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NETHERLAND, SEWELL & ASSOCIATES, INC.

WORLDWIDE PETROLEUM CONSULTANTS

Well Spacing and Reserves Impacts

SPEE – Houston Chapter

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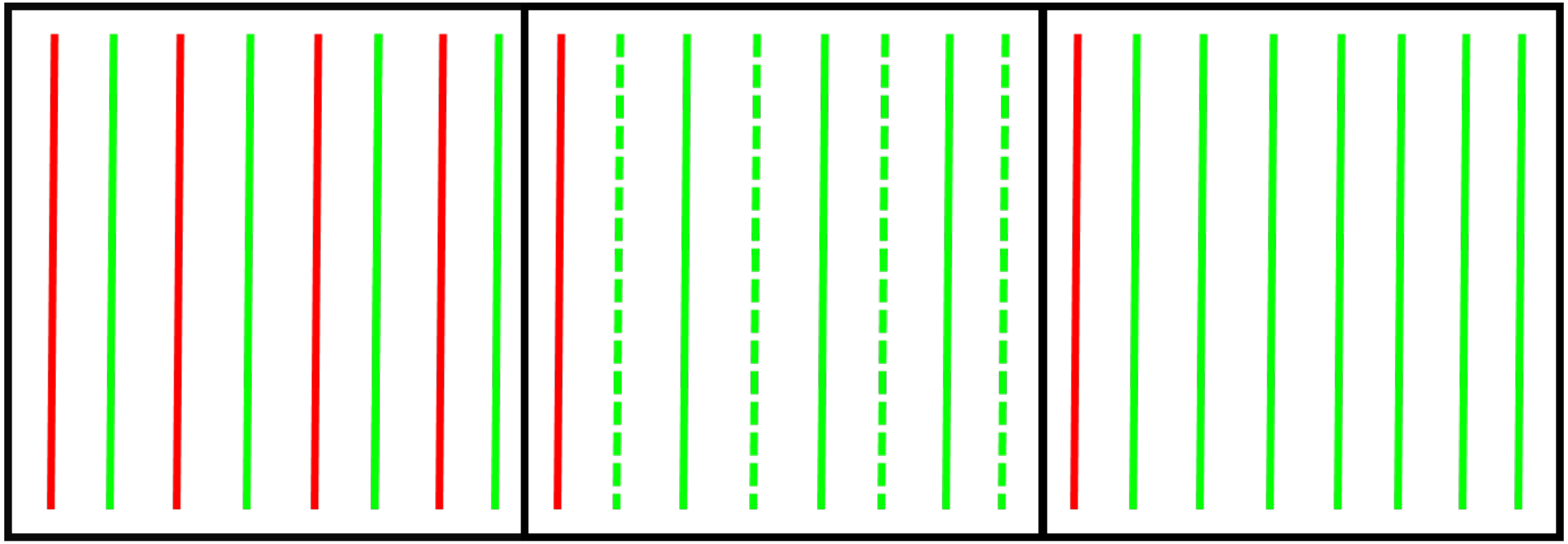
NSAI's Role and Point of View

- Typically engaged by an E&P company or investor
- Product: independent evaluation or audit of resources
  - For company-internal assurance purposes
  - For external disclosures (e.g. SEC reporting)
  - For investment due diligence
  - For financial purposes (e.g. reserves-based lending)
- Typical technical data received and analyzed
  - By well: production data, completions details, location
  - Geologic information, including well logs
  - Forward development plan

How are Well Interactions Defined?



