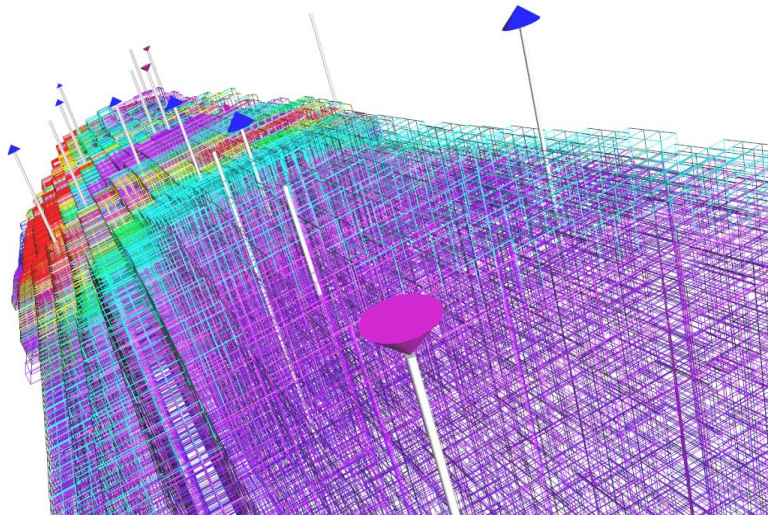
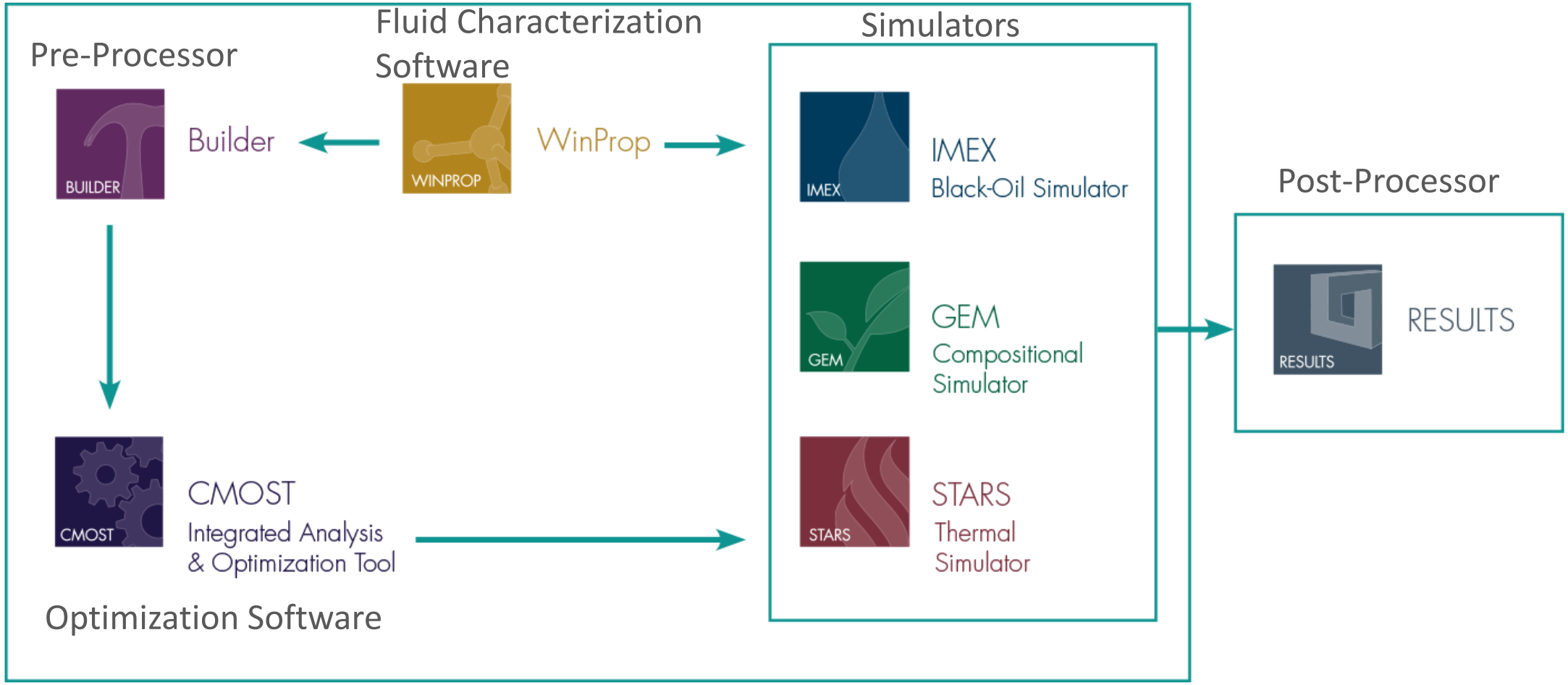


Introduction to CMG's Modelling Workflows

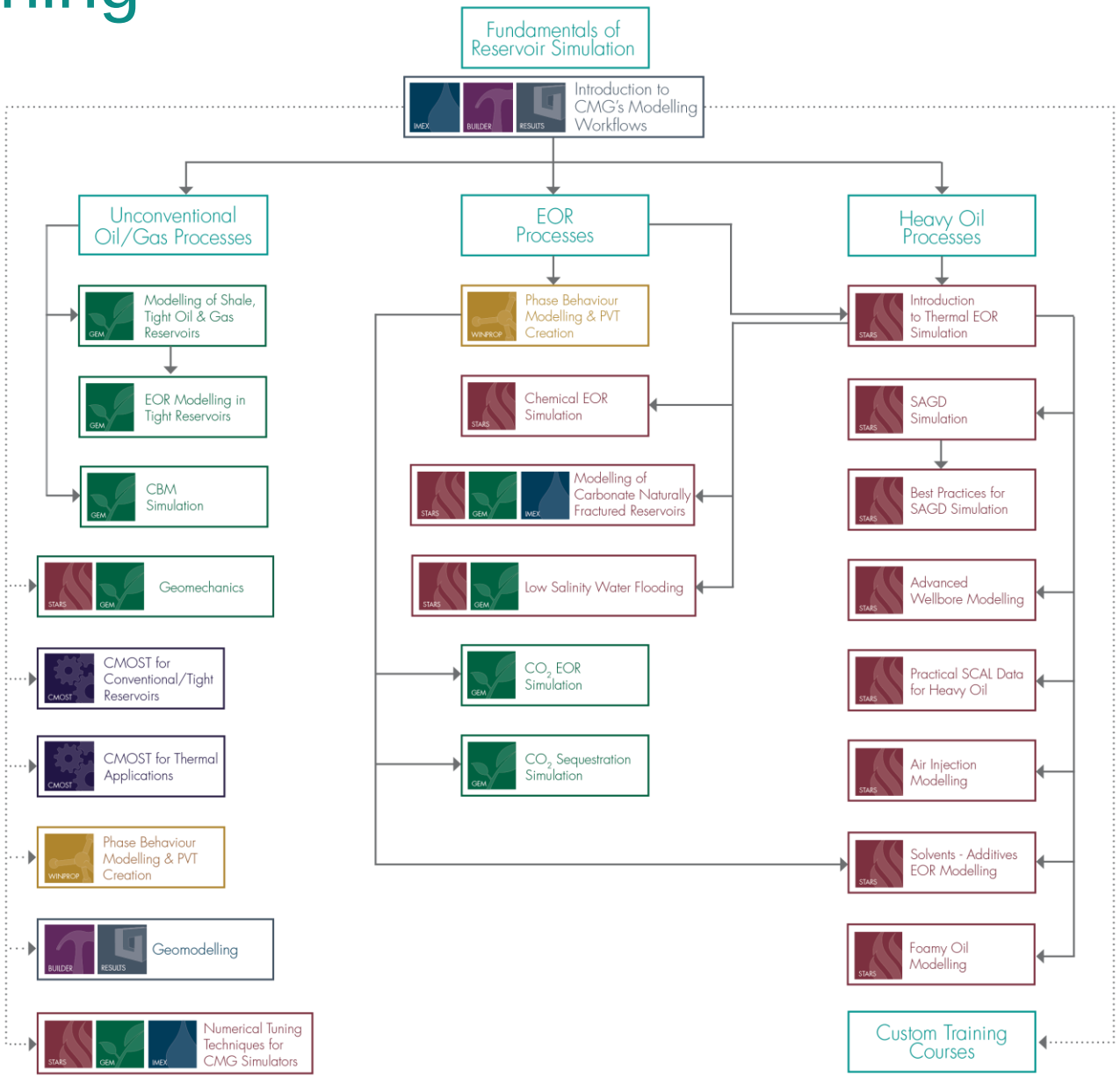
Agenda

- **CMG Software**
- **CMG Launcher**
  - Launcher Tutorial
- **Simulator data organization**
- **Builder**
  - Sections
  - Applications/Tutorials
- **IMEX**
  - Applications/Tutorials
- **Hands on exercises**

CMG Software



CMG Training



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CMG Software

- **Project manager**

  Launcher

- **Pre/Post Processors**

  Builder

  Results 3D

  Results Graph

  Results Report

  Results

- **Reservoir Simulators**

  IMEX (Black Oil simulator)

  GEM (EOS compositional & geomechanical simulator)

  STARS (K-value compositional, thermal, chemical & geomechanical simulator)

- **History Match, Optimization, Sensitivity & Uncertainty Assessment**

  CMOST

- **Phase Behaviour**

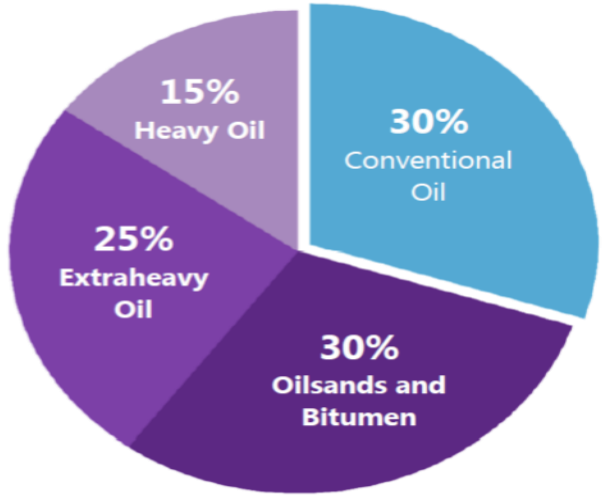
  WinProp

CMG Software

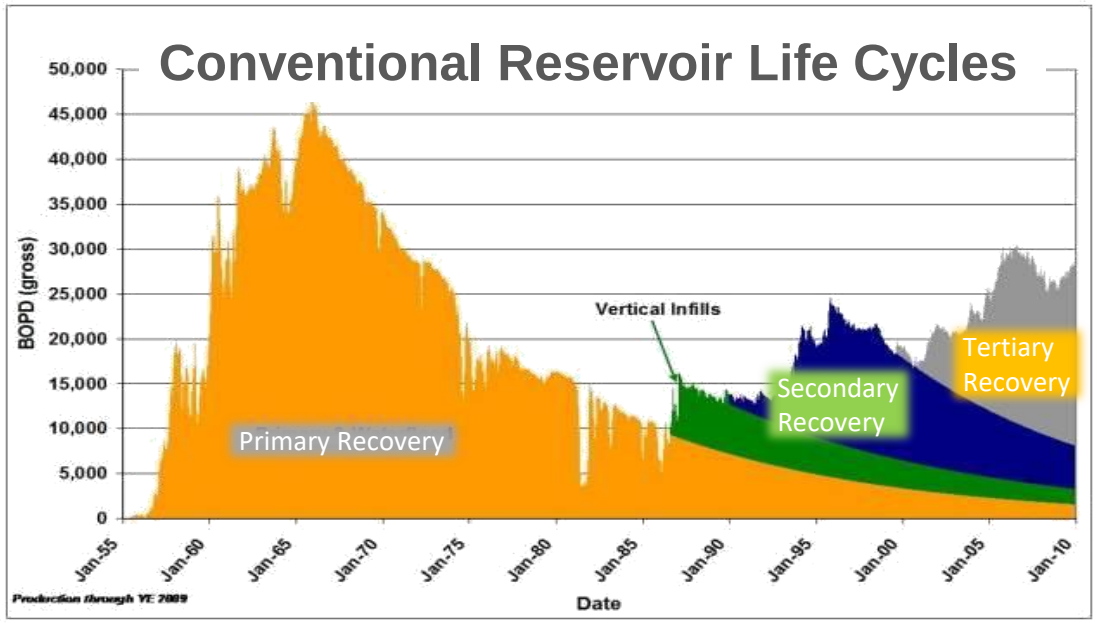
Total World Oil Reserves
(% of total reserves)

70% of the world's oil reserves are unconventional sources

This is CMG's SPECIALTY



CMG Software, Simulators



- Natural Depletion

Primary Recovery

IMEX

- Gas
- Water

Secondary Recovery

IMEX

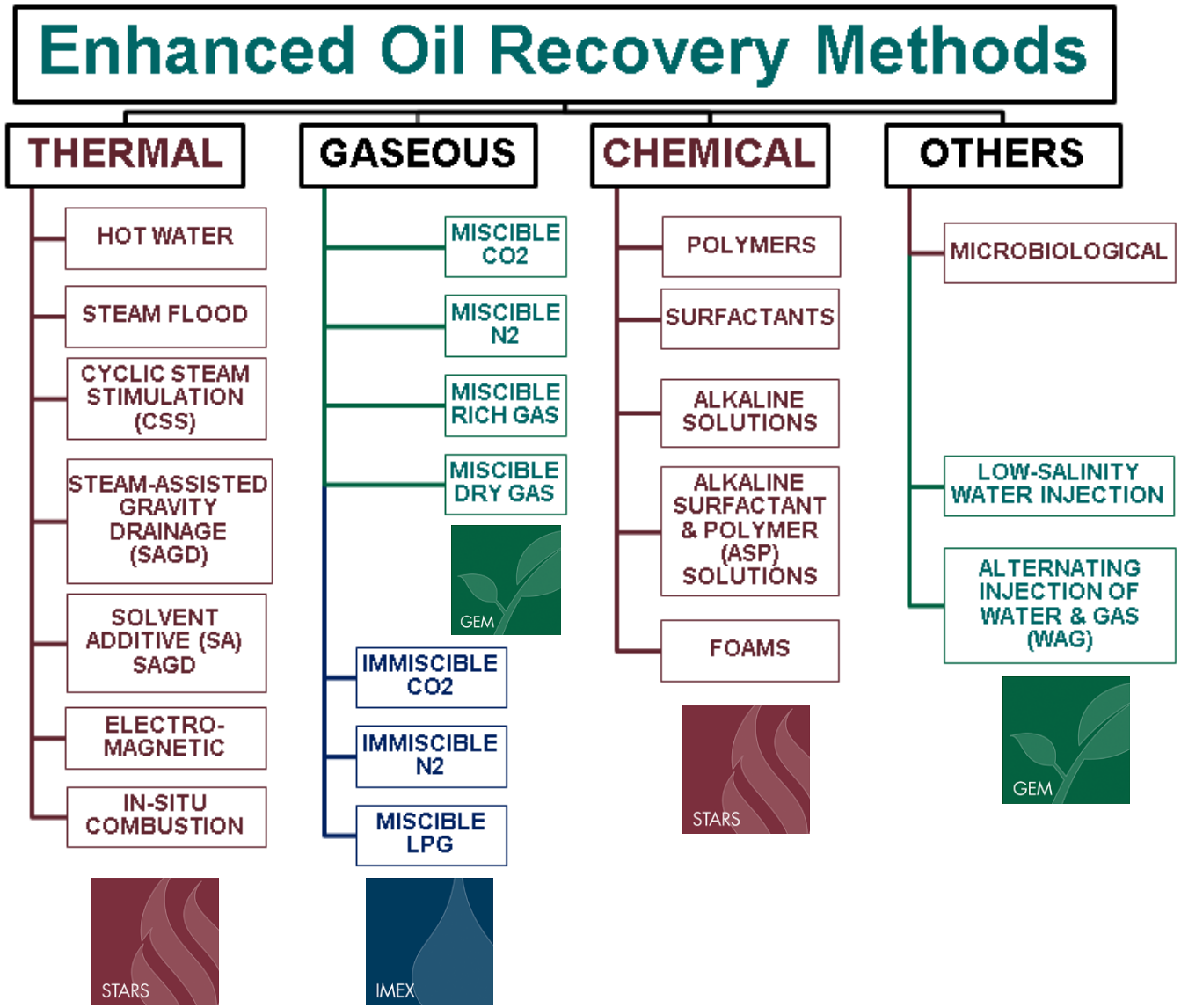
- Thermal
- Chemical
- Immiscible Processes

