

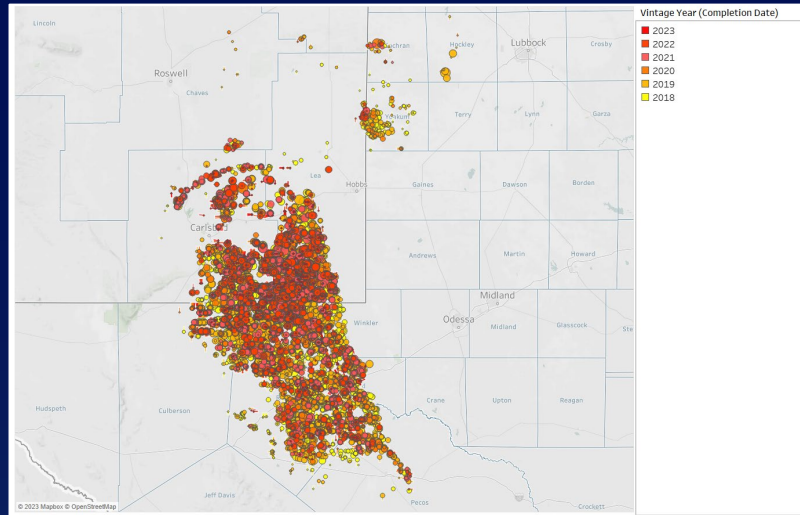
# Welcome!

The program will begin soon.  
You will not hear audio until we begin.

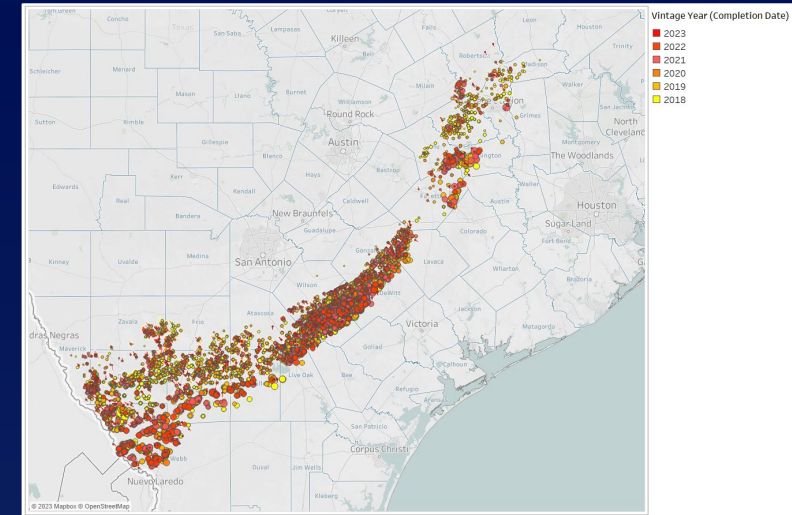
# Unconventional Basins: Frac and Completion Trends

Mike Mayerhofer, Liberty Energy  
January 24, 2024

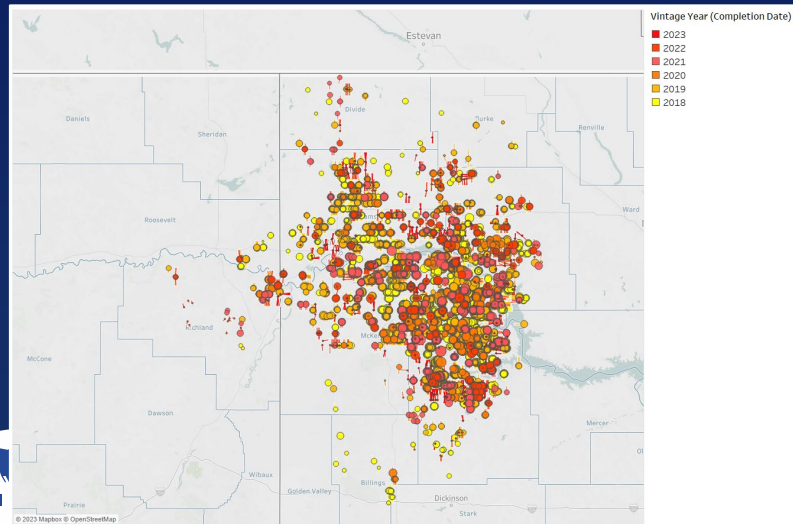
# Delaware Basin



# Eagleford

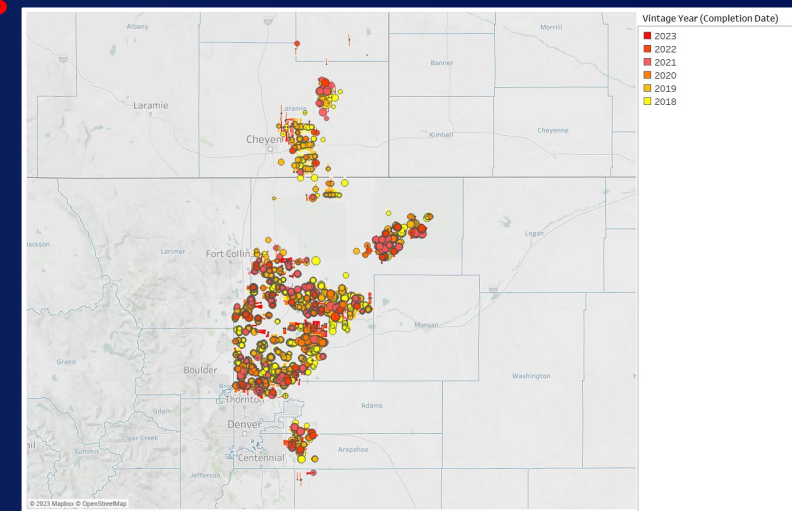


# Williston

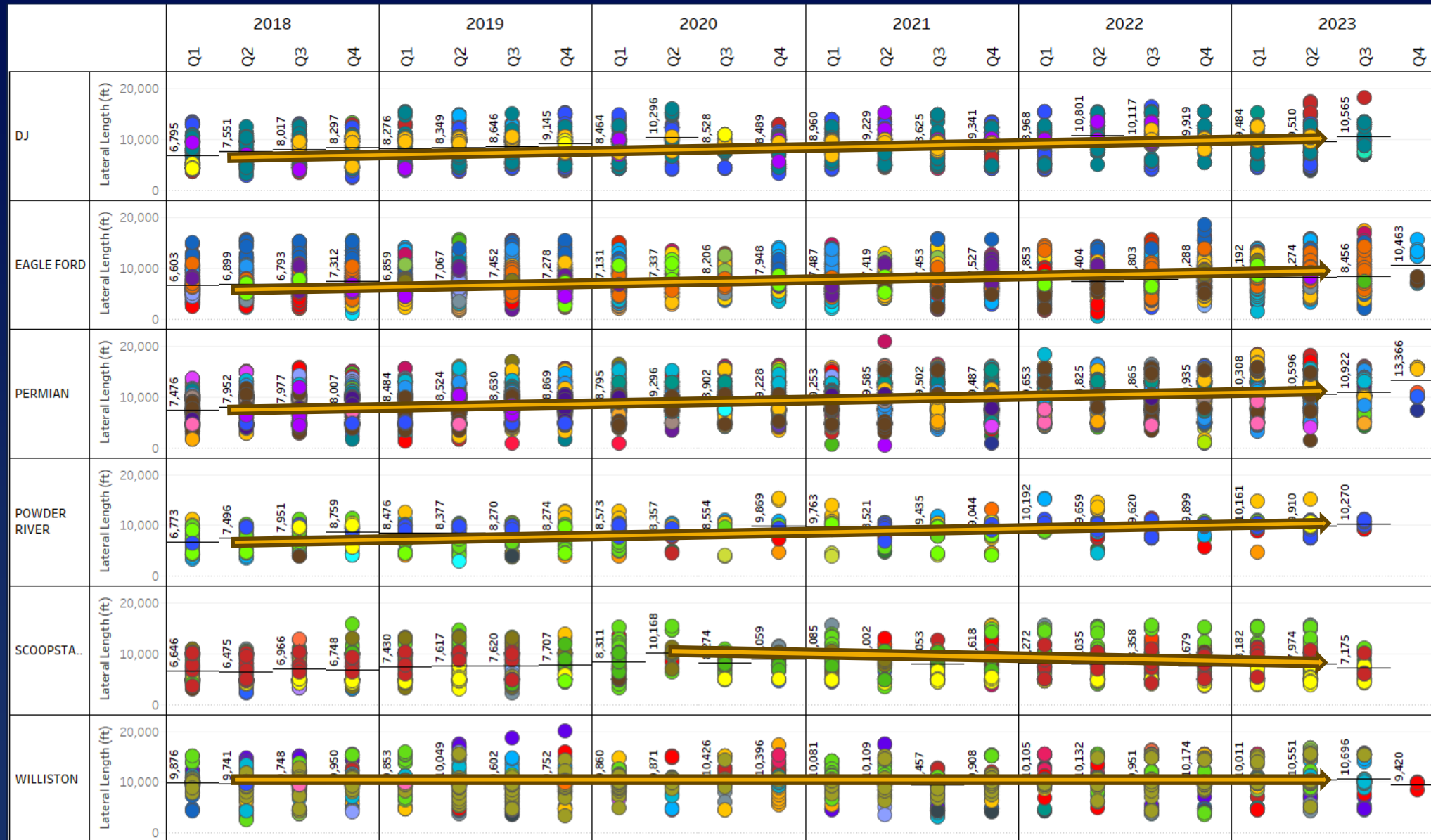


Horizontal Wells  
Completed from  
2018 to 2023

# DJ



# Unconventional Basins Horizontal Well Length Trends

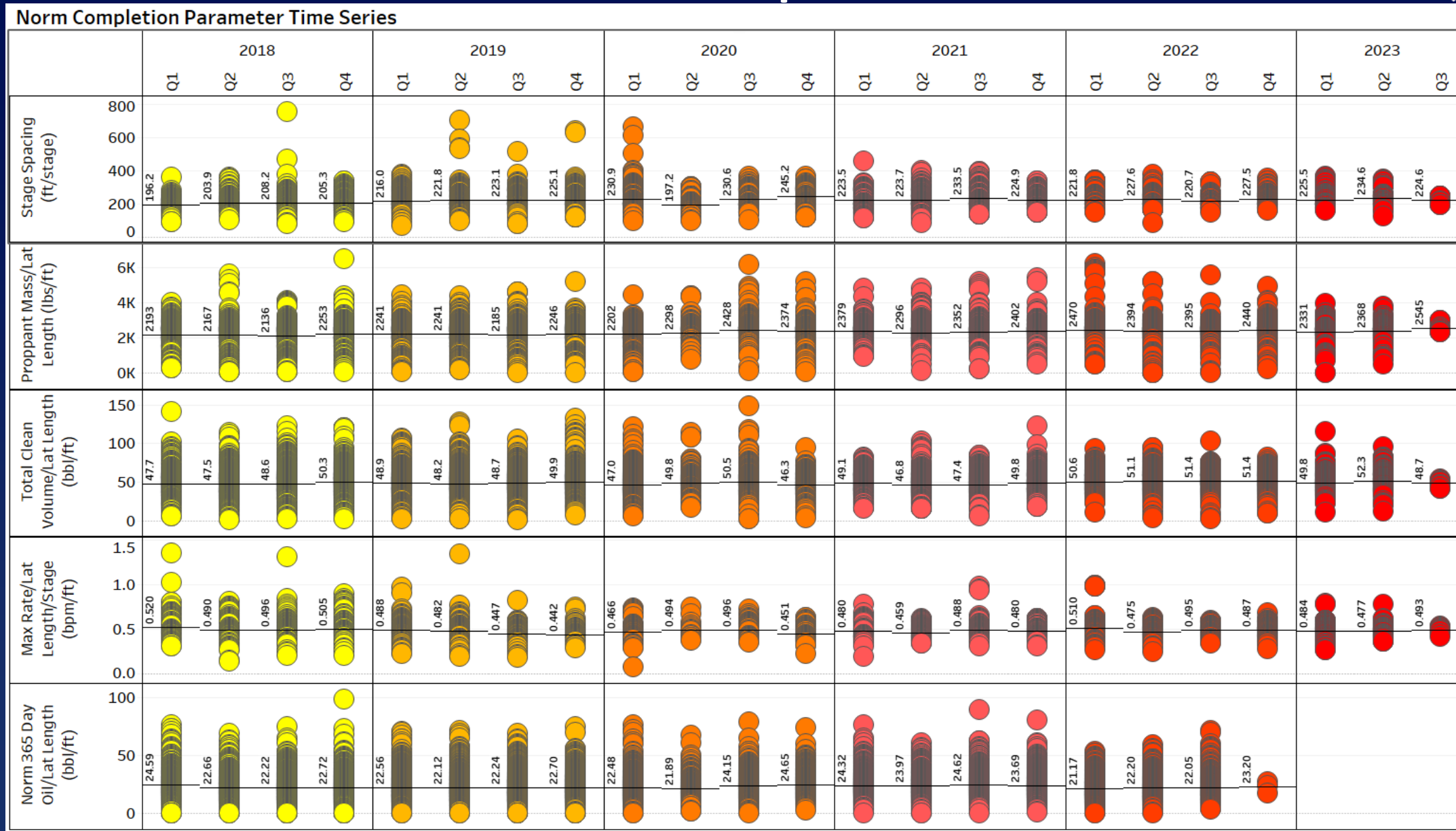


Increasing Average Lengths (7,000 ft to >10,000 ft) but large range still in 2023

Decrease from 2020 to 2023

Flat at 10,000 ft average

# Delaware Basin Completion Trends



Flat trend  
225 ft/stage

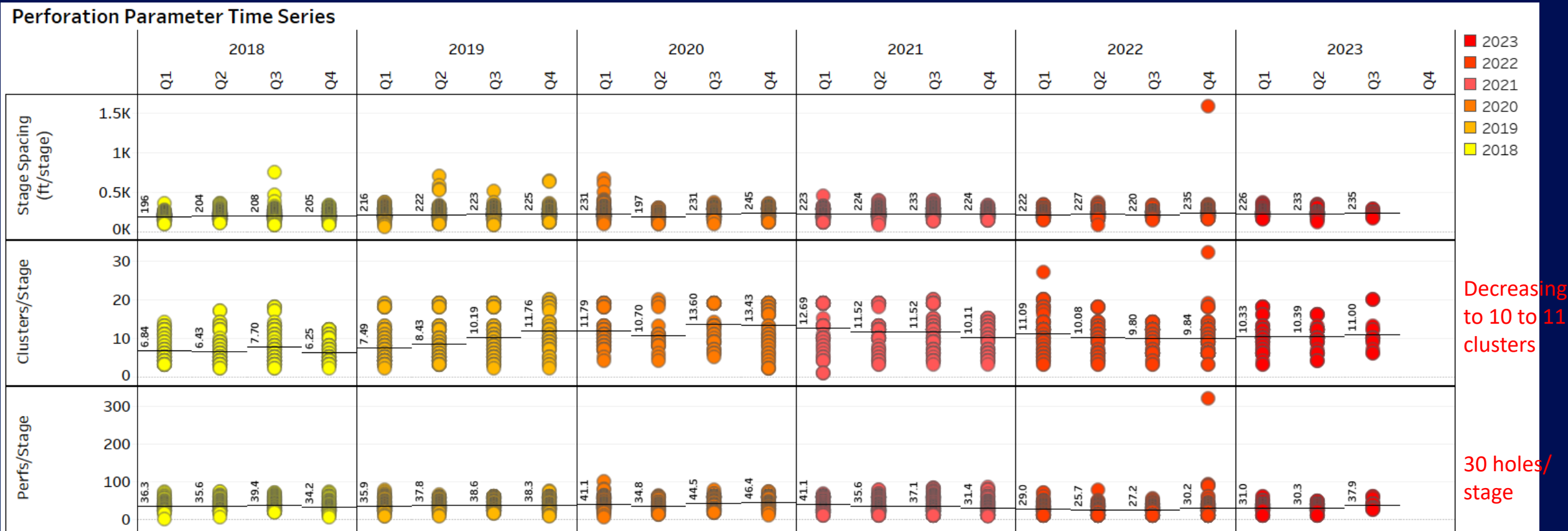
Flat trend  
2,400 lbs/ft

Flat trend  
50 bbls /ft

Flat trend  
0.5 bpm /ft

Decrease of  
BO/ft in 2022

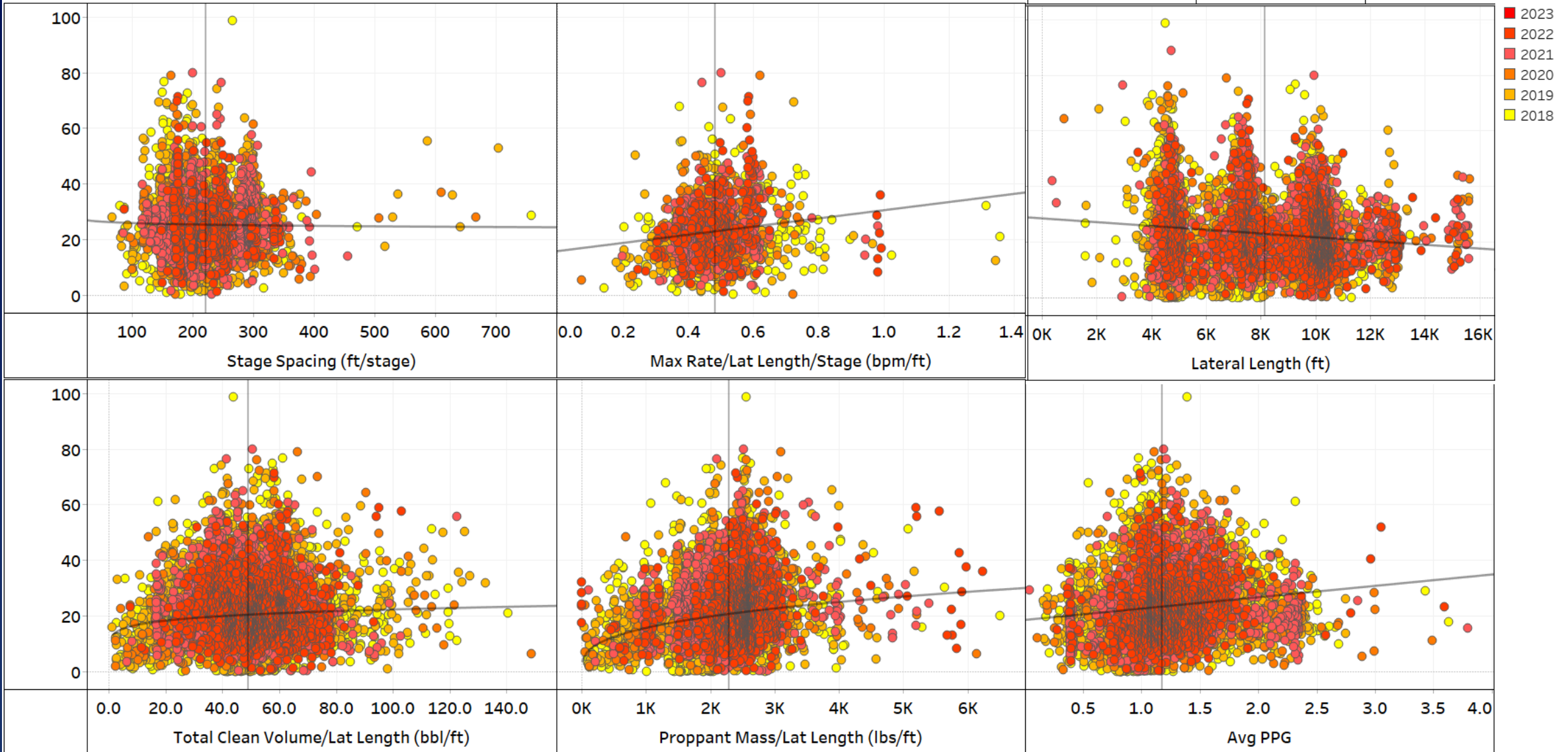
# Delaware Basin Completion Trends



# Delaware Basin Completion Trends



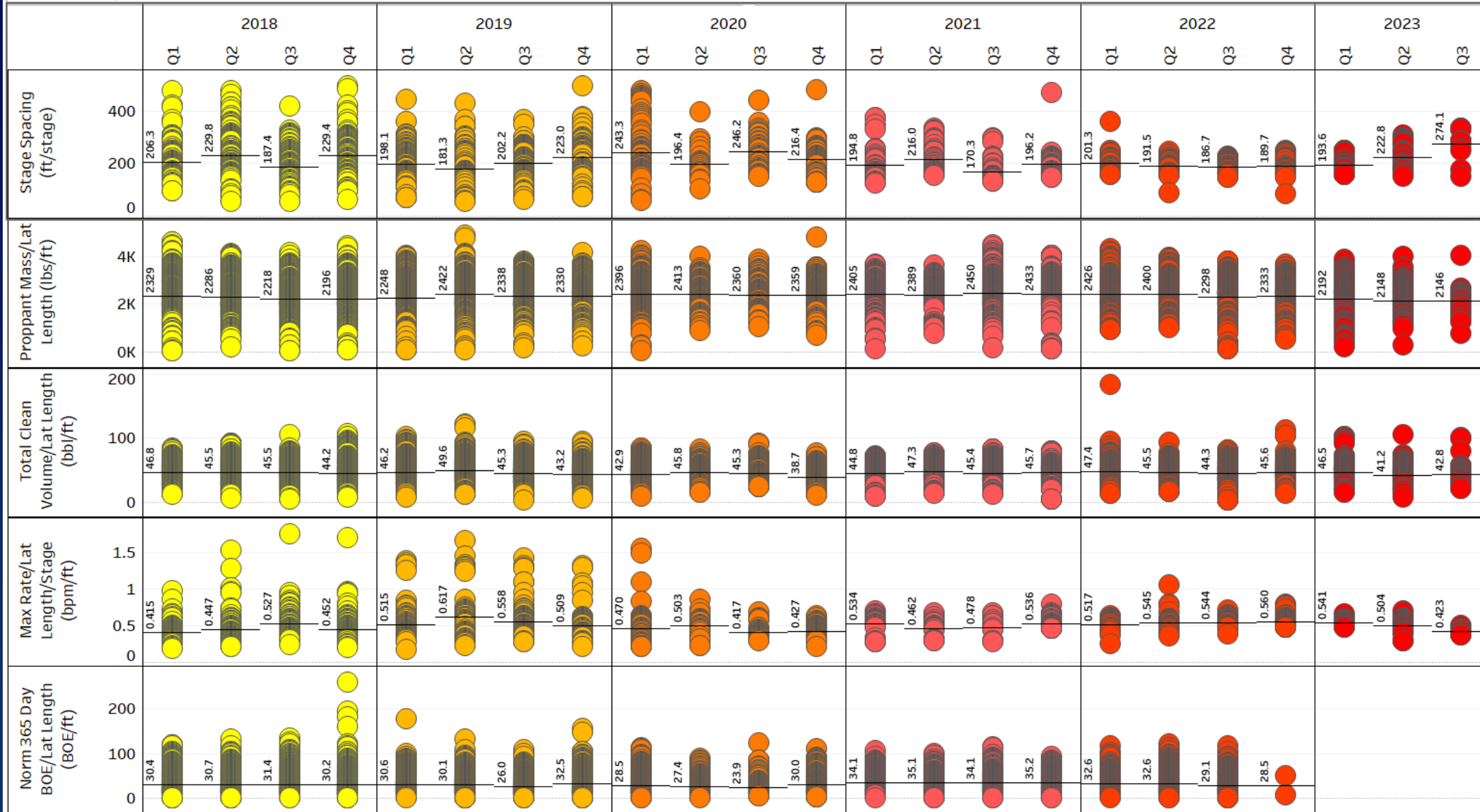
Norm 365 Day Oil/Lat Length (bbl/ft) vs. General Completions Parameters