Producing Horizontal Well (PDP)

Initial Infill Drilling Horizontal Location

Second Infill Drilling Horizontal Location

Downspacing – We've Been There Before

"Tolerate" interference while capturing profitable incremental hydrocarbons

Similar Impact: True infill vs Close proximity step-outs

San Andres/Clearfork

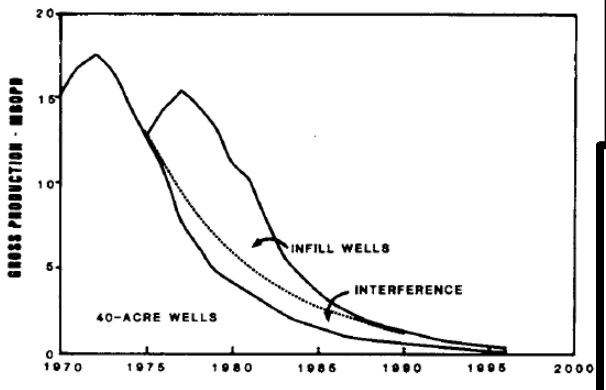


Fig. 4—Production datagraph—Means San Andres Unit.

SPE 11023: Infill Drilling to Increase Reserves – Actual Experience in Nine Fields in Texas, Oklahoma, and Illinois; Barber, George, Stiles, and Thompson, 1983

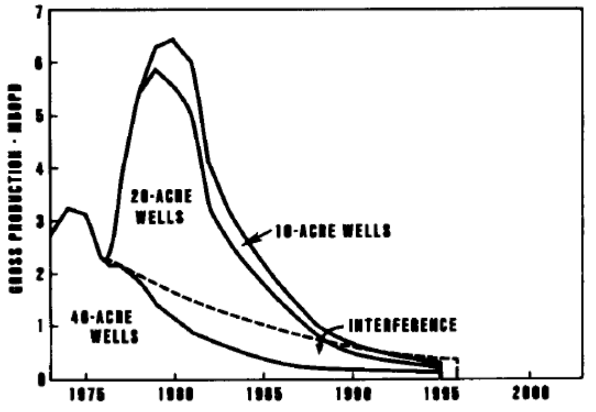
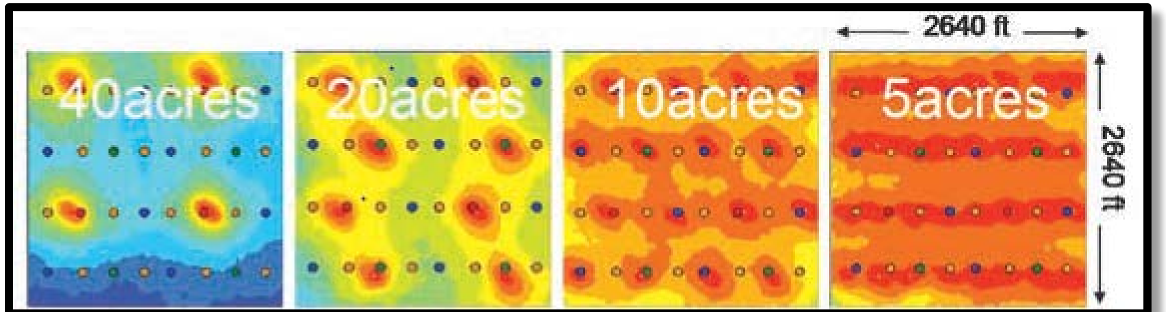


