Optimizing EVO Formulations

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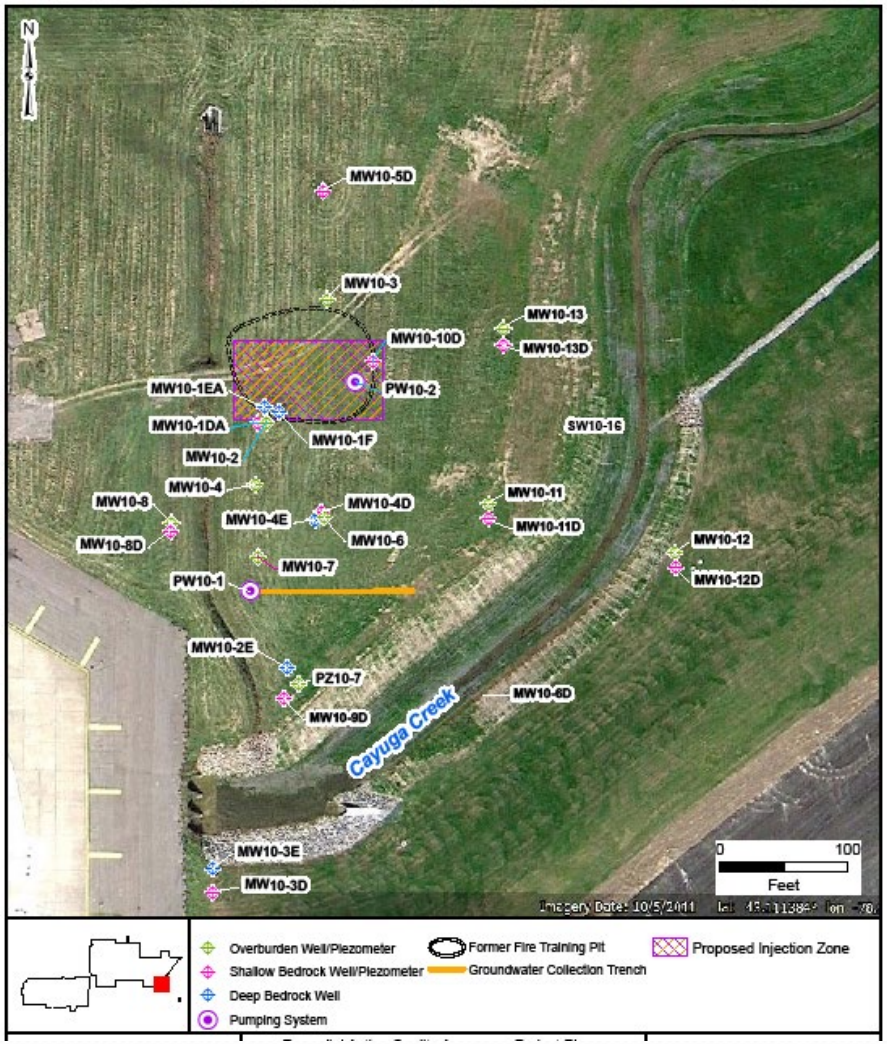
Terra Systems
INCORPORATED

Terra Systems SRS® EVO Products Designed for Enhanced Anaerobic Bioremediation

SRS®-SD	EVO for Maximum Radius of Influence
SRS®-FRL	EVO for Maximum Retention for High Groundwater Flow Rates
SRS®-SE	Self-emulsifying EVO with 100% Fermentable Carbon, No Nutrients
SRS®-Basic	EVO without Nutrients or Quick Release Substrate
SRS®-ZVI (micro scale iron)	Anaerobic and Abiotic Reduction; Cl Solvents; DNAPL; PRB
SRS®-EZVI (fine 2-3 μm iron)	Anaerobic and Abiotic Reduction; Cl Solvents; DNAPL; PRB
SRS®-NR	EVO for Remediation of Nitrate and Perchlorate
SRS®-STA	EVO Includes Shear Thinning Agent for Heterogeneous Aquifers
SRS®-M20 or M40	Moderate to High Cr^{6+} → Cr^{3+} Reduction; Cl Solvents
SRS®-$B_{uffered}$	EVO for Low pH Aquifer
SRS®-C_{ustom}	Custom Formulations, Packaging, 50/50 Mix of SRS®-SD and SRS®- FRL, Bromide or Dye Tracer, etc.

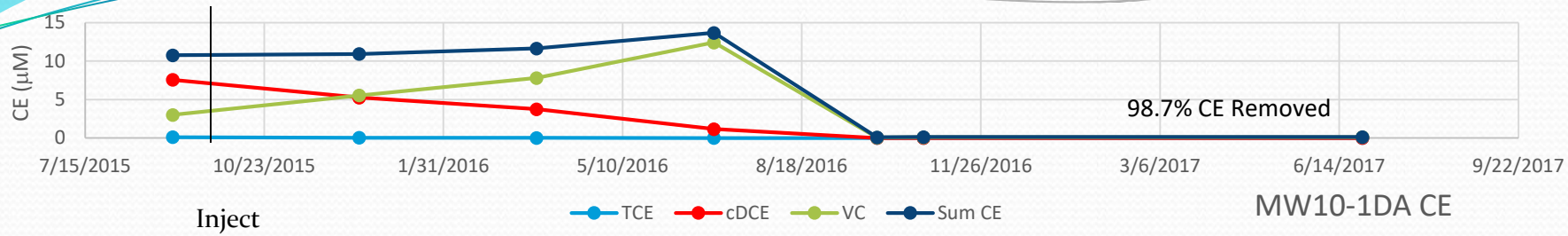
Terra Systems owns and operates its own manufacturing facility

