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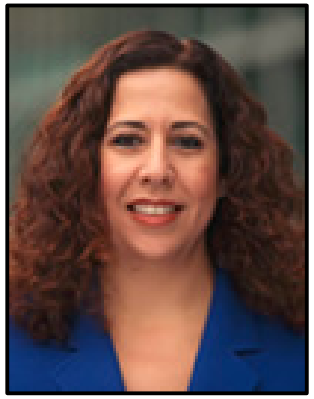
Advances in Remediating Groundwater Contaminated with Chlorinated Solvents

December 12, 2019

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions



Rula A. Deeb, Ph.D.
Webinar Coordinator

Webinar Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Rula Deeb, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Dr. Andrea Leeson, SERDP and ESTCP
- **New Application of a Geotechnical Technology to Remediate Low-Permeability Contaminated Media** (25 minutes + Q&A)
  Dr. Stephen Richardson, GSI
- **The Horizontal Reactive Media Treatment Well (HRX Well®): A New Technology for In-Situ Remediation** (25 minutes + Q&A)
  Dr. Craig Divine, ARCADIS
- **Final Q&A session**

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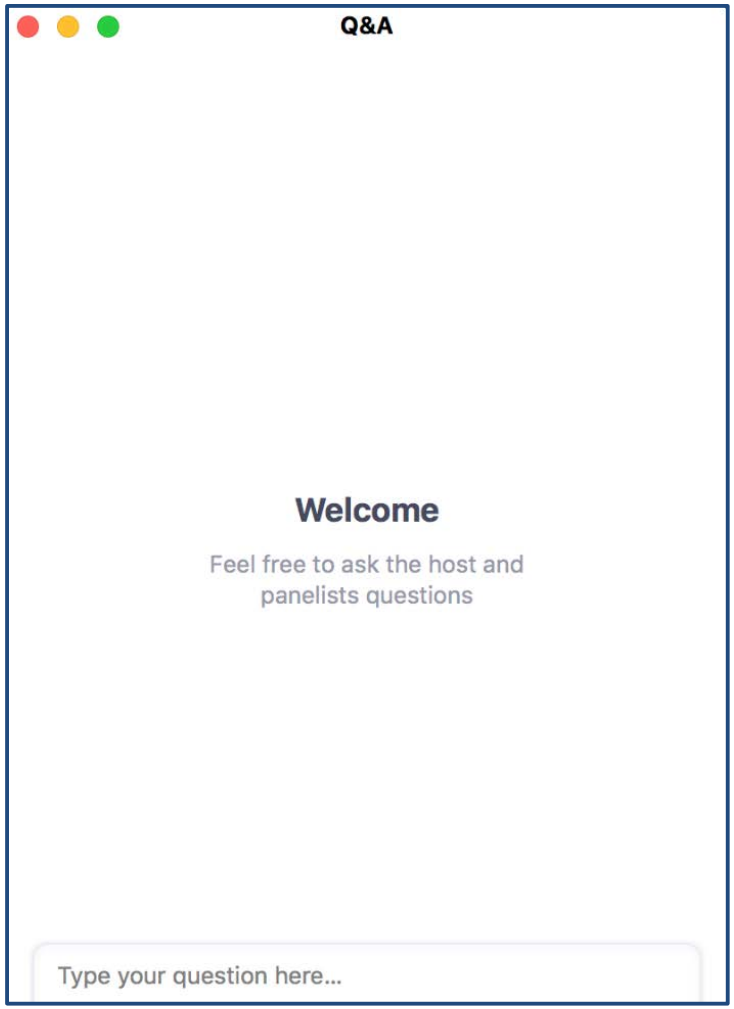


SERDP and ESTCP Overview

Andrea Leeson, Ph.D.
SERDP and ESTCP

DoD's Environmental Technology Programs

Science and Technology

- Statutory program established 1991
- DoD, DOE, EPA partnership
  - Advanced technology development to address near-term needs
  - Fundamental research to impact real world environmental management

Demonstration and Validation

- Demonstrate innovative cost-effective environmental and energy technologies
  - Transition technology out of the lab
  - Establish cost and performance
  - Partner with end user and regulator
  - Technology transfer
    - Accelerate commercialization or broader adoption
    - Direct technology insertion

