Understanding Type-well Curve Complexities & Analytic Techniques

Reservoir, Evaluation and Production Optimization

VERDAZO

Disclaimer and Objectives

- The content of this presentation is intended to illustrate the complexities associated with type-well curve development using monthly vendor/public production data and demonstrate analytic techniques that may provide insights when developing type-well curves.

- These type-well curve analysis techniques are complimentary and informative to workflows involving scientific modelling tools, forecasting tools and economic evaluation tools.

- The relevance of each topic will depend on what you're trying to accomplish.

Clarification: Type-well Curve vs Type Curve

While "Type-well Curves" are often referred to as "Type Curves", they are different.

Type Curves more properly refer to idealized production plots (based on equations and/or numerical simulation) to which actual well production results are compared.

Type-Well Curves are based on actual well production data and represent an average production profile for a collection of wells for a specified duration.

Why are Type-well Curves Important?

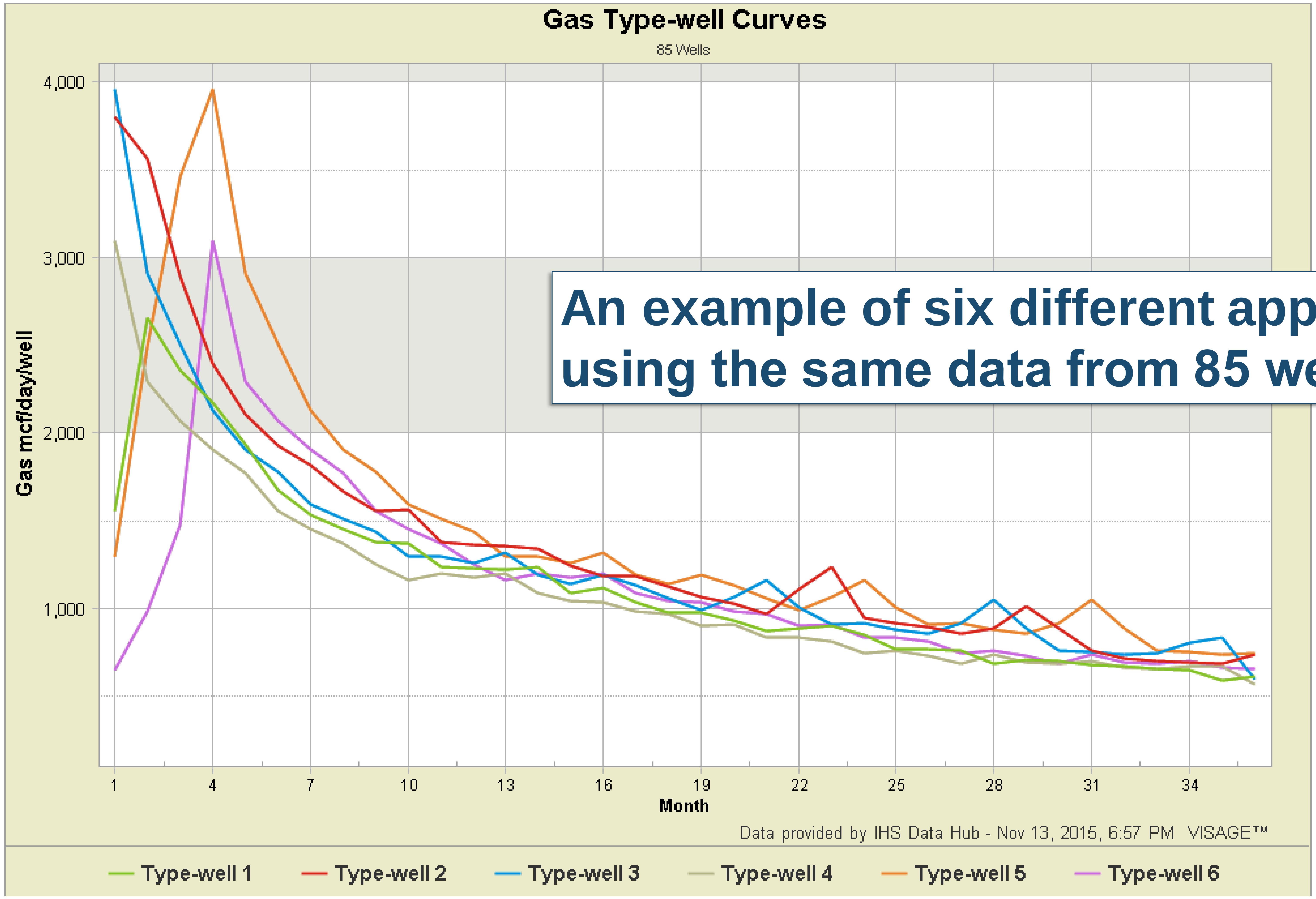
Type-well Curves are a foundation of:

- reserves evaluations
- development planning
- production performance comparisons
- completion optimization analysis

The dangers of not understanding the complexities of Type-well Curves, and failing to communicate how they were designed/developed, can result in:

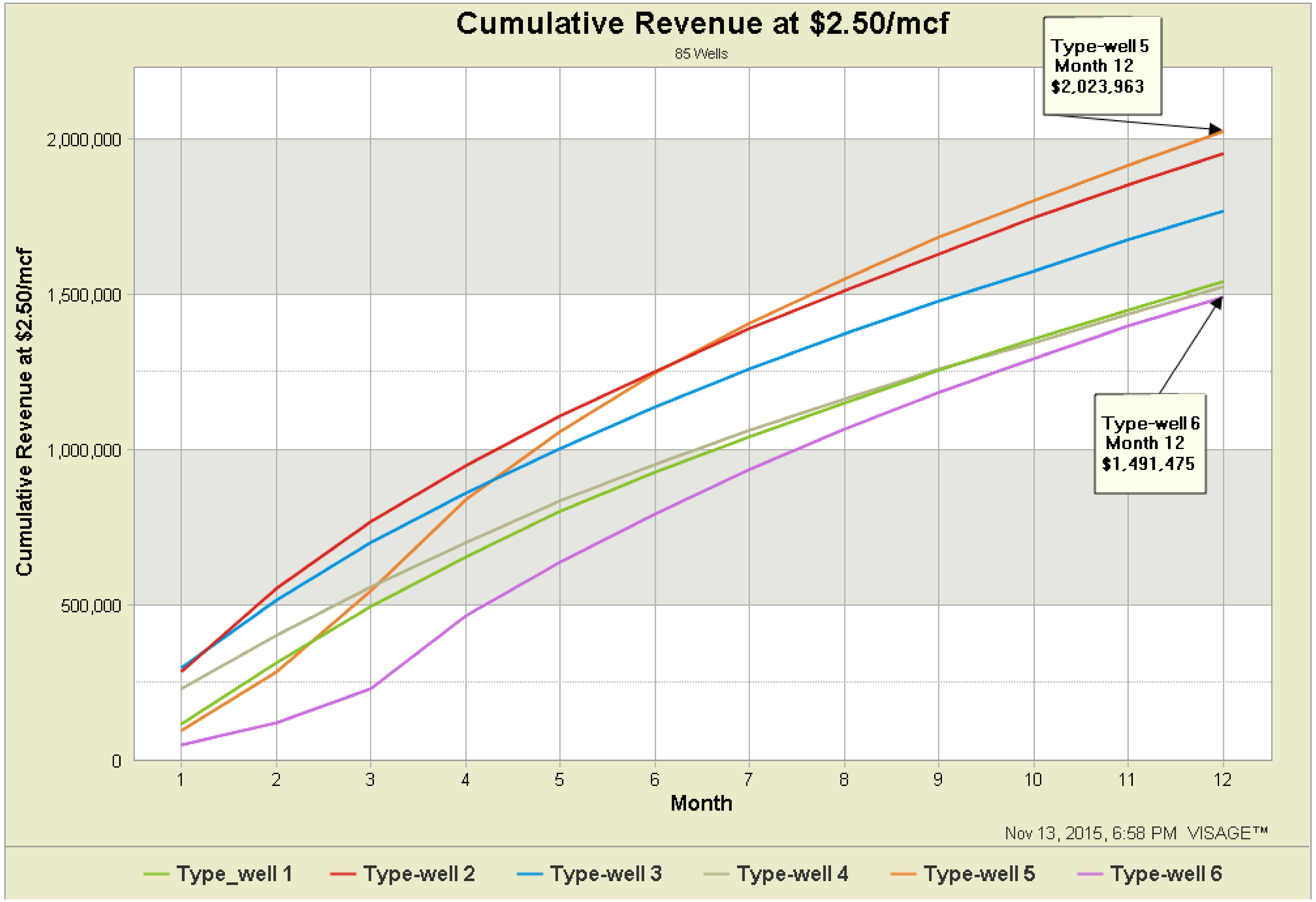
- large statistical variability
- inconsistent information used in development decisions
- unattainable economic plans (especially in the unforgiving times of low commodity prices).

Why are Type-well Curves Important?



An example of six different approaches to Type-well Curves using the same data from 85 wells…

Why are Type-well Curves Important?



For this example the different type-well curves yield results that vary >$500K in the first year.

This should concern any decision maker!

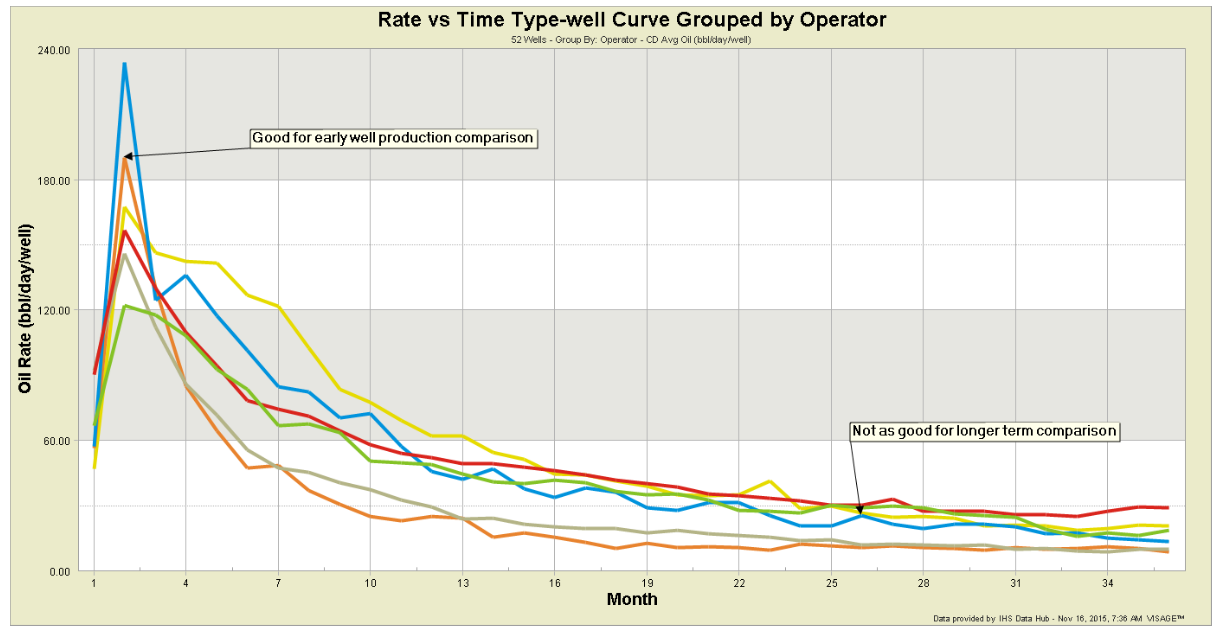
Presentation Outline

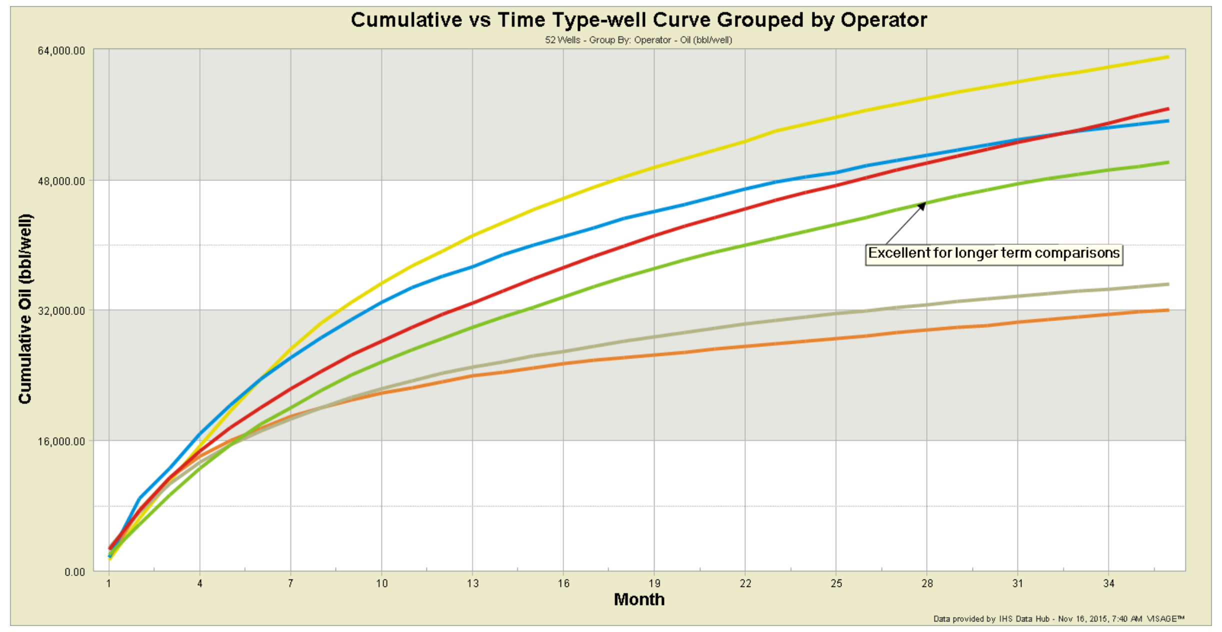
1) Chart Types
2) Analogue Selection
3) Normalization
4) Calendar Day vs Producing Day
5) Condensing Time
6) Operational/Downtime Factors on Idealized Curves
7) Survivor Bias
8) Truncation Using Sample Size Cut-off
9) Forecast the Average vs Average the Forecasts
10) Representing Uncertainty
11) Auto-forecast Tools

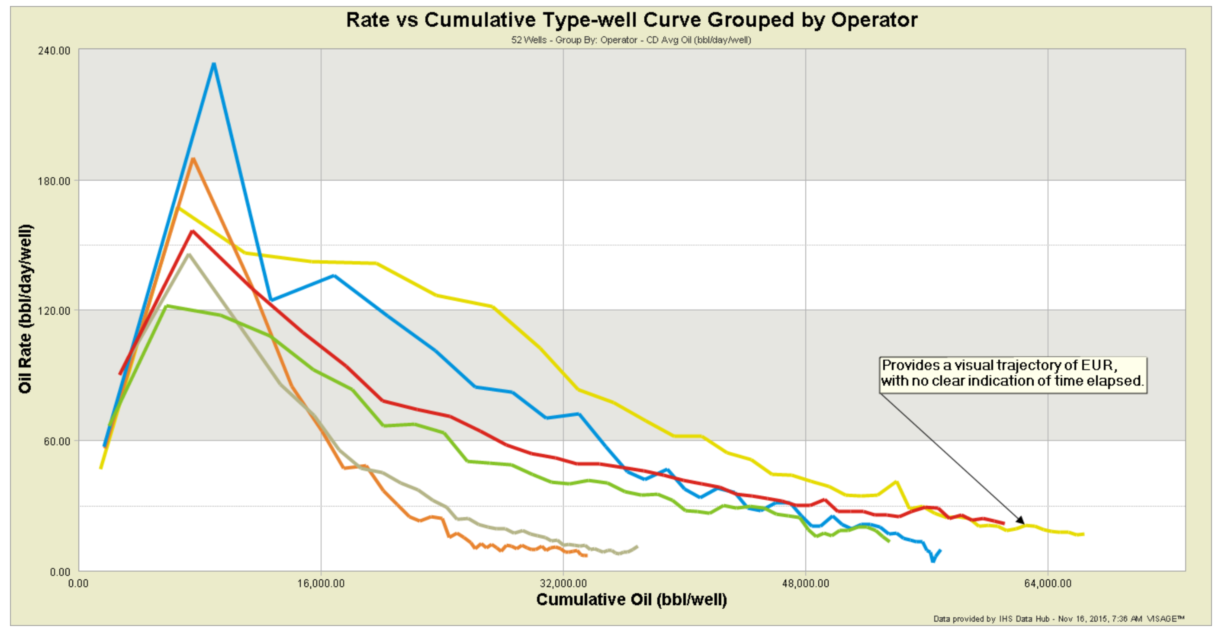
1) Use Multiple Charts to Build a Narrative

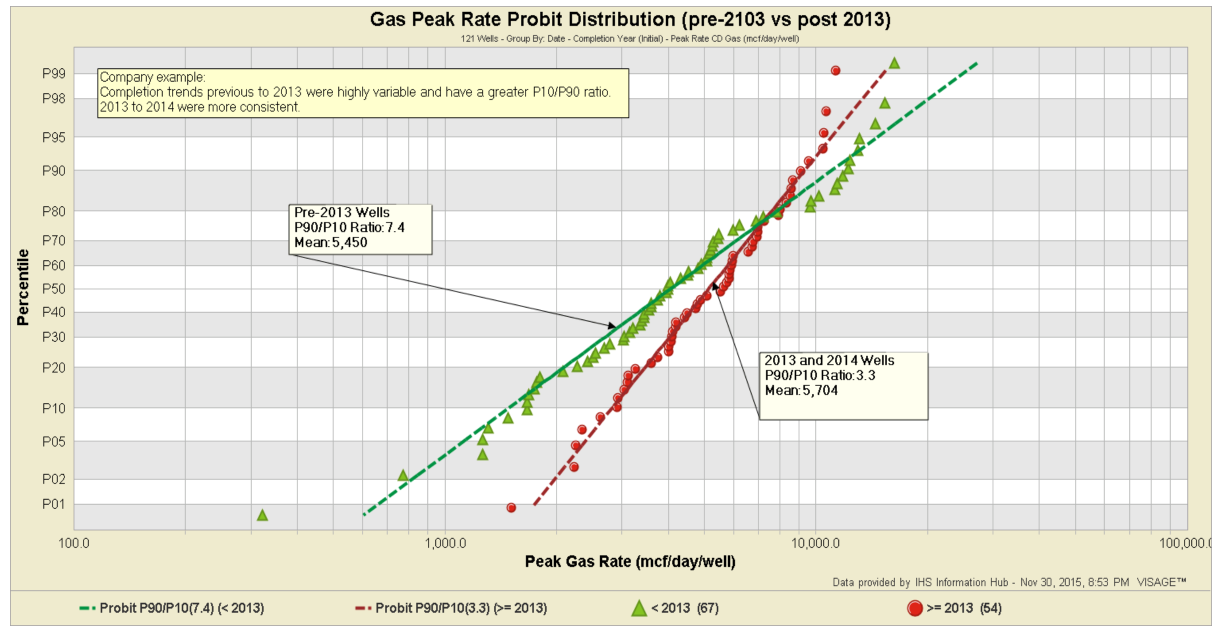
Common chart types include:

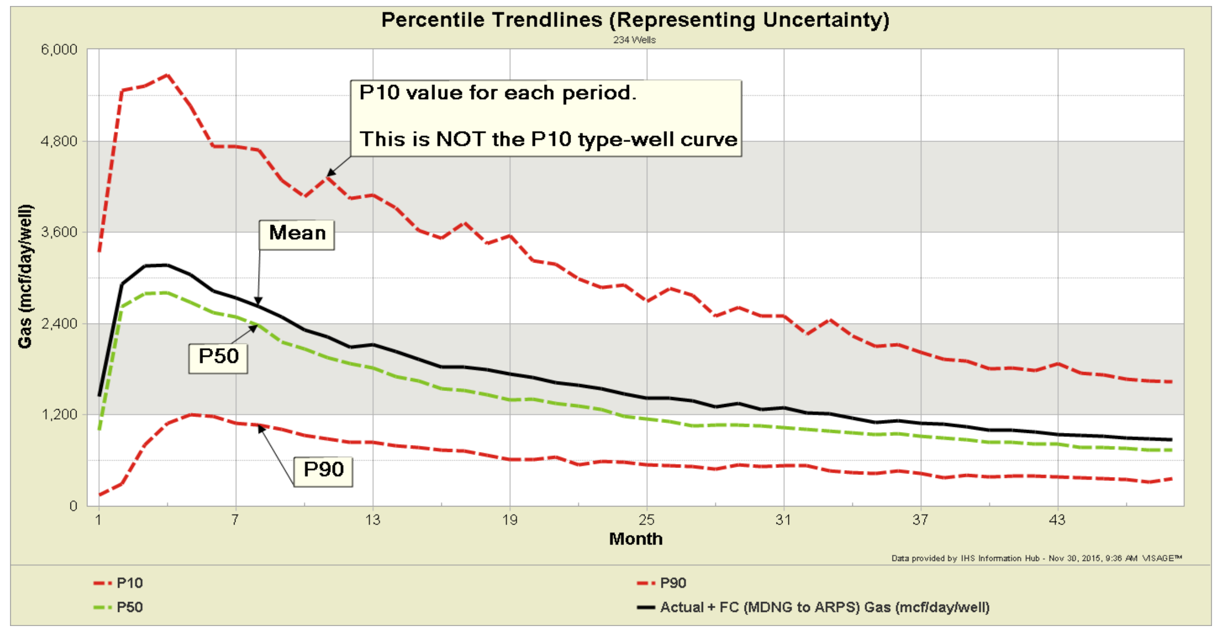
1) Rate vs Time
2) Cumulative Production vs Time
3) Rate vs Cumulative Production
4) Percentile (Cumulative Probability)
5) Probit Scale Percentile

