Webinars

Welcome!

The program will begin soon.

You will not hear audio until we begin.

SPE International

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Webinars

Unconventional Basins: Frac and Completion Trends

Mike Mayerhofer, Liberty Energy

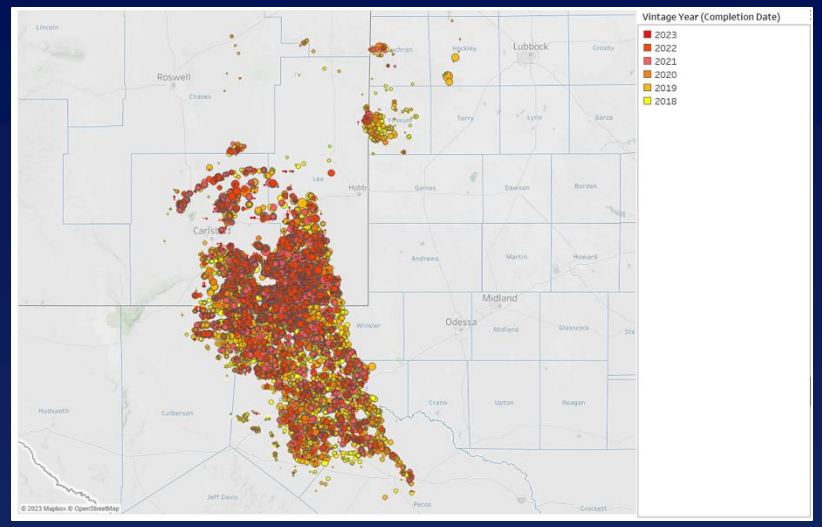
January 24,2024

SPE International

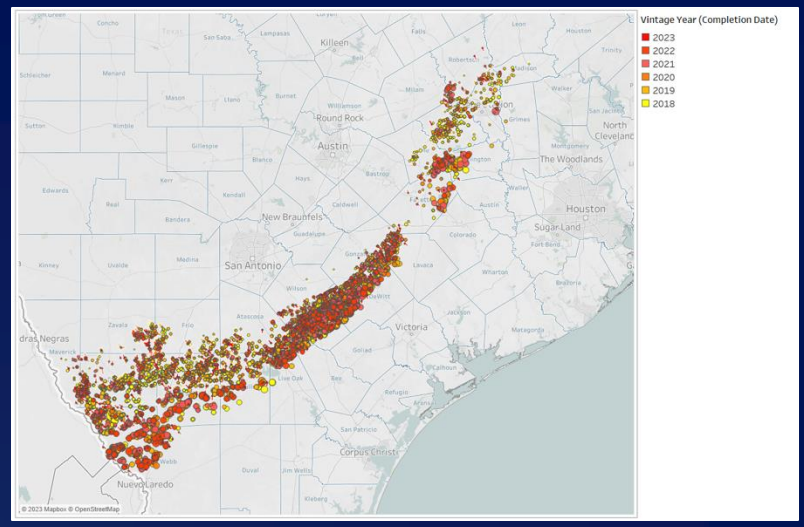
Interstate Oil & Gas Compact Commission

EDF Environmental Defense Fund — Finding the ways that work

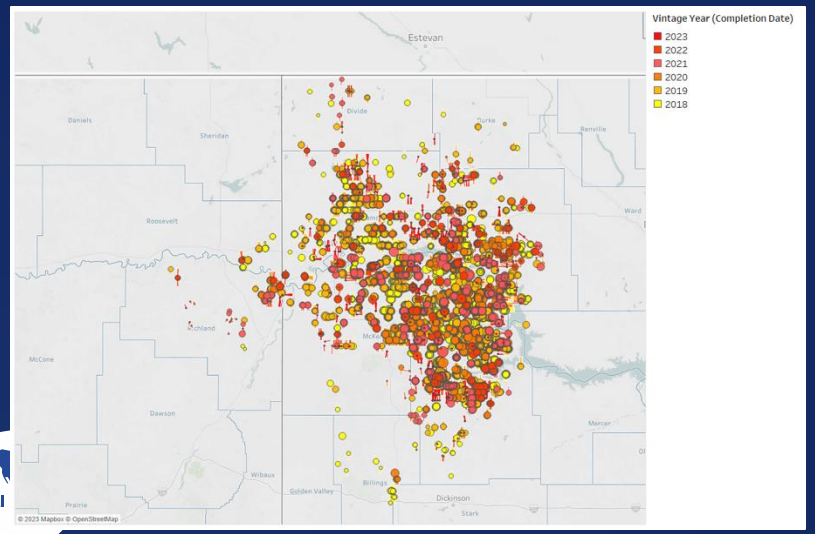
Delaware Basin



Eagleford

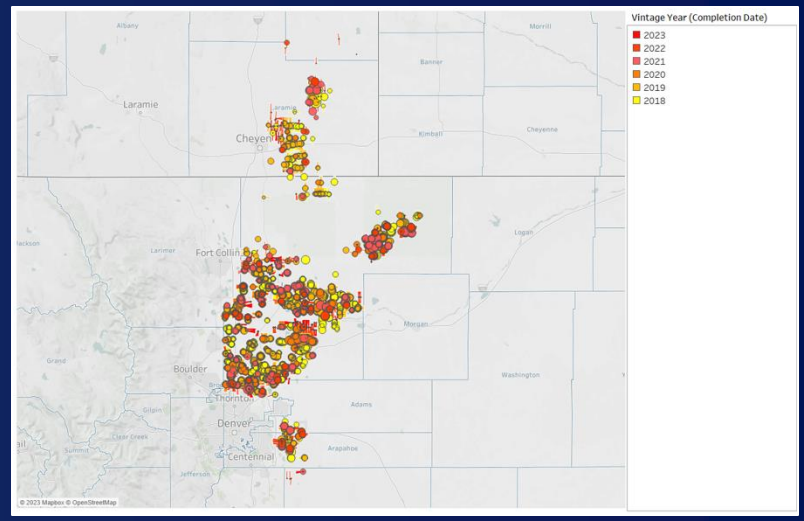


Williston



Horizontal Wells Completed from 2018 to 2023

DJ



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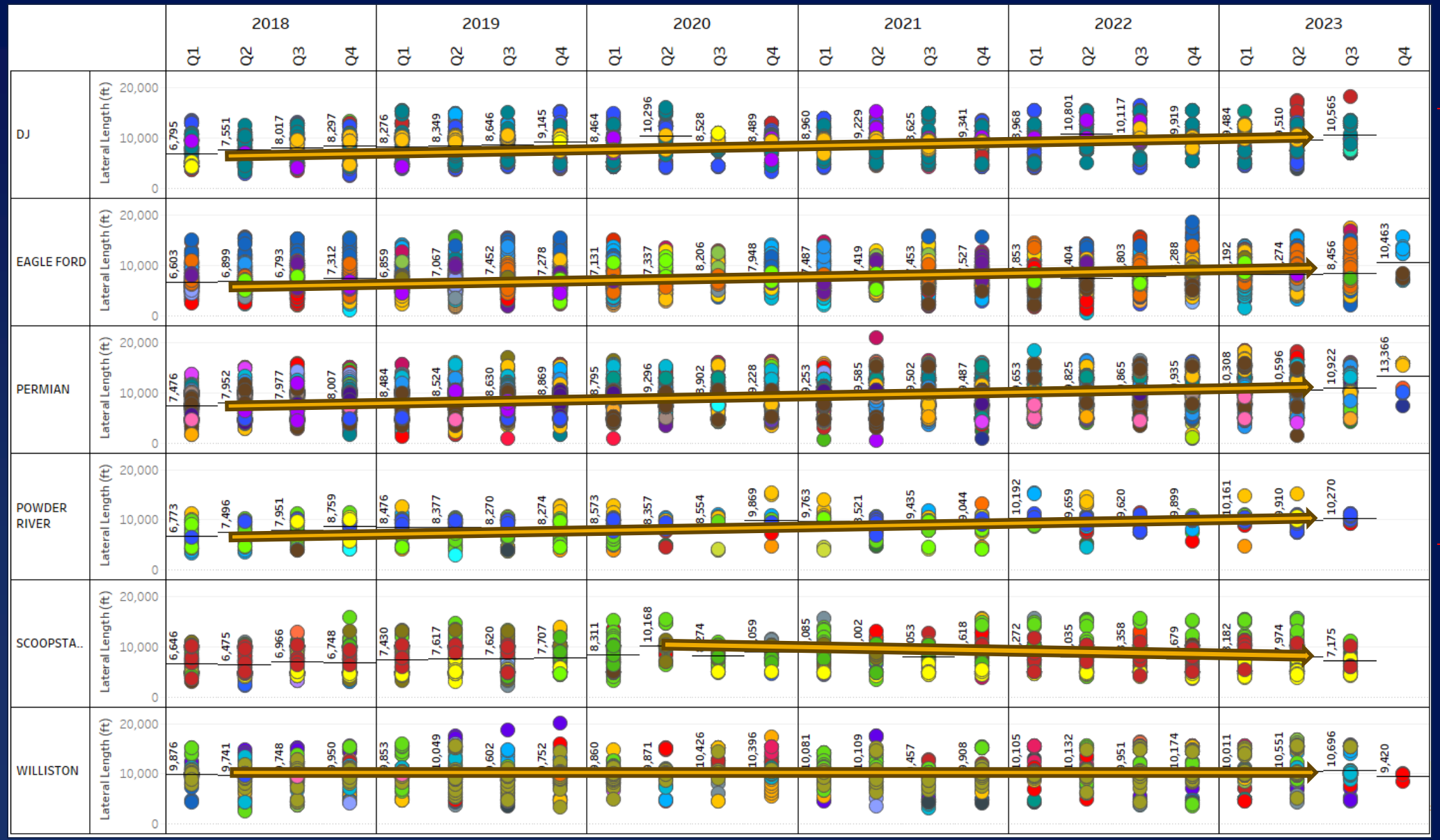
Unconventional Basins Horizontal Well Length Trends

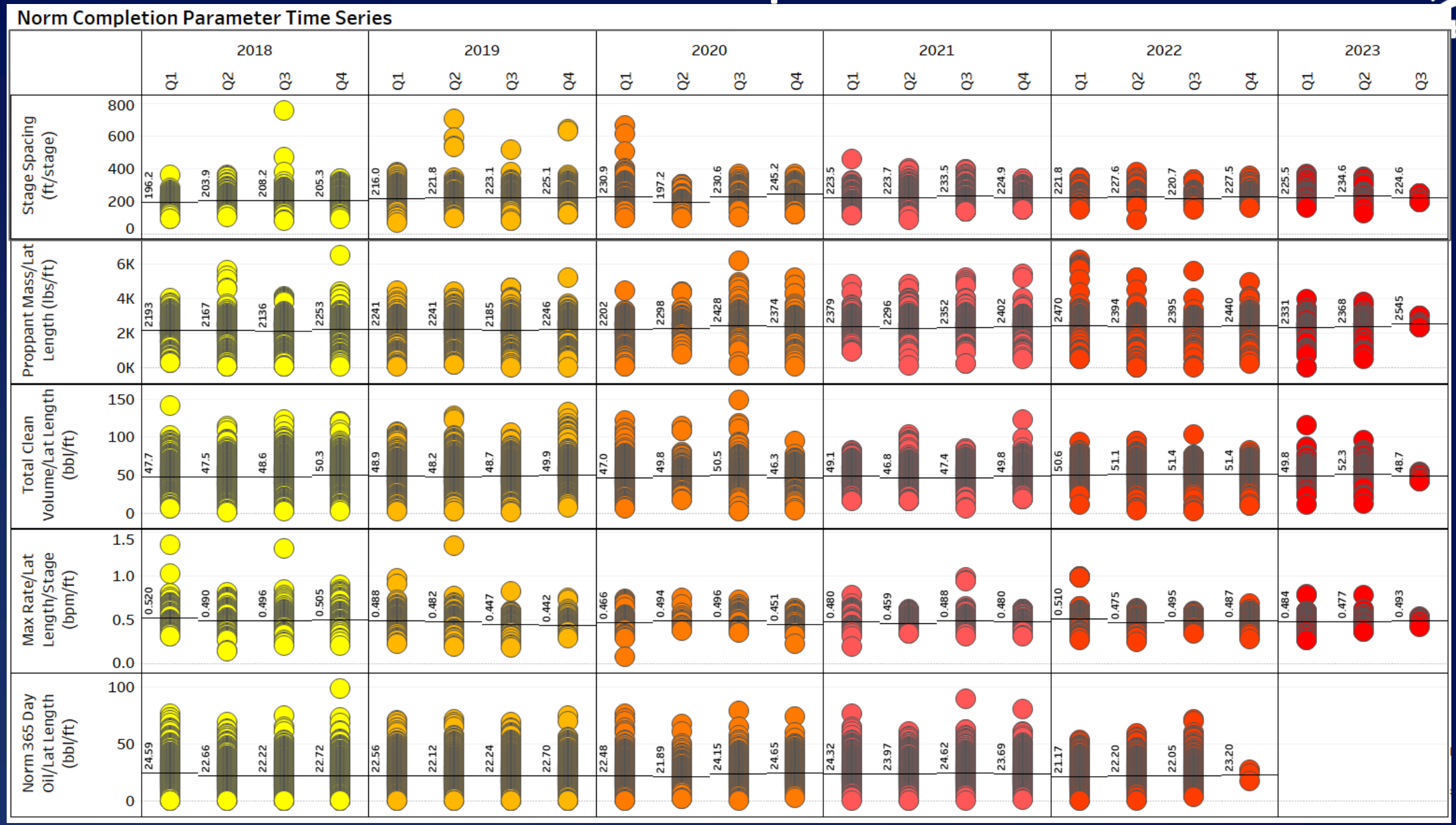


Increasing Average Lengths (7,000 ft to >10,000 ft) but large range still in 2023

