

Understanding Depletion Effects on Well Performance in the Middle Bakken Formation*

Michael Roth² and Murray Roth¹

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¹Ground Truth Consulting, Highlands Ranch, Colorado, United States

²Ground Truth Consulting, Pittsburgh, Pennsylvania, United States (michael@groundedtruth.com)

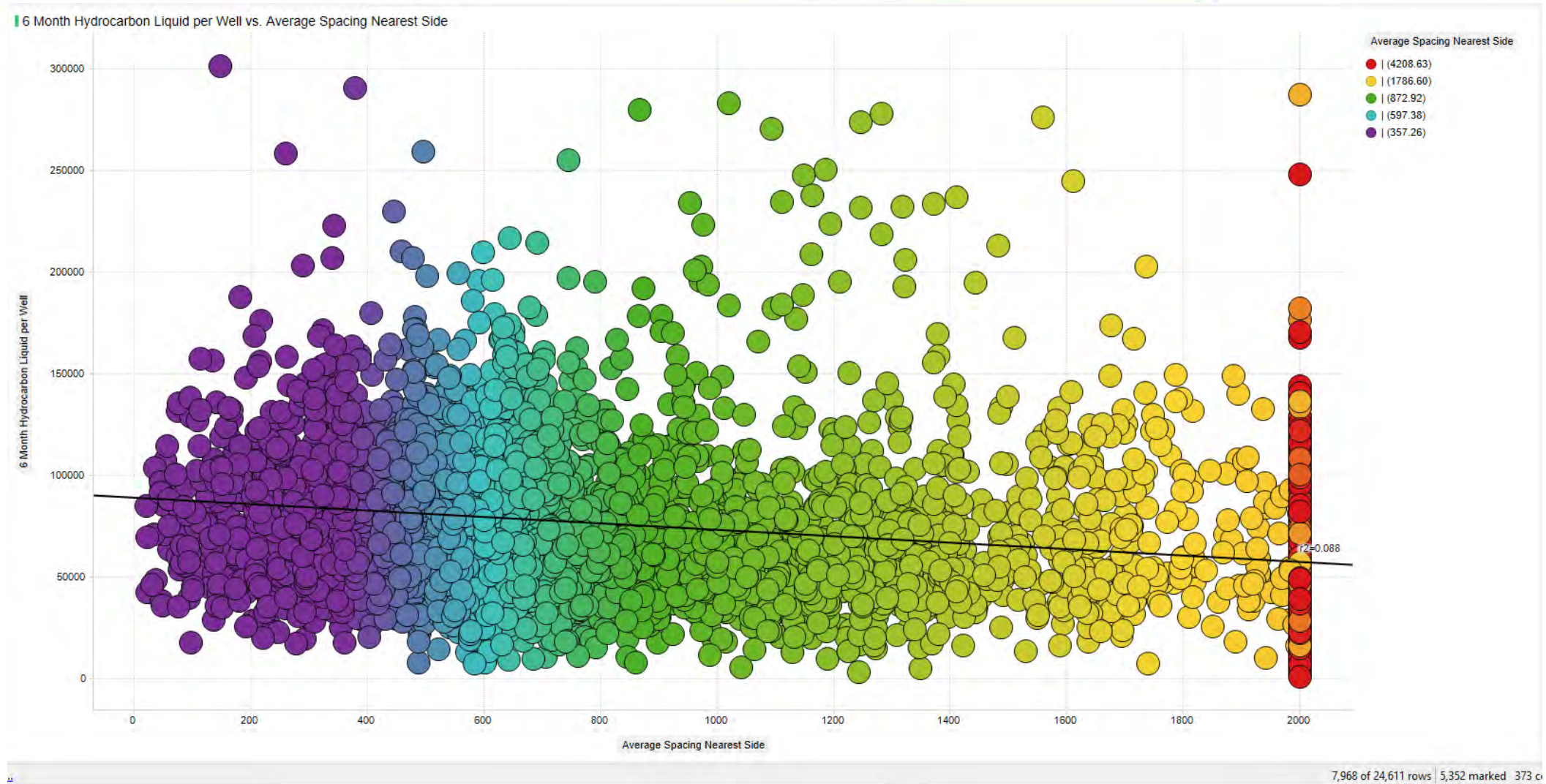
Abstract

One of the more mature unconventional resource plays, the Williston Basin has over ten thousand hydraulically fractured, horizontal wells spanning the Middle Bakken and Three Forks formations. With fewer and fewer new, standalone well locations remaining in the basin, focus has shifted towards understanding the dynamics of geologic sweet-spots, in a heavily developed environment. In other words, in the context of original oil in place (OOIP) models, how do we optimize recovery factors by economically increasing drainage volumes and efficiencies, through the addition of infill wells and the refracturing of existing producing wells. Previous studies have highlighted the importance of TOC, thermal maturity, depth and thickness when modeling expected well performance across the Bakken/Three Forks play. The volume of statistics surrounding the variable completion designs of these horizontal wells and their subsequent production performance, in particular geologic settings, has spawned various efforts to model well performance using multivariate analytics. Such techniques have allowed operators to more optimally “right size” well designs for specific geologic conditions. However, the Bakken/Three Forks challenge has evolved from modeling individual, isolated well performance - to comprehending the complex interaction of multiple horizontal wells, across multiple targeted landing zones. A geologic framework of the Bakken and Three Forks formation depths and thicknesses, is developed from geologic interpretation of numerous vertical wells; augmented with geochemical and well log data to highlight prospect variability. Against this geologic backdrop, this study looks at well interactions that include “frac hits”, driven by per-well injections of water volumes of 250,000+ bbl; as well as estimates of production interference. Well spacing metrics have been developed to characterize the dynamic impact of: vertical and lateral well spacing; length of well overlap; cumulative adjacent well footage; and more. Calibration of spacing impact is achieved using multi-variate analytic techniques that model multi-well performance by comparing geologic attributes, drilling and completions parameters, and a suite of dynamic well spacing metrics. The results of this study highlight remaining Bakken/Three Forks prospects and the importance of considering the timing of infill wells and recompletions, in addition to lateral and vertical spacing, in unconventional field development.

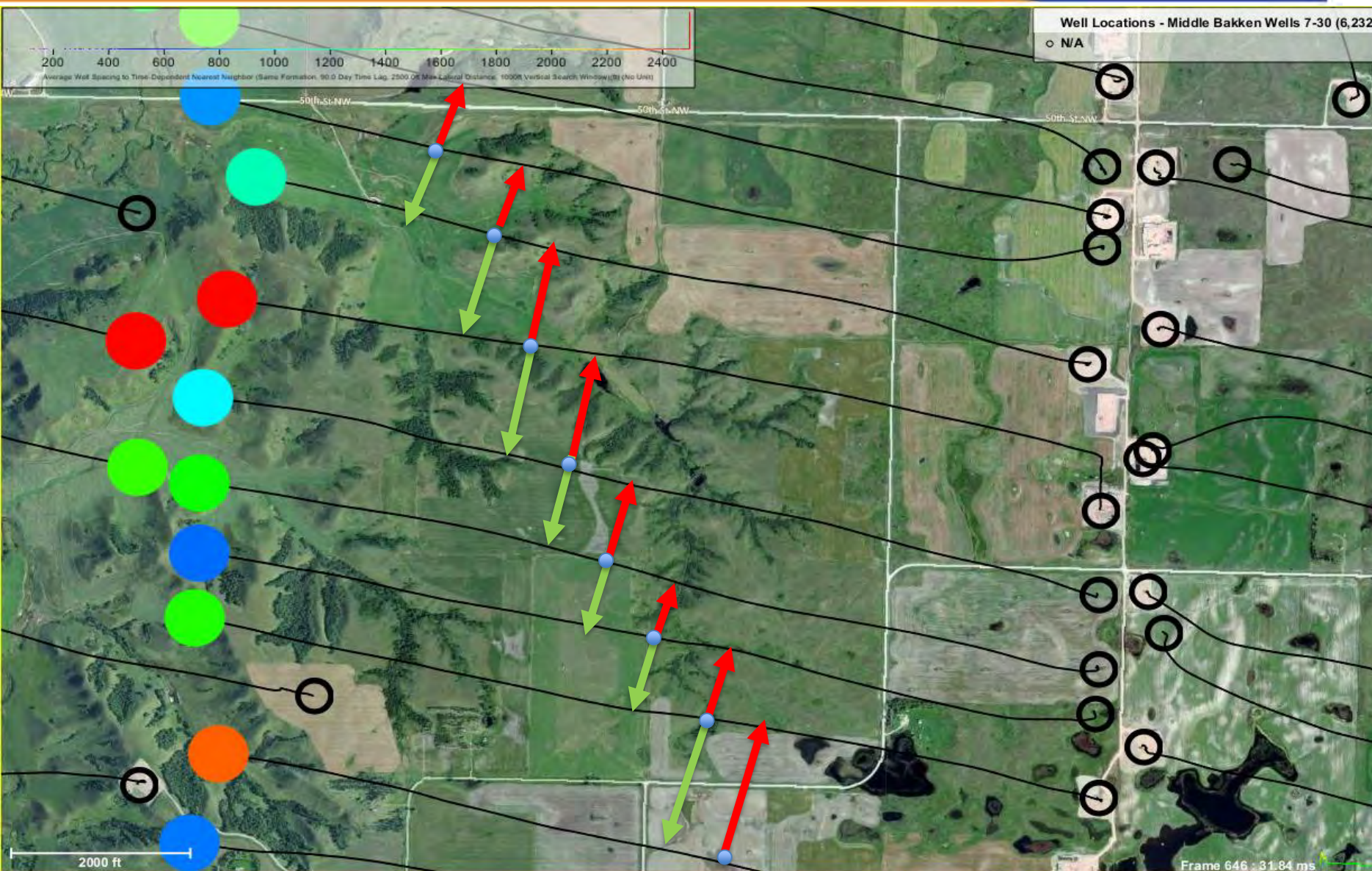
UNDERSTANDING DEPLETION EFFECTS ON WELL PERFORMANCE IN THE MIDDLE BAKKEN FORMATION



Lateral Spacing vs. 6 Month Cum Oil



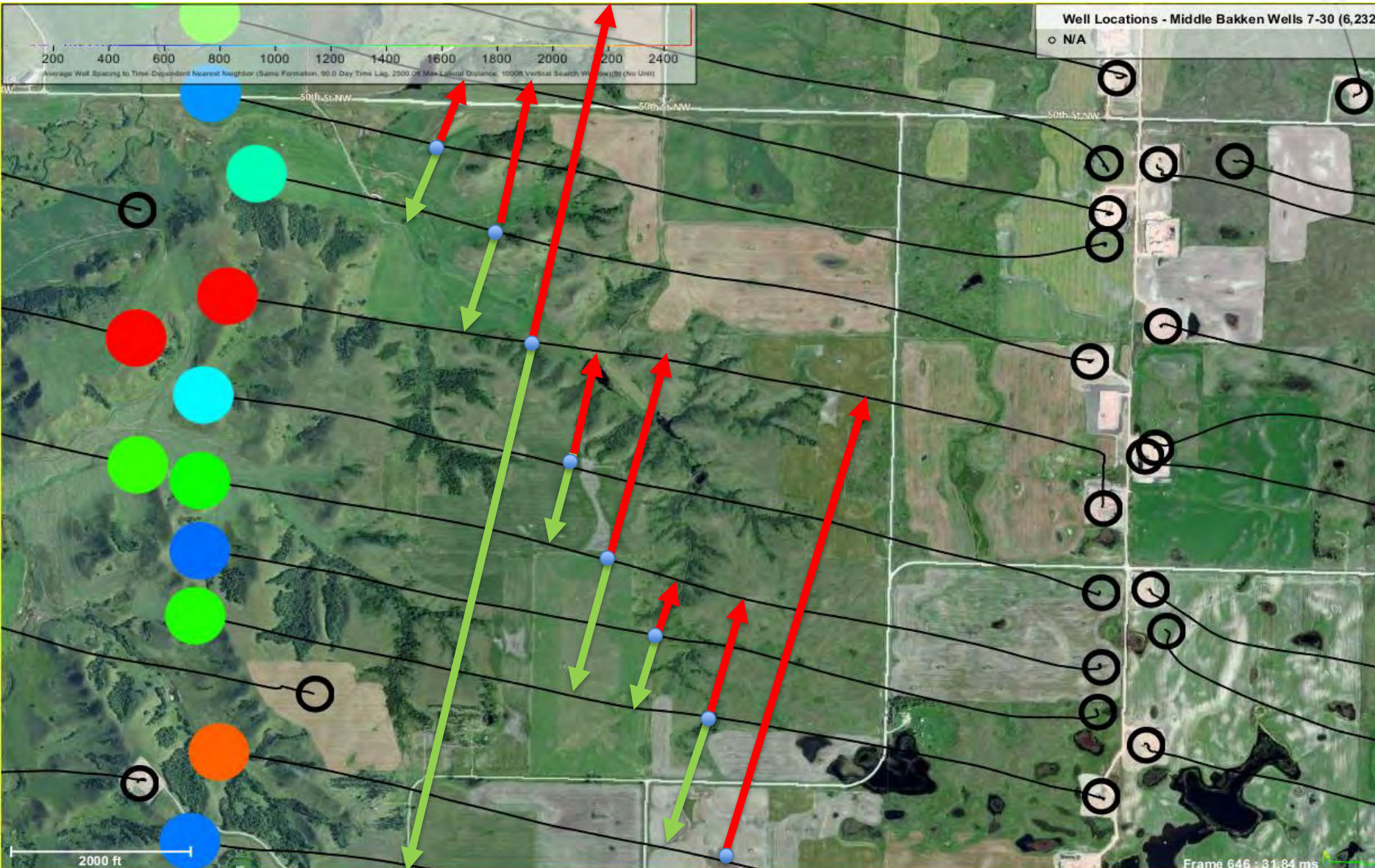
Present Day Spacing



Completion Date

- 2010
- 2011
- 2012
- 2013
- 2014

Time-Dependent Spacing

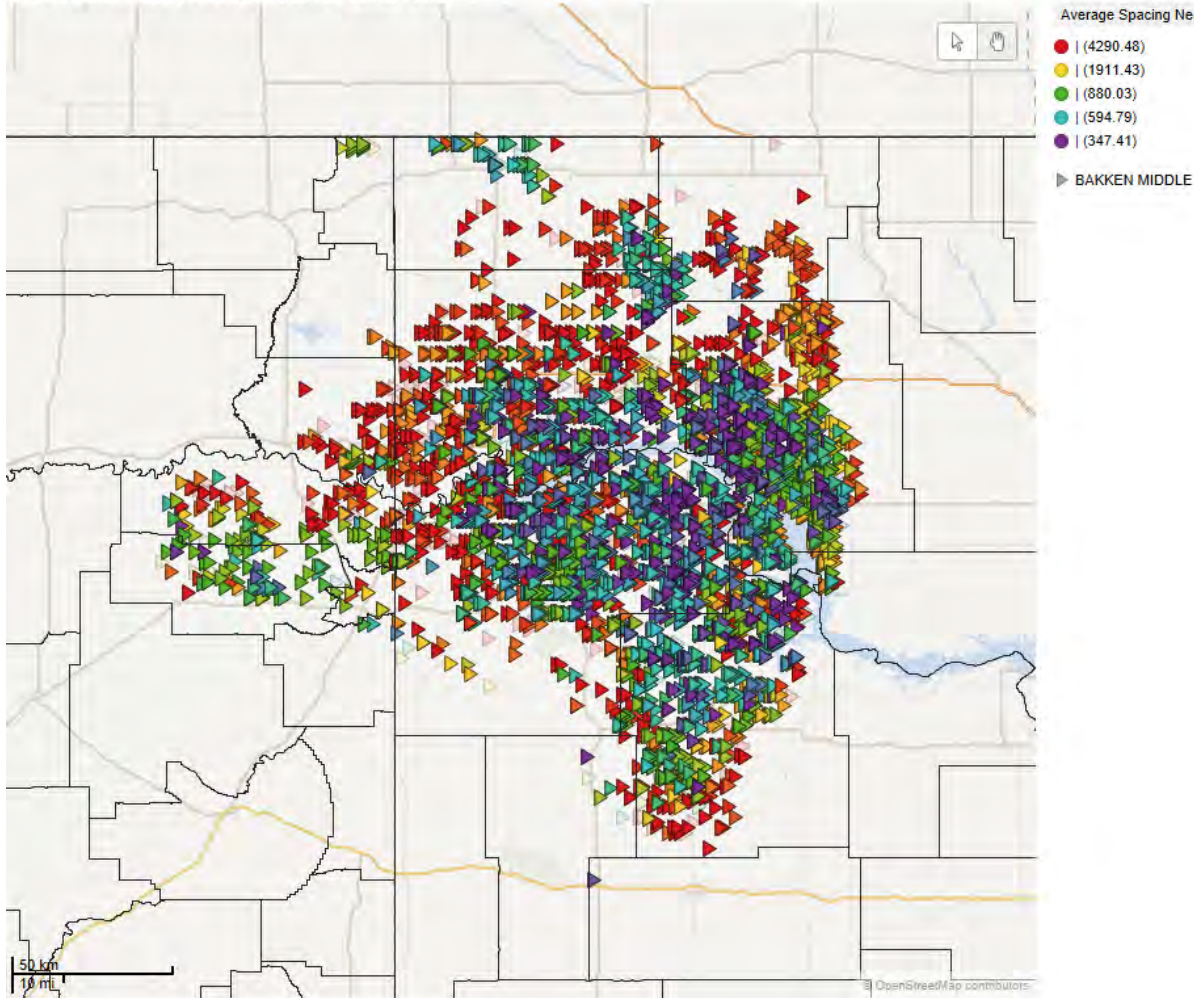


Completion Date

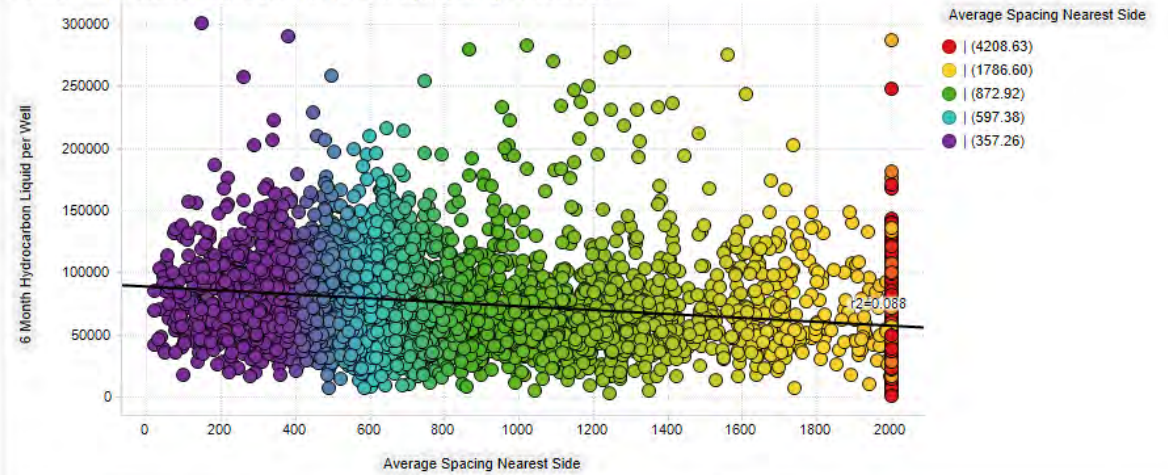
- 2010
- 2011
- 2012
- 2013
- 2014

Lateral Spacing vs. 6 Month Oil

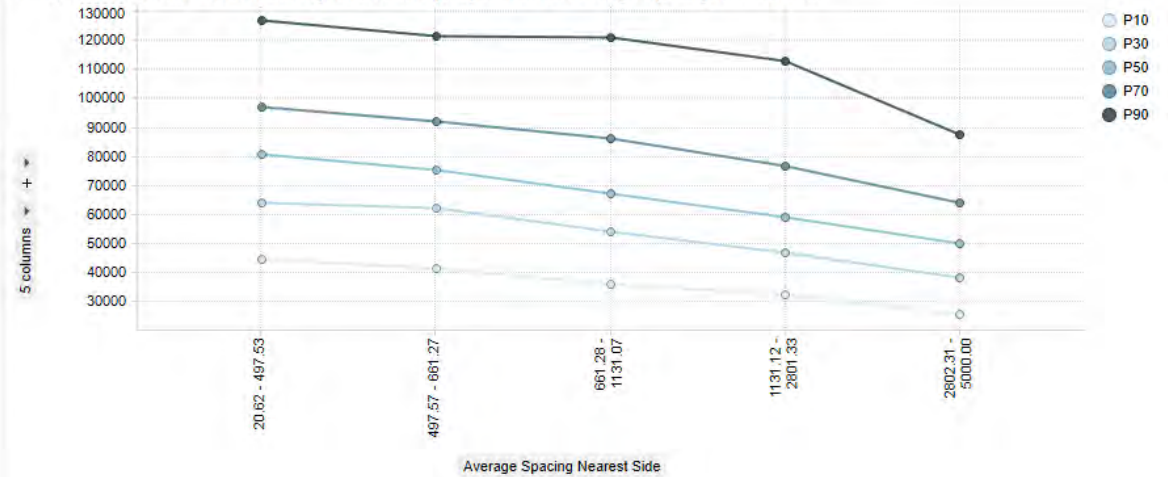
Well Location Map by Average Spacing Nearest Side



6 Month Hydrocarbon Liquid per Well vs. Average Spacing Nearest Side

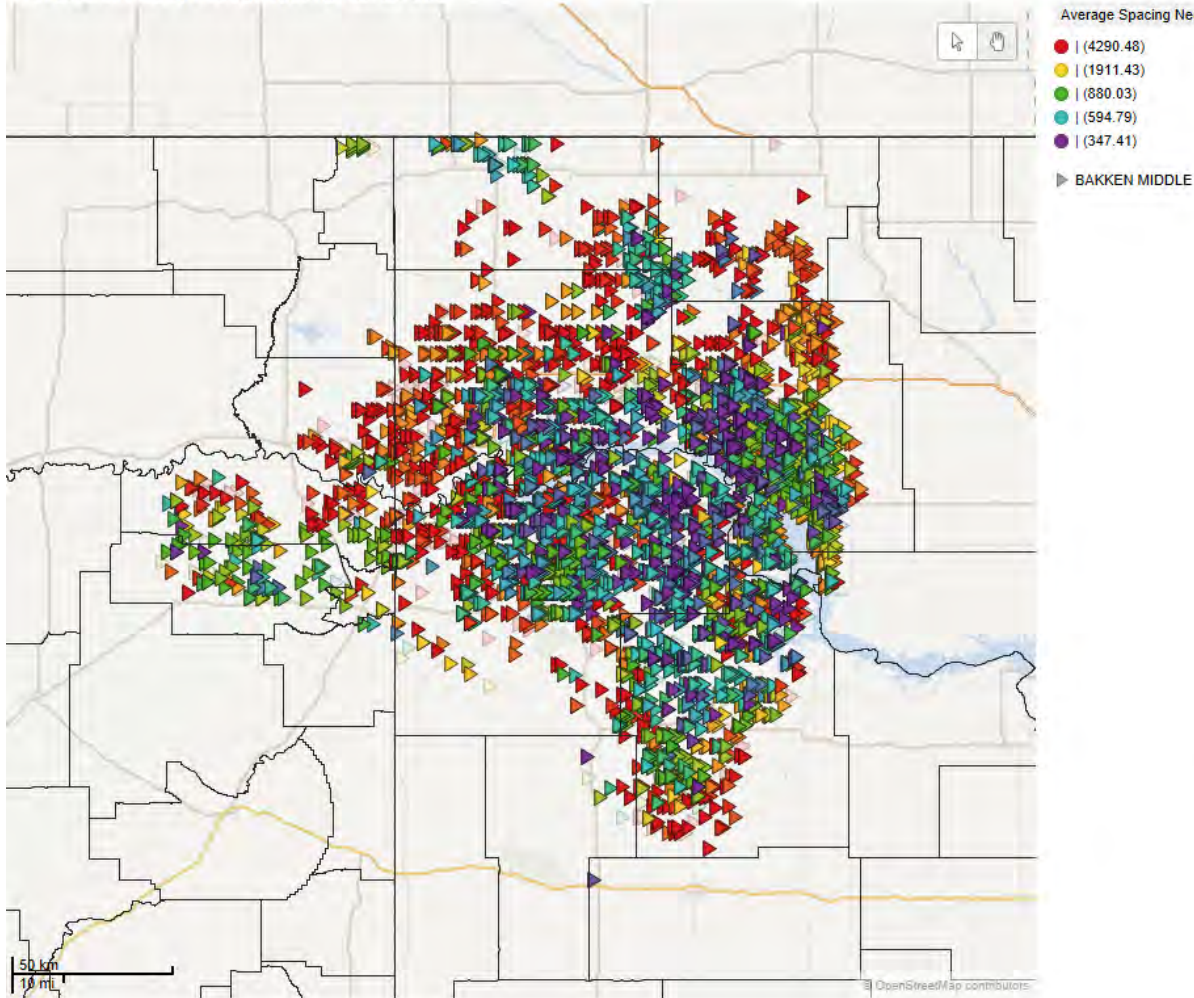


P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per Well vs. Average Spacing Nearest Side

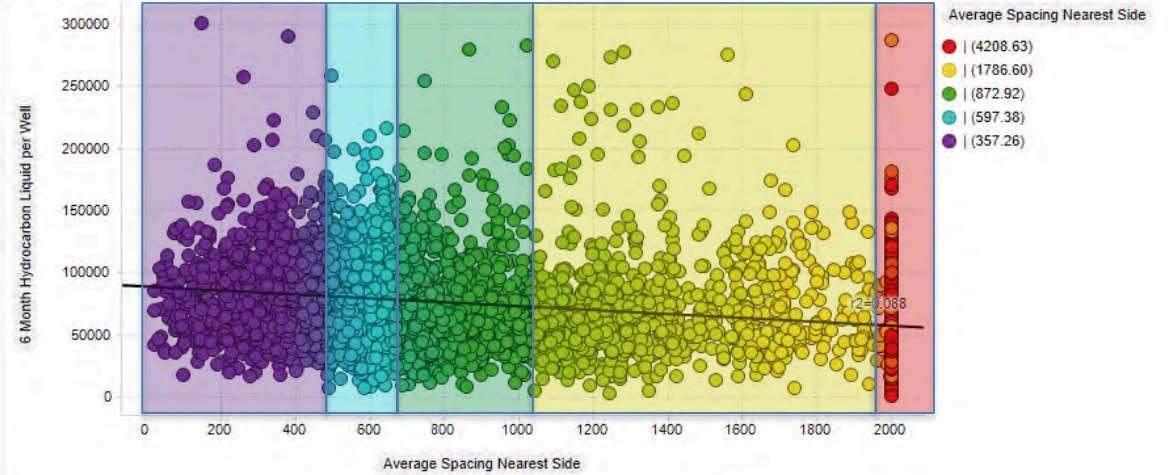


Lateral Spacing vs. 6 Month Oil

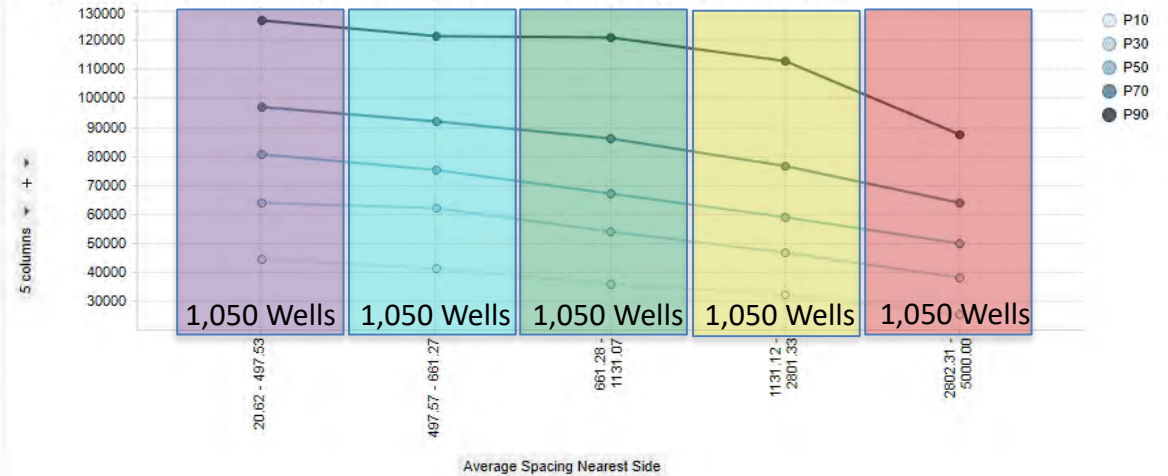
Well Location Map by Average Spacing Nearest Side



6 Month Hydrocarbon Liquid per Well vs. Average Spacing Nearest Side

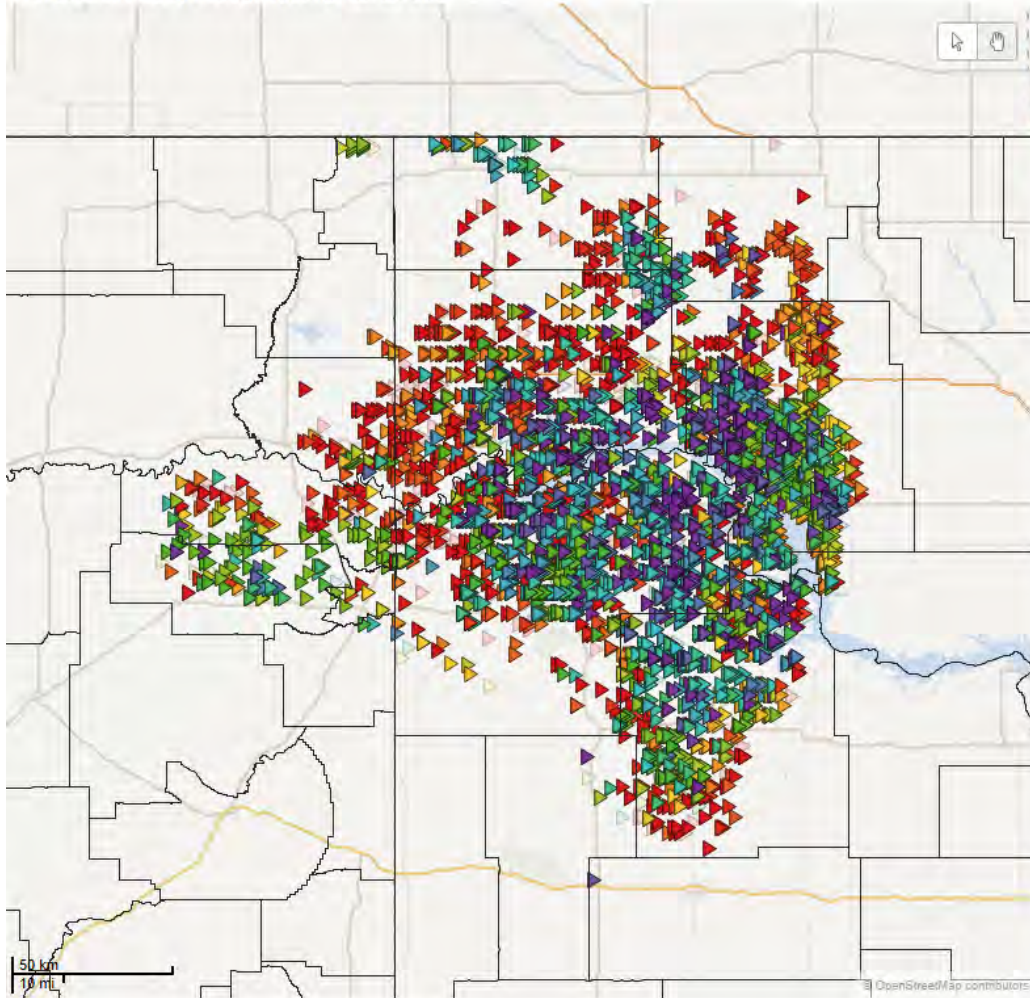


P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per Well vs. Average Spacing Nearest Side

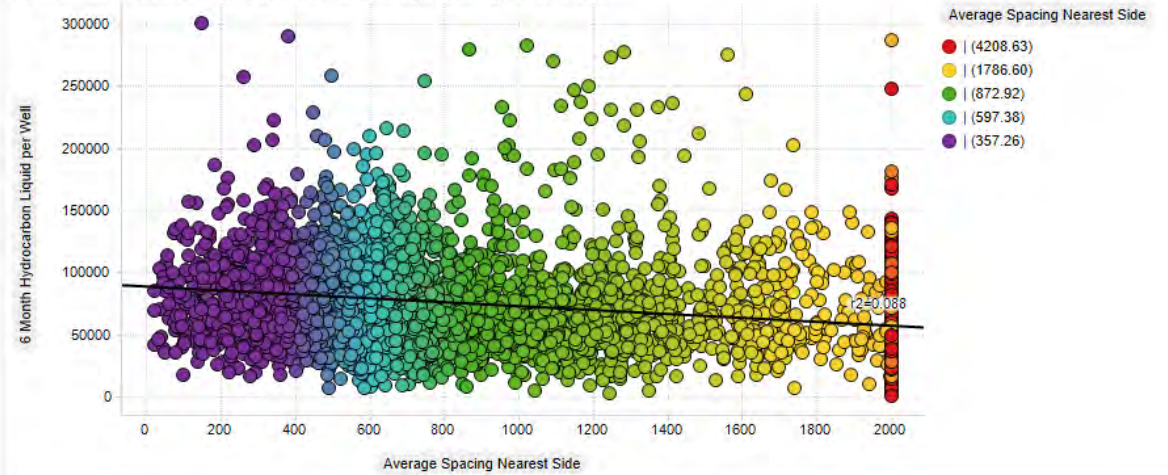


Lateral Spacing vs. 6 Month Oil

Well Location Map by Average Spacing Nearest Side

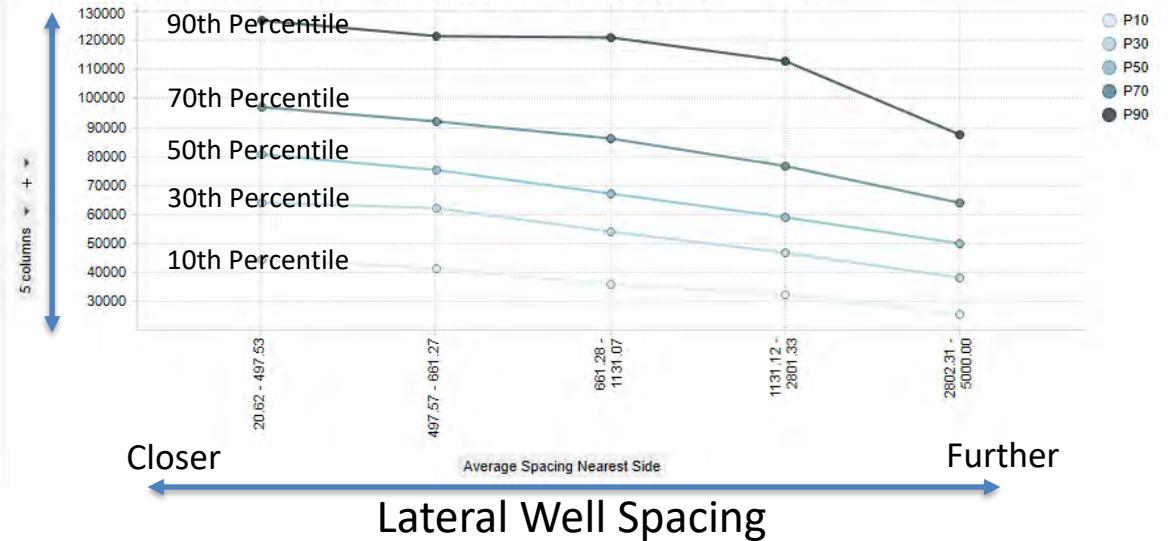


6 Month Hydrocarbon Liquid per Well vs. Average Spacing Nearest Side



Cum 6 Month Oil

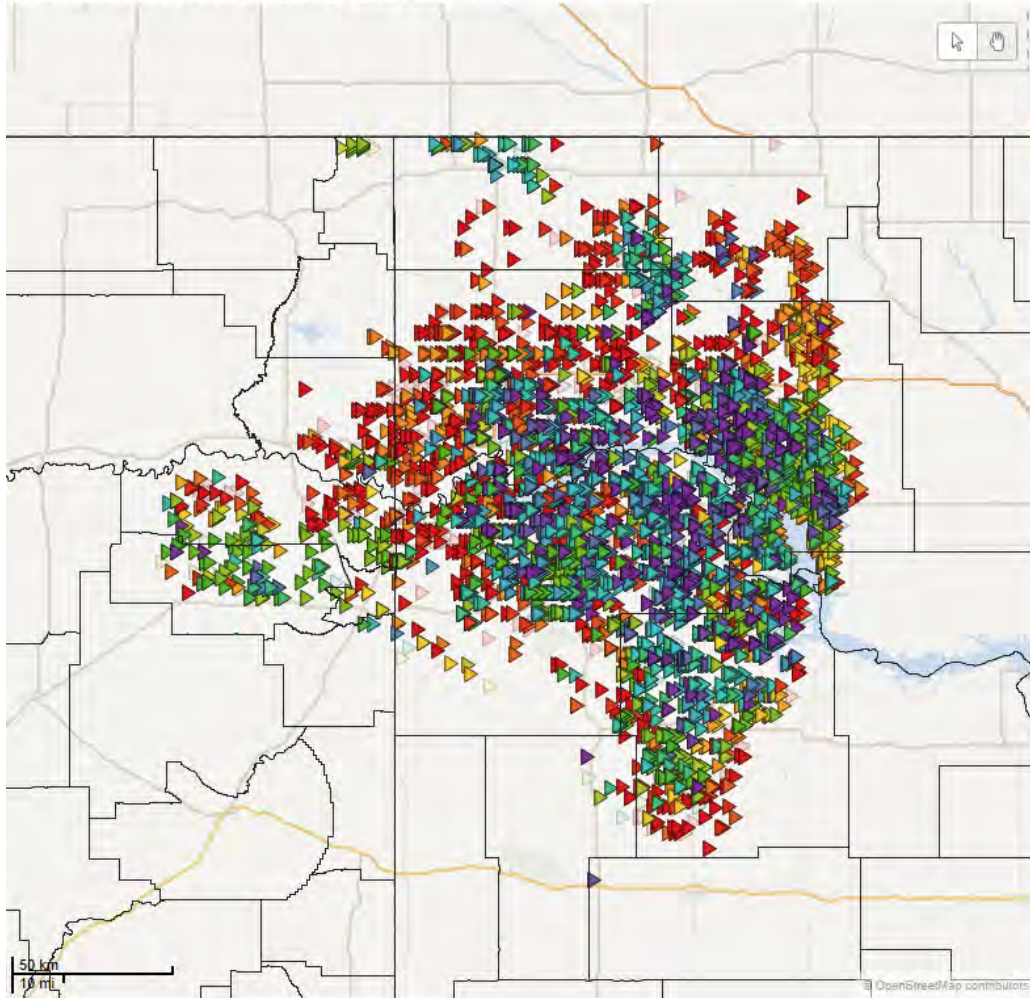
P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per Well vs. Average Spacing Nearest Side



