Determining Optimum Well Spacing Using Fracture Characterization in Unconventional Reservoirs*

Vivek Sahai[1], Greg Jackson[2], and Rakesh Rai[2]

Search and Discovery Article #80418 (2014)**
Posted November 24, 2014

*Adapted from oral presentation given at AAPG Education Directorate Woodford Shale Forum, Oklahoma City, Oklahoma, May 29, 2014.

[1]Weartheford, Houston, Texas (viveksahai_phd@yahoo.com)
[2]Weatherford, Houston, Texas

Abstract

Early in the development of a shale gas resource, optimal well spacing remains unknown as wells are sparsely drilled to hold leases by production. Developing the acreage requires operators to select locations, specify drilling plans, and design completions for multi-stage horizontal wells to maximize the operating metrics as defined by the company.

This presentation builds on our earlier work which presented sensitivity analysis for optimal well spacing with respect to permeability, fracture spacing and half-length under the assumption of uniform and symmetric completion configurations. The well spacing sensitivity to heterogeneity in completion configurations (i.e., non-uniform fracture half-length and asymmetric fracture spacing) are presented in this paper using deterministic modeling and stochastic modeling approaches.

Deterministic modeling results show a strong bias towards the longest repeated fracture half-length in determining the optimal well spacing. Higher reservoir permeability abates the impact of fracture heterogeneity. Fracture modeling, constrained by production logs, temperature logs, and/or microseismic, can be used to aid in the identification of the longest repeated half-length.

This work demonstrates the challenges associated with stochastic modeling of well performance. Examples from synthetic and field results from the Woodford Shale are presented to illustrate uncertainty in reservoir and completion parameter determination. The spacing optimization workflow used captures this uncertain range to effectively determine the impact on recovery factor and Net Present Value (NPV). The importance of the quantity of production history needed to determine optimal well spacing is also presented. Results reveal that with increasing heterogeneity longer production history is required for reliable determination of optimal well spacing. Finally, a completion optimization study is shown how changing the completion design impacts well performance and influences future well spacing decisions.

These conclusions, via the application of deterministic and stochastic modeling on production from field cases and synthetic wells, will aid operators in answering the multi-billion dollar question: how many wells should be placed in a given area? The workflow described in this

presentation not only can answer this question but also help us to understand how to maximize economic return and the ultimate gas recovery.

References Cited

Boulis A., R. Jayakumar, C. Nyaaba, R. Rai, and V. Sahai, 2013, Challenges Evaluating Shale Gas Well Performance: How do we account for What We Don't Know?: IPTC 16396.

Jackson, G., and R. Rai, 2012, The Impact Of Completion Related Pressure Losses On Productivity In Shale Gas Wells: SPE 162213-MS.

Jayakumar, R., A. Boulis, and V. Sahai, 2011, A Better Understanding of Finite Element Simulation for Shale Gas Reservoirs through a Series of Different Case Histories: SPE 142464.

Kennon, S.R., A. Araque-Martinez, R. Lolly, and G. Fernandez, 2009, Multiphase Simulation of Integrated Hydraulic Fracture/Reservoir Flows Applied to Sierras Blancas Retrograde Condensate: SPE 122052.

Miller, M.A., C. Jenkins, and R. Rai, 2010, Applying Innovative Production Modeling Techniques to Quantify Fracture Characteristics, Reservoir Properties, and Well Performance in Shale Gas Reservoirs: SPE 139097.

Weatherford®

Determining Optimum Well Spacing Using Fracture Characterization in Unconventional Reservoirs

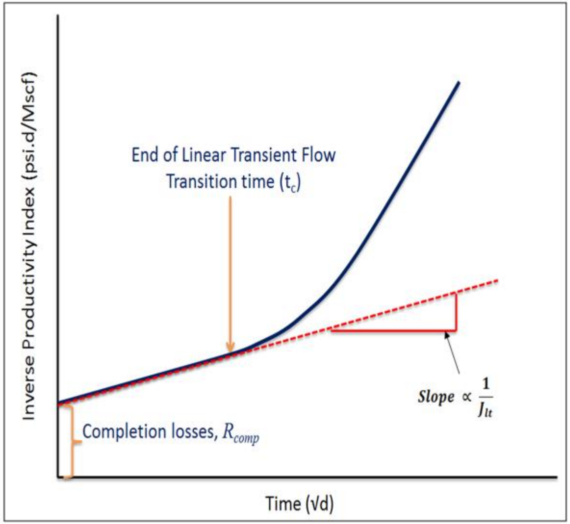
Vivek Sahai, Greg Jackson, Rakesh Rai | May 29, 2014

