A Comparison of Cost and Performance Between Permeability Enhancement Technology and Conventional Injection Techniques at Low Permeability Sites

ESTCP ER-201430

Nathan T. Smith, PMP

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CDM Smith

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Technical Objectives

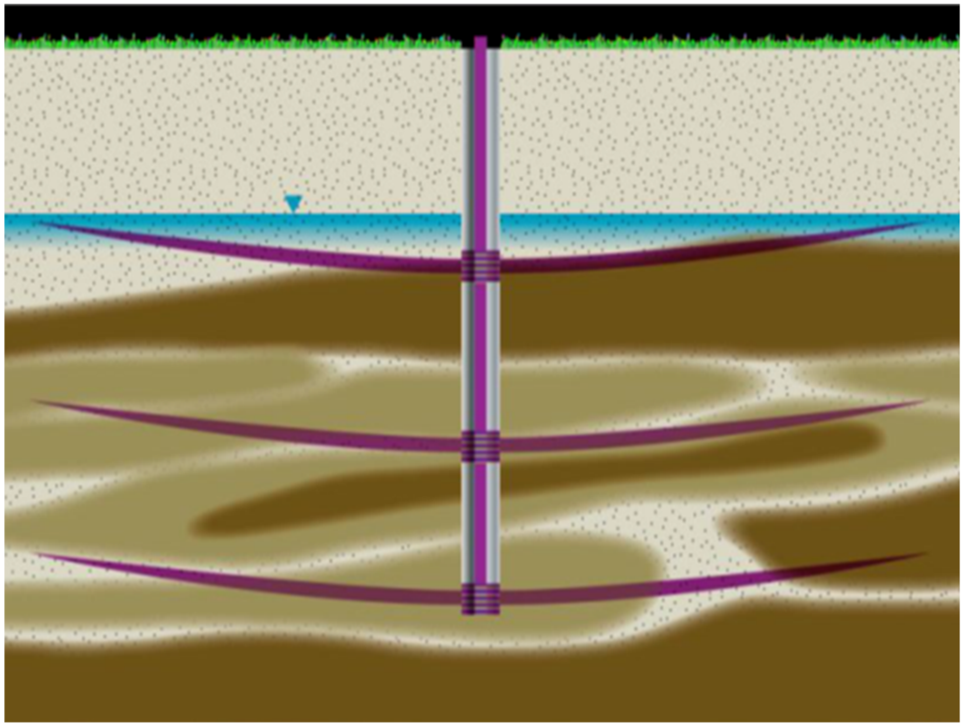
- Demonstrate improved injection methods for low K sites
  - Permeability Enhancement Technology (PET)
- Document costs and benefits
- Develop clear guidance for practitioners
- Alleviate misperceptions of environmental soil fracturing

Project Approach

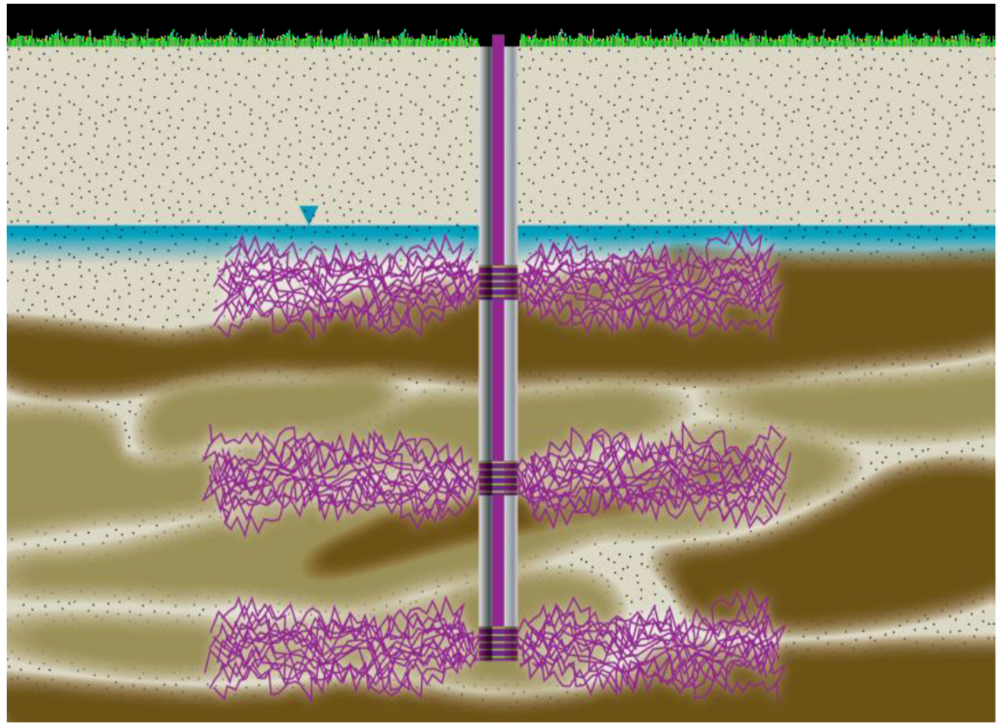
- Demonstrate PET amendment distribution in three geologies
  - Effective radius
  - Volume
  - Orientation
  - Vertical distribution
- Demonstrate and validate high-resolution sensing and mapping techniques
- Develop guidance, including cost and performance data