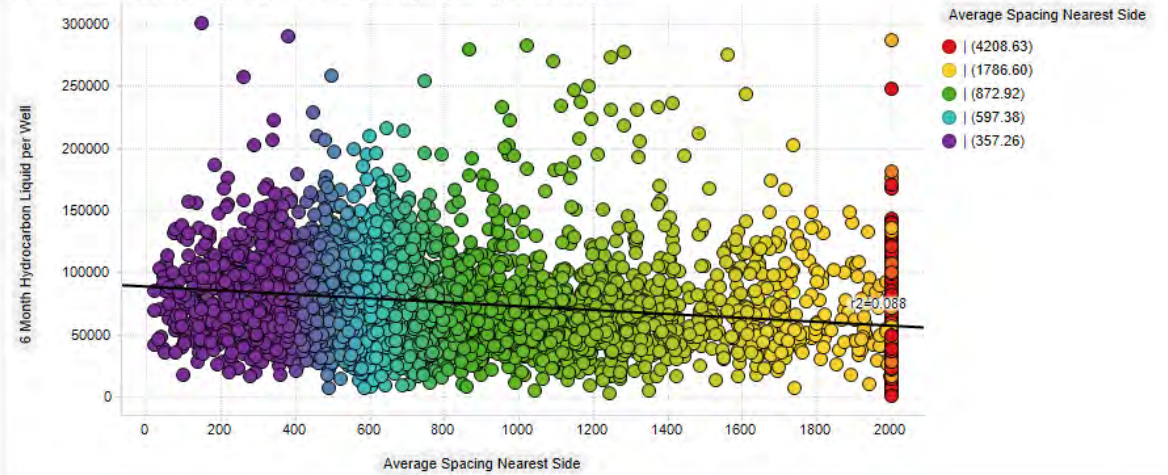
Lateral Well Spacing

Lateral Spacing vs. 6 Month Oil

Well Location Map by Average Spacing Nearest Side

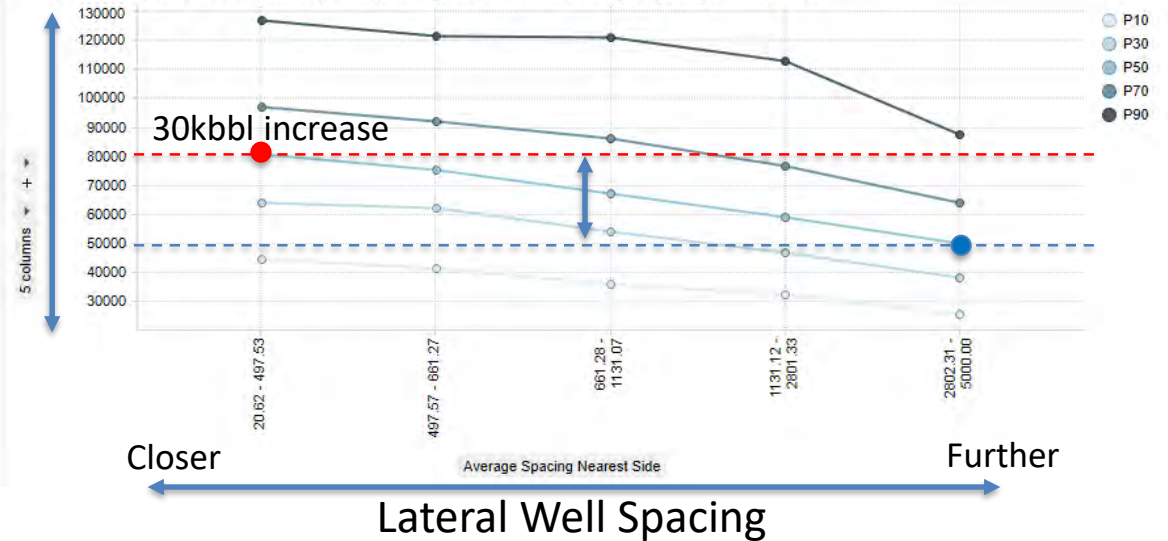


6 Month Hydrocarbon Liquid per Well vs. Average Spacing Nearest Side



Cum 6 Month Oil

P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per Well vs. Average Spacing Nearest Side



Closely Spaced Infill Wells Performing 60% Better than Standalone Wells?

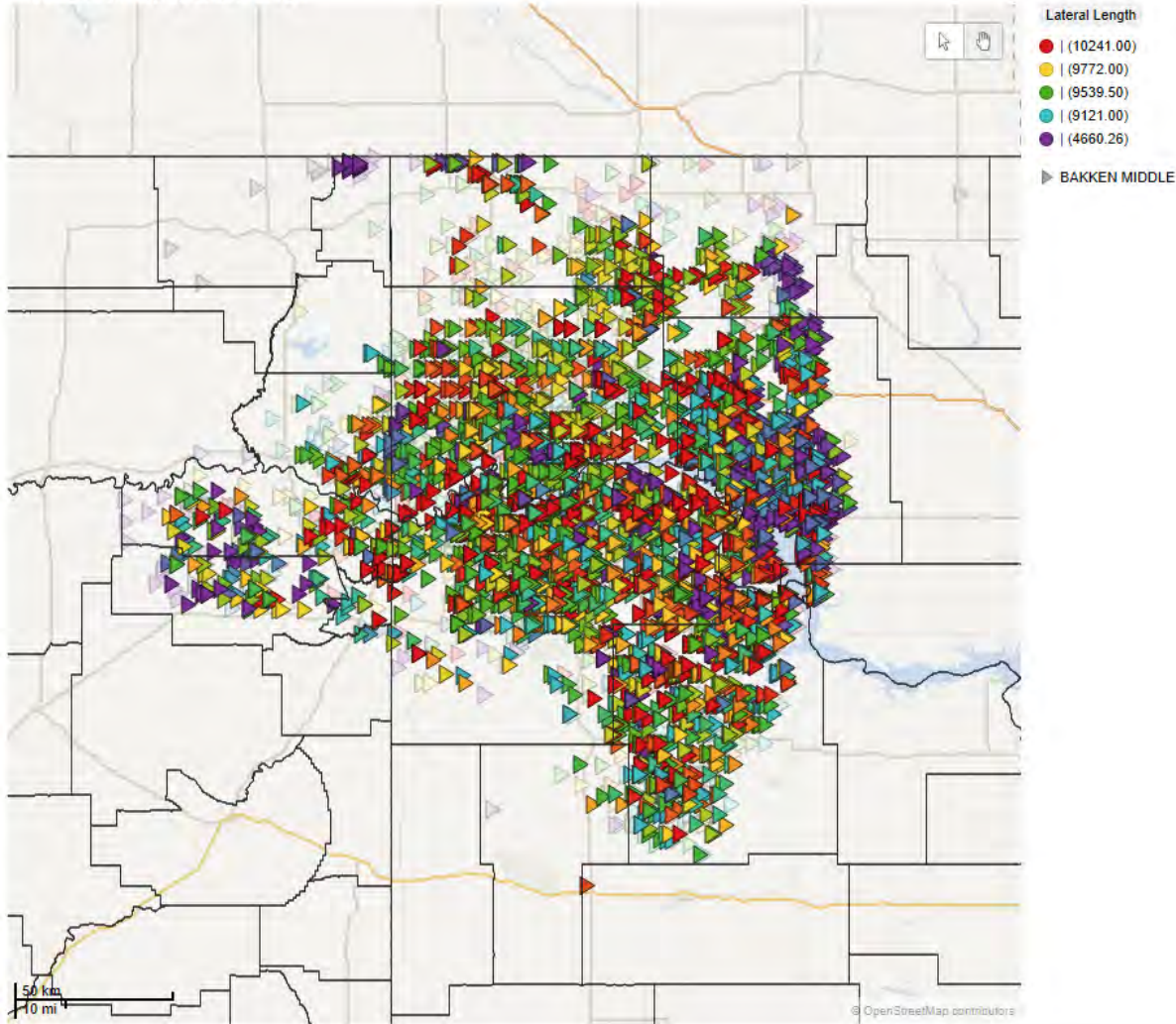
- Before we get too excited, we should first review potential shortcomings of the analysis:
 - Not accounting for improvements in technology over time (e.g. longer/bigger fracs)?
 - Too much variability in geology to identify the real relationship?
 - Is “Nearest Neighbor” not the right metric to measure well spacing?
 - Is the system too complex to be investigated using bi-variate techniques?

Closely Spaced Infill Wells Performing 60% Better than Standalone Wells?

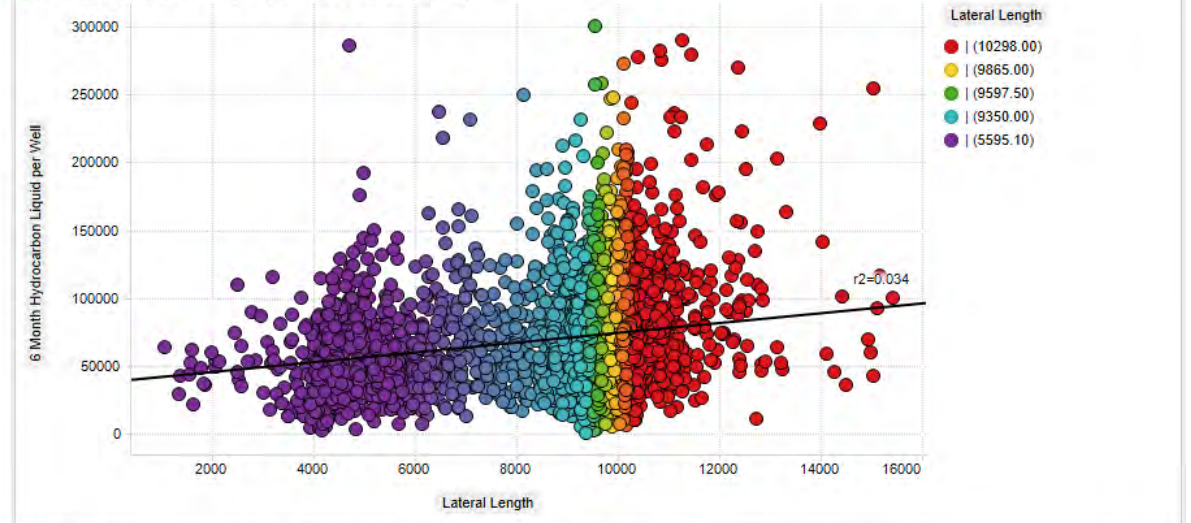
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Lateral Length vs. 6 Month Oil

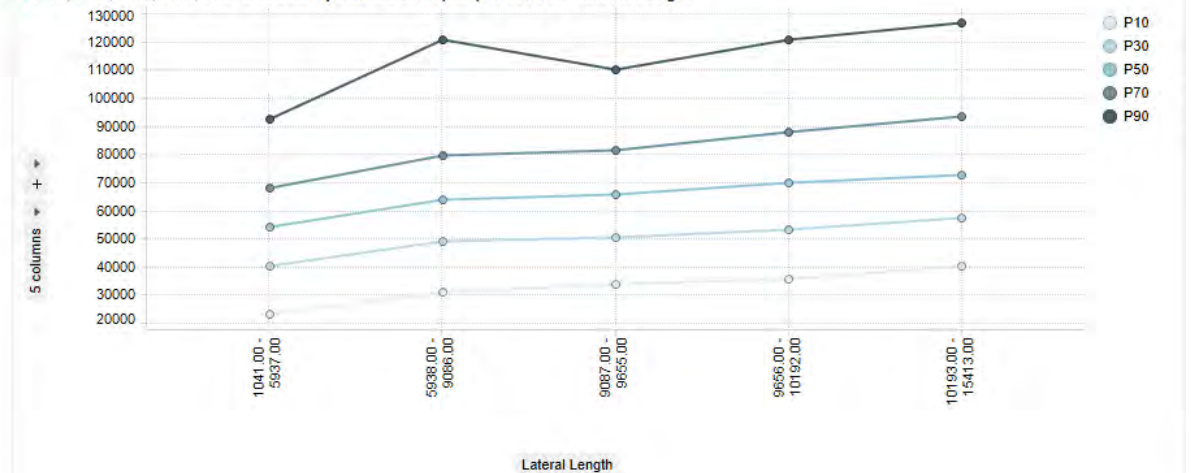
Well Location Map by Lateral Length



6 Month Hydrocarbon Liquid per Well vs. Lateral Length

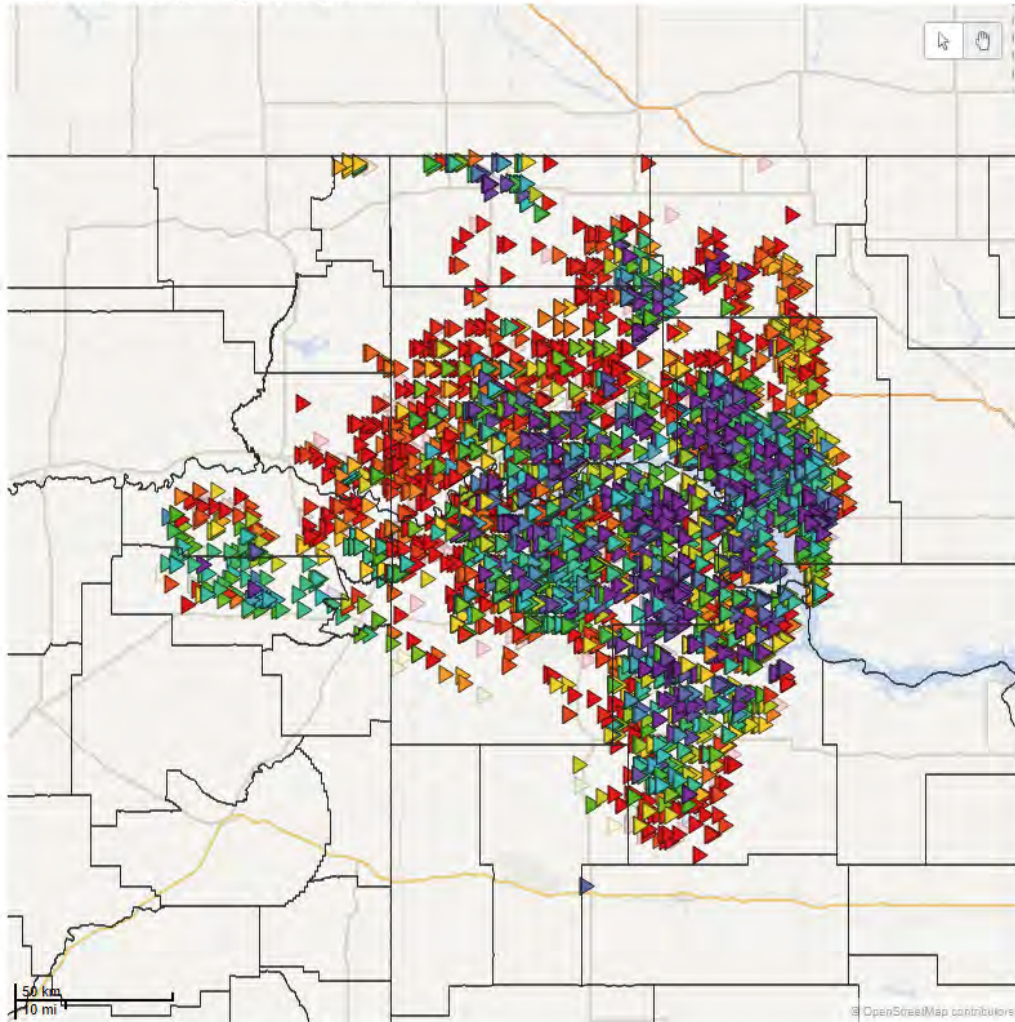


P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per Well vs. Lateral Length

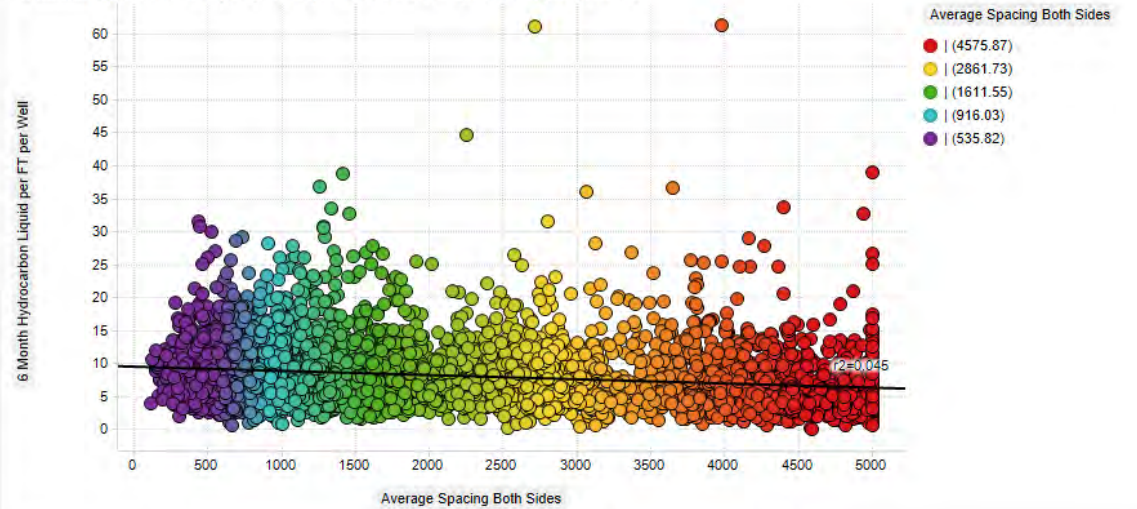


Lateral Spacing vs. 6 Month Oil/ft

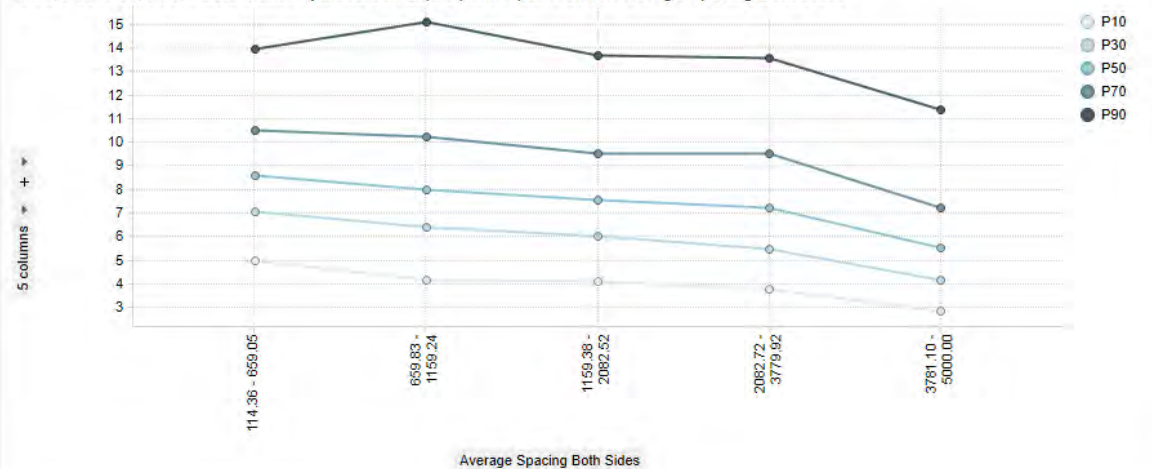
Well Location Map by Average Spacing Both Sides



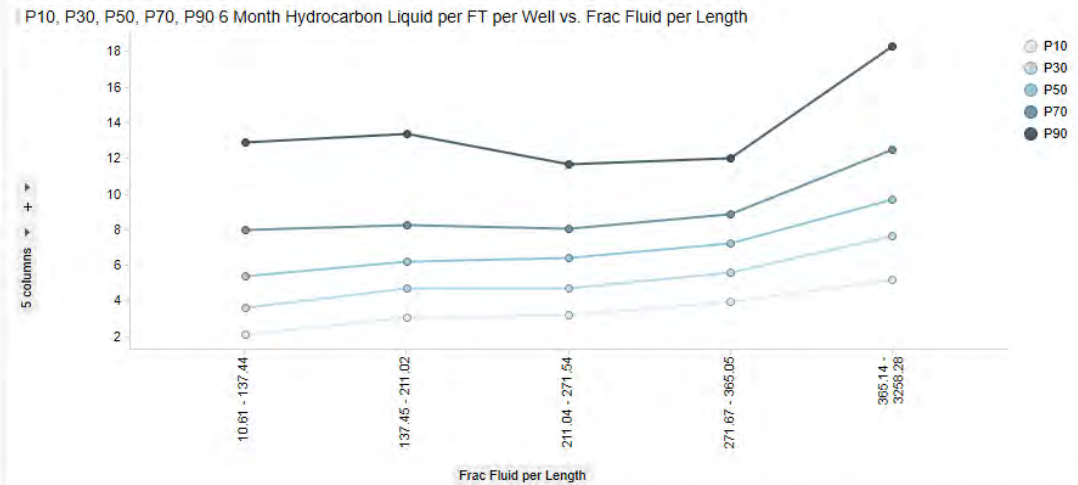
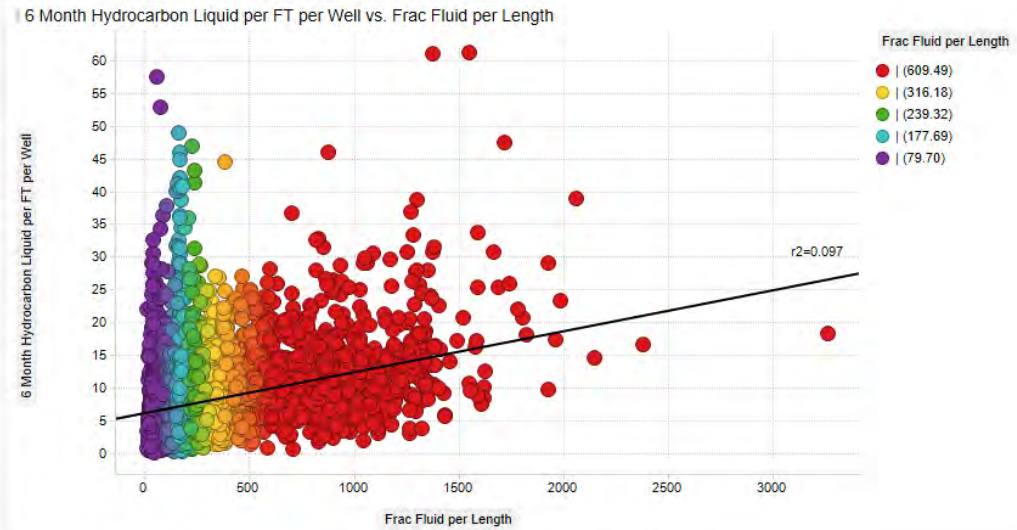
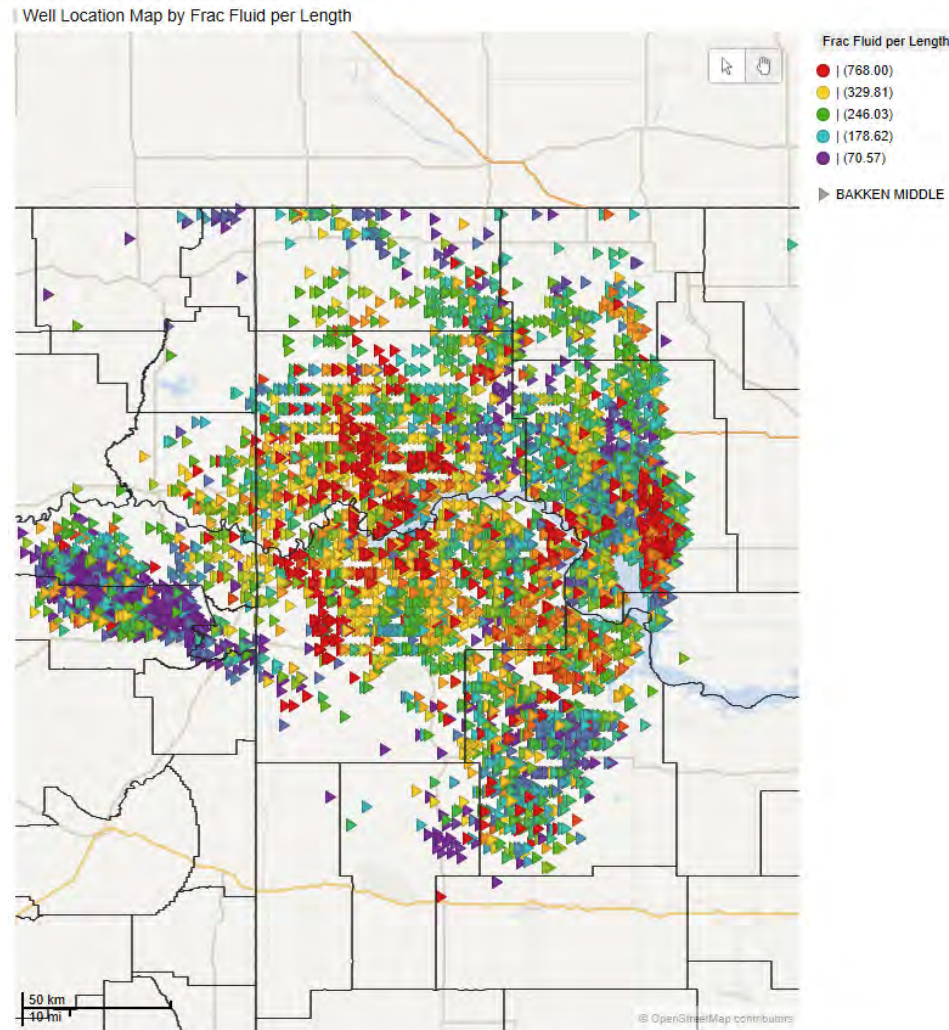
6 Month Hydrocarbon Liquid per FT per Well vs. Average Spacing Both Sides



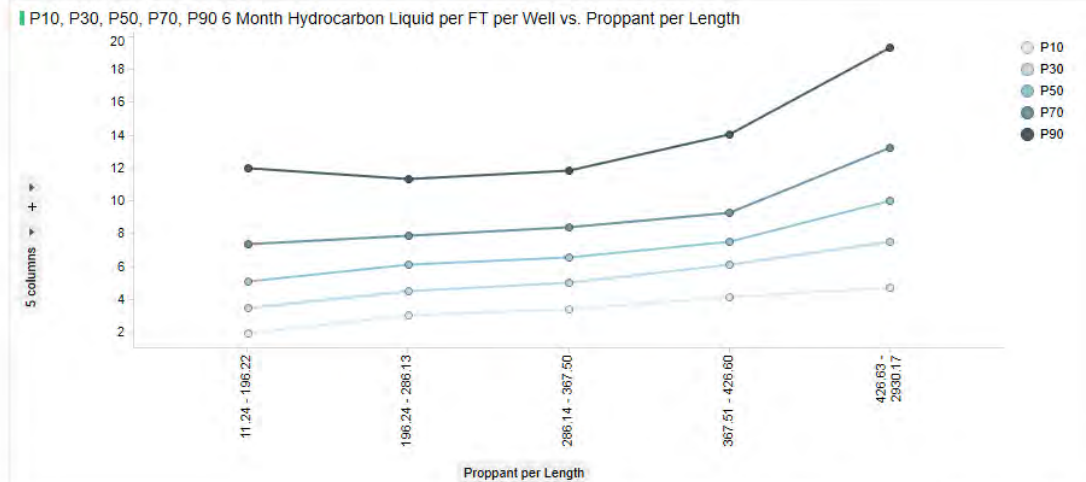
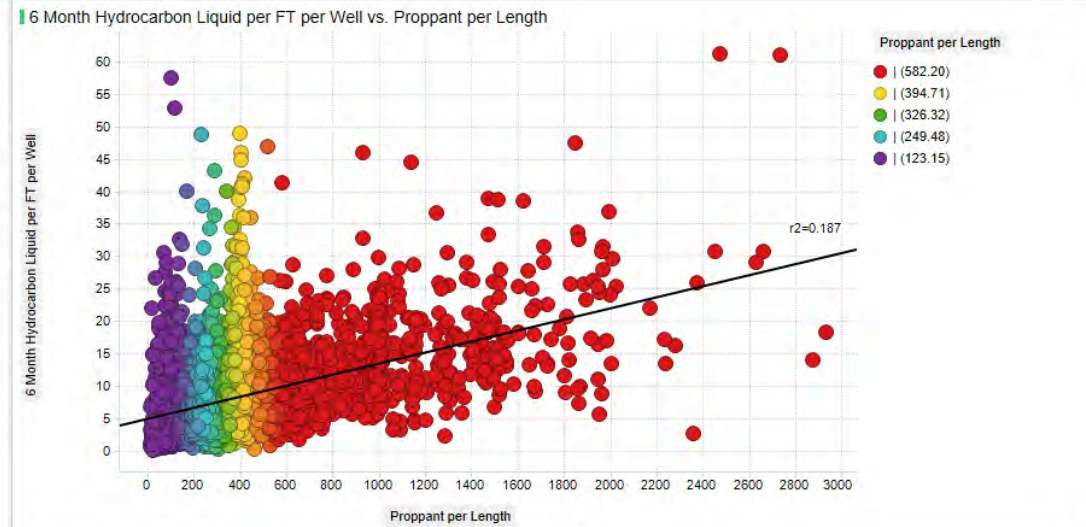
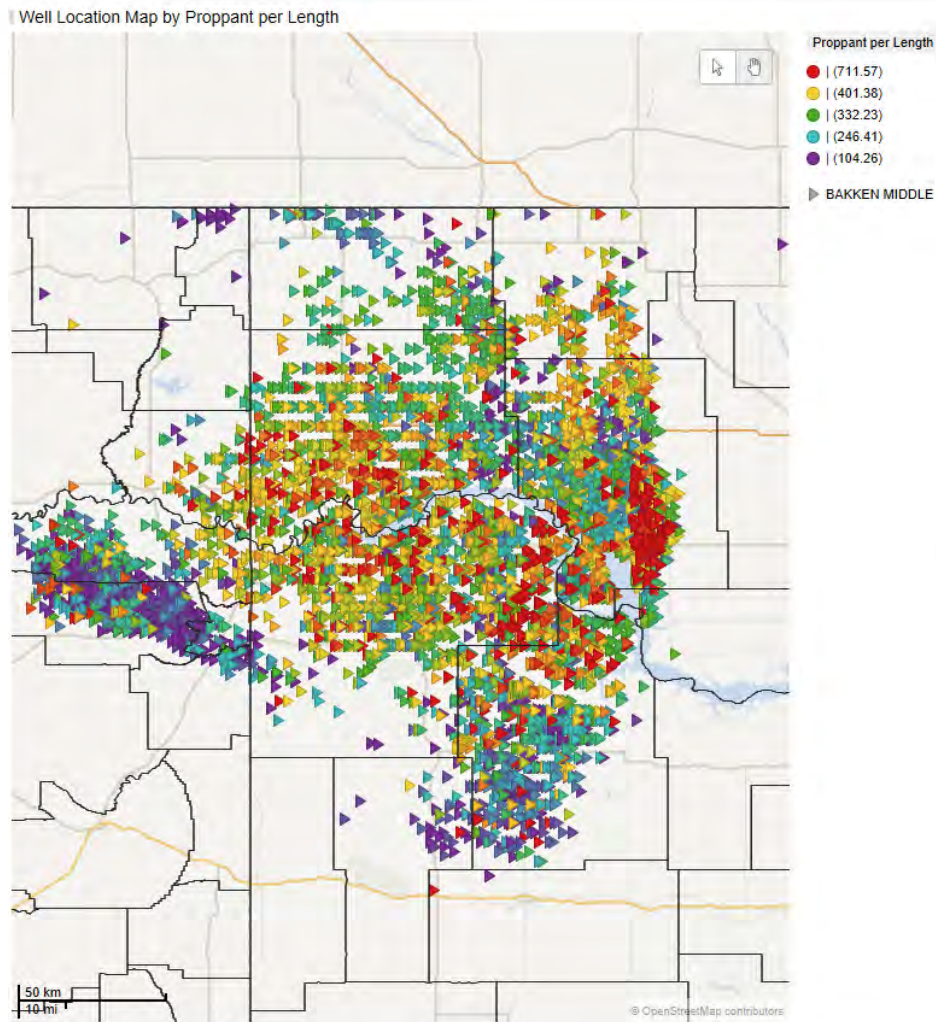
P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per FT per Well vs. Average Spacing Both Sides



