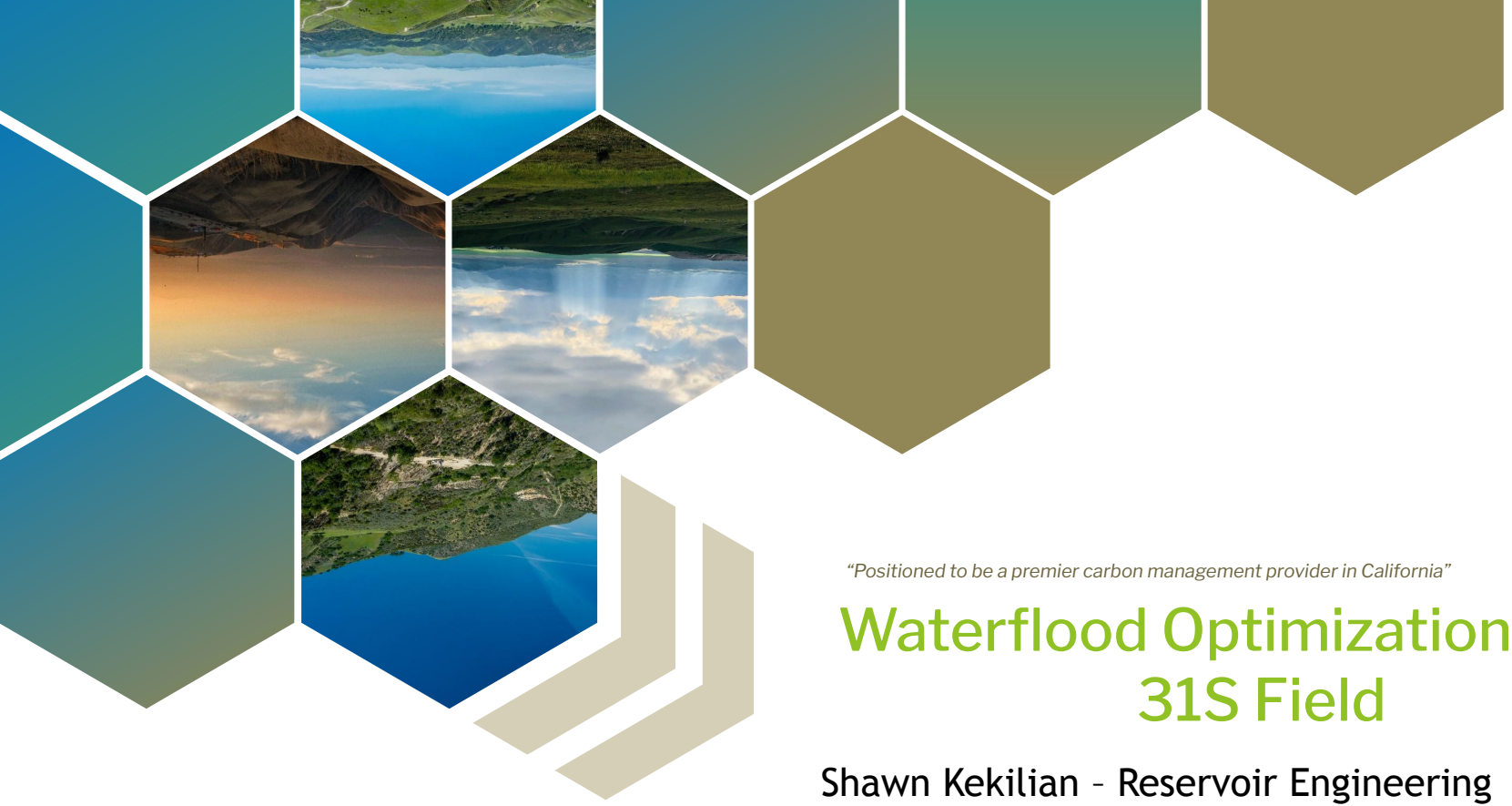


"Positioned to be a premier carbon management provider in California"

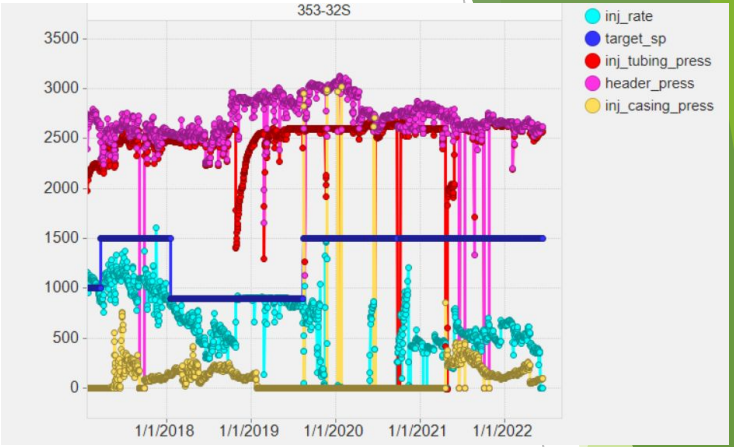
Waterflood Optimization of the 31S Field

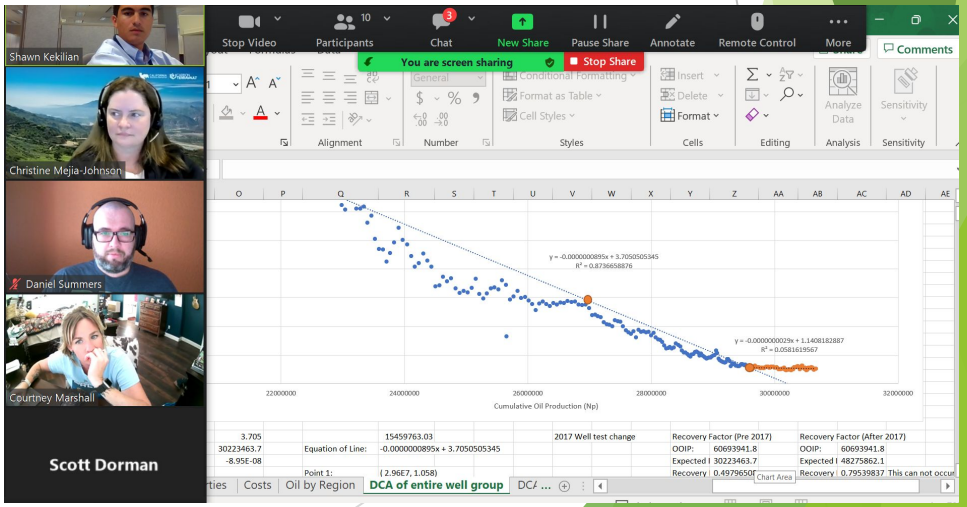
Shawn Kekilian – Reservoir Engineering Intern

CALIFORNIA RESOURCES CORPORATION | CARBON TERRAVAULT

Project Scope

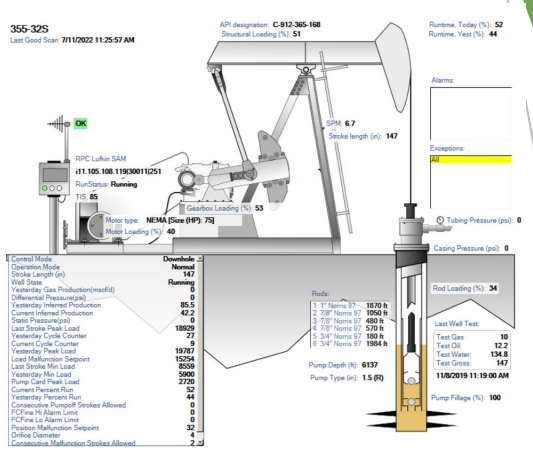
- **Waterflooding Optimization in the 31S Field**
  - Originally tasked with reconfiguring flood patterns and looking for injection improvements
  - Overall goals changed after reviewing wells in surveillance meetings:
    - Wellbore infrastructure improvements to reduce out-of-zone injection
    - Identify injection inefficiencies and optimize waterflooding within the MBB





