PetroSkills®

The Perfect Well Ratio:

A Practical Tool to Easily Benchmark Drilling Performance

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Ref: AADE-06-DF-HO-13

Outline

- **Purpose:**
  - Introduce a concept that can help identify how much drilling performance improvement is possible.
- **Process: Answer in ~20 minutes *(+Questions)***
  - Why do we need to define the Perfect Well?
  - How can we estimate the Perfect Well’s time?
  - What are some example Applications and Next Steps?
- **Payoff: Tool to Identify where to best focus activities to improve.**

Why Define a “Perfect Well”?

- Change the well construction conversation from ‘arguing about the performance metric’ to ‘explaining deviations from an objective standard’.

- Normalize differences between wells and create a purely objective indicator of well construction effectiveness.

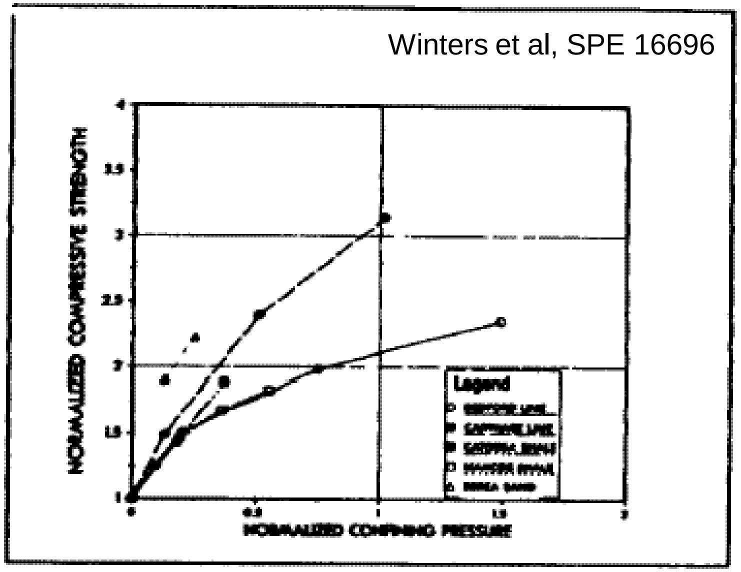
- ~15 minutes per well to calculate and define a non-ambiguous technical limit.

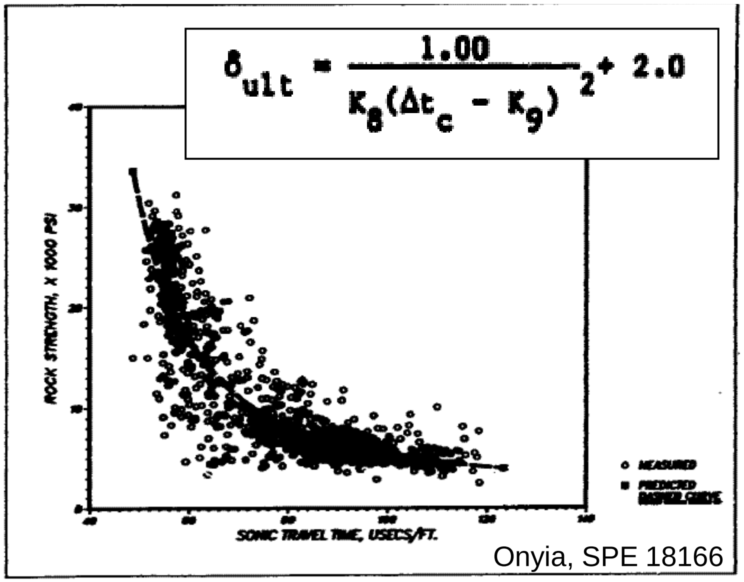
The Specific Energy Concept

- **One of the Original Drilling Rate Models:**
  - It takes a fixed amount of energy to break rock into chips.
  - The time to cut an interval of hole depends on the horsepower being applied to the bottom hole.
  - With a sharp bit & perfectly clean hole bottom there is a maximum rate that a hole can be cut.
  - The minimum time to cut an interval of rock, depends on the HP applied to the bottom, the compressive strength of the rock, the hole’s area.

Perfect Well Assumptions – Time to Cut the Rock…

- **Compressive strength of a rock is a function of the unconfined compressive strength and the mud weight *(ref. Winters SPE16696)*.**
- **Sonic Travel Time reasonably correlates with unconfined Rock Strength *(ref. Onyia SPE18166)*.**
- **It's easy to estimate the fastest time a foot or rock can be cut using the Specific Energy Concept and a *Sonic Log.***



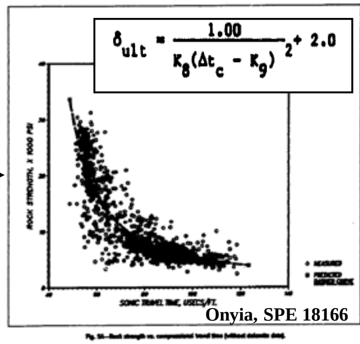


Perfect Well Assumptions – Time to Cut the Rock…

__* Sonic Travel Time__

__* Mud Weight;__
__* Well Depth__

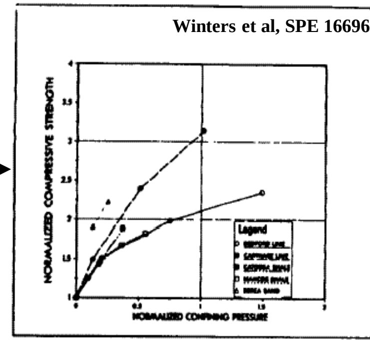
__* Hole Area__



Onyia, SPE 18166

Unconfined Rock Strength

Winters et al, SPE 16696



Apparent Rock Strength (RS)

Specific Energy (SE) = Hole Volume/ f t * RS

Specific Energy Required to turn a foot of hole to chips (Energy/Ft)

__* Inputs__
Output
Intermediate Quantities

__* HP on Bottom;__
__* Weight on Bit__
__* RPM__
__* Mech. HP on Bottom__
__* Mech. Eff. (80%)__

$$ROP \sim \frac{HP * Eff}{SE - WOB * Eff}$$

Pessier et al, SPE 24584

Maximum Rate of Penetration (ROP)

$$Time = \frac{\text{Feet Drilled}}{ROP}$$

__* Footage Drilled__

Minimum Time to Drill interval = (Perfect Well Time to cut interval)

Note: Based on Specific Energy Concept an "Old" bit penetration rate modeling concept that is difficult to apply in real cases since bit wear, bit efficiency, drilling condition, hole cleaning and rock strength are all lumped into one factor. Since the perfect well assumes perfect cleaning, "perfect" bit, maximum HP on bottom, perfect cleaning and a sonic correlated Rock Strength it can be used to create a reasonable estimate of the minimum time required to drill a hole interval (ref: Detournay et al SPE 78221, Pessier & Fear SPE 24584, Rabia SPE 12355 and Teale J. Rock Mech (1965) for discussion of Specific Energy Concept)

Perfect Well Assumptions

Each hole interval is made up of the following elements:

Rig up / BOP + Trip in time+ Drill Out / LOT + Connections Time + Time to Cut Rock + Time to Trip Out in OH + Time to Trip Out in Cased Hole + time to Log + time to Run Casing + time to Pump Cement

