GROUNDWATER PROTECTION COUNCIL

2020 VIRTUAL ANNUAL FORUM

Injection Strategy Impacts on Formation Capacity

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Injection strategy has multiple dimensions which impact on total capacity

Injection capacity can be measured several ways:

1. Total volume before the near wellbore formation "plugs"
2. Total solids in a slurry well before safe injection capacity is exhausted
3. Total volume injected before reservoir pressure reaches MASIP
4. Total volume injected before adverse effect (e.g., fault activation)

Whatever your relevant measure, injection strategy has a dramatic impact

This talk explores injection strategy's impact on the first two measures, as well as how capacity is shared by competing wells. (The fourth measure was explored by Reed Davis this morning in the seismicity session)

Case Study

Total volume before formation plugs

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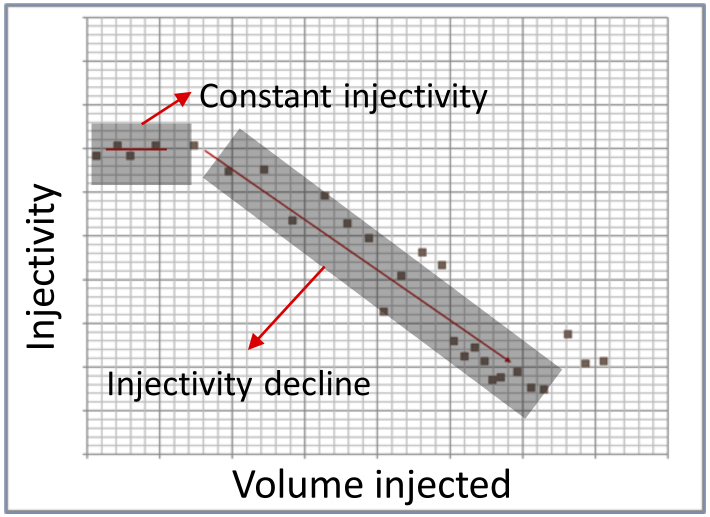
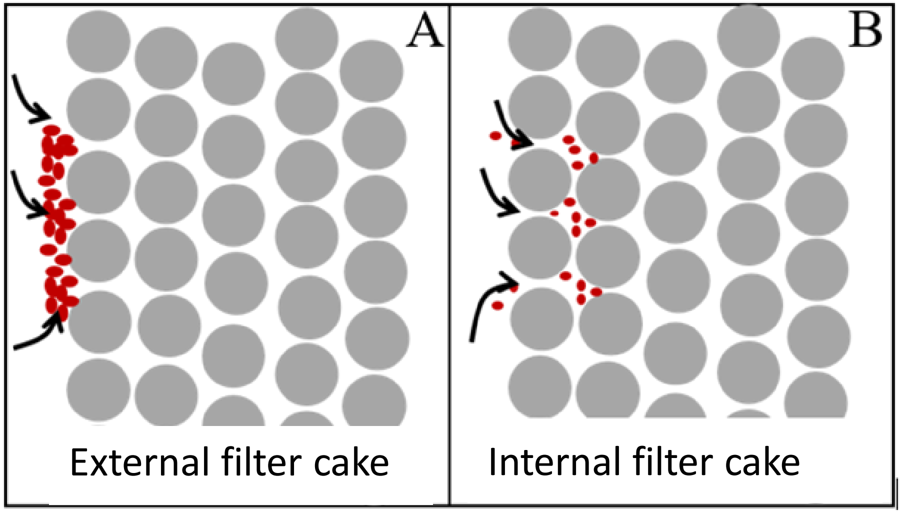
Wellbore damage is the main driver of injection capacity loss





