How Can We Take Possible Well Interference into Account in Production Forecasting?

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Ryder Scott Reserves Conference

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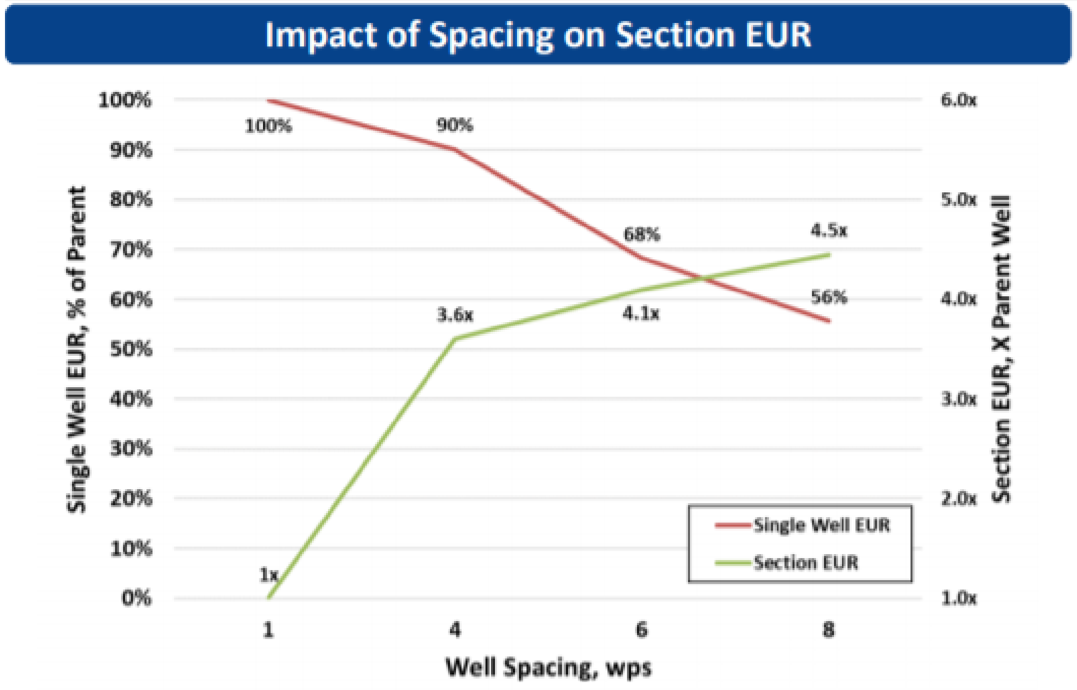
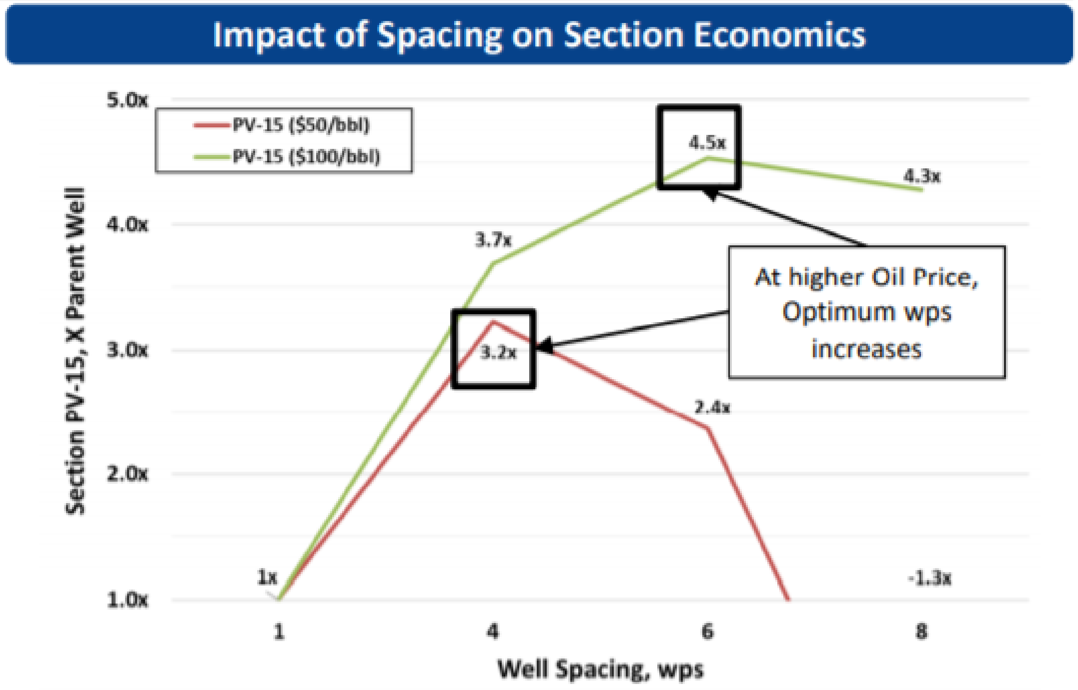
Who Says Well Interference is a Problem?

- ***Wall Street Journal***, in series of articles published in 2019, claimed
  - Typical well production profiles (‘type wells’ or ‘type curves’), based on averages of production profiles of existing wells, tend to be overly optimistic
  - “Parent, child” well relationships (particularly EURs in infill or closely spaced wells) improperly and optimistically forecasted
  - Wells generally interfered with one another more than forecasted

Any Supporting Field Evidence Available?

- VSO 2019 study indicated substantial interference in Bakken (*based on observed field data)*





Valdez, presentation to Ft. Worth Geological Society, October 2019

Do We Observe This Interference with DCA?