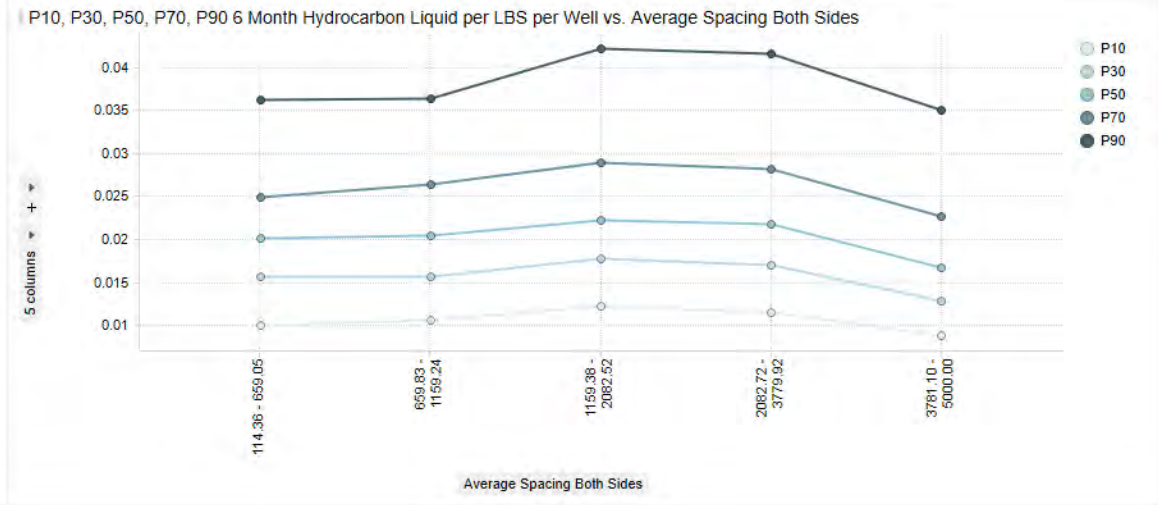
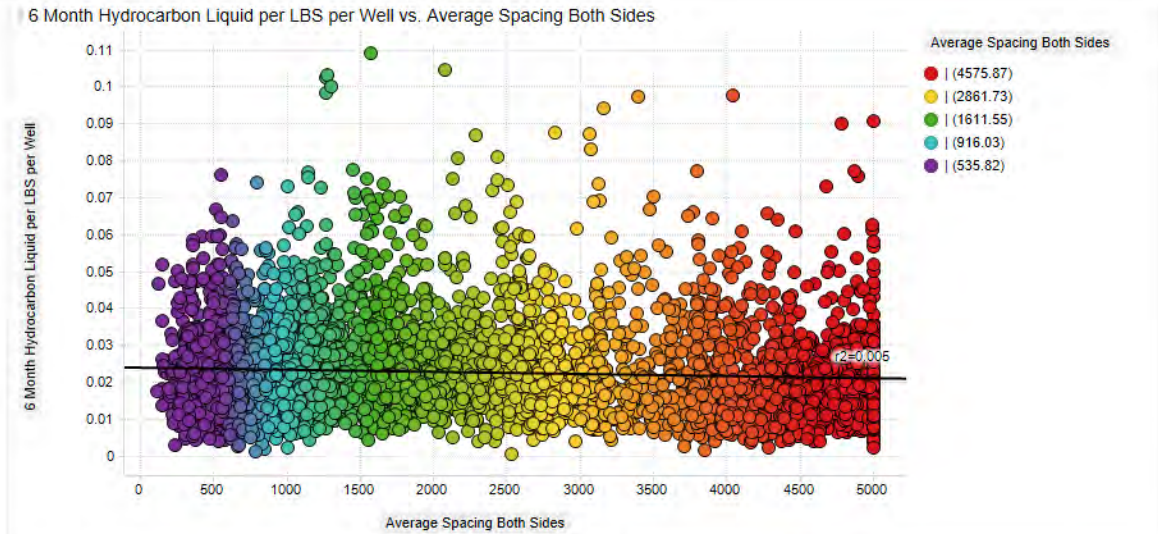
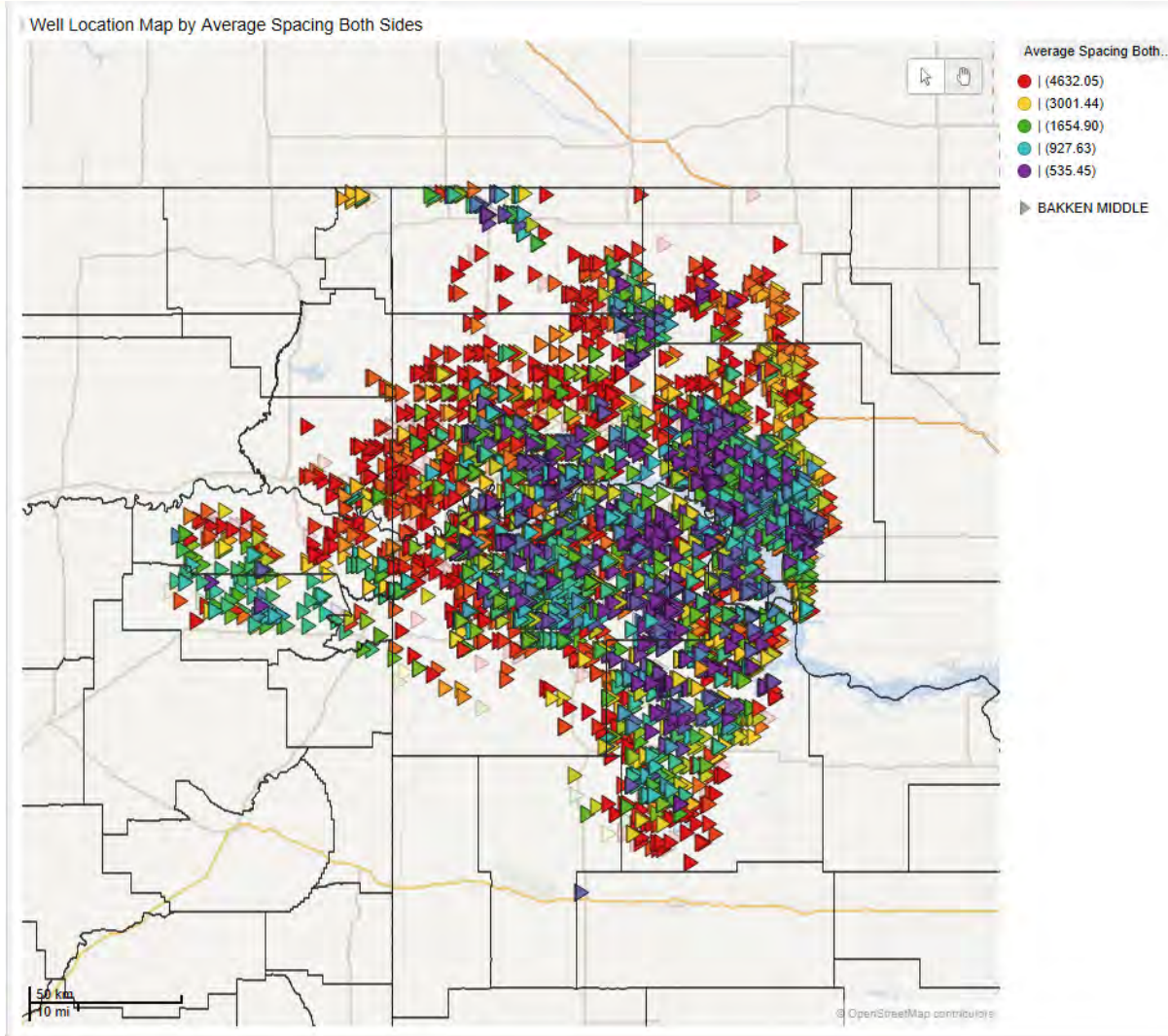
Frac Fluid/ft vs. 6 Month Oil/ft



Proppant/ft vs. 6 Month Cum Oil/ft



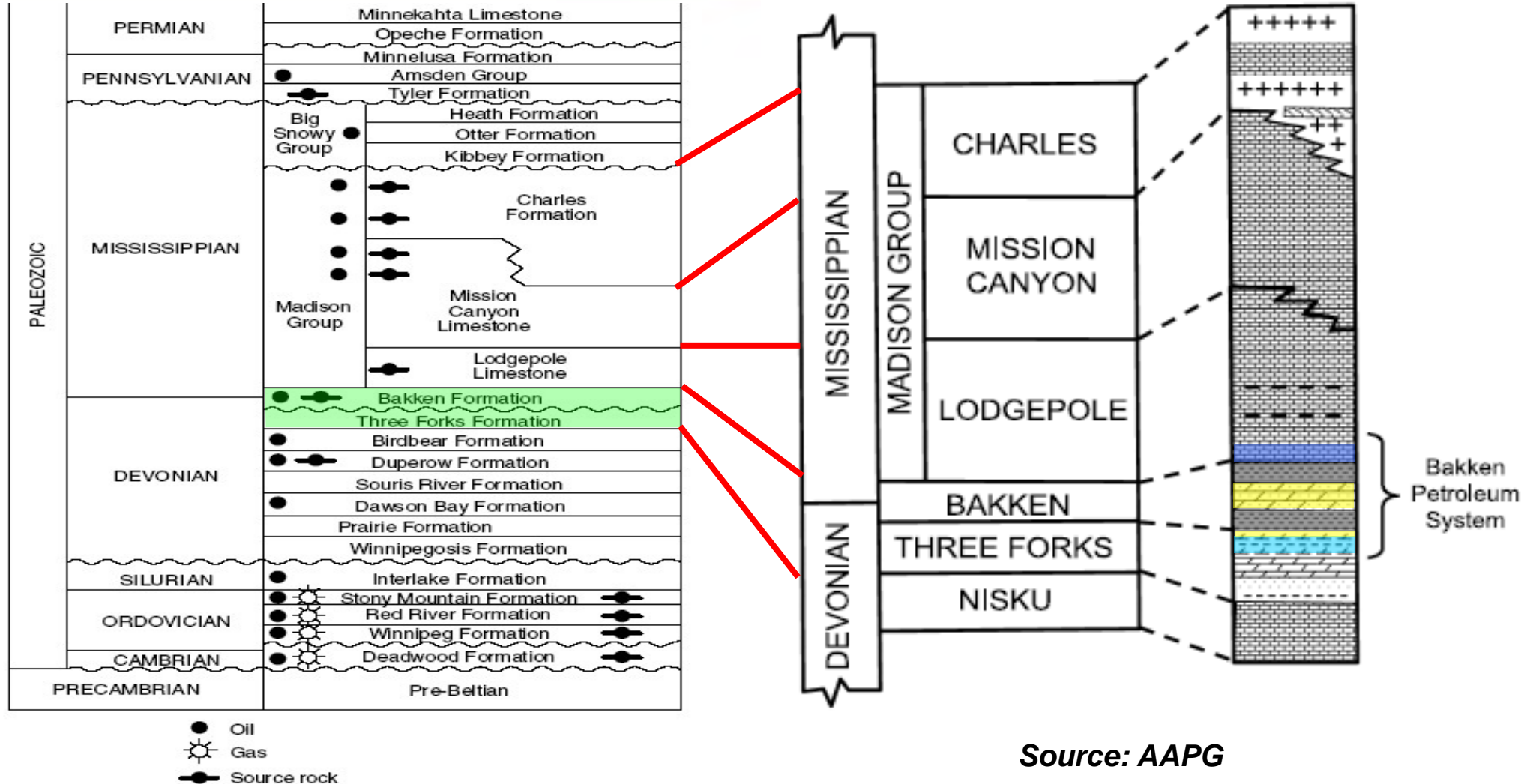
Lateral Spacing vs. 6 Month Oil/lbs



Closely Spaced Infill Wells Performing 60% Better than Standalone Wells?

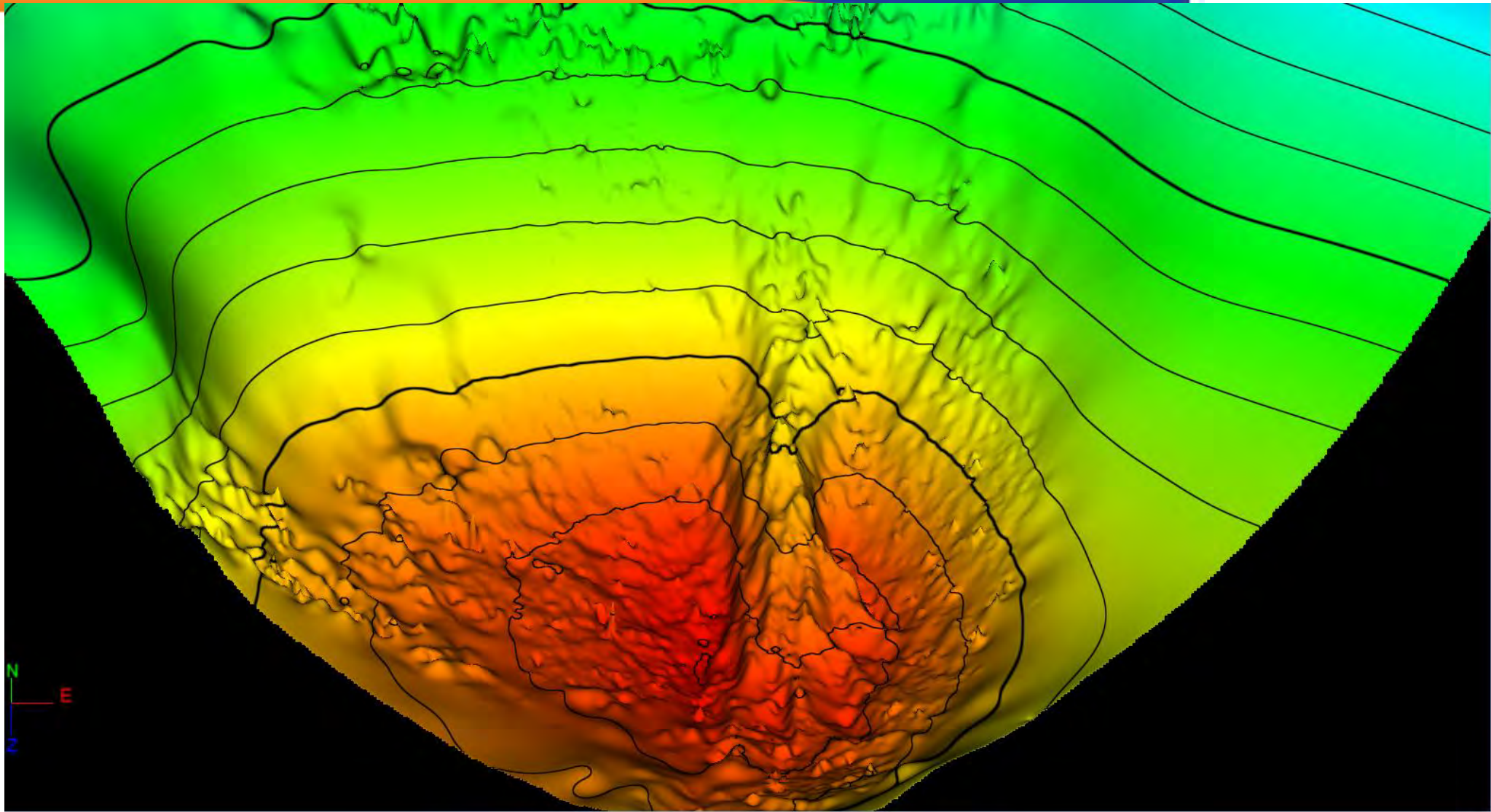
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Williston Basin Stratigraphy



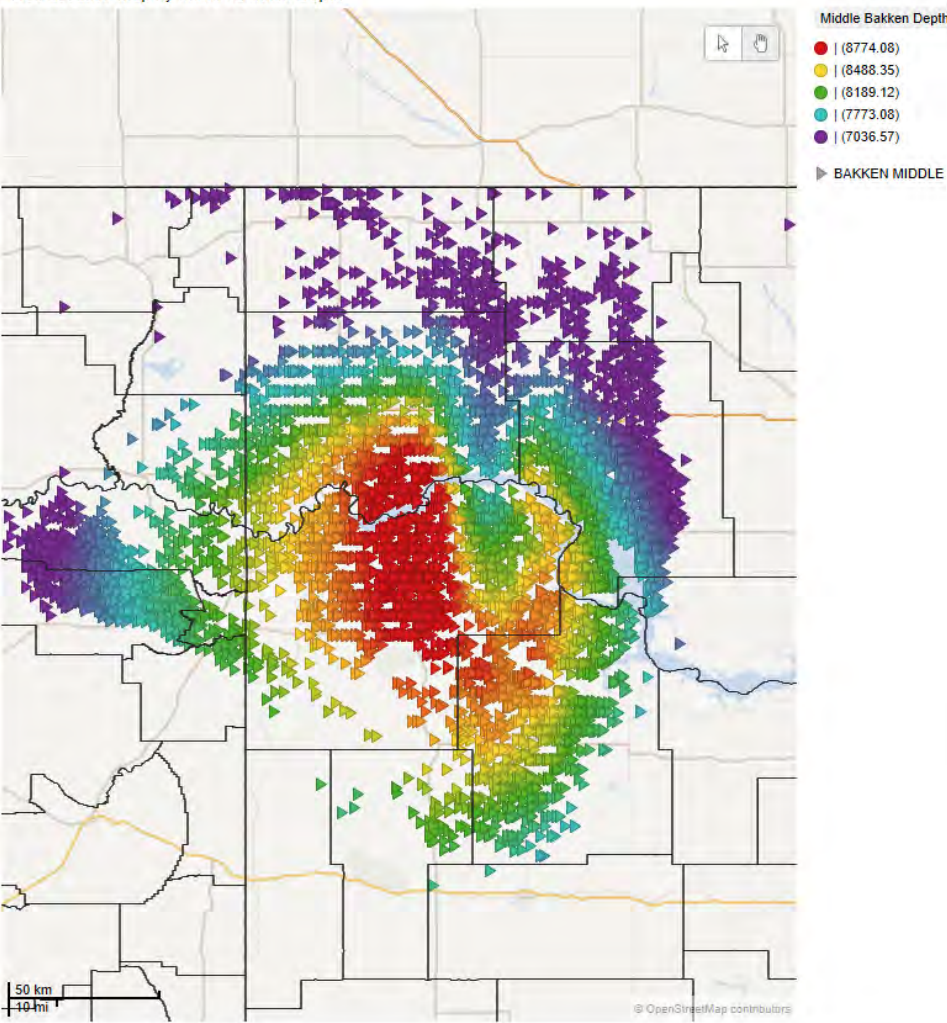
Source: AAPG

Williston Basin – Middle Bakken Depth

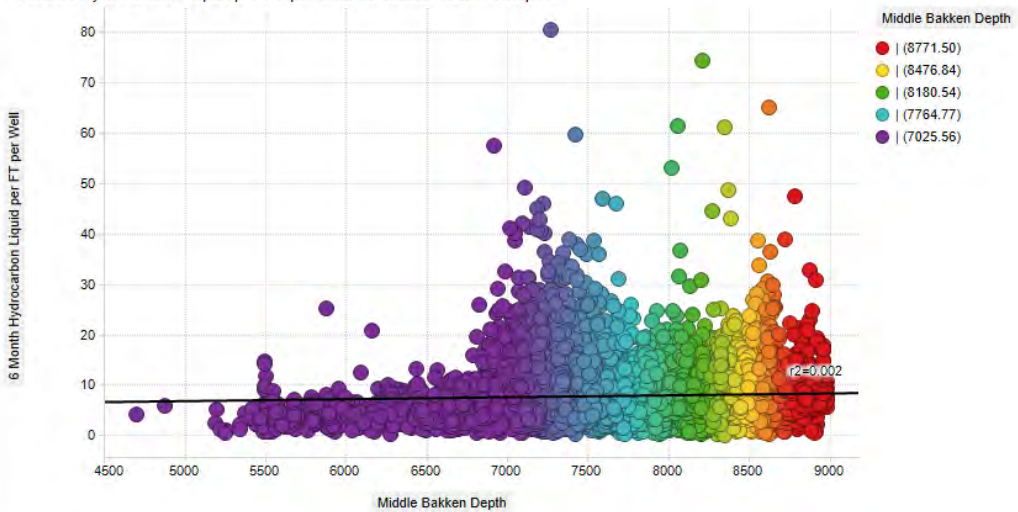


Middle Bakken Depth vs. 6 Month Cum Oil/ft

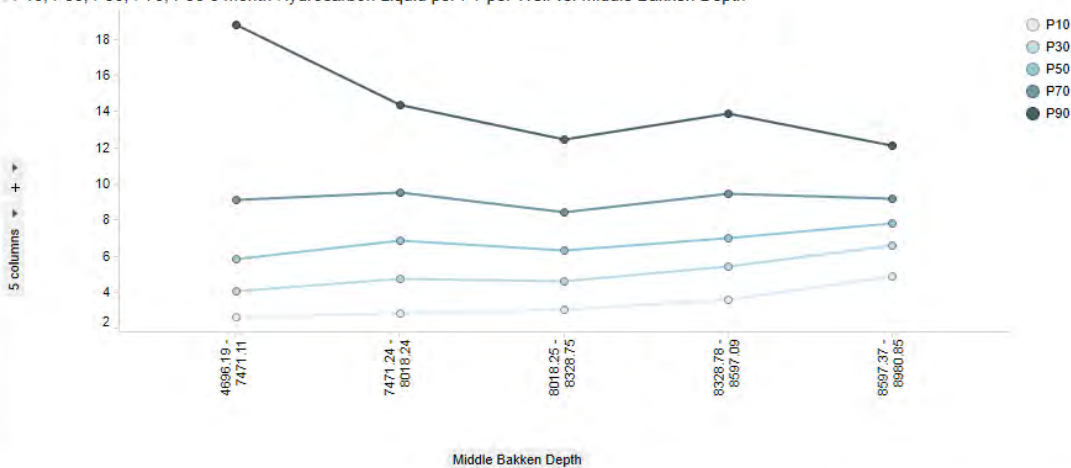
Well Location Map by Middle Bakken Depth



6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Depth

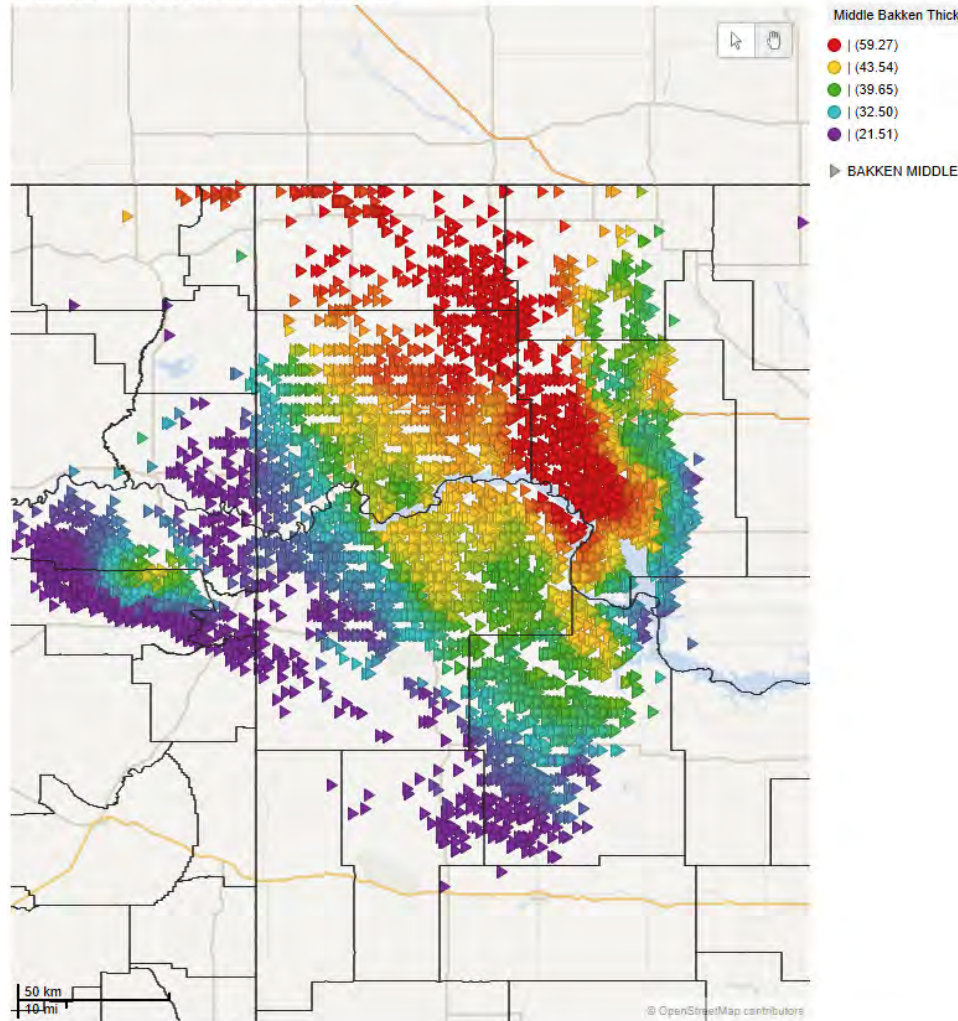


P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Depth

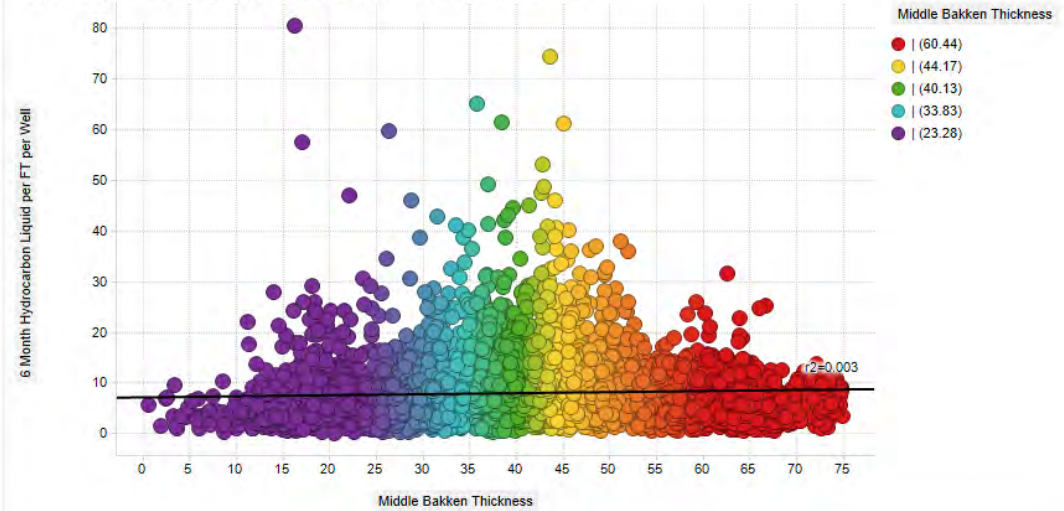


Middle Bakken Thickness vs. 6 Month Cum Oil/ft

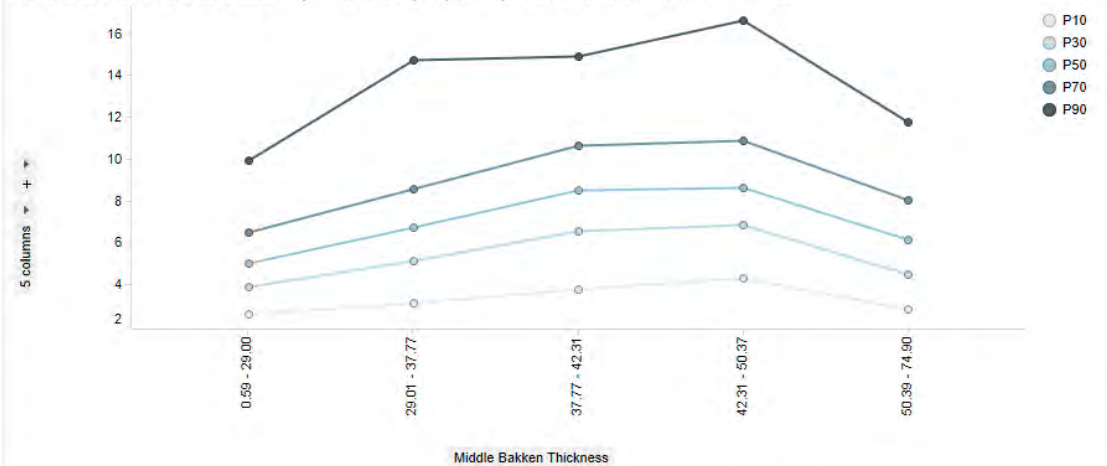
Well Location Map by Middle Bakken Thickness



6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Thickness

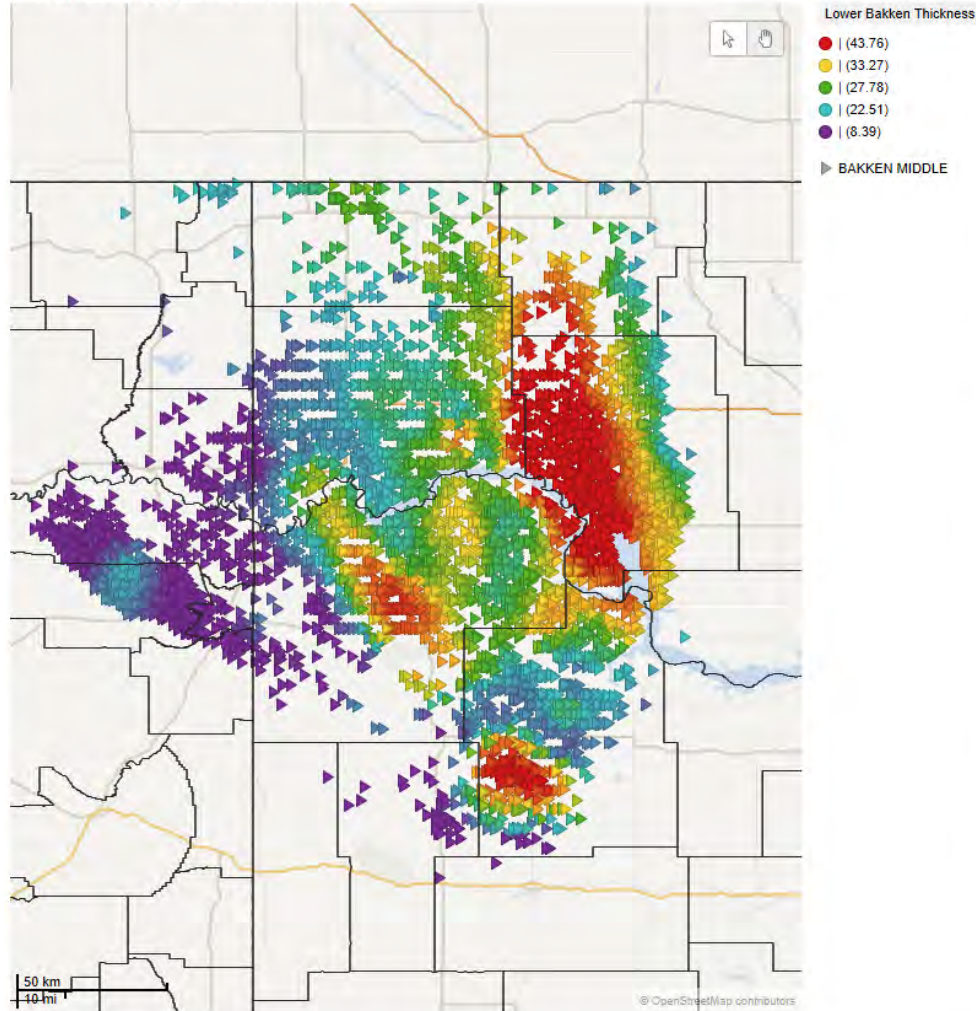


P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Thickness

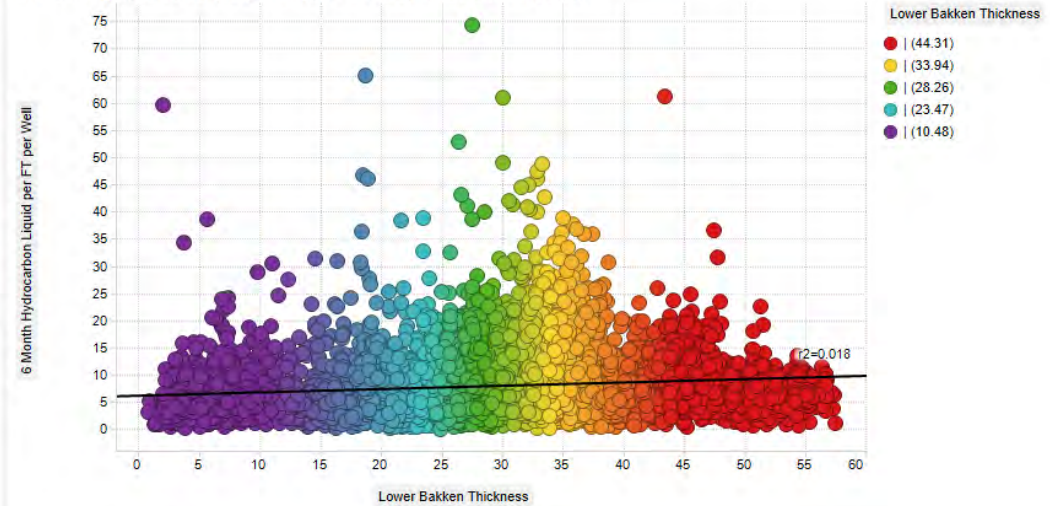


Lower Bakken Thickness vs. 6 Month Cum Oil/ft

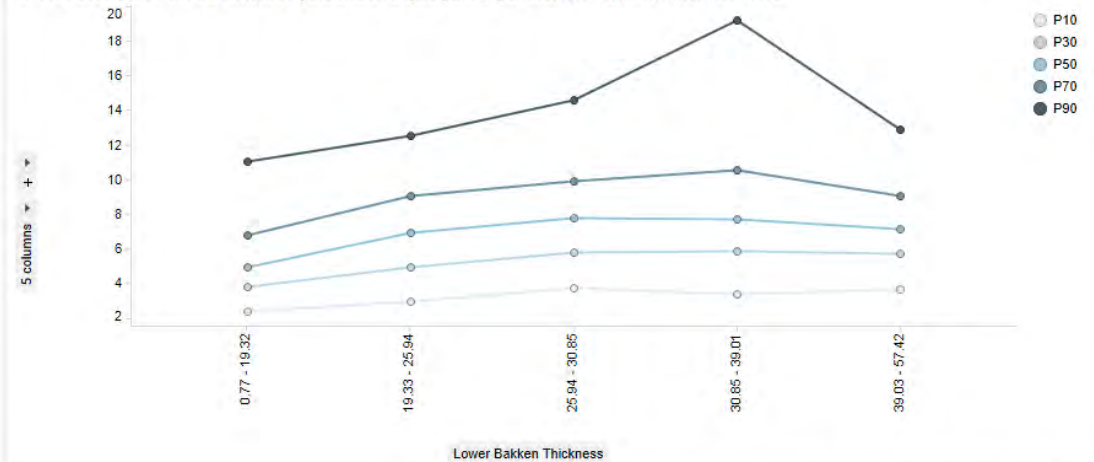
Well Location Map by Lower Bakken Thickness



