NITEC LLC

A Full-Featured User Friendly CO_2-EOR and Sequestration Planning Software

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ABSTRACT

A Full-Featured, User Friendly CO_2-EOR and Sequestration Planning Software

This project addressed the development of an integrated software solution that includes a graphical user interface, numerical simulation, visualization tools and optimization processes for reservoir simulation modeling of CO_2-EOR. The objective was to assist the industry in the development of domestic energy resources by expanding the application of CO_2-EOR technologies, and ultimately to maximize the CO_2 sequestration capacity of the U.S.

The software resulted in a field-ready application for the industry to address the current CO_2-EOR technologies. The software has been made available to the public without restrictions and with user friendly operating documentation and tutorials. The software (executable only) can be downloaded from NITEC's website at www.nitecllc.com.

This integrated solution enables the design, optimization and operation of CO_2-EOR processes for small and mid-sized operators, who currently cannot afford the expensive, time intensive solutions that the major oil companies enjoy. Based on one estimate, small oil fields comprise 30% of the of total economic resource potential for the application of CO_2-EOR processes in the U.S. This corresponds to 21.7 billion barrels of incremental, technically recoverable oil using the current "best practices", and 31.9 billion barrels using "next-generation" CO_2-EOR techniques. The project included a Case Study of a prospective CO_2-EOR candidate field in Wyoming by a small independent, Linc Energy Petroleum Wyoming, Inc.

NITEC LLC has an established track record of developing innovative and user friendly software. The Principle Investigator is an experienced manager and engineer with expertise in software development, numerical techniques, and GUI applications. Unique, presently-proprietary NITEC technologies have been integrated into this application to further its ease of use and technical functionality.

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EXECUTIVE SUMMARY

The primary objective of this project was to develop an easy to use, technically rigorous CO_2-EOR reservoir simulation software. Ease of use was addressed with an interactive user interface (COZView) which makes significant use of graphical and 3D displays. Technical correctness was addressed by developing a fully implicit, 3-dimensional, 4-component reservoir simulator (COZSim) capable of modeling the complexities of CO_2-EOR (continuous and WAG) and CO_2 sequestration, as well as conventional oil reservoir recovery processes – primary depletion, water flooding, and hydrocarbon gas injection.

The user interface guides the user through the process of creating a valid geologic model of the area being studied and generating future performance predictions based on user defined well and field operating constraint. The software allows the user to replicate the structural surface of the reservoir or area being studied without the complications of map-file importing. The software utilizes industry accepted correlations for generation of PVT properties (oil, water, gas), CO_2-oil interactions, relative permeability relationships (oil, water, gas) and capillary pressure relationships. The volumetrics of the user developed model can be easily verified against expectations before proceeding with simulation prediction runs. Prediction scenarios employing user defined well locations, well completions, well operating conditions and field/facility constraints, can be easily defined and simulation runs submitted. Simulation results are automatically loaded at the conclusion of the processing and can be viewed by the user as plots and 3D displays. Comparison plots of alternative prediction scenarios are also available. Once the user is satisfied with the general prediction results, optimization functionality is available to optimize the prediction performance based on calculation of net present value (NPV) generated from user defined economic parameters. There are no reasonable limitations on number of wells or simulation model size other than computer space and run time considerations.

The software was tested against two commercial compositional reservoir simulators – ECLIPSE 300®, marketed by Schlumberger, and Sensor®, marketed by Coats Engineering. Simulation results were found to be comparable among the three simulators for the same input data. (Appendix 3) The software was also exercised in a Case Study by Linc Energy Petroleum Wyoming of Casper, WY. They conducted a simulation study of their Cole Creek South Field in

Converse County, Wyoming. The field is a candidate for CO_2-EOR. The Linc Energy engineer worked with NITEC to perform the study and provided valuable user comments to improve its functionality. (Appendix 4)

The software is available on Windows 7 operating systems with reasonable requirements for processor speed and disk size. The software was made available for download (executable only) from NITEC's website on February 28, 2013. An Installation manual (Appendix 7), a comprehensive User manual (Appendix 6), which can be interactively accessed from the user interface, a number of tutorial examples (Appendix 8) and a simulator white paper (Appendix 5) are available for download as well. A Data Input Requirements List (Appendix 1) and a COZView/COZSim Nomenclature list (Appendix 2) are accessible from the interactive HELP. Approximately 60 individuals from various small to mid-size companies have downloaded the software as of mid-November 2013.

NITEC provided Technology Transfer to the industry through the following presentations and workshops:

Presentation: **"Investigating ROZ Exploitation with COZSim",** CO_2 Flooding Conference, Midland, TX, December 7, 2012.

Presentation: **"Investigating ROZ Exploitation with COZSim",** Wyoming Enhanced Oil Recovery Institute's Tensleep III-ROZ EOR in the Bighorn Basin Tensleep Workshop, Casper, WY, July 11, 2013.

Presentation: **"Frannie Tensleep in COZ",** Wyoming Enhanced Oil Recovery Institute's 7th Annual Wyoming CO_2 Conference, Casper, WY, July 13, 2013.

Workshop: **"COZ - New Reservoir Simulation Software Designed to Aid Smaller Operators in Conducting More Rigorous Reservoir Studies",** PTTC Workshop, Denver, CO, November 7, 2013.

Workshop: **"COZ - New Reservoir Simulation Software Designed to Aid Smaller Operators in Conducting More Rigorous Reservoir Studies",** PTTC Workshop, Tulsa OK, November 19, 2013.

Presentations were attended by a total of approximately 400 people. Workshops were attended by a total of approximately 30 people.

The software was adopted by the Colorado School of Mines' Unconventional Reservoir Engineering Project (UREP) industry consortium in November 2012 as the basis for an enhanced reservoir simulator to address unconventional reservoir systems. NITEC is providing enhancements to the simulator under a funding agreement with the consortium.

Conclusions:

- The software was delivered to DOE as required by the contract.
- All contract obligations were fulfilled within the original approved budget.
- The software functionality exceeded the contract requirements.
- NITEC is distributing the software at no cost to DOE.
- NITEC is providing installation support and application support at no cost to DOE.
- A significant number of users have downloaded the software in the first 8.5 months of its availability.

DOE has provided no funding for the distribution or support of this software. NITEC is distributing the software from its website with notification to prospective users that only limited installation and application support can be provided without other contractual arrangements with the user.

TECHNICAL DISCUSSION

Project Tasks

The project was divided to the following major tasks:

1. Project Management and Planning
2. Static Module Development
3. Dynamic Module Development
4. Simulator Development
5. 3D Visualization Development
6. Optimization Module Development
7. User Manual Development
8. Tutorial Development
9. Technology Transfer
10. Case Study

Tasks 2, 3, 5, 6 were associated with the interactive user interface modules for pre and post processing of simulation model data. Task 4 was the actual simulator module development. Many of the user interface concepts were derived from proprietary- software technology previously developed by NITEC. However, most code developed for this software was developed from scratch using current generation software languages; primarily C# for the user interface, in addition to a SQL database and OpenGL libraries for graphical and 3D displays. All user interface screens utilized interactive HELP via direct access to a comprehensive User Manual.

It is important to note that the user interface was designed to develop simulation models for submission of prediction scenarios (cases). It was not design to carry out history match simulation runs. (*This is a function of the user interface and not a limitation imposed by the simulator itself.*)

Static Module

A graphical approach is utilized to allow the user to replicate a reservoir's structural surface as the basis for the geologic model. It was originally proposed to provide a library of geologic

shapes that could be scaled, but a more general graphical technique was found to be an improvement on the library concept. Multiple layer definitions via tabular input provide for assignment of layer properties – net and gross thickness, porosity, absolute permeability (x, y and z-directions) and formation compressibility. Well locations can be assigned interactively on the structural surface or via table import. Vertical faults can also be placed in the user defined model area. The simulation grid dimensions and overall model size is automatically generated based on the user defined model area boundaries and default grid dimensions (which can be overridden by the user). The grid is generated with areal dimensions in the x and y-direction being the same. (*This is a function of the user interface and not a limitation imposed by the simulator itself.*) The grid is converted to a three-dimensional, corner-point geometry for input to the simulator itself. Non-neighbor connections are generated automatically. Figure 1 is a structural model view with contours and boundaries shown.

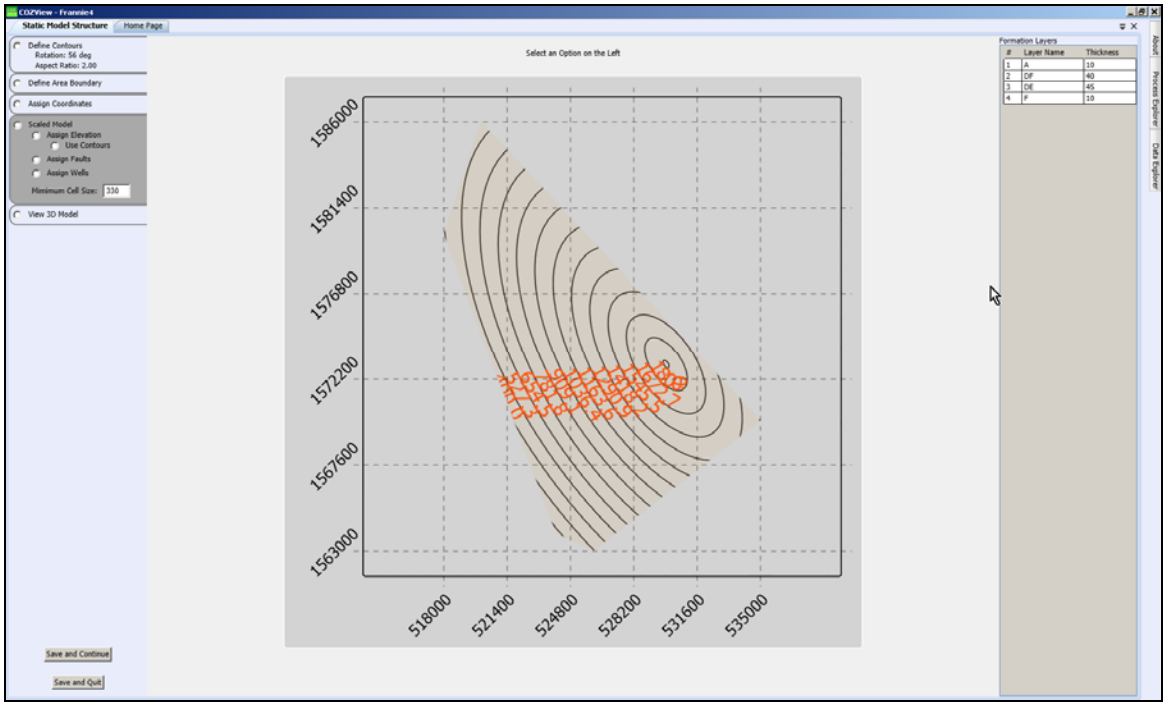

Figure 1: Structural Model

PVT properties and saturation functions (relative permeability and capillary pressure) are part of the static model. PVT properties are generated for input to the simulator using industry correlations. Input requirements are the gas gravity, the oil API gravity, water salinity and

reservoir temperature. Default values are provided, however these are not intended to be recommendations for the user's specific application. The following properties are generated as a function of pressure

Oil[4]

- Formation volume factor (Bo, RB/STB)
- Solution gas-oil ratio (Rso, SCF/STB)
- Viscosity (μ, cp)

Gas[1,2,3]

- Z-factor (z, fraction)
- Formation volume factor (Bg, RB/SCF)
- Viscosity (μ, cp)

Water[5]

- Formation volume factor (Bw, RB/STB)
- Viscosity (μcp)
- Compressibility (Cw, 1/psi)

These properties are generated over a default pressure range of 14.7 to 4000 psi. The maximum pressure of 4000 psi is based on the reliable pressure range for the correlations used to generate CO_2-oil interaction relationships and CO_2 properties. These correlations may not have validity at higher pressures. A higher maximum pressure can be safely specified by the user when non- CO_2 simulations are being made. The oil, gas and water correlations do not have this pressure limitation associated with the CO_2 correlations. The user may create multiple PVT tables, but only one can be used for a simulation. (*This is a function of the user interface and not a limitation imposed by the simulator itself.*)

Only black-oil PVT properties are displayed for the user, Figure 2.

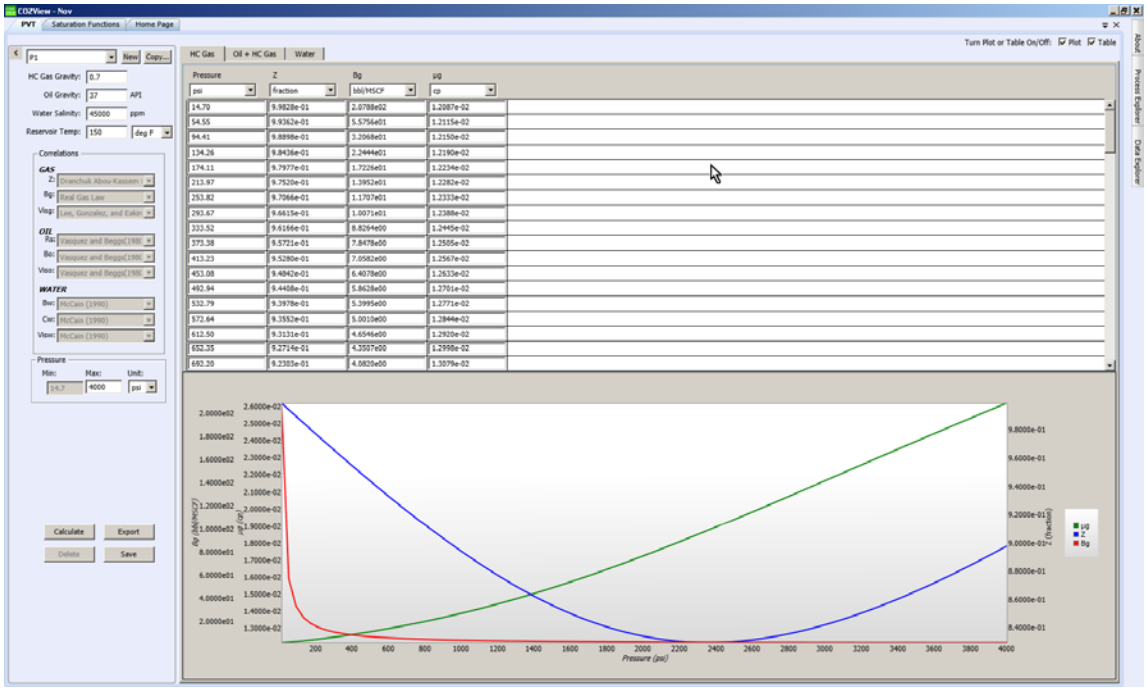

Figure 2: PVT Property Screen

The saturation functions are generated for input to the simulator using industry correlations[6]. Input requirements are Lambda, Swirr, Sorw. Water-oil and gas-oil relative permeability curves and tables are generated based on these user defined properties. Default values are provided, however these are not intended to be recommendations for the user's specific application. The following properties are generated as a function of water or liquid saturation. See Figure 3.

Krw

Kro (drainage)

Kro (imbibition)

Krg (drainage)

Krg (imbibition)

Krog

Capillary pressure curves and tables are not generated by default. Capillary pressure relationships can be generated by specifying the capillary threshold pressure (PEWO).

Other parameters that may impact the relative permeability and capillary pressure relationships are available for specification by the user (override default values). These are Sgc, Sorg, Sorm. In

addition, an advanced setting functionality allows the relative permeability curve shapes to be modified consistent with the correlations.

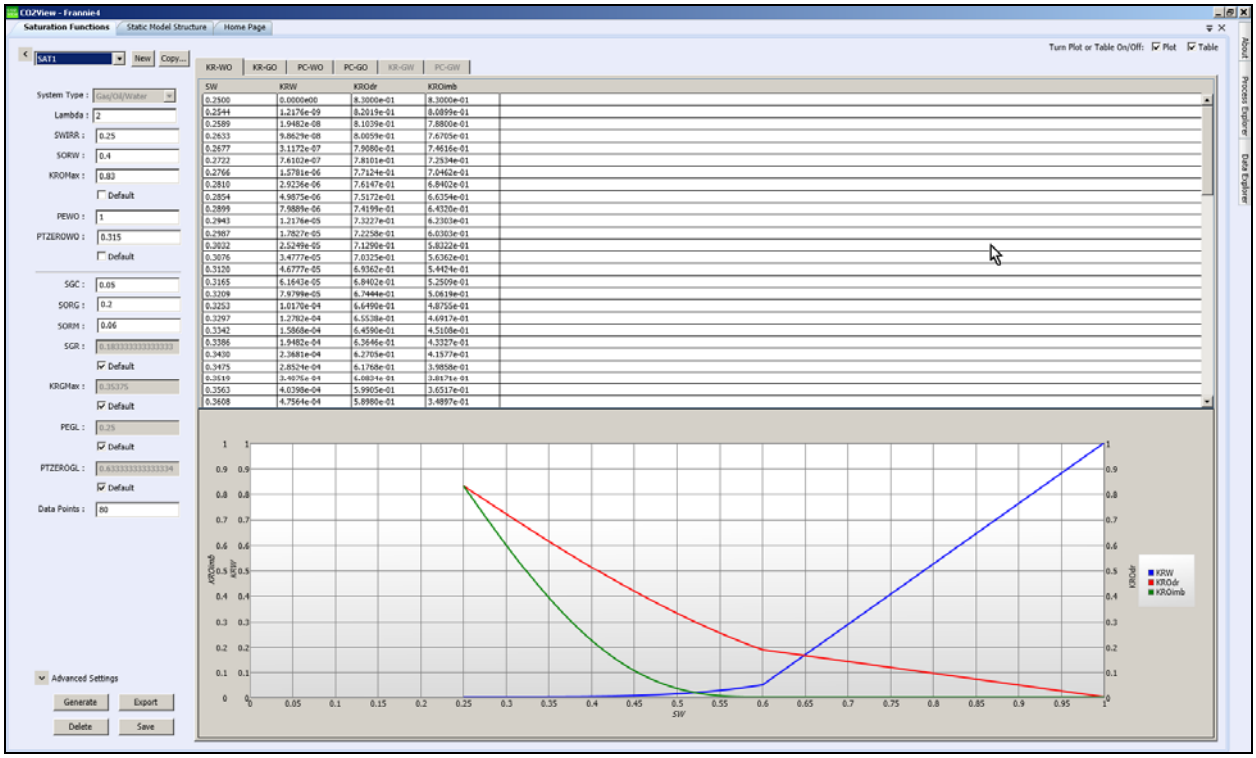

Figure 3: Saturation Function Screen

The user may create multiple saturation function tables, but only one can be used for a simulation. (*This is a function of the user interface and not a limitation imposed by the simulator itself.*)

The final aspect of the static module is the integration of all the properties noted above and calculation of the reservoir model fluids-in-place. This requires the data to be submitted to the simulator and the in-place volumes of each phase to be calculated. This allows the user to validate the model that has been developed against the user's expectations. This is carried out by an initialization of the model at static equilibrium at a user defined date, reservoir pressure at a specified elevation, water-oil and gas-oil contact elevations, and bubble point pressure. Using this information the simulator quickly calculates the in-place volumes and returns the values in a summary table. If the calculated volumes are not consistent with the user's expectations, the user can return to the static properties and PVT and saturation function relationships and make

modifications until the desired in-place volumes are computed by the simulator. Because the simulator was accessed to make these calculations, 3D array maps and tables of the computed saturations and pressure are available for review.

A procedure is also available (described in a Tutorial #1-2 and the User Manual) to calculate the in-place volumes (initialize the model) at a time associated with post water flood (gas flood) or post aquifer (gas cap) encroachment. This allows the user to affect a pseudo history match and initialize the model pressures and saturations at levels that are consistent with the above mechanisms and are different than original reservoir conditions (pre-production). This results in a more representative starting point (albeit on an average basis) for the model for predicting a secondary or tertiary process after prior historical production and injection.

This volumetric validation process assures that the user has the opportunity to verify the model volumes in place relative to known of perceived data before launching a simulation run.

Dynamic Module

The dynamic module provides the well and operational specification to the simulator. These parameters control how the wells and total field operate (produce, inject, shut-in, worked-over) and are constrained in the simulator. These specifications can change over the life of the simulation run per user inputs.

Initially, wells located in the structural model during the Static model development, or imported in the Well Locations area, are completed through all layers of the model as of the model initialization date (start date for prediction scenarios). The user has the ability to change the layer completions and the time at which any well is introduced to the model (drill date). All wells to be used in a simulation prediction case can be introduced at the beginning of the simulation, but their activation is based on the user's inputs. Wells must be identified by a well type in order to activate the well in a simulation case. Well types (7) are

- liquid producer,
- oil producer ,
- gas producer,
- water producer,

- gas/ CO_2 injector,
- water injector, and
- WAG injector.

Well types can be changed via user specification over the life of the simulation case if desired.

Field or facility constraints can also be introduced to the model. These control field level production and/or injection volumes (minimums and maximums), the availability of external source gas, CO_2 or water for injection, and produced gas, CO_2 or water recycle conditions.

Subsequent to the software's release in February 2013, NITEC added two useful functionalities to the software – Case Management and a WAG scheduler. Case Management allows the user to create multiple cases within the same project and compare simulation plot results on the same plots. Simulation of a WAG process was available in the original release, but scheduling the WAG cycle for individual wells was cumbersome. NITEC facilitated this process by adding the WAG scheduler.

Simulator Module

The simulator code (Fortran) was developed from scratch which allowed a number of innovative concepts to be utilized and provided for possible enhancement in the future. Only the linear solver code was adopted from another source. This was anticipated in the original proposal and was done due to the time required to develop this code from scratch. This simulator is referred to as COZSim.

COZSim is a three-phase, four-component, fully implicit, finite-difference extended black oil reservoir simulator. The simulator uses black oil type input data for fluid descriptions and converts the data to a compositional form internally.

The simulator considers 3 phases (oleic, gaseous and aqueous) and consists of mass balances for four components (water, oil, hydrocarbon gas and CO_2). Components may thermodynamically partition among three phases and both hydrocarbon gas and CO_2 may partition into gaseous and aqueous phases as shown in Table 1.

In addition, COZSim can handle hydrocarbon gas and CO_2 solubility in the aqueous phase. While this may not be important in the main oil zone, it may influence the simulation results where the water saturation is high, such as in transition and residual oil zones, previously water flooded reservoirs, or reservoirs under water alternating gas (WAG) injection.

The software was developed to ease the building and simulation of CO_2-EOR processes. However, the software is not restricted to modeling of CO_2-EOR. Natural depletion, infill drilling, water flooding and hydrocarbon gas injection can also be models.

Table 1: Phases and Components in COZSim

Component Number	Component	Phase		
		Oleic	Gaseous	Aqueous
1	Water	-	-	w1
2	Oil	x2	-	-
3	HC Gas	x3	y3	w3
4	CO_2	x4	y4	w4

Even though the data that is required to run the simulator is in black-oil format, all the information is converted to compositional form internally.

Built-in CO_2 correlations are used to calculate

- pure CO_2 properties,
- CO_2 solubility in the aqueous and oleic phases in the presence of hydrocarbon gas,
- CO_2 swelling of the oleic phase in the presence of hydrocarbon gas and

- phase viscosities that reflect CO_2 solubility.

Vapor-Liquid Equilibrium (Flash) calculations are performed at the bulk pressure, which is the pressure corresponding to unconfined laboratory conditions. However, the phase properties (e.g. viscosity, density) are calculated at the pressures of each phase. This requires an iterative solution of the phase properties and the capillary pressures until they converge.

Miscibility calculations are based on interfacial tension using black-oil data. Interfacial tension reduction due to partitioning of CO_2 in the oleic and gaseous phases is calculated using parachors; it is also used to simulate transition from immiscible to partially miscible, and finally to fully miscible conditions. Viscous fingering is handled through a Todd-Longstaff type viscosity model using interfacial tension rather than using a constant mixing parameter. Residual oil saturation can be modeled under fully or partial miscibility conditions. The impact of both full and partial miscibility on gas-oil capillary pressure and relative permeability is accounted for in the fully implicit formulation.

COZSim treats wells in a fully implicit manner and it is able to simulate well and field level constraints.

COZSim uses three dimensional corner-point geometry grid with Cartesian coordinates, and it is able to handle faults (limited to vertical in COZView); required non-neighbor connections are generated automatically.

The mathematical formulation consists of 4 coupled mass balance (continuum) equations for each cell. The molar continuity equation for any component c is:

$$\nabla\left(\rho\vec{v}w_c\right)_a + \nabla\left(\rho\vec{v}x_c\right)_o + \nabla\left(\rho\vec{v}y_c\right)_g - q_c = \frac{\partial\left(\phi z_c \rho_t\right)}{\partial t} \tag{1}$$

where subscript a, o and g denotes the phase – aqueous, oleic and gaseous phase, respectively and ρ_t is molar density of a phase. z_c is the overall mole fraction of component c. w, x and y are the mole fractions of the component in the aqueous, oleic and gaseous phases, respectively. The right hand side of the equation represents accumulation terms and left hand side is the total contribution from inter-block flow terms and source or sink. q is the molar rate and $\vec{v}$ is the directional Darcy velocity. It is defined as:

$$v = kk_r \lambda \left(\nabla P - \gamma \nabla D \right) \tag{2}$$

The non-linear continuum equation is discretized in time and space by using standard finite-difference calculations. Time indexing of variables is all fully implicit. Four independent variables, bulk pressure and overall mole fractions of water, hydrocarbon gas and **CO_2**, are solved in fully implicit manner. The aqueous phase is treated in the same way as the other phases in terms of the continuity equation.

In order to solve the non-linear continuum equation, all terms are converted into linear form of the primary variables. Time difference formulation of accumulation terms can be expanded as following for grid block i:

$$\frac{\partial \left(\phi z_c \rho_t \right)}{\partial t} = \frac{1}{\Delta t} \left[\left(\phi z_c \rho_t \right)^{n+1} - \left(\phi z_c \rho_t \right)^{n} \right]_i \tag{3}$$

where subscript n represents the time level and the parameter value at nth time level is known (old time level) whereas n+1 denotes next time step which is unknown. Since all parameters are linearized with the primary variables, the next time step can be approximated with Taylor series expansion as following:

$$\left(\phi z_c \rho_t \right)_i^{n+1} \approx \left(\phi z_c \rho_t \right)_i^{l+1} = \left(\phi z_c \rho_t \right)_i^{l} + \sum_{j=1}^{4} \left[\frac{\partial \left(\phi z_c \rho_t \right)}{\partial X_j} \right]_i^l \partial X_j^{l+1} \tag{4}$$

Here ∂X_j denotes the primary variables as ∂P_{bulk}, ∂z_1, ∂z_3 and ∂z_4, bulk pressure and overall mole fractions of water, hydrocarbon gas and CO_2 components, respectively. Superscript l is the iteration number. Iteration l represents known parameter value and l+1 is unknown as following:

$$\partial X^{l+1} = X^{l+1} - X^{l} \tag{5}$$

Similar to accumulation term, inter-block flow terms are expanded in fully implicit manner and Taylor series expansion is also used. As a result of this linearization procedure, a set of linear equations are solved using a linear solver. COZSim uses HYPRE linear solver[7] from Lawrence Livermore National Laboratory. A simplified demonstration of solution matrix is shown below.

$$\begin{bmatrix} E_1 & F_1 & 0 & G_1 & 0 & 0 & H_1 & 0 & 0 \\ D_2 & E_2 & F_2 & 0 & G_2 & 0 & 0 & H_2 & 0 \\ 0 & D_3 & E_3 & F_3 & 0 & G_3 & 0 & 0 & H_3 \\ C_4 & 0 & D_4 & E_4 & F_4 & 0 & G_4 & 0 & 0 \\ 0 & C_5 & 0 & D_5 & E_5 & F_5 & 0 & G_5 & 0 \\ 0 & 0 & C_6 & 0 & D_6 & E_6 & F_6 & 0 & G_6 \\ B_7 & 0 & 0 & C_7 & 0 & D_7 & E_7 & F_7 & 0 \\ 0 & B_8 & 0 & 0 & C_8 & 0 & D_8 & E_8 & F_8 \\ 0 & 0 & B_9 & 0 & 0 & C_9 & 0 & D_9 & E_9 \end{bmatrix} \begin{bmatrix} \partial X_{1,1,1} \\ \partial X_{2,1,1} \\ \partial X_{3,1,1} \\ \partial X_{1,2,1} \\ \partial X_{2,2,1} \\ \partial X_{3,2,1} \\ \partial X_{1,1,2} \\ \partial X_{2,1,2} \\ \partial X_{3,1,2} \end{bmatrix} = \begin{bmatrix} \partial R_{1,1,1} \\ \partial R_{2,1,1} \\ \partial R_{3,1,1} \\ \partial R_{1,2,1} \\ \partial R_{2,2,1} \\ \partial R_{3,2,1} \\ \partial R_{1,1,2} \\ \partial R_{2,1,2} \\ \partial R_{3,1,2} \end{bmatrix}$$

Each element in the left hand side of the Jacobian matrix represents a 4x4 coupled matrix where F and D represent the flow in the X direction; G and C represent the flow in the Y direction; and H and B represents the flow in the Z direction. Each R is a 4x1 coupled matrix, representing the residual or result vector. ∂X is a 4x1 primary variable vector, representing $\left[\partial P_{bulk} \quad \partial z_1 \quad \partial z_3 \quad \partial z_4\right]^T$.

Bulk pressure (P_{bulk}), which is the pressure corresponding to unconfined laboratory conditions, is one of the solution variables solved from the discretization of the continuum equations. Flash calculations are performed at the bulk pressure which is obtained from the solution of non-linear conservation equations. Phase properties, such as density and viscosity, are calculated at the pressures of each phase. This procedure requires an iterative solution of the phase properties and the capillary pressures until they converge. Estimated capillary pressure values are used to calculate mole fractions, phase properties and saturations. Then these calculated saturations are used to calculate capillary pressures using the capillary pressure curves. This loop will go on until the solution converges to a tolerance value. A simplified flow diagram of the iterative solution technique is given in Figure 4.

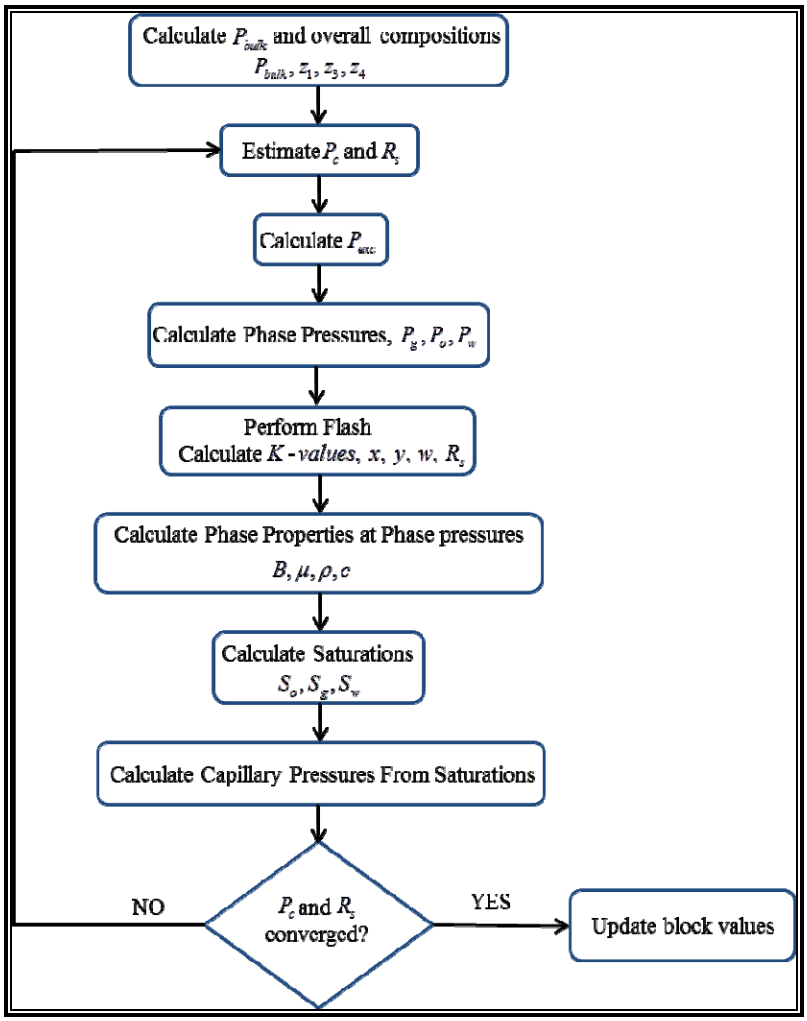

Figure 4: Iterative Solution Technique of COZSim

COZSim uses vertical capillary-gravity equilibrium to calculate initial reservoir pressure, saturation and, composition distributions. Gas-oil and water oil contacts can be defined by user. COZSim is able to implement multiple initializations (different initialization times) for bypassing history matching process. This also allows initializing residual oil zones with imbibition capillary pressure curves. Phase properties are calculated at the pressures of each phase. This method also requires an iterative solution similar to the procedure given in Figure 4. First, initial saturations are calculated from capillary pressure curves. Using these initial saturations, capillary pressure values, fluid properties, mole fractions and saturations are updated. This iteration continues until reaching a convergence.

Figure 5 shows general flow chart of the simulator modules.

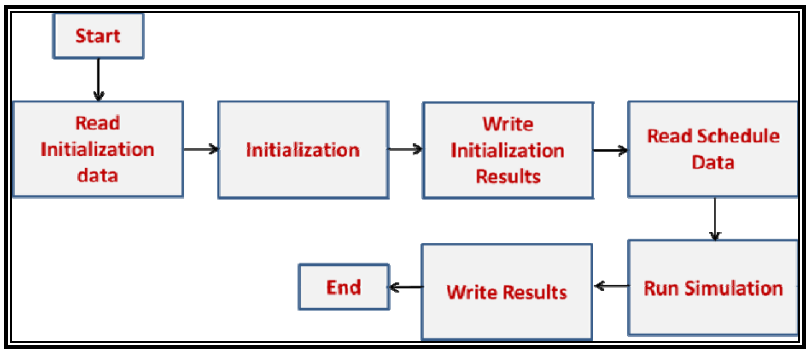

Figure 5: General Flow Chart of Simulator Modules

Figure 6 shows the general flow diagram of the simulation module. First item in the flow chart includes the iterative procedure given in Figure 4 to calculate block properties. Convergence criteria include pressure, overall mole fractions and material balance along with the convergence criteria of the linear solver. COZSim calculates time-step sizes automatically with an algorithm based on the convergence of previous time step. The current maximum time-step size defaults to monthly.

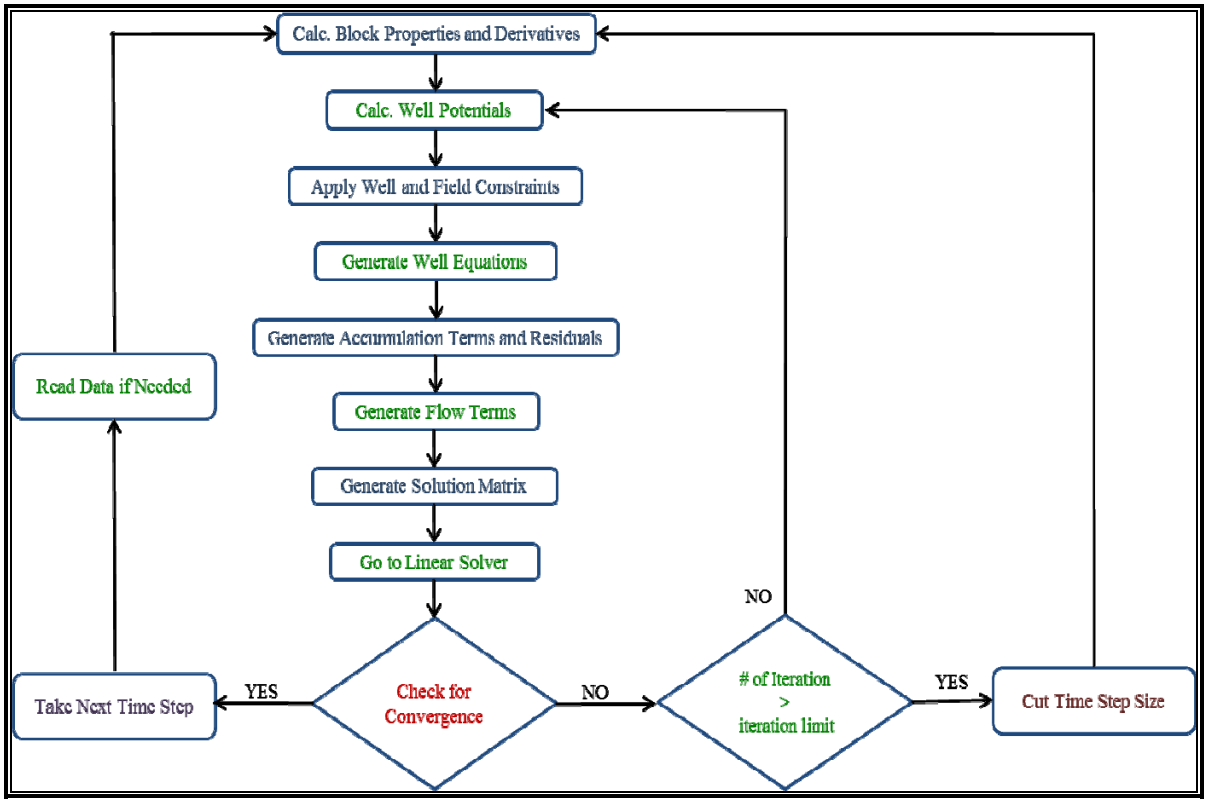

Figure 6: General Flow Diagram for Simulation Module

Special Simulator Functionalities

Miscibility and Viscous Fingering

Miscible flooding may create an unstable frontal advance due to viscous fingering or gravity over-riding because of the unfavorable viscosity and density ratio between the solvent (CO_2) and the oil. Accurate characterization of displacement processes requires describing unstable flood front formed by physical dispersion. Simulators which assume that solvent and oil are completely mixed within a grid block such as compositional simulators, give optimistic displacement results for coarsely gridded models. Using finely gridded models may provide more realistic results; on the other hand, it may be impractical for modeling full-scale miscible flooding projects.

If the CO_2 displaced zone is large with respect to grid size block, oil and solvent can be treated as completely mixed in the grid block. If the CO_2 displaced zone is very small with respect to size of grid block, oil and solvent can be considered completely segregated as pure components and no mixing occurs. Generally, the actual fluid behavior is somewhere between the two mixing limits, which correspond to partial mixing. Todd and Longstaff [8] proposed an empirical model to include viscous fingering effects for coarsely gridded models assuming partial mixing of solvent and oil. The Todd and Longstaff model is based on modification of classical black oil type properties such as relative permeabilities, densities and viscosities with a constant user-defined mixing parameter.

COZSim uses a viscous fingering model based on the interfacial tension function rather than using a constant mixing parameter proposed by Todd-Longstaff. Effective viscosities of the oil and solvent system are calculated from their immiscible viscosity values as following:

$$\mu_{oe} = \mu_o^{1-f(\sigma)} \mu_m^{f(\sigma)} \tag{6}$$

and

$$\mu_{se} = \mu_s^{1-f(\sigma)} \mu_m^{f(\sigma)} \tag{7}$$

Where

$$\mu_m = \mu_o \mu_s \Big/ \left(\frac{S_g \mu_o^{1/4} + S_o \mu_s^{1/4}}{S_o + S_g} \right)^4 \tag{8}$$

where μ_m is viscosity of the mixture and $f(\sigma)$ is the mixing parameter function. $f(\sigma)$ represents a channeling function to impose partial or full mixing within a grid. It is calculated internally. $f(\sigma)$ is a function of pressure, molar densities, parachors and mole fraction of components. A value of $f(\sigma)$ =1 corresponds to full mixing of solvent and oil within a grid block and it results a piston like displacement. $f(\sigma)$ =0 corresponds to negligible mixing or negligible dispersion similar to immiscible displacement. Partial mixing is represented by values of 0< $f(\sigma)$ <1. In this case, effective viscosity of the solvent will be less than the effective viscosity of oil, hence, solvent will travel faster than oil and create viscous fingers.

COZSim predicts miscibility using interfacial tension based on Macleod-Sugden[9] correlation between the two phases. The interfacial tension between the oil and gas phases is used to measure how miscible the two fluids are. Miscibility occurs when the interfacial tension between the two phases drops to zero. Relative permeabilities and capillary pressures are interpolated as functions of interfacial tension between immiscible and miscible values. The Macleod-Sugden correlation is used to calculate interfacial tension as following:

$$\sigma = \left[\sum_{i=1}^{4} P_i \left(\rho_o x_i - \rho_g y_i \right) \right]^4 \tag{9}$$

where x_i and y_i are the liquid and gas mole fractions, ρ_o and ρ_g oleic and gaseous phase molar densities and P_i is the parachors of the i^{th} component. Parachor value for oil component is calculated from:

$$P_2 = 18.824 + 3.0453 MW_{C_{5+}} \tag{10}$$

where $MW_{C_{5+}}$ is C_{5+} oil molecular weight and it is estimated from the API value of oil by using Lasater[10] correlation:

$$MW_{C_{5+}} = \left(\frac{7864.9}{API} \right)^{1/1.0386} \tag{11}$$

Gas parachor value:

$$P_g = 18.824 + 3.0453 \times MW_g \tag{12}$$

where gas molecular weight:

$$MW_g = SG_g \times \rho_{air}^{sc} \times \rho_g^{sc} \tag{13}$$

PVT and Flash Calculations

The fluid data required by COZSim is in black-oil format and it is converted to compositional form internally. This procedure consists of the calculation of overall mole fractions and mole fractions for each component. As an example, calculation of overall mole fraction of oil component from black oil data for initialization:

$$z_2 = \left(\frac{S_o}{B_o \rho_o^{sc}}\right) \Bigg/ \left(\frac{S_a}{B_a \rho_w^{sc}} + \frac{S_o}{B_o \rho_o^{sc}} + \frac{S_g}{B_g \rho_g^{sc}}\right) \tag{14}$$

Mole fraction of oil component in oleic phase:

$$x_2 = 1 \Bigg/ \left(1 + R_{sa} \frac{\rho_o^{sc}}{\rho_g^{sc}}\right) \tag{15}$$

COZSim does not use fugacity constraints, equation of state based flash procedure or table lookup *K-values*. Equilibrium *K-values* used in COZSim are defined as:

$$K_{o,3} = \frac{y_3}{x_3} \qquad K_{w,3} = \frac{y_3}{w_3}$$

$$K_{o,4} = \frac{y_4}{x_4} \qquad K_{w,4} = \frac{y_4}{w_4}$$

K-values are calculated internally using solution gas-oil ratio, solution gas-water ratio and molar density of the phases. The following is an example calculation of equilibrium *K-values* for the oleic phase with hydrocarbon gas.

$$K_{o,3} = \frac{1 + R_{so,3}^m}{R_{so,3}^m} \tag{16}$$

where

$$R_{so,3}^m = R_{so,3} \frac{\rho_o^{sc}}{\rho_g^{sc}} \tag{17}$$

$R_{so,3}$ is solution hydrocarbon gas – oil ratio; ρ_o^{sc} and ρ_g^{sc} densities of oleic and gaseous phase pressures at standard pressure and temperature conditions, respectively. $R_{so,3}^m$ is molar solution

gas – oil ratio. *K-values* are calculated using the R_s tables calculated with built-in correlations[11] and it is able to model variable saturation pressure cases.

CO_2 Correlations

The most important mechanisms of a CO_2-oil displacement process are the oil viscosity reduction and the oil swelling which are results of CO_2 solubility in oil. Therefore, it is important to calculate CO_2 solubility effects in the simulation model. CO_2 – oil solubility, oil swelling factor and CO_2-oil mixture viscosity is calculated using genetic algorithm-based correlations. [12] This model is a generalized approach and gives more accurate predictions than conventional correlations which are limited by data ranges and conditions. Genetic algorithm-based correlations are universal and can be used to predict the effect of CO_2 for both dead oil and live oil properties. Table 2 gives the solubility related parameters and input variables that are used to calculate those parameters.

Table 2: Parameters and Variables Related to CO2 Solubility

Parameter	Input Variables
CO_2 Solubility	Saturation Pressure, Temperature, Oil Gravity, Oil Molecular Weight, CO_2 Liquefaction Pressure
CO_2-Oil Mixture Viscosity	Initial Oil Viscosity, CO_2 Solubility, Saturation Pressure, Temperature, Oil Specific Gravity
Oil Swelling Factor	Oil Molecular Size, CO_2 Solubility

Water – hydrocarbon gas solubility [13], water – hydrocarbon gas solubility salinity correction [14], water formation volume factor for saturated conditions [13,14] is calculated with built-in correlations. Density, *z* factor and viscosity of pure CO_2 are also calculated internally. [12]

Two & Three Phase Relative Permeability

COZView/COZSim uses Corey-type two phase imbibition and drainage relative permeability curves. Modified Stone's second method[15] is used for 3 phase oil permeability model. Modified Stone's second method version in COZSim is defined as:

$$k_{ro} = k_{rocw}\left[\left(\frac{k_{row}}{k_{rocw}} + k_{rw}\right)\left(\frac{k_{rog}}{k_{rocw}} + k_{rg}\right) - k_{rw} - k_{rg}\right] \tag{18}$$

where k_{rog} is oil relative permeability for an oil, gas and connate water system, k_{row} is oil relative permeability for a system with oil and water only.

Nomenclature

x_i	=	Mole fraction of i^{th} component in oleic phase
y_i	=	Mole fraction of i^{th} component in gaseous phase
w_i	=	Mole fraction of i^{th} component in aqueous phase
z_i	=	Overall mole fraction of i^{th} component
t	=	time
k	=	Absolute permeability
D	=	Depth
S	=	Saturation
S_{orm}	=	Residual oil saturation to miscible flooding
ρ	=	Molar density
ρ_t	=	Molar density of a phase
k_{rn}	=	Relative permeability of phase n
P_{bulk}	=	Bulk pressure
P_{exc}	=	Excess pressure
R_{sn}	=	Solution oil-gas ratio of phase n
P_c	=	Capillary pressure
P_i	=	Parachors of i^{th} component
K	=	K-value
B	=	Formation volume factor
k_{rocw}	=	oil relative permeability in the presence of connate water only
σ	=	Interfacial tension
μ	=	viscosity
γ	=	Specific gravity
λ	=	Mobility

Sub/Superscripts

o	=	Oleic
a	=	Aqueous
g	=	Gaseous

s = Solvent
e = Effective
m = Mixture
sc = Standard conditions

3D Visualization Module

The 3D Visualization Module development was carried out in parallel with development of the other software modules. 3D visualization is a key functionality in the building of various data parameters for the simulation model and in visualization and analysis of the resulting simulation runs. Current software technology in the form of OpenGL was used in developing the 3D visualization in COZView.

3D visualization includes creation of the structural surface for the reservoir through an interactive process, 3D display of the reservoir properties (structure, porosity, permeability, thickness) on a layer by layer basis, and display of a wide array of simulation results at various points in time during the simulation (pressure, oil, water and gas saturation, CO_2 concentration, miscibility index). All 3D displays allow the user to carry out typical pan, zoom and rotate actions interactively with mouse controls. Additional 3D functionality, includes

- display a property value in any simulation cell with a simple pick command with the mouse;
- creation of fence diagrams of any simulation array result;
- tabular display of any simulation array result and the ability to export the array values to a file;
- selection of individual layer simulation array results;
- user modification of color range scales, wellbore and well name colors and font sizes, and maximum and minimum parameter values on all displays; and
- selection of items to be shown (grid, wells, structure contours, perforations, faults) on any display.

All 3D views provide for saving of the display to a bitmap or the clipboard for use in reports and presentations. 3D displays of simulation results are shown below for a stratigraphic reservoir with

an initial gas cap and aquifer where crestal CO_2 injection is being simulated, Figure 7, Figure 8, and Figure 9.

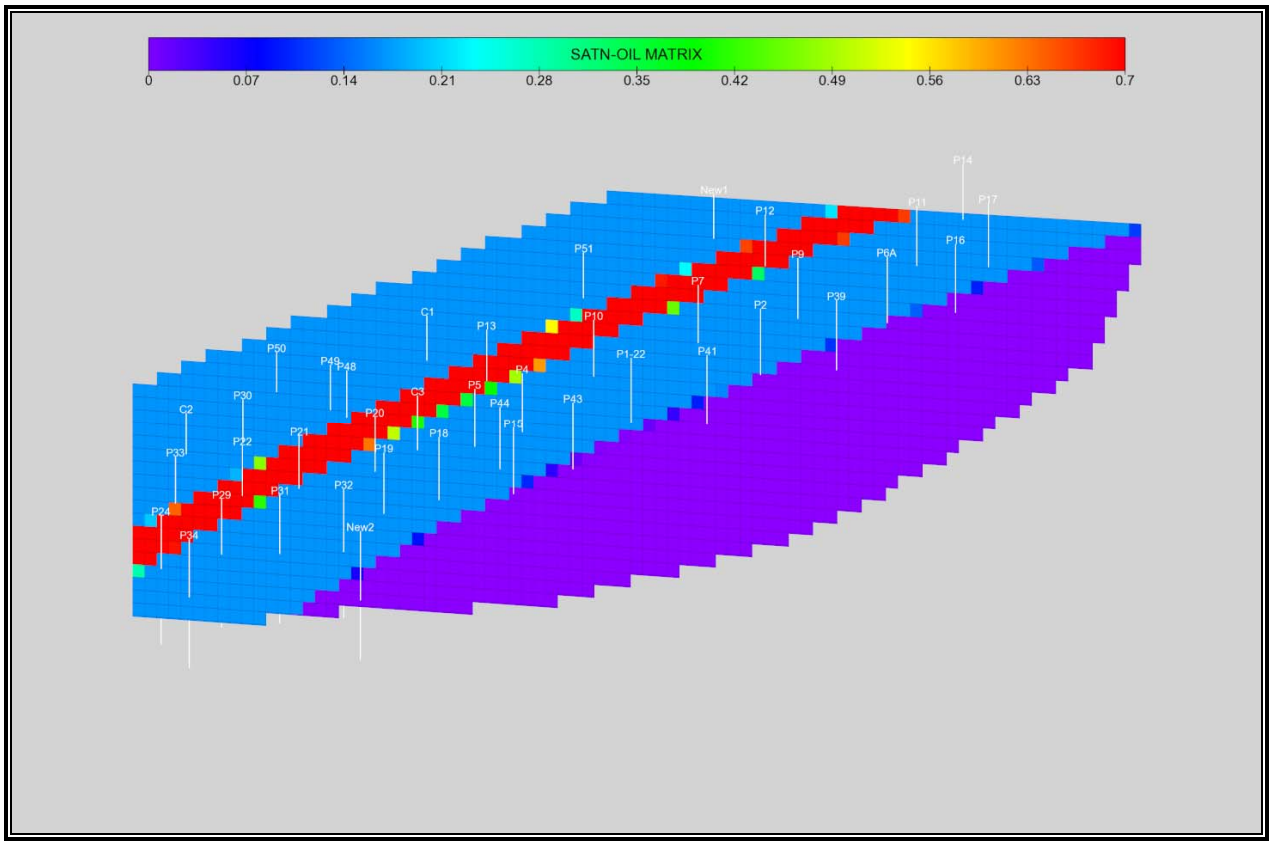

Figure 7: Field-wide Oil Saturation Array with Wells

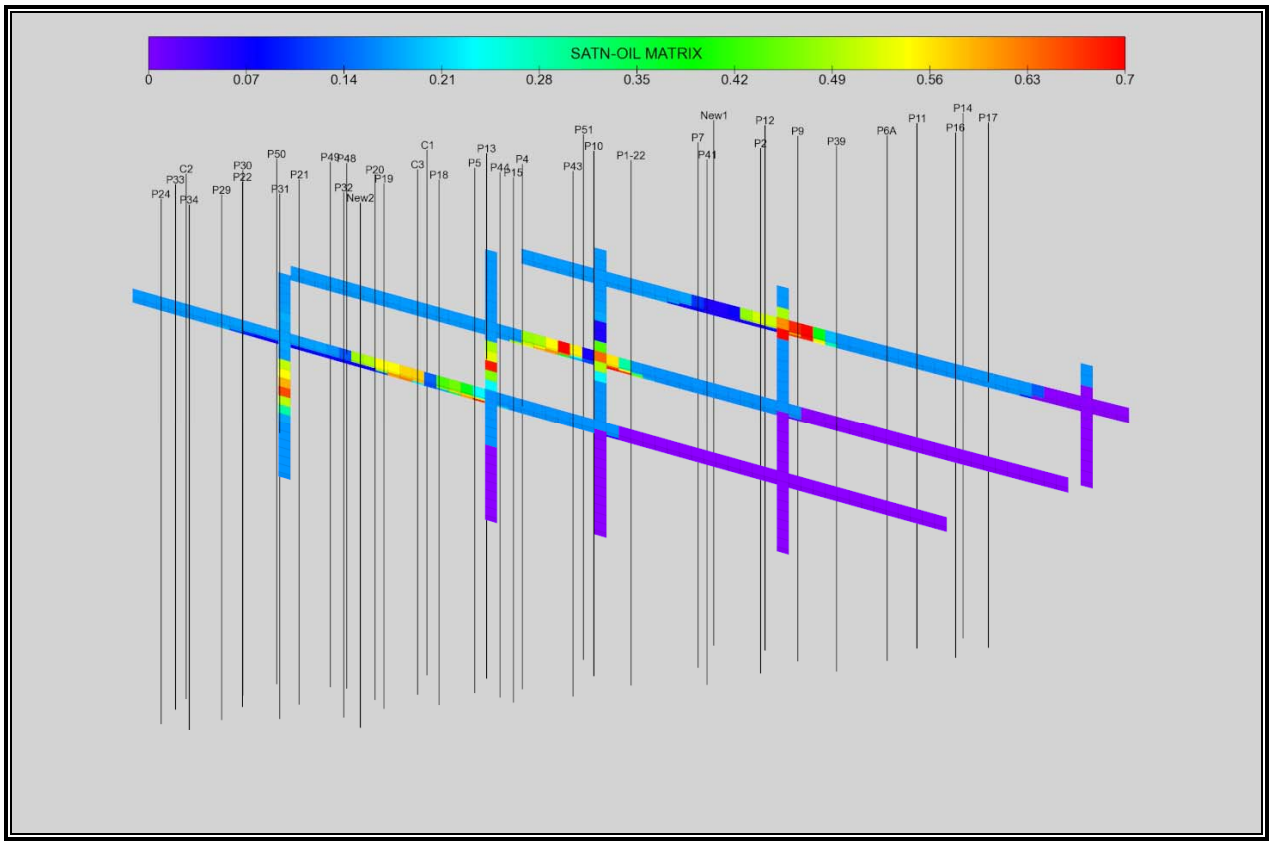

Figure 8: Fence Diagram, Oil Saturation with Wells

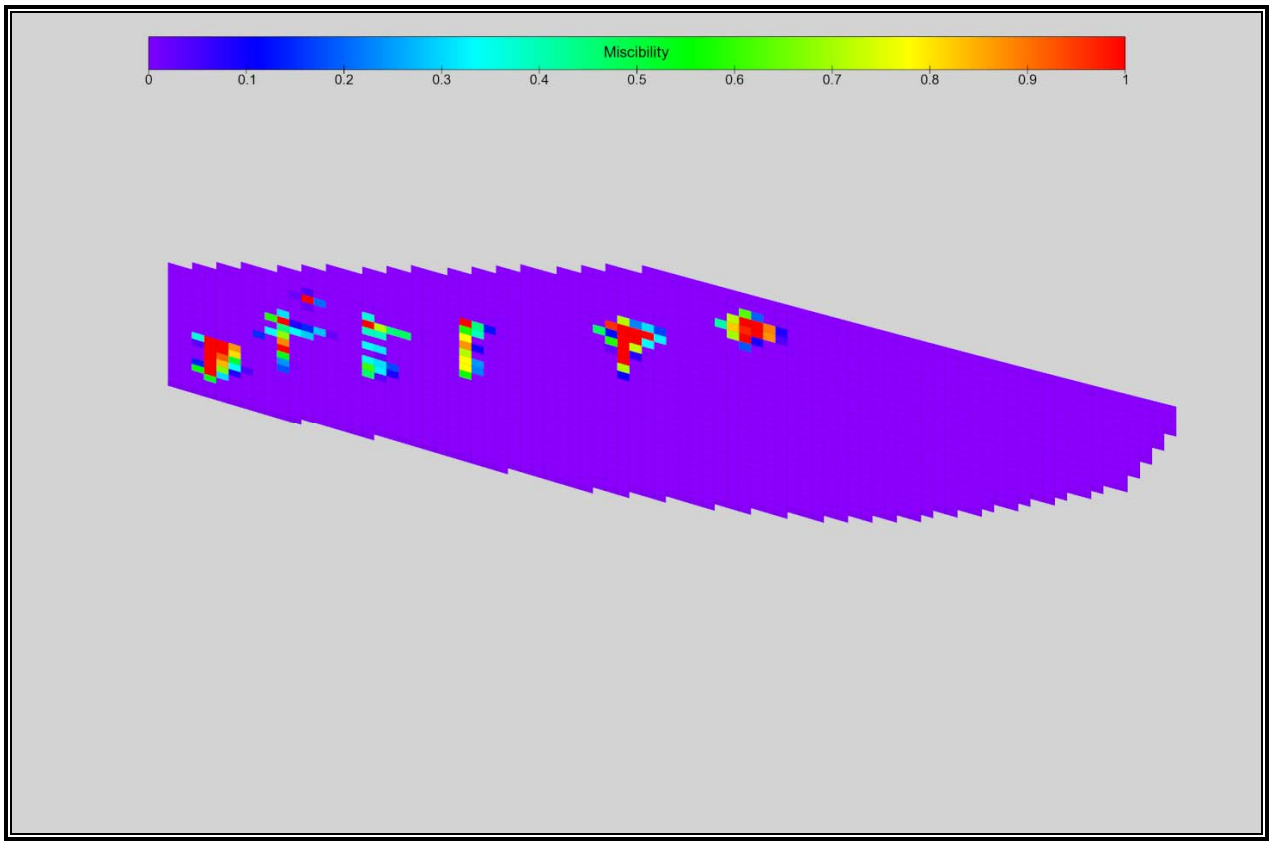

Figure 9: Field-wide Miscibility Index

While not 3D visualization, during this development NITEC added various 2D plot capabilities. These include field and well performance-time plots (production and injection) for rates and cumulatives, as well as in-place-volumes over the life of the simulation run. Multiple cases can be displayed on the same plots to facilitate comparison of different simulated scenarios.

Optimization Module

The process of evaluating a reservoir for its CO_2-EOR potential requires knowledge, or reasonable assumptions, about a large amount of data. COZView/COZSim has attempted to simplify the model building process, while not seriously impacting the efficacy of the model and the physical rigorousness of the simulation itself. As the ultimate intent of the software is to evaluate the best solution for exploitation of a reservoir using CO_2 injection, it was felt that functionality to sift through many of the operational variables and optimize the simulation results was needed.

Certain ANN (artificial neural network), AI (artificial intelligence) and genetic algorithm processes, successfully employed in NITEC's proprietary simulation history matching technology, were utilized in this software. This approach calculates the Net Present Value (NPV) of a series of simulation runs that are created by the optimization functionality. NPV is calculated based on detailed economic parameters inputs by the user. (This ability to calculate NPV can also be used on a run by run basis independent of the optimization process.)

The economic parameters that can be specified by the user are shown in Figure 10.

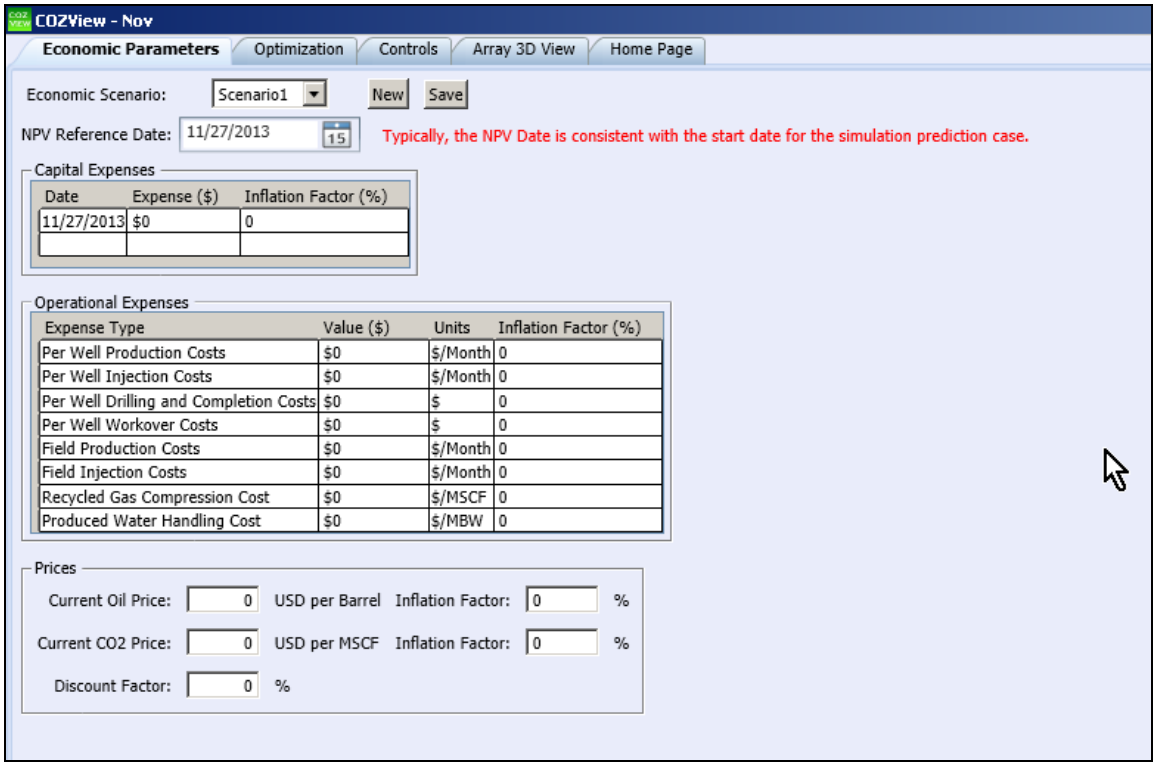

Figure 10: Economic Parameter Screen

While the objective function in the optimization process is NPV, the variables being changed are field level or facility constraints. The possible field or facility constraints are shown in Figure 11. These can be changed by the user over the life of the simulation run as may be appropriate.

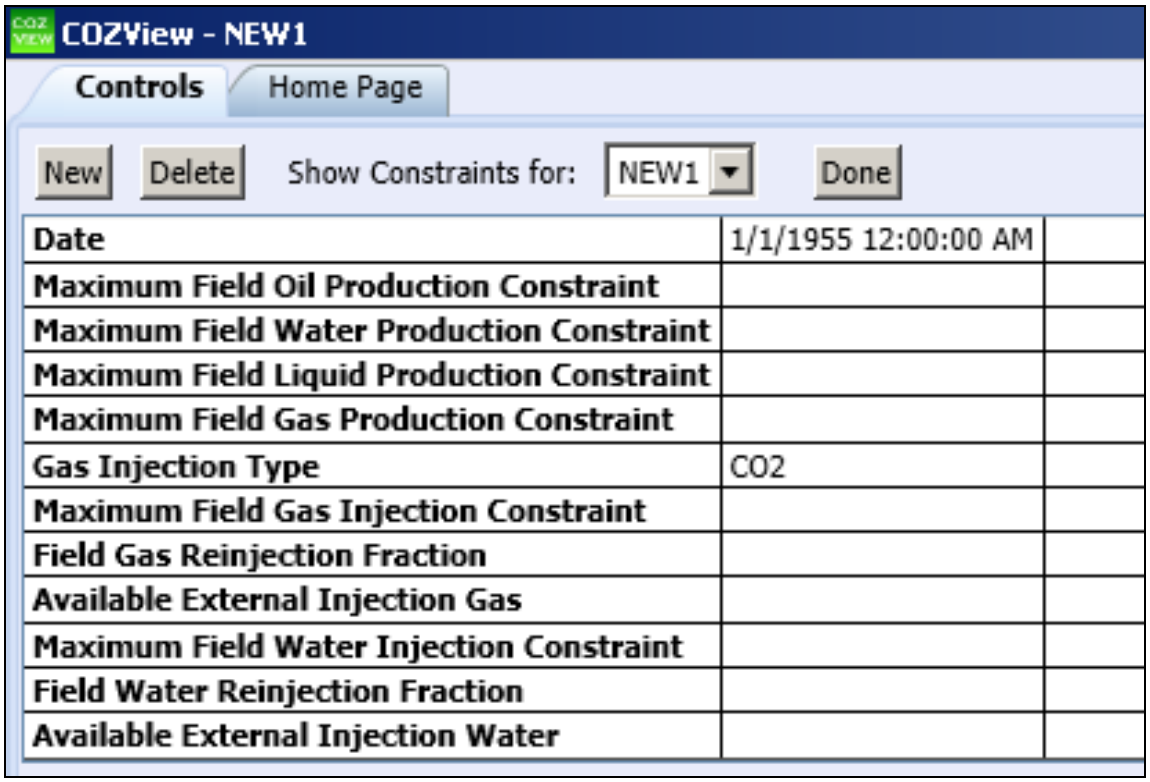

Figure 11: Field/Facility Controls Screen

The optimization functionality allows the user to investigate up to 7 of these parameters in an optimization sequence of simulation runs. In the optimization setup screen (Figure 12), the user has specified 3 field/facility constraints to investigate and the range of values that will be used in the process for each parameter.

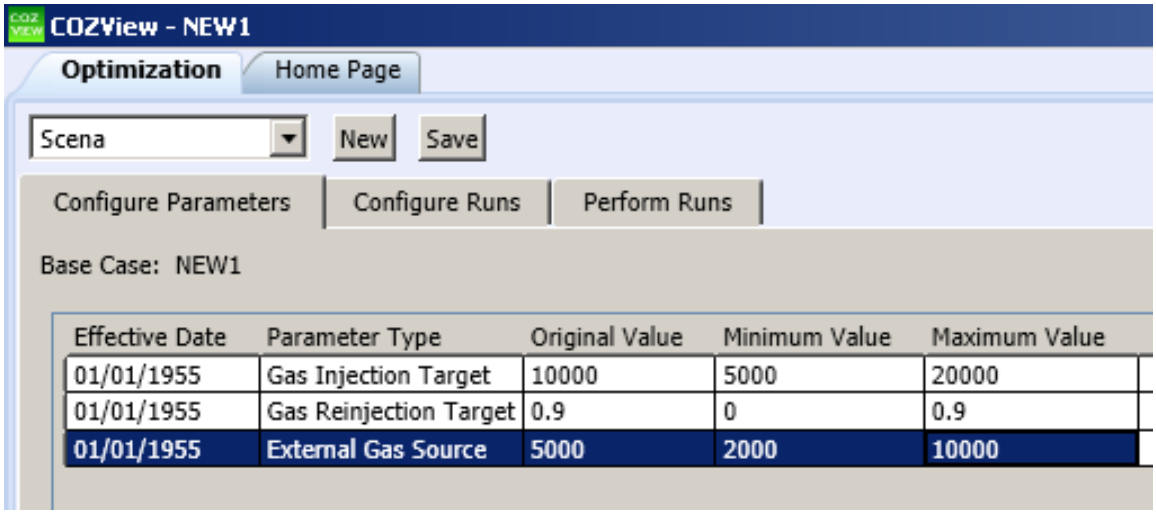

Figure 12: Optimization Parameter Configuration Screen

The optimization process makes a series of full simulation runs over the time period specified by the user. Each simulation runs is created (combination of the field/facility parameters being investigated) based on a unique combination of ANN, AI and genetic algorithm processes. Each simulation run made in the process is displayed (NPV) in graphical and tabular format. Sorting of the results by NPV provides the best solution and the associated combination of field/facility parameters. See Figure 13 below.

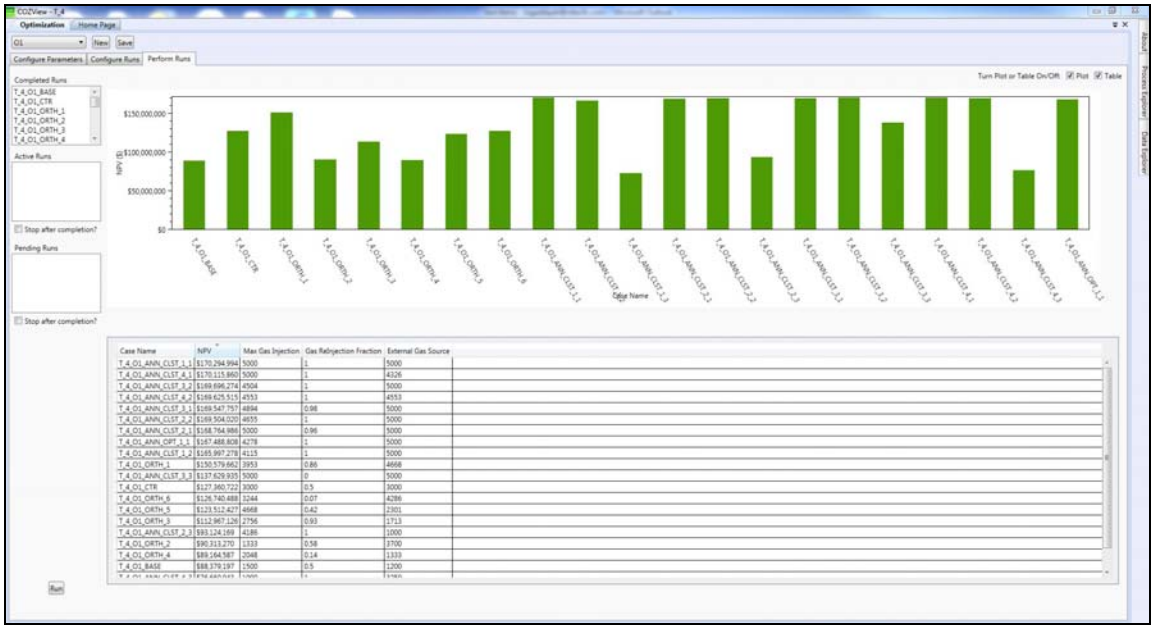

Figure 13: Optimization Results Screen

The process can utilize multiple CPUs, based on the user's specification, to speed the processing of all simulation runs some of which can run simultaneously. Once the user has developed an appropriate base simulation case, this optimization functionality can be used to make numerous runs in a relatively short time period subject to overall run times, CPU power, and the number of field/facility parameters being investigated. The number of simulation runs that the process plans to make is displayed for the user prior to launching the process. The number of simulation runs is based on the number of field/facility parameters being investigated.

User Manual

A comprehensive User Manual was prepared. It is provided as both a pdf file which can be downloaded by the user and via an interactive HELP functionality in COZView itself. The User Manual is provided in the Appendices.

An Installation Guide is also provided on NITEC's website to assist users in the installation process. The Installation Guide is provided in the Appendices.

Tutorials

Six tutorials were prepared to describe various capabilities of the software. The tutorials provide a description of the simulation model, expected results, and various screen shots to guide the user through the model building process. These tutorials are summarized as follows:

#1	40acre, 5-spot pattern, Soi=1-Swirr, continuous CO_2injection
#1-1	40acre, 5-spot pattern, Soi=Sorw, continuous CO_2 injection
#1-2	40acre, 5-spot pattern, 1-Swirr>Soi>Sorw, continuous CO_2 injection
#2	Full field, stratigraphic reservoir, crestal CO_2 injection
#3	Full field, anticline, pattern CO_2 injection
#4	40acre, 5-spot pattern, Soi=1-Swirr, continuous CO_2 injection, optimization

The tutorials are included in the Appendices.

Technology Transfer

Technology transfer was to be carried out by one major industry conference and two user forums. NITEC exceeded these requirements. The following presentations and user forums (workshops) were conducted.

Presentation: **"Investigating ROZ Exploitation with COZSim",** CO_2 Flooding Conference, Midland, TX, December 7, 2012.

Presentation: **"Investigating ROZ Exploitation with COZSim",** Wyoming Enhanced Oil Recovery Institute's Tensleep III-ROZ EOR in the Bighorn Basin Tensleep Workshop, Casper, WY, July 11, 2013.

Presentation: **"Frannie Tensleep in COZ",** Wyoming Enhanced Oil Recovery Institute's 7th Annual Wyoming CO_2 Conference, Casper, WY, July 13, 2013.

Workshop: **"COZ - New Reservoir Simulation Software Designed to Aid Smaller Operators in Conducting More Rigorous Reservoir Studies",** PTTC Workshop, Denver, CO, November 7, 2013.

Workshop: **"COZ - New Reservoir Simulation Software Designed to Aid Smaller Operators in Conducting More Rigorous Reservoir Studies",** PTTC Workshop, Tulsa OK, November 19, 2013.

Participant feedback from the two Workshops was summarized by PTTC and is provided below.

Workshop Summary
Petroleum Technology Transfer Council
Rocky Mountain Region

Name: COZ - New Reservoir Simulation Software Designed to Aid Smaller Operators in Conducting More Rigorous Reservoir Studies
Date: November 7, 2013
Location: Golden, CO
Instructor: Bill Savage, NiTec
Fee: $130
Attendees: 16
Synopsis:

DOE-NETL has recently funded development of a new PC-based reservoir simulator by Denver based reservoir engineering firm, NITEC LLC. The user focus was on small to mid-size operators who may have limited simulation expertise in-house or who may not wish to deal with the cost of commercial simulation software. The simulator was to also focus on application to CO2-EOR field problems in a timely manner. The software (COZ) was released to the public, free of charge in February 2013 and can be downloaded from NITEC's website (www.nitecllc.com).

This workshop will lead the attendees through the process of building a simulation model, submitting prediction cases and evaluating the simulation results. While there are many features to ease the process of simulating CO2-EOR, the finite difference, 4-component, compositional simulator can also handle more conventional reservoir exploitation process – primary depletion, water injection, and hydrocarbon gas injection at the well, pattern or field levels. The software has been validated against other commercial compositional simulation software. The user interface, complete with graphical plots and 3D displays, is focused on setting up the prediction cases.

Assessment:

Attendees were happy with the workshop. May pursue more workshops in the future as the software capabilities expand.

Tabulation of Evaluation Forms Completed by Participants

How did you hear about workshop? Percent responding:

NiTec	PTTC Newsletter	Colleague	Website	Email	Other (postcard)
8%	33%	25%	8%	17%	8%

Registration fee. Percent responding:

Too High	About Right	Too Low
0.0%	100.0%	0.0%

Was the workshop worth your time?

Yes	No
92%	8%

Rank the Instructor: Scale 1=Poor, 2-Fair, 3=Satisfactory, 4=Good, 5=Excellent, Average for each category:

Instructor Name: Bill Savage

Overall Presentation	Quality of Information	Q&A Opportunities
4.3	4.4	4.5

Will you be able to use the information? Percent responding:

Immediately	Future	Never
64.0%	18.0%	18.0%

Before this workshop, had you heard of PTTC? Percent responding:

Yes	No
82%	18%

Written Responses from Evaluation Forms

What was the most valuable part of the workshop?
Seeing the model run; going through he steps of running the simulator
Just learning the basics of putting together a reservoir model was very much worth my time
Taking the time to wak through the process and helpful hints.
Addressing CO2 EOR
Learning about COZ – this is great simulator at a reasonable price
Data entry
General outline of program
Running the simulator
To have a general understanding on reservoir modeling packages available.
Concepts and introduction to modeling for EOR

What was the least valuable part of the workshop?
The points in the lecture which described modules within the software. I find it more useful to simply run through the modules rather than talk about them
2) Waterflood examples
We are a non-conventional company. Some of the CO2 stuff are new concepts

Are there other courses or topics you would suggest PTTC Address?
Inexpensive log analysis for small operators
PVT
Decline Curve analysis
Shale oil topics
Basic Petroleum Engineering for Non Engineers

Additional comments:
This was an excellent course!
Very thorough, great examples, Thank you!
Great job
Would be nice to have hands on practice
Thanks! Let me know when the un-conventional CO2 version is available (Australian guy)

Workshop Summary
Petroleum Technology Transfer Council
Mid-Continent Region

Name: COZ - New Reservoir Simulation Software Designed to Aid Smaller Operators in Conducting More Rigorous Reservoir Studies
Date: November 19, 2013
Location: Tulsa, OK
Instructor: Bill Savage, NITEC
Fee: $150
Attendees: 16
Synopsis:

DOE-NETL has recently funded development of a new PC-based reservoir simulator by Denver based reservoir engineering firm, NITEC LLC. The user focus was on small to mid-size operators who may have limited simulation expertise in-house or who may not wish to deal with the cost of commercial simulation software. The simulator was to also focus on application to CO2-EOR field problems in a timely manner. The software (COZ) was released to the public, free of charge in February 2013 and can be downloaded from NITEC's website (www.nitecllc.com).

This workshop will lead the attendees through the process of building a simulation model, submitting prediction cases and evaluating the simulation results. While there are many features to ease the process of simulating CO2-EOR, the finite difference, 4-component, compositional simulator can also handle more conventional reservoir exploitation process – primary depletion, water injection, and hydrocarbon gas injection at the well, pattern or field levels. The software has been validated against other commercial compositional simulation software. The user interface, complete with graphical plots and 3D displays, is focused on setting up the prediction cases.

Assessment:

Overall attendees were happy with the content of the workshop. Many shared interest in learning more about applications of the software and learning more about how it can be used in their operations.

Tabulation of Evaluation Forms Completed by Participants

Participants were asked to rate various elements of this workshop rating each element on a scale of 1 – 5, one being the least satisfied to five being the most satisfied. 100% of the participants responded with the following percentage of results:

	1	2	3	4	5
• Onsite Check-in	0%	0%	6%	46%	48%
• Workshop Format	0%	0%	6%	46%	48%
• Workshop Content/Topics	0%	0%	6%	40%	54%
• Expertise of Presenter	0%	0%	6%	13%	81%
• Presentation Techniques	0%	0%	6%	26%	68%
• Timeliness of Material	0%	6%	6%	26%	62%
• Use of Practicle Examples	0%	0%	6%	20%	74%
• Your Learning Experience	0%	0%	0%	33%	67%
• Timing of Event	0%	0%	20%	20%	60%
• Value of Workshop	0%	0%	0%	26%	72%
• Workshop Location	0%	0%	0%	26%	72%
• Workshop Facility	0%	0%	6%	26%	68%

• Food	0%	6%	33%	20%	61%
• Parking	0%	0%	0%	26%	74%

Written Responses from Evaluation Forms

Provide any additional suggestions or comments that you would believe would help improve this workshop in the future:

Great Job
Possibly some more hands on work through use of our own computers or computers provided
More hands-on simulation
Would have helped to work on own projector/PC. Would require more time but would be worth it. Hard to see projection on wall.

In addition, NITEC promoted the software via posters and information handouts in its exhibit booth at the 2012 SPE ATCE (Annual Technical Conference & Exhibition) in San Antonio (September 2012) and the 2013 ATCE in New Orleans (September 2013). ATCE attendance is typically in excess of 3000 each year.

NITEC has provided ongoing user support to individuals/companies who have downloaded the "free" software from NITEC's website since February 28, 2013. This has been done at no cost to DOE project.

Case Study

The software was exercised in a Case Study by Linc Energy Petroleum Wyoming of Casper, WY. They conducted a simulation study of their Cole Creek South Field in Converse County, Wyoming. The field is a candidate for CO_2-EOR. The Linc engineer worked with NITEC to perform the study and provided valuable user comments to improve its functionality.

Conclusions from the Case Study were:

1. This Case Study was initiated on January 20, 2013 and completed on April 8; approximately 2.5 months of elapsed time. Work was carried out in conjunction with numerous other operational tasks for the Linc Energy engineer during the period.
2. The study indicates that the reservoir is a strong candidate for CO_2-EOR, subject to all of the operational and economic assumptions made.
3. The study indicated that a number of operational modifications to the final plan (number of new wells, new well locations, use of water injection for re-pressuring, etc.) may warrant further investigation.
4. The belief that natural fractures are present in the reservoir and have an impact on the total permeability warrants field injectivity tests and a possible small pilot. Should the fractures dominate the movement of CO_2 in the reservoir more so than the model has shown, a dual porosity simulation model should be investigated.
5. During the Case Study a number of small, but important, errors or incorrect calculations were found and corrected in COZView and COZSim. Hence, the Cast Study provided further useful testing of the software.

The Case Study report is provided in the Appendices.

File Management

Numerous files are generated during the process of building a model and simulating performance. Generally, the user does not have to be concerned with these files. Each file contains the project name followed by the case name. A suffix identifies the file type. The project data is stored in an SQL database (.mdf). The simulation input (ASCII format) is a .COZdat file. The simulation results output (ASCII format) is a .COZOUT file. The .COZOUTMAP and .COZOUTPLT files contain simulation array and well/field performance results.

As discussed in the User Manual, access to the .COZdat and .COZOUT files may be useful once the user becomes comfortable with creating models, simulating performance and analyzing results.

Sharing of the simulation model files (.mdf and associated files) with other users on other computers may be useful at some point in a study. These files **cannot** merely be copied from one computer to another. NITEC developed a small utility program (COZ Project Utility) which is

provided with the installation that allows the user to consolidate appropriate project files into a "moveable" format. This .cvsf file can be emailed or passed between computers easily. The same utility program can be used to return the project files to a format compatible with the COZ software.

Additional file management utilities are provided on the COZView Home page. These include

New Project

(Create a new project)

Open Project

(Open a prior project which is not shown in the Home page *Recent Projects* list.)

Clean Project

(Option to delete prior case and/or simulation result files for existing project, but retain the project input data.)

Save Project As

(Create a duplicate of a project with a new name; options to retain prior simulation result files or delete prior simulation results files.)

Delete Project

(Delete a project and all associated files.)

Deliverables

- Interactive pre and post processor for simulator (COZView) (executable code)
- Fully implicit, 3-dimensional, 4-component reservoir simulator (COZSim) (executable code)
- Installation Guide
    - Available from download site - www.nitecllc.com
- User Manual
    - Available from download site - www.nitecllc.com
- Tutorial Examples (6)
    - Available from download site - www.nitecllc.com
- Case Study Report
- COZSim Validation Exercise Paper
- COZSim White Paper

  - Available from download site - www.nitecllc.com
- Forum Presentations (3)
- User Workshops (2)
- Distribution mechanism (not a contractual requirement)
  - Download site – www.nitecllc.com

Conclusions

The following conclusions have resulted from this project:

- The software was delivered to DOE as required by the contract.
- All contract obligations were fulfilled within the original approved budget.
- The software functionality exceeded the contract requirements.
- NITEC is distributing the software at no cost to DOE (not a contract requirement).
- NITEC is providing installation support and application support at no cost to DOE (not a contract requirement).
- A significant number of users have downloaded the software in the first 8.5 months of its availability.

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APPENDICES

Appendix 1 – COZView Data Input Requirements List

Appendix 2 – COZView/COZSim Nomenclature

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APPENDIX 1

COZView Data Input Requirements List

COZView Data Input Requirements List

		Units	User Value	Defaults	Comments
	PROJECT NAME	Alphanumeric(no spaces)			
	Field Structural Model				
	Layer Name	Alphanumeric			
	Structural Surface	feet or meters			
	Area of Interest Coordinates - X,Y	feet or meters			
	No. Layers			1	
	Gross Thickness for each layer	feet or meters			
	Fault location(s)				
	Well Locations - X,Y	feet or meters			
	Formation/Layer Properties				
	Layers	integer		1	
	Net Thickness equals Gross thickness	feet or meters			
	Net to Gross Thickness Ratio	fraction		1	
	Average Porosity	fraction or percent		0.2	
	Average Horizontal Permeability Y-direction	md or D		50	
	Average Horizontal Permeability X-direction	md or D		50	
	Average Verical Permeability, md or D	md or D		5	
	Rock compressibility	E-06/psi		4	
	PVT				
	PVT Table Name	Alphanumeric			
	Gas Specific Gravity	fraction or percent		0.855	
	Oil API	degrees		40.7	
	Water Salinity	ppm		45000	
	Reservoir Temperature	degrees F		220	
	Table Minimum Pressure	psia		14.7	
	Table Maximum Pressure	psia		4000	

		Units	User Value	Defaults	Comments
Saturation Functions					
	Rock Table Name	Alphanumeric			
	Fluid System Type - **gas/water** or **gas/oil/water**				
	Lambda			10	
	Irreducible Water Saturation (Swir)	fraction		0.3	
	Residual Oil Saturation to Water (Sorw)	fraction		0.3	
	Kromax	fraction		0.623	
	Water/oil Capillary Pressure Entry Pressure	psia		0	
	PTZEROWO	psia		NA	
	Critical Gas saturation (Sgc)	fraction		0.05	
	Residual Oil saturation to Gas (Sorg)	fraction		0.3	
	Residual Oil saturation to miscible fluid (Sorm)	fraction		0.06	
	Residual Gas Saturation (Sgr)	fraction		0.133	
	Krgmax	fraction		0.623	
	Gas/liquid Capillary Pressure Entry Pressure	psia		0	
	PTZEROGL	psia		NA	
	Number of Data Points in plots			20	
Initialization Data					
	Initialization date (Idate)	mm/dd/year			
	Saturation table to use	Alphanumeric			
	PVT table to use	Alphanumeric			
	Reference elevation	feet or meters			
	Reservoir pressure at reference elevation @Idate	psia			
	Reservoir temperature at reference elevation @Idate	degrees F			
	Elevation of gas-oil contact @Idate	feet or meters			
	Elevation of water-oil contact @Idate	feet or meters			
	Saturation pressure	psia			
Well Data					
	Well X, Y coordinate locations	feet or meters			Not needed if located interactively
	Well completions	Layer no.s		All layers	
	KB Elevation	feet or meters		0	optional
	Total Depth	feet or meters		0	optional

		Units	User Value	Defaults	Comments
Simulation - Predictions					
	Field Operational Controls				
	Maximum Oil Production Rate	STB/D			optional
	Maximum Water Production Rate	STB/D			optional
	Maximum Liquid Production Rate	STB/D			optional
	Maximum Gas Production Rate	MSCF/D			optional
	Maximum Water Injection Rate	STB/D			optional
	Maximum Gas Injection Rate (HC or CO2)	MSCF/D			optional
	Water Re-Injection Fraction	fraction			optional
	Gas Re-Injection Fraction	fraction			optional
	External Gas Injection Rate (HC or CO2)	MSCF/D			optional
	External Water Injection Rate	STB/D			optional
	Type of Gas Injection (HC or CO2)				optional
	Well Operational Controls*				
	Well Type (**Oil, water, gas** or **liquid producer, Water injector, Gas/CO2 injector**)				
	Oil Production Rate	STB/D			
	Water Production Rate	STB/D			
	Gas Production Rate	MSCF/D			
	Liquid Production Rate	MSCF/D			
	Water Injection Rate	STB/D			
	Gas Injection Rate (HC or CO2)	MSCF/D			
	Bottomhole Pressure (BHP)	psia			
	*It is recommended that at least one **production** or **injection rate** and **BHP** be specified for each active well.				

		Units	User Value	Defaults	Comments
	Field Operational Limits				
	Minimum Oil Production Rate	STB/D			optional
	Minimum Gas Production Rate	MSCF/D			optional
	Well Operational Limits**				
	Maximum Water cut	fraction			optional
	Maximum GOR	SCF/STB			optional
	Maximum Water-Gas Ratio	STB/MMSCF			optional
	Minimum Oil Production Rate	STB/D			optional
	Minimum Gas Production Rate	MSCF/D			optional
	Minimum CO2 Production Rate	MSCF/D			optional
	Minimum Water Production Rate	STB/D			optional
	Action to Take if well limit exceeded, **shut-in well or **shut-in responsible completion**				Only if one or some of the above selected

APPENDIX 2

COZView/COZSim Nomenclature

COZView/COZSim Nomenclature

Static Model Structure

Area Boundary: Boundary of simulation model

Scaled Model: Establishes vertical dimension to simulation model

Layer Properties

TVT: True Vertical Thickness

PHI MATRIX: Porosity of the Matrix

KX, KY and KZ MATRIX: Absolute permeabilities in X,Y and Z directions

PVT

Z: Gas compressibility factor

HC: Hydrocarbon

Bo, Bg, Bw: Formation volume factor of oil, gas, and water phase

Viso, Visg, Visw: Viscosities of oil, gas and water

Saturation Functions

Lambda: Pore size distribution index

Swirr: Irreducible Water saturation

Sorw: Residual Oil Saturation to water

KroMax: Maximum relative Permeability to oil

Pewo: Entry pressure on oil-water capillary pressure curve

Ptzerowo: Water saturation value for which Oil-water capillary pressure is zero

Sgc: Critical gas saturation

Sorg: Residual oil saturation to gas

Sorm: Residual oil saturation to miscible CO2

Sgr: Residual gas saturation

KrgMax: Maximum relative permeability to gas

Pegl: Entry pressure on gas-liquid capillary pressure curve

Ptzerogl: Pressure value for which gas-oil capillary pressure is zero

Kr-wo: Water-oil relative permeability curves

Sw: Water saturation

Krw: Water relative permeability

Krodr: Oil relative permeability for drainage

Kroimb: Oil imbibition relative permeability for imbibition

Kr-go: Gas-oil relative permeability

Sl: Liquid saturation

Krgdr: Gas relative permeability for drainage

Krgimb: Gas relative permeability for imbibition

Krog: Gas-oil relative permeability curve

Pcow: Oil-water capillary pressure (drainage)

Pcowi: Oil-water capillary pressure (imbibition)

Pcgo: Gas-oil capillary pressure (drainage)

Pcgoi: Gas-oil capillary pressure (imbibition)

Kr-gw: Gas water relative permeability curves

Pcgw: Gas-water capillary pressure (drainage)

Model Initialization

PSATHCG: Saturation pressure (Bubble point pressure)

GOC: Gas-oil Contact

WOC: Water-oil contact

Well Limits – Prediction

WTR Cut: Fraction of water in the total fluid stream (w/ (o+w))

GOR Max: Maximum gas-oil ratio

WGR Max: Maximum water-gas ratio

WTR: Water

BHP: Bottom hole pressure

Field Limits – Prediction

Reinjection Fraction: Fraction of total field produced phase (gas or water) being reinjected in injection (gas or water) wells

External Injection: Amount of injection phase (gas or water) being supplied (purchased) from outside the field

APPENDIX 3

COZSim Validation Exercise

COZSim Validation Exercise

NITEC prepared this validation exercise at the request of DOE/NETL. The objective was to provide assurance that COZSim results were compatible with other commercial compositional simulators for similar reservoir model datasets.

The following discussions provide confirmation that COZSim results are consistent with two other commercial simulators. Functionality differences between the simulators are also discussed.

I. Model Validation

In this validation exercise, COZSim (4-component, extended black oil simulator) was compared to two commercial compositional simulators ECLIPSE 300 (E300) from Schlumberger and SENSOR from Coats Engineering. A reservoir model was created in COZView and then exported to E300 and SENSOR. Simulations were conducted in all simulators (COZSIM, E300 and SENSOR) for the same set of Initial and operating conditions.

1. Reservoir Model

The structure map is shown in Figure 1. The structure is dipping from North-west to South East at a dip angle of 8°.

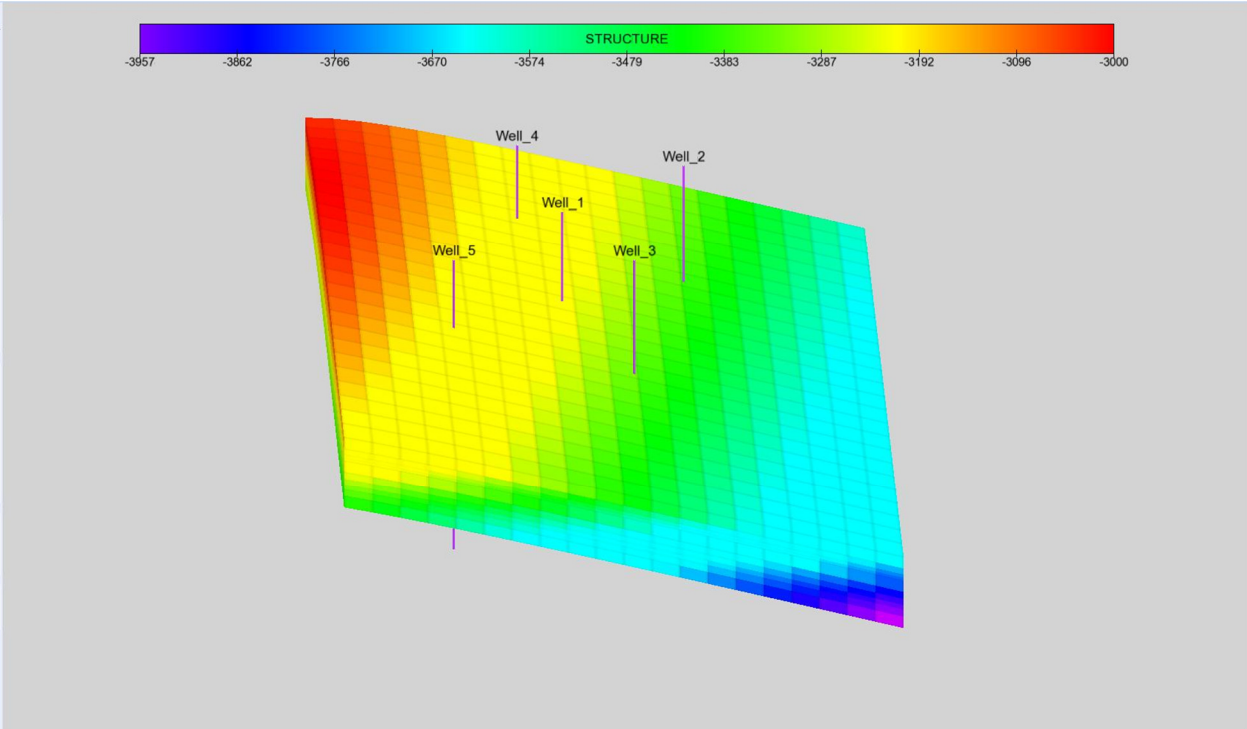


Figure 1: 3D view of the structure of the reservoir model.

The reservoir model consists of 10 layers with varying thickness. Figure 2 shows a 3-D view of the true vertical thickness of the 10 layers. Reservoir properties for each layer are shown in Table 1.

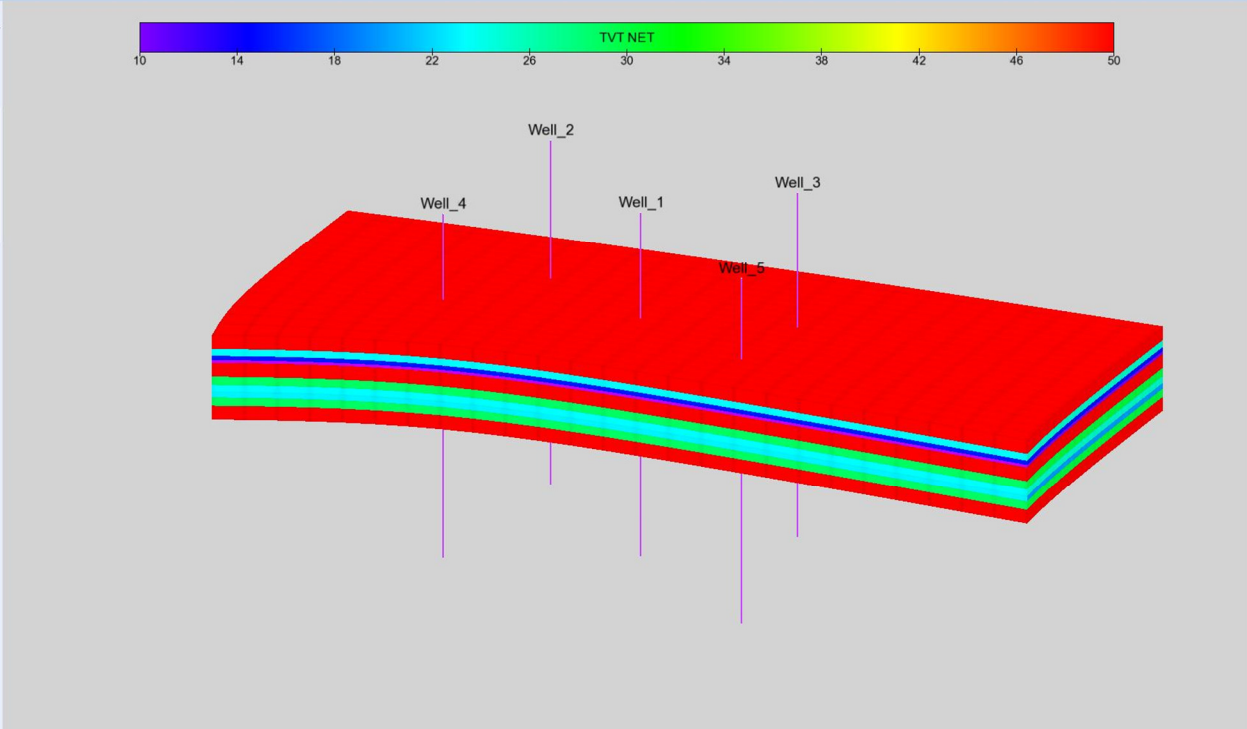


Figure 2: 3D view of true vertical thickness of 10 layers.

Table 1: Reservoir properties

Layer No.	TVT Gross feet	NTG	Porosity fraction	KX mD	KY mD	KZ mD
Layer 1	50	1	0.01	0.1	0.1	0.01
Layer 2	25	1	0.1	1	1	0.1
Layer 3	15	1	0.2	10	10	1
Layer 4	10	1	0.2	50	50	5
Layer 5	50	1	0.2	50	50	5
Layer 6	30	1	0.2	50	50	5
Layer 7	25	1	0.2	50	50	5
Layer 8	20	1	0.2	10	10	1
Layer 9	30	1	0.1	1	1	0.1
Layer 10	50	1	0.01	0.1	0.1	0.01

Net thickness (feet)	305
No of grid blocks (total)	5000
Rock Compressibility (1/psi)	4E-6

1.1 EOS data for SENSOR and ECLIPSE

An actual oil sample from NITEC's data archives was used for this exercise. E300 and the compositional mode in SENSOR require an equation of state (EOS) to characterize the fluid PVT behavior. The Soave-Redlich-Kwong (SRK) EOS was used based on a reservoir temperature of 196°F. The tables below represent compositional EOS data with the binary interaction coefficients used in both SENSOR and E300. The Lorentz-Bray-Clark (LBC) viscosity correlation was used to calculate viscosities and the coefficients used are listed in the Table 2 and 3. While actual laboratory data was used for this relatively heavy oil to calibrate the EOS, the LBC coefficients for this EOS were tuned to match the laboratory measured oil viscosities in the absence of CO2. This mistuning in the EOS can lead to erroneous results in both oil and gas viscosities predicted by both compositional simulators E300 and SENSOR when CO2 is present.

Table 2: EOS parameters used in E300 and SENSOR simulations

Components	Mol. Wt.	P critical	T critical	Omega-a	Omega-b	Z - factors	EOS Volume shift	Acentric factor	Parachor
'CO2'	44.01	1069.87	547.56	0.42748	0.08664	0.2741	0.10192	0.225	78
'Def_1'	17.28	610.33	326.383	0.42748	0.08664	0.272	0.02126	0.0135	71.2
'Def_2'	36.463	628.9	618.765	0.42748	0.08664	0.2705	0.06544	0.1295	132.6
'Def_3'	77.624	440.6	881.987	0.42748	0.08664	0.2526	0.12489	0.2721	250.3
'Pseudo_1'	120.558	375.88	1023.337	0.42748	0.08664	0.296	0.0821	0.5663	347.7
'Pseudo_2'	199.947	280.08	1141.891	0.42748	0.08664	0.3056	0.04193	0.7908	537.5
'Pseudo_3	360.953	302.27	1209.998	0.42748	0.08664	0.5982	-0.42068	1.1463	922.3

Table 3: Binary Interaction Coefficients and LBC viscosity correlation coefficients used in E300 and SENSOR dataset

Binary Interaction Coefficients - Equation of State						LBC viscosity Coefficients
0.104						
0.120	0.006					0.0379984
0.120	0.008	0.000				0.0225132
0.100	0.009	0.000	0.000			0.0528402
0.134	0.039	0.031	0.026	0.026		-0.0421773
0.134	0.039	0.031	0.026	0.026	0.026	0.0087723

1.2 PVT data – COZSIM

COZSim requires conventional black-oil data to characterize the fluid PVT behavior. PVT data was generated in COZView using the following Information.

Hydrocarbon Gas Gravity	0.8407
Oil Gravity (API)	23.243
Water Salinity (ppm)	45000
Reservoir Temperature (°F)	196
Oil Correlations (Bo, Rs, Viso)	VaSquez and Beggs (1980)
Water Correlations (Bw, Cw, Visw)	Mc Cain (1990)
Gas Correlations	
Z	Dranchuk Abou-Kasser (1975)
Bg	Real Gas Law
Visg	Lee, Gonzalez and Eakin (1966)

Initial oil and gas viscosities calculated using the above correlations in COZView were different from those values used in SENSOR and E300 which were based on the EOS. For example, at a saturation pressure of 119 psia the viscosities calculated by the EOS (SENSOR and E300) for the gas and oil phases were 0.104 cp and 1.20 cp respectively, whereas the correlations used in COZView at the same pressure calculated gas and oil phase viscosities as 0.0124 cp and 4.86 cp. This difference is not of general concern, as correlations are based on averaging of many laboratory data points, while this EOS was calibrated to actual laboratory data for this relatively heavy oil.

In order to assure that input data to the different simulators was comparable for this validation exercise, the PVT data used in COZSim was manually edited to match the SENSOR and E300 EOS compositional data. The following changes were made in the COZSim PVT data in order to have comparable properties in the models.

- Oil Compressibility values were multiplied by 0.5
- Oil Viscosity was multiplied by 0.25
- Oil formation factor (Bo) was multiplied by 0.98
- Gas Viscosity was divided by 1.2 (multiplied by 0.83)

1.3 Saturation Functions

The following endpoint saturations were used to generate relative permeability curves (Corey type curves) in each simulator. The capillary pressure was assumed to be zero in all the simulators.

Irreducible water saturation, Swirr (fraction)	0.3
Residual oil saturation to water, Sorw (fraction)	0.3
Lambda	10
Maximum relative permeability to oil, KROMax (fraction)	0.623
Critical gas saturation, Sgc (fraction)	0.05
Residual oil saturation to gas, Sorg (fraction)	0.3

Residual oil saturation to miscible CO2, Sorm (fraction)	0.0
Residual gas saturation, Sgr (fraction)	0.05

1.4 Model Initialization

The reservoir model was initialized using the following initial conditions.

Initialization date	08/31/2012
Model Type	2 Phase
Reference Elevation (feet)	-10
Pressure @ Ref Elevation (psia)	2000
Elevation @ WOC (feet)	-4000
Bubble point pressure (psia)	119

Model Initialization results from each simulator are shown in Table 4.

Table 4: Model Initialization results for all the simulators (COZSim, E300 and SENSOR)

Simulator	Oil MMSTB	Gas MMSCF	Water MMSTB	Res. Volume MMbbl
COZSim	106	1517	46	157
SENSOR	107	1198	47	157
E300	107	1208	47	157

The minor differences in the reported fluid-in-place values are due to the fact that COZSim calculates the undersaturated fluid properties (for both oleic and aqueous phases) at the individual phase pressure values, rather than the gas phase pressure (at which the other two compositional simulators perform their flash calculations).

1.5 Well Data

A five spot pattern was simulated in the models. The well locations are shown on the structure model in Figure 1.

Well Constraints

Injection well (WELL01): Center well in the five spot

Maximum Bottom hole pressure (psia)	3200
Maximum CO2 Injection rate (MSCF/day)	5000

Producers (WELL02-WELL05)

Minimum BHP (psia)	2500
Maximum Production Liquid rate (STB/day)	1000

Well limits

Minimum Oil rate (STB/day)	10
Maximum GOR (SCF/STB)	10,000

2. Results and Discussion

CO2 was injected in the central injection well at 5000 MSCF/day into this heavy oil reservoir at a maximum bottom hole pressure of 3200 psia. The changes that were made in the COZSim PVT data were only valid at the saturation pressure of 119 psia. As mentioned earlier in Section 1.1 (EOS data for SENSOR and E300), the LBC coefficients used in the EOS were tuned to oil viscosities in the absence of CO2. Therefore for validation purposes, it was necessary to match COZSim oil and gas viscosities which account for the presence of CO2 with the EOS data. This was achieved by making the following changes

- CO2 mobility in the gas phase was multiplied by a factor of 3 (Note: gas phase viscosities are divided by 3
- CO2 solubility in the oil phase is multiplied by 0.7 to affect oil phase viscosity
- COZSim accounts for CO2 solubility in the water phase in the presence of hydrocarbon gas, whereas the other simulators in this case (E300 and SENSOR) do not account for CO2 solubility in water phase. Hence for validation purposes, changes were made in the COZSim dataset to deactivate the CO2 solubility in the water phase.

Please note that the above changes to the viscosities, mobility and solubility in the COZSIM dataset were only made to give generally comparable values to the data used in the compositional simulators (SENSOR and E300).

Figure 3 shows oil and total gas production rates predicted by all the simulators COZSim, E300 and SENSOR.

In all plots shown in this document, gas production (rates and cumulative) are the total gas – hydrocarbon and CO2. As the solution gas oil ratio at the bubble point is very low (14 SCF/STB) for this oil, the hydrocarbon gas portion of the total gas produced is small once CO2 breakthrough occurs. Hence, gas rate and cumulative production plots can generally be interpreted as CO2 being the gas phase.

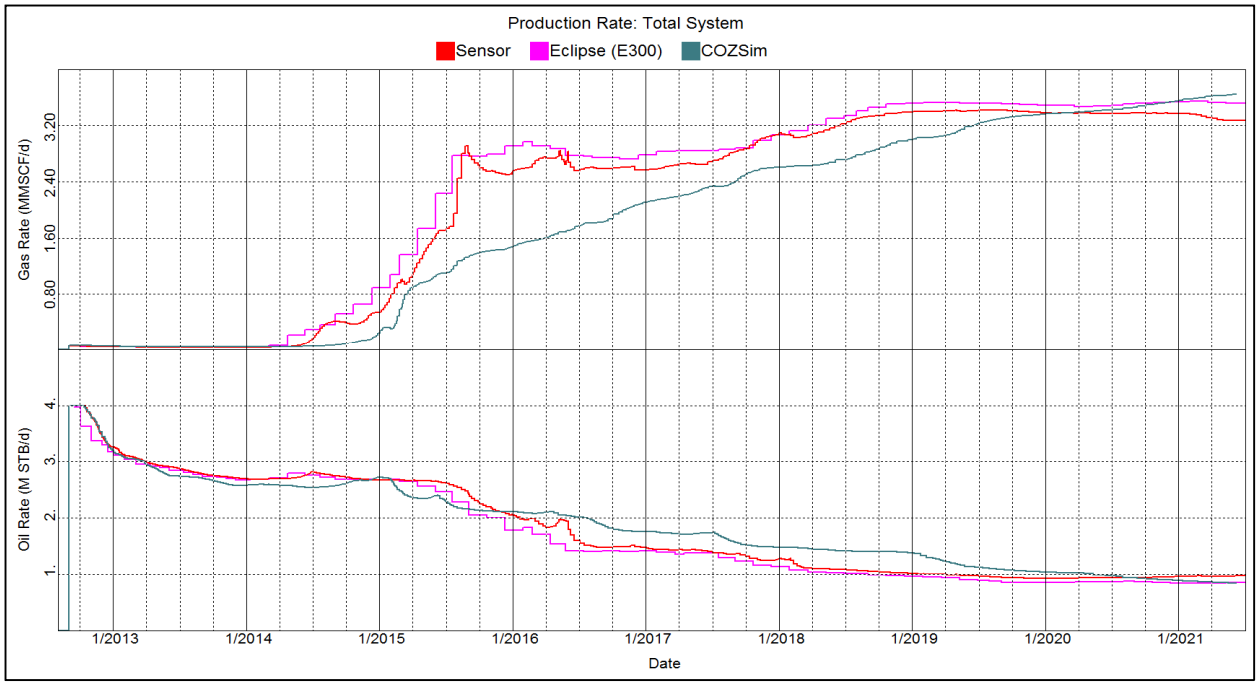


Figure 3 Field oil and gas production rates predicted by COZSim, E300 and SENSOR

Figure 4 shows cumulative oil and total gas production predictions from COZSim, E300 and SENSOR. At the end of 8 years cumulative oil production predicted by COZSim was 5770 MSTB, whereas predictions of E300 and SENSOR are 5300 MSTB and 5535 MSTB.

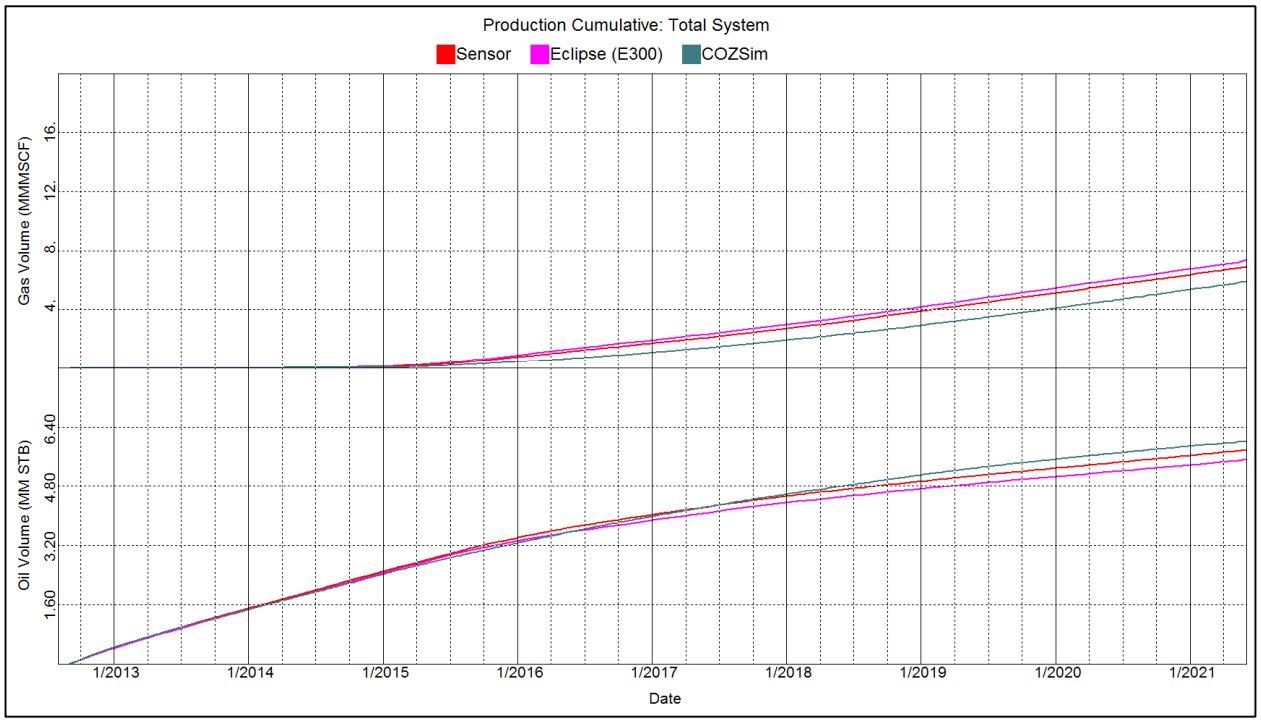


Figure 4: Cumulative oil and gas production predicted by COZSim, SENSOR and E300

It is believed that the differences in the predicted results between COZSim, SENSOR and E300 are due to the differences in the oil miscibility calculations that are governed by differences in the oil and gas phase viscosities. To "history" match the results of E300 and SENSOR with COZSim, the miscibility parameters were tuned manually in the COZSim dataset.

The miscibility parameters are the Interfacial tensions at Minimum Miscibility Pressure (MMP) and First Contact Miscibility (FCM). The default values in COZSim for these miscibility parameters are 6 (IFT at MMP) and 3 (IFT at FCM). A better (acceptable) match was obtained by increasing the Interfacial tension at MMP from 6 to 9. (This modification to the default miscibility parameters was solely an attempt to match the SENSOR and E300 results.)

Figure 5 shows the field injected gas (CO2) rates and cumulative gas (CO2) injection calculated by the simulators. The profiles and the injected volumes calculated by COZSim are in excellent agreement with E300 and SENSOR.

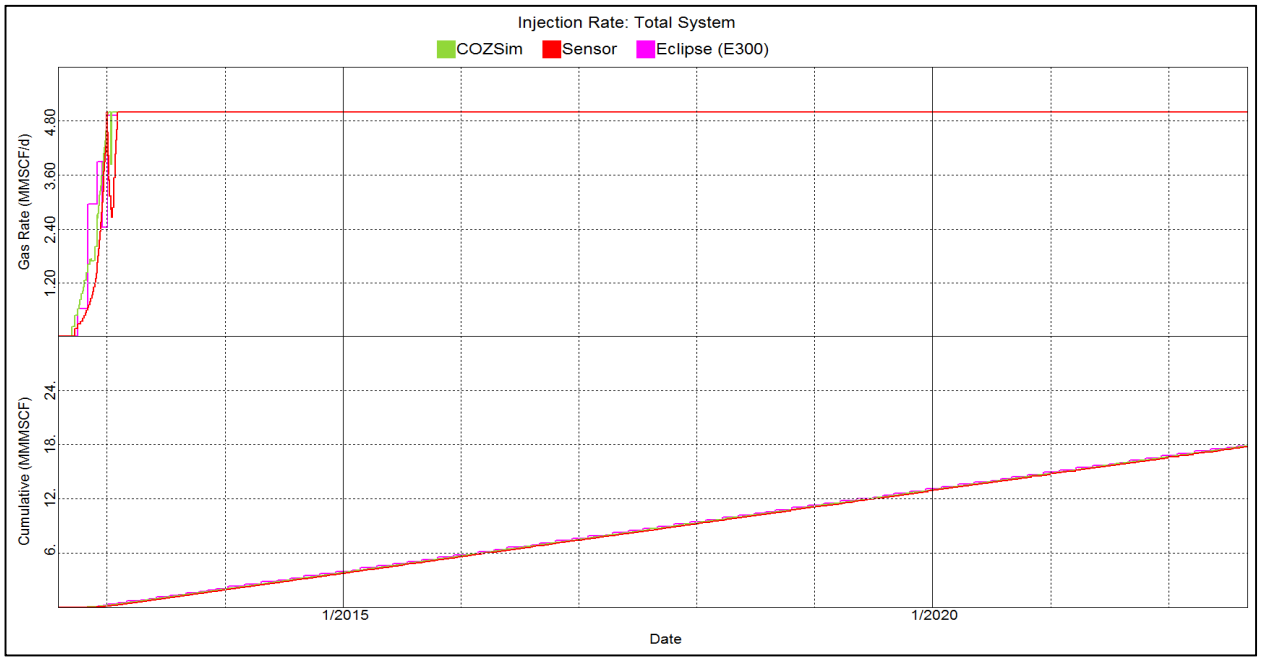


Figure 5: CO_2 Injection rates and cumulative calculated by the three simulators.

Figure 6 shows the field oil and total gas production rates calculated by the simulators. Oil production started with a maximum liquid rate of 4000 STB/day (1000 STB/day/well) and declined gradually to an oil rate of 839 STB/day at the end of 10 years. The differences observed in Figure 6, especially in the total gas production rate are attributed to the differences in the gas viscosities specified in COZSim versus those calculated by the E300 and SENSOR. The maximum total gas production rate mismatch is at the end of 3 years, where the total gas rate calculated by SENSOR and E300 is approximately 2400 MSCF/day, whereas COZSim calculated the total gas rate to be 1500 MSCF/day. The rates converge to similar values thereafter.

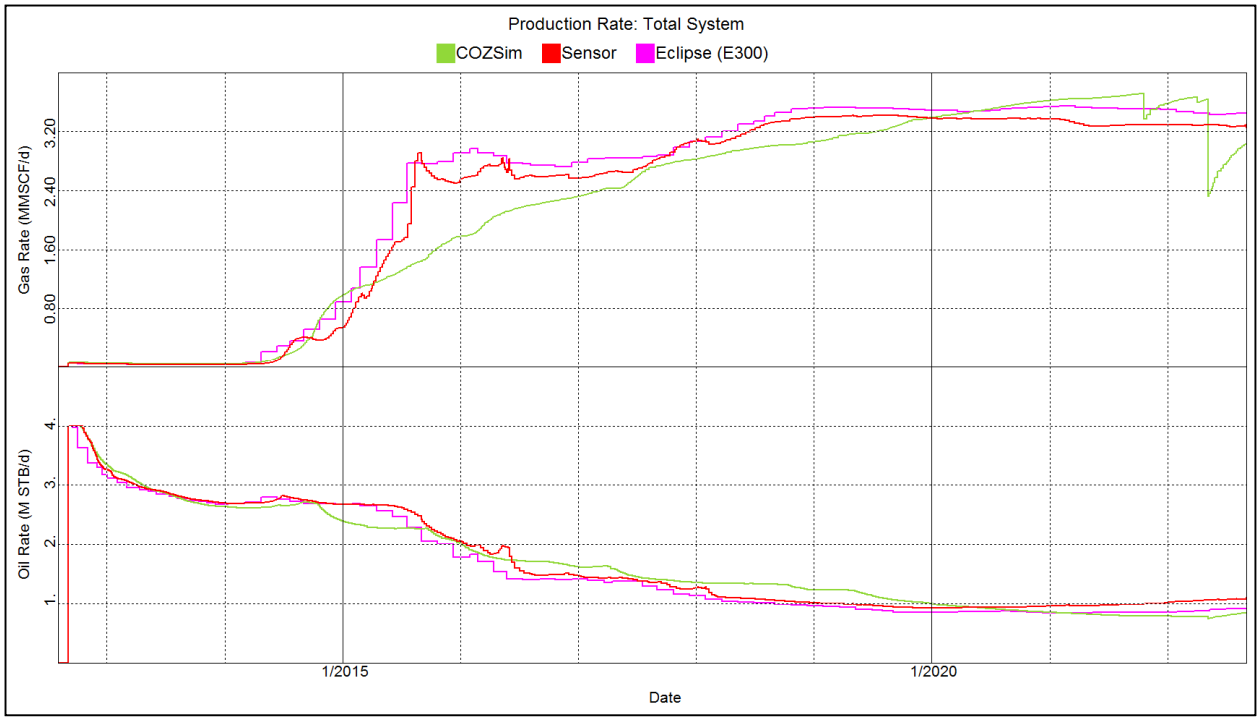


Figure 6: Field oil and gas rates calculated by the three simulators

Figure 7 shows the field cumulative oil and total gas production calculated by all the simulators. COZSim results are in good agreement with SENSOR and E300.

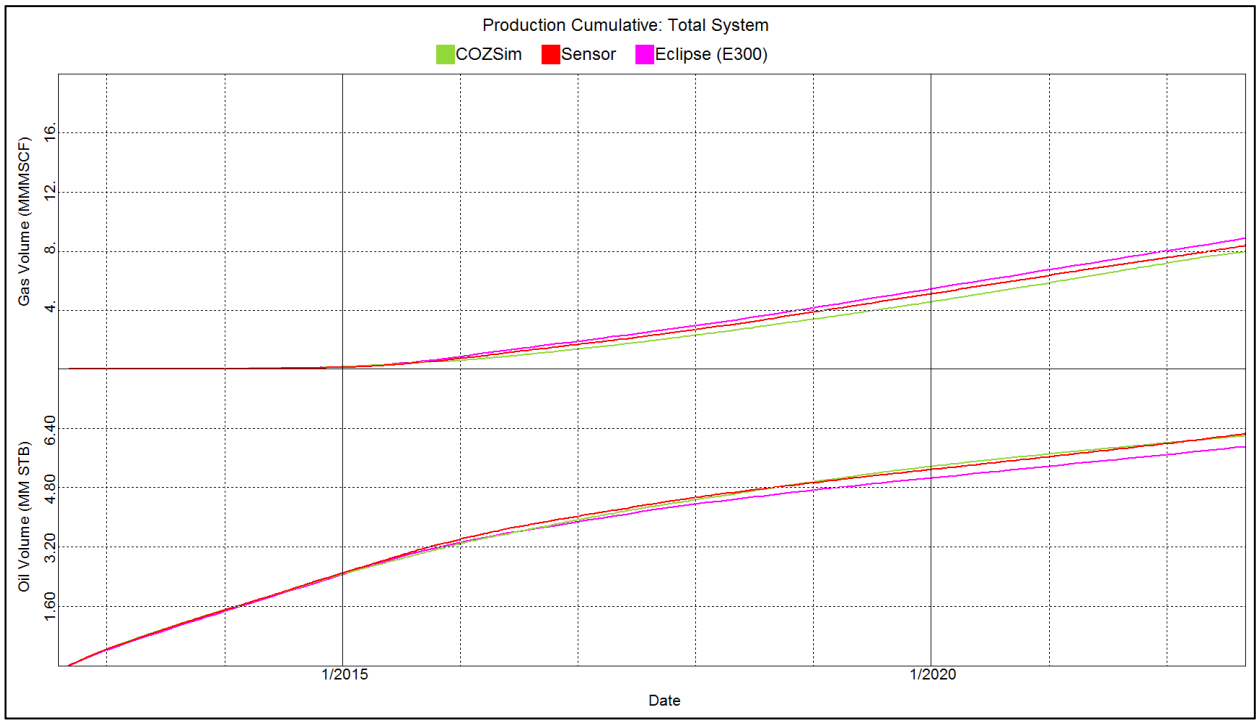


Figure 7: Cumulative oil and gas production for the field

Figures 8 and 9 show the oil saturation maps for Layer 4 at the end of 2.5 years and 10 years from COZSim and SENSOR. As shown in Figure 8, the oil in only a small area (one grid block) has become fully miscible to CO2 at the end of 10 years. Full miscibility is interpreted as being when the Sorm value is achieved (zero in this example.) This was confirmed by the COZSim miscibility map which is not available in SENSOR and E300.

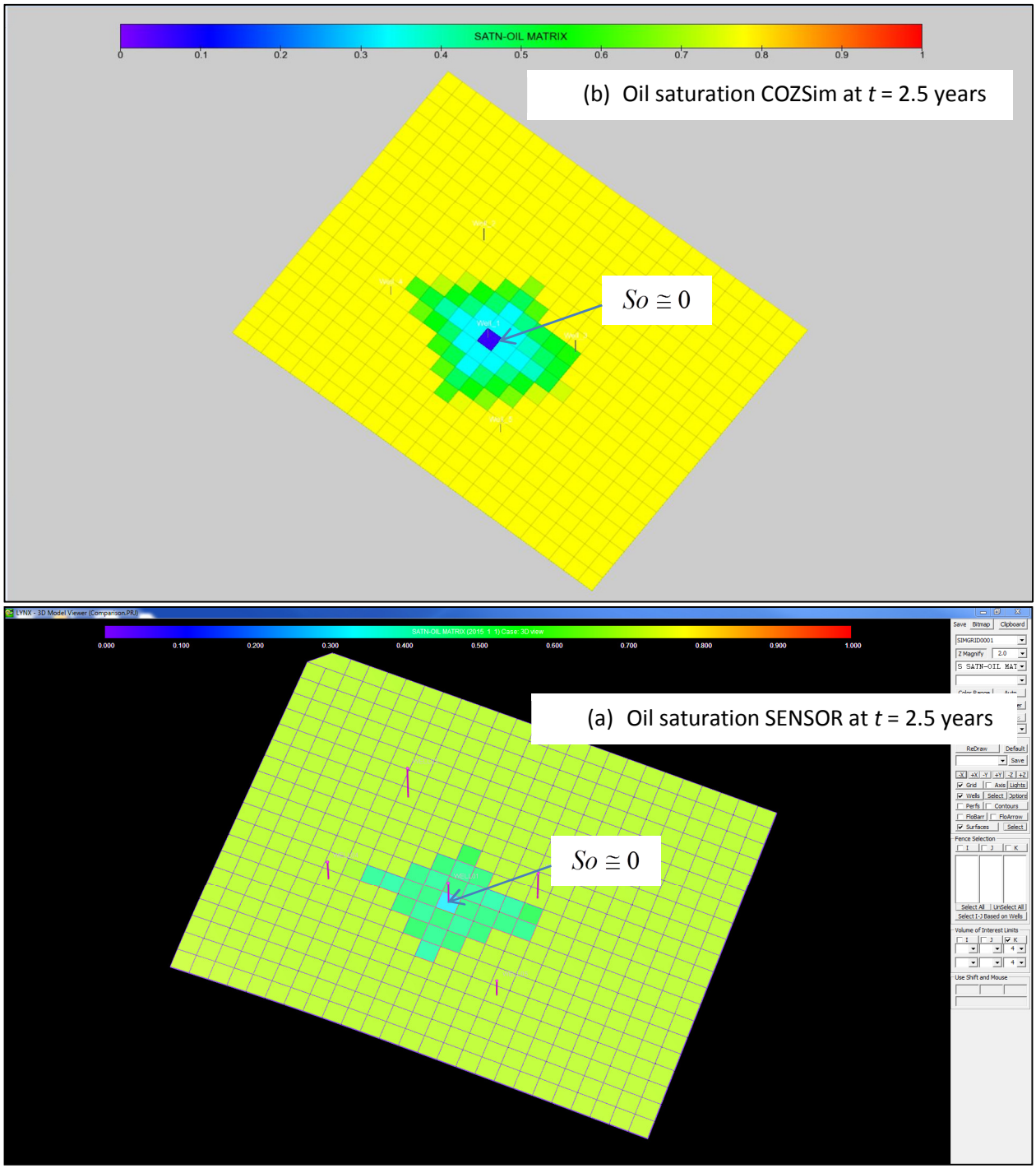


Figure 8: Oil Saturation (Layer 4) at the end of 2.5 years from (a) COZSim (b) SENSOR

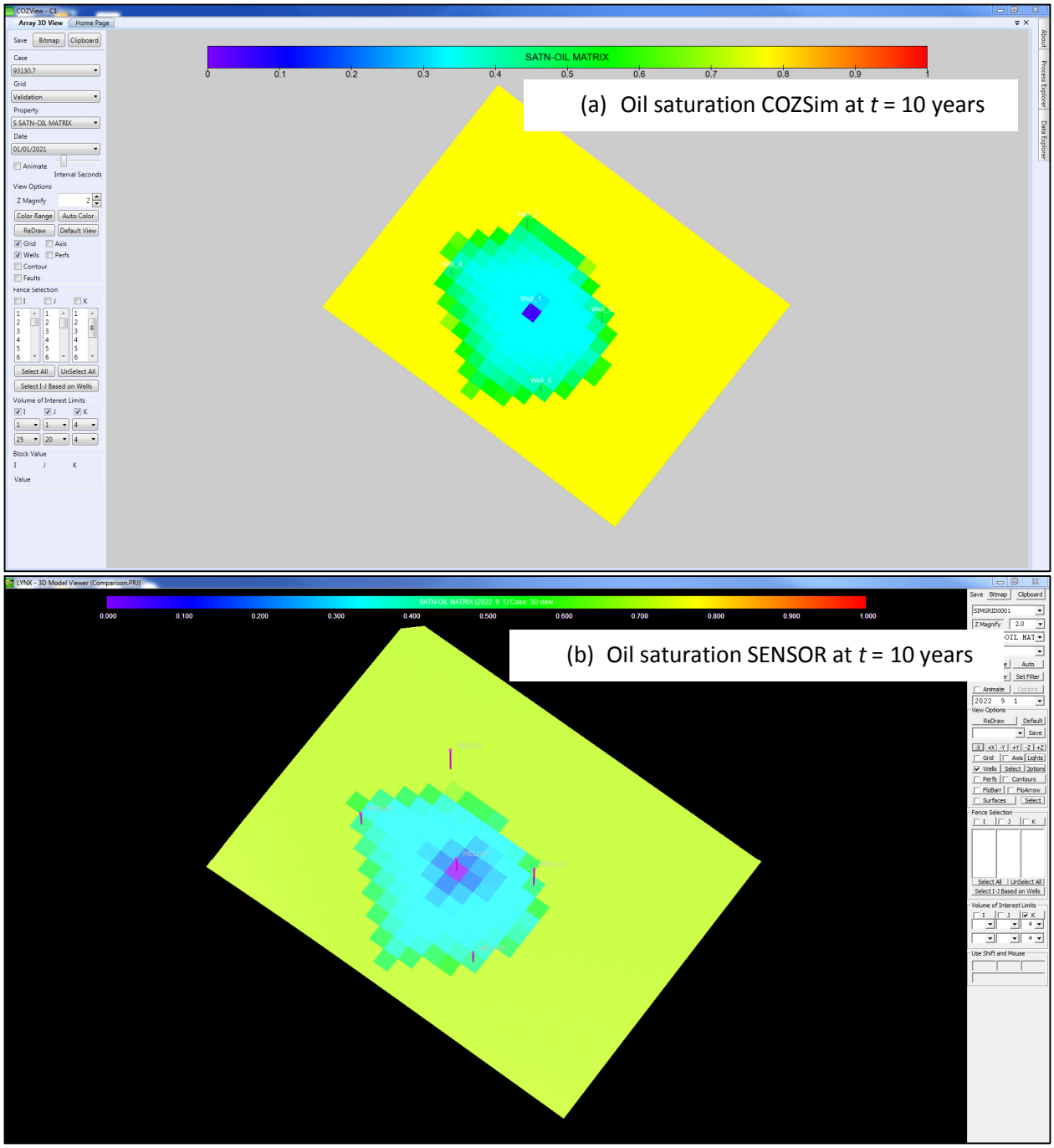


Figure 9: Oil Saturation (Layer 4) at the end of 10 years from (a) COZSim (b) SENSOR

Because of the limited miscibility achieved in the original simulation case, a Special Case was simulated with each of the simulators where a larger area of miscibility was achieved as a further validation of the COZSim results. The operating conditions (BHP of the wells) and the reservoir porosity were changed in order to achieve a larger area of miscibility of the CO2 and oil. Porosity was reduced in the original model merely to reduce the pore volume and accelerate reservoir pressure changes.

3. Special Case Scenario

A larger area of full oil-CO2 miscibility was achieved by operating the wells at higher bottom hole pressure values and decreasing the porosity values. The porosity was decreased to reduce the pore volume and to accelerate the increase in reservoir pressure due to CO2 injection. The following changes were made to all simulator models:

- Maximum Bottom hole pressure for the injector (Center well: Well01) was set as 3800 psia
- Minimum Bottom hole pressure for all producers (Well02-Well05) was specified as 3200 psia
- Porosity of Layers 3-8 was modified from 0.2 to 0.1

All other parameters and PVT and EOS data were the same as specified above (Section 1.1. 1.2 and 1.3).

3.1 Model Initialization

The parameters for Model Initialization are the same as in Section 1.4. The results of the Model initialization are shown in Table 5.

Table 5: Model Initialization results for the Special Case

Simulator	Oil MMSTB	Gas MMSCF	Water MMSTB	Res. Volume MMbbl
COZSim	62	884	27	92
SENSOR	63	705	27	92
E300	63	700	27	92

3.2 Results and Discussion

Figure 10 shows profiles of field injected gas (CO2) rate and the cumulative gas (CO2) injection for the field calculated by COZSim, SENSOR and E300.

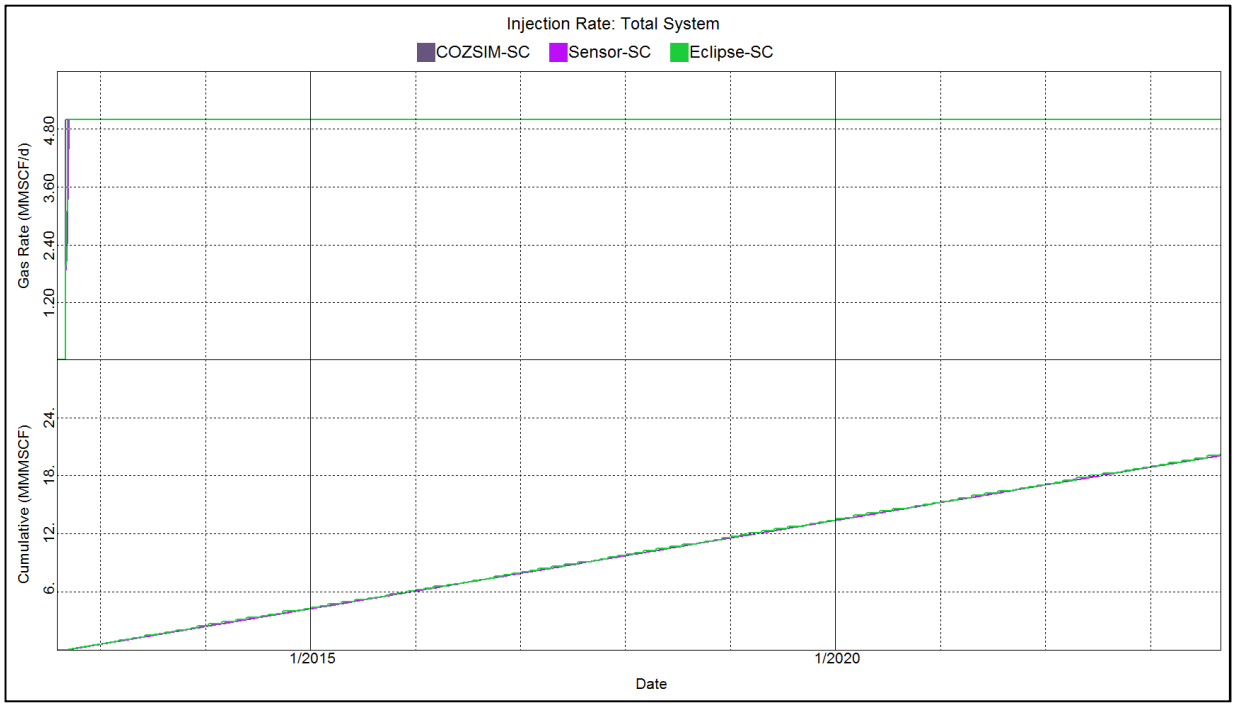


Figure 10: Injection gas rates and cumulative injection predicted using COZSim, SENSOR and E300

The field production rates and the cumulative production for COZSim, SENSOR and E300 are shown in Figure 11 and Figure 12. COZSim results are in good agreement with SENSOR and E300.

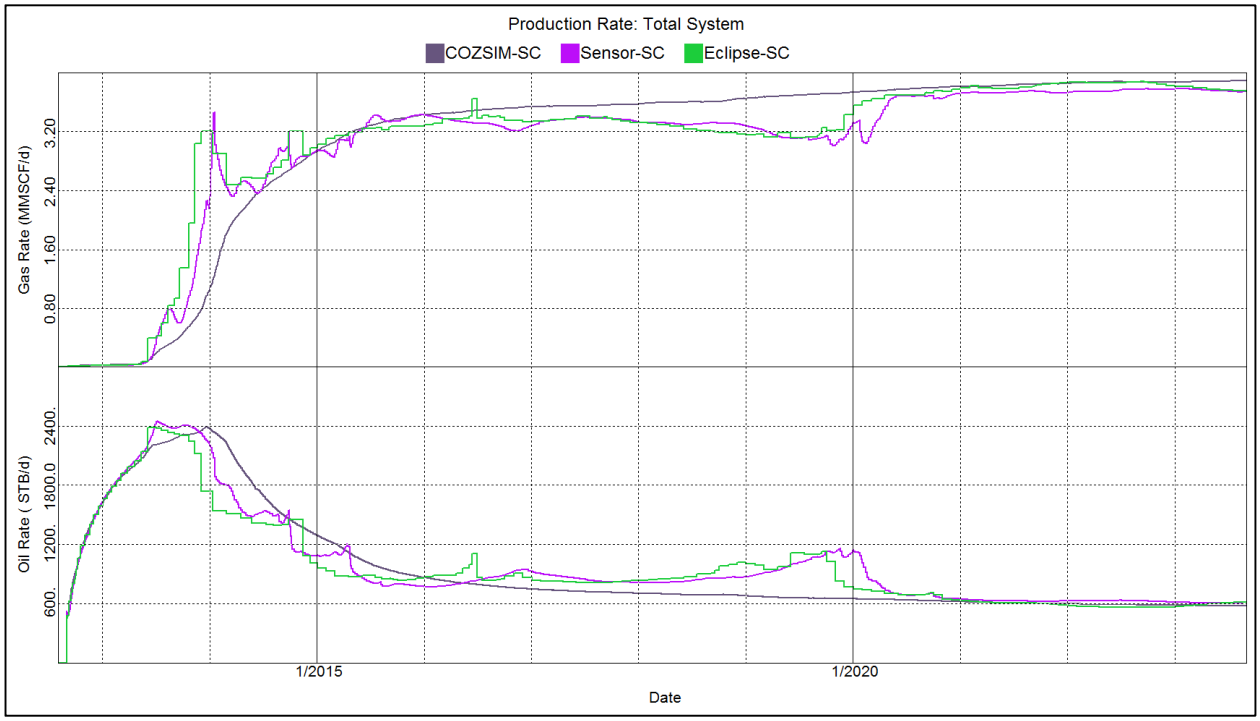


Figure 11: Predicted oil and gas production rates from COZSIM, SENSOR and E300

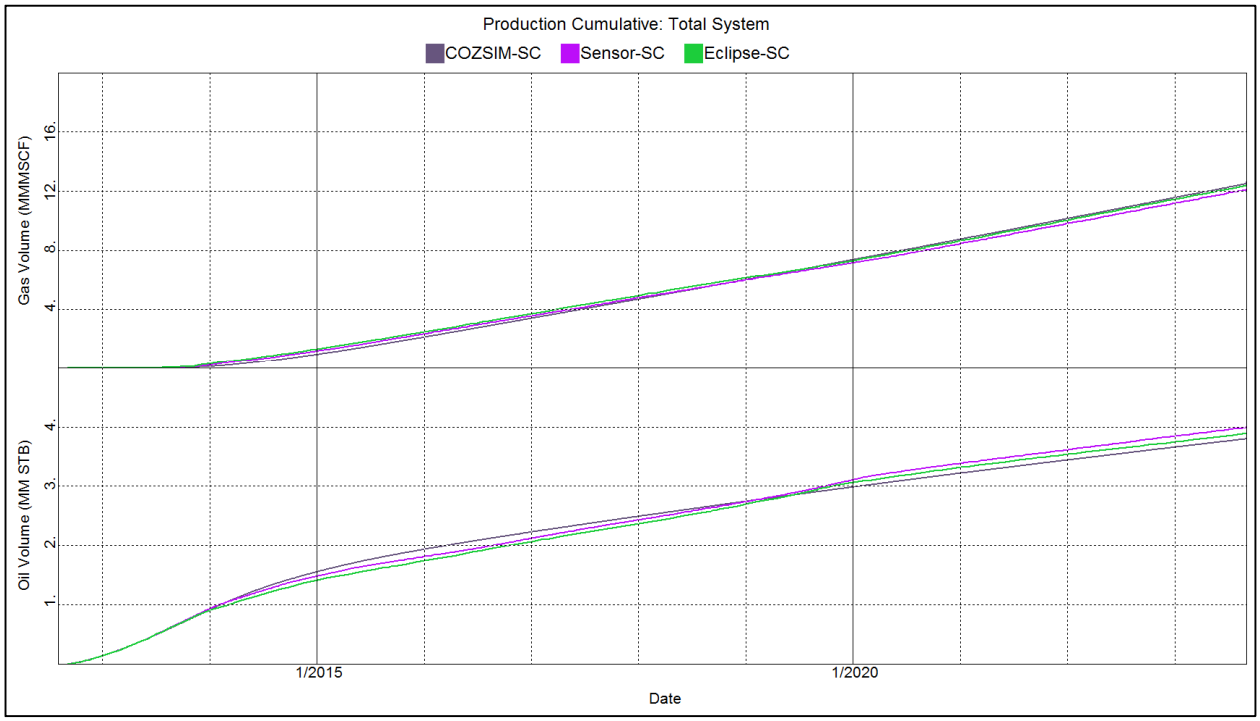


Figure 12: Cumulative oil and gas production predicted using COZSIM, SENSOR and E300

Figures 13-15 show oil saturation maps for layers 4 and 5 (as predicted at the end of 10 years) from COZSim, SENSOR and E300, respectively. As shown in Figure 13(a), COZSim predicted a larger area that achieved full miscibility than compared to SENSOR (Figure 14 (a)) and E300 (Figure 15 (a)). For Layer 5 COZSim predicted a smaller area of full miscibility compared to SENSOR and E300 (Compare Figure 13 (b), Figure 14 (b) and Figure 15 (b)). This is attributed to the difference in the wellbore flow formulation in multiple zone completions between the simulators. The interesting point to note here is that the net area that is fully miscible is similar for SENSOR, E300 and COZSim.

Again, full miscibility is interpreted as having been achieved when the Sorm value is reached (zero in this example).

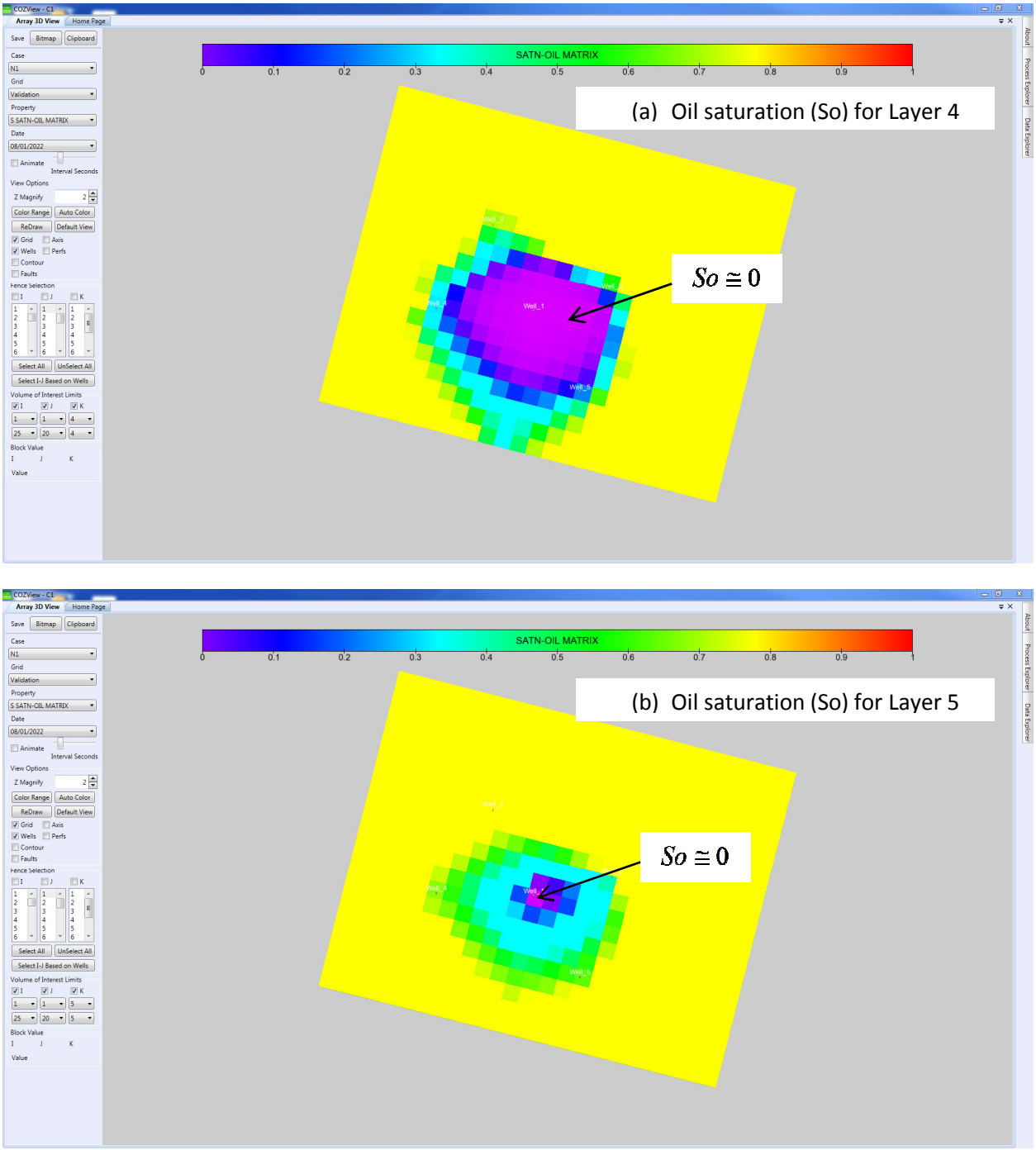
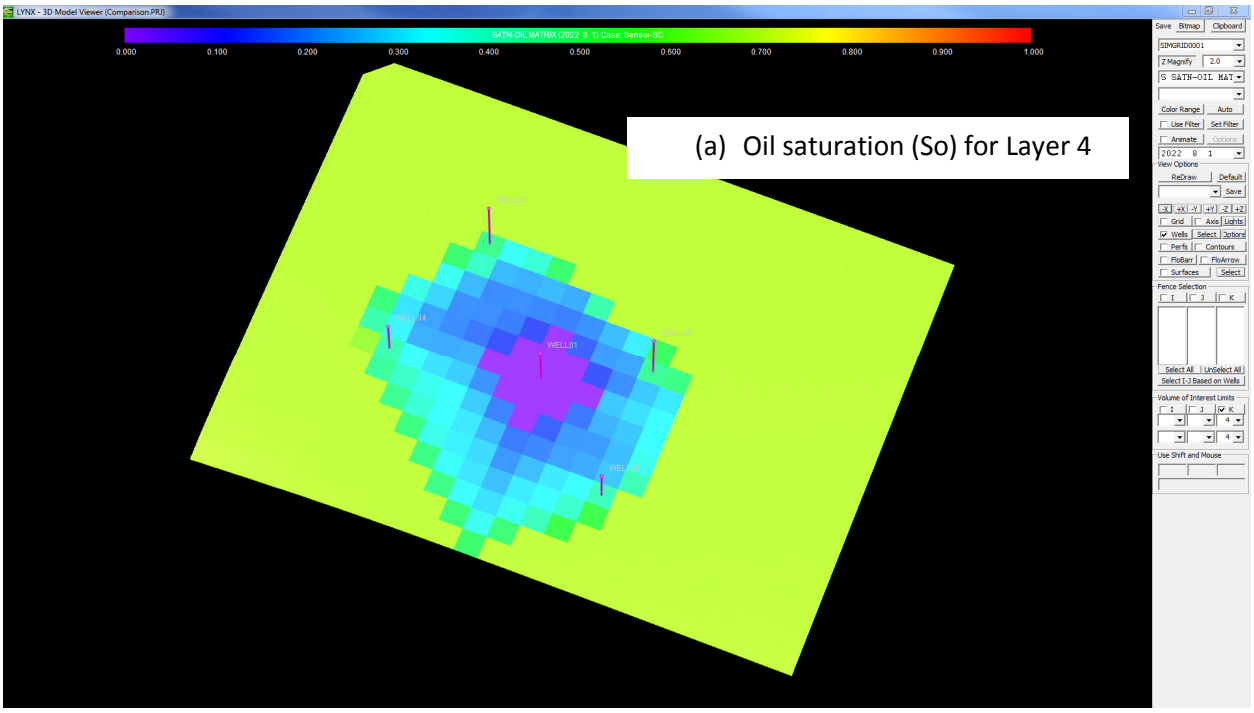


Figure 13: Oil Saturation map predicted by COZSim at the end of 10 years (a) Layer 4 (b) Layer 5



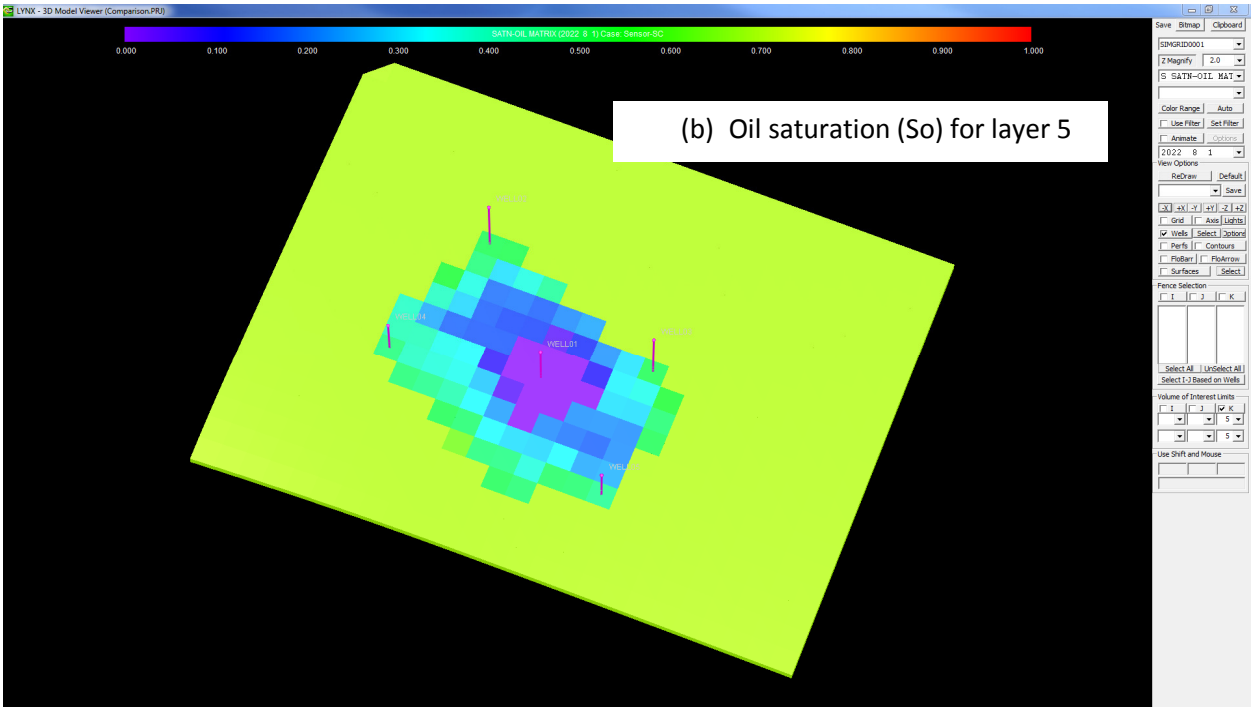


Figure 14: Oil Saturation map predicted by SENSOR at the end of 10 years (a) Layer 4 (b) Layer 5

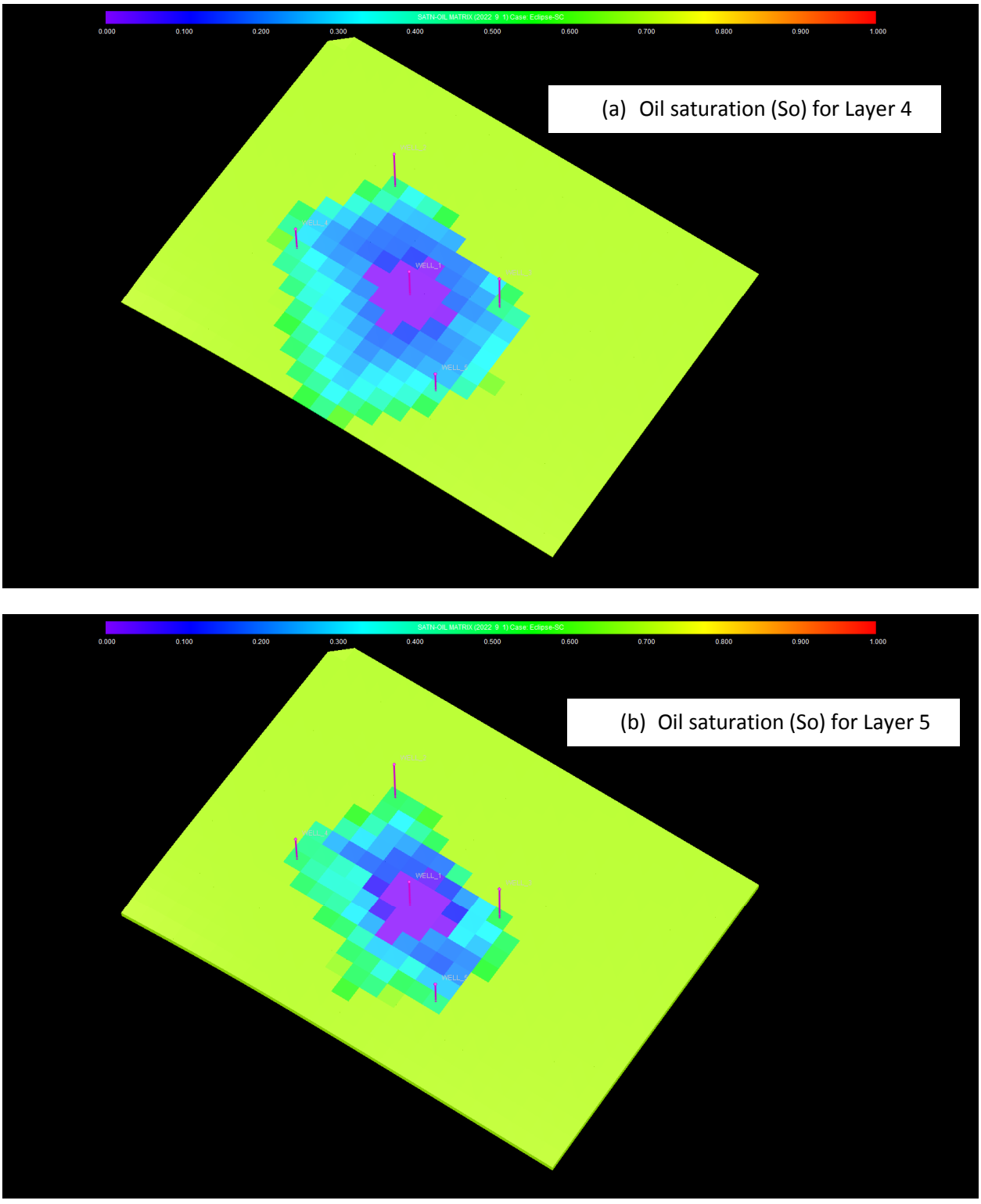


Figure 15: Oil saturation map predicted by E300 at the end of 10 years (a) Layer 4 (b) Layer 5

II. Impact of CO2 solubility in water on prediction results

As mentioned earlier in the previous section, E300 and SENSOR do not account for the CO2 solubility in the aqueous phase. This can lead to errors in the prediction of oil and gas production rates in CO2 injection projects. All the previous Special Cases (COZSIM-SC, E300-SC and SENSOR-SC) do not account for solubility in the aqueous phase. The prediction case COZSim-SC is in good agreement with cases E300-SC and SENSOR-SC

COZSim by default accounts for solubility of CO2 in the aqueous phase. Figure 16 shows the difference in the oil and total gas production rates from COZSim using the default CO2 solubility in water (case COZSim-default) compared to the Special Cases E300-SC, SENSOR-SC and COZSim-SC. As CO2 dissolves in the water phase, the CO2 available for oil swelling is reduced and affects production of all phases.

