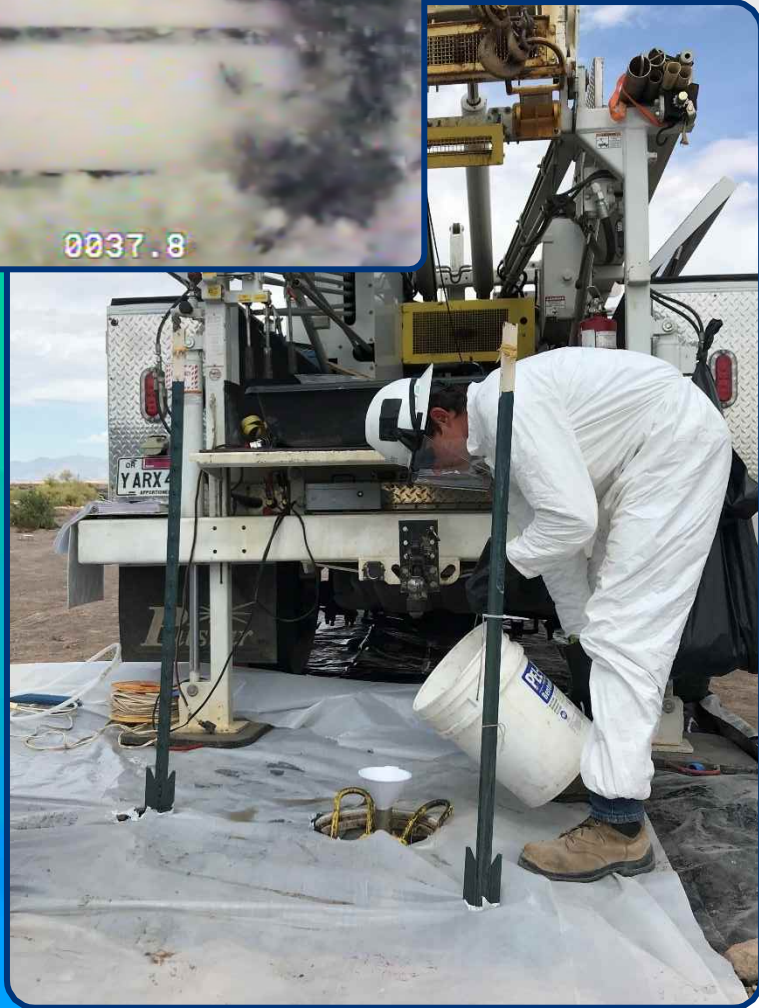




Well Maintenance Techniques to Improve Injectability Over Time for Long-Term In-Situ Bioremediation

Jenny Dabbs, P.G.,

Dana Grady, P.E., and Ronnie Britto, Ph.D.,
P.E.

(Tetra Tech, Tennessee, USA)

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Presentation Overview

- Challenges for Long-Term In-Situ Bioremediation (ISB) Operations
- Treatability Study Overview
- Injection Well Maintenance Program
- Injection Well Maintenance Results
- Summary and Conclusions

Challenges for Long-Term ISB Operations

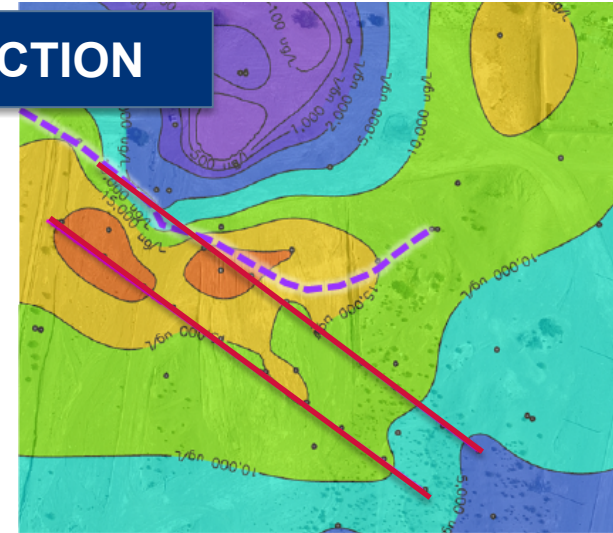
- Periodic injections of carbon substrate into an aquifer can result in:
 - Accumulated biomass
 - Precipitation of inorganic solids (e.g., calcium or magnesium carbonates)
 - Buildup of intermediate by-products
- Routinely observed in immediate vicinity of injection well screens/filter pack rather than broader aquifer formation
- Complications from these accumulations include:
 - Decreased injection well efficiency
 - Decreased injection rates
 - Increased injection pressures
 - Reduced to sub-optimal injectate distribution in subsurface