Decrease from 2020 to 2023

Flat at 10,000 ft average

Delaware Basin Completion Trends



Flat trend
225 ft/stage

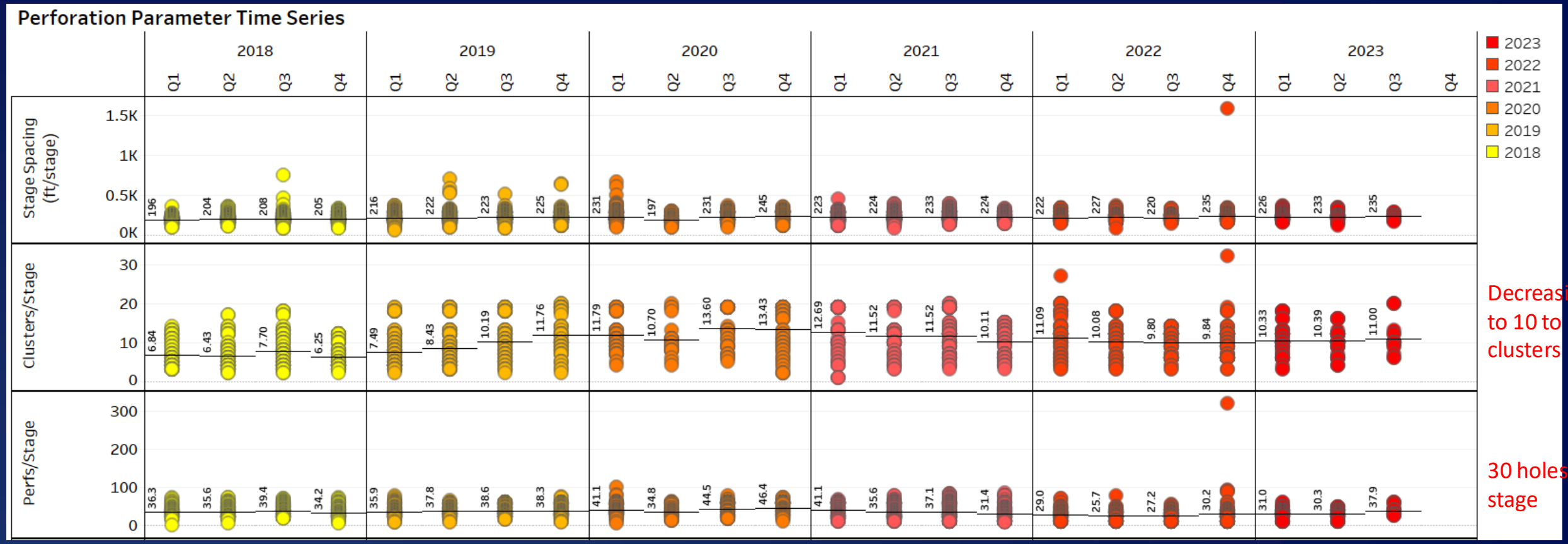
Flat trend
2,400 lbs/ft

Flat trend
50 bbls /ft

Flat trend
0.5 bpm /ft

Decrease of
BO/ft in 2022

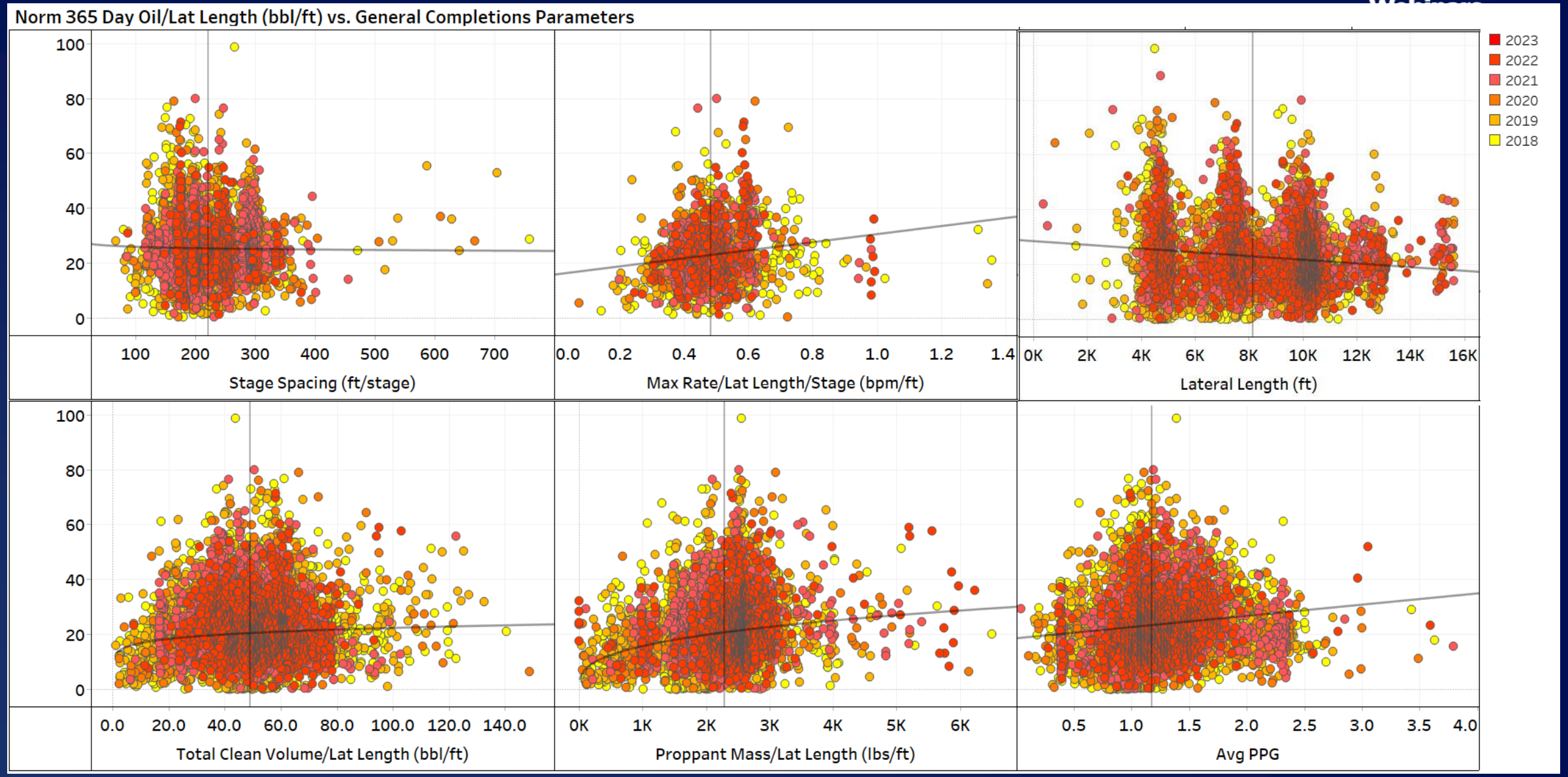
Delaware Basin Completion Trends



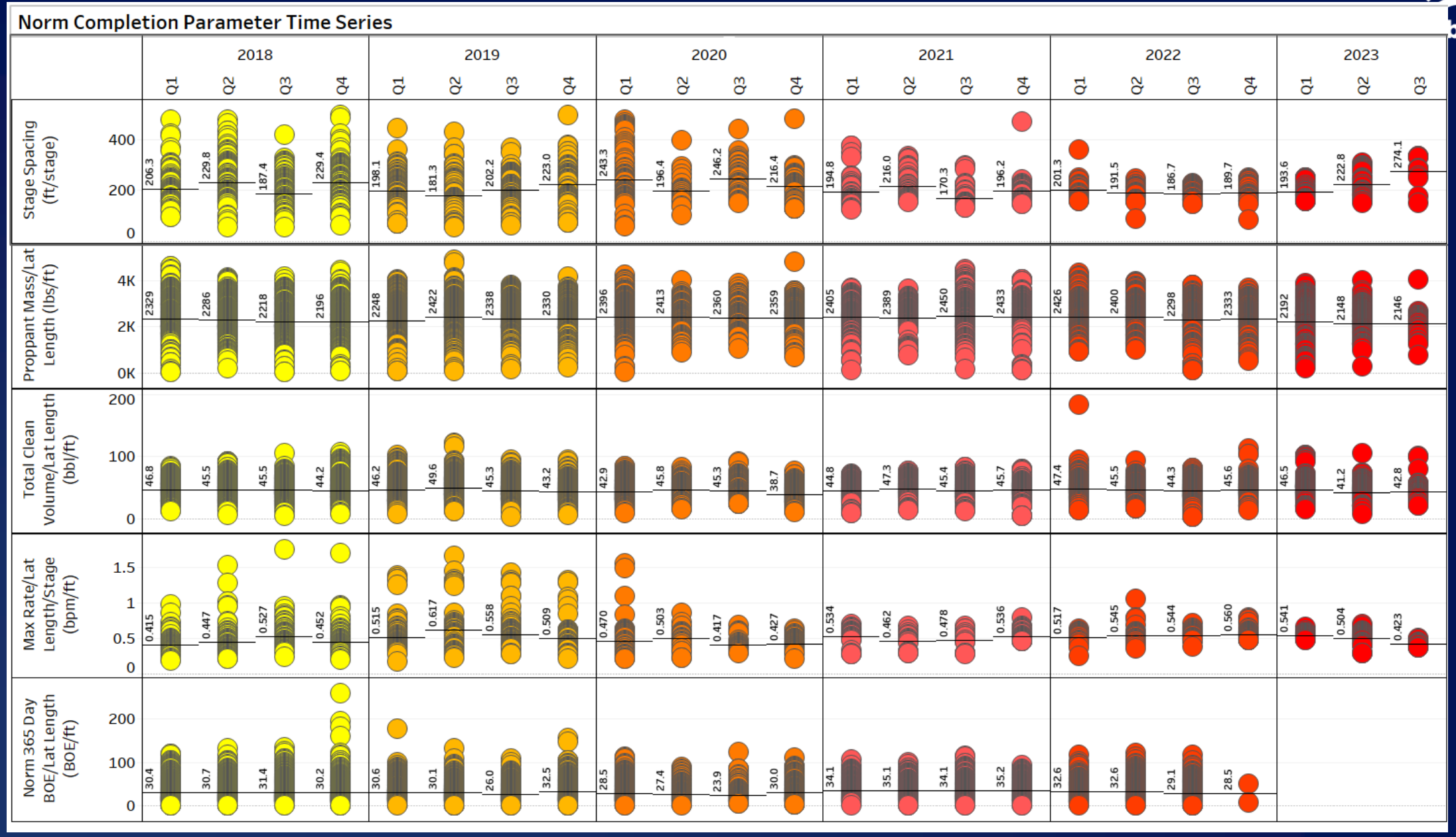
Decreasing to 10 to 11 clusters

30 holes/ stage

Delaware Basin Completion Trends



Eagleford Completion Trends



Increasing trend to over 220 ft/stage

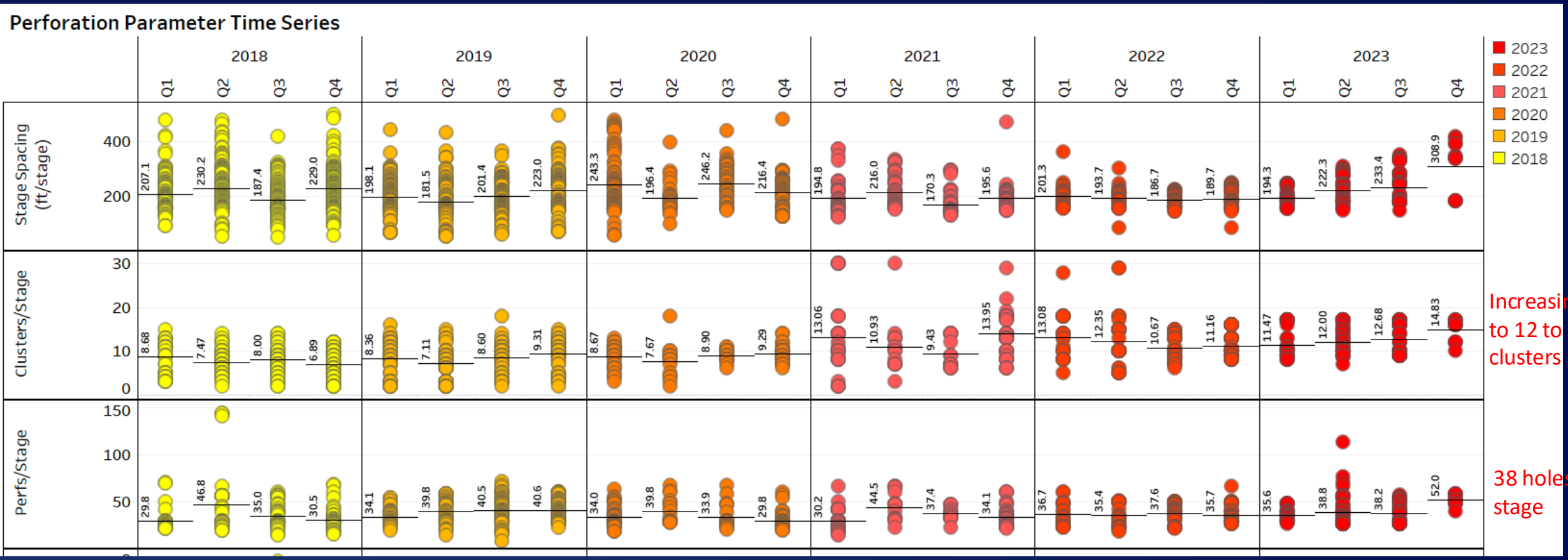
Decreasing trend to 2,100 lbs/ft

Flat trend 45 bbls /ft

Flat trend 0.5 bpm /ft

Decrease of BOE/ft in 2022

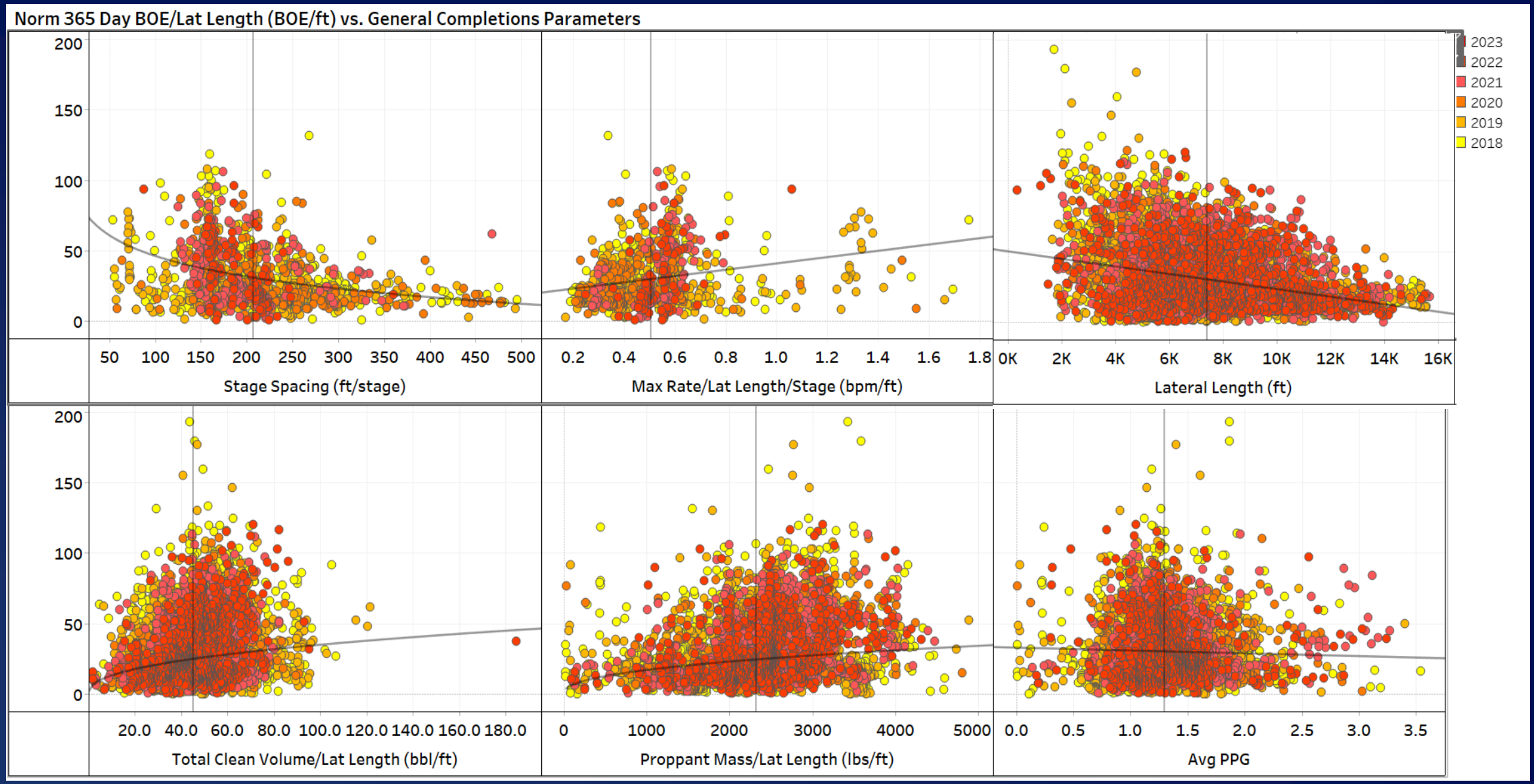
Eagleford Completion Trends



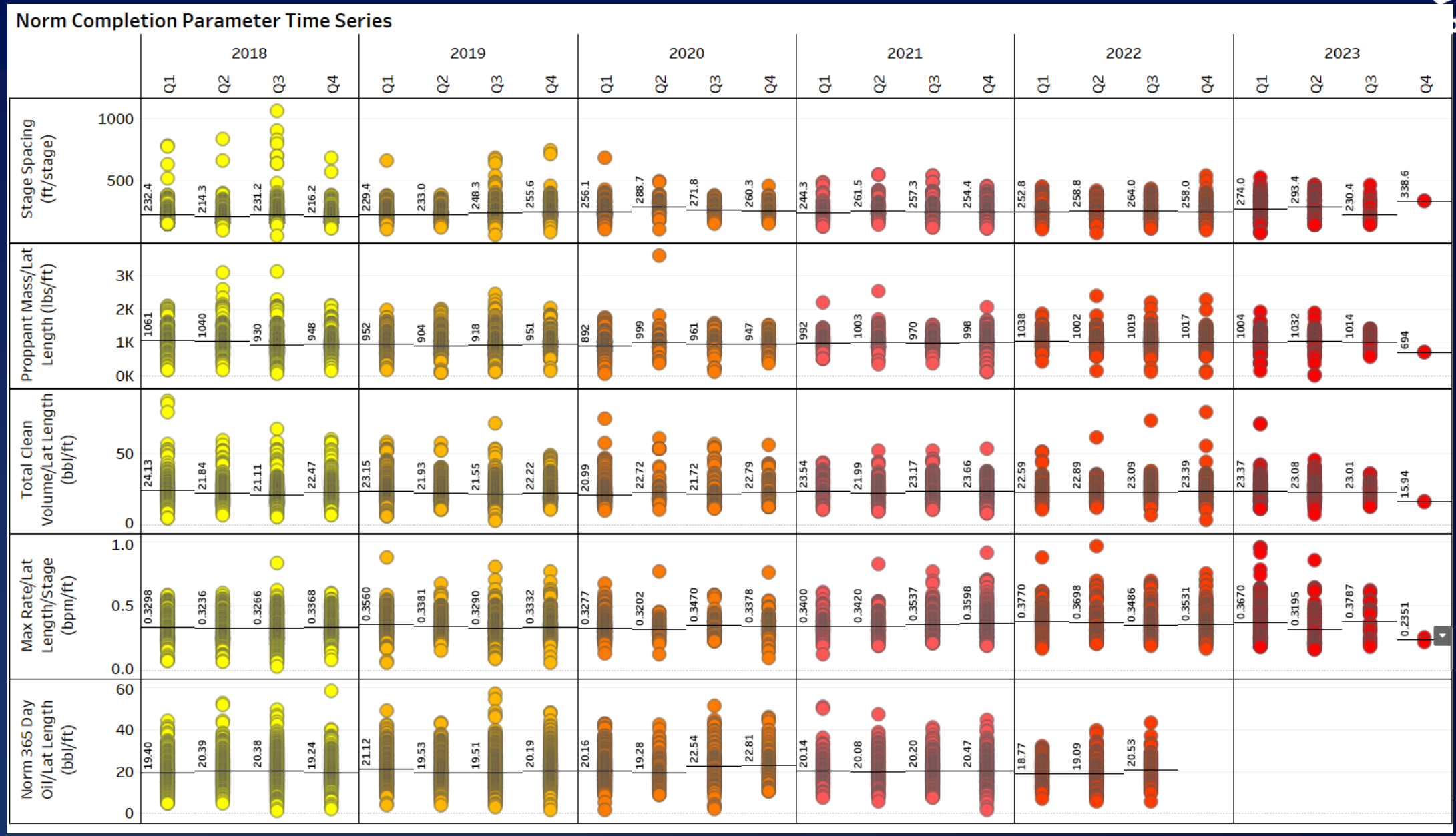
Increasing to 12 to 15 clusters

38 holes/ stage

Eagleford Completion Trends



Williston Basin Completion Trends



Fairly flat >250 ft/stage

Leveled off at 1,000 lbs/ft

Flat trend 23 bbls /ft

Flat trend 0.37 bpm /ft

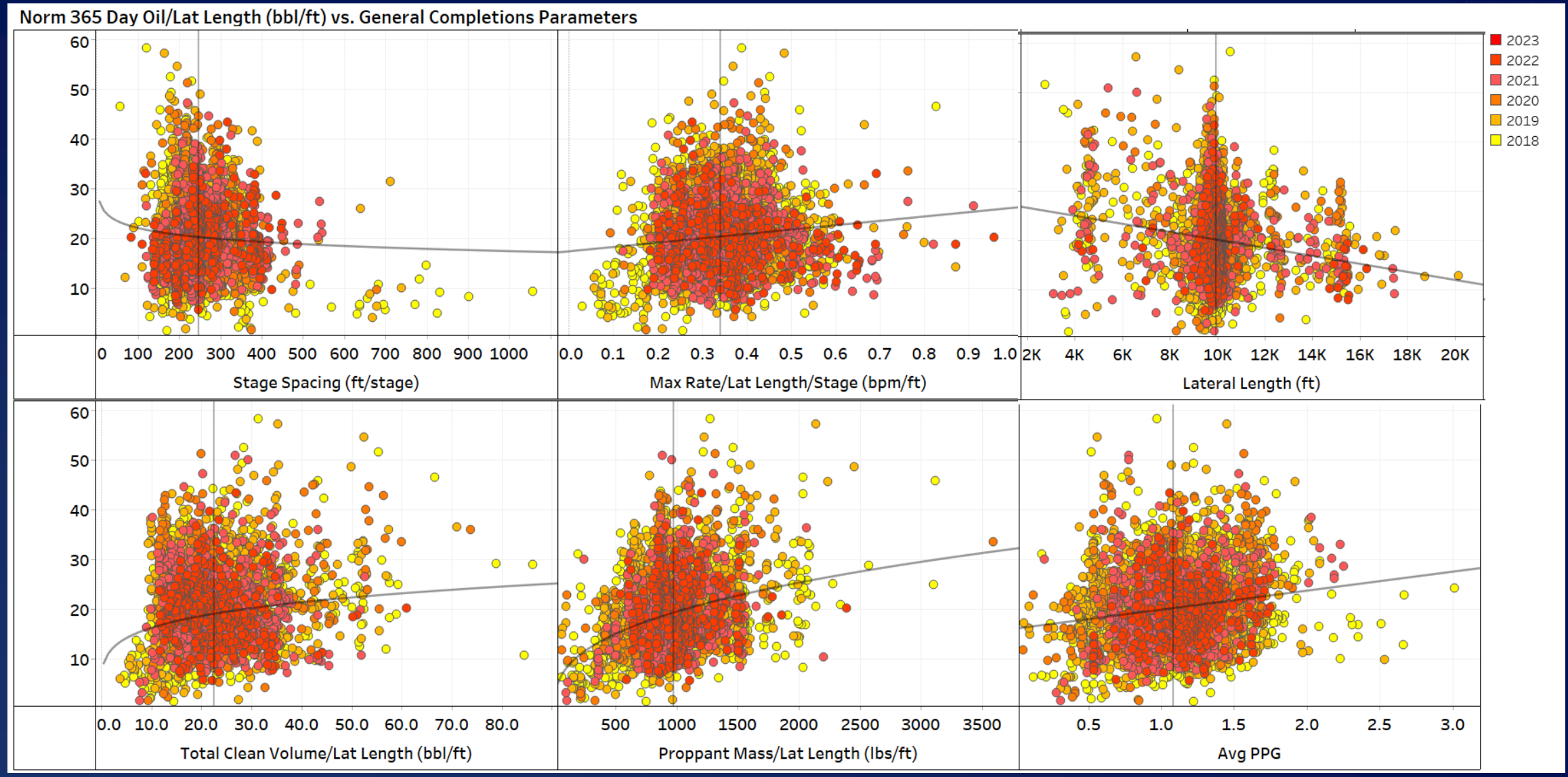
Decrease in 2021 and 2022

Williston Basin Completion Trends

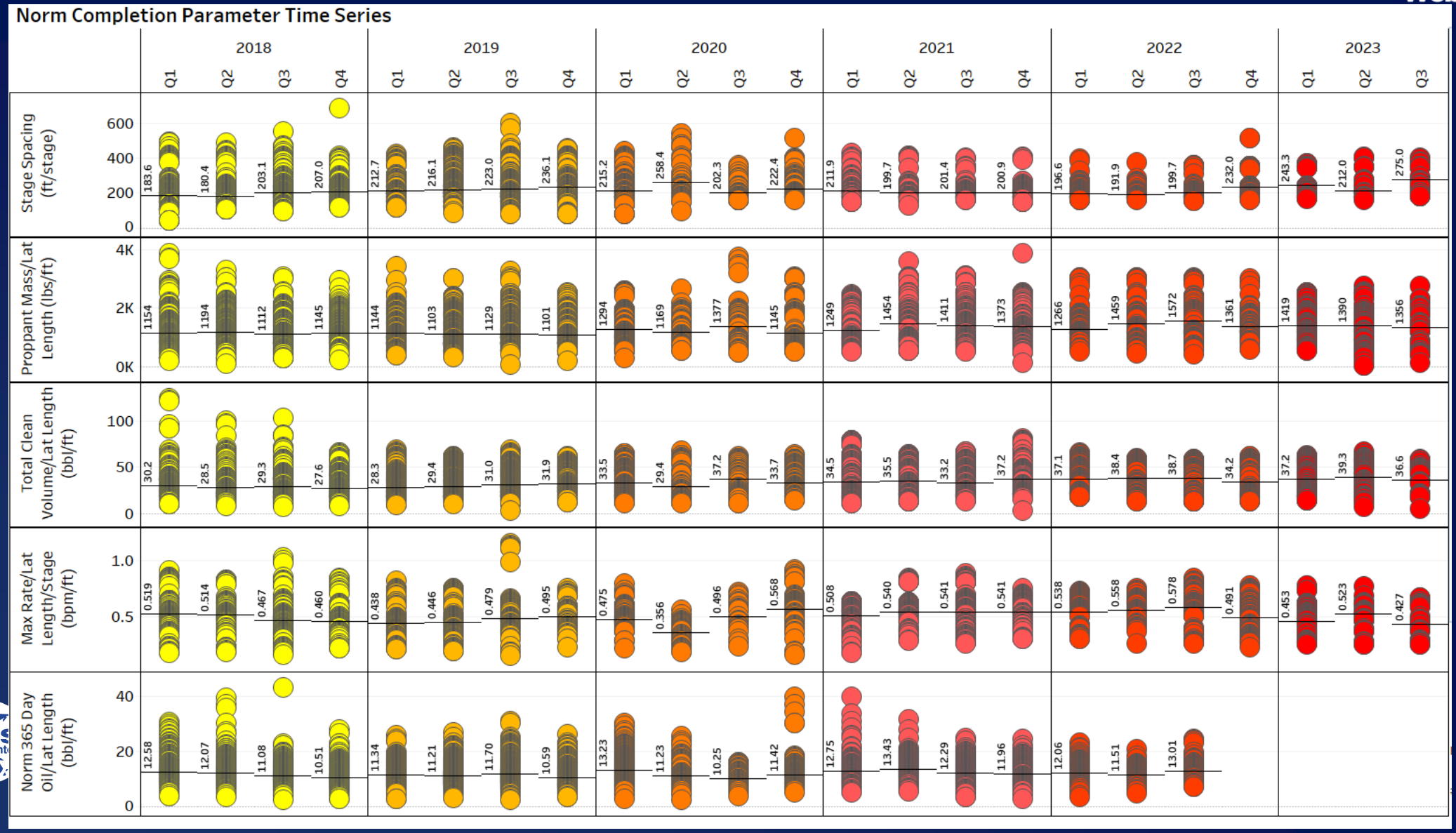
Leveling off at 10 clusters

Fairly flat 30 holes /stage

Williston Basin Completion Trends



DJ Basin Completion Trends



Increasing trend to over 240 ft/stage

Leveled off at 1,400 lbs/ft

Flat trend 38 bbls /ft

Flat trend 0.54 bpm /ft

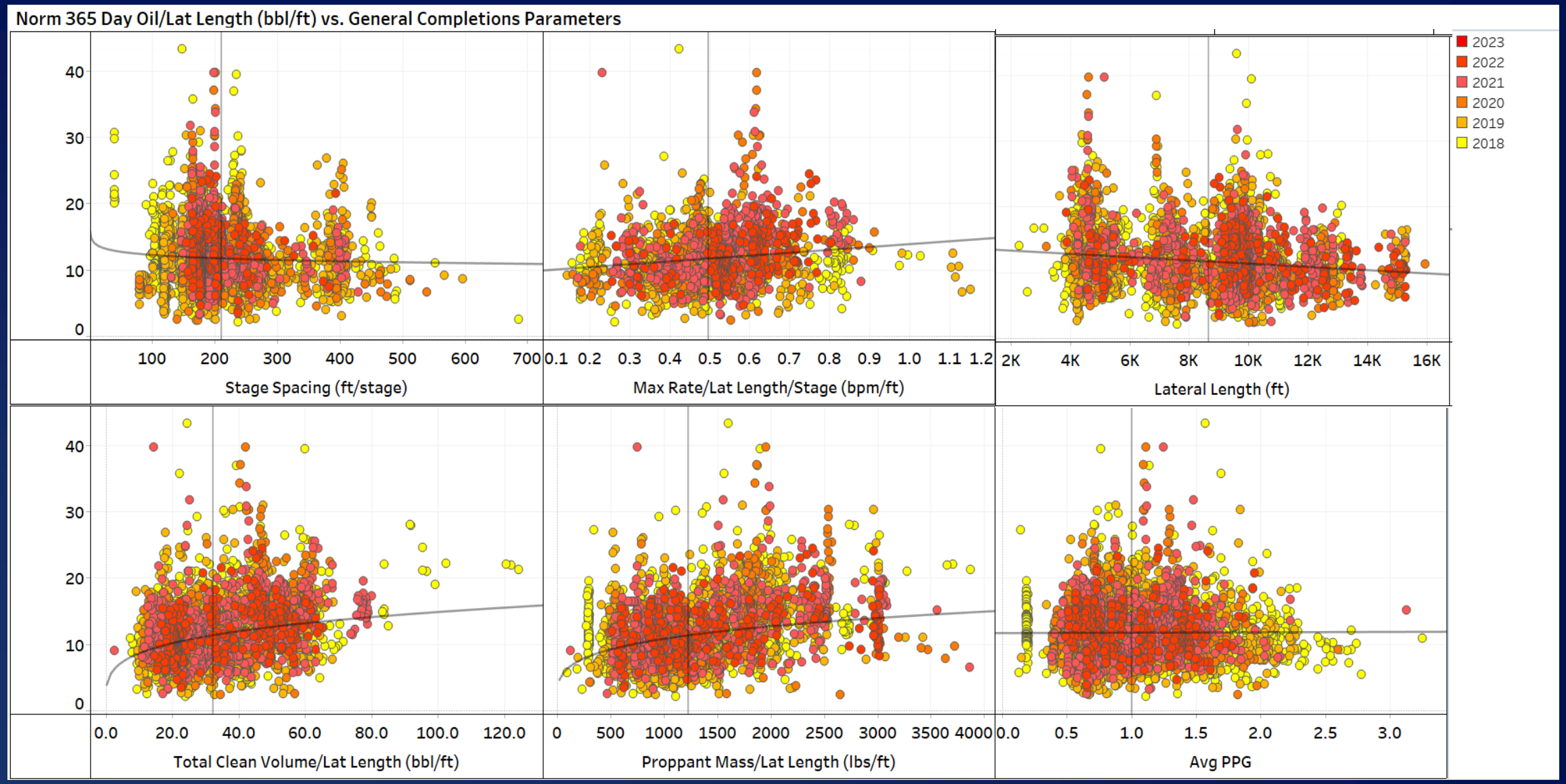
Fairly flat

DJ Basin Completion Trends

Leveling off at 7 to 9 clusters

Fairly flat 34 holes/ stage

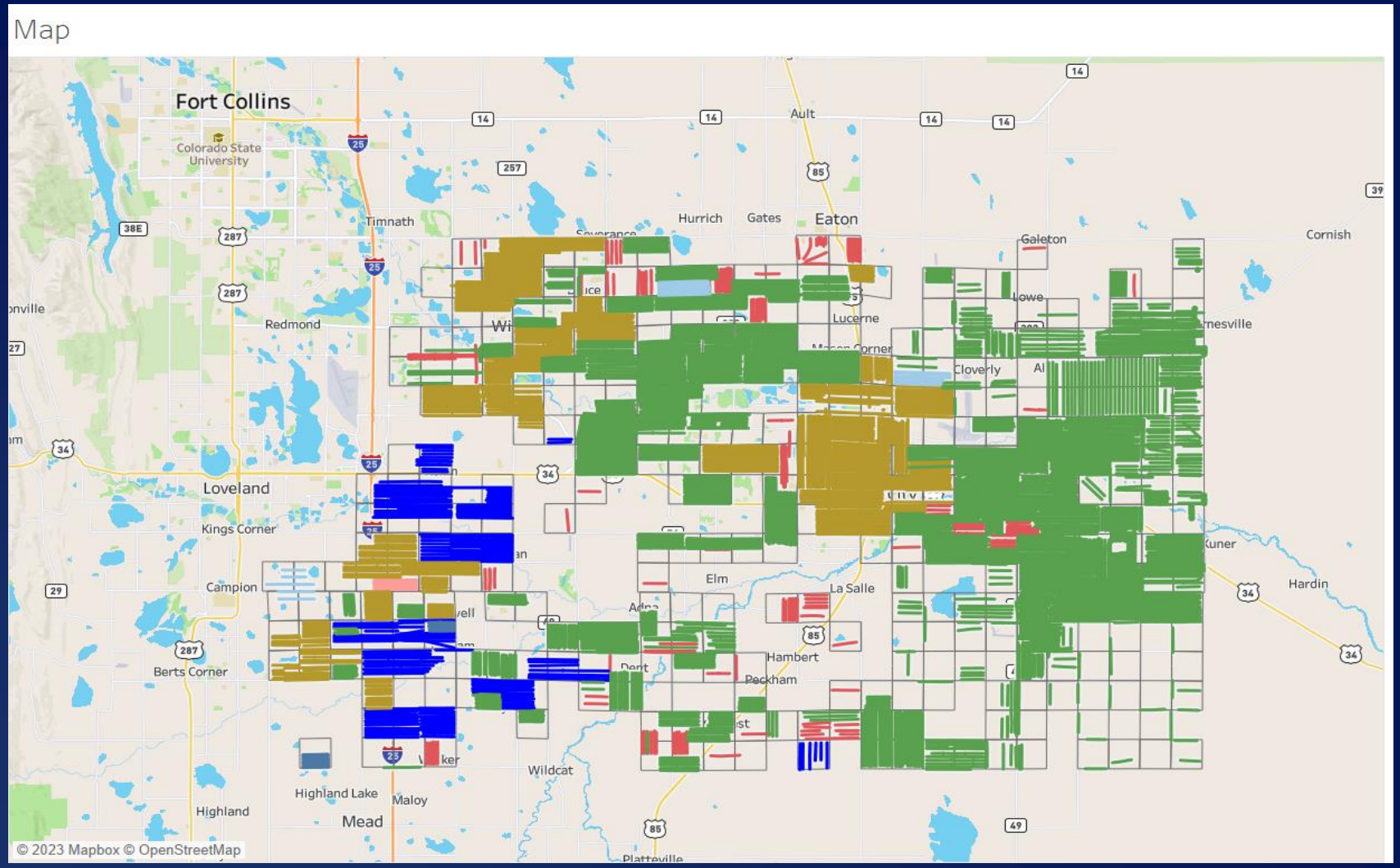
DJ Basin Completion Trends



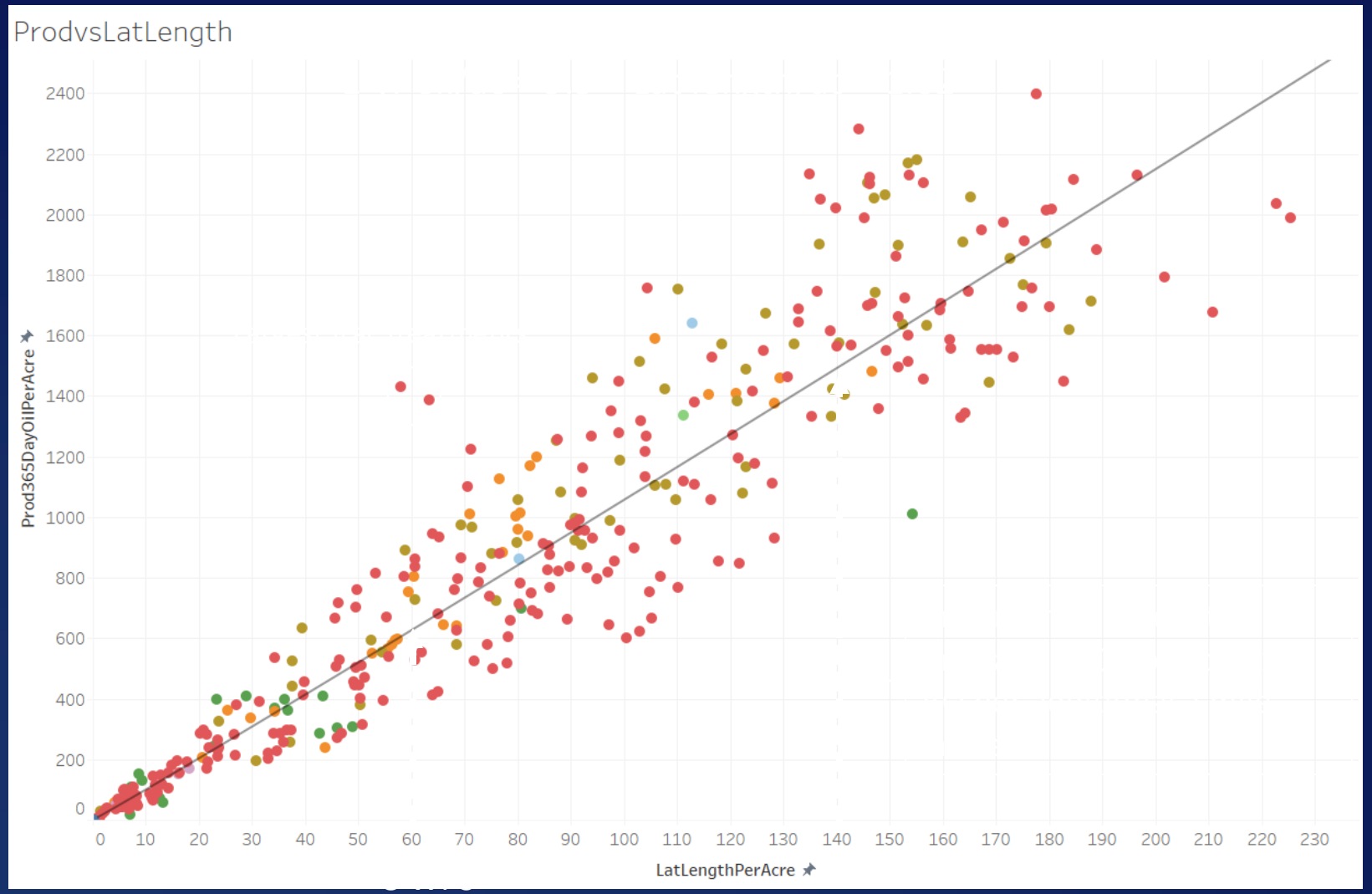
Main Takeaways

- All Basins except Scoop/Stack show increasing average horizontal well lengths (3 milers are common and 4 milers are being tested in the DJ). This leads to higher average well production.
- On average most completion parameters are “locked in” but some experimentation is still going on.
- Average stage lengths are fairly consistent at 200 to 250 ft in all basins but companies are evaluating longer stage lengths using more clusters and better perforation strategies to reduce cost.
- Due to larger formation thicknesses larger treatments are pumped in Texas Basins (2,100 to 2,400 lbs/ft and 45 to 50 bbls/ft) than in the Rockies (1,000 to 1,400 lbs/ft and 23 to 38 bbls/ft).

DJ Basin Section Analysis Example



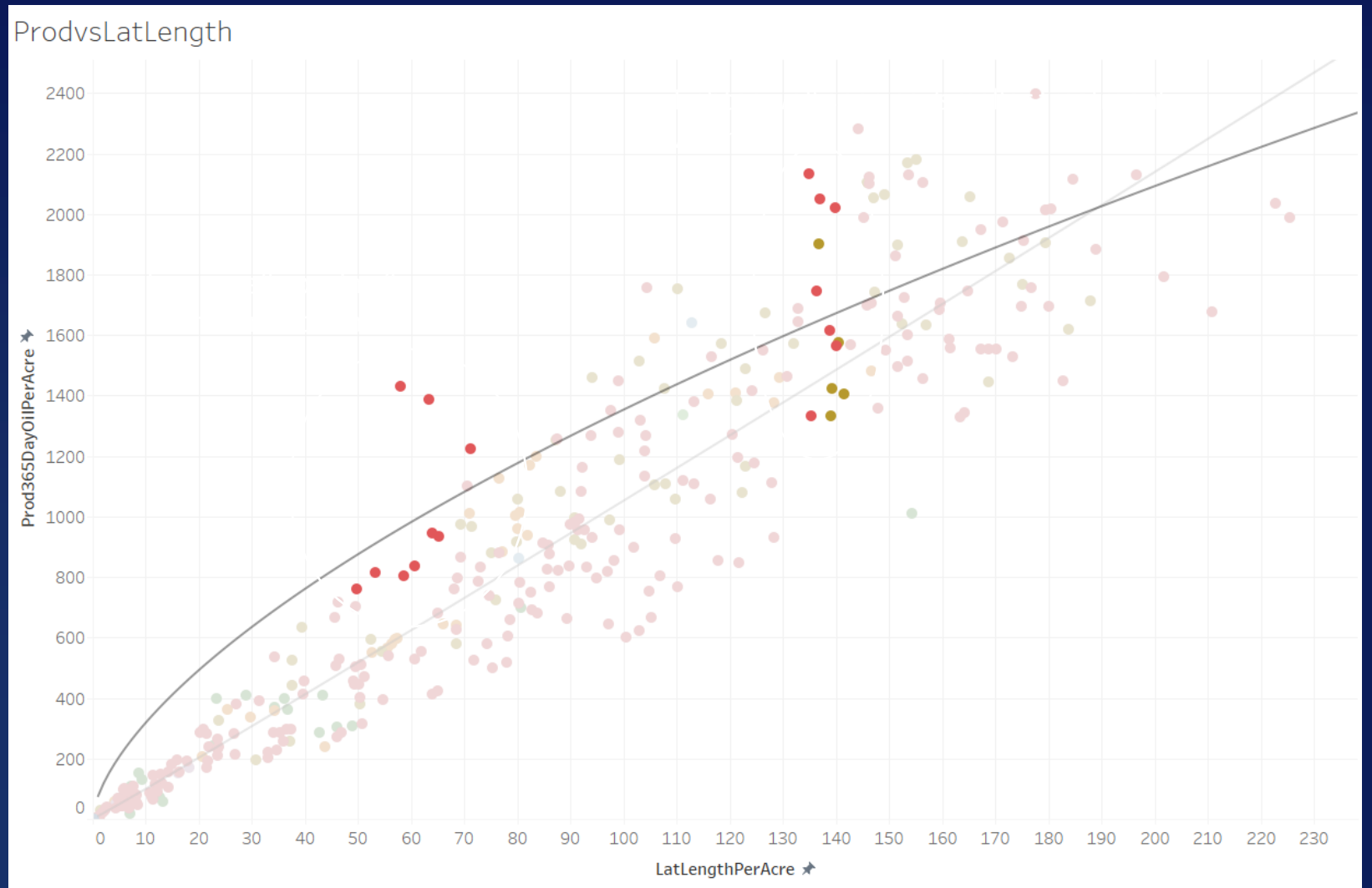
365 Day Oil per Acre vs Lat Length per Acre (WPS) (All Landing Zones)



$ 59,500/ac in additional revenue (at $70 oil) when going from 8 WPS to 18 WPS

One-Year payout if D&C are below $743/ft ($59,500 divided by incremental 80 ft/ac)

