

SPE London Section Evening Meeting

Fractured Horizontal Well Decline

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The Geological Society, Piccadilly
London

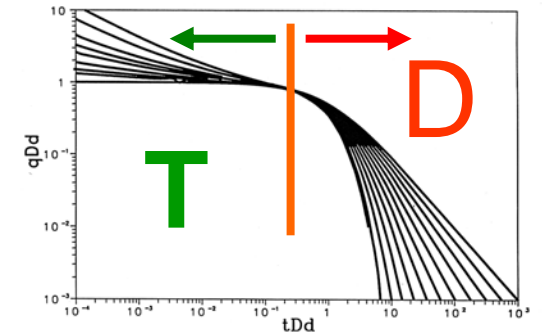
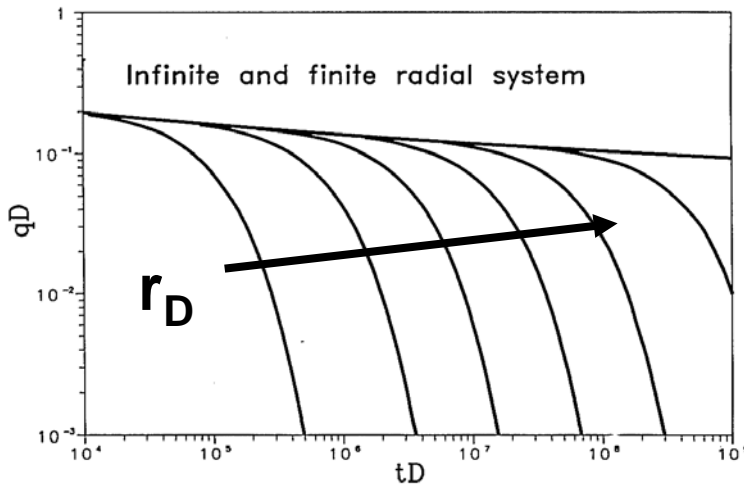
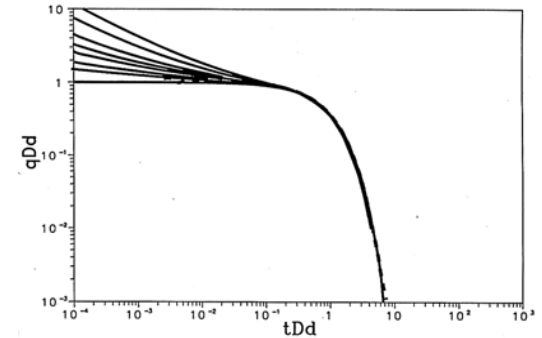
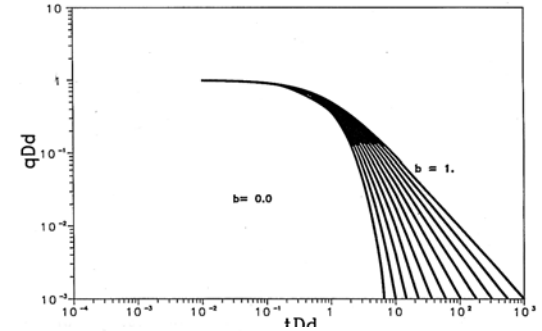
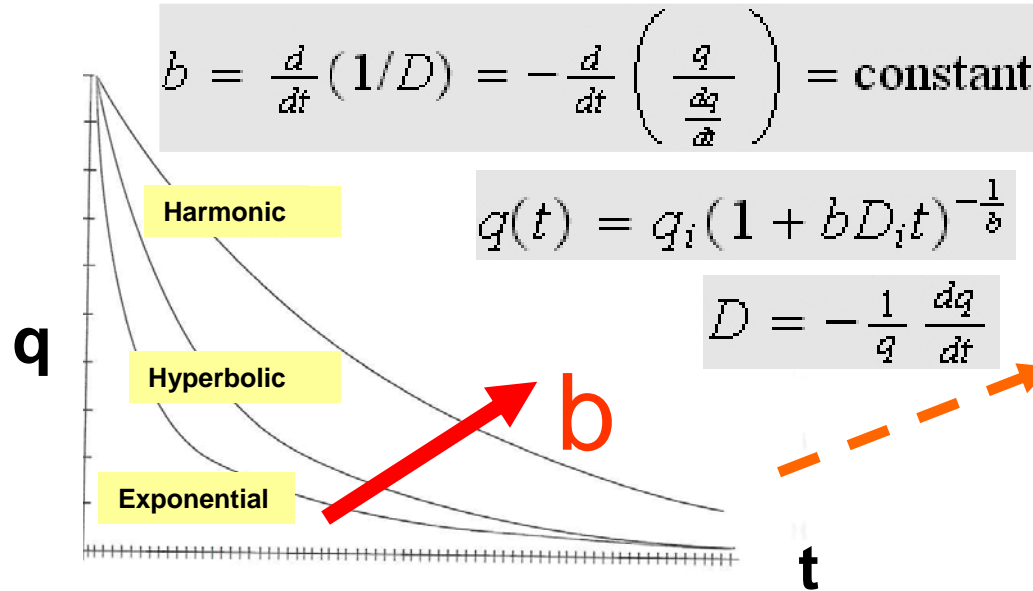
September 28th 2010