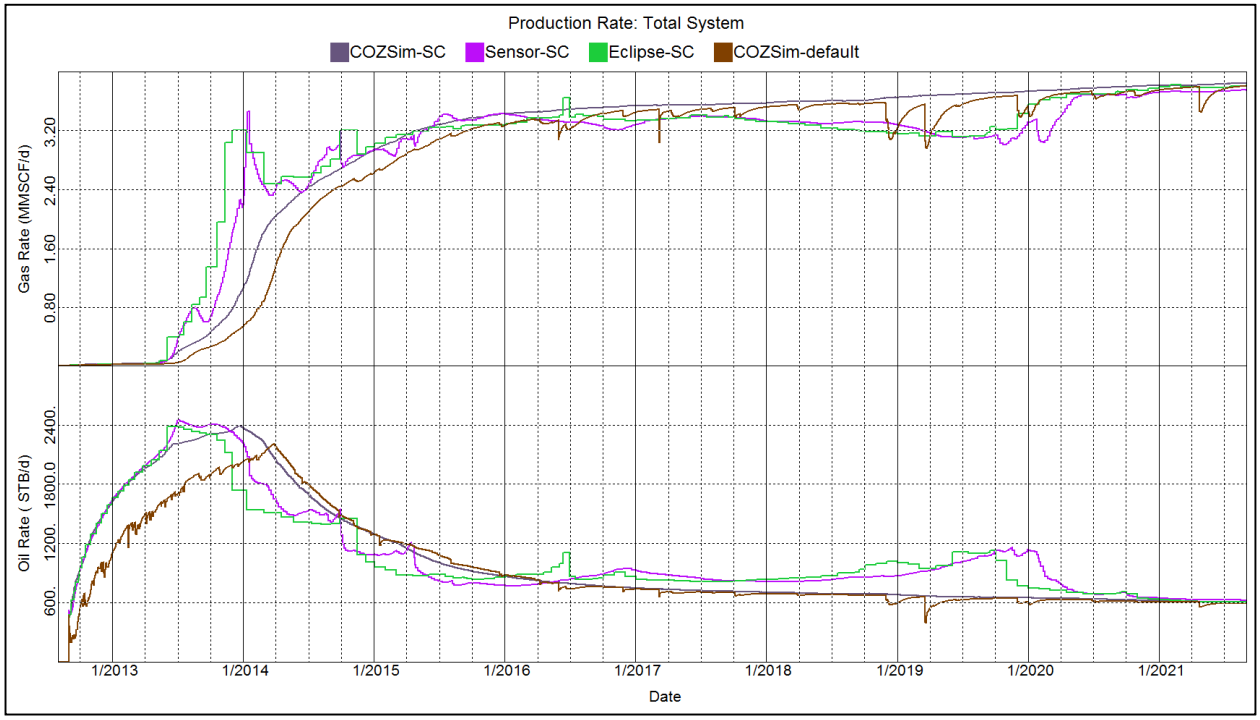


Figure 16: Oil and gas production rates predicted using COZSim, SENSOR and E300

Figure 17 shows the cumulative production of oil and total gas from this case (COZSim-default). The cumulative total gas production predicted by SENSOR and E300 at the end of 5 years is 4650 MMSCF, whereas COZSim (COZSim-default) calculated 4120 MMSCF. This reflects the loss of approximately 530 MMSCF of CO2 through solubility in water phase.

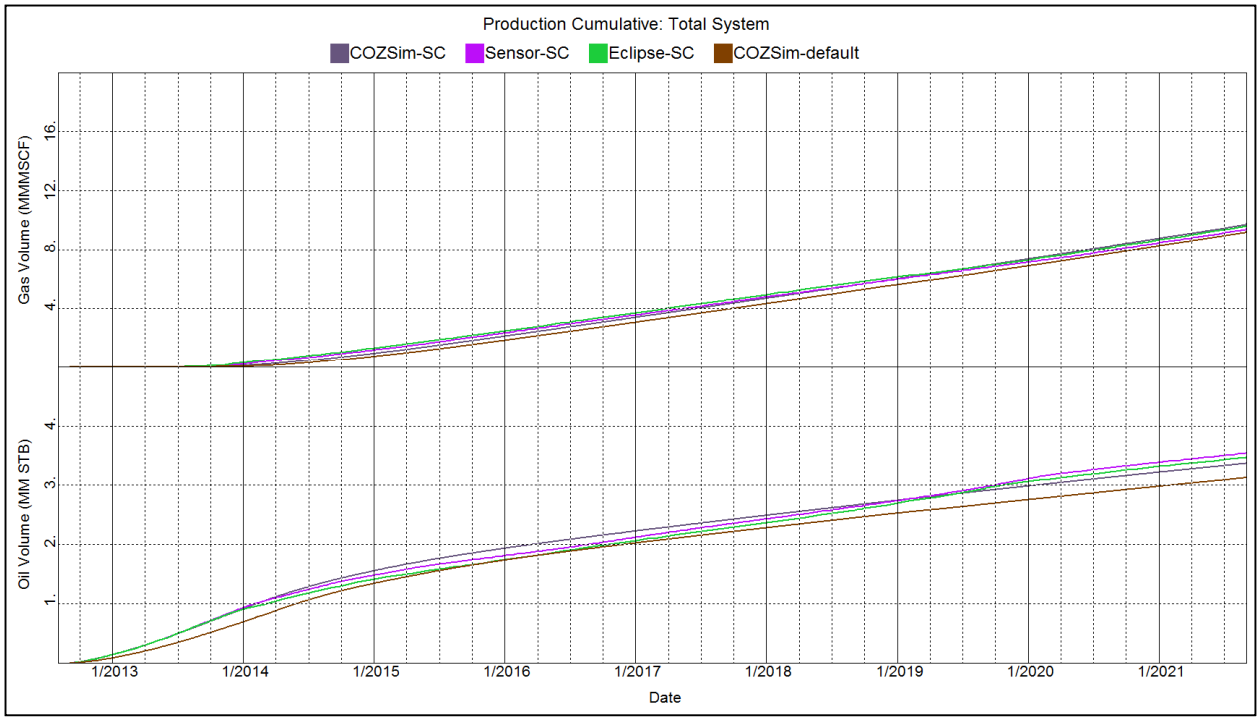


Figure 17: Cumulative oil and gas production predicted using COZSim, SENSOR and E300

APPENDIX 4

Case Study Report

DOE/NETL Project: A Full-Featured, User Friendly CO2-EOR and Sequestration Planning Software

The Case Study

Case Study Participating Company:

Linc Energy Petroleum Wyoming, Inc.

Casper, Wyoming

DOE/NETL Award: DE-FE0006015

NITEC LLC

Denver, Colorado

May 29, 2013

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List of Figures

General

Linc Energy Petroleum Wyoming, Inc. agreed to participate in the project Case Study. Linc Energy's Casper, WY office directly participated in the work which was officially initiated with a kick-off meeting on January 21-22 in Casper with Linc Energy staff and NITEC's Project Manager, Bill Savage. Linc Energy elected to utilize the COZView/COZSim software in investigations of the CO2-EOR potential for the Dakota formation in their Cole Creek South Field (SCC) in Converse County, Wyoming (Figure 1).

Figure 1: Location of SCC Field

Field Summary

The Cole Creek South Field was discovered in October 1948 by Phillips Petroleum with the drilling of the 1 Unit well in SWSWNW 17-34N-76W. The well was drilled to a total depth of 8380 ft to the Jurassic Morrison formation. Initial production was 360 STBO/D from the Lakota formation. The discovery well for the Dakota is attributed to well 5 Unit in SWSWSW 8-34N-76W in June 1950 (85 STBO/D). A number of productive horizons exist in the field and have been produced over the years – Shannon, Frontier,

Muddy, Dakota, Lakota (all Cretaceous).[1] The SCC Field is approximately 23 miles east of Casper. Linc Energy has operated the field since March 1, 2011.

A structure map on the top of the Dakota formation and the current Dakota sand unit boundary (SCCU) is shown in Figure 2.

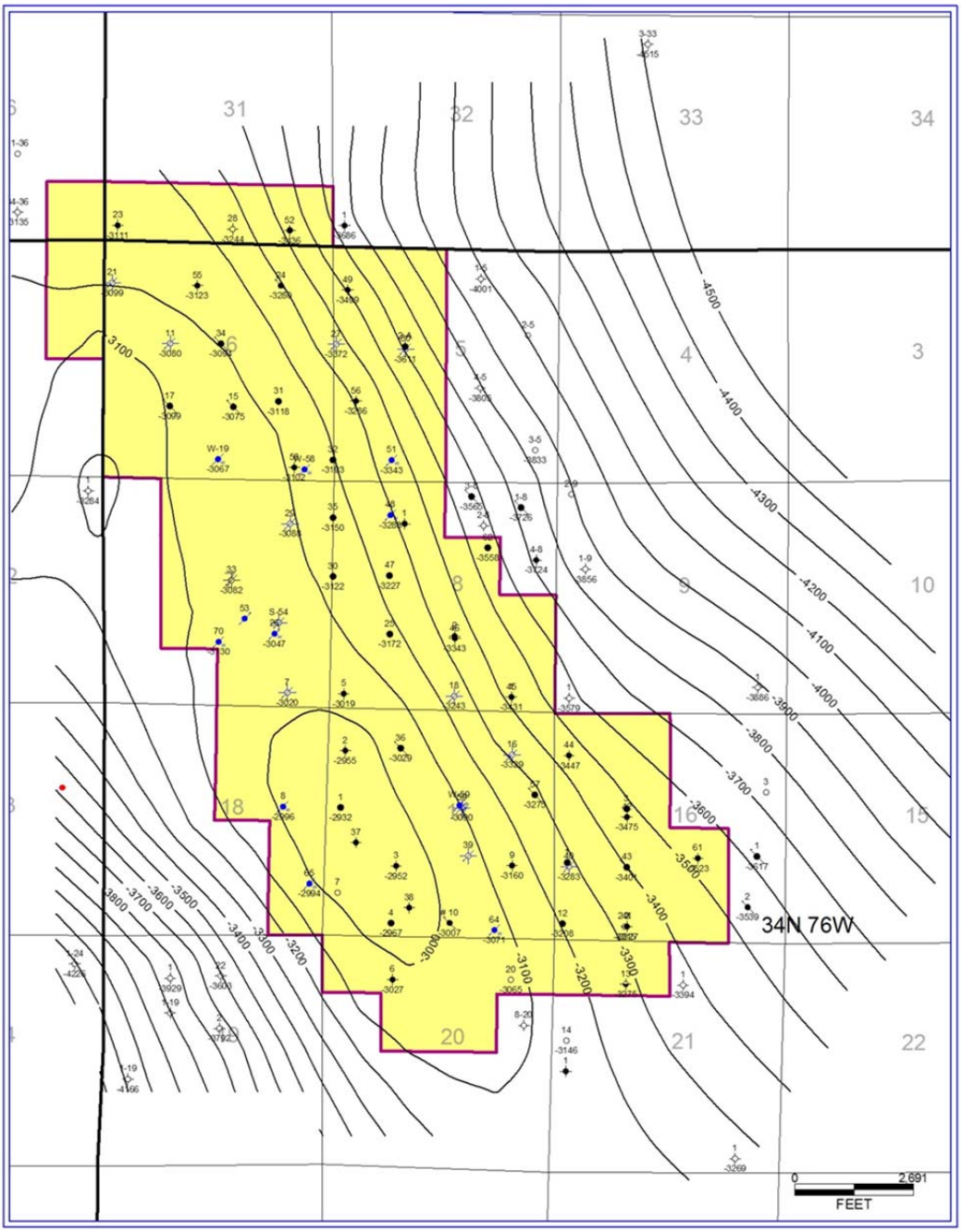


Figure 2: Dakota Top of Structure

[1] 2000 Wyoming Oil and Gas Fields Symposium, Powder River Basin Vol. I, Wyoming Geological Association

Currently Linc Energy operates 26 wells in the SCC Field; most in the Dakota formation. The SCC Field production history is shown below.

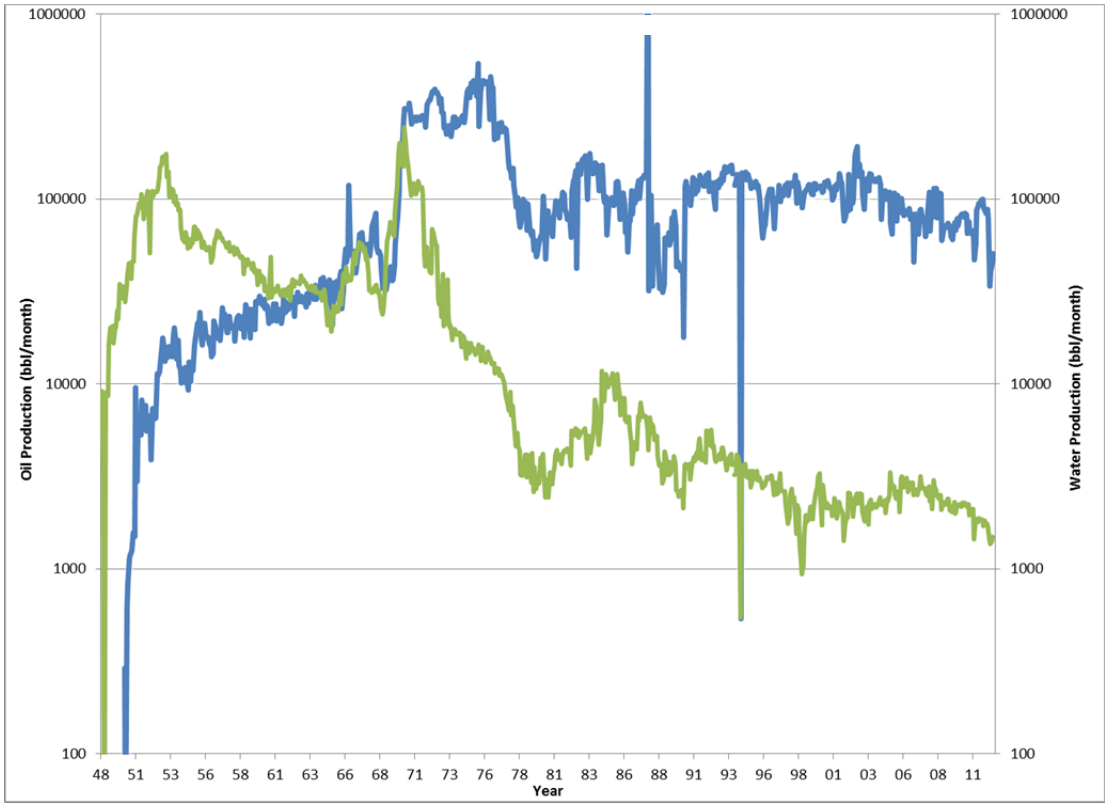


Figure 3: SCC Field Monthly Oil and Water Production

The monthly production history indicates that the SCC field production from all formations increased approximately five fold due to the water flood operations from the start of Wyoming State reported water injection in 1961 to peak production in 1970 (~5,500 STB/D from ~1100 STB/D). Overall response to water injection into all formations was good based on the production decline before and after water injection initiation. Using a combination of Wyoming State records[2] and WGA publications[1], Linc estimates Dakota reservoir cumulative oil production to be approximately 11,193 MSTB as of January 1, 2013.

Geology

The Dakota reservoir rocks at SCC Field were deposited as part of low stand system tracts during periods of sea level lows. At low sea level, the shelf was exposed allowing fluvial systems to incise now-exposed deep water shales for tens of miles. When sea levels rose, the fluvial sands were often reworked into tidal or upper shore face sandstones. Two NE-trending Dakota channel systems define the productive reservoir system at SCC Field.

[2] Wyoming Oil and Gas Conservation Commission website (www.wogcc.state.wy.us)

Figure 4 is a type log showing both Dakota and underlying Lakota sandstones. Figure 5 is an isopach map for the Dakota. The channelized character of the Dakota reservoir is apparent in the thickness map. Trapping mechanisms include both stratigraphic and structural, as the channels drape over the structure.

While an initial tilted water-oil contact has been reported at approximately -3850 ft ss (NW) to -3700 ft ss (SE), a mobile aquifer, if present, has not been observed to provide any significant pressure support.

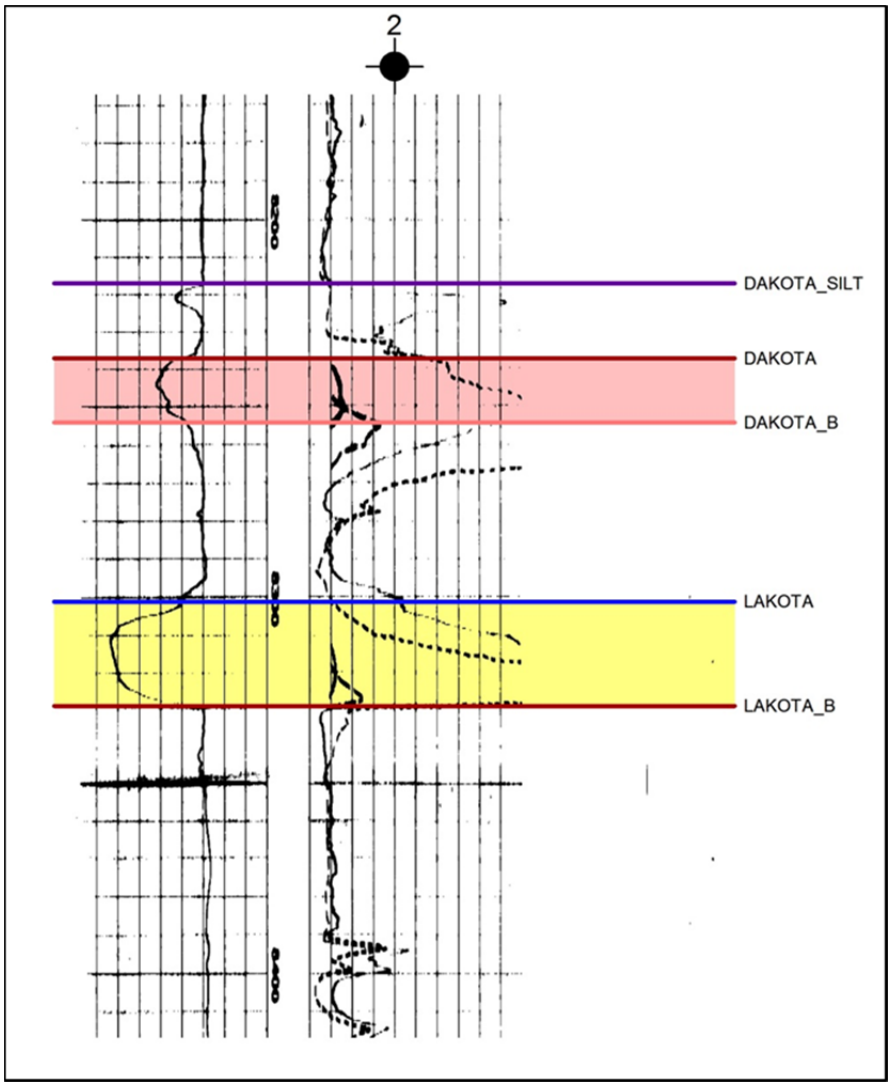


Figure 4: Type Log

The OOIP for the Dakota formation in SCC Field was estimated by Phillips Petroleum Company to be 35.8 MMSTB[3].

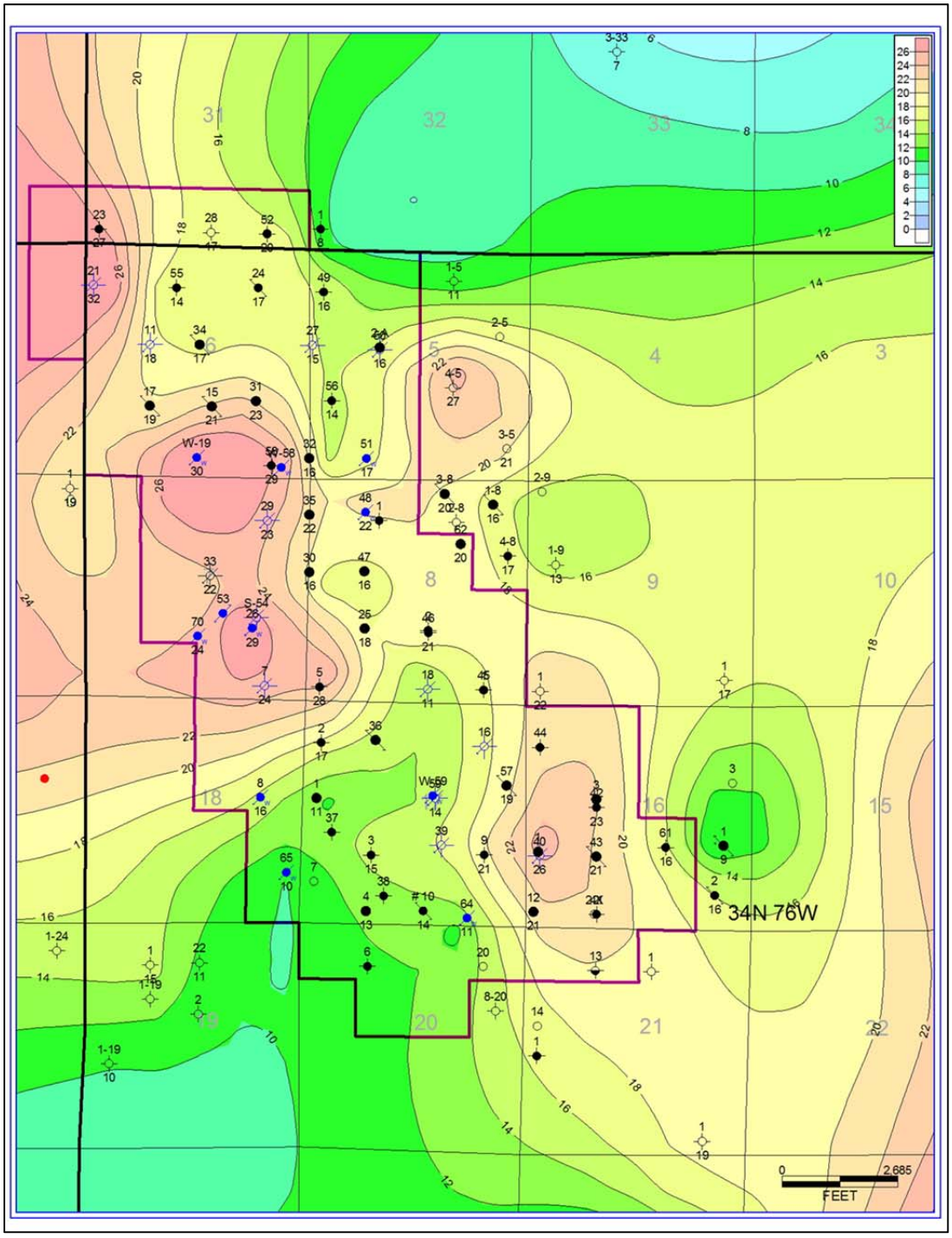


Figure 5: Dakota Isopach

[3] South Cole Creek Dakota Sand Reservoir Engineering Report, Phillips Petroleum Company, January 1967, Accessed from the Wyoming Oil and Gas Conservation Commission website (www.wogcc.state.wy.us)

Modeling Approach

Static Model

COZView/COZSim was developed as a predictive tool for evaluation of CO2-EOR. Initialization of the simulation model is to be at current conditions. In the case of the Dakota formation in the SCC Field, the reservoir has undergone primary depletion and secondary recovery under water flood operations. Current reservoir conditions (OIP and saturations) must be estimated and/or inferred to the best of our ability.

Oil in Place

While current fluid saturations in the reservoir are not known (no recent well log surveys), the current oil in place (OIP) can be estimated based on the OOIP and the cumulative oil production to date (Np). This results in the following estimate of OIP:

OOIP, MSTB	35,800
Np, MSTB	11,193
OIP, MSTB	24,607

Saturation Functions

Laboratory SCAL Data are often not available for these older oil producing properties. When they are available, they may be in core from the better portions of the reservoir; hence they may not be representative, on average, of the entire reservoir. Relative permeability relationships will be developed using internal correlations based on the initial connate water saturation (Swirr), and the residual oil saturation to water (Sorw). There will be a discussion on capillary pressure later in the report. Swirr was assumed to be 27.0% based on well log and core data and Sorw was set to 35.0% based on core studies and analogous field data.

PVT Properties

It is not unique for older oil producing properties in the U.S. to not have laboratory PVT analyses. Often only oil gravity and possibly gas gravity data are available for sales purposes. This is the case for the Dakota reservoir at SCC Field. PVT relationships will be developed using the internal correlations based on an oil API of 35, a gas gravity of 0.79, and a reservoir temperature of 151°F.

Volumetric Properties

Volumetric properties are defined as Net thickness, Porosity, and Areal extent. Net thickness and porosity are assumed to be constant within a layer in COZView/COZSim, but they can vary from layer to layer. Initial values were based on WGA[1] geologic interpretations and prior volumetric calculations of OOIP.

Net Thickness, ft	16
Porosity, fraction	0.115

Areal extent, acres	3715

Permeability

Permeabilities in the X, Y and Z directions must be specified in the simulator. As with the volumetric properties, permeabilities are constant within a layer, but they can vary from layer to layer. Initial values were based on WGA[1] past geologic studies of limited core data. No permeability anisotropy was indicated in core data or general water flood response.

X-direction Permeability, md	20.6
Y-direction Permeability, md	20.6
Z-direction Permeability, md	5

Fluid Saturations

While significant gas production was likely produced during primary depletion, current producing operations suggest a very low GOR; hence free gas is unlikely to exist in the reservoir in any significant quantities. Current reservoir saturations (So and Sw) are

Sorw < So <1-Swirr

Swirr < Sw < 1-Sorw

Pressure

The initial reservoir pressure (January 1950) was 4700 psia at a datum of approximately 8250 ft TVD (-3000 ft ss)[Error! Bookmark not defined.]. The current reservoir pressure is believed to be approximately 600 psia at the same datum.

Model Initialization (OOIP and OIP validation)

COZView provides the tools for the user to reproduce the structural surface in the model. This is followed by definition of formation layers and properties consistent with the geologic information. Saturation functions and PVT relationships are then generated. Appropriate screen shots of the model creation process are shown in Figure 6 to Figure 11.

It is noted that all plots, maps, etc. from COZView shown in this report were inserted into the report directly from COZView using the Clipboard feature included in most screens.

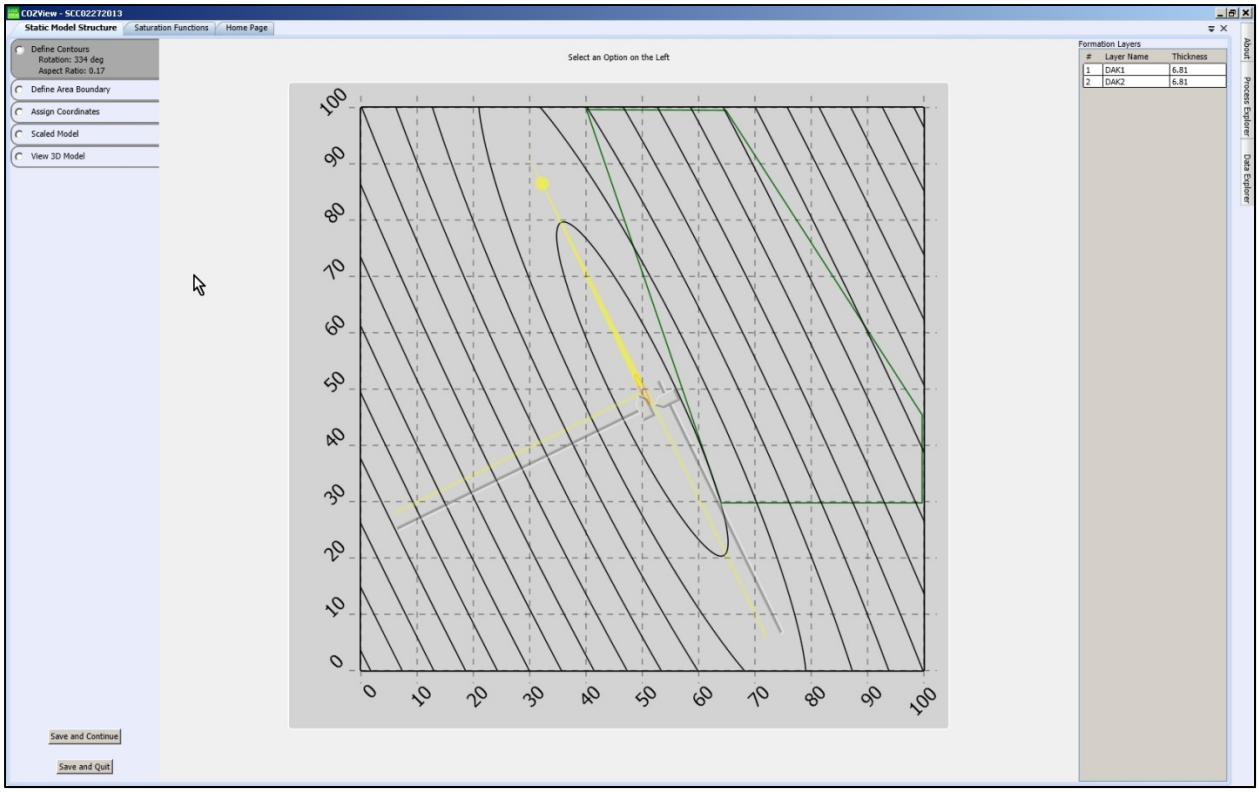


Figure 6: Static Model Structure Creation

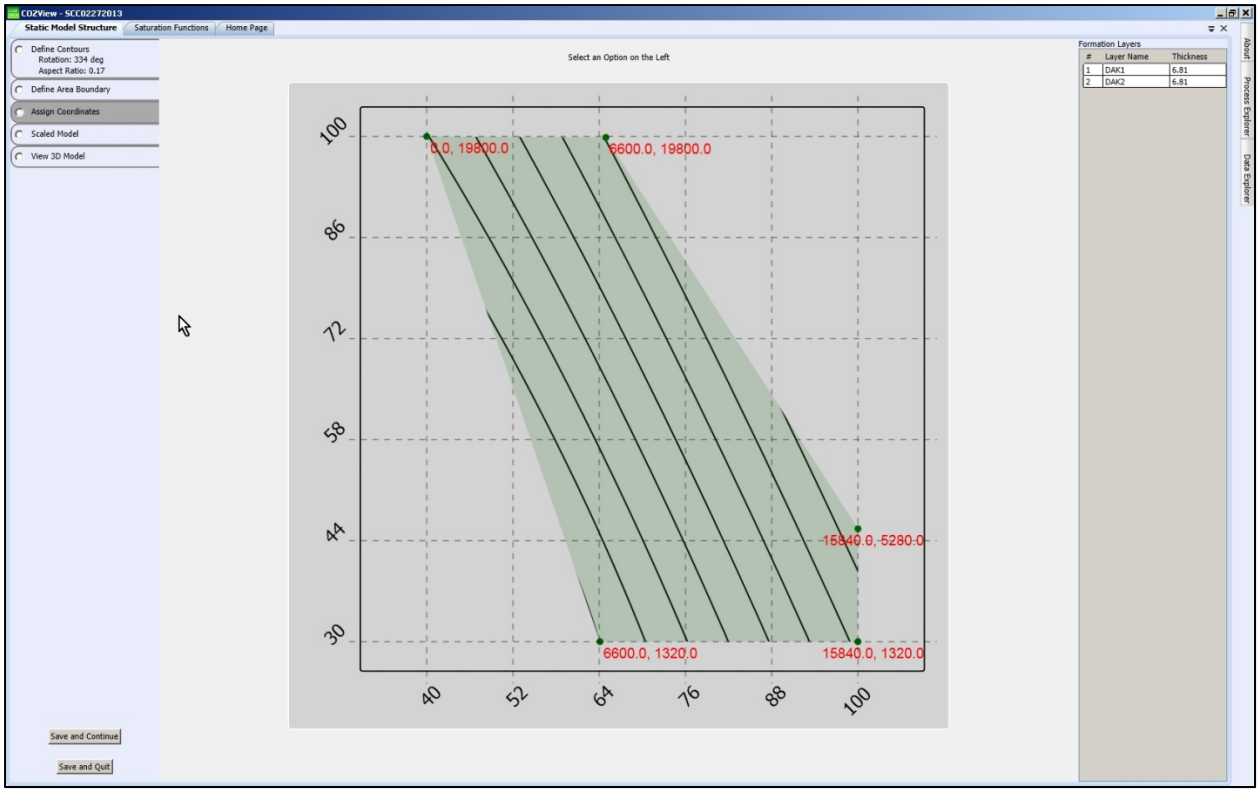


Figure 7: Static Model Boundaries

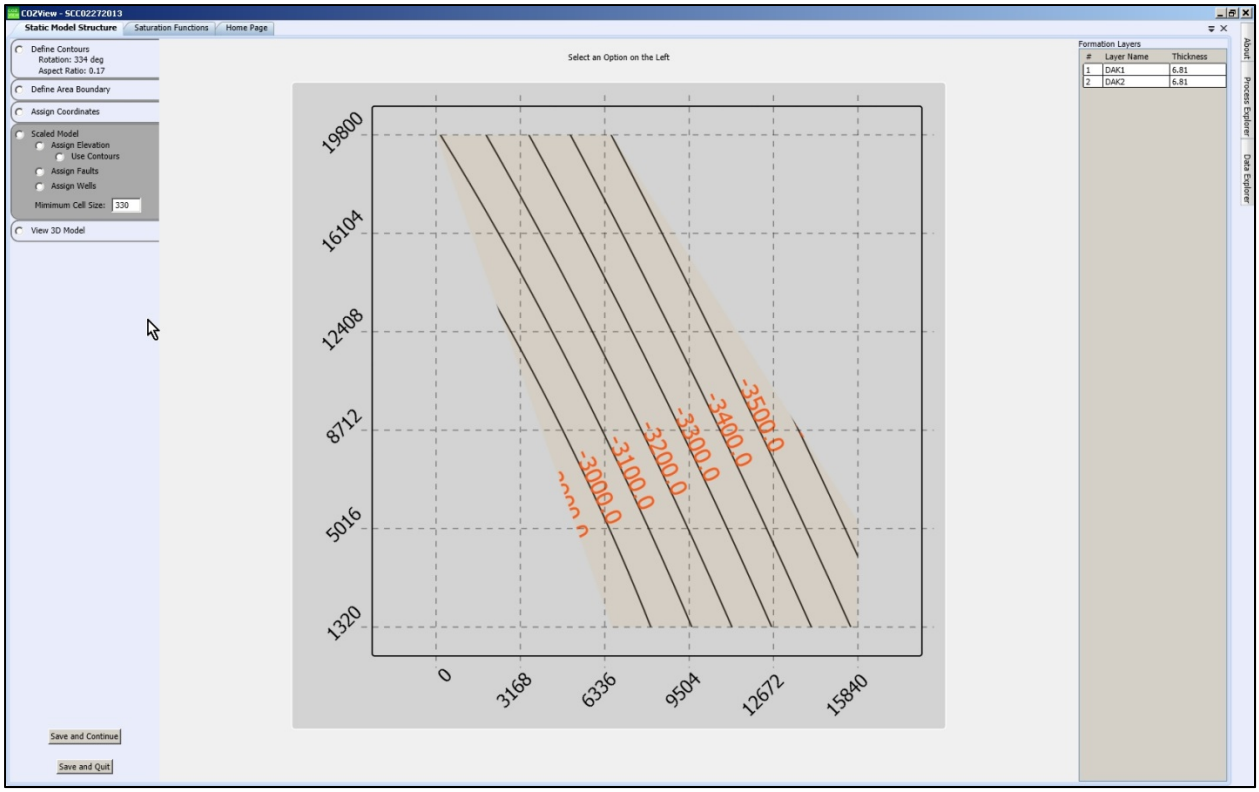


Figure 8: Static Model Structural Contours

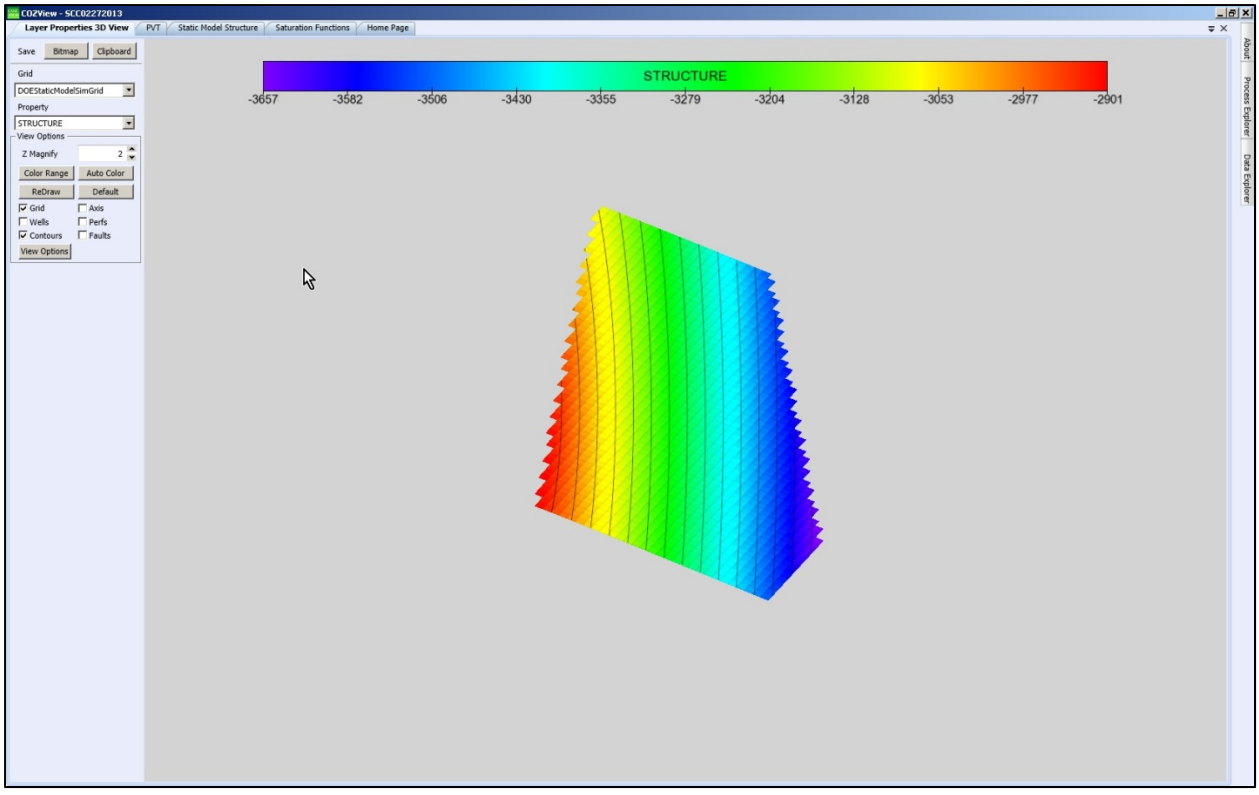


Figure 9: Static Model 3D Structural Display

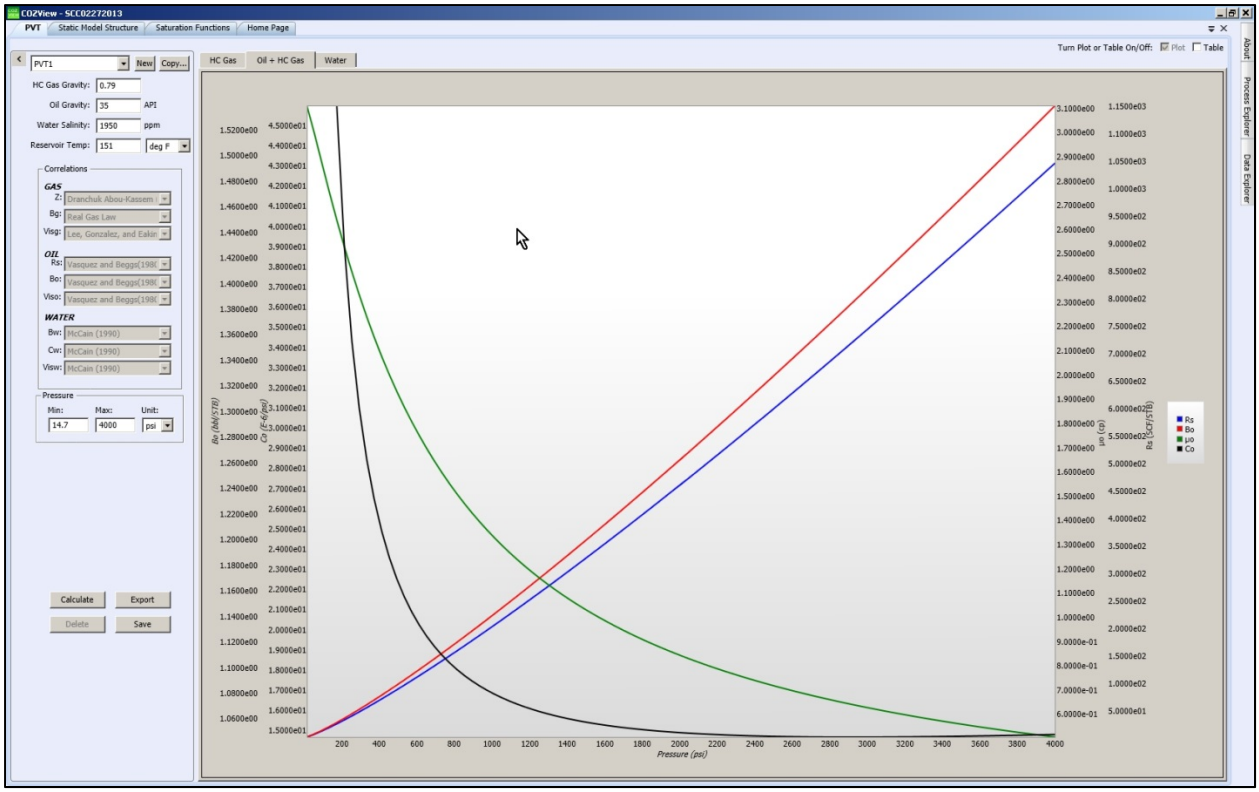


Figure 10: PVT Development

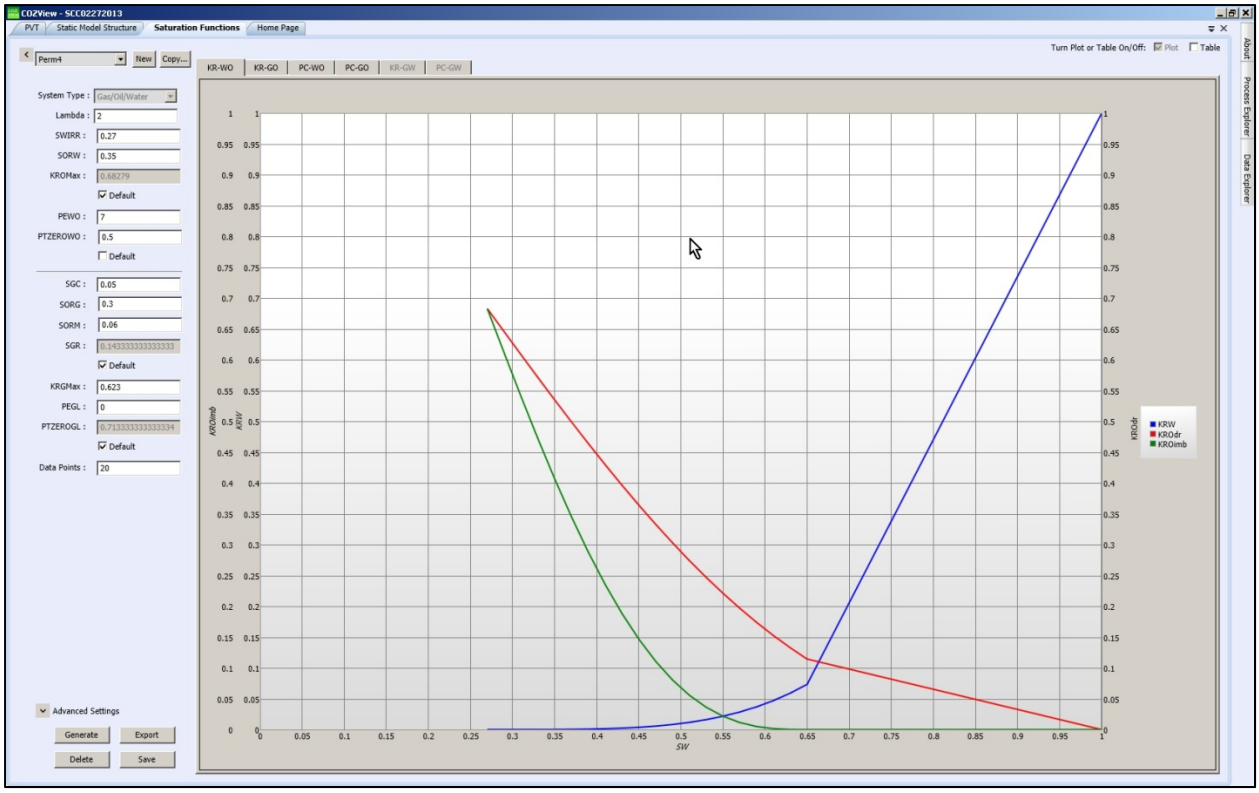


Figure 11: Relative Permeability Development

User comments: Creation of the static model by drawing a simple structure map and entering basic properties allows the user to have the ability to quickly get started on modeling reservoir behavior. This is especially helpful for engineers and geologists at smaller energy companies that may not have access to geological mapping software and rely on hand drawn maps or reproductions of maps from published literature. The ability to import from available geological mapping software programs might be considered as an additional tool to accommodate those users who have already created more complex structure maps within geological mapping software programs, and would prefer to use those maps within COZView/COZSim.

As the OOIP is one of the more reliable quantitative values that are assumed to be known, the static model created by the user should be tested against this value. The Model Validation functionality allows the user to utilize all static model data and the appropriate PVT and saturation functions to calculate the OOIP. If the model calculated OOIP is not consistent with the user's expectation the input data should be reviewed and adjusted as necessary. Generally, adjustments will be to net thickness and porosity, but Swirr, the areal boundaries, the initial pressure assumption and PVT properties may also require adjustment.

The initial volumetric calculation for SCC Field using the input parameter values resulted in an OOIP that was slightly higher than the assumed value. It was believed that the average porosity and net thickness over the model area were high due to the lack of formation tapering at the boundaries in the model. These values were adjusted such that the model OOIP was consistent with the assumed value of 35.8 MMSTB.

User comments: The Process Explorer menu within COZView/COZSim provides a logical framework procedure for creating a reservoir model. By working through each step, the Process Explorer menu helps the user to make decisions about setting realistic reservoir properties before moving on to more detailed decisions (such as individual well constraints). The Model Initialization and Model Volumetrics tabs provide feedback on the effects of the properties the user has chosen.

The next step in the process was to establish the current oil in place and the associated fluid saturations. Neither of these is known directly at this time. However, the cumulative oil production to date is known with some certainty based on historical production records. The cumulative oil production as of 1/1/2013 is estimated to be 11.2 MMSTB. This oil production resulted from primary depletion and water flood operations.

The current oil in place (OIP) should be the OOIP less the cumulative oil production. This calculation yields an implied OIP of 24.6 MMSTB as of 1/1/2013. While water injection has occurred in the reservoir, as well as water production, knowledge of the actual volumes of water produced and injected is not required. If the current reservoir pressure is known, the next model initialization step will account for the net water volume that has been added to the reservoir. The goal of the next model initialization (1/1/2013) is to achieve the implied OIP volume at the current reservoir pressure.

The Model Initialization process allows the user to initialize the model at original reservoir conditions, thereby calculating OOIP, and at current reservoir conditions, thereby calculating OIP. In this case the

assumption is made that the historical water flood operations swept the oil saturations down to some level throughout the reservoir. (This is a generalization, as individual patterns or areas of the reservoir may have performed differently.) The current time model initialization parameters were set as follows

Initialization Date: 1/1/2013

Model Type: 2-phase

Pressure @Ref: 600 psia

Reference elevation: -3000 ft ss

Elevation @WOC: -2920 ft ss

PSATHCG: 50 psia

The current reservoir pressure is estimated to be 600 psia (at the reference elevation which is the same as the original conditions). The PSATHCG (bubble point pressure) was lowered to 50 psia from the original condition of 500 psia, as the current oil produced is a dead oil with very little solution gas. The WOC was raised to the top of the simulation model. This suggests that water has swept the entire reservoir *from the "original" WOC to the top of the reservoir (This is consistent with the assumption that the water flood has swept the entire reservoir).* In the absence of capillary pressure, this would reduce the oil saturation to Sorw. Initialization of the model using these parameters and the same PVT and Saturation Function tables yields an OIP of 16.4 MMSTB. This is much lower than the implied OIP calculated above. In addition, review of the saturation maps in 3D Array View shows the oil saturation at Sorw. As the actual field production indicates that wells are currently producing at 1-3 percent oil cuts, it is recognized that the model oil saturations are not correct. The current oil saturations in the reservoir must be in excess of Sorw.

In order to initialize to the current oil saturations, a capillary pressure relationship must be introduced. Capillary pressure correlations are included in the Saturation Functions area. The saturation function used in the last initialization of OOIP and OIP was named Perm4. Capillary pressure is added to the existing tables by inputting a value for PEWO (water-oil capillary pressure entry pressure value). A value of 7 was used. Generate created the capillary pressure curves. Selection of the PC-WO tab displayed the water-oil curves for drainage and imbibition (See Figure 12). The drainage curve is valid in areas of the reservoir that have not been swept by water. The imbibition curve is valid for areas of the reservoir that have been swept by water. In this case, all areas of the reservoir have been swept by water (WOC is at the top of the reservoir).

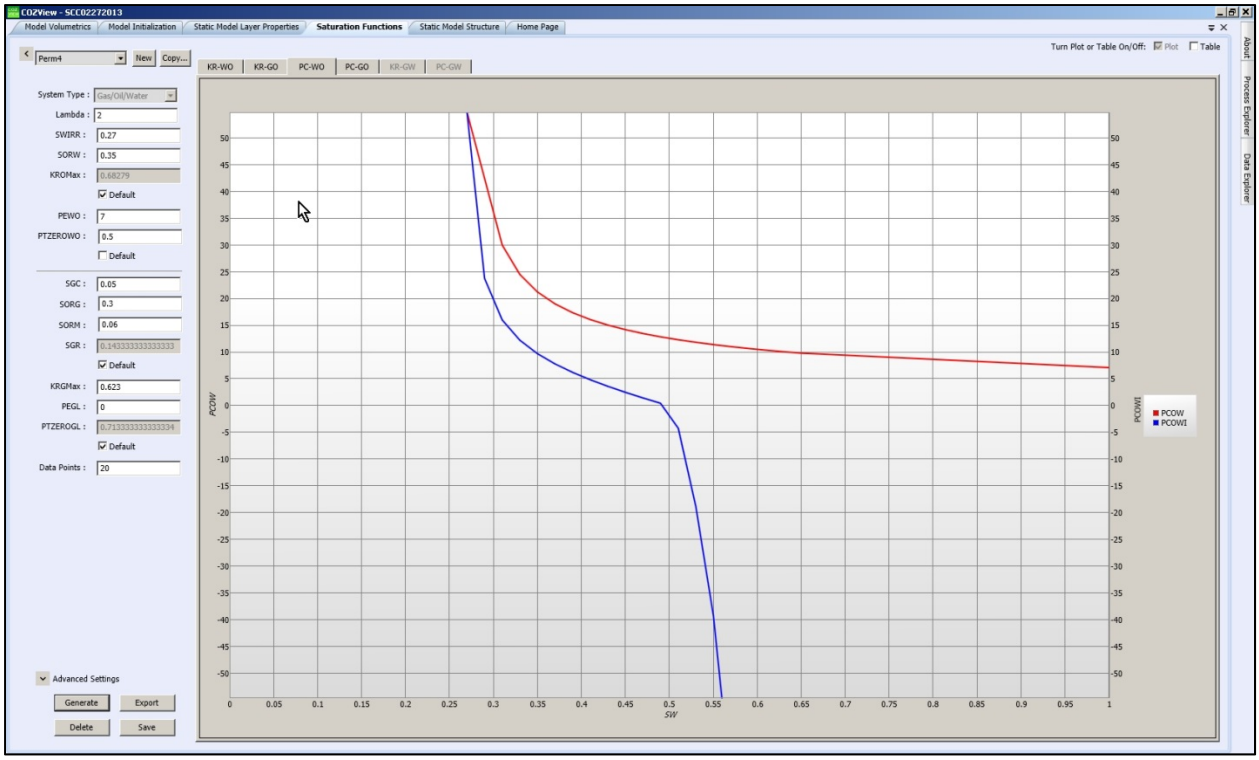


Figure 12: Base Water-Oil Capillary Pressure

The new saturation functions were saved and the Model Initialization rerun. The new volumes were

OOIP (1/1/1950)	35.8 MMSTB
OIP (1/1/2013)	21.7 MMSTB

The OOIP value did not change from the value calculated previously. This indicated that the capillary pressure curve was consistent with the original reservoir saturations conditions (Sw=Swirr and So=1-Swirr). The OIP value was increased from the previous calculated value, but was still too low relative to the implied OIP that we wished to achieve (24.6 MMSTB). Movement of the imbibition capillary pressure curve to the left will increase the So in the reservoir; movement to the right will decrease the So in the reservoir. The imbibition curve is adjusted by altering the PTZEROWO value (currently set to 0.5). This is the Sw value where the Pc curve crosses zero on the pressure axis. Changing this value to 0.425 and generating a new curve provided the curve in Figure 13.

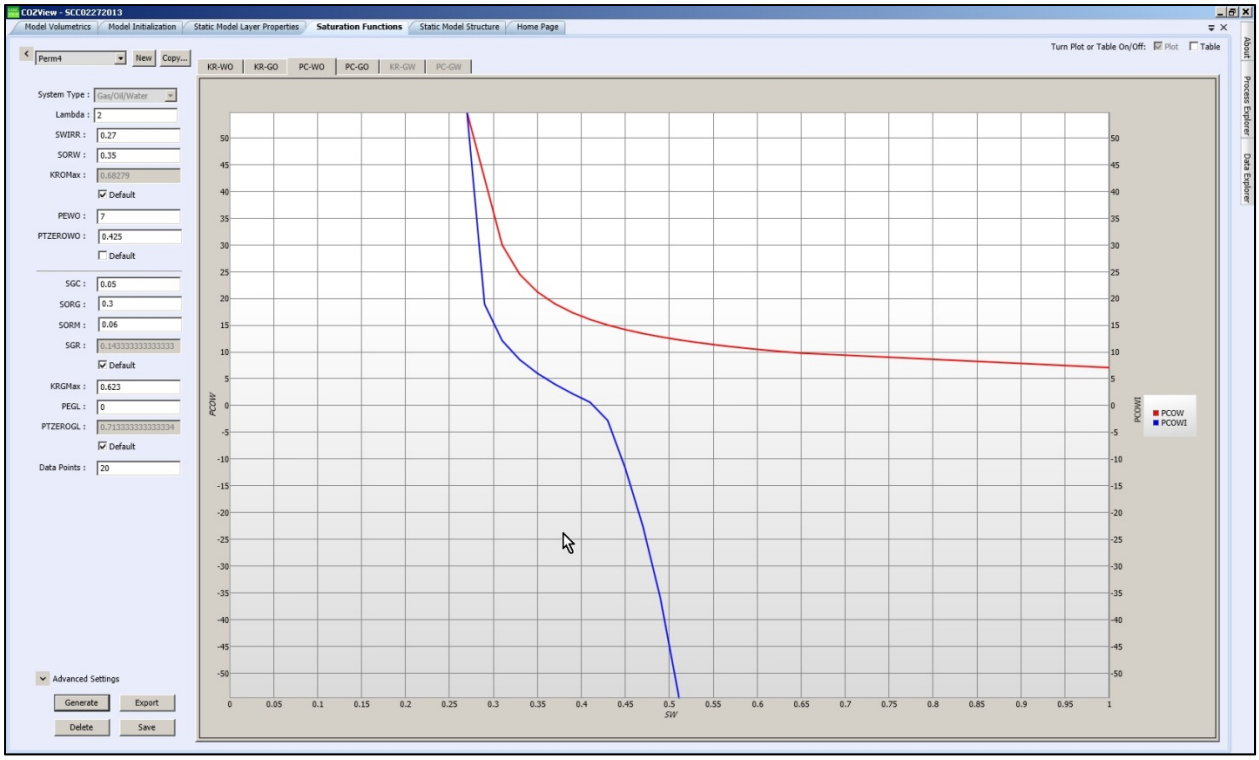


Figure 13: Adjusted Water-oil Capillary Pressure

The new curve was saved and the Model Initialization was rerun. The resulting OOIP and OIP are shown below.

OOIP (1/1/1950)	35.8 MMSTB
OIP (1/1/2013)	24.4 MMSTB

This was an iterative process that actually took multiple Pc curve changes to achieve the desired OIP value. Review of the oil saturation map in 3D Array View showed the reservoir at an oil saturation of 49.7 – 55.5 percent. As the Sorw is 35.0 percent, the oil in place at 1/1/2013 is mobile which is consistent with current well production rates.

At this point it was felt that the model was calibrated to the original OOIP and close enough to the current OIP volume; hence it was ready to initiate prediction scenarios.

User comments: While some users may not have access to saturation curve data for their desired reservoir, changing the saturation functions to match expected remaining oil in place in many cases may be more manageable. Even if saturation data is available, it may not be representative of the entire modeled area, and saturations may need to be adjusted to estimate the average behavior within the modeled area.

Well Tuning

Prior to initiating any prediction cases, it was important to be sure that wells in the simulation model were producing at current conditions in a manner consistent with those wells in the field (total liquid rate and water cut). All active wells had been loaded into the model during the static model input. These are shown on the structure map in Figure 14. The structure dips SW to NE from approximately -2900 ft ss to -3600 ft ss.

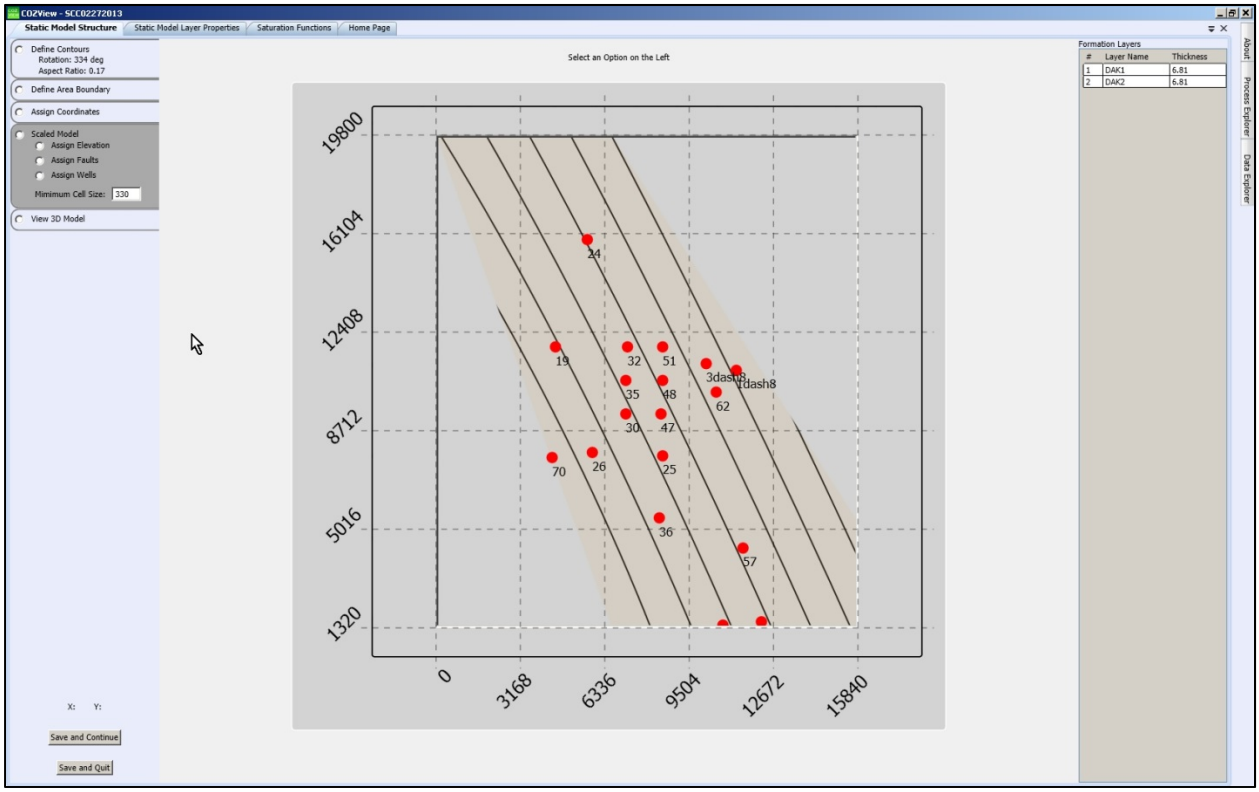


Figure 14: Well Locations

A short prediction run was made to test the well production and injection rates and water cuts in the model versus actual rates and cuts. The individual production well BHPs were set to 300 psia. The injection well BHPs were set to 2500 psia. A one month simulation run was made. This indicated that the production wells were producing 10-15 STB/D of total fluid at water cuts of 30-35 percent. The injection wells were injecting at 150 STB/D.

Actual well production rates in the field are 400-500 STB/D of total fluid at water cuts of 95-98 percent. Water injection rates average approximately 200 STBW/D per well.

Based on this initial run, it was clear that production well rates and water cuts were too low in the simulation model. This is not inconsistent with simulation models that have undergone rigorous history matching. Typically, individual well fluid capacities and water cuts require adjustment during the history matching process or prior to the start of prediction cases. As we are not doing rigorous history matching,

other adjustments to the model are required prior to starting prediction cases to bring the simulated rates and cuts into agreement with current field performance.

Permeability

Reservoir studies of the Dakota formation in other fields in the area have consistently indicated that effective permeabilities are higher than indicated from core data. This has been attributed to natural fractures which have been documented in core studies. Simulation studies in other fields have shown that core permeabilities are inconsistent with production and pressure performance in those fields. It is surmised that the very low fluid production rates in the short simulation run were due to the low permeability being used (~20 md). A nearby field was found to have an effective permeability of 200 md in a detailed Dakota reservoir simulation study by another operator. This higher permeability was input to the simulation model and a test prediction run was made. This simulation run resulted in well total fluid rates of 50-60 STB/D and water cuts of 30-35 percent. The injection well rates were approximately 1000 STBW/D.

Relative Permeability

As water is the dominate phase in the current well production, it was decided to adjust the Krw curve. This would impact the water cuts and possibly increase the total fluid production rates. This was done by using the Advanced Setting option on the Saturation Function screen. Using this option, the krw curve was increased, consistent with the relative permeability correlations, to the curve shown in Figure 15. This straight line curve is consistent with a naturally fracture reservoir.

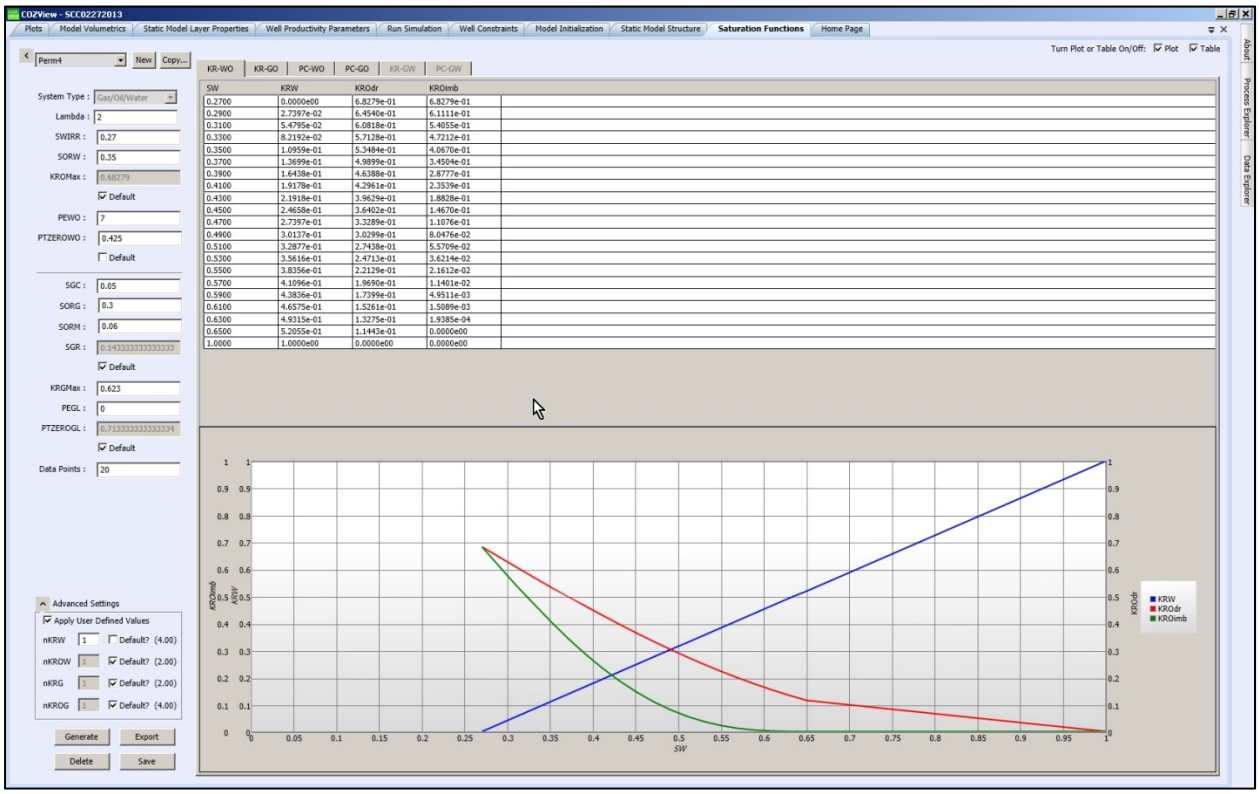


Figure 15: Adjusted Krw Curve

The short simulation prediction was rerun using the new saturation functions shown in Figure 15. This resulted in well fluid rates of 450-500 STB/D and water cuts of 95-96 percent.

Further similar adjustments to the Krow curve (reduced) and the well PIs (multiplied by 0.3) yielded well fluid and water cuts very close to current reported production.

Predictions

A number of development scenarios are possible for a CO2-EOR program for this reservoir. It was decided that the Case Study would focus on maximum utilization of the active wells in the field. Drilling of new wells or re-entry of old wells would initially be kept to a minimum.

The active well locations and the structure of the reservoir appear to be suited for crestal CO2 injection. While other development scenarios can be investigated, the Case Study investigated this approach. The current reservoir pressure is estimated to be approximately 600 psia. The minimum miscibility pressure (MMP) for CO2 with this oil at the reservoir temperature is estimated to be in the 2000-2500 psia range based on correlations. If a miscible displacement of the oil by CO2 is to occur in the development plan, the reservoir pressure must be increased. Ideally, this pressure increase would occur before the start of production. Re-pressuring this reservoir can be achieved with water injection and/or CO2 injection. Water injection is currently being implemented in the reservoir. The infrastructure for CO2 injection does not currently exist in the field. Hence, it seems logical to at least start the re-pressuring process with water injection.

Current (1/1/2013) oil saturations in the reservoir are estimated to average approximately 50 percent based on the earlier model initialization process. This suggests there is a significant amount of mobile water in the reservoir at this time. While there is also a significant amount of oil saturation in the reservoir, it is less mobile due to relative permeability effects. Any further addition of water to the existing active well area, would likely be detrimental to short term oil production. Hence, it was decided to initiate re-pressuring with water injection via the most structurally low wells in the reservoir.

However, review of the current active well locations in Figure 14, indicates that only well 1dash8 is sufficiently down dip. It was therefore decided to drill three additional down dip wells for the purpose of water injection. Wells 49_D, 50_D and 63_D were completed in the model as shown in Figure 16.

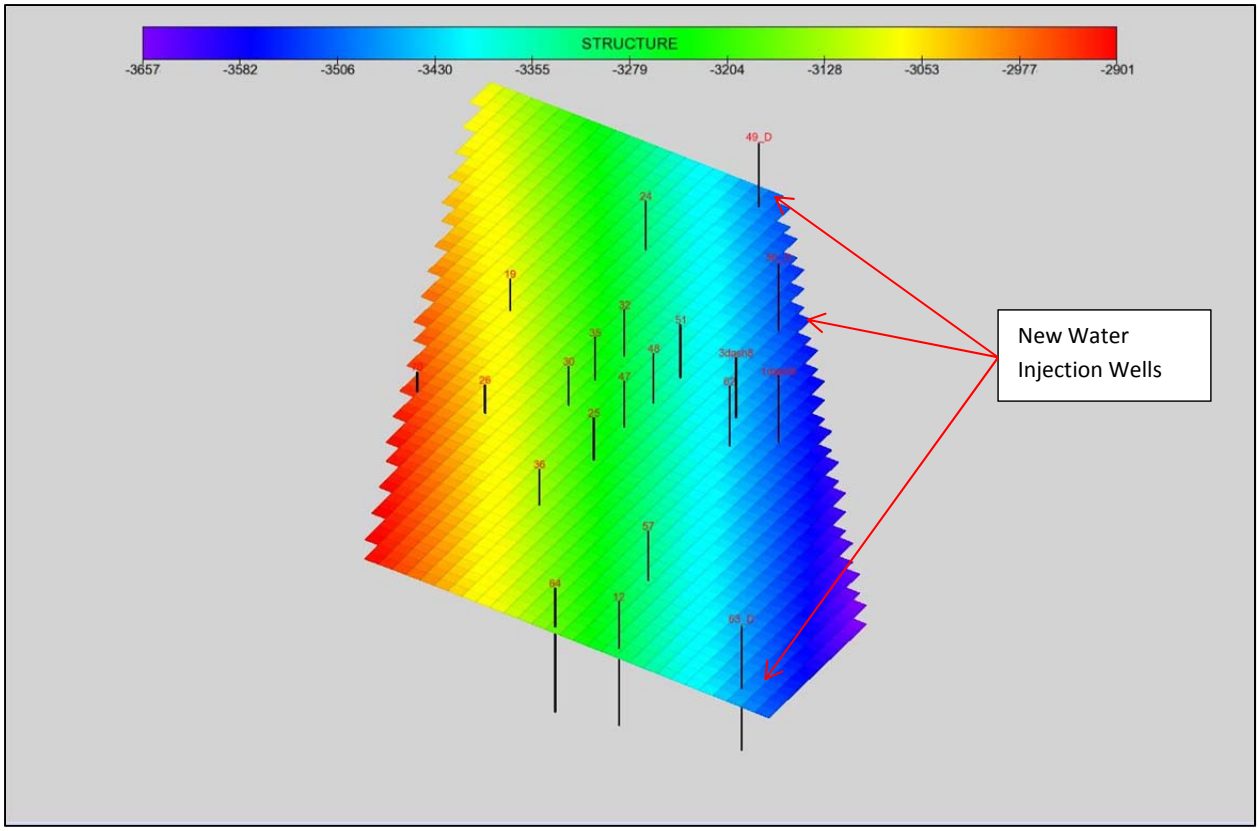


Figure 16: Active and New Injection Well Locations

Sensitivity runs were made of 1-3 years duration where only the four water injection wells were active (no production) to test the injection volumes, BHPs and time to re-pressure the reservoir to approximately 2000-2500 psia. Final simulation runs suggested that maximum well injection rates of 2000 STB/D and maximum well bottom hole pressures of 2250 psia would increase the reservoir pressure in approximately 1.5 – 2.0 years.

Figure 17 shows the reservoir pressure in layer 1 after one month of water injection in the four down dip wells. Reservoir pressures were approximately 600 psia at the wells at the start of water injection.

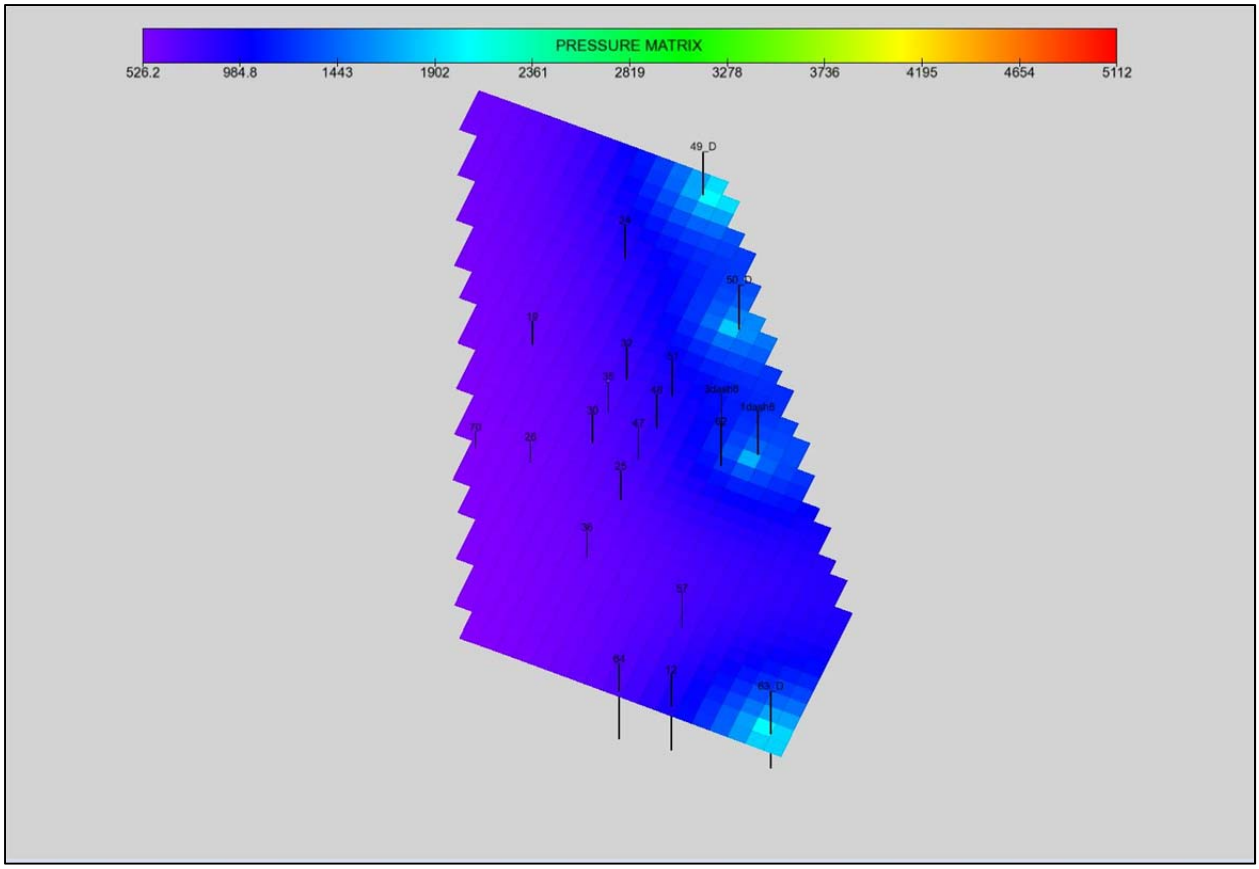


Figure 17: Reservoir Pressure at 2/1/2013 - Layer 1

Sensitivity simulation runs were then made relative to the start time, injection volumes and bottom hole injection pressures for the CO2 injection wells. Five structurally high, currently active wells were selected for CO2 injection. These were wells 36, 64, 70, 19 and 24. These injection locations are shown on the Molefrac-Z-CO2 map in Figure 18.

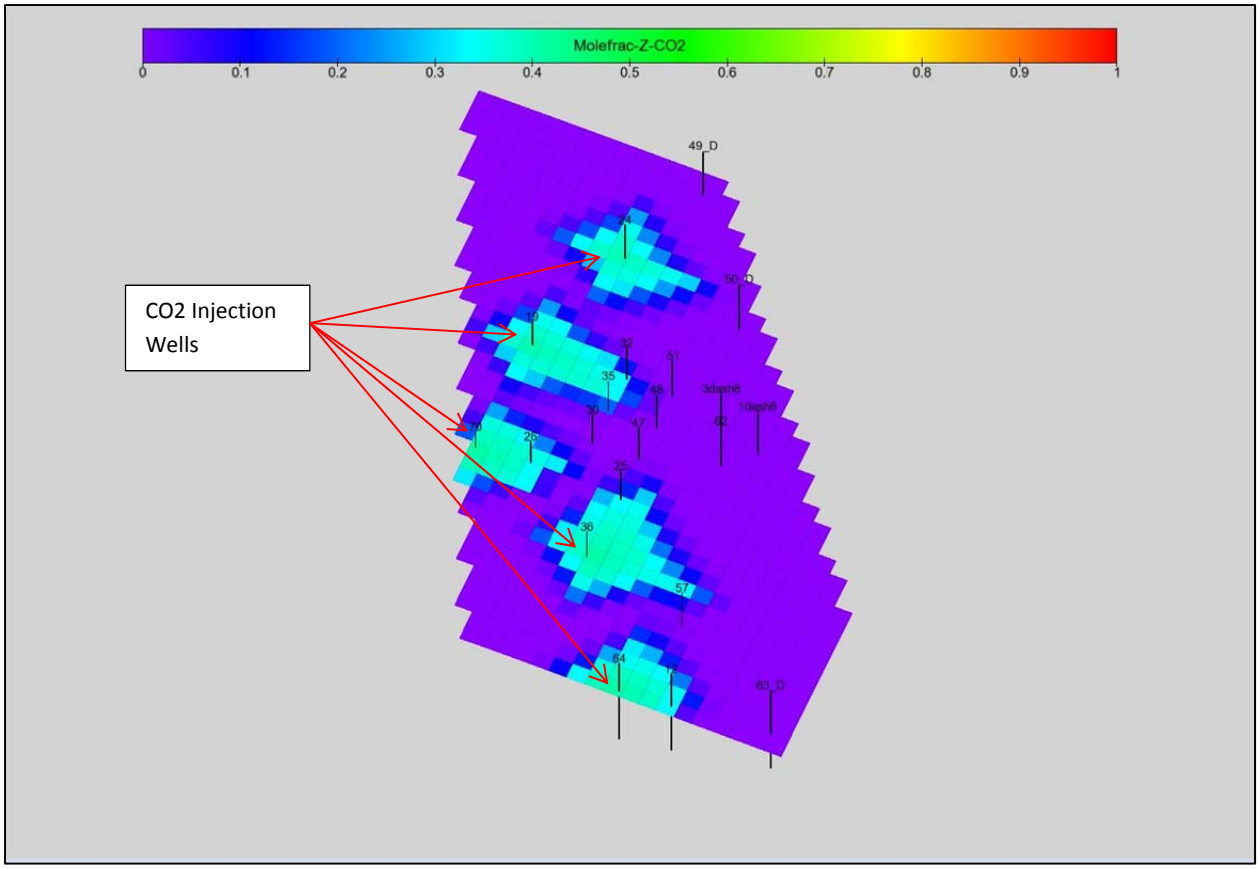


Figure 18: Molefrac-Z-CO2 at 1/1/2015 - Layer 1

The individual CO2 injection wells were limited to a maximum injection rate of 10,000 MSCF/D and a maximum bottom hole pressure of 3000 psia. Initial sensitivity runs initiated CO2 injection on 1/1/2014, one year after initiation of down dip water injection. Producing wells were brought on production as of 2/1/2014 based on a bottom hole pressure of 2250 psia. The well maximum liquid production rate was set at 2000 STB/D.

Figure 19 shows the field production and injection rate for a prediction to 1/1/2026. An oil rate plateau is achieved in late 2016 at approximately 900 STB/D. The oil rate increases to 1150 STB/D in early 2022. Cumulative oil production for this case was 3.6 MMSTB (10.1% of OOIP/14.8% of OIP) at 1/1/2026. (Note that the default Sorm (residual oil saturation to miscible displacement) of 6.0% was used in all runs to this point.)

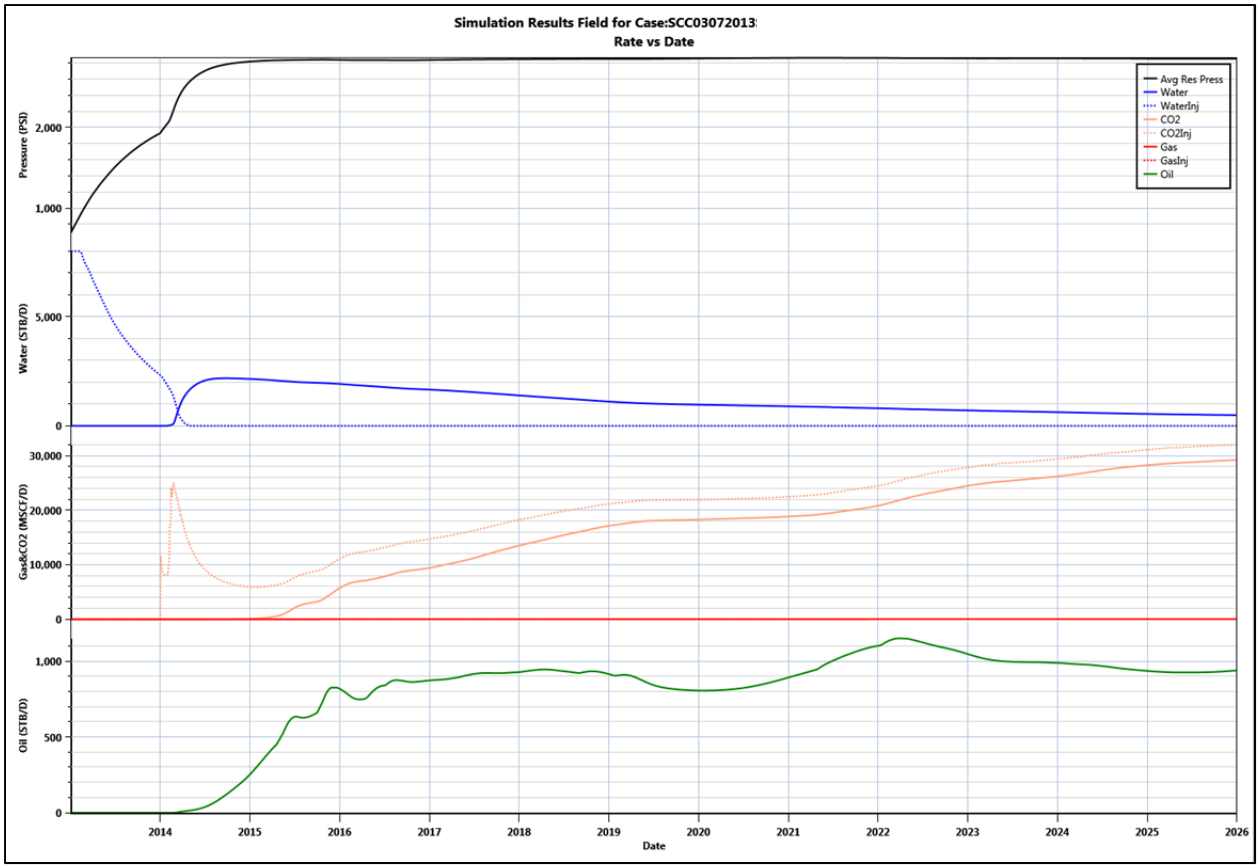


Figure 19: Field Rates, Base Prediction

At this time the full prediction simulation run time was quite long (~26 hrs). This was deemed to be too long for effective progression of the study. The model default cell size of 330 ft x 330 ft resulted in a model size of 48 by 56 cells by two layers (5376 total cells). All of these cells were not active due to the model boundaries. In addition to the model size, the long run time was also due to the slower processer in the computer being used at this time. It was decided to upgrade the computer to a faster processer and reduce the model grid size. The model default cell size was overridden in the Static Model area and set to 500 ft by 500 ft. This reduced the grid size to a total of 2160 cells. The 13 year simulation run completed in approximately 4 hours with the smaller grid and faster processor (2.40 GHz). Comparison of the OOIP, OIP and prediction results for the large and small grid models was very compatible.

CO2 Injection Well BHPs

At this time it was felt that the BHP limit (3000 psia) for the CO2 injection wells was not as high as could be safely achieved in the field. A higher injection pressure should result in more CO2 injection being injected earlier in the life of the project which should be beneficial to the oil production rate response. The BHP for the CO2 injection wells was increased to 3500 psia. Figure 20 shows the improved oil production rate that resulted from the increased CO2 injection well BHP. This oil rate increase is due in

large part to the increased well productivity resulting from the higher reservoir pressure (more CO2 injection). The cumulative oil production was 6.7 MMSTB for this case.

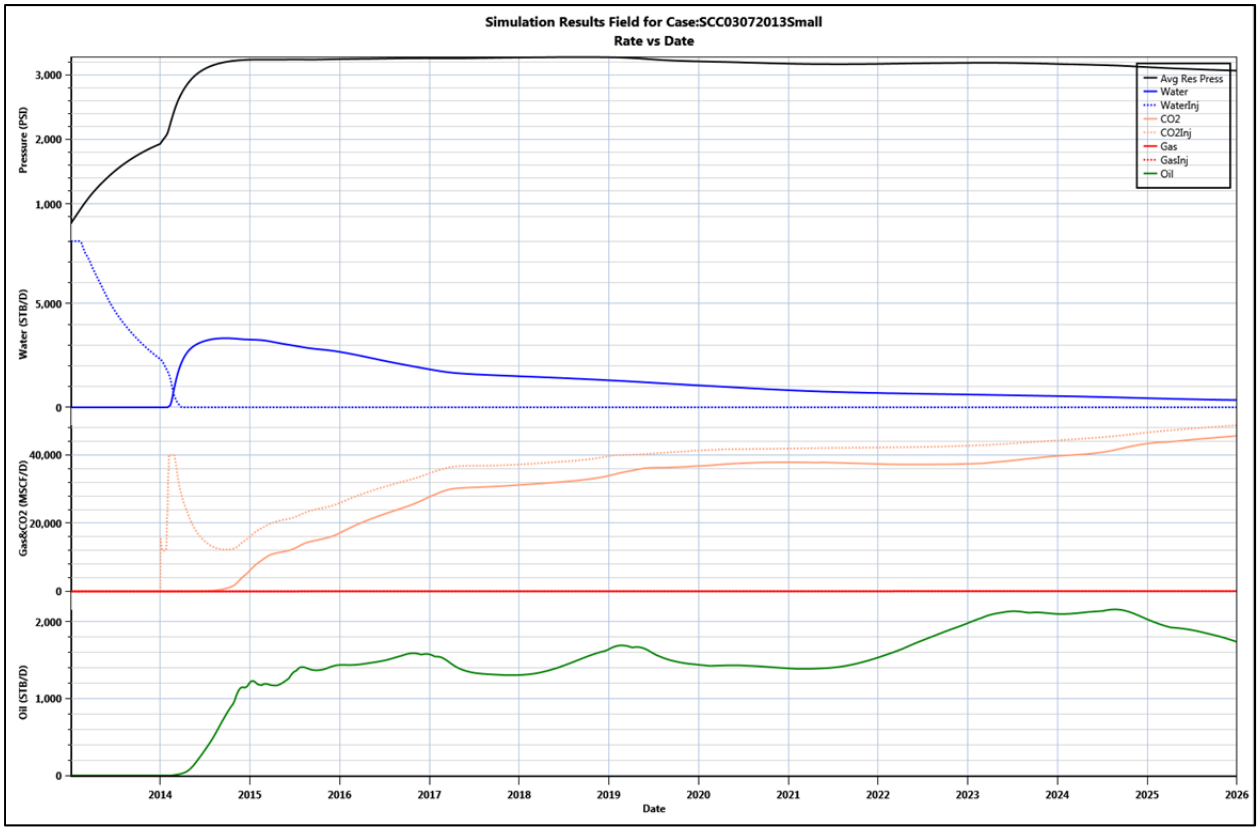


Figure 20: Field Rates, Injection BHP Increased to 3500 psia

New Production Wells

The oil saturation map at 1/1/2018 is shown in Figure 21. This indicates that a number of areas of the reservoir are being swept by the injected CO2, but no wells are available to produce the mobilized oil.

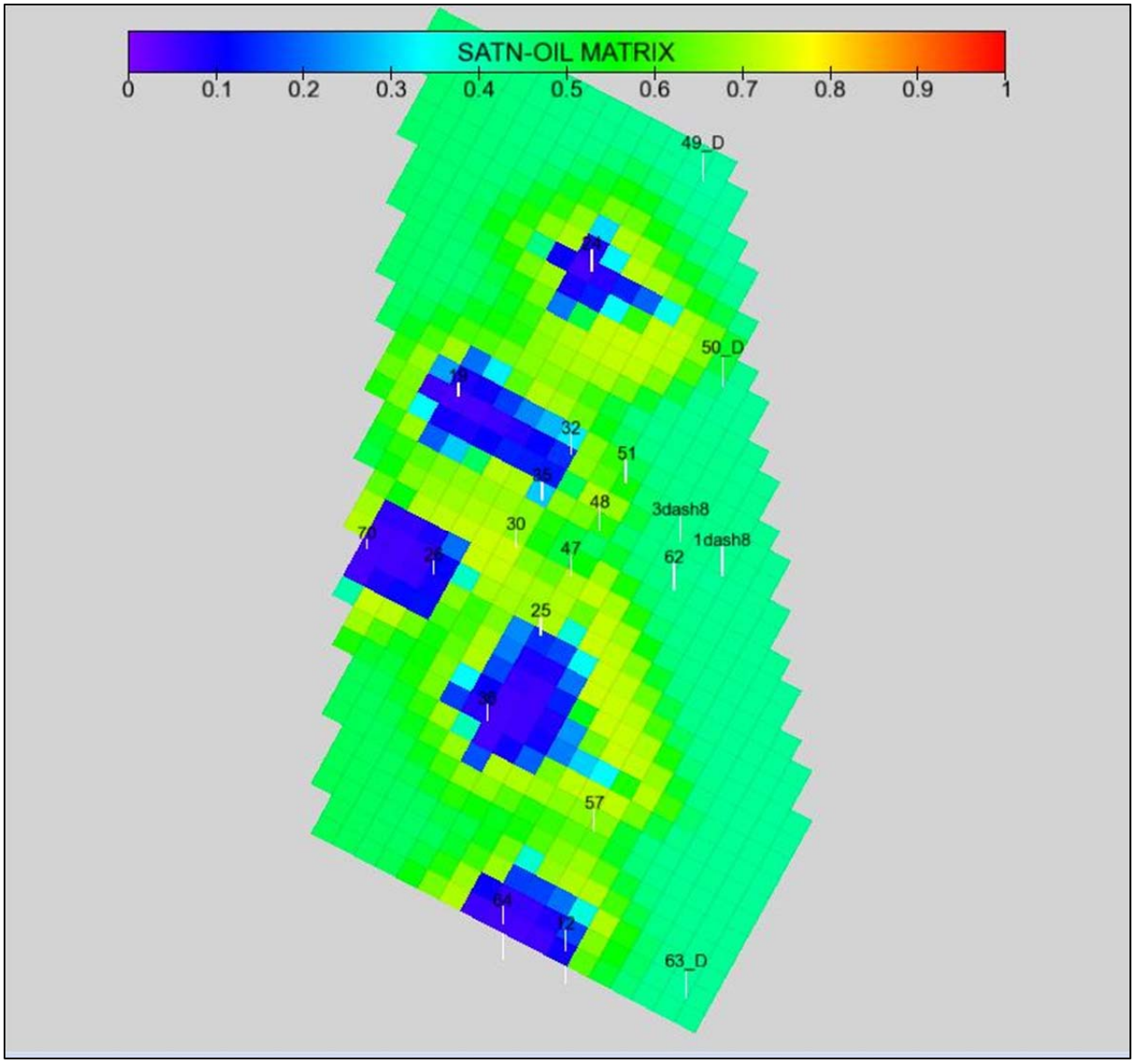


Figure 21: Early Oil Saturations, Base Prediction

Two new production wells (New1 and New2) were added to the model to attempt to recover additional oil. See Figure 22. The addition of a limited number of new wells was in keeping with the concept of minimizing new wells at this point in the study.

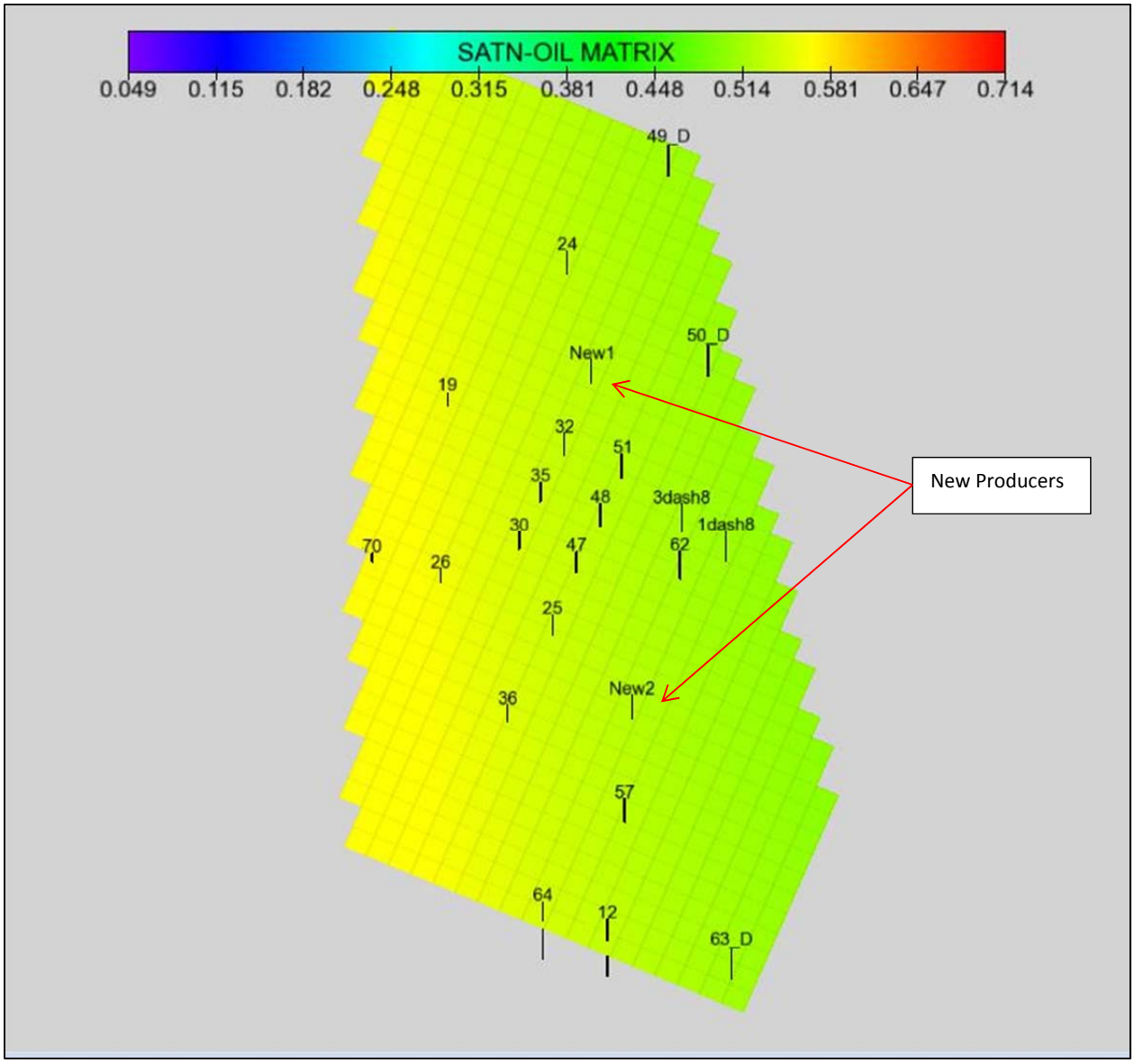


Figure 22: Well Locations with New Production Wells

Acceleration of Oil Production

In addition, it was felt that the reservoir pressure was increasing fast enough once CO2 injection was initiated that earlier CO2 injection would accelerate the oil recovery. Hence, sensitivity cases were run with CO2 injection starting six months earlier in 6/1/2013. The oil producers were allowed to start production subject to the BHP constraint of 2250 psia effective 8/1/2013. This combination of these operational and new well changes significantly accelerated the oil recovery and produced more oil over the simulate project life.

Cumulative oil production after 13 years was 7.6 MMSTB after these changes. However, based on the belief that the reservoir is naturally fractured, it was felt that this recovery was a bit optimistic. The

model was utilizing a residual oil saturation to the miscible CO2 (Sorm) of 6.0% to this point. After a number of sensitivity runs, it was decided to run the model with a Sorm of 20%. This resulted in a reduction of the cumulative oil production to 6.9 MMSTB. The production profile is shown in Figure 23.

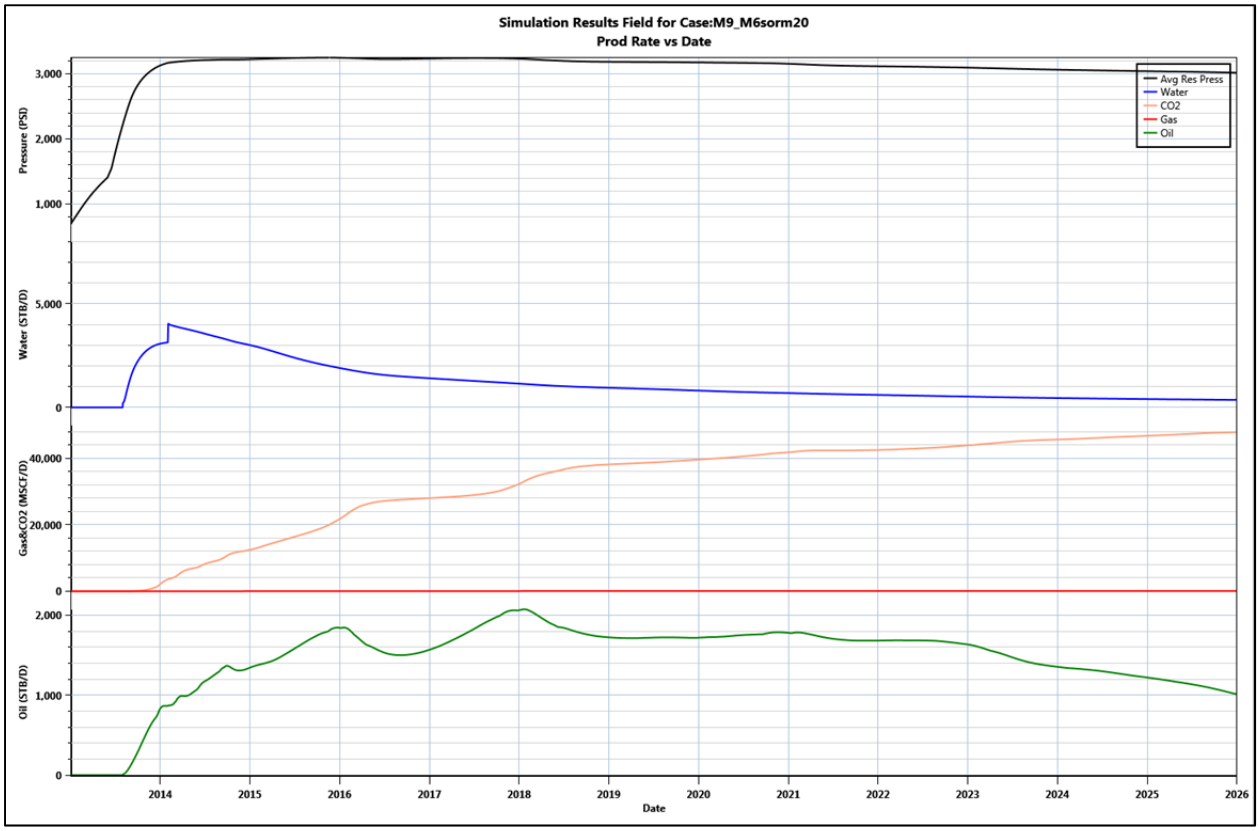


Figure 23: Field Rates, Accelerated Production and Injection

Final Prediction Configuration

A final review of the CO2 injection well constraints suggested that individual well CO2 injection rates, which reached 10,000 MSCF/D during the simulation life, may be excessive. A constraint of 3000 MSCF/D per well was felt to be more reasonable and conservative. This reduction of the maximum well CO2 injection rate coupled with the irregular CO2 sweep in the reservoir due to the distance between the CO2 injection wells, led to an increase in the number of CO2 injection wells from 5 to 14. The improved sweep was supplemented with 4 additional production wells. This final case utilized 4 down dip water injectors, 14 crestal CO2 injectors (10 new wells), 12 existing producers and 6 new producers. Well locations are shown in Figure 24. The field production and injection profiles are shown in Figure 25. Cumulative oil production over a 16 year simulation period was 11.4 MMSTB.

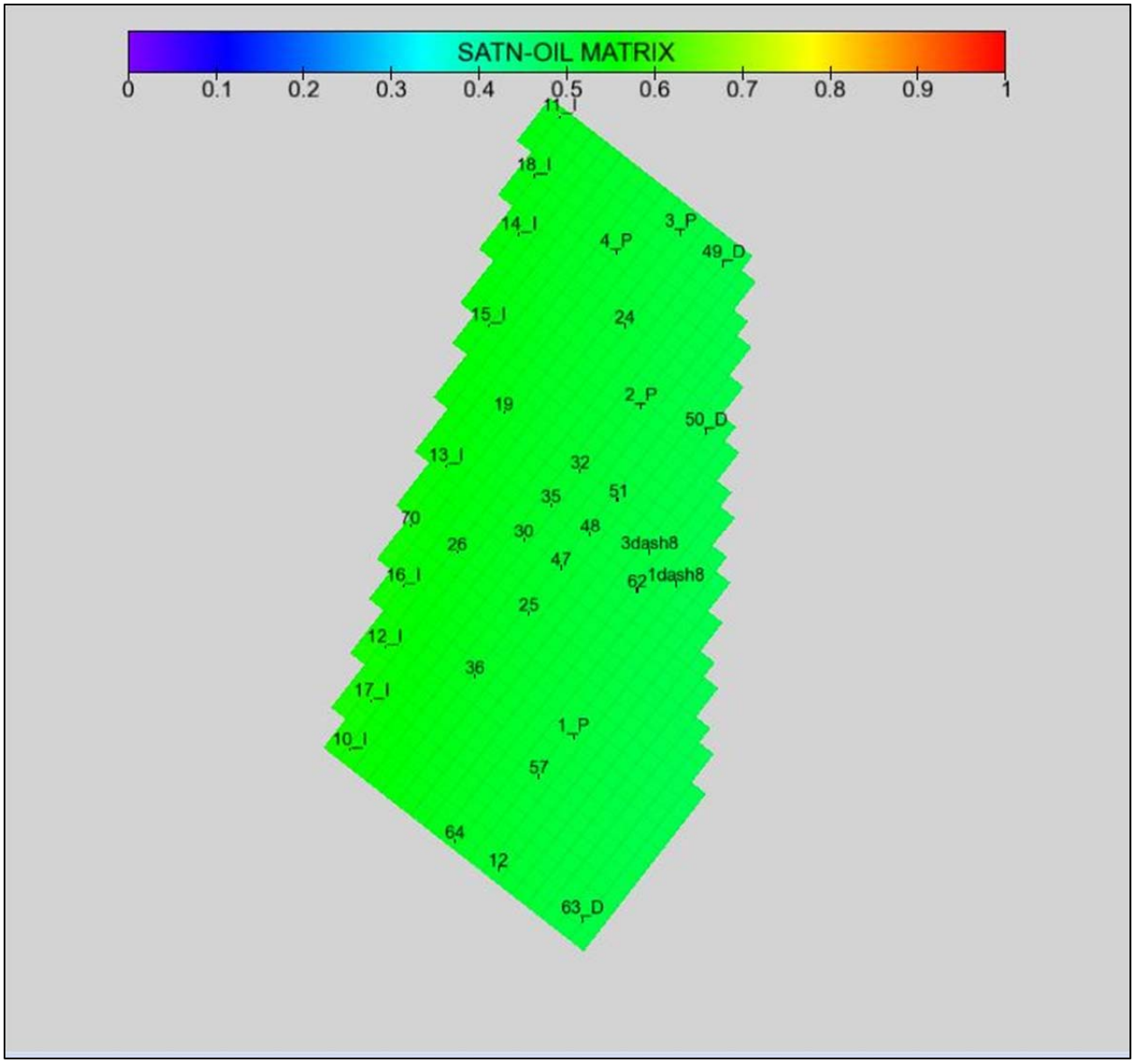


Figure 24: Well Locations, Final Prediction Case

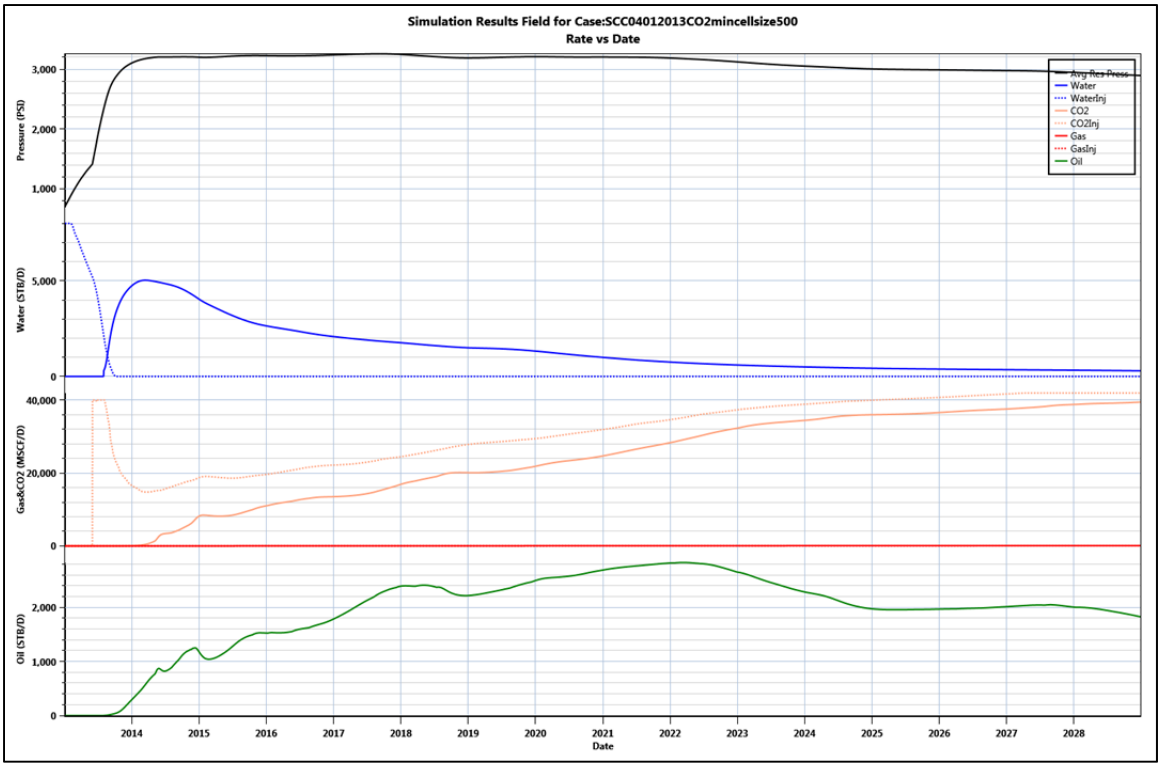


Figure 25: Field Rates, Final Prediction Case

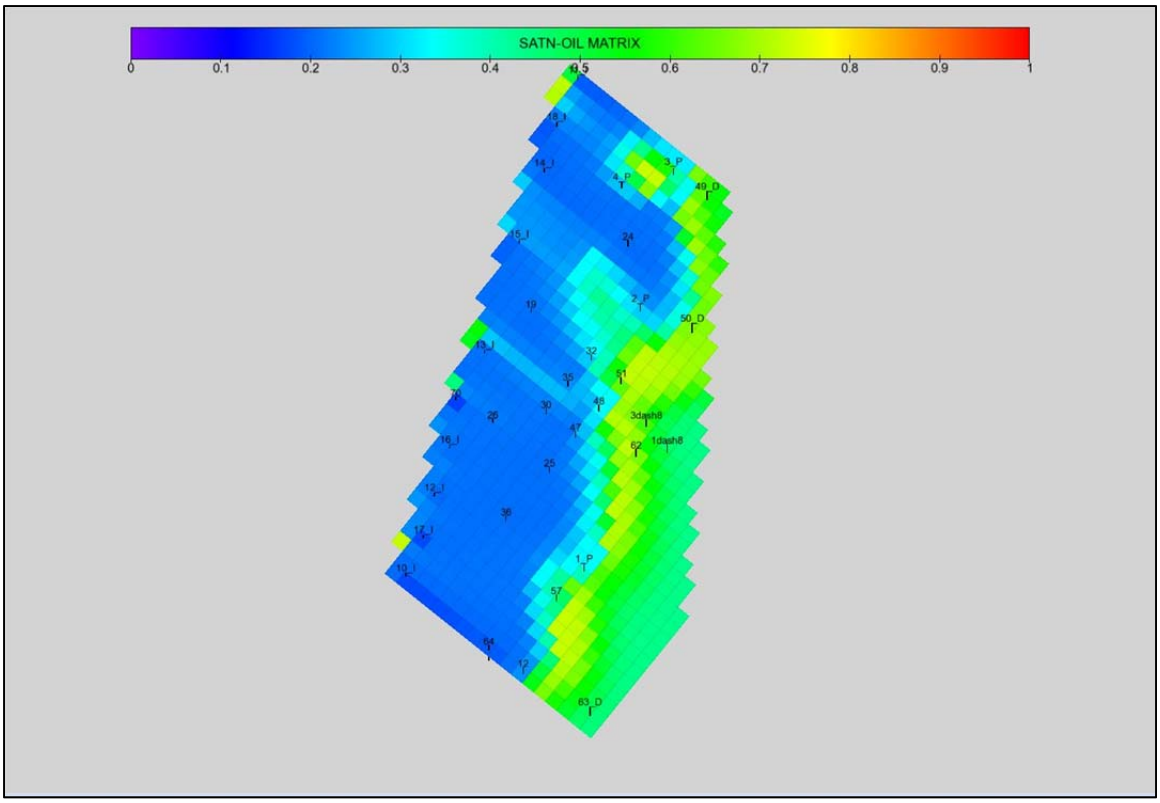


Figure 26: Oil Saturation (12/31/2028), Final Prediction Case

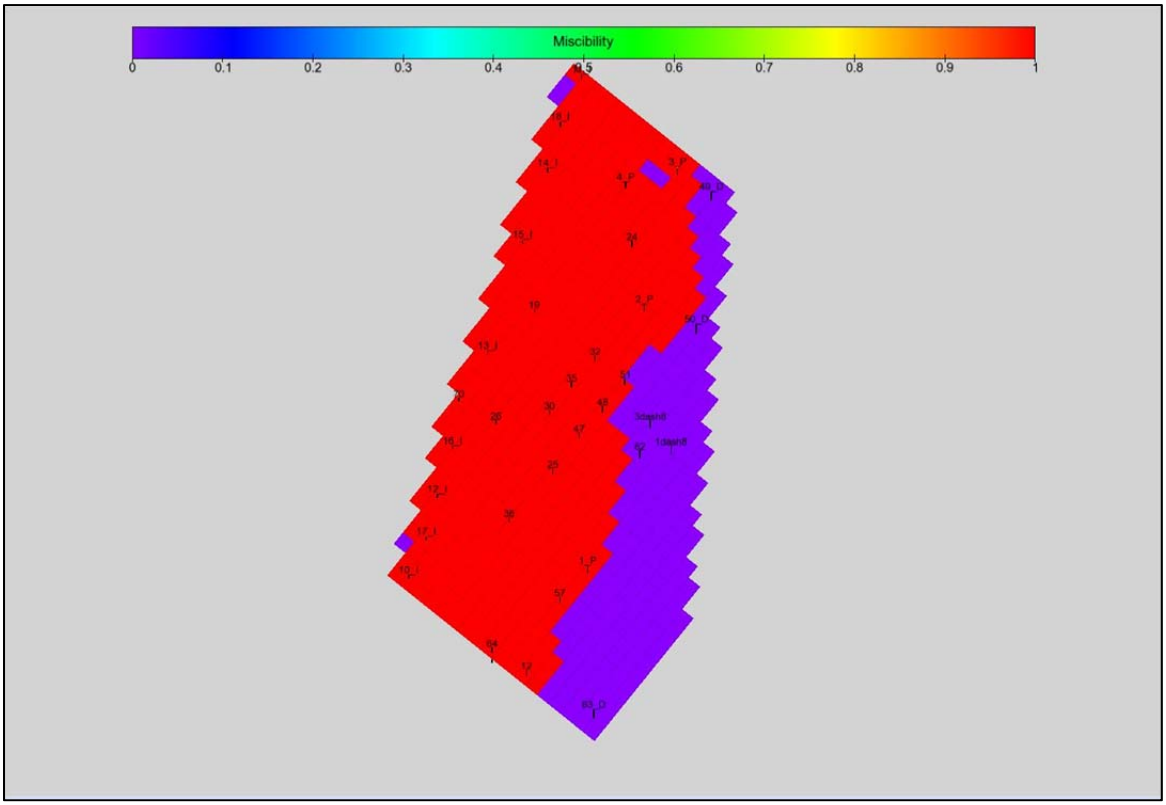


Figure 27: Miscibility (12/31/2028), Final Prediction Case

Economic Assessment

The economic feasibility of the final CO2-EOR scenario that was developed, through multiple prediction simulations, was investigated. COZView/COZSim allows the user to create Economic Scenarios –sets of economic parameters that can be applied against given prediction case results. This results in the calculation of an overall project Net Present Value (NPV). Testing of different Economic Scenarios does not require rerunning the simulation case(s).

The basis for establishing economic parameters for evaluation purposes is typically a very confidential process for most companies. For this reason, the rational or efficacy of this data utilized by Linc Energy will not be discussed. The following economic parameters were input for use in the NPV calculation. Inflation was assumed to be zero.

Economic Parameter	Units	Value
Capital Expenses (1/1/2013)	$	8,500,000
Well Production Cost	$/month/well	4,000
Well Injection Cost	$/month/well	1,000
Produced Gas Compression Cost	$/MMSCF	1.0
Produced Water Handling Cost	$/MSTB	1,000
Oil Price	$	85
CO2 Price	$/MSCF	7.18

Discount Factor	%	10.0

Once these economic parameters were input Calculate NPV was selected. The calculation resulted in a NPV of $137 MM.

A quick change in the oil price to $60/STB results in an NPV of $12.8 MM. This allows the user to quickly assess the sensitivity of the NPV to individual economic parameters for a given prediction case.

User comments: The Economic Parameters and Calculate NPV tabs are helpful for the user to compare different operating assumptions, capital assumptions, and pricing scenarios to understand the relative value of a particular project or operating scenario. As a future improvement, it may be worthwhile to add the ability for the user to input his particular working interest and net revenue interest into the program to provide more individualized NPV estimates. However, most users would be using the calculated NPV within COZView/COZSim for comparing the effects of different economic assumptions relative to each other and would likely be performing more detailed economic analysis in another economics program once they narrowed down their desired parameters.

Once the user establishes the economic parameters, the optimization functionality can be utilized. Optimization is based on maximizing the NPV, hence these parameters are critical to the process.

Optimization

The optimization functionality in COZView/COZSim allows the user to determine the combination of field controls that maximize the NPV for the prediction case being investigated. Each field control parameter used in the Prediction Period/Field/Facility Parameters/Controls section of COZView can be used in the optimization process. A field control parameter that is not used (has no assigned value) cannot be used in the optimization process.

In the final prediction case, six field control parameters were identified. These were

Parameter	**Value**
Liquid Production Target	50,000
Gas Injection Target	80,000
Water Injection Target	10,000
Gas Reinjection Target	0.93
External Gas Source	40,000
External Water source	10,000

The individual well rates in the final prediction case were constrained as follows

Producing wells	2,000 STB/D total liquid
Gas Injection wells	3,000 MSCF/D

Water Injection wells 2,000 STB/D

The final prediction case had 4 water injection wells, 14 gas injection wells and 18 production wells. If all wells were operating at their constrained volumes the field volumes would be

Total fluid production 36,000 STB/D

Total water injection 8,000 STB/D

Total gas injection 42,000 MSCF/D

It is important to keep the individual well constraints in mind when setting the field controls (constraints).

The optimization input table allows the user to set the value range for each field control to be varied during the process. Field controls that are not to be varied are left at the value used in the original prediction case. In this case 3 parameters were varied – water injection target, gas reinjection target and external gas source. It is important when setting the parameter range that the original parameter value is within the range set. The maximum or minimum parameter value in the range may be the original parameter value.

The following ranges were set for each of the three parameters.

Parameter	**Original Value**	**Minimum Value**	**Maximum Value**
Water Injection Target	10,000	4,000	10,000
Gas Reinjection Target	0.93	0	0.99
External Gas Source	40,000	20,000	50,000

It is important to note that the individual well gas (CO2) injection constraints will only allow a maximum field injection of 42,000 MSCF/D at the final prediction case level of 3,000 MSCF/D per well. In order to test the impact of the external gas source field maximum rate of 50,000 MSCF/D, the individual well gas injection constraints were changed to 3,600 MSCF/D.

Once the parameter ranges were input in the Optimization/Configure Parameters screen, the user provided input to the Configure Runs screen shown in Figure 28.

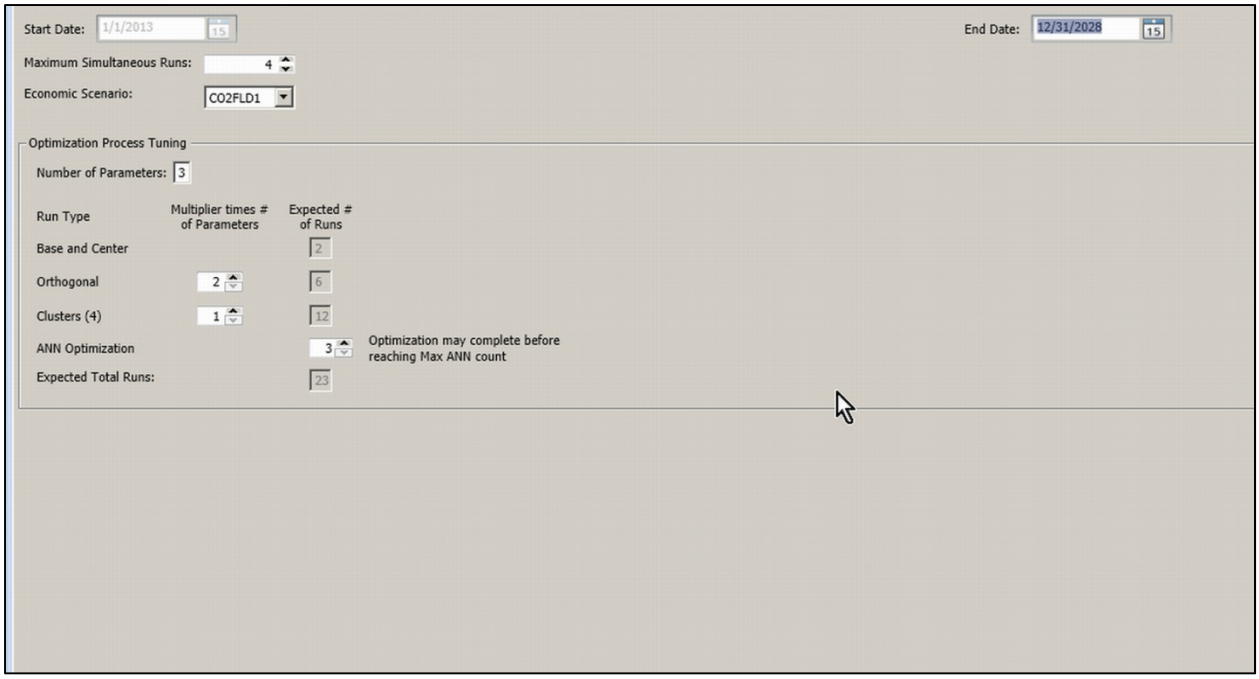


Figure 28: Optimization Run Configuration

The user chose to process a maximum of 4 Simultaneous Runs to speed the overall elapse time required to complete the number of Expected Total Runs of 23. These runs include

1 Base Case

1 Center Case (parameter values at the center of the range)

2 Orthogonal cases per parameter (total of 6 runs)

4 Cluster Cases per parameter (total of 12 runs)

3 Optimization Cases

Figure 29 shows a bar chart of the NPV calculated for each case in the order in which the case completed processing.

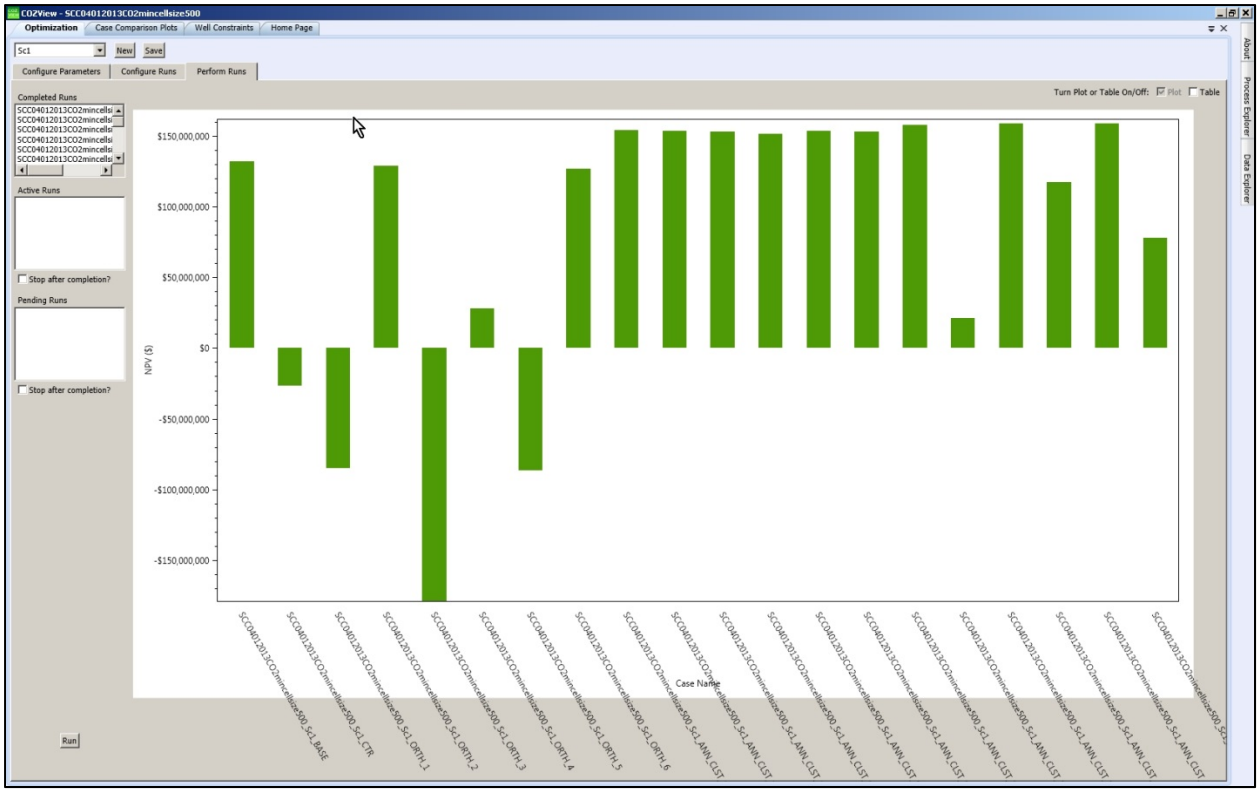
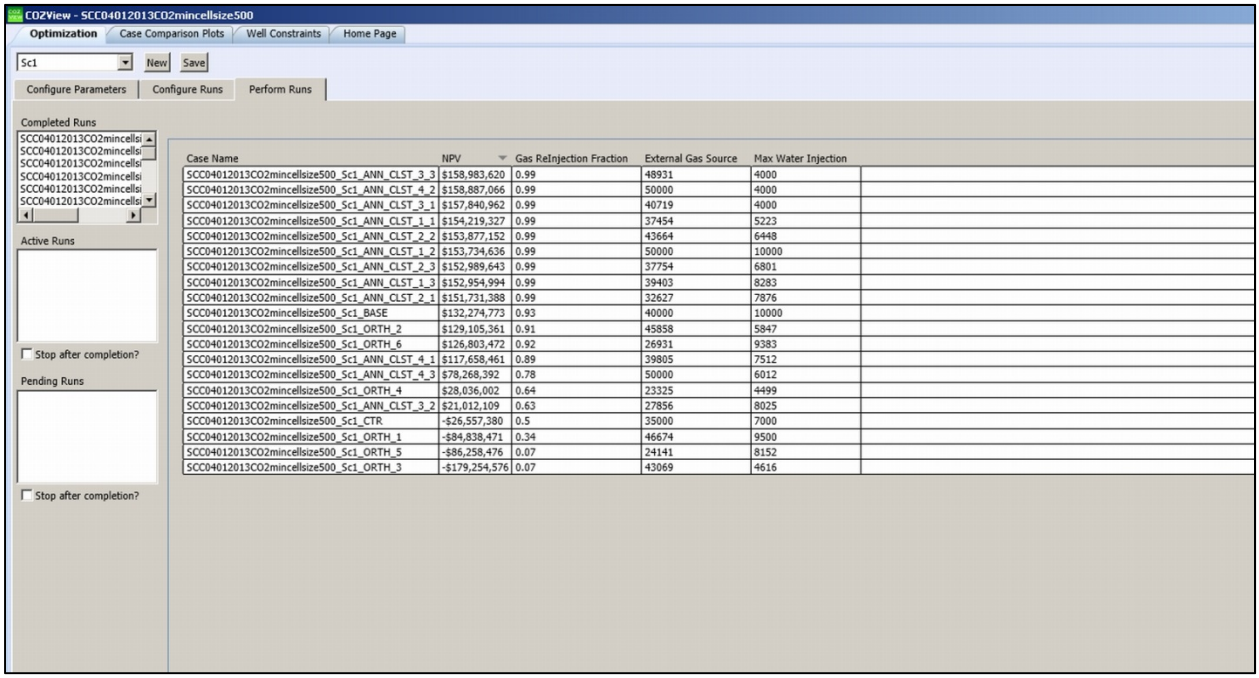


Figure 29: Optimization NPV Bar Chart

Figure 30 shows a table of the same results where the Cases are ordered from highest to lowest NPV.



Case Name	NPV	Gas ReInjection Fraction	External Gas Source	Max Water Injection
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_3_3	$158,983,620	0.99	48931	4000
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_4_2	$158,887,066	0.99	50000	4000
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_3_1	$157,840,962	0.99	40719	4000
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_1_1	$154,219,327	0.99	37454	5223
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_2_2	$153,877,152	0.99	43664	6448
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_1_2	$153,734,636	0.99	50000	10000
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_2_3	$152,989,643	0.99	37754	6801
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_1_3	$152,954,994	0.99	39403	8283
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_2_1	$151,731,388	0.99	32627	7876
SCC04012013CO2mincellsize500_Sc1_BASE	$132,274,773	0.93	40000	10000
SCC04012013CO2mincellsize500_Sc1_ORTH_2	$129,105,361	0.91	45858	5847
SCC04012013CO2mincellsize500_Sc1_ORTH_6	$126,803,472	0.92	26931	9383
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_4_1	$117,658,461	0.89	39805	7512
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_4_3	$78,268,392	0.78	50000	6012
SCC04012013CO2mincellsize500_Sc1_ORTH_4	$28,036,002	0.64	23325	4499
SCC04012013CO2mincellsize500_Sc1_ANN_CLST_3_2	$21,012,109	0.63	27856	8025
SCC04012013CO2mincellsize500_Sc1_CTR	-$26,557,380	0.5	35000	7000
SCC04012013CO2mincellsize500_Sc1_ORTH_1	-$84,838,471	0.34	46674	9500
SCC04012013CO2mincellsize500_Sc1_ORTH_5	-$86,258,476	0.07	24141	8152
SCC04012013CO2mincellsize500_Sc1_ORTH_3	-$179,254,576	0.07	43069	4616

Figure 30: Optimization NPV Table

Analysis of the results suggest the following

1. The best case, ANN CLST 3_3, resulted in an NPV of $154,983,620.
2. Maximizing the reinjection fraction increases the NPV. This is likely due to the reduced volume of external (purchased) CO2 required when the produced gas is re-injected.
3. Maximizing the external gas (CO2) source volume increases the NPV. This is likely due to increased oil production which results from higher CO2 injection rates.
4. Maximizing water injection reduces the NPV. This is likely due to the cost of handling the increase water production that results. Apparently, the water injection impact on re-pressuring the reservoir is not significant relative to the NPV.

Figure 31 shows a comparison of the Base Case in black (Final Prediction Case) and the highest NPV Case in red (ANN CLST 3_3) the performance result differences are subtle; however, the difference in NPV between the two cases is significant ($154,983,620 versus $132,274,773).

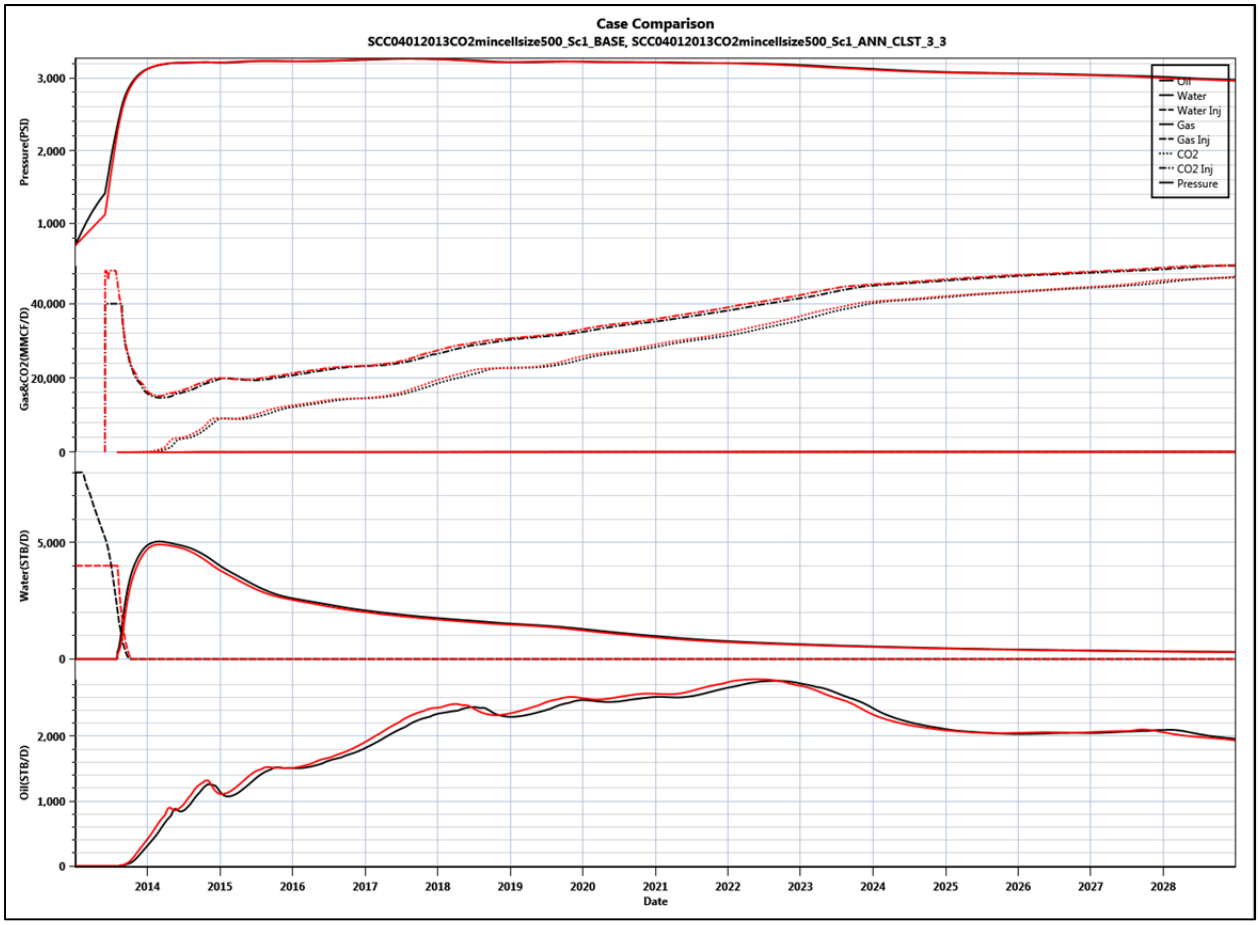


Figure 31: Optimization Case Comparison-Base & CLST 3_3

The impact of slightly more oil production due to increased external source gas supply; slightly less water production due to reduced water injection; and slightly higher reinjection fraction (ANN CLST 3_ 3 versus Base) provides the difference in NPV.

It is also of interest to compare the highest NPV case in red (ANN CLST 3_3) to the lowest NPV case in blue (ORTH 3). Figure 32 shows the rate performance for these two cases. The oil, water and gas production are very nearly the same. The difference in NPV ($154,983,620 versus $-179,254,576) is due primarily to the low reinjection fraction (0.07 versus 0.99) in the ORTH 3 case. Hence, most of the injected CO2 must be purchased which is detrimental to the NPV.

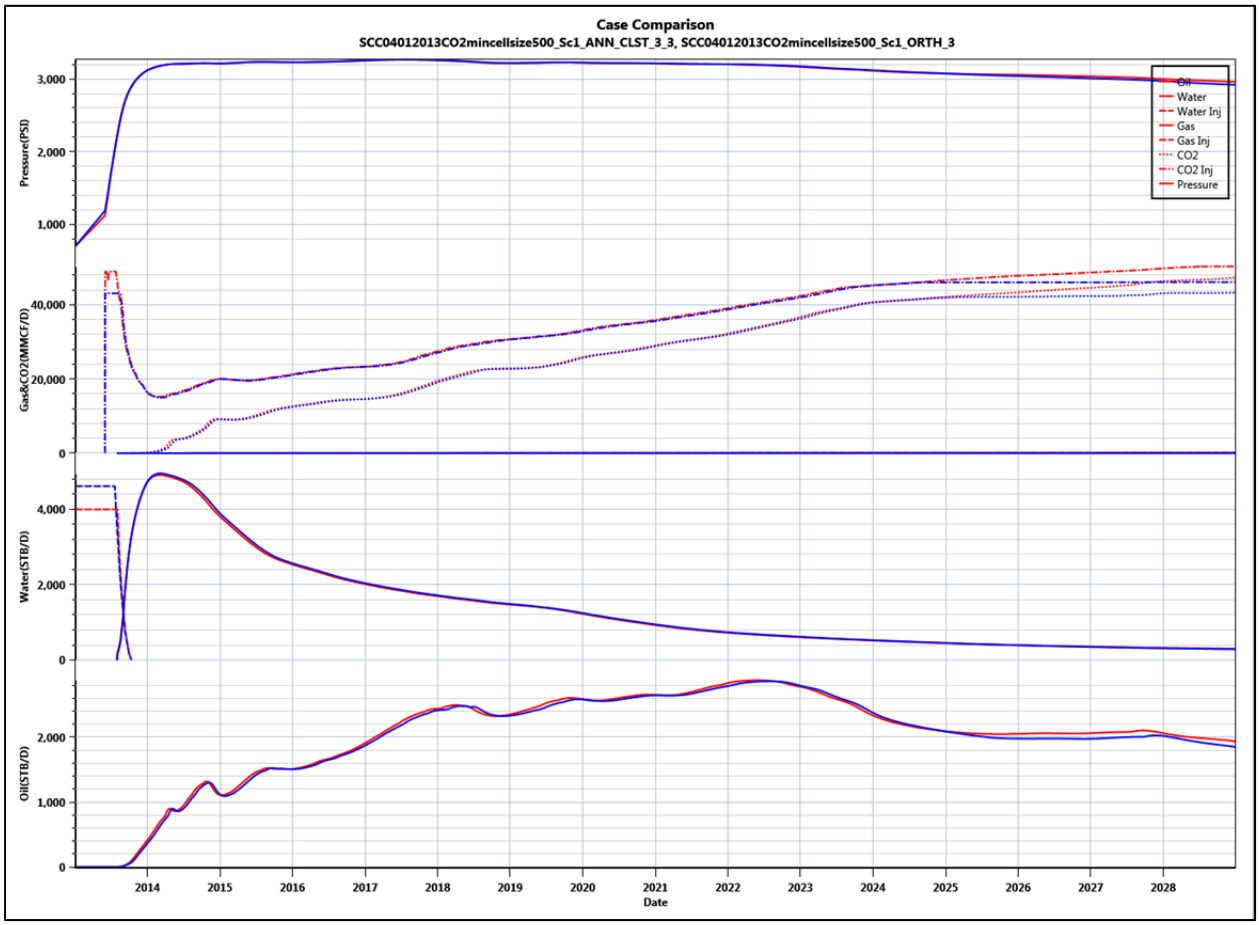


Figure 32: Optimization Case Comparison - Best & Worst

User comments: The optimization process within COZView/COZSim allows the user to understand the effect of altering different operating parameters, within ranges set by the user, on the NPV of the project or scenario. This process can uncover premier operating scenarios that may lead the user to a development scenario that may increase the value of the project or scenario.

Conclusions

1. This Case Study was initiated on January 20, 2013 and completed on April 8; approximately 2.5 months of elapsed time. Work was carried out in conjunction with numerous other operational tasks for the Linc Energy engineer during the period.
2. The study indicates that the reservoir is a strong candidate for CO2-EOR, subject to all of the operational and economic assumptions made.
3. The study indicated that a number of operational modifications to the final plan (number of new wells, new well locations, use of water injection for re-pressuring, etc.) may warrant further investigation.
4. The belief that natural fractures are present in the reservoir and have an impact on the total permeability warrants field injectivity tests and a possible small pilot. Should the fractures dominate the movement of CO2 in the reservoir more so than the model has shown, a dual porosity simulation model should be investigated.
5. During the Case Study a number of small, but important, errors or incorrect calculations were found and corrected in COZView and COZSim. Hence, the Cast Study provided further useful testing of the software.

At the conclusion of the study a minor error was found in the software which impacted the creation of oil compressibility tables from the PVT data. This in term impacted the calculated OOIP (+2.9%) and OIP (+1.6%) from the simulator and the oil production response in the prediction cases. The process of characterizing and modeling this reservoir in COZView/COZSim as discussed in this document is not impacted by this error which was corrected in COZView version 2.1.212.0. As the OOIP, OIP and prediction performance results reported in this document were slightly impacted, any user who might attempt to reproduce the results documented in this report will not achieve the same results. We do believe that the conclusions drawn from this study are valid; only absolute numbers may have changed.

APPENDIX 5

A White Paper Description of COZSim

A White Paper Description of COZSim

Introduction

Fully compositional and extended black-oil reservoir flow simulators are two types of modeling tools that have been successfully used to model CO_2 flood performance. Fully compositional simulators, while widely used for CO_2 injection studies, require comprehensive laboratory fluid data and have some technical limitations. Extended black-oil simulators are an efficient alternative approach to compositional simulation and provide a robust solution for oil displacement by a miscible fluid.

COZSim is an extended black-oil flow simulator.

Overview – General Description of the Simulator

COZSim is a three-phase, four-component, fully implicit, finite-difference extended black oil reservoir simulator. The simulator uses black oil type input data for fluid description and converts the data to a compositional form internally. The model can be used for variety of cases such as:

- Depletion and water flooding,
- Immiscible, first contact and multi-contact miscible CO_2 injection,
- Hydrocarbon gas injection and cycling,
- CO_2 sequestration in aquifers and oil/gas reservoirs.

The simulator considers 3 phases (oleic, gaseous and aqueous) and consists of mass balances for four components (water, oil, hydrocarbon gas and CO_2). Components may thermodynamically partition among three phases and both hydrocarbon gas and CO_2 may partition into gaseous and aqueous phases as shown in Table 1.

In addition, COZSim can handle hydrocarbon gas and CO_2 solubility in the aqueous phase. While this may not be important in the main oil zone, it may influence the simulation results where the water saturation is high, such as in transition and residual oil zones or reservoirs under water alternating gas (WAG) injection.

Table 1. Phases and Components in COZSim

Component Number	Component	Phase		
		Oleic	Gaseous	Aqueous
1	Water	-	-	w_1
2	Oil	x_2	-	-
3	HC Gas	x_3	y_3	w_3
4	CO_2	x_4	y_4	w_4

Even though the data that is required to run the simulator is in black-oil format, all the information is converted to compositional form internally. Built-in correlations estimate component molecular weights, parachors, fluid properties and mole fractions based on the specific gravity of oil and hydrocarbon gas.

Built-in CO_2 correlations are used calculate pure CO_2 properties, CO_2 solubility in the aqueous and oleic phases in the presence of hydrocarbon gas, CO_2 swelling of the oleic phase in the presence of hydrocarbon gas and phase viscosities that reflect CO_2 solubility.

Vapor-Liquid Equilibrium (Flash) calculations are performed at the bulk pressure, which is the pressure corresponding to unconfined laboratory conditions. However, the phase properties (e.g. viscosity, density) are calculated at the pressures of each phase. This requires an iterative solution of the phase properties and the capillary pressures until they converge.

Miscibility calculations are based on interfacial tension using black-oil data. Interfacial tension reduction due to partitioning of CO_2 in the oleic and gaseous phases is calculated using parachors; it is also used to simulate transition from immiscible to partially miscible, and finally to fully miscible conditions. Viscous fingering is handled through a Todd-Longstaff type viscosity model using interfacial tension rather than using a constant mixing parameter. Residual oil saturation can be modeled under fully or partial miscibility conditions. The impact of both full and partial miscibility on gas-oil capillary pressure and relative permeability is accounted with fully implicit formulation.

COZSim treats wells in fully implicit manner and it is able to simulate well and field constraints. Well modeling includes:

- Rate and BHP constrains for production and injection wells
- Wellbore cross-flow for production wells

- Well actions (workover and shut-in) based on the well limits
- Field constraints for production, injection and re-cycling

COZSim uses three dimensional corner-point geometry grid with Cartesian coordinates, and it is able to handle faults (limited to vertical in COZView). Required non-neighbor connections are generated automatically.

Mathematical Formulation and Solution Method

The formulation consists of 4 coupled mass balance (continuum) equations for each cell. The molar continuity equation for any component *c* is:

$$\nabla\left(\rho\vec{v}w_c\right)_a + \nabla\left(\rho\vec{v}x_c\right)_o + \nabla\left(\rho\vec{v}y_c\right)_g - q_c = \frac{\partial\left(\phi z_c \rho_t\right)}{\partial t} \tag{1}$$

where subscript *a*, *o* and *g* denotes the phase – aqueous, oleic and gaseous phase, respectively and ρ_t is molar density of a phase. z_c is the overall mole fraction of component *c*. *w*, *x* and *y* are the mole fractions of the component in the aqueous, oleic and gaseous phases, respectively. The right hand side of the equation represents accumulation terms and left hand side is the total contribution from inter-block flow terms and source or sink. *q* is the molar rate and $\vec{v}$ is the directional Darcy velocity. It is defined as:

$$v = kk_r\lambda\left(\nabla P - \gamma\nabla D\right) \tag{2}$$

The non-linear continuum equation is discretized in time and space by using standard finite-difference calculations. Time indexing of variables are all fully implicit. Four independent variables, bulk pressure and overall mole fractions of water, hydrocarbon gas and CO_2, are solved in fully implicit manner. The aqueous phase is treated in the same way as the other phases in terms of the continuity equation.

In order to solve the non-linear continuum equation, all terms are converted into linear form of the primary variables. Time difference formulation of accumulation terms can be expanded as following for grid block *i*:

$$\frac{\partial\left(\phi z_c \rho_t\right)}{\partial t} = \frac{1}{\Delta t}\left[\left(\phi z_c \rho_t\right)^{n+1} - \left(\phi z_c \rho_t\right)^{n}\right]_i \tag{3}$$

where subscript *n* represents the time level and the parameter value at n^{th} time level is known (old time

level) whereas *n+1* denotes next time step which is unknown. Since all parameters are linearized with the primary variables, the next time step can be approximated with Taylor series expansion as following:

$$\left(\phi z_c \rho_t\right)_i^{n+1} \approx \left(\phi z_c \rho_t\right)_i^{l+1} = \left(\phi z_c \rho_t\right)_i^{l} + \sum_{j=1}^{4}\left[\frac{\partial\left(\phi z_c \rho_t\right)}{\partial X_j}\right]_i^{l} \partial X_j^{\,l+1} \tag{4}$$

Here ∂X_j denotes the primary variables as ∂P_{bulk}, ∂z_1, ∂z_3 and ∂z_4, bulk pressure and overall mole fractions of water, hydrocarbon gas and CO_2 components, respectively. Superscript *l* is the iteration number. Iteration *l* represents known parameter value and *l+1* is unknown as following:

$$\partial X^{l+1} = X^{l+1} - X^{l} \tag{5}$$

Similar to accumulation term, inter-block flow terms are expanded in fully implicit manner and Taylor series expansion is also used. As a result of this linearization procedure, a set of linear equations are solved using a linear solver. COZSim uses HYPRE linear solver[1] from Lawrence Livermore National Laboratory. A simplified demonstration of solution matrix is shown below.

$$\begin{bmatrix}
E_1 & F_1 & 0 & G_1 & 0 & 0 & H_1 & 0 & 0 \\
D_2 & E_2 & F_2 & 0 & G_2 & 0 & 0 & H_2 & 0 \\
0 & D_3 & E_3 & F_3 & 0 & G_3 & 0 & 0 & H_3 \\
C_4 & 0 & D_4 & E_4 & F_4 & 0 & G_4 & 0 & 0 \\
0 & C_5 & 0 & D_5 & E_5 & F_5 & 0 & G_5 & 0 \\
0 & 0 & C_6 & 0 & D_6 & E_6 & F_6 & 0 & G_6 \\
B_7 & 0 & 0 & C_7 & 0 & D_7 & E_7 & F_7 & 0 \\
0 & B_8 & 0 & 0 & C_8 & 0 & D_8 & E_8 & F_8 \\
0 & 0 & B_9 & 0 & 0 & C_9 & 0 & D_9 & E_9
\end{bmatrix}
\begin{bmatrix}
\partial X_{1,1,1} \\ \partial X_{2,1,1} \\ \partial X_{3,1,1} \\ \partial X_{1,2,1} \\ \partial X_{2,2,1} \\ \partial X_{3,2,1} \\ \partial X_{1,1,2} \\ \partial X_{2,1,2} \\ \partial X_{3,1,2}
\end{bmatrix} =
\begin{bmatrix}
\partial R_{1,1,1} \\ \partial R_{2,1,1} \\ \partial R_{3,1,1} \\ \partial R_{1,2,1} \\ \partial R_{2,2,1} \\ \partial R_{3,2,1} \\ \partial R_{1,1,2} \\ \partial R_{2,1,2} \\ \partial R_{3,1,2}
\end{bmatrix}$$

Each element in the left hand side of the Jacobian matrix represents a 4x4 coupled matrix where *F* and *D* represent the flow in the *X* direction; *G* and *C* represent the flow in the *Y* direction; and *H* and *B* represents the flow in the *Z* direction. Each *R* is a 4x1 coupled matrix, representing the residual or result vector. ∂X is a 4x1 primary variable vector, representing $\left[\partial P_{bulk} \quad \partial z_1 \quad \partial z_3 \quad \partial z_4\right]^T$.

Bulk pressure (P_{bulk}), which is the pressure corresponding to unconfined laboratory conditions, is one of the solution variables solved from the discretization of the continuum equations. Flash calculations are performed at the bulk pressure which is obtained from the solution of non-linear conservation equations. Phase properties, such as density and viscosity, are calculated at the pressures of each phase. This procedure requires an iterative solution of the phase properties and the capillary pressures until they

converge. Estimated capillary pressure values are used to calculate mole fractions, phase properties and saturations. Then these calculated saturations are used to calculate capillary pressures using the capillary pressure curves. This loop will go on until the solution converges to a tolerance value. A simplified flow diagram of the iterative solution technique is given in Figure 1.

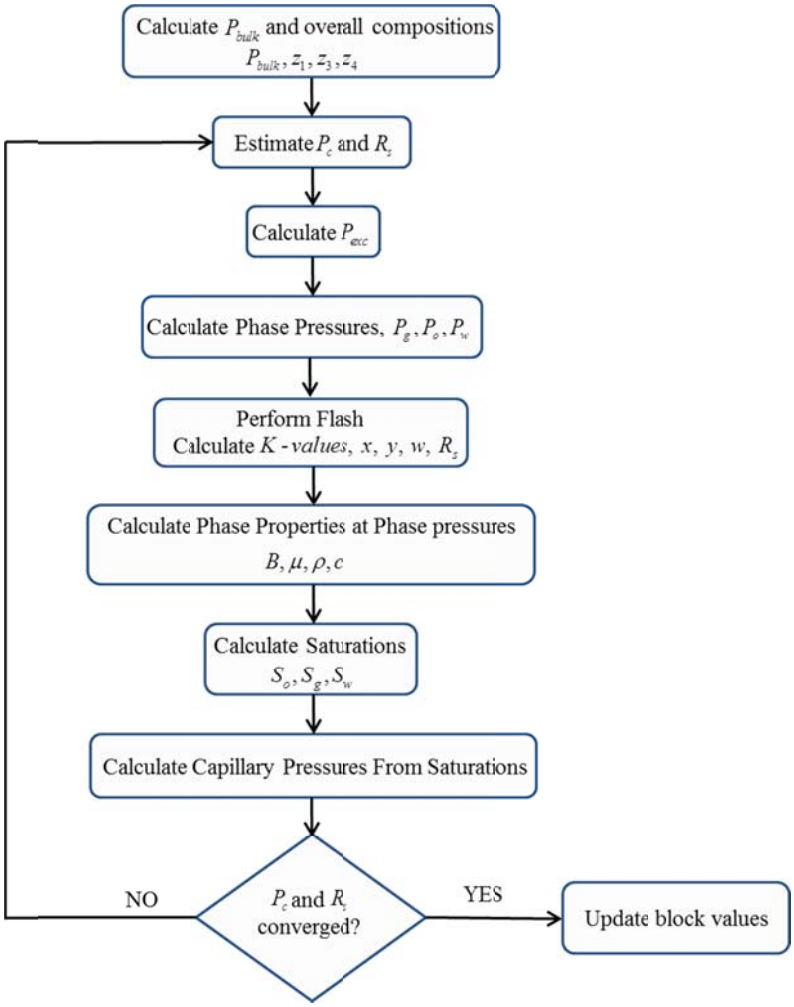


Figure 1. Iterative Solution Technique of COZSim

COZSim uses vertical capillary-gravity equilibrium to calculate initial reservoir pressure, saturation and, composition distributions. Gas-oil and water oil contacts can be defined by user. COZSim is able to implement multiple initializations (different initialization times) for bypassing history matching process. This also allows initializing residual oil zones with imbibition capillary pressure curves. Phase properties are calculated at the pressures of each phase. This method also requires an iterative solution similar to the procedure given in Figure 1. First, initial saturations are calculated from capillary pressure curves. Using these initial saturations, capillary pressure values, fluid properties, mole fractions and saturations are updated. This iteration continues until reaching a convergence.

Figure 2 shows general flow chart of the simulator modules.

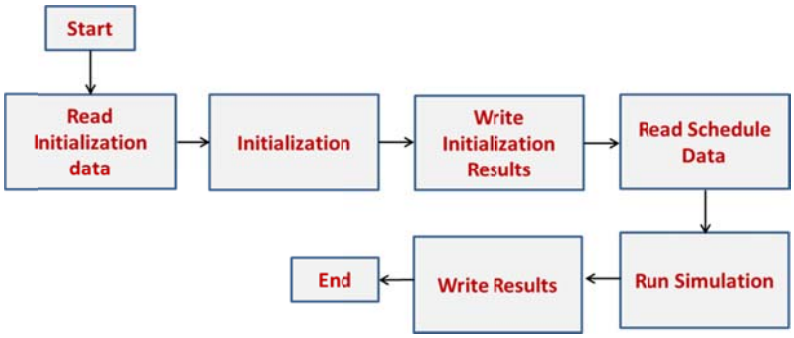


Figure 2. General Flow Chart of Simulator Modules

Figure 3 shows the general flow diagram of the simulation module. First item in the flow chart includes the iterative procedure given in Figure 1 to calculate block properties. Convergence criteria include pressure, overall mole fractions and material balance along with the convergence criteria of the linear solver. COZSim calculates time-step sizes automatically with an algorithm based on the convergence of previous time step. The current maximum time-step size defaults to monthly.

