# The Society of Petroleum Evaluation Engineers

**SPEE Denver Chapter announces its July Luncheon Meeting.**

**(Members and Guests are cordially invited to attend.)**

## Thursday, July 27, 2017

# Mr. Randy Freeborn

**Chief Research Engineer, Energy Navigator, Inc.**

**Will be speaking on:**

**<u>Production Rate Scaling Principles for use in Type Well Construction</u>**

**LUNCHEON STARTS AT 11:30 A.M.**
**(A plate lunch will be served.)**
**PRESENTATION BEGINS AT NOON**

## The Denver Athletic Club

**3rd Floor, The New Petroleum Club Room**
**1325 Glenarm Place (14th and Glenarm) Denver CO 80204**
**Parking flat rate $7.00 on space available basis**

## Cost: $25.00 per Person

**Special pricing of $25 continued into 2017. Normally $35.**

**Please RSVP by Noon Tuesday, July 25, 2017**

**RSVP and simultaneously pay by credit card online at:**

https://secure.spee.org/civicrm/event/info?reset=1&id=137

If the above link does not work, alternatively go to www.spee.org then select ‘Local Chapters’, then ‘Denver’, then ‘Register Now’.

# Production Rate Scaling Principles for Use in Type Well Construction

Randy Freeborn, P. Eng.
July 2017

# Topics

## Sample Size Matters

## Scaling to get more analogs

- Time to end of linear flow
- Well length
- Number of fractures
- Permeability

## Diagnostics

- Estimate unknown parameters for a well
- Scale a well's data to your planned drilling and completion design

# Sample Size Matters

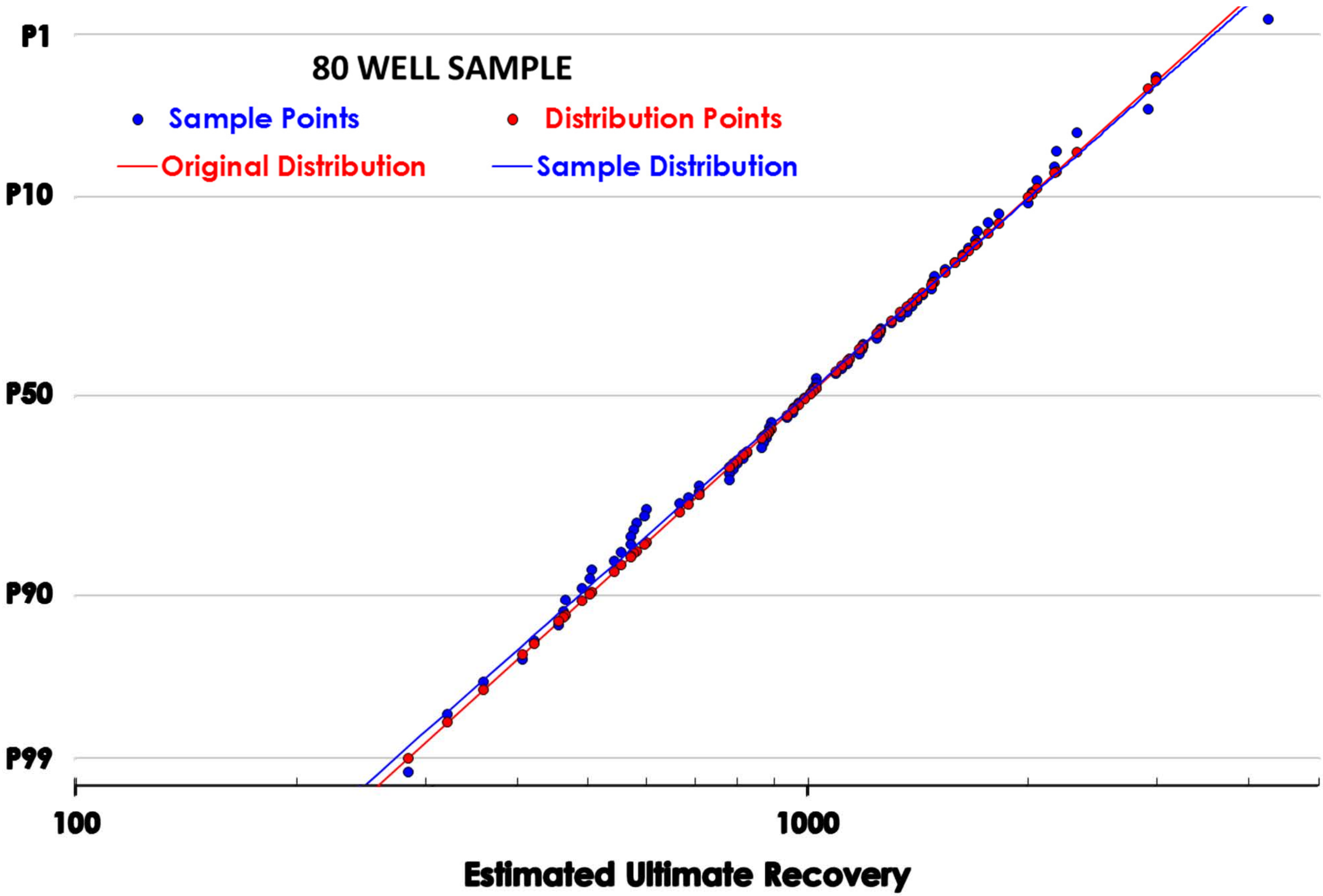
# Sample Size Matters?

