ROSE
SUBSURFACE ASSESSMENT

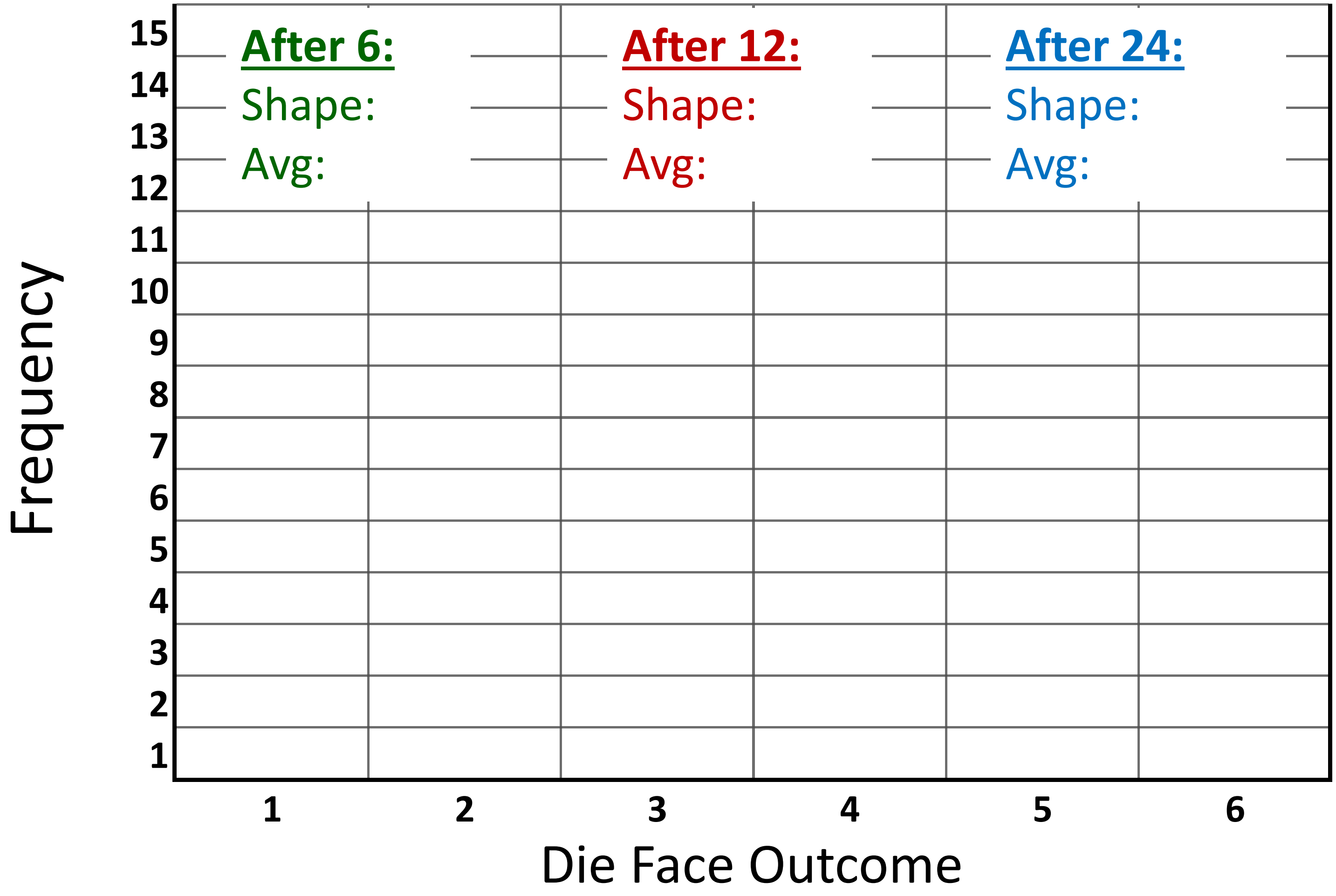
PILOT DESIGN PRINCIPLES

ROSE
SUBSURFACE ASSESSMENT

Pilot Design Principles

- Sampling Exercise
- Principles of Estimating Under Uncertainty
- Chance of Success Overview
- Value of Information
- Aggregation Principles
- Pilot Design Exercise

Exercise: Histogram of Die Rolls



After 6:
Shape:
Avg:

After 12:
Shape:
Avg:

After 24:
Shape:
Avg:

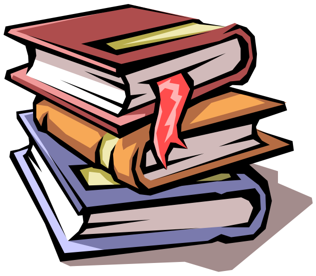
Where do we See Uncertainty?

- The simply answer is in pretty much in every aspect of our industry
- To minimize surprises, we need to honor the known uncertainty in the key variables. This may result in more than one critical path. This is an added element of complexity that only the best project managers have embraced
- Gant charts are invaluable in focusing our Project Managers on the Project's critical timeline to assure that our projects come in on time
- Gant charts commonly set each variable at their mean and then determine the "critical path".
- Should we be surprised when a variable does not come in at its mean outcome?

We shouldn't be!

The Undiscussed Issue With Critical Paths is Uncertainty

- Published Retrospect data by IPA on E&P firm's major projects confirms that we are not meeting our target timelines
- The root cause is our deterministic focus on the critical path of our projects
- Meeting our targets will require embracing probabilistic time estimates into our critical path assessments
- Today we are seeing an enhanced need to understand and characterize uncertainty in areas other than the subsurface



Engineers and Geoscients

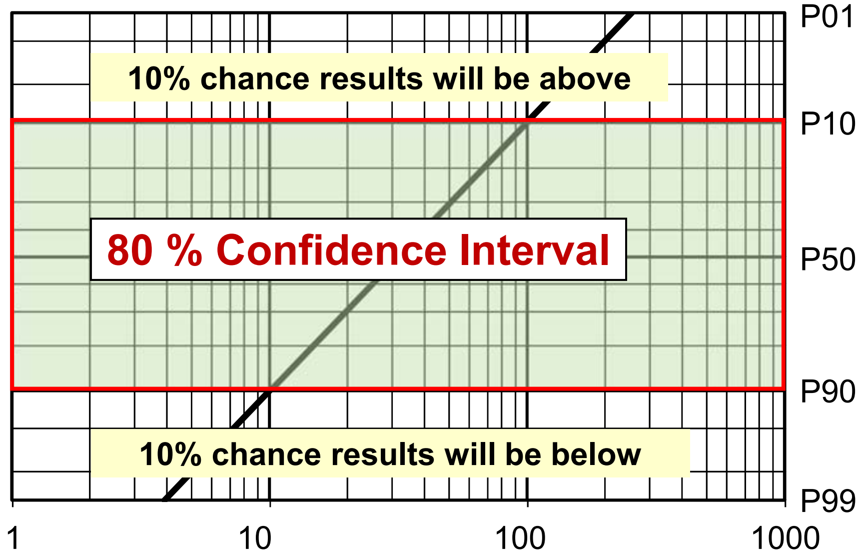
Have Formal Training In

Mathematics Physical Sciences Computer Science	Geologic Principles Scientific Method Engineering

But Who Has Ever Had A Course In

EFFECTIVE ESTIMATING?

Estimating With Probabilistic Ranges



Canada Edition

P90	**P10**	
___________	___________	What is the length (km) of the main stem of the Mackenzie River?
___________	___________	How many mobile phones were in use in Canada in 3Q 2023?
___________	___________	How many certified airports were in Canada as of December 2023?
___________	___________	What is the total length (km) of Canada's seacoast, including all islands?
___________	___________	How many helicopters were registered in Canada as of December 2020?

Uncertainty

	P90	P50	P10
Practice	____________	____________	____________
Slide A	____________	____________	____________
Slide B	____________	____________	____________
Slide C	____________	____________	____________

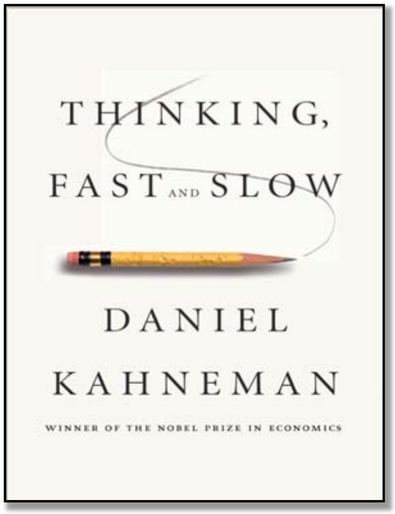
The Perils of Leading with Intuition

- "Intuition" in this case refers to our instinct, impulse, gut-reaction, most recent experience, what we've been told by others, etc.
- This information allows us to make decisions quickly (FAST THINKING) as opposed to devoting time and effort to collecting, analyzing and interpreting data (SLOW THINKING)
- However, the use of "intuition" encourages biases into our decision-making
- Let's explore this in a little more detail…

Thinking Fast and Slow

Kahneman (2011) describes two systems we often use to think and process information

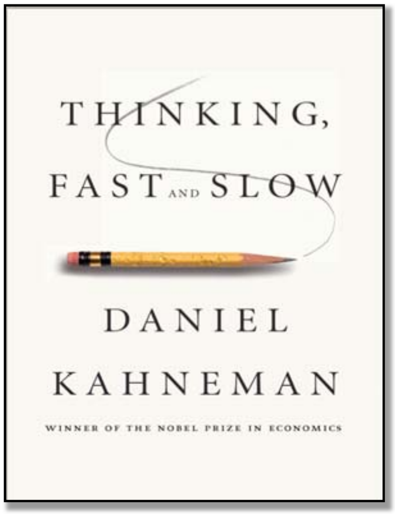
- SYSTEM 1 (FAST, Reflexive) uses association and metaphor to produce a quick and easy draft of reality. Evolved as a preservation instinct.
- SYSTEM 2 (SLOW, Reflective) thinks deliberately and rationally, arriving at reasoned choices. Has advanced humanity through the ages (technology)



Kahneman, 2011

Thinking Fast and Slow

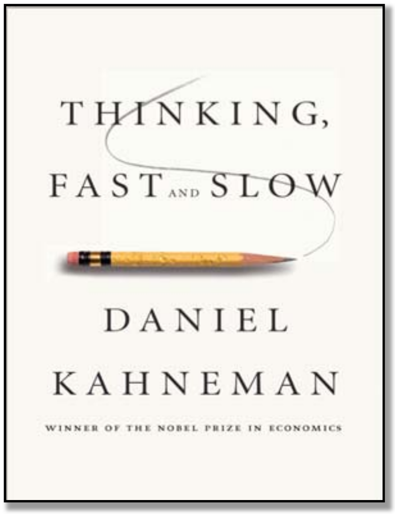
- A Bat and a ball cost $1.10
- The Bat costs $1 more than the ball
- How much does the ball cost?
- Our FAST thinking (intuition) tells us the ball costs $0.10



Kahneman, 2011

Thinking Fast and Slow

- Our estimation process is an interaction between Systems 1 and 2
- System 1 provides an immediate, but unreasoned response
- We are prone to accept it because we are under pressure to make decisions quickly that result in activity (such as drilling and completing wells)
- In doing so, we are setting the stage for biases to impact our decision-making



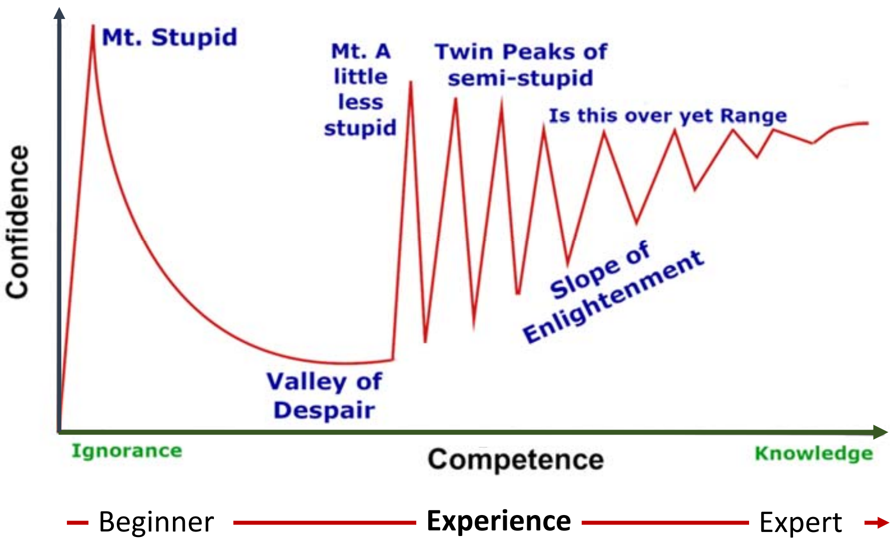
Kahneman, 2011

The Dunning-Kruger Effect

- People tend to hold overly favorable views of their abilities in many social and intellectual domains.
- The authors suggest that this overestimation occurs, in part, because people who are unskilled in these domains suffer a dual burden:
  - Not only do these people reach erroneous conclusions and make unfortunate choices, but their incompetence robs them of the metacognitive ability to realize it.

(Kruger, J. and Dunning, D., 1999)

The Dunning-Kruger Effect



Modified From Kruger, J. and Dunning, D., 1999

Cognitive Biases

- Consistent, repeatable and predictable errors in thinking and information processing, and result in:
  - Interpretations and decisions that may seem logical, but are not valid
- Awareness alone does not mitigate
- There are many of them – we will introduce six

Overconfidence
Information
Anchoring

Availability
Framing
Confirmation

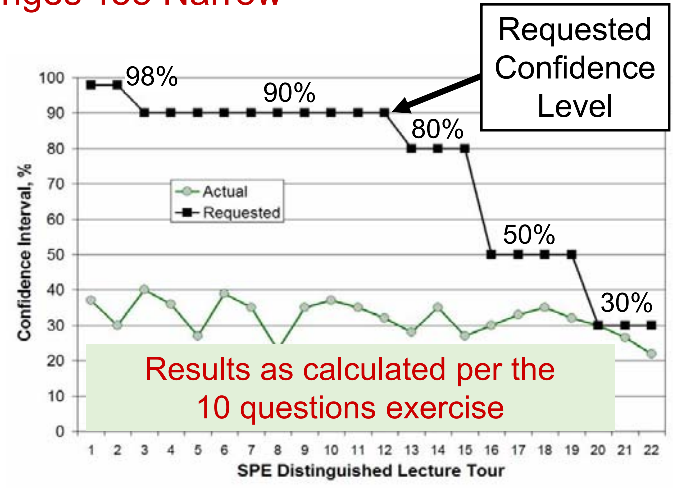
Tversky & Kahneman, 1981; Kahneman 2011

Overconfidence Bias

We Think We Are Smarter Than We Actually Are!

Setting Predictive Ranges Too Narrow

We have little comprehension of comparative levels of confidence



Requested Confidence Level

Results as calculated per the 10 questions exercise

Capen, 1976

Information Bias (Representativeness)

Having a distorted assessment of information and its significance (in this case, the impact of sample size)

A certain town is served by two hospitals. In the larger hospital, about 45 babies are born each day, and in the smaller hospital, about 15 babies are born each day. Although the overall proportion of boys is about 50% the actual proportion at either hospital may be greater or less than 50% on any given day.

QUESTION:

At the end of one year, which hospital is likely to have the greater number of days on which more than 60% of the babies born were boys? (Check only one answer)

- ➢ The large hospital
- ➢ The small hospital
- ➢ Neither hospital - The number of days will be about the same (within 5% of each other)

Anchoring Bias

- Is the area of the U.S. greater or less than 3 million square miles?
  - ➢What is your estimate of the area of the U.S.?
- Is the area of Canada greater or less than 5 million square miles?
  - ➢What is your estimate of the area of Canada?

Anchoring Bias

- You likely anchored your evaluation on the map which appears to show Canada is bigger than the U.S.
  - However, this map is based on a Mercator projection, which inflates the size of objects as you approach the poles
- The two countries are nearly identical in size
  - The U.S. is 3.7 million square miles in area while Canada is 3.8 million square miles
- The emphasizes the need to understand and state the assumption(s) supporting your estimates
  - Which may be flawed due to an inaccurate anchor(s)

Availability Bias

Tendency to overestimate the likelihood of events that are more memorable

For the following pair, choose the one you think caused more deaths in the United States

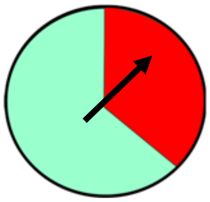
Lung Cancer versus Motor Vehicle Accidents

Russo & Schoemaker, 1989

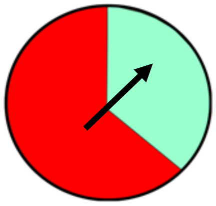
Framing Bias Awareness Exercise

Estimating based on our specific experience or expertise can unreasonably reduce the range of possible outcomes. Seek the input of others!

1. Which would you prefer...
   - A. A 65% chance to win $1,000
   - B. Sure gain of $650



2. Which would you prefer…
   - A. A 65% chance of losing $1,000
   - B. Sure loss of $650



Most people choose 1B and 2A

- The notion of accepting a sure loss is unthinkable for most people
- This can lead them to take an unreasonable risk of a much greater loss in order to avoid a smaller sure loss

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Confirmation Bias

- Confirmation bias is where we search for and interpret data that confirm our beliefs
  - We assign more weight to data that support our hypotheses, and less weight to data that don’t
- Like other biases, it is fed by System 1 thinking which leads to a quick conclusion
  - Which may be wrong if you don’t…
    - Consider other possibilities
    - Gather sufficient data to distinguish among the possibilities
- The following exercise illustrates the problem

Motivational Bias - A Non-Cognitive Bias

- Appears when we are motivated by personal gain over the company's gain, thus is placed upon ourselves by the current situation.
- In companies, often influenced by the stated reward system or observations of what behaviors are rewarded.
- Motivational bias is not considered a cognitive (that is, innate) bias, but it is present in our daily work
- Often manifested with an overestimation of Pg, EUR, or economic assumptions to get a project authorized for drilling

How Do We Overcome Bias?

- Require every estimate to include a level of confidence
- Ask disconfirming questions about ideas and sources
- Expose the hidden sources of future problems (turn unknown unknowns into known unknowns)
- Provide technical assurance and performance lookbacks to help people calibrate
- Participate in a *Mitigating Bias, Blindness, and Illusion in E&P Decision-Making Course*
  - https://www.roseassoc.com/mitigating-bias-blindness-and-illusion-in-ep-decision-making/
  - This chapter provides Awareness exercises whereas the "BBI course" provides Mitigation exercises and strategies
- Use Multiple Working Hypotheses

How We Get To Multiple Working Hypotheses

There is a Progression of Methods…

Ruling Theory

Working Hypothesis

Multiple Working Hypotheses

Chamberlin, 1895,

Ruling Theory

- Single, dogmatic idea or explanation
- Theory often formed prematurely
- New facts are twisted to fit the theory
- Often accompanied by pride of ownership…and personal offense if challenged

Working Hypothesis

- An improvement upon ruling theory
- Used as a vehicle to guide inquiry, not to find facts to fit the theory:
  ‘If this is true, then these other facts should follow…’
- Although a working hypothesis may (after appropriate investigation) legitimately evolve into ruling theory, it is all too easy for it to become embraced as ruling theory without sufficient factual support

Multiple Working Hypotheses

- Pursued simultaneously, none championed
- Helps pinpoint critical elements common to all possible scenarios
- Promotes thoroughness
- Requires discipline and imagination
- Allows for later adjustments

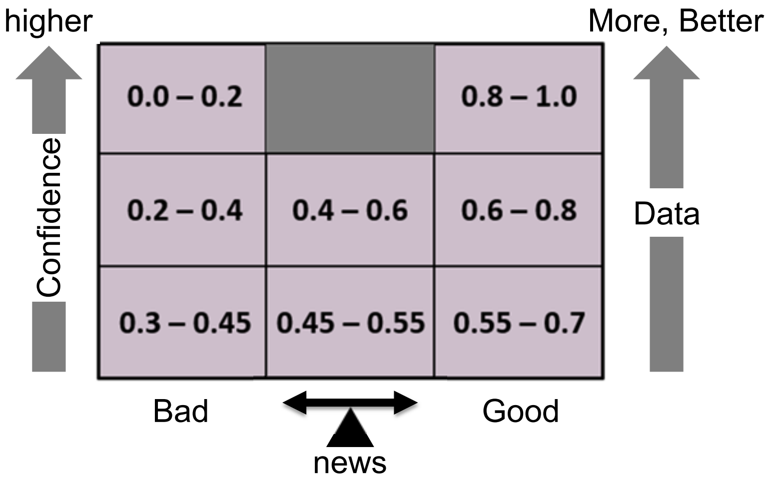
Search for disconfirming evidence

Consider alternative scenarios

Brainstorm with experts

Interact with “naysayers”

Chance Factor Estimation Matrix



0.0 – 0.2		0.8 – 1.0
0.2 – 0.4	0.4 – 0.6	0.6 – 0.8
0.3 – 0.45	0.45 – 0.55	0.55 – 0.7

- Recognize you only have about +/- 5% resolving power on chance factors. A numeric approach works better than words alone
- With little data, chance ≈ 50%
- Absence of evidence ≠ evidence of absence

- Remember to check the trend specific **base rate of success** for each chance factor and ask if your number is much different than the base rate, why?

Why Collect More Data Prior to an Investment?

Comments often heard in our consulting work with clients:

- We don't have time to analyze the data we already have
- By the time we acquire it and start to use it, it will be too late to impact our decision
- The results are likely to be too ambiguous to be useful
- It's too risky to acquire (e.g., the wellbore remains open for a longer period, etc.)

A decision tree and some critical thinking can help determine the value of this additional information.

Let's look at an example using 3D seismic data…

Completion Intervention Decision Tree

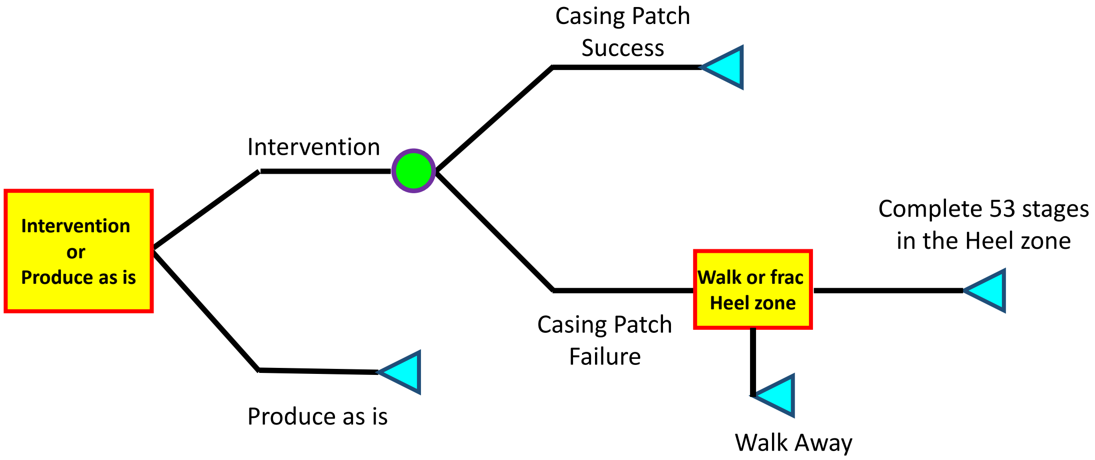
You experience a casing failure after 20 stages are completed of a planned 73-stage completion. Drill, Case and Equip costs are treated as sunk costs in all scenarios. Completions advises that your options are:

1. Tie-in & produce the well as is at an incremental capital cost of $1 MM for Tie-in plus completion cost of $5 MM (for 53 stages from the heel to the burst casing). Your expected value from the tie-in decision is equal to 53 x $250,000 - $1 MM -$5MM, which equals $7,250,000.
2. Re-enter the well, patch the casing using emerging technology, fracture stimulate 53 additional stages, Tie-in the well for a total incremental capital cost of $9 MM. There is risk associated with this re-entry. If all 73 stages are successful, you realize a success case value of 73 new fracs x $250,000. If the Casing patch fails, you have two options:
   - A) Recover what production you can, assuming 53 stages in the Heel zone and on average a total incremental capital of $9 MM which includes the tie-in and the cost of the failed casing patch.
   - B) Walk away having spent $2MM on the failed casing patch operation.

Calculate the percentage confidence in the casing patch holding, during fracture operations, to justify proceeding with a casing patch repair to produce the 20 additional stages of fracture stimulation.

