

A Rigorous Demonstration of Permeability Enhancement Technology for *In Situ* Remediation at Three Low-Permeability Sites

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**CDM
Smith**

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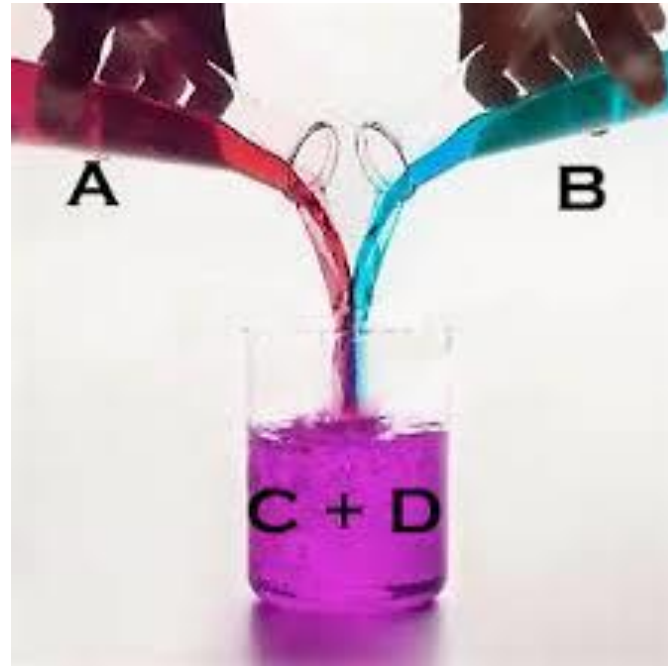
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- H. Anderson (AFCEC)
- G. Guest (Geotactical)
- R. Kelley (Cascade)

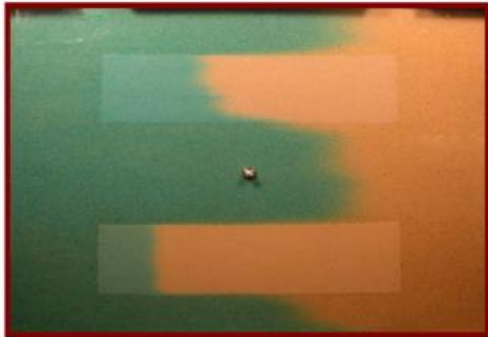
The Challenge

- All in situ technologies work in a beaker
 - Perfect mixing
 - No sorbed phase
 - No matrix diffusion



The Challenge

- The subsurface is not so kind...
 - Heterogeneity
 - Low Permeability
 - Sorption
 - Diffusion-dominated systems



Technical Objectives

- Demonstrate permeability enhancement technology in three low permeability geologic settings
 - Effective radius
 - Volume
 - Orientation
 - Vertical distribution
- Demonstrate and validate high-resolution sensing and mapping techniques

Overview

- Three sites with low hydraulic conductivity in three different geologic settings:

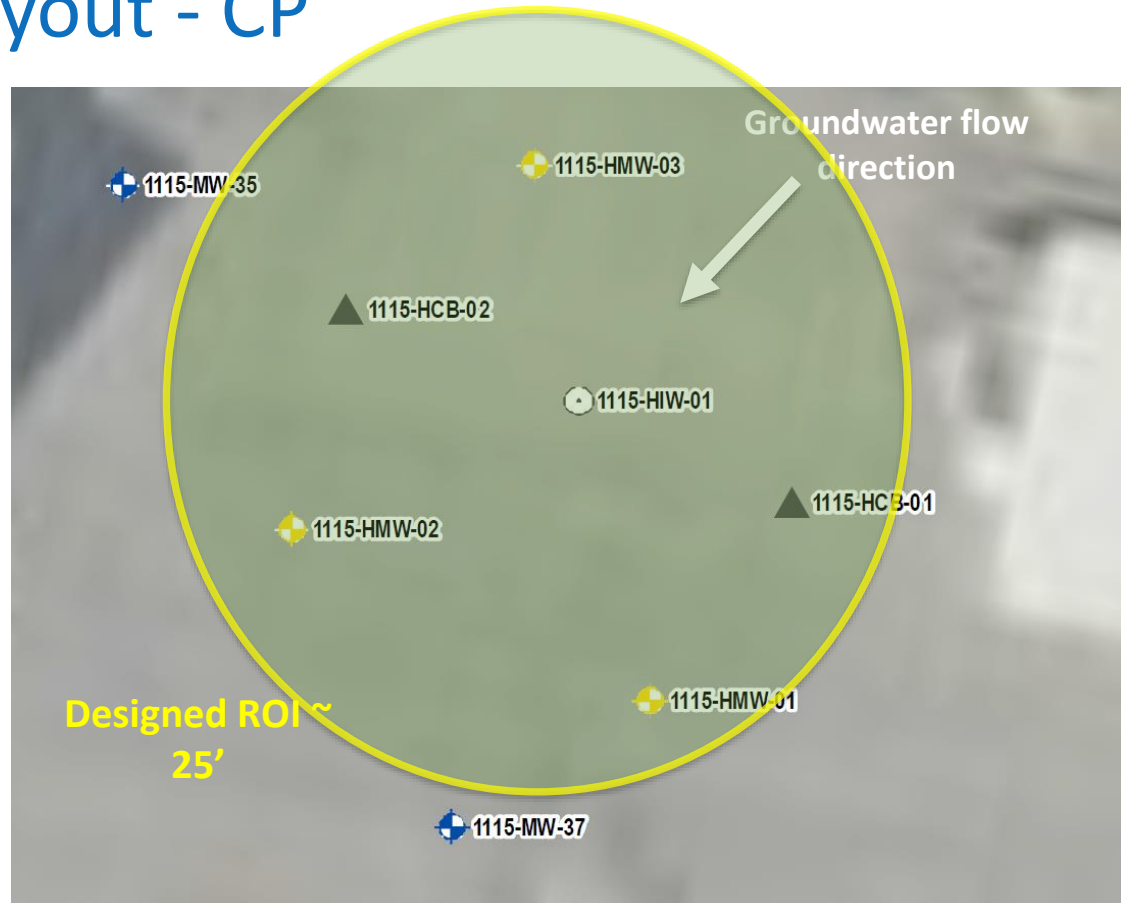
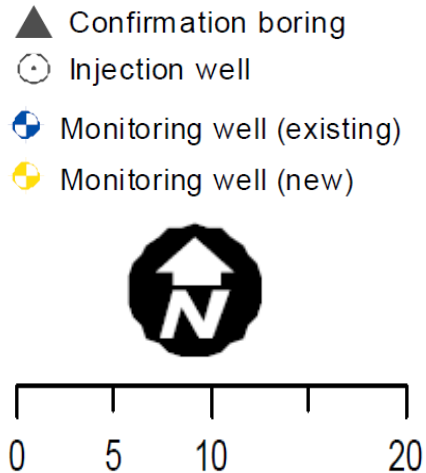
Geology	Site
Silty clay/glacial till	Grand Forks Air Force Base Site TU504 (GFAFB)
Residuum/weathered shale	Lake City Army Ammunition Plant Site 17D (LCAAP)
Claystone/siltstone	Camp Pendleton Site 1115 (CP)

Test Design – CP

- Evaluate hydraulic permeability enhancement (HPE) at a claystone/siltstone site with BTEX
- Selected delivery technologies:
 - Sand and guar emplacement via HPE followed by removal of guar during well development and in-well persulfate injections
 - 1 permeability enhancement point
 - 5 depth intervals between 30 and 50 ft bgs