We bin to get representative wells

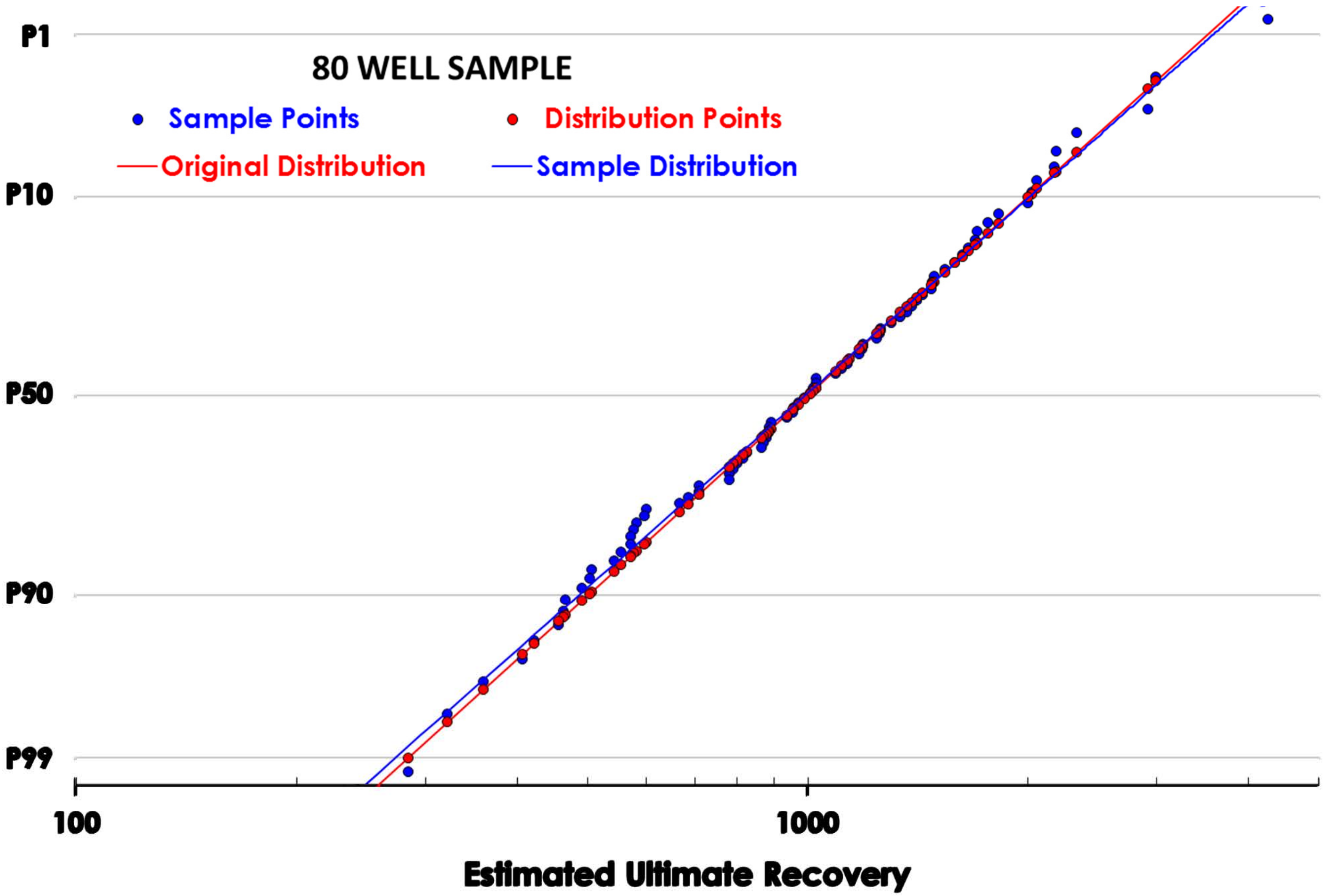
- Drilling longer wells
- More fractures, greater fracture density
- Bigger fractures, both volume and proppant
- Sweet spots are getting drilled up

How does sample size influence accuracy?

- Each new bin halves the sample size
- Scaling may provide representative wells without binning?
- Trade off: scaling error vs error from small samples



80 WELL SAMPLE
Sample Points
Distribution Points
Original Distribution
Sample Distribution
P1
P10
P50
P90
P99
100
1000
Estimated Ultimate Recovery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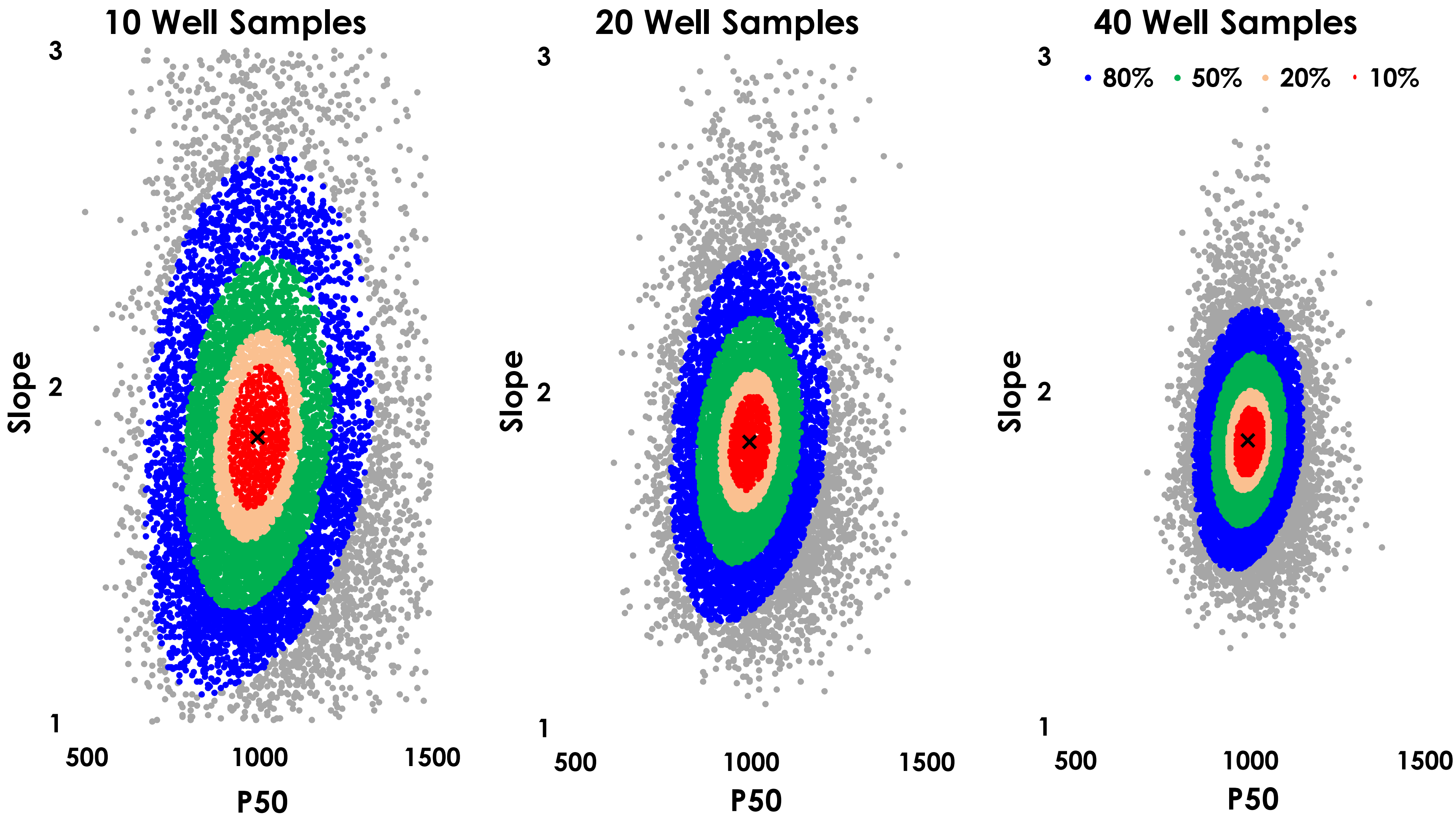