Permeability Enhancement Technology

- Environmental Soil Fracturing (U.S. Patent No. 7,179,381)



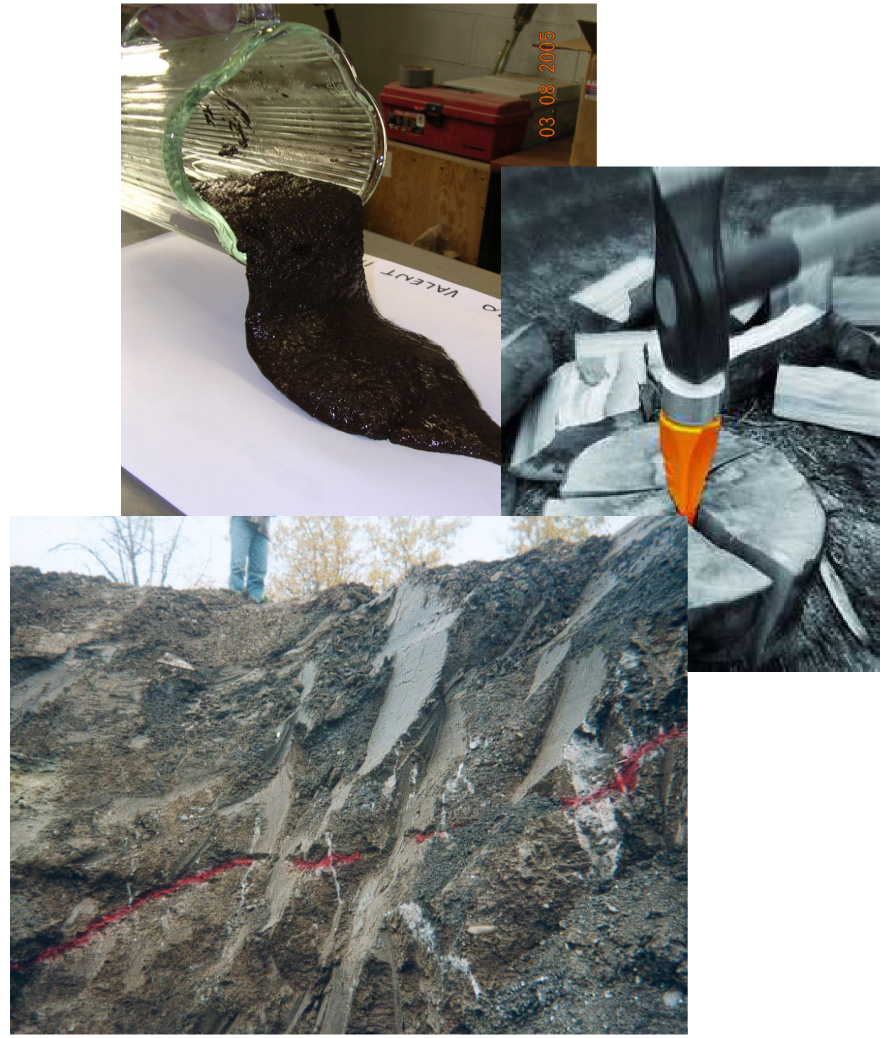
Hydraulic



Pneumatic

Hydraulic PET (HPE)

- Cross-linked gel mixed with proppant (sand) and/or treatment reagent
  - All materials food-grade
- Injected under pressure to create parting of soil
- Discrete fractures at pre-determined depths



Pneumatic PET (PPE)

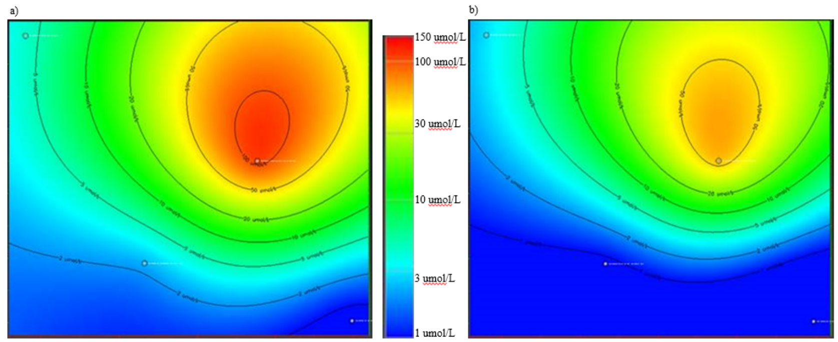
- Pressurized gas stream initiates fractures
  - Enhances existing fractures/planes
- Atomization of liquid amendment and injection
- “Hybrid” PPE uses hydraulic delivery following pneumatic fracture initiation