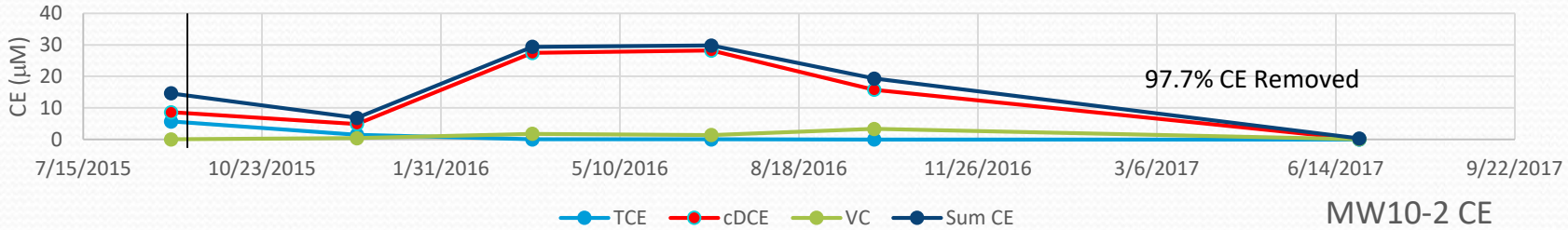
Combined SRS and MicroZVI
Upstate New York Airport

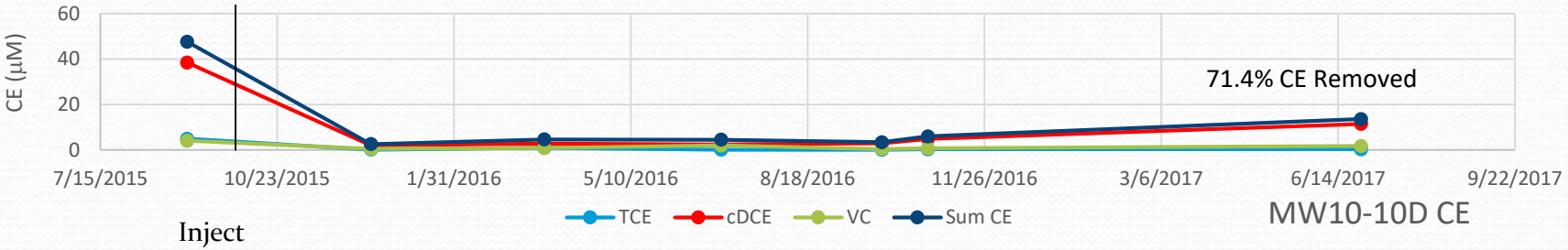


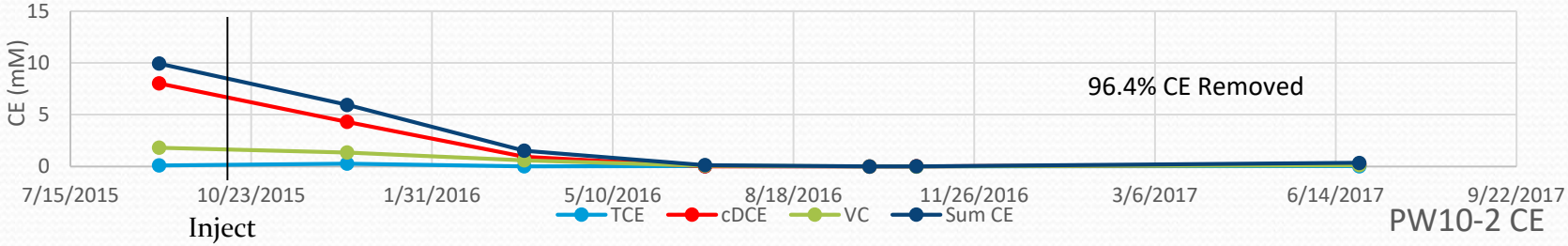
Former Fire Training Pit
Geology – overburden and fractured bedrock
Injected 3,800 gal of 45% SRS with 2-3 μm MicroZVI in August 2015

Upstate New York Airport





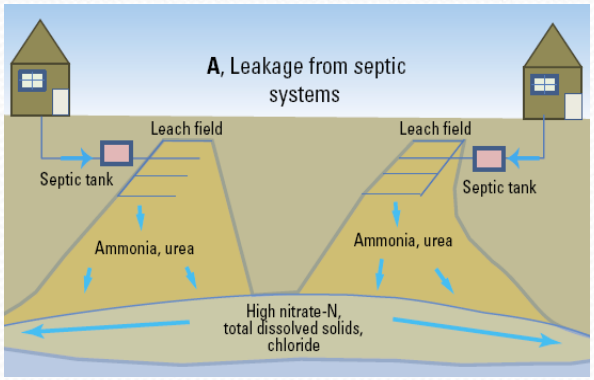




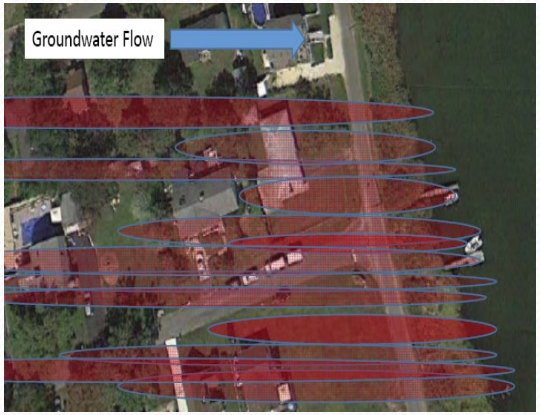
Second application of 2,060 gallons of SRS and MicroZVI in June 2018

Nitrogen Impact of Cape Cod Salt Ponds

- **Septic systems used for ~85% of wastewater treatment on Cape Cod**



Modified from USGS 2013



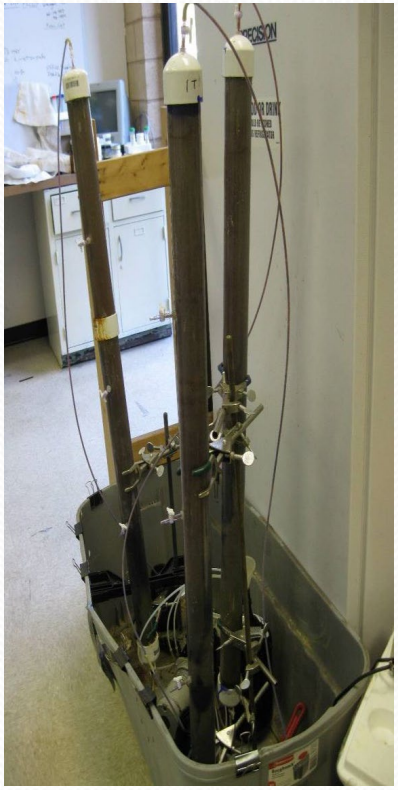
- **Multiple smaller plumes that can combine into larger nitrate groundwater plumes that discharge into coastal waters. Loading is cyclic.**
- **Remedial goal is to reduce nitrogen load in order to achieve TMDL (total maximum daily load).**
- **High groundwater flow rate of 1-3 ft/day**