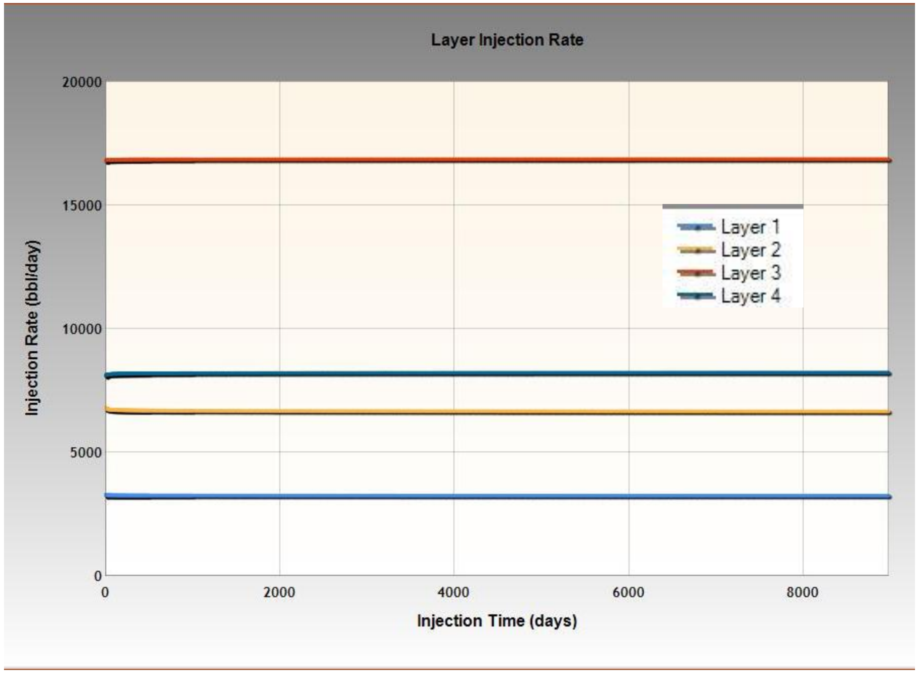
Wellbore damage is a function of solids content, particle size, pore throat size, and fracturing strategy

Case: Matrix injection w/ no damage in an infinite reservoir

Formation Parameters	Layer 1	Layer 2	Layer 3	Layer 4
K, md	2000	1000	4000	8000
h, ft	15	60	40	10
σ_{min}, psi/ft	0.6	0.55	0.58	0.6
Top, ft	9415	9510	9620	9700
Bottom, ft	9430	0570	9660	9710
Pressure, psi/ft	0.445	0.445	0.445	0.445

Other parameters

- No Damage - Assume 100% of the injected solids pass through the formation
- No wellhead Restriction - Well head pressure = 3500 psi



As expected, in a case with no damage or fracturing, the flow distribution nearly mirrors the Kh distribution, save for the small effect of wellbore friction and the differing reservoir pressures which slightly decreases the flow to the deeper layers.

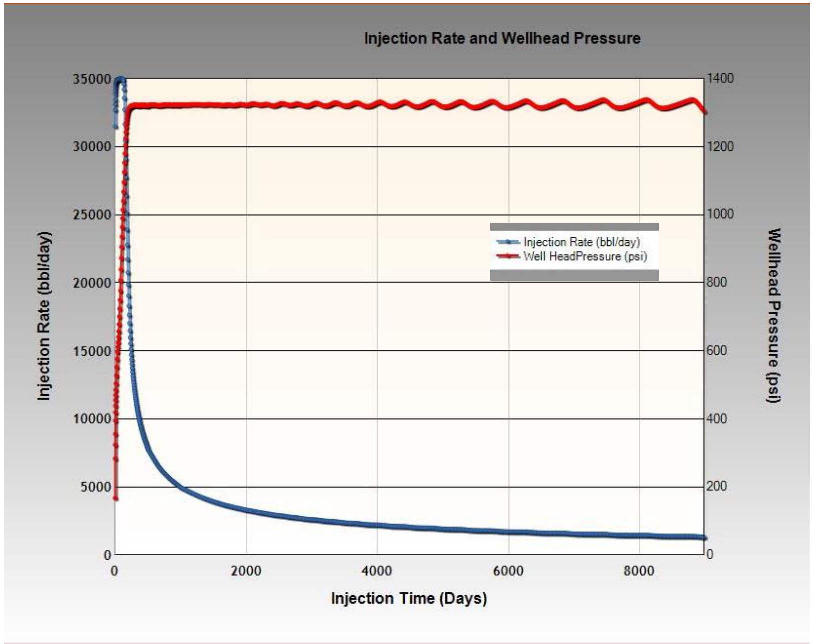
	Layer 1	Layer 2	Layer 3	Layer 4
Kh % of total	9.1%	18.2%	48.5%	24.2%
Q % of total	9.3%	19.1%	48.2%	23.5%