Agenda

Methodologies

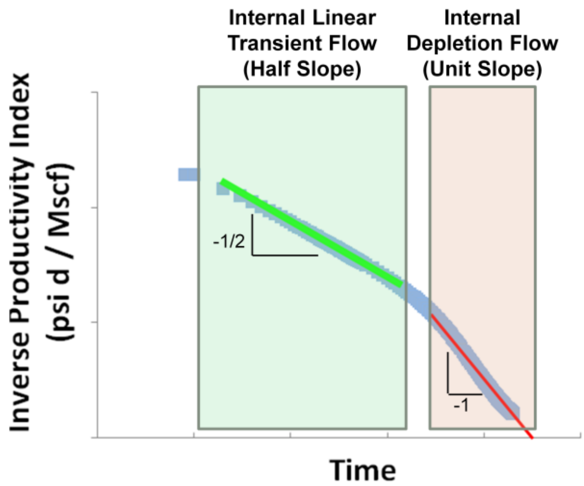
- Deterministic modeling
  - One set of input parameters
  - One cumulative recovery
    - Kennon et al. (2009), Jayakumar et al. (2011)
- Stochastic modeling
  - Range of input parameters
  - Range of cumulative recovery
    - Miller et al. (2010), Boulis et al. (2013)

Stochastic Modeling

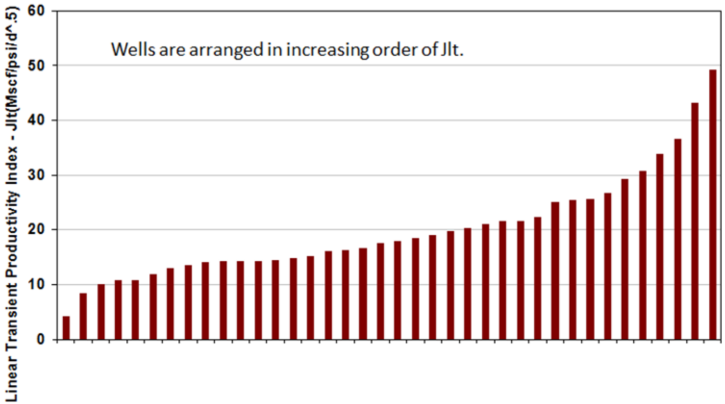


J_{lt}, R_{comp}, and t_c: See Miller et al. (2010)

