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1

"Fooled by Randomness"

- Improving Decision Making With Limited Data

Jim Gouveia P. Eng.
Partner
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Rose & Associates

Society of Petroleum Engineers
Distinguished Lecturer Program
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2

"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.

3

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

4

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.

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?

6

Aggregation Principles

- What would you conclude if on your first trial of the new technology you rolled a 5?

0 = 10

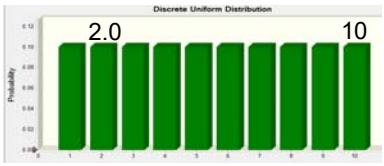
- Should you feel better or worse about the new technology?

- Could we conclude that the technology failed?
- Lets review a pragmatic statistical approach to provide quick solutions.

7

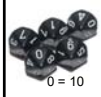
Aggregation Principles

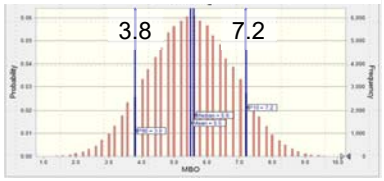
Single Die Outcome



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

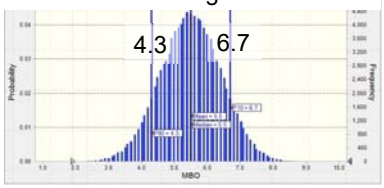
Five Dice Averaged outcome