Denitrification Permeable Reactive Barrier (PRB)

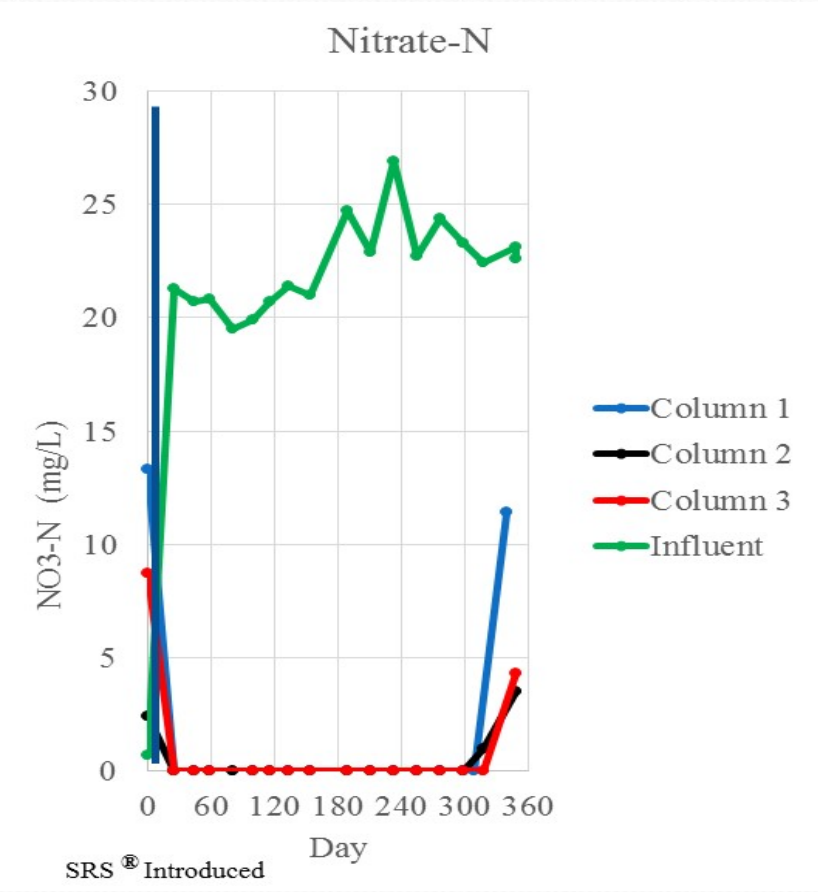
- Denitrifying bacteria ubiquitous
- $NO_3^- \rightarrow NO_2^- \rightarrow NO + N_2O \rightarrow N_{2(g)}$
- Emplace carbon substrate into PRB
- Intercepts and treats nitrate plume
- EVO can be injected into PRB to provide carbon for extended period
- Public concerned about migration of oil into surface water and persistence/rejuvenation frequency

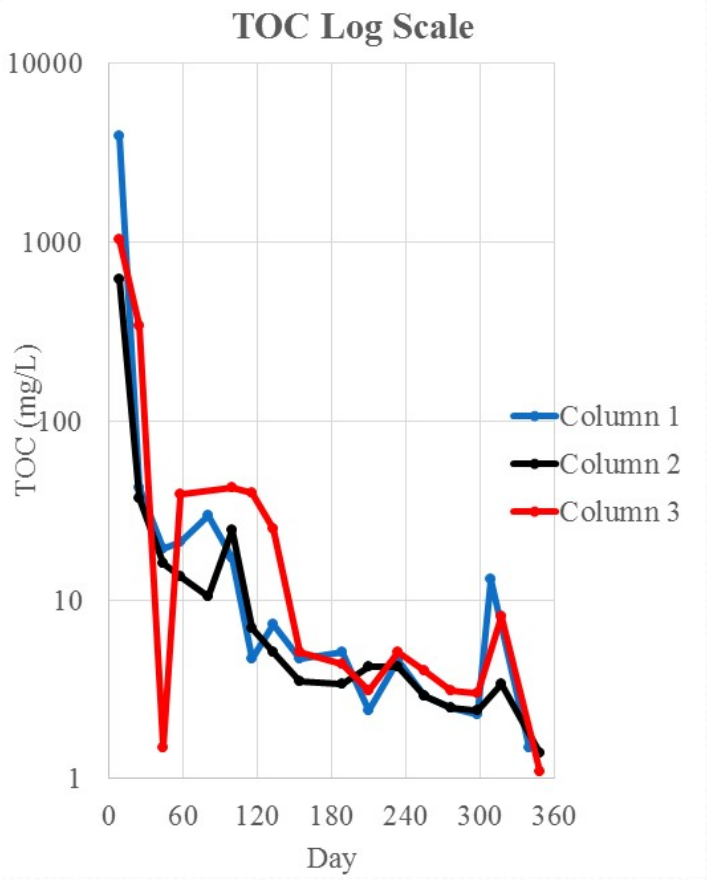
Bench Scale Test

- Evaluate EVO loading and formulations to support denitrification
  - Effectiveness
  - Persistence
  - Migration – community concern
- Soil & groundwater from Acapesket Cape Cod site
- 3 column reactors (3.8 ft, 2” diam)
  - Column 1 – 30.8 g SRS® & 277 mL water – filled to 21 in
  - Column 2 – 61 g SRS® & 555 mL water – filled to 27 in
  - Column 3 – 61 g SRS®, 25 g ZVI, & 513 mL water – filled to 27 in
- Influent
  - ~20 mg/L nitrate
  - 10-43 mg/L sulfate
- Flow rate = 1.2 ft/day
- 354 days (98-109 pore volumes)