Time Based Assumptions:

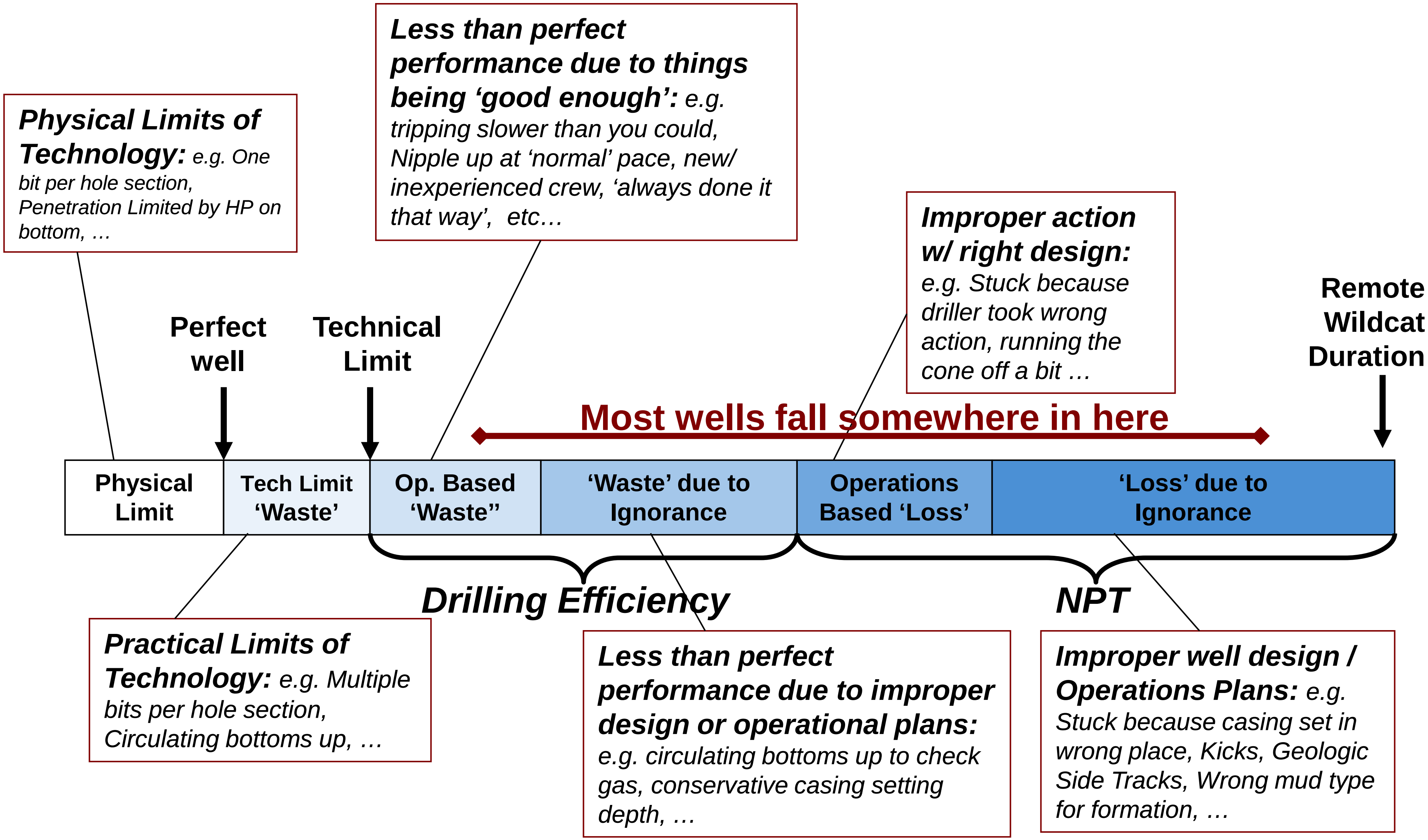
BOP Rig up/Test	- 3 hrs	
Drillout/LOT	- 1 hr	
Trip time Cased Hole	- 5400 ft/hr	(90 ft stands; 35 sec lift, 15 sec break, 10 sec down)
Trip Time Open Hole	- 3400 ft/hr	(90 ft stands; 70 sec lift, 15 sec break, 10 sec down)
Casing Running Time	- 2700 ft/hr	(45 ft joint; 10 sec lift, 15 sec make, 35 sec down)
Pump Cement	- 20 bpm	(Cementing time assumes we place 1000ft behind Casing)
Drilling Connection	- 1800 ft/hr	(30 ft joints; 20 sec up, 15 sec break, 15 sec make, 10 sec down)
Logging	- 2000 ft/hr	(2000 ft/hr over interval of interest - one pass)
Rig On Bottom HP	- 100 HP	(Bottom HP Determines Penetration Rate)

Other Assumptions:

Always 100 psi Overbalanced
No waiting on cement (beyond Rigup/BOP, Trip in, Drillout)
Perfect Cleaning Hole
Always place 1000 ft of cement behind pipe
Mix Cement at 1/4 as fast as you pump
Take 30 min. to rig up to pump cement
One bit per hole section

ROP Limited by rig on bottom HP

Defining the Perfect Well – Components of a Well's Duration



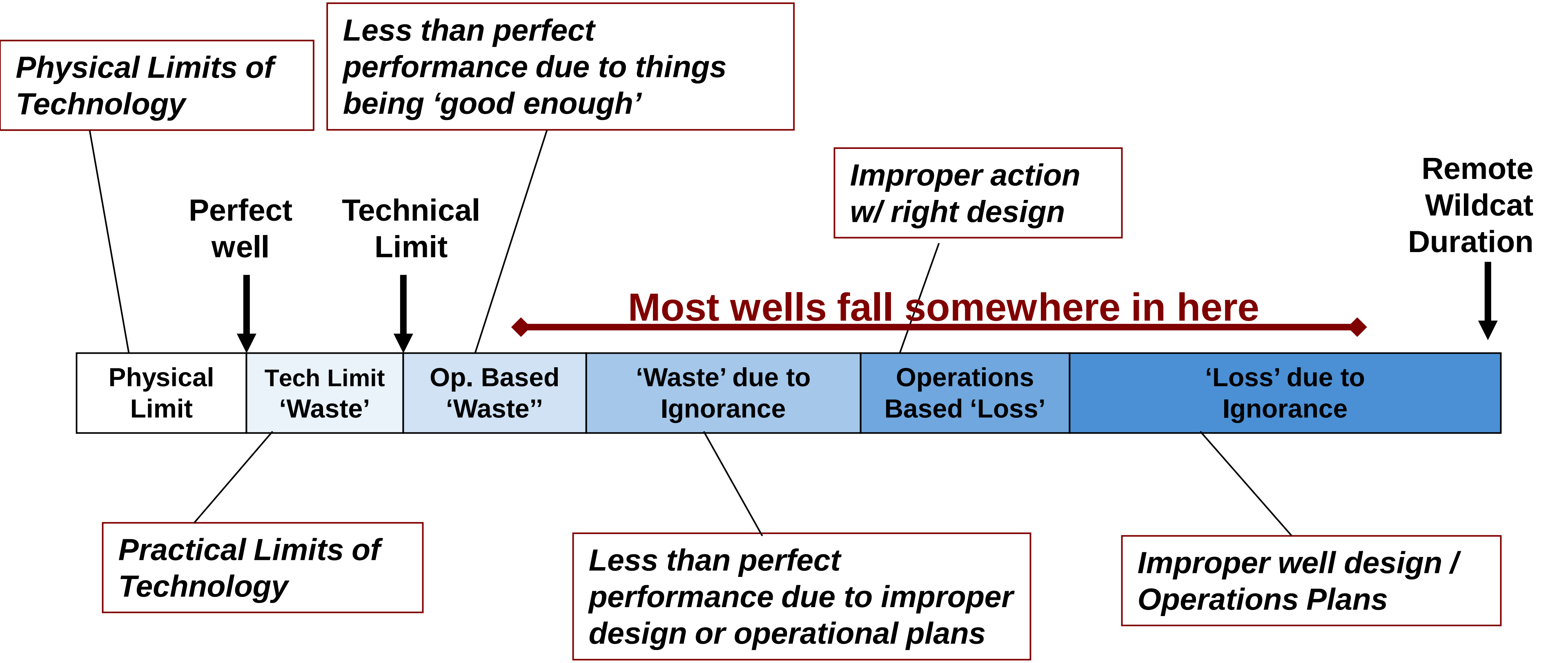
Note: Drawn roughly to scale based on Perfect Well Work to date