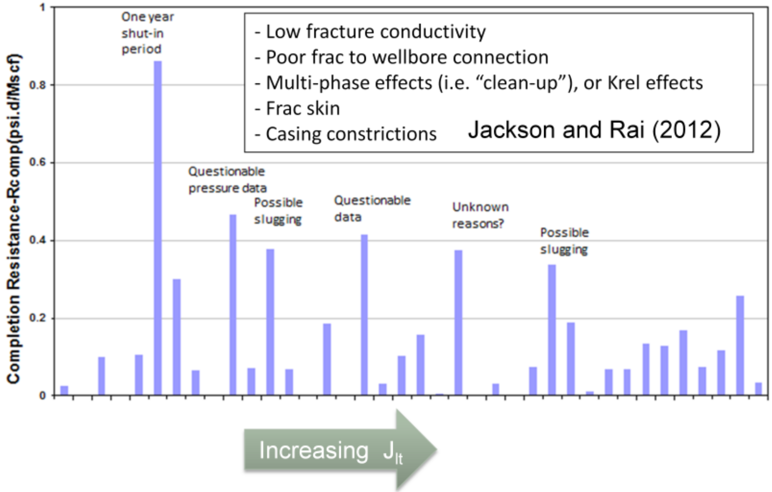
Flow Regimes



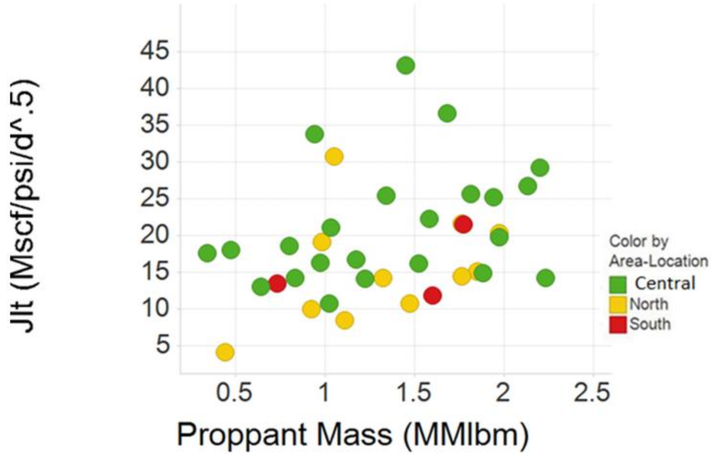
Woodford Wells Productivity Index Behavior (J_{lt})