Bench Scale Test Results





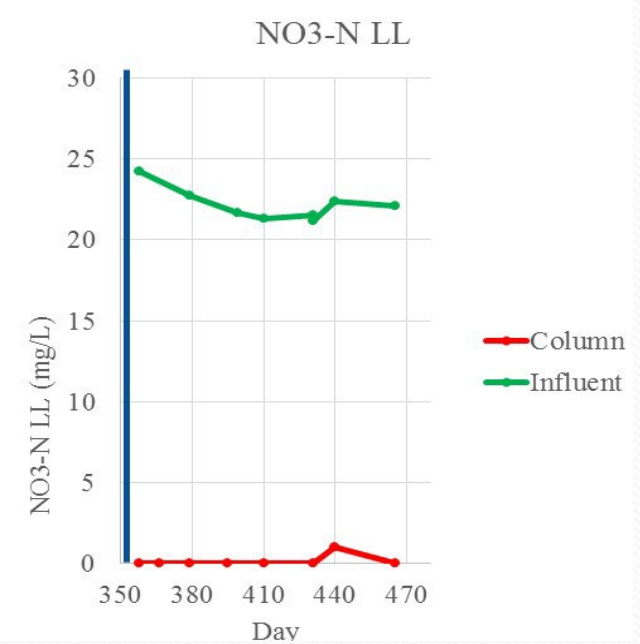
Bench Scale Test Conclusions

- Complete continuous removal of nitrate for over 317 days using indigenous bacteria
  - 83-93 pore volumes
- Emulsion breakthrough no longer observed after 1.3 -2.4 pore volumes in Columns 1 & 2
- When TOC <4.0 mg/L, nitrate began to appear
- Sulfate consumed, but began to increase after 210 days
- No difference in longevity or effectiveness with increased loading or ZVI

- <u>Can the emulsified vegetable oil be made stickier?</u>

More Bench Scale Testing

- Day 355 connect all 3 columns together (11.4’ column)
- Feed Column 1 with 31 g SRS®-NR
  - large droplet (5 micron mean droplet)
  - anionic surfactant
  - no lactate
- Influent 21 to 24 mg/L NO_3
- Flow rate 1.9 ft/day
- Emulsion did not appear in effluent
- Sustained nitrate removal at 2.9 mg/L TOC in effluent
- SRS®-NR formulation better retained on soil matrix



Field Pilot Test Design

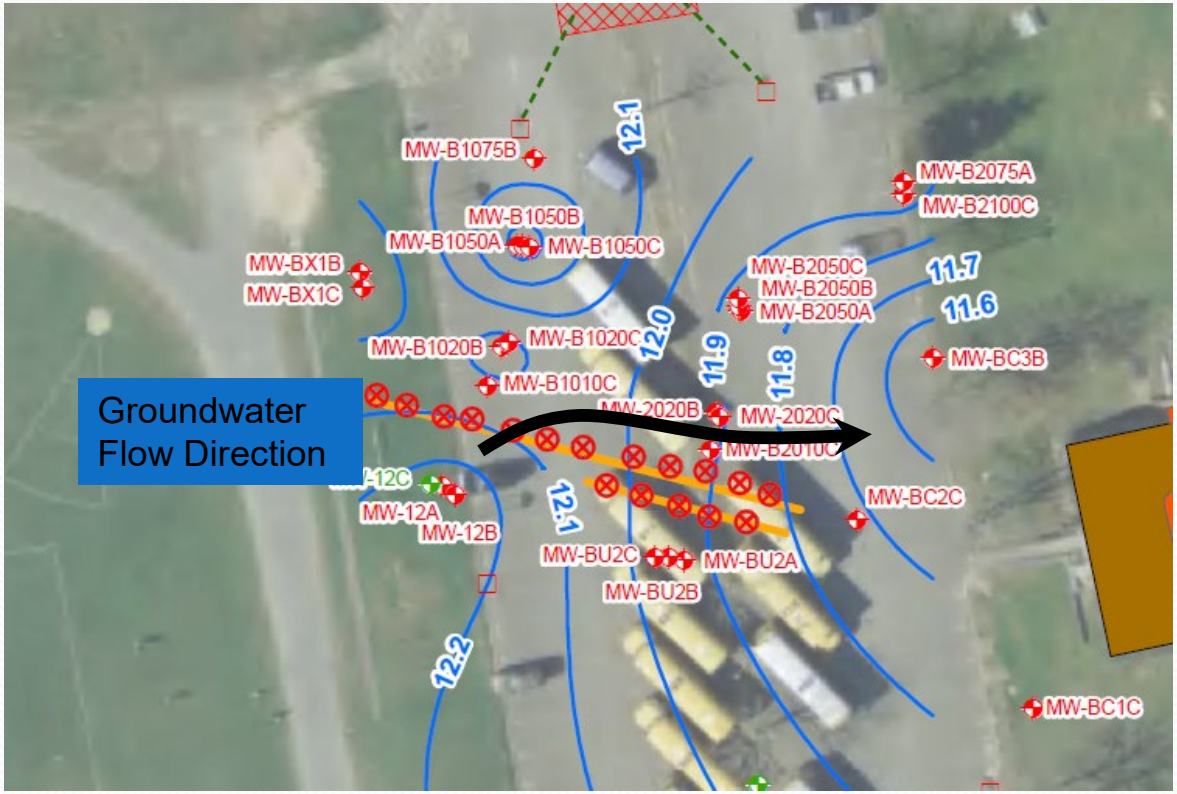
- 110 foot PRB
- 17 Injection Points
  - 1 and 2 rows of points
  - 10 foot spacing
  - 36 to 68 feet bgs
- Monitoring well network
  - Upgradient
  - Downgradient
  - 10-75 feet from PRB
- 14% pore volume target
- 10,800 gallons injected in 11/16
- SRS-NR (14%)
  - Diluted 4.3:1 in field

ELDREDGE PARK PRB MONITORING

- **Initial testing of PRB monitoring wells - baseline concentrations measured as high as 35 mg/L nitrate-nitrogen**
- **Wide range of nitrate concentrations at different sampling locations**
- **No migration of EVO detected during injection (monitoring turbidity and dissolved organic carbon 7, 10, 20, 50 and 100 ft. downgradient)**