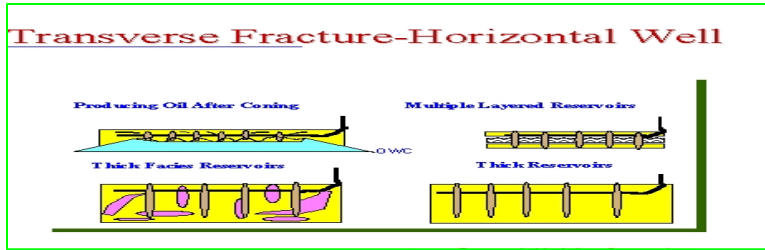
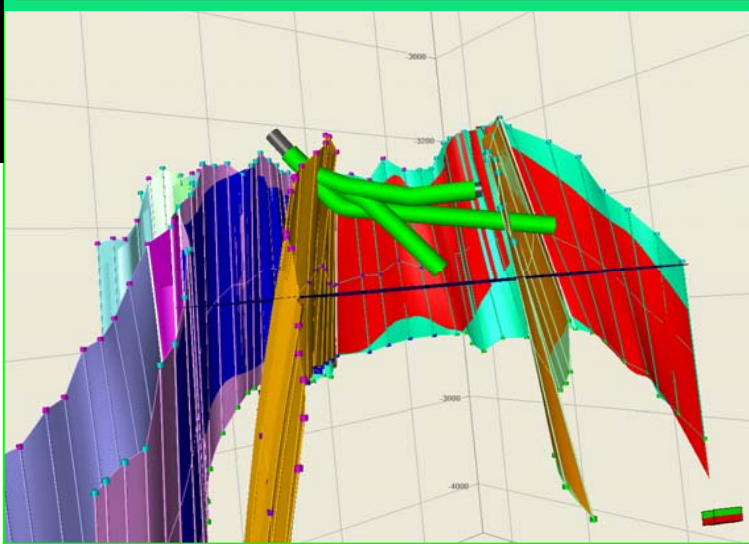
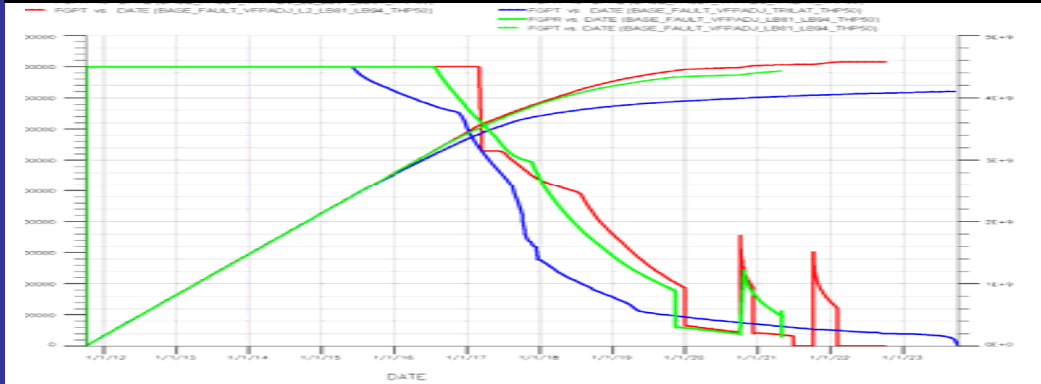
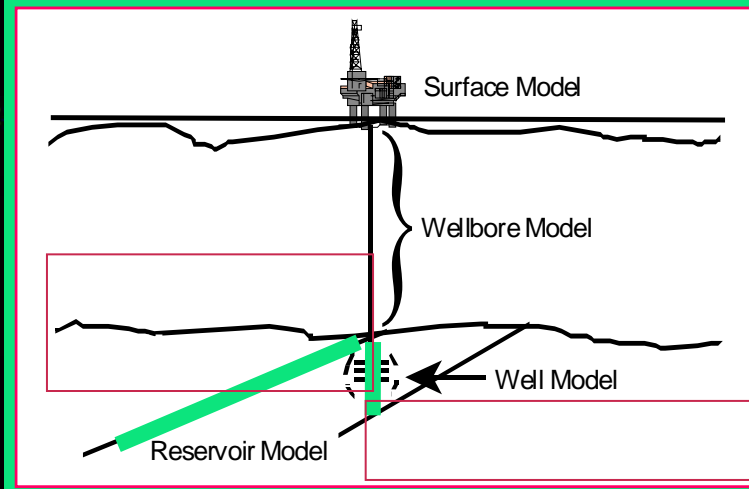
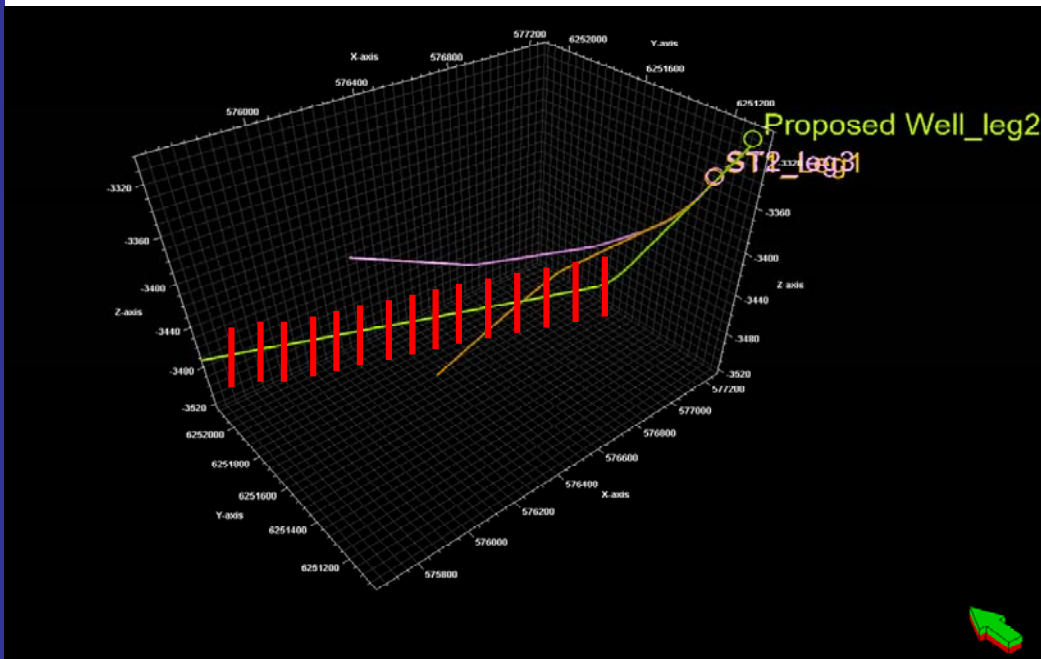
Overview of Presentation

- Motivation
- Objectives
- Main Challenges
- Implementation - Type Curves
- Model Validations - Case Studies
- Model Summary
- Risk Analysis Workflow
- Concluding Remarks
- Acknowledgments

Rate - Time Type Curves

- Empirical Arps' rate-time curves (1945)
- Fetkovich's composite transient-depletion rate-time curves (1973, 1980)





Overall Objectives

Fractured horizontal well model

- Full-time scope screening analysis tool for modelling of flow from a reservoir to a fractured well
- Selected pressure-rate wellbore conditions with late-time approximations
- Validation (case studies with model comparisons)
- Risk Analysis Workflow

Main Challenges

Horizontal well with fractures

- Modelling features
 - Design-integration
 - Validation
- Model
 - Changing IBC
 - From constant rate to constant pressure
- Fracture responses
- Late time approximations
 - Equivalent well radius
 - Equivalent fracture half-length

Late-Time Approximations for Rates

(Horizontal Well with N Fractures)

N	r	r_{wv}		Approximations
1		r_{wv1}	$= \frac{L_f}{e}$	
2	$\frac{L}{L_f}$	r_{wv2}	$= \frac{L_f}{e} (1 + r^2)^{\frac{1}{4}} e^{\frac{1}{2} r \cot^{-1} r}$	$\frac{L_f}{e} e^{\frac{1}{2}} r^{\frac{1}{2}}$
3	$\frac{L}{2L_f}$	r_{wv3}	$= \frac{L_f}{e} \exp \left\{ \frac{2 \left[r \cot^{-1} r + \frac{1}{2} \log(1 + r^2) \right]^2}{2r \cot^{-1} \frac{2r^3}{1 + 3r^2} + \frac{1}{2} \log \frac{(1 + r^2)^4}{1 + 4r^2}} \right\}$	$\frac{L_f}{e} 2^{\frac{2}{9}} e^{\frac{4}{3}} r^{\frac{2}{3}}$