Tertiary Recovery

GEM

STARS

Enhanced Oil Recovery Methods



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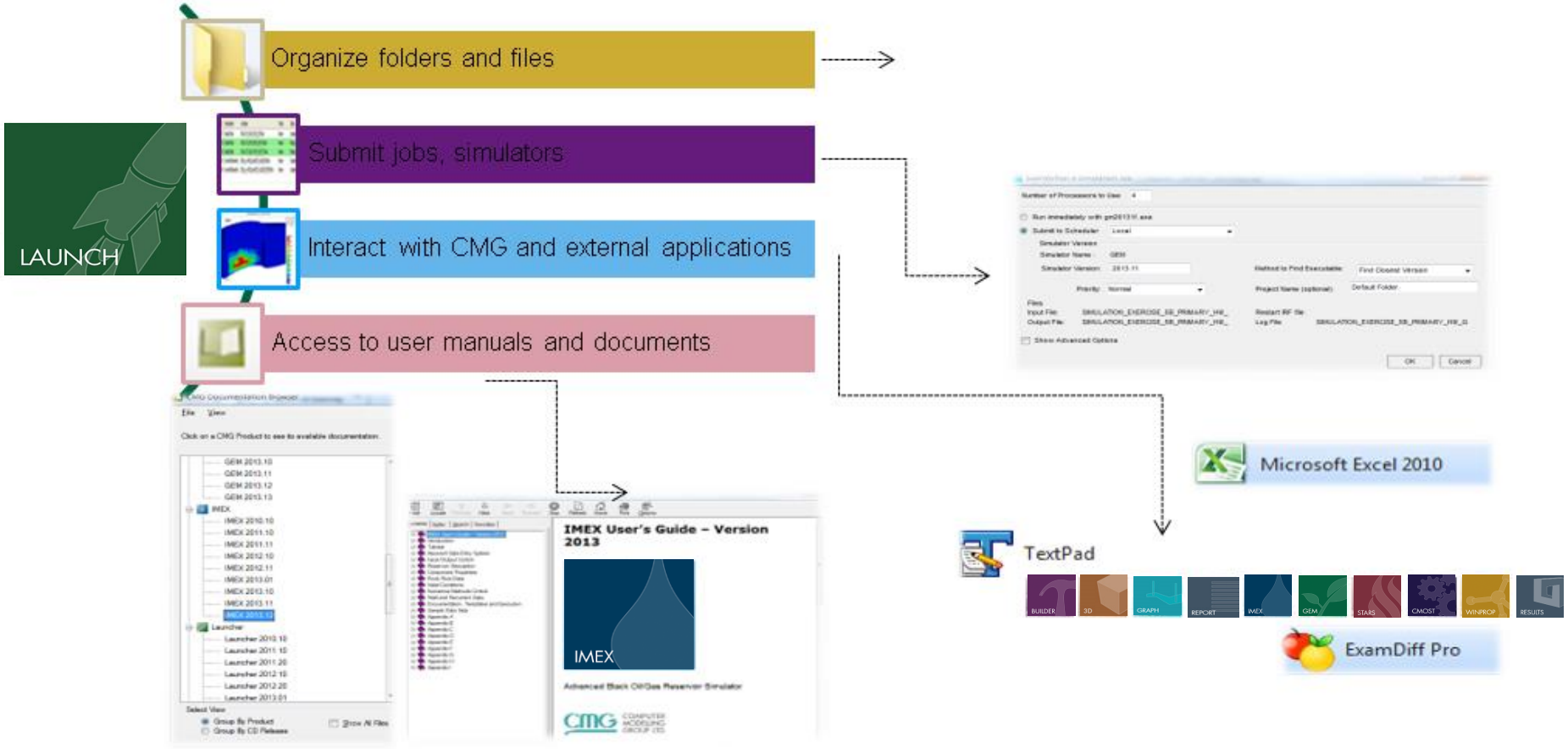
CMG Launcher

CMG Launcher



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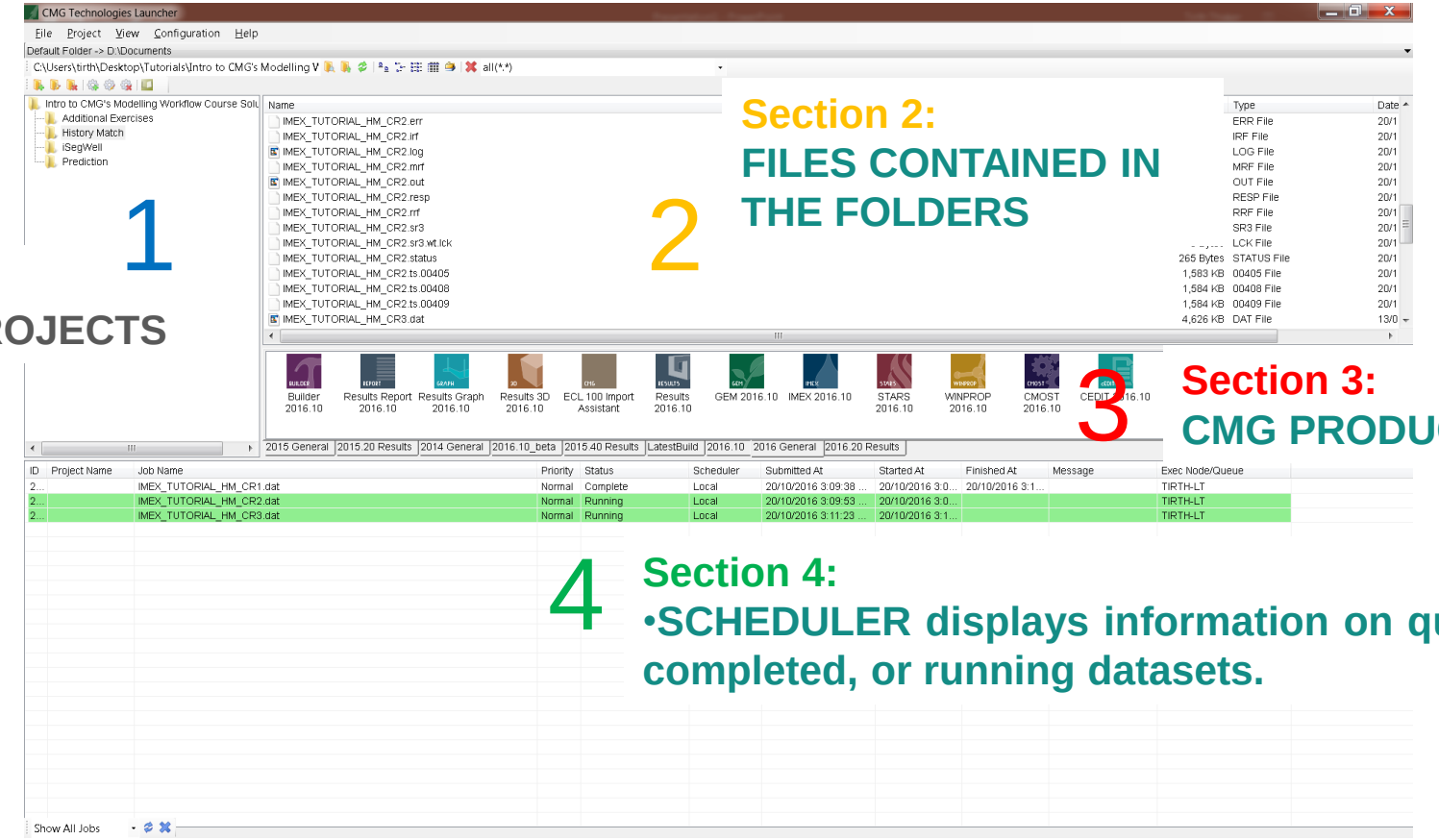
CMG Launcher

Section 1:
- **FOLDERS AND PROJECTS**



Section 2:
FILES CONTAINED IN THE FOLDERS

Section 3:
CMG PRODUCTS

Section 4:
- **SCHEDULER displays information on queued, completed, or running datasets.**

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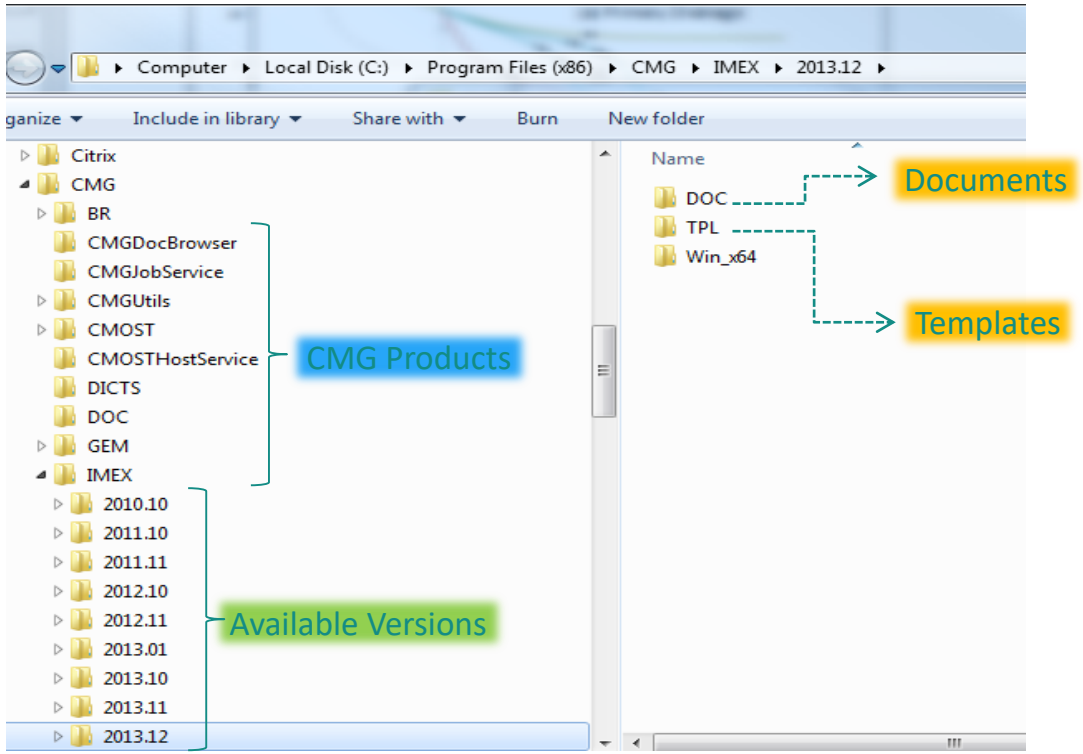
Simulator Data Organization

Simulator Data Organization

CMG directory usually stored under

C:\Program Files (x86)\CMG

- Product
- Version
- Documentation and examples



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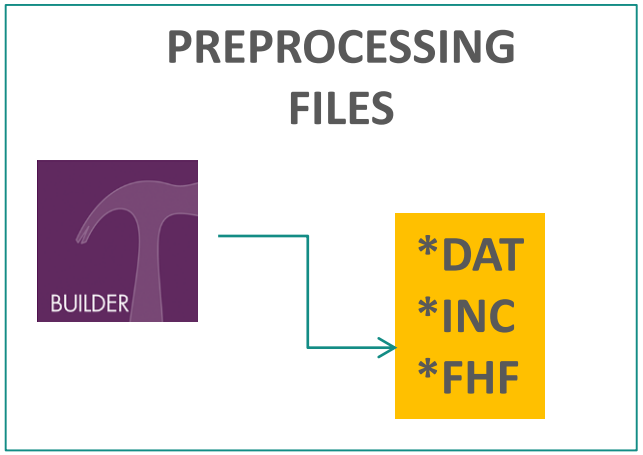
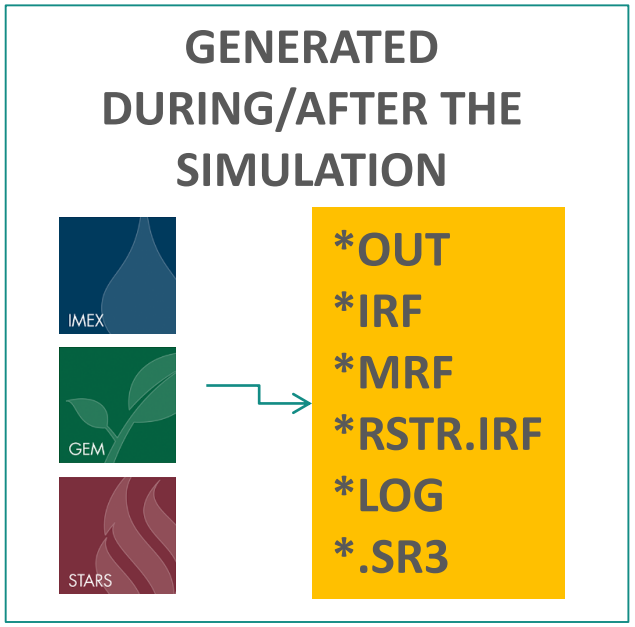
Simulator Data Organization





Basic file extensions:

.dat - Simulator input file that contains all the information the simulator requires to perform its flow calculations

.inc - Additional input files referred to in the .dat file

.fhf - Historical data can be stored in this file type for superimposing on simulated results to aid history matching

*.out - File output by the simulator containing information on the model in ASCII text

.irf - Header file output for graphical post processing

.mrf - Binary data file containing the simulator results

.sr3 (new) - Binary data file containing the simulator results

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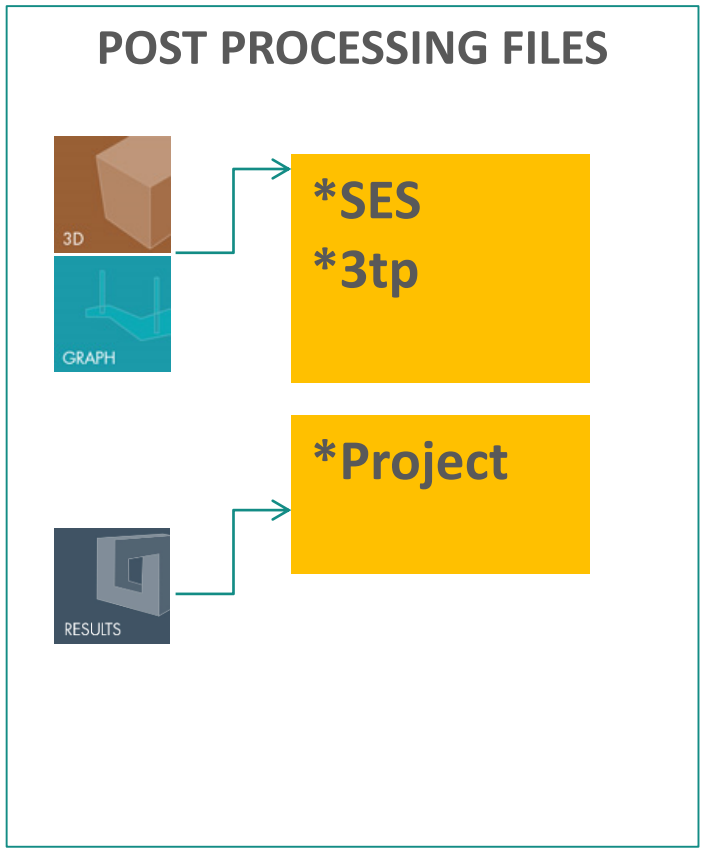
Simulator Data Organization



Basic file extensions:

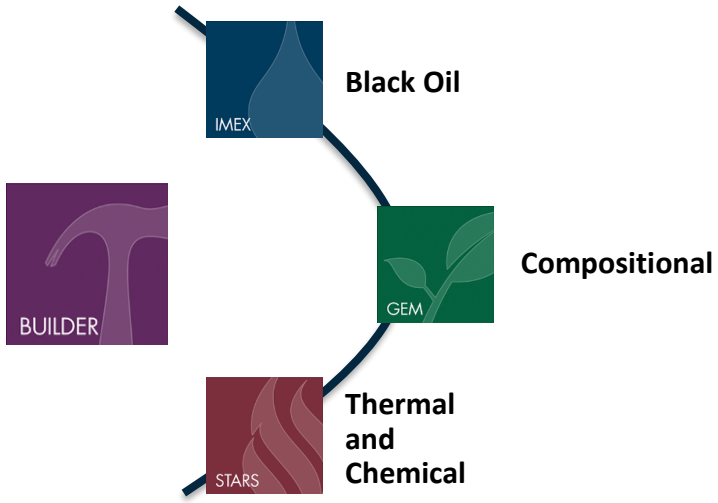
.ses - Template file for post processing line plots