365 Day Oil per Acre vs Lat Length per Acre (Highlighting Different Development Strategies)



$ 42,000/ac in additional revenue (at $70 oil) when going from 8 WPS to 18 WPS

One-Year payout if D&C are below $525/ft ($42,000 divided by incremental 80 ft/ac)

Webinars

Production as a Diagnostic Tool

Stephen Schubarth

January 24,2024

SPE International

Interstate Oil & Gas Compact Commission

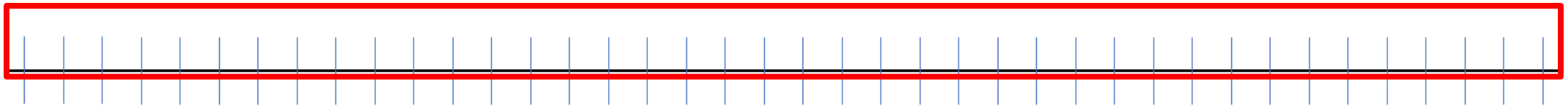
EDF Environmental Defense Fund — Finding the ways that work

Production as a Diagnostic Tool

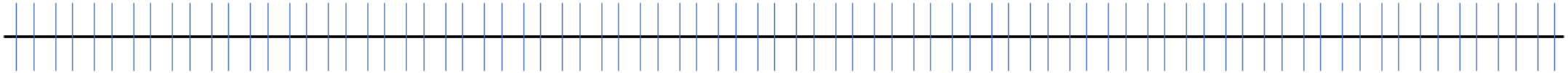
- How a well produces and the behavior of the production decline can be interpreted to determine the configuration of the stimulated reservoir and the characteristics of the reservoir being drained
- Interpreting the production behavior can be complicated, but the data is “free” and there are several Unconventional Reservoir characteristics that help uncomplicate things

Examples of Fracture Spacing along 10k Lateral

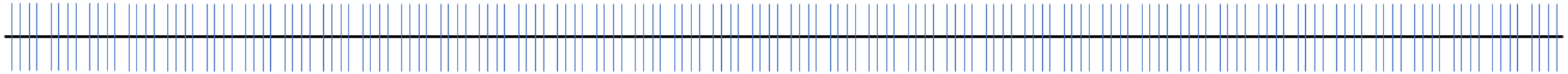
Fractured Area = SRV



40 Created Fracs – 250’ between fracs – Lf = 250 feet



80 Created Fracs – 125’ between fracs – Lf = 250 feet



160 Created Fracs – 62.5’ between fracs – Lf = 250 feet

320 Created Fracs – 31.25’ between fracs – Lf = 250 feet

Producing History

- Wells producing from completions shaped like the previous slide will:
  - Have very similar decline characteristics
  - Their production histories can be used to determine:
    - Formation Permeability
    - The average effective fracture half-length of the producing fractures
    - The number of the producing fractures
      - Thus, the spacing of the producing fractures

Rate Normalization

- Normalized rate:
  - $Qn = \frac{Q}{(Pi - Pwf)} * (\mathrm{Pi} - \mathrm{Pn})$ .....*for Oil*
  - $Qn = \frac{Q}{(Pi^2 - Pwf^2)} * (\mathrm{Pi}^2 - \mathrm{Pn}^2)$ .....*for Gas*

  - Where:
    - Qn = Normalized Rate
    - Q = Actual Rate
    - Pi = Initial Pressure
    - Pwf = Flowing pressure
    - Pn = Normalized flowing pressure (the flowing pressure the model will be produced at)

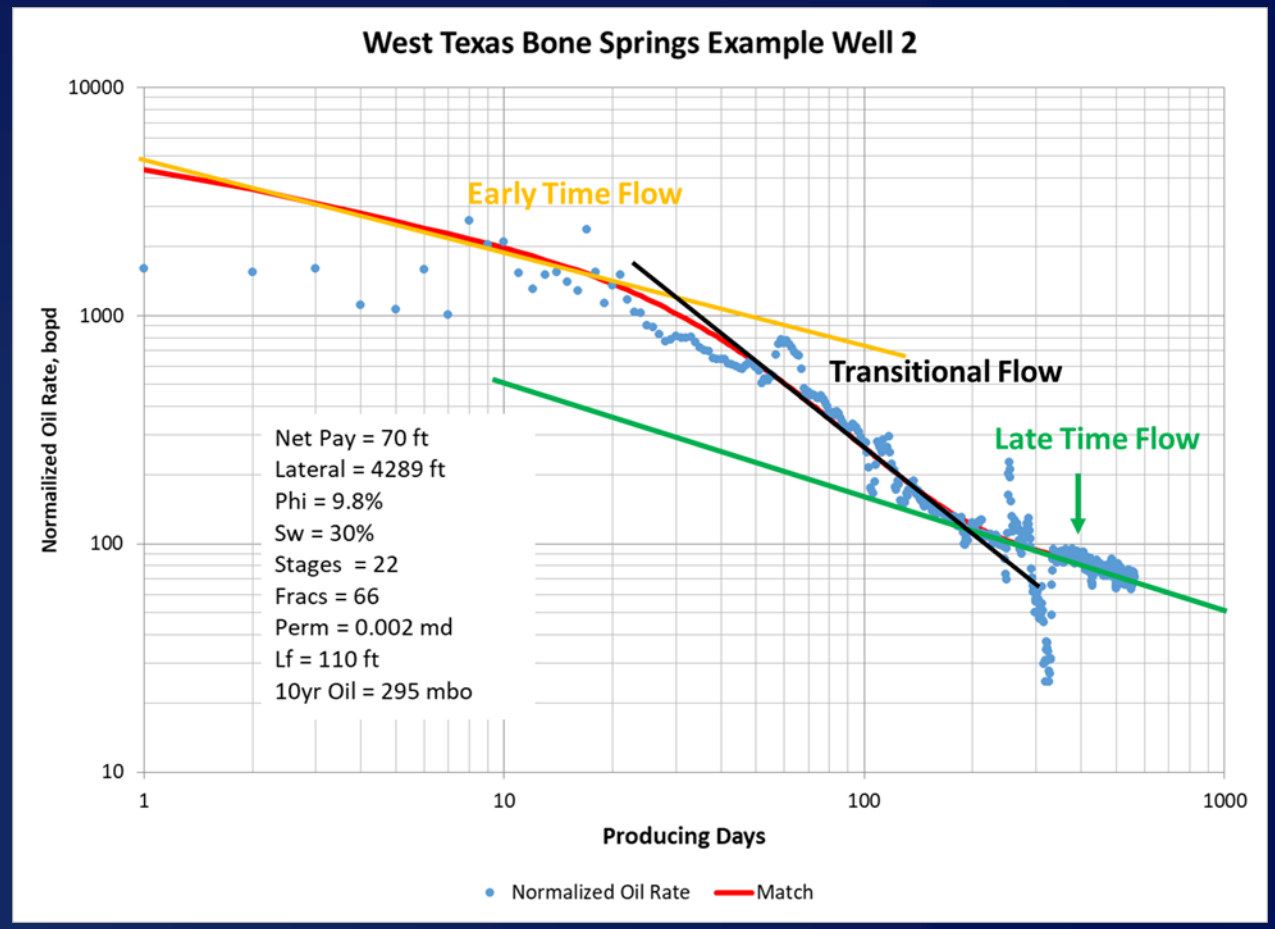
Time Normalization

- Normalized time:
  - $\Delta tn = \frac{Q}{Qn}$
  - Where:
    - Δtn = Normalized incremental time
    - Q = Actual Rate
    - Qn = Normalized rate

Production Characteristics of Horizontal Multi-Stage Fractured Wells

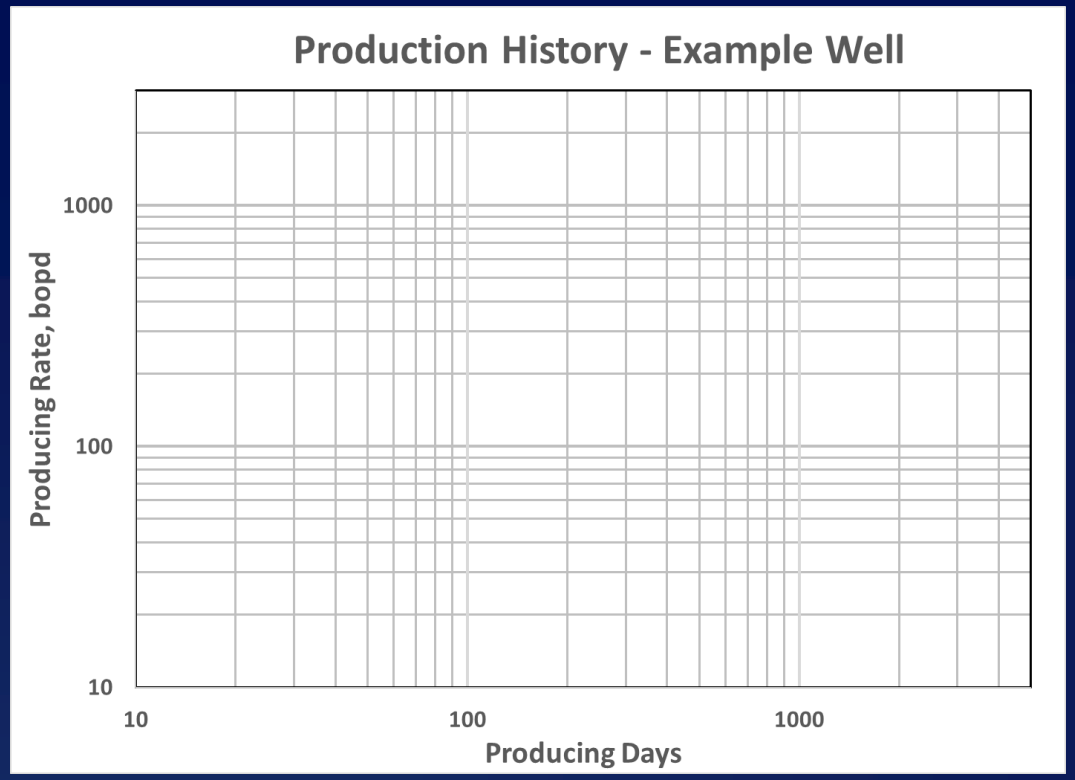
- Early time flow
  - f($k^{1/2}$ and effective frac surface area)
- Transitional flow
  - f(k and distance between fracs)
- Late time flow
  - f($k^{1/2}$ & Lateral Length)