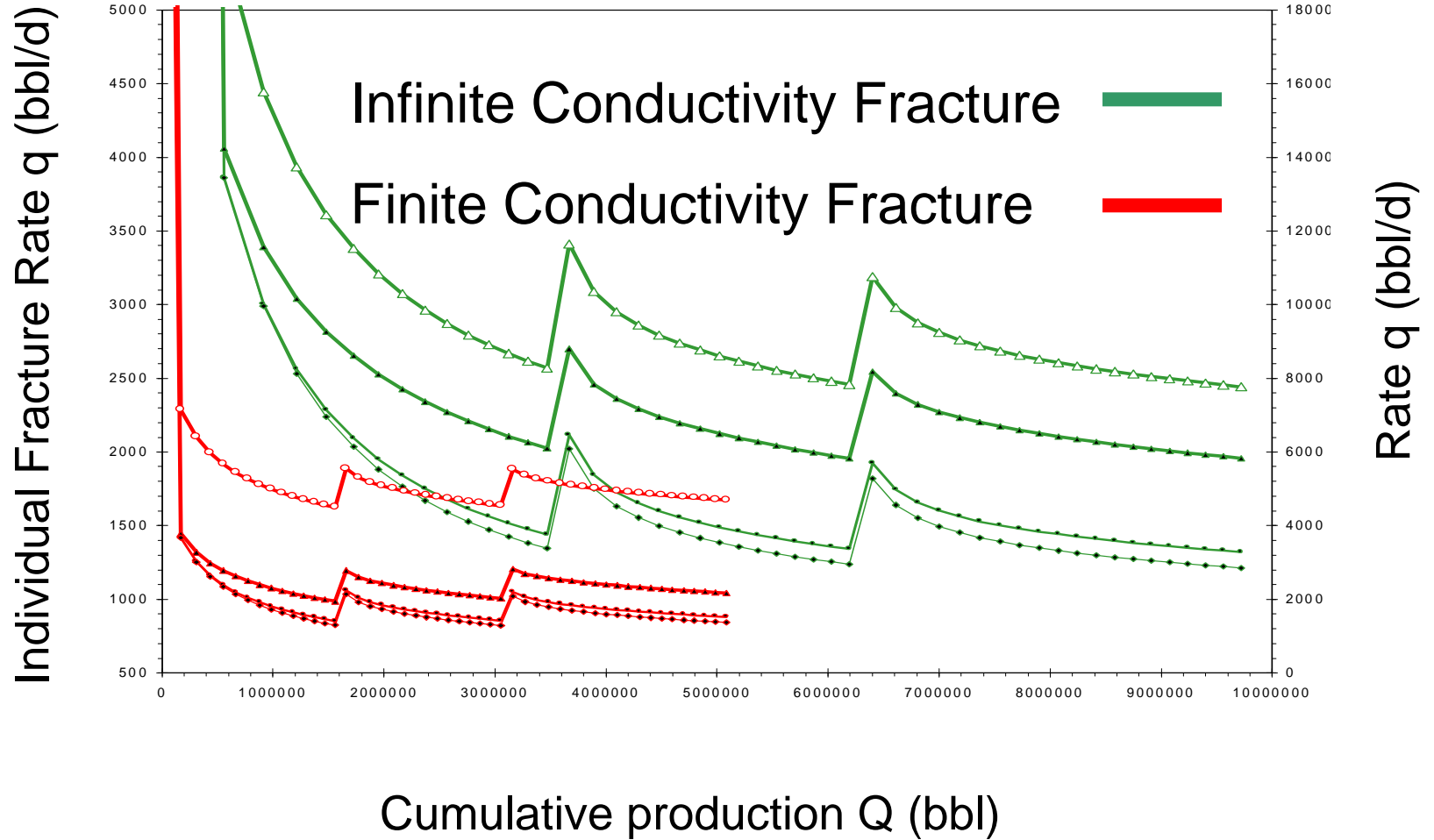
Reservoir, Well and Fracture Input

(Horizontal Well with N Fractures)

- **Reservoir**
 - Isotropic
 - Non-isotropic
- **Horizontal well**
 - No flow to the wellbore
 - Direct flow to the wellbore
 - Wellbore friction
- **Model Boundary Conditions**
 - Inner BC
 - Outer BC

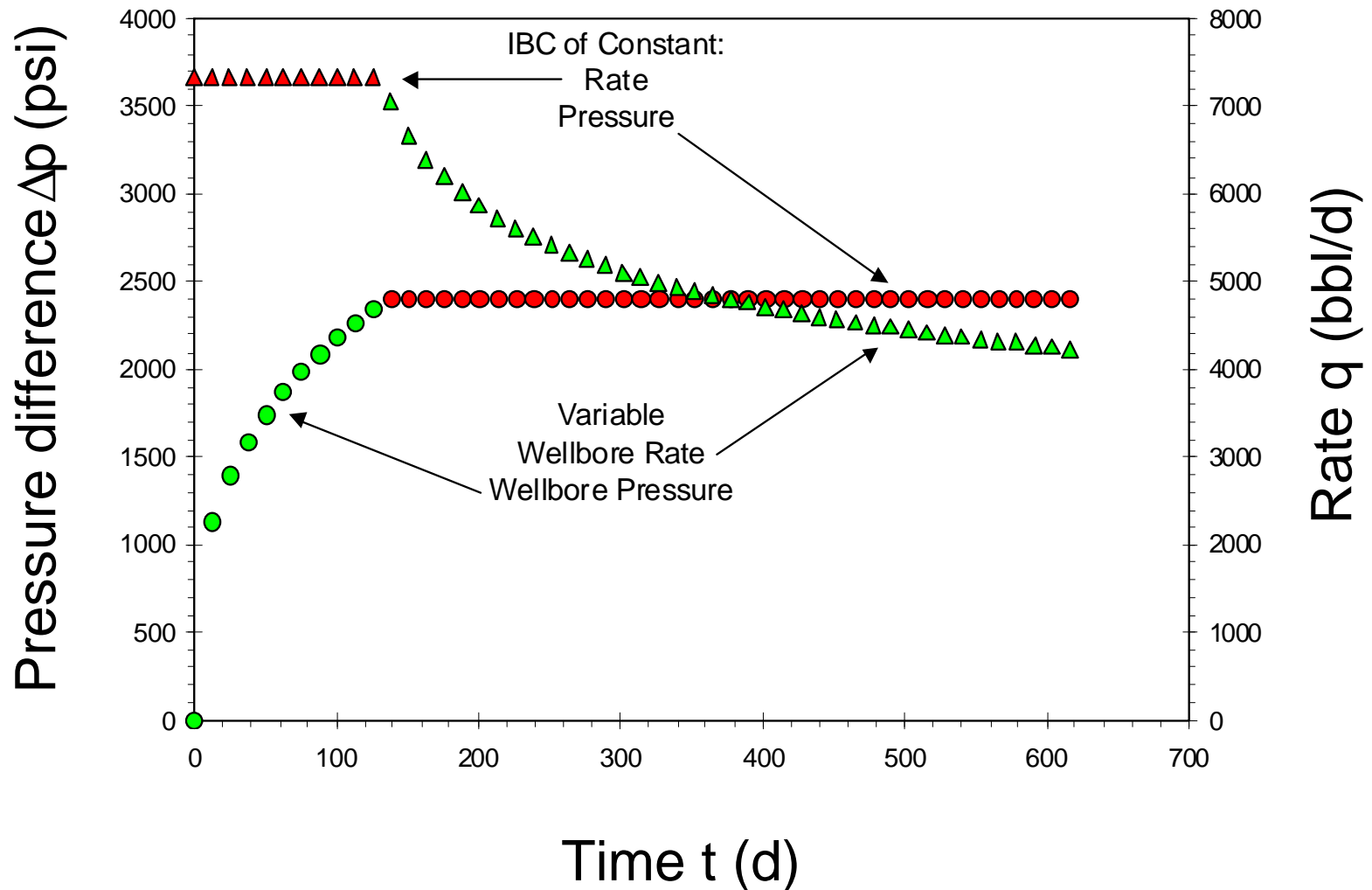
Stepwise Constant Pressure IBC

(3 intervals)