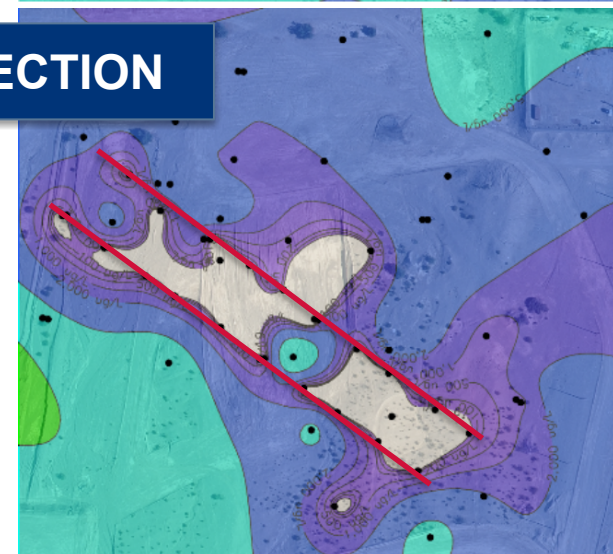
Treatability Study Overview

- **Initial Treatability Study Objective:**
 - Evaluate effectiveness of through injection of emulsified vegetable oil (EVO) to reduce flux of perchlorate in groundwater
- **Treatability Study Extension Objectives:**
 - Evaluate injection frequency and quantities of substrate as biologically active zone matures
 - Assess long-term injection well operation and maintenance requirements

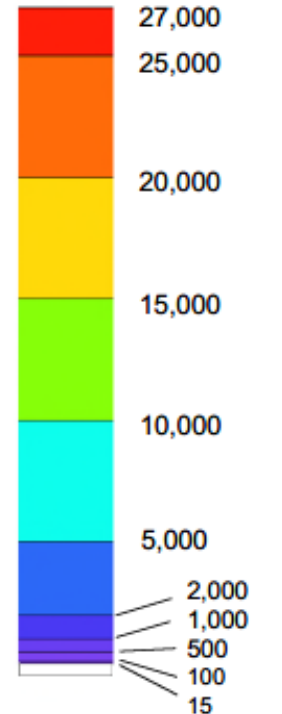
PRE-INJECTION



POST-INJECTION



Perchlorate in groundwater (µg/L)