Environmental Drivers

Sustaining Ranges, Facilities and Operations

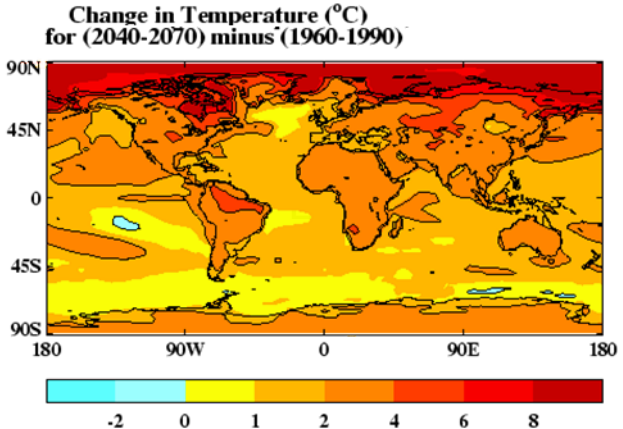
Maritime Sustainability
Threatened and Endangered Species

Toxic Air Emissions and Dust

UXO and Munitions Constituents

Noise

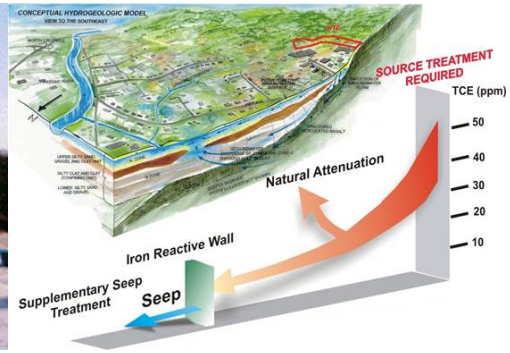
Sustainable FOB



Environmental Drivers

Reducing Current and Future Liability

Contamination from Past Practices



- Groundwater, soils and sediments
- Large UXO liability
- Emerging contaminants

Pollution Prevention to Control Life Cycle Costs

- Elimination of pollutants and hazardous materials in manufacturing, maintenance, and operations
- Achieve compliance through pollution prevention

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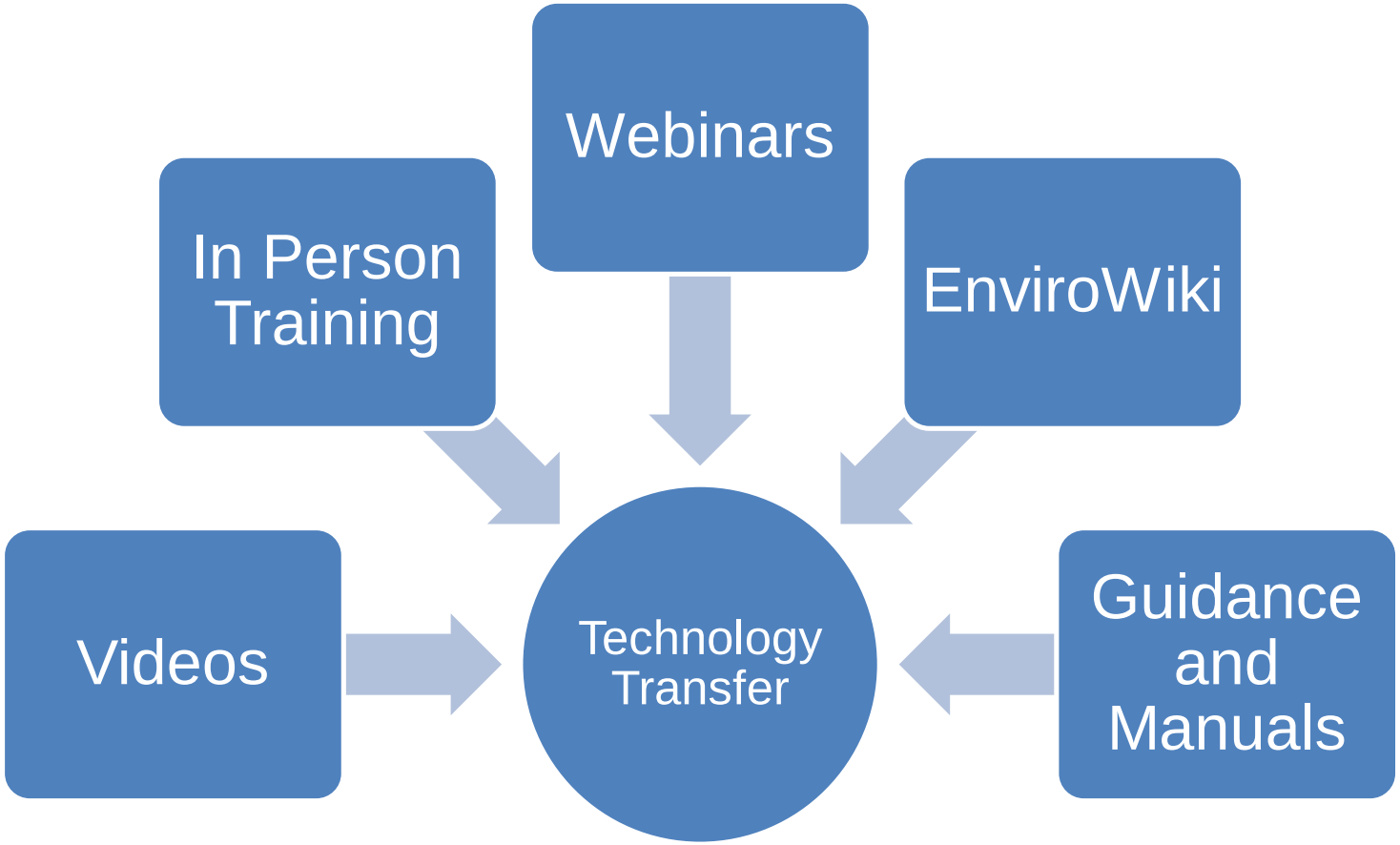

