Navigating the Changing World of Reserves and Resources in the Context of the PRMS

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An Integrated "Model-Based" Methodology to Construct Type-Well Profiles in Unconventional Reservoirs

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Presentation Outline:

- Introduction
- Methodology for constructing type well profiles
- Diagnostics of production performance
- Utilization of rate-transient analysis
- Incorporation of fracture modeling
- Production profiles based on specific well completions and spacing
- Summary and conclusions

Introduction:

Challenges Associated with Engineering Aspects of Unconventional Reservoirs

Reservoir Characterization
- In-place volume
- Thermal maturity (PVT)
- Natural fractures
- In-situ stresses
- Lateral landing point
- Fracture dimensions
- Mineralogy/brittleness
- Reservoir pressure

Completion Design and Efficiency
- Fracturing fluids
- Proppant types and amounts
- Number of stages/clusters
- Flowback/choke management
- Fracture properties…

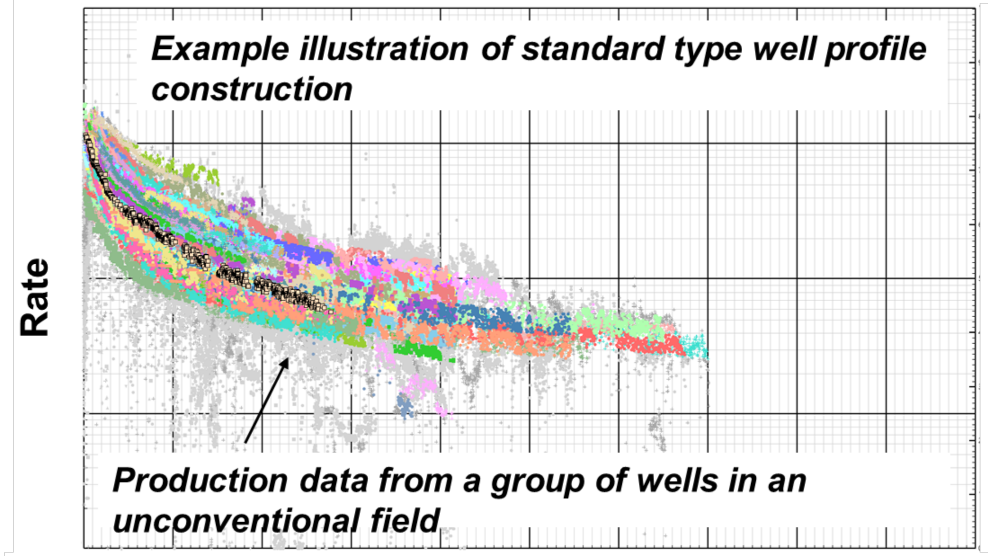
Well Performance Analysis
- Flowback evaluation
- Flow regime identification
- Data driven models
- Rate transient analysis
- Reservoir/fracture modeling
- Well interference/fracture hits

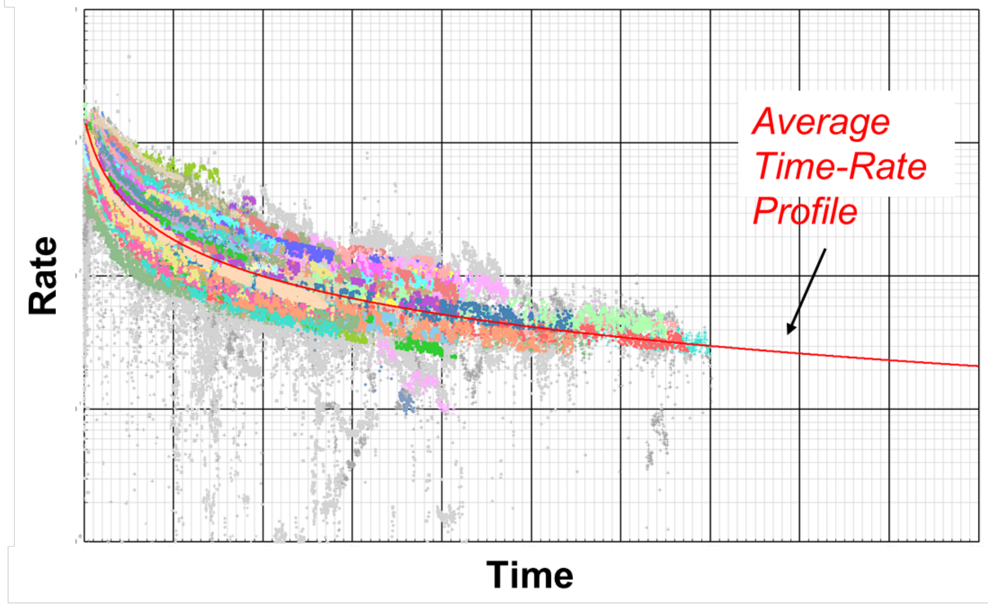
Reserves and Resources
- Classification and categorization
- Type well profile for undeveloped locations
- Incorporation of uncertainty
- Impact of well spacing/completion design
- Specific definitions and guidelines (e.g., SPE PRMS)

Introduction:

Type Well Profiles

- Type well profile is a representation of future production rates of an undeveloped (well) location.
- Type well profiles are critical for estimating undeveloped reserves/resources and capital allocation.
- Type well profiles are typically based on a statistical measure (e.g., “average”) of individual rates from representative producing wells (“well groupings”).
- Well groupings are generally based on:
    - Reservoir, fluid and rock properties. Well spacing and completions
- Major limitation of the standard approach:
    - Absence of “representative” well groupings for the future undeveloped locations.
    - Development plans different than historical field production.



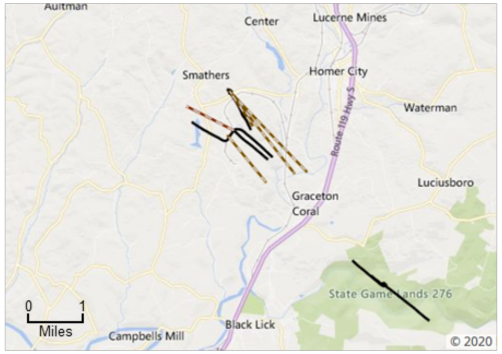


Introduction:

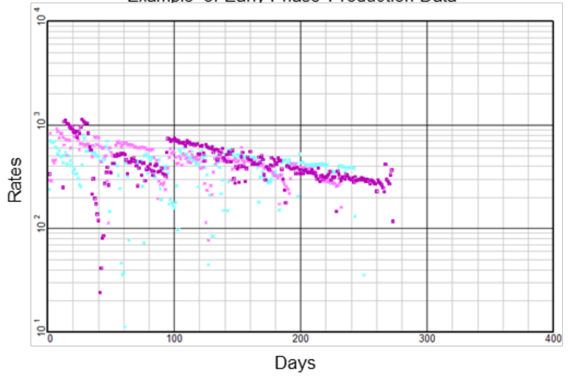
Phases of Unconventional Field Development

Early Phase

Consists of few wells with limited production history.