Defining the Perfect Well – Components of a Well's Duration

'Loss' & 'Waste' are Quality Management Concepts.

<u>'Waste'</u> is less than total quality that is a product of the process operating normally – *e.g. left over french fries, circulating to condition mud (would not be done in the perfect world)*

<u>'Loss'</u> is less than total quality that is a product of some kind of failure – *e.g. fries dropped on the floor, stuck pipe.*



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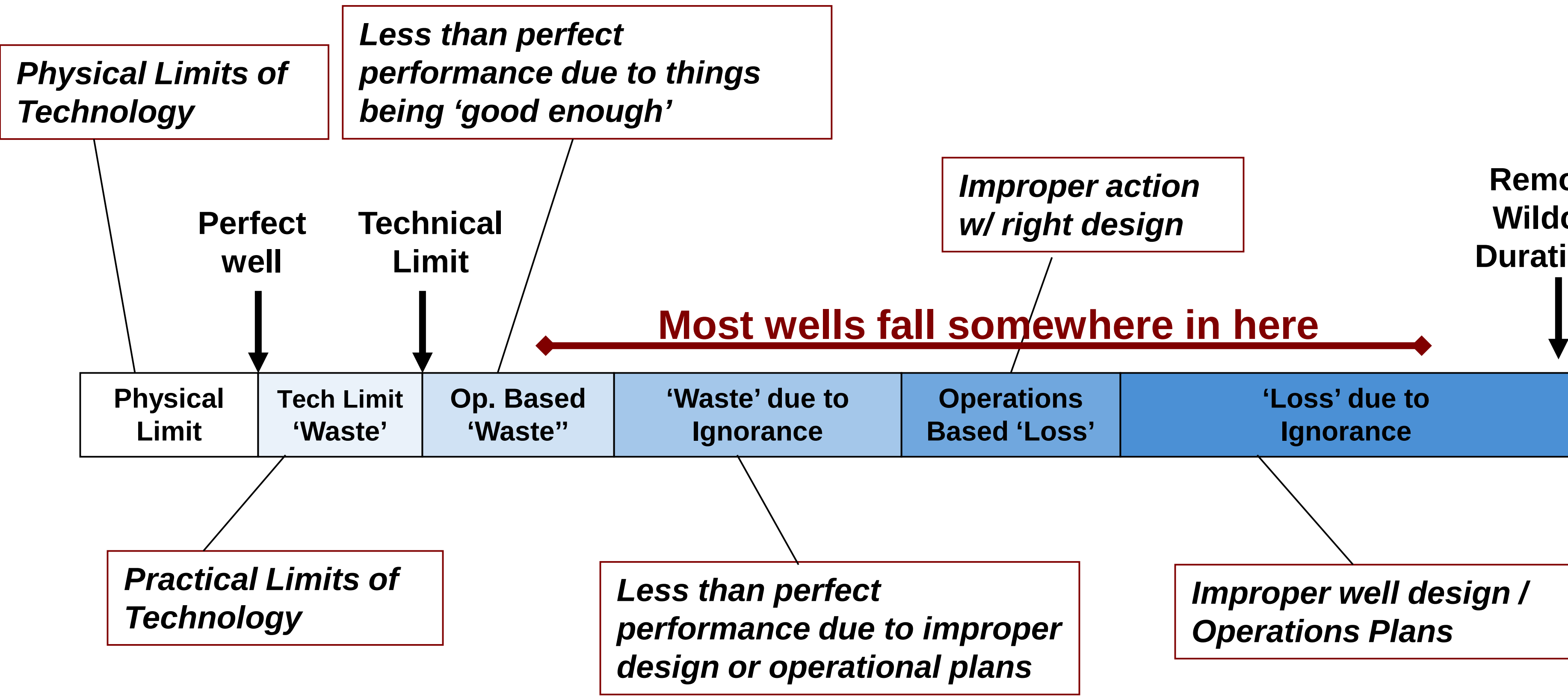
Defining the Perfect Well – Components of a Well's Duration

Waste and Loss has two classes of root causes:

<u>'Ignorance'</u> less than perfect due to not knowing something *– e.g. Using the wrong golf club but hitting the ball correctly.*

<u>'Operations'</u> less than perfect due to some kind of action *– e.g. Using the right club but 'topping' the golf ball.*