.3tp - Template file for post processing reservoir displays

.project – Template file for post processing in Results software

Builder

Builder, Main Features



Use BUILDER to CONSTRUCT IMEX, GEM and STARS datasets

Use BUILDER to CONVERT IMEX to GEM and STARS

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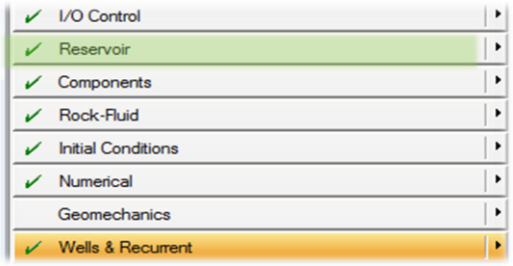
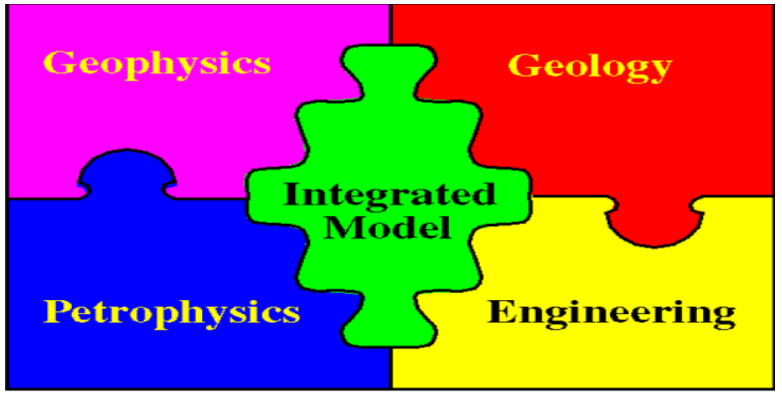
Builder, Reservoir Section



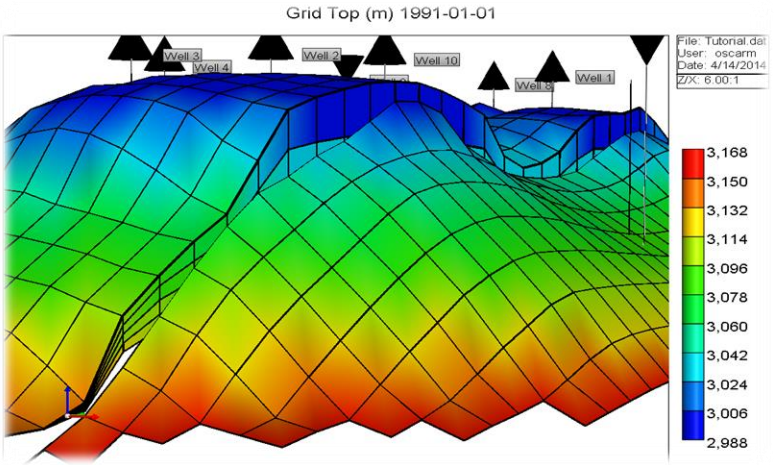


Builder integrates all the static and dynamic properties to construct a reservoir model

Reservoir section

Consider all the aspects related to geological data and reservoir properties

- **Reservoir Structure**
  - Tops, layers and faults
- **Reservoir Properties**
  - Different geological properties such as porosity, permeability and water distribution



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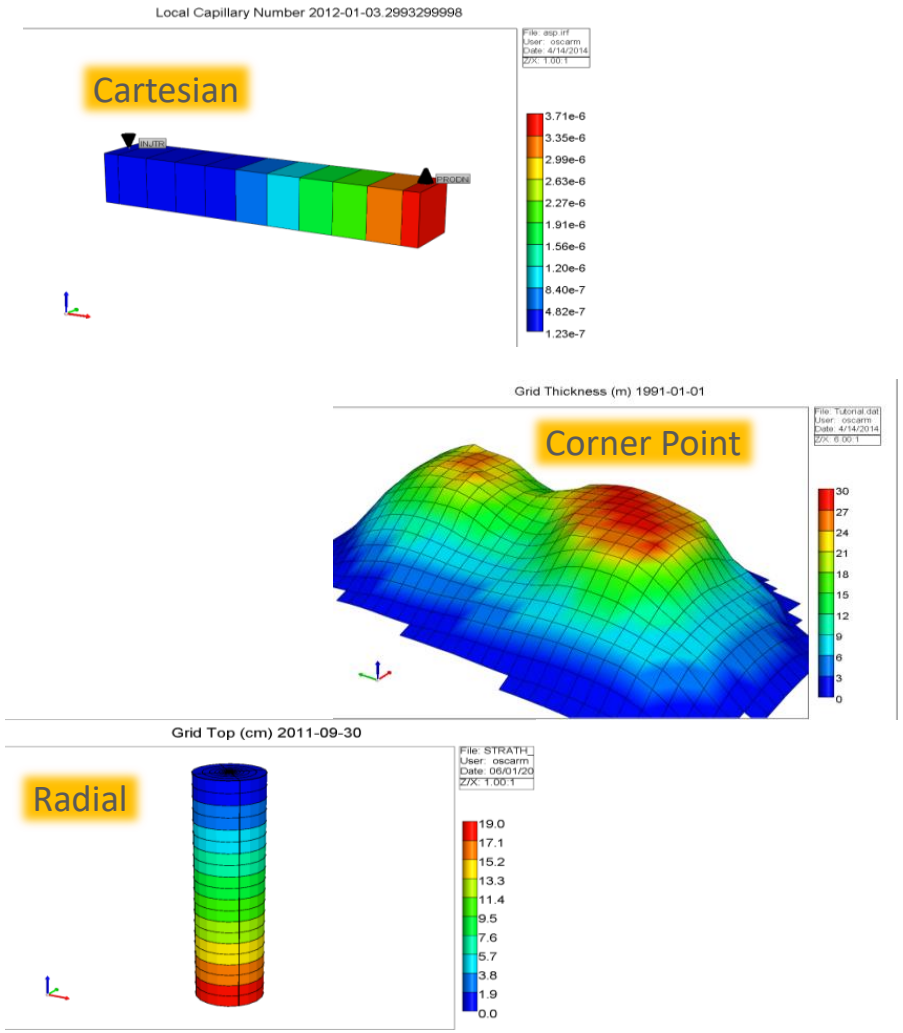
Builder, Reservoir Section

Reservoir structure

Different types of grids can be created in Builder:

- **Cartesian**
  - Blocks are rectangular in shape
- **Corner point Gridding**
  - Blocks are defined by eight points (3 coordinates each)
- **Quick Pattern Grid**
  - Quickly creates available pattern types with properly placed producer and injector
- **Radial**
  - Cylindrical coordinate system



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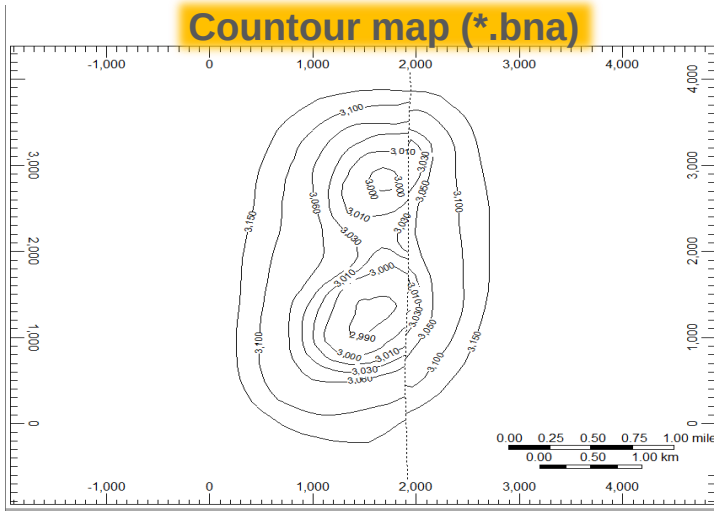
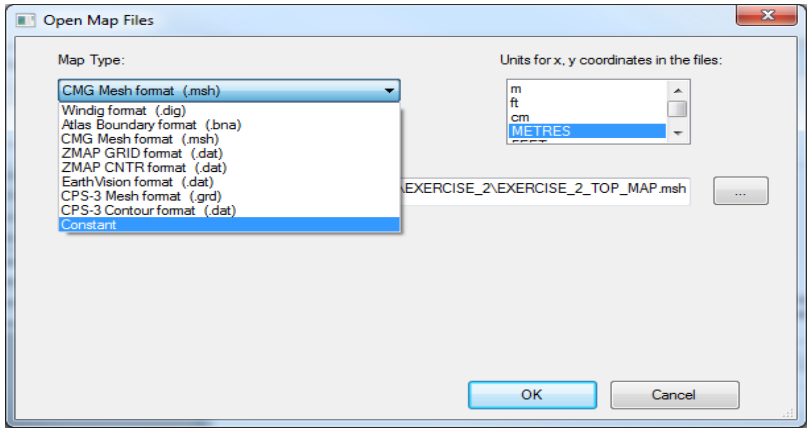
Builder, Reservoir Section

Reservoir properties

Types of accepted data:

- **Scattered data points**
  - Not on regular grid, sparse (e.g. picks at wells)
- **Contour maps of 2D surface**
  - Sets of connected points forming line with value, may contain faults and well locations
- **Mesh maps of 2D surface**
  - Regular, orthogonal “grid” of data, value at each point, may contain fault lines and well locations





Different map types accepted

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Builder, Reservoir Section

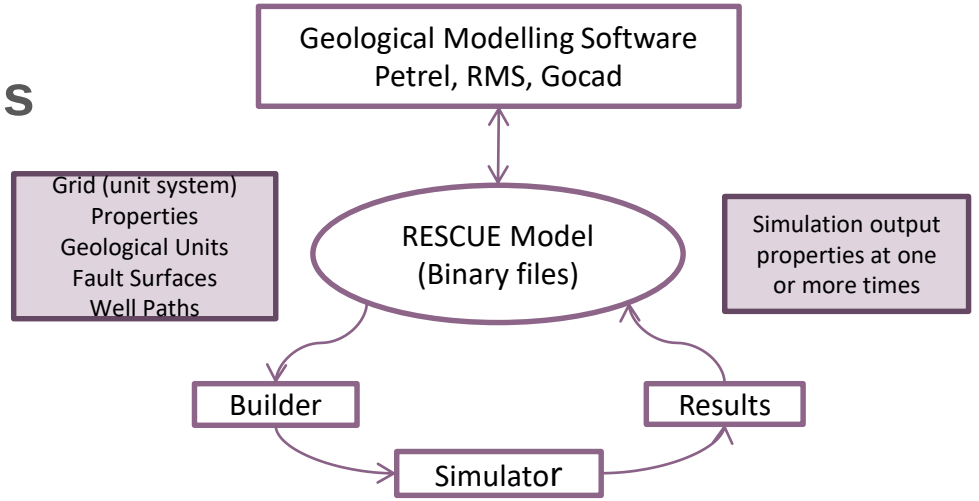
Reservoir properties

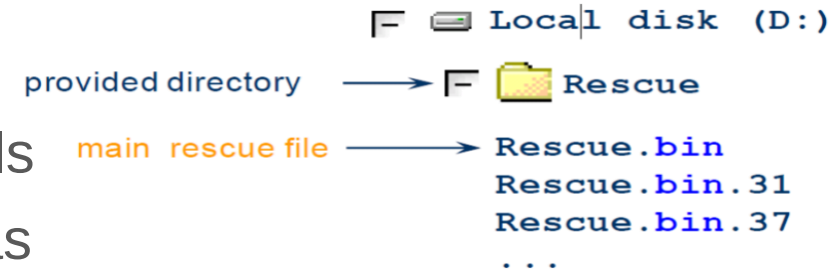
Some geological and geostatistical programs directly create 3D grids

- Schlumberger – Petrel
- Roxar - RMS
- Landmark – Decision Space Geology
- Earthvision
- Paradigm-GOCAD

Builder can import those grids

- One way it to import the grids as rescue models
- **Rescue Models** can include properties such as porosity, permeability, etc. (*.BIN)





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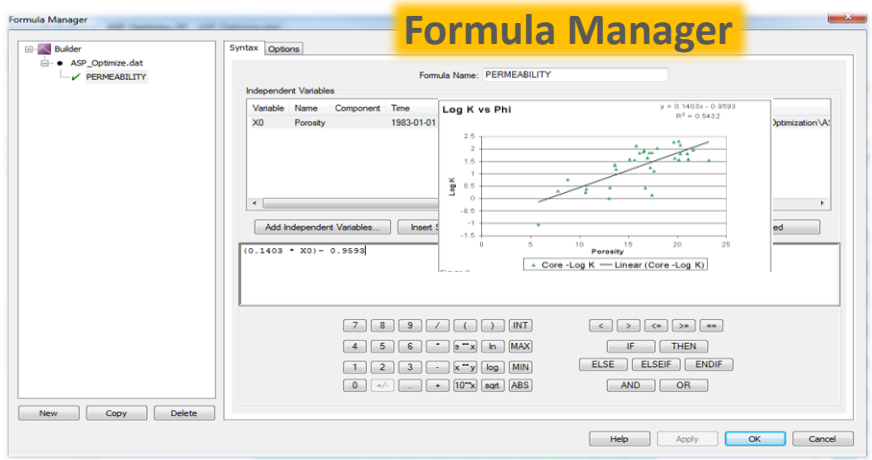
Builder, Reservoir Section

Reservoir properties

Additional sources of data to construct a model:

- **Formulas**
  - Formula manager is a tool in Builder to generate and assign new properties (E.g. permeability as a function of porosity)
- **Constant values**
  - Some simple models can use an average single value (E.g. core flood model)



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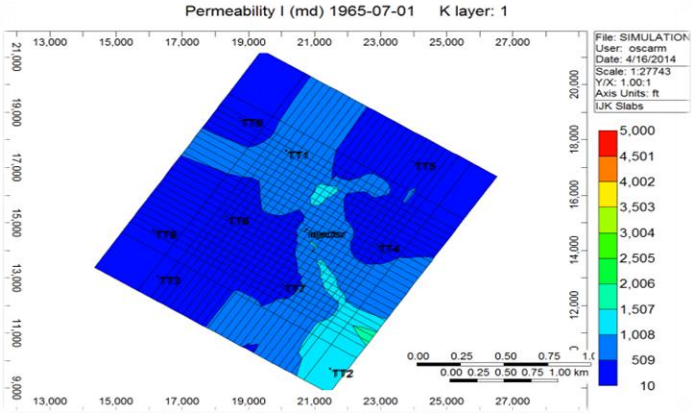
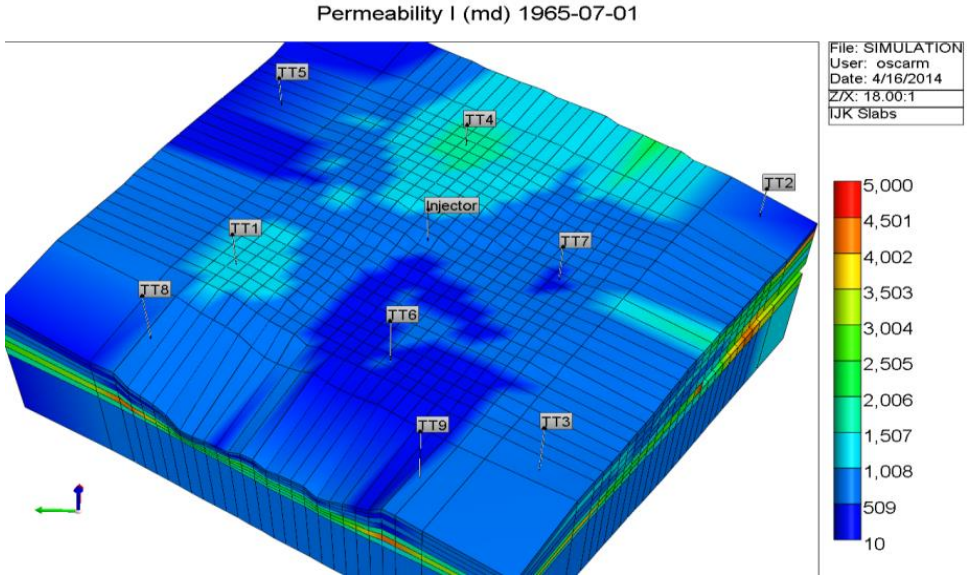
Builder, Reservoir Section

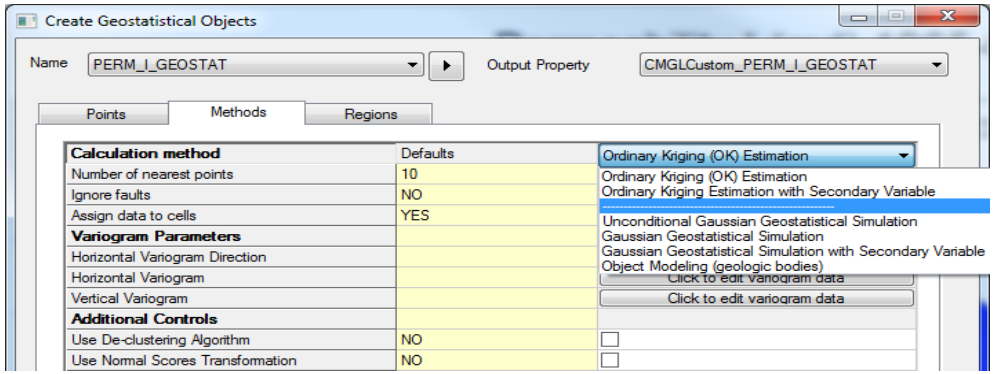
Properties Interpolation and Geostatistics

- Builder can create more realistic distributions of reservoir properties when interpolation is required

- Different algorithms/methods are available in Builder (Kriging, Gaussian, etc.)