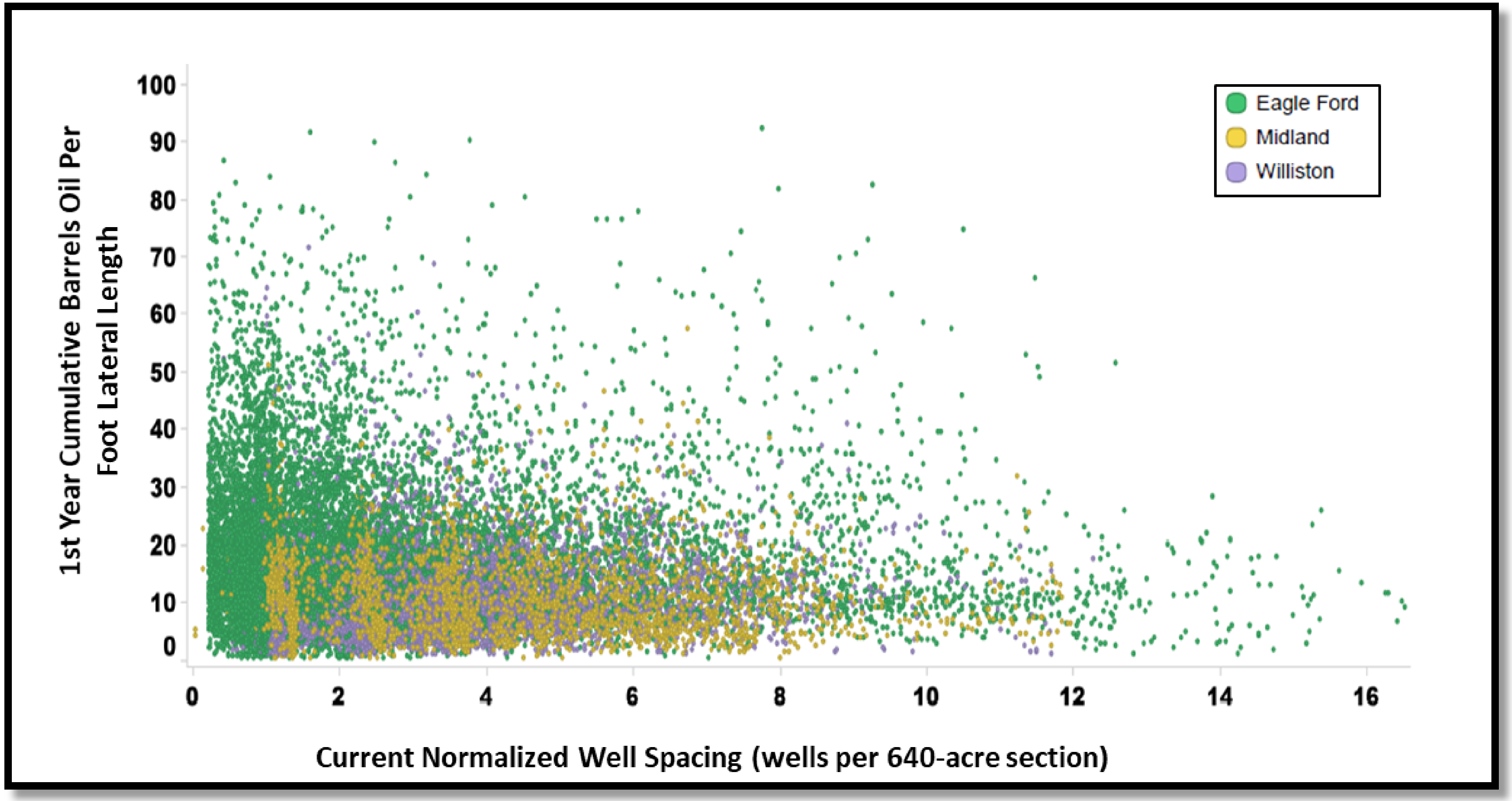
Fig. 11—Production datagraph—Robertson Clearfork Unit.

Jonah/Pinedale



Infill well evaluations of Jonah Field tight gas: characterization and simulation of complex architectural elements; Michelena, Gilman, Angola, Uland, Pasternack; First Break, Vol 27, April 2009

Downspacing – Unconventionals



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Similar outcome, but more variance in spacing and timing of development

