“Fooled by Randomness”

- Improving Decision Making With Limited Data

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“Fooled by Randomness”

- As professionals we are continuously challenged to make informed decisions with limited data sets.

- Our exploitation of Unconventional resources in a time of budget restraints, low commodity prices, and competitive pressures has driven the desire to get the right answers as soon as possible.

- Our decisions on “sweet spots”, new technologies and indeed new plays are often based simply on the arithmetic average of the results from a few wells.

- Where we have erred as an profession is in honouring limited data sets without consideration of the representativeness of the data.

Outline

- Background on Aggregation Principles
- Review Aggregation Curves and their application to limited data sets
- Review the use of Sequential Accumulation plots for real time validation of our distributions
- Conclusions & Recommendations

Aggregation Principles 101

Consider a Ten sided Die

- There is an equal probability of rolling a 1 to a 10.
- 90% of the time we will realize an outcome that equals or exceeds 2.
- 10% of the time we will realize an outcome that equals or exceeds 10.
- The ratio of the P_{10} (high) to the P_{90} (low) is 5.
- We know the distribution of a die is discrete uniform, and that with repeated trials the average outcome will be 5.5.

Aggregation Principles

0 = 10

- What is our confidence that we will realize the mean outcome of 5.5, after 1 die roll, 5 dice rolls, 10 dice rolls?

- What if we developed a new technology that would improve "Die" performance by 20%.

- How many dice rolls would we need to confirm the effectiveness of the new technology?

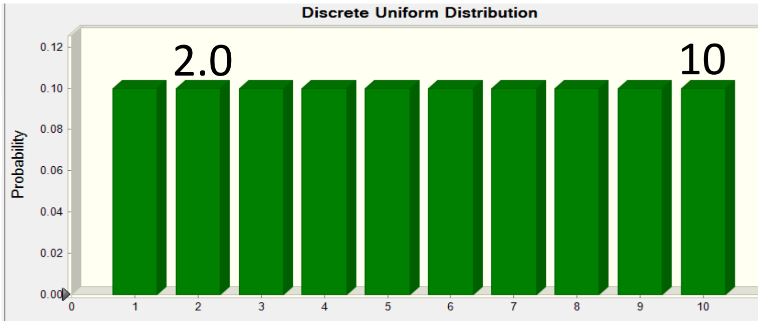
Aggregation Principles

0 = 10

- What would you conclude if on your first trial of the new technology you rolled a 5?
- Should you feel better or worse about the new technology?
- Could we conclude that the technology failed?
- Lets review a pragmatic statistical approach to provide quick solutions.

Aggregation Principles

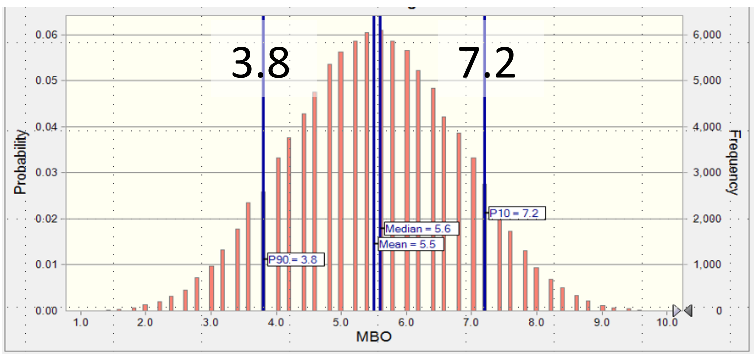
Single Die Outcome



- We are reasonably certain we will roll a 2 or more 90% of the time. The P_{10}:P_{90} ratio is 5.0

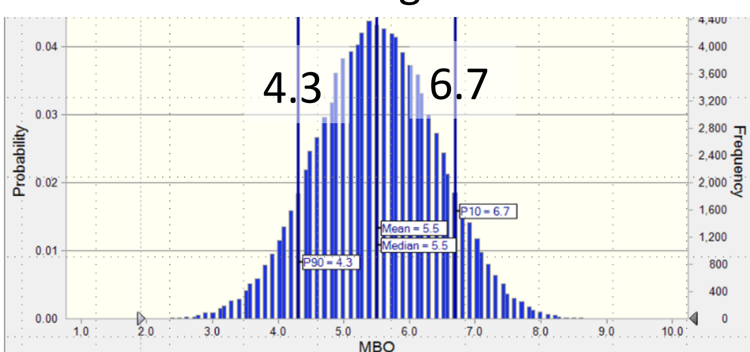
Five Dice Averaged outcome

0 = 10



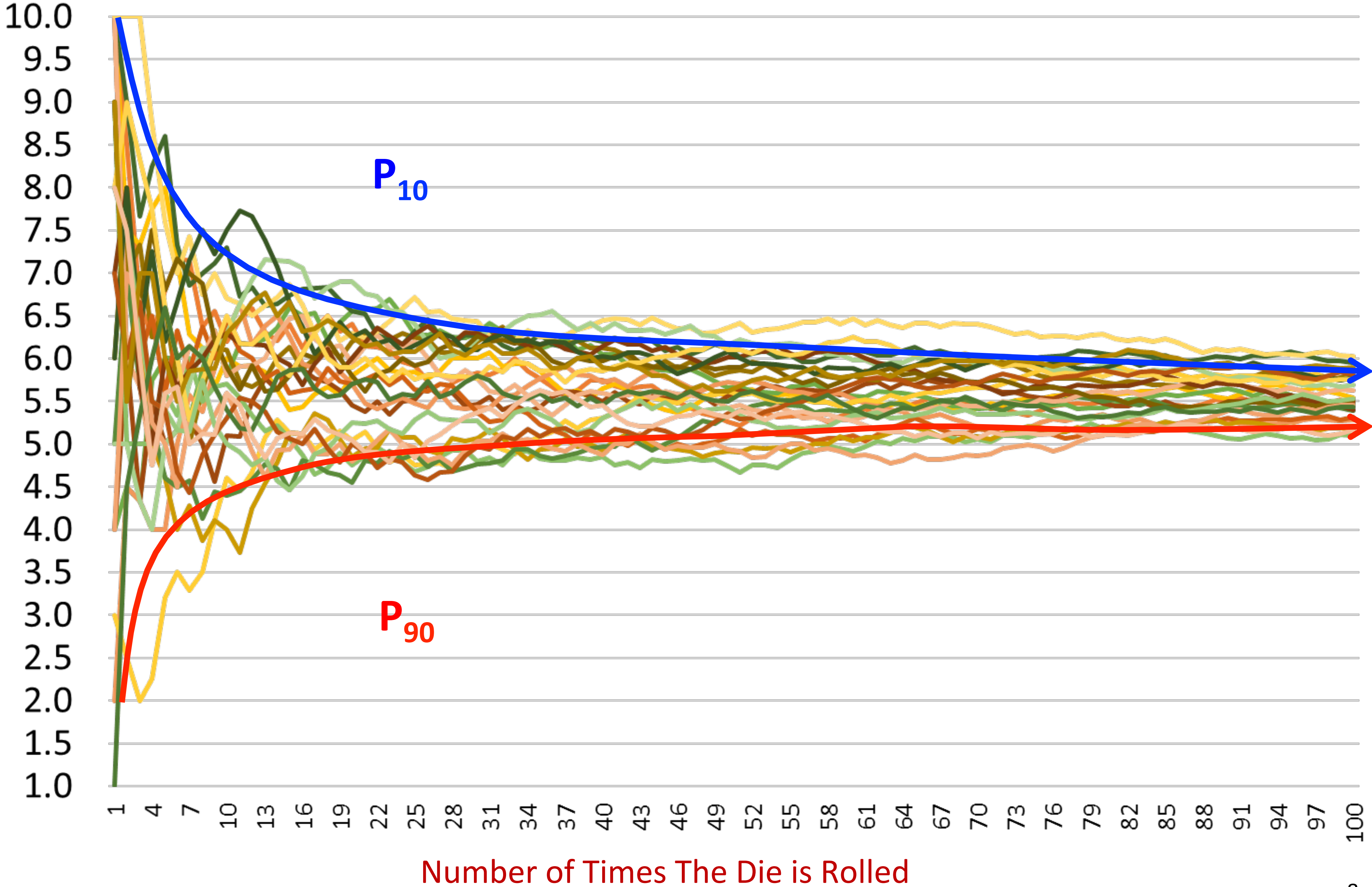
- Roll five dice. Divide sum by 5, repeat. We will average 2 or more 99.86% of the time. The P_{90} of the aggregated outcome is 3.8 The P_{10}:P_{90} ratio is 1.9

Ten Dice Averaged outcome

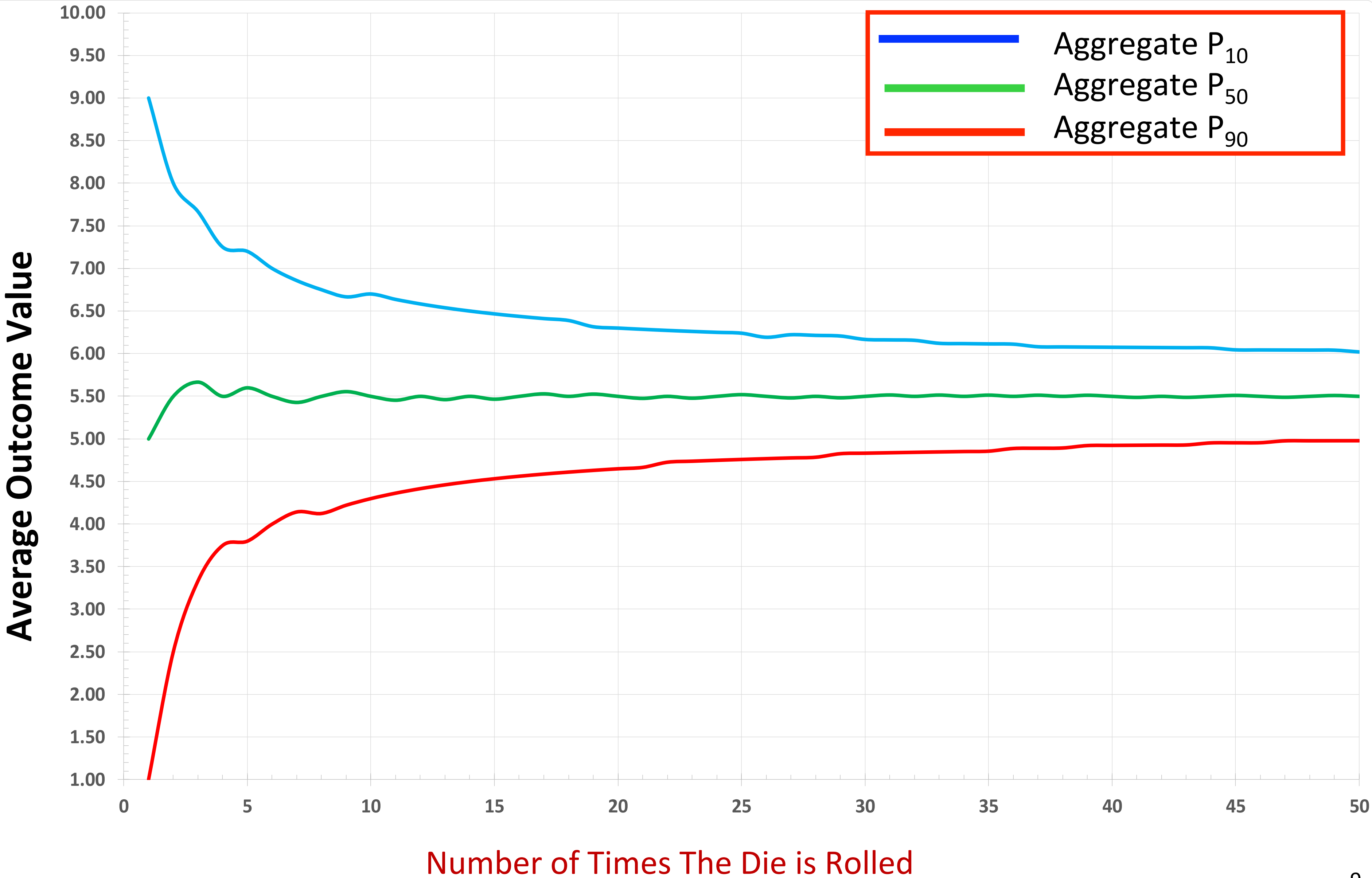


- Roll ten dice. Divide sum by 10, repeat. The Probability of averaging a 2 or more is 99.999%. This is not a P_{90}! The P_{10}:P_{90} ratio is 1.6

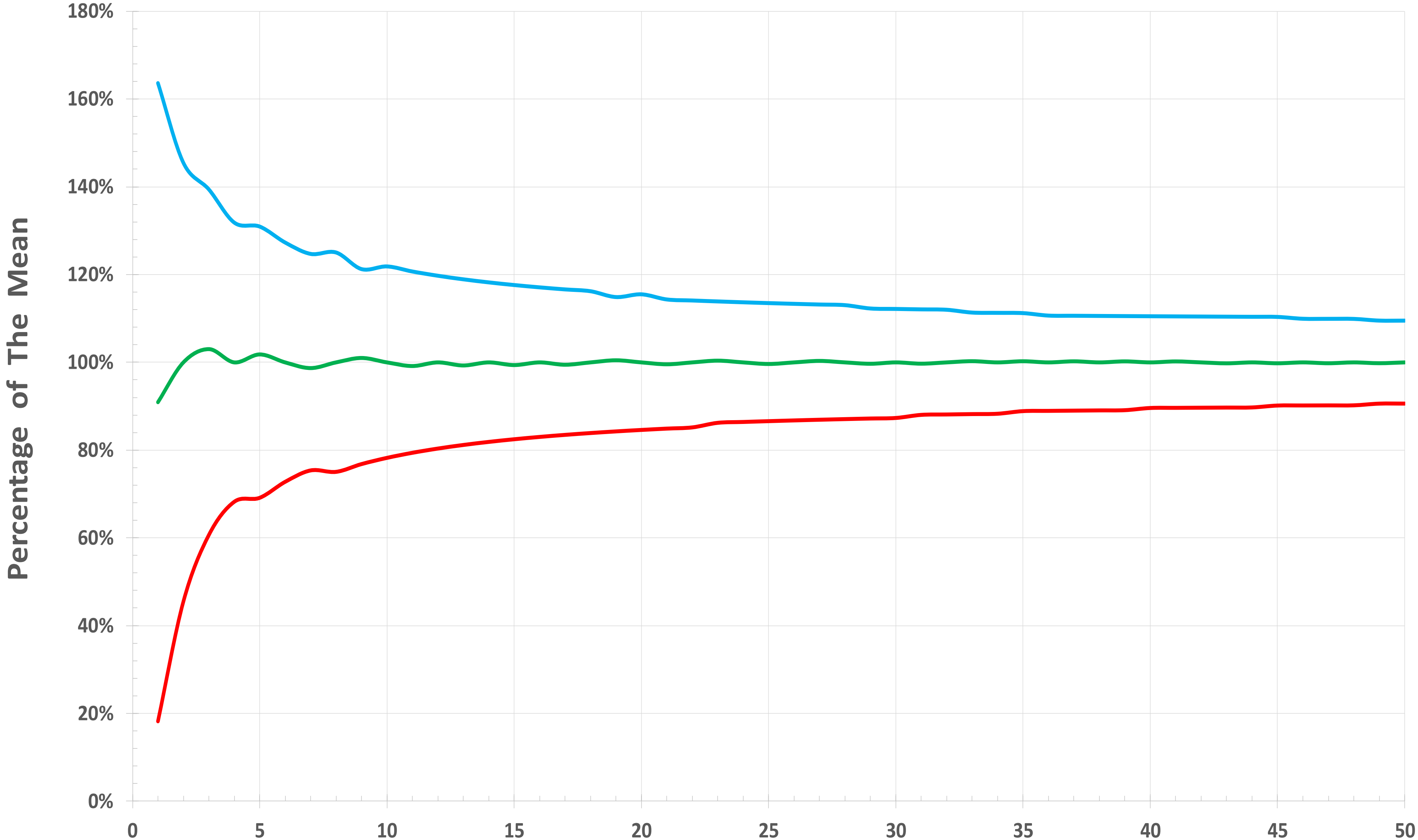
With Increasing Dice Rolls The Variance Decreases