Calculating Time to the End of Linear Flow		
k	2000	nD
Porosity	9.8%	
Viscosity	0.21	cps
Co	2.5E-05	psi-1
Cf	4.0E-06	psi-1
Sw	30%	
# of Fracs/Stage	3	
Ct	2.26E-05	psi-1
Stage Length	195	ft
Time End LF	12.3	days



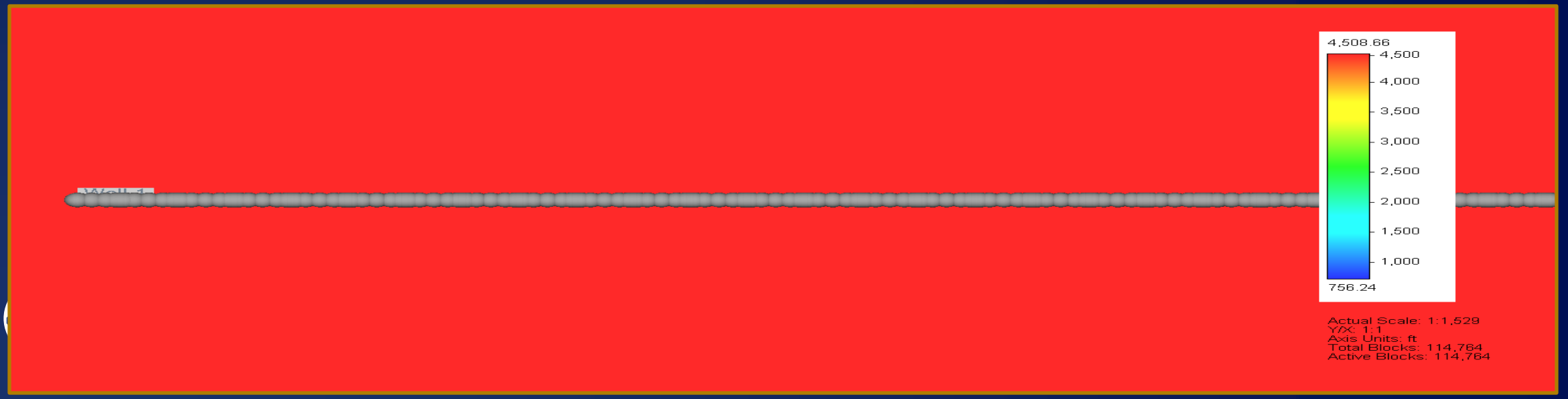
Month 0

Calculating Time to the End of Linear Flow		
k	250	nD
Porosity	5.3%	
Viscosity	0.18	cps
Co	2.5E-05	psi-1
Cf	4.0E-06	psi-1
Sw	30%	
# of Fracs/Stage	2	
Ct	2.26E-05	psi-1
Stage Length	200	ft
Time End LF	108.3	days



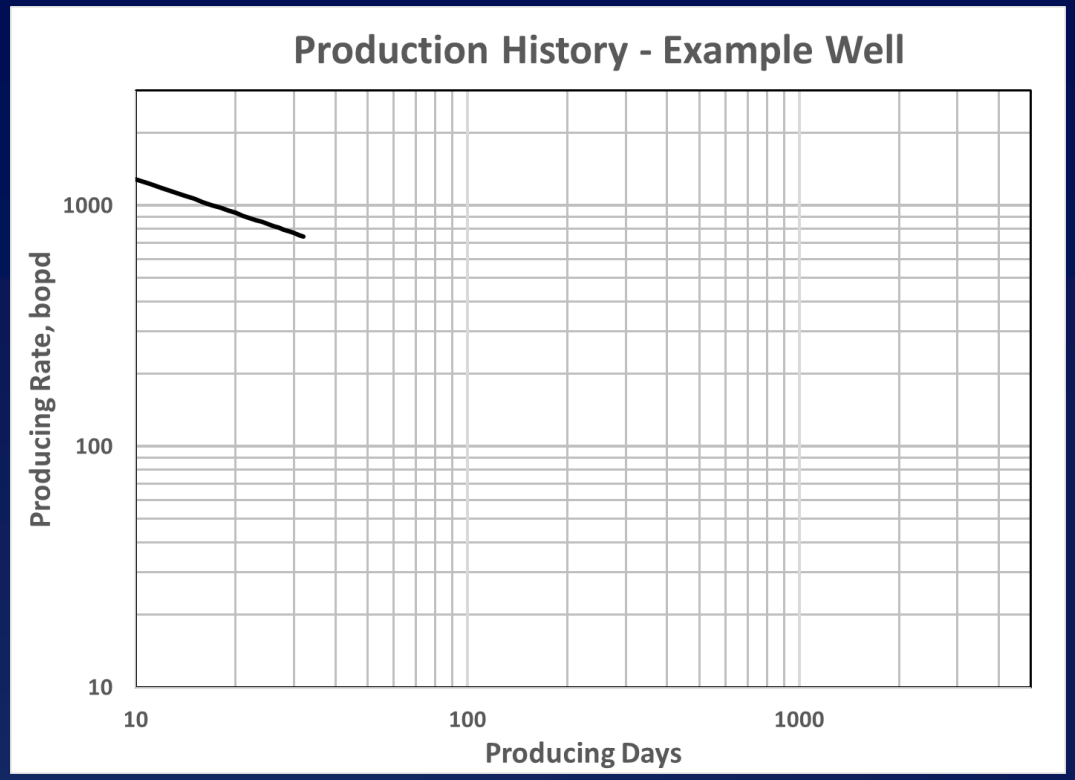
Net Pay = 78 feet
Porosity = 5.3%
Permeability = 250 nD
Sw = 15%
Bo = 2.1
Oil Visc. = 0.18 cps
Pi = 4500 psi
Pwf = 750 psi
Lateral Length = 10,800 feet
Fracture Spacing = 100 feet
Effective Lf = 250 feet

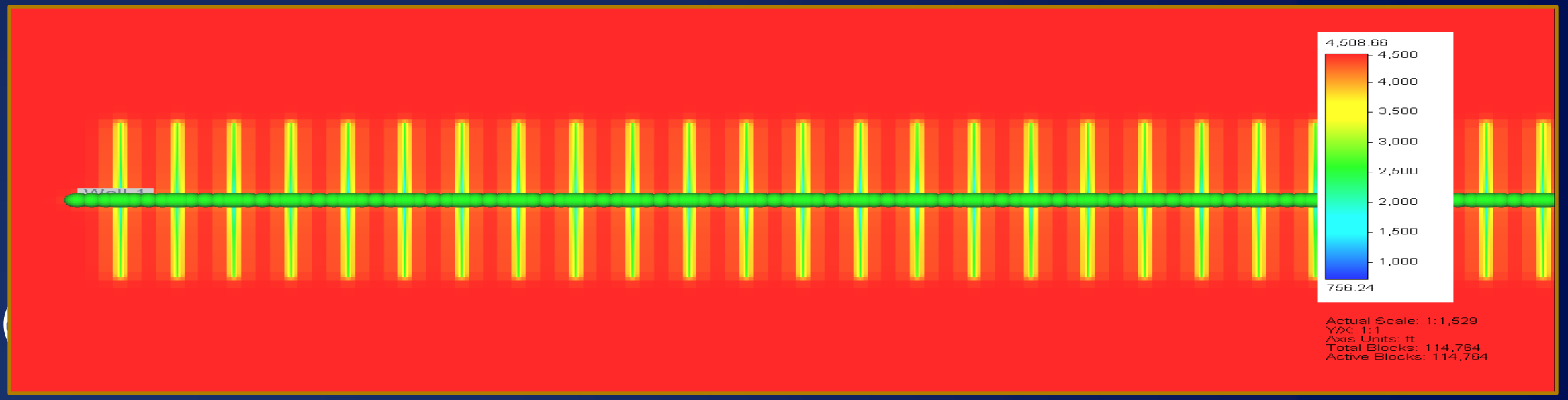
Reservoir Pressure Map



Month 1

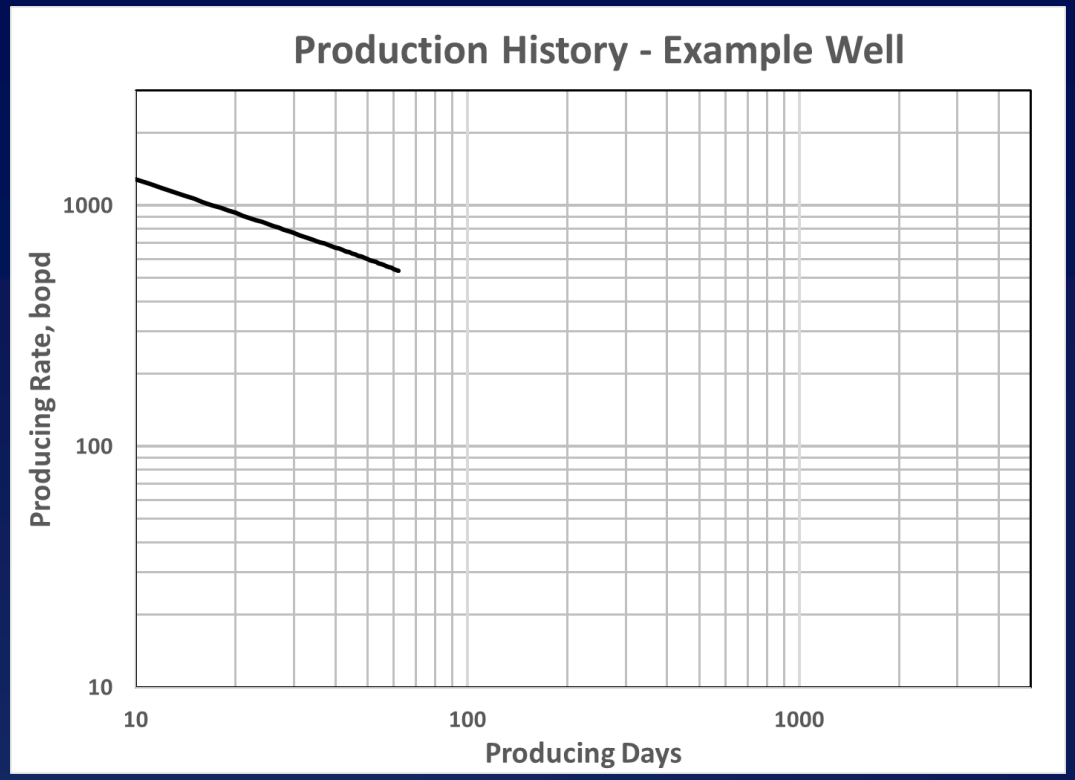
Calculating Time to the End of Linear Flow		
k	250	nD
Porosity	5.3%	
Viscosity	0.18	cps
Co	2.5E-05	psi-1
Cf	4.0E-06	psi-1
Sw	30%	
# of Fracs/Stage	2	
Ct	2.26E-05	psi-1
Stage Length	200	ft
Time End LF	108.3	days

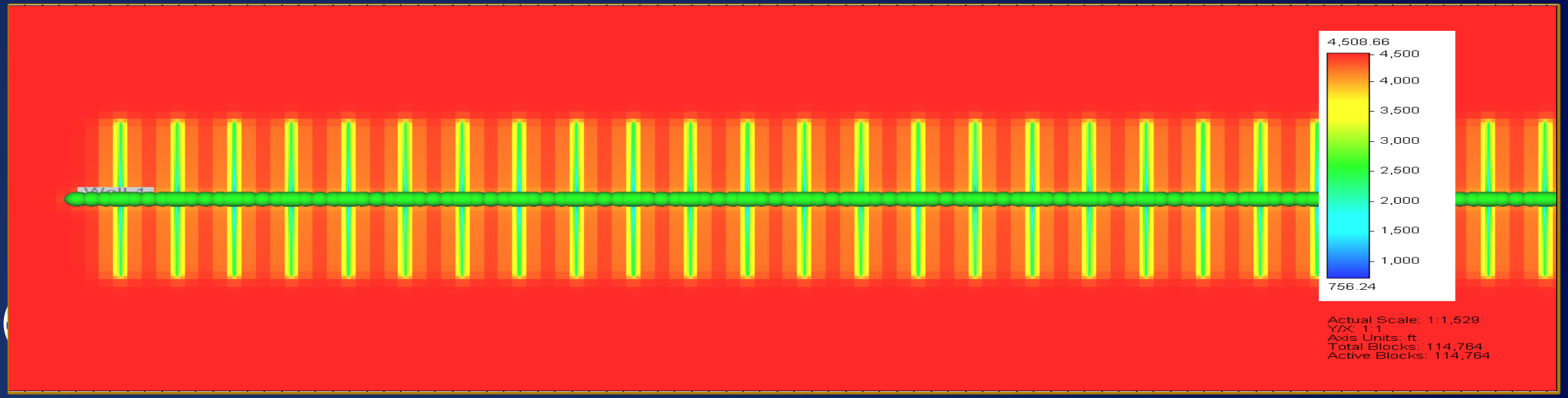




Month 2

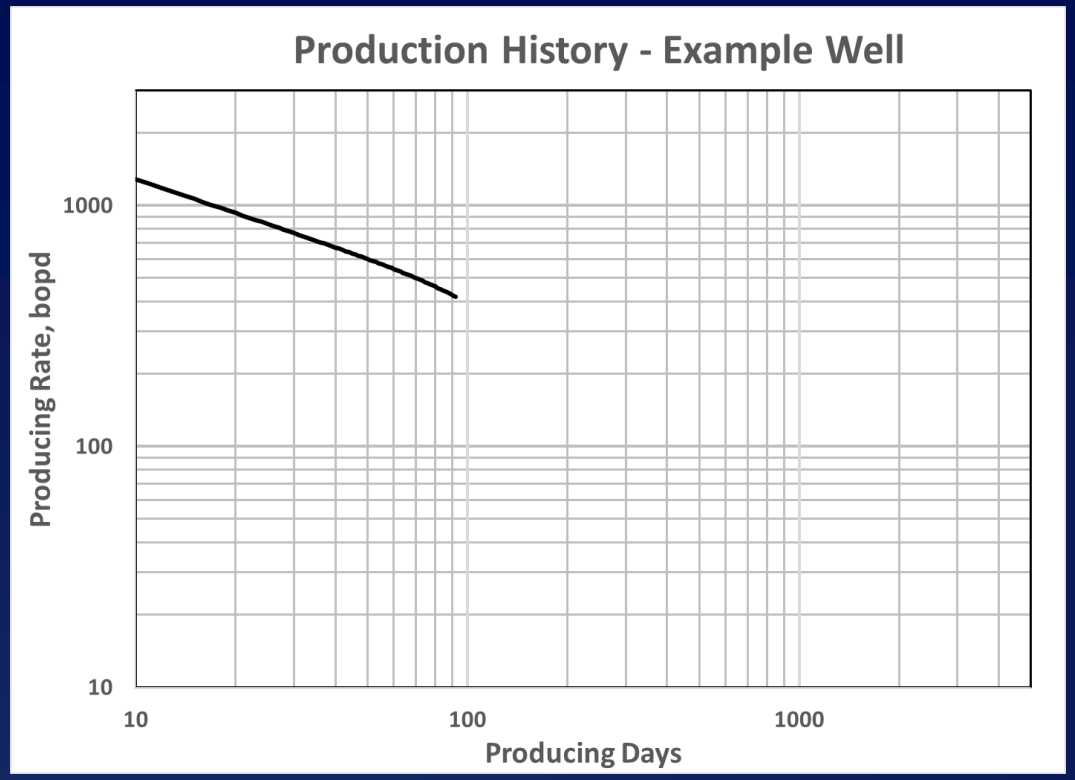
Calculating Time to the End of Linear Flow		
k	250	nD
Porosity	5.3%	
Viscosity	0.18	cps
Co	2.5E-05	psi-1
Cf	4.0E-06	psi-1
Sw	30%	
# of Fracs/Stage	2	
Ct	2.26E-05	psi-1
Stage Length	200	ft
Time End LF	108.3	days

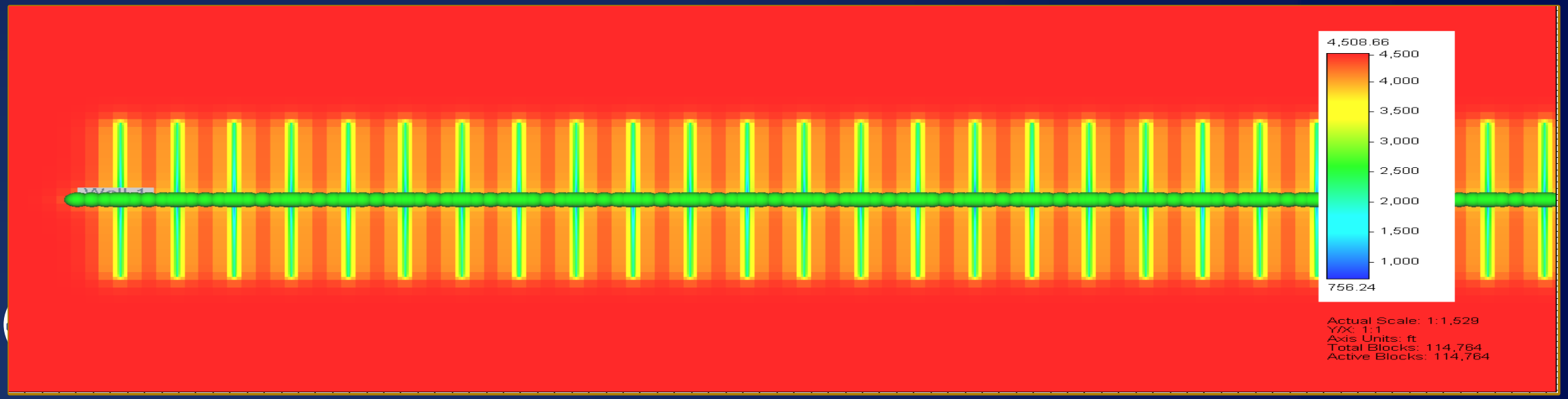




Month 3

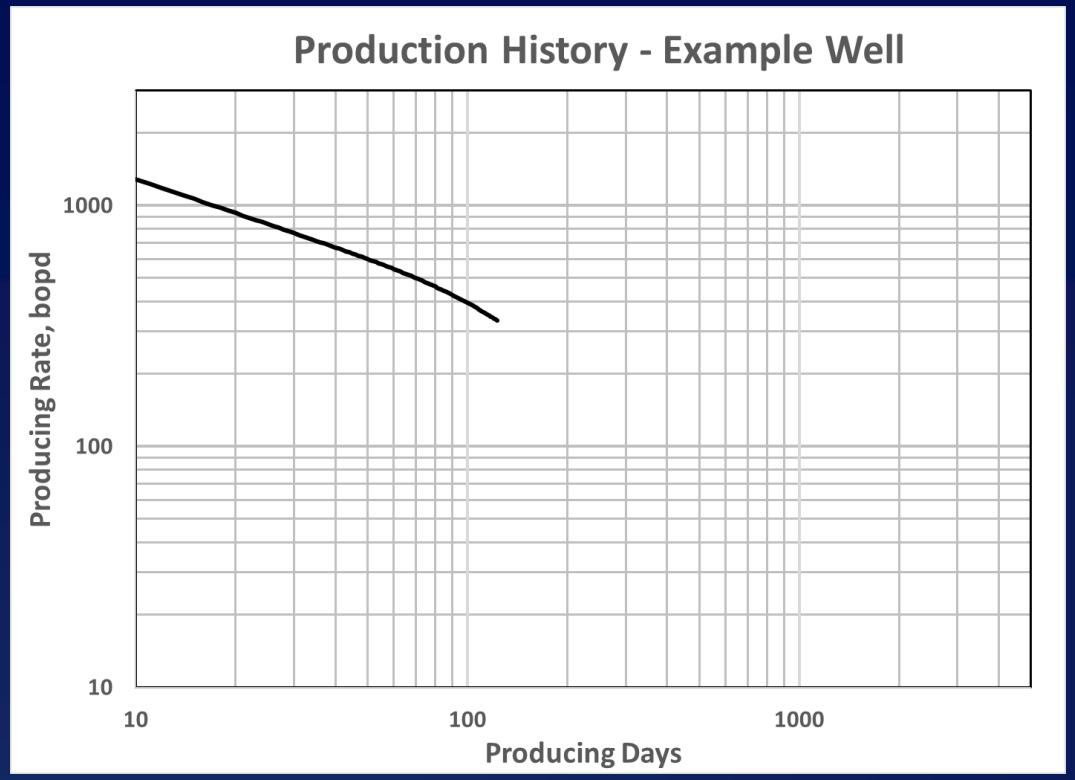
Calculating Time to the End of Linear Flow		
k	250	nD
Porosity	5.3%	
Viscosity	0.18	cps
Co	2.5E-05	psi-1
Cf	4.0E-06	psi-1
Sw	30%	
# of Fracs/Stage	2	
Ct	2.26E-05	psi-1
Stage Length	200	ft
Time End LF	108.3	days