6 Month Hydrocarbon Liquid per FT per Well vs. Lower Bakken Thickness

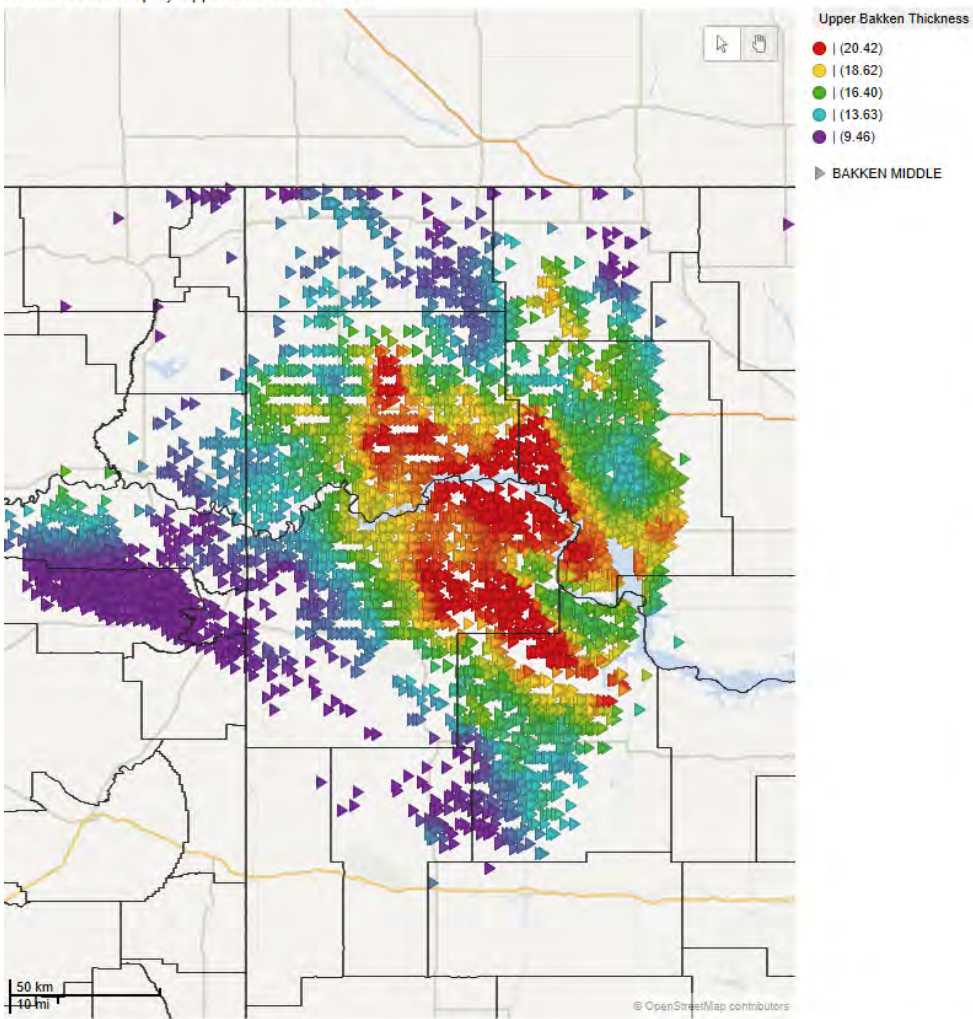


P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per FT per Well vs. Lower Bakken Thickness

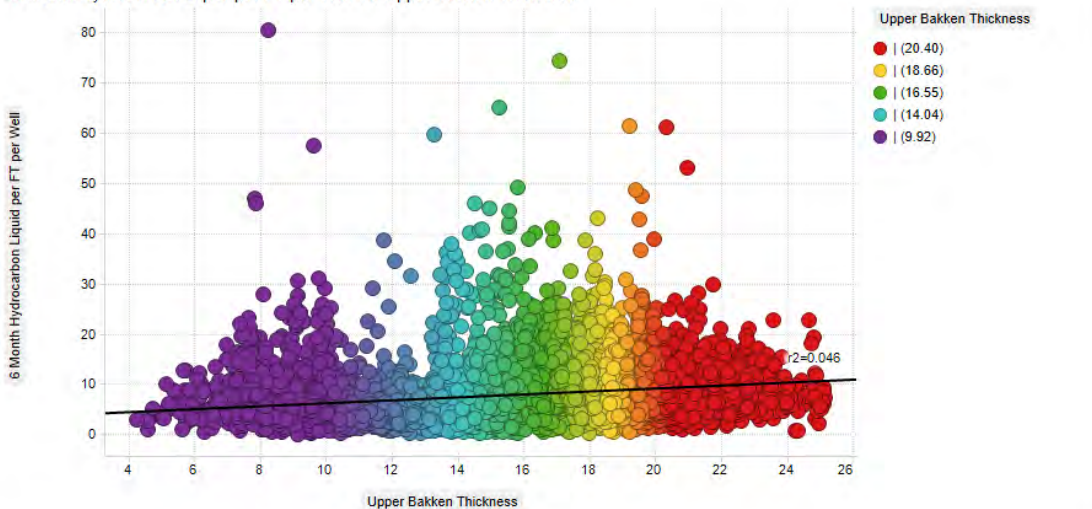


Upper Bakken Thickness vs. Cum 6 Month Oil/ft

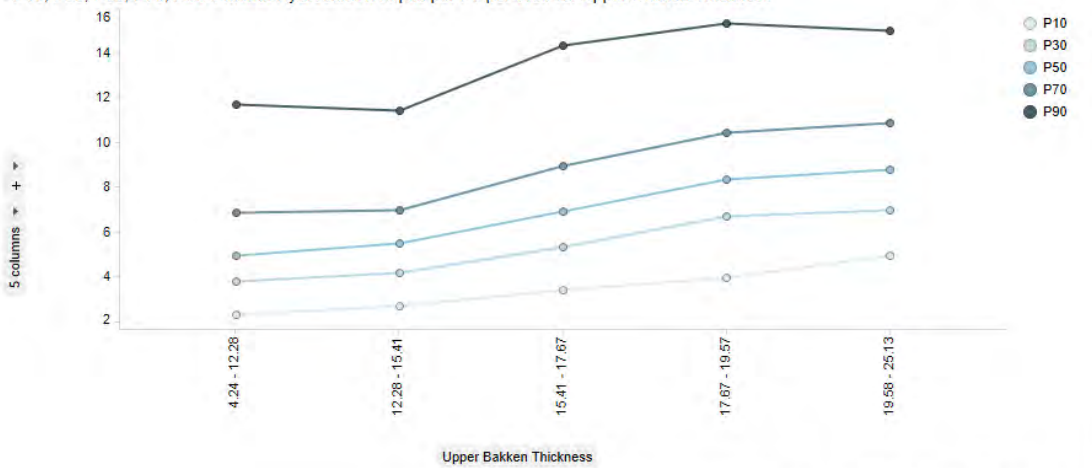
Well Location Map by Upper Bakken Thickness



6 Month Hydrocarbon Liquid per FT per Well vs. Upper Bakken Thickness

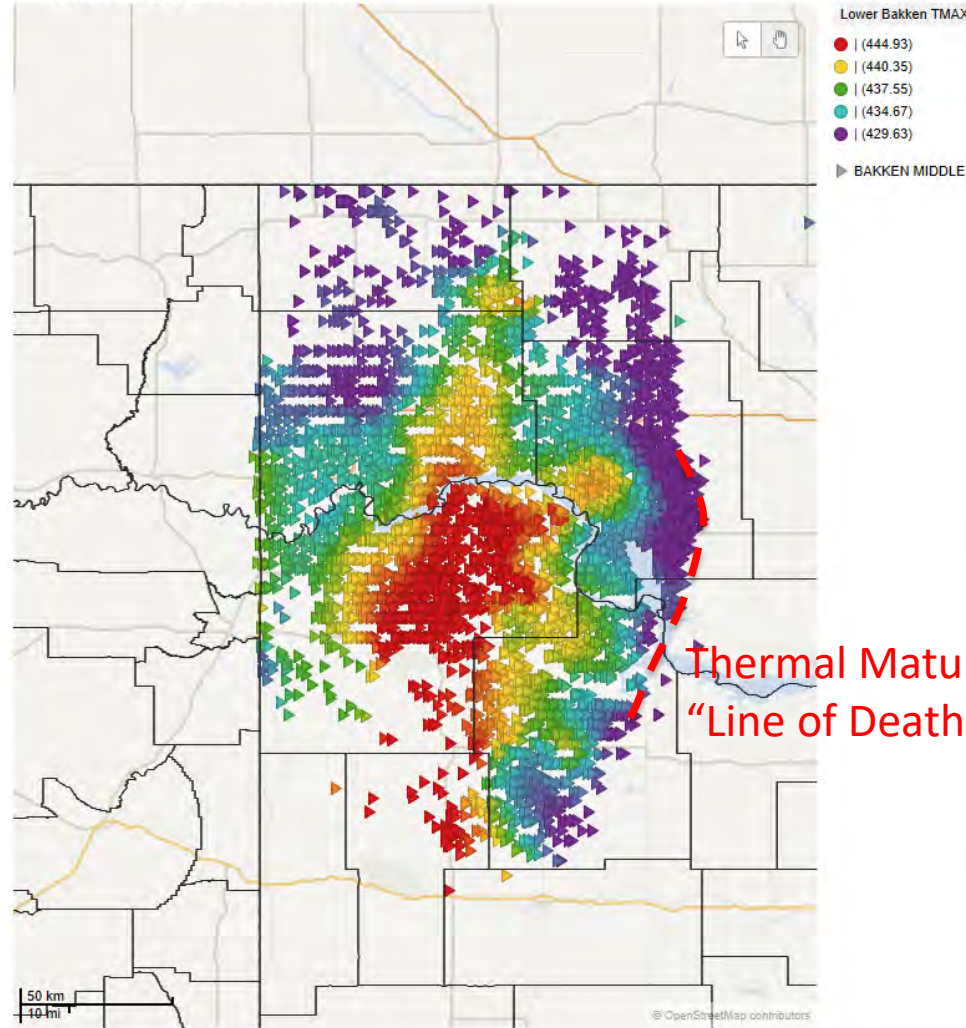


P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per FT per Well vs. Upper Bakken Thickness

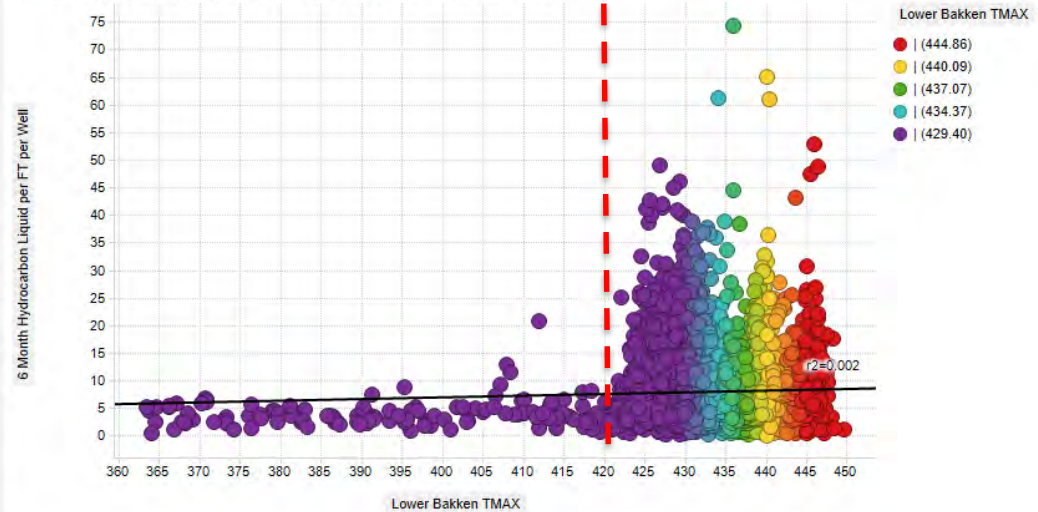


Lower Bakken TMAX vs. 6 Month Cum Oil/ft

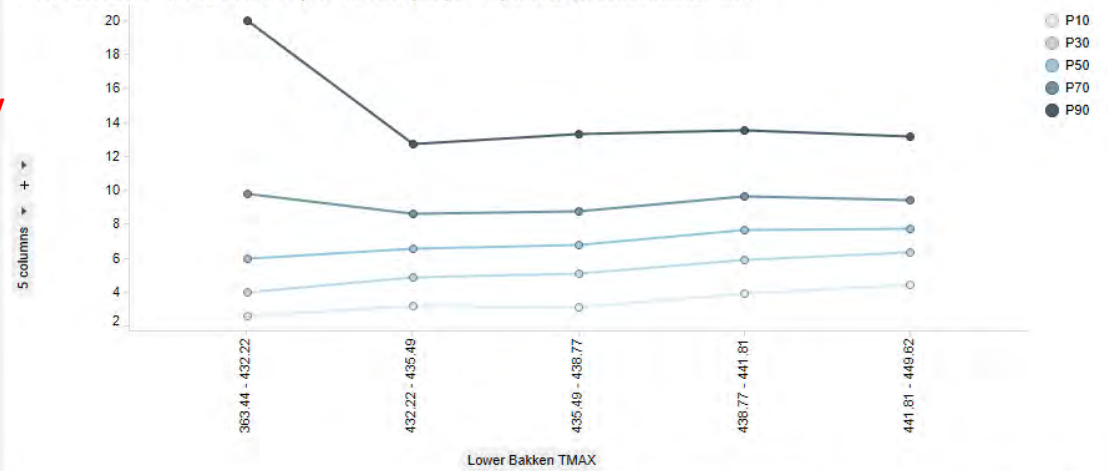
Well Location Map by Lower Bakken TMAX



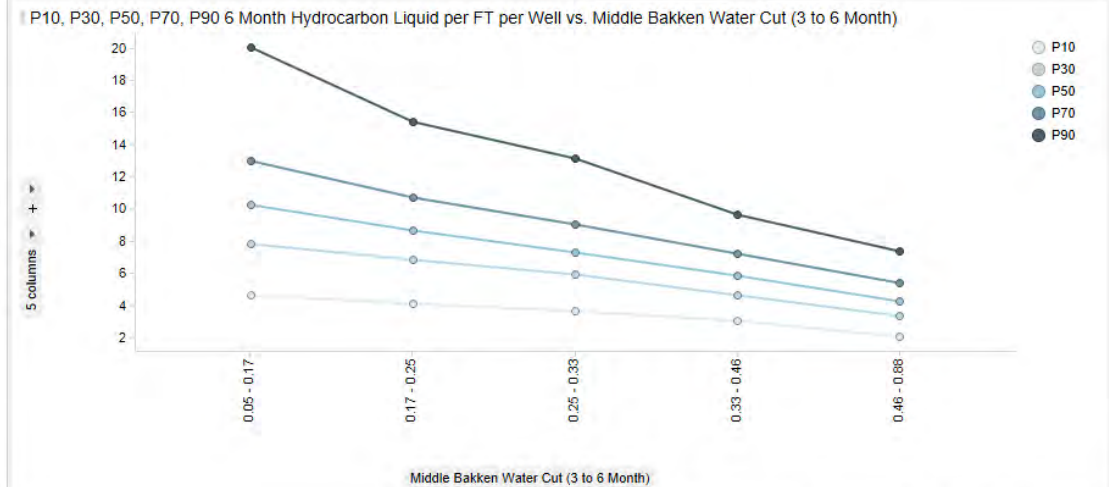
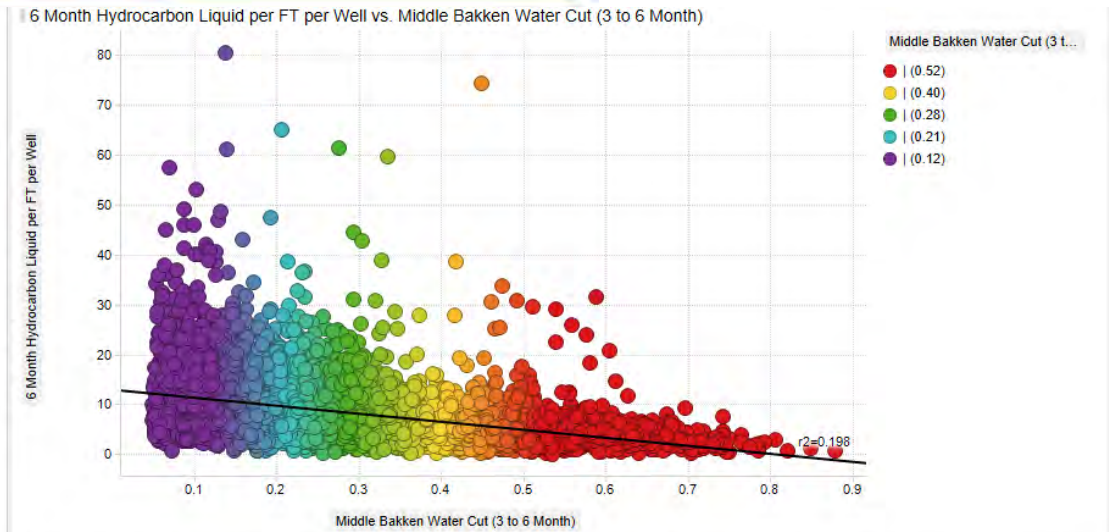
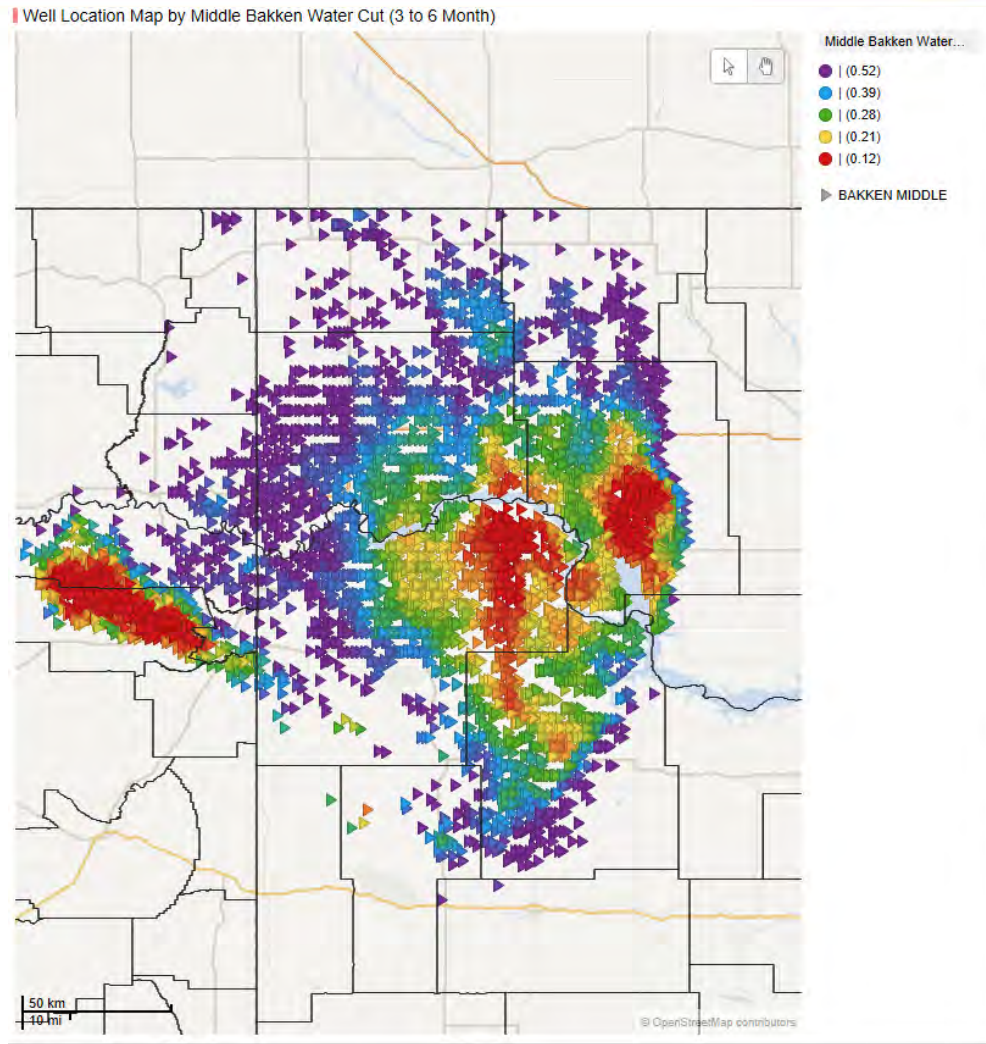
6 Month Hydrocarbon Liquid per FT per Well vs. Lower Bakken TMAX



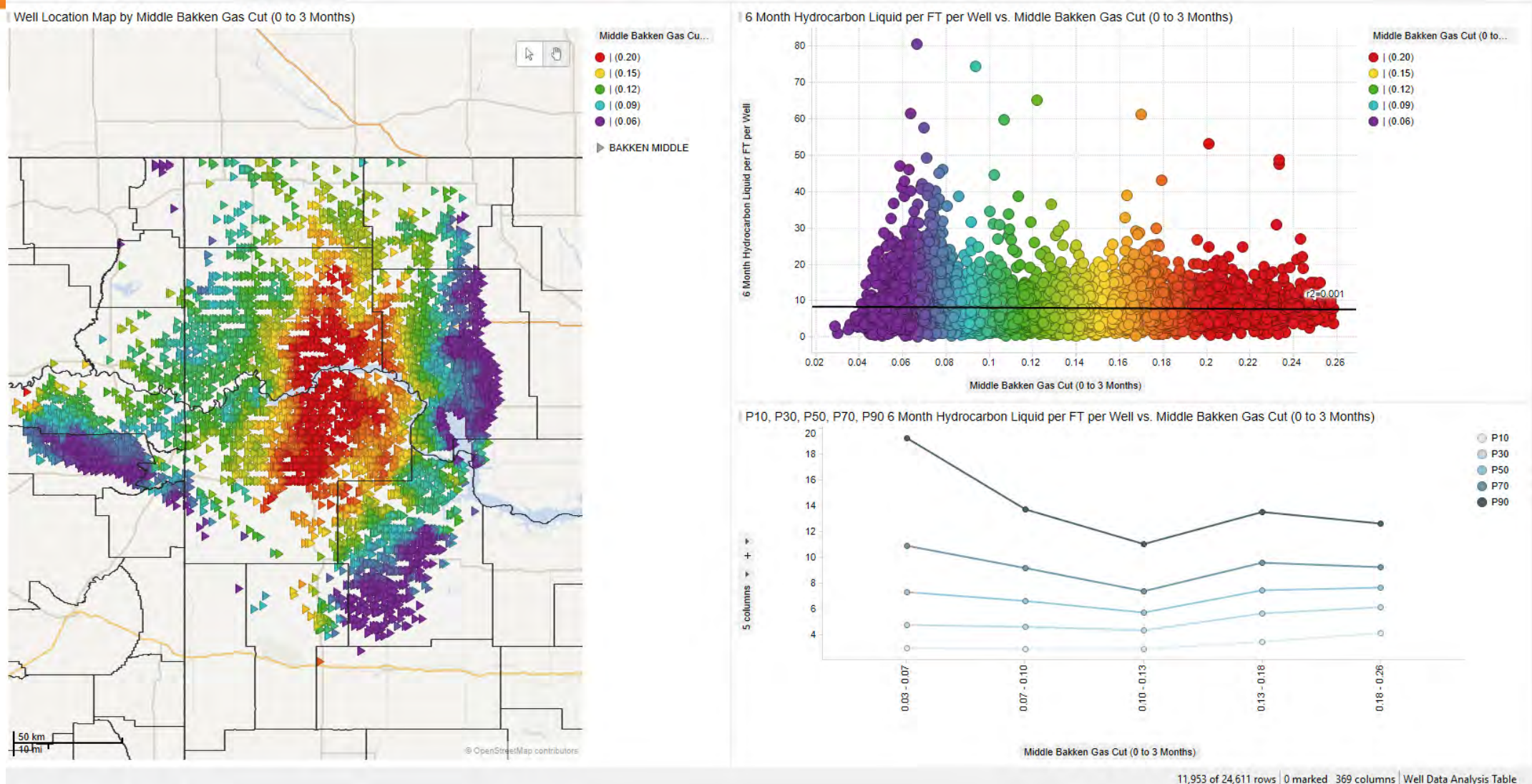
P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per FT per Well vs. Lower Bakken TMAX



Middle Bakken 3 to 6 Month Water Cut vs. 6 Month Oil/ft

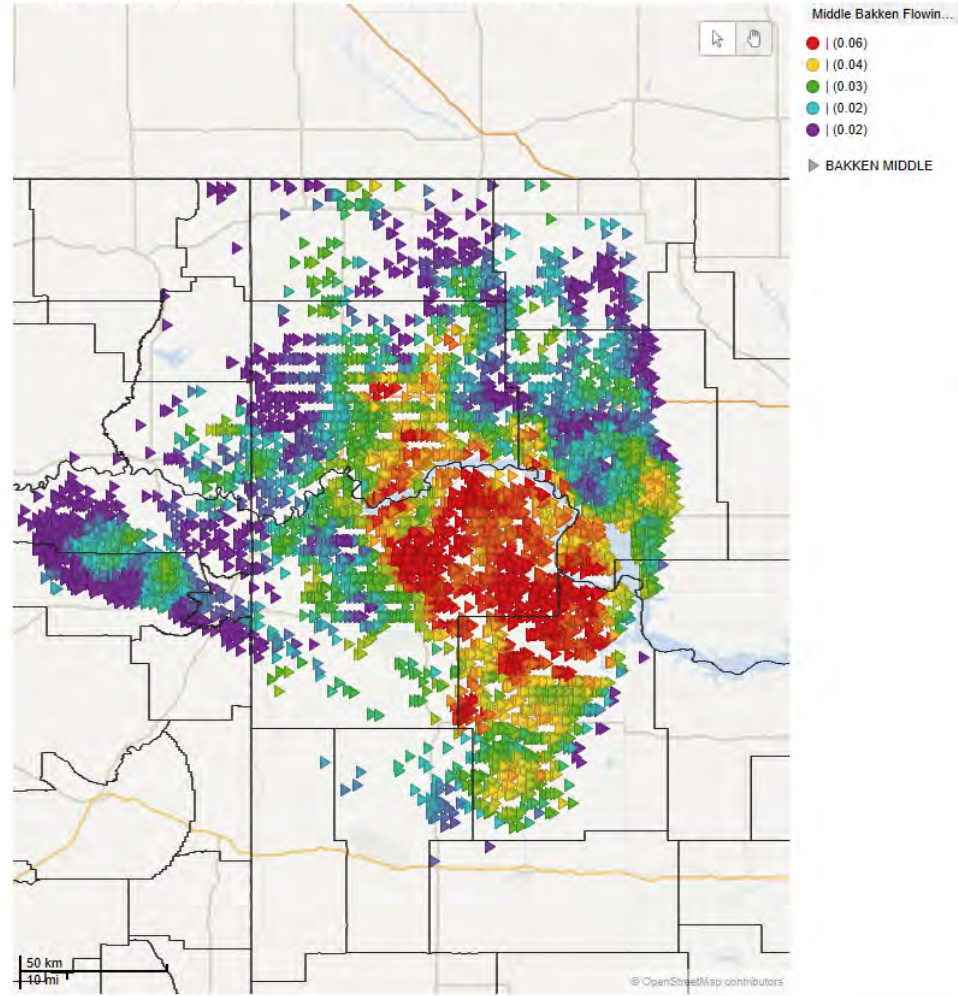


Middle Bakken Gas Cut vs. 6 Month Oil/ft

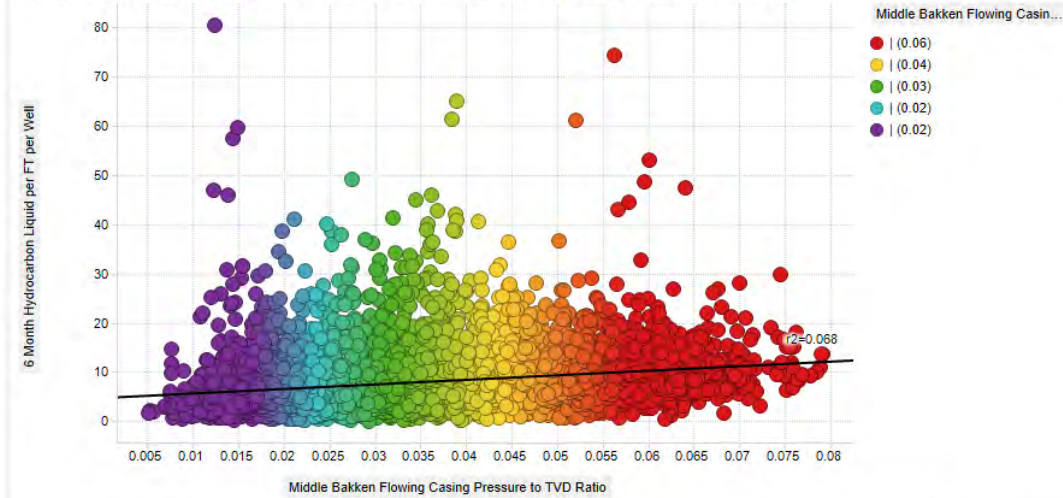


Middle Bakken Flowing Casing Pressure Gradient vs. 6 Month Cum Oil/ft

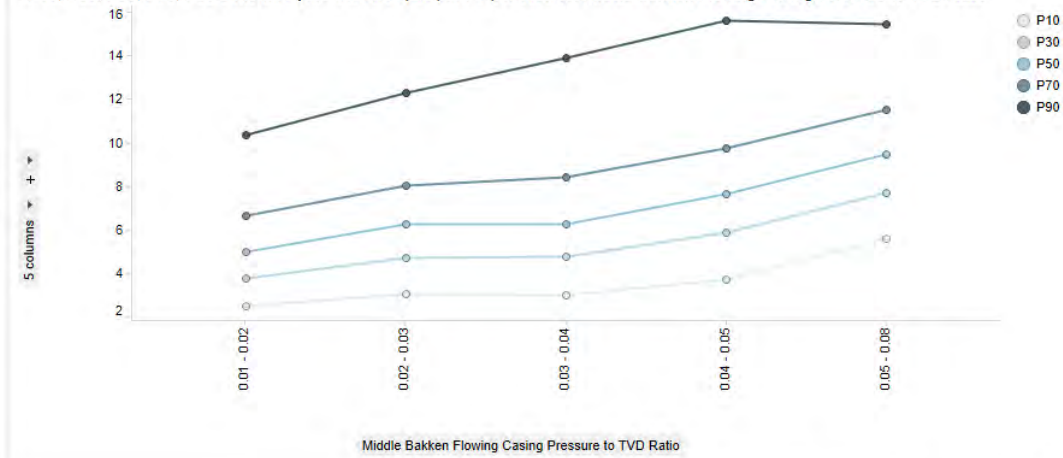
Well Location Map by Middle Bakken Flowing Casing Pressure to TVD Ratio



6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Flowing Casing Pressure to TVD Ratio



P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Flowing Casing Pressure to TVD Ratio

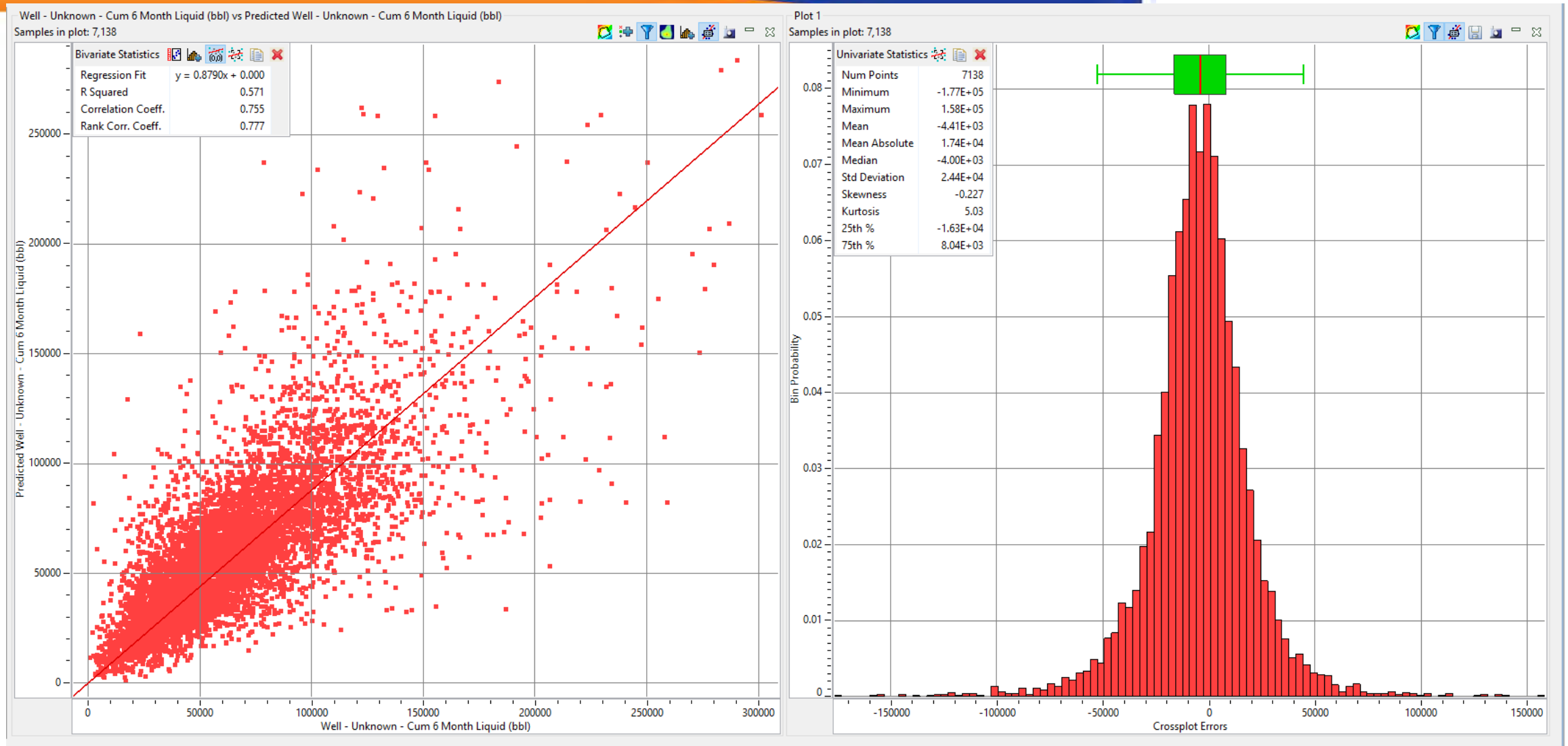


Geologic Attribute Maps

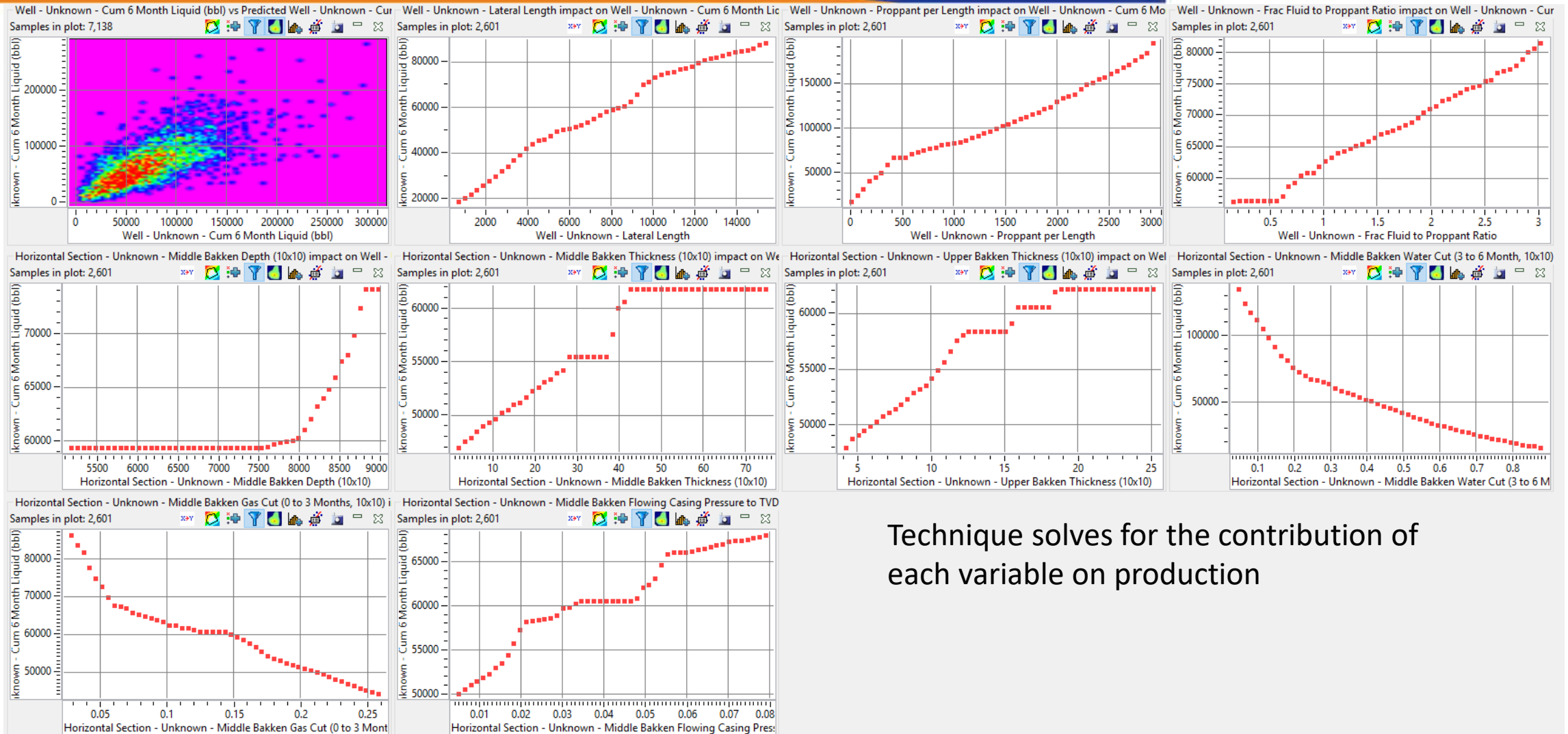


- Structure:
 - Middle Bakken Depth/Thickness
- Source Rocks:
 - Lower Bakken/Upper Bakken Thickness
- Reservoir Quality:
 - Water Cut/Gas Cut
- Pressure:
 - Flowing Casing Pressure Gradient