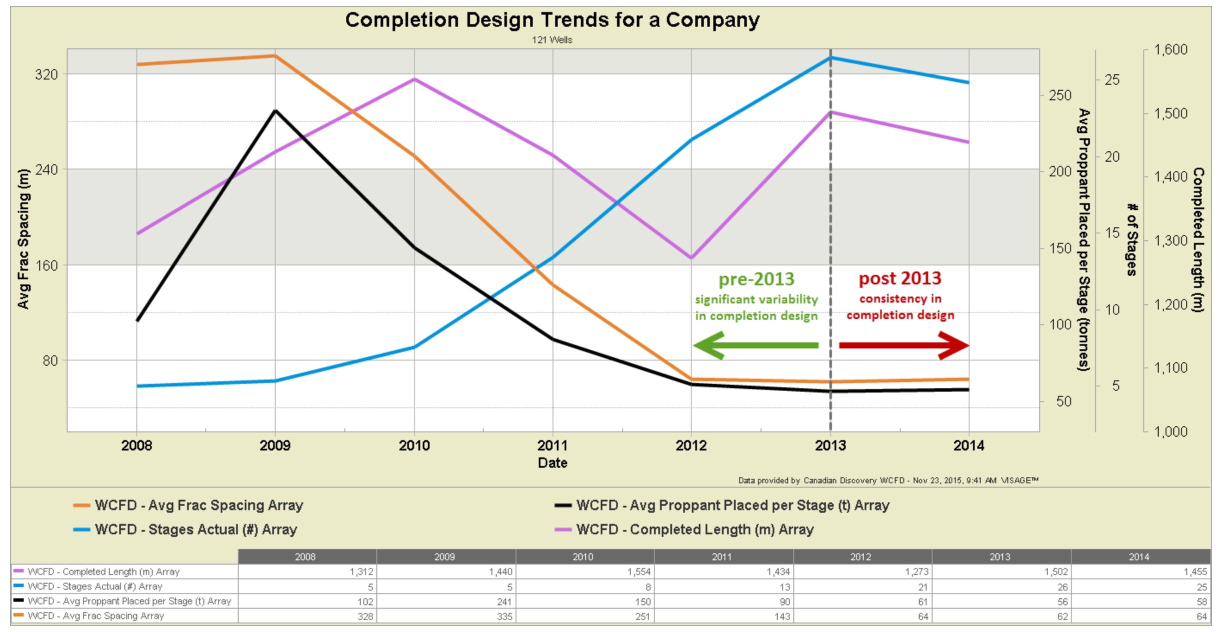












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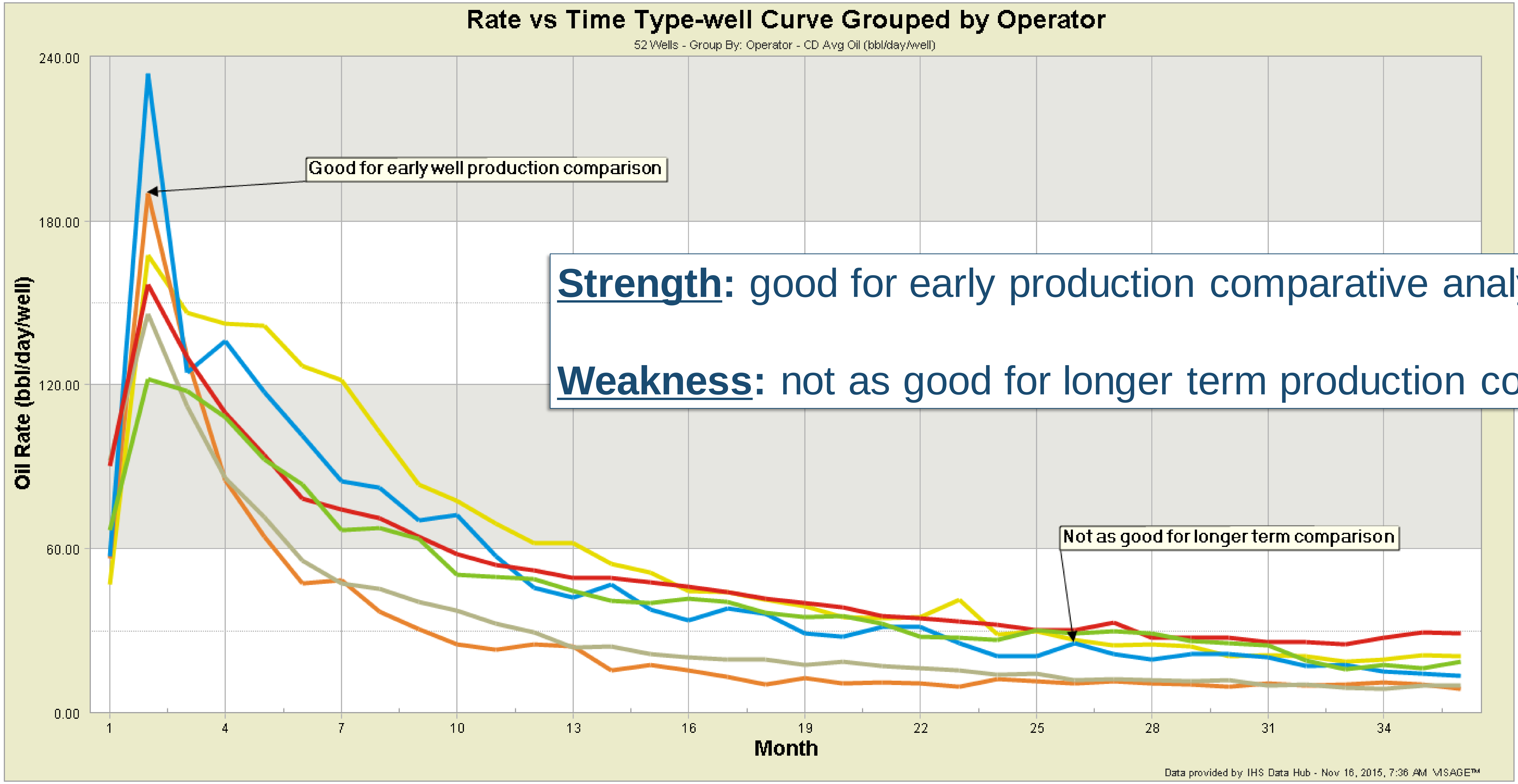
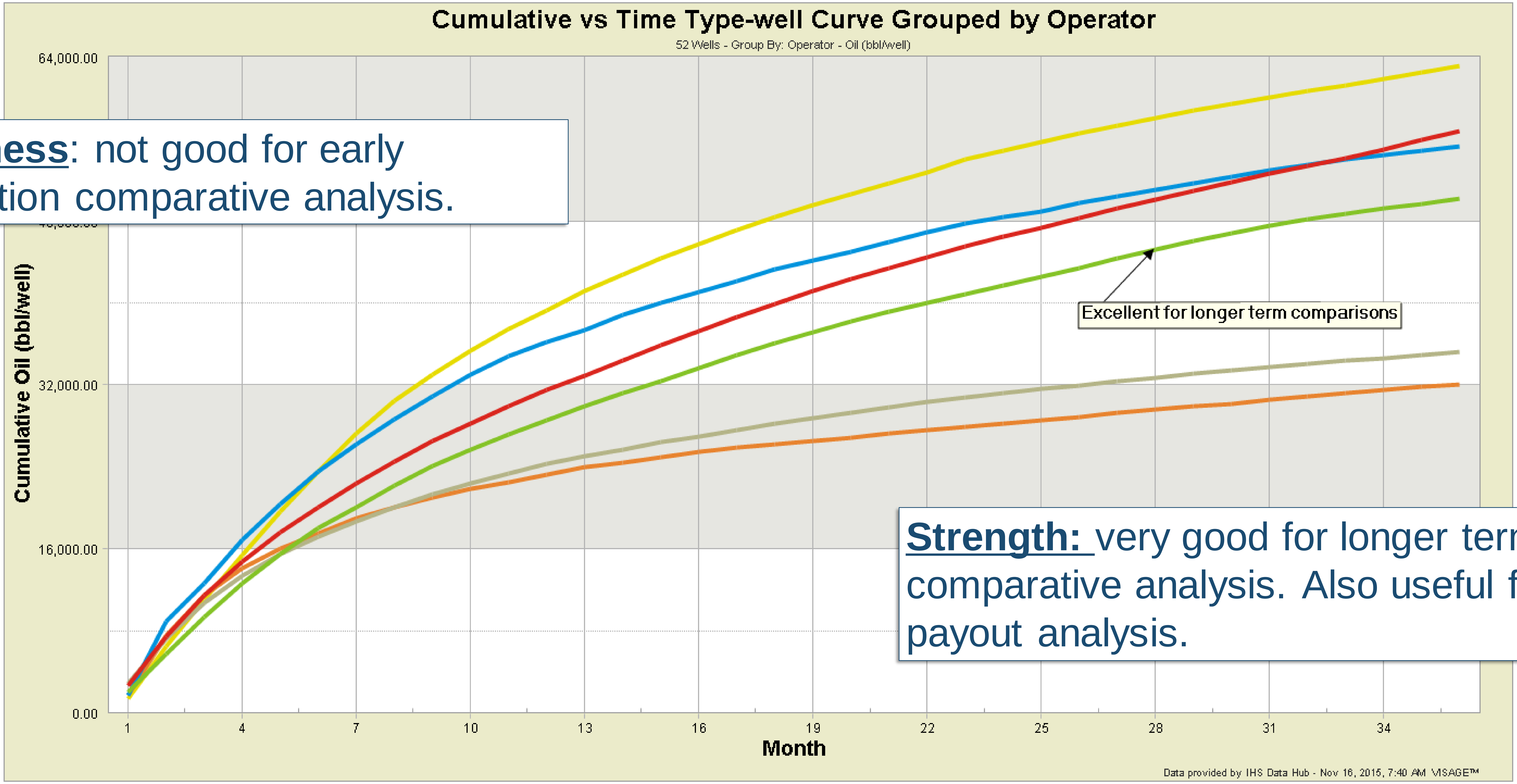
1.1) Rate vs Time



Strength: good for early production comparative analysis.

Weakness: not as good for longer term production comparative analysis.

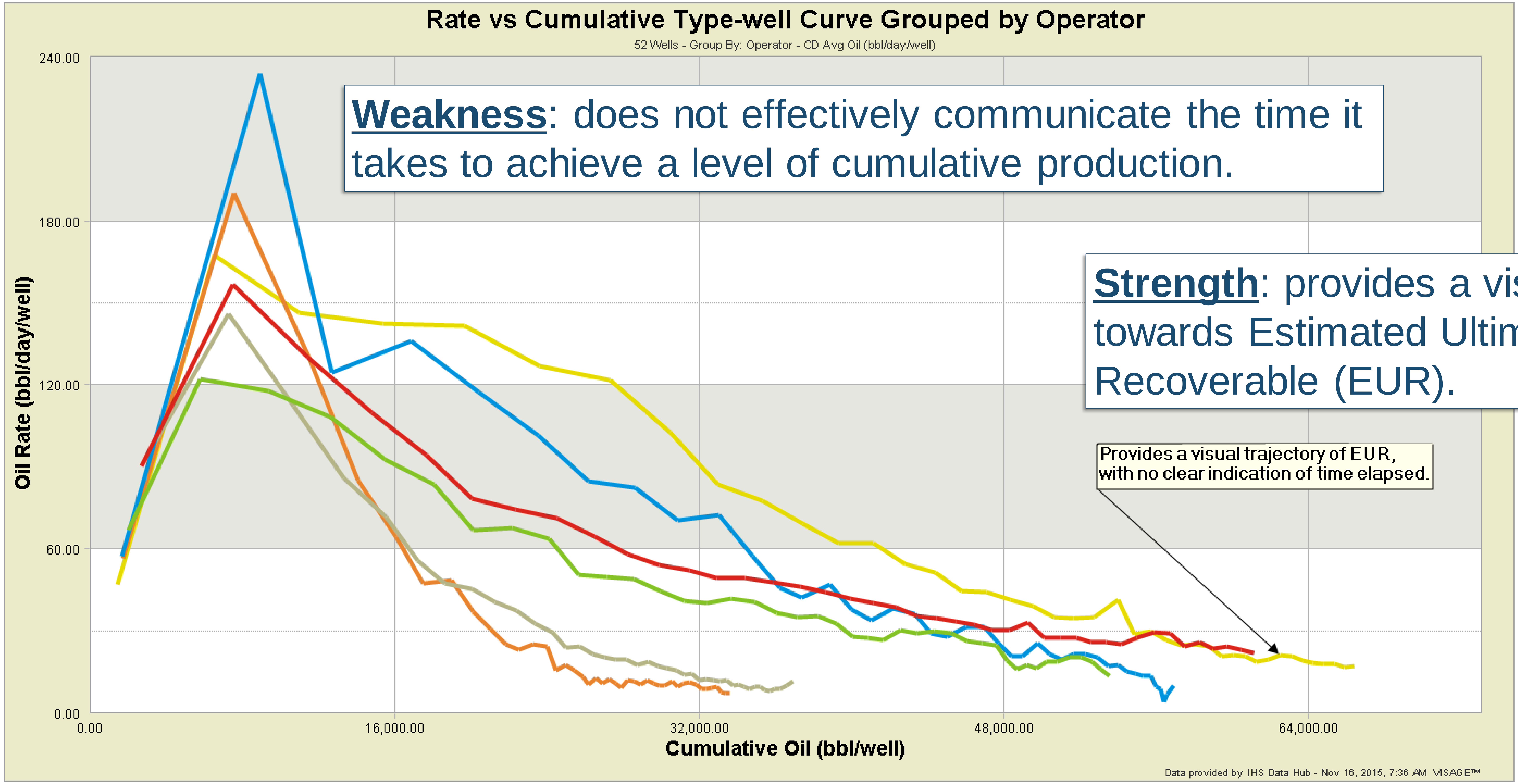
1.2) Cumulative Production vs Time



Weakness: not good for early production comparative analysis.

Strength: very good for longer term comparative analysis. Also useful for quick payout analysis.

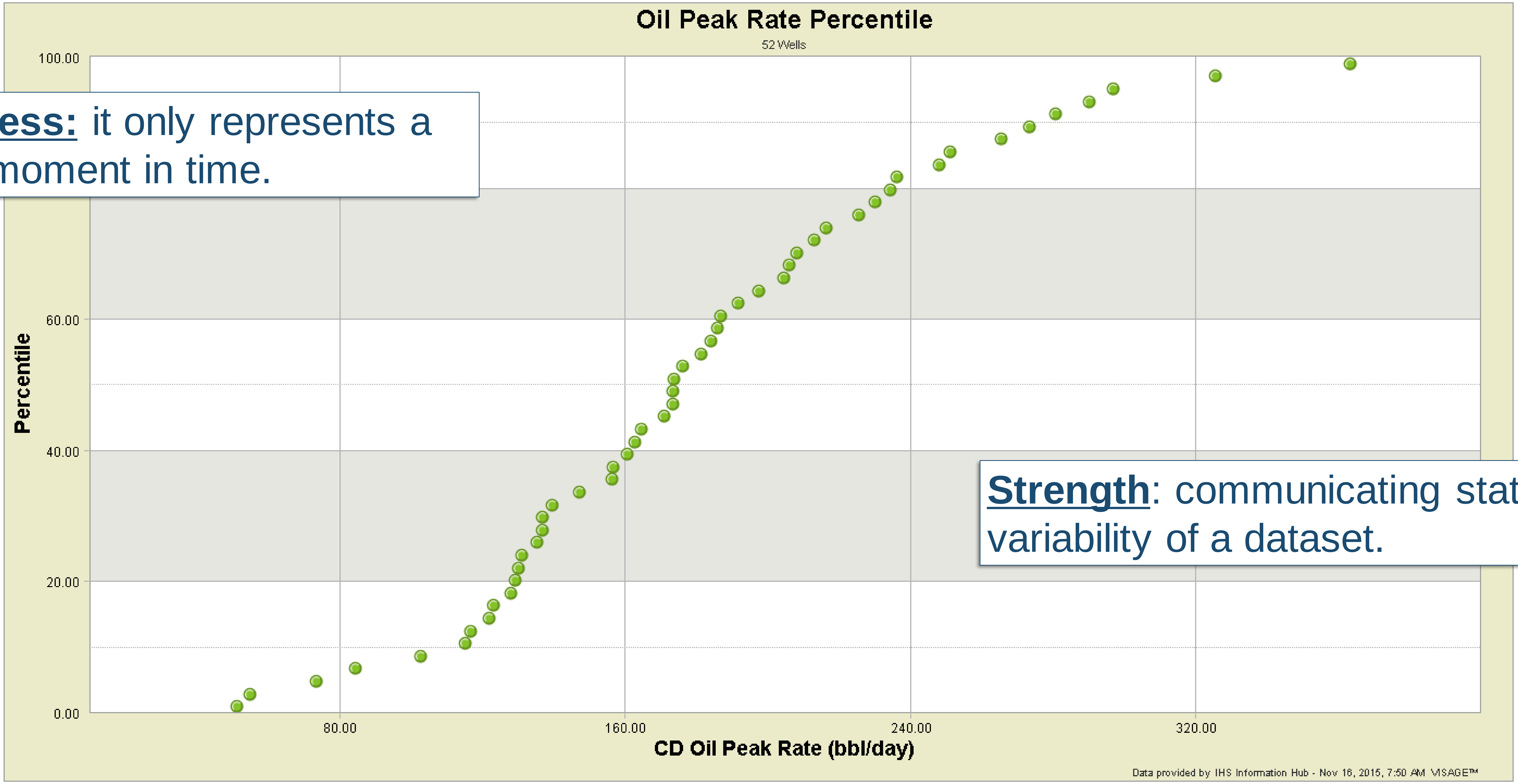
1.3) Rate vs Cumulative Production



Weakness: does not effectively communicate the time it takes to achieve a level of cumulative production.

Strength: provides a visual trajectory towards Estimated Ultimate Recoverable (EUR).

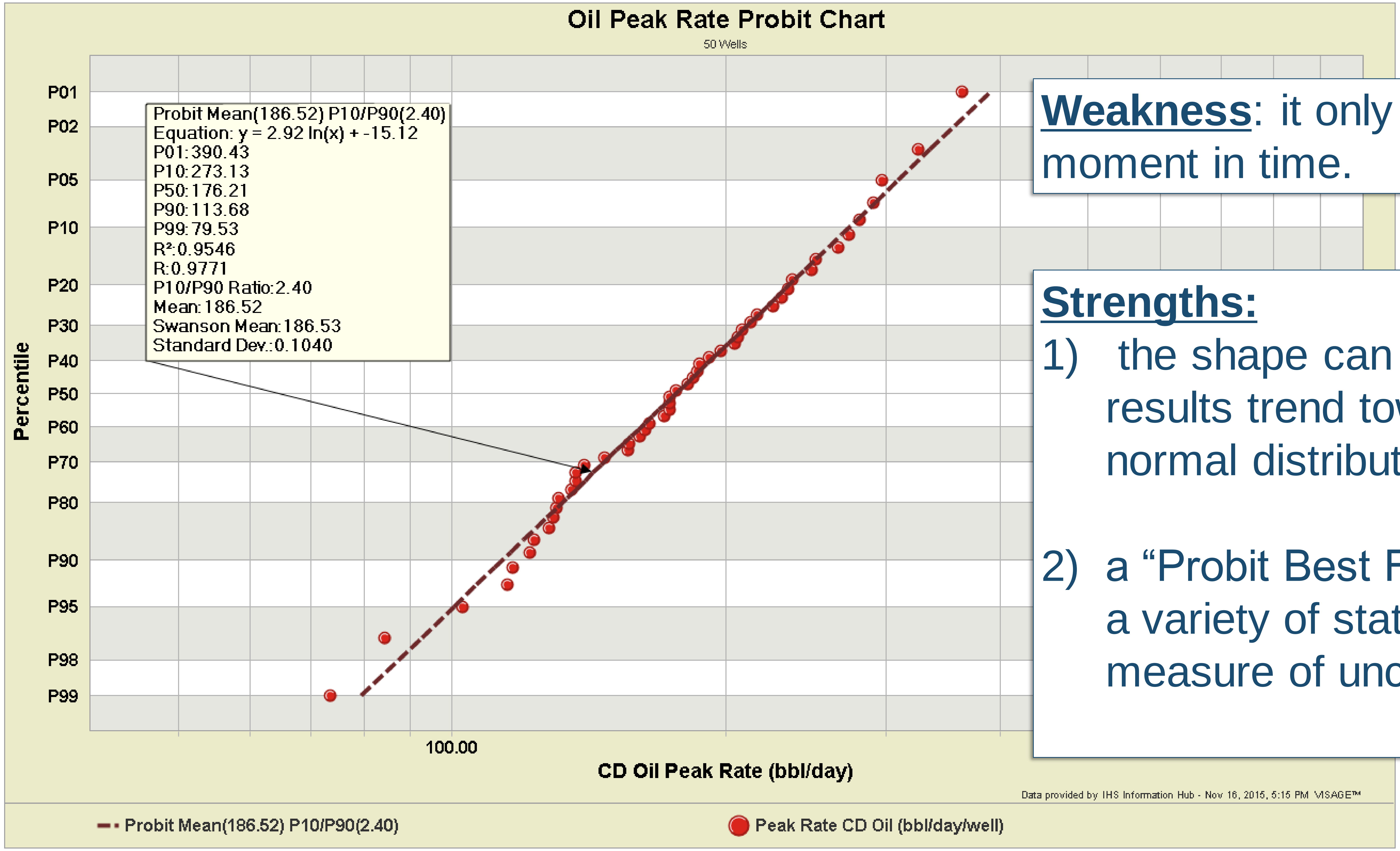
1.4) Percentile (Cumulative Probability)



Weakness: it only represents a single moment in time.

Strength: communicating statistical variability of a dataset.

1.5) Probit Scale (Cumulative Probability)



Weakness: it only represents a single moment in time.