Site Background

- ESTCP ER-201430 - Three different low K settings:
  - Silty clay/glacial till: Grand Forks Air Force Base (GFAFB)
  - Residuum/weathered shale: Lake City Army Ammunition Plant (LCAAP)
  - Claystone/siltstone: Camp Pendleton (CP)
- Added an additional site to expand cost evaluation:
  - Interbedded sand/silt/clay: Bountiful/Woods Cross OU1 Superfund Site (BWC OU1)

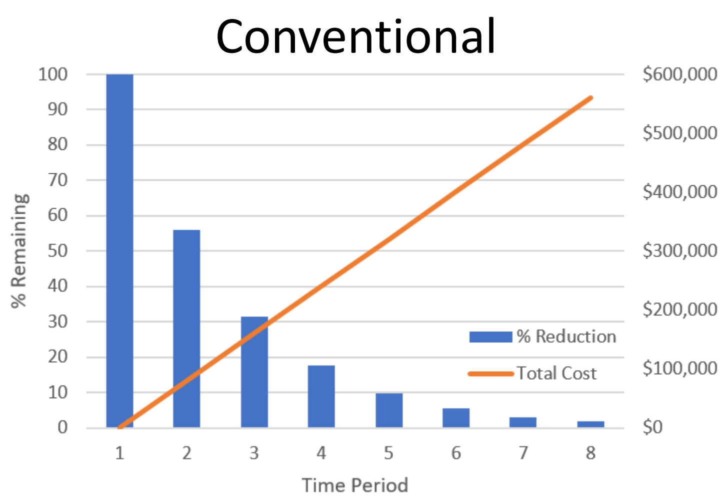
Cost Comparison Approach

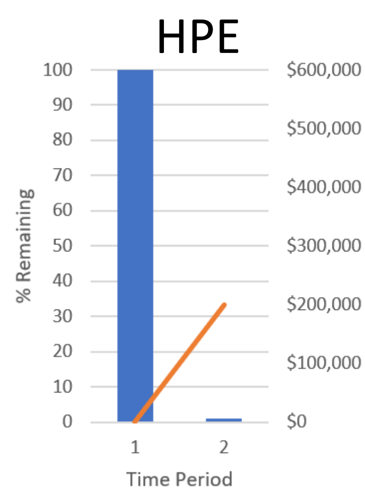
- Sites with prior conventional treatment approach – permeation injection
- Used site data from pre- and post-injection
  - 3D model in Leapfrog
  - Calculated total contaminant mass in treatment area
  - Compared cost effectiveness based on percent mass reduction
- 30-year project lifecycle costs



Cost Comparison Detail

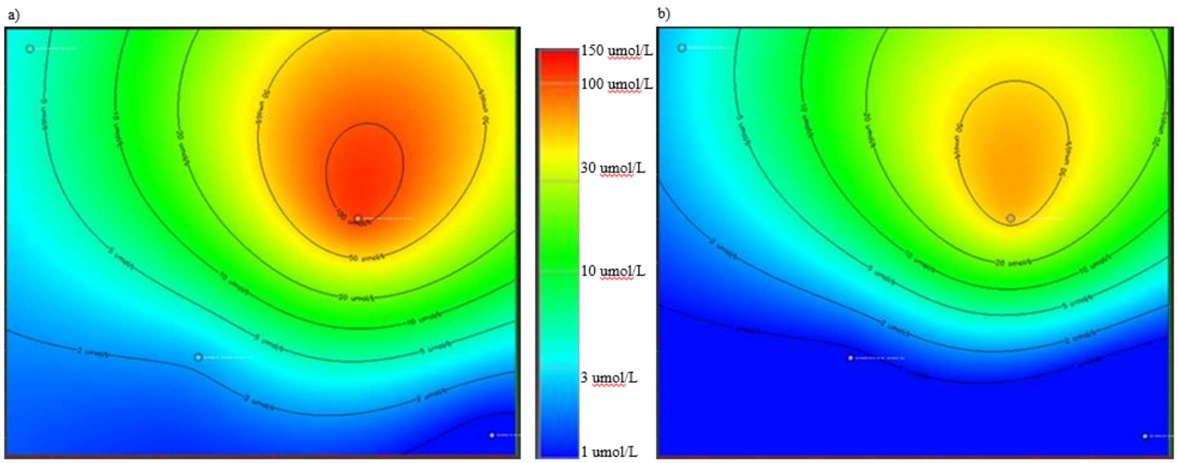
- Estimated costs for implementing conventional
- Actual costs for PET
- Calculated cost per unit mass destroyed per unit time
  - Normalized by compounding conventional percent reduction to reach the same percent reduction achieved by permeability enhancement