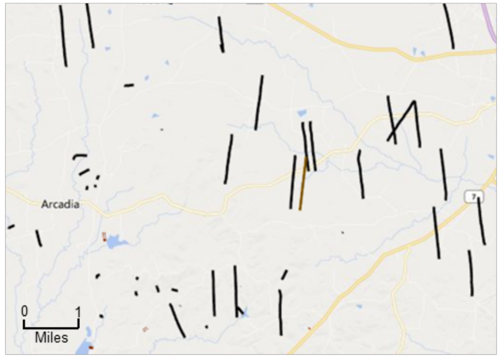


Example of Early Phase Production Data

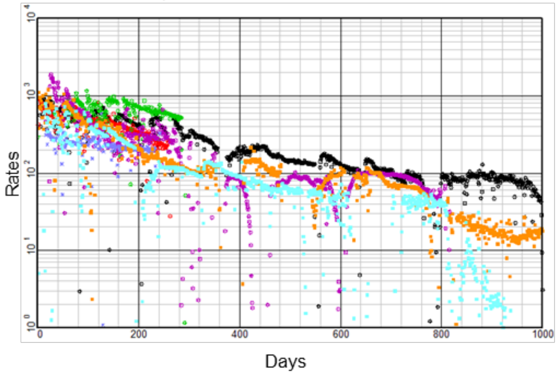


Intermediate Phase

Consists of ten or more wells, some with long term history.

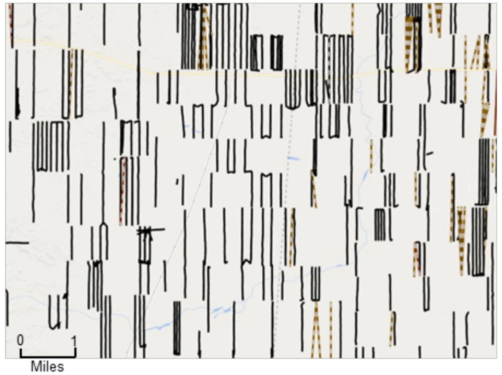


Example of Moderate Phase Production Data

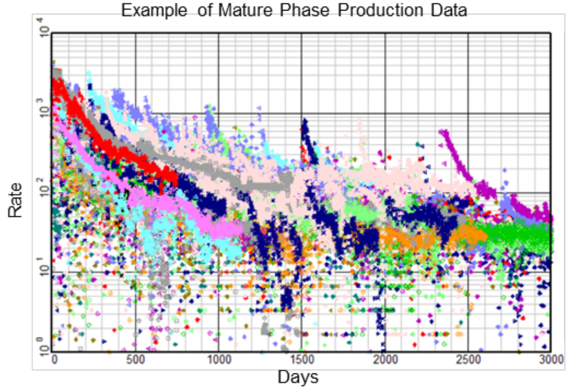


Mature Phase

Consists of many wells, most with long term history.



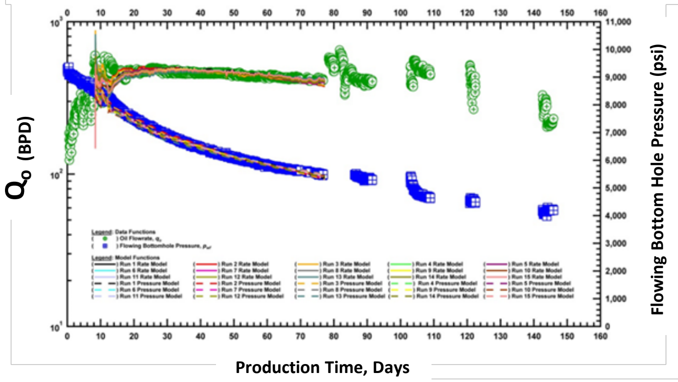
Example of Mature Phase Production Data



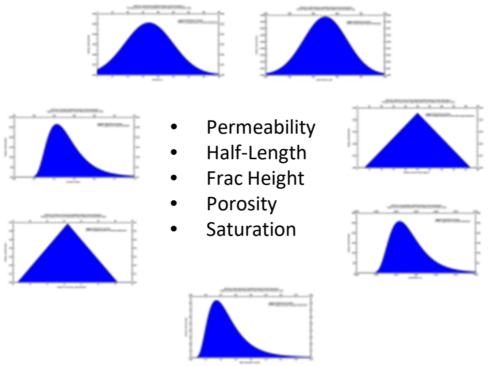
Methodology for constructing type well profiles:

Early Phase of Development

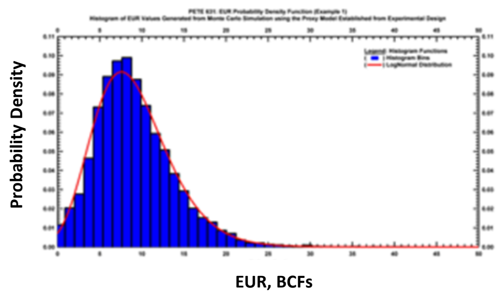
Various history matches for a well with limited production history



