should be at Swirr = 0.35. Check the Water saturation arrays in the Array 3D View of the Simulation Results area.

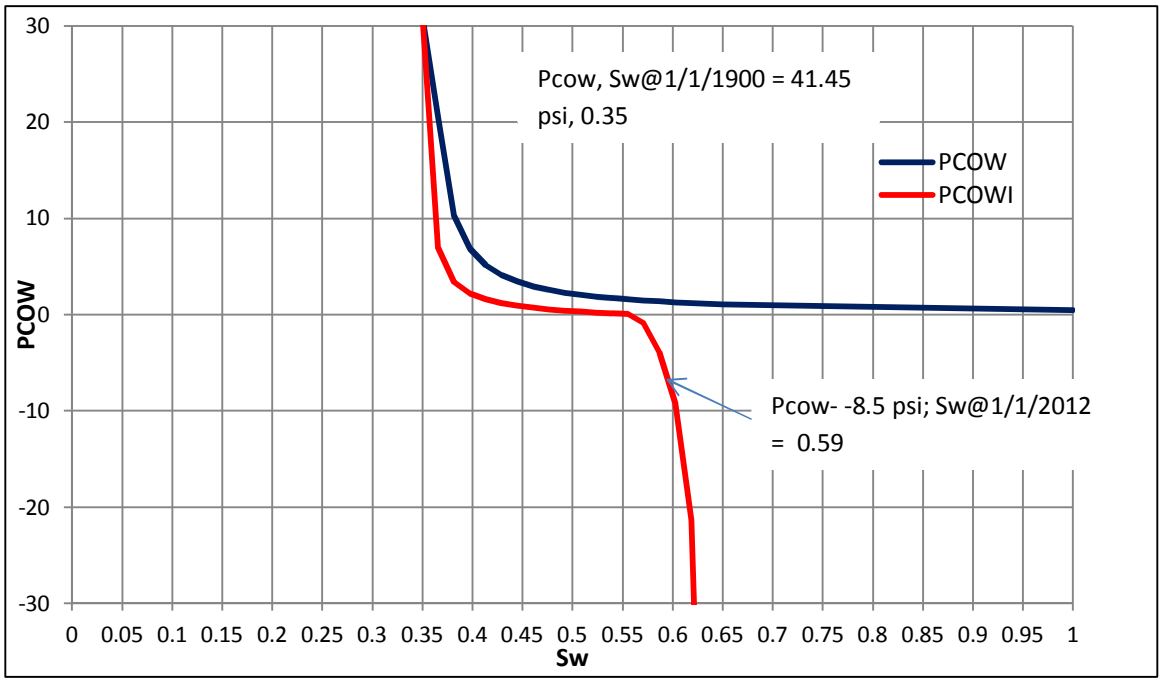
- If Sw is not Swirr at 1/1/1990, change the capillary pressure curve scale such that Pcow at the Midpoint is much higher than the maximum value shown.
- If OOIP is not correct, but Sw is correct, adjust Rock volume (Porosity and Net thickness) and rerun the Model initialization.

Matching OIP at 1/1/2012 (1.7 MMSTB)

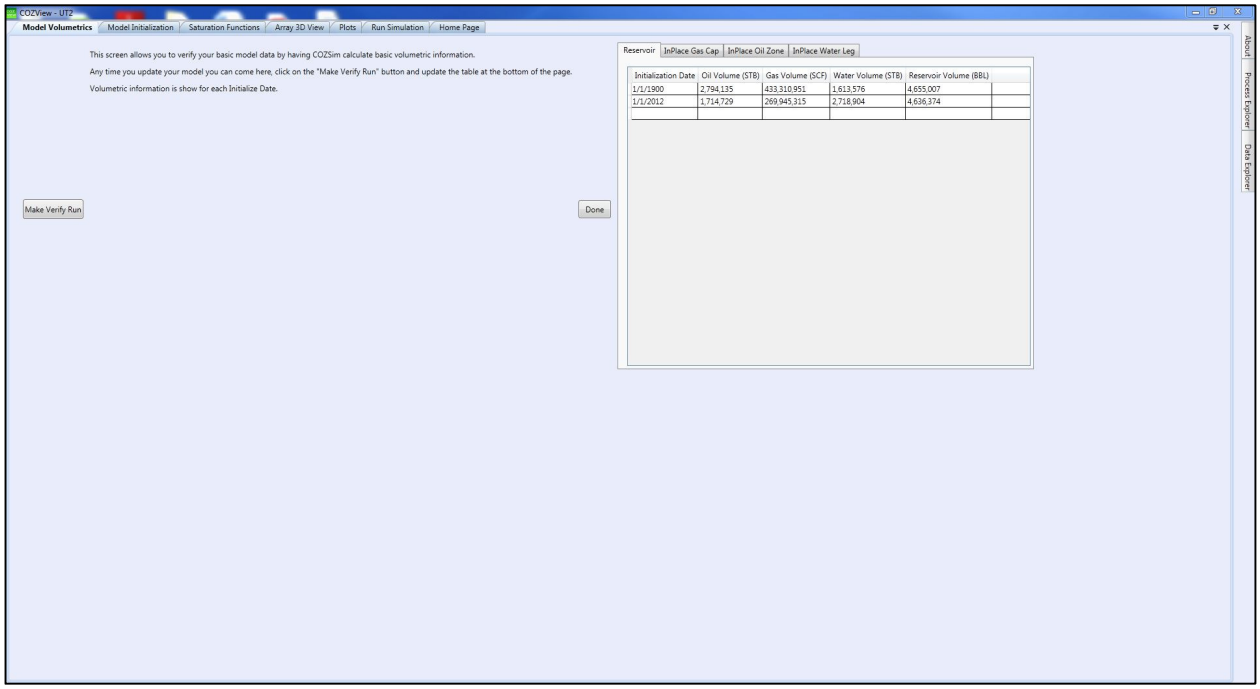
- The water saturation values should have a range of values across the reservoir. Please note that the PCOW calculated at the Midpoint at 1/1/2012 was -8.5 psi. This represents the location of the midpoint of the reservoir on the Pcow curve (Imbibition).
- 3-D arrays should show oil saturation values in the range of Sorw<So<(1-Swirr)
- If OIP is not correct after getting the correct OOIP, adjust PTZEROWO value and rerun the model initialization. Decreasing the PTZEROWO value will increase OIP and increasing PTZEROWO value will decrease OIP. (The area to the right of the imbibition curve and left of Sw= 1-Sorw represents the oil volume in the reservoir at OIP conditions.)