# Eagleford Completion Trends



Norm Completion Parameter Time Series



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

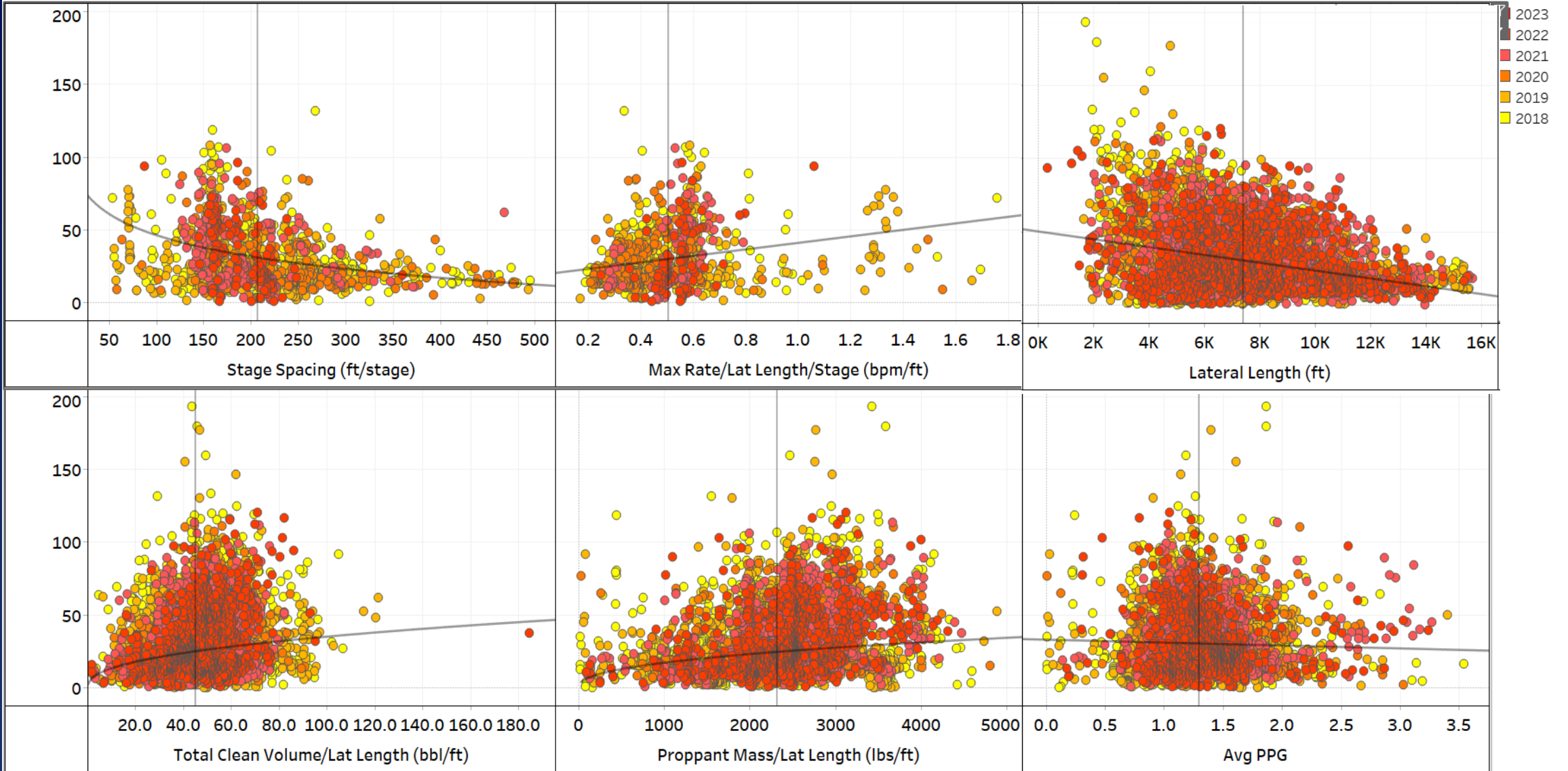


Perforation Parameter Time Series



# Eagleford Completion Trends

Norm 365 Day BOE/Lat Length (BOE/ft) vs. General Completions Parameters

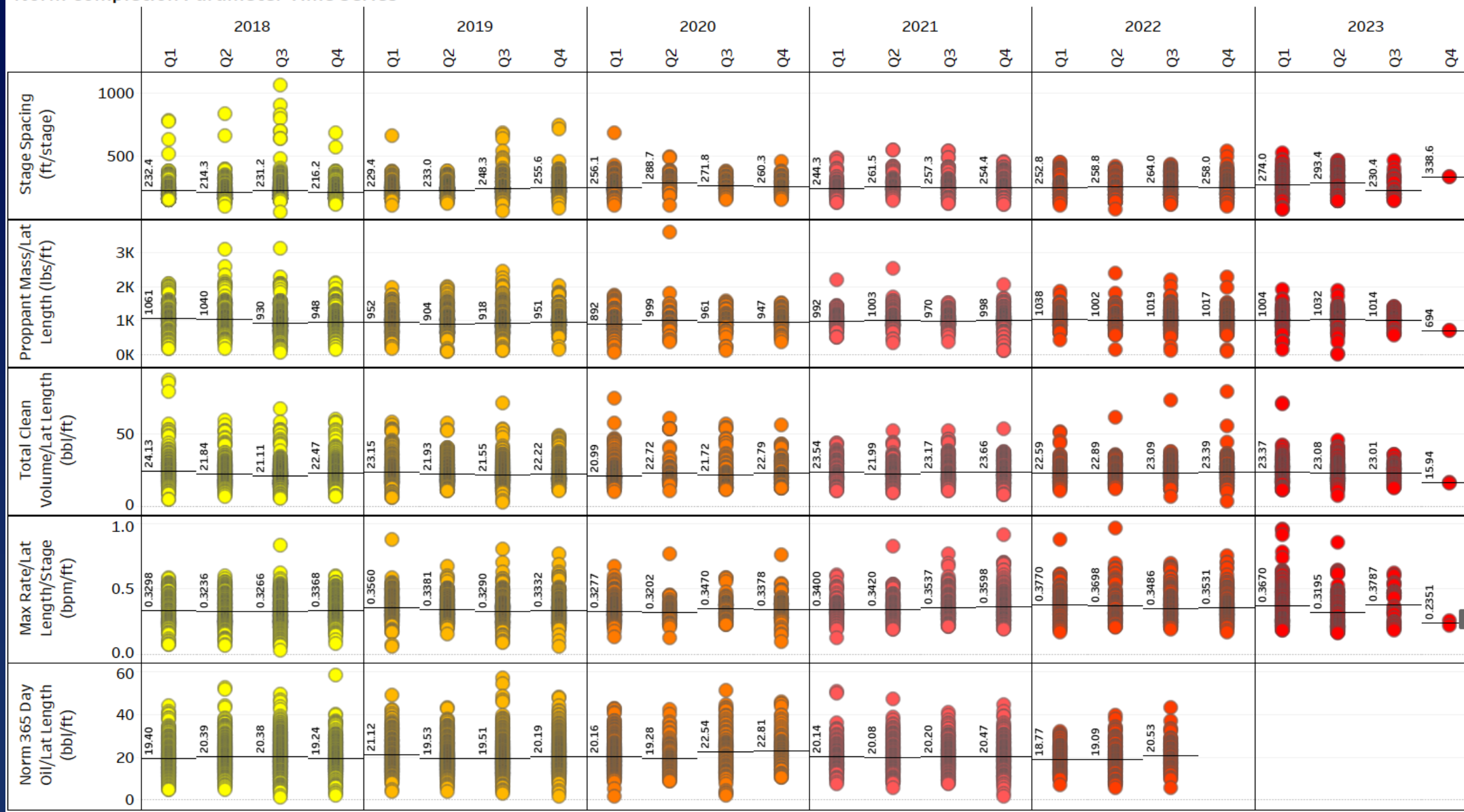


# Williston Basin Completion Trends



binars

Norm Completion Parameter Time Series



Fairly flat  
>250 ft/stage

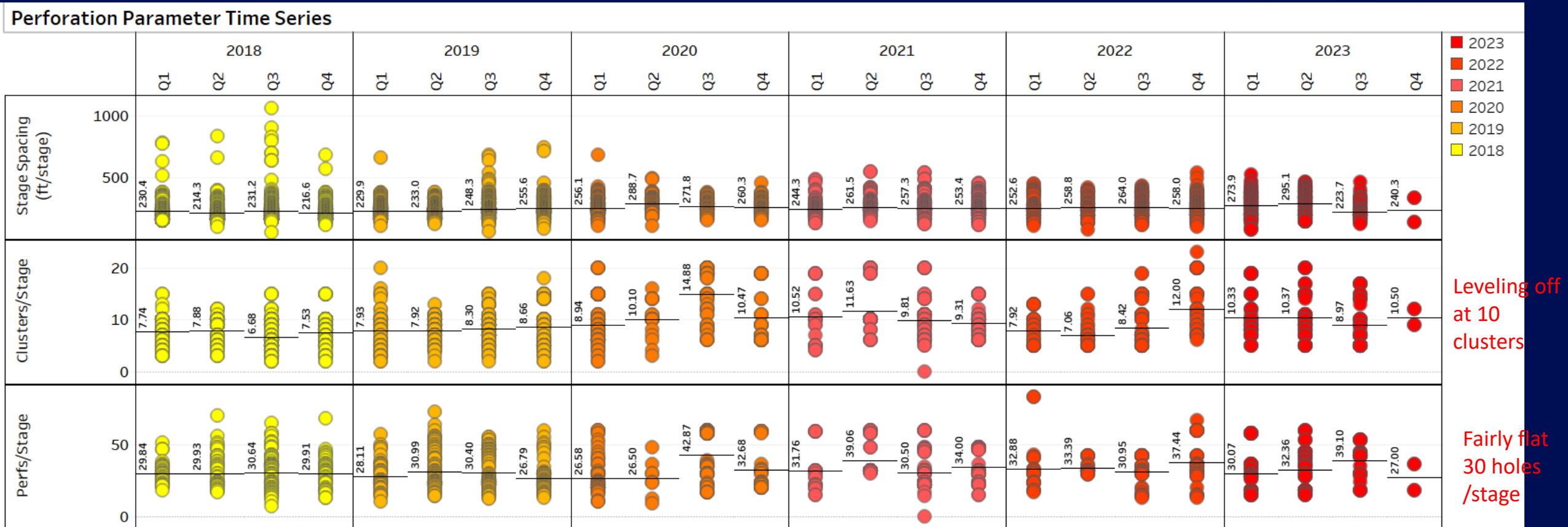
Leveled off  
at 1,000  
lbs/ft

Flat trend  
23 bbls /ft

Flat trend  
0.37 bpm /ft

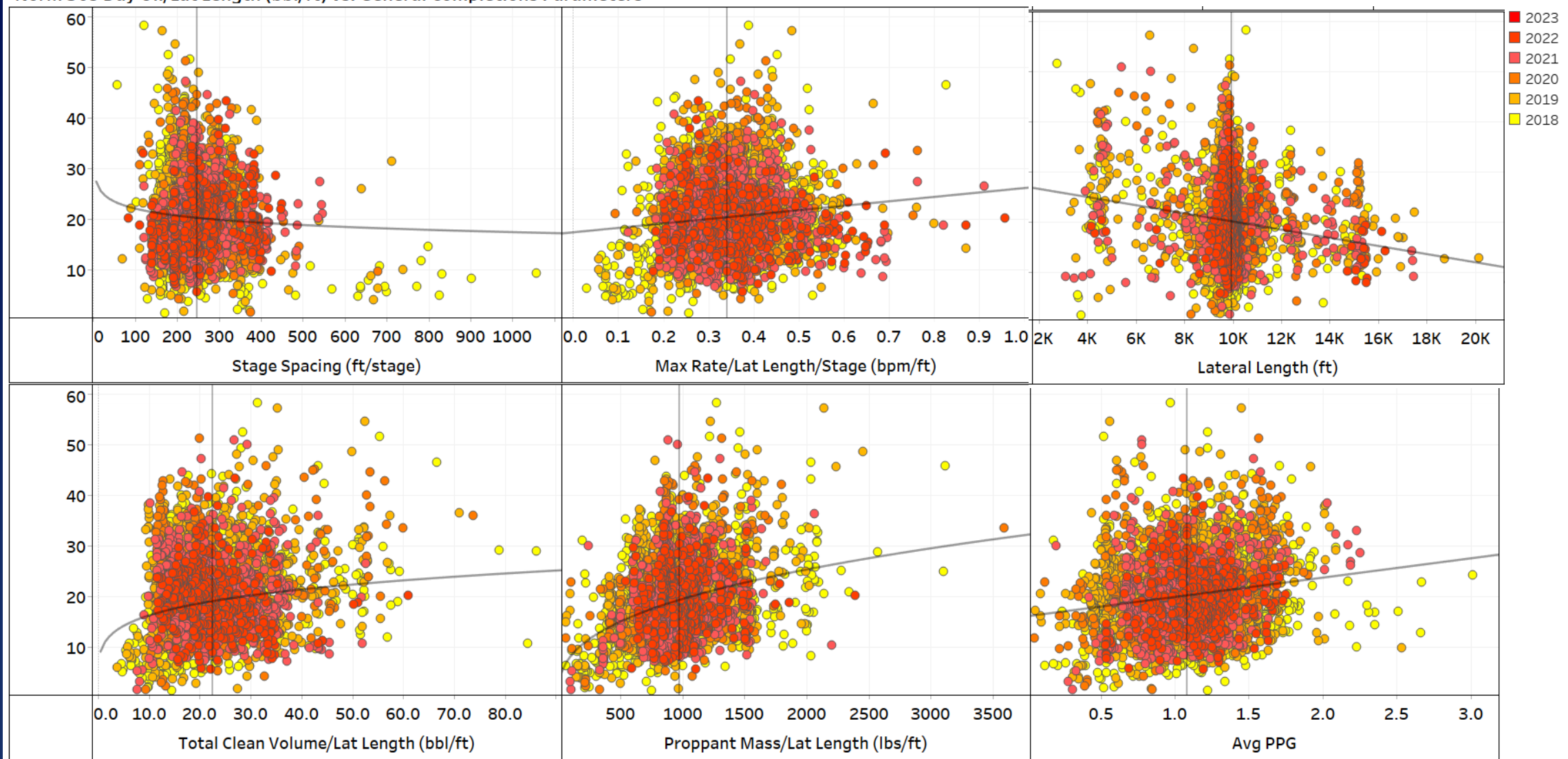
Decrease in  
2021 and 2022

# Williston Basin Completion Trends



# Williston Basin Completion Trends

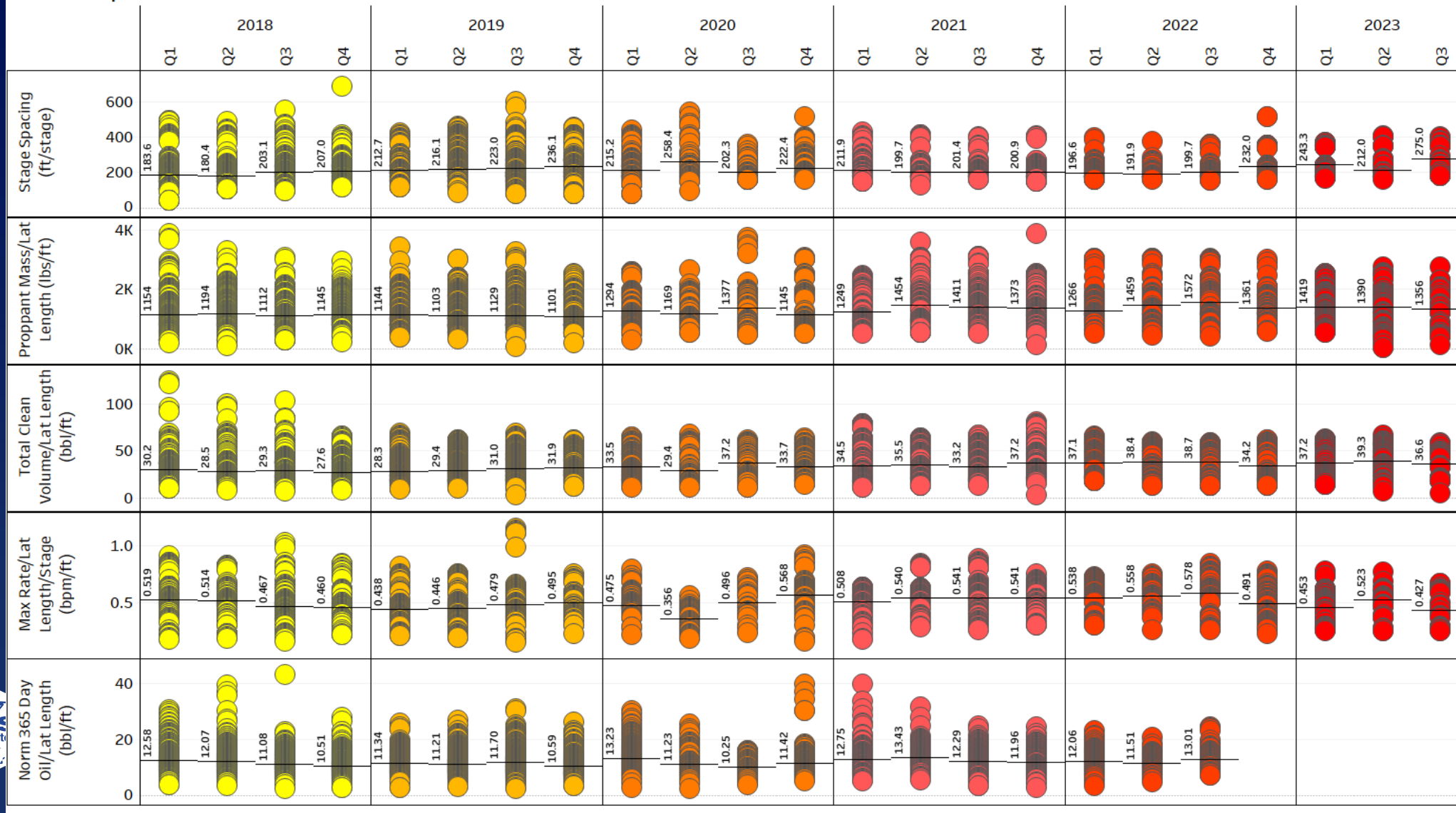
Norm 365 Day Oil/Lat Length (bbl/ft) vs. General Completions Parameters