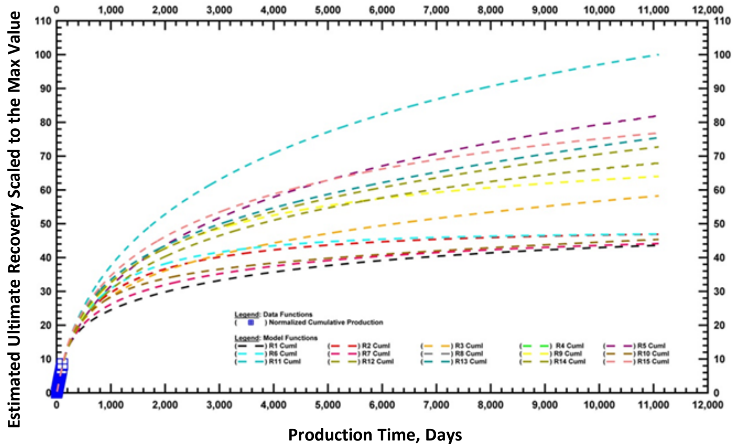
Input Parameter Distributions

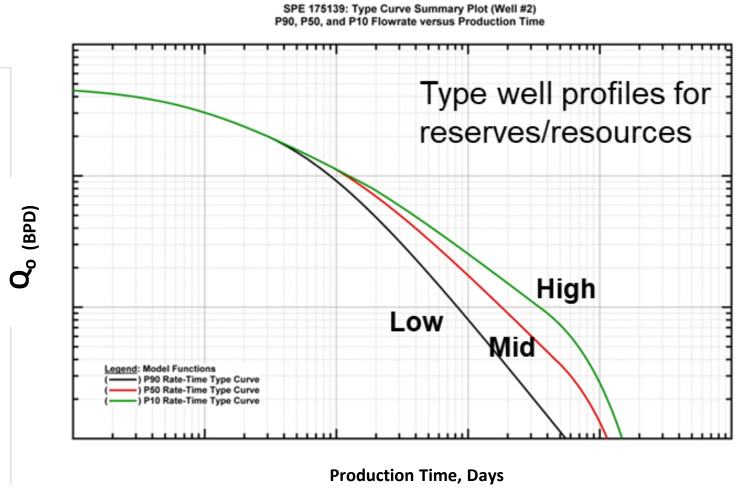


EUR Distribution



Production forecasts for a well with limited production history

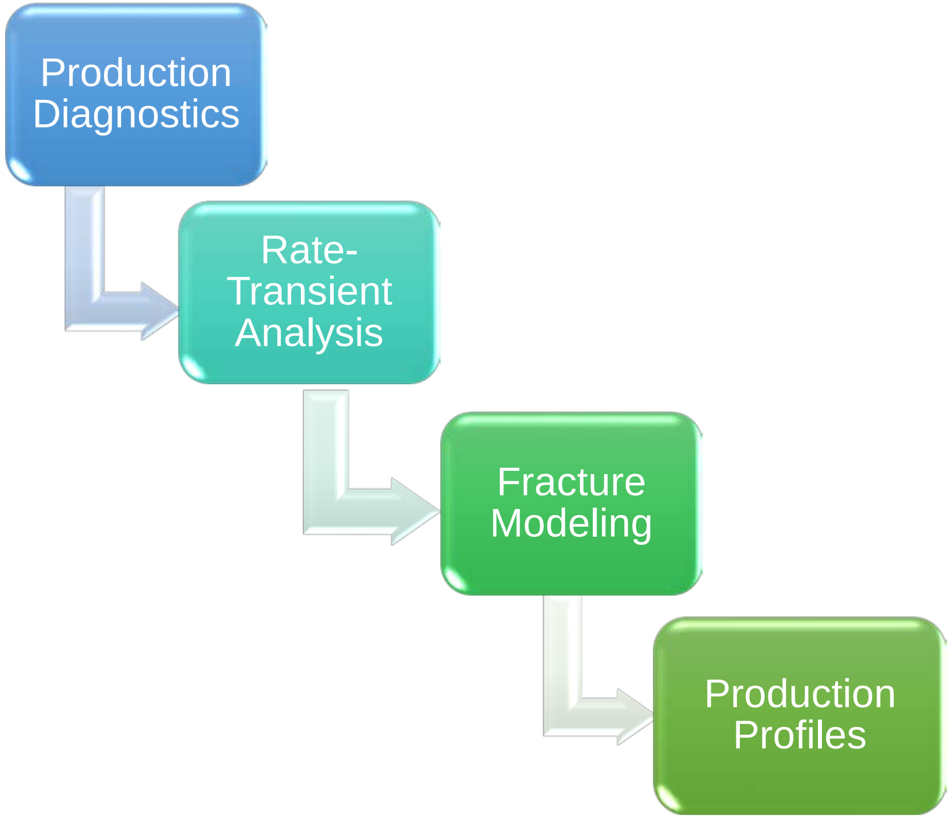




Reference: SPE 175139

Methodology for constructing type well profiles:

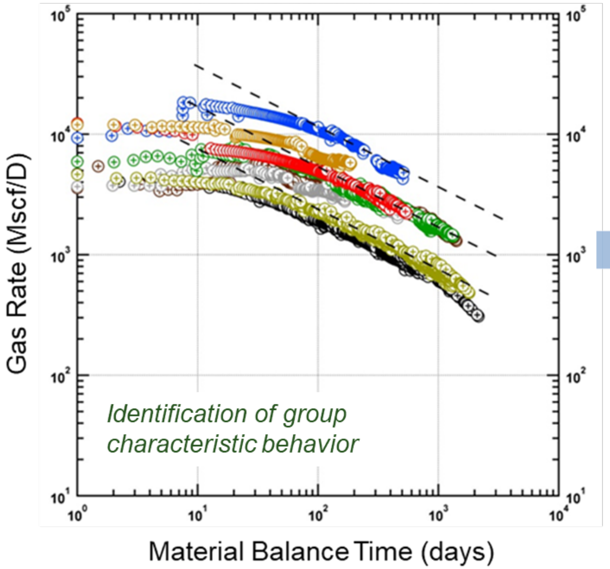
Using Model-Based Approach

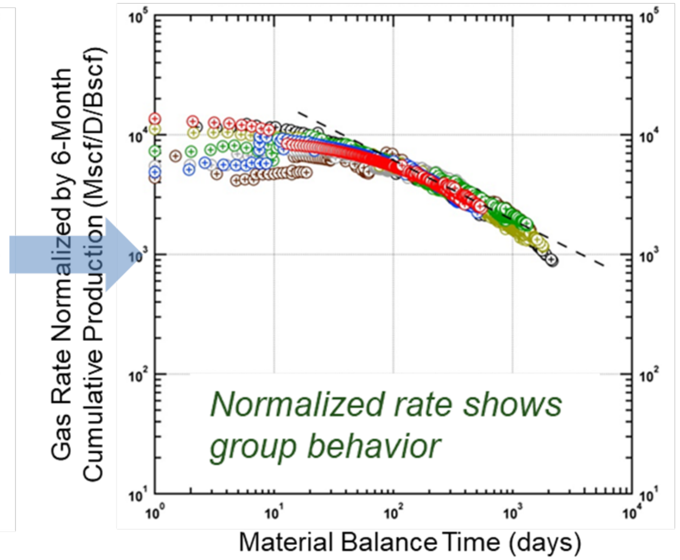


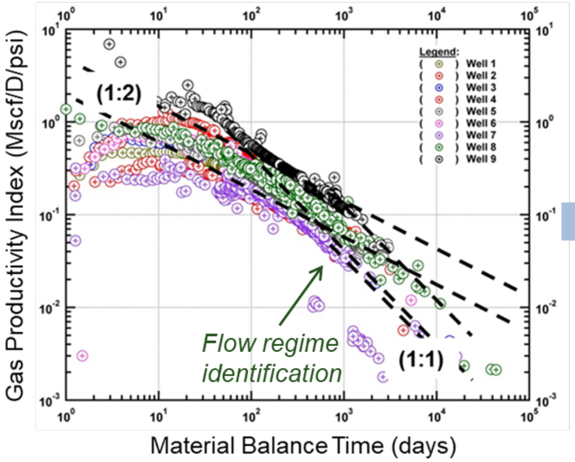
- Production diagnostics for identifying **flow regimes** and characteristic behavior.
- Rate-transient analysis is performed on **representative well(s).**
- Appropriate model selection and **uncertainty analysis.**
- Hydraulic fracture modeling (simulation) to characterize **fracture geometry**.
- Once calibrated **production profiles** are generated based on a specific completion design and well spacing.

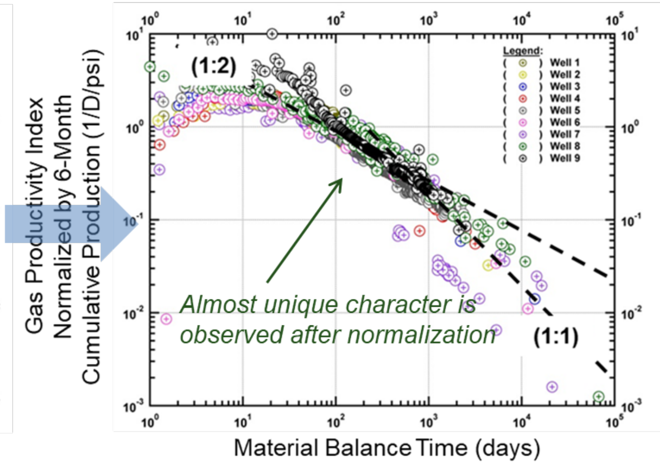
Diagnostics of Production Performance:

