June, 2017

ExcSim 2.4 User Manual

Reservoir Simulator add-in for Excel

ExcSim Development

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Table of Contents

ExcSim 2.4 User Manual

Reservoir Simulator add-in for Excel

1 What This Manual is about

This user's manual applies to ExcSim version 2.4. ExcSim is a 2D 3-phase reservoir simulator containing 35×35 grid blocks. This guide also serves as user documentation for the smaller 10×10 grid block ExcSim Personal version.

2 How This Manual is Organized

The main sections are

- Installing EXCSIM
- Introduction
- The ExcSim Ribbon
    - Describes the ribbon (or menu buttons)
- How to Build a Model
    - Describes how to create a reservoir and simulation model
- The History worksheet
    - Describes how to enter historical production/injection data for history matching purposes
- Simulation output
    - Describes the various simulation out
- Map generation
    - Describes how to generate maps (structure maps, thickness maps, permeability maps, etc) using ExcSim's simplified map generator

3 Installing EXCSIM

EXCSIM version 2 comes with an automatic installer for Excel 32 bits, "**Setup ExcSim Excel32.exe**". Just run the installer and follow the instructions. The installer will also provide this User's Manual as a pdf-file in the installation directory.

4 Introduction

4.1 What Is EXCSIM?

EXCSIM is a two-dimensional 3-phase fully implicit reservoir simulator add-in for Microsoft® Excel 2007 and later versions of Microsoft® Office. It simulates production of oil and gas from underground oil and gas fields, as predictions and forecasts.

EXCSIM handles both metric and field units.

An EXCSIM reservoir model consists of up to 35×35=1225 grid blocks of any size in a single layer or cross-section, and any number of wells (producers and injectors). It is a modified black oil (MBO) simulator with the three primary phases: oil, gas, water, and two secondary phases: gas dissolved in oil (solution gas) and oil dissolved in gas (vaporized oil).

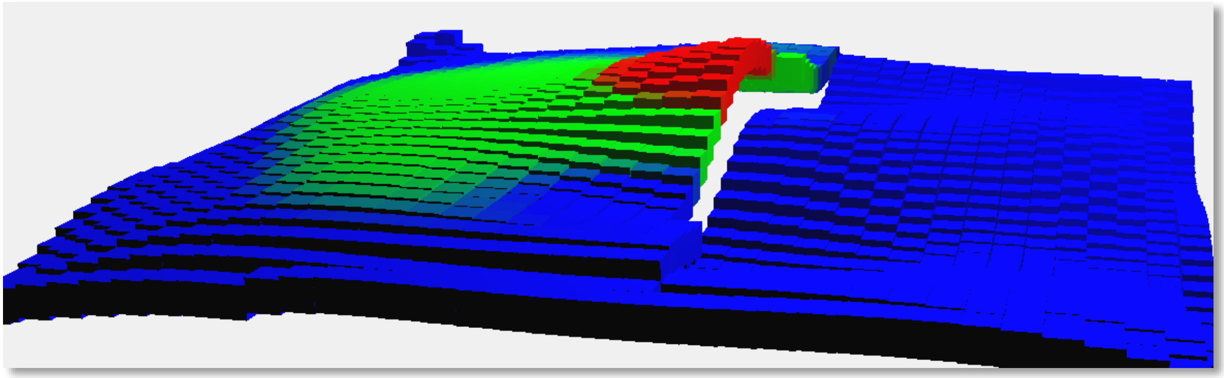


Figure 1 Example of a 35 × 35 ExcSim model with water (blue), oil (green) and gas (red) and a geological fault.

A fully implicit formulation implies that the simulator can take longer time steps and thereby run faster and remain more stable than an explicit formulation (or IMPES).

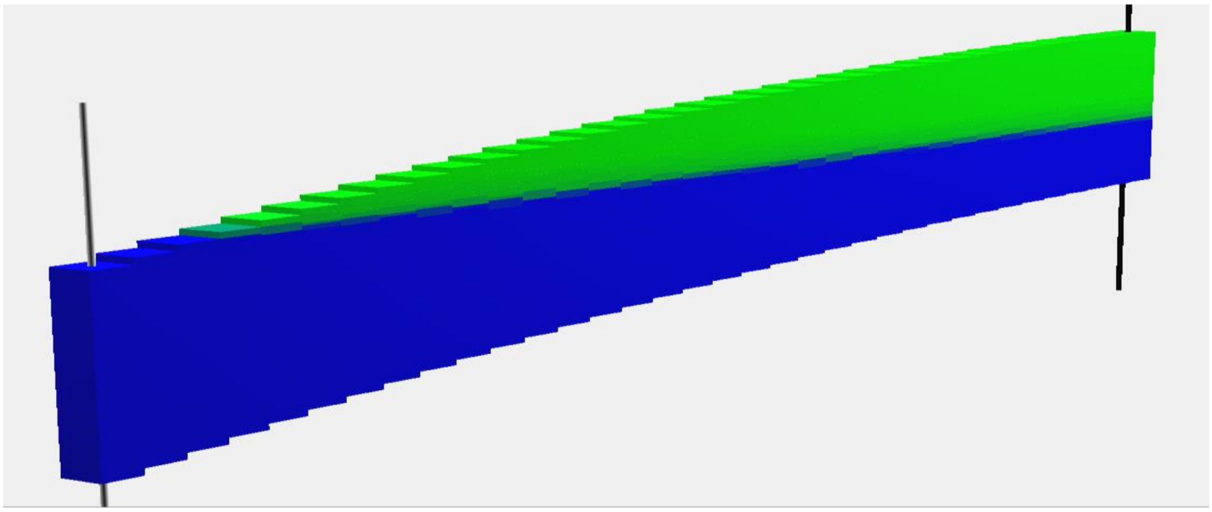


Figure 2 Example of a cross-sectional model (through up to 35 layers) with water (blue) and oil (green) saturation.

EXCSIM is a Microsoft Excel add-in. A single Microsoft Excel workbook (Excel file) contains both the model input and the simulated output. Users may freely distribute EXCSIM workbook files to anyone having Microsoft Excel. The workbooks can be opened, read and edited by anyone, even if they do not have EXCSIM on their computer. Recipients of the Excel file can do their calculations, plot data, copy and paste, insert their particular purpose worksheets and add their own personalized VBA macros for automatically performing repetitive tasks, like in any other regular Excel file. With ExcSim you retain full flexibility.

With EXCSIM you can

- Model complex reservoirs with internal barriers, geological faults, and inactive grid blocks.
- Make production forecasts of oil, gas, and water from oil and gas fields.
- Optimize the number of wells and their locations.
- Optimize sweep by inspecting saturation maps and moving wells to superior locations.
- Optimize the size and capacities of production facilities by providing a range of potential development scenarios for economic evaluation, comparison, and final selection.
- Do sensitivities, feasibility studies, and uncertainty analyses by running multiple simulations covering the range of possible outcomes.
- Design well tests.
- Justify drilling of new wells by signifying their simulated production potential.
- Moreover, much more.

4.2 Who Uses EXCSIM?

The typical EXCSIM user is a professional reservoir engineer, petroleum engineer, geologist, geophysicist or a professional decision maker in the oil business.

Some colleges and universities also use EXCSIM as part of their courses and activities.

4.3 Why Use EXCSIM?

When time is of the essence, and your project team requires quick production forecasts and predictions, many petroleum engineers resort to the equivalence to drawing a simple straight line on a piece of paper. They need two fixed points: 1) the initial flow rate potential when cumulative production is zero and 2) zero flow rate potential when the cumulative production has reached ultimate recovery. Hence, they have to *guess* the initial flow potential and the ultimate cumulative production.

Since the cumulative production grows slower as the flow rate declines, the straight line becomes curved (exponential decline) when plotted versus time. Production ‘forecasts’ thus created are then passed up the value chain for economic analysis and evaluation.

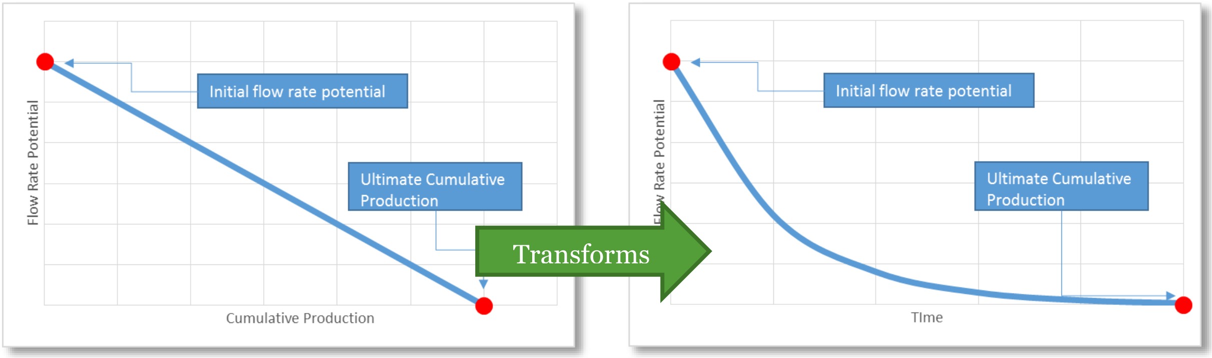


Figure 3 A typical exponential decline curve used by many companies for quick evaluations

Such predictions are questionable, to say the least. Many oil companies have surely gone bust due to forecasts as the one described. Oil companies continue to base huge business decisions on precisely this kind of 'analysis.'

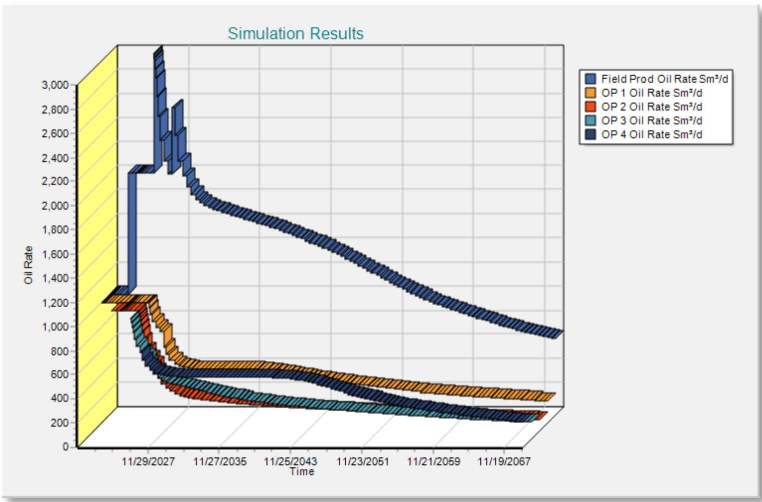


Figure 4 Example of 50-year forecast showing total field and individual well production rates

Business developers, for example, often decide whether to acquire, buy shares, farm into oil and gas fields or even buy entire oil companies, based on very little data and with a very short time for making the decision.

With EXCSIM, engineers can set up simulation models based on real data, for example at a data room[1], and provide forecasts that are far more realistic.

EXCSIM will also show pressure and fluid saturation changes during and after the simulation, as seen in Figure 5. This allows engineers to easily identify where any bypassed and remaining oil most likely resides.

[1] When oil companies want to sell part of their share in an oil or gas field, they typically invite potential bidders to a 'data room' where basic information about the prospect is provided. A data room can last from a few hours to several days, depending on the size of the project. After the data room, potential bidders normally have very little time to make the final bid.