Potential Determinants of Performance

Completed lateral length

Fluid flow regimes

Reservoir thickness

Artificial lift type

OOIP

Reservoir Sw

Downspacing strategy

Landing zone

Permeability

Production strategy

Perf clusters/stage

Downspacing timing

Extent of natural fractures

Initial pressure

Fluid type/character

Porosity

Frac hit management

Offset maturity

Offset Interference

Completion sequence

Horizontal inclination

Restimulation strategy

Frac delivery/HP/Rate

Proppant/stage

Well orientation

Formation Stress

Operator

Proximity to faulting

Fluid/stage

Secondary ratio

OGIP

Extent of SRV

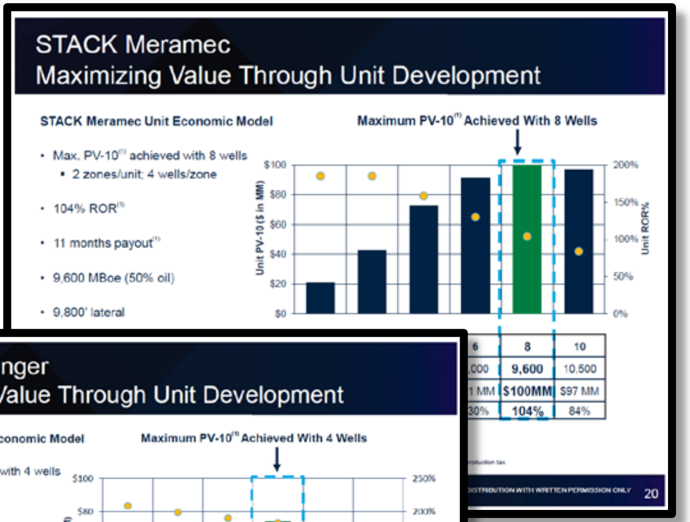
Spatial geologic variation

Frac stage count

Production drawdown

Well Interference

- Optimization controls for well economics
  - Well length
  - Completion / stimulation
  - **Well spacing / Wells per section**
- Particularly with well spacing: Maximum value usually achieved at stage of diminishing returns per well
- Goal - "Tolerate" interference while capturing profitable incremental hydrocarbons



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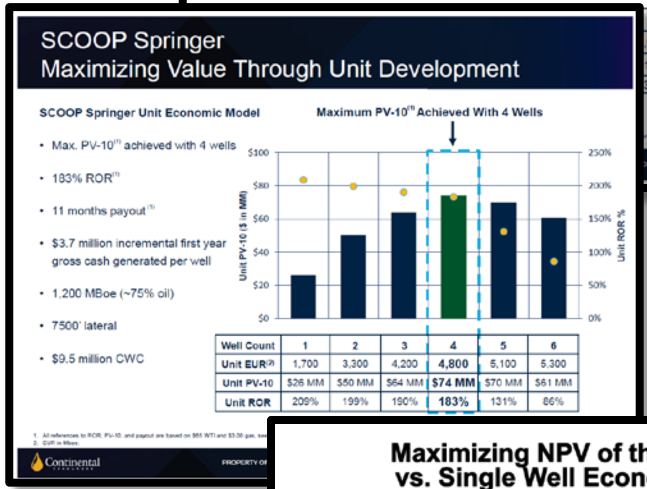

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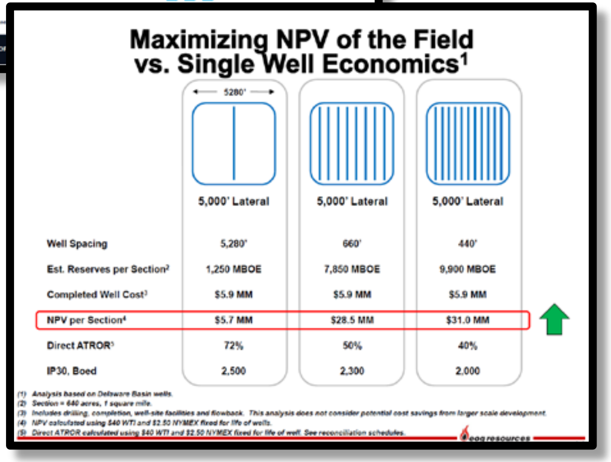