Flow Regimes and Characteristic Behavior









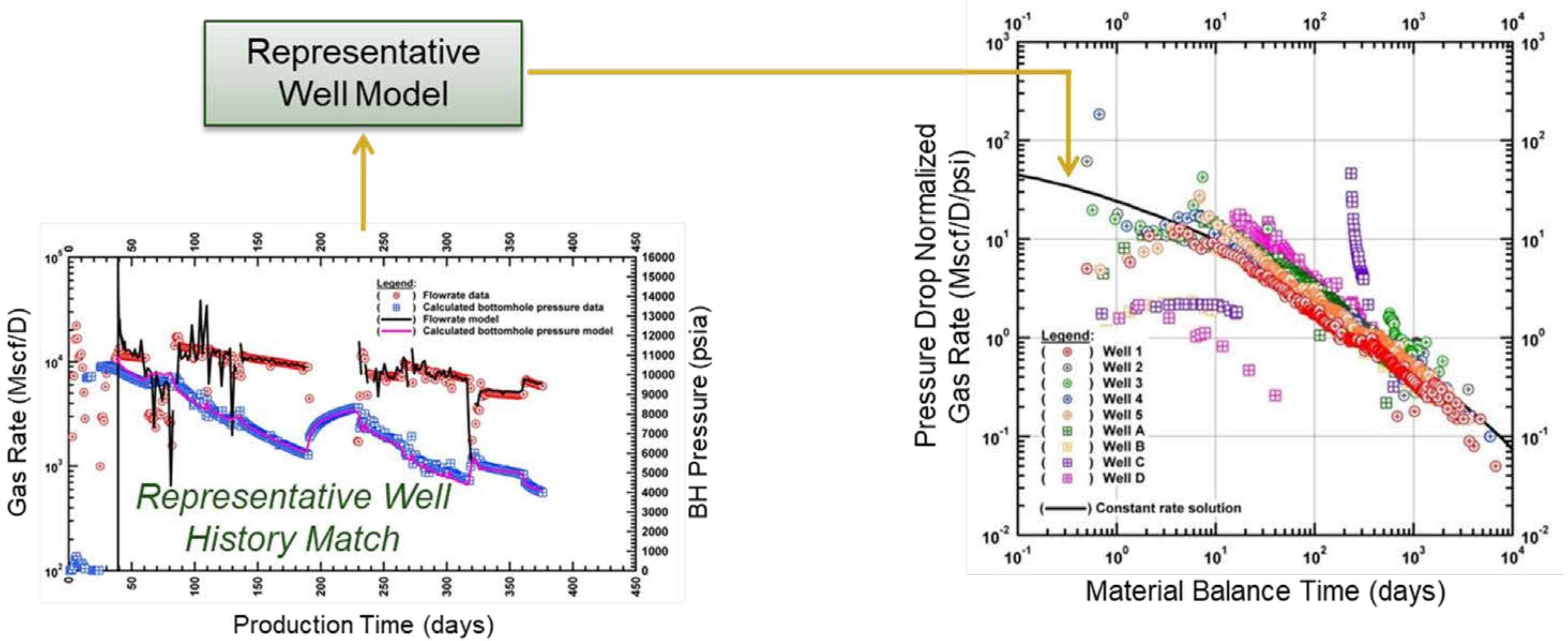
Discussion:

- Wells may be grouped by specific characteristics such as geology/location, PVT behavior, completion parameters, etc.
- It is possible to use a metric for data normalization (e.g., lateral length, cumulative production at 6 months, etc.)
- Almost unique character of the group is observed after normalization.

- Flow regimes/behavior exhibited by production data is identified.
- Identified character based on diagnostics is utilized for the interpretation and modeling.

Diagnostics of Production Performance:

Representative Well(s)

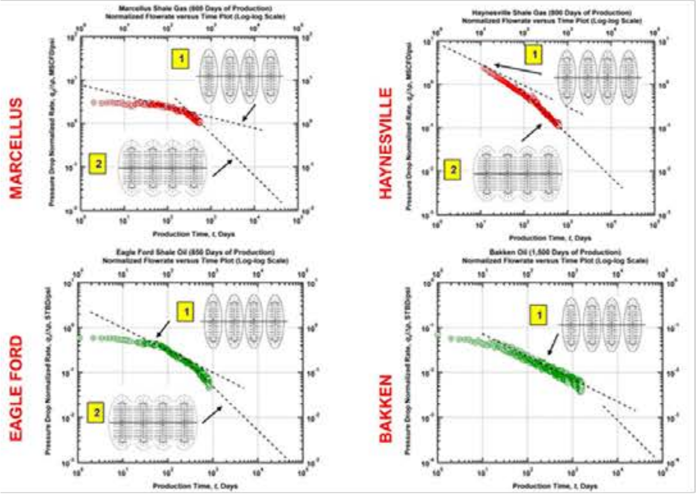


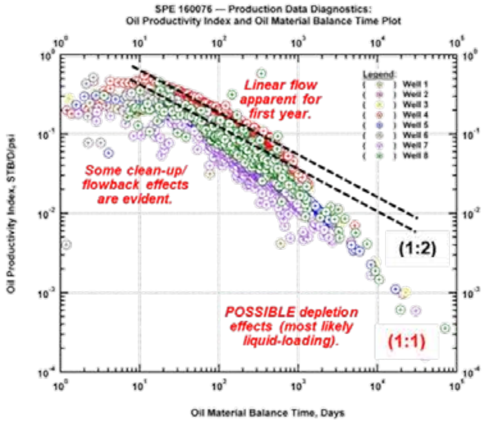
Discussion:

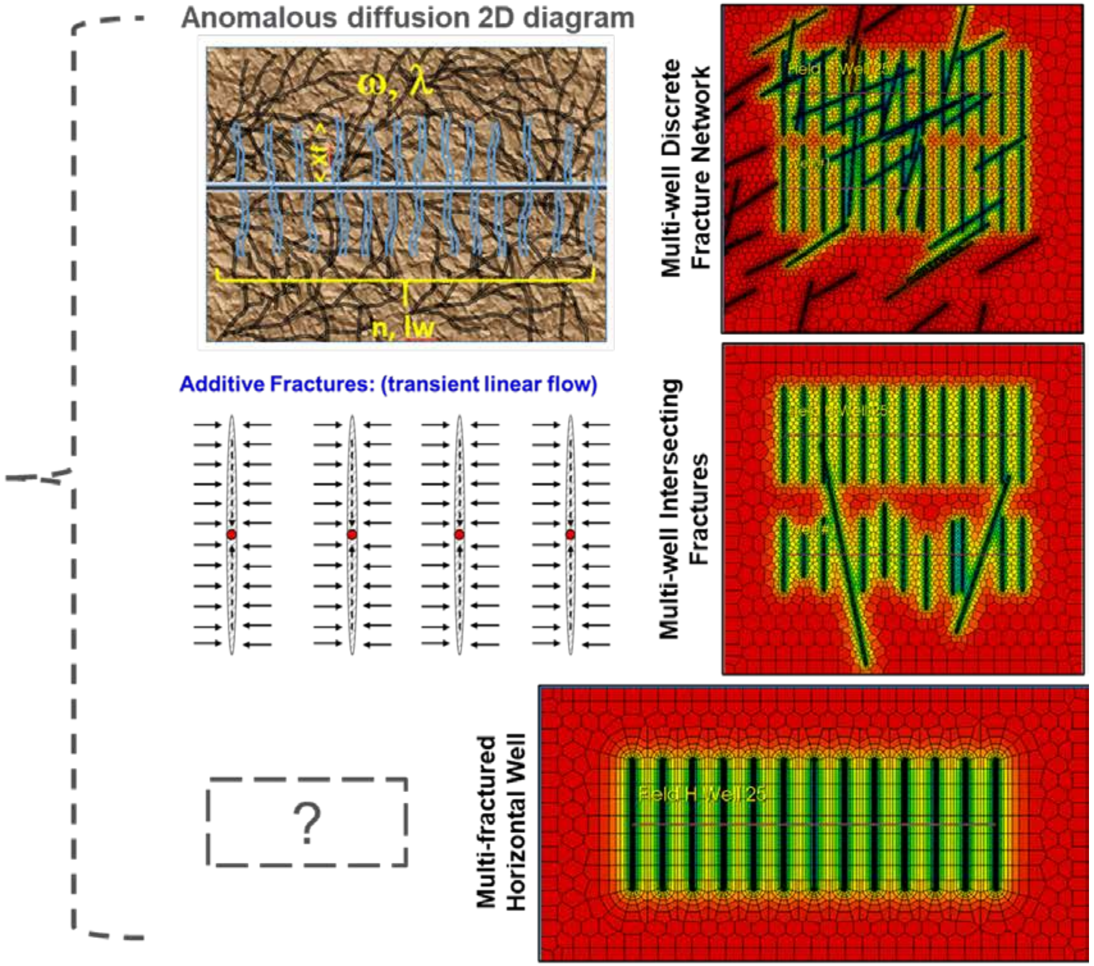
- If production diagnostics indicate characteristic behavior for a group of wells then the group production behavior can be described by a specific solution (analytical, numerical or empirical).
- Characteristic behavior can be translated into a time-rate type well profile.