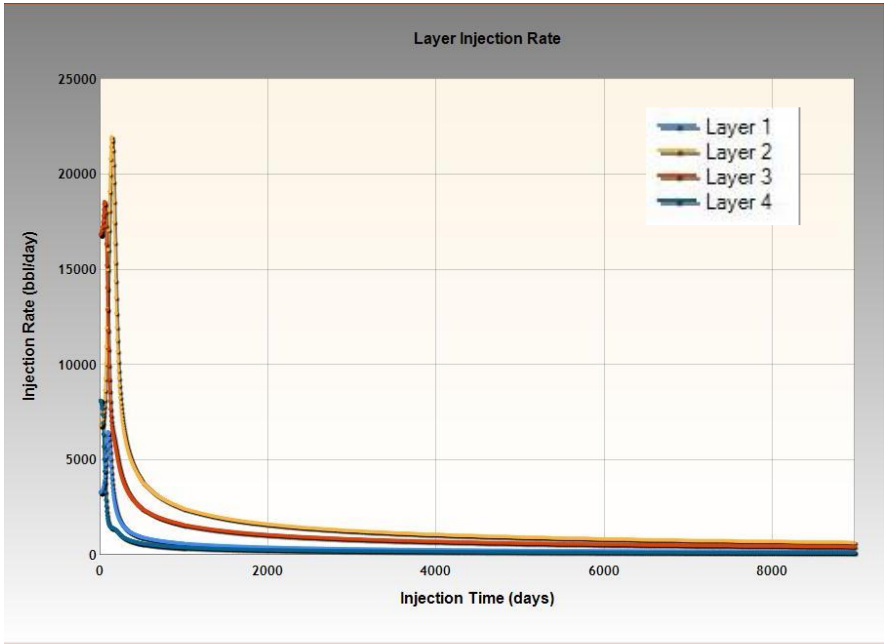
Case: Wellbore Damage with Constrained Surface Pressure

Formation Parameters	Layer 1	Layer 2	Layer 3	Layer 4
K, md	2000	1000	4000	8000
h, ft	15	60	40	10
σ_{min}, psi/ft	0.6	0.55	0.58	0.6
Top, ft	9415	9510	9620	9700
Bottom, ft	9430	0570	9660	9710
Pressure, psi/ft	0.445	0.445	0.445	0.445

Other parameters

- Assume 80% of the injected solids pass through the formation
- Well head pressure = 1350 psi
- Filter Cake Permeability = 1 md





With the surface pressure restricted, the total flow rate decreases as the damage builds, then increases again as an open fracture reduces the restriction

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Injectivity loss can be identified with monitoring before becoming critical

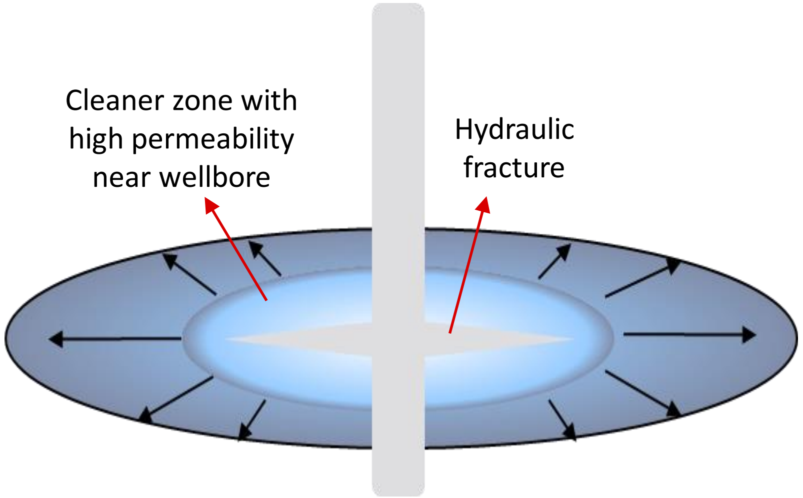
A consistent rise in injection pressure along with a consistent decline in permeability is an indication of plugging, usually driven by solids in the injectate or precipitation downhole

Class II and some Class V injection wells can maintain the injectivity even with the solids in the injectate

Injection at pressure sufficient to cause formation breakdown creates a hydraulic fracture which increases the permeability around the wellbore

Class I wells cannot inject above frac gradient but are allowed to be stimulated using propped fractures which can accomplish a similar result