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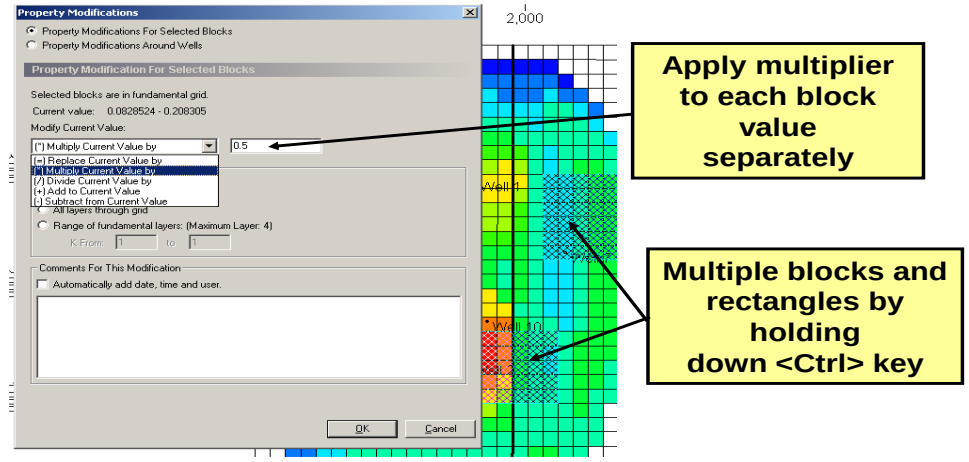
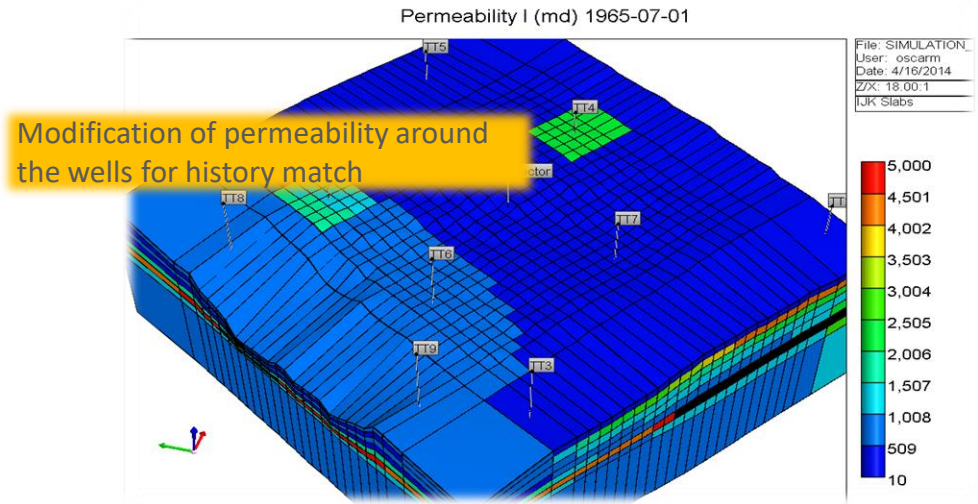
Builder, Reservoir Section

Properties modification

- Properties in grid cells or regions can be modified in Builder
- Constant property values can be reassigned to the model or addition/subtraction/division/multiplication of the original property value can be assigned





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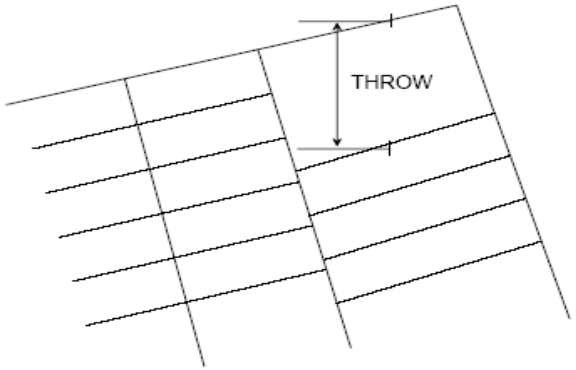
Builder

Modeling Faults



- **Scale of Fault**
  - Can it be seen from seismic or well tests?
  - Does it have significant throw?
- **Implicit Fault**
  - *TRANSI etc i.e. using Transmissibility multiplier of 0
- **Explicit Fault**
  - Grid cell dislocation
- **Point distributed grids allow most fault traces to be followed exactly**
- **Default**
  - All fault connections are sand to sand and transmissibility must be specified
- **Can use map files to import Faults**

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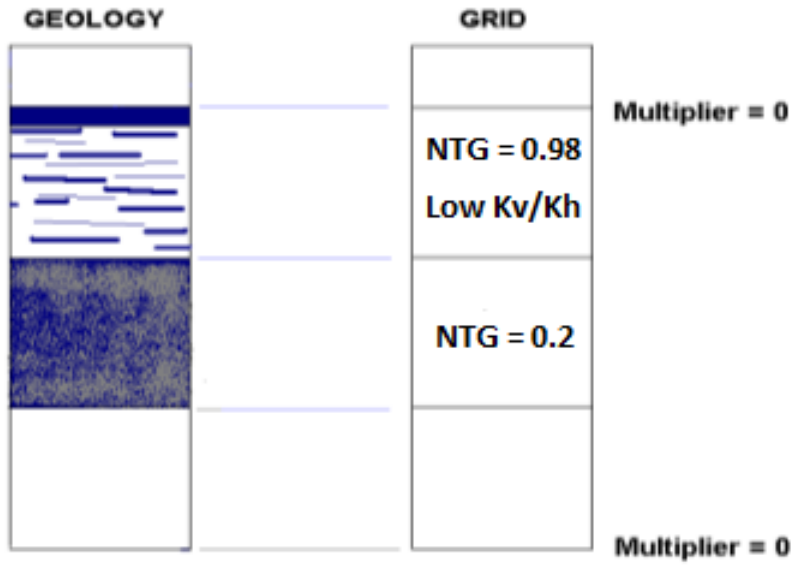
Modelling Shale

Several ways to model extensive shale horizons:

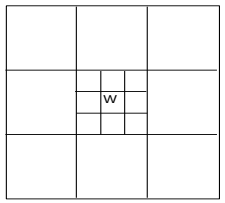
- **Explicit layer of cells**
  - Allows direct modelling of flow and hydrocarbon volume
- **Transmissibility barrier**
  - Quicker modelling of thin horizons
- **Gaps in grid**

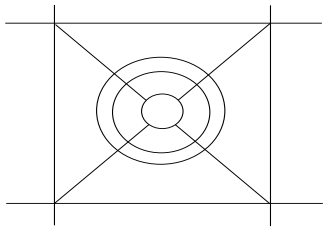


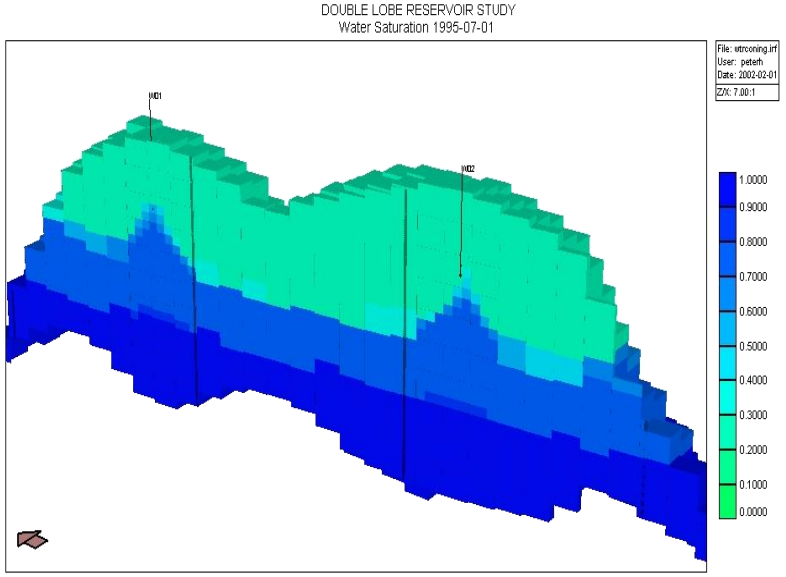
Builder, Reservoir Section

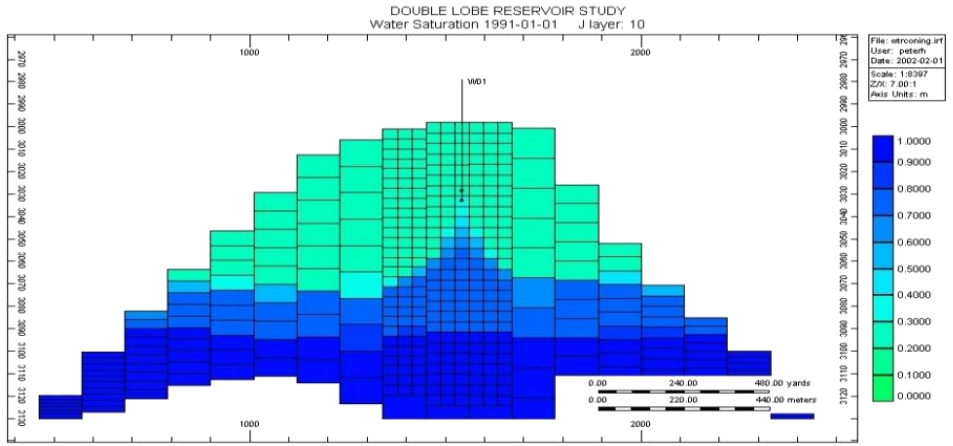
Grid refinements

- Builder can perform refinements in order to improve resolution in saturation distributions
- This can be useful for well studies of water/gas conning effects
- Cartesian and hybrid refinements are available









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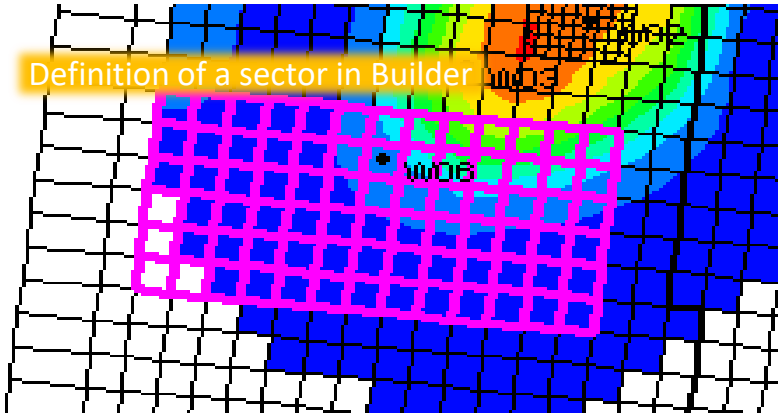
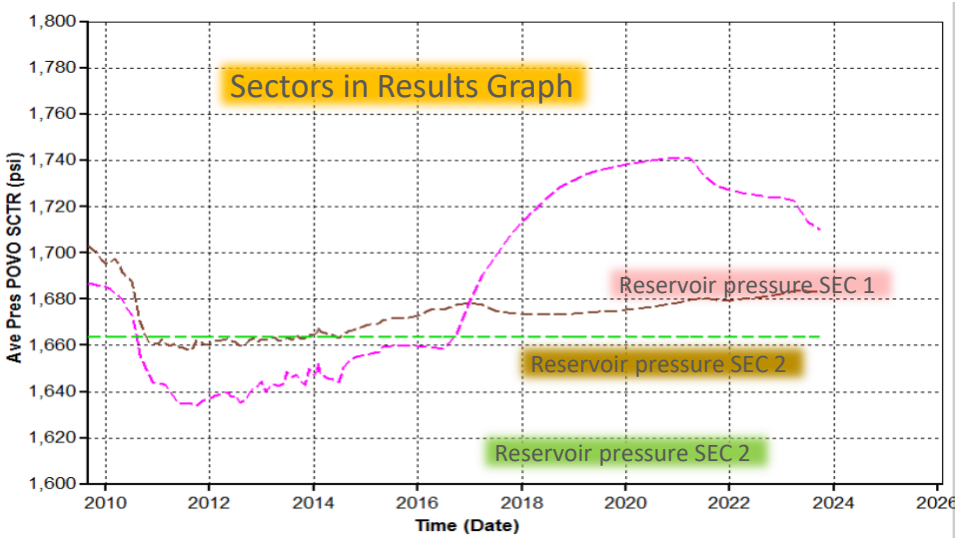
Builder, Reservoir Section

Sectors

Sectors define individual reporting areas in the reservoir

- Used to quantify changes in production/injection and fluid in place values
- Specially useful for pilot tests and reservoirs with multiple formations or regions
- Simulators generate individual reports per sector





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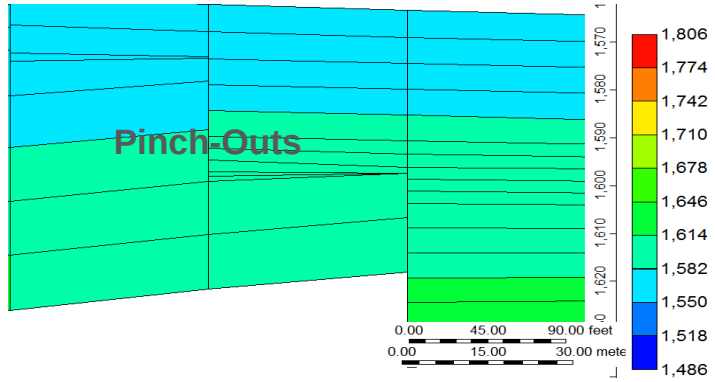
Builder, Reservoir Section

Quality control on grid and properties

- Builder automatically remove problematic cells

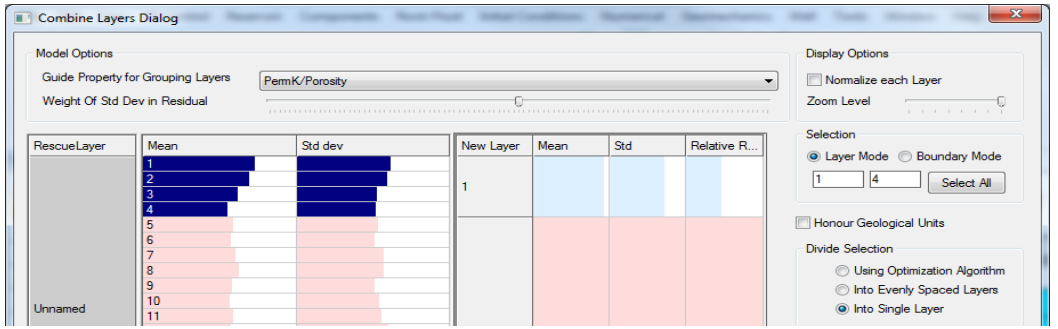
  PVCUTOFF, CORNER-TOL, PINCHOUT-TOL

- Manually remove problem cells, NULL



Combining Layers

- Builder can combine layers
- Different methods to calculate the properties of the combined layers