Utilization of Rate-transient Analysis:

Model Uncertainty







Utilization of Rate-transient Analysis:

Model Orientation

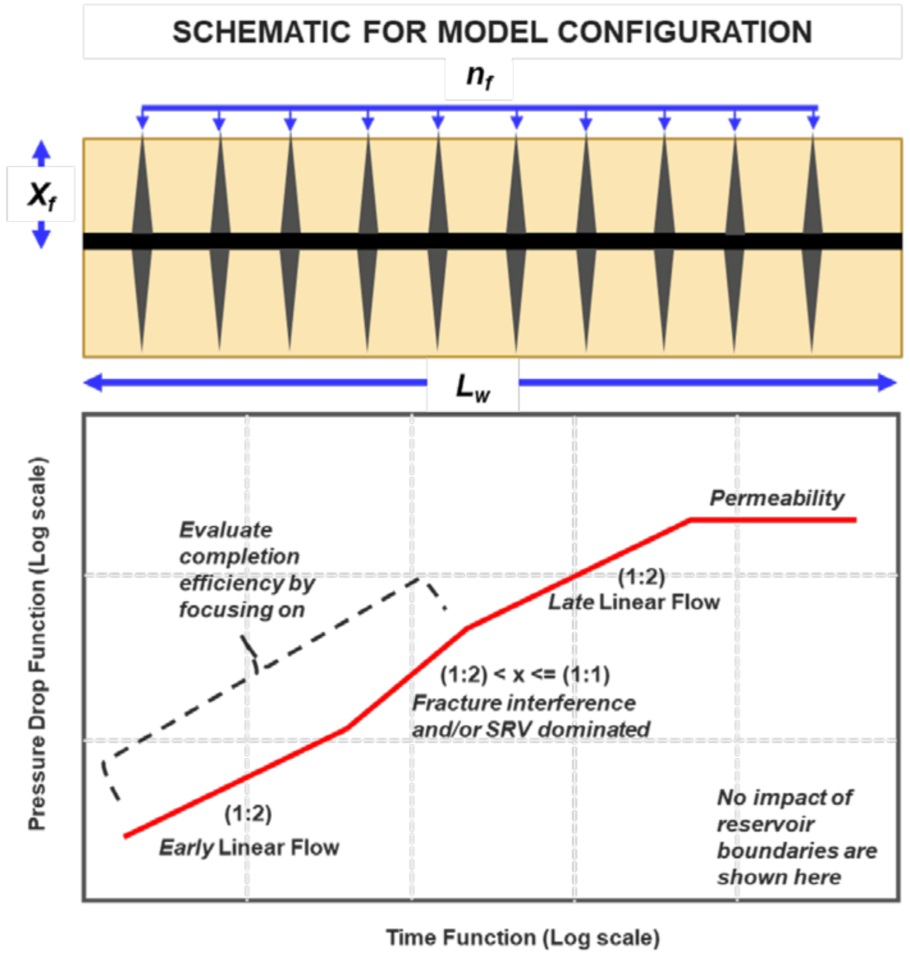
Multi-Fracture Horizontal Well (MFHW) Overview

Primary Model Parameters for Calibration:

- Permeability *(k)* → ***Major Unknown***
- Fracture half-length *(Xf)*
- Fracture height *(hf)* → ***Parameters will be tied to completion efficiency***
- Number of Fractures *(nf)*
- Skin Factor *(s)* → ***Generally last to calibrate or refine the history match***

Assumptions / Remarks / Issues

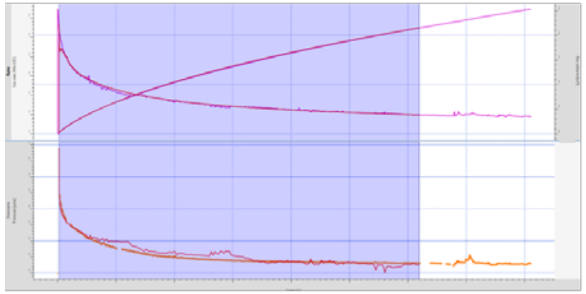
1. ***Non-uniqueness***: more than one answer satisfying solution.
2. ***Uncertainty:*** No clear consensus on values for model parameters.
3. Infinite conductivity.
4. Single phase (dry gas) – simpler/cleaner approach. Multiphase (more complex).
5. Petrophysical and fluid properties are direct inputs.
6. Drainage area may be limited to actual well spacing.
7. No stress-dependent properties.
8. No dual porosity / permeability
9. Remember this is a model, it is likely wrong



Utilization of Rate-transient Analysis:

Addressing Non-uniqueness

Sample Single Calibration



Sample Results Table

Run	INPUTS: Frac Height, h (ft)	INPUTS: Permeability, k (nD)	OUTPUTS / TUNING PARAMETERS: Number of Fractures, n_f (dim.less)	OUTPUTS / TUNING PARAMETERS: Fracture Half Length, x_f (ft)	OUTPUTS / TUNING PARAMETERS: Skin, s (dim.less)	CALCULATIONS: Cluster Efficiency, $n_f/n_{f,total}$ (dim.less)	CALCULATIONS: Fracture Surface Area, A_c (ft^2)	CALCULATIONS: Model $A_c k^{1/2}$ ($ft^2 md^{1/2}$)
a1	50	50	25	1700	0.00141	57%	8500000	60104
a2	50	100	19	1550	0.00128	43%	5890000	58900
a3	50	200	15	1400	0.00286	34%	4200000	59397
b1	100	50	25	840	0.00147	57%	8400000	59397
b2	100	100	19	770	2.71E-03	43%	5852000	58520
b3	100	200	15	670	0.00541	34%	4020000	56851
c1	150	50	25	555	0.00205	57%	8325000	58867
c2	150	100	19	525	0.004848	43%	5985000	59850
c3	150	200	14	475	0.00905	32%	3990000	56427

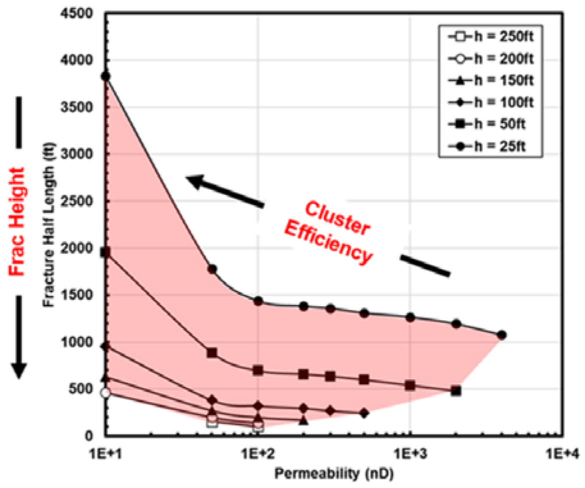
Procedure:

- Investigate the driving factors predominant flow regimes
  - Understand ranges on permeability
  - Incorporate completion design

Discussion:

- Performed multiple RTA calibrations for each well to address non-uniqueness
- $A_c k^{1/2}$ is kept relatively constant for all solutions
- Results are plotted to create a "solution space"

Sample "Solution Space"



Methodology

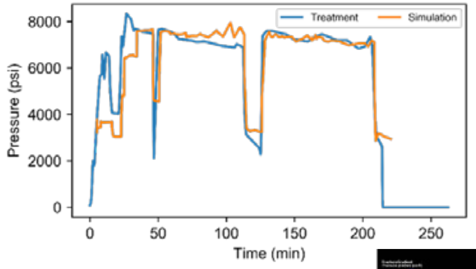
1. Evaluate Flow Regimes
2. Assume various values for (k and h_f)
3. Solve for n_f and x_f from diagnostic plot
4. Perform history match and calibrate further as appropriate

Incorporation of Fracture Modeling:

Petrophysics and geomechanics are used to generate the model.