# DJ Basin Completion Trends



Norm Completion Parameter Time Series



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

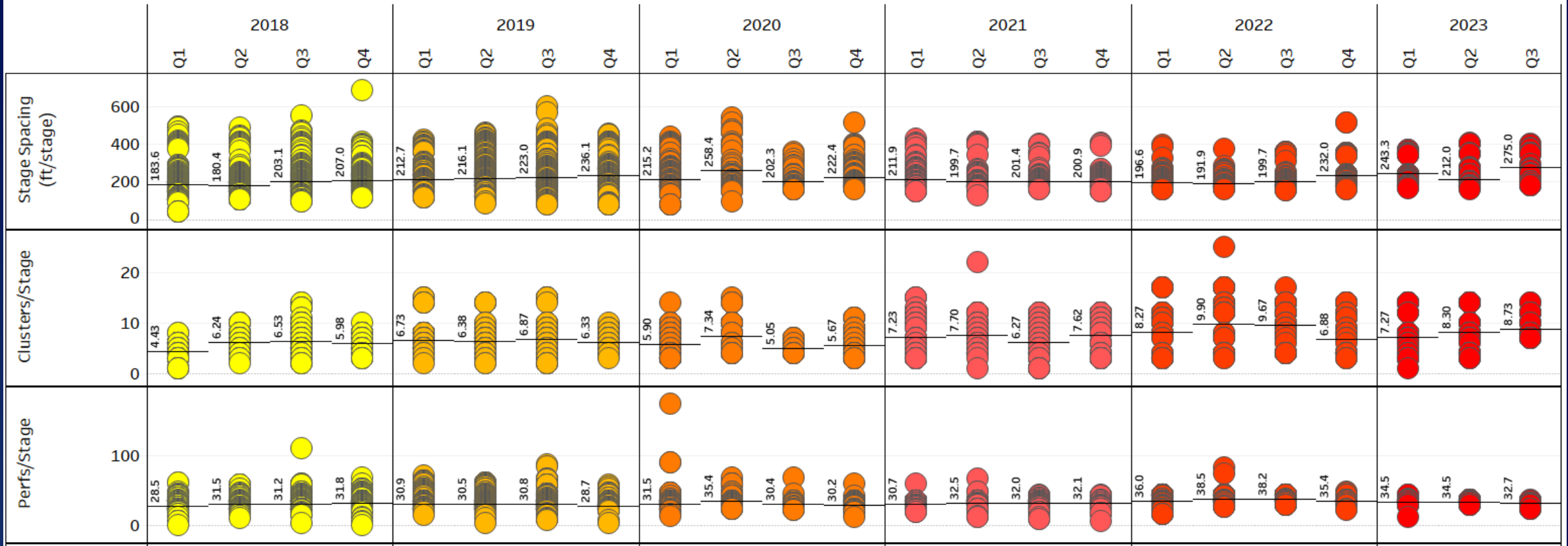
Fairly flat



# DJ Basin Completion Trends



Perforation Parameter Time Series

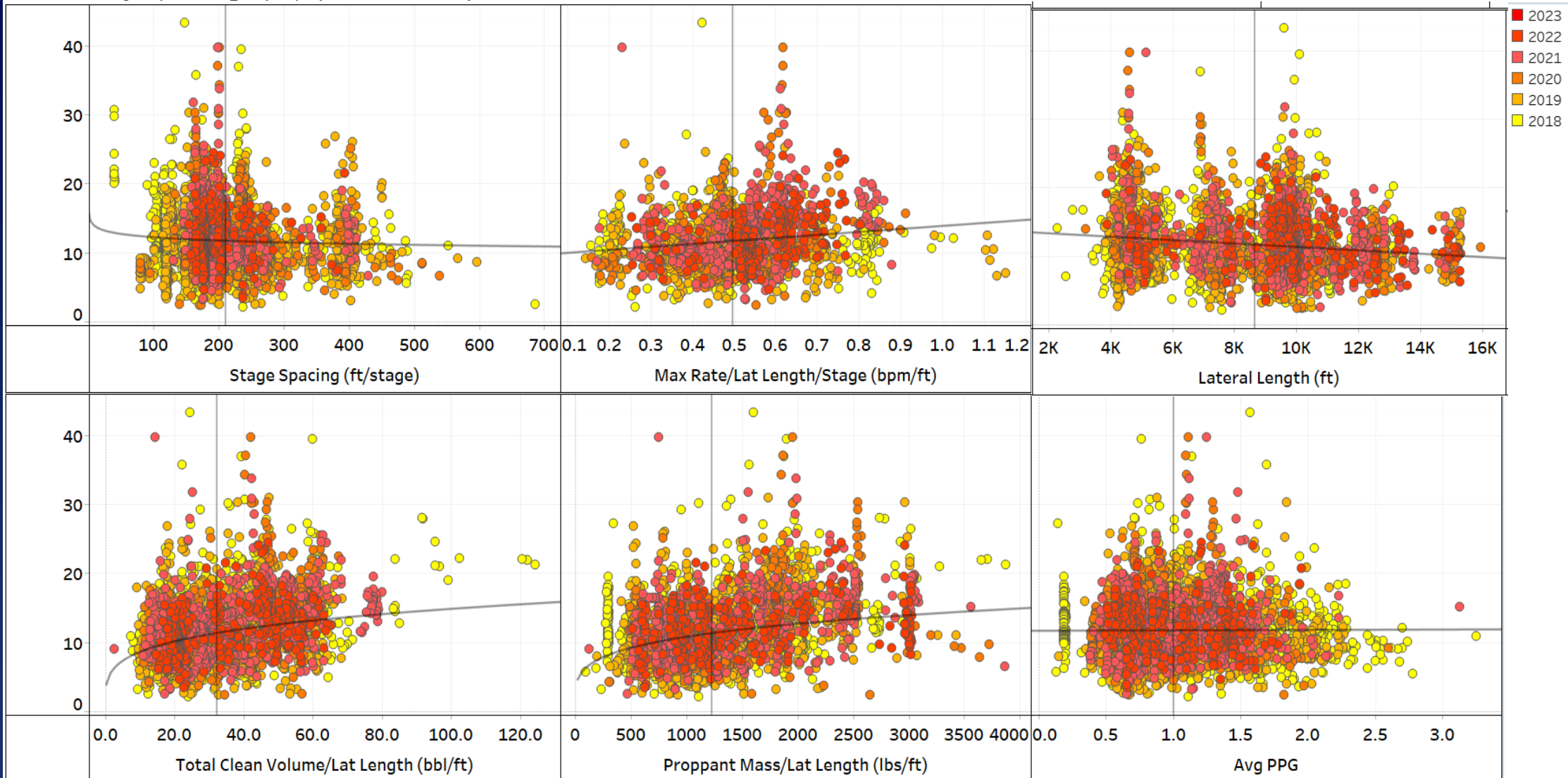


Leveling off  
at 7 to 9  
clusters

Fairly flat  
34 holes/  
stage

# DJ Basin Completion Trends

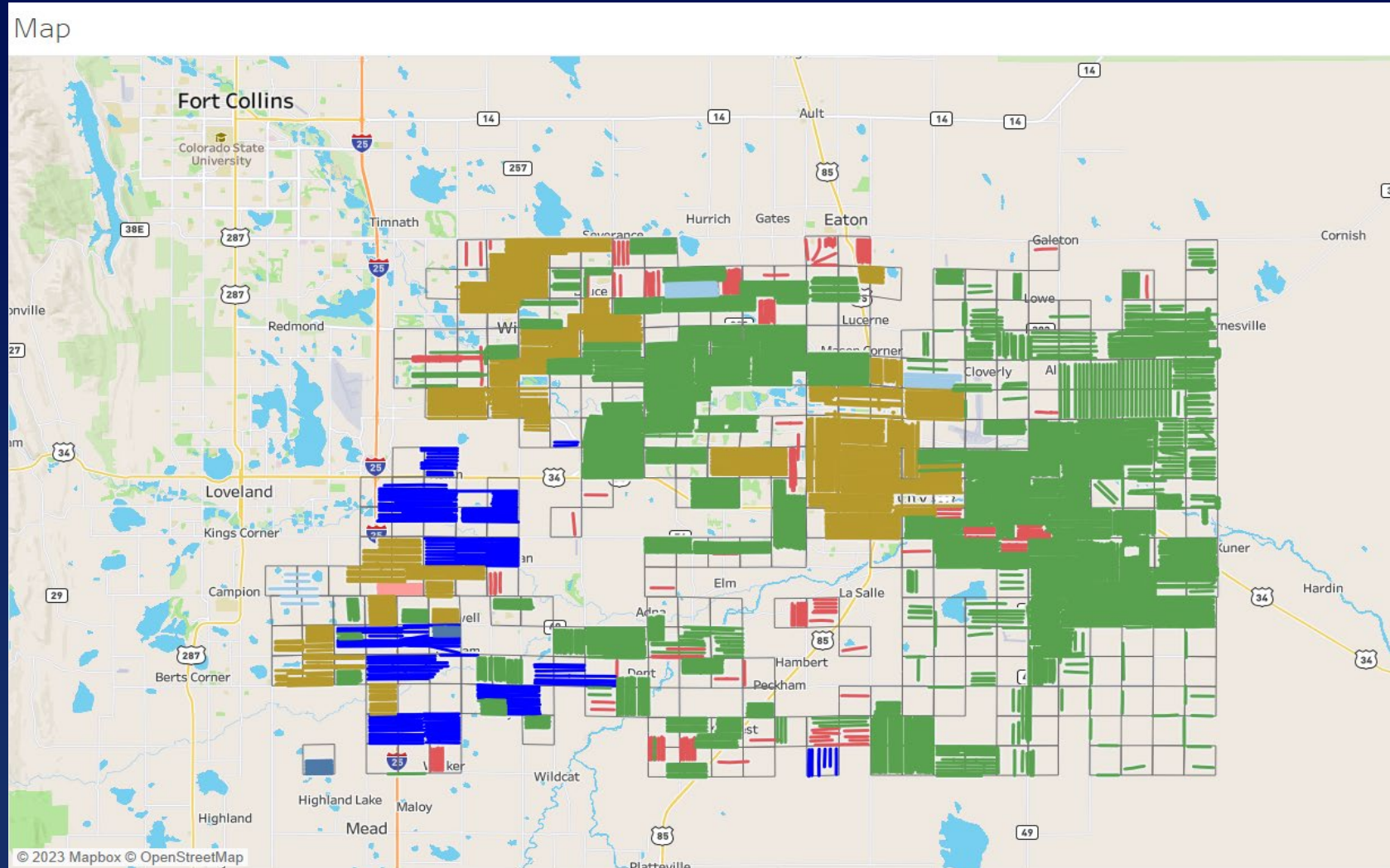
Norm 365 Day Oil/Lat Length (bbl/ft) vs. General Completions Parameters



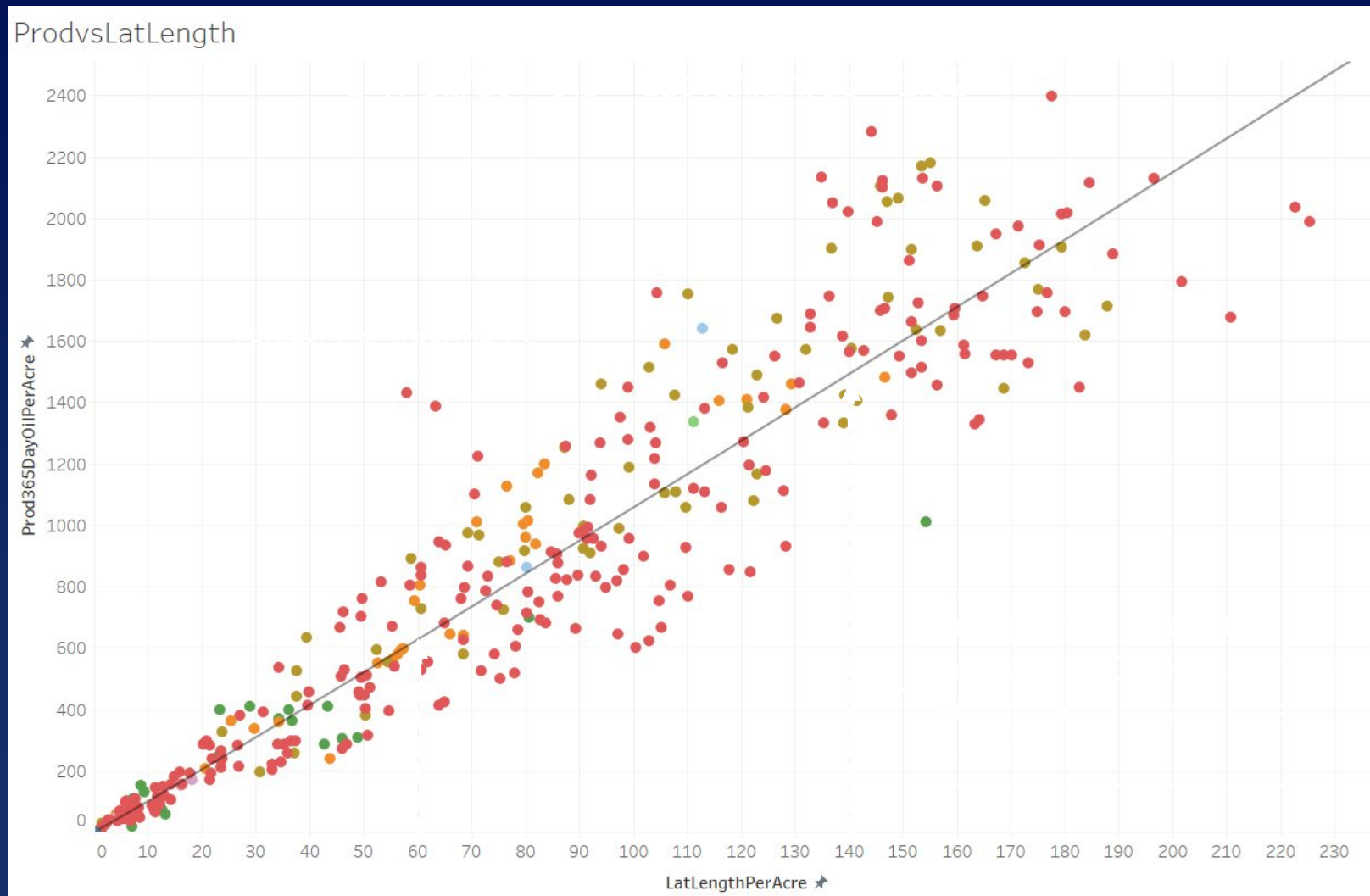
# Main Takeaways

- 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



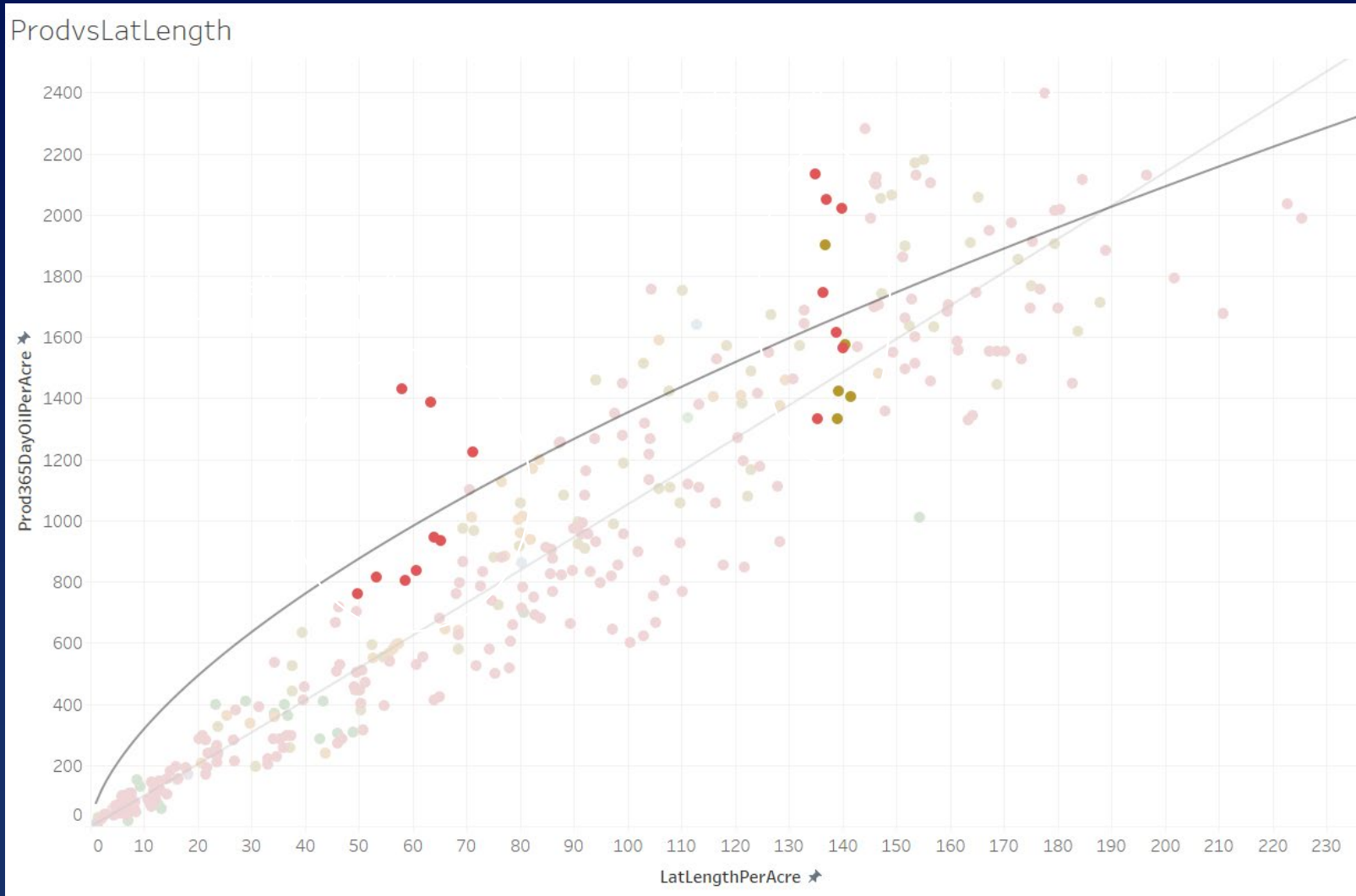
# 365 Day Oil per Acre vs Lat Length per Acre (WPS) (All Landing Zones)



\$ 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)

# Production as a Diagnostic Tool

Stephen Schubarth

1-24-2024



# 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



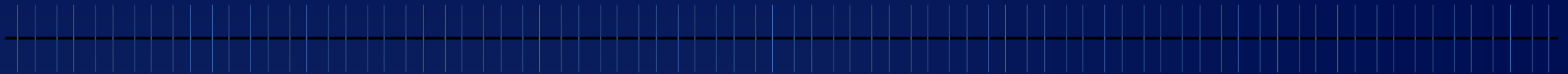
# Examples of Fracture Spacing along 10k Lateral



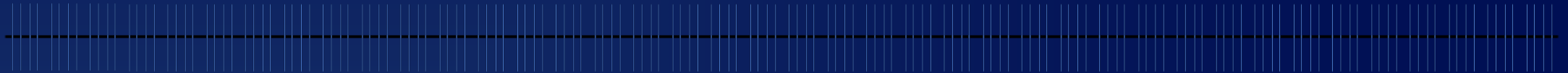
Fractured Area = SRV



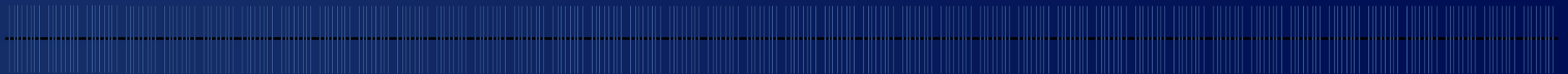
40 Created Fracs – 250' between fracs –  $L_f = 250$  feet



80 Created Fracs – 125' between fracs –  $L_f = 250$  feet



160 Created Fracs – 62.5' between fracs –  $L_f = 250$  feet



320 Created Fracs – 31.25' between fracs –  $L_f = 250$  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:

- $Q_n = \frac{Q}{(P_i - P_{wf})} * (P_i - P_n) \dots\dots\text{for Oil}$

- $Q_n = \frac{Q}{(P_i^2 - P_{wf}^2)} * (P_i^2 - P_n^2) \dots\dots\text{for Gas}$

- Where:

- $Q_n$  = Normalized Rate
    - $Q$  = Actual Rate
    - $P_i$  = Initial Pressure
    - $P_{wf}$  = Flowing pressure
    - $P_n$  = Normalized flowing pressure (the flowing pressure the model will be produced at)

# Time Normalization



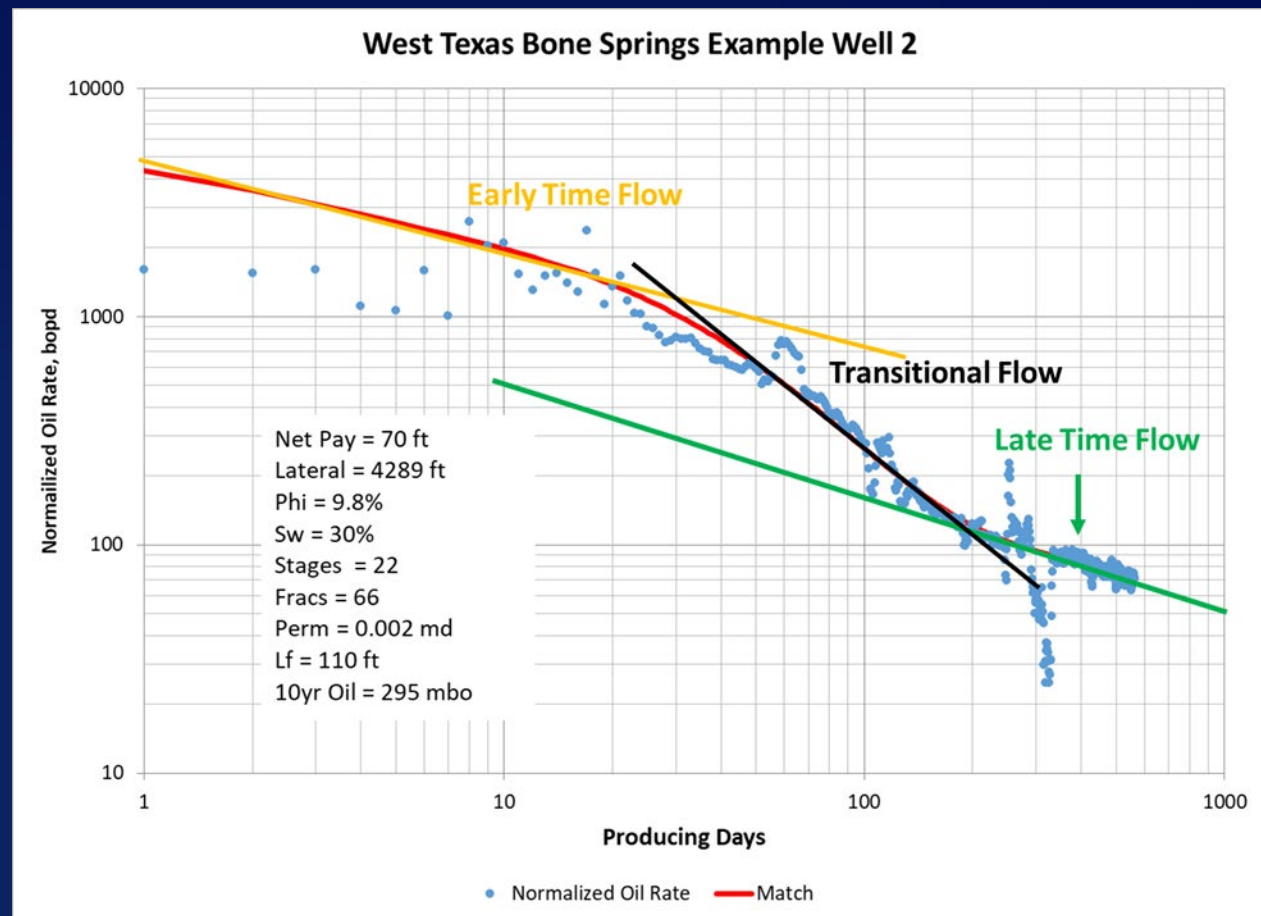
- Normalized time:
  - $\Delta tn = \frac{Q}{Qn}$
  - Where:
    - $\Delta tn$  = Normalized incremental time
    - $Q$  = Actual Rate
    - $Qn$  = Normalized rate