35

Determine The Probability of Each Outcome Branch



36

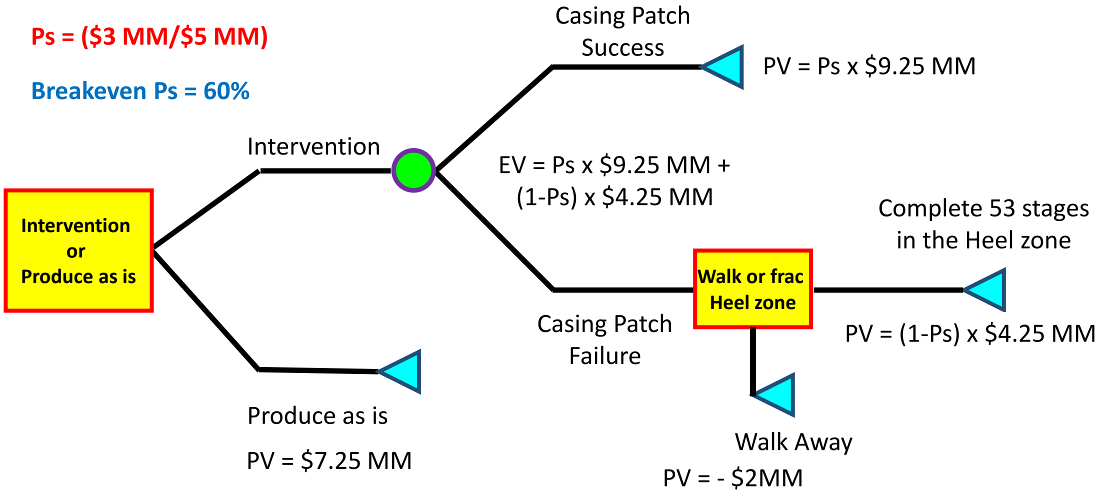
Determine The Probability of Each Outcome Branch

Ps x $9.25 MM + (1-Ps) x $4.25 MM = $7.25 MM

Ps x ($9.25 MM - $4.25 MM) = $7.25 MM -$4.25 MM

Ps = ($3 MM/$5 MM)

Breakeven Ps = 60%



Why do we Pilot?

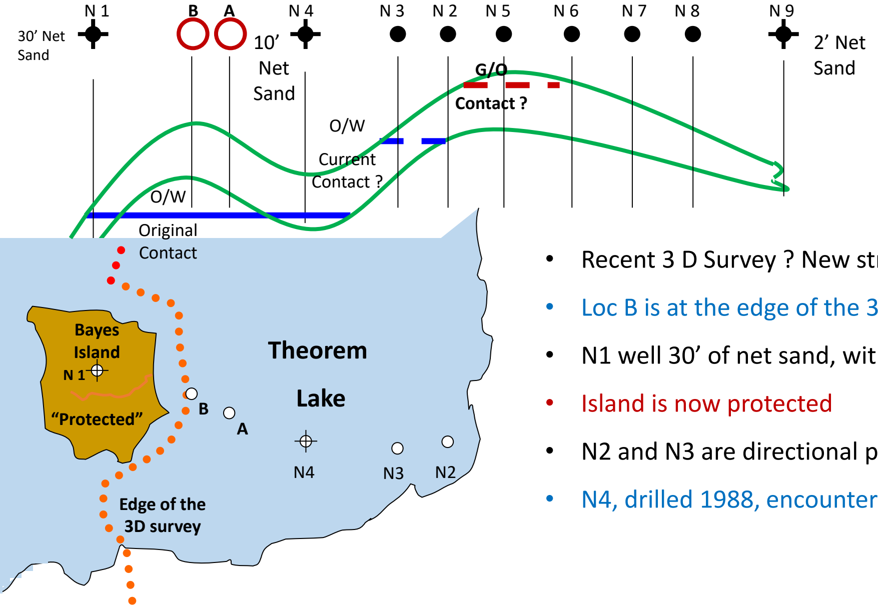
To prove commerciality? That requires a lot of trials. A better answer is to mitigate the downside and increase our confidence of a commercially successful venture.

To evaluate the economic impact of a Pilot we need to build a Decision Tree and build a dependency between a failed and a successful pilot.

As previously discussed when assessing new technology with no track record we can reverse engineer the confidence we need in a Pilot being successful.

Lets walk through an example where we know with confidence what the Pilot, a new well in this case, will do to mitigate the risk (chance of failure) in a follow-up well.

Bayes Island Exercise: Contingent Well Location



- Recent 3 D Survey ? New structural high
- Loc B is at the edge of the 3 D survey
- N1 well 30' of net sand, with 4' net oil pay
- Island is now protected
- N2 and N3 are directional producers
- N4, drilled 1988, encountered 2' of oil pay

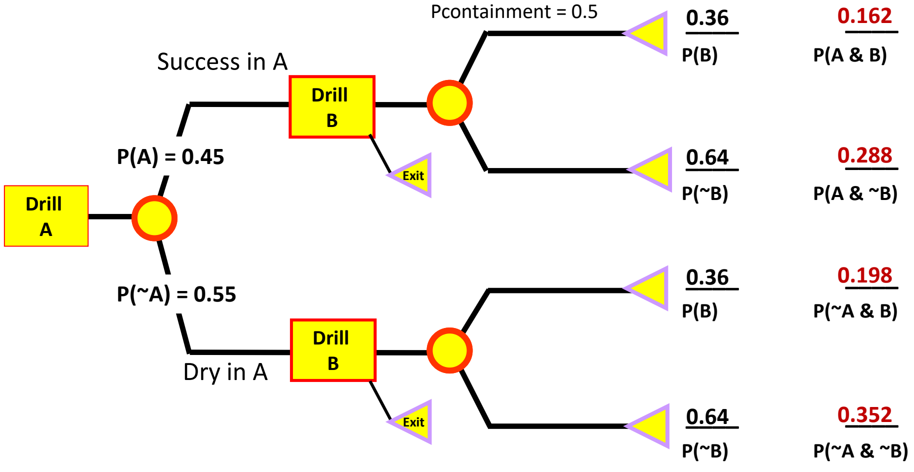
Bayes Island Exercise: Contingent Well Location

Decision Tree For Fully Independent Wells

Well A ; P(A) = 0.45
Pres = 0.9
Pcontainment = 0.5

Well B, P(B) = 0.36
Pres = 0.9
Pclosure = 0.8
Pcontainment = 0.5

CHANCE



Bayes Island Exercise: Contingent Well Location

Decision Tree For Fully Independent Wells

Given: PV(A) = $4.5 MM, PV(~A) = $(1.5) MM, PV(B) = $4.2 MM, PV(~B) = $(2) MM

EV**(B&A)** = $8.7 MM * 0.162 = 1.409

$4.5 MM from A and $4.2 MM from B

EV**(A Only)** = $2.5 MM * 0.288 = 0.72

$4.5 MM from A and $(2) MM from B

EV**(B Only)** = $2.7 MM * 0.198 = 0.535

$(1.5) MM from A and $4.2 MM from B

EV**(Both Dry)** = $(3.5) MM * 0.352 = - 1.232

$(1.5) MM from A and $(2) MM from B

EV per DHC = 1.43 / 3.5 = 0.41

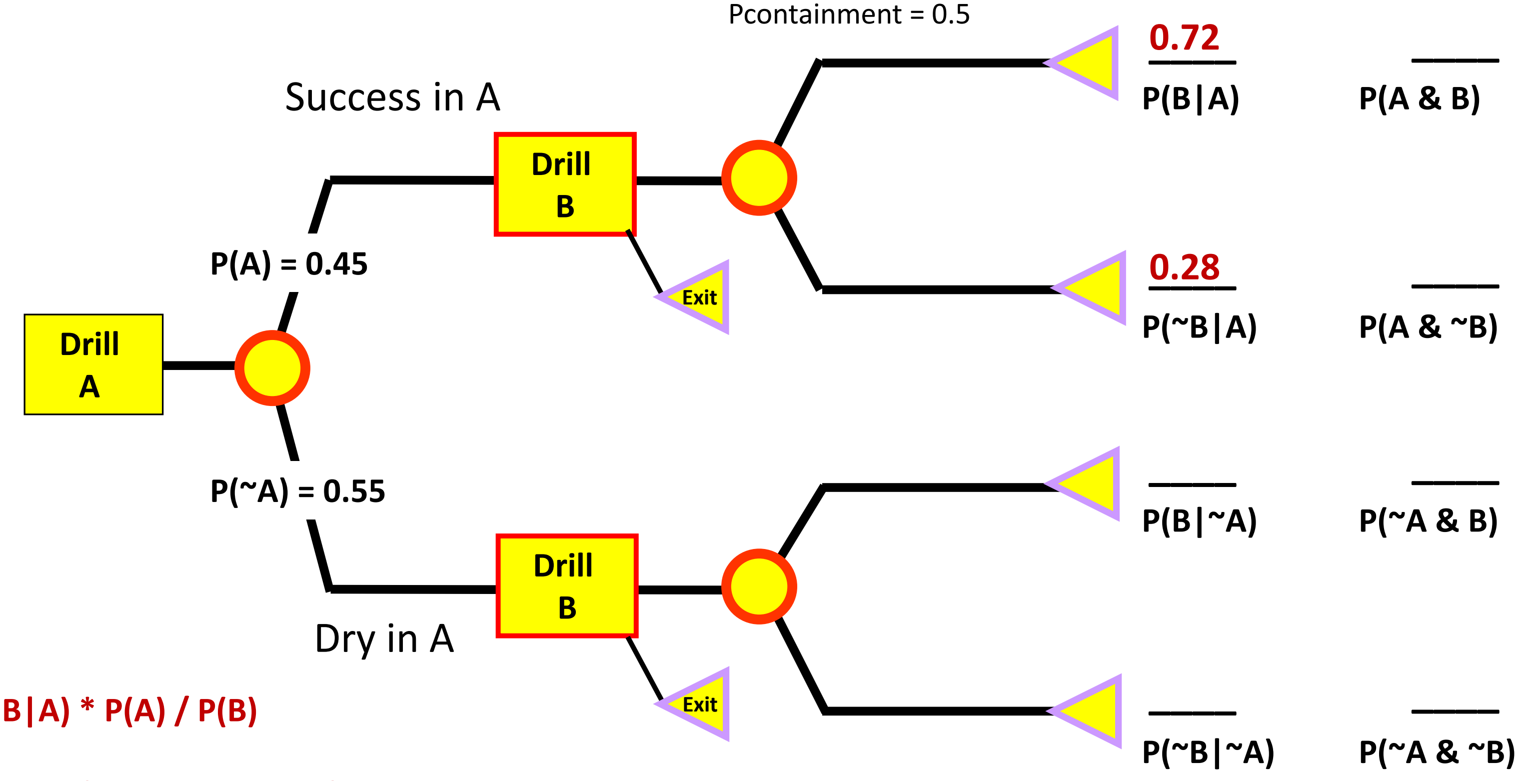
TOTAL EV = $ 1.43 MM

Bayes Island Exercise: Contingent Well Location

STEPS:

- Complete the Independent decision tree and EV
- Complete the Dependent decision tree and EV
- Develop a recommendation on the path forward – use a metric of EV/PV_DHC
- Does this impact this project’s ranking within your company’s portfolio?

Decision Tree For Partly Dependent Wells



Well A ; P(A) = 0.45
Pres = 0.9
Pcontainment = 0.5

Well B, P(B) = 0.36
Pres = 0.9
Pclosure = 0.8
Pcontainment = 0.5

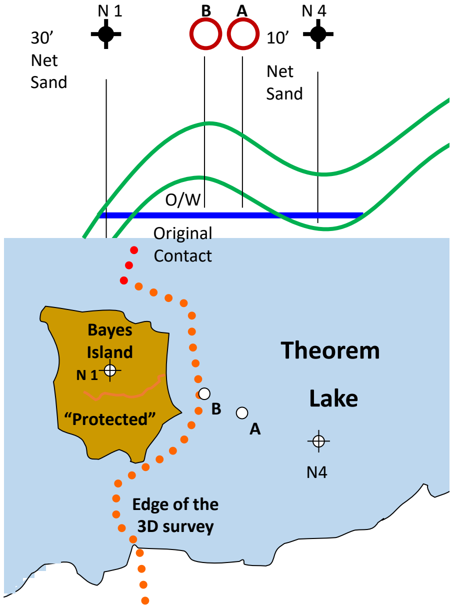
CHANCE

0.72 **P(B|A)**	_____ **P(A & B)**
0.28 **P(~B|A)**	_____ **P(A & ~B)**
_____ **P(B|~A)**	_____ **P(~A & B)**
_____ **P(~B|~A)**	_____ **P(~A & ~B)**

P(A|B) = P(B|A) * P(A) / P(B)

P(B) = P(A) * P(B|A) + P(~A) * P(B|~A)

What is The Impact on B of a Success at A?



Impact of Success in A on B

- Given 'A' is a success then the Reservoir has not been swept…..Pcontainment at 'B' 1.0
- The Structure is present at 'A', but the issue at 'B' was proximity to the edge of the 3D seismic
  - Pclosure at 'B' remains = 0.8
- A Tight or Channelized system remains an issue
  - Preservoir at 'B' remains = 0.9
- P(B|A) = 0.8 * 0.9 = 0.72
  The probability of success at 'B', given a success at 'A', has increased to 72%.
  P(~B|A) = 1 – 0.72 = 0.28

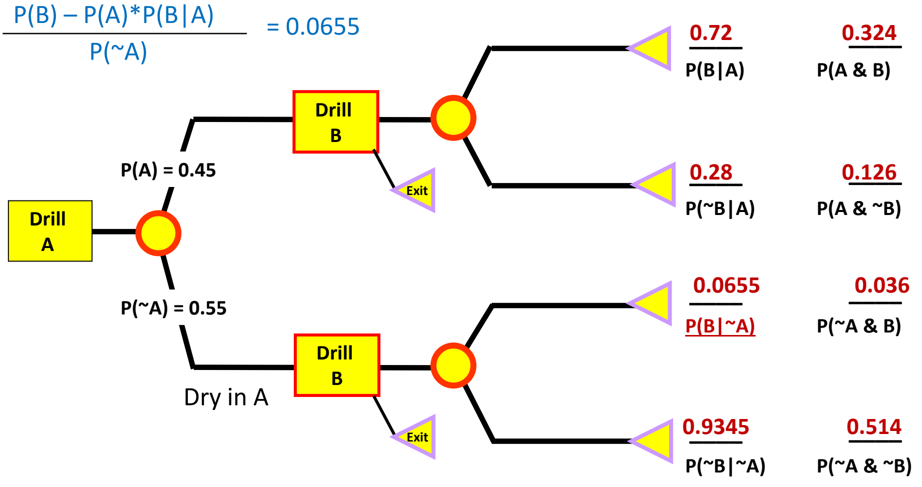
Decision Tree For Partly Dependent Wells - Solution Using Bayes

P(B) = P(A) * P(B|A) + P(~A) * P(B|~A)

$$P(B|\sim A) = \frac{P(B) - P(A)*P(B|A)}{P(\sim A)} = 0.0655$$

Well B, P(B) = 0.36

CHANCE



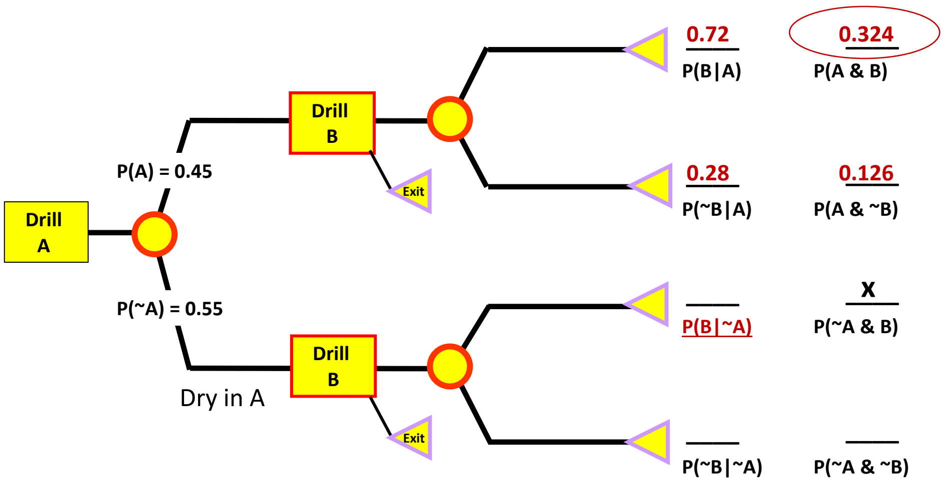
Decision Tree For Partly Dependent Wells – Tree Balancing

So, 0.324 + x = 0.36

x = 0.036

Well B, P(B) = 0.36

CHANCE



Drill A

P(A) = 0.45

P(~A) = 0.55

Dry in A

Drill B

Exit

0.72 P(B|A) — **0.324** P(A & B)

0.28 P(~B|A) — **0.126** P(A & ~B)

P(B|~A) — **X** P(~A & B)

P(~B|~A) — P(~A & ~B)

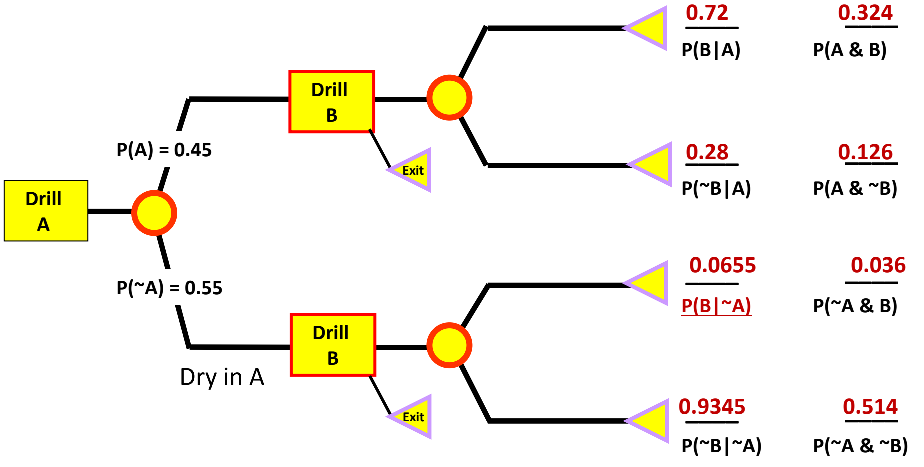
Decision Tree For Partly Dependent Wells – Tree Balancing

So, 0.324 + x = 0.36

x = 0.036

Well B, P(B) = 0.36

CHANCE



Drill A

P(A) = 0.45

P(~A) = 0.55

Dry in A

Drill B

Exit

0.72 P(B|A) — **0.324** P(A & B)

0.28 P(~B|A) — **0.126** P(A & ~B)

0.0655 P(B|~A) — **0.036** P(~A & B)

0.9345 P(~B|~A) — **0.514** P(~A & ~B)

Bayes Island Exercise: Contingent Well Location

Decision Tree For Partly Dependent Wells

Given: PV(A) = $4.5 MM, PV(~A) = $(1.5) MM, PV(B) = $4.2 MM, PV(~B) = $(2) MM

EV**(B&A)** = $8.7 MM * 0.324 = 2.819

$4.5 MM from A and $4.2 MM from B

EV**(A Only)** = $2.5 MM * 0.126 = 0.315

$4.5 MM from A and $(2) MM from B

EV**(B Only)** = $2.7 MM * 0.036 = 0.097

$(1.5) MM from A and $4.2 MM from B

EV**(Both Dry)** = $(3.5) MM * 0.514 = - 1.8

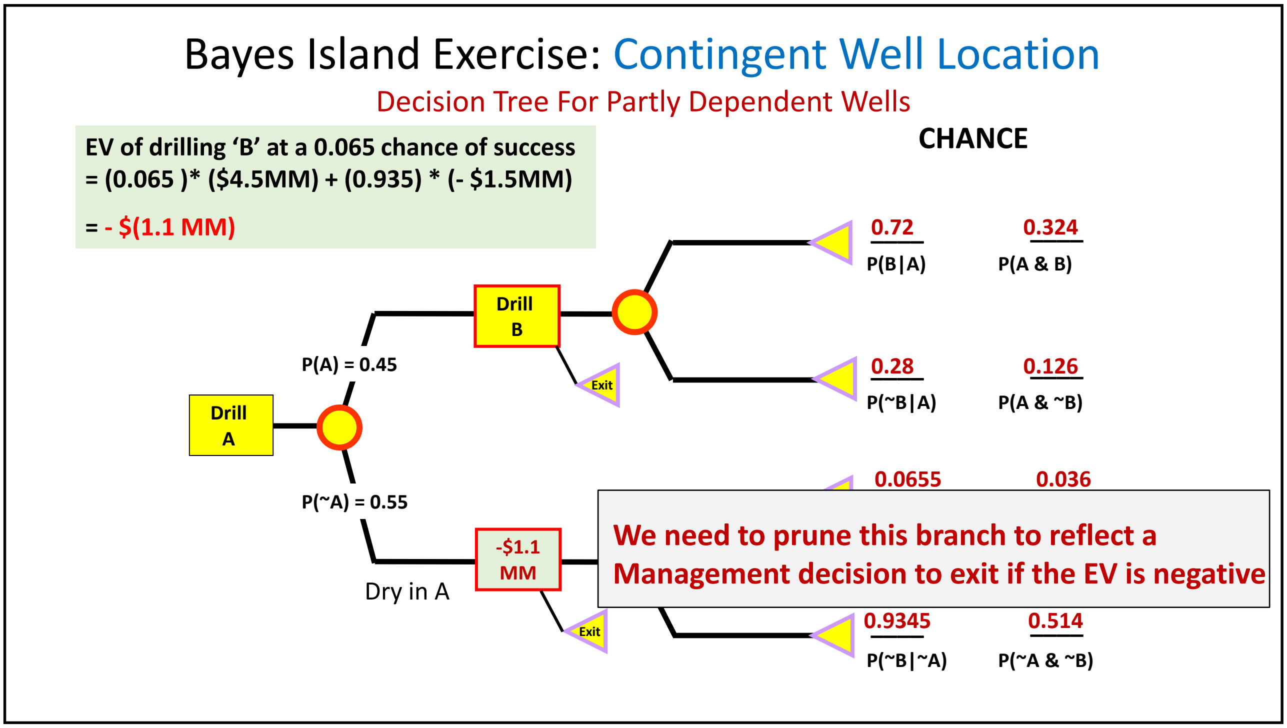
$(1.5) MM from A and $(2) MM from B

EV per DHC = 1.43 / 3.5 = 0.41

TOTAL EV = $ 1.43 MM

BUT WHY WOULD WE DRILL B, IF A WERE DRY?

Only if we thought it could add value, so let's determine that



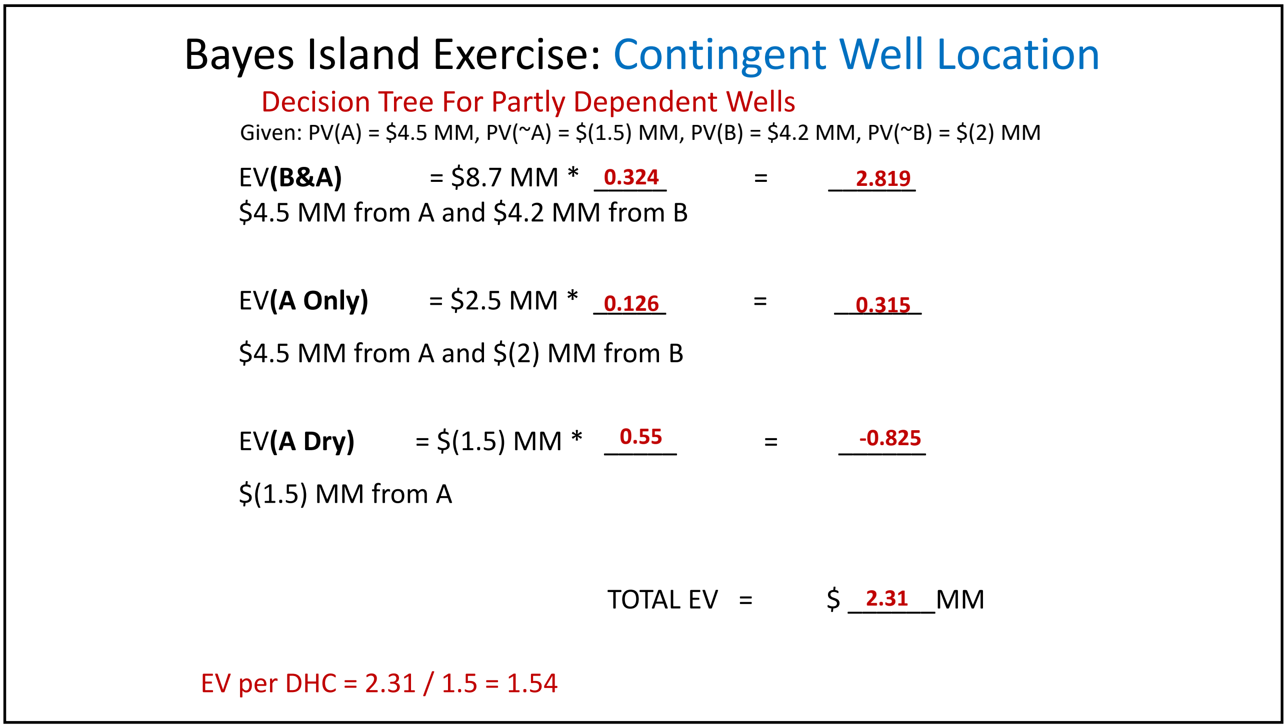
Bayes Island Exercise: Contingent Well Location

Decision Tree For Partly Dependent Wells

EV of drilling 'B' at a 0.065 chance of success
= (0.065)* ($4.5MM) + (0.935) * (- $1.5MM)

= - $(1.1 MM)

We need to prune this branch to reflect a Management decision to exit if the EV is negative



Bayes Island Exercise: Contingent Well Location

Decision Tree For Partly Dependent Wells

Given: PV(A) = $4.5 MM, PV(~A) = $(1.5) MM, PV(B) = $4.2 MM, PV(~B) = $(2) MM

EV**(B&A)** = $8.7 MM * 0.324 = 2.819
$4.5 MM from A and $4.2 MM from B

EV**(A Only)** = $2.5 MM * 0.126 = 0.315

$4.5 MM from A and $(2) MM from B

EV**(A Dry)** = $(1.5) MM * 0.55 = -0.825

$(1.5) MM from A

TOTAL EV = $ 2.31 MM

EV per DHC = 2.31 / 1.5 = 1.54

Bayes Island Exercise: Contingent Well Location

OUTCOMES	DEPENDENT	INDEPENDENT
A	12.6%	28.8%
B	3.6%	19.8%
A & B	32.4%	16.2%
DRY	51.4%	35.2%
EV	$2.31 MM	$1.43 MM
EV/DHC*	2.31/1.5 1.54	1.43/3.5 0.41

***Dry Hole Cost**

Decision Making Under Uncertainty

A major issue in our industry is the lack of a disciplined process in evaluating new technologies, new plays etc. where we are exposed to the greatest uncertainty.