Demonstration Layout - CP



Field Implementation Photos - CP

HPE equipment setup



Sand transfer into the HPE mixing tank



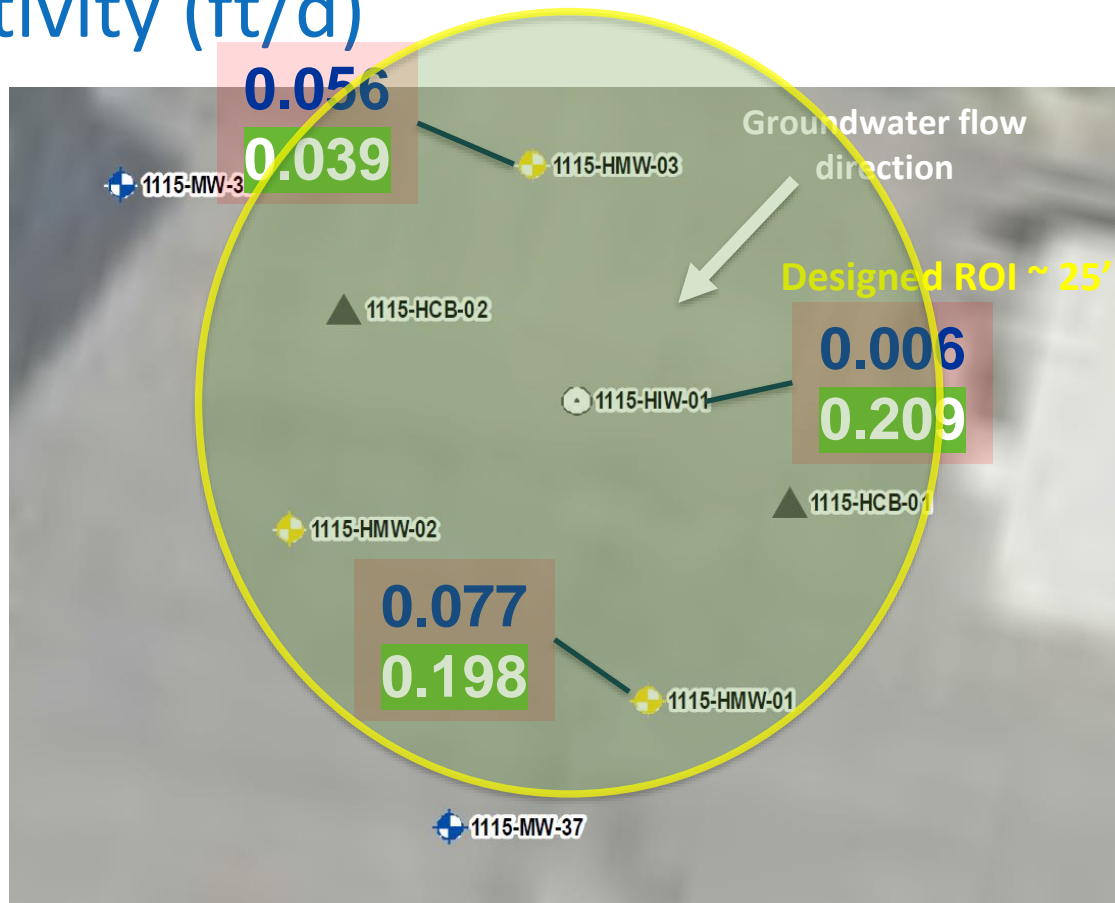
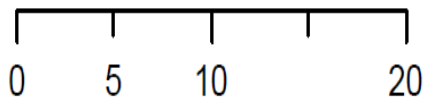
Field Implementation Photos - CP



Hydraulic Conductivity (ft/d)

Pre-enhancement k
Post-enhancement k

- ▲ Confirmation boring
- ⊙ Injection well
- ⊕ Monitoring well (existing)
- ⊕ Monitoring well (new)



Persulfate (mg/L)

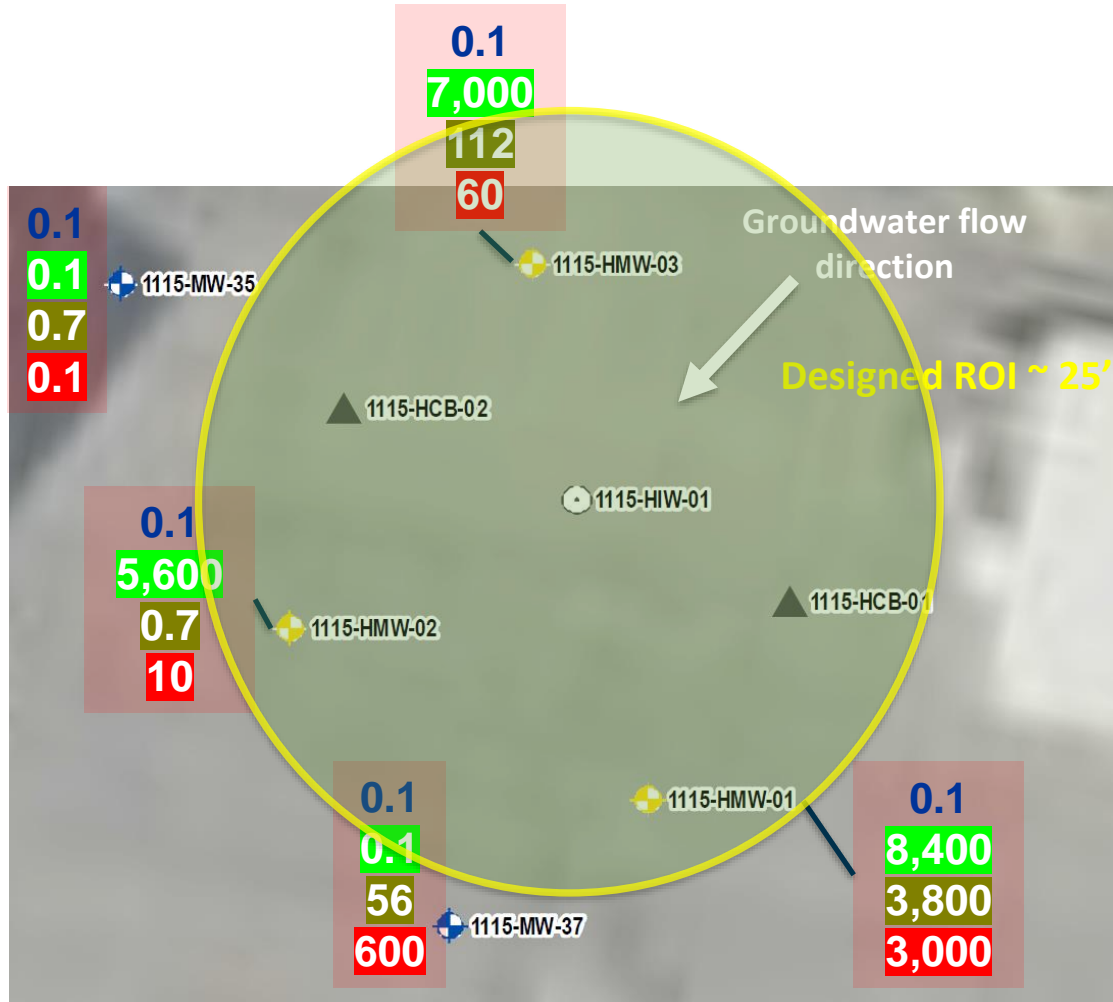
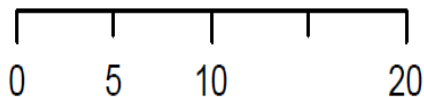
Pre-enhancement

1.5 m post-enhancement

5 m post-enhancement

9 m post-enhancement

- ▲ Confirmation boring
- Injection well
- ⊕ Monitoring well (existing)
- ⊙ Monitoring well (new)



Total BTEX Persulfate ($\mu\text{g/L}$)