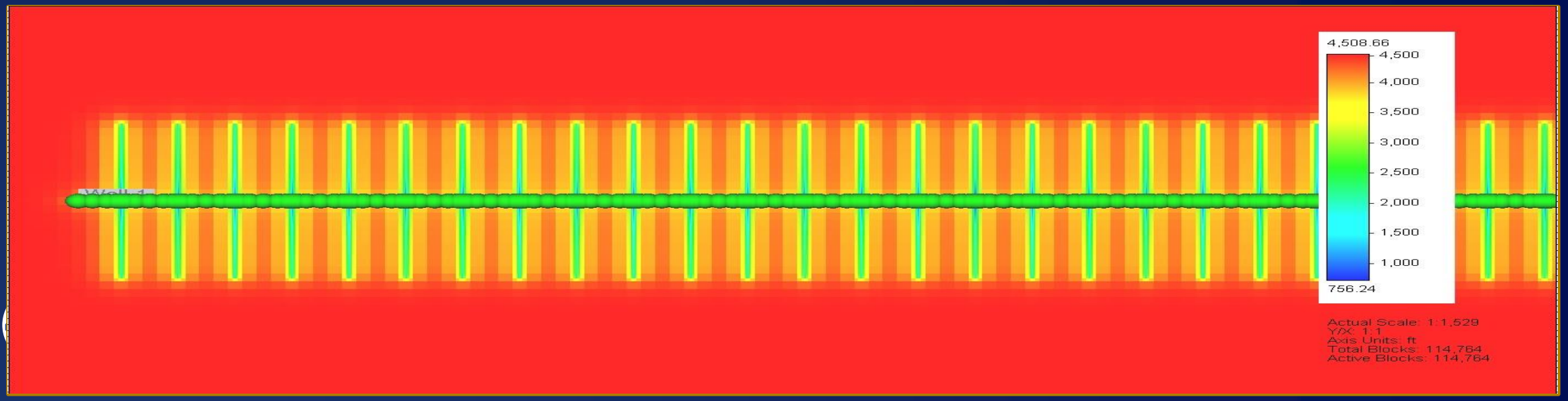




Month 4

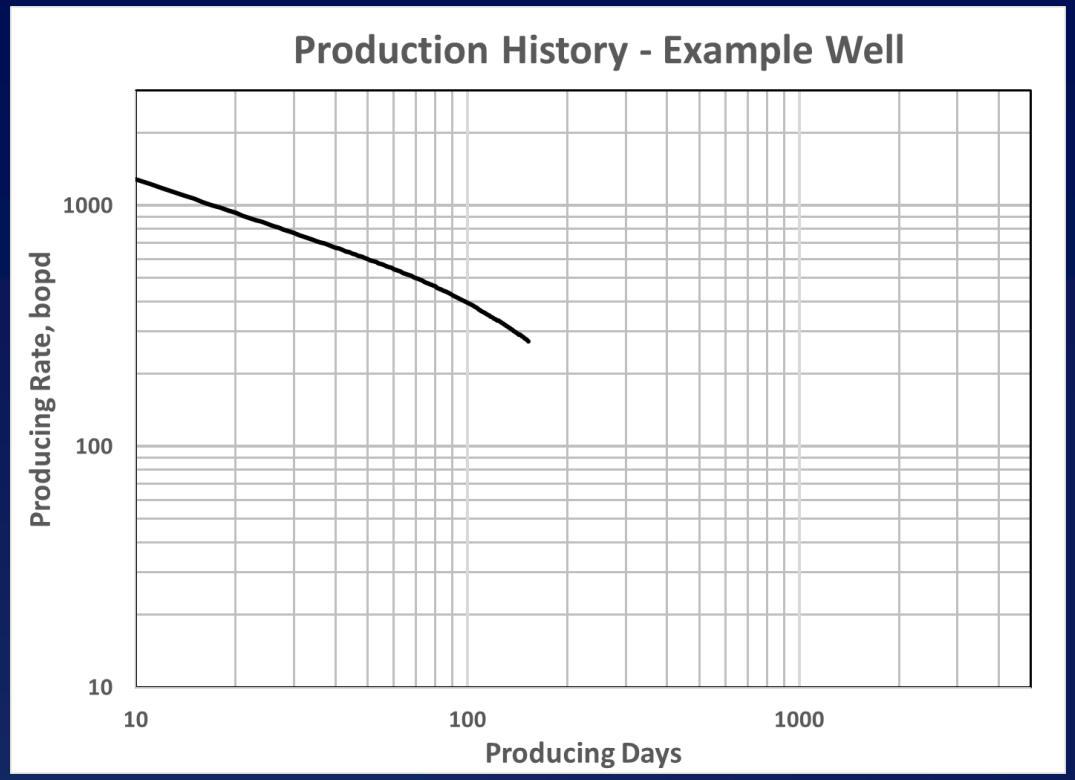
Calculating Time to the End of Linear Flow		
k	250	nD
Porosity	5.3%	
Viscosity	0.18	cps
Co	2.5E-05	psi-1
Cf	4.0E-06	psi-1
Sw	30%	
# of Fracs/Stage	2	
Ct	2.26E-05	psi-1
Stage Length	200	ft
Time End LF	108.3	days

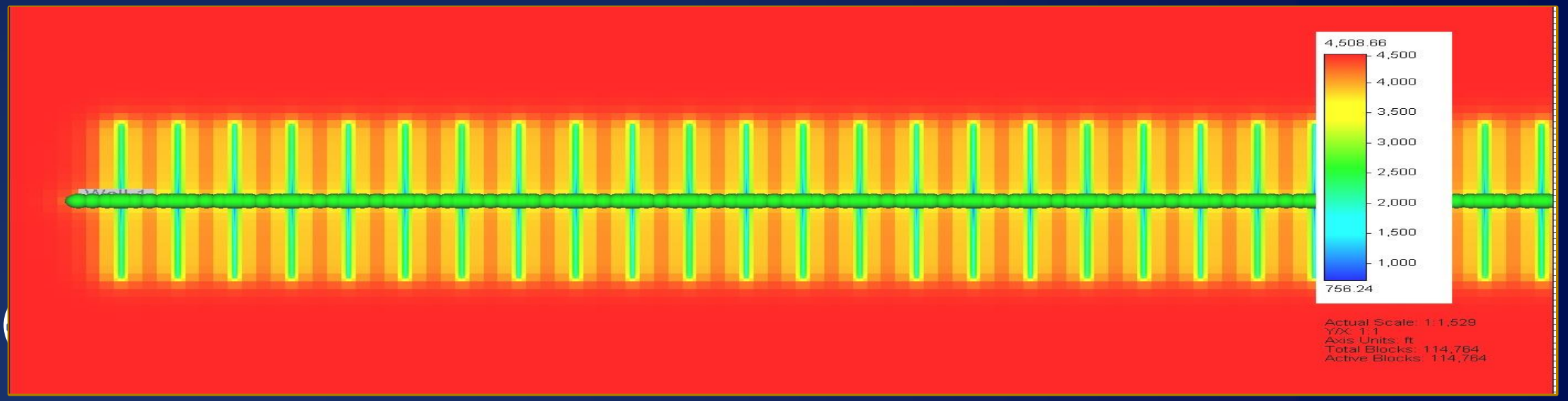




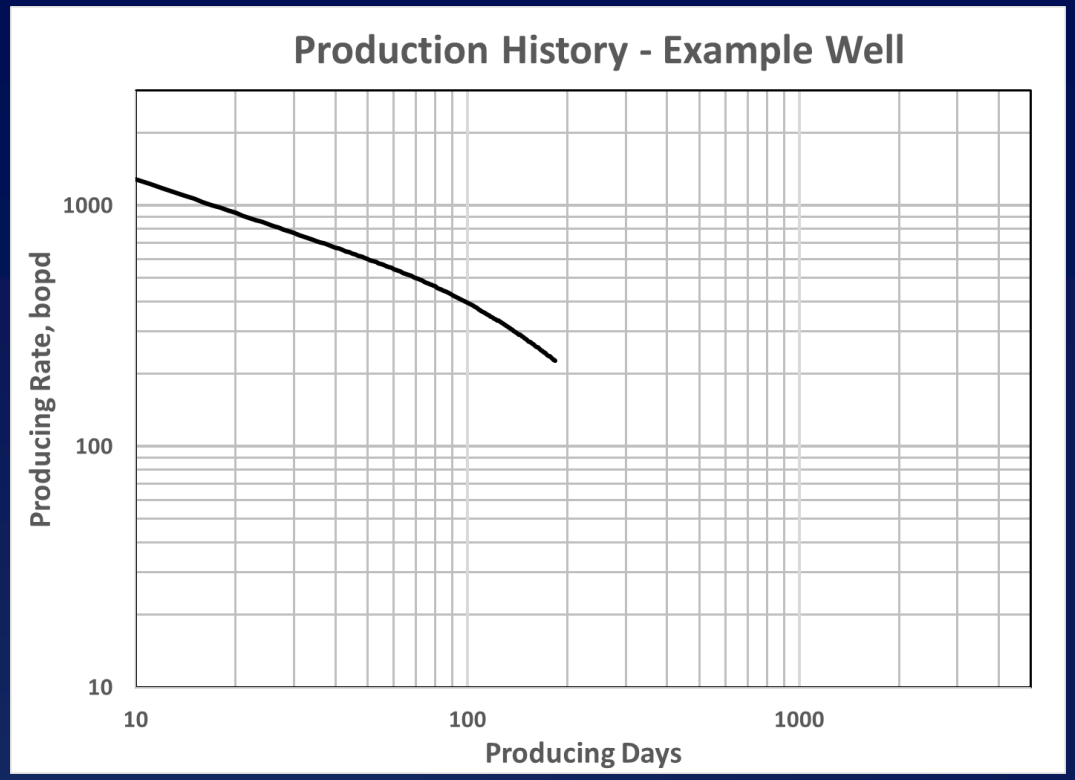
Month 5

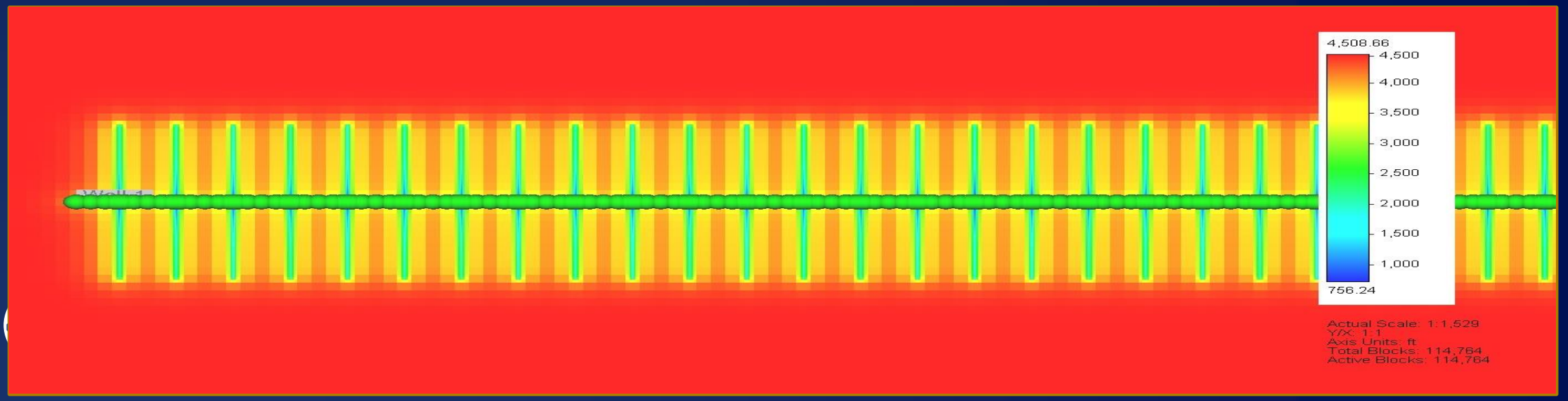
Calculating Time to the End of Linear Flow		
k	250	nD
Porosity	5.3%	
Viscosity	0.18	cps
Co	2.5E-05	psi-1
Cf	4.0E-06	psi-1
Sw	30%	
# of Fracs/Stage	2	
Ct	2.26E-05	psi-1
Stage Length	200	ft
Time End LF	108.3	days



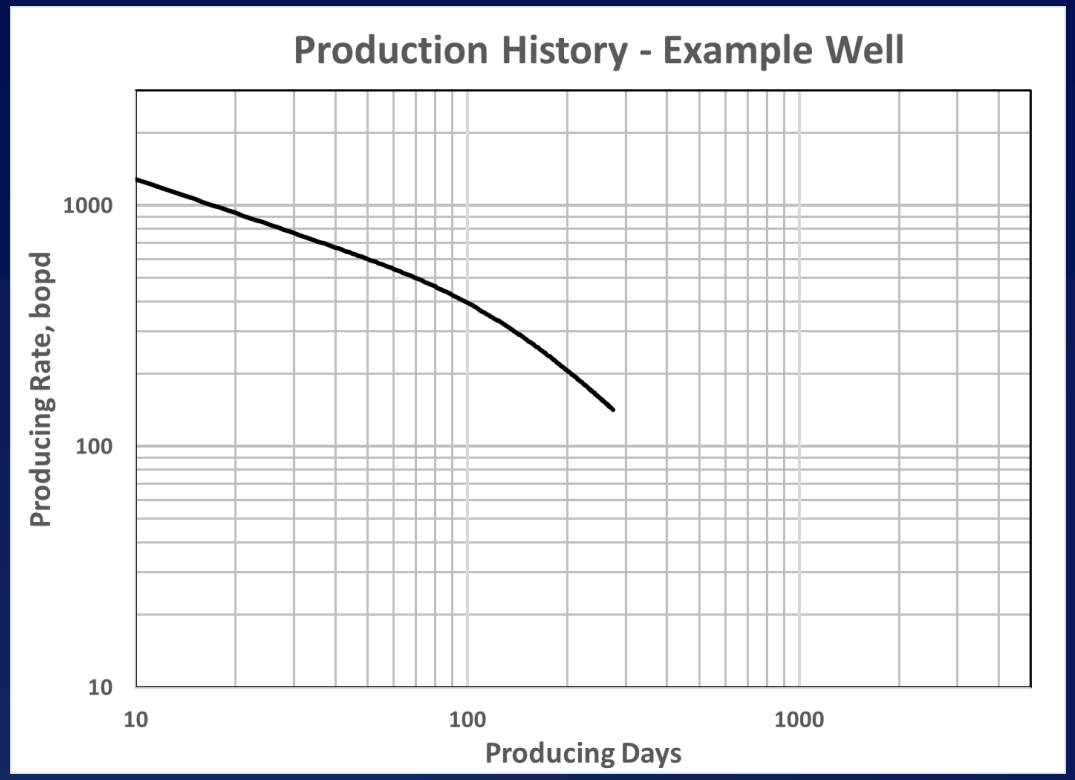


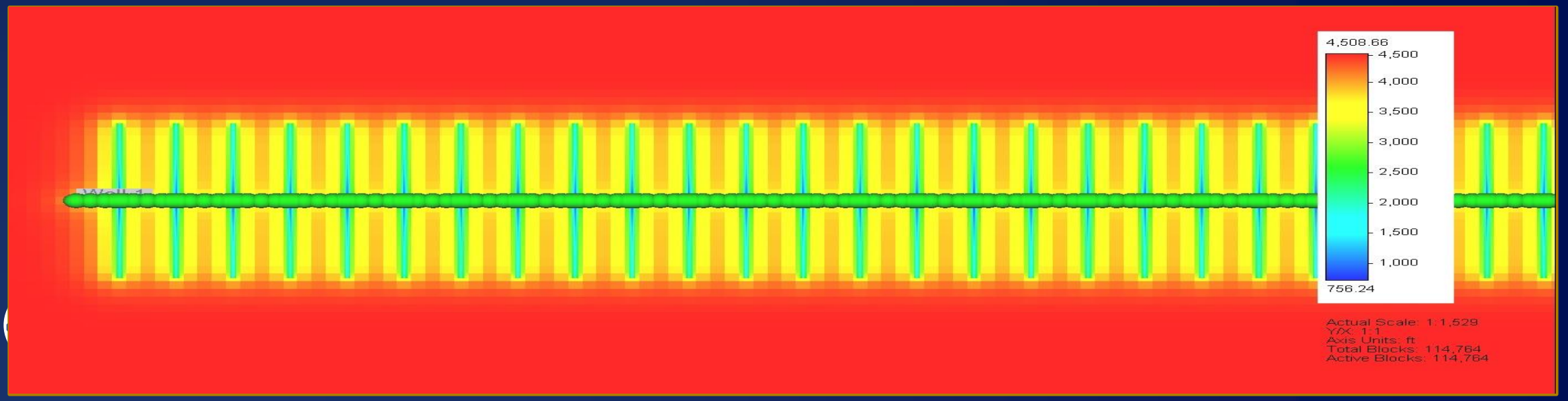
Month 6


Production History - Example Well
Producing Rate, bopd
1000
100
10
10
100
1000
Producing Days

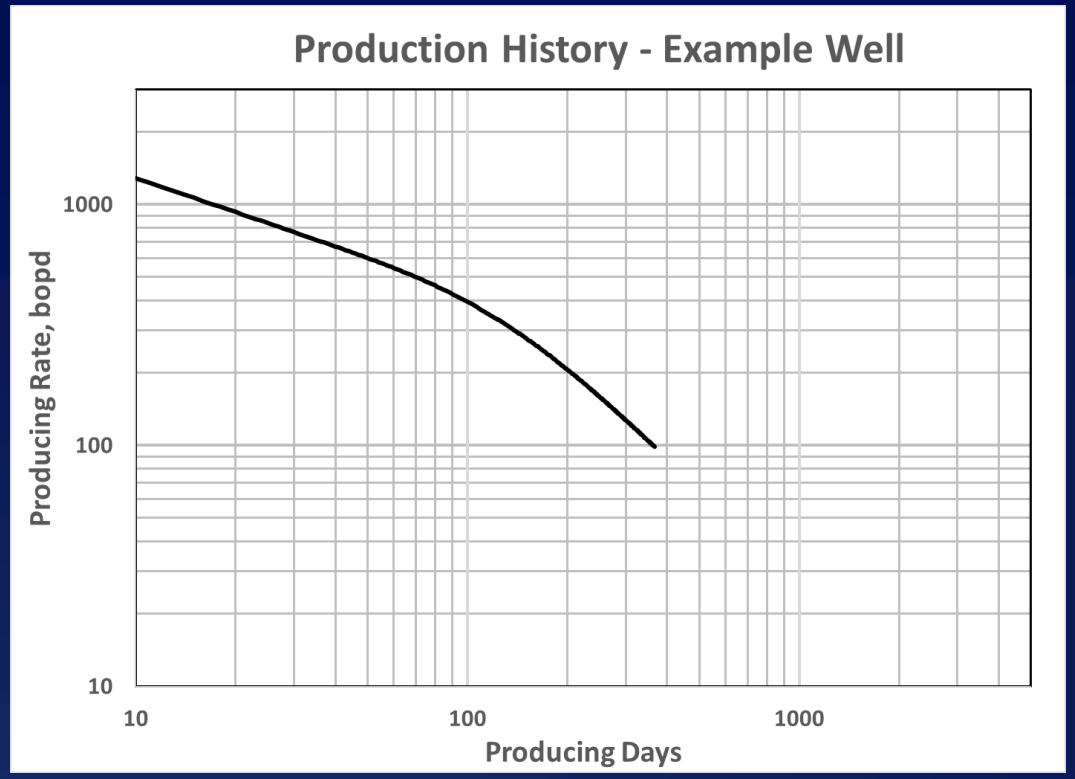

4,508.66
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
756.24
Actual Scale: 1:1,529
Y/X: 1:1
Axis Units: ft
Total Blocks: 114,784
Active Blocks: 114,784

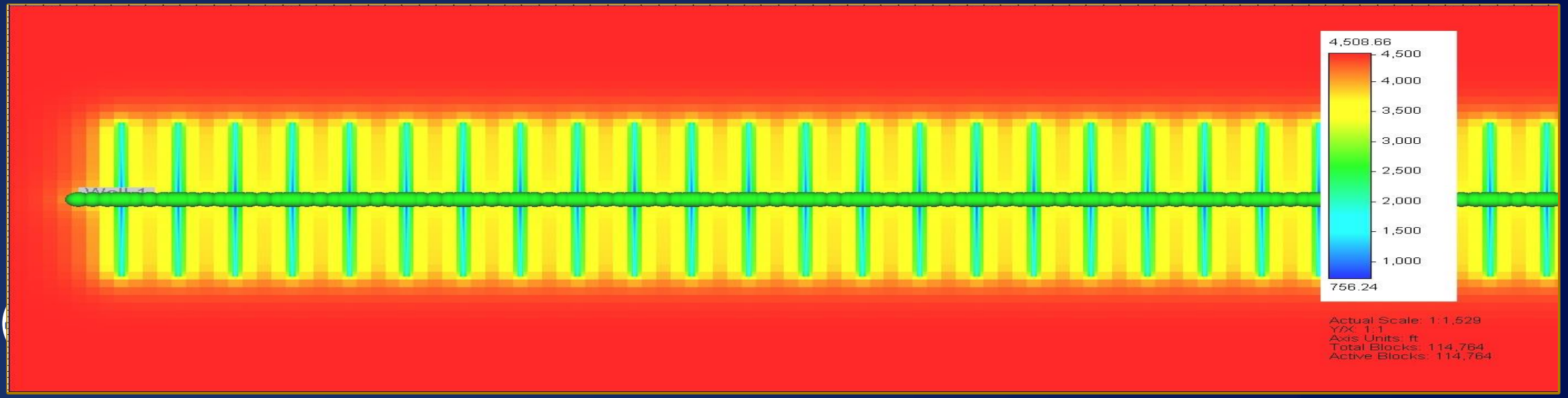
Month 9


Production History - Example Well
Producing Rate, bopd
1000
100
10
10
100
1000
Producing Days

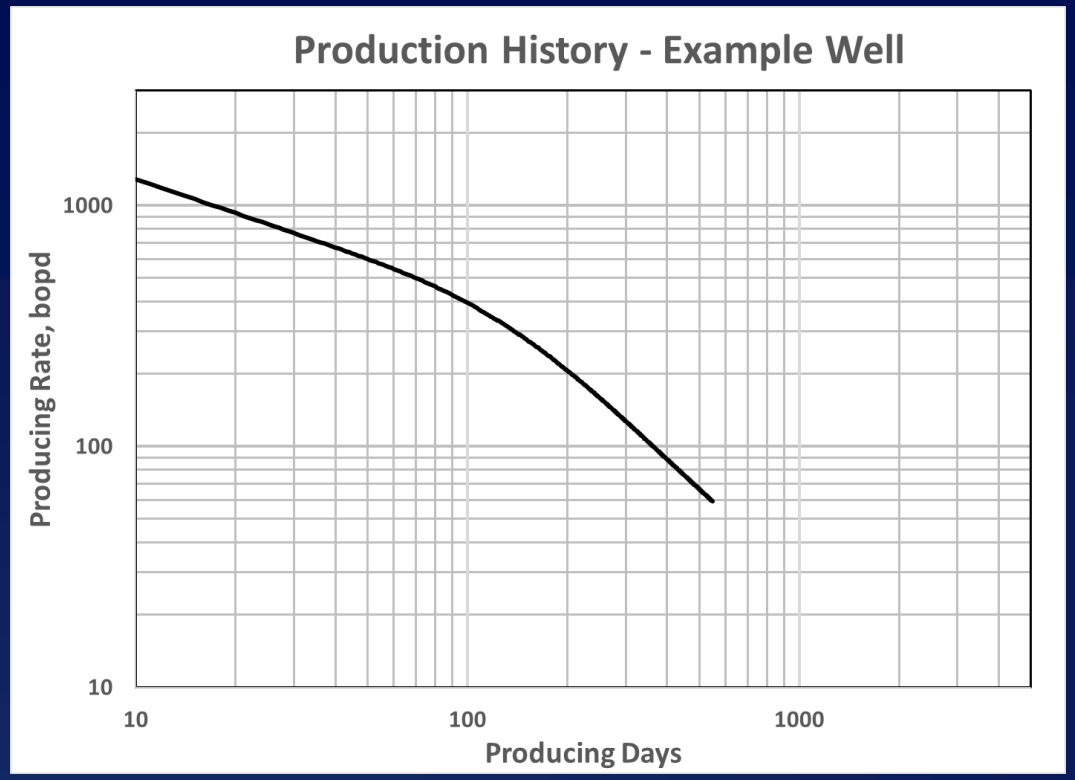

4,508.66
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
756.24
Actual Scale: 1:1,529
Y/X: 1:1
Axis Units: ft
Total Blocks: 114,764
Active Blocks: 114,764

Month 12


Production History - Example Well
Producing Rate, bopd
1000
100
10
10
100
1000
Producing Days


4,508.66
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
756.24
Actual Scale: 1:1,529
Y/X 1:1
Axis Units: ft
Total Blocks: 114,764
Active Blocks: 114,764