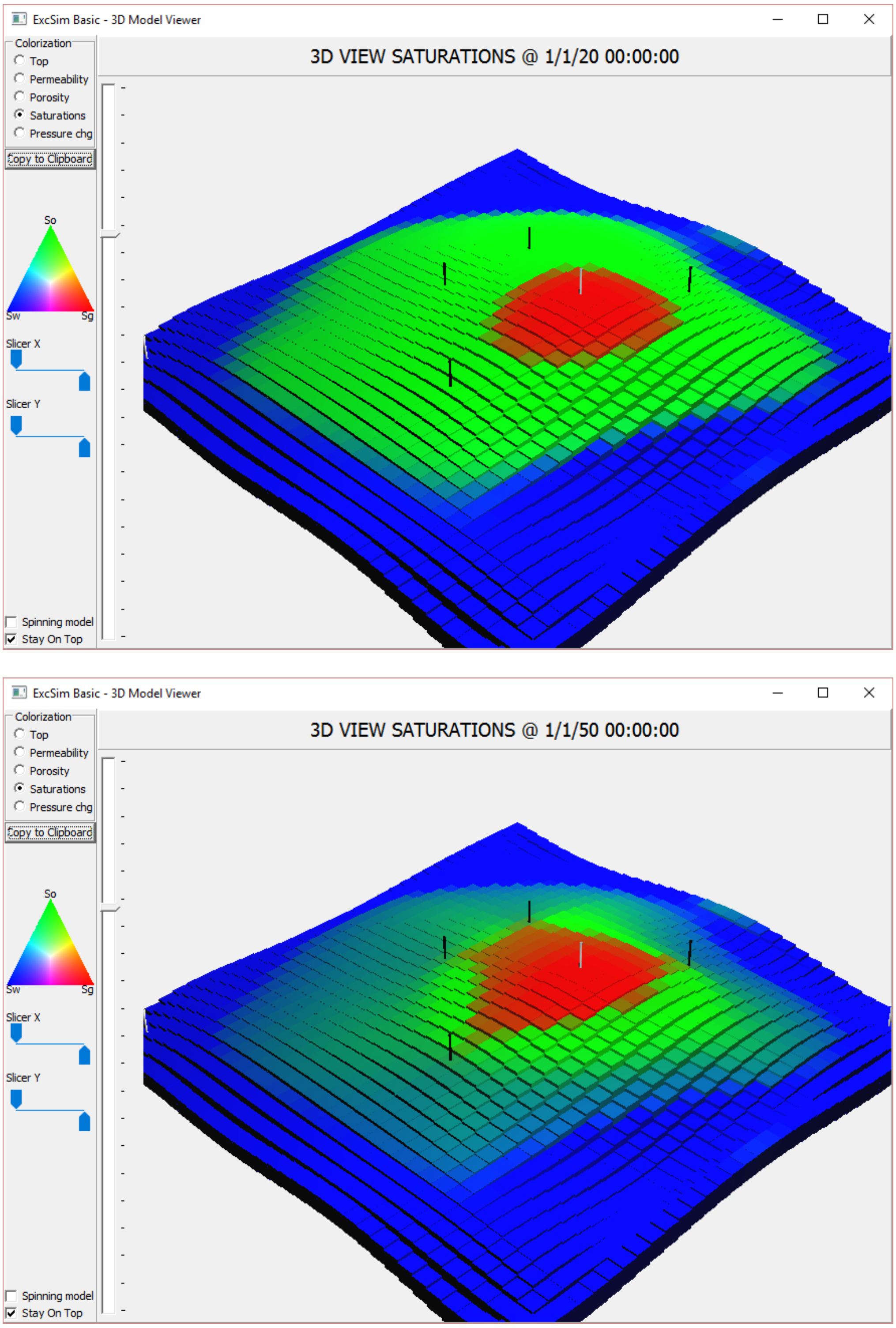


Figure 5 Visualizing sweep and remaining oil

5 Getting Started

5.1 The EXCSIM Ribbon

In Windows 2007, Microsoft replaced menus and toolbars by a Ribbon, which is a part of the Microsoft Office Fluent User Interface. The EXCSIM ribbon in Excel acts as a menu for the simulator.

Figure 6 EXCSIM ribbon in Excel

The Ribbon Buttons are grouped according to their function and purpose. Below is a short description of each of them.

5.2 The SIMULATION Ribbon Group

The SIMULATION group contains three buttons directly associated with running the simulator.

5.2.1 The **New ExcSim** Ribbon Button

If EXCSIM does not recognize an Excel file as being an EXCSIM file all ribbon buttons, except the “New ExcSim” button, will be disabled. Pressing the “New ExcSim” button will open a new Excel spreadsheet containing a working template model and enable all the other ribbon buttons. You should change the data in the template file to fit your own particular needs and save the changes under a different file name for future work and reference. All Ribbon Buttons will be enabled the next time the file loaded.

5.2.2 The **Initialize** Ribbon Button

When a valid ExcSim workbook is loaded, pressing the “Initialize” button will initialize the model, i.e. will read all relevant input data and calculate the initial state of the reservoir regarding oil, gas, and water pressures, saturations, fluid contacts, and volumes. Note that any output from previous runs may be deleted or overwritten in preparation for a new simulation run.

5.2.3 The **Run** Ribbon Button

Pressing the “Run” button will first initialize the model (the same as pressing the “Initialize” button), then immediately start the dynamic simulation. A small “Simulation Progress” window will pop up providing essential information regarding the simulation progress and status.

Figure 7 shows a snapshot of the progress window. The first line indicates that the simulator has completed the time-step leading up to 2/24/2006 23:38:54. The second line shows that it is currently running with 180-day time steps. The third line shows that it has been running for 24 seconds, and the fourth line that it is in its third iteration of the next time step. The progress bar at the bottom shows that the simulation is 30% complete.

The Stop button will complete the current loop of iterations and then end execution.

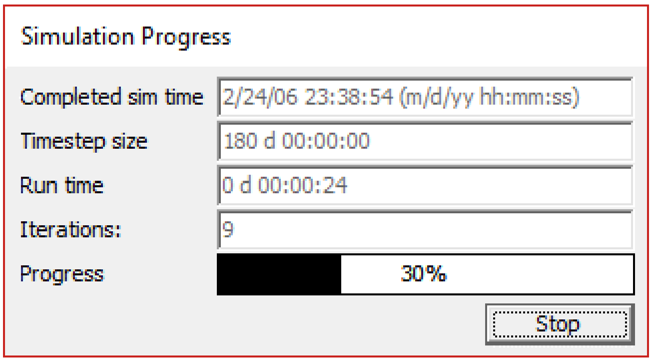
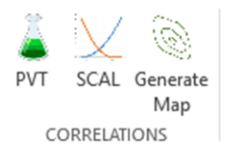


Figure 7 Simulation Progress pop-up window during a simulation run

5.3 The CORRELATIONS Ribbon Group



EXCSIM comes with correlations to aid the user in generating reasonable input when real data is not available. In particular, one correlation for generating fluid properties and one for generating relative permeability and capillary pressure data is included.

Use correlations only when actual laboratory measurements are unobtainable.

5.3.1 The **PVT** Ribbon Button

Pressing the “PVT” button will generate PVT (Pressure-Volume-Temperature) tables based on input provided by the user. The table format is similar to that of Schlumberger’s Eclipse® PVTO, PVTG, and PVTW keywords. The PVT correlation is modeled after the popular but no longer manufactured Hewlett Packard Petroleum Fluids Pack for their HP-41 series programmable hand-held calculators.

The required input to the correlations is entered into the light blue cells to the right of the tables in the “PVT & Relperm” worksheet, as seen in Figure 9, and shown closer up in Figure 8.

Fluid densities, the green cells above the input table in Figure 9, are also required for the correlation to work, but they are not considered correlation input since they are required in every simulation - regardless of whether the PVT correlations are used or not.

Input to PVT Correlation

ONLY for generating new PVT tables from correlation

PVT correlation input		
Reservoir temperature	200	Celcius
Separator Temperature	15	Celcius
Separator Pressure	1.1	bara
N_2	0	%
CO_2	0	%
H_2S	0	%
Salinity	4	%

Correlation output ranges				
		Low	High	
Rs range		10	100	Sm³/Sm³
Reservoir pressure		100	500	bara
# rows	Saturated	10		>1
	Under-sat	5		>1

Figure 8 Input form for PVT correlation

5.3.2 The **SCAL** Ribbon Button

Pressing the "SCAL" button will generate SCAL (Special Core Analysis) tables similar to Schlumberger's Eclipse® SWOF and SGOF keywords. The required input to the correlations is entered on the right-hand side of the "PVT & Relperm" worksheet, as shown in Figure 9, and shown closer up in Figure 10.

EXCSIM requires two sets of SCAL data - for oil/water and gas/oil mixtures, respectively. Each set of SCAL data is a table with four columns. The first column of the oil/water table contains the range of water saturation values; the second column gives the water relative permeability corresponding to each water saturation, the third column gives the corresponding oil relative permeability (assuming that $S_o = 1 - S_w$), and the fourth column gives the corresponding oil/water capillary pressure, $P_{cow} = P_o - P_w$.

EXCSIM requires a similar table for the gas/oil SCAL data.

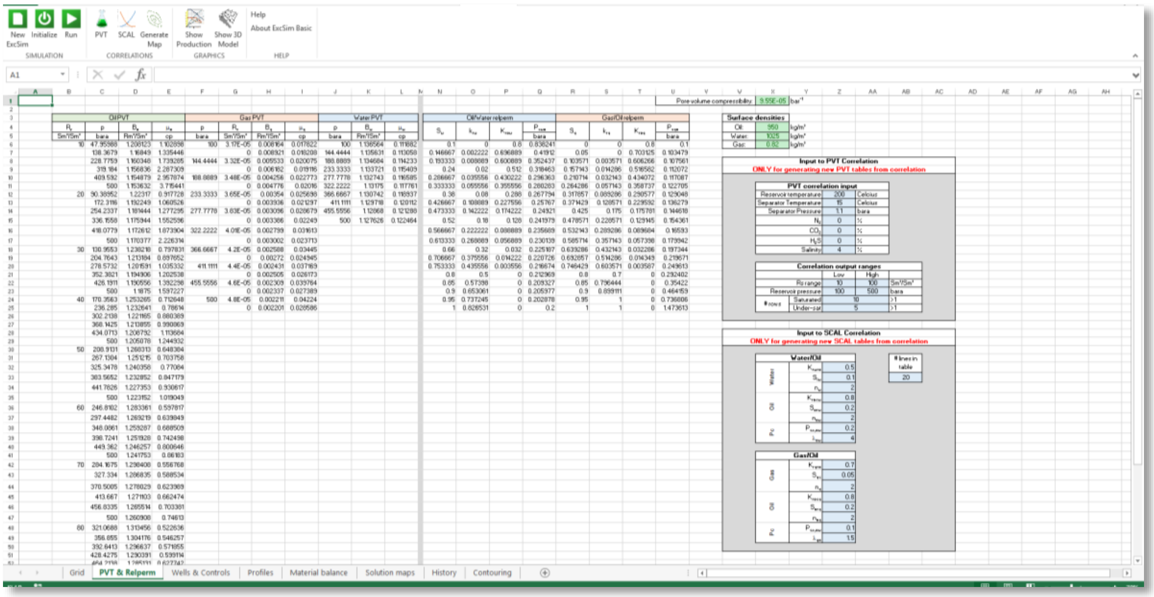


Figure 9 The "PVT & Relperm" tab

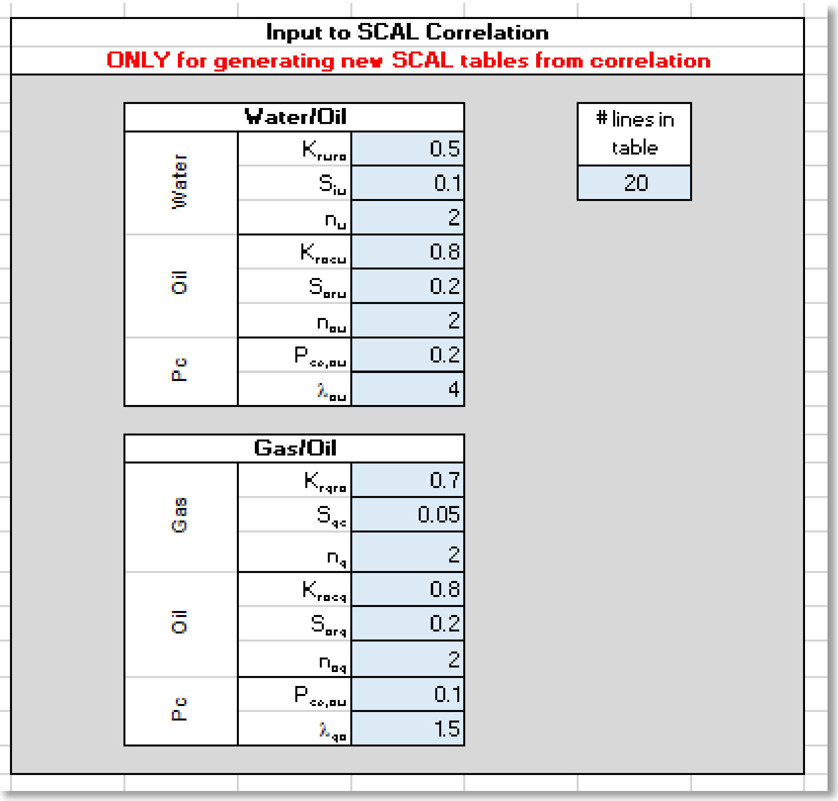


Figure 10 Input form for SCAL correlations

When all three phases co-exist in a grid block, oil relative permeability is calculated by combining the two SCAL tables.