ISOTEC

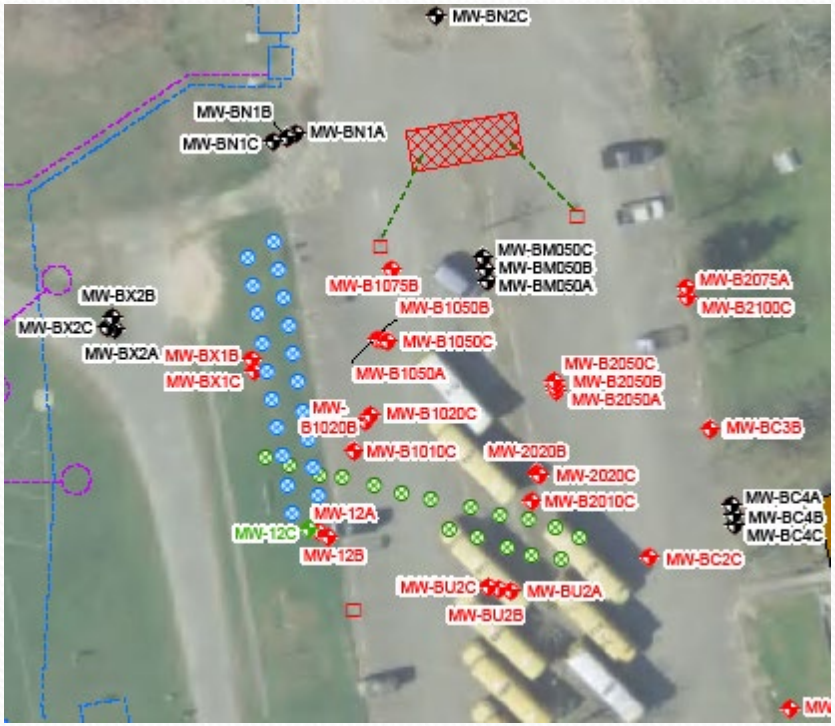
Typical Groundwater Flow Direction



Based upon initial characterization, expected groundwater flow through PRB to north. Actual flow was more to east at about 0.22 ft/day.

SECOND SRS-NR INJECTION JUNE 2018

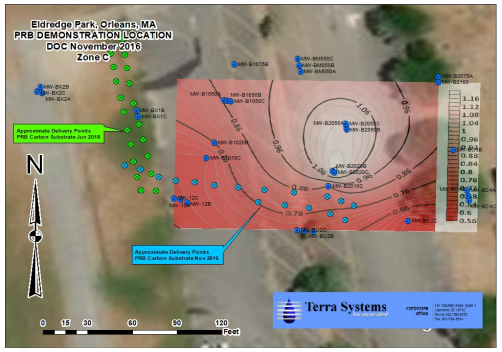
- 100 foot PRB
- 20 Injection Points
  - 2 rows of points
  - 10 foot spacing
  - 32 to 70 feet bgs
- 14,800 gallons SRS-NR injected
- Diluted SRS-NR 4.3:1 in field
- 225 gallons 60% sodium lactate
- Added sodium bicarbonate

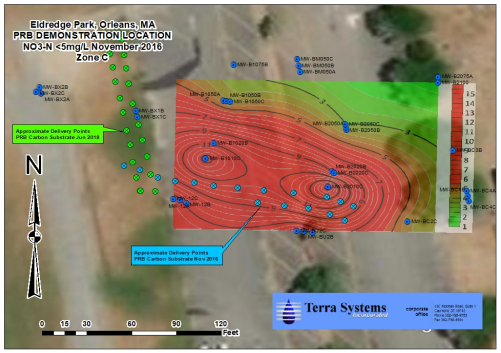


DOC (mg/L)

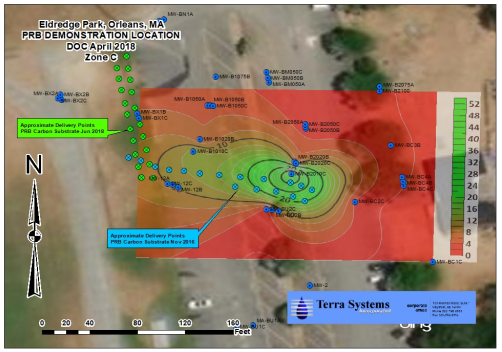
NO3-N (mg/L)