Golf Analogy

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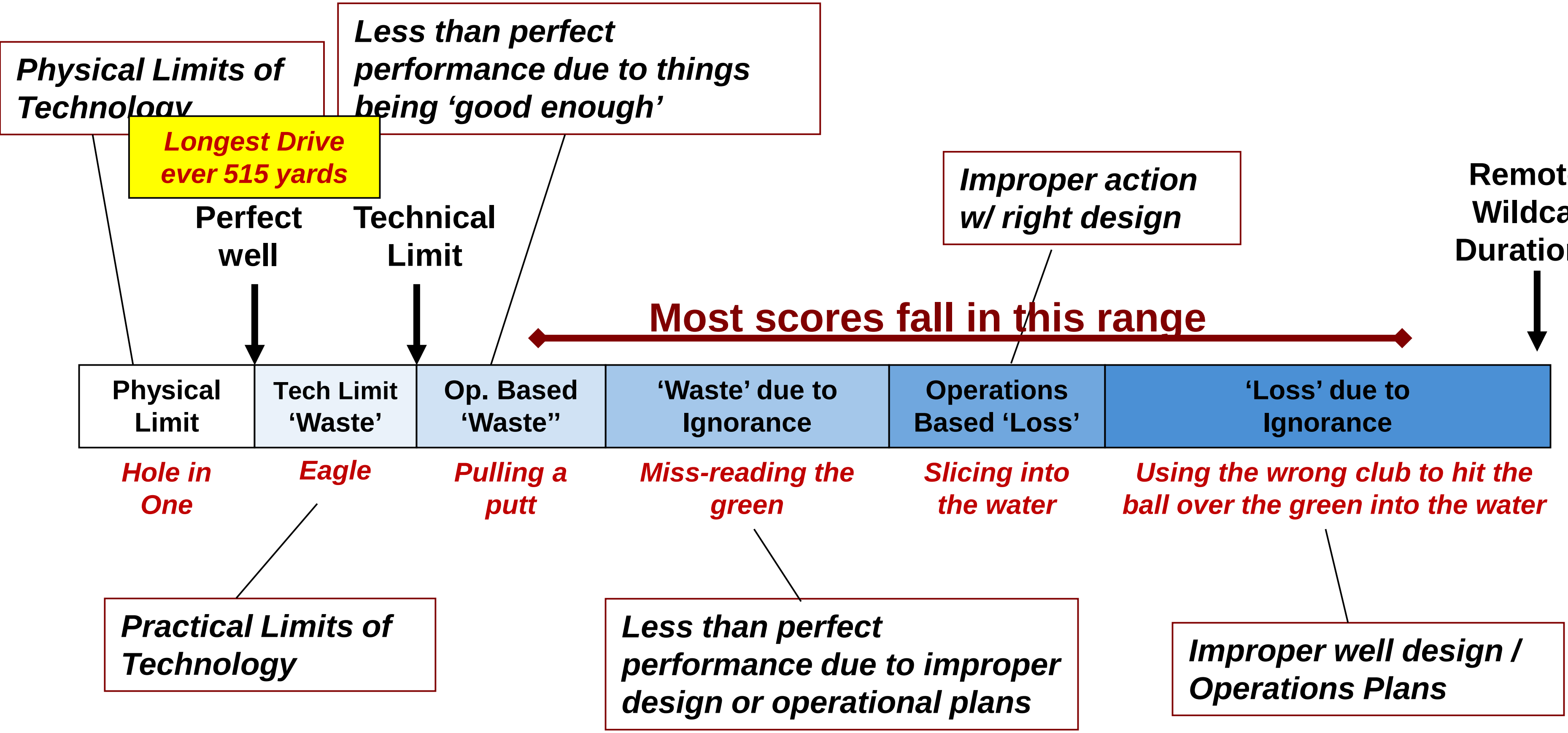
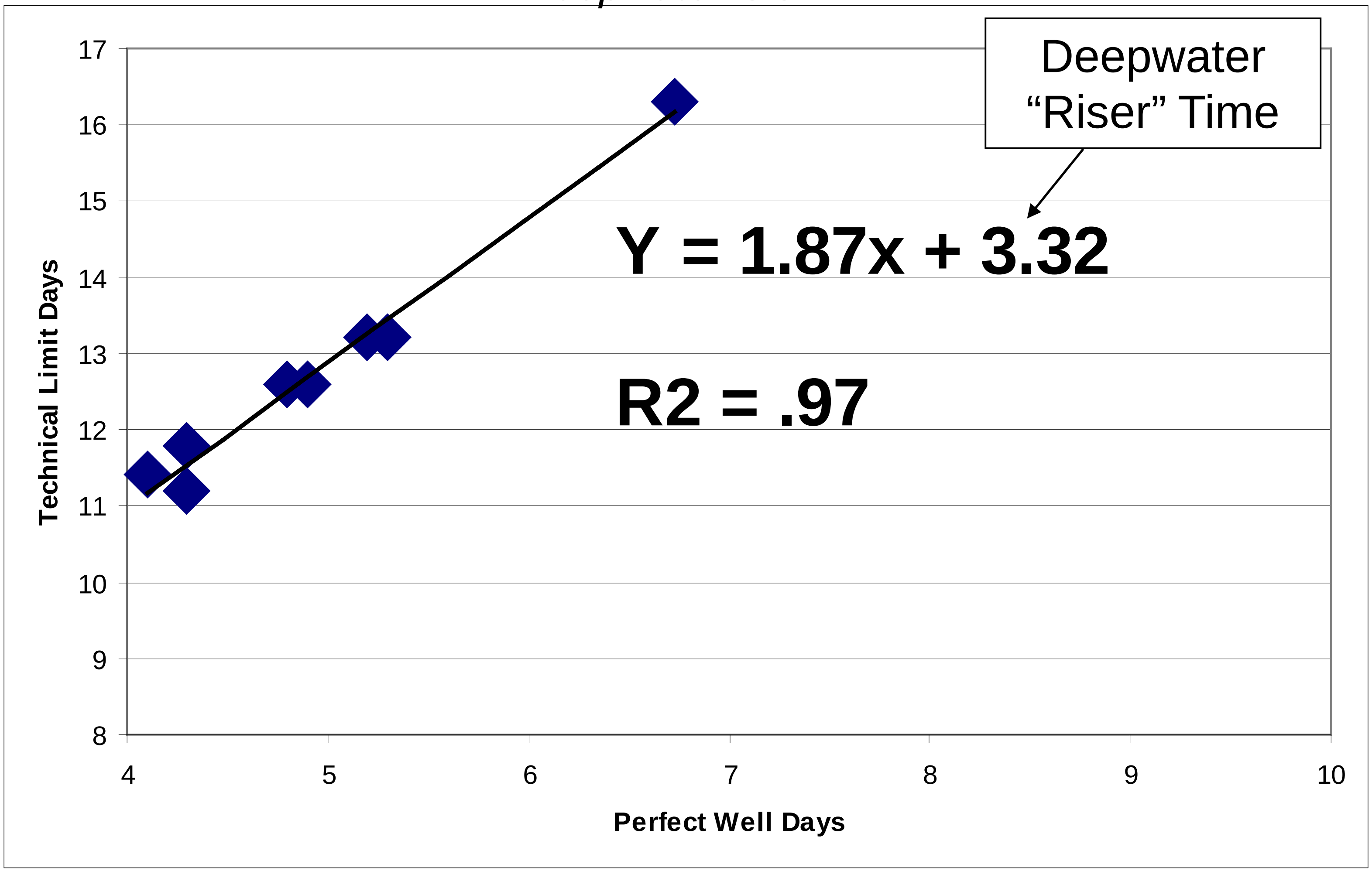


How does the Perfect Well Compare with the T.L.?