5.3.3 The **Generate Map** Ribbon Button

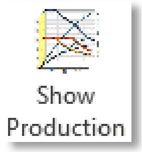
When a numerical structure map for the grid is not available, EXCSIM provides a rough contouring feature for generating the needed input from a picture or drawing showing the contours.

Although most people would not consider map generation a correlation, that is, in fact, what it is in EXCSIM. It is a best-fit polynomial regression or correlation between sets of contour values and their corresponding X and Y coordinates.

The required input is given in the "Contouring" worksheet, and the output is also generated there. The maps may be structure maps or property maps, such as permeability or layer thickness maps. The output includes the map in matrix form ready to copy and paste, as well as the mathematical formula used for the generating the matrix.

5.4 The GRAPHICS Ribbon Group

The GRAPHICS ribbon group contains routines for visually viewing the output data. The first button shows the production and injection profiles as functions of time. The second button shows the material balance as a function of time. The third button shows the pressure and saturations across the model, in 3D, as the simulation progresses.



5.4.1 The **Production Profiles** Ribbon Button

The "Production Profiles" button will open a pop-up window that displays the production profiles for the total field and the individual wells. The data plotted includes daily rates, cumulative production, water cut, gas/oil ratios as well as bottom-hole pressures.

The production profiles are curves in plain 2D plots, but the curves may also be displayed with a distinct 3D separation. The user may zoom in and out for a closer view. A special button for copying the plot to the clipboard provides a convenient possibility to paste the plot in any word processor for reporting and documenting purposes.

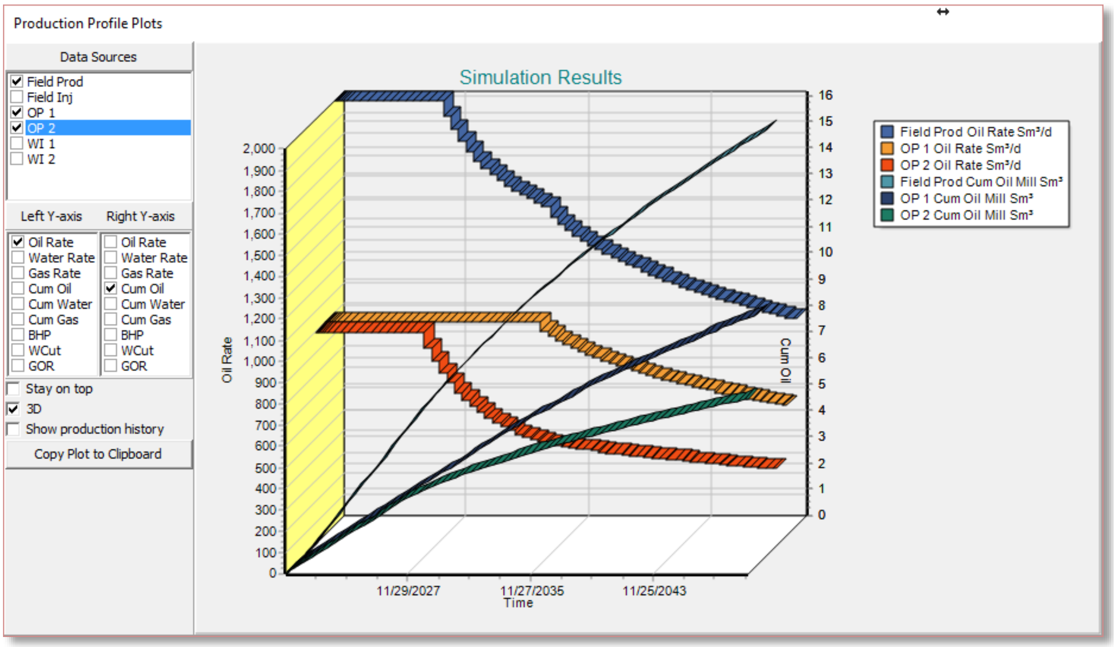


Figure 11 Production Profile plot

5.4.2 The **Material Balance** Ribbon Button

The "Material Balance" button will open a graphic window showing two graphs: the reservoir offtake represented as oil, gas, and water production under reservoir conditions, and the reservoir drive energy represented by water and gas injection, oil expansion (including solution gas drive), formation and connate water expansion, gas cap expansion, and aquifer influx. Both graphs are shown in reservoir volumes or volumetric rates, alternatively. Adding all the offtake should yield a value (curve) identical to the sum of the drive mechanisms.

As with the Production Profiles graphics previously described, the user may zoom in, pan along the axes and copy the graphs to the clipboard for reporting and documentation purposes.

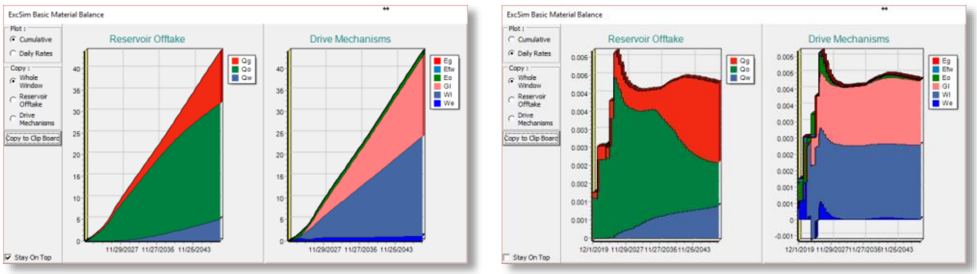


Figure 12 Material Balance Graphs of reservoir offtake and drive mechanisms, both cumulatively and daily

5.4.3 The **3D Viewer** Ribbon Button

The "3D Viewer" button will open a pop-up window that displays pressure and saturations as the simulation steps forward over time. The viewer may also be used to display some static properties in 3D. Figure 13 demonstrates two views side by side: saturations to the left and pressure changes to the right. The model can easily be rotated using the mouse and zoomed in and out using a slider track bar to the left of the view. Handles are also provided beneath the plot legend to make slices in both the X and Y direction. Double-clicking on the handles let you type in the respective row and column numbers directly.

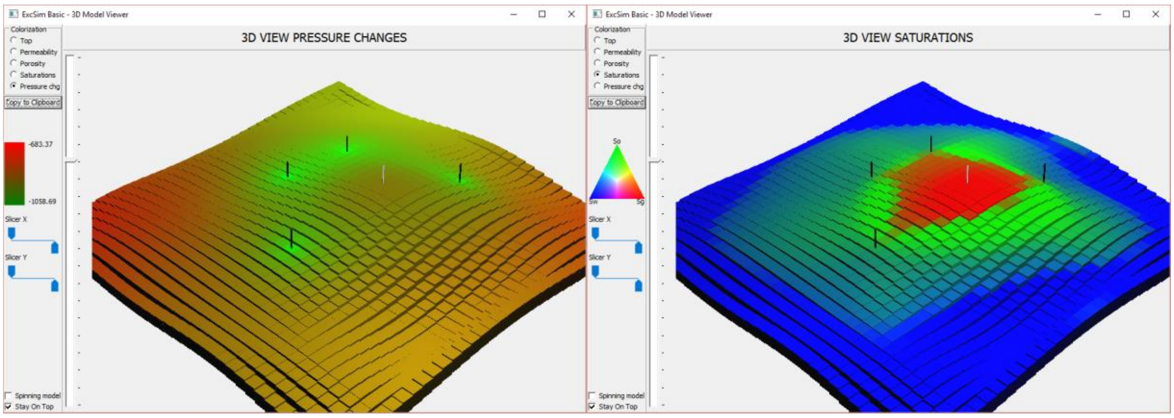


Figure 13 3D Model Viewer displaying changes in saturations and pressure

5.5 The ABOUT Ribbon Group

5.5.1 The **About ExcSim** Ribbon Button

The about button opens a window that displays the current version of ExcSim and a copyright message.

5.6 The LICENSE Ribbon Group

The LICENSE ribbon group displays information relating to the user's ExcSim License. To the left of the divider is

1. the User Name as reported by Windows
2. a unique User Code that must be included when the user registers ExcSim
3. the expiry date of the ExcSim License

5.6.1 The **Register** Ribbon Button

Use this button to register your copy of ExcSim. It will take you to a special registration web page, http://www.excsim.com/Register.html. Upon registration, you will receive a LICENSE CODE that will unlock ExcSim for the entire purchased License Period.

When registering ExcSim you need to provide the following information:

- Your First and Last Names (required)
- The email address to which your LICENSE CODE will be sent (required)
- The unique User Code found to the left of the divider of the Ribbon Group (required)
- The Order Confirmation Number that you received by email

5.6.2 The **Enter LICENSE CODE** Ribbon Button

Use this button to enter new LICENSE CODEs received from ExcSim (see Chapter 5.6.1.)

6 How to Build a Model

6.1 Choice of Units

EXCSIM can handle both metric and field units. Choose your preferred unit system from a drop-down list, found in cell "U2" in the "Wells & Controls" worksheet. See Figure 13 for a close-up.

Notice that the unit selection cell has a red outline for easy identification (when not selected). EXCSIM uses drop-down lists for cells that have only a small number of permissible values. The red outline is a feature common to all such drop-down lists.

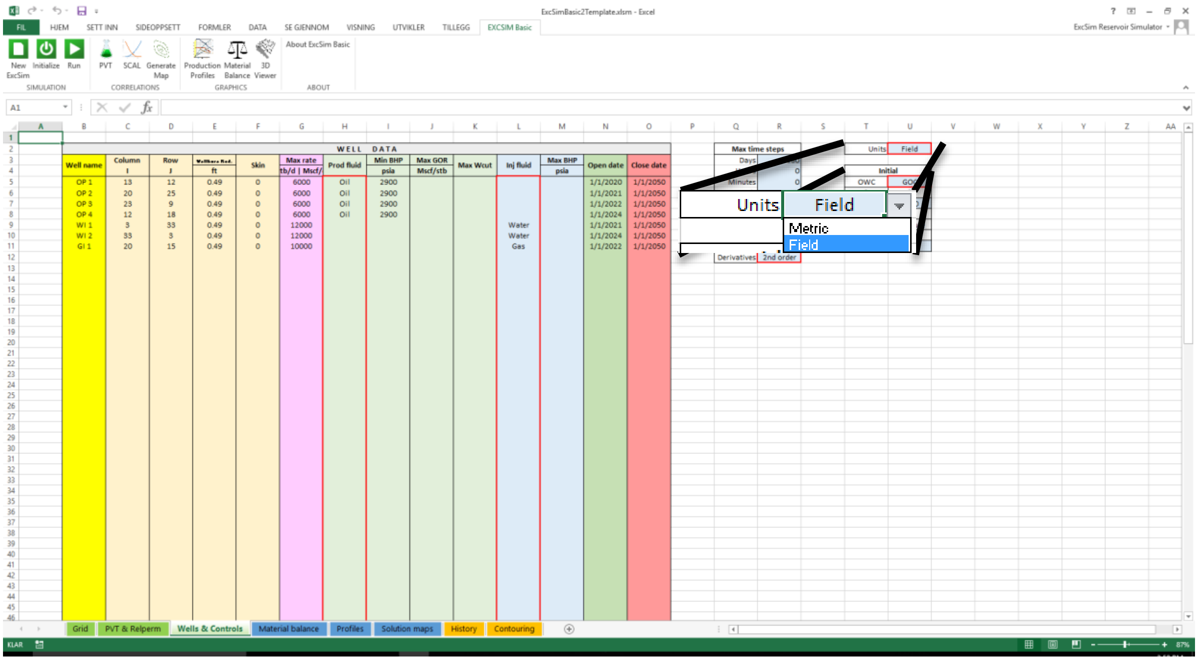


Figure 14 Units selection drop-down menu

When the user changes the units system, EXCSIM automatically changes all *relevant* text and number fields in the workbook. By *relevant* we mean all numerical input and output data and all text in column headings describing the units. For example, the text "Sm³/d" may change to "stb/d" when changing from metric to field units.