Strengths:

1) the shape can help determine if the results trend towards a lognormal or normal distribution
2) a "Probit Best Fit" regression can provide a variety of statistical insights including a measure of uncertainty (P10/P90 Ratio)

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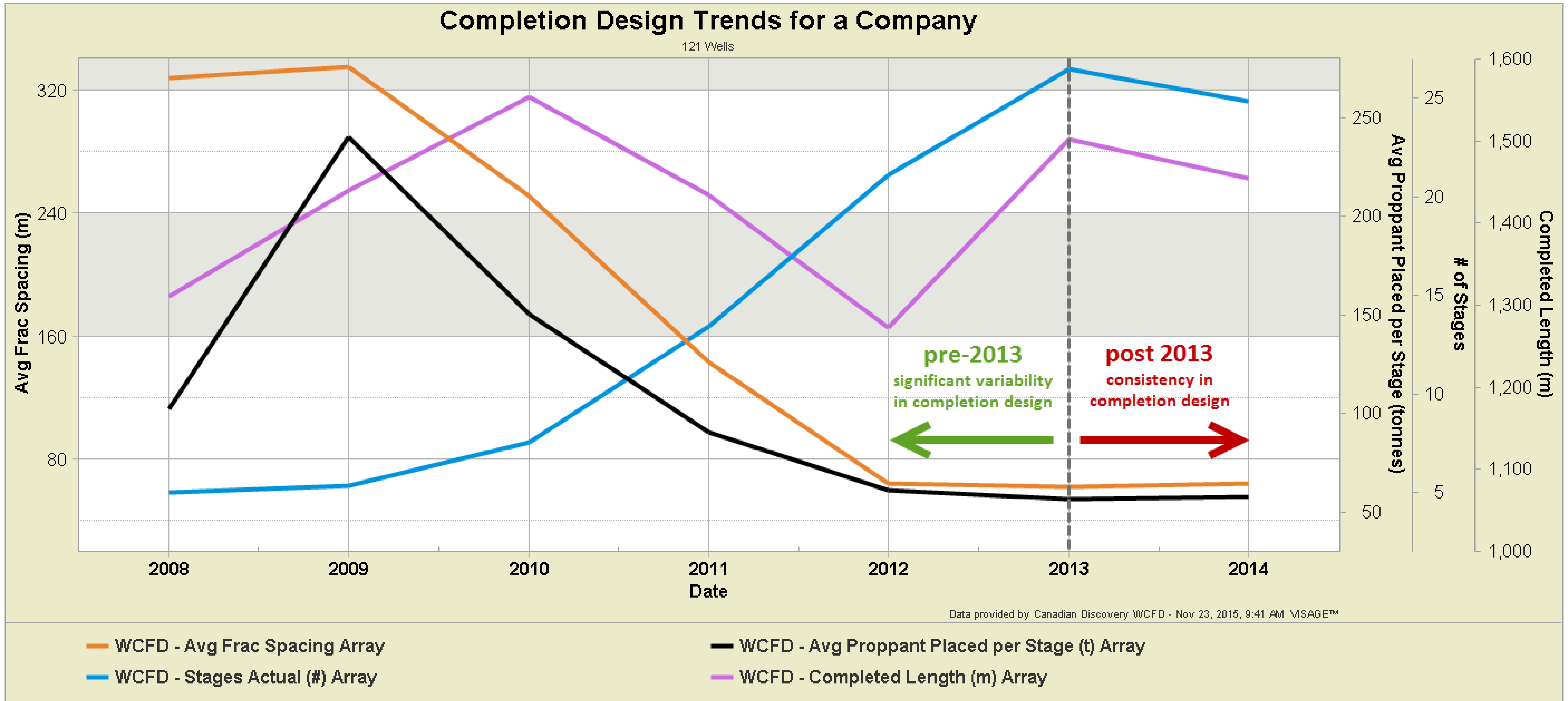
2) Analogue Selection (the most important step)

- Analogue wells should have a similarity on which a comparison may be based and represent the range of possible outcomes (i.e. don't just select the best wells).
- Selecting wells with similar characteristics may reduce the range of uncertainty in your type-well curve.
- Common criteria for selecting similar wells include:
  1) Geology
  2) Reservoir
  3) Well Design
  4) Well Density
  5) Operational Design

2.3) Analogue Selection (Well Design)



	2008	2009	2010	2011	2012	2013	2014
WCFD - Completed Length (m) Array	1,312	1,440	1,554	1,434	1,273	1,502	1,455
WCFD - Stages Actual (#) Array	5	5	8	13	21	26	25
WCFD - Avg Proppant Placed per Stage (t) Array	102	241	150	90	61	56	58
WCFD - Avg Frac Spacing Array	328	335	251	143	64	62	64

How do distributions of initial rates compare for these data sets?

1) pre-2013 wells (highly variable completion design)

2) post-2013 wells (consistent completion design = similar wells)

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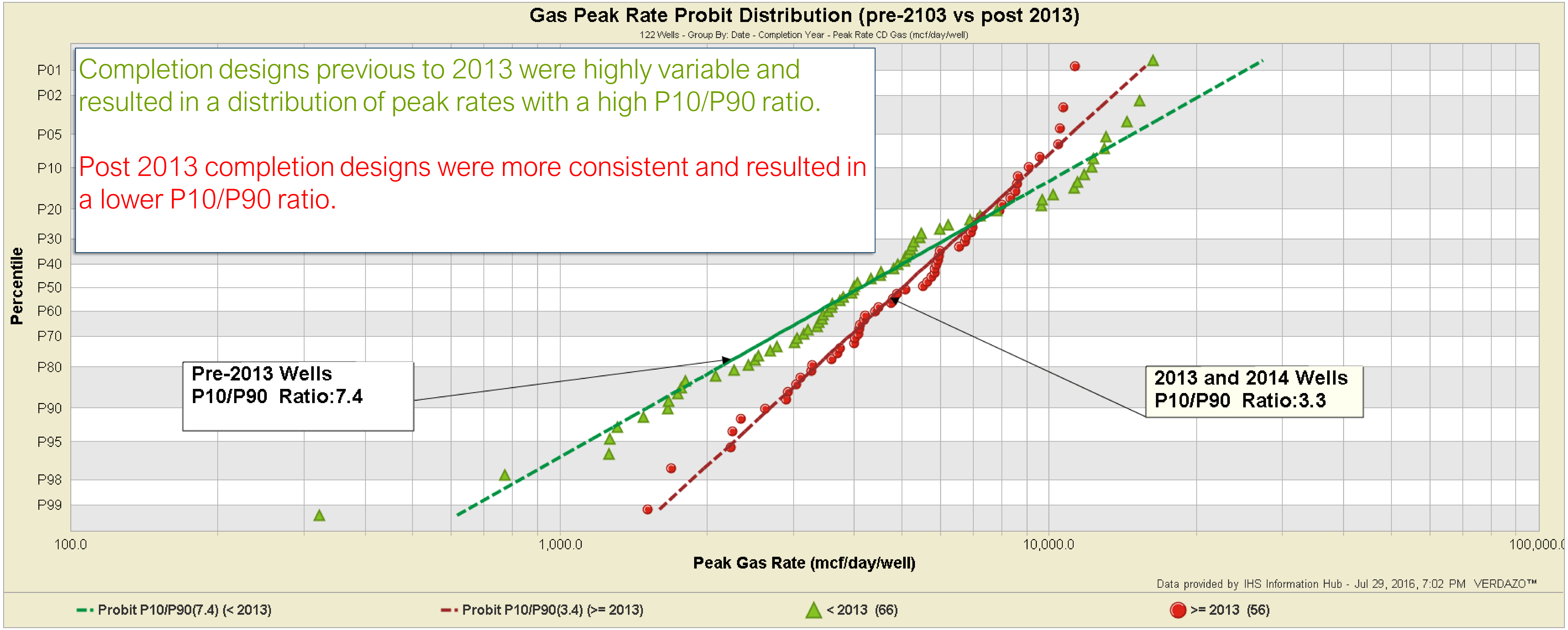
2.3) Analogue Selection (Reducing Uncertainty)



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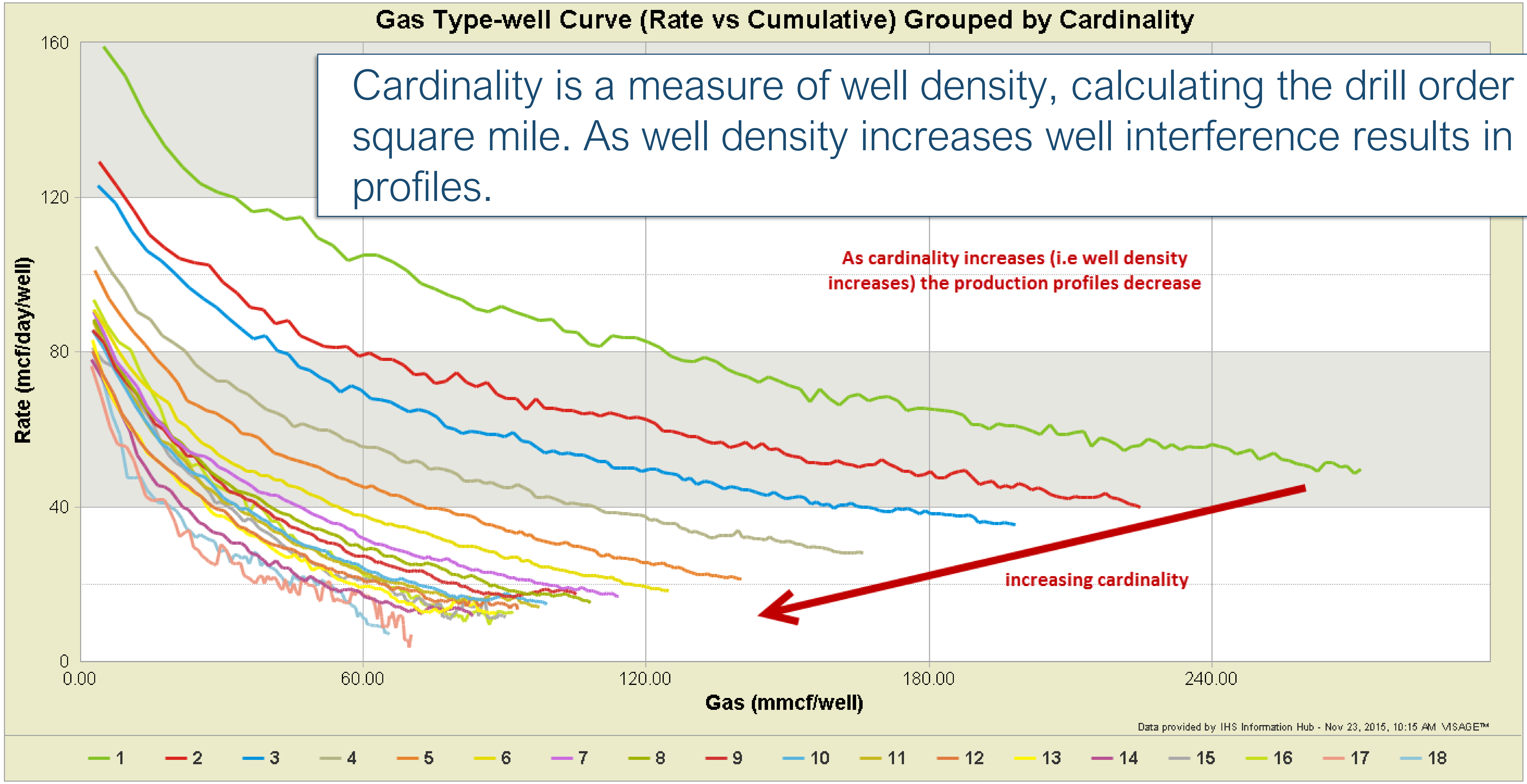
2.4) Well Density (using Cardinality)



Cardinality is a measure of well density, calculating the drill order of each well within a square mile. As well density increases well interference results in lower production profiles.

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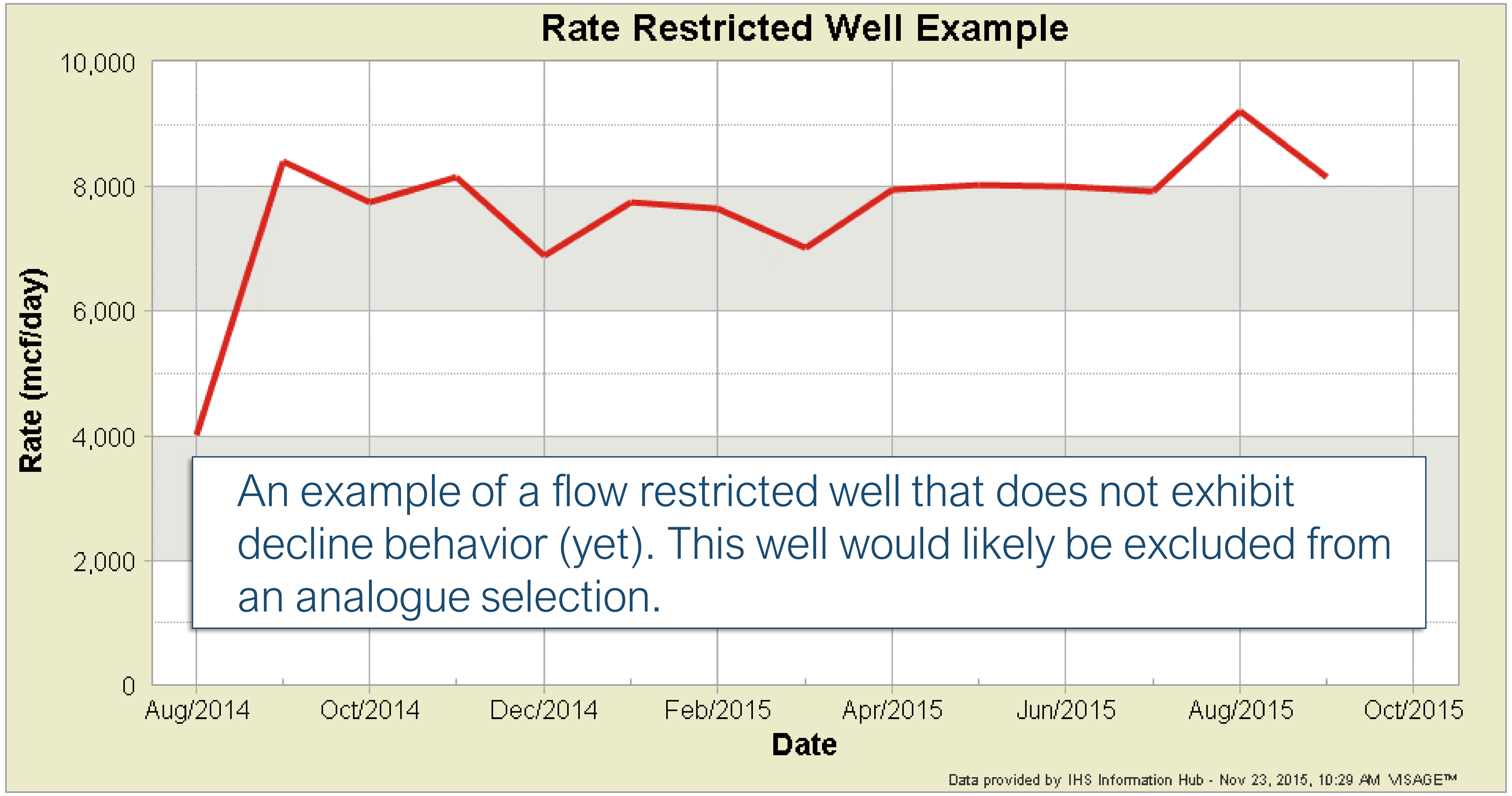
2.5) Operational Design

- Capacity constraints (curtailment), contracts and operational constraints (line pressure) are examples of production restrictions **imposed on you** given your operational environment.

- With the increase in proppant loading and better deliverability some operational designs that **you choose to impose** may strive to maintain bottom hole pressure, control flowback of sand, minimize base decline, enhance production yields (e.g. condensate-gas ratio), or maximize EUR.

2.5) Operational Design



1) Scroll through your dataset and look at each well
2) Isolate and exclude wells that do not demonstrate expected production decline behavior
3) Where identifiable declines begin after a period of rate restriction, you may (cautiously) consider manually adjusting the normalization date and include the well

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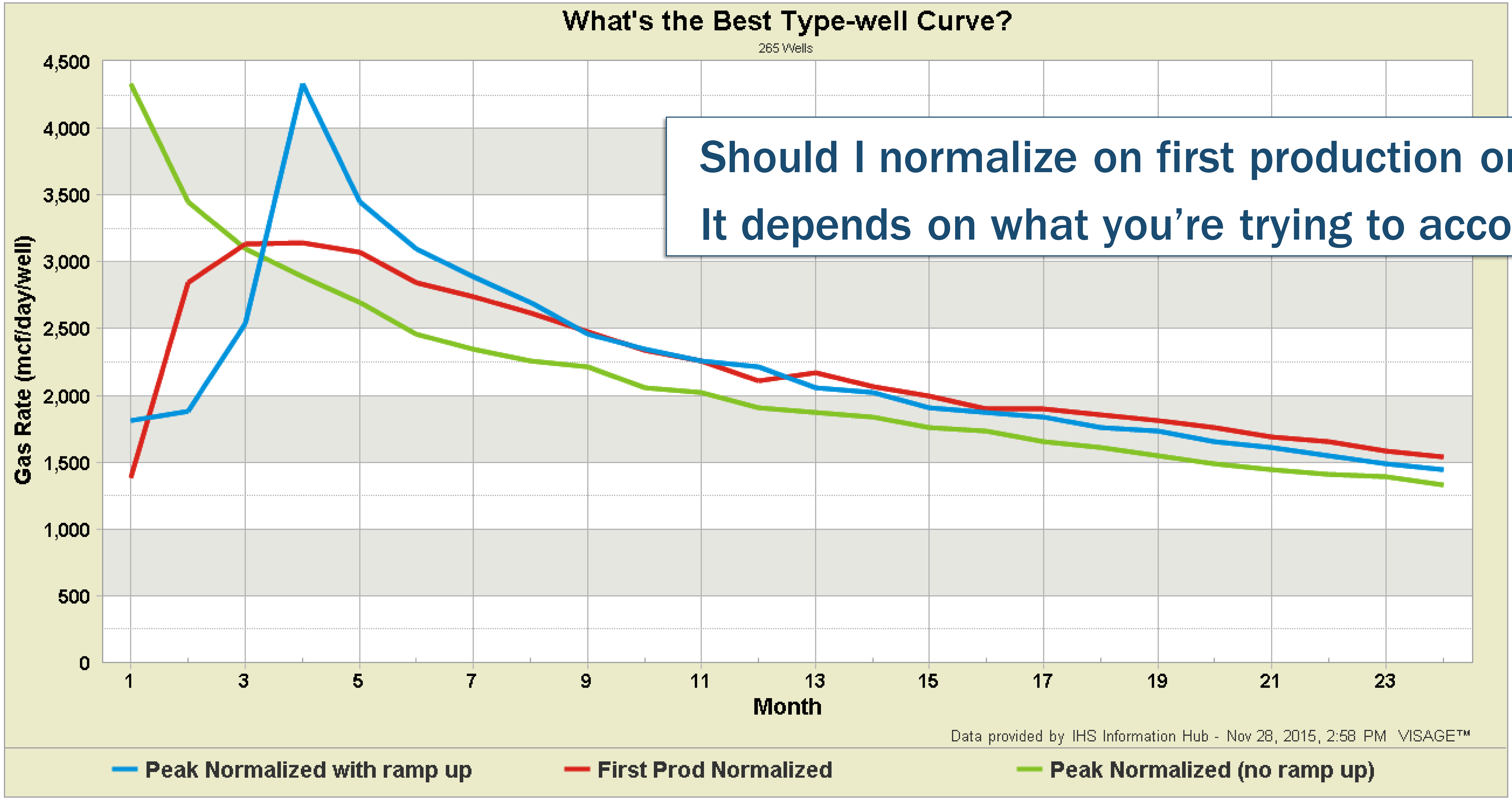
3) Normalization

Normalization is a means of restructuring data to improve comparability (i.e. “leveling the playing field”).

1) <u>Time Normalization</u>
   - Alignment of months relative to a common date or event
   - Common dates used are first production date and peak rate date
2) <u>Dimensional Normalization</u>
   - Sometimes referred to as “Unitization”
   - Scaling production values relative to a well design parameter (Example: production/lateral length)
3) <u>Fractional Normalization</u>
   - Scaling production values relative to the peak rate

3.1) Time Normalization



Should I normalize on first production or peak rate date?

It depends on what you're trying to accomplish.

3.1) Time Normalization

Time Align on First Production

Strength: on larger well sets, communicates the average production profile taking into account variability in time to peak. Suitable for some comparisons (e.g. operator, vintage).