Double the sample size, confidence improves two fold

# Scale to get more analogs

## Transform old wells to new wells

Reference: Freeborn et al, SPE 175967

# Scaling

- Scale what you can, bin the rest
- Accuracy trade off: scaling vs small samples
- Logic is physics based intuition
  - Adjusting initial rate and $t_{elf}$
  - Based on Dr. Lee's equation $t_{elf} = \frac{1896\ \emptyset\ \mu\ C_t\ {d_i}^2}{k}$
  - Improvement possible from parametric simulation
- Create wells scaled to new drill/complete plan
  - Bin the scaled wells as necessary
  - For each bin, build type well from scaled wells

# Scaling – End of Linear Flow

$$t_{elf} = \frac{1896\, \emptyset\, \mu\, C_t\, {d_i}^2}{k} \qquad t_{elf} \sim \frac{{d_i}^2}{k}$$

| | | |
|---|---|---|
| Time | $t$ | hours |
| viscosity | $\mu$ | cp |
| compressibility | $c_t$ | psi$^{-1}$ |
| inter-fracture distance | $d_i$ | ft |
| permeability | $k$ | md |

Dr. Lee, Reservoir Engineering Aspects of Unconventional Resources
SPE Course Oct 29, 2012

# Scaling – Sweet spot

## Intuition from physics

- Rate is proportional to permeability
- Proppant concentration may act as increase in perm
- For gas, $c_t \approx {}^{1}/_{p}$: pressure may act like k
- New permeability changes $t_{elf}$

## Math and process

- $Scale\ Factor = \frac{perm_{target}}{perm_{well}}$

$$t_{elf} = \left(\frac{perm_{well}}{perm_{target}}\right)$$

- Remove history < $t_{elf}$ and multiply rates by the $Scale\ Factor$
- Forecast linear flow, transition at calculated $t_{elf}$

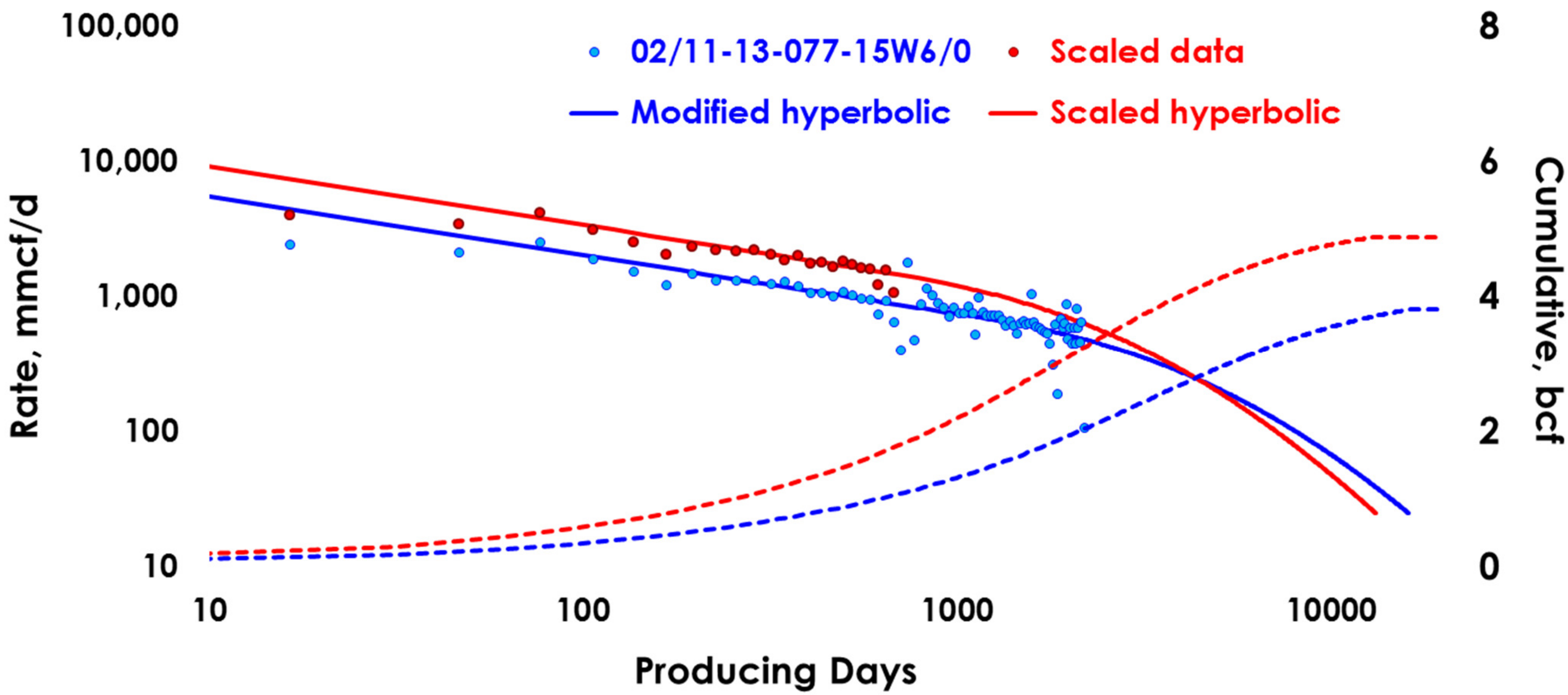
# Scaling – Sweet spot

| | Hyperbolic | Scaled | |
|---|---|---|---|
| $q_i$ | 83000 | 138336 | $83000\ (1.667)$ |
| $d_i$ | 8000 | 8000 | |
| $b_i$ | 2.30 | 2.30 | |
| $b_f$ | 0.30 | 0.30 | |
| $t_{elf}$ | 1134 | 681 | $1134/1.667$ |
| $length$ | 6599 | 6599 | |
| $fracs$ | 9 | 9 | |
| $distance$ | 825 | 825 | |
| $wlf$ | 0.743 | 0.743 | |
| k | 1.000 | 1.667 | $(1.667/1.00) = 1.667$ |