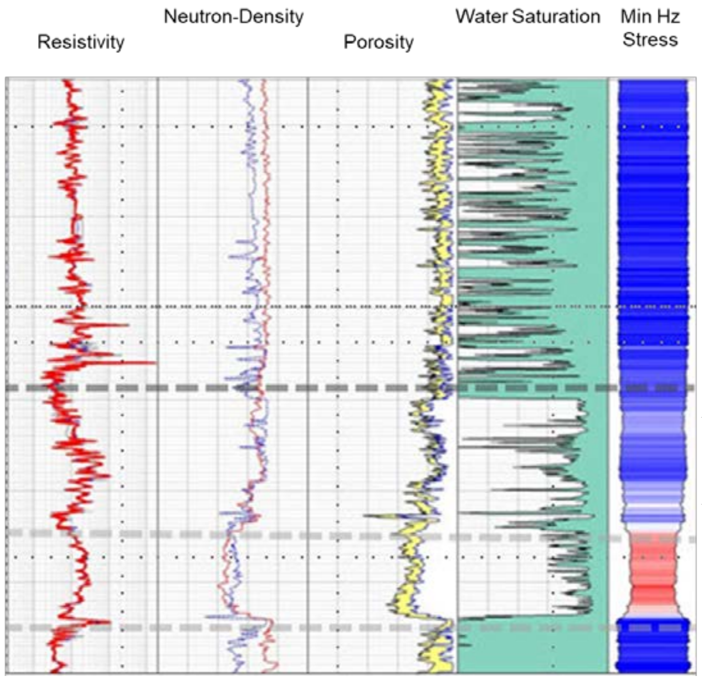
Each stage is simulated by **matching treatment pressures.**

Fracture properties are the main output.

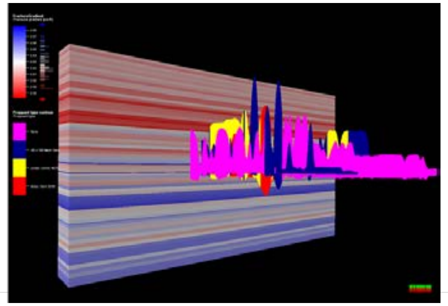


Matching Actual Treatment Pressure Data

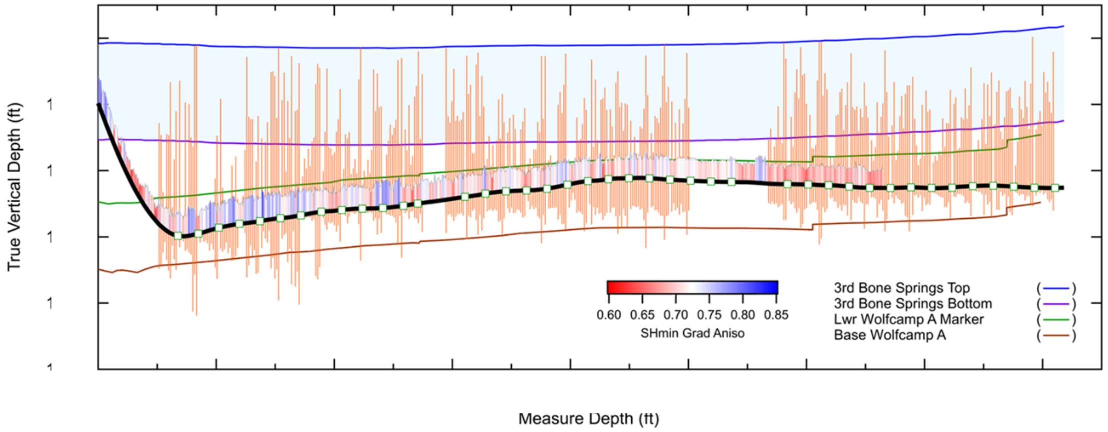
Petrophysical and Geomechanical Properties from Logs



3-D View – Proppant type distribution along the fracture plane overlain the formation fracture gradient



Maximum fracture height shown along the lateral



Incorporation of Fracture Modeling:

Illustrative Example (UrTEC 3869654)

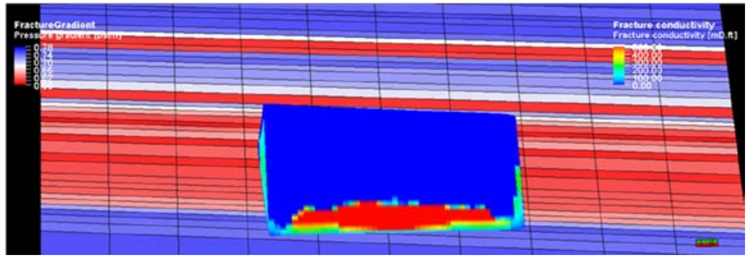
Original Completion Parameters:

- 17 stages
- 80 bpm slurry rate
- 2 clusters/stage
- 214-ft cluster spacing
- 75,000 lbs/cluster – Proppant Loading 700 lbs/ft
- 7,200 bbl/cluster – Fluid Loading 70 bbl/ft

Model Calibration: Matched modeled to observed

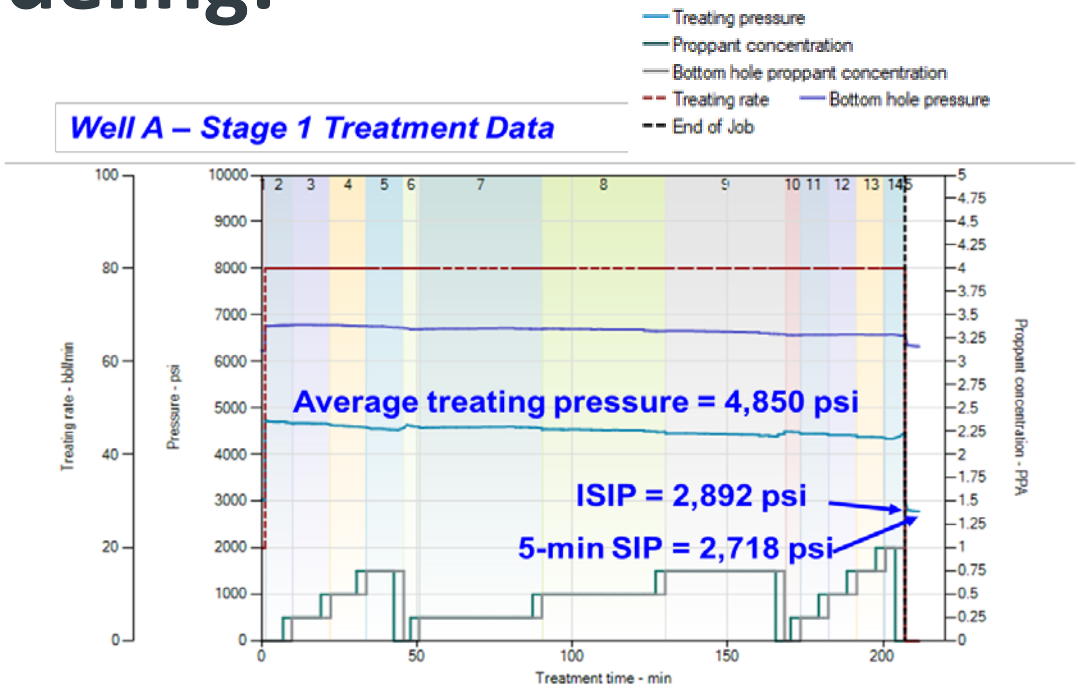
- ISIP
- Treating pressure
- Post-frac pressure decline
- Frac geometry (iterative from RTA)