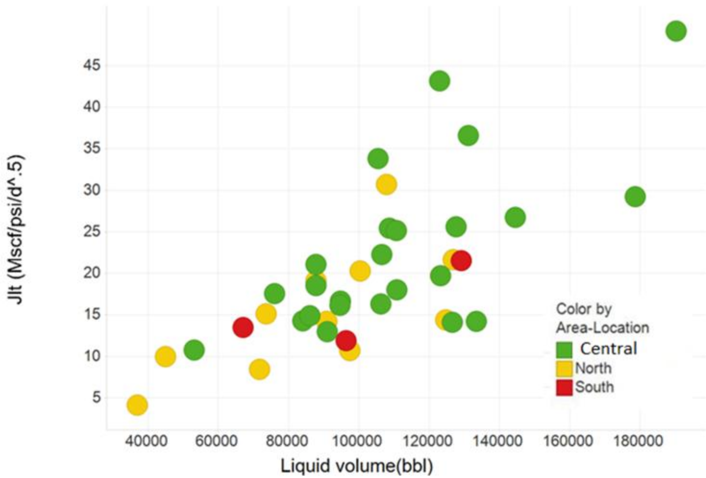
Woodford Wells – Completion Resistance



Jlt vs. Proppant Mass



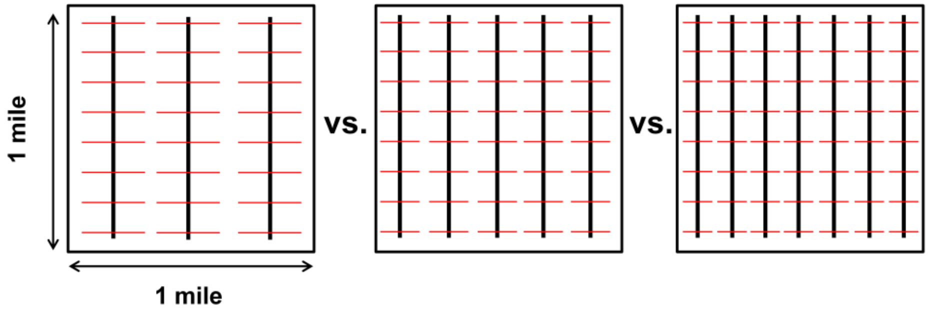
Jlt vs. Liquid Pumped



Observations Based on Woodford Wells

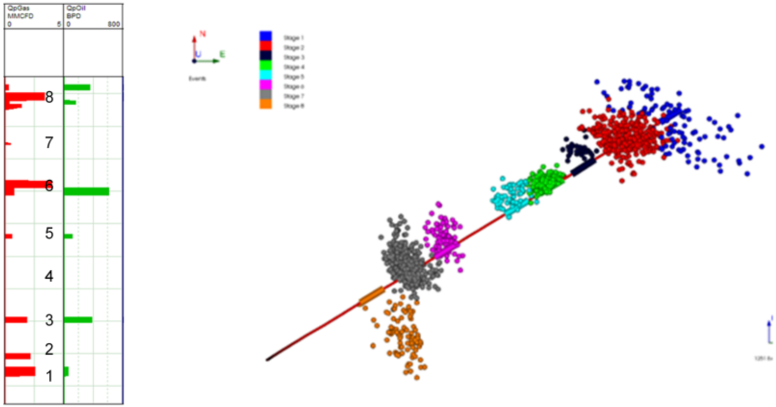
- Stochastic Modeling:
  - Gives a framework to identify productivity and completion resistance trends
  - Provides for a consistent comparison within a play
- All wells appear to be in linear transient flow
- Linear transient productivity index:
  - Better productivity comparator than IP or 3/6/9 month cum
  - Can be used to identify areas where to optimize completion design

Homogeneous Well Spacing



Presenter's notes: Our previous work demonstrated no drainage extend from the extent of the SRV which depends on the fracture half length. The non-stimulated region does not provide much contribution when considering optimal well spacing. This work assumed that the fracture area in the SRV had uniform fracture half length and uniform fracture spacing. So for large fracture half lengths you will need less wells to get optimal recovery vs. the two cases on the right which show lower fracture half length.

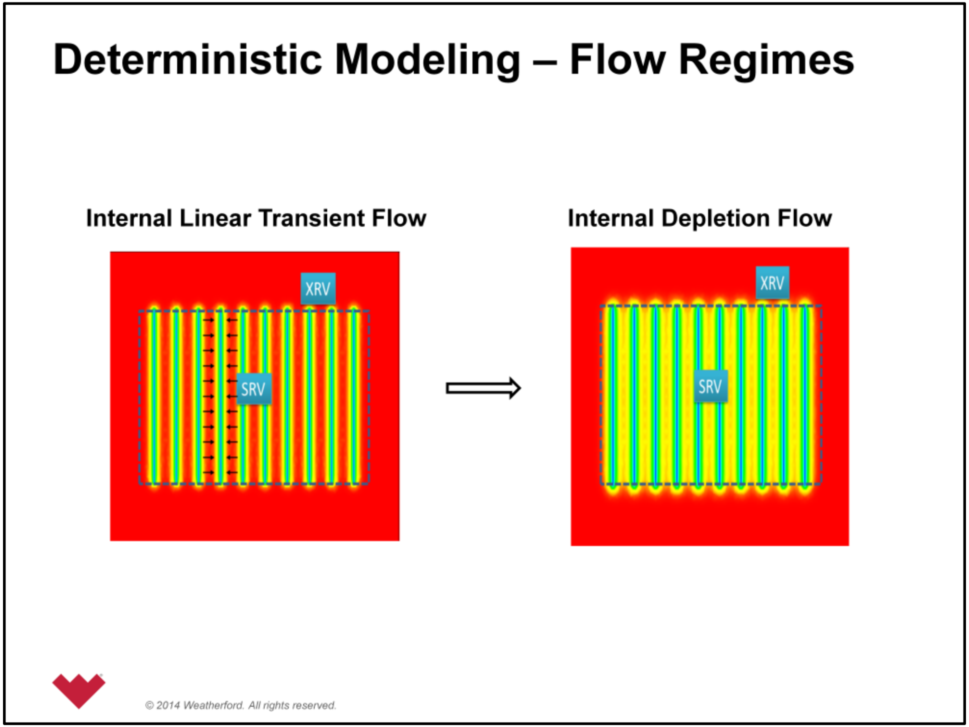
Optimum Well Spacing



Presenter's notes: This previous work was for an idealistic case. Information from PLT show that only a few stages and clusters can be contributing to the flow, which results in non-uniform fracture spacing. Microseismic homogeneity does not exist, so we must account for heterogeneity so our study focused on how heterogeneity affected our answer on optimum well spacing.