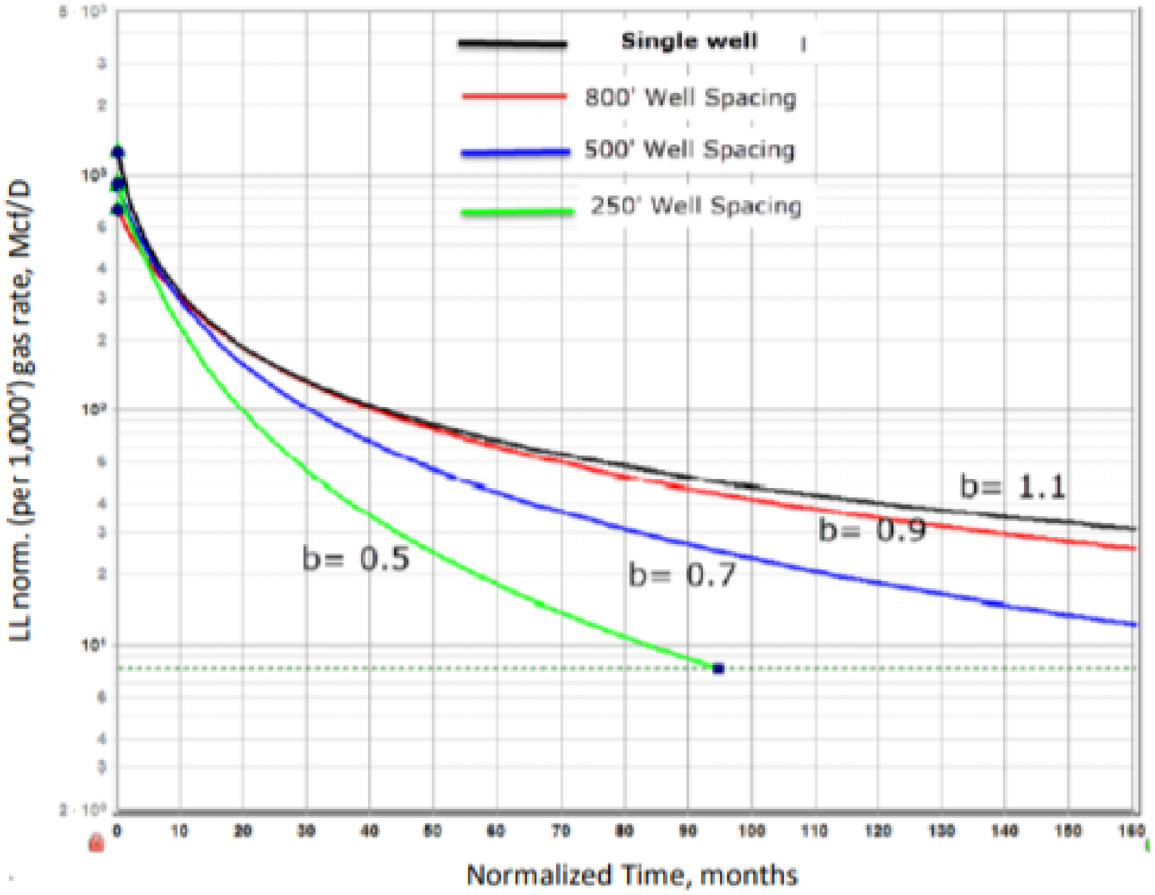


Figure 14 – Decline curve analysis from groupings of wells at different spacing indicate similar initial rates, but higher declines and lower b-factors associated with tighter-spaced wells. (Modified from Rafiee et al. 2017)

Rafiee, et al., URTeC 2695433, 2017

What is the Major Problem That We Must Solve? How Can We Solve It?

- Predictions of infill well performance optimistic
- Possible approaches
  - Construct typical well production profiles or TWPs (aka type wells or type curves) from averages of area wells – current favorite
  - Perform rigorous reservoir simulation, coupling geomechanical and flow models (Schlumberger, SPE 191799)
  - Use analytical flow models in RTA software
  - Use simulation, but implement in rapid, practical way

Rapid Simulation Proposed for Routine Applications: SBF

- Science Based Forecasting (SBF)
  - Provides physics-based approach to forecasting
  - Creates TWPs using reservoir simulation
  - Requires reservoir, completion, pressure data inputs
  - Uses pre-run simulations to history match (HM) primary well
    - Stores simulated results systematically
    - Retrieves reservoir and completion results stored
    - Finds “best fit” to historical data using best fit parameters

Comparison of SBF and DCA-Based TWPs

SBF

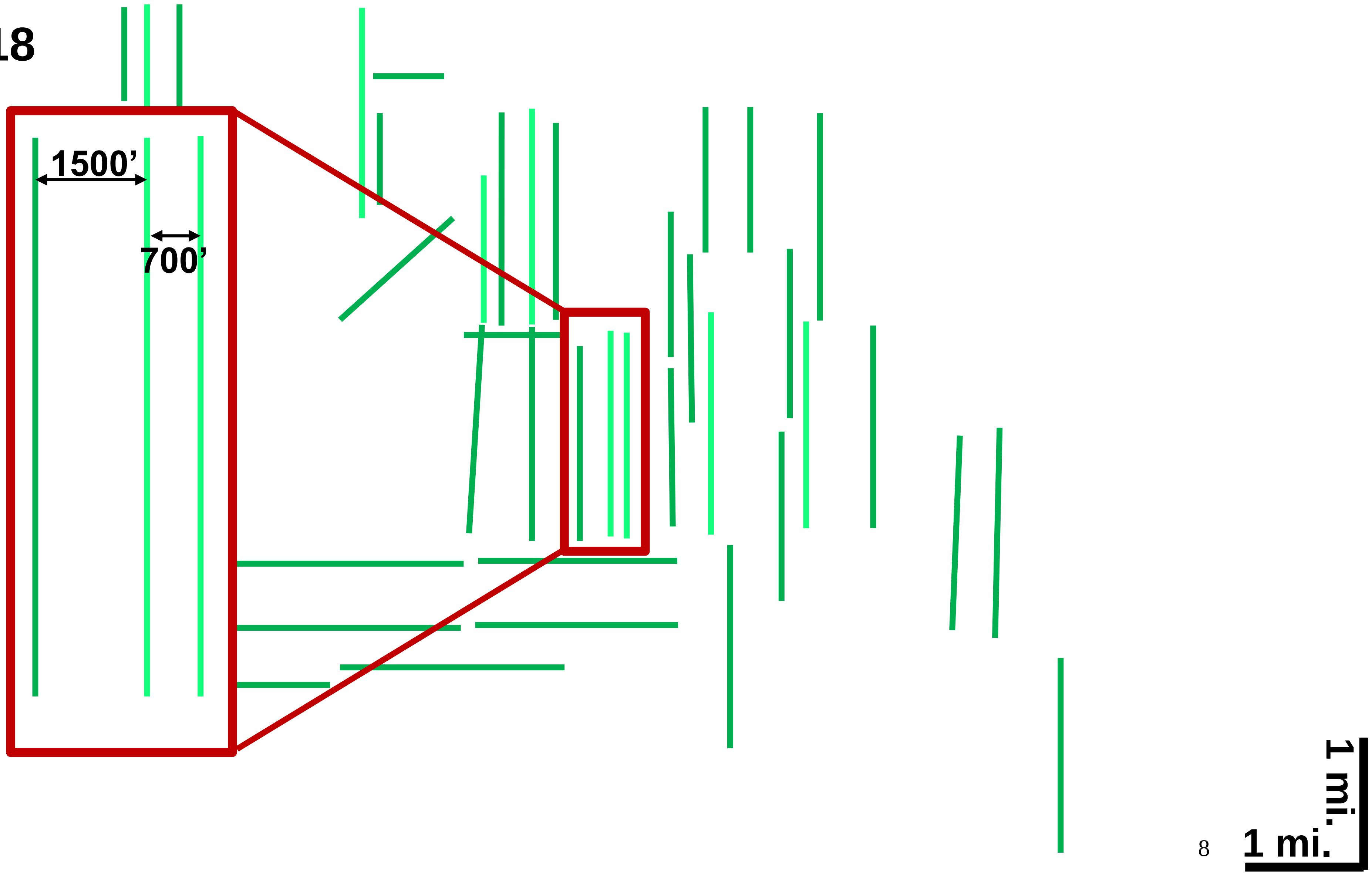
- Fast, easily learned and applied
- Models well interference
- Includes multiphase flow when pressure drops below bubble point or dew point
- Allows studies of different well spacing alternatives
- Allows investigation of variable timing of infill drilling
- EUR based on rigorous modeling

DCA

- Fast, easily learned and applied
- Interference modeled only if present in well data used to construct TWP
- Includes multiphase flow only if present in data used to construct TWP
- Restricted to well spacing affecting data used to construct TWP
- Restricted to actual timing of infill wells in available data
- EUR depends on D_{min} and final b assumed