Fracturing can be used to preserve injectivity



Injectate migrating away from wellbore

**k – permeability*
Xf – Fracture half length
S – skin factor

Case: Formation Damage with Fracturing Allowed

Formation Parameters	Layer 1	Layer 2	Layer 3	Layer 4
K, md	2000	1000	4000	8000
h, ft	15	60	40	10
σ_{min}, psi/ft	0.6	0.55	0.58	0.6
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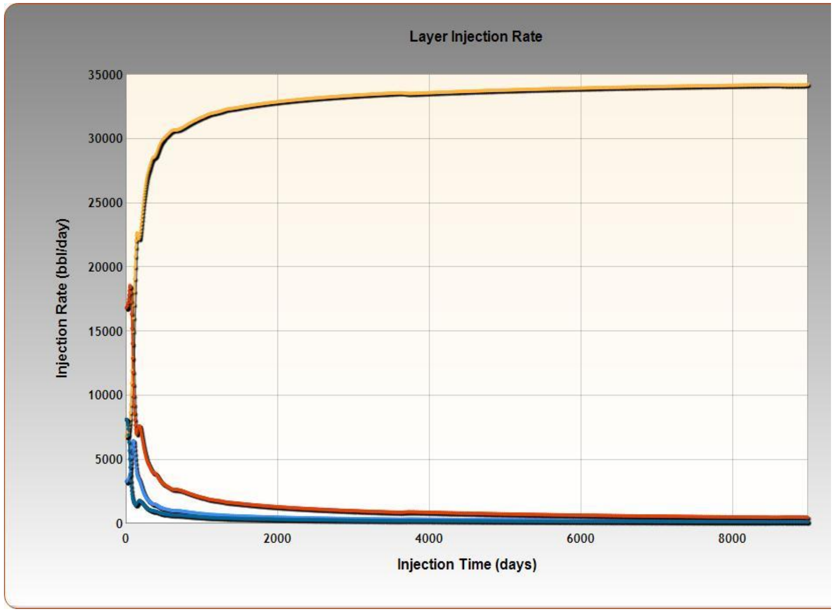

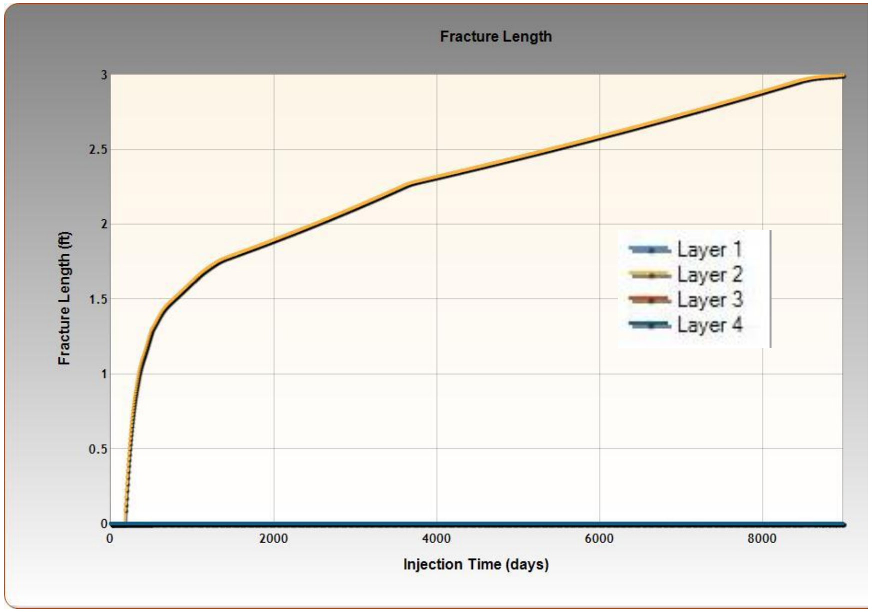

Once the first fracture opens up, the fractured layer (2) takes nearly all the flow.