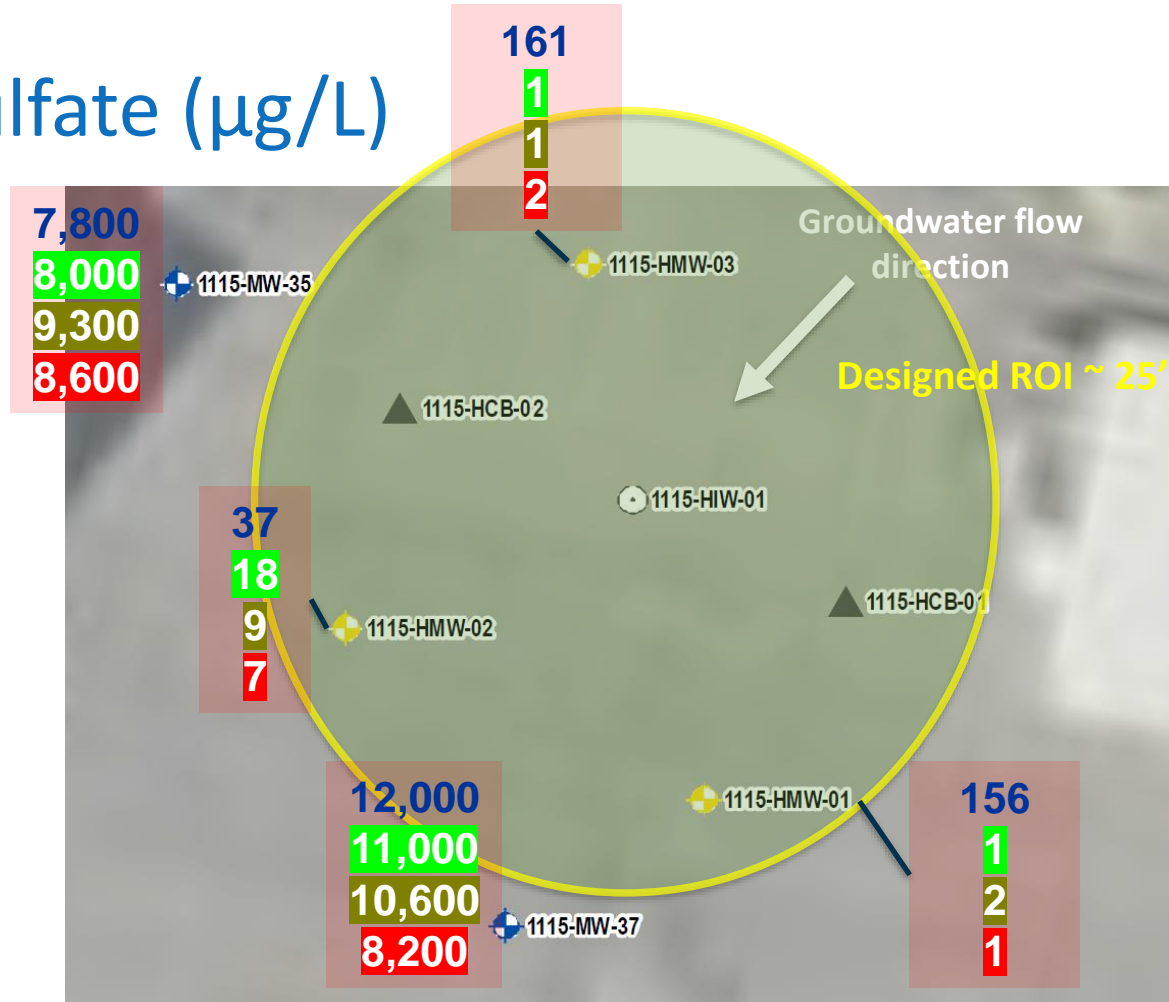
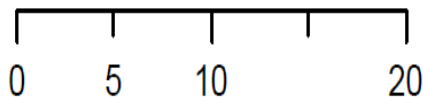
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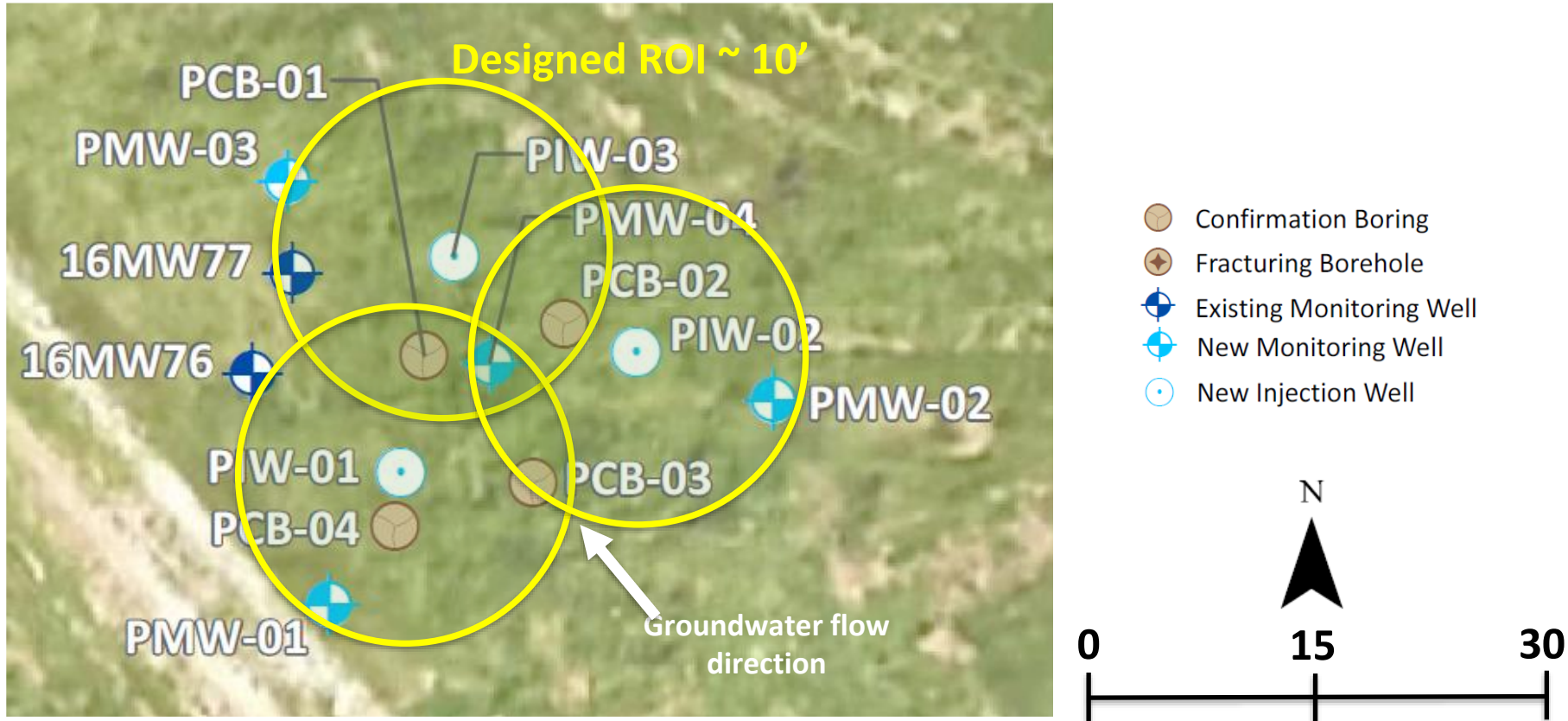
- ▲ Confirmation boring
- Injection well
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- ⊕ Monitoring well (new)