Example Study: West Texas, Delaware Basin, Wolfcamp A

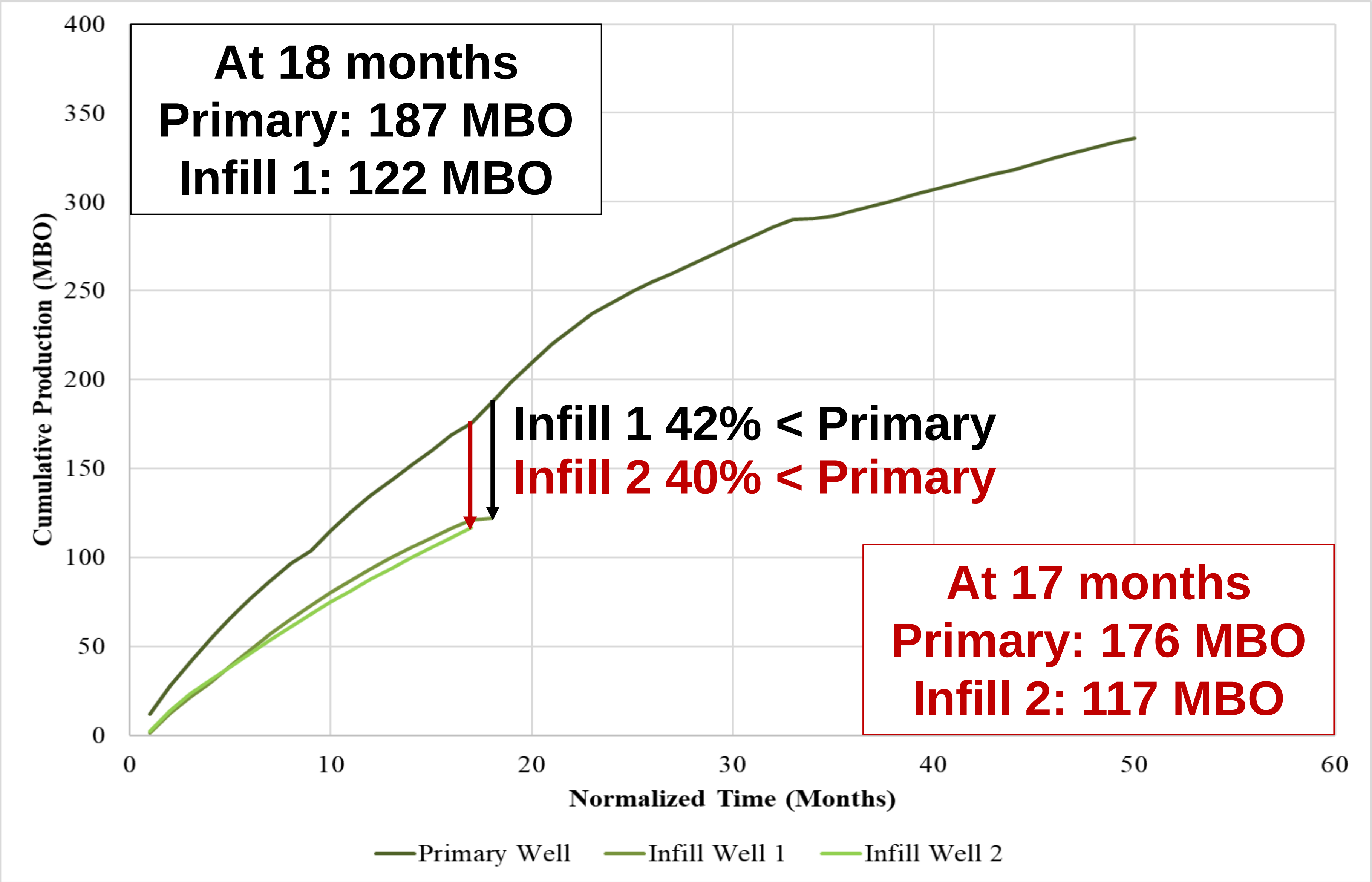
As of 09/2018



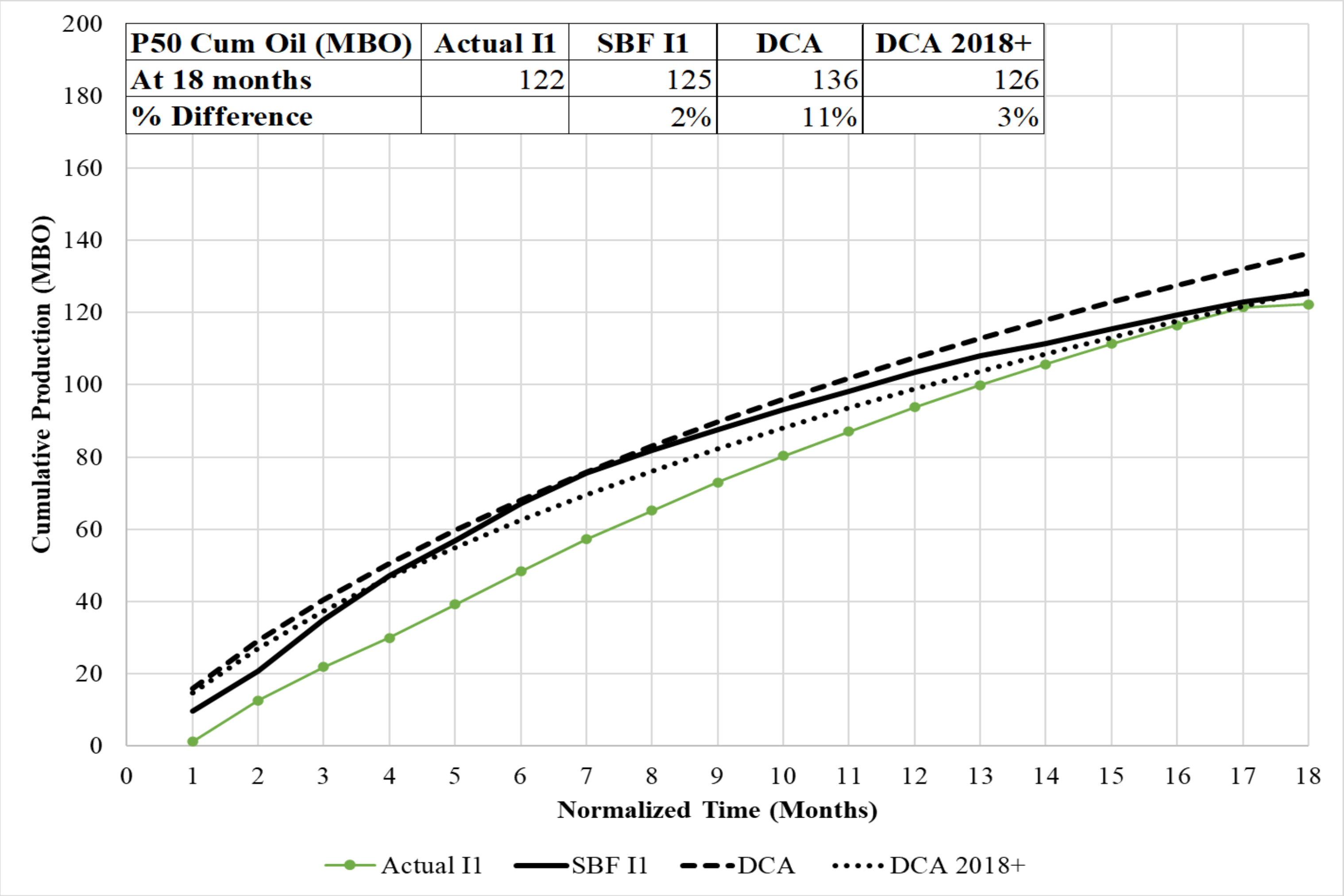
Legend

- Primary
- Infill
- Wells analyzed in study

The Fundamental Problem Illustrated: Primary Well Outperforms Two Infill Wells



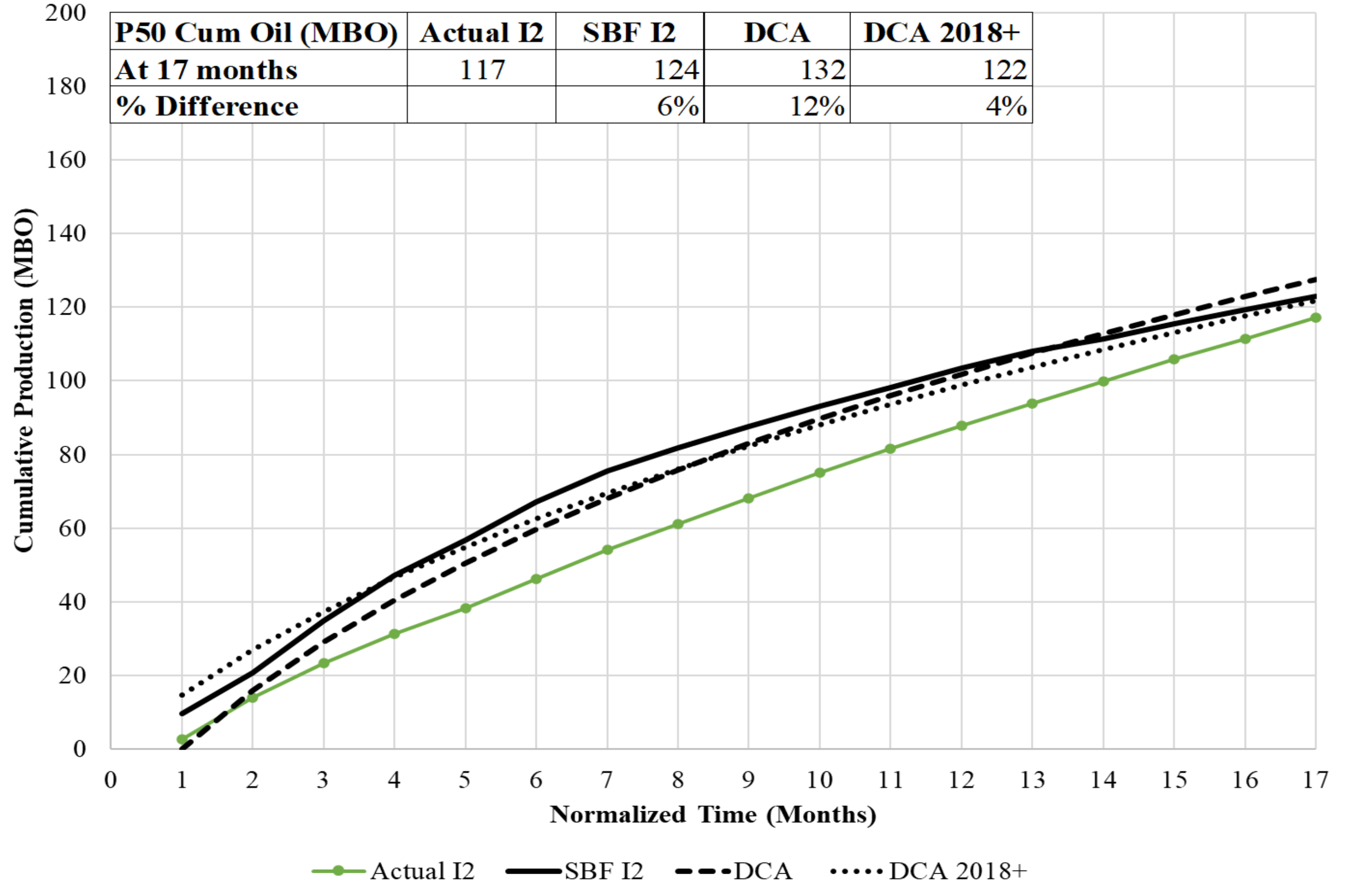
Both DCA and SBF TWPs Match 18-Month History for Infill Well 1



P50 Cum Oil (MBO)	Actual I1	SBF I1	DCA	DCA 2018+
At 18 months	122	125	136	126
% Difference		2%	11%	3%

Both DCA and SBF TWPs Match 17-Month History for Infill Well 2

P50 Cum Oil (MBO)	Actual I2	SBF I2	DCA	DCA 2018+
At 17 months	117	124	132	122
% Difference		6%	12%	4%



Summary P50 Cumulative Oil Results

Infill Well 1

Cum at 18 months	Actual C1 (MBO)	SBF P50 Cum (MB0)	DCA P50 Cum (MBO)	DCA 2018+P50 Cum (MBO)
Case 1	122	125	136	127
% Difference (wrt C1)		2%	11%	4%

Infill Well 2

Cum at 17 months	Actual C2 (MBO)	SBF P50 Cum (MB0)	DCA P50 Cum (MBO)	DCA 2018+P50 Cum (MBO)
Case 1	117	124	132	122
% Difference (wrt C1)		6%	12%	4%

- SBF accurately approximates infill production
  - I1: 2% difference actual vs. SBF
  - I2: 6% difference actual vs. SBF
- DCA also approximates infill production accurately
- Cannot quantify effect of interference with DCA alone

So What Does Analysis with SBF Have to Offer Beyond TWP?