SATN-OIL MATRIX
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Well_2
Well_5
Well_1
Well_4
So @1/1/2012
0.41
0.42
0.4

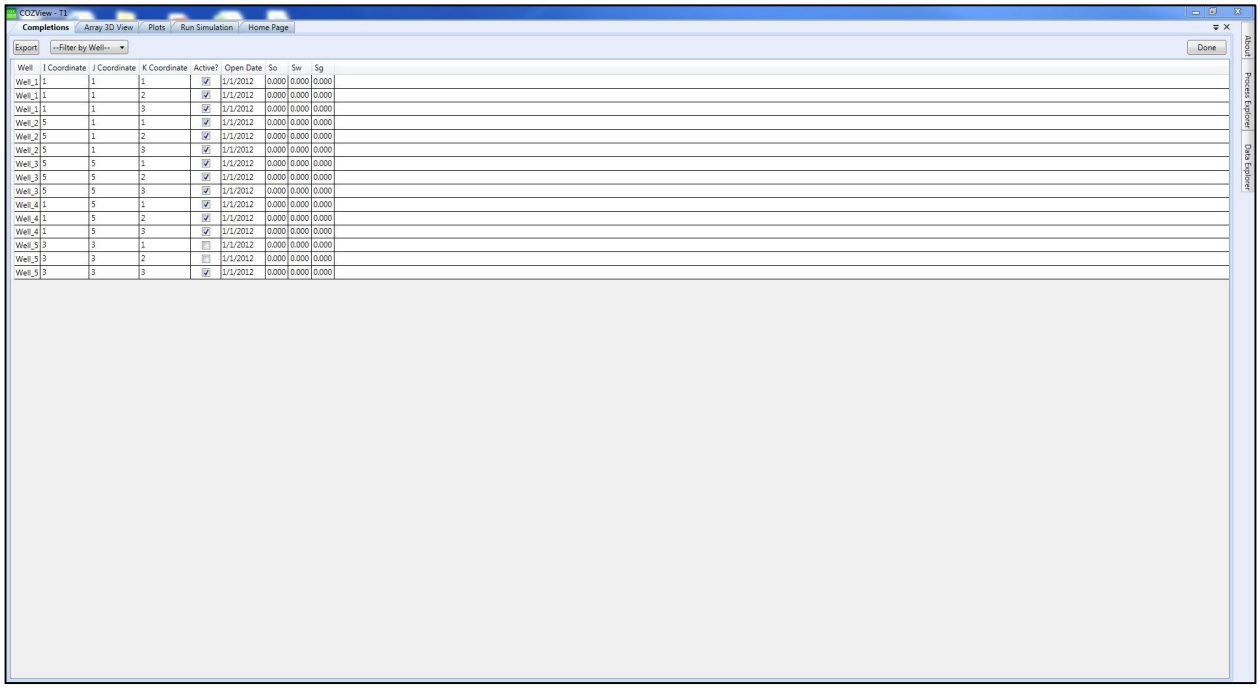

30
20
10
0
-10
-20
-30
PCOW
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
Sw
Pcow, Sw@1/1/1900 = 41.45 psi, 0.35
PCOW
PCOWI
Pcow- -8.5 psi; Sw@1/1/2012 = 0.59

For this example, a PTZEROWO value of 0.57 is appropriate to match the OIP of 1.71 MMSTB. (It is suggested that the number of data points be increased from the default of 20 to 40 during this exercise. This will better display the imbibition curve and the PTZEROWO point.)