- 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

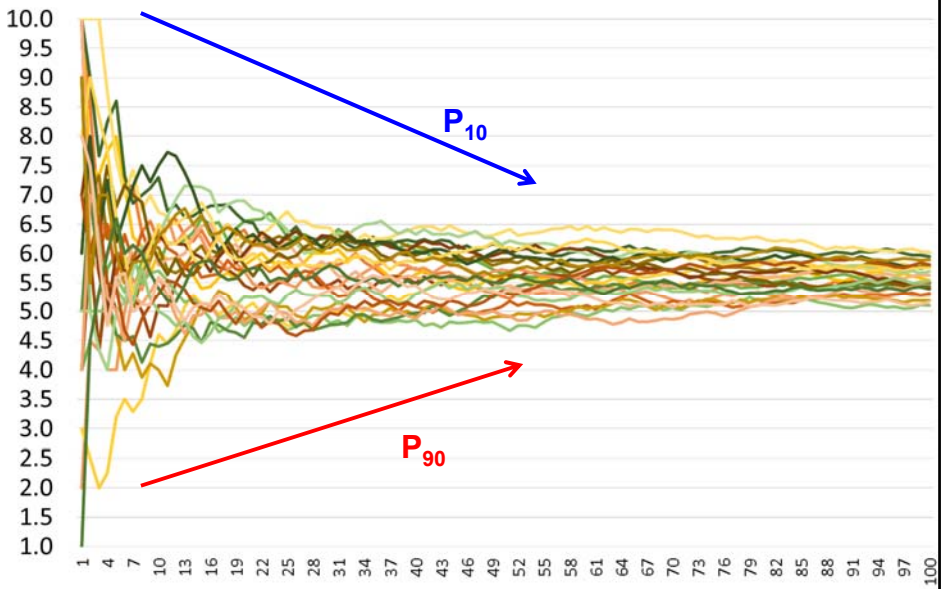
Ten Dice Averaged outcome



- 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

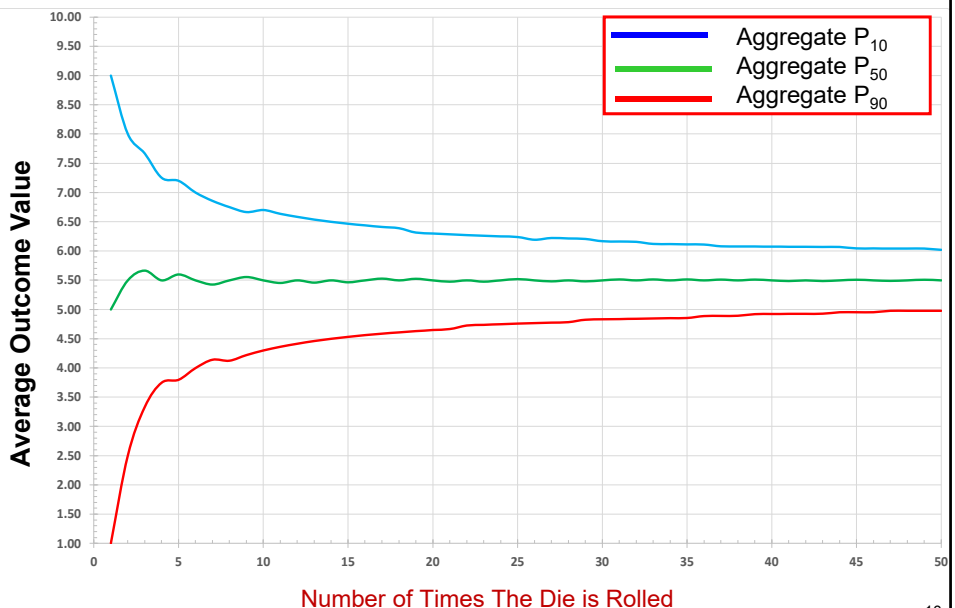
8

With Increasing Dice Rolls The Variance Decreases



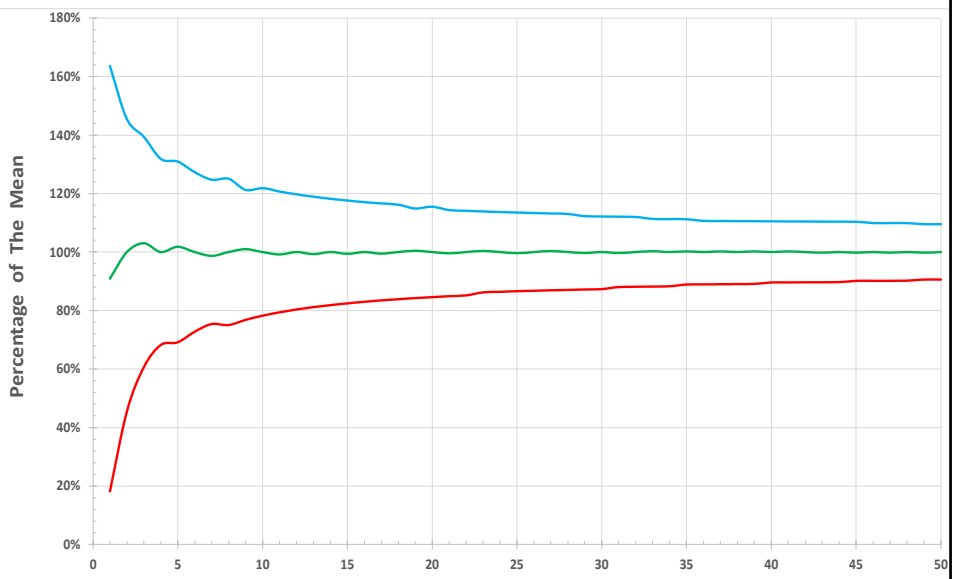
9

Aggregation Charts Reveal How The Variance Decreases With Increasing Dice Rolls



10

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



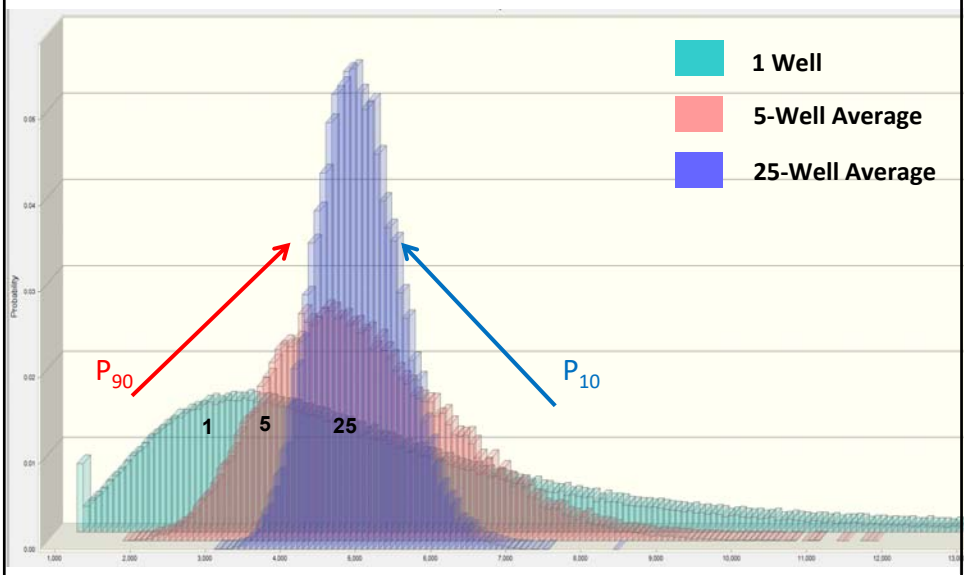
11

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.

12

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



EUR – MMscf

The Impact of Aggregation on a 5 & 25 well program

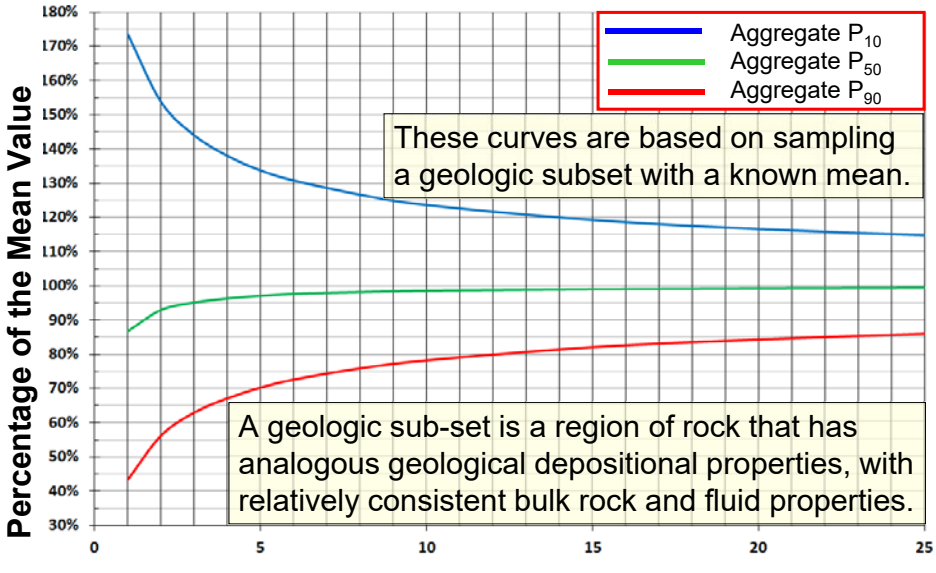
13

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.

14

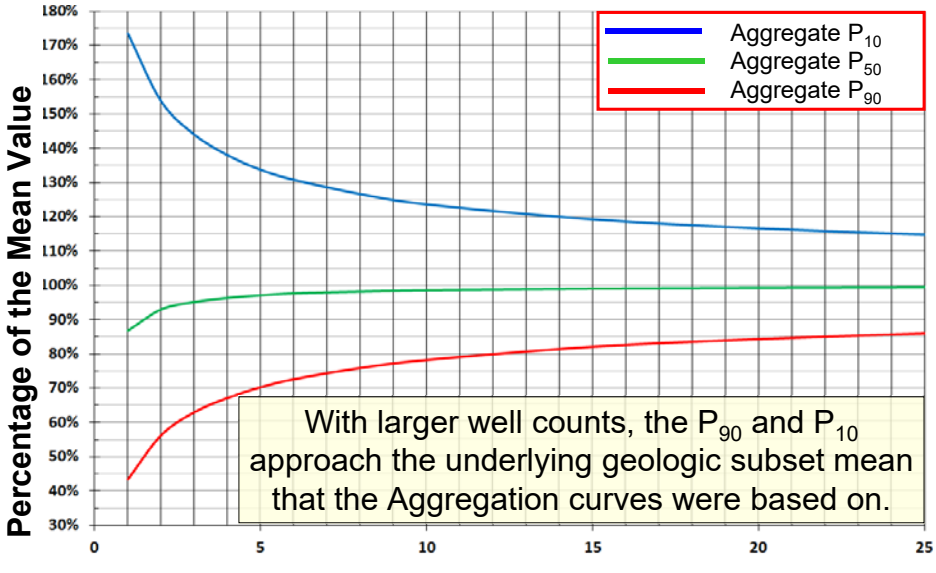
Aggregating EUR Distributions - P_{10}:P_{90} Ratio of 4



SPE 175527 by McLane & Gouveia

15

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



16

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:
  - o Horizontal well length is consistent or normalized.
  - o Drilling and completion techniques are analogous.
  - o 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.