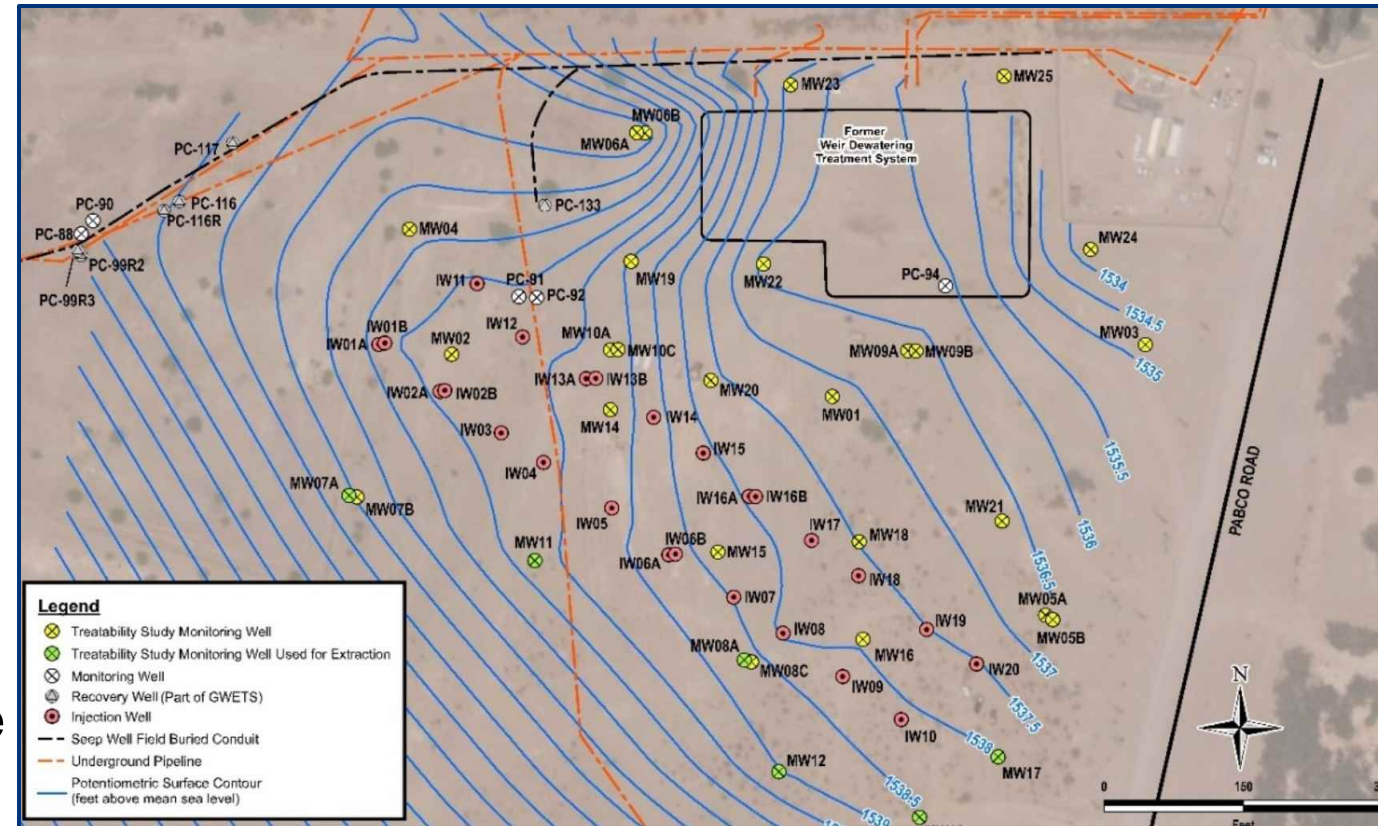


— Injection Well Transect

- - - Approximate Paleochannel Centerline

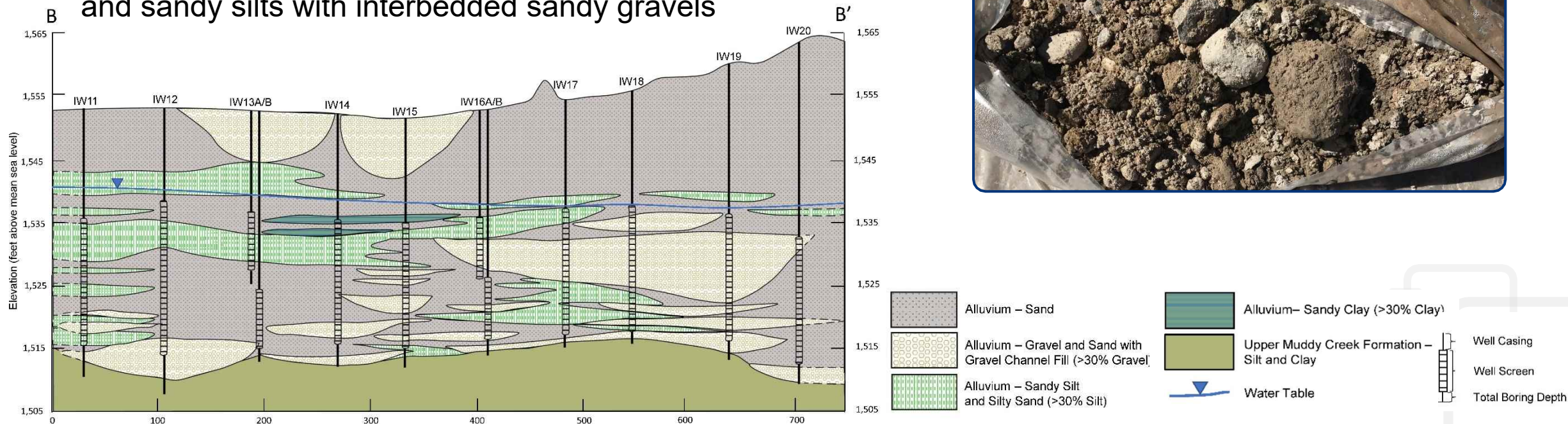
Treatability Study Overview

- 25 injection wells situated in two staggered transects
 - Wells spaced 75 feet apart
 - Transects spaced 100 feet apart
- Eight injection events over 5-year time period
 - Injectate – EVO, glycerin, phosphate, sodium sulfite, and extracted groundwater
 - Hourly readings of injection pressure and injection flow rate at individual injection wells