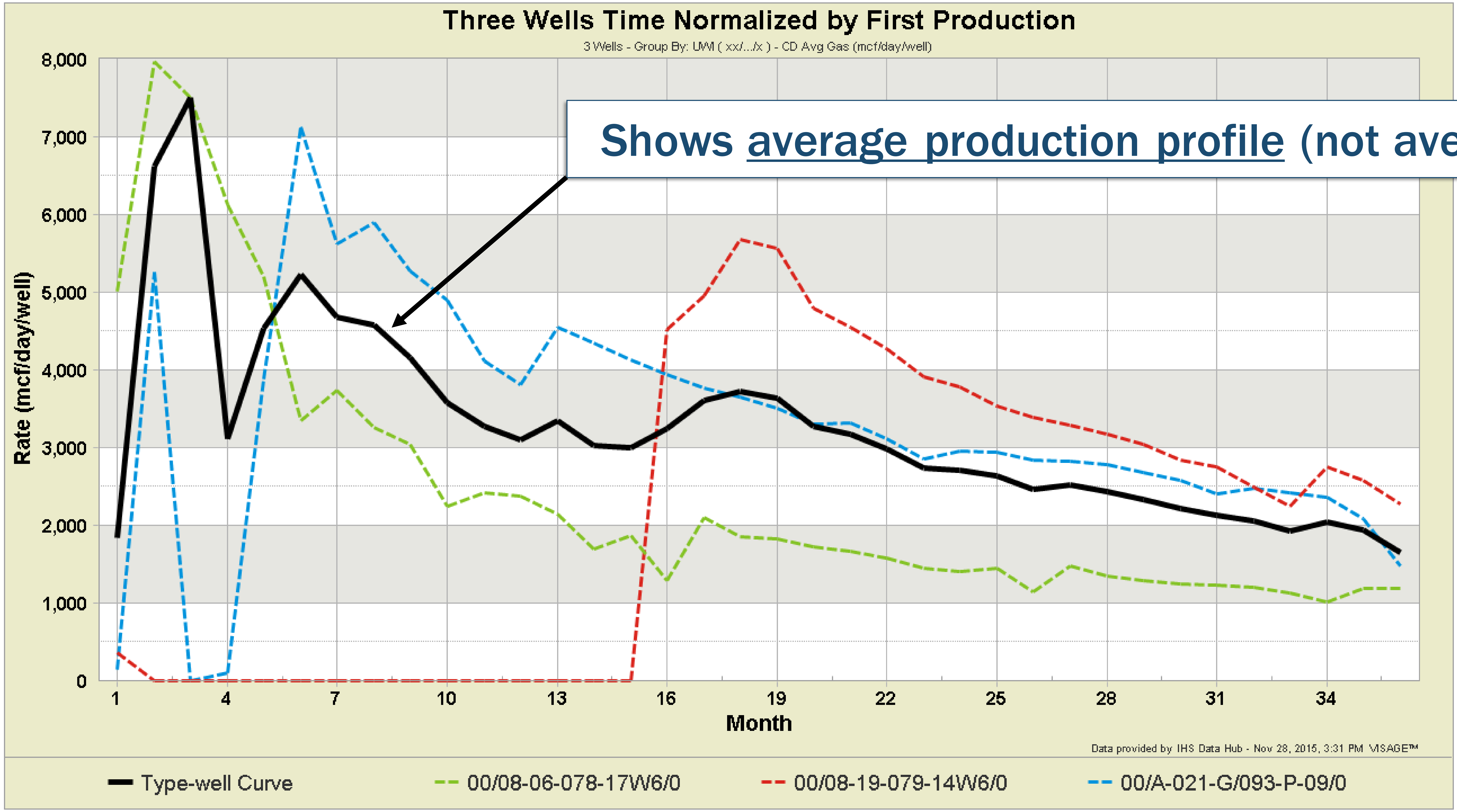
Weakness: may not accurately reflect production decline behavior.

Time Align on Peak Rate Date:

Strength: more accurately reflects production decline behavior.

Weakness: excludes ramp up time (to peak) which has a small impact on EUR but is important to first year revenue projections.

3.1a) Time Normalization on First Production



Shows average production profile (not average decline profile)

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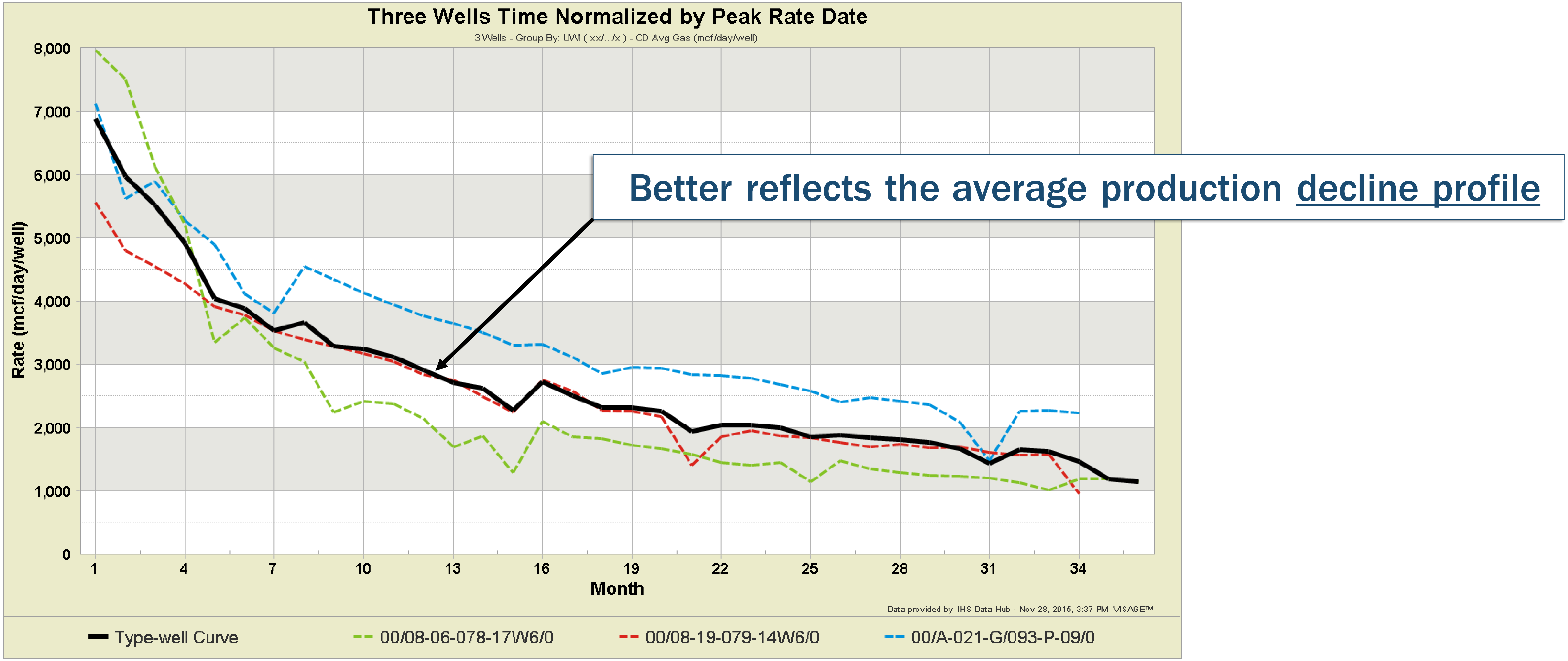
3.1b) Time Normalization on Peak Rate Date



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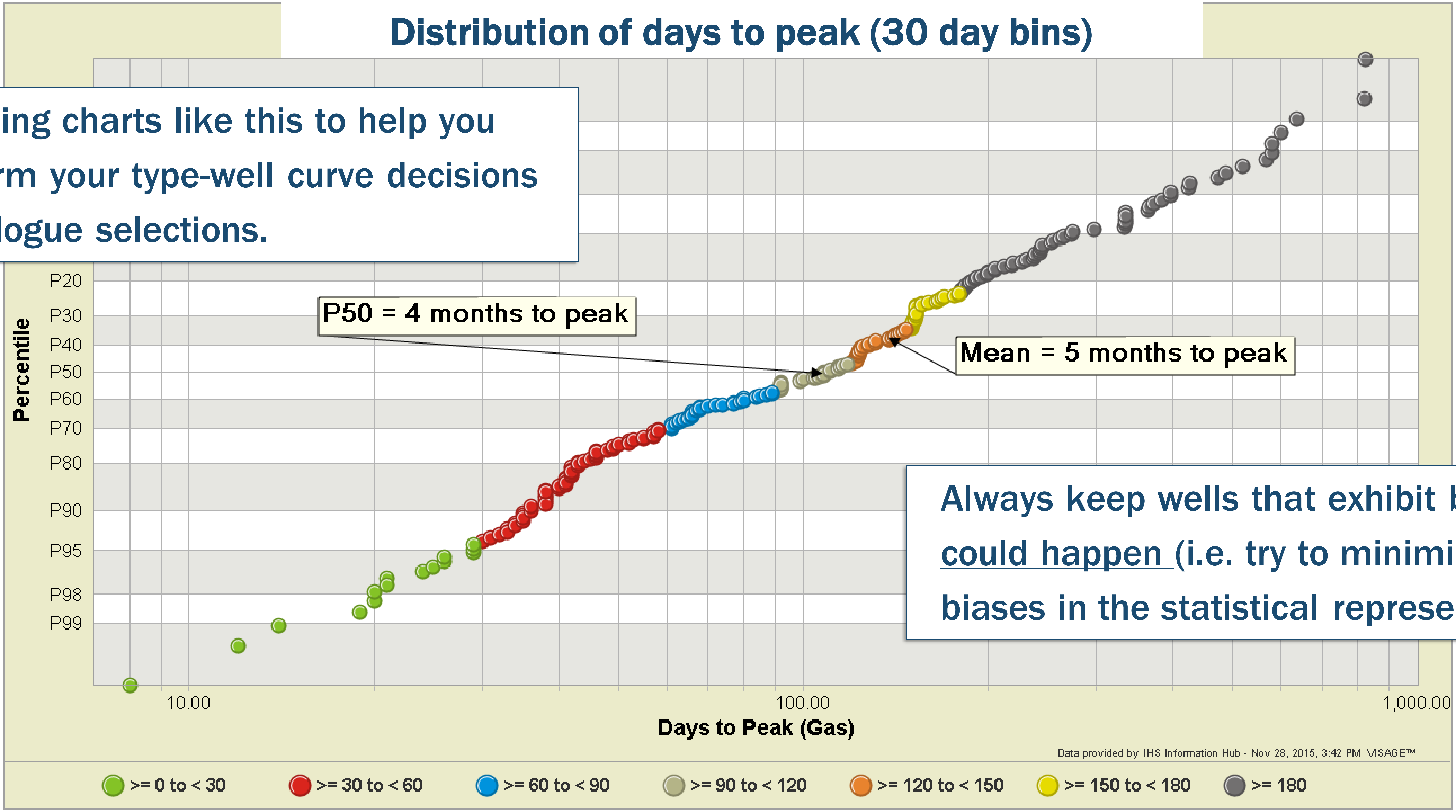
3.1c) Use Charts to Inform (e.g. ramp up time)

Consider using charts like this to help you further inform your type-well curve decisions and/or analogue selections.



Always keep wells that exhibit behavior that could happen (i.e. try to minimize your biases in the statistical representation).

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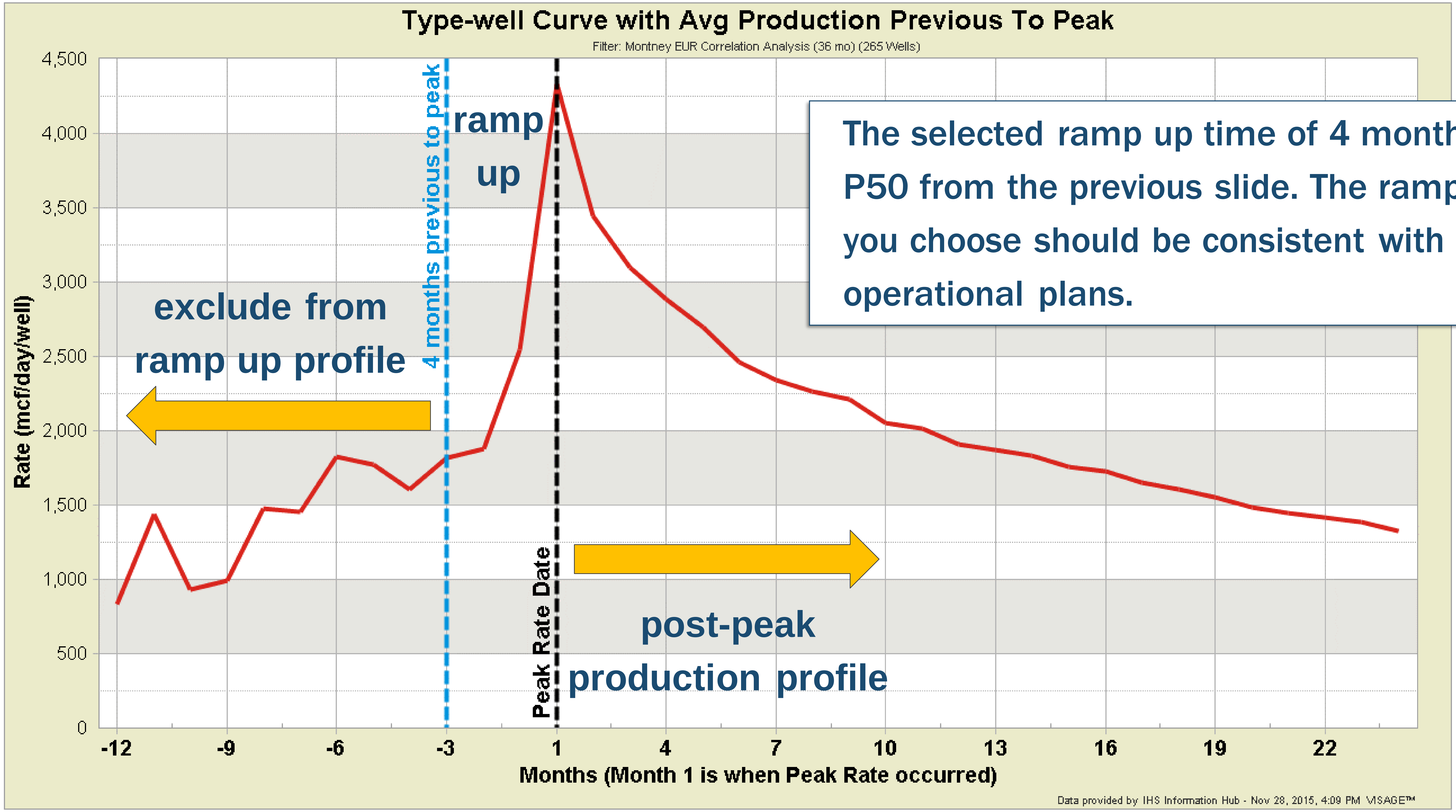
3.1c) Ramp Up Profile (Negative Time from Peak)

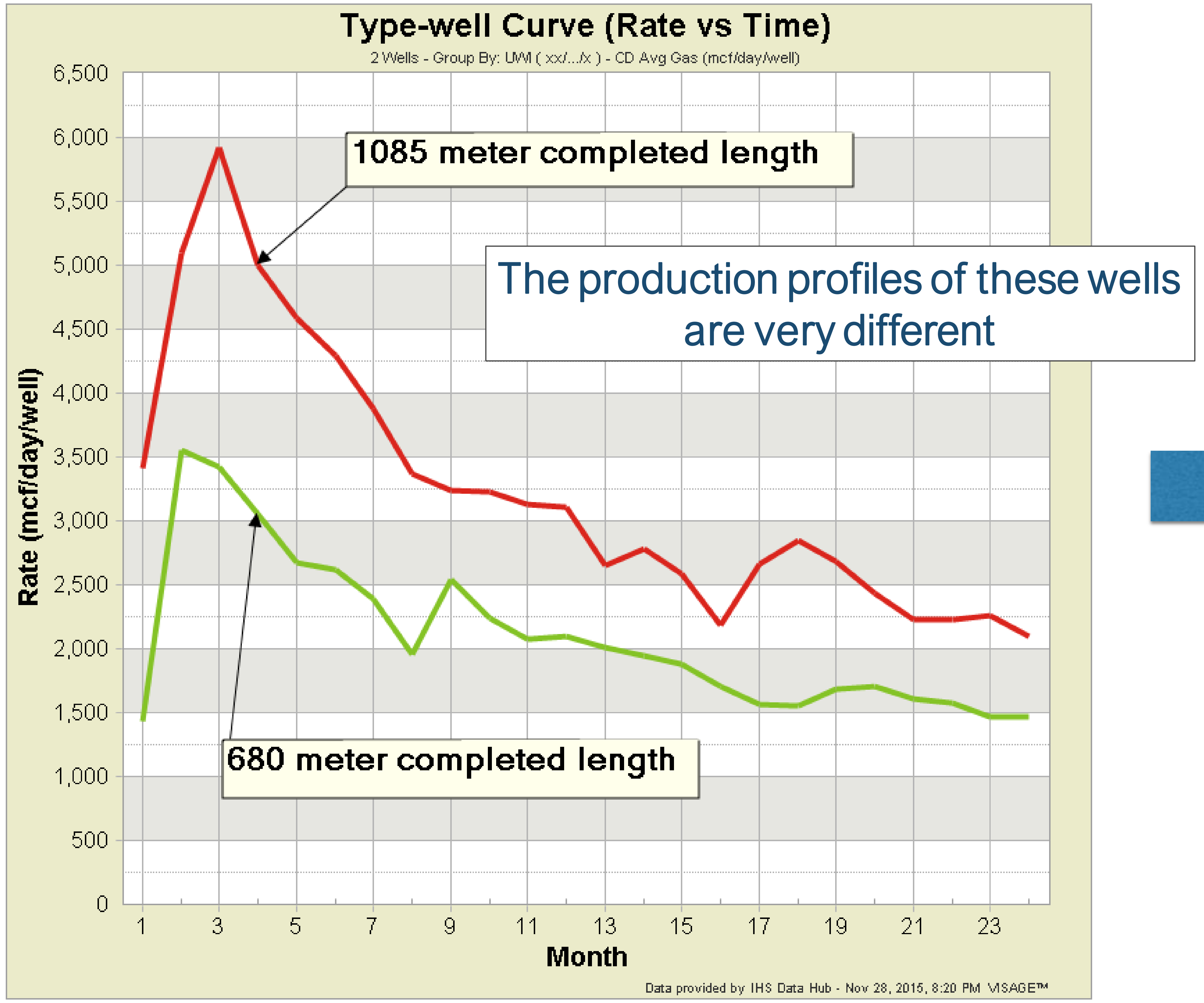


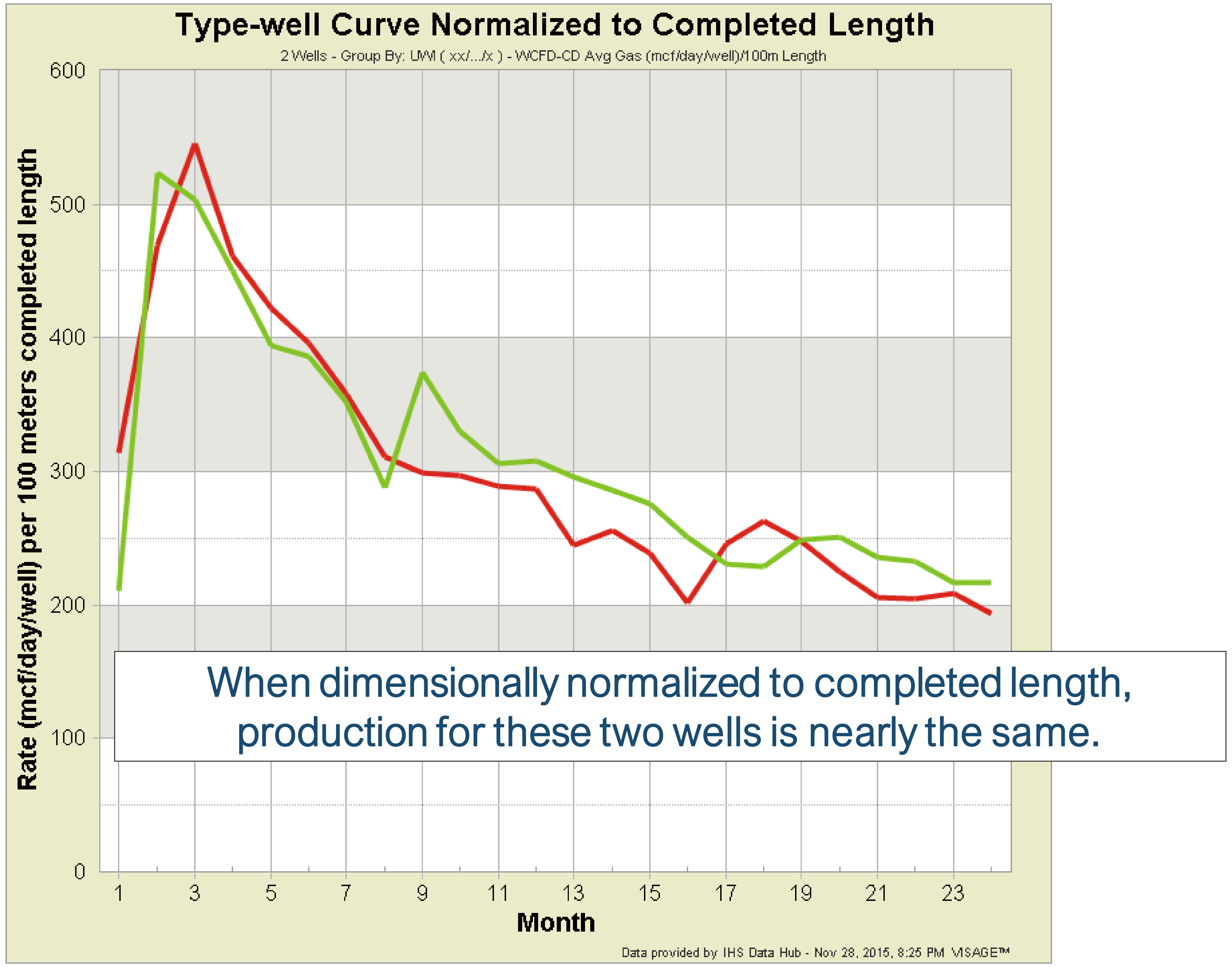
The selected ramp up time of 4 months was the P50 from the previous slide. The ramp up time you choose should be consistent with your operational plans.