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Webinars

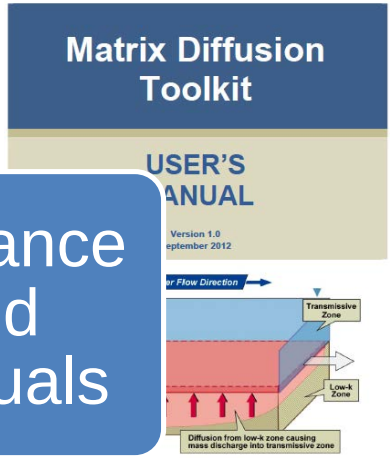
In Person Training

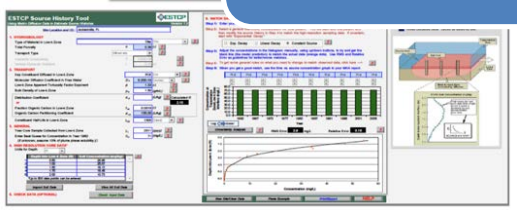
EnviroWiki

Videos

Technology Transfer

Guidance and Manuals





SERDP and ESTCP Webinar Series

- A list of 2020 webinars with registration information will be released soon at http://serdp-estcp.org/Tools-and-Training/Webinar-Series

New Application of a Geotechnical Technology to Remediate Low-Permeability Contaminated Media

Stephen Richardson, Ph.D., P.E.
GSI Environmental, Inc.