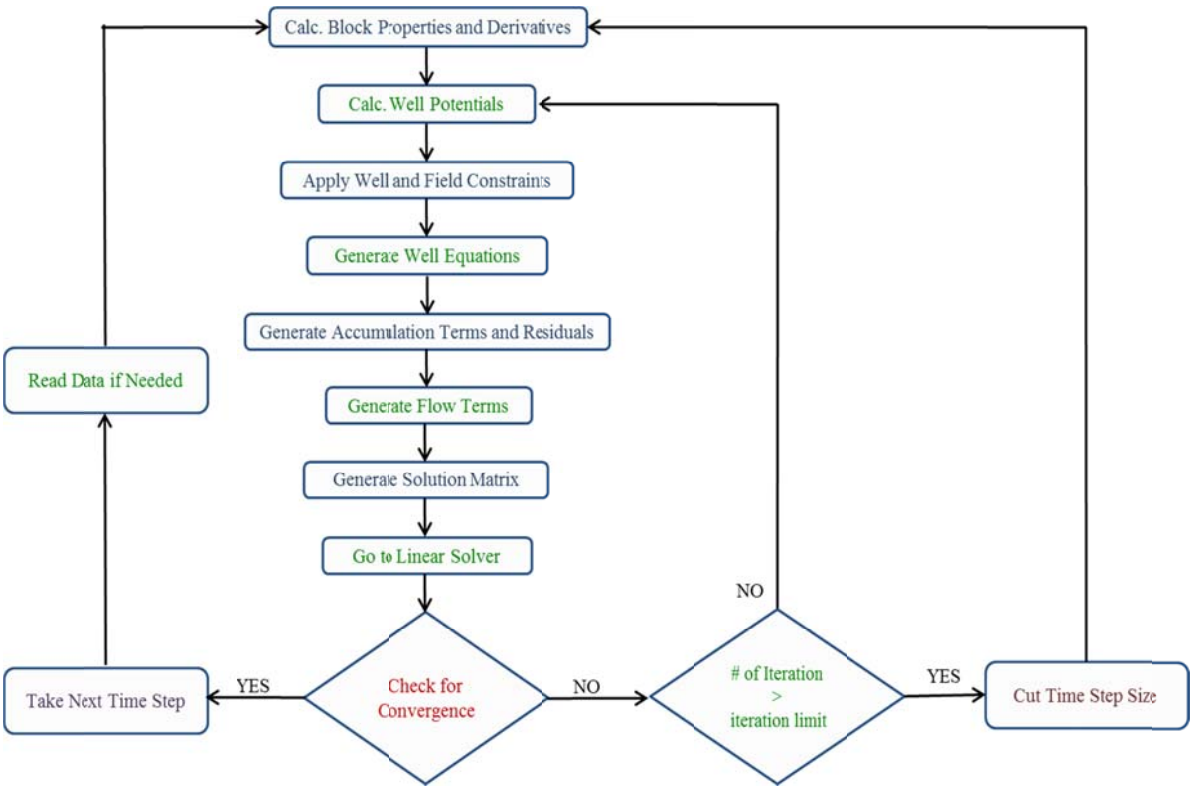


Figure 3. General Flow Diagram for Simulation Module

Miscibility and Viscous Fingering

Miscible flooding may create an unstable frontal advance due to viscous fingering or gravity over-riding because of the unfavorable viscosity and density ratio between the solvent (CO_2) and the oil. Accurate characterization of displacement processes requires describing unstable flood front formed by physical dispersion. Simulators which assume that solvent and oil are completely mixed within a grid block such as compositional simulators, give optimistic displacement results for coarsely gridded models. Using finely gridded models may provide more realistic results; on the other hand, it may be impractical for modeling full-scale miscible flooding projects.

If the CO_2 displaced zone is large with respect to grid size block, oil and solvent can be treated as completely mixed in the grid block. If the CO_2 displaced zone is very small with respect to size of grid block, oil and solvent can be considered completely segregated as pure components and no mixing occurs. Generally, the actual fluid behavior is somewhere between the two mixing limits, which correspond to partial mixing. Todd and Longstaff [2] proposed an empirical model to include viscous fingering effects for coarsely gridded models assuming partial mixing of solvent and oil. The Todd and Longstaff model is based on modification of classical black oil type properties such as relative permeabilities, densities and viscosities with a constant user-defined mixing parameter.

COZSim uses a viscous fingering model based on the interfacial tension function rather than using a constant mixing parameter proposed by Todd-Longstaff. Effective viscosities of the oil and solvent system are calculated from their immiscible viscosity values as following:

$$\mu_{oe} = \mu_o^{1-f(\sigma)} \mu_m^{f(\sigma)} \tag{6}$$

and

$$\mu_{se} = \mu_s^{1-f(\sigma)} \mu_m^{f(\sigma)} \tag{7}$$

Where

$$\mu_m = \mu_o \mu_s \Big/ \left(\frac{S_g \mu_o^{1/4} + S_o \mu_s^{1/4}}{S_o + S_g} \right)^4 \tag{8}$$

where μ_m is viscosity of the mixture and $f(\sigma)$ is the mixing parameter function. $f(\sigma)$ represents a channeling function to impose partial or full mixing within a grid. It is calculated internally. $f(\sigma)$ is a function of pressure, molar densities, parachors and mole fraction of components. A value of $f(\sigma)$ =1

corresponds to full mixing of solvent and oil within a grid block and it results a piston like displacement. $f(\sigma)$ =0 corresponds to negligible mixing or negligible dispersion similar to immiscible displacement. Partial mixing is represented by values of 0< $f(\sigma)$ <1. In this case, effective viscosity of the solvent will be less than the effective viscosity of oil, hence, solvent will travel faster than oil and create viscous fingers.

COZSim predicts miscibility using interfacial tension based on Macleod-Sugden[3] correlation between the two phases. The interfacial tension between the oil and gas phases is used to measure how miscible the two fluids are. Miscibility occurs when the interfacial tension between the two phases drops to zero. Relative permeabilities and capillary pressures are interpolated as functions of interfacial tension between immiscible and miscible values. The Macleod-Sugden correlation is used to calculate interfacial tension as following:

$$\sigma = \left[\sum_{i=1}^{4} P_i \left(\rho_o x_i - \rho_g y_i \right) \right]^4 \tag{9}$$

where x_i and y_i are the liquid and gas mole fractions, ρ_o and ρ_g oleic and gaseous phase molar densities and P_i is the parachors of the i^{th} component. Parachor value for oil component is calculated from:

$$P_2 = 18.824 + 3.0453 MW_{C_{5+}} \tag{10}$$

where $MW_{C_{5+}}$ is C_{5+} oil molecular weight and it is estimated from the API value of oil by using Lasater[4] correlation:

$$MW_{C_{5+}} = \left(\frac{7864.9}{API} \right)^{1/1.0386} \tag{11}$$

Gas parachor value:

$$P_g = 18.824 + 3.0453 \times MW_g \tag{12}$$

where gas molecular weight:

$$MW_g = SG_g \times \rho_{air}^{sc} \times \rho_g^{sc} \tag{13}$$

PVT and Flash Calculations

The fluid data required by COZSim is in black-oil format and it is converted to compositional form internally. This procedure consists of the calculation of overall mole fractions and mole fractions for each component. As an example, calculation of overall mole fraction of oil component from black oil data for initialization:

$$z_2 = \left(\frac{S_o}{B_o \rho_o^{sc}} \right) \Bigg/ \left(\frac{S_a}{B_a \rho_w^{sc}} + \frac{S_o}{B_o \rho_o^{sc}} + \frac{S_g}{B_g \rho_g^{sc}} \right) \tag{14}$$

Mole fraction of oil component in oleic phase:

$$x_2 = 1 \Bigg/ \left(1 + R_{sa} \frac{\rho_o^{sc}}{\rho_g^{sc}} \right) \tag{15}$$

COZSim does not use fugacity constraints, equation of state based flash procedure or table lookup *K-values*. Equilibrium *K-values* used in COZSim are defined as:

$$K_{o,3} = \frac{y_3}{x_3} \qquad K_{w,3} = \frac{y_3}{w_3}$$

$$K_{o,4} = \frac{y_4}{x_4} \qquad K_{w,4} = \frac{y_4}{w_4}$$

K-values are calculated internally using solution gas-oil ratio, solution gas-water ratio and molar density of the phases. The following is an example calculation of equilibrium *K-values* for the oleic phase with hydrocarbon gas.

$$K_{o,3} = \frac{1 + R_{so,3}^m}{R_{so,3}^m} \tag{16}$$

where

$$R_{so,3}^m = R_{so,3} \frac{\rho_o^{sc}}{\rho_g^{sc}} \tag{17}$$

$R_{so,3}$ is solution hydrocarbon gas – oil ratio; ρ_o^{sc} and ρ_g^{sc} densities of oleic and gaseous phase pressures at standard pressure and temperature conditions, respectively. $R_{so,3}^m$ is molar solution gas – oil ratio. *K-*

values are calculated using the R_s tables calculated with built-in correlations[5] and it is able to model variable saturation pressure cases.

Built-in Correlations

The most important mechanisms of a CO_2-oil displacement process are the oil viscosity reduction and the oil swelling which are results of CO_2 solubility in oil. Therefore, it is important to calculate CO_2 solubility effects in the simulation model. CO_2 – oil solubility, oil swelling factor and CO_2-oil mixture viscosity is calculated using genetic algorithm-based correlations.[6] This model is a generalized approach and gives more accurate predictions than conventional correlations which are limited by data ranges and conditions. Genetic algorithm-based correlations are universal and can be used to predict the effect of CO_2 for both dead oil and live oil properties. Table 2 gives the solubility related parameters and input variables that are used to calculate those parameters.

Table 2. Parameters and Variables related CO_2 solubility

Parameter	Input Variables
CO_2 Solubility	Saturation Pressure, Temperature, Oil Gravity, Oil Molecular Weight, CO_2 Liquefaction Pressure
CO_2-Oil Mixture Viscosity	Initial Oil Viscosity, CO_2 Solubility, Saturation Pressure, Temperature, Oil Specific Gravity
Oil Swelling Factor	Oil Molecular Size, CO_2 Solubility

Water – hydrocarbon gas solubility [7], water – hydrocarbon gas solubility salinity correction [8], water formation volume factor for saturated conditions [7,8] is calculated with built-in correlations. Density, *z* factor and viscosity of pure CO_2 are also calculated internally. [6]

COZView/COZSim uses Corey-type two phase imbibition and drainage relative permeability curves. Modified Stone's second method[9] is used for 3 phase oil permeability model. Modified Stone's second method version in COZSim is defined as:

$$k_{ro} = k_{rocw}\left[\left(\frac{k_{row}}{k_{rocw}} + k_{rw}\right)\left(\frac{k_{rog}}{k_{rocw}} + k_{rg}\right) - k_{rw} - k_{rg}\right] \quad (18)$$

where k_{rog} is oil relative permeability for an oil, gas and connate water system, k_{row} is oil relative permeability for a system with oil and water only.

Efficiency of Formulation and Solution Technique

COZSim does not use water saturation as an independent variable. Water saturation cannot be a truly independent variable in CO_2 displacement cases because CO_2 solubility impacts water saturation and simulators that use water saturation as an independent variable may have difficulty addressing the impact of CO_2 solubility variations in the aqueous phase.

Simulator enables argument passing of grid block pressure and overall compositions to a kernel. The kernel calculates all the necessary parameters (i.e. saturations, densities, capillary pressures, relative permeabilities, miscibility, and all the derivatives) independent from the rest of the code. It provides multi-threading and hence, full-use of a computer's multiple CPUs and threads

Nomenclature

x_i	=	Mole fraction of i^{th} component in oleic phase
y_i	=	Mole fraction of i^{th} component in gaseous phase
w_i	=	Mole fraction of i^{th} component in aqueous phase
z_i	=	Overall mole fraction of i^{th} component
t	=	time
k	=	Absolute permeability
D	=	Depth
S	=	Saturation
S_{orm}	=	Residual oil saturation to miscible flooding
ρ	=	Molar density
ρ_t	=	Molar density of a phase
k_{rn}	=	Relative permeability of phase n
P_{bulk}	=	Bulk pressure
P_{exc}	=	Excess pressure
R_{sn}	=	Solution oil-gas ratio of phase n
P_c	=	Capillary pressure
P_i	=	Parachors of i^{th} component
K	=	K-value
B	=	Formation volume factor
k_{rocw}	=	oil relative permeability in the presence of connate water only
σ	=	Interfacial tension

μ = viscosity
γ = Specific gravity
λ = Mobility

Sub/Superscripts

o = Oleic
a = Aqueous
g = Gaseous
s = Solvent
e = Effective
m = Mixture
sc = Standard conditions

Reference

[1] R.D. Falgout and U.M. Yang, HYPRE: a Library of High Performance Preconditioners, in Computational Science - ICCS 2002 Part III, P.M.A. Sloot, C.J.K. Tan. J.J. Dongarra, and A.G. Hoekstra, eds., vol. 2331 of Lecture Notes in Computer Science, Springer-Verlag (2002), pp. 632-641.

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APPENDIX 6

User Manual

COZVIEW/COZSIM USER MANUAL

COZView/COZSim integrates an easy to use user interface for pre and post processing of the reservoir simulation results, a technically rigorous 3D, 3-phase, 4-component, extended black oil simulator, and a net present value (NPV) optimization functionality for evaluation of CO2-EOR in oil reservoirs.

Developed by NITEC LLC under a Federal Assistance Agreement with the U.S. Department of Energy/National Energy Technology Laboratory

Last Update 02/22/2013

Table of Contents

1 COZView/COZSim Introduction

COZView/COZSim was developed by NITEC LLC under a Federal Assistance Agreement with the U.S. Department of Energy/National Energy Technology Laboratory. The software was developed during 2011 and 2012.

COZView/COZSim was developed with the goal that

1) a technically respectable field-wide CO2-EOR feasibility analysis can be accomplished in less than one month, and
2) such an analysis can be affordable to small and mid-size companies.

From a technical perspective, the objective was to develop a credible CO2-EOR software solution that includes:

1) the necessary physics that is lacking in simplistic solutions,
2) ease of use through present-day graphical user interface technologies,
3) sophisticated numerical algorithms and procedures for field development planning, and
4) global optimization technology to maximize the net present value of the CO2-EOR application.

The software integrates an easy to use user interface for pre and post processing of the reservoir simulation results, a technically rigorous 3D, 3-phase, 4-component, extended black oil simulator, and a net present value (NPV) optimization functionality for evaluation of CO2-EOR in oil reservoirs.

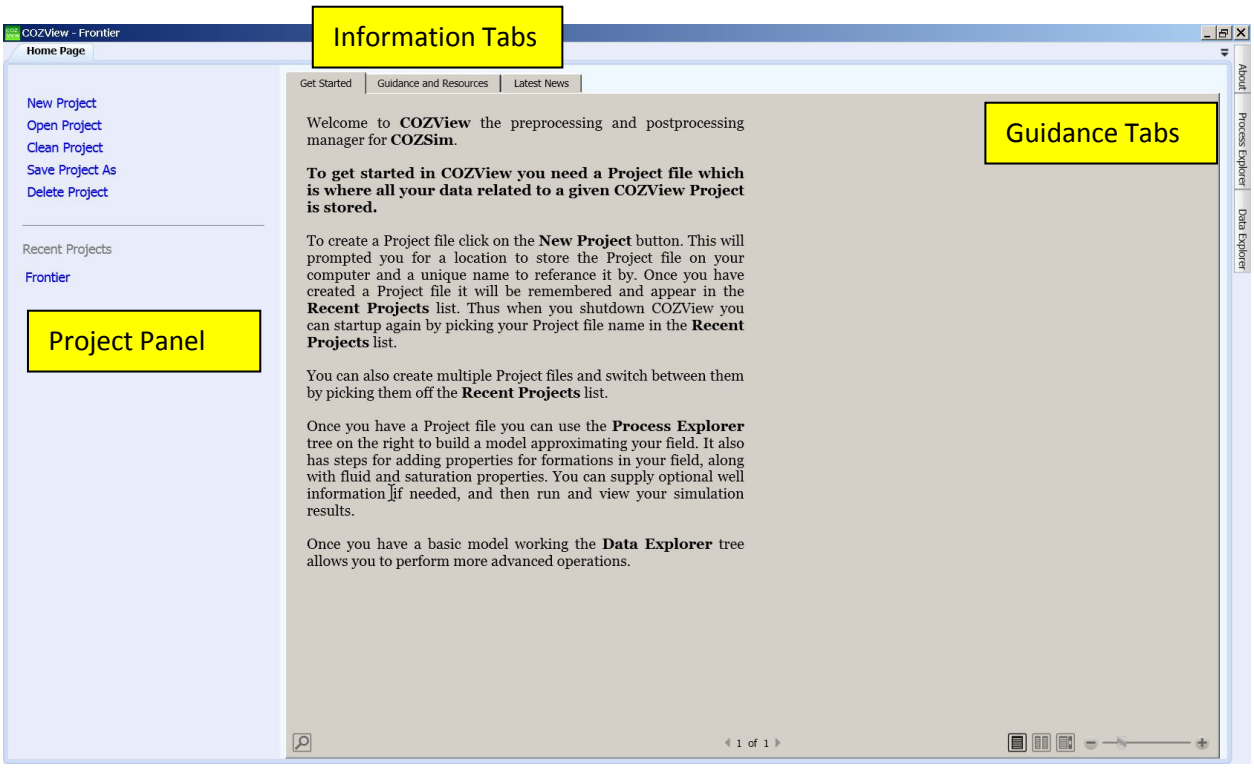
COZView attempts to simplify the simulation model development process while emulating the actual reservoir under evaluation as closely as possible. A white paper will be available on numerical aspects of COZSim.

1.1 Home Page

The Home page consists of a Project panel on the left, Information Tabs at the top and Guidance Tabs on the right.

The Information Tabs – *Get Started, Guidance and Resources* and *Latest News* provide useful information to the user.

The Guidance Tabs – *Data Explorer, Process Explorer,* and *About* are the key operational tabs for the software. A Single-click on these tabs will display a menu of operations.



The Project panel provides the user the opportunity to manage old and new projects. Old projects may be archived in the COZView project folder and/or identified under **Recent Projects**. A Single-click will activate any of the items in the Project Panel.

The user should select *New Project* upon first use of COZView. The user will be asked to enter a project name. A Project Name cannot contain any blank spaces. The name of the new active project will appear in the upper left as **COZView-*Project Name.***

The user will not be allowed to enter COZView without an activated project.

1.2 Project Management

Project management for **COZView** is handled from the Home Page. A number of options are available to the user.

- New Project

  Allows the user to initiate a new project from scratch.

- Open Project

  Allows the user to open a previously created project that is in the **COZView** project directory, but is not in the Recent Project list.

- Clean Project

Allows the user to retain all project input data, but remove all simulation result files from the current project.

- Save Project As

  Allows the user to create a duplicate of the active project under a new project name.

- Delete Project

  Allows the user to remove all input and simulation result files associated with the project from the COZView directory.

- Recent Projects

  Allows the user to select a recent project as the active project. A right-click on the project name will allow the user to remove the project from the Recent Projects list. This does not impact any of the input or simulation result files in the COZView directory.

1.3 Guidance Tabs

The Guidance Tabs are the *Process Explorer* and *Data Explorer*. The *Process Explorer* is intended as the primary guidance tool for most users. It will systematically guide the user through the required steps to build a simulation model that is representative of the actual reservoir to be investigated and to make a simulation prediction run or optimization runs.

The *Data Explorer* tab provides additional functionalities for the simulation model run submission and data loading which are typically not needed by the user.

1.4 About

The *About* Tab provides version numbers and release dates for **COZView** and the integrated simulator **COZSim**. These are important should the need arise to communicate with the software developers concerning apparent software bugs of the software version being used.

2 Guidance and Resources

The software has been designed to make the building of the representative simulation model and viewing the simulation results as easy as possible. Parameter default values and internal correlation to develop certain data will be used when appropriate.

The user is encouraged to utilize the Process Explorer menus whenever possible as these have been designed to streamline the process.

2.1 Data Requirements

The software has been designed with the primary intent that the user will build a representative simulation model of their reservoir and run user designed CO2-EOR prediction cases.

A list of required and optional data that the user will need to supply during the model building process is provided in the ***Data List*** file. The user may find it useful to print this list and gather the relevant data before starting the data input process in **COZView**.

2.2 Mouse Operations

A number of unique, user friendly features have been incorporated in **COZView** which are controlled by the mouse. These mouse operations are documented below as a guide to the user.

Left-Click

Single – selects

Right-Click

Displays a menu

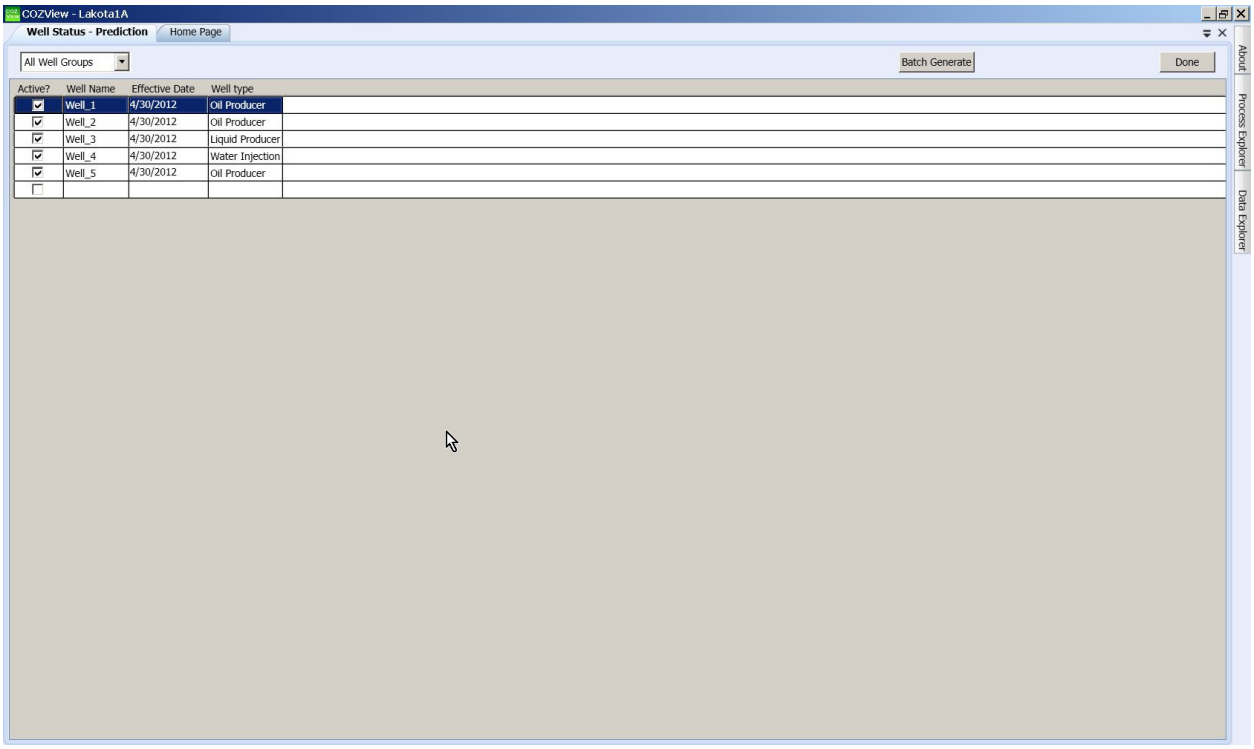
Lists /Tables

Highlight a range of items

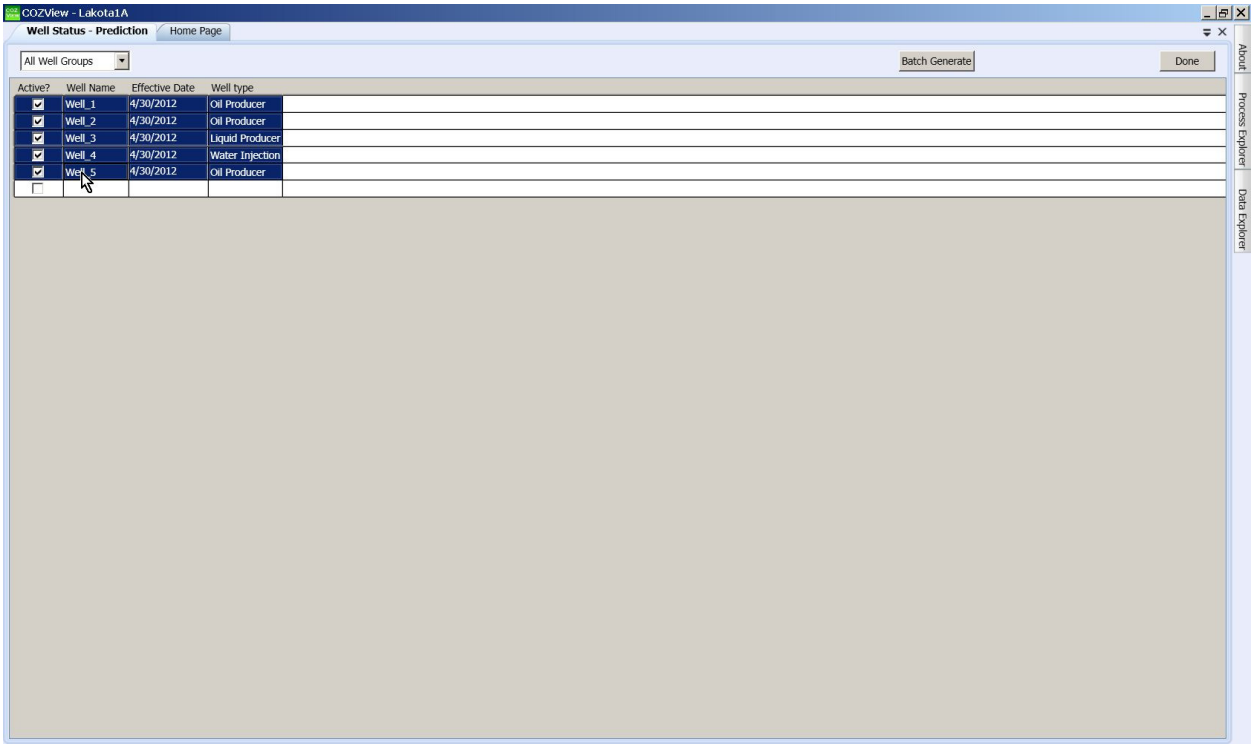
Select and highlight (left-click) followed by SHIFT+ select and highlight (left-click) further down the list of items. This will highlight the range selected.

EXAMPLE:

Select and highlight (left-click)



SHIFT+ select and highlight (left-click)



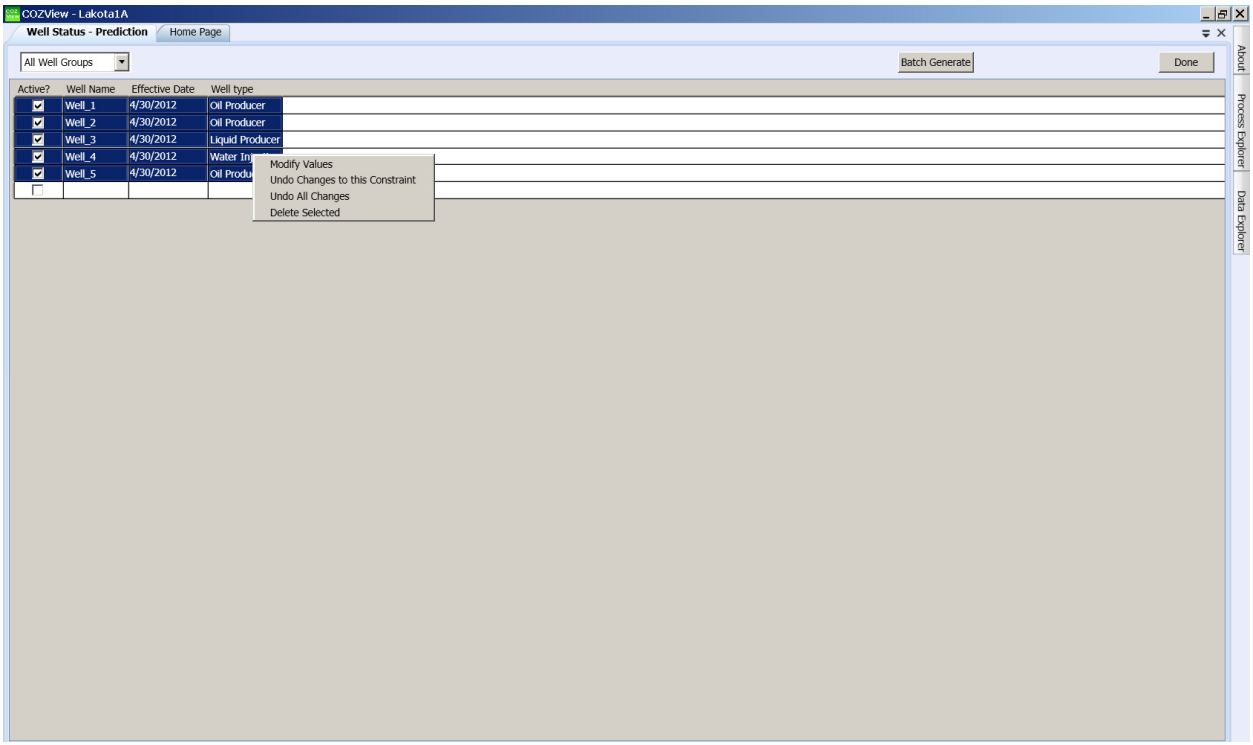
A right-click in a column of the highlighted data will display a menu

Modify Values – provides a menu of choices for the selected column; all rows changed to the selected choice

Undo Changes to this constraint - cancels changes made to the selected column for all rows

Undo All Changes – cancels all changes since last Save

Delete Selected – deletes all highlighted rows



Highlighting

CTRL + Select and drag will highlight the "drag" range. CTRL also allows multiple selection of individual items. Each CTRL click adds to the current selection,

Delete a range of items

Highlight as noted above and right-click for menu to delete or select Delete key

Tabs

Left-click to select.

Right-click on Menu tabs across top of screen for menu to close tab or float tab

3D Operations

Pan

Right-click and drag

Zoom

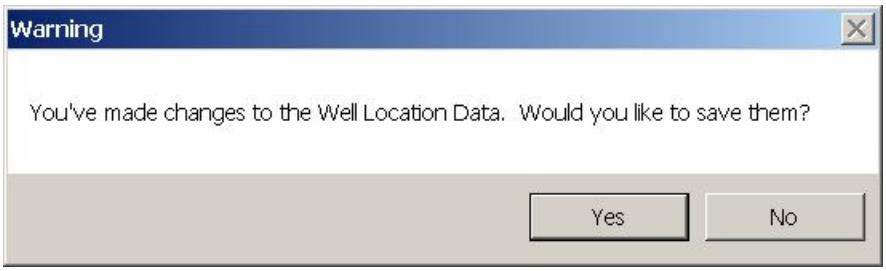
Left-click and drag

Rotate

Center-click and drag

2.3 Saving Data

The saving of data input by the user does not occur automatically in **COZView**. There are three buttons used in the various windows that cause the data to be saved. These are **Save and Continue**, **Save and Quit** and **Done**. **Save and Continue** saves the data and does not close the window that is in use. **Save and Quit** saves the data and returns to the prior window. **Done** saves the data and returns to the prior window also. Any of these selections should result in a message similar to the one below. The user should respond accordingly.



In some cases the user my wish to make a copy of the current project, such that the duplicate project can be altered in some minor manner. The user should use **Save Project As** on the **Home Page** window.

2.4 Screen Refreshing

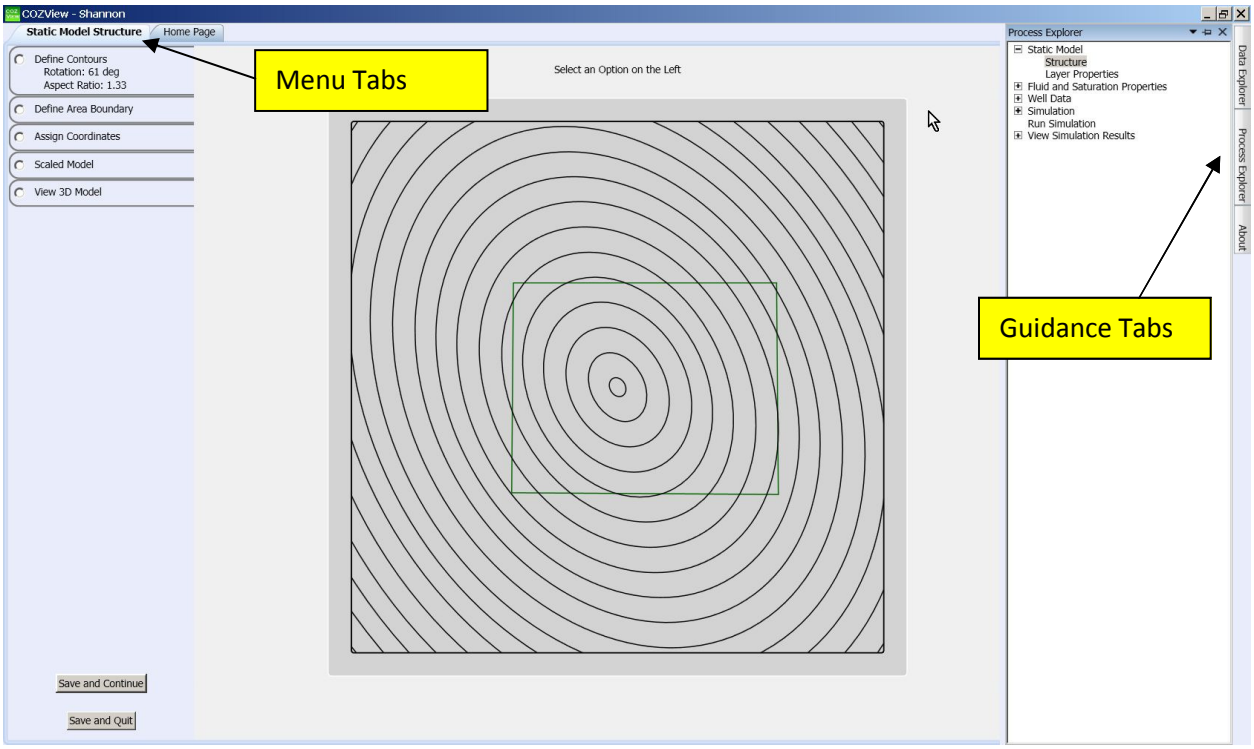
Throughout **COZView** data provided in one screen may be related to data on another screen. In many cases a particular menu tab may not be automatically refreshed when a data change impacting that screen is made elsewhere even though the data has been saved by the user using the **Save** or **Done** buttons.

To refresh an affected screen, close the menu tab at the top of the window for that screen and reopen the screen from the *Process Explorer* menu area.

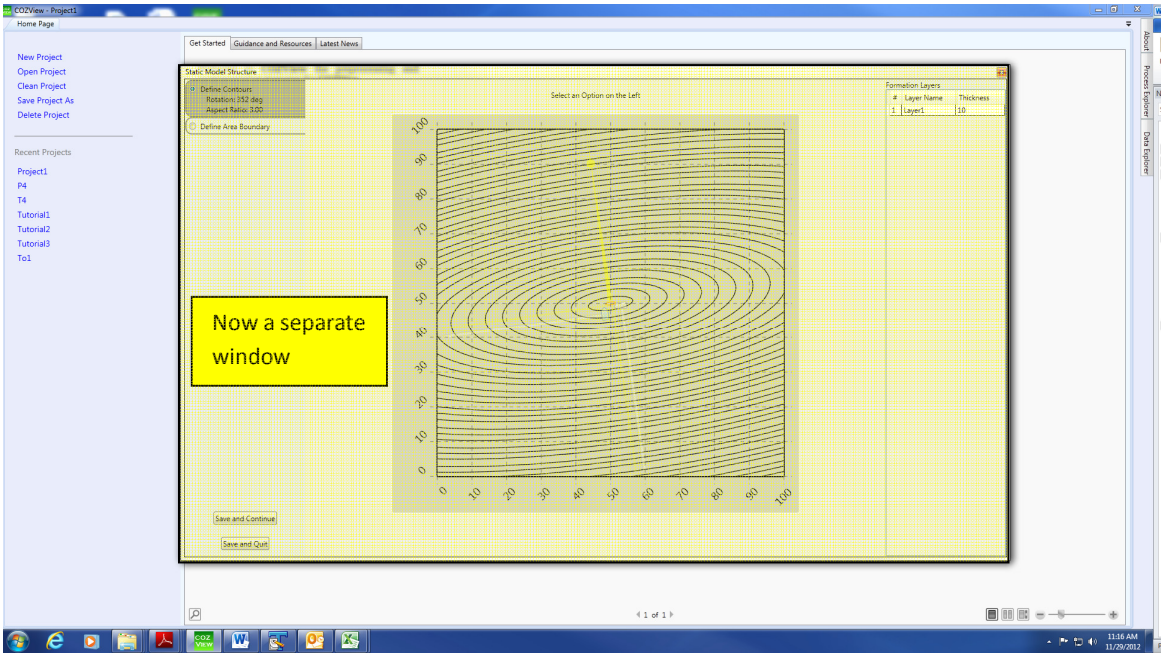
2.5 Guidance and Menu Tabs

The Guidance tabs are the vertical tabs on the right side of the **COZView** window. The Menu tabs are the horizontal tabs across the top of the **COZView** window.

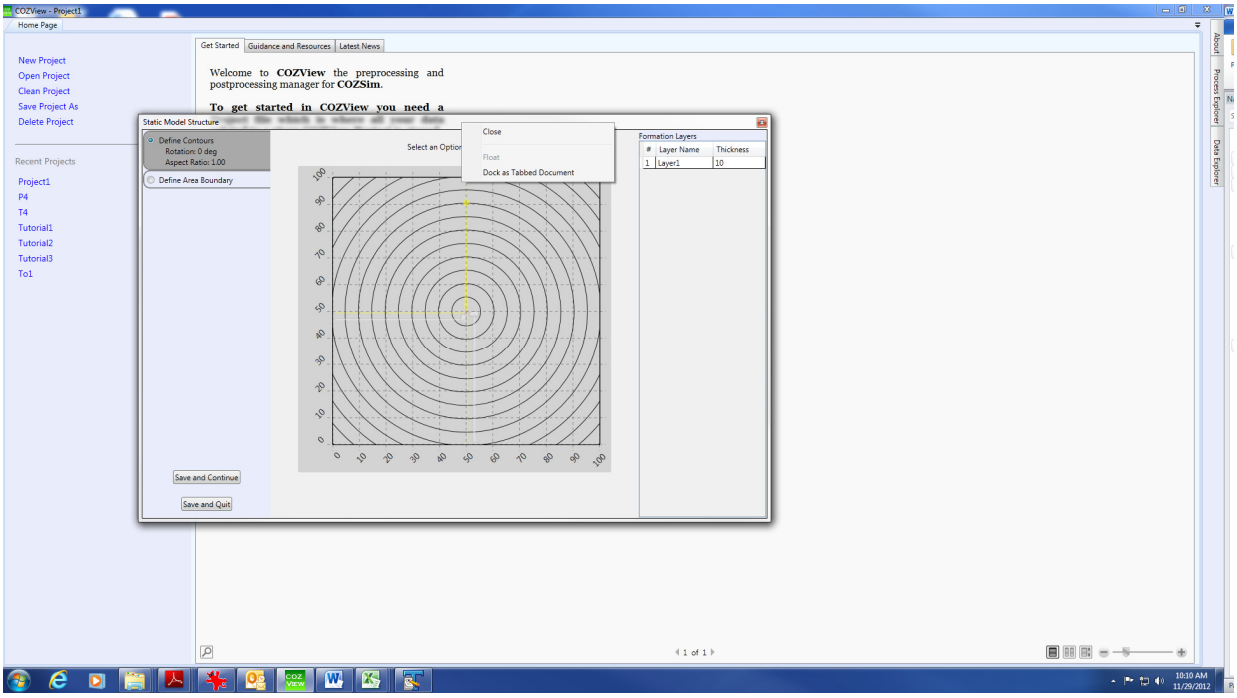
The Menu tabs appear when a specific menu item is selected from within one of the Guidance tabs. The picture below shows the Static Model Structure Menu tab alongside the Home Page tab. This was the result of single-clicking on the Structure Menu under the Static Model in the Process Explorer Guidance tab.



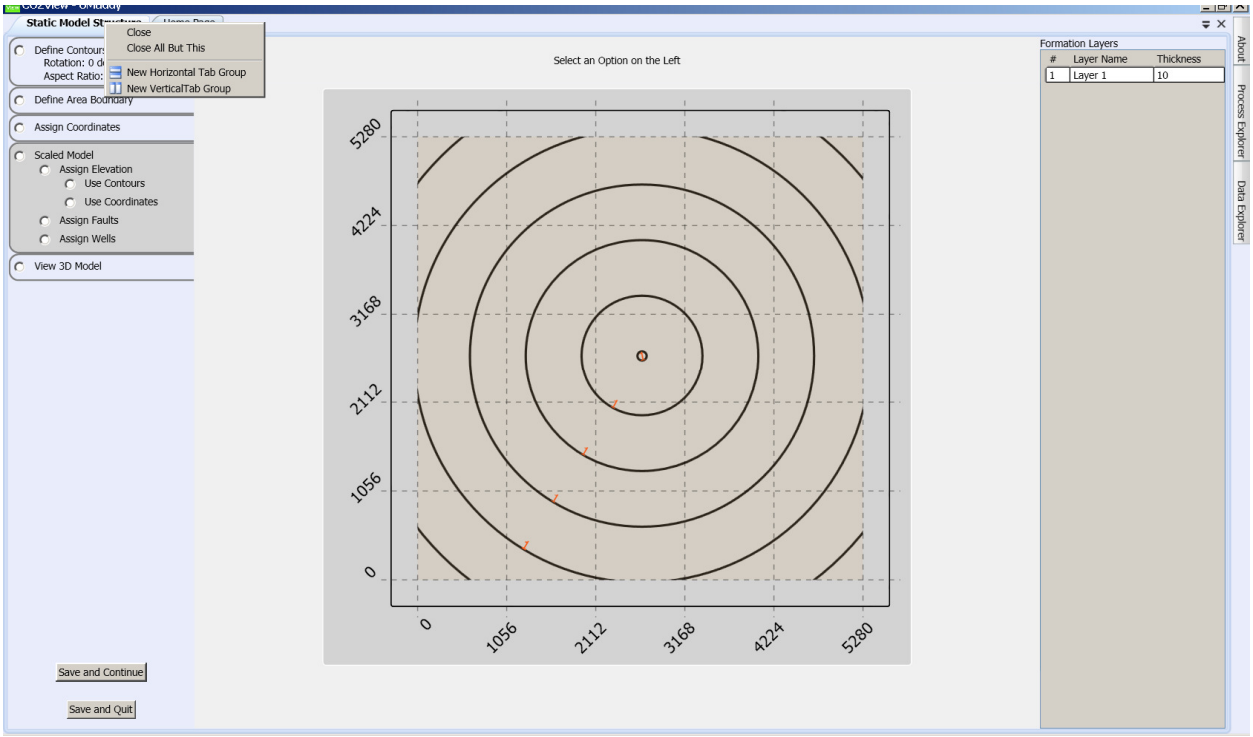
Any menu tab can be transferred to a separate window by selecting and dragging the tab to another area of the screen as shown below. This can be very useful when multiple monitors are available. This allows multiple **COZView** menus to be viewed at the same time.



A menu tab window can be returned to the horizontal tab area by right-clicking the Title bar and selecting *Dock as Tabbed document*. The menu window and the tab can be closed by right-clicking the Title bar and selecting *Close*.



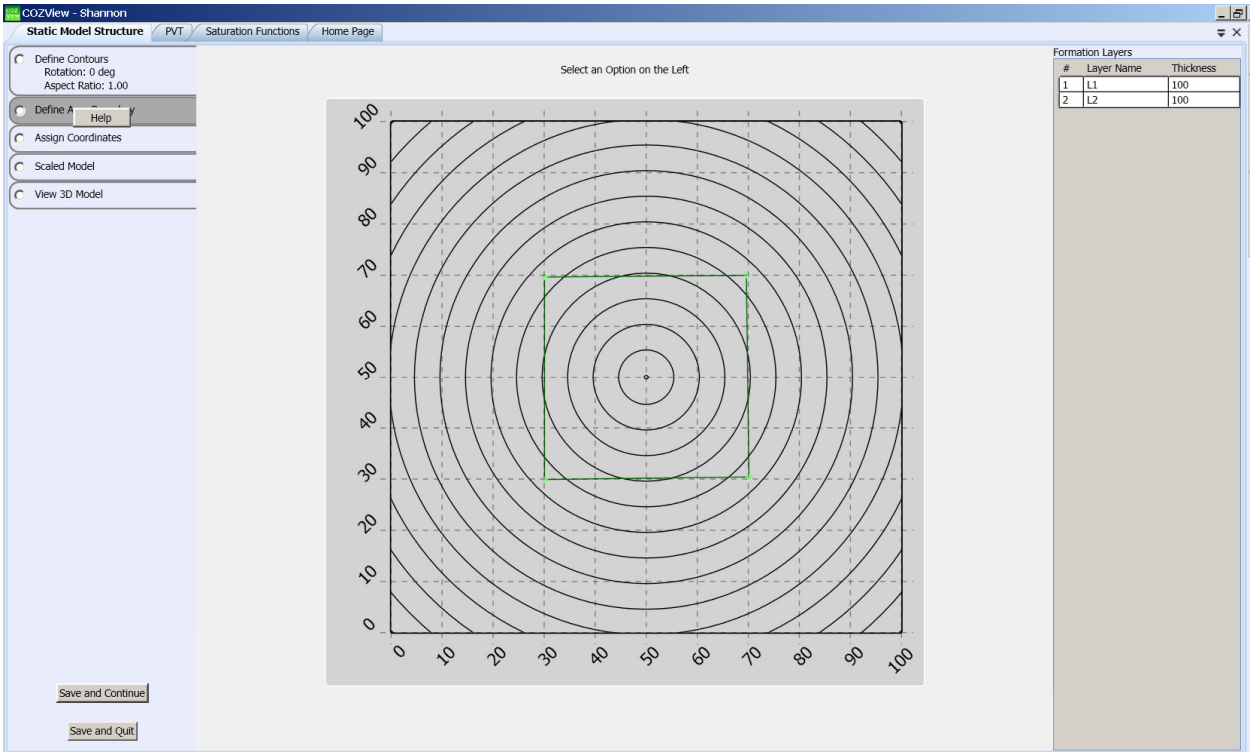
Right-clicking on a menu tab, while in the horizontal tab area, allows the user to select *Close* or *Close All But This* in order to reduce the number of tabs in the horizontal tab area.



2.6 Help

A **COZView/COZSim** User Manual is available for access by the user. This manual can be downloaded and printed as a pdf file from the area where installation materials were provided. The manual can also be accessed from any **COZView** window.

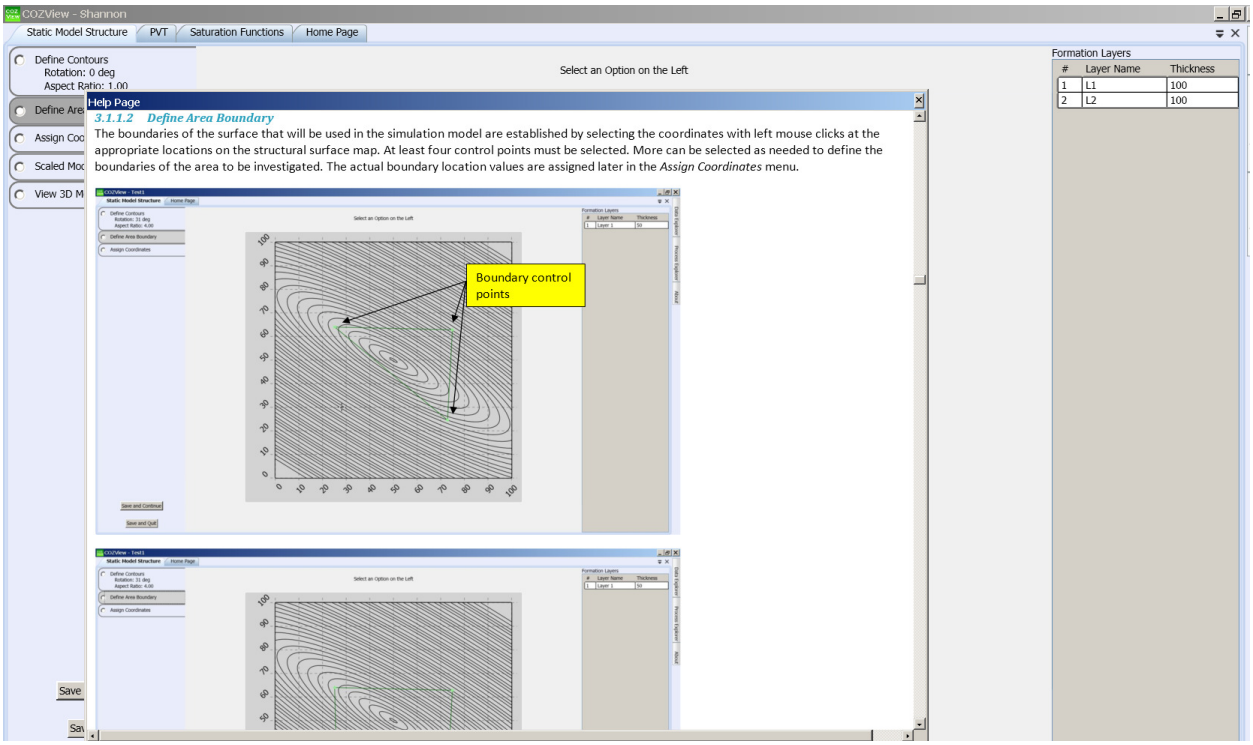
To activate *Help* for a specific topic, the topic must be active. In the Static Model Structure window below, the topic *Define Area Boundary* was selected. A right-click on the topic displays a Help box. Help may be accessed on some screens by a right-click on the screen itself.



Selection of *Help* accesses the related topic in the User Manual and displays it as a separate window. This window can be dragged to a different location by the user if desired. The window can be closed by selecting the X in the upper right corner of the Help window.

The user can view multiple *Help* windows by selecting a different topic on a COZView window and activating *HELP*.

In addition, the scroll bar on the right of any HELP window can be used to move forward or backward in the documentation.


COZView - Shannon
Static Model Structure
PVT
Saturation Functions
Home Page
Define Contours
Rotation: 0 deg
Aspect Ratio: 1.00
Define Area
Assign Coo
Scaled Moc
View 3D M
Select an Option on the Left
Formation Layers
Layer Name Thickness
1 L1 100
2 L2 100
Help Page
3.1.1.2 Define Area Boundary
The boundaries of the surface that will be used in the simulation model are established by selecting the coordinates with left mouse clicks at the appropriate locations on the structural surface map. At least four control points must be selected. More can be selected as needed to define the boundaries of the area to be investigated. The actual boundary location values are assigned later in the Assign Coordinates menu.
Boundary control points
Save

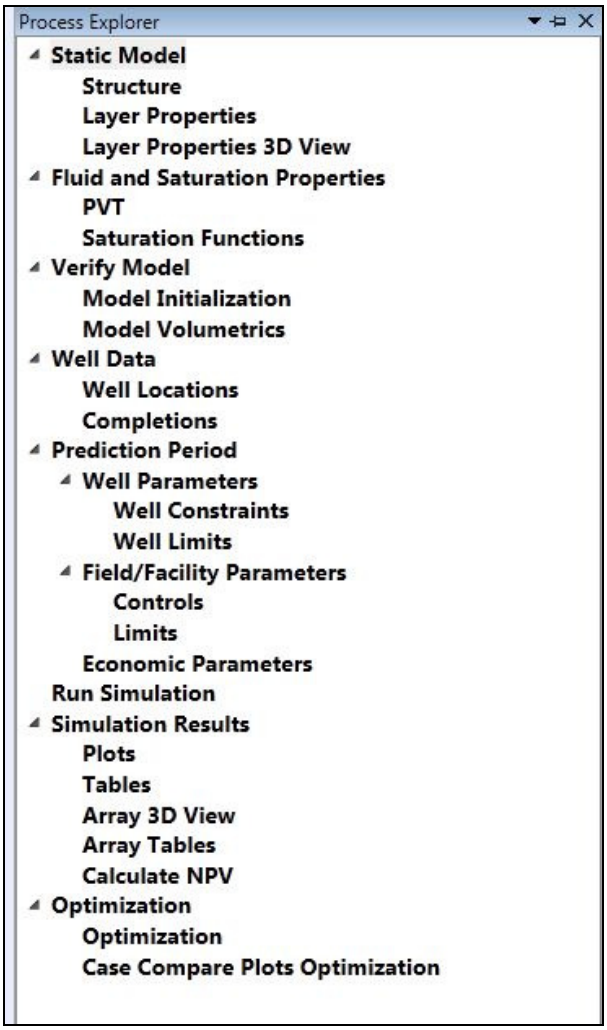
3 Process Explorer

The *Process Explorer* is designed to aid the user in quickly creating a representative simulation model of the reservoir to be investigated. The necessary steps to

- Create a *static model;*
- Define appropriate *PVT* and *Saturation Functions* (*relative permeability* and *capillary pressure*);
- Identify *well locations* and *completions;*
- Establish field and well simulation model *operating controls* and *limits;*
- Define *economic parameters;*
- Launch a *simulation run;*
- Review the *simulation results;* and
- Make *optimization* runs

are provided in the *Process Explorer* area. **We strongly advise initial users to develop their model by systematically moving step by step through the Process Explorer menus.**

Other less frequently needed functionality is provided in the *Data Explorer* area.

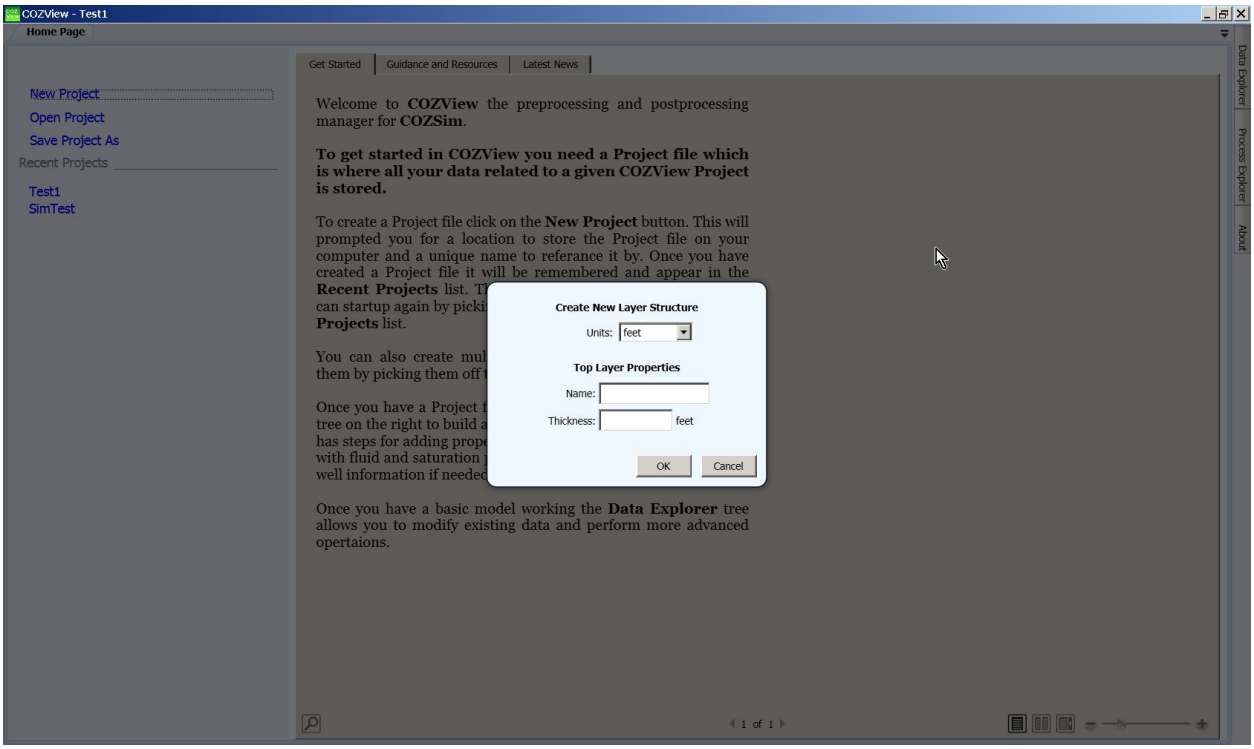


3.1 Static Model

The static model defines the geologic properties of the reservoir to be investigated which do not change with time, pressure or saturation. These are the

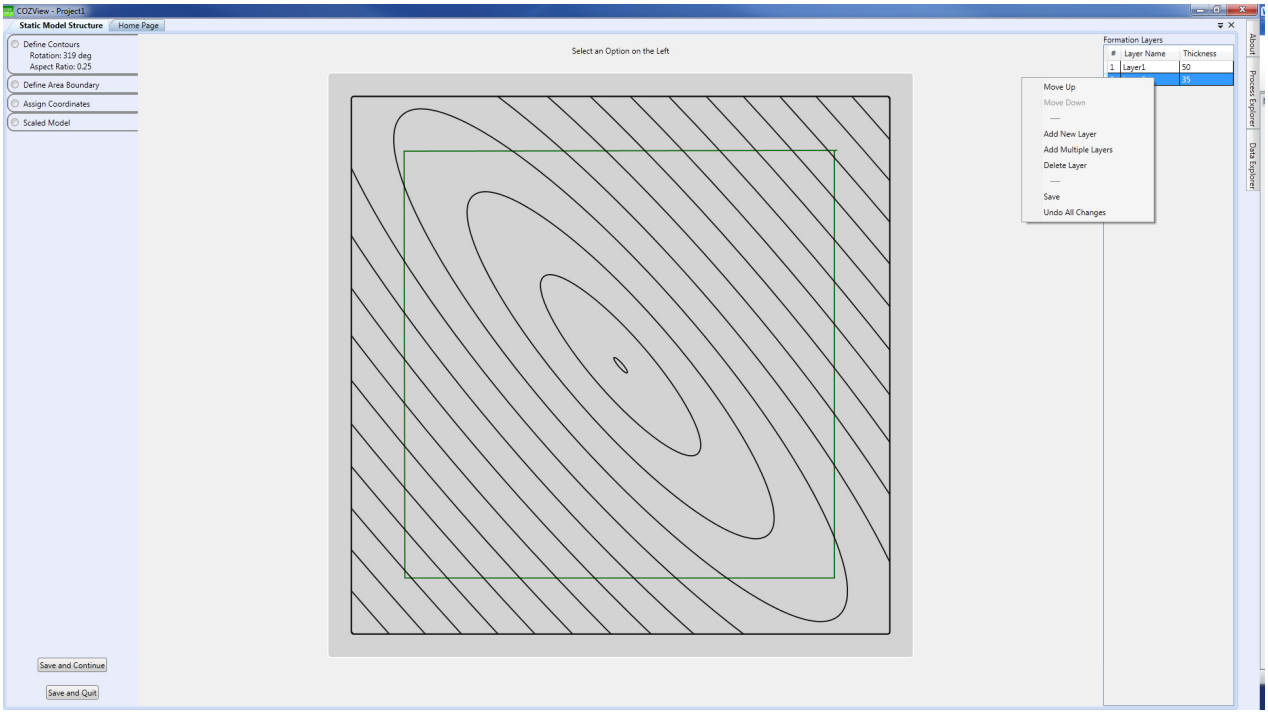
- Structural surface
- Formation thicknesses (net and gross)
- Porosity
- Absolute permeability
- Rock compressibility
- Irreducible water saturation

First time selection of the *Static Model* results in a request for a *Top Layer Name* and gross *Thickness* along with identification of the thickness units. The *Top Layer Name* can be any alpha numeric description. This starts the definition process of the model in **COZView**.



At any time after defining the *Top Layer Properties*, the user can save the model by clicking the **Save and Continue** button or the **Save and Quit** button. Periodic saving is suggested as the model is built. Leaving the *Static Model* area without saving may result in a loss of data.

Once a new model has been created or when an existing model has been selected, the Layer Name(s) and gross thickness will appear in the upper right corner of the *Static Model* screen. New layers can be created with a right-click on the last layer name and selection of Add New Layer. Multiple layers can also be added by selecting Add Multiple Layers. The Layers are assumed to be ordered from top to bottom – 1, 2, 3, etc.



3.1.1 Structure

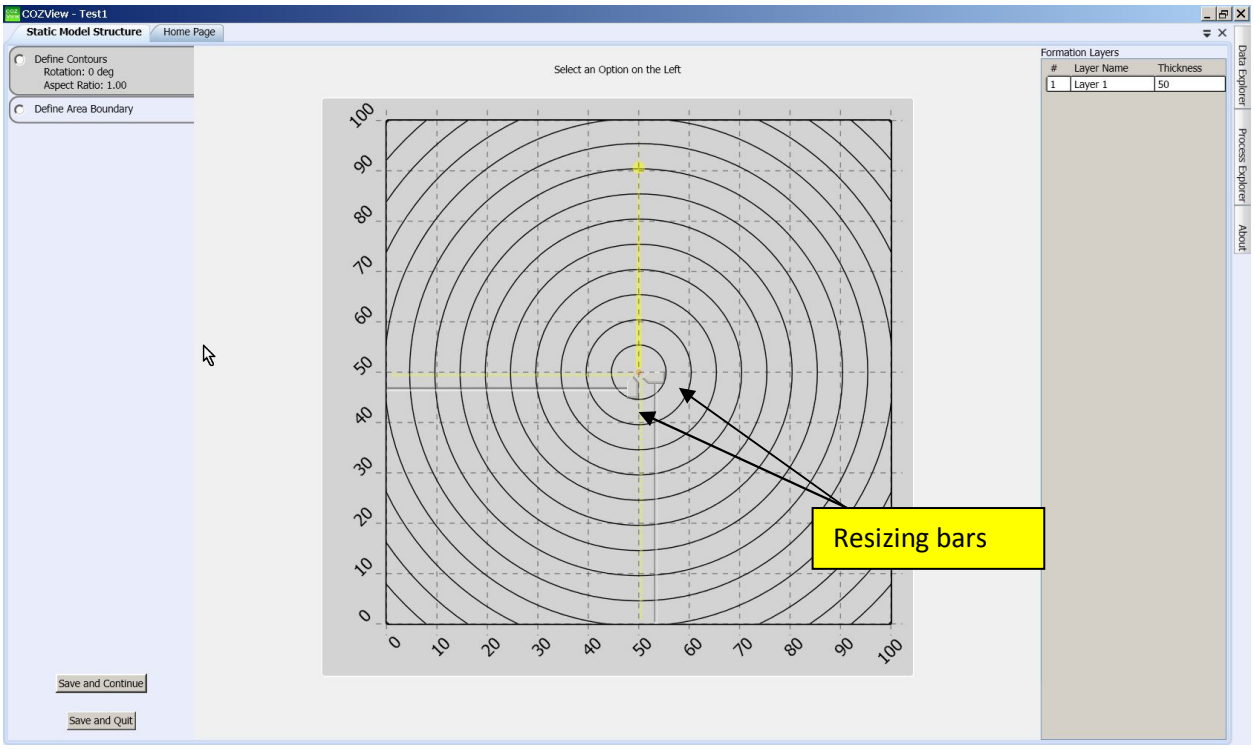
The *Structure* section of the *Static Model* allows the user to define a structural surface and adjust it to approximate the reservoir to be investigated. In the *Static Model Structure* menu

- boundaries for the simulation model are established,
- faults are located and
- well locations can be defined.

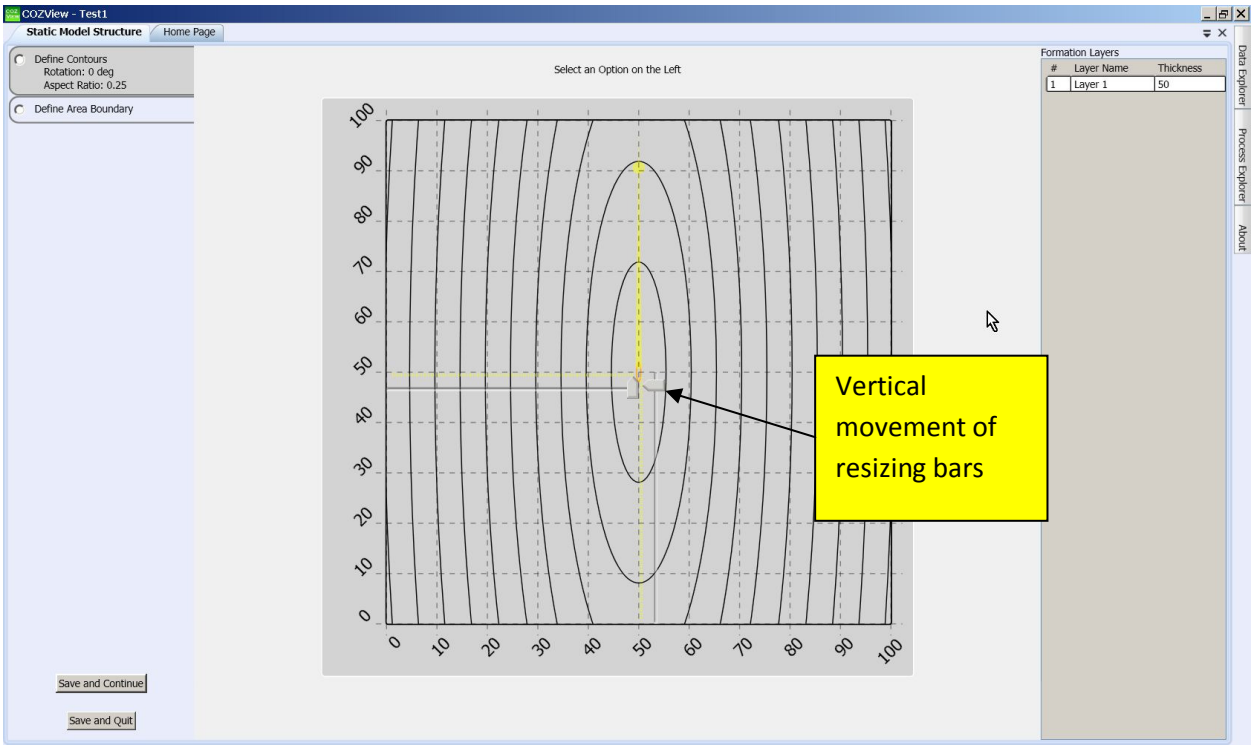
3.1.1.1 Define Contours

COZView allows the user to develop a structural surface for the simulation model that approximates the user's top structure map of the reservoir to be investigated. If available, the user should have their top structure map for reference when creating the structural surface for the simulation model.

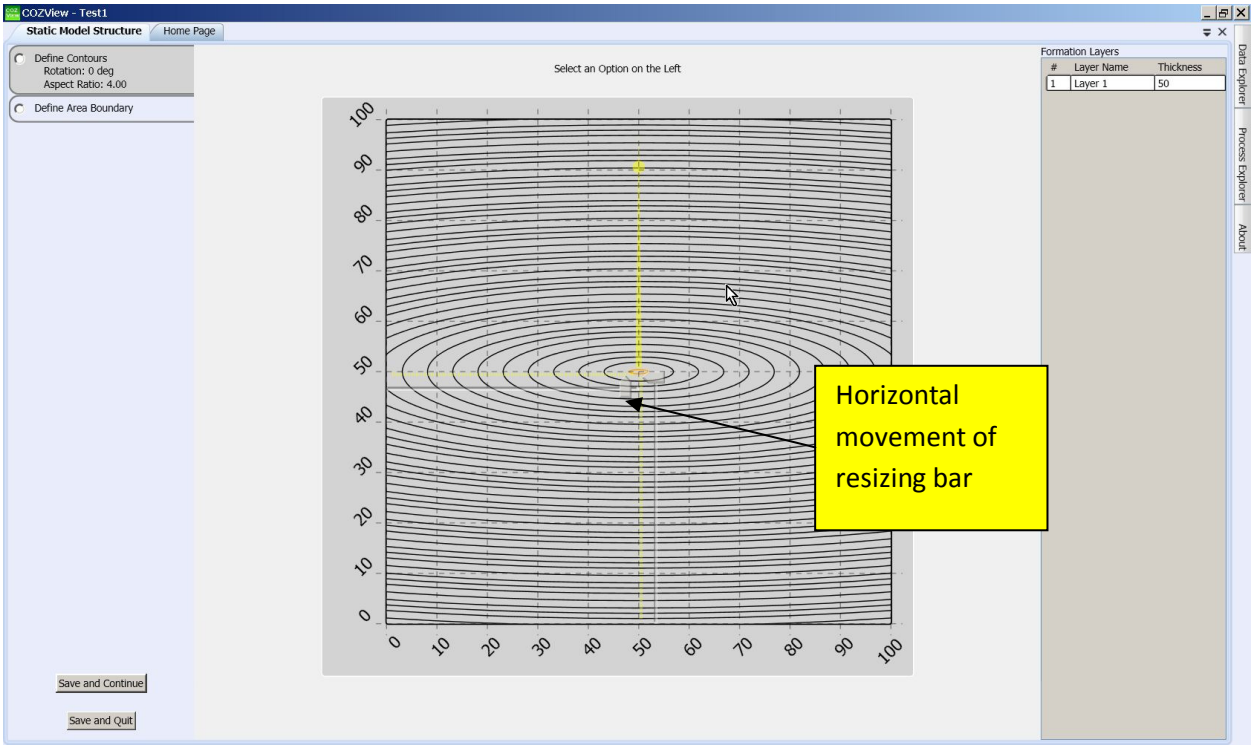
Select *Define Contours*. The default screen shows a circular set of evenly spaced contours. Layer 1, defined earlier, is shown in the upper right panel along with the gross thickness.



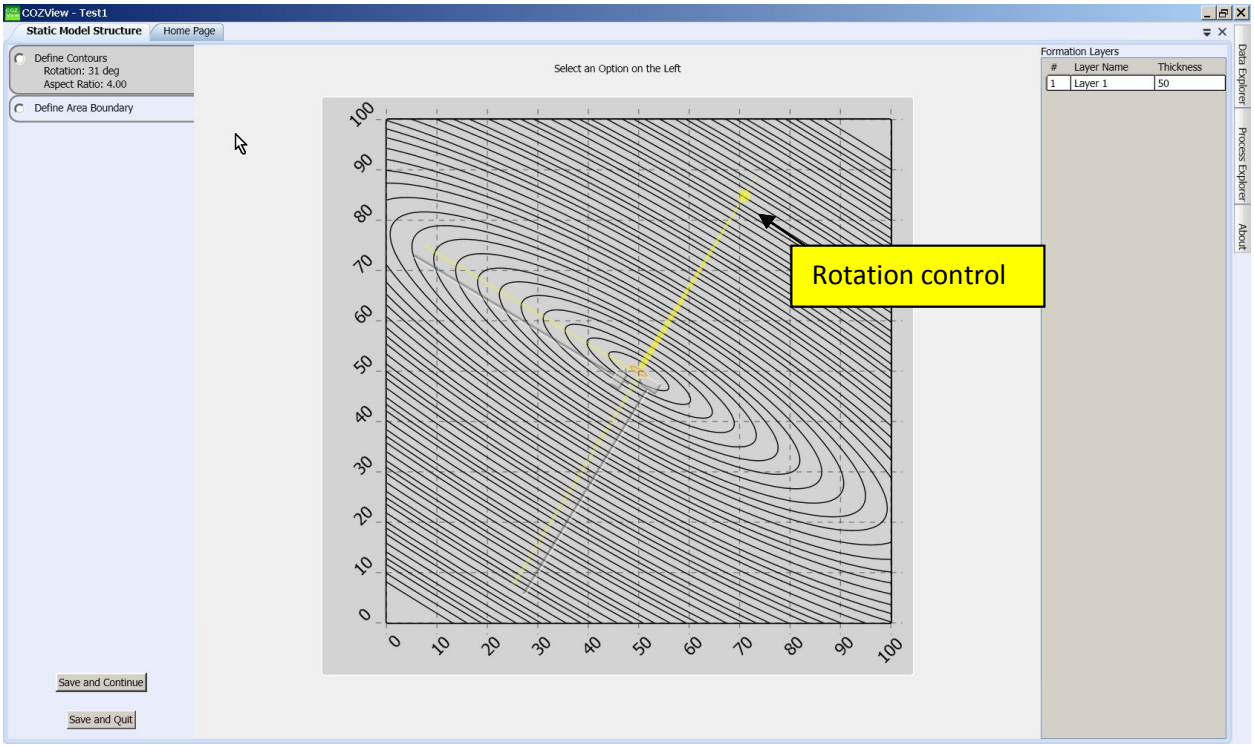
To the right and below the center of the interior circle are two *resizing bars* which allow the user to alter the shape of the contour surface. Movement of the *resizing bar* vertically with a left *click and drag* mouse operation, results in the figure below.



Movement of *the resizing bar* horizontally results in the figure below.



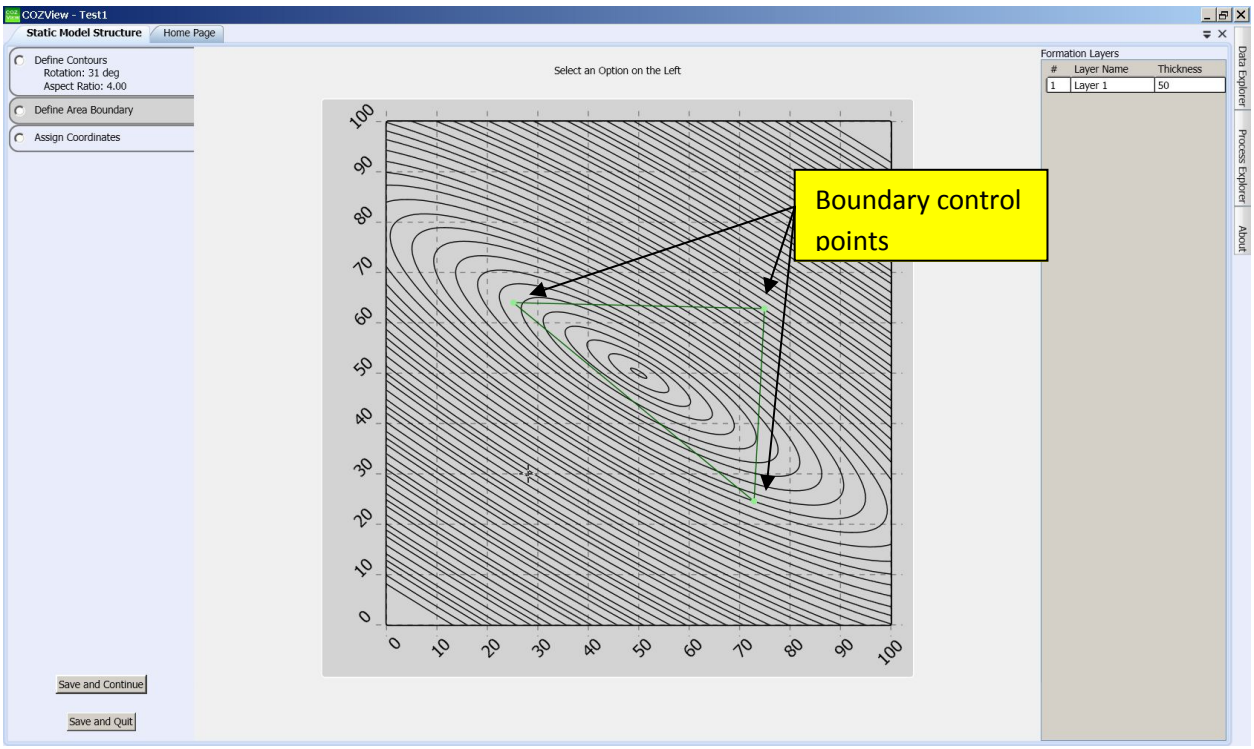
The yellow ball (*rotation control*) at the end of the yellow pillar can be used to rotate the surface clockwise or counterclockwise with a left *click and drag* mouse operation.

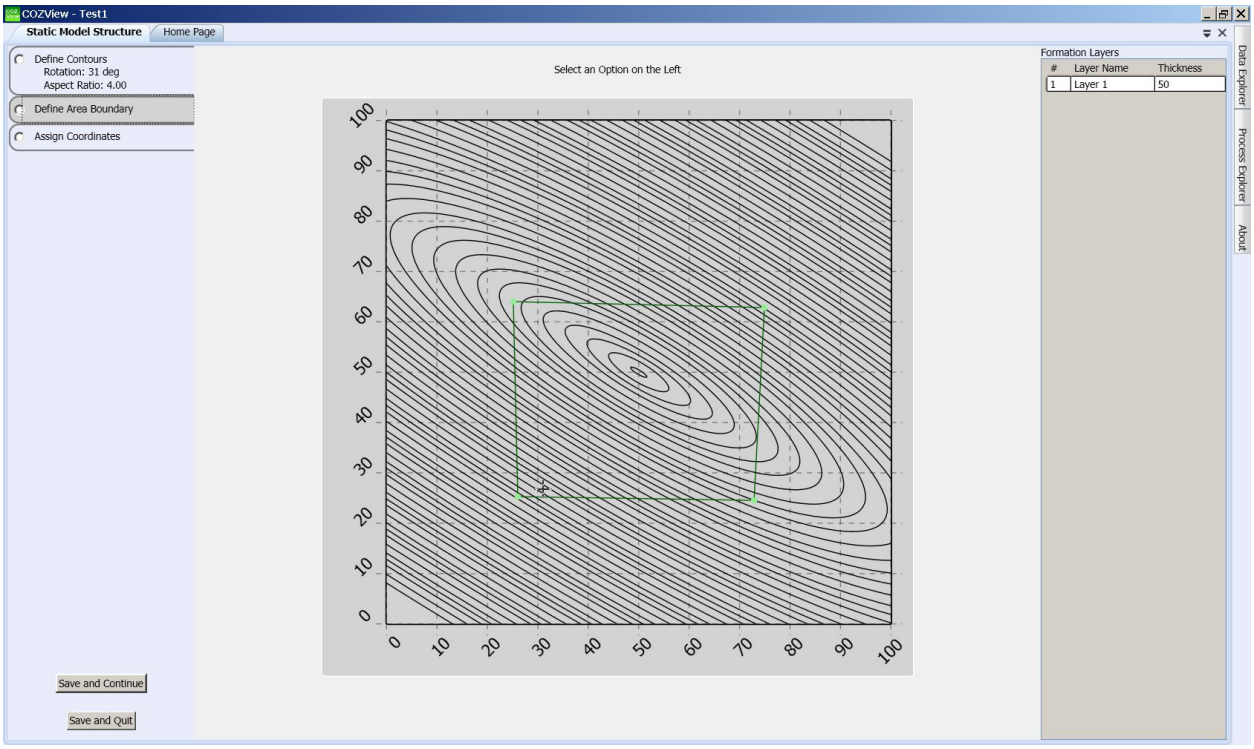


These controls can be used to create a surface that replicates the actual structure top map as closely as possible.

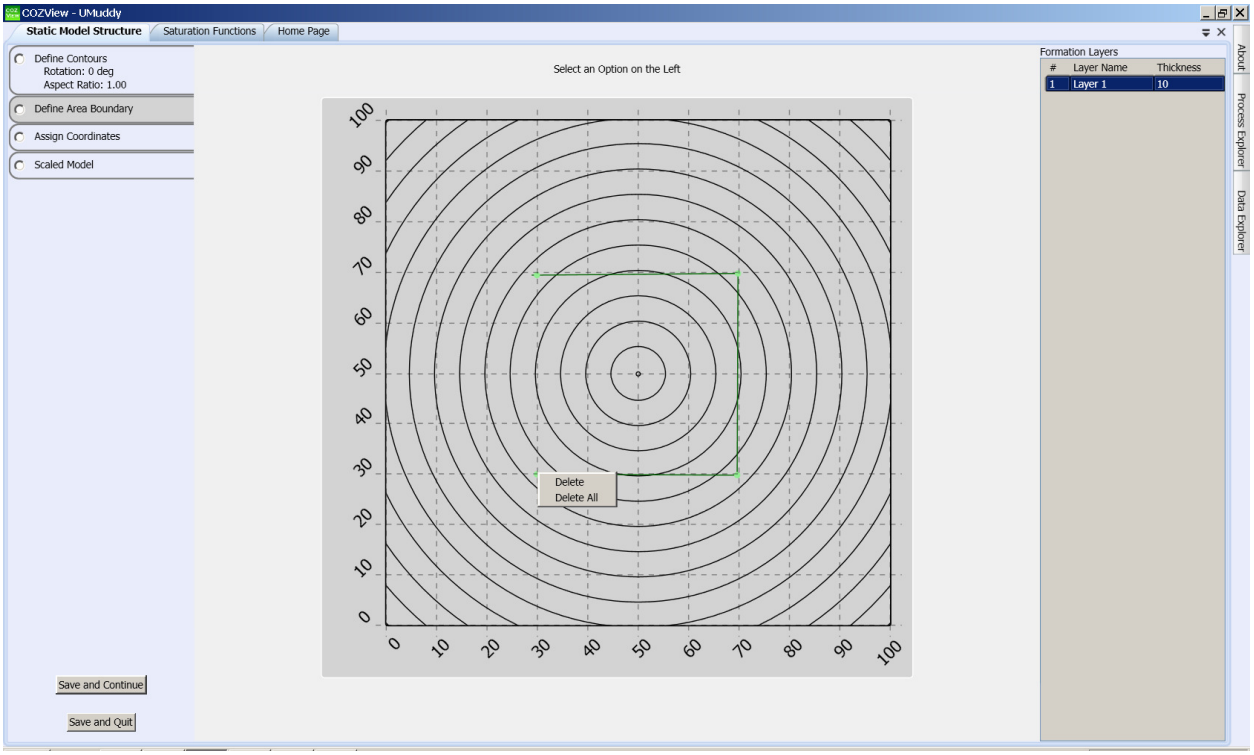
3.1.1.2 Define Area Boundary

Select *Define Area Boundary*. The boundaries of the surface that will be used in the simulation model are established by selecting the coordinates with left mouse clicks at the appropriate locations on the structural surface map. At least four control points must be selected. More can be selected as needed to define the boundaries of the area to be investigated. The actual boundary location values are assigned later in the *Assign Coordinates* menu.





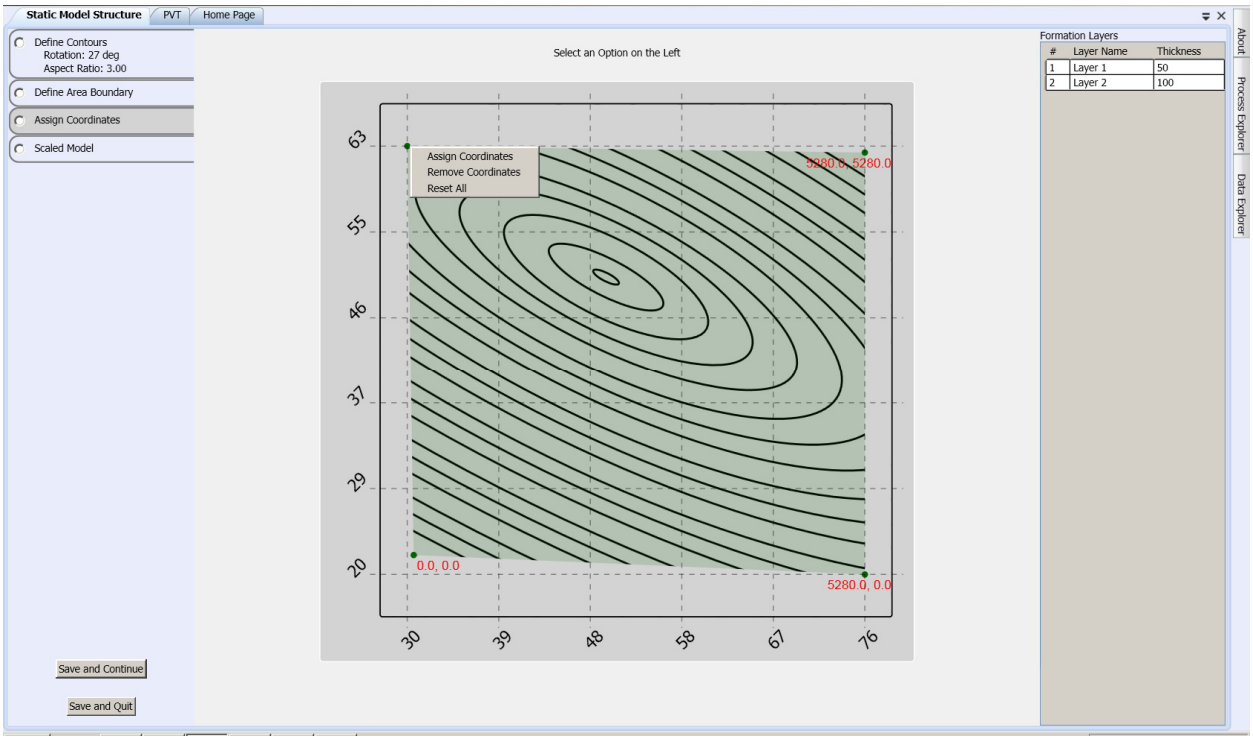
Should the user wish to change a boundary control point, a right-click on the control point will allow that point to be deleted or all points to be deleted. The user can reset the desired control points with appropriate left mouse clicks.

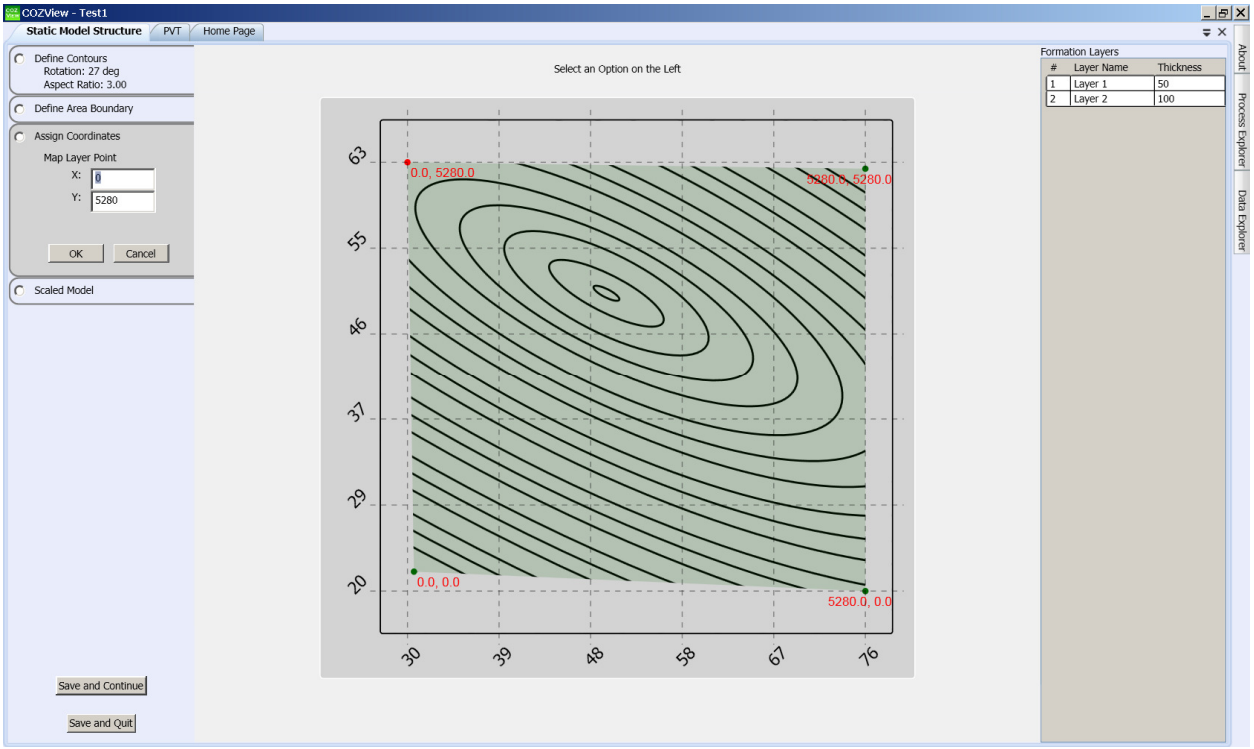


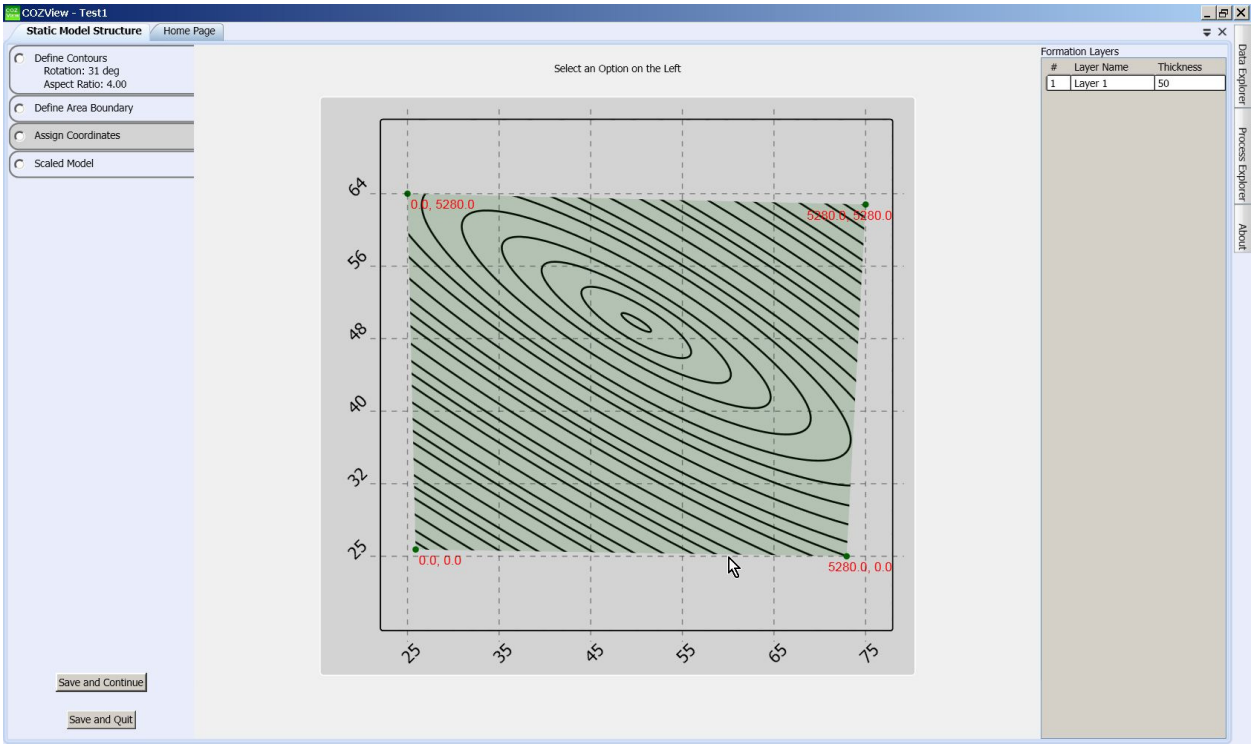
Individual boundary control points can be moved by a left-click and drag to a new location. If this is done after the coordinates of the boundary control point have been set, the coordinates for the moved-points must be re-defined.

3.1.1.3 Assign Coordinates

Selection of *Assign Coordinates* and a right-click on each boundary control point will prompt the user to input the X and Y coordinates for that control point. These coordinate values can be determined from the actual structure top map or approximated by the user.







3.1.1.4 Scaled Model

Selection of *Scaled Model* results in display of the structure surface developed by the user and the model boundaries on the map. The user must provide

- contour elevations.

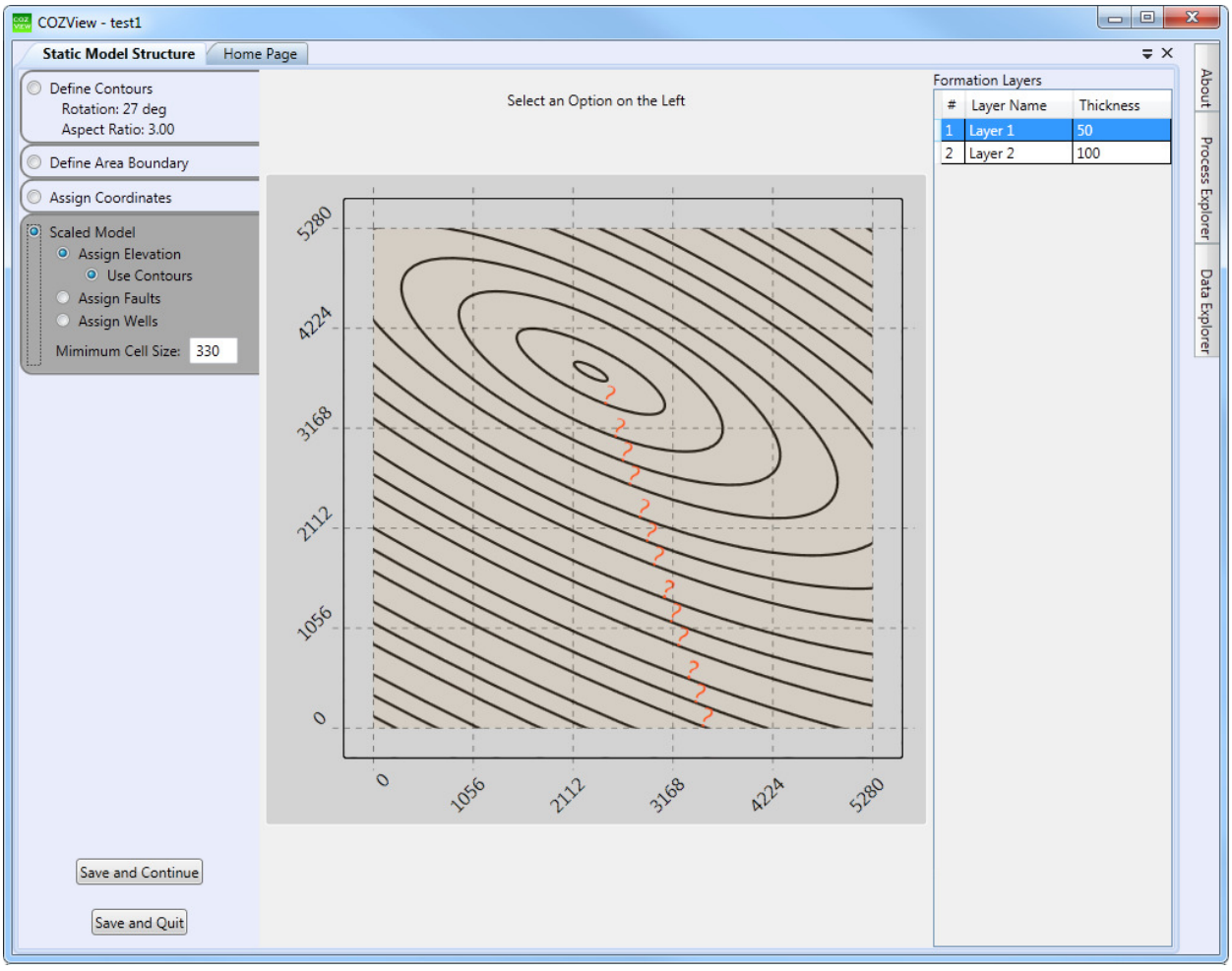
The user can also

- locate faults and
- locate wells in this area.

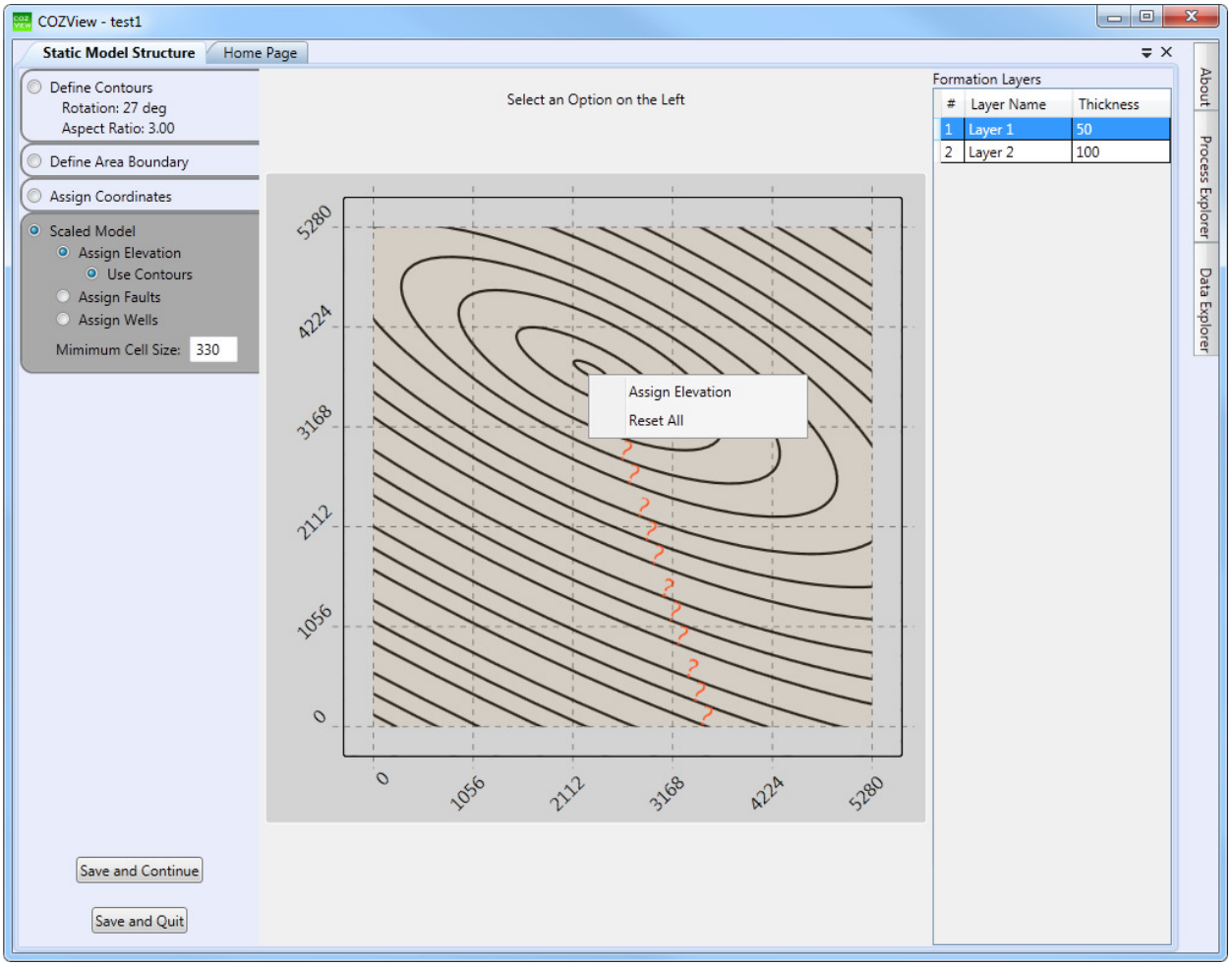
Behind the scenes, the model uses kriging technology to create information needed for the simulation grid cells.

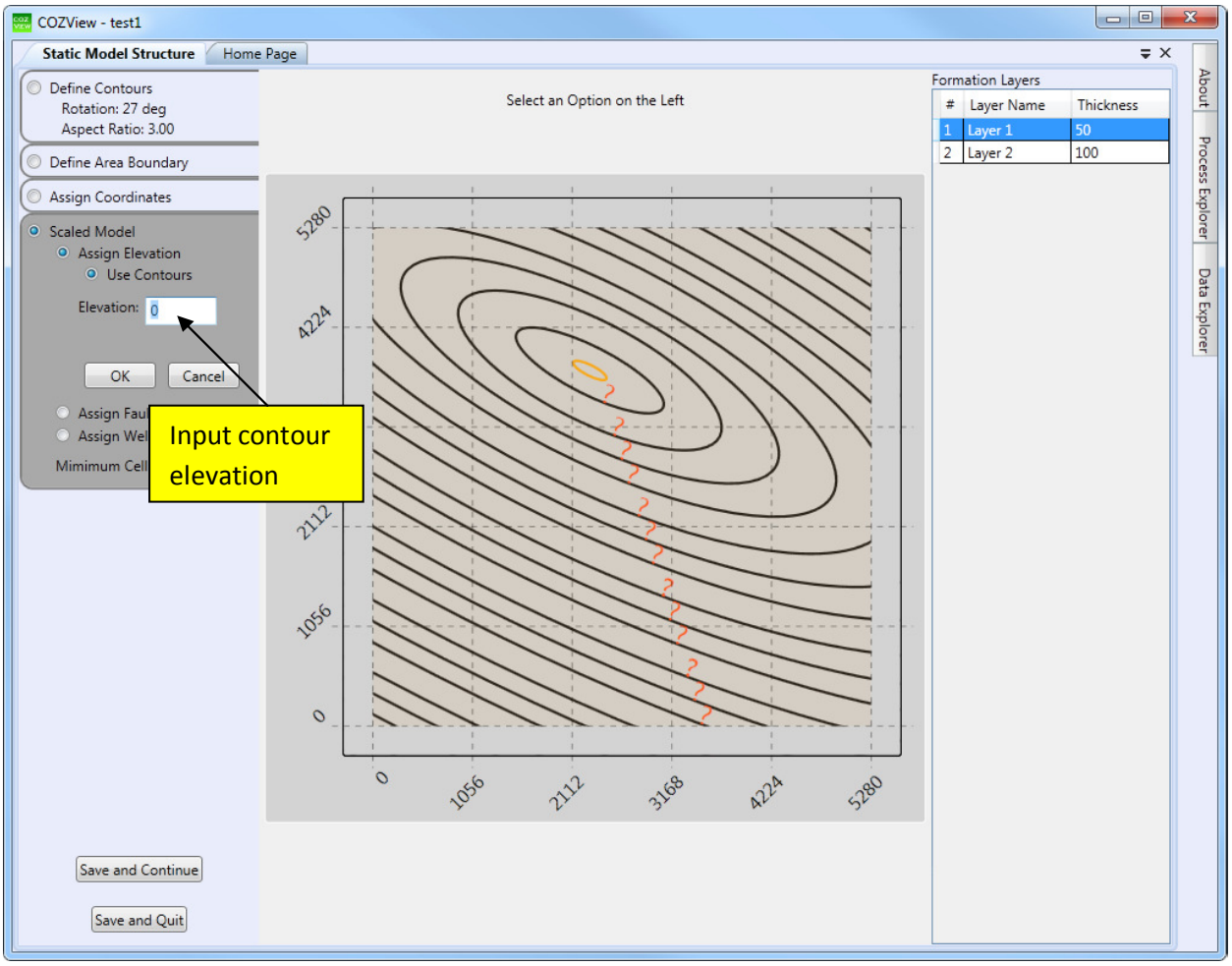
3.1.1.4.1Assign Elevations

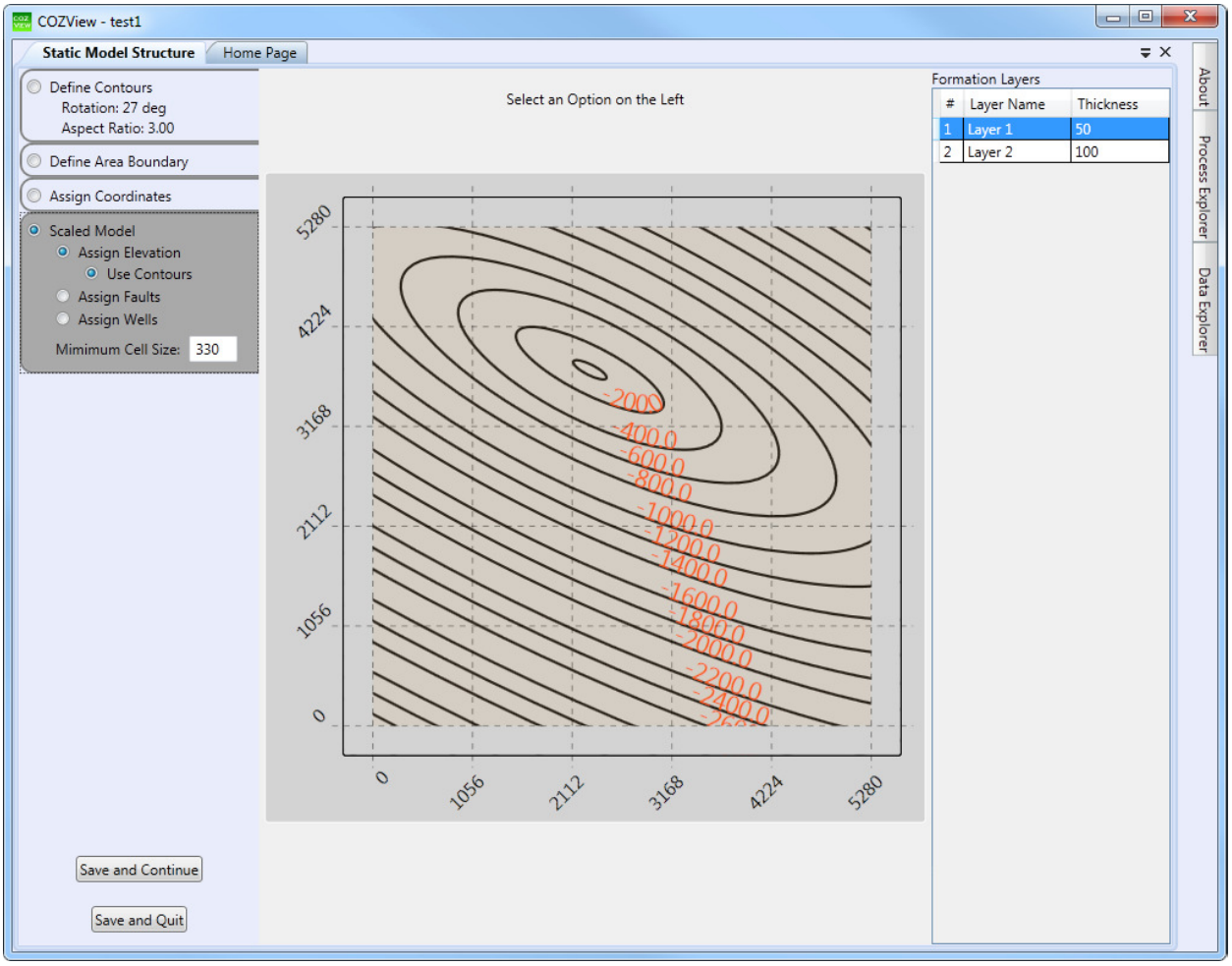
Selection of Assign *Elevations* results in the following display.



A right-click on a contour allows the user to assign a value to that contour. The user can assign contour values to any **two** contours. The implied contour interval calculated by the software will be used to assign values to the rest of the contours. Should the user wish to start over with the contour value assignment, a right-click on the contour and selection of *Reset All* is available.


COZView - test1
Static Model Structure
Home Page
Define Contours
Rotation: 27 deg
Aspect Ratio: 3.00
Define Area Boundary
Assign Coordinates
Scaled Model
Assign Elevation
Use Contours
Assign Faults
Assign Wells
Mimimum Cell Size: 330
Save and Continue
Save and Quit
Select an Option on the Left
Assign Elevation
Reset All
5280
4224
3168
2112
1056
0
0
1056
2112
3168
4224
5280
Formation Layers
Layer Name Thickness
1 Layer 1 50
2 Layer 2 100
About
Process Explorer
Data Explorer


COZView - test1
Static Model Structure
Home Page
Define Contours
Rotation: 27 deg
Aspect Ratio: 3.00
Define Area Boundary
Assign Coordinates
Scaled Model
Assign Elevation
Use Contours
Elevation: 0
OK
Cancel
Assign Fau
Assign Wel
Mimimum Cell
Input contour elevation
Save and Continue
Save and Quit
Select an Option on the Left
Formation Layers
Layer Name Thickness
1 Layer 1 50
2 Layer 2 100
About
Process Explorer
Data Explorer
5280
4224
2112
1056
0
0
1056
2112
3168
4224
5280

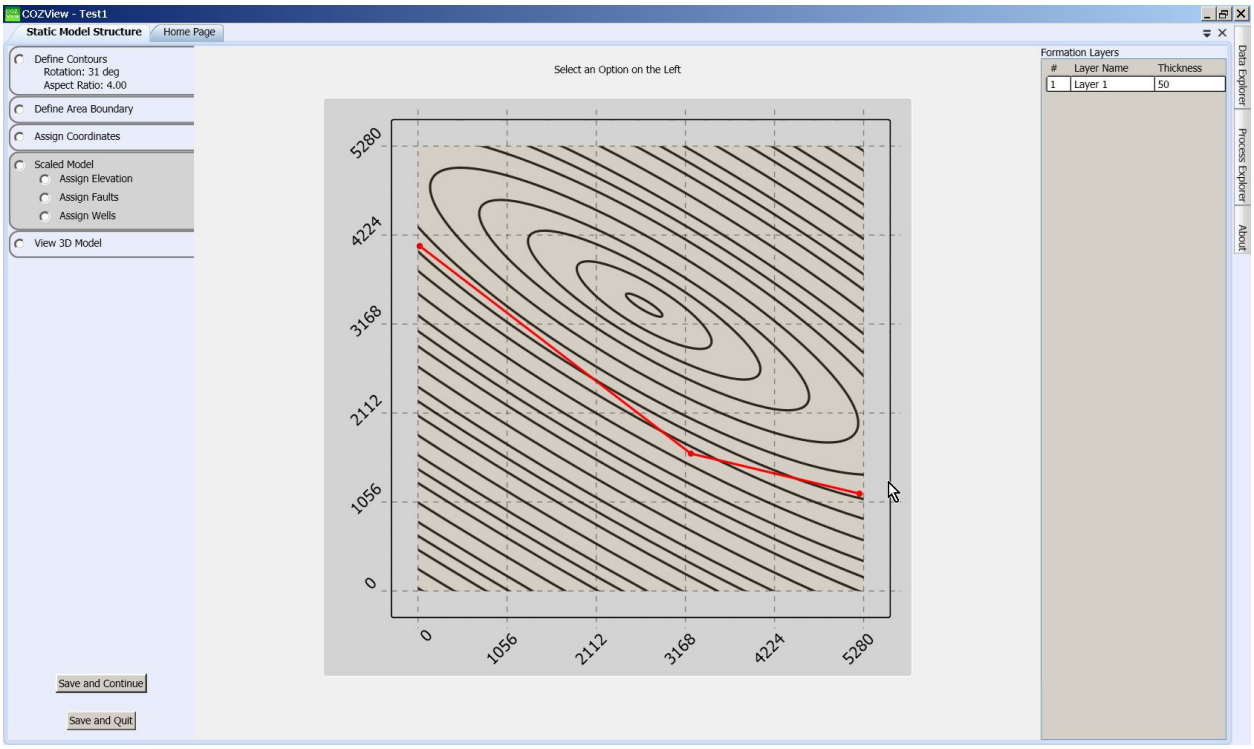


Be sure to click the **Save and Continue** button before leaving the *Assign Elevations* area.

Additionally, if the elevation contour values are changed at a later time, they must be saved or the model is not updated and the 3D View will be incorrect.

3.1.1.4.2Assign Faults

Selection of *Assign Faults* allows the user to define a vertical fault with left mouse clicks at the appropriate locations. The *vertical fault* will penetrate all layers in the model and will act as a barrier to flow. Partial communication across a fault is not allowed.



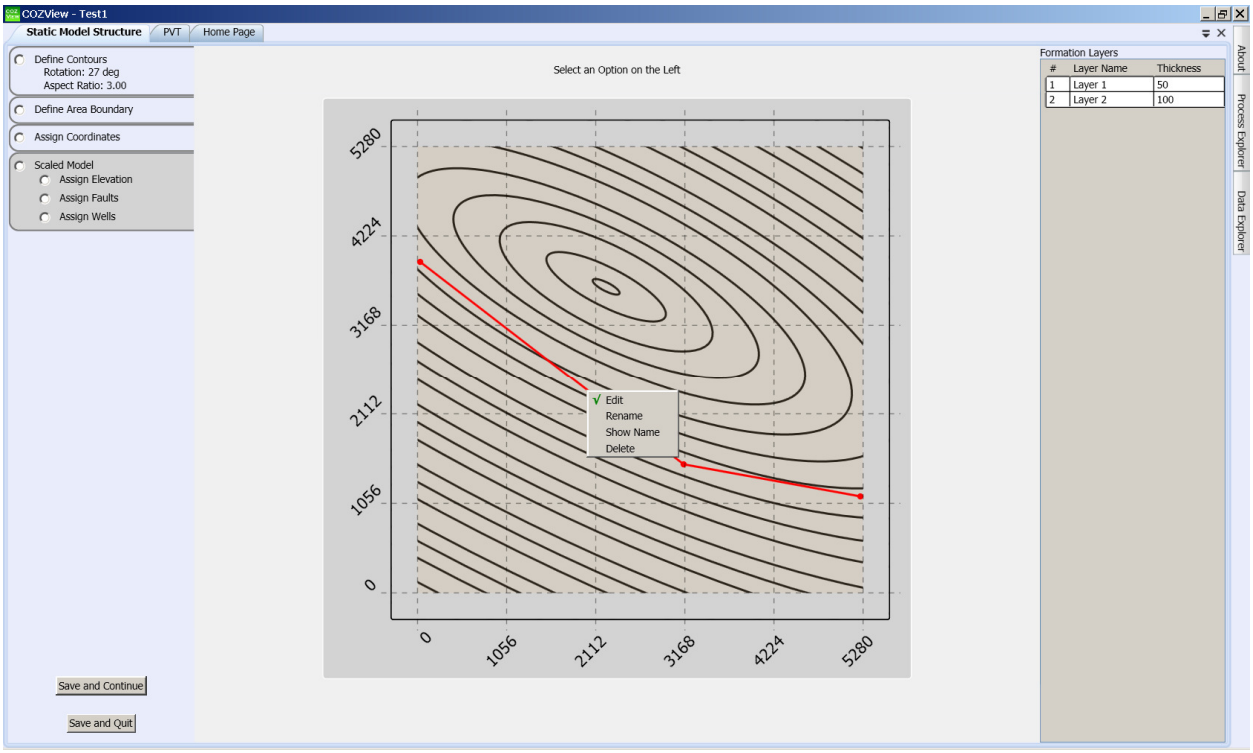
Changes to a fault which has been created can be done as follows:

Delete a fault control point: a right-click on the control point allows the user to delete that control point;

Delete a fault trace: a right-click on a segment of the fault allows the user to delete the entire fault trace.

Display or change fault name: A Fault name is assigned at the time of fault creation; this can be displayed and changed by the user with a right-click on a segment of the fault trace.

If the user wishes to input *multiple faults*, a right-click on a segment of the most recently defined fault allows the user to select **√Edit**. This selection stops (unchecks) further editing of the current fault trace and allows the user to start input of a new fault trace.



Be sure to click the **Save and Continue** button before leaving *Assign Faults*.

3.1.1.4.3Assign Wells

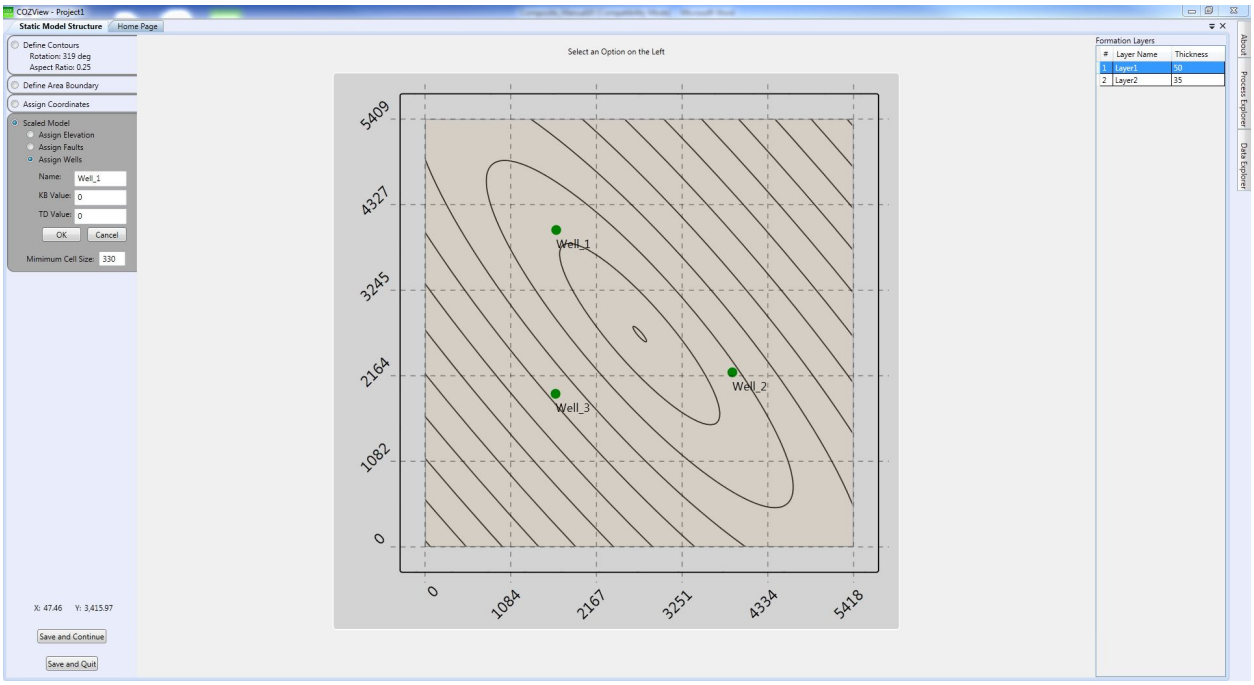
Selection of *Assign Wells* allows the user to locate wells on the structure surface map previously created.

Placement of well on the map: a left-click with the cursor at the desired location will result in placement of a well. The default name is Well #. The well # defaults to 1 and each new well is incremented to the next number.

Change well name: a right-click on the well symbol displays a well panel for changing or inputting the well name.

Input well KB and TD: KB elevation and TD values for the well are input in the well panel. Click OK to close the well panel. These parameters are for reference only; they are not used in COZView or COZSim.

The x, y coordinate location of the cursor is displayed in the lower left of the window. This may assist the user in locating wells in the model when the actual well coordinates are known.



Be sure to click **Save and Continue** or **Save and Quit** before leaving *Assign Wells*.

If the user has the actual well locations and there are a number of wells to identify in the model, this manual location of each well may be too time consuming. The user may wish to load the well locations using the Import functionality in the *Well Data, Well Location Data* section 3.4.1.

If the active screen is in the Static Model window, any Save operation after assignment of elevations will result in a "Loading" message next to *View 3D Model*. **Wait until the Loading message has disappeared before proceeding.**

3.1.1.4.4Simulation Grid

COZView will create the simulation grid automatically during the *Scaled Model* process. The grid can be viewed in the 3D displays. The number of cells in the simulation grid is based on the areal boundaries and the shape of the area to be modeled. There are two overriding principles in creating the grid – 1) a grid cell's dimensions will not be less than 330 ft by 330 ft and 2) all grid cells will be square.

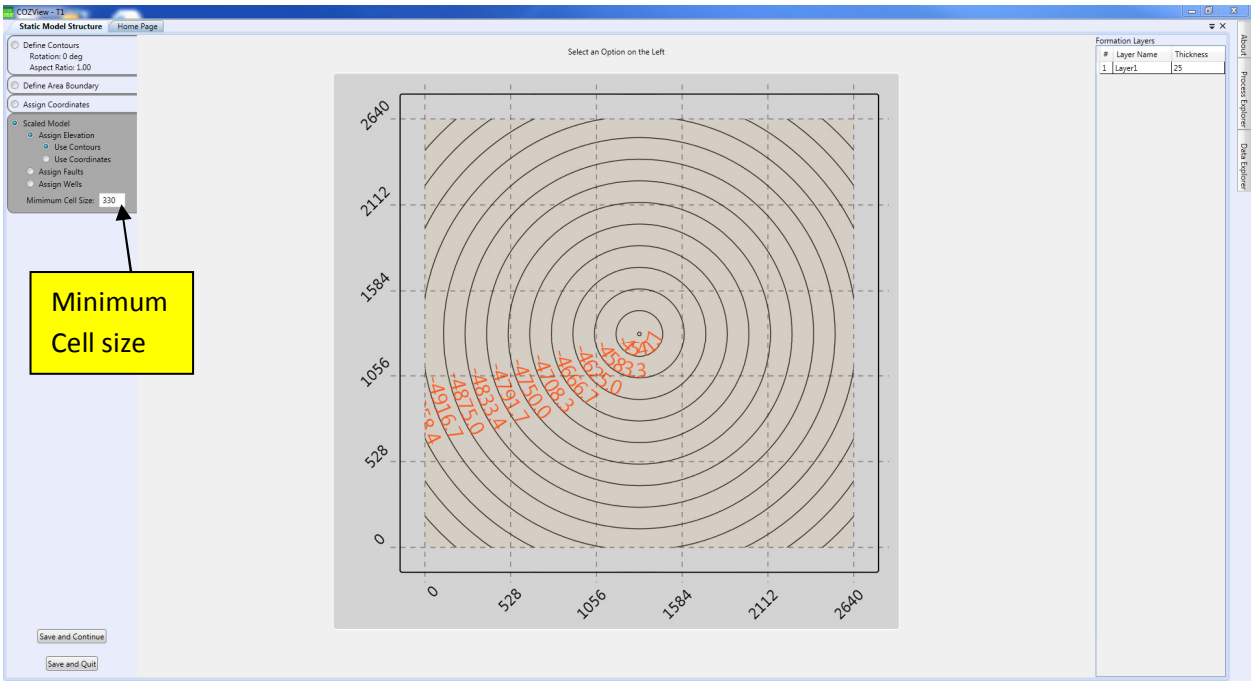
The maximum number of grid cells in either the X- or Y-direction will be 100. If the model area is square and the model area exceeds 33,300 ft on each side, the grid will be 100 by 100 (10,000 total cells per layer).

If the square model area is less than 33,300 ft on each side, say 10,000 ft, the grid will be 30 by 30 (900 total cells per layer). Each grid cell will be 333 ft by 333 ft.

If the model area is rectangular in shape, the longest dimension of the rectangular area will determine the cell dimensions. For a model area with rectangular dimensions (X and Y) of 25,000 ft by 15,000 ft,

the grid will 75 cells in the X-direction and 45 cells in the Y-direction (3375 total cells per layer). The cell size will be 333 ft by 333 ft.

When modeling areas of small dimensions, like a small acreage pattern or element of symmetry, the default minimum cell dimensions may result in too few cells in the model. Hence, the user may wish to override the default minimum cell dimensions of 330 in the minimum Cell Size box at the bottom of the Scaled Model area.

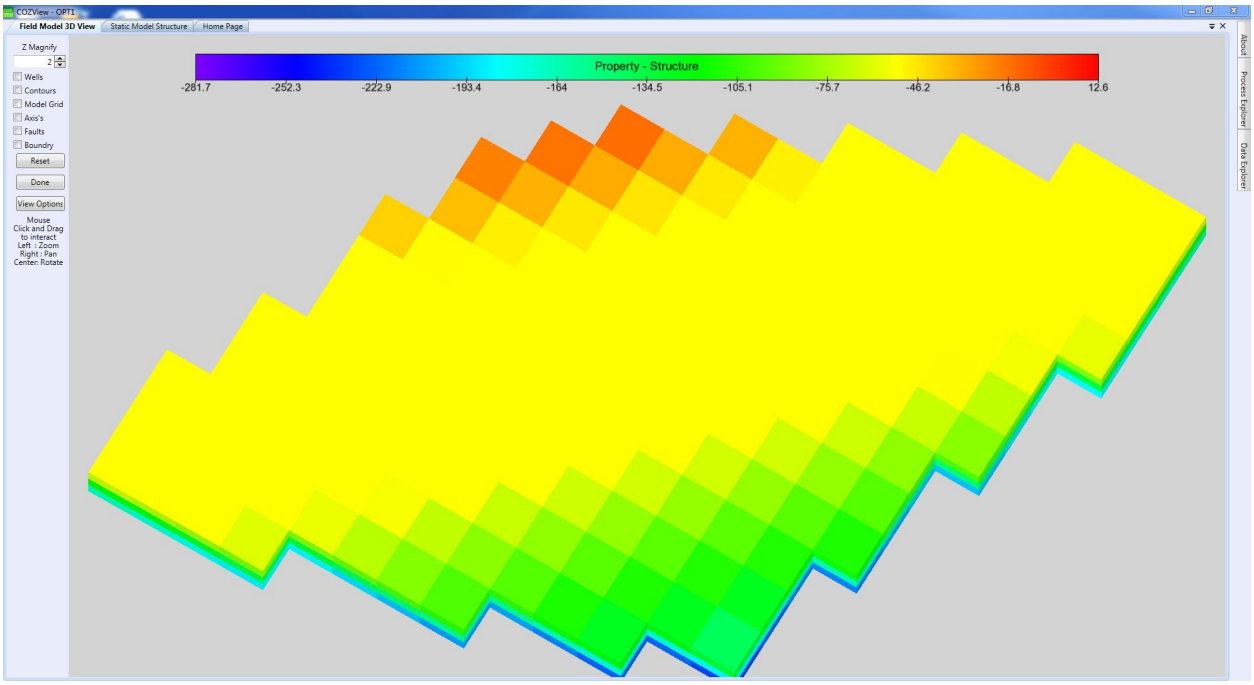


This should be done with caution. Reducing the minimum cell size will increase the number of total cells in the model, which will increase the simulation run time. This should only be done for the noted "small acreage" models. The minimum cell size is 220 ft. The maximum number of cells in the X- and Y-directions will not be allowed to exceed 100.

Be sure to select *Save and Continue* before leaving the **Scaled Model** area to effect the change.

3.1.1.5 View 3D Model

Selection of *View 3D Model* allows the user to visualize the structure model that has been created in a three dimensional format.



The initial 3D view will be a high angle representation of the surface with a vertical Z Magnification of 2. This Z magnification can be changed by the user.

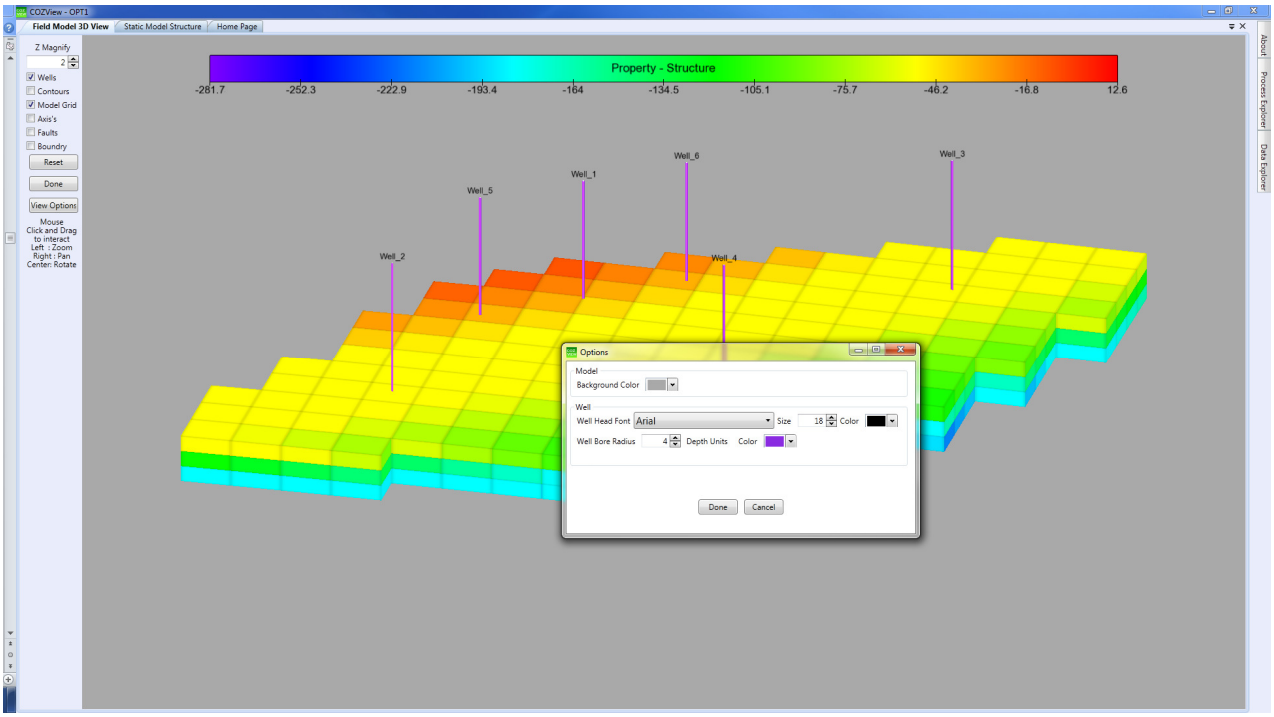
A color bar at the top of the view denotes the range of property values in the model area.

A number of views and operations can be implemented in the *3D View*. The following *click and drag* mouse operations can be used: Left – Zoom, Right – Pan, and Center – Rotate.

The display of wells, contours, (simulation) model grid, view axis's, faults and area boundaries can be activated with selection of the appropriate check boxes.

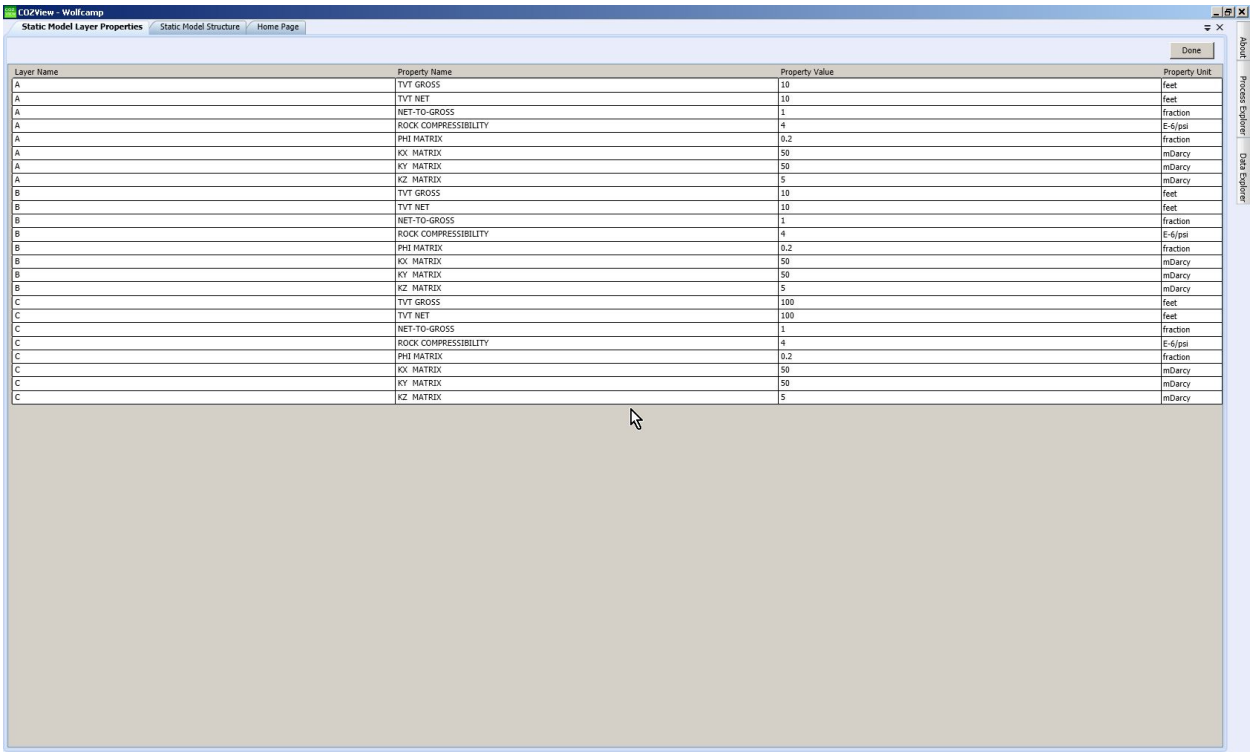
The **Reset** button allows the user to return to the initial orientation on the screen. The **Done** button exits the 3D View screen and returns the user to the prior screen view.

The **View Options** button allows the user to select the background display color (Default color is grey). The size, font, and color of the well names can be selected by the user (Default is Arial font, size 18, and color white). Users are also allowed to choose the well radius size (Default display size is 2, color is white.)



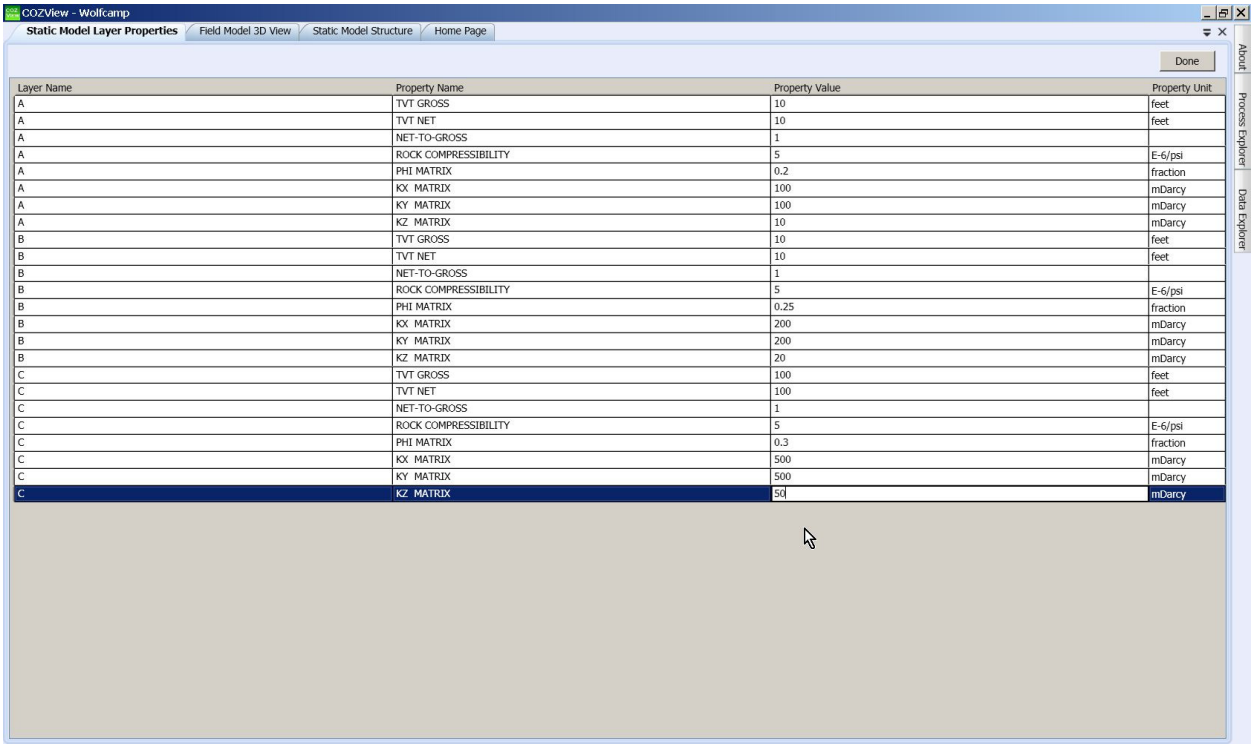
3.1.2 Layer Properties

Selection of *Layer Properties* allows the user to input various static reservoir properties required in the simulation model. A group of properties for each layer which has been previously defined is shown in the table. The properties are constant for each layer, but may be different between layers. The gross thickness previously defined for each layer and the net thickness and net-to-gross values are shown in the table. Default values are provided for all other layer properties in the table. *These default values should not be construed as acceptable values for the user's specific application.*



Layer Name	Property Name	Property Value	Property Unit
A	TVT GROSS	10	feet
A	TVT NET	10	feet
A	NET-TO-GROSS	1	fraction
A	ROCK COMPRESSIBILITY	4	E-6/psi
A	PHI MATRIX	0.2	fraction
A	KX MATRIX	50	mDarcy
A	KY MATRIX	50	mDarcy
A	KZ MATRIX	5	mDarcy
B	TVT GROSS	10	feet
B	TVT NET	10	feet
B	NET-TO-GROSS	1	fraction
B	ROCK COMPRESSIBILITY	4	E-6/psi
B	PHI MATRIX	0.2	fraction
B	KX MATRIX	50	mDarcy
B	KY MATRIX	50	mDarcy
B	KZ MATRIX	5	mDarcy
C	TVT GROSS	100	feet
C	TVT NET	100	feet
C	NET-TO-GROSS	1	fraction
C	ROCK COMPRESSIBILITY	4	E-6/psi
C	PHI MATRIX	0.2	fraction
C	KX MATRIX	50	mDarcy
C	KY MATRIX	50	mDarcy
C	KZ MATRIX	5	mDarcy

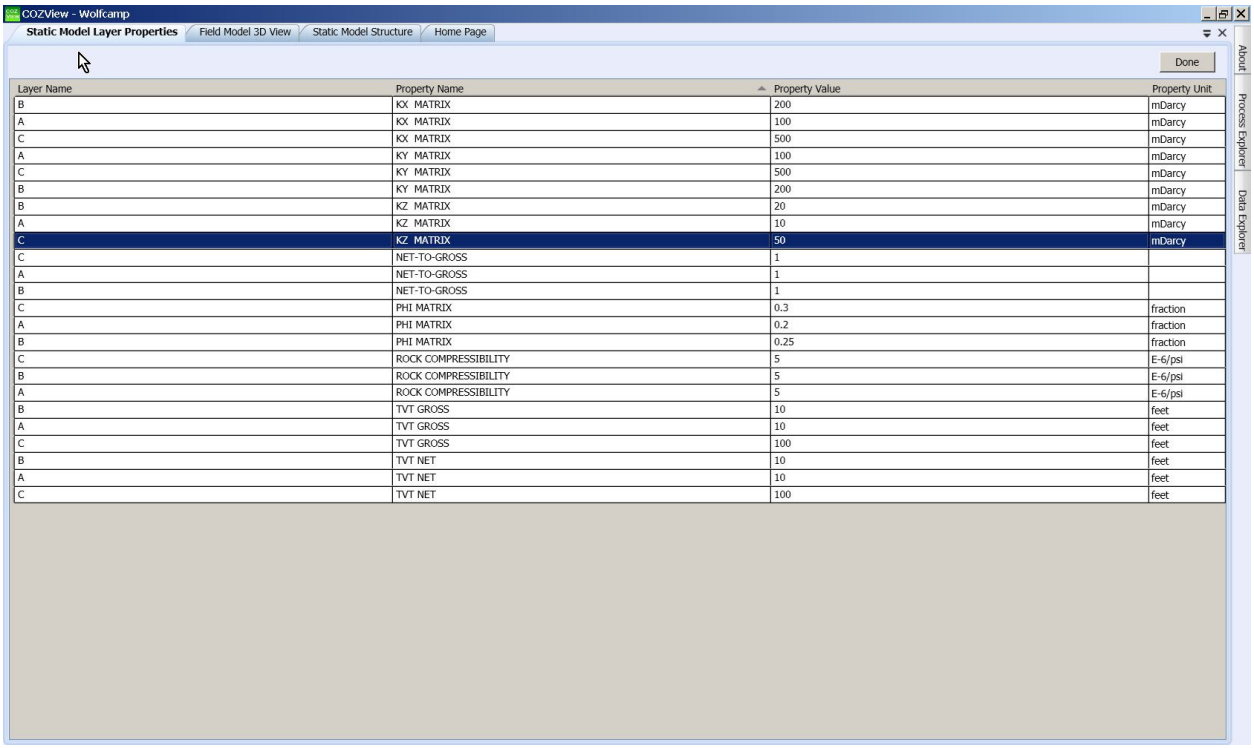
Property values are input by double clicking in the Property Value field and inputting the desired value. The property units for each property have defaulted to typical units. However, double clicking in the Property Unit field for a given property provides a dropdown menu for selection of alternative units.



Layer Name	Property Name	Property Value	Property Unit
A	TVT GROSS	10	feet
A	TVT NET	10	feet
A	NET-TO-GROSS	1	
A	ROCK COMPRESSIBILITY	5	E-6/psi
A	PHI MATRIX	0.2	fraction
A	KX MATRIX	100	mDarcy
A	KY MATRIX	100	mDarcy
A	KZ MATRIX	10	mDarcy
B	TVT GROSS	10	feet
B	TVT NET	10	feet
B	NET-TO-GROSS	1	
B	ROCK COMPRESSIBILITY	5	E-6/psi
B	PHI MATRIX	0.25	fraction
B	KX MATRIX	200	mDarcy
B	KY MATRIX	200	mDarcy
B	KZ MATRIX	20	mDarcy
C	TVT GROSS	100	feet
C	TVT NET	100	feet
C	NET-TO-GROSS	1	
C	ROCK COMPRESSIBILITY	5	E-6/psi
C	PHI MATRIX	0.3	fraction
C	KX MATRIX	500	mDarcy
C	KY MATRIX	500	mDarcy
C	KZ MATRIX	50	mDarcy

Once all values have been input select **Done** to save the values.

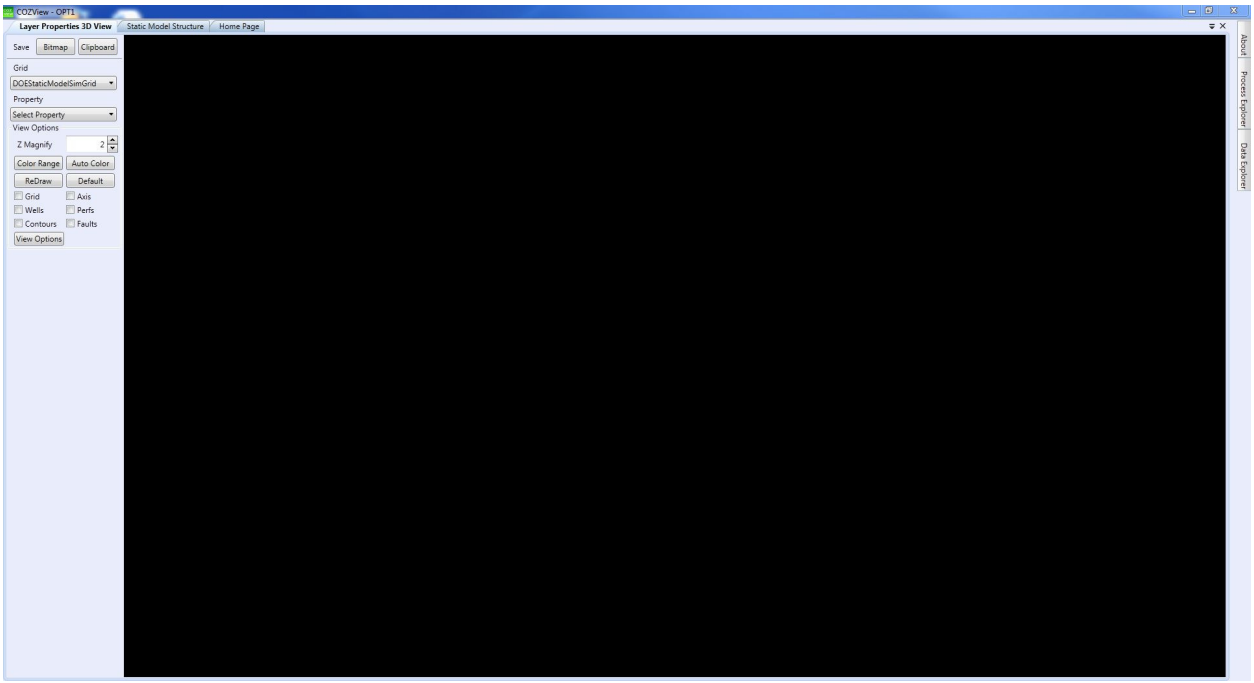
Individual layers (all properties) or individual properties (all layers) can be displayed with a left-click on the *Layer Name* or *Property Name*. Selection of the triangle at the far right of each title will cause the order of the list to be inverted.



Layer Name	Property Name	Property Value	Property Unit
B	KX_MATRIX	200	mDarcy
A	KX_MATRIX	100	mDarcy
C	KX_MATRIX	500	mDarcy
A	KY_MATRIX	100	mDarcy
C	KY_MATRIX	500	mDarcy
B	KY_MATRIX	200	mDarcy
B	KZ_MATRIX	20	mDarcy
A	KZ_MATRIX	10	mDarcy
C	KZ_MATRIX	50	mDarcy
C	NET-TO-GROSS	1	
A	NET-TO-GROSS	1	
B	NET-TO-GROSS	1	
C	PHI MATRIX	0.3	fraction
A	PHI MATRIX	0.2	fraction
B	PHI MATRIX	0.25	fraction
C	ROCK COMPRESSIBILITY	5	E-6/psi
B	ROCK COMPRESSIBILITY	5	E-6/psi
A	ROCK COMPRESSIBILITY	5	E-6/psi
B	TVT GROSS	10	feet
A	TVT GROSS	10	feet
C	TVT GROSS	100	feet
B	TVT NET	10	feet
A	TVT NET	10	feet
C	TVT NET	100	feet

3.1.3 View Layer Properties

Selection of *View Layer Properties* displays a 3D viewer window. It is initially blank.



The menu in the **Select Property** box allows the user to select any of the formation properties previously input and saved. These reservoir properties are TVT NET (Net True Vertical Thickness), PHI Matrix (Matrix Porosity), Rock Compressibility, KX,KY and KZ (Permeability of matrix in X,Y and Z directions).

As these formation properties are constant within a layer, the 3D view may not be particularly interesting. If multiple layers have been input and properties are different between the layers, color variations will be noted on the edges of the model display subject to the color range settings.

The **Color Range** button can be used to set the Minimum and Maximum value for color bar. Please note that COZView will not save the user set minimum and maximum value. Switching to a different property or closing the tab will reset the default minimum and maximum values.

The **Auto Color** sets the color range to the default Minimum and Maximum values.

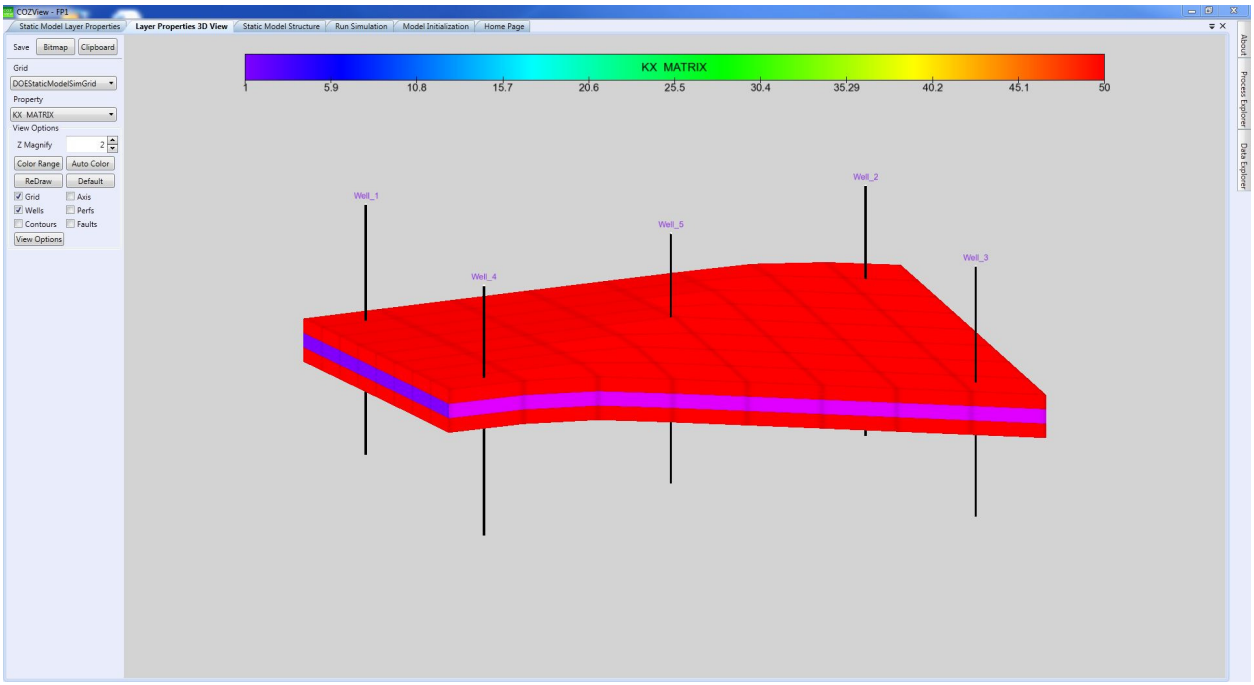
The **ReDraw** button refreshes the 3-D window to the original view. This is useful when the 3D view has been changed while using mouse operations (Zoom, Pan and Rotate).

The display of **Grid**, **Axis**, **Wells**, **Perfs** (Perforations), **Contours**, and **Faults** can be activated with selection of the appropriate check boxes.

The **View Options** button allows the user to select the background display color, size and font of well names, and color of the well bore.

COZView saves the *View Options* information. Selecting a different property will not reset the *View Options* information to the default values. However, closing the tab will reset the Color Range and View Options to the default values.

As in all 3D views in **COZView**, the view can be panned, zoomed and rotated with appropriate mouse operations.



The user can leave the *View Formation Properties* window by selecting a new menu item in the *Process Explorer* area on the right or the active *Menu Tabs* at the top

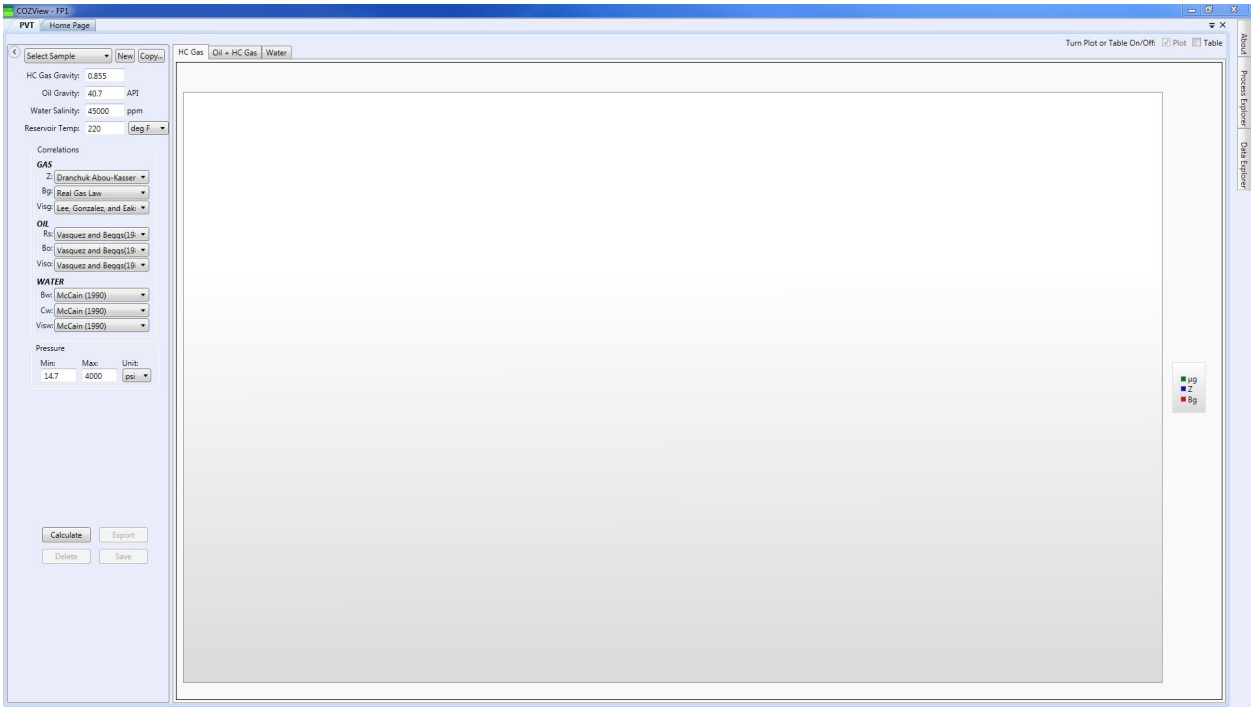
3.2 Fluid and Saturation Properties

The fluid properties (PVT) define the expansion and solubility characteristics of the reservoir fluids. Typically a reservoir will have one set of PVT properties unless areas of the reservoir are isolated from others due to barriers. Multiple PVT "tables" can be created in **COZView**; however, only one may be used in the simulation model.

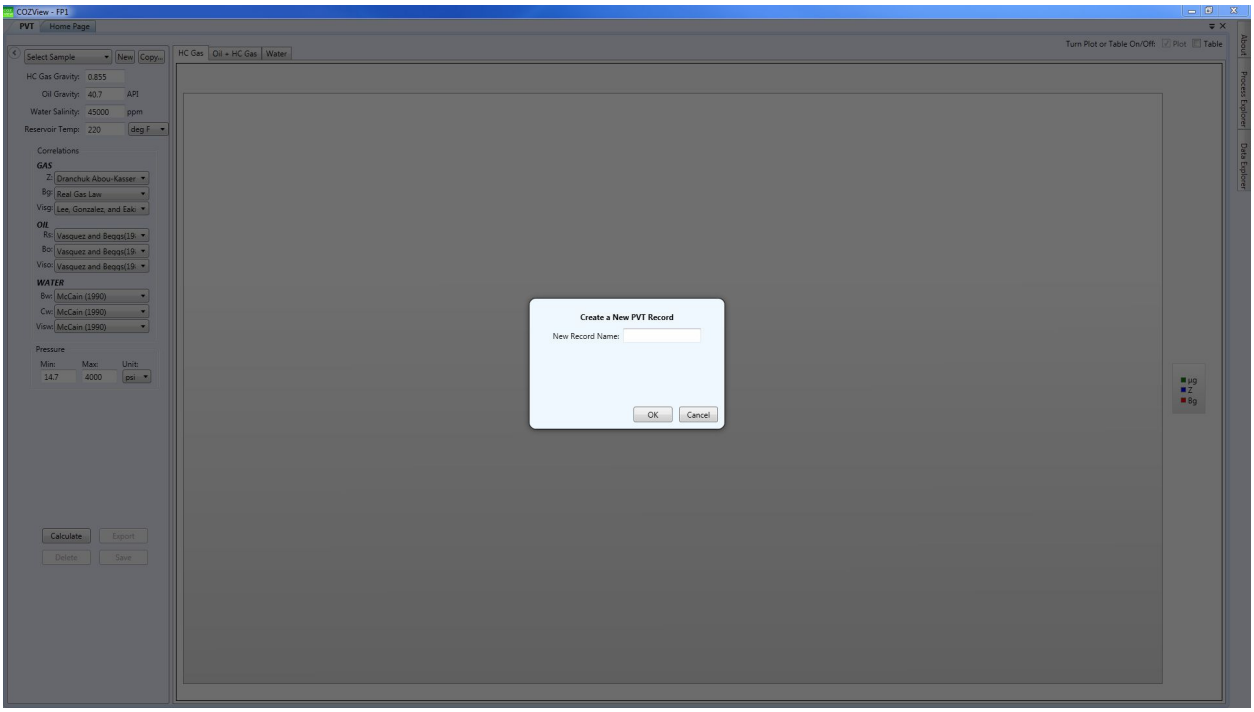
Saturation functions define the relative permeability and capillary pressure relationships (rock tables) for the reservoir. Typically, different rock types (sandstone, dolomite, limestone etc.) will have different rock tables. Multiple rock tables can be created in **COZView**; however, only one may be used in the simulation model.