3.2) Dimensional Normalization

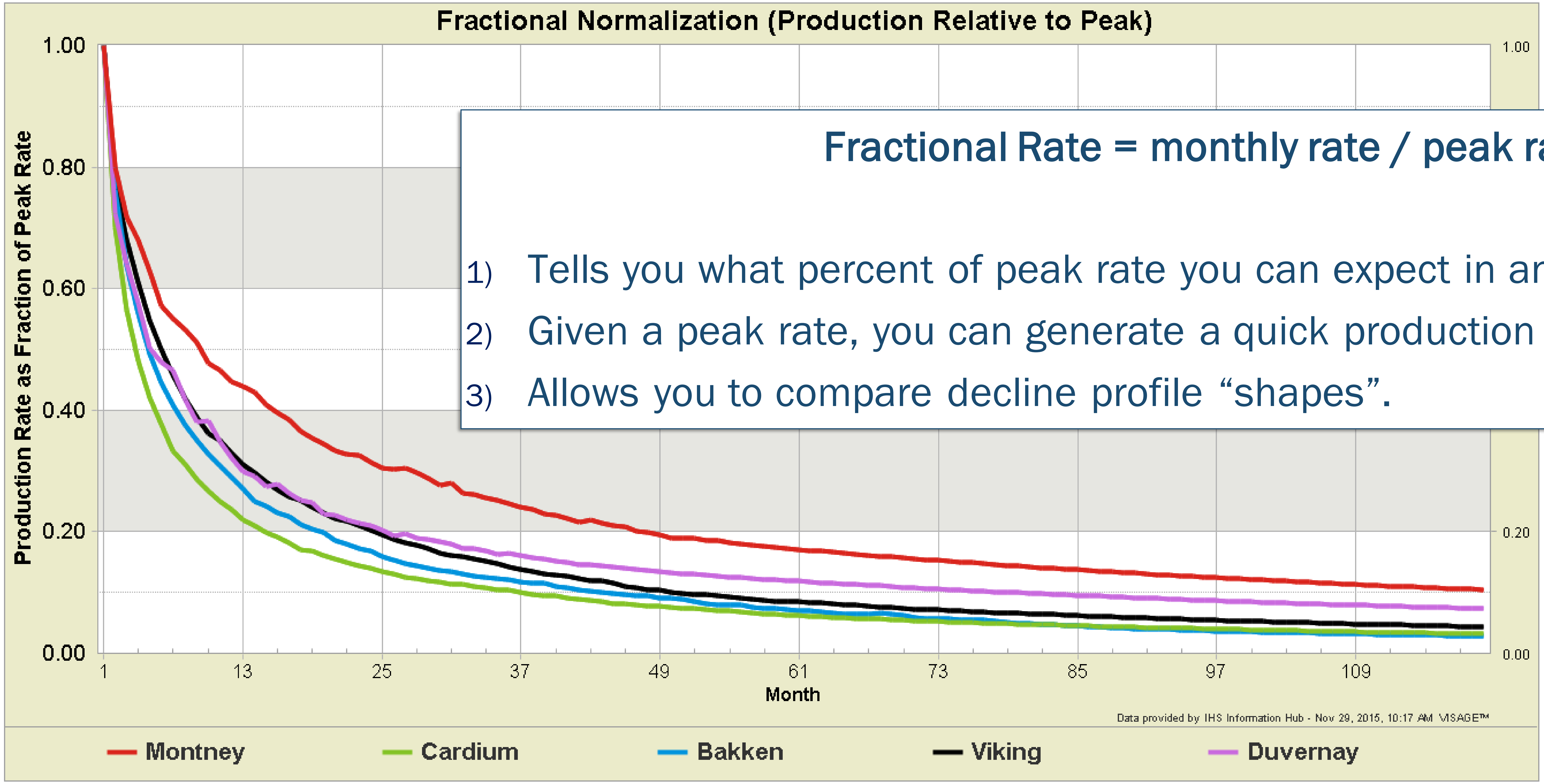
Dimensional normalization puts wells into a meaningful comparative context.

The production profiles of these wells are similar when dimensioned by their completed length.





3.3) Fractional Normalization (Decline Profile Shape)



Fractional Rate = monthly rate / peak rate

1) Tells you what percent of peak rate you can expect in any given month?
2) Given a peak rate, you can generate a quick production profile.
3) Allows you to compare decline profile "shapes".

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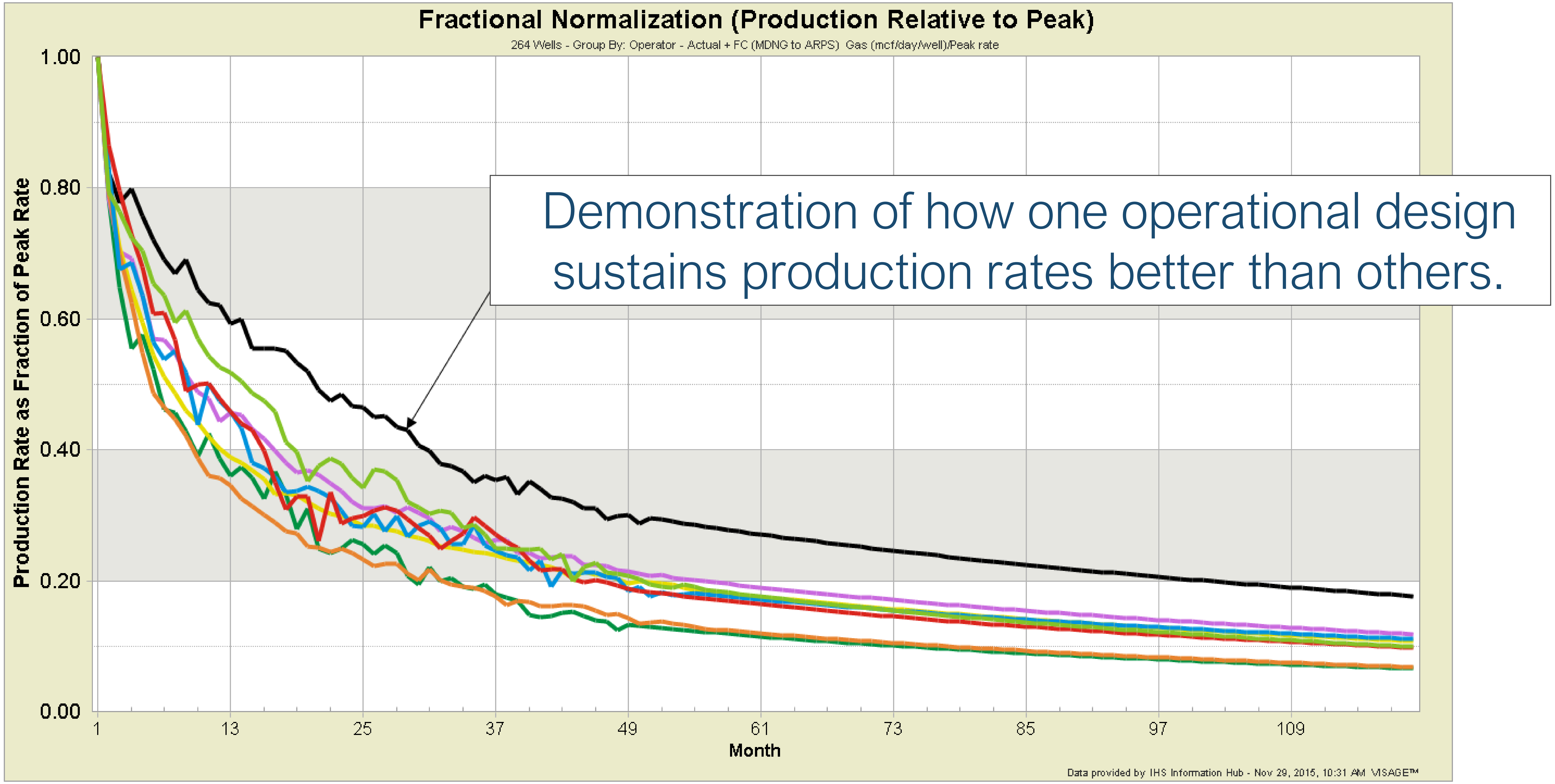
3.3) Fractional Normalization (useful comparative tool)



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4) Calendar Day vs Producing Day Rates

Calendar Day Rate = (volume) / (days in month)

Strength: representative of operational reality (i.e. what actually happened).

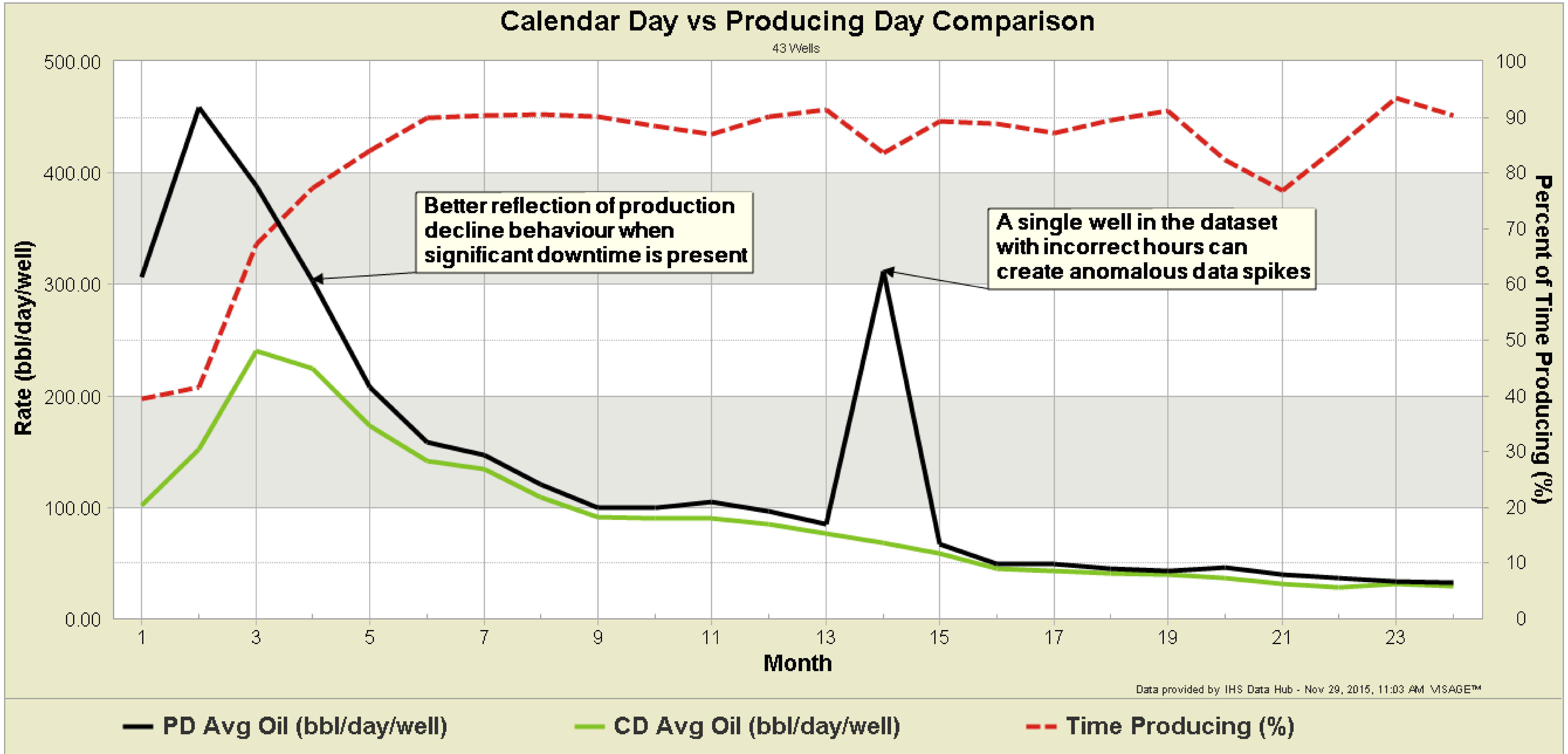
Weakness: significant downtime can disrupt the decline shape.

Producing Day Rate = (volume) / (hours producing) * 24

Strength: sometimes more accurately reflects production decline behavior when significant downtime occurs.

Weakness: inflates every production period's value (with downtime) and can overestimate EUR potential. Incorrect hours and flush production (on gas wells) can result in anomalous data spikes. This is reliant on accurate reporting of producing hours.

4) Calendar Day vs Producing Day Rates



	1	2	3	4	5	6	7	8	9	10	11	12
Time Producing (%)	39	42	67	77	84	90	90	90	90	89	87	90
CD Avg Oil (bbl/day/well)	102.27	152.10	240.84	224.46	173.41	142.29	134.04	109.31	91.51	89.96	89.90	85.25
PD Avg Oil (bbl/day/well)	306.20	459.28	388.38	303.62	208.01	158.43	147.32	120.52	99.85	100.04	104.81	96.88

	13	14	15	16	17	18	19	20	21	22	23	24
Time Producing (%)	91	84	89	89	87	89	91	82	77	85	93	90
CD Avg Oil (bbl/day/well)	76.93	68.12	59.33	45.06	43.54	40.54	39.68	36.70	31.65	28.67	31.07	29.76
PD Avg Oil (bbl/day/well)	84.79	312.00	66.71	49.32	49.23	45.68	43.25	46.37	39.47	36.45	33.32	32.56

5) Condensing Time (Idealized Type-well Curves)

"Idealized" type-well curves typically better reflect production decline profiles, but do not accurately reflect elapsed time.

Method 1 (remove months)

Example 1: remove months where production values are zero. Aligns producing months across the dataset. Good on Rate vs Cumulative Charts (see ****Note** below)

Example 2: remove months where producing hours is less than a threshold of 200 hours. Used to isolate only "representative" producing months (introduces bias).

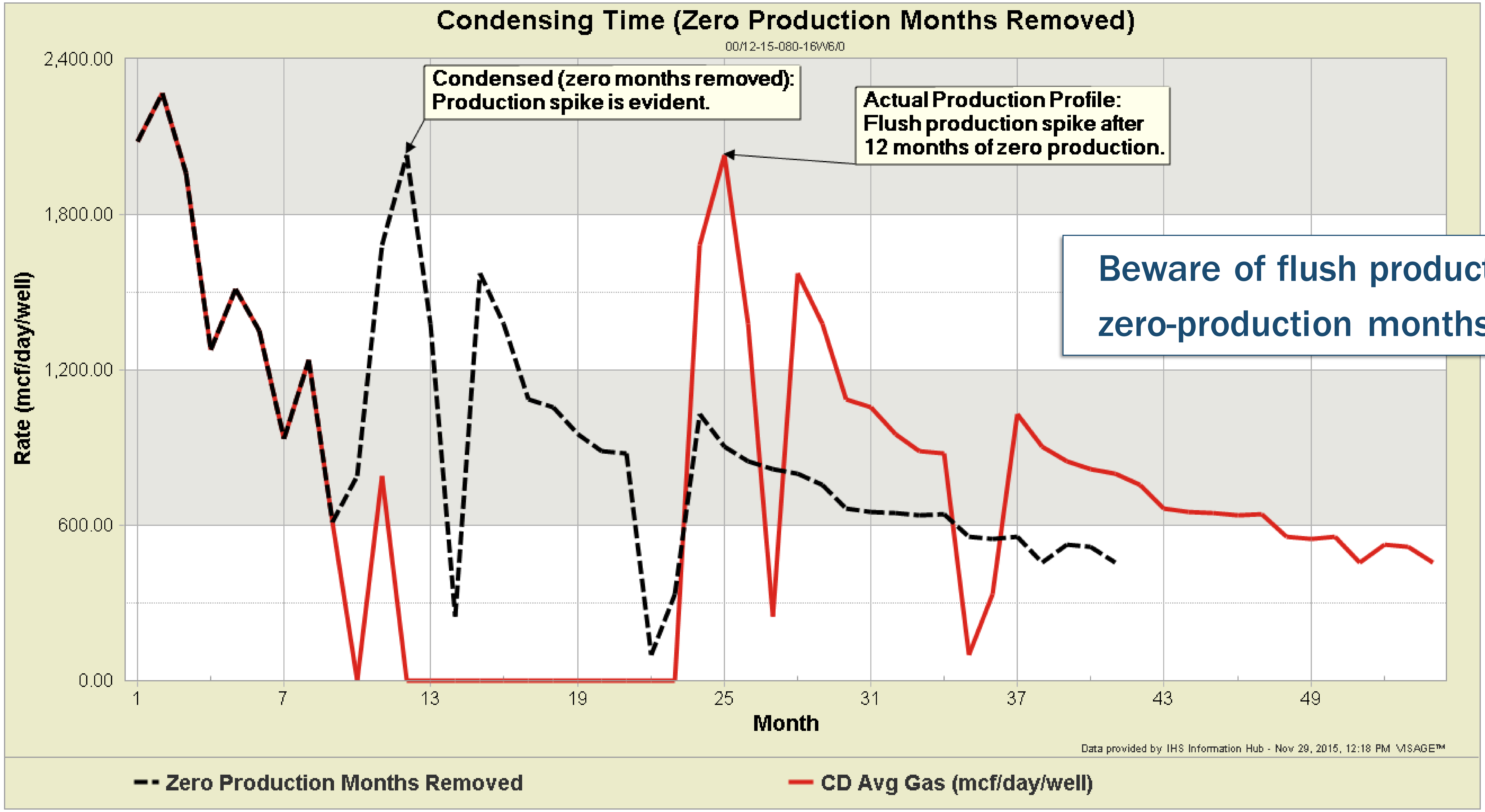
Method 2 (cumulative producing time)

Example 1: plot Producing Day Rate against Cumulative Hours produced.

Example 2: plot Cumulative Production against Cumulative Hours produced.

**Note: Excluding zero producing months on Rate vs Cumulative charts ensures that the average of the cumulatives equals the cumulative of the averages.

5.1) Condensing Time (removing months)



Beware of flush production spikes when removing zero-production months (more so on gas wells).

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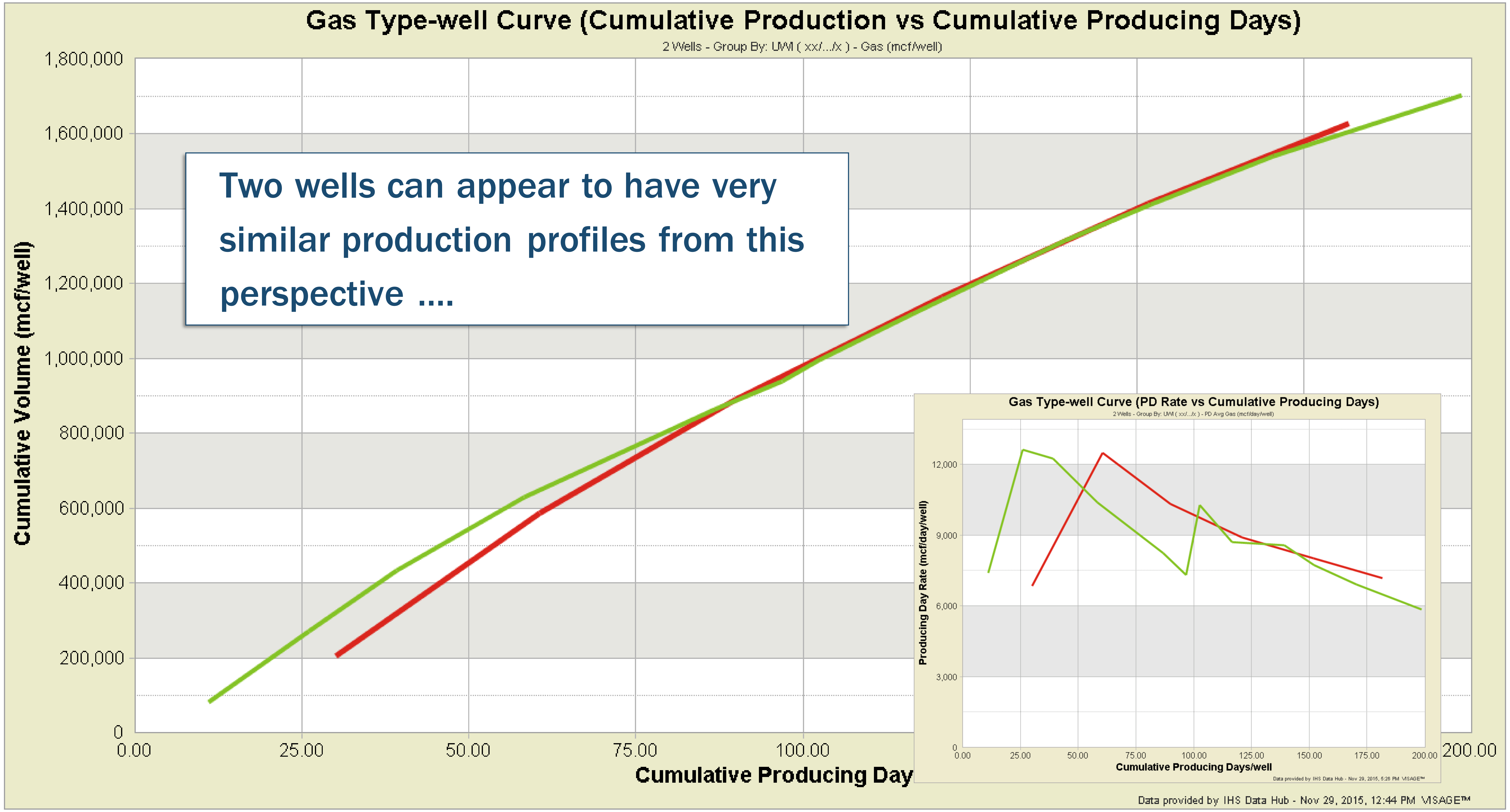
5.2) Condensing Time (cumulative hours producing)