**Note: same rate increase as frac example where EUR decreased 9%**

**Montney: 02/11-13-077-15W6/0**

# Scaling – Sweet spot




67% increase in permeability (improved drainage)

EUR increases 28% (577 to 740 mcf/ft)

$^{c}/_{w}$ fracs, more time at high rate, shallow final decline

# Scaling – Number of fractures (stage count)

## Intuition from physics

- Prior to $t_{elf}$, each fracture behaves as vertical well
- $P_{wf}$ different at each frac; captured in the average
- New fracture spacing changes $t_{elf}$

## Math and process

- $Scale\ Factor = \frac{\#\ fracs_{target}}{\#\ fracs_{well}}$

$$t_{elf} = \left(\frac{d_{i_{target}}}{d_{i_{well}}}\right)^2$$

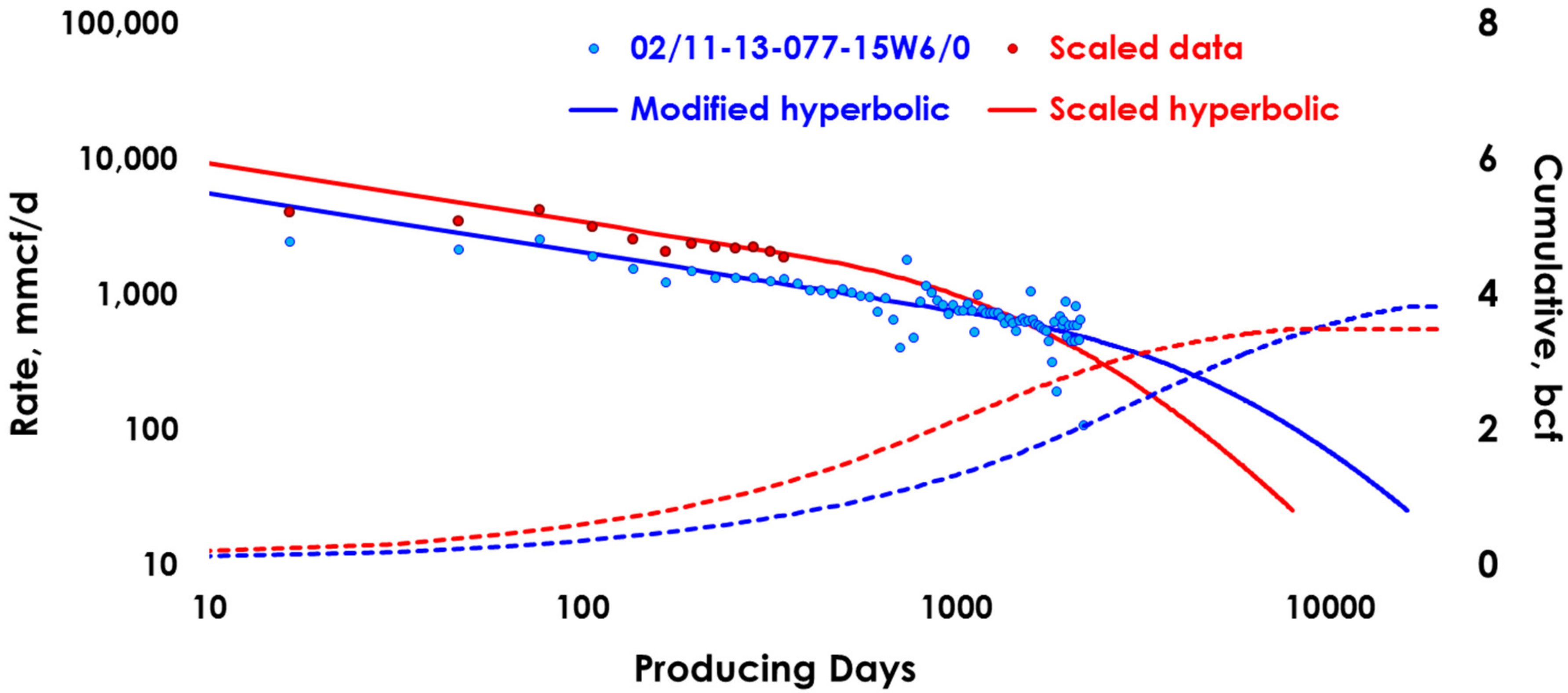
- Remove history < $t_{elf}$ and multiply rates by the $Scale\ Factor$
- Forecast linear flow, transition at calculated $t_{elf}$

# Scaling – Number of fractures (stage count)

| | Hyperbolic | Scaled | |
|---|---|---|---|
| $q_i$ | 83000 | 138336 | 83000 (1.667) |
| $d_i$ | 8000 | 8000 | |
| $b_i$ | 2.30 | 2.30 | |
| $b_f$ | 0.30 | 0.30 | |
| $t_{elf}$ | 1134 | 370 | 1134 (0.326) |
| | | | |
| $length$ | 6599 | 6599 | |
| $fracs$ | 9 | 15 | $(15/9) = 1.667$ |
| $distance$ | 825 | 471 | $(471/825)^2 = 0.32$ |
| $wlf$ | 0.743 | 0.743 | |