Before the decision is made to test a new concept/technology or play/horizon, we should address the following:

- How many wells should be in our testing?
- What confidence level in the data do we require before proceeding to the next step?
- How will the decision be made? For example, if we are seeking improved production, what production rate increase do we need to validate before proceeding to the next stage of development?

Aggregation Principles

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 P10 (high) to the P90 (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.

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Aggregation Principles

0 = 10

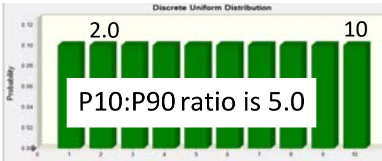
- What is our confidence that we will realize the mean outcome of 5.5, after 1 die roll, 5 dice rolls and 10 dice rolls?
- What if we developed a new technology that would improve "Die" performance by 20%.
- How many dice rolls would we need to confirm the effectiveness of the new technology?

Aggregation Principles

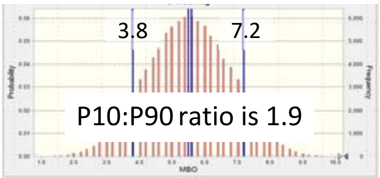
- What would you conclude if on your first trial of the new technology you rolled a 5?
- Should you feel better or worse about the new technology?
- Could we conclude that the technology failed?
- Let's review a pragmatic statistical approach to provide quick solutions.

Aggregation Principles

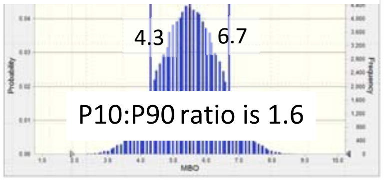
Single Die Outcome



Five Dice Averaged outcome

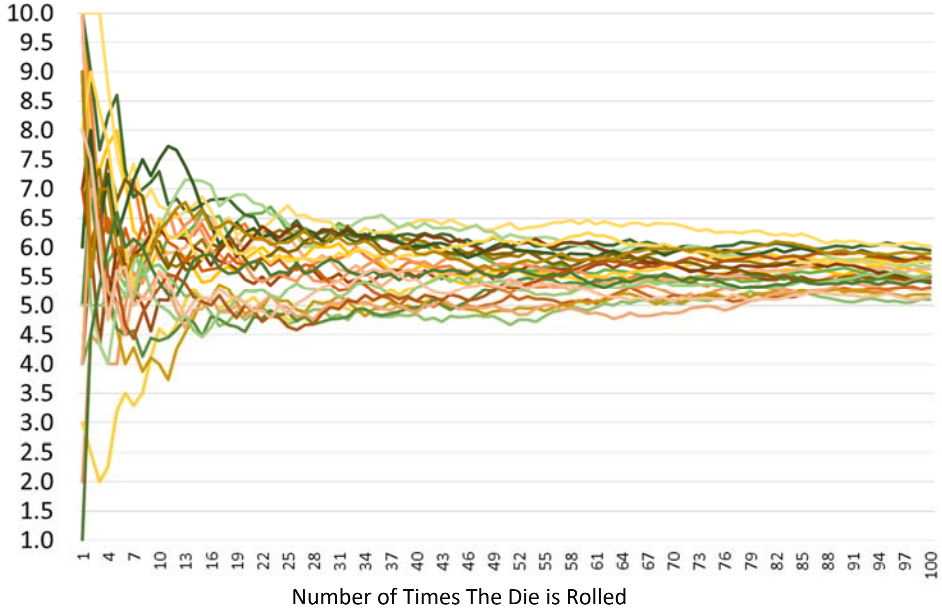


Ten Dice Averaged outcome

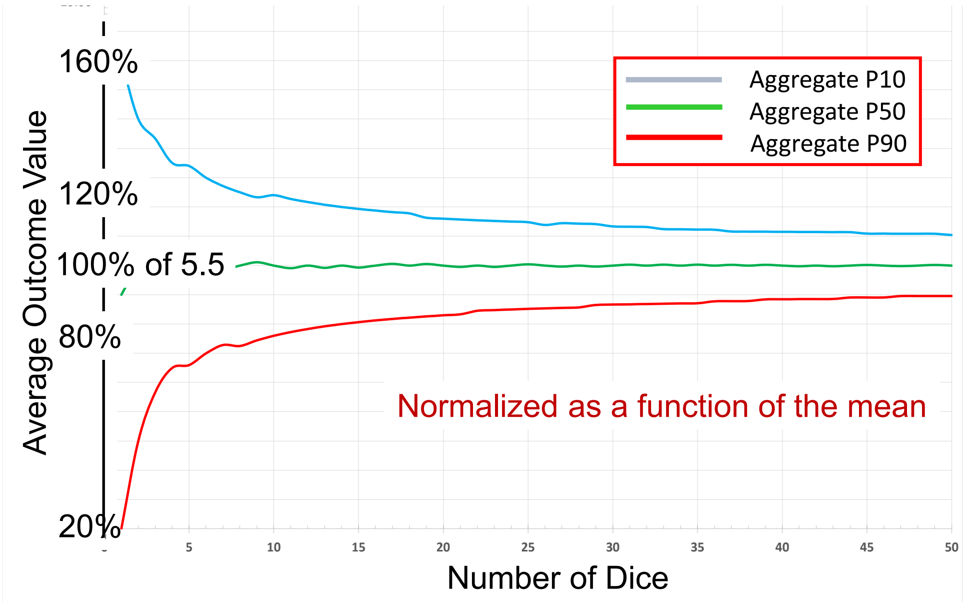


- We are reasonably certain to roll a 2 or more 90% of the time.
- Roll five dice. Divide sum by 5, repeat. We will average 2 or more 99.86% of the time. The P90 of the aggregated outcome is 3.8
- Roll Ten dice. Divide sum by 10, repeat. The Probability of averaging a 2 or more is 99.999%. This is not a P90!

With Increasing Dice Rolls, Variance Decreases



Variance Decreases With Increasing Dice Rolls

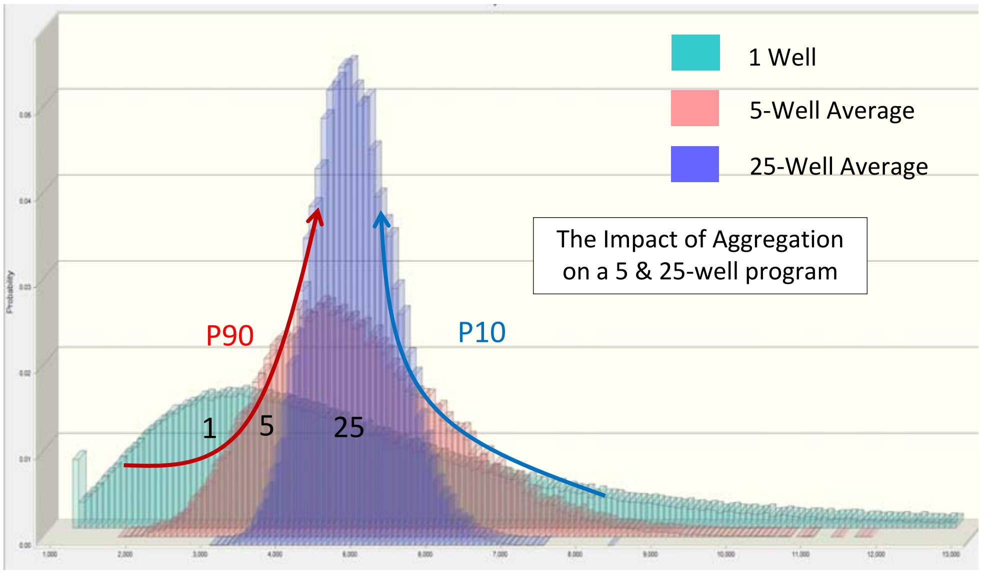


Normalized as a function of the mean

Aggregation Applied to Valuation 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 using a lognormal distribution for estimated ultimate recovery (EUR), on a per well basis, to better understand this.

Aggregating EUR Distributions; P10:P90 = 4



The Impact of Aggregation on a 5 & 25-well program

Range of Average EUR – MMscf

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Aggregation Derivative Applications

Aggregation Curves (Trumpet Plots) – Used to illustrate reduction in uncertainty (variance) as a function of increasing well count
- Based on available Analogs
- Function of Analog uncertainty (P10:P90), 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
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- Helps define Pre-development stage gate thresholds based on analog data
- Confidence is a function of uncertainty (P10:P90), your target (objective) and the number of wells to be drilled (sample size)

Sequential Aggregation Plots – Used to assess validity of forecasts
- Tracks actuals against the forecasted P10 and P90 of the aggregation curves
- Provides early feedback about the validity of the forecasted parameter

Exercise A: Application of Aggregation Curves

Assignment:

Your team is developing the next year of an ongoing multi-year program. The planning group has requested Probabilistic ranges of the avg peak oil rate for each quarter, in which **25 wells per quarter** will be simultaneously brought on-line.

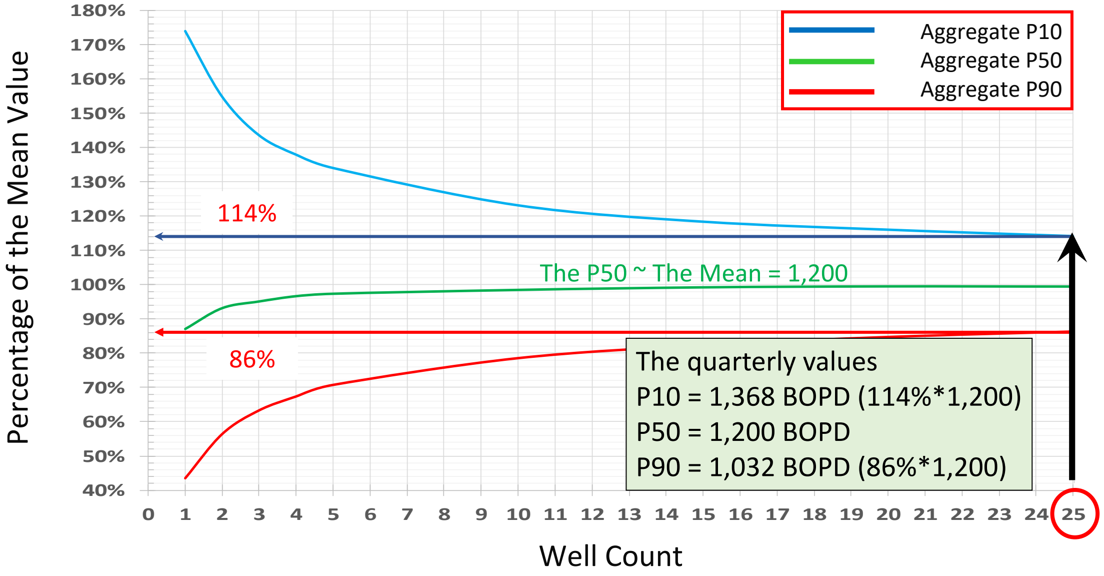
You are executing an identical drill and complete program in a geologically analogous area. The program to date (427 wells) has averaged a Peak oil rate of 1,200 BOPD with a P10:P90 of 4.

You are provided with Log Cumulative Probability paper (is this needed?) and Aggregation curves based on a P10:P90 of 4.

What values will you provide to the Planning group?

Exercise A: Application of Aggregation Curves

Determining uncertainty in the mean based on sample size, P10:P90 of 4



The quarterly values
P10 = 1,368 BOPD (114%*1,200)
P50 = 1,200 BOPD
P90 = 1,032 BOPD (86%*1,200)

Aggregation Derivative Applications

Aggregation Curves (Trumpet Plots) – Used to illustrate reduction in uncertainty (variance) as a function of increasing well count

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Sequential Aggregation Plots – Used to assess validity of forecasts

- Tracks actuals against the forecasted P10 and P90 of the aggregation curves
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Aggregation Principles

- The reality is that budgets and competitive pressures force us to make 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.

Modeling Uncertainty Around the Mean

Company Jackpot has drilled 5 wells in a new area that has an arithmetic average peak daily oil rate of 700 BOPD.

Your reverse-engineered peak daily oil rate to deliver a breakeven ROR is 475 BOPD.

Your executives are extremely excited because at current well costs this is a very high ROR play. They have initiated discussions about dropping other plays and focusing on this “de-risked” oil play to maximize corporate returns.

What questions should you be prepared to answer before your executives make this strategic decision?

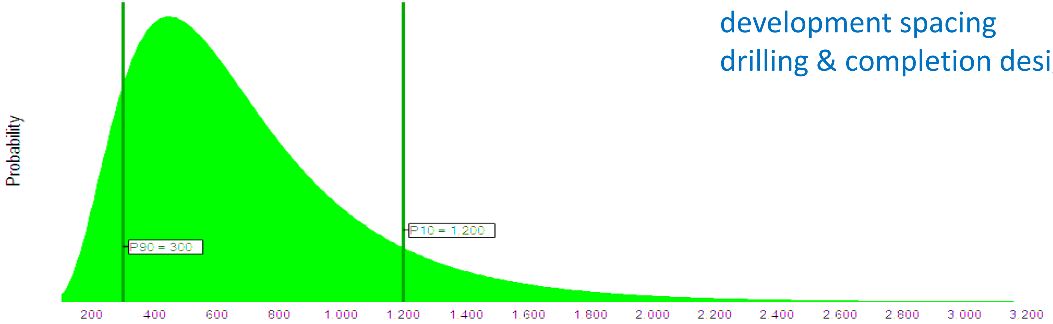
Modeling Uncertainty Around the Mean

We know with confidence that the only parameter that the Executives should base their decision upon is the mean of the distribution. Knowledge of the per well variability should be viewed as “noise”.

The right question is, “What value will the play converge on given the sample of 5 wells?” To determine this, we will need to assume the per well variance.

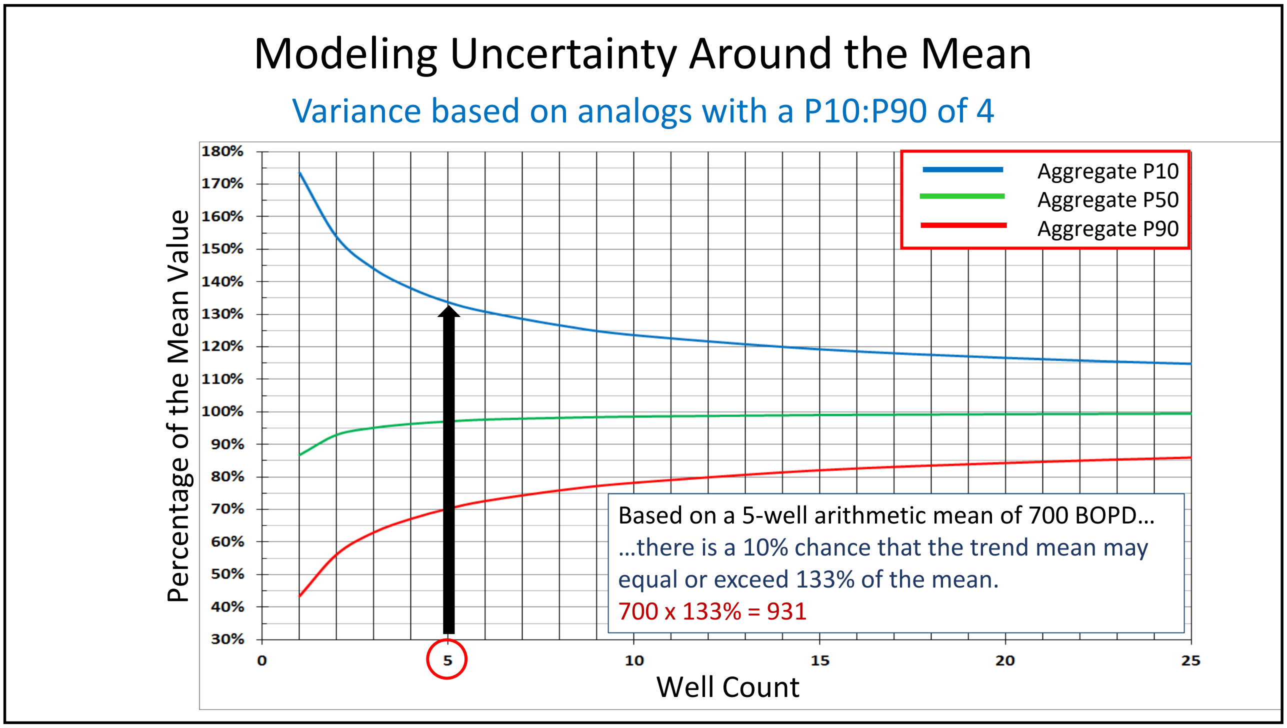
Our analogs support the use of a **P10:P90 of 4**, with similar:

geology and fluid properties
development spacing
drilling & completion design



Modeling Uncertainty Around the Mean

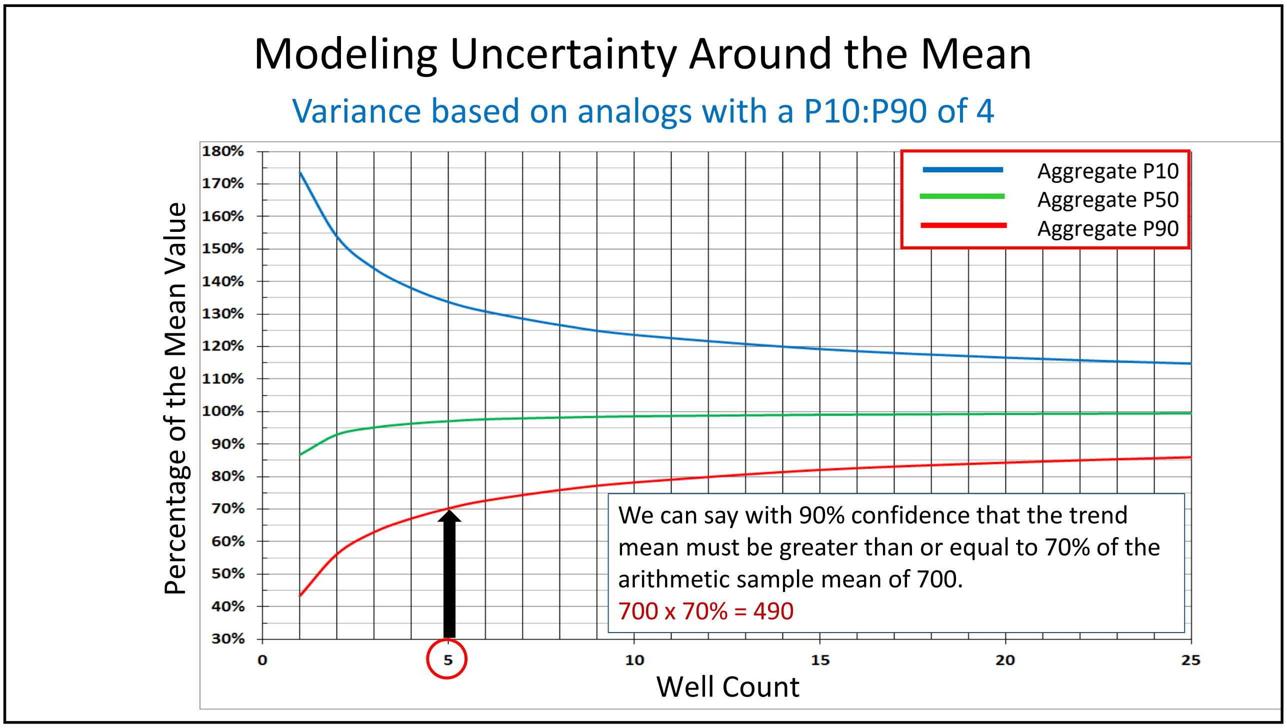
- Aggregation curves are developed on the basis of a known mean and a known variance.
- For a given Project well count we can determine the arithmetic P90-P50-P10 for the average well within the given well count.
- When we are dealing with limited data sets, we know the arithmetic average of the given well count, but we do not know what the mean or variance of the project segment population, when fully sampled, are.
- We will estimate the variance based on analogs with similar averaged lithology and drilling & completion techniques.
- To estimate the mean of the new area to be developed (or of a new technology being applied) we will need to reverse engineer the Aggregation curves to determine the range of the trend mean given the arithmetic mean of the sample.



Modeling Uncertainty Around the Mean

Variance based on analogs with a P10:P90 of 4

Based on a 5-well arithmetic mean of 700 BOPD…
…there is a 10% chance that the trend mean may equal or exceed 133% of the mean.
700 x 133% = 931

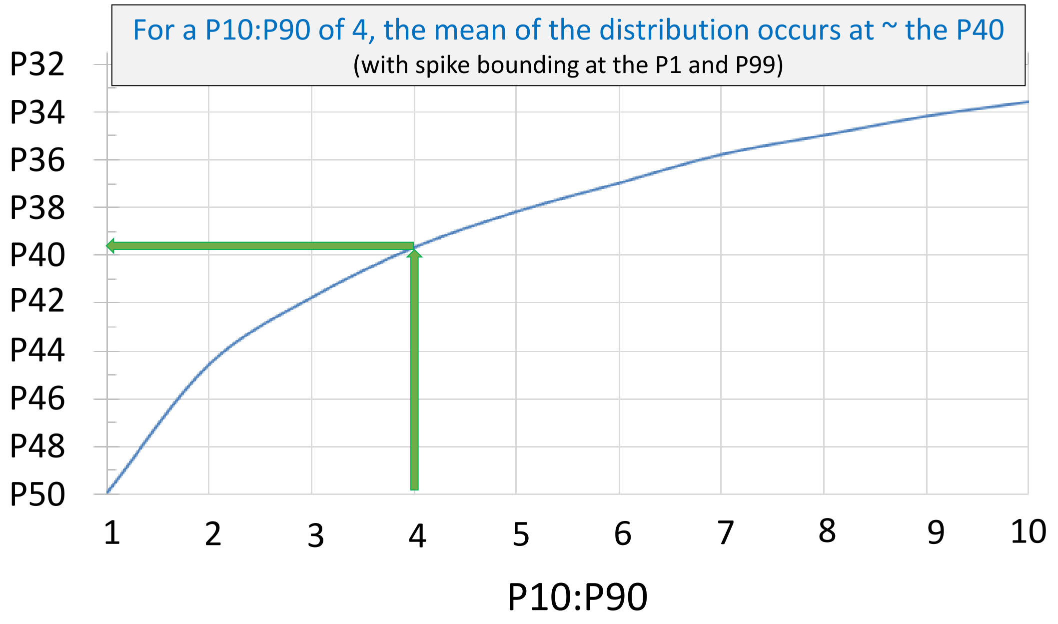


Modeling Uncertainty Around the Mean

Variance based on analogs with a P10:P90 of 4

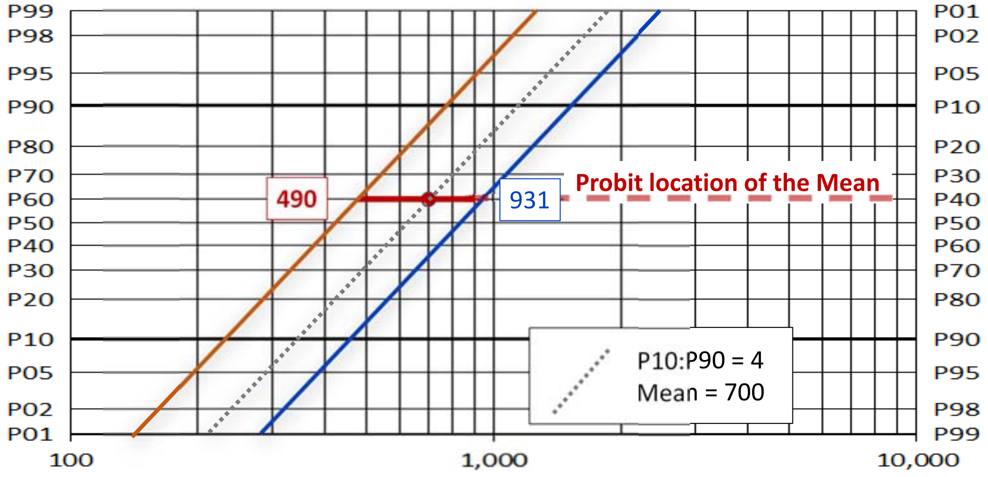
We can say with 90% confidence that the trend mean must be greater than or equal to 70% of the arithmetic sample mean of 700.
700 x 70% = 490

Probit Location of the Mean Outcome Versus P10:P90


For a P10:P90 of 4, the mean of the distribution occurs at ~ the P40
(with spike bounding at the P1 and P99)

Modeling Uncertainty Around the Mean

A log-probit view:
Using a P10:P90 of 4, the mean value will be found at the Probit plot's P40.
We plot parallel P10:P90 of 4 lines through the P40 at the derived P90 and P10 of the uncertain mean. This graphically illustrates our uncertainty around the trend mean outcome.