Aggregation Charts Reveal How The Variance Decreases With Increasing Dice Rolls



In This Aggregation Chart The Outcomes Are Normalized as a Function of The Mean



Number of Times The Die is Rolled

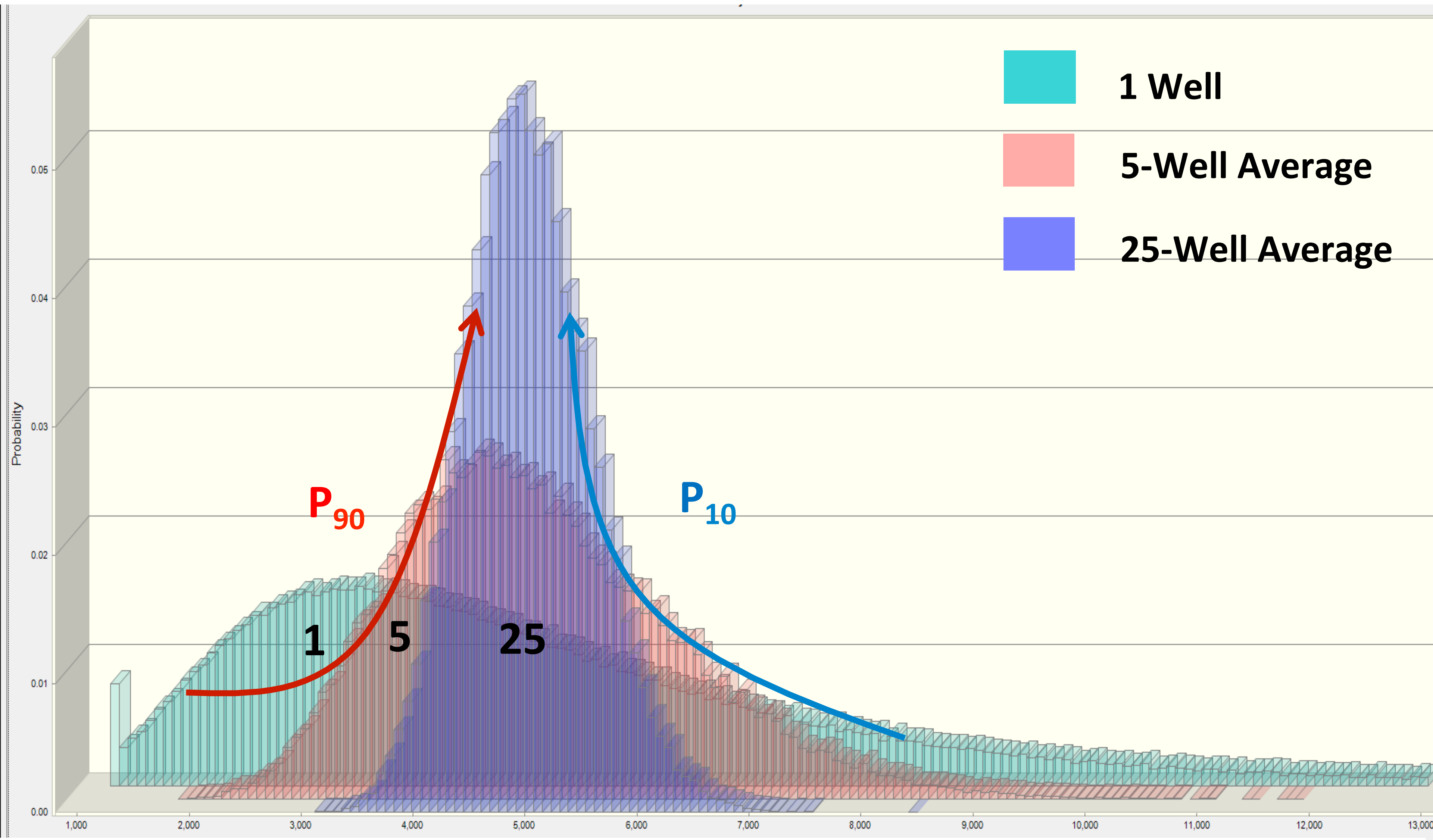
Aggregation Applied to Subsurface Parameters

- The key drivers of economic valuations after product price are typically:
    - Reserves
    - Rate
    - Capital cost
    - Cycle Time

- As each of the above is based on multiplicative processes they can be well fitted with lognormal distributions, with “spiked” end members.

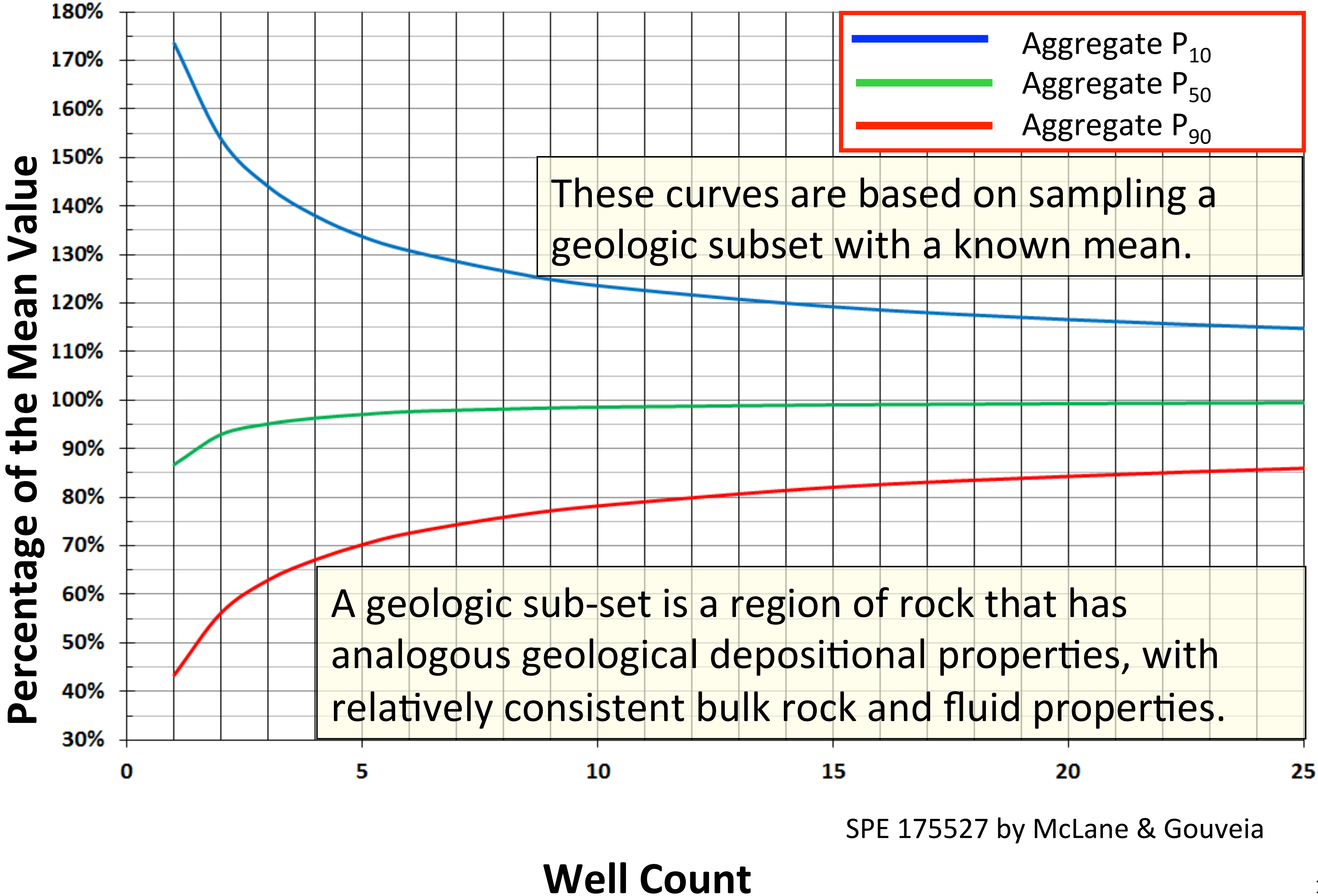
- Let’s review an example of aggregation using a lognormal distribution for estimated ultimate recovery (EUR), on a per well basis.

Aggregating EUR Distributions - P_{10}:P_{90} Ratio of 4



EUR – MMscf
The Impact of Aggregation on a 5 & 25 well program

Aggregating EUR Distributions - P_{10}:P_{90} Ratio of 4



SPE 175527 by McLane & Gouveia

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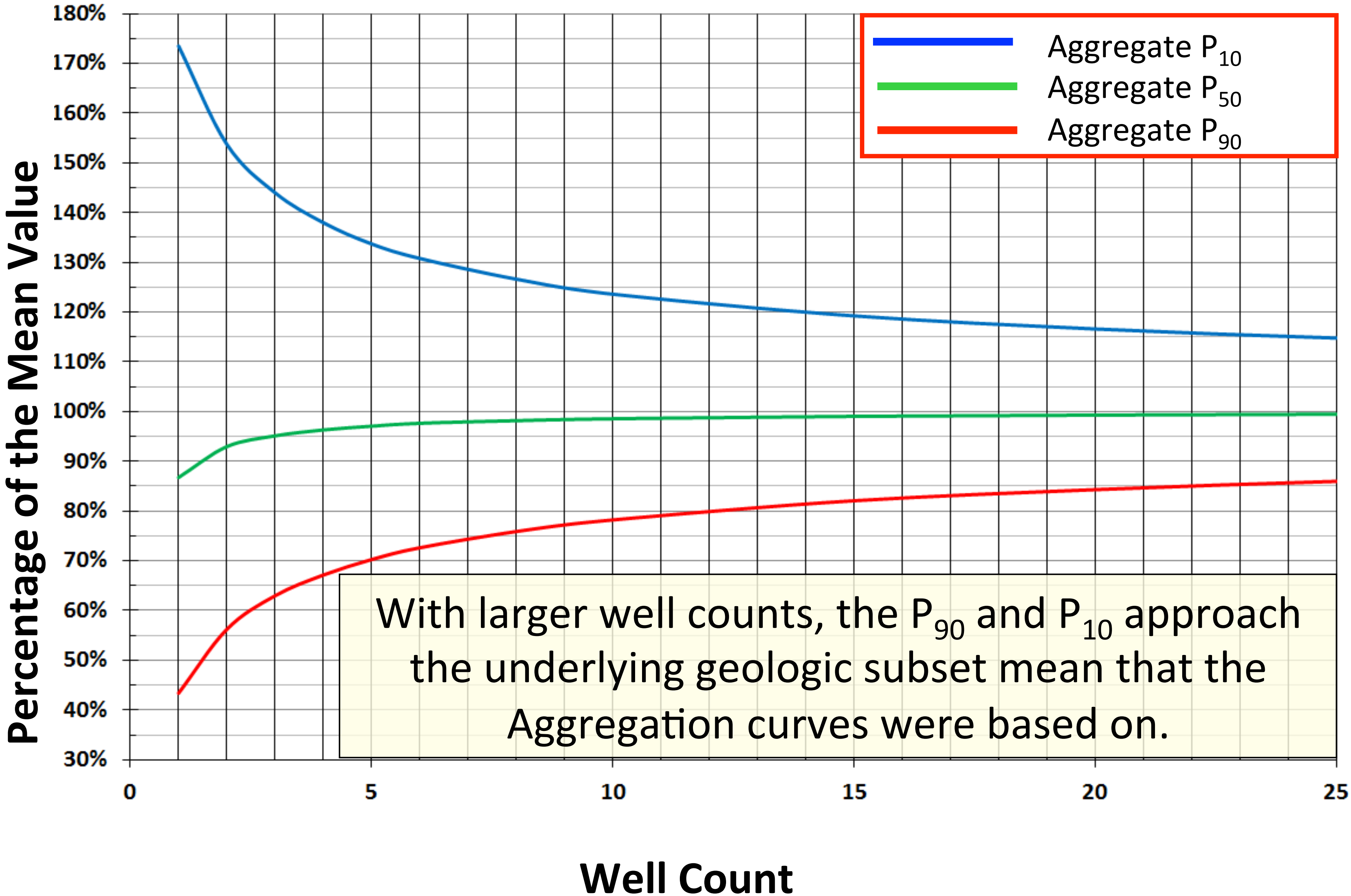


Aggregation Principles

- The reality is that budgets and competitive pressures force our hands in making decisions with limited data.
- Understanding the inherent uncertainty in our data is not intended to prevent decision making.
- The goal should be a better understanding of the inherent uncertainty in our data sets and then making decisions with knowledge of their representativeness.
- Let's review how Aggregation curves will guide us.

Application of Aggregation Curves

- North American experience has demonstrated a high degree of congruence in P_{10}:P_{90} ratios for horizontal wells with common horizontal lengths and completions.

- P_{10}:P_{90} ratios of 4 to 5 are common for a single Operator with a consistent completion technique in laterals of 5,000 feet (1500^{+} m) and 20^{+} fracture stages.

- P_{10}:P_{90} ratios of 2 to 3 are being experienced when laterals are drilled using 3D Seismic driven Geo-steering and consistent completion technique in laterals of 3 000 m+.

- The technique requires us to assume lognormality and the variance from analogous reservoirs with similar horizontal well lengths and completion techniques.

Application of Aggregation Curves

- Resource plays show repeatable distributions, year over year for a given geologic sub set (Society of Petroleum Evaluation Engineers Monograph 3).

- Caveats to this approach:
  - Horizontal well length is consistent or normalized.
  - Drilling and completion techniques are analogous.
  - We are reasonably certain that the "averaged" geology does not vary significantly within the geologic subset.

- In emerging plays the aggregation curves can be used to bound the range of the geologic subset mean as a function of well count. A critical insight for early decision making.

Aggregation Derivative Applications

Aggregation Curves (Trumpet Plots) – Used to illustrate reduction in uncertainty (variance) as a function of increasing well count using known analogs
•Function of Analog uncertainty (P10:P90 ratio), and well count

Aggregation Curves – Reverse engineered to determine the range of the mean based on a known sample size and arithmetic mean
•Variance based on Analogs

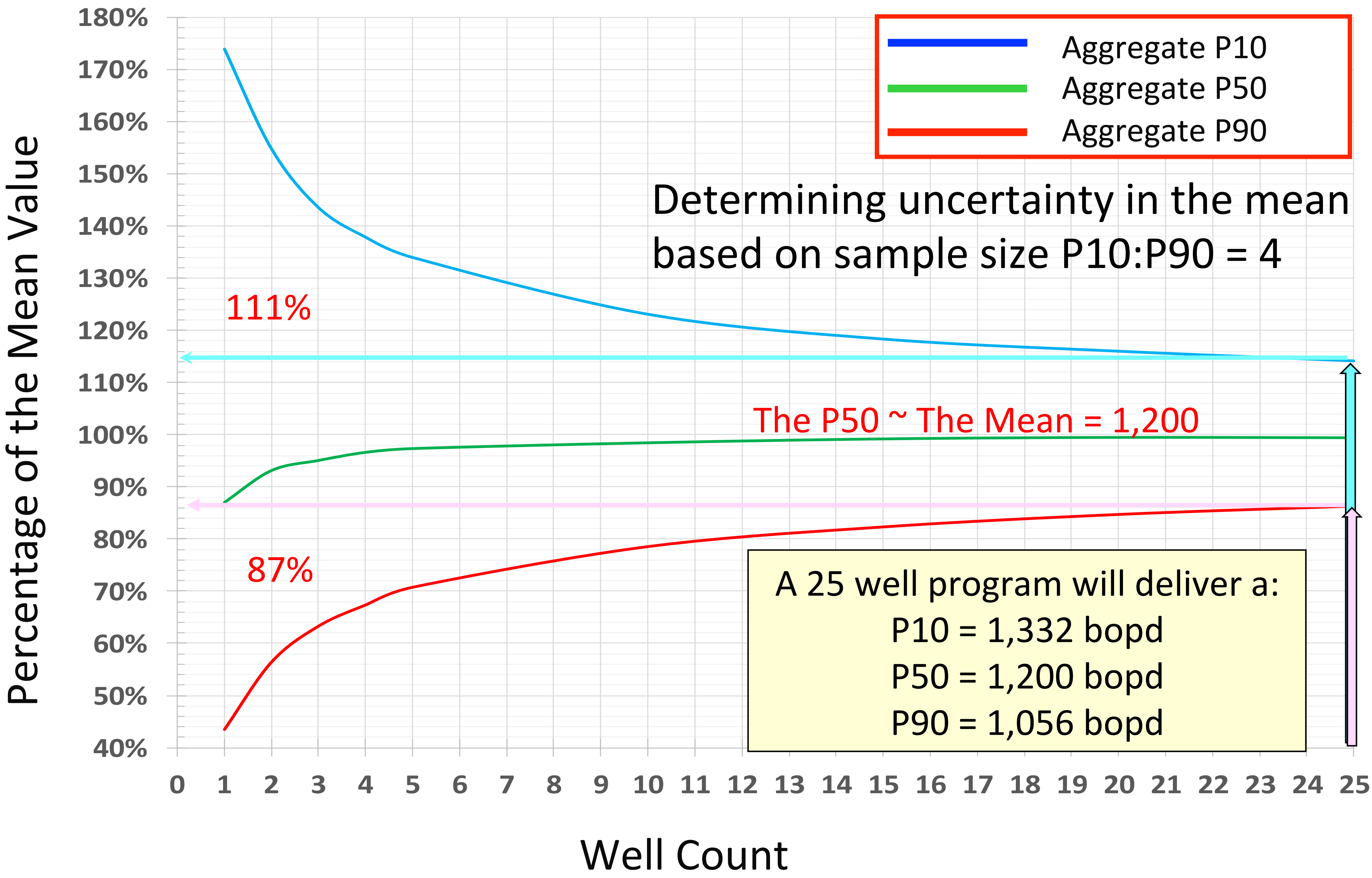
Confidence Curves – Used to communicate confidence in outcomes
•Based on mean and variance in Production Type Curves.
•Helps define Pre-development stage gate thresholds based on analog data
•Confidence is a function of uncertainty (P10:P90 ratio), your target (objective) and the number of wells to be drilled (sample size).