**Montney: 02/11-13-077-15W6/0**

# Scaling – Number of fractures (stage count)

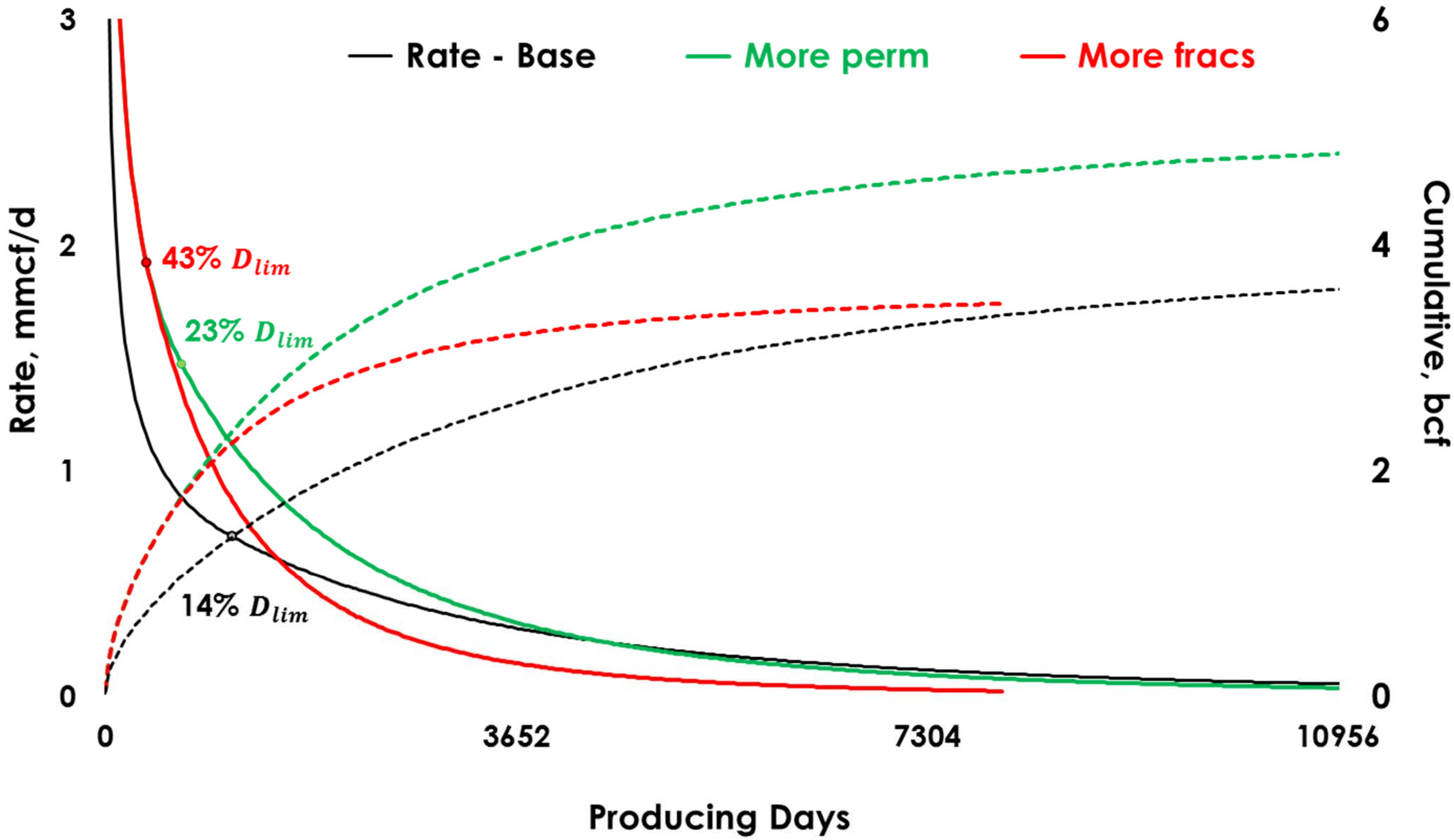



Increase from 9 fractures to 15

EUR decreases 9% (577 to 528 mcf/ft)

Earlier $t_{elf}$, less time at high rate, steeper final decline

# Scaling – Why less EUR with more fracs?



# Scaling – Well length

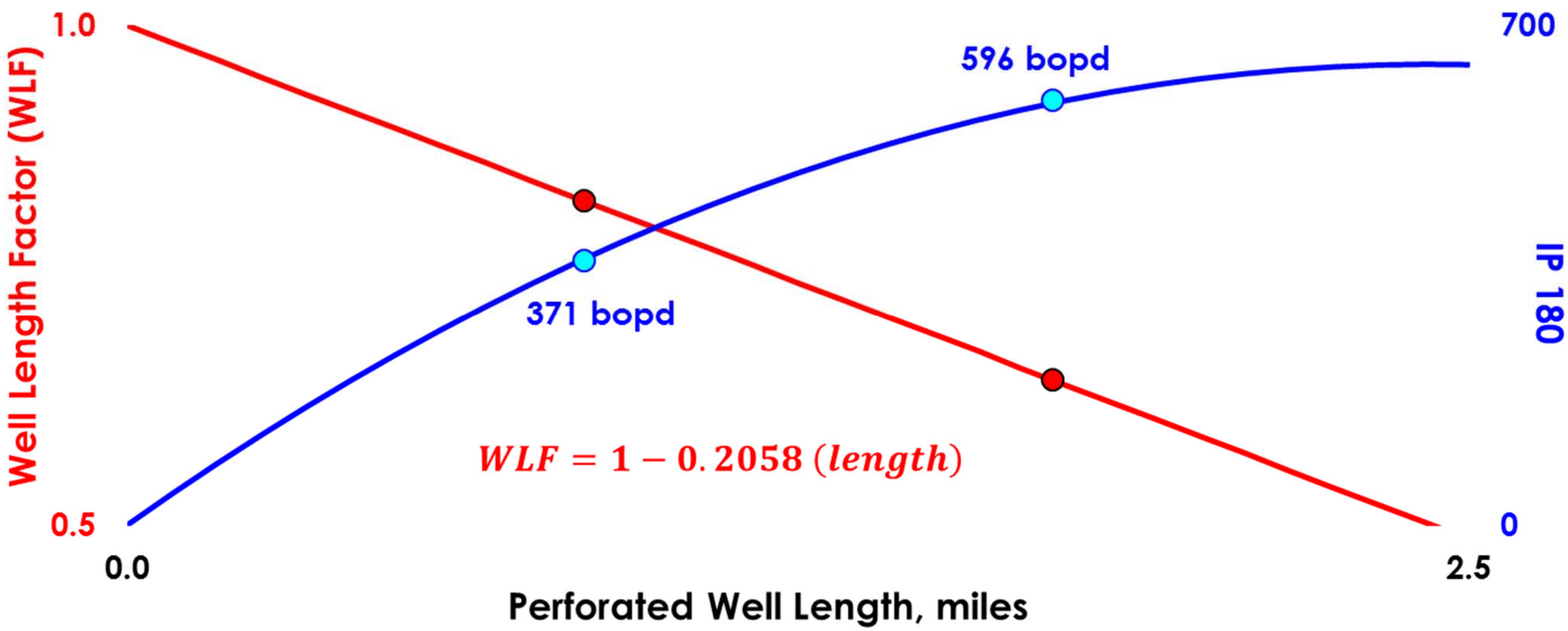
## Intuition from physics

- Longer well with same $d_i$ and $t_{elf}$
- Prior to $t_{elf}$, each fracture behaves as vertical well
- More fracs, greater rate
- Rate improvement diminishes with length
  - Friction & liquid buildup in wellbore
  - Lower effective frac length and drawdown at the toe