Grand Forks – Conventional Approach

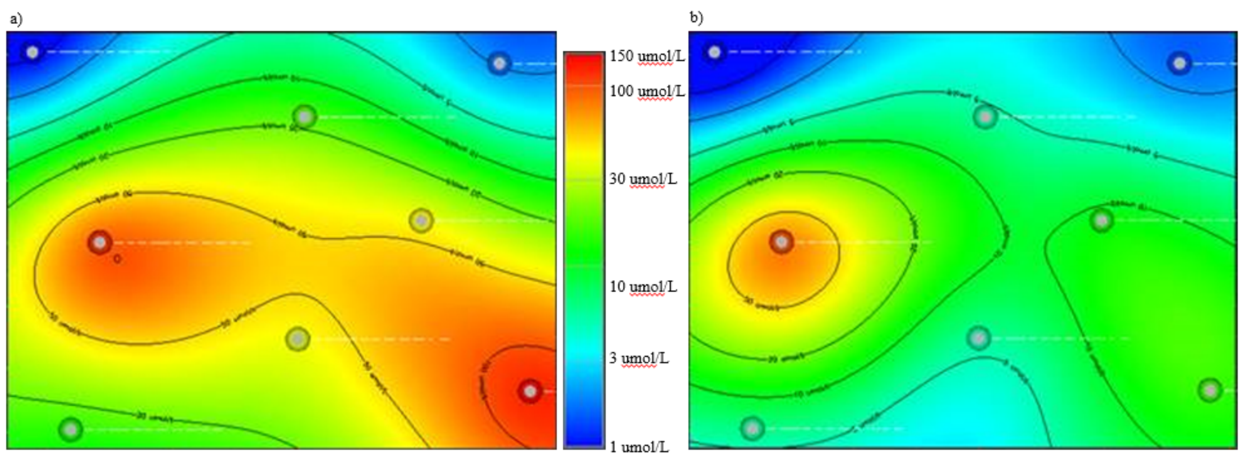
- Thirty DPT-installed injection wells
- 1-inch wells with 3-foot screens
- Oil injections: ~150 gallons of dilute solution per well
- 28% reduction in one year



Pre- versus post-conventional injection TCE concentrations

Grand Forks – Hydraulic Permeability Enhancement Approach

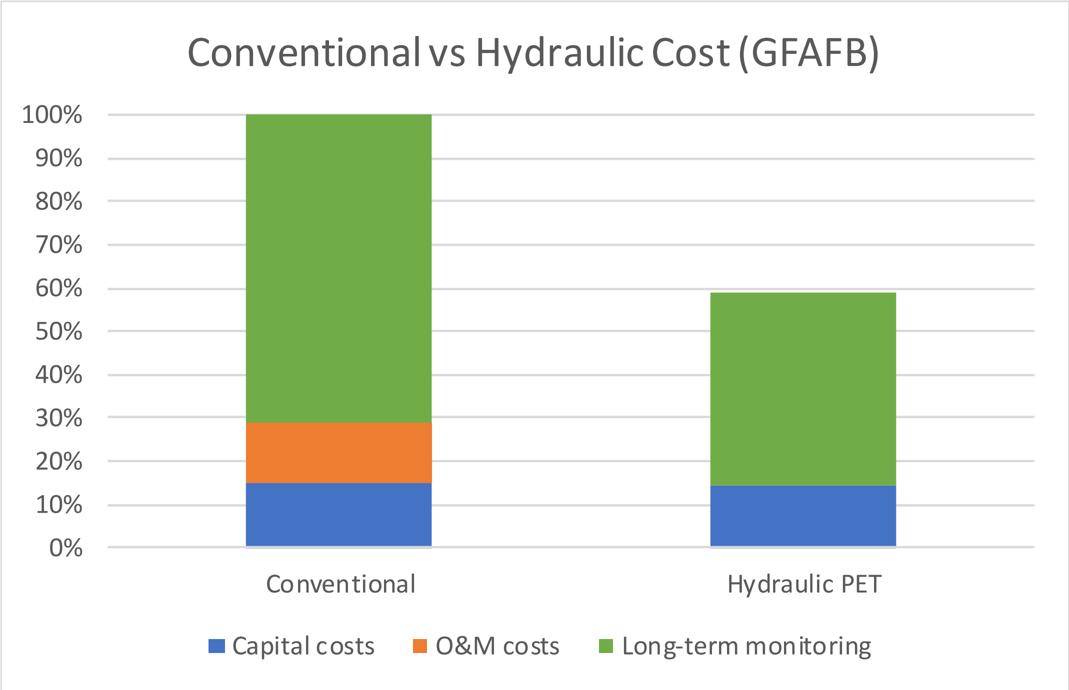
- Four HPE borings
- Three fracture initiation points in each boring
- Oil injections: ~130 gallons of dilute solution per fracture
- 64% reduction in one year