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Case Study

Total solids injected before safe injection capacity is exhausted

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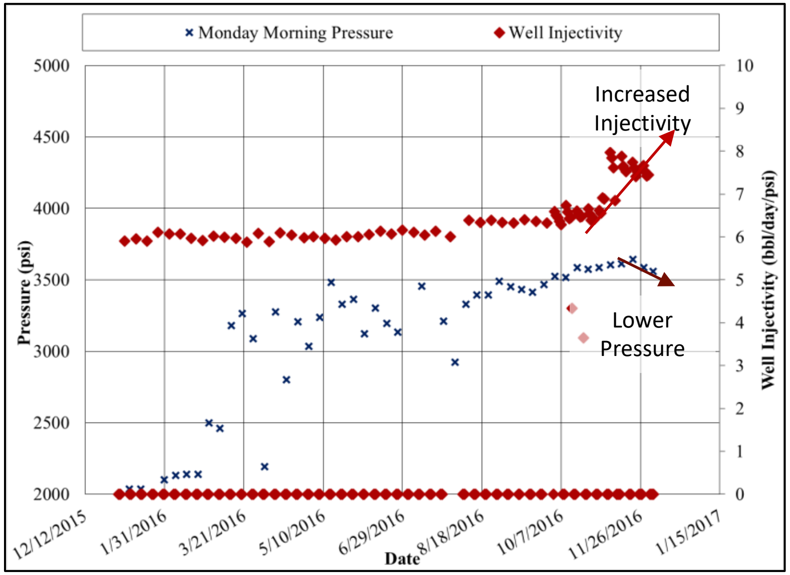
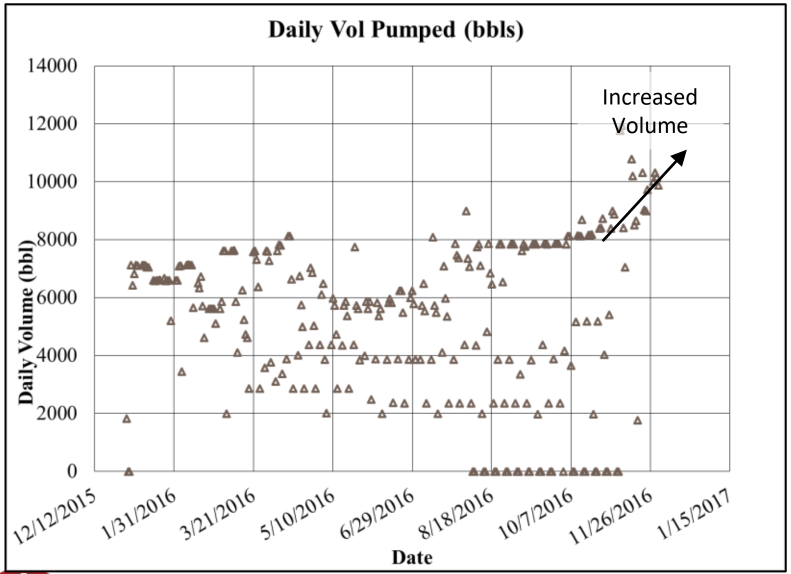
A change of injection strategy can increase capacity: LA TIRE Facility





An increase in injection rate and total batch size allowed for better solids distribution within the fracture and results in lower fracture closure pressure / stress accumulation per batch.

These modifications resulted in increased injectivity and decreased leak-off pressure, despite increased daily injection volume.

Parameter	Previous	Current
Injection Rate (bpm)	8.2	10
Injection days/week	5	4
Stand-By days/week	2.5	3.5
Weekly truck loads	26	40
Average weekly injected volume (equivalent tons)	800	1200

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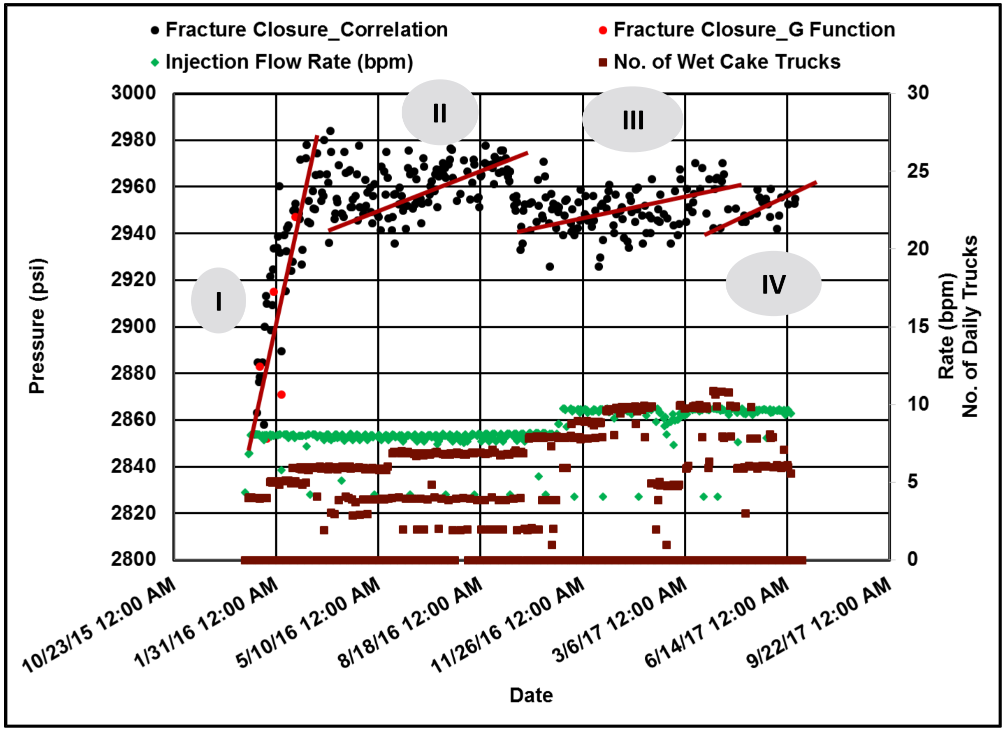
Total solids capacity can be calculated by observing trends in closure pressure