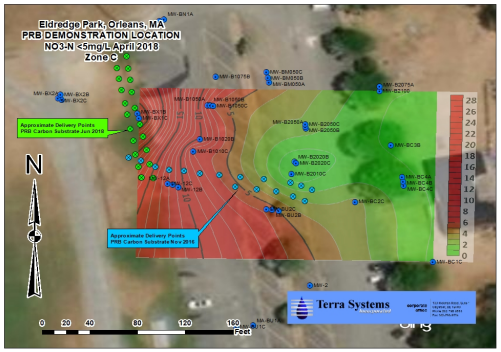
C-Zone (shallow) Nov 2016



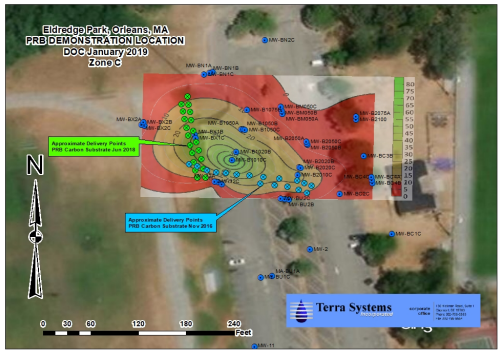


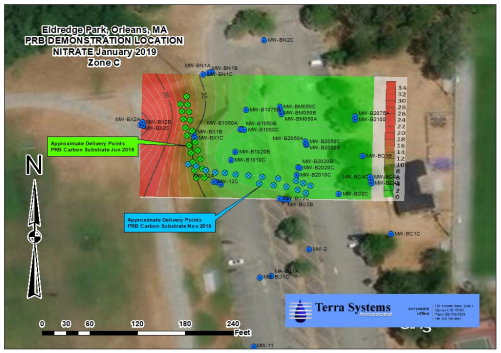
April 2018





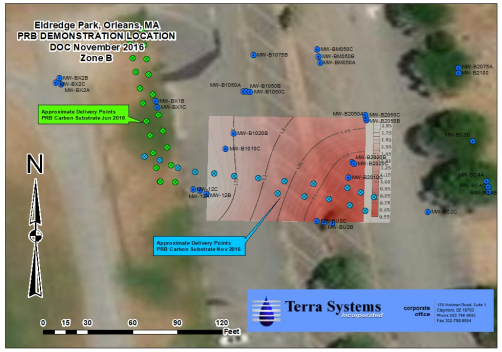
Jan 2019

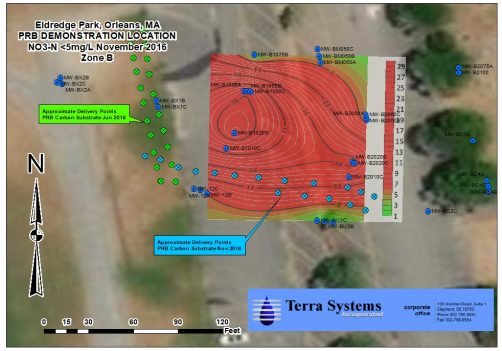




DOC (mg/L) NO3-N (mg/L)

B-Zone (Intermediate Nov 2016





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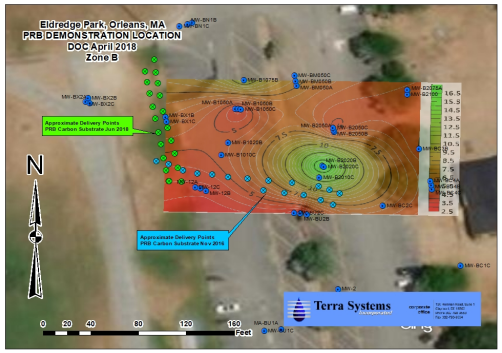

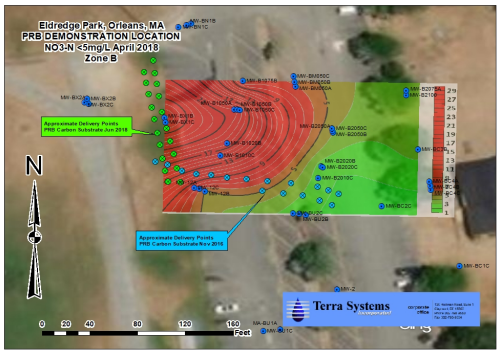

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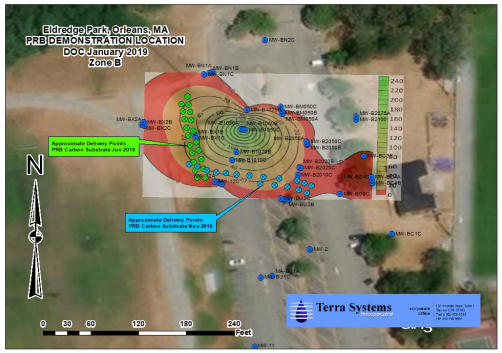
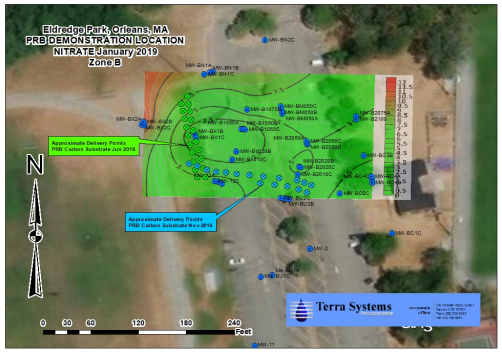




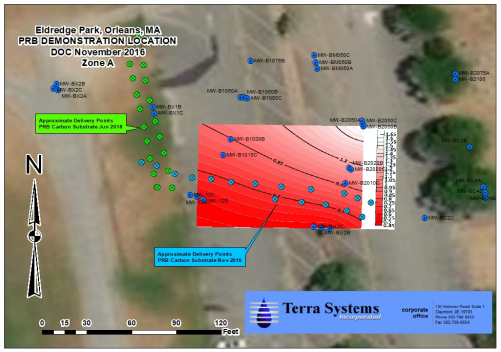
DOC (mg/L)

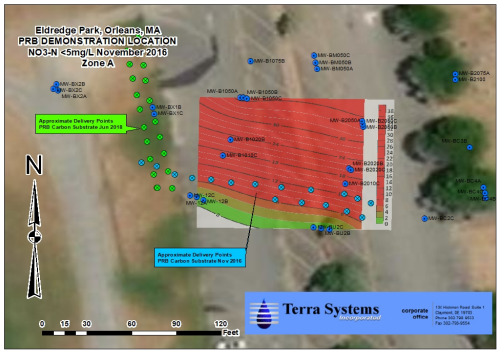
NO3-N (mg/L)