3.2.1 PVT

The *PVT* section allows the user to identify the PVT data and to generate appropriate PVT tables (oil, gas and water) for use in the simulator. Selection of *PVT* in the Process Explorer menu displays the *PVT* tab.

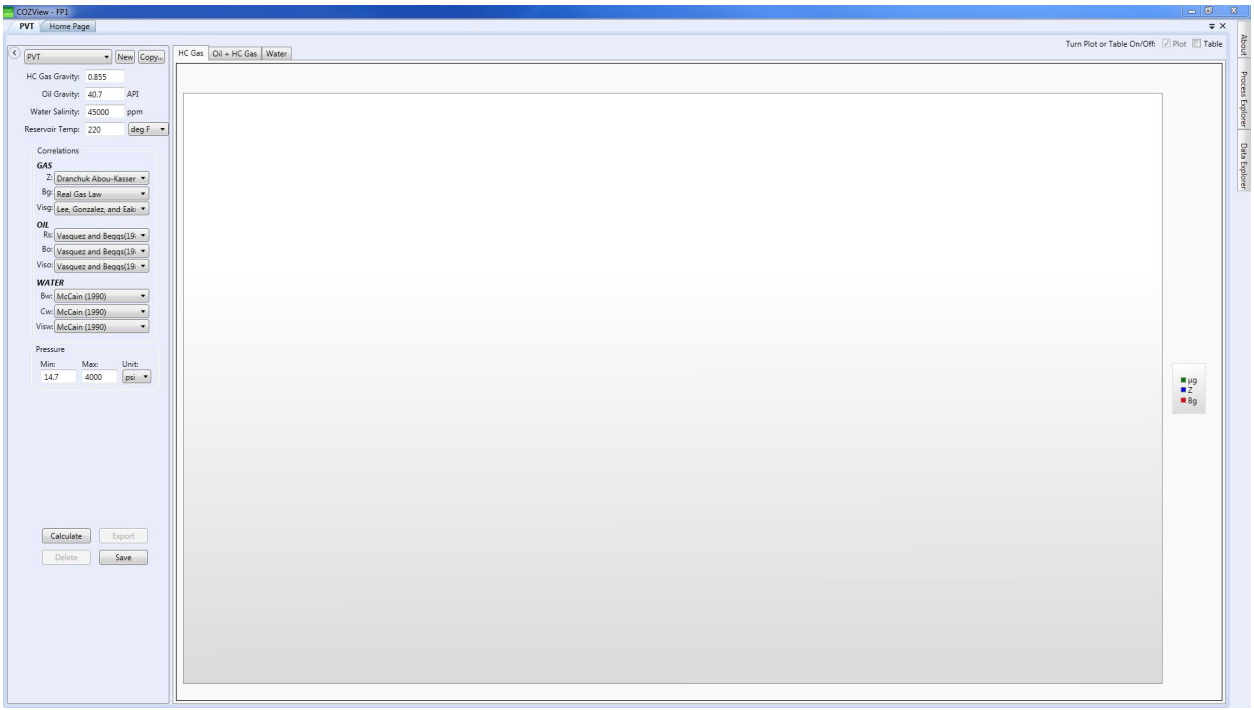


Initially this table is blank. Selection of the New button allows the user to define a PVT table by name.



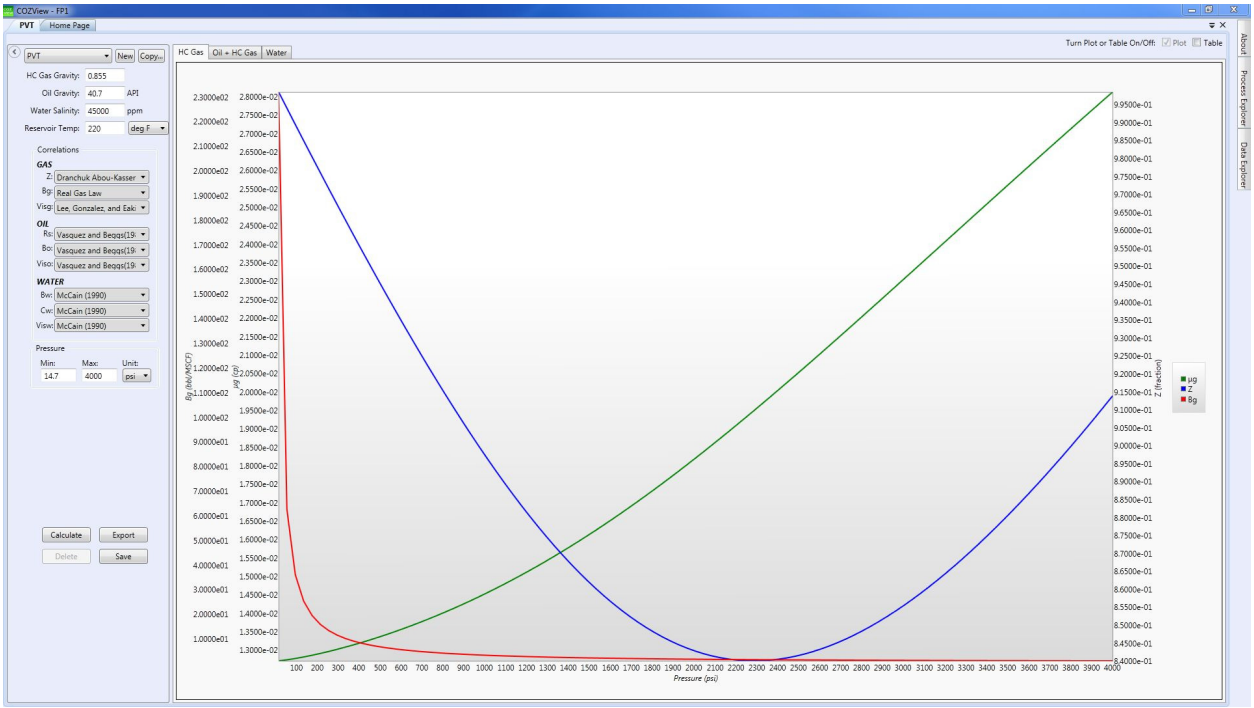
The parameter panel is on the left and a plot window is on the right. Tabs at the top of the plot window identify the phase (oil, gas, water) which is displayed in the plot window. The plot window is initially blank and default values are shown in the parameter panel. (*It is important to note that these default*

values are not intended to be representative of the user's reservoir per se.) The New PVT sample name appears in the Sample box.



The user must then input appropriate values for the hydrocarbon gas (HC) *Gas Gravity*, *Oil Gravity*, *Water Salinity*, *Reservoir Temperature* and *Temperature Units*. At the bottom of the parameter panel, the minimum and maximum pressure range for the PVT values to be calculated must also be specified. The maximum pressure should be greater than any static or dynamic pressure the user expects to occur in the model during the simulation runs.

Selection of the **Calculate** button will result in calculation and plotting of the PVT properties based on the input parameters. Selection of the appropriate tab at the top of the plot window will display the desired phase. Tables of the calculated values can be viewed by selecting the Table box in the upper right of the window.



The correlations used to calculate the various parameters are noted in the Correlation portion of the parameter panel. A specific correlation can be selected from the associated drop down menu.

Multiple groups of PVT properties can be generated by selecting New Sample name for each group.

Once the required PVT parameters have been generated, selection of the **Save** button will save the properties. Previously calculated and saved PVT properties can be changed and the new curves can be saved without defining a new *PVT Sample Name*.

The **Export** button will save the oil, water and gas PVT property tables as text files in a location of the user's selection.

The correlations used are noted below.

Gas:

- *Z factor: Dranchuk*, P. and *Abou-Kassem*, J. (*1975*), "Calculation of Z-factors for Natural Gases Using Equations-of-State", JCPT, July-September *1975*, p. 34-36.
- Bg: *Real gas law*
- µg: *Lee, A. L. Gonzales, M.H. and Eakin, B. E. : "The Viscosity of Natural Gases"*, Journal of Petroleum Technology *(Aug. 1966) p. 997-1000, Trans., AIME, 37.*

Oil:

- Rs, Bo, µo: Vasquez, M. and H. D. Beggs. "Correlations for Fluid Physical Property Prediction" Journal of Petroleum Technology (June 1980) p. 968-970.

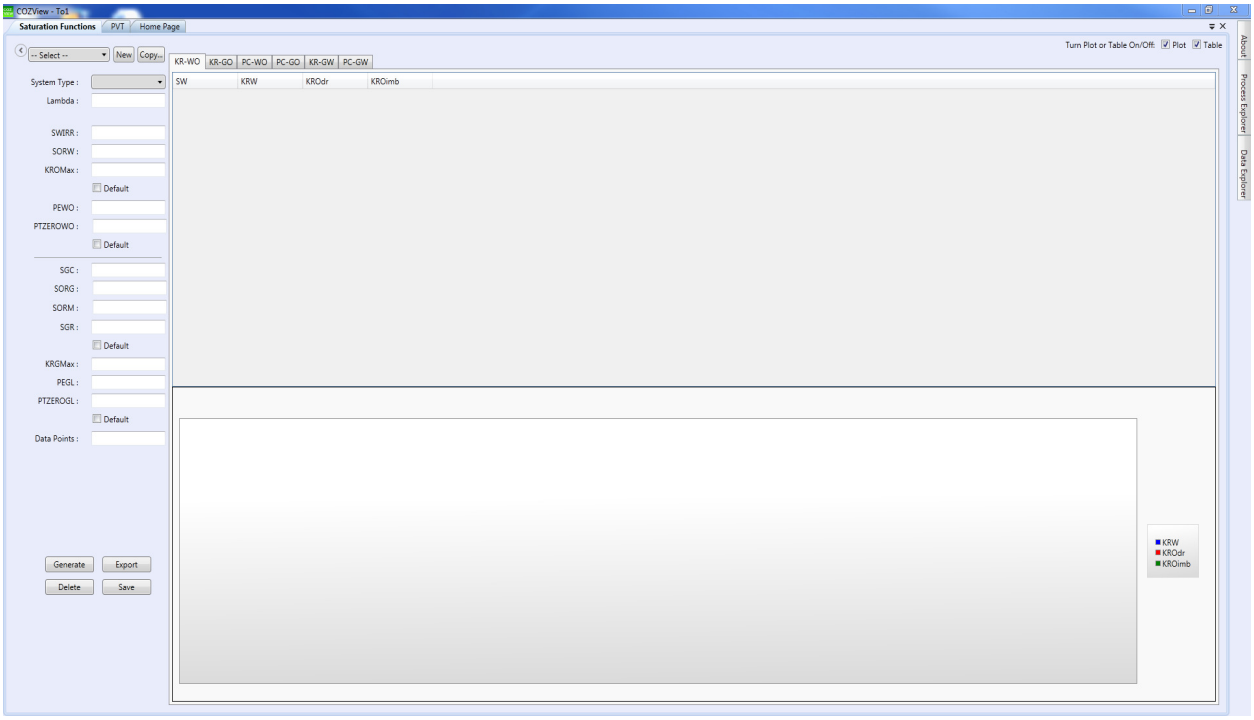
Water:

- Bw, cw, µw: McCain, W.D. *"The Properties of Petroleum Fluids."* Tulsa: PennWell Publishing Company, 1989.

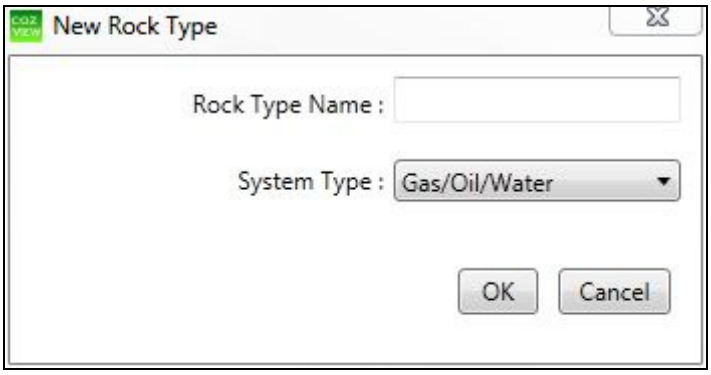
The default maximum pressure for the PVT data is 4000 psia. This default value can be overridden by the user. However, it must be noted that the CO2 property correlations' that are used in COZSim are based on actual laboratory measurements up to approximately 4000 psia. The correlations have been extended for higher pressures, but are not validated by actual data.

3.2.2 Saturation Functions

The *Saturation Functions* section allows the user to define the relative permeability and capillary pressure relationships for use in the simulation model. Multiple sets of functions can be defined. These are often referred to as rock tables. The user can define data for a gas-liquid or oil-water-gas system.



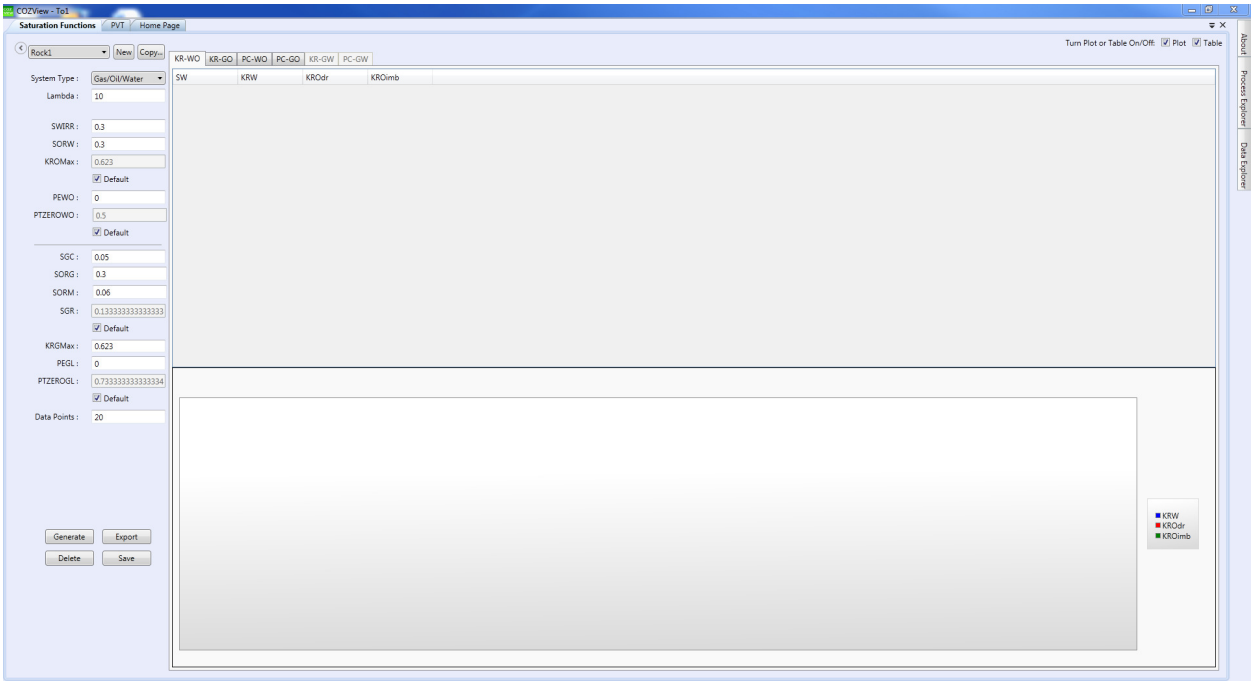
The first time the user enters this screen, a new Rock Type (table) must be identified by selecting the **New** button. This prompts the user to provide a rock type name and identify the relevant fluid system. The rock type will associate the generated curves to proper rock tables in the simulator.



The saturation functions are calculated based on the set of parameters which are shown in the left panel. Most of these parameter values will be available if laboratory data are available. A definition of each parameter is shown below. The correlations used by **COZView** are based on M.B. Standing's *Notes on Relative Permeability Relationships*, *The University of Trondheim, August 1974.*

The panel includes the default values which can be used directly or modified by the user. The default selections that are available for the KROMax, PTZEROWO, SGR and PTZEROGL use the endpoints SWIRR and SORW to calculate the proper values using the correlations. If the Default is unselected for any of these four parameters, the user can enter their own values.

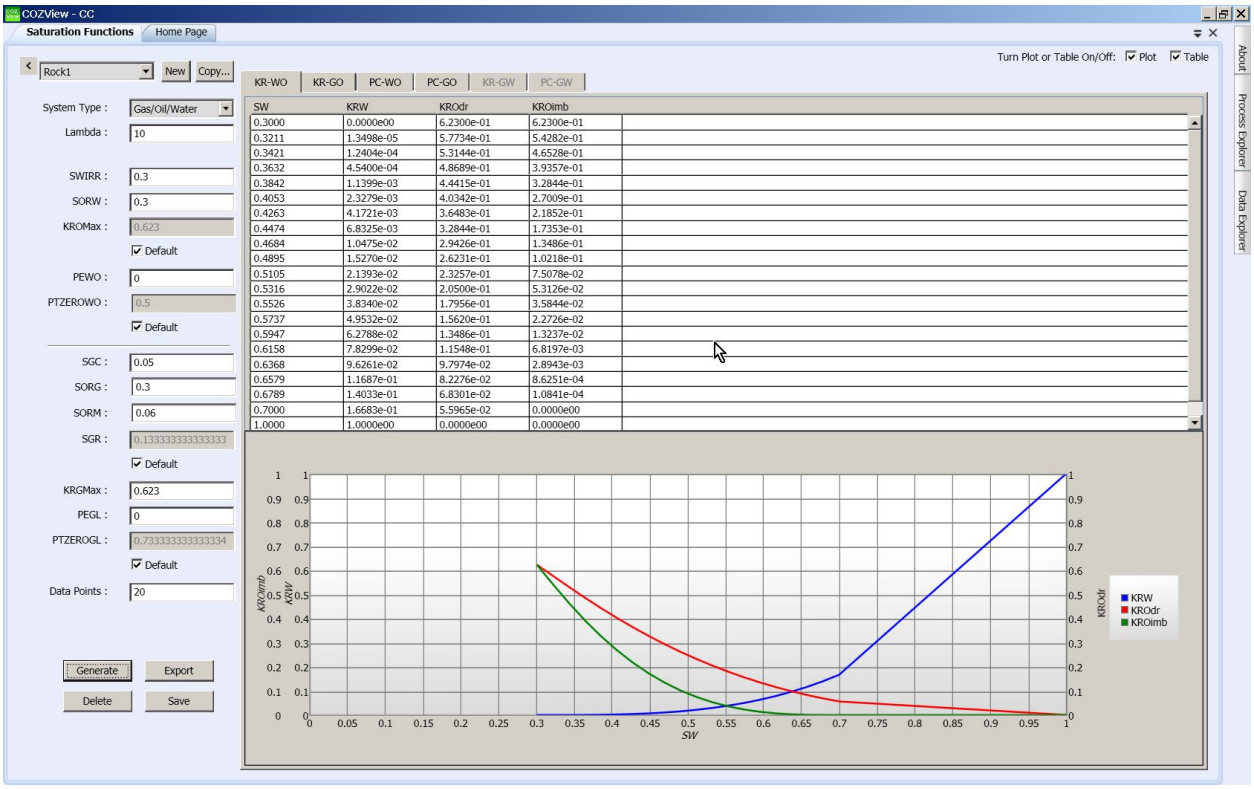
A default value is also provided for the residual oil saturation, Sorm, to the miscible fluid (CO2) displacement. The default is calculated as 0.20 times the Sorg. The user can override the default by inputting a new value.



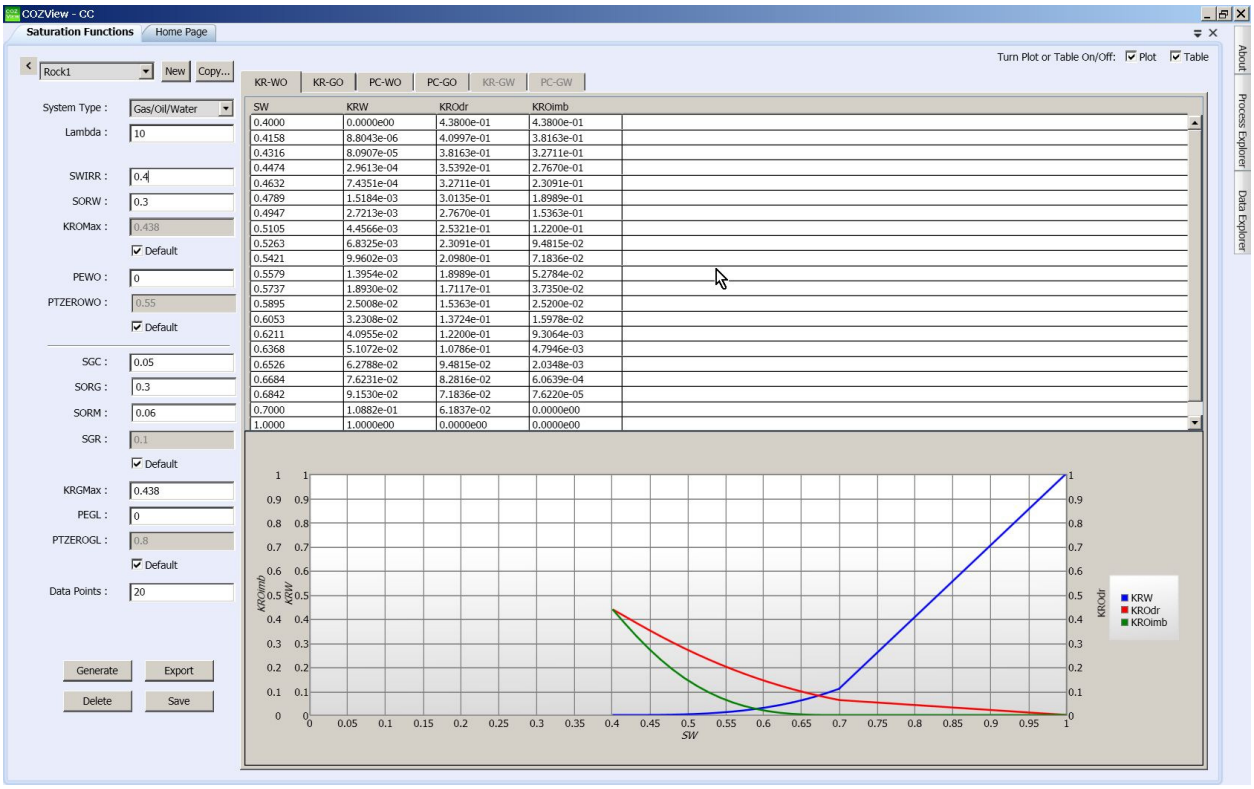
The default values associated with capillary pressure will result in a capillary pressure with no saturation transition from one phase to the other (no capillary pressure). This will have an impact on any phase volumetric calculations at the time of model initialization.

Parameter	Description	Default Value
Lambda	Pore size distribution index	10
SWIRR	Irreducible water saturation; connate water saturation	0.3
SORW	Residual oil saturation to water	0.3
KROMax	Maximum relative permeability to oil at SO=(1-SWIRR)	Default correlation
PEWO	Entry pressure on oil-water capillary pressure curve	0.0
PTZEROWO	The zero point where forced imbibition starts for the water-oil capillary pressure curve (the saturation value that capillary pressure is zero; used to rescale the curve for imbibition)	Default relationship
SGC	Critical gas saturation; SG at which gas begins to flow	0.05
SORG	Residual oil saturation to gas	0.3
SGR	Residual gas saturation; trapped gas saturation	Default relationship
KRGMax	Maximum relative permeability to gas at SG= (1-SOR-SWIRR)	Equal to KROMax
PEGL	Entry pressure on gas-liquid capillary pressure curve	0.0
PTZEROGL	The zero point where forced imbibition starts for the gas-oil capillary pressure curve(the saturation value that capillary pressure is zero; used to rescale the curve for imbibition)	Default relationship
Data points	Number of saturation values that will be used in the tables (curves). This will determine the saturation increments in the generated tables (curves).	20
SORM	Residual oil saturation to miscible CO2 displacement	Equals 0.20 times SORG

Select the **Generate** button to calculate the individual relative permeability and capillary pressure curves. The curves are generated for both drainage and imbibition process automatically. Both the curves and the tables associated with the curves are ready to view once they are generated. Different curves can be reviewed by clicking the proper tab in the window.



The screen above has generated the saturation function using the default values for all parameters. The screen below is the result of changing only the SWIRR value from 0.3 to 0.4 and generating new curves.

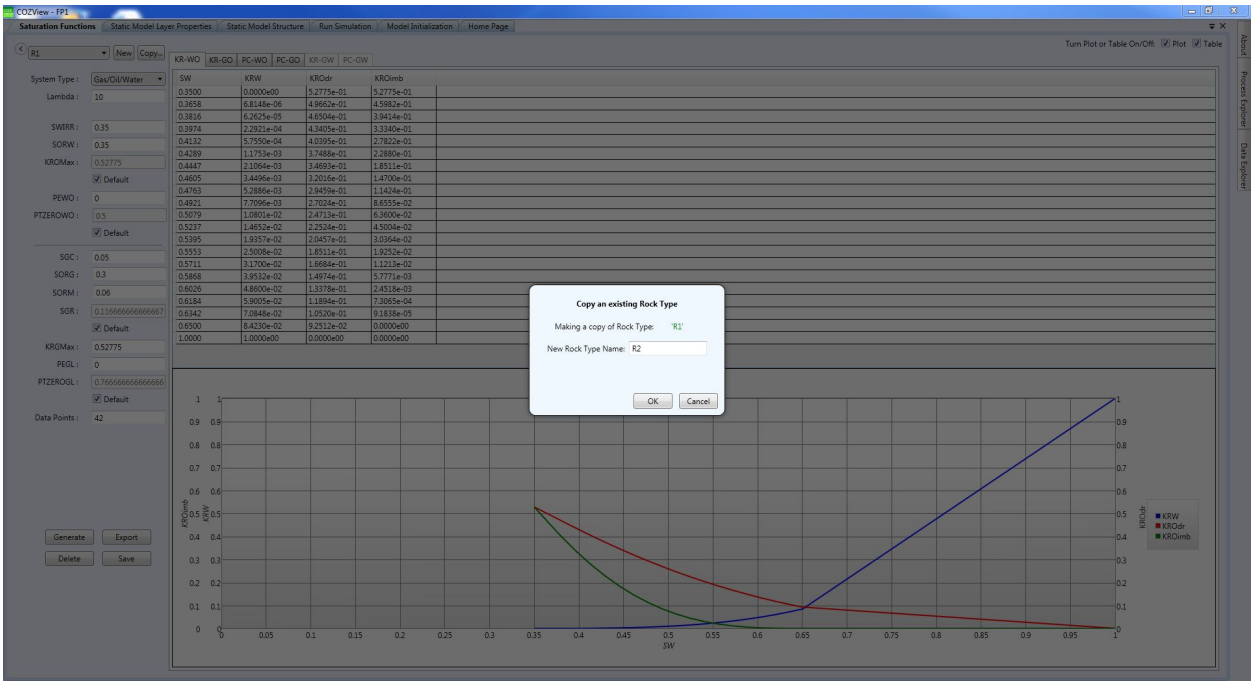


As noted above, the user can modify the shape of the individual saturation function curves with appropriate changes to endpoint parameters.

If the user selects the **Generate** button and an input parameter box changes color to red, this denotes that a previous user parameter change has created an invalid parameter value. Passing the cursor over the “red” parameter box will provide information on how to correct the problem. The **Generate** button will not create the required curves and tables until the “red” parameter box problem is resolved.

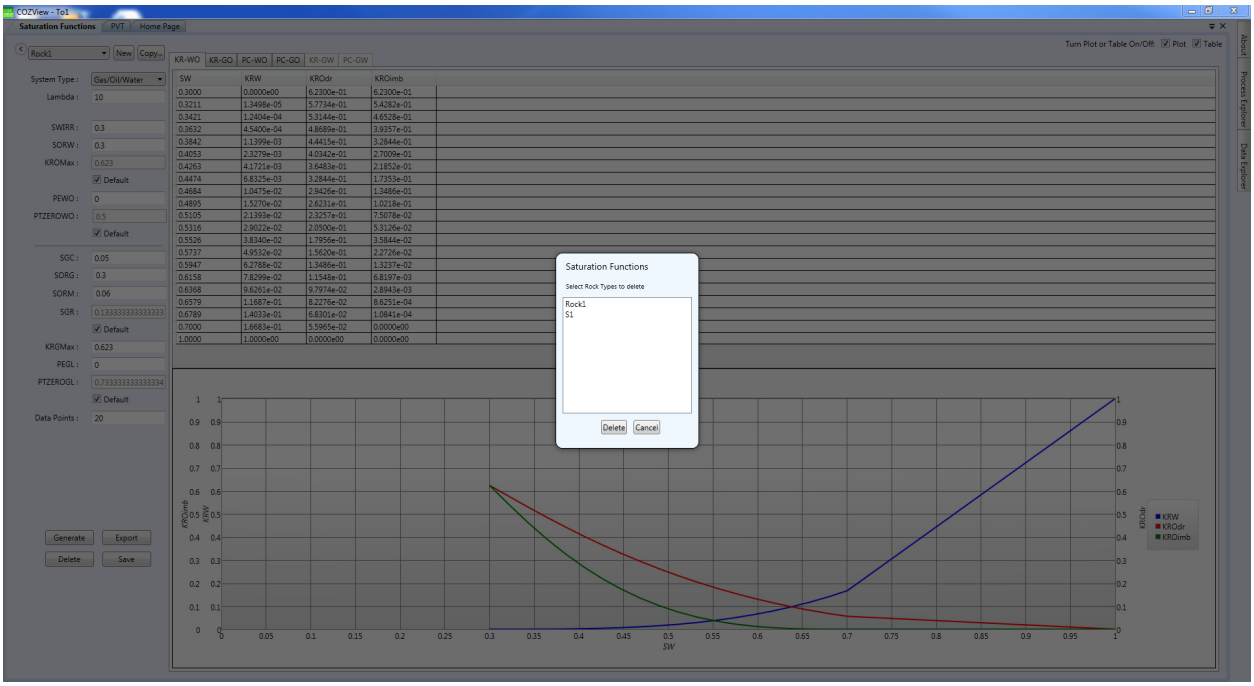
Once the required Saturation Function parameters have been generated or modified, selection of the **Save** button will save the properties. Previously calculated and saved Saturation function properties can be changed and the new curves can be saved without defining a new *Rock Type Name*.

The user can copy an existing Rock Type (table) using the **Copy** button. Please note that the **Copy** button will only copy values of endpoint saturations. The user must click Generate to create the full Saturation function property table.



The **Export** button will save the saturation function property tables as text files in a location of the user's selection.

A **Delete** button is available to remove previously saved Rock tables from the project database. The user is asked to identify the appropriate Rock table to be deleted and select *Delete.*

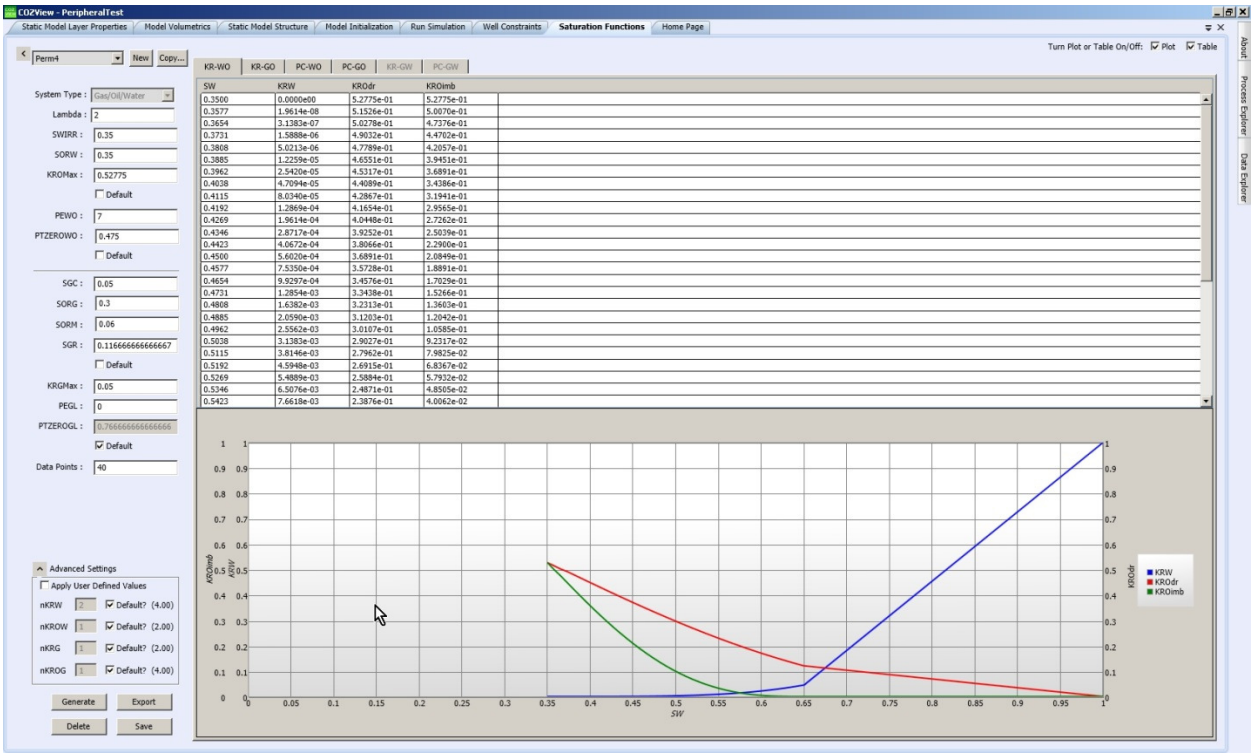


3.2.2.1 Advanced Settings

The Advanced Saturation Function Settings should only be used after the model OOIP and OIP (if appropriate) have been verified in the ***Verify Model*** section. These options are used to modify the shape of the relative permeability curves generated by **COZView**. The end point saturations (Sorw, Swirr, Sgc, Sorg, Sorm) are not changed. This is normally done to adjust water cuts and/or gas-oil ratios at the individual well or field level at the start of a prediction run. (This is a common practice in conventional history matching of a model to historical performance.)

Warning: Other parameters associate with generation of the relative permeability and capillary pressure curves are available to the user on this screen. These parameters were likely used/modified during calibration of the model to the OOIP and OIP. Changes to any of the parameters that are not in the Advanced Options section may change the OOIP and OIP.

Selection of **Advanced Settings** in the lower left portion of the screen will display the options shown below.



The parameters nKRW, nKROW, nKRG, nKROG are the exponents in the following equations. These are the same M.B. Standing correlations referenced earlier.

$KRW = Sw^{*nKRW}$

where $Sw^* = (Sw-Swirr)/(1-Swirr)$ and $nKRW = (3*Lambda+2)/Lambda$

nKRW can be overwritten directly to modify the relative permeability curves using the advanced settings.

$KROW_{drainage} = KROMax\ (1-Sw^*)^2 * (1-(Sw^*)^{nKROW})$

where Sw* = (Sw-Swirr)/(1-Swirr) and nKROW = (2+Lambda)/Lambda

nKROW can be overwritten directly to modify the relative permeability curves using the advanced settings.

$KROW_{imbibition} = KROMax\ *(Snf^*)^2 * (1-(1-Snf^*)^{nKROW})$

where Sw* = (1-Sw-Sorw)/(1-Swirr-Sorw) and nKROW = (2+Lambda)/Lambda

nKROW can be overwritten directly to modify the relative permeability curves using the advanced settings.

$KROG = (SL^*)^{nKROG}$

where SL* = (SL-Swirr-Sorg)/(1-Swirr-Sorg) and nKROG = (3*Lambda+2)/2

SL= (Sw+So)

nKROG can be overwritten directly to modify the relative permeability curves using the advanced settings.

$KRG_{drainage} = KRGMax^*(Sn^*)^2 * (1-(1-Sn^*)^{n\ KRG})$

where Sn* = (1-SL-Sgc)/(1-Swirr-Sorg-Sgc) and nKRG = (2+Lambda)/Lambda

$KRG_{imbibition} = KRGMax^*(Snf^*)^2 * (1-(1-Snf^*)^{nKRG})$

where Snf* = (1-SL-Sgr)/1-Swirr-Sorg-Sgr and nKRG = (2+Lambda)/Lambda

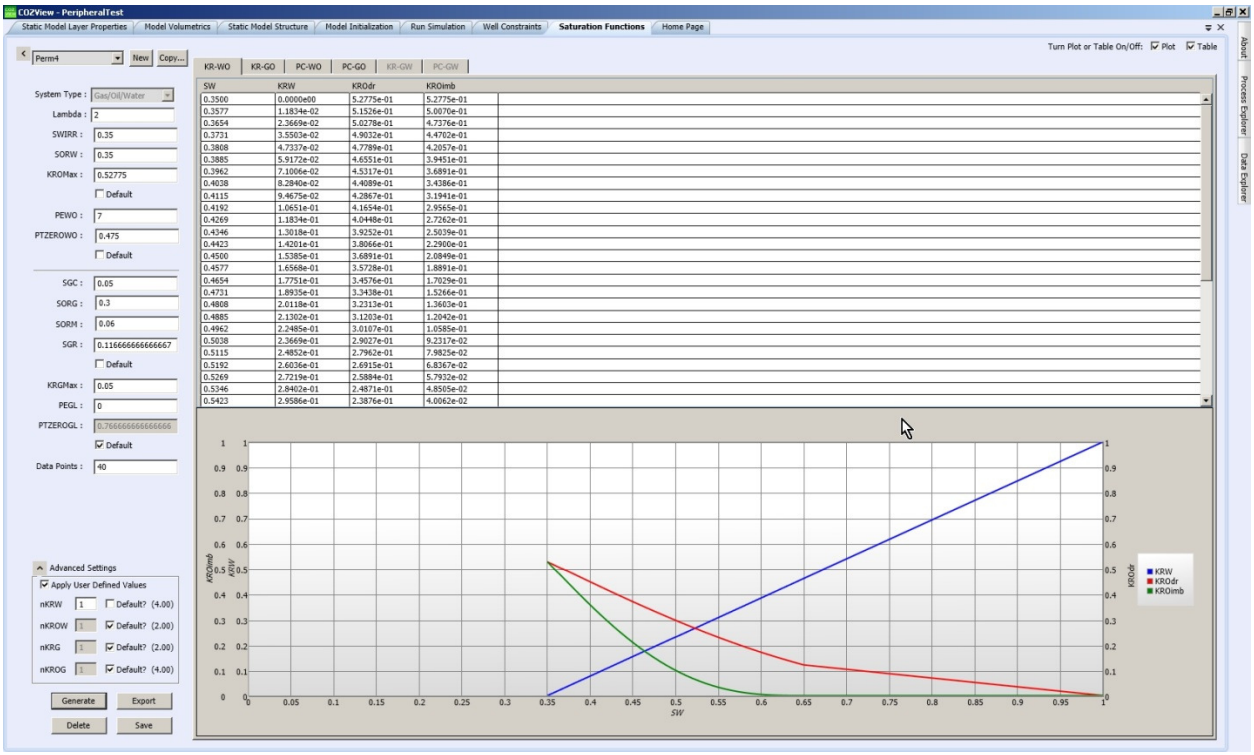
Please note that the exponent values nKROW and nKROG impact both drainage and imbibition curves.

The default “n” values are based on the Lambda value in the upper left portion of the screen. Changing the “n” exponent alters the shape of the relative permeability curve. Lowering or raising the “n” value impacts the curve shape as noted below. Imbibition and drainage curves are impacted in the same manner.

Curve	**Larger n**	**Smaller n**
KRW	Lowers	Raises
KROW	Raises	Lowers
KROG	Lowers	Raises

KRG Raises Lowers

To see the impact of changing the exponent on a specific relative permeability curve, the user must first Check the box *Apply User Defined Values*. Next the **Default** box should be unchecked for the relative permeability curve to be changed. (KRW in this example.) The user is then able to input a value for the new "n". A higher value of 1.0 is input. Selection of **Generate** displays a modified relative permeability curve (KRW in this example) shown below.



The user can toggle between the Default value and the user defined value by checking and unchecking the *Apply User Defined Values* check box. When the appropriate relative permeability curves have been generated, select **Save**.

If none of the non-Advanced Setting parameters have been changed, there should be no impact on the OOIP and/or OIP. The user can run ***Verify Model*** with the new **Advanced Settings** to confirm that this is the case.

This functionality is new and earlier pictures of this screen may not show the Advanced Settings panel.

3.3 Verify Model

The *Verify Model* area allows the user to define field initialization parameters and verify the model volumetrics before launching a simulation run.

3.3.1 Model Initialization and View Model Volumetrics

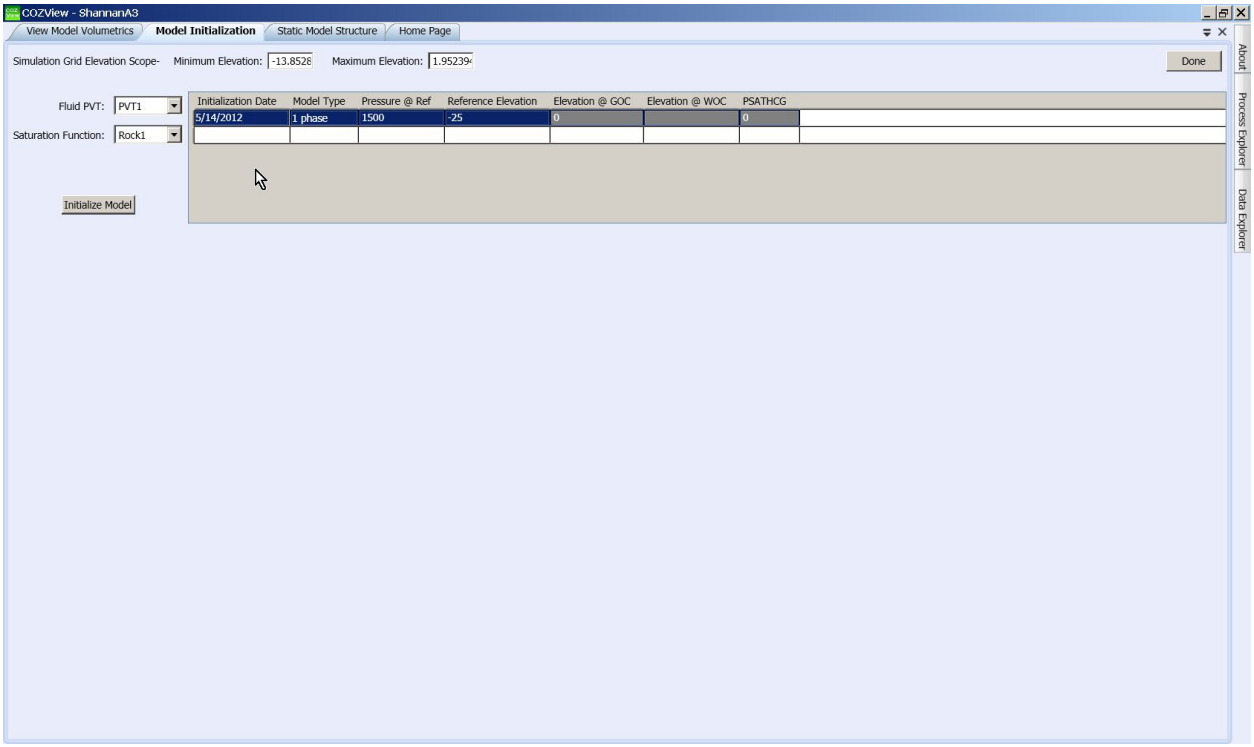
Initialization of the simulation model requires all or some of the information below

- date of the initialization,
- pressure at the reference elevation,
- reference elevation,
- GOC elevation,
- WOC elevation, and
- saturation pressure.

With this information and the data provided in the Static Model, Fluid and Saturation Properties, the volumes of oil, water and gas in the model can be calculated.

COZView allows the user to specify multiple initialization times and the associated data. The last initialization time will be the starting time for the prediction simulation run.

Selection of *Model Initialization* will display the screen below.



The model initialization is based on the premise that **one of three** possible reservoir conditions exist

- The reservoir has three phases present – free gas, oil and water. The water can be in the oil zone, as well as an aquifer. Solution gas will be present in the oil. There will be a Sorg in the free gas zone.

- The reservoir has two phases present – an oil zone and water. The water can be in the oil zone, as well as an aquifer. Solution gas will be present in the oil. **COZSim** does not currently support a gas-water two phase system.

- The reservoir has one phase present – an aquifer. **COZSim** only supports a water only, one phase system.

Examples:

1. Oil zone with no gas cap or water leg. – 2 phase

2. Oil zone with a gas cap and no water leg. – 3 phase

3. Oil zone with water leg and no gas cap. – 2 phase

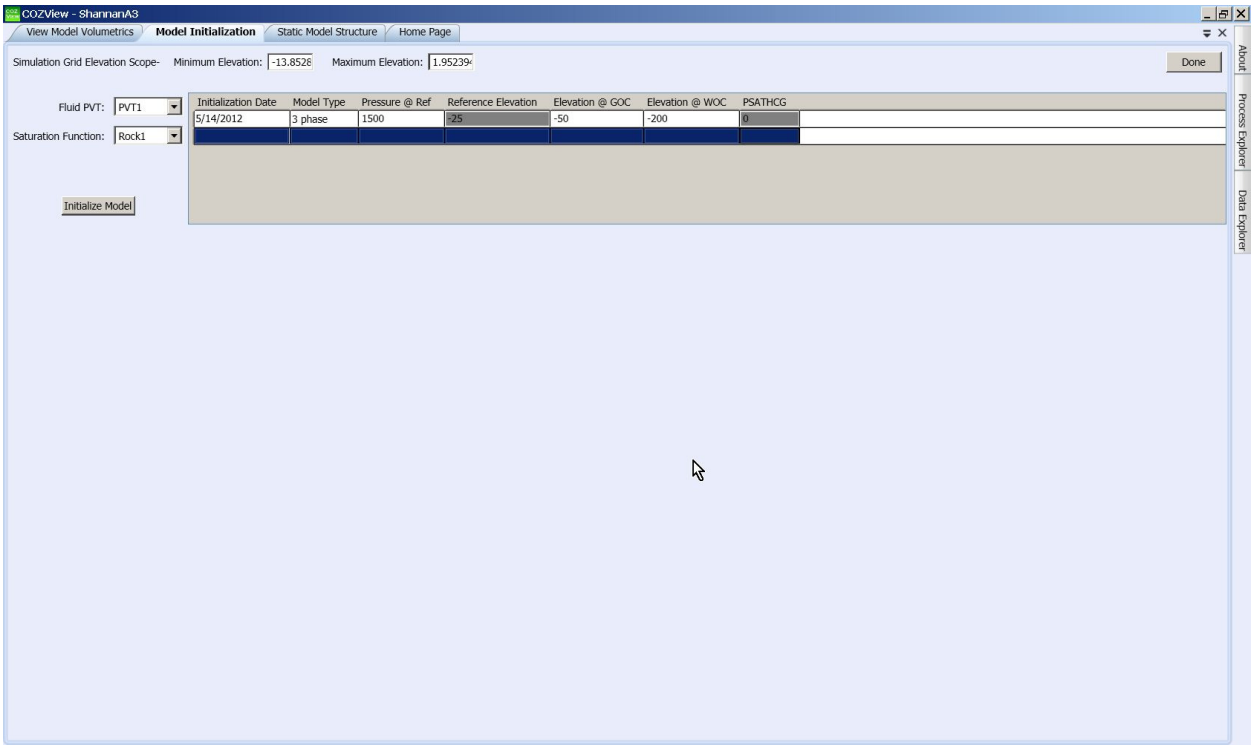
4. Oil zone with water leg and gas cap gas cap. – 3 phase

Selection of a particular *Model Type* in the Model Initialization window will alter the data required to the right. Some data will be greyed-out and not available to the user based on the Model Type selected. It is recommended to select the appropriate *Model Type* first.

It is important to note that this selection is only related to establishing initial saturation and pressure conditions at the start of the simulation run. A 2-phase model type may well become a 3-phase model type during the simulation period.

The *Model Initialization* window reports the Minimum and Maximum elevations found in the model. This can be used as a guide when inputting GOC and WOC elevations. The model defaults to the first PVT and Saturation function tables created by the user. These can be changed if appropriate, but only one PVT and one Saturation function can be used.

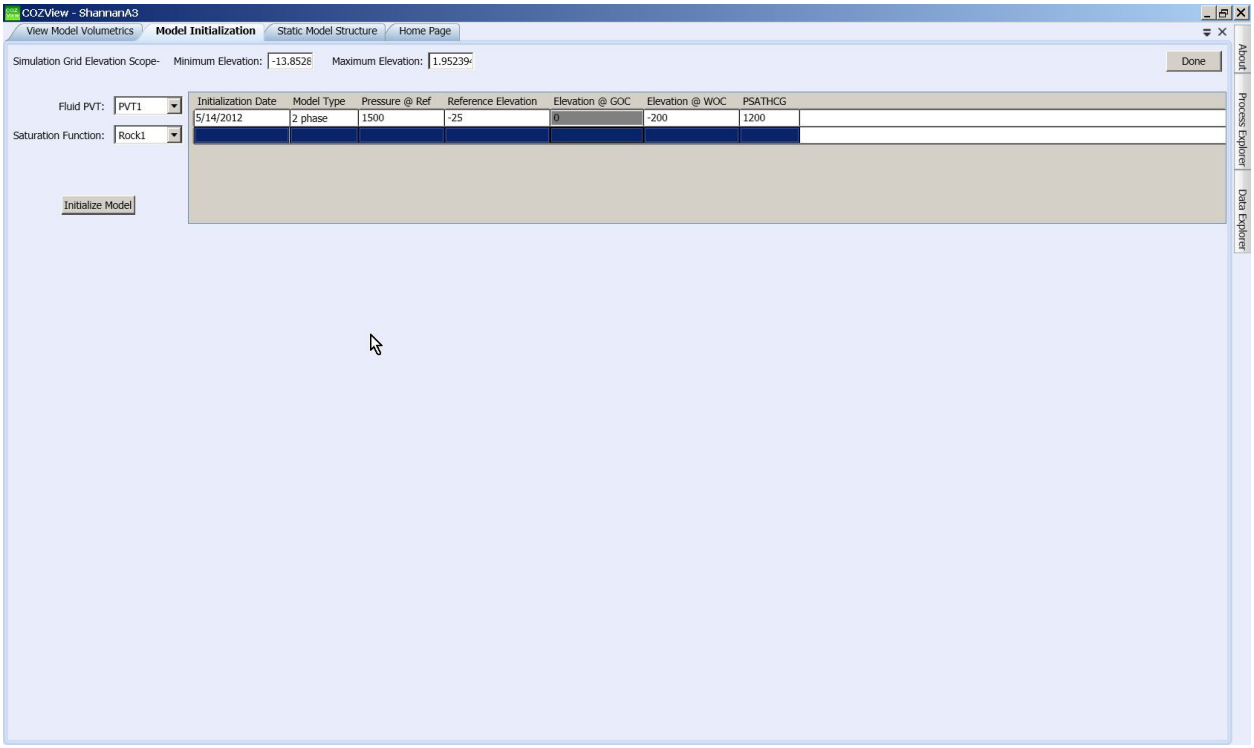
Model Type – 3-phase



If the GOC is specified above the shallowest elevation in the model, the model type is not 3-phase; it is 2-phase. If the WOC is specified below the deepest elevation in the model there will not be a water leg (aquifer) in the model, but the model type is still 3-phase as long as the GOC is deeper than the shallowest elevation in the model.

In the 3-phase model type, the reference elevation is not required, as it is assumed to be the GOC elevation. The saturation pressure is also not required. It is assumed to be the pressure at the GOC.

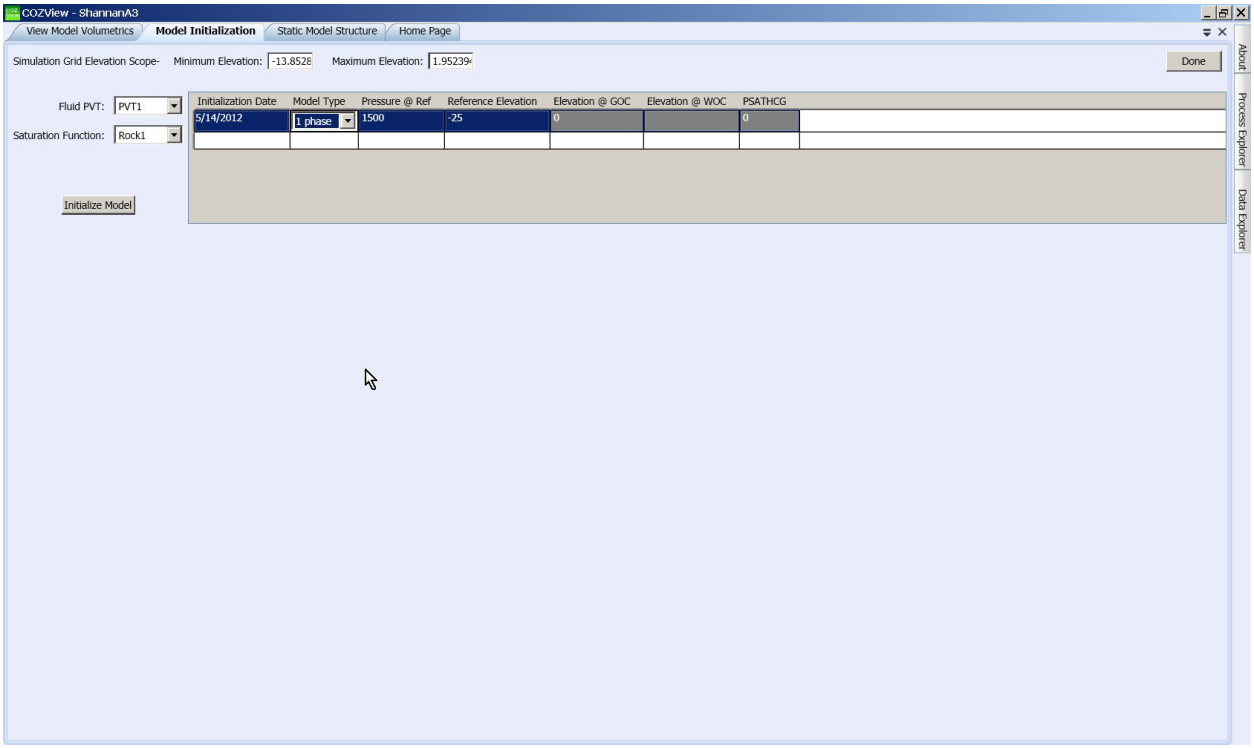
Model Type – 2-phase



If the WOC is specified below the deepest elevation in the model there will not be a water leg (aquifer) in the model, but the model type is still 2-phase.

In the 2-phase model type, the reference elevation is required. In addition the saturation pressure must also be provided. Depending on the production history of the reservoir, the saturation pressure may be the original bubble point pressure.

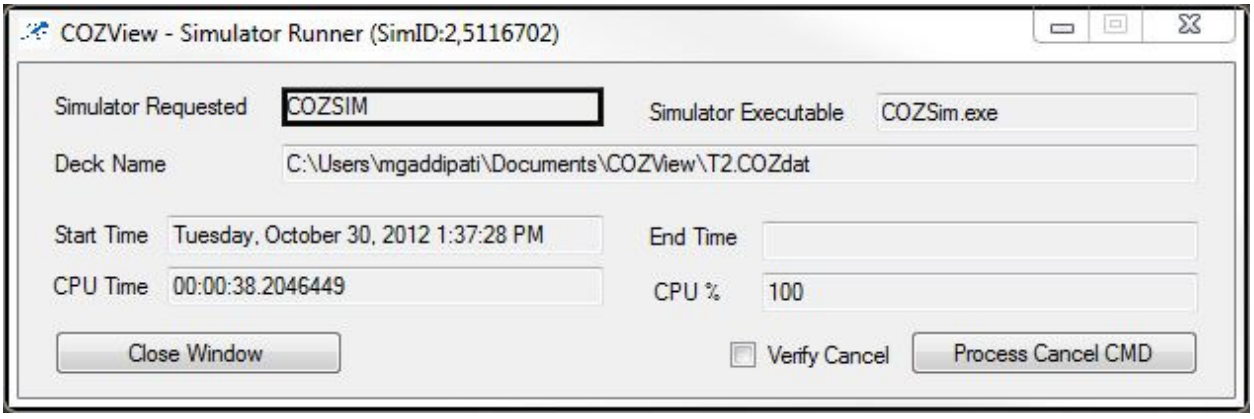
Model Type – 1-phase



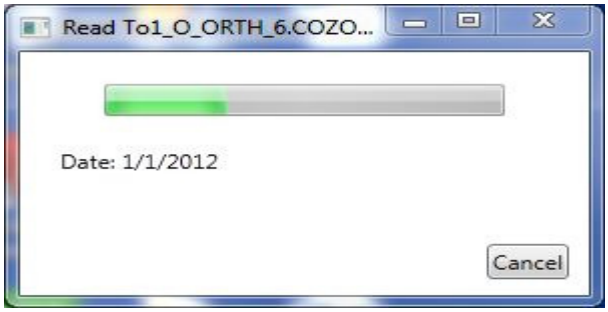
Only the reference pressure and elevation are required for the 1-phase model.

Selection of the **Initialize Model** button allows the user to make a volumetric calculation of the fluids in place in the model at each initialization time with the associated reservoir equilibrium conditions.

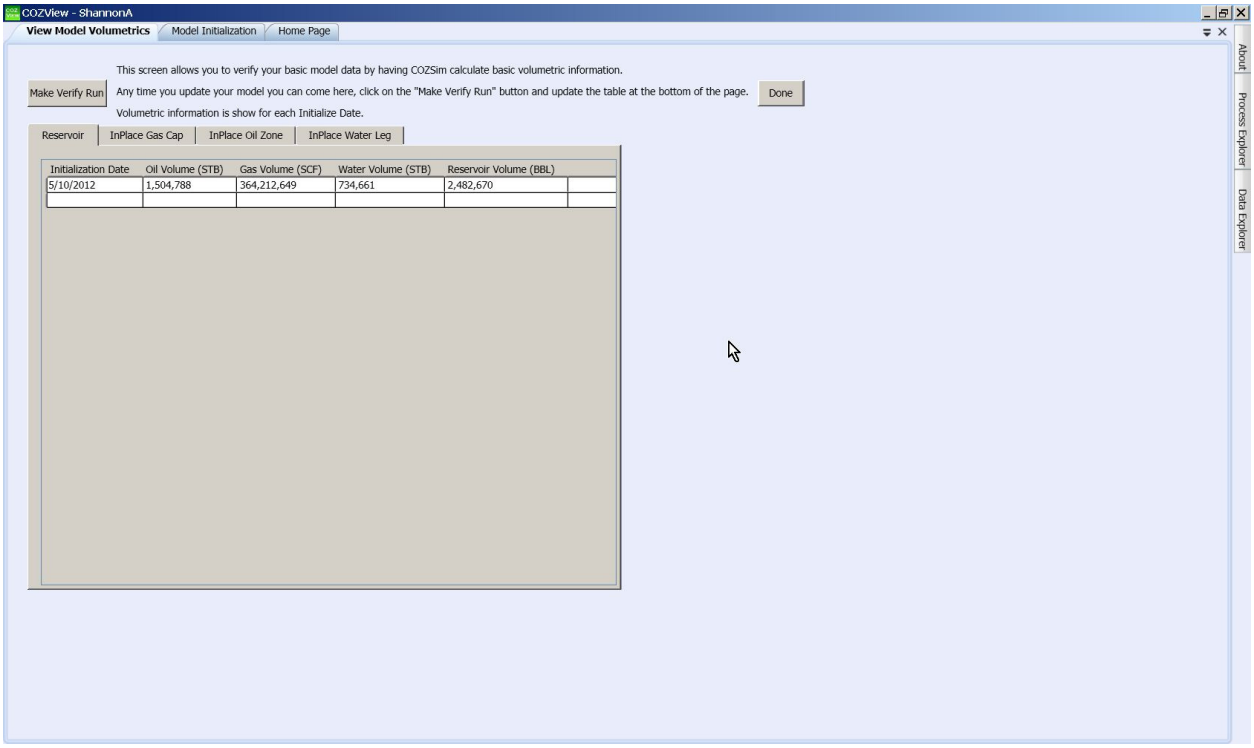
A zero timestep run is launched for the simulator and the Simulator Runner screen (below) will appear. Typically the simulator only requires a short time to initialize the model and compute the phase volumetrics.



Notification that COZView is reading the volumetric results form the binary PLTOUT file created by the simulator will also appear briefly.

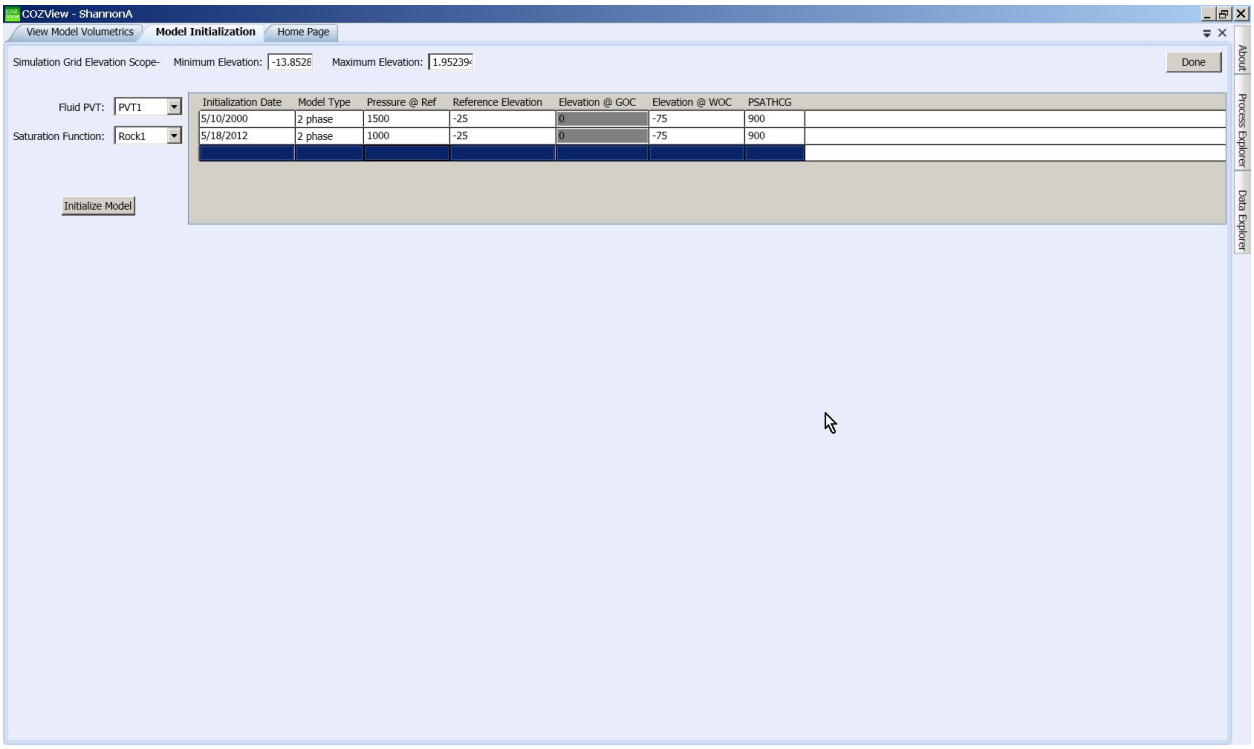


The calculated volumes are provided for the total reservoir, gas cap, oil zone and water leg. The volumes are all in stock tank units except the reservoir pore volume which is in reservoir barrels.



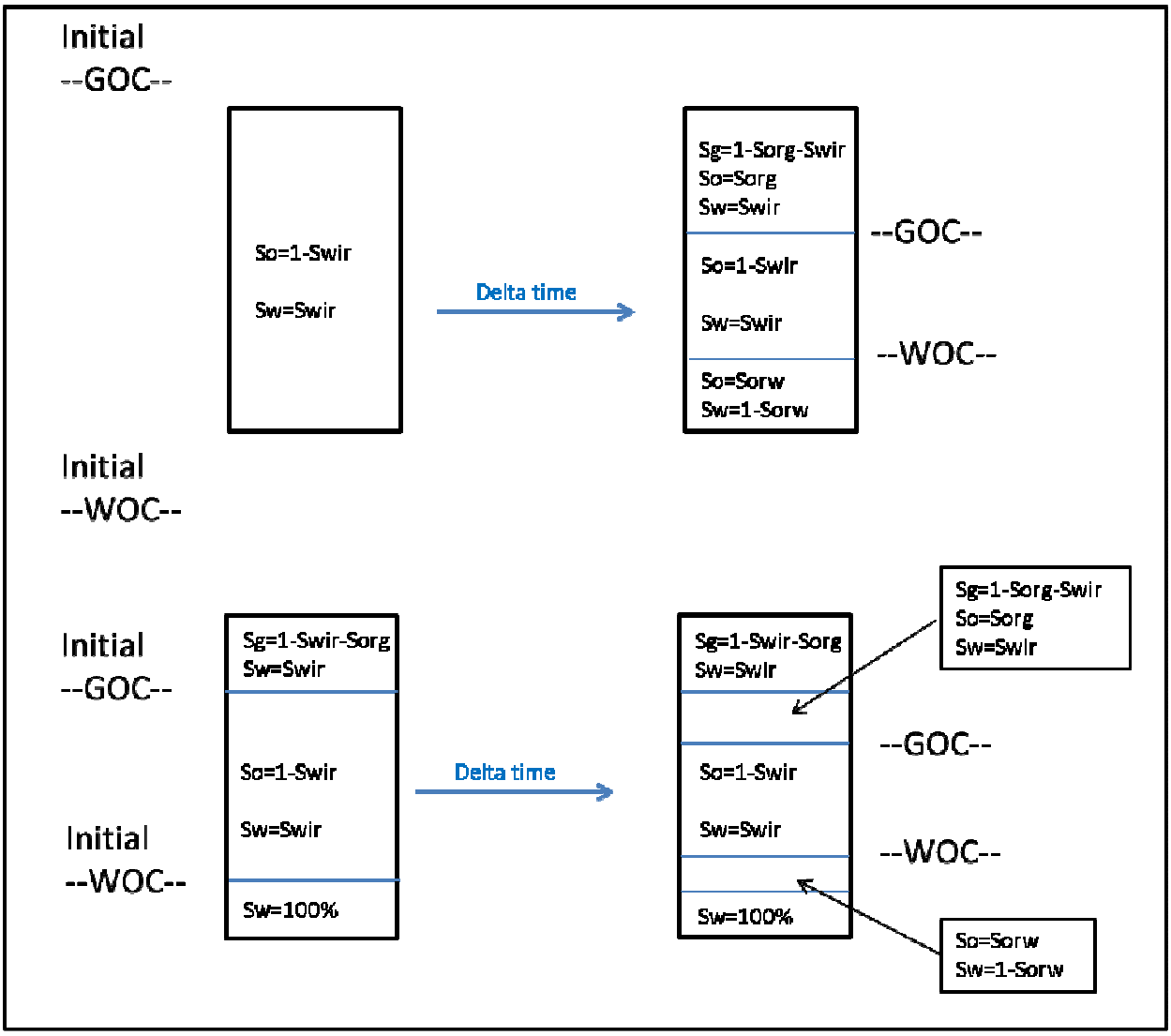
This functionality can be used to conduct a pseudo history match of the actual performance of the field in order to establish appropriate average reservoir conditions for the start of the prediction run.

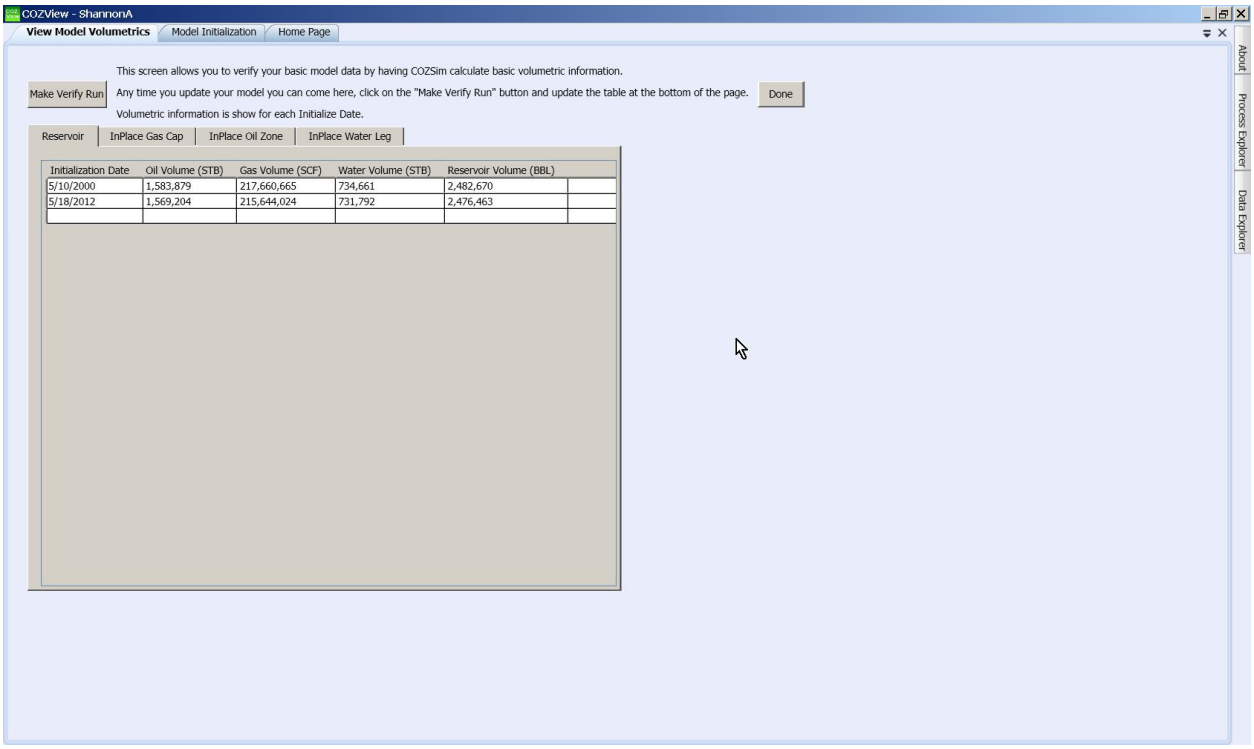
Use of multiple initialization times and the associated adjustments in the reference pressure and the GOC and WOC elevations in the *Model Initialization* section will result in different in place volumes. The volume differences between the two times will reflect the net hydrocarbon production. The user will likely have a reasonable idea of the past cumulative production volumes and the current average reservoir pressure to compare to these calculated values.



In this example, the difference in Pressure@Ref between the two initialization dates results in different in place volumes.

In the volumetric calculations the following assumptions are made about the saturations in the original oil, water and gas zones and in the zones invaded by the GOC or WOC.


Initial
--GOC--
So=1-Swir
Sw=Swir
Delta time
Sg=1-Sorg-Swir
So=Sorg
Sw=Swir
--GOC--
So=1-Swir
Sw=Swir
--WOC--
So=Sorw
Sw=1-Sorw
Initial
--WOC--
Initial
--GOC--
Sg=1-Swir-Sorg
Sw=Swir
So=1-Swir
Sw=Swir
Initial
--WOC--
Sw=100%
Delta time
Sg=1-Swir-Sorg
Sw=Swir
Sg=1-Sorg-Swir
So=Sorg
Sw=Swir
--GOC--
So=1-Swir
Sw=Swir
--WOC--
Sw=100%
So=Sorw
Sw=1-Sorw



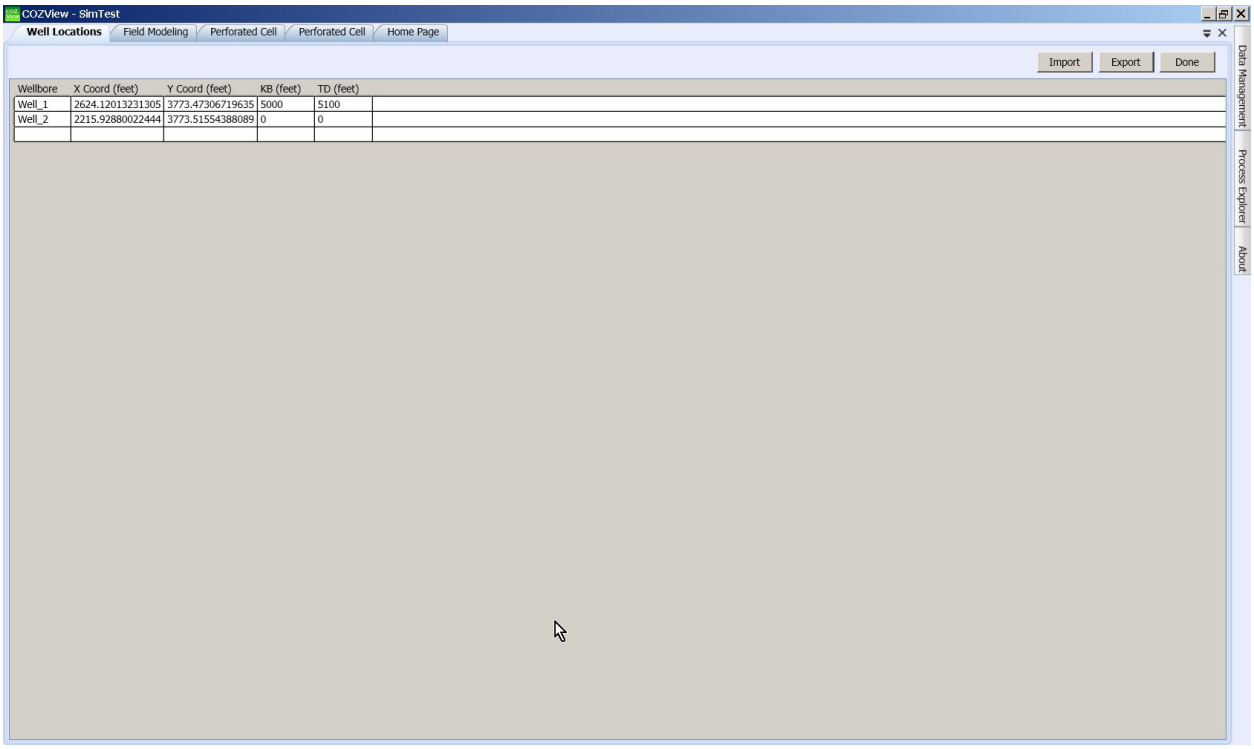
The user may also choose to make adjustments to the static model/formation properties in order to alter the calculated initial in place volumes. If formation properties are changed, but the model initialization parameters are not changed, the user can return to the *View Model Volumetrics* window and select Make Verify Run to recalculate the initial volumetrics.

3.4 Well Data

The *Well Data* section in the Process Explorer area provides the user tabular information concerning a well's location, KB, TD, completion layers and completion dates. This information is based on the definition of well locations in the *Static Model* section. If the data were not provided in the *Static Model* section, it can be input in these tables.

3.4.1 Well Location Data

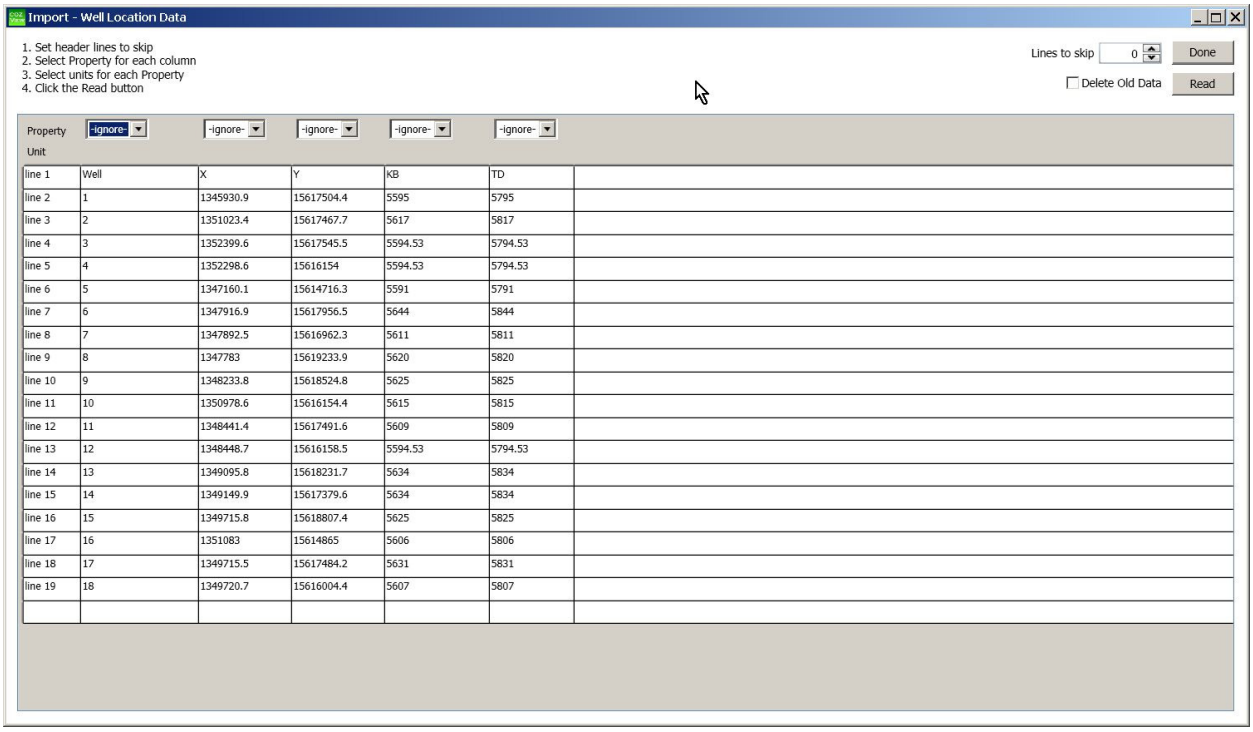
Selection of *Well Location* displays a table for the wells previously created in the *Static Model*. The X and Y coordinates in the table are based on the map well location. If the user input the KB and TD for the well in the Static Model, it will be shown in the table.



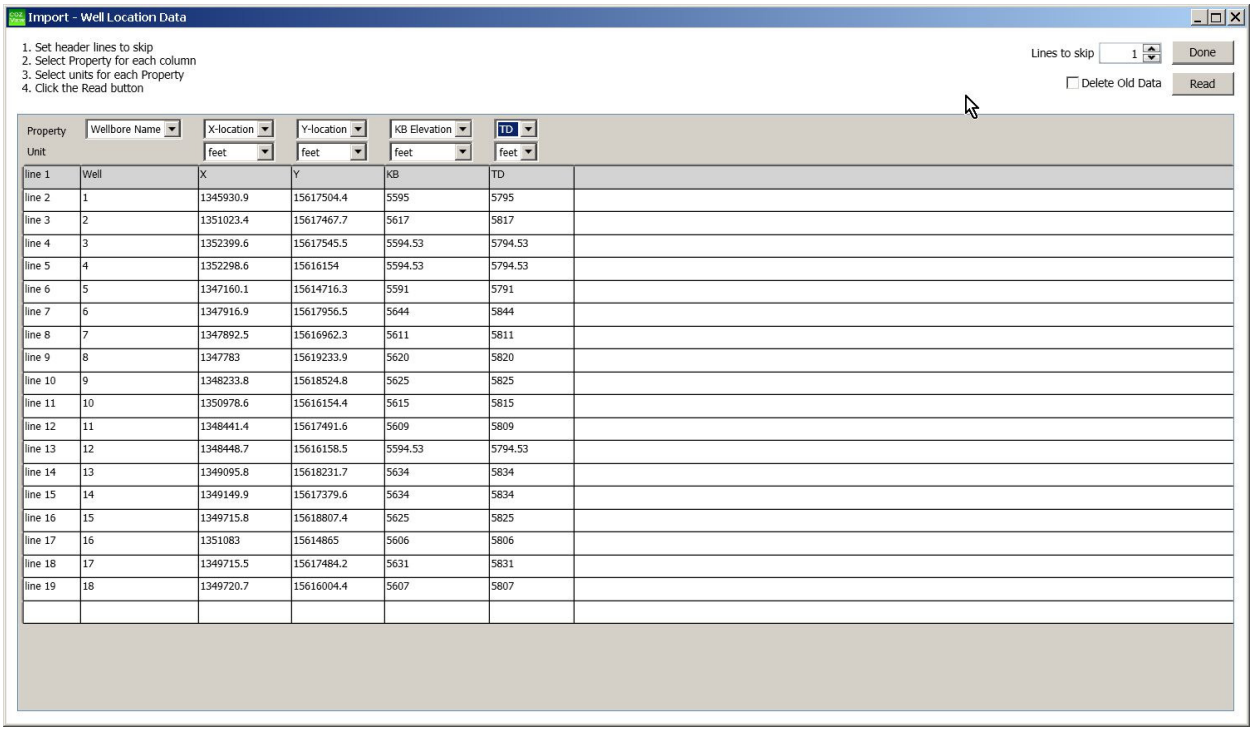
The user can input any missing data and change any data already provided by clicking on the appropriate *Well Name*. The entire well line will be highlighted in blue. The user can then double-click the data field to be input or changed.

New wells cannot be added to the model using this screen except with data *Import*. It is suggested that the user returns to the Static Model section to add any new wells.

The user may choose to input well locations using the *Import* facility rather than identifying well locations in the *Static Model*. Selection of the **Import** button generates a request for a *.csv* file location. The format of the *.csv* file should be consistent with the columns in the Well completion table.



Each of the columns has a drop down menu from which the user must select a parameter in order to identify the column content. If the .csv file contains a header row(s), the user must skip those rows when loading the data. This can be done by selecting the appropriate Lines to Skip in the upper right corner of the window. The lines (rows) to skip will be highlighted grey.



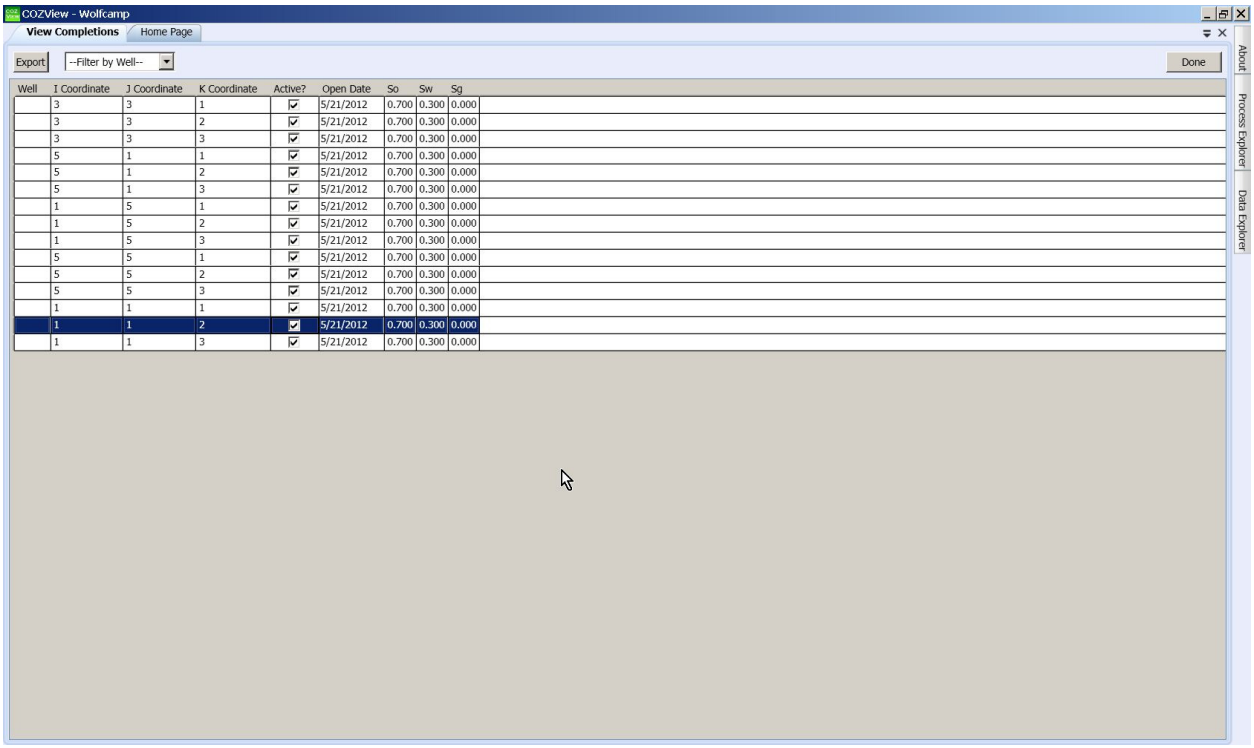
Select **Read** to load the data. A message notifying the user that the load has Completed will appear upon successful loading of the data. Select **Done** to save the data.

After the well locations have been loaded and saved, they can be viewed in the *Static Model* section in *View 3D Model* or in the *Scaled Model* area in *Assign Wells*. (*The user is reminded of rules on screen refreshing noted in section 2.4.)*

When loading well locations from a .csv file, it is important to be sure that the X,Y locations are within the boundaries of the coordinates assigned in the Static Model section.

3.4.2 Well Completions

Selection of *Well Completions* provides the user tabular information concerning each well's I,J,K location in the simulation grid, whether the well's status is active or not, the *Open Date* for the completions and the phase saturations in the well cells at the initialization time.



Well	I Coordinate	J Coordinate	K Coordinate	Active?	Open Date	So	Sw	Sg
	3	3	1	☑	5/21/2012	0.700	0.300	0.000
	3	3	2	☑	5/21/2012	0.700	0.300	0.000
	3	3	3	☑	5/21/2012	0.700	0.300	0.000
	5	1	1	☑	5/21/2012	0.700	0.300	0.000
	5	1	2	☑	5/21/2012	0.700	0.300	0.000
	5	1	3	☑	5/21/2012	0.700	0.300	0.000
	1	5	1	☑	5/21/2012	0.700	0.300	0.000
	1	5	2	☑	5/21/2012	0.700	0.300	0.000
	1	5	3	☑	5/21/2012	0.700	0.300	0.000
	5	5	1	☑	5/21/2012	0.700	0.300	0.000
	5	5	2	☑	5/21/2012	0.700	0.300	0.000
	5	5	3	☑	5/21/2012	0.700	0.300	0.000
	1	1	1	☑	5/21/2012	0.700	0.300	0.000
	1	1	2	☑	5/21/2012	0.700	0.300	0.000
	1	1	3	☑	5/21/2012	0.700	0.300	0.000

The user can change the well's active status and the Open Date already provided by clicking on the appropriate *Well Name*. The entire well line will be highlighted in blue. The user can then uncheck the Active box or double-click Open Date data field to be changed. The Open Date for each well is generated based on the date when the well completions were created in the model. The user should be sure that Open Dates for individual wells are consistent with the simulation run **Initialization Date** and the requirements of the simulation run to be made.

Each well is initially assumed to be completed in all layers of the model.

The I, J, K location and the reported fluid saturations for each well are based on the default grid used in COZSim and the *Model Initialization* previously carried out. If fluid saturations are not consistent with the user's expectations, changes to the layer completions and the *Model Initialization* parameters may be required.

After making any changes or entering new data, click the **Done** button to save the changes.

Changes to the *Model Initialization* may change the saturations in the well completion simulation cells. However, the *View Completions* screen will not reflect these changes unless the screen is refreshed. The screen can be refreshed by closing the *View Completions* menu tab at the top of the window (right-click) and reopening the screen from the *Process Explorer* menu area.

3.5 Prediction Period

The *Prediction* section is used to forecast future performance based on well and field constraints and limits provided by the user. Prediction simulation runs can be launched from reservoir conditions based on the static model.

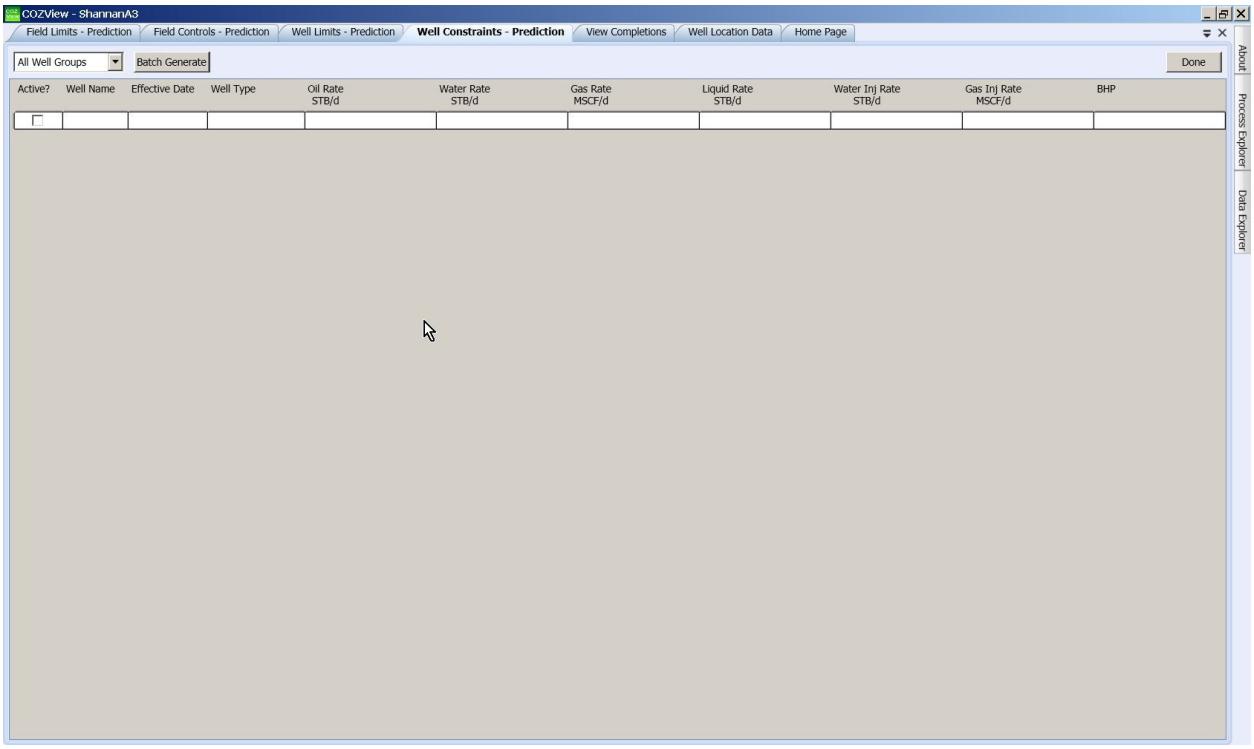
It is noted that there are a number of menu tabs that are related to well information throughout COZView. Changes in one well related menu tab should be reflected in other well related menu tabs; however, for reasons associated with **COZView'**s database it is recommended that the user close the active Menu Tab after saving any changes to the well data. This will assure that that menu tab is refreshed the next time it is accessed. A menu tab can be closed with a right-click mouse operation on the appropriate Menu Tab at the top of the **COZView** window.

3.5.1 Well Parameters

The *Well Parameters* section allows the user to specify well constraints and limits which force the simulation run to emulate actual or desired field operating practices.

3.5.1.1 Well Constraints

Selection of the *Well Constraints* menu displays the screen below.



The *Well Constraints* menu identifies the Well type, desired production and injection rates and bottom hole flowing pressure for each well. A left-click on the blank row followed by a left-click in a data field provides either a drop down menu or the ability to input a value.

The user must check the Active box to activate the control for a given well. The well must be selected from the drop down menu; the activation date must be specified; and a well type

- Oil producer
- Gas producer
- Water producer
- Liquid producer
- Water injector
- Gas/CO2 injector

must be selected. Only one well type can be specified per well at any given time.

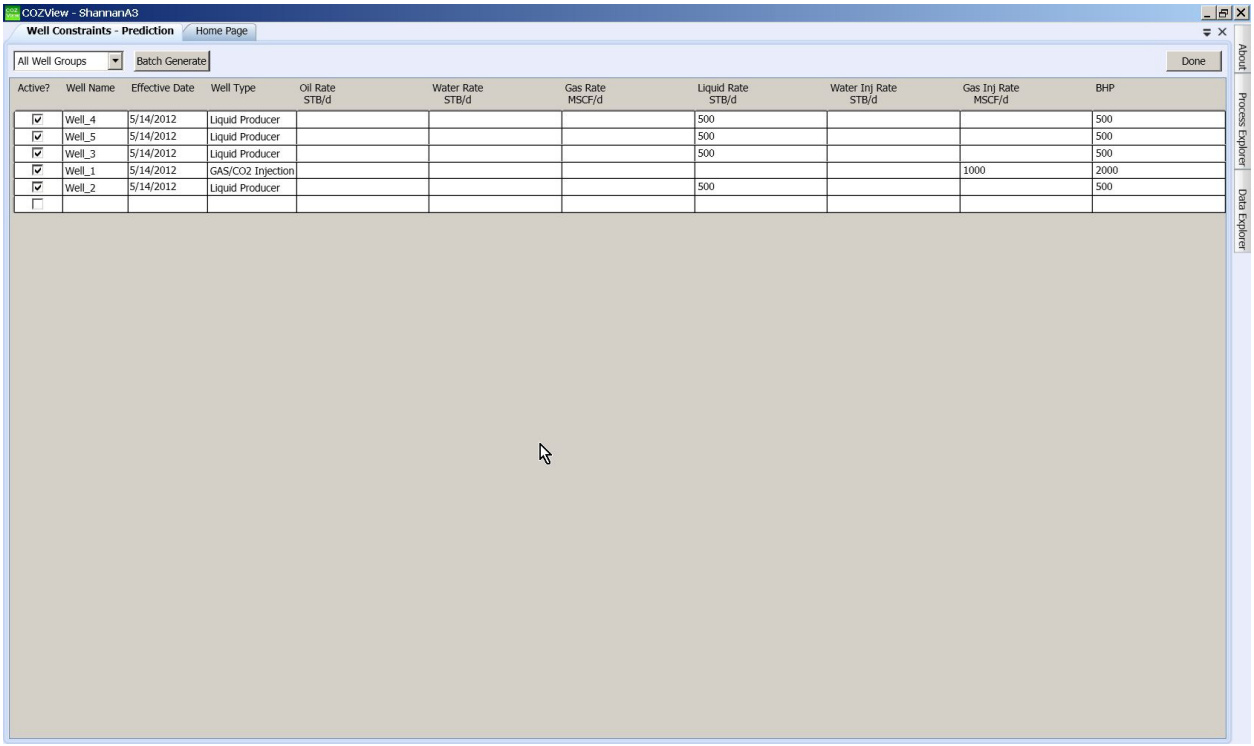
These well types must be specified if a well is to produce or inject in the simulation model.

The available well rates are

- Oil production rate (STB/D)

- Water production rate (STB/D)
- Gas production rate (MSCF/D)
- Liquid production rate (STB/D)
- Water injection rate (STB/D)
- Gas injection rate (MSCF/D)

In general, the user may specify a liquid, oil and water rate based on the maximum lift capacity or a desired rate for the production wells. Injection rates may be specified based on a user desired rate. These rates may or may not be achieved by the simulation model. These rates will not be exceeded in the simulation model. At least one rate should be specified for each production and injection well.



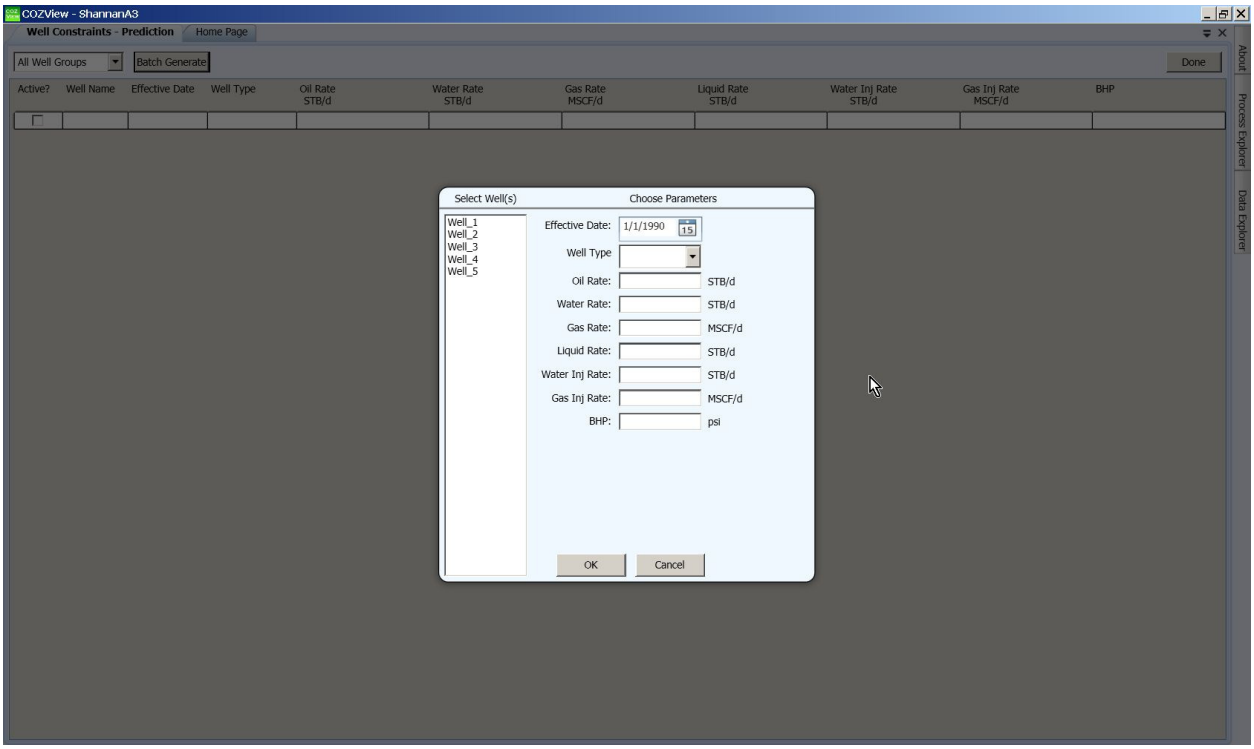
Active?	Well Name	Effective Date	Well Type	Oil Rate STB/d	Water Rate STB/d	Gas Rate MSCF/d	Liquid Rate STB/d	Water Inj Rate STB/d	Gas Inj Rate MSCF/d	BHP
☑	Well_4	5/14/2012	Liquid Producer				500			500
☑	Well_5	5/14/2012	Liquid Producer				500			500
☑	Well_3	5/14/2012	Liquid Producer				500			500
☑	Well_1	5/14/2012	GAS/CO2 Injection						1000	2000
☑	Well_2	5/14/2012	Liquid Producer				500			500
☐										

The simulator will initiate individual well production based on the greater of an assumed bottom hole flowing pressure of 14.7 psia or the user specified BHP. The well's production rate will be constrained by the well rates specified above.

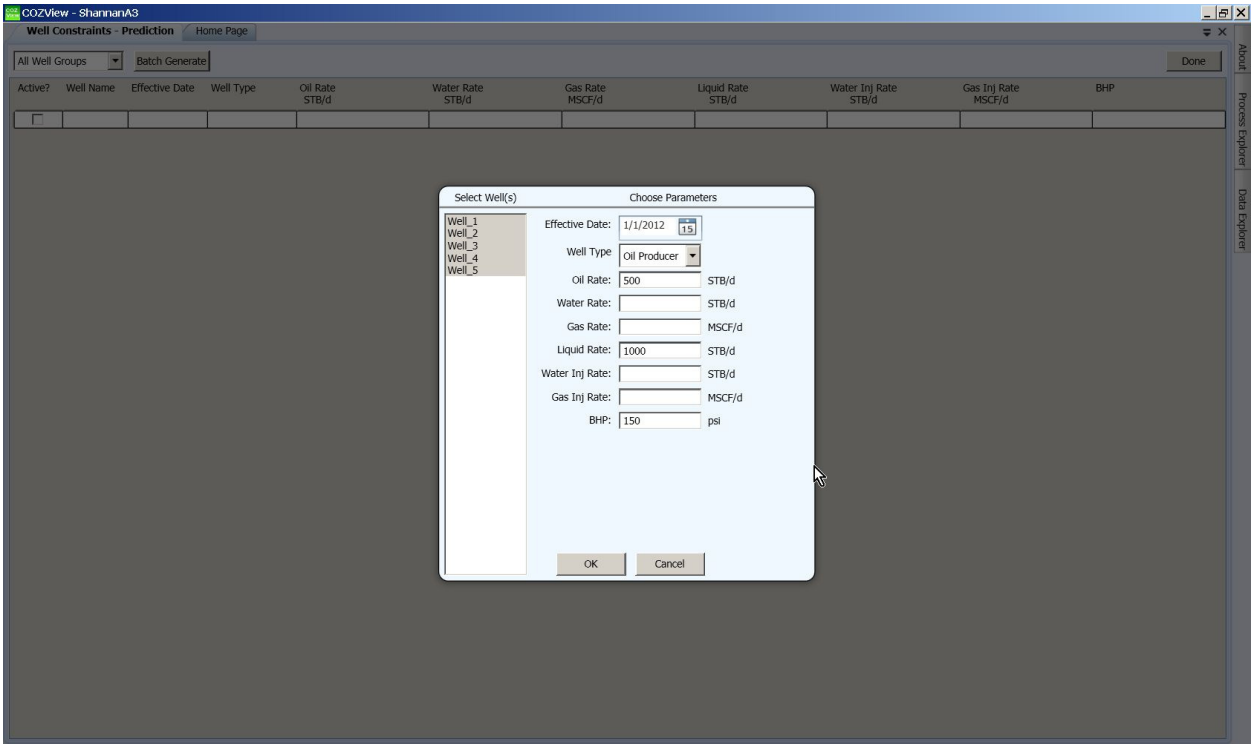
The simulator will initiate individual well injection based on the lesser of an assumed bottom hole flowing pressure equal to the maximum pressure in the PVT property tables or the user specified BHP. The well's injection rate will be constrained by the well rates specified above.

Selection of the **Done** button will save and exit the screen.

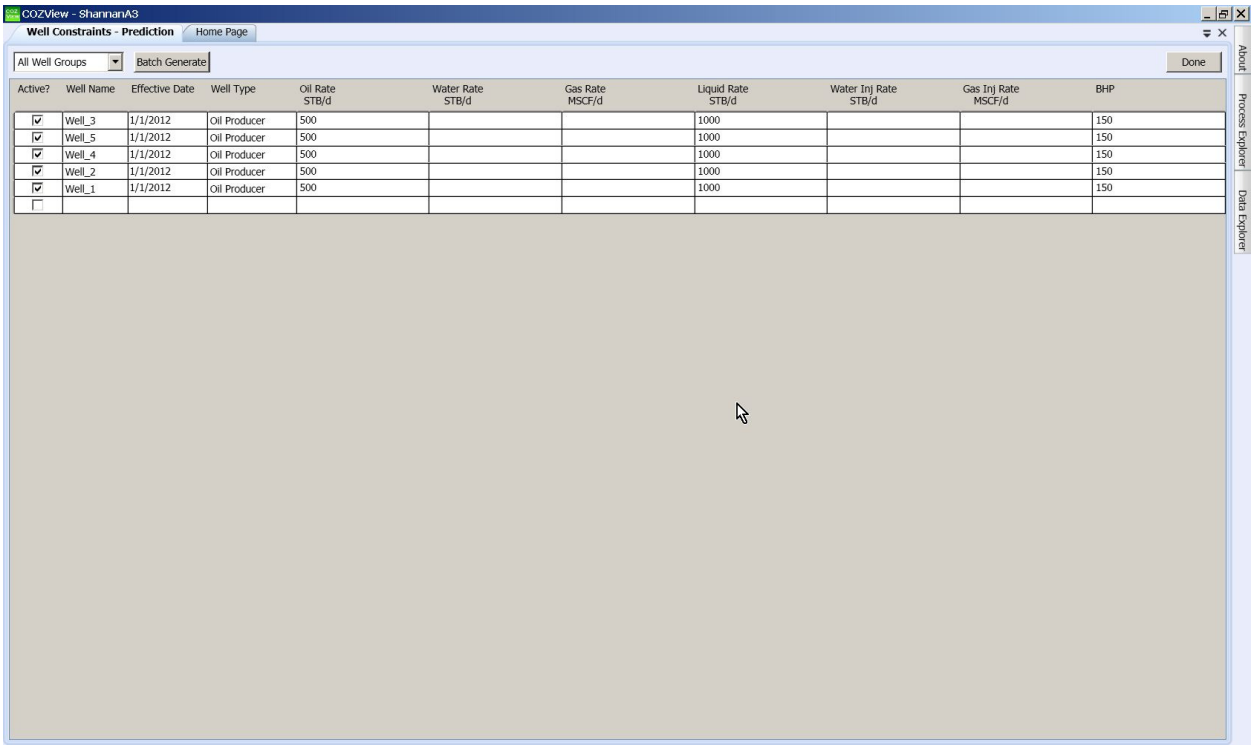
When a large number of wells are involved, the user may choose to use the **Batch Generate** button. The Batch Generate functionality allows quick assignment of parameter values to multiple wells.



The user must select the appropriate wells, define the activation date, and define the well type.



Selection of **OK** will generate a table for all wells selected. Parameter values for any given well can be changed by selecting the appropriate data field and inputting the new value. (A left-click on the data row and a left-click on the data field to be changed.)



Active?	Well Name	Effective Date	Well Type	Oil Rate STB/d	Water Rate STB/d	Gas Rate MSCF/d	Liquid Rate STB/d	Water Inj Rate STB/d	Gas Inj Rate MSCF/d	BHP
☑	Well_3	1/1/2012	Oil Producer	500			1000			150
☑	Well_5	1/1/2012	Oil Producer	500			1000			150
☑	Well_4	1/1/2012	Oil Producer	500			1000			150
☑	Well_2	1/1/2012	Oil Producer	500			1000			150
☑	Well_1	1/1/2012	Oil Producer	500			1000			150
☐										

The user may change the well constraints with time by repeating the process at a different date for the affected wells.

Select **Done** to save the data before leaving this screen.

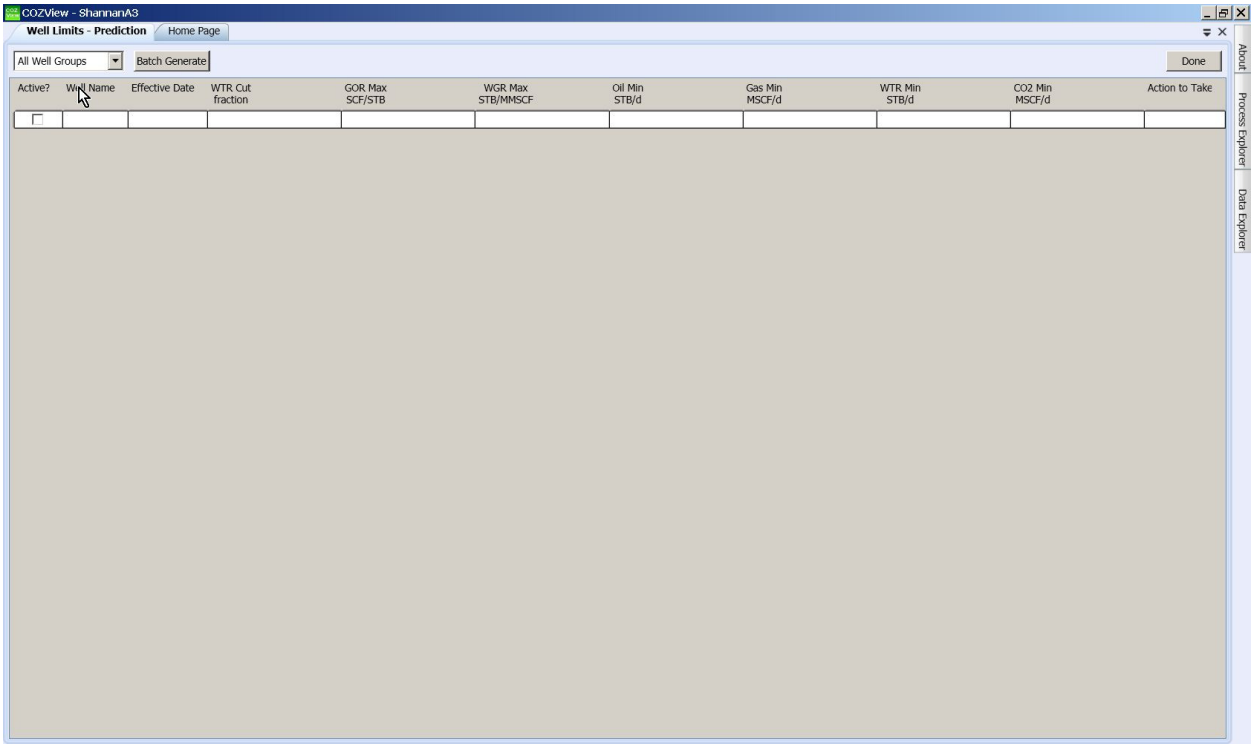
3.5.1.2 Well Limits

The *Well Limits* menu establishes the manner in which the wells will be constrained or limited in the simulation run - maximum water cut, maximum GOR, minimum oil rate, etc.). When a *Well Limit* is exceeded during the simulation, there are two user directed actions that will result (shut-in well or shut-in a perforation). The well limits that can be specified are

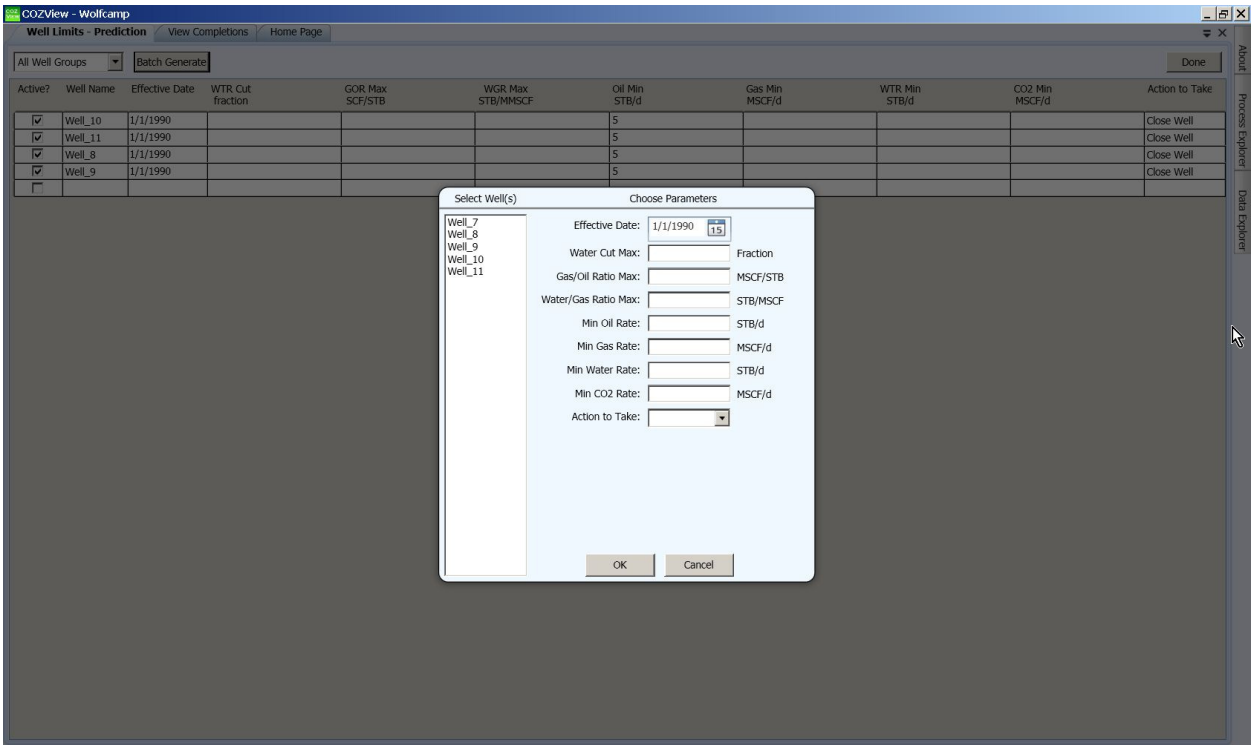
- Maximum water cut (fraction)
- Maximum producing gas-oil ratio (MSCF/STB)
- Maximum producing water-gas ratio (STB/MSCF)
- Minimum oil production rate (STB/D)
- Minimum water production rate (STB/D)

- Minimum gas production rate (MSCF/D)
- Minimum CO2 production rate (MSCF/D)

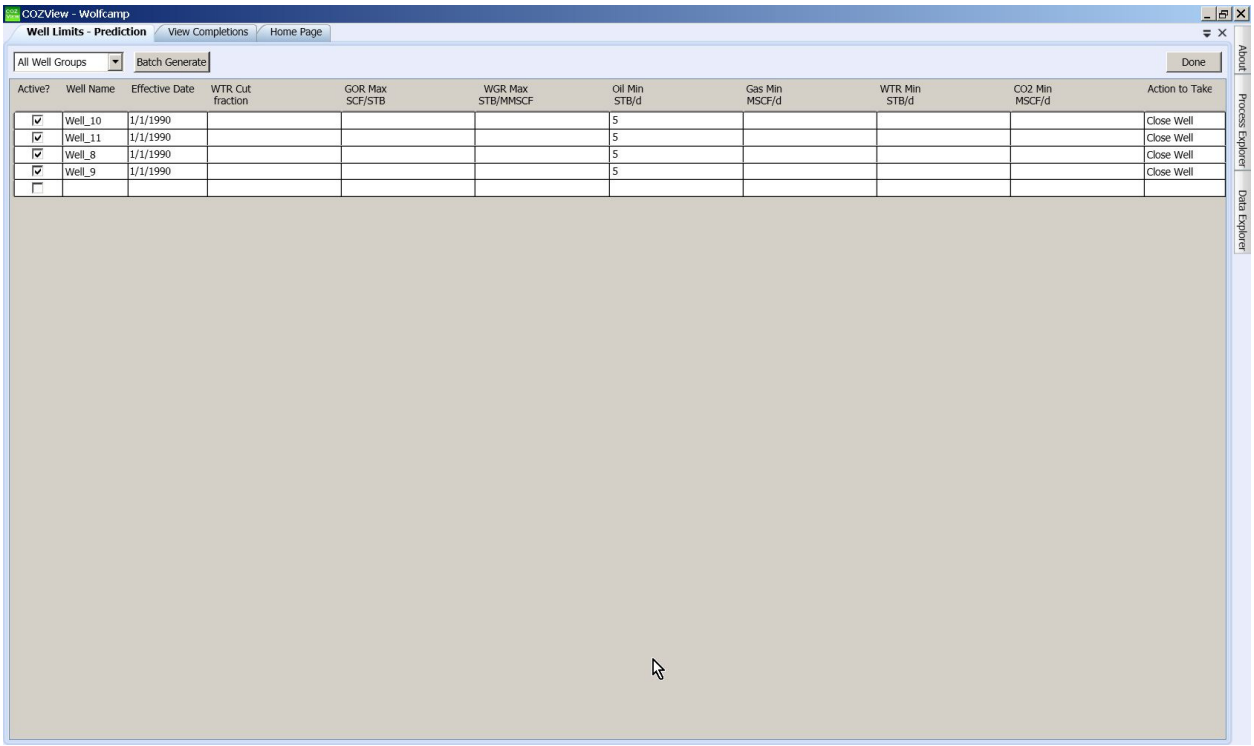
The Active box must be checked and the Effective Date specified if appropriate for each well.



When a large number of wells are involved, the user may choose to use the **Batch Generate** button. The Batch Generate functionality allows quick assignment of parameter values to multiple wells.



The user must select the appropriate wells, define the activation date, and specify the appropriate limits. Selection of **OK** will generate a table of the well limits for all selected wells. Parameter values for any given well can be changed by selecting the appropriate data field and inputting the new value.



The user may change the well limits with time by repeating the process at a different date for the affected wells.

Select **Done** to save the data before leaving this screen.

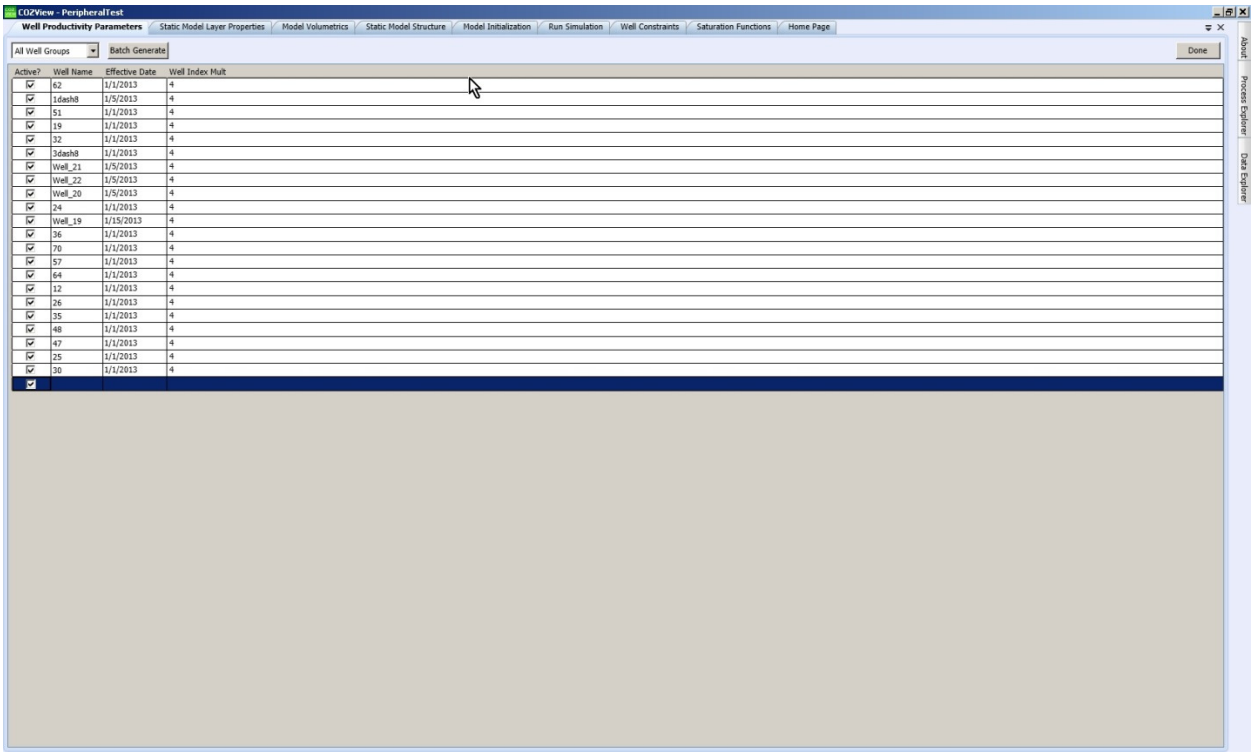
3.5.1.3 Well Productivity Parameters

The Well Productivity Parameter screen is found in the *Prediction Period/Well Parameters* section. This functionality allows the user to modify the well index (PI) calculated by the **COZSim** based on the well's location, permeability and thickness in the model. These calculated PI's are not displayed by **COZView**. It may be appropriate to adjust these values in the simulator at the start of a prediction run to better reflect actual well performance in the field. This is a common adjustment made at the end of conventional history matching before proceeding to prediction cases.

The Well Productivity Parameters screen allows the user to input a **Well Index (PI) multiplier** which is applied to the well index calculated by the simulator. A multiplier greater than 1.0 will generally increase the production capacity of a well at the start of the prediction run. A multiplier less than 1.0 will generally decrease the production capacity of a well at the start of the prediction run.

These multipliers should only be applied after the model has been successfully calibrated to the OOIP and/or OIP and a short prediction run made to determine how the simulated well rates compare to actual well rates in the field.

The user can input the parameter values on a well by well basis or the **Batch Generate** feature can be user to address multiple wells at the same time. Typically, all wells will be given the same multiplier, but this need not be the case.



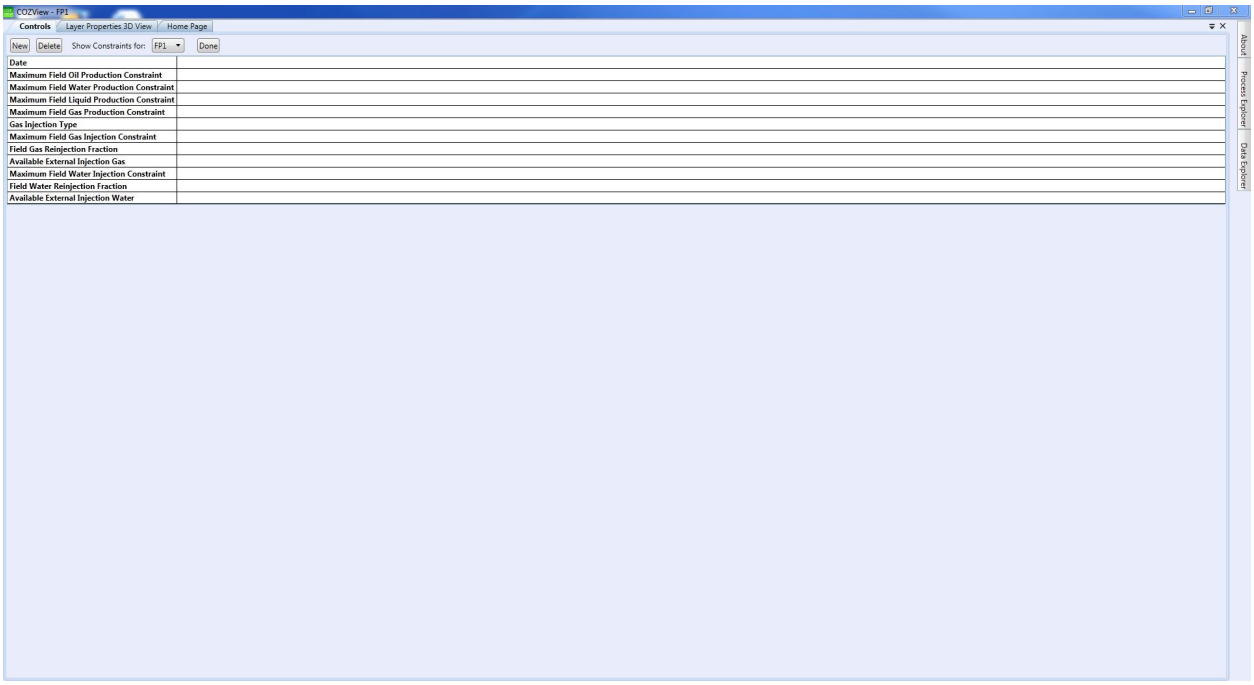
This functionality is new and earlier pictures of the Process Explorer menus may not show the Well Productivity Parameters option.

3.5.2 Field Parameters

The *Field Parameters* section allows the user to specify field controls and constraints which force the simulation run to emulate actual or desired facility capacity and operating constraints.

3.5.2.1 Field Controls

Selection of the *Field Controls* displays the screen below.



This screen provides the user with a number of field control options

Maximum Field Oil Production Constraint (STB/D)

Maximum Field Water Production Constraint (STB/D)

Maximum Field Liquid Production Constraint (STB/D)

Maximum Field Gas Production Constraint (MSCF/D)

Gas Injection Type (HC or CO2)

Maximum Field Gas Injection Constraint (MSCF/D)

Field Gas Re-Injection Fraction

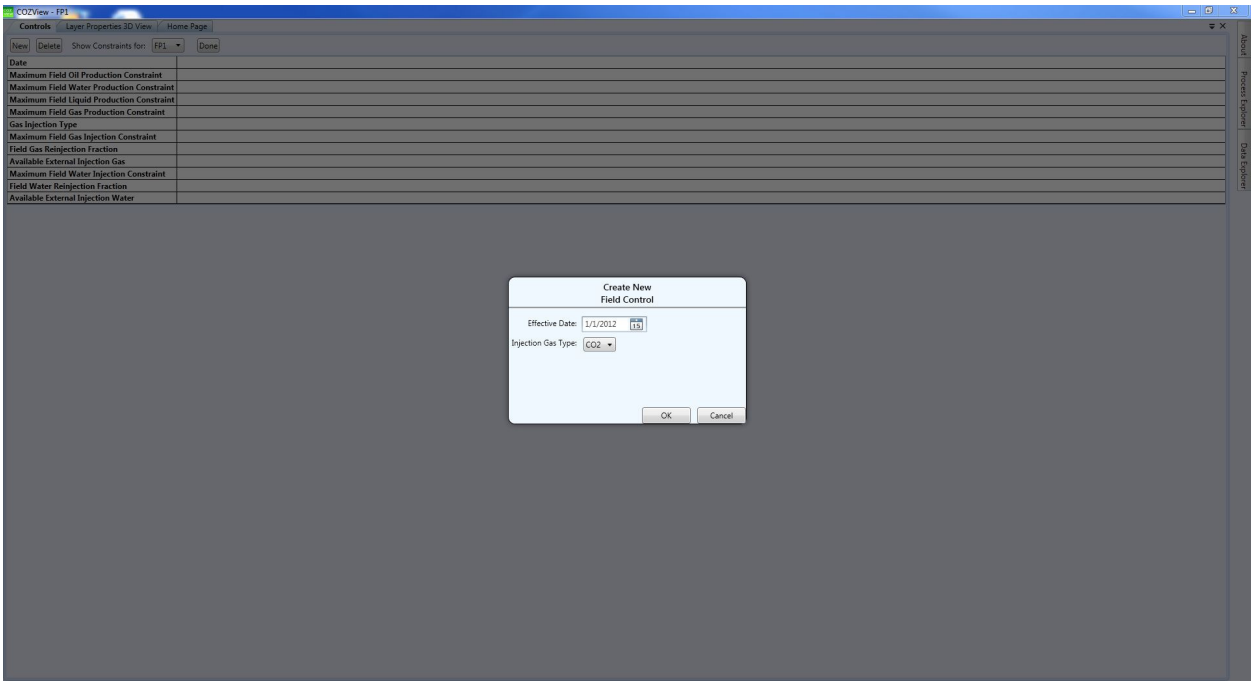
Available External Injection Gas (MSCF/D)

Maximum Field Water Injection Constraint (STB/D)

Field Water Re-Injection Fraction

Available External Injection Water (STB/D)

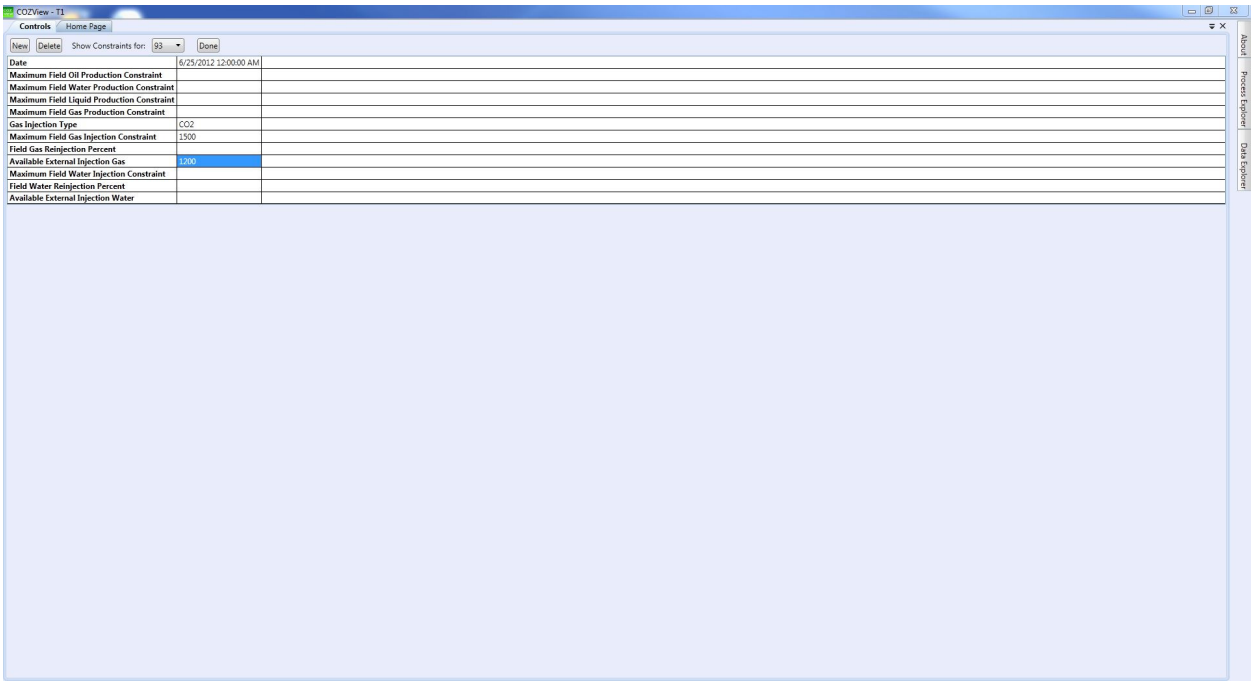
The user must first select the date at which the assigned field controls are to become effective. This is done by selecting the **New** box and assigning the appropriate activation date and Injection Gas Type from the drop down menu. Multiple dates can be provided allowing field controls to change over time during the simulation.



Select Effective date and Injection Gas Type. There are two options available for injection gas type 1) CO2 and 2) HC gas. Click Ok to Continue.

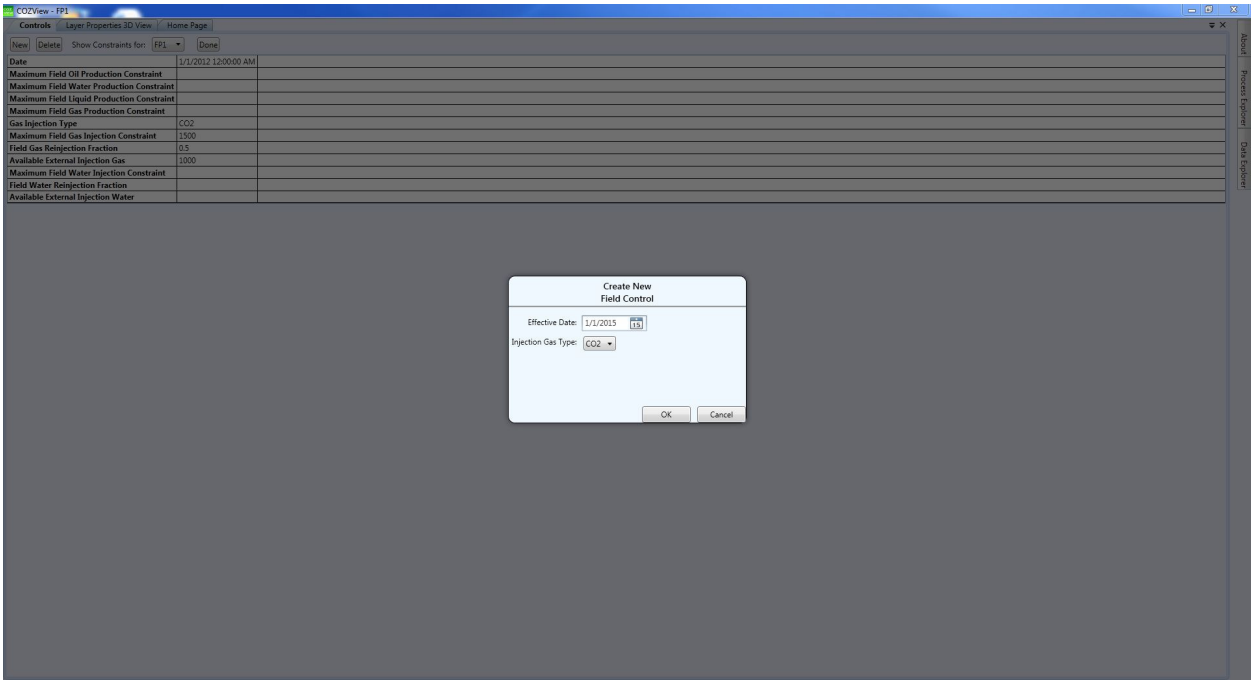
It is important to note that this is the only place where the injection gas type is identified. Even if the user does not input values for the various field controls, the injection gas type must be identified. The default is CO2 gas.

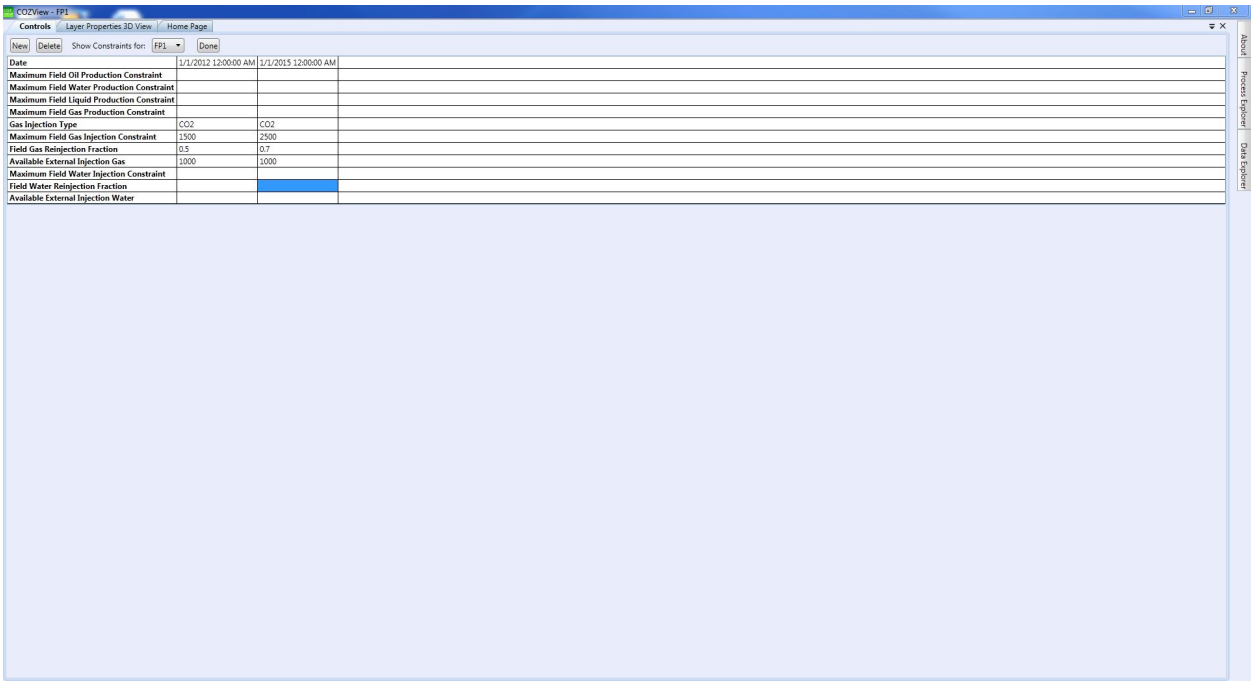
When any of these field control options are selected, the simulation run's priority is to meet these field target rates subject to individual well operational controls which may have been selected.



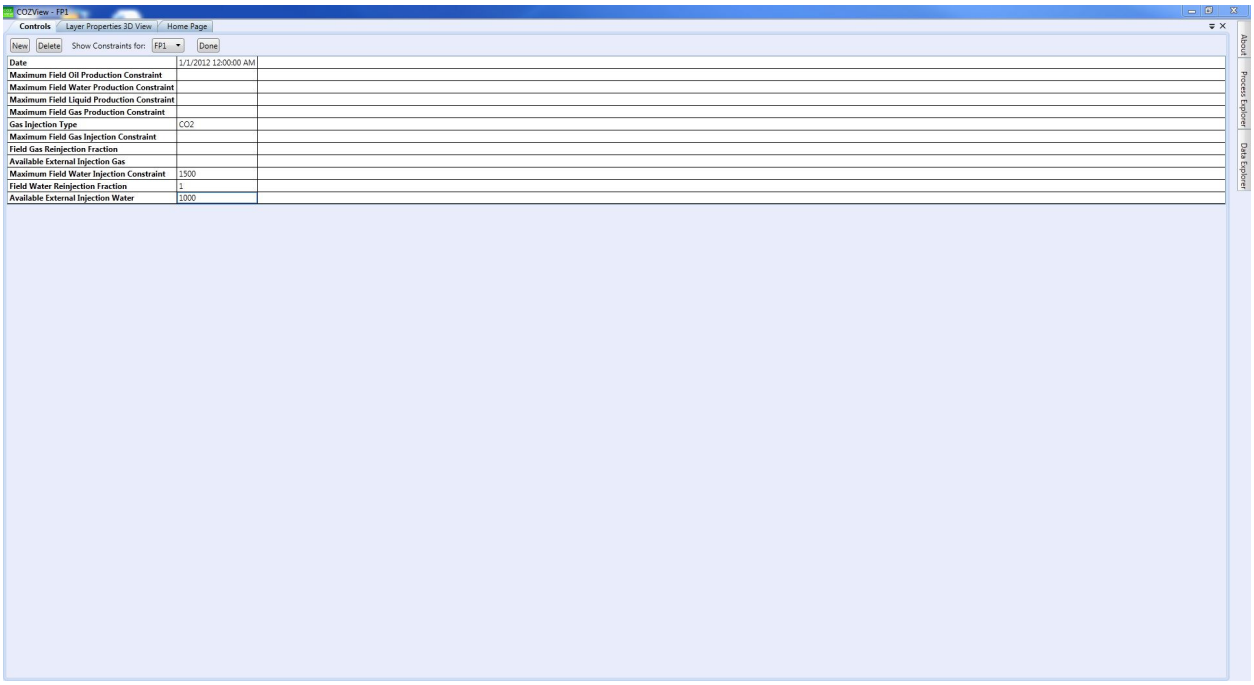
Please note that the Maximum Field injection constraint should always be greater than or equal to Available External Injection.

Selection of **Done** will save and exit the screen. Multiple dates can be provided allowing field controls to change over time during the simulation. Click Field Controls again under Process Explorer to input multiple Field Controls. Click New to add the new Field Controls



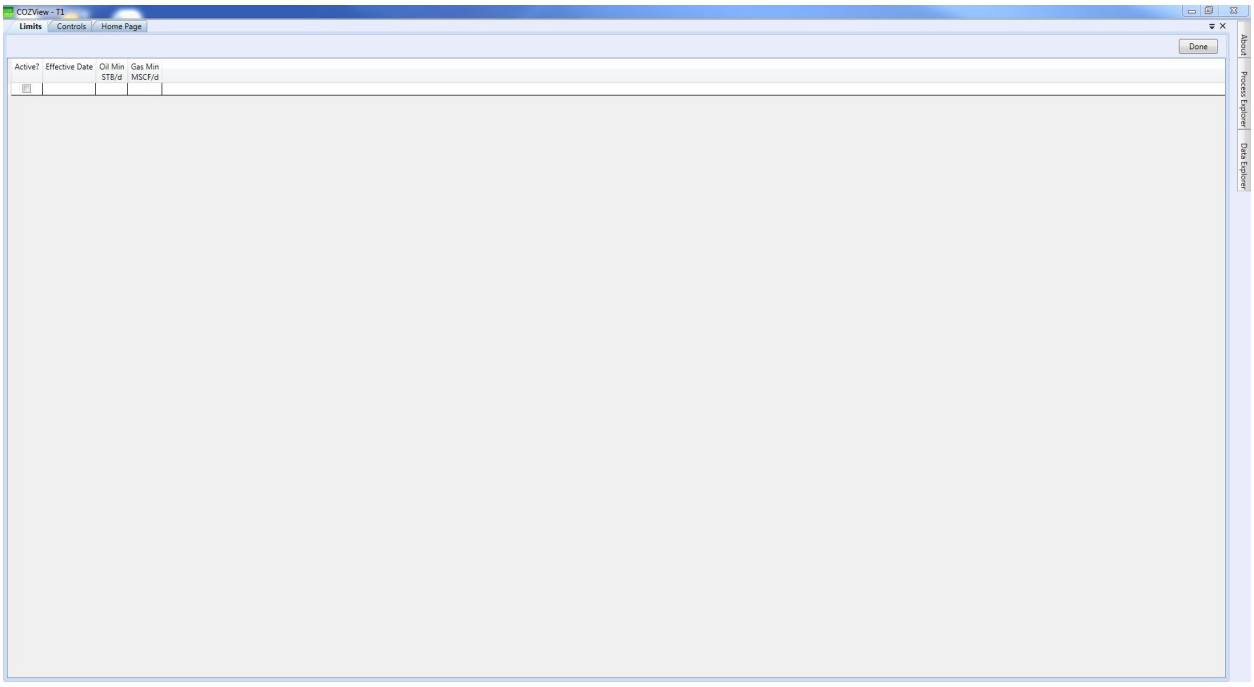


COZSim is primarily designed for CO2 injection studies. However, the user can also study a water injection scenario. Click *Field Controls* under Process Explorer. Click New to create a set of Field Controls parameters. Select CO2 as Gas Injection Type (The user must select either CO2 or HC). The user can now specify values for *Maximum Field Water Injection Constraint*, *Field Water Reinjection Fraction* and *Available External Injection Water.* Please note that assuming no well controls are set for gas injection, the Gas Injection Type “CO2” or “HC” will not inject CO2 or HC and will not affect simulation results as there are no Field Control values specified for Gas injection (Please see figure below).



3.5.2.2 Field Limits

Selection of *Field Limits* displays the screen below.



A left-click on the blank row followed by a left-click in a data field provides the ability to input a value.

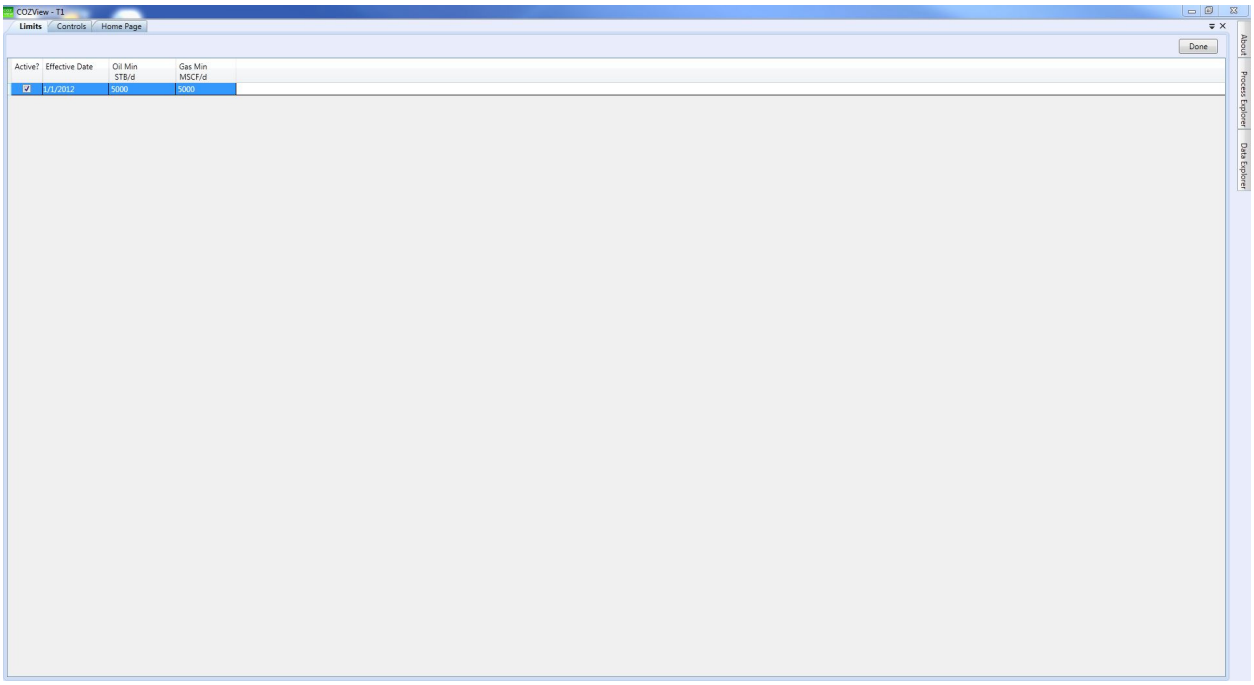
The user must check the Active box to activate the control. The available field limits are

Minimum oil production rate (STB/D)

Minimum gas production rate (MSCF/D)

If minimum field limits are reached in the simulation run, the simulator will shut-in the entire field and the simulation run will be stopped.

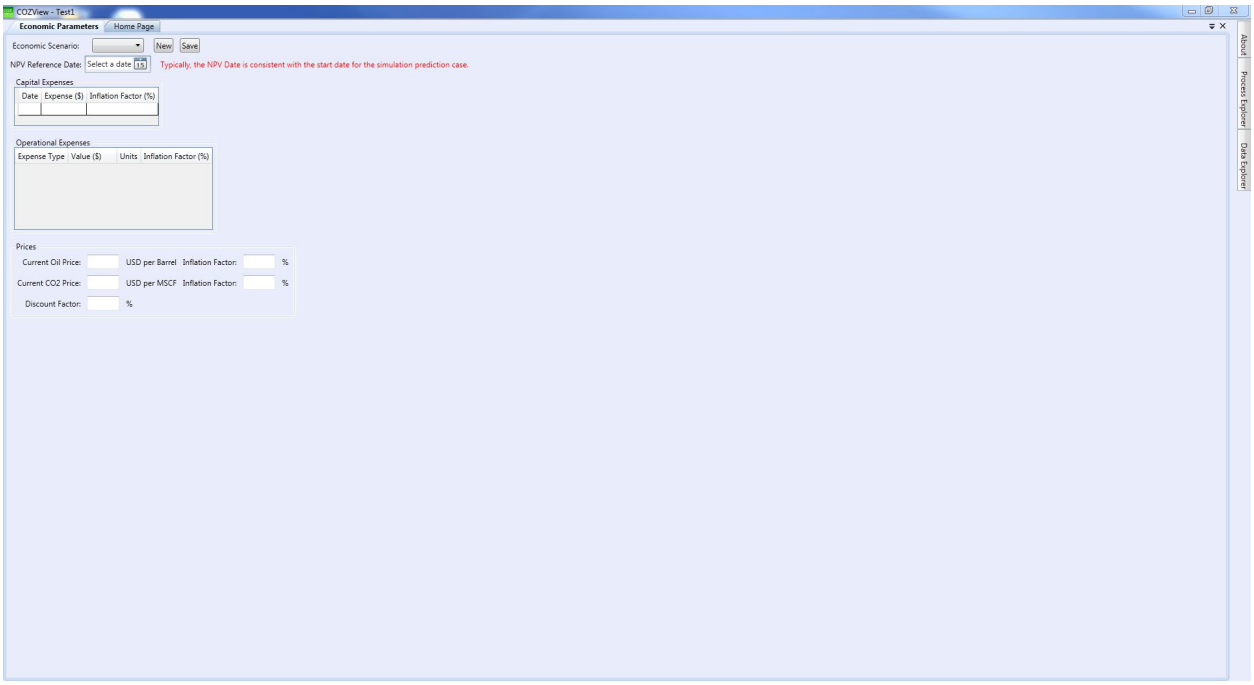
Selection of **Done** will save and exit the screen.



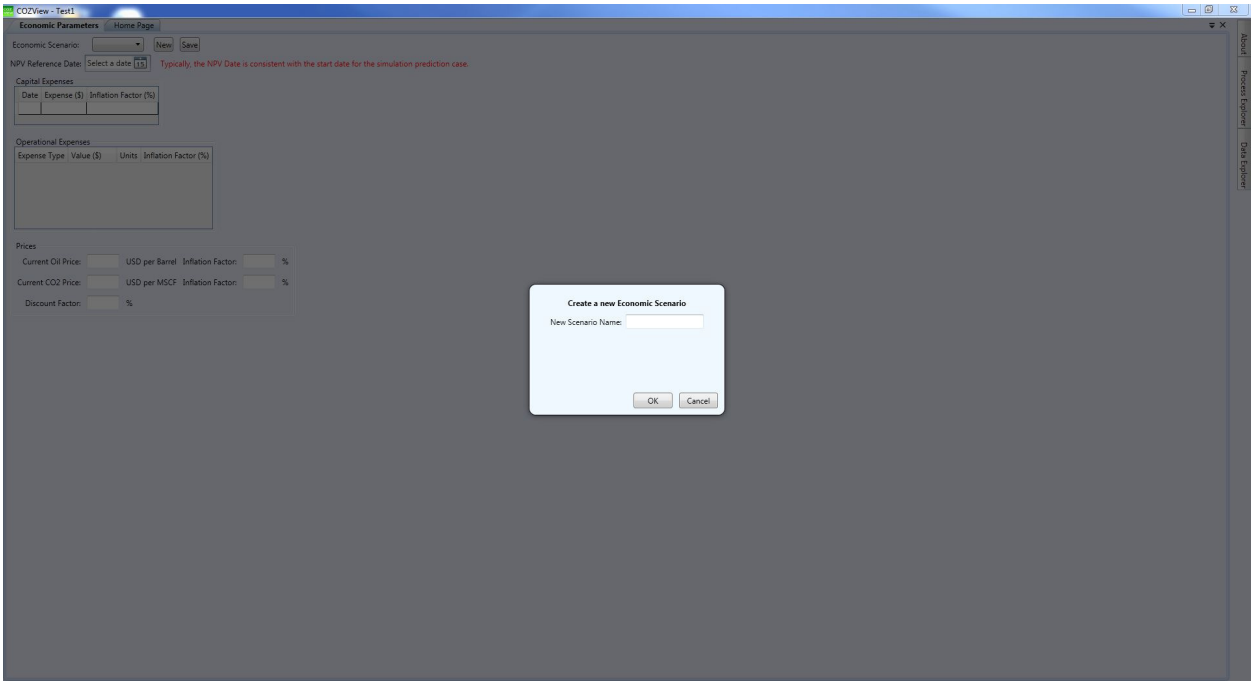
Changes to the field limits with time can be made by repeating the input process on the next row of the initial *Field Limits* screen. (A blank row is now available under the original row.)

3.5.3 Economic Parameters

The *Economic Parameters* section allows the user to specify Capital and Operational expenses for the field. The economic parameters can be tied to the optimization module for maximizing Net Present Value (See section 3.7 for details about Optimization of Net Present Value) or individual case Net Present Value calculations (section 3.6.5).



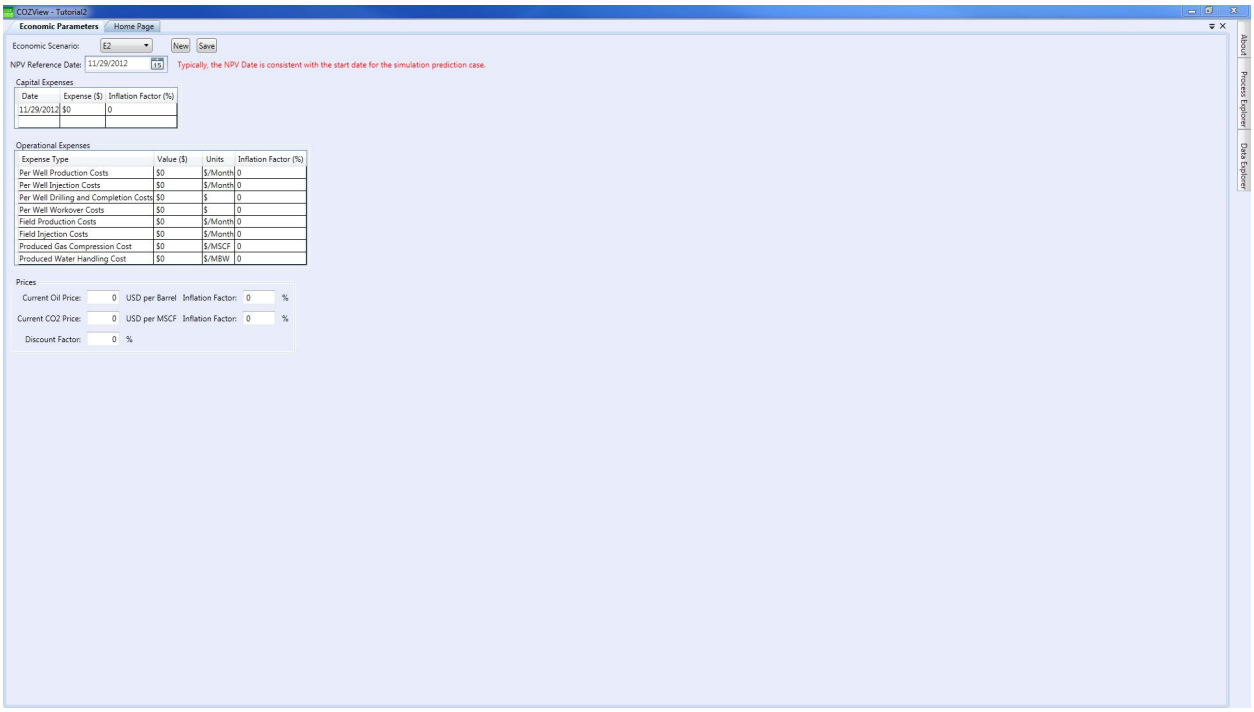
The first time the user enters this screen, a new Economic scenario must be defined by selecting the **New** button.



The Economic scenario allows the user to specify a set of economics parameters (Capital expenses, Operation expenses, Oil price, CO2 price, etc.).

Multiple Economic scenarios can be defined by clicking the **New** button and providing a new scenario name.

The NPV Reference Date typically is set to the start date of the project. All discounting and inflation of the project revenues and expenses using the specified Discount Factor and Inflation Factors will be referenced to this date.



3.5.3.1 Capital Expenses

The user can specify appropriate capital expenses associated with the field. Capital expenses are generally initial investment and equipment installation costs or costs at a specific time during the project.