Application of Aggregation Curves

- When developing a new geologic subset, we can determine the uncertainty in the production performance of the average well based on:
  - The variance of the valid analogy
  - The arithmetic mean of the wells in the new area
  - The well count used to calculate the arithmetic mean
- This technique requires us to assume lognormality and the variance from analogous reservoirs, appropriately normalized.

Application of Aggregation Curves

Our industry has done a poor job of acknowledging the uncertainty that exists in limited data sets.

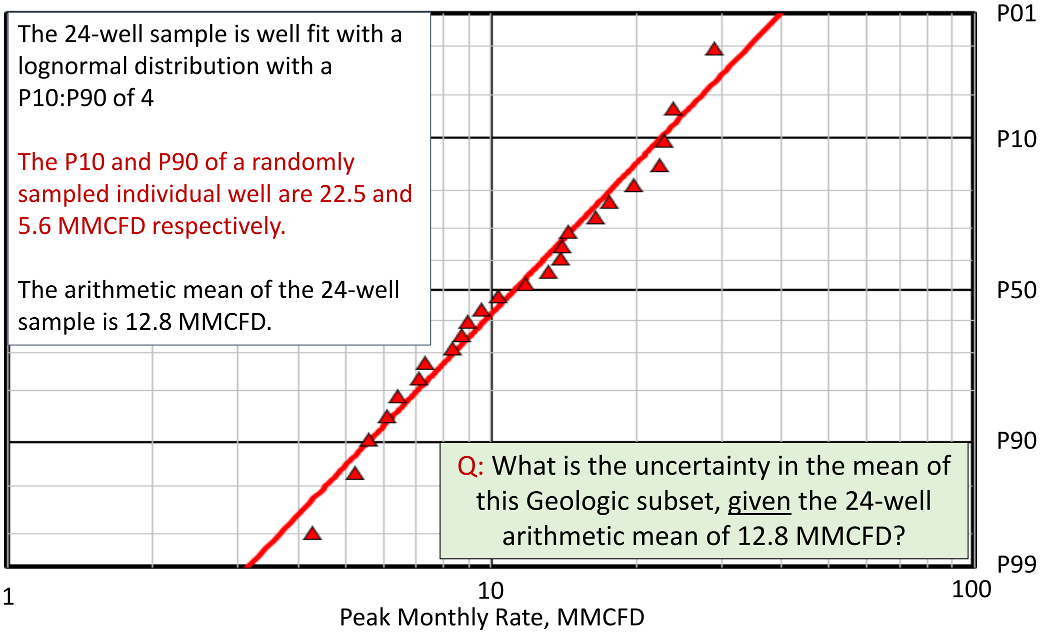
Let’s look at an example based on the Falher “H’ Pool in Alberta, Canada to illustrate how limited data sets can be evaluated from a “Business Decision” perspective.

Exercise B: Application of Aggregation Curves

Assignment:

- You are evaluating the 10-well drilling program for next year. What is your 80% confidence range of the 10-well program per well average 3-month peak rate outcome? We will approach this solution in two steps:
  1. Determine the range of the Analog population mean based on the initial 24-well sample size.
  2. Determine your 80% confidence range of the per well average 3-month peak rate outcome for the 10-well program based on the range of the population mean determined in step 1.
- You are provided with a log cum probability plot of the first 24 wells, and a Trumpet chart for a P10:P90 of 4.

Exercise B: Application of Aggregation Curves

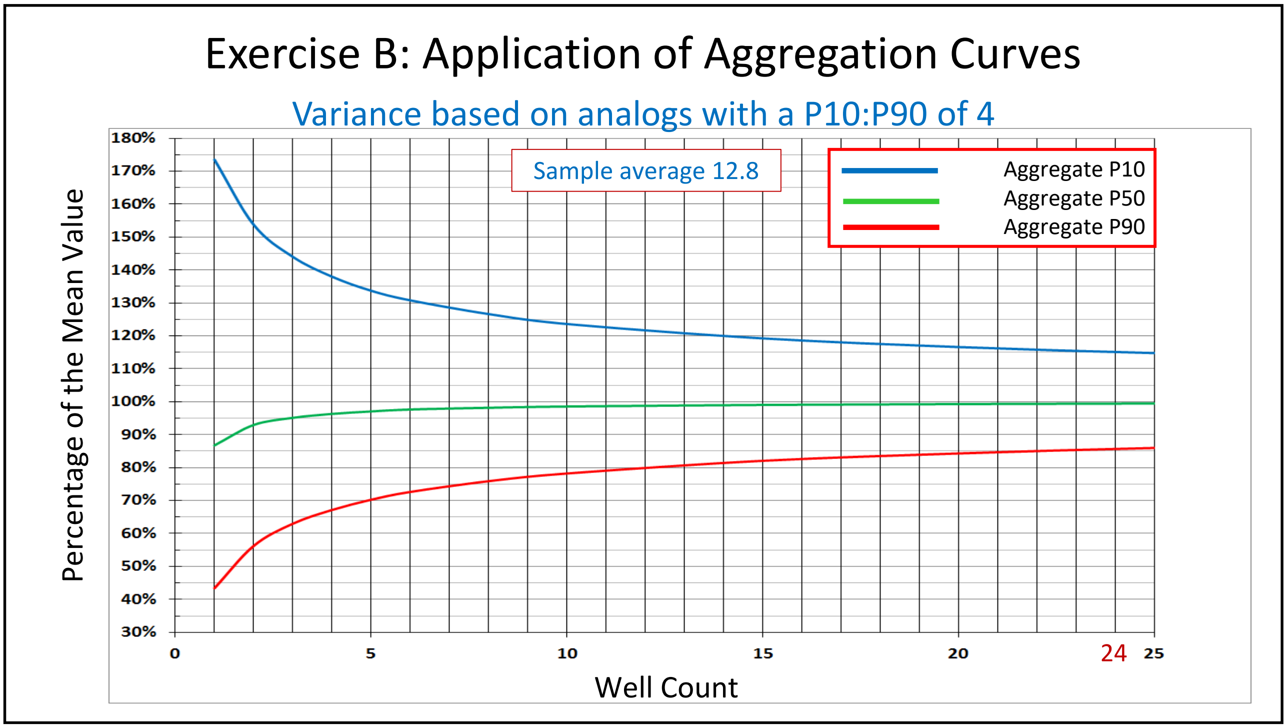


The 24-well sample is well fit with a lognormal distribution with a P10:P90 of 4

The P10 and P90 of a randomly sampled individual well are 22.5 and 5.6 MMCFD respectively.

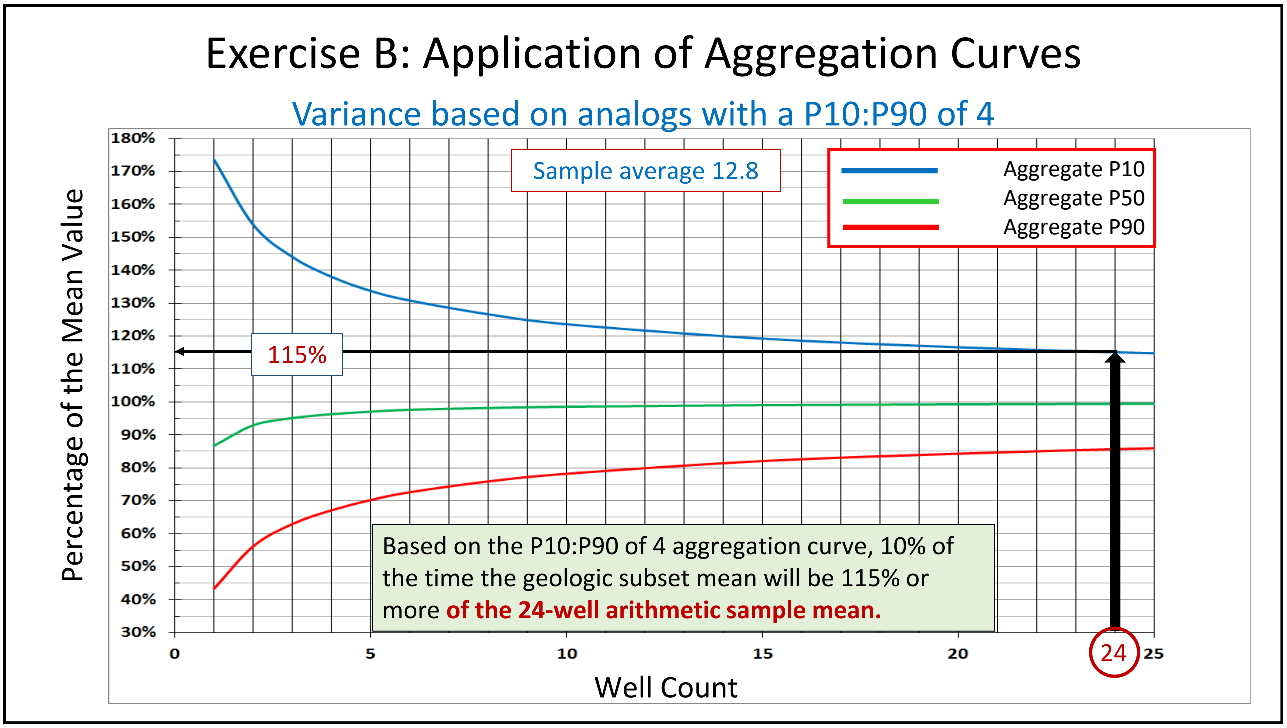
The arithmetic mean of the 24-well sample is 12.8 MMCFD.

Q: What is the uncertainty in the mean of this Geologic subset, given the 24-well arithmetic mean of 12.8 MMCFD?



Exercise B: Application of Aggregation Curves

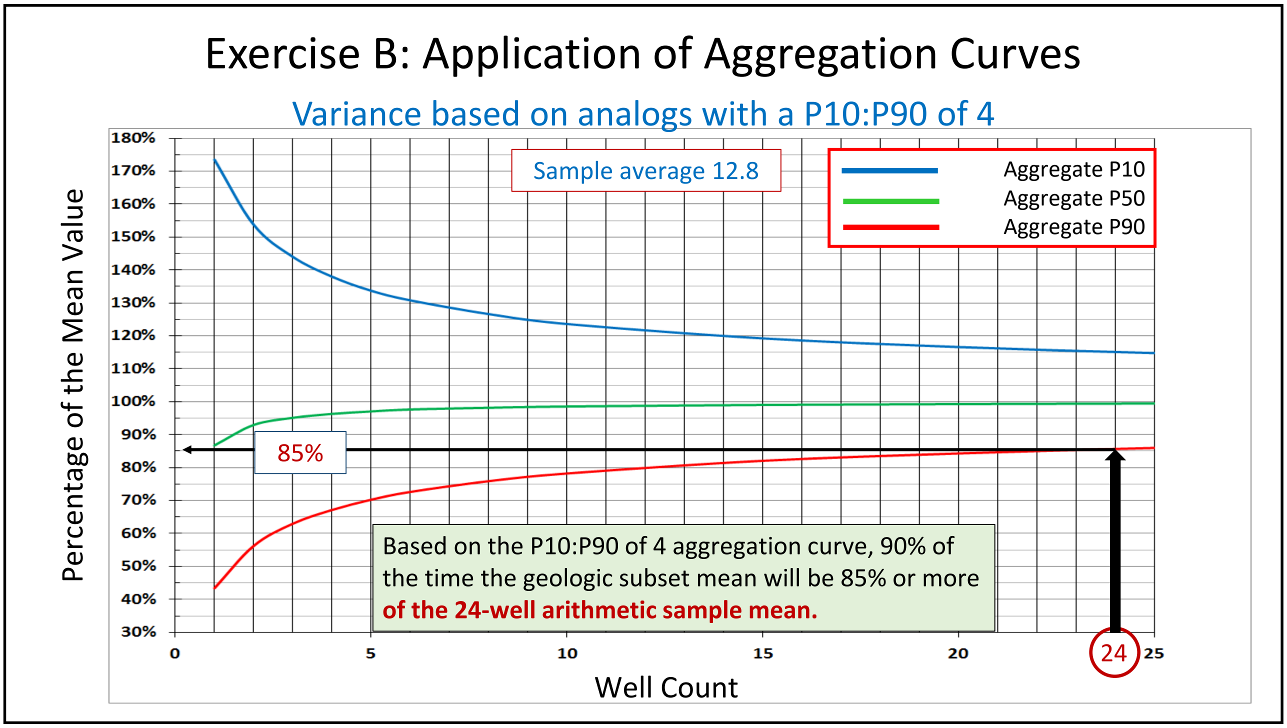
Variance based on analogs with a P10:P90 of 4



Exercise B: Application of Aggregation Curves

Variance based on analogs with a P10:P90 of 4

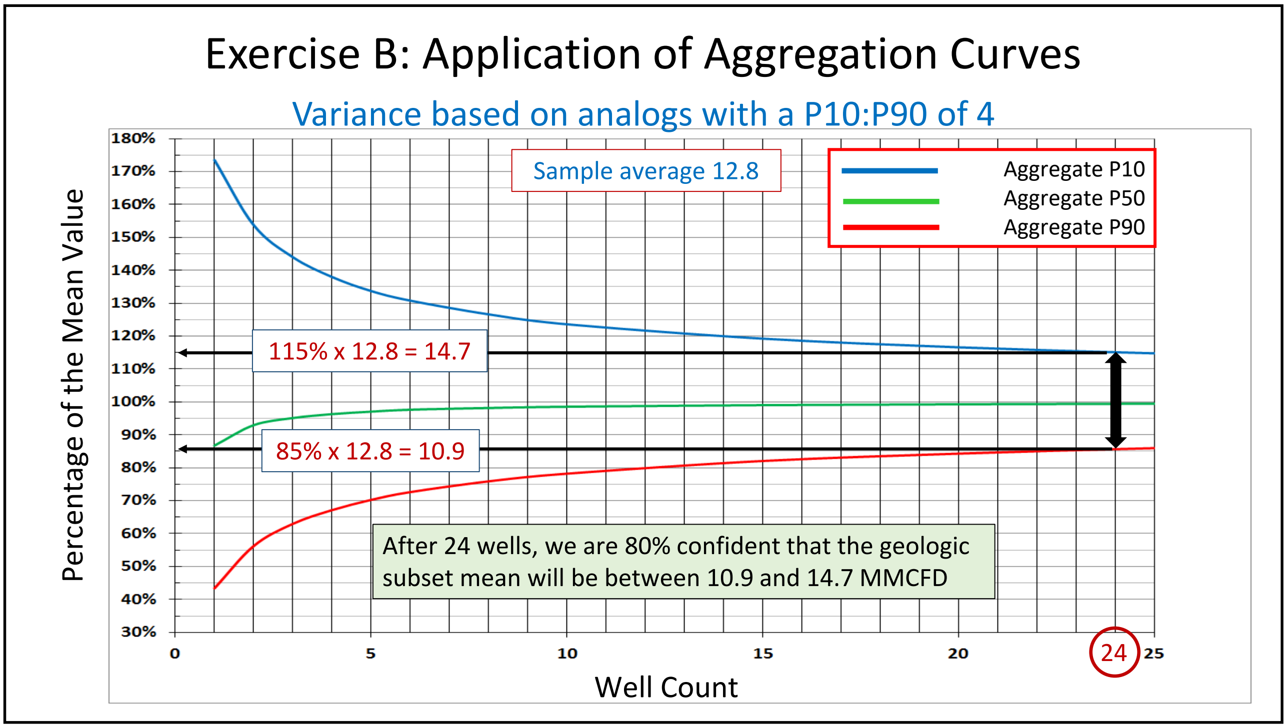
Based on the P10:P90 of 4 aggregation curve, 10% of the time the geologic subset mean will be 115% or more **of the 24-well arithmetic sample mean.**



Exercise B: Application of Aggregation Curves

Variance based on analogs with a P10:P90 of 4

Based on the P10:P90 of 4 aggregation curve, 90% of the time the geologic subset mean will be 85% or more **of the 24-well arithmetic sample mean.**



Exercise B: Application of Aggregation Curves

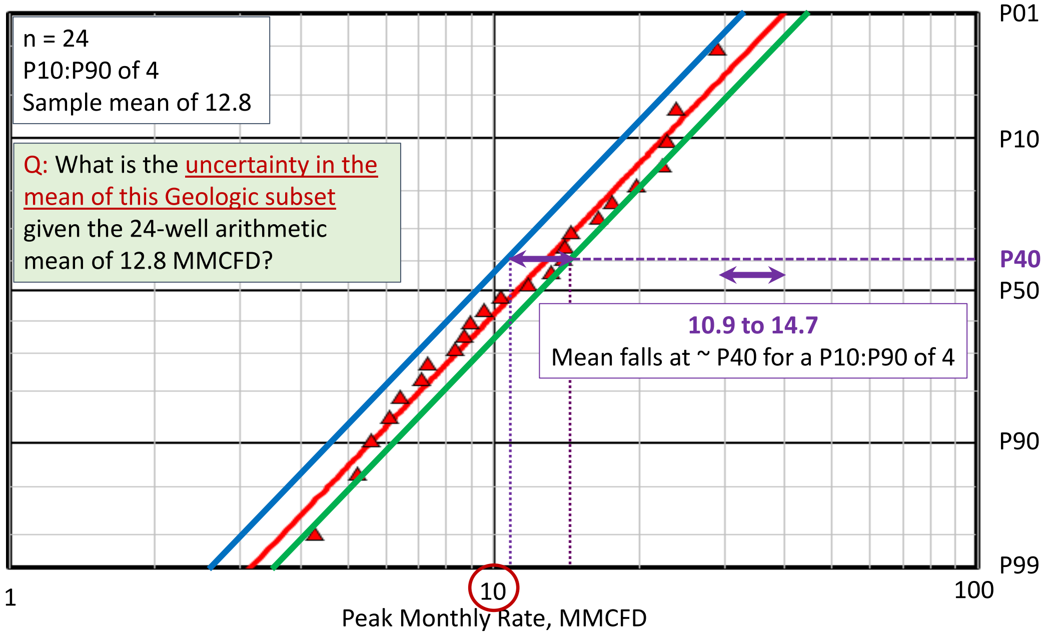
Variance based on analogs with a P10:P90 of 4

After 24 wells, we are 80% confident that the geologic subset mean will be between 10.9 and 14.7 MMCFD

Exercise B: Application of Aggregation Curves

- We have now established that the 80% confidence range of the true population mean is between 10.9 to 14.7 MMCFD. Think of the term 'true population mean' as the average of a 1,000 well program.
- If our minimum acceptable rate is 10.9 MMCFD, to realize an acceptable rate of return, we can say that there is only a 10% chance of us not achieving our minimum return or better.
- If our minimum acceptable rate is 14.7 MMCFD, it would be wise to proceed with caution. The play may still work but our confidence is lowered to 10%.
- All the above is contingent on our confidence that we expect analogous rock, fluids etc.

Exercise B: Application of Aggregation Curves



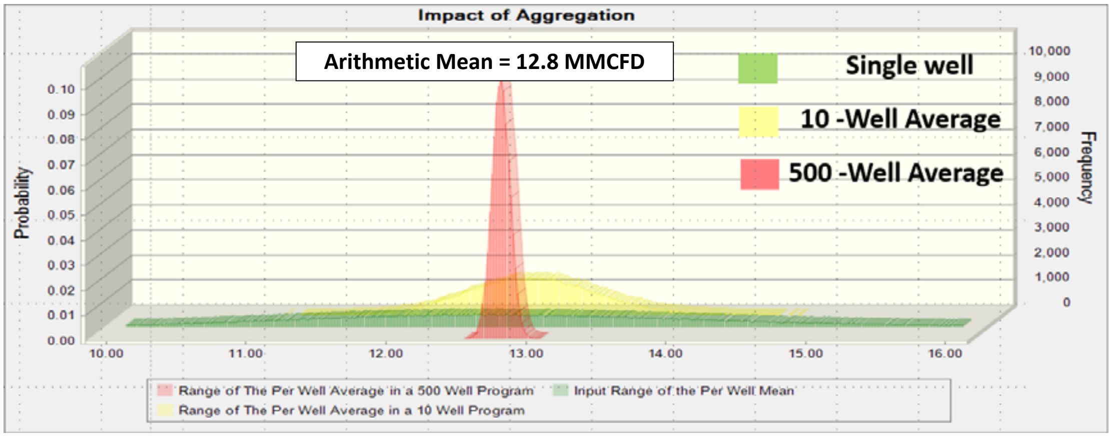
n = 24
P10:P90 of 4
Sample mean of 12.8

Q: What is the uncertainty in the mean of this Geologic subset given the 24-well arithmetic mean of 12.8 MMCFD?

10.9 to 14.7
Mean falls at ~ P40 for a P10:P90 of 4

Forecasting Based on Limited Samples

- 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 honor the irreducible uncertainty based on the original 24-well sample set.