Operating parameters (injection rate, daily injection duration, weekly rest time) have a strong impact on total formation capacity

Here we see four different periods each trending to a different total solids capacity in the zone

The method shown for calculating formation capacity is patent pending

Period #	Number of Daily Trucks	Flow Rate (bbl/min)	Batch volume (bbl)	Stress increase (psi/batch)	Formation Capacity (bbl)*	Total Solids Capacity (bbl)
I	4 to 5	8	5825	2.54	1.83M	91,500
II	6 to 8	8	7850	0.53	11.82M	591,000
III	9 to 11	10	10500	0.38	21.95M	1,100,000
IV	6	10	8080	0.39	16.43M	821,000

* Formation capacity is estimated by using the calculated stress increase per batch and projecting the number of batches at which the accumulated stress increase in the injection layer produces injection pressures which approximate the fracture pressure of the confining layer. This is when injection into the current zone must cease to prevent fracturing of the confining layer. By understanding the number of batches until this condition is met, as well as the volume of solids injected per batch, we can estimate total solids capacity for the current interval under different scenarios.

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Case Study

Competition for pore space favors Class II wells over Class I

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Reservoir models forecasting formation capacity of Class I vs Class II wells

Three 10-year cases were modeled for Class I and II injection into a fictional naturally fractured carbonate formation (which we shall call the "CARBUCKLE")

Case A: Two Class I wells

- The injection fluid stays close to the wellbore due to low injection pressure
- Formation utilization is evenly distributed

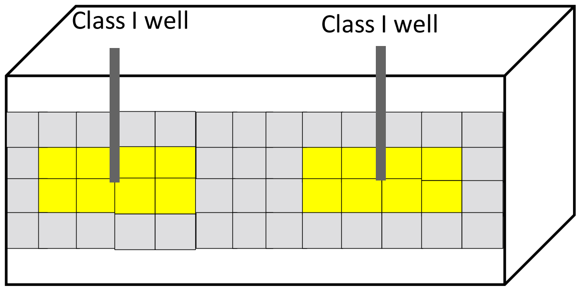
Case B: Two Class II wells

- Higher injection pressure allows injected fluid to occupy larger radius around the wellbore
- Formation utilization is evenly distributed because injection pressures are the same

Case C: One Class I and one Class II well

- Higher Class II injection pressure allows drives the movement of injected fluids and compromises the formation capacity of the Class I well
- Figure C shows the Class II fluids occupy 3X the pore space of the Class I well

A



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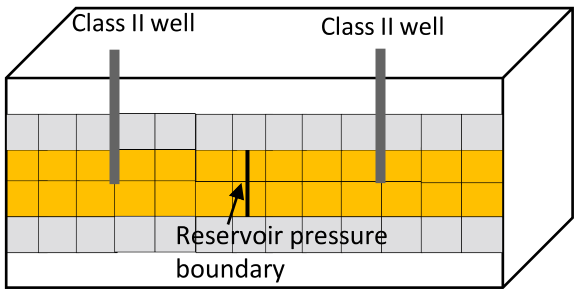