Technical Limit vs. Perfect Well Comparison

Deepwater GOM



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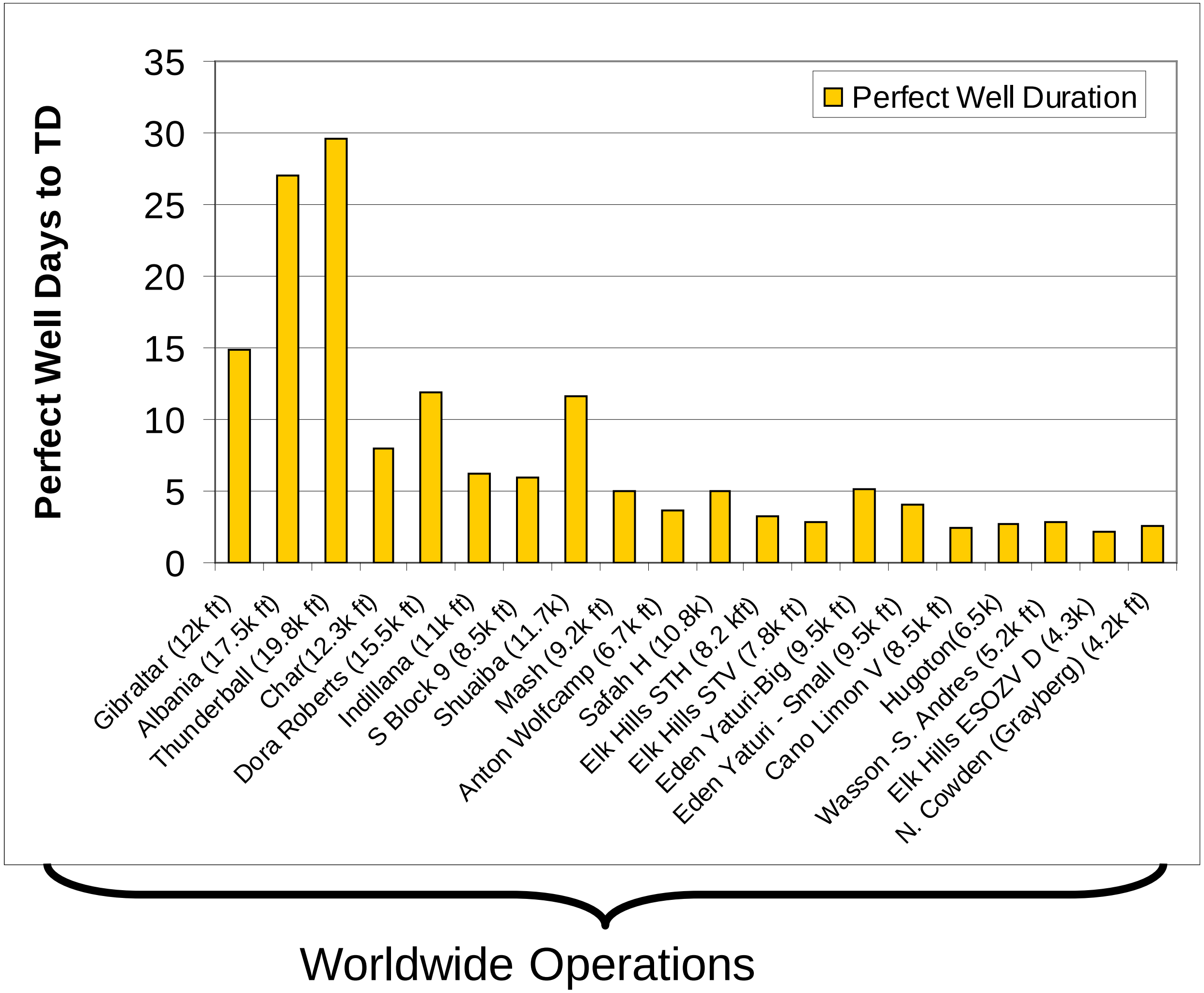
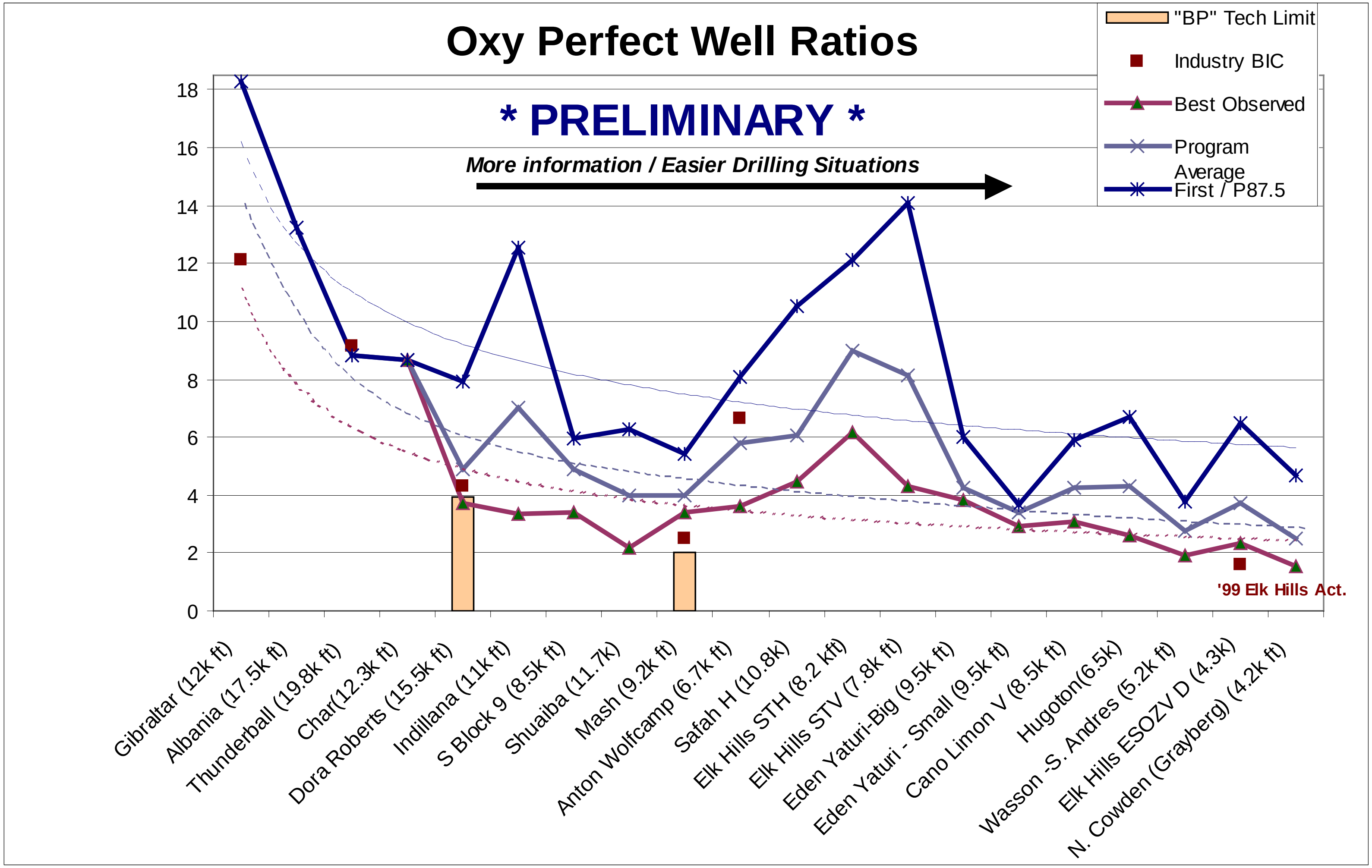
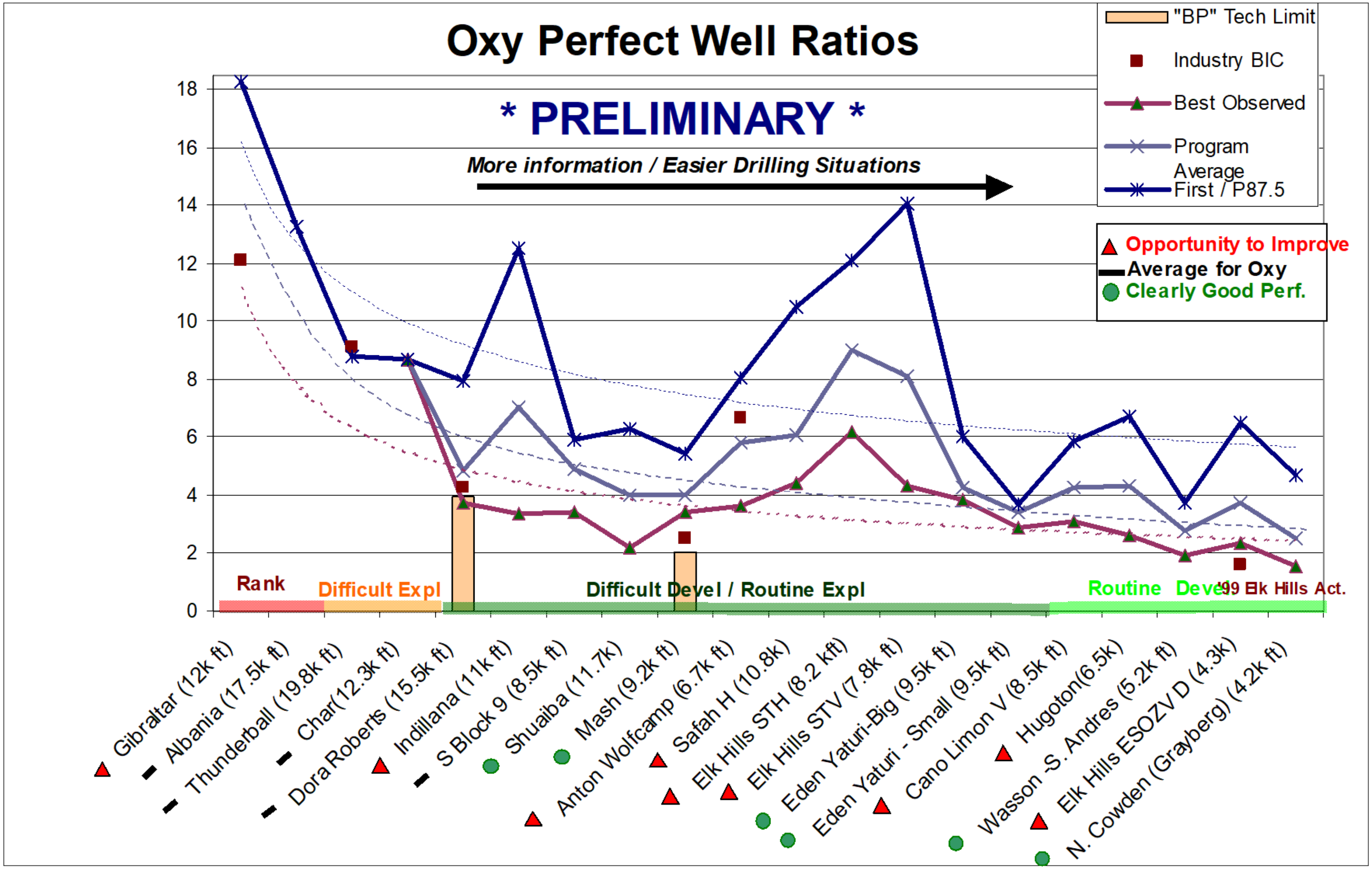
Perfect Well Durations for Various Oxy & Partner Operations