17

Application of Aggregation Curves

- When developing a new geologic subset we can determine the uncertainty in the average well's performance based on:
  - o The variance (P_{10}:P_{90} ratio) of an analogously drilled and completed data set
  - o The arithmetic mean of the wells in the new area
  - o The well count used to calculate the arithmetic mean
- The technique requires us to assume lognormality and the variance from analogous reservoirs with similar horizontal well lengths and completion techniques.

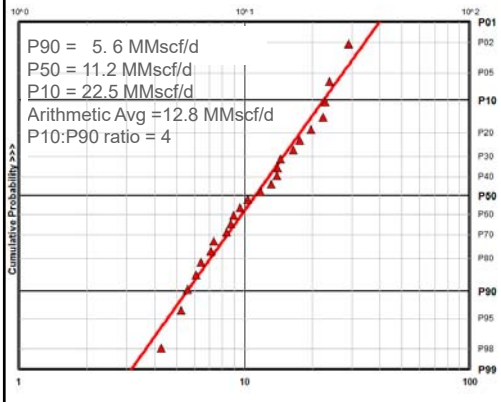
18

Application of Aggregation Curves

- North American experience has demonstrated that there has been a high degree of congruence in P_{10}:P_{90} ratios for horizontal wells in unconventional reservoirs with common horizontal well lengths and completion technologies.
- P_{10}:P_{90} ratios of 2.5 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.
- Let's see how we can use aggregation curves to provide us with insights into the representativeness of a limited data set of per well peak gas rates.

19

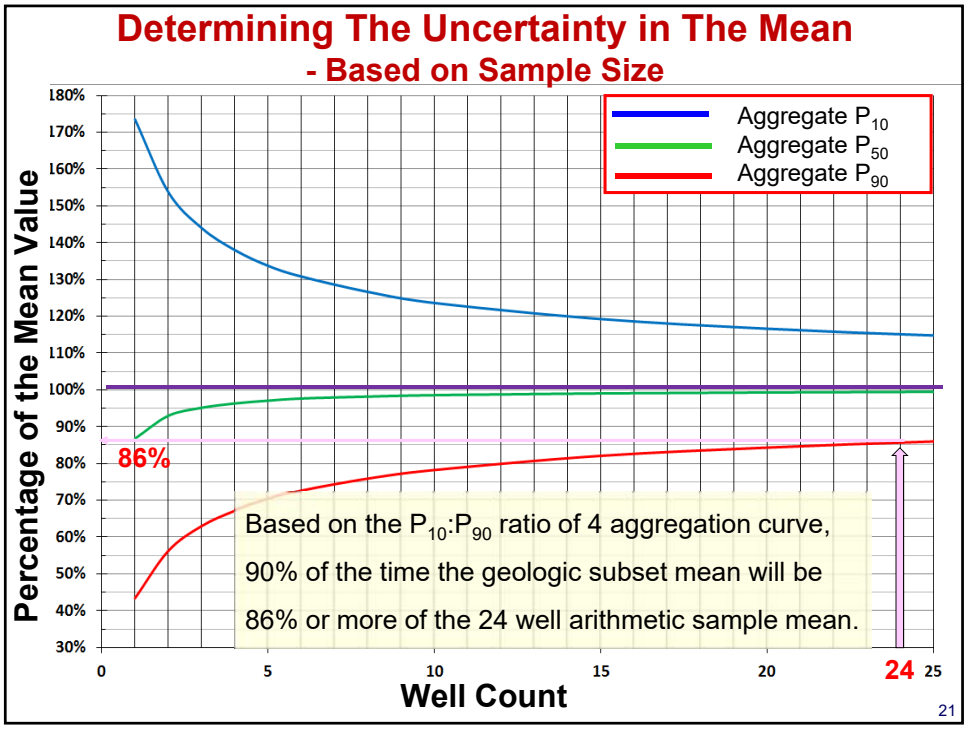
Falher 'H' – Peak Daily Gas Rate of The First 24 Wells

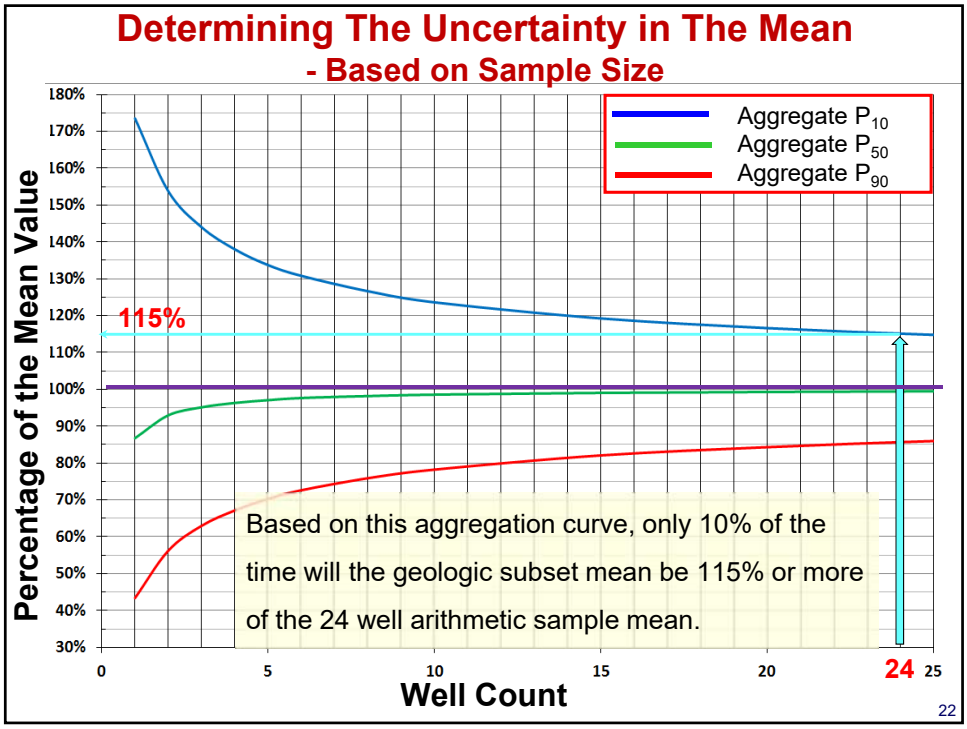


- Based on the 24 well sample we observe that the distribution is well fit with a lognormal distribution.
- The P_{90} and P_{10} of a randomly sampled individual well is 5.6 and 22.5 MMscf/d respectively.
- The arithmetic mean of the 24 well sample is 12.8 MMscf/d.