Treatability Study Overview

- Injection Well Construction
 - 2-inch Schedule 40 PVC
 - 0.020" slotted screen, ranging from 5 to 25 feet long
 - Filter pack 8x20 sand
- Geology – saturated alluvium comprised of silty sands and sandy silts with interbedded sandy gravels



Injection Well Maintenance Program

- Injection Well Video Logging
- Analysis of Accumulated Solids
- Injection Well Maintenance via 3 Methods
 - Surge and Bail
 - Hydrojetting
 - Combination of Surge and Bail, Hydrojetting, and Chemical Treatment
- Three separate injection well maintenance events

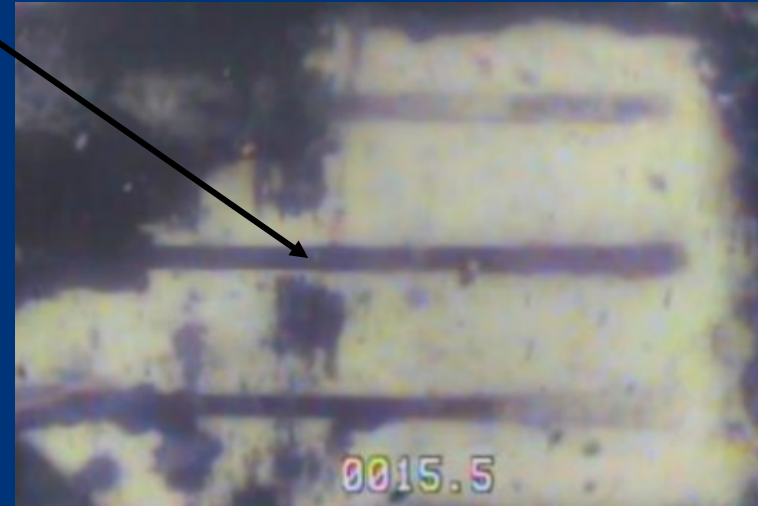


Injection Well Video Logging

Slotted Well Screens



**White inorganics
(likely calcium precipitates)**



**Dark-colored biomass
along well casing**

- Turbidity increased with depth
- Visible biomass and precipitates in some wells without reduced injectability

Analysis of Accumulated Solids

- Mixture of biomass and precipitates varied by location
- Precipitates primarily white to yellowish, malleable, soapy texture; limited effervescence observed with application of HCl acid
- Select locations with more brittle solids, strong HCl acid reaction
- Samples collected for analysis from 2 wells not accepting injectate and 2 wells with reduced injection performance

Likely Constituents	No Injectability	Reduced Injectability
Calcium Oleate	Primary	Minor
Calcium Sulfate	Minor	None
Calcium Carbonate	Minor	Some
Biomass	Some	Primary



Injection Well Maintenance Program

- Injection wells evaluated based on injection rates and injection pressures
 - Permeable subsurface initially accepted injectate at <15 pounds per square inch (psi) at rates averaging 6.5 gallons per minute (gpm)
 - After four injection events over two years, approximately a third of injection wells indicated reduced performance (increasing injection pressures/decreasing injection rates)
- The ratios of injection pressures to injection rates were calculated for each injection well following the fourth injection event
- Nine injection wells were selected for the first maintenance event:
 - Ratio of injection pressure to injection rate of greater than 5 (selected as early signal for well maintenance)
 - Two of the nine injection wells did not accept injectate during the fourth injection event