EOG

Toolbox for Unconventional Analysis

- Performance analysis
  - **Performance / Decline Curve Analysis**
  - **Analogy / Type well profiles**
  - Transient versus Boundary Dominated Flow (BDF)
    - BDF Analysis
    - Transient Flow Analysis
  - Analytical models
  - Flowing Material Balance
  - Productivity Index
- **Volumetrics**
- Numerical simulation

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

$$P_p = \left(\frac{\mu_{gi} z_i}{P_i}\right) \int_0^P \frac{P}{\mu_g z} dp$$

and

$$t_a = (\mu_{gi} c_{ti}) \int_0^t \frac{1}{\bar{u}_g \bar{c}_t} dt$$

Material Balance Equation

$$C_t = -\frac{1}{V} \times \frac{\Delta V}{\Delta p}$$

$$p_i - \bar{p} = m_{pss} N_P$$

$$\bar{p} - p_{wf} = b_{pss} \times q_{oil}$$

$$\frac{q}{p_i - p_{wf}} = \frac{1}{m_{pss} MBT + b_{pss}}$$

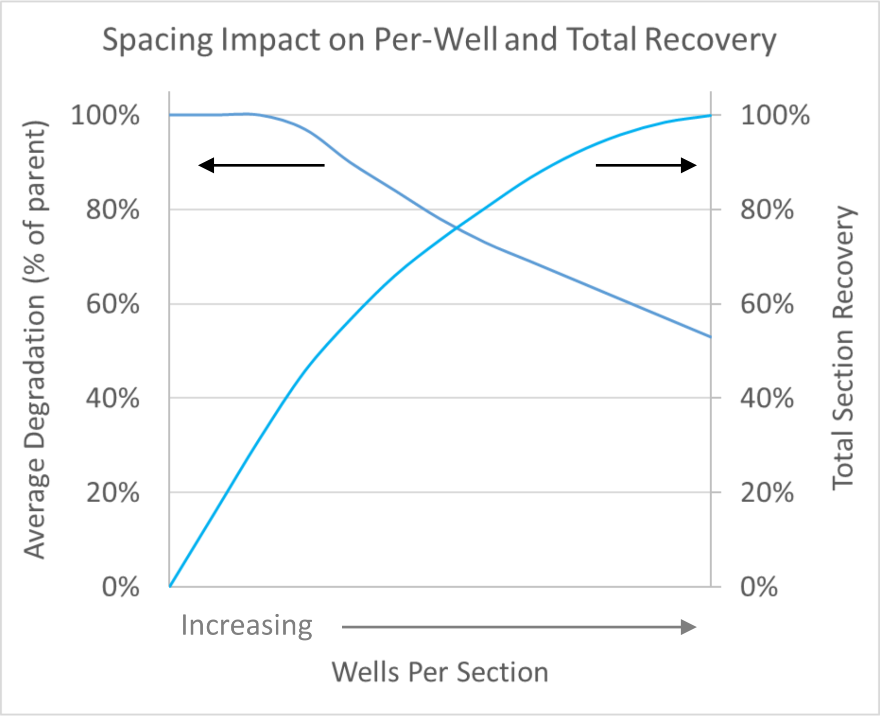
$$\frac{m(p_i) - m(p_{wf})}{q_g} = \frac{1.632 \times 10^6 T}{kh} \left[\log\left(\frac{kt}{\phi \mu c_t r_w^2}\right) - 3.23 + 0.87s\right] \text{ ... gas}$$