Project Scope

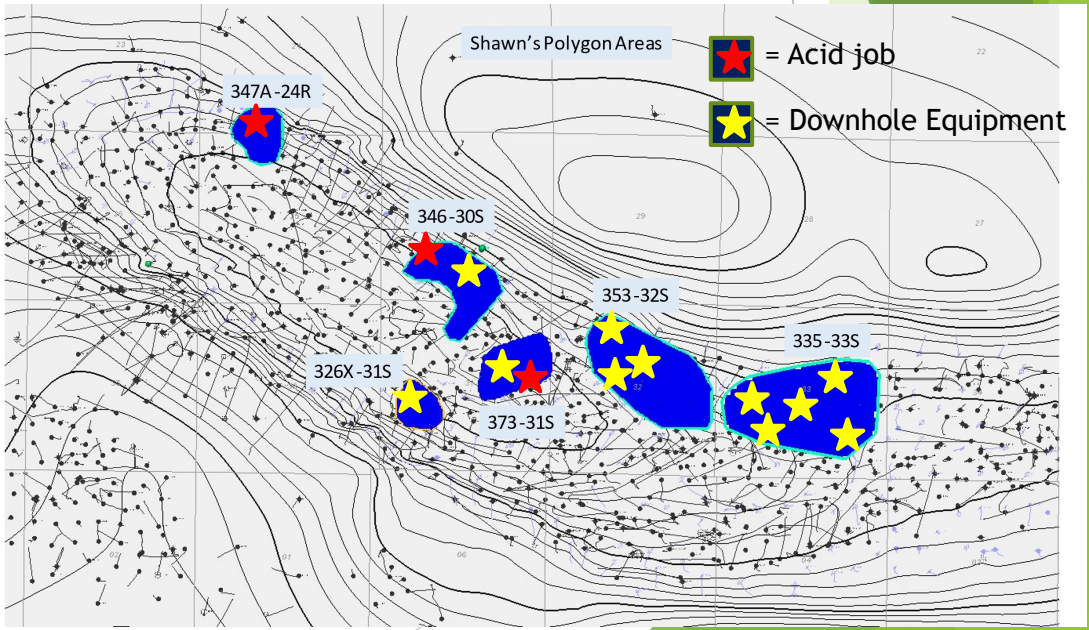
- Identify producers that are not pumped off or at max pumping capacity
  - Using XSPOC to analyze fluid levels within the well
  - Collecting fluid level shots to confirm results
  - Upgrade current equipment to lower fluid levels



Surveillance Process

- **Injector Surveillance**
  - Identified wells that were under-injecting based on historical averages
  - Looked for the root causes during collaborative surveillance meetings
    - 14 injectors analyzed in-depth
      - 3 wells for acid jobs
      - 11 wells need downhole equipment (packers, plugs, casing, cement…)

Injector Name	Target Rate (bbl)	Current Rate (bbl)	Δ Change (bbl)
353-32S	1500	359	1141
373-32S	1000	248	752
313-5G	3600	2863	737



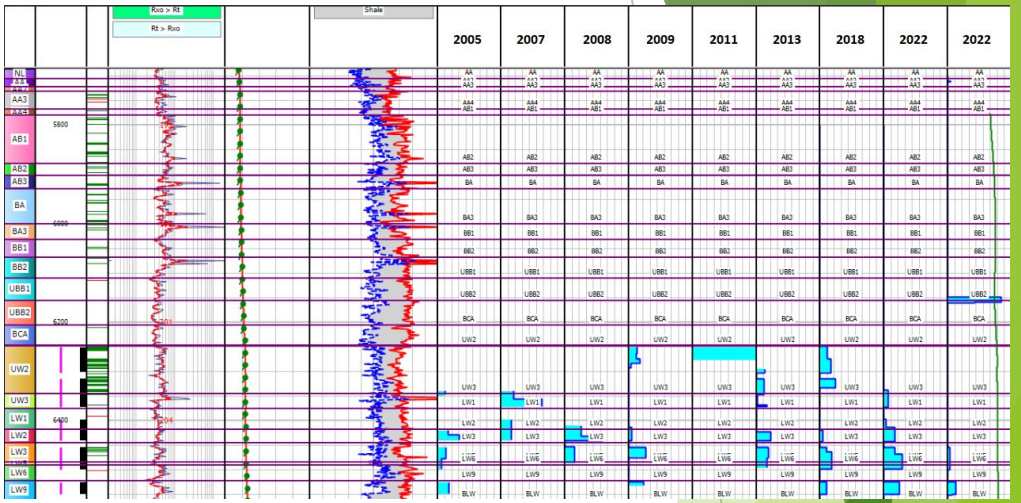
Surveillance of Injectors

- **Finding Injection Inefficiencies Through Surveillance**
  - We look at:
    - Injection surveys/Warmback surveys
    - Well configuration reports
    - Cement Bond Logs
  - Examining the problem and finding a solution
    - Skin buildup
    - Casing leak
    - Failed Packer
    - **78% of 14 are injecting out of zone**

Coiled Tubing/
Acid Dump

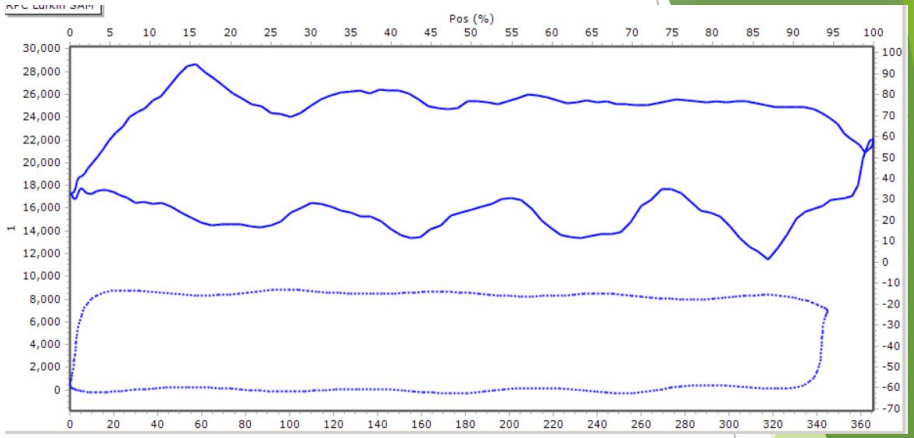
Cement Squeeze
Equipment Replacement

Well 367-30S

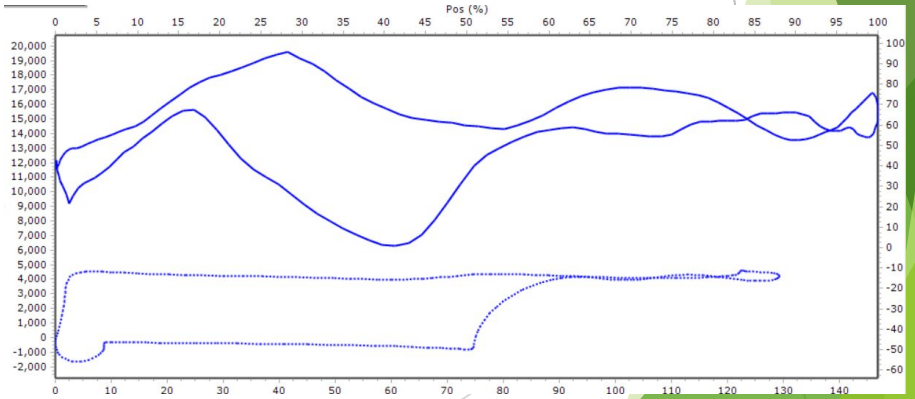


Surveillance of Producers

- **Upsizing Opportunities**
  - Our well analyst group did a full field evaluation using 12 key metrics
  - <u>Identified wells that are at or near lift capacity</u>
    - Unit upsize
    - SPM increase/stroke out
    - Downhole pump upsize
  - Fixing producers allows for more collection of fluid from injectors