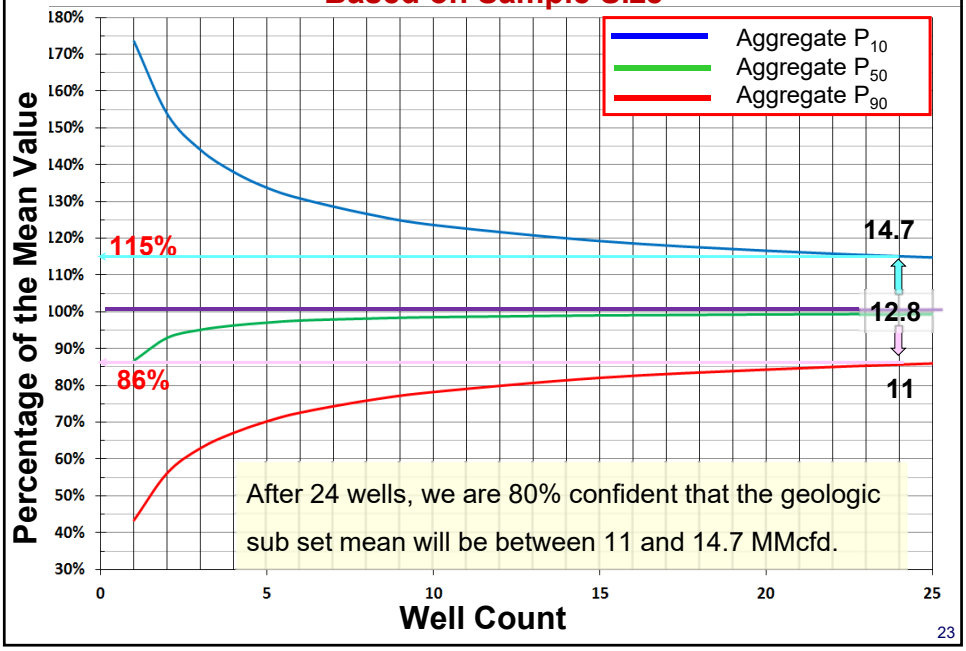
What is the uncertainty in the mean of this Geologic subset given the 24 well arithmetic mean of 12.8 MMscf/d?

20


Determining The Uncertainty in The Mean
- Based on Sample Size
Aggregate P10
Aggregate P50
Aggregate P90
Percentage of the Mean Value
180%
170%
160%
150%
140%
130%
120%
110%
100%
90%
80%
70%
60%
50%
40%
30%
86%
Based on the P10:P90 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.
0
5
10
15
20
24
25
Well Count
21


Determining The Uncertainty in The Mean
- Based on Sample Size
Aggregate P10
Aggregate P50
Aggregate P90
Percentage of the Mean Value
180%
170%
160%
150%
140%
130%
120%
110%
100%
90%
80%
70%
60%
50%
40%
30%
115%
Based on this aggregation curve, only 10% of the
time will the geologic subset mean be 115% or more
of the 24 well arithmetic sample mean.
0
5
10
15
20
24
25
Well Count
22

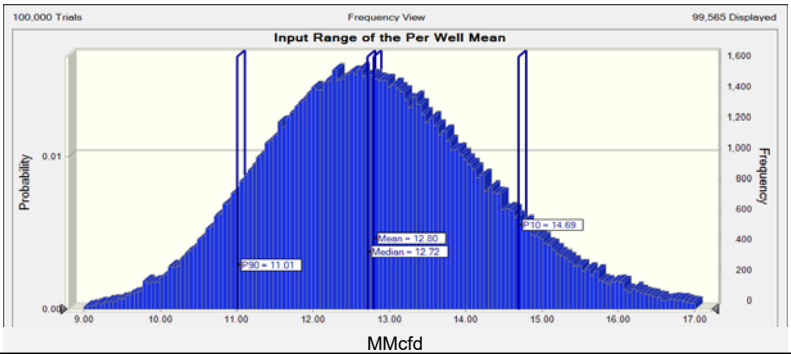
Determining The Uncertainty in The Mean
- Based on Sample Size



23

Forecasting Based on Limited Samples

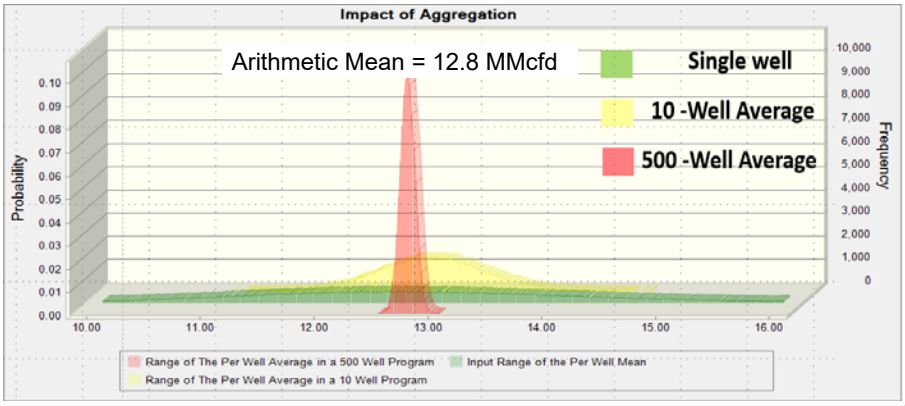
- Employers have an expectation that their professionals can forecast the results of future programs based on prior results.
- With increased sample size the arithmetic well average will converge on the true geological subset mean. With limited wells, the best we can do is evaluate the uncertainty in the mean of the subset.



24

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.