Pilot Design – How many wells and what average rate

Sequential Accumulation Plots – Used to assess validity of forecasts
•Tracks actuals against the forecasted P10 and P90 of the aggregation curves
•Provides <u>early</u> feedback about the validity of the forecasted parameter

Application of Aggregation Curves

– Known Mean of 1,200 Bopd



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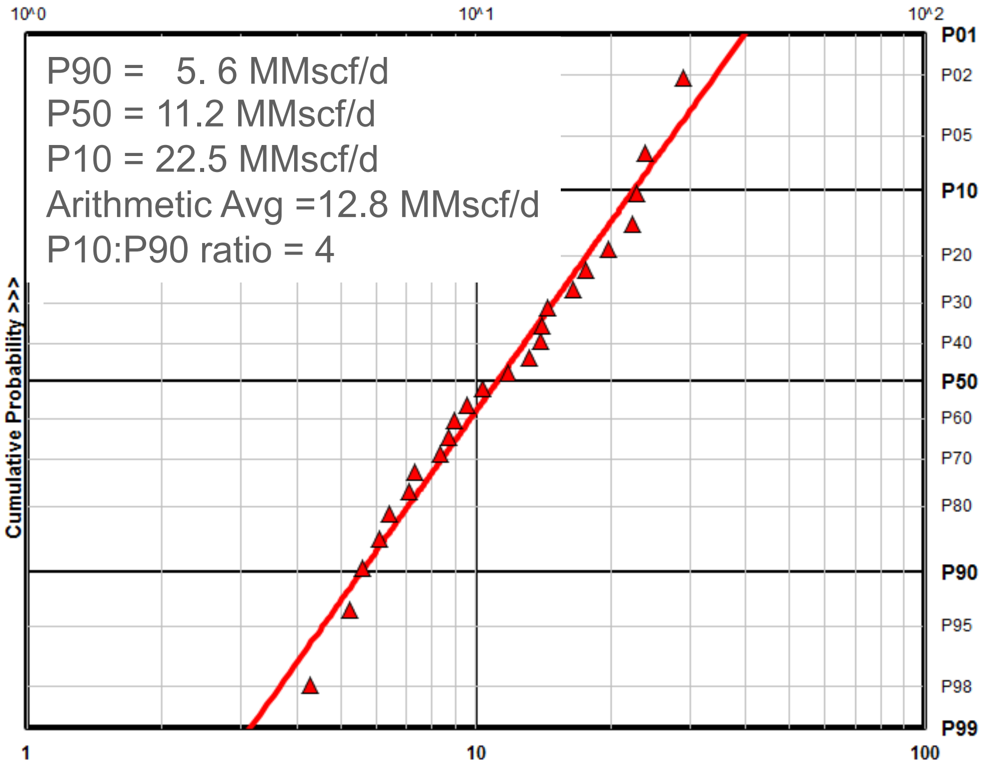
Falher 'H' – Peak Daily Gas Rate of The First 24 Wells

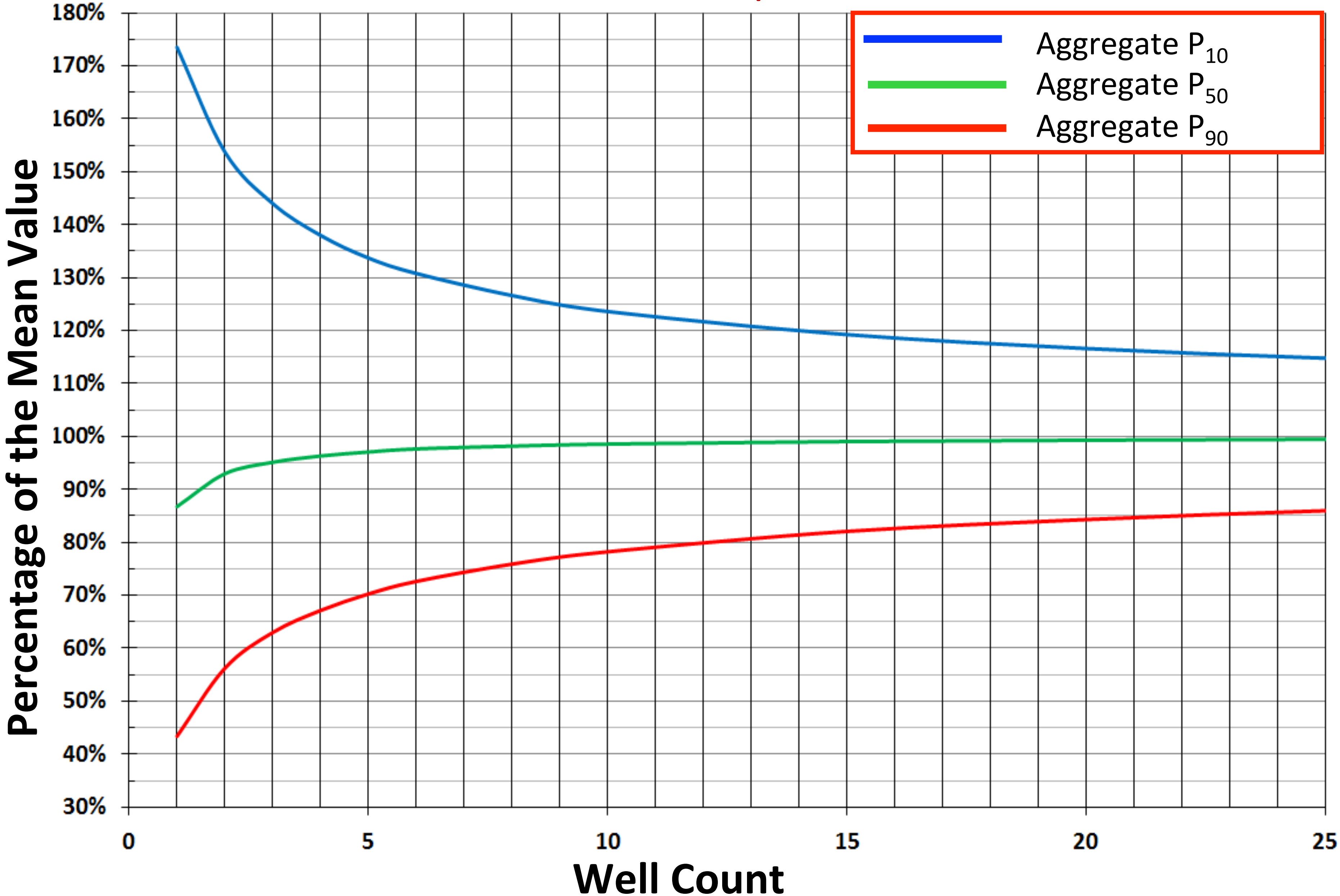


- Based on the 24 well sample we observe that the distribution is well fit with a lognormal distribution.
- The P_{90} and P_{10} of a randomly sampled individual well is 5.6 and 22.5 MMscf/d respectively.
- The arithmetic mean of the 24 well sample is 12.8 MMscf/d.

What is the uncertainty in the mean of this Geologic subset given the 24 well arithmetic mean of 12.8 MMscf/d?

Determining The Uncertainty in The Mean

- Based on Sample Size



Determining The Uncertainty in The Mean

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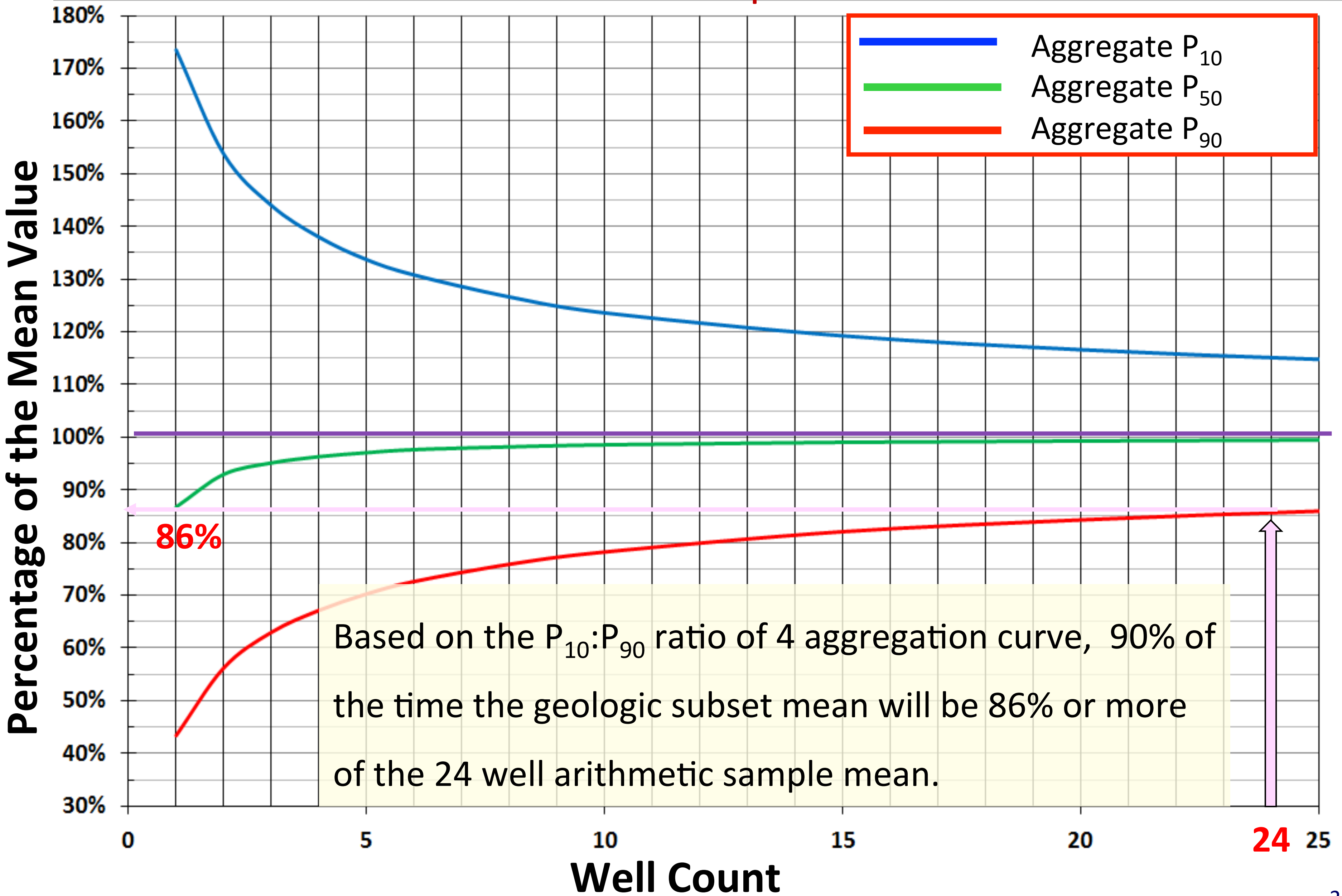
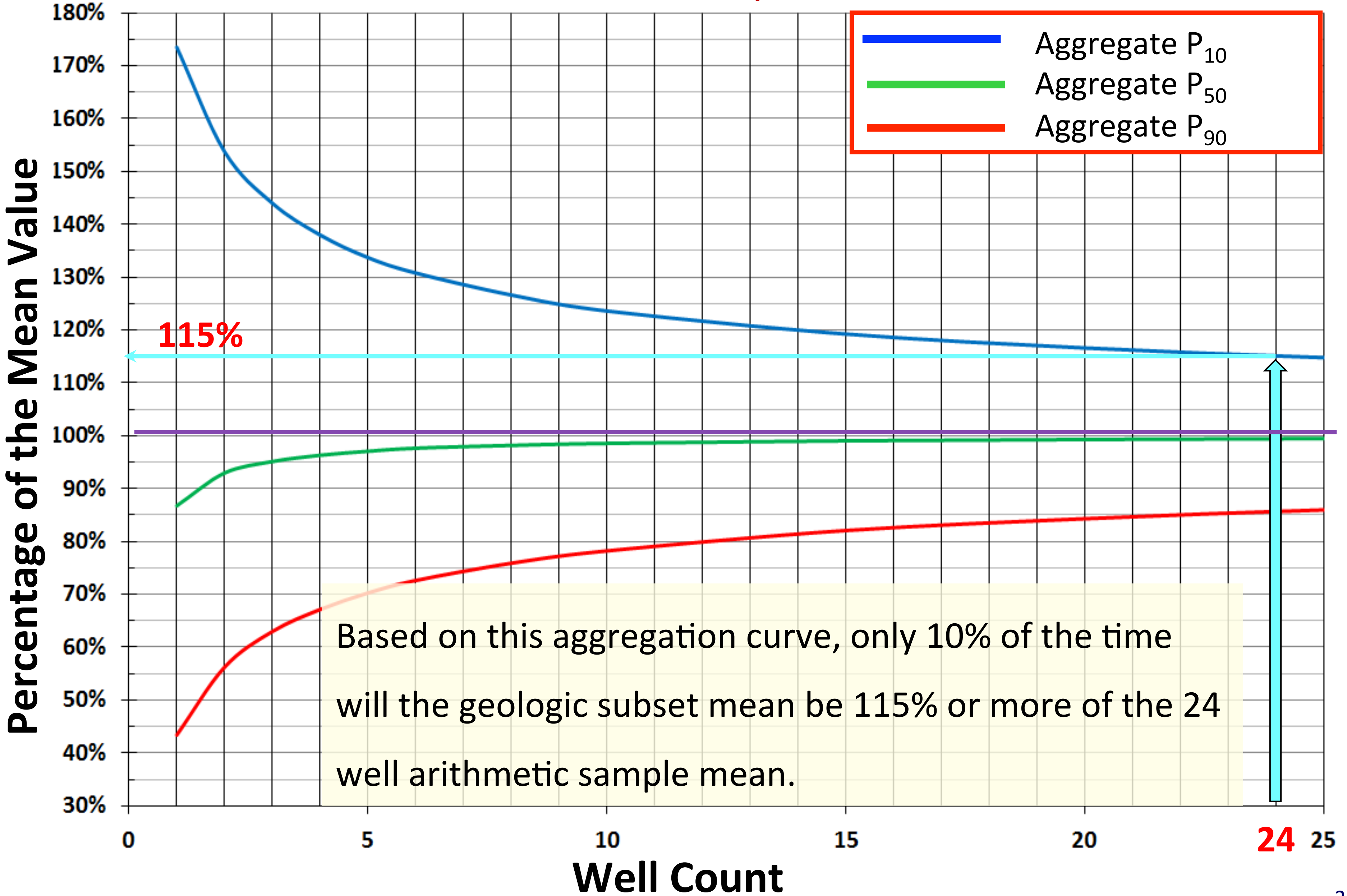


Based on the P_{10}:P_{90} ratio of 4 aggregation curve, 90% of the time the geologic subset mean will be 86% or more of the 24 well arithmetic sample mean.