Multi-Variate Modeling of 6 Month Cum Oil

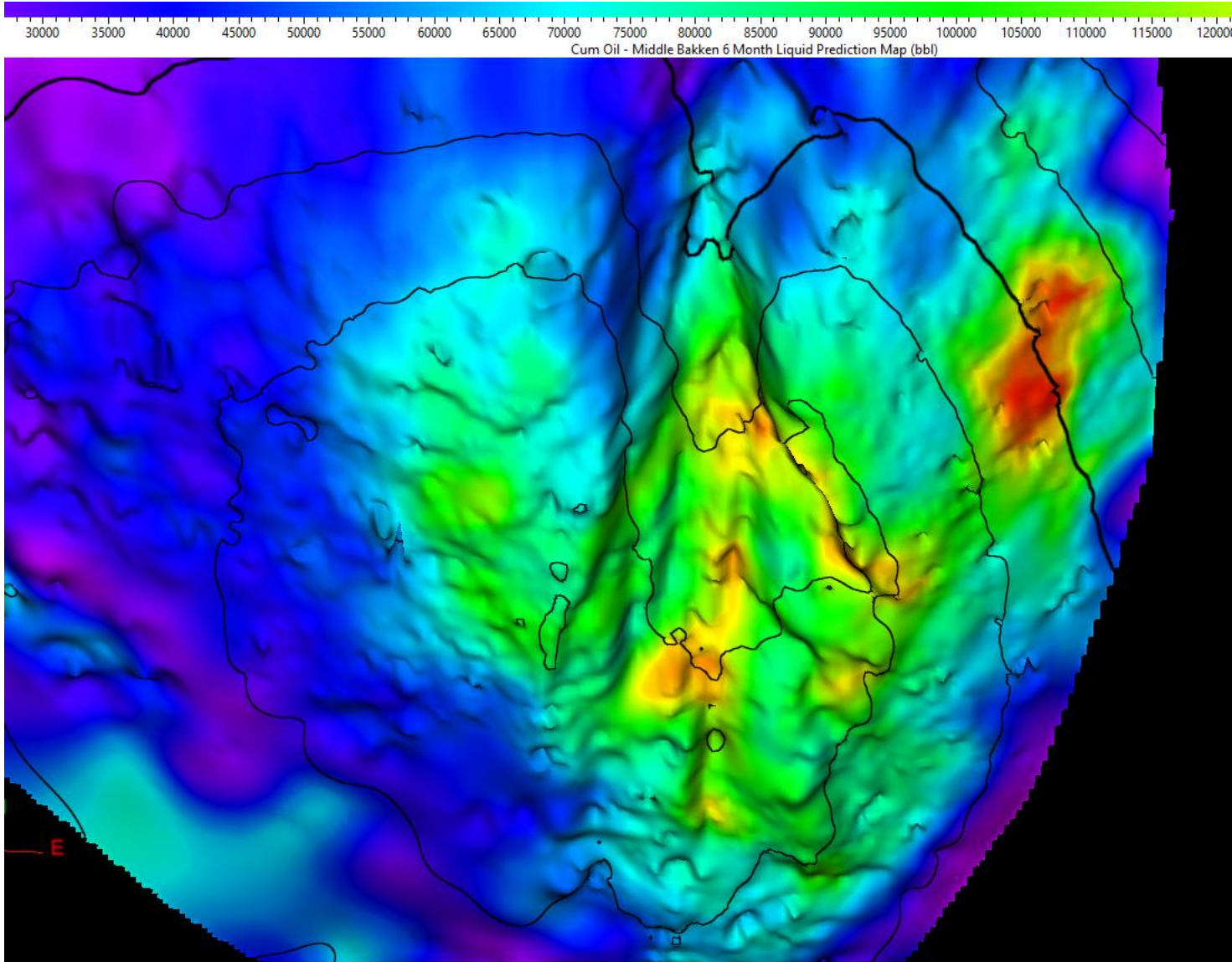


Non-Linear Variable Transformations



Technique solves for the contribution of each variable on production

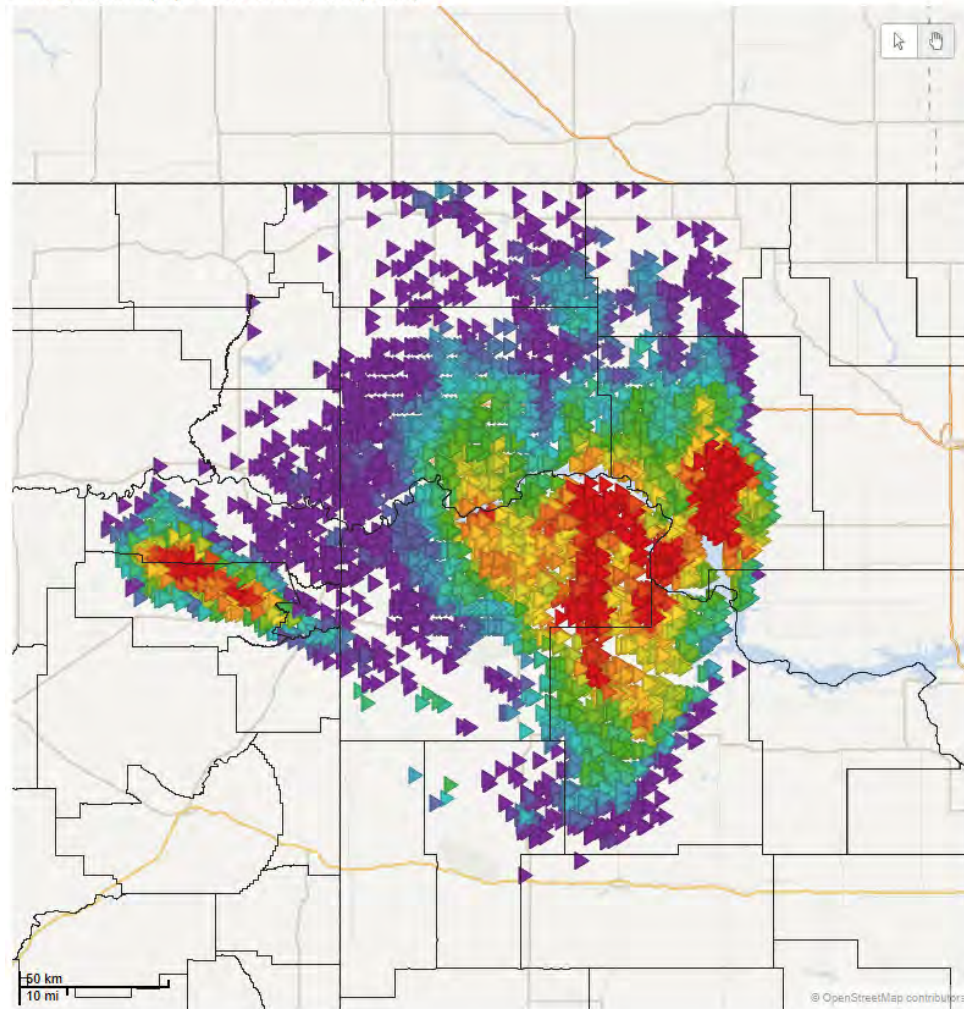
Model Output: Oil Sweetspot Map



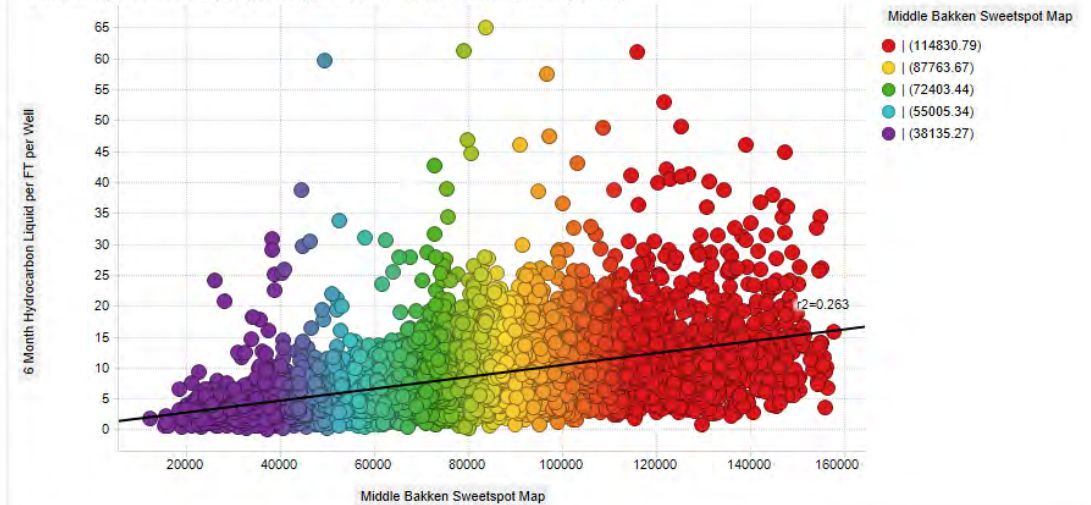
Using the relationships determined by the model and the geologic attribute maps, a sweetspot map can be generated to show geologic variability across the basin

Sweetspot Map vs. 6 Month Oil/ft

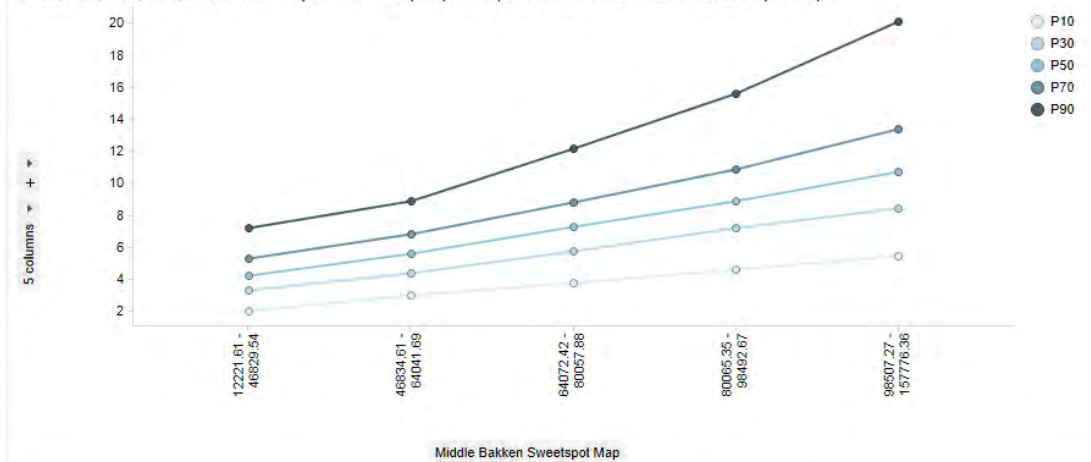
Well Location Map by Middle Bakken Sweetspot Map



6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Sweetspot Map



P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Sweetspot Map

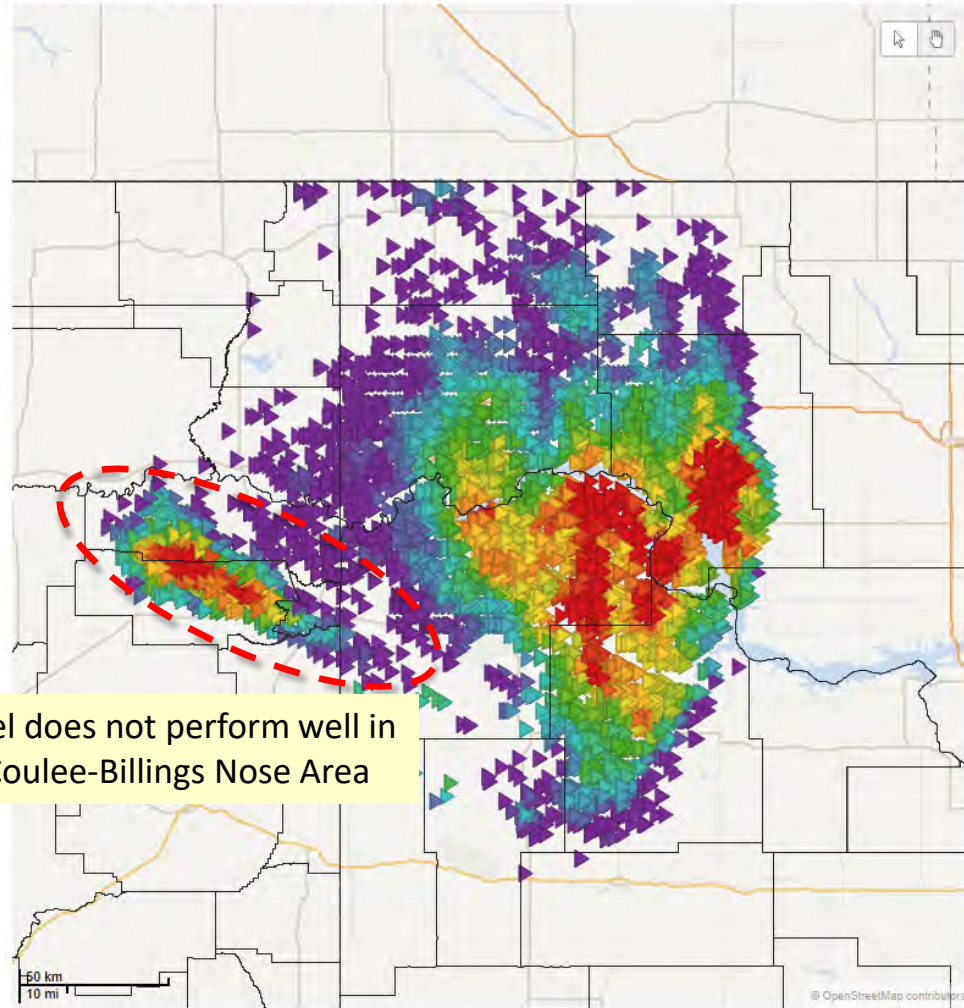


[Details...](#)

11,925 of 24,611 rows | 0 marked | 370 columns | Well Data Analysis Table

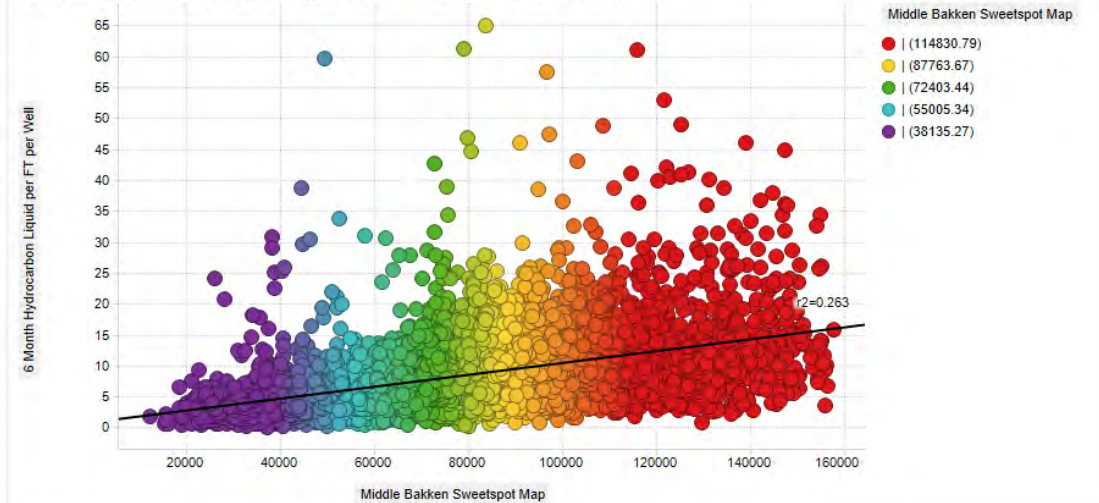
Sweetspot Map vs. 6 Month Oil/ft

Well Location Map by Middle Bakken Sweetspot Map

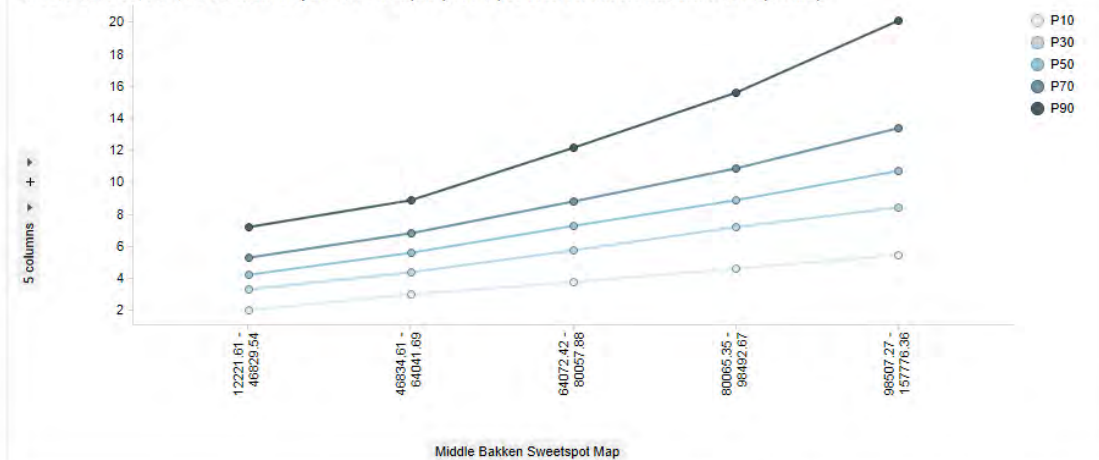


Model does not perform well in Elm Coulee-Billings Nose Area

6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Sweetspot Map

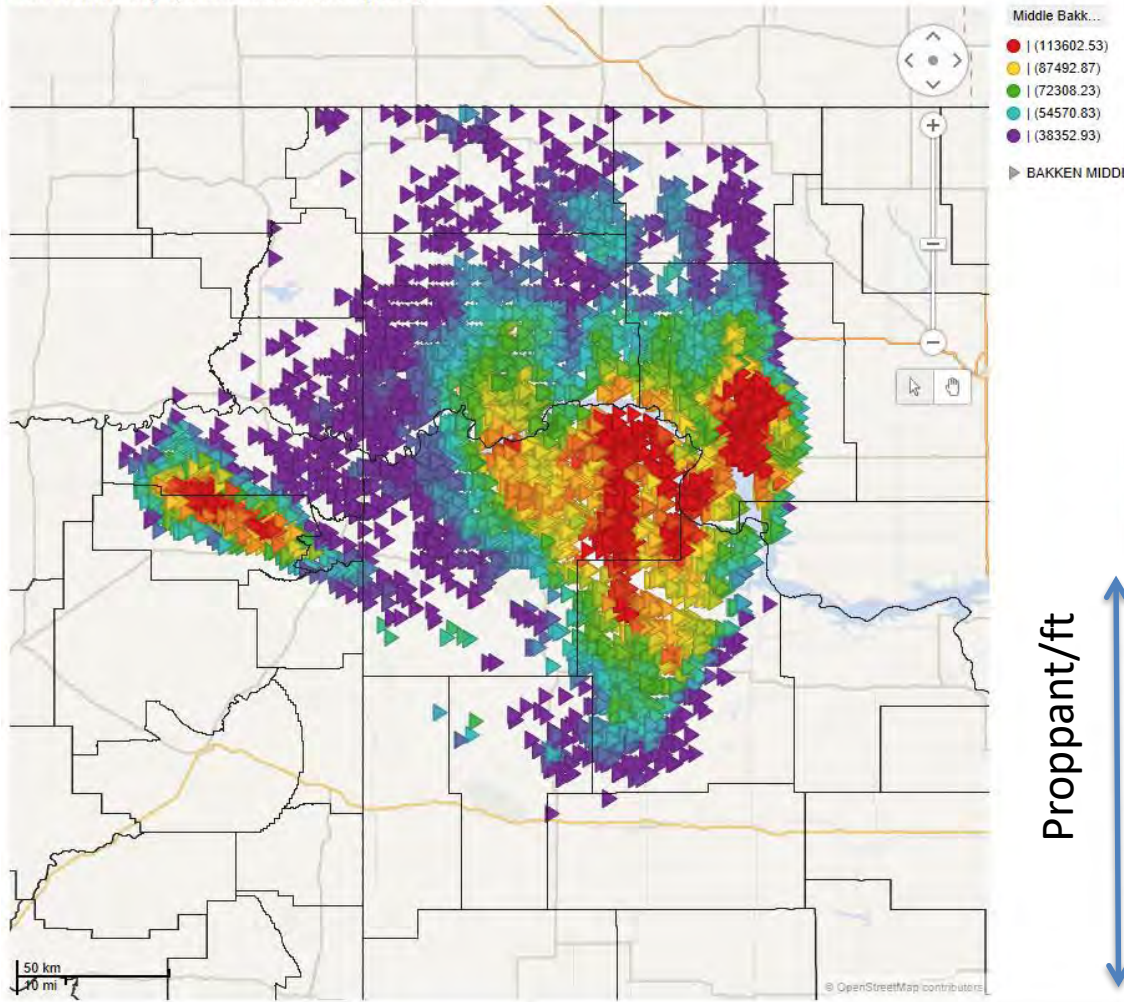


P10, P30, P50, P70, P90 6 Month Hydrocarbon Liquid per FT per Well vs. Middle Bakken Sweetspot Map

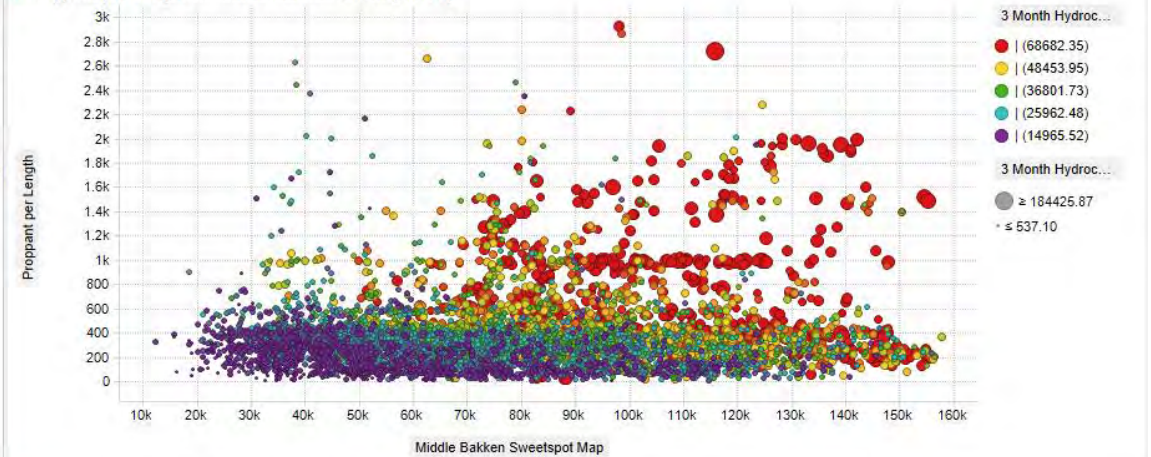


Benchmarking using Sweetspot Map

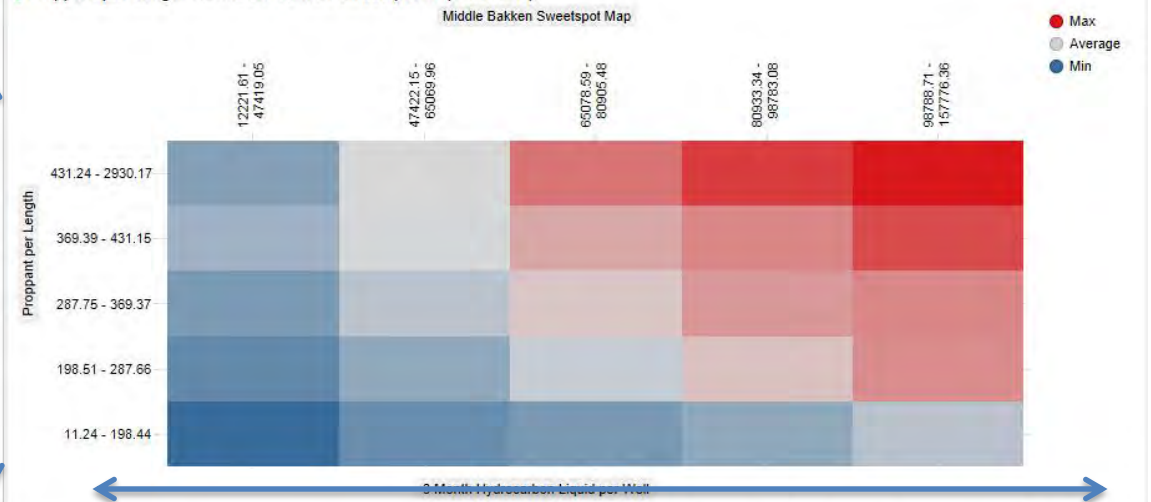
Well Location Map by Middle Bakken Sweetspot Map



Proppant per Length vs. Middle Bakken Sweetspot Map



Proppant per Length vs. Middle Bakken Sweetspot Map Heat Map



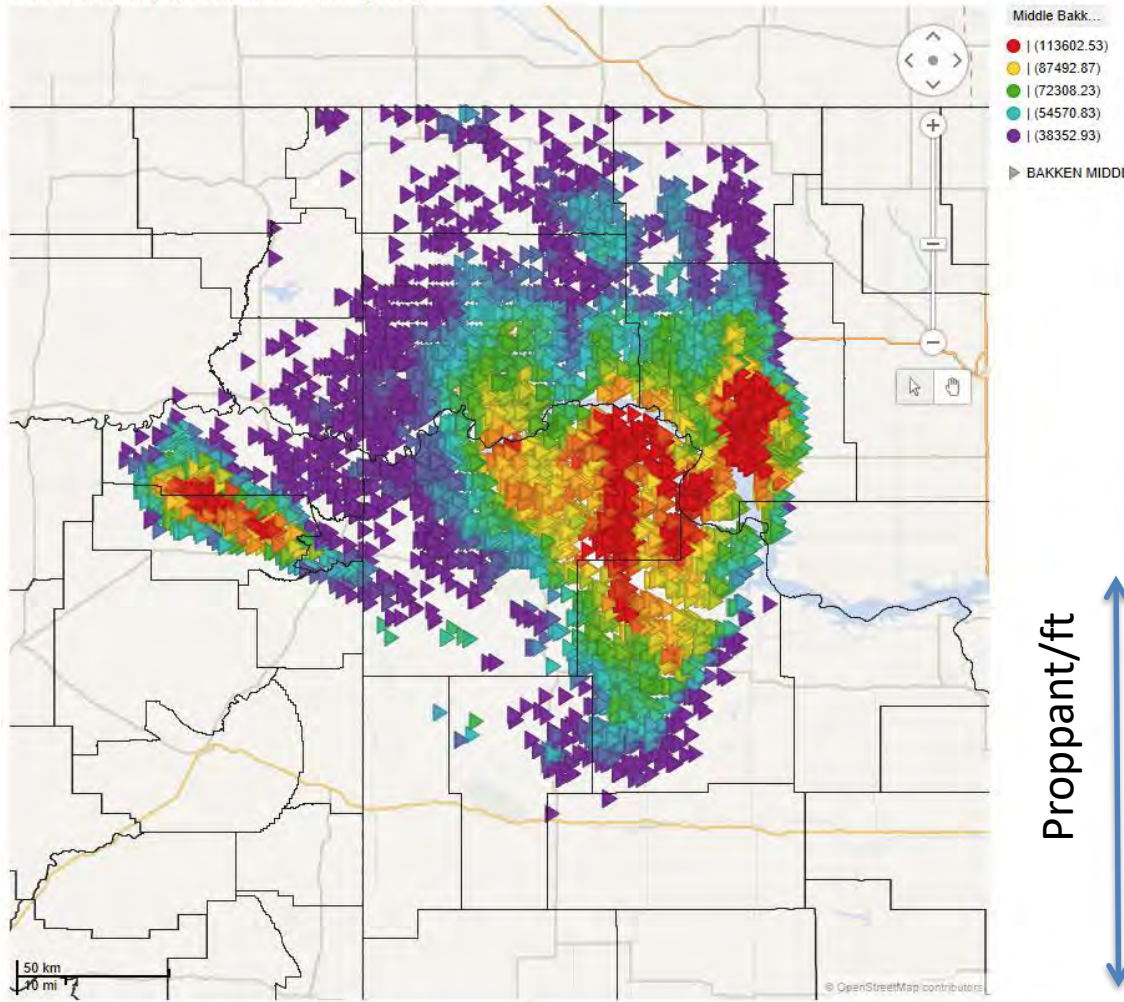
worse

Sweetspot Index

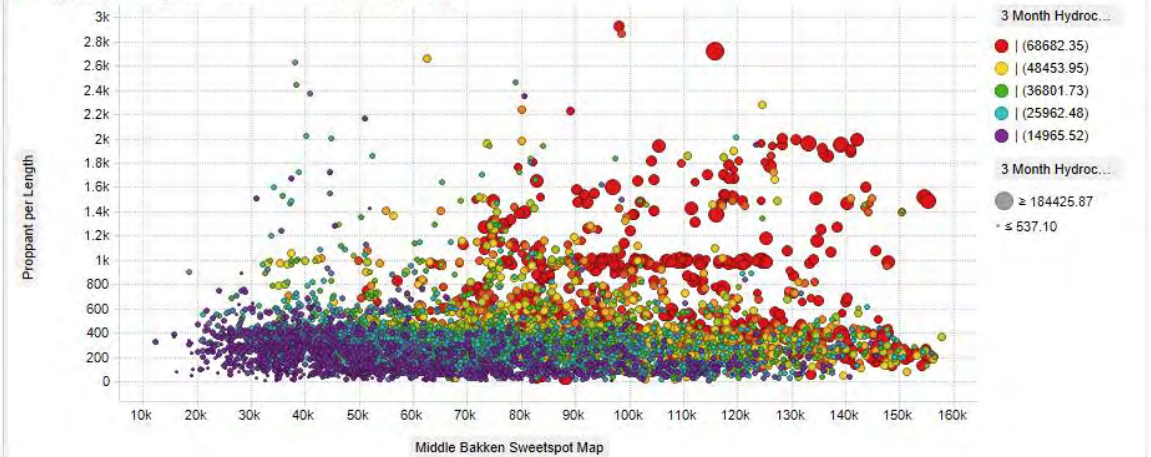
11,925 of 24,611 rows | 0 marked | 370 columns | Well Data Analysis Tab | better

Benchmarking using Sweetspot Map

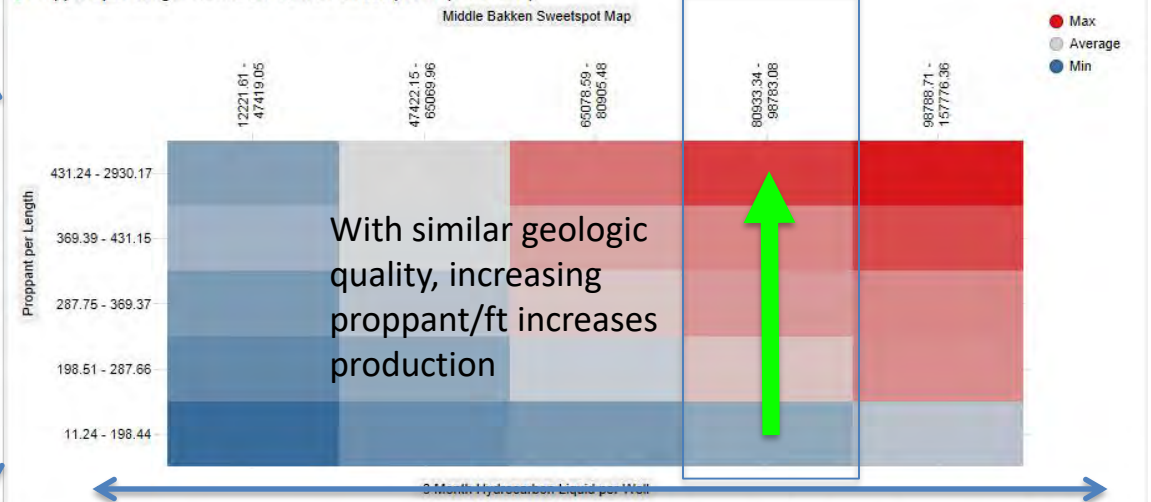
Well Location Map by Middle Bakken Sweetspot Map