Well A – Fracture Conductivity



Representative Hydraulic Fracture Model, displaying post treatment fracture conductivity

Well A – Stage 1 Treatment Data



Results:

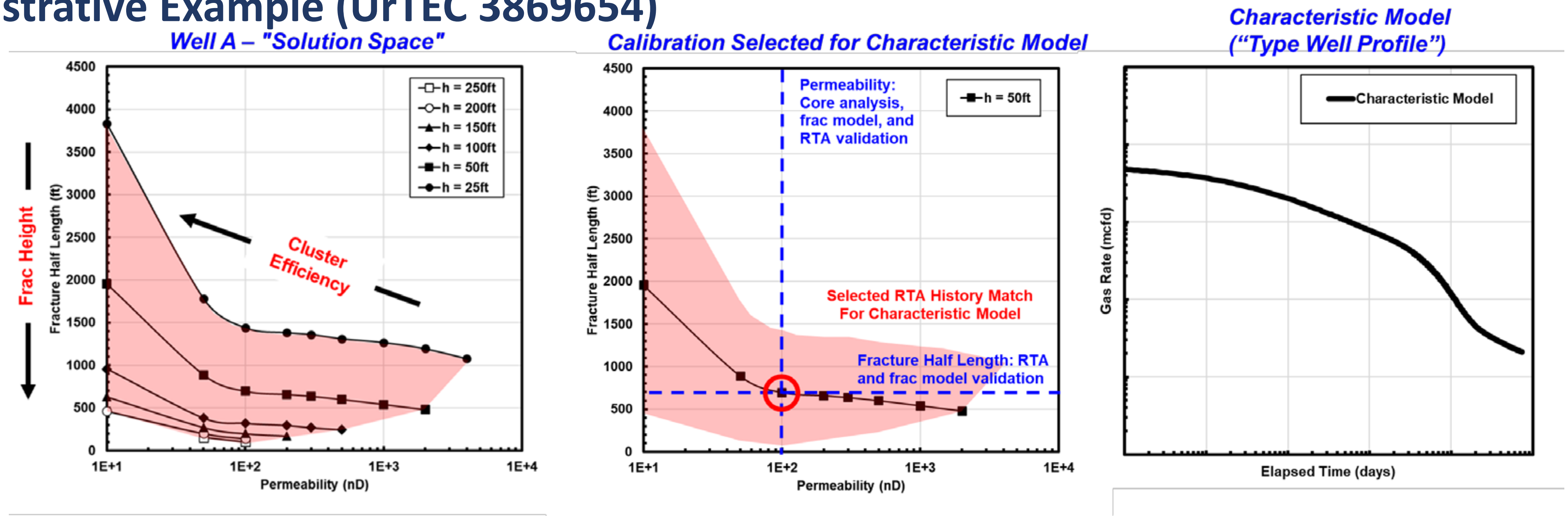
- Propped xf range: 646 – 740 ft
- Propped h range: 60 – 65 ft

Integration:

- Selected RTA calibration that most accurately represented the frac model results
- Integration of the frac model helps decrease uncertainty of parameters
- Characteristic solution created from this RTA calibration

Incorporation of Fracture Modeling:

Illustrative Example (UrTEC 3869654)

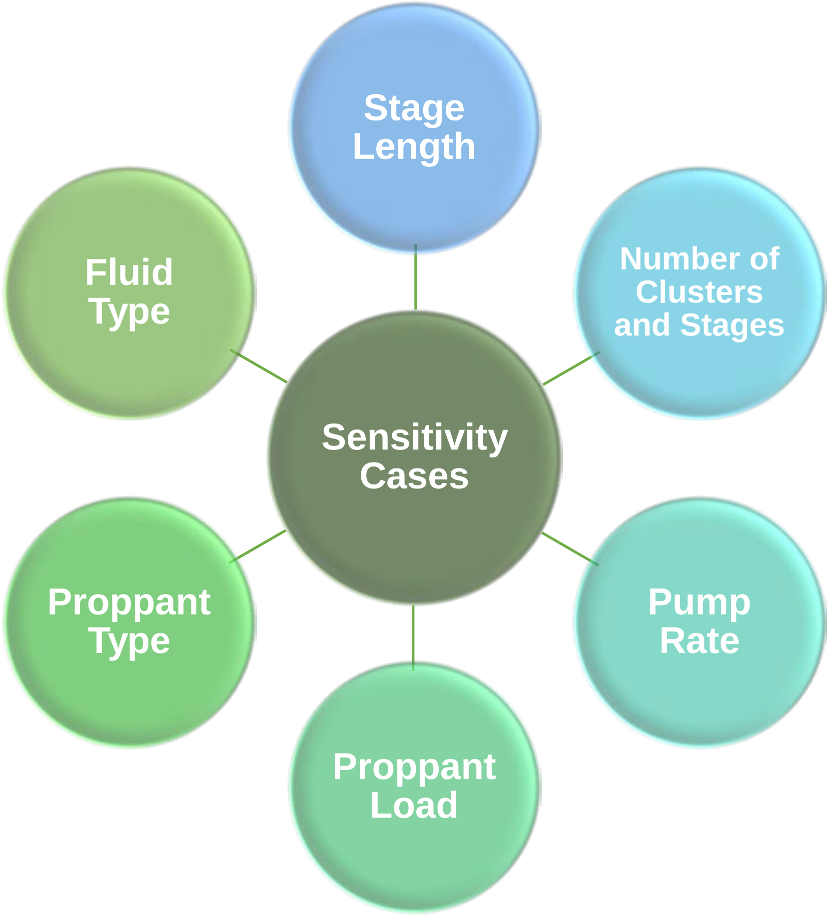


Discussion:

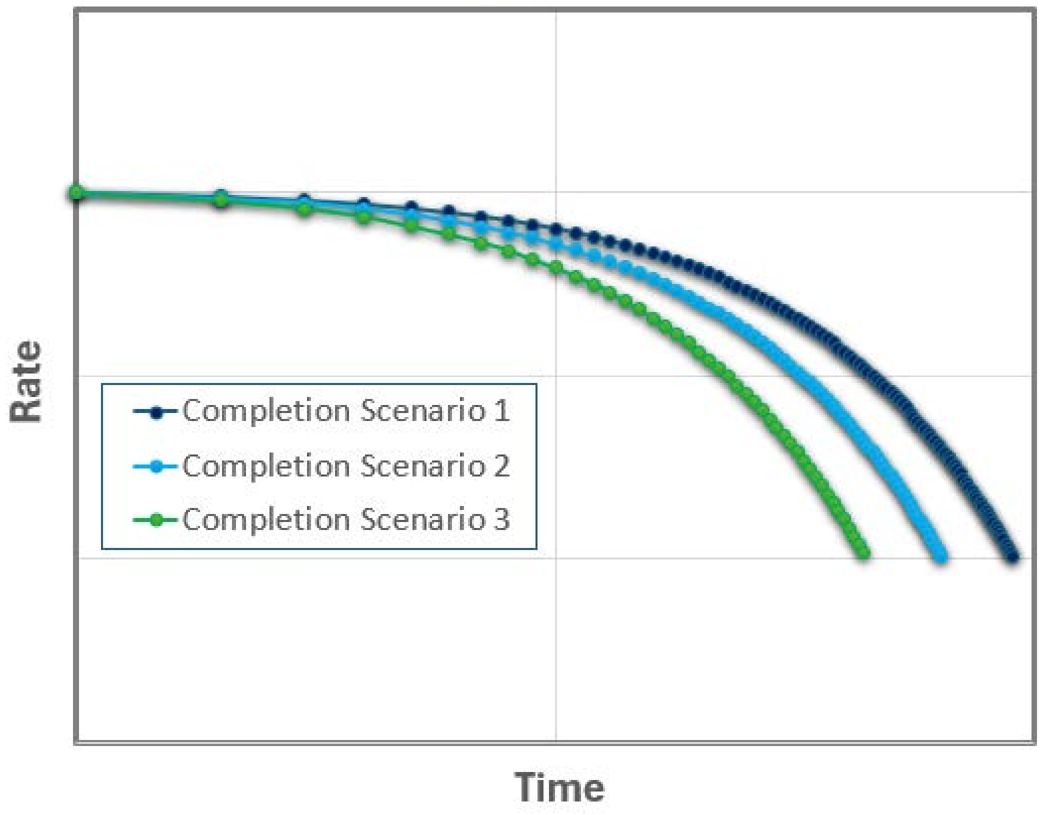
- Solution spaces were created for each analyzed well based upon the multiple calibrations
- Every point on these graphs represents a single calibration
- Calibration for the characteristic solution was determined using geological data, RTA and frac model results
- Characteristic model ("type well profile") is created by utilizing workflow results