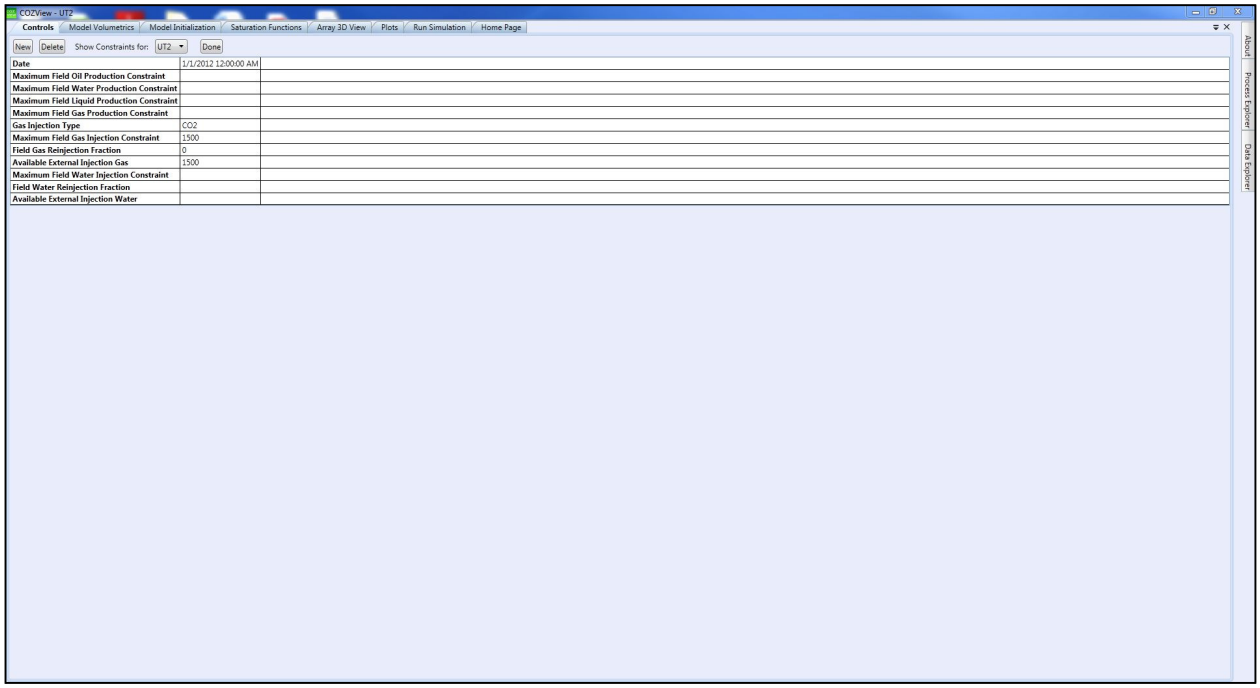
Click **Done** to save the Model Initialization.

Select **Completions** from the **Well Data** area to view and alter the well completions of the CO2 Injection well (Well 5) which is perforated only in the bottom layer (Layer 3) in this example.



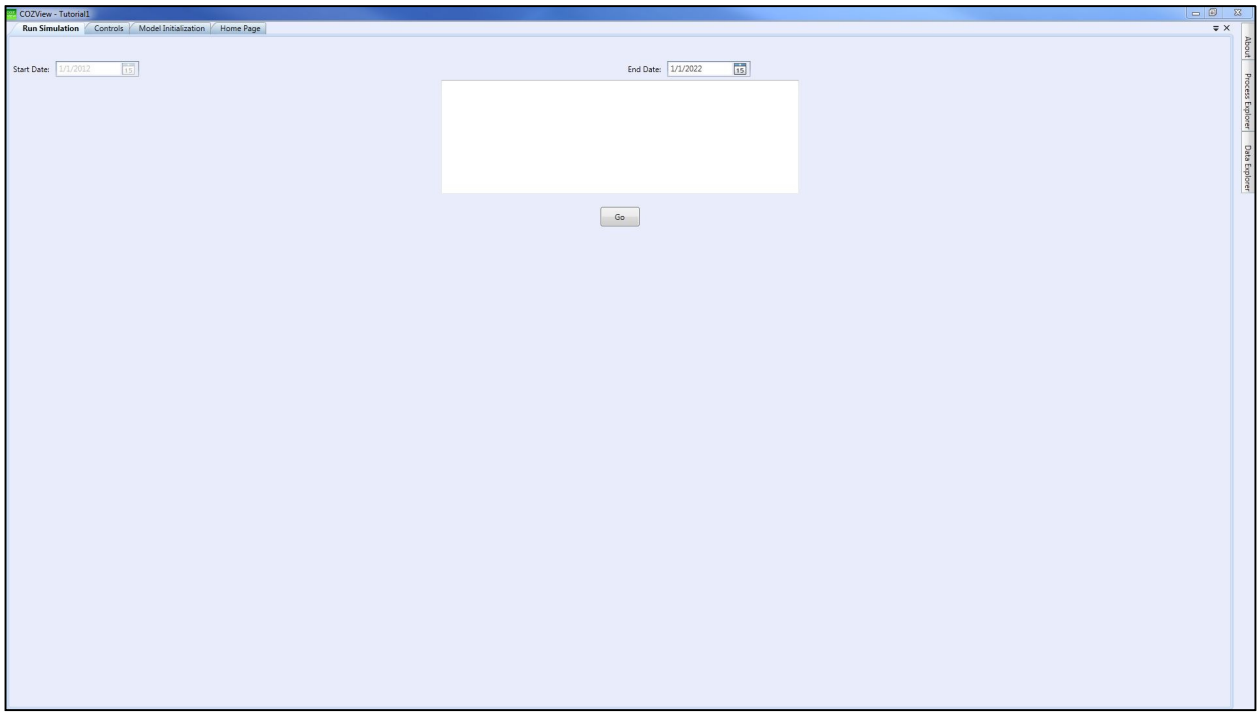
Well	I Coordinate	J Coordinate	K Coordinate	Active?	Open Date	So	Sw	Sg
Well_1	1	1	1	☑	1/1/2012	0.000	0.000	0.000
Well_1	1	1	2	☑	1/1/2012	0.000	0.000	0.000
Well_1	1	1	3	☑	1/1/2012	0.000	0.000	0.000
Well_2	5	1	1	☑	1/1/2012	0.000	0.000	0.000
Well_2	5	1	2	☑	1/1/2012	0.000	0.000	0.000
Well_2	5	1	3	☑	1/1/2012	0.000	0.000	0.000
Well_3	5	5	1	☑	1/1/2012	0.000	0.000	0.000
Well_3	5	5	2	☑	1/1/2012	0.000	0.000	0.000
Well_3	5	5	3	☑	1/1/2012	0.000	0.000	0.000
Well_4	1	5	1	☑	1/1/2012	0.000	0.000	0.000
Well_4	1	5	2	☑	1/1/2012	0.000	0.000	0.000
Well_4	1	5	3	☑	1/1/2012	0.000	0.000	0.000
Well_5	3	3	1	☐	1/1/2012	0.000	0.000	0.000
Well_5	3	3	2	☐	1/1/2012	0.000	0.000	0.000
Well_5	3	3	3	☑	1/1/2012	0.000	0.000	0.000