25

Aggregation Curve Application to Limited Data Sets

- Use the Aggregation curves to bound the range of the geological sub-set mean.
- Acknowledge that we cannot further resolve the inherent uncertainty in the original 24 well sample.
- Let's review an example of how we would forecast for budget or project sanctioning, the range of outcomes for the next year's program of 10 wells.

26

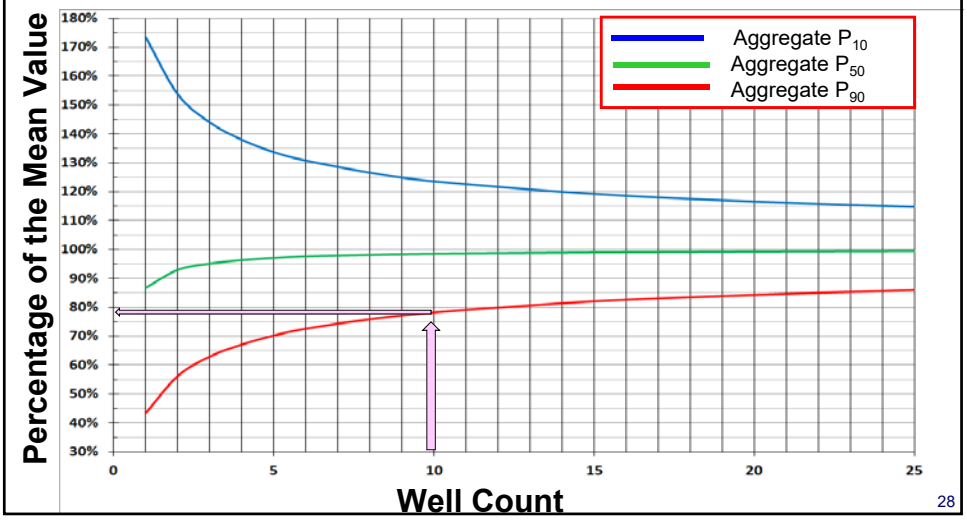
Aggregation Curve Application to Limited Data Sets

- We have established that we are 80% confident that the true population mean is between 11 to 14.7 MMcfd.
- Utilize the P_{90} and P_{10} values from the first 24 wells as your low side and high side scenario assessment of the geologic sub-set mean.
- Read the P_{90} and P_{10} percentage of the mean factor for a 10 well program using the P_{90}:P_{10} ratio of 4 Aggregation curves.
- Apply the P_{90} percentage of the mean factor to the low side scenario value of the geologic sub-set mean.
- Apply the P_{10} percentage of the mean factor to the high side scenario value of the geologic sub-set mean.

27

The P_{90} Scenario:

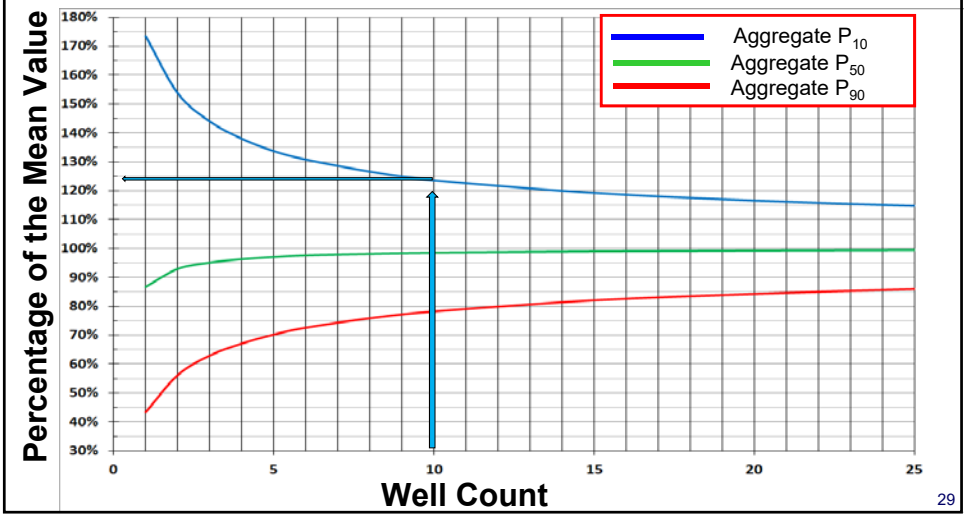
- The geologic subset mean may be as low as 11 MMcfd.
- The ten well project may average as low as 78% of 11 MMcfd = 8.6 MMcfd.



28

The P_{10} Scenario:

- The geologic subset mean may be as high as 14.7 MMcfd.
- The ten well project may average as high as 124 % of 14.7 MMcfd = 18.2 MMcfd.



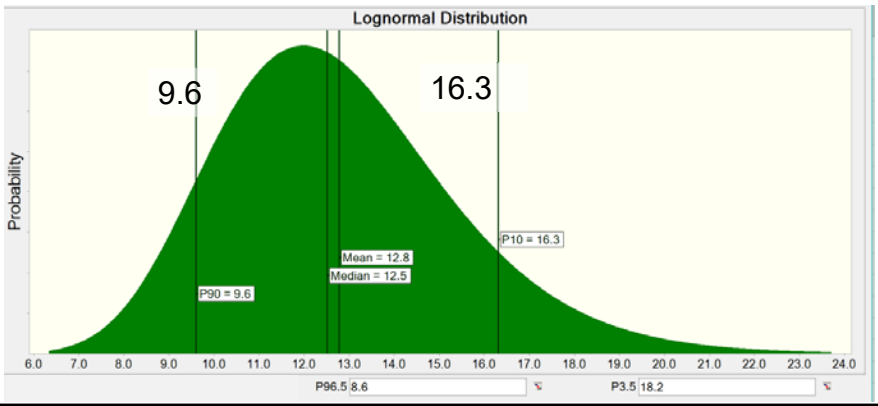
29

We Evaluated P_{90} & P_{10} Scenarios & Extracted P_{90} & P_{10} Values

Ed Capen, circa 1990 proved that:

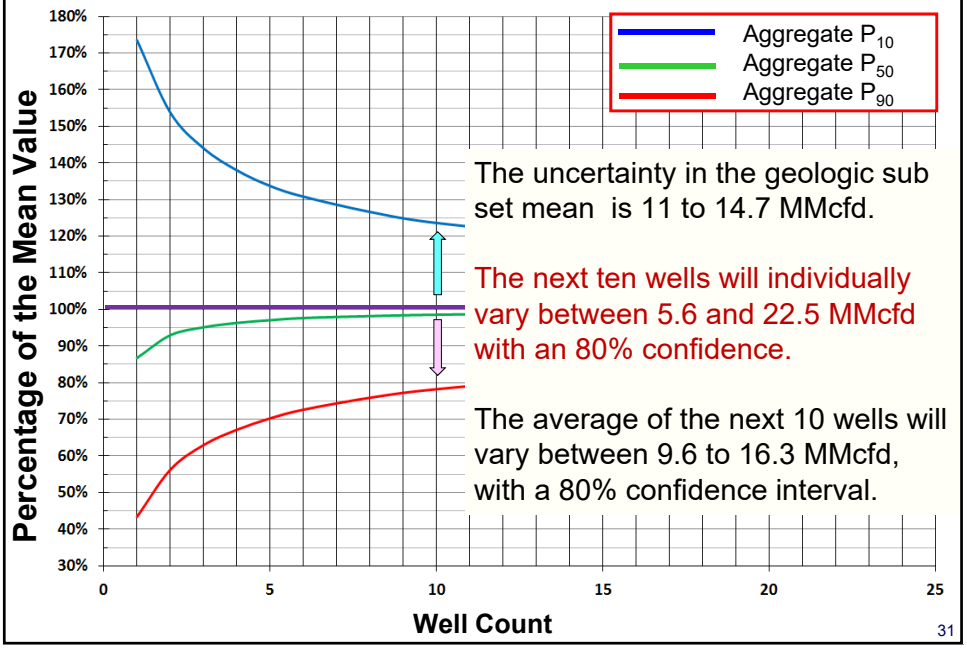
- Two P_{90} values multiplied generated a $P_{96.5}$ realization.
- Two P_{10} values multiplied are a $P_{3.5}$ realization

Based on this we have the P_{10} & P_{90} values for a ten well program



30

Forecasting Based on Limited Samples



The uncertainty in the geologic sub set mean is 11 to 14.7 MMcfd.

The next ten wells will individually vary between 5.6 and 22.5 MMcfd with an 80% confidence.

The average of the next 10 wells will vary between 9.6 to 16.3 MMcfd, with a 80% confidence interval.

31

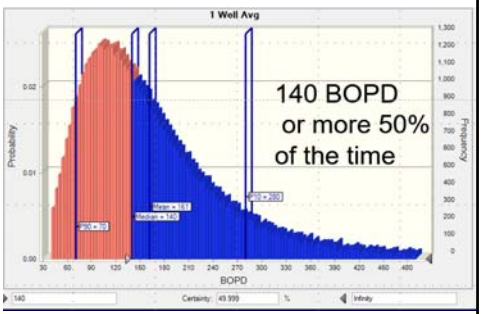
Aggregation Curve Application to Limited Data Sets

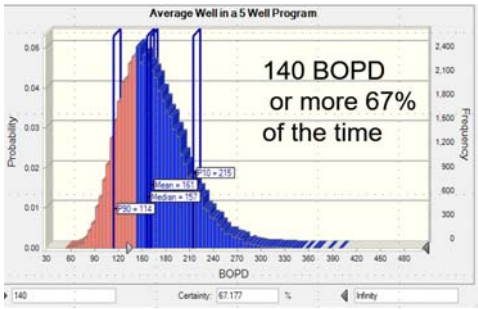
- Next we will bring probabilistic assessments into play so that we can have a meaningful discussions around either:
  - The confidence level that we need to achieve a performance target versus well count?
  - For a given well count and confidence level, our recommended performance target level?
  - For a given well count and performance target, what is our confidence of meeting or exceeding the performance target?

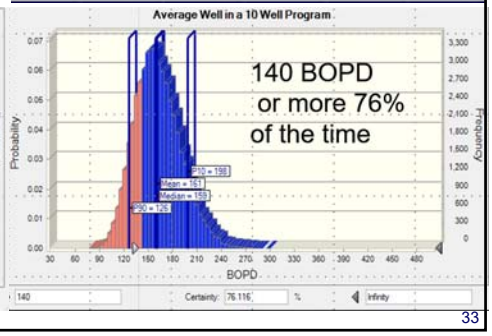
32

Developing These Relationships Requires Monte Carlo Software

In this visual example we illustrate how Monte Carlo software develops confidence levels in our target value as a function of well count