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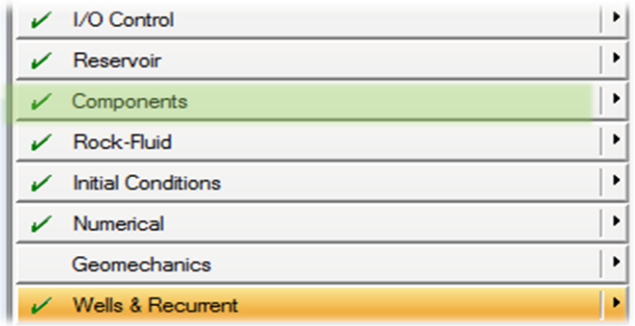
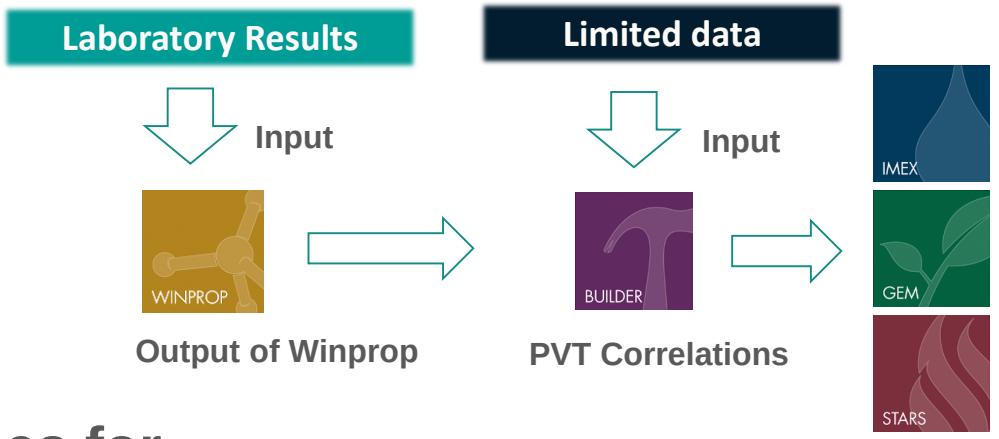
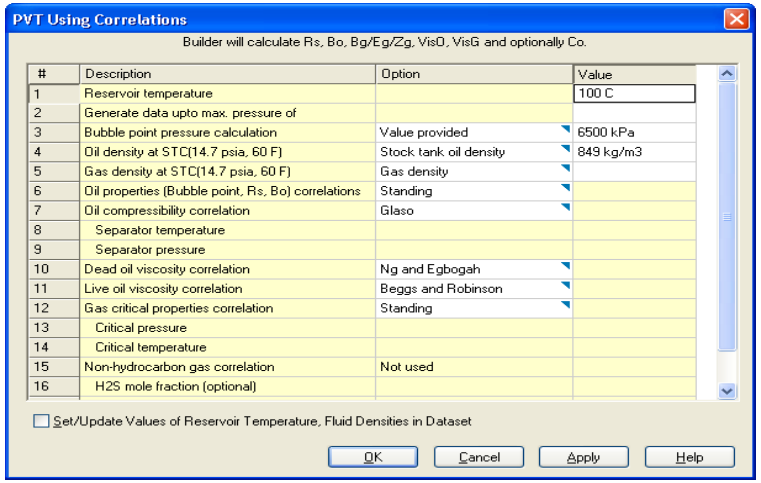
Builder, Components Section



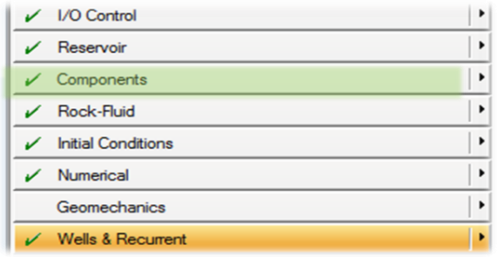


Builder can handle two different approaches for PVT modelling:

- **Laboratory Results (Winprop)**
  - Typically include composition and experiments (Differential Liberation, Separator test, etc.)
- **Limited data (Correlations)**
  - Basic information related to gas and oil densities, Saturation Pressure and Reservoir Temperature is required



Builder, Components Section



- **“Black-oil” PVT description (IMEX)**
  - Primary depletion
  - Waterflooding
  - Immiscible gas injection (solvent model allows pseudo-miscible)
- **EOS PVT description (GEM)**
  - Miscible gas injection (solvents/CO2)
  - Volatile oil systems
  - Gas condensate systems
- **K value PVT description (STARS)**
  - Temperature variation

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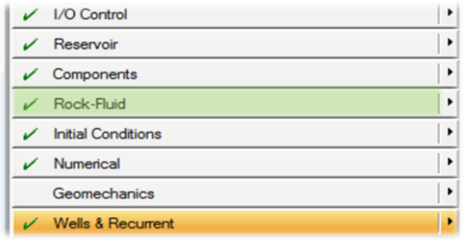
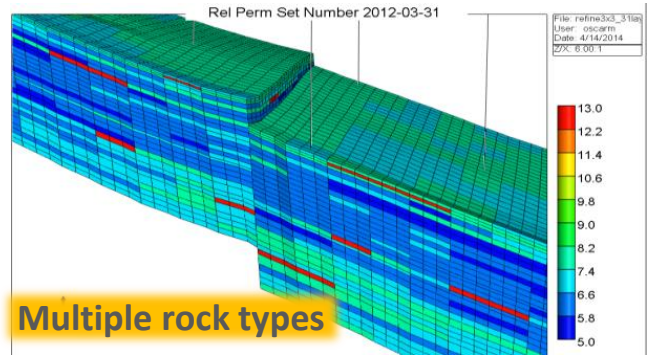
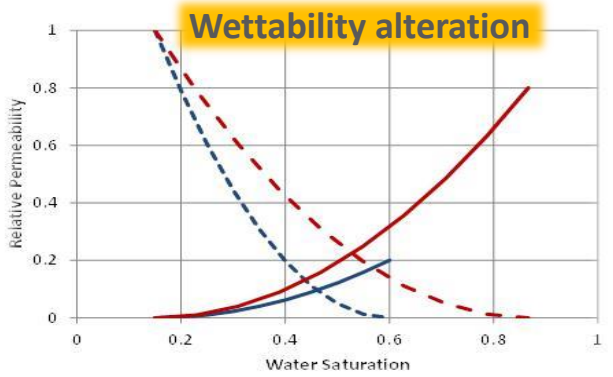
Builder, Rock-Fluid Section

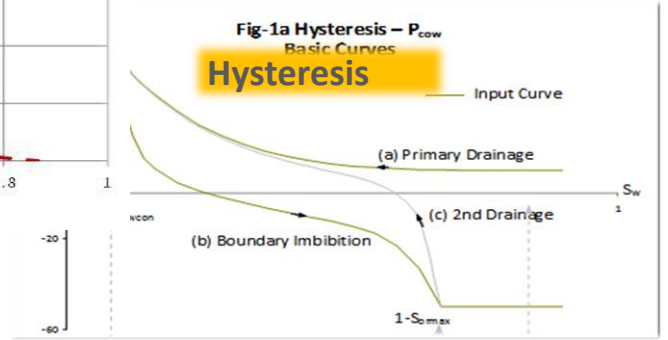


Relative Permeability curves and different phenomena can be modelled in Builder

- Multiple rock types and lithotypes
- Capillary pressure,
- Wettability alteration
- Hysteresis
- Interpolations between Kr curves
- Adsorption
- End-point scaling
- 3pt scaling







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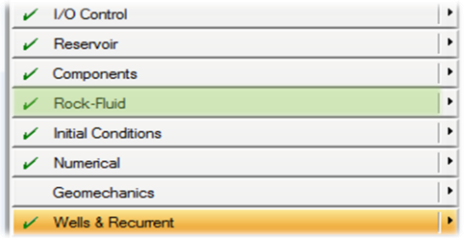
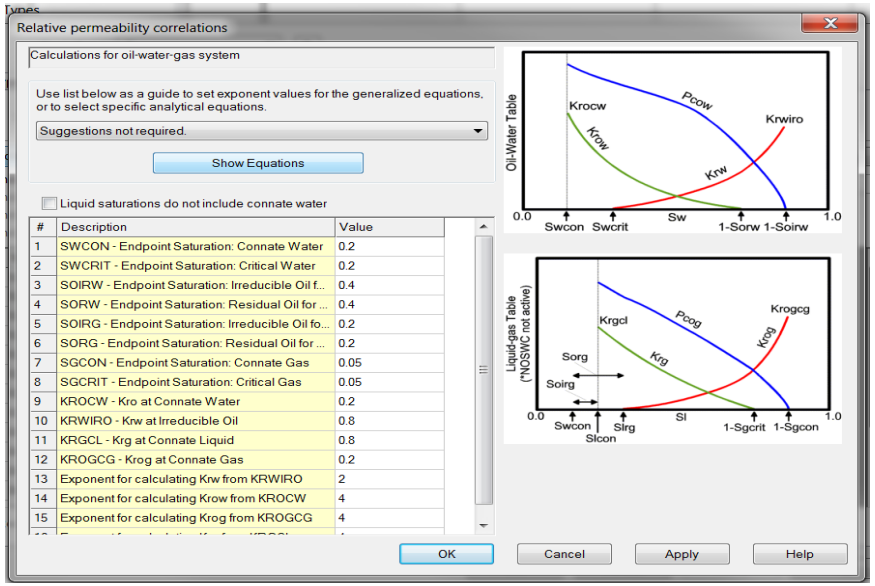
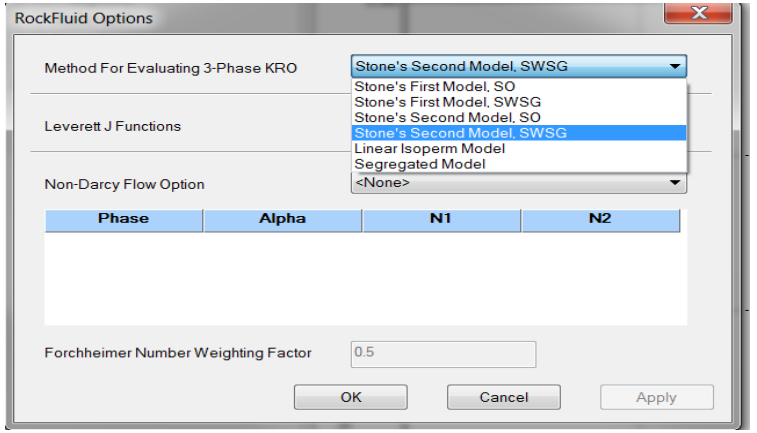
Builder, Rock-Fluid Section



Three phases kr models:

- Stone's 1st Model
- Stone's 2nd Model
- Linear Isoperm Model
- Segregated Model





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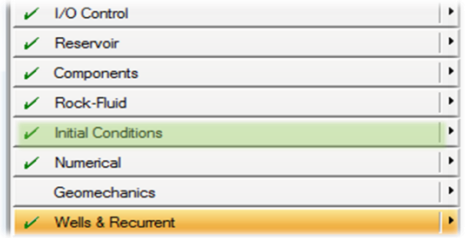
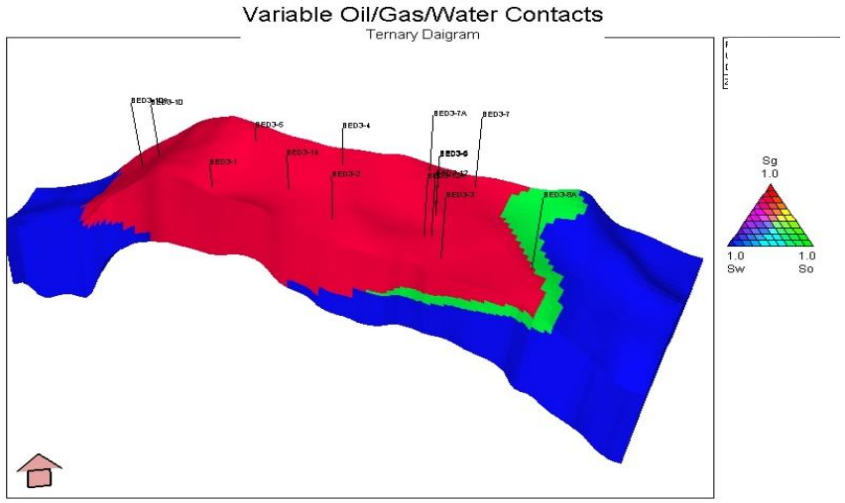
Builder, Initial Conditions



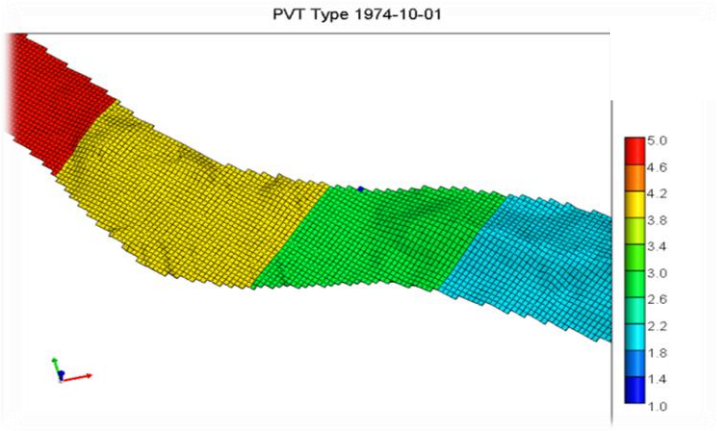
Original conditions in the reservoir are defined in this section

- Reservoir Pressure at datum depth
- Position of Water and Gas Oil contacts



Initial Conditions, Advanced Options

- Multiple W-O and G-O contacts and PVT regions
- Bubble point defined as constant: array: or tables (PBT)
- Gas Cap Initialization with residual oil saturation
- Initialization Regions Separate from PVT Regions



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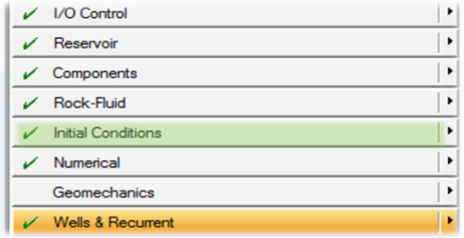
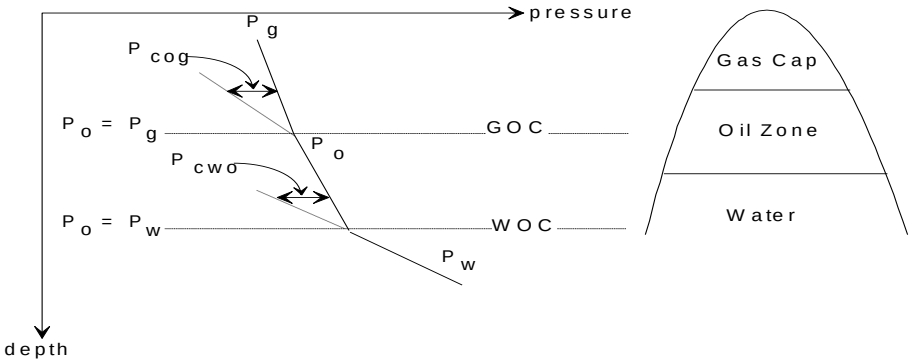
Builder, Initial Conditions



Calculation Methods

- **VERTICAL DEPTH_AVE**

Gravity-capillary equilibrium calculations are performed to calculate all grid blocks pressure and saturations (S_w, S_g, S_o)



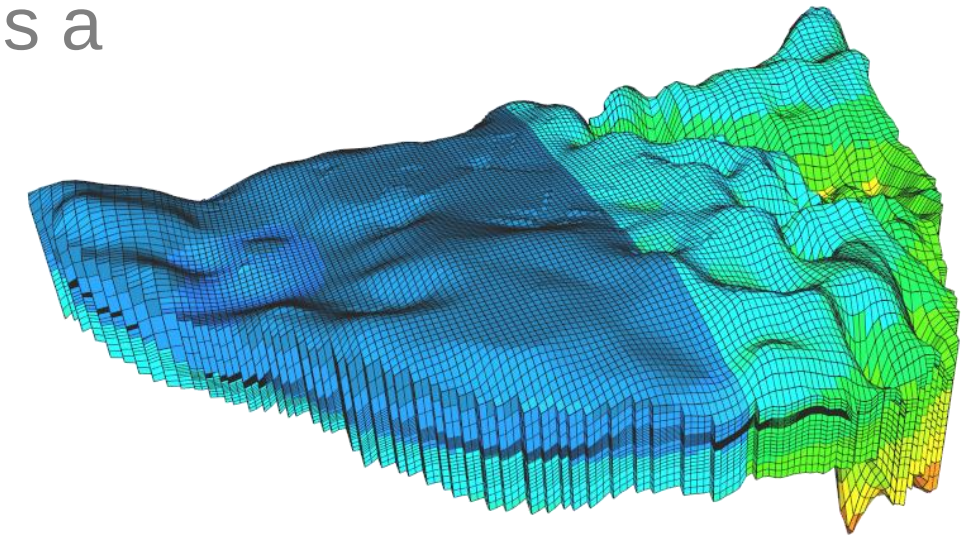
- **USER_INPUT**

Pressure, water saturation and oil saturation are specified for each grid block. Gas saturations are then determined by subtraction

Builder, Initial Conditions

Threshold Pressure

- Prevent flow from occurring across adjacent regions and/or fault planes, until the pressure difference exceeds a desired threshold value
  - “Barrier” between regions
  - Elastic and Plastic options



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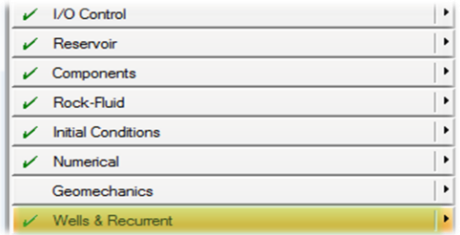
Builder, Wells & Recurrent