Determining The Uncertainty in The Mean

- Based on Sample Size



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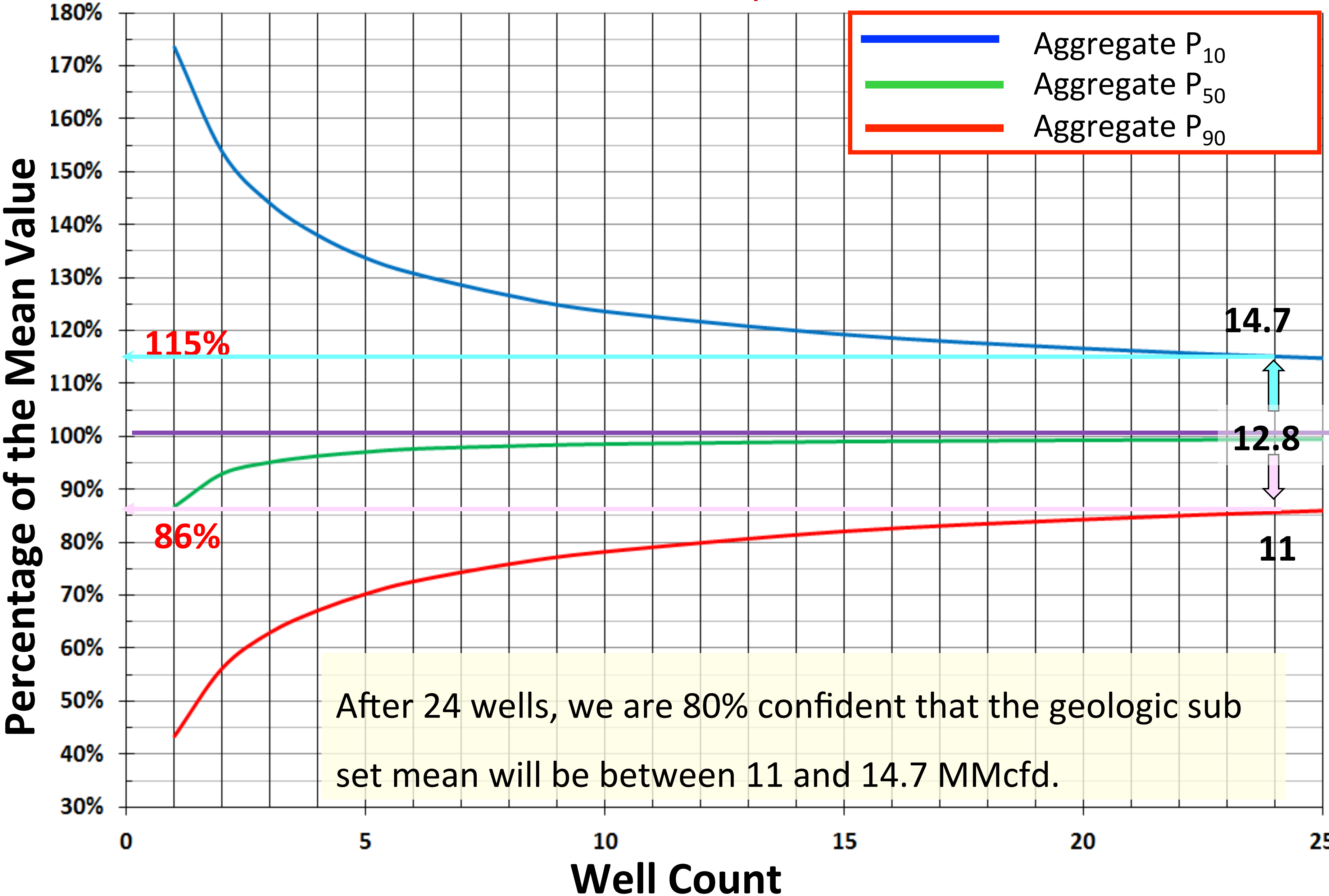

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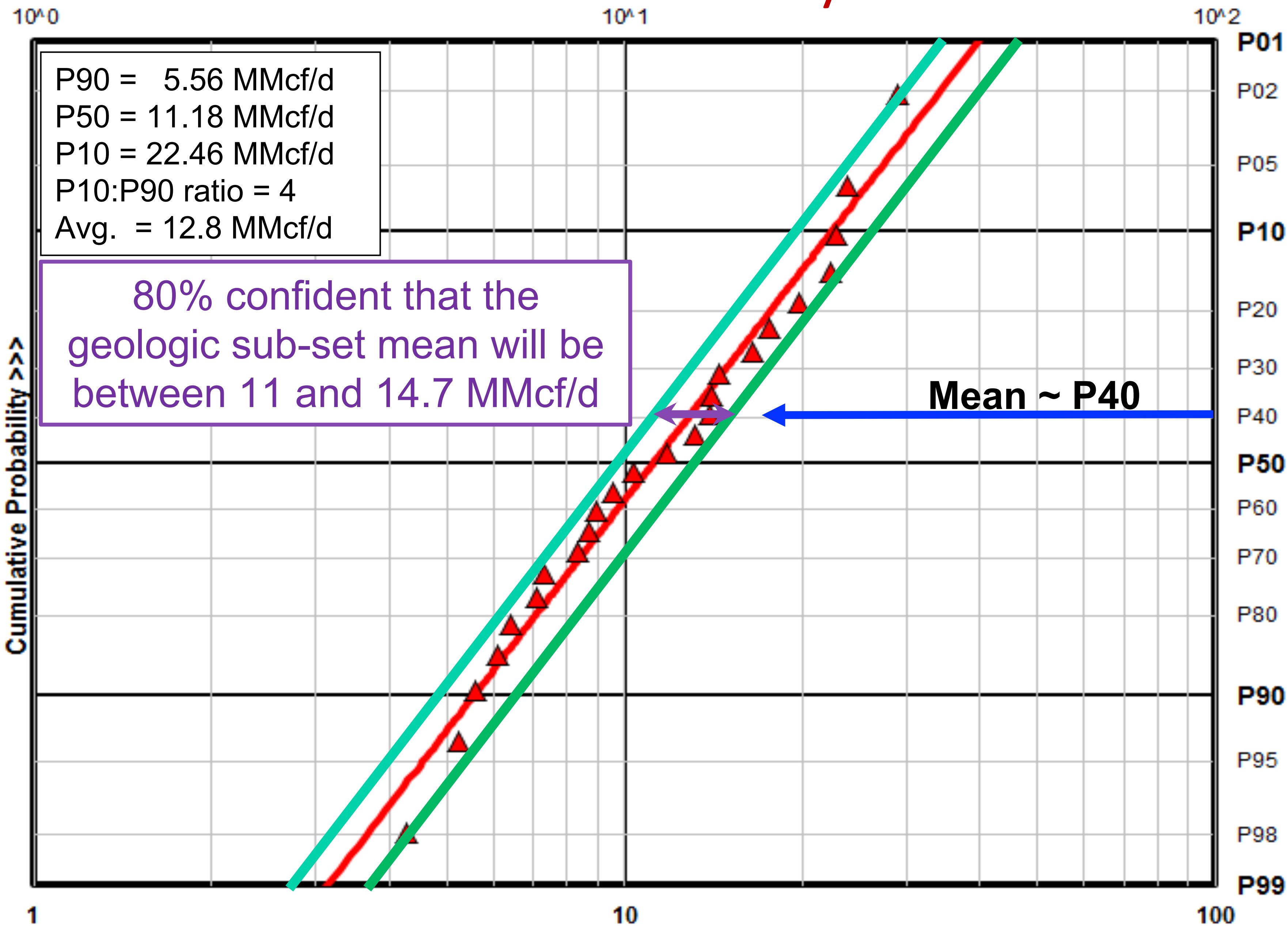
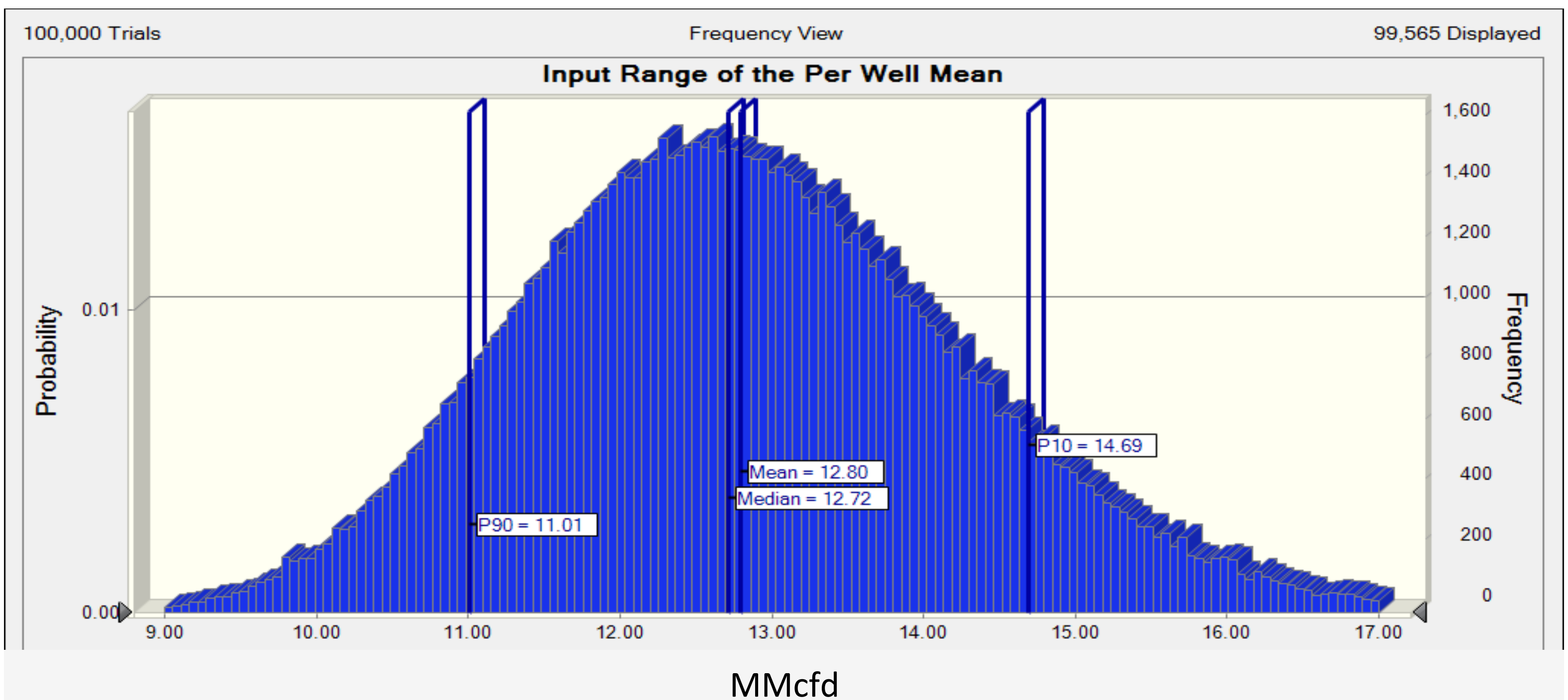


Forecasting Based on Limited Samples

- Employers have an expectation that their professionals can forecast the results of future programs based on prior results.

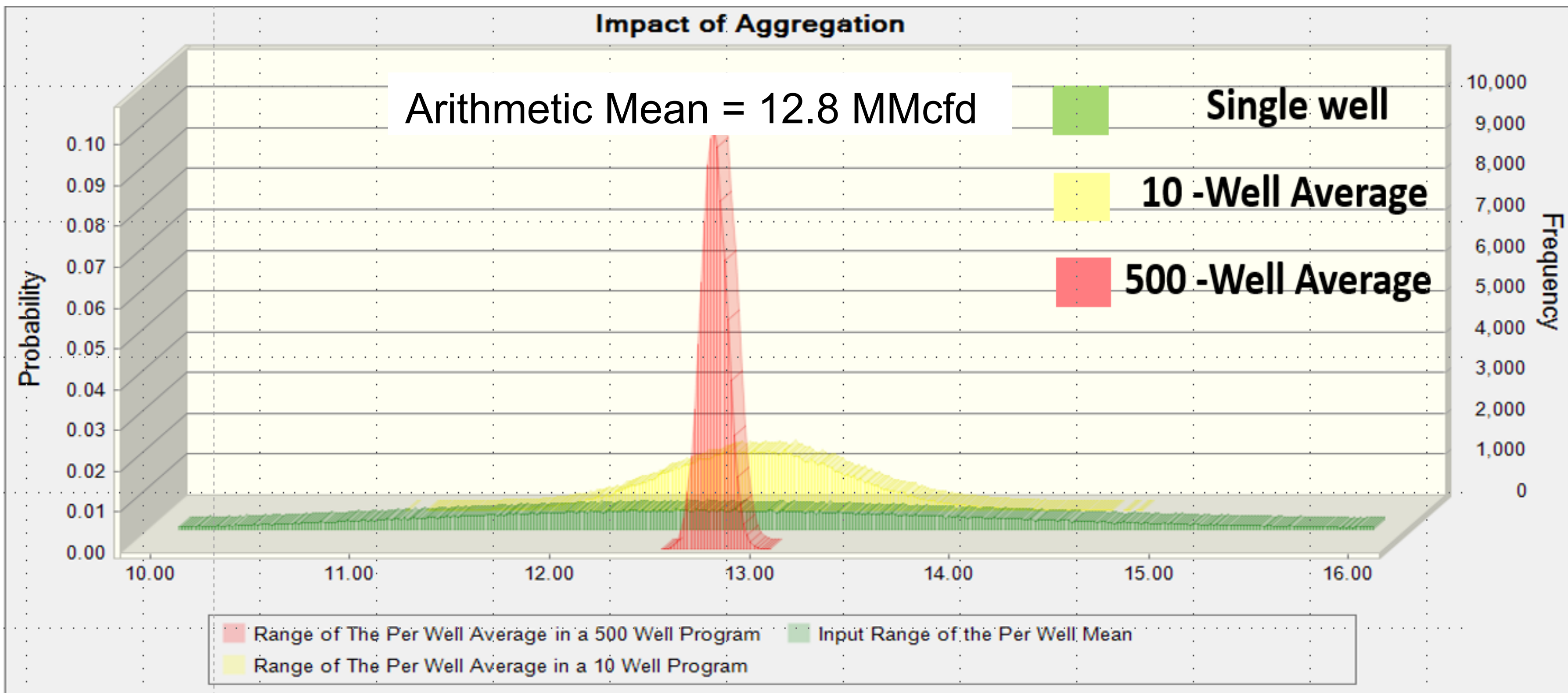
- With increased sample size the arithmetic well average will converge on the true geological subset mean. With limited wells, the best we can do is evaluate the uncertainty in the mean of the subset.



Aggregation Curve Application –

- E&P professionals often ignore the uncertainty in the mean value. As a consequence forecasted aggregation will converge on the mean of the sampled wells.

- This simple aggregation does not honour the irreducible uncertainty based on the original 24 well sample set.