3.5.3.2 Operational Expenses

The user can specify operational expenses in this section. The available options are

Per Well Production Costs ($/Month)

Per Well Injection Costs ($/Month)

Per Well Drilling and Completion Costs ($)

Per Well Workover Costs ($)

Field Production Costs ($/Month)

Field Injection Costs ($/Month)

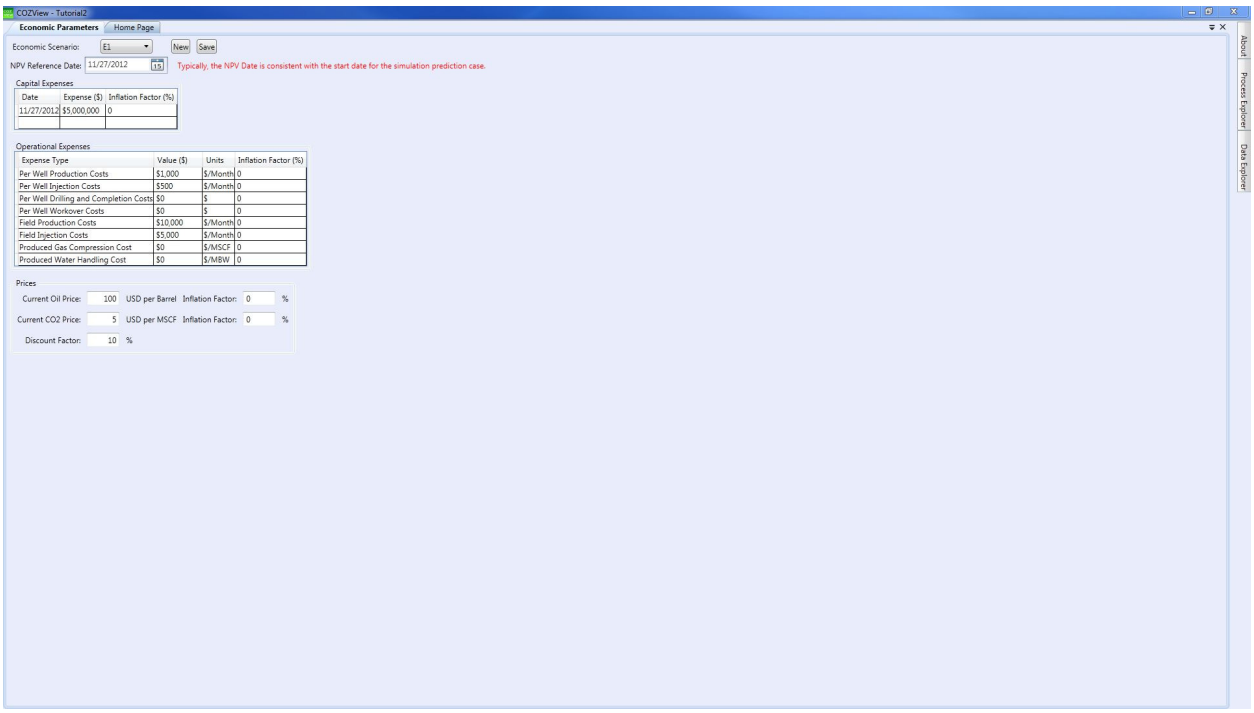
Produced Gas Compression Cost ($/MSCF)

Water Handling Costs ($/MBW)

Current oil and CO2 prices, as well as an Inflation factor for each must be specified. The Discount Factor must be provided for Net Present Value calculations.

The **New** button must be selected to provide an Economic Scenario name. Then the individual parameters can be input. Multiple Economic Scenarios can be created, but only one will be used in the NPV calculations for a prediction case or optimization runs.

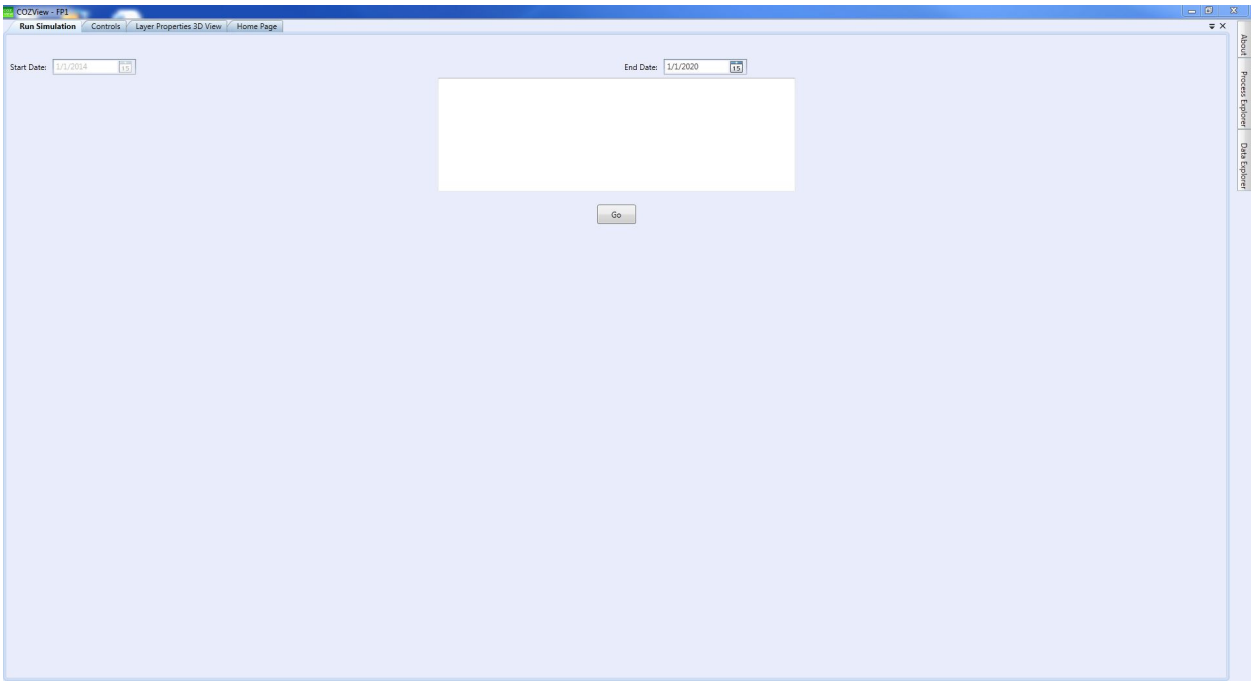
Be sure to select **Save** before exiting the screen.



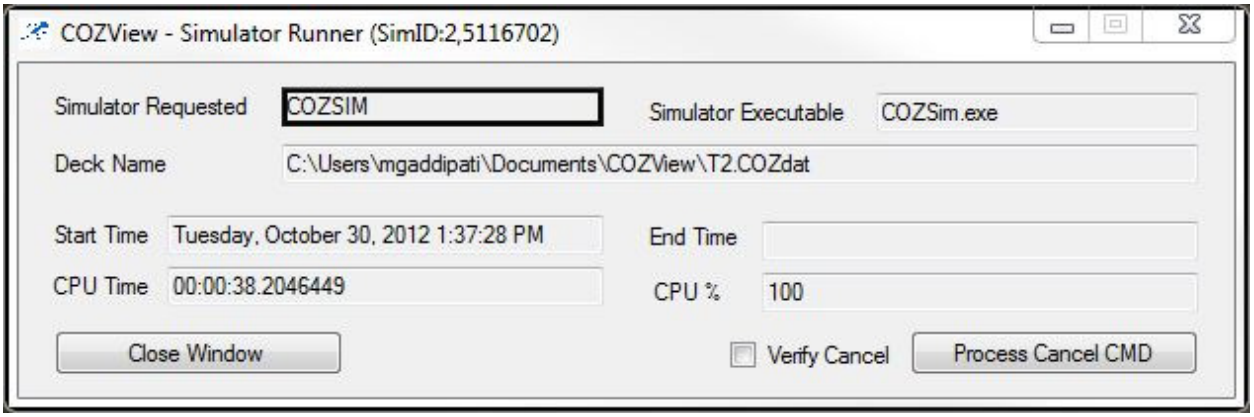
3.5.4 Run Simulation

Selection of *Run Simulation* displays the screen below. The user is only required to input the *End Date* for the simulation run. The *Start Date* is provided for reference. The Start Date is based on the last *Initialization Date* provided in the *Model Initialization* section**. The End Date must be at least one month after the Start Date.**

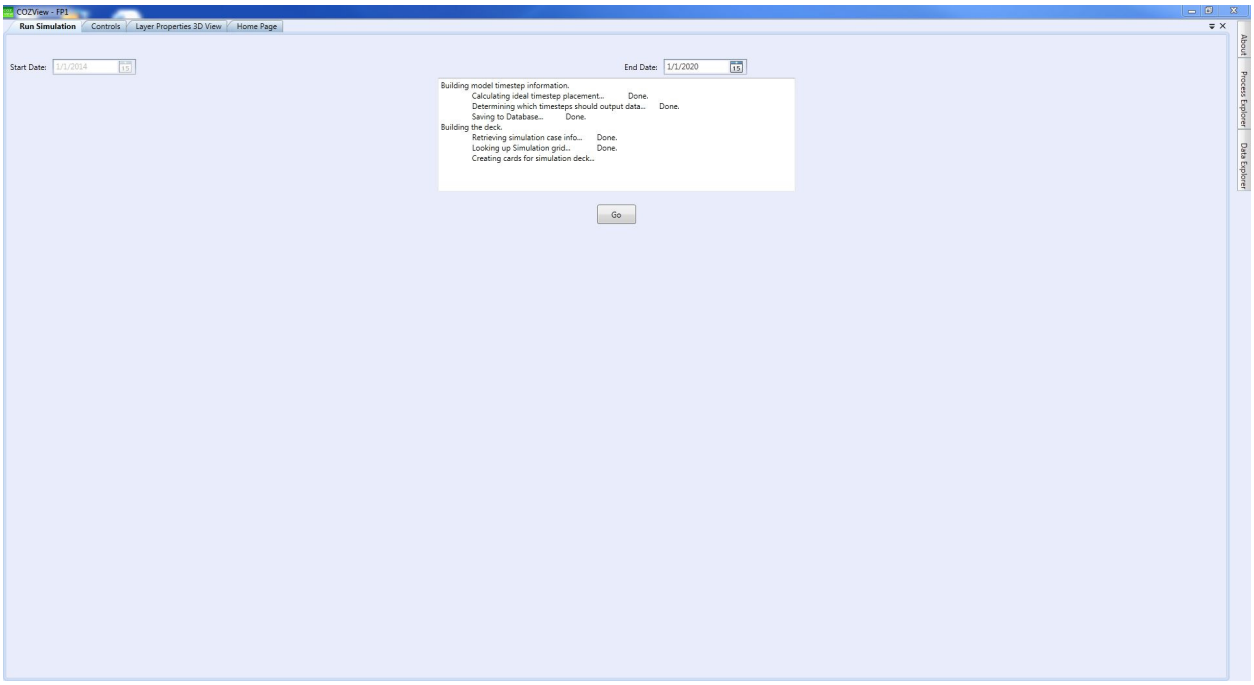
`



When the **GO** button is selected the simulation run is launched. A Simulator Runner window will appear and the CPU Time and CPU% utilization will be continuously updated.



The Run Simulation screen will be updated as the simulation model is prepared for processing.



Once the simulation run completes the Simulator Runner window will close and the simulation run results will be automatically loaded into **COZView** for display in the *Simulation Results* section.

The **COZVIEW** window can be minimized while the simulation run is in progress. **DO NOT** close **COZView** while the simulation run is in progress, as the simulation results will not be loaded if **COZView** and the active project are not open. *The user can view various windows within the project that is processing in COZView while the simulation run is in progress.*

The Simulator Runner window can be minimized while the simulation run is processing. While closing the Simulator Runner window will not cancel the simulation run, it is not recommended.

If the user wishes to cancel a simulation run that is in progress, select the *Verify Cancel* check box on the Simulator Runner window and click the **Process Cancel CMD** button. *The simulation results to the point of the run cancelation will be loaded subject to the frequency of reporting of the well and map results.*

The user can do other work on their computer while the simulator is running.

Depending on the duration and complexity of the simulation run, the run can take a long time to process. **COZView** does not provide any dynamic information on the progress of the run. However, two files created by **COZSim** can be accessed by the user to get an indication of run progress and to view the dynamic results. These files are ***Project name*.COZdat** and ***Project name*.COZOUT**. The .COZdat file is the input data to the simulator. The .COZOUT file contains dynamic run information including timestep size, material balance errors, individual well rates and pressures. These files can be opened with a Text editor such as TextPad or WordPad. DO NOT delete or edit these files during the progress of the simulation

run. These files will be overwritten by **COZView** and **COZSim** when a new Verify or Simulation run is submitted for the same Project Name.

These files reside in the COZView directory created at the time COZView/COZSim was installed on the user's computer. This directory is typically in the users My Documents area.

3.5.4.1 Simulation Run Times

It is difficult to assess how long a particular simulation run will take prior to its submission. Once the simulation run is submitted there is little information available to the user relative to progress of the run. (Note the *Project name*.COZOUT file comments above.) Some general guides to what impacts simulation run time are offered here. These are not necessarily things that the user can control as most are reservoir dependent.

Parameter	**Variation**	**Impact on Total Run time**
Permeability	Larger	Slower
Areal size	Larger	Slower
Porosity	Smaller	Slower
Thickness	Smaller	Slower
Production rate	Higher	Slower
Injection rate	Higher	Slower
Duration	Longer	Slower
# of layers	Higher	Slower

3.6 View Simulation Results

When the simulation run is completed, arrays of the time dependent results and well and field plots will be automatically loaded into COZView. The arrays currently are pressure, oil saturation, gas saturation, water saturation, miscibility, and mole fraction of total CO2.

3.6.1 Plots

Selection of *Plots* will display the plot template with no simulation results. The **Simulation Results** area on the left contains five selection boxes. The boxes are

- Plot Format Type

  Individual Stacked

Single Combination

- Project
- Wells or Field

  (Only field plots are available for optimization cases.)

- Plot Type

  Injection Cumulative vs. Date

  Injection Rate vs. Date

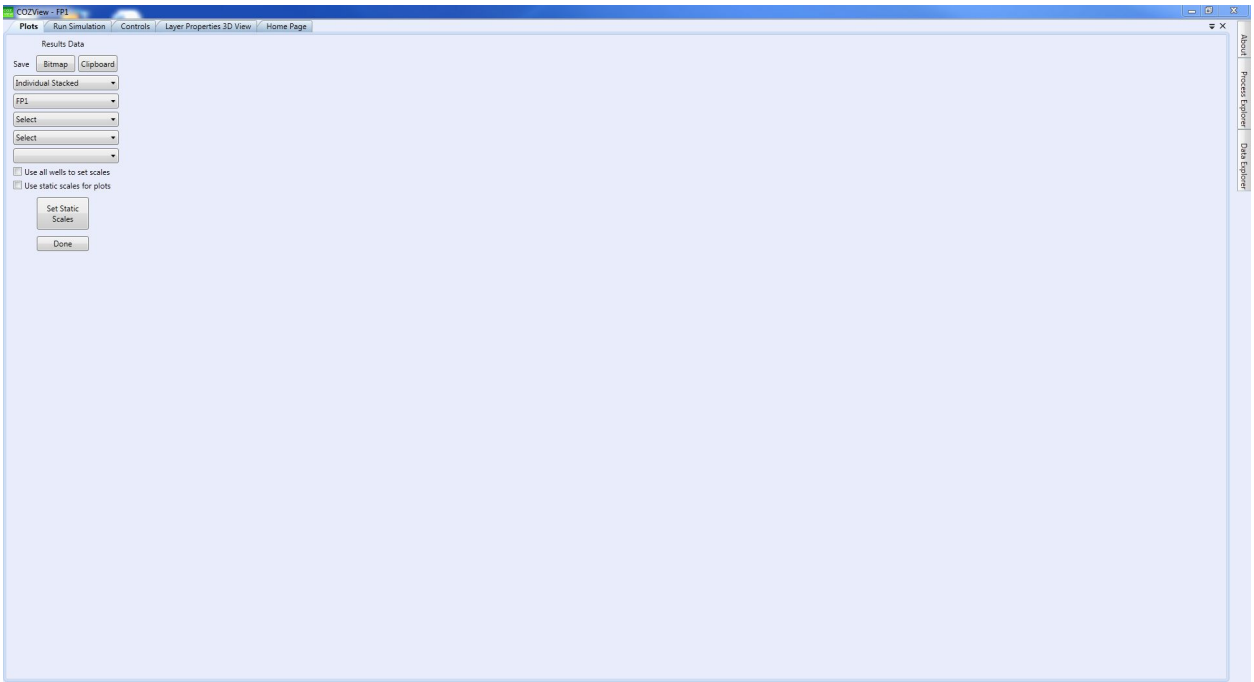
  Production Cumulative vs. Date

  Production Rate vs. date

  All Cumulative vs. Date

  All Rates vs. Date

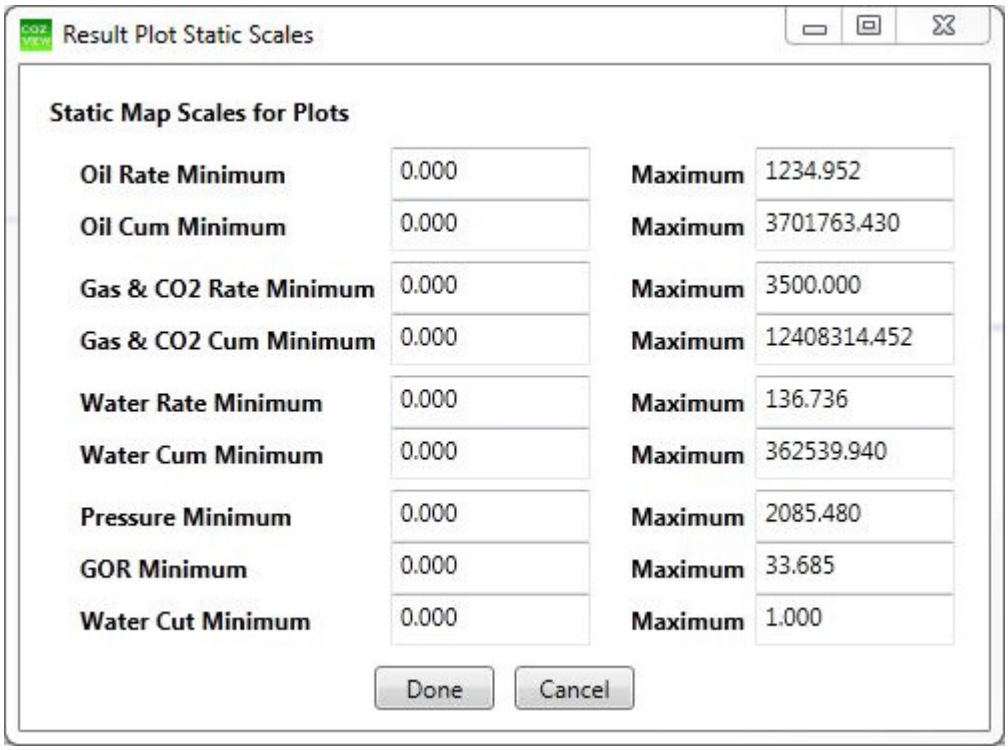
  GOR and Water Cut vs. Date



COZView has two options to set the scale for the Plots. (i) User can check the box "*Use all wells to set scales*". Selection of this box will automatically control the scales (X and Y axis) based on Property (Rates, Pressure, Cumulative, GOR and Water Cut) values for all wells. (ii) User is allowed to change the

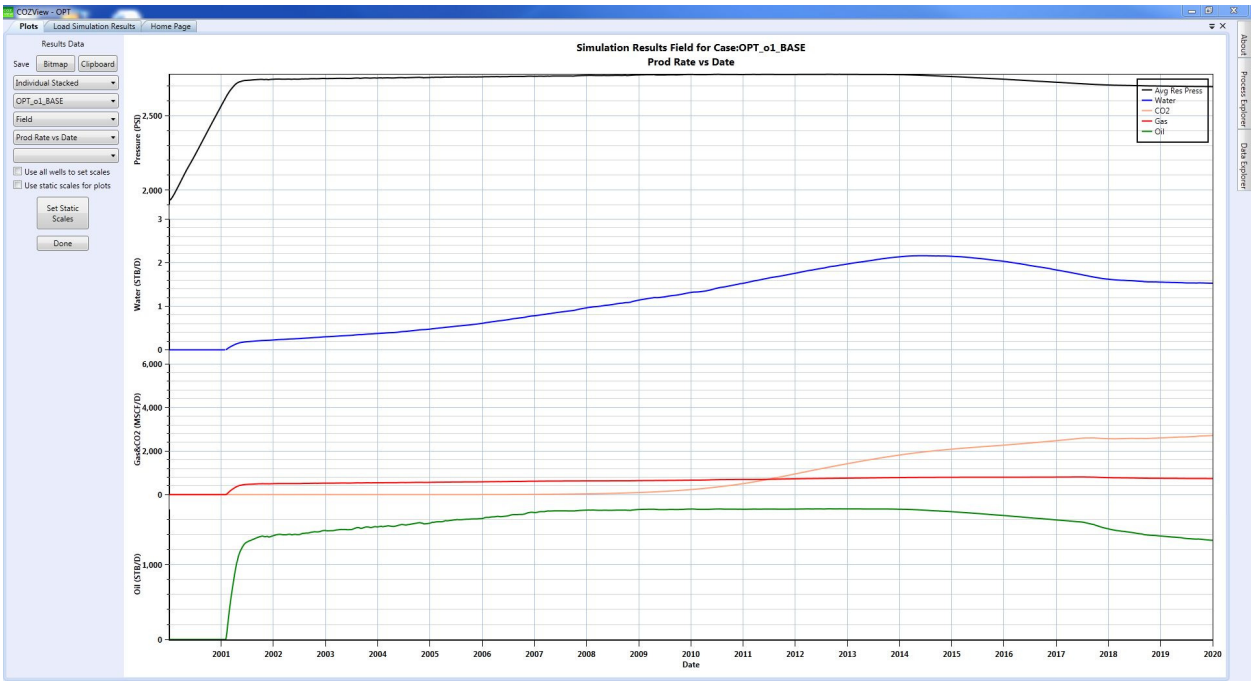
scale (X and Y axis) for each plot manually by using **Set Static Scales** button. Selection of "*Use static scales for plots"* will use the user defined scales for the X and Y axis.

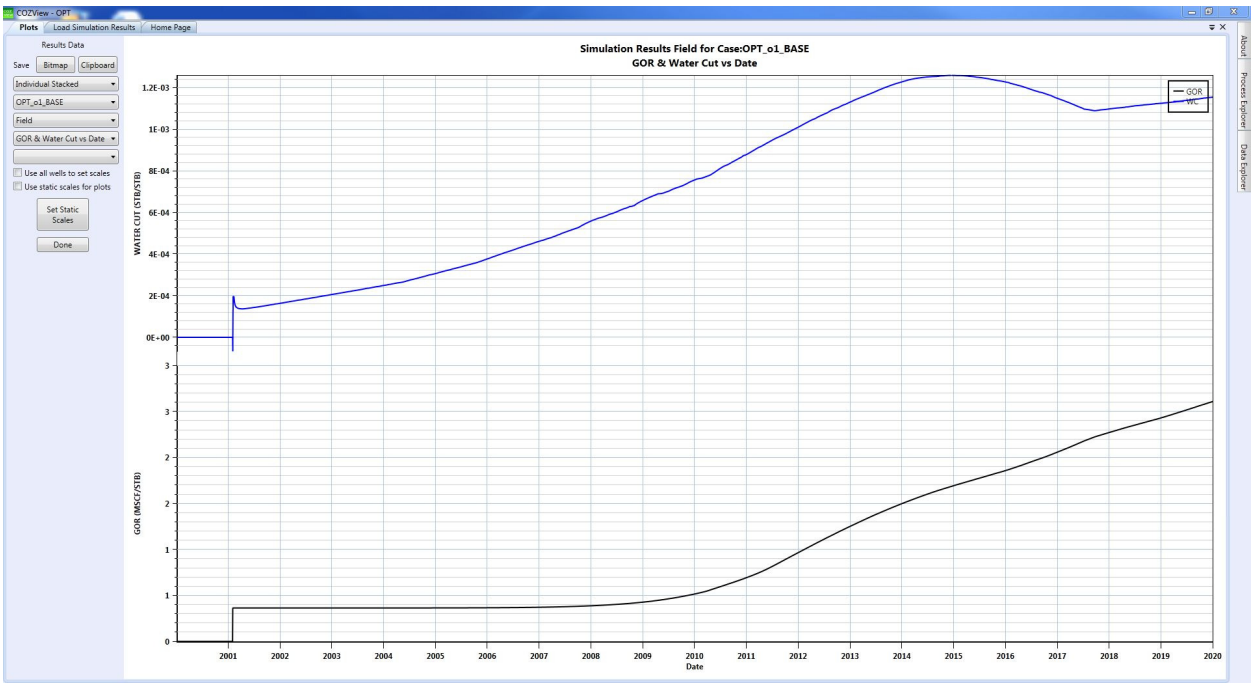
Selection of *Set Static Scales* will open a new window as shown below. The user can change the Minimum and Maximum values for each property as necessary.

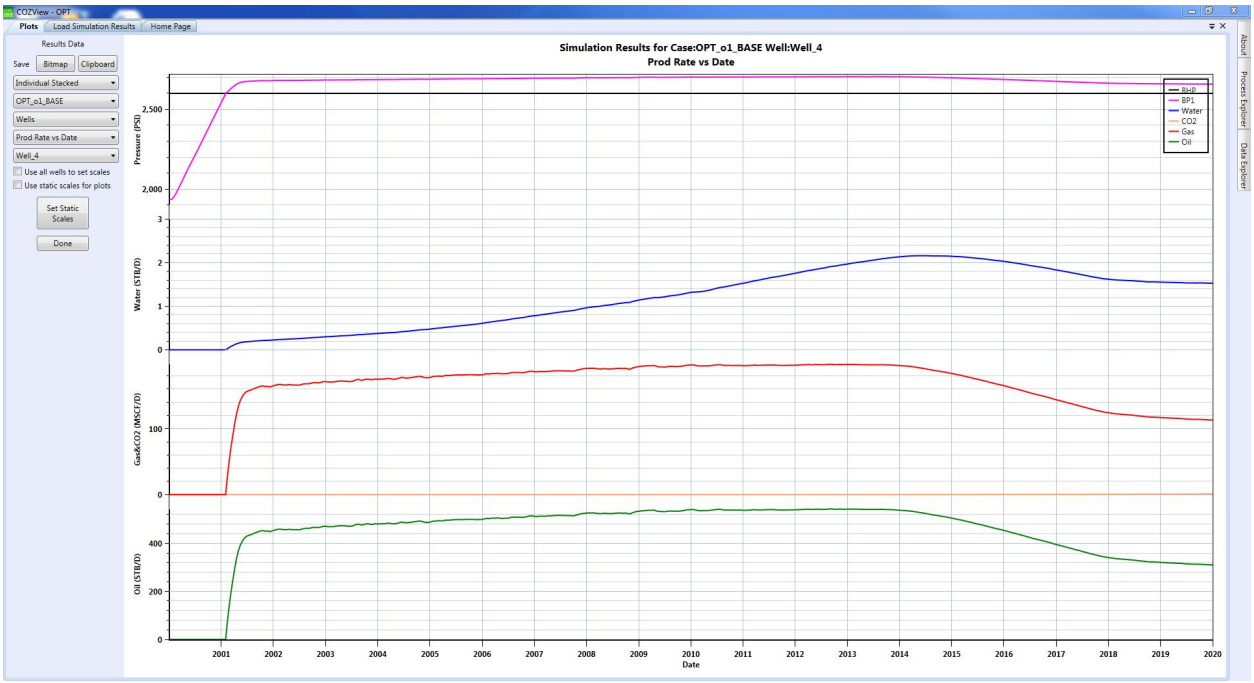


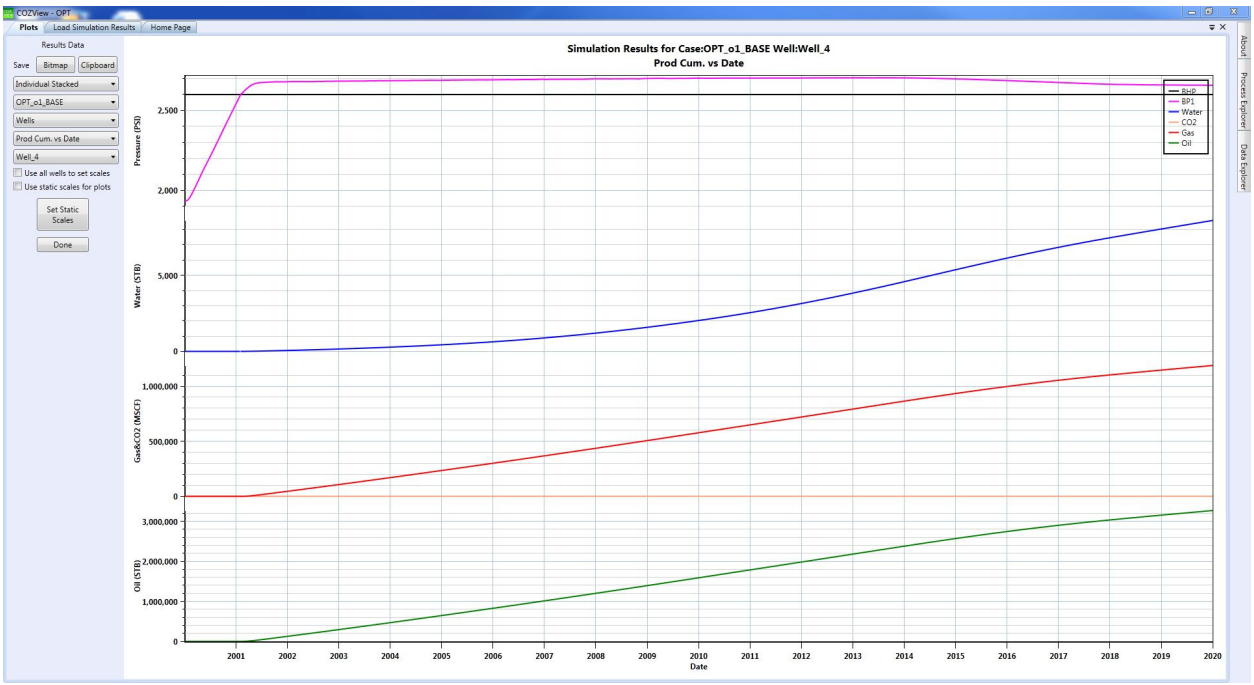
Selection of **Done** will save and close the *Plot Static Scales* window.

Some typical plots are shown below.

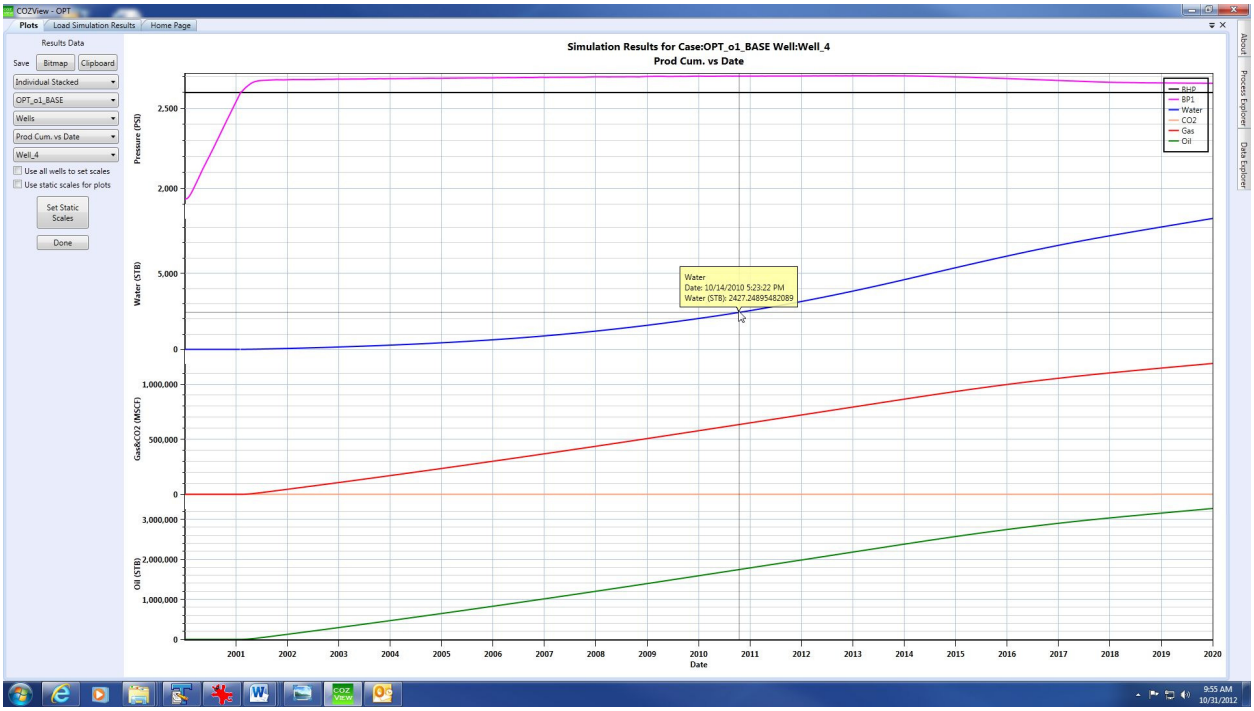

COZView - OPT
Plots
Load Simulation Results
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
OPT_o1_BASE
Field
Prod Rate vs Date
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
About
Process Explorer
Data Explorer
Simulation Results Field for Case:OPT_o1_BASE
Prod Rate vs Date
Avg Res Press
Water
CO2
Gas
Oil
Pressure (PSI)
Water (STB/D)
Gas&CO2 (MSCF/D)
Oil (STB/D)
Date


COZView - OPT
Plots
Load Simulation Results
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
OPT_o1_BASE
Field
GOR & Water Cut 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:OPT_o1_BASE
GOR & Water Cut vs Date
GOR
WC
WATER CUT (STB/STB)
GOR (MSCF/STB)
Date





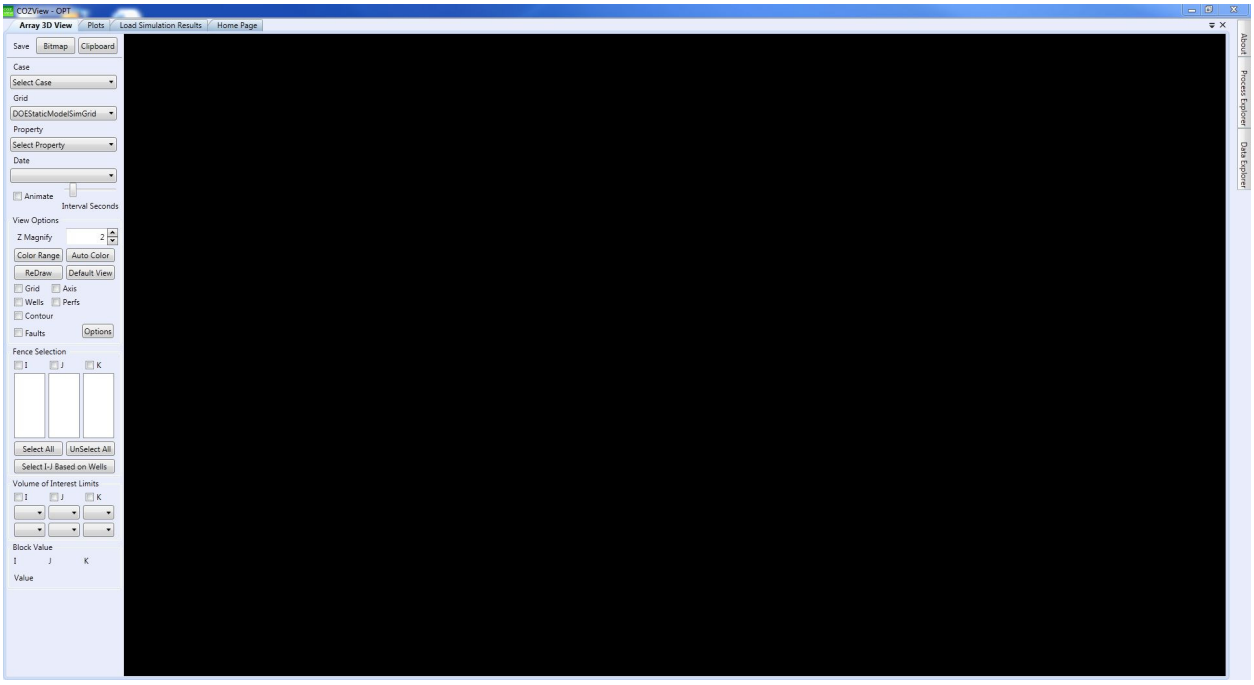
A unique functionality in COZView is the ability to assess a specific plot parameter value using the mouse. Placing the cursor on a specific plot trace and holding down the left button will display the value and date of the selected point. Continue holding down on the left mouse button and move the cursor to view other points on the same plot trace. The process can be repeated on other plot traces.



Any selected plot can be exported to a bitmap file for archiving by selecting the **Bitmap** button. Selection of the **Clipboard** button will place the plot image on the clipboard for pasting into a user selected document.

3.6.2 Array 3D View

Selection of *Array 3D View* displays a blank screen.



There are numerous simulation result map display controls in the panel on the left. The **Select Property** box will display a drop down menu of properties that are available for display.

The list of available arrays is shown below. The letter in front of each array name stands for D-data, I-initialization, and S-simulation result.

D-STRUCTURE: Structure of the reservoir

I-KRGMATRIX: Maximum relative permeability to gas in the Matrix

I-KROMATRIX: Maximum relative permeability to oil

I-KX MATRIX, I-KY MATRIX, I-KZ MATRIX: Absolute permeability's in X, Y and Z directions

I-NET-TO-GROSS: Net to Gross ratio of the reservoir

I-PHI MATRIX: Porosity

I-PORE VOL MATRIX: Pore volume (Cubic feet)

I-SORG MATRIX: Residual Oil Saturation to gas

I-SORW MATRIX: Residual Oil Saturation to water

I TRAN X MATRIX, I TRAN Y MATRIX, I TRAN Z MATRIX: Matrix transmissibility's in X, Y and Z directions

S-Miscibility: Oil Miscibility factor (0 to 1)

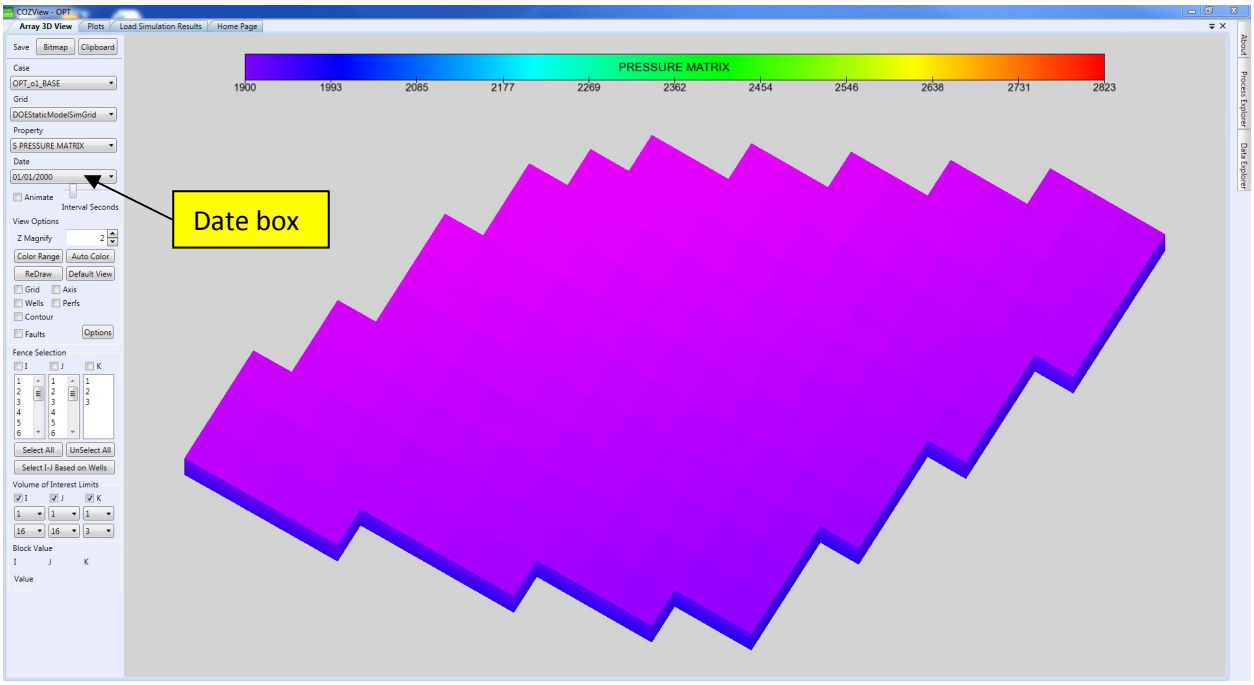
S-PRESSURE MATRIX: Reservoir Pressure

S-SATN-GAS MATRIX: Gas saturation

S-SATN-OIL MATRIX: Oil saturation

S-SATN-WAT MATRIX: Water saturation

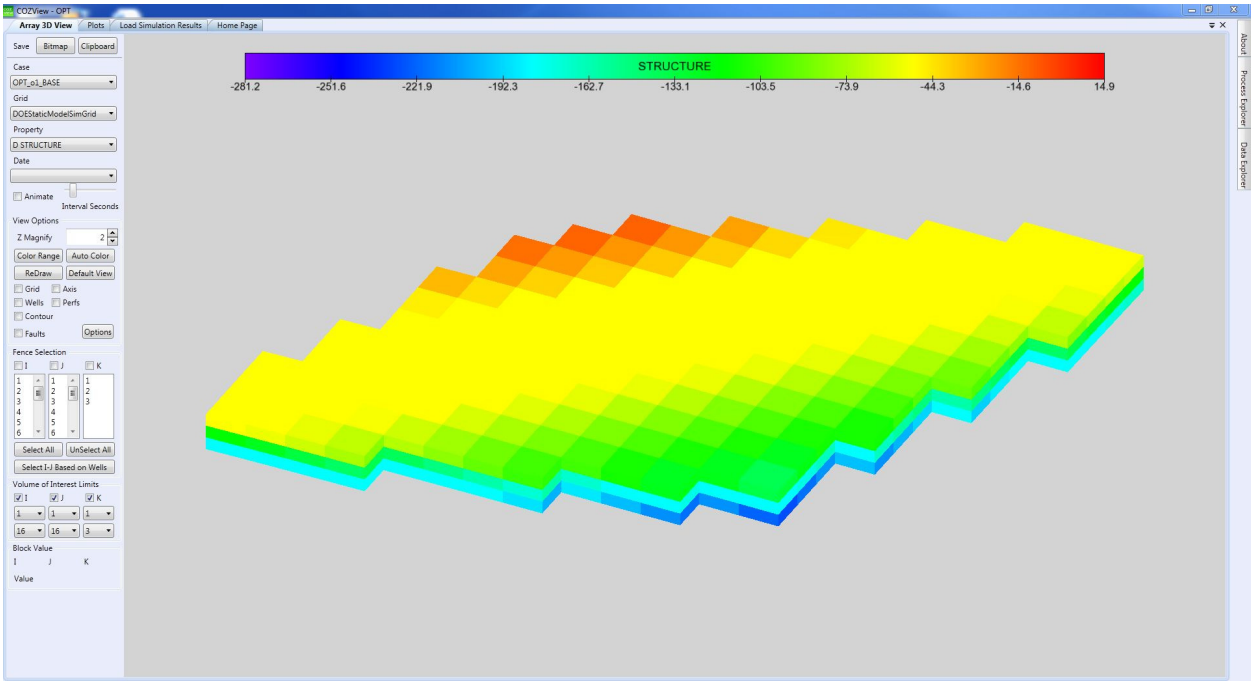
All properties when first selected will display in a high angle view. A color bar with a range scale is at the top of each property display. If the model has multiple layers, all layers will be displayed. The date of the property being displayed is shown in the date box. If multiple dates are available from the simulation run, the user may select the appropriate date.



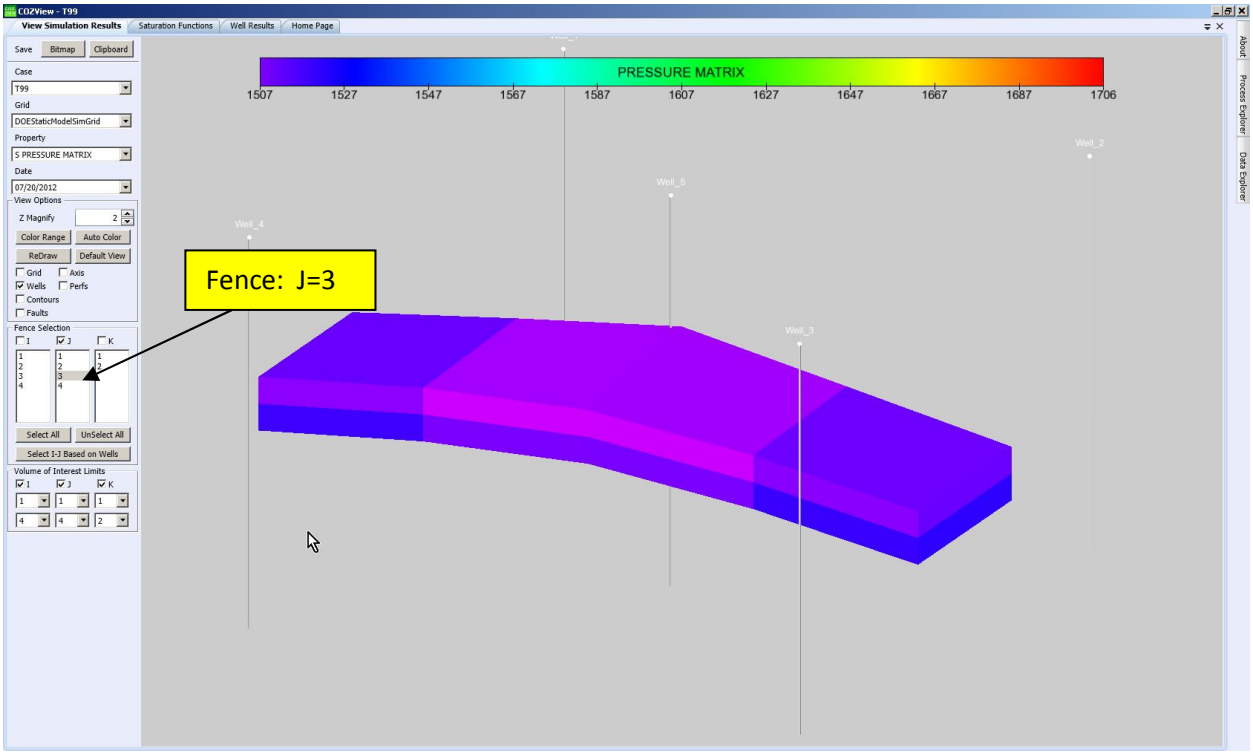
The pan, rotate and zoom operations with the mouse are functional in *Array 3D View*. Check boxes are available to display

Wells Grid Axis Perfs Faults Contours

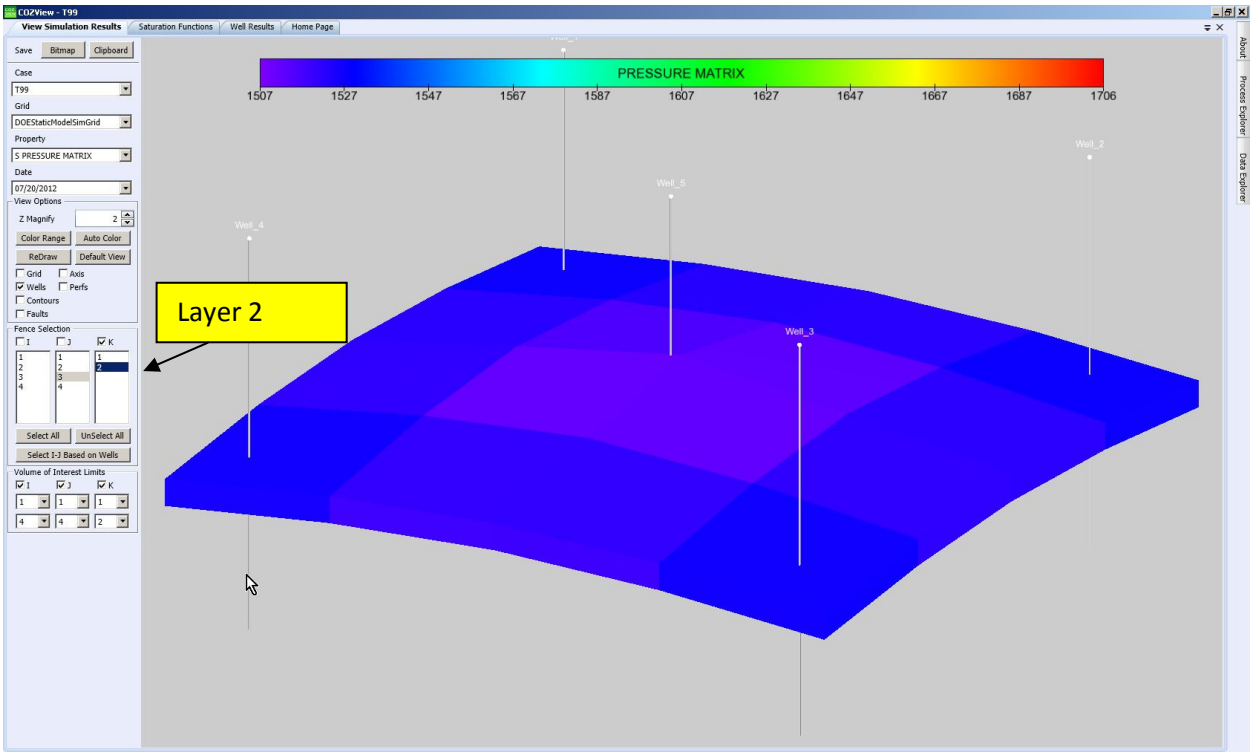
The contours will always be the structure top of the model.



Fence diagrams of any of the property displays can be created in the Fence Selection area. Checking the J box and picking row 3 will provide the display below

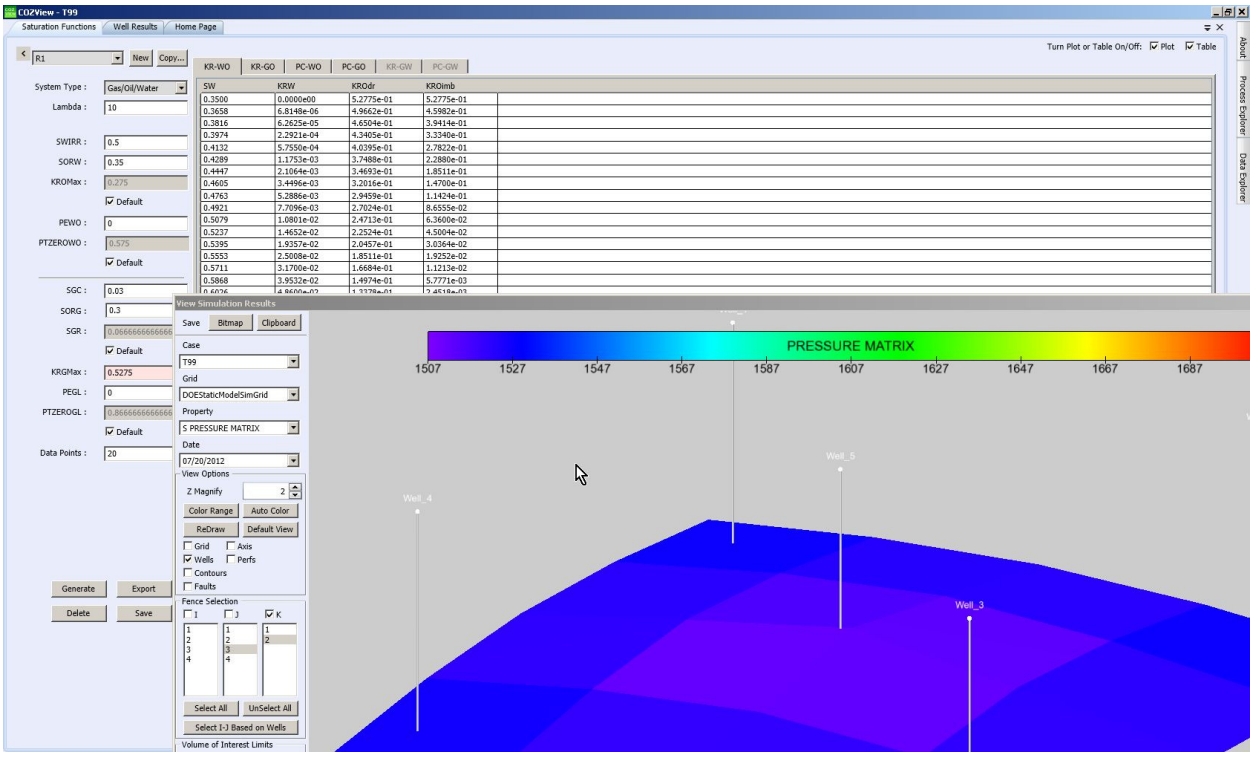


Picking the K box and 2 will display the layer 2 property below.



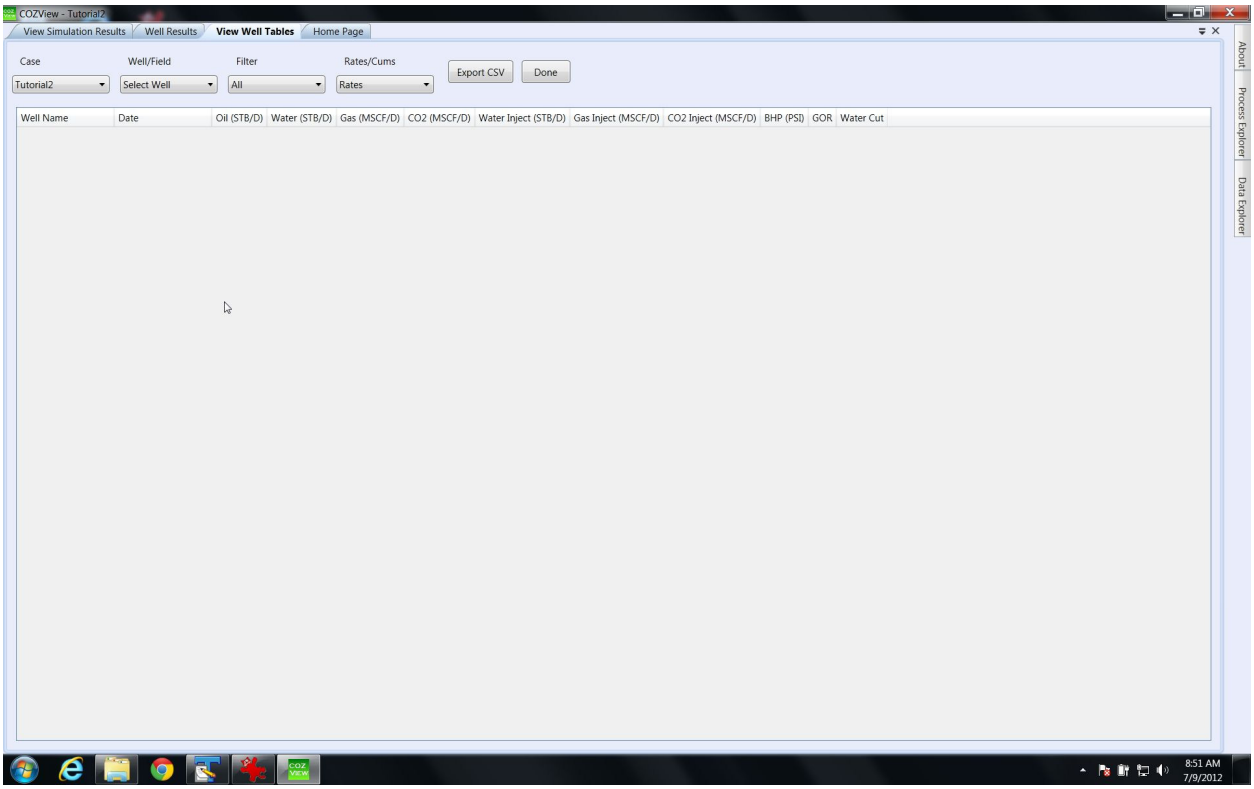
The range for the color scale can be changed by selecting the **Color Range** button. The maximum and minimum range values can be changed. This change will be applied to the current property only. It will not be saved upon selection of a different property.

The ability to view separate windows by selecting and dragging a tab to another area of the screen can be very useful when reviewing simulation results. Below the *View Maps* window has been dragged to a separate area; the *Saturation Function* window is also show as it was the last window opened prior to the *Array 3D View* window. If multiple monitors are available these views can be placed on separate monitors.



3.6.3 Tables

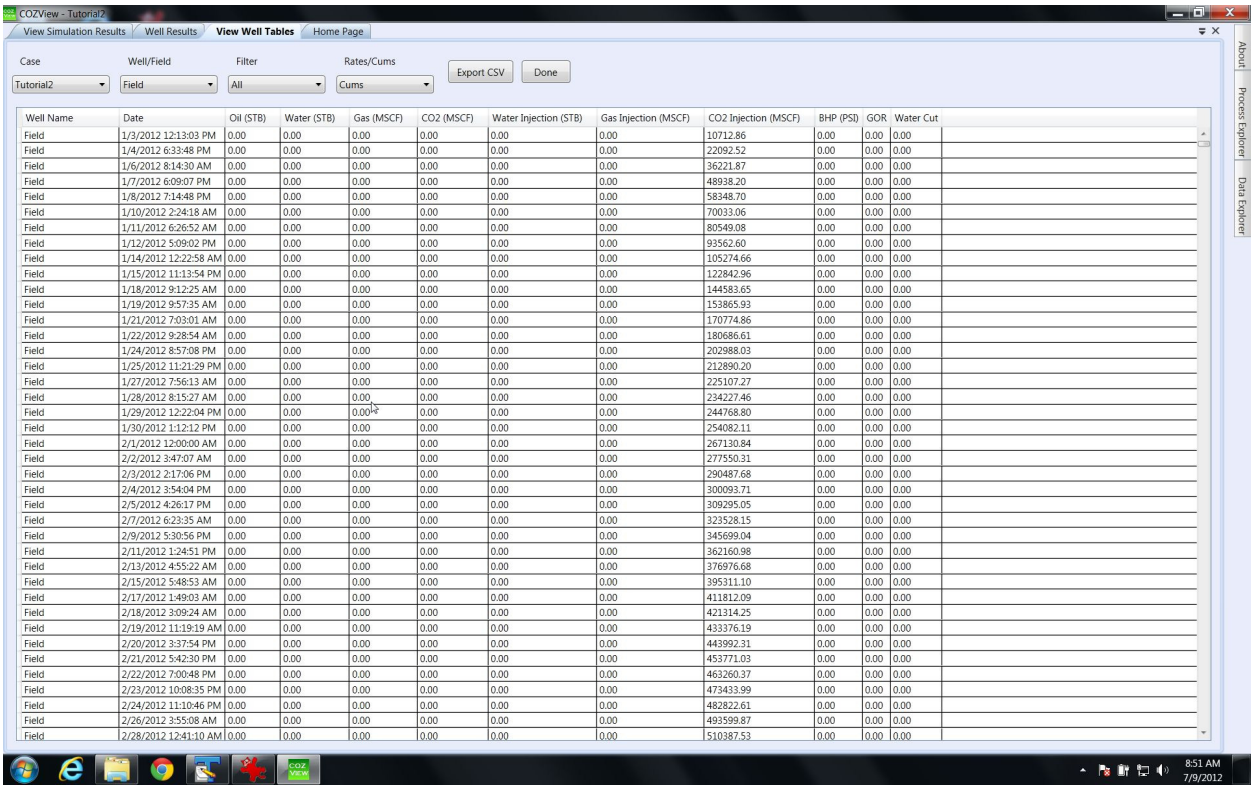
The production/injection (rate and cumulative) and bottom hole pressure simulation results at the well and field levels can be displayed in the *Tables* menu. Upon selection the initial screen is blank.



The user can select the relevant Project (Case) and the well or field data required from drop down menus. Field results can be displayed independent of the well results or with the well results. Individual well results can also be displayed. Any selected table of results can be exported to a .CSV file by selecting the **Export CSV** button. Field results are shown below.

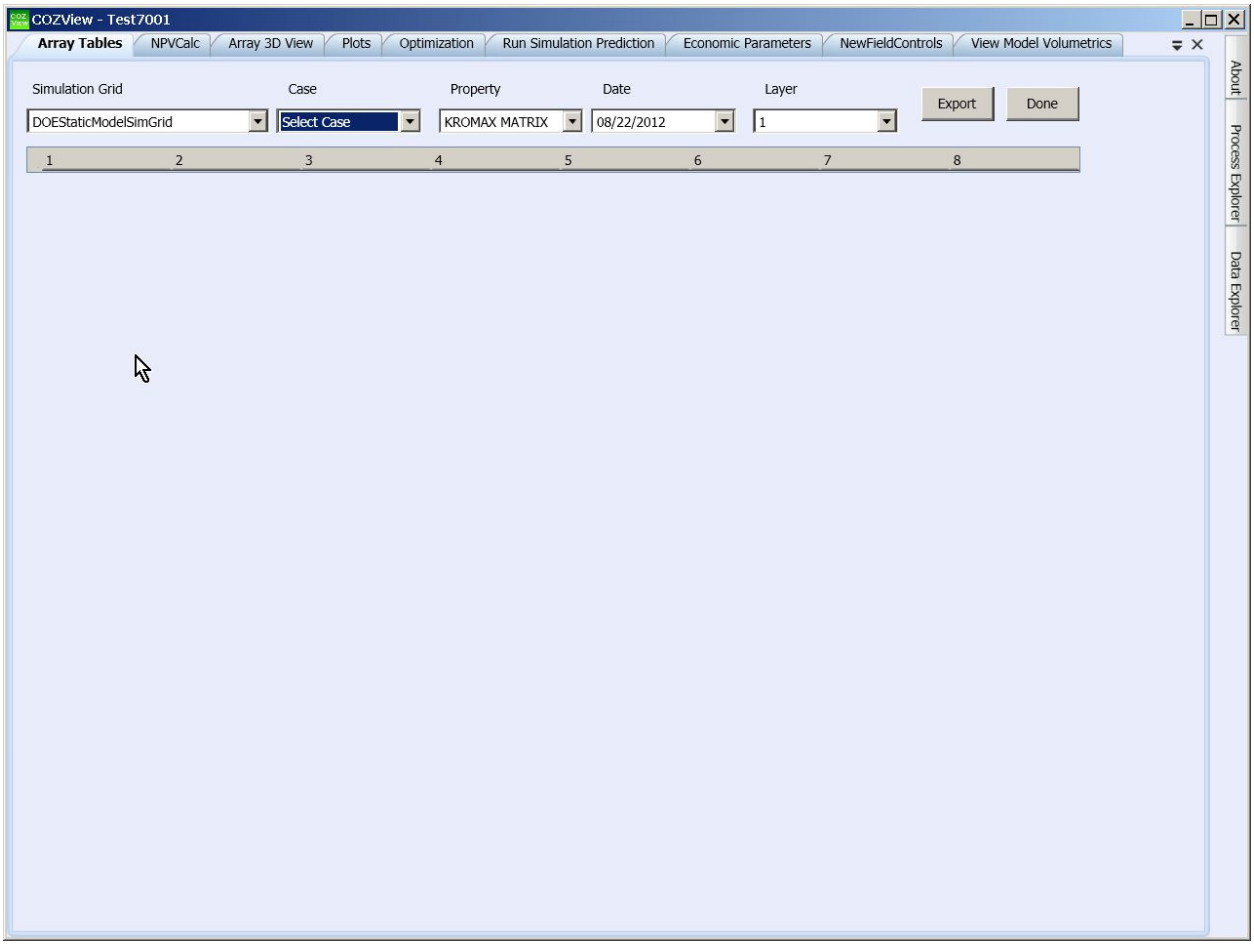
Only field results are available for optimization cases.

Selection of **Done** closes the screen.



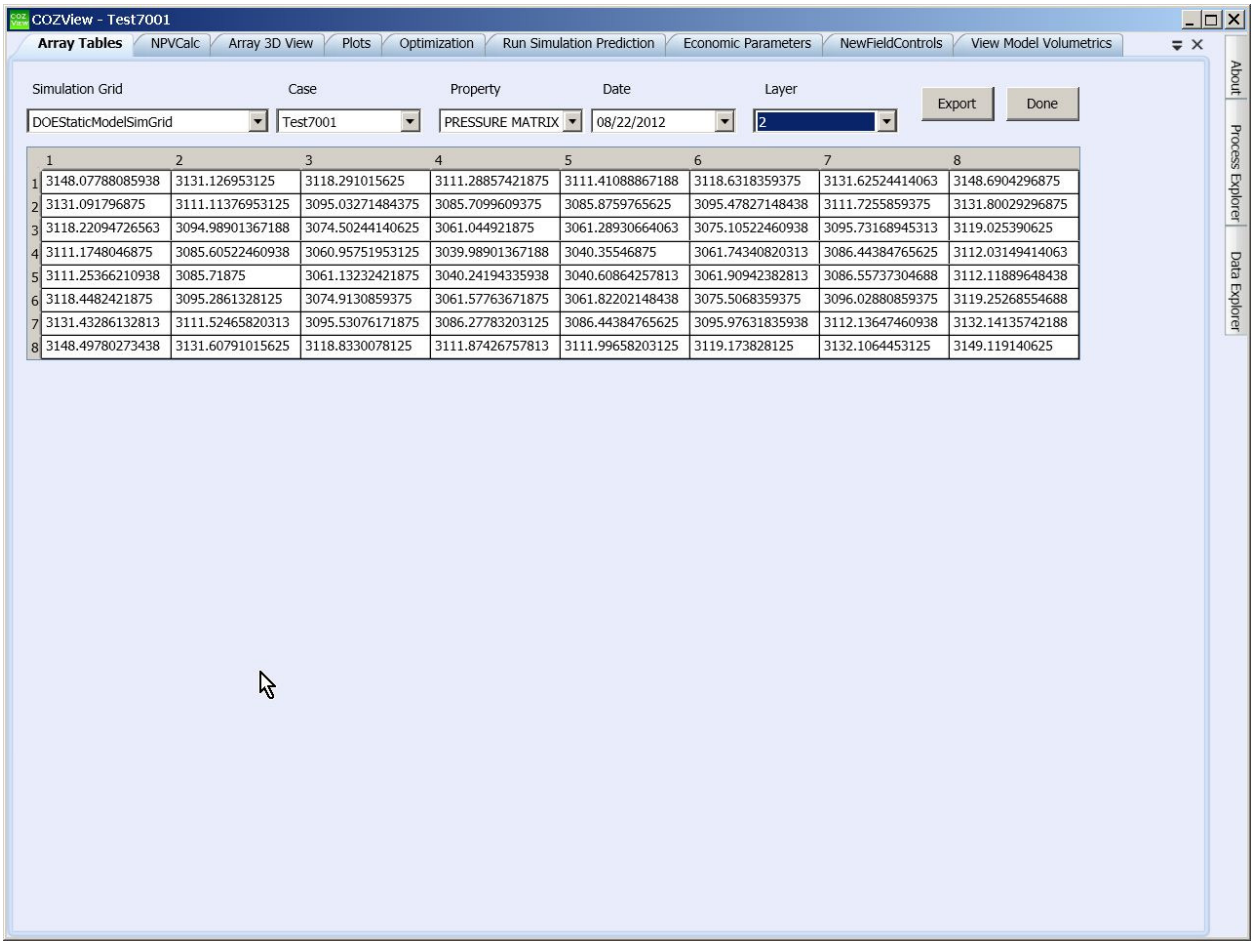
3.6.4 Array Tables

Selection of *Array Tables* in the **Simulation Results** area allows the user to display the array values at selected time steps during the simulation run. The initial screen is shown below.



The user can select the simulation case, the array property, the date and the layer to display. The display below shows the pressure in each grid cell in layer 2 at 08/22/1012 of the case Test7001 simulation run.

This information is not available for optimization cases.



	1	2	3	4	5	6	7	8
1	3148.07788085938	3131.126953125	3118.291015625	3111.28857421875	3111.41088867188	3118.6318359375	3131.62524414063	3148.6904296875
2	3131.091796875	3111.11376953125	3095.03271484375	3085.7099609375	3085.8759765625	3095.47827148438	3111.7255859375	3131.80029296875
3	3118.22094726563	3094.98901367188	3074.50244140625	3061.044921875	3061.28930664063	3075.10522460938	3095.73168945313	3119.025390625
4	3111.1748046875	3085.60522460938	3060.95751953125	3039.98901367188	3040.35546875	3061.74340820313	3086.44384765625	3112.03149414063
5	3111.25366210938	3085.71875	3061.13232421875	3040.24194335938	3040.60864257813	3061.90942382813	3086.55737304688	3112.11889648438
6	3118.4482421875	3095.2861328125	3074.9130859375	3061.57763671875	3061.82202148438	3075.5068359375	3096.02880859375	3119.25268554688
7	3131.43286132813	3111.52465820313	3095.53076171875	3086.27783203125	3086.44384765625	3095.97631835938	3112.13647460938	3132.14135742188
8	3148.49780273438	3131.60791015625	3118.8330078125	3111.87426757813	3111.99658203125	3119.173828125	3132.1064453125	3149.119140625

The selected array results can be exported to a .CSV file if desired.

3.6.5 Calculate NPV

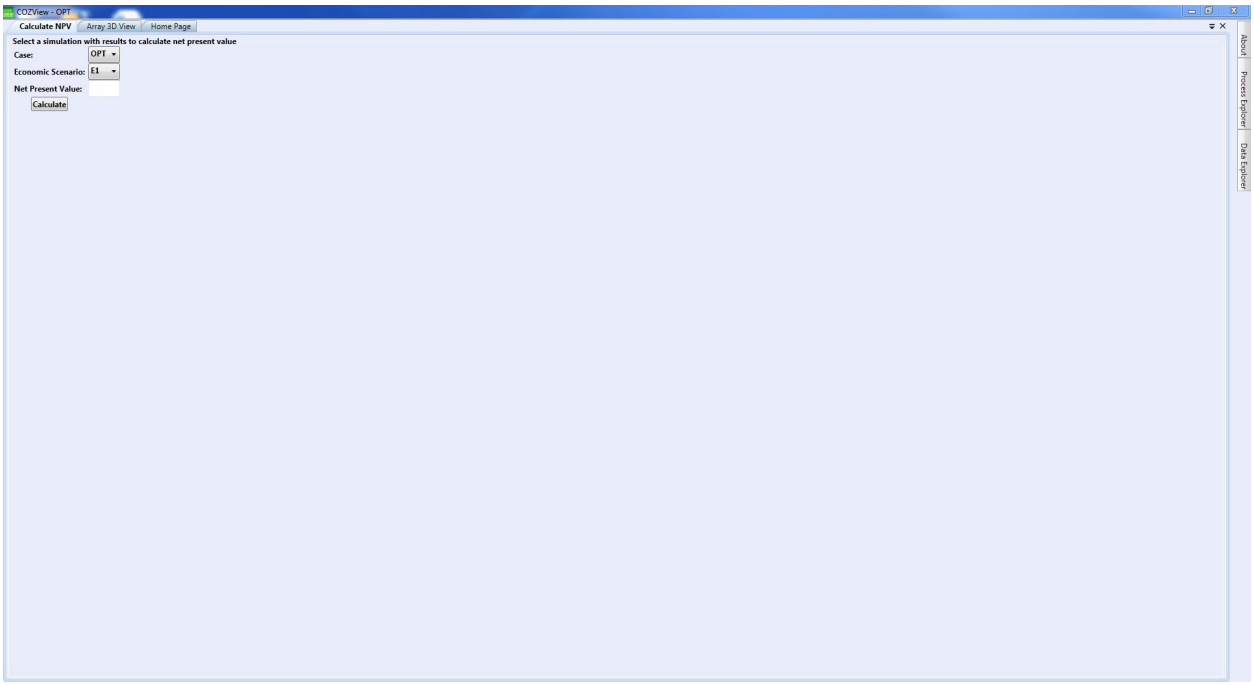
The net present value (NPV) criterion is considered as a standard measure of investment. It is the total present worth of future cash flows. The NPV method is used extensively for decision making regarding investments. It is used to realize the time value of money for approval of long term projects.

$$NPV(i) = \sum_{n=0}^{N} \frac{F_n}{(1+i)^n} - Capital, OperationalExpenses$$

F_n is the net cash flow, i is the rate of interest or the discount rate, n is the time period and N is total time. Each cash flow is discounted to the present value and sum of all discounted cash inflows gives the Net Present Value.

To calculate NPV in **COZView**, the user is required to define an Economic Scenario. Please see Section 3.5.3 for defining Economic Scenarios.

As soon as the simulation run is completed, the user can calculate NPV under *Process Explorer, Simulation Results*, *Calculate NPV.* Select the case and the Economic Scenario.



The user can also define a New Economic Scenario and use the simulation result to calculate a new NPV without rerunning the simulation case.

3.7 Optimization

The optimization functionality allows the user to determine the maximum net present value (NPV) for a specified prediction case, range of Field *(Facility)* Controls and set of economic parameters.

The optimization process attempts to establish the best combination of the Field Control parameters to maximize the NPV. A minimum of 1 and a maximum of 7 Field Control parameters can be varied in the optimization process. During the optimization process artificial neural network and genetic algorithm technologies are used to vary the appropriate Field Control parameters within a range of values defined by the user and simulation runs are made with those values. The optimization process designs runs with the objective of maximizing the NPV for the prediction case.

The economic parameters assigned to a specific Scenario name in the Economic Parameters section are used in the optimization process.

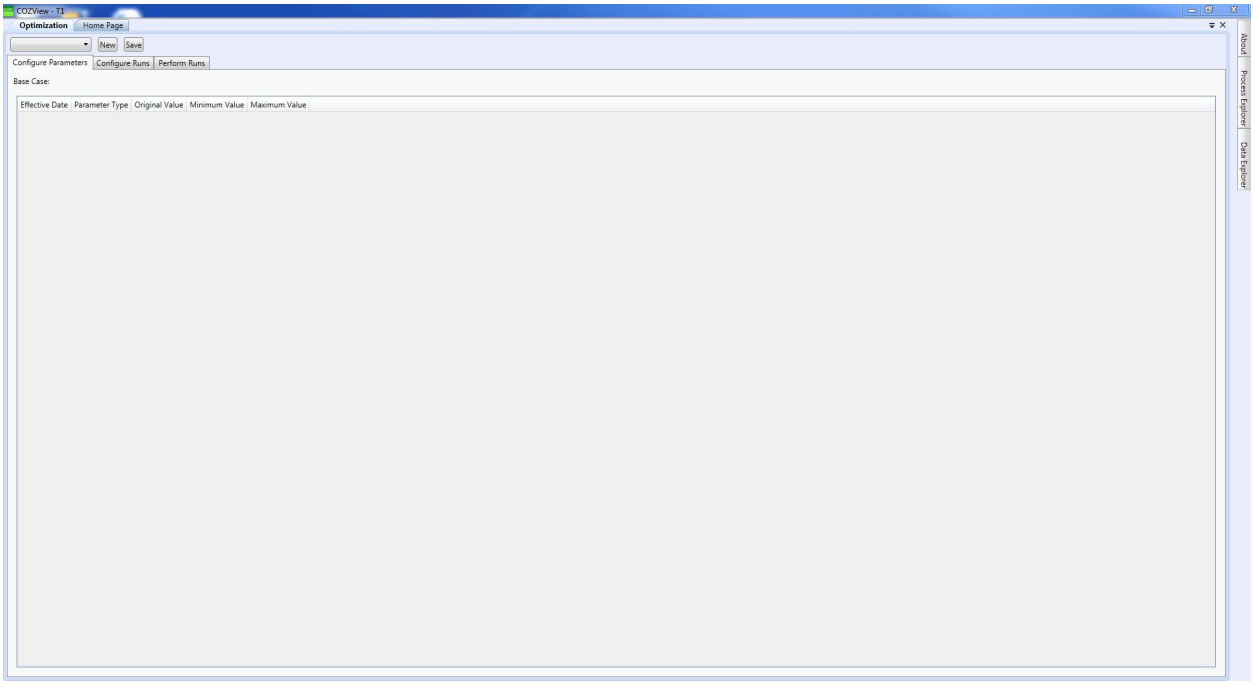
It is recommended that the user submit the Base Case simulation run as a normal prediction case before utilizing the optimization process. This will assure that the various simulation inputs are consistent with the user's wishes and the run progresses properly. This will also give the user information on how long a single simulation run requires to process.

The user can move between tabs in COZView during the optimization process. **However, the user should not close the Optimization tab, cancel any simulation run or close COZView while the optimization process is in progress. It is also recommended that the user does NOT make changes to any of the data used by the optimization process while it is in progress.** This will result in a loss of data and/or an incomplete optimization process.

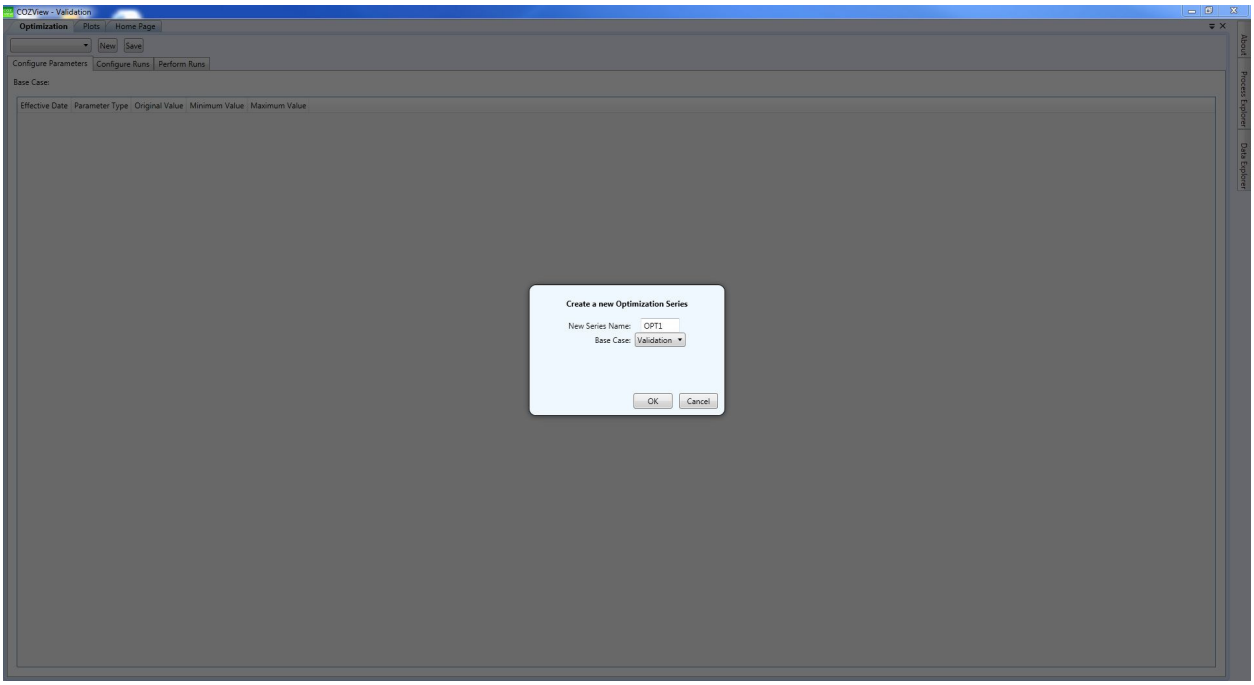
Only field results calculated by **COZSim** are loaded into **COZView** for optimization cases. **No well results or simulation result arrays are loaded for optimization cases.**

Select **Optimization** from the **Process Explorer** section. Three internal tabs are shown in this section – *Configure Parameters*, *Configure Runs*, and *Perform Runs.* The user will be in *Configure Parameters* upon initial entry to the **Optimization** section.

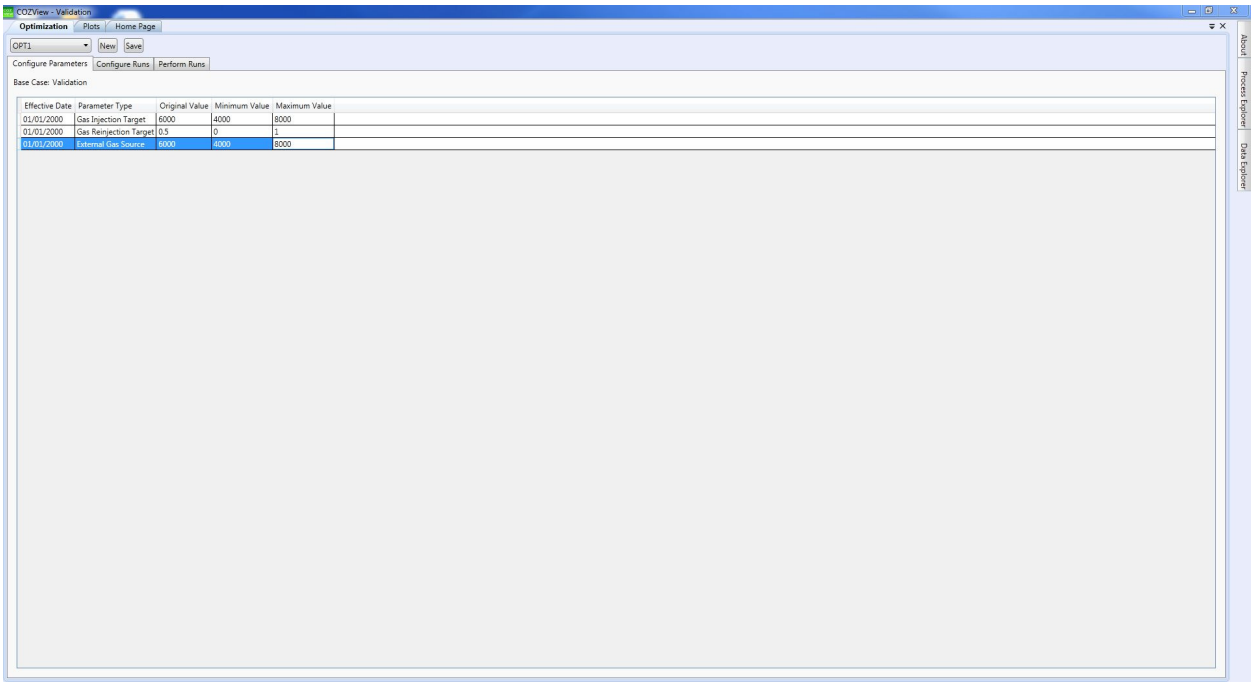
3.7.1 Configure Parameters



Select **New** to assign a *Series Name* to the optimization cases to be run. Select the *Base Case* that is the starting point for the optimization process from the drop down menu.



A table of the previously specified Field/Facility parameters and their original values will be displayed. These are the parameters available for investigation in the optimization process. The user can specify a range (minimum and maximum) over which each parameter's value can be varied during the optimization process. The user can choose to not vary a particular parameter by not providing minimum and maximum values.



The optimization process has a predefined sequence of simulation runs that will be made as it attempts to maximize the NPV. The default number of runs and the minimum and maximum number of runs in the optimization process are based on the number of Field Control parameters being varied. **COZSim** uses the default number of simulation runs for the optimization process, unless the user overrides the defaults values.

Parameters Varied	Default Number of Simulation Runs	Minimum Number of Runs	Maximum Number of Runs
1	26	23	40
2	26	23	54
3	26	23	70
4	32	29	86
5	38	35	102
6	44	41	118
7	50	47	134

The optimization process generates three types of simulation runs which are identified as Orthogonal runs (ORTH), Cluster runs (CLST), and Optimization runs (OPT).

3.7.2 Configure Runs

Select *Configure Runs* upon completion of the *Configure Parameters* section. This section allows the user to define

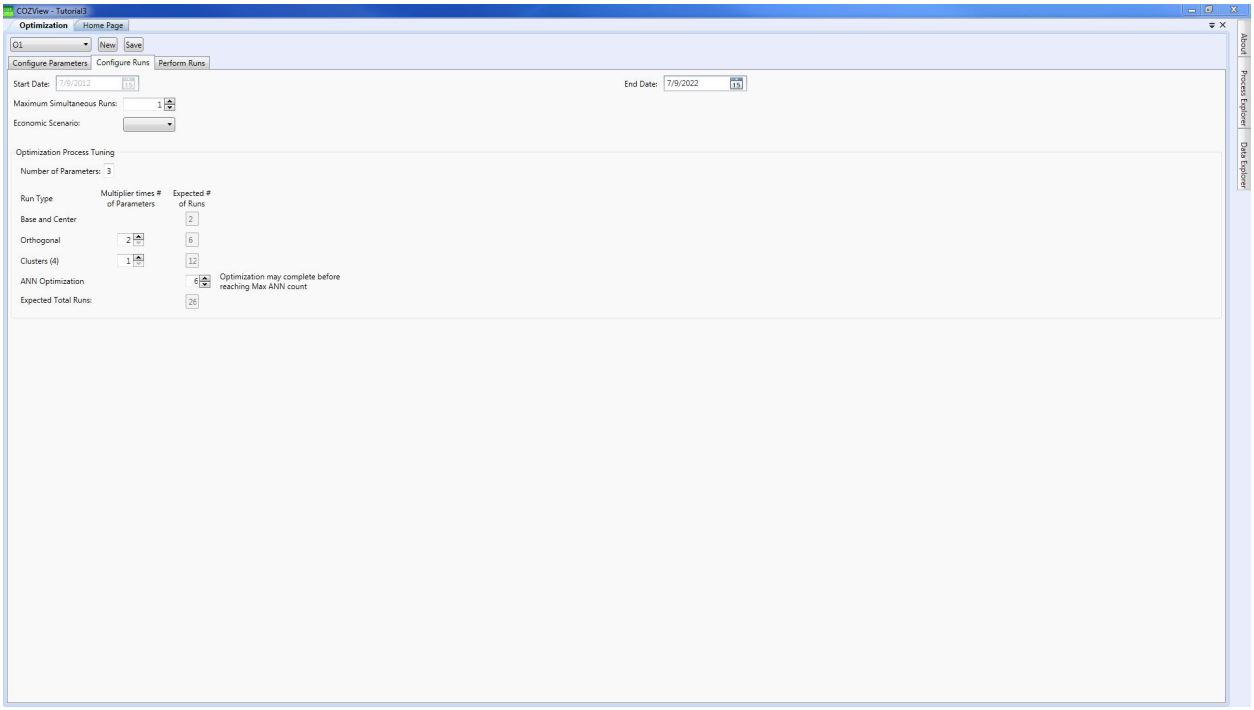
- the prediction case duration or End Date,
- the maximum number of simultaneous runs to allow during the optimization process, and
- the Economic Scenario (previously defined) to be used.

This section also identifies the default number (multipliers times # parameters) of each type of simulation run to be made (ORTH, CLST, OPT). The user may change these default values. **However, doing so may adversely impact the optimization process results.**

The ORTH simulation runs are independent of each other and can run simultaneously. The number of ORTH simulation runs is generally 2 x # of varied parameters (minimum of 6). The number of CLST simulation runs is generally four groups of 1 x # of varied parameters (minimum of 12); each group can run simultaneously, but each group must complete before the next group can start. The number of OPT simulation runs is 6. The OPT simulation runs are dependent on all prior runs. Each OPT run must complete before a new OPT run can start. In addition to these optimization process designed simulation runs, there are two additional runs in the process.

The Optimization process also runs the Base and the Center case. The user is allowed to change the number of ORTH, CLST and OPT runs in the boxes.

Run Type	Multiplier times # of Parameters	Expected # of runs
Base and Center		2
Orthogonal	2	6 (for 3 parameters)
Cluster (4)	1	12 (for 3 parameters)
ANN Optimization		6



Specify the *End Date* for the simulation runs.

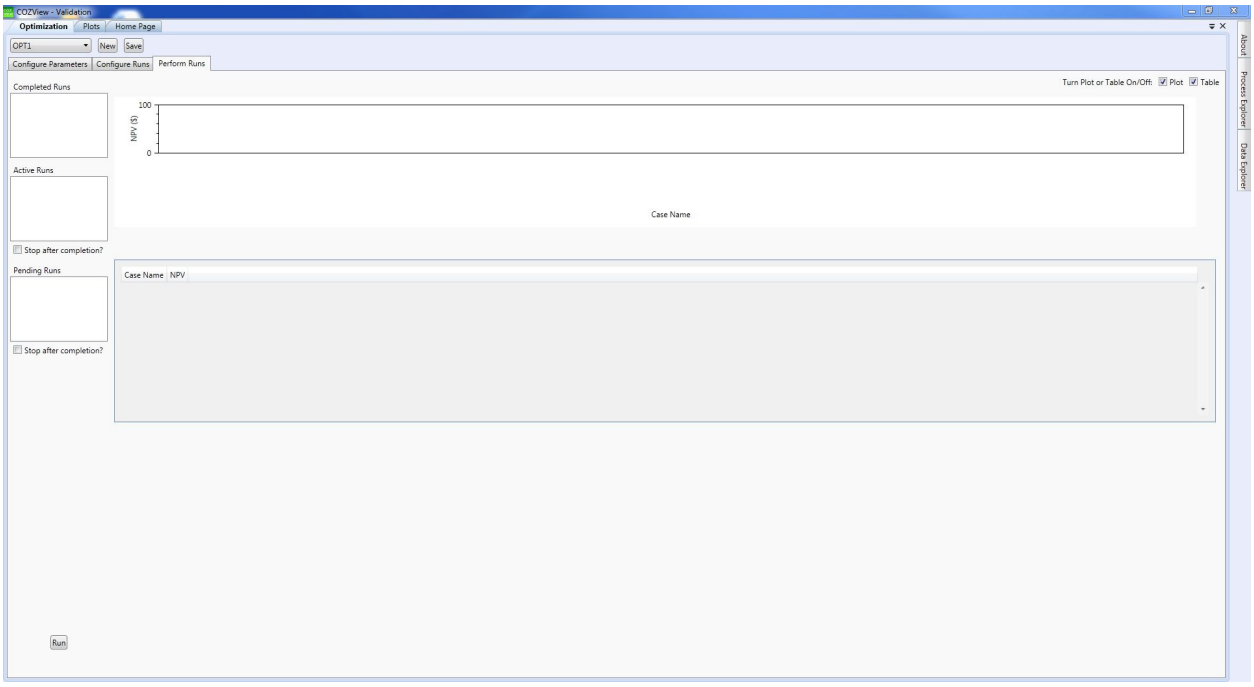
The optimization process is capable of processing multiple simulation runs simultaneously depending on where in the predefined run process the runs are being made. If the user has a multi-core CPU, simultaneous runs can be made with little processer time degradation. Use of this feature can greatly speed up the overall optimization process as many simulation runs may be required. Typically this number can be between 2 and 4.

Specify the *Economic Scenario* from the drop down menu to use in the process. Select **Save** before leaving this section.

3.7.3 Perform Runs

Select *Perform Runs* upon completion of the *Configure Runs* section. This section is used to launch the optimization process simulation runs. This is done by selecting **RUN**.

The screen will provide information about the simulation runs that have been *Completed*, are *Active* (in progress) and *Pending* (waiting to run) on the left side of the screen. Pending Runs are only those that have been designed at that point in time. New runs may be designed as the process progresses. The Simrunner window will appear for each active simulation run.

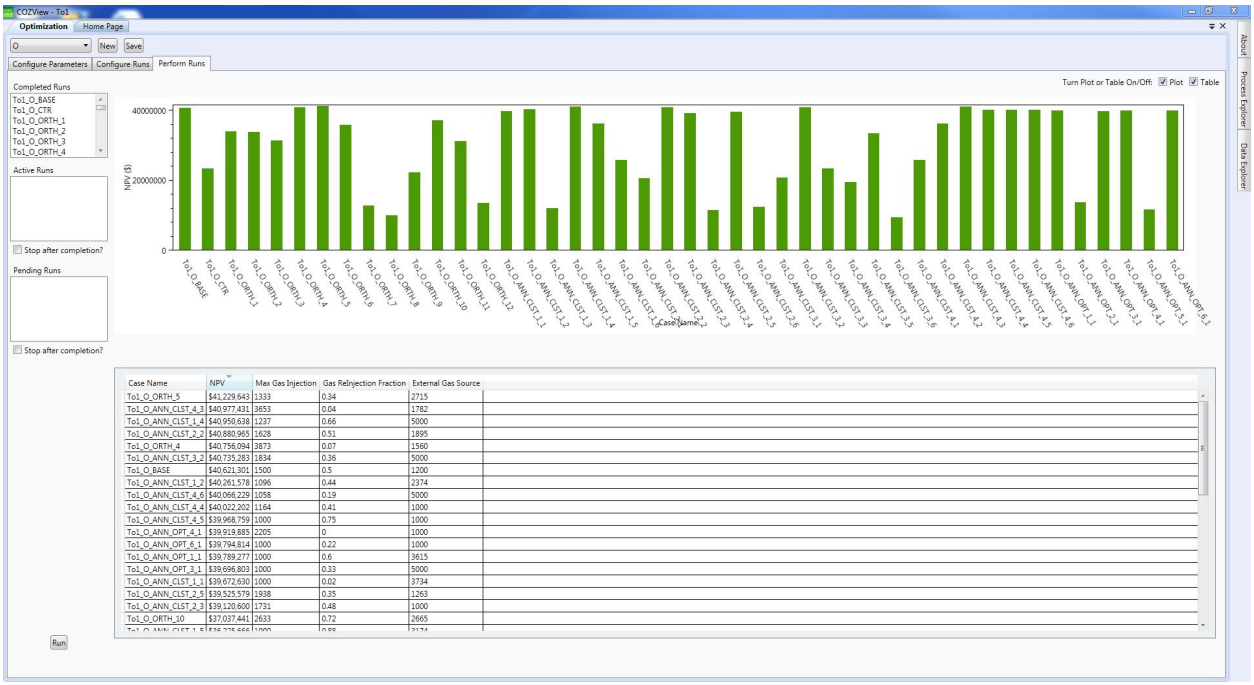


As a simulation run completes, a small window will appear notifying the user that the results of the completed simulation run are being loaded. Once the results are loaded a bar chart will display the calculated NPV for the case. The NPV is also displayed in the table. It should be noted that the optimization process does not necessarily find the maximum NPV case in a sequential process; rather multiple simulation runs designed by the process ensure that a maximum NPV is realized by the end of the process. A left click on any of the bars in the chart will display the calculated NPV value for that case.

Plots and Tables of the simulation results at the Field level only are available in the Simulation Results section once a run is completed.

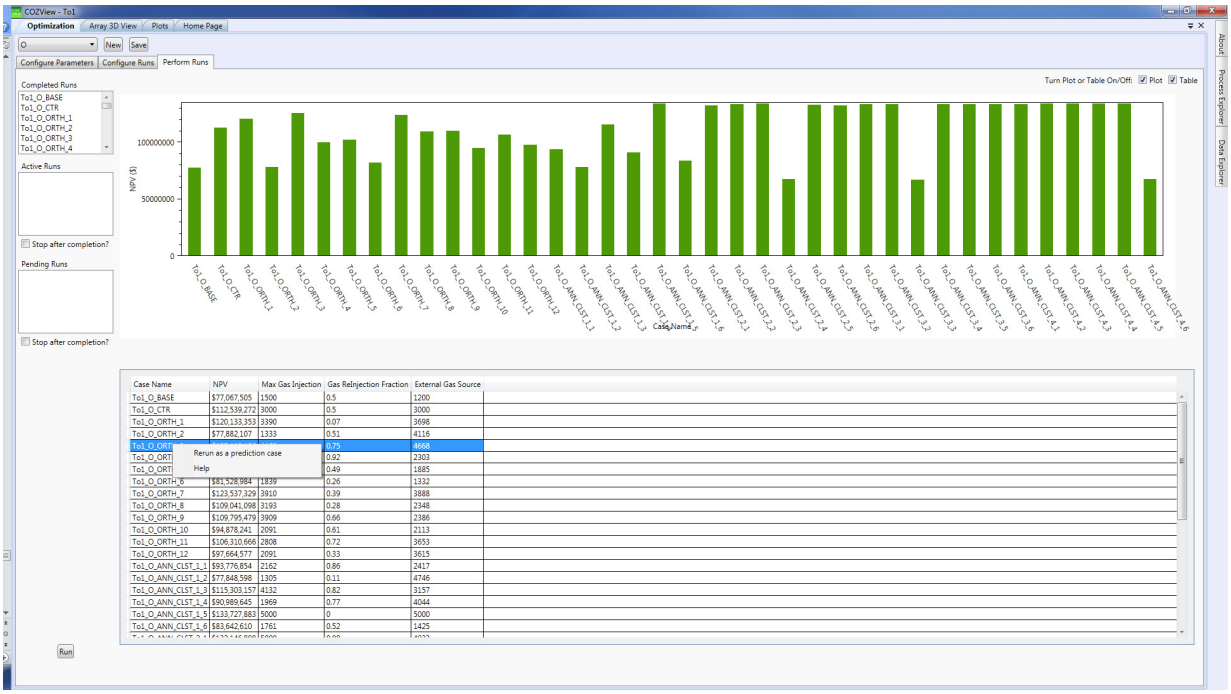
When the Optimization process is completed, the *Perform Runs* window should be similar to the figure below.

The initial order of cases in the table is based on when the case is completed. A left-click on any of the column headers in the table will sort the cases in ascending or descending order of the selected column.



Since the Optimization runs will only have saved field plots and not individual well plots or arrays, the user can select a Case and rerun it as prediction case. The prediction run will provided individual well plots and result arrays.

The user can right click on any case in the optimization table and select *Rerun as Prediction Case*. A new simulation run with the name *Old Case Name_Rerun* will be added to the database. All result plots (field and well) and result arrays will be available for viewing from the *Simulation Results* area.



3.7.4 Case Comparison Plots

The results of different optimization cases can be compared using *Case Comparison Plots* under the *Optimization* tab in the Process Explorer.

Selection of *Case Comparison Plots* provides a plot template and no simulation results

The **Optimization Case Results Data** area on the left contains five selection boxes. The boxes are:

- Base Case
- Optimization Series

  (Note that the user is allowed to run multiple optimization series with the same base case.)
- Child Cases (Ordered by NPV)

  (These are cases run in the optimization process – ORTH, CLST, OPT.)
- Rates/Cumulative
- Data to show

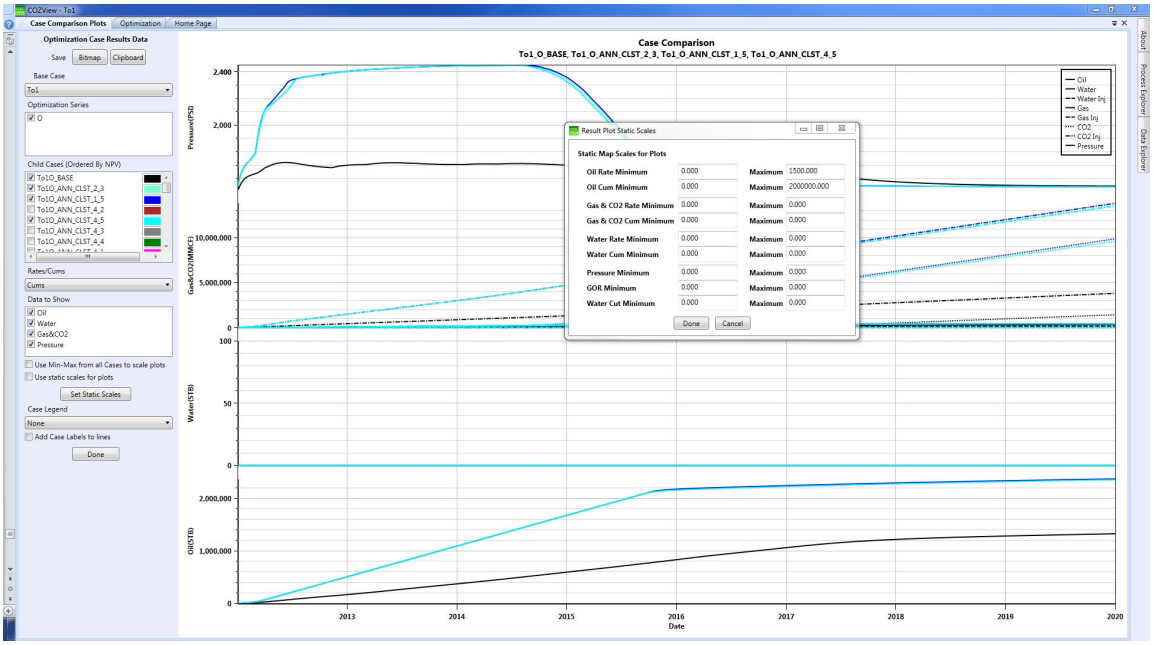
    Oil

    Water

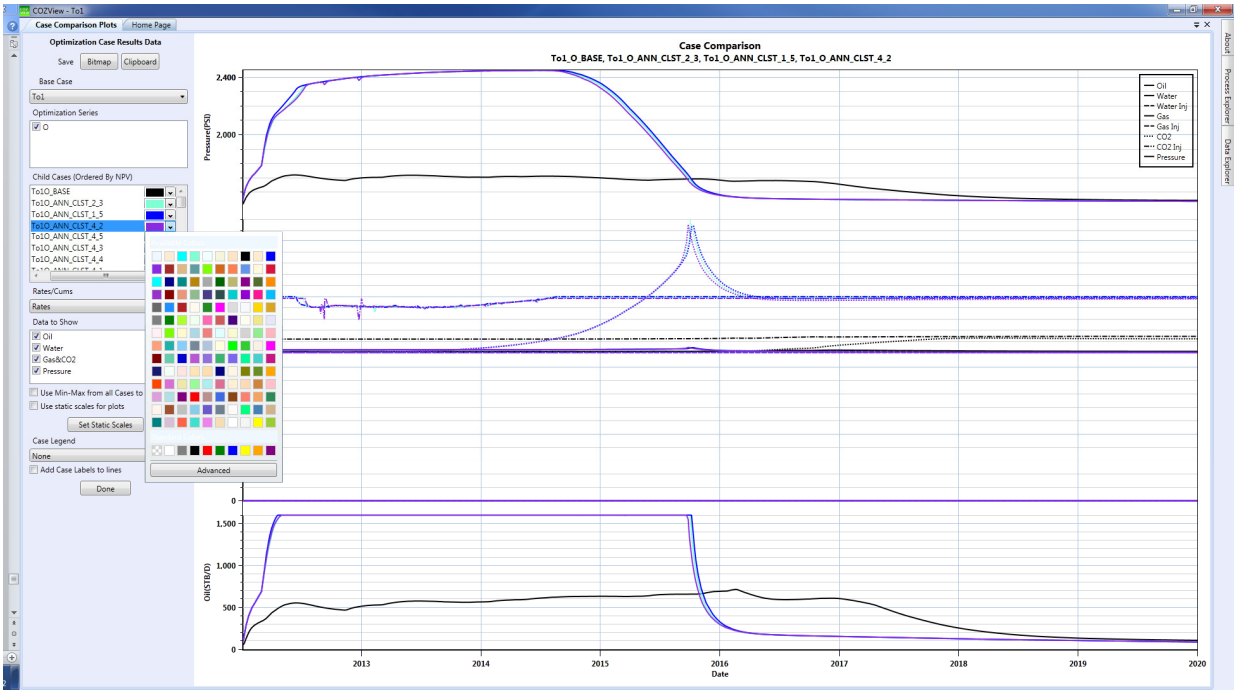
    Gas & CO2

    Pressure (Field Average Reservoir Pressure)

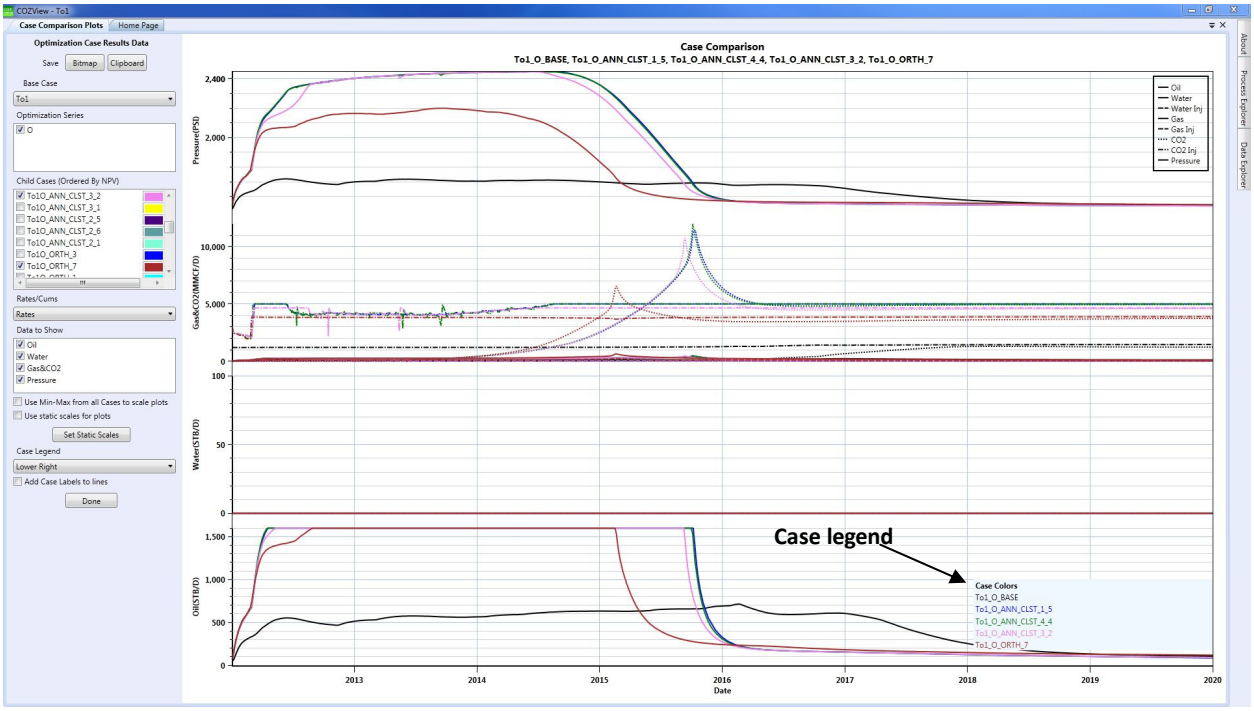
The Plot Setup in the *Case Comparison Plots* is very similar to the Plot set up in the *Simulation Results* under *Process Explorer* (Section 3.6.1). The Plot Setup has two options (i) User can check the box "*Use Min-Max from all Cases to scale plots".* (Selection of this box will automatically control the scales X and Y axis using minimum and maximum values of the property from all cases.) (ii) User is allowed to change the scale (X and Y axis) for each plot manually by using *Set Static Scales* button and selecting *"Use static scales for plots".*



COZView automatically assigns colors for each child case. However the user is allowed to change the color for each case. The color bar for each case is on the right side of the Child Cases Box.



The *Case Legend* can be selected to be at four different places on the plot (i) Lower right, (ii) Upper right, (iii) Lower Left and (IV) Upper left. Selection of the box "*Add Case Labels to lines*" will add case names to each plot curve.



The **Done** button for the *Plots* closes the *Case Comparison Plots* window.

4 Data Explorer

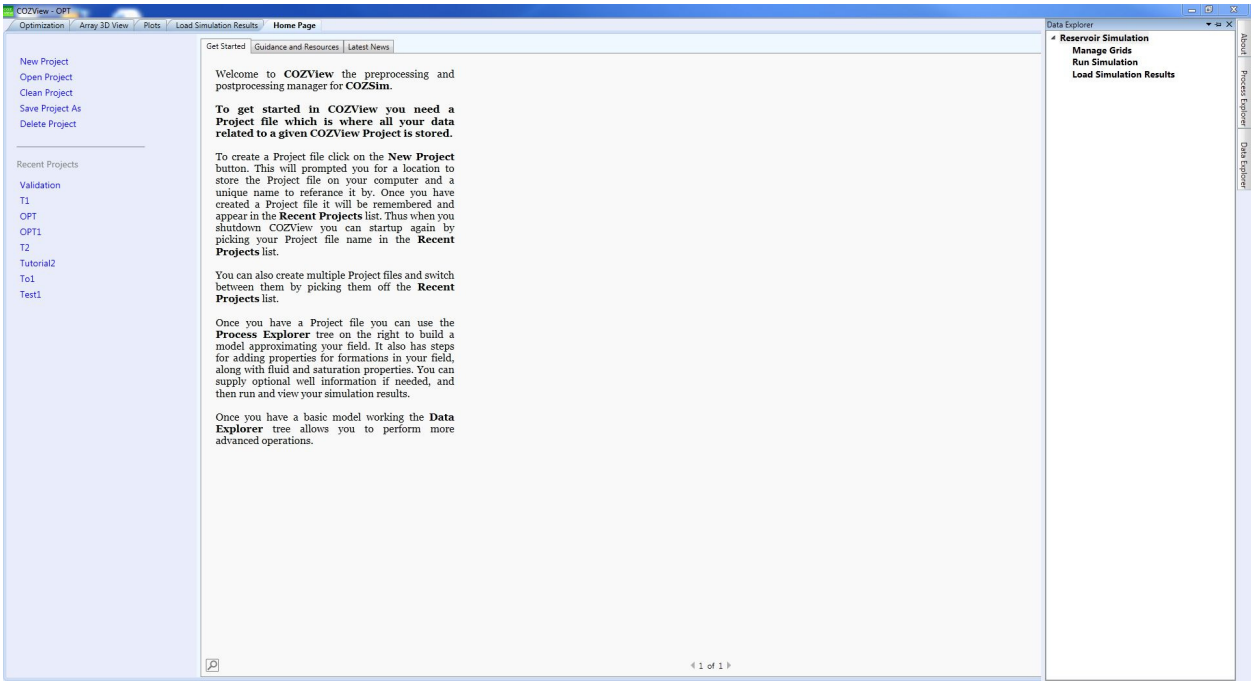
Data Explorer is designed to aid the user with some functionalities not typically required in the use of **COZView**. These are associated with submitting simulation runs and loading simulation results "outside" of the normal **COZView** user interface.

This has the benefit of allowing an advanced user to manually edit the **COZSim** input data file and run the simulation without going through the necessary steps in the Process Explorer.

In addition, past simulation results or simulation results that did not successfully load into **COZView** at the conclusion of the simulation run can be loaded into **COZView** for display from the *Data Explorer* area.

The available options in *Data Explorer* are

- Manage grids
- Run simulation
- Load simulation results



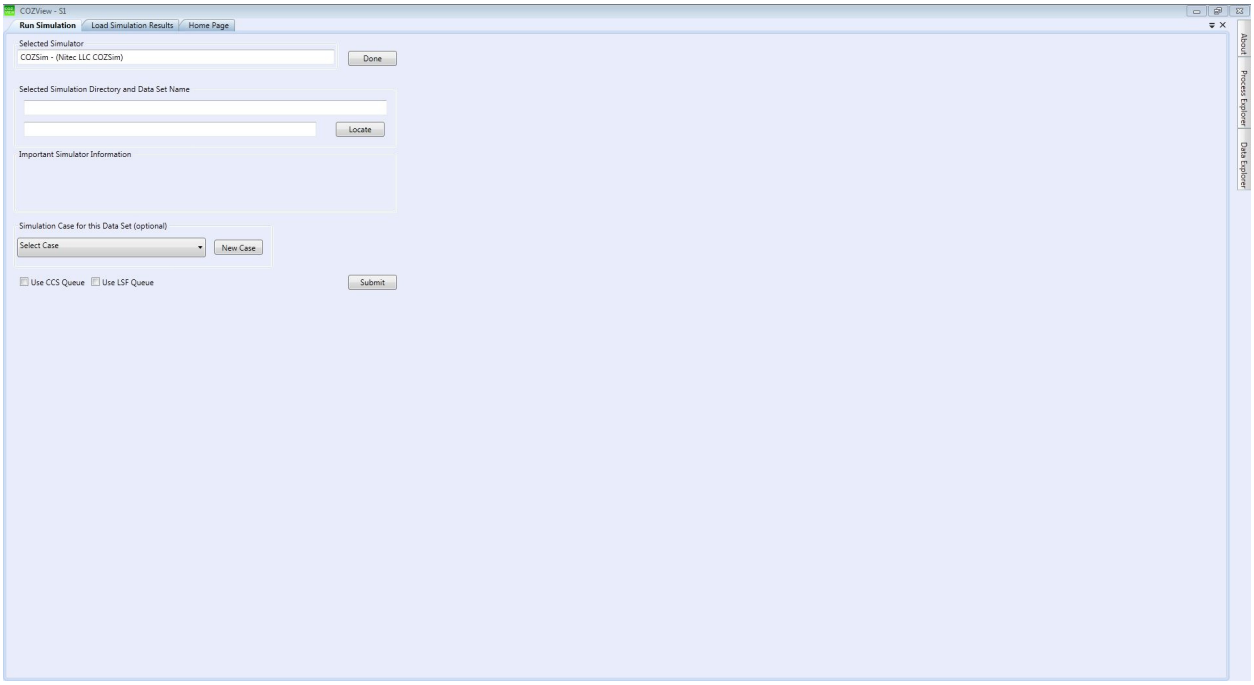
4.1 Manage Grids

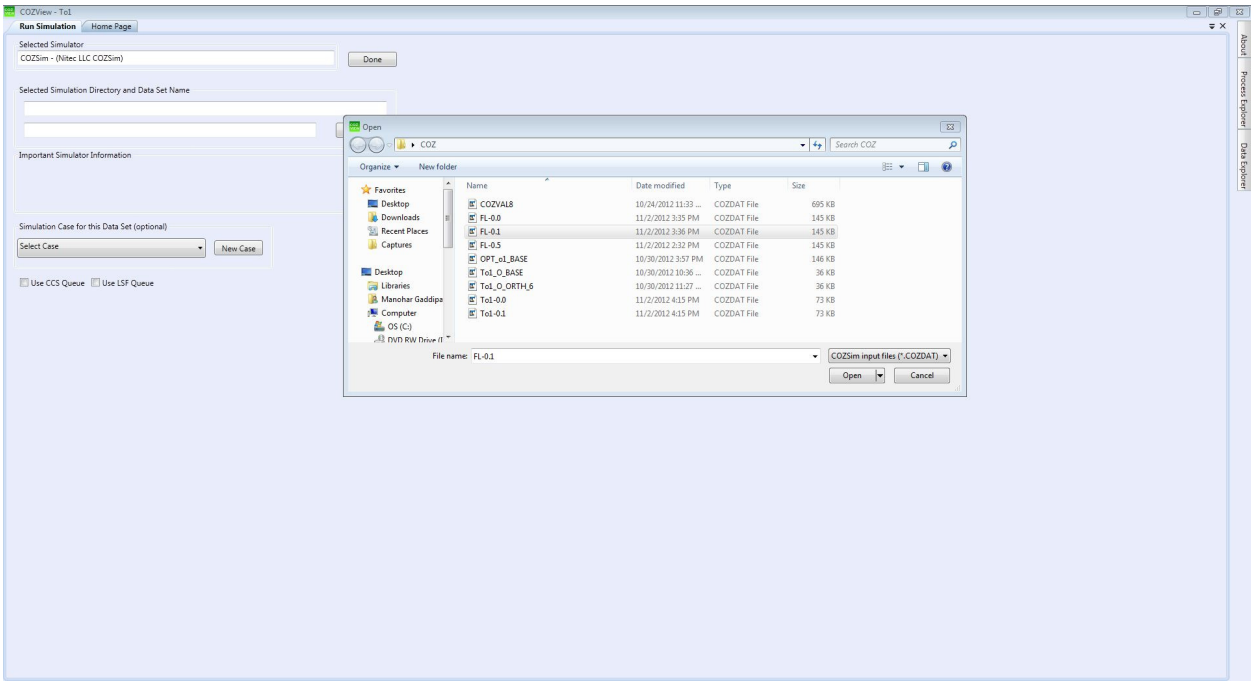
This is an undocumented functionality generally used only by the software developers and testers.

4.2 Manual Run Simulation

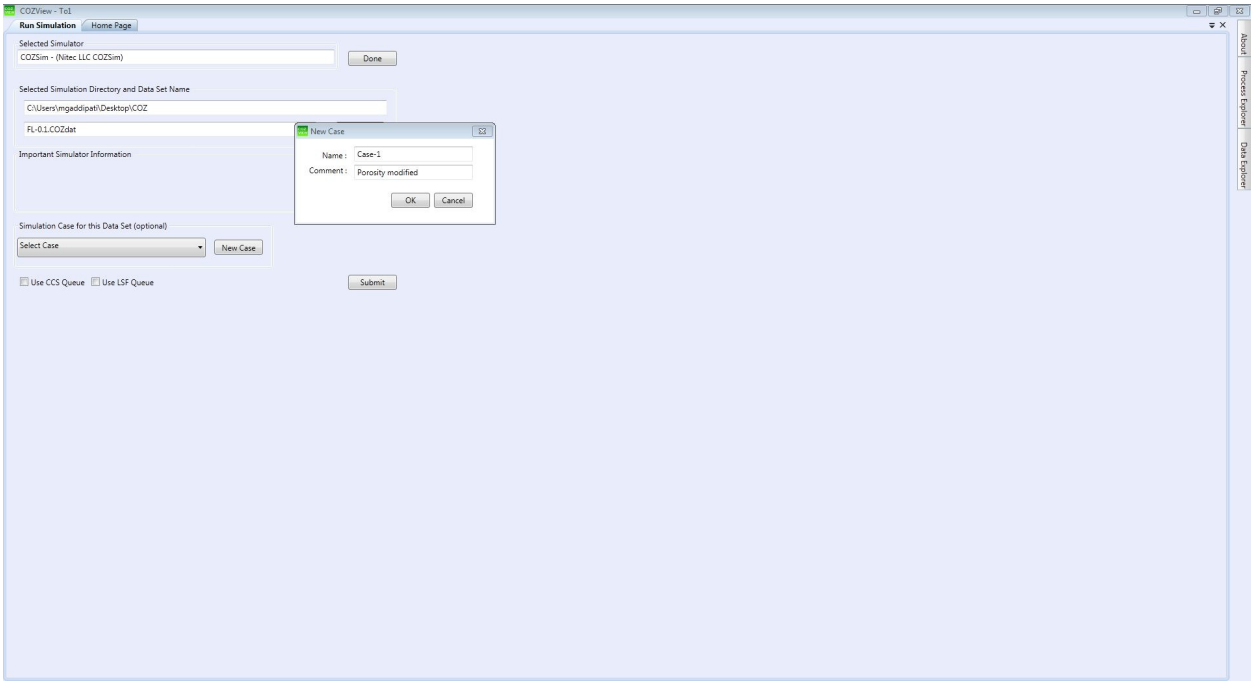
If the user is familiar with the keyword structure of the simulation run data file (ProjectName.COZDAT), this file can be edited directly by the user with a text editing program. Once the desired changes are made the data file can be loaded into **COZView** for submission to COZSim.

Selection of Run Simulation in the Data Explorer area displays the screen below. The selected simulator is always **COZSim**. The **COZSim** input data file (ProjectName.COZDAT) has to be located using the Locate button.





The simulation case name for the simulation run to be made must be selected from existing case names (dropdown menu) or a new name must be provided. If an existing case name is used, any prior simulation results for that case will be overwritten by the new simulation run.



Select *Submit* to run the simulation case. A Simulator Runner window will appear and the CPU Time and CPU% utilization will be continuously updated. Simulation results (plots and arrays) should be loaded automatically at the end of this simulation run.

4.3 Load Simulation Results

Past **COZSim** simulation run results or **COZSim** simulation results that did not successfully load into **COZView** at the conclusion of the simulation run can be loaded into **COZView** for display from the Data Explorer area.

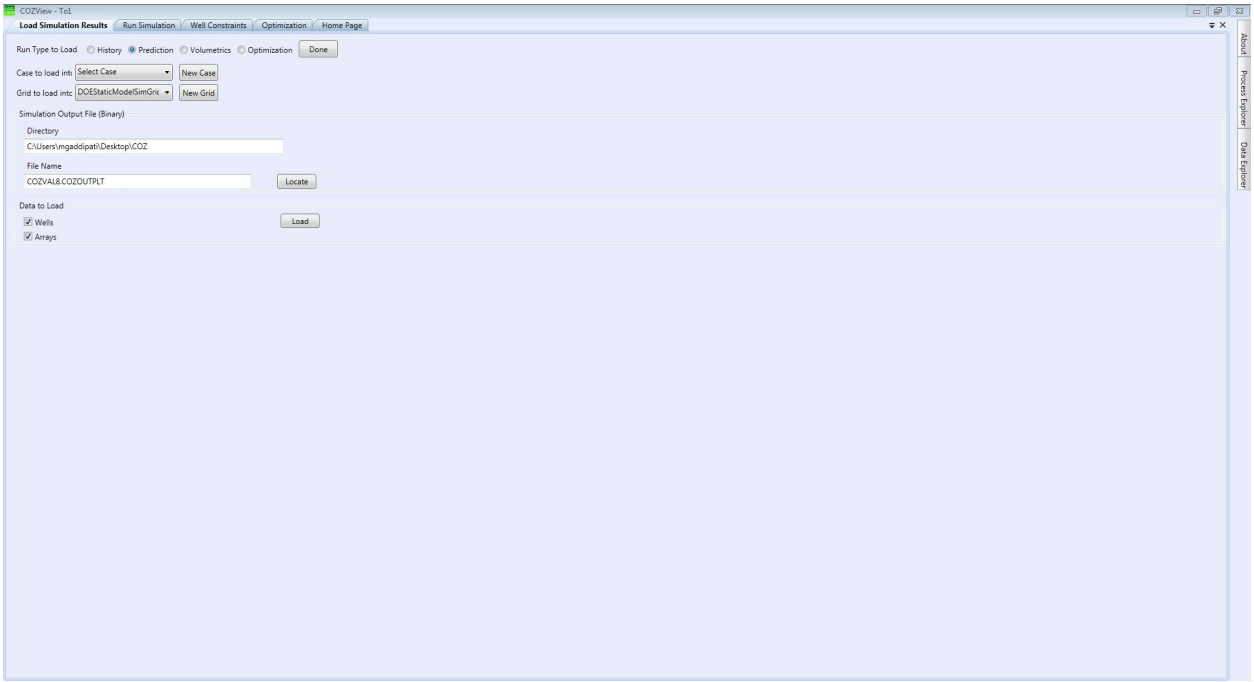
The user can load four Run types (i) History, (ii) Prediction, (iii) Volumetrics and (iv) Optimization. The results can be loaded as a New Case or can be loaded into a previously defined case. The Grid information is required to load results Arrays.

The **COZSim** Output file has to be located using the **Locate** button. There are two different binary output files that **COZSim** writes. These should be located in the **COZView** directory set up at the time of installation for all COZ project files.

ProjectName.COZOUTMAP : 3D arrays results

ProjectName.COZOUTPLT : Field and well production and injection results

Select *Locate* and browse to find the *ProjectName.*COZOUTPLT file. Then select the data to load (Wells, Arrays).



Select *Load* to load results into **COZView** for display from the *Simulation Results* area in Process Explorer.

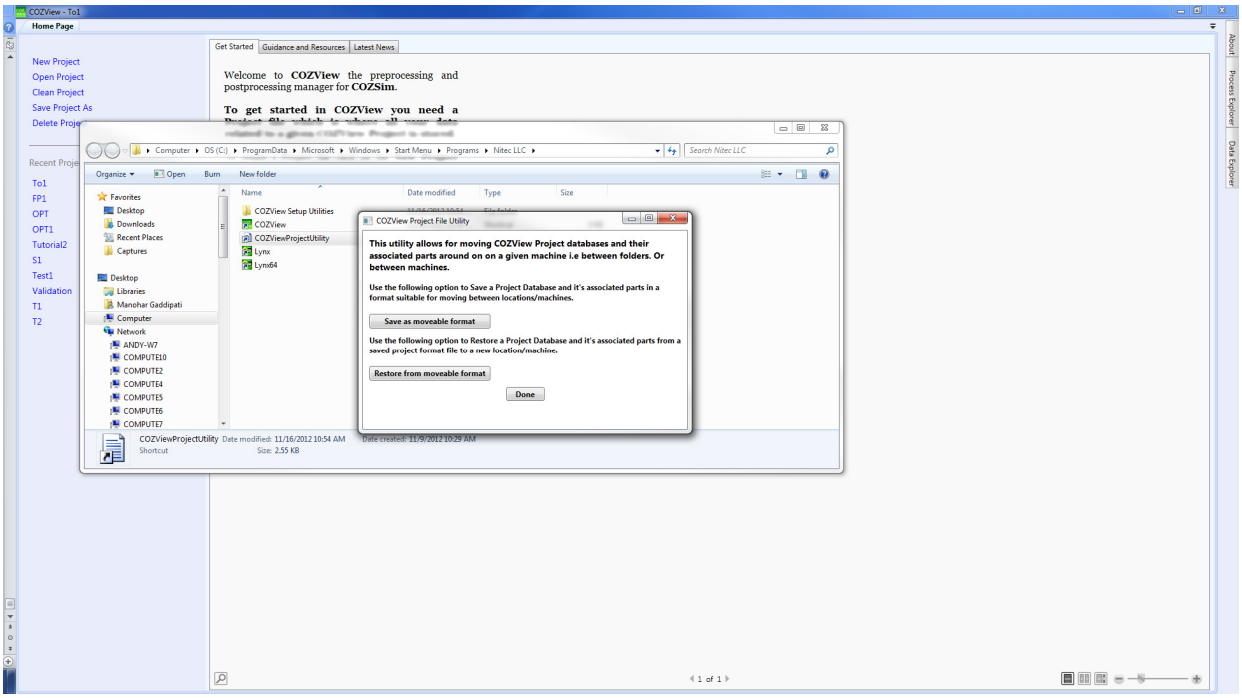
5 Sharing a Project Database

Users are also allowed to share project databases using *COZView Project Utility tool*. The project utility tool is located in the following address C:\ProgramFiles \NITEC LLC\COZView. The user can also search for *COZView Project Utility* tool in the Windows Start Menu.

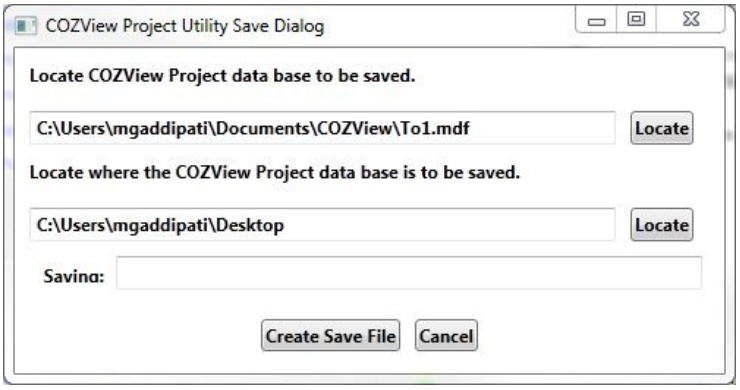
The project utility tool allows the user to move **COZView** project databases and their associated parts between different computers. The project database must be saved as a *moveable* format. The saved file (ProjectName.cvsf) can be copied or saved into a different folder or a different computer. The saved file will have all the information required to restore (load) the project database. The project database can be restored using *Restore from moveable format* button.

5.1 Saving a Project database

Click on *COZView Project Utility*, a new window pops up as shown below. The user should first save the project database as moveable format. This can be done by selecting *Save as moveable format*.



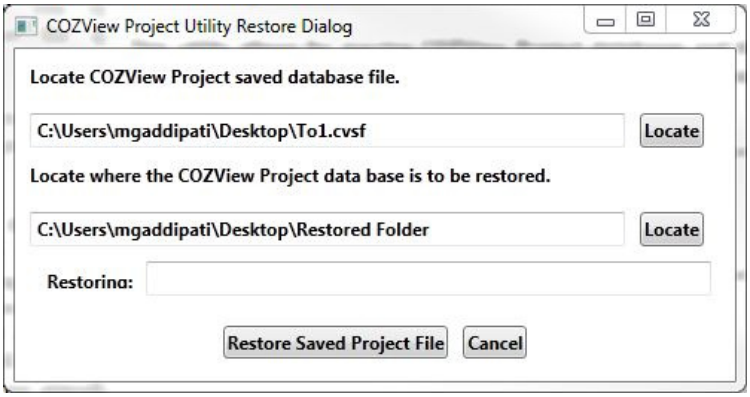
The user has to locate the Project database (.mdf file) to be saved.



The user must then select the location for the saved file. Select **Create Save** file. A completion window pops up when the process is completed.

5.2 Restoring the project database

The Project database can be restored using **COZView** project Utility tool. Click on *Restore from moveable format.* User need to locate the saved file obtained in Section 5.1 and the directory where the project database is to be restored.



Select *Restore Saved Project File.* A window pops up when the process is completed.

COZVIEW/COZSIM

User Manual Supplement No. 1

Issued Date: August 20, 2013

This user manual supplement includes the following new functionalities:

- Case management
- WAG Schedule

Case Management

General Description:

It is often useful in conducting a study to modify a single or a few parameters in the data and make a new simulation run. Once the simulation run is complete the user will want to compare the results (plots and 3D views) of the two (or more) case. In the case of plots, the user may wish to show multiple case results on the same plot. For 3D views the user will want to easily view the same array (e.g. oil saturation) for two different simulation cases. The goal is to ease the analysis process as the user attempts to improve or compare simulated performance of alternative cases.

Cases are defined as a set of input data within a COZ project that have different property values for user selected properties.

Examples of properties that may change between cases:

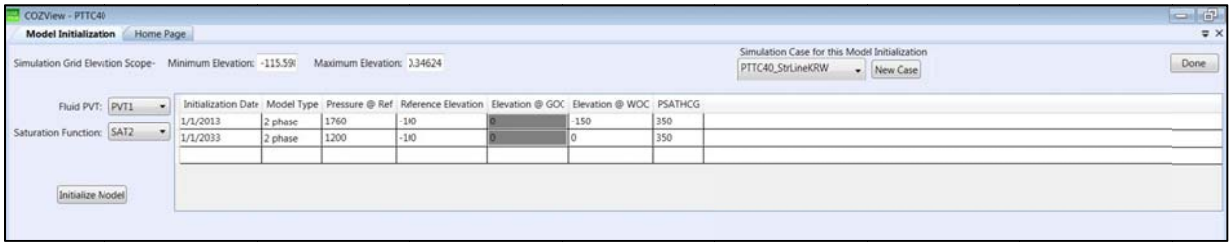
1. relative permeability curves
2. well completions
3. well constraints
4. depletion strategies
5. layer properties *
6. initialization properties*

*The user is cautioned relative to creation of multiple cases with different volumetrics. While this is allowed, comparison of simulation results may not be appropriate.

WARNING: The user should not change the structure, well locations, or grid dimensions between cases. The user is cautioned to keep a record of parameter changes between cases. While COZView allows many parameters to be changed between cases, only a few can be identified or retrieved by the case name in COZView.

New Case – Initialization Changes

Case management may start at the **Model Initialization**. A selection box has been added to create a New Case or utilize the existing case. A New Case name is suggested, but the user can change this name as they wish. A comments field is also provided to aid the user in distinguishing between cases. This should be filled in by the user. The user **cannot** return to a previous case.



This allows the user to change formation properties, PVT table, Saturation function table and/or initialization parameters for the new case. All other data from the prior case will be retained in the new case subject to changes in the ***Prediction Period Section***.

When the user selects the **Initialize Model** button the **Model Volumetrics** screen will appear along with the Simulation status window. Once the simulator has completed the initialization, the volumetric values by phase will appear in the table. The table now has a Case Name associated with each volumetric calculation; otherwise there is no change from the previous version.

If the user has only changed pre-Model Initialization data to this point and does not wish to change any well or field constraints or limits, they can proceed directly to **Run Simulation**. The user should select the new Case Name created in ***Model Initialization Section*** from the dropdown menu and set the End Date to the appropriate value. The simulation run will be launched accordingly. Note that all well and field constraints and limits will be the same as the prior case.

If the user wishes to change well or field constraints or limits in addition to the Initialization parameters, they may do so in the appropriate screens. Be sure to **Save** when changes are made. When the user is ready to submit the new simulation run (**Run Simulation**), they should select the new Case Name created in ***Model Initialization Section*** from the dropdown menu and set the End Date to the appropriate value. Select GO to launch the simulation run.

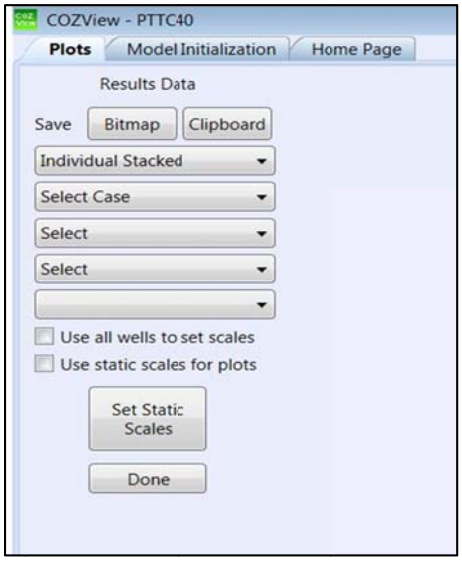
New Case – Prediction Period Changes Only

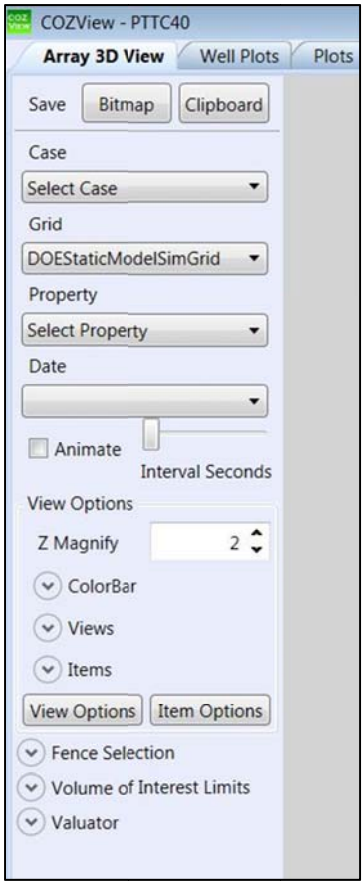
If the user wishes to create a new Case that is based on changes to well and field constraints and limits, but does not require changes to Model Initialization data, they can change the data in the appropriate screens. In the **Field/Facility Parameter/Controls** screen select the correct Case in the *Show Constraints for* box. Be sure to Save when changes are made. (As a new case cannot be created on the **Field/Facility Parameter/Controls** screen, this may require the new case to be defined on the **Run Simulation** screen, a refresh of **the Controls** screen, and selection of the new case on the refreshed **Controls** screen.

When the user is ready to submit the new simulation run, a New Case can be created at the **Run Simulation** screen. Be sure the new case name is selected after creating the New Case. Select GO to launch the simulation run. All well and field data changes will be associated with the new case name.

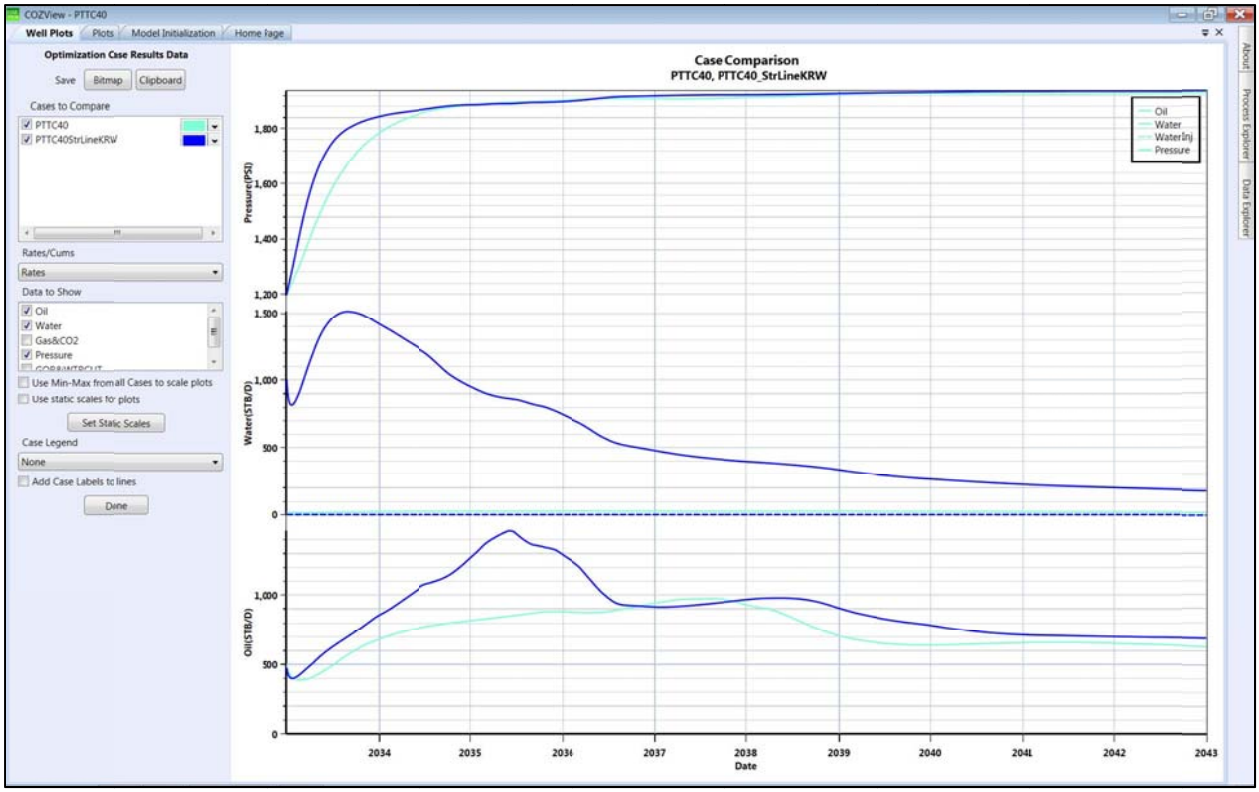
Simulation Results

All plots, tables and 3D Views contain a selection box for the Case. All prior cases run in the project will be available for viewing in the appropriate display.



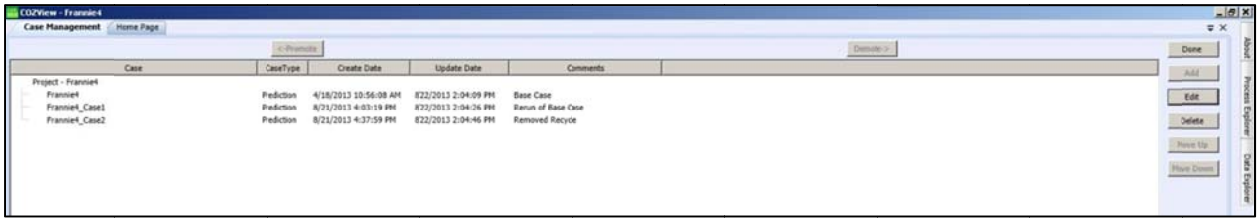


Case Comparison Plots in the **Simulation Results** menu allows the user to compare selected field level results on any of the cases run in a project on the same display plot.



Case Summary

The user can view a table of all cases run in the project under **Case Management** in **Utility Functions** in the ***Process Explorer*** section. The comments field can be altered by selecting a case and the **Edit** button. Cases can also be deleted by selecting the case and the **Delete** button.



The status of the project data base (layer properties, well constraints, field constraints, etc.) is consistent with the last case run only. (SQL data bases for prior simulation runs are NOT retained.) The user is cautioned not to delete the last case run unless all cases (excluding the “base” case) are being deleted and the “base” case is being re-formulated. Deleting the last case run may result in an incomplete data base and impact subsequent simulation runs in this project.

File Naming Convention

The file naming convention has been changed to include the case name in addition to the project name. A typical file name is now *Projectname_Casename*.COZOUT or *Projectname_Casename*.COZdat.

Be sure to keep in mind the rules concerning screen refreshing. A new case will not appear in a Case box if the particular screen has not been refreshed since the creation of the new case.

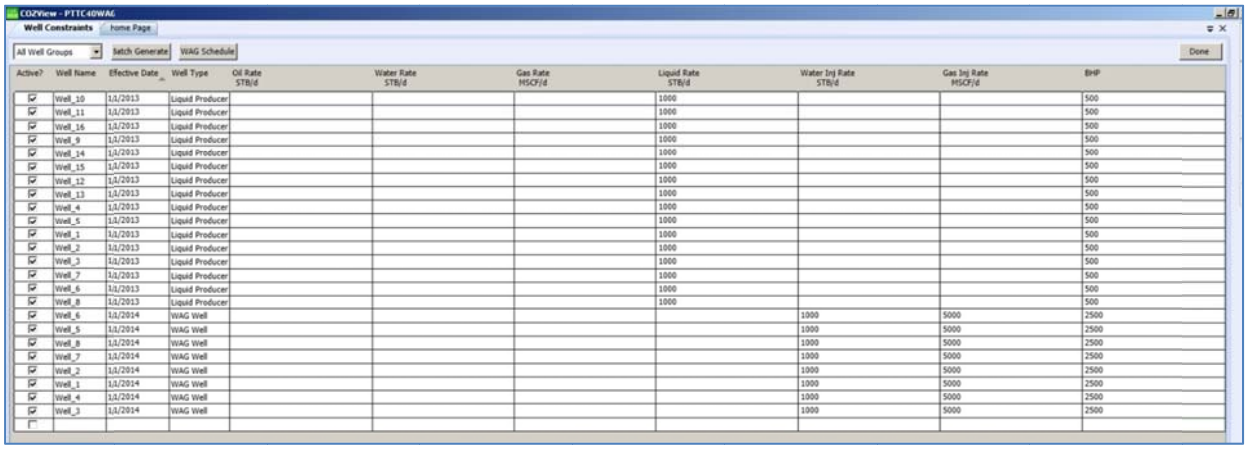
WAG Schedule

General Description:

Many CO2 injection projects utilize a process referred to as WAG (water-alternating-gas). Injection into designated wells is varied between CO2 and water on a defined schedule. In theory this maximizes use of the scarce CO2 resource and provides mobility control for the advancing CO2 front. A new functionality has been added to COZView to make scheduling of the WAG process easier. Prior to this, WAG scheduling had to be manually specified. COZSim has been able to handle this process from the beginning.

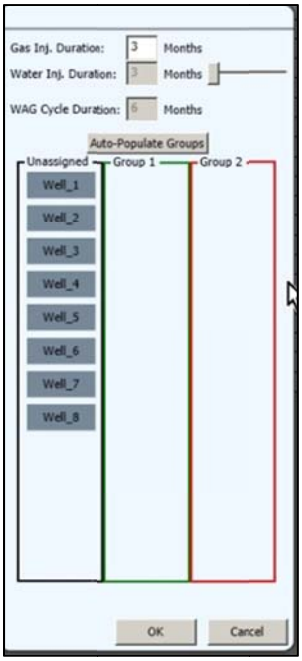
Establishing WAG Injection Wells

In the **Well Constraints** section each well used in the simulation must be identified with a specific *Well Type*. A new Well Type has been added, ***WAG Well***. The user must identify the injection wells that will be used in the WAG process, when they will start the WAG, the maximum individual well water and gas injection rates and the maximum individual bottom hole injection pressure. The gas injected during a WAG cycle can be hydrocarbon gas (HCG) or CO2. This will be identified in the **Field/Facility Parameters/Controls section**. Select **Done** to save.



Setting WAG Cycle Schedule

The user must then select the **WAG Schedule** button. Select **Yes** to the save query. The first time this screen is entered all wells previously identified as WAG wells will be shown in the left *Unassigned* column.



Each of these wells must be "assigned" to a Group. The number of possible Groups is based on the duration of the gas and water injection per WAG cycle. The concept is that all WAG wells will be active once the WAG schedule is initiated. A full cycle requires that all wells have injected water and gas for the defined durations once.

In the WAG screen above, the gas injection duration has been set to 3 months by the user (the default value is 1). Based on the gas injection duration, the water injection duration is initially set to the same value; 3 months in this case. This establishes the total WAG cycle duration at 6 months – 3 months of water injection and three months of gas injection. As the injected gas is typically purchased from an outside source and must be used on a near constant volume basis; gas injection must occur in at least some wells throughout the WAG cycle; hence, the need for two groups in this example – one of the groups always injecting gas. (The number of wells in each group is up to the user.)

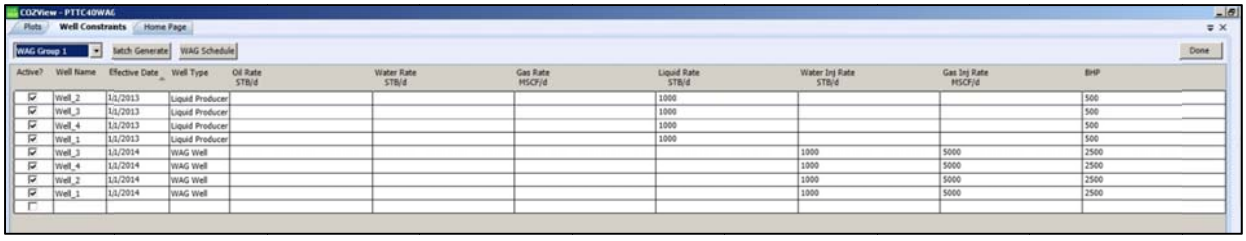
The user can assign the wells to groups by dragging each well from the *Unassigned* column to one of the *Group* columns. Typically, wells are grouped based on surface facilities and/or pattern requirements.

Select **OK** to save.

Note that the WAG schedule will be repeated in the simulation run until the run completes or the well types are changed for the WAG wells by the user in the **Well Constraint** section. The gas and water volumes used in each well in the WAG cycle can be changed later in the simulation run period in the **Well Constraints** screen, but the injection duration times during the WAG cycle cannot be changed.

The number of months of water injection relative to the number of months of gas injection can be changed with the slide bar. The duration of water injection can be changed to multiples of the gas injection duration – in this case 3 months of gas, 3, 6, 9, etc. months of water. Changing the water injection duration will change the total WAG cycle duration. This in turn changes the number of possible groups.

Once the WAG groups have been established the user can view the well constraints for all wells in a given group by selecting a group from the dropdown menu in the top left corner of the **Well Constraints** screen.



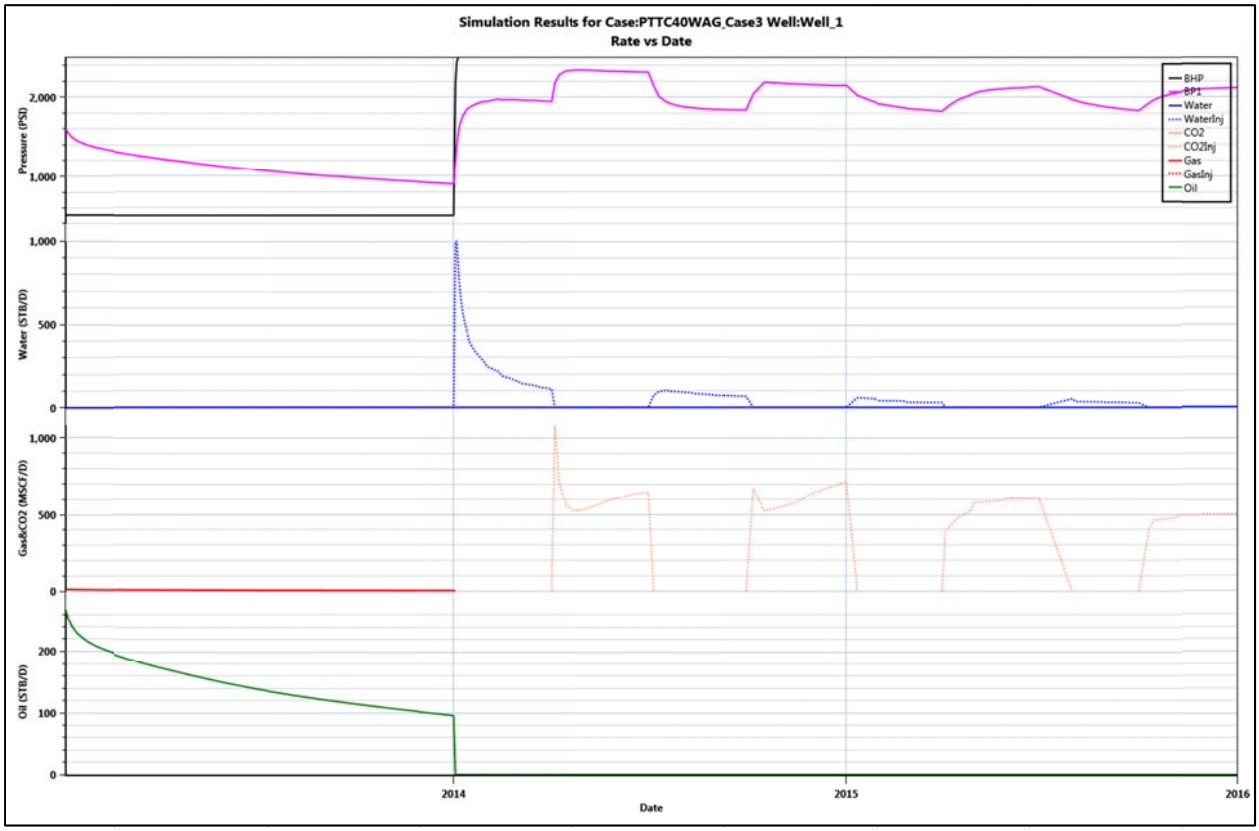
Group WAG Implementation

As described above, the number of Groups is dependent on the duration of injection for water and gas. The user does not need to place wells in all of the Groups. However, not doing so will result in some portion of the total WAG cycle duration being carried out with no gas injection.

If multiple Groups (say 3) are required, the cycle sequence is as follows for a total WAG cycle through all wells:

Group	First Gas Injection Period	Second Gas Injection Period	Third Gas Injection Period
1	Gas	Water	Water
2	Water	Gas	Water
3	Water	Water	Gas

The well plot below is an example of a 1 month CO2 injection/1 month water injection WAG cycle starting in 1/1/2014 after one year of production.



APPENDIX 7

Installation Guide

COZVIEW/COZSIM INSTALLATION GUIDE

COZView/COZSim integrates an easy to use user interface for pre and post processing of the reservoir simulation results, a technically rigorous 3D, 3-phase, 4-component, extended black oil simulator, and a net present value (NPV) optimization functionality for evaluation of CO2-EOR in oil reservoirs.

Developed by NITEC LLC under a Federal Assistance Agreement with the U.S. Department of Energy/National Energy Technology Laboratory

Last Update 02/28/2013

Table of Contents

1 Prerequisites

This Installation for COZView/COZSim is intended for systems running Microsoft Windows 7 (32bit or 64bit) which are up to date on service packs and patches. It assumes that Microsoft SQL Server is not installed or that Microsoft SQL Server 2008 Express is installed, see SQL Server section for further details. It also assumes that the user doing the install has sufficient administrative rights to allow the various installers to correctly run.

Note the Setup program mentioned below checks the system for required infrastructure components and will download and install them as needed.

2 Base Installation

If you downloaded from the Nitec LLC web site go to the where you saved the **COZSetup.exe** file and double click on it. If you are using an install disk go to the Installation folder and double click on **setup.exe**.

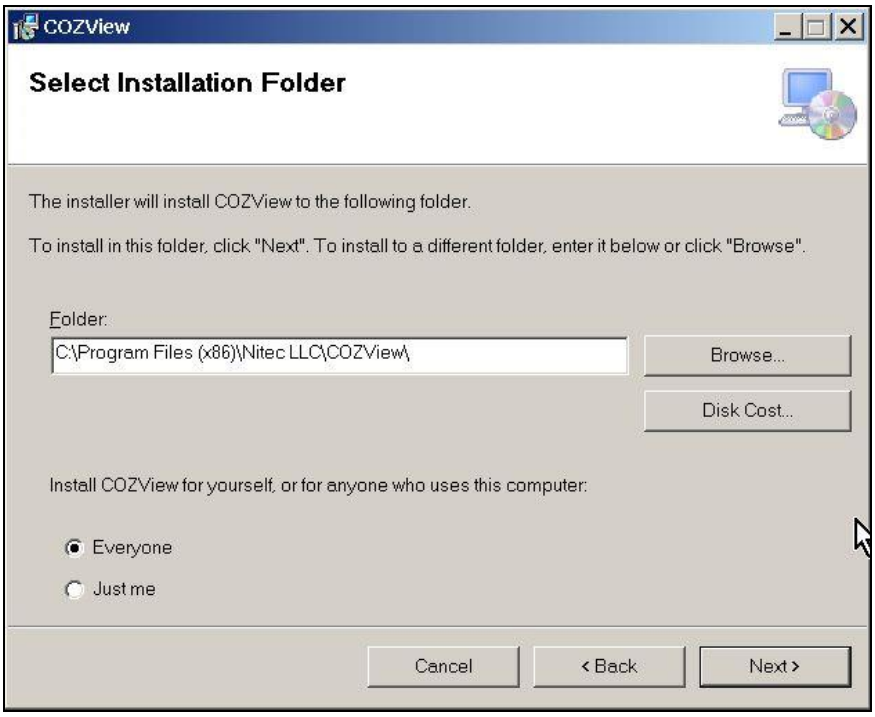
COZSetup.exe with screens related to unzipping the installation to a temporary folder then it launches **setup.exe** for you.

Setup.exe will launch the base installation of **COZVIew/COZSim**.

Depending on the state of the system up to five more products related to Microsoft .Net components and Microsoft SQL Server 2008 Express will appear. Several of these will require system reboots. This typically will only occur on the initial installation.

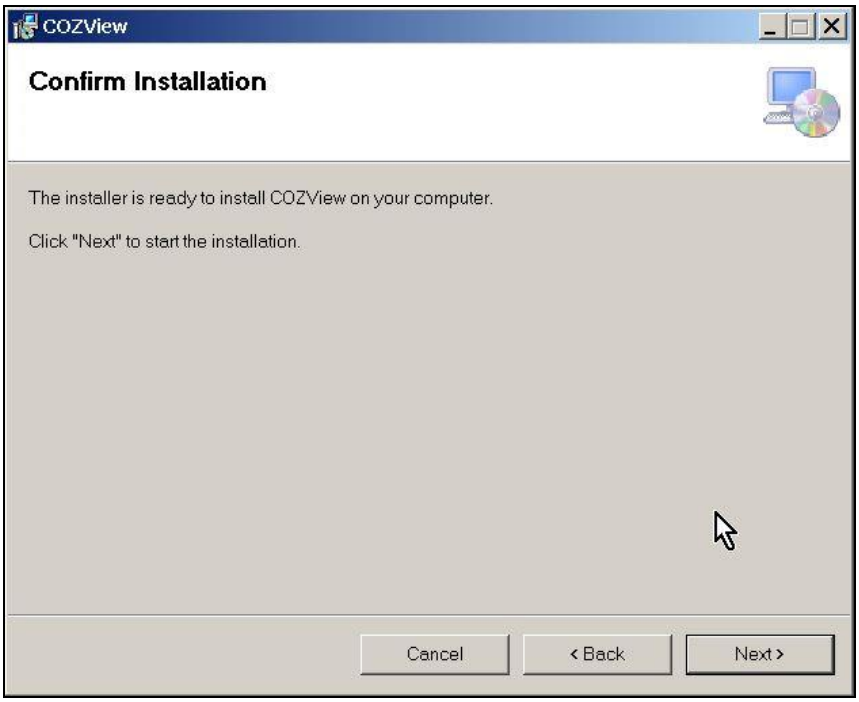
The **COZView Setup Wizard** window will appear.