Aggregation Derivative Applications

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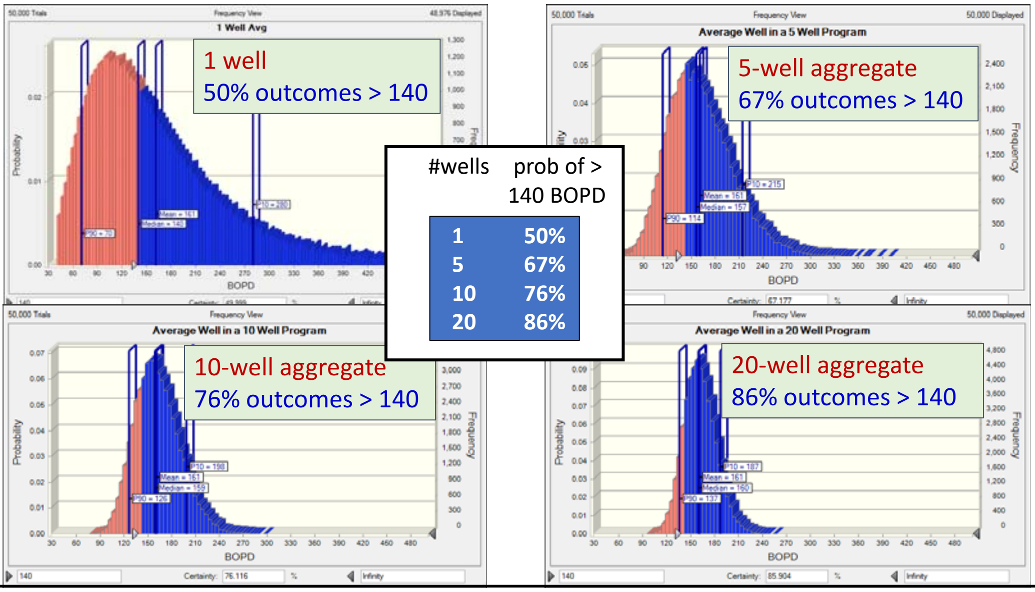
- Provides <u>early</u> feedback about the validity of the forecasted parameter

Building Confidence vs Well Count Curves

- Confidence of exceeding 140 target



1 well
50% outcomes > 140

5-well aggregate
67% outcomes > 140

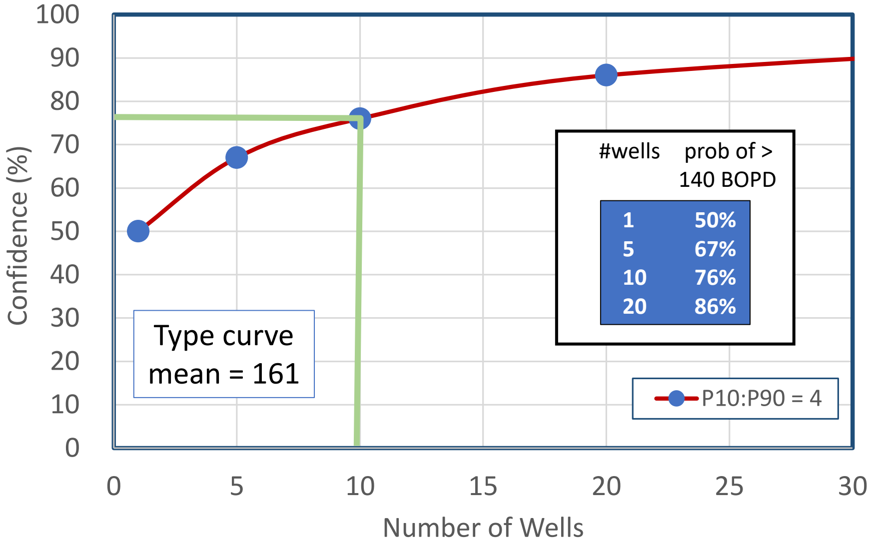
10-well aggregate
76% outcomes > 140

20-well aggregate
86% outcomes > 140

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

Building Confidence vs Well Count Curves

- Ex: 76% chance avg of 10 wells > 140 target

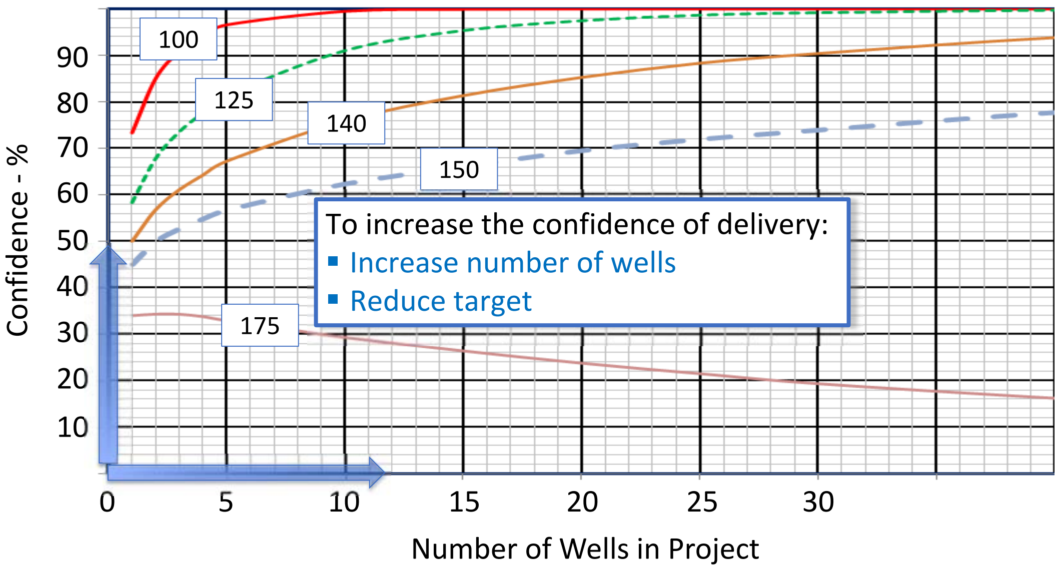


Type curve
mean = 161

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

Building Confidence vs Well Count Curves

- Confidence of exceeding various targets



To increase the confidence of delivery:

- Increase number of wells
- Reduce target

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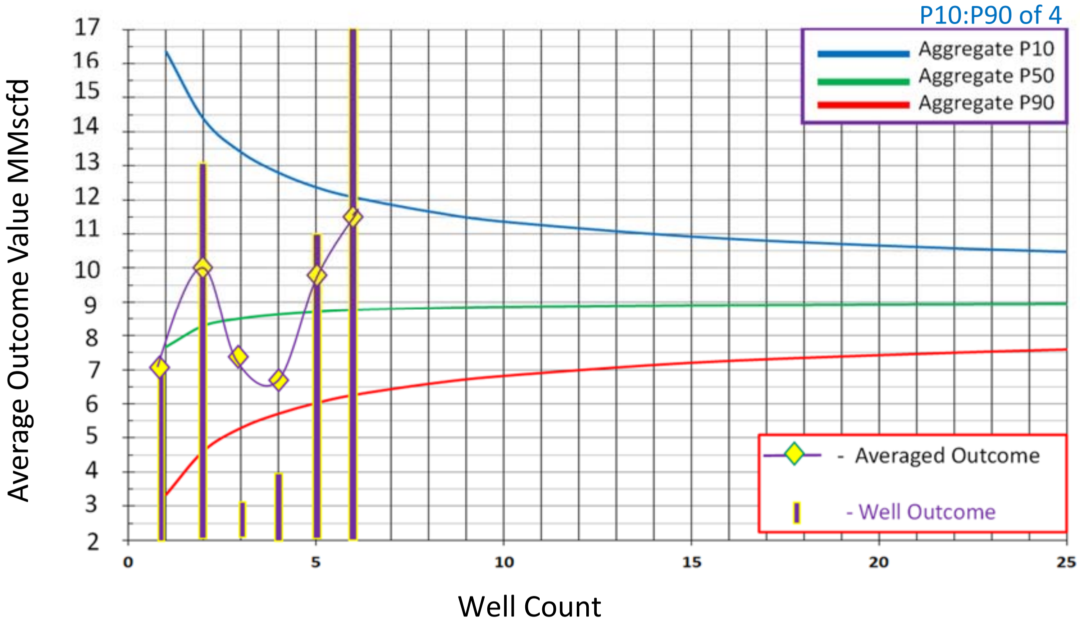
Performance Tracking Using Trumpet Plots

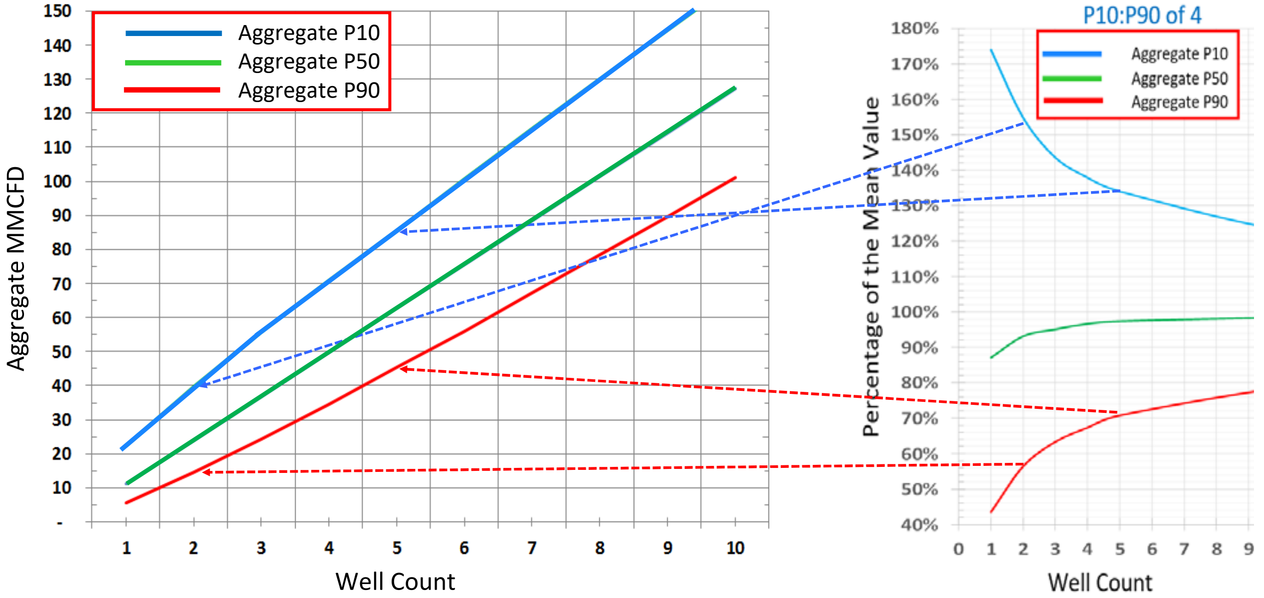


Making Better Decisions Based on Limited Data

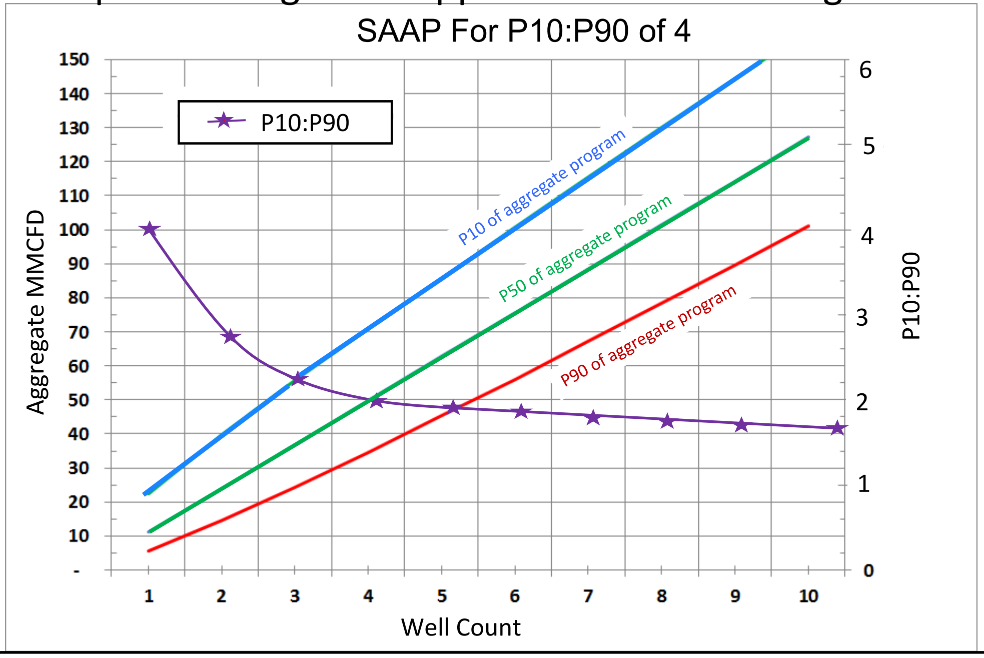
- With a large degree of inherent uncertainty, how do we assure our management team that our programs are on track?
- We can use Aggregation curves to determine our 80% confidence intervals as a function of well count.
- By plotting our actual results against the 80% confidence bands we are generating **“Sequential Aggregation/Accumulation Plot” or SAAP.**
- This graphical approach provides early indication of possible issues and facilitates “real-time” early decision making.

The Aggregation curve's average well, a function of well count is converted to an accumulating total.

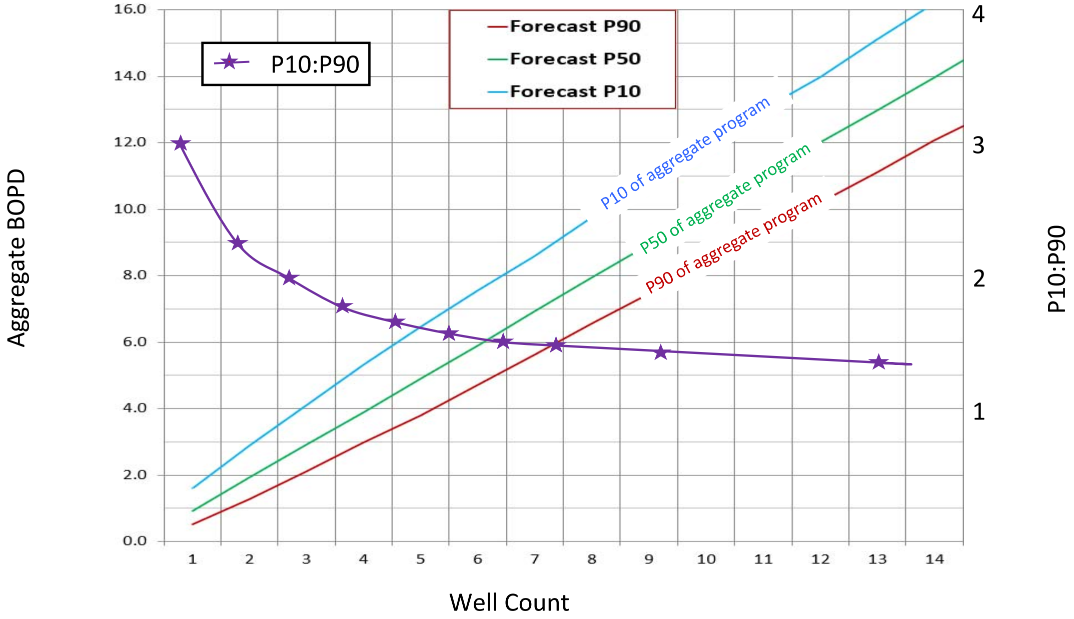
This is accomplished by multiplying the percentage of the mean on the left axis of the trumpet curve, by the mean value, and by the selected well count.



The Rapid Convergence Supports Decision Making with Fewer Wells



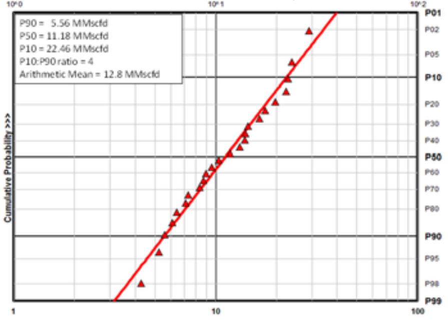
SAAP For P10:P90 of 3 With a Mean of 1,000 BOPD



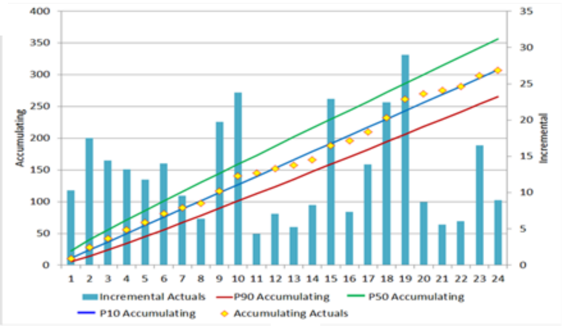
Sequential Accumulation/Aggregation Plots (SAAP)

- SAAP plots present the data in chronological order, unlike the log cum prob curve presentation of the data.

Falher 'H' – Peak Monthly Gas Rate



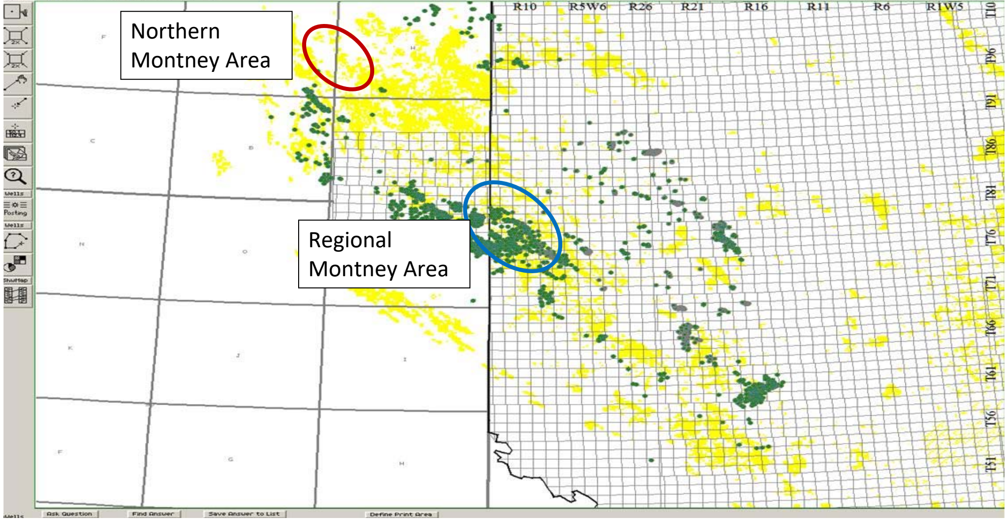
Sequential Accumulation/Aggregation Plots Identify Bias



- Trumpet plots illustrate the range of the average well
- Sequential Aggregation/Accumulation curves show the range of the aggregate sum as a function of the accumulating well count

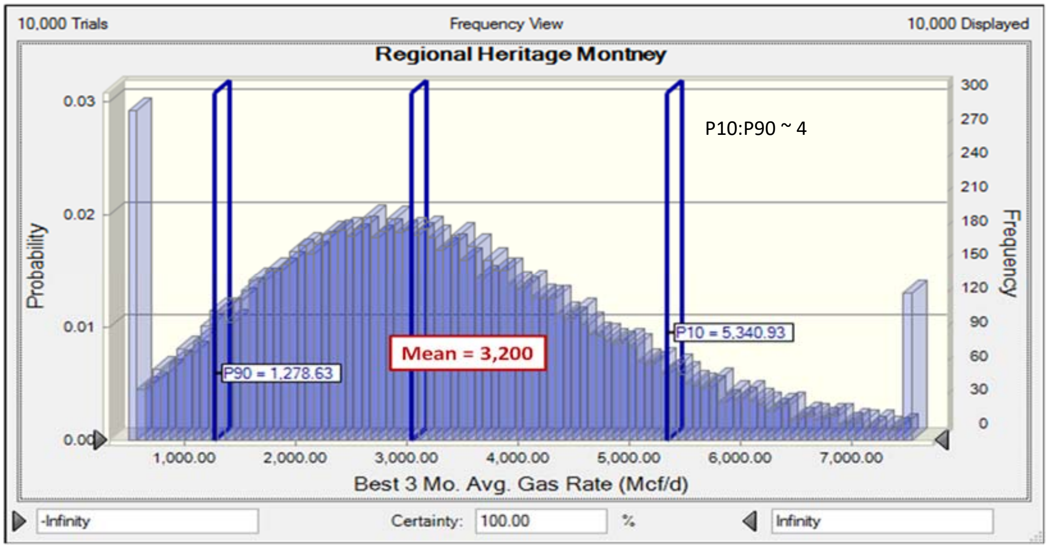
Case Study – Northern Montney

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



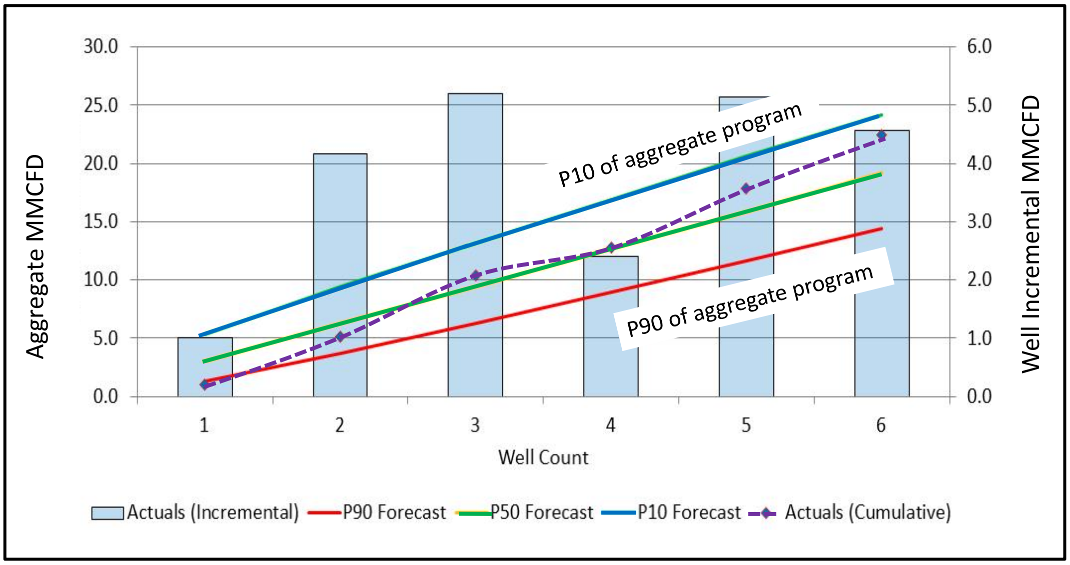
Green dots are Montney Horizontals at the end of 2012.

Analog Best 3-Month Average Gas Rate



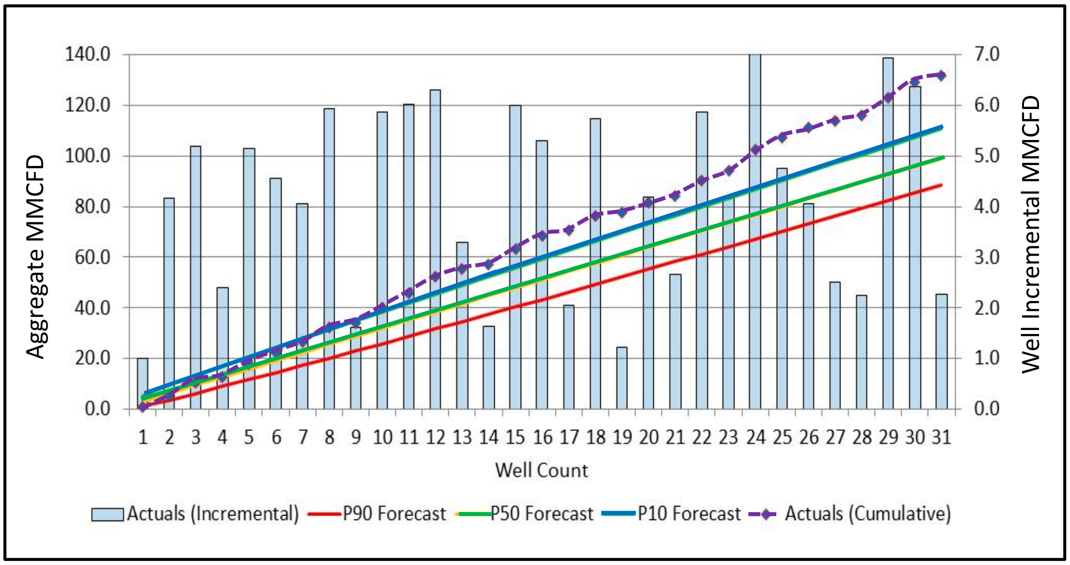
Based on Regional Heritage Montney selected analog wells

SAAP Best 3-Month Average Gas Rate – First 6 Wells



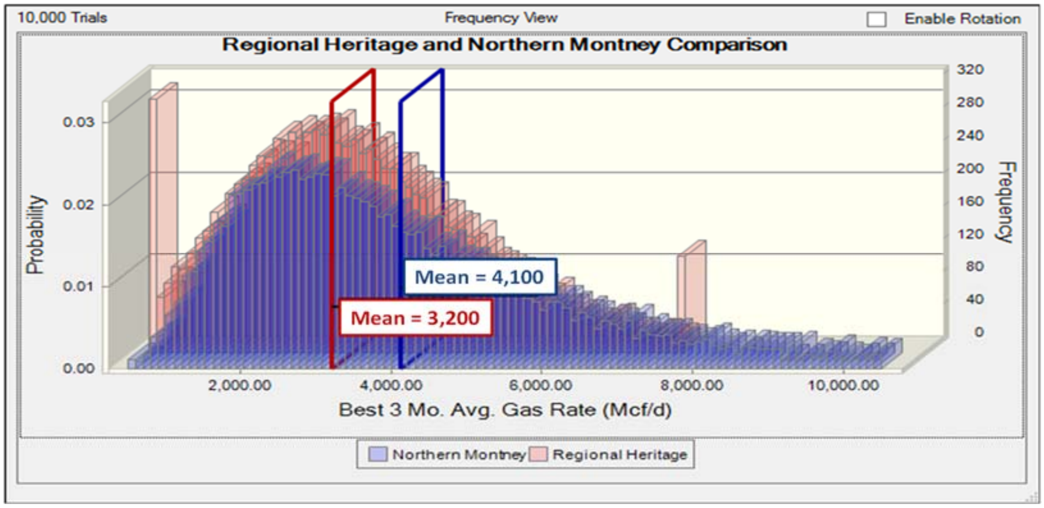
Actuals based on case study of northern Montney wells

SAAP Best 3-Month Average Gas Rate – First 31 Wells



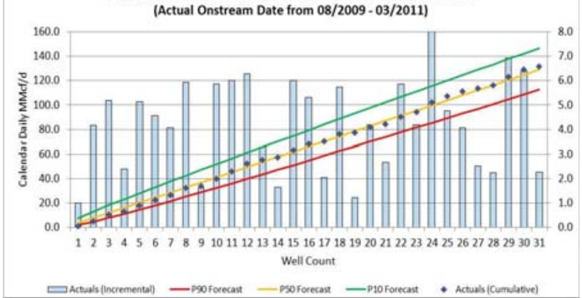
Actuals based on case study of northern Montney wells

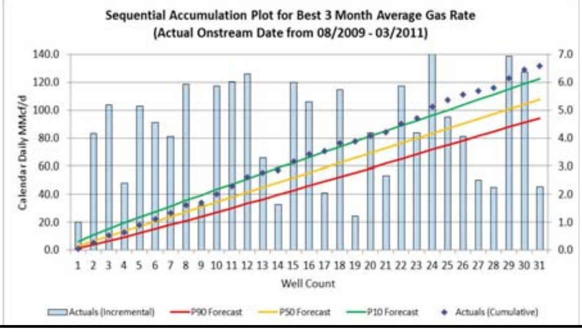
Comparison of Best 3-Month Average Gas Rate



Data from Northern Montney. Revised distribution, in blue, reflects an increased mean with approximately the same variance (P10:P90 of 4)

SAAP Plot Comparison





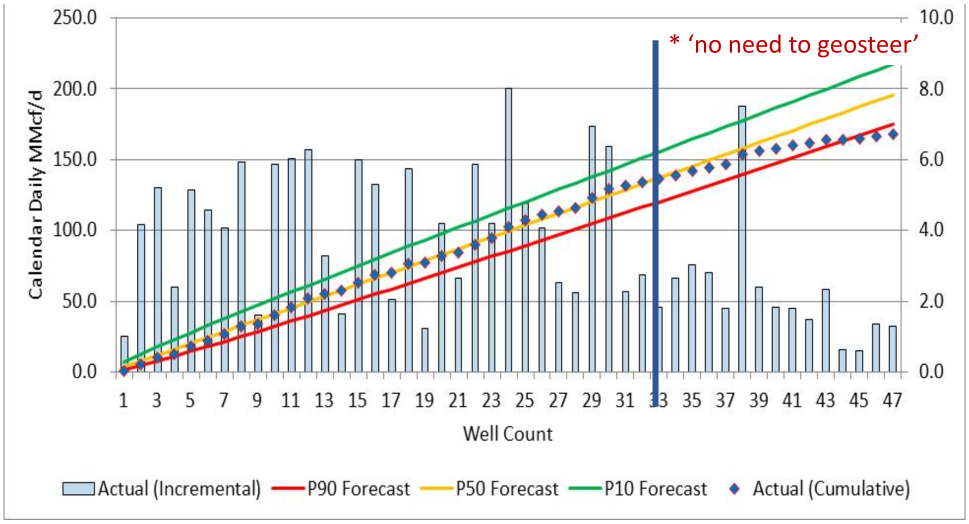
The accumulating totals of the first 31 wells, with existing technology, plotted against the sequential aggregation curves, that were based on the average of the first 31 wells.