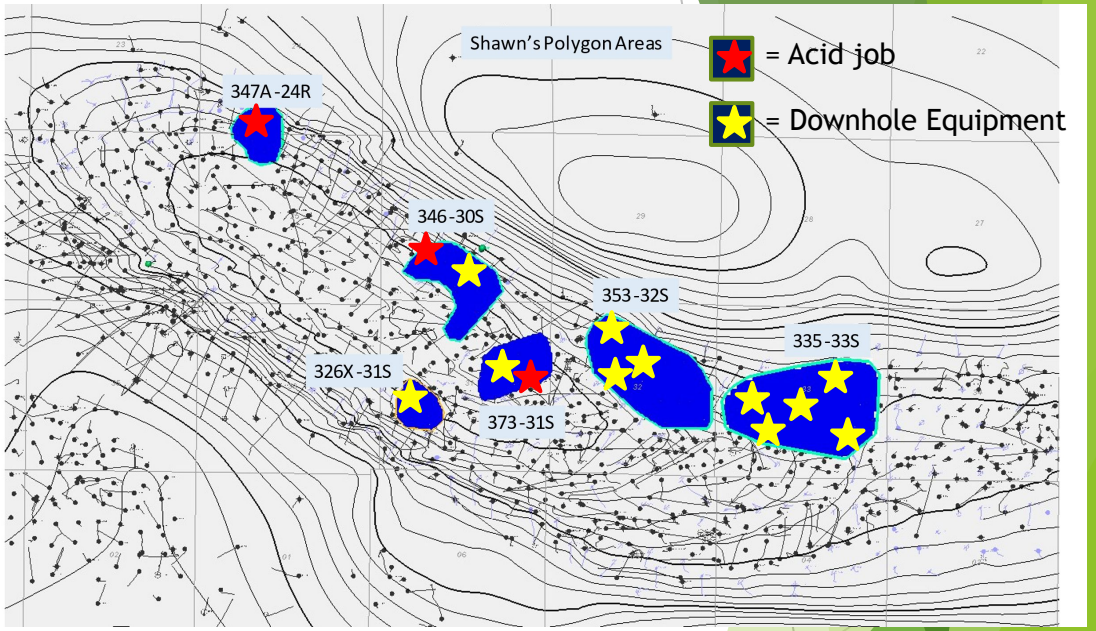
Full Pump



Pumped Off Well

Pattern Identification

- **Pattern Selection**
  - Mapped injectors and created a radius that reaches the closest producers perforated in the UBA, UBB, UW, LW zones
    - Filtered out any producers in NAB (only)
    - 55 Active Producers with WF perforation
    - 17 Injectors



347A-24R	326X-31S	373-31S	346-30S	353-32S	335-33S
4 Producers	3 Producers	5 Producers	10 Producers	16 Producers	17 Producers

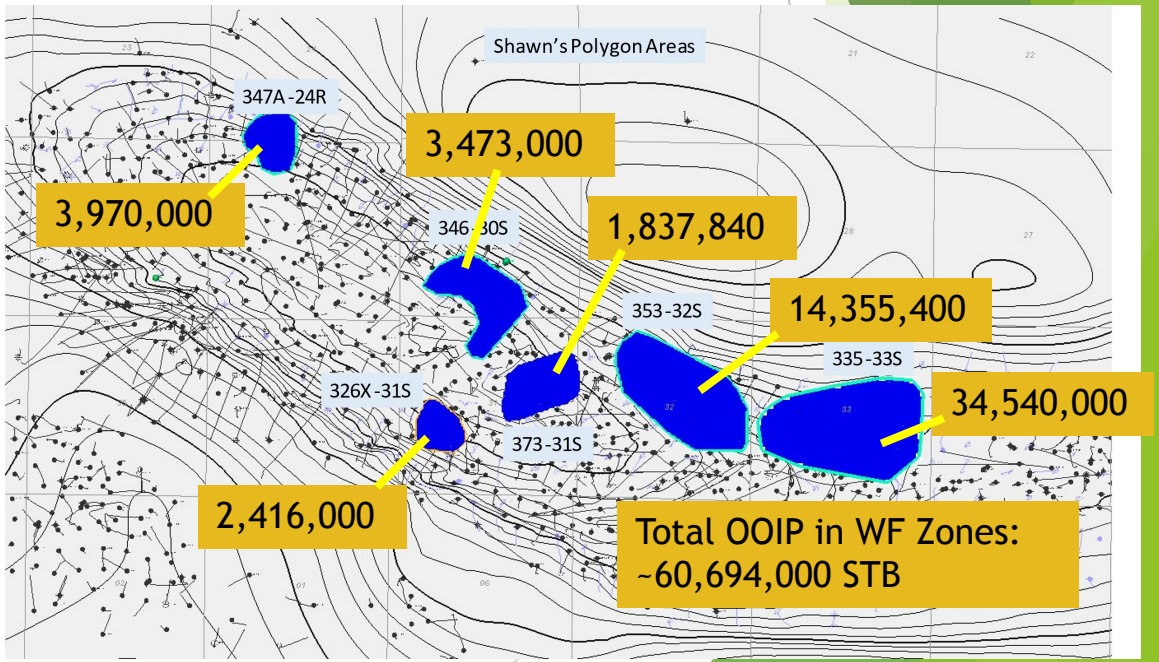
Volumetrics

- **OOIP**

$$OOIP(STB) = \frac{A \times h \times 7{,}758 \times \emptyset \times (1 - S_w)}{B_{oi}}$$

  - Geologists provided data for each zone:[1]
    - Average Sand Thickness
    - Average Permeability (K)
    - Area in acres
    - Water saturation[2]

	Sand Thickness	Avg PHIT Sand	Avg Ka Sand (mD)
347A-24R Polygon			
BA	22	0.18	14
UBA	0.88	0.17	4
UBB	3.46	0.19	10
WESTERNS	146.6	0.2	12



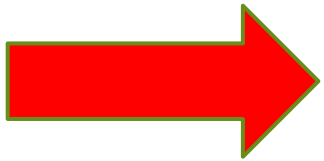
[1] Assuming Two Phase Flow and Bo=1.45
[2] constant oil and water saturation in WF zones

Volumetrics

- Developed a process in excel to calculate production from WF zones
  - **Zonal Production using KH**
    - User can select a well from the region
    - Tool will use Ka and h of each zone to allocate production rates to each zone accordingly
    - Uses a combination of perf history data and geologic data

	Sand Thickness	Avg PHIT Sand	Avg Ka Sand (mD)
347A-24R Polygon			
BA	22	0.18	14
UBA	0.88	0.17	4
UBB	3.46	0.19	10
WESTERNS	146.6	0.2	12

326-31S	326X-31S Polygon
337-31S-RD1	326X-31S Polygon
336-30S	346-30S Polygon
327-30S	346-30S Polygon
348-30S	346-30S Polygon