Ratio of Actual Duration to Perfect Well Duration

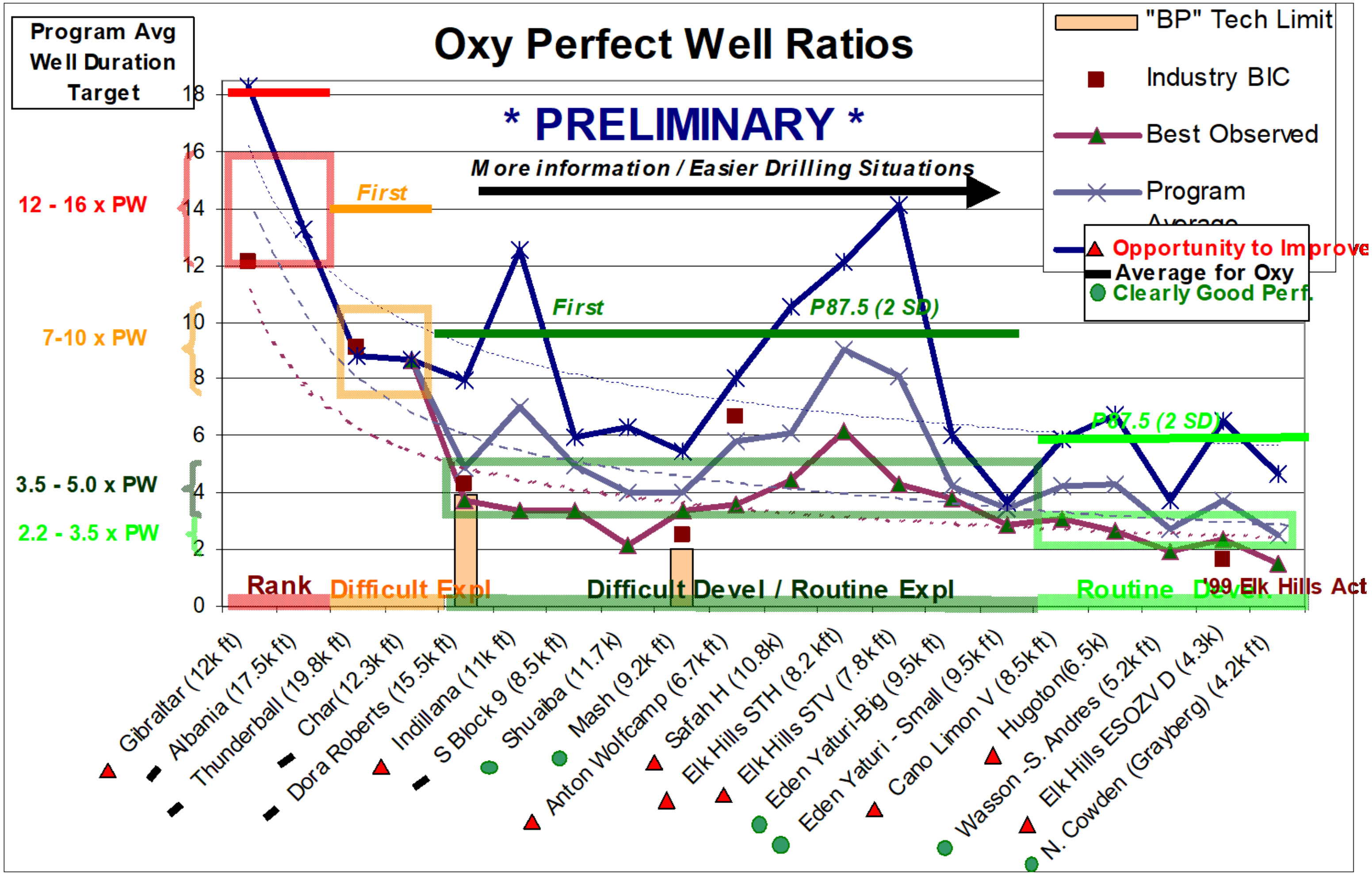


Grouped by Similar Degree of Difficulty and Compared with Trend Line

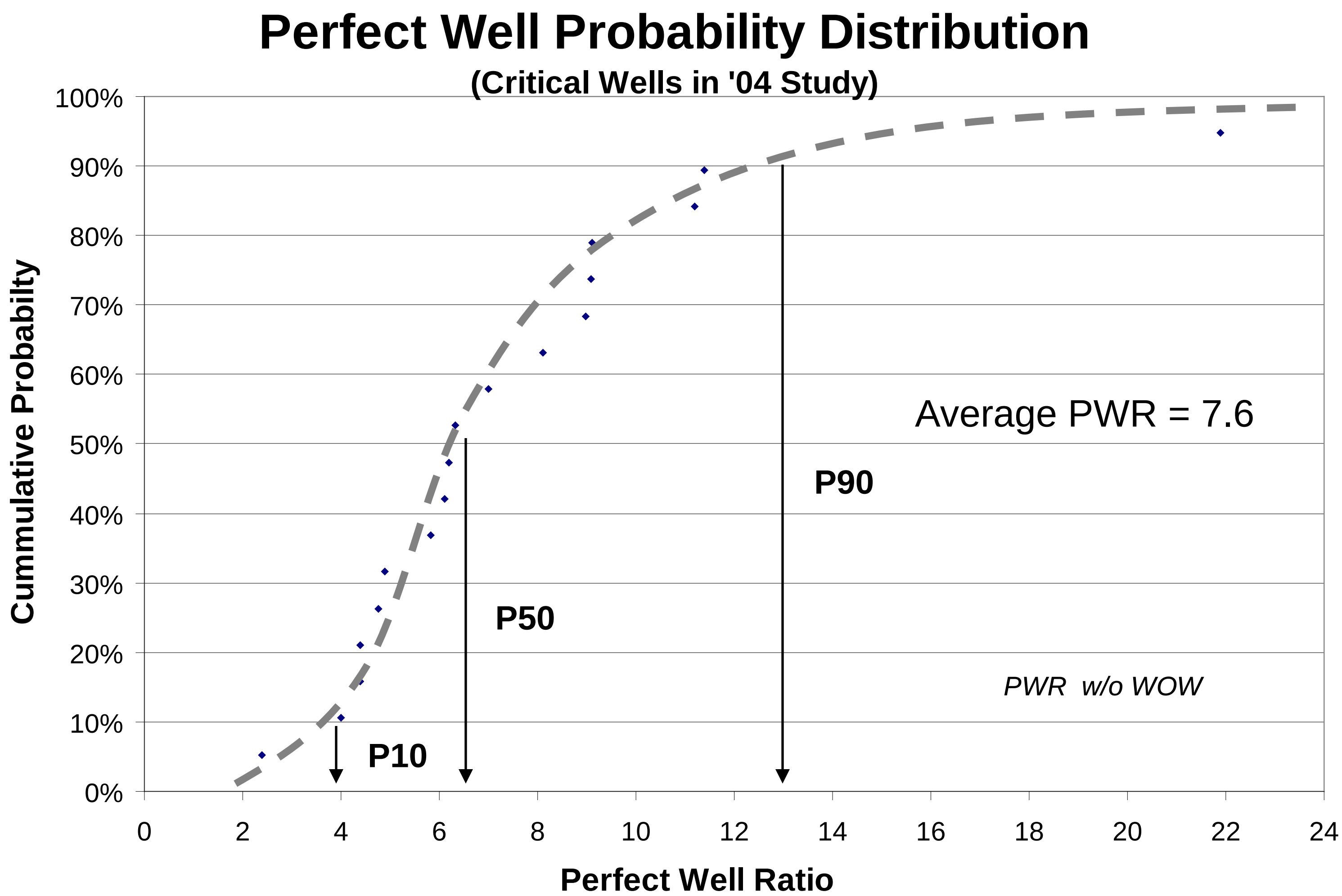