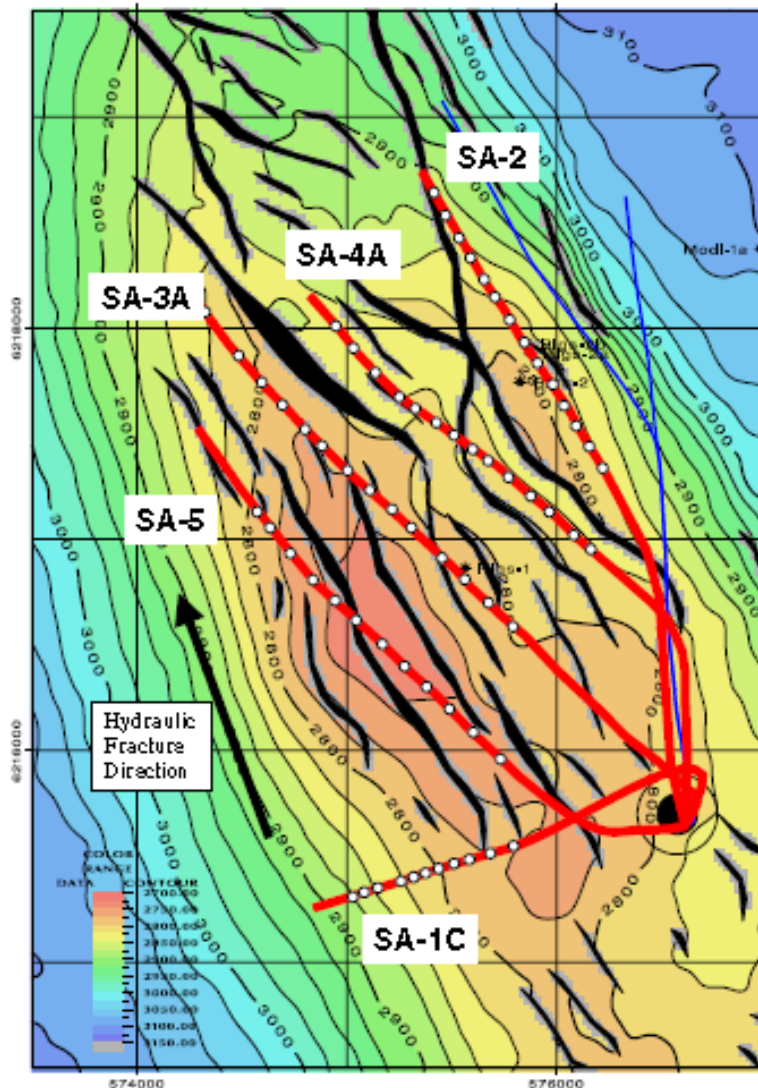


- ▲ Fracture qfr1 and qfr5 - infinite conductivity flow
- ◆ Fracture qfr3 - infinite conductivity flow
- Fracture qfr2 and qfr4 - infinite conductivity flow
- ▲ Fracture qfr1 and qfr5 - finite conductivity flow
- ◆ Fracture qfr3 - finite conductivity flow
- Fracture qfr2 and qfr4 - finite conductivity flow
- ▲ Rate, q infinite conductivity fractures
- Rate, q finite conductivity fractures