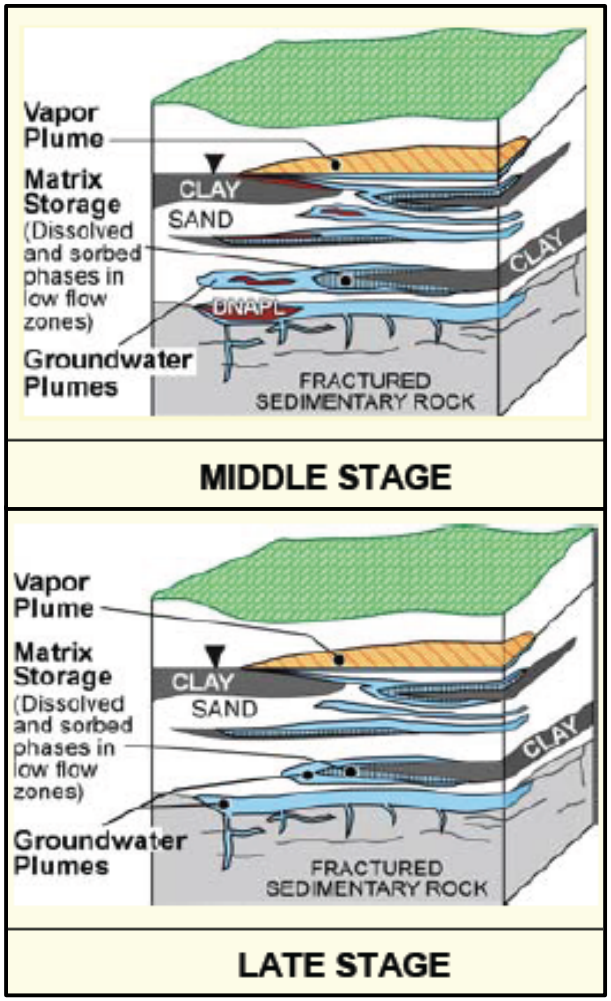
SERDP DOD • EPA • DOE | ESTCP

Agenda

- Problem statement
- Technology description
- Field demonstration
- Performance results and operational Considerations
- Conclusions
- Benefits to DoD

Problem Statement

- Matrix diffusion from low-permeability (low-k) zones is challenging to clean up
  - High life-cycle costs
  - Long remedial timeframes
  - Limited natural attenuation
  - Large source areas
- Need inexpensive technology
  - Address matrix diffusion from low-k source zones
  - Enhance treatment of contaminants leaving low-k source zones



***Source**: Sale et al., 2008*

The Solution: Look to the Geotechs!

Wick Drain Installer

“Grout Bomber”

Geotechnical industry offers well-established techniques to quickly and efficiently access subsurface

***Sources**: Global Synthetics, 2011; Hayward Baker, 2017*

"Grout Bomber"

Technology Description

- Soil stabilization technology
  - Delivers cement grout into subsurface voids
- Direct-push technique
- Appropriate for silts and clays
  - Some challenges for consolidated materials (blow counts > 35)

100+ installs per day	✓
Close spacing (2-3 ft)	✓
Depths > 50 ft	✓
Low costs	✓

***Source**: Hayward Baker, 2017*

"Grout Bomber"

Technology Description

Batch-mix ingredients

Amendment pumping and delivery

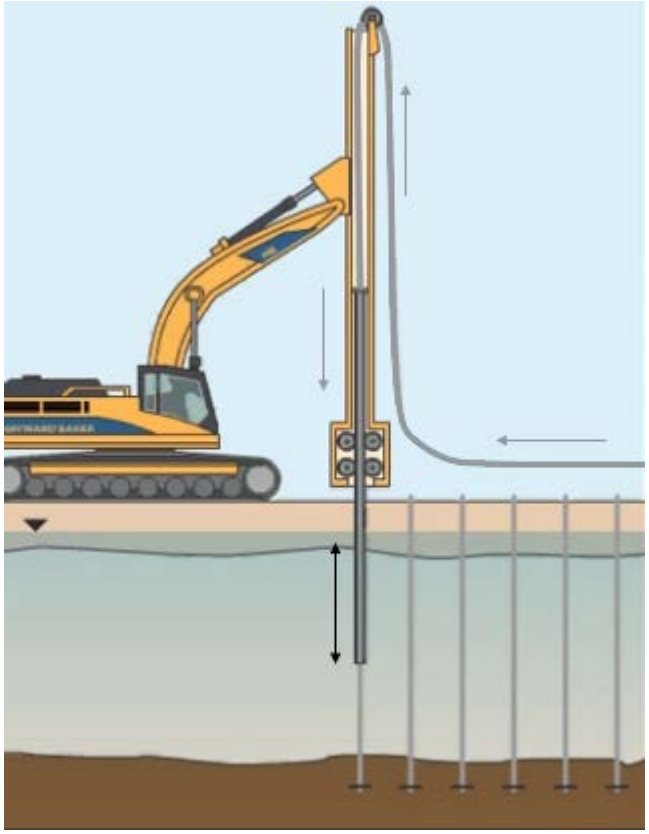
Amendment emplacement

For <u>Our</u> Application…

Repurpose "Grout Bomber" technology to deliver remedial amendments (zero-valent iron and oil) in the subsurface, *<u>not</u>* cement grout