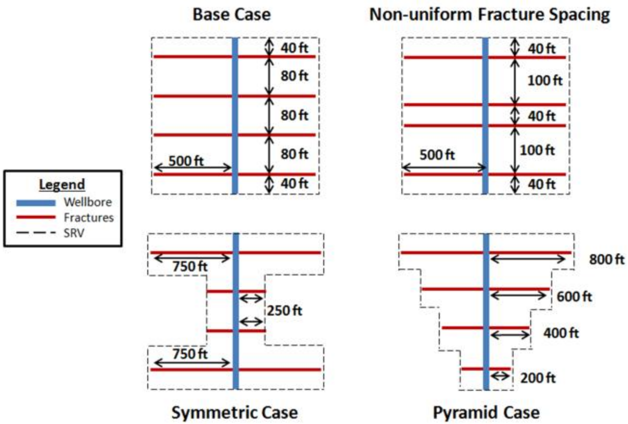
Optimum Well Spacing

- How do we define “optimal”
- What is the impact of heterogeneity in
  - Fracture area/half-length
  - Fracture spacing
  - Drainage profile
- How does length of production history impact our decision



Presenter's notes: We use the term "fractures" to refer to hydraulically-induced and propped fractures. Fracture spacing is defined as the distance between two adjacent planar hydraulically-induced fractures along the wellbore. Permeability is simply the matrix or rock permeability connected to the propped hydraulic fractures. The stimulated reservoir volume (SRV) is the total volume that encompasses all fractures (i.e., fracture tip-to-fracture tip). The external reservoir volume (XRV), is the volume outside the SRV that is still assigned to a given well based on its current or future no-flow boundaries. The internal flow (flow within the SRV) and external flow (from XRV, area outside the SRV, toward the SRV) as defined in this paper. The image on the left shows internal linear transient flow that occurs within the SRV at early times, and the image on the right shows a well in predominantly external linear transient flow (Miller et al., 2010) from the XRV to the SRV which happens later in the life of well once the SRV has been depleted.

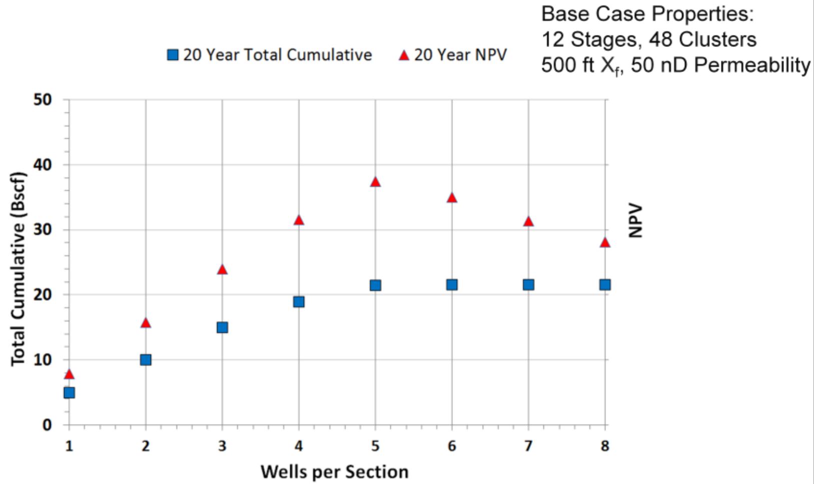
Synthetic Cases



Total fracture area conserved across all cases

Case R1

Base Case – Total Cumulative



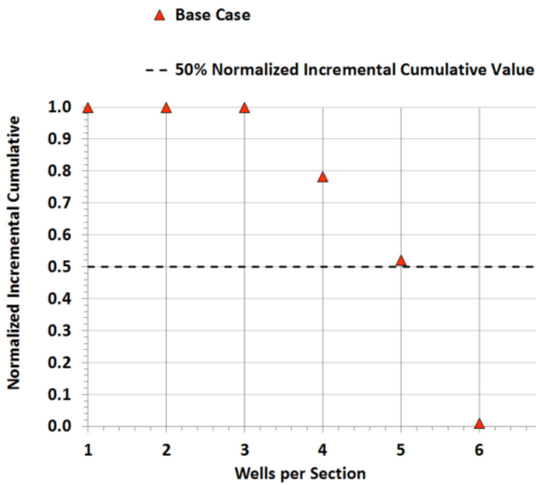
Presenter's notes: The SRV lines up at 5 wells. It is interesting to note that the NPV has only a slight increase past 10 years of production. Again the optimal point defined as the maximum NPV occurs at 5 wells per section. No scales are shown on the NPV curves, since the character of the plot does not change despite what economic assumptions were used.