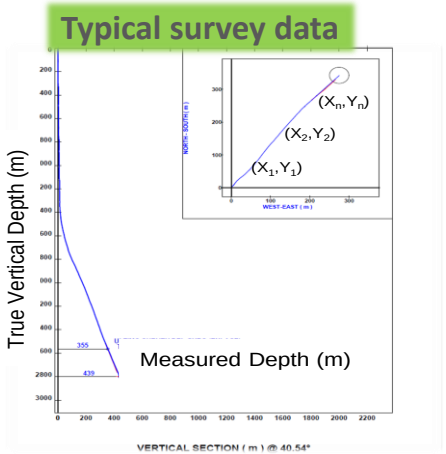
Wells and Trajectories

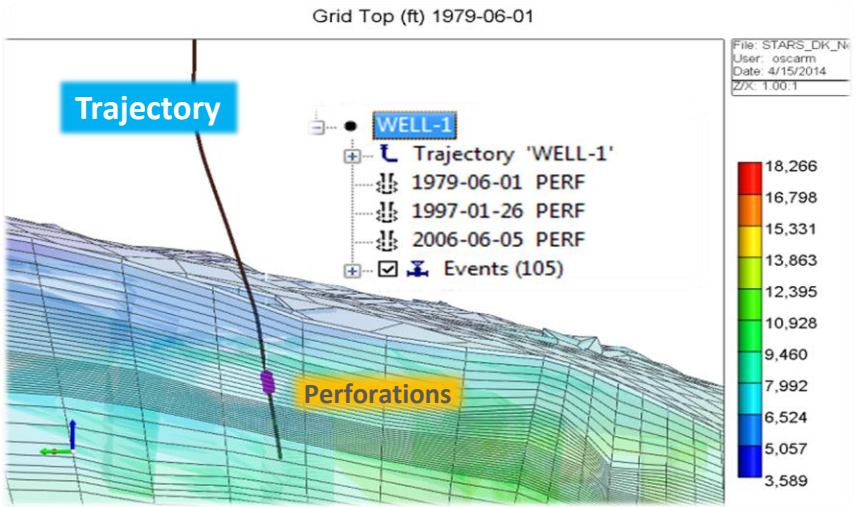
- **Well Trajectories**

Measured data of trajectory can be imported by Builder in different formats

- **Well Perforations**

History of perforated intervals can be added to the trajectory of the wells in Builder





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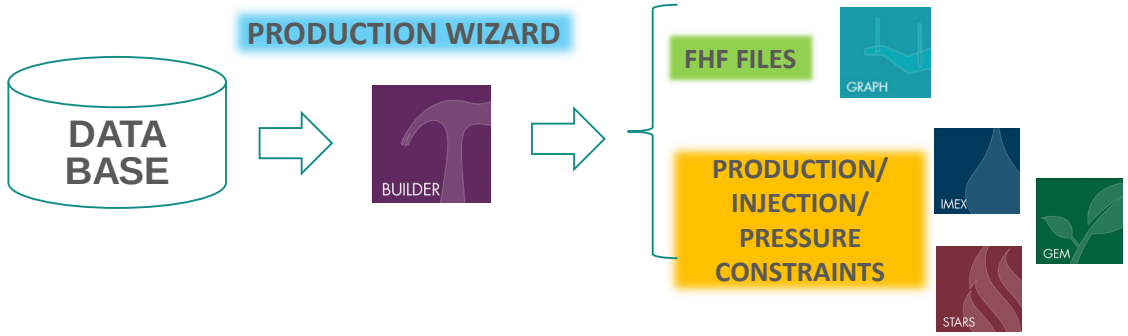
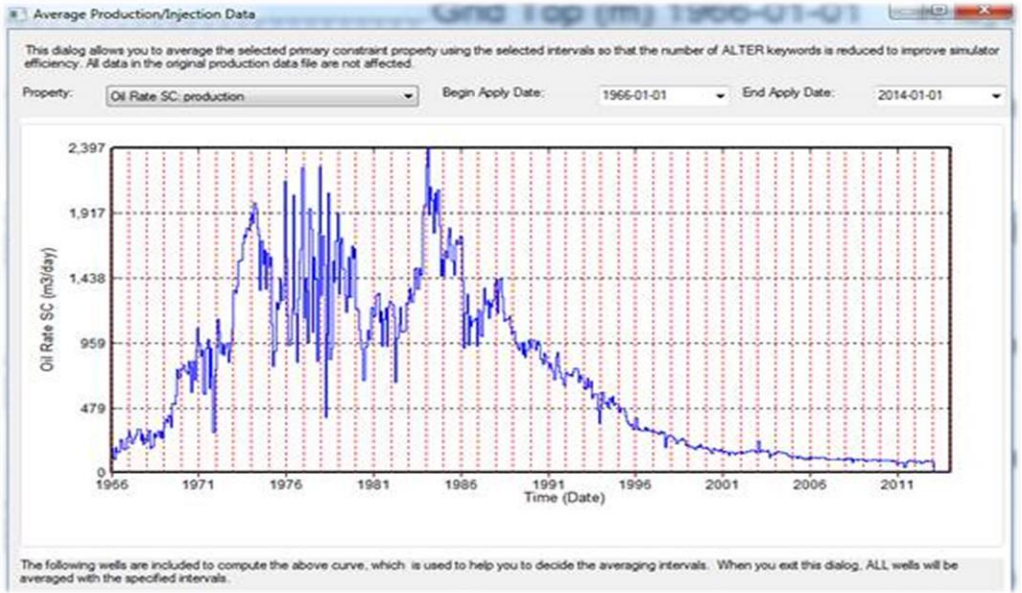
Builder, Wells & Recurrent

Production/Injection data Wizard

- This wizard can import simple production data (ASCII, Excel) or robust files created on different commercial software (E.g. OFM)
- Can handle any number of producer/injector wells and historical years
- Options to average production on a monthly basis, yearly, etc.
- Can create history files (FHF) to compare simulation results





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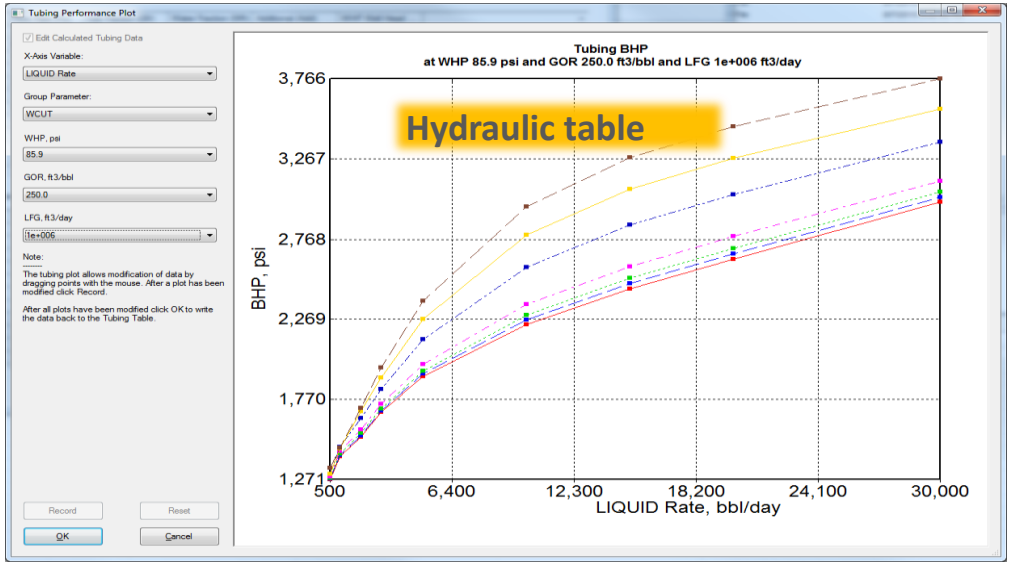
Builder, Wells & Recurrent

Well constraints and well performance

- **Builder can use fixed constraints for prediction**
  - Liquid rate
  - Bottom Hole pressure, BHP
  - Well head pressure, WHP
  - Alter History

- **Builder can import and handle well models created on commercial software (Prosper, Pipesim, etc)**

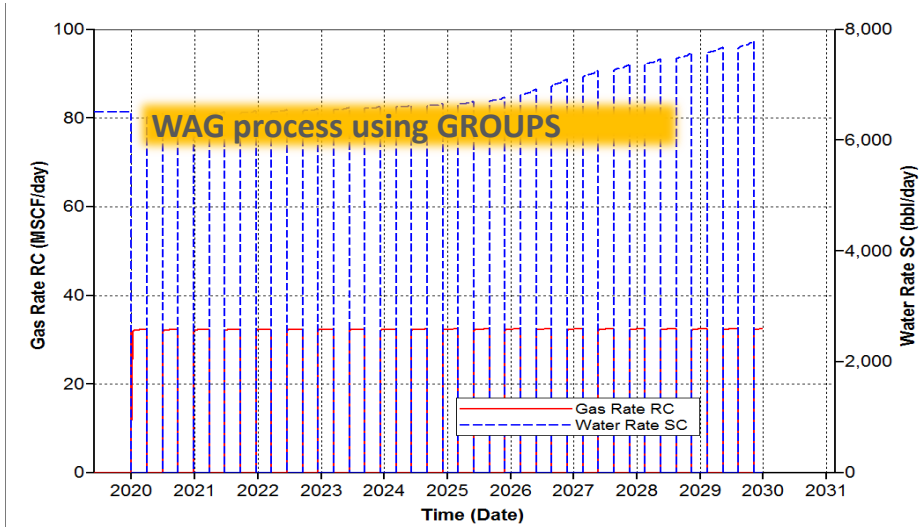


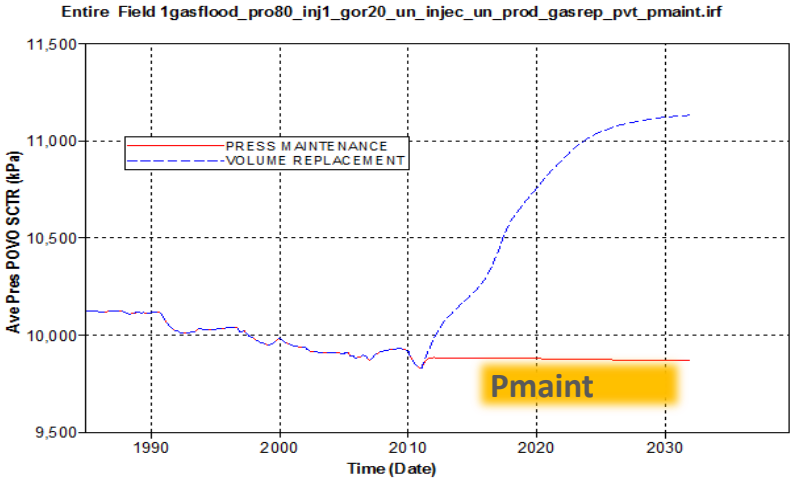
Builder, Wells & Recurrent

Groups

Builder can control production/injection by using GROUPS, some of the options available are:

- Cycling Groups
- Voidage Replacement
- Injection/Production rate per group
- Pressure Maintenance
- Recycling Option





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Builder, Built-in Wizards

Wizard to generate fractures

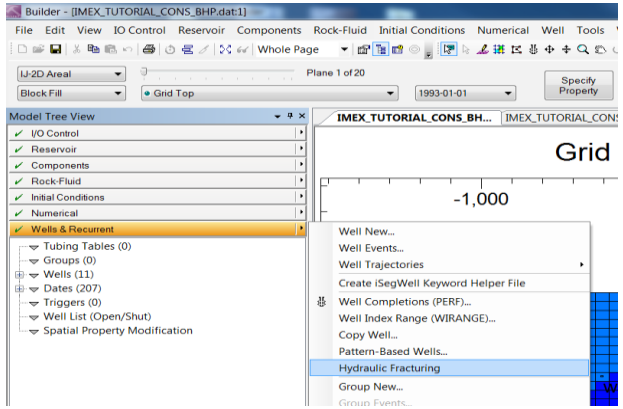
Three ways to model Fractures

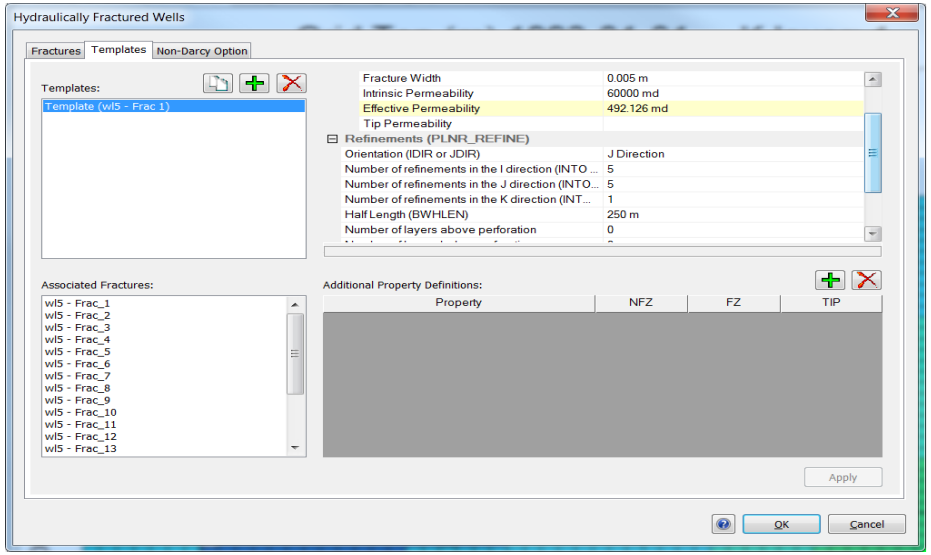
- Planar Fracture
- Complex Fracture Stage
  - Enter data manually or based on Microseismic data
- Create a fracture by importing data from GOHFER

Non Darcy Flow options

- Geertsma correlation
- Frederick and Graves first correlation
- Frederick and Graves second correlation
- General

  Use table of coefficients that define the non-Darcy flow as function of saturation, φ and K of each phase





Fracture Wizard

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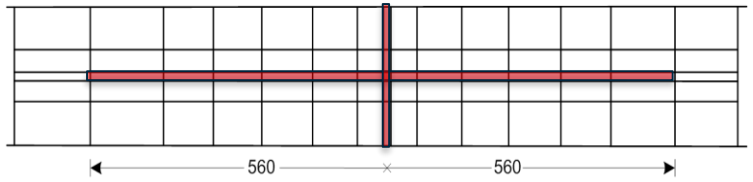
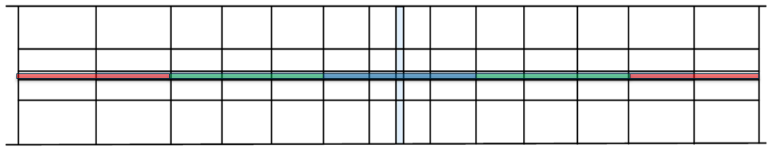
Builder, Importing Hydraulic Fracture Data

Import multiple hydraulic fractures per file from GOHFER, StimPlan, FracProPT, FracGeo, FieldPro

- Multiple Structured Block Groups (SBG's) are created to model fracture
  - Import array of permeability for the fracture
  - Import fractures in transverse and longitudinal direction
- Activate SBG creation by adding keyword "SBG_FORMAT"





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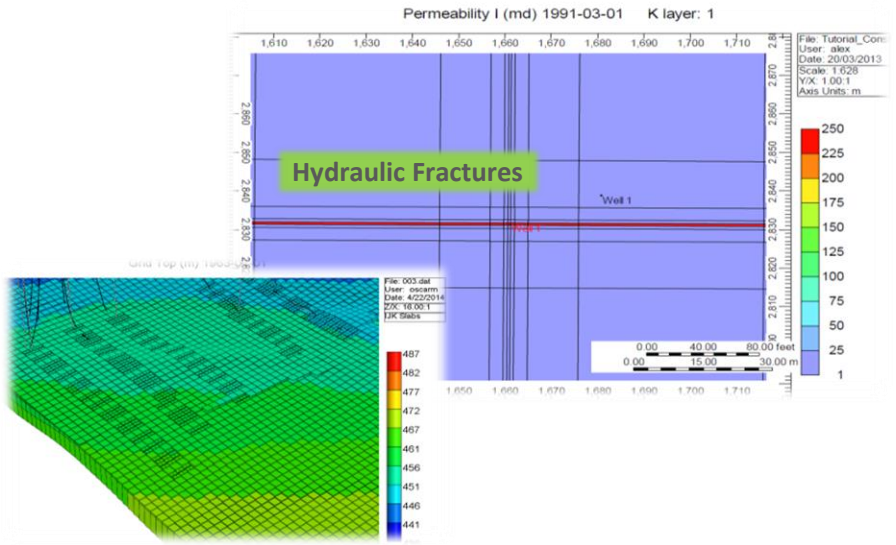
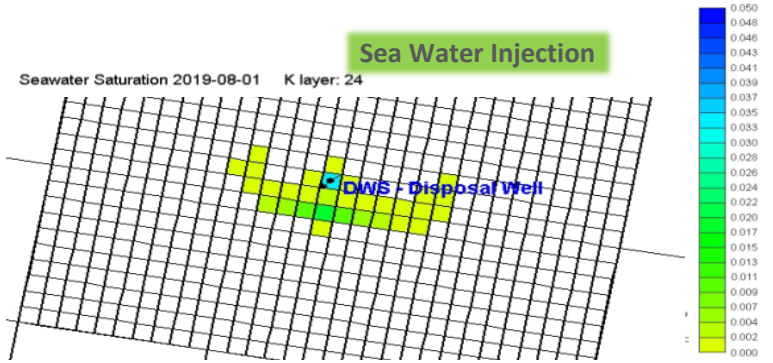
IMEX