Injection Well Maintenance Program

Initial Injection Well Selection

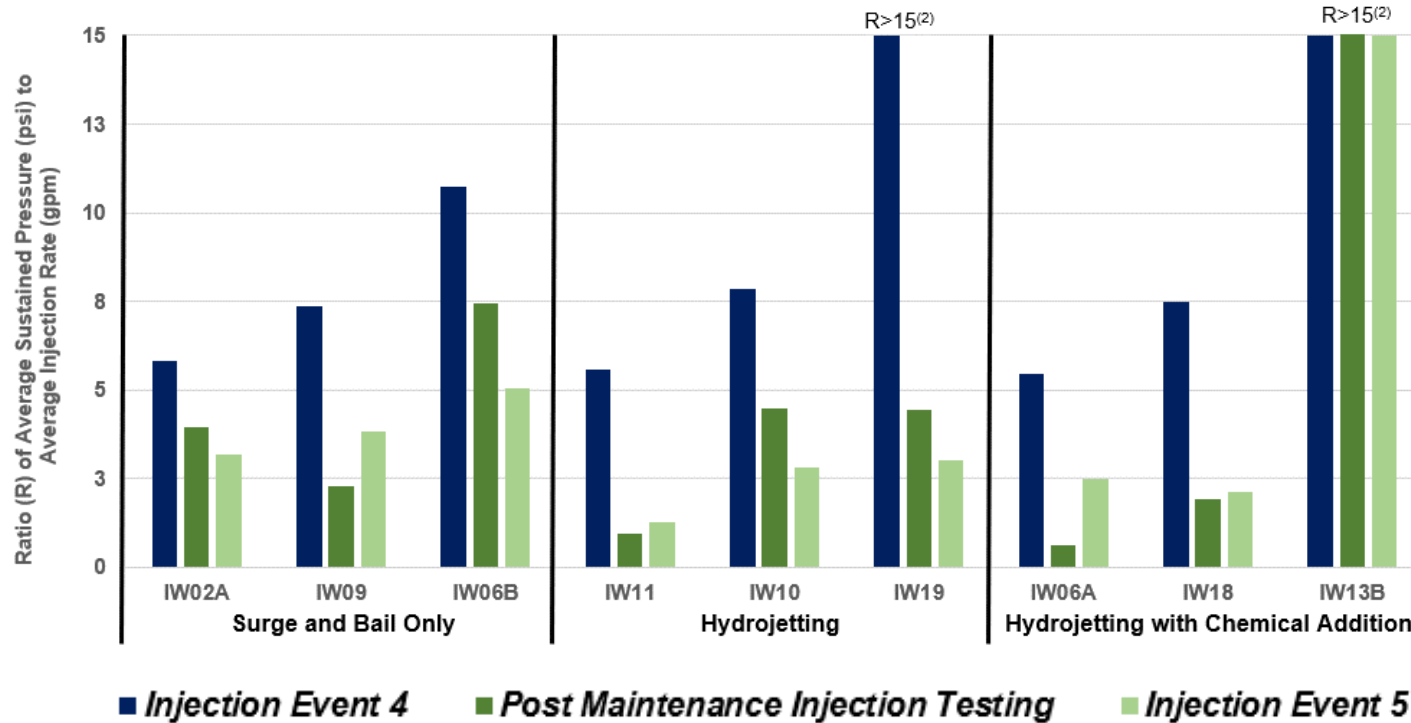
Maintenance Technique	Well	Screen Length (feet)	Pressure/Flow Ratio (psi/gpm)
Surge and Bail	IW02A	10	5.8
	IW09	20	7.4
	IW06B	5	10.8
Hydrojetting	IW11	20	5.6
	IW10	20	7.8
	IW19	20	>15
Combination of Surge and Bail and Hydrojetting with Chemical Addition	IW06A	10	5.4
	IW18	20	7.5
	IW13B	10	>15

- Surge and Bail – Brushed/surged to dislodge solids, bailed to remove solids, followed by pumping
- Hydrojetting – Bailed to remove solids, jetted well screen at rate of 1 min/foot to dislodge solids, followed by pumping
- Chemical Treatment with Acidic Agents
 - Descaling agent – AQUA-CLEAR® MGA (dry blend of granular sulfamic acid and sodium chloride)
 - Biomass Control – AQUA-CLEAR® AE (liquid blend of hydroxyacetic acid)
- Step-rate water injection testing performed to assess results



Results from Injection Well Maintenance Event 1

Injection Well Performance by Well Maintenance Method⁽¹⁾



Notes:

R - ratio of average sustained pressure to average injection rate

psi - pounds per square inch

gpm - gallons per minute

(1) Well maintenance (surge and bail only, hydrojetting, or hydrojetting with chemical addition) performed between injection events 4 and 5.

(2) No injections possible at pressures less than permitted limit of 35 psi.