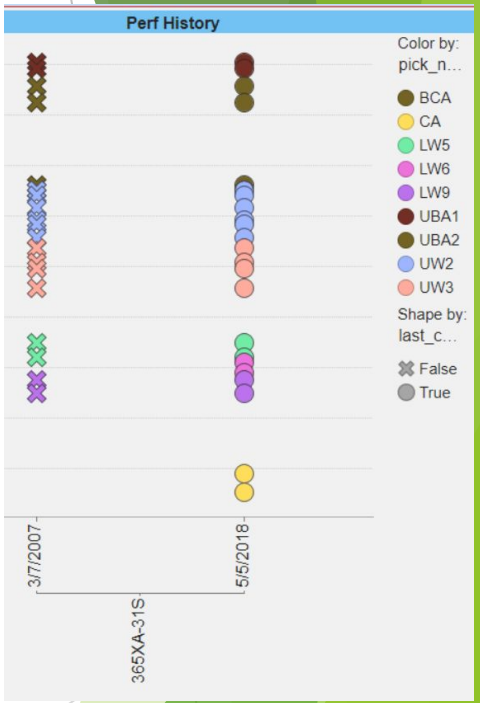
Rates & Volumes Per Zone

Volumetrics

Ex. 365XA-31S

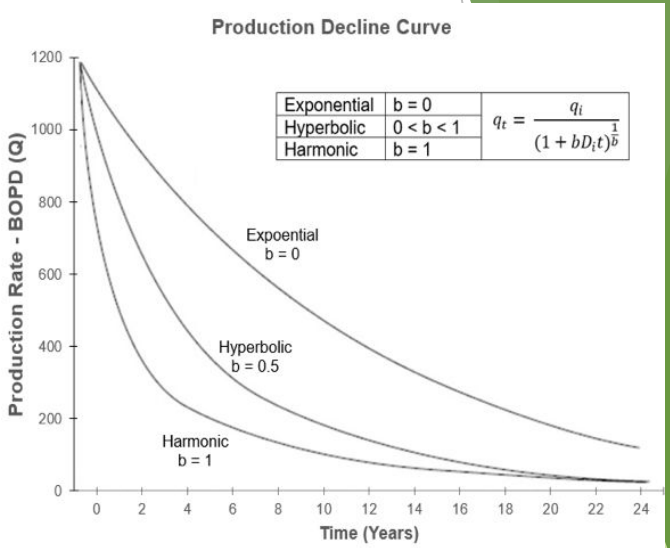
Well Selector:	384H-31S	mulative Production of Well				Total Oil (STB)	50740
						Summed WF P	36937
				UBA	UBB	Westerns	Non-WF Oil Pr
		Cumulative Production by Zone		0	0	36936.69653	13802.95
				OIL Production Rates (STB/D)			
		Dates Read across	Assigning	UBA	UBB	Westerns	Non-WF Oil Pr
			4	0.00	0.00	0.00	0.00
			4	0.00	0.00	18.95	7.08
			4	0.00	0.00	23.75	8.88
			4	0.00	0.00	28.79	10.76
			4	0.00	0.00	26.88	10.05
			4	0.00	0.00	40.77	15.23

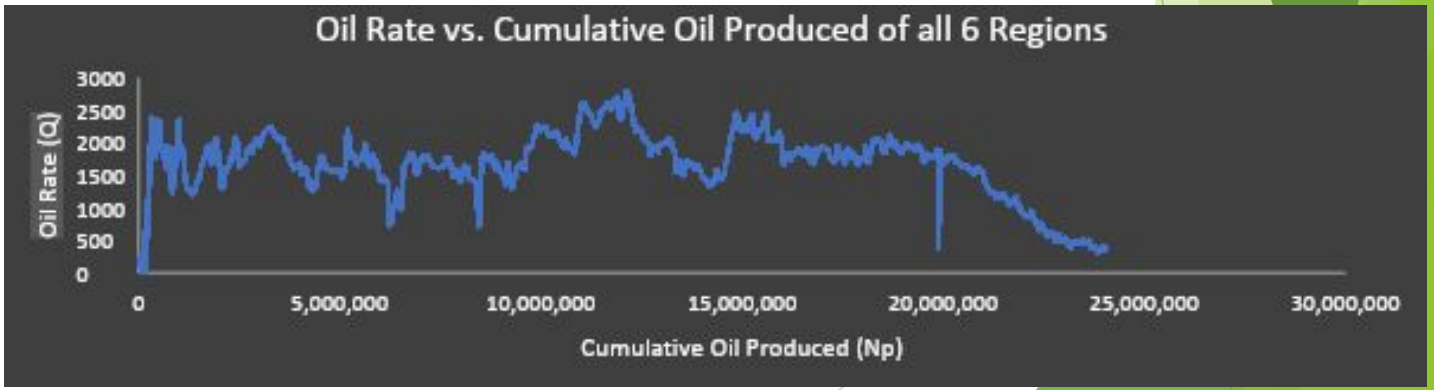
Well Info:					
Polygon Grouping of Selected Well	Well name				
373-31S Polygon	384H-31S				
Open Zones:					
9/28/1952	4/28/1999		6/21/1999	2/7/2007	
NAB	0		0	0	0
UBA	NAB	NAB		NAB	
UBB		WESTERNS		WESTERNS	
WESTERNS					
0					



Decline Curve Analysis

- **Using the Excel Data to Estimate Total Cumulative Volumes**
  - Data from excel and spotfire allow us to track cumulative volumes over time
  - Plotting volumes against $1/F_w$ and Oil Rates of all six regions allow us to estimate RF's and total volumes





Decline Curve Analysis

- **The Process and Outcomes of Decline Curve Analysis**
  - Able to run decline curve analysis using the data from the tool
  - Analysis and Interpretation of Water-Oil-Ratio Performance by V.V. Dondar, T.A. Blasingame
  - Rate vs. Cumulative Volumes
  - Assumptions:
    - "the assumption that the mobility ratio is equal to unity and that a plot of log (krw/kro) versus So is linear"
    - Pseudo-Steady Flow

Figure 1 – Fractional Flow of Water Versus Cumulative Oil Production, NRU Well 3106.

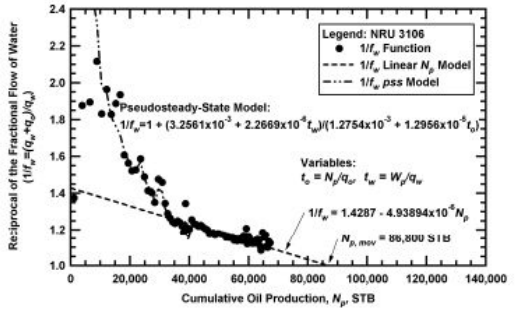


Figure 2 – Reciprocal of Fractional Flow of Water Versus Cumulative Oil Production, NRU Well 3106.

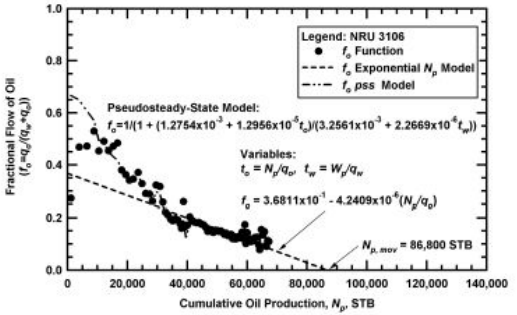
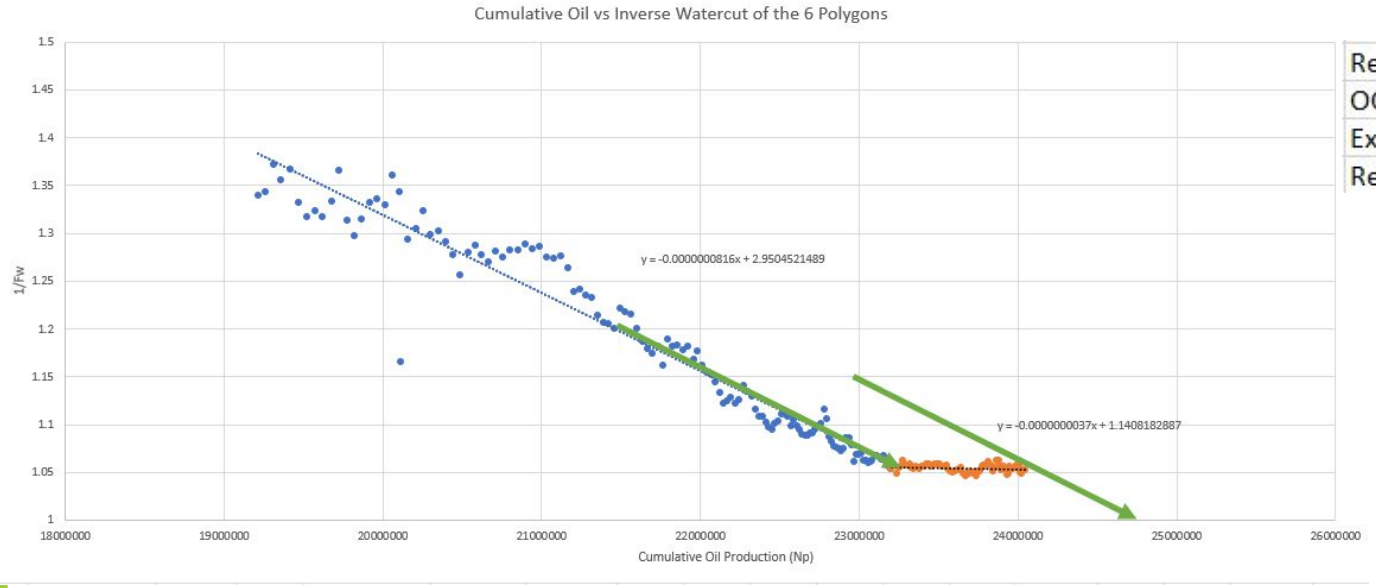


Figure 3 – Fractional Flow of Oil Versus Cumulative Oil Production, NRU Well 3106.