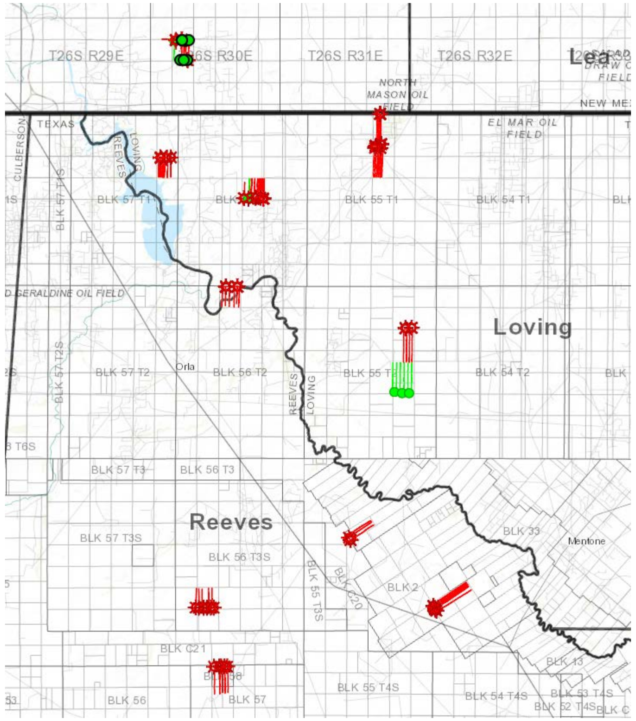
Dealing with Well Interactions
The Evaluators' Approach

- Boundary conditions/limitations
  - Existing development
  - Operator's plan of future development (POD)
  - OHIP/Recovery factor
- Levers available
  - Reserves categorization
  - Volume adjustment – degradation factors against "parent" well
- Timing
  - Predrill - Parents kept whole, volume adjustment to undrilled children
  - Some Time Post-drill – Impact inherent in performance of parent and child

  } In between – transition to shared impact
- Complications
  - Frac hits on parents
  - Pad/Batch drilling
  - POD more dense than analog spacing
  - Public allocated data

Spacing Tests – Delaware WCA





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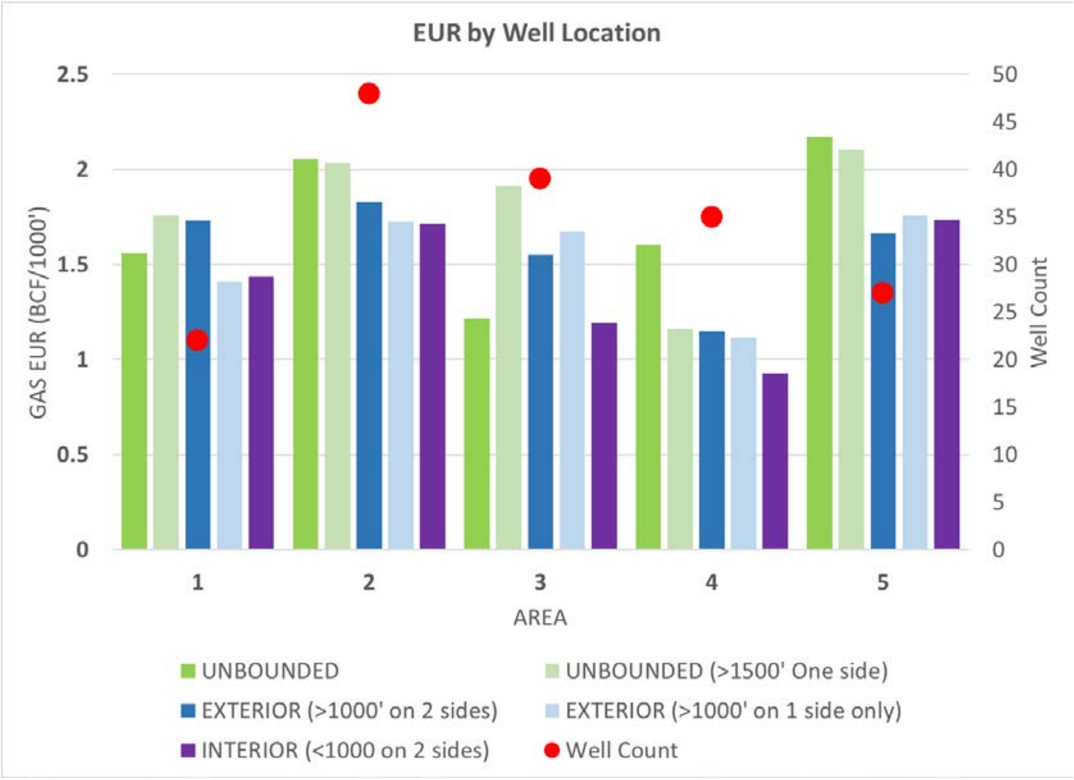
- Demonstrated results to assign EURs at operator's planned development spacing – single zone
- Adjust for local well performance and geology
- Confirm total section EUR increases as well count increases with assigned degradation factor