6.2 The Grid Worksheet

The EXCSIM model uses a 35 × 35 Cartesian grid. Each grid block is represented in the worksheet as a spreadsheet cell, and the whole model is represented by a set of 35 × 35 arrays of cells in Excel. The set of arrays is located in EXCSIM's "Grid" worksheet and consist of a

1. **Top** map, i.e. the depth to the top of each grid block.
    - Deeper grid blocks have greater depths. Hence, the top of the model will be the shallowest point with the lowest numerical value.
2. **Thickness** map gives the vertical height of each grid block.
3. **Permeability** map gives the permeability of each grid block.
4. **Porosity** map gives the porosity of each grid block.
    - A real number between 0.0 and 1.0.
5. **X+ Transmissibility Multiplier** map gives the transmissibility multipliers in the positive X-direction for each grid block.
    - Transmissibility multipliers are non-negative numbers. The default values are 1.0.

- Any number other than 1.0 will change the transmissibility between the grid block in question and the grid block to its right (i.e. in the X+ direction).

6. **Y+ Transmissibility Multiplier** map gives the transmissibility multipliers in the positive Y-direction for each grid block.
    - Transmissibility multipliers are non-negative numbers.
    - The default values are 1.0.
    - Any number other than 1.0 will change the transmissibility between the grid block in question and the grid block beneath it (i.e. in the Y+ direction).

Two additional 1D arrays hold the X- and Y-dimensions of the grid blocks along the upper and left edges of the Top map, respectively. Figure 15 shows an example where all grid blocks have an area extent of 100 × 100m².

	A	B	C	D	E	F	
1							
2	DY\DX	100	100	100	100	100	1
3	100	2826.58431	2810.80753	2871.55115	2910.18568	2931.39125	293
4	100	2842.36109	2868.55243	2886.10463	2896.21197	2900.02298	2898
5	100	2906.15189	2899.19546	2892.63722	2885.98488	2878.8998	2871
6	100	2932.76965	2911.23202	2893.11802	2877.67947	2864.3059	2852
7	100	2936.68085	2911.32906	2889.21104	2870.01872	2853.46782	283
8	100	2928.68013	2904.57339	2882.30516	2862.18379	2844.41182	282
9	100	2916.45339	2894.70384	2873.54269	2853.73081	2835.83128	282
10	100	2905.10052	2884.32721	2863.8465	2844.5144	2826.96423	2811
11	100	2897.6179	2875.11814	2853.94573	2834.61763	2817.48087	2802

Figure 15 X and Y grid block sizes in cells with black background along edges of the Top map

EXCSIM uses a right-handed coordinate system: think of the X-direction being oriented towards the east, the Y-direction towards the south and the Z-direction towards the center of the earth. Consequently, grid blocks are referenced by (i, j) labels, where i is the column number and j is the row number, starting from (1, 1) in the upper left-hand corner.

6.2.1 General Grid Considerations

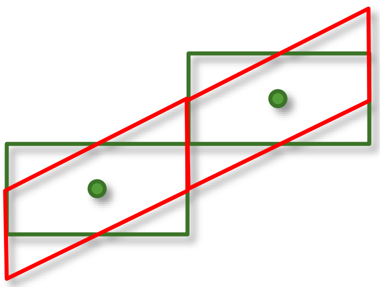


Figure 16 The red and green blocks have the same volumes

The EXCSIM grid projects a 35×35 two-dimensional Cartesian grid on the XY plane. However, the grid blocks' location in the Z-direction (i.e. their depths) and their Z-dimensions (thicknesses) may vary. Although it is natural to think of the grid blocks as a 2D array of tightly packed cuboids (rectangular boxes), this interpretation may be misleading. It is better to think of them as points in space (associated with volume elements) connected to other similar points in space.

In Figure 16 both the red and the green cells have the same volume, but different flux surfaces and different separation (measured along the direction of flow).

Due to the Cartesian nature of the grid, the grid blocks form rows and columns. All grid blocks in one column have identical DX-dimensions, and all grid blocks in the same row have identical DY-dimensions. The X- and Y-dimensions are specified along the top and left edges of the Top Map array in the “Grid” worksheet. See Figure 15 for an example.

6.2.2 The Top Map

The Top map gives the depth to the top surface of each grid block in the model. To be more precise, the top map gives the depth to the *center* of the top surface of each grid block. Notice that the crest of the structure has the shallowest depth, and hence the smallest Z-value. The units are meters or feet.

For visual purposes, grid blocks are presented as cuboids, but EXCSIM assumes free flow between neighboring grid blocks (unless the transmissibility multipliers are set to zero), even if they appear to be offset from each other, in accordance with transmissibility calculations.

6.2.3 The Thickness Map

The Thickness map gives the thicknesses, or vertical height, of each grid block in the model. The units are meters or feet.

6.2.4 The Permeability Map

The Permeability map gives the horizontal permeability for each grid block in the model. Since the model is a 2D single-layer model, there is no permeability in the vertical direction. The units are milli-Darcies.

6.2.5 The Porosity Map

The Porosity map gives the porosity for each grid block in the model. Note: EXCSIM does not use any Net-To-Gross parameter. Porosity is a dimensionless number between 0.0 and 1.0. If a value of zero is entered, that grid block becomes inactive.

6.2.6 The X+ Transmissibility Multiplier Map

The X+ Transmissibility Multiplier map modifies the default transmissibility between the grid block in question and the grid block to its right (in the positive X-direction), by a factor. This is useful when the user wants to emulate a barrier to flow, in which case the factor should be 0.0 (zero), or a restriction to flow, perhaps in connection with a geological fault.

6.2.7 The Y+ Transmissibility Multiplier Map

The Y+ Transmissibility Multiplier map modifies the default transmissibility between the grid block in question and the grid block below it (in the positive Y-direction), by a factor. This is useful when the user wants to emulate a barrier to flow, in which case the factor should be 0.0 (zero), or a restriction to flow, perhaps in connection with a geological fault.

6.2.8 Cross-sectional models

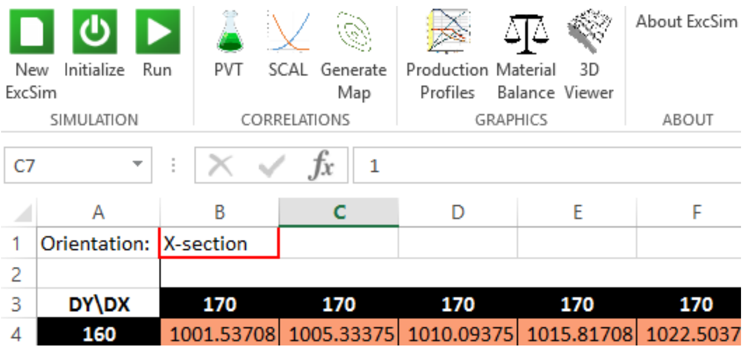


Figure 17 Select X-section (see red outline) to generate a cross-sectional model in the Grid worksheet

When you select 'X-section' in the Orientation cell (red outline) at the top of the Grid worksheet, ExcSim will generate a cross-sectional model rather than a single layer model. Input to the Top map is interpreted very differently. In particular, only the top row of the Top map is relevant; the top of the uppermost layer and the thicknesses of the layers above determine the top of each layer in the cross-section. Note that a full 35 × 35 Top map must be provided, but only the first row matters when in X-section mode.

Furthermore, every grid block in a cross section will have identical DY values or 'widths.' Hence, only the first DY value is relevant. Regarding the Thickness map, they will be the vertical thicknesses of each grid block and may vary along any 'layer.'

The Transmissibility multipliers in the Y-direction will be interpreted by ExcSim to be vertical transmissibility multipliers and could be used to account for the fact that vertical permeability normally is lower than horizontal permeability. Typical transmissibility multipliers could be in the 0.001 to 1.000 range.

Also, note that X-section mode affects wells. For details, refer to chapter 6.4.1.1.

6.3 The PVT & Relperm Worksheet

The PVT & Relperm worksheet contains three fluid description tables (PVT tables), one for each fluid, and 2 SCAL (Special Core Analysis) tables for oil/water and gas/oil mixtures.

The worksheet also contains rock compressibility data and fluid densities.

Furthermore, the worksheet contains input to the PVT correlations and the SCAL data correlations. These are provided only in the case that the user lacks real data.

6.3.1 PVT Data

6.3.1.1 Oil PVT Table

EXCSIM uses the same format as the Eclipse PVTO keyword for oil PVT. The data comprises a table of live oil PVT functions. The table consists of at least two groups of data. Each group gives PVT data for a particular dissolved gas-oil ratio (R_s). The first non-numeric entry in the second column terminates the table.

All groups start with the following items of data:

1. The dissolved gas-oil ratio (R_s). Within a table, groups should be arranged in order of increasing R_s. The units are Sm³/ Sm³ and Mscf/stb
2. The bubble point pressure (P_{bub}) for oil with dissolved gas-oil ratio given by item 1. The units are bara and psia
3. The oil formation volume factor for saturated oil at P_{bub}. The units are Rm³/ Sm³ and rb/stb
4. The oil viscosity for saturated oil at P_{bub}. The units are cP

However some groups (optionally all) contain additional data which defines the properties of under-saturated oil at the specified value of R_s. This extra data must be specified for at least one R_s in the table. The additional data takes the form of 3 columns that continue from items 2, 3 and 4 in the list above. See Figure 18 below.

Oil PVT				
R_s	p	B_o	μ_o	
Sm³/Sm³	bara	Rm³/Sm³	cp	
10	48.6086304	1.21086782	1.10289833	← Saturated data
	274.304315	1.16095437	1.98947387	← Under-saturated
	500	1.15621304	3.69029175	← Under-saturated
55	231.018819	1.2778204	0.62169809	← Saturated data
	365.50941	1.24817519	0.75576522	← Under-saturated
	500	1.23471126	0.92754516	← Under-saturated
100	399.062479	1.34477298	0.4688083	← Saturated data
	449.53124	1.33328365	0.49684365	← Under-saturated
	500	1.32418421	0.52691387	← Under-saturated

Figure 18 Example of Oil PVT Table

Together, saturated and under-saturated data describe a 2-dimensional table. The table may be visualized as in Figure 19.

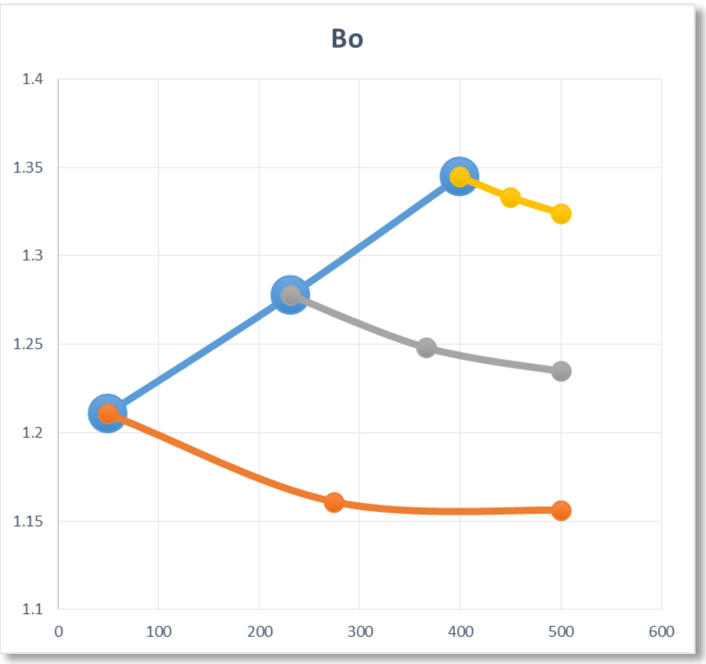


Figure 19 Example of Bo from the PVT table above: Saturated points shown in blue. The under-saturated points shown in other colors.

6.3.1.2 Gas PVT Table

EXCSIM uses the same format as the Eclipse PVTG keyword for gas PVT. The data comprises a table of wet gas PVT functions. The table consists of at least 2 groups of data. Each group gives PVT data for a particular gas phase pressure (P_g). The first non-numeric entry in the second column terminates the table.