Develop Target ranges for Types of Operations

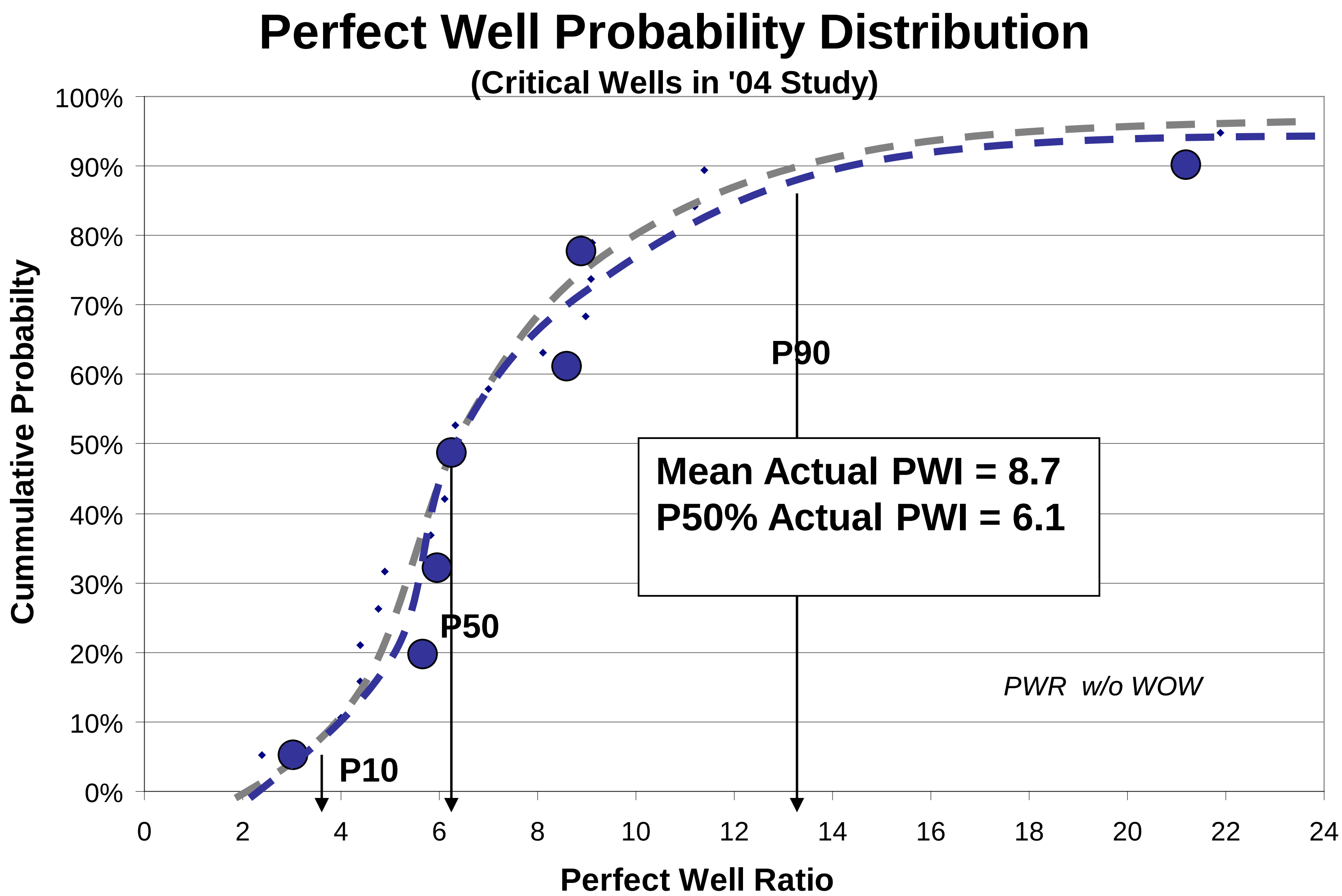
Use perfect well ratios for similar types of operations to identify normal ranges for different types of wells.