Pre- versus post-HPE injection
TCE concentrations

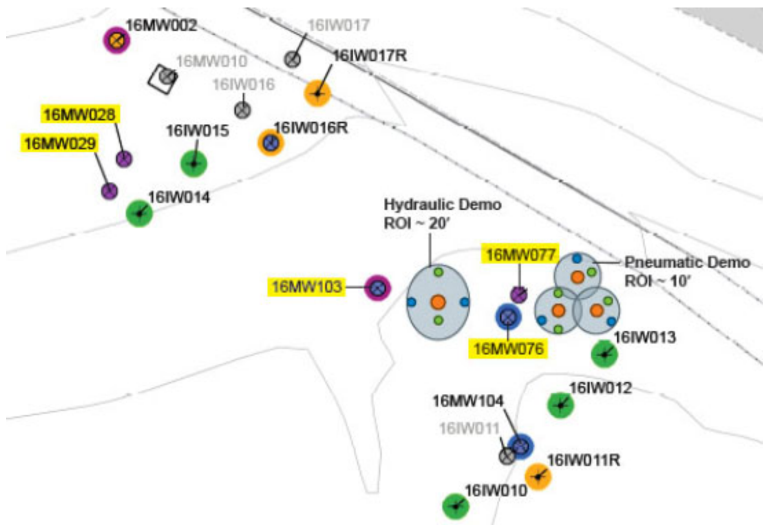
Grand Forks Cost Comparison

- Conventional injections previously performed:
  - 28% mass reduction in one year
  - Total project NPV cost ~$612k
- HPE:
  - 64% mass reduction in one year
  - Total project NPV cost ~$363k



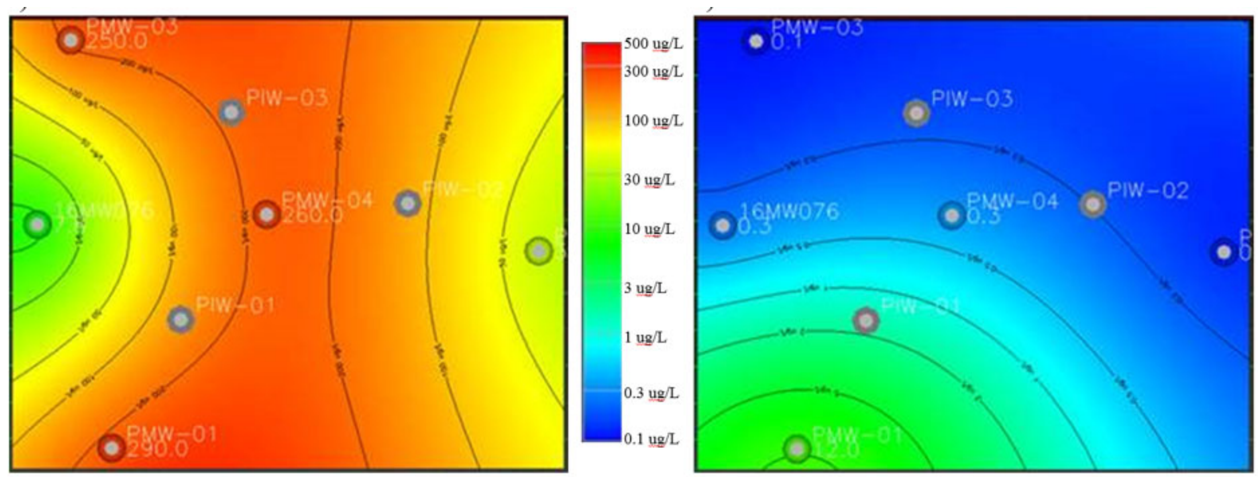
Lake City – Conventional Approach

- Biobarrier approach
- Gravity-feed molasses injections
- ~2,500 gallons of dilute solution per well
- Eight injections over five years
- 2.3% reduction in five years