IBC Changing from Constant Rate to Constant Pressure

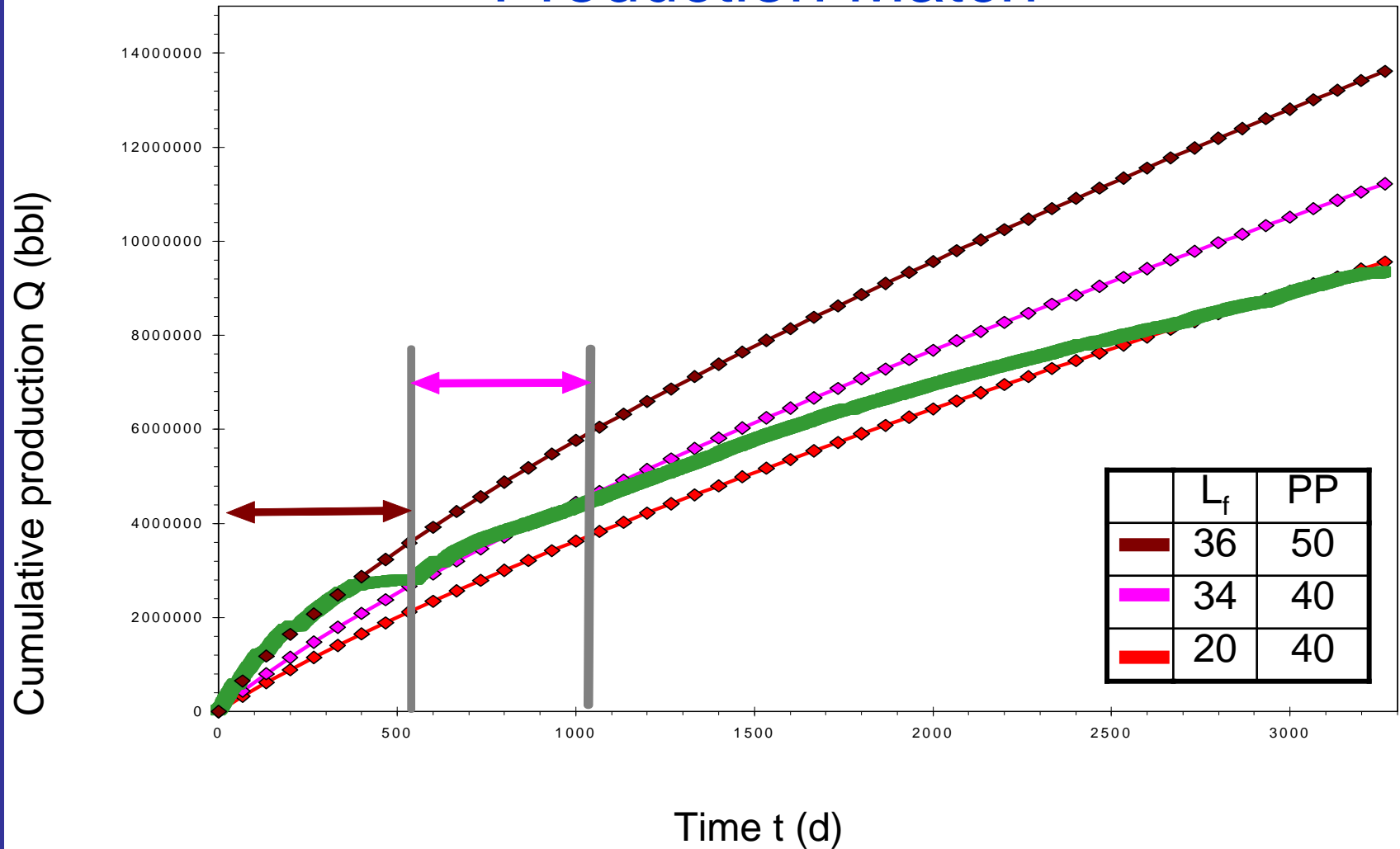


Field A - North Sea

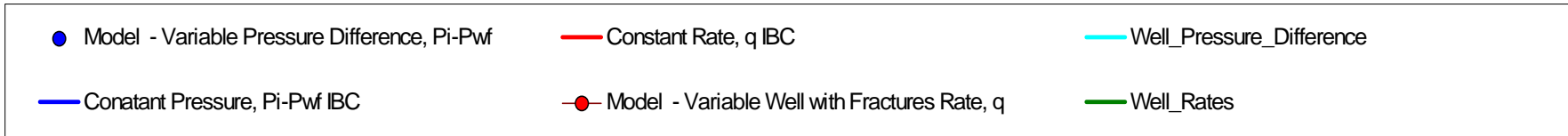
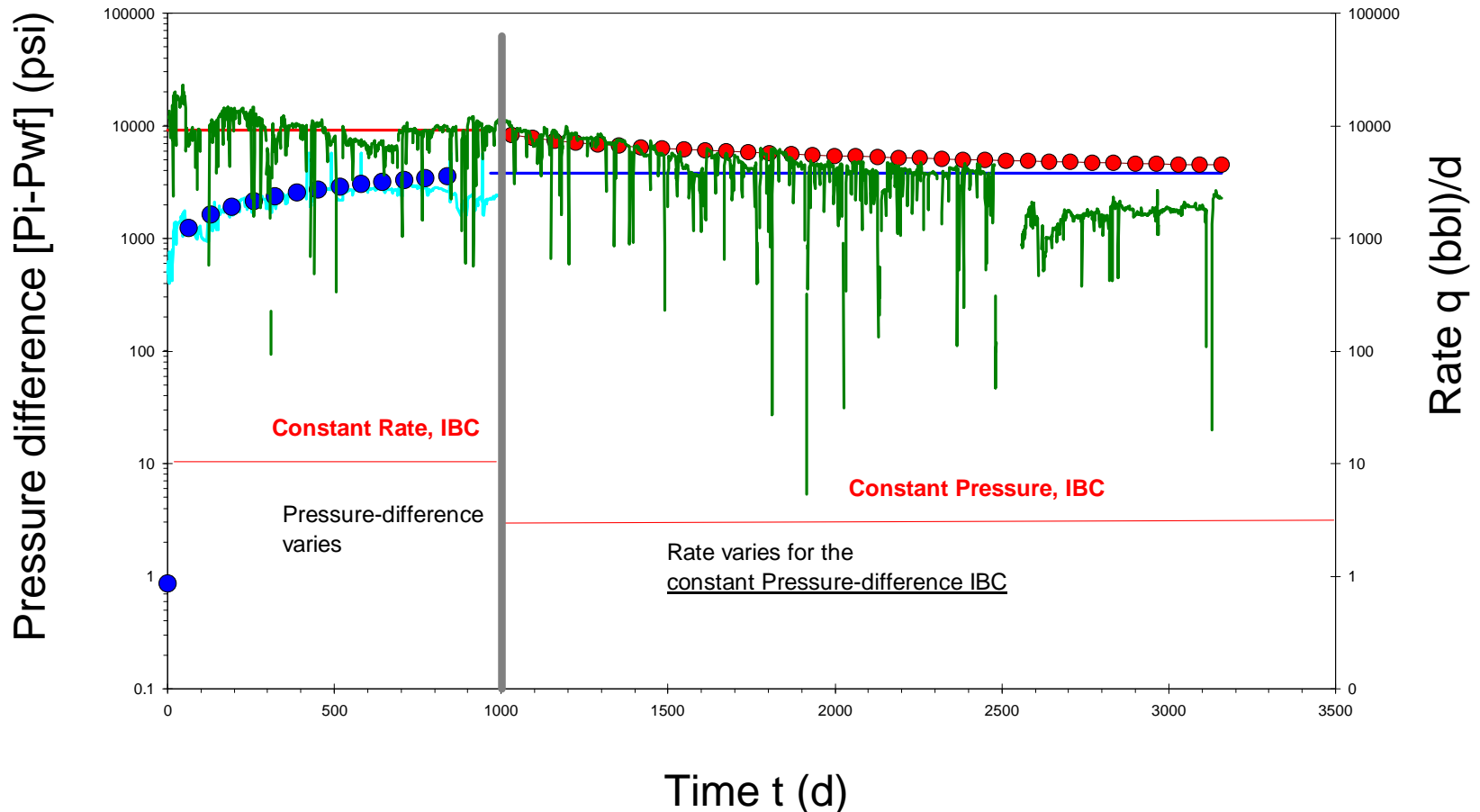


- Horizontal well with fractures
 - 9 injection wells
 - 11 production wells
- Provided data for:
 - 2-oil production wells
 - 14 fractures
 - A water injection well
 - 16 fractures

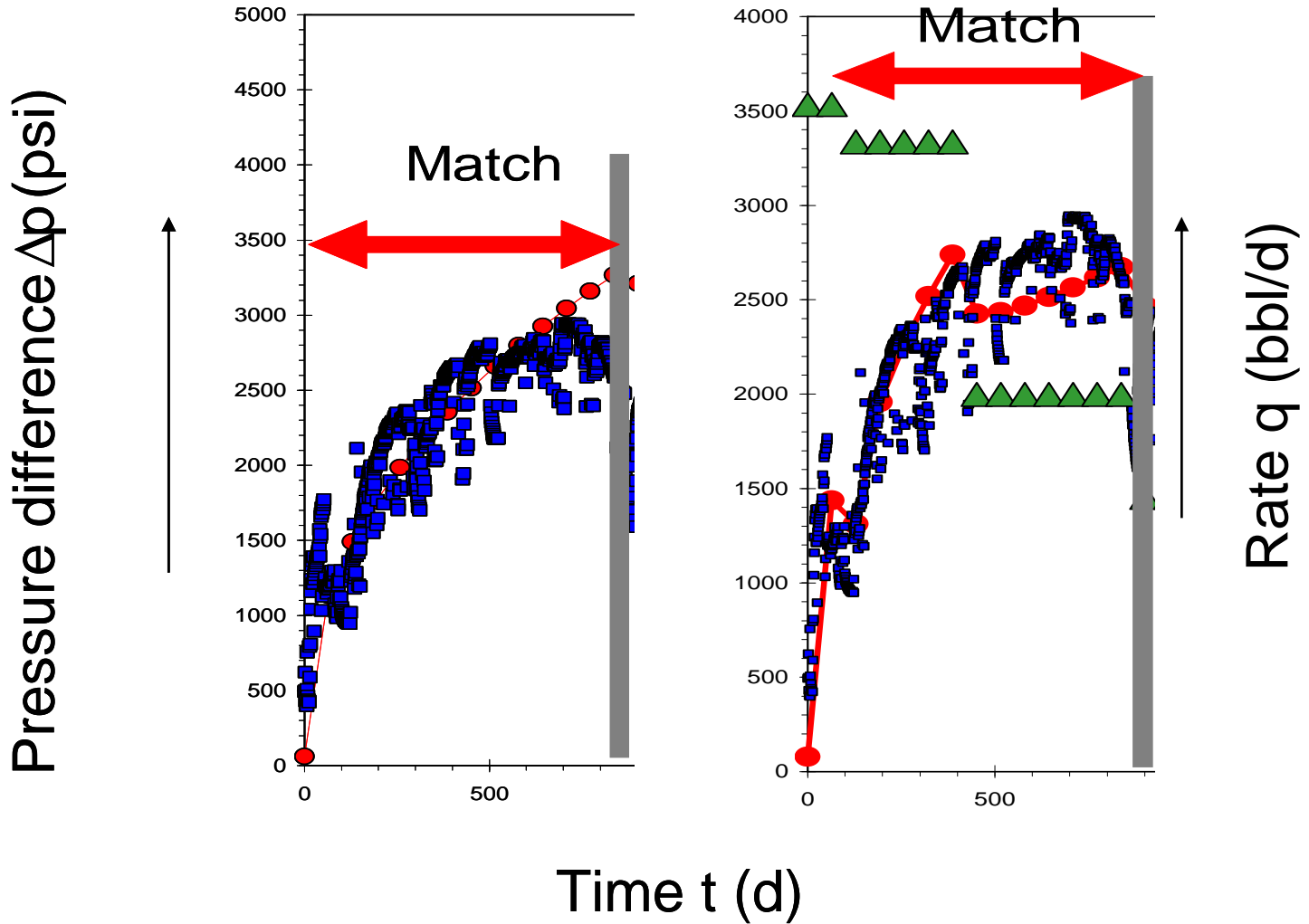
The Model vs. Observed Cumulative Production Match