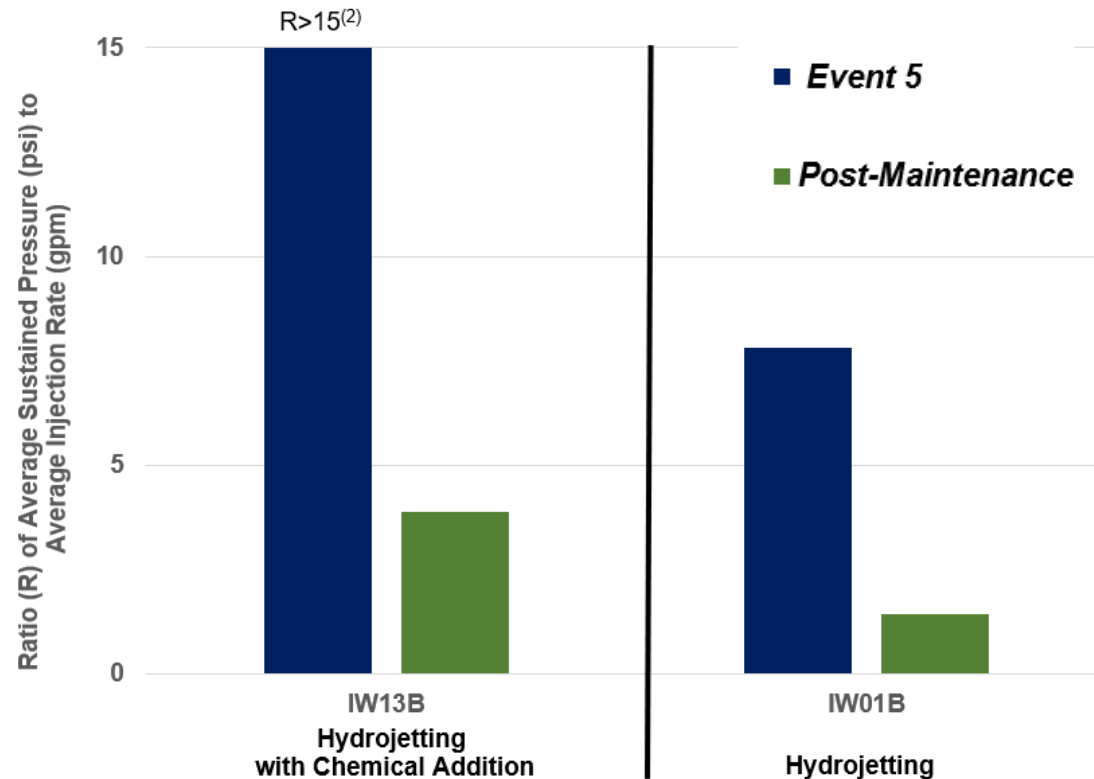
(3) Note that the prefix "SWFTS-" was removed from well name displayed. IW02A indicates injection well SWFTS-IW02A.

➤ Post-Maintenance Results:

- 8 of the 9 injection wells demonstrated improved injectability
- IW19 (did not accept injectate during previous injection event) exhibited an average injection rate of 10 gpm (maximum of 18.5 gpm) during next injection event after hydrojetting only
- IW13B did not accept injectate both pre- and post-maintenance despite using most aggressive method

Results from Injection Well Maintenance Event 2

Injection Well Performance by Well Maintenance Method⁽¹⁾



Notes:

R - ratio of average sustained pressure to average injection rate

psi - pounds per square inch

gpm - gallons per minute

➤ Well Selection:

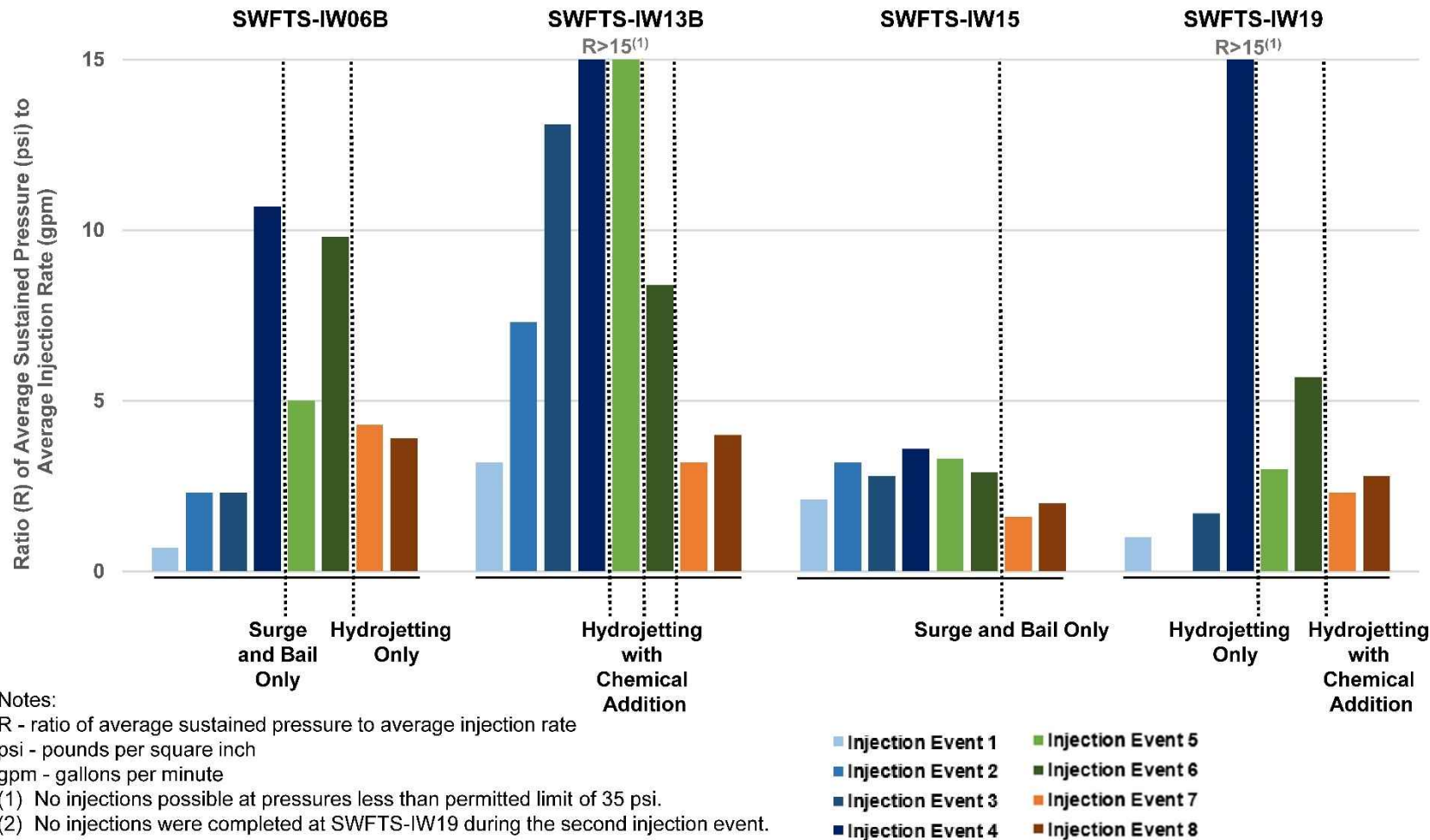
- IW13B – previous maintenance efforts performed but still did not accept injectate
- IW01B – no previous maintenance, Pressure/Flow Ratio > 5 observed during injection event 5
- Most aggressive method used again for IW13B, less aggressive method for initial maintenance on IW01B

➤ Post-Maintenance Results:

- Injectability improved for both IW01B and IW13B
- IW13B – average injection rate of 9 gpm during step-rate injection testing, highest injection rate achieved to date

Results from Injection Well Maintenance Event 3

Injection Well Performance by Well Maintenance Method



- Four wells selected for final maintenance
- If previous maintenance performed, more aggressive technique applied
- Injectability at IW13B incrementally restored
- All 25 injection wells sustained pressure to flow rate ratios less than 5 in the final two injection events

Summary and Conclusions

- Biomass and calcium precipitates (primarily calcium oleate with minor calcium sulfate and calcium carbonate) accumulated within well screen and filter pack
- Presence of biomass and precipitates in video log did not always correlate with reduced performance
- Wells with no injectability had higher proportion of calcium precipitates, especially calcium oleate



Summary and Conclusions

- 14 of the 25 injection wells (56% of total) required no maintenance during the 5-year treatability study
- 3 of 11 wells (10% of total) required more than one maintenance event
- Repeated maintenance with most aggressive technique ultimately restored injectability
- Traditional surge and bail and hydrojetting effective for wells with lower pressure to flow rate ratios (i.e., between 5 and 10)
- Hydrojetting with chemical addition required for wells with ratio > 10 ; Additional maintenance also typically required