- 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  |

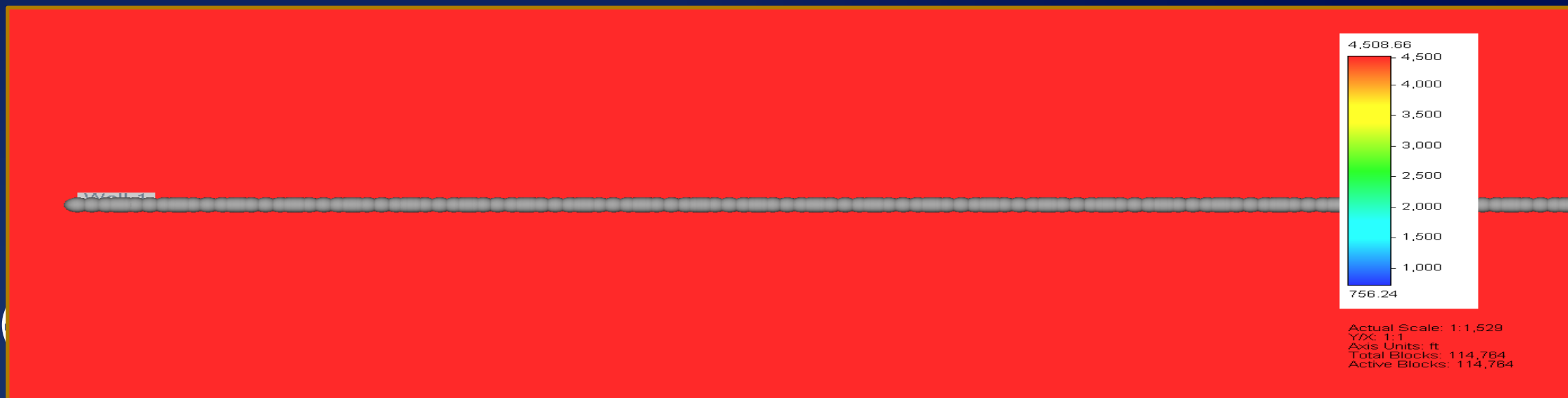
## Production Characteristics of Horizontal Multi-Stage Fractured Wells



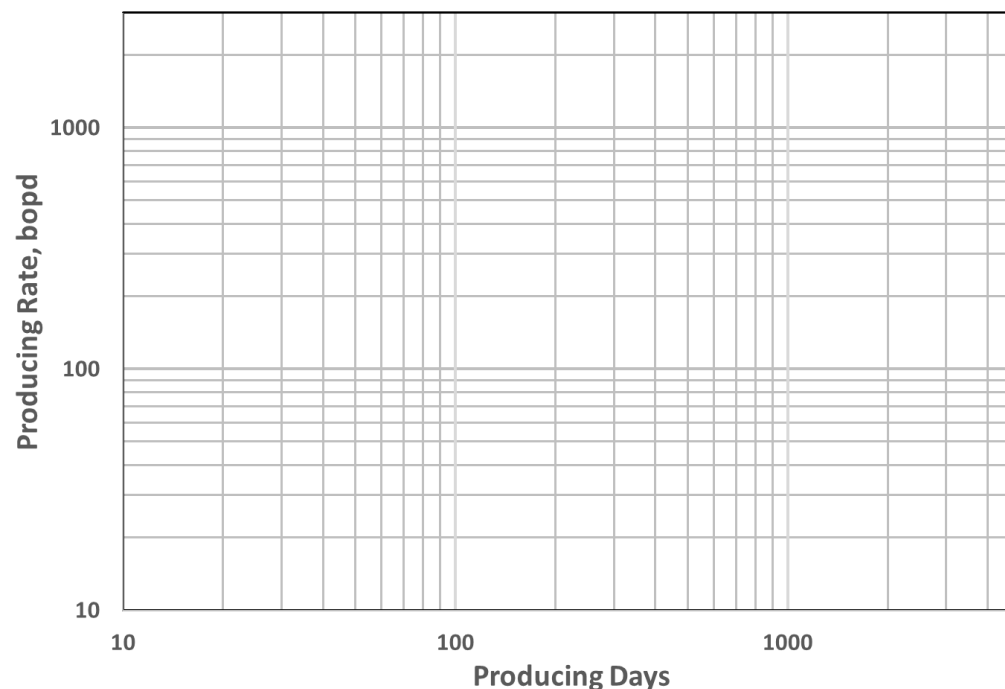
# Month 0

| 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  |

## Reservoir Pressure Map



## Production History - Example Well



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

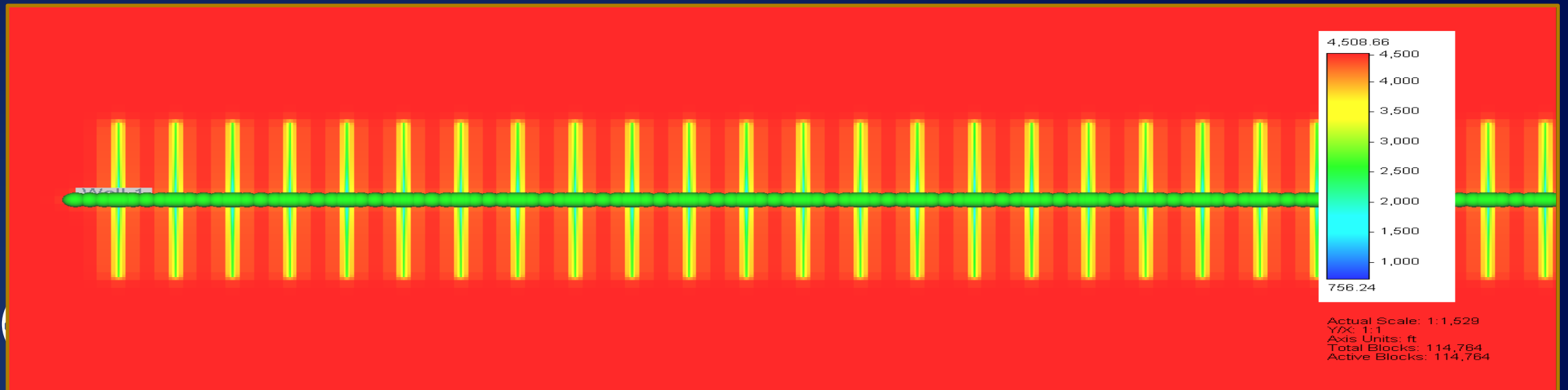
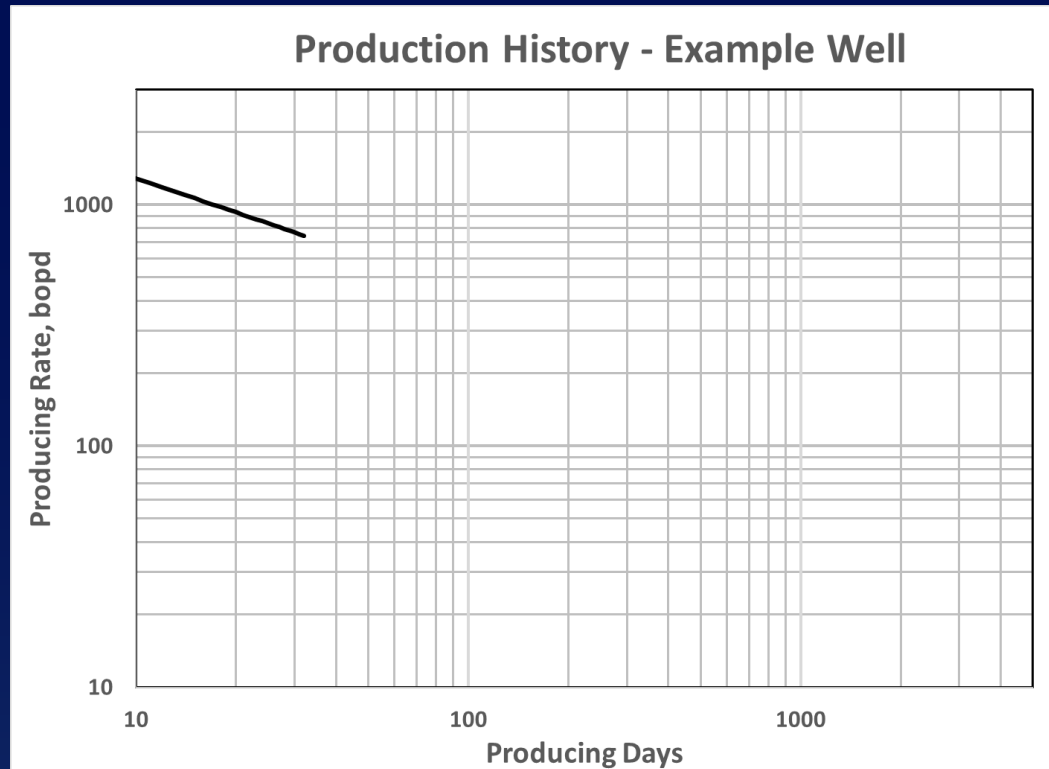
Fracture Spacing = 100 feet

Effective Lf = 250 feet



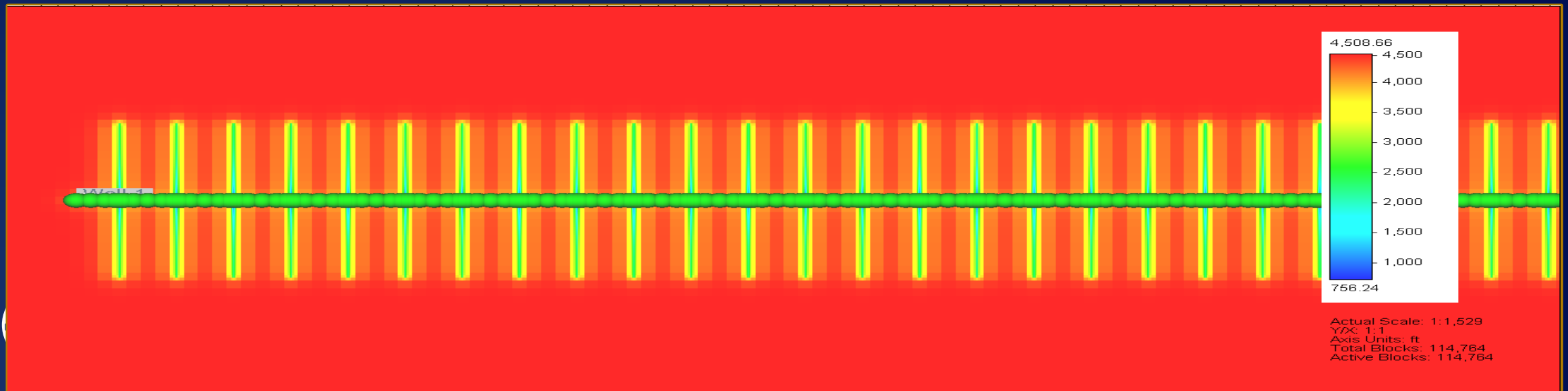
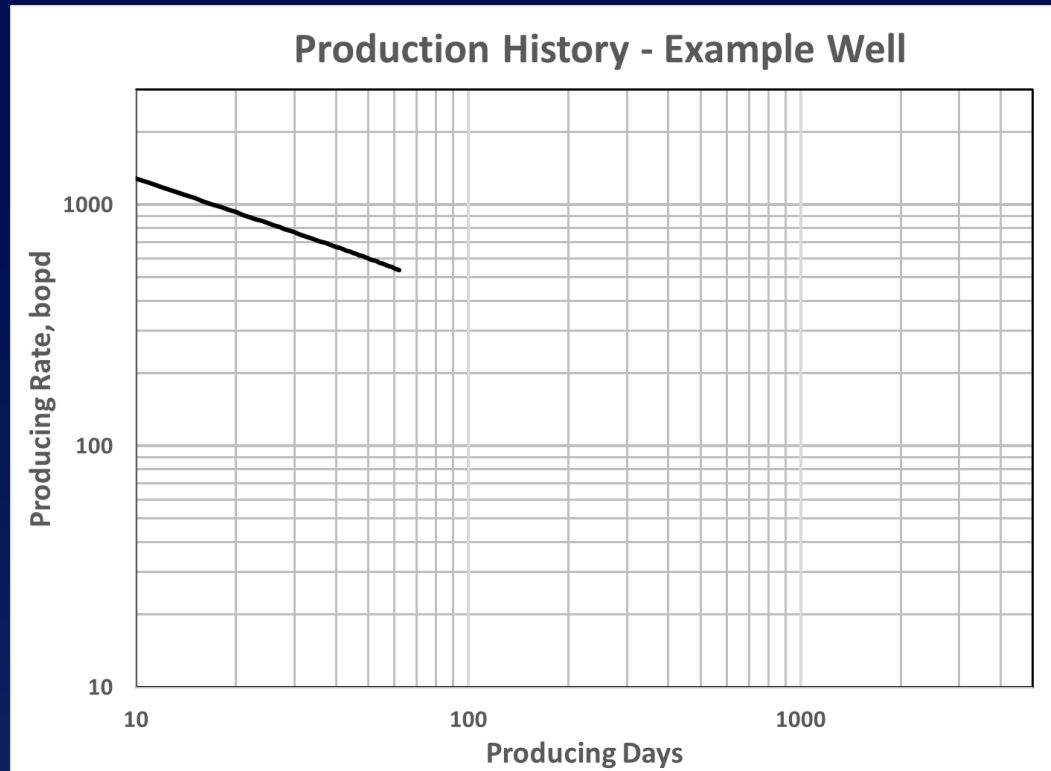
# Month 1

| 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  |



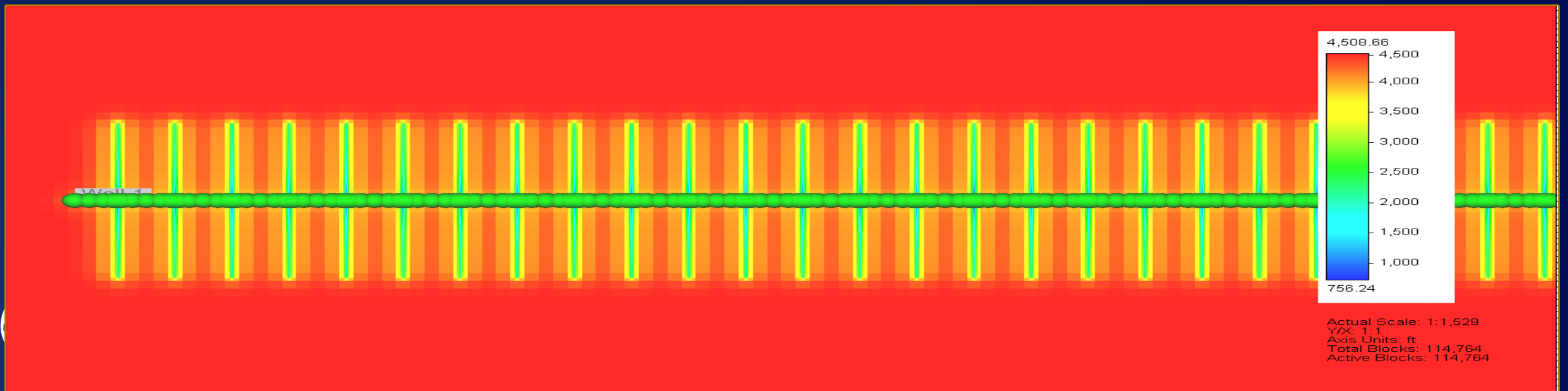
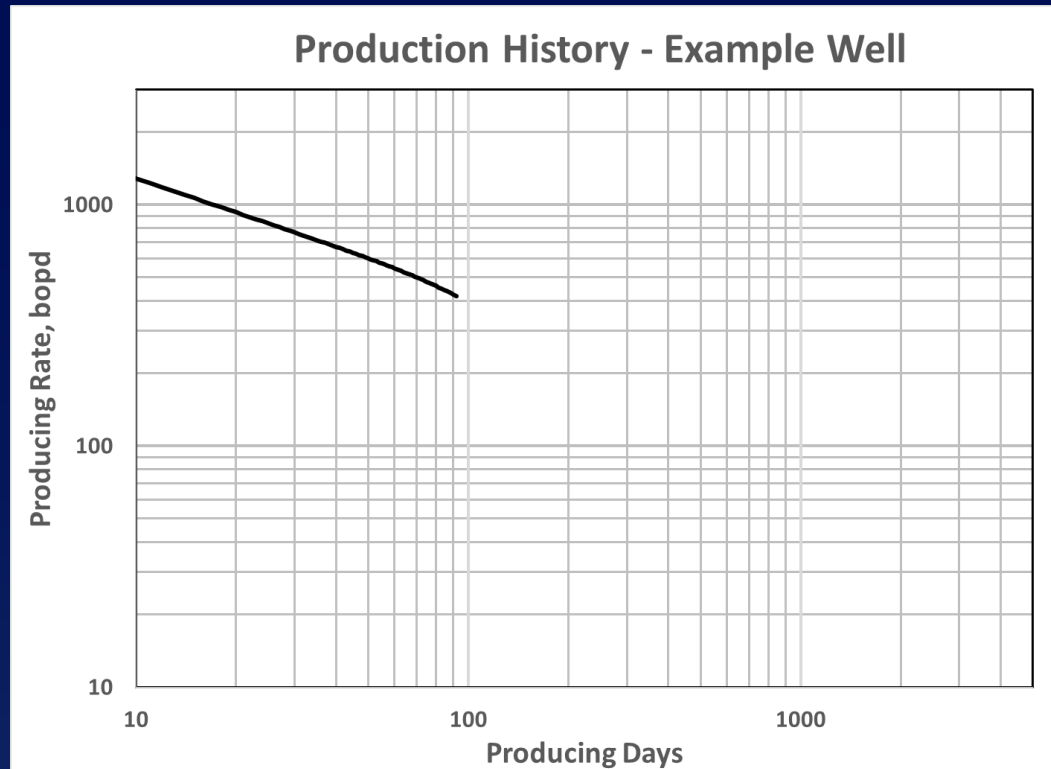
# Month 2