Optimal Well Spacing Definition

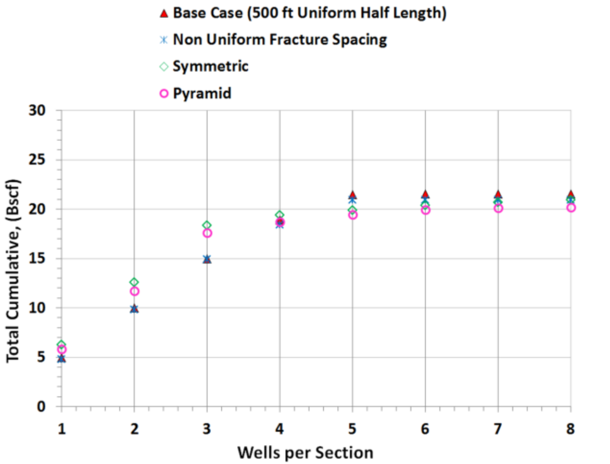
- Number of wells after which next additional well increased the slope less than 50%

$$Incremental\ Cumulative\ for\ n^{th}\ well = \frac{Gp - \sum_{i=1}^{n-1} Gp_i}{Gp_1}$$

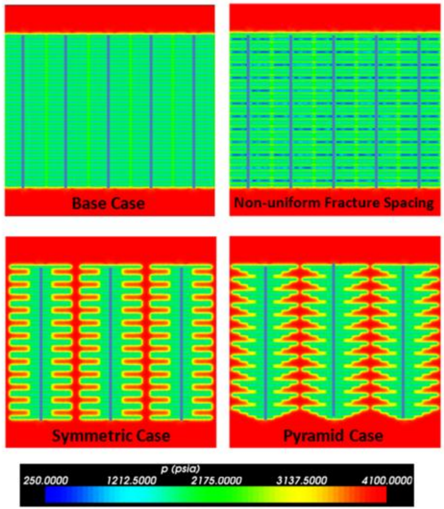
Base Case – Incremental Cumulative



Impact of Fracture Half-Length & Fracture Spacing Heterogeneity

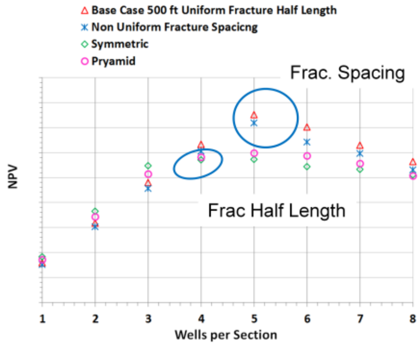


Reservoir Depletion

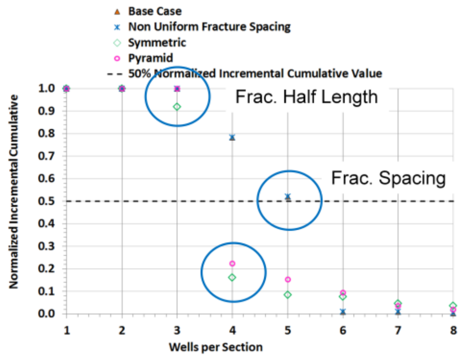


Impact of Fracture Half-Length & Fracture Spacing Heterogeneity

NPV



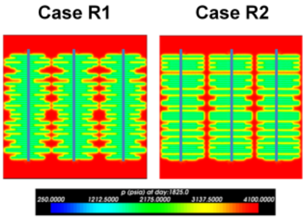
Incremental Cumulative



Optimum well spacing when additional well provides less than 50% of 1st well