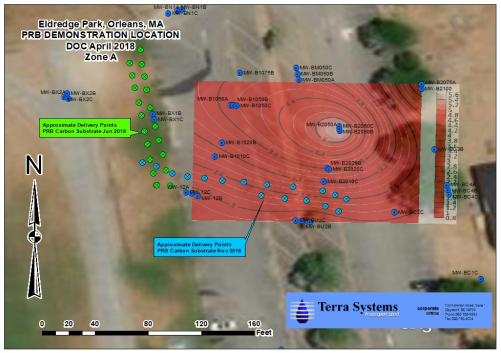
A-Zone (Deep) Nov 2016

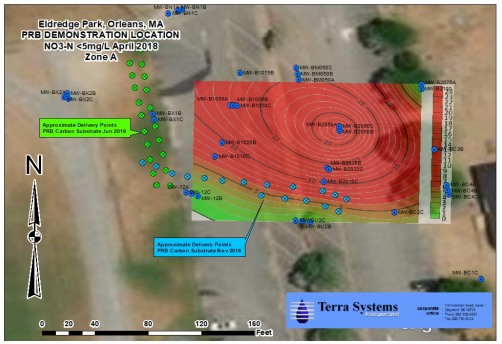
April 2018

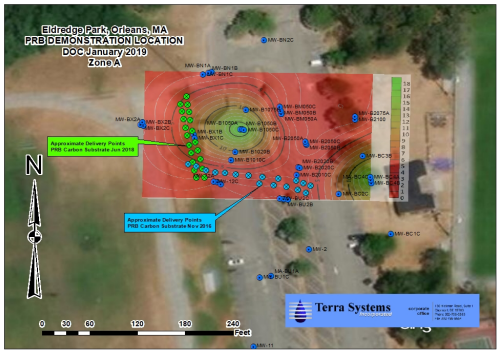
Jan 2019

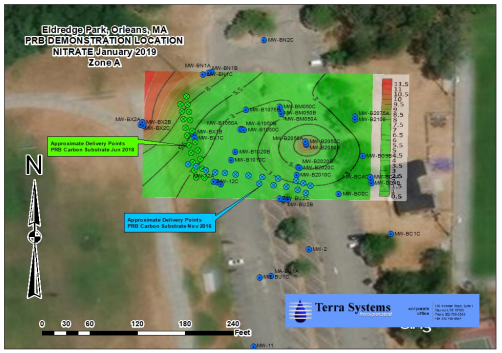




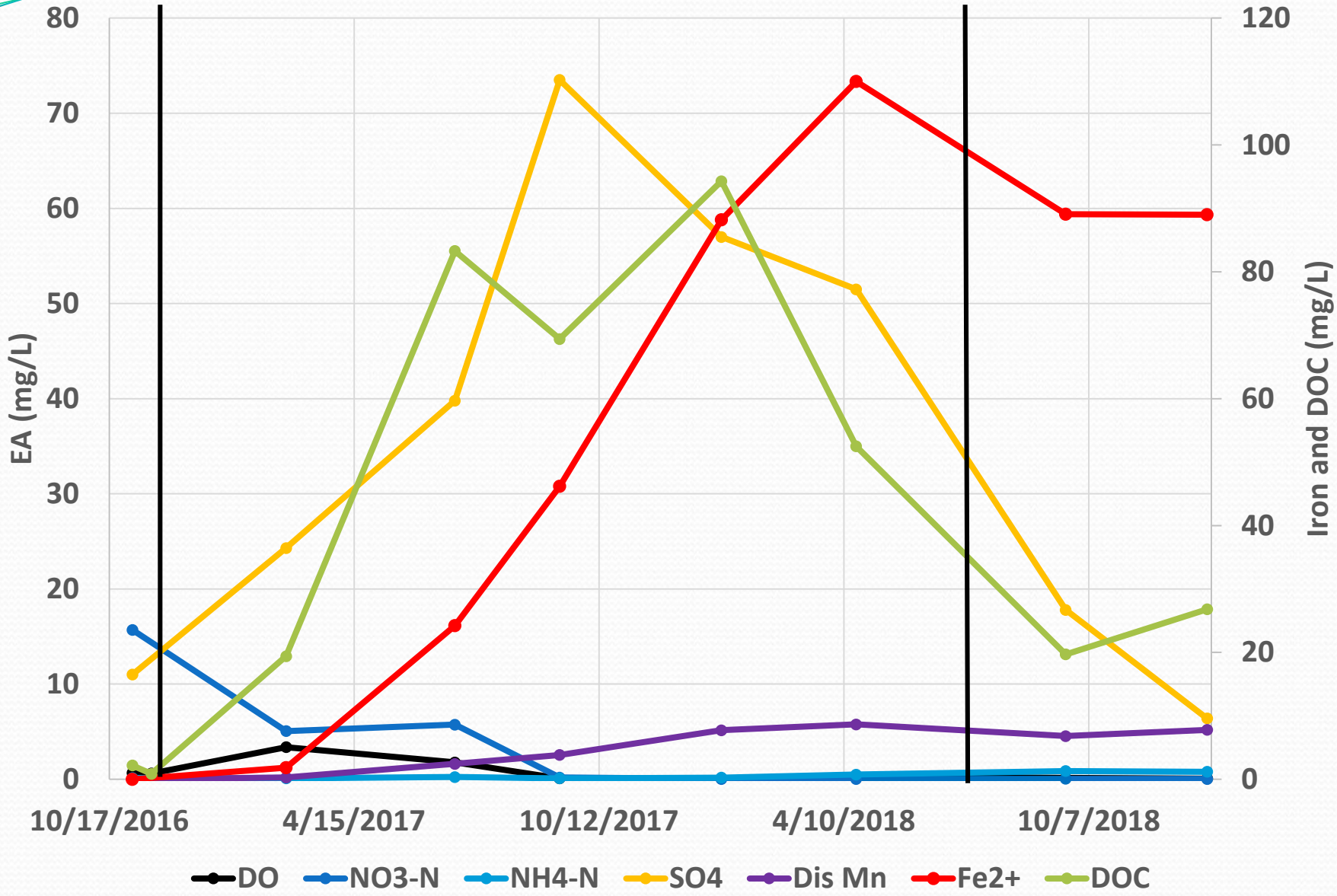








MW-B2010C EA and DOC



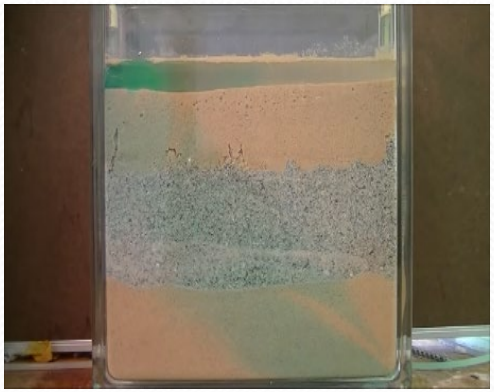
Elredge Park Conclusions

1. Where DOC exceeded 10 mg/L, generally good removals (average of 80.9%) of nitrate-N.
2. The water table sloshes around due to rainfall and septic tank discharge, but groundwater flow is predominantly to east at 0.2 to 0.3 ft/day.
3. DOC retained within about 50 feet from injection wells.