Select **Next.**

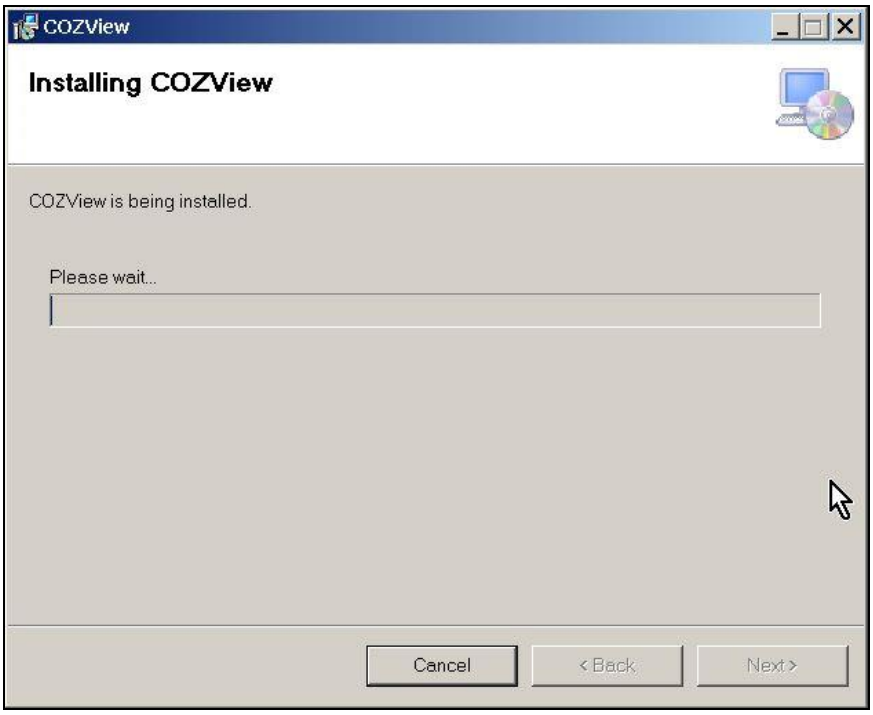


A default location for **COZView/COZSim** will be identified. If the user wishes to store the software in a different area, the folder location can be changed. The default **Everyone** should be selected.

Select **Next.**



The installation will be started.



A message will appear:

Do you want to allow the following program to make changes to this computer?

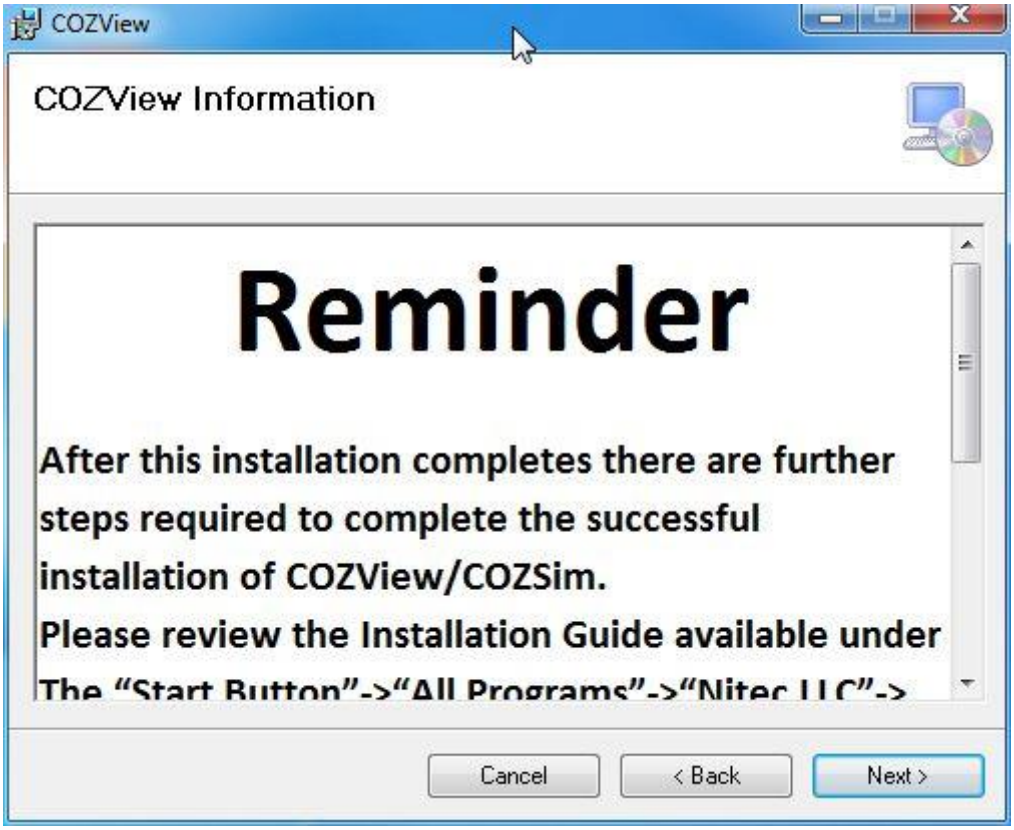
Program Name COZView.msi

Select **Yes.**

A Registration screen will appear.

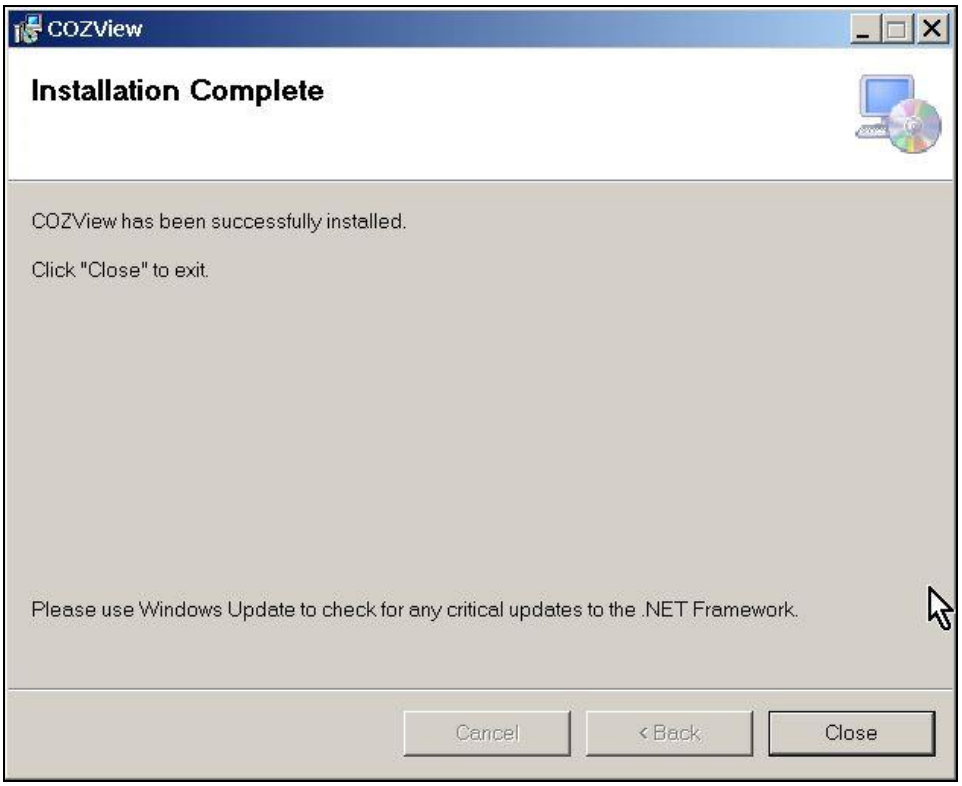
Select the “Register Now…” button if this is a first installation on this machine. Completing the registration will allow a license to be generated for this machine, which is required for the software to run. For updates this can be skipped. Select **Next** to continue.

A COZView Information screen will appear with a reminder about completing the installation.



Select **Next** to continue.

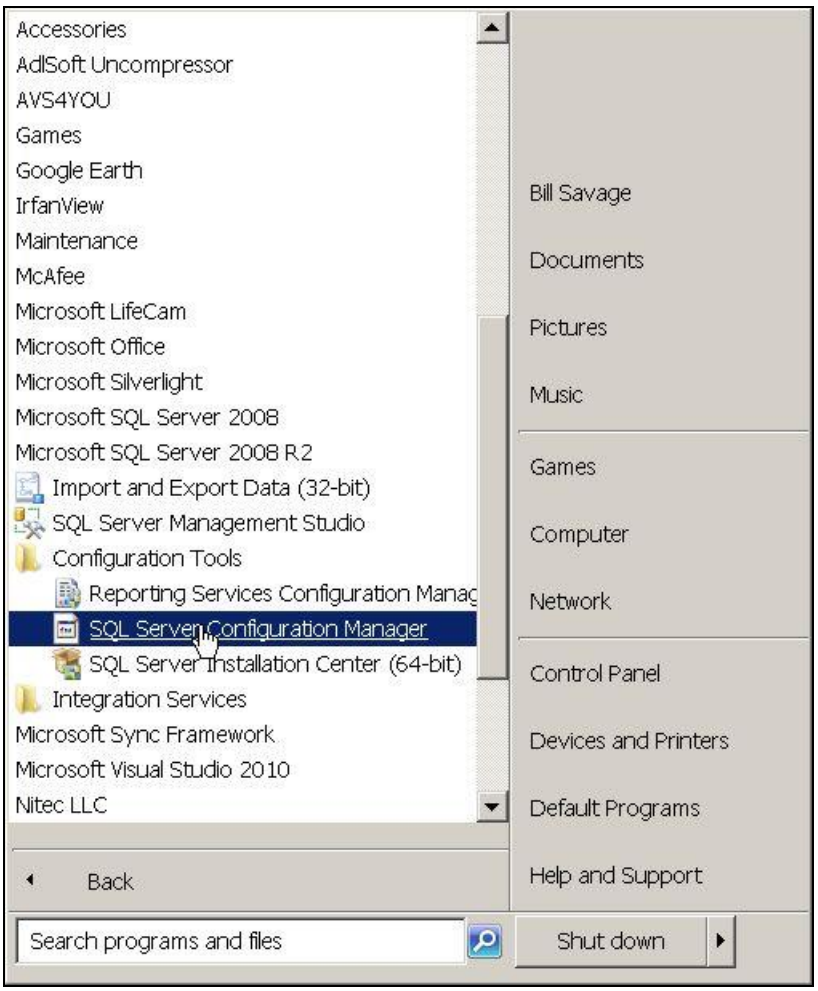
Select **Close** upon completion of the installation.



3 Post Installation Configuration

One time Microsoft SQL Server 2008 Express configuration

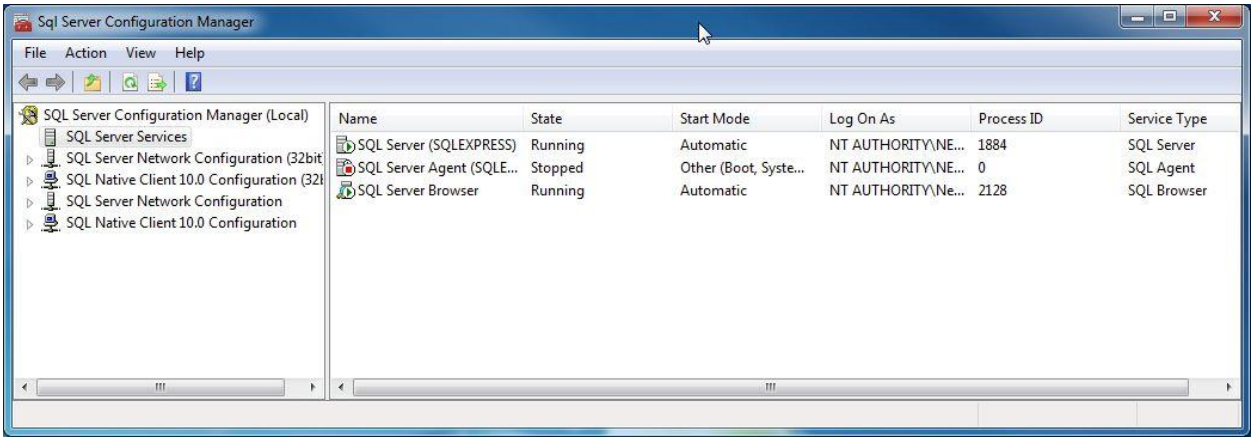
Click the **Start** button and select **All Programs** scroll to “Microsoft SQL Server 2008” or “Microsoft SQL Server 2008 R2” and expand it. Select ”Configuration Tools” and expand it. Select “SQL Server Configuration Manager”.



A User Account Control Warning Window may appear asking for permission for the program to make changes to your system.

Click **Yes**

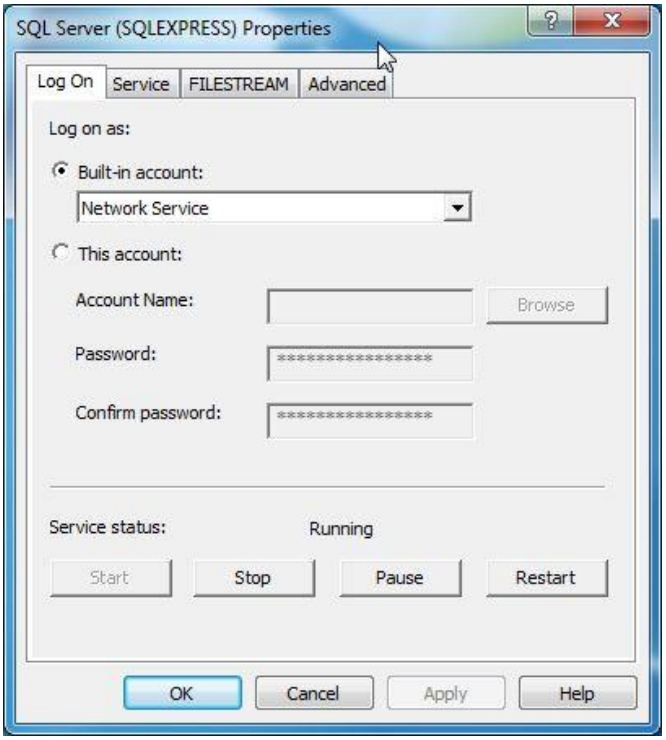
A screen similar to the following will open.



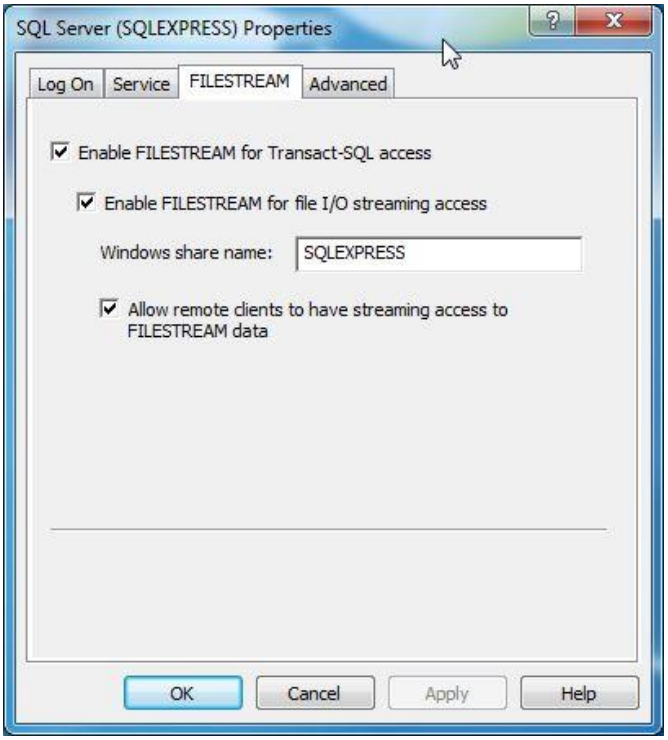
If the right window does not show as displayed above, select “SQL Server Services” in the left window.

Right Click on “SQL Server (SQLEXPRESS) in the right window and select **Properties** in the pop up box.

A screen similar to the following will open.



Click on the FILESTREAM tab



Select each of the checkbox's in order, leaving the Default SQLEXPRESS name for the Windows share name.

Select **OK.**

On the main screen left hand column select each of the SQL Server network Configuration Options in turn

SQL Server Network Configuration (32bit)

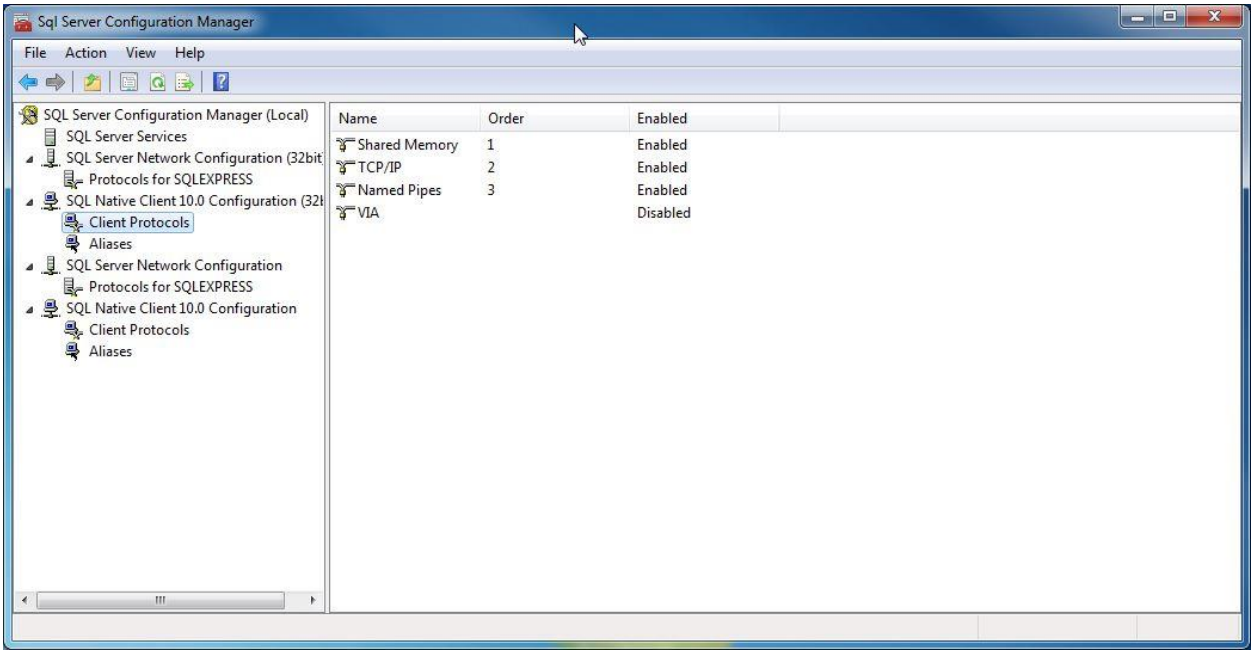
SQL Native Client 10.0 Configuration (32bit)

SQL Server Network Configuration

SQL Server Native Client 10.0 Configuration

For each of these Select the **Protocols** or **Client Protocols** items. In the right hand window "Shared Memory", "TCP/IP" and "Named Piped" should all show as Enabled. If they are not Right Click those that are not and select Enabled from the popup list.

Example



Reselect "SQL Server Services" and in the right window Right Click on "SQL Server (SQLEXPRESS) in the right window and select **Restart** from the popup menu.

After the restart check in the right window for "SQL Server Browser Running".

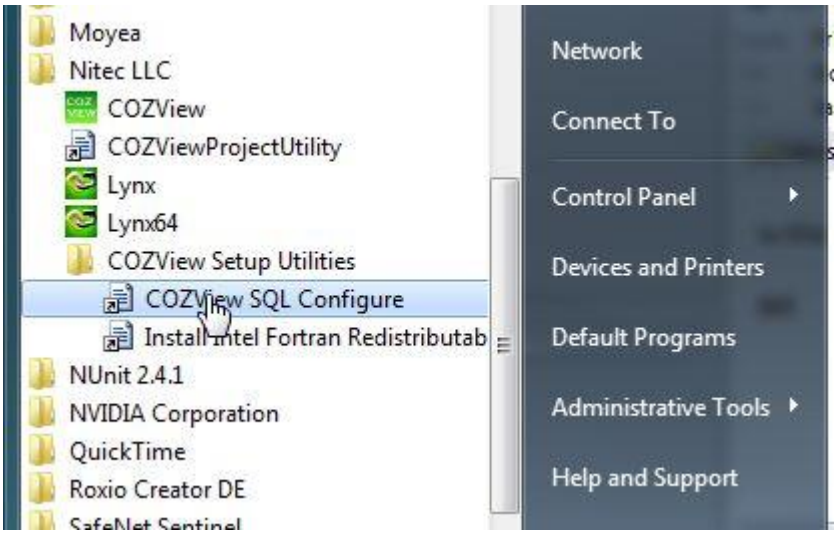
If it is not Right Click it and from the popup select **Properties**. Check on the service tab that the “Start Mode” is set to “Automatic”. If not change it and click OK.

Right Click “SQL Server Browser” and select Start.

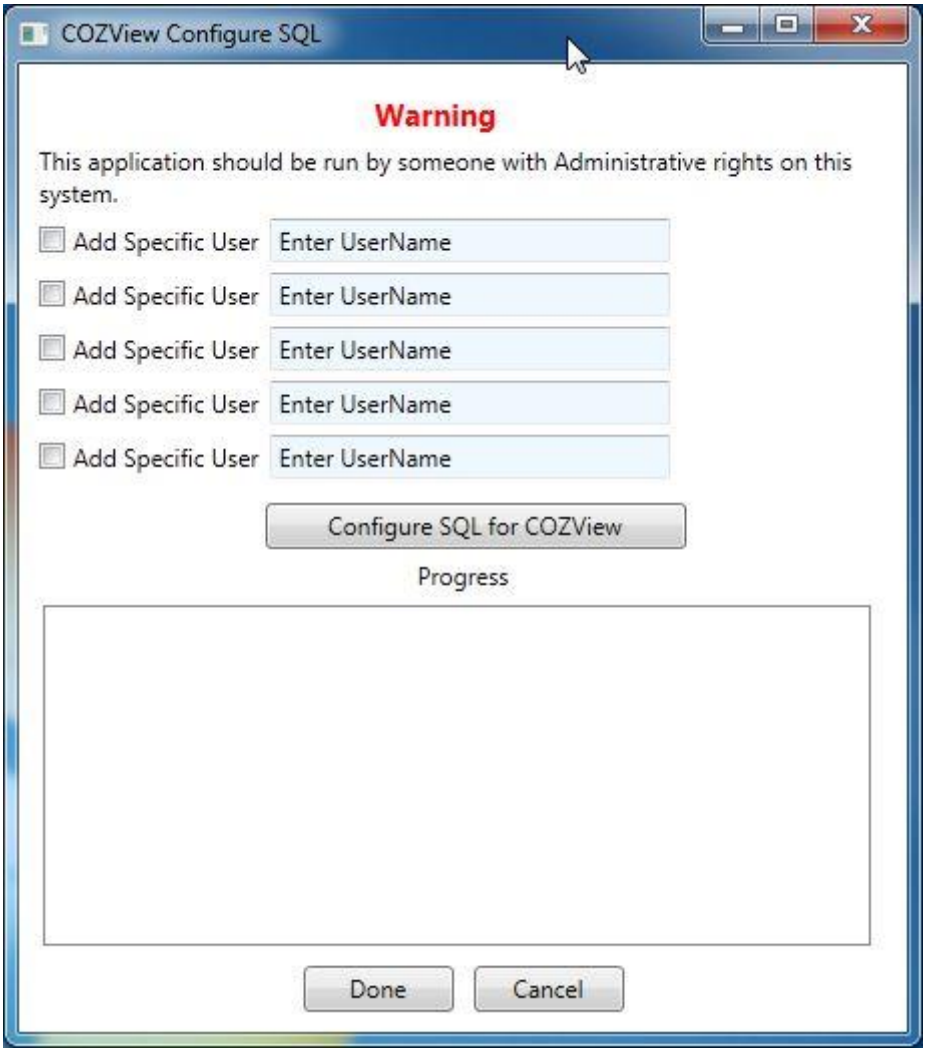
Close SQL Server Configuration Manager by clicking the X in the upper right corner.

One time COZView SQL Configure

Click Start followed by All Programs then scroll to Nitec LLC, click to expand then scroll to COZView Setup Utilities, then click to expand and select COZView SQL Configure.



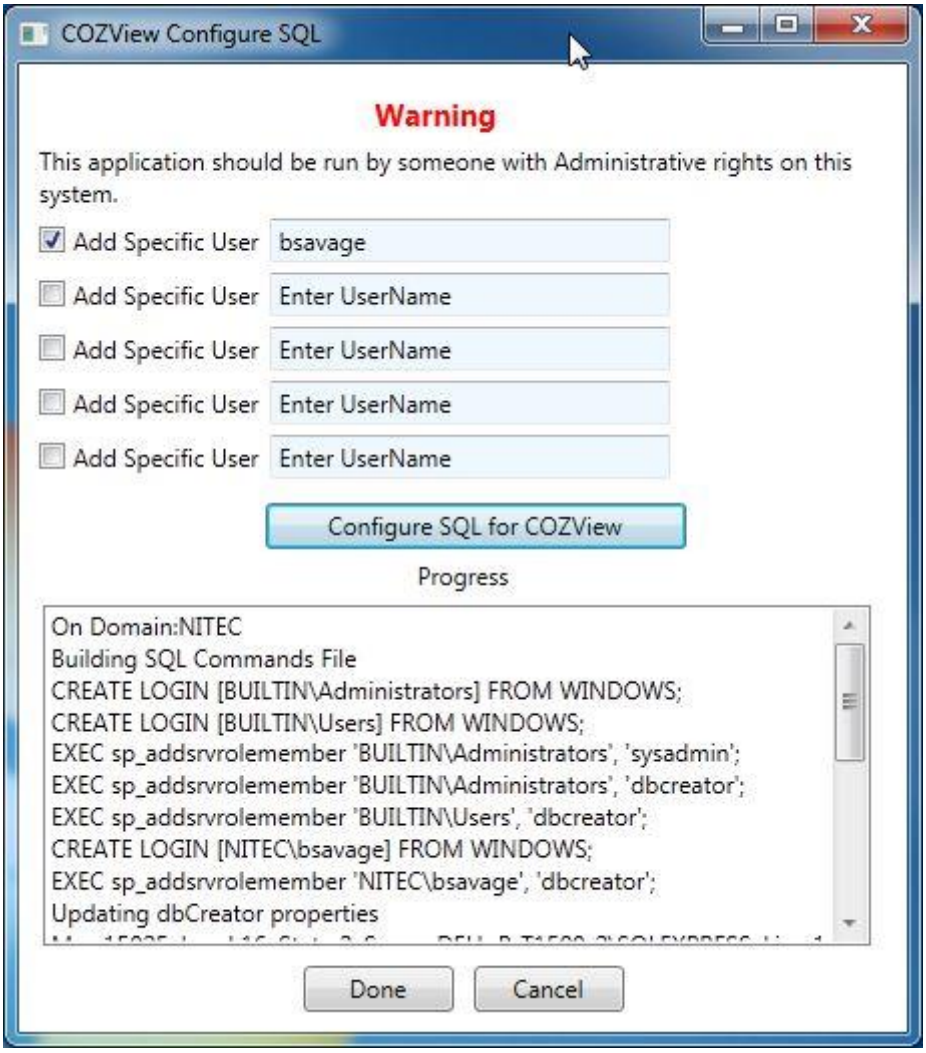
The following window will open.



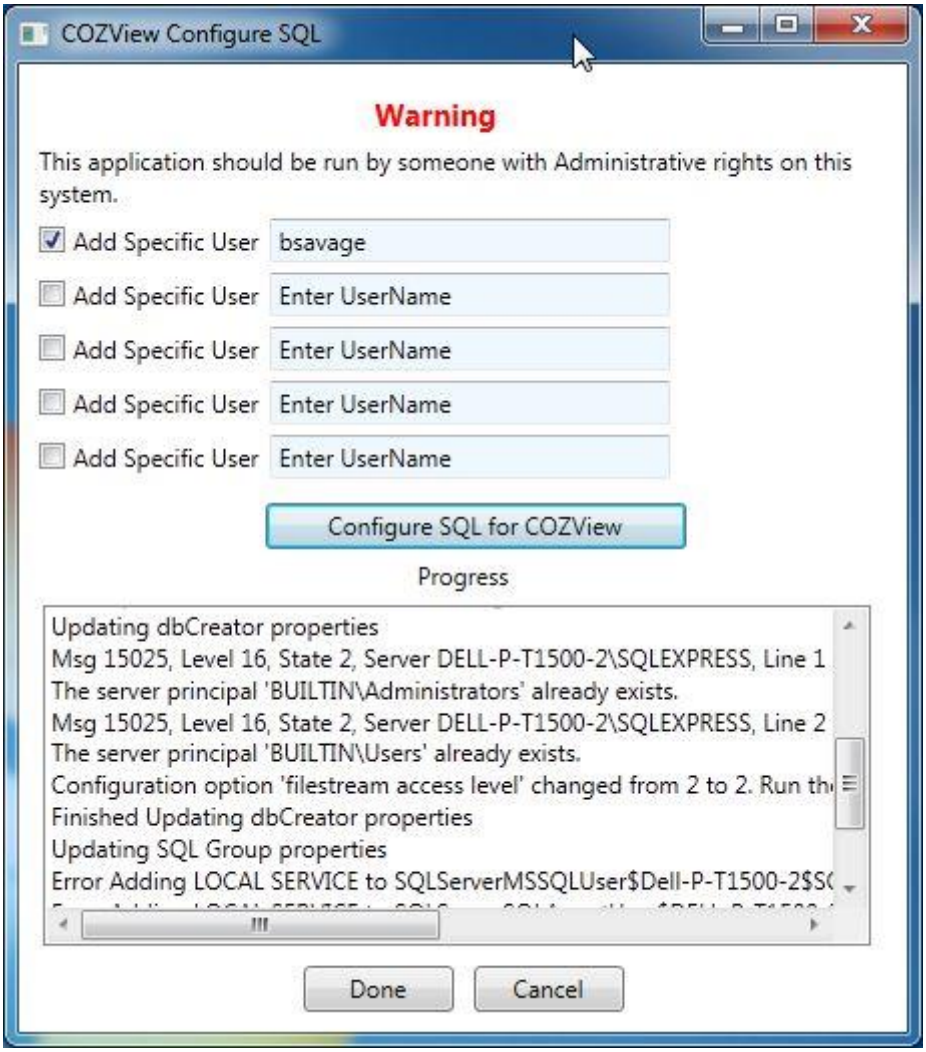
Up to five users can be configured per time. Click the checkbox's and insert valid user names for regular users (non Administrative) who will be using COZView/COZSim. For Domain Users the Domain is not needed.

Click the **Configure SQL for COZView** button.

Example


COZView Configure SQL
Warning
This application should be run by someone with Administrative rights on this system.
Add Specific User
bsavage
Add Specific User
Enter UserName
Add Specific User
Enter UserName
Add Specific User
Enter UserName
Add Specific User
Enter UserName
Configure SQL for COZView
Progress
On Domain:NITEC
Building SQL Commands File
CREATE LOGIN [BUILTIN\Administrators] FROM WINDOWS;
CREATE LOGIN [BUILTIN\Users] FROM WINDOWS;
EXEC sp_addsrvrolemember 'BUILTIN\Administrators', 'sysadmin';
EXEC sp_addsrvrolemember 'BUILTIN\Administrators', 'dbcreator';
EXEC sp_addsrvrolemember 'BUILTIN\Users', 'dbcreator';
CREATE LOGIN [NITEC\bsavage] FROM WINDOWS;
EXEC sp_addsrvrolemember 'NITEC\bsavage', 'dbcreator';
Updating dbCreator properties
Done
Cancel

Messages in the Progress window about existing users and roles are normal.



Click Done to exit.

As a precaution Start SQL Configuration Manager again (see page 10); select **SQL Server Services** if needed. Then Right Click “SQL Server (SQLEXPRESS)” and select **Restart** from the popup.

The installation should be complete and COZView icon can be selected from the desktop to start COZView/COZSim.

4 One Time Intel Fortran Redistributables Install

Click Start followed by All Programs then scroll to Nitec LLC, click to expand then scroll to COZView Setup Utilities, click to expand then select Intel Fortran Redistributables.

A message box will appear stating that “Intel IA32 Redist from Path:……” will appear. Click OK.

A standard installation for Intel IA32 Fortran redistributables will appear, take all the default options.

If this system is running Windows 7 64bit a message box will appear stating that “Intel Intel64 Redist from Path:……” will appear. Click OK.

A standard installation for Intel Intel64 Fortran redistributables will appear, take all the default options.

5 SQL Server

COZView utilizes Microsoft SQL Server 2008 Express as its database. If older versions of SQL are installed which utilize and Instance name of SQLEXPRESS, Microsoft SQL Server 2008 Express will not install correctly. Check your Start All Programs list for references to other SQL versions such as Microsoft SQL Server 2005 Express. It may be necessary to uninstall these for Microsoft SQL Server 2008 Express to install correctly.

APPENDIX 8

Tutorials

TUTORIAL #1

This is a 40 acre pilot test of a 5-spot pattern (10 acre well spacing) for CO2 injection in a good quality sandstone formation with a net thickness of 75 ft. Due to the small areal size the structure is relatively flat. The initial OIP was 2.75 MMSTB. There is no gas cap or associated aquifer. Well depths are approximately 5000 ft.

Initial pressure @ -4500 ft ss, psia	1500
Initial bubble point pressure, psia	800
Water-oil contact, ft ss	NA
Porosity, percent	20
Horizontal permeability, md	50
Vertical permeability, md	5
Oil gravity, API	36.3
Gas specific gravity	0.7
Reservoir Temperature, F	125
Swirr, fraction	.35
Sorw, fraction	.35
Sgc, fraction	.03
Sorg, fraction	.30

CO2 injection was initiated in 1/1/2012. The reservoir pressure was assumed to be near miscibility pressure at this time. The bottom hole injection pressure was limited to 2500 psia and the production well bottom hole pressures were not allowed to fall below 1500 psia. The maximum pilot (field) CO2 injection capacity was 1.5 MMSCF/D. The purchased CO2 was constrained at 1.2 MMSCF/D. Produced gas was not recycled.

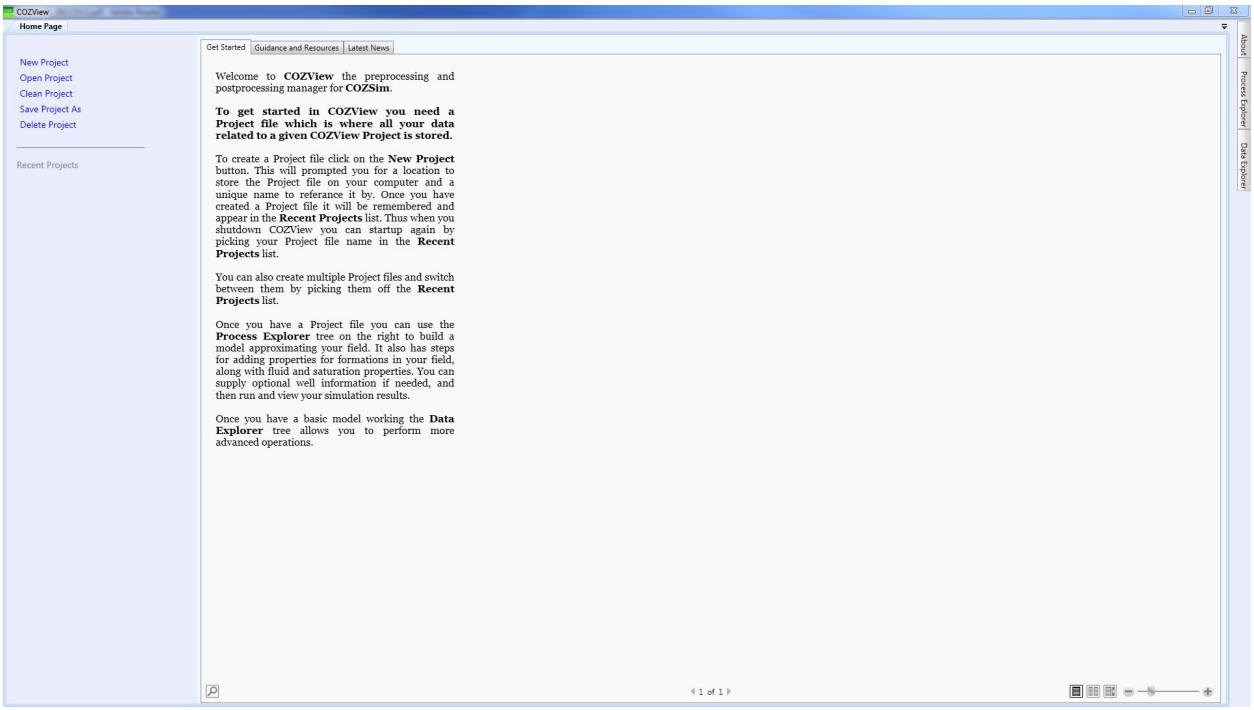
The 15 year simulation prediction resulted in a cumulative incremental oil production of 1.63 MMSTB (59.3% of OOIP). Cumulative CO2 injection was 7.5 BSCF. Cumulative CO2 production was 4.6 BSCF and 2.3 BSCF (50%) was recycled. Cumulative hydrocarbon gas production was 0.5 BSCF out of which 0.25 BSCF (50%) was recycled.

Run time was approximately 5 minute elapse time.

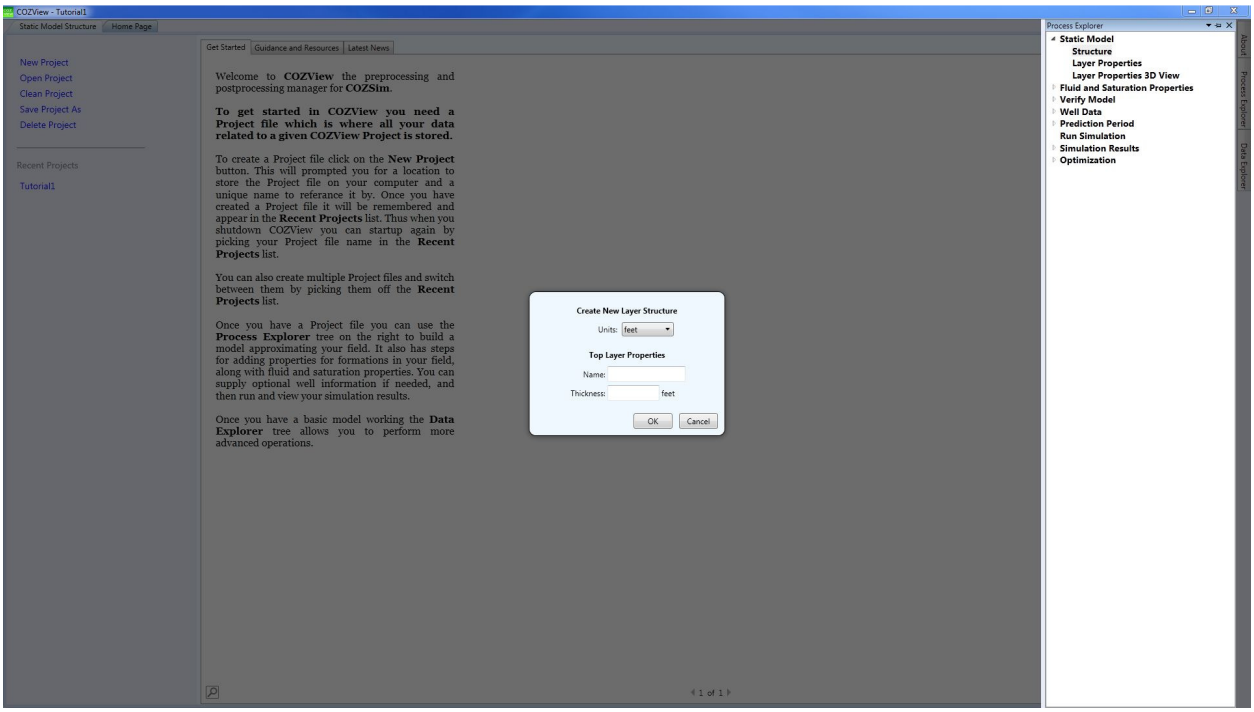
In the course of developing the tutorial examples, some COZView screens may have changed slightly from the views shown in this document. These changes should not impact the model building and simulation process.

Model Building Process

The process starts with creation of a New Project. Select **New Project** and provide a project name on the **Home Page**.

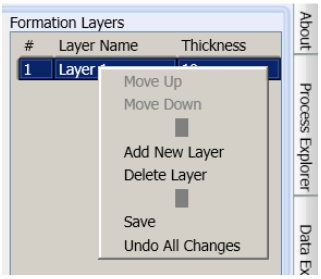


Under the *Process Explorer* tab, select **Structure** in the **Static Model** area. *The Create New Layer Structure* window will appear. Input a top layer name and the net thickness (25 for this example). **OK** will save the information.



All menus referenced in this tutorial are in the Process Explorer menu area.

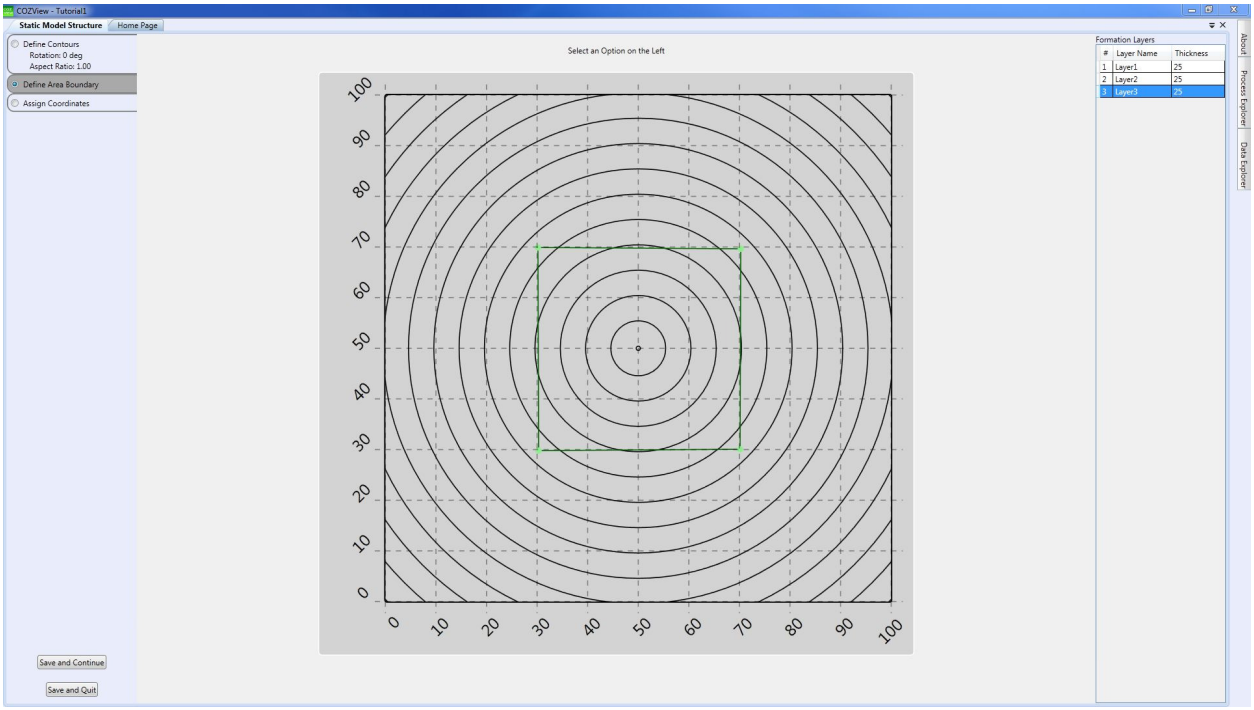
The model building starts with the structural surface of the productive formation. Before beginning the structural model definition, add any additional layers that are required by right-clicking the layer 1 row in the upper right of the **Static Model Structure** screen. Select *Add New Layer* and input the required data. Repeat the process as needed. In this tutorial, three layers each of thickness 25 ft. are required.



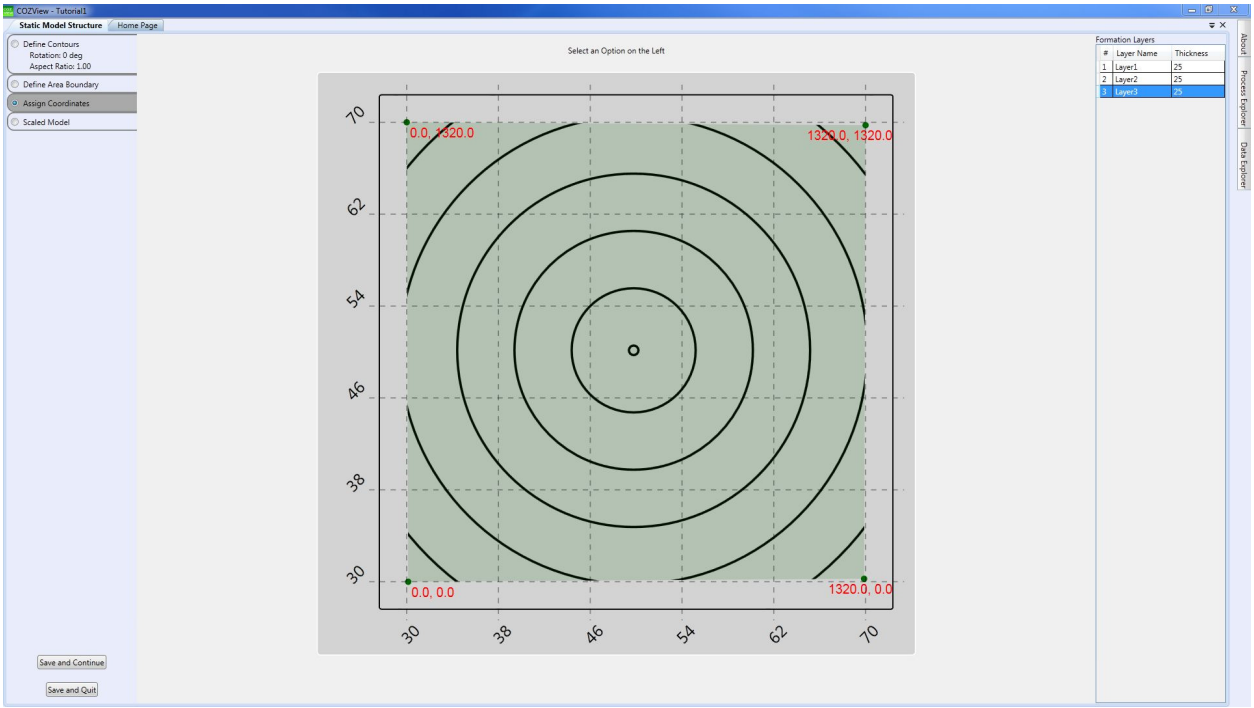
The **Static Model Structure** area allows the user to first *Define Contours* by using the resizing bars and rotation control ball. In this example the contours were not modified from the default view.

Save and Continue is recommended.

This is followed by **Define Area Boundary** (the green area shown below). The simulation model will be the area inside the green boundaries. The user selects the boundary points to reflect the reservoir area on the structure top map.

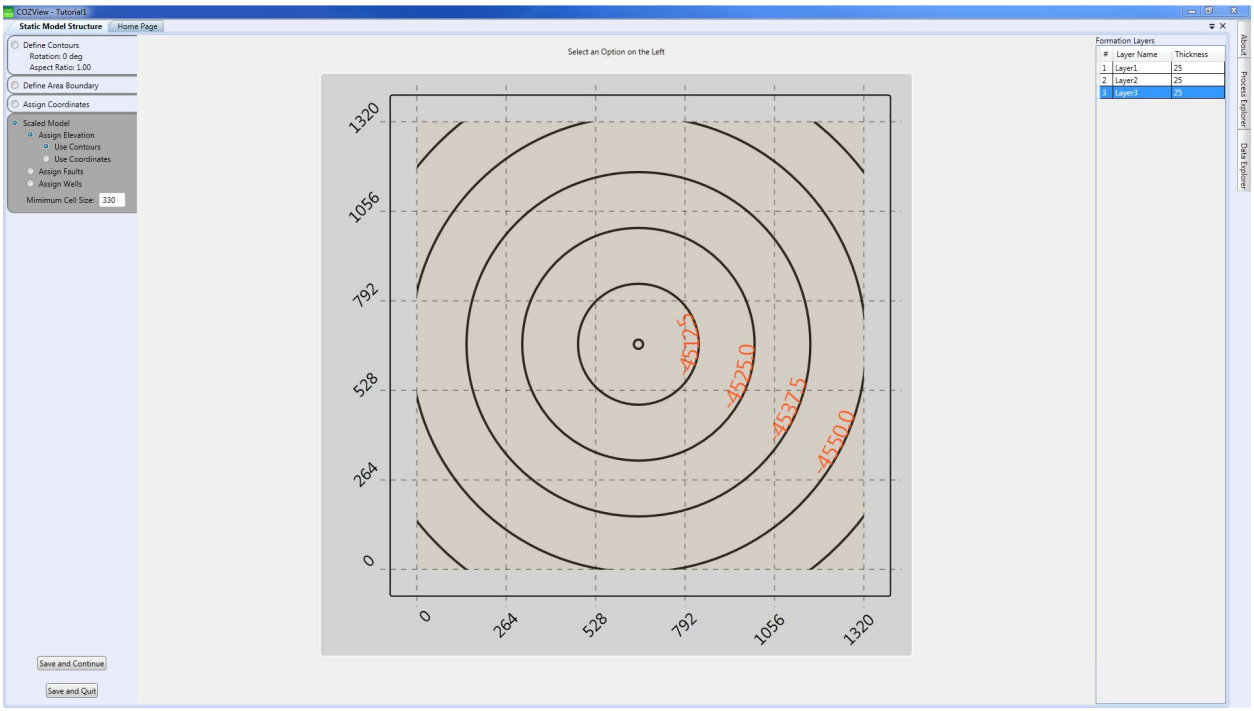


Assign Coordinates allows the user to provide coordinate positions for each of the boundary points provided. These are typically in feet as shown below.



Save and Continue is recommended.

Selection of **Scaled Model** and *Assign Elevation/Use Contours* allows the user to establish the structural contour elevations. The shallowest contour elevation (smallest circle) of -4500 ft ss and the deepest contour elevation of -4550 ft ss establish the contour interval.

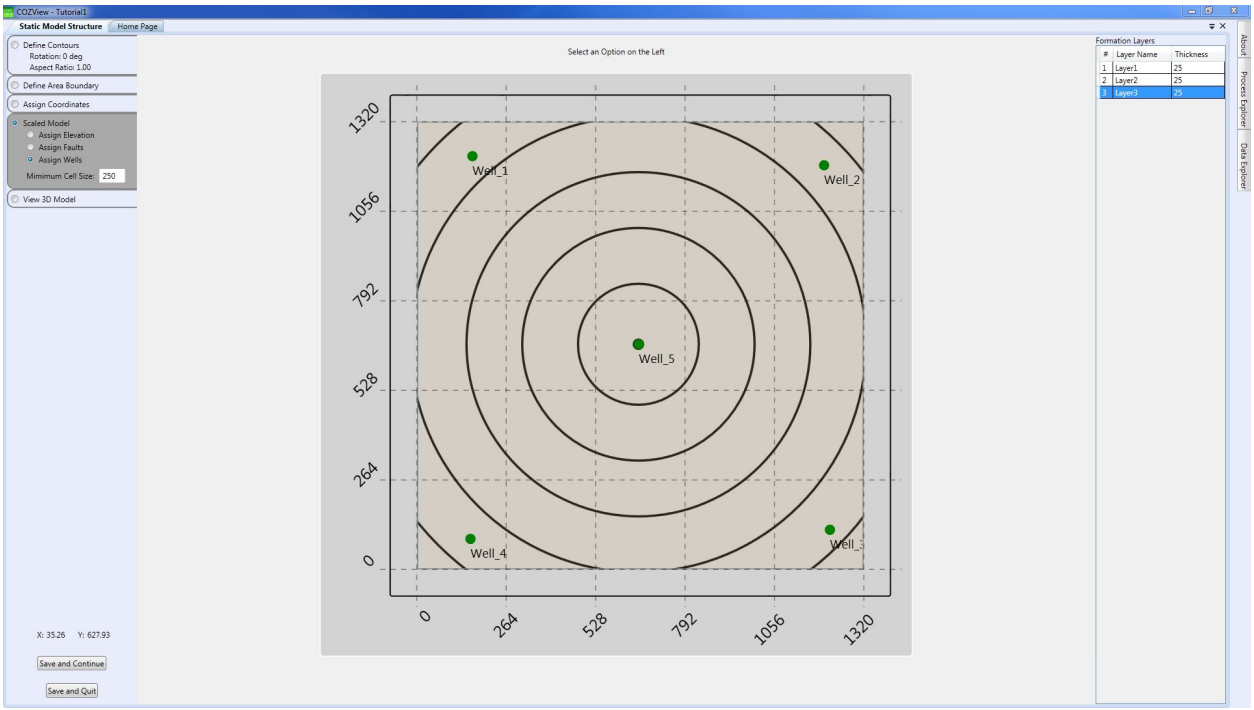


Save and Continue is recommended.

The default Minimum Cell Size displayed at the bottom of the Scaled Model area is 330 ft. Based on the model area boundary dimensions of 1320 ft by 1320 ft assigned previously, this would result in a 4 x 4 cell areal grid. For this example, which will use an injection well in the center of the area, we would prefer a 5 by 5 cell areal grid. Change the Minimum Cell Size to 250 ft and select **Save and Continue**.

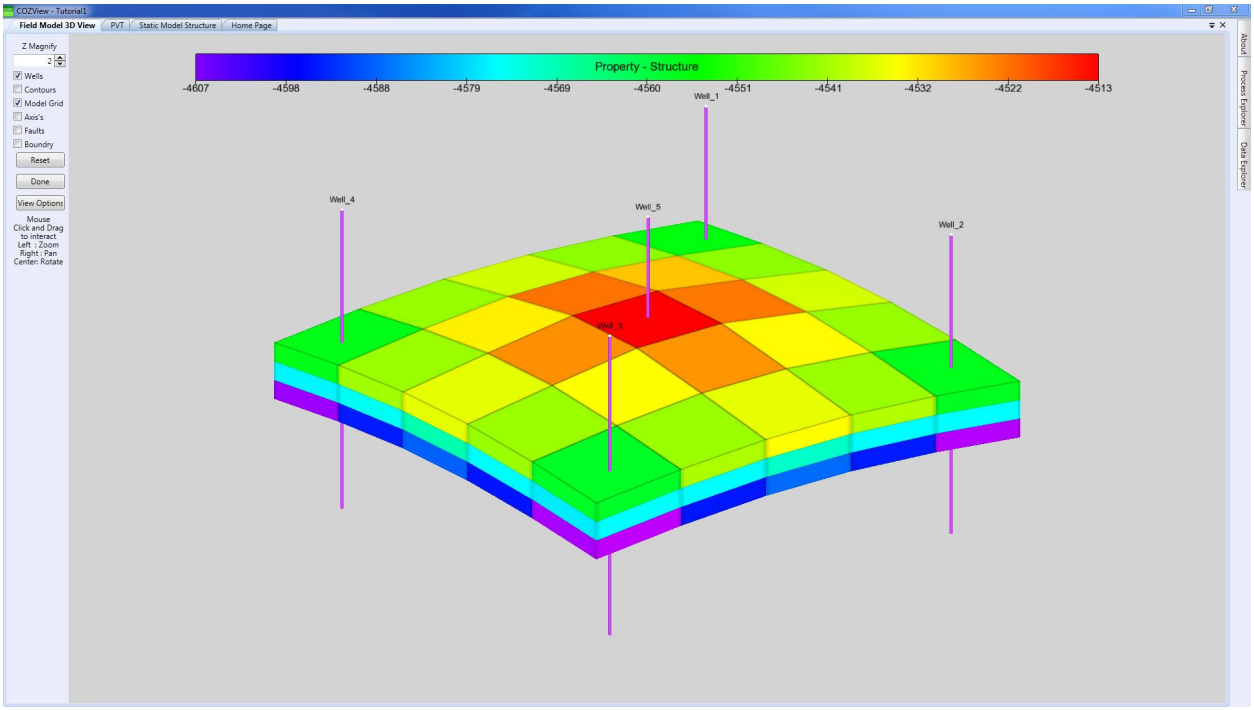
Assign Wells allows the user to position wells on the structural surface. Once all wells are positioned their KB and TD may be defined (optional). The KB and TD data are

Well	KB	TD
1	100	5100
2	100	5200
3	100	5100
4	100	5050
5	100	5200

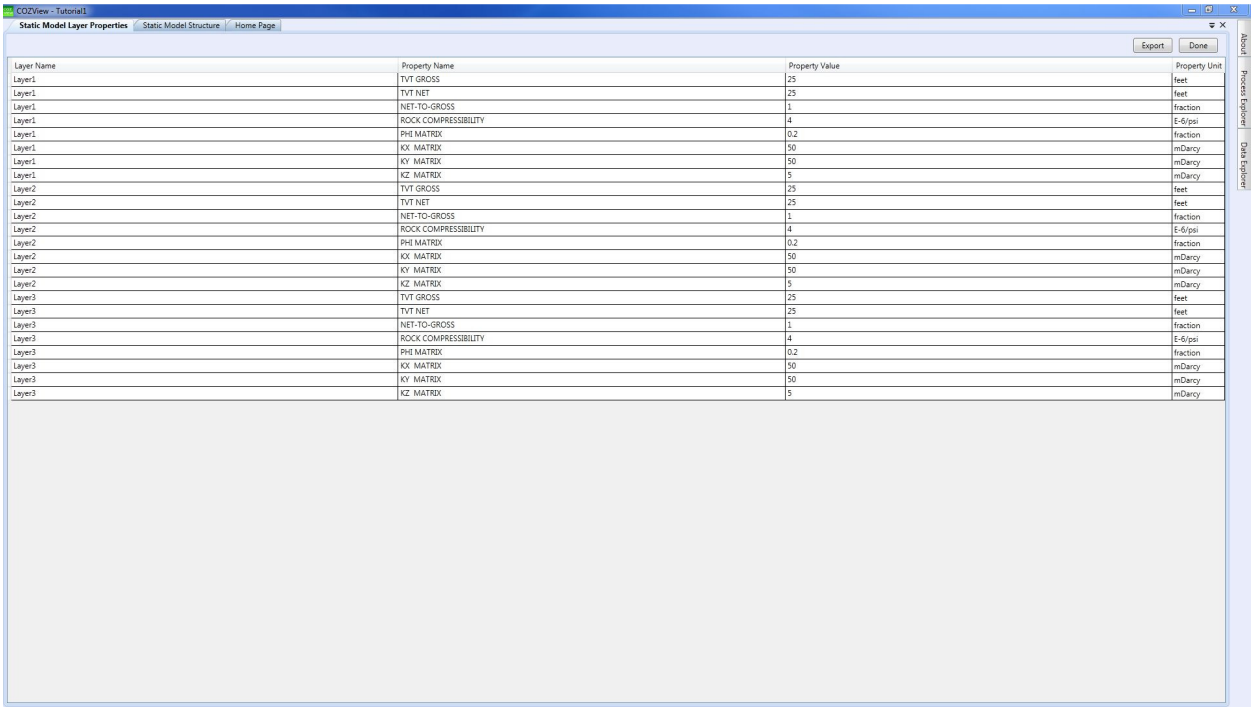


Save and Continue is recommended.

Select **Layer Properties 3D View** to confirm the structural model and well positions in a 3D view.



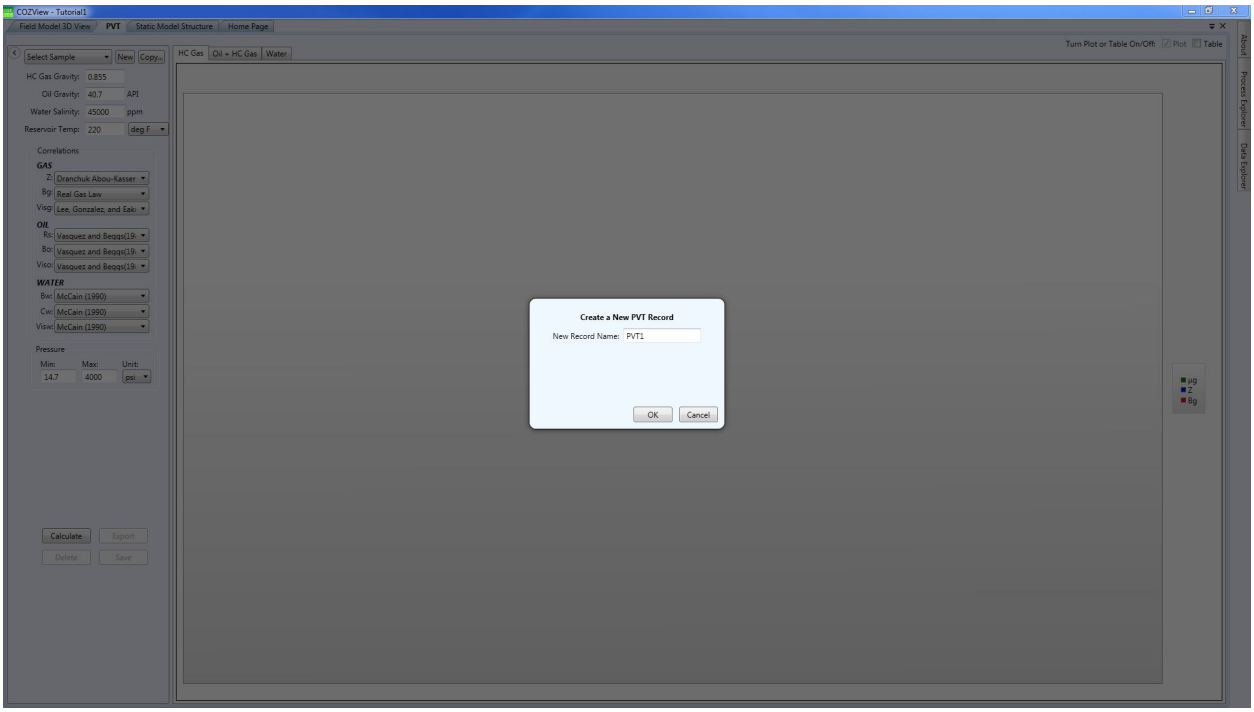
Layer Properties should be selected from the **Static Model** menu area. Values will already be input for the layers previously defined. The default units for each property are shown. The default values can be changed if appropriate.

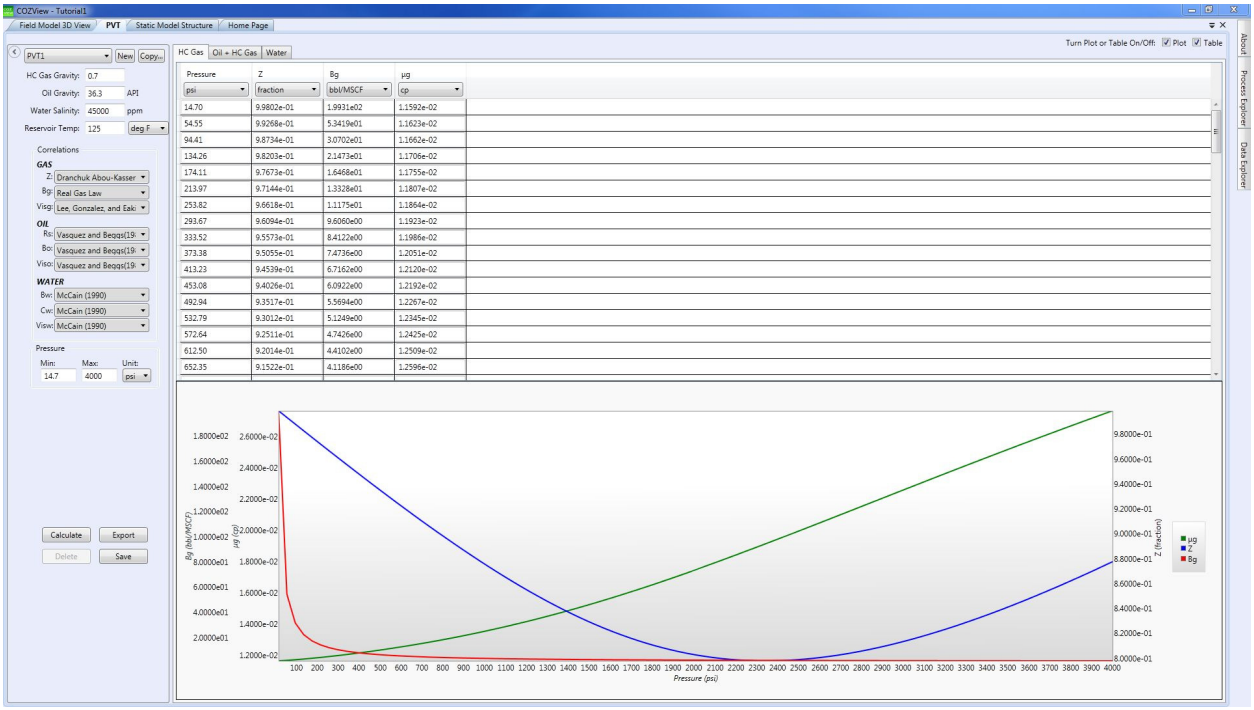


Layer Name	Property Name	Property Value	Property Unit
Layer1	TVT GROSS	25	feet
Layer1	TVT NET	25	feet
Layer1	NET-TO-GROSS	1	fraction
Layer1	ROCK COMPRESSIBILITY	4	E-6/psi
Layer1	PHI MATRIX	0.2	fraction
Layer1	KX MATRIX	50	mDarcy
Layer1	KY MATRIX	50	mDarcy
Layer1	KZ MATRIX	5	mDarcy
Layer2	TVT GROSS	25	feet
Layer2	TVT NET	25	feet
Layer2	NET-TO-GROSS	1	fraction
Layer2	ROCK COMPRESSIBILITY	4	E-6/psi
Layer2	PHI MATRIX	0.2	fraction
Layer2	KX MATRIX	50	mDarcy
Layer2	KY MATRIX	50	mDarcy
Layer2	KZ MATRIX	5	mDarcy
Layer3	TVT GROSS	25	feet
Layer3	TVT NET	25	feet
Layer3	NET-TO-GROSS	1	fraction
Layer3	ROCK COMPRESSIBILITY	4	E-6/psi
Layer3	PHI MATRIX	0.2	fraction
Layer3	KX MATRIX	50	mDarcy
Layer3	KY MATRIX	50	mDarcy
Layer3	KZ MATRIX	5	mDarcy

Select **Done** when finished to save the layer properties.

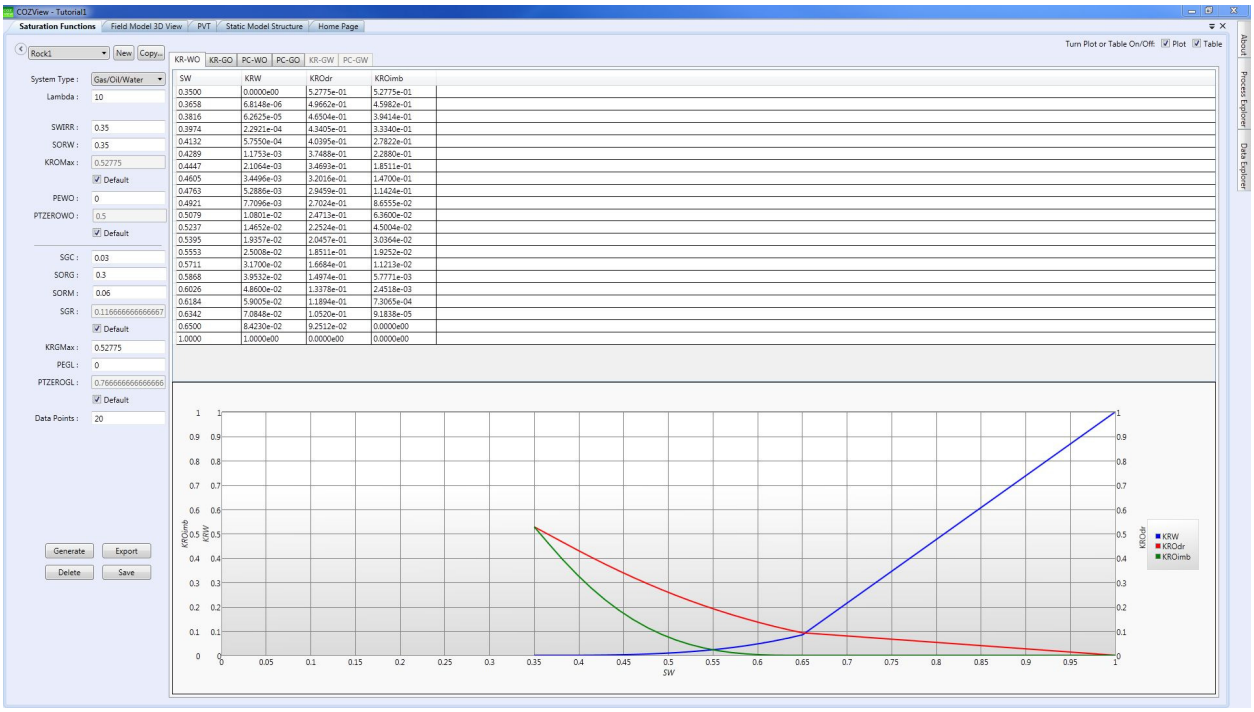
PVT should be selected from the **Fluid and Saturation Properties** menu area. The initial PVT properties screen will be blank. The **New** button should be selected to create a new set of PVT properties (table). The default values must be overridden by the user to create the PVT data shown below when the **Calculate** button is selected.





Select **Save** to save the data.

Saturation Functions should be selected from the **Fluid and Saturation Properties** menu area. The initial Saturation Function properties screen will be blank. The **New** button should be selected to create a new set of Saturation Function properties (table). The default values must be overridden by the user to create the Saturation Function data shown below when the **Generate** button is selected.

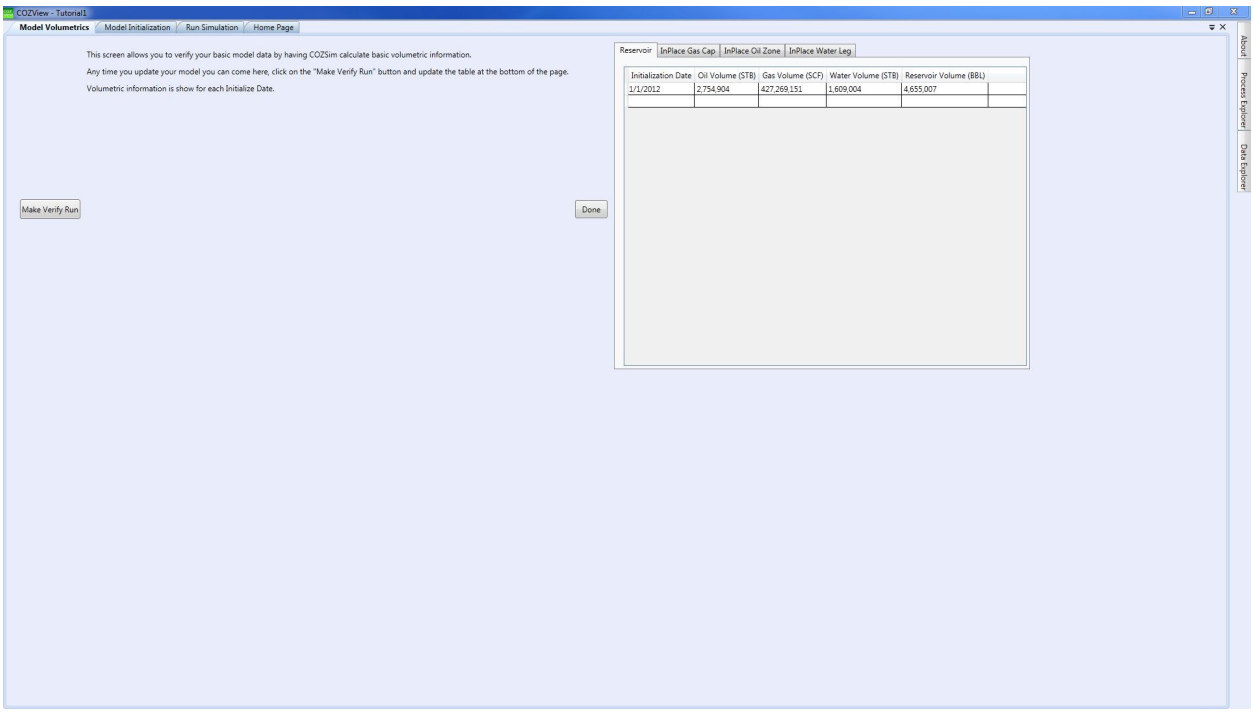


Select **Save** to save the data.

Model Initialization should be selected from the **Verify Model** menu area. This screen will initially be blank. The user can verify the volumetrics of the model that has been created by inputting appropriate values in the data fields. Initially the volumetrics of the model can be checked for the original conditions, if desired. This requires identification of the Fluid PVT and Saturation Function tables previously defined. The following data should be input for the initialization (current) conditions.

Initialization Date	1/1/2012
Model Type	2 phase
Pressure @Ref	1500
Reference Elevation	-4500
Elevation @ WOC	-5000 (is below 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 OIP of approximately 2.75 MMSTB should be reported subject to differences in the user defined model and this example.

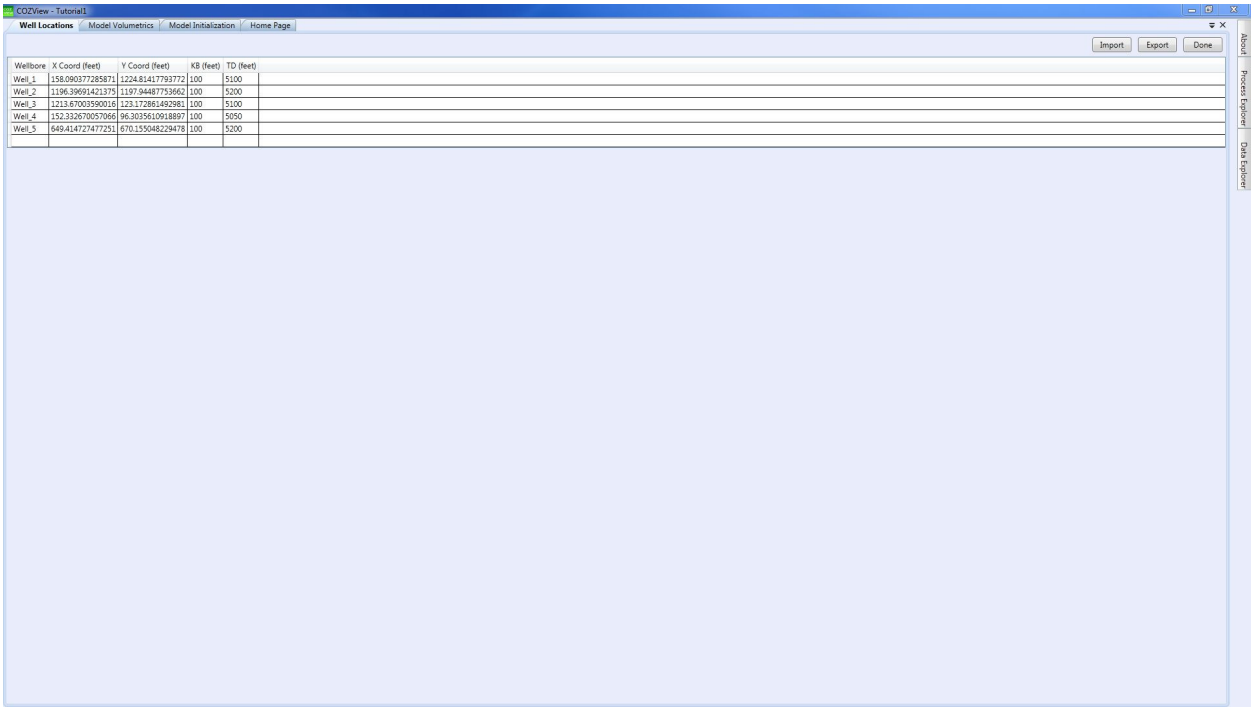


Select **Done** when finished.

If the user is not satisfied with the volumetric values calculated, changes to the model data created to this point can be made and saved and new volumetrics calculated.

The following steps will define well and field operating conditions for the prediction case to be run.

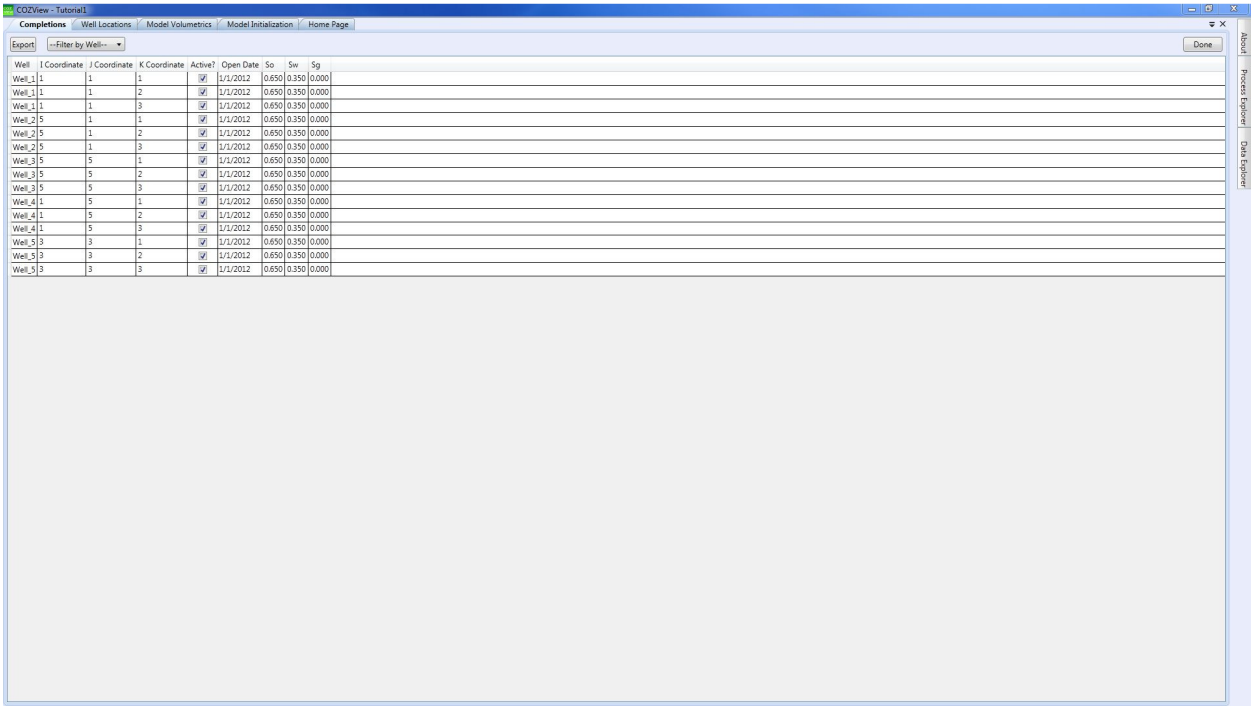
Select **Well Location** from the **Well Data** menu area to verify previously input well locations, KB elevations and TD. This is generally informational reporting only. If additional wells are required, the user should return to the **Static Model** menu area and interactively locate the new well(s). KB and TD values can be change if required.



Select **Done** to save.

Select **Completions** from the **Well Data** area to view and alter the well completions if appropriate. Initially all wells are assumed to be completed in all layers. The *Active check box* can be unchecked for any well layer completion, if desired. No completion changes were made to the default values for this example.

It is important to keep track of the dates shown in the various well and field control screens. These must be consistent with the Initialization Date (start date for the prediction simulation run). These dates should be changed if necessary.



Well	I Coordinate	J Coordinate	K Coordinate	Active?	Open Date	So	Sw	Sg
Well_1	1	1	1	☑	1/1/2012	0.650	0.350	0.000
Well_1	1	1	2	☑	1/1/2012	0.650	0.350	0.000
Well_1	1	1	3	☑	1/1/2012	0.650	0.350	0.000
Well_2	5	1	1	☑	1/1/2012	0.650	0.350	0.000
Well_2	5	1	2	☑	1/1/2012	0.650	0.350	0.000
Well_2	5	1	3	☑	1/1/2012	0.650	0.350	0.000
Well_3	5	5	1	☑	1/1/2012	0.650	0.350	0.000
Well_3	5	5	2	☑	1/1/2012	0.650	0.350	0.000
Well_3	5	5	3	☑	1/1/2012	0.650	0.350	0.000
Well_4	1	5	1	☑	1/1/2012	0.650	0.350	0.000
Well_4	1	5	2	☑	1/1/2012	0.650	0.350	0.000
Well_4	1	5	3	☑	1/1/2012	0.650	0.350	0.000
Well_5	3	3	1	☑	1/1/2012	0.650	0.350	0.000
Well_5	3	3	2	☑	1/1/2012	0.650	0.350	0.000
Well_5	3	3	3	☑	1/1/2012	0.650	0.350	0.000

If any changes are made to the well completions select **Done** to save.

Select **Well Constraints** from the **Prediction/Well Parameters** menu area. This screen will initially be blank. The **Batch Generate** button is a fast way to input values for multiple wells. The user can input the values noted below for the Liquid Producer wells and separately for the GAS/CO2 Injection wells.

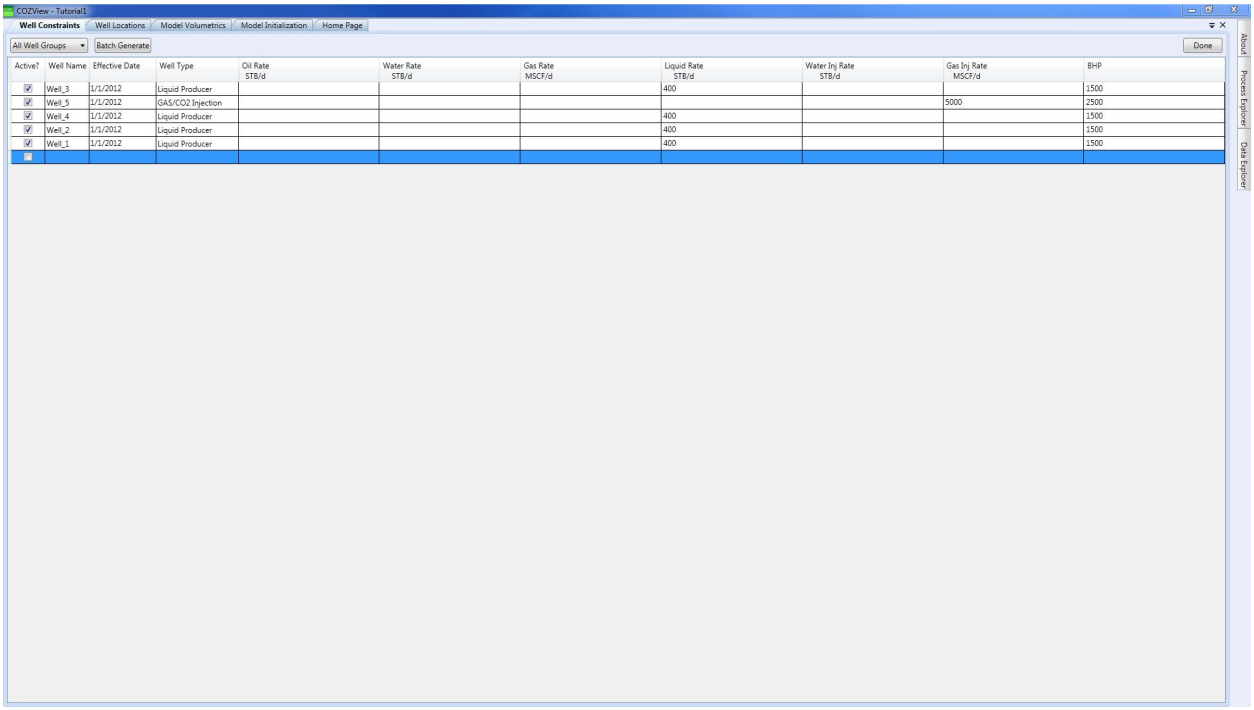
Well Constraints

Injection well (Well_5): Center well in the five spot

Maximum Bottom hole pressure (psia)	2500
Maximum CO2 Injection rate (MSCF/day)	5000

Producers (Well_1 – Well_4)

Minimum BHP (psia)	1500
Maximum Production Liquid rate (STB/day)	400

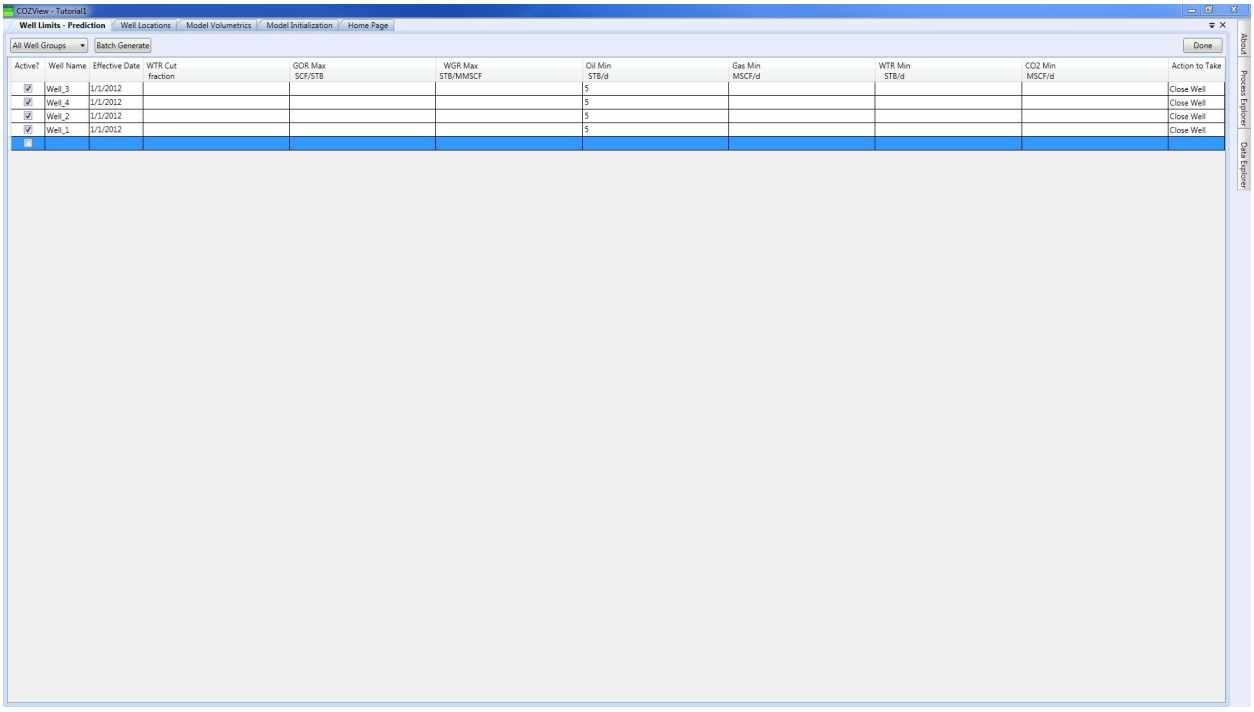


Select **Done** to save.

Select **Well Limits** from the **Prediction/Well Parameters** menu area. This screen will initially be blank. The **Batch Generate** button is a fast way to input values for multiple wells.

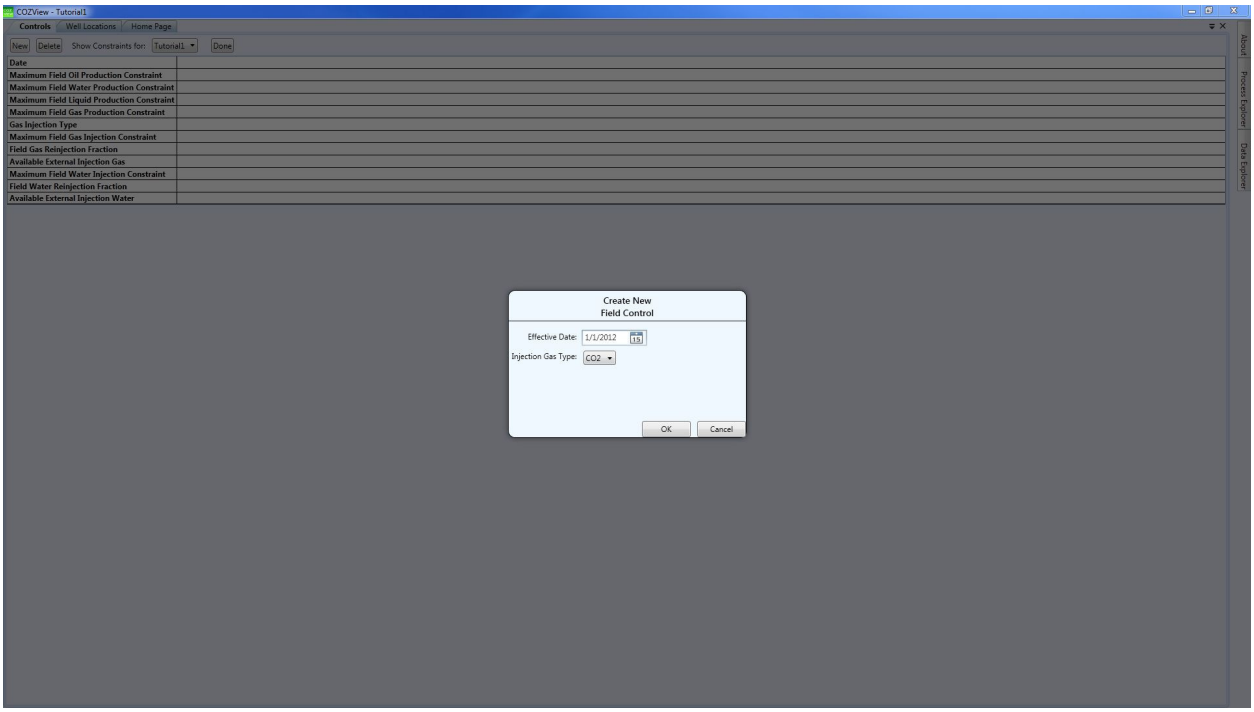
Well limits

Minimum Oil rate (STB/day)	5
Action to take	Close well



Select **Done** to save.

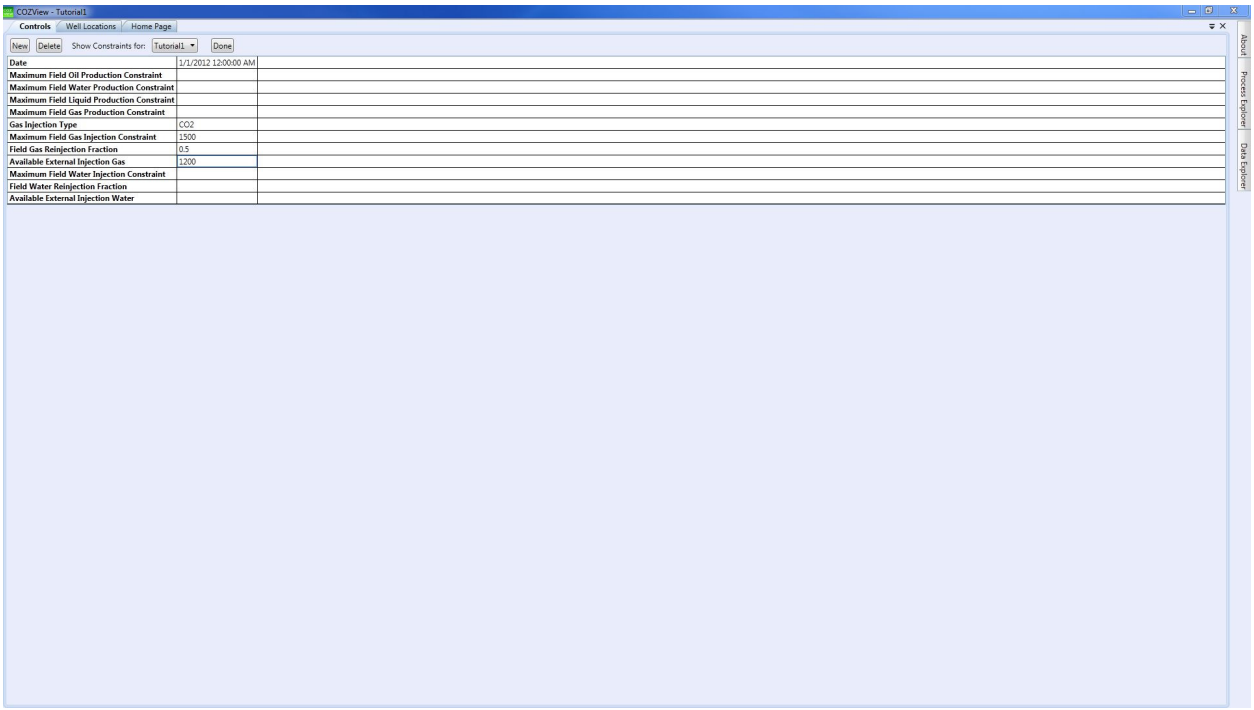
Select **Field** (Facility) **Controls** from the **Prediction Period/Field Parameters** menu area. Select **New** to establish the Effective Date (start date for Field Controls) and the **Injection Gas Type**. Please note that the default Injection Gas Type is CO2 gas. In this tutorial it is required to select CO2 as **Injection Gas Type.**



Select **OK** to continue.

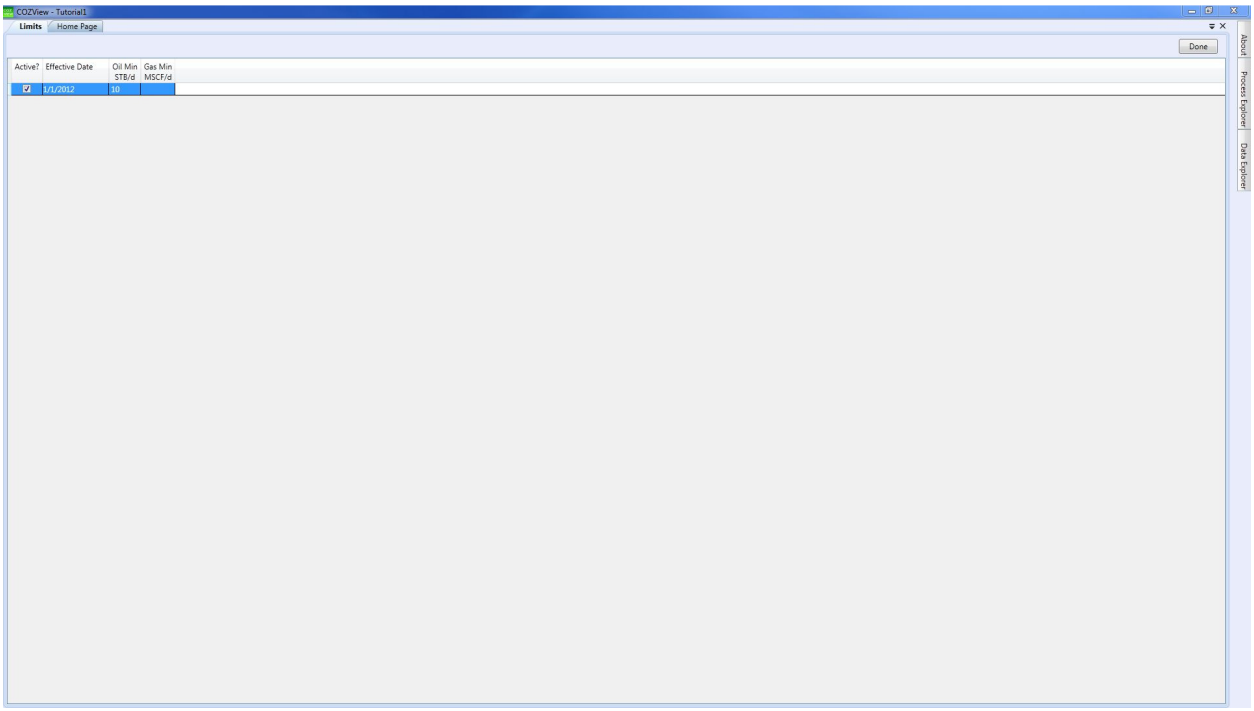
Field Controls

Maximum Field Gas Injection Constraint (MSCF/day)	1500
Field Gas Reinjection Fraction	0.5
Available External Injection gas (MSCF/day)	1200



Select **Done** to save.

Select **Limits** from the **Prediction Period/Field Parameters** menu area. Check the **Active** box and input appropriate values. It is always wise to have a field limit specified such that the simulation run will stop when the field limit is reached.

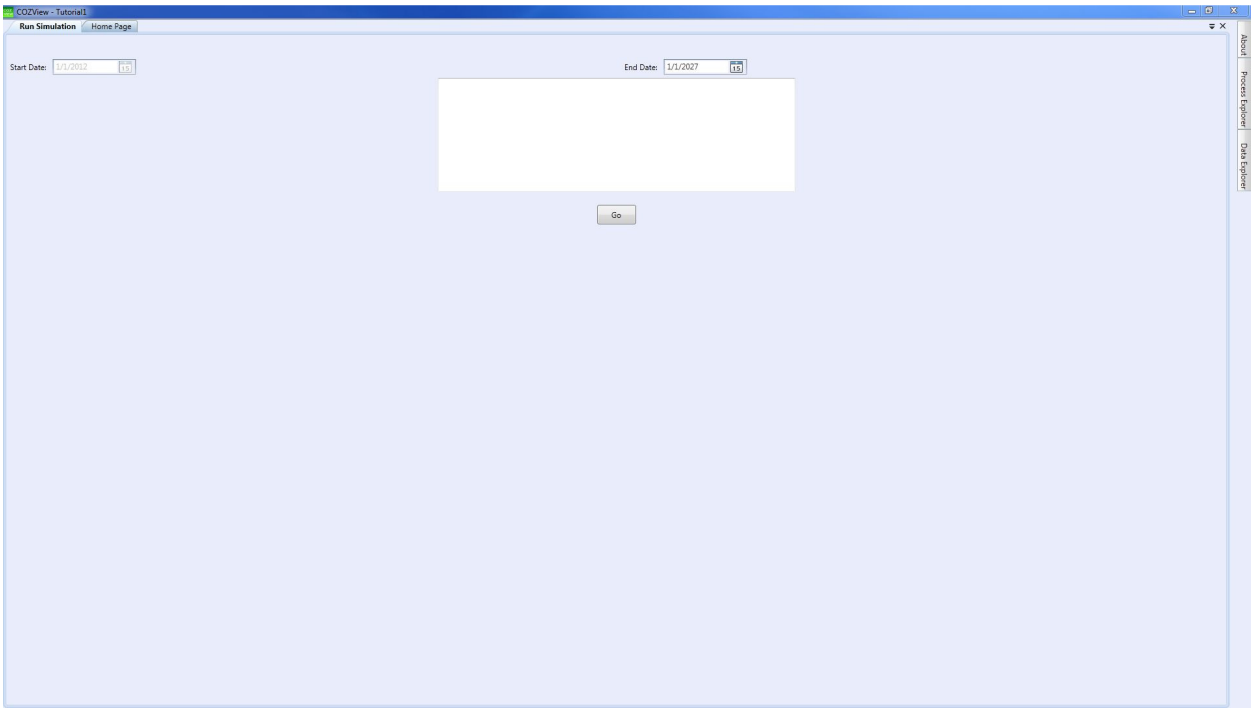


Select **Done** to save.

It is prudent at this stage to return to the various well and field parameter screen to insure that data, particularly dates, are set appropriately.

Select **Run Simulation**. The **Model Initialization** date 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 1/1/2027.



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

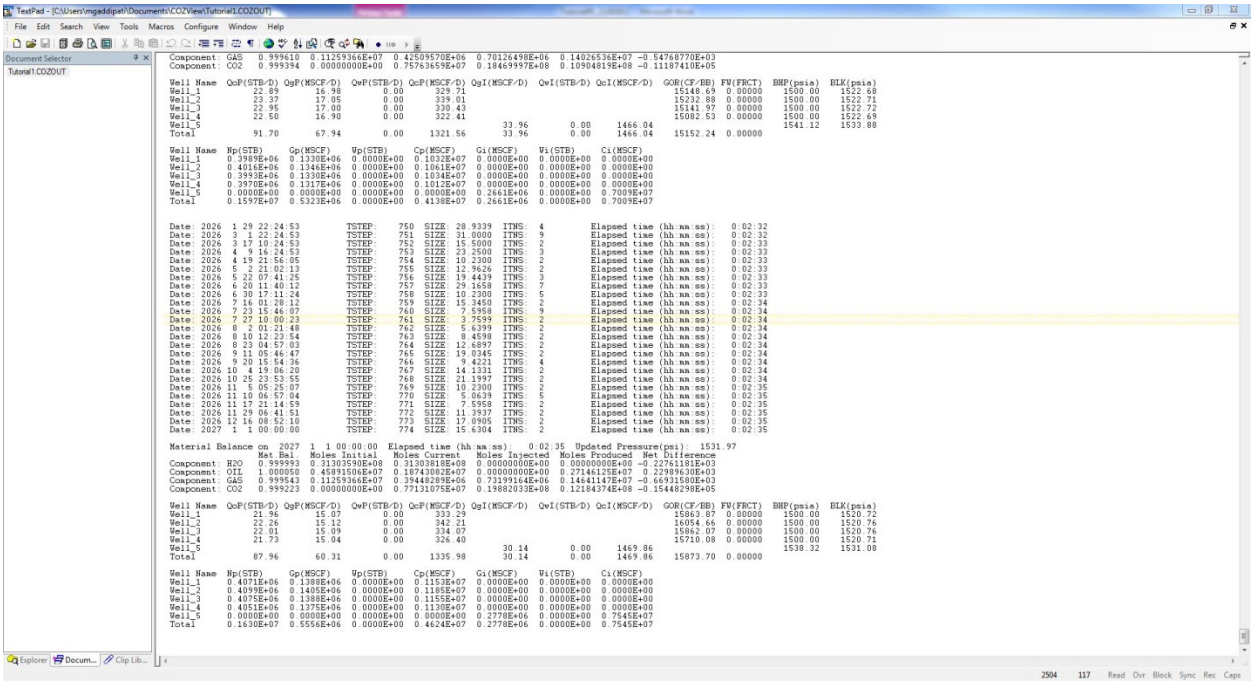
The Simulator Runner window will appear and update the CPU activity for the simulation run. **DO NOT** close the Simulator Runner window during the simulation run. It can be minimized. Closing the Simulator runner window will stop the simulation run.

DO NOT close COZView during the simulation run. It can be minimized. Closing COZView will not stop the simulation run, but the simulation results will not be loaded at the conclusion of the simulation run. **DO NOT** change projects in COZView during a simulation run for this same reason. **DO NOT** turn the computer off during the simulation run. All simulation results will be lost.

Two files are created early during the simulation run which may help the user track the progress of the simulation run. These are stored in the COZView directory along with various project database and result files. The files are *Projectname*.COZOUT and *Projectname*.COZDAT. The .COZDAT file is the input data "deck" prepared by COZView for COZSim. The .COZOUT file reports well production and injection activity for timesteps during the simulation run. It is update frequently. Both of these files can be opened with a Text editor. The .COZDAT file can be reviewed to assure that the data "deck" is setup as

the user anticipated. The .COZOUT file can be reviewed as the simulation run progresses. If the results are not as anticipated the run can be stopped in the **Simulator Runner** window.

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



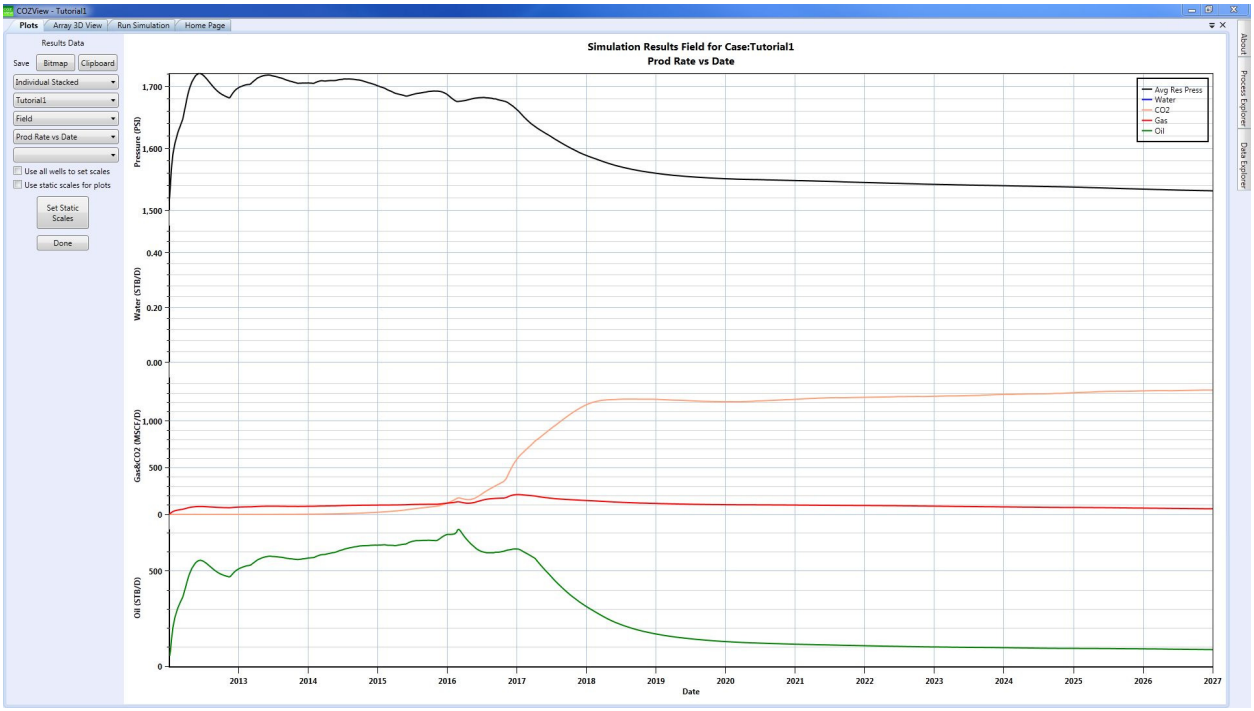
DO NOT delete are change these files during the simulation run. If the same project is re-run with changes to some parameters, these files will be overwritten.

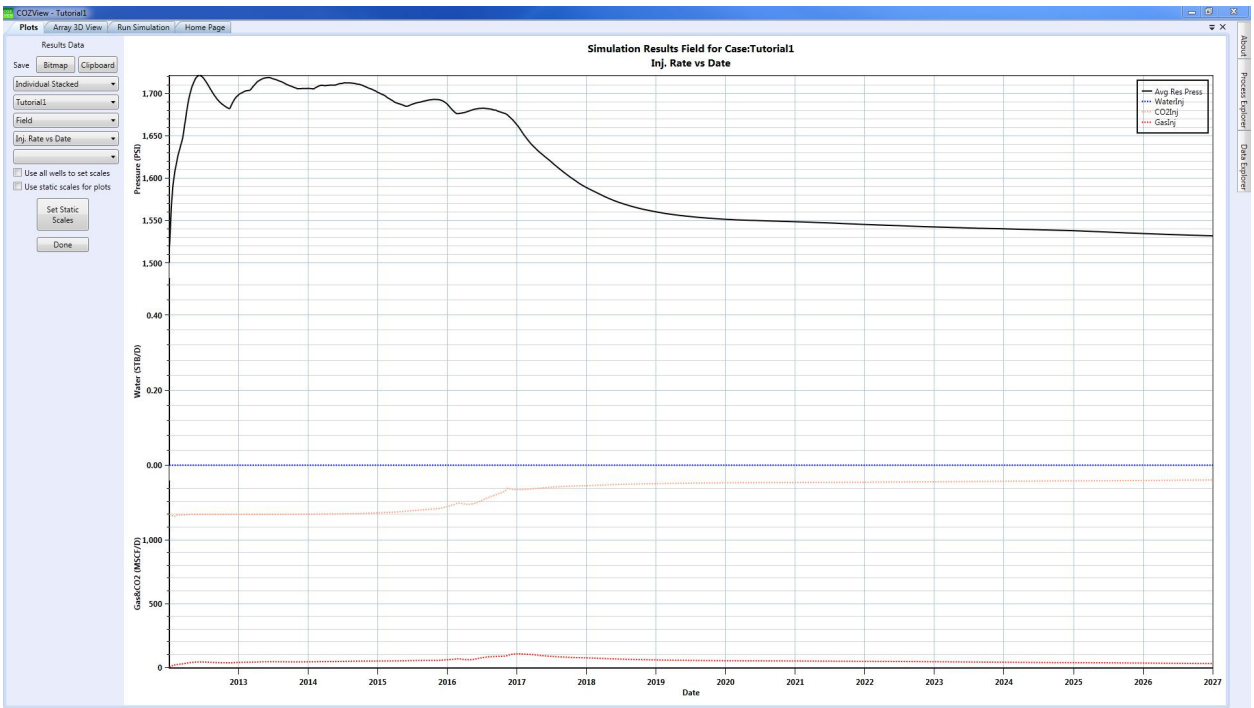
When the **Simulation Runner** window disappears, the simulation run has completed.

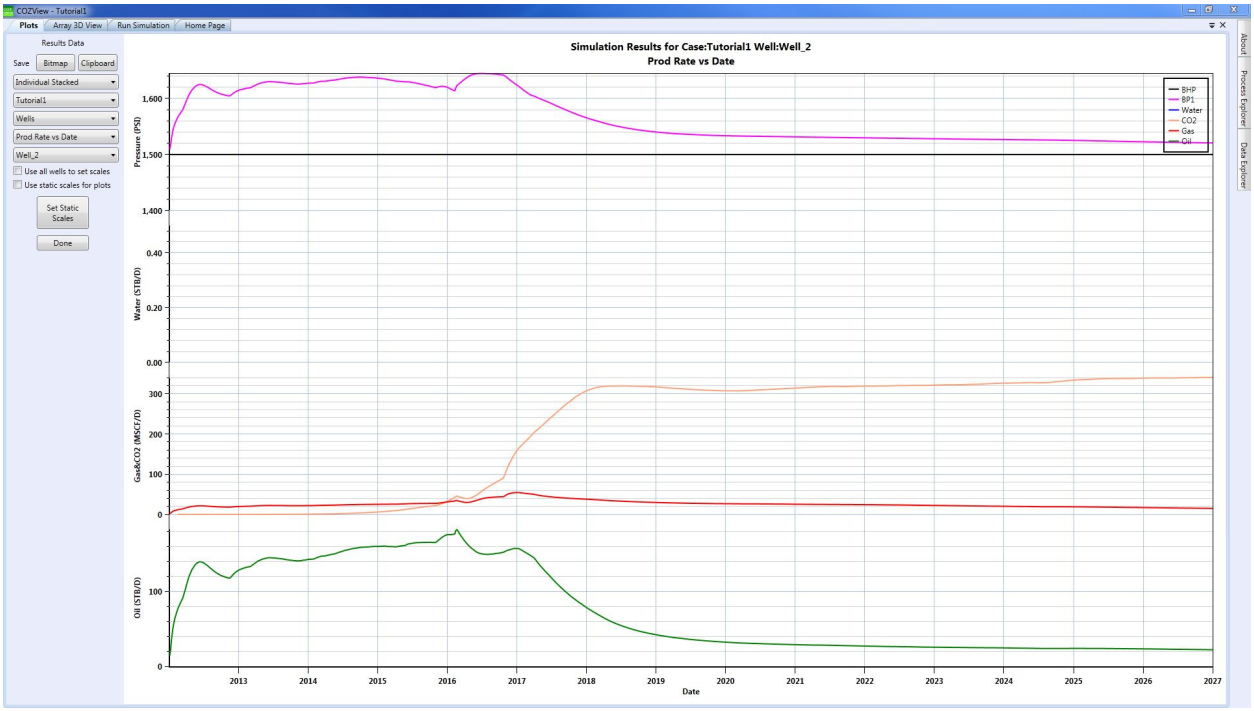
At the completion of the simulation run two small windows will appear which advise the user that the Map and PLT (plot) results are being loaded into COZView.

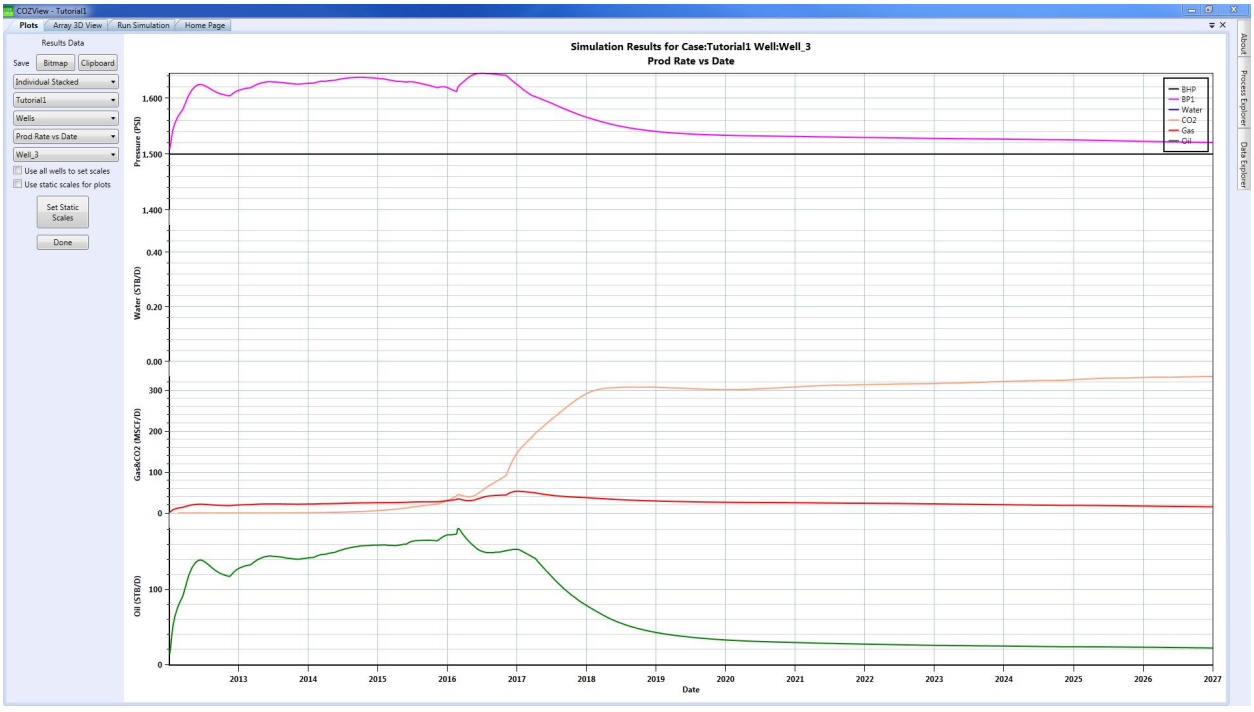
Select **Plots** from the **Simulation Results** area. This will give the user access to various simulation plots for the wells and field. A sample of the available plots for this prediction simulation is shown below.

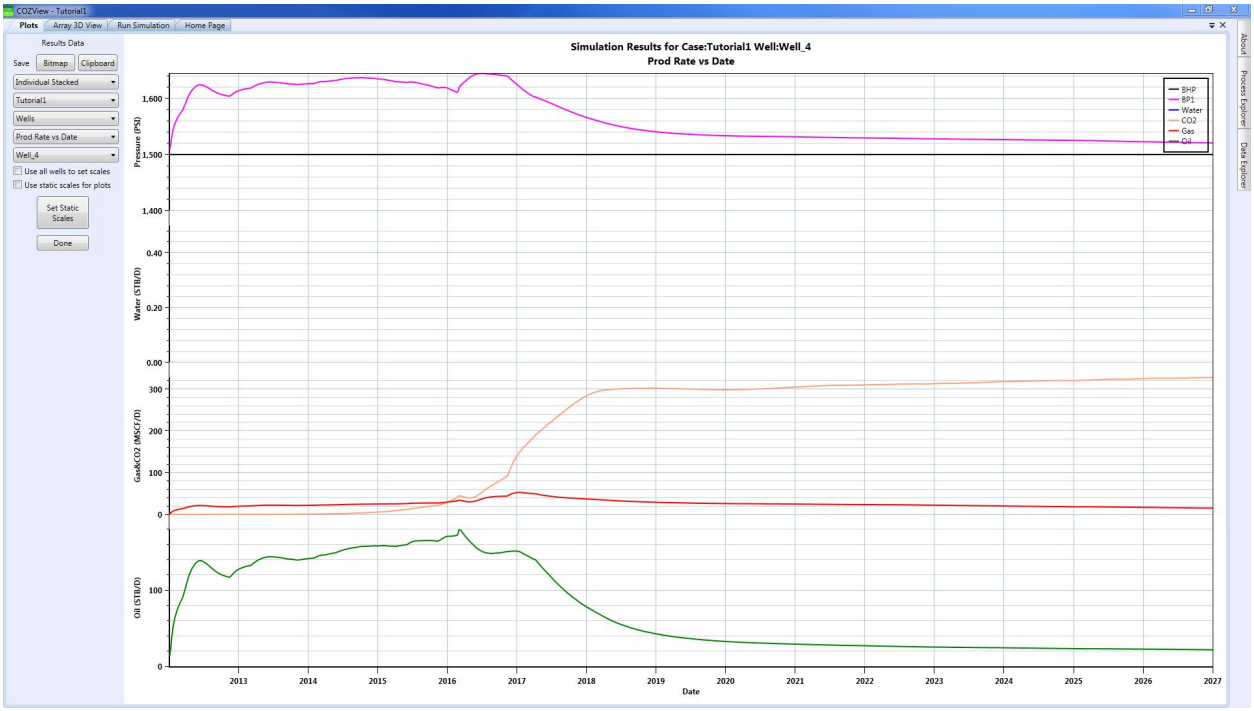
It has been found prudent to close all menu tabs except the **Home Page** and save data as may be requested before selecting any of the **Simulation Results** menus. This assures that the plot, map and table files are refreshed and prior results are not shown in error.

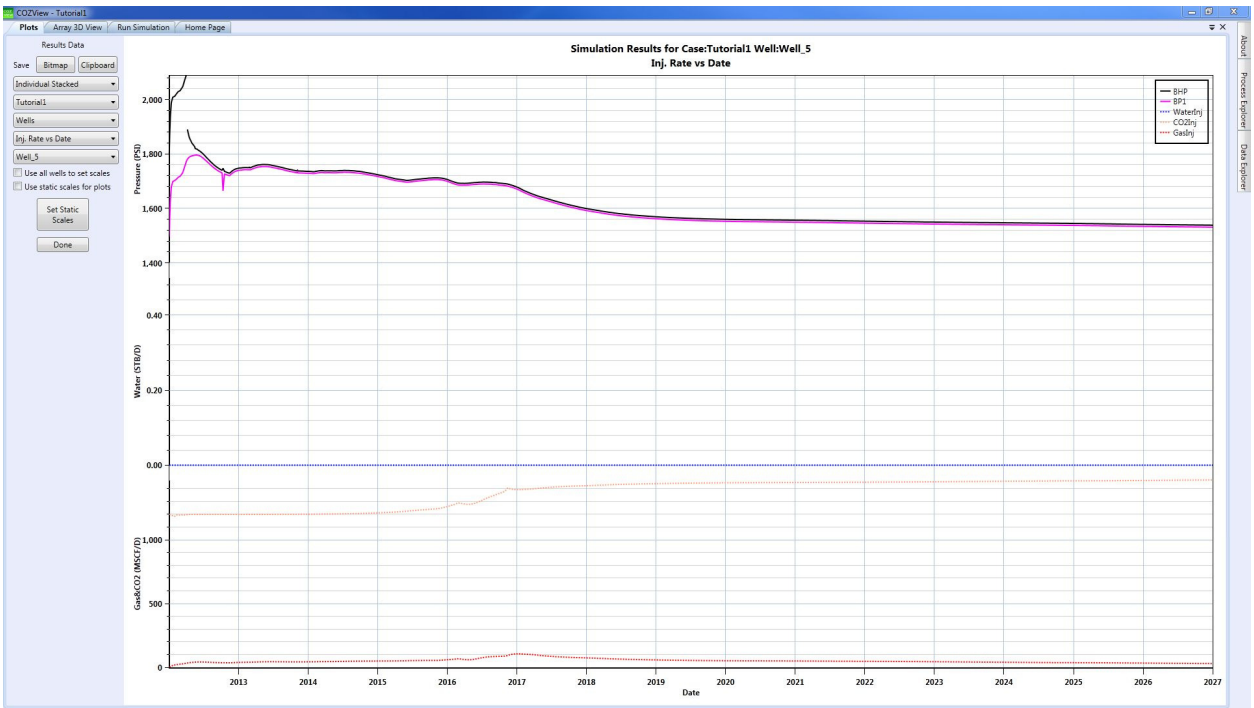

COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
Tutorial1
Field
Prod Rate vs Date
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
About
Process Explorer
Data Explorer
Simulation Results Field for Case:Tutorial1
Prod Rate vs Date
Avg Res Press
Water
CO2
Gas
Oil
Pressure (PSI)
Water (STB/D)
Gas&CO2 (MSCF/D)
Oil (STB/D)
Date


COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
Tutorial1
Field
Inj. 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:Tutorial1
Inj. Rate vs Date
Avg Res Press
WaterInj
CO2Inj
GasInj
Pressure (PSI)
Water (STB/D)
Gas&CO2 (MSCF/D)
Date

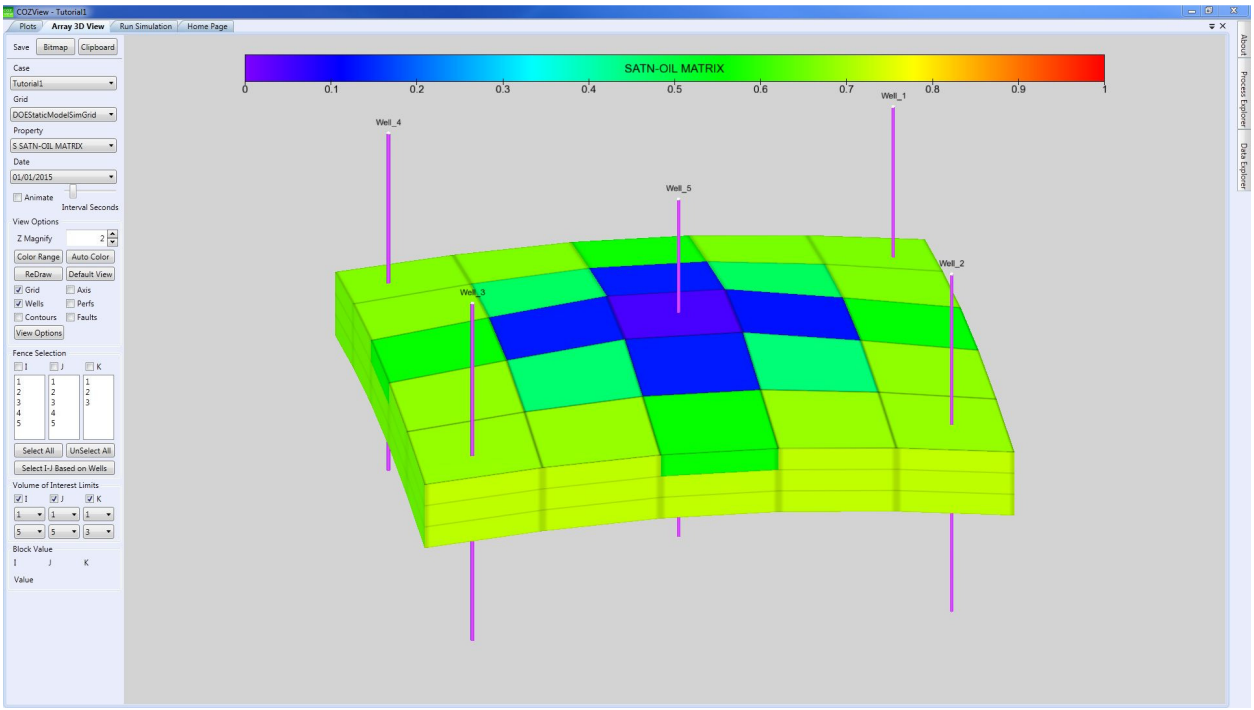

COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
Tutorial1
Wells
Prod Rate vs Date
Well_2
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
Simulation Results for Case:Tutorial1 Well:Well_2
Prod Rate vs Date
BHP
BP1
Water
CO2
Gas
Oil
Pressure (PSI)
Water (STB/D)
Gas&CO2 (MSCF/D)
Oil (STB/D)
Date
About
Process Explorer
Data Explorer

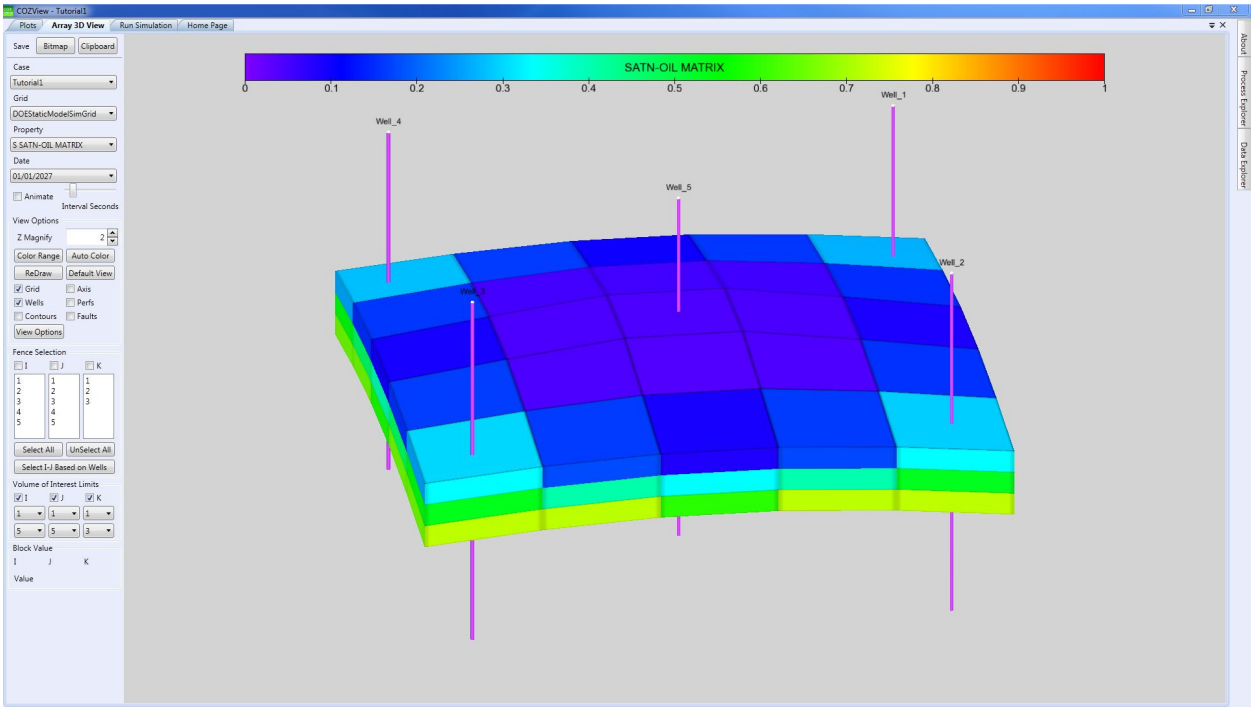

COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
Tutorial1
Wells
Prod Rate vs Date
Well_3
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
Simulation Results for Case:Tutorial1 Well:Well_3
Prod Rate vs Date
BHP
BP1
Water
CO2
Gas
Oil
Pressure (PSI)
Water (STB/D)
Gas&CO2 (MSCF/D)
Oil (STB/D)
Date
About
Process Explorer
Data Explorer

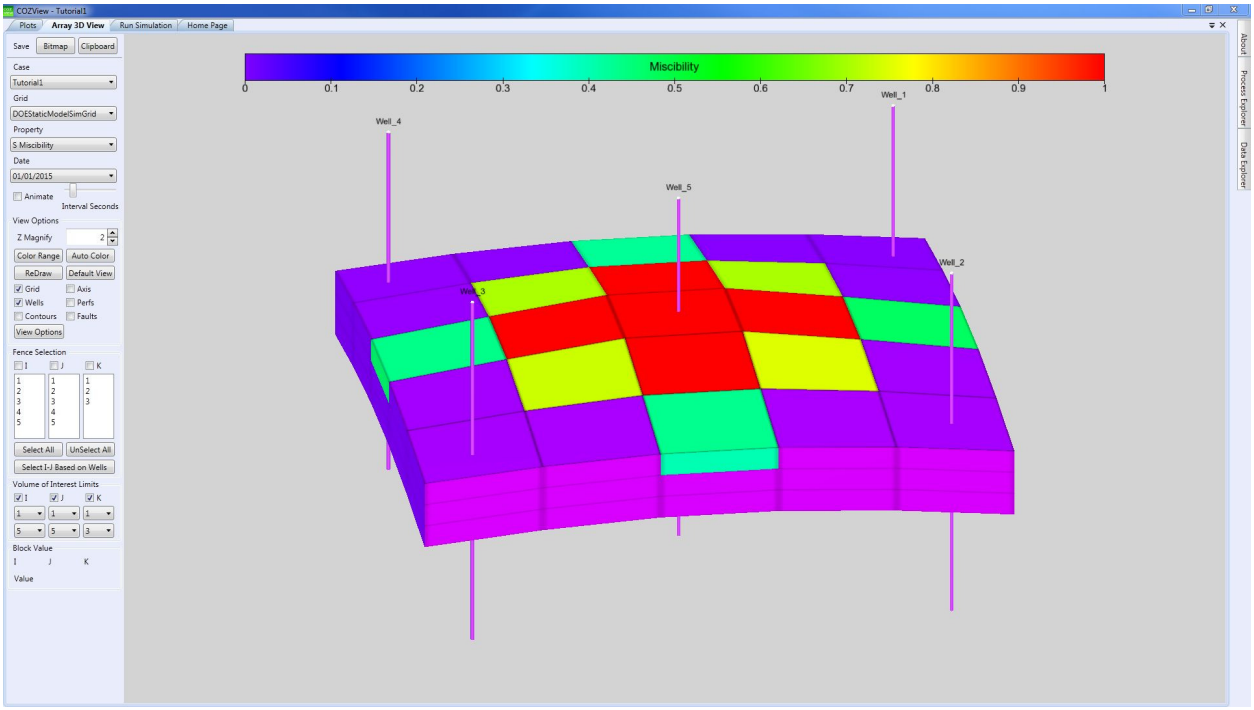

COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
Tutorial1
Wells
Prod Rate vs Date
Well_4
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
Simulation Results for Case:Tutorial1 Well:Well_4
Prod Rate vs Date
BHP
BP1
Water
CO2
Gas
Oil
Pressure (PSI)
Water (STB/D)
Gas&CO2 (MSCF/D)
Oil (STB/D)
Date
About
Process Explorer
Data Explorer

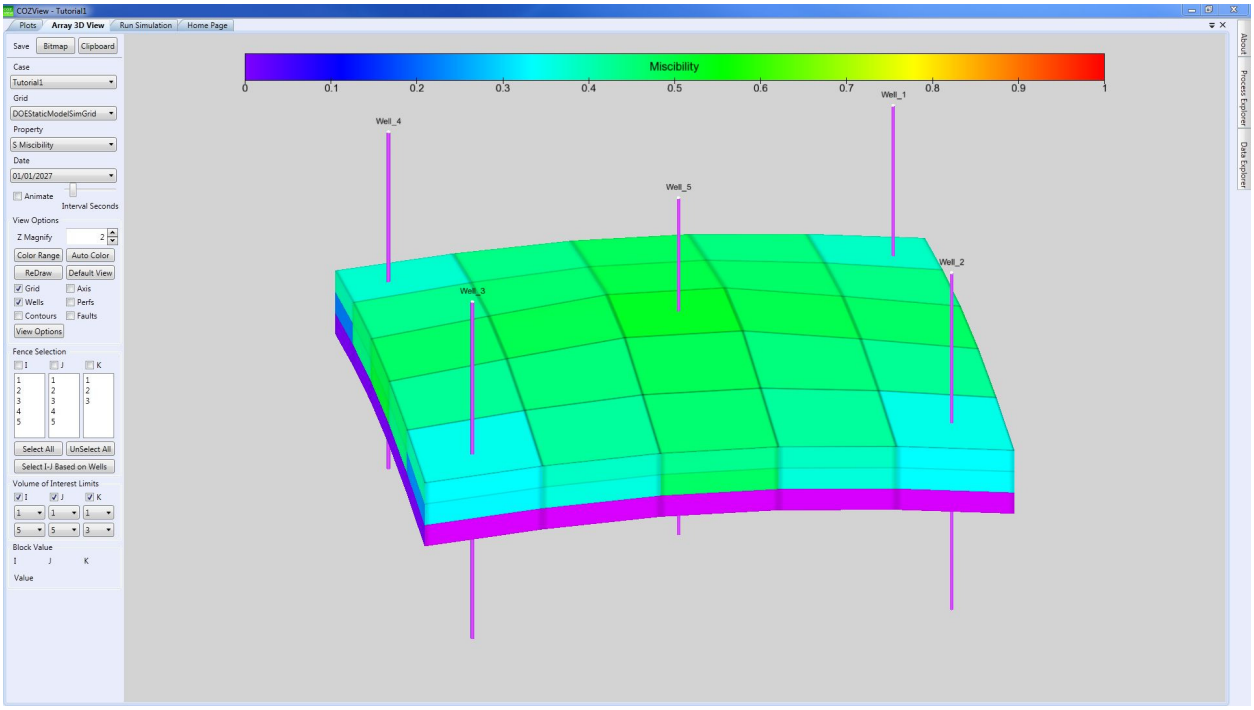

COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
Tutorial1
Wells
Inj. Rate vs Date
Well_5
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
Simulation Results for Case:Tutorial1 Well:Well_5
Inj. Rate vs Date
BHP
BP1
WaterInj
CO2Inj
GasInj
Pressure (PSI)
Water (STB/D)
Gas&CO2 (MSCF/D)
Date
About
Process Explorer
Data Explorer

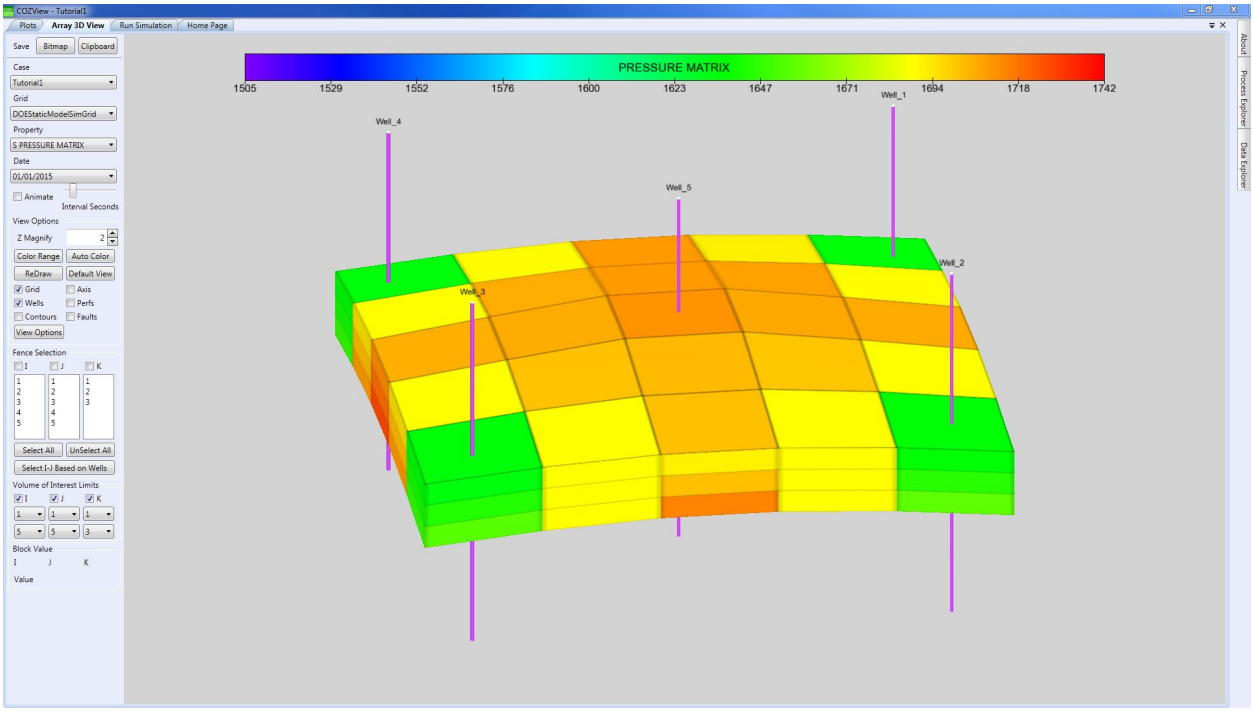
Select **Array 3D View** from the **Simulation Results** area. This will give the user access to various simulation maps for the field. A sample of the available maps for this prediction simulation is shown below.

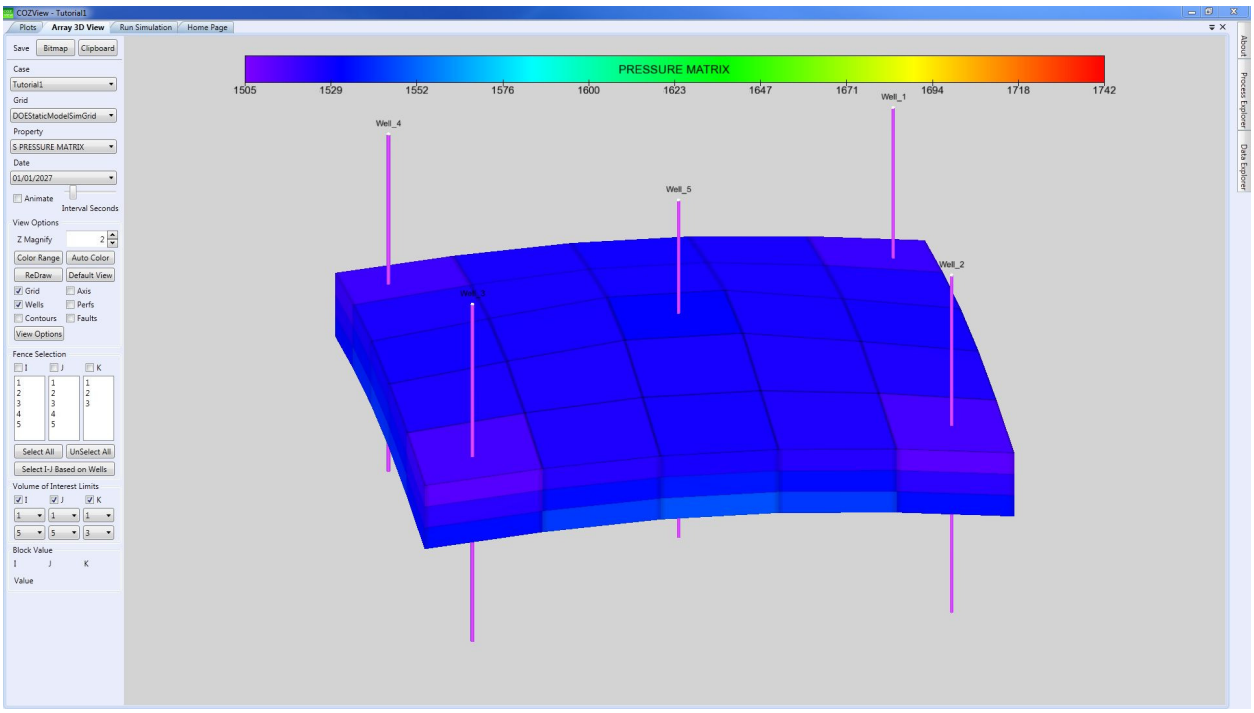





COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Save
Bitmap
Clipboard
Case
Tutorial1
Grid
DOEStaticModelSimGrid
Property
S Miscibility
Date
01/01/2015
Animate
Interval Seconds
View Options
Z Magnify
Color Range
Auto Color
ReDraw
Default View
Grid
Axis
Wells
Perfs
Contours
Faults
View Options
Fence Selection
Select All
UnSelect All
Select I-J Based on Wells
Volume of Interest Limits
Block Value
Value
Miscibility
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
About
Process Explorer
Data Explorer


COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Save
Bitmap
Clipboard
Case
Tutorial1
Grid
DOEStaticModelSimGrid
Property
S Miscibility
Date
01/01/2027
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
Value
Miscibility
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
About
Process Explorer
Data Explorer


COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Save
Bitmap
Clipboard
Case
Tutorial1
Grid
DOEStaticModelSimGrid
Property
S PRESSURE MATRIX
Date
01/01/2015
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
Value
PRESSURE MATRIX
1505
1529
1552
1576
1600
1623
1647
1671
1694
1718
1742
Well_1
Well_2
Well_3
Well_4
Well_5
About
Process Explorer
Data Explorer


COZView - Tutorial1
Plots
Array 3D View
Run Simulation
Home Page
Save
Bitmap
Clipboard
Case
Tutorial1
Grid
DOEStaticModelSimGrid
Property
S PRESSURE MATRIX
Date
01/01/2027
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
Value
PRESSURE MATRIX
1505
1529
1552
1576
1600
1623
1647
1671
1694
1718
1742
Well_1
Well_2
Well_4
Well_5
About
Process Explorer
Data Explorer

The user can also select **Tables** from the **Simulation Results** area. This will provide access to tabular simulation results for wells and the field. These tables can be exported to .csv files for use in spreadsheet applications.

It is also noted that any plot displays can be saved to Bitmap files or to the Clipboard for pasting into report documents. Any map displays can be saved to Bitmap files.

Simulation Results

The simulation results for this pilot are very interesting.

First Contact miscibility was achieved (Miscibility index of 1.0) near the injection well as shown in the Miscibility map in all layers by 1/1/2015. The reservoir pressure map in Layer 1 at 1/1/2015 indicates a pressure of 1729 psia at the injection well. By 1/1/2027 the Miscibility map in Layer 1 show less than full miscibility at the injection well. This is due to a decline in the reservoir pressure.

This presents the user with an opportunity to use the model to optimize the pilot performance by better management of well completions and production practices to maintain miscible conditions in the reservoir.

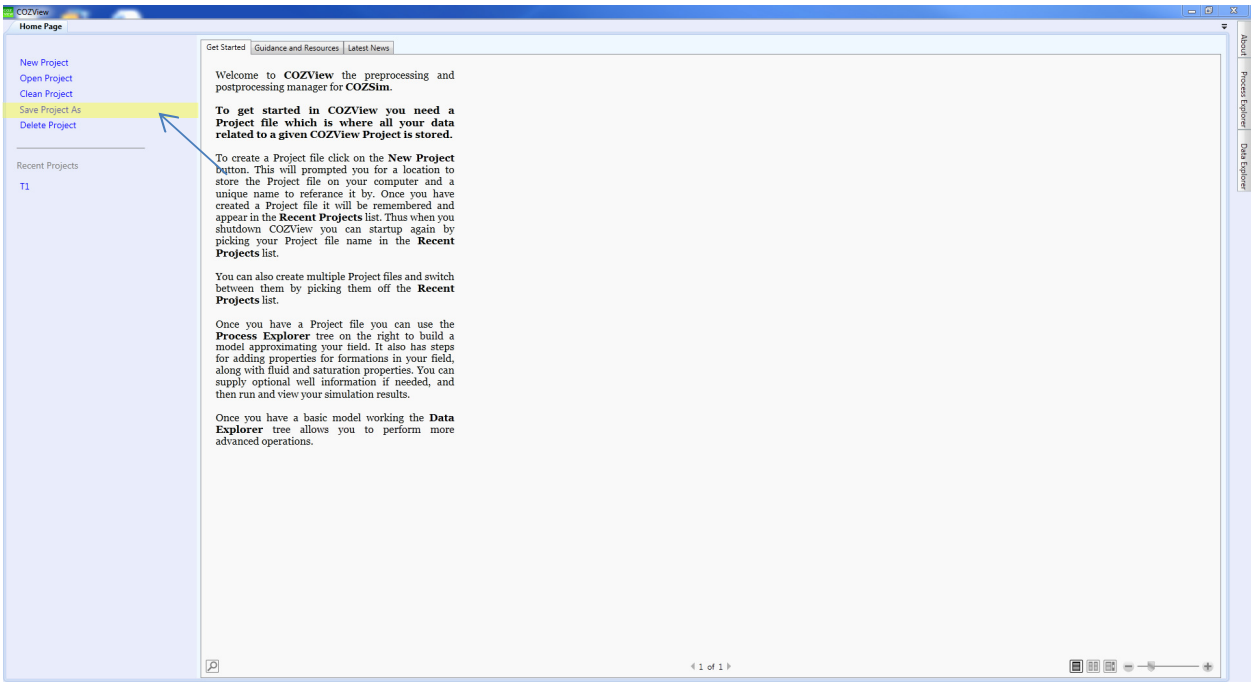
TUTORIAL #1-1

This tutorial is a minor modification of the model developed in Tutorial 1. This is an example of how to model a pattern area for CO2 injection that has been previously water flood. It is assumed that the area has been uniformly swept by water down to a uniform oil saturation. In this case, the oil saturation at the end of the water flood is 50 percent. This value is higher than the SORW originally used in Tutorial 1.

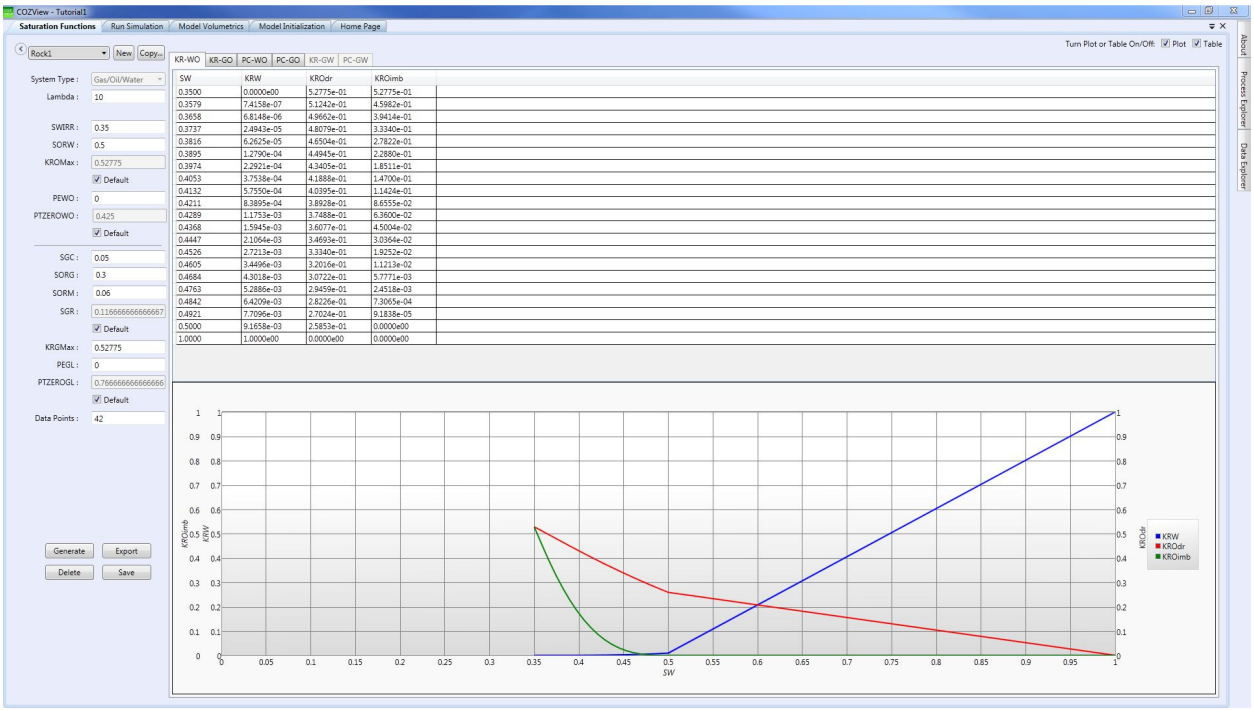
The initial OOIP was 2.79 MMSTB. The reservoir was depleted from 1/1/1990 (2500 psi @ -4500 ft ss) to 1/1/2012 (1500 psi @ -4500 ft ss) during the primary recovery and water flood operations.

This example shows how to quickly initialize the model at the end of the water flood and initiate CO2 injection. Oil production results for this example are much different than for Tutorial 1 because of the oil saturation in the reservoir at the start of CO2 injection.

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.



Select **Saturation Functions** from the **Fluid and Saturation properties** menu area. Select **Rock1 as** defined by the user in Tutorial 1. The user should change the Residual oil saturation to water (SORW) from 0.35 (default in Tutorial 1) to 0.5.



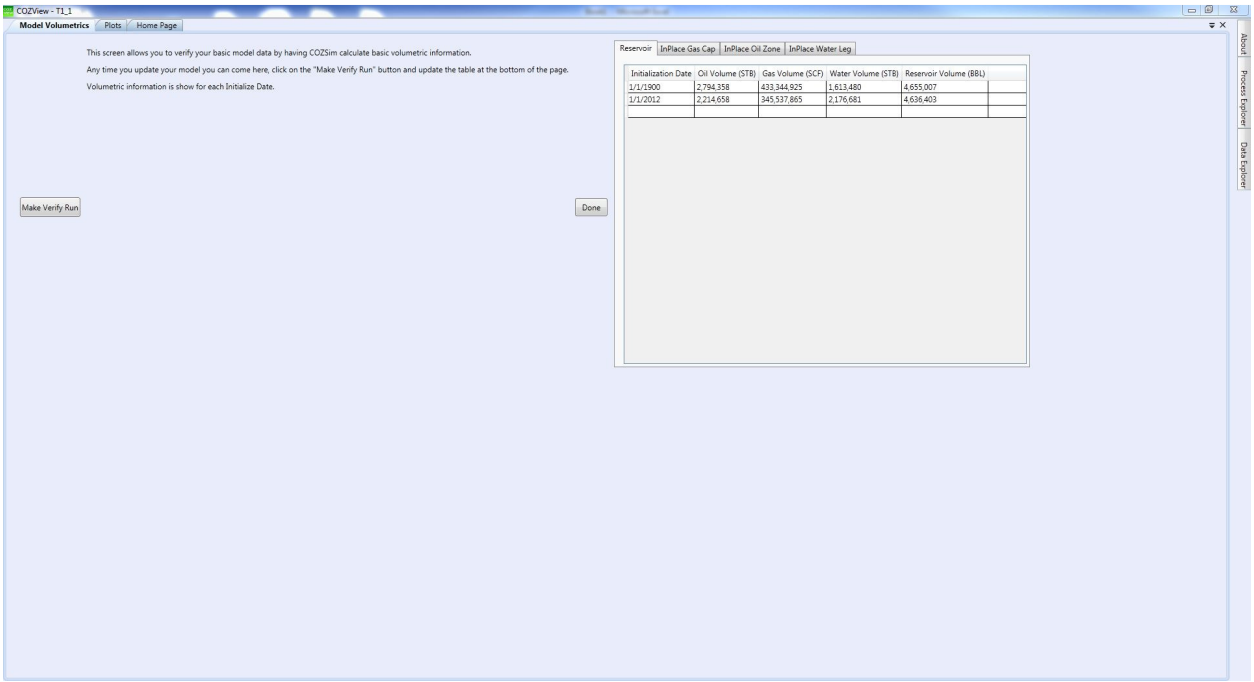
Click **Generate** to update the relative permeability tables and then **Save** the rock properties.

Model Initialization should be selected from the **Verify Model** menu area. The user must input two Initialization times and the associated data for 1/1/1990 (start of primary/secondary operations) and 1/1/2012 (end of water flood/start of CO2 injection). The Fluid PVT (**PVT1** is same as in Tutorial 1) and saturation functions (**Rock1**) are as just modified in this section.