All groups contain the following items of data:

1. The gas phase pressure (Pg). Within the table, groups should be arranged in order of increasing P_g. The units are bara and psia
2. The vaporized oil-gas ratio for saturated gas at pressure P_g. The units are Sm³/Sm³ and stb/Mscf
3. The gas formation volume factor for saturated gas at P_g. The units are Rm³/Sm³ and rb/Mscf
4. Item 4 The gas viscosity for saturated gas at P_g. The units are cP

However, some groups (optionally all) contain additional data that defines the properties of the under-saturated gas at the specified value of P_g. This extra data must be specified for at least one P_g in the table. The additional data takes the form of 3 columns which continue from items 2, 3 and 4 above. See Figure 20 below.

6.3.1.3 Water PVT Table

The water PVT table comprises a table that is terminated by the first non-numeric entry.

Each table row consists of the following items of data:

1. The water pressure. The units are bara or psia
2. The water formation volume factor at that pressure. The units are Rm³/Sm³ or rb/stb
3. The water viscosity. The units are cP.

See Figure 21 below.

Gas PVT			
p	R_v	B_g	μ_g
bara	Sm³/Sm³	Rm³/Sm³	cp
100	3.1733E-05	0.0081639	0.01782161
	0	0.00892139	0.018208
300	3.92E-05	0.00293421	0.03015581
	0	0.0031782	0.02309949
500	4.8008E-05	0.00221124	0.04224024
	0	0.00220086	0.02858611

Figure 20 Example Gas PVT Table

Water PVT		
p	B_w	μ_w
bara	Rm^3/Sm^3	cp
100	1.1365638	0.11188194
144.444444	1.13563127	0.11305771
188.888889	1.13468362	0.11423349
233.333333	1.13372085	0.11540927
277.777778	1.13274294	0.11658504
322.222222	1.13174989	0.11776082
366.666667	1.13074169	0.11893659
411.111111	1.12971833	0.12011237
455.555556	1.1286798	0.12128815
500	1.12762609	0.12246392

Figure 21 Example of Water PVT table

6.3.1.4 PVT Correlations

When no PVT data is available, EXCSIM provides a simple PVT generator to provide reasonable PVT data for the simulations. The PVT generator is modeled after the popular but no longer manufactured Hewlett Packard Petroleum Fluids Pack for their HP-41 series programmable hand-held calculators.

6.3.1.4.1 PVT Generator Input and Output Ranges

The required input to the PVT correlation is

- Reservoir temperature
- Separator temperature
- Separator pressure
- Nitrogen content in %
- Carbon dioxide in %
- Hydrogen Sulfate content in %
- Salinity in %

Also, the correlation relies on densities of all three phases.

Input to PVT Correlation

ONLY for generating new PVT tables from correlation

PVT correlation input		
Reservoir temperature	392	fahrenheit
Separator Temperature	59	fahrenheit
Separator Pressure	16	psia
N_2	0	%
CO_2	0	%
H_2S	0	%
Salinity	4	%

Correlation output ranges				
		Low	High	
Rs range		0.05	0.6	Mscf/stb
Reservoir pressure		1450	7500	psia
# rows	Saturated	10		>1
	Under-sat	5		>1

Figure 22 Input to PVT correlations and specification of output ranges

The user must also provide ranges for the output tables. This includes upper and lower bounds for the R_s (solution gas/oil ratio) and pressure ranges for the oil PVT and pressure and R_v (vaporized oil/gas ratio) for the gas PVT table. The ranges should cover all values expected to occur during the simulations.

Furthermore, the user should specify the number of saturated points in the table and, for the oil PVT table, the number of under-saturated points associated with each saturated point.

There should be at least two saturated points and at least two associated under-saturated points. The more points in the table, the smoother the simulation will run in general.

6.3.2 SCAL Data

In the petroleum industry, special core analysis, often abbreviated SCAL, is a laboratory procedure for conducting flow experiments on core plugs taken from a petroleum reservoir. Special core analysis is distinguished from "routine or conventional core analysis" by adding more experiments, in particular including measurements of two-phase flow properties, determining relative permeability and capillary pressure.

6.3.2.1 *Relative permeability*

In multiphase flow in porous media, the relative permeability of a phase is a dimensionless measure of the effective permeability of that phase. It is the ratio of the effective permeability of that phase to the absolute permeability. It is an adaptation of Darcy's law, originally a single-phase law, to two-phase (sometime multi-phase) flow.

Two 2-phase SCAL tables must be entered in the 'PVT & Relperm' worksheet in EXCSIM; one for oil-water and one for gas/oil mixtures. EXCSIM looks up the relative permeability of one phase in the presence of another from the tables, for example, to find the relative permeability of oil in the presence of water.

When three phases coexist in a grid block, EXCSIM combines both relative permeability tables to get the resulting oil relative permeability. The method for three-phase oil relative permeability is based on an assumption of complete segregation of the water and gas within each grid block. This model provides a simple but effective formula that avoids some problems associated with other methods. The method is identical to the Schlumberger Eclipse® default model for the three-phase oil relative permeability.

Relative permeability values vary depending on phase saturations, and EXCSIM will interpolate linearly between data-points as required.

The SCAL tables also give corresponding capillary pressures between the phases. The capillary pressure is the pressure difference between the non-wetting and the wetting phases. In EXCSIM, water is always assumed the wetting phase in oil/water mixtures, and oil is assumed the wetting phase in gas/oil mixtures.

EXCSIM gets water and gas pressures from the oil pressure and the capillary pressures, P_{cow} and P_{cgo}, associated with S_w and S_g, respectively. For example, $P_g = P_o + P_{cgo}(S_g)$ where the parenthesis in the term $P_{cgo}(S_g)$ signifies that the capillary pressure is a function, by means of table look-up, of S_g.

6.3.2.2 *Oil/Water SCAL data*

The oil/water SCAL table has the same general format as the SWOF keyword used by the Eclipse simulator. The table is used to provide water relative permeability (krw), oil-in-water relative permeability (krow), and oil/water capillary pressure (Pcwo) as functions of the water saturation. The table ends at the first non-numeric cell in the saturation column. Any missing values in the other three columns will trigger an initialization error alerting the user to the location of the first encountered empty cell.

Oil/Water relperm			
S_w	k_{rw}	K_{row}	P_{cwo}
			bara
0.1	0	0.9	0.86498946
0.1875	0.0078125	0.6890625	0.58519182
0.275	0.03125	0.50625	0.4137931
0.3625	0.0703125	0.3515625	0.33786065
0.45	0.125	0.225	0.29259591
0.5375	0.1953125	0.1265625	0.26170574
0.625	0.28125	0.05625	0.23890356
0.7125	0.3828125	0.0140625	0.22118172
0.8	0.5	0	0.20689655
1	1	0	0.2

Figure 23 Example of an oil/water SCAL table

6.3.2.3 SCAL Correlations

When no SCAL data is available, EXCSIM provides a simple SCAL generator to provide reasonable data for the simulations. The generator uses a Corey exponent model.

6.3.2.3.1 SCAL Generator Input and Output Ranges

6.3.2.3.1.1 The Water /Oil Table

The required input to the Water/Oil correlations is

- Relative permeability to water at $S_w = 1 - S_{orw}$
- Irreducible water saturation, S_{wi}
- Corey exponent to water, n_w
- Relative permeability of oil at $S_w = S_{wi}$
- Residual oil saturation in water, S_{orw}
- Corey exponent to oil in water, n_{ow}
- Capillary entry pressure, $P_{ce,ow}$
- Pore size distribution index, λ_{ow}

6.3.2.3.1.2 The Gas/Oil Table

The required input to the Gas/Oil correlations is

- Relative permeability to gas at $S_g = 1 - S_{org}$
- Critical gas saturation, S_{gc}
- Corey exponent to gas, n_g
- Relative permeability of oil at $S_g = 1 - S_{org}$
- Residual oil saturation in gas, S_{org}
- Corey exponent to oil in water, n_{og}
- Capillary entry pressure, $P_{ce,og}$

- Pore size distribution index, λ_{og}

Input to SCAL Correlation
ONLY for generating new SCAL tables from correlation

Water/Oil		
Water	K_{rwro}	0.5
	S_{iw}	0.1
	n_w	2
Oil	K_{rocw}	0.8
	S_{orw}	0.2
	n_{ow}	2
Pc	$P_{ce,ow}$	0.2
	λ_{ow}	4

lines in table
20

Gas/Oil		
Gas	K_{rgro}	0.7
	S_{gc}	0.05
	n_g	2
Oil	K_{rocg}	0.8
	S_{org}	0.2
	n_{og}	2
Pc	$P_{ce,ow}$	0.1
	λ_{go}	1.5

Figure 24 Input to SCAL correlations and specification of table size

6.3.2.3.1.3 Table Size

Specify the size of the generated SCAL tables in the "# lines in table" box to the right of the input tables. See Figure 24 for details.

6.4 The Wells & Controls Worksheet

The Wells & Controls worksheet contains the well definitions and run controls. The number of possible wells is 10,000 and it therefore practically limitless. However, ExcSim will not read any well data beyond the first encountered invalid well.

6.4.1 Well Data

The Well Data Table in the Wells & Controls Worksheet consists of a table of all relevant well data. The example in Figure 25 shows four oil producers, one water injector, and one gas injector.

WELL DATA

Well name	Column I	Row J	Wellbore Rad. m	Skin	Max rate Sm³/d	Prod fluid	Min BHP bara	Max GOR Sm³/Sm³	Max Wcut	Inj fluid	Max BHP bara	Open date	Close date
OP 1	15	15	0.15	0	1000	Oil	200					1/1/2020	1/1/2050
OP 2	25	18	0.15	0	1000	Oil	200					1/1/2021	1/1/2050
OP 3	23	12	0.15	0	1000	Oil	200					1/1/2024	1/1/2050
OP 4	12	18	0.15	0	1000	Oil	200					1/1/2025	1/1/2050
WI 1	3	33	0.15	0	2000					Water	350	1/1/2022	1/1/2050
GI 1	33	3	0.15	0						Gas	310	1/1/2023	1/1/2050

Figure 25 Example of Well Data

The first column is a text field holding the well's name. Wells whose names start with the two letters 'HX' or 'HY', such as in 'HX_OilProd1' for example, will be representing horizontal wells in the direction specified by the second letter (X or Y). The order in which wells appear in the well data input table persists in the production output tables. If a well is stopped and started repeatedly, the data must be entered in separate rows in the Well Data table. Such wells can, and should, have the same name in each row.

The next two columns hold the 'I' and 'J' indices for the well's location in the reservoir model. The upper leftmost grid block has indices [I = 1, J = 1], where 'I' specifies the column number and 'J' the row number. Then follows the wellbore radius and skin factor. The first five fields are required for all wells.

The 6th field holds the maximum rate for the well in question. This field is not required, but if it is empty, then the Min BHP (for producers) or Max BHP (for injectors) *must* be specified.

Fields 7 - 10 are green and intended *only* for producers. The 7th field holds the target fluid, i.e. the fluid whose maximum rate (if provided) refers to. The target fluid has to be Oil, Water, or Gas. The value may be typed in directly or selected from a drop-down list. The 8th field holds the minimum bottom hole pressure. This field is not required, but if it is empty, then the maximum rate *must* be specified. The 9th and 10th fields contain optional maximum gas/oil ratio and maximum water cut, respectively. If any of these limits are reached the well will shut in. If conditions change, i.e. gas or water regresses, the well may restart. Persistent stopping and starting may result from this, so it is advisable to close the well permanently, in the 14th field, if this happens.

Fields 11 and 12 are blue in color and reserved for injectors. The 11th field is the injection fluid: Water or Gas. The choice may be typed in directly or selected from a drop-down list. The 12th field holds the maximum bottom hole pressure. This field is not required, but if it is empty, then the maximum rate in the 6th field *must* be specified.

Note that at least one of the 6th or 8th field, or *both*, must be entered for producers, and at least one of the 6th or 12th field, or *both*, must be entered for injectors.

The 13th and 14th fields provide the opening and closing times for the wells. The times must be entered in the m/d/yyyy or m/d/yyyy hh:mm:ss format, such as in '1/1/2020', '1/1/2020 1:00:00 PM' or '1/1/2020 13:00:00'.

6.4.1.1 Wells in cross-section models

For details about building a cross-sectional model, refer to Chapter 6.2.8.

Wells in cross-sections are defined in much the same way as in a single layer model, but each row in the well table will represent a perforation in the specified single grid block. A well may be perforated across several layers and grid blocks, but each perforation must be defined on its own row.