CO2 injection is initiated in 1/1/2012 as in Tutorial 1.



Date	1/1/2012 12:00:00 AM	
Maximum Field Oil Production Constraint		
Maximum Field Water Production Constraint		
Maximum Field Liquid Production Constraint		
Maximum Field Gas Production Constraint		
Gas Injection Type	CO2	
Maximum Field Gas Injection Constraint	1500	
Field Gas Reinjection Fraction	0	
Available External Injection Gas	1500	
Maximum Field Water Injection Constraint		
Field Water Reinjection Fraction		
Available External Injection Water		

Select **Run Simulation**. The last **Model Initialization** date (1/1/2012) will be shown in the **Start Date** box. If this is not correct, return to the **Model Initialization** screen and reset the date and save. The user must provide a value in the **End Date** box. This must be at least one month after the **Start Date**.

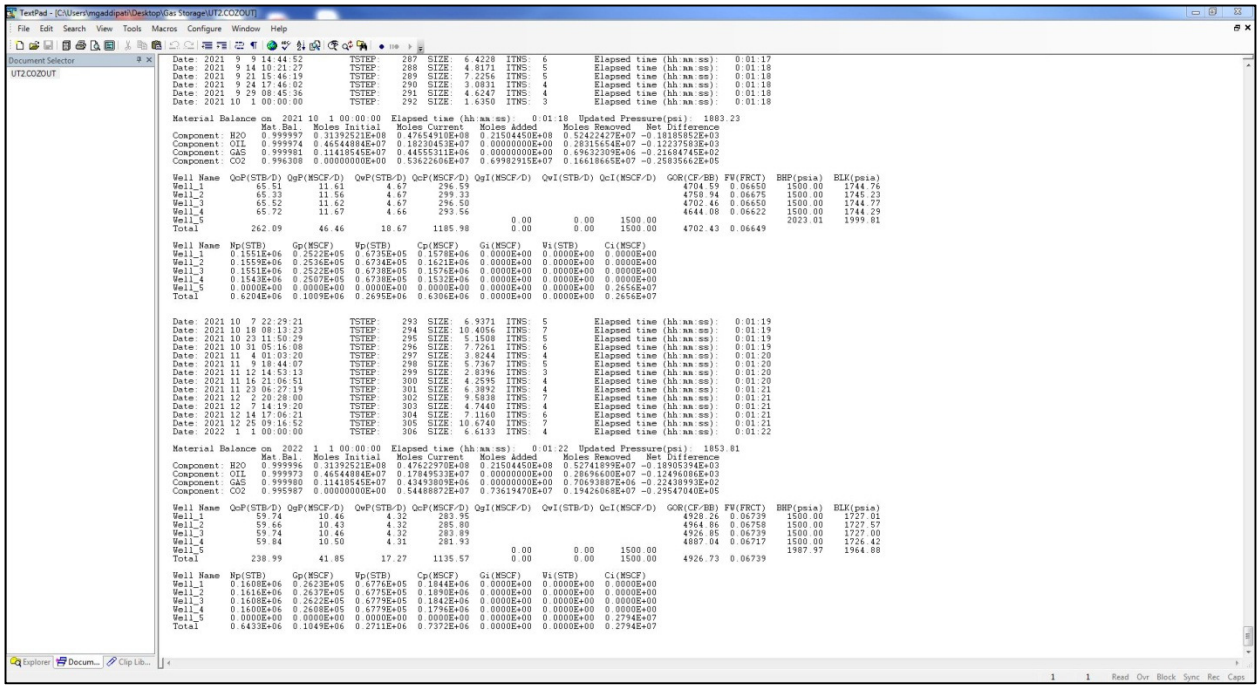


The **End Date** for this example is 1/1/2022.