Month 18


Production History - Example Well
Producing Rate, bopd
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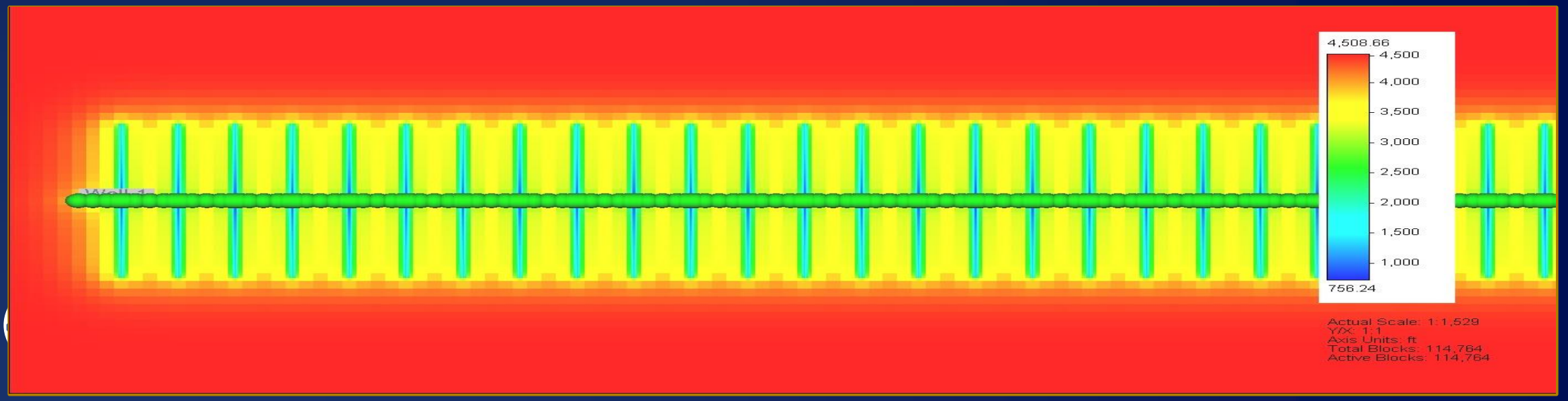
100
10
10
100
1000
Producing Days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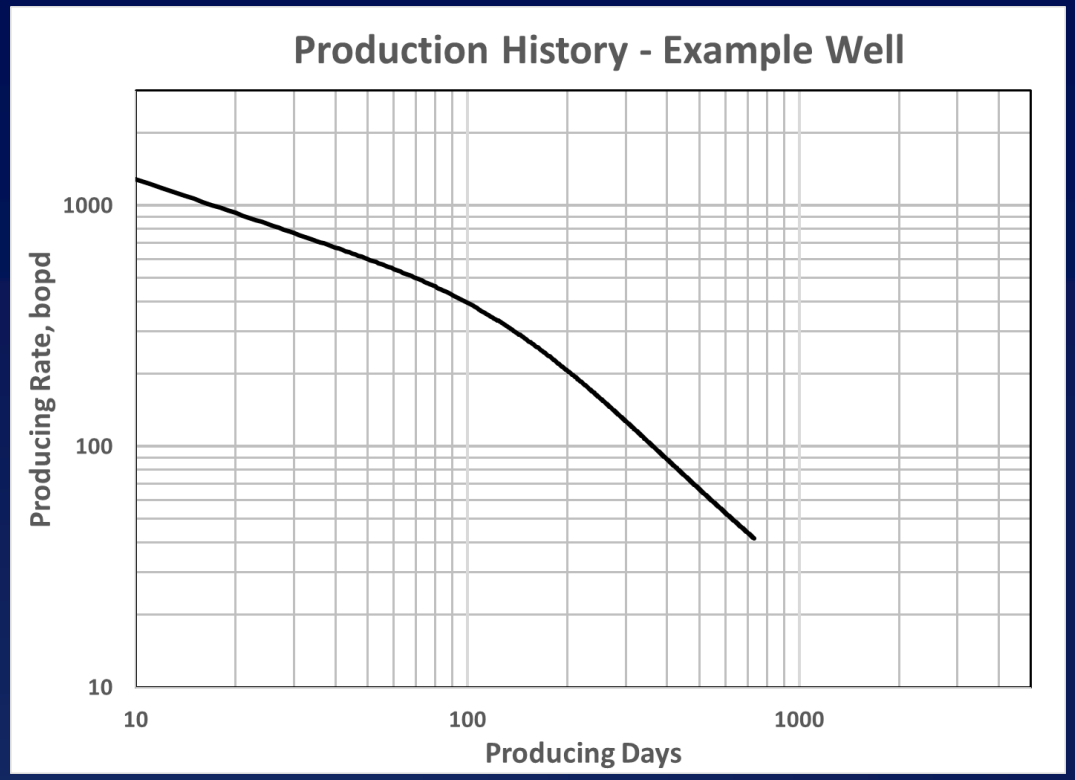
3,500
3,000
2,500
2,000
1,500
1,000
756.24
Actual Scale: 1:1,529
Y/X: 1:1
Axis Units: ft
Total Blocks: 114,764
Active Blocks: 114,764

Month 24


Production History - Example Well
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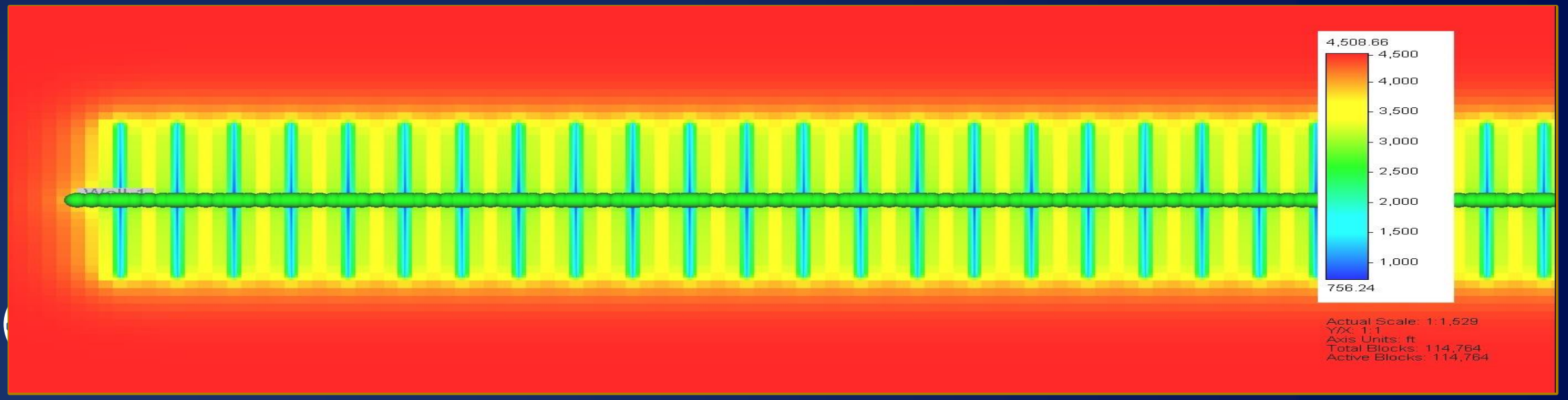
100
10
10
100
1000
Producing Days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Axis Units: ft
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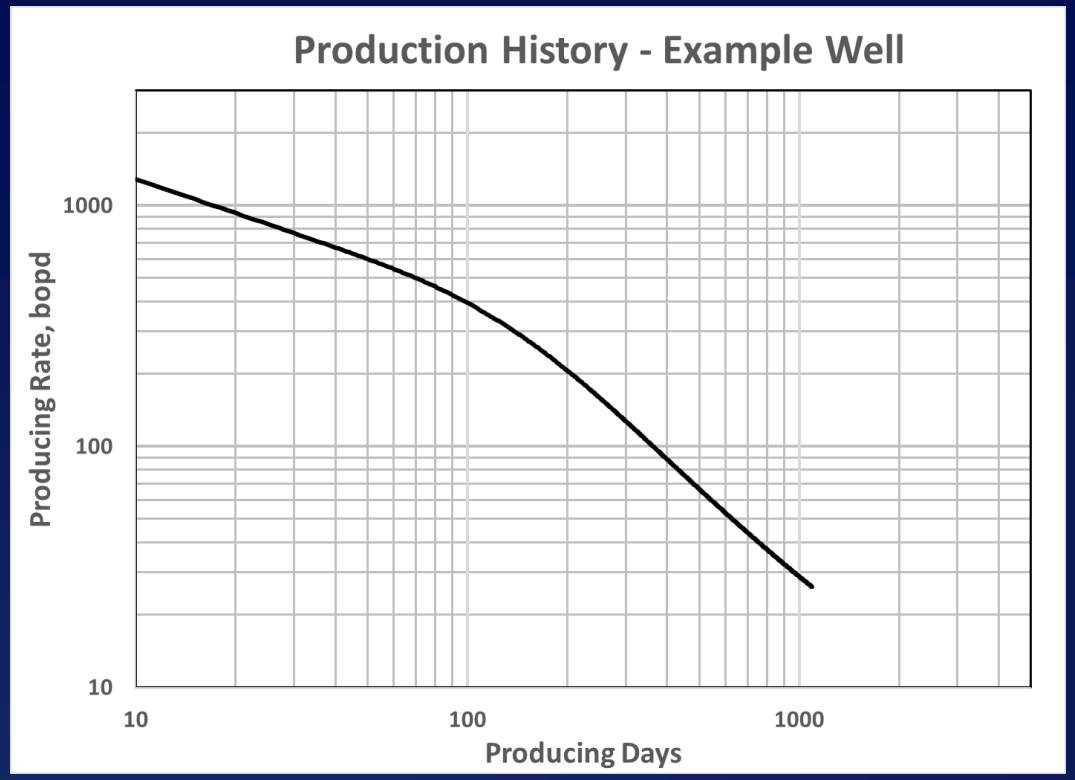
Active Blocks: 114,764

Month 36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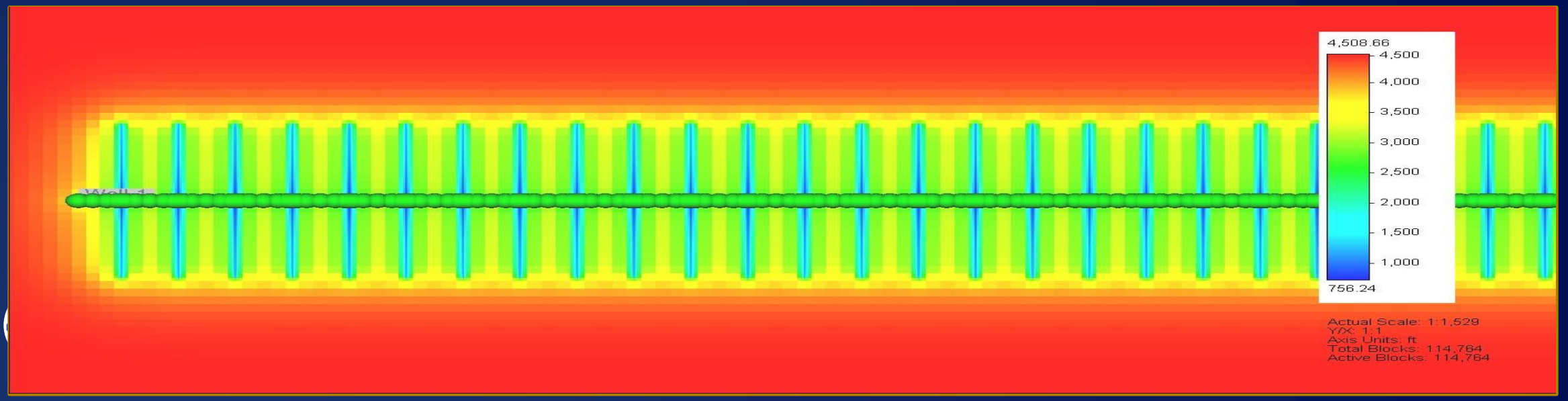
100
1000
Producing Days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Y/X: 1:1
Axis Units: ft
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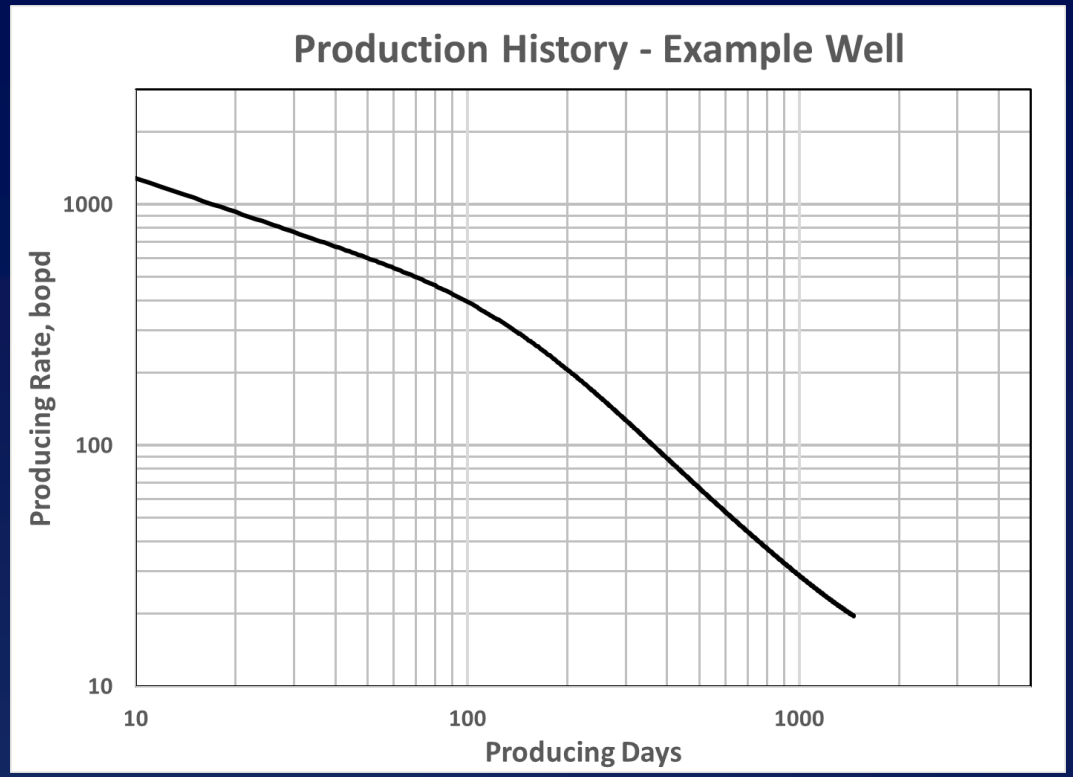
Month 48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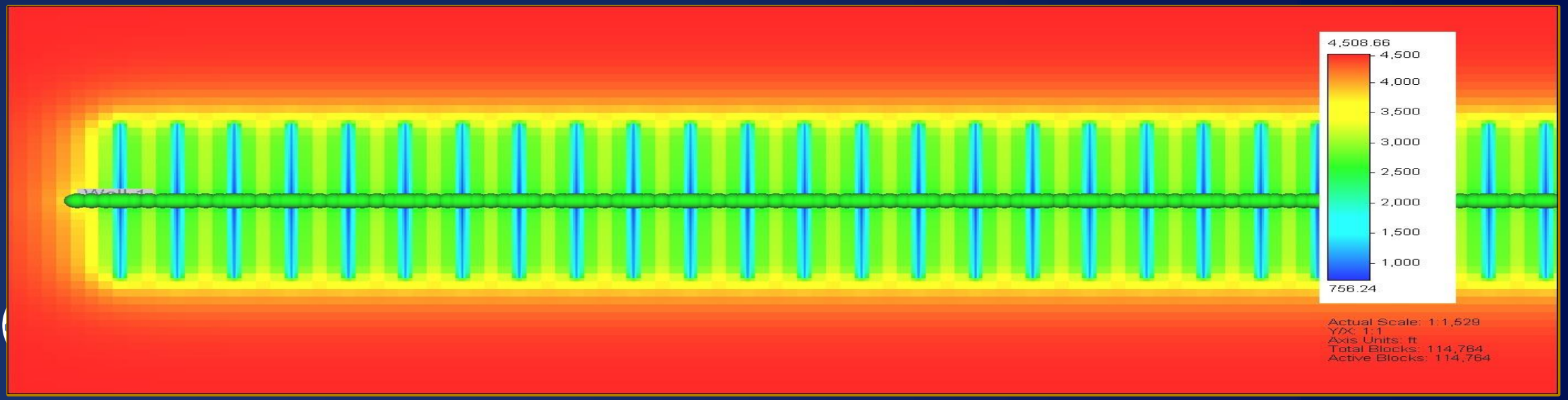
10
10
100
1000
Producing Days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Y/X: 1:1
Axis Units: ft
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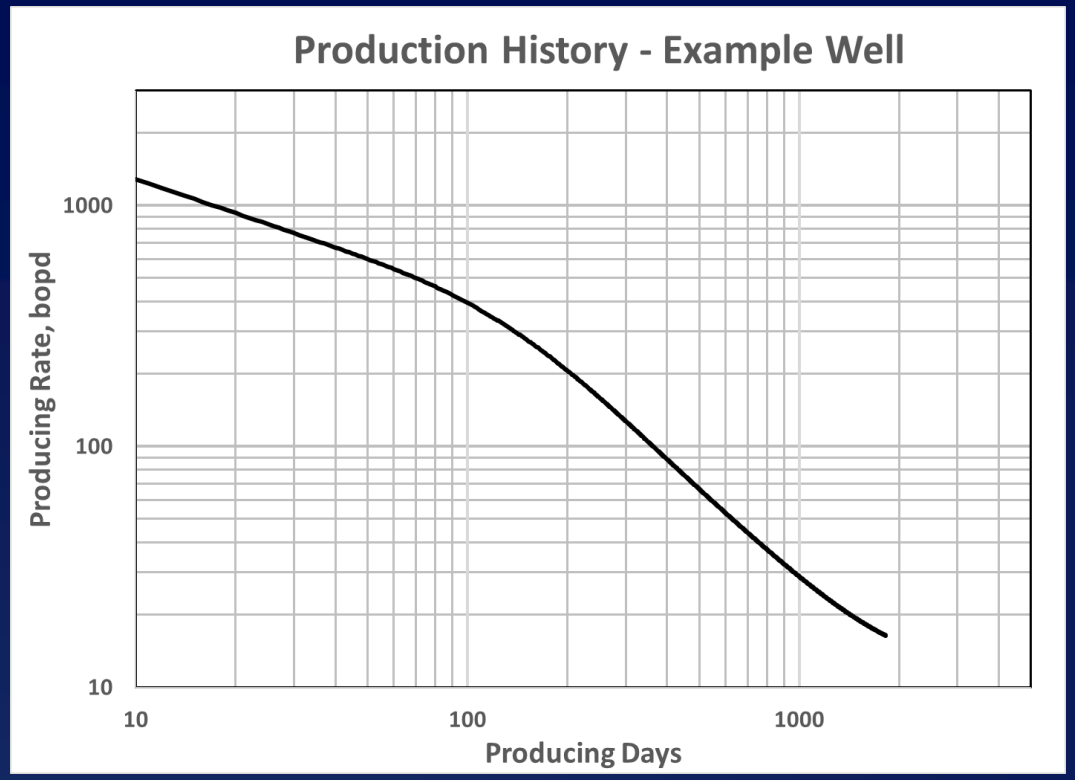
Active Blocks: 114,764

Month 60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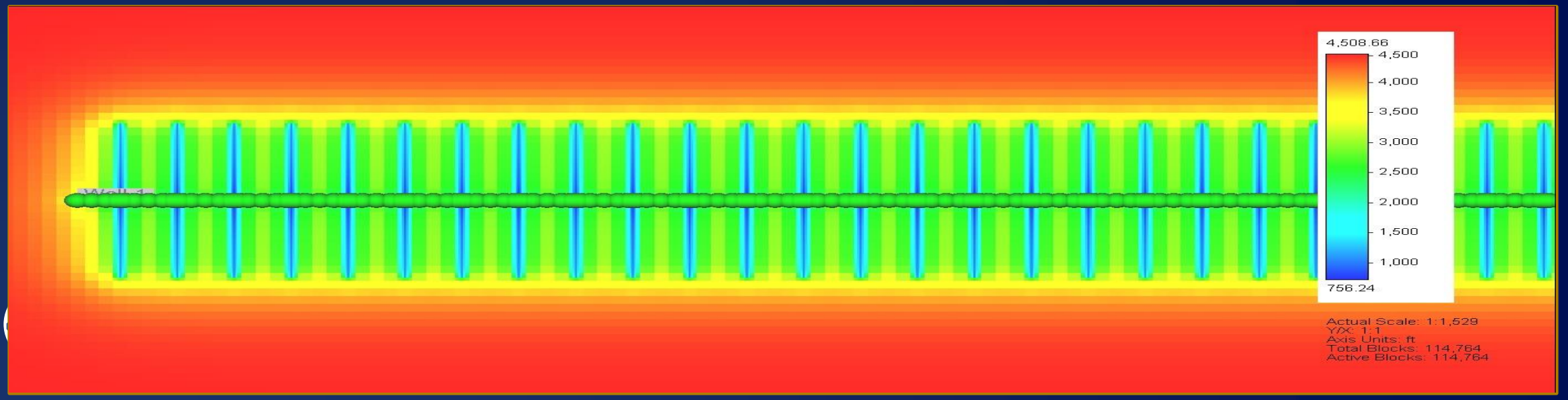
10
10
100
1000
Producing Days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Y/X: 1:1
Axis Units: ft
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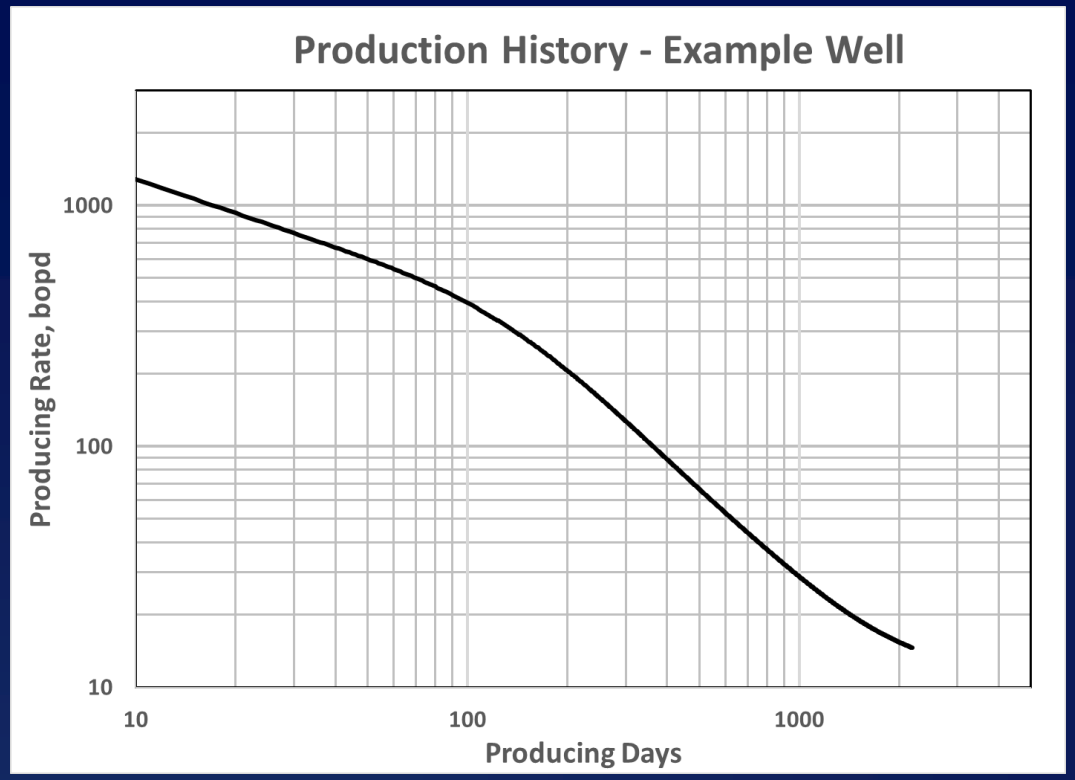
Active Blocks: 114,764