WELL DATA

Well name	Column	Row	Wellbore Rad.	Skin	Max rate	Prod fluid	Min BHP	Max GOR	Max Wcut	Inj fluid	Max BHP	Open date	Close date
	I	J	ft		stb/d | Mscf/d		psia	Mscf/stb			psia		
OP	1	1	0.3	0	100	Oil	402.724779					1/1/2020	1/1/2050
OP	1	2	0.3	0	100	Oil	415.479705					1/1/2020	1/1/2050
OP	1	3	0.3	0	100	Oil	424.521002					1/1/2020	1/1/2050
OP	1	4	0.3	0	100	Oil	430.520154					1/1/2020	1/1/2050
OP	1	5	0.3	0	100	Oil	440.383476					1/1/2020	1/1/2050
OP	1	6	0.3	0	100	Oil	448.579644					1/1/2020	1/1/2050
OP	1	7	0.3	0	100	Oil	452.883118					1/1/2020	1/1/2050
OP	1	8	0.3	0	100	Oil	462.076768					1/1/2020	1/1/2050
OP	1	9	0.3	0	100	Oil	472.120854					1/1/2020	1/1/2050
OP	1	10	0.3	0	100	Oil	483.192124					1/1/2020	1/1/2050
OP	1	11	0.3	0	100	Oil	498.630608					1/1/2020	1/1/2050

Figure 26 Example of a well that penetrates 11 layers in a cross-section

Note that although perforations may be assigned maximum water-cut or gas-oil-ratio limits individually, there are no provisions for assigning Wcut or GOR limits to a multiple-perforation well as a whole.

6.4.2 Run Controls

Max time steps	
Days	90
Hours	0
Minutes	0
Seconds	0
Max Iter	20
Tolerance	1.00E-06
Block Conv	0.001
First Step	1:00:00
Step factor	1.3
Differential	1.00E-04
Derivatives	1st order

Units	Field
Initial	
OWC	GOC
ft	ft
9200	9200
Datum	
Depth	Pressure
ft	psia
9200	4350

Figure 27 Run Controls, Unit Control, and Initialization Controls

The **Run Controls** comprise time step, convergence, units and initialization related controls.

* **Maximum time steps:** are given in **Days**, **Hours**, **Minutes**, and **Seconds**.

* **Step factor**: Specifies how fast ExcSim increases or decreases (when not converging) time steps. Note that the step factor will be disregarded when the simulation approaches a new well event. In that case, the time step will be cut as much as required to coincide with the time of the next event (well opening or closing).

* **Max Iter:** Specifies how many times ExcSim should try to solve the equations for a given time step before abandoning the attempt and cutting the time step.

* **Tolerance**: Specifies the total reservoir material balance error, for each fluid phase. The default value is 1E-6.

* **Block Conv:** Convergence criteria for each grid block and each phase in terms of a saturation-like measure. The default value is 0.001.

* **Derivatives**: ExcSim also lets the user choose between 1st, 2nd and 4th order approximation of the partial derivatives that are used to build the Jacobian matrix used by the solver. The 4th order should be used only as a last resort when having severe convergence problems. The default value is '1st order'. This field can be changed during simulation runs.

Computation of 2nd order approximations (of the derivatives) takes about twice as long as 1st order computations. The computation time of 4th order approximation is roughly four times that of a 1st order approximation.

1st order approximations are of the form $f'(x) \approx \frac{f(x+\Delta x)-f(x)}{\Delta x}$.

2nd order approximations are of the form $f'(x) \approx \frac{f(x+\Delta x)-f(x-\Delta x)}{2\,\Delta x}$.

4th order approximations are of the form $f'(x) \approx \frac{-f(x+2\Delta x)+8f(x+\Delta x)-8f(x-\Delta x)+f(x-2\Delta x)}{12\,\Delta x}$.

Although higher order approximations, in principle, should require fewer iterations for time steps to converge, there is no guarantee that it will be the case. The real benefit of using higher order approximations is in highly non-linear cases, for example when a large number of grid blocks are near critical saturations or near saturated pressures.

* **The Differential** is the size of the incremental changes in variables (pressures and saturations) when approximating derivatives for the Jacobian, i.e. the size of Δx in the $\frac{f(x+\Delta x)-f(x)}{\Delta x}$ terms. The default value is 1E-4.

The differential is closely related to 1st, 2nd, and 4th order approximation of the derivatives. An nth order approximation is accurate to $O(dx^n)$. For example, a 2nd order approximation together with a differential of 10^{-4} will produce derivatives accurate to about $(10^{-4})^2 = 10^{-8}$. In comparison, floating point numbers (of type Double) are accurate to about 15 digits.

* **Field or Metric units:** Select from a drop-down list. When the selection changes, EXCSIM will automatically convert all input and output to the user selected unit system (**British** or **Metric**).

* **Initial fluid contact depths:** oil-water contact (**OWC**) and gas-oil contact (**GOC**). These may be below or above the reservoir, respectively.

* **Datum Depth: Depth** within the model where a pressure (**Datum Pressure)** is the initial pressure at that **Depth**. If the Datum Depth is in the water zone, then the Datum Pressure will be the water pressure, and if the Datum Depth is in the oil zone, then the Datum Pressure will be the oil pressure, etc.

7 The History Worksheet

For history matching purposes, a separate worksheet for entering production history is provided. Data can be entered both as field-aggregated data and as individual well production/injection history. The historical production/injection data can be overlaid simulation output to assist in the history matching process.

8 Simulation Output

When the 'Run' button in the EXCSIM Ribbon is pressed, the simulation will start. During the simulation, the user can view the simulation results as they happen. Tabulated output appears in the 'Profiles' and 'Material balance' worksheets, while grid block values such as pressure and saturations appear in the 'Solution maps' worksheet.

Furthermore, most of the output can be viewed live graphically on the screen.

8.1 The Profiles Worksheet

All production and injection data is tabulated in the Profiles Worksheet. Starting to the left, the first column shows the start and end times for each time step.

Then follows the field-aggregated production data:

- Oil recovery factor
- Oil, water, and gas daily production rates, and
- Oil, water, and cumulative gas production.

Next follows the field-aggregated injection data:

- Water and gas daily injection rates, and
- Water and gas cumulative injection.

Following the field-aggregated data is the individual well data:

- Bottom hole pressure
- Oil, water, and gas daily production or injection rates, and
- Oil, water, and gas cumulative production or injection.

In the case of injectors, the oil rate and cumulative oil columns will always be zero. See Figure 28 for an example.

		Field Production						
Time From	Time To	Recovery	Oil Rate	Water Rate	Gas Rate	Cum Oil	Cum Water	Cum Gas
m/d/yy h:mm:ss	m/d/yy h:mm:ss	Factor	Sm^3/d	Sm^3/d	Sm^3/d	Mill Sm^3	Mill Sm^3	Mill Sm^3
1/1/20 0:00:00	1/3/20 0:00:00	2.4556E-05	1000	0.02729173	53122.9545	0.002	5.4583E-08	0.10624591
1/3/20 0:00:00	1/9/20 0:00:00	9.8223E-05	1000	0.0408161	53154.7997	0.008	2.9948E-07	0.42517471
1/9/20 0:00:00	1/27/20 0:00:00	0.00031922	1000	0.05104125	53167.4162	0.026	1.2182E-06	1.3821882
1/27/20 0:00:00	3/21/20 0:00:00	0.00098223	1000	0.06081608	53161.7752	0.08	4.5023E-06	4.25292406
3/21/20 0:00:00	8/30/20 0:00:00	0.00297124	1000	0.07755098	53159.4965	0.242	1.7066E-05	12.8647625
8/30/20 0:00:00	1/1/21 0:00:00	0.00449369	1000	0.08974289	53155.7528	0.366	2.8194E-05	19.4560758
1/1/21 0:00:00	6/30/21 0:00:00	0.00891372	2000	0.26056163	106283.432	0.726	7.5095E-05	38.5870936
6/30/21 0:00:00	12/27/21 0:00:00	1.333%	2000	0.357554	106277.59	1.086	0.00013945	57.7170598
12/27/21 0:00:00	1/1/22 0:00:00	1.346%	2000	0.36022715	106277.449	1.096	0.00014126	58.248447
1/1/22 0:00:00	1/16/22 0:00:00	1.382%	2000	0.36766886	106277.179	1.126	0.00014677	59.8426047
1/16/22 0:00:00	3/2/22 0:00:00	1.493%	2000	0.38384146	106276.334	1.216	0.00016404	64.6250397
3/2/22 0:00:00	7/15/22 0:00:00	1.824%	2000	0.43456828	106274.381	1.486	0.00022271	78.9720812
7/15/22 0:00:00	1/1/23 0:00:00	2.242%	2000	0.57318431	106271.988	1.826	0.00032015	97.0383193
1/1/23 0:00:00	6/30/23 0:00:00	2.684%	2000	0.95541744	106271.069	2.186	0.00049213	116.167112
6/30/23 0:00:00	12/27/23 0:00:00	3.126%	2000	2.02027813	106270.371	2.546	0.00085578	135.295778
12/27/23 0:00:00	1/1/24 0:00:00	3.138%	2000	2.05088506	106270.408	2.556	0.00086603	135.827131
1/1/24 0:00:00	1/16/24 0:00:00	3.193%	3000	2.27281483	159406.612	2.601	0.00090012	138.21823
1/16/24 0:00:00	3/1/24 0:00:00	3.359%	3000	2.72832105	159452.332	2.736	0.0010229	145.393585
3/1/24 0:00:00	7/14/24 0:00:00	3.856%	3000	6.52172442	159433.83	3.141	0.00190333	166.917152
7/14/24 0:00:00	1/1/25 0:00:00	4.486%	3000	17.9385229	159422.586	3.654	0.00497082	194.178414
1/1/25 0:00:00	6/30/25 0:00:00	5.370%	4000	67.329792	212559.559	4.374	0.01709018	232.439134
6/30/25 0:00:00	12/27/25 0:00:00	6.254%	4000	131.067737	212559	5.094	0.04068237	270.699754
12/27/25 0:00:00	6/25/26 0:00:00	7.138%	4000	208.87035	212553.33	5.814	0.07827904	308.959354
6/25/26 0:00:00	12/22/26 0:00:00	8.015%	3964.73493	280.536297	210686.037	6.52765229	0.12877557	346.882841
12/22/26 0:00:00	6/20/27 0:00:00	8.869%	3864.57147	324.266745	205366.398	7.22327515	0.18714358	383.848792
6/20/27 0:00:00	12/17/27 0:00:00	9.704%	3778.37914	360.057622	200781.501	7.9033834	0.25195396	419.989463