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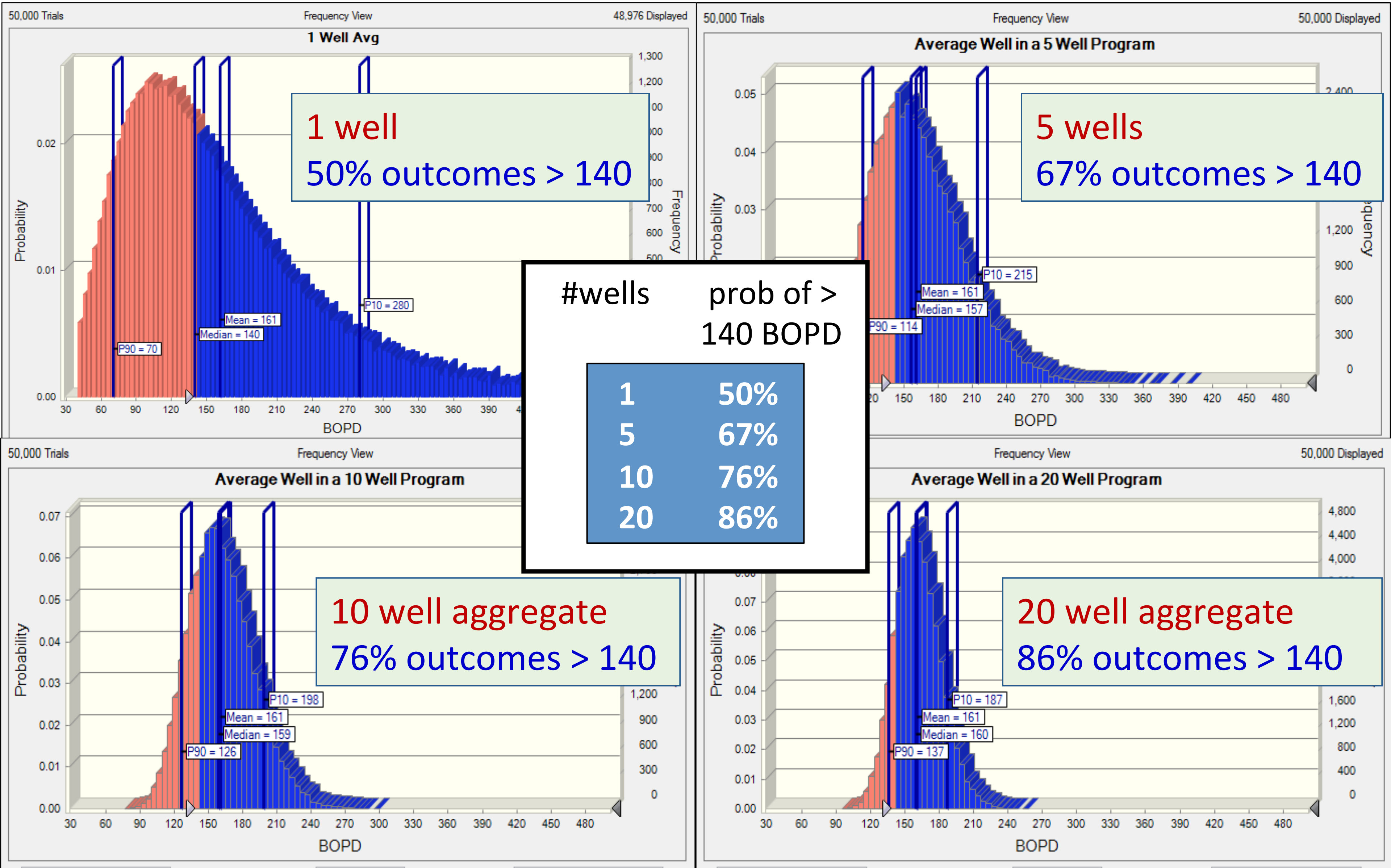
Building Confidence Curves from Aggregation

- Confidence of exceeding 140 target vs well count



#wells	prob of > 140 BOPD
1	50%
5	67%
10	76%
20	86%

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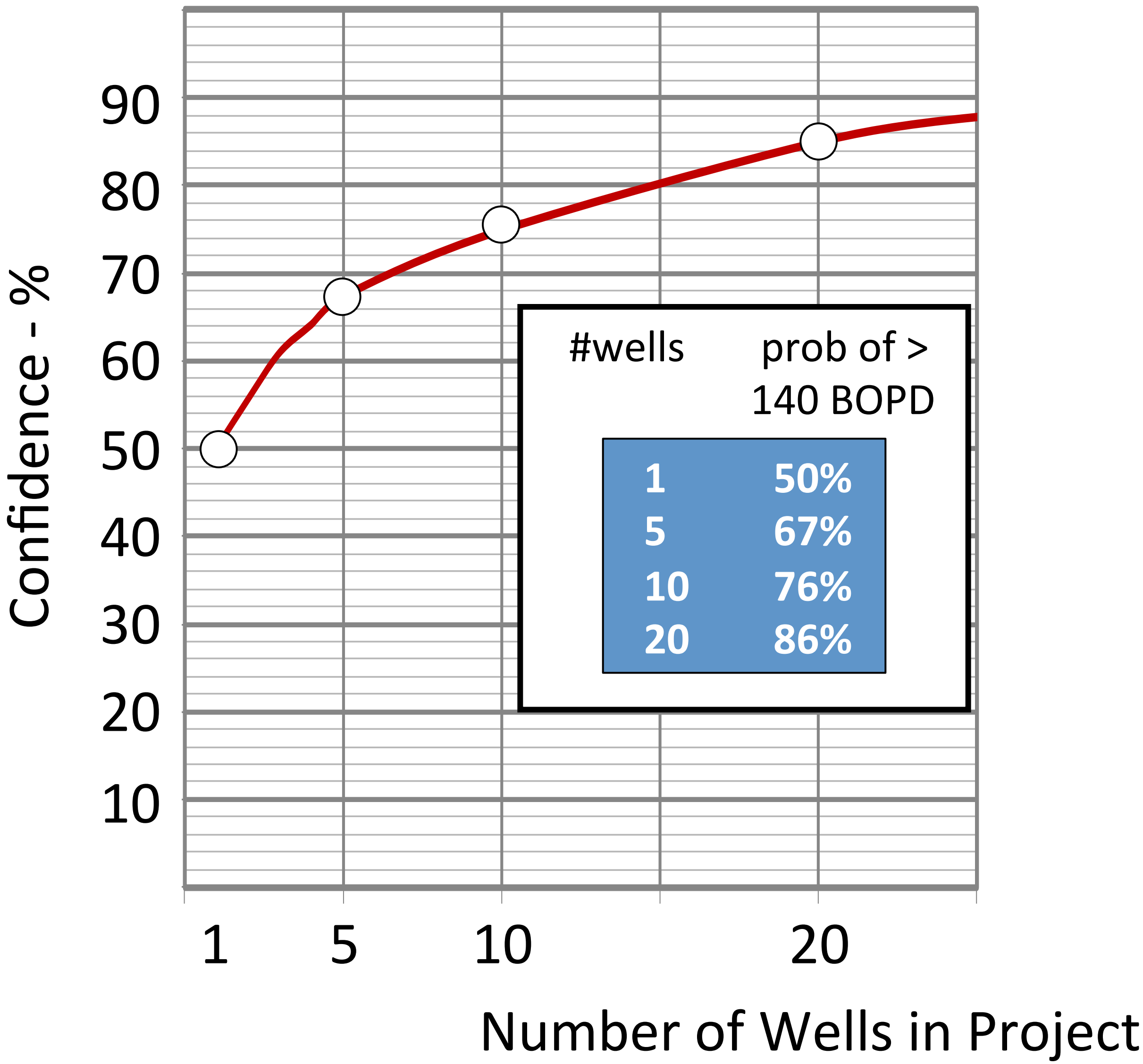

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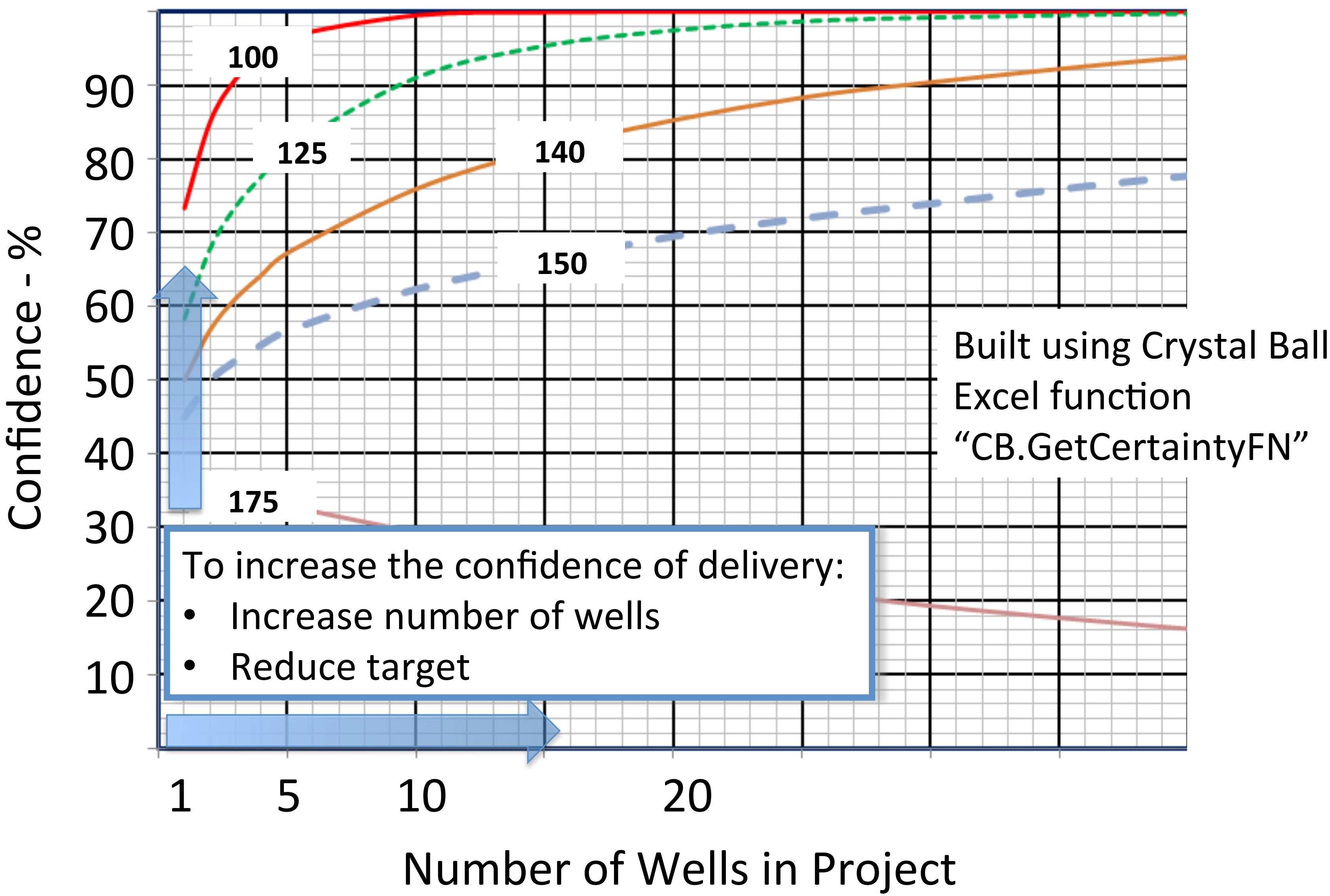
Variable Rate Confidence Curves

- Confidence of exceeding a target vs well count



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Decision Making in Unconventional Reservoirs

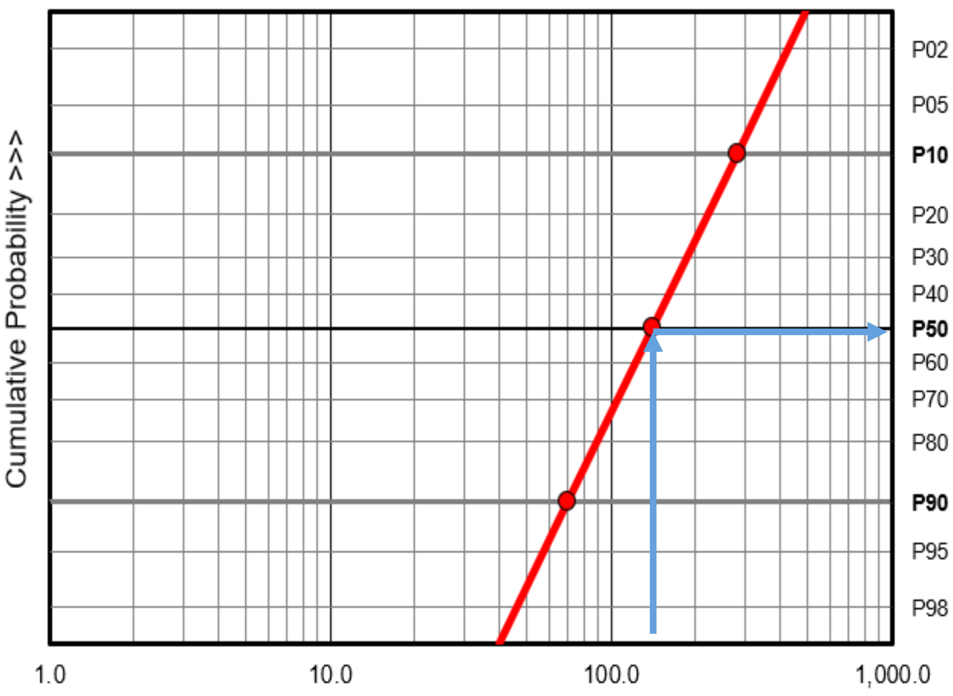
In designing Pilots the key questions should be:

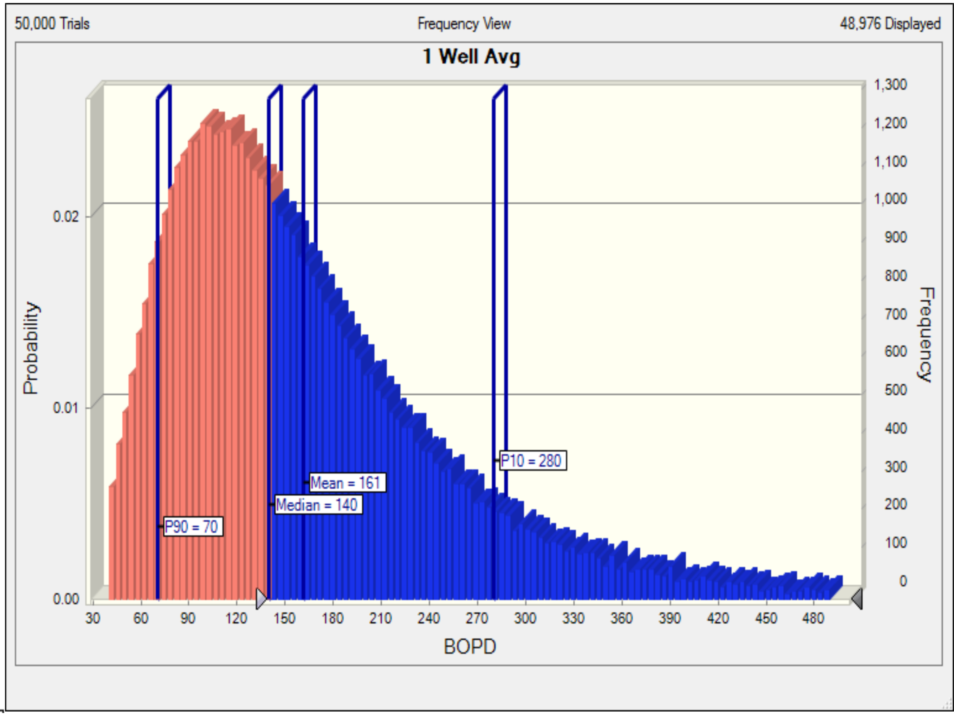
- How many wells should be in our pilot?
- What confidence level in the data do we require?
- What rate do we need to validate before proceeding to the next stage of development?

Lets review an example of Pilot design

Pilot Design: Step 1 – Build Analog Distributions

The per well Peak rate data can be presented via the log cumulative probability plot or a frequency plot.





140 bopd is the P_{50} of the distribution. We know that 50% of the time a new well will meet or exceed that target. 50% of the time a new well will sample less than or equal to 140 bopd.

Pilot Design: Step 2

– Reverse Engineer a Minimum Economic Target of Peak Rate in bopd.

- These values are set by the firm’s leadership. For example all new plays must provide a full cycle ROR of 15% or more.

- The Asset team will develop a curve of daily average production rate divided by peak rate versus time for their selected analog.

- The peak rate is then reduced in the development model until the full cycle economic return equals the required 15% ROR.

- This is the reverse engineered Peak rate that we will test against in our Pilot design.

- We will use a break-even rate of **100 bopd** to build an example.