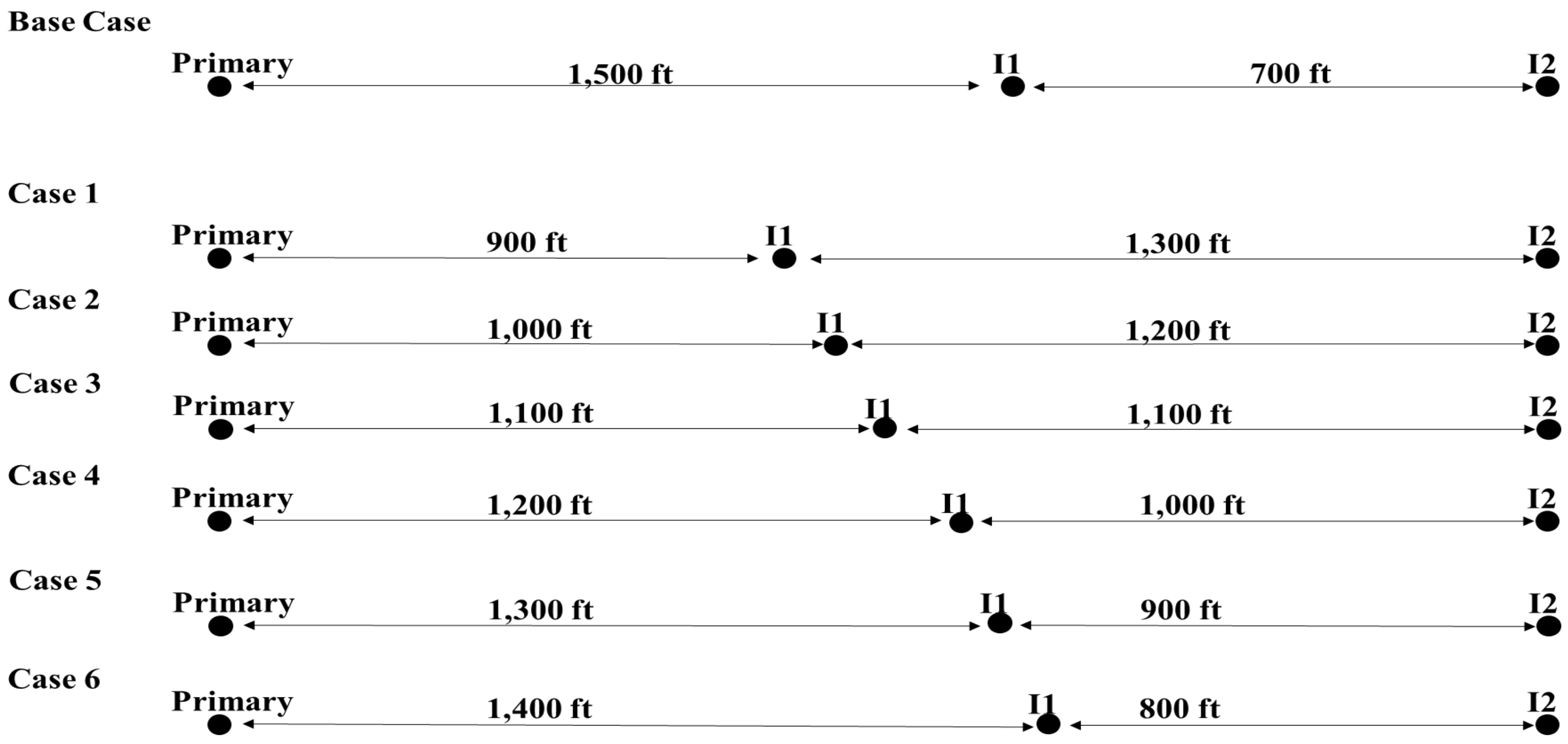
<u>Answers important questions</u>

- How could we have planned ahead?
- What could we have done better?
- How can we improve future infill wells that we drill?

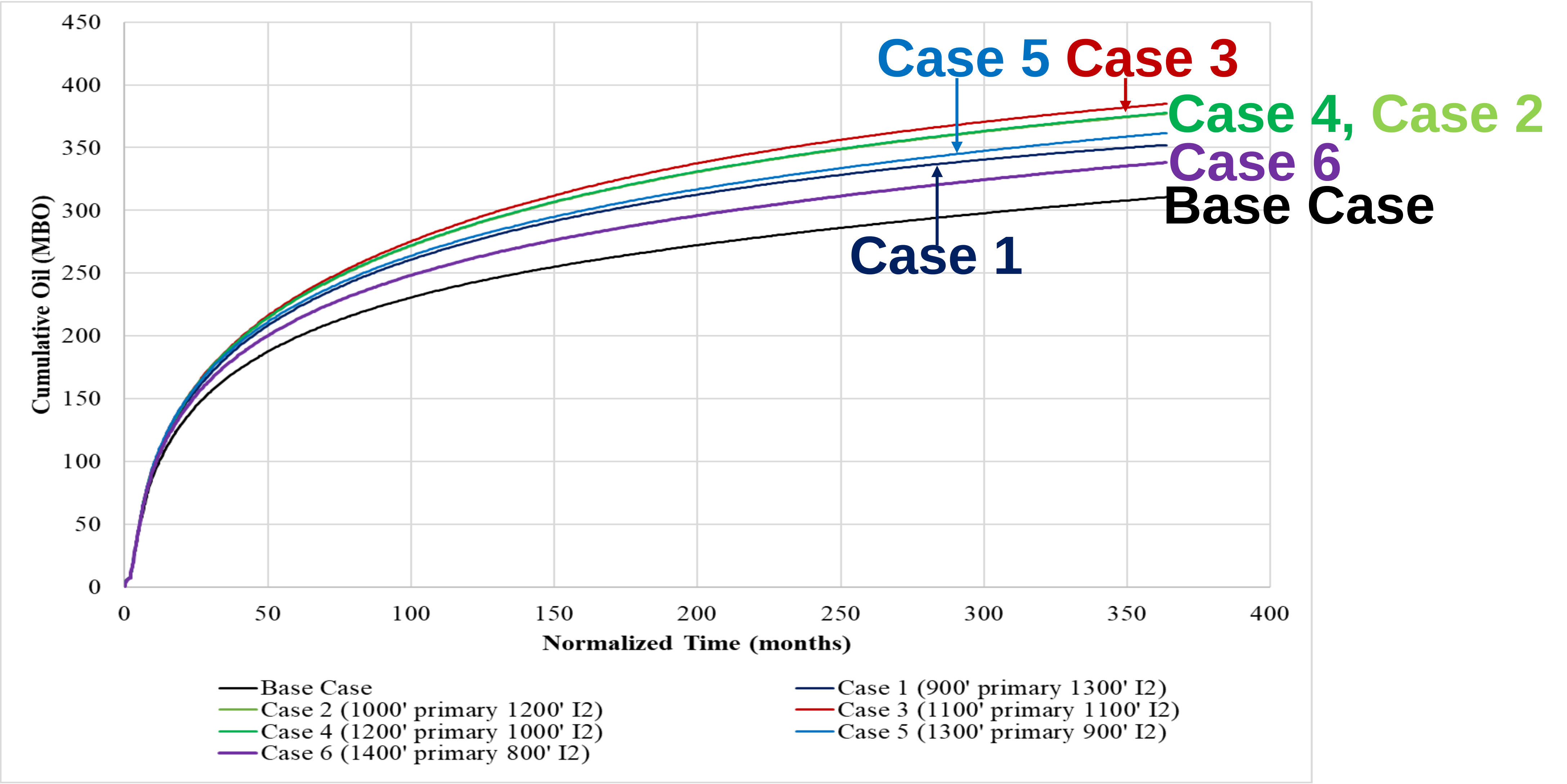
<u>Analysis techniques available</u>

- Pre- and post-drill TWP comparison
  - Well spacing analysis
  - Fracture interference analysis
  - Infill timing analysis