Lake City – Hybrid Pneumatic Permeability Enhancement Approach

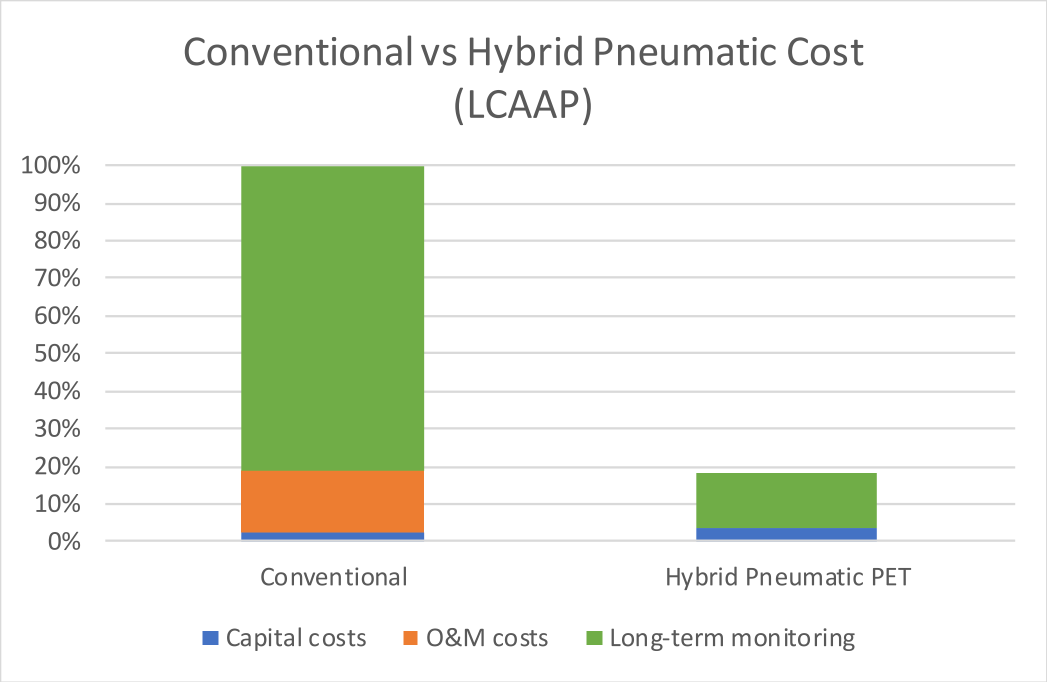
- Three hybrid PPE borings
- Five fracture initiation points in each boring
- Oil injections: ~200 gallons of dilute solution per fracture
- 87% reduction in six months



Pre- versus post-hybrid PPE injection TCE concentrations

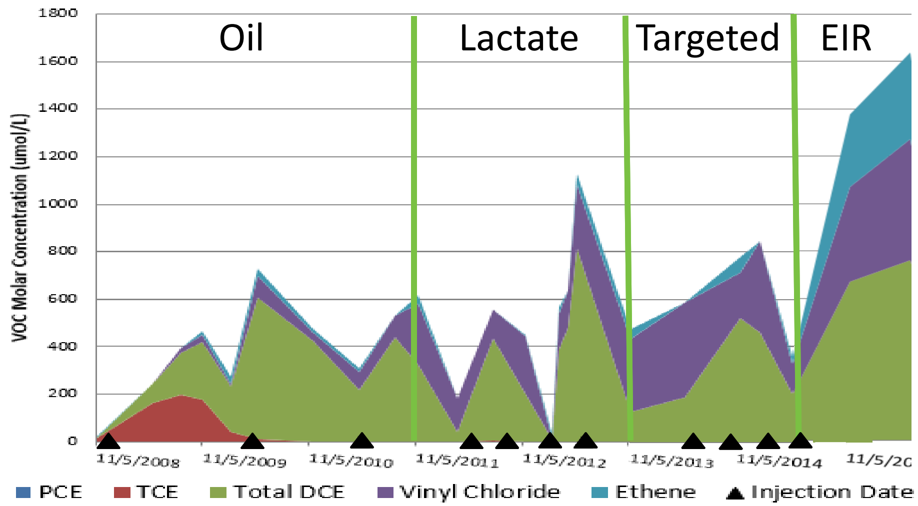
Lake City Cost Comparison

- Conventional injections previously performed:
  - 2.3% mass reduction in five years
  - Total project NPV cost >>$1.9M
- Hybrid PPE:
  - 87% mass reduction in one year
  - Total project NPV cost ~$347k



BWC OU1 – Conventional Approach

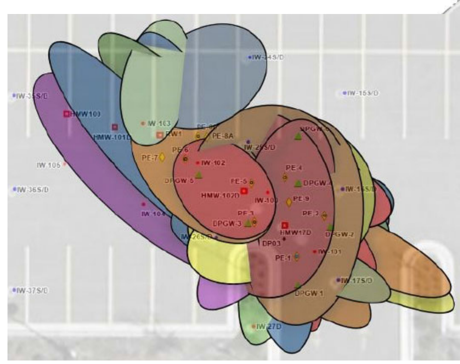
- Injection well network
- Targeted well screens
- Oil or lactate injections: ~1,500 gallons of dilute solution per well
- Three injection events
- 44% reduction in one year

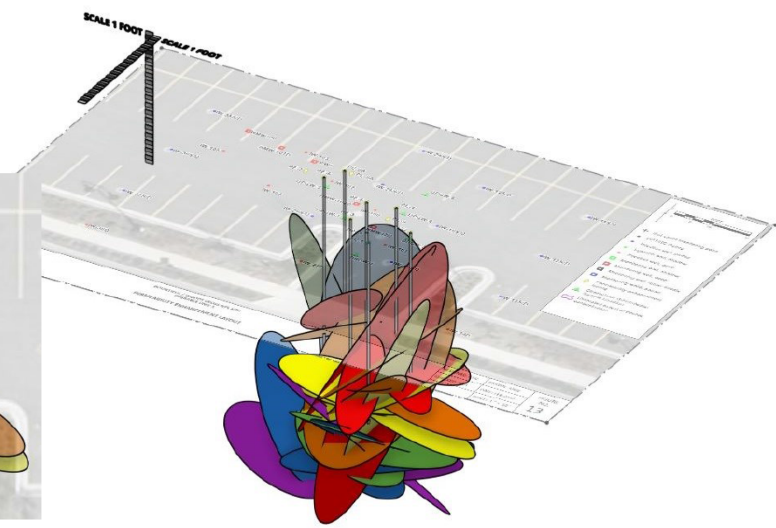


Molar concentration trend during conventional treatment

BWC OU1 – Hydraulic Permeability Enhancement Approach

- Nine HPE borings
- Two to three fracture initiation points in each boring
- ZVI/Sand injections: ~140 gallons of solution per fracture
- 99.4% reduction in four months