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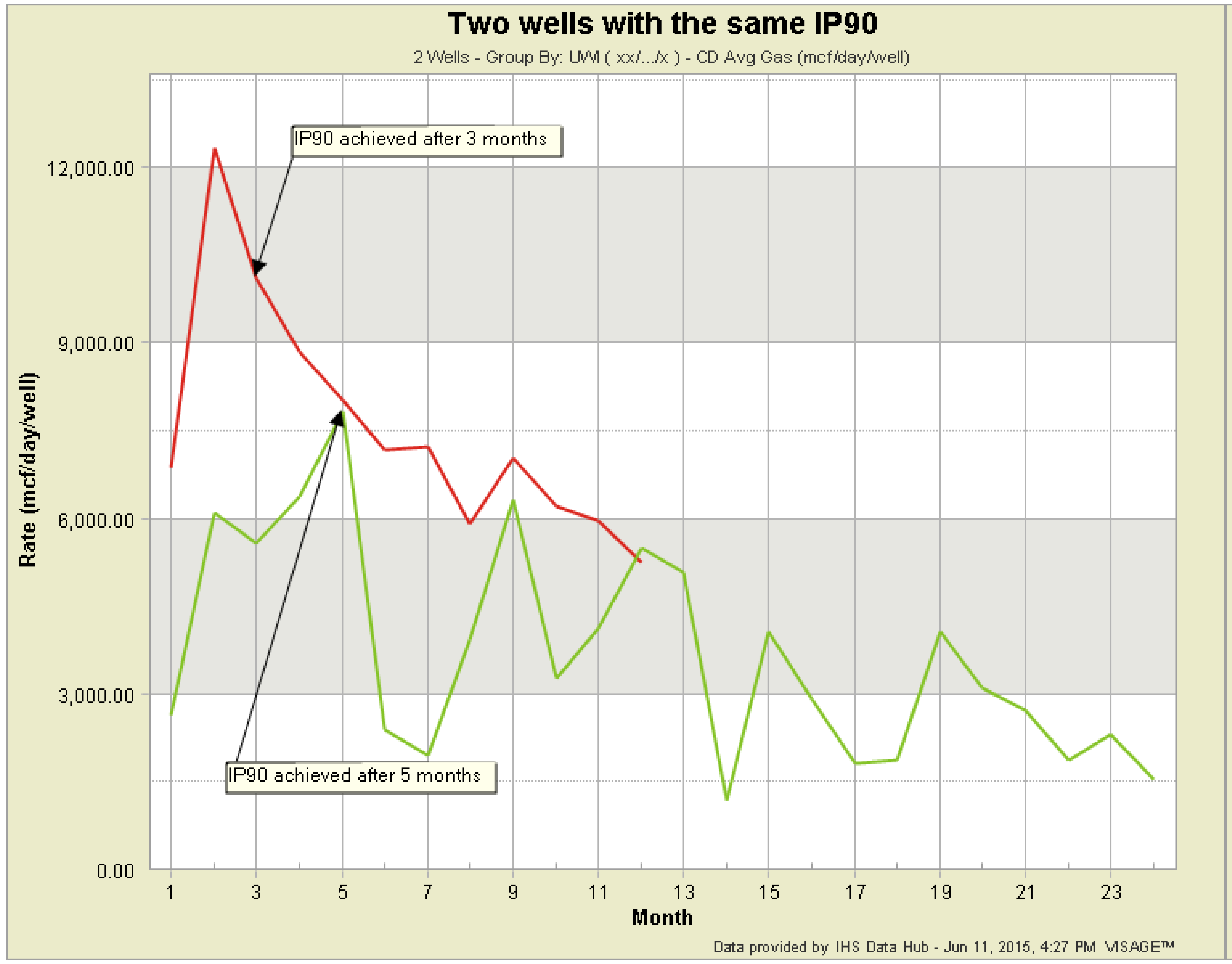
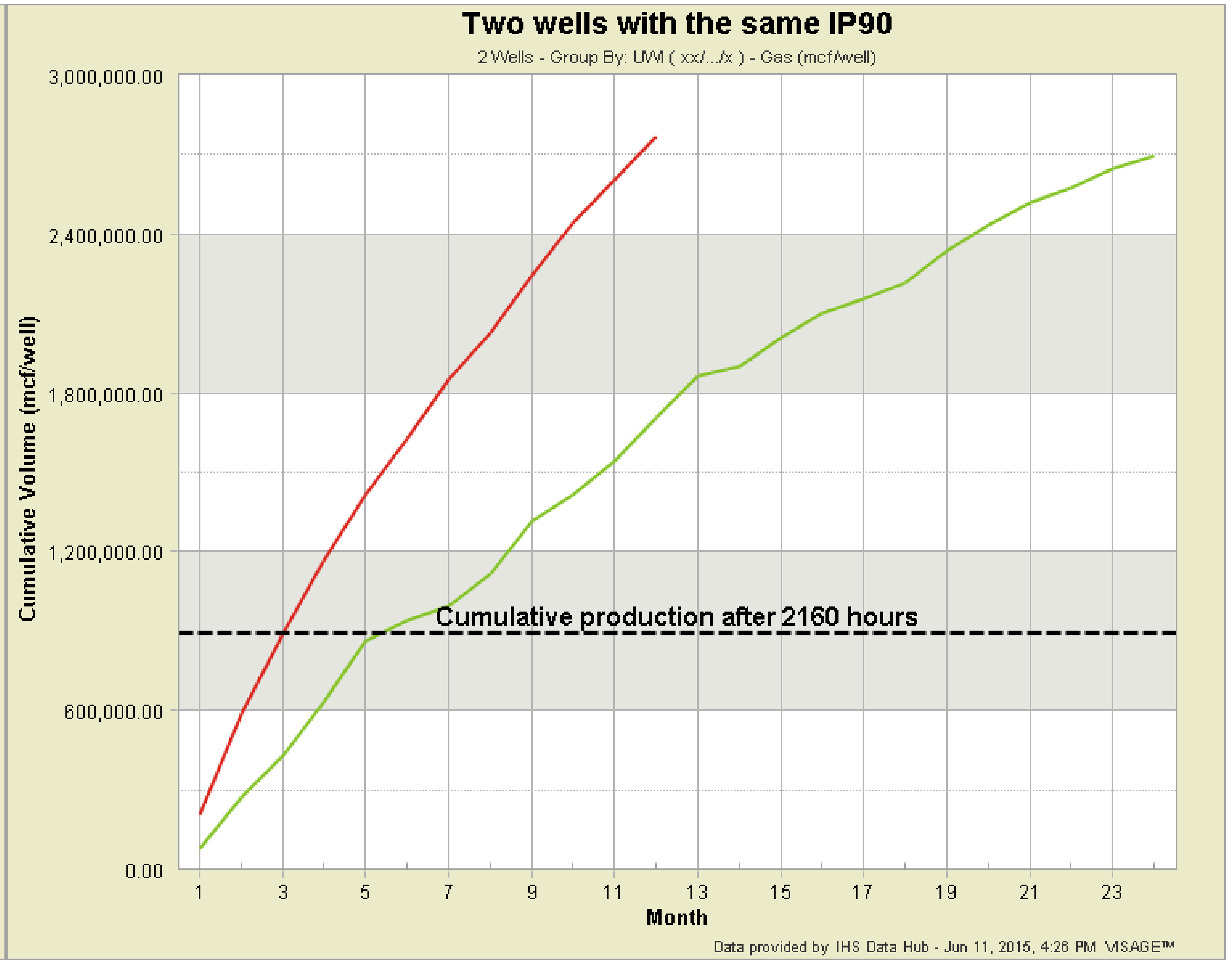
5.2) Condensing Time (cumulative hours producing)

Beware of <u>the danger of factoring out elapsed time</u>. Condensing time by using cumulative-producing-hours could present two wells as similar (see previous slide), while there are dramatic differences in actual production performance (the same two wells from previous slide are shown below in rate vs time and cum vs time).





Source: [How useful are IP30, IP60, IP90 … initial production measures?]

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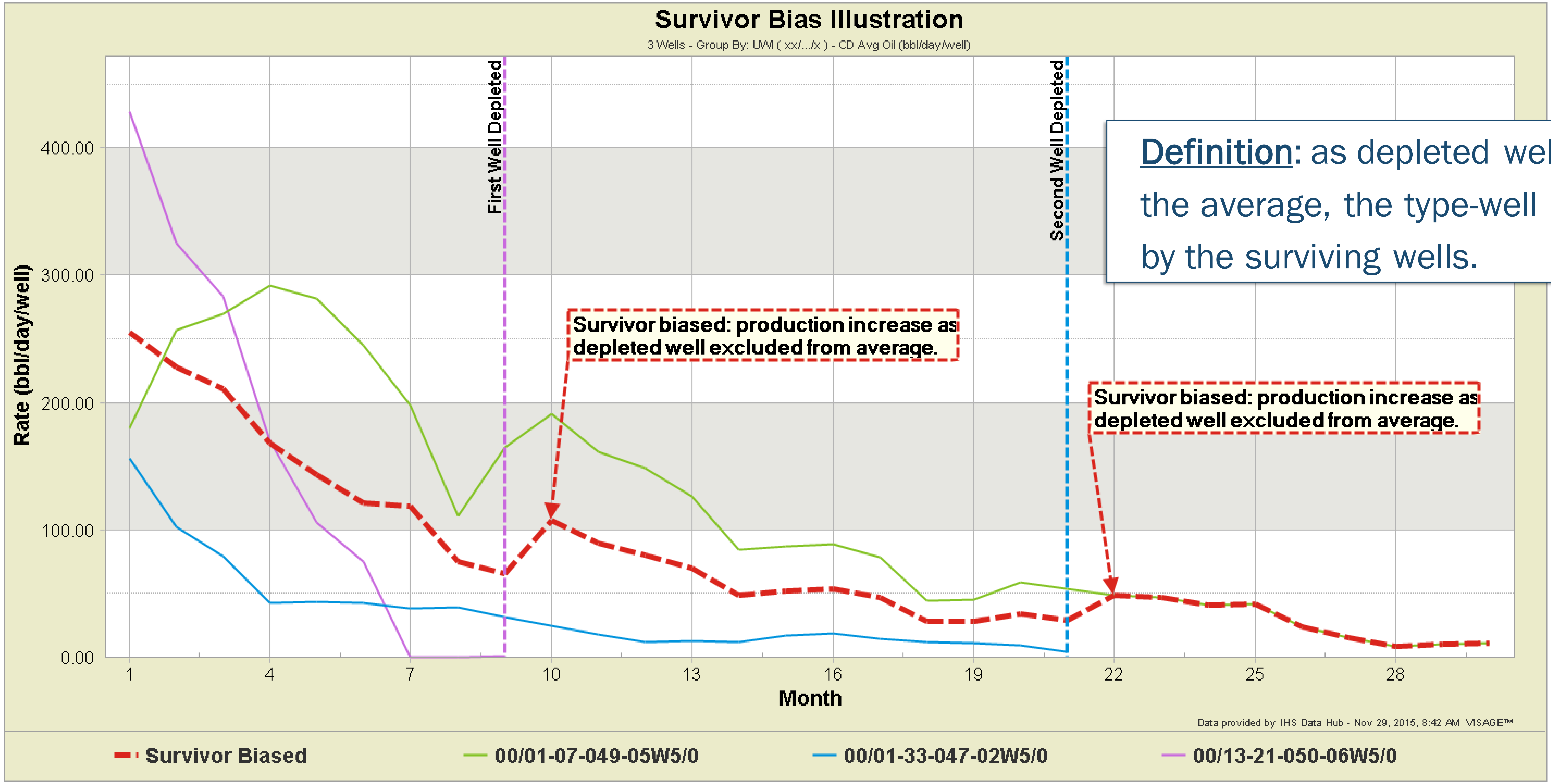
6) Important Questions for Decision Makers

1) How was this type-well curve developed? What does it represent?

2) Is this type-well curve being used to inform economic decisions or development plans?

3) Yes… then has it been scaled to accurately reflect operational realities?

7) What is Survivor Bias?



Definition: as depleted wells are excluded from the average, the type-well curve values are biased by the surviving wells.

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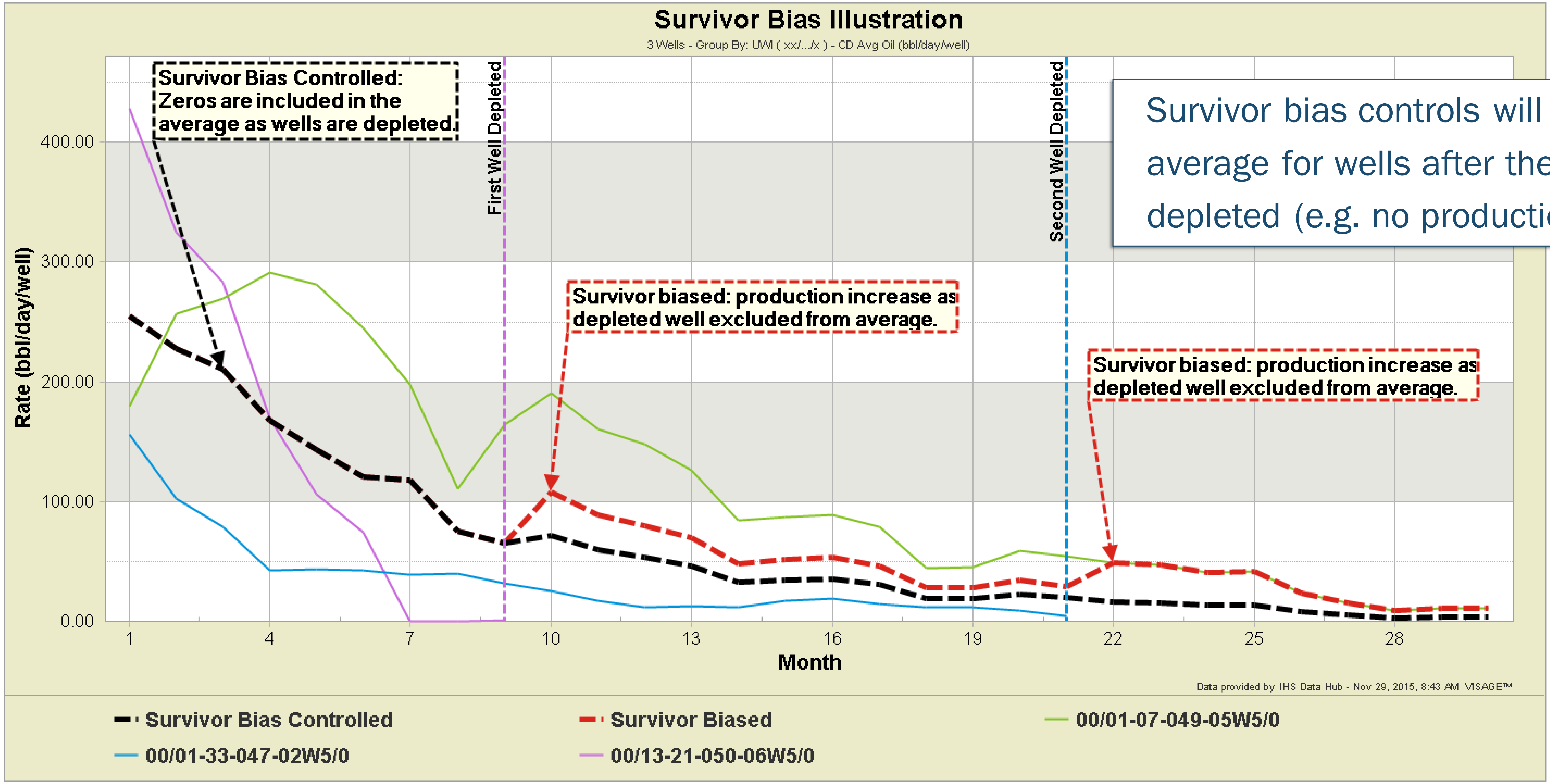
7) Survivor Bias Controls



Survivor bias controls will include zeros in the average for wells after they are identifiably depleted (e.g. no production in last 12 months).

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8) Truncation using Sample Size Cut-off

- Sample sets often have wells with a range of production history, meaning the latter portion of the type-well curve is based on, and increasingly biased by, older wells.

- "**Sample size cut-off**" is expressed as a percent of the first month's sample size. When the number of producing wells contributing to the average drops below the specified percentage the type-well curve average will stop calculating.

- Common values used are 50% or greater.

- Consider selecting wells by vintage to ensure contributing wells have a similar amount of production history.

9) Forecast the Average vs Average the Forecasts

Forecast the Average

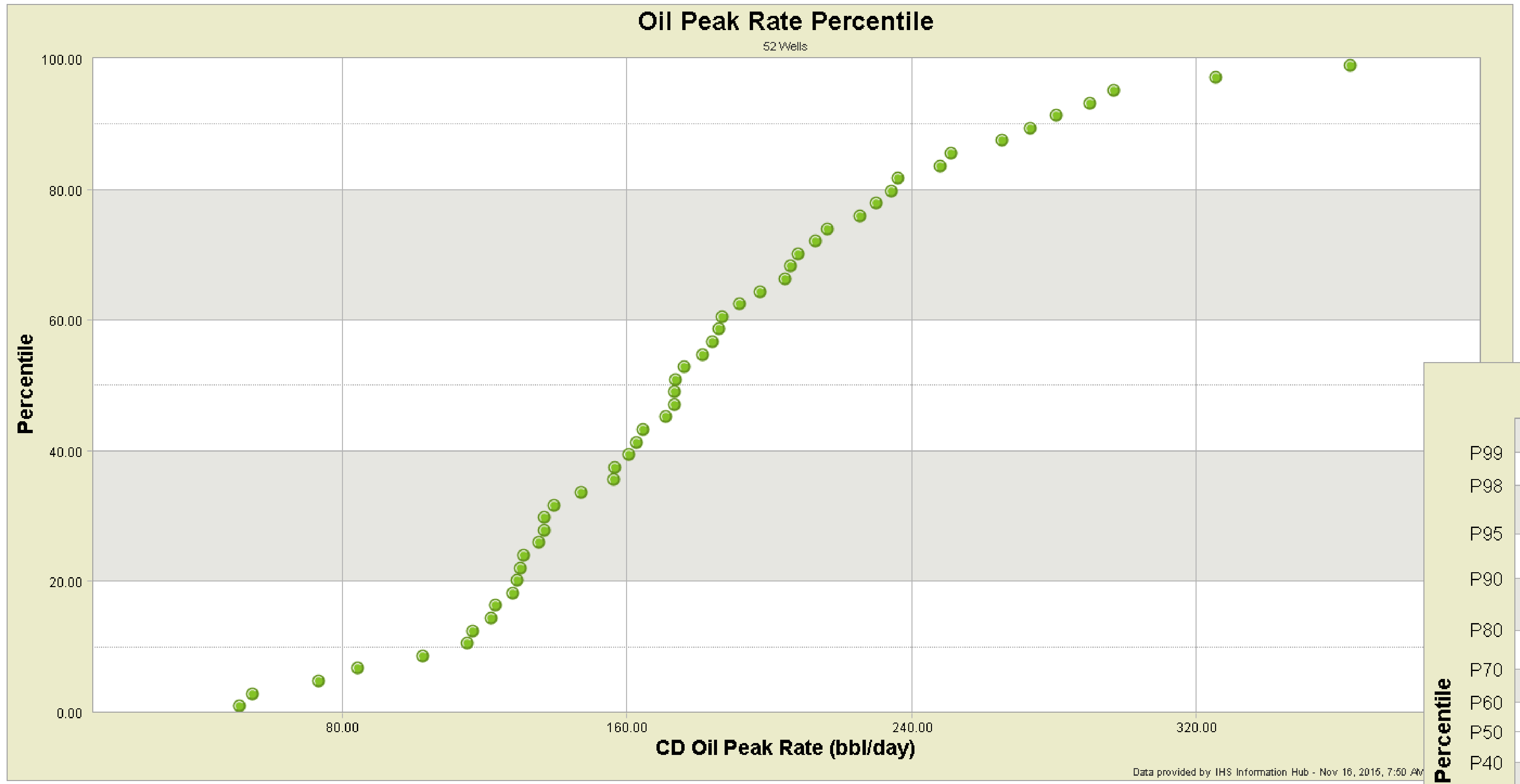
- Apply a decline profile to the truncated average type-well curve to get a single full life profile of EUR
- Time effective, but does not provide a distribution of EUR values

Average the Forecasts (of all wells)

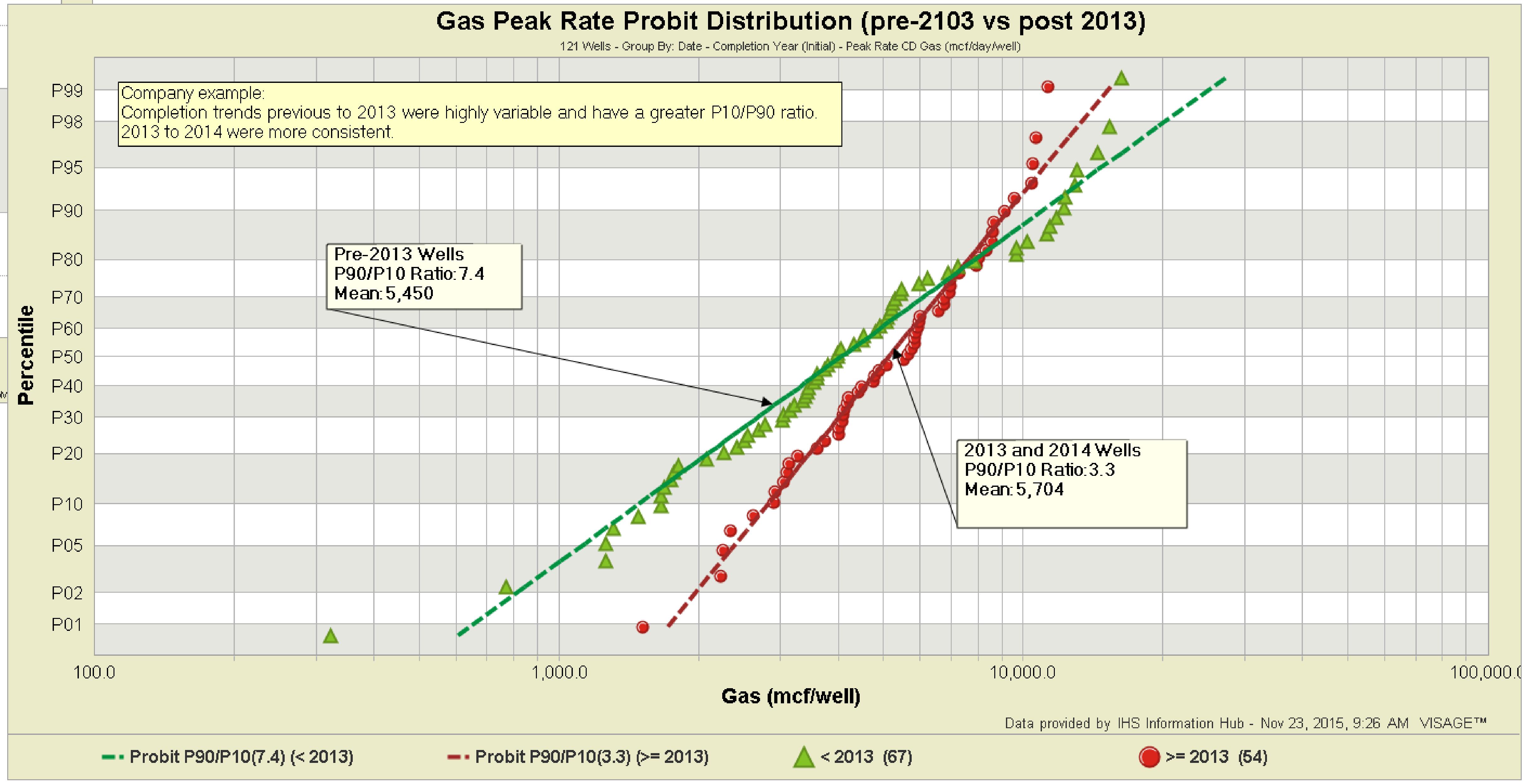
- Time consuming unless auto-forecasting is used
- Auto-forecasting typically does not have any “human” judgement applied to it, but forecast results can be vetted
- Useful for statistical evaluation and P10/P90 quantification of EUR uncertainty