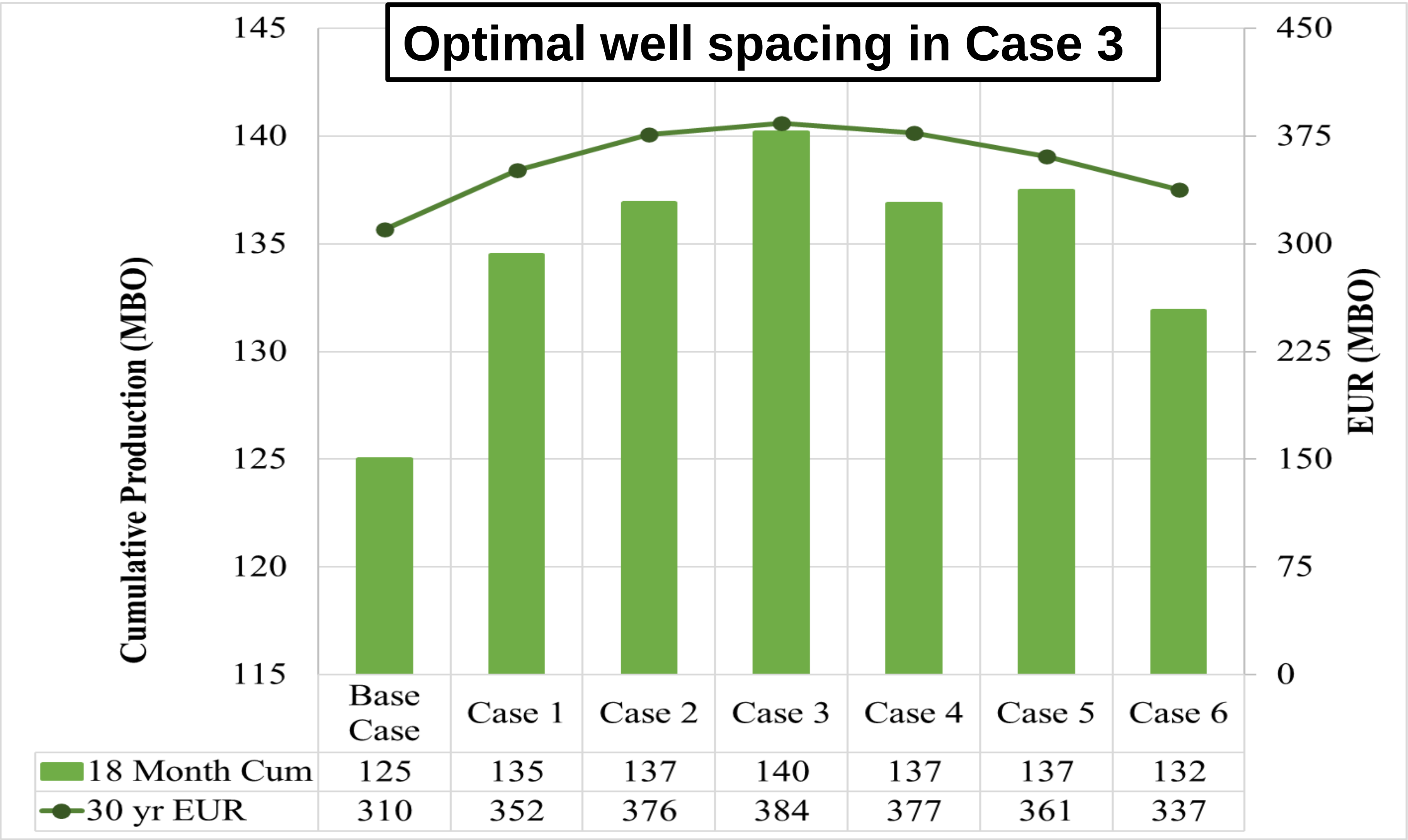
Infill 1 (I1) Well Spacing Sensitivity Analysis for Delaware Basin Example



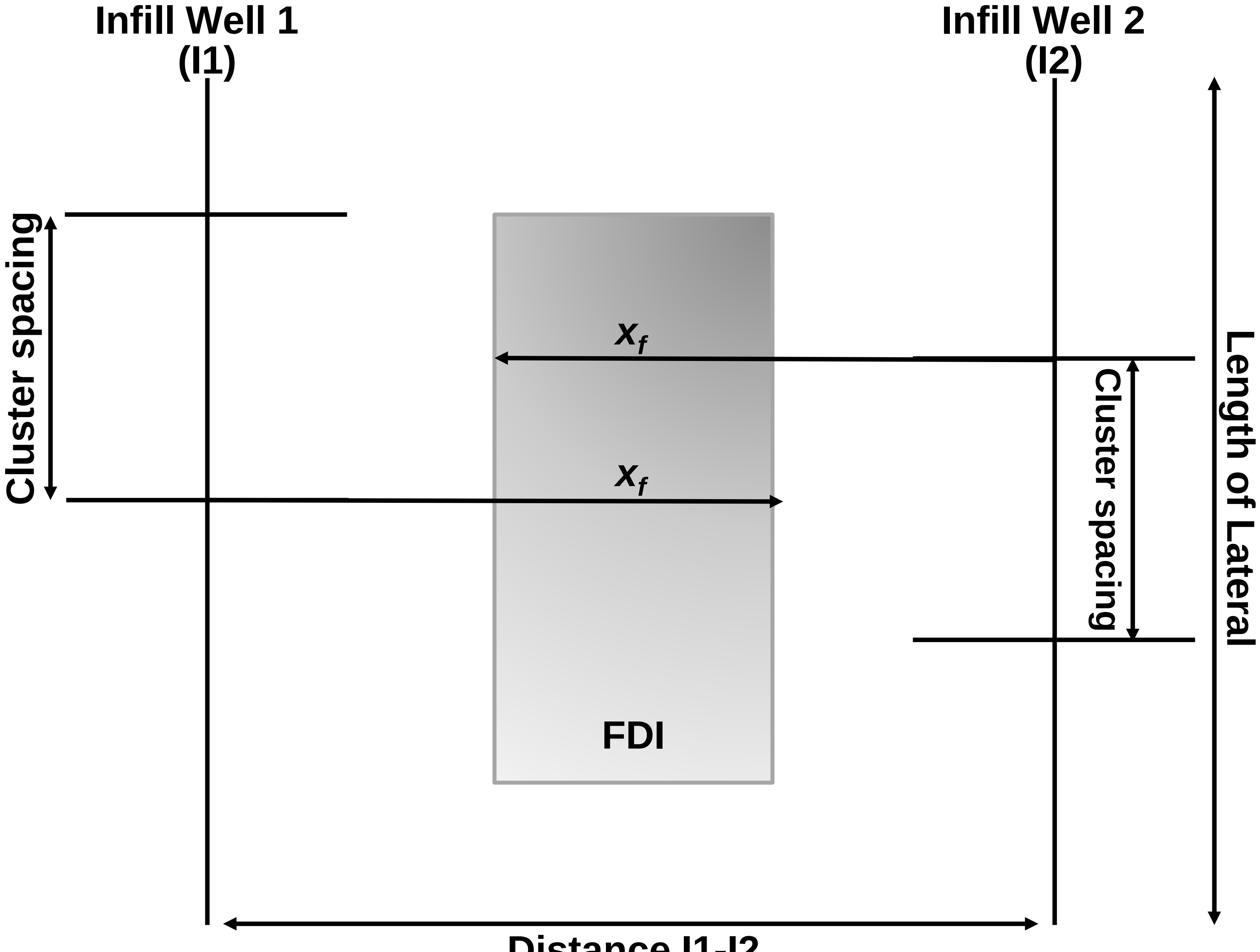
Sensitivity of 1 EUR to I1 Infill Well Spacing