IMEX

Variety of reservoir recovery applications:

- Primary recovery, waterflood, gas injection, infill drilling, horizontal wells, WAG process, artificial Lift
- Advanced EOR process such as pseudo miscible flood, polymer flood
- Hydraulic Fractures and Non Darcy Flow
- Sea water injection
- Multiple PVT regions





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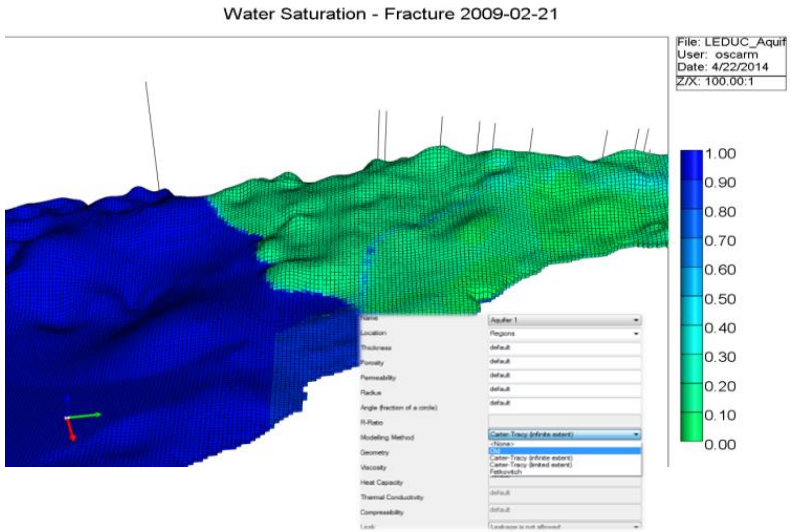
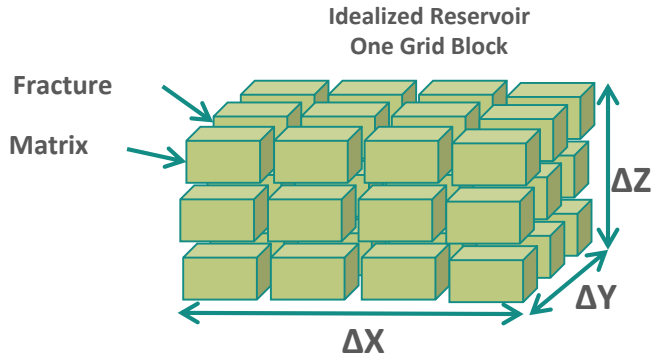
IMEX

Reservoir interactions:

- **Different aquifers model**
  - Analytical aquifer pressure support including Fetkovitch, Carter-Tracy
  - Bottom, boundary or edge drive with leak-off
  - Can apply Aquifer to reservoir boundary or grid boundary

- **Fractured Reservoirs**
  - Fracture-Matrix and Matrix-Matrix Connections
  - Dual Porosity and permeability





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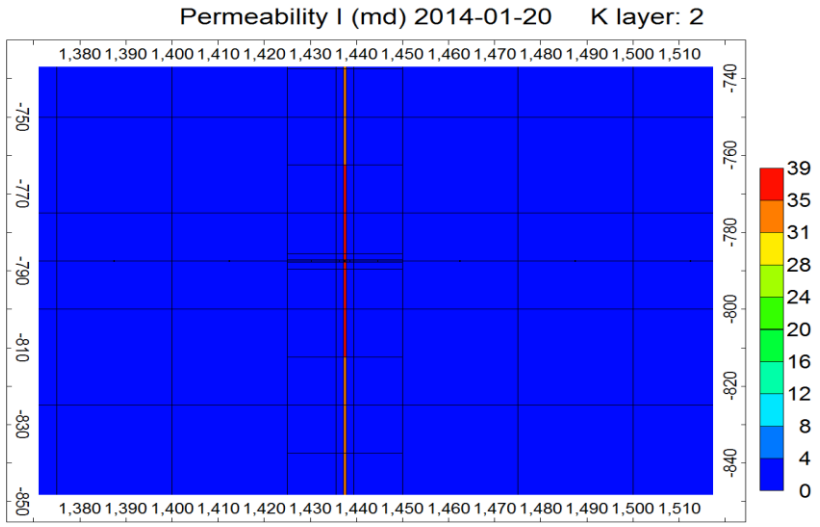
IMEX

Grid Features:

- **Block Groups**
  - Identify an arbitrary group of cells to be used for quick property modifications, or grid refinements
  - Allows for easier history matching or changing properties in and around fractures
- **New Fracture keywords**
  - Improved definition to reduce file size by 90%
  - Easy fracture property modification




```
*PLNRFRAC_TEMPLATE 'Template (Well-1 - Frac 1)'
   *PLNR_REFINE *INTO  5 5 1
      *BWHLEN 140
      *JDIR
      *INNERWIDTH 0.6096
      *LAYERSUP 1
      *LAYERSDOWN 1
      *K2INT 500
      *WF2 0.0005
   *PERMI MATRIX *FZ 39.3701 20.0
   *PERMJ MATRIX *FZ 39.3701 20.0
   *PERMK MATRIX *FZ 39.3701 20.0
*END_TEMPLATE

*PLNRFRAC 'Template (Well-1 - Frac 1)' 50,32,2 *BG_NAME 'Well-1 - Frac_1'
*PLNRFRAC 'Template (Well-1 - Frac 1)' 64,32,2 *BG_NAME 'Well-1 - Frac_3'
*PLNRFRAC 'Template (Well-1 - Frac 1)' 80,32,2 *BG_NAME 'Well-1 - Frac_5'
```

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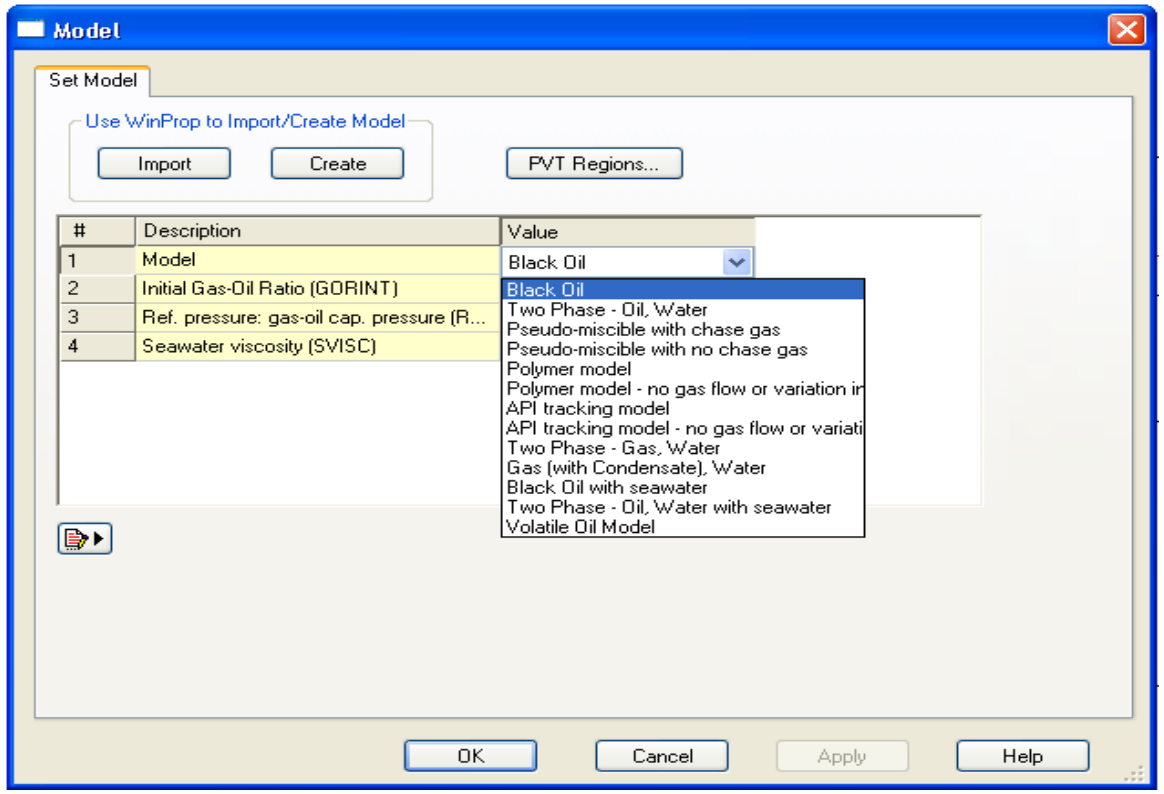
IMEX

Different Fluid model types:

- Black Oil
- Oil Water
- Pseudo-Miscible Processes
- Polymer Model
- API Tracking
- Solvent Model



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IMEX

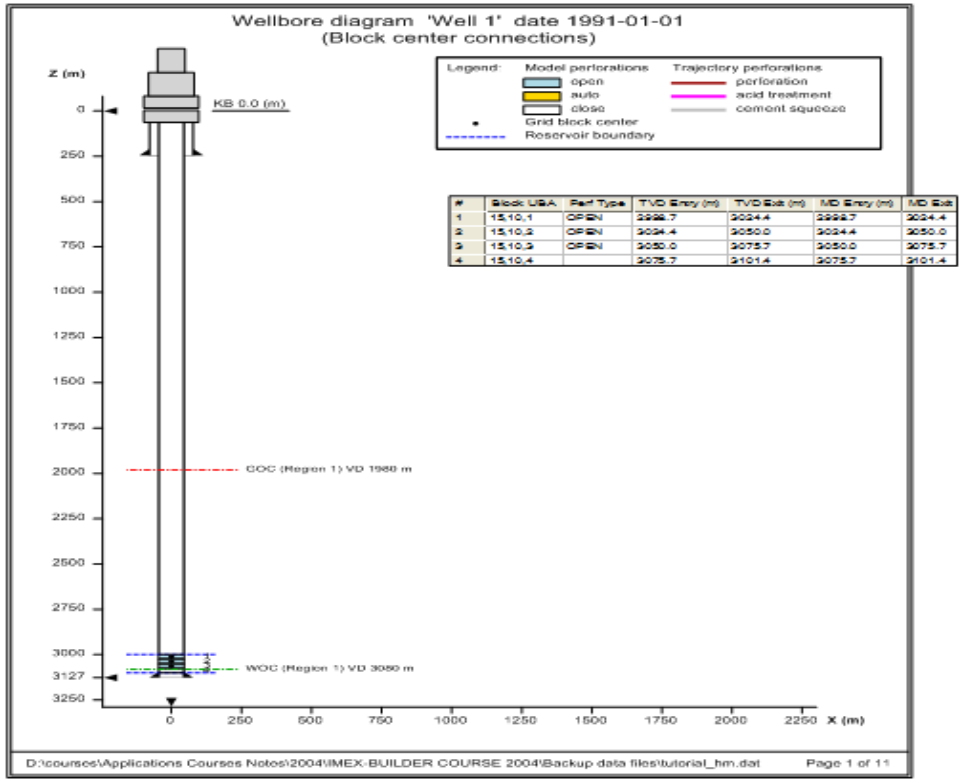
Sophisticated solvers & Technology to improve run time:

- **Parallelization**
  - Efficient simulation runs using larger number of threads on Shared Memory Processors Static
- **Static Amalgamation**

IMEX

Advanced well features:

- Artificial gas lift options
- Cross-flow among layers
- Vertical, horizontal or multi-lateral wells
- Perforations, stimulation, work over history, skin & turbulent effects
- Wellbore frictional loss



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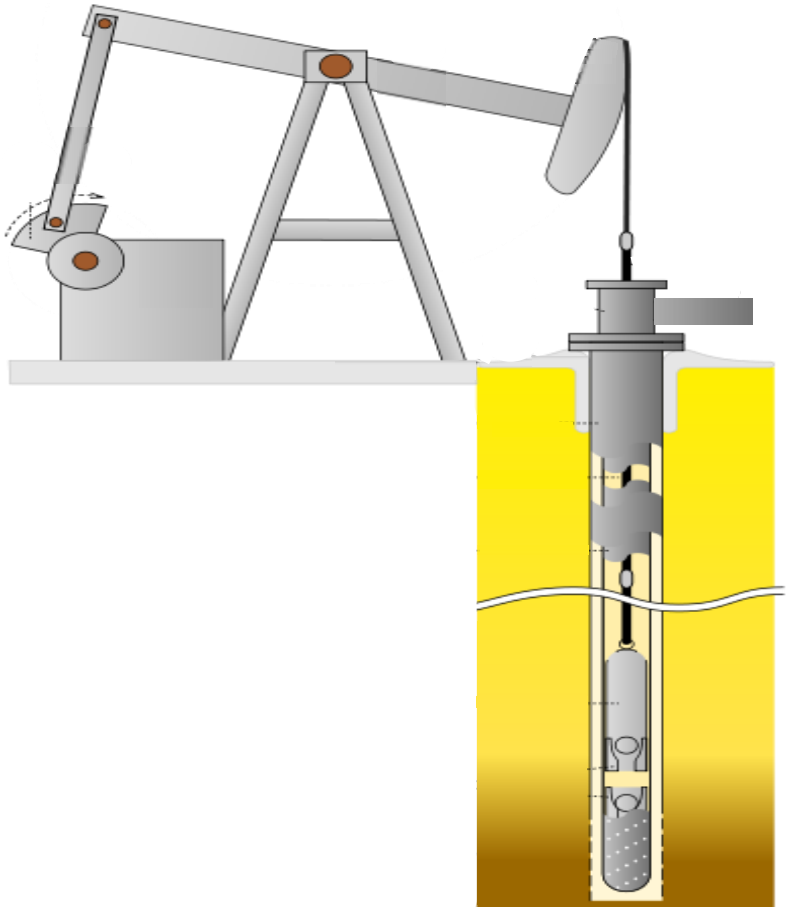
IMEX

Advanced well features:

- **Flexible Perforation and Well index input**
  - Specify well geometry globally
    - Eg. Applying a skin factor to a group of wells
  - Specify well index parameters on a per layer basis
  - Specify a range of acceptable WI values

IMEX

Intelligent Segmented Wells (iSegWell)



- Multiple Tubing Strings
- Tubing Opening/End
- DHS — Downhole Separator
- Compressor
- Pump
- Valve
- Orifice
- Choke
- Monitor Point
- Packer

Source: http://commons.wikimedia.org/wiki/File:Oil_well_scheme.svg

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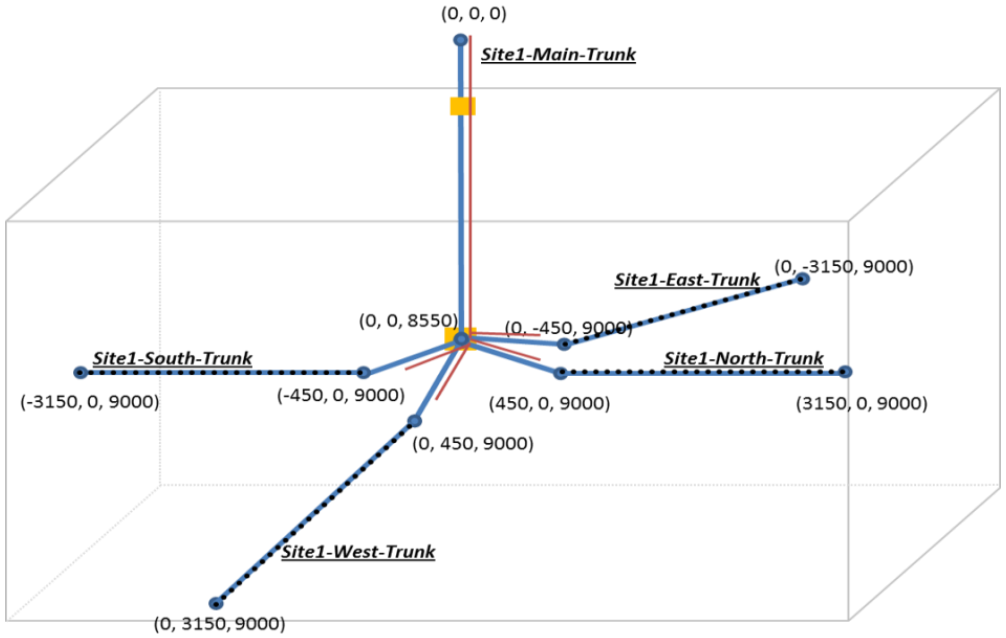
IMEX

iSegWell Main Features:

- **Secondary wells within a Wellsite can handle:**
  - Gas lift
  - Recirculating well
- **Complex Well Geometry**
  - Multiple Branches
  - Multiple Tubing Strings
  - Any Shape