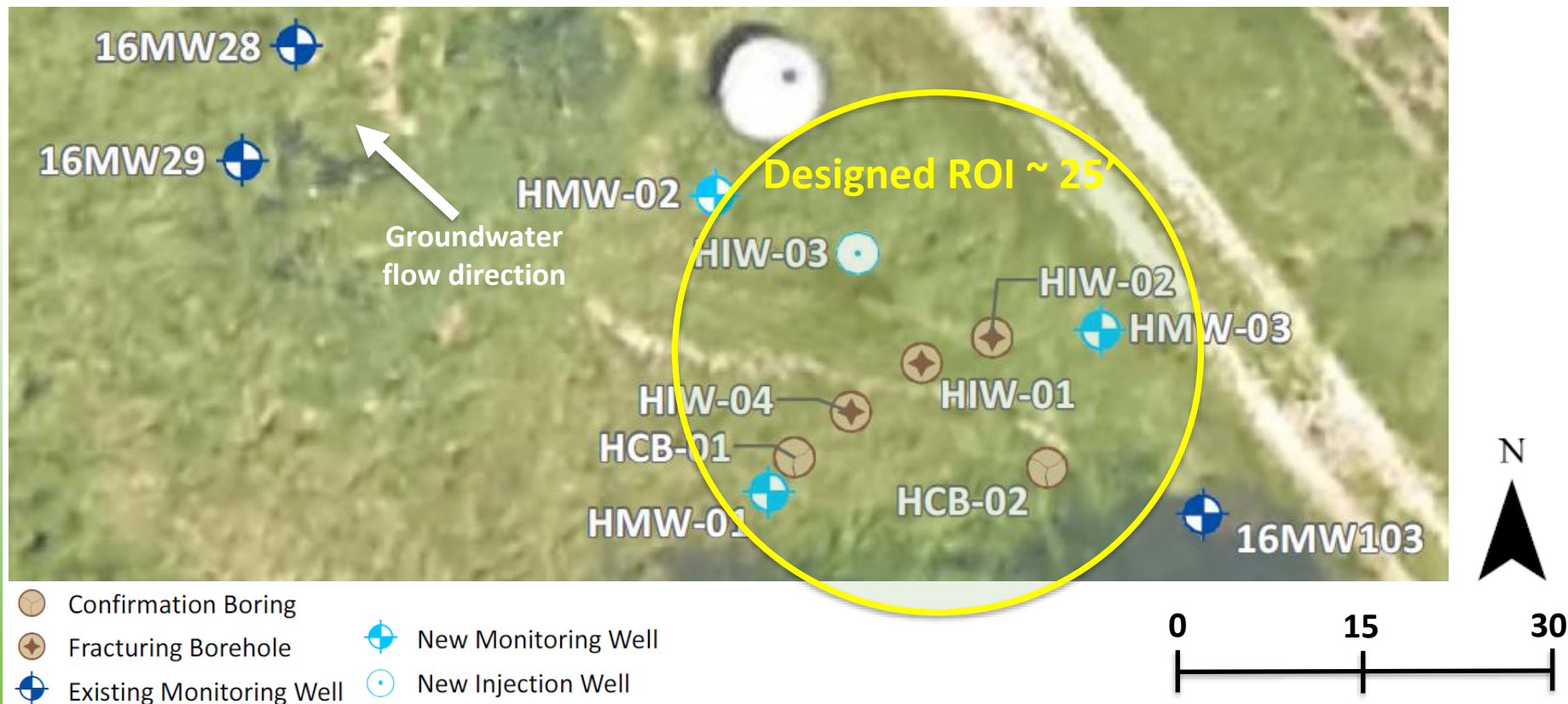
Test Design - LCAAP

- Direct comparison between HPE and Pneumatic PE (PPE)
- Site info:
 - Silty clay overburden, silty clay/weathered shale residuum
 - Chlorinated solvents
 - Hydraulic conductivity $\sim 4 \times 10^{-5}$ cm/sec
- Selected delivery technologies:
 - HPE with sand and guar followed by in-well EVO injections
 - PPE with EVO and nitrogen
 - Up to 5 depth intervals per permeability enhancement point

Pneumatic Demonstration Layout



Hydraulic Demonstration Layout



Field Implementation Summary

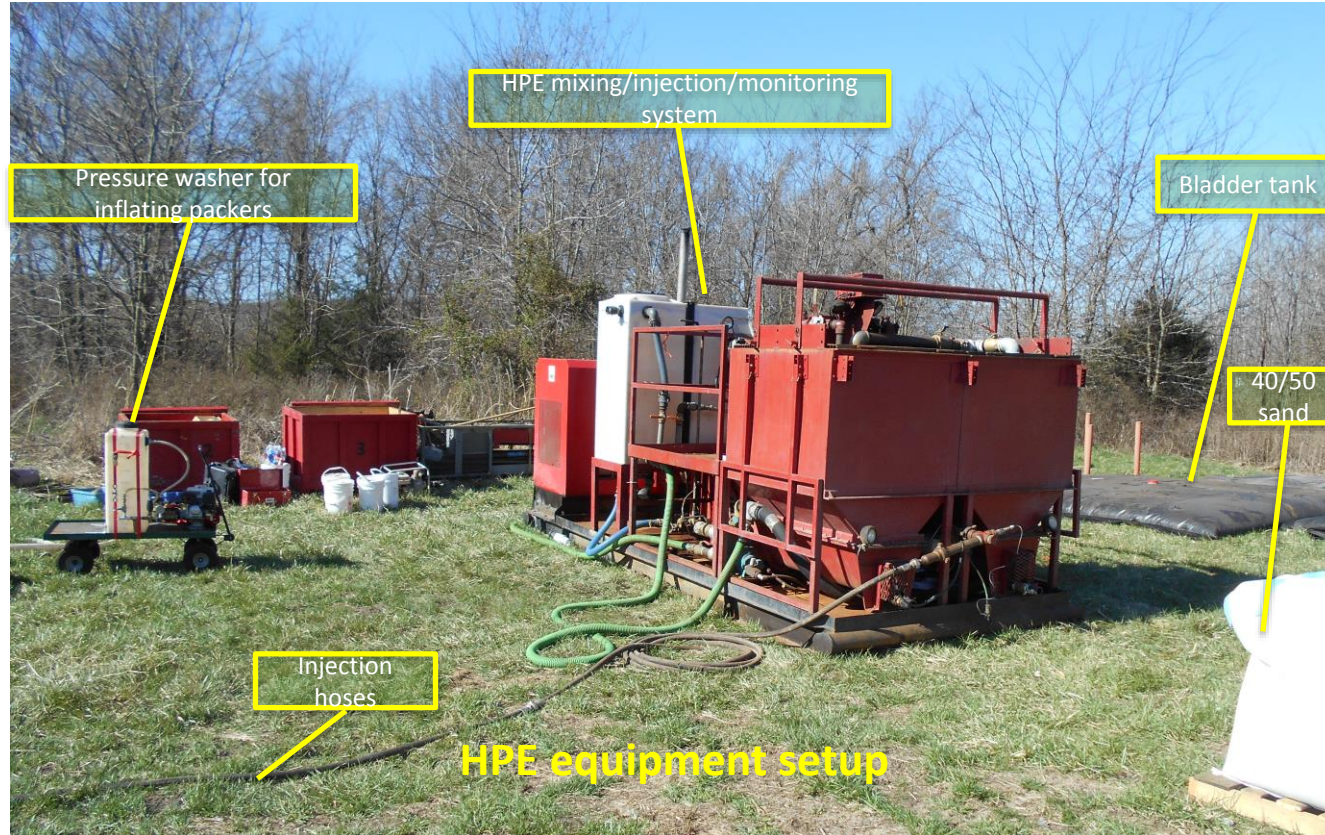
	Pneumatic	Hydraulic
	Fracturing with nitrogen followed by hydraulic injection in open boreholes	Hydraulic fracturing for sand emplacement followed by injection through permanent well
Target ROI	10 ft	25 ft
Volume of sand emplaced	0	~ 18,000 lbs
Amendment injected	3% LactOil & 0.75% KCl	3% LactOil & 0.75% KCl
Volume of amendment injected	3,000 gal	3,000 gal