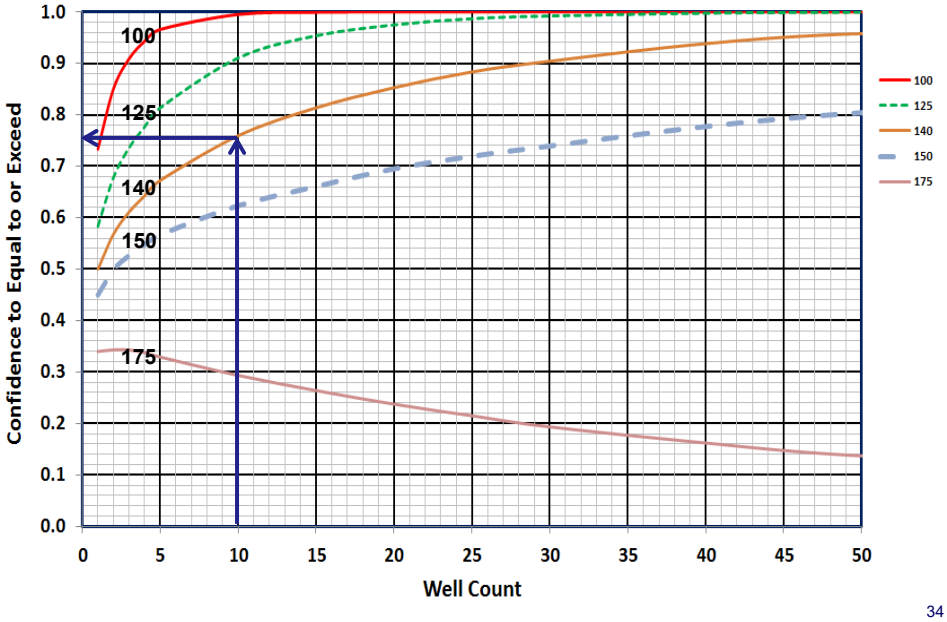






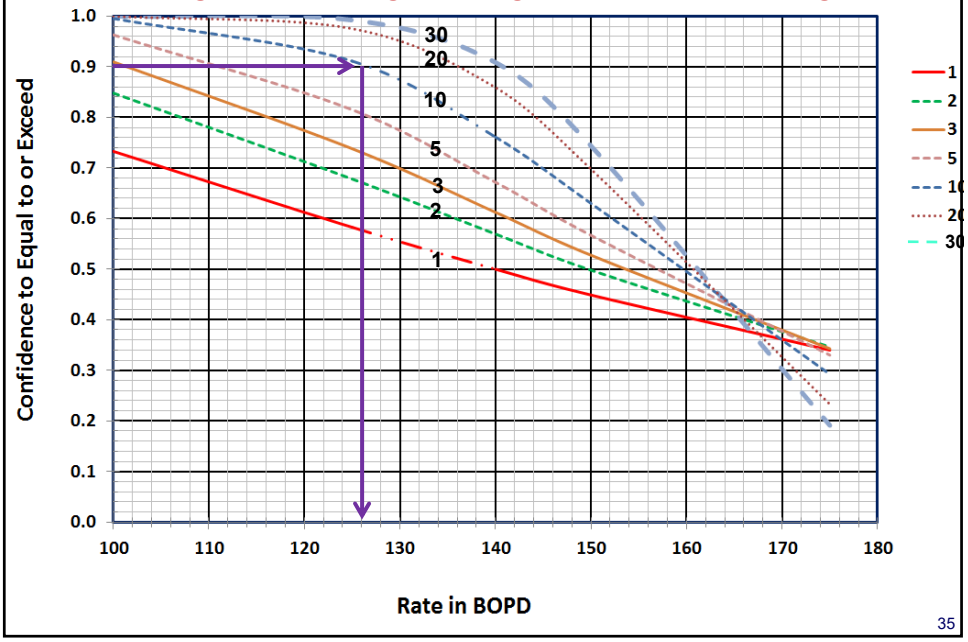
33

What is Our Confidence of Meeting or Exceeding our Target of 140 Bopd if we Drill a 10 Well Program?



34

What Production Target Should we Set to Have a 90% Confidence in Meeting or Exceeding the Target With a 10 Well Program?



35

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.

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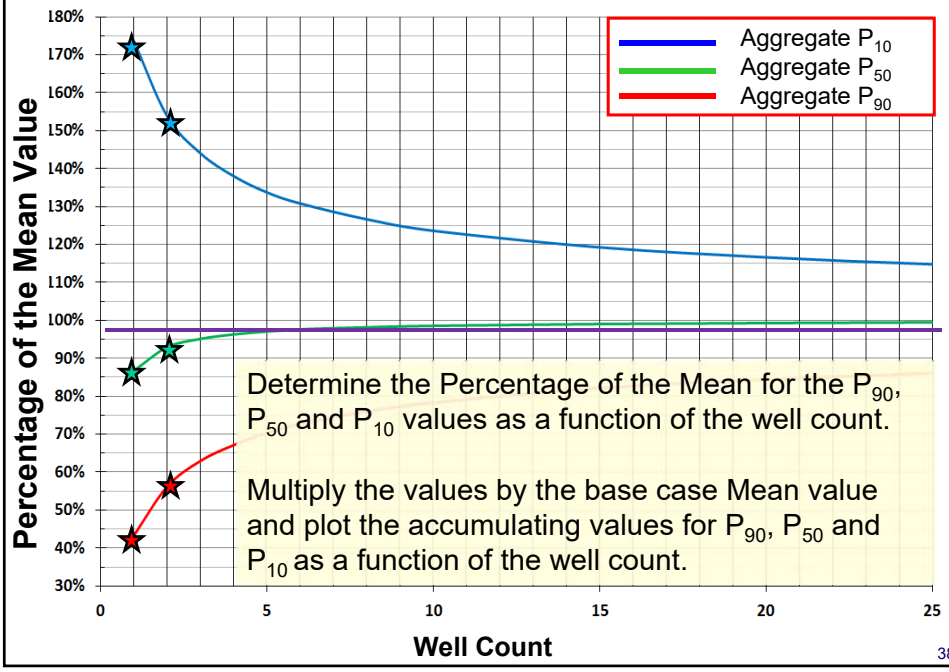
Sequential Accumulation Plots

Use the following steps to validate EUR, Peak Rates, learning curves, or the applications of a new technology:

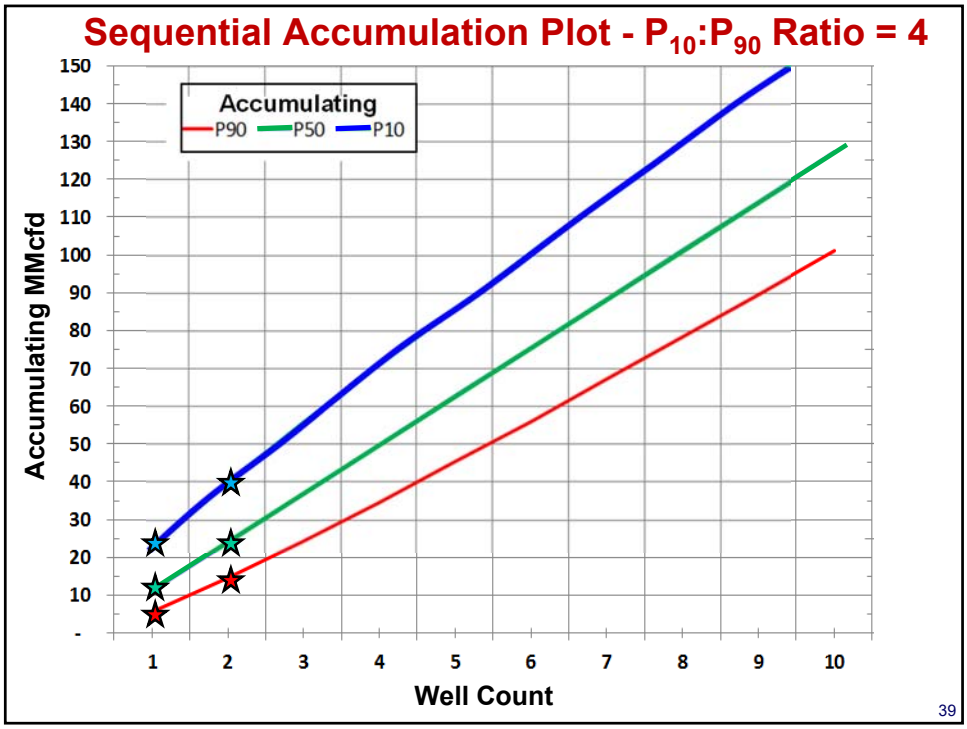
- Plot the accumulating well totals against the theoretical P_{90}, P_{50} and P_{10} sequentially aggregated curves.
- Until there is adequate well count use the P_{90}:P_{10} ratio based upon your analog wells.
- "Boundary Conditions". If the sequentially totalled values of the new wells falls below the aggregate P_{90}, or above the P_{10}, review the results with the decision maker.