This chart presents the break-even sequential aggregation curve with accumulating actuals from the first 31 wells

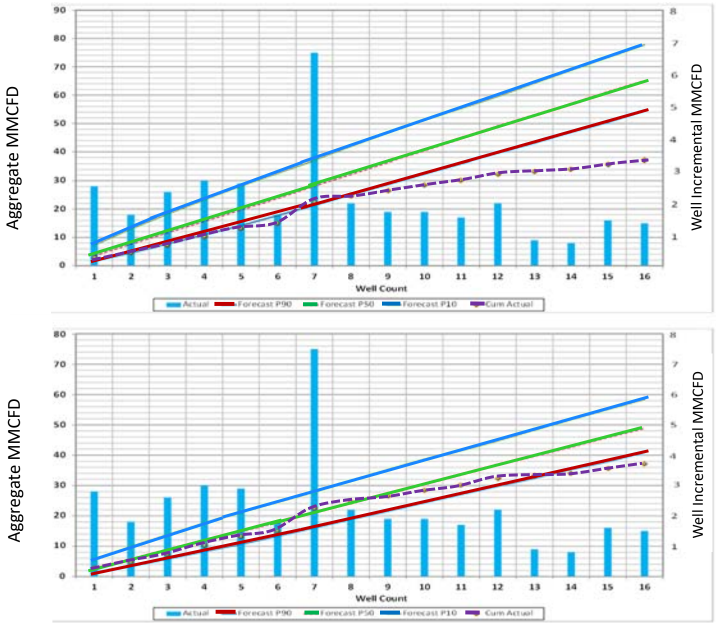
The first 31 wells are outperforming the high-end of the breakeven type well

Case Study: Northern Montney

Wells 32-47 incorporated cost savings*



SAAP Comparison – Forecast vs Breakeven Analysis



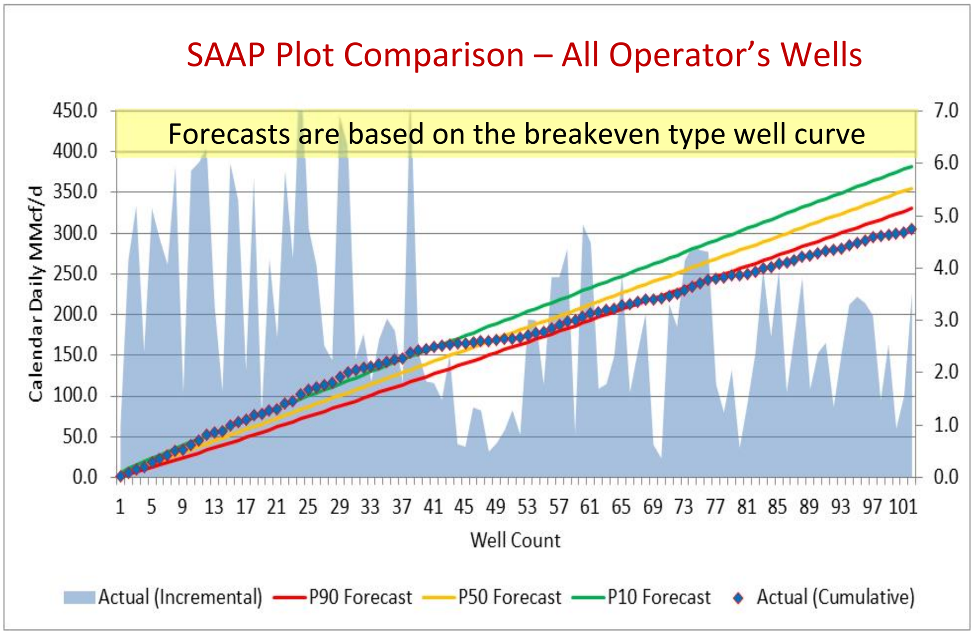
The accumulating totals of the first 16 wells, with revised technology, plotted against the sequential aggregation curves, that were based on the average of the first 31 wells.

This chart presents the break-even sequential aggregation curve with accumulating actuals from the first 16 wells with revised technology.

After approximately 14 new wells the actual results are falling below the P90 of the breakeven type well.

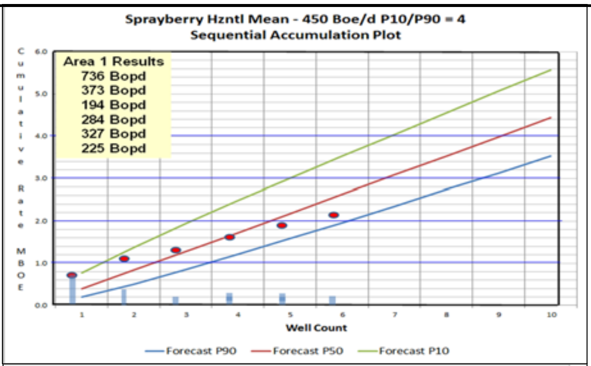
The more they spent the more they lost!

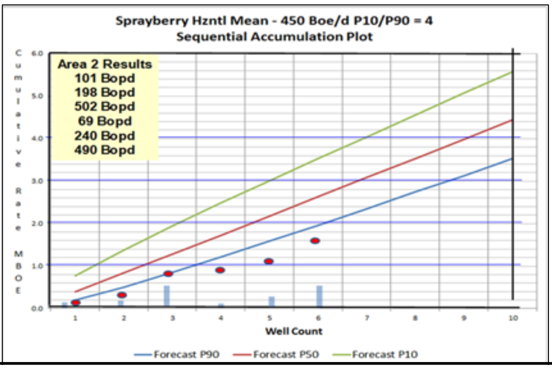
How to Erode $1 Billion in Shareholder Value

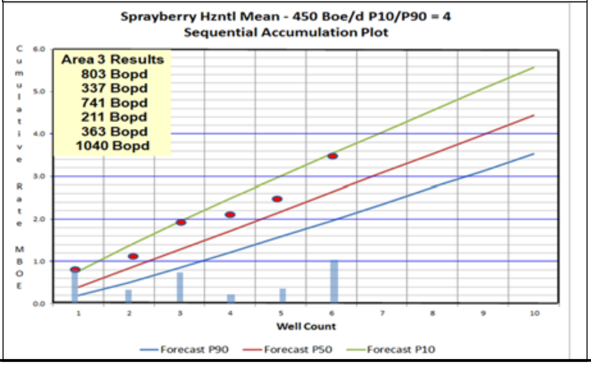


Your Team's Assignment:

- You are testing three areas in an emerging trend.
- Your Management team has cut your budget and increased expectations per $MM of Capital budget.
- Each area has adequate acreage to ramp up to the existing oil battery capacity for 5 years.
- Each area has significant expiring acreage in the next one to two-year timeframe.
- What would your team recommend going forward?







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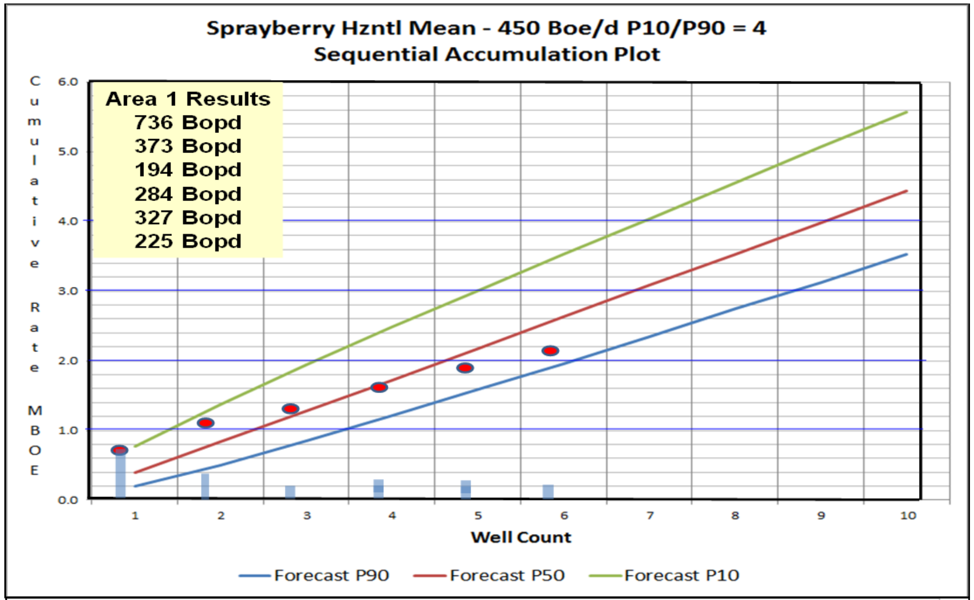
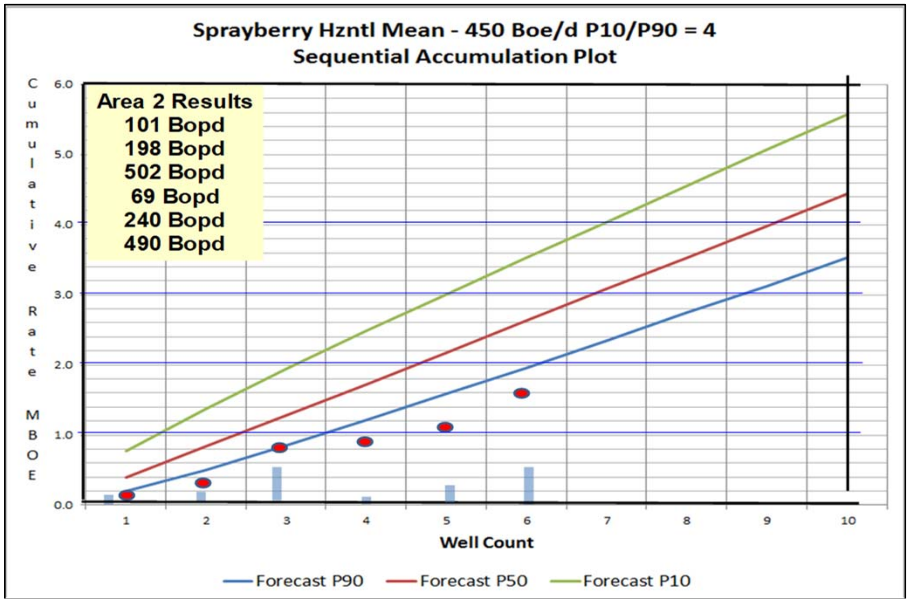
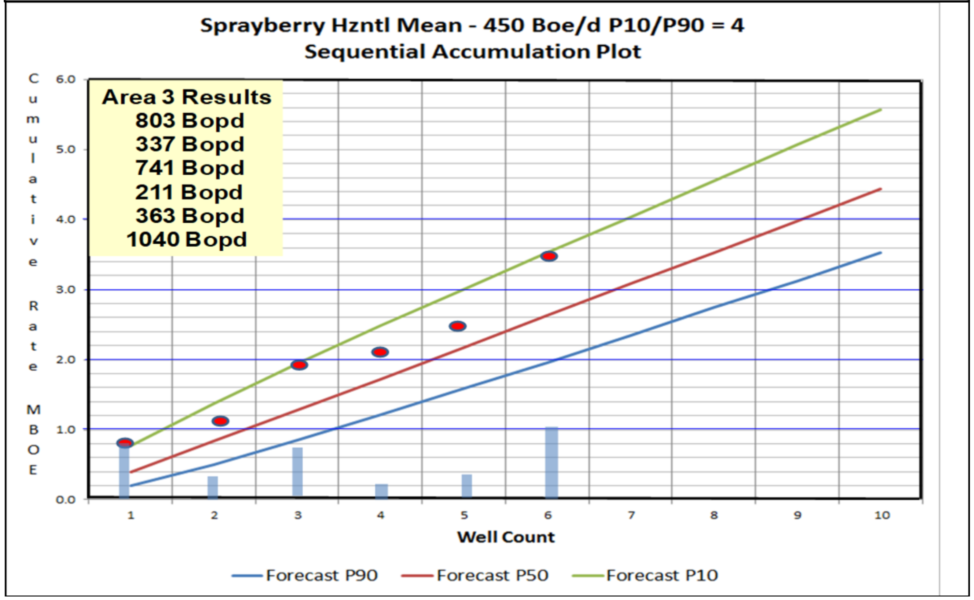






Why Do We Need An Assessment Process?

Reservoir	Wells Drilled	# Wells >12% ROR
Shale	307	53
Shale	96	40
Carbonate	52	39
Sandstone	57	28
Sandstone	104	24
Sandstone	86	19
Sandstone	115	11
Shale	18	2
Shale	10	1
Carbonate	15	1
Shale	79	1
Shale	80	1
Carbonate	2	0
Shale	16	0
Shale	6	0
Shale	6	0
Total	1049	220

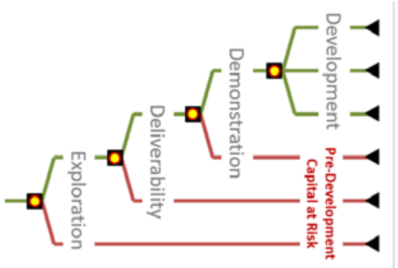
A company's recent experience in low perm reservoirs

Why is Pilot Design Challenging?

The Decision Tree outline is straightforward

Success

Failure



The challenge is that the % values assigned to the success and failure branches at each Decision/Outcome node are dynamic values. To determine their values we must first determine:

- The decision Hurdle rate
- The number of Pilot wells
- The required Confidence in the outcomes – This is best viewed as a calculated value and not a value set by our Leadership team.

Why is Pilot Design Challenging?

Pilot design requires the use of stochastic software. There are many unknowns to model:

- The average well in the program – the Program mean.
- Given a Program mean, the variance in the per well performance which will, in aggregate, deliver the mean. We model this with a P10:P90 ratio.
- The "Learning Curve". Our costs are high initially, but strategic funding decisions should be based on what wells will cost in the future not on the high initial well costs.
- Competitive pressures push us to bid on acreage prior to the Program being proven to be commercial **– RISK!**
- Infrastructure, we want proof of concept and markets before committing to large infrastructure. **Otherwise there is additional risk.**

109

Challenges in Piloting New Technology

- Base forecast uncertainty
  - In SAGD oil operations we have observed a +/- 25% variance between forecast and actual production on a well-by-well basis.
  - Allocation errors and production variability are key drivers
  - At the Pad level (4-8 wells) this will decrease to about +/- 5%
- Time delay to see improvements
  - Impact of forecast uncertainty is compounded when the incremental wedge is years out – solvent enhancements
- Incremental changes are small relative to other uncertainties. The signal (performance improvement) relative to the noise (measurement uncertainty, and base production forecast uncertainty)

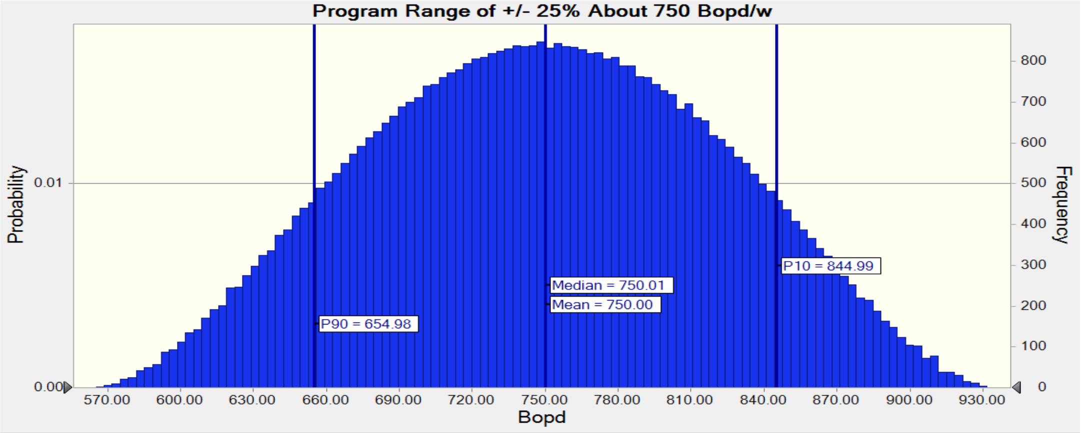
110

Why is Pilot Design Challenging?

The cost of a Pilot can be prohibitive in terms of supporting the number of wells required and the time it takes to validate an outcome. These are our challenges in SAGD.

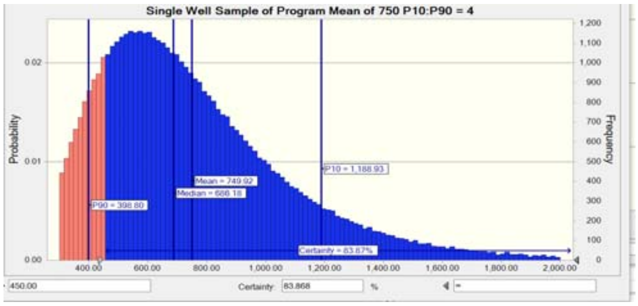
- Allocations factors of +/- 25% are a curse for pilot design. We can reduce this to +/- 5% by testing the new technology on all wells on a pad but the costs have often proven to be prohibitive to leadership.
- Solvents that require 5+ years to validate measurable impacts are too long a time frame for leadership teams.
- A solution that R&A co-develop with a major SAGD player was the use of a technology matrix that took advantage of group wisdom which was informed based on modelling results and their professional judgement using the matrix to quantify their judgments.
- There is no way to "statistically" validate a pilot with limited wells counts when "noise" significantly exceeds the expected signal.

Beta-Pert Simulated Program Mean of 750 bopd/w +/- 25%

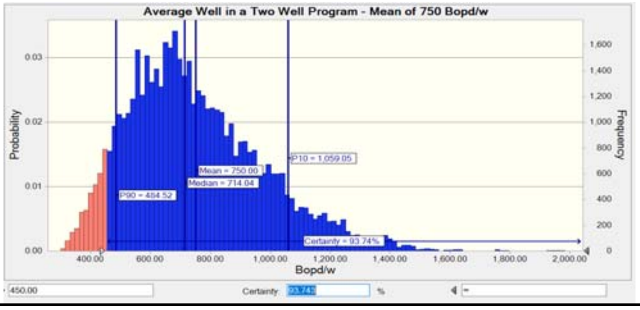


- By using a Beta Pert distribution, we are advising that our worst-case outcome has an average of 570 bopd which exceeds the Management threshold target **of 550** bopd.
- Can a pilot fail given the above? Do we need to pilot if this is a validated distribution?

Lognormal Distribution - Program Mean of 750 bopd, P10:P90 of 4

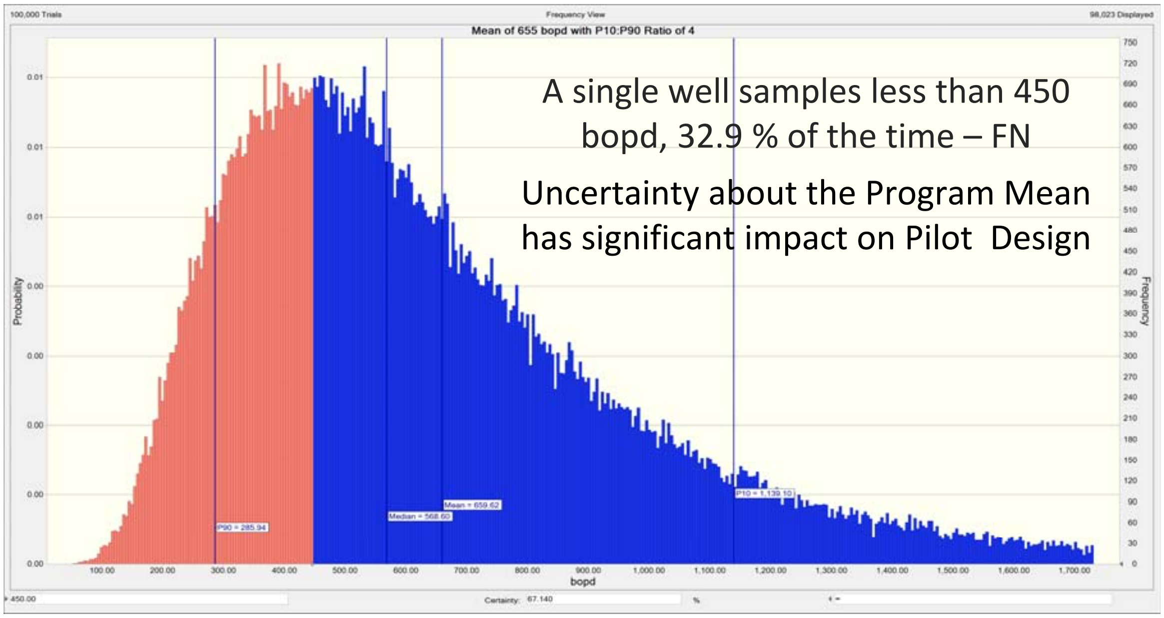


A single well samples less than 450 bopd 16.1% of the time - FN



The 2 well Program averages less than 450 bopd 6.3% of the time -FN

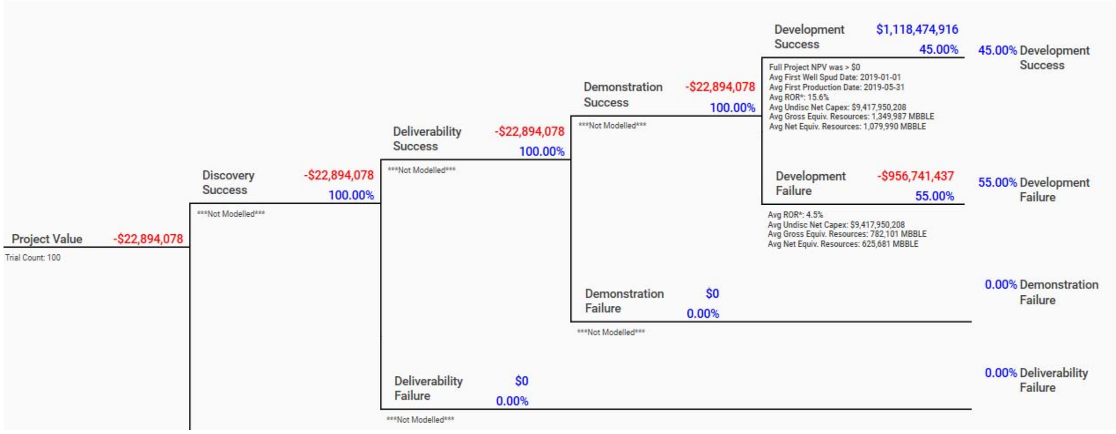
What if the Program Mean Was 655 bopd?