	Field Injection				OP 1						
Time From	Water Rate	Gas Rate	Cum Water	Cum Gas	BHP	Oil Rate	Water Rate	Gas Rate	Cum Oil	Cum Water	Cum Gas
m/d/yy h:mm:ss	Sm^3/d	Sm^3/d	Mill Sm^3	Mill Sm^3	bara	Sm^3/d	Sm^3/d	Sm^3/d	Mill Sm^3	Mill Sm^3	Mill Sm^3
1/1/20 0:00:00	0	0	0	0	244.058494	1000	0.02729173	53122.9545	0.002	5.4583E-08	0.10624591
1/3/20 0:00:00	0	0	0	0	240.992827	1000	0.0408161	53154.7997	0.008	2.9948E-07	0.42517471
1/9/20 0:00:00	0	0	0	0	238.548512	1000	0.05104125	53167.4162	0.026	1.2182E-06	1.3821882
1/27/20 0:00:00	0	0	0	0	235.949455	1000	0.06081608	53161.7752	0.08	4.5023E-06	4.25292406
3/21/20 0:00:00	0	0	0	0	231.398836	1000	0.07755098	53159.4965	0.242	1.7066E-05	12.8647625
8/30/20 0:00:00	0	0	0	0	228.244474	1000	0.08974289	53155.7528	0.366	2.8194E-05	19.4560758
1/1/21 0:00:00	0	0	0	0	219.86721	1000	0.12544796	53151.9204	0.546	5.0774E-05	29.0234215
6/30/21 0:00:00	0	0	0	0	211.094134	1000	0.16354941	53149.32	0.726	8.0213E-05	38.5902991
12/27/21 0:00:00	0	0	0	0	210.849738	1000	0.16460102	53149.253	0.731	8.1036E-05	38.8560454
1/1/22 0:00:00	2000	0	0.03	0	210.209967	1000	0.1673697	53149.0527	0.746	8.3547E-05	39.6532812
1/16/22 0:00:00	2000	0	0.12	0	209.243269	1000	0.17175562	53148.4107	0.791	9.1276E-05	42.0449597
3/2/22 0:00:00	2000	0	0.39	0	208.203338	1000	0.1777945	53146.6193	0.926	0.00011528	49.2197533
7/15/22 0:00:00	2000	0	0.73	0	207.278065	1000	0.18469956	53145.0827	1.096	0.00014668	58.2544173
1/1/23 0:00:00	4000	0	1.45	0	212.765194	1000	0.16529431	53143.9159	1.276	0.00017643	67.8203222
6/30/23 0:00:00	4000	0	2.17	0	219.608062	1000	0.14037589	53142.5732	1.456	0.0002017	77.3859854
12/27/23 0:00:00	4000	0	2.19	0	219.798784	1000	0.13967669	53142.5256	1.461	0.0002024	77.651698
1/1/24 0:00:00	4000	0	2.25	0	220.096926	1000	0.13877921	53142.4422	1.476	0.00020448	78.4488346
1/16/24 0:00:00	4000	0	2.43	0	220.620056	1000	0.13783713	53141.1465	1.521	0.00021068	80.8401862
3/1/24 0:00:00	4000	0	2.97	0	222.498041	1000	0.1343237	53140.4617	1.656	0.00022881	88.0141485
7/14/24 0:00:00	4000	0	3.654	0	224.985665	1000	0.1301689	53139.7017	1.827	0.00025107	97.1010375
1/1/25 0:00:00	4000	0	4.374	0	220.632634	1000	0.15364318	53138.8004	2.007	0.00027873	106.666022
6/30/25 0:00:00	4000	0	5.094	0	218.0008	1000	0.16973563	53137.674	2.187	0.00030928	116.230803
12/27/25 0:00:00	4000	0	5.814	0	215.322289	1000	0.18626545	53137.0736	2.367	0.00034281	125.795476
6/25/26 0:00:00	4000	0	6.534	0	212.517614	1000	0.20351756	53136.569	2.547	0.00037944	135.360059
12/22/26 0:00:00	4000	0	7.254	0	209.930111	1000	0.21991009	53136.1061	2.727	0.00041903	144.924558
6/20/27 0:00:00	4000	0	7.974	0	207.562085	1000	0.23542575	53135.7045	2.907	0.0004614	154.488985

	OP 2						
Time From	BHP	Oil Rate	Water Rate	Gas Rate	Cum Oil	Cum Water	Cum Gas
m/d/yy h:mm:ss	bara	Sm^3/d	Sm^3/d	Sm^3/d	Mill Sm^3	Mill Sm^3	Mill Sm^3
1/1/20 0:00:00							
1/3/20 0:00:00							
1/9/20 0:00:00							
1/27/20 0:00:00							
3/21/20 0:00:00							
8/30/20 0:00:00							
1/1/21 0:00:00	218.749498	1000	0.13511367	53131.5116	0.18	2.432E-05	9.56367209
6/30/21 0:00:00	209.342884	1000	0.19400459	53128.2698	0.36	5.9241E-05	19.1267607
12/27/21 0:00:00	209.084134	1000	0.19562613	53128.1958	0.365	6.0219E-05	19.3924016
1/1/22 0:00:00	208.380703	1000	0.20029916	53128.1262	0.38	6.3224E-05	20.1893235
1/16/22 0:00:00	207.099911	1000	0.21208583	53127.9232	0.425	7.2768E-05	22.5800801
3/2/22 0:00:00	205.604821	1000	0.25677378	53127.7622	0.56	0.00010743	29.752328
7/15/22 0:00:00	204.468935	1000	0.38848474	53126.9057	0.73	0.00017347	38.7839019
1/1/23 0:00:00	211.403859	1000	0.79012313	53127.1528	0.91	0.0003157	48.3467895
6/30/23 0:00:00	218.396912	1000	1.87990224	53127.7982	1.09	0.00065408	57.9097931
12/27/23 0:00:00	218.591915	1000	1.91120837	53127.882	1.095	0.00066364	58.1754325
1/1/24 0:00:00	218.5559	1000	2.01572902	53127.8701	1.11	0.00069387	58.9723506
1/16/24 0:00:00	218.508412	1000	2.46705235	53130.941	1.155	0.00080489	61.3632429
3/1/24 0:00:00	219.375733	1000	6.27272251	53126.7553	1.29	0.00165171	68.5353549
7/14/24 0:00:00	219.77335	1000	17.7071166	53124.6032	1.461	0.00467962	77.619662
1/1/25 0:00:00	215.608313	1000	60.1106827	53125.3872	1.641	0.01549955	87.1822317
6/30/25 0:00:00	210.023938	1000	123.56392	53133.3256	1.821	0.03774105	96.7462303
12/27/25 0:00:00	204.122333	1000	201.08034	53131.6058	2.001	0.07393551	106.309919
6/25/26 0:00:00	200	964.734932	272.431266	51267.4085	2.17465229	0.12297314	115.538053
12/22/26 0:00:00	200	864.571469	315.765908	45950.2811	2.33027515	0.179811	123.809104
6/20/27 0:00:00	200	778.379145	350.941684	41367.3779	2.4703834	0.24298051	131.255232

Figure 28 Example of tabulated production and injection data in the Profiles Worksheet

8.2 The Material Balance Worksheet

The reservoir offtake and drive mechanisms are displayed in the Material balance worksheet. The same worksheet also shows the initial and current volumetrics and recovery factors.

The material balance follows the Walsh formulation for volatile oil and wet gas, and is summarized in the following table:

Item	Description
$F = N\,E_t + (W_e + W_i)B_w + G_i B_g$	Simplified general equation.
$F = N_p\left(\frac{B_O - B_g R_s}{1 - R_s R_v}\right) + G_p\left(\frac{B_g - B_O R_v}{1 - R_s R_v}\right) + W_p B_w$	The volume of withdrawal (production) at reservoir conditions is determined by the oil, water, and gas produced at the surface.
$E_t = E_o + \frac{B_{oi}}{B_{gi}} m E_g + B_{oi}(1+m)E_{fw}$	Total expansion.
$E_o = \frac{(B_O - B_{oi}) + B_g(R_{si} - R_s) + R_v(B_{oi}R_s - B_O R_{si})}{1 - R_s R_v}$	Oil expansion term for volatile oil.
$E_g = \frac{(B_g - B_{gi}) + B_O(R_{vi} - R_v) + R_s(B_{gi}R_v - B_g R_{vi})}{1 - R_s R_v}$	Gas expansion term for volatile oil.
$E_{fw} = \frac{c_f + c_w S_w}{1 - S_w}\Delta p$	Even though water has low compressibility, the volume of connate water in the system is usually large enough to be significant. The water will expand as the reservoir depletes. As the reservoir is produced, the pressure declines and the entire reservoir pore volume is reduced due to compaction. The change in volume expels an equal volume of fluid as production and is, therefore, additive in the expansion terms.
$m = \frac{G\,B_{gi}}{N\,B_{oi}}$	Ratio of gas cap to original oil in place. A gas cap also implies that the initial pressure at the gas/oil contact is the bubble point pressure.
$W_e B_w$	If the reservoir has an active aquifer, then once the pressure drop propagates throughout the reservoir, the water will encroach into the reservoir resulting in a net water influx.
$W_i B_w$ and $G_i B_g$	Water and gas injection.

8.2.1 Material Balance

The first two columns show the time and the average hydrocarbon pressure. The next three columns show the oil, water, and gas cumulative offtake under reservoir conditions following the Walsh formulation. Then follows the water and gas injection terms, followed by oil expansion (including solution gas), pore volume compaction & initial water expansion, gas cap expansion and aquifer influx. The last 5 columns show volumetric ratios, i.e. oil, water and gas formation volume factors, and solution gas/oil and vaporized oil/gas ratios.

Time		Production reservoir volumes			Injection res. Volume		Expansion reservoir volumes				FVF			Ratios	
	Pressure	Qo	Qw	Qg	WI	GI	Eo	Efw	Eg	We	Bo	Bw	Bg	Rs	Rv
1/1/20 0:00	277.045113	0	0	0	0	0	0	0	0	0	1.25701902	1.13247864	0.00311981	53.13189354	3.82153E-05
1/9/20 0:00	276.832562	0.00874732	3.3916E-07	0.00130966	0	0	0.00465386	0.00076295	0	0.00464051	1.25707616	1.13247976	0.00312208	53.13189176	3.82153E-05
1/27/20 0:00	276.229191	0.02842463	1.3796E-06	0.00426572	0	0	0.01724421	0.00292908	0	0.01251842	1.25723072	1.13248542	0.00312798	53.13188432	3.82153E-05
3/21/20 0:00	274.640615	0.08743108	5.0989E-06	0.0131864	0	0	0.0494761	0.00863465	0	0.04251182	1.25762639	1.13251289	0.00314231	53.13186429	3.82153E-05
8/30/20 0:00	270.296314	0.26423484	1.9329E-05	0.04040726	0	0	0.14202838	0.0242571	0	0.13837595	1.25876256	1.1326068	0.00318265	53.13180823	3.82153E-05
1/1/21 0:00	267.083869	0.39935238	3.1934E-05	0.06171239	0	0	0.21468023	0.03582891	0	0.21058756	1.25965445	1.13267796	0.00321358	53.13177155	3.82153E-05
6/30/21 0:00	257.740145	0.79059546	8.5073E-05	0.12590458	0	0	0.43311891	0.06958449	0	0.41388171	1.26233625	1.132875	0.00330448	53.1317267	3.82153E-05
12/27/21 0:00	248.530546	1.1804365	0.00015801	0.193407	0	0	0.65006675	0.10299722	0	0.62093754	1.26499978	1.13307732	0.00339249	53.13169434	3.82153E-05
1/1/22 0:00	248.274223	1.19124272	0.00016005	0.19533231	0	0	0.65610488	0.10392917	0	0.62670103	1.26507391	1.13308295	0.00339497	53.13169345	3.82153E-05
1/16/22 0:00	247.94842	1.22366546	0.0001663	0.20096866	0.03399222	0	0.66377979	0.1051139	0	0.62191452	1.26516813	1.13307397	0.00339982	53.13169095	3.82153E-05
3/2/22 0:00	247.515031	1.32119712	0.00018587	0.21745663	0.13596853	0	0.67398948	0.10669012	0	0.6221915	1.26529346	1.1330711	0.00340642	53.13168354	3.82153E-05
7/15/22 0:00	246.695662	1.61414986	0.00025235	0.26649048	0.44190263	0	0.69329251	0.10967097	0	0.63602658	1.26553039	1.13308366	0.003416	53.13166395	3.82153E-05
1/1/23 0:00	245.747711	1.9830142	0.00036276	0.3284123	0.82716544	0	0.71562424	0.11312099	0	0.65587859	1.26580451	1.13310335	0.00342586	53.13164507	3.82153E-05
6/30/23 0:00	252.656865	2.37756313	0.00055754	0.38518812	1.64274173	0	0.55287145	0.08800946	0	0.47968615	1.26380621	1.13292533	0.00335737	53.13162791	3.82153E-05
12/27/23 0:00	259.93867	2.77326051	0.00096939	0.43911808	2.45809154	0	0.38186377	0.06162922	0	0.31176345	1.26170656	1.13276108	0.00328724	53.13160822	3.82153E-05
1/1/24 0:00	260.141855	2.78427073	0.000981	0.4405762	2.4807367	0	0.37712215	0.06089435	0	0.30707473	1.26164834	1.13275648	0.00328528	53.13160777	3.82153E-05
1/16/24 0:00	260.249485	2.83328108	0.00101961	0.44826327	2.54867929	0	0.37470086	0.06050519	0	0.29867861	1.26161861	1.13274635	0.00328478	53.13160545	3.82153E-05
3/1/24 0:00	260.818339	2.98060983	0.00115866	0.47082223	2.75252525	0	0.36163027	0.05844849	0	0.27998671	1.26145802	1.13272644	0.00327989	53.13157161	3.82153E-05
7/14/24 0:00	262.810752	3.42324357	0.00215586	0.53733437	3.36405609	0	0.31596298	0.05124906	0	0.23146568	1.26089711	1.13267882	0.00326082	53.13150315	3.82153E-05
1/1/25 0:00	265.372178	3.98458255	0.00563005	0.62025631	4.13859694	0	0.25814527	0.04200329	0	0.17172341	1.26018704	1.13262095	0.00323593	53.13144065	3.82153E-05
6/30/25 0:00	262.822408	4.76710172	0.01935733	0.74821059	4.95424668	0	0.31621147	0.0512072	0	0.21300429	1.26089971	1.13265814	0.0032606	53.1313621	3.82153E-05
12/27/25 0:00	260.267715	5.54900388	0.04608144	0.87784723	5.77003895	0	0.37489826	0.06043958	0	0.26755576	1.26161998	1.13271279	0.00328451	53.13128167	3.82153E-05
6/25/26 0:00	257.41227	6.32978749	0.08867263	1.01019046	6.58596089	0	0.44133723	0.07077187	0	0.33058058	1.26243547	1.13277621	0.00331126	53.13121392	3.82153E-05
12/22/26 0:00	254.41875	7.10265237	0.14588254	1.14391178	7.40199807	0	0.51151138	0.08161847	0	0.39731878	1.26329676	1.13284329	0.00333927	53.13113013	3.82153E-05
6/20/27 0:00	251.710604	7.85543837	0.21201586	1.27557642	8.21809117	0	0.57520523	0.09144392	0	0.45829033	1.26407847	1.13290477	0.00336468	53.13103955	3.8212E-05
12/17/27 0:00	249.24131	8.59064695	0.28545397	1.4057426	9.03422977	0	0.63336508	0.1004134	0	0.51383526	1.26479226	1.13296084	0.00338862	53.13096035	3.82119E-05