## Math and process

- $Scale\ Factor = \left(\frac{\#\ fracs_{target}}{\#\ fracs_{well}}\right)\left(\frac{WLF_{target}}{WLF_{well}}\right)$
- Multiply rates by the $Scale\ Factor$
- Forecast linear flow with no change to $t_{elf}$

# Scaling – Well Length




Increase well length from 1 mile to 2 miles

IP 180 only increased by 60%

Convert the data to well length factor

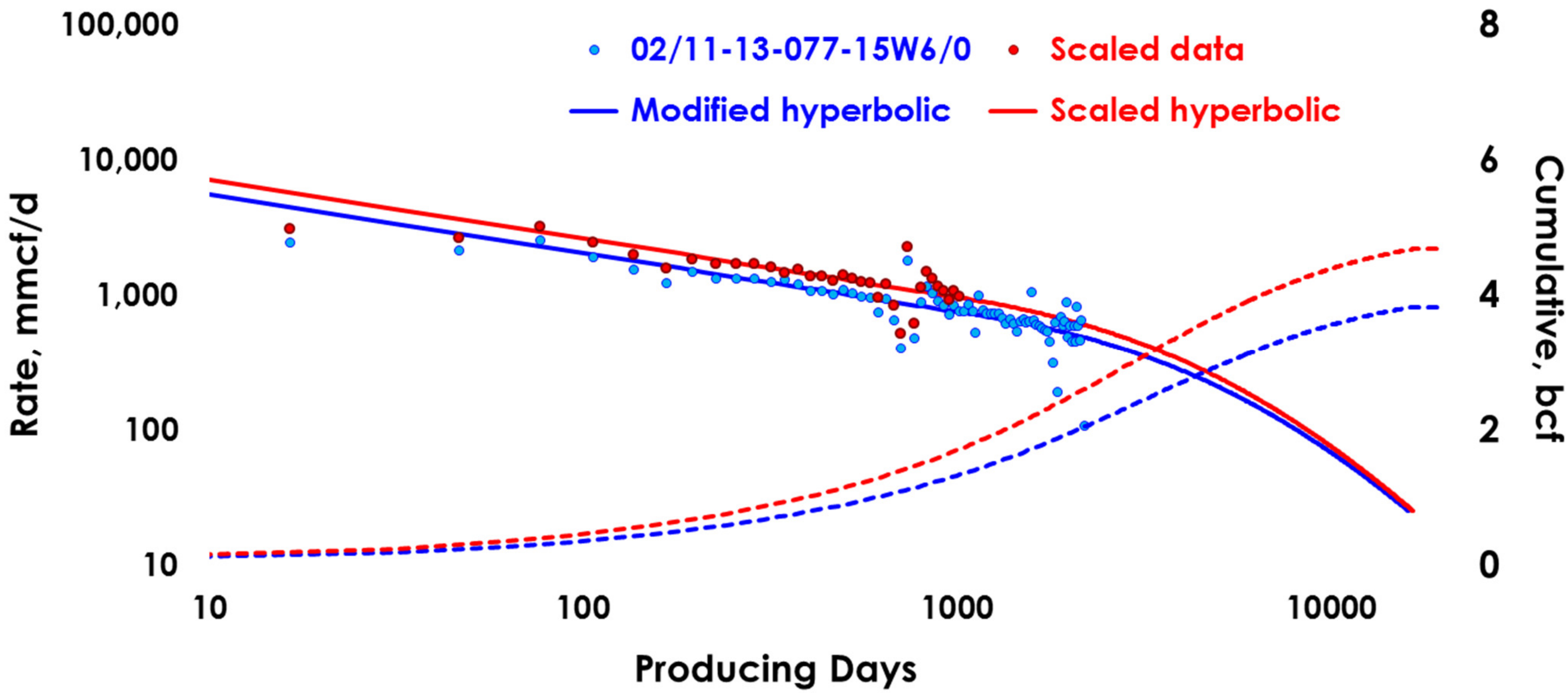
Braun et. al., SPE 171658

# Scaling – Well Length

| | Hyperbolic | Scaled | |
|---|---|---|---|
| $q_i$ | 83000 | 102404 | $83000\ (1.667)\ (0.740)$ |
| $d_i$ | 8000 | 8000 | |
| $b_i$ | 2.30 | 2.30 | |
| $b_f$ | 0.30 | 0.30 | |
| $t_{elf}$ | 1134 | 1134 | |
| $length$ | 6599 | 11549 | |
| $fracs$ | 9 | 15 | $(15/9) = 1.667$ |
| $distance$ | 825 | 825 | |
| $wlf$ | 0.743 | 0.550 | $(0.550/0.743) = 0.740$ |

**Montney: 02/11-13-077-15W6/0**

# Scaling – Well length




67% increase in length

Normalized EUR decreases 26% (577 to 425 mcf/ft)