| 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  |



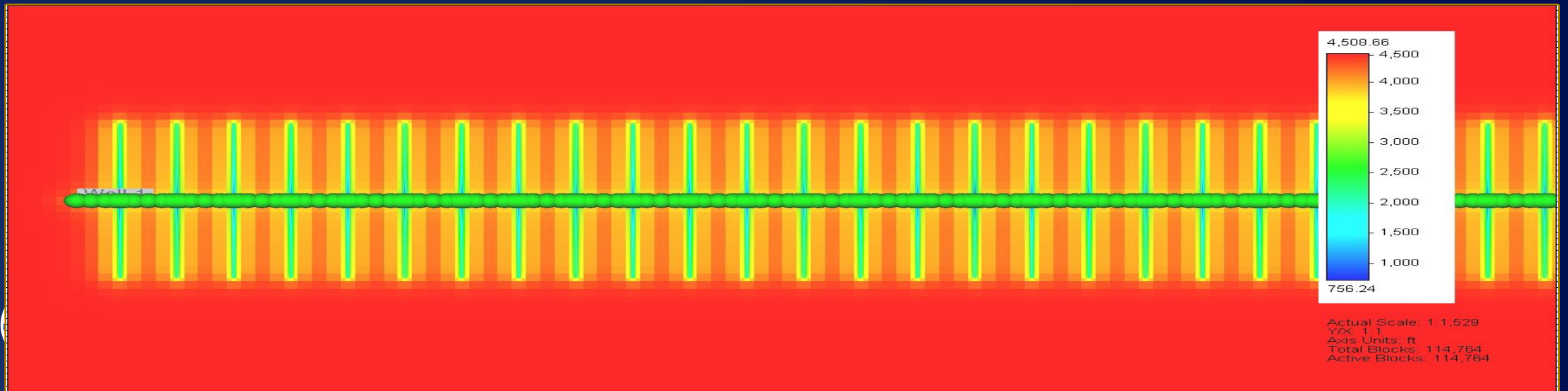
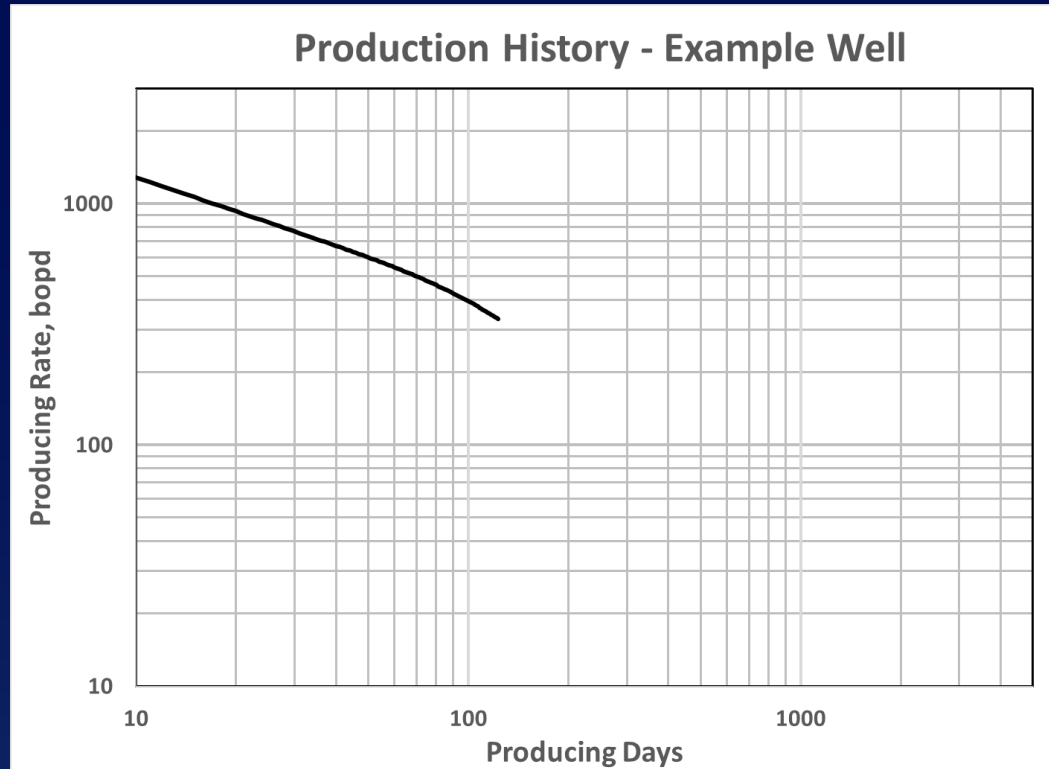
# Month 3

| 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  |



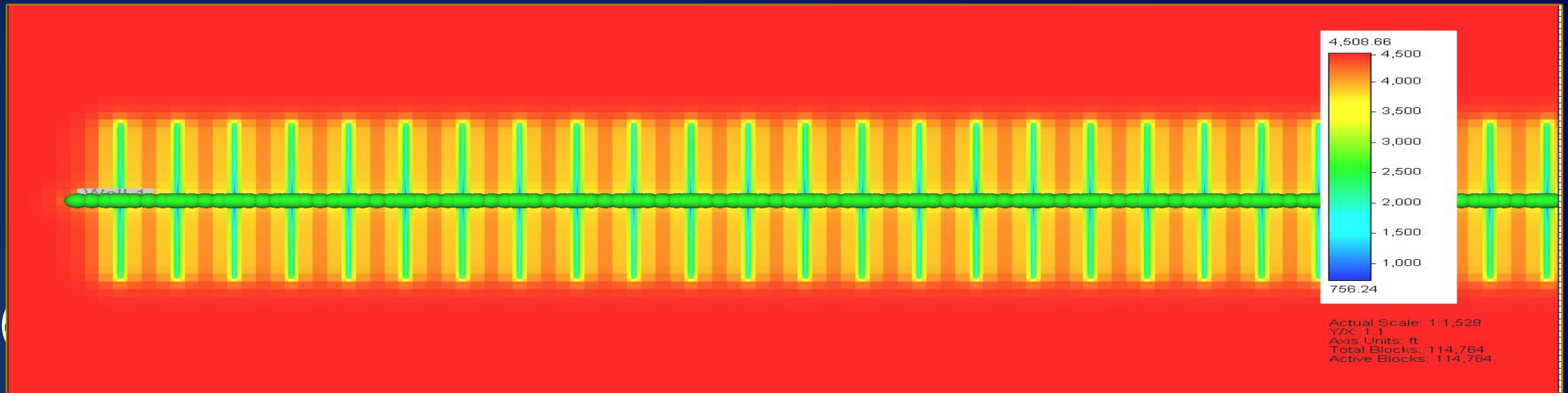
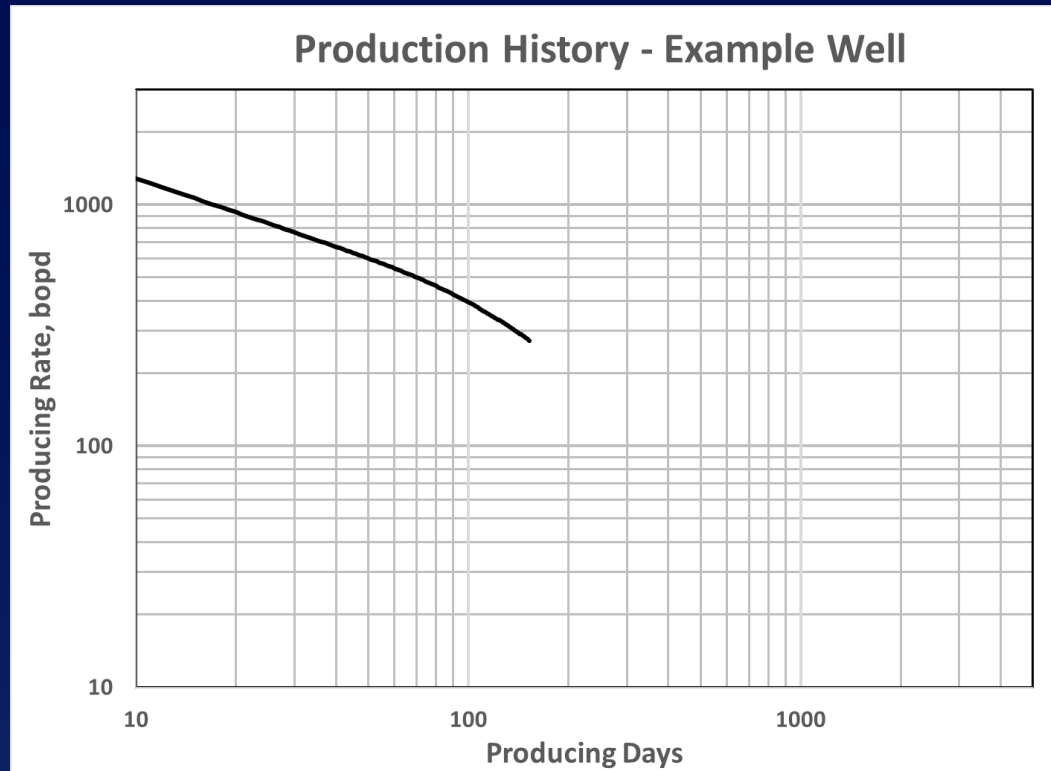
# Month 4

| 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  |

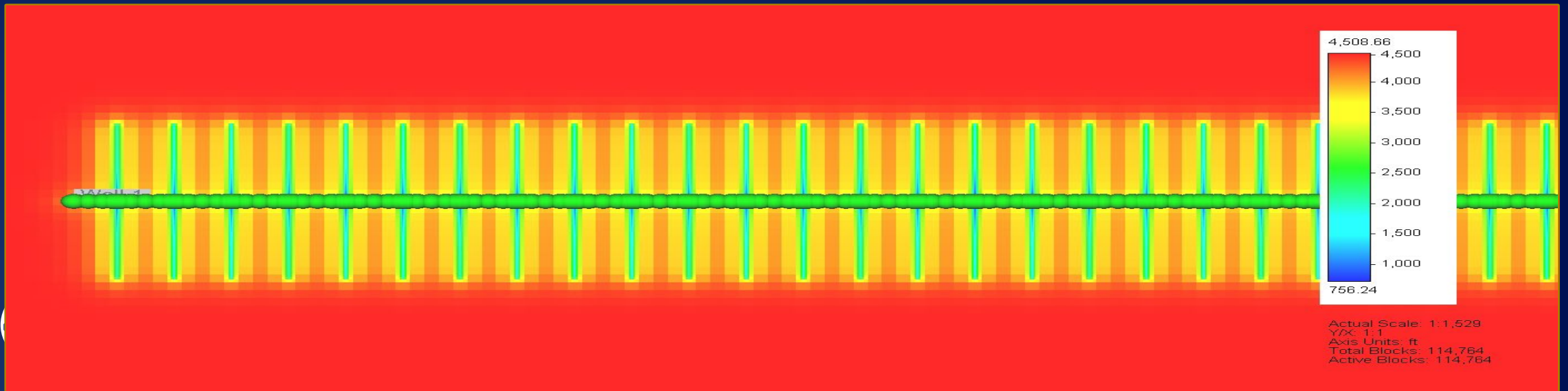
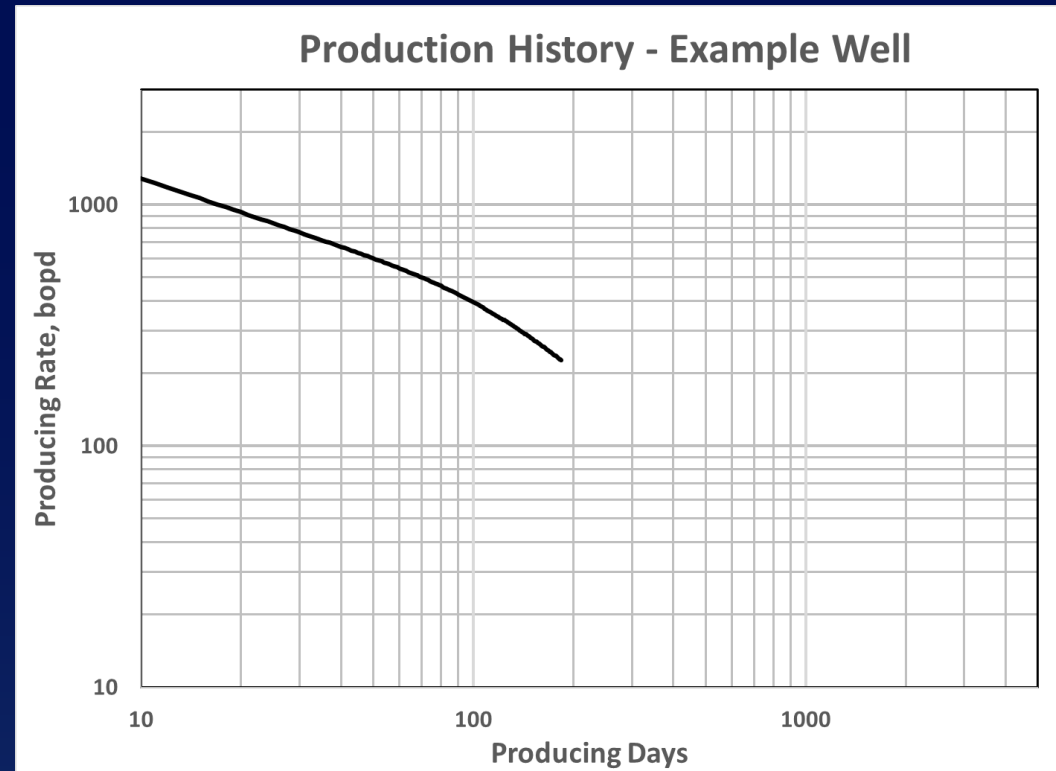


# Month 5

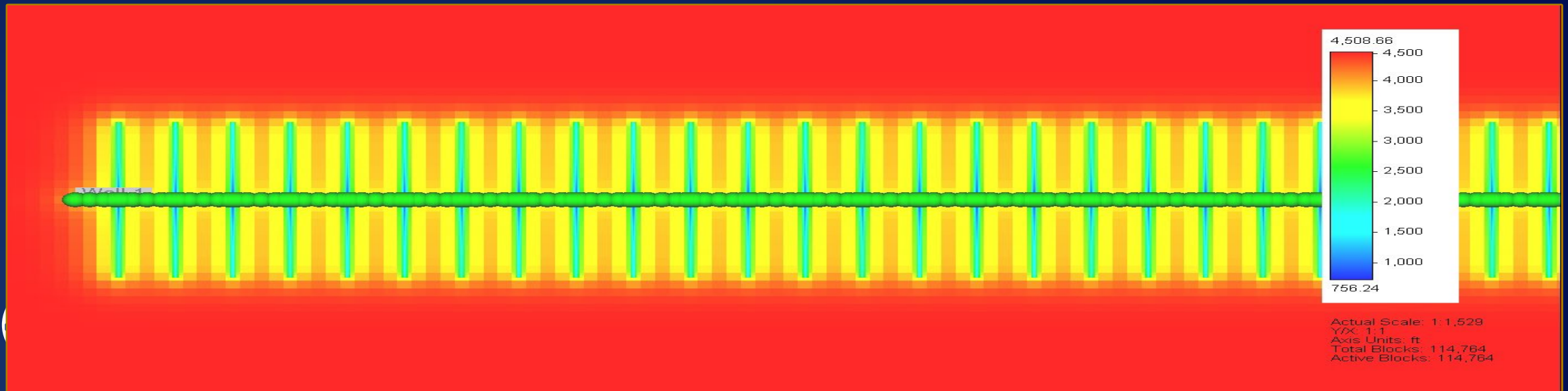
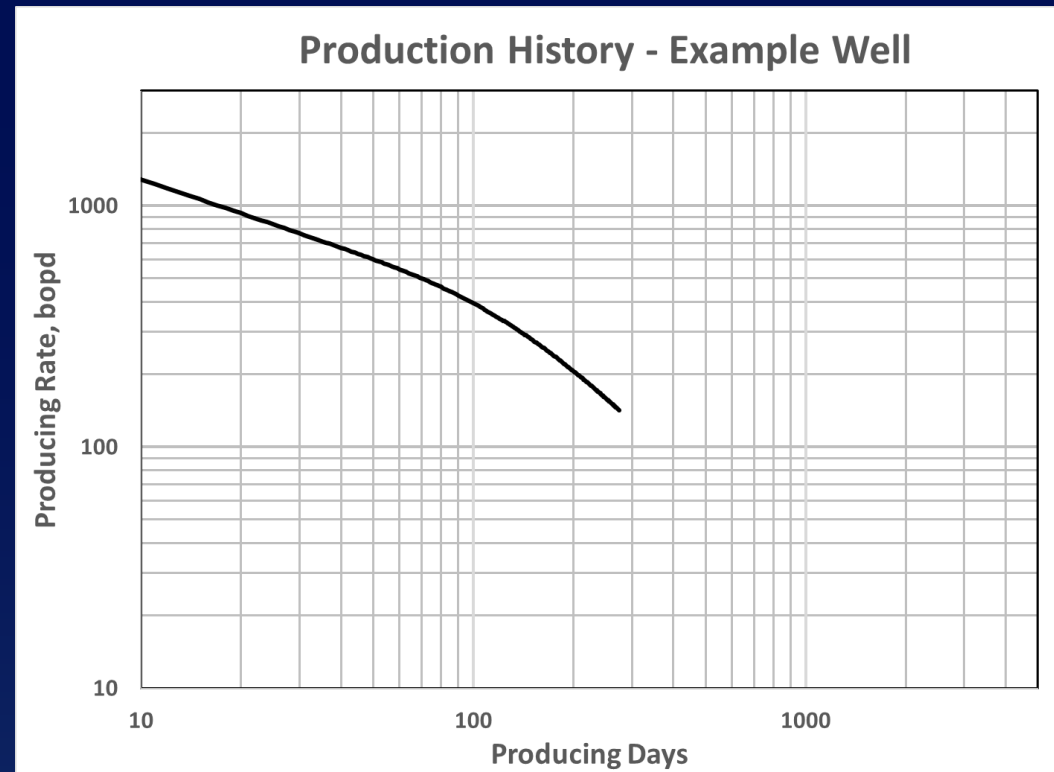
| Calculating Time to the End of Linear Flow |          |       |
|--------------------------------------------|----------|-------|
| k                                          | 250      | nD    |
| Porosity                                   | 5.3%     |       |
| Viscosity                                  | 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  |



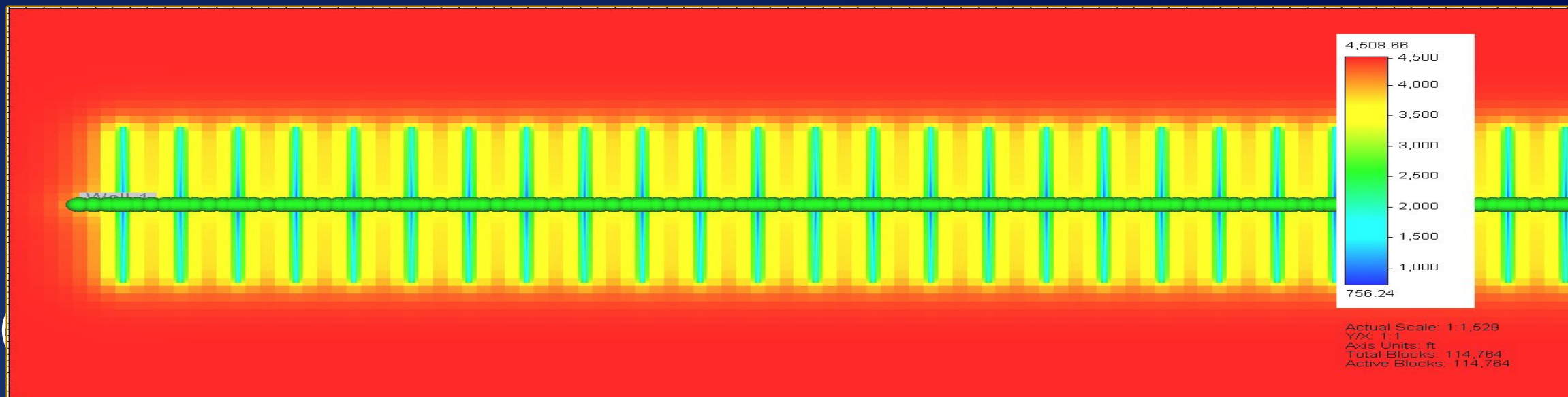
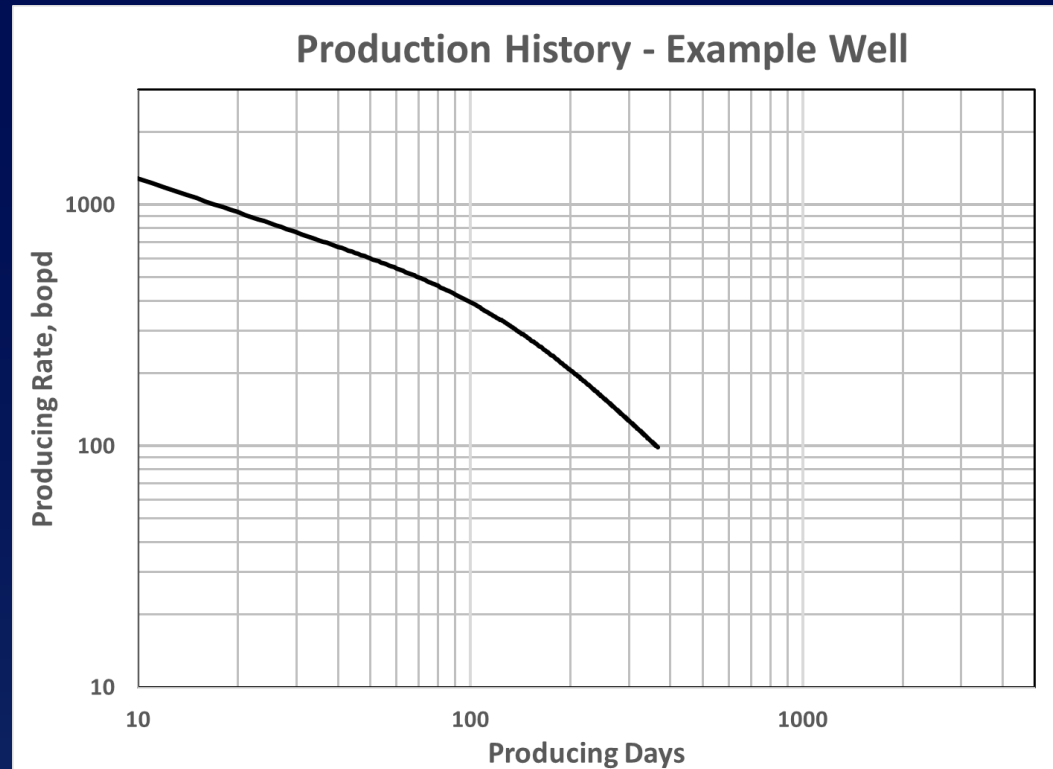
# Month 6