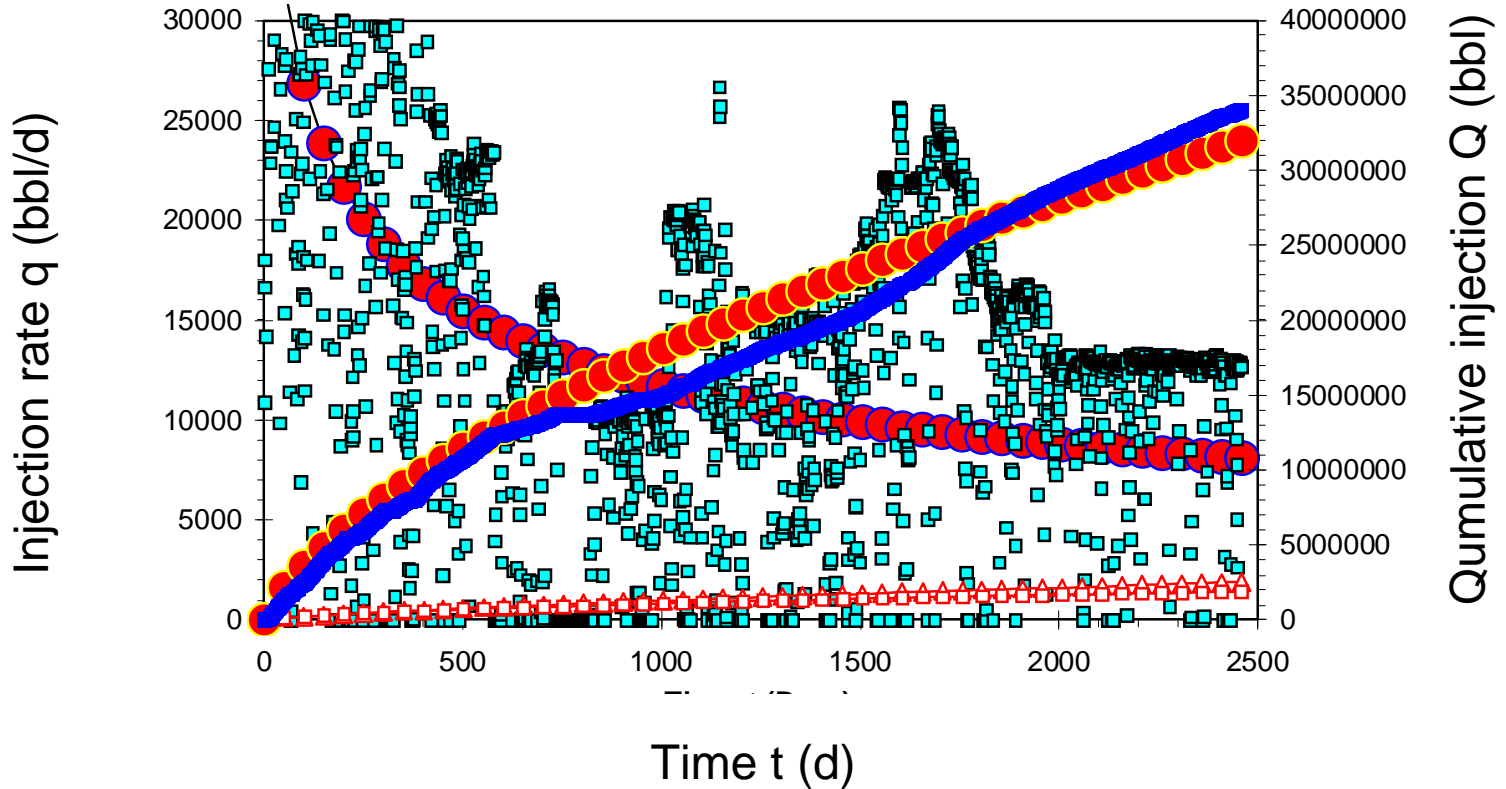
IBC Changing from Constant Rate to Constant Pressure



Stepwise Constant Rate IBC (1 and 3 intervals)

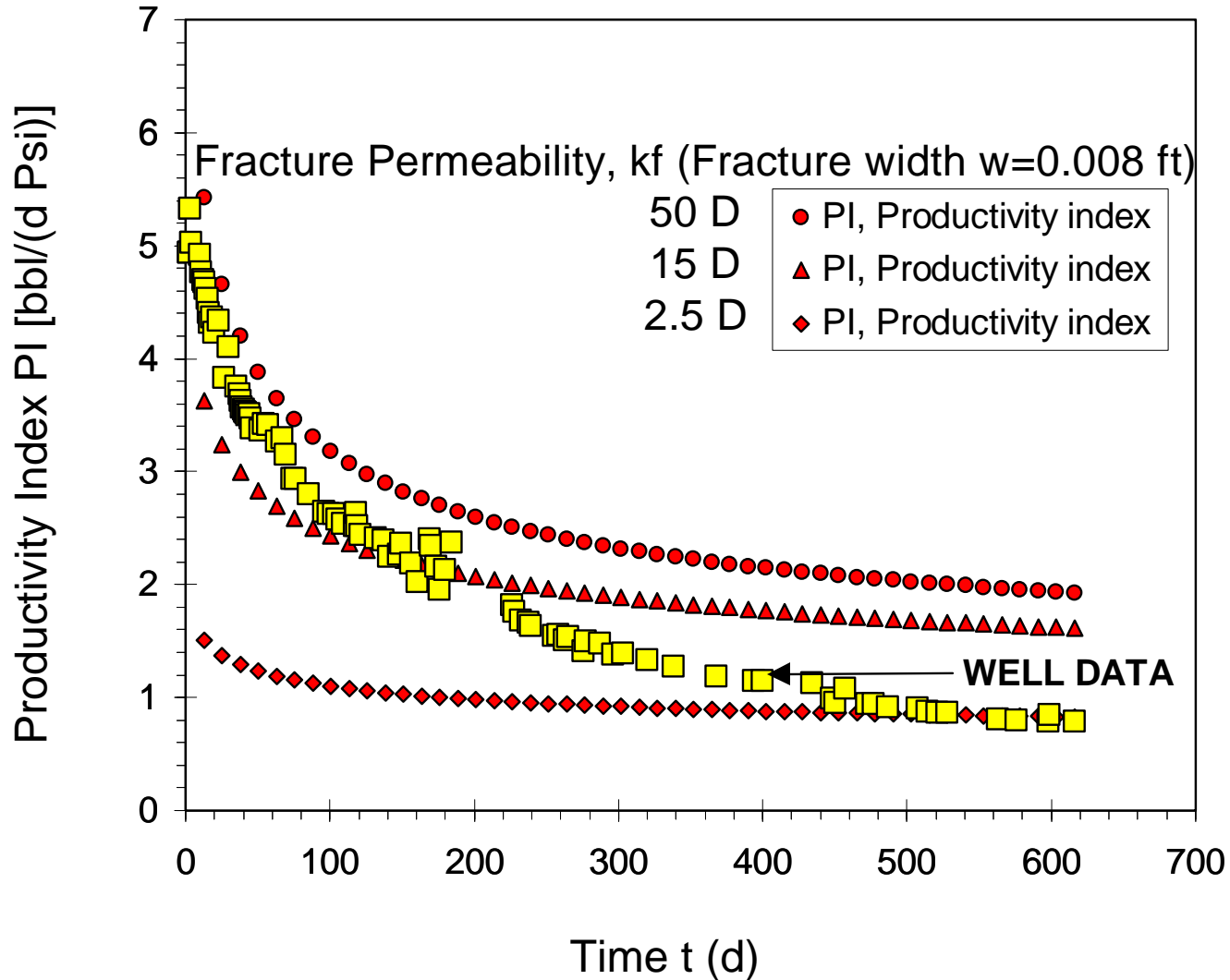


Water Injection Case



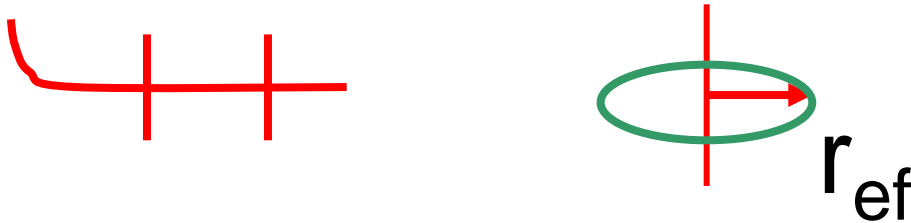
- Model - Water injection rate, q_w
- Water Injection Rate
- Model - Cumulative water injection, Q_w
- △— Fracture injection rate (equal for fracture 1 and 14)
- Fracture injection rate (equal for fracture 7 and 8)
- Well cumulative water injection