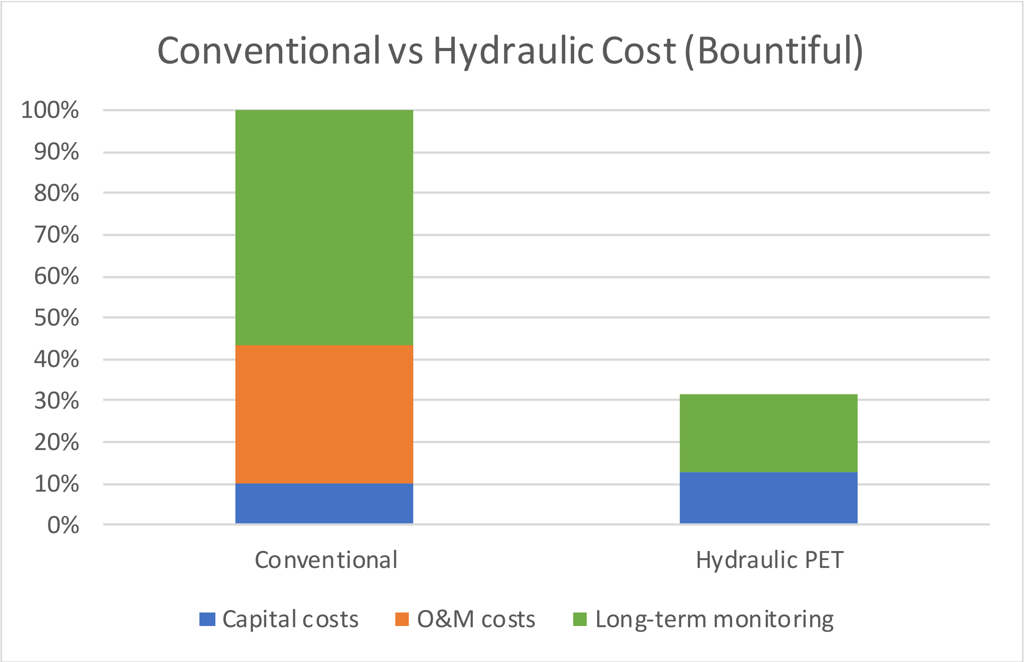




HPE fracture network
(figures courtesy of
GeoTactical Remediation)

BWC OU1 Cost Comparison

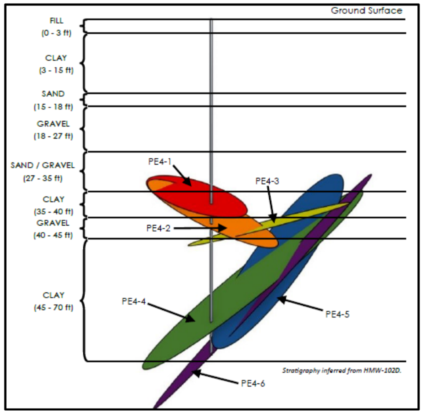
- Conventional injections previously performed:
  - 44% mass reduction in one year
  - Total project NPV cost ~$1.47M
- HPE:
  - 99.4% mass reduction in four months
  - Total project NPV cost ~$463k



Primary Cost Drivers for PET

- Target lithology, depth
  - Drilling methods
  - Approach to PET (DPT vs. packers for HPE)
  - Field time for PET implementation
- Mobilization charges
  - Smaller percentage of total based on amount of work
- Amendment costs
  - Balance longevity with up-front cost