Proppant per Length vs. Middle Bakken Sweetspot Map



Proppant per Length vs. Middle Bakken Sweetspot Map Heat Map



Proppant/ft

worse

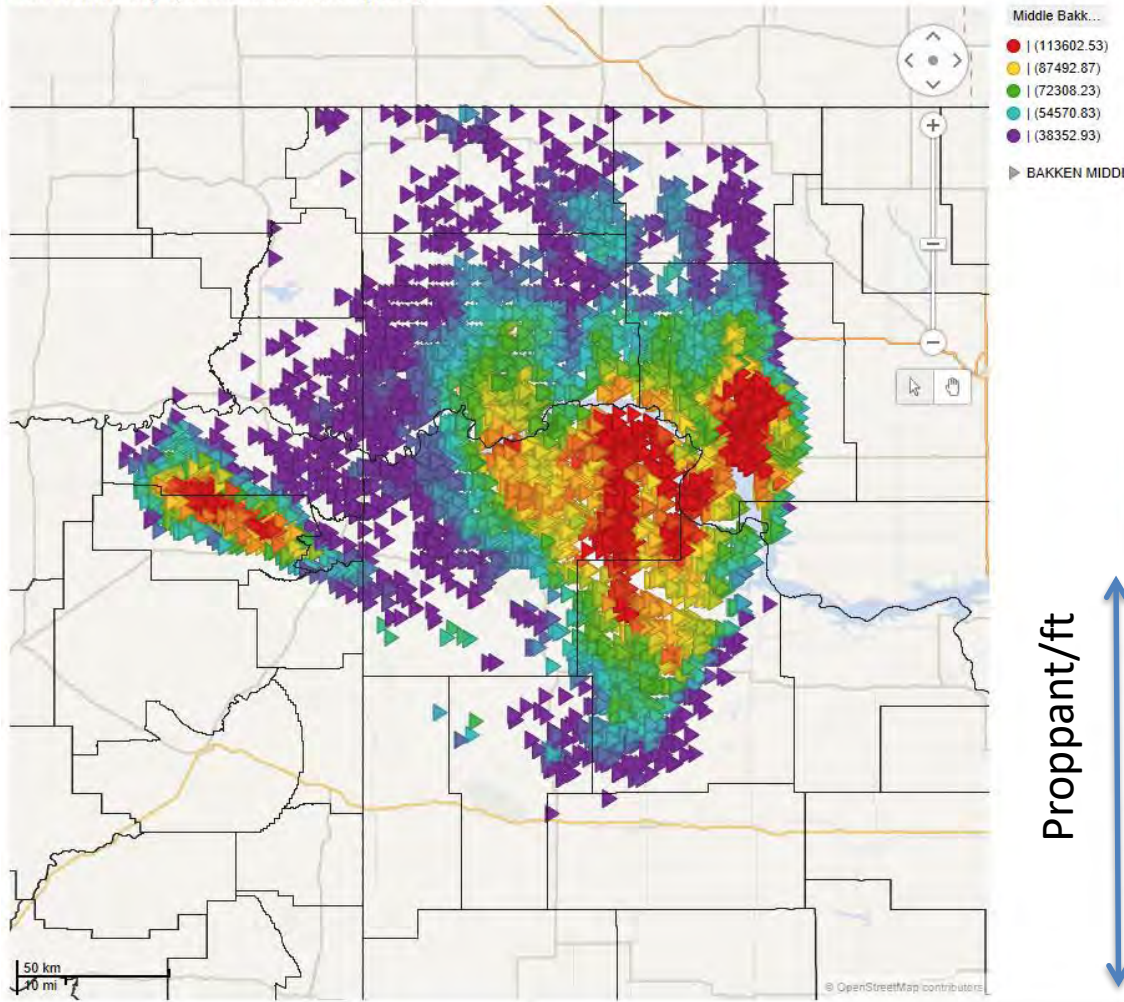
Sweetspot Index

11,925 of 24,611 rows | 0 marked | 370 columns | Well Data Analysis Tab

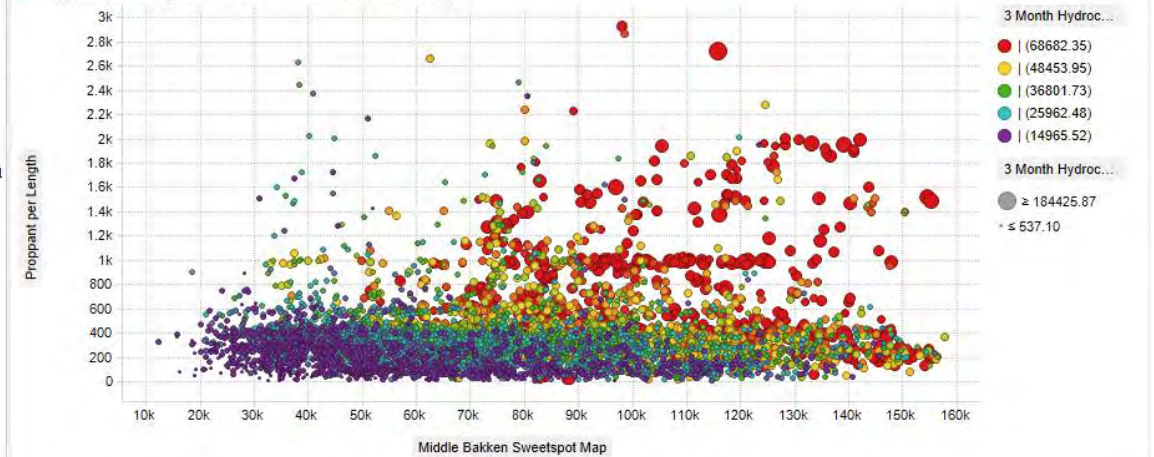
better

Benchmarking using Sweetspot Map

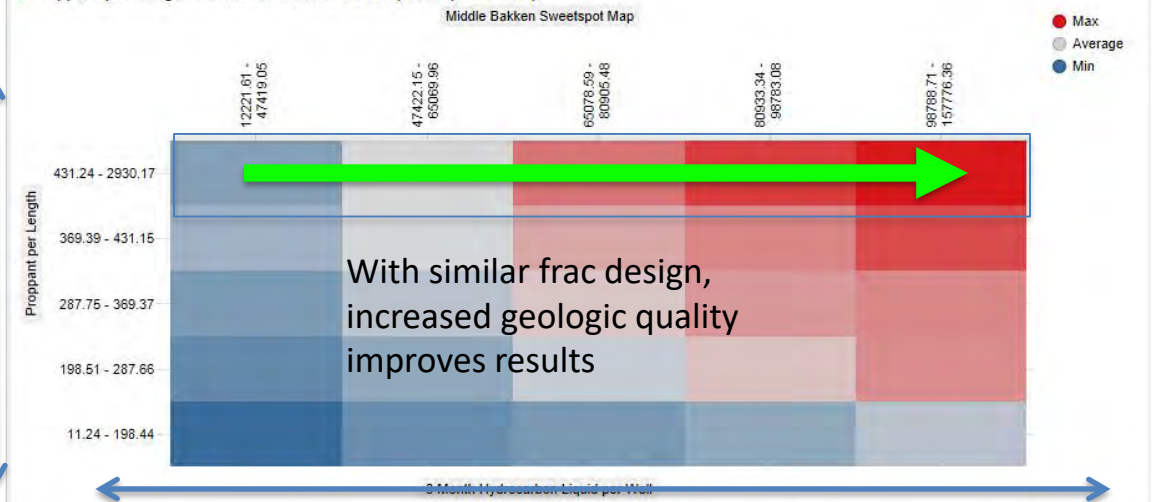
Well Location Map by Middle Bakken Sweetspot Map



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Proppant/ft

worse

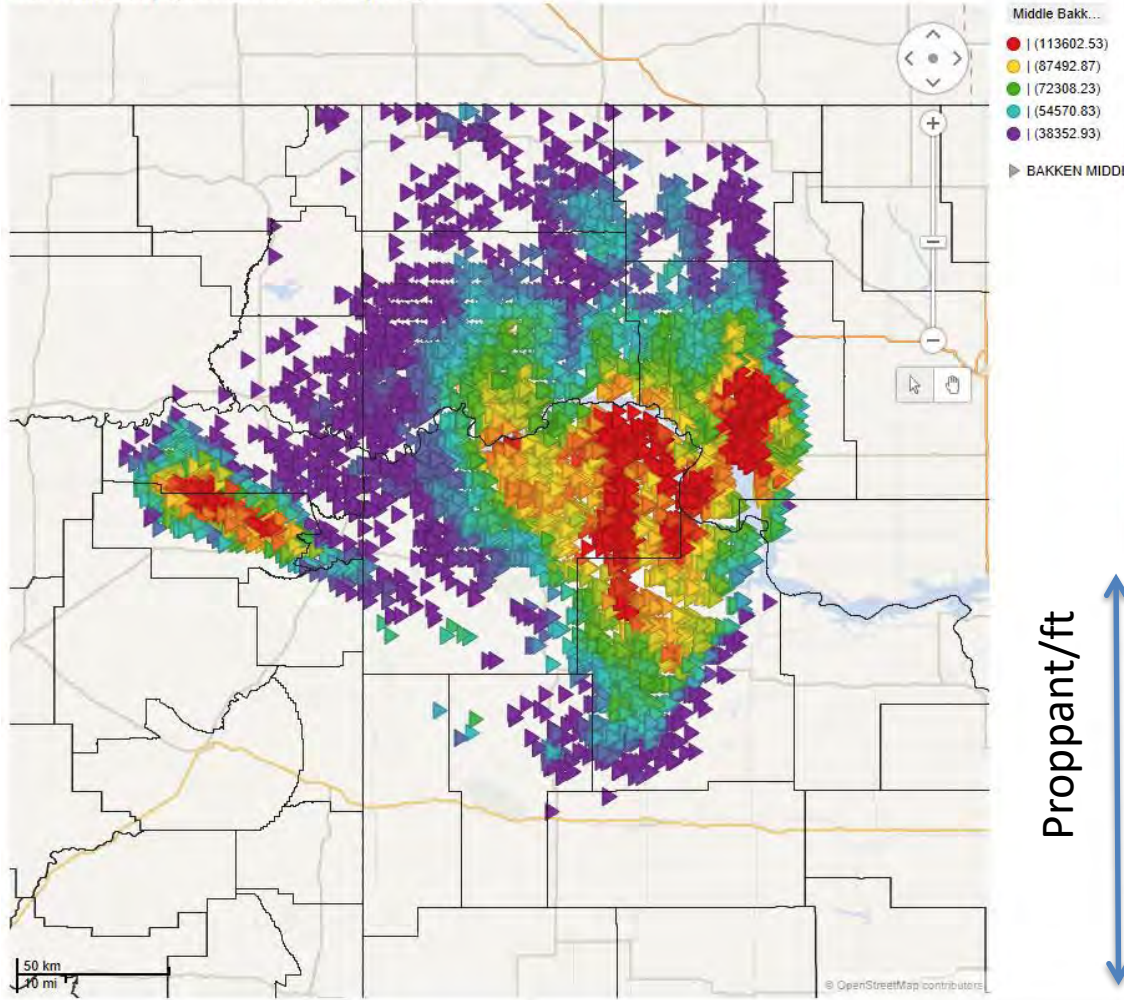
Sweetspot Index

11,925 of 24,611 rows | 0 marked | 370 columns | Well Data Analysis Tab

better

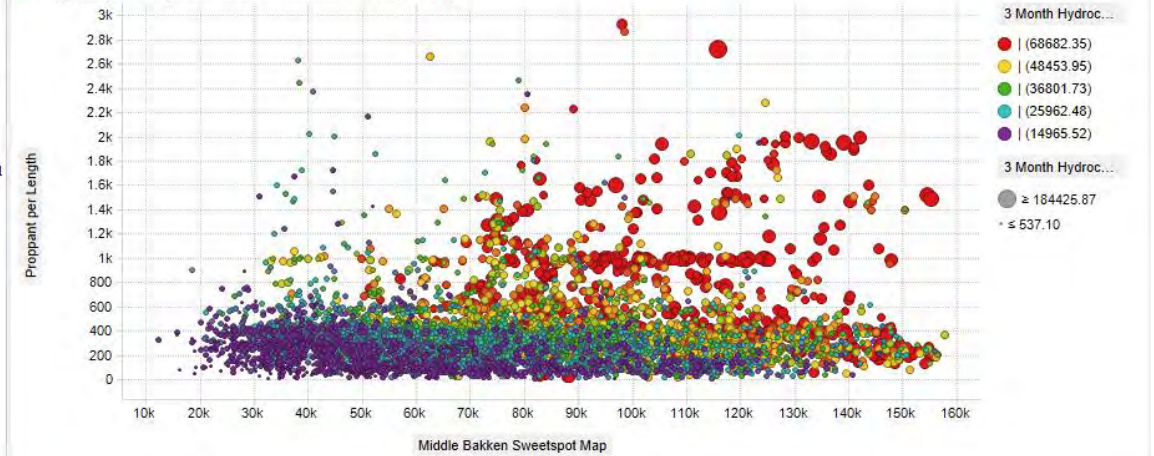
Benchmarking using Sweetspot Map

Well Location Map by Middle Bakken Sweetspot Map

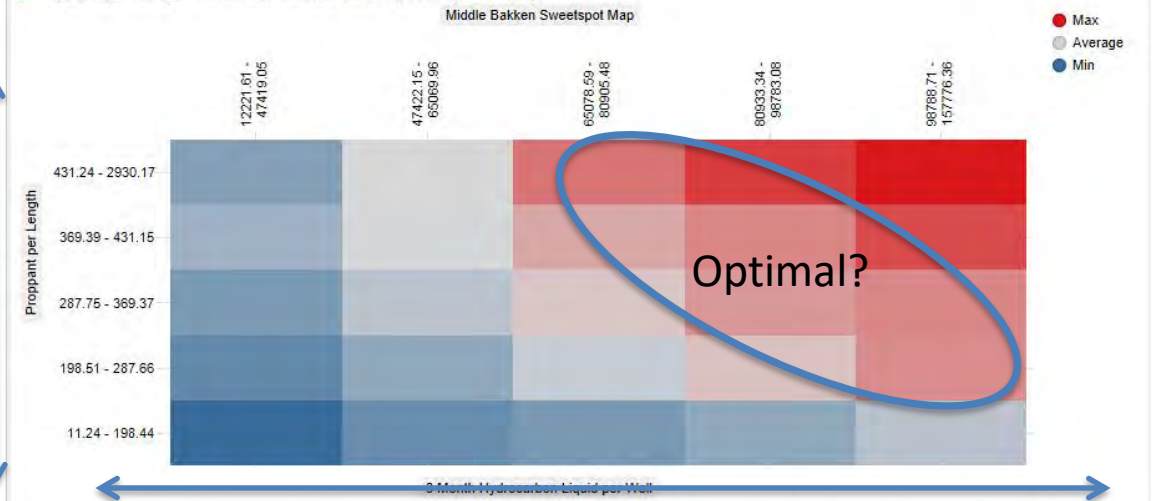


15...

Proppant per Length vs. Middle Bakken Sweetspot Map



Proppant per Length vs. Middle Bakken Sweetspot Map Heat Map



worse

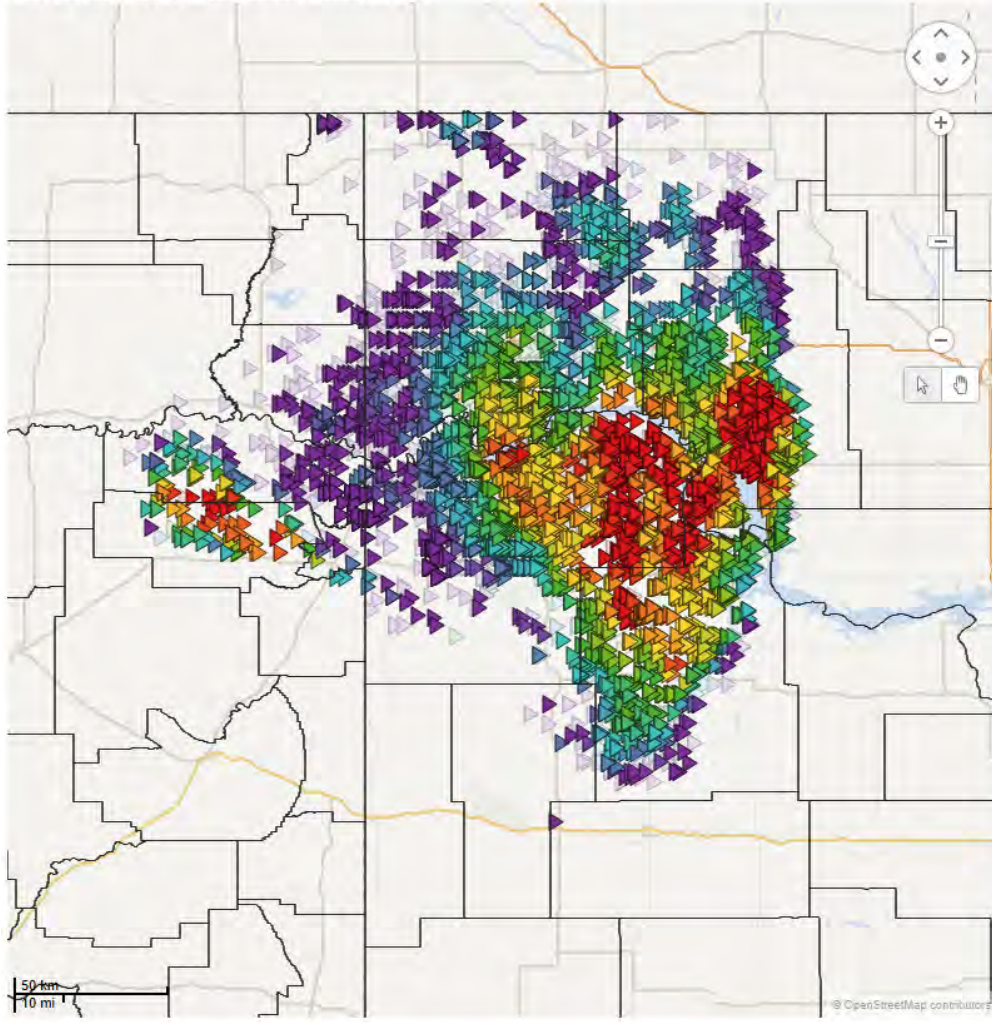
Sweetspot Index

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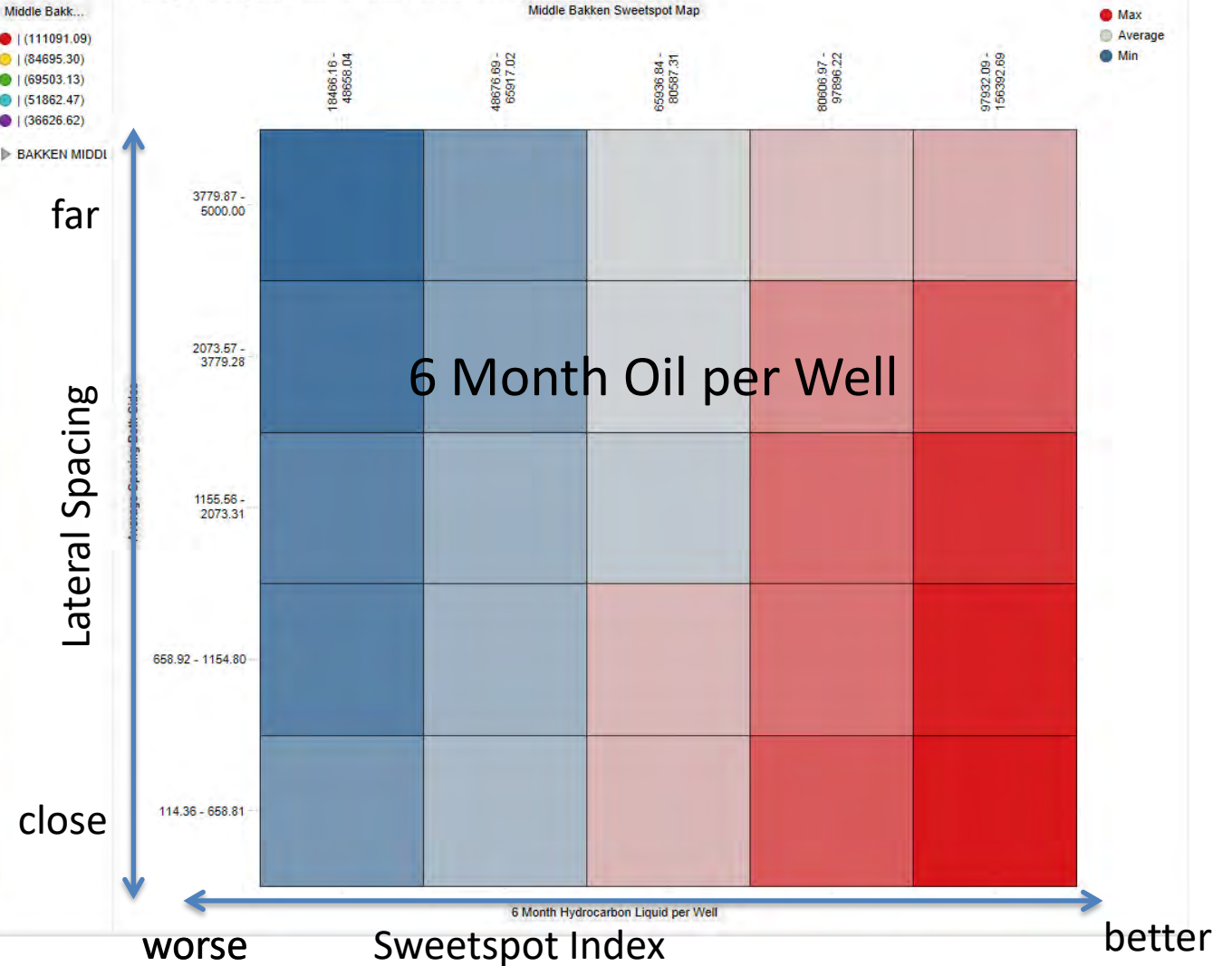
better