Field V - North Sea



Late-Time Approximations for Rates

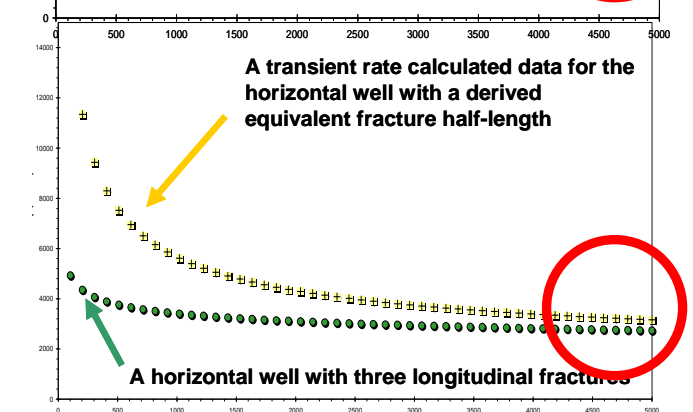
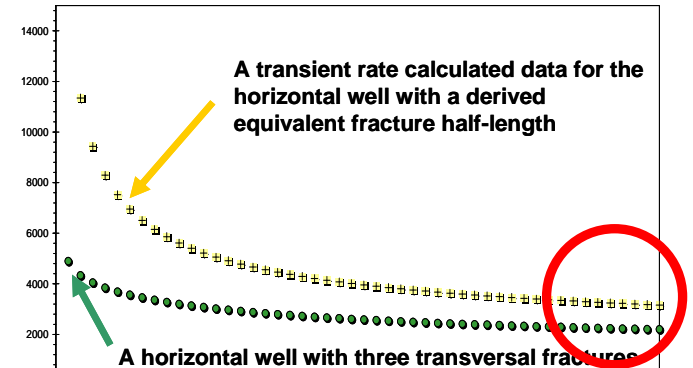
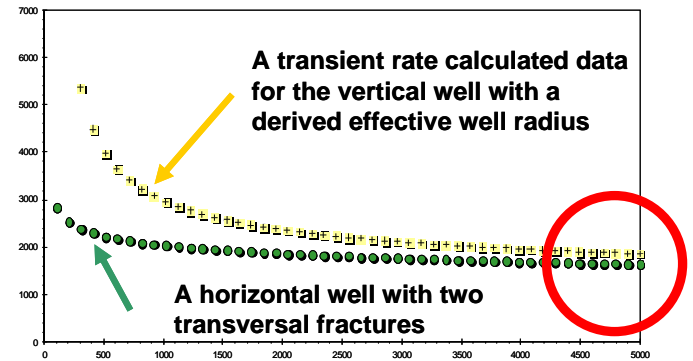
Rate vs. time match for:



- A fractured horizontal well (2 transversal fractures) vs. vertical well with calculated effective radius

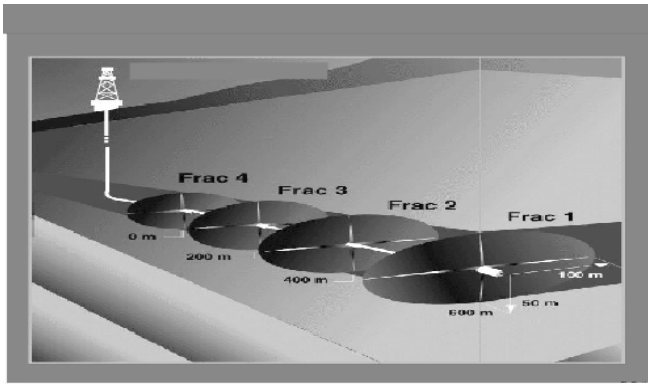


- A fractured horizontal well (3-transversal fractures) vs. a single transversal fractured horizontal well with calculated effective half-length
- A fractured horizontal well (3-longitudinal fractures) vs. a single longitudinal fractured horizontal well with calculated effective half-length



The Horizontal Fractured Well Model- Concluding Remarks

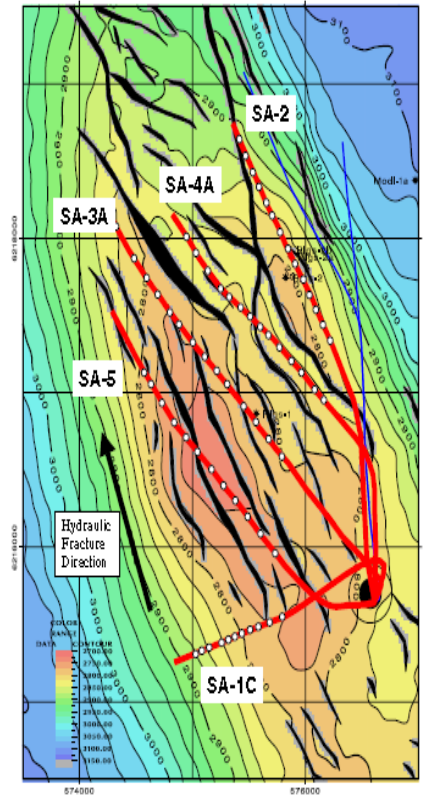
- A fast and robust algorithm is developed
 - transient (SLAB model)
 - basic depletion (BOX model)
- The bringing together of
 - rate-time and
 - pressure-time analyses
- The semi-analytical tool aids in
 - optimizing the well production
 - screening analysis
 - the late-time approximations were verified