Value is in drill cost reduction

# Scaling – Combination of factors

## Scenario

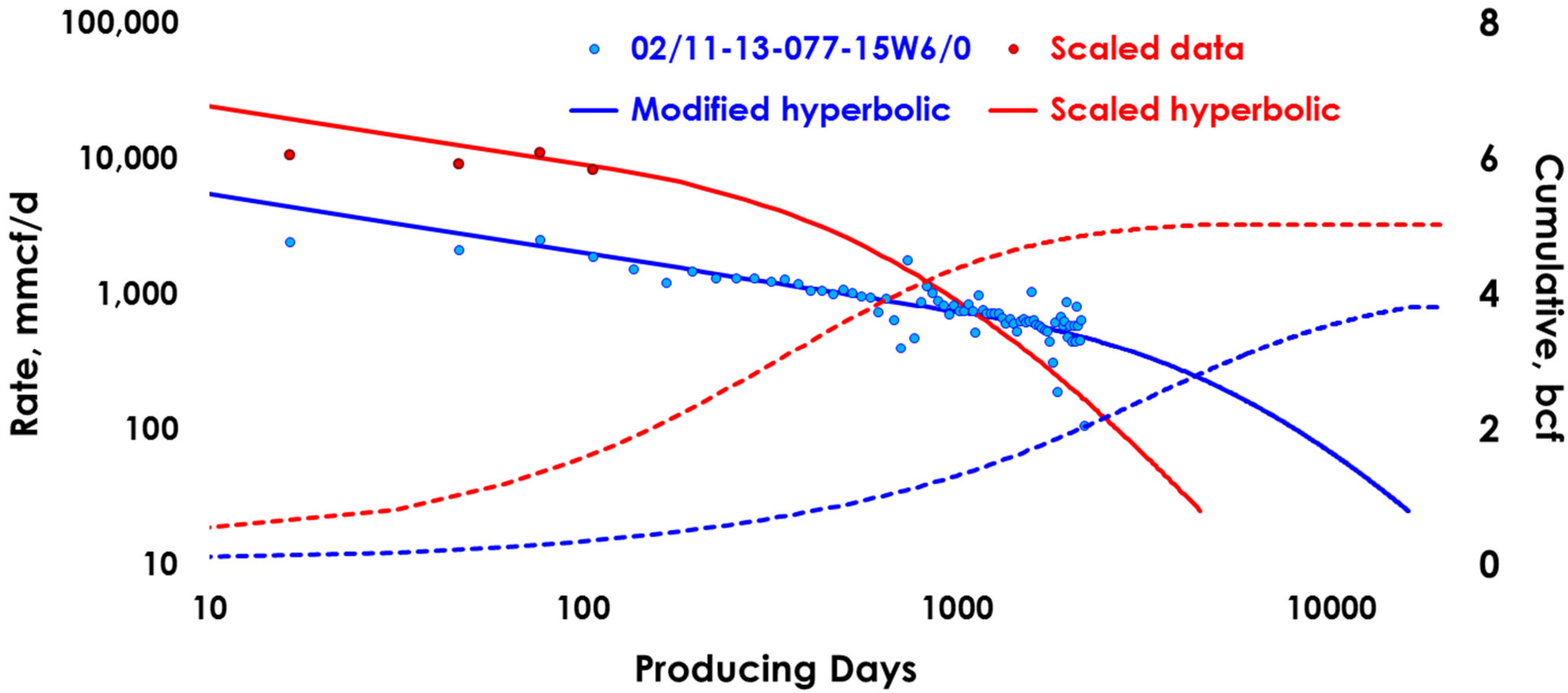
- Older wells that were drilled 3 or 4 years ago
- Technology and our understanding has changed
  - Previous 9 stage plug 'n perf fractures
    Replaced with 30 stages of 2 perf clusters (60% efficient)
  - Longer wells: 11549 ft compared with prior 6559
  - Now drilling sweet spots with 25% greater $k$
  - 20% grater proppant volume per frac

# Scaling – Combination

| | Hyperbolic | Scaled | |
|---|---|---|---|
| $q_i$ | 83000 | 368654 | $83000\,(1.5)(4.0)(.74)$ |
| $d_i$ | 8000 | 8000 | |
| $b_i$ | 2.30 | 2.30 | |
| $b_f$ | 0.30 | 0.30 | |
| $t_{elf}$ | 1134 | 121 | $1134(0.16)/1.50$ |
| | | | |
| $length$ | 6599 | 11549 | |
| $fracs$ | 9 | 36 | $30(2)(60\%)/9 = 4$ |
| $distance$ | 825 | 330 | $(330/825)^2 = 0.16$ |
| $k$ | 1.00 | 1.50 | $1.25(1.2) = 1.50$ |
| $wlf$ | 0.743 | 0.550 | $(0.550/0.743) = 0.740$ |

**Montney: 02/11-13-077-15W6/0**

# Scaling – Combination




Only two adjustments required

- Rate multiple
- Revised $t_{elf}$

# Scaling

- Other parameters suited to scaling
  - Frac size (proppant volume)
  - Frac quality $k_{eff}$ (proppant concentration)
  - Reservoir pressure (for gas $c_t \cong {}^1/_p$)
  - Effective fracture length
- Examples of parameters suited to binning
  - Operator, vintage, cardinality, frac fluid
- Issues with scaling
  - Unknown or unavailable parameters
  - Assumes uniform reservoir drainable with completion
  - Scaling algorithm may not be developed
  - Flawed or incomplete intuition

# Scaling – Summary

Confidence in probability distributions and type well profiles is roughly proportional to sample size.

Scaling has the potential to improve type well confidence

- Increase in analog well count
- Decrease in P10/P90 ratio – more similar wells

Less error results in more reliable type wells with more reliable reserve and economic assessments.