Decline Curve Analysis

Plot of Fraction Flow of Water vs. Cumulative Oil Production of the 6 Regions

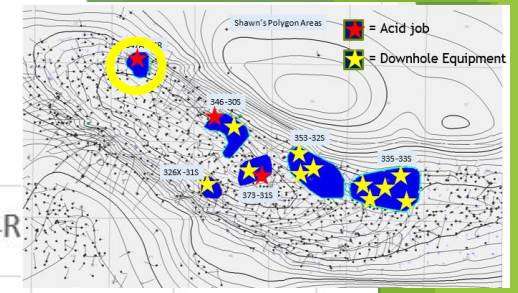


Recovery Factor (Pre 2017)	
OOIP:	60693942
Expected Recovery	23897059
Recovery Factor:	0.3937305

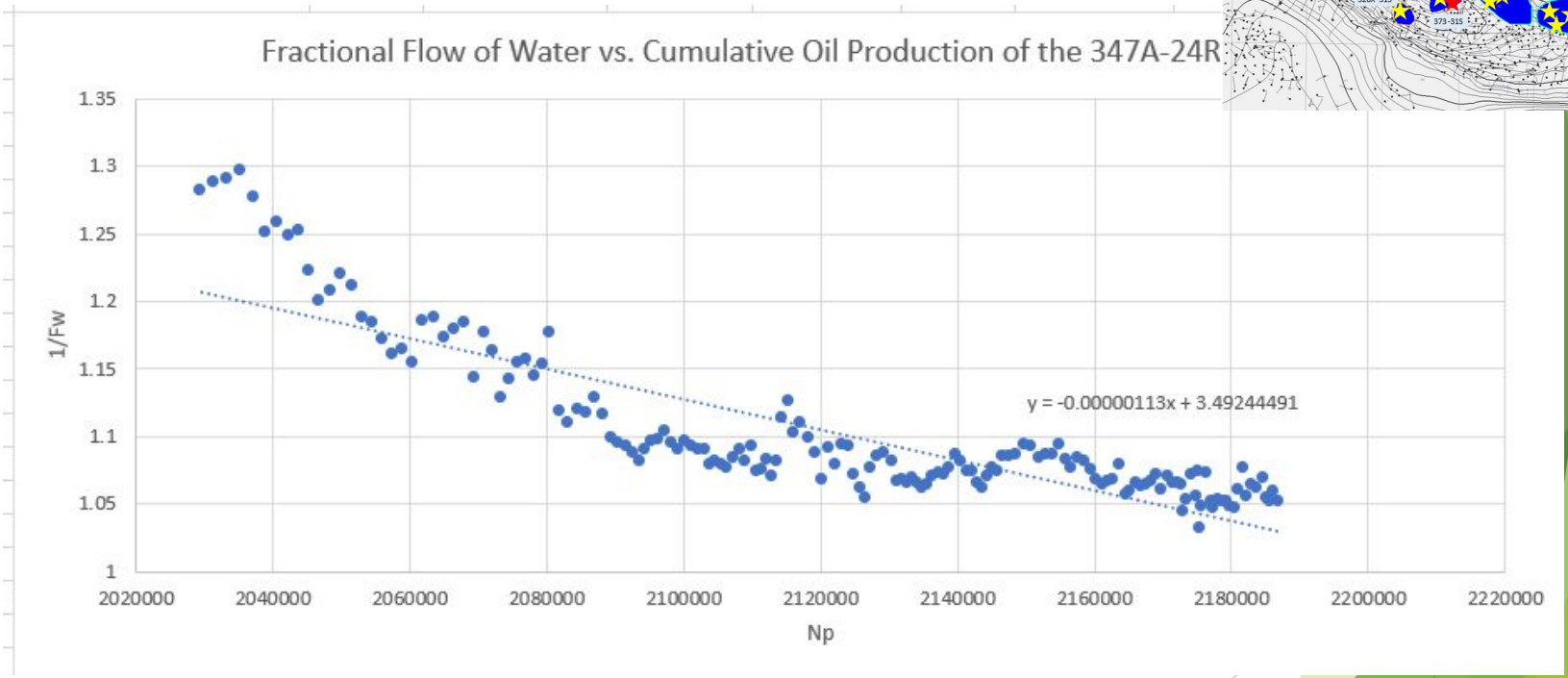
Recovery Factor (After 2017)	
OOIP:	60693942
Expected Recovery	37837838
Recovery Factor:	0.6234203

- Trendline change in 2017 from .39 RF to .62 RF
- Trendline Pre-2017 was used for volumetric calculations
- Trendline stops at 1/Fw=1.005
  - 99.5% watercut