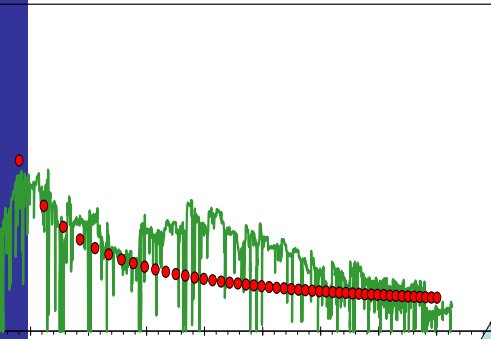
Define the Model

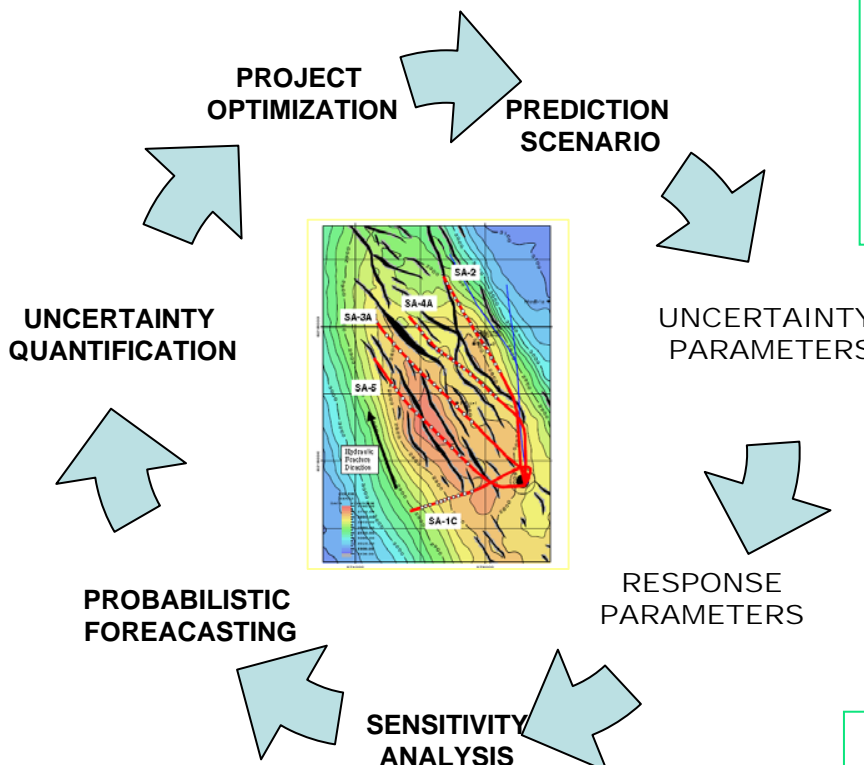
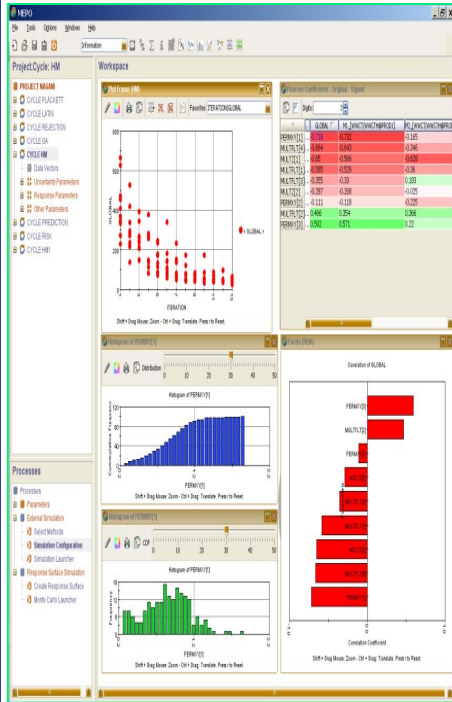
Gathering Data

Semi-Analytical Simulations
Of the Provided Input
Using the Model Results
Match Observed Well
with Fractures Data

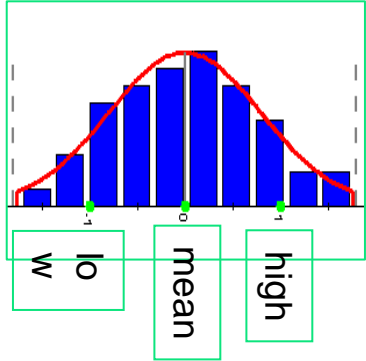


Phase A: Matching production profiles for the Fixed Number of Fractures



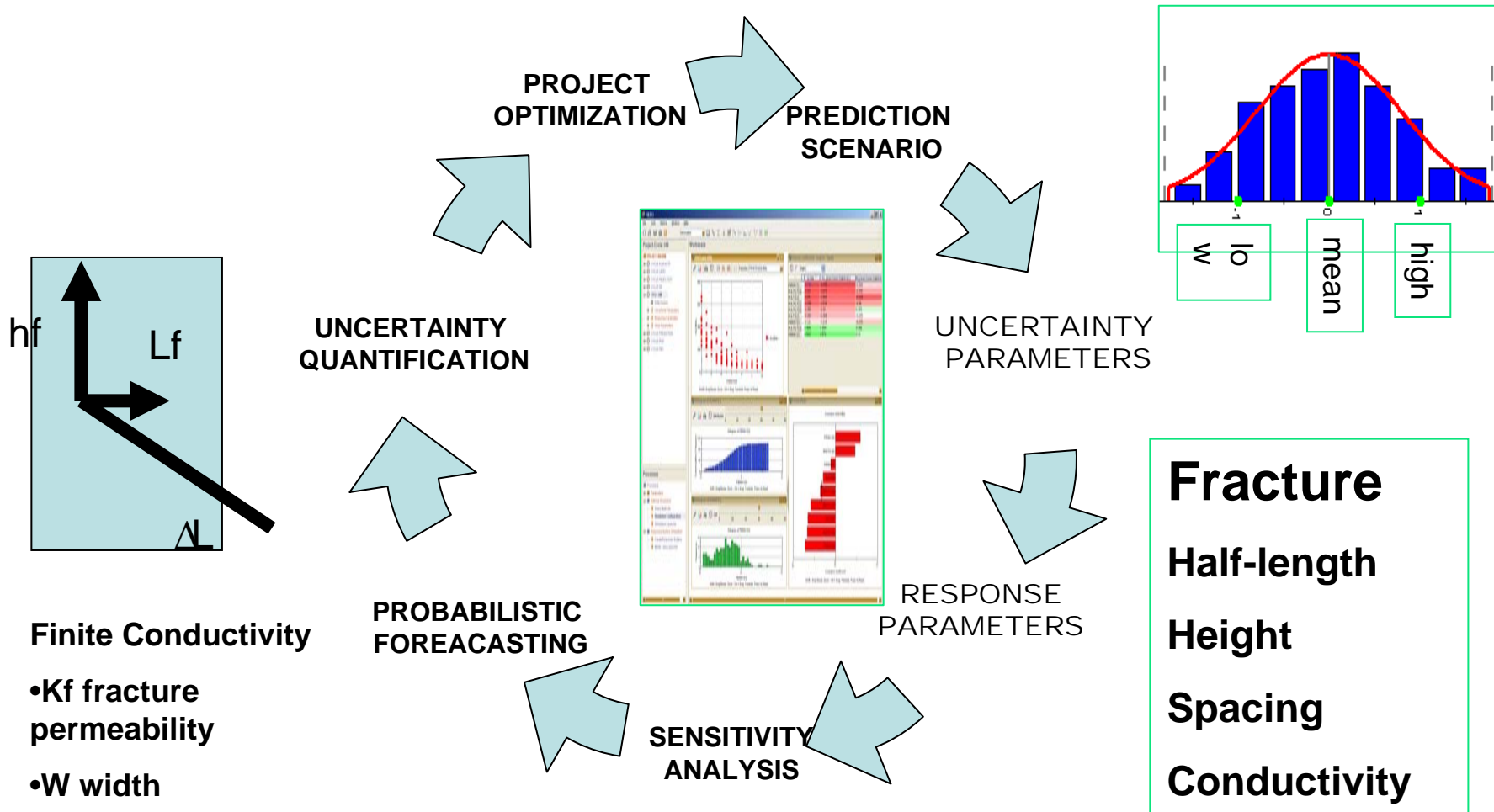


•Define 'Base Case Model'-pre-screening process



Reservoir data
Fracture data
Well data

Phase B: Screening Analysis and Optimizing Number of Transversal Fractures Positioned Along a Horizontal Well



Phase C: History Match of Observed Well Data with the Model Obtained Data

Fracture Diagnosis Analyses

- Study is based on the screening analysis of a horizontal well with fractures production data.
- Prognosis profiles were generated manually and compared to the real observed data.
- Study provides workflow for optimising number of fractures along a horizontal well.
- Matching procedure should be further improved with risking tool features for the fracture closure diagnosis.
- The semi-analytical model for a multiple-fractured-horizontal well, was applied providing fast and robust features and were used as screening tools for diagnostic and forecasting purposes.

Recommendations

Fractured horizontal well model limitations

- Reservoir
 - Heterogeneous features
- Fracture
 - orientation
- Well
 - Undulating well
- Gas extension
 - including non-Darcy flow
- Further modelling features
 - multiple well approach
 - Multilateral
- Combaining the risk analysis with the network simulation
 - Linking the semy-analytical model to the risk analysis software (commercial SW tool as MEPPPO SPT-Group Kjeller Norway)
 - Linking the semy-analytical model to a network model (METTE – Yggdrasil A/S, Oslo Norway)

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