# Diagnostics

## Scaling to find completion unknowns and explain anomalies

Reference: Freeborn et al, SPE 175967

# Diagnostic – Example 1

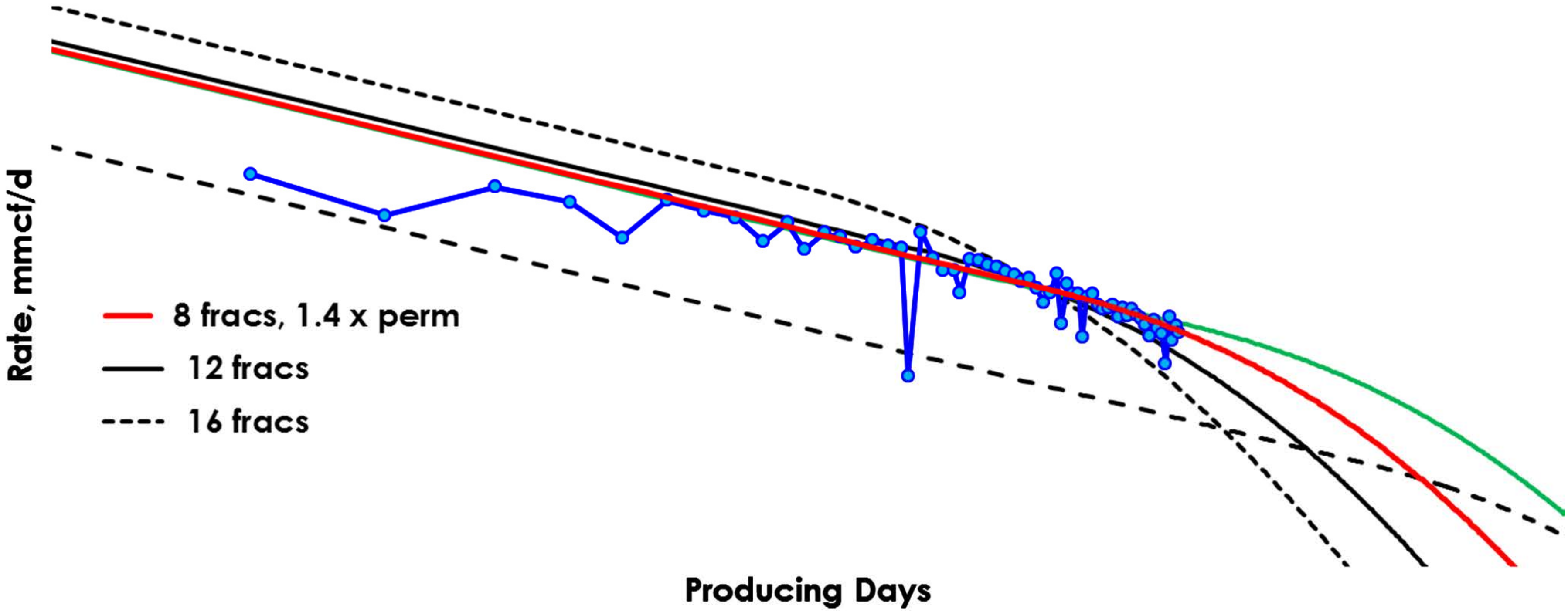
A well was cluster fractured. How may fractures?

- Control well: 9 fracs, plug and perf
  Estimate 900 tonnes placed
  horizontal length of 6599 ft
- Target well: 5 frac stages (16 perf intervals)
  1100 tonnes placed
  horizontal length of 6170 ft
- Result: 8 fractures (50% efficiency)

**Control well 02/11-13-077-15W6/0**

**Target well 00/05-13-077-15W6/0**

# Diagnostic – Example 1




- Match with fracs – 12 is best, but $t_{elf}$ wrong
- Match with perm – $t_{elf}$ still wrong
- Trade fracs for perm – match with 8 fracs, 40% more perm
- With 8 fracs, the target well had 37% more sand/frac

# Diagnostic – Example 2

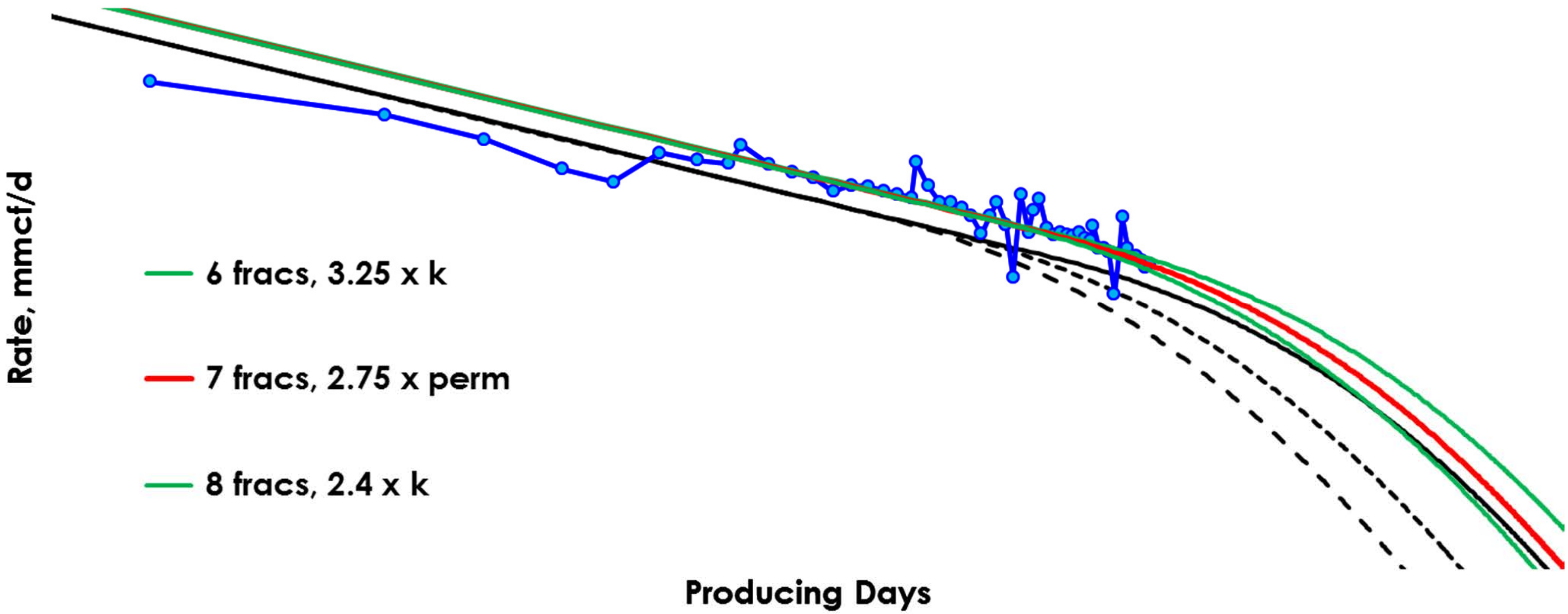
## Conflicting results

- Control well: 9 fracs, plug and perf
  Estimate 900 tonnes placed
  horizontal length of 6599 ft
- Target well: 16 fracs, plug and perf
  1600 tonnes placed (same/frac)
  horizontal length of 7375 ft
- Result: 7 fractures
  connecting behind pipe

**Control well 02/11-13-077-15W6/0**

**Target well 00/10-13-077-15W6/0**

# Diagnostic – Example 2




- Rates too low, even with sand volume adjusted perm
- Best scaling is with 7 fracs and 2.75 x $k$
  - Perm increase has 2 factors: 2.3 fold proppant, 20% $k$
  - Fractures must be connecting behind pipe

# Diagnostic – Summary

- Diagnostics are a useful tool for understanding what really happened with your completions.
- Diagnostics pay permit determining the completion parameters needed for scaling when they are unknown.
- When a source well is not available, it could come from RTA or simulation.
- Scaling / diagnostics combined with economics are useful for reducing the number of completion optimization alternatives.

# Thank you

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