A single well samples less than 450 bopd, 32.9 % of the time – FN

Uncertainty about the Program Mean has significant impact on Pilot Design

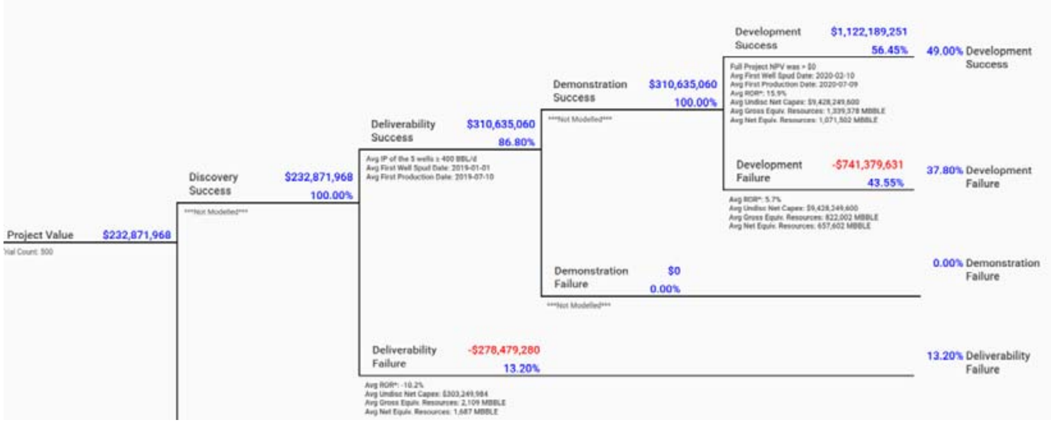
Would You Invest in This Program?



This Program failed to secure Portfolio funding as on a Risked basis it is EPV negative.

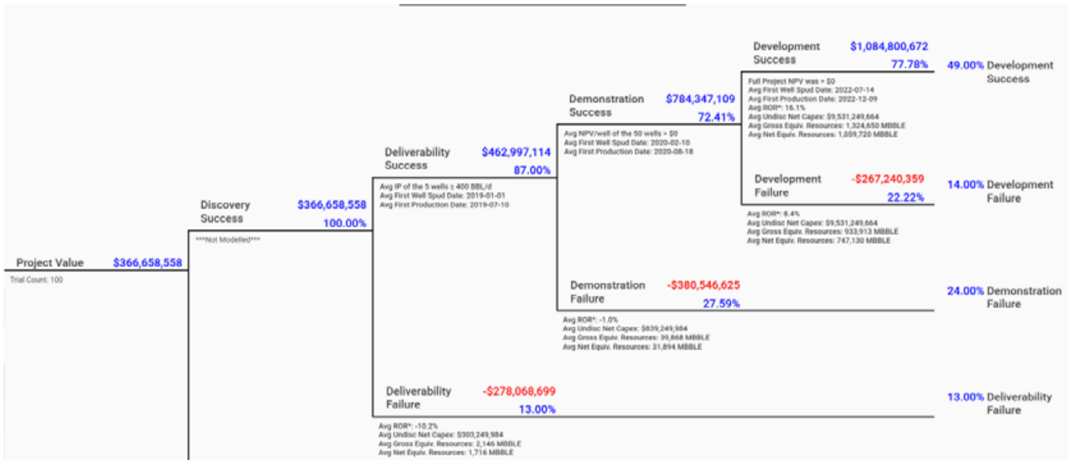
Can a Pilot program de-risk and change how we view the Project?

The Impact of a 5 Well Deliverability Pilot



A 5 well Pilot with a hurdle rate of 400 bopd/w created a good Project
EPV increases from -$23 MM to + $233 MM
Will adding a Development Stage Pilot provide incremental value?

5 Well Deliverability & 50 Well Demonstration Pilots



By conducting a 5 well Pilot with a hurdle rate of 400 bopd/w & a 50 well Demonstration Pilot, we have a very attractive Project.

EPV increases from + $233 MM to +$367 MM

Technology Readiness Levels

Level 1	**Basic principles of concept are observed and reported.** At this level scientific research begins to translated into applied research and development. Activities might include paper studies of a technology's basic properties.
Level 2	**Technology concept and/or application formulated.** At this level invention begins. Once the basic principles are observed, practical applications can be invented. Activities are limited to analytical studies.
Level 3	**Analytical and experimental critical function and/or proof of concept.** At this level active research and development is initiated. Activities might include components that are not yet integrated or representative.
Level 4	**Component and/or validation in a laboratory environment.** At this level basic technological components are integrated to establish that they will work together. Activities include integration of "ad hoc" hardware in the laboratory.
Level 5	**Component and/or validation in a simulated environment.** At this level the basic technological components are integrated for testing in a simulated environment. Activities include laboratory integration of components.
Level 6	**System/subsystem model or prototype demonstration in a simulated environment.** At this level a model or prototype is developed that represents a near desired configuration. Activities include testing in a simulated operational environment or laboratory.
Level 7	**Prototype ready for demonstration in an appropriate operational environment.** At this level the prototype should be at planned operational level and is ready for demonstration of an actual prototype in an operational environment. Activities include prototype field testing.
Level 8	**Actual technology completed and qualified through tests and demonstrations.** At this level the technology has been proven to work in its final form and under expected conditions. Activities include developmental testing and evaluation of whether it will meet operational requirements.
Level 9	**Actual technology proven through successful deployment in an operational setting.** At this level there is actual application of the technology in its final form and under real-life conditions, such as those encountered in operational test and evaluations. Activities include using the innovation under operational conditions.

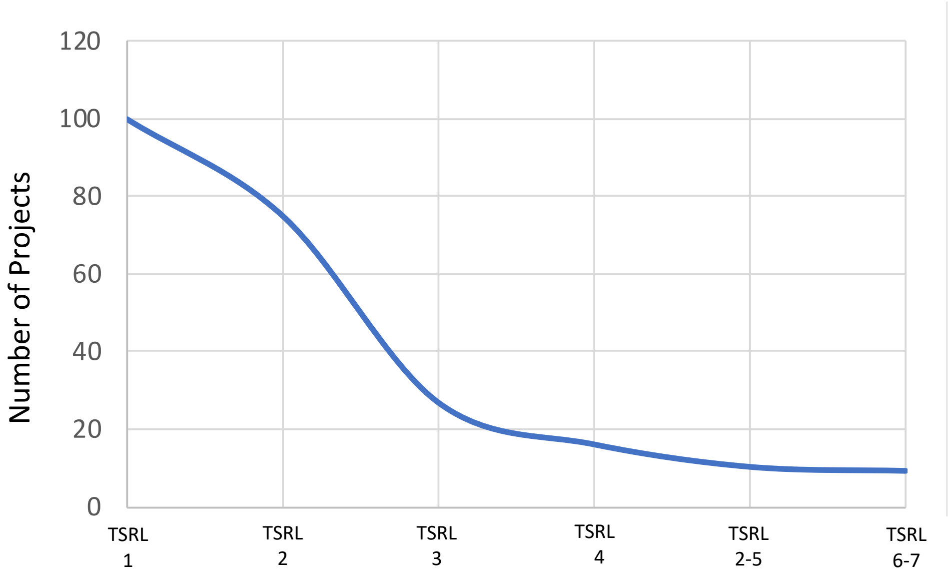
Technology Readiness Levels

- **TSRL 1-3: Research and solution validation:** Research is primarily done in the lab and ranges from fundamental research to proof of concept in a lab setting. Theory and scientific principles are focused on knowledge and application to define the concept. Analytical tools are developed. A potential business model is outlined, with problem and solution validation required. A market and competitive analysis is performed to align the proposed solution with the market need.
- **TSRL 4-6: Development:** The basic technological components are integrated for testing in a simulated environment and include alpha testing of prototypes. Knowledge and operational practices (e.g., best management practices) are tested at small scales in the field. A roadmap for the solution's technical requirements is developed to complete a demonstration of design prototypes in specific applications.
- **TSRL 7: Field Pilot:** The prototype is tested in the field in an operational environment and is well integrated with other systems. The proposed solution package is tested by end-users to validate performance and integration.
- **TSRL 8-9: Demonstration:** The technology is scaled up and tested in its final form and under expected conditions. Activities include the development of handbooks, documentation and maintenance. The solution ahs been developed to the stage of a minimum viable product, validating the proposed business model and confirming market applicability.
- **TSRL 10: Commercial:** The first commercial application of the technology; the technology is ready for licensing and widespread adoption by others.

Pilot Design: Stages

1. Screening – Conceptual, Screening -Early Peer Review and Technical literature Due Diligence	TSRL 1-3: Research and solution validation
2. Subject Matter Expert Early Assurance Review	
3. Small scale lab and or simulation models	
4. Appraisal – Test technology in an Operating environment	TSRL 4-6
5. Field Pilot of Commercial scale	TSRL 7
6. Apply commercial scale in Commercial Demonstration	TSRL 8-9
7. Commercial Development	TSRL 10

How Our Concepts Materialize to Successful Projects

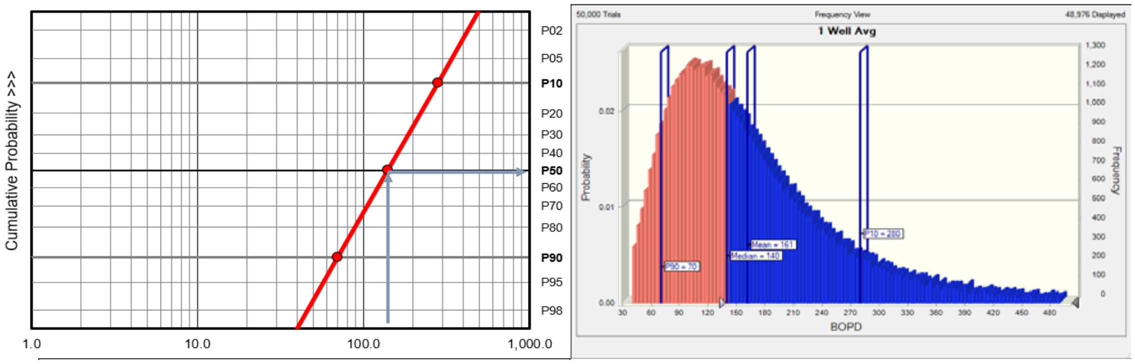


For Subsurface Technologies TSRL Stage 7 Pilot Design: Steps

1. Determine the applicable P10:P90 Ratio based on analogs
2. Reverse Engineer a Minimum Economic Target of Peak Rate in bopd.
3. Provided 2 of the 3 unknowns solve for the third
4. Determine the “No Regrets Rate”

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. 50% of the time a new well will meet or exceed 140 bopd and 50% of the time the 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.
- Develop a Normalized Production Type Well curve of daily average production rate (oil, gas, water) divided by peak rate for their selected analog(s).
- 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 **250 bopd** to build an example.

Pilot Design: Step 3

Three Key Questions:

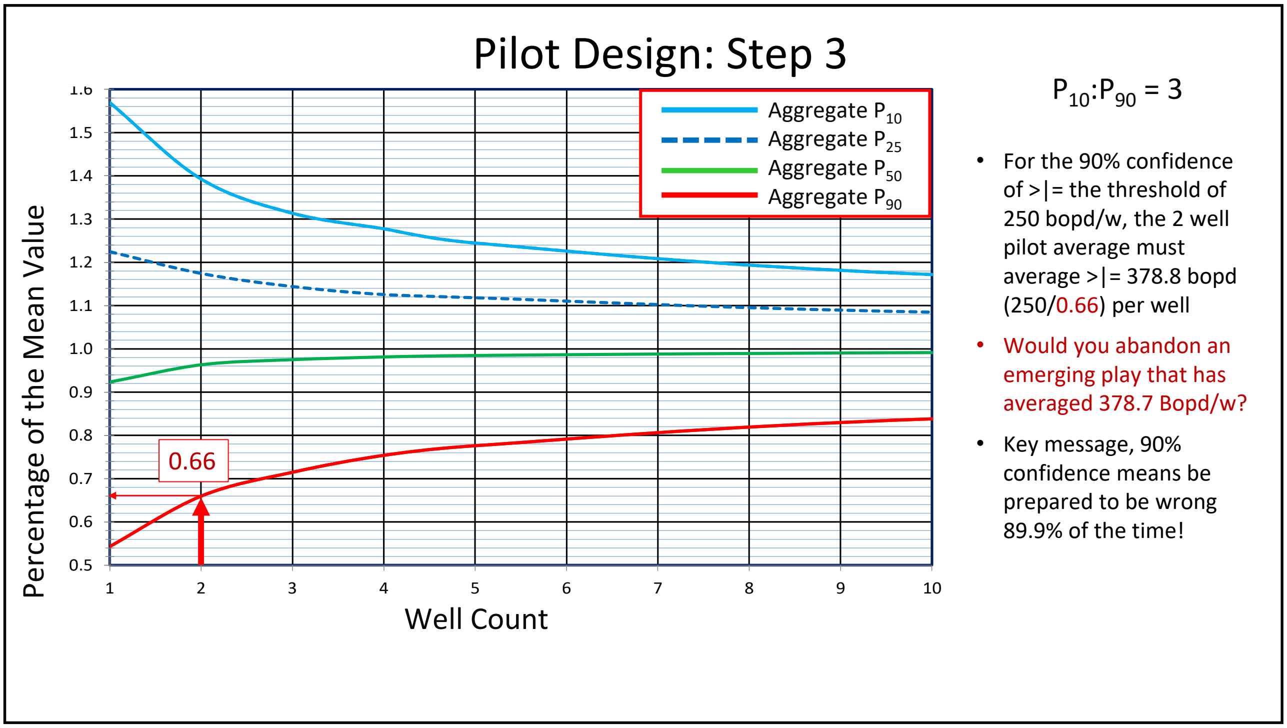
- How many wells should be in our pilot(s)?
- What confidence level in the data do we require before proceeding to the next step?
- What production rate do we need to validate before proceeding to the next stage of development?

125

Pilot Design: Step 3

- Leadership has set the Pilot targets as the following:
  - 90% Confidence that the authorized two well Pilot will validate that full development will meet or exceed the desired minimum ROR of 15%.
- We determined based on analogous horizontal well completions that a P10:P90 ratio of 3 is to be used.
- Next, we will calculate the rate we need to meet or exceed.

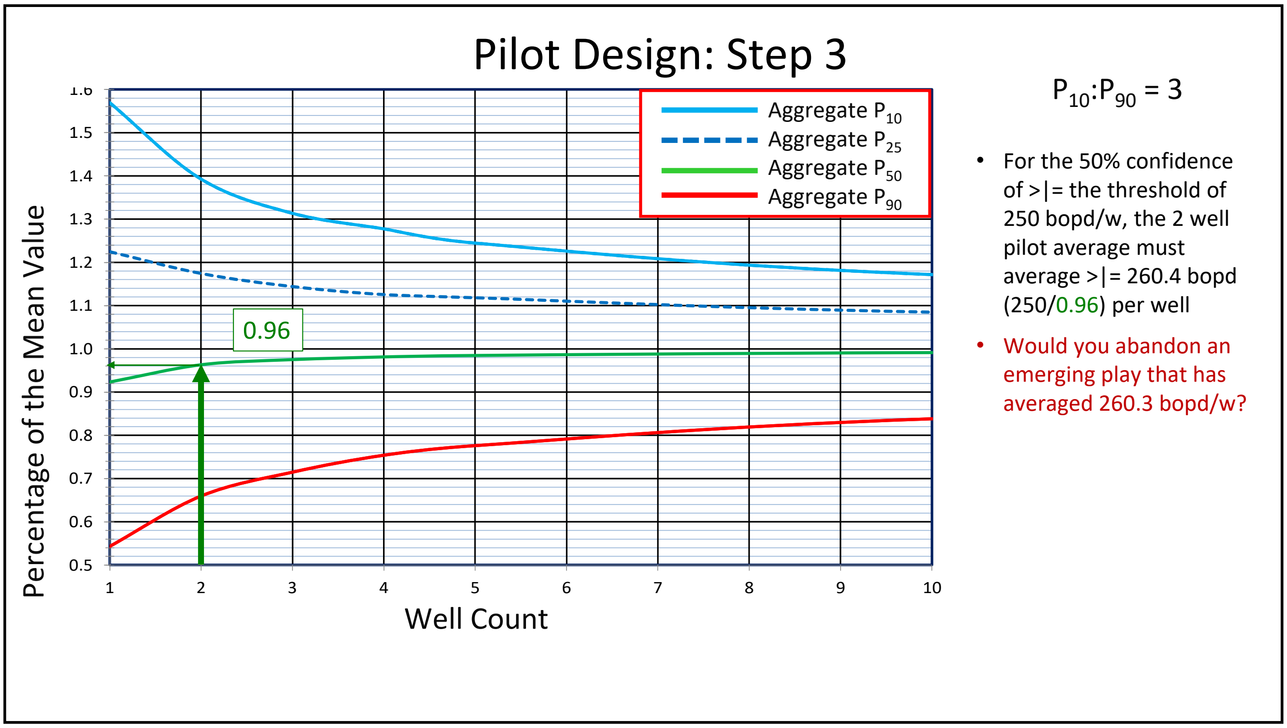
126



Pilot Design: Step 3

P_{10}:P_{90} = 3

- For the 90% confidence of >|= the threshold of 250 bopd/w, the 2 well pilot average must average >|= 378.8 bopd (250/0.66) per well
- Would you abandon an emerging play that has averaged 378.7 Bopd/w?
- Key message, 90% confidence means be prepared to be wrong 89.9% of the time!



Pilot Design: Step 3

P_{10}:P_{90} = 3

- For the 50% confidence of >|= the threshold of 250 bopd/w, the 2 well pilot average must average >|= 260.4 bopd (250/0.96) per well
- Would you abandon an emerging play that has averaged 260.3 bopd/w?

Pilot Design: Step 4 - The “No Regrets” Rates

This brings about a consideration of what we will refer to as the “No Regrets Rate”

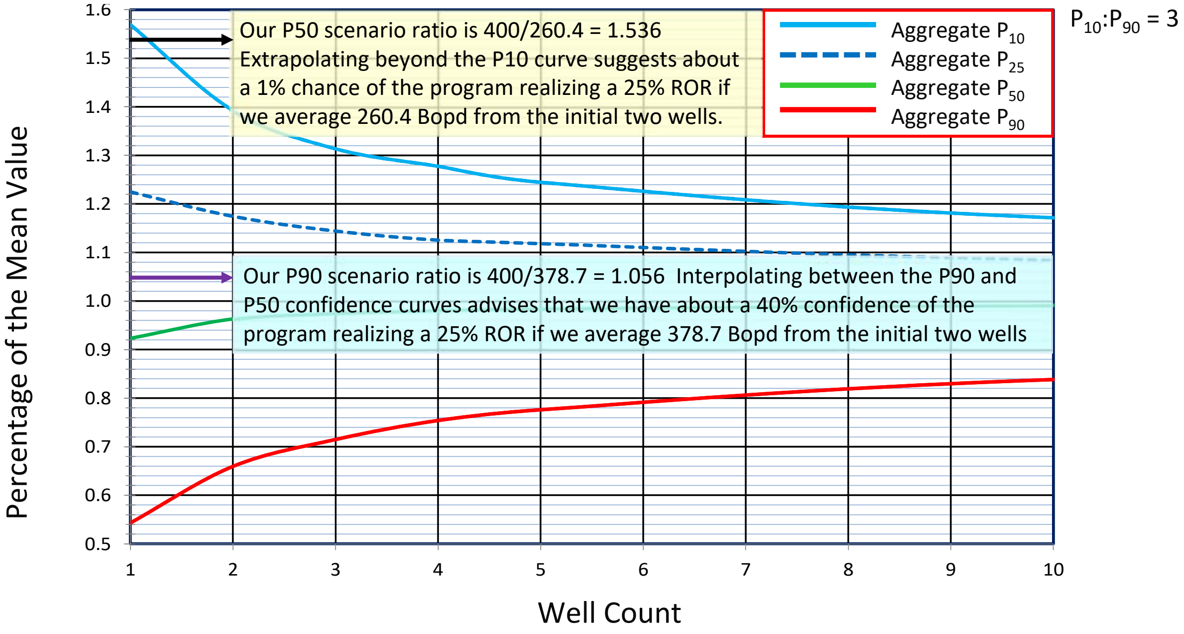
The production rate that you would have no regrets walking away from, knowing that it might work in the future. There are several factors to consider:

- The “no regrets rate” with consideration of the ROR “break-even” rate.
- Consideration of which Projects will be funded in the future i.e. “Portfolio Management”.
- Corporate hurdle rates typically significantly exceed their “Break-even” RORs.
- The “No Regrets” rate incorporates the probability of realizing a “Break-even ROR” or more, with the probability of a project being part of the funded Portfolio.

Pilot Design: Step 4 - The “No Regrets” Rates

- We determined that we need to deliver an average rate of at least 250 bopd to realize a breakeven ROR of 15%.
- Our 90% confidence value was 378.7 bopd/w and our 50% confidence value was 260.4 bopd/w.
- The next step in deriving the “No Regrets” rate is to determine the probability that the threshold rates (378.7 & 260.4) would secure Portfolio funding if they were the pilot result.
- Next step, calculate the probability of exceeding the Corporate ROR hurdle to secure Portfolio funding. We will use 25% ROR as our Corporate funding hurdle rate.
- To deliver a 25% ROR your project will need to deliver an average rate per well of 400 bopd.
- The question to be answered is what is the likelihood that the project will average 400 bopd/w given the result of the initial 2 well pilot?
- So.. If we averaged 378.7 or 260.4 bopd/w after the two well pilot, what is our confidence that the project, when fully developed, will average 400 bopd/w or more?

400 Bopd/w is Required to Meet the Portfolio ROR Hurdle Rate of 25%



Our P50 scenario ratio is 400/260.4 = 1.536 Extrapolating beyond the P10 curve suggests about a 1% chance of the program realizing a 25% ROR if we average 260.4 Bopd from the initial two wells.

Our P90 scenario ratio is 400/378.7 = 1.056 Interpolating between the P90 and P50 confidence curves advises that we have about a 40% confidence of the program realizing a 25% ROR if we average 378.7 Bopd from the initial two wells

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Pilot Design Exercise

Answers to the Key Question to Leadership, prior to Pilot Design:

- How many wells should be in our pilot(s)?
  Management has set it at 4 wells.

- What production rates do the first 4 wells need to average to deliver:
  a. At least the cost of capital ~ 15% with a 75% confidence.
  b. Based on a., what is the resulting confidence of being Portfolio competitive i.e. a ROR of 30%?