Select **Go** to initiate the simulation run.

The Simulator Runner window will appear and update the CPU activity for the simulation run. **DO NOT** close the Simulator Runner window during the simulation run. It can be minimized. Closing the Simulator runner window will stop the simulation run.

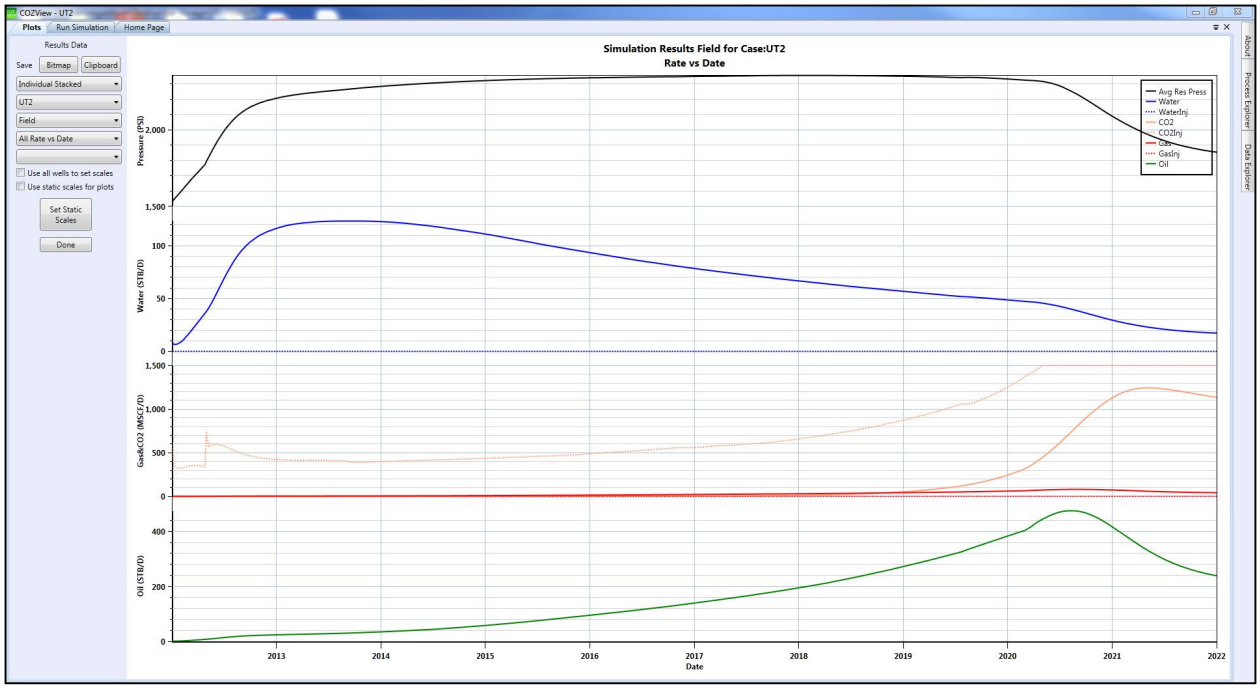
The COZOUT file at the end of this simulation run is shown below.