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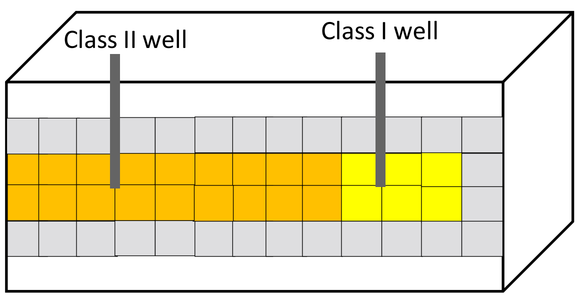

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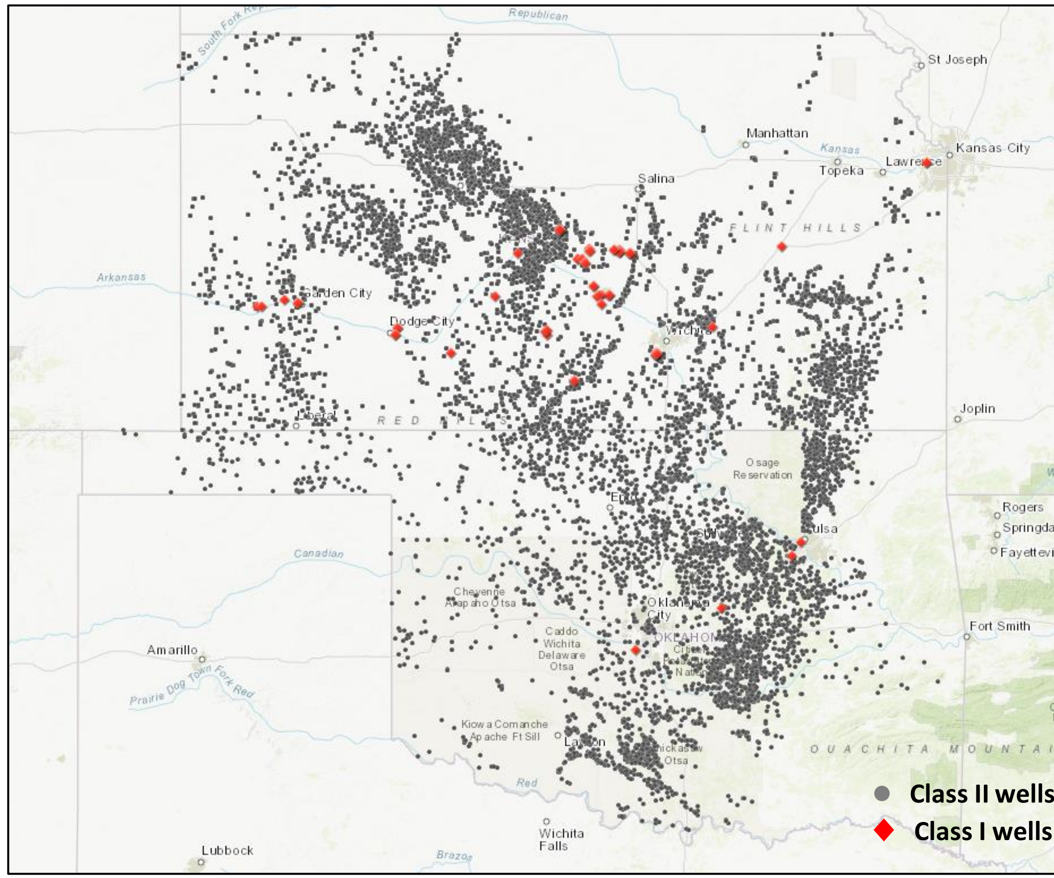
Map of Oklahoma and Kansas showing Class I and Class II wells

There are ~55,000 Class II wells and ~73 Class I wells the OK and KS injecting in the Arbuckle

Each Class I is surrounded by a cluster of Class II wells

Based on the reservoir model studied, the Class II wells will occupy majority of the formation capacity



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Key takeaways

Injection strategy has a dramatic impact in utilizing the maximum formation capacity

Wellbore damage is a function of solids content, particle size, pore throat size, and fracturing strategy

With the surface pressure restricted, the total flow rate decreases as the damage builds, then increases again as an open fracture reduces the restriction

Different strategies can result in substantially different capacities, whether measured in fluid capacity or solids capacity

Due to lower injection pressure, Class II wells are less susceptible to capacity losses from wellbore damage and competition as compared to Class I wells

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Thank You

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