Monitoring Techniques - Tiltmeters

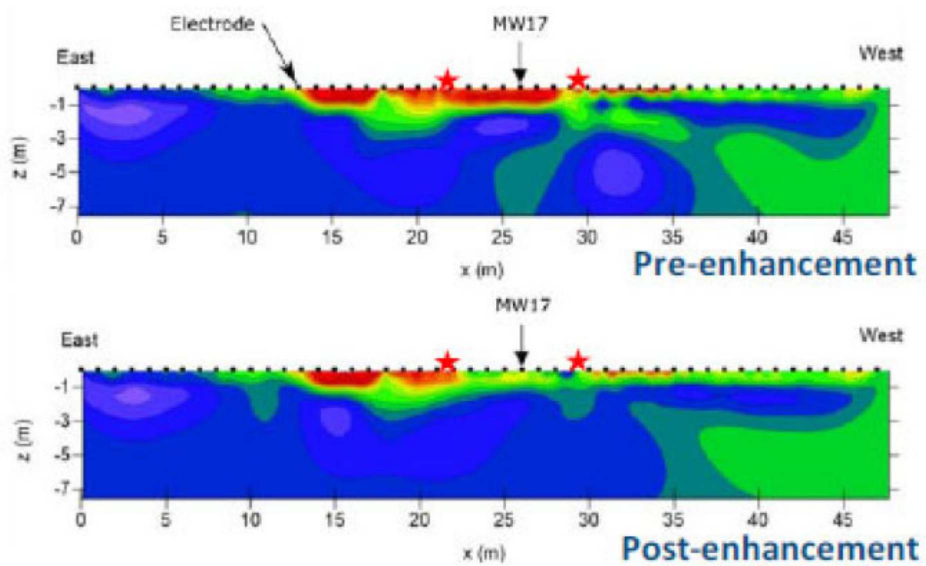


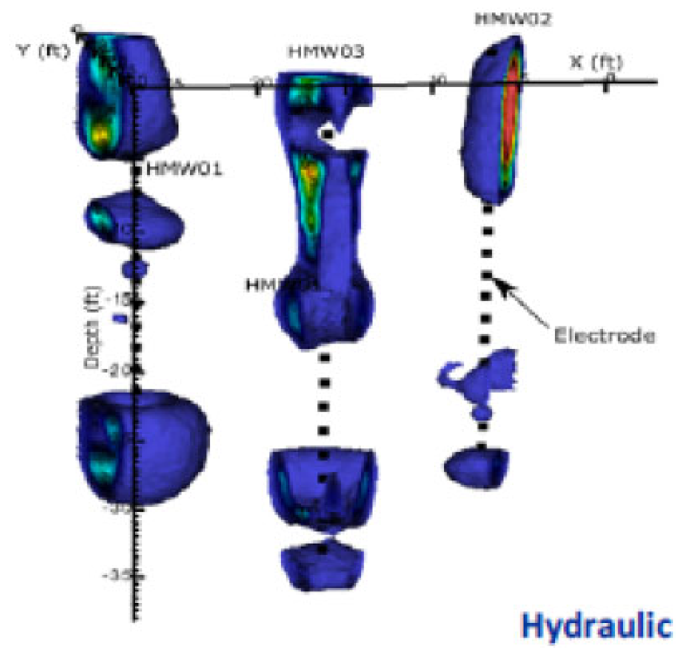
- High sensitivity to small deformations
- 3D fracture mapping

Site ID	Number of predicted fractures	Number of intervals within 1-3 inches of predicted fractured intervals exhibiting elevated TOC/sulfate/fluorescein	Percent accuracy
MCB-CP	8	8	100%
LCAAP - hydraulic	5	3	60%
LCAAP - pneumatic	8	7	88%
GFAFB	15	15	100%

Monitoring Techniques – Electrical Resistivity Tomography

- Changes to electrical resistivity
- 2D and 3D subsurface mapping

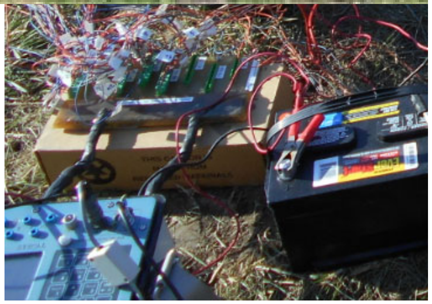




2D and 3D ERT images (figures courtesy of Rutgers University)

Primary Cost Considerations for Monitoring

- Tiltmeters
  - Good accuracy/prediction of fracture location and depth
  - Require additional field setup and subsequent modeling (may not impede work depending on drilling conditions)
  - Implementation cost $6k - $26k
- ERT
  - General indication of amendment delivery
  - 3D ERT heavily influenced by depth and drilling approach
  - Implementation cost $34k - $48k



Conclusions from Demonstration

	Till	Sandstone	Shale Residuum	Sand/Silt/Clay
HPE	★	★	★	★
PPE	--	--	★	--
HPE saves $$	★	★	★	★
PPE saves $$	--	--	★	--

-- = not tested at this location

- Before implementing treatment in low-K lithology, consider PETs!

Acknowledgements

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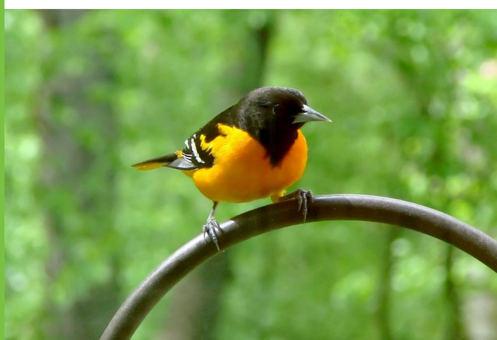

Questions?