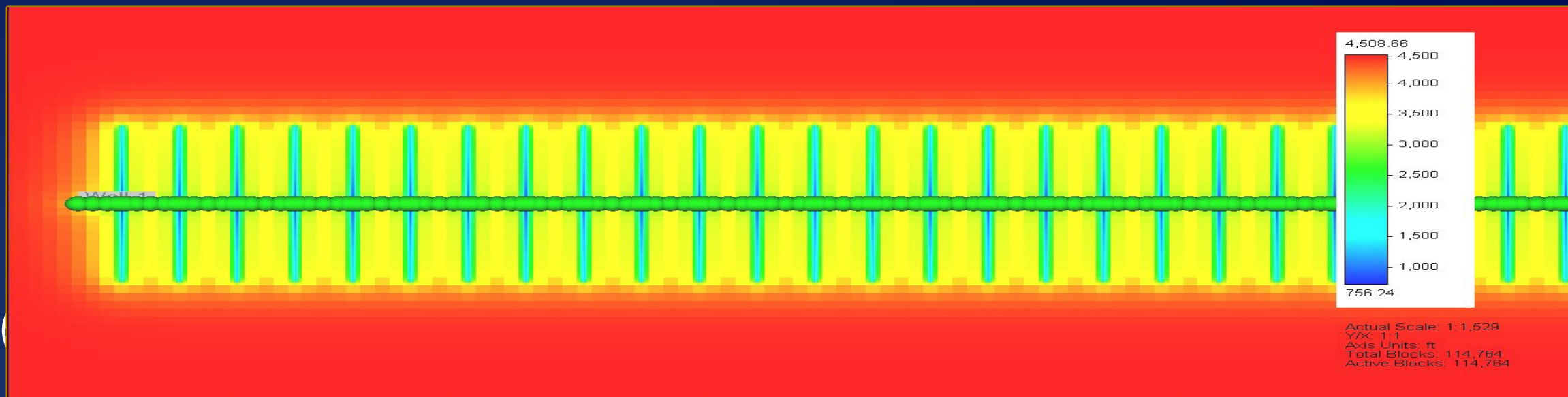
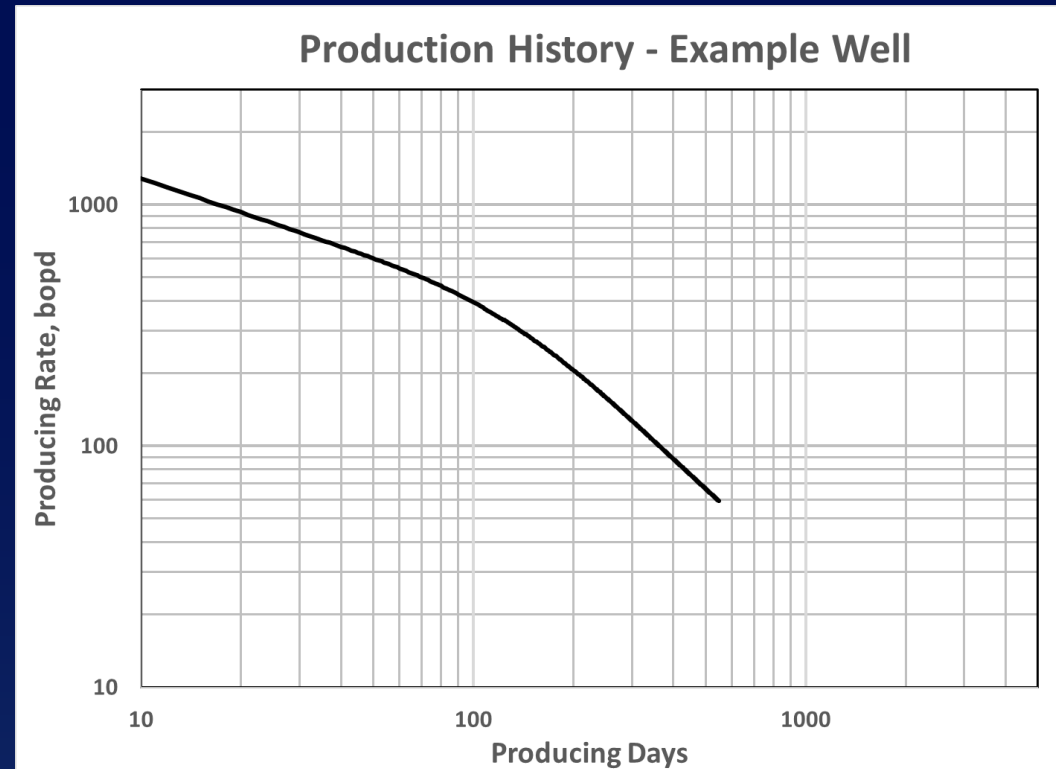
# Month 9



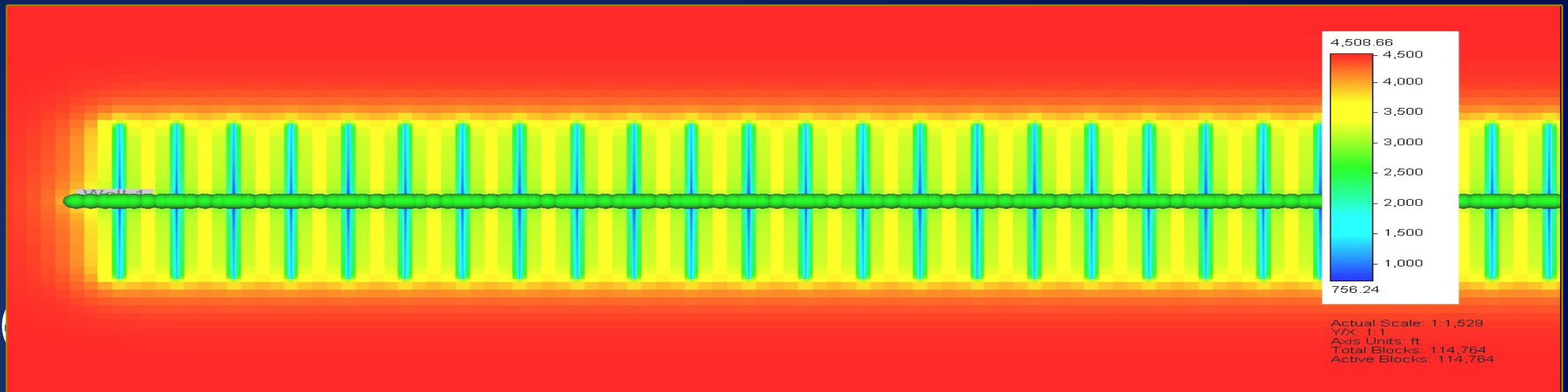
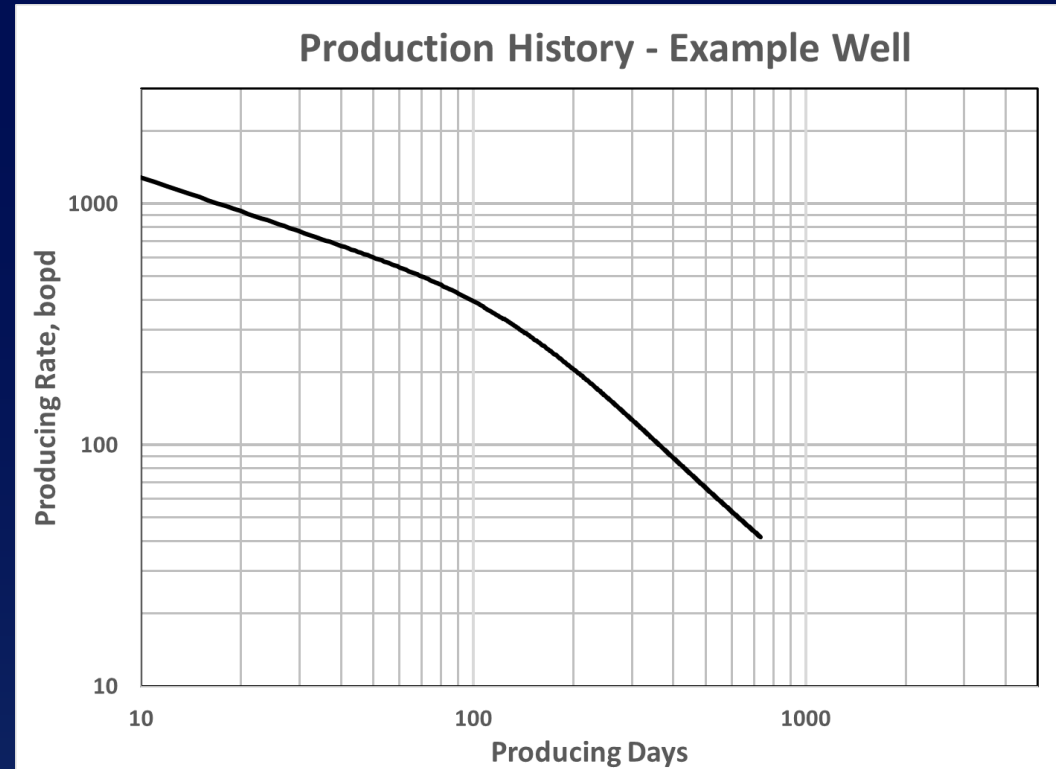
# Month 12



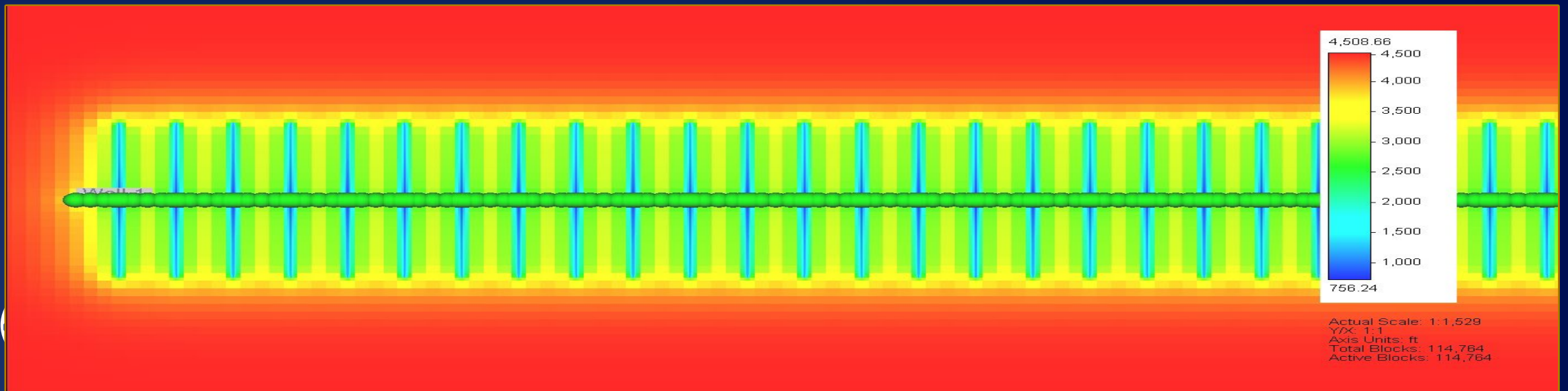
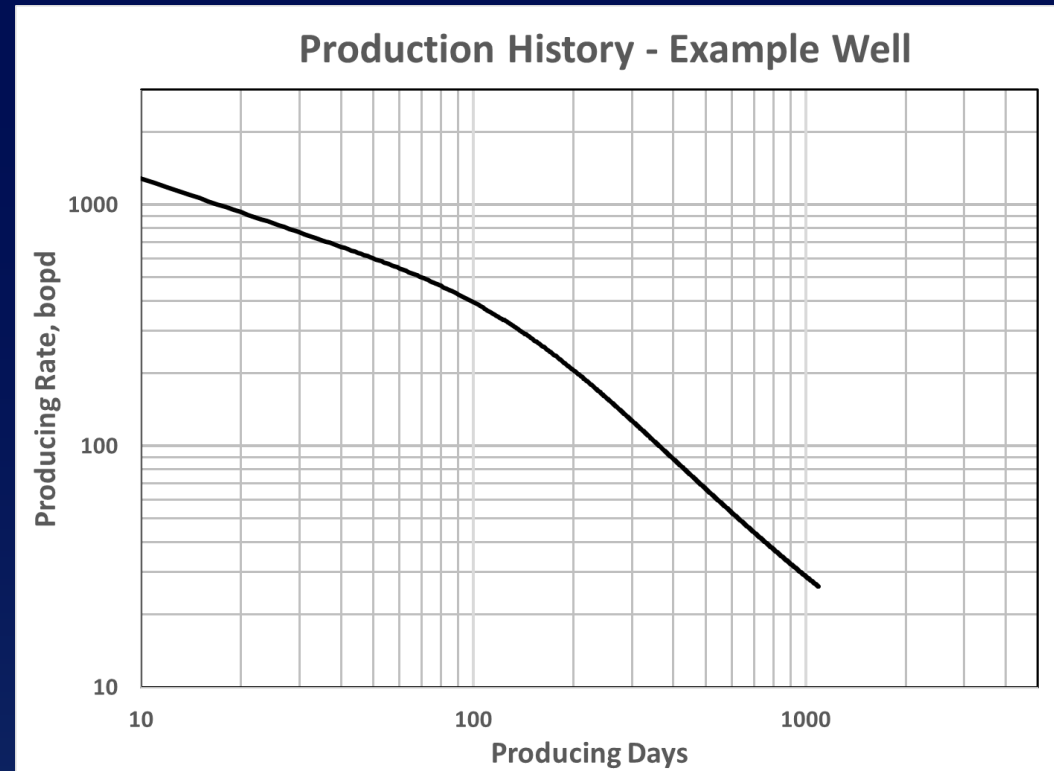
# Month 18



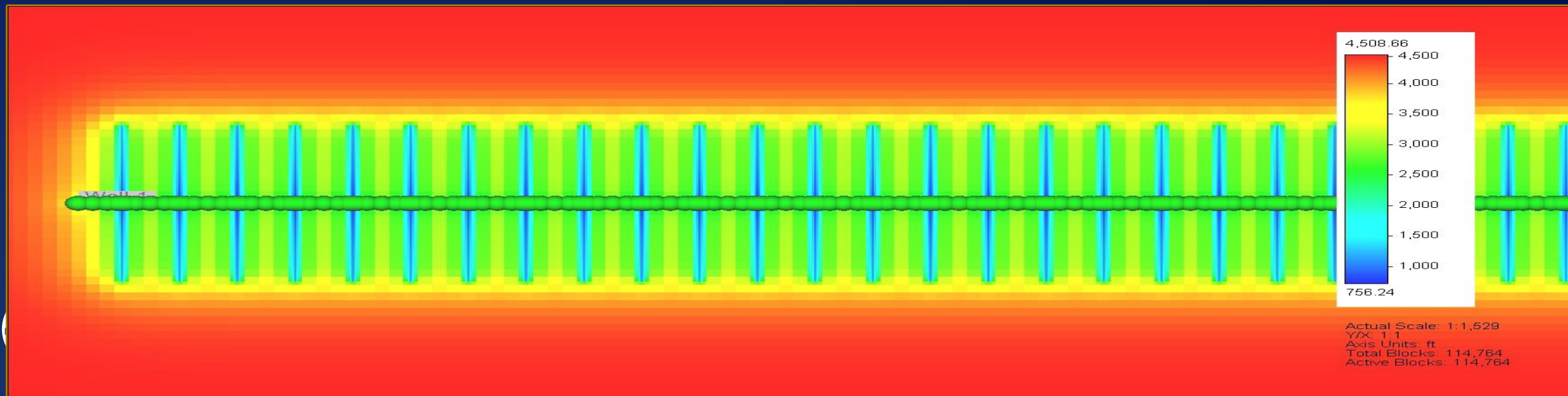
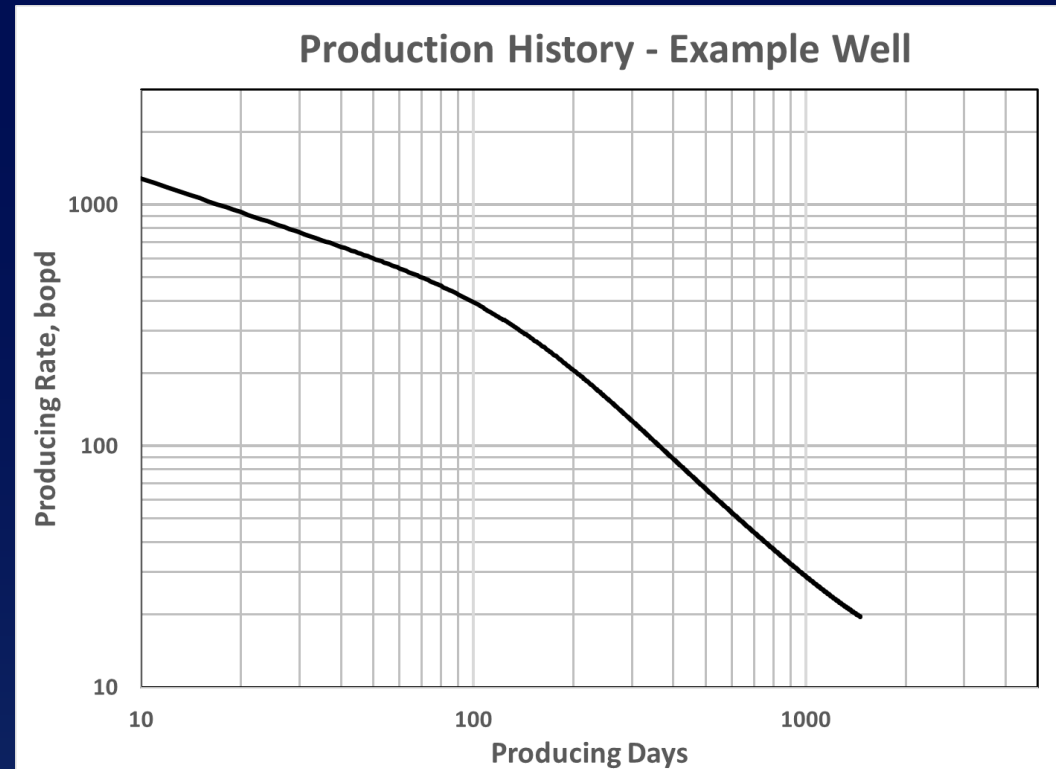
Month 24



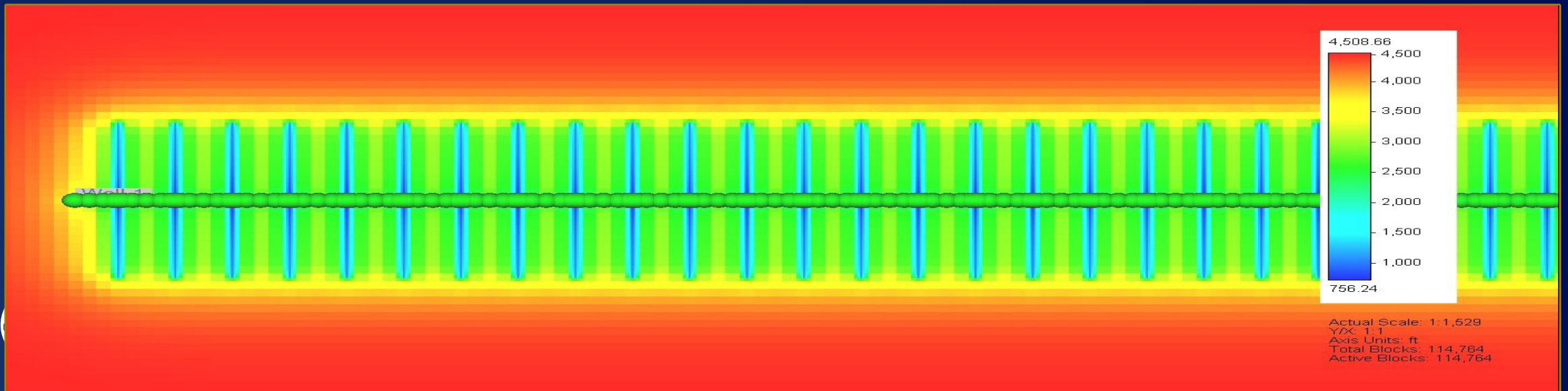
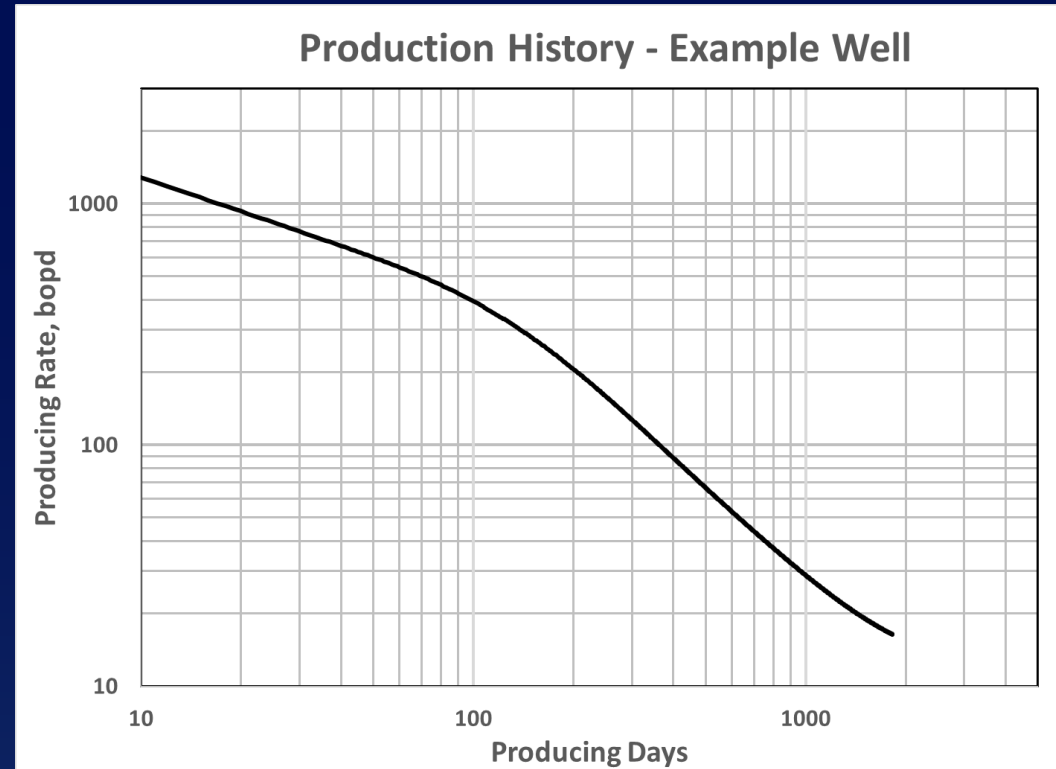
# Month 36