- Production rates associated with a 15% and 30% ROR?
  - a 15% ROR requires 4,500 Mscfd.
  - a 30% ROR requires 6,000 Mscfd

- Based on analog control expect a P10:P90 ratio of 3

Exercise : Pilot Design

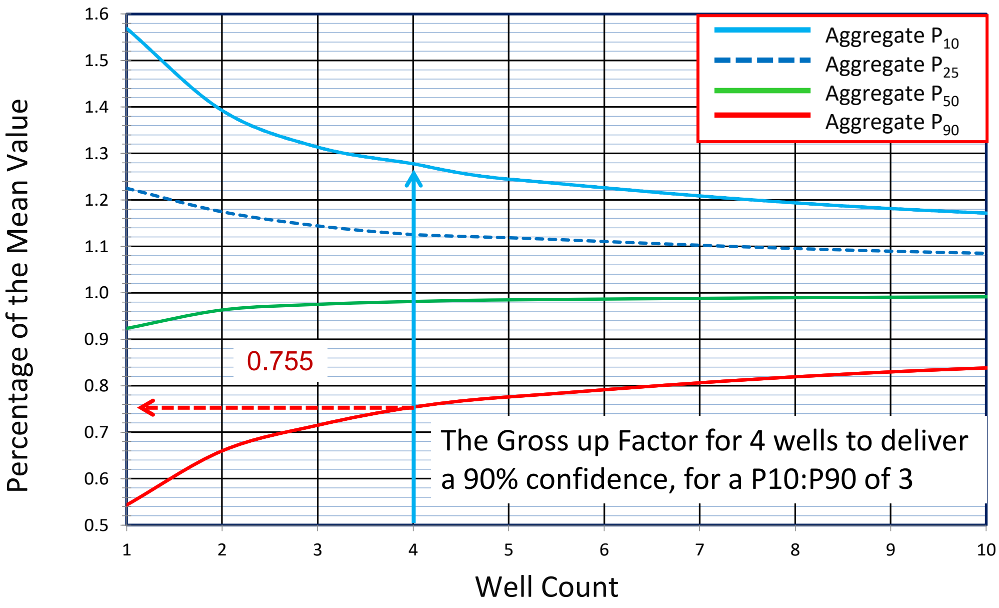
Results: 4, 500 Mscfd 6, 000 Mscfd

Probability	Trumpet Plot Factor	Grossed-up Break-even 15% ROR Rate Mscfd	Target 6,000 Mscfd / Grossed-up Break-even 15% ROR Rate Mscfd	Approximate confidence of realizing a 30% ROR given the pilot outcome
90				
50				
25				
10				

For simplicity assume a linear relationship to extrapolate or interpolate between values

Exercise : Pilot Design

P_{10}:P_{90} = 3



The Gross up Factor for 4 wells to deliver a 90% confidence, for a P10:P90 of 3

Exercise : Pilot Design

Results: 4, 500 Mscfd 6, 000 Mscfd

Probability	Trumpet Plot Factor	Grossed-up Break-even 15% ROR Rate Mscfd	Target 6,000 Mscfd / Grossed-up Break-even 15% ROR Rate Mscfd	Approximate confidence of realizing a 30% ROR given the pilot outcome
90	0.755			
50				
25				
10				

For simplicity assume a linear relationship to extrapolate or interpolate between values

Exercise : Pilot Design

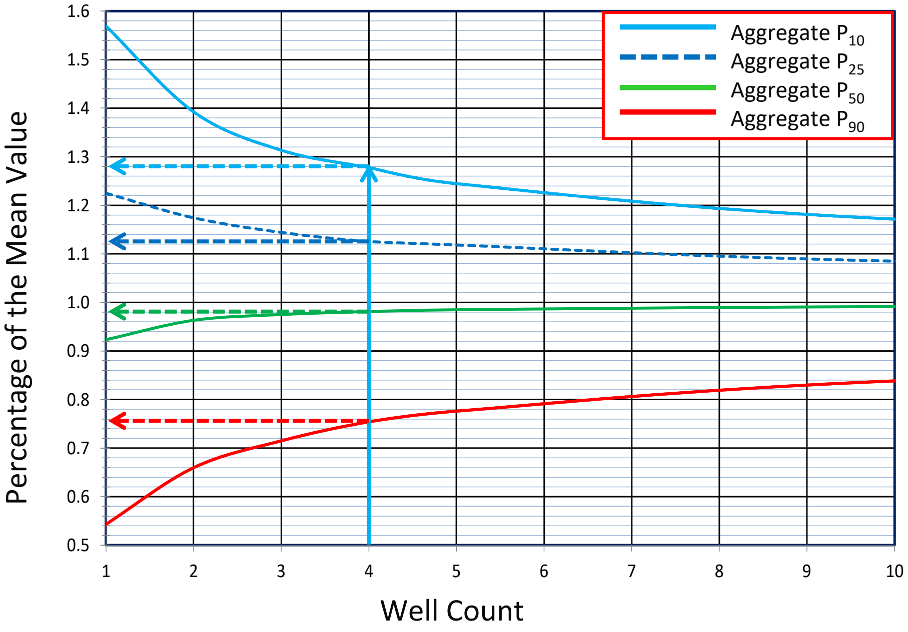
Results: 4, 500 Mscfd 6, 000 Mscfd

Probability	Trumpet Plot Factor	Grossed-up Break-even 15% ROR Rate Mscfd	Target 6,000 Mscfd / Grossed-up Break-even 15% ROR Rate Mscfd	Approximate confidence of realizing a 30% ROR given the pilot outcome
90	0.755	4,500/0.755 = 5,960.3		
50				
25				
10				

For simplicity assume a linear relationship to extrapolate or interpolate between values

Exercise : Pilot Design

$P_{10}:P_{90} = 3$



Exercise : Pilot Design

Results: 4, 500 Mscfd 6, 000 Mscfd

Probability	Trumpet Plot Factor	Grossed-up Break-even 15% ROR Rate Mscfd	Target 6,000 Mscfd / Grossed-up Break-even 15% ROR Rate Mscfd	Approximate confidence of realizing a 30% ROR given the pilot outcome
90	0.755	5960.3		
50	0.98	4591.8		
25	1.125	4000.0		
10	1.277	3523.9		

There is no right answer. The agreed upon values will be a function of your leadership team's Risk Aversion For example, with an averaged rate of 5,960 Mscfd/w, from the 4 well pilot, we would be 90% confident that the project development will meet or exceed the 15% ROR hurdle.

To answer the question, given this pilot outcome what is our confidence that the project will deliver a 30% ROR, which would result in the project securing portfolio funding?

We will first determine the Trumpet plot factor from which we will estimate confidence levels.

Exercise : Pilot Design

Results: 4, 500 Mscfd 6, 000 Mscfd

Probability	Trumpet Plot Factor	Grossed-up Break-even 15% ROR Rate Mscfd	Target 6,000 Mscfd / Grossed-up Break-even 15% ROR Rate Mscfd	Approximate confidence of realizing a 30% ROR given the pilot outcome
90	0.755	5960.3	6,000/ 5,960.3 =1.007	
50	0.98	4591.8	6,000/ 4,591.8 =1.307	
25	1.125	4000.0	6,000/ 4,000 =1.007	
10	1.277	3523.9	6,000/ 3,523.9 =1.307	

To determine the Trumpet plot factor from which we will estimate confidence levels we must take the grossed up break-even rate and assume that it is the Pilot outcome.

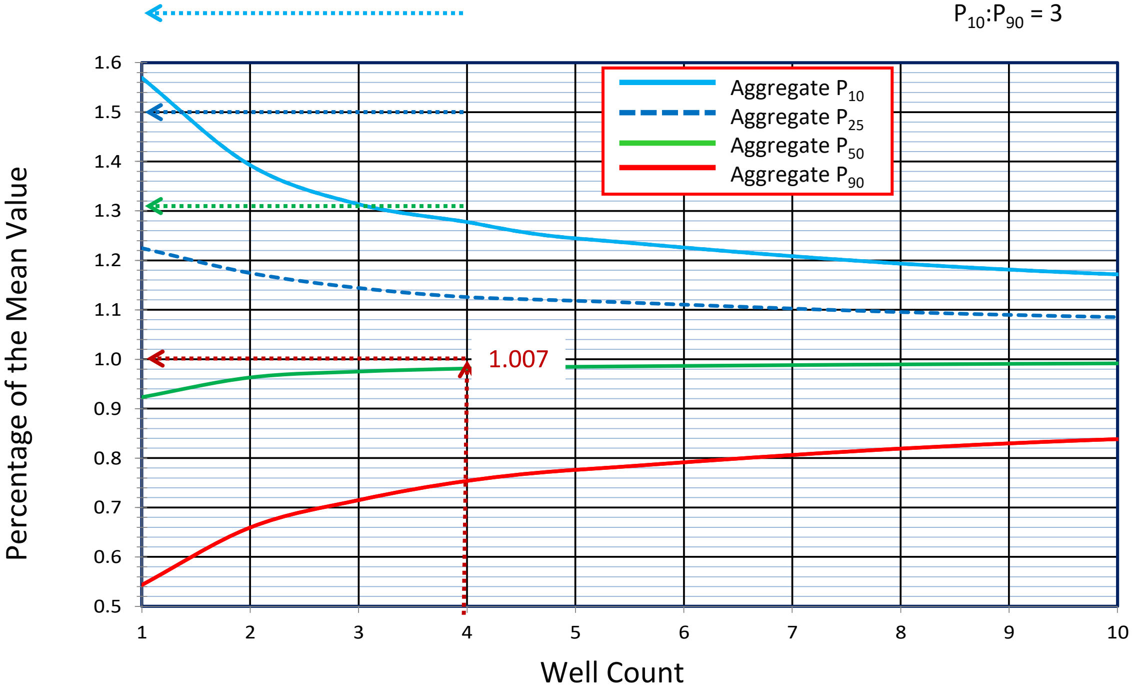
The factor, which we will use next in the Trumpet plot, is the ratio of the target (6,000) divided by the pilot outcome – which in this case we get from the column of grossed up break-even rates

Exercise : Pilot Design

Results: 4, 500 Mscfd 6, 000 Mscfd

Probability	Trumpet Plot Factor	Grossed-up Break-even 15% ROR Rate Mscfd	Target 6,000 Mscfd / Grossed-up Break-even 15% ROR Rate Mscfd	Approximate confidence of realizing a 30% ROR given the pilot outcome
90	0.755	5960.3	1.007	~ 46%
50	0.98	4591.8	1.307	
25	1.125	4000.0	1.500	
10	1.277	3523.9	1.703	

We plotted 1.007 at 4 wells and interpolated between the 50% and 25% confidence intervals.



Exercise : Pilot Design

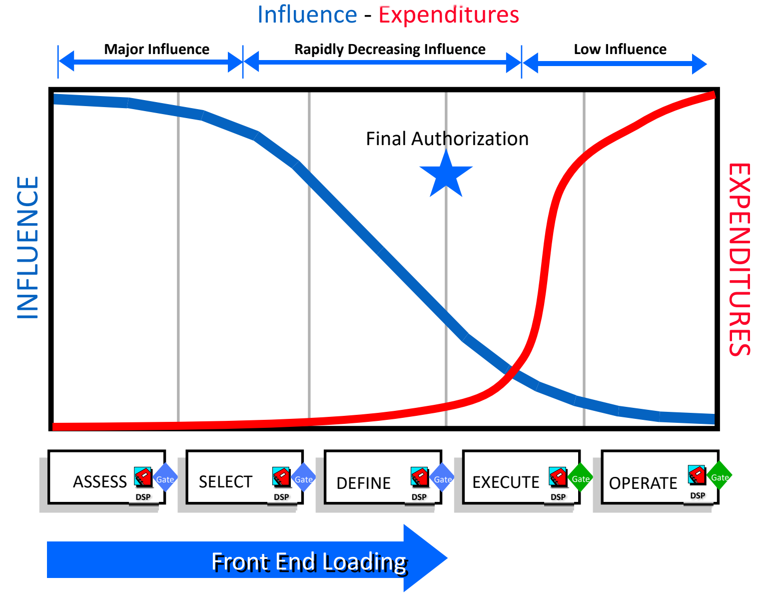
Results: 4, 500 Mscfd 6, 000 Mscfd

Probability	Trumpet Plot Factor	Grossed-up Break-even 15% ROR Rate Mscfd	Target 6,000 Mscfd / Grossed-up Break-even 15% ROR Rate Mscfd	Approximate confidence of realizing a 30% ROR given the pilot outcome
90	0.755	5960.3	1.007	46%
50	0.98	4591.8	1.307	8%
25	1.125	4000.0	1.500	1%
10	1.277	3523.9	1.703	0.10%

There is No Right or Wrong answer.

In this example we have a 90% chance of realizing our minimum ROR of 15% with a hurdle rate of 5,960 Mscfd/w. If the 4 well pilot does average 5,960 Mscfd/w, then we would have a 46% confidence that the project would deliver a 30% ROR or more if we proceed.

Project Life Cycle



Probability of Technical Success Estimating Confidence of Success

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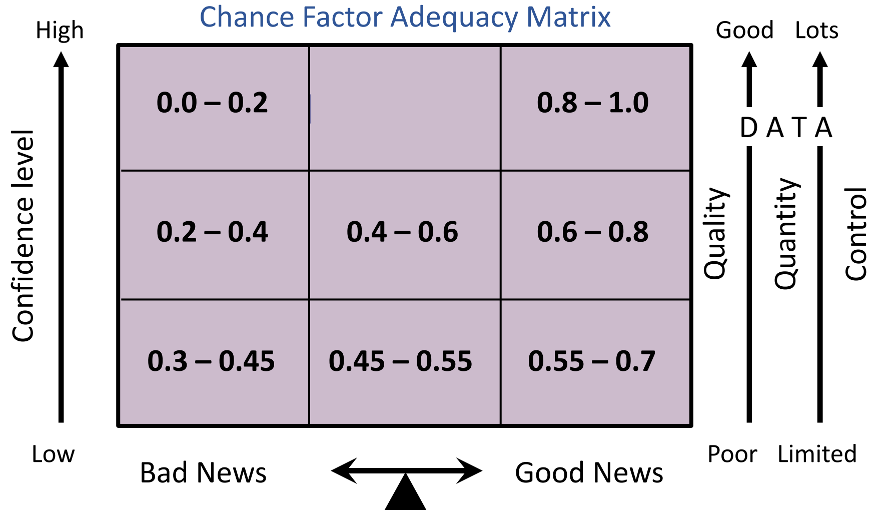


0.0 – 0.2		0.8 – 1.0
0.2 – 0.4	0.4 – 0.6	0.6 – 0.8
0.3 – 0.45	0.45 – 0.55	0.55 – 0.7

Methodology for Estimating the Value of Technology

Premise

- Technology by itself does not create wealth. Only the products and services created by that technology can be sold [1]
  - The value of a technology is best assed by estimating the commercial application of the technology
  - The commercial application of the technology, whenever possible, should be based on the application of the technology to the best credible business plan for that technology
    - Sales projections for new products
    - Business development plan for exploration and production …
- From experience, technology business case evaluations in the oil and gas industry take on clearly defined steps
  1. Evaluation of the technical impacts (positive and negative) of the technology
  2. Application of the technical impacts to agreed upon economic model or business plan
  3. Scaling (or risking) of the impacts (typically the NPV) of the technology based on the uncertainty inherent with new technology
  4. For multiple technologies applied to a single business plan or project repeat process accounting for double dipping and synergizes between technologies

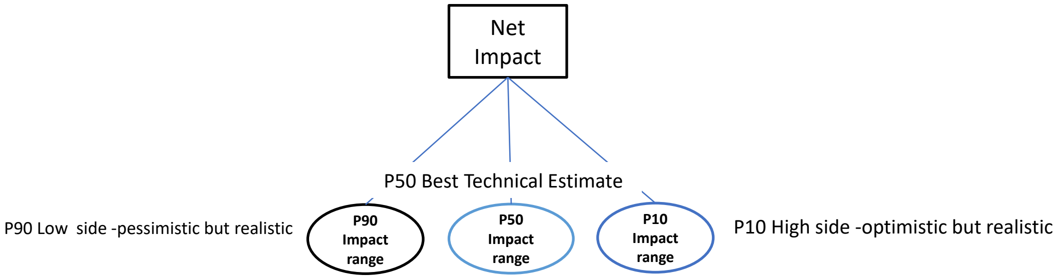
[1] Doyle, D.J., (1992). Making Technology Happen. Ontario Canada, Westboro Printers

Evaluation of the Technical Impacts

- During the initial stages of technology development, the “Professional” should be assessing how “the physics” a.k.a. the science behind the technology, could impact the key performance drivers of the firm.
- These evaluations usually take place by either assessing the available literature on documented performance of the technology or by a combination of first principal evaluations, analytical or computer models or simulations, controlled and scientific experiments, pilot or field demonstrations.
- All of these evaluations should be focused on resolving the technical uncertainty as it relates to the business case application of the technology
- The evaluations should summarize:
  - What parameters will the new technology impact?
  - How the performance improvement will be measured to validate the new technology?
  - The key areas of business impact (for example SOR, improved recovery, capital costs, GHG emissions, footprint).
  - Given technical success, what is the range of uncertainty for each impacted variable, for example the range of SOR improvement.
  - An estimate for the capital and operating costs, commensurate with the TSRL stage you are in.

Methodology for Estimating the Value of Technology

- Each impacted variable should be modeled to show the net impact that technical uncertainty in this area has on the business case.
  - The impact should be measured as a P90, P50, P10 outcomes.
  - Determine which of the variables are independent and which are dependent. Model the dependency between variables using first order linear correlations (for example SOR and GHG improvements).
- The variables should be combined in a probability tree to best assess the full impact the technology would have on the business case



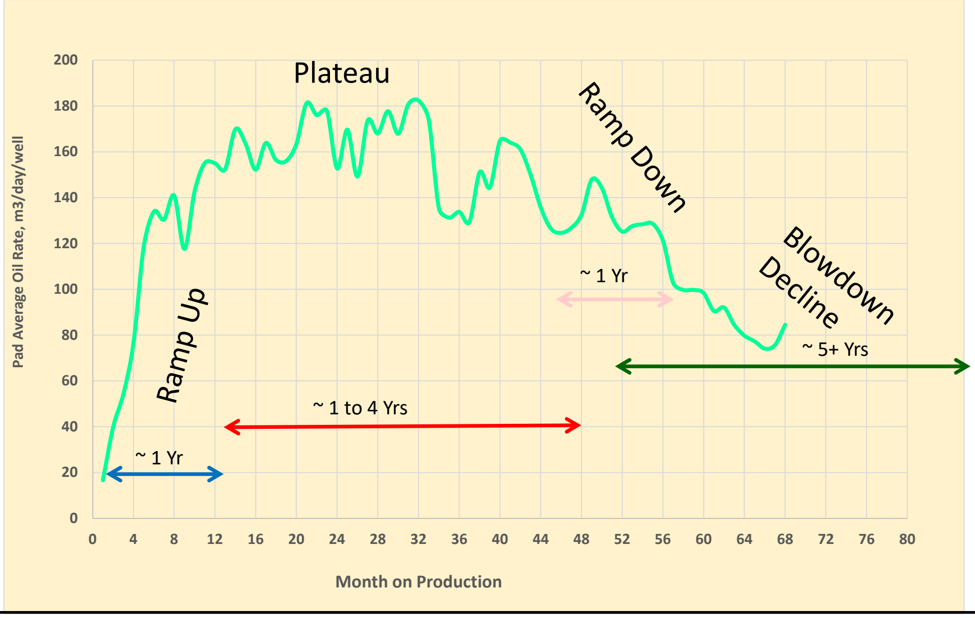
Modeling The Inputs

- The thought process of understanding what can cause Technical failure, with the application of a new technology, leads to an insightful discussion on what we need to design our lab work and/or pilots around.
- Contrary to intuition the best pilots test for failure and not just success. The supports an early exit.
- By breaking down how each new technology will impact, for example, the SAGD process, from surface to sub-surface, we can have a meaningful discussion on the probability of technical success as well as the range of possible outcomes.

Modeling The Inputs

- Technologies can be modeled based on their impacts on the drivers of economic value: Eg. EUR, Rate, SOR etc.
    - Eg. Plant steam efficieniency can be modeled as allowing new wells to be drilled sooner. The impact is an increased oil rate.
- Other technologies are better modeled with OPEX reductions or an increase in product price. Such as:
    - Solvent reduction
    - Maintenance Capital reduction (reliability)
    - Facilities De-bottlenecking (may also impact rate and SOR)
    - In-situ Upgrading – changing the sales product
- To Evaluate "new technology" we will need to
    - Determine input ranges with the current technology
    - Reality check the possible range of the impacted variable(s) using the new technology

Modeling The Inputs – What Stage Will The Tech Impact?



Determining The Chance of Commercial Success

Steps:

1. Determine the range of Uncertainty in the impact of the technology
    - Know what the impacted variables are and how success and failure will be measured.
    - Must be able to translate the impact to at least one of an economic model's variables.
    - Build a reverse cumulative plot of the incremental values of the impacted variable(s)

2. Run an incremental economic model. All variables other then the impacted variables are kept at their mean input value. New Tech case with CAPEX, OPEX and Royalty changes etc. less the base case development.

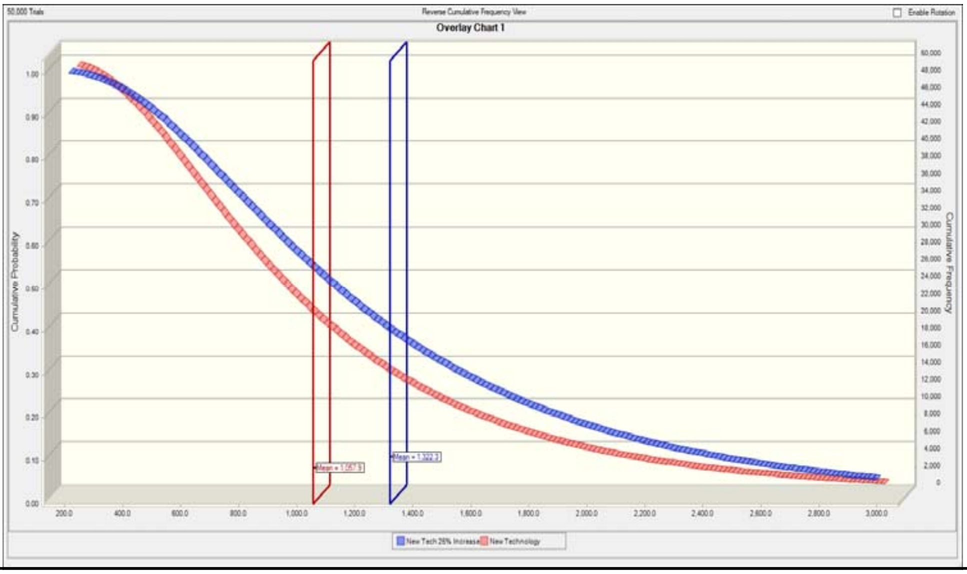
3. Reverse engineer the incremental economic model until we realize a minimum acceptable economic return for the success case – E.g. PV10 = 0, or ROR = 20% etc.

4. Determine the value of the impacted variable that delivers the PV10 = 0 break-even scenario

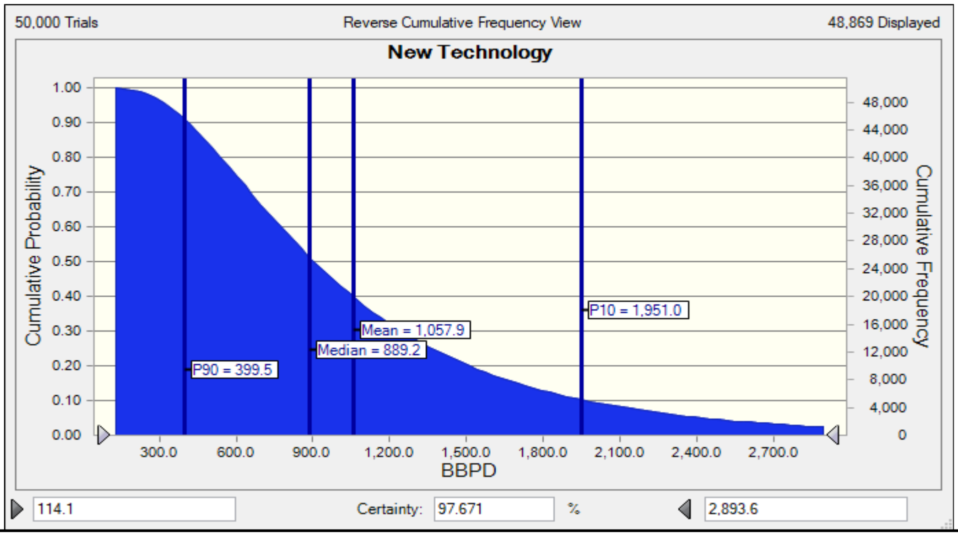
5. Build a reverse cumulative plot of the impacted variable in step 1 to derive the Probability that a successful implementation of the technology will be commercial.

A Technology Has an Expected Increase of 25%

Blue Curve Represents The Range of Outcomes, Given Technical Success.

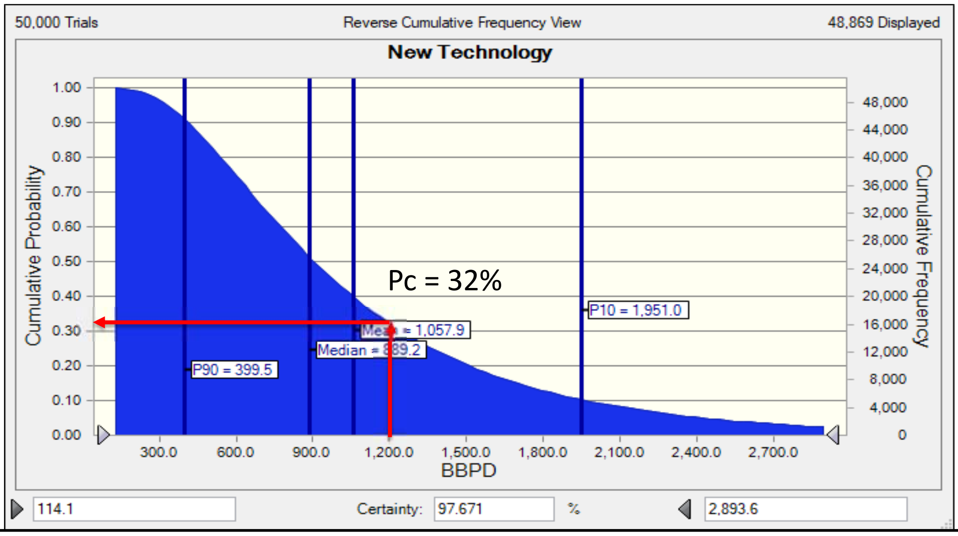


To determine the Probability of Commercial success we need to reverse engineer our economic model to determine what minimum incremental value, from a successful application of the new technology, will meet or exceed our firm's cost of capital - E.g. PV10 = 0



114.1 Certainty: 97.671 % 2,893.6

Enter the reverse cumulative plot with the minimum incremental rate, e.g. 1,200 BB/d on the X axis and then project up to the reverse cum. curve and record the Cumulative Probability on the Y axis.
This is the Probability that the Project will meet or exceed the Commercial threshold of 1,200 BB'd.



114.1 Certainty: 97.671 % 2,893.6