Month 72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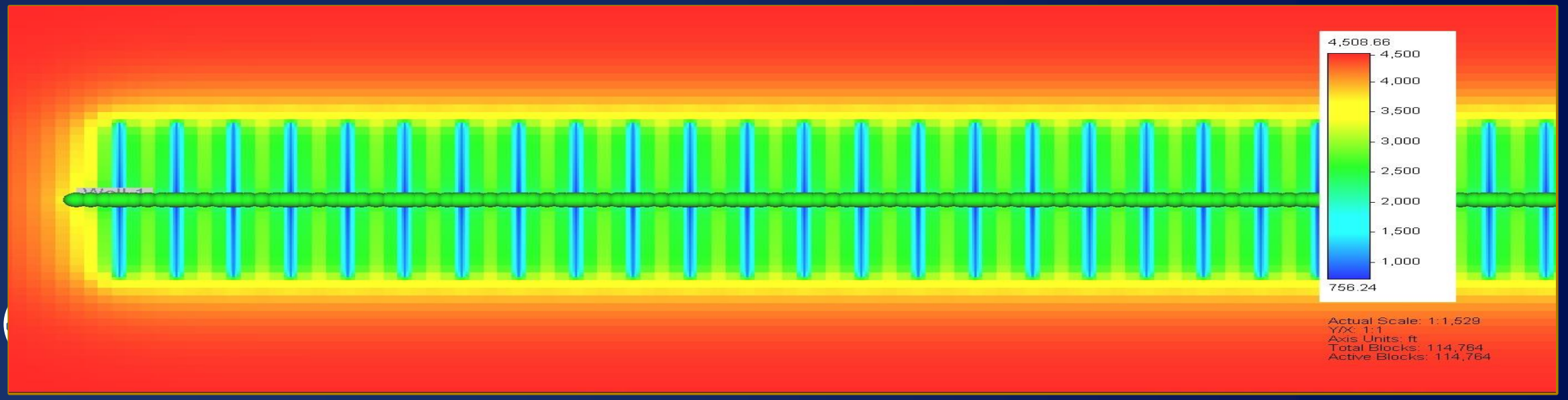
10
10
100
1000
Producing Days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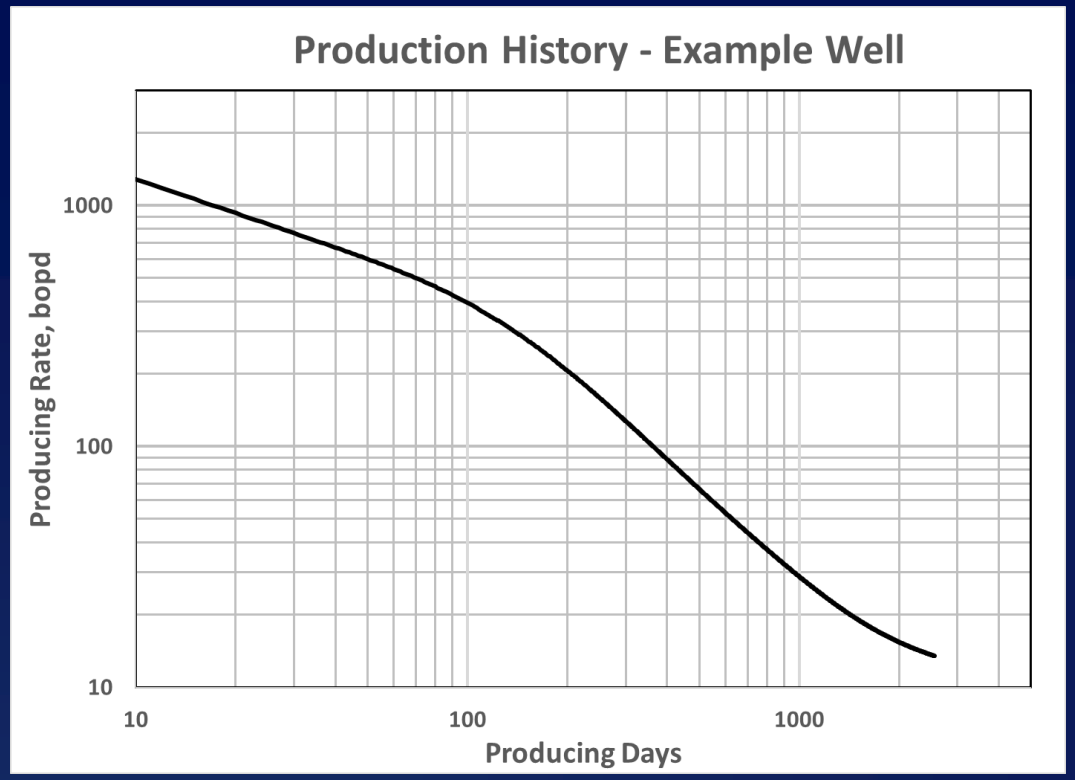
Y/X: 1:1
Axis Units: ft
Total Blocks: 114,764
Active Blocks: 114,764

Month 84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Producing Rate, bopd
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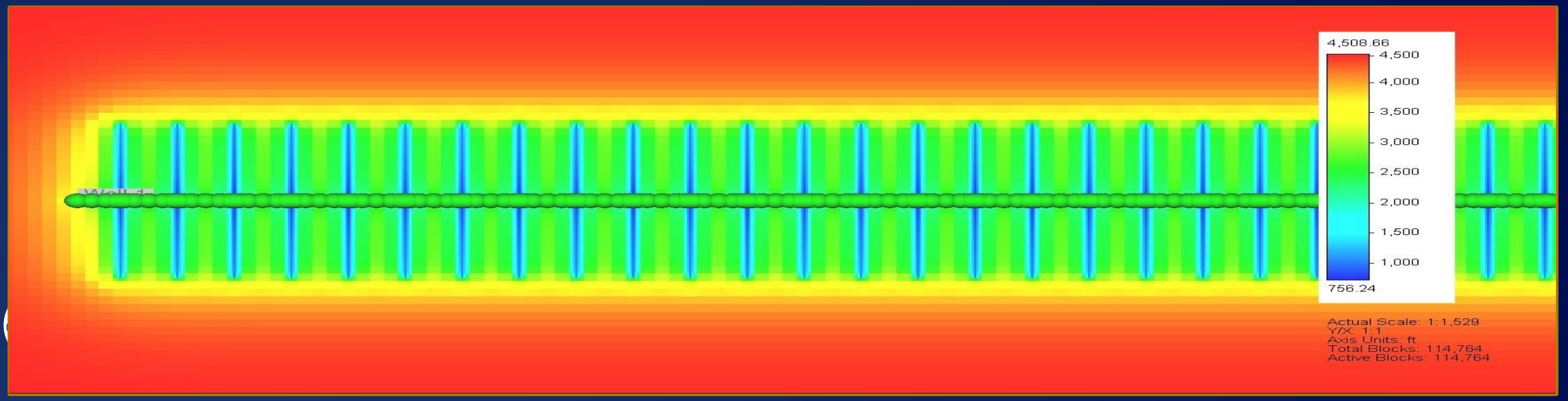
100
10
10
100
1000
Producing Days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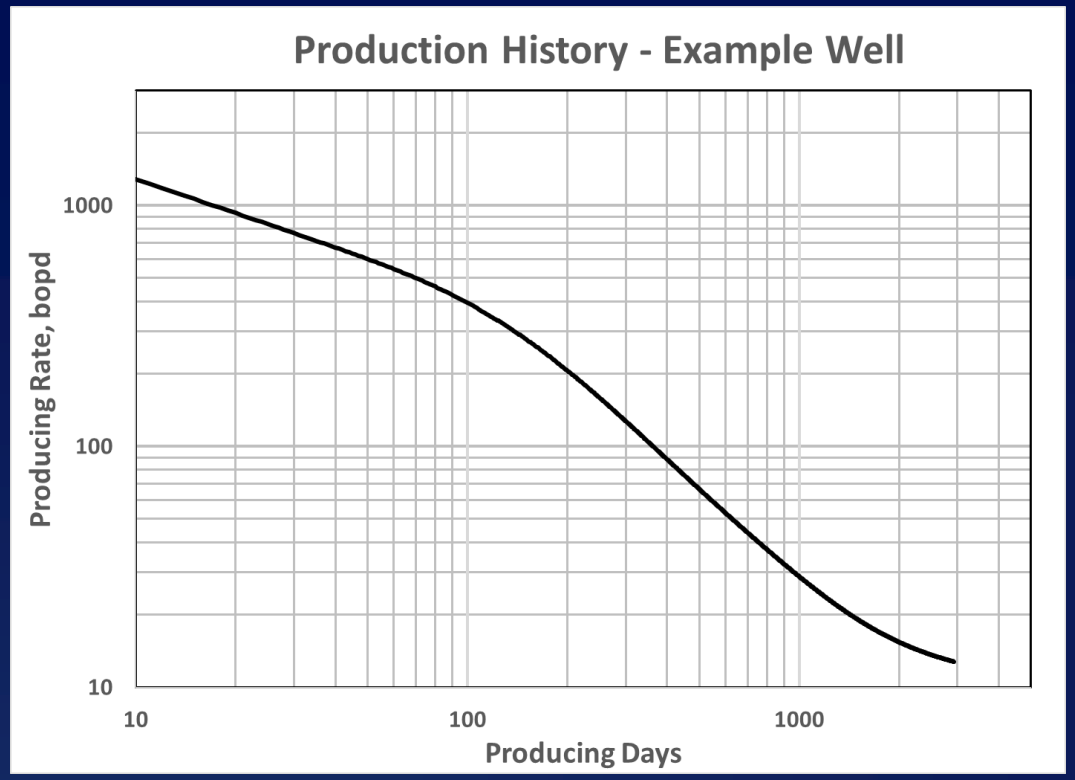
Y/X: 1:1
Axis Units: ft
Total Blocks: 114,764
Active Blocks: 114,764

Month 96


Production History - Example Well
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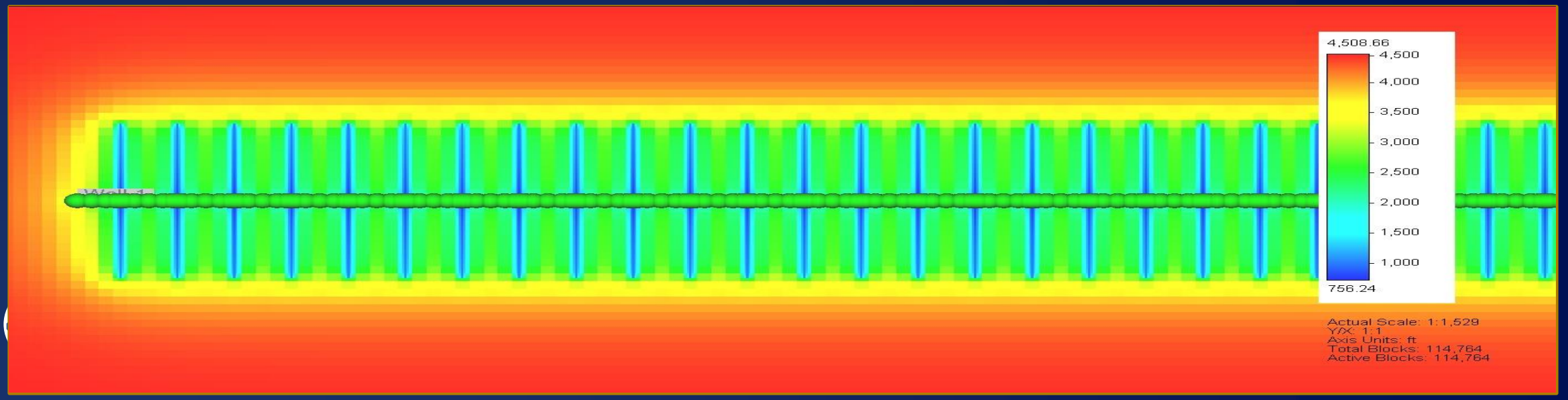
10
10
100
1000
Producing Days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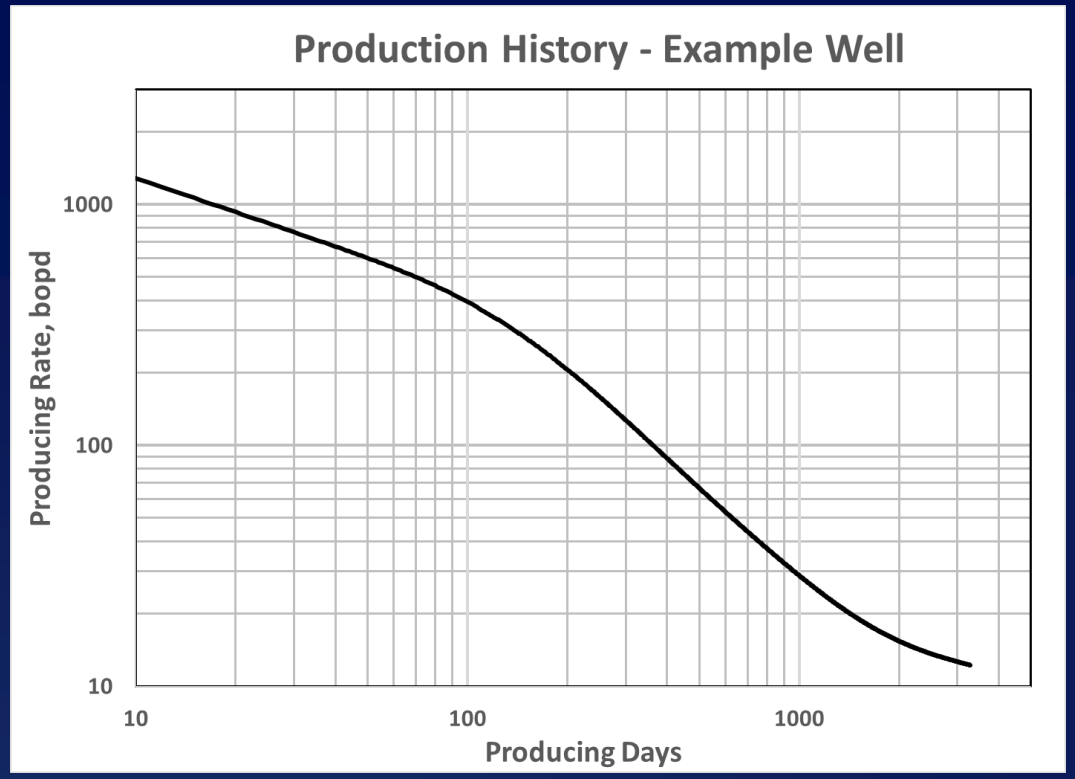
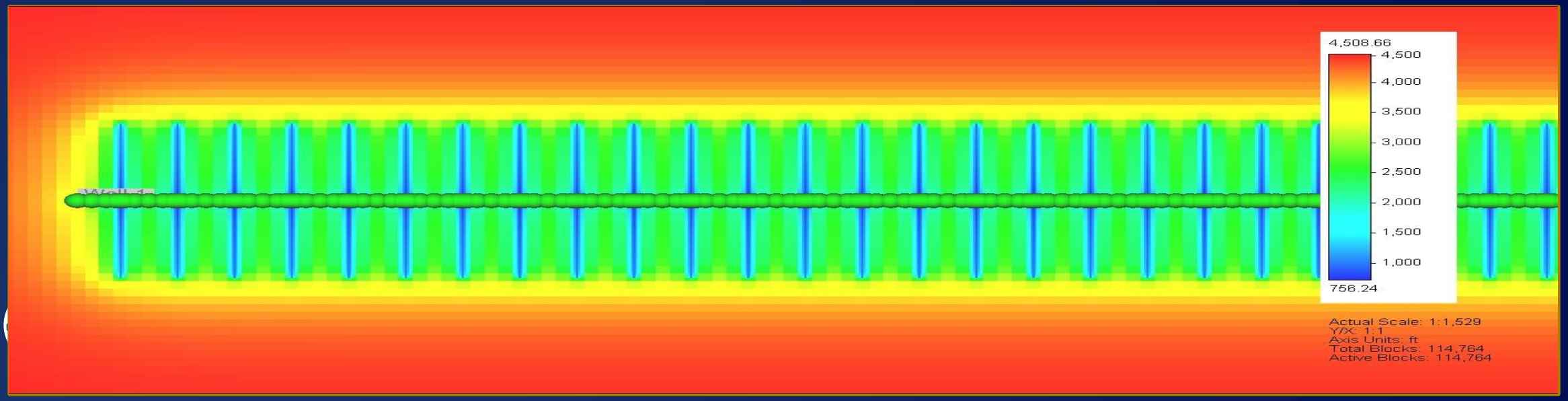
Y/X: 1:1
Axis Units: ft
Total Blocks: 114,764
Active Blocks: 114,764

Month 108


Production History - Example Well
Producing Rate, bopd
1000
100
10
10
100
1000
Producing Days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Y/X: 1:1
Axis Units: ft
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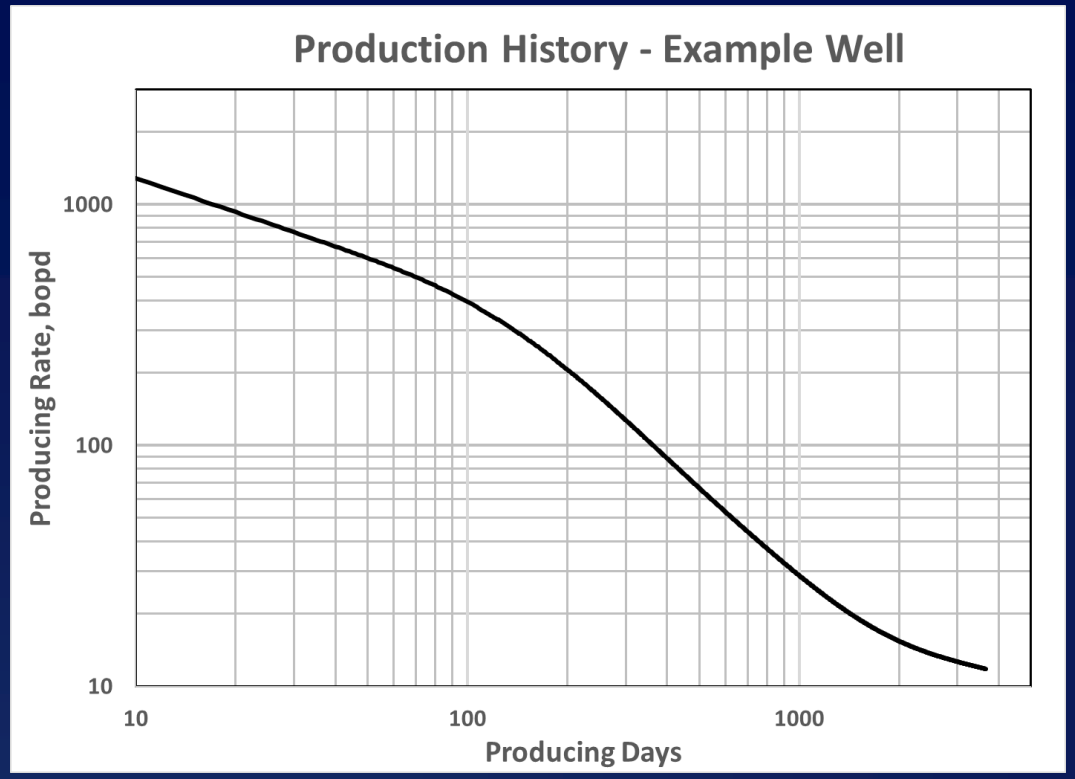
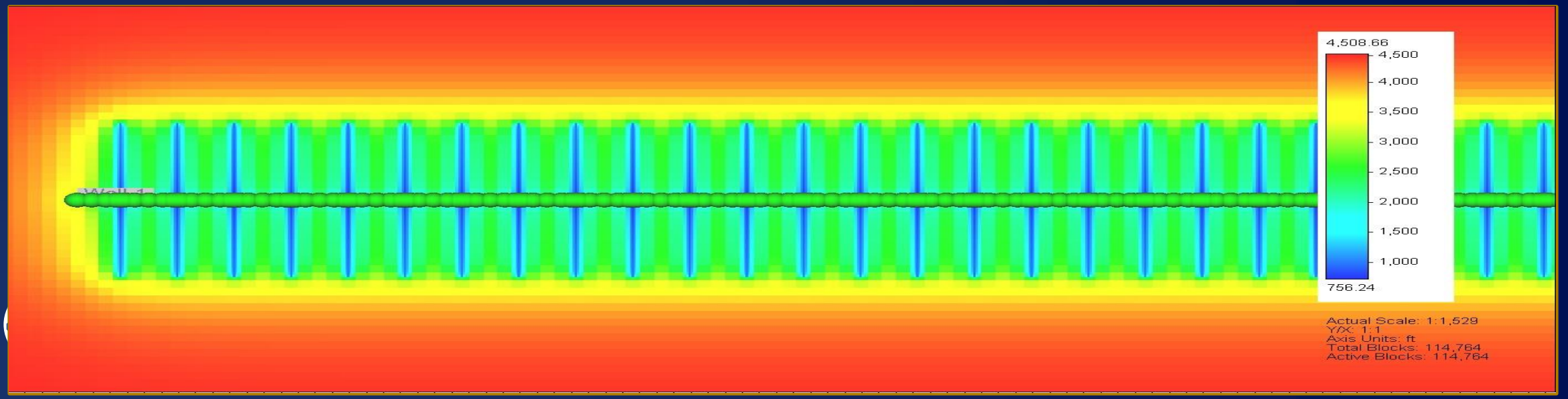
Active Blocks: 114,764