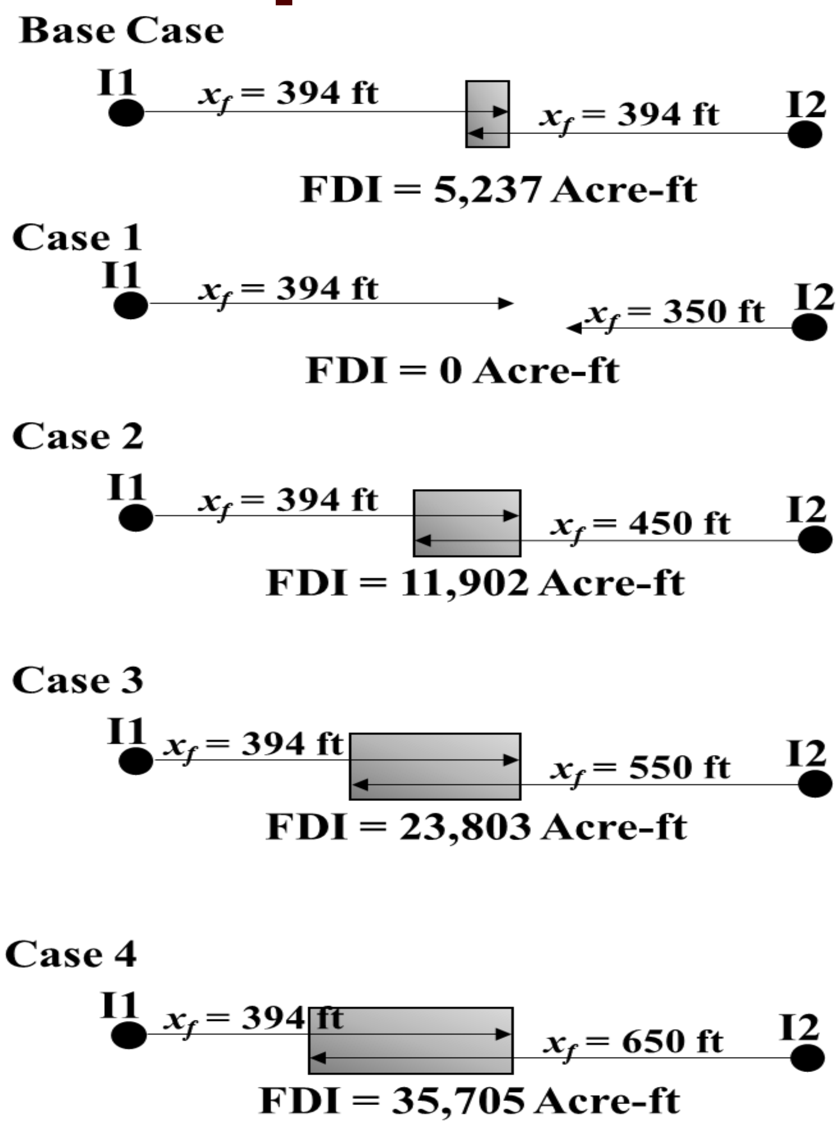
Equally-Spaced Infills Optimize EUR



Quantifying Fracture Interference



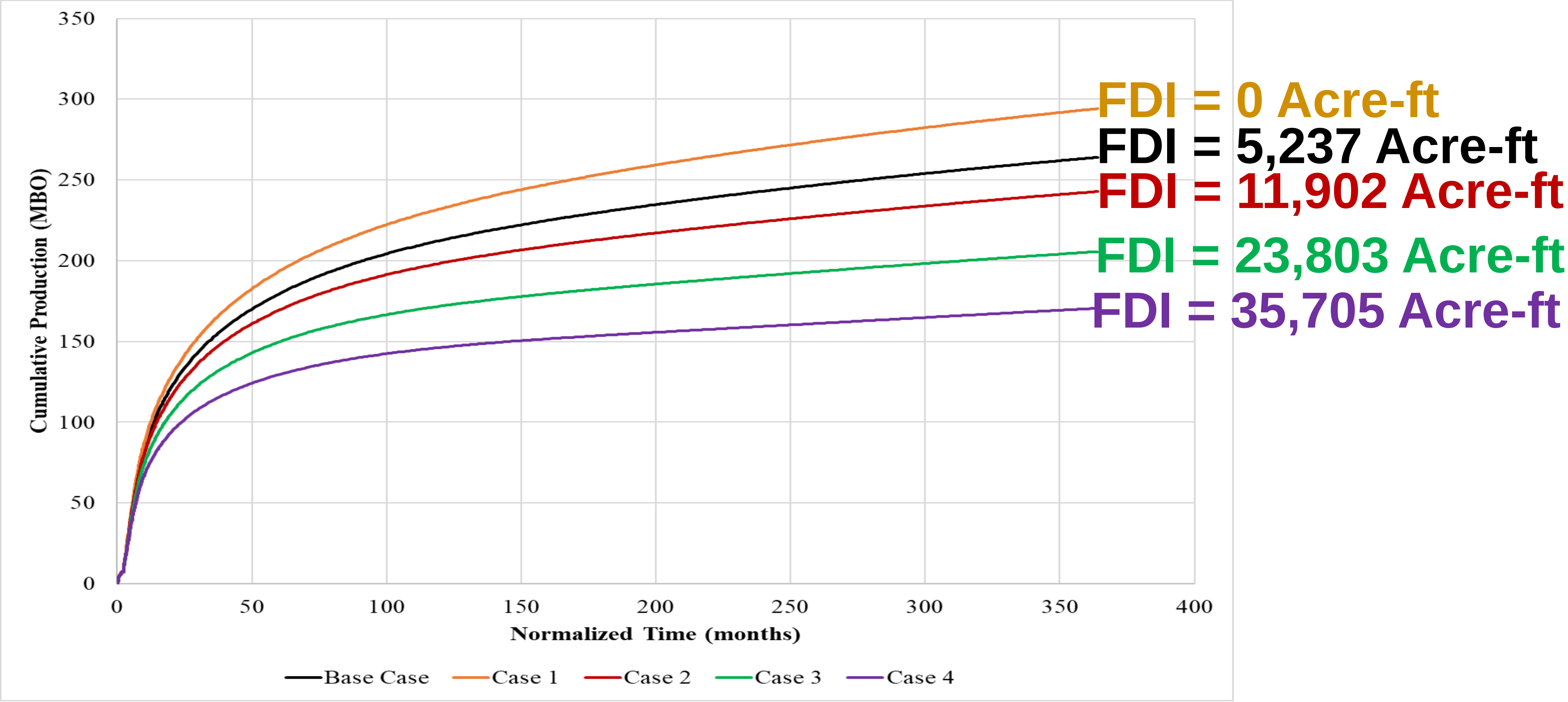
Impact of FDI on Production Forecasts



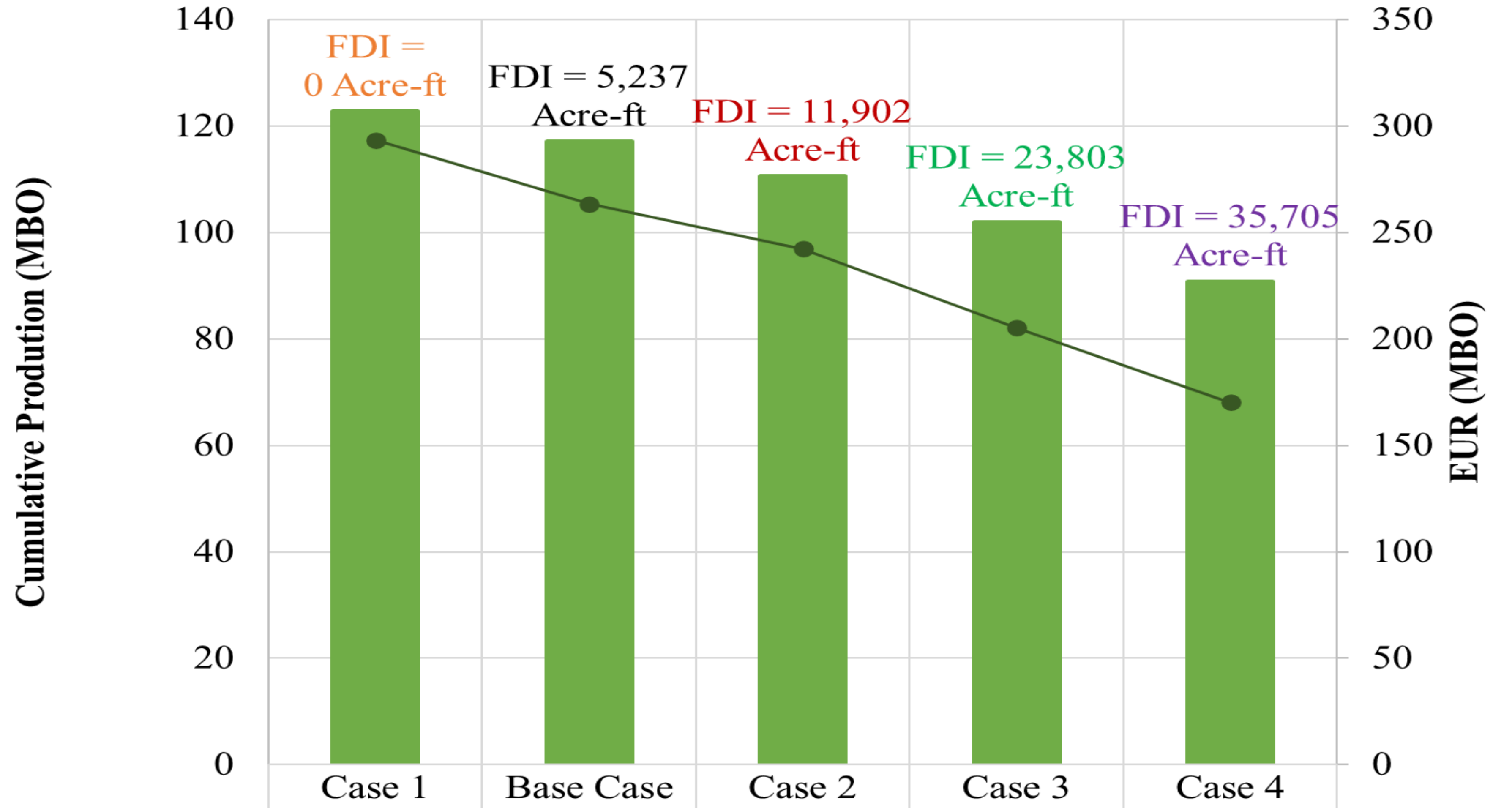
<u>Sensitivity analysis, 4 cases studied</u>

- Fracture half-length, x_f, varied
- FDI increased systematically
- Recovery decreases as FDI increases

Effect of Fracture Interference on EUR



Effect of Fracture Interference on EUR



	Case 1	Base Case	Case 2	Case 3	Case 4
Cum 18 mo	123	117	111	102	91
EUR 30 yrs	294	263	242	205	170

Summary of Spacing, Interference, and Timing Sensitivity Results

- Spacing significantly impacts recovery of I1
  - Highest increase in Case 3
    - I1 in center of both wells
    - Interference only if $x_f > 550$ ft
    - Case with least amount of interference
  - Lowest increase in Case 6
    - 800 ft from I2, interference with $x_f > 400$ ft

- Increased FDI decreases recovery

Strengths and Limitations of Two Approaches

- SBF:
  - Just as fast as DCA, and more accurate
  - Uses reservoir, completion, and pressure data
  - History matches primary well to construct infill well model
  - No more expensive than leading DCA software
- DCA:
  - Industry-standard approach to forecasting
  - Uses only production data in analysis
  - Requires arbitrary *b*-factor and decline rate selections
  - Historical accuracy problems in unconventional reservoirs

Conclusions

- Interference clearly occurs in resource plays with close well spacing, long fractures
  - Often ignored or underestimated in historical TWP construction
- Tools used in industry to include interference in forecasts, TWP construction
  - TWPs based on averages of history plus forecasts with decline curves
    - Difficult to model interference unless effects present in histories