Lateral Spacing vs. Sweetspot Map

Well Location Map by Middle Bakken Sweetspot Map

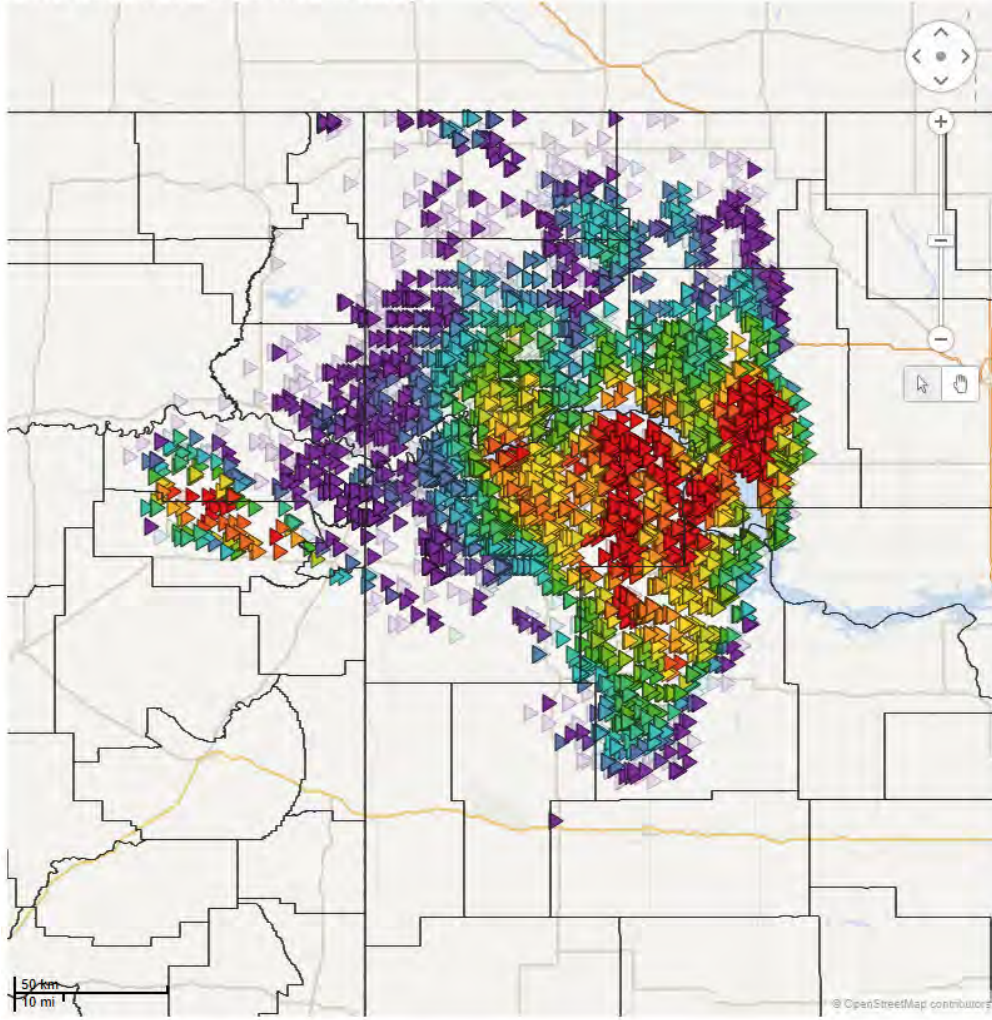


Average Spacing Both Sides vs. Middle Bakken Sweetspot Map Heat Map

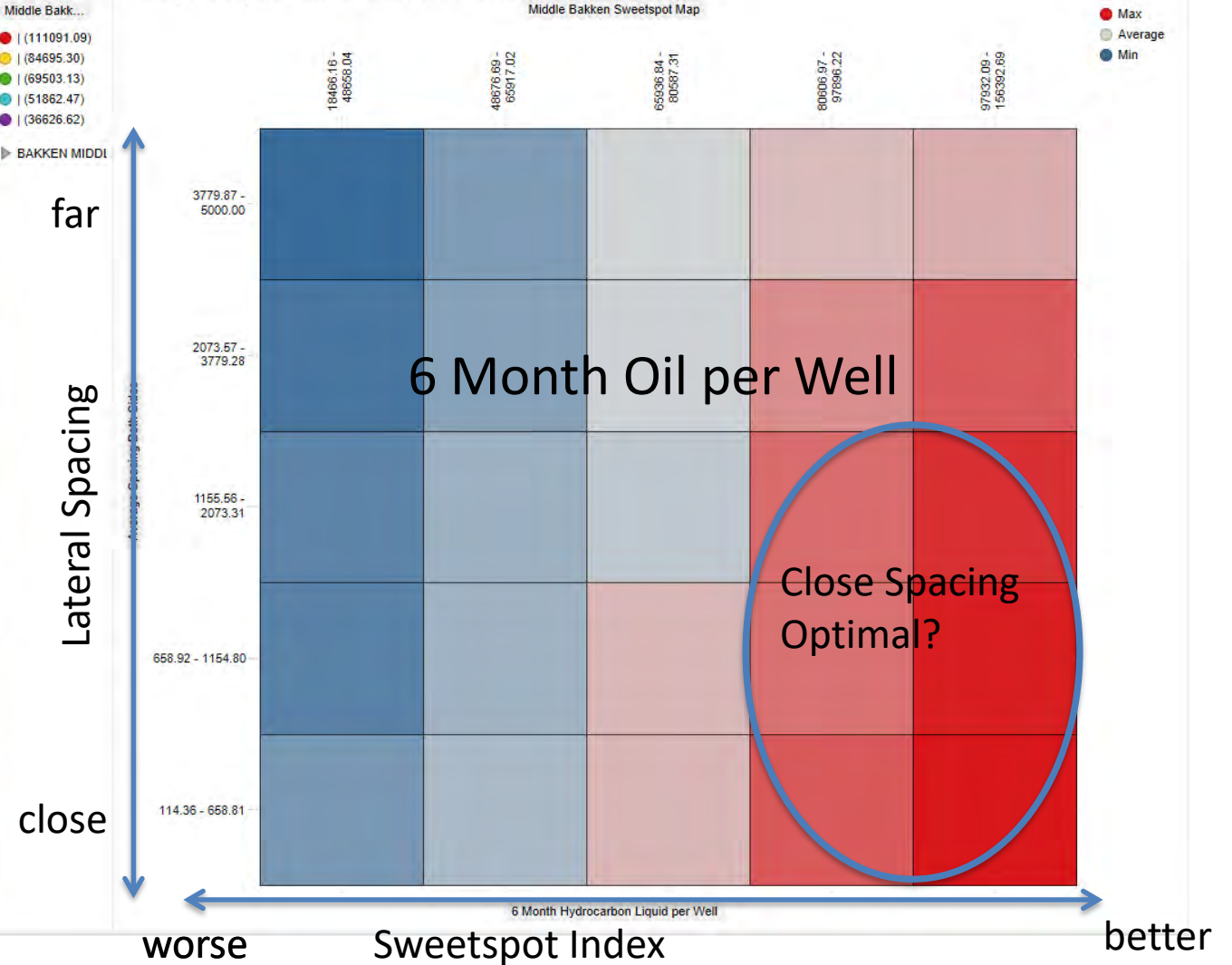


Lateral Spacing vs. Sweetspot Map

Well Location Map by Middle Bakken Sweetspot Map

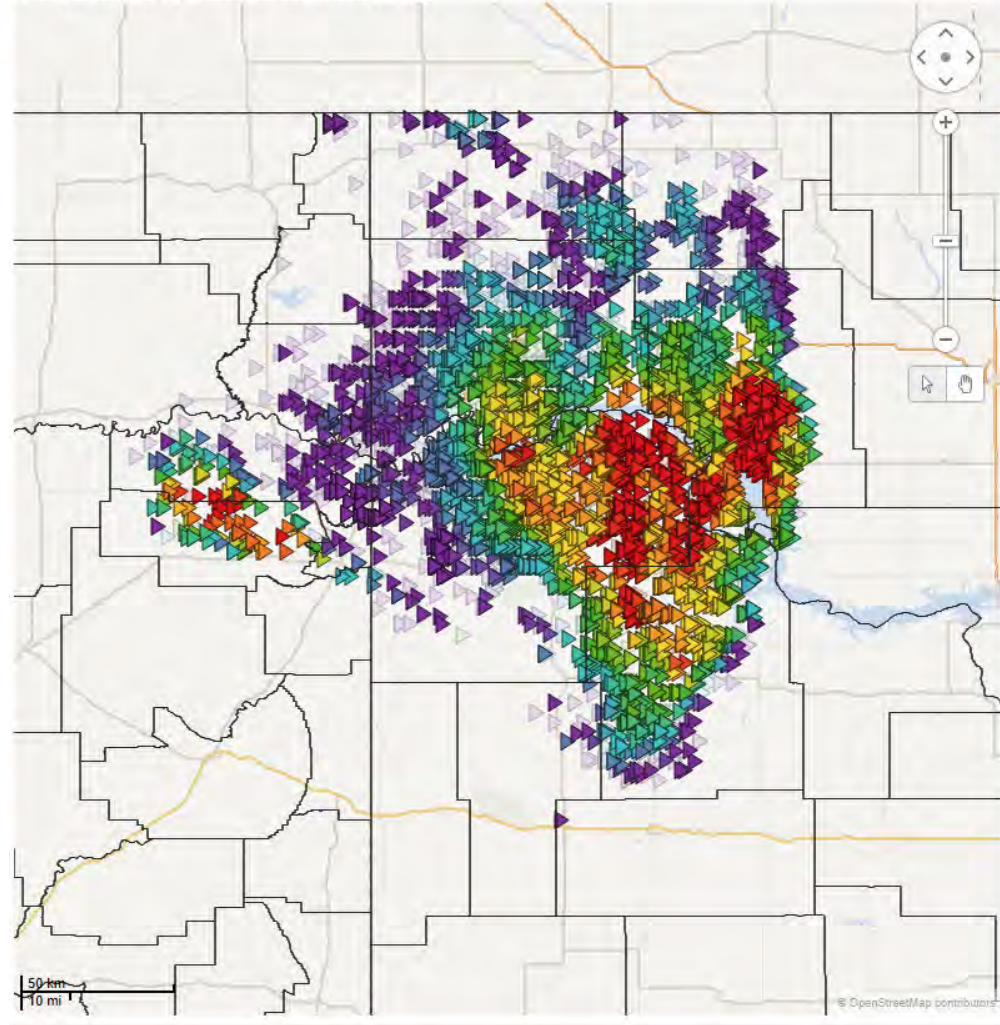


Average Spacing Both Sides vs. Middle Bakken Sweetspot Map Heat Map

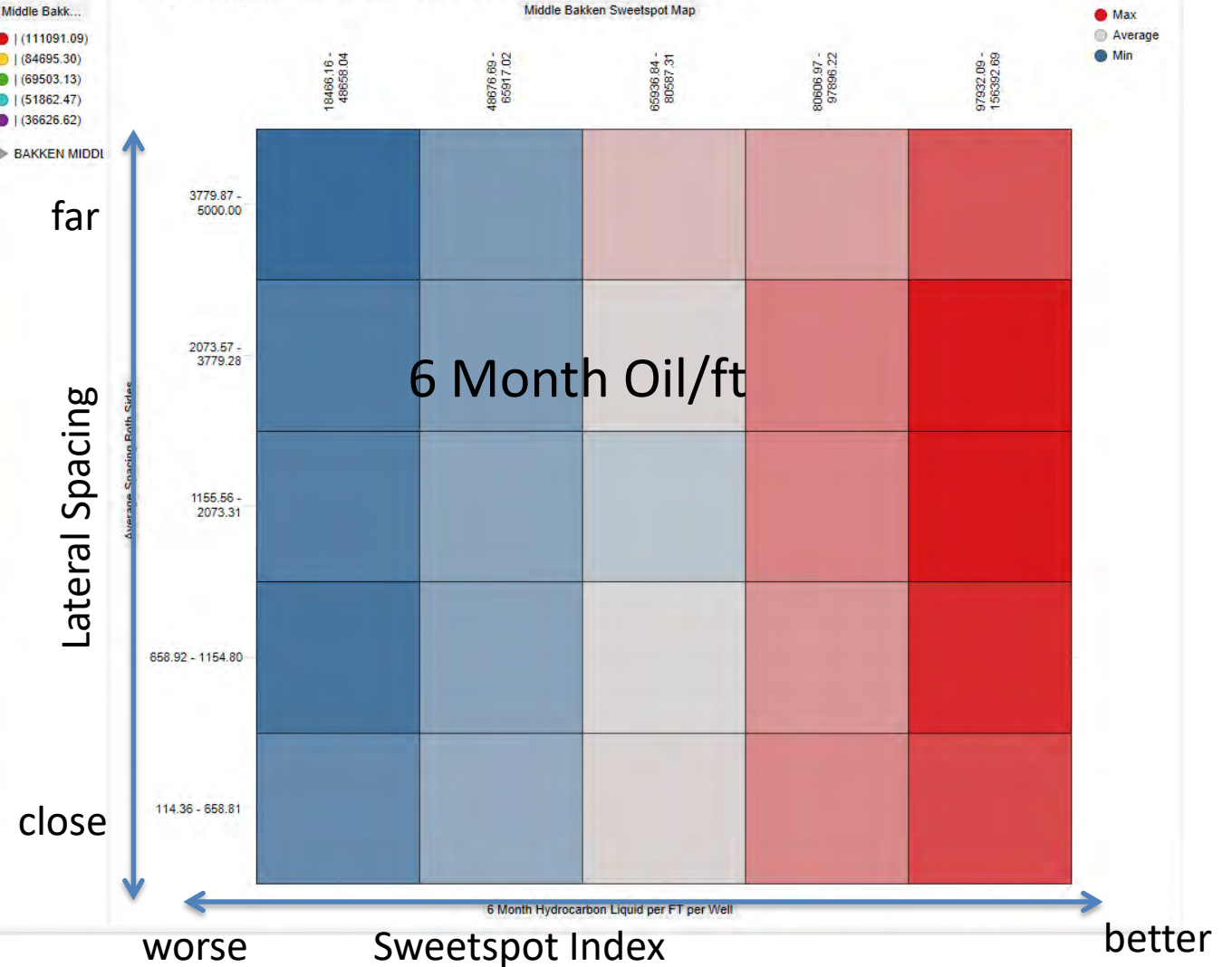


Lateral Spacing vs. Sweetspot Map

Well Location Map by Middle Bakken Sweetspot Map

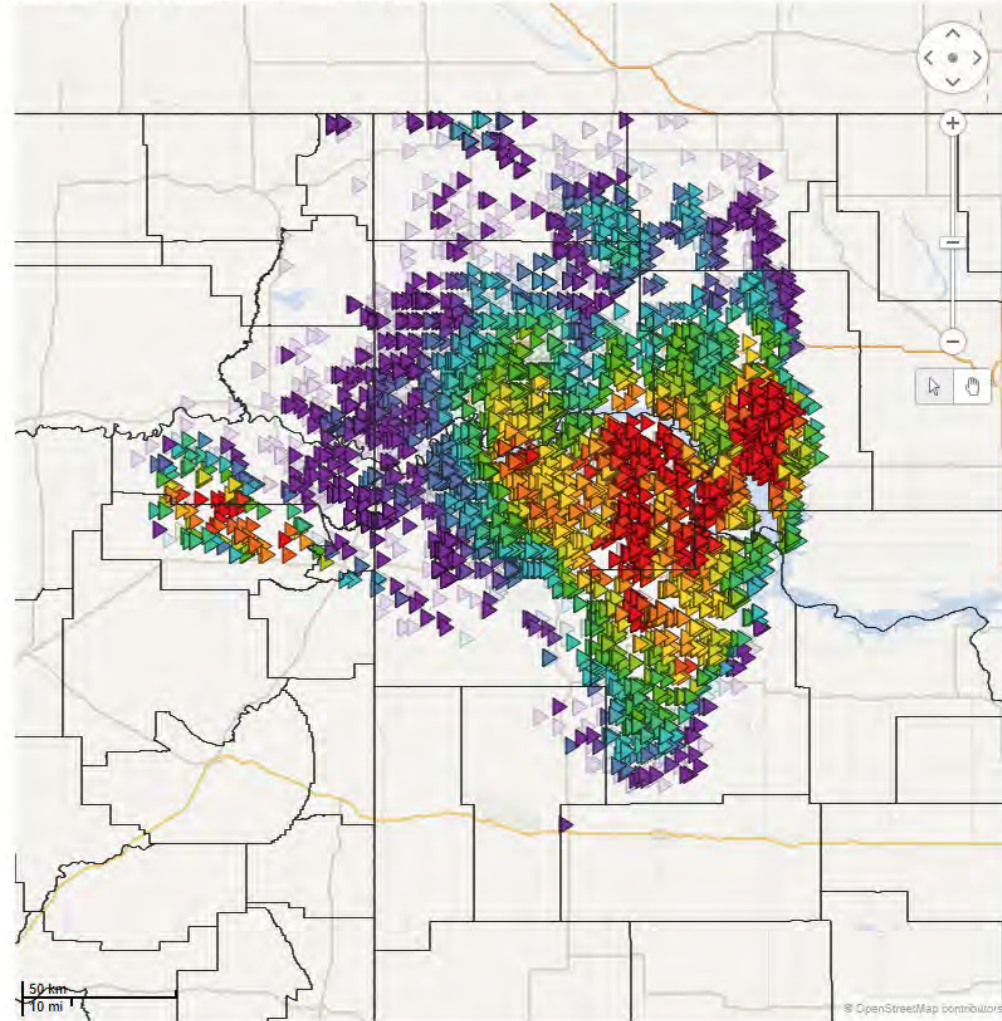


Average Spacing Both Sides vs. Middle Bakken Sweetspot Map Heat Map

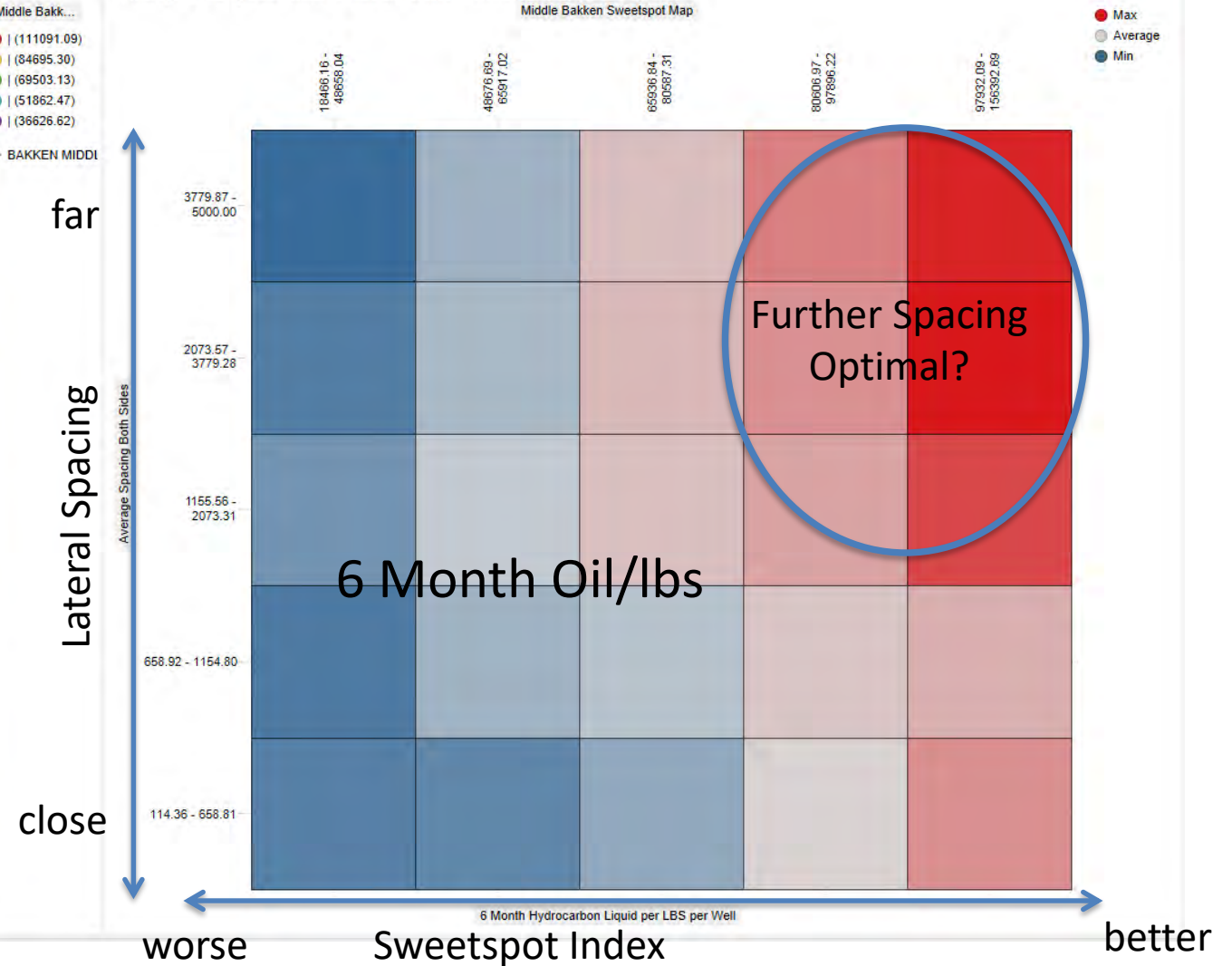


Lateral Spacing vs. Sweetspot Map

Well Location Map by Middle Bakken Sweetspot Map



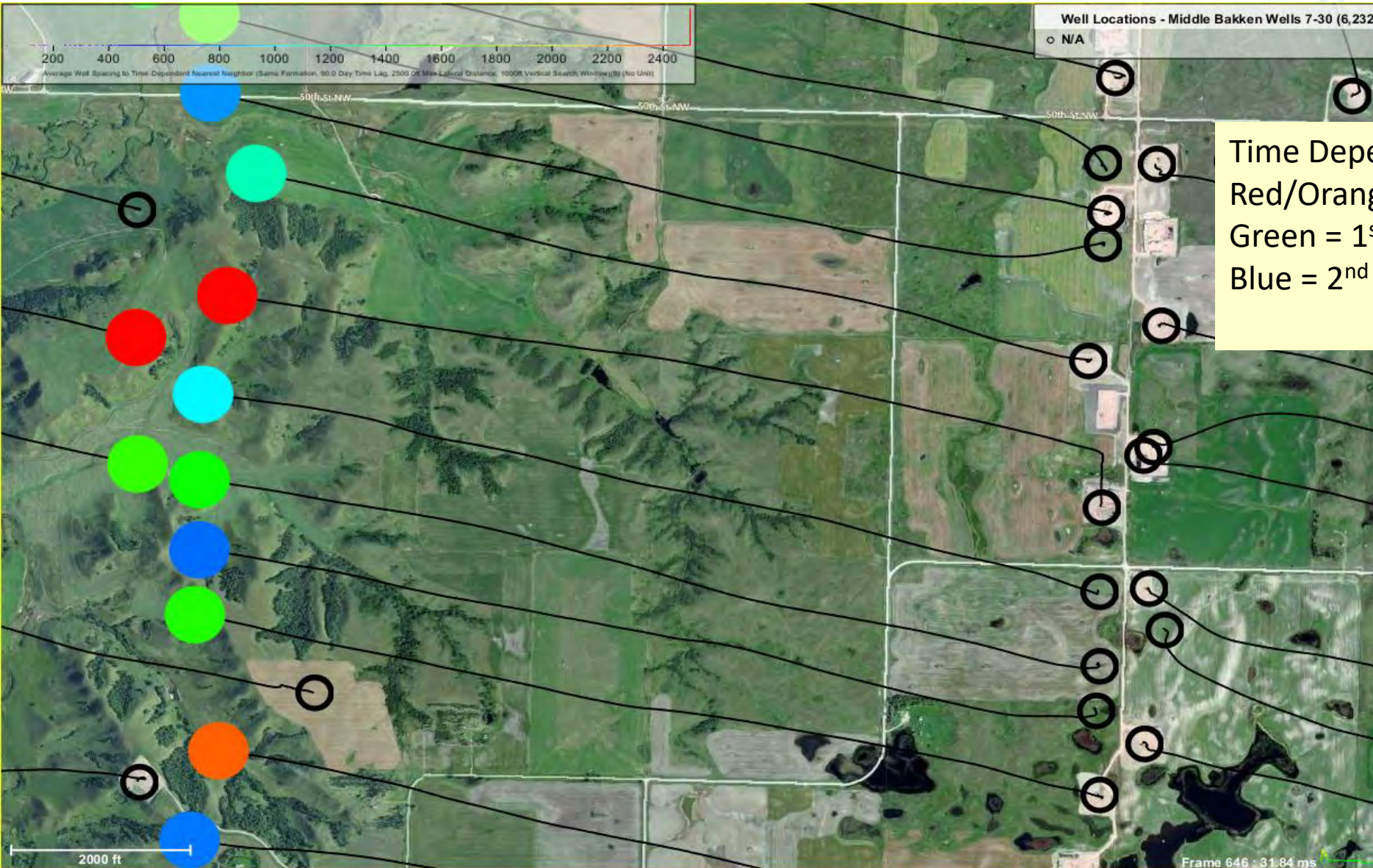
Average Spacing Both Sides vs. Middle Bakken Sweetspot Map Heat Map



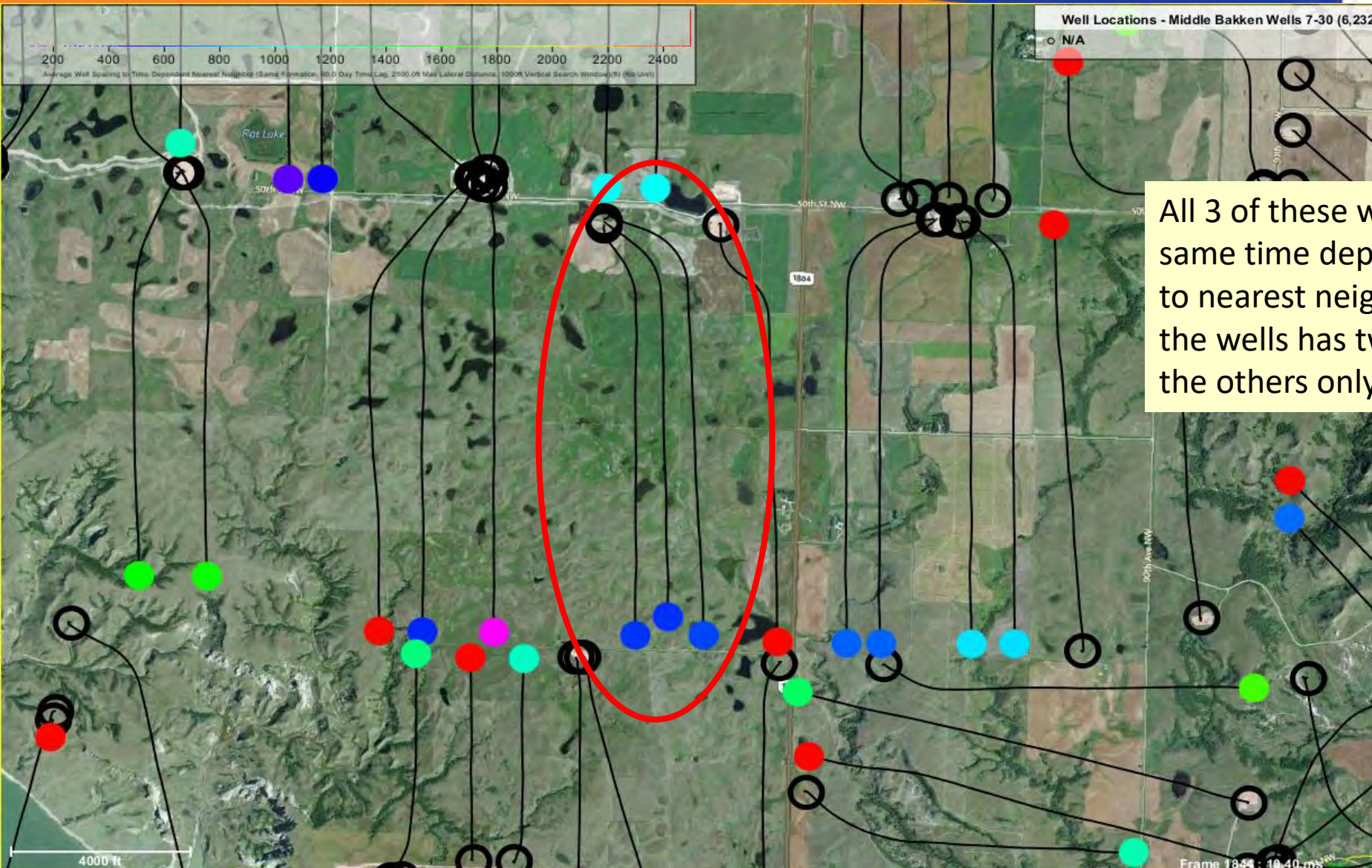
Closely Spaced Infill Wells Performing 60% Better than Standalone Wells?

- Before we get too excited, we should first review potential shortcomings of the analysis:
 - Not accounting for improvements in technology over time (e.g. longer/bigger fracs)?
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 - Is the system too complex to be investigated using bi-variate techniques?

Time-Dependent Spacing Example

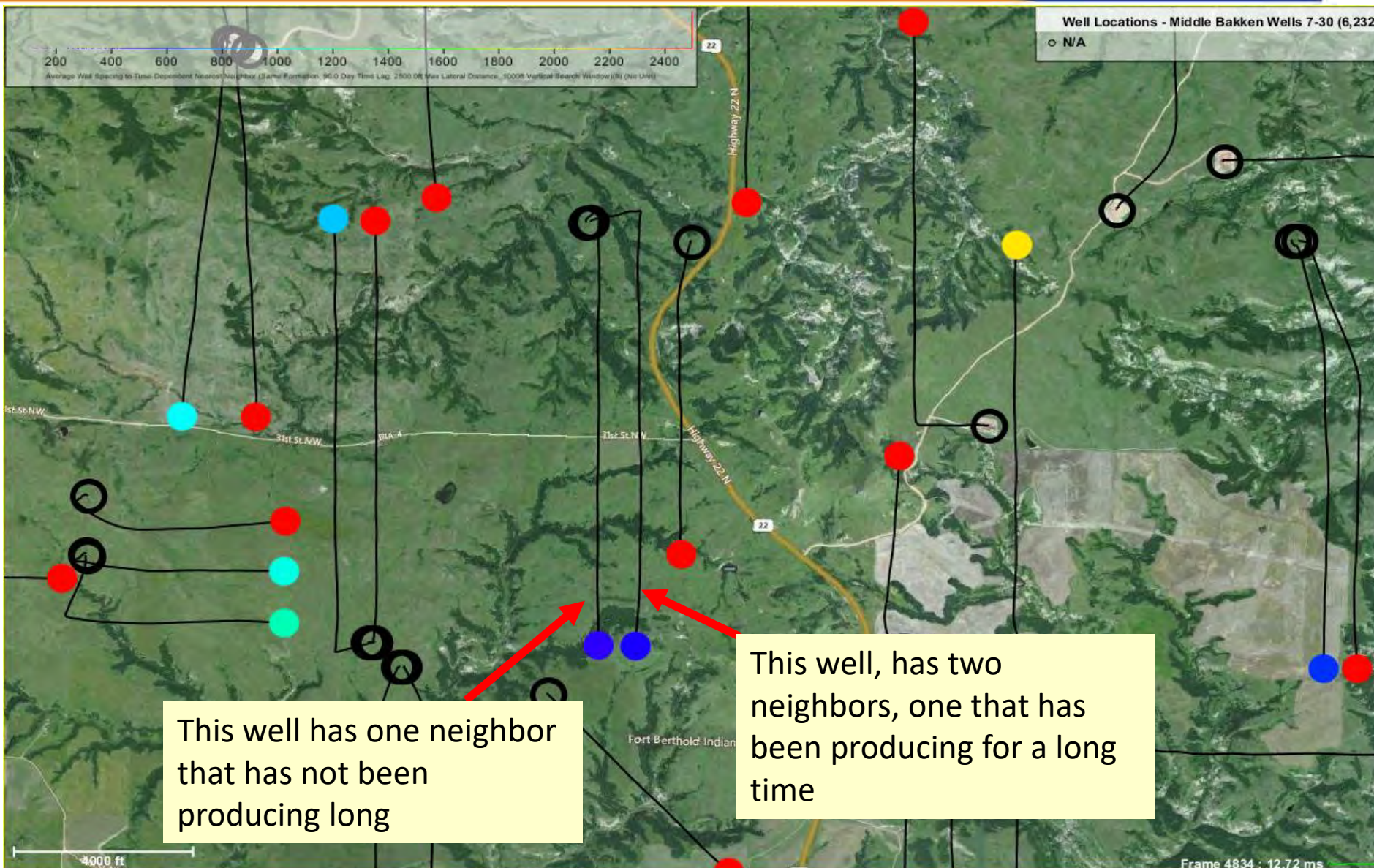


Doesn't Tell the Whole Story....

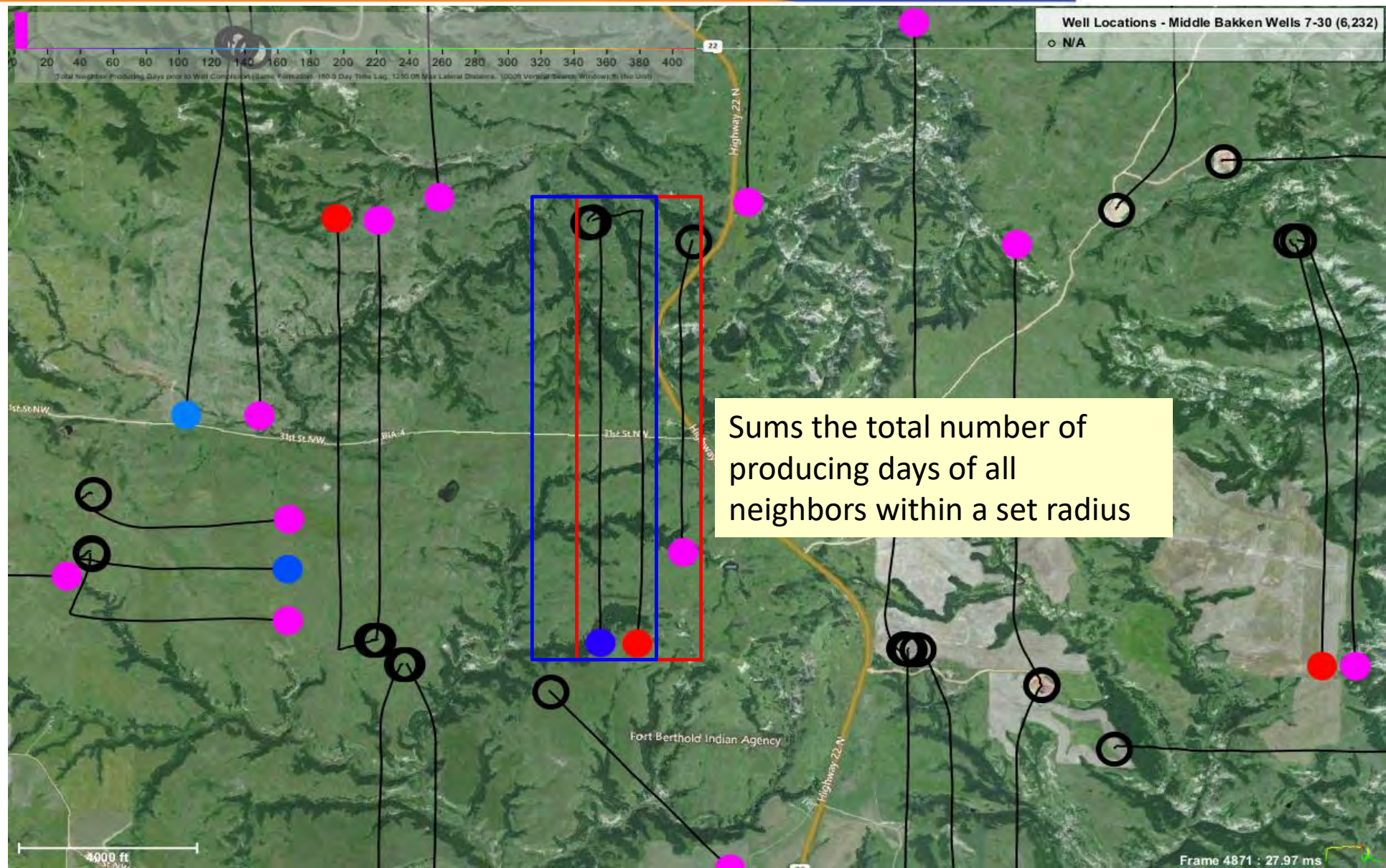


All 3 of these wells have the same time dependent spacing to nearest neighbor, but one of the wells has two neighbors and the others only have one.

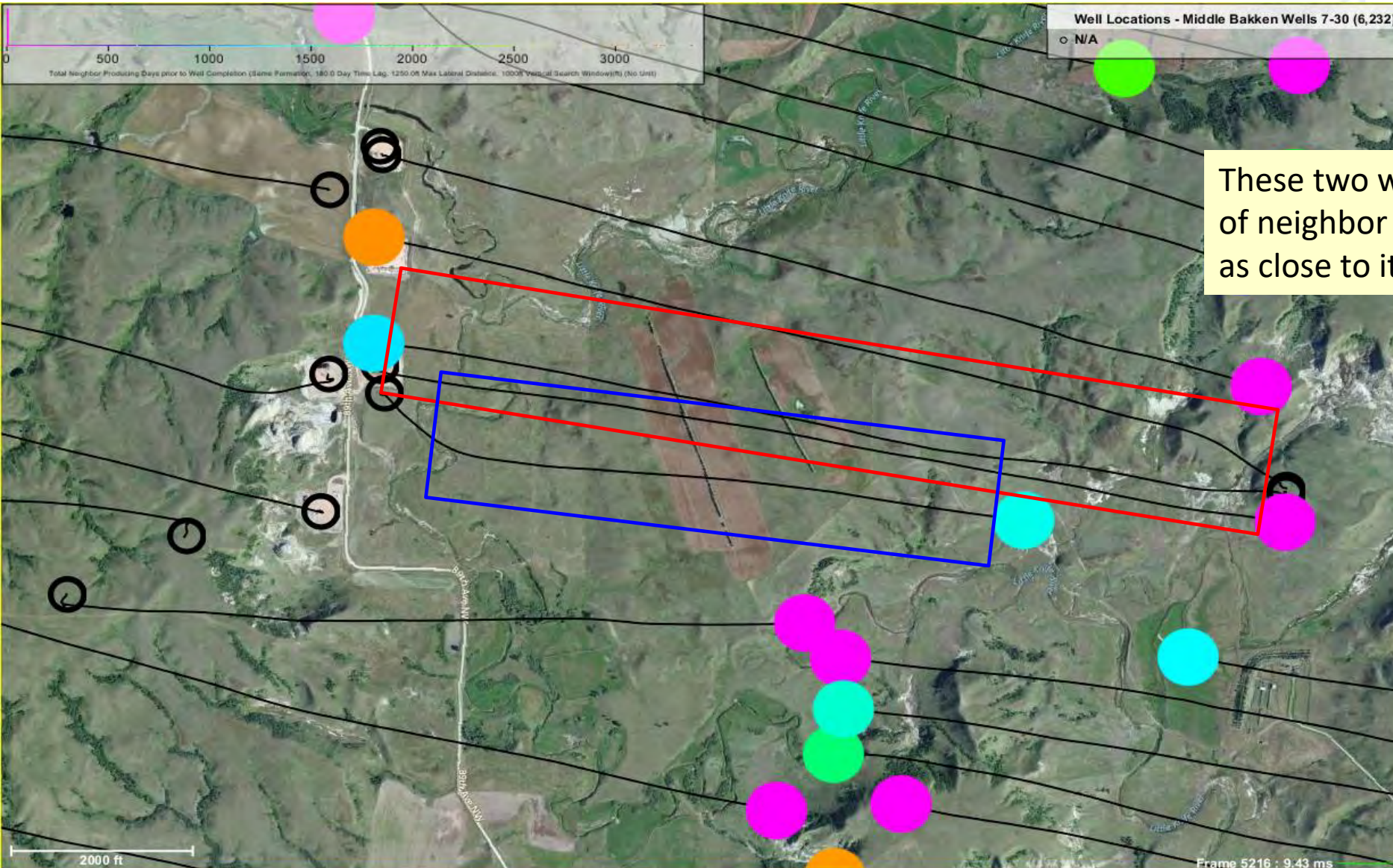
Doesn't Tell the Whole Story....



Time-Dependent Total Number of Neighbor Producing Days

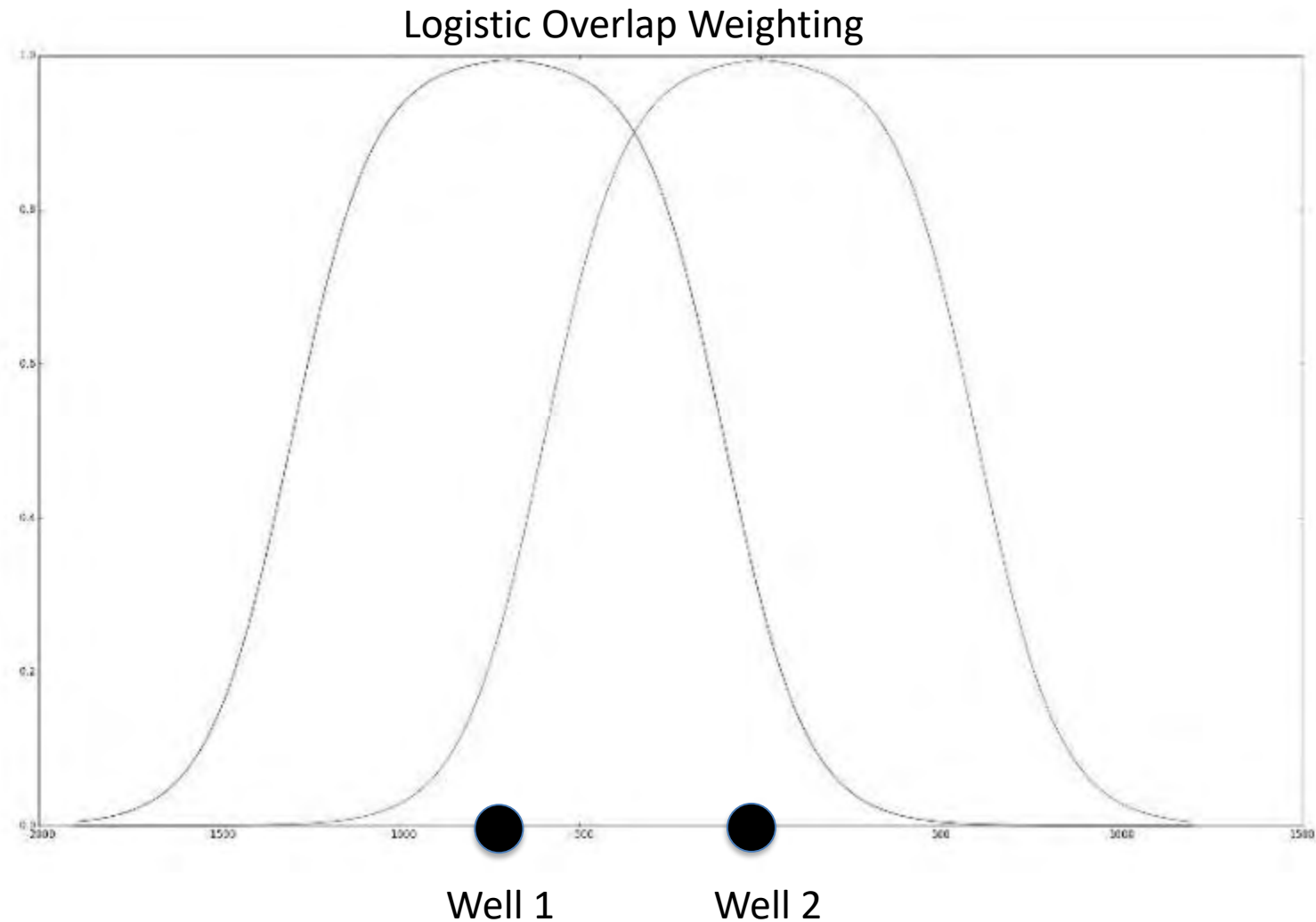


Doesn't Tell the Whole Story....