10.1) Representing Uncertainty (Distributions)

Percentile (Cumulative Probability)



Probit with P10/P90 ratios



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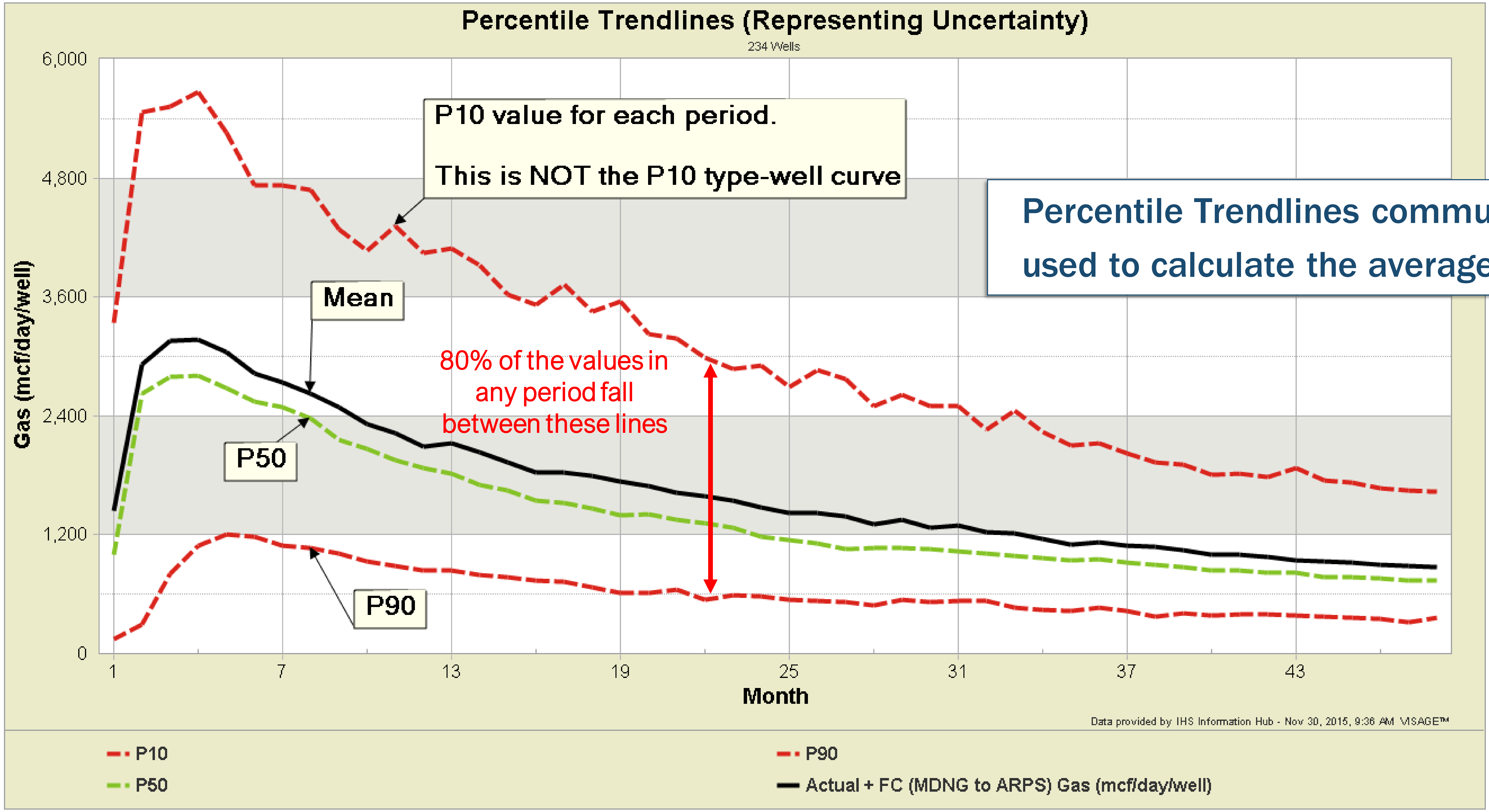
10.2) Percentile Trendlines



Percentile Trendlines communicate the range of values used to calculate the average of each month.

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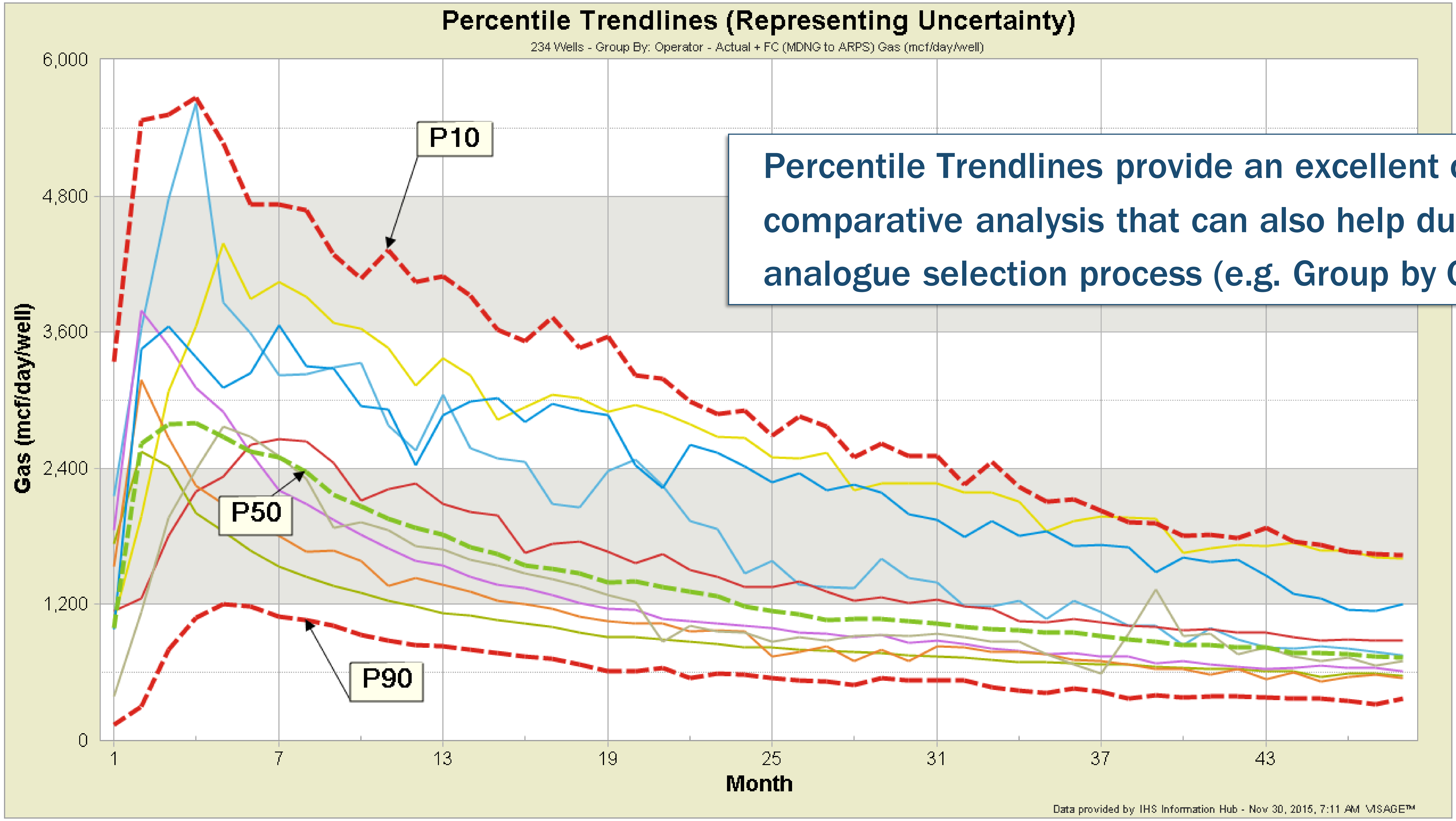
10.3) Percentile Trendlines



Percentile Trendlines provide an excellent context for comparative analysis that can also help during the analogue selection process (e.g. Group by Operator)

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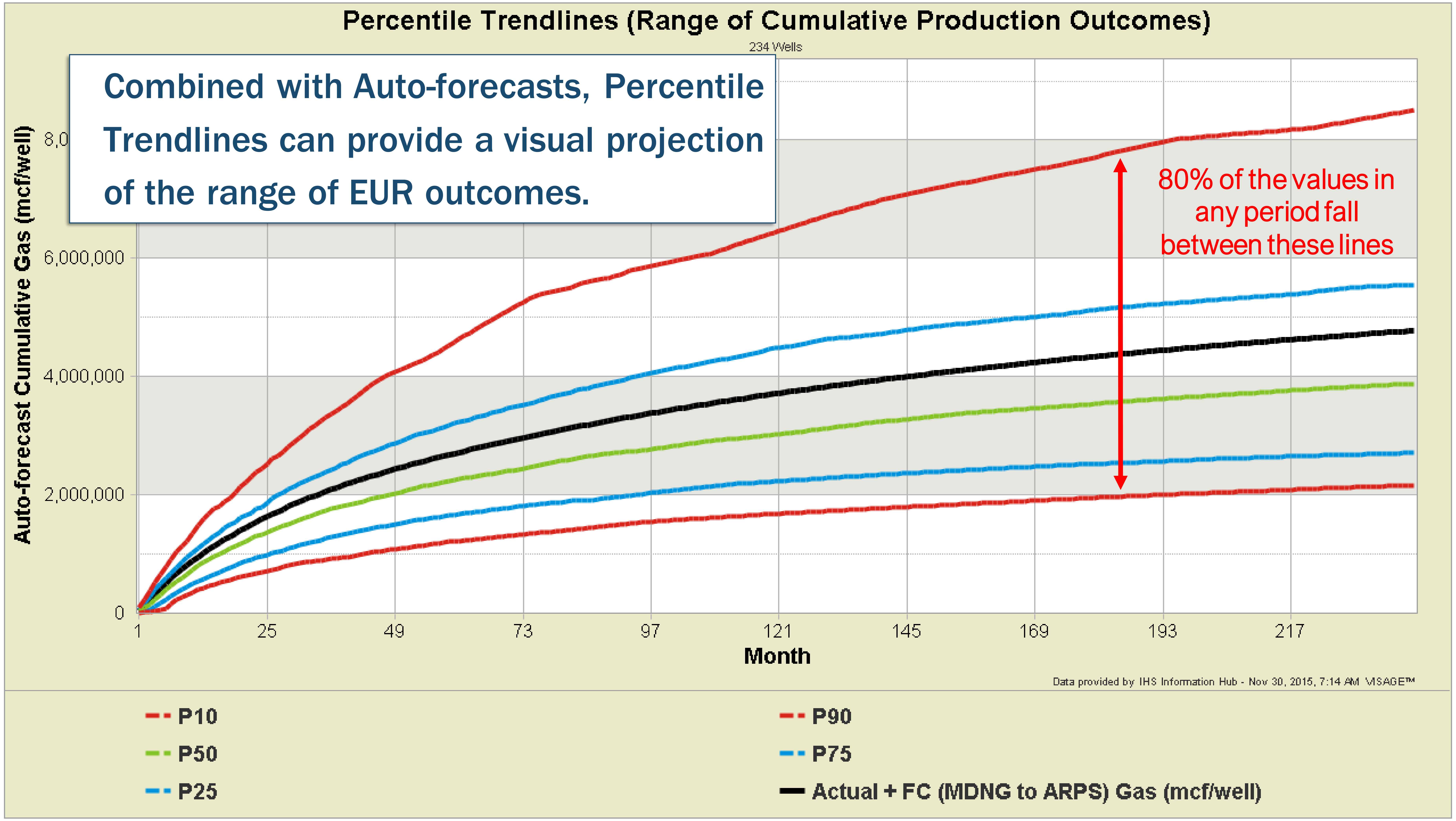
10.4) Percentile Trendlines (EUR Outcomes)



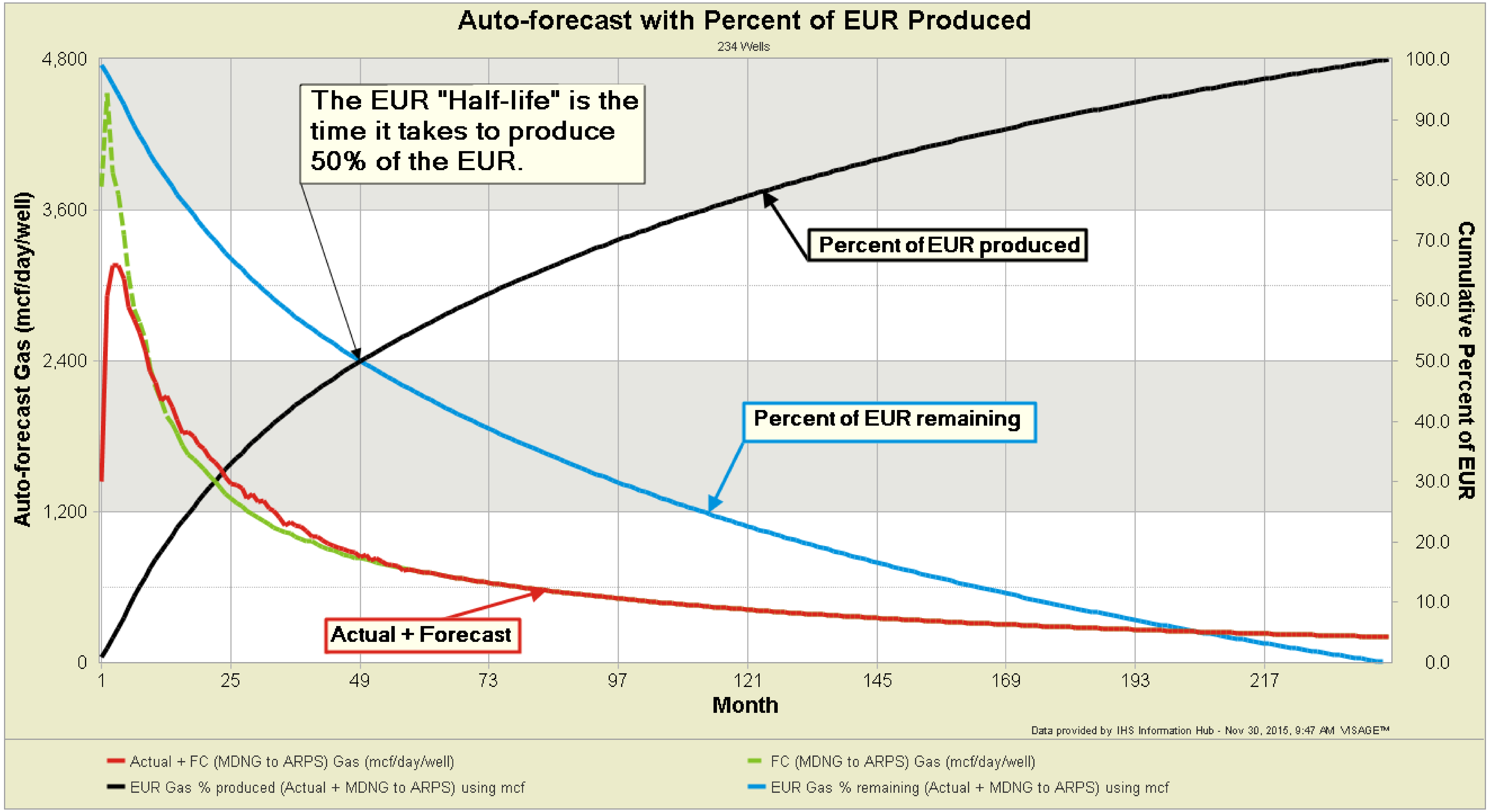
11) Auto-forecast Tools

Auto-forecasts provide a complementary set of tools and insights that can not be achieved by looking at production history alone. They include:

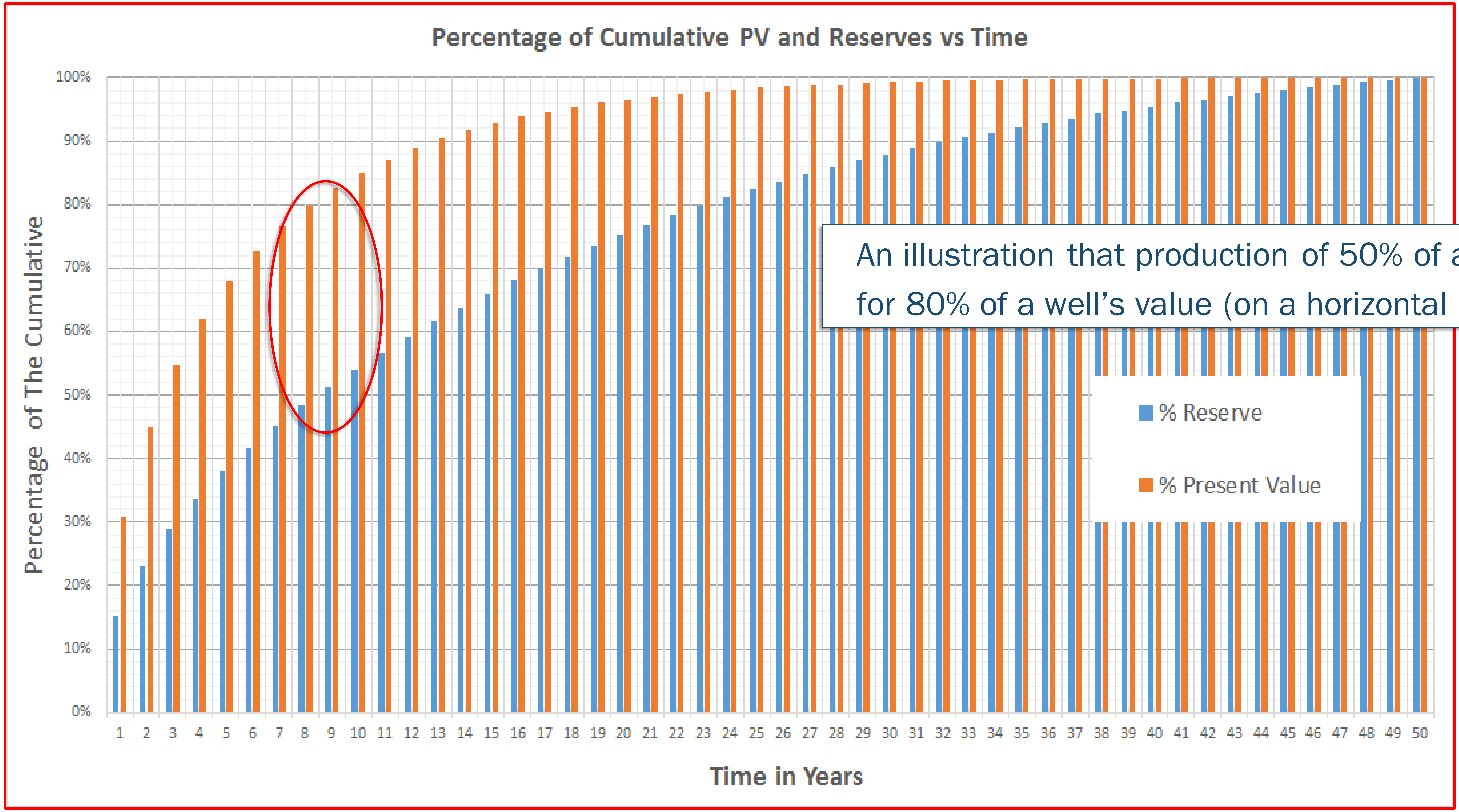
- **EUR Half-life** (time to produce 50% EUR ~ 80% NPV)
- **Instantaneous b values**
- **Effective Annual Decline Rates**
- **EUR** (distributions, dimensional normalization)

These can be used to characterize uncertainty, validate manual forecasts, provide supporting material for multi-segment Arps forecasts, and spatial analysis.

11.1) Auto-forecast Tools (EUR "Half-life")



11.2) 50% EUR as a Proxy for 80% Value



An illustration that production of 50% of a well's EUR is a reasonable proxy for 80% of a well's value (on a horizontal multi-stage well).