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

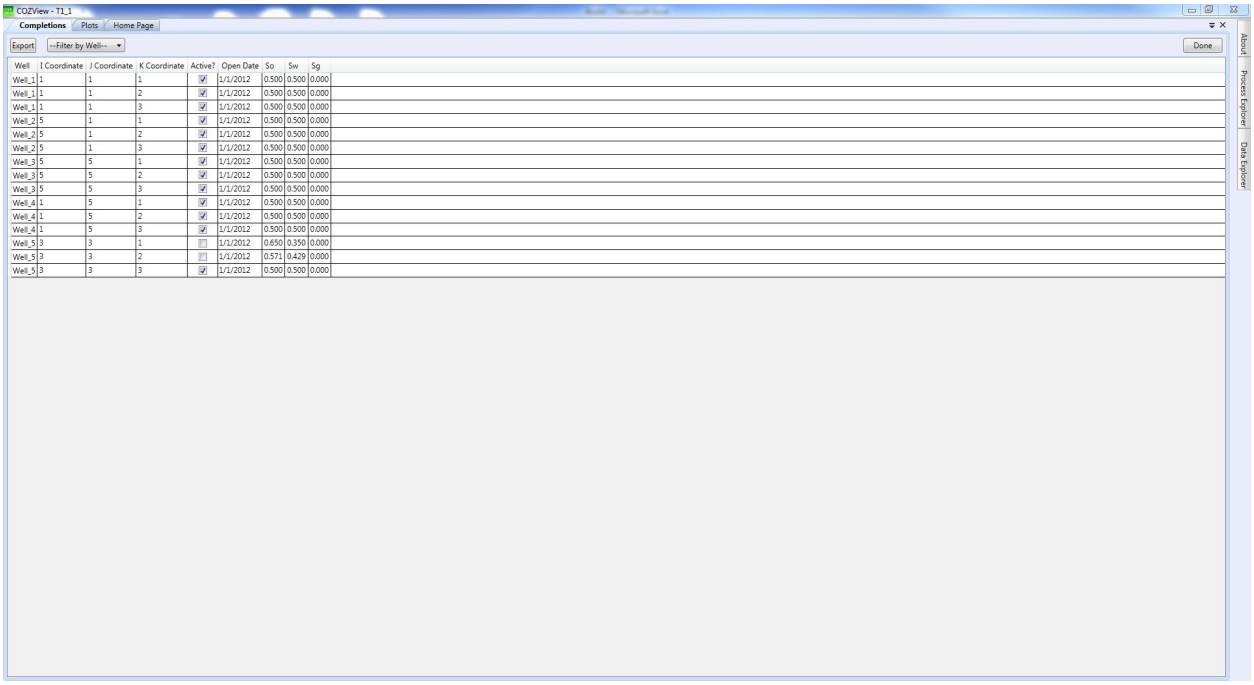
Initialization Date	**1/1/2012**
Model Type	2 phase
Pressure @Ref	1500
Reference Elevation	-4500
Elevation @ WOC	-4550 (is below the model)
PSATHCG	800

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 Initialization date 1/1/1990 and OIP of 2.21 MMSTB for 1/1/2012. The difference in oil volumes between the two dates is the "implied" oil recovery over that period. In this example, this is approximately 0.58 MMSTB of oil (21% of the OOIP).



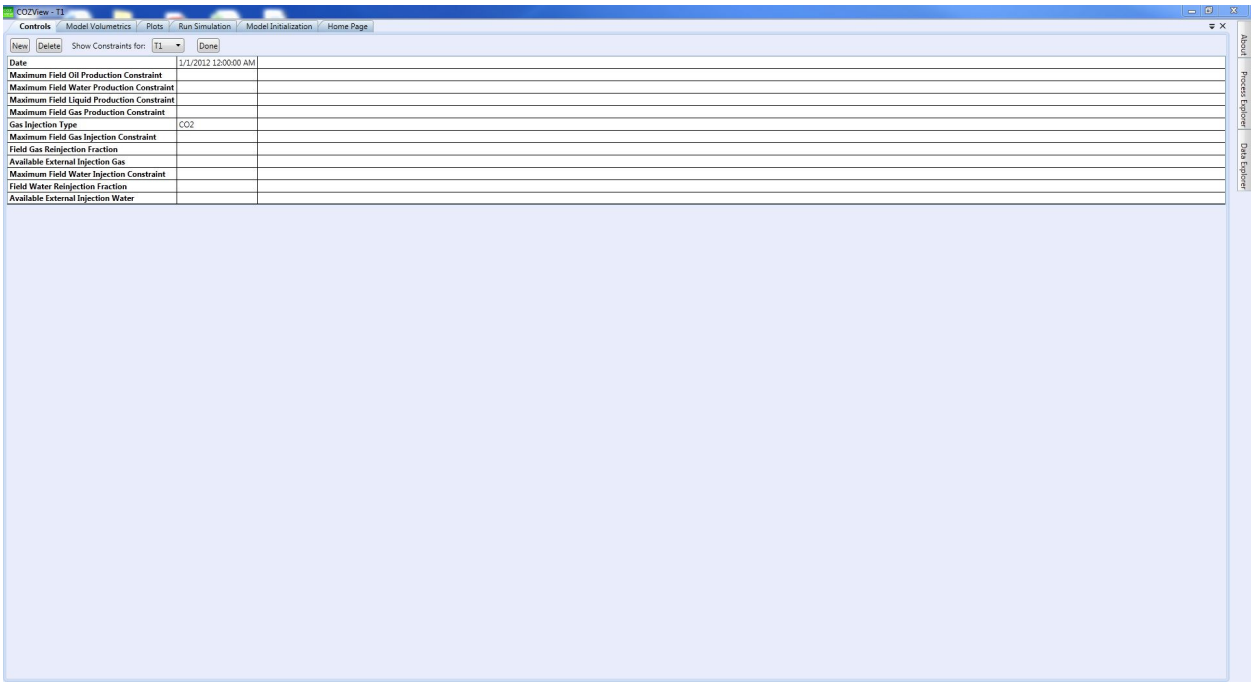
Click **Done** to save the Model Initialization.

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.



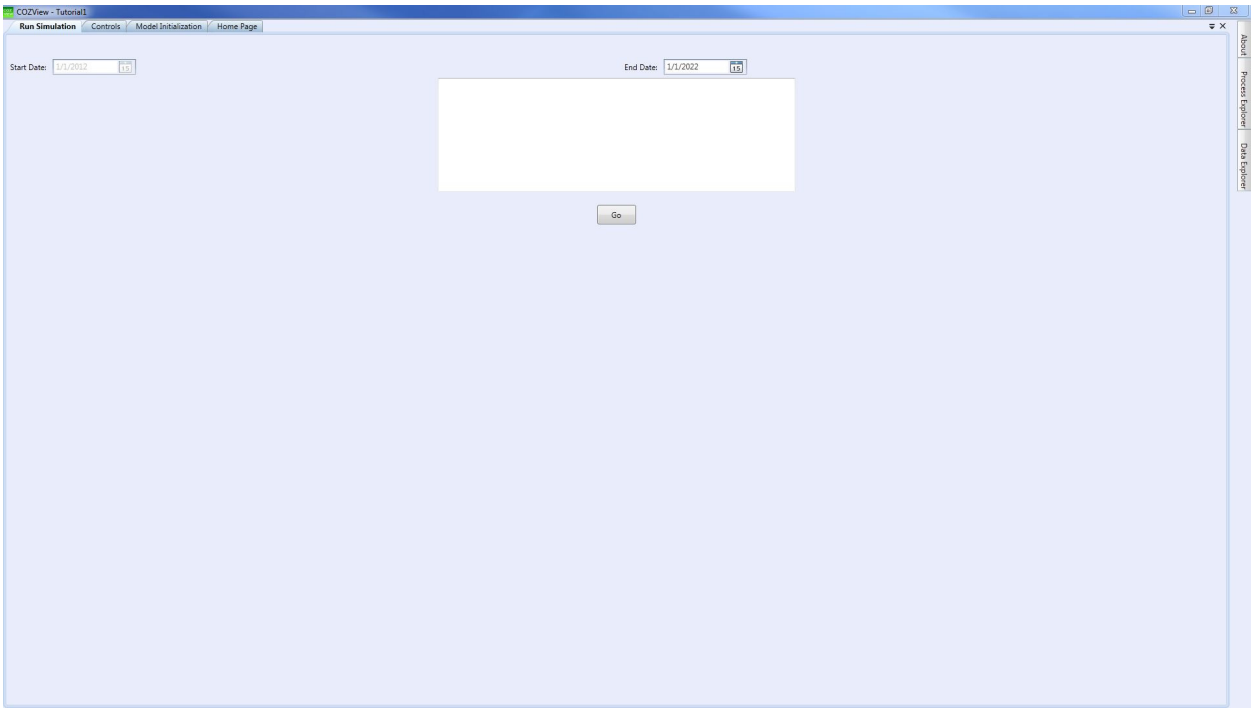
Well	I Coordinate	J Coordinate	K Coordinate	Active?	Open Date	So	Sw	Sg
Well_1	1	1	1	☑	1/1/2012	0.500	0.500	0.000
Well_1	1	1	2	☑	1/1/2012	0.500	0.500	0.000
Well_1	1	1	3	☑	1/1/2012	0.500	0.500	0.000
Well_2	5	1	1	☑	1/1/2012	0.500	0.500	0.000
Well_2	5	1	2	☑	1/1/2012	0.500	0.500	0.000
Well_2	5	1	3	☑	1/1/2012	0.500	0.500	0.000
Well_3	5	5	1	☑	1/1/2012	0.500	0.500	0.000
Well_3	5	5	2	☑	1/1/2012	0.500	0.500	0.000
Well_3	5	5	3	☑	1/1/2012	0.500	0.500	0.000
Well_4	1	5	1	☑	1/1/2012	0.500	0.500	0.000
Well_4	1	5	2	☑	1/1/2012	0.500	0.500	0.000
Well_4	1	5	3	☑	1/1/2012	0.500	0.500	0.000
Well_5	3	3	1	☐	1/1/2012	0.650	0.350	0.000
Well_5	3	3	2	☐	1/1/2012	0.571	0.429	0.000
Well_5	3	3	3	☑	1/1/2012	0.500	0.500	0.000

CO2 injection is initiated in 1/1/2012 as in Tutorial 1. There are no field constraints in this example, but CO2 must be selected as the injection gas in the **Field Controls** section. All other data are the same as in the original project.



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	
Field Gas Reinjection Fraction	
Available External Injection Gas	
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**.

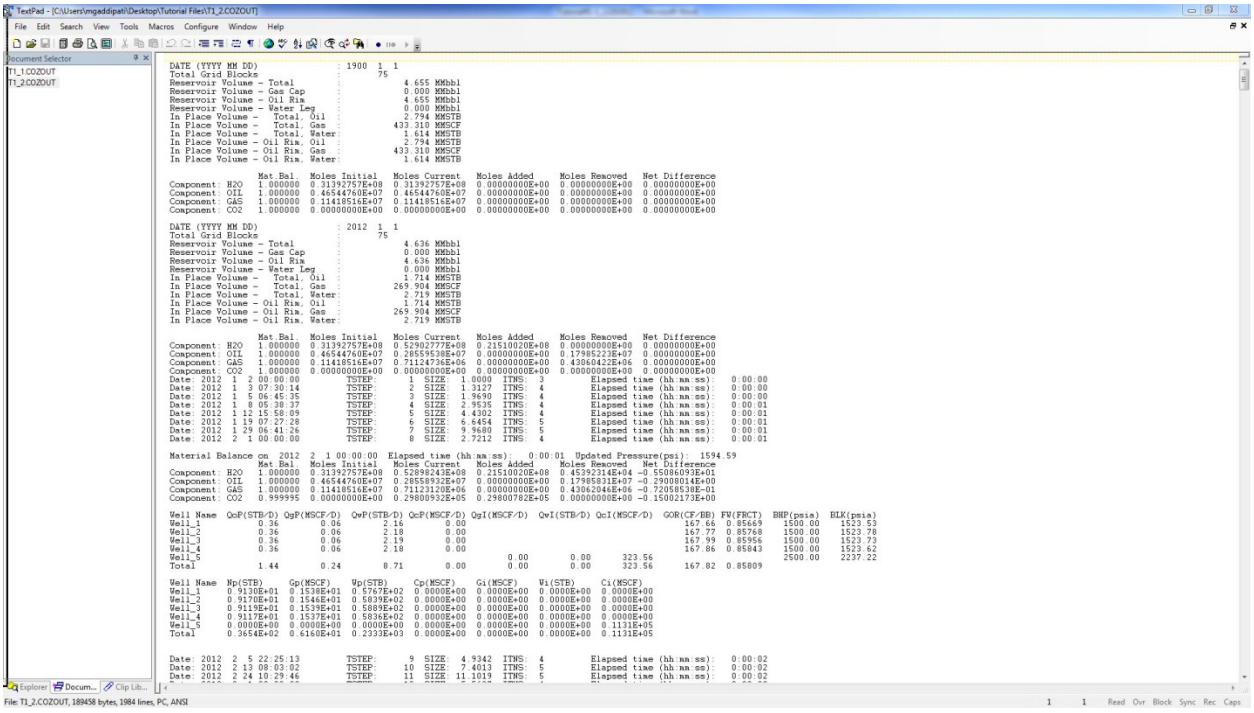


The **End Date** for this example is 1/1/2022.

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

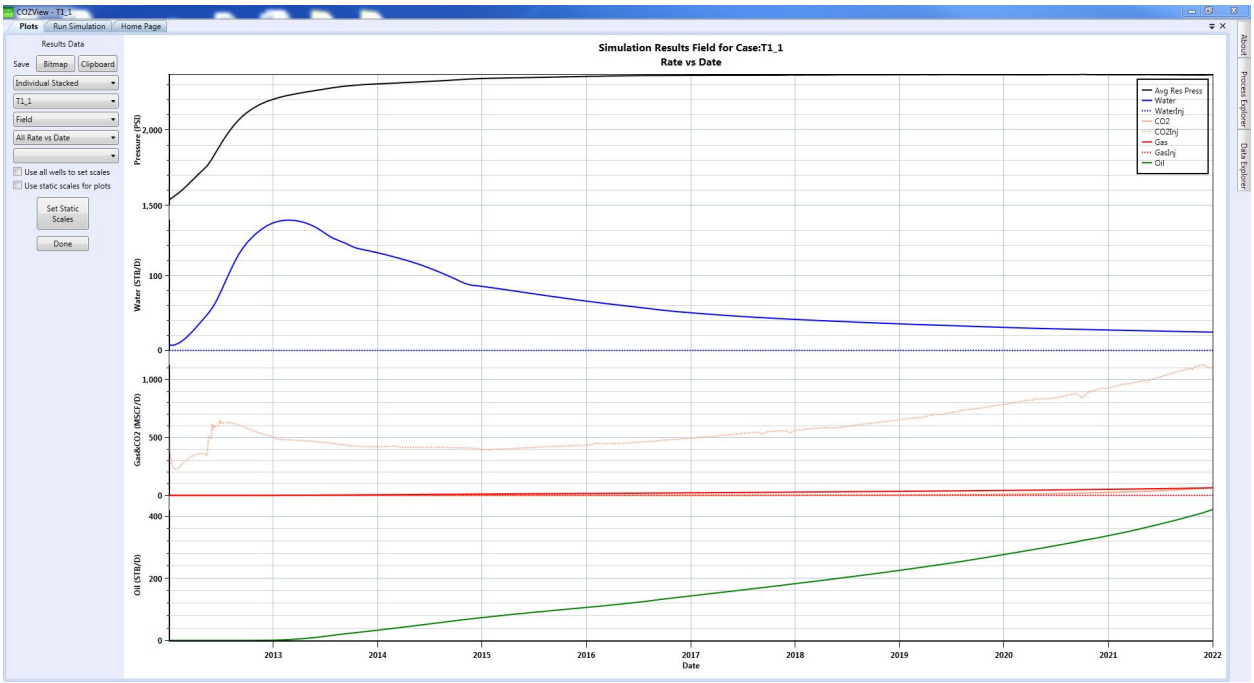
The Simulator Runner window will appear and update the CPU activity for the simulation run. **DO NOT** close the Simulator Runner window during the simulation run. It can be minimized. Closing the Simulator runner window will stop the simulation run.

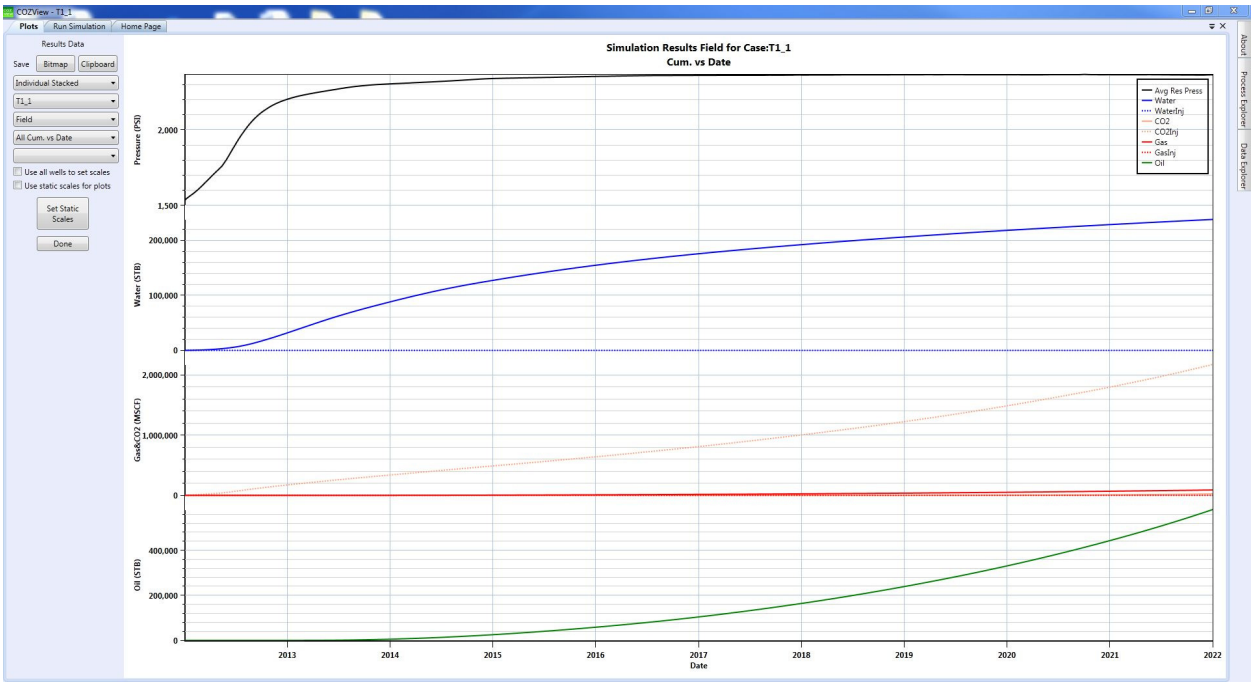
The COZOUT file at the end of this simulation run is shown below.

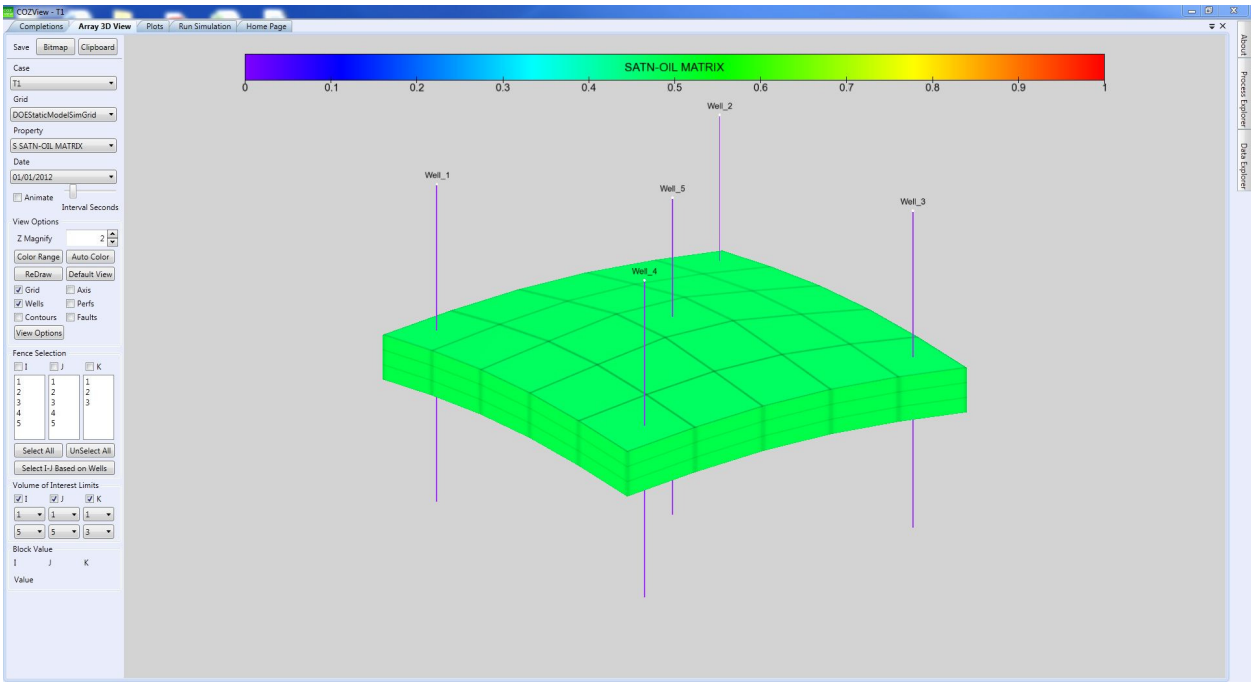


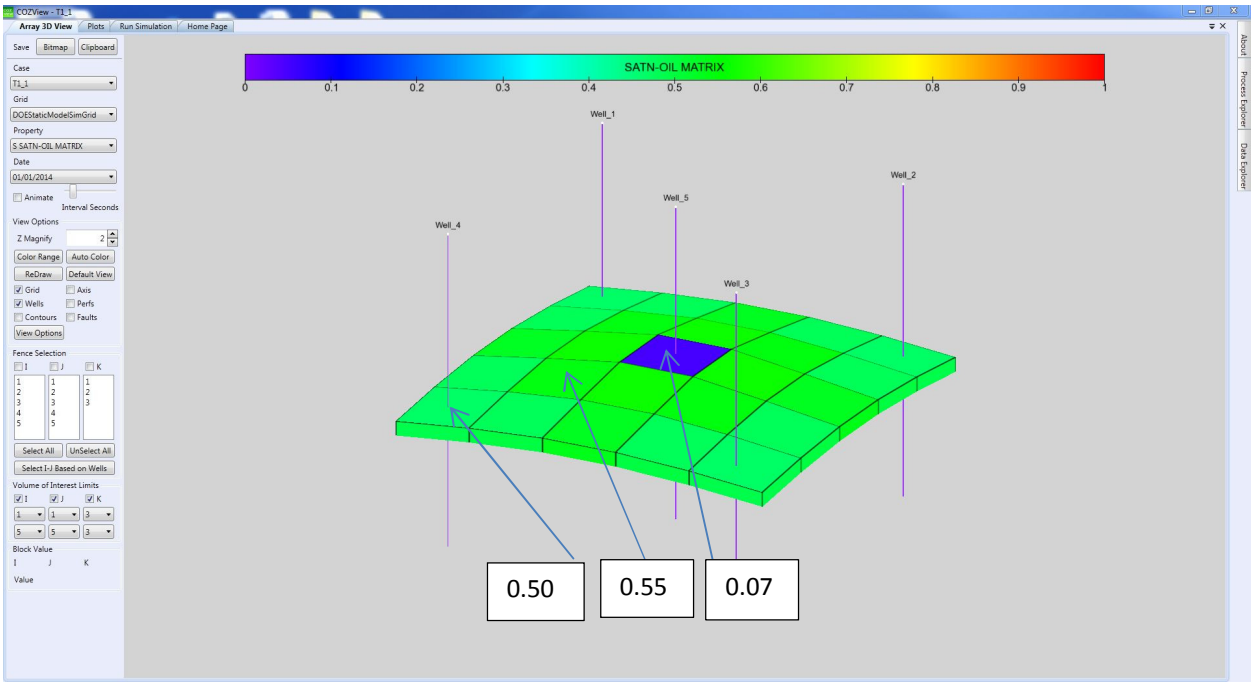
In this example, the reservoir is depleted through primary recovery and water flooding from 1/1/1990 to 1/1/2012. The available oil for production at that time is from unswept (residual) oil in the rocks. All producers (Well 1 to Well 4) produce water only for the first three years. Producers start producing oil from 1/1/2015. The field cumulative oil produced (due to CO2 injection) by the end of 10 years (1/1/2022) is 0.57 MMSTB and the cumulative CO2 injected is 2.2 BSCF at that time.

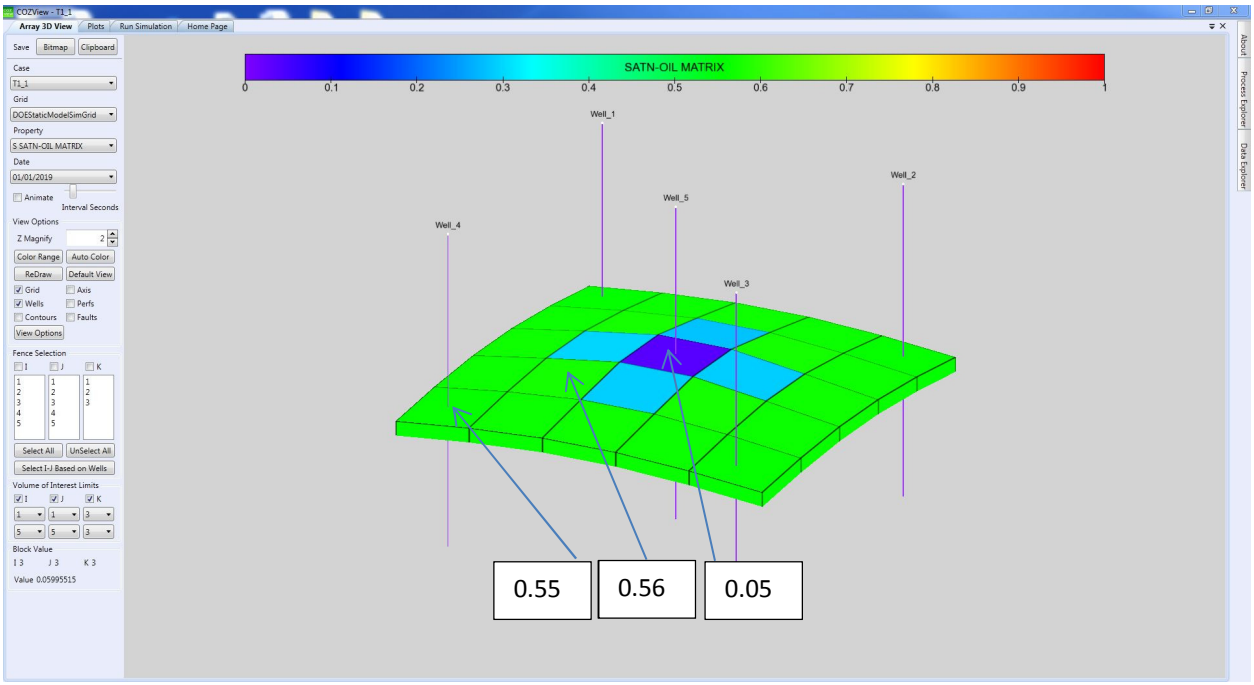
The oil saturation maps below show the oil bank forming around the injection well and moving toward the producers.


COZView - T1_1
Plots
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
T1_1
Field
All Rate vs Date
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
Simulation Results Field for Case:T1_1
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
About
Process Explorer
Data Explorer


COZView - T1_1
Plots
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
T1_1
Field
All Cum. vs Date
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
Simulation Results Field for Case:T1_1
Cum. vs Date
Avg Res Press
Water
WaterInj
CO2
CO2Inj
Gas
GasInj
Oil
Pressure (PSI)
Water (STB)
Gas&CO2 (MSCF)
Oil (STB)
Date
About
Process Explorer
Data Explorer


COZView - T1
Completions
Array 3D View
Plots
Run Simulation
Home Page
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_2
Well_3
Well_4
Well_5


COZView - T1_1
Array 3D View
Plots
Run Simulation
Home Page
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_2
Well_3
Well_4
Well_5
0.50
0.55
0.07


COZView - T1_1
Array 3D View
Plots
Run Simulation
Home Page
Save
Bitmap
Clipboard
Case
T1_1
Grid
DOEStaticModelSimGrid
Property
S SATN-OIL MATRIX
Date
01/01/2019
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
Value 0.05995515
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_2
Well_3
Well_4
Well_5
About
Process Explorer
Data Explorer
0.55
0.56
0.05

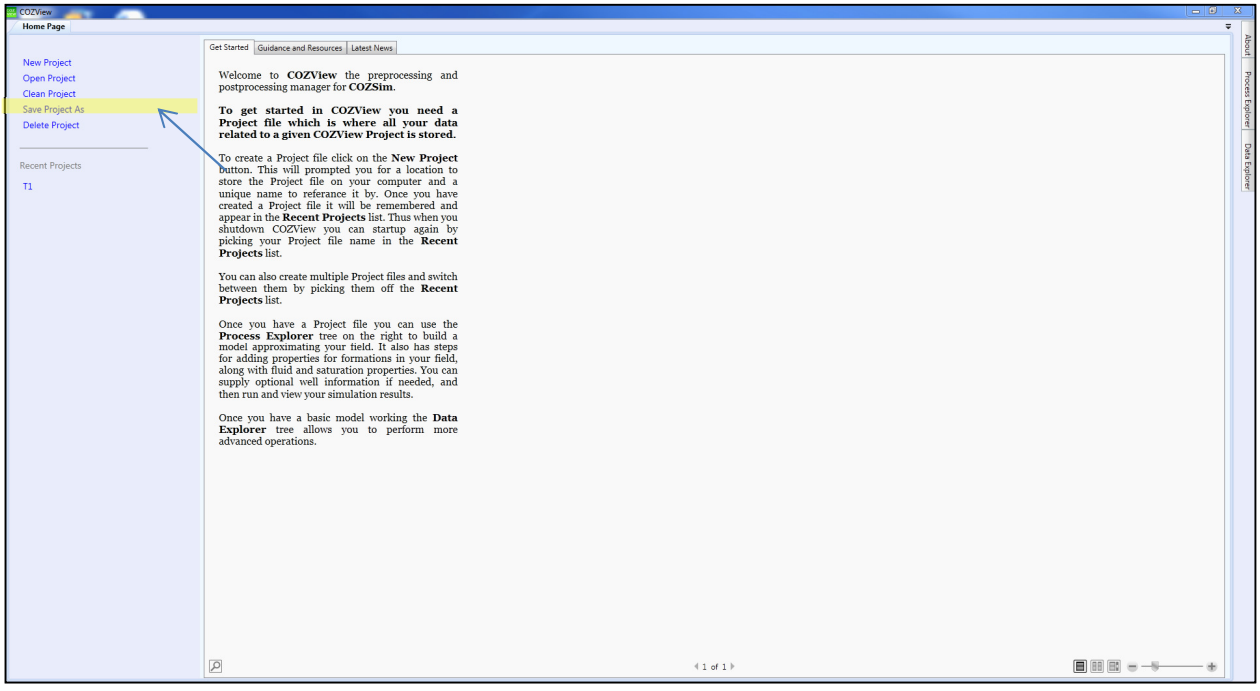
TUTORIAL #1-2

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.

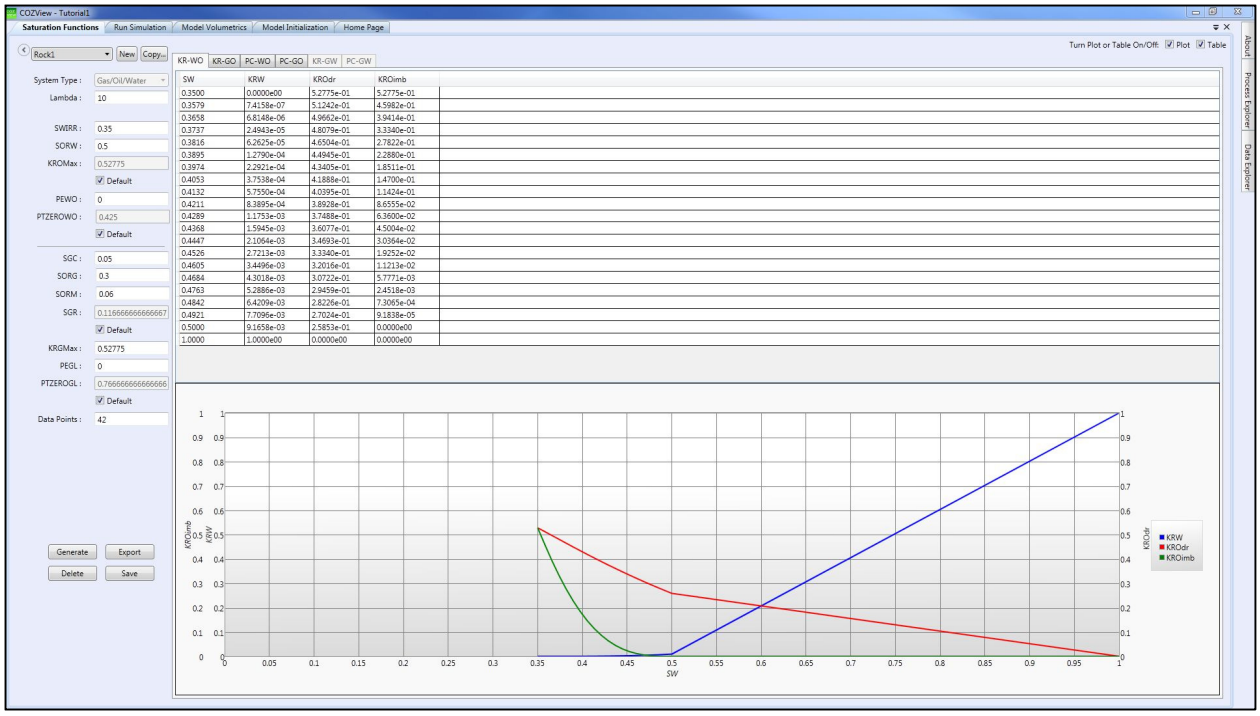
This example shows how to initialize the model at the original conditions and at current conditions and initiate CO2 injection. Oil production results for this example are much different than for Tutorials 1 or 1-1 due to the difference in the saturations conditions at the start of CO2 injection. Tutorial 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.

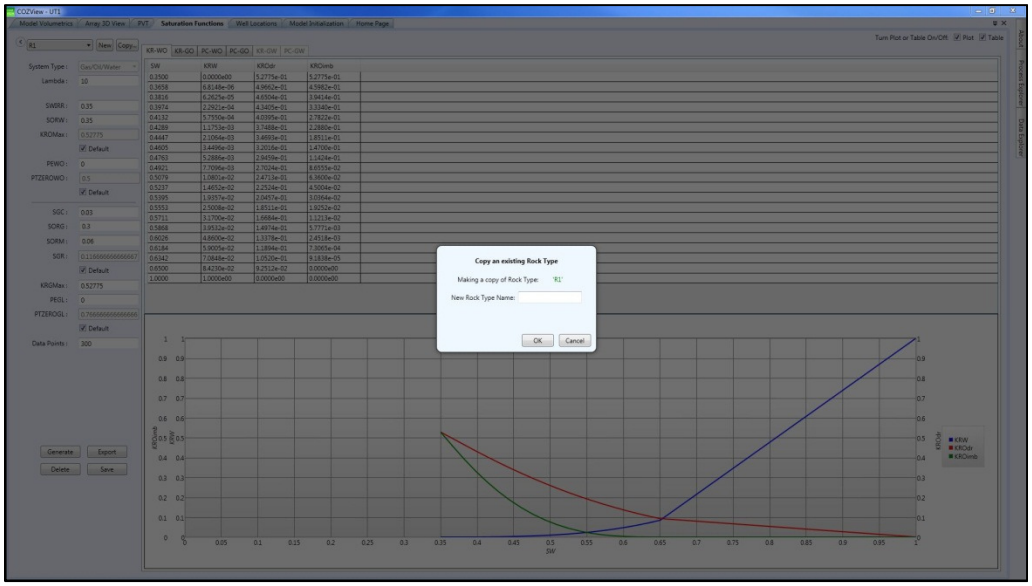


Click **Generate** to update the relative permeability tables and then **Save** the rock properties.

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

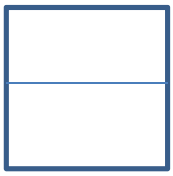
$$Pcow = (\rho_w - \rho_o)gh$$

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

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)

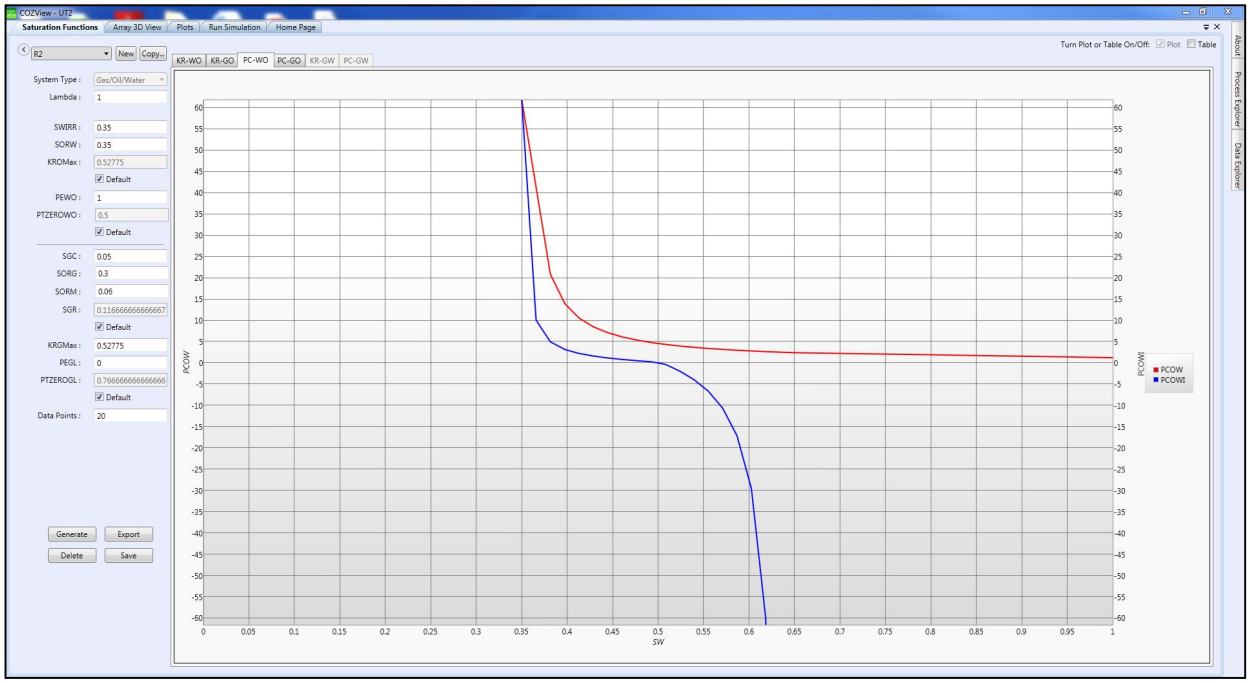
Pcow at Zmidpoint ~ 0.1*(-4585.35-(-5000)) = 41.45 psi; WOC is -5000 ft ss

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

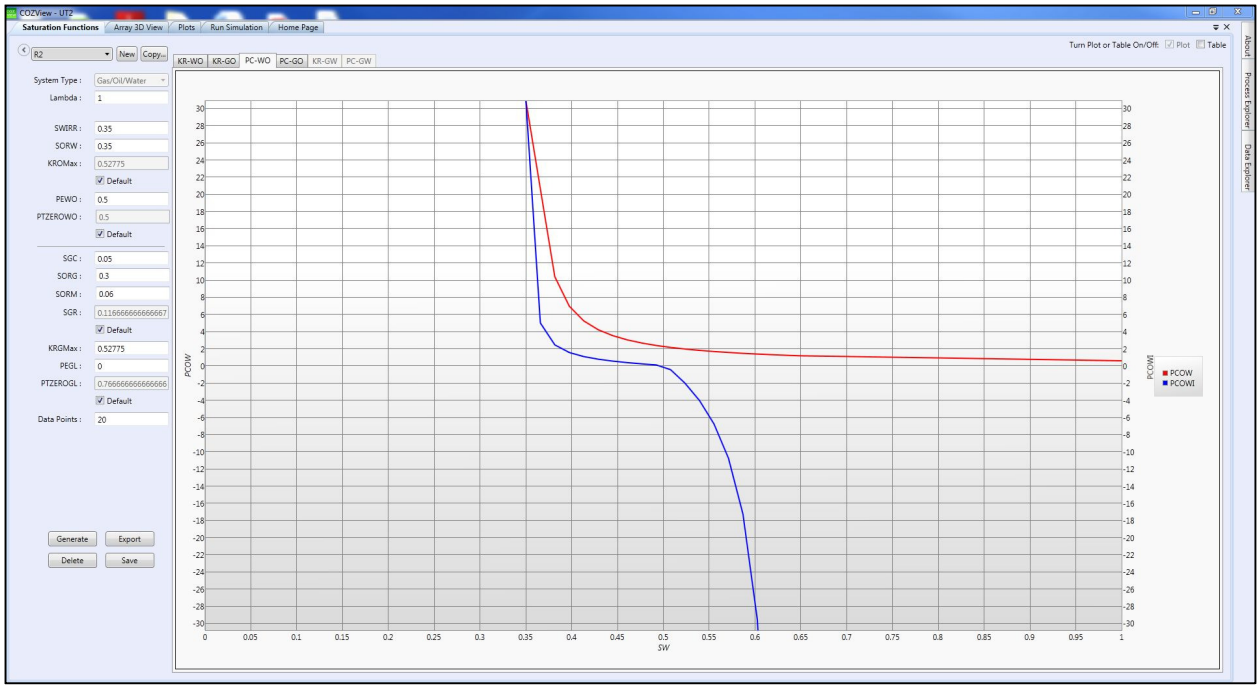
Set Lambda value to 1.0 (Default) and PEWO to 1 and select **Generate.** Click on PC-WO to view Oil-water capillary pressure curves. (PEWO must be greater than zero for a capillary pressure curve to be generated.)



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

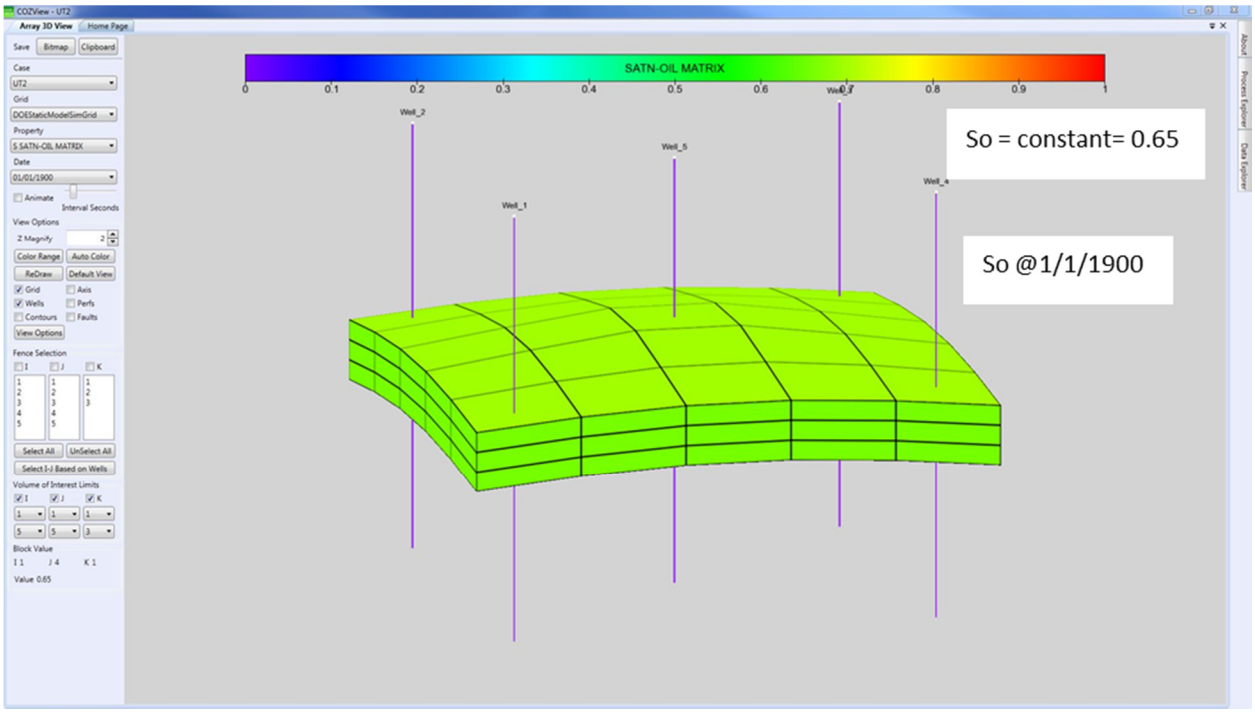
Initialization Date	**1/1/2012**
Model Type	2 phase
Pressure @Ref	1500
Reference Elevation	-4500
Elevation @ WOC	-4500 (is above the model)
PSATHCG	800

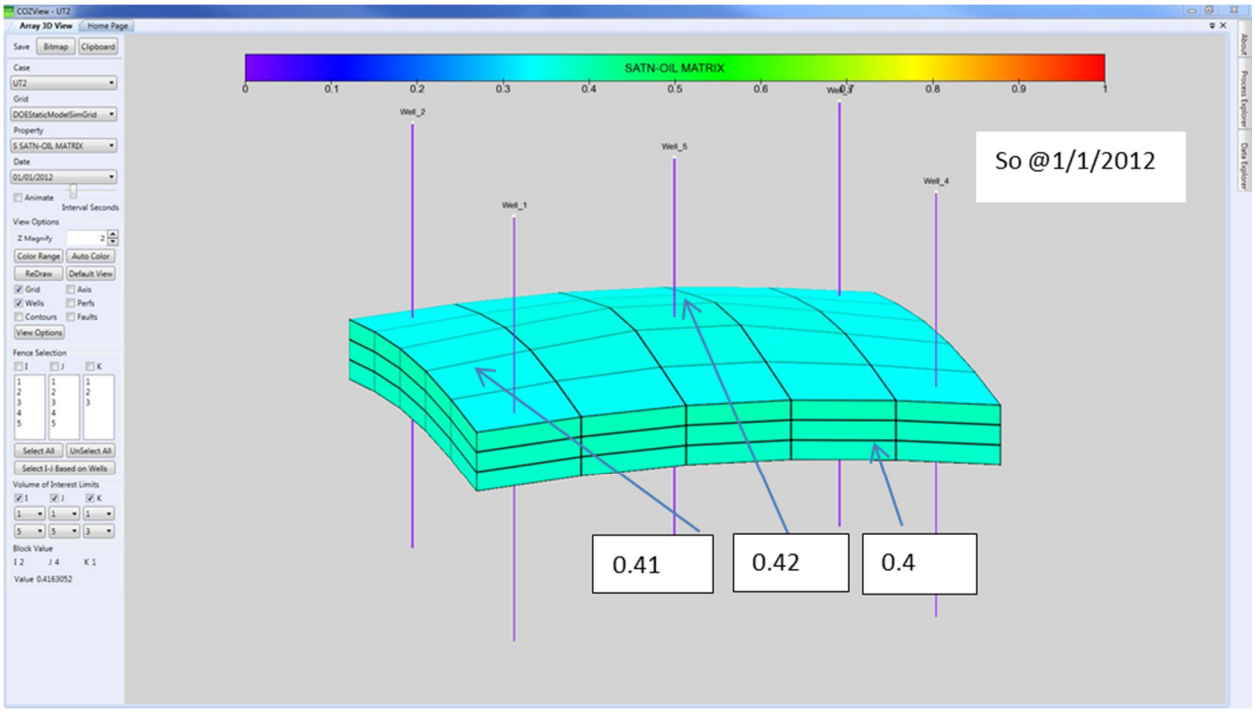
Selection of **Initialize Model** will provide the results of the volumetric calculation on the **View Model Volumetrics** screen. A brief view of the **Simulator Runner** window will appear before the volumetrics are reported. An OOIP of approximately 2.79 MMSTB should be reported subject to differences 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.

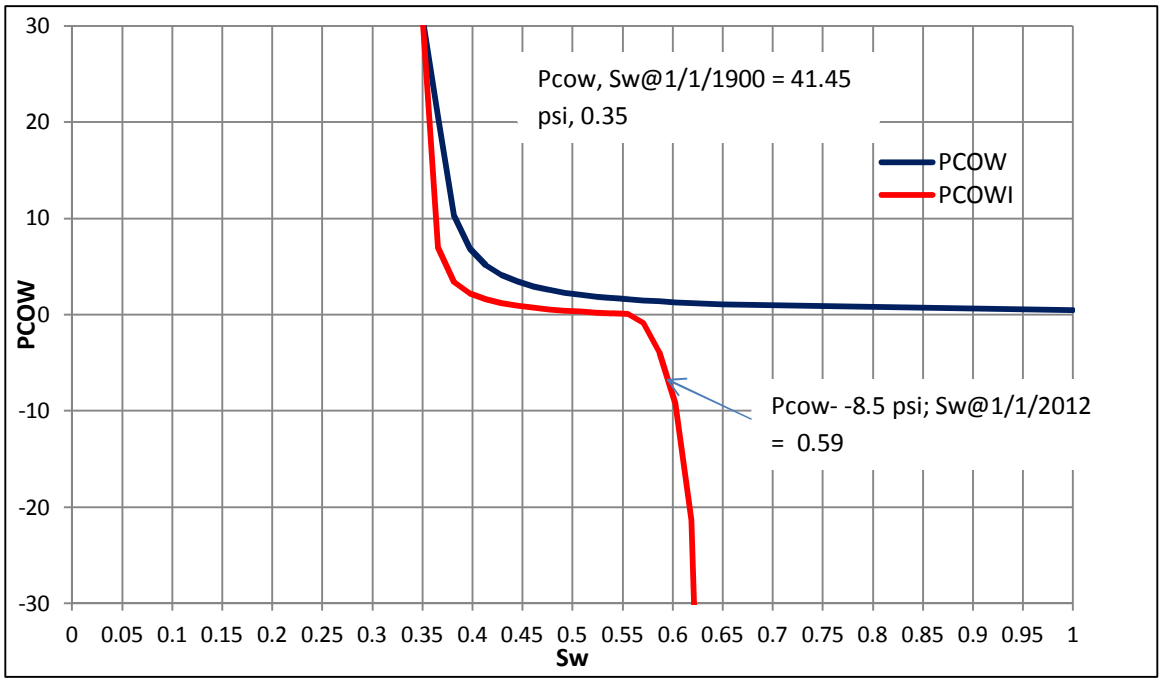
- If Sw is not Swirr at 1/1/1990, change the capillary pressure curve scale such that Pcow at the Midpoint is much higher than the maximum value shown.
- If OOIP is not correct, but Sw is correct, adjust Rock volume (Porosity and Net thickness) and rerun the Model initialization.

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

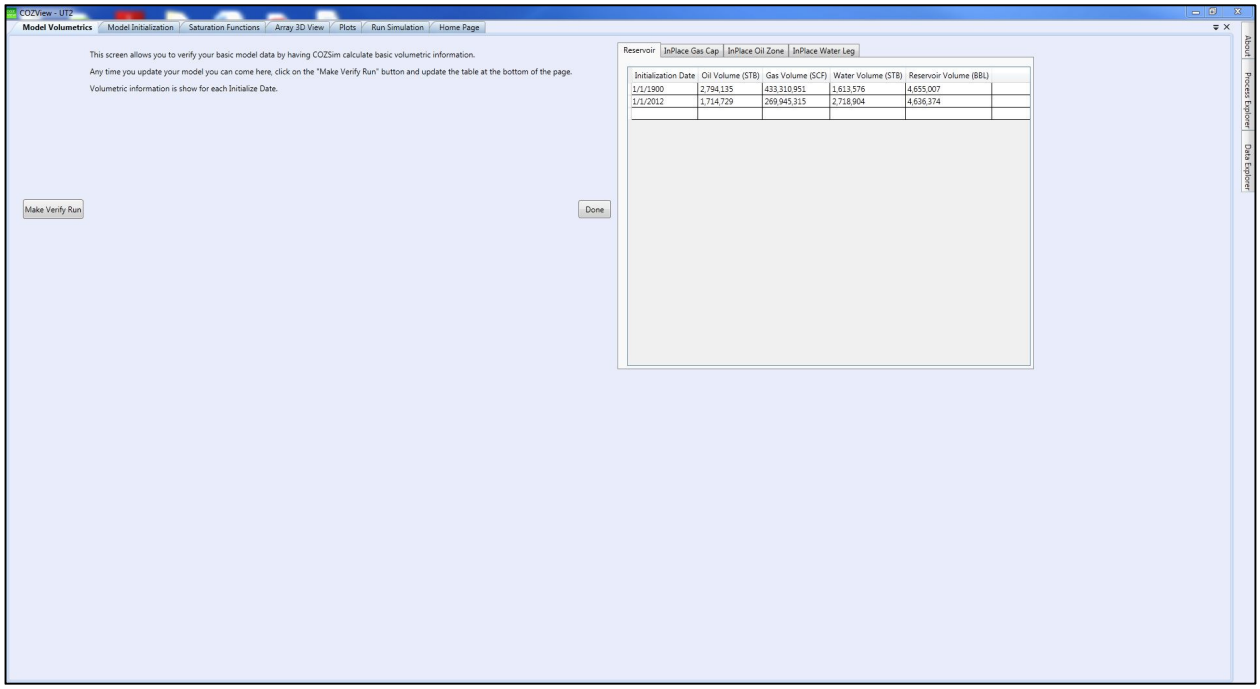
- The water saturation values should have a range of values across the reservoir. Please note that the PCOW calculated at the Midpoint at 1/1/2012 was -8.5 psi. This represents the location of the midpoint of the reservoir on the Pcow curve (Imbibition).
- 3-D arrays should show oil saturation values 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

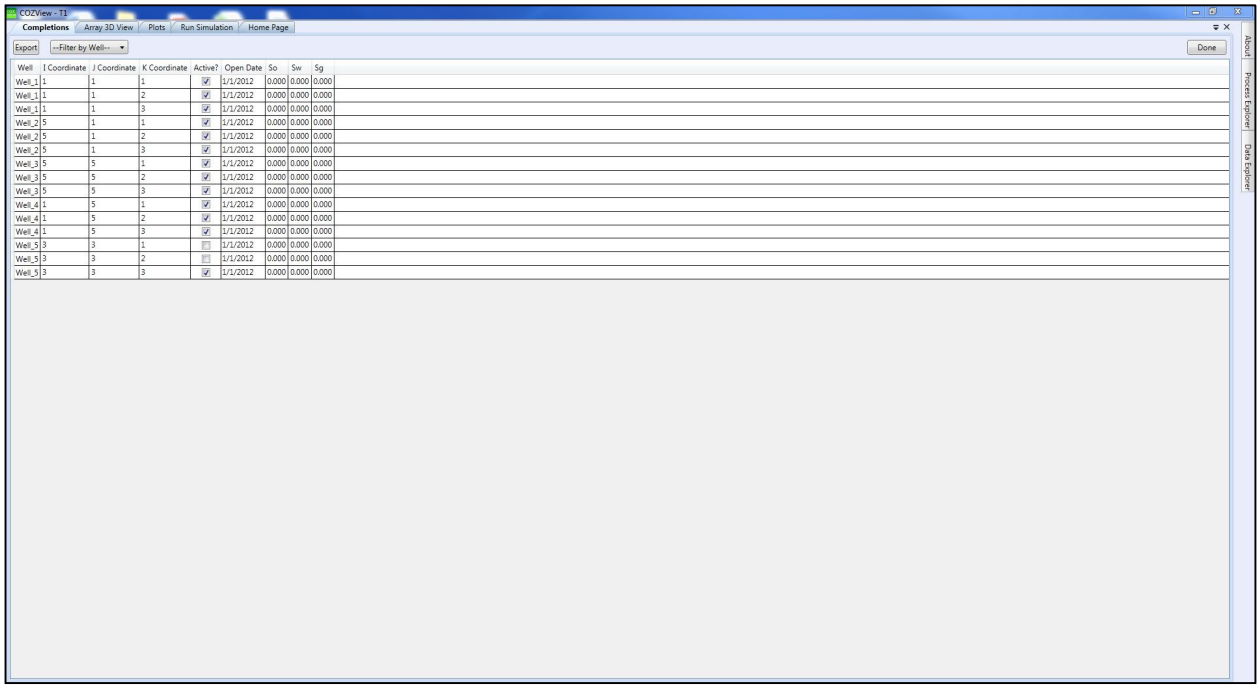

30
20
10
0
-10
-20
-30
PCOW
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
Sw
Pcow, Sw@1/1/1900 = 41.45 psi, 0.35
PCOW
PCOWI
Pcow- -8.5 psi; Sw@1/1/2012 = 0.59

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.)



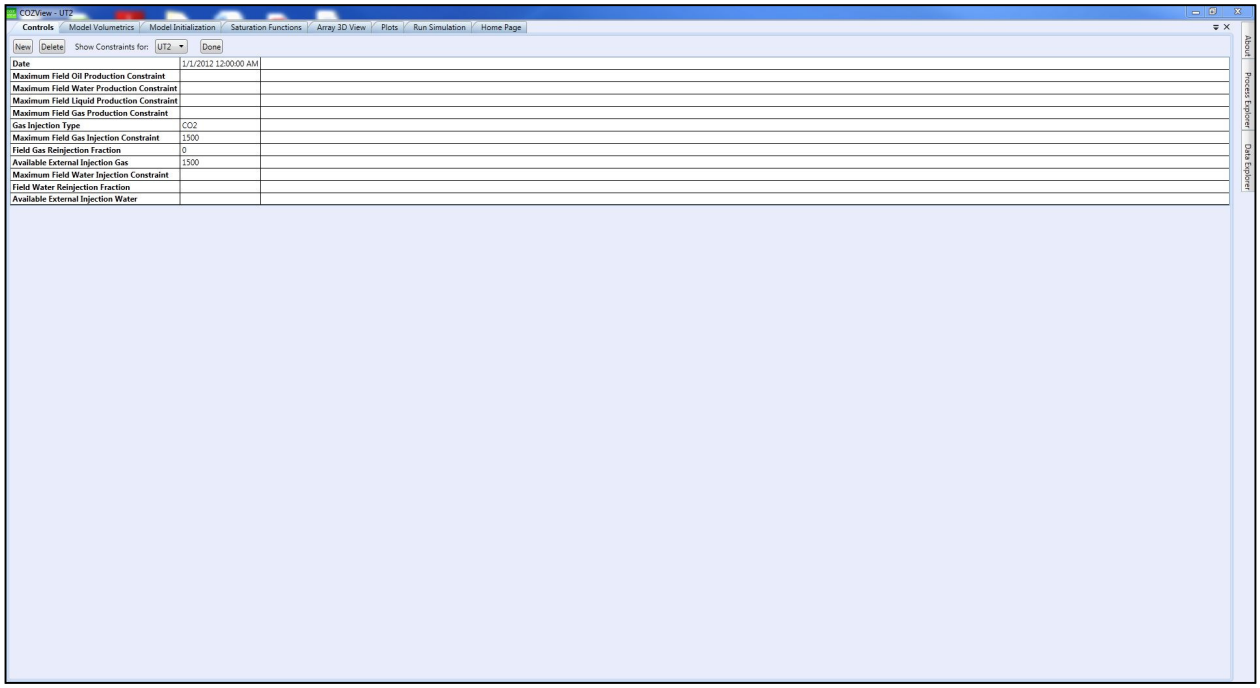
Click **Done** to save the Model Initialization.

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.



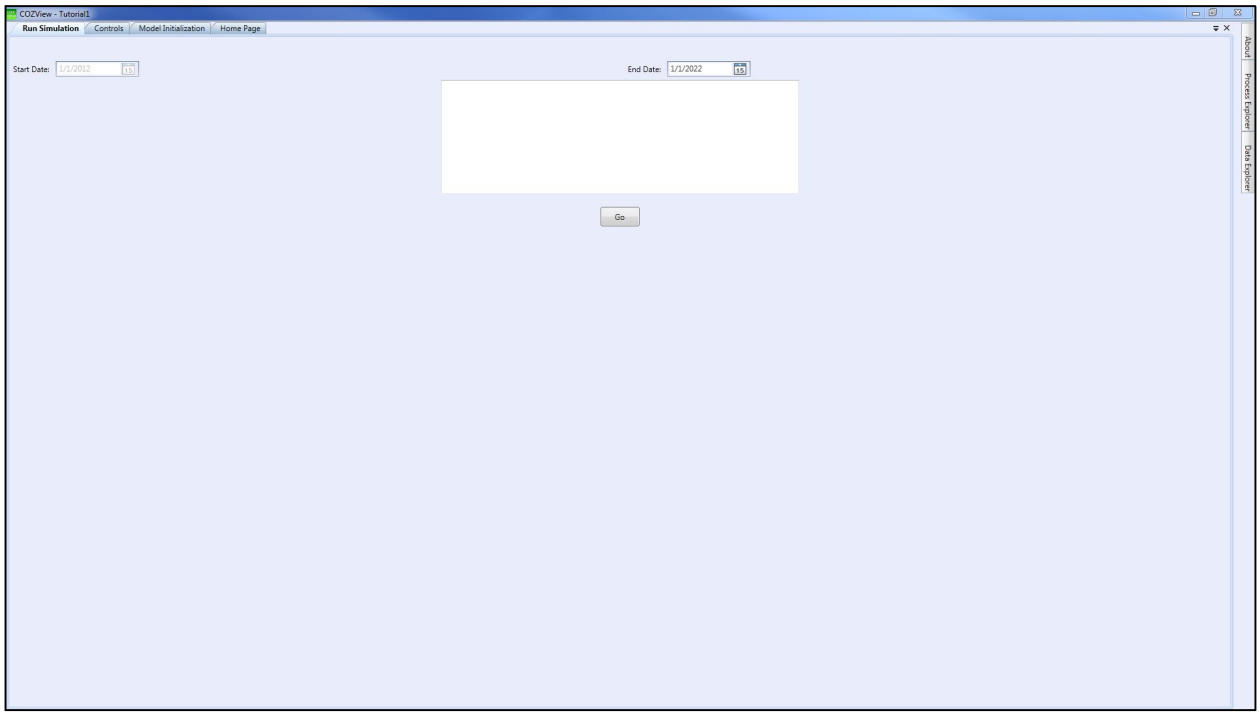
Well	I Coordinate	J Coordinate	K Coordinate	Active?	Open Date	So	Sw	Sg
Well_1	1	1	1	☑	1/1/2012	0.000	0.000	0.000
Well_1	1	1	2	☑	1/1/2012	0.000	0.000	0.000
Well_1	1	1	3	☑	1/1/2012	0.000	0.000	0.000
Well_2	5	1	1	☑	1/1/2012	0.000	0.000	0.000
Well_2	5	1	2	☑	1/1/2012	0.000	0.000	0.000
Well_2	5	1	3	☑	1/1/2012	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**.

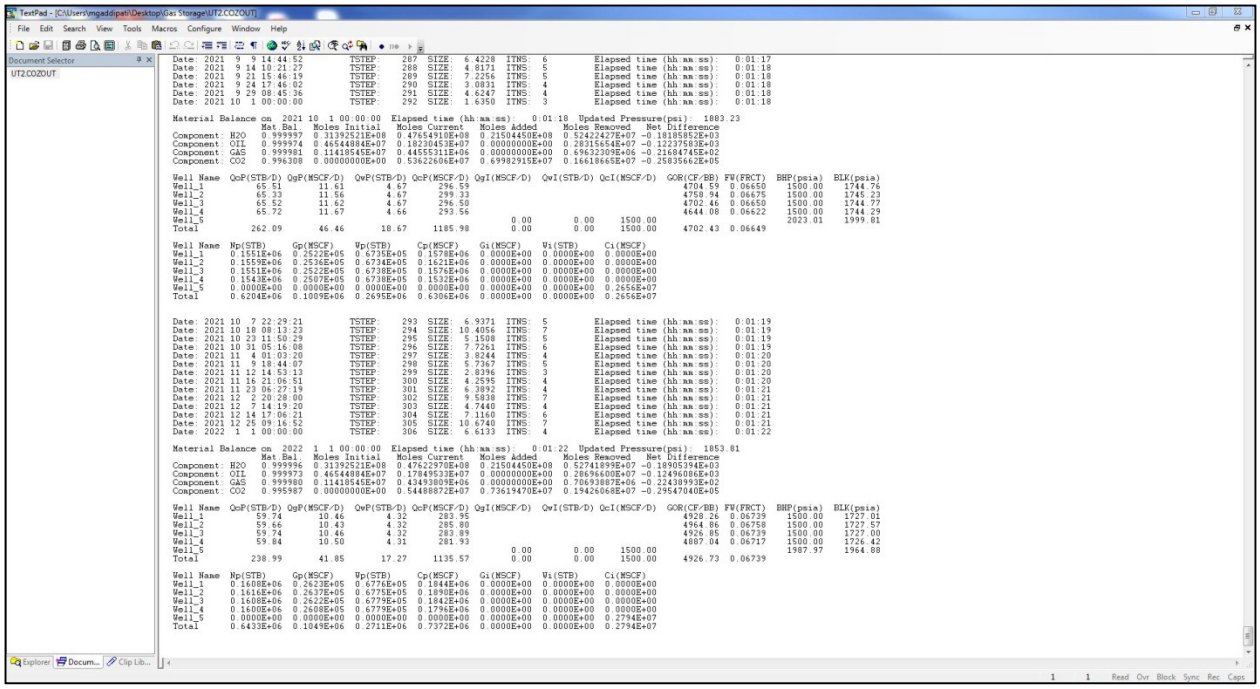


The **End Date** for this example is 1/1/2022.

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.

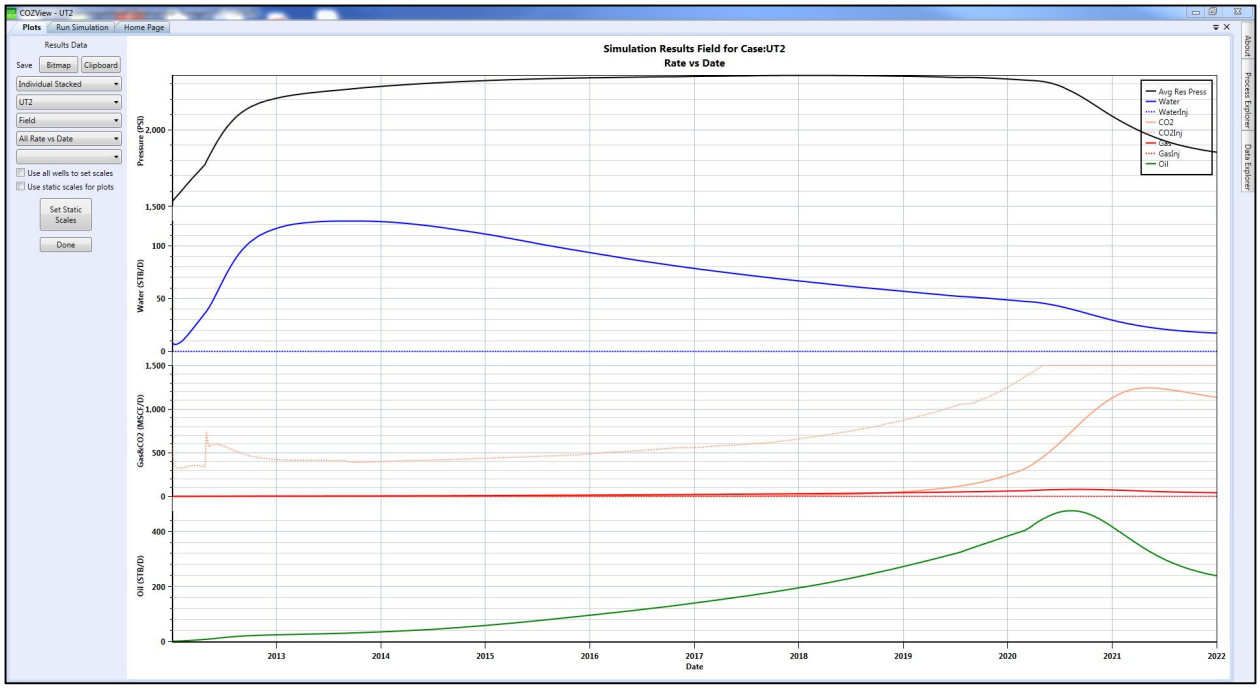
The COZOUT file at the end of this simulation run is shown below.

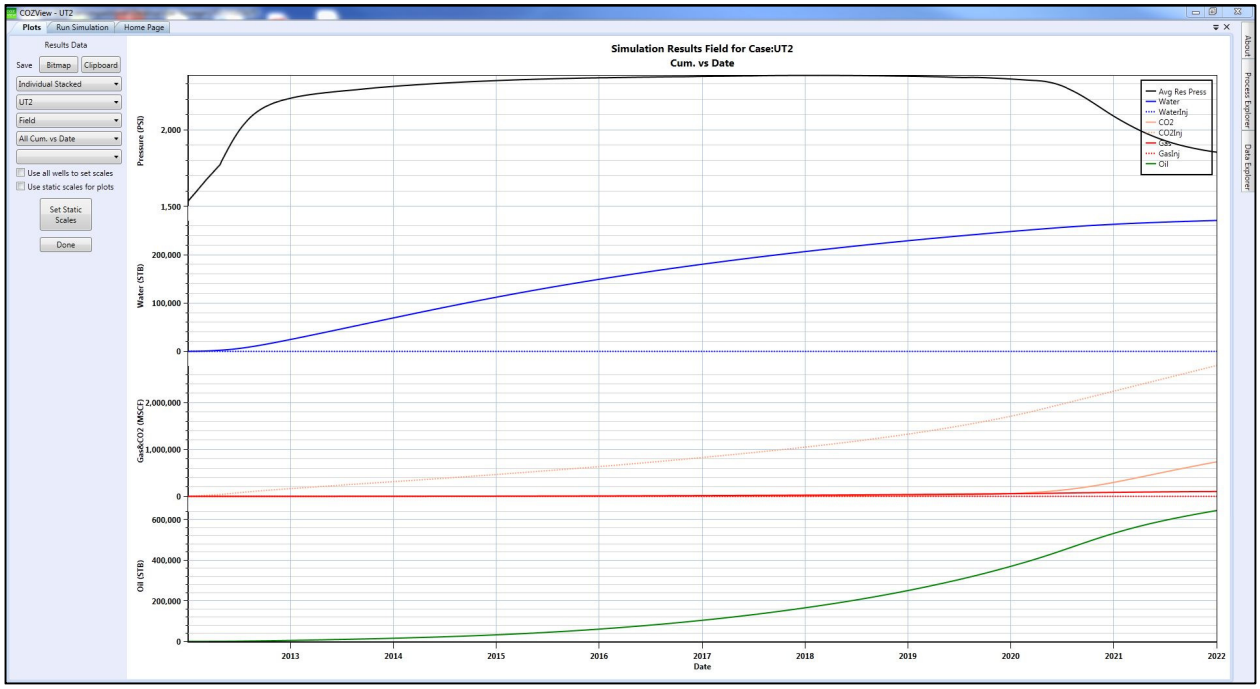


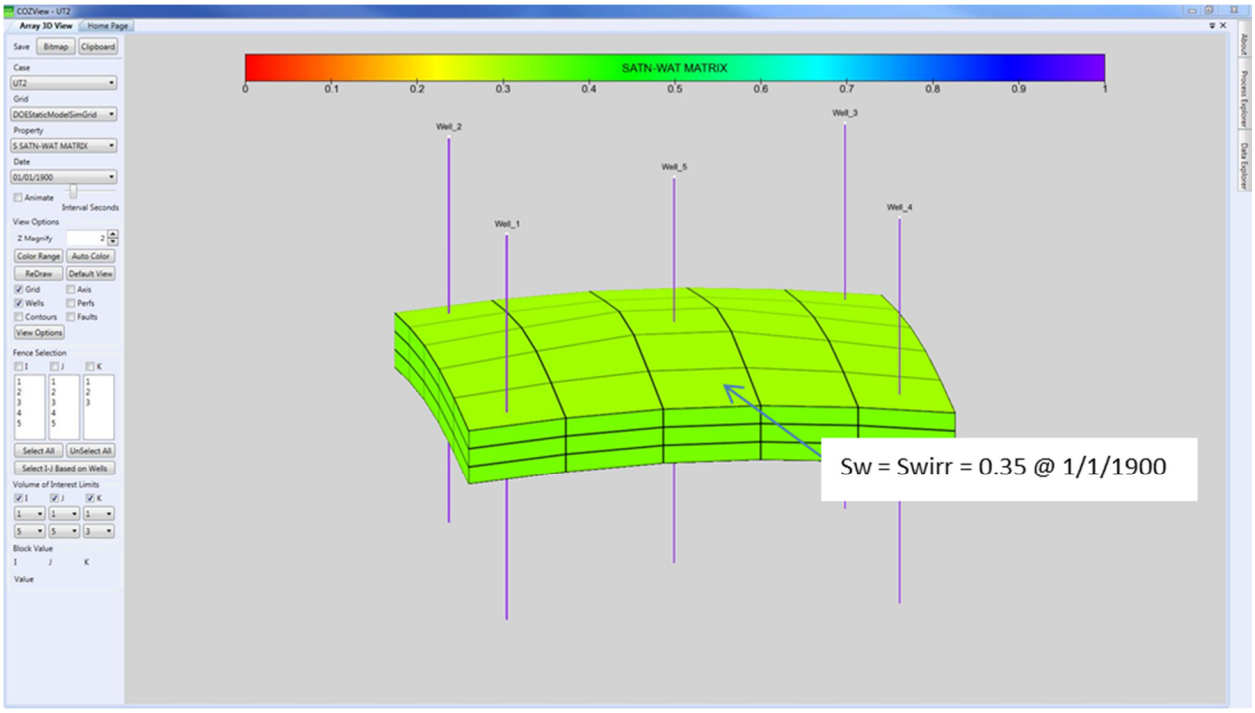
In this example, the reservoir is depleted through primary recovery and water flooding from 1/1/1990 to 1/1/2012. The available oil for production at that time is from unswept oil in the rocks. (Much of the reservoir was not swept to Sorw in this example.) To accomplish a successful prediction run, the 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.

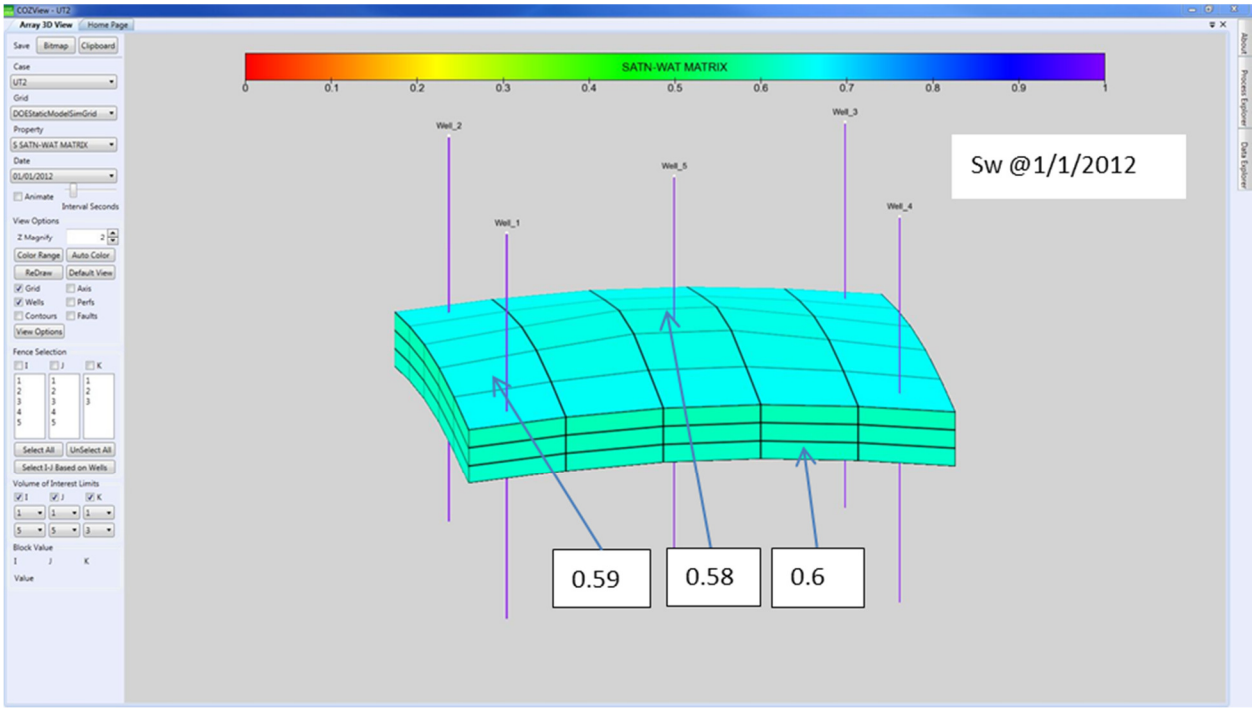
- Check initial oil rates and water cuts to match current data. If the rates are not correct adjust PI (Productivity Index) of the wells (*Process Explorer/Prediction Period/Well Parameters/Well Productivity Parameters*) and/or modify relative permeability curves (*Process Explorer/Fluid and Saturation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

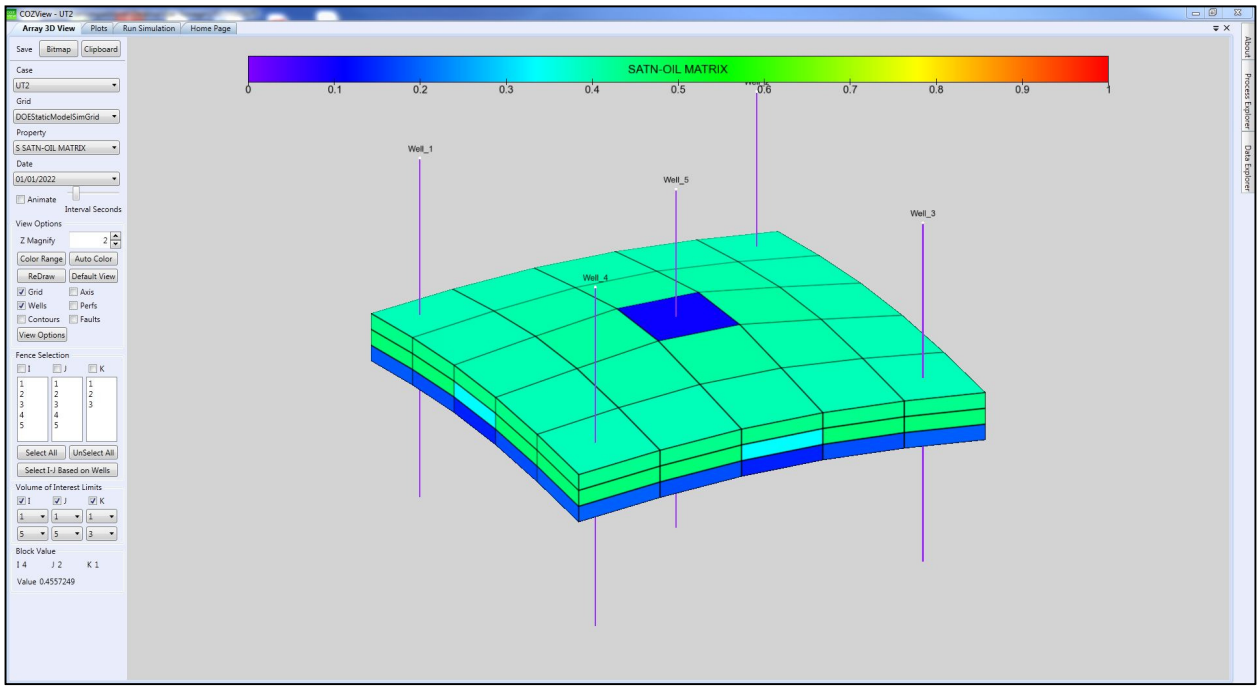
The field cumulative oil produced (due to CO2 injection) by the end of 10 years (1/1/2022) is 0.65 MMSTB and the cumulative CO2 injected is 2.7 BSCF at that time. CO2 Miscibility is achieved around the injection well and all through Layer 3 as shown in the 3D array at 1/1/2022.

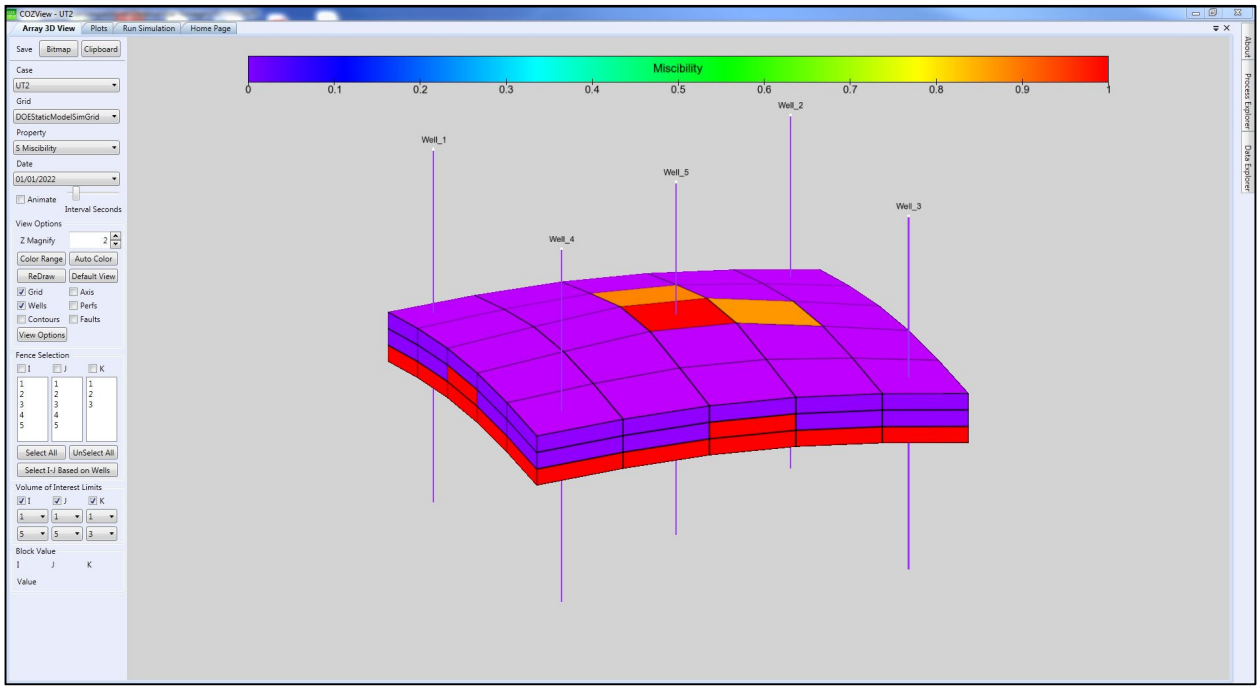

COZView - UT2
Plots
Run Simulation
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
UT2
Field
All Rate vs Date
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
About
Process Explorer
Data Explorer
Simulation Results Field for Case:UT2
Rate vs Date
Avg Res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


COZView - UT2
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
Save
Bitmap
Clipboard
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
Array 3D View
Plots
Run Simulation
Home Page
Save
Bitmap
Clipboard
Case
UT2
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

TUTORIAL #2

This is a NW-SE dipping stratigraphic reservoir with 150 feet of net thickness. The initial OOIP was 54.812 MMSTB as of 1/1/1900. There was no initial gas cap and the associated aquifer was small. Well depths are approximately 7000 ft.

Initial pressure @ -10 ft ss, psia	3000
Initial bubble point pressure, psia	1800
Water-oil contact, ft ss	-400
Net thickness, ft	150
Porosity, percent	20
Horizontal permeability, md	50
Vertical permeability, md	5
Oil gravity, API	35.5
Gas specific gravity	0.65
Reservoir Temperature, F	150
Swirr, fraction	.25
Sorw, fraction	.25
Sgc, fraction	.05
Sorg, fraction	.30

The field was depleted to 1900 psia reservoir pressure as of 1/1/2012. Cumulative oil production was 2.0 MMSTB (3.64% of OOIP) from the four original wells (1-4).A small gas cap was formed with a GOC at -15 ft ss. The aquifer encroached to -250 ft ss. The model will be initialized in COZView at 1900 psia reservoir pressure.

Crestal CO2 injection was initiated in 1/1/2012. The reservoir pressure needed to be increased to approximately 2600 psia to achieve CO2-oil miscibility. Two additional crestal wells (5 and 6) were drilled to supplement CO2 injection and shorten the re-pressuring period. The bottom hole injection pressure was limited to 2800 psia and the production bottom hole pressures were not allowed to fall below 2600 psia. The maximum field (facilities) CO2 injection capacity was 15 MMSCF/D. The purchased CO2 was constrained at 9 MMSCF/D. Produced gas was not recycled.

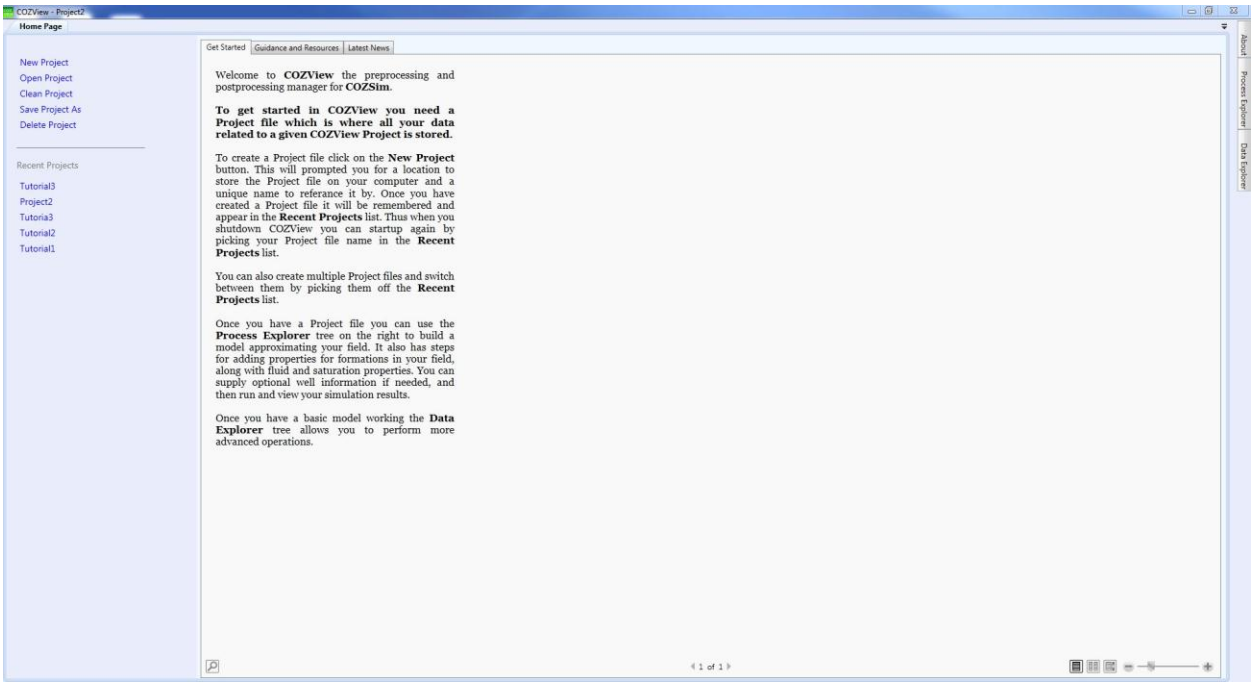
The 15 year simulation prediction resulted in a cumulative incremental oil production was 8.8 MMSTB (16.1% of OOIP). Wells were still producing at 1313 STB/D at the end of the prediction. Cumulative CO2 injection, all of which was from the external source (purchased), was 37.16 BSCF. Cumulative CO2 production was 12.68 BSCF; none of this was recycled. Cumulative hydrocarbon gas production was 3.4 BSCF.

Run time was approximately 30 minutes.

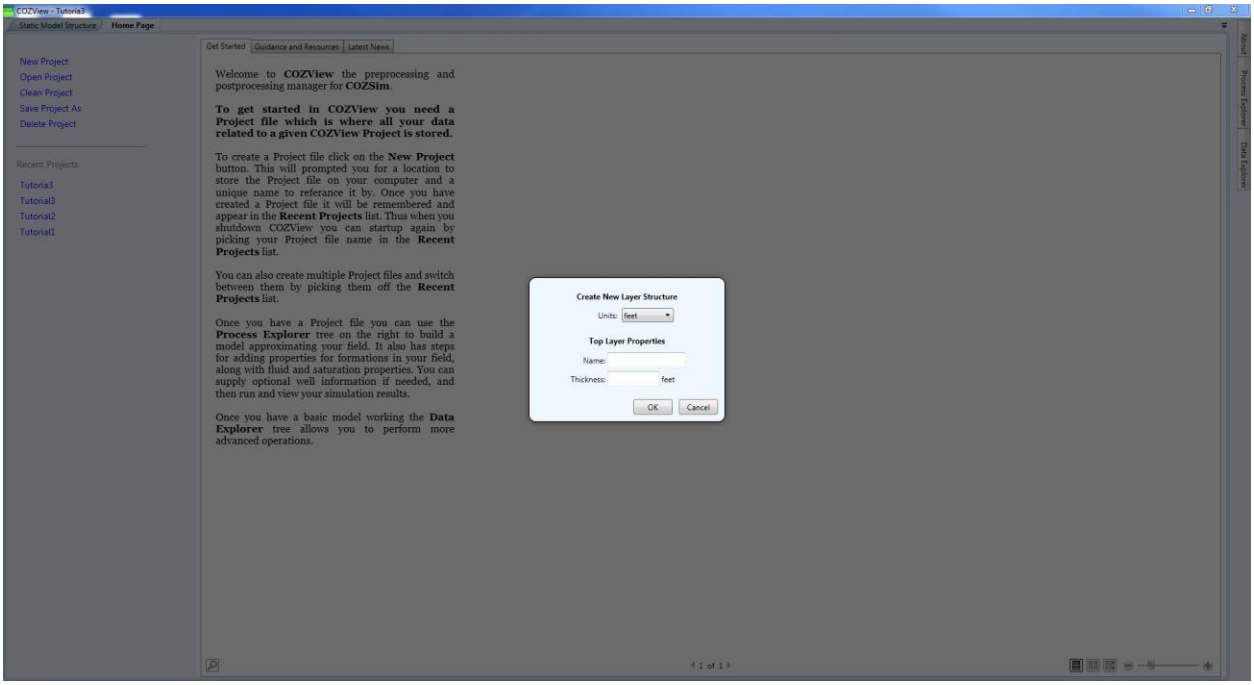
In the course of developing the tutorial examples, some COZView screens may have changed slightly from the views shown in this document. These changes should not impact the model building and simulation process.

Model Building Process

The process starts with creation of a New Project. Select **New Project** and provide a project name on the **Home Page**.

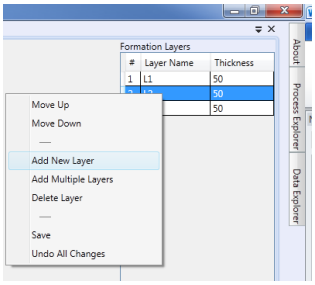


Select **Structure** in the **Static Model** area. *The Create New Layer Structure* window will appear. Input a top layer name and the net thickness (50 for this example). **OK** will save the information.



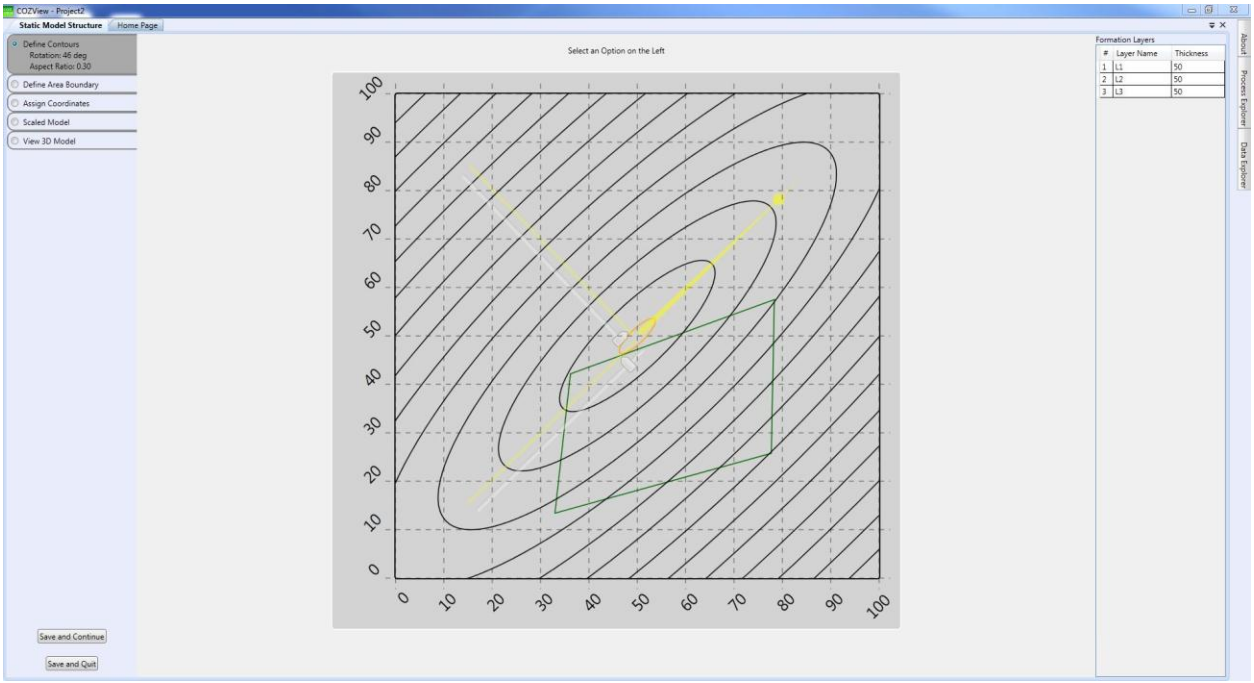
All menus referenced in this tutorial are in the Process Explorer menu area.

The model building starts with the structural surface of the productive formation. Before beginning the structural model definition, add any additional layers that are required by right-clicking the layer 1 row in the upper right of the **Static Model Structure** screen. Select *Add New Layer* and input the required data. Repeat the process as needed. The total net thickness of 150 ft should be divided equally between three layers for this example.



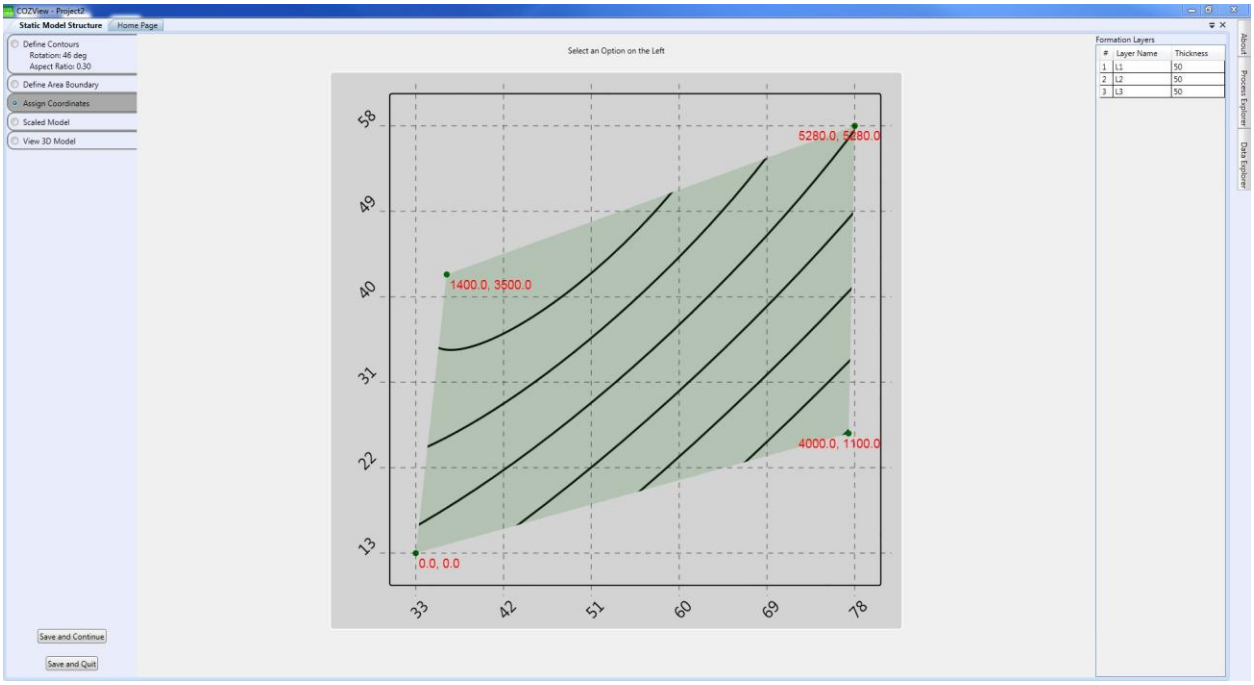
The **Static Model Structure** area allows the user to first *Define Contours* by using the resizing bars and rotation control ball.

This is followed by **Define Area Boundary** (the green area shown below). The simulation model will be the area inside the green boundaries. The user selects the boundary points to reflect the reservoir area on the structure top map.



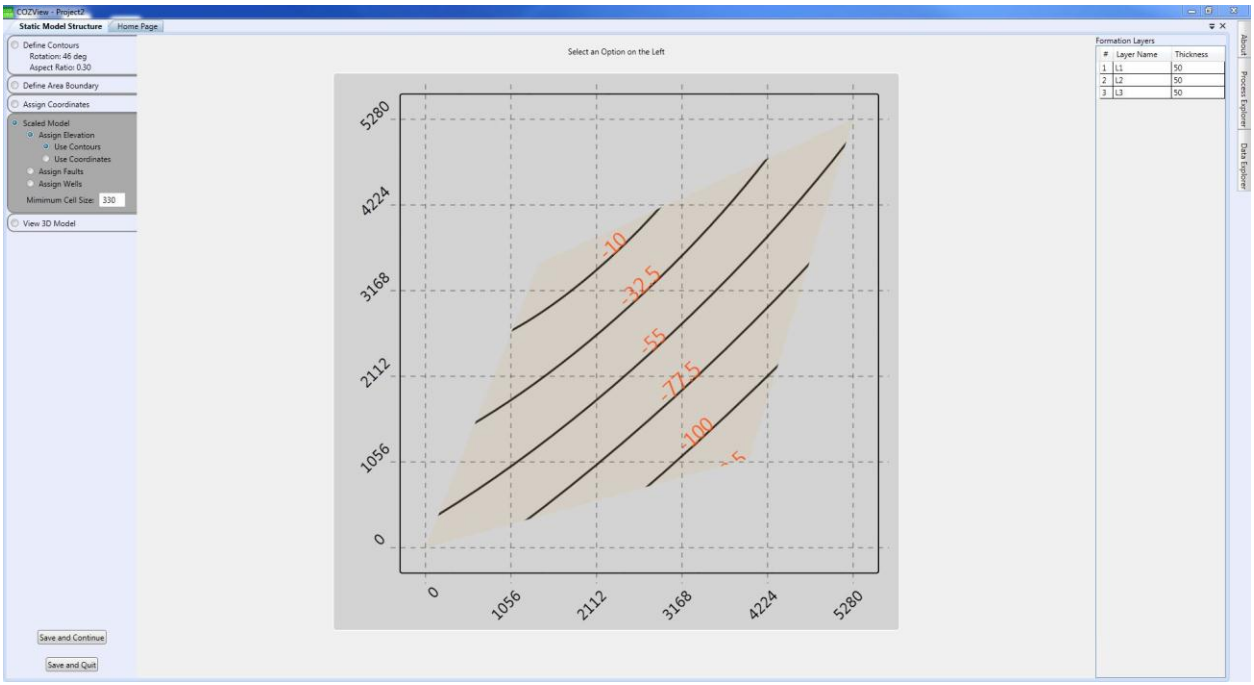
Save and Continue is recommended.

Assign Coordinates allows the user to provide coordinate positions for each of the boundary points provided. These are typically in feet as shown below.



Save and Continue is recommended.

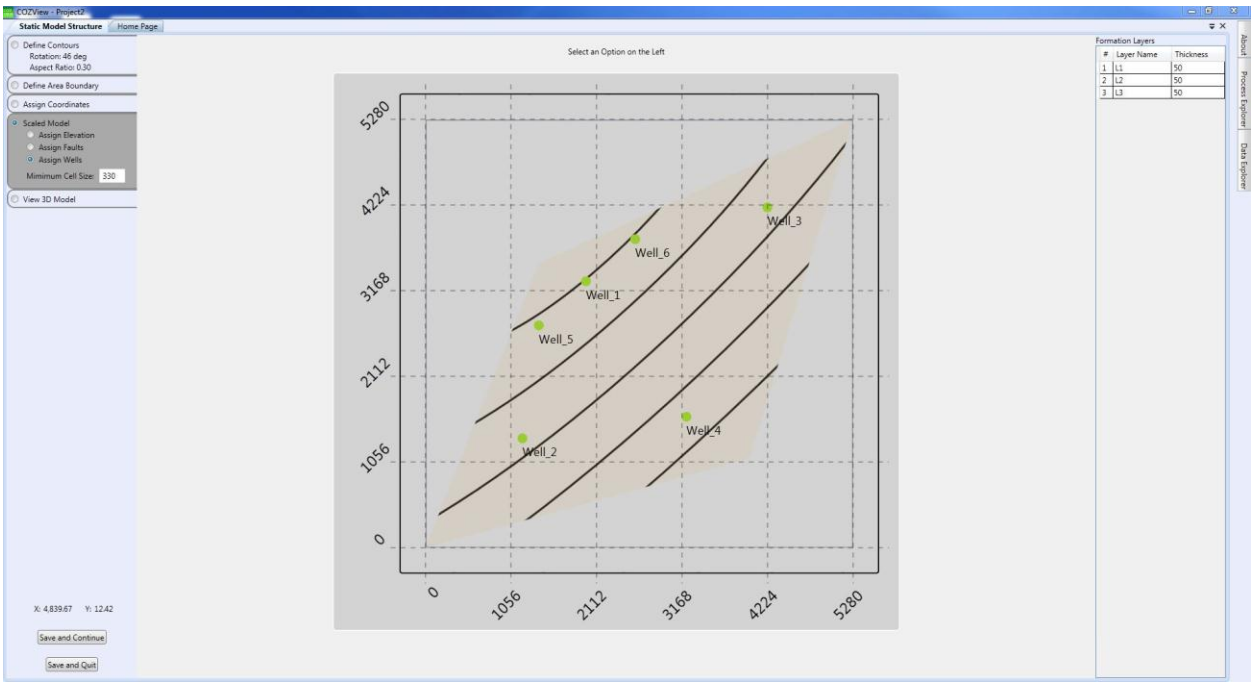
Selection of **Scaled Model** and *Assign Elevation/Use Contours* allows the user to establish the structural contour elevations. A top contour elevation of -10 ft ss and a bottom contour elevation of -100 ft ss establish the contour interval.



Save and Continue is recommended.

Assign Wells allows the user to position wells on the structural surface. Once all wells are positioned their KB and TD should be defined (optional). The KB and TD data are

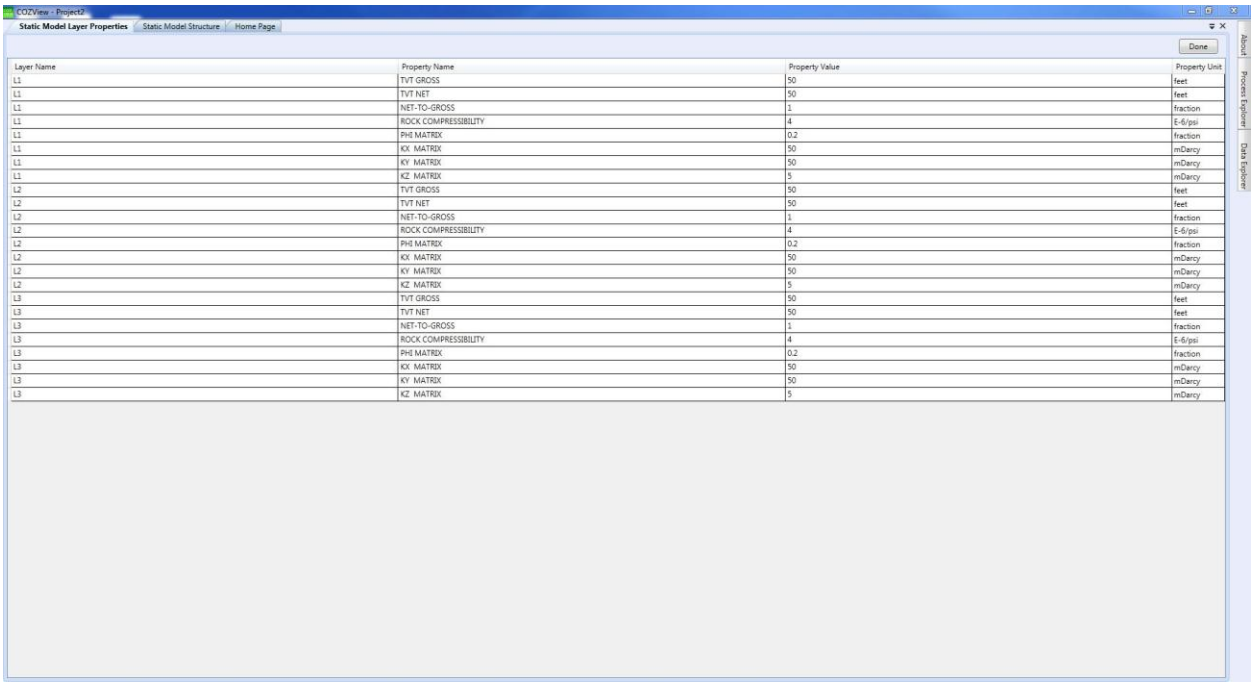
Well	KB	TD
1	7000	7600
2	7200	7400
3	7050	7500
4	7100	7300
5	7000	7500
6	7100	7600



Save and Continue is recommended.

Select **Layer Properties 3D View** to confirm the structural model and well positions in a 3D view.

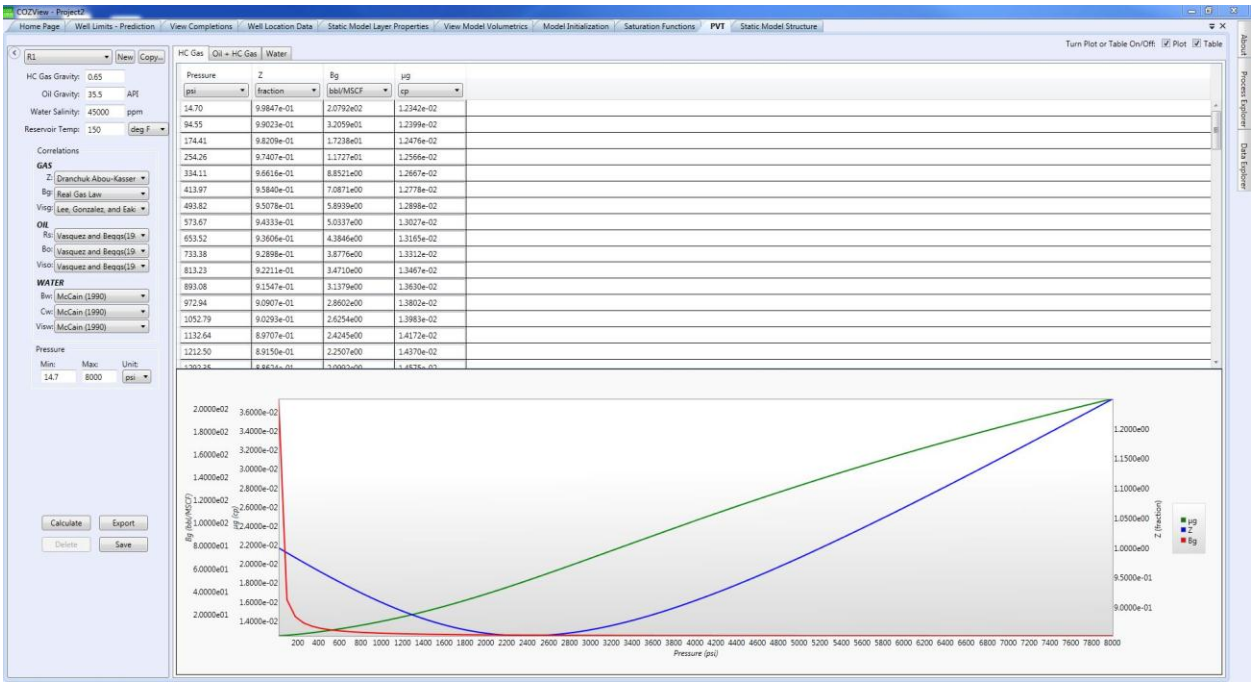
Layer Properties should be selected from the **Static Model** menu area. Values will already be input for the layers previously defined. The default values can be changed if appropriate.



Layer Name	Property Name	Property Value	Property Unit
L1	TVT GROSS	50	feet
L1	TVT NET	50	feet
L1	NET-TO-GROSS	1	fraction
L1	ROCK COMPRESSIBILITY	4	E-6/psi
L1	PHI MATRIX	0.2	fraction
L1	KX MATRIX	50	mDarcy
L1	KY MATRIX	50	mDarcy
L1	KZ MATRIX	5	mDarcy
L2	TVT GROSS	50	feet
L2	TVT NET	50	feet
L2	NET-TO-GROSS	1	fraction
L2	ROCK COMPRESSIBILITY	4	E-6/psi
L2	PHI MATRIX	0.2	fraction
L2	KX MATRIX	50	mDarcy
L2	KY MATRIX	50	mDarcy
L2	KZ MATRIX	5	mDarcy
L3	TVT GROSS	50	feet
L3	TVT NET	50	feet
L3	NET-TO-GROSS	1	fraction
L3	ROCK COMPRESSIBILITY	4	E-6/psi
L3	PHI MATRIX	0.2	fraction
L3	KX MATRIX	50	mDarcy
L3	KY MATRIX	50	mDarcy
L3	KZ MATRIX	5	mDarcy

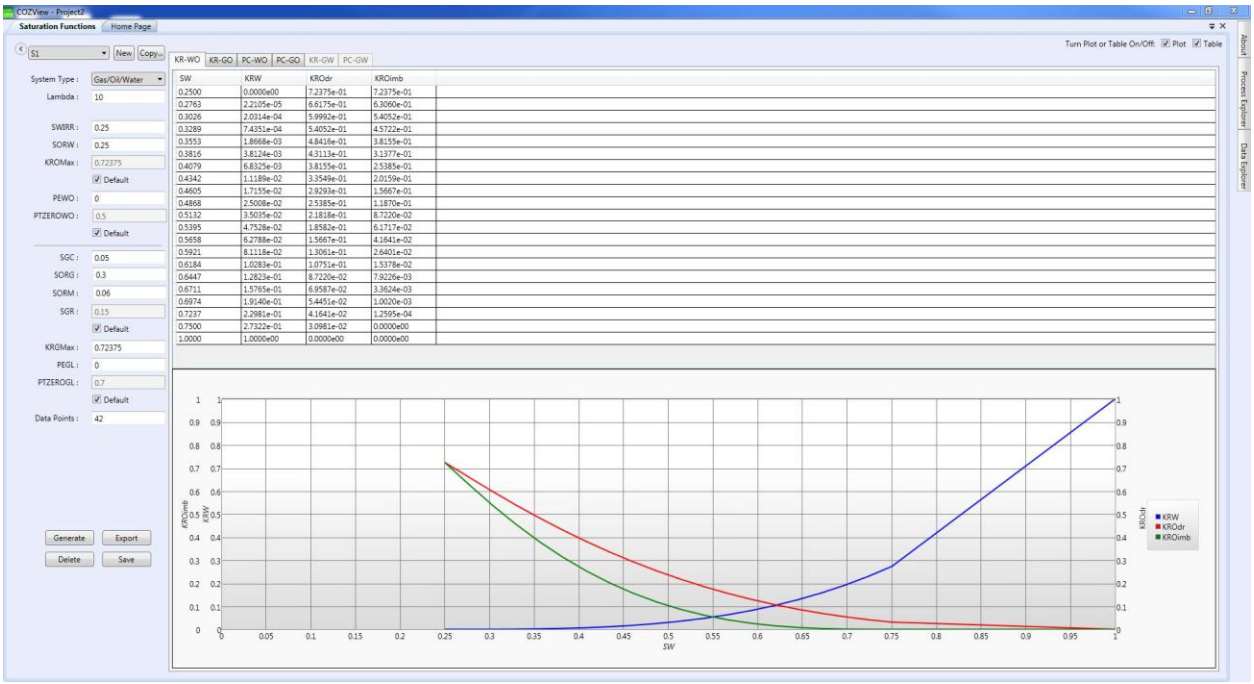
Select **Done** when finished to save the layer properties.

PVT should be selected from the **Fluid and Saturation Properties** menu area. The initial PVT properties screen will be blank. The **New** button should be selected to create a new set of PVT properties (table). The default values must be overridden by the user to create the PVT data shown below when the **Calculate** button is selected.



Select **Save** to save the data.

Saturation Functions should be selected from the **Fluid and Saturation Properties** menu area. The initial Saturation Function properties screen will be blank. The **New** button should be selected to create a new set of Saturation Function properties (table). The default values must be overridden by the user to create the Saturation Function data shown below when the **Generate** button is selected.



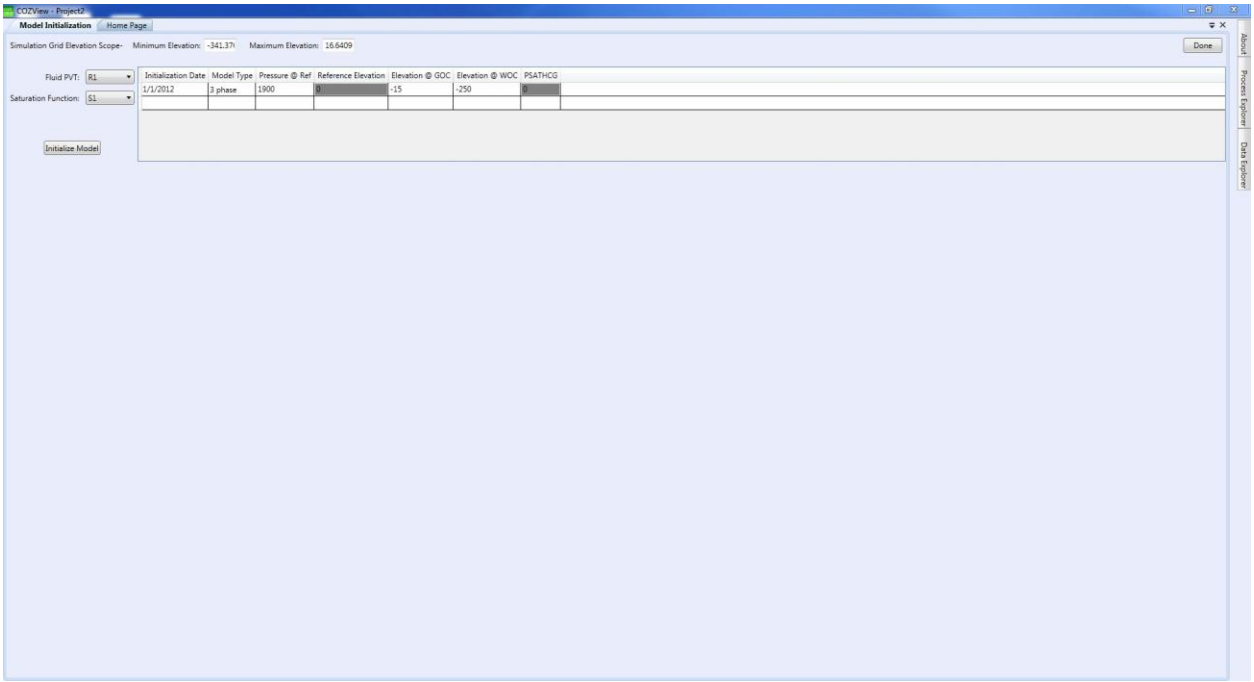
Select **Save** to save the data.

Model Initialization should be selected from the **Verify Model** menu area. This screen will initially be blank. The user can verify the volumetrics of the model that has been created by inputting appropriate values in the data fields. Initially the volumetrics of the model can be checked for the original conditions (1/1/1990), if desired. This requires identification of the Fluid PVT and Saturation Function tables previously defined. The following data would be input for the current conditions at 1/1/2012.

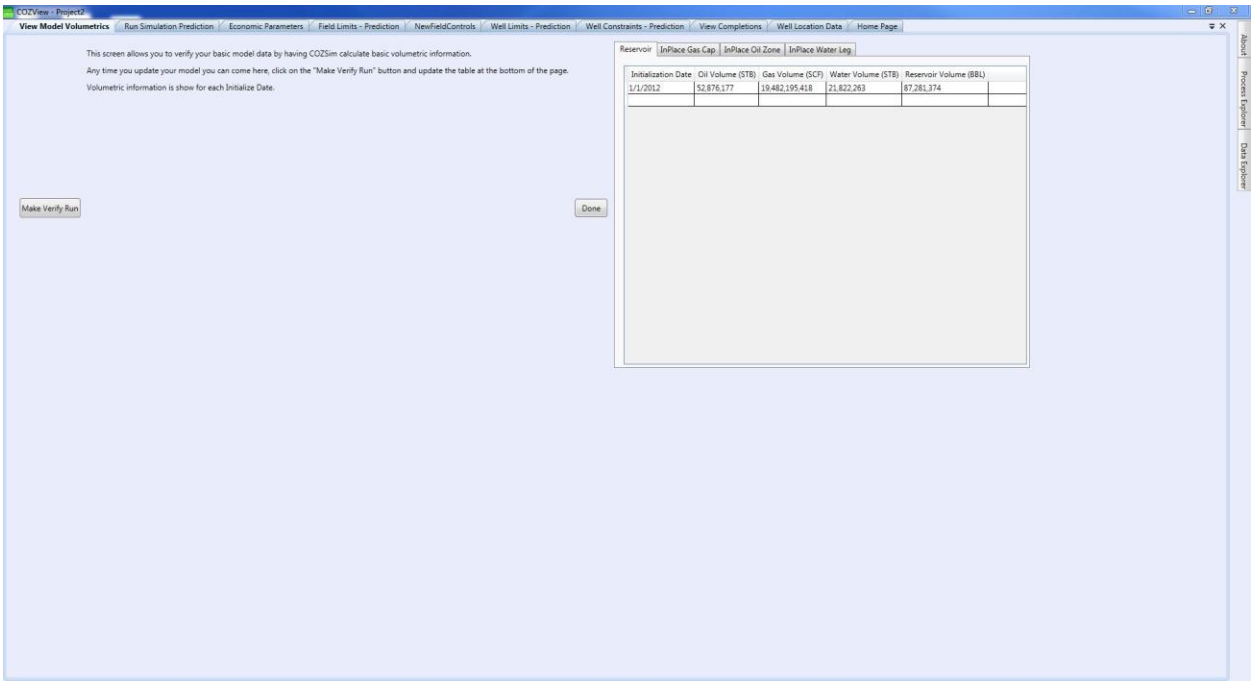
Initialization Date	1/1/2012
Model Type	3 phase
Pressure @Ref	1900
Elevation @ GOC	-15
Elevation @ WOC	-250

Selection of **Initialize Model** will provide the results of the volumetric calculation on the **Model Volumetrics** screen. A brief view of the **Simulator Runner** window will appear before the volumetrics are reported. If initial conditions (1/1/1990) are run, an OOIP of approximately 54.812 MMSTB should be reported subject to differences in the user defined model and this example.

The screen below shows the current conditions (1/1/2012) **Model Initialization** data. Selection of **Initialize Model** will provide the results of the volumetric calculation on the **Model Volumetrics** screen.



An OIP of approximately 52.876 MMSTB should be reported subject to differences in the user defined model and this example.

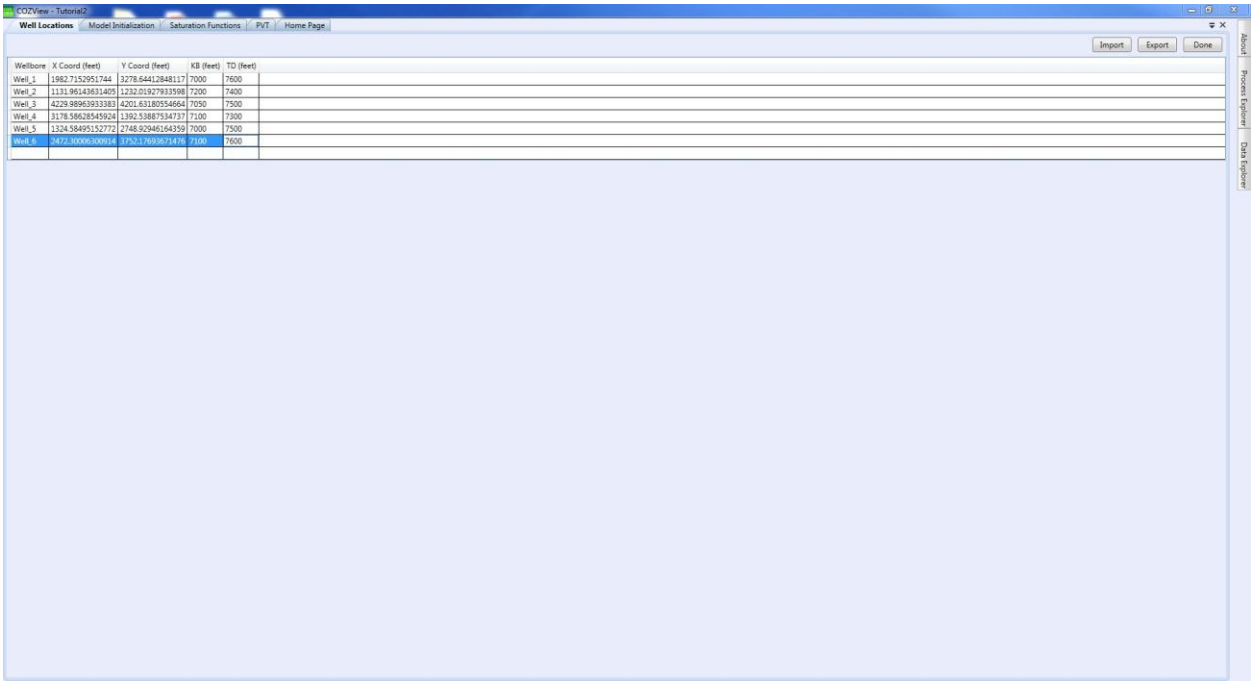


If the user is not satisfied with the volumetric values calculated, changes to the model data created to this point can be made and saved and new volumetrics calculated.

Select **Done** when finished.

The following steps will define well and field operating conditions for the prediction case to be run.

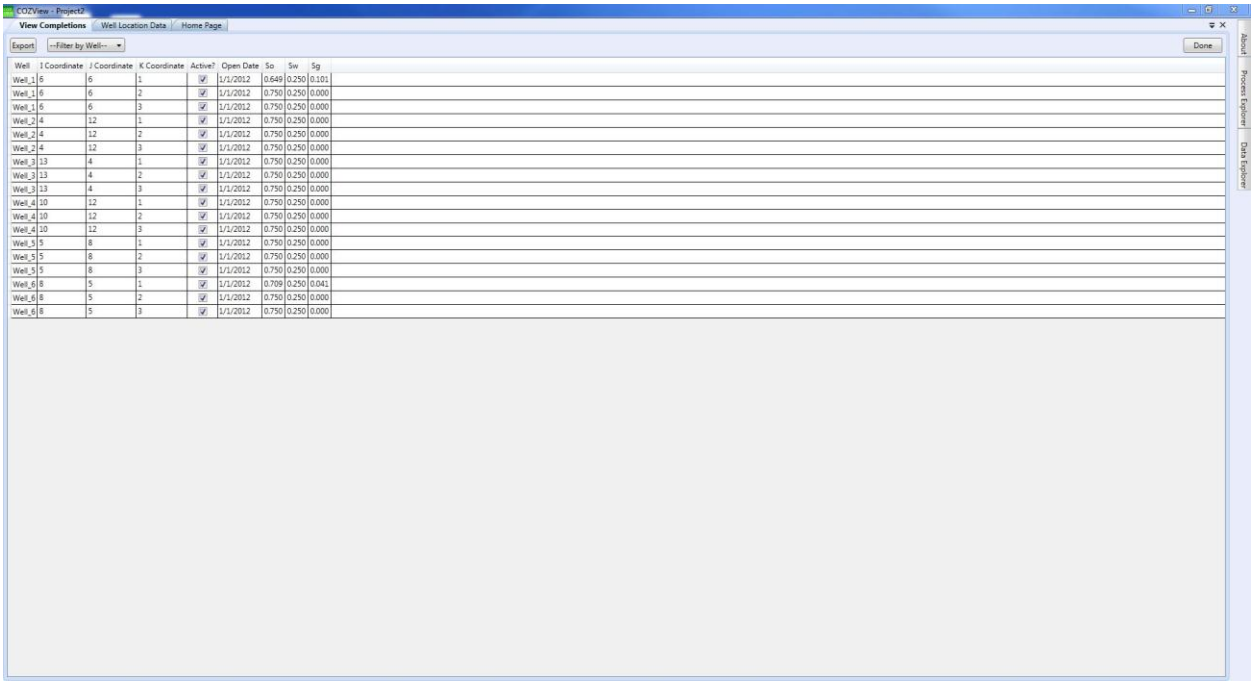
Select **Well Locations** from the **Well Data** menu area to verify previously input well locations, KB elevations and TD. This is generally informational reporting only. If additional wells are required, the user should return to the **Static Model** menu area and interactively locate the new well(s). KB and TD values can be change if required.



Select **Done** to save.

Select **Completions** from the **Well Data** area to view and alter the well completions if appropriate. Initially all wells are assumed to be completed in all layers. The *Active check box* can be unchecked for any well layer completion, if desired. No completion changes were made to the default values for this example.

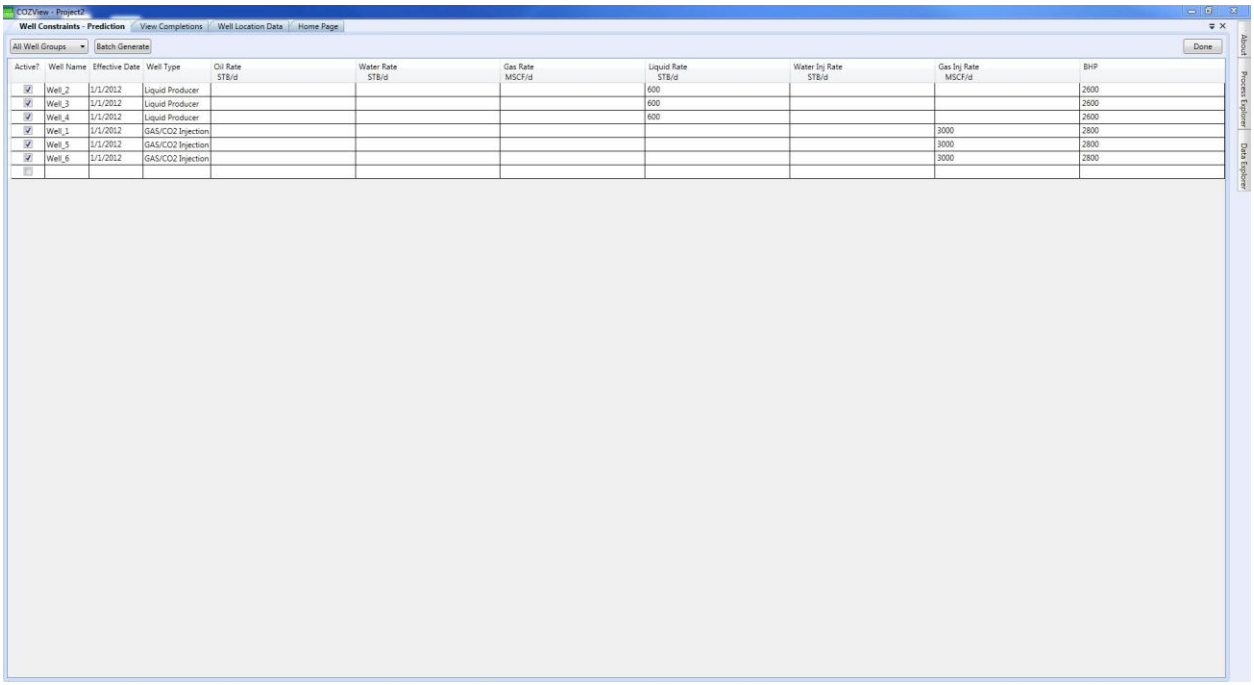
It is important to keep track of the dates shown in the various well and field control screens. These must be consistent with the Initialization Date (start date for the prediction simulation run). These dates should be changed if necessary.



Well	I Coordinate	J Coordinate	K Coordinate	Active?	Open Date	So	Sw	Sg
Well_1	6	6	1	☑	1/1/2012	0.649	0.250	0.101
Well_1	6	6	2	☑	1/1/2012	0.750	0.250	0.000
Well_1	6	6	3	☑	1/1/2012	0.750	0.250	0.000
Well_2	4	12	1	☑	1/1/2012	0.750	0.250	0.000
Well_2	4	12	2	☑	1/1/2012	0.750	0.250	0.000
Well_2	4	12	3	☑	1/1/2012	0.750	0.250	0.000
Well_3	13	4	1	☑	1/1/2012	0.750	0.250	0.000
Well_3	13	4	2	☑	1/1/2012	0.750	0.250	0.000
Well_3	13	4	3	☑	1/1/2012	0.750	0.250	0.000
Well_4	10	12	1	☑	1/1/2012	0.750	0.250	0.000
Well_4	10	12	2	☑	1/1/2012	0.750	0.250	0.000
Well_4	10	12	3	☑	1/1/2012	0.750	0.250	0.000
Well_5	5	8	1	☑	1/1/2012	0.750	0.250	0.000
Well_5	5	8	2	☑	1/1/2012	0.750	0.250	0.000
Well_5	5	8	3	☑	1/1/2012	0.750	0.250	0.000
Well_6	8	5	1	☑	1/1/2012	0.709	0.250	0.041
Well_6	8	5	2	☑	1/1/2012	0.750	0.250	0.000
Well_6	8	5	3	☑	1/1/2012	0.750	0.250	0.000

If any changes are made to the completion select **Done** to save.

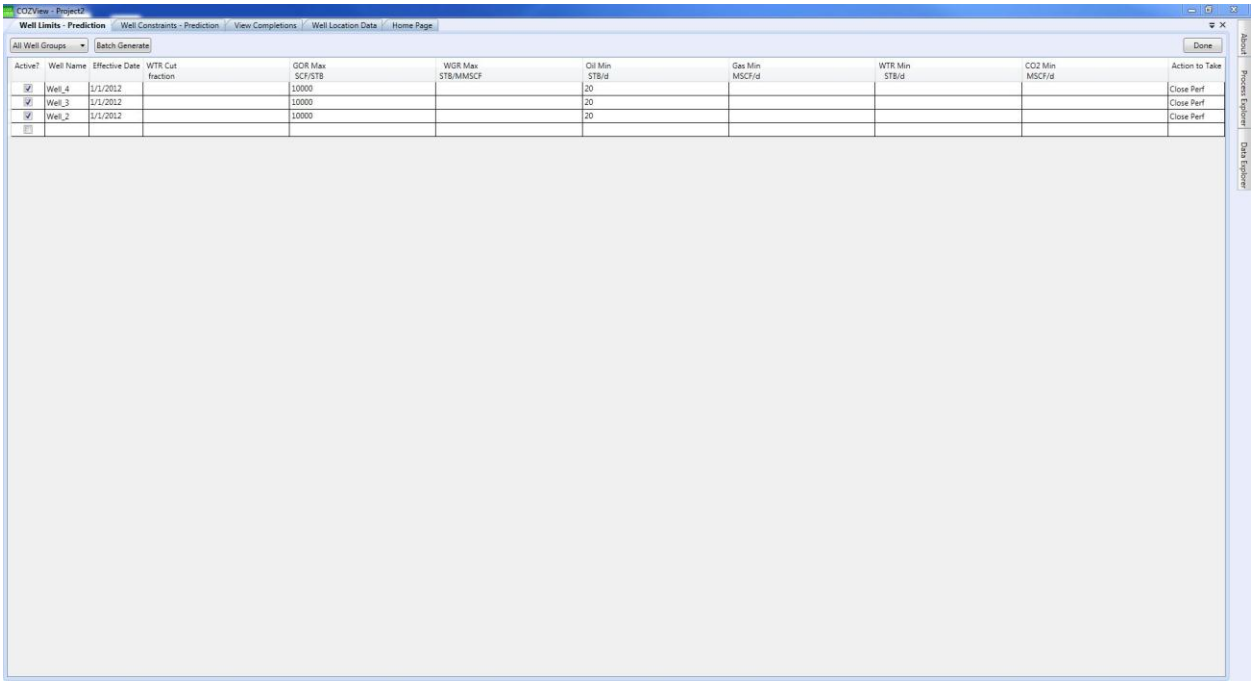
Select **Well Constraints** from the **Prediction/Well Parameters** menu area. This screen will initially be blank. The **Batch Generate** button is a fast way to input values for multiple wells. The user can input the values noted below for the GAS/CO2 Injection wells and separately for the Liquid Producer wells.



Active?	Well Name	Effective Date	Well Type	Oil Rate STB/d	Water Rate STB/d	Gas Rate MSCF/d	Liquid Rate STB/d	Water Inj Rate STB/d	Gas Inj Rate MSCF/d	BHP
☑	Well_2	1/1/2012	Liquid Producer				600			2600
☑	Well_3	1/1/2012	Liquid Producer				600			2600
☑	Well_4	1/1/2012	Liquid Producer				600			2600
☑	Well_1	1/1/2012	GAS/CO2 Injection						3000	2800
☑	Well_5	1/1/2012	GAS/CO2 Injection						3000	2800
☑	Well_6	1/1/2012	GAS/CO2 Injection						3000	2800

Select **Done** to save.

Select **Well Limits** from the **Prediction/Well Parameters** menu area. This screen will initially be blank. The **Batch Generate** button is a fast way to input the values noted below for multiple wells.

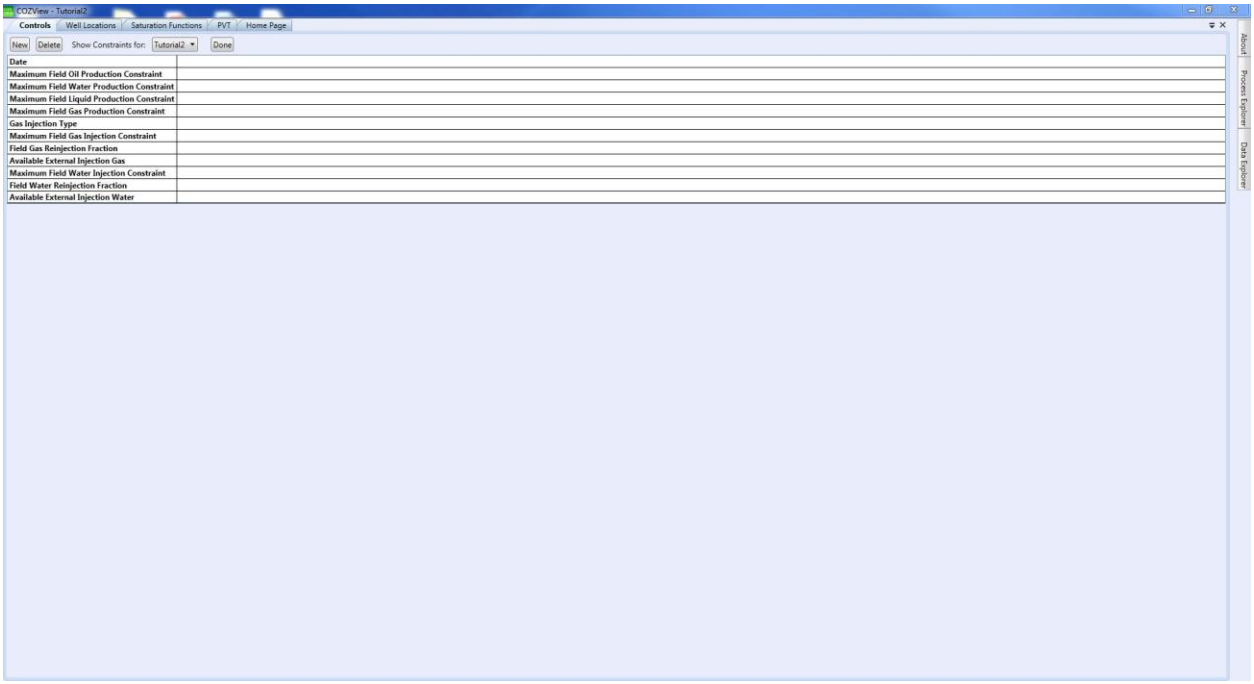


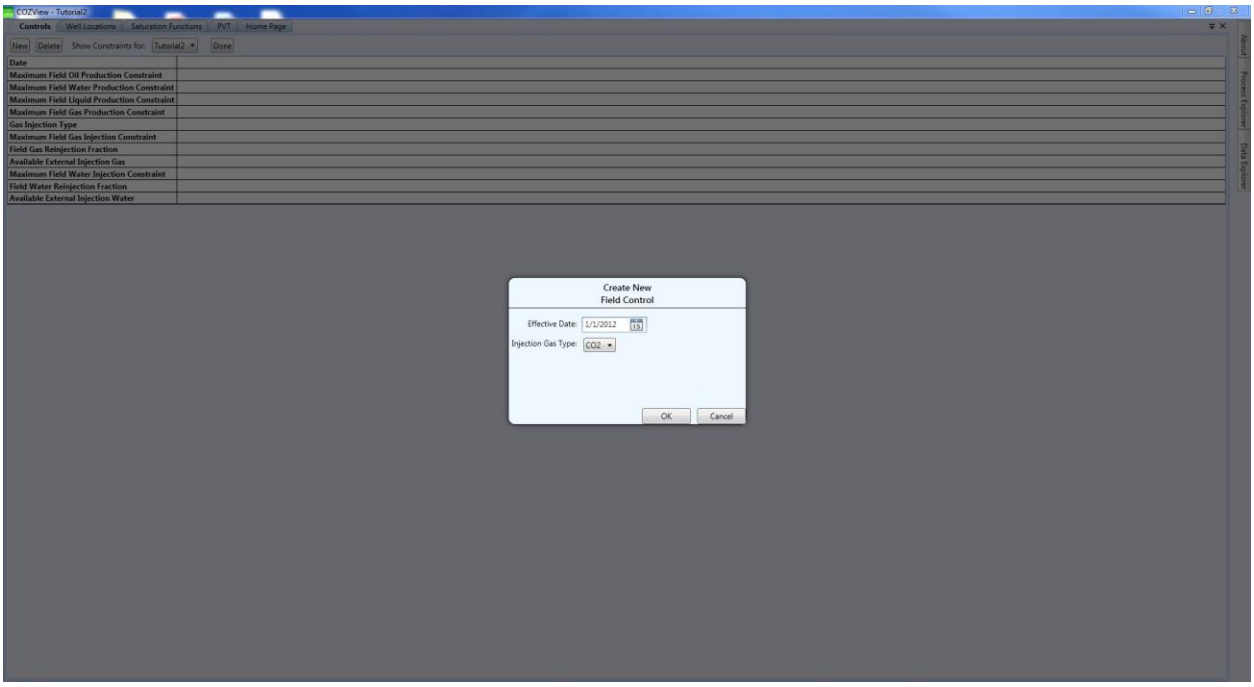
Sect **Done** to save.

Select **Field** (Facility) **Controls** from the **Prediction Period/Field Parameters** menu area. Click *New* to select a date at which Field Controls are to become effective. The user can specify Production Controls and Injection Controls for the field. Select “CO2” for the **Injection Gas Type**.

Effective Date 1/1/2012

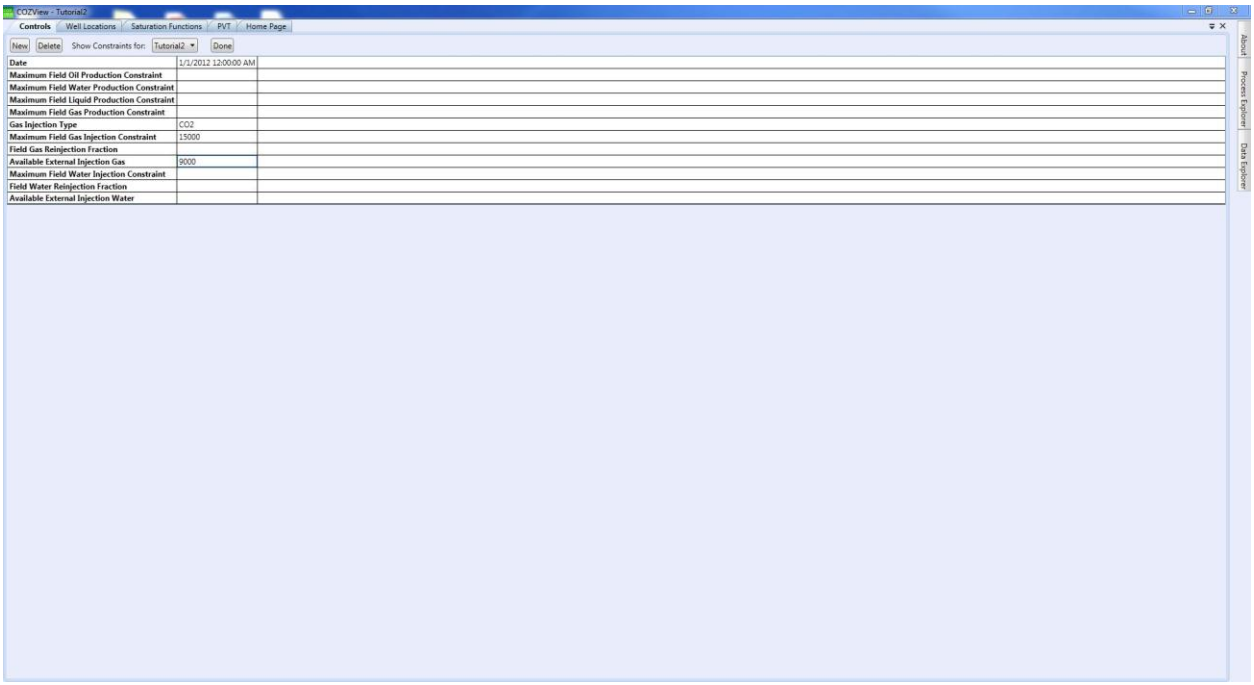
Injection Gas Type CO2





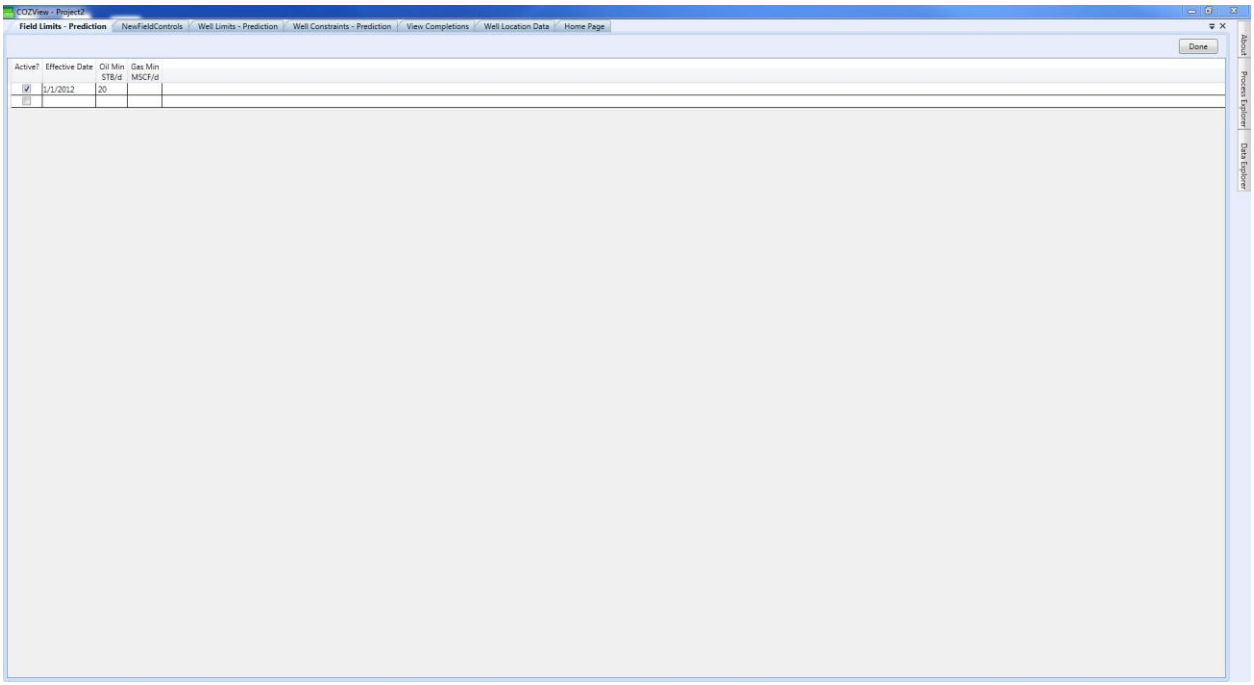
Select **OK** to continue.

The Maximum Field Gas Injection Constraint in this case is 15,000 MSCF/D and the Available External Gas Injection Gas is 9000 MSCF/D.



Select **Done** to save.

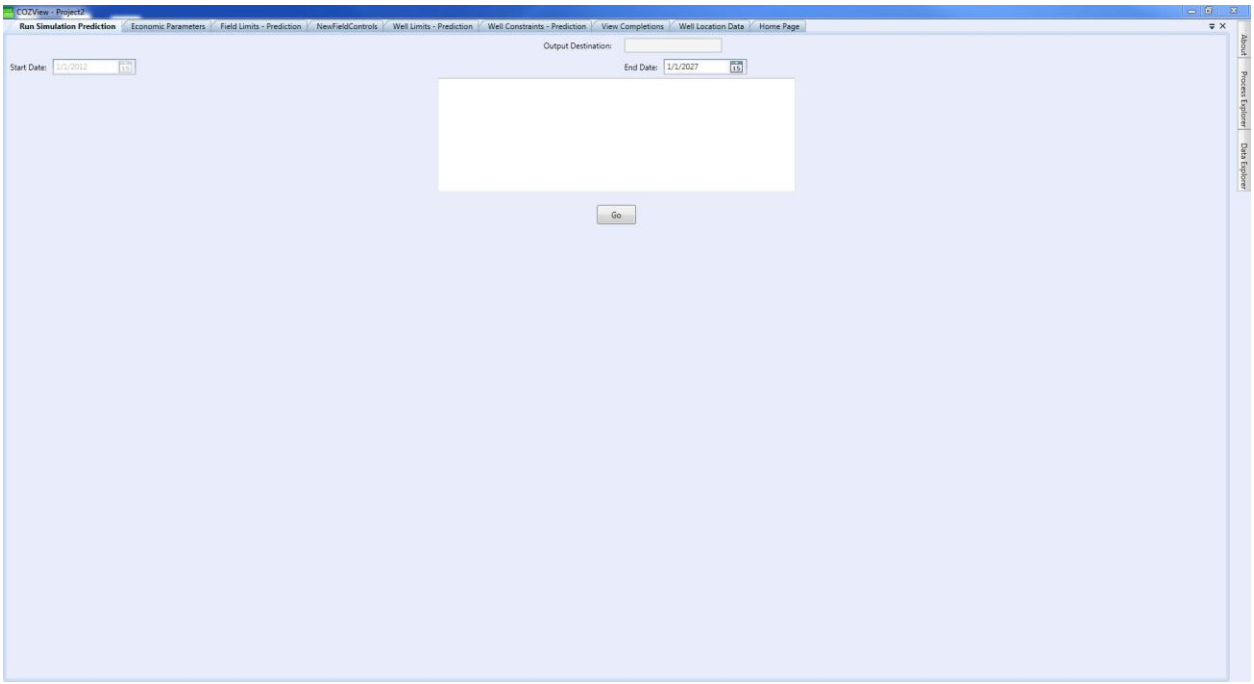
Select **Limits** from the **Prediction Period/Field Parameters** menu area. Check the **Active** box and input appropriate values. It is always wise to have a field limit specified such that the simulation run will stop when the field limit is reached.



Select **Done** to save.

It is prudent at this stage to return to the various well and field parameter screen to insure that data, particularly dates, are set appropriately.

Select **Run Simulation**. The **Model Initialization** date will be shown in the **Start Date** box. If this is not correct, return to the **Model Initialization** screen and reset the date, rerun volumetrics and save. The user must provide a value in the **End Date** box. This must be at least one month after the **Start Date**. 1/1/2027 was used for this example.



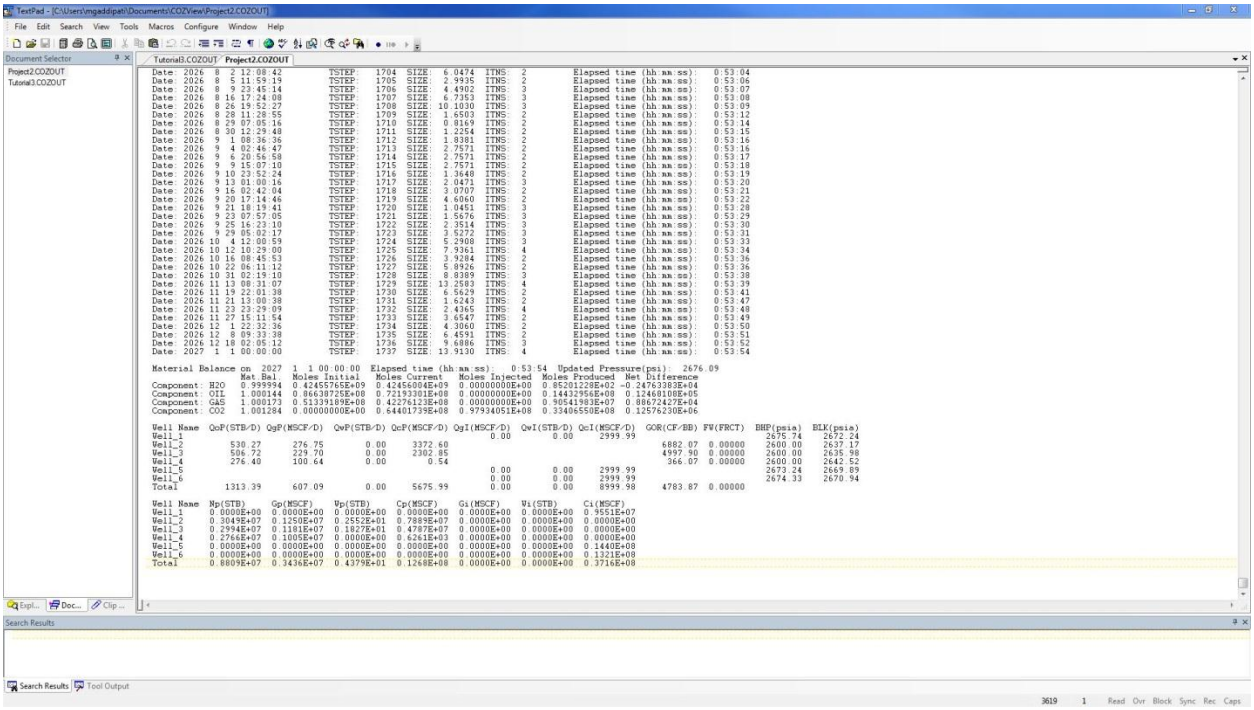
Select **Go** to initiate the simulation run.

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.

DO NOT close COZView during the simulation run. It can be minimized. Closing COZView will not stop the simulation run, but the simulation results will not be loaded at the conclusion of the simulation run. **DO NOT** change projects in COZView during a simulation run for this same reason. **DO NOT** turn the computer off during the simulation run. All simulation results will be lost.

Two files are created early during the simulation run which may help the user track the progress of the simulation run. These are stored in the COZView directory along with various project database and result files. The files are *Projectname*.COZOUT and *Projectname*.COZDAT. The .COZDAT file is the input data "deck" prepared by COZView for COZSim. The .COZOUT file reports well production and injection activity for each timestep during the simulation run. It is update frequently. Both of these files can be opened with a Text editor. The .COZDAT file can be reviewed to assure that the data "deck" is setup as the user anticipated. The .COZOUT file can be reviewed as the simulation run progresses. If the results are not as anticipated the run can be stopped in the **Simulator Runner** window.

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



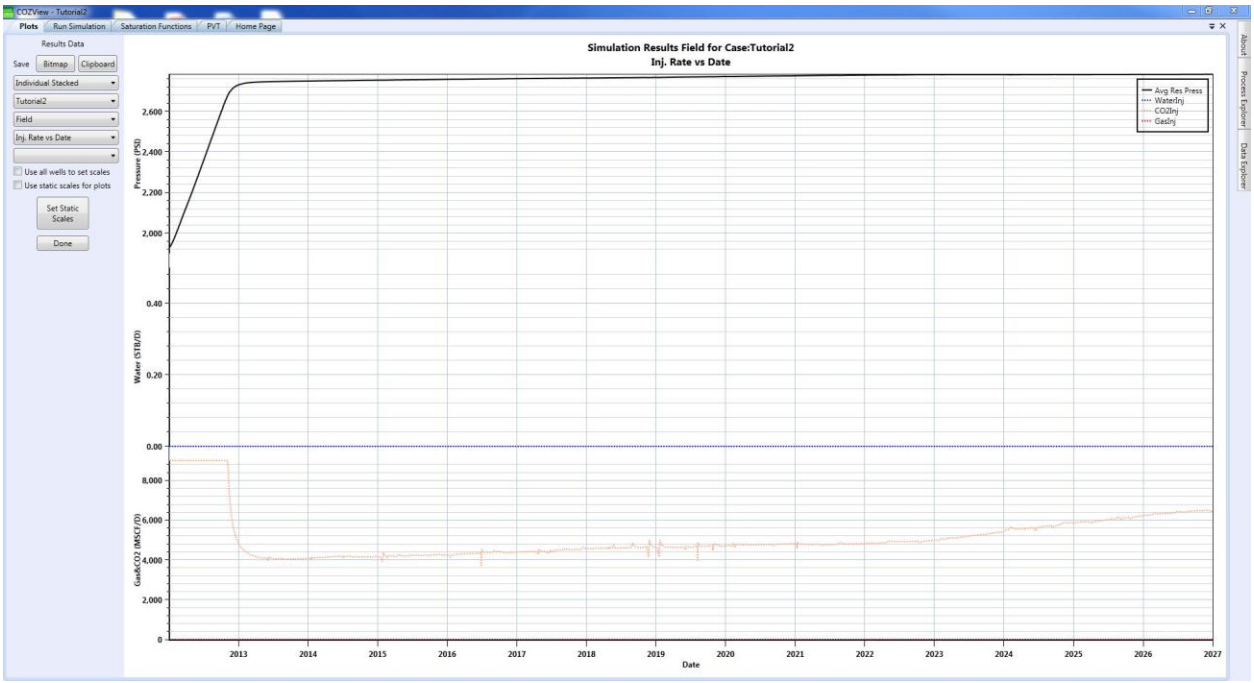
DO NOT delete are change these files during the simulation run. If the same project is re-run with changes to some parameters, these files will be overwritten.