Impact of Well Location – Utica



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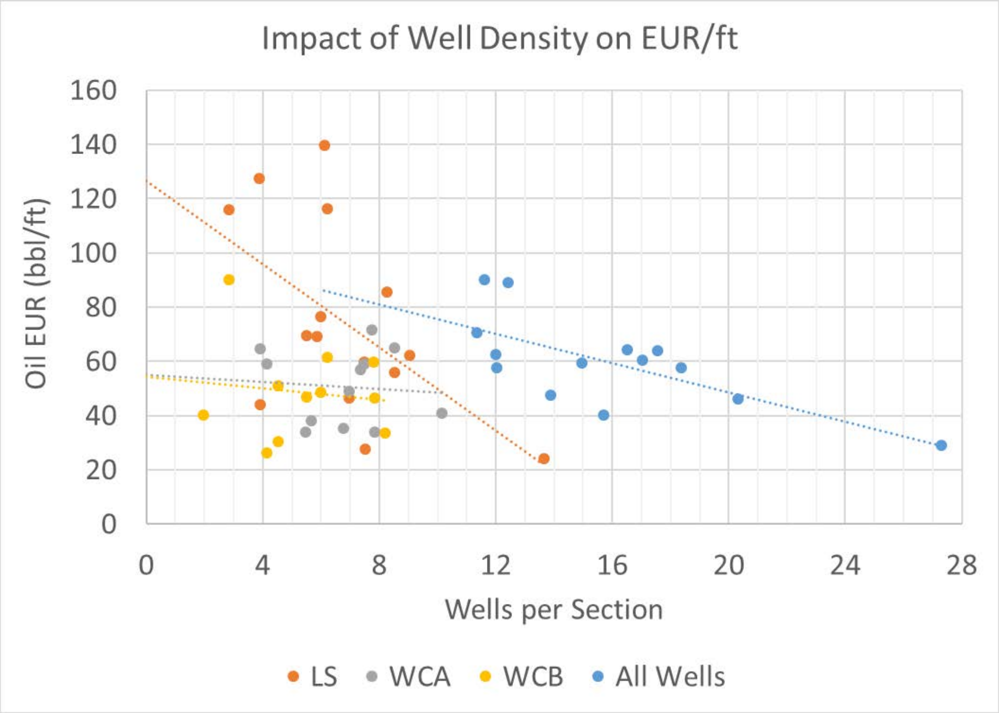
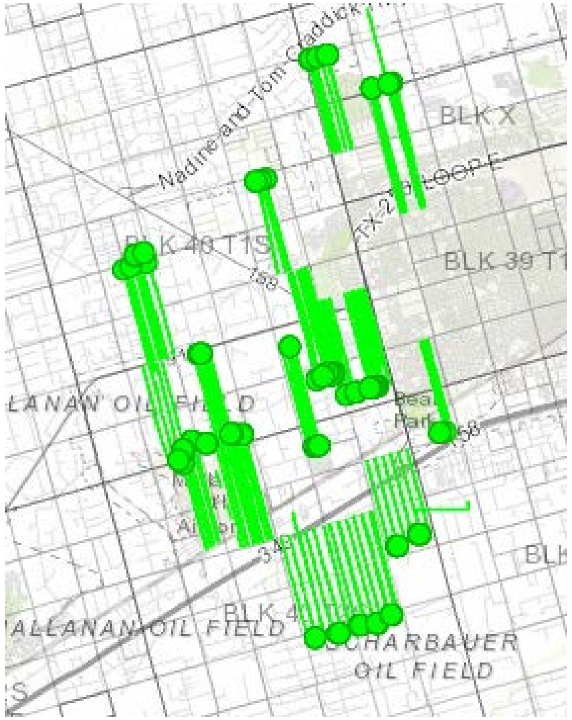
- Expect unbounded or exterior well to have higher EUR than well interior to development
- Assign undeveloped reserves based on position relative to other wells