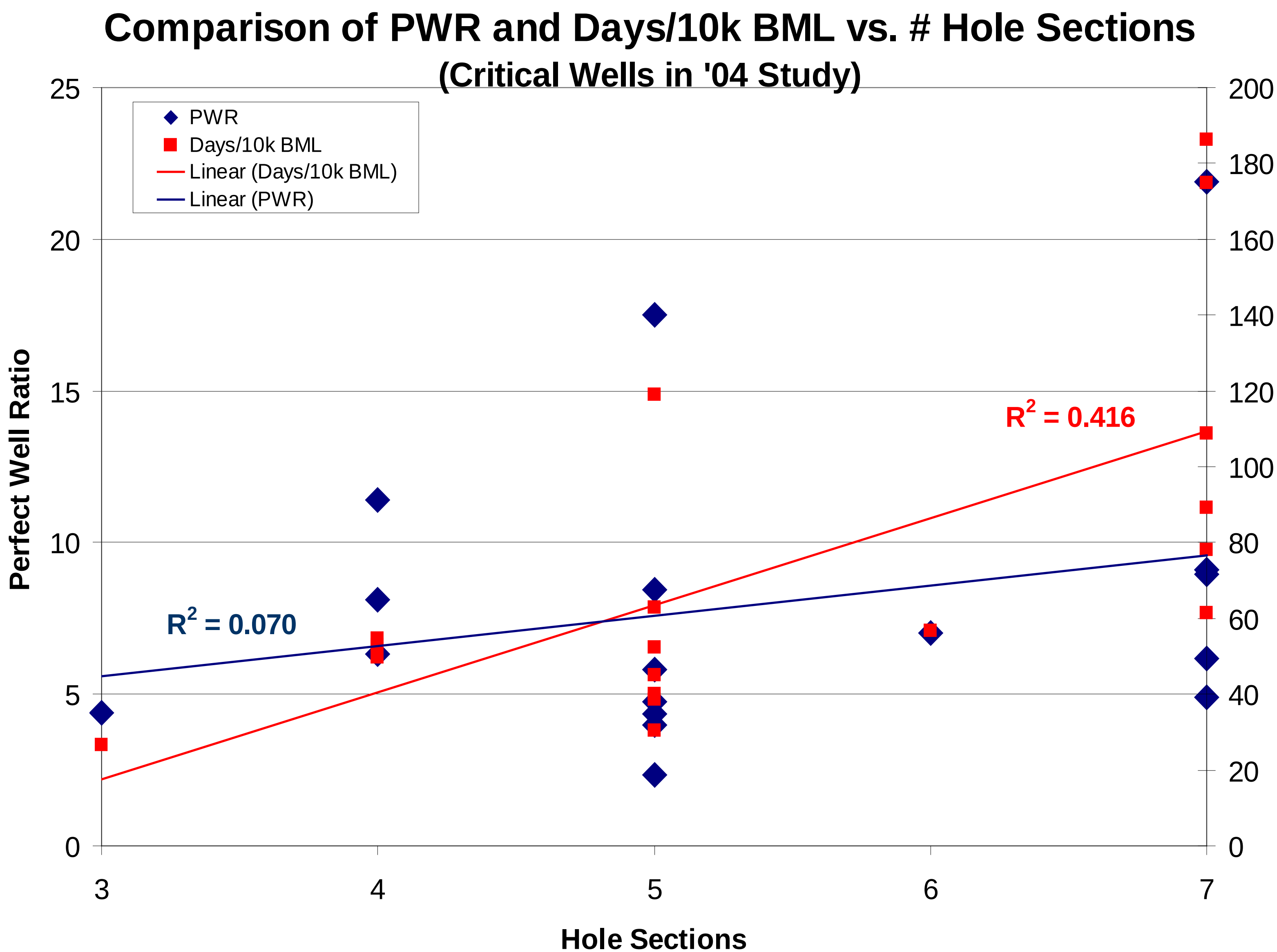


Perfect Well Ratio – How Stable as a measure?



Actual PWR Comparison Two Organizations "Rank" Exploration Wells





Comparison of PWR and Days/10k BML vs. # Hole Sections
(Critical Wells in '04 Study)
PWR
Days/10k BML
Linear (Days/10k BML)
Linear (PWR)
$R^2 = 0.416$
$R^2 = 0.070$
Perfect Well Ratio
Hole Sections
0
5
10
15
20
25
3
4
5
6
7
0
20
40
60
80
100
120
140
160
180
200

Perfect Well Data Requirements

For Calibration Wells (e.g. wells already drilled):

- **vs. Measured Depth***: Sonic Log, Mud Weight, Pore Pressure, Days**
- **Casing Points, Casing Sizes, and Hole Sizes (Hole diagram is OK).**

For Prospective wells (e.g. wells to be drilled):

- **Anticipated Properties vs. Measured Depth: Mud Weight, Pore Pressure**
- **Anticipated Days vs Depth (if available)**
- **Seismic Travel Time (if there happens to be a sonic log – unlikely in frontier wells – that would be useful as well).**
- **Geologic Cross Section w/ formation type and age.**
- **Casing Points, Casing Sizes, and Hole Sizes (Hole diagram is OK).**

*** NOTE: For wells with a substantial directional program we also need directional information to correlate MD with TVD

Perfect Well Analysis

- A quick, easy, quantitative drilling performance benchmark.
- Identify Opportunity to improve based on 'non-arguable' benchmark.
- Change the conversation from 'arguing about the performance metric' to 'explaining deviations from an objective standard'.
- Patented Approach #7,031,840

The Maximum Conceivable "Prize" from TECHNICAL LIMIT Performance

	MAXIMUM Possible TIME Improvement	% of Well Costs Driven by Time 33% — Cost Reduction Possible due to Time	50%
Lekhwair (1.3km)	39%	13%	20%
Thuleilat-Vert (1.05km)	58%	19%	29%
Thuleilat-Dev (1.1km)	66%	22%	33%
Thuleilat-Deepset (1.05km)	51%	17%	26%
Fahud (.60km)	66%	22%	33%
Marmul (1.5km)	76%	25%	38%
Nimr (1.1km)	74%	24%	37%
Barik Oil (3.0km)	67%	22%	33%
Musallim MultiLats (2.4km+1.2km lats)	64%	21%	32%
Saih Rawl (5.3km)	74%	25%	37%

Assumes Target Average PWR:
2.0 for all well types

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