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IMEX

iSegWell Main Features:

- Accurate ΔP calculation from wellsite perforations to the surface
- Modelling equipment (Compressor, Pump, Valve, Choke, Orifice, Downhole Separator)
- Smart w ells with passive control
- Smart wells with active control

IMEX

Couple IMEX to External software

- Perform wellbore calculations with external software
- Couple to surface facility software
- Example software
  - GAP Surface Network Model
  - FORGAS

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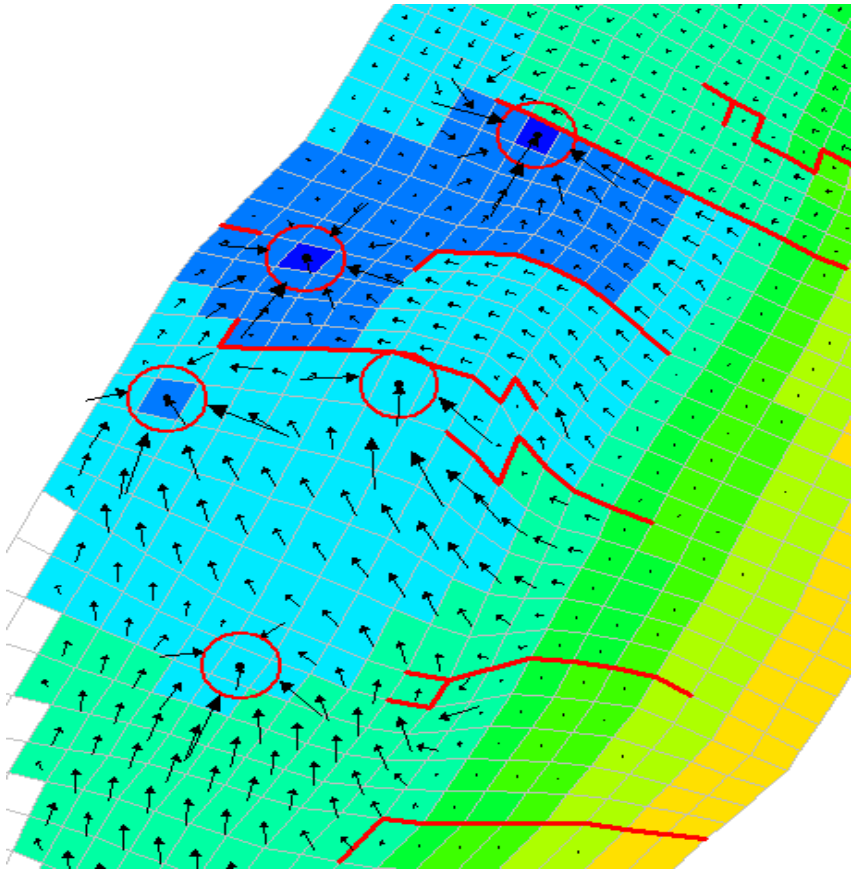
IMEX

Comprehensive graphical and text output

- Flux and velocity vectors as well as stream line representations
- User defined variables output
- Restart records for easy job resuming
- Efficient and fast calculation routines



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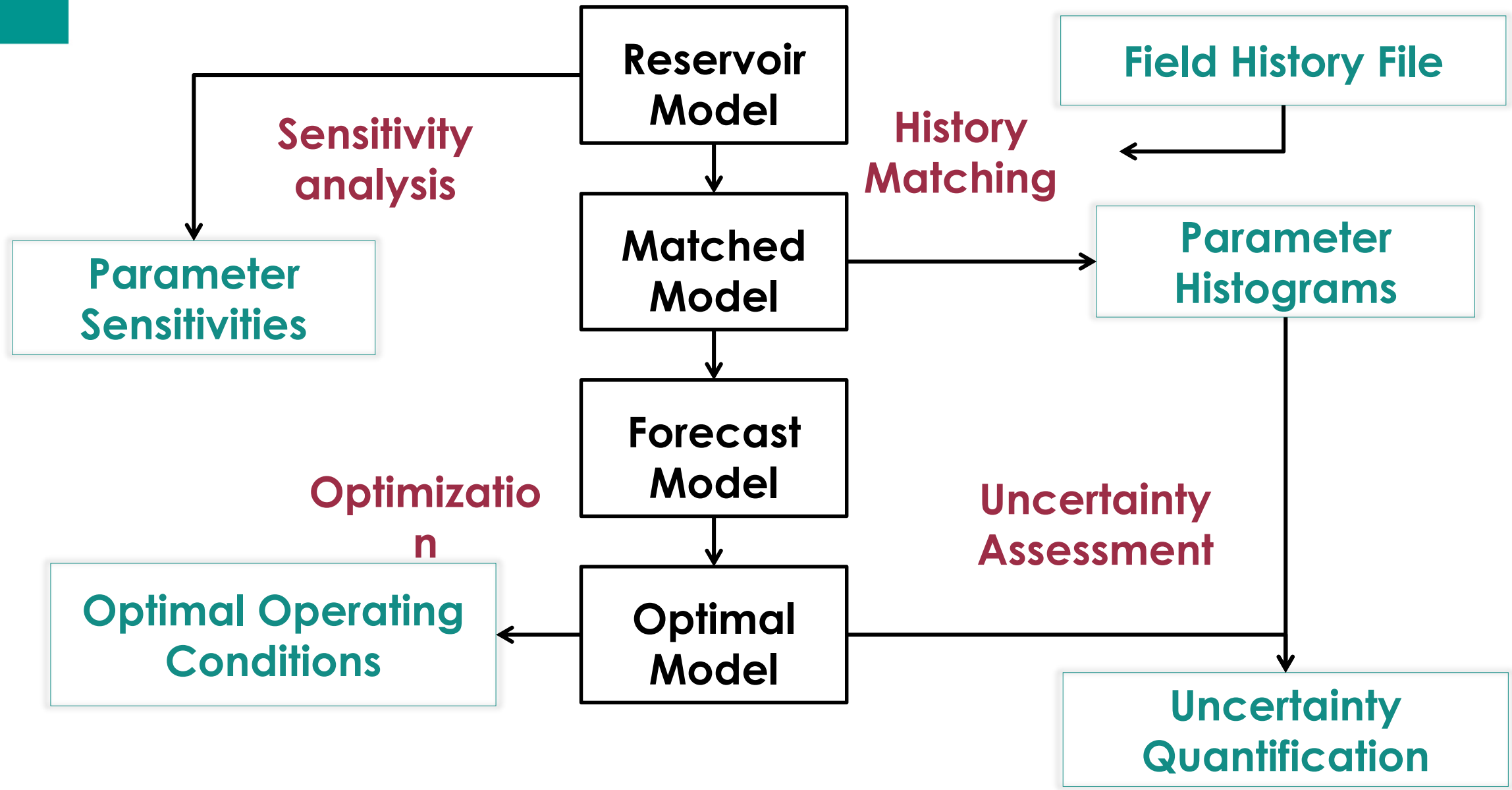
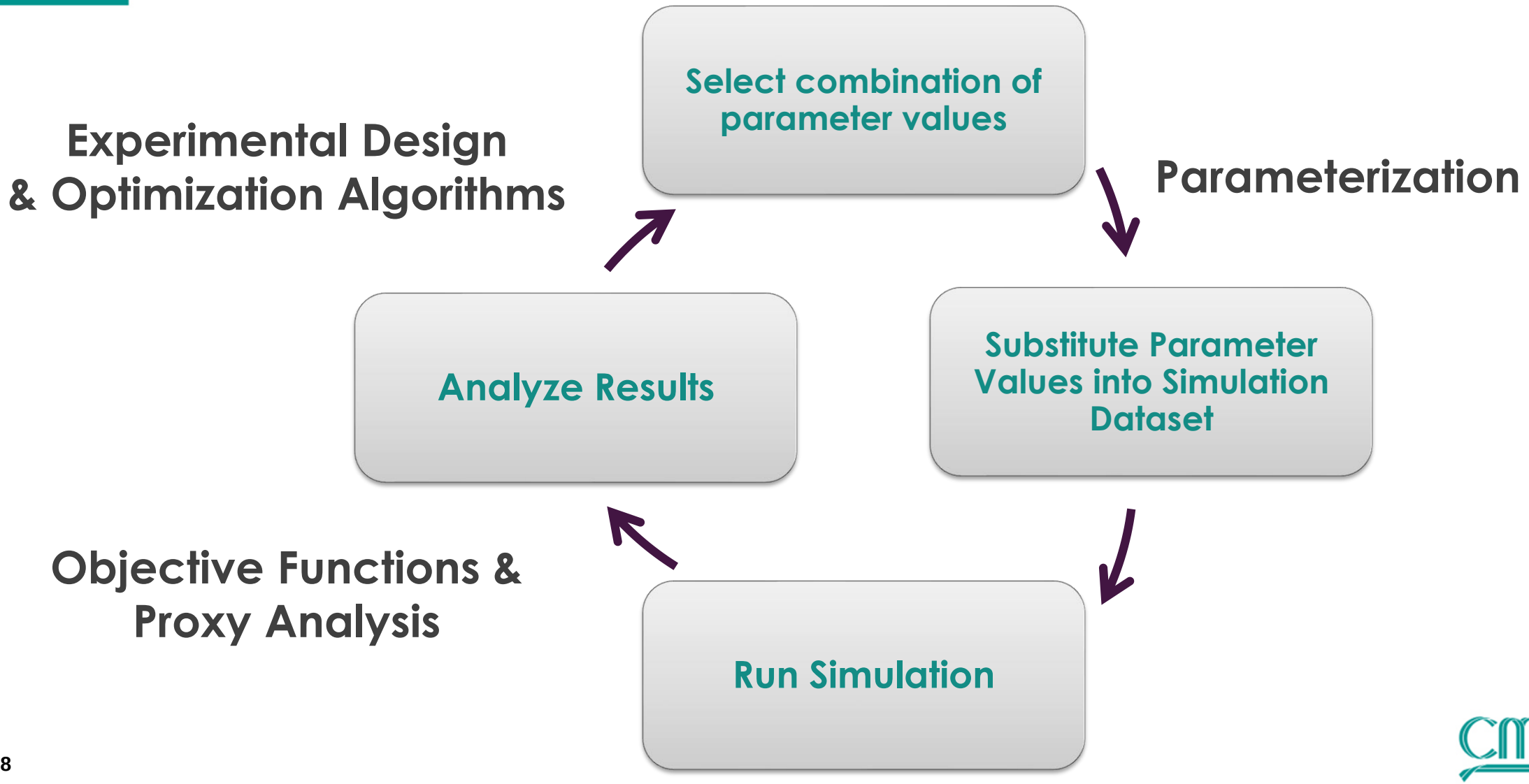
CMG Workflows for Uncertainty and Optimisation

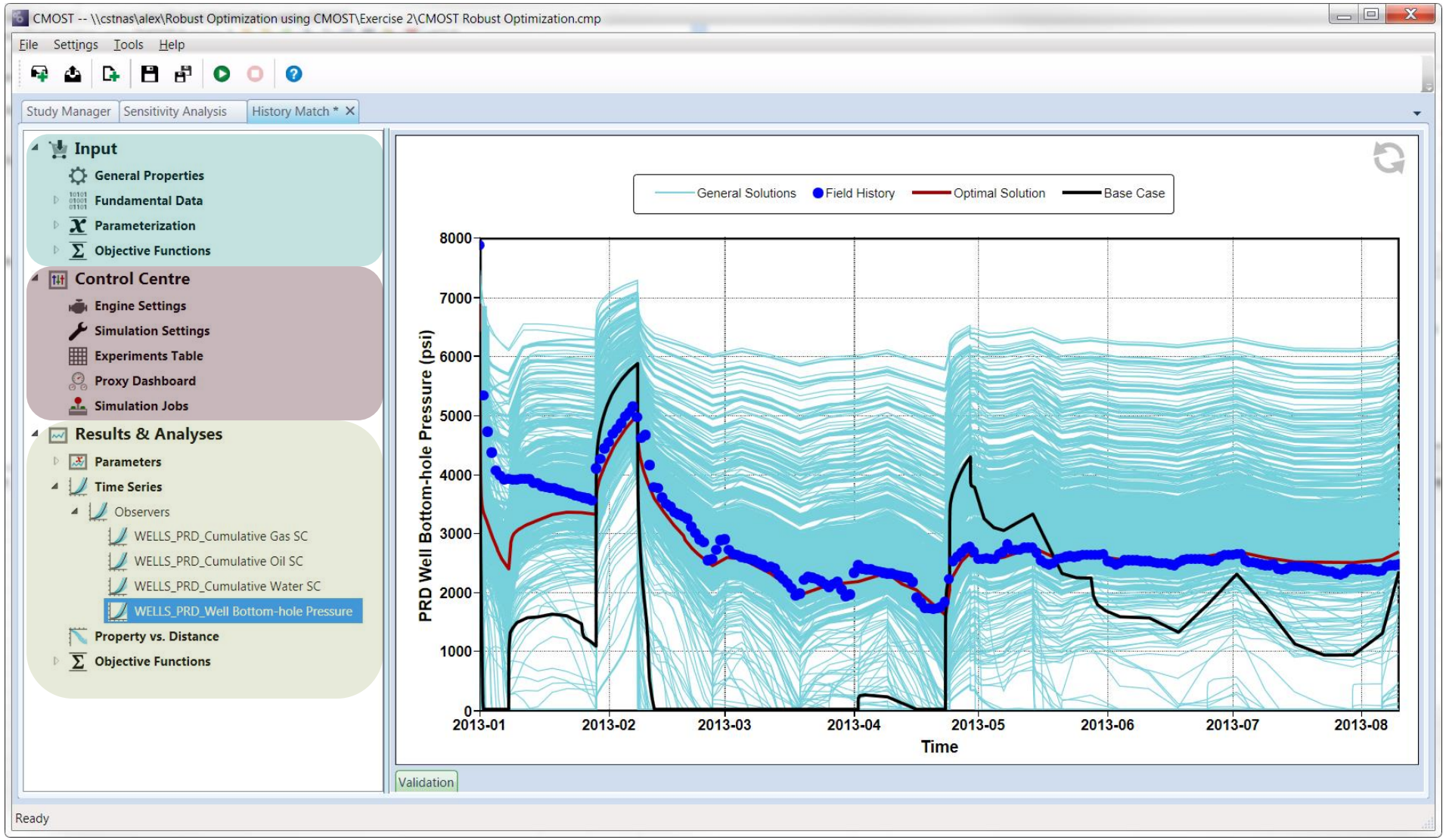
Typical Workflow for a Brown Field



CMOST Process



CMOST User Interface



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History Matching Goals

- In history matching, we are trying to reduce the error between the simulation results and field measured data
- By matching the simulation model to the historical behaviour, we have more confidence that the model will be able to predict future behavior
- When creating a simulation model, there may be uncertainty in the input parameters. These will be the parameters that should be adjusted when history matching

History Match Process

Select parameters to analyze

- E.g. porosity, permeability

Select range of values to analyze

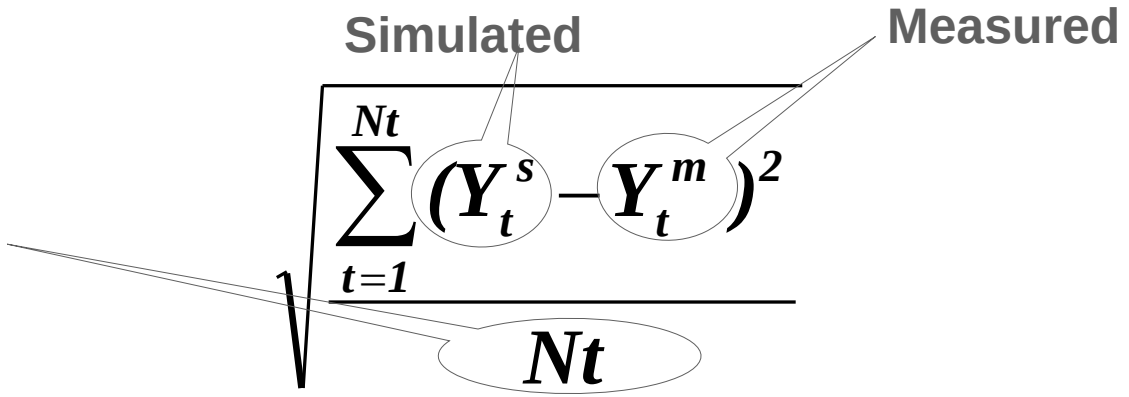
- E.g. between 20-30% porosity

Select results (Objective Functions) to match

- E.g. Cumulative Oil

CMOST will search for the best combination of parameter values that will give the lowest history match error

Calculating History Match Error



- For each measured data point, calculate different between simulation and measured result
- Square terms to make them positive
- Sum up all of the points at all times
- Divide by the number of measurements to get average square
- Square root to get average error