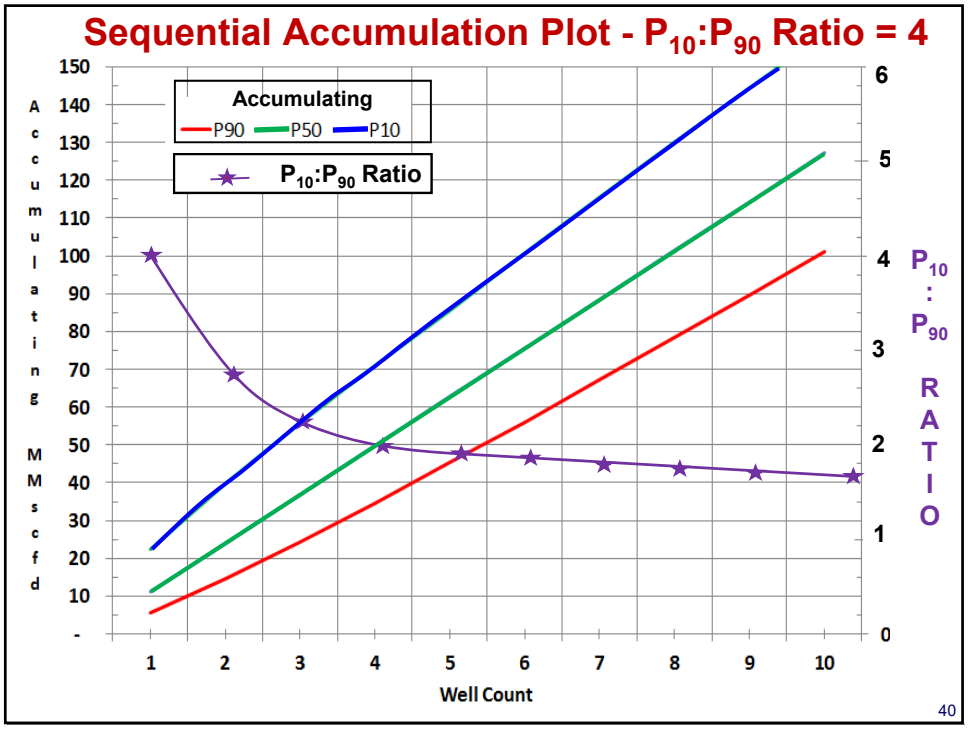
37

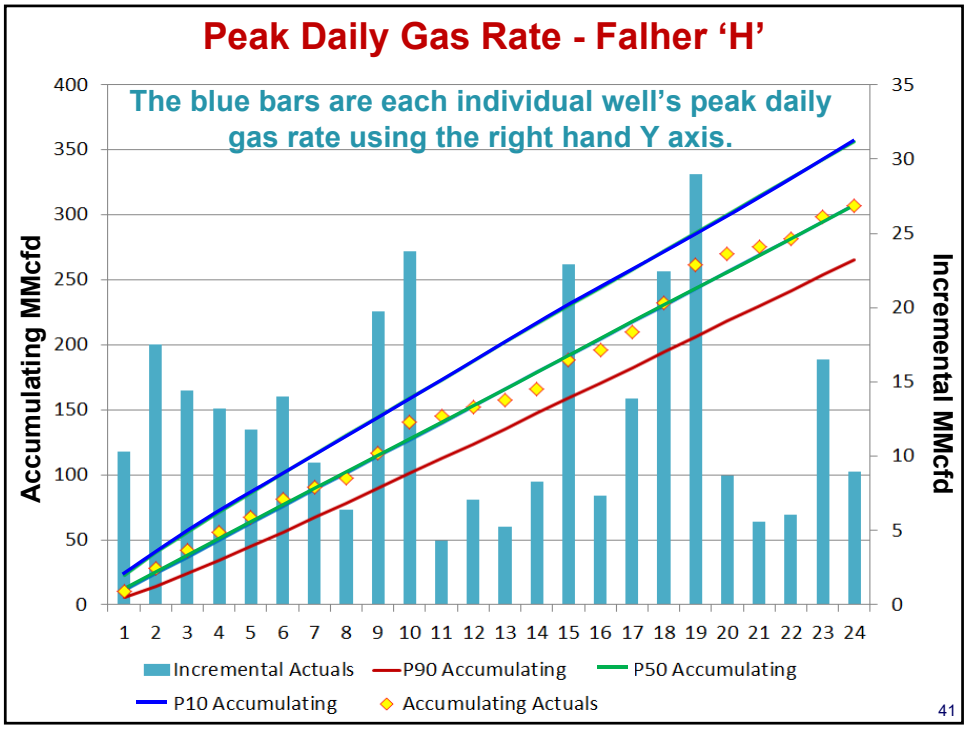
Aggregation Curve - P_{10}:P_{90} Ratio = 4



38


Sequential Accumulation Plot - P10:P90 Ratio = 4
Accumulating
P90
P50
P10
Accumulating MMcfd
Well Count
39


Sequential Accumulation Plot - P10:P90 Ratio = 4
Accumulating
P90
P50
P10
P10:P90 Ratio
Accumulating MMscfd
P10 : P90 RATIO
Well Count
40



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.

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Conclusions

- Utilizing Sequential Accumulation plots to track your programs as they mature will provide "real time" feedback.
- Make real time Sequential Accumulation plots a component of your Project sanctioning as "Boundary Conditions".
- Conduct a mandatory Decision Maker review when the aggregate P_{90} or P_{10} boundary values are crossed.

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