Field Implementation Photos - LCAAP

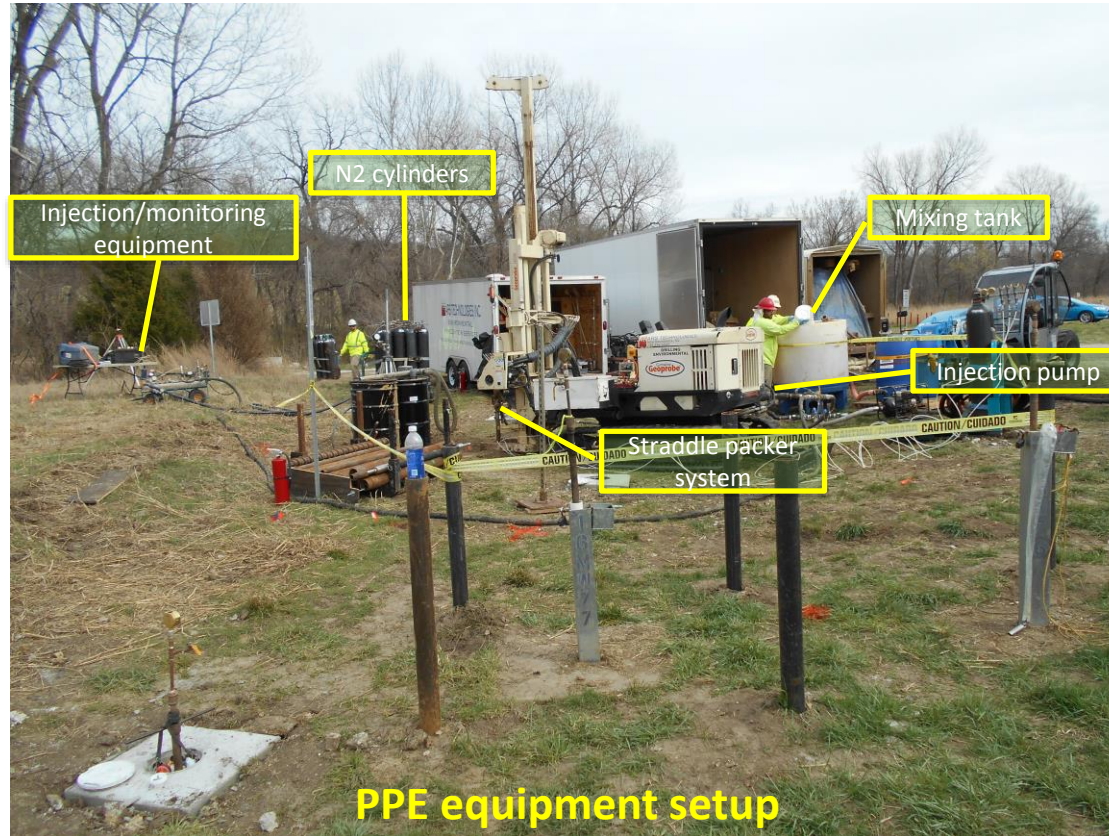


- Oops! DNAPL
- Disturbed Soil

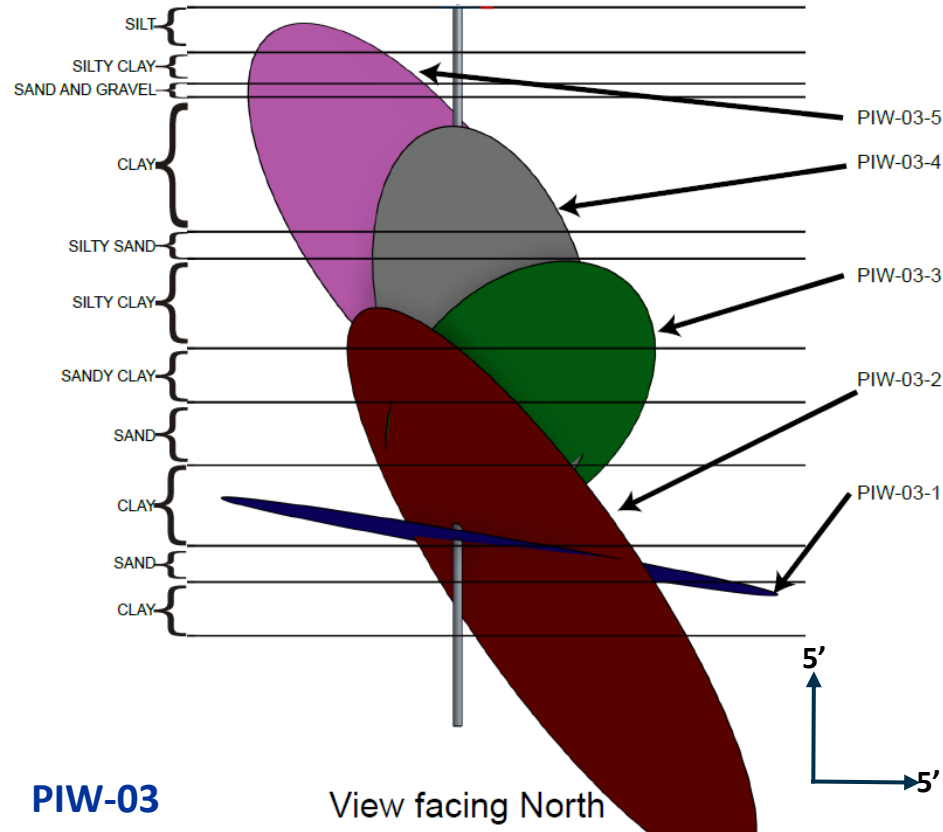
Field Implementation Photos - LCAAP



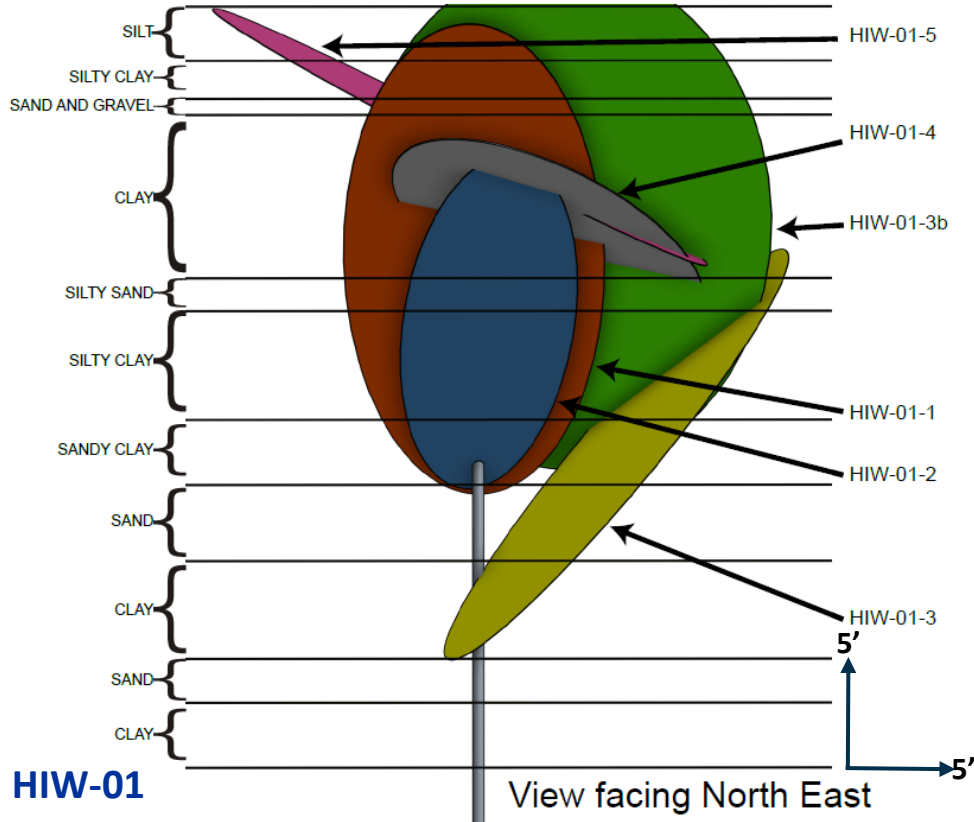
Field Implementation Photos - LCAAP



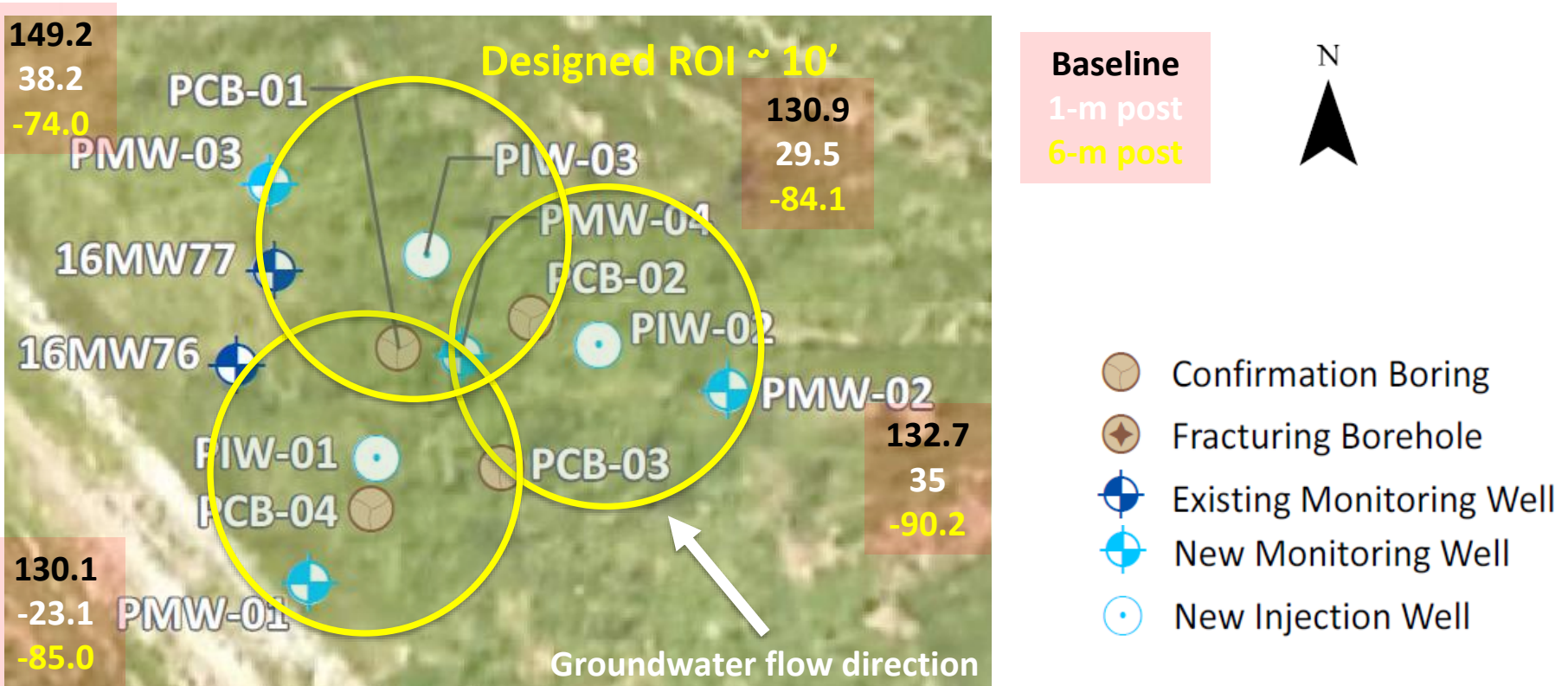
Tiltmeter Results – Pneumatic Cell



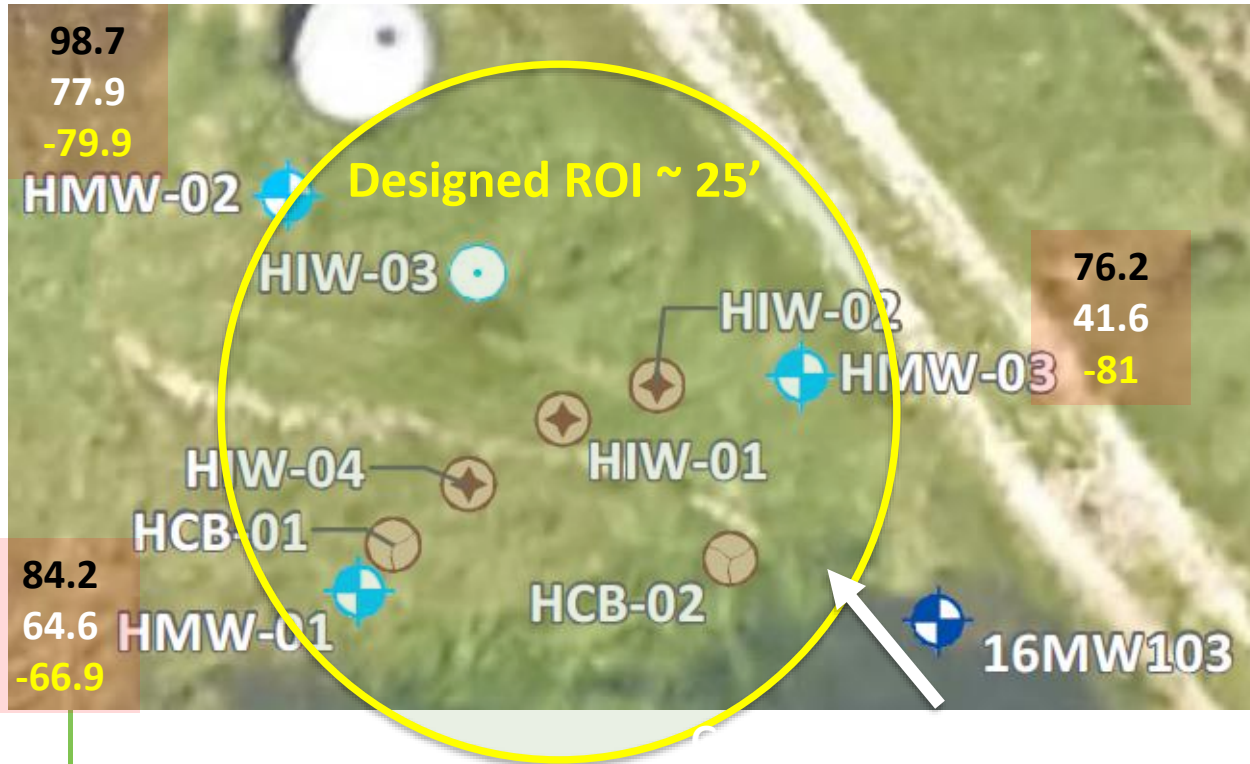