Month 120


Production History - Example Well
Producing Rate, bopd
1000
100
10
10
100
1000
Producing Days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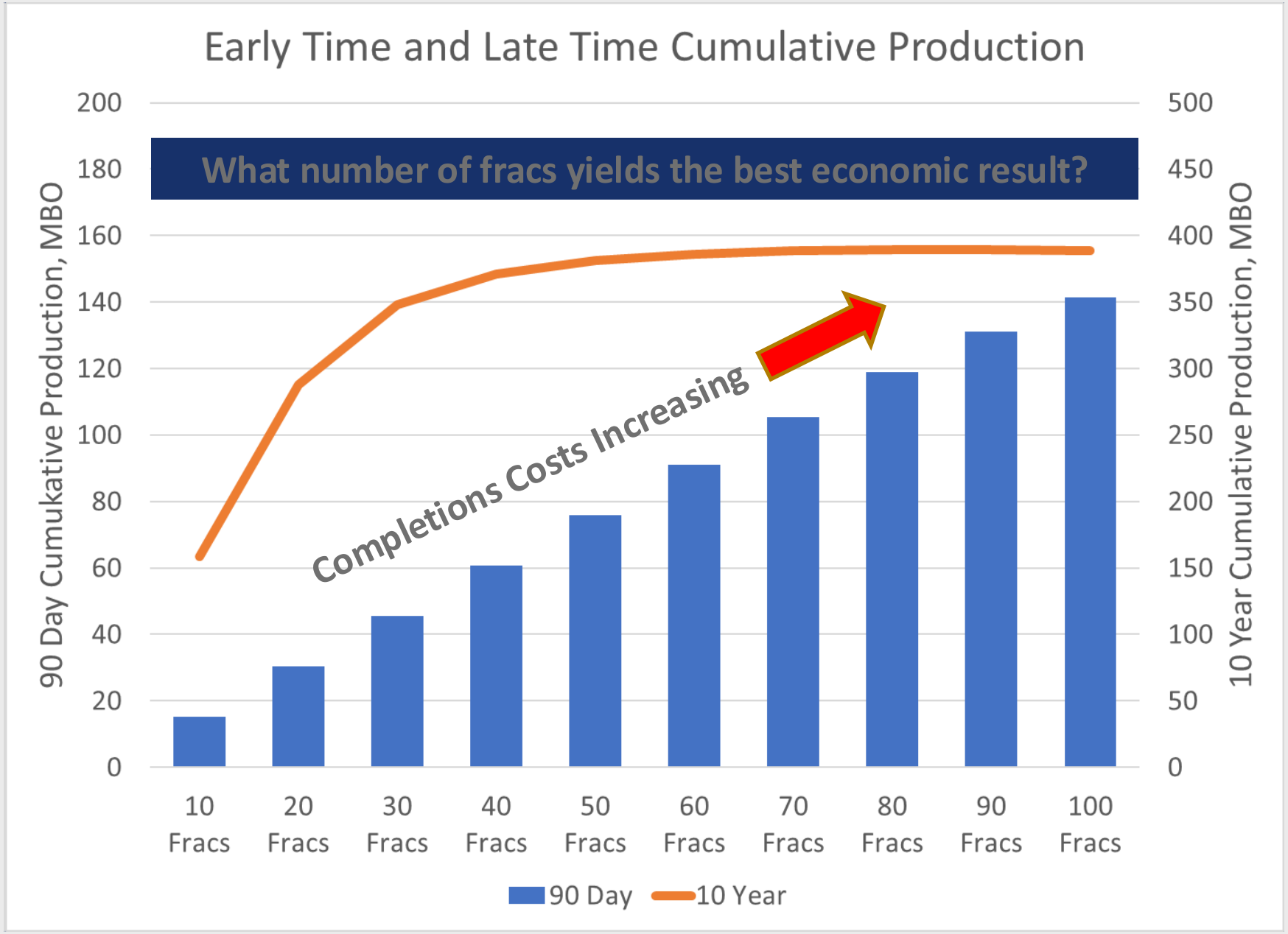

Early Time and Late Time Cumulative Production
What number of fracs yields the best economic result?
Completions Costs Increasing
90 Day Cumukative Production, MBO
10 Year Cumulative Production, MBO
200
180
160
140
120
100
80
60
40
20
0
500
450
400
350
300
250
200
150
100
50
0
10 Fracs
20 Fracs
30 Fracs
40 Fracs
50 Fracs
60 Fracs
70 Fracs
80 Fracs
90 Fracs
100 Fracs
90 Day
10 Year

Field Perm Distribution

- Tight Gas Sand Example from SPE 28610 – Moxa Arch Frontier Formation
- 3 orders of magnitude variation in permeability from well to well
- Over 80 wells evaluated

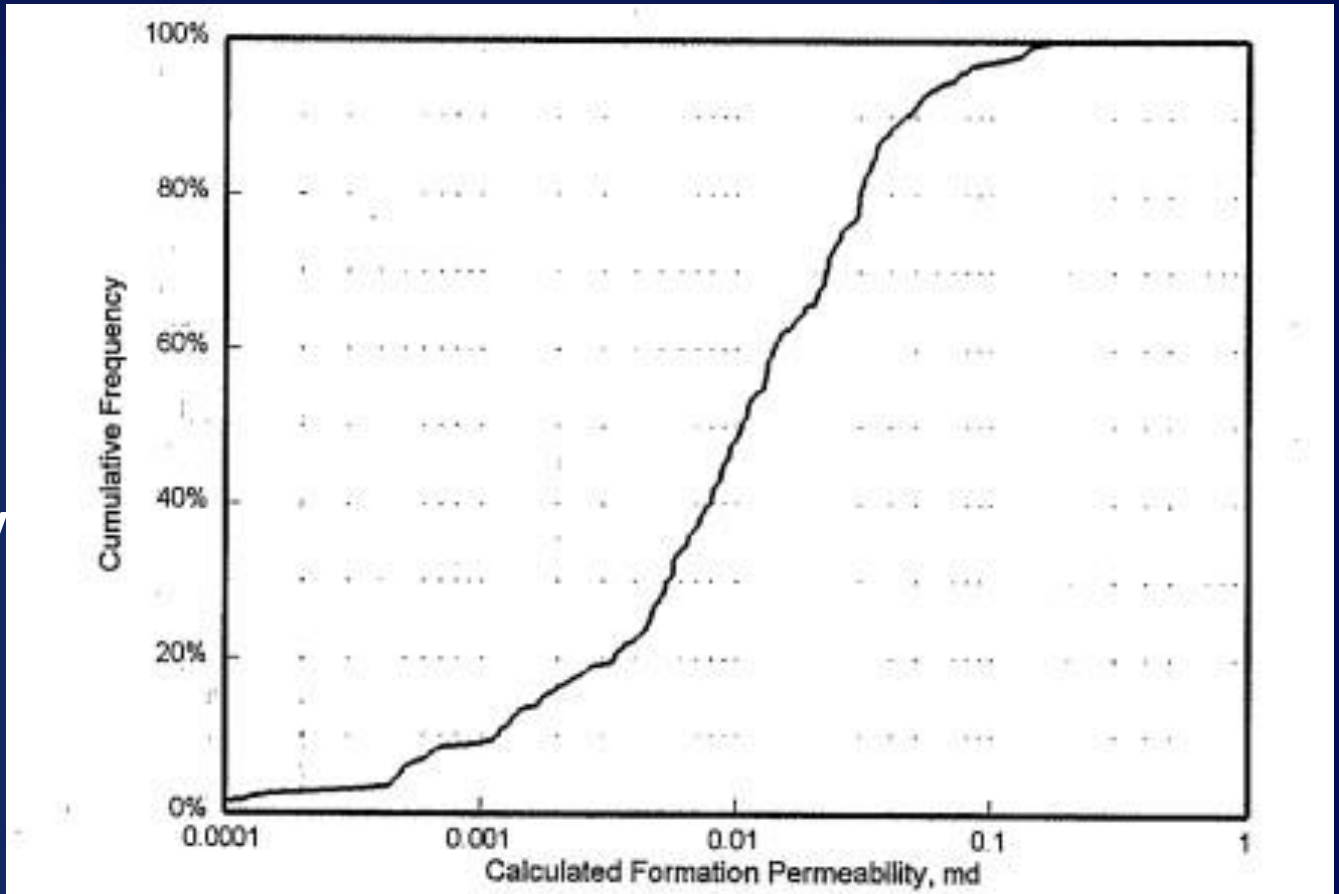
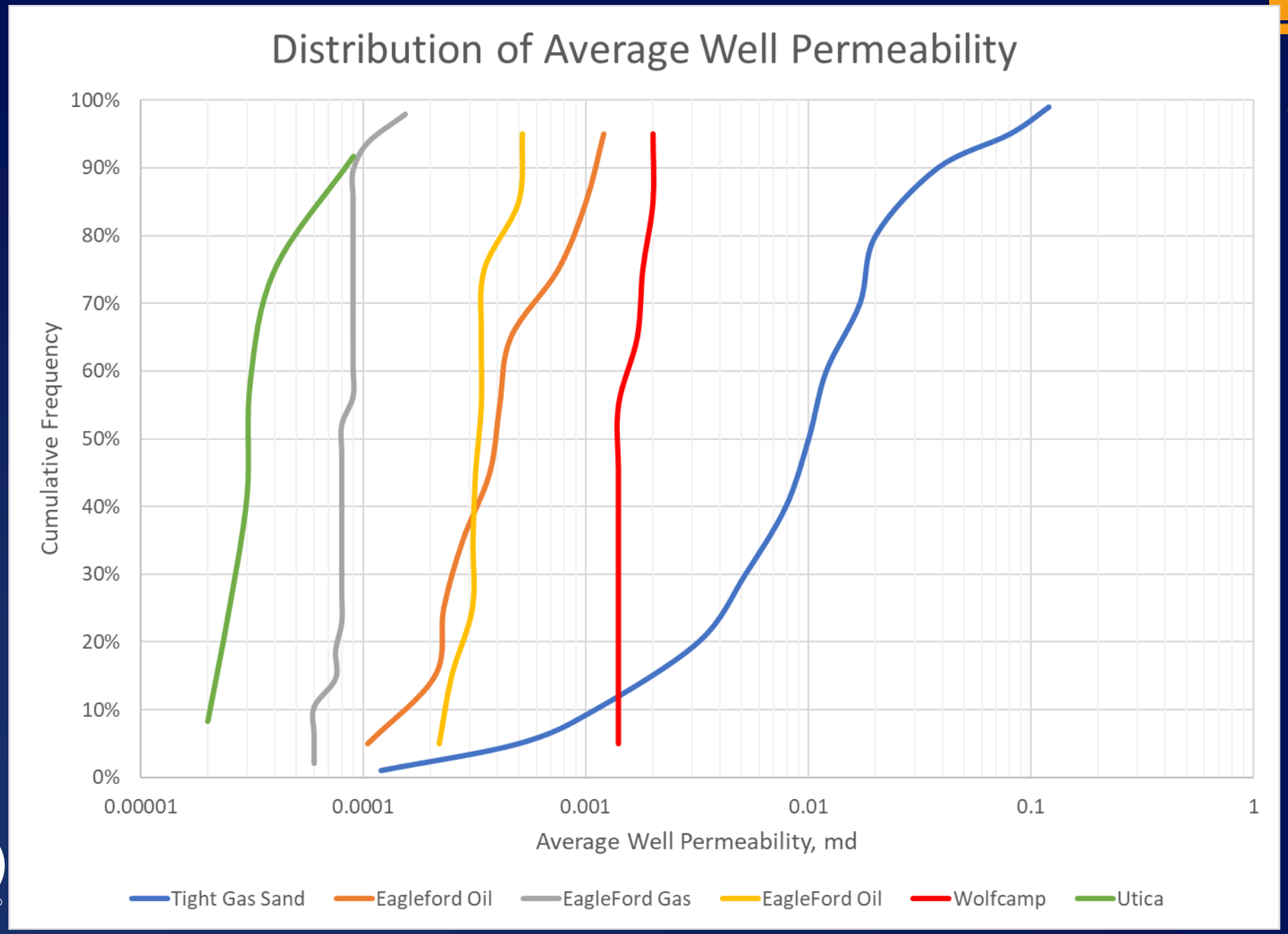


Figure 17. Calculated Formation Permeability Distribution


Distribution of Average Well Permeability
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative Frequency
0.00001
0.0001
0.001
0.01
0.1
1
Average Well Permeability, md
Tight Gas Sand
Eagleford Oil
EagleFord Gas
EagleFord Oil
Wolfcamp
Utica

Reservoir Characterization leads to Optimization

- Using production evaluation & production history matching
  - Formation permeability can be estimated
  - Effective lengths of created fractures can be determined
  - The number of producing fractures for a given completion design can be determined
- Using the same models we used to evaluate the production
  - Estimate the production from different future completion designs
  - Perform economics to determine the optimum design

- Knowing the well cost for all possible completion scenarios we can run the reservoir simulator for all possible completion configurations and determine revenue generated for each scenario
- We do this for over 1000 completion design scenarios and determine the NPV for each case
- This let's us know where the current completion design economics are and which direction we need to go to improve

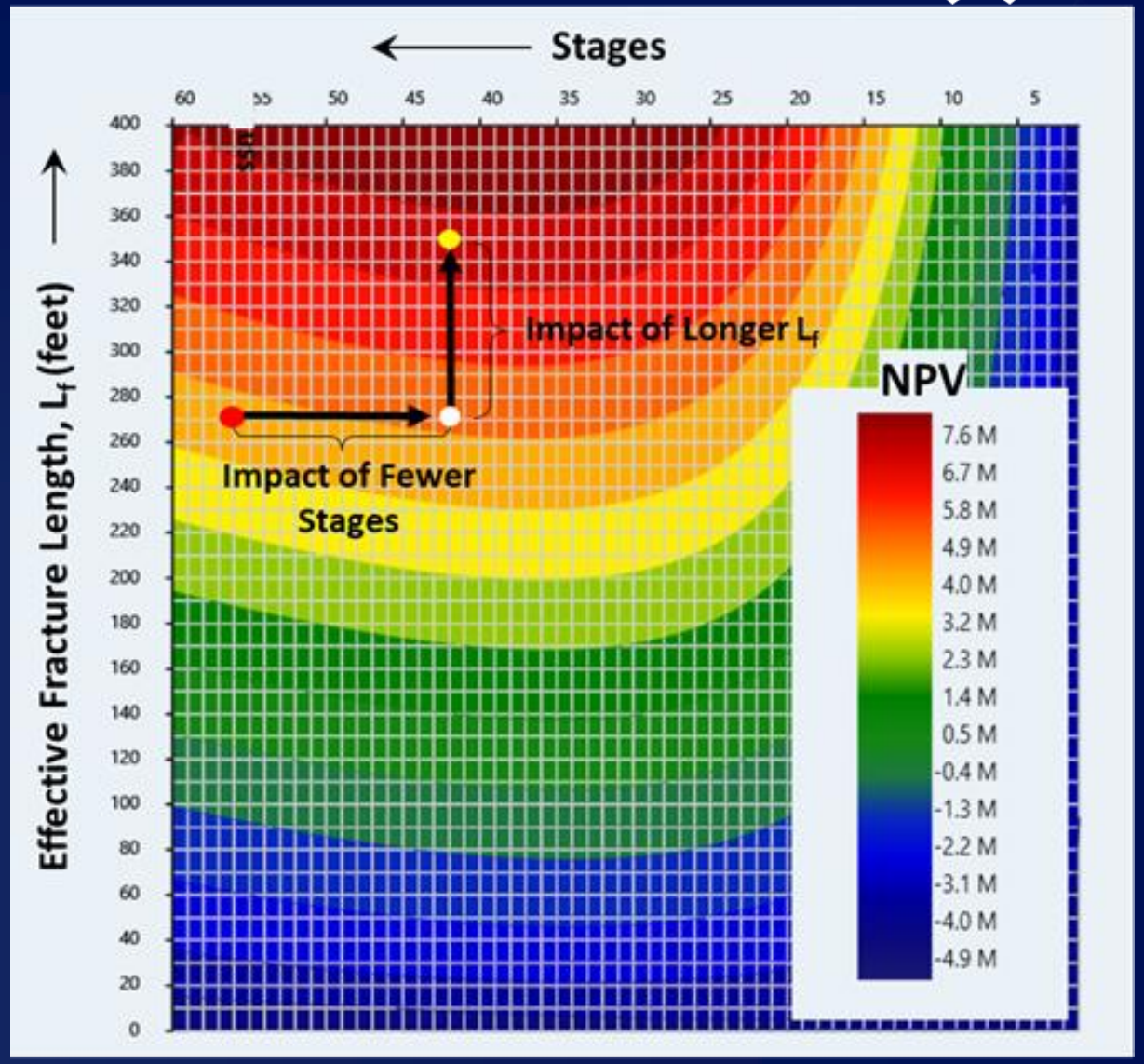
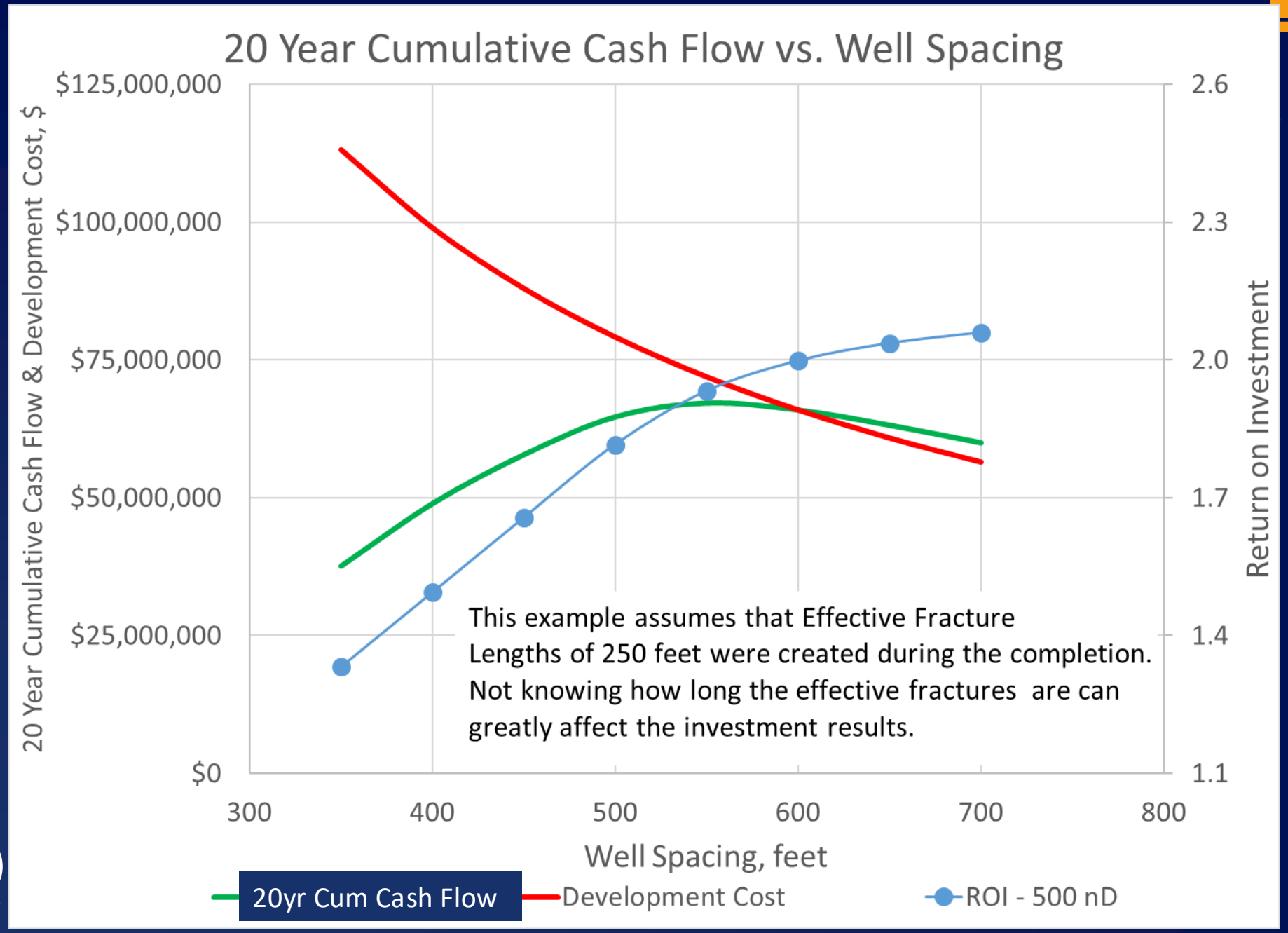


Figure 5 - NPV Road Map @ 400 nD

SPE 201716

Optimizing Well Spacing

- Reservoir simulation models can be used to Optimize Well Spacing using Optimized Completion Design
  - Determine the effect of well spacing on ultimate recovery
  - Perform field development economics on acreage to be developed


20 Year Cumulative Cash Flow vs. Well Spacing
20 Year Cumulative Cash Flow & Development Cost, $
$125,000,000
$100,000,000
$75,000,000
$50,000,000
$25,000,000
$0
2.6
2.3
2.0
1.7
1.4
1.1
Return on Investment
300
400
500
600
700
800
Well Spacing, feet
This example assumes that Effective Fracture Lengths of 250 feet were created during the completion. Not knowing how long the effective fractures are can greatly affect the investment results.
20yr Cum Cash Flow
Development Cost
ROI - 500 nD

Environmental Impact of Optimized Design – Stage & Well Spacing

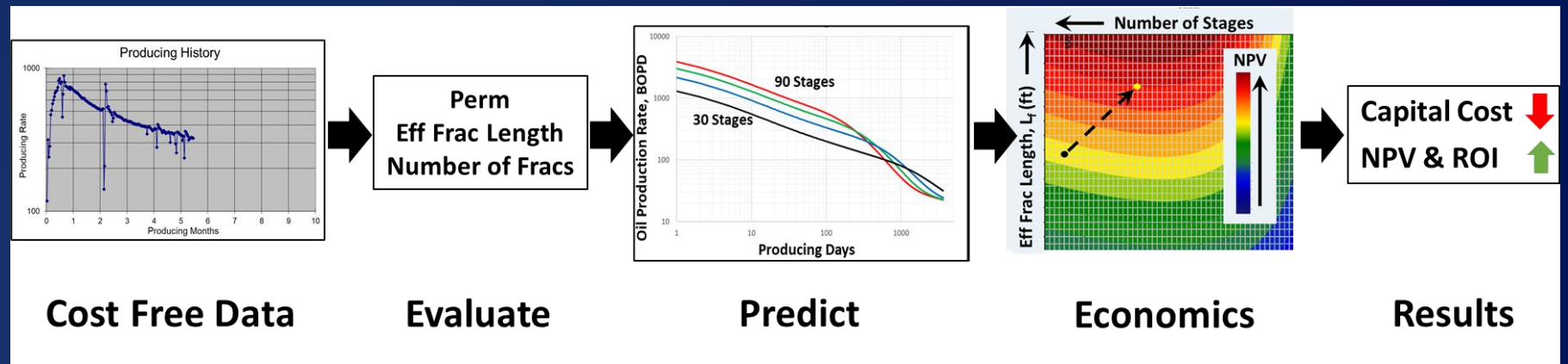
***assuming the development of 50,000 acres**

- Reduced number of wells to develop acreage – **234 vs. 335**
- Reduced frac water volume needed by **80 million barrels**
- Reduced frac sand needed by **3.2 billion pounds**
- Reduced diesel fuel needed by **15 million gallons**
- Reduced CO_2 emissions from diesel fuel by **195 thousand tons**

- Reduced capital needed to develop acreage - **$932 million**

Summary

- Optimizing economics on horizontal multi-stage completions can be a complex process
- Production history matching can determine the primary reservoir/completion properties we need to know:
  - Formation permeability
  - Effective fracture half-length achieved
  - Number of dominant producing fractures
- Millions of dollars of capital costs can be Reduced and Profit added
- A major **positive Environmental Impact** can be achieved



Webinars

Thank you for joining today!

SPE International

Interstate Oil & Gas Compact Commission

EDF Environmental Defense Fund — Finding the ways that work