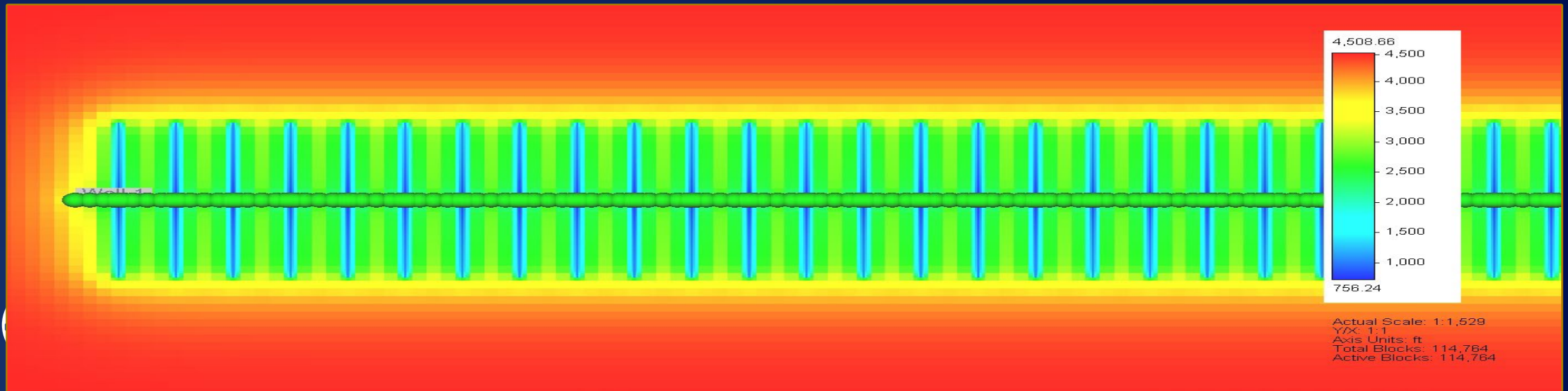
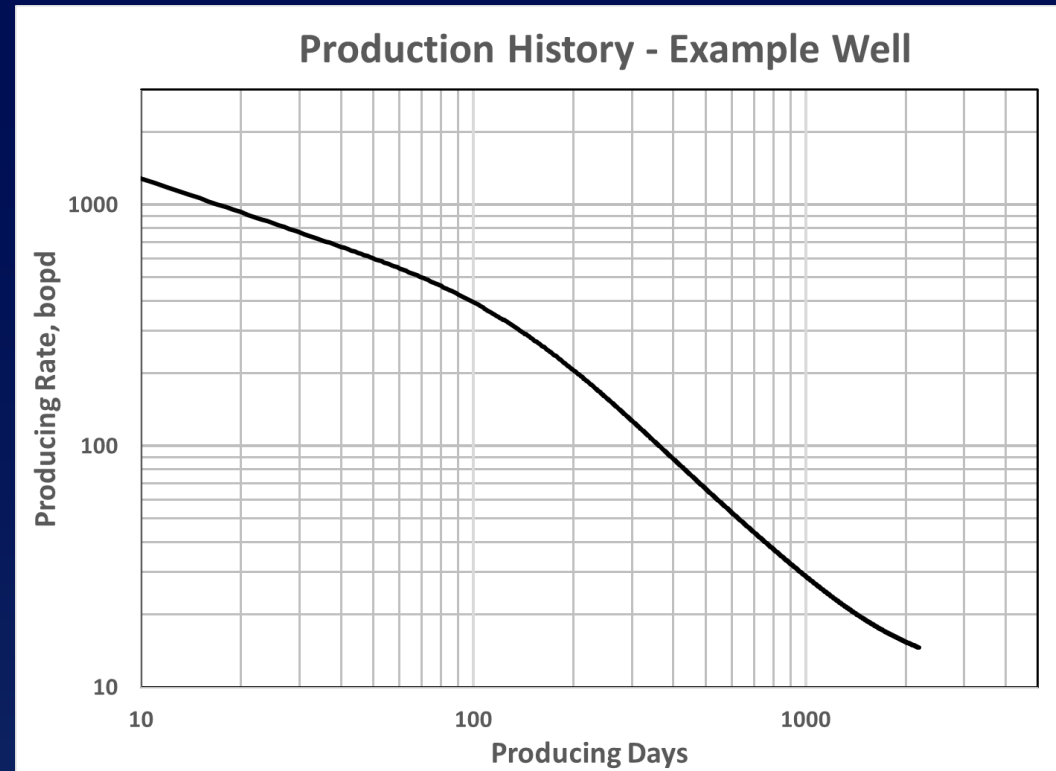
Month 48



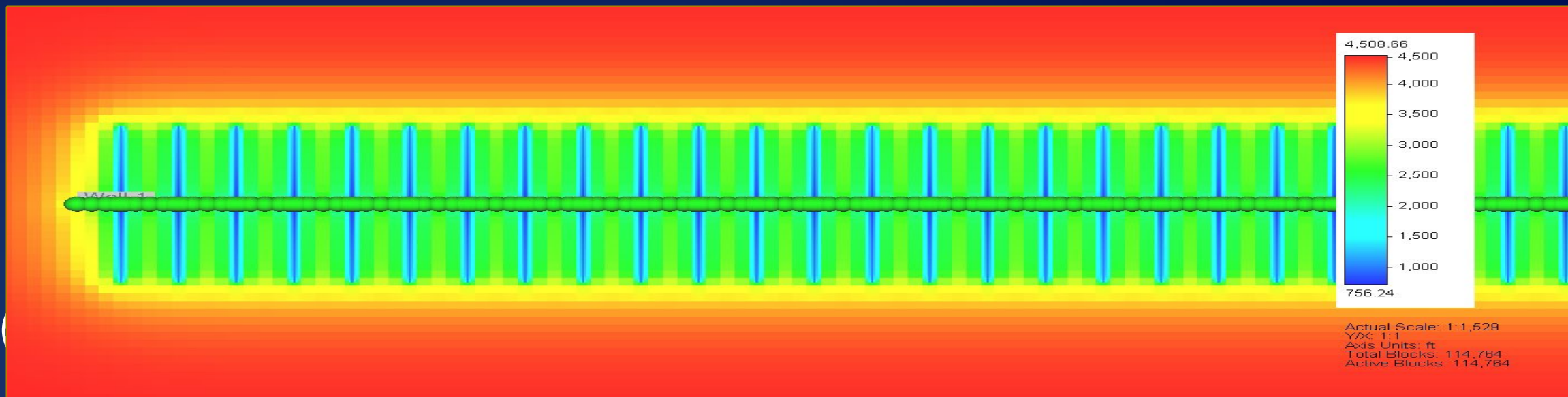
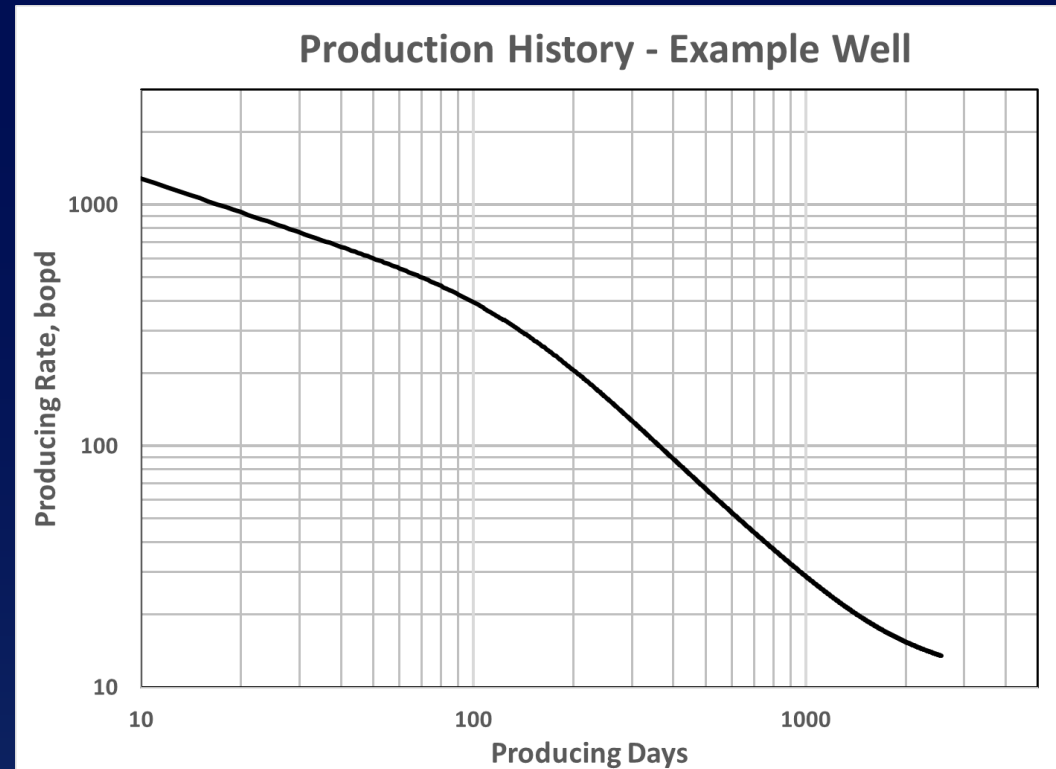
# Month 60



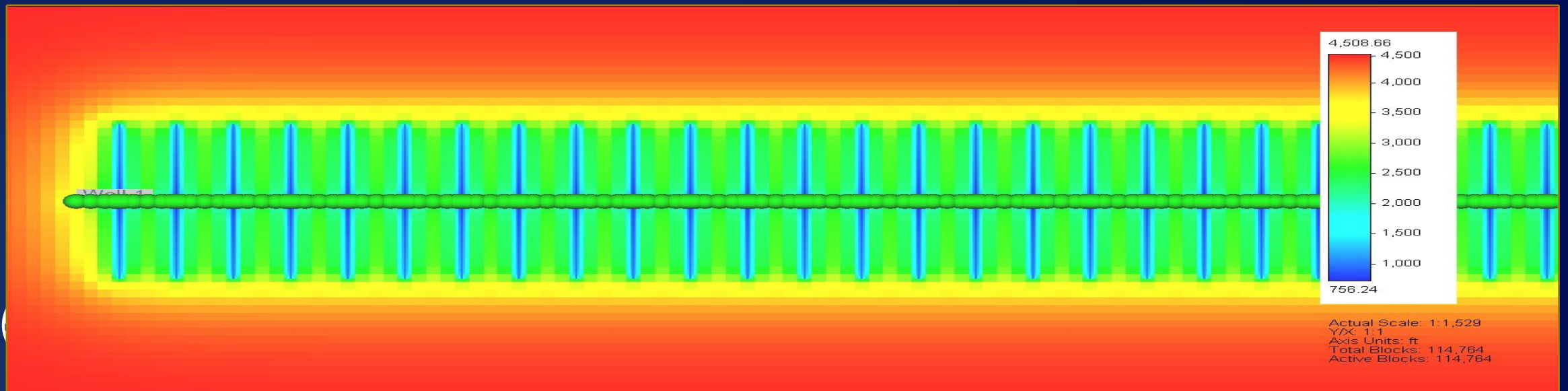
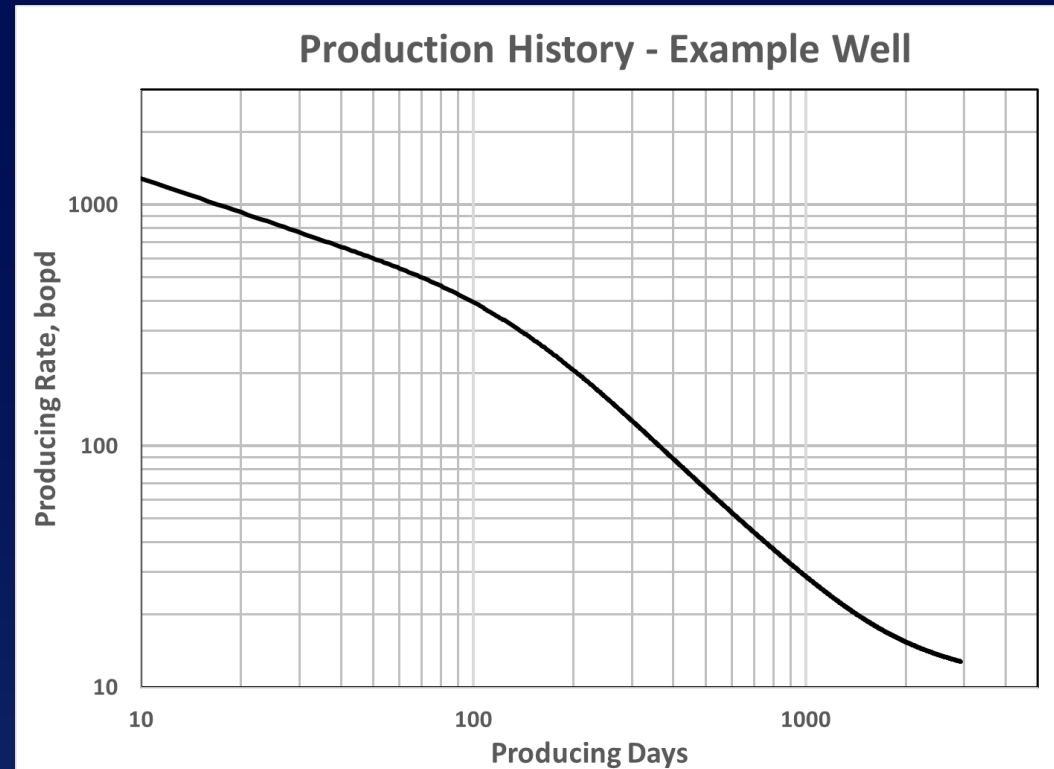
Month 72



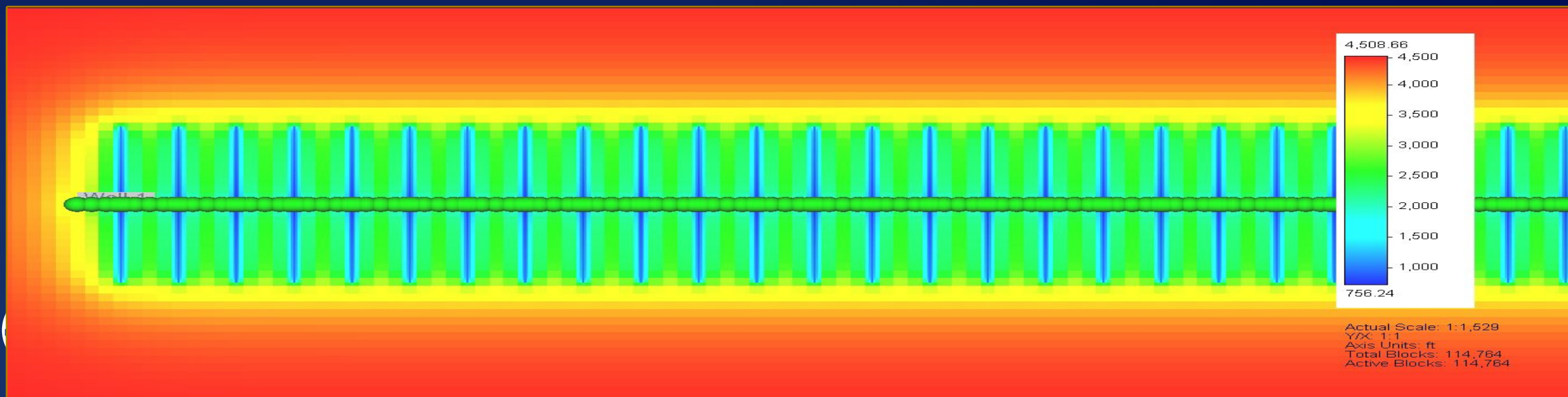
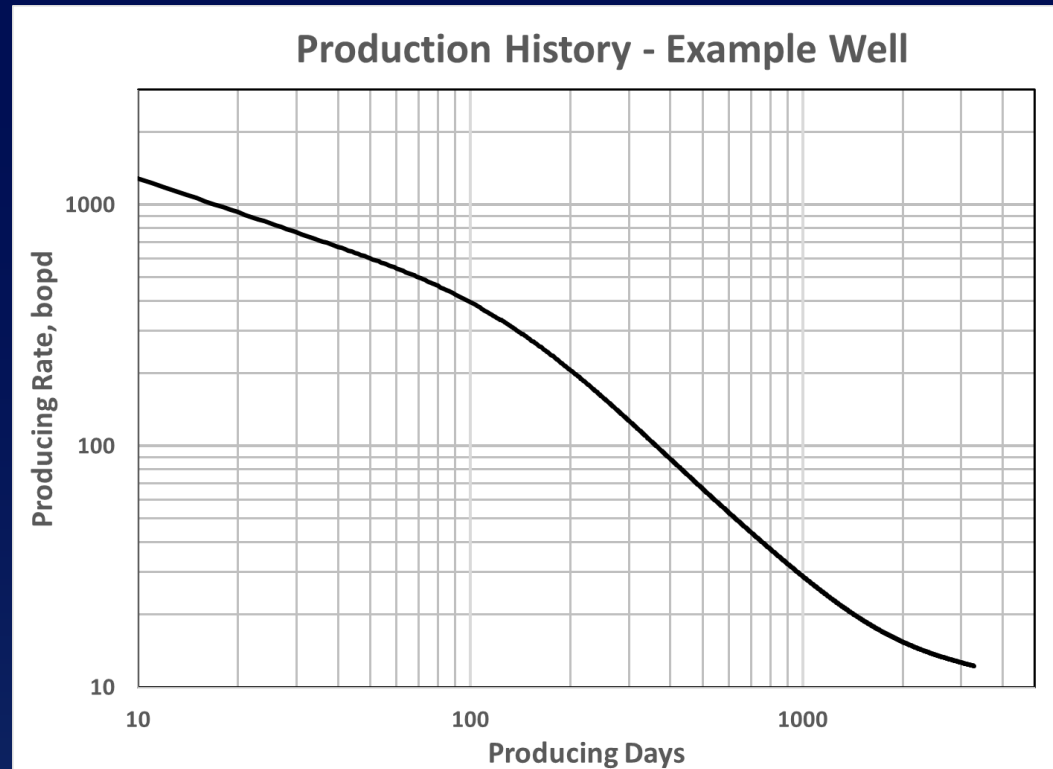
# Month 84



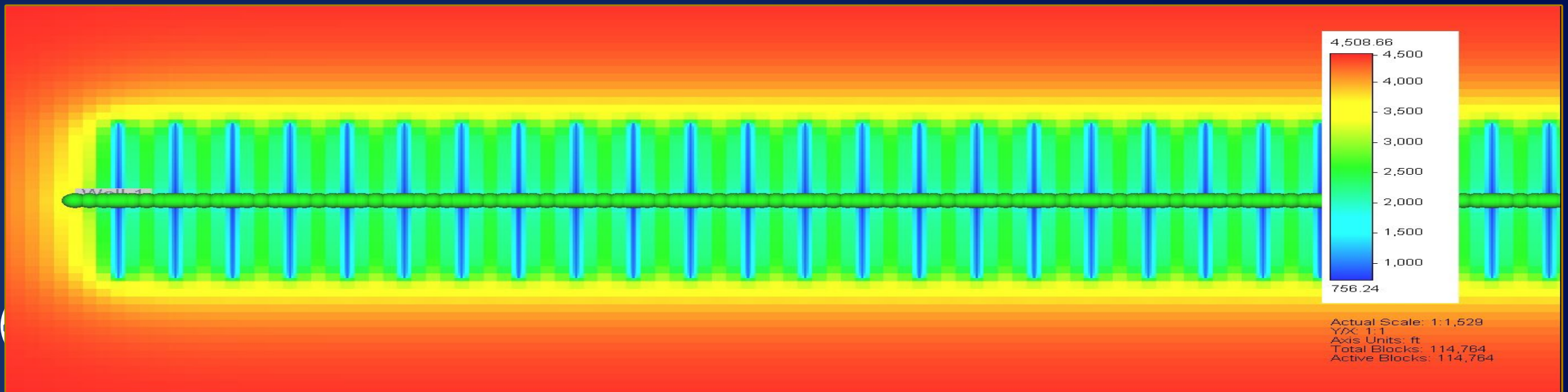
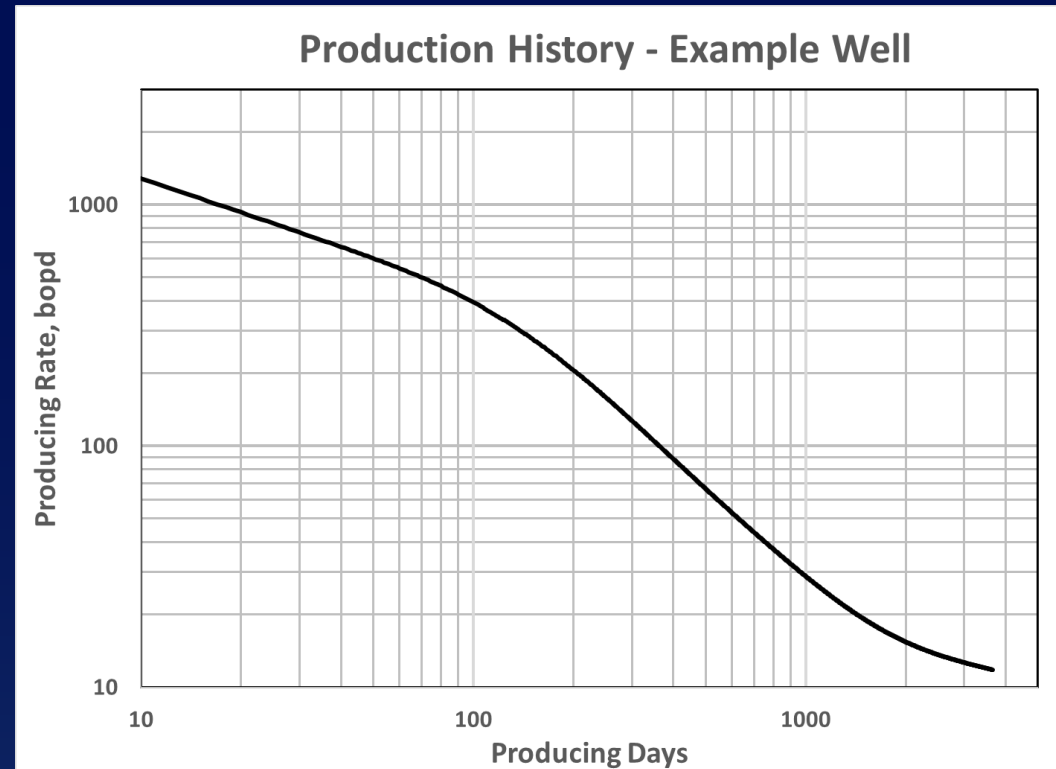
# Month 96