Courtesy of [Rose & Associates]

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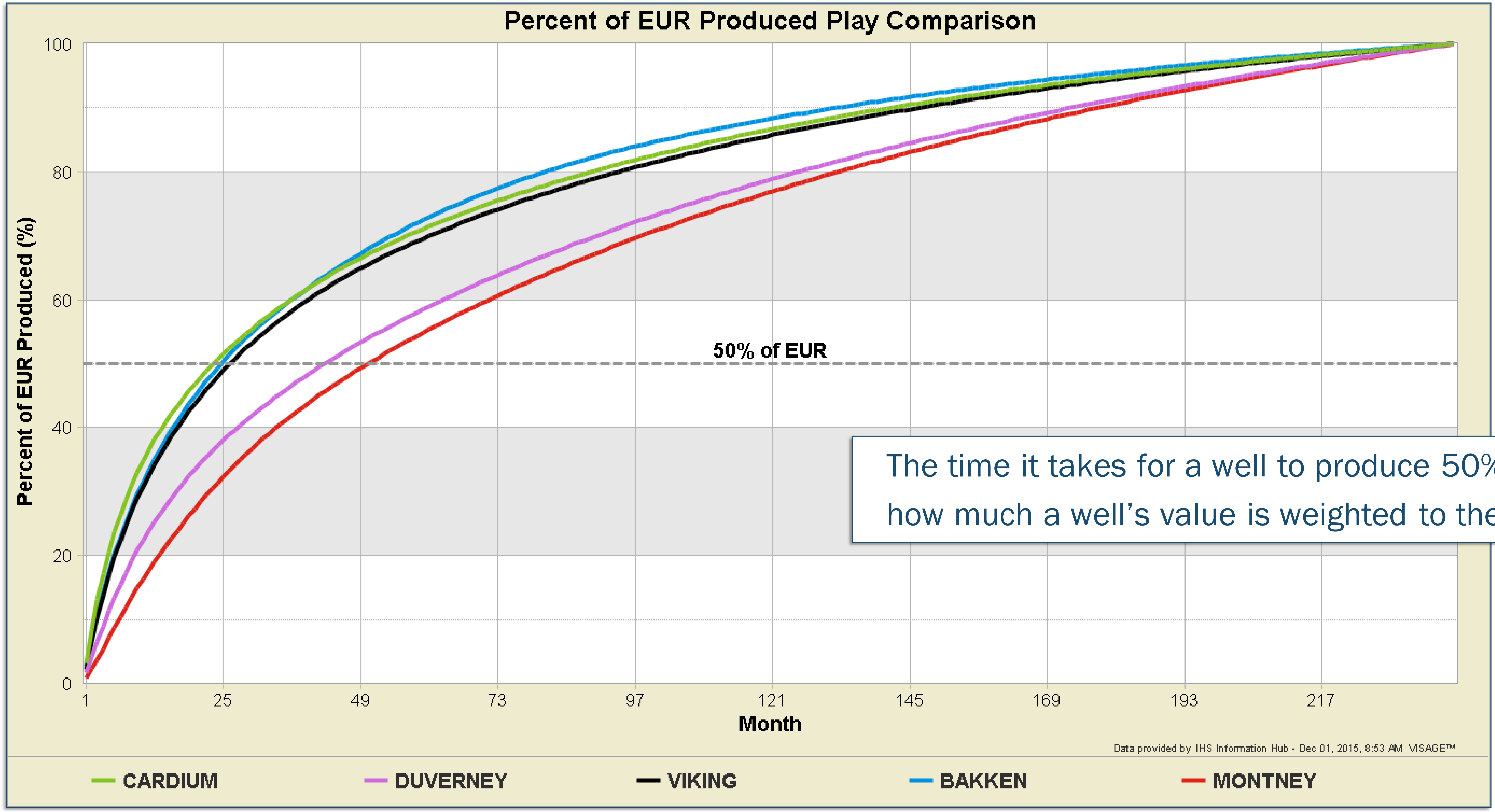
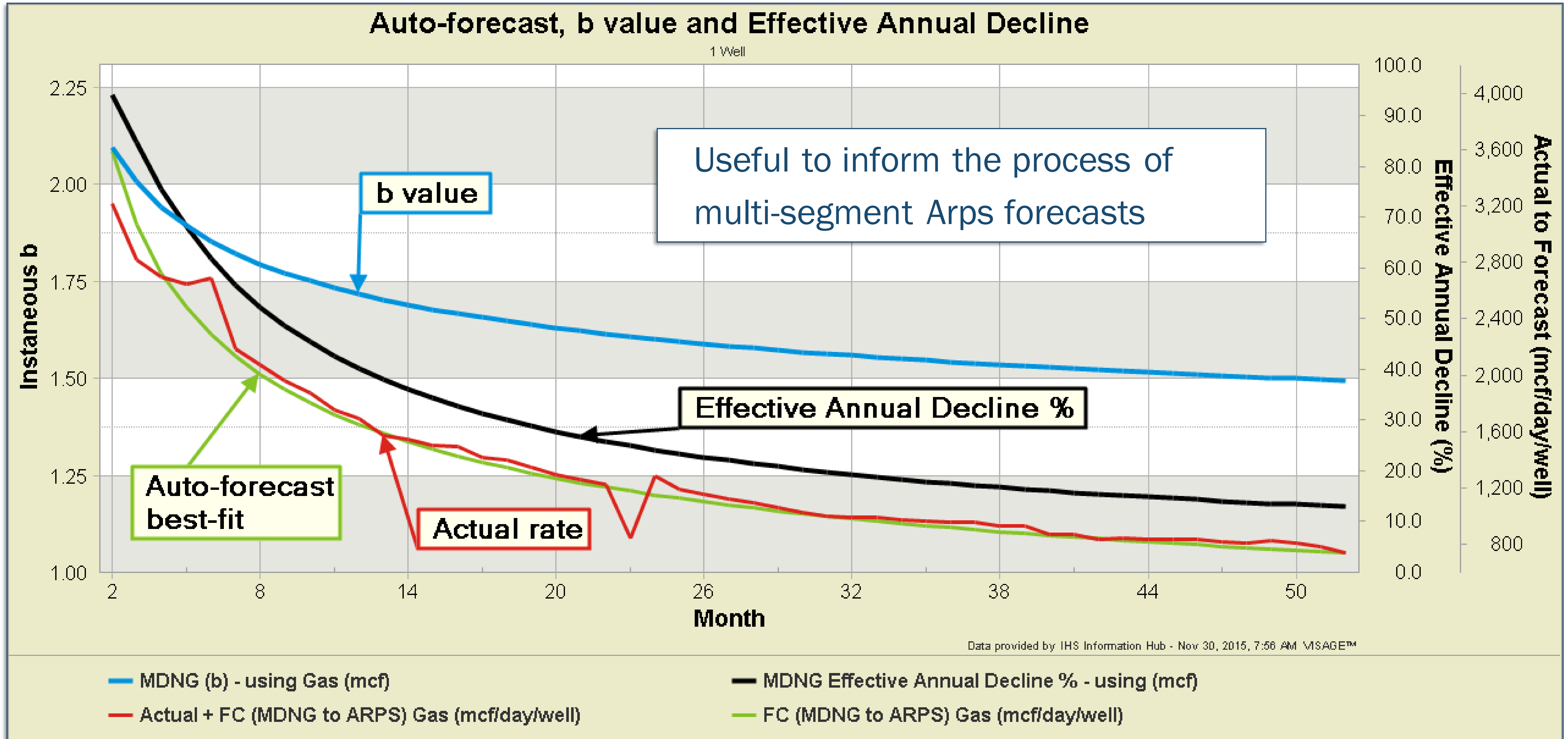
11.3) EUR Half Life Comparison



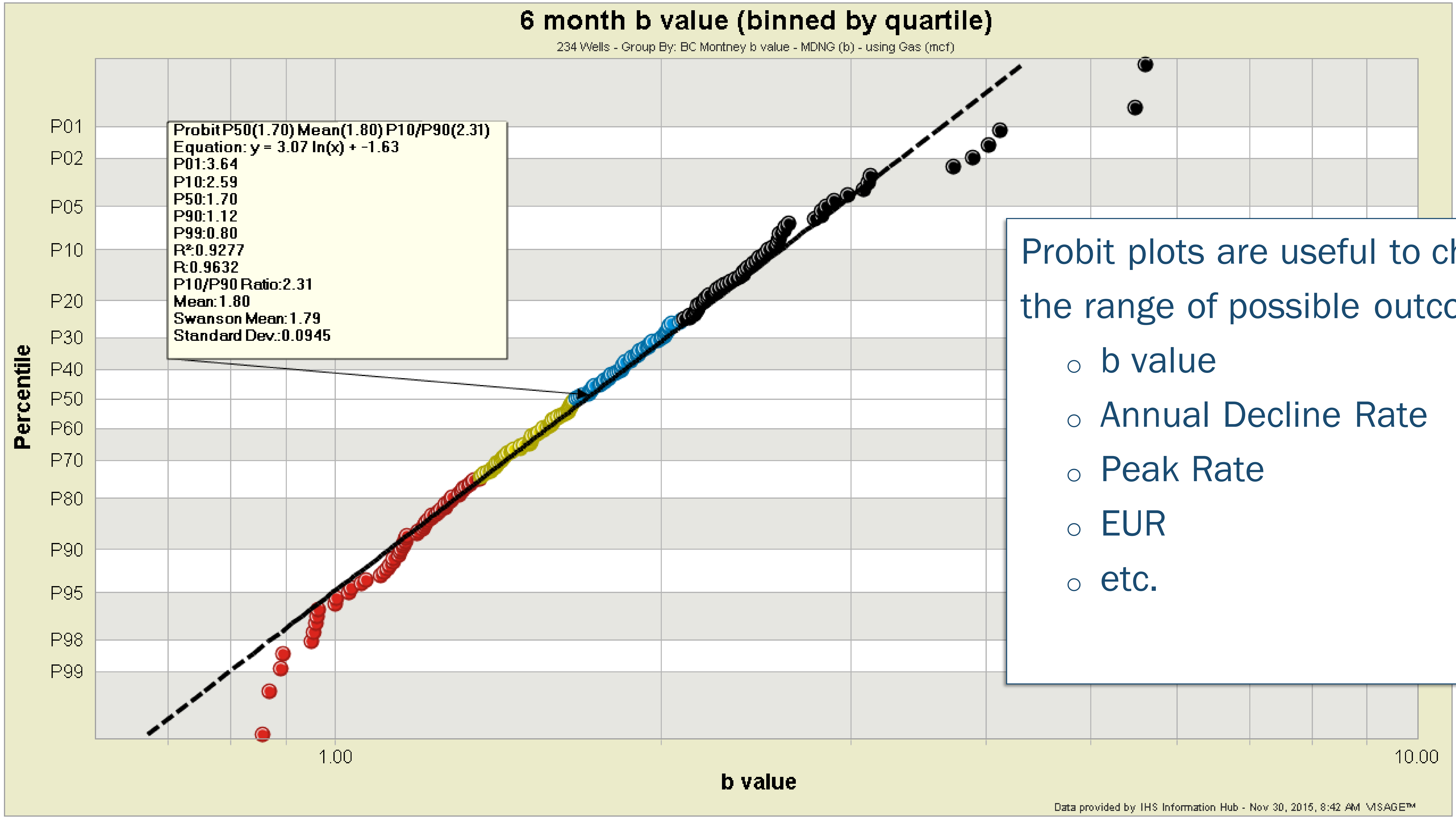
The time it takes for a well to produce 50% of EUR is an indicator of how much a well's value is weighted to the early life of the well.

11.4) b value and Annual Decline Rate



	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
FC (MDNG to ARPS) Gas (mcf/day/well)	3,591	3,070	2,728	2,480	2,288	2,134	2,006	1,898	1,804	1,722	1,650	1,585	1,527	1,475	1,426	1,382	1,342	1,304	1,269	1,237	1,206	1,177
Actual + FC (MDNG to ARPS) Gas (mcf/day/well)	3,223	2,817	2,698	2,650	2,688	2,189	2,074	1,960	1,874	1,757	1,695	1,576	1,546	1,506	1,492	1,414	1,398	1,343	1,297	1,262	1,221	844
MDNG Effective Annual Decline % - using (mcf)	94.3	84.8	75.7	68.2	61.9	56.7	52.4	48.7	45.5	42.7	40.2	38.1	36.1	34.4	32.8	31.4	30.1	28.9	27.8	26.8	25.9	25.0
MDNG (b) - using Gas (mcf)	2.10	2.01	1.94	1.89	1.85	1.82	1.79	1.77	1.75	1.73	1.72	1.70	1.69	1.68	1.67	1.66	1.65	1.64	1.63	1.62	1.61	1.61

11.4) Probit Plots on Forecast Parameters



Probit plots are useful to characterize the range of possible outcomes of:

- b value
- Annual Decline Rate
- Peak Rate
- EUR
- etc.

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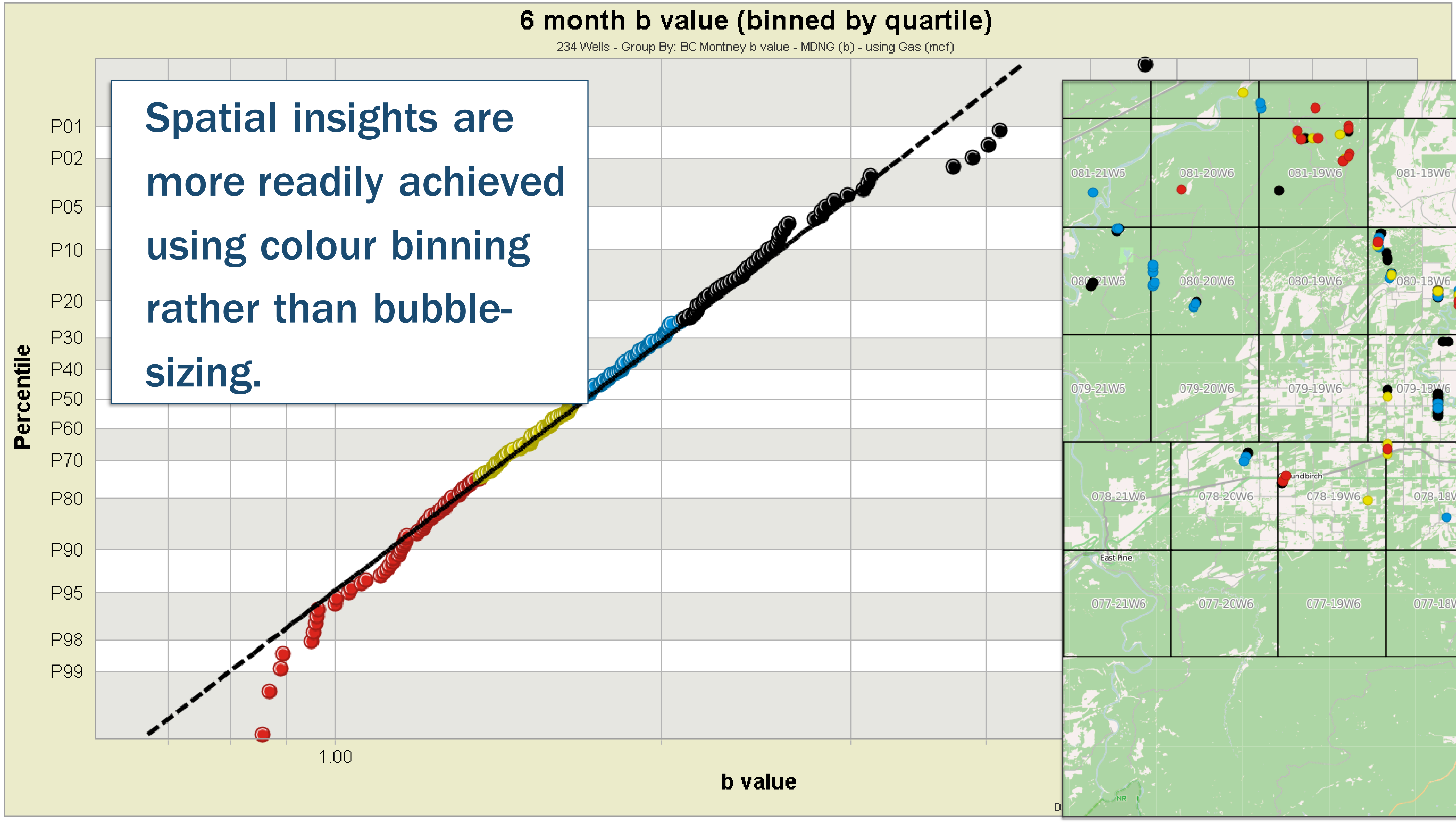
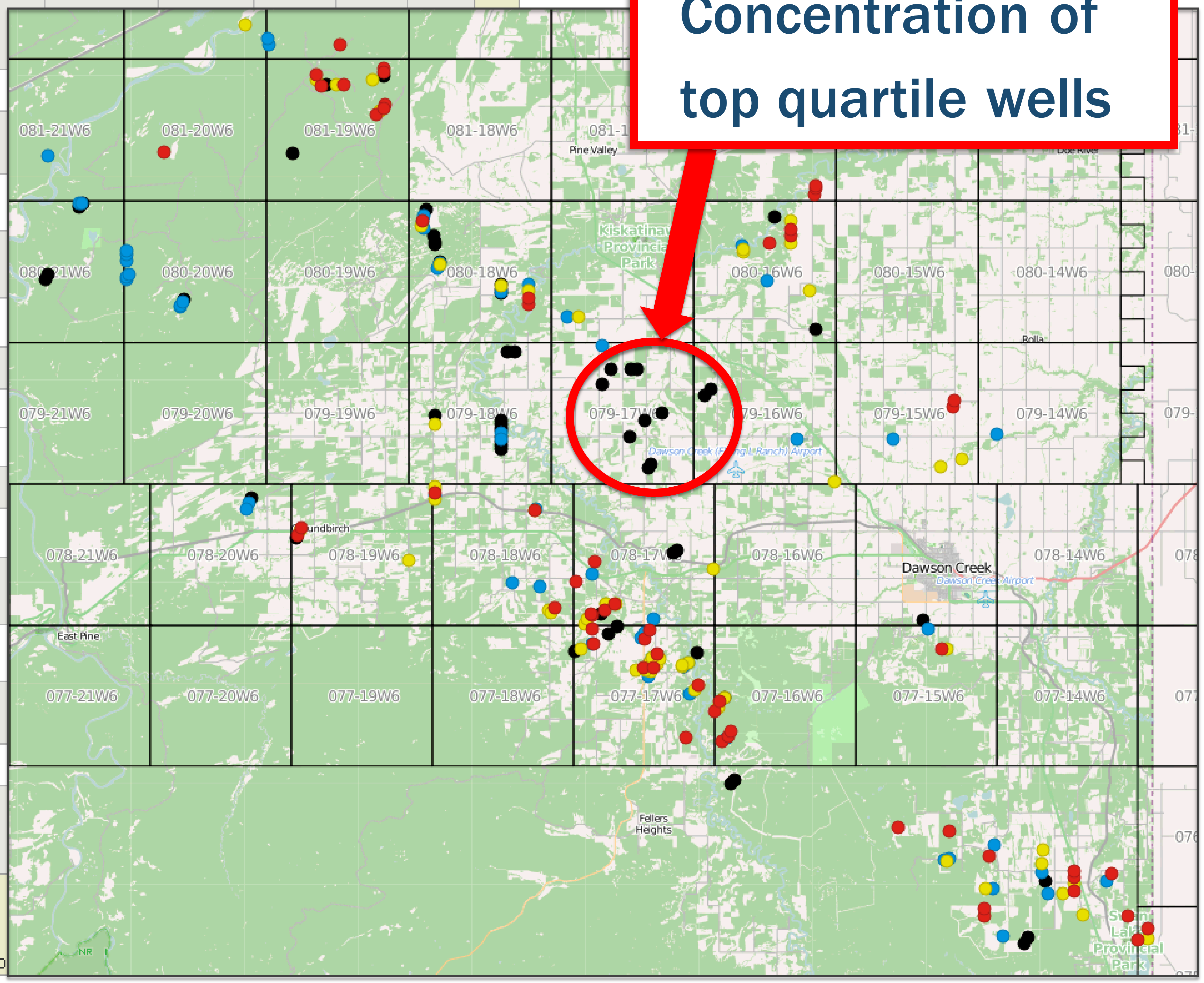
11.5) Percentile Quartile Binning on Maps



Spatial insights are more readily achieved using colour binning rather than bubble-sizing.



Concentration of top quartile wells

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Presentation Recap

1) Chart Types
2) Analogue Selection
3) Normalization
4) Calendar Day vs Producing Day
5) Condensing Time
6) Operational/Downtime Factors on Idealized Curves
7) Survivor Bias
8) Truncation Using Sample Size Cut-off
9) Forecast the Average vs Average the Forecasts
10) Representing Uncertainty
11) Auto-forecast Tools

Closing Comments

1) All of the techniques in this presentation take minutes to perform (with the right tools). They are within your grasp.

2) Take time to investigate and ask questions. It will help you characterize, reduce, and manage uncertainty.

3) Understanding what you're trying to accomplish with your analysis can help you focus on the techniques that will best meet your needs.

4) Capture the steps, assumptions, analogue selection criteria, well exclusions… to help communicate with colleagues how your type-well curves were developed.

5) Use many charts … build a narrative!

Thanks to Advisors & Trusted Experts

Matt Ockenden

Auto-forecast design contributions, quartile mapping & industry expertise

Jim Gouveia (Rose & Associates)

Uncertainty coaching, risk analysis workflows & best practices

GLJ Petroleum Consultants

Industry expertise, technical advice & software design contributions

Brian Hamm (McDaniel & Associates)

Survivor bias design contributions & type-well curve insights

Data Sources Used In This Presentation

IHS

Information Hub

Canadian Discovery Ltd.

WELL COMPLETIONS & FRAC DATABASE

VERDAZO Blog Links With Supporting Information

Type-well Curves Part 1: Definitions and Chart Types

Type-well Curves Part 2: Analogue Selection

Type-well Curves Part 3: Normalization

Type-well Curves Part 4: Calendar Day vs. Producing Day

Type-well Curves Part 5: Condensing Time (Idealized Type-well Curves)

Type-well Curves Part 6: Operational/Downtime Factors on Idealized Curves

Type-well Curves Part 7: Survivor Bias

Type-well Curves Part 8: EUR, Value, Uncertainty & Auto-forecasts

How useful are IP30, IP60, IP90 … initial production measures? (the dangers of factoring out elapsed time)

What production performance measure should I use? (for production performance comparisons)

So What Is The Problem With Production Type Curves? (Percentile trendline overview)

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