Tiltmeter Results – Hydraulic Cell



ORP – Pneumatic Cell



ORP – Hydraulic Cell



Baseline

1-m post

6-m post

N



Confirmation Boring



Fracturing Borehole



Existing Monitoring Well



New Monitoring Well



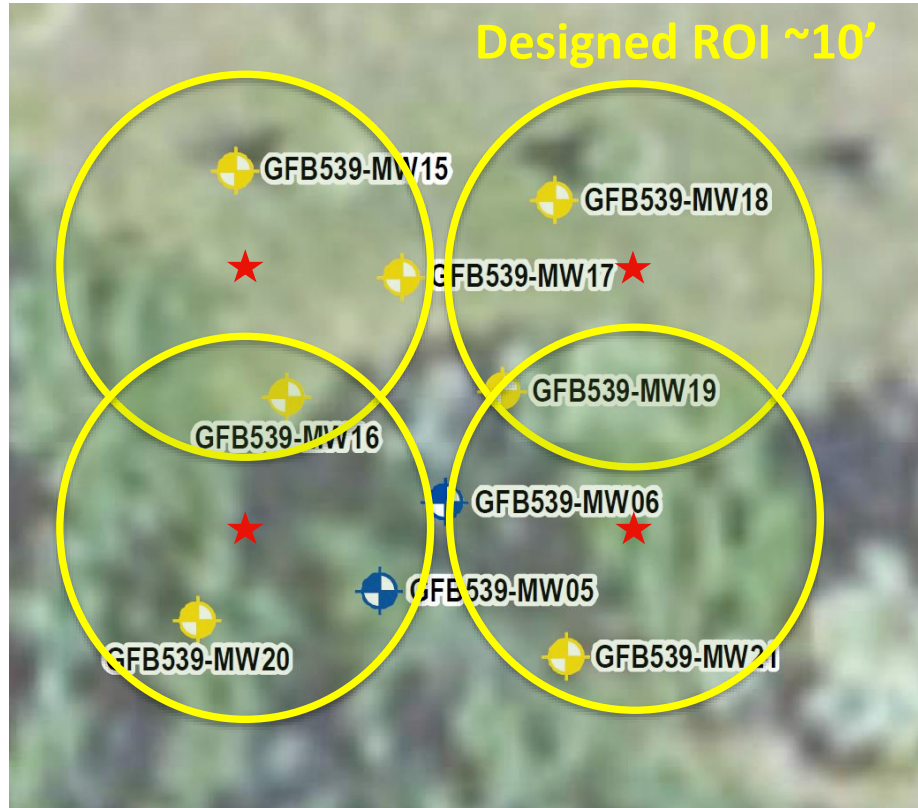
New Injection Well

Existing downgradient MWs 16MW28 & 16MW29 not shown

Test Design - GFAFB

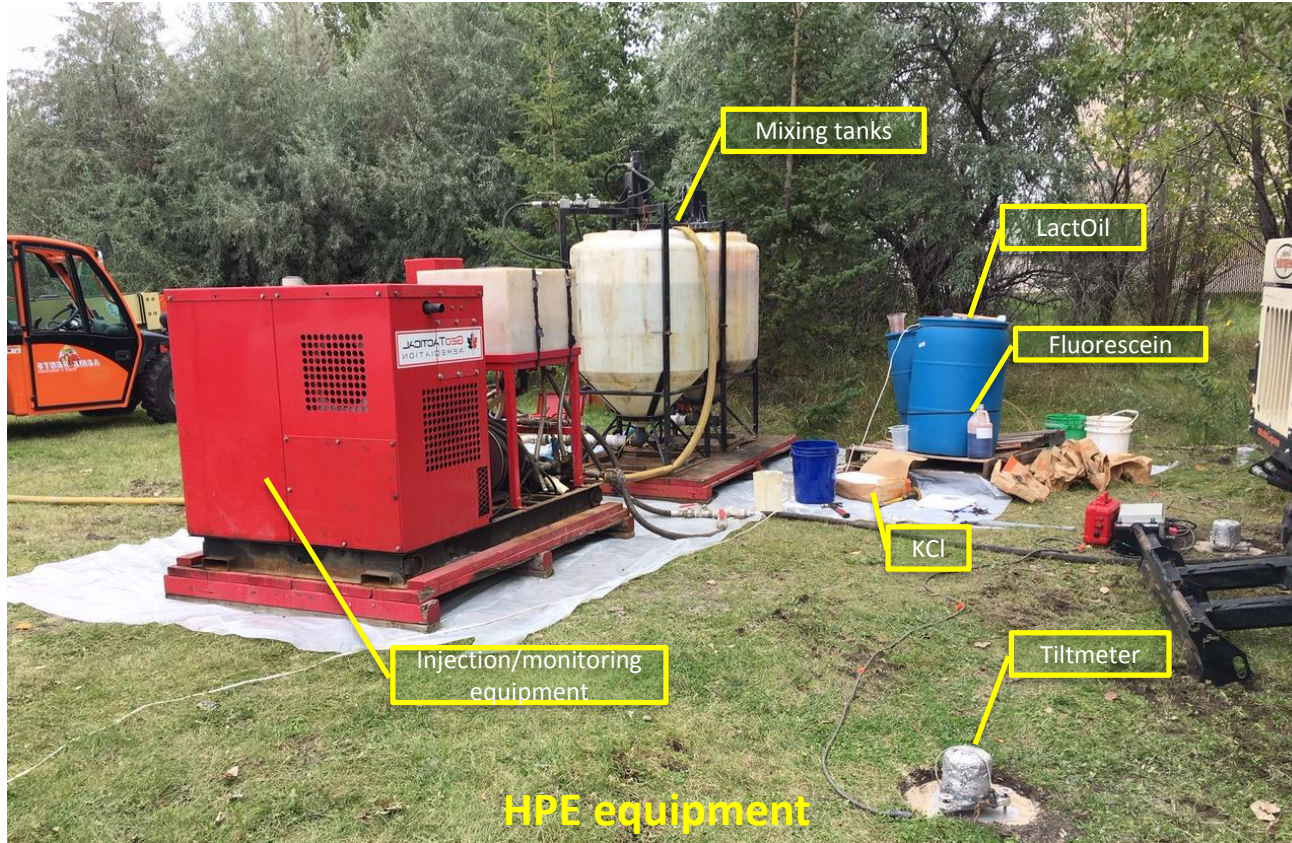
- Direct comparison between HPE and conventional direct-push
- Site info:
 - Silts from 0 to 3 ft bgs followed by clays from 3 to 30 ft bgs
 - Shallow water table at 4 to 8 ft bgs
 - Groundwater flow ~ 13 ft/year in shallow unit
- Selected delivery technologies:
 - HPE with EVO (LactOil), no sand emplacement via DPT
 - 4-8 permeability enhancement points
 - 3 vertical intervals per permeability enhancement point