Multi-Zone Development – Midland Basin





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- Consider inter-zone interference for areas with multiple landing zones
- Projections at lease level can help mitigate allocation errors
- Assign reserves category based on data density and consistency

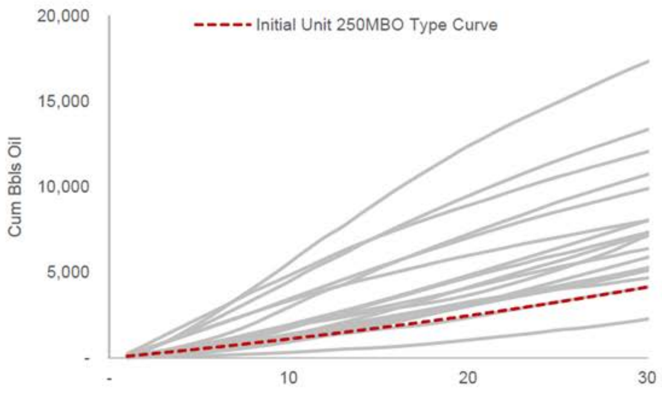
Early Time Can Be Deceiving

2018 Pattern Results Degraded Over Time

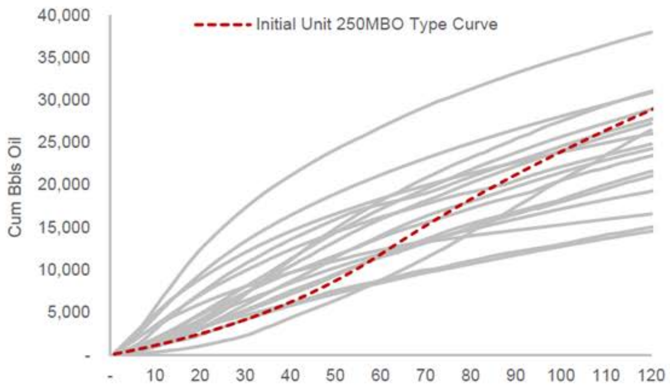
Summary of 2018 Drilling Program

- Drilled 175 wells and completed 174 wells in 2018
- At year-end 2018 we had 17 patterns with 6-10 wells per section density with meaningful production results
- While early pattern well results appear strong vs. the type curve, they have consistently degraded over time
- Oil EUR for the average 2018 pattern well is ~120 MBO in the YE 2018 reserve report
- 2018 results driving management focus in 2019 on improved infill economics through:
  - Upspacing and lateral placement
  - Lowering D&C costs
  - Lowering LOE and overhead

16 of 17 Patterns Above 250 MBO TC at 30 days



4 of 17 Patterns Above 250 MBO TC at 120 days



Alta Mesa

Dealing with Parent/Child and Well Spacing Incorporating Technology & Geology

- Know the play – no substitute for having seen many wells
- Be cognizant of completion types and lateral lengths
- Statistical analysis may be valuable, but
  - "Close-ology" and EUR trends are meaningful, and
  - Honoring geology (and volumetric in-place) is critical
- Analogy can be highly useful but verify applicability; every well is still unique
- Expect decreased EUR once density reaches some point, but it may not be immediately apparent
- Reasonableness check (and upper limit) involves OHIP/Recovery factor

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