Pilot Design: Step 3

- How many wells, and at what per well average peak rate will our Pilot need to produce to validate a 50% and 90% confidence that the new zone will meet or exceed Management's expectations

- If decisions are to be made on an 50 or 90% confidence interval, we will need to reverse engineer the required ***"Pilot target"*** based on an averaged per well outcome from our pilot.

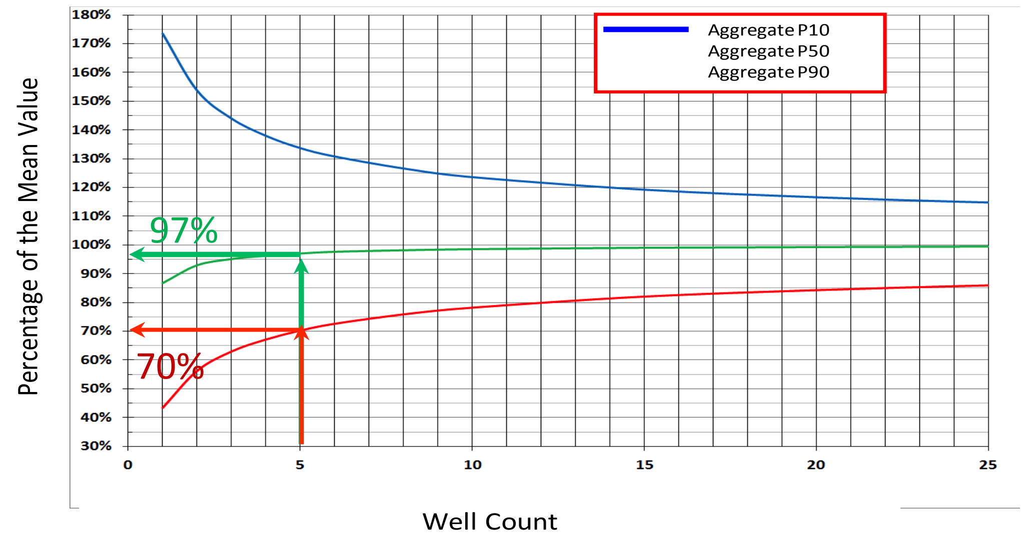
- We will need to assume lognormality and the variance (P10:P90 ratio) based on our best available analog(s).

- The "Uptick" of the "break-even rate of 100 bopd will be a function of the pilot well curve and the derived value from the P90 and P50 aggregation curves.

Pilot Design: Step 4

- Enter the P90 and P50 Aggregation curves at the number of pilot wells being evaluated. Read off the respective % of the mean values.

- The P50 = 97% of the mean
- The P90 = 70% of the mean



- To be 50% confident that our development will meet or exceed the minimum threshold value of 100 bopd, the 5 well pilot average must meet or exceed (100/0.97) 103 bopd.
- To be 90% confident that our development will meet or exceed the minimum threshold of 100 bopd, the 5 well pilot average must meet or exceed (100/0.7) 142.9 bopd.

Pilot Design

- The “No Regrets” Rates

- We determined that we need to realize an average rate of at least 103 bopd/well to be 50% confident that the new area would realize a breakeven ROR. Question is, what if you tested 100 bopd, would you walk knowing there is close to a 50% chance you will be embarrassed?

- This brings about a consideration of what we will refer to as the “No Regrets Rate”. That production rate at which you would have no regrets walking away, knowing that it might actually work. There are two key factors to consider:
    - Determining a no regrets volume on a break-even basis
    - Determining the likelihood of the play meeting you desired economic hurdles given that it failed to meet your 50% breakeven rate.

Pilot Design

- The "No Regrets" Rates

Determining a no regrets volume on a break-even basis

- We need a frank discussion with our decision makers before the well results and our emotions come into play.
- You will need to have additional aggregation curves to show a 25% confidence level plus other values they may request. R&A recommends the addition of a P25 and P10 value.
- Rerun the numbers using your corporate hurdle rates in addition to the "break-even" ROR values.

Pilot Design
- "Challenges in Piloting New Technology"

- Base forecast uncertainty
  - In SAGD well we have observed a +/- 20% variance
  - At the Pad level this can decrease to +/- 5%
  - Measurement proration issues amplified at the well level
- Time delay to see improvements
  - Impact of forecast uncertainty is compounded
  - Impatience
- Incremental changes are small relative to other uncertainties

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Making Better Decisions Based on Limited Data

- With such a large degree of innate uncertainty how do we assure our management team that our programs are on track?

- We can use the Aggregation curves to determine our 80% confidence intervals as a function of well count.

- By plotting our actual results against the 80% confidence bands we are generating what are referred to as "Sequential Accumulation Plots".

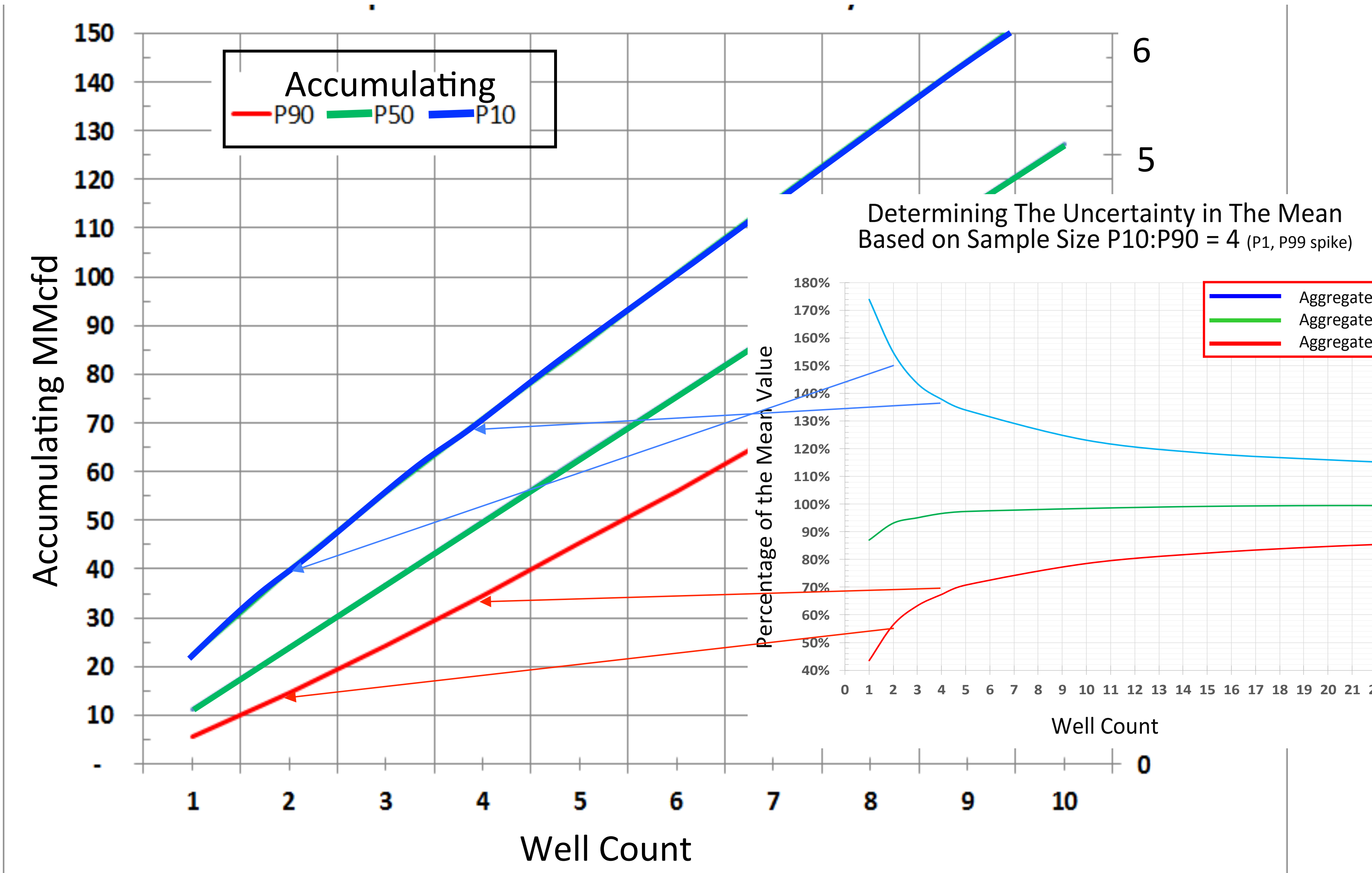
- This graphical approach provides an early indication of possible issues and facilitate "real-time" early decision making.

Sequential Accumulation Plots (SAP)

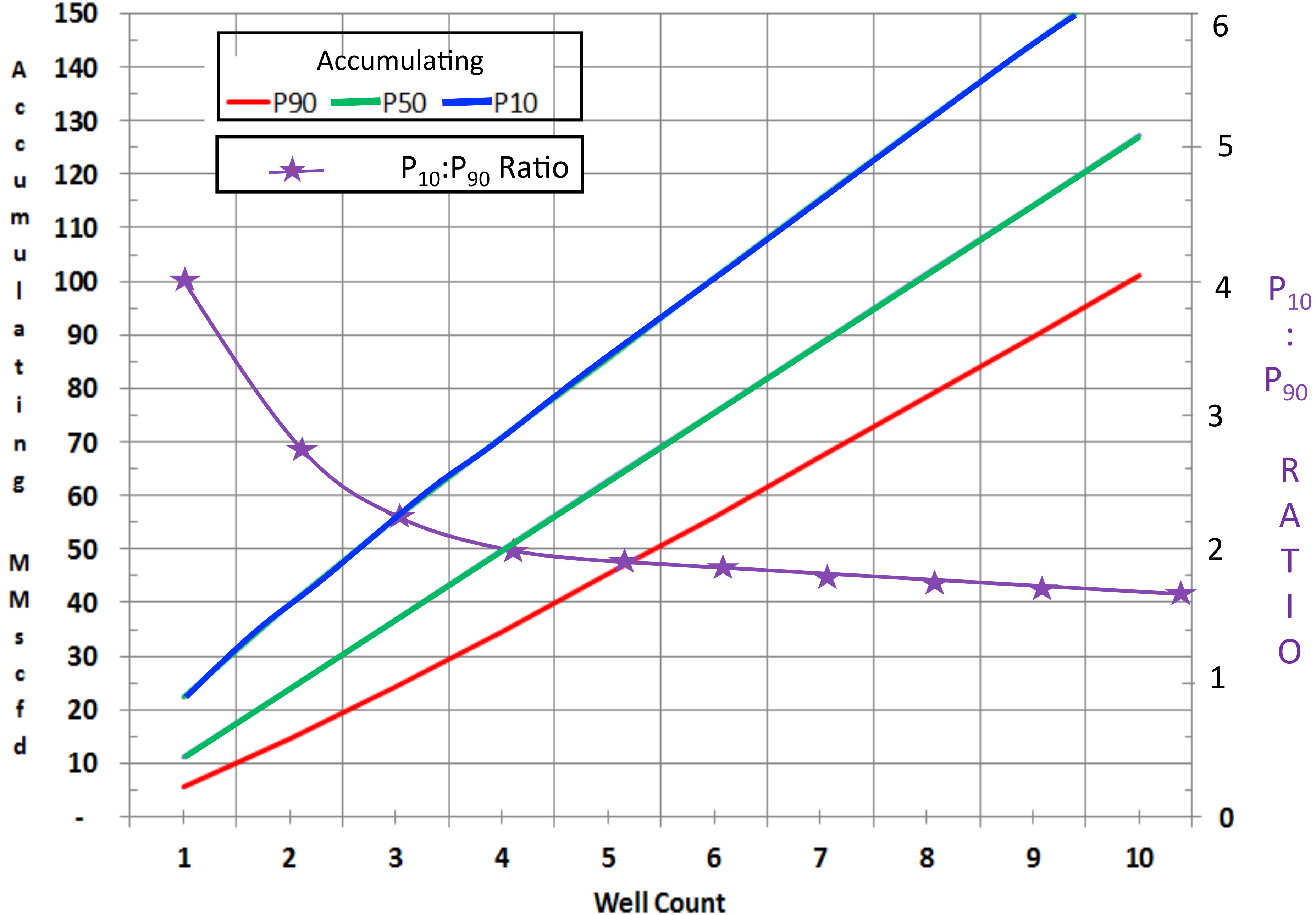
- SAP Plots are based on the Aggregation Curves
- Rather than presenting data as the average well in a multiple well program, the data is presented as the total P10-P50-P10 value for the full well count

- Useful for comparing actual to expected outcomes
  - So that expectations can be adjusted and, if necessary, the program can be halted if underperforming

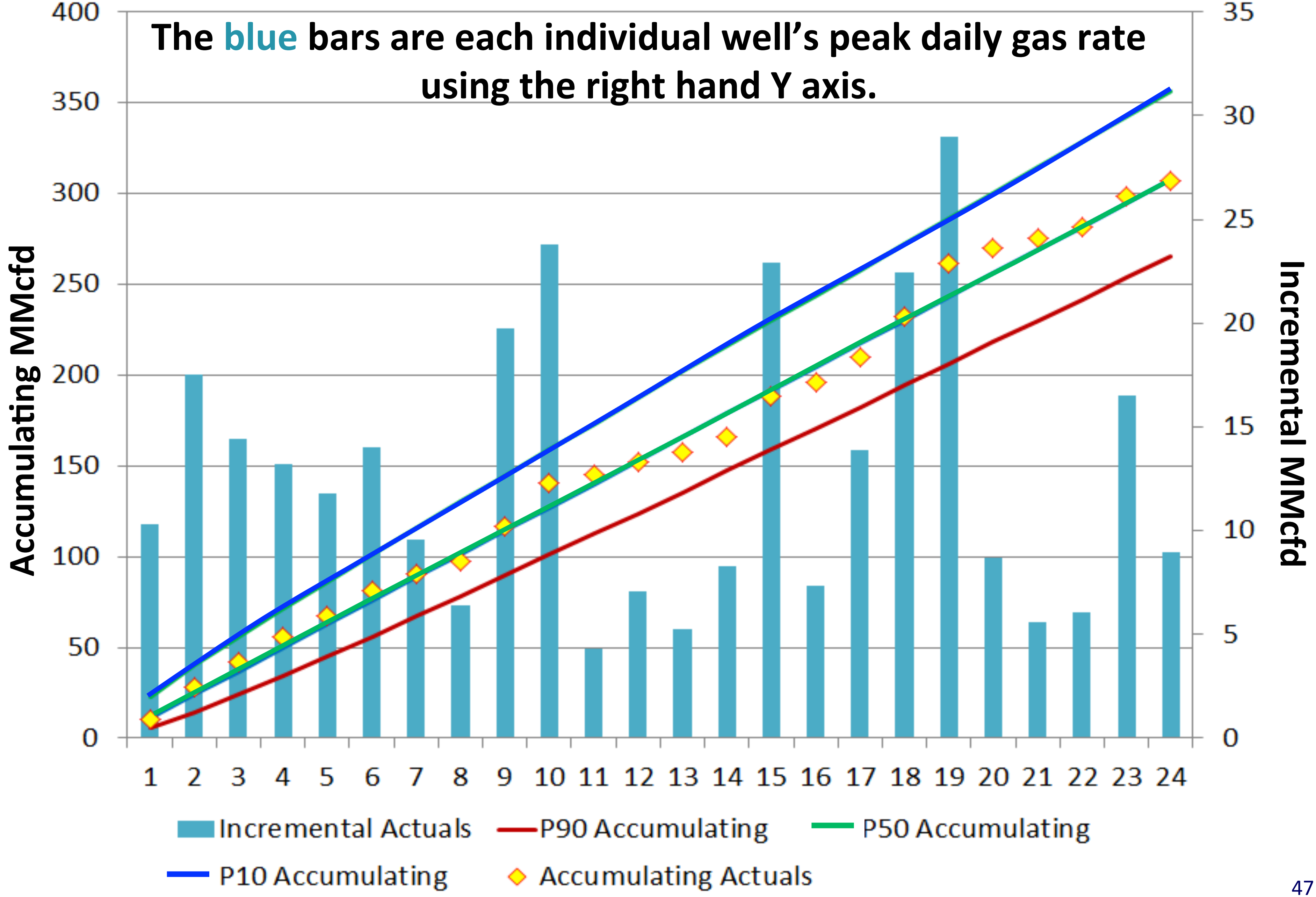
We convert the Aggregation curve, which presents the average well as a function of well count, to the accumulating totals, in this plot, by multiplying the % of the mean from the aggregation curve by the mean value and by the total number of wells.