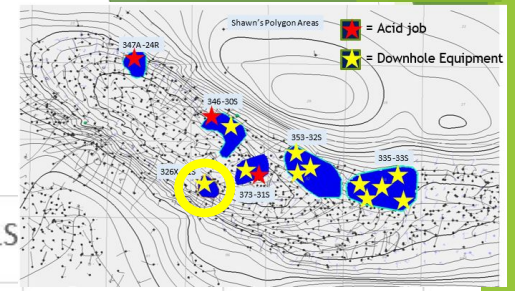
Decline Curve Analysis



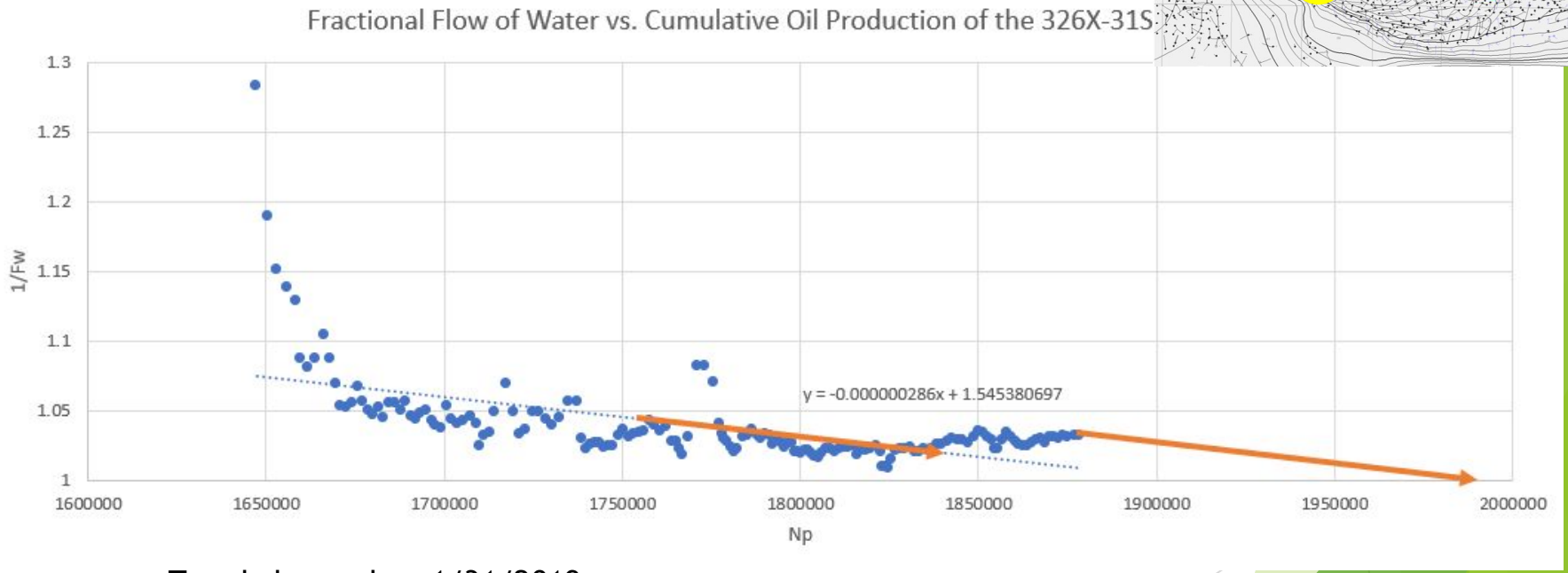
Region 347A-24R



Decline Curve Analysis



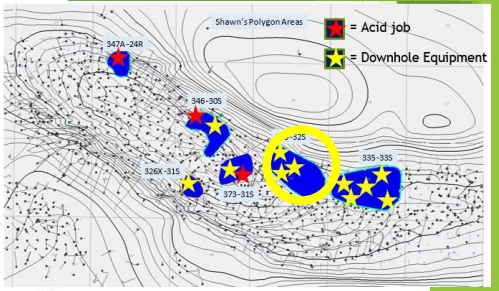
Region 326X-31S

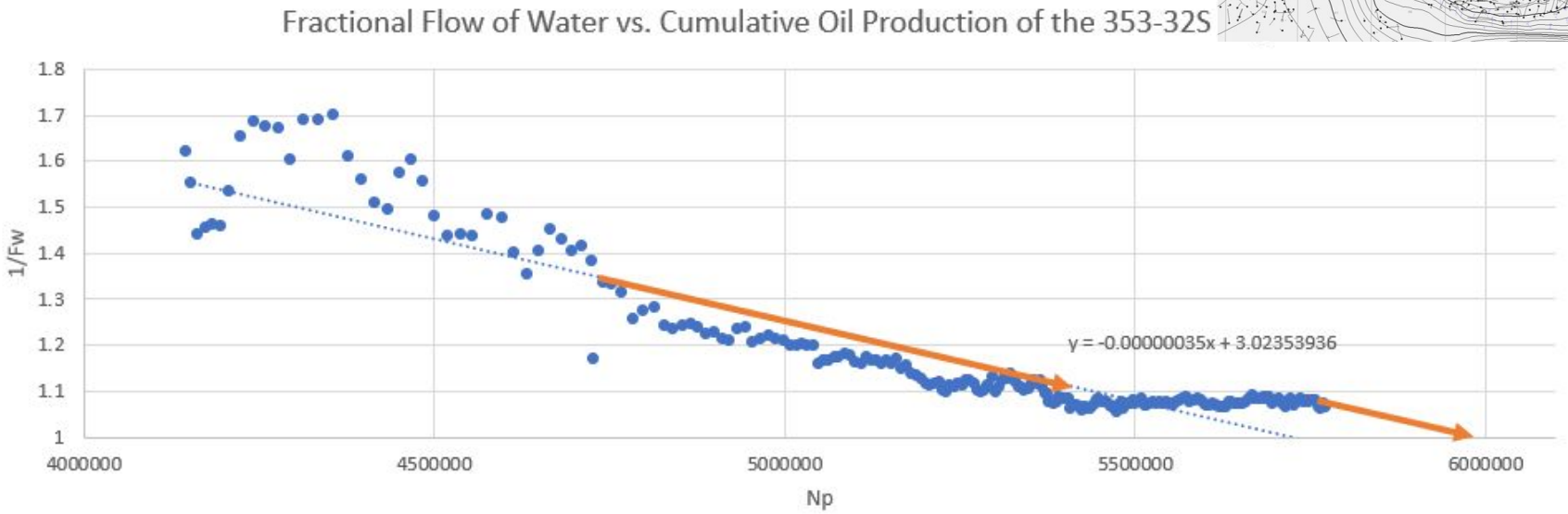


- Trend changed on 1/31/2019
- Reasons for increase after 2019 is being explored

Decline Curve Analysis

Region 353-32S

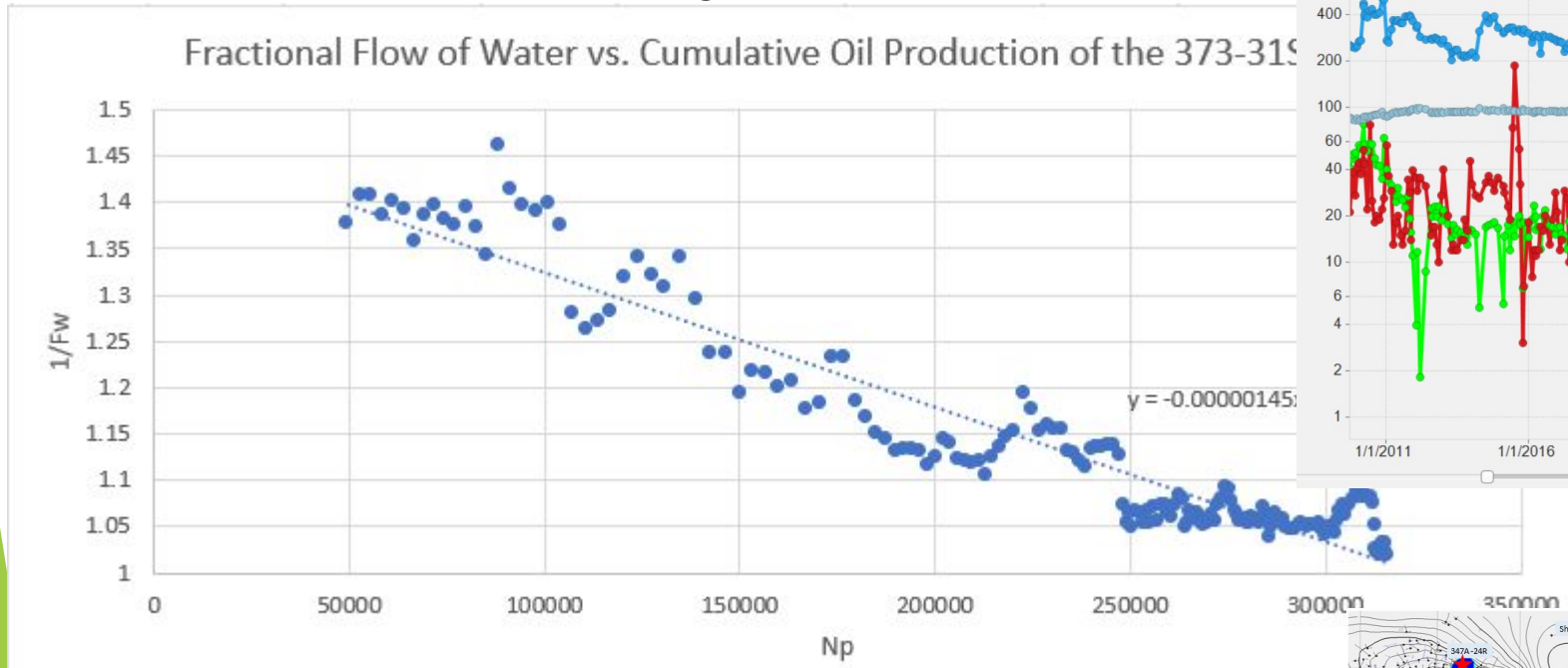


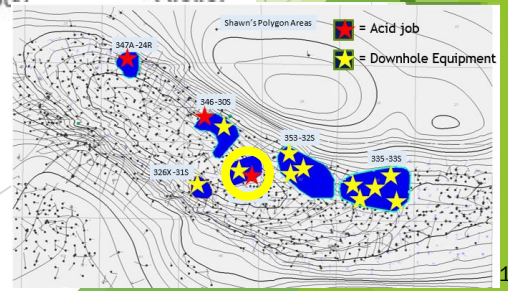


- Trend changed at 9/30/2015
- Most likely caused by carrying water cuts