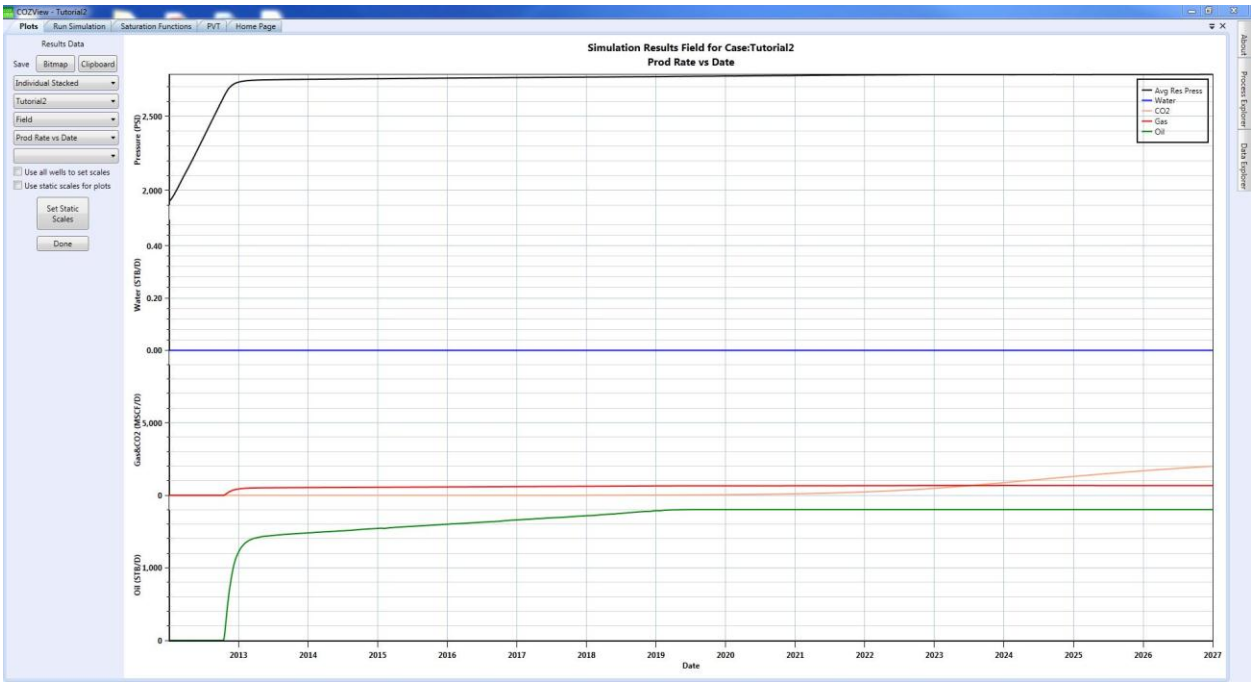
When the **Simulation Runner** window disappears, the simulation run has completed.

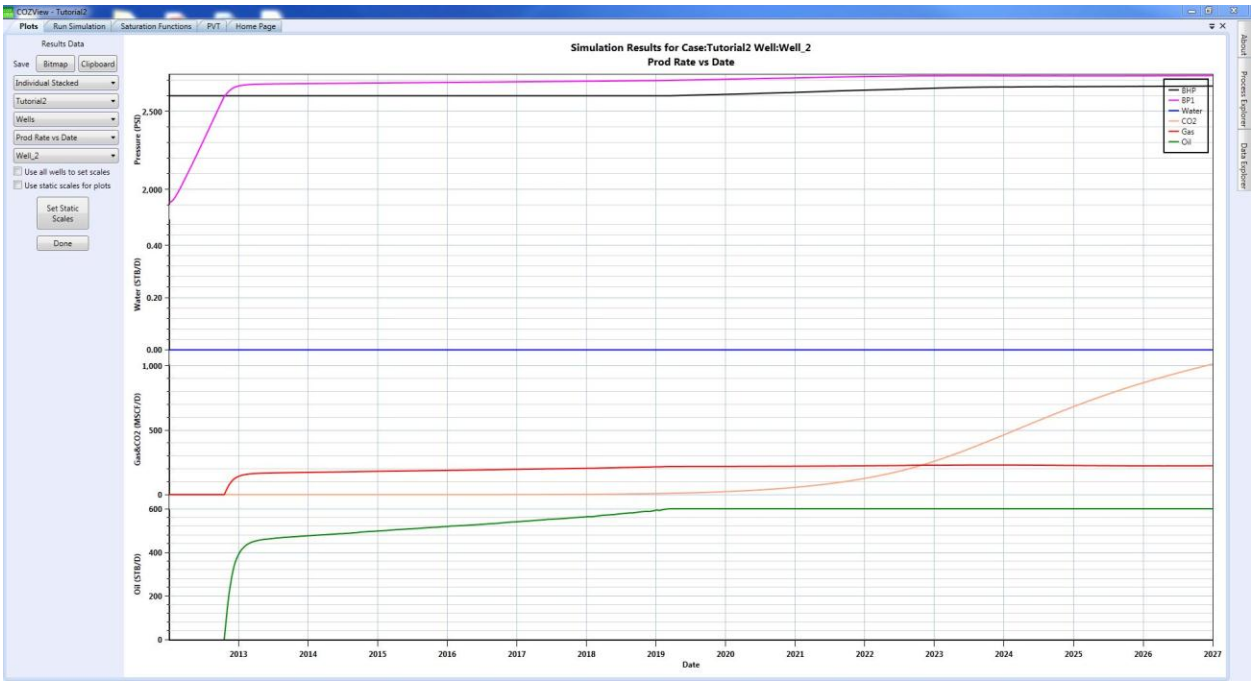
At the completion of the simulation run two small windows will appear which advise the user that the Map and PLT (plot) results are being loaded into COZView.

Select **Plots** from the **Simulation Results** area. This will give the user access to various simulation plots for the wells and field. A sample of the available plots for this prediction simulation is shown below.

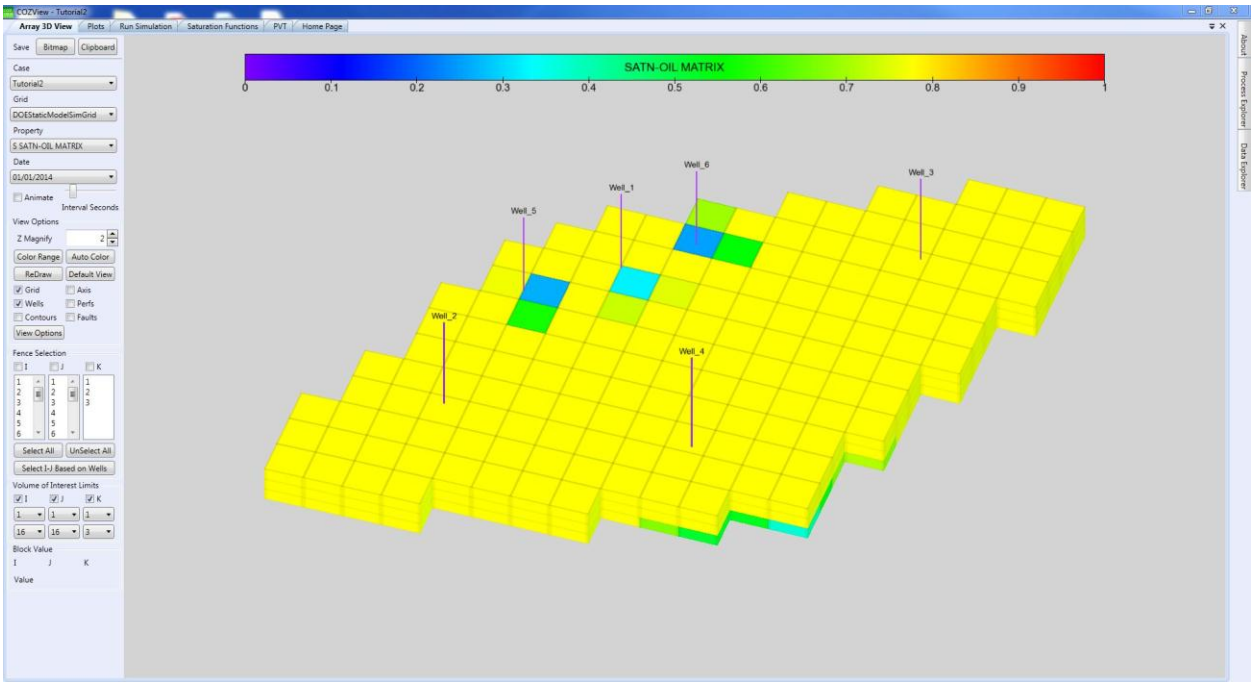
It has been found prudent to close all menu tabs except the **Home Page** and save data as may be requested before selecting any of the **Simulation Results** menus. This assures that the plot, map and table files are refreshed and prior results are not shown in error.

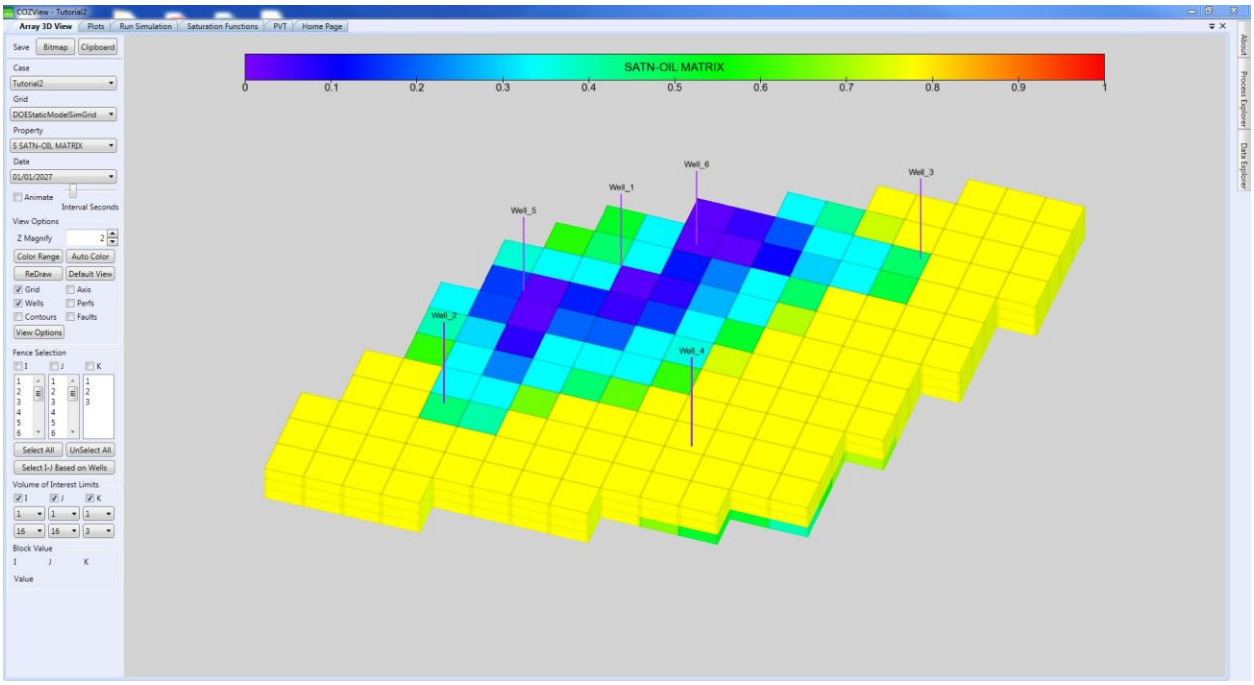

COZView - Tutorial2
Plots
Run Simulation
Saturation Functions
PVT
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
Tutorial2
Field
Inj. Rate vs Date
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
Simulation Results Field for Case:Tutorial2
Inj. Rate vs Date
Avg Res Press
WaterInj
CO2Inj
GasInj
Pressure (PSI)
Water (STB/D)
GasSCO2 (MSCF/D)
Date
About
Process Explorer
Data Explorer


COZView - Tutorial2
Plots
Run Simulation
Saturation Functions
PVT
Home Page
Results Data
Save
Bitmap
Clipboard
Individual Stacked
Tutorial2
Field
Prod Rate vs Date
Use all wells to set scales
Use static scales for plots
Set Static Scales
Done
Simulation Results Field for Case:Tutorial2
Prod Rate vs Date
Avg Res Press
Water
CO2
Gas
Oil
Pressure (PSI)
Water (STB/D)
GasSCO2 (MSCF/D)
Oil (STB/D)
Date
About
Process Explorer
Data Explorer



Select **Array 3D View** from the **Simulation Results** area. This will give the user access to various simulation maps for the field. A sample of the available maps for this prediction simulation is shown below.




COZView - Tutorial2
Array 3D View
Plots
Run Simulation
Saturation Functions
PVT
Home Page
Save
Bitmap
Clipboard
Case
Tutorial2
Grid
DOEStaticModelSimGrid
Property
5 SATN-OIL MATRIX
Date
01/01/2027
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
Value
SATN-OIL MATRIX
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Well_6
Well_1
Well_3
Well_5
Well_2
Well_4
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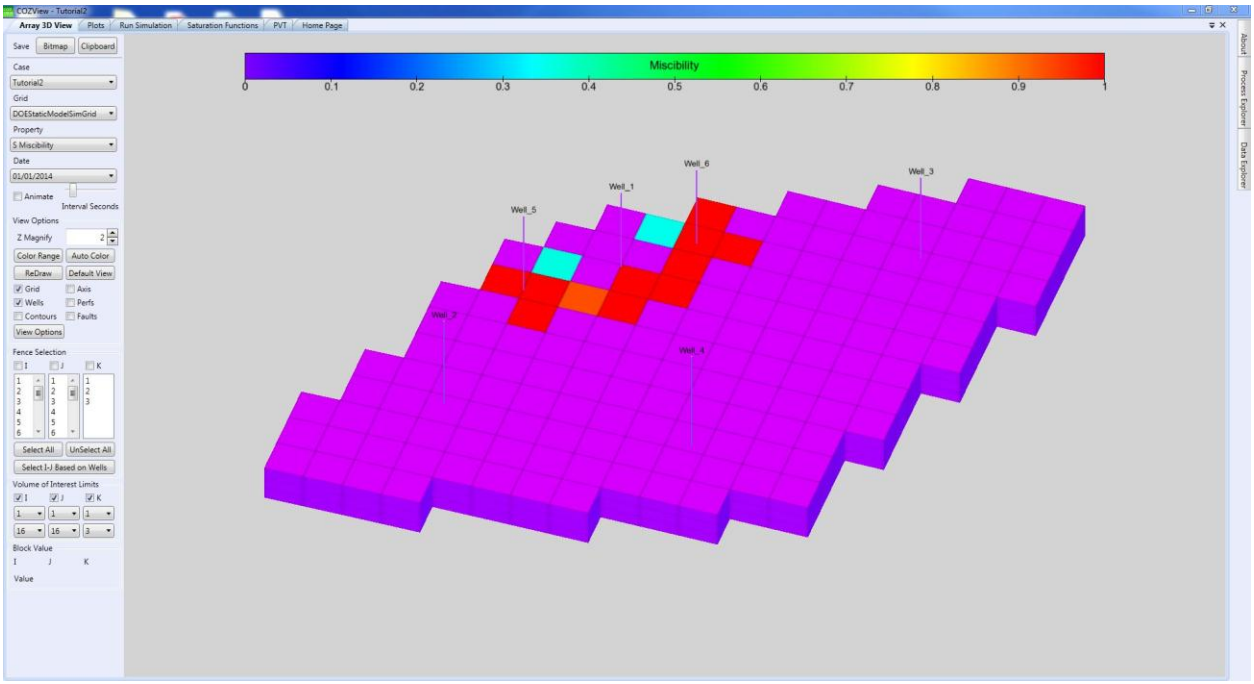
COZView - Tutorial2
Array 3D View
Plots
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Animate
Interval Seconds
View Options
Z Magnify
Color Range
Auto Color
ReDraw
Default View
Grid
Axis
Wells
Perfs
Contours
Faults
View Options
Fence Selection
Select All
UnSelect All
Select I-J Based on Wells
Volume of Interest Limits
Block Value
Value
Miscibility
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Well_6
Well_1
Well_3
Well_5
Well_2
Well_4
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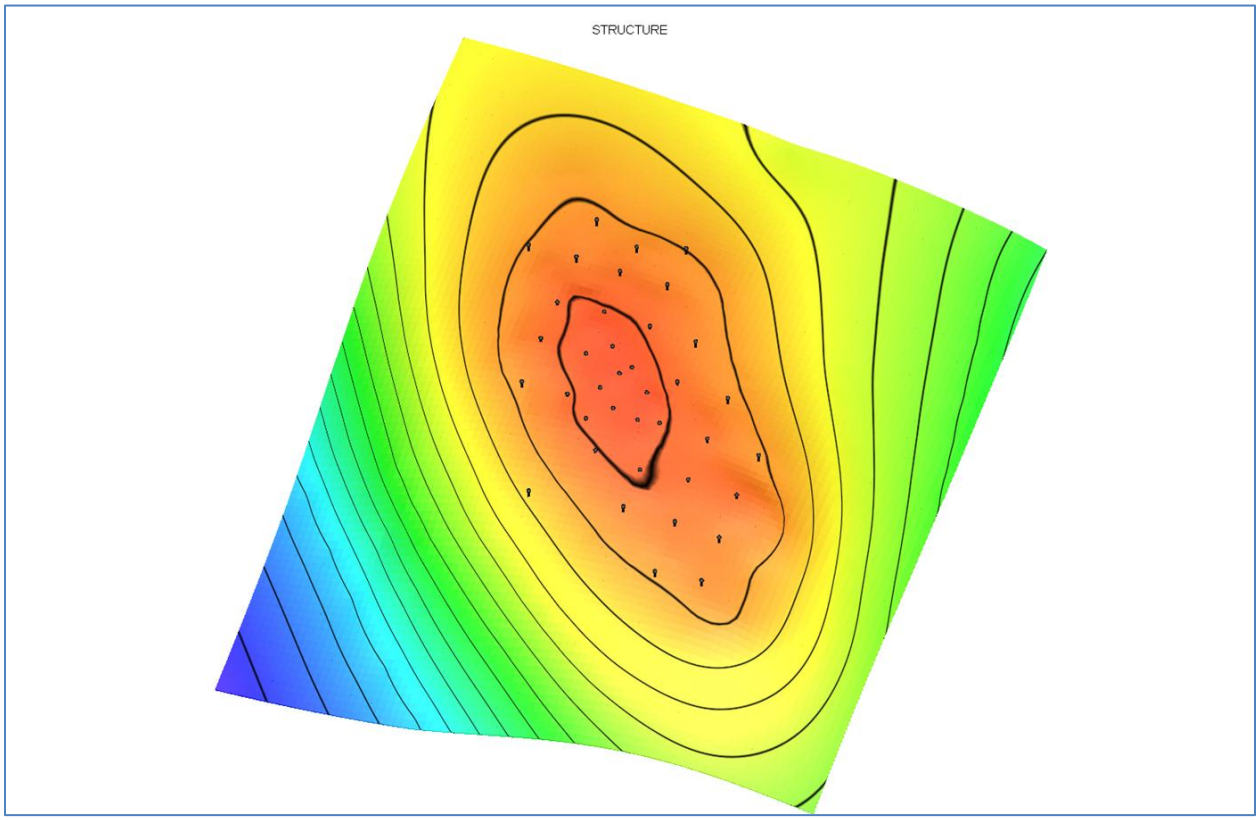
The user can also select **Tables** from the **Simulation Results** area. This will provide access to tabular simulation results for wells and the field. These tables can be exported to .csv files for use in spreadsheet applications.

It is also noted that any plot displays can be saved to Bitmap files or to the Clipboard for pasting into report documents. Any map displays can be saved to Bitmap files.

TUTORIAL #3

The XYZ Field in Wyoming was developed in the early 1940s. The field was essentially depleted in the early 1990s, although minor production continued to the late 1990s.

A structure map with productive and non-productive well locations is shown below.



Current pressure @ +1075 ft ss, psia	1650
Bubble point pressure, psia	800
Current water-oil contact, ft ss	+945
Net thickness, ft	60
Porosity, percent	20.0
Horizontal permeability, md	70
Vertical permeability, md	7
Oil gravity, API	34.0

Gas specific gravity	0.5
Reservoir Temperature, F	123
Swirr, fraction	.30
Sorw, fraction	.30
Sgc, fraction	.03
Sorg, fraction	.30
OIP, MMSTB	35.86 (Oil leg-34.32, Water leg-1.54)

A 5-spot CO2 injection pattern was investigated. The bottom hole injection pressure was limited to 2500 psia and the production bottom hole pressures were not allowed to fall below 1600 psia. The maximum field CO2 injection capacity was 5 MMSCF/D. The purchased CO2 was constrained at 5 MMSCF/D. Produced gas was not recycled.

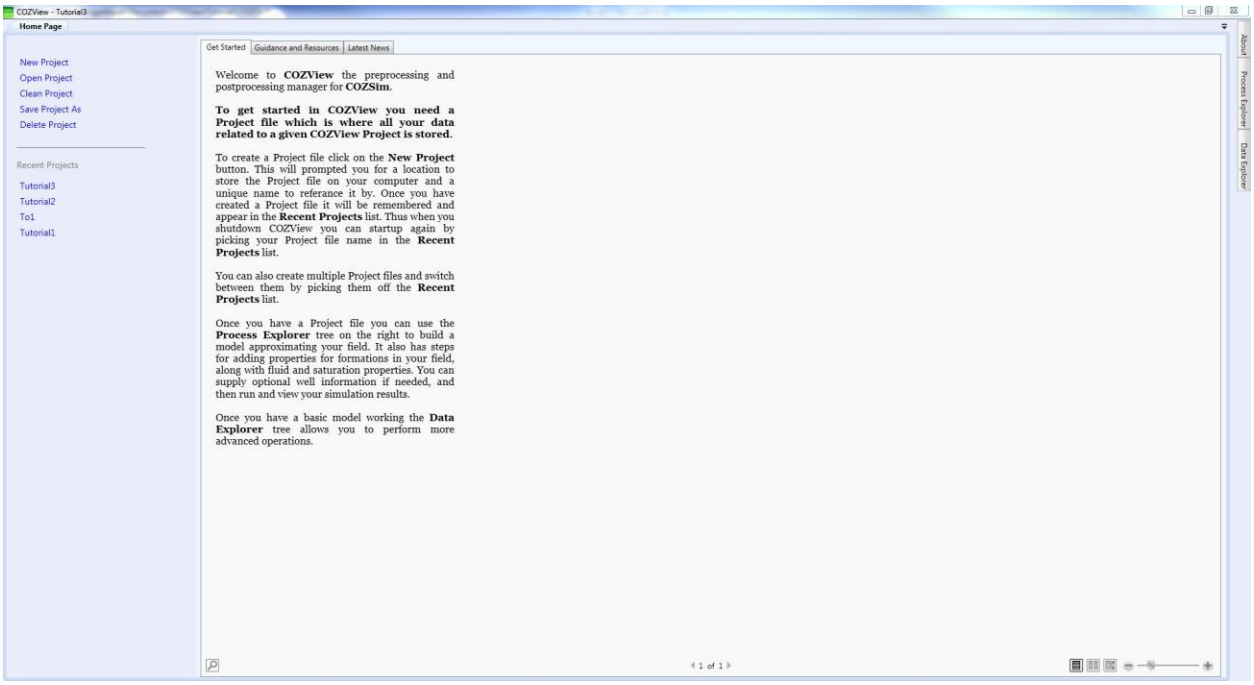
The simulation prediction resulted in a cumulative incremental oil production was 4.003 MMSTB (8.92% of OIP) over the 10 year period. Wells were still producing at 1200 STB/D at the end of the prediction. Cumulative CO2 injection, all of which was from and external source (purchased), was 12.8 BSCF. Cumulative CO2 production was 0.8 BSCF; none of this was recycled. Cumulative hydrocarbon gas production was 0.4 BSCF.

Run time was approximately 1 hour elapse time.

In the course of developing the tutorial examples, some COZView screens may have changed slightly from the views shown in this document. These changes should not impact the model building and simulation process.

Model Building Process

The process starts with creation of a New Project. Select **New Project** and provide a project name on the **Home Page**.


COZView - Tutorial3
Home Page
New Project
Open Project
Clean Project
Save Project As
Delete Project
Recent Projects
Tutorial3
Tutorial2
To1
Tutorial1
Get Started
Guidance and Resources
Latest News
Welcome to COZView the preprocessing and postprocessing manager for COZSim.
To get started in COZView you need a Project file which is where all your data related to a given COZView Project is stored.
To create a Project file click on the New Project button. This will prompted you for a location to store the Project file on your computer and a unique name to referance it by. Once you have created a Project file it will be remembered and appear in the Recent Projects list. Thus when you shutdown COZView you can startup again by picking your Project file name in the Recent Projects list.
You can also create multiple Project files and switch between them by picking them off the Recent Projects list.
Once you have a Project file you can use the Process Explorer tree on the right to build a model approximating your field. It also has steps for adding properties for formations in your field, along with fluid and saturation properties. You can supply optional well information if needed, and then run and view your simulation results.
Once you have a basic model working the Data Explorer tree allows you to perform more advanced operations.
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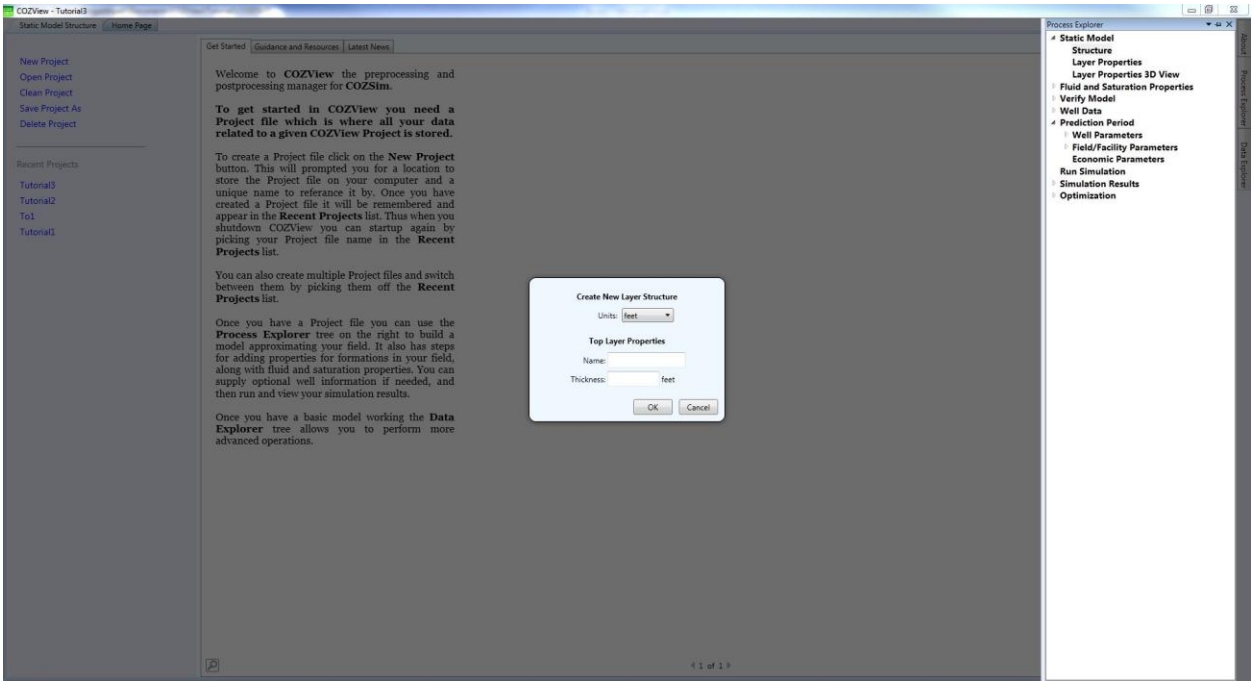
Select **Structure** in the **Static Model** area. *The Create New Layer Structure* window will appear. Input a top layer name and the net thickness (25 for this example). **OK** will save the information.



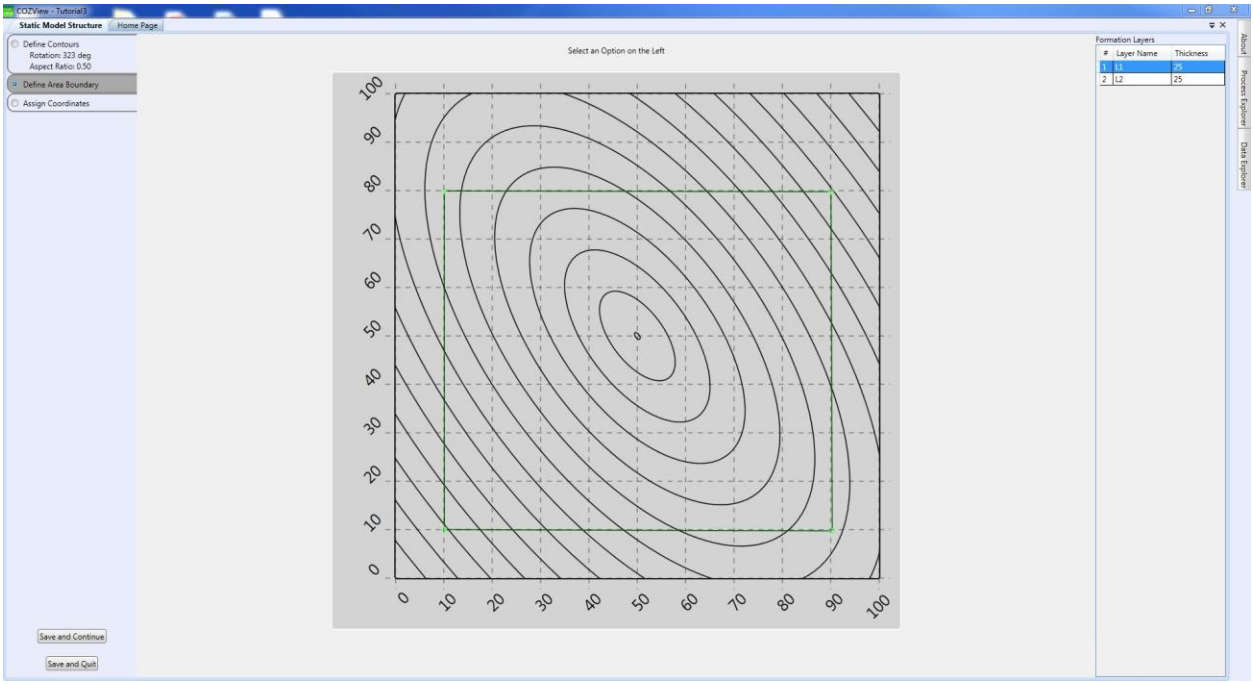
All menus referenced in this tutorial are in the Process Explorer menu area.

The model building starts with the structural surface of the productive formation. Before beginning the structural model definition, add any additional layers that are required by right-clicking the layer 1 row in the upper right of the **Static Model Structure** screen. Select *Add New Layer* and input the required data. Repeat the process as needed. In this tutorial, two layers are required - Layer 1 (25 ft), Layer 2 (25 ft).

The **Static Model Structure** area allows the user to first *Define Contours* by using the resizing bars and rotation control ball.

Save and Continue is recommended.

This is followed by **Define Area Boundary** (the green area shown below). The simulation model will be the area inside the green boundaries. The user selects the boundary points to reflect the reservoir area on the structure top map.



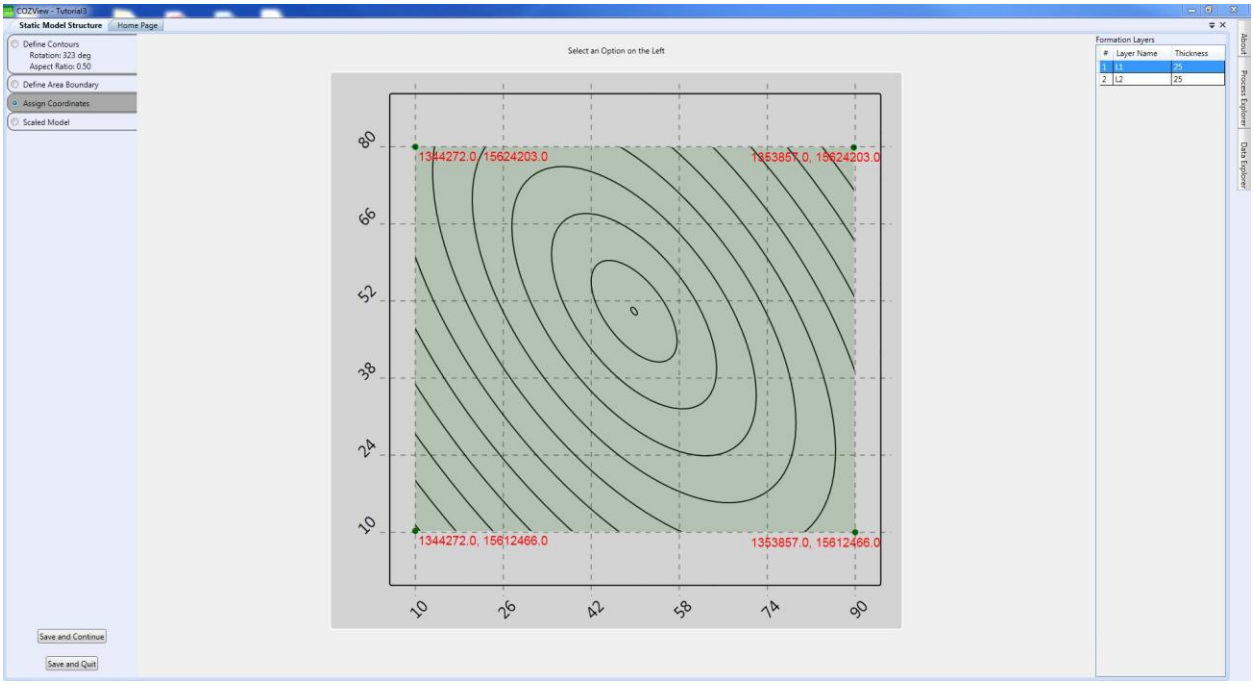
Assign Coordinates allows the user to provide coordinate positions for each of the boundary points provided. These are typically in feet as shown below.

In this example, map coordinates from mapping software were used to define the model area coordinates.

Min X – 1344272, Max X – 1353857

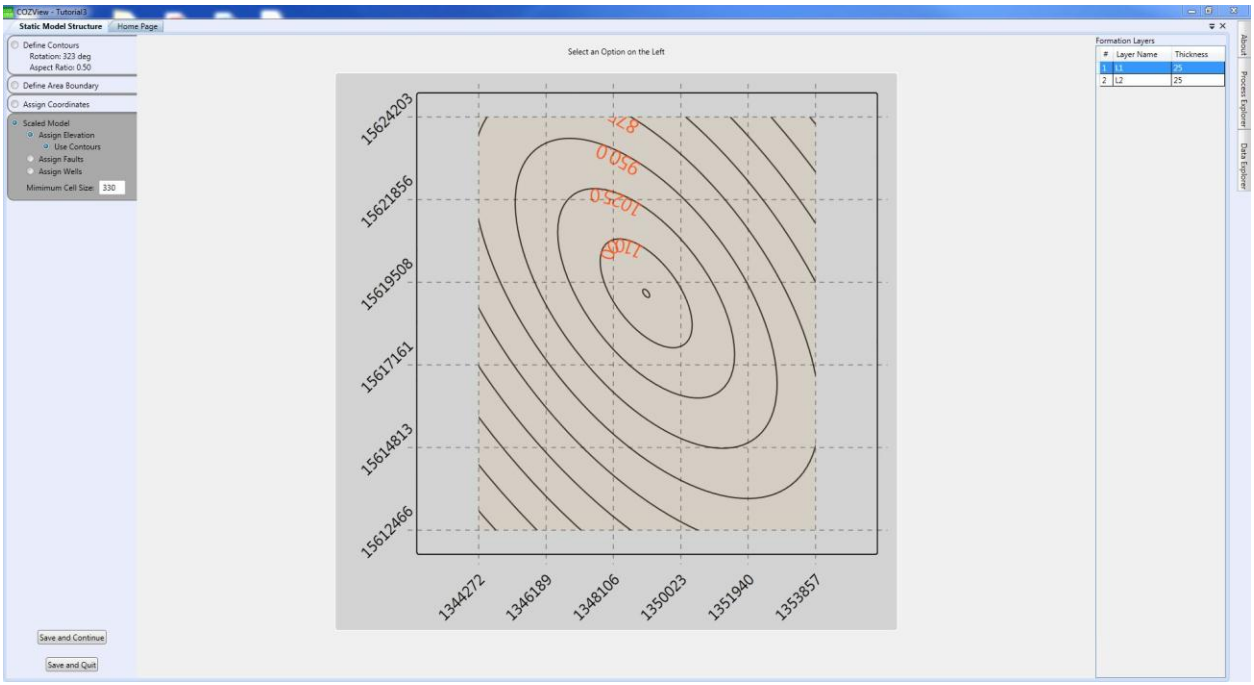
Min Y – 15612466, Max Y - 15624203

The field is approximately 2.2 miles (N-S) by 1.8 miles (E-W). Use of these map coordinates was important as the well locations were available in the same coordinate system.



Save and Continue is recommended.

Selection of **Scaled Model** and *Assign Elevation/Use Contours* allows the user to establish the structural contour elevations. A top contour elevation of +1100 ft ss and a bottom contour elevation of +875 ft ss establish the contour interval.



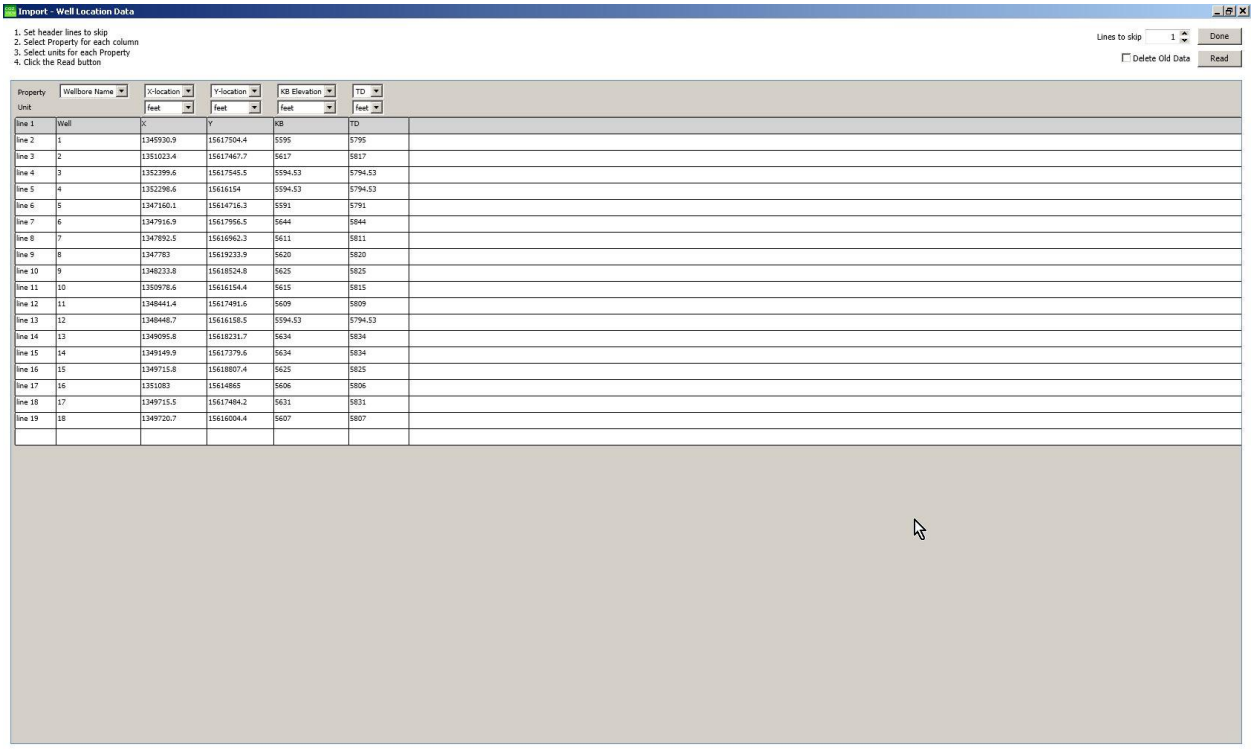
Save and Continue is recommended.

Assign Wells allows the user to position wells on the structural surface.

However in this example, the well locations, KB and TD shown below were imported from a .CSV file.

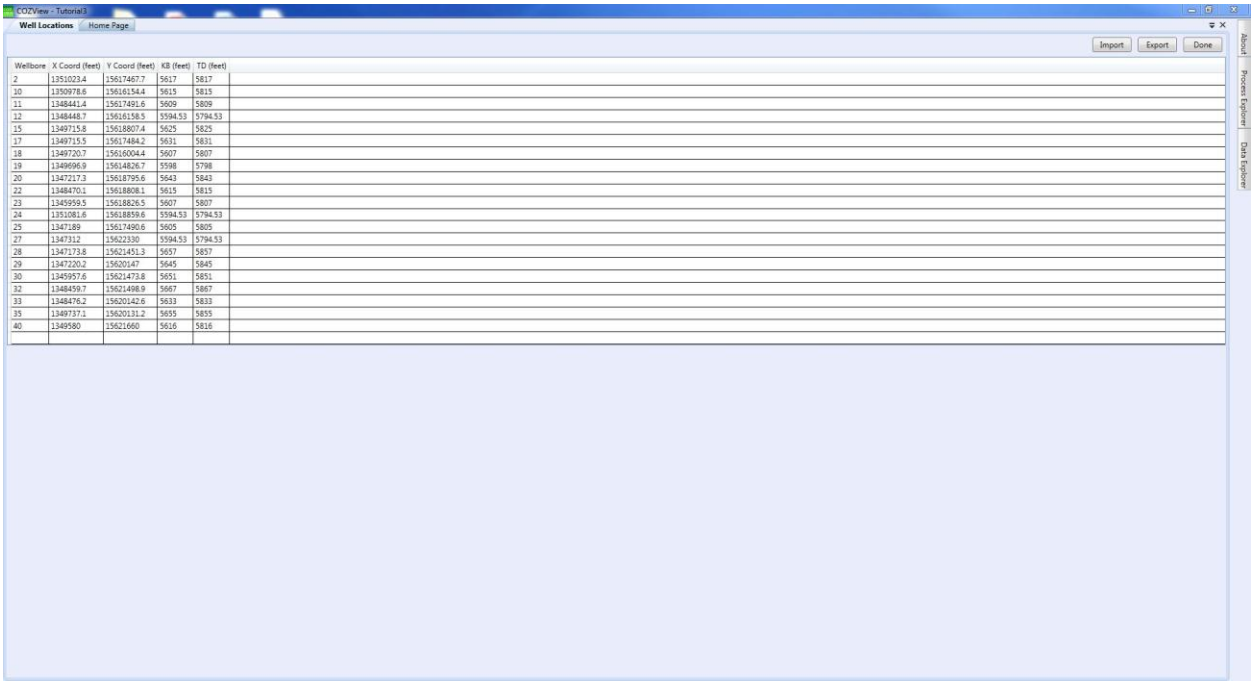
Well	X	Y	KB	TD
2	1351023	15617468	5617	5817
10	1350979	15616154	5615	5815
11	1348441	15617492	5609	5809
12	1348449	15616159	5594.53	5794.53
15	1349716	15618807	5625	5825
17	1349716	15617484	5631	5831
18	1349721	15616004	5607	5807
19	1349697	15614827	5598	5798
20	1347217	15618796	5643	5843
22	1348470	15618808	5615	5815
23	1345960	15618827	5607	5807
24	1351082	15618860	5594.53	5794.53
25	1347189	15617491	5605	5805
27	1347312	15622330	5594.53	5794.53
28	1347174	15621451	5657	5857
29	1347220	15620147	5645	5845
30	1345958	15621474	5651	5851
32	1348460	15621499	5667	5867
33	1348476	15620143	5633	5833
35	1349737	15620131	5655	5855
40	1349580	15621660	5616	5816

This is done by selecting *WellData/Well Location Data* in the **Process Explorer** menu. Select the **Import** button and identify the location of the csv file with the data.

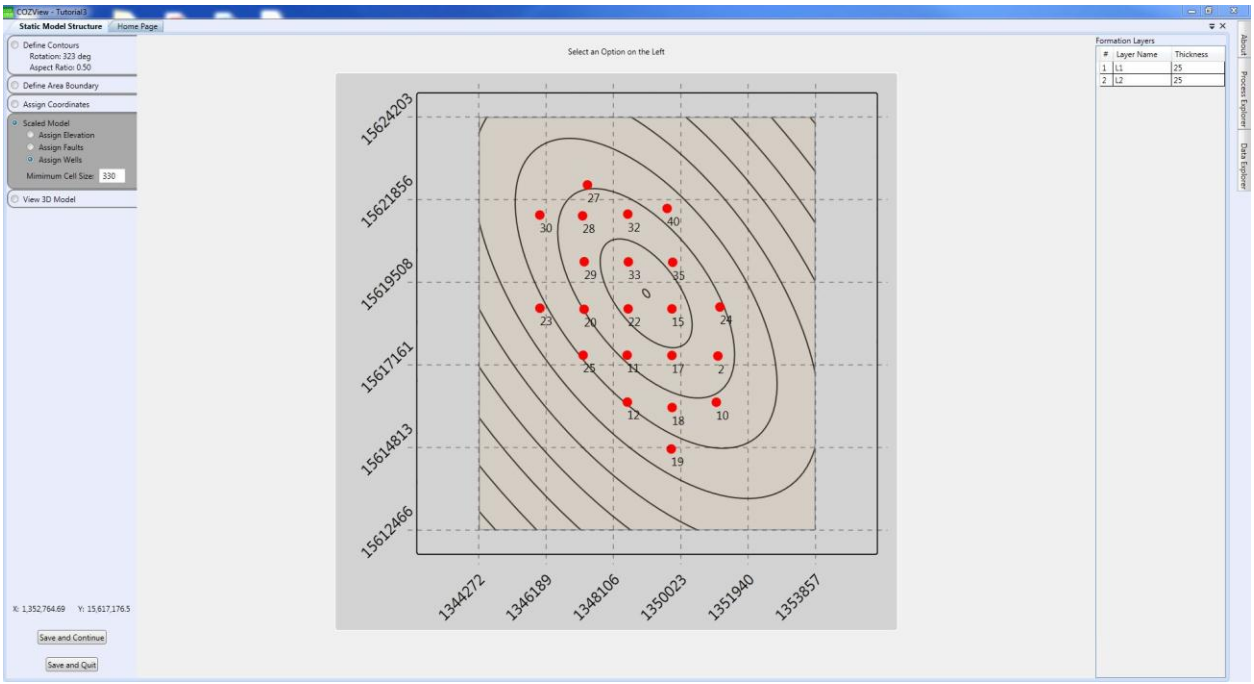


Select the column headings that are consistent with the csv file. If the first line of the file is a column identifier, be sure to select **Lines to Skip** (1 in this case). Select **Done** to read the file.

The read data will be displayed. Select **Done** to save the data.



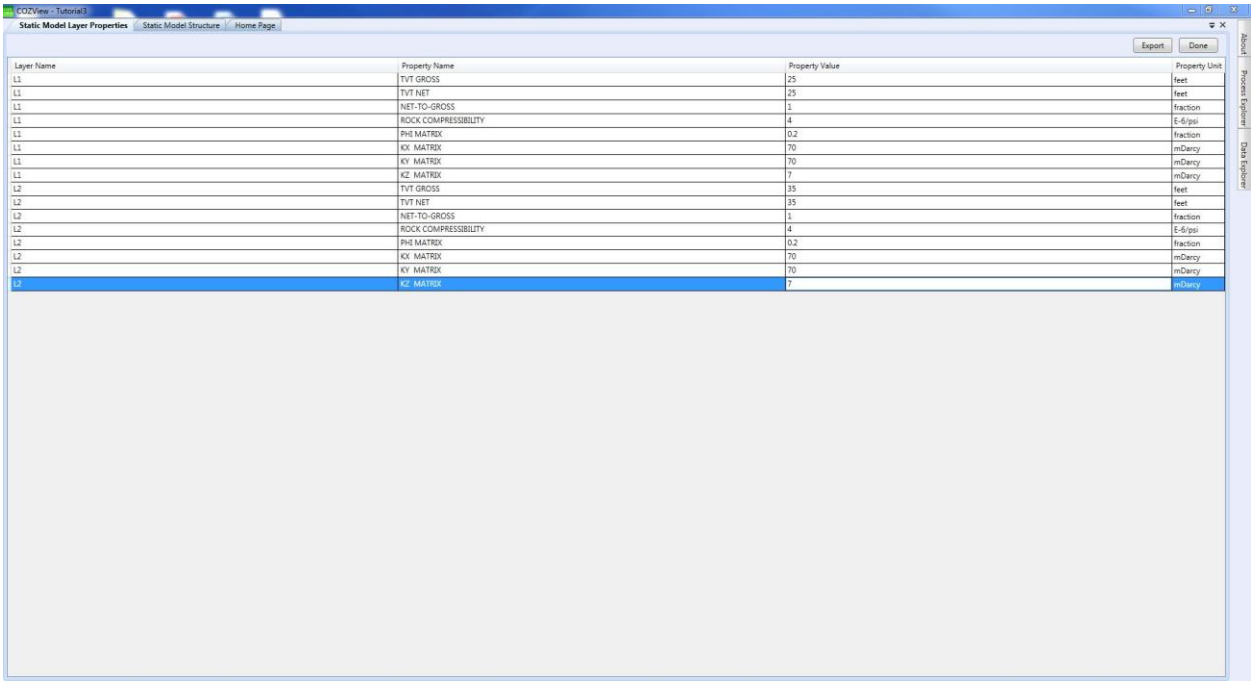
If the user closes the Static Model Structure menu tab at the top and then reselects *Static Model/Structure* from the **Process Explorer** menu, the well locations can be viewed in the *Scaled Model/Assign Wells* area. *(This closing and reopening of the Static Model menu forces a refresh on the screen.)*



Save and Continue is recommended.

Layer Properties 3D View can be selected to confirm the structural model and well positions in a 3D view.

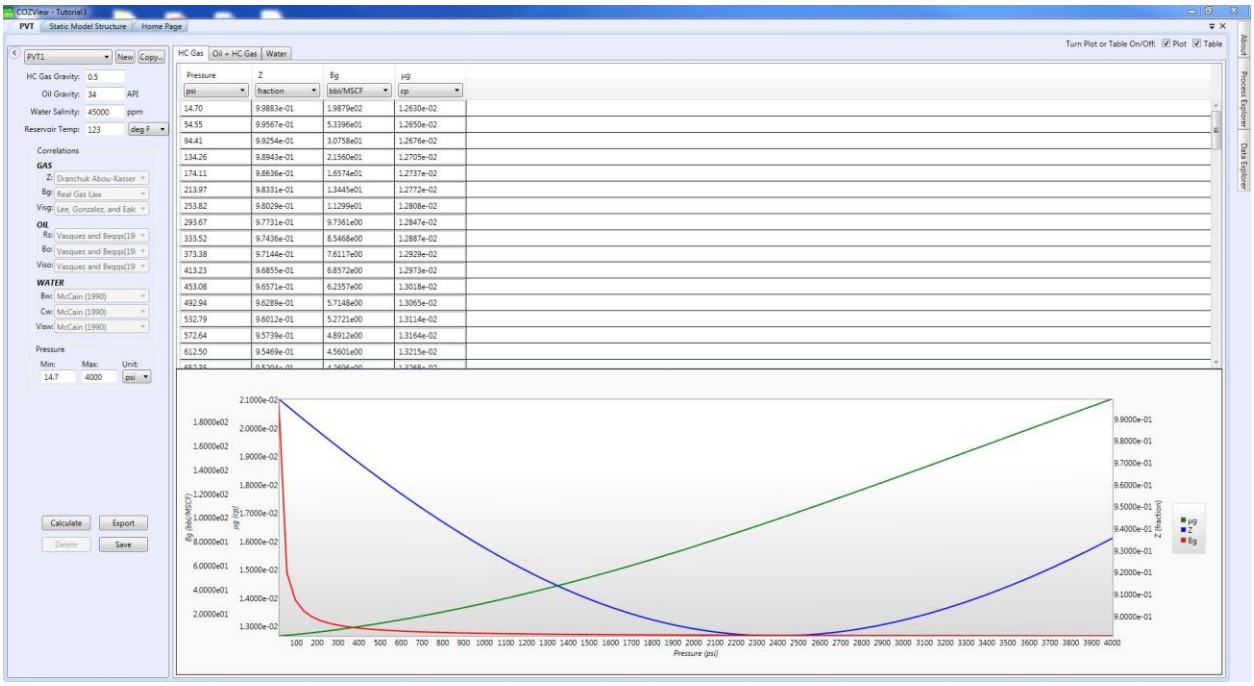
Layer Properties should be selected from the **Static Model** menu area. Values will already be input for the layers previously defined. The default units for each property are shown. The default values can be changed if appropriate.



Layer Name	Property Name	Property Value	Property Unit
L1	TVT GROSS	25	feet
L1	TVT NET	25	feet
L1	NET-TO-GROSS	1	fraction
L1	ROCK COMPRESSIBILITY	4	E-6/psi
L1	PHI MATRIX	0.2	fraction
L1	KX MATRIX	70	mDarcy
L1	KY MATRIX	70	mDarcy
L1	KZ MATRIX	7	mDarcy
L2	TVT GROSS	35	feet
L2	TVT NET	35	feet
L2	NET-TO-GROSS	1	fraction
L2	ROCK COMPRESSIBILITY	4	E-6/psi
L2	PHI MATRIX	0.2	fraction
L2	KX MATRIX	70	mDarcy
L2	KY MATRIX	70	mDarcy
L2	KZ MATRIX	7	mDarcy

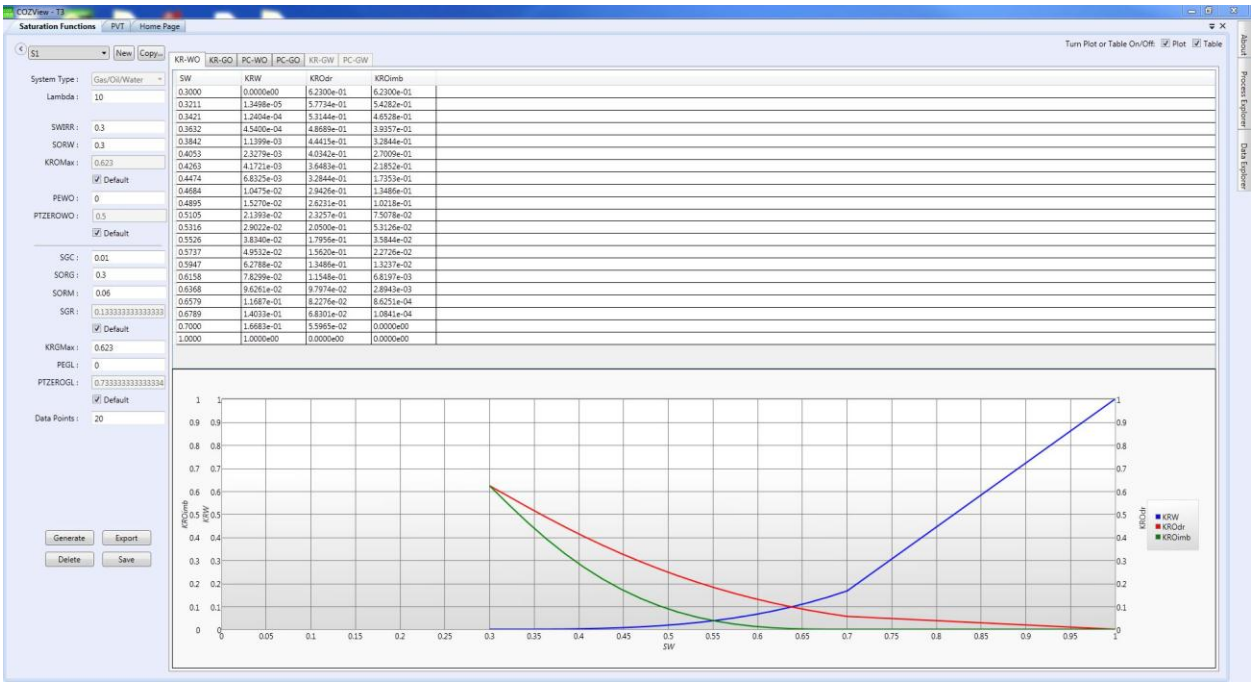
Select **Done** when finished to save the layer properties.

PVT should be selected from the **Fluid and Saturation Properties** menu area. The initial PVT properties screen will be blank. The **New** button should be selected to create a new set of PVT properties (table). The default values can be overridden by the user to create the PVT data shown below when the **Calculate** button is selected.



Select **Save** to save the data.

Saturation Functions should be selected from the **Fluid and Saturation Properties** menu area. The initial Saturation Function properties screen will be blank. The **New** button should be selected to create a new set of Saturation Function properties (table). The default values can be overridden by the user to create the Saturation Function data shown below when the **Generate** button is selected.

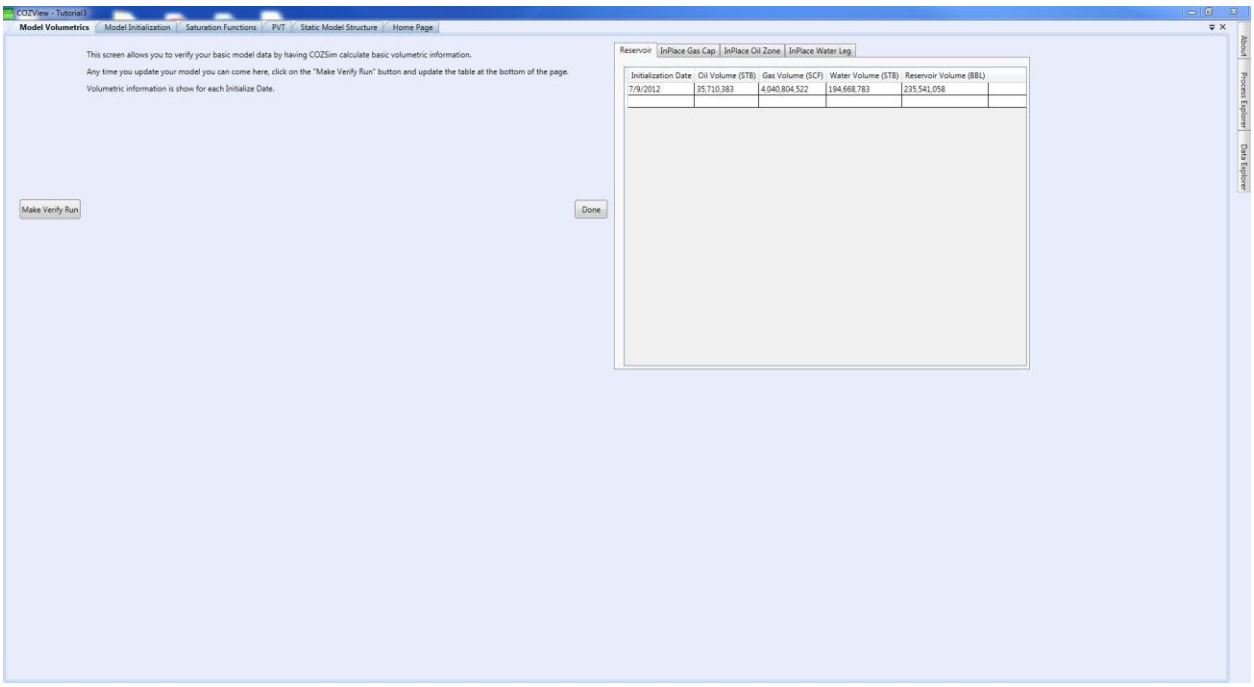


Select **Save** to save the data.

Model Initialization should be selected from the **Verify Model** menu area. This screen will initially be blank. The user can verify the volumetrics of the model that has been created by inputting appropriate values in the data fields. Initially the volumetrics of the model can be checked for the original conditions, if desired. This requires identification of the Fluid PVT table and Saturation Function table previously defined. The following data would be input for the current reservoir conditions

Initialization Date	7/9/2012
Model Type	2 phase
Pressure @Ref	1650
Reference Elevation	+1075
Elevation @ WOC	+945
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 OIP of approximately 35.71 MMSTB should be reported subject to differences in the user defined model and this example.



Select **Done** when finished.

If the user is not satisfied with the volumetric values calculated, changes to the model data created to this point can be made and saved and new volumetrics calculated.

The following steps will define well and field operating conditions for the prediction case to be run.

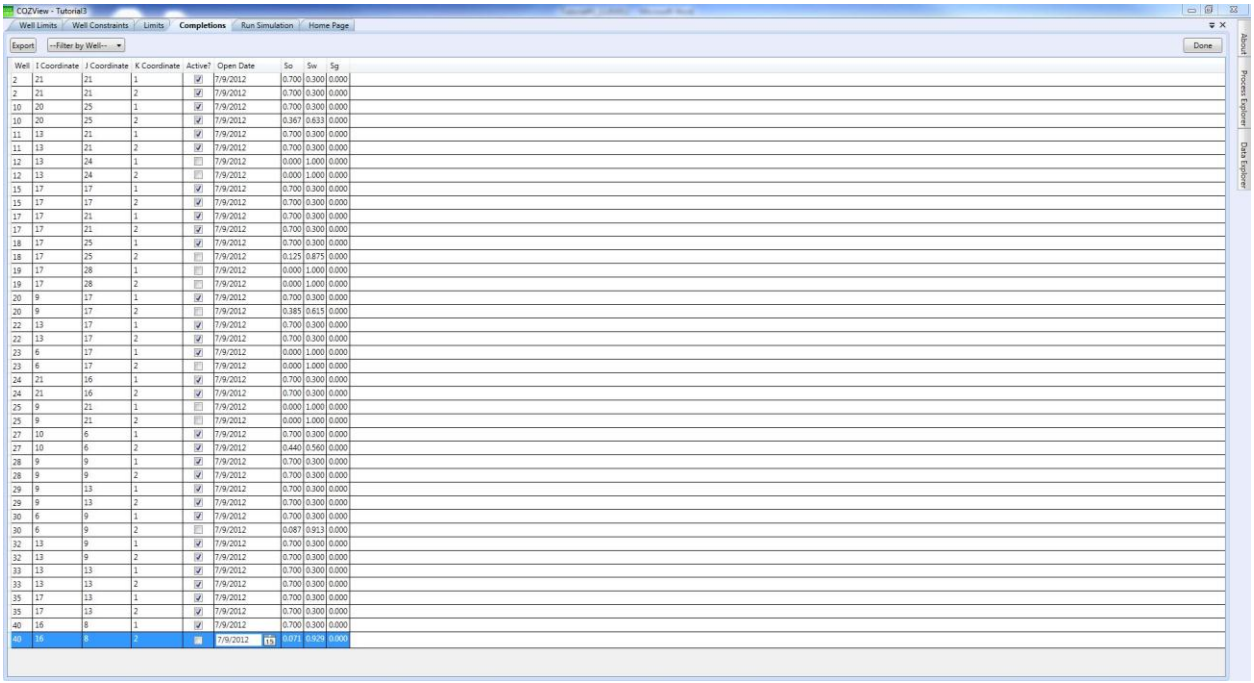
Select **Well Location** from the **Well Data** menu area to verify previously input well locations, KB elevations and TD. This is generally informational reporting only. If additional wells are required, the user should return to the **Static Model** menu area and interactively locate the new well(s). KB and TD values can be change if required.

Wellbore	X Coord (feet)	Y Coord (feet)	KB (feet)	TD (feet)
2	1351023.4	15617467.7	5617	5817
10	1350978.6	15616154.4	5615	5815
11	1348441.4	15617491.6	5609	5809
12	1348448.7	15616158.5	5594.53	5794.53
15	1349715.8	15618807.4	5625	5825
17	1349715.5	15617484.2	5631	5831
18	1349720.7	15616004.4	5607	5807
19	1349696.9	15614826.7	5598	5798
20	1347217.3	15618795.6	5643	5843
22	1348470.1	15618808.1	5615	5815
23	1345959.5	15618826.5	5607	5807
24	1351081.6	15618859.6	5594.53	5794.53
25	1347189	15617490.6	5605	5805
27	1347312	15622330	5594.53	5794.53
28	1347173.8	15621451.3	5657	5857
29	1347220.2	15620147	5645	5845
30	1345957.6	15621473.8	5651	5851
32	1348459.7	15621498.9	5667	5867
33	1348476.2	15620142.6	5633	5833
35	1349737.1	15620131.2	5655	5855
40	1349580	15621660	5616	5816

Select **Done** to save.

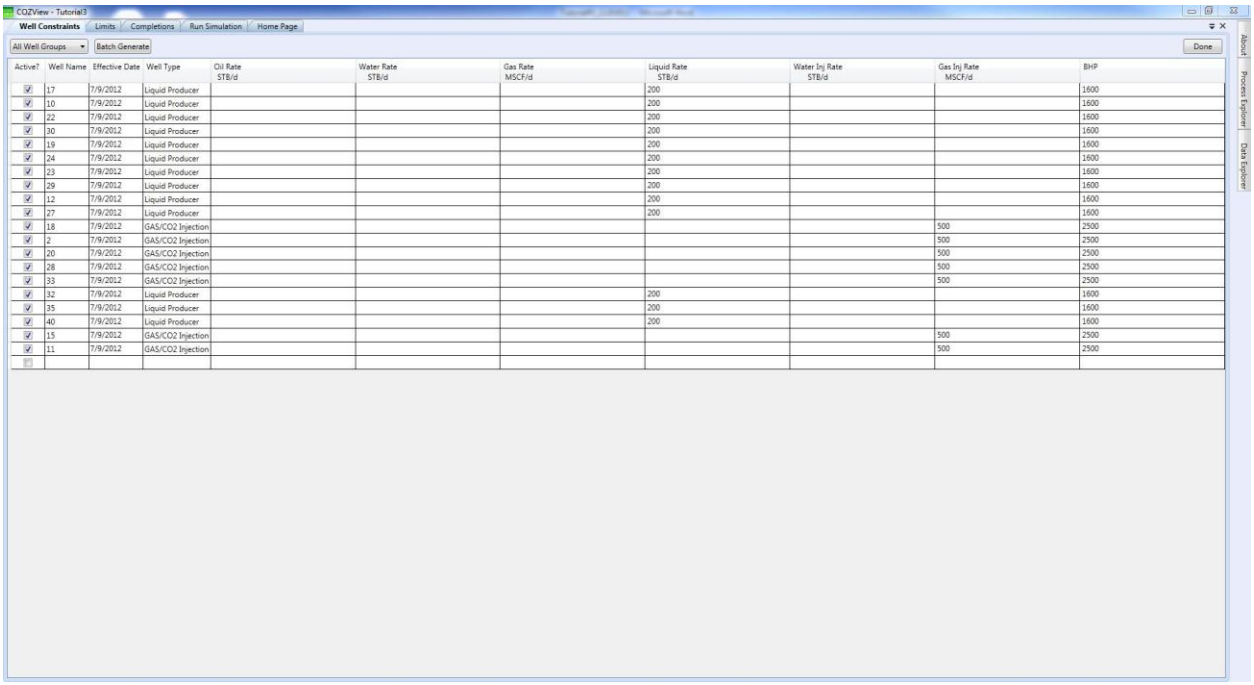
Select **View Completions** from the **Well Data** area to view and alter the well completions if appropriate. Initially all wells are assumed to be completed in all layers. The *Active check box* can be unchecked for any well layer completion, if desired. Be sure to note the completion changes made for this example in the screen below.

It is important to keep track of the dates shown in the various well and field control screens. These must be consistent with the Initialization Date (start date for the prediction simulation run). These dates should be changed if necessary.



If any changes are made to the completion select **Done** to save.

Select **Well Constraints** from the **Prediction/Well Parameters** menu area. This screen will initially be blank. The **Batch Generate** button is a fast way to input values for multiple wells. The user can input the values noted below for the GAS/CO2 Injection wells and separately for the Liquid Producer wells.



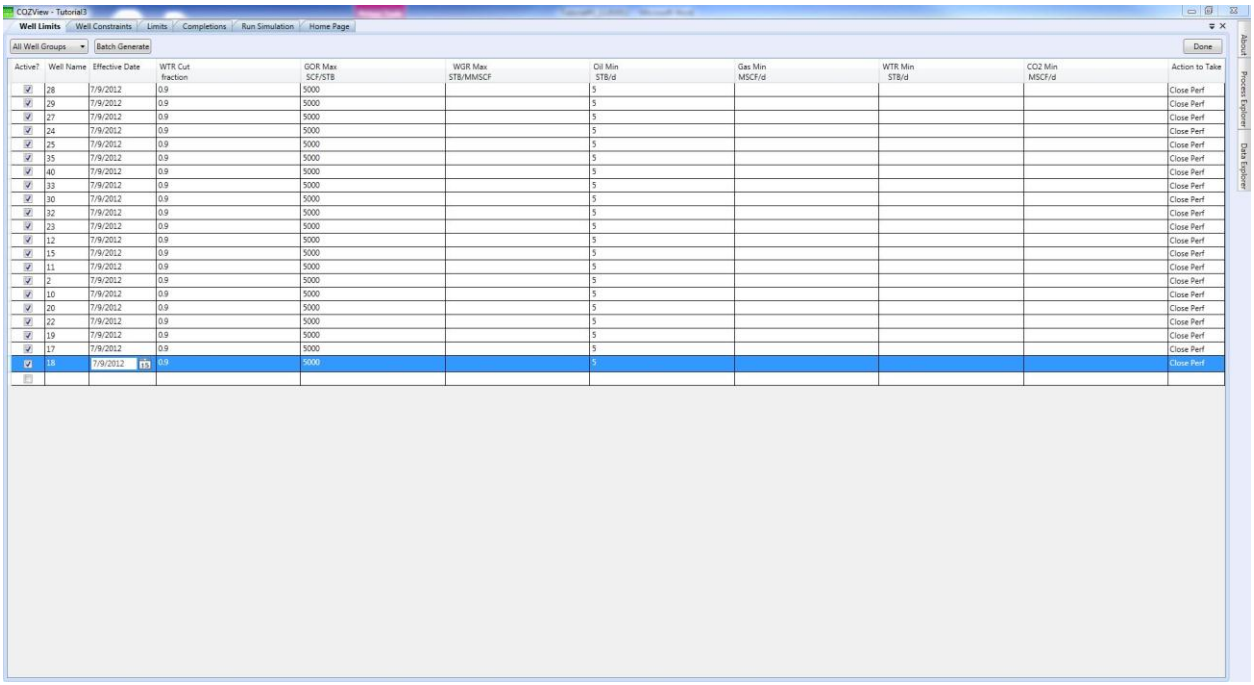
Active?	Well Name	Effective Date	Well Type	Oil Rate STB/d	Water Rate STB/d	Gas Rate MSCF/d	Liquid Rate STB/d	Water Inj Rate STB/d	Gas Inj Rate MSCF/d	BHP
☑	17	7/9/2012	Liquid Producer				200			1600
☑	10	7/9/2012	Liquid Producer				200			1600
☑	22	7/9/2012	Liquid Producer				200			1600
☑	30	7/9/2012	Liquid Producer				200			1600
☑	19	7/9/2012	Liquid Producer				200			1600
☑	24	7/9/2012	Liquid Producer				200			1600
☑	23	7/9/2012	Liquid Producer				200			1600
☑	29	7/9/2012	Liquid Producer				200			1600
☑	12	7/9/2012	Liquid Producer				200			1600
☑	27	7/9/2012	Liquid Producer				200			1600
☑	18	7/9/2012	GAS/CO2 Injection						500	2500
☑	2	7/9/2012	GAS/CO2 Injection						500	2500
☑	20	7/9/2012	GAS/CO2 Injection						500	2500
☑	28	7/9/2012	GAS/CO2 Injection						500	2500
☑	33	7/9/2012	GAS/CO2 Injection						500	2500
☑	32	7/9/2012	Liquid Producer				200			1600
☑	35	7/9/2012	Liquid Producer				200			1600
☑	40	7/9/2012	Liquid Producer				200			1600
☑	15	7/9/2012	GAS/CO2 Injection						500	2500
☑	11	7/9/2012	GAS/CO2 Injection						500	2500

Select **Done** to save.

Select **Well Limits** from the **Prediction/Well Parameters** menu area. This screen will initially be blank. The **Batch Generate** button is a fast way to input values for multiple wells.

Well limits

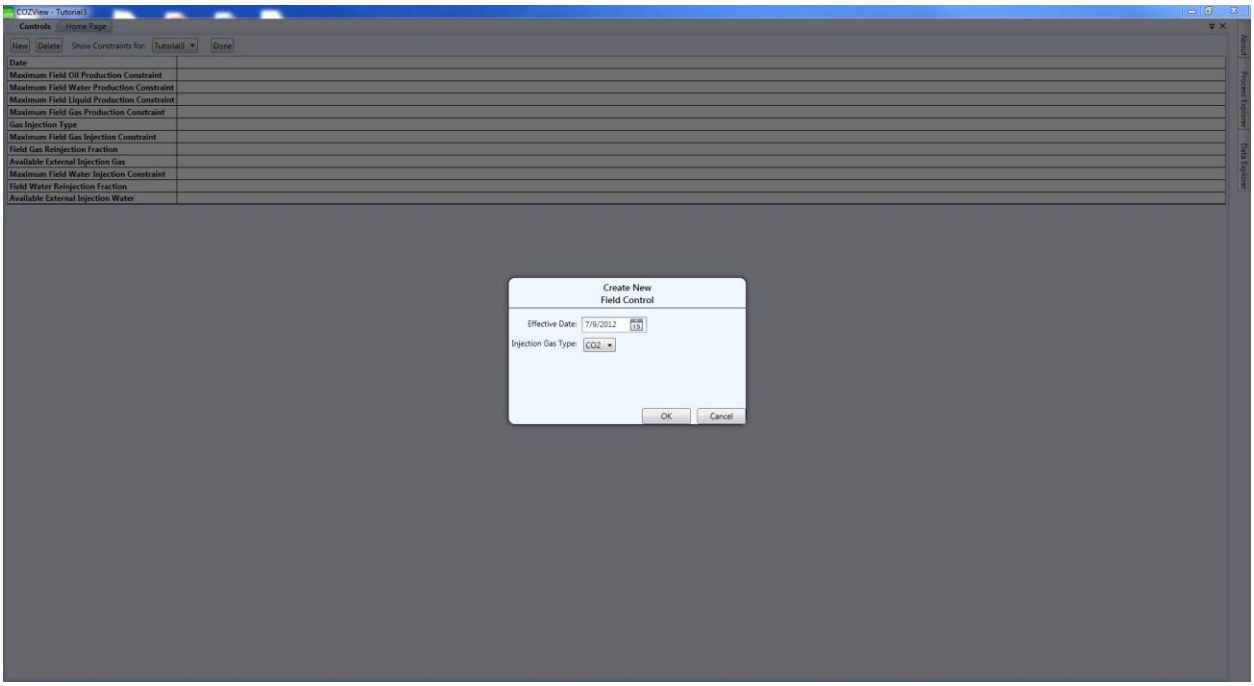
Minimum Oil rate (STB/day)	5
Maximum GOR (SCF/STB)	5000
Action to take	Close completion (perf)



Active?	Well Name	Effective Date	WTR Cut fraction	GOR Max SCF/STB	WGR Max STB/MMSCF	Oil Min STB/d	Gas Min MSCF/d	WTR Min STB/d	CO2 Min MSCF/d	Action to Take
☑	28	7/9/2012	0.9	5000		5				Close Perf
☑	29	7/9/2012	0.9	5000		5				Close Perf
☑	27	7/9/2012	0.9	5000		5				Close Perf
☑	24	7/9/2012	0.9	5000		5				Close Perf
☑	25	7/9/2012	0.9	5000		5				Close Perf
☑	35	7/9/2012	0.9	5000		5				Close Perf
☑	40	7/9/2012	0.9	5000		5				Close Perf
☑	33	7/9/2012	0.9	5000		5				Close Perf
☑	30	7/9/2012	0.9	5000		5				Close Perf
☑	32	7/9/2012	0.9	5000		5				Close Perf
☑	23	7/9/2012	0.9	5000		5				Close Perf
☑	12	7/9/2012	0.9	5000		5				Close Perf
☑	15	7/9/2012	0.9	5000		5				Close Perf
☑	11	7/9/2012	0.9	5000		5				Close Perf
☑	2	7/9/2012	0.9	5000		5				Close Perf
☑	10	7/9/2012	0.9	5000		5				Close Perf
☑	20	7/9/2012	0.9	5000		5				Close Perf
☑	22	7/9/2012	0.9	5000		5				Close Perf
☑	19	7/9/2012	0.9	5000		5				Close Perf
☑	17	7/9/2012	0.9	5000		5				Close Perf
☑	18	7/9/2012	0.9	5000		5				Close Perf
☐										

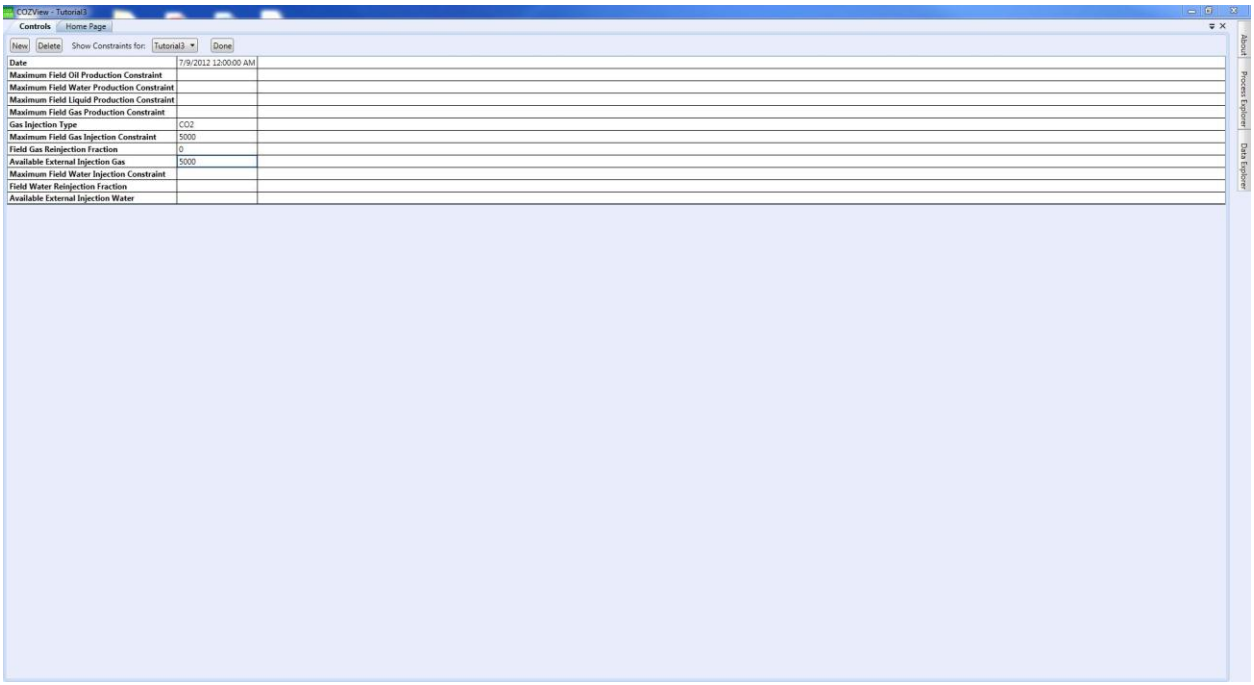
Select **Done** to save.

Select **Field** (Facility) **Controls** from the **Prediction Period/Field/Facility Parameters** menu area. Select **New** to establish the Effective Date (start date for Field Controls) and the **Injection Gas Type**. Please note that the default Injection Gas Type is CO2 gas. In this tutorial it is required to select CO2 as **Injection Gas Type.**



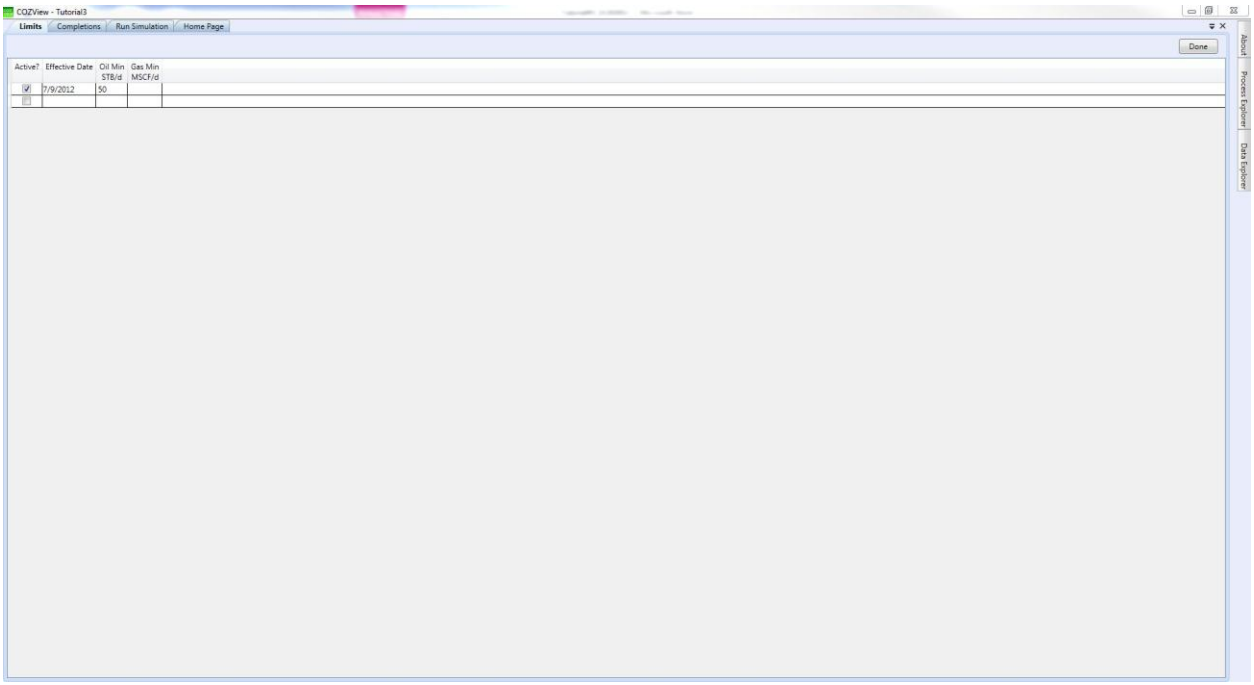
Select **OK** to continue.

Input the **Maximum Field Gas Injection Constraint** (5000 MSCF/day), the **Available External Injection Gas** (5000 MSCF/day). The produced gas is not reinjected in this tutorial, **Field Gas Reinjection Fraction** (0).



Select **Done** to save.

Select **Limits** from the **Prediction Period/Field/Facility Parameters** menu area. Check the **Active** box and input appropriate values. It is always wise to have a field limit specified such that the simulation run will stop when the field limit is reached.

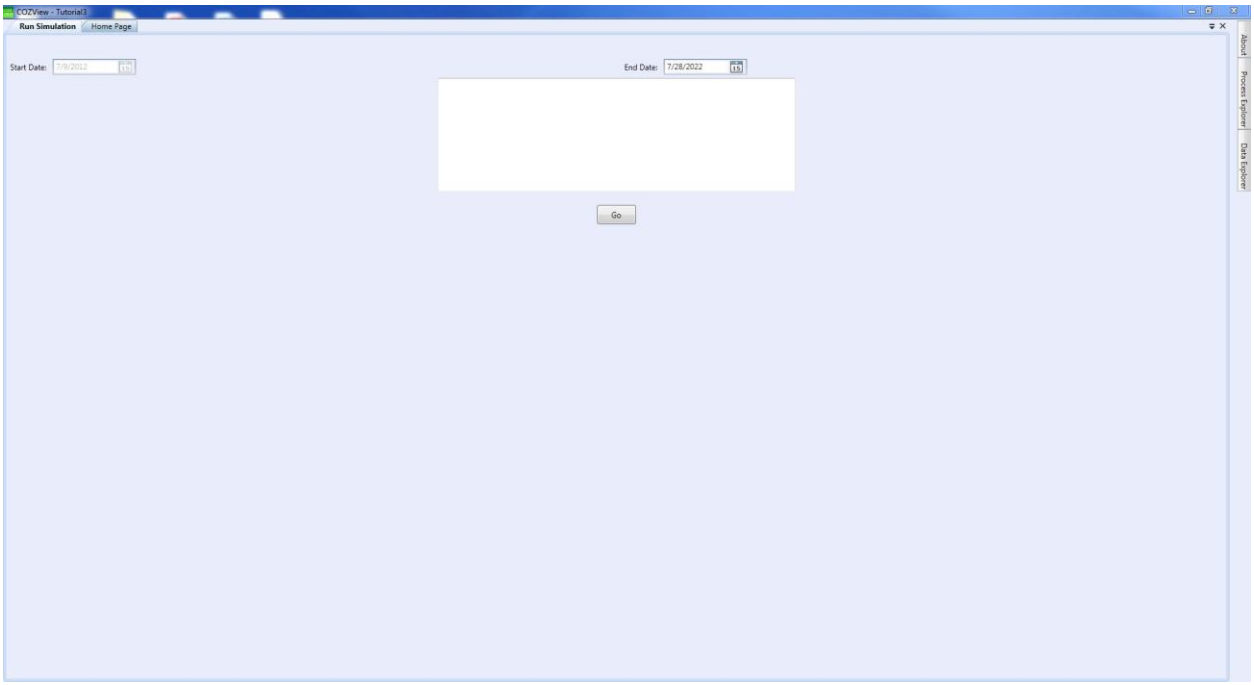


Select **Done** to save.

It is prudent at this stage to return to the various well and field parameter screen to insure that data, particularly dates, are set appropriately.

Select **Run Simulation**. The **Model Initialization** date 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**.

Input the End Date of 7/28/2022. This will create a ten year prediction.



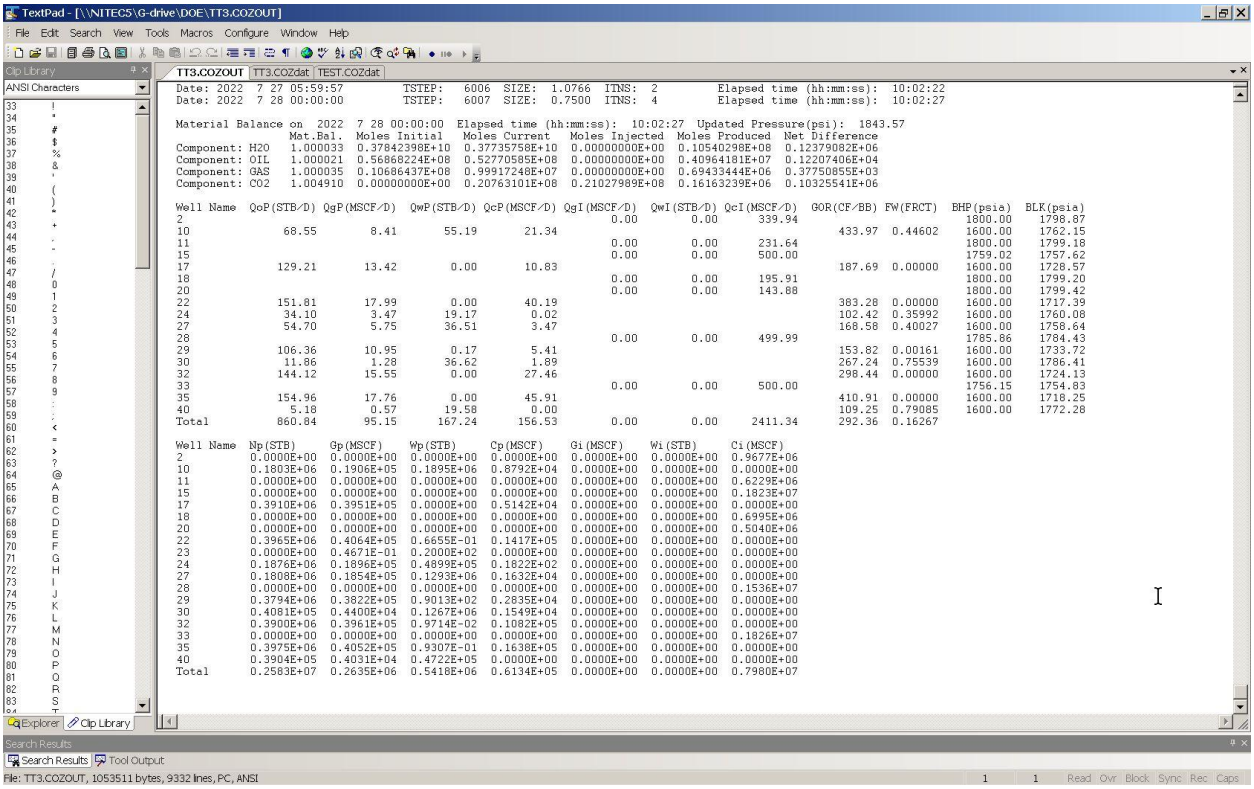
Select **Go** to initiate the simulation run.

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.

DO NOT close COZView during the simulation run. It can be minimized. Closing COZView will not stop the simulation run, but the simulation results will not be loaded at the conclusion of the simulation run. **DO NOT** change projects in COZView during a simulation run for this same reason. **DO NOT** turn the computer off during the simulation run. All simulation results will be lost.

Two files are created early during the simulation run which may help the user track the progress of the simulation run. These are stored in the COZView directory along with various project database and result files. The files are *Projectname*.COZOUT and *Projectname*.COZDAT. The .COZDAT file is the input data "deck" prepared by COZView for COZSim. The .COZOUT file reports well production and injection activity for each timestep during the simulation run. It is update frequently. Both of these files can be opened with a Text editor. The .COZDAT file can be reviewed to assure that the data "deck" is setup as the user anticipated. The .COZOUT file can be reviewed as the simulation run progresses. If the results are not as anticipated the run can be stopped in the **Simulator Runner** window.

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



TextPad - [\\NITEC5\G-drive\DOE\TT3.COZOUT]

File Edit Search View Tools Macros Configure Window Help

TT3.COZOUT | TT3.COZdat | TEST.COZdat

```
 Date: 2022  7 27 05:59:57          TSTEP:   6006  SIZE:  1.0766  ITNS:  2         Elapsed time (hh:mm:ss):  10:02:22
 Date: 2022  7 28 00:00:00          TSTEP:   6007  SIZE:  0.7500  ITNS:  4         Elapsed time (hh:mm:ss):  10:02:27

 Material Balance on  2022  7 28 00:00:00  Elapsed time (hh:mm:ss):  10:02:27  Updated Pressure(psi):  1843.57
                  Mat.Bal.  Moles Initial   Moles Current   Moles Injected  Moles Produced  Net Difference
 Component: H2O   1.000033  0.37842398E+10  0.37735758E+10  0.00000000E+00  0.10540298E+08  0.12379082E+06
 Component: OIL   1.000021  0.56868224E+08  0.52770585E+08  0.00000000E+00  0.40964181E+07  0.12207406E+04
 Component: GAS   1.000035  0.10686437E+08  0.99917248E+07  0.00000000E+00  0.69433444E+06  0.37750855E+03
 Component: CO2   1.004910  0.00000000E+00  0.20763101E+08  0.21027989E+08  0.16163239E+06  0.10325541E+06

 Well Name  QoP(STB/D) QgP(MSCF/D)  QwP(STB/D) QcP(MSCF/D) QgI(MSCF/D)  QwI(STB/D) QcI(MSCF/D)  GOR(CF/BB) FW(FRCT)  BHP(psia)   BLK(psia)
 2                                                      0.00        0.00      339.94                            1800.00    1798.87
 10             68.55        8.41       55.19       21.34                                                 433.97  0.44602    1600.00    1762.15
 11                                                                 0.00        0.00      231.64                            1800.00    1799.18
 15                                                                 0.00        0.00      500.00                            1759.02    1757.62
 17            129.21       13.42        0.00       10.83                                                 187.69  0.00000    1600.00    1728.57
 18                                                                 0.00        0.00      195.91                            1800.00    1799.20
 20                                                                 0.00        0.00      143.88                            1800.00    1799.42
 22            151.81       17.99        0.00       40.19                                                 383.28  0.00000    1600.00    1717.39
 24             34.10        3.47       19.17        0.02                                                 102.42  0.35992    1600.00    1760.08
 27             54.70        5.75       36.51        3.47                                                 168.58  0.40027    1600.00    1758.64
 28                                                                 0.00        0.00      499.99                            1785.86    1784.43
 29            106.36       10.95        0.17        5.41                                                 153.82  0.00161    1600.00    1733.72
 30             11.86        1.28       36.62        1.89                                                 267.24  0.75539    1600.00    1786.41
 32            144.12       15.55        0.00       27.46                                                 298.44  0.00000    1600.00    1724.13
 33                                                                 0.00        0.00      500.00                            1756.15    1754.83
 35            154.96       17.76        0.00       45.91                                                 410.91  0.00000    1600.00    1718.25
 40              5.18        0.57       19.58        0.00                                                 109.25  0.79085    1600.00    1772.28
 Total         860.84       95.15      167.24      156.53        0.00        0.00     2411.34            292.36  0.16267

 Well Name  Np(STB)      Gp(MSCF)    Wp(STB)     Cp(MSCF)    Gi(MSCF)    Wi(STB)     Ci(MSCF)
 2          0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.9677E+06
 10         0.1803E+06  0.1906E+05  0.1895E+06  0.8792E+04  0.0000E+00  0.0000E+00  0.0000E+00
 11         0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.6229E+06
 15         0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.1823E+07
 17         0.3910E+06  0.3951E+05  0.0000E+00  0.5142E+04  0.0000E+00  0.0000E+00  0.0000E+00
 18         0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.6995E+06
 20         0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.5040E+06
 22         0.3965E+06  0.4064E+05  0.6655E-01  0.1417E+05  0.0000E+00  0.0000E+00  0.0000E+00
 23         0.0000E+00  0.4671E-01  0.2000E+02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 24         0.1876E+06  0.1896E+05  0.4899E+05  0.1822E+02  0.0000E+00  0.0000E+00  0.0000E+00
 27         0.1808E+06  0.1854E+05  0.1293E+06  0.1632E+04  0.0000E+00  0.0000E+00  0.0000E+00
 28         0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.1536E+07
 29         0.3794E+06  0.3822E+05  0.9013E+02  0.2835E+04  0.0000E+00  0.0000E+00  0.0000E+00
 30         0.4081E+05  0.4400E+04  0.1267E+06  0.1549E+04  0.0000E+00  0.0000E+00  0.0000E+00
 32         0.3900E+06  0.3961E+05  0.9714E-02  0.1082E+05  0.0000E+00  0.0000E+00  0.0000E+00
 33         0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.1826E+07
 35         0.3975E+06  0.4052E+05  0.9307E-01  0.1638E+05  0.0000E+00  0.0000E+00  0.0000E+00
 40         0.3904E+05  0.4031E+04  0.4722E+05  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 Total      0.2583E+07  0.2635E+06  0.5418E+06  0.6134E+05  0.0000E+00  0.0000E+00  0.7980E+07
```

Clip Library | Explorer | Search Results | Tool Output

File: TT3.COZOUT, 1053511 bytes, 9332 lines, PC, ANSI

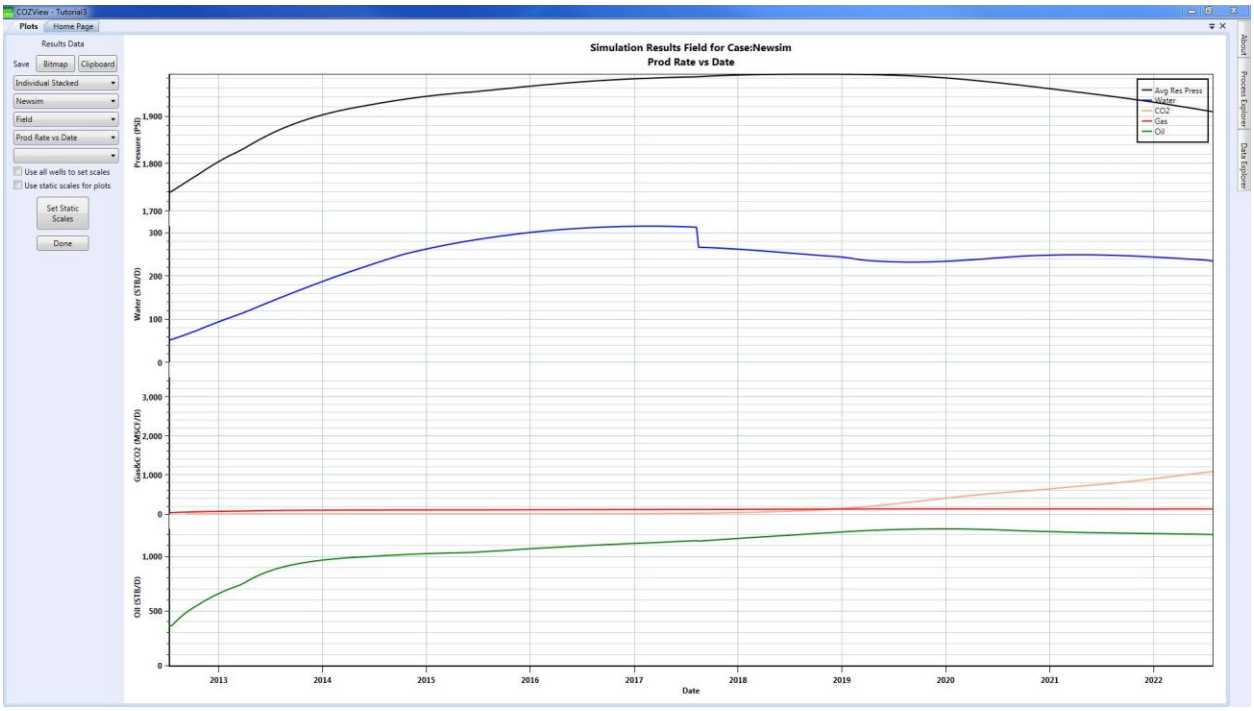
DO NOT delete are change these files during the simulation run. If the same project is re-run with changes to some parameters, these files will be overwritten.

When the **Simulation Runner** window disappears, the simulation run has completed.

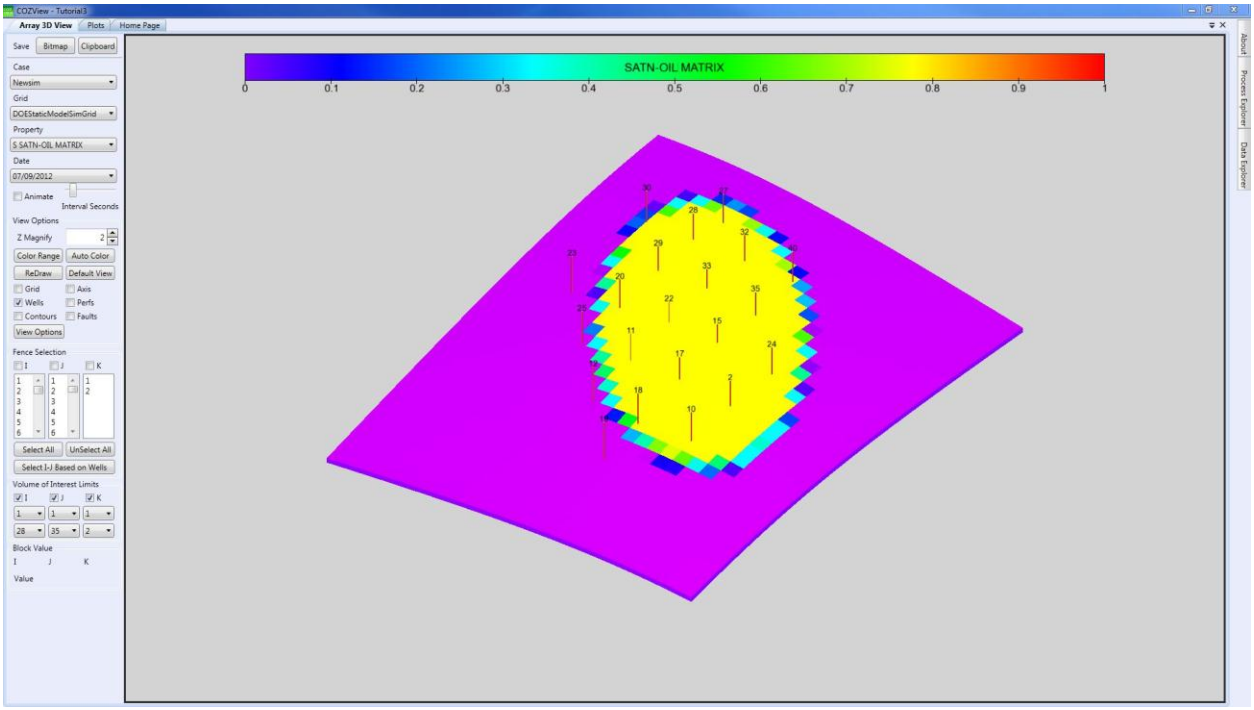
At the completion of the simulation run two small windows will appear which advise the user that the Map and PLT (plot) results are being loaded into COZView.

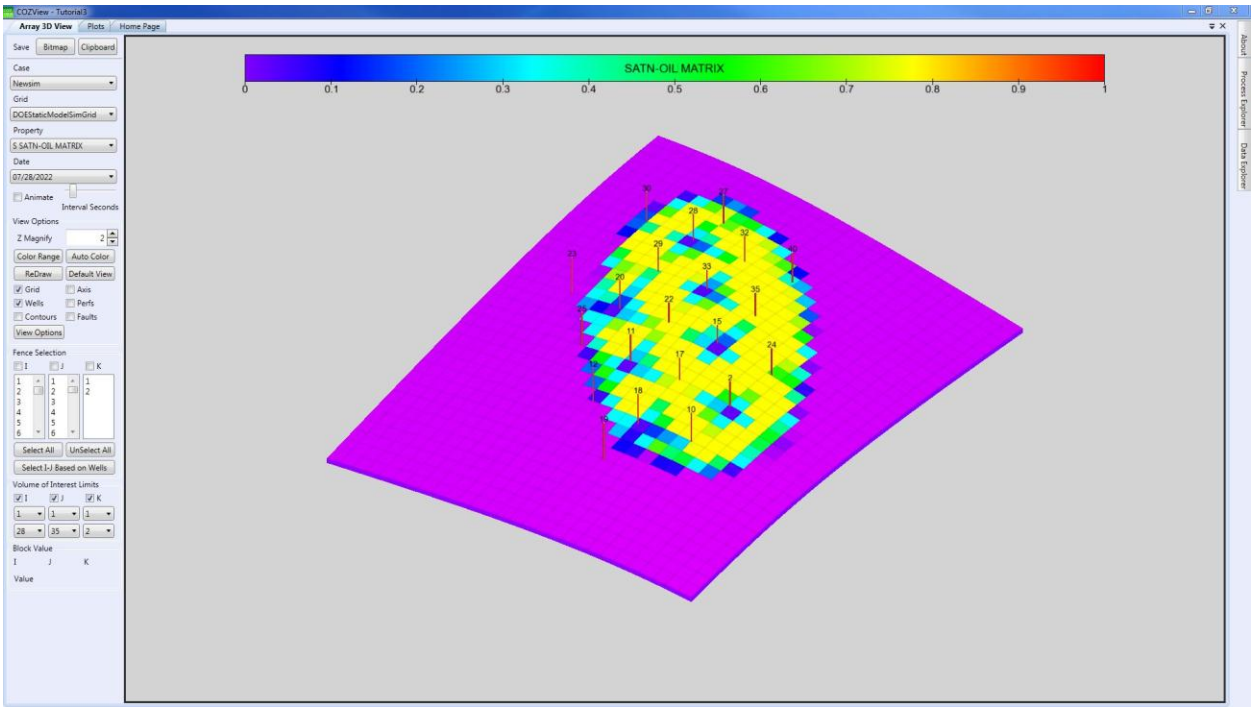
Select **Plots** from the **Simulation Results** area. This will give the user access to various simulation plots for the wells and field. A sample of the available plots for this prediction simulation is shown below.

It has been found prudent to close all menu tabs except the **Home Page** and save data as may be requested before selecting any of the **Simulation Results** menus. This assures that the plot, map and table files are refreshed and prior results are not shown in error.



Select **Array 3D View** from the **Simulation Results** area. This will give the user access to various simulation maps for the field. A sample of the available maps for this prediction simulation is shown below.




COZView - Tutorial3
Array 3D View
Plots
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Color Range
Auto Color
ReDraw
Default View
Grid
Axis
Wells
Perfs
Contours
Faults
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Select I-J Based on Wells
Volume of Interest Limits
Block Value
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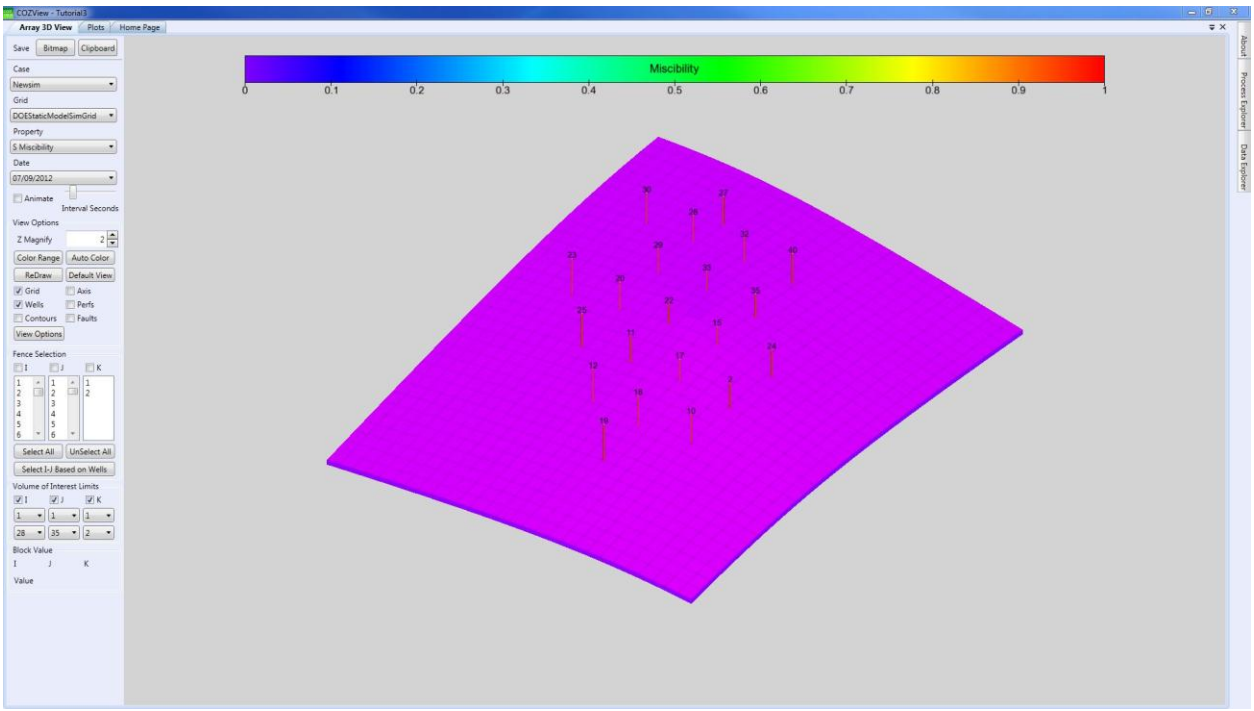
About
Process Explorer
Data Explorer


COZView - Tutorial3
Array 3D View
Plots
Home Page
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Interval Seconds
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Color Range
Auto Color
ReDraw
Default View
Grid
Axis
Wells
Perfs
Contours
Faults
View Options
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Select All
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Select I-J Based on Wells
Volume of Interest Limits
Block Value
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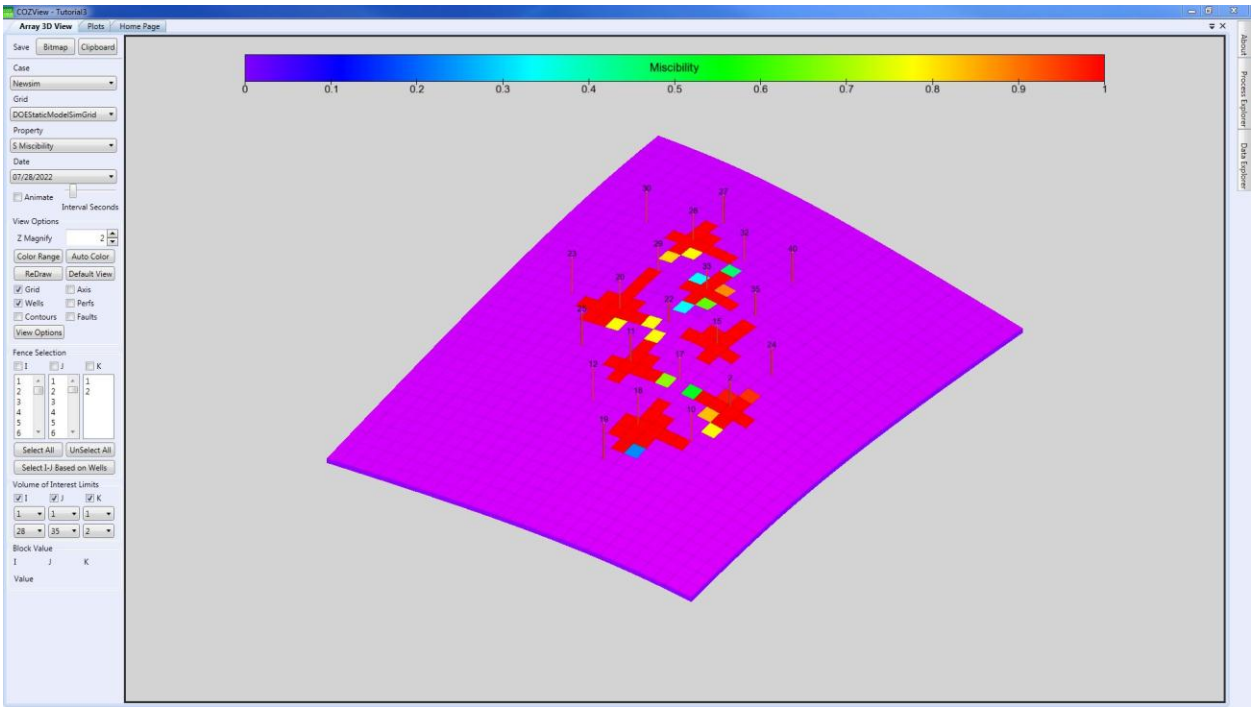
Data Explorer



The user can also select **Tables** from the **Simulation Results** area. This will provide access to tabular simulation results for wells and the field. These tables can be exported to .csv files for use in spreadsheet applications.

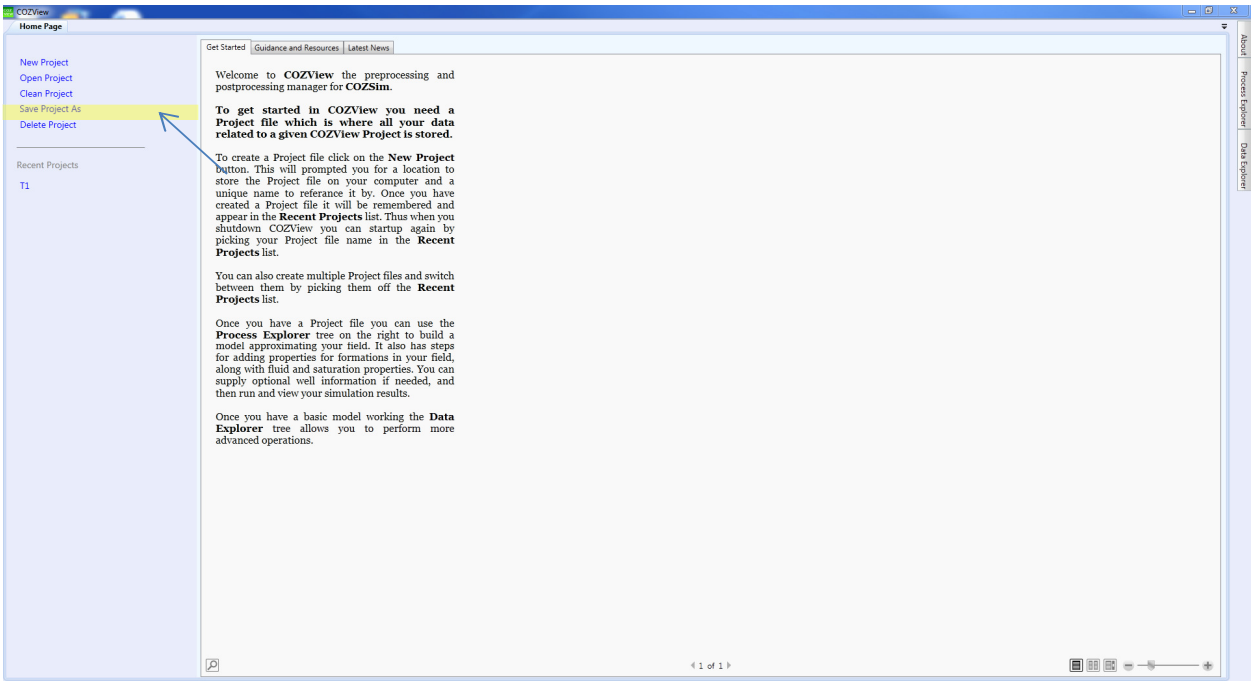
It is also noted that any plot displays can be saved to Bitmap files or to the Clipboard for pasting into report documents. Any map displays can be saved to Bitmap files.

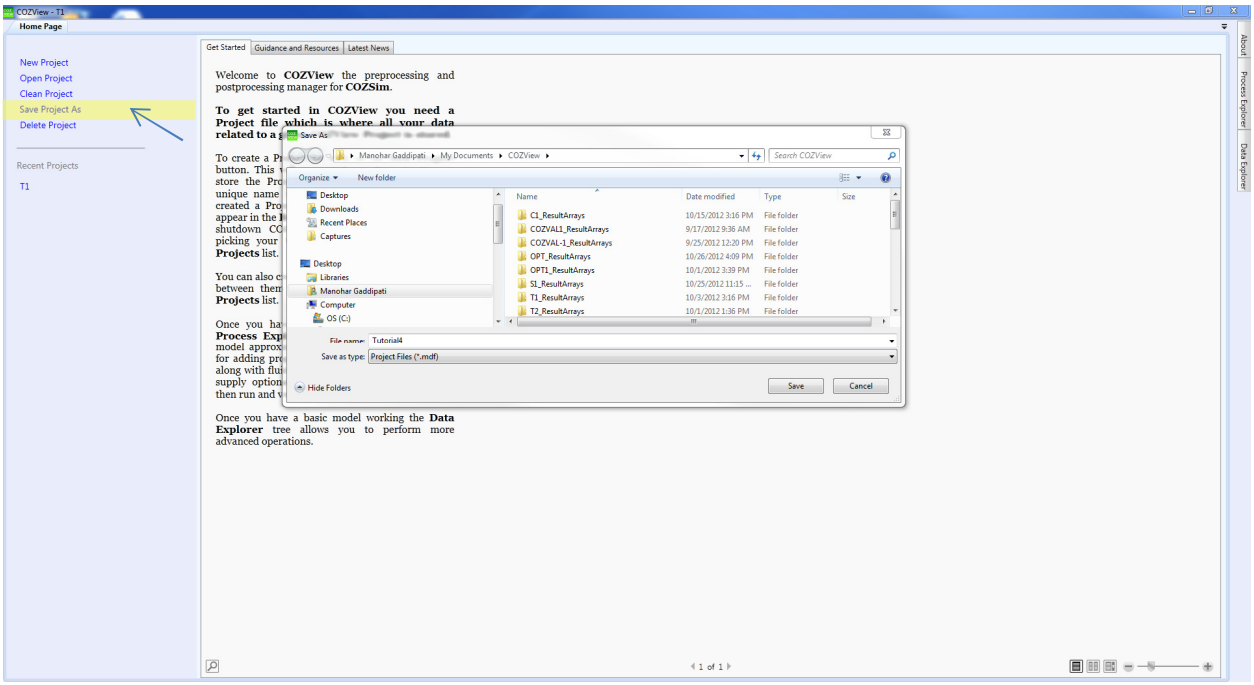
TUTORIAL #4

This tutorial demonstrates the optimization functionality that allows the user to determine maximum net present value (NPV) for a base case and a set of economic parameters. The optimization process attempts to establish the best combination of the Field (Facility) Control parameters to maximize the NPV. A minimum of 1 and a maximum of 7 Field Control parameters can be varied in the optimization process. During the optimization process artificial neural network and genetic algorithm technology are used to vary the appropriate Field Control parameters within a range of values defined by the user and to make simulation runs with those values. The optimization process designs runs with the objective of maximizing the NPV for the prediction case and its associate economic parameters. The user is allowed to run multiple optimization scenarios by using different sets of Economic scenarios and also different ranges (minimum and maximum) of each of the field controls.

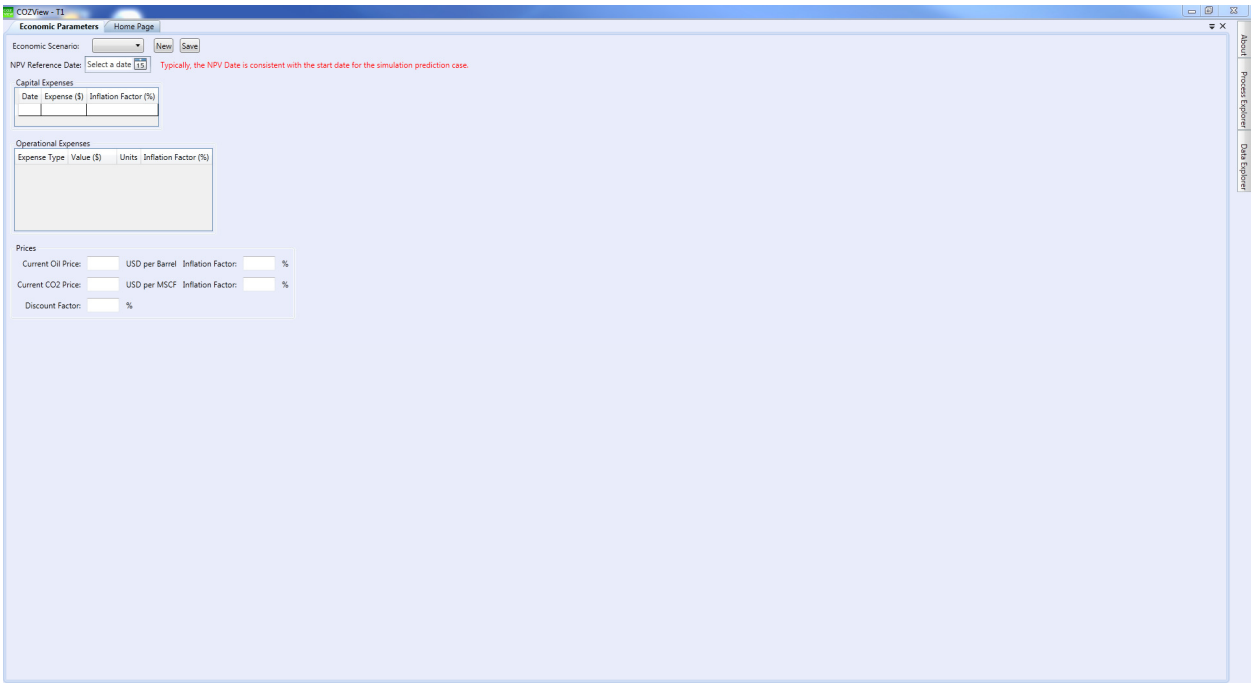
In the course of developing the tutorial examples, some COZView screens may have changed slightly from the views shown in this document. These changes should not impact the model building and simulation process.

The base case in this tutorial is Tutorial #1. From the *Recent projects* Tab 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**.

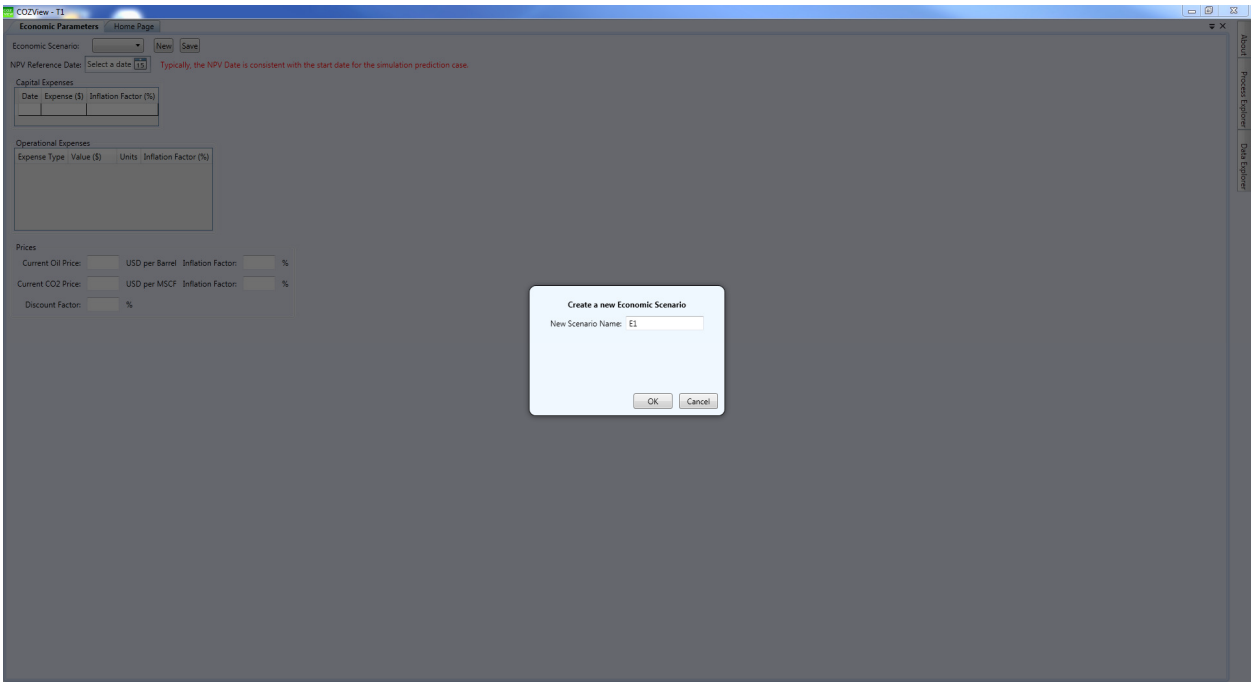


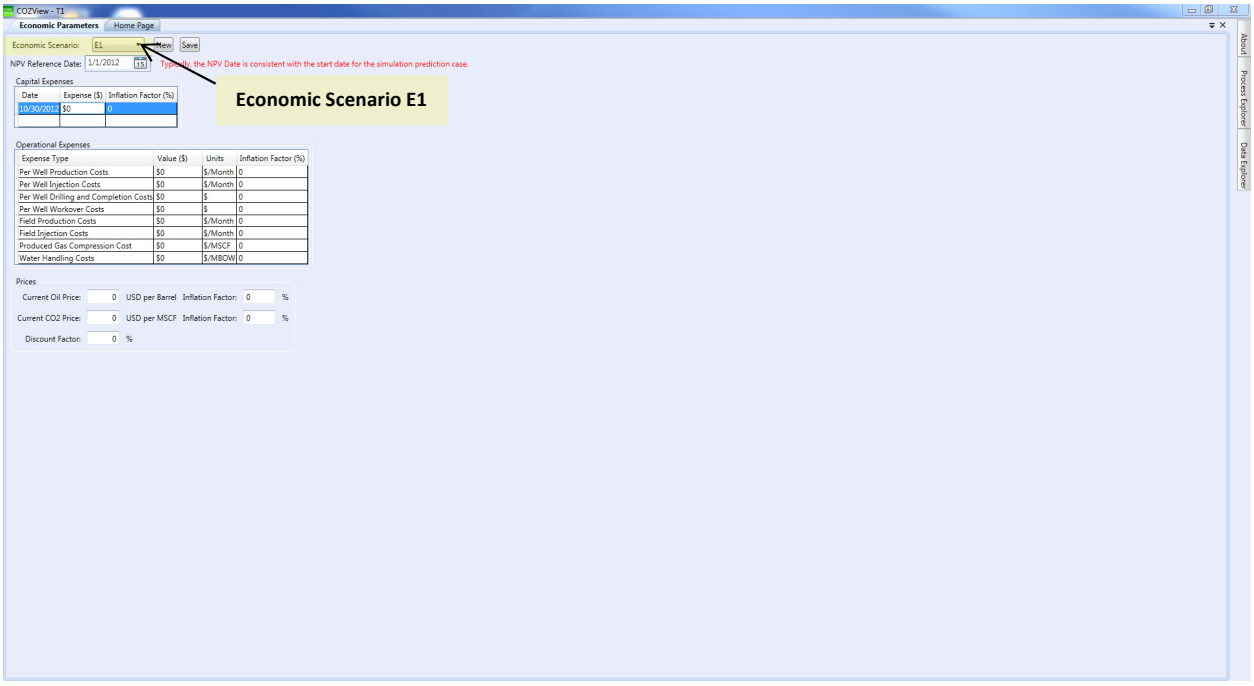


The **Economic Parameters** section allows the user to specify Capital and Operational expenses for the field. Click the **Economic Parameters** tab in the **Prediction Period** section of the **Process Explorer**. The Economic Parameter window is displayed as shown below.



Click **New** to create a new set of economic parameters. In the figure below, the new Economic Scenario is named E1. The user can define multiple economic scenarios by clicking the **New** button as many times as may be appropriate.





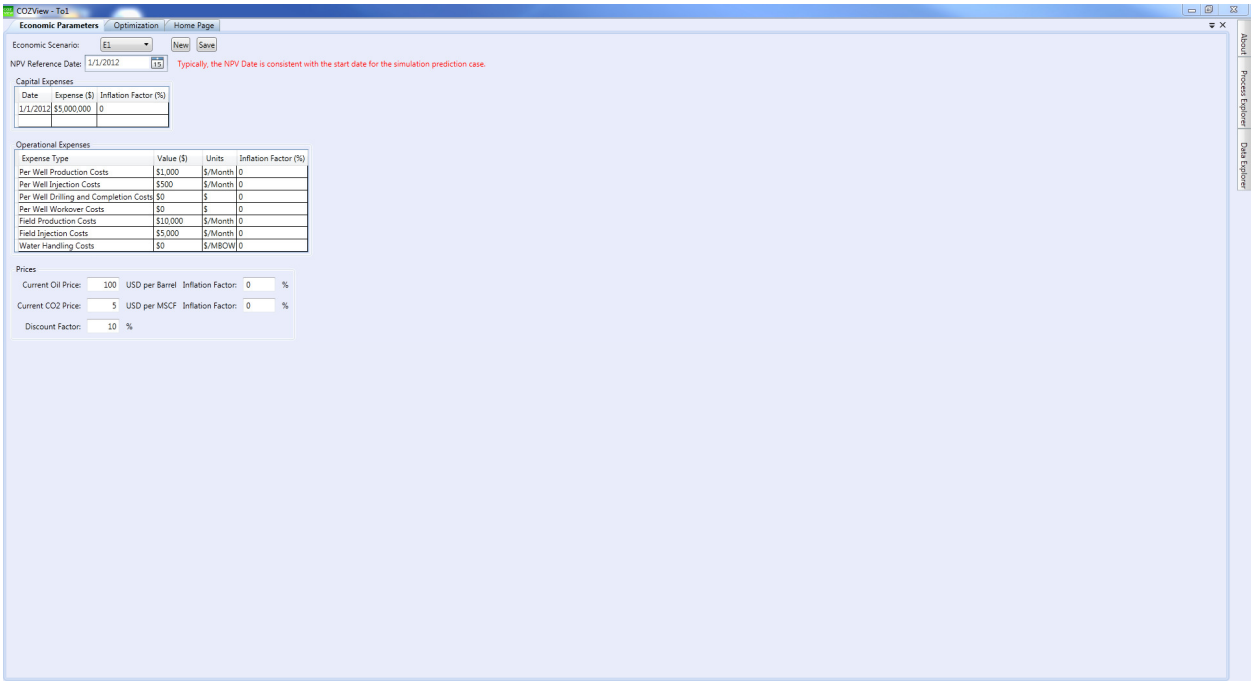
The following parameters (Capital and Operational expenses) are specified for this tutorial.

Capital Expenses

Date	01/01/2012 (same as Initialization date)
Expense ($)	5,000,000
All Inflation Factors, %	0

Operational Expenses

Per well Production costs, $/Month	1000
Per well Injection costs, $/Month	500
Per well Workover costs, $/Month	0
Field Production costs, $/Month	10,000
Field Injection Costs, $/Month	5,000
Current oil price, USD/STB	100
Current CO2 price, USD/MSCF	5
Discount Factor, %	10



Click **Save** to save the economic parameters.

The reservoir in Tutorial #1 consists of three layers, each of thickness 25 ft.

The following are the well and field limits used in Tutorial 1.

Well Constraints

Injection well (Well_5): Center well in the five spot

Maximum Bottom hole pressure (psia)	2500
Maximum CO2 Injection rate (MSCF/day)	5000

Producers (Well_1 – Well_4)

Minimum BHP (psia)	1500
Maximum Production Liquid rate (STB/day)	400

Well limits

Minimum Oil rate (STB/day)	5
Action to take	Close well

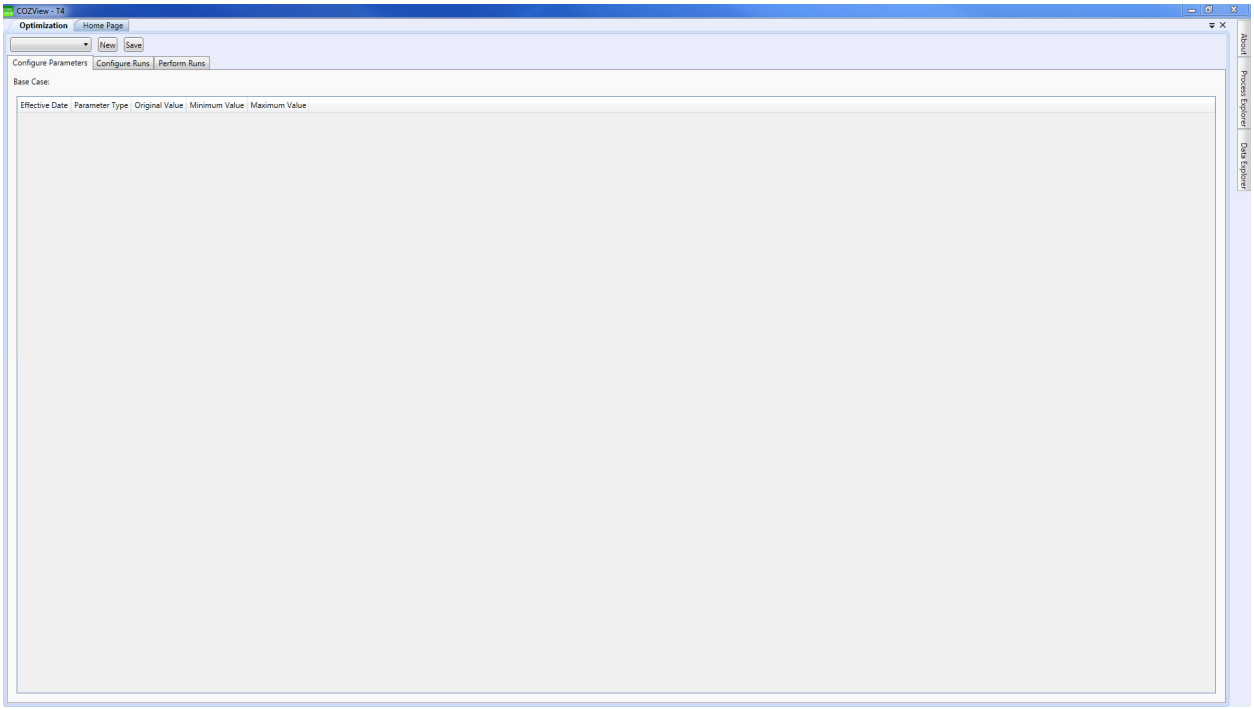
Field (Facility) Controls

Maximum Field Gas Injection Constraint (MSCF/day)	1500
Field Gas Reinjection Fraction	0.5
Available External Injection gas (MSCF/day)	1200

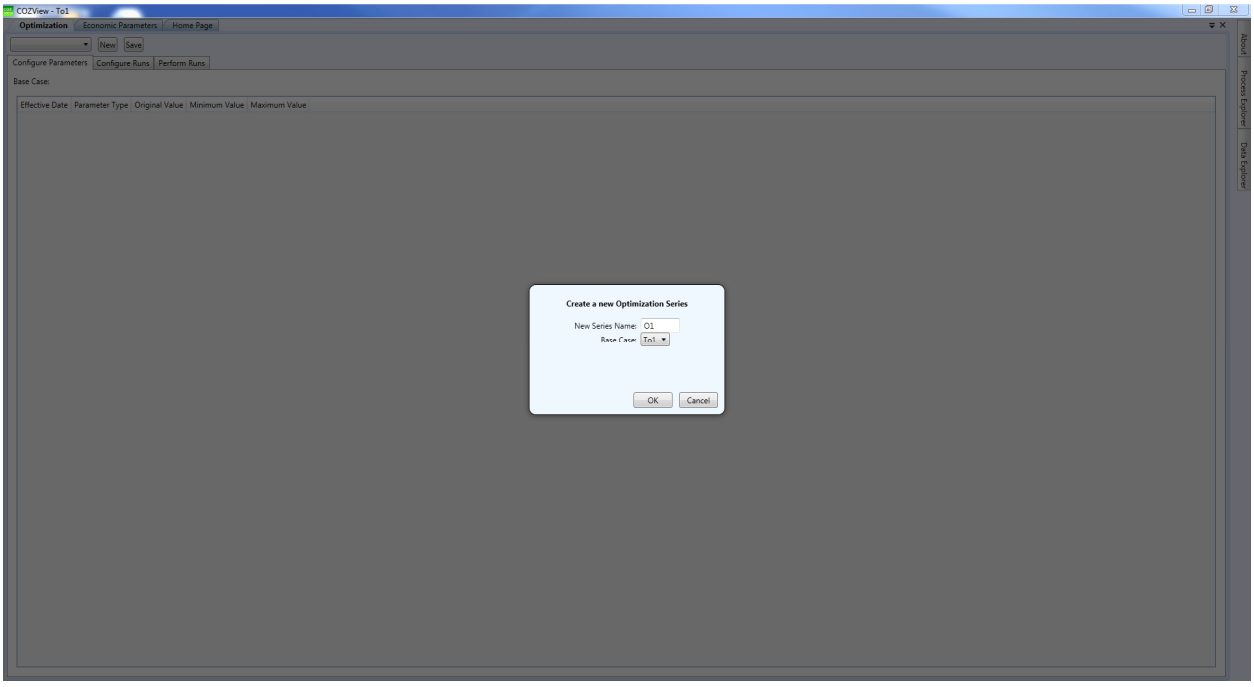
Field limits

Minimum Oil rate, STB/d	10

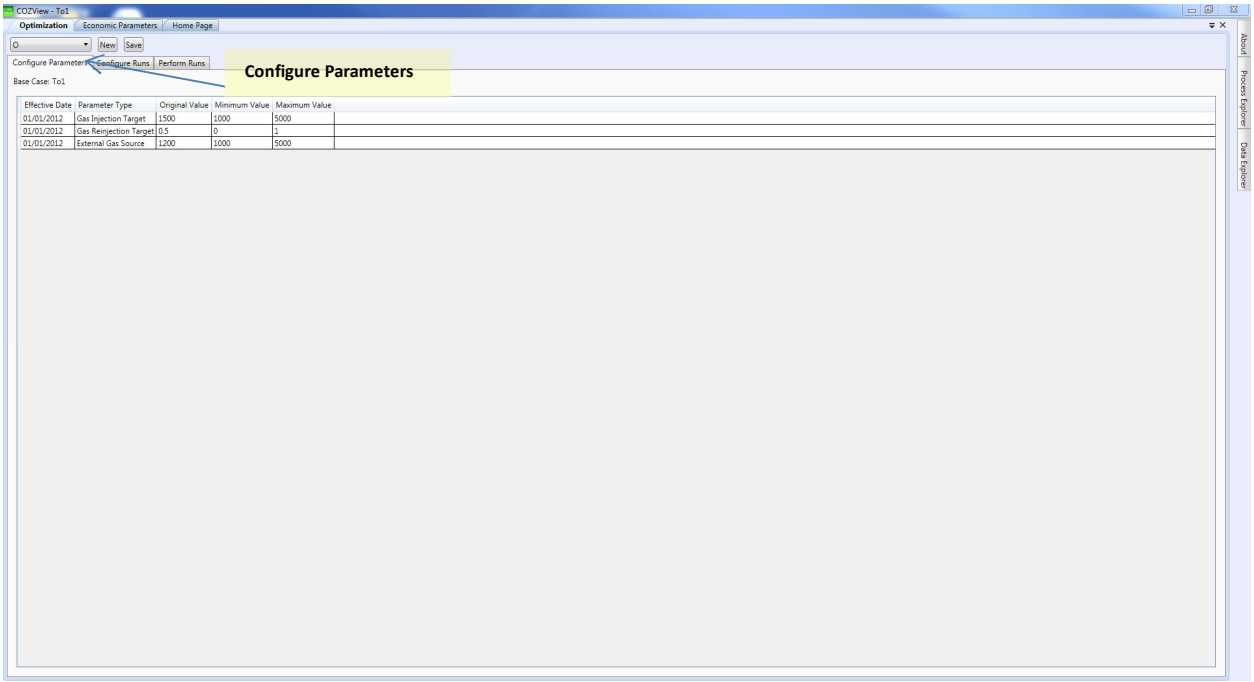
Select the **Optimization** tab under Process Explorer.



Click **New** to create a new Optimization Series name. Name the Optimization Series and select the base case (Tutorial1 for this example). An Optimization Series will be a particular set of Field (Facility) parameters and ranges and a given Economic Scenario.



A table of the previously specified Field parameters and their original values will be displayed in the Configure Parameters section. These are the parameters available for investigation in the optimization process. The user can specify a range (minimum and maximum) over which each parameter's value can be varied during the optimization process. The user can choose to not vary a particular parameter by not providing minimum and maximum values.



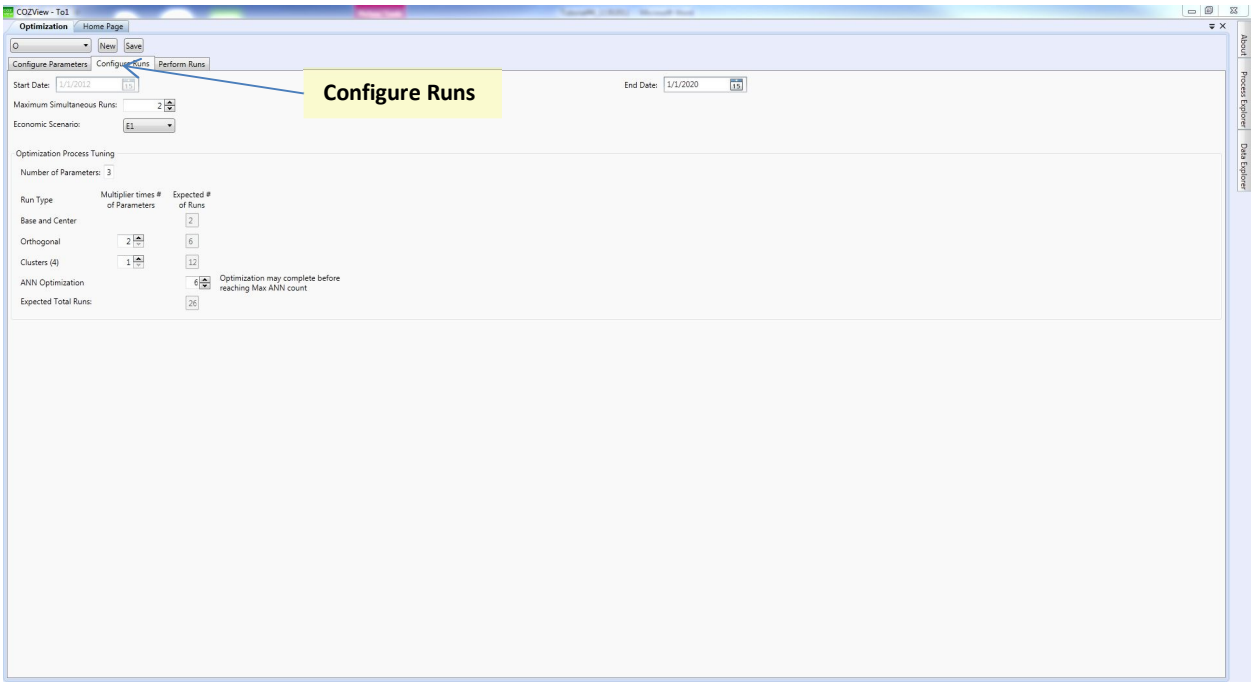
The following are the parameters used in this tutorial.

	Minimum Value	Maximum Value
Gas Injection Target, MSCF/D	1000	5000
Gas Reinjection Target, fraction	0.0	1.0
External Gas Source, MSCF/D	1000	5000

Select the **Configure Runs** tab. This section allows the user to specify the End Date of the optimization process. The user can specify the maximum number of runs that can be run simultaneously. For users with multi-core CPUs, the Maximum simultaneous runs can typically be set to the number of cores available. Because many of the simulation runs made during the optimization process are independent of other runs, multiple runs can be processed simultaneously if multiple CPUs are available. This can significantly speed the elapse time required for the runs made during the optimization process.

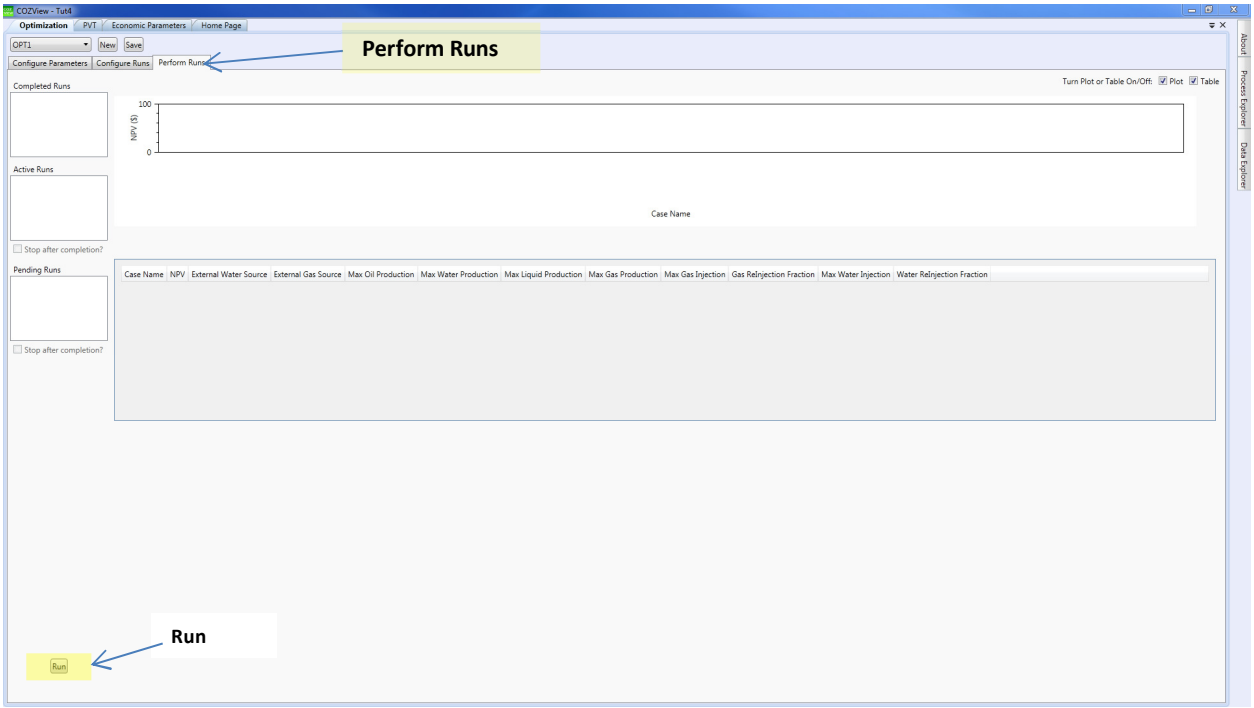
Economic scenario to be used for optimization process must be selected from the drop down menu as shown below. The following are the parameters used in this tutorial

Start Date	1/1/2012
End Date	1/1/2020
Maximum Simultaneous Runs	2
Economic Scenario	E1 (Economic Scenario defined previously)
Expected number of runs	26 (Default for 3 parameters)



Click **Save** before leaving this section.

Select Perform **Runs**. This section is used to launch the optimization process simulation runs. Click **Run** to start the process.

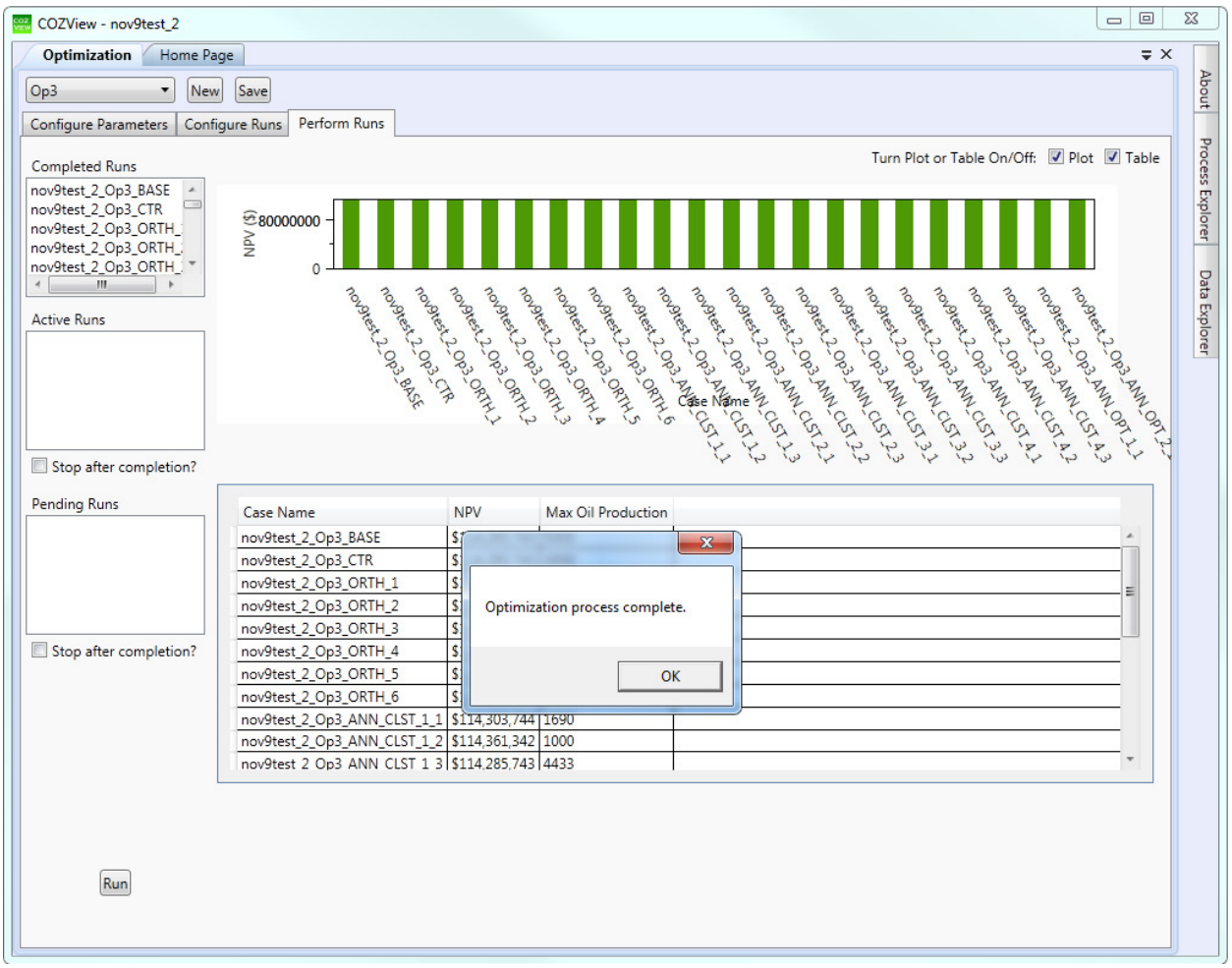


The user can monitor all the optimization process simulation runs in this section. The screen will provide information about the simulation runs that have been *Completed*, are *Active* (in progress) and *Pending* (waiting to run) on the left side of the screen. Pending Runs are only those that have been designed at that point in time. New runs may be designed as the process progresses. The Simrunner window will appear for each active simulation run. As a simulation run completes, a small window will appear notifying the user that the results of the completed simulation run are being loaded. Once the results are loaded a bar chart will display the calculated NPV for the case.

DO NOT close COZView or the Optimization tab during the simulation run as this will stop the optimization process. COZView can be minimized while the process is in progress.

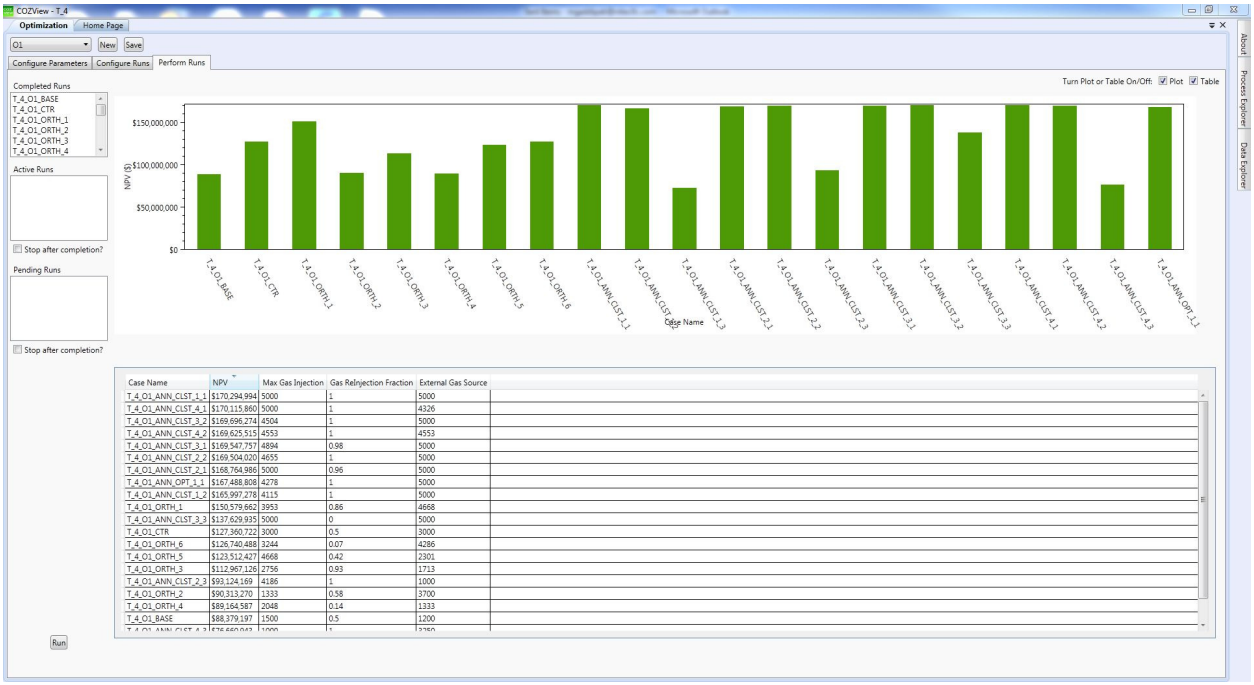
DO NOT cancel any simulation run during the optimization process. This will result in an incomplete optimization process. As soon as the simulations are completed, a window will appear saying "Optimization process Complete" as shown below. If the user wishes to cancel the optimization process before it completes all simulation runs, select check box **Stop after completion** under the Active and Pending run areas. This will result in a proper shut down of the process.

The simulation cases made during the optimization process will have unique case names. These names will start with the Base Case name provided by the user (T2 in this case) followed by SER_#, followed by an optimization process identification name. The SER_# is associated with the number of Economic Scenario and Field parameter combinations run through the optimization process for the Base Case.



In some cases the optimization process will not utilize the maximum number of simulation runs expected for the number of Field parameters being varied. If the optimization process determines that additional simulation runs are not warranted, the process will complete with the message “Optimization process has completed before maximum run count was reached”.

The *Perform Runs* screen will display a table and a bar chart showing all the simulation results.



Click the **NPV** column heading on the table to sort NPV in increasing or decreasing order. Clearly in this tutorial the best case is the CLST case (Case Name: To1_O_ANN_CLST_2_3) with NPV of $170 Million USD.

The Field controls that will maximize NPV are

Maximum Gas Injection	5000 MSCF/D
Gas Reinjection fraction	0
External gas source	5000 MSCF/D

As each simulation run completes in the optimization process the Field production/injection results are loaded into the **Simulation Results** Plots and Tables. Only the field results are loaded for the optimization simulation runs. The Plots and Tables can be viewed while the optimization process is in progress. However, **DO NOT** close the Optimization tab until the total optimization process is completed.

The results of different optimization cases can be compared using **Case Comparison Plots** under **Optimization** tab. For more details about Optimization and Case Comparison Plots please refer to User Manual (Section 3.7)

Click on the **Case Comparison Plots**.

Select the base case and click on the Optimization series. The figure below shows the base run and the run that has high NPV.