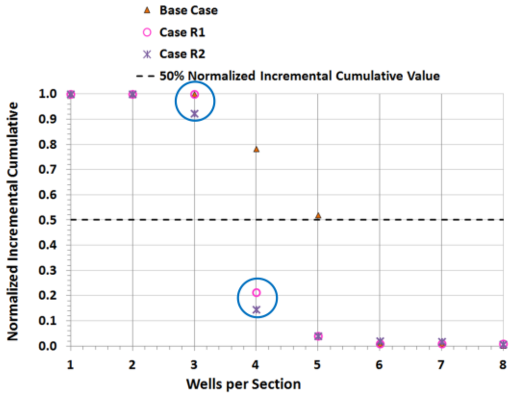
Impact of Additional Heterogeneity

Drainage Profile

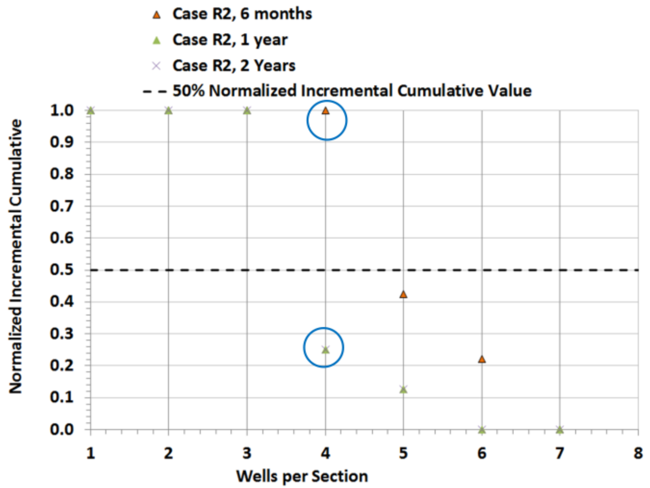


Case R1 – Random Half-length
Case R2 – Random Half-length & Fracture spacing

Incremental Cum Behavior



Effect of Production History



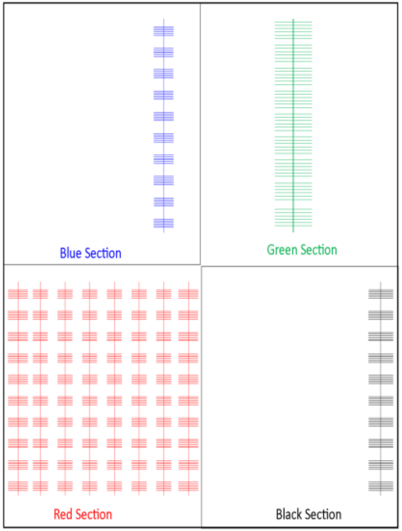
Effect of Completion Design
Woodford Case Study

Red Section (Completion Design A)

Inner wells have 20% less productivity

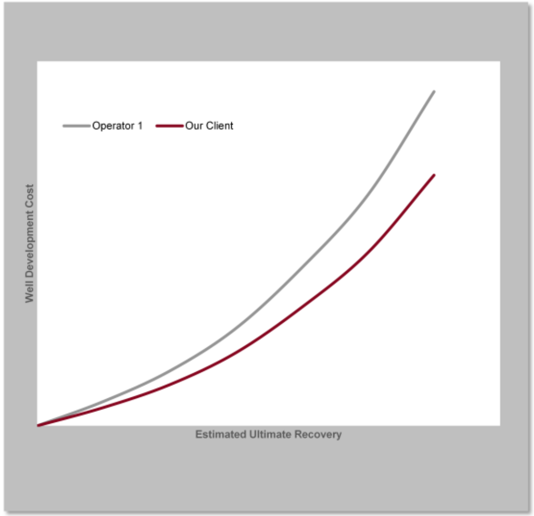
- Inner wells drive economics
- Outer wells suggest larger spacing

Completion Design	% More Proppant	% Better Productivity	% Higher $Rate_{90}$
B	80	40	55
C	100	60	80
D	125	90	135