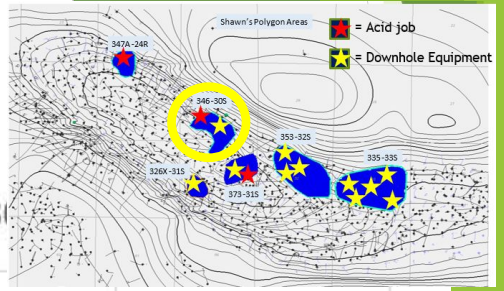
Decline Curve Analysis

Region 373-31S

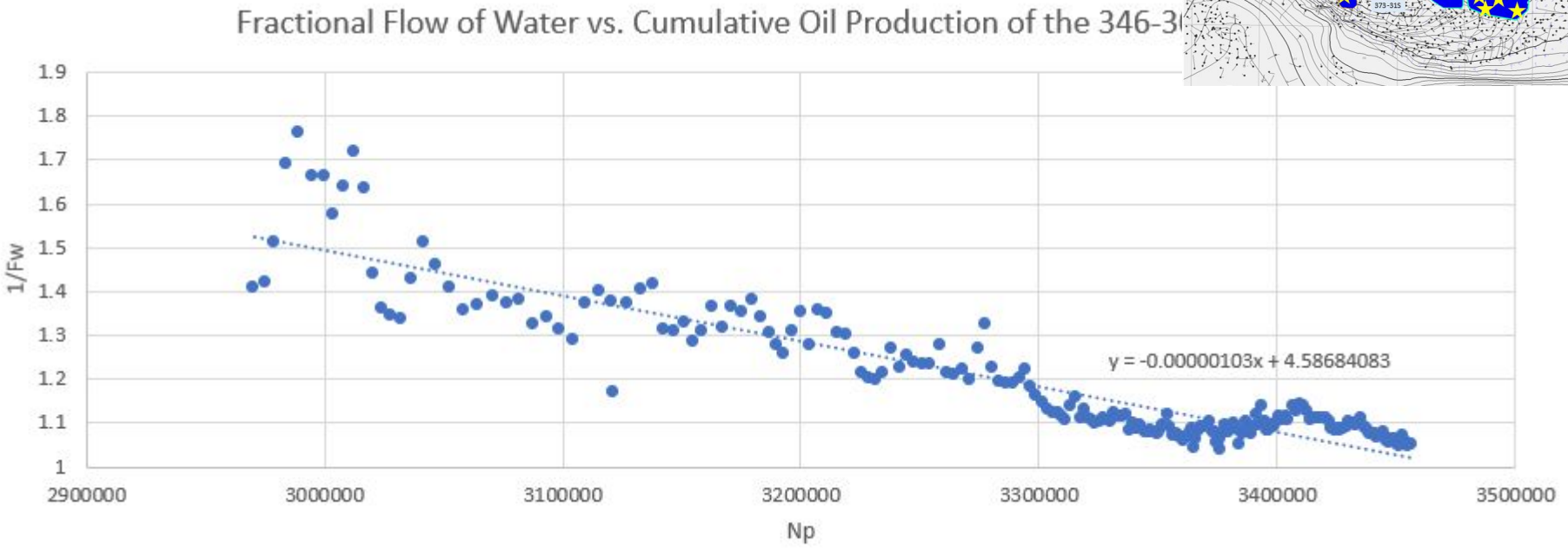




Decline Curve Analysis

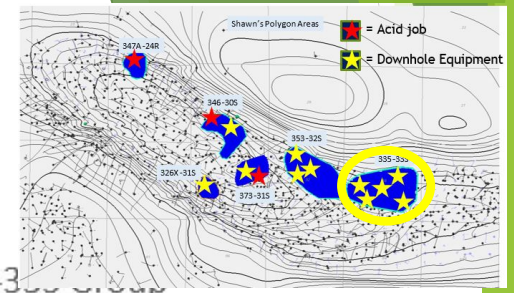


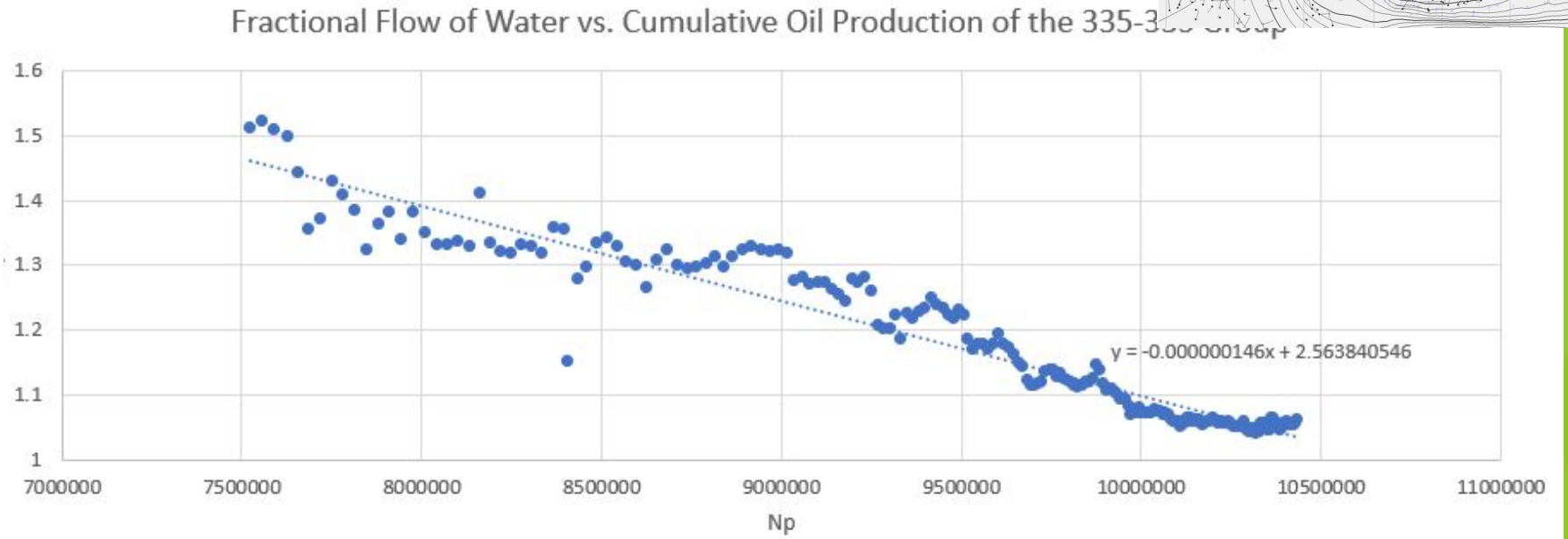
Region 346-30S



Decline Curve Analysis

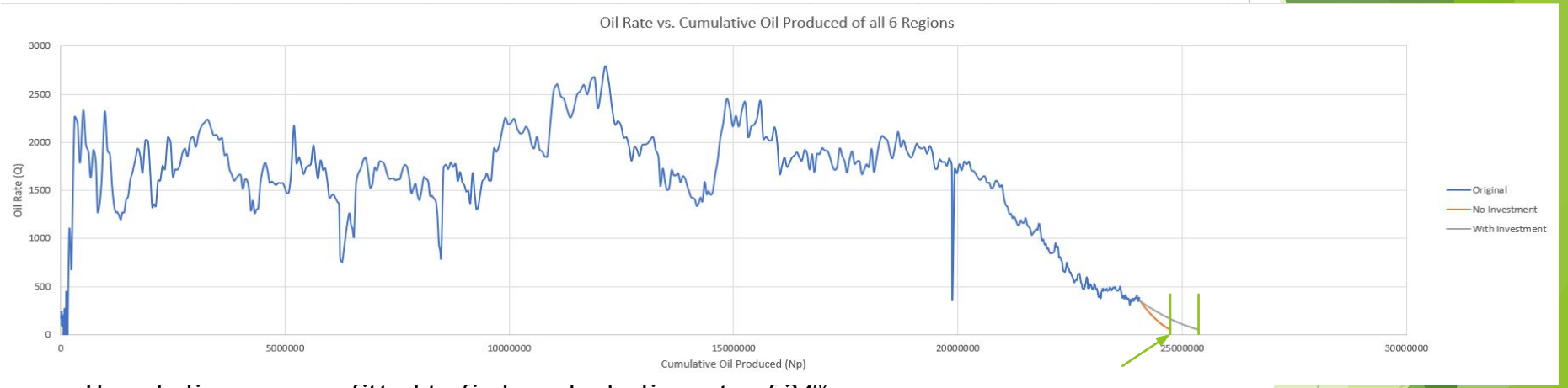
Region 335-33S





Decline Curve Analysis

- **Outcomes of Investment for the 6 Regions**



- Hyperbolic curve was fitted to find yearly decline rate of 24%
- Fixing Injection problems can decrease yearly decline to 12%