Sequential Accumulation Plot - P_{10}:P_{90} Ratio = 4

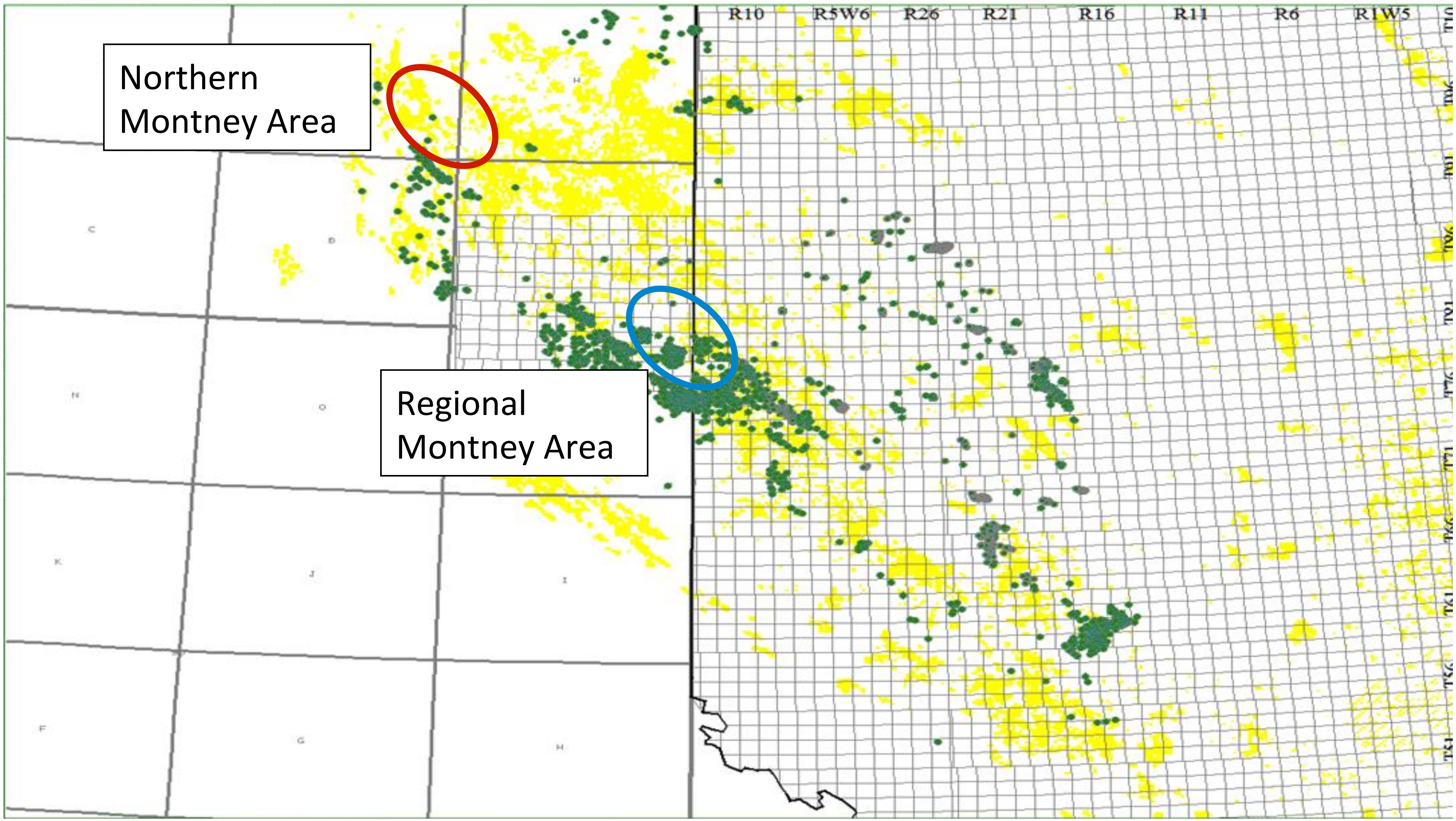


Peak Daily Gas Rate - Falher ‘H’



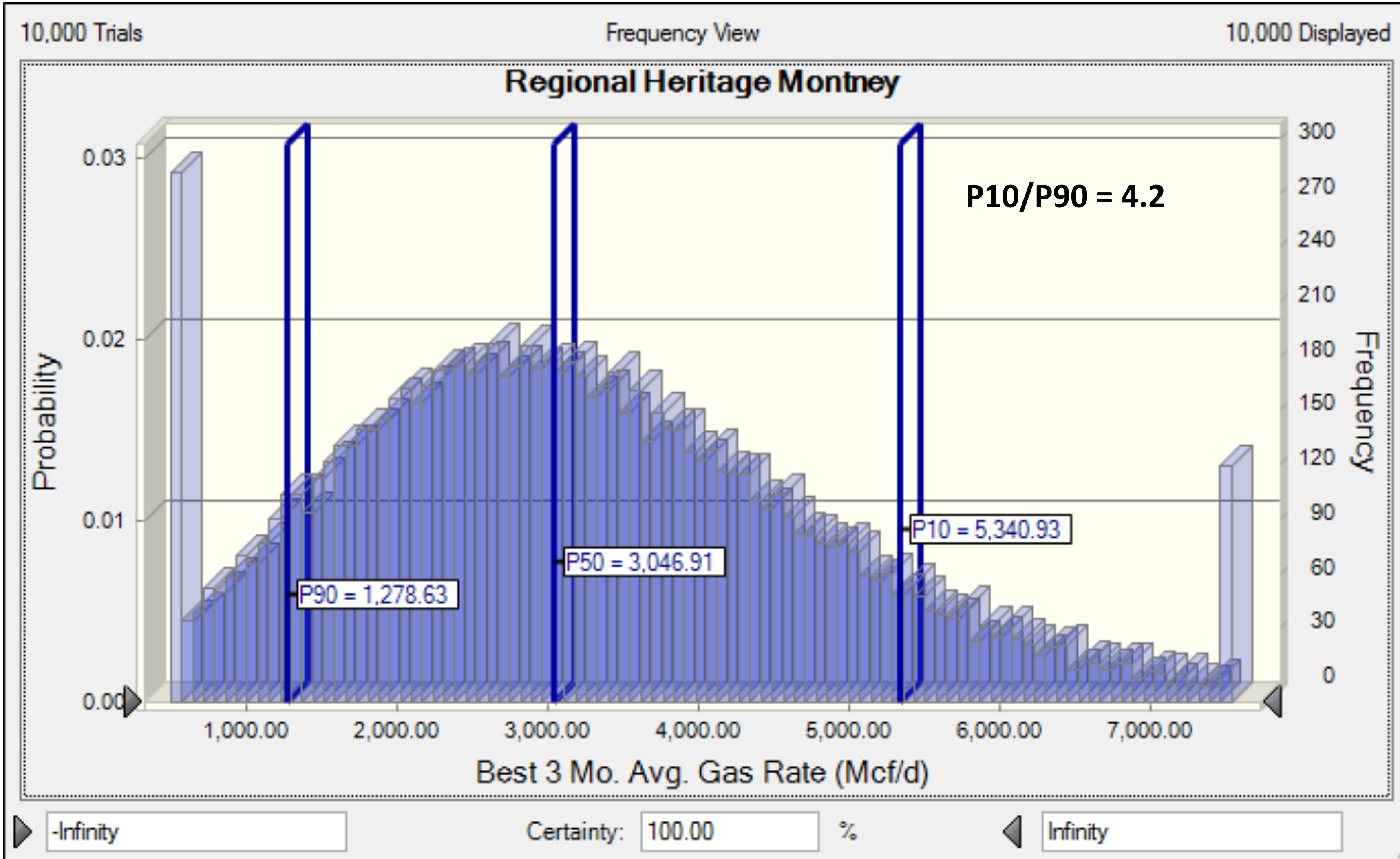
Case Study – Northern Montney, WCSB

The Initial Analog Production Type Curve Was Based on Regional Heritage Montney. Is This Type Curve Representative?



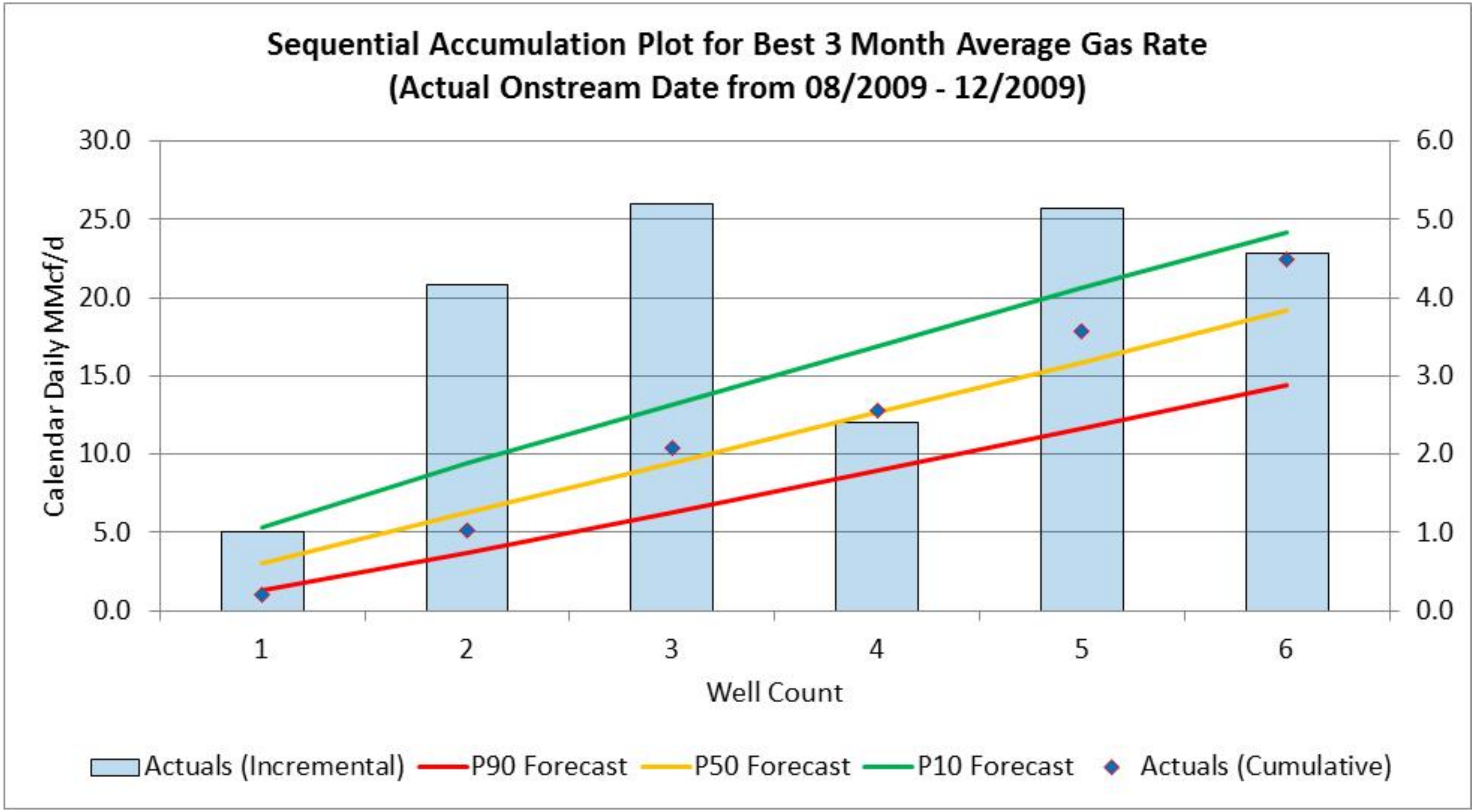
Green dots are Montney Horizontals at the end of 2012.

Analogue Best 3 Mo. Avg. Gas Rate



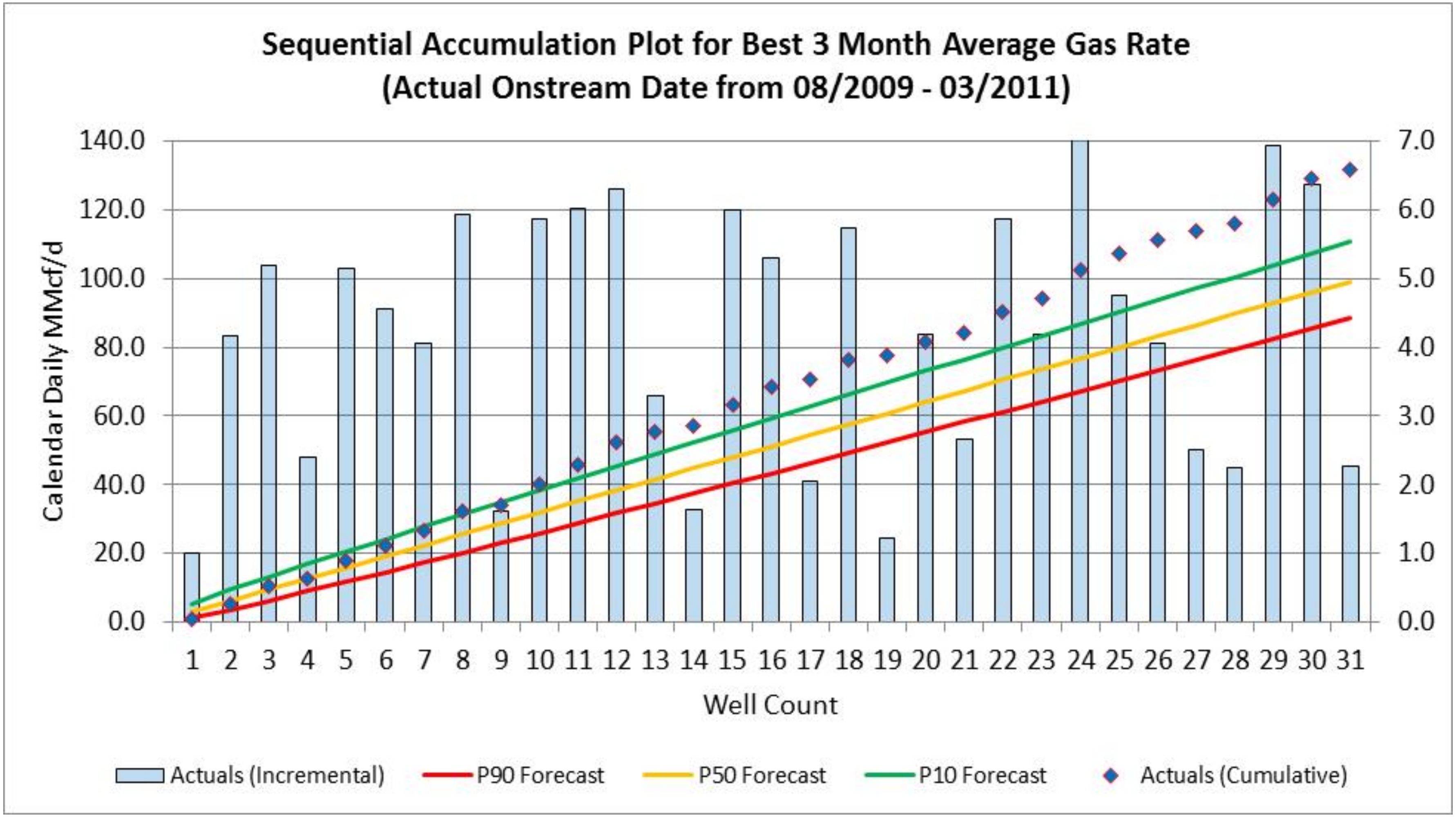
Based on Regional Heritage Montney selected analogue wells