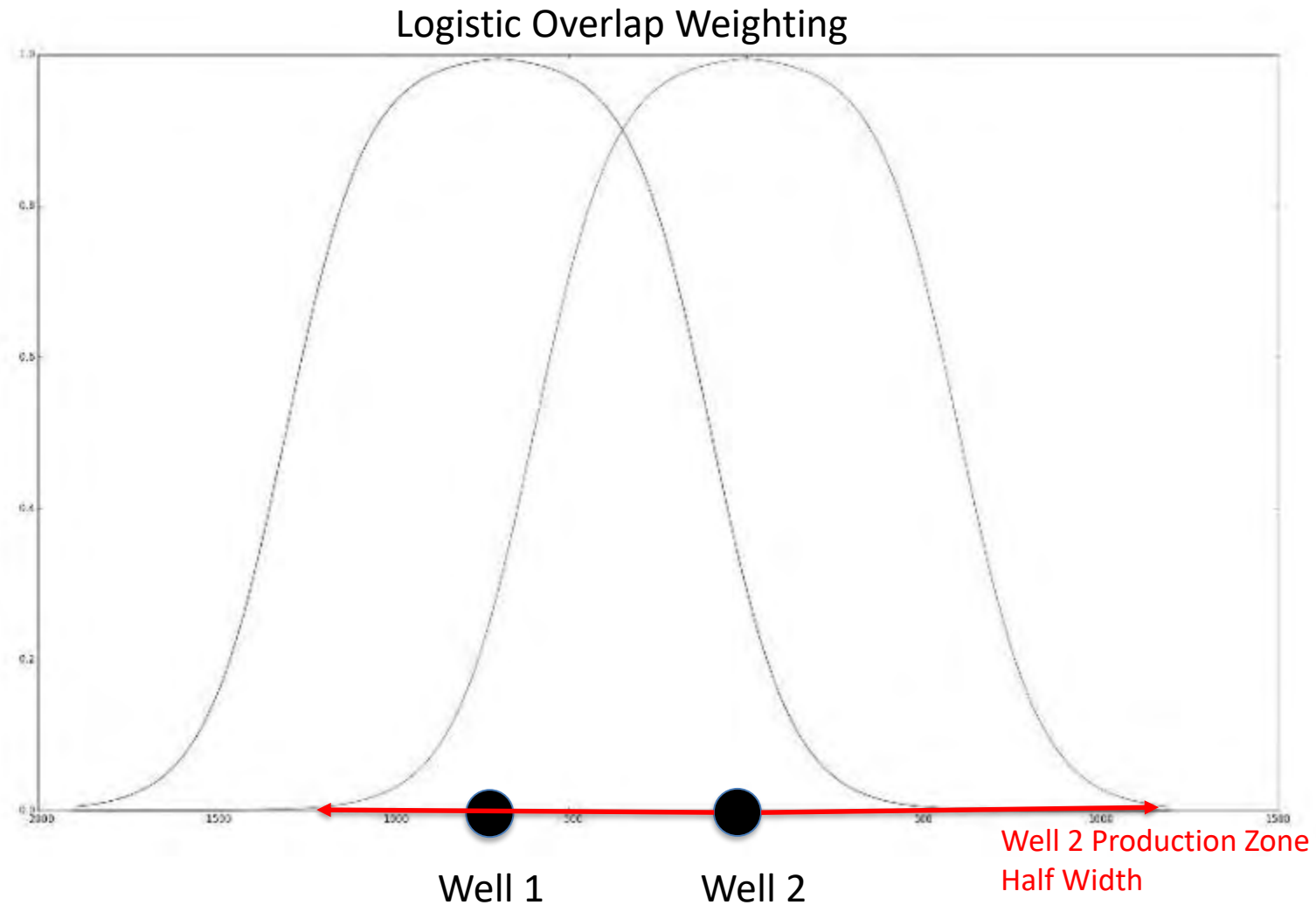


These two wells, both have the same number of neighbor producing days, but one is twice as close to its neighbor as the other

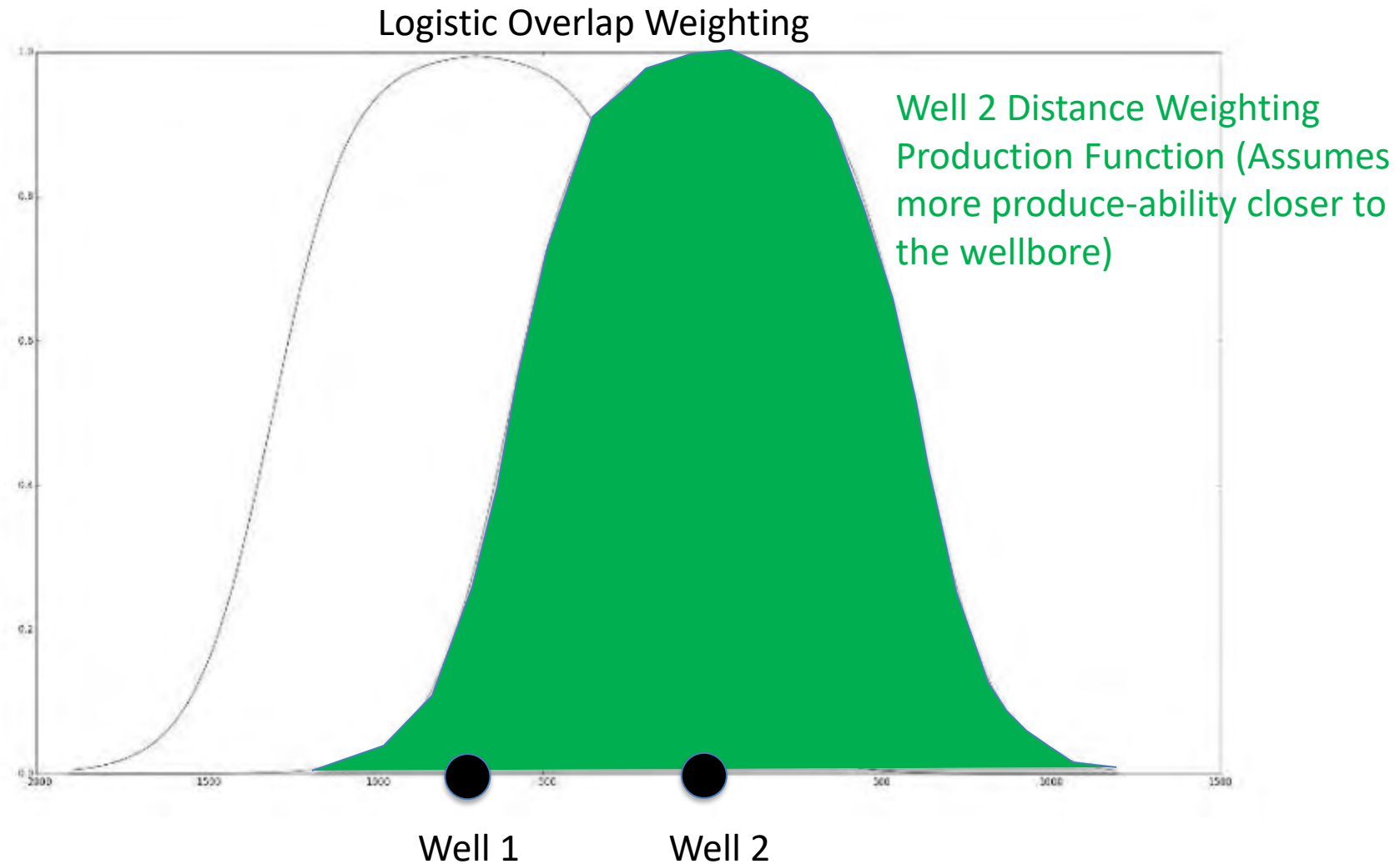
Depletion Estimation Attribute



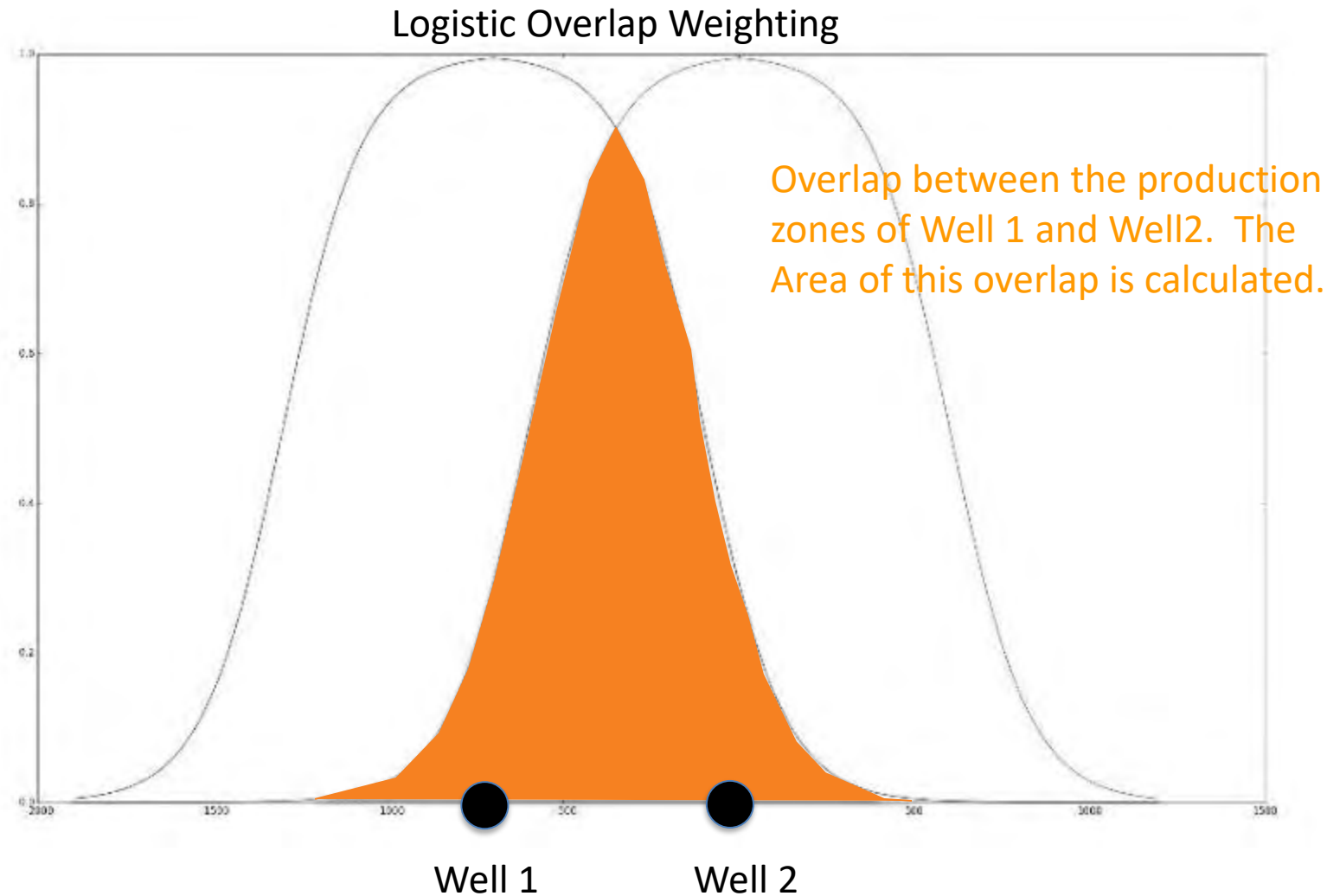
Depletion Estimation Attribute



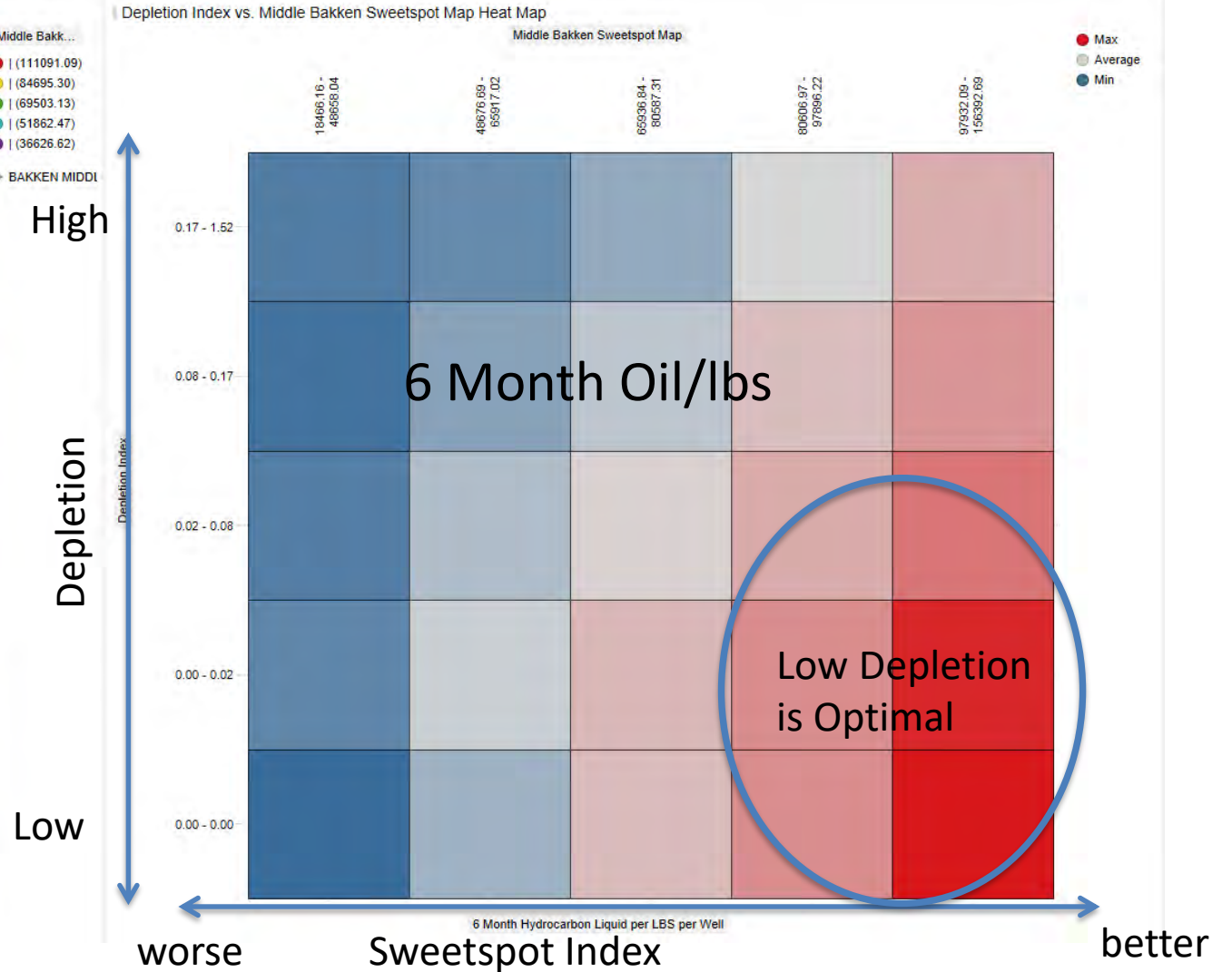
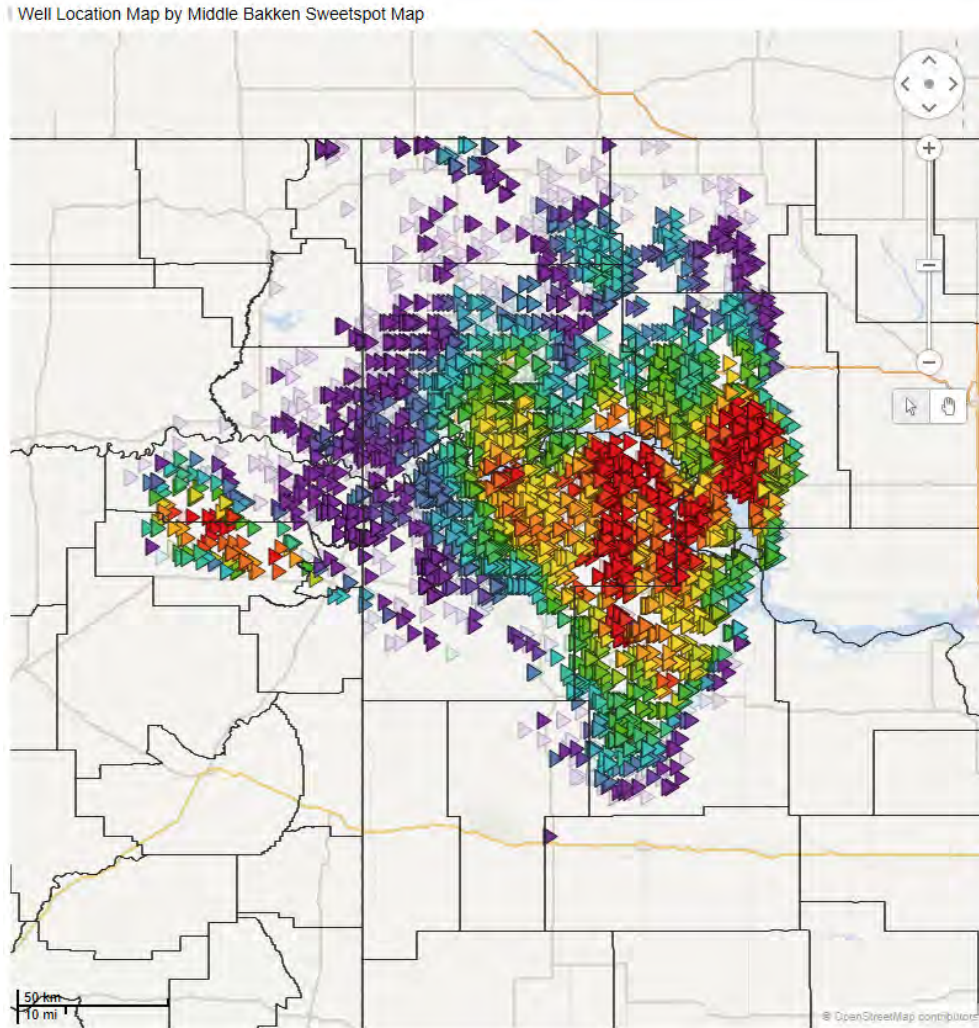
Depletion Estimation Attribute



Depletion Estimation Attribute



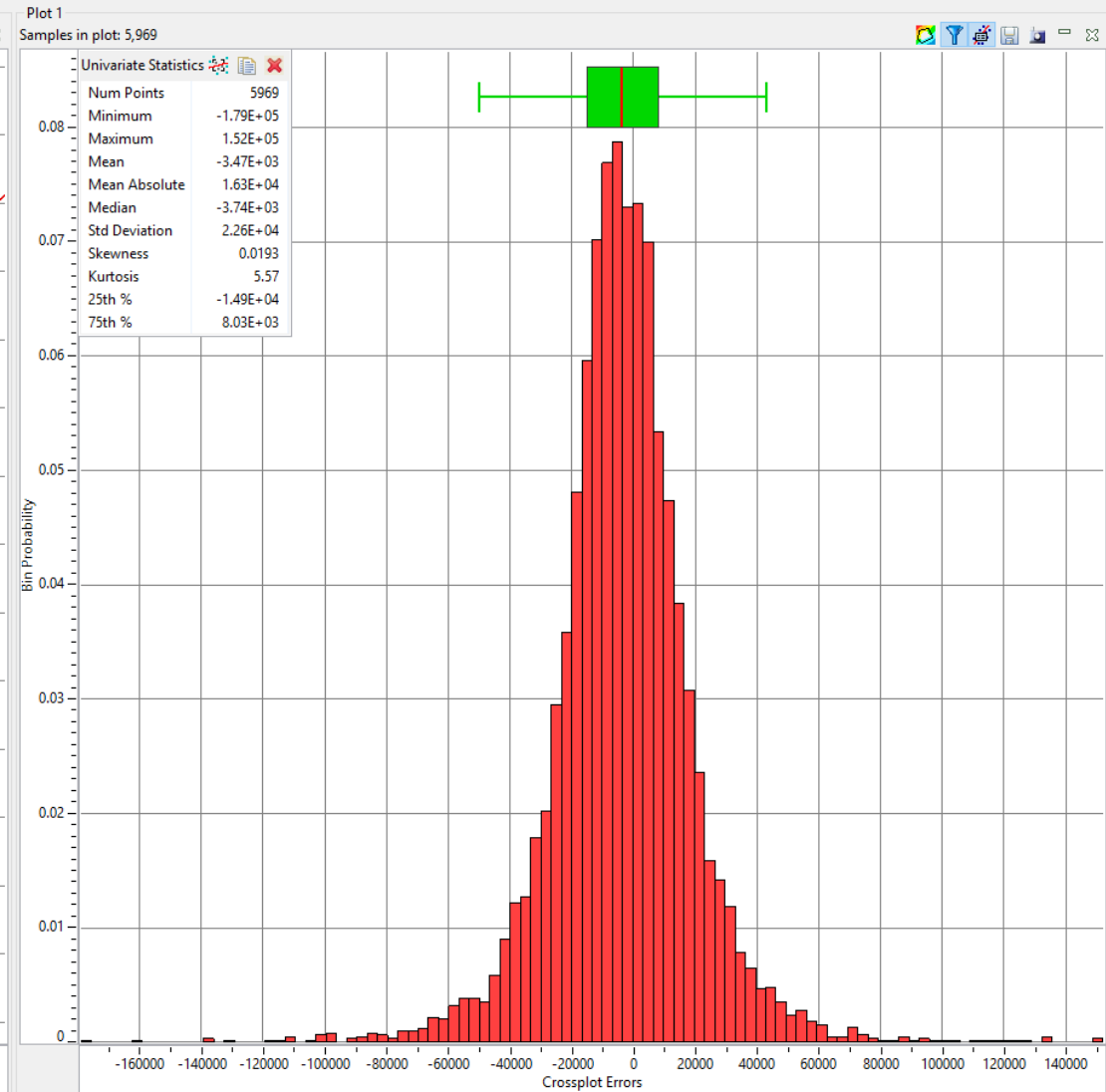
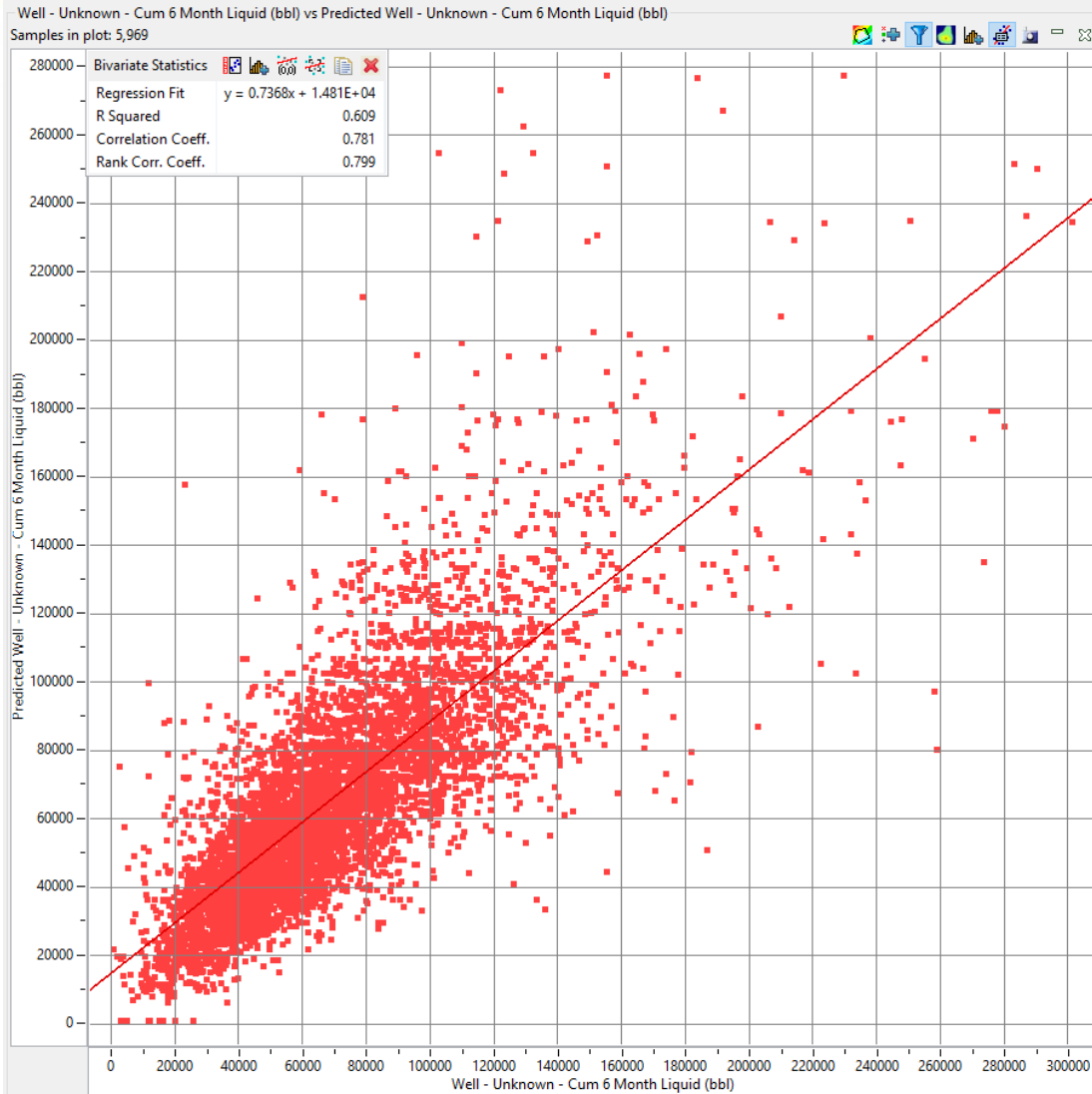
Depletion Index vs. Sweetspot Map



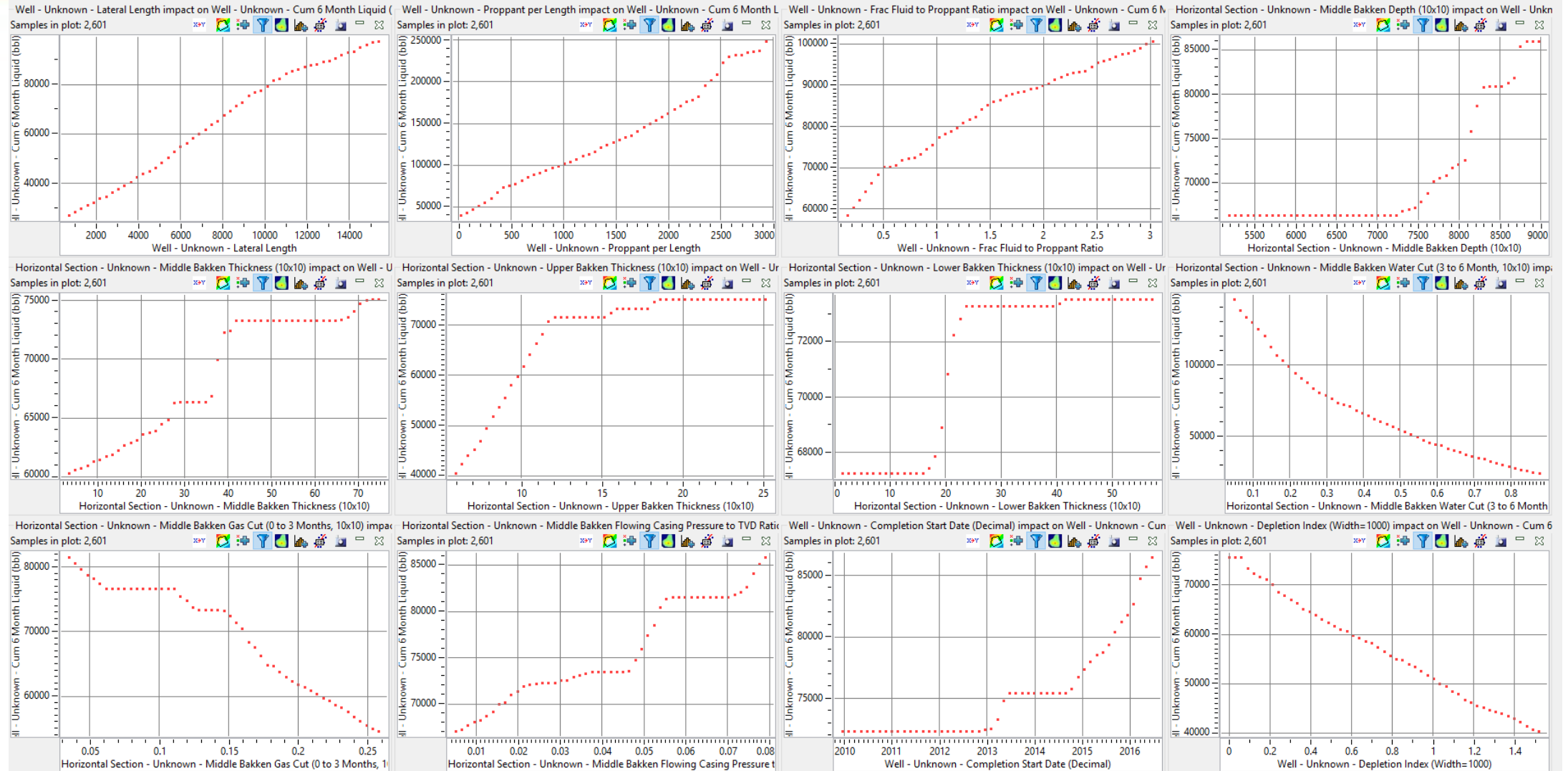
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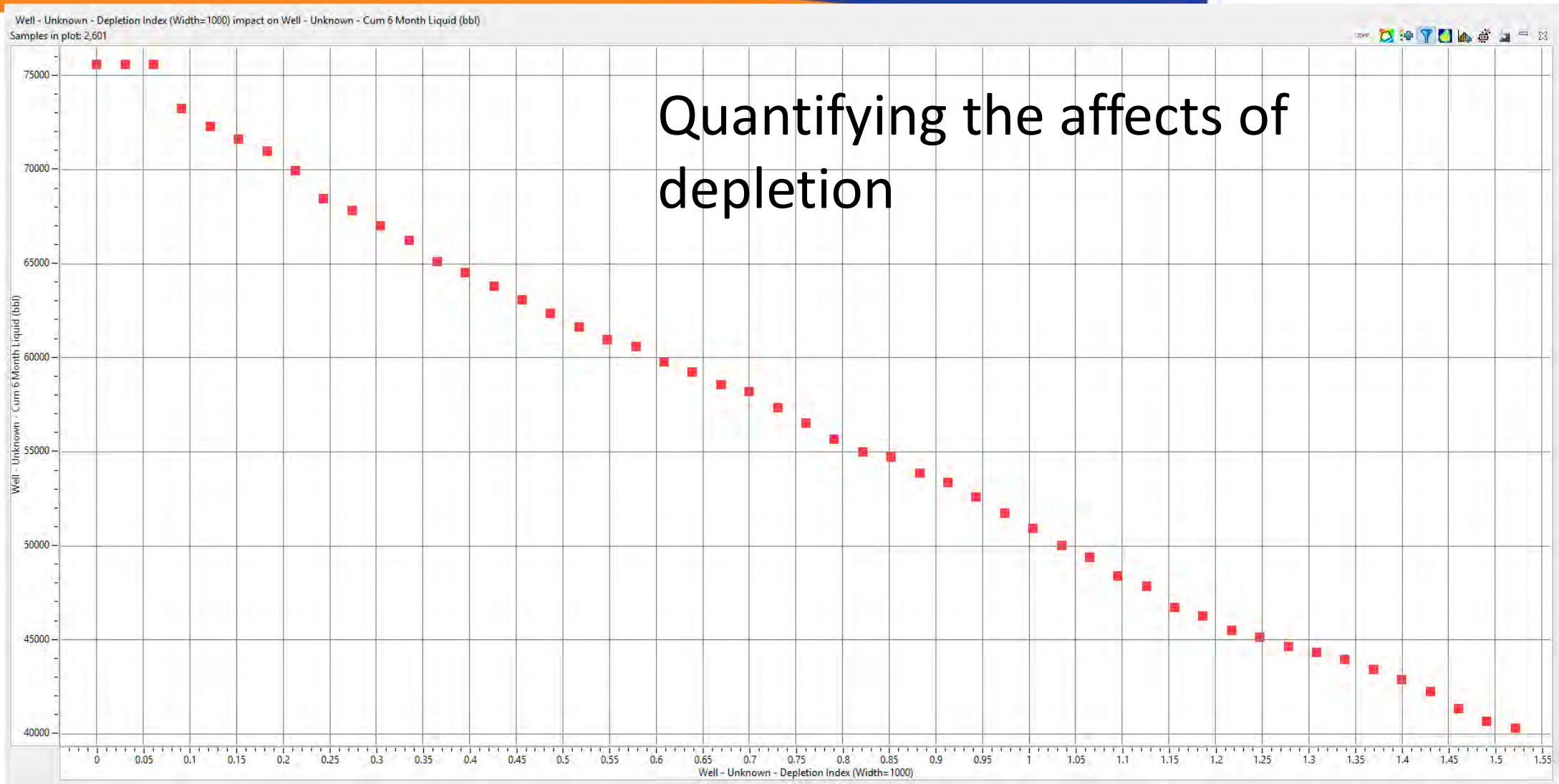
Multivariate Modeling of 6 Month Oil including Depletion Metric



Non-Linear Transformation Function

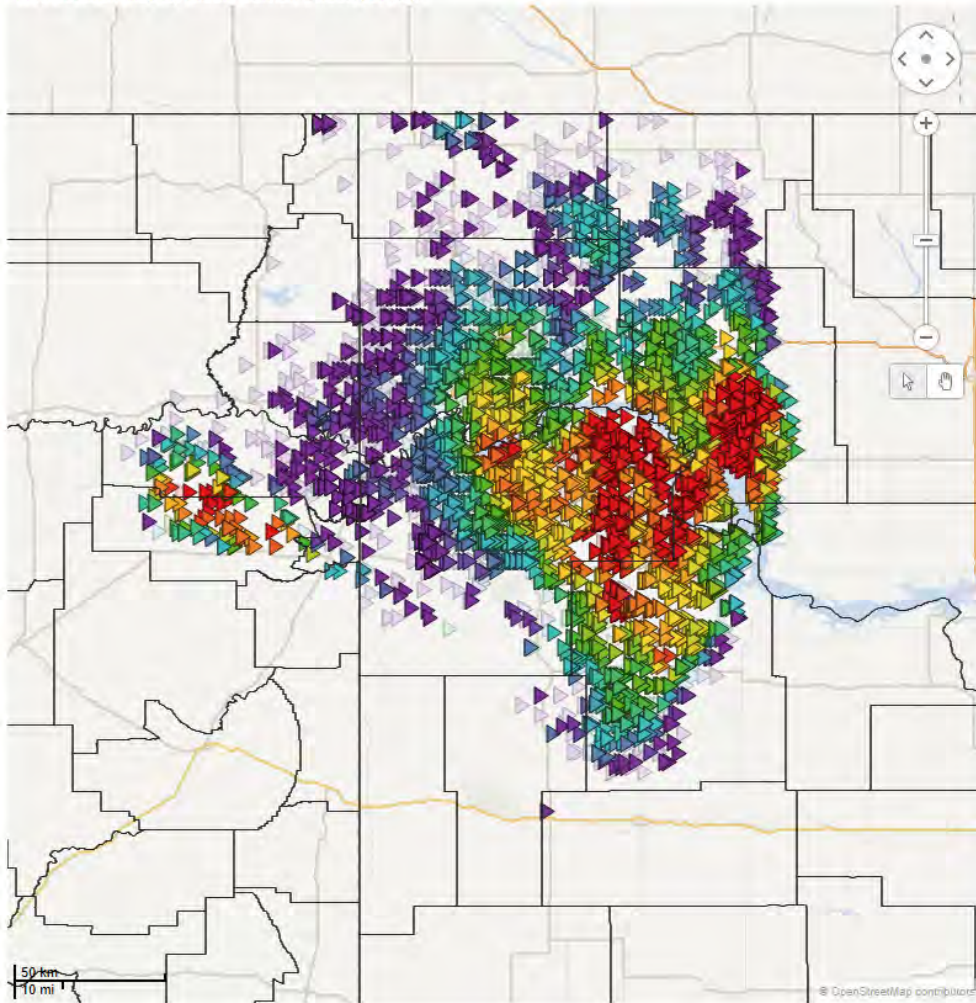


Depletion Metric Transformation Function

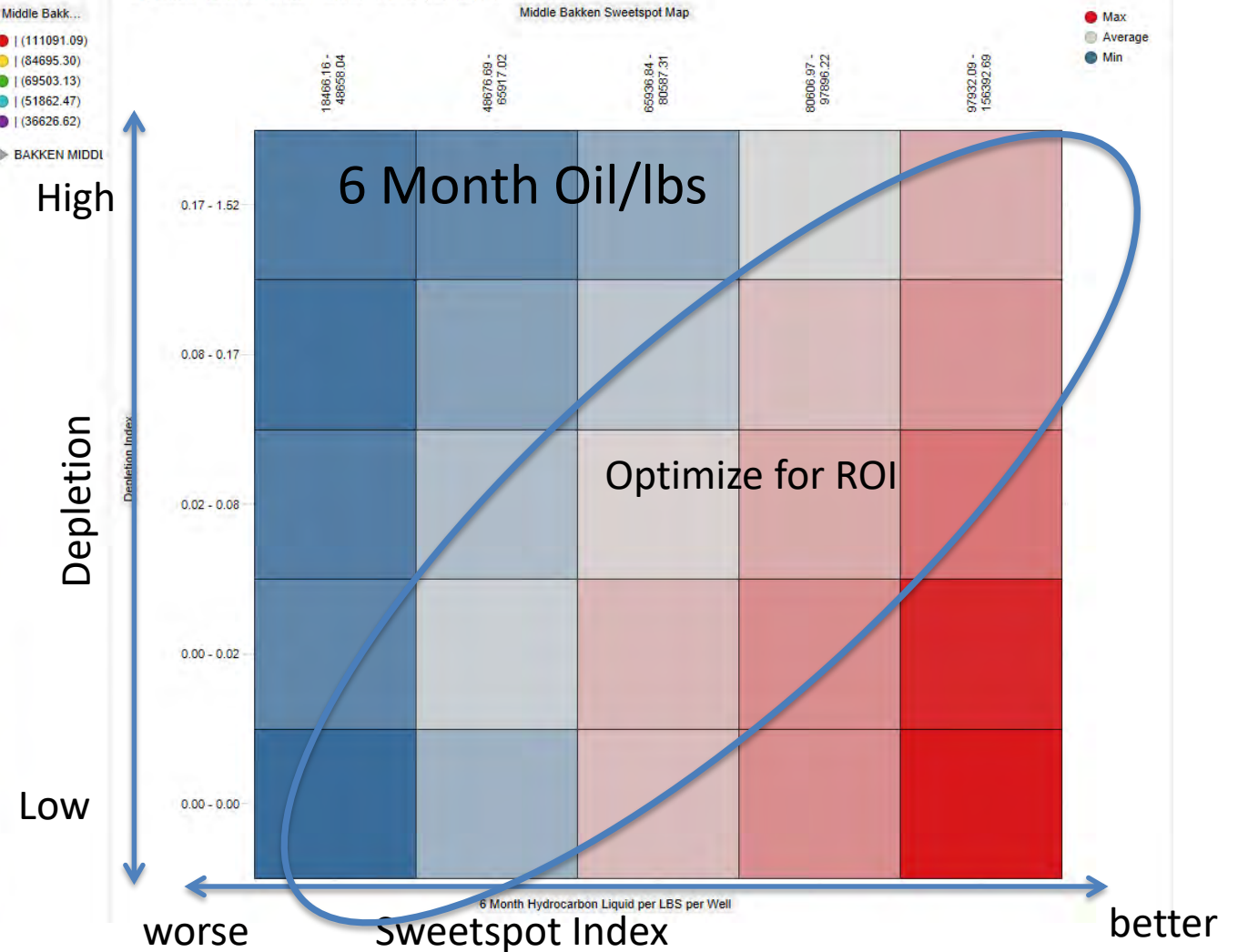


Optimize for the Economics

Well Location Map by Middle Bakken Sweetspot Map



Depletion Index vs. Middle Bakken Sweetspot Map Heat Map



Conclusions



- Though improvements in frac technology have limited the effects of depletion of total well production, depletion still effects the “bang for buck” value of proppant
- In order to effectively model well spacing affects, engineering and geologic variability must be accounted for
- Lateral well spacing attributes do not show the whole picture. Advanced depletion metrics are required
- Multi-variate modeling can quantify the impact of depletion by isolating its relationship with production

ACKNOWLEDGEMENTS

Thank you to IHS for providing
the data for this presentation