  (based on 31S field decline)
- Δ Cumulative Oil = 622108

Δ Cumulative Oil

Costs

- **Costs Analysis**
  - Costs based on historical job estimates in the 31S field
  - Estimates may differ due to supply side constraints and inflation
  - Cost to fix the 14 injectors and 4 producers in the 6 regions is $3,275,000

Group 347A-24R

well name	Well Type	Job Type	Avg Cost,$M	Count	Total M
347A-24	Injector	CT acid job	25	1	$25
				Group Total:	$25

Group 326X-31S

well name	Well Type	Job Type	Avg Cost,$M	Count	Total M
326X-31	Injector	clean out. PU at 6320ft. Dual p	450	1	$450
326-31S	Produce	New Unit	150	1	$150
325X-31	Produce	Consider pull tubing and upsiz	130	1	$130
335-31S	Produce	Consider rotoflex	130	1	$130
				Group Total:	$860

Group 373-31S

well name	Well Type	Job Type	Avg Cost,$M	Count	Total M
373-31S	Injector	Cement from 5520-5550ft. Ou	413	1	$413
383X-31	Injector	ct Acid job	25	1	$25
				Group Total:	$438

Group 346-30S

well name	Well Type	Job Type	Avg Cost,$M	Count	Total M
346-30S	Injector	Acid dump (acid impact uncle	5.5	1	$6
367-30S	Injector	Wellbore cleanout and cemen	413	1	$413
				Group Total:	$419

Group 353-33S

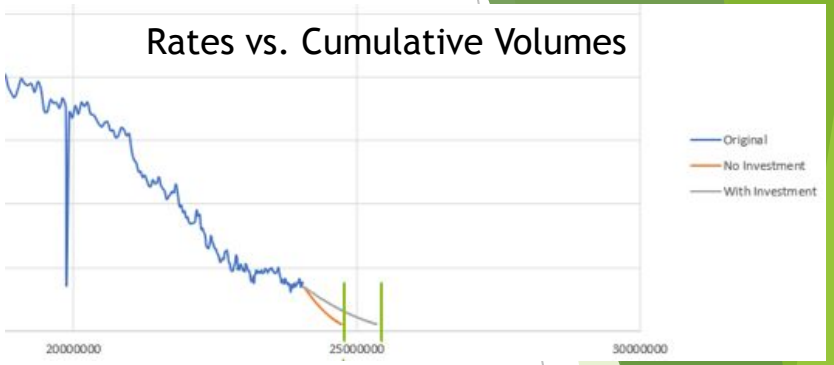
well name	Well Type	Job Type	Avg Cost,$M	Count	Total M
353-32S	Injector	Add perfs 6460-6470ft. Ceme	437	1	$437
373-32S	Injector	Clean out. PU at 6465ft	25	1	$25
375-32S	Injector	Bridge Plug Replacement	50	1	$50
				Group Total:	$512

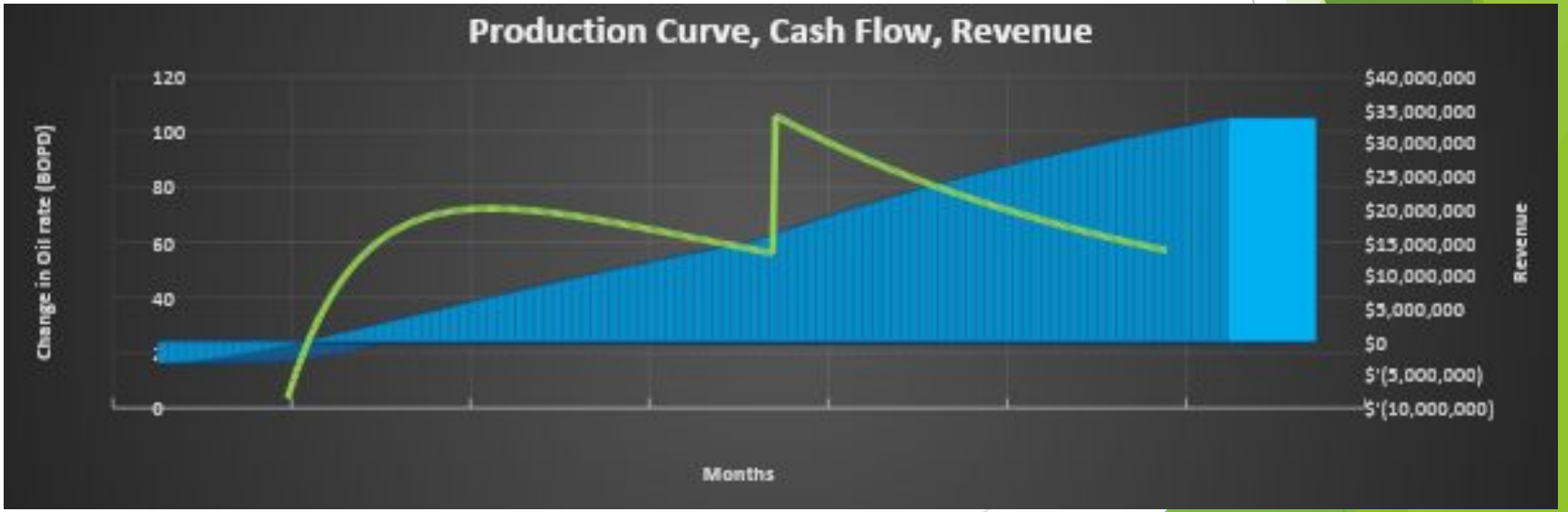
Group 335-33S

well name	Well Type	Job Type	Avg Cost,$M	Count	Total M
335-33S	Injector	Packer from 6610-6740ft. Isol	296	1	$296
355-33S	Injector	CO, Dual Packer 6650ft-678	296	1	$296
363X-33	Injector	Cement from 7280-7315ft	413	1	$413
366-33S	Injector	Dual packer isolating 6717ft-6	15	1	$15
327XA-3	Injector	Up injection rate to 10k stb/d	0	1	$0
356X-33	Produce	SPM inc	1.5	1	$2
				Group Total:	$1,022
				Absolute total	$3,275

Economics

- Breakeven point @ 44 months based on:
  - $65/bbl after lift costs
  - 25-year project lifespan
- Total Profit after 25 years is $37,162,020





Summary

- Extensively analyzed ~14 injectors to perform work on
  - 3 wells for acid jobs
  - 11 wells that need downhole equipment (packers, plugs, casing, cement…)
- Total Profit after 25 years is $37,162,020 if work is executed
  - Breakeven point is 44 months
- Created algorithms in excel to calculate oil rates and volumes from WF zones

Recovery Factor with no investment	
OOIP	60693941.75
Expected Recovery	24637990.2
Recovery Factor:	0.406

Recovery Factor if work is completed	
OOIP	60693941.75
Expected Recovery	25343796.67
Recovery Factor:	0.42