    - Difficult to model effects of timing, spacing with DCA alone

Conclusions (Cont'd)

Tools used in industry to include interference in forecasts, TWP construction (cont'd)

- Rigorous simulation with coupled flow, geomechanical models
  - Gold standard in rigor, accuracy, and comprehensive features
  - Time-consuming, expensive, not well suited for routine analysis
- Analytical models, as in RTA packages
  - Suitable for studying well spacing
  - Based on single-phase solutions to flow equations
- Rapid, low-cost simulation with SBF
  - Provides rigor and accuracy
  - Suitable for well spacing studies

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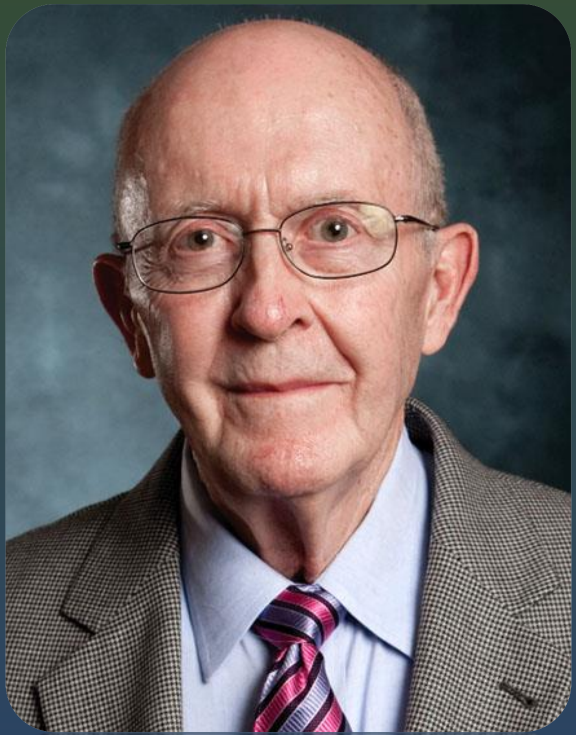

John Lee holds the DVG Endowed Chair in Petroleum Engineering at Texas A&M University. He holds a B.S., an M.S. and a PhD degree in Chemical Engineering from Georgia Tech.

John worked for ExxonMobil early in his career and specialized in integrated reservoir studies. He has taught at Mississippi State University, the University of Houston, and Texas A&M. While at A&M, he also served as a consultant with S.A. Holditch & Associates, where he specialized in reservoir engineering aspects of unconventional gas resources. He served as an Academic Engineering Fellow with the U.S. Securities & Exchange Commission (SEC) in Washington during 2007-2008 to help modernize SEC rules for reporting oil and gas reserves.

John is the author of four textbooks published by SPE and has received numerous awards from SPE, including the Lucas Medal (the society's top technical award), the DeGolyer Distinguished Service Medal and Honorary Membership (the highest recognition awarded society members). He is a member of the U.S. National Academy of Engineering and the Russian Academy of Natural Sciences.

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