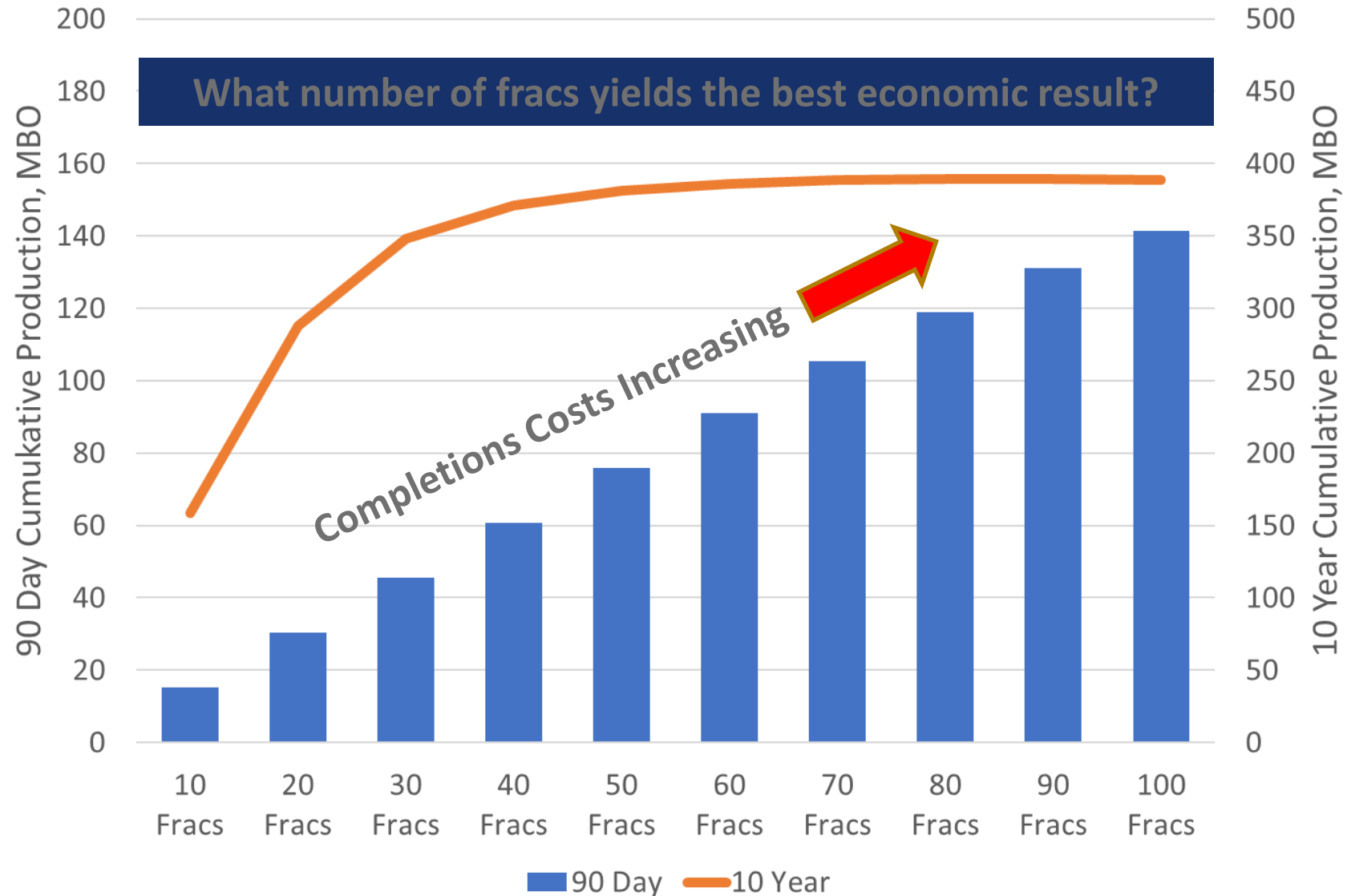
# Month 108



Month 120



## Early Time and Late Time Cumulative Production



# 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

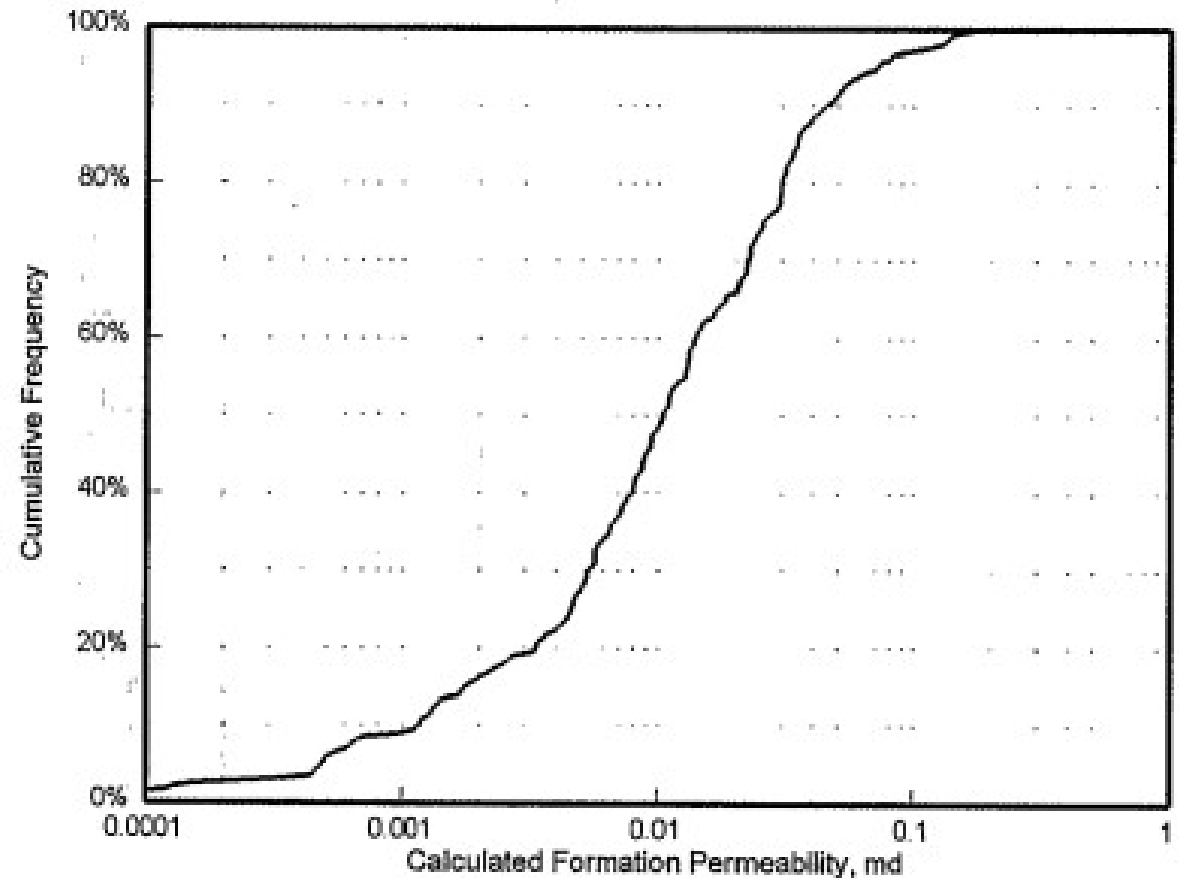
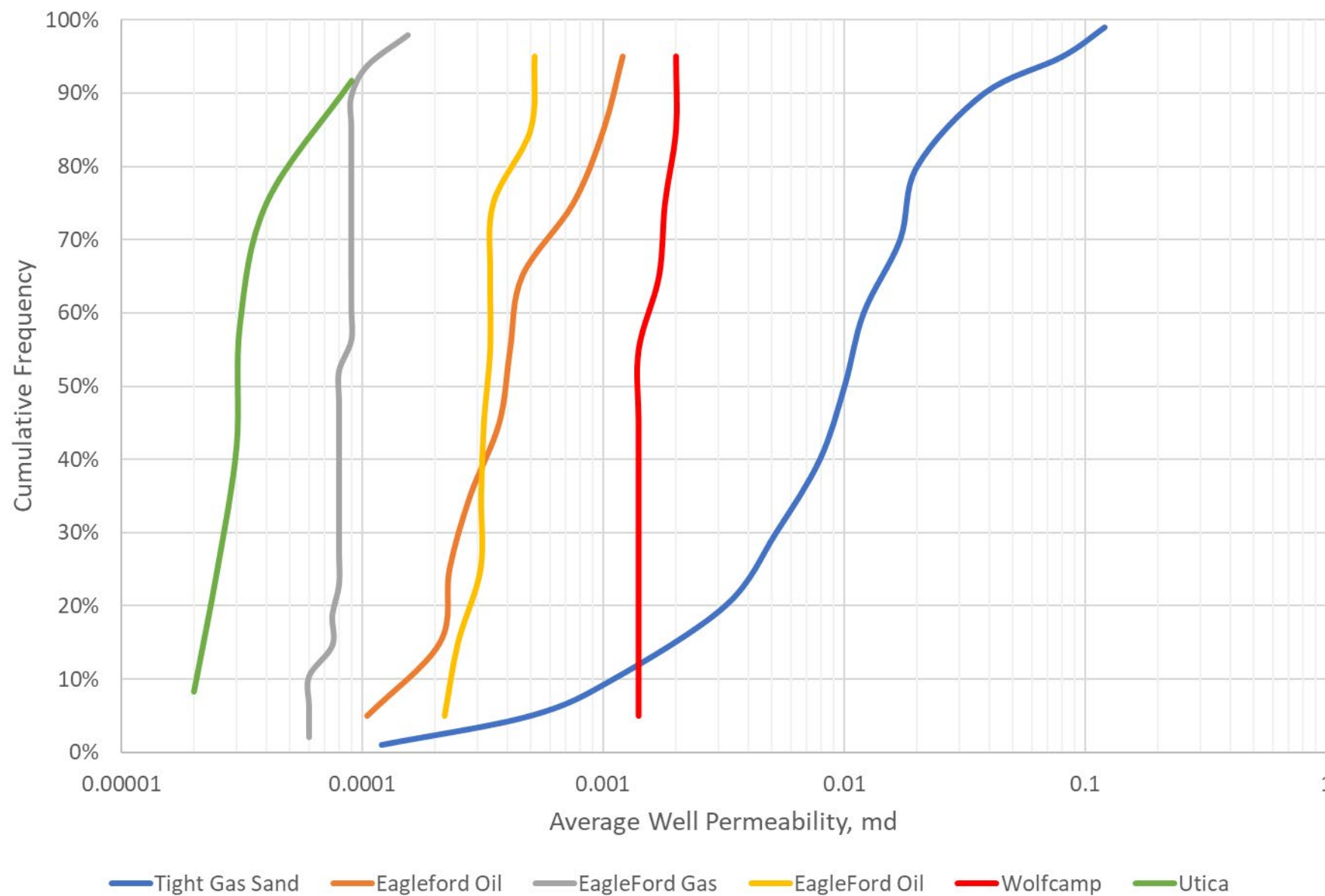


Figure 17. Calculated Formation Permeability Distribution

# Distribution of Average Well Permeability



# 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

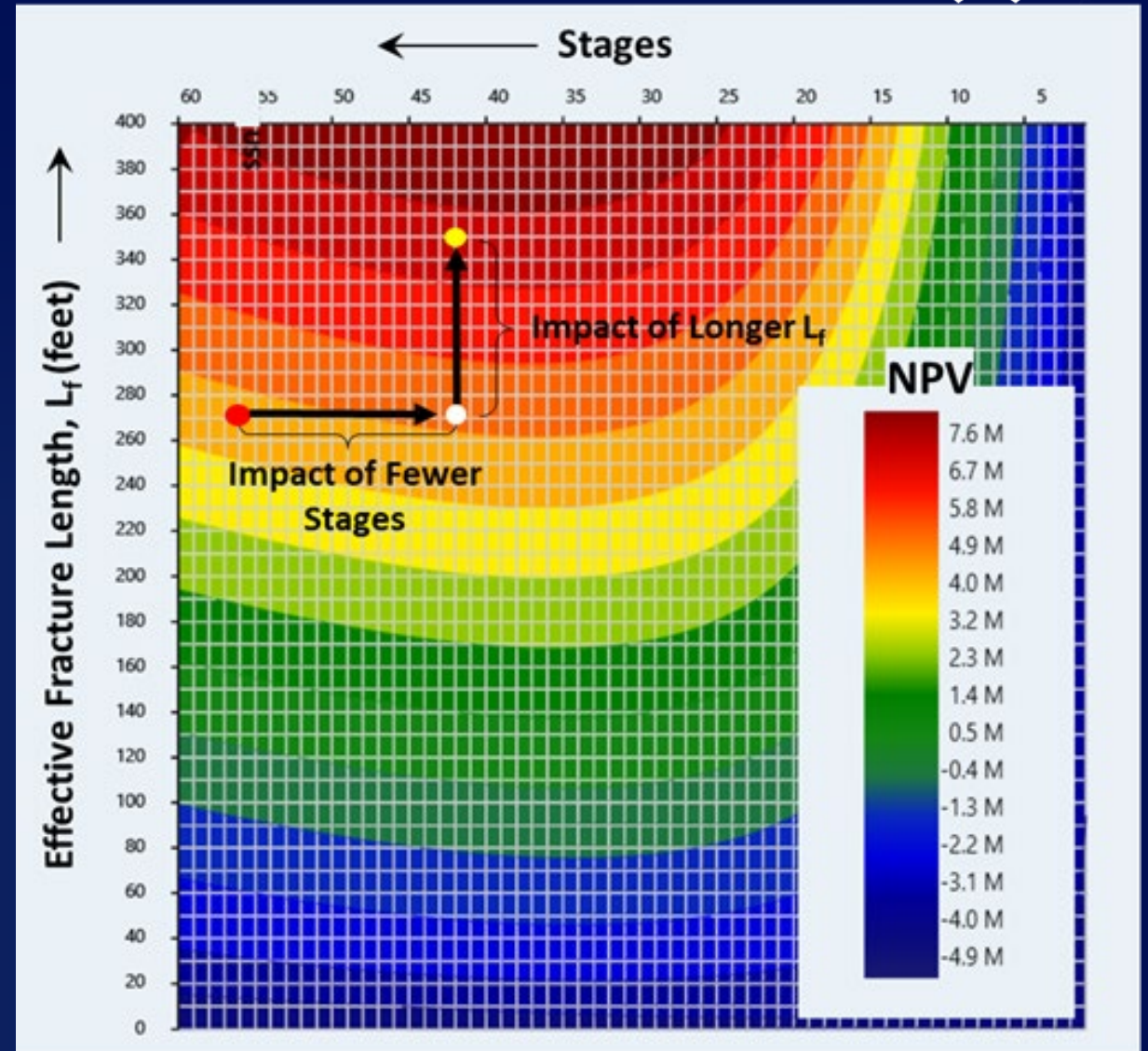


Figure 5 - NPV Road Map @ 400 nD

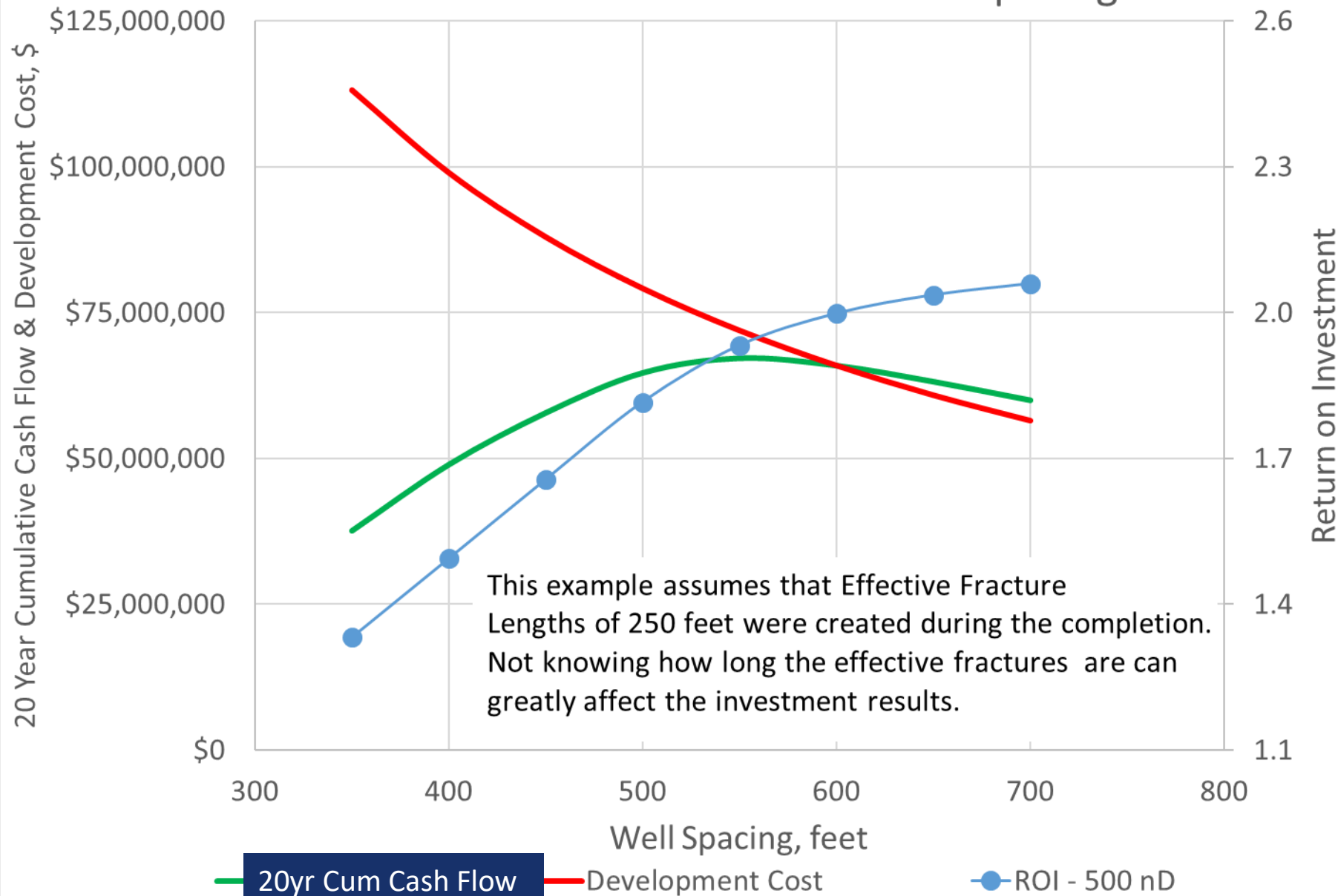
# Optimizing Well Spacing



- 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



# Environmental Impact of Optimized Design – Stage & Well Spacing



\*assuming the development of 50,000 acres

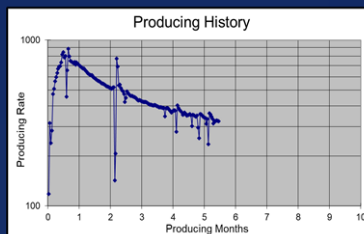
- Reduced number of wells to develop acreage – **234 vs. 335**
- Reduced frac water volume needed by **80 million barrels**
- Reduced frac sand needed by **3.2 billion pounds**
- Reduced diesel fuel needed by **15 million gallons**
- Reduced CO<sub>2</sub> emissions from diesel fuel by **195 thousand tons**
- Reduced capital needed to develop acreage - **\$932 million**



# Summary



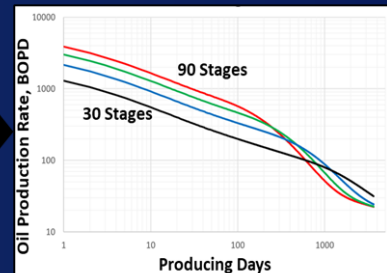
- Optimizing economics on horizontal multi-stage completions can be a complex process
- Production history matching can determine the primary reservoir/completion properties we need to know:
  - Formation permeability
  - Effective fracture half-length achieved
  - Number of dominant producing fractures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



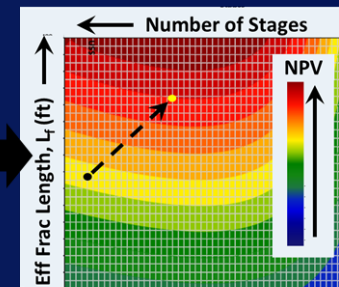
Cost Free Data

Perm  
Eff Frac Length  
Number of Fracs

Evaluate



Predict



Economics

Capital Cost ↓  
NPV & ROI ↑

Results