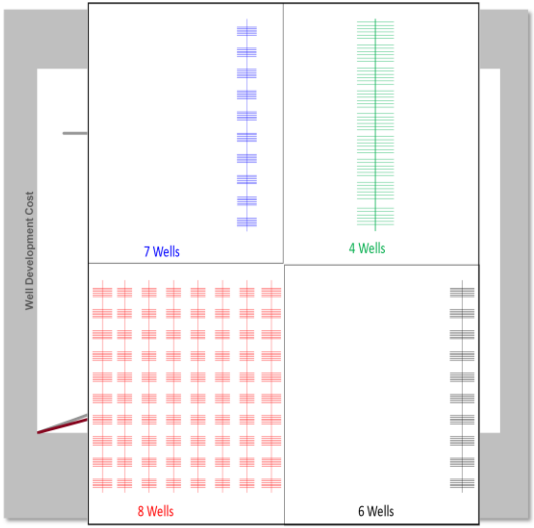
Asset Monitoring & Reserves Progression Woodford Case Study

- Eight wells initially planned per section as per completion design A
- Evolution of completion design (B, C & D) impacts well performance and influences future well spacing decisions
- Increased completion cost offset by higher productivity wells
- Planning cycle: Multiple months became 3 weeks



Asset Monitoring & Reserves Progression Woodford Case Study

- Eight wells initially planned per section as per completion design A
- Evolution of completion design (B, C & D) impacts well performance and influences future well spacing decisions
- Increased completion cost offset by higher productivity wells
- Planning cycle: Multiple months became 3 weeks



Conclusions

- Well spacing decision varies by the choice of optimization metric
- Longest repeated half-length has a strong influence on optimal well spacing
  - High permeability will reduce the impact of heterogeneity
- Non-uniform fracture spacing does not impact the optimal number of wells per section; however, it does reduce cumulative and NPV

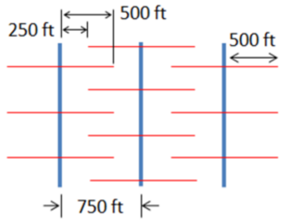
Conclusions

- Non-homogeneous fracture half-lengths also reduce the recovery factor and NPV

- Well spacing decisions based on early production tend to overestimate the number of wells required to optimally produce the section

Future Investigation

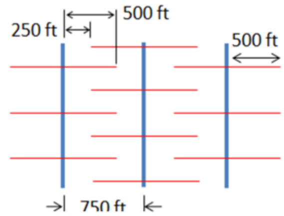
- Extend into Oil Reservoirs
- Effect of SRV overlap
- Effect of Timing

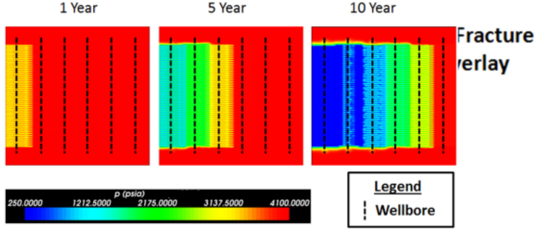


Zipper Fracture
50% Overlay

Future Investigation

- Extend into Oil Reservoirs
- Effect of SRV overlap
- Effect of Timing





References

- Kennon, S.R., Araque-Martinez, A., Lolly, R., and Fernandez, G., 2009, Multiphase Simulation of Integrated Hydraulic Fracture/Reservoir Flows Applied to Sierras Blancas Retrograde Condensate. SPE 122052.
- Jayakumar, R., Boulis A., and Sahai V., 2011, A Better Understanding of Finite Element Simulation for Shale Gas Reservoirs through a Series of Different Case Histories SPE 142464.
- Miller, M.A., Jenkins, C., and Rai, R., 2010, Applying Innovative Production Modeling Techniques to Quantify Fracture Characteristics, Reservoir Properties, and Well Performance in Shale Gas Reservoirs   SPE 139097.
- Boulis A., Jayakumar, R., Nyaaba, C., Rai, R., Sahai V., 2013, Challenges Evaluating Shale Gas Well Performance: How do we account for What We Don’t Know? IPTC 16396 .

Thank You!