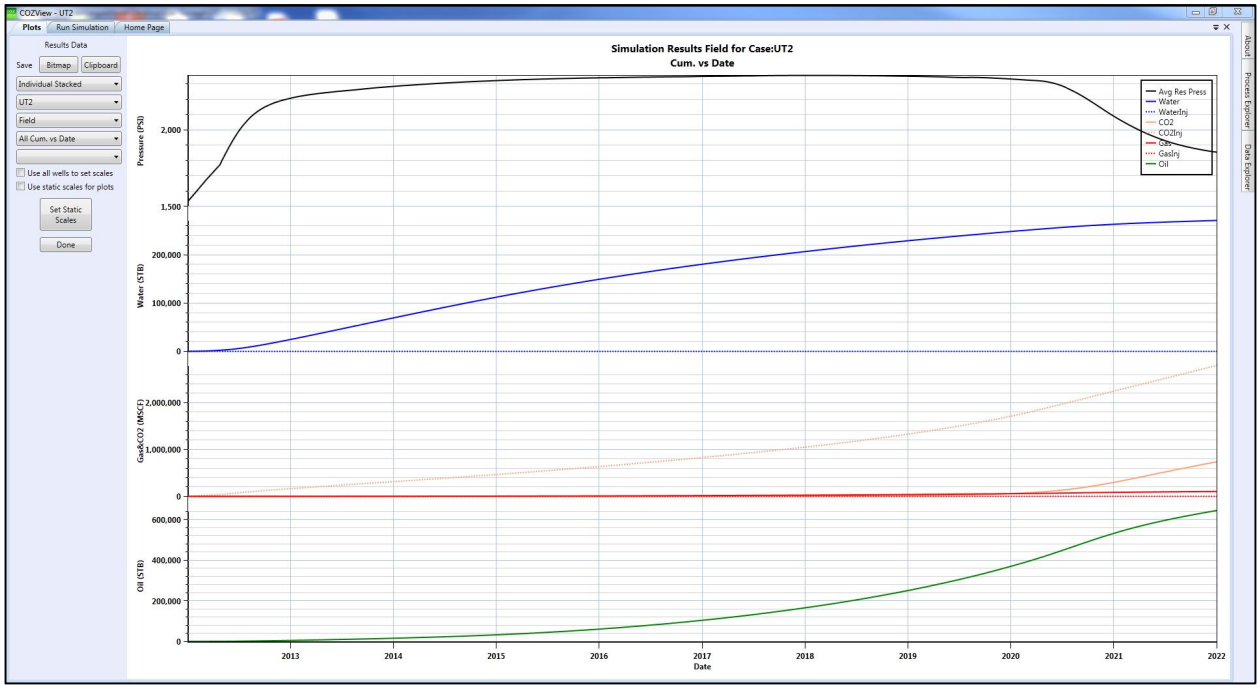


In this example, the reservoir is depleted through primary recovery and water flooding from 1/1/1990 to 1/1/2012. The available oil for production at that time is from unswept oil in the rocks. (Much of the reservoir was not swept to Sorw in this example.) To accomplish a successful prediction run, the user should make sure that the initial well rates and water cuts of the producers before the start of CO2 injection are consistent with the current day data.

- Check initial oil rates and water cuts to match current data. If the rates are not correct adjust PI (Productivity Index) of the wells (*Process Explorer/Prediction Period/Well Parameters/Well Productivity Parameters*) and/or modify relative permeability curves (*Process Explorer/Fluid and Saturation Properties/Saturation Functions-Advanced Settings).*

The field cumulative oil produced (due to CO2 injection) by the end of 10 years (1/1/2022) is 0.65 MMSTB and the cumulative CO2 injected is 2.7 BSCF at that time. CO2 Miscibility is achieved around the injection well and all through Layer 3 as shown in the 3D array at 1/1/2022.