Figure 29 Example of tabulated material balance output in the Material balance worksheet

8.2.2 Volumetrics

In addition to the material balance data, the Material balance worksheet also gives the initial and current volumetrics:

INITIAL:	TOTAL	Oil Phase	Gas Phase	Aquifer	
STOOIP:	**81.4475065**	81.4475065	0	0	Mill Sm³
GIIP:	**4327.46012**	4327.46012	0	0	Mill Sm³
WIIP:	**125.936752**	35.6872081	0	90.2495438	Mill Sm³
CURRENT:	**TOTAL**	Oil Phase	Gas Phase	Aquifer	
OIP	**73.5441225**	73.5441225	0	0	Mill Sm³
GIP	**3907.46954**	3907.46954	0	0	Mill Sm³
WIP	**133.658799**	43.7979827	0	89.8608161	Mill Sm³
RECOVERED:	**TOTAL**	Oil Phase	Gas Phase	Aquifer	
Oil	**7.90338398**	7.90338398	0	0	Mill Sm³
Gas	**419.990578**	419.990578	0	0	Mill Sm³
Water	**-7.72204695**	-8.11077462	0	0.38872767	Mill Sm³
RF:	**TOTAL**				
Oil	**9.70%**				
Gas	**9.71%**				
Water	**-6.13%**				

Figure 30 Example of volumetrics in the Material balance worksheet

8.3 The Solution maps Worksheet

The Solution maps worksheet shows the solutions to the unknowns (pressure and saturations) of flow equations for each time step. For comparison, the initial values are also shown, as well as the differences between the current and initial values.

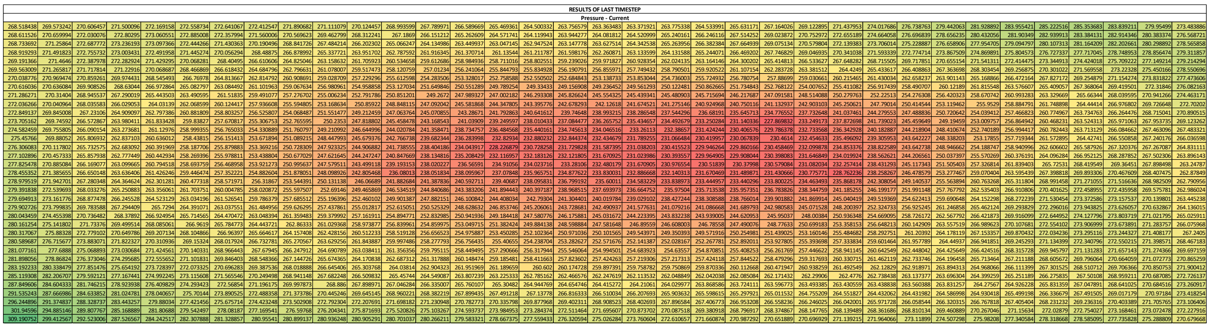


Figure 31 Example of a (zoomed out) matrix of oil pressure from the latest time step

The solution variables from top to bottom of the worksheet, are:

1. Oil pressure
2. Gas saturation
3. Oil saturation
4. Water saturation
5. Solution gas/oil ratio (R_s)
6. Vaporized oil/gas ratio (R_v)
7. Pore volume

For each variable, the most recent solution values are shown together with the initial values and their differences.

9 Map Generation

9.1 The Contouring Worksheet

The Contouring worksheet lets the user generate numerical maps (matrices) for input to the simulation model. The maps (matrices) will be 2-dimensional 35x35 matrices matched to contours traced by the mouse cursor.

The procedure for generating a map is as follows:

1. Open the "Contouring" worksheet.
2. Delete all pictures, drawings, and shapes from previous sessions, if any.
3. Paste a picture or drawing with contours of the map to be traced anywhere in the worksheet.
4. Select Excel's Rectangle Tool from the Shapes palette and draw a rectangle on top of the contoured picture, representing the extent of the desired EXCSIM map.
    a. Remove the Rectangle's color filling, so the whole picture becomes visible.
    b. Click on the rectangle to select it. Its name appears in the box to the left of the formula bar.
    c. Change the name to 'Model.'
5. Set the model dimensions in the green cells under the 'Model size' heading:
6. Select Excel's 'Free form' drawing tool ( ) from the Shapes palette and trace one contour at a time on the picture.
    a. Only the points of the free form shape matter. The lines connecting the points are irrelevant.
    b. Remove the interior filling color so you can see behind it. Name the first contour "Cont1". Subsequent contours will be named "Cont2", "Cont3", etc.
    c. Write their contour levels in the Contours list, next to their names. Expand the list to more names and contour levels if required.
7. Depending on the number of crests and troughs (ups and downs) in the picture, select suitable numbers of degrees for the polynomial best-fit, in the Best Fit table.
8. Check that all 'Free form' contours have been given correct names and numeric contour levels and that the outlining 'Rectangle' (named 'Model') has correct dimensions.
9. Press the 'Generate Map' ribbon button.
10. When the map has been generated, copy it and paste it in its correct location in the 'Grid' worksheet.

Model size	
Width	3500
Height	3500

Contours	
Contour Names:	Contour Levels:
Cont1	2500
Cont2	2600
Cont3	2700
Cont4	2800
Cont5	2900
Cont6	3100
Cont7	

Best Fit	
X degrees	5
Y degrees	5

Note that the map generation process also provides a mathematical formula for the map in terms of X and Y, where X is the horizontal distance from the left edge of the rectangle 'Model', and Y is the distance from the top edge of 'Model'.

This equation may be copied and pasted into the spreadsheet if you want to change the default grid block sizes while automatically updating the associated map.

9.2 Generating maps with geological faults

If you are contouring a map with geological faults, we recommend contouring each side of the fault independently, thus generating two maps that in turn are merged along the fault line using copy and paste.

As a second step in the process, you should consider transmissibility multipliers across the fault.

Appendices

Appendix A. Reserved Named Ranges

A named range in Excel is a set of grid cells that have been given a name for easy reference. ExcSim uses many named ranges in Excel. For example, the range of depths to the top structure has the name 'Top' and is located on the 'Grid' worksheet.

You may access these named ranges in your own worksheet functions and Excel macros.

The total list of reserved named ranges in ExcSim is:

Range Name	**Default Range Location**	**Comment**
	Grid Worksheet	
Dx	=Grid!$B$2:$AJ$2	X-dimension of grid blocks
Dy	=Grid!$A$3:$A$37	Y-dimension of grid blocks
Permeability	=Grid!$B$77:$AJ$111	Permeability of each grid block
Poro	=Grid!$B$114:$AJ$148	Porosity of each grid block
Thickness	=Grid!$B$40:$AJ$74	Thickness of each grid block
Top	=Grid!$B$3:$AJ$37	Depth to each grid block
Transmissibility_X	=Grid!$B$151:$AI$185	Transmissibility multiplier in the *positive* X-direction
Transmissibility_Y	=Grid!$B$190:$AJ$223	Transmissibility multiplier in the *positive* Y-direction
	PVT & Relperm Worksheet	
Density	='PVT & Relperm'!$X$4:$X$6	Densities of oil, gas, and water
GasPVT	='PVT & Relperm'!$F$6	Gas PVT table
GO_SCAL	='PVT & Relperm'!$Z$42:$Z$49	Input to Gas/Oil SCAL correlations
Krog	='PVT & Relperm'!$R$6	Oil relative permeability in gas
Krow	='PVT & Relperm'!$N$6	Oil relative permeability in water
OilPVT	='PVT & Relperm'!$B$6	Oil PVT table
PVComp	='PVT & Relperm'!$X$1:$X$1	Pore Volume Compressibility
PVTcorrInput	='PVT & Relperm'!$Z$12:$Z$18	Input to PVT correlations
PVToutputSize	='PVT & Relperm'!$Z$22:$AA$25	Size of PVT table output
SCALlines	='PVT & Relperm'!$AB$33	Size of SCAL table output
WaterPVT	='PVT & Relperm'!$J$6	Water PVT table
WO_SCAL	='PVT & Relperm'!$Z$32:$Z$39	Input to Water/Oil SCAL correlations
	Wells & Controls Worksheet	
ChooseGOCRS	='Wells & Controls'!$U$5	
DatumDepth	='Wells & Controls'!$T$11	
DatumPressure	='Wells & Controls'!$U$11	
Derivatives	='Wells & Controls'!$R$14	
Differential	='Wells & Controls'!$R$13	
FirstStep	='Wells & Controls'!$R$10	
GOCorRS	='Wells & Controls'!$U$7:$U$7	
InnerConv	='Wells & Controls'!$R$9	
MaxIter	='Wells & Controls'!$R$7:$R$7	
MaxTimeSteps	='Wells & Controls'!$R$3:$R$6	

OWC	='Wells & Controls'!$T$7:$T$7	
Schedule	='Wells & Controls'!$B$5:$O$5	
StepFactor	='Wells & Controls'!$R$11	
Tolerance	='Wells & Controls'!$R$8:$R$8	
Units	='Wells & Controls'!$U$2	
Material balance Worksheet		
CurrVolumes	='Material balance'!$R$9:$U$11	
GBResiduals	='Material balance'!$U$25:$U$27	
GlobalResiduals	='Material balance'!$V$25:$V$27	
InitVolumes	='Material balance'!$R$4:$U$6	
RecoveredVolumes	='Material balance'!$R$14:$U$16	
Solution maps Worksheet		
InitPressure	='Solution maps'!$AL$3:$BT$37	
InitRs	='Solution maps'!$AL$151:$BT$185	
InitRv	='Solution maps'!$AL$188:$BT$222	
InitSg	='Solution maps'!$AL$40:$BT$74	
InitSo	='Solution maps'!$AL$77:$BT$111	
InitSw	='Solution maps'!$AL$114:$BT$148	
PoreVolume	='Solution maps'!$B$225:$AJ$259	
Pressure	='Solution maps'!$B$3:$AJ$37	
Rs	='Solution maps'!$B$151:$AJ$185	
Rv	='Solution maps'!$B$188:$AJ$222	
Sg	='Solution maps'!$B$40:$AJ$74	
So	='Solution maps'!$B$77:$AJ$111	
Sw	='Solution maps'!$B$114:$AJ$148	
Contouring Worksheet		
ContourDegrees	=Contouring!$E$2:$E$3	
ContourDX	=Contouring!$F$29:$AN$29	
ContourDY	=Contouring!$E$30:$E$64	
ContourLevels	=Contouring!$B$4:$B$1048576	
ContourModelSize	=Contouring!$E$6:$E$7	
ContourOutput	=Contouring!$F$30:$AN$64	
X	=Contouring!$F$28:$AN$28	
Y	=Contouring!$D$30:$D$64	
ExcSimHidden Worksheet		
ClosePlot	=ExcSimHidden!$A$2	
Graphing	=ExcSimHidden!$B$4	
MatBaling	=ExcSimHidden!$B$3	
Plotting	=ExcSimHidden!$B$2	