Production profiles:

Based on specific well completions and spacing:

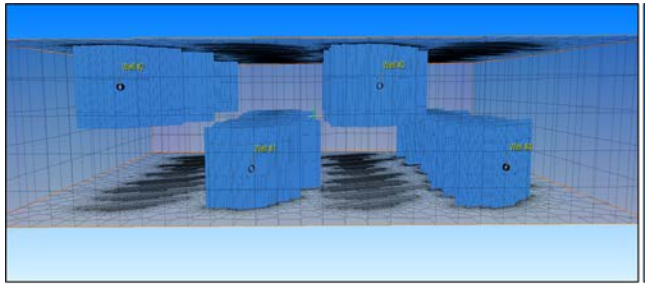


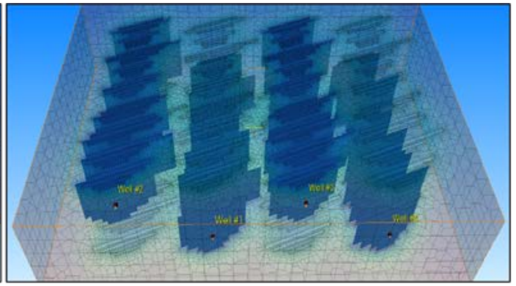
Type Well Profiles based on Specific Completion Design



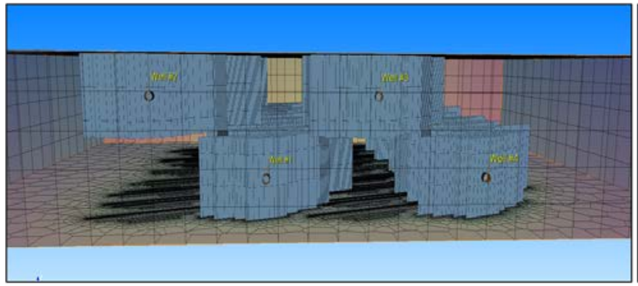
Production profiles:

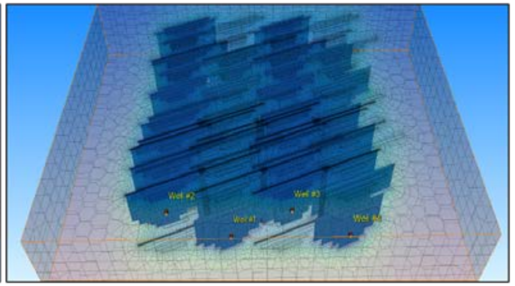
Based on specific well completions and spacing:





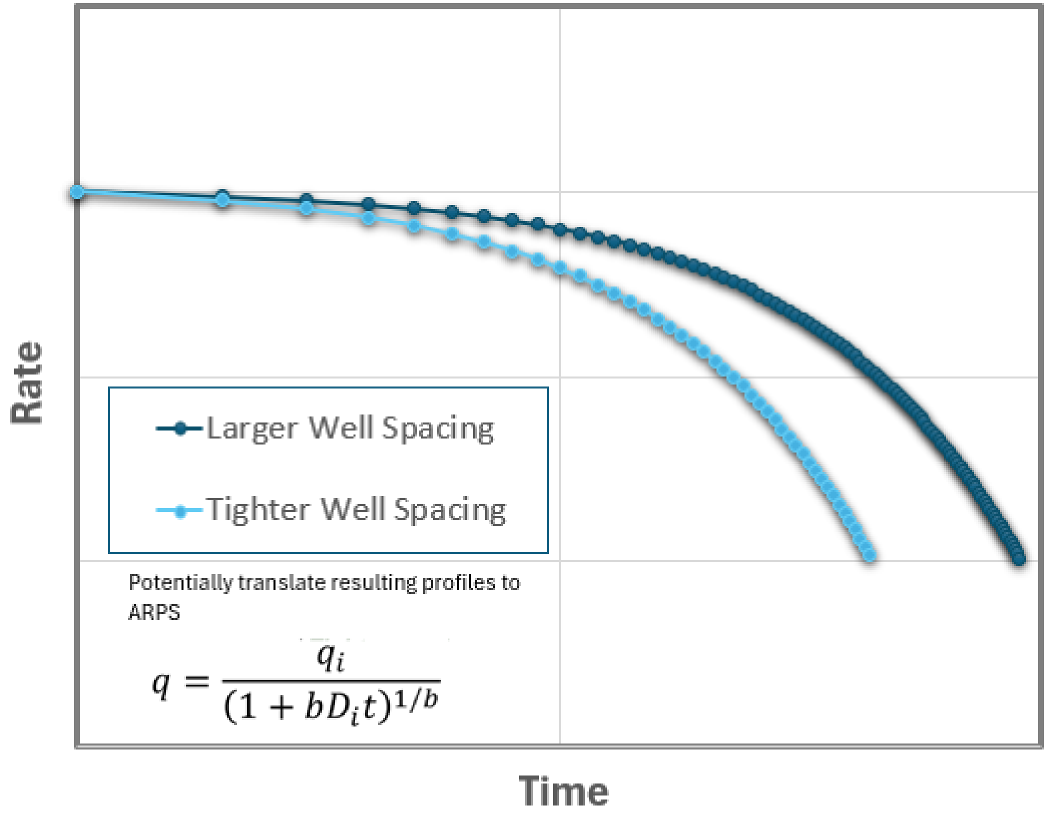
Modeled treatments are evaluated with different well-spacing configurations





Tighter spacings can cause well's fractures to overlap and steeper decline

Type Well Profiles based on Well Spacing



$$q = \frac{q_i}{(1 + bD_i t)^{1/b}}$$

Summary and conclusions:

- This work provides a comprehensive methodology **to construct type-well profiles in unconventional reservoirs** incorporating time-rate-pressure data along with reservoir properties and well completions.
- The application of this methodology **in emerging plays with short production history** has considerable potential with resource classification and development planning.
- The incorporation of history-matching the as-pumped conditions from fracture modeling **eliminates the uncertainty associated with fracture geometry** obtained from model-based analysis.
- The incorporation of a model calibrated by rate transient analysis and fracture modeling is able to capture implied flow behavior and **predict potential changes** based on various development considerations.
- **The calibrated model is used to generate future production profiles** based on a specific pressure drawdown, well completion, and well spacing.
- The resulting profiles can be **translated to a standard decline-curve** equation (e.g., modified Arps' hyperbolic decline) to be used in economic analysis.
- Various economic runs can be performed to investigate favorable development conditions based on a specific well spacing and completion.