Sequential Accumulation Plot



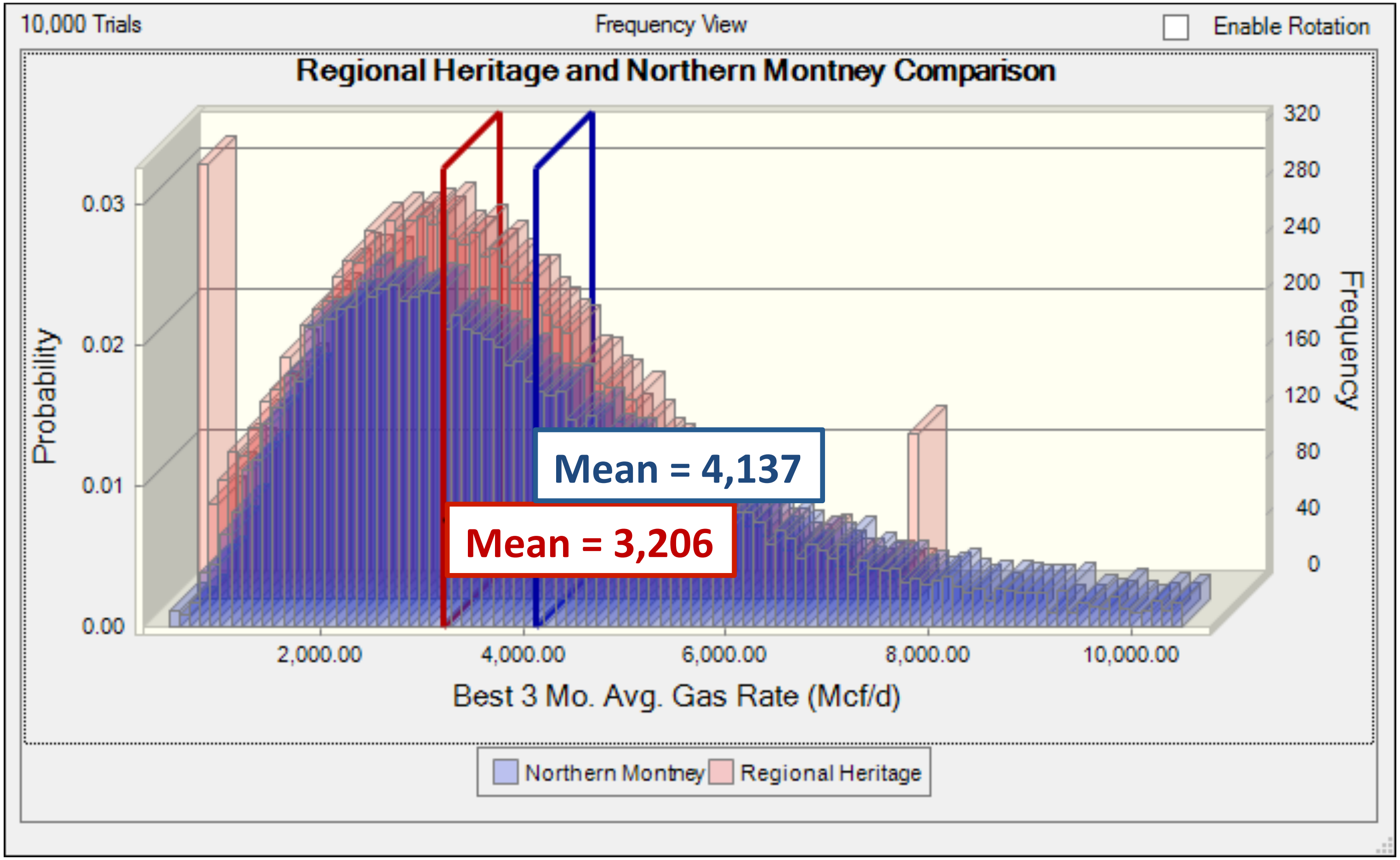
Forecast based on Regional Heritage Analogue wells. Actuals based on case study Operator's Northern Montney wells coming on-stream from the period from 08-2009 through 12-2009 (next well on-stream in 07-2010).

Sequential Accumulation Plot



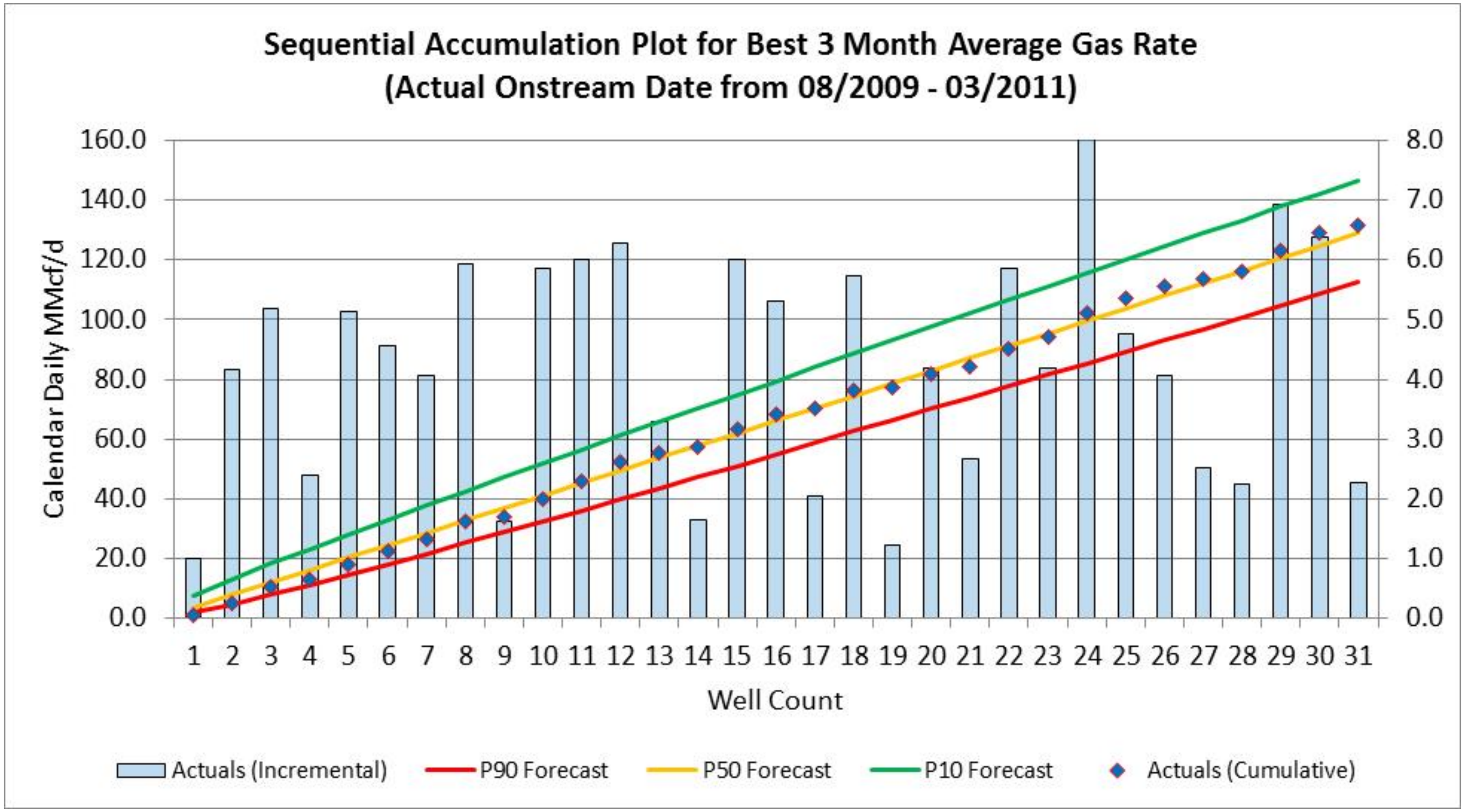
Forecast based on Regional Heritage Analogue wells. Actuals based on case study Operator's Northern Montney wells coming on-stream from the period from 08-2009 through 03/2011 (next wells on-stream in 08/2011).

Comparison of Best 3 Mo. Avg. Gas Rate



Based on actual results-to-date from case study Operator's Northern Montney revise distribution to reflect mean from case study Operator's Northern Montney wells with same variance (P10/P90 = 4.2) from analogue wells.

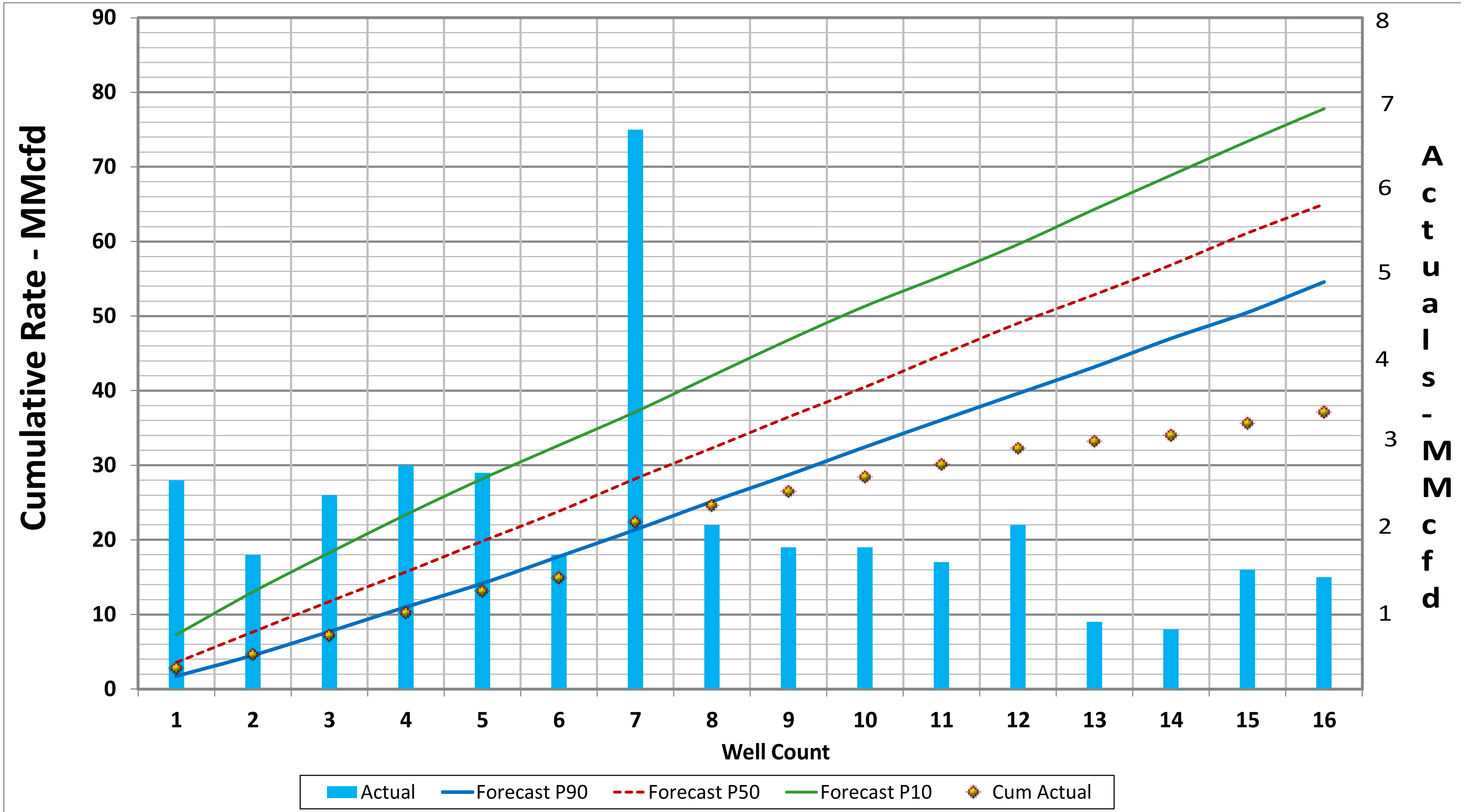
Sequential Accumulation Plot
(Revised Mean to Reflect Results-To-Date)



Forecast based on <u>revised</u> mean using case study Operator’s Northern Montney actual results-to-date. Actuals based on case study Operator’s Northern Montney wells coming on-stream from the period from 08-2009 through 03/2011.

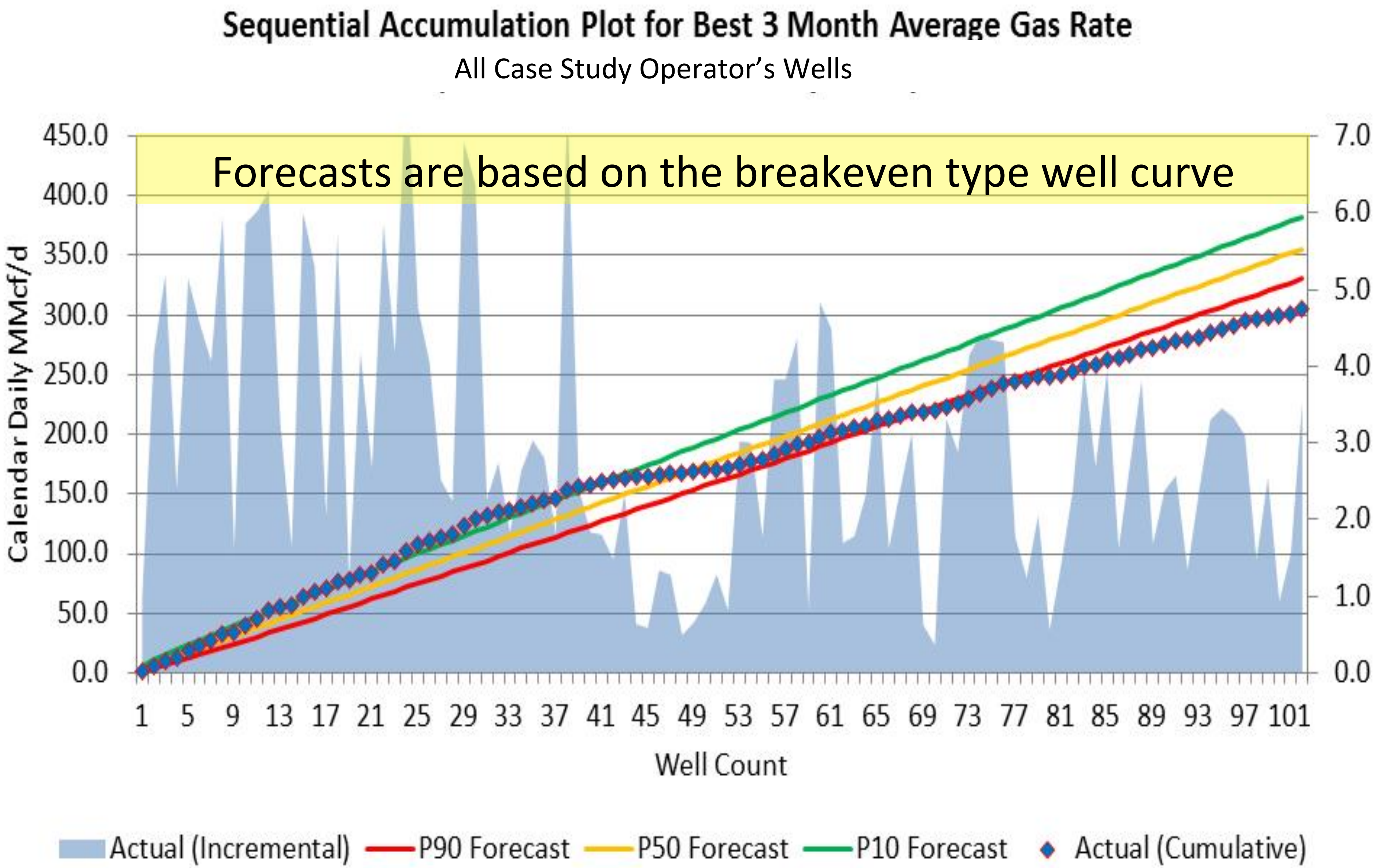
Sequential Accumulation Plot

(Revised Mean to Reflect Results-To-Date)



Forecast based on <u>revised</u> mean using Operator's Northern Montney first 31 wells. Actuals are from the next 16 wells drilled with revised technology.

How to Erode $1 Billion in Shareholder Value



Conclusions

- As Professionals we tend to rely on the observed data without acknowledging and understanding the representativeness of the sampled data.
- Allowing statistics to speak for themselves requires large well counts that are often not practical in high cost competitive plays.
- Aggregation curves are pragmatic approaches that provide insightful illustrations of the innate uncertainty in our limited data sets.
- The observed variance in drilling programs does not always imply that things are changing.

"Fooled by Randomness"

- Improving Decision Making With Limited Data

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