COZView - UT2
Plots
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
UT2
Field
All Rate vs Date
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
About
Process Explorer
Data Explorer
Simulation Results Field for Case:UT2
Rate vs Date
Avg Res Press
Water
WaterInj
CO2
CO2Inj
Gas
GasInj
Oil
Pressure (PSI)
Water (STB/D)
Gas&CO2 (MSCF/D)
Oil (STB/D)
Date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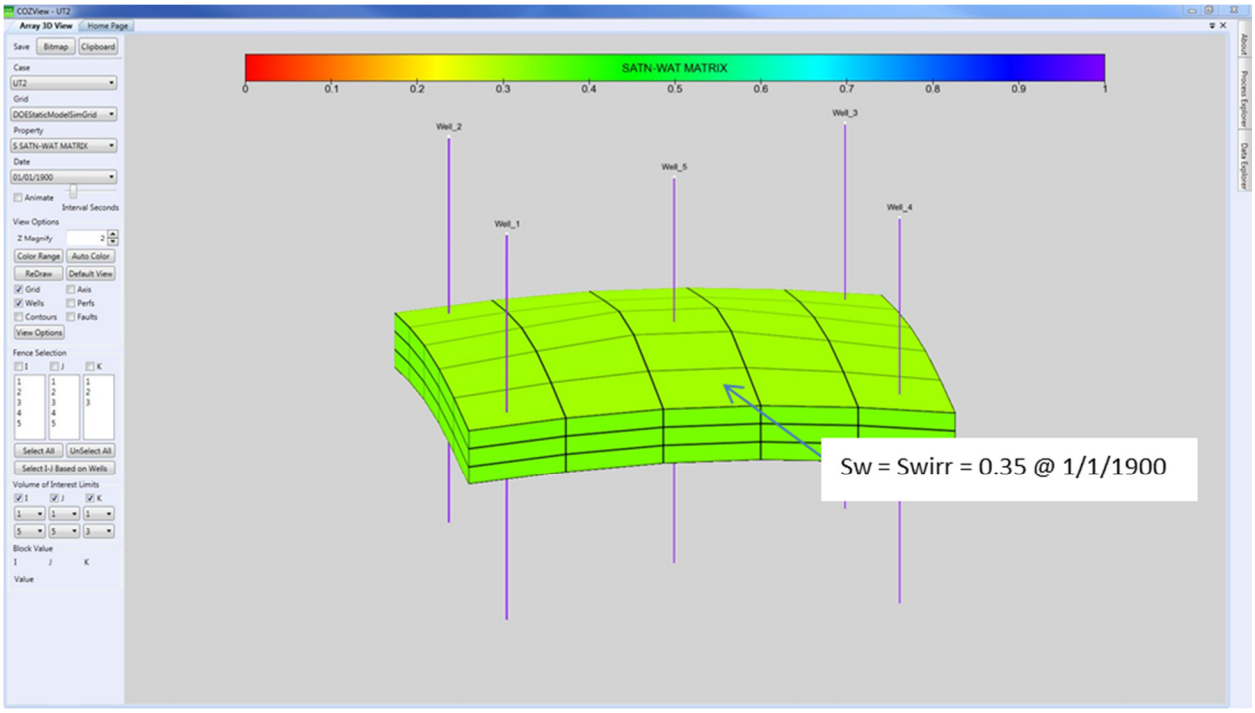
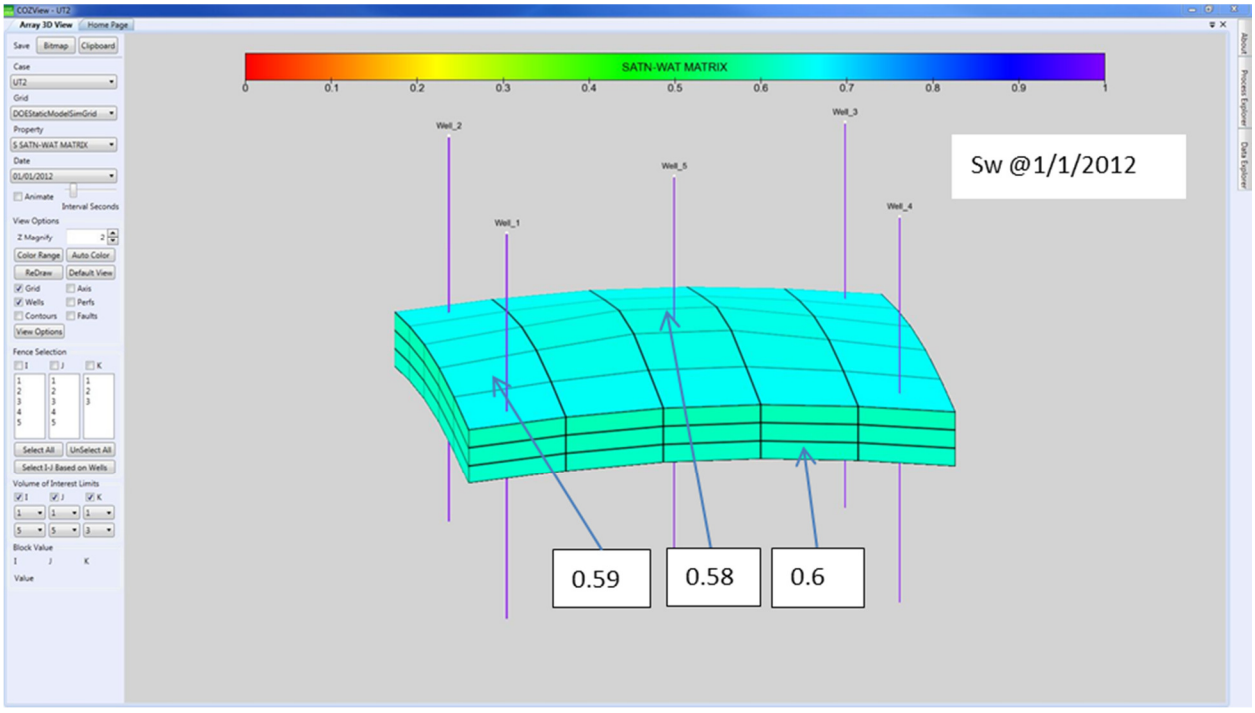
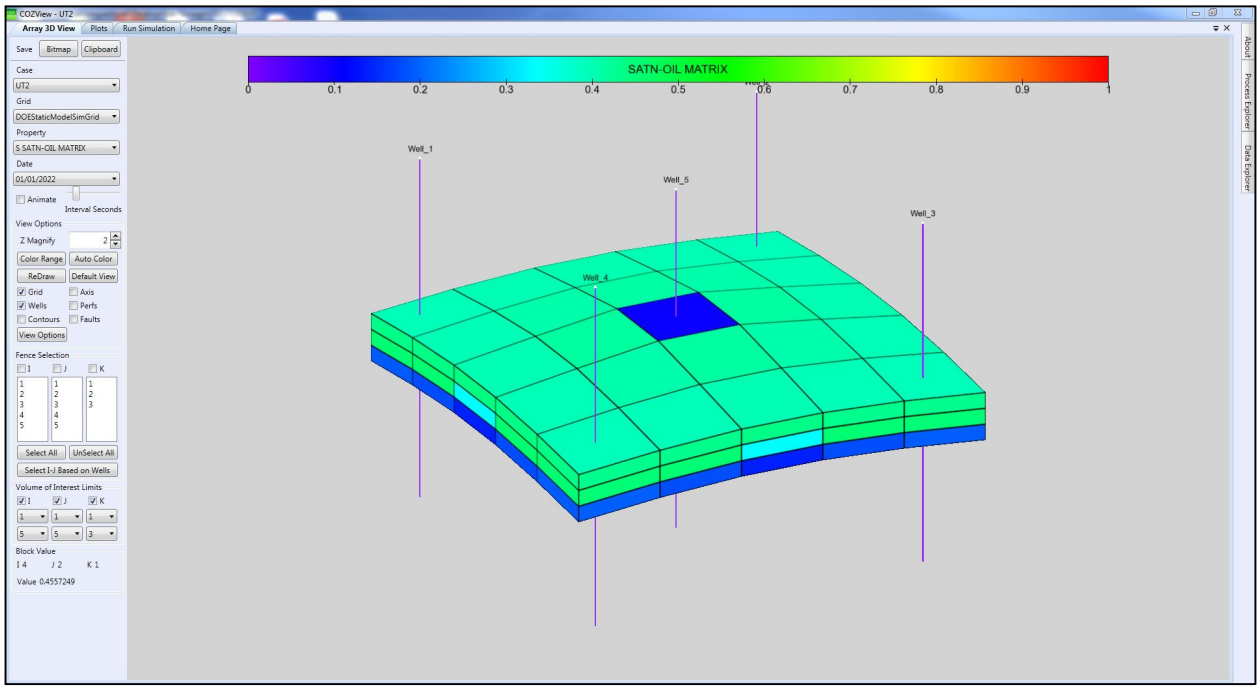
Plots
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
UT2
Field
All Cum. vs Date
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
About
Process Explorer
Data Explorer
Simulation Results Field for Case:UT2
Cum. vs Date
Avg Res Press
Water
WaterInj
CO2
CO2Inj
Gas
GasInj
Oil
Pressure (PSI)
Water (STB)
Gas&CO2 (MSCF)
Oil (STB)
Date