Demonstration Layout - GFAFB



- Monitoring well (existing)
- Monitoring well (new)
- Hydraulic injection point

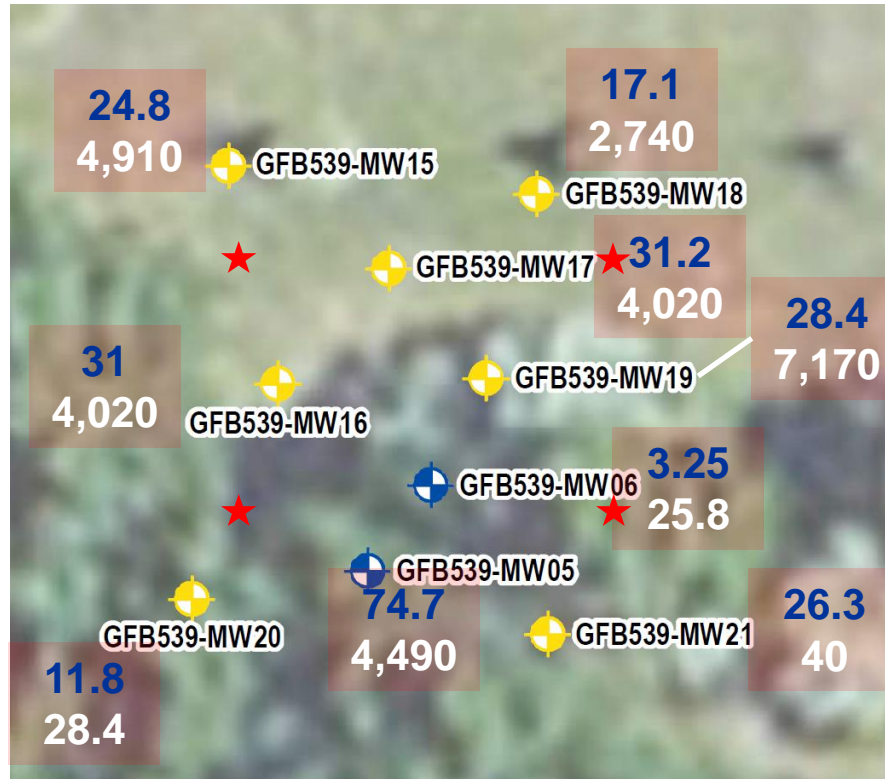
Field Implementation Photos



Field Implementation Photos



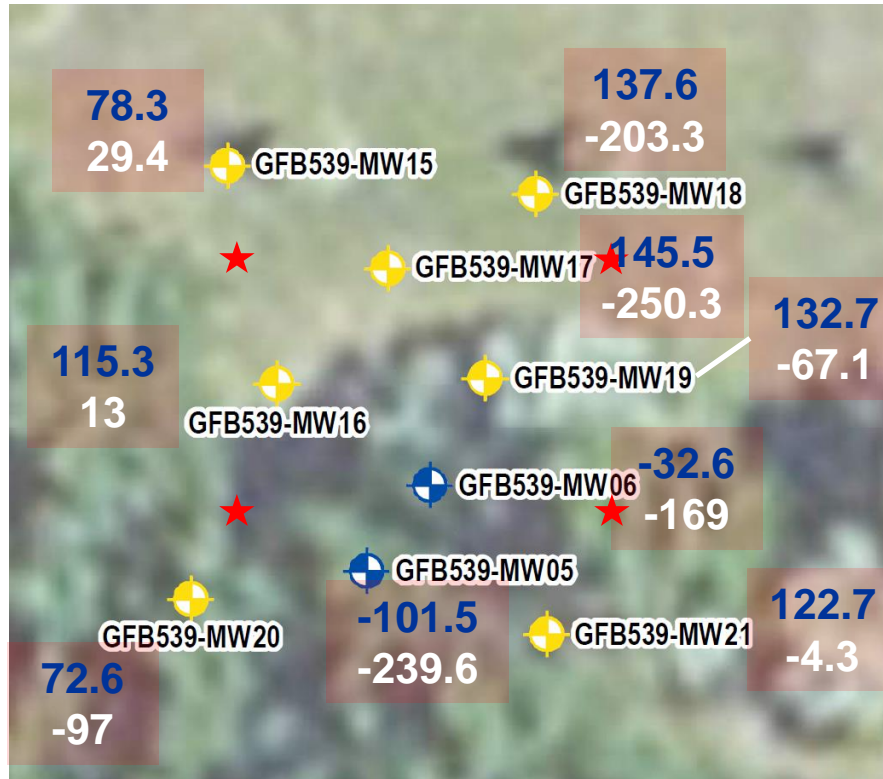
TOC (mg/L)



- Monitoring well (existing)
- Monitoring well (new)
- Hydraulic injection point

Baseline
1-m post

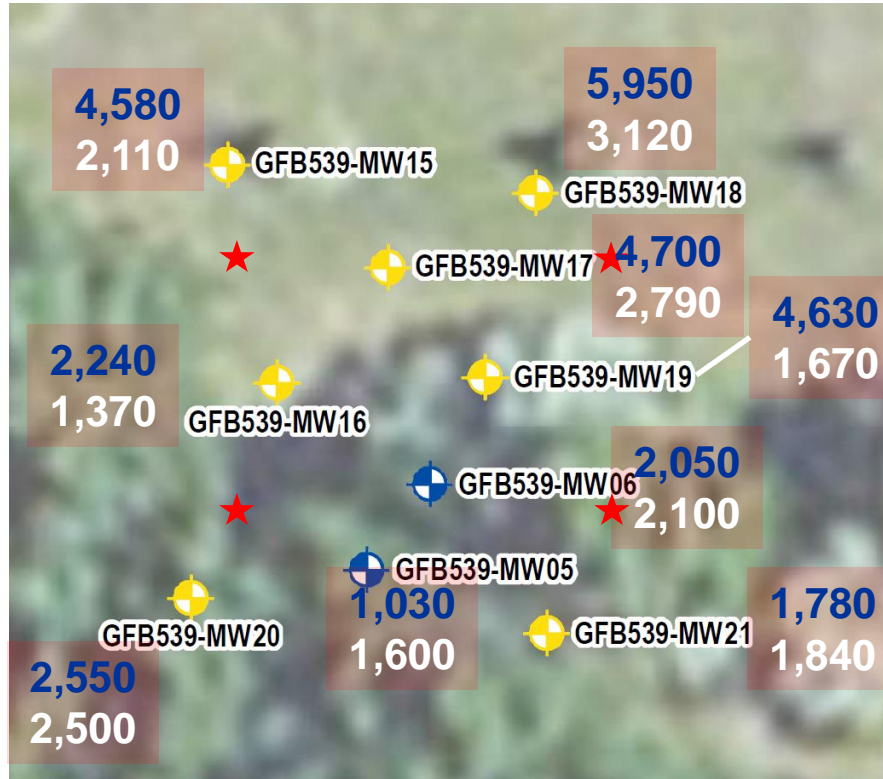
ORP (mV)



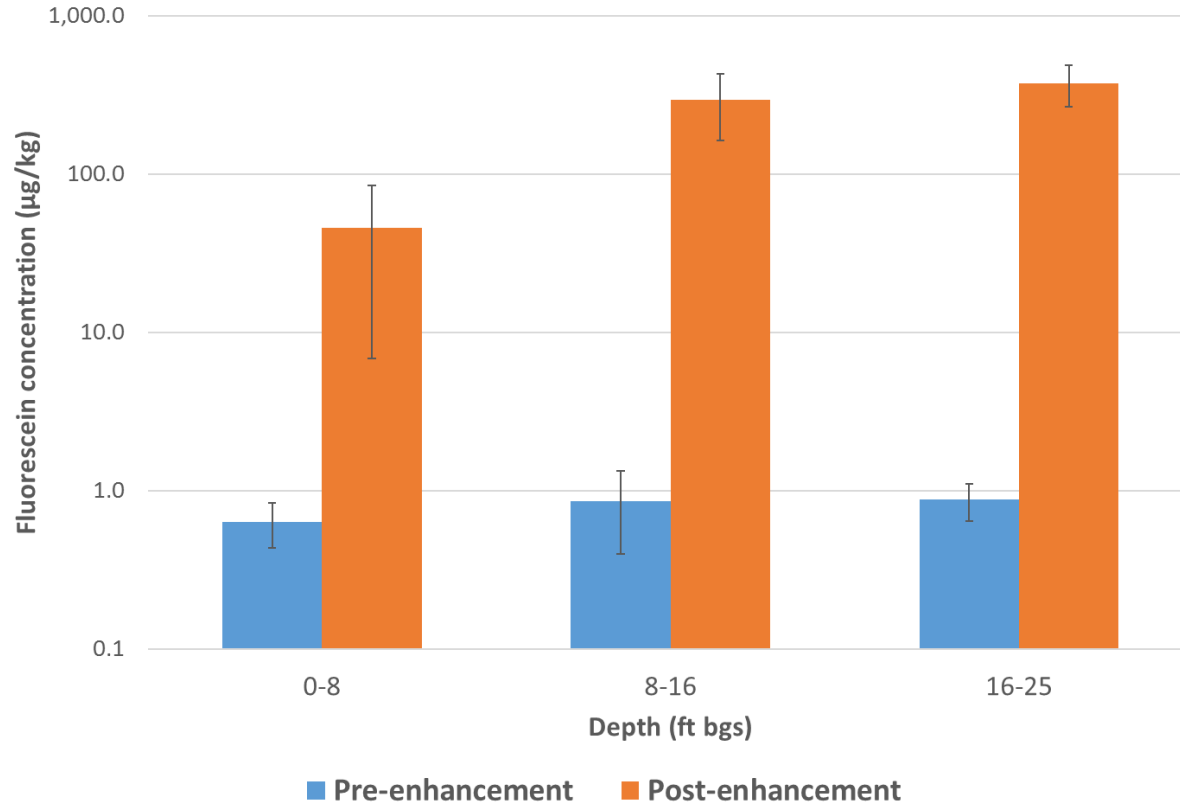
- Monitoring well (existing)
- Monitoring well (new)
- Hydraulic injection point

Baseline
1-m post

Sulfate (mg/L)



Fluorescein in Soil



Status

- Permeability Enhancement Technology highly successful in three low permeability geologies
- One last sampling event at GFAFB
- Tiltmeter data to be finalized
- Cost data to be analyzed
- Guidance document to be prepared



Questions?