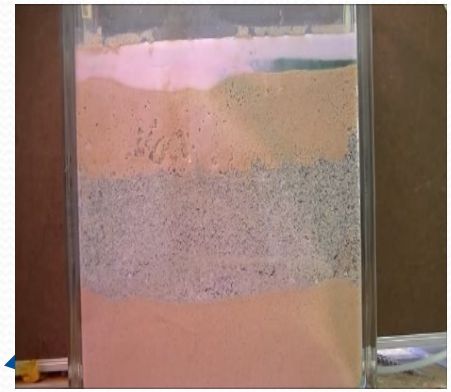
NEW SRS®-STA FOR HETEROGENEOUS FORMATIONS

SRS®-STA combines the standard SRS products with a shear thinning agent for heterogeneous formations. When injected at high velocity, the shear thinning agent promotes cross-flow from high to low-permeability zones.

Laboratory sandbox studies have demonstrated that SRS®-STA promotes transport into tighter and more permeable layers.

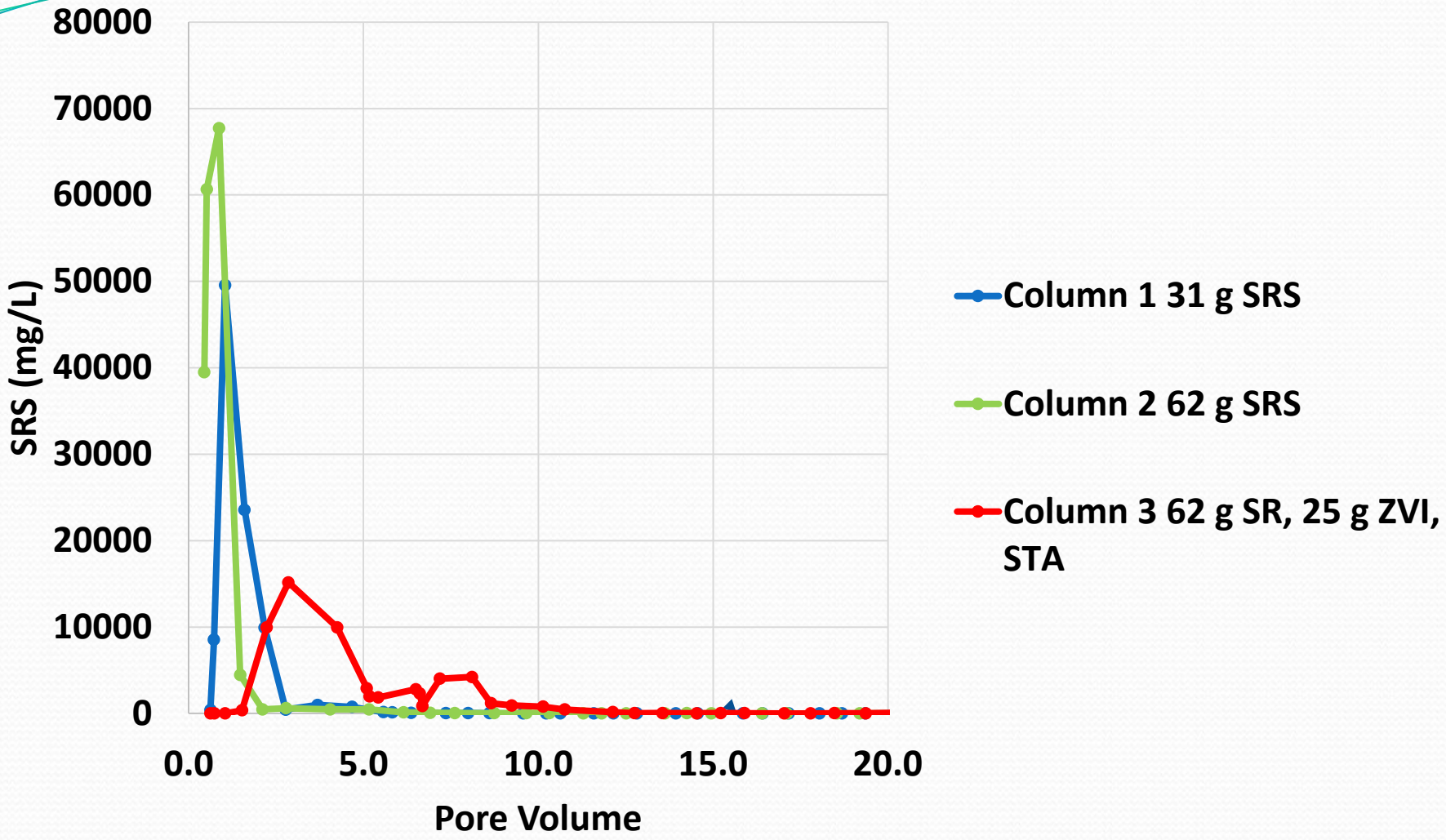


Sandbox with fine, coarse, fine sands with water



Sandbox with fine, coarse, fine sands with SRS®-STA

SRS (Turbidity)



SRS + STA retained on column longer than SRS alone

PREVIOUS FIELD TESTS FOR HETEROGENEOUS FORMATIONS

Site	Geology	Amendments	Results	References
Joint Base Lewis McChord	Gravel, clean sand, and interbedded sands and gravels	Ethyl Lactate and STA	Increased coverage from 49% with bromide tracer to 69% with ethyl lactate and SFT and chloride tracer	Adamson et al. 2014 of GSI
Well 12A site in Tacoma, WA with DNAPL	Medium grained sand with gravel and silt, to fine-grained silt, to highly variable sand and gravel.	Emulsified vegetable oil with STA loading based upon pressure and injection flow rate	Increases in cis- and trans-DCE, and VC within 3 months and ethene within 8 months. Amendment remaining after 8 months.	Smith et al 2014 and 2015 of CDM Smith and Lynch et al 2016 of EPA

Conclusions from STA

- STA can promote distribution in heterogeneous formations
- STA can extend SRS retention in sandy formation
- Looking for a field site for demonstration project

Acknowledgements

SRS-EZVI Project – John Freim - Regenesis

SRS-NR Project

- **Paul Dombrowski – Isotec – See Poster in B6 Biobarrier Installation and Management on Wednesday**
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SRS-STF Project

- **Jenny Lee**
- **Sam Lee**

Questions?

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