COZView - UT2
Array 3D View
Home Page
SATN-WAT MATRIX
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Well_1
Well_2
Well_3
Well_4
Well_5
Sw = Swirr = 0.35 @ 1/1/1900


COZView - UT2
Array 3D View
Home Page
SATN-WAT MATRIX
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Well_1
Well_2
Well_3
Well_4
Well_5
Sw @1/1/2012
0.59
0.58
0.6


COZView - UT2
Array 3D View
Plots
Run Simulation
Home Page
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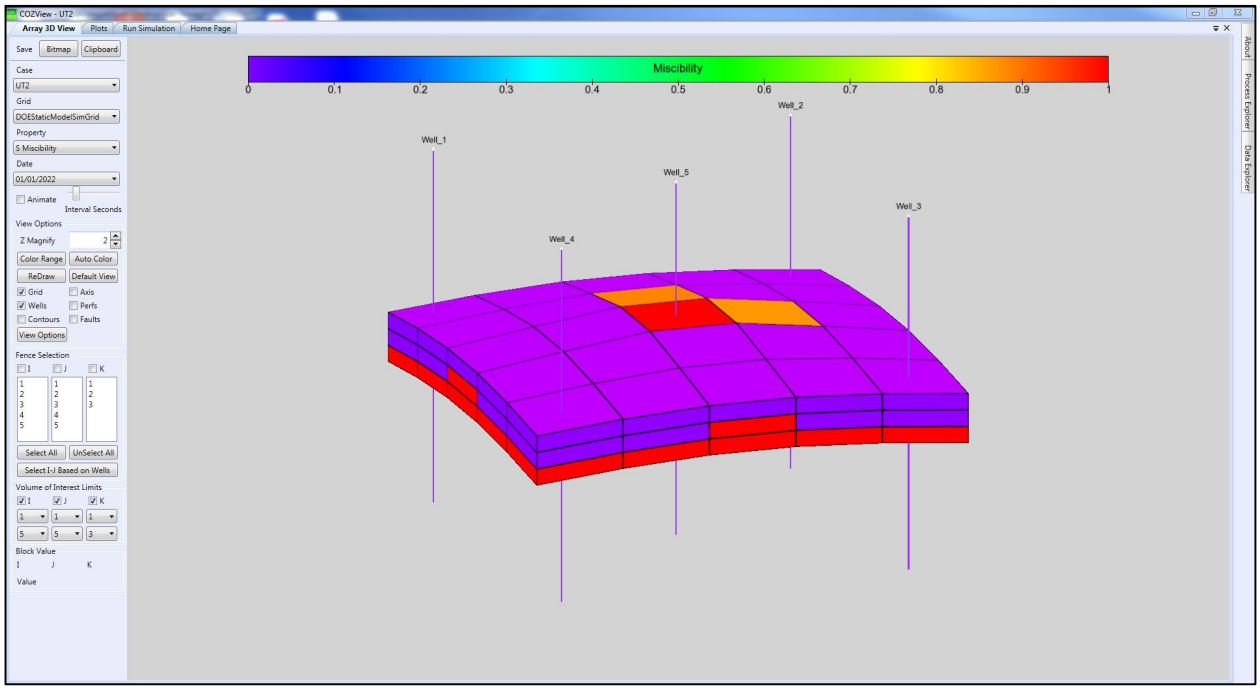
Case
UT2
Grid
DOEStaticModelSimGrid
Property
S SATN-OIL MATRIX
Date
01/01/2022
Animate
Interval Seconds
View Options
Z Magnify
Color Range
Auto Color
ReDraw
Default View
Grid
Axis
Wells
Perfs
Contours
Faults
View Options
Fence Selection
Select All
UnSelect All
Select I-J Based on Wells
Volume of Interest Limits
Block Value
I 4
J 2
K 1
Value 0.4557249
SATN-OIL MATRIX
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Well_1
Well_5
Well_3
Well_4
About
Process Explorer
Data Explorer


COZView - UT2
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Plots
Run Simulation
Home Page
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Case
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Grid
DOEStaticModelSimGrid
Property
S Miscibility
Date
01/01/2022
Animate
Interval Seconds
View Options
Z Magnify
Color Range
Auto Color
ReDraw
Default View
Grid
Axis
Wells
Perfs
Contours
Faults
View Options
Fence Selection
Select All
UnSelect All
Select I-J Based on Wells
Volume of Interest Limits
Block Value
I
J
K
Value
Miscibility
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Well_2
Well_1
Well_5
Well_3
Well_4
About
Process Explorer
Data Explorer