Technical Objectives

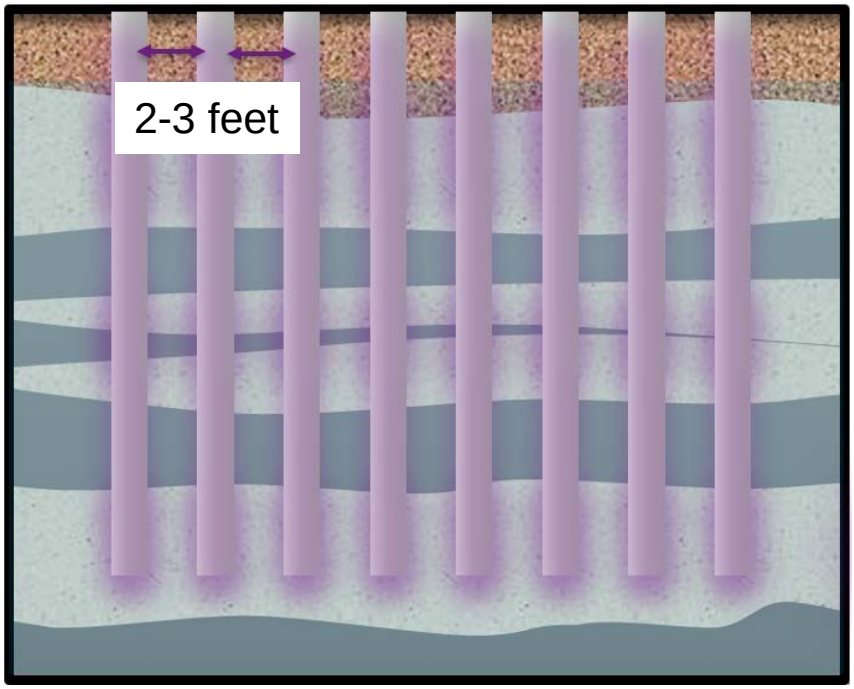
- Demonstrate that the “Grout Bomber” can be repurposed to reduce cleanup times at low-k sites
  - Install closely-spaced (2-3 ft) reaction columns to shorten contaminant diffusion pathways
  - Improve subsurface amendment delivery
  - Create hundreds of vertical reaction zones to degrade chlorinated volatile organic compounds (CVOCs) and shorten “long tail” of back diffusion



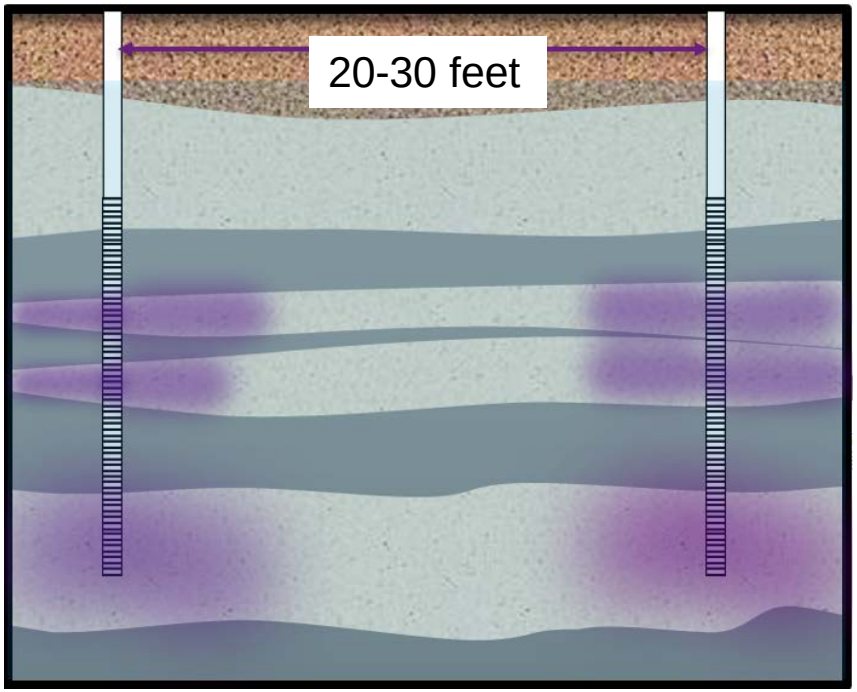
Reaction columns filled with ZVI, oil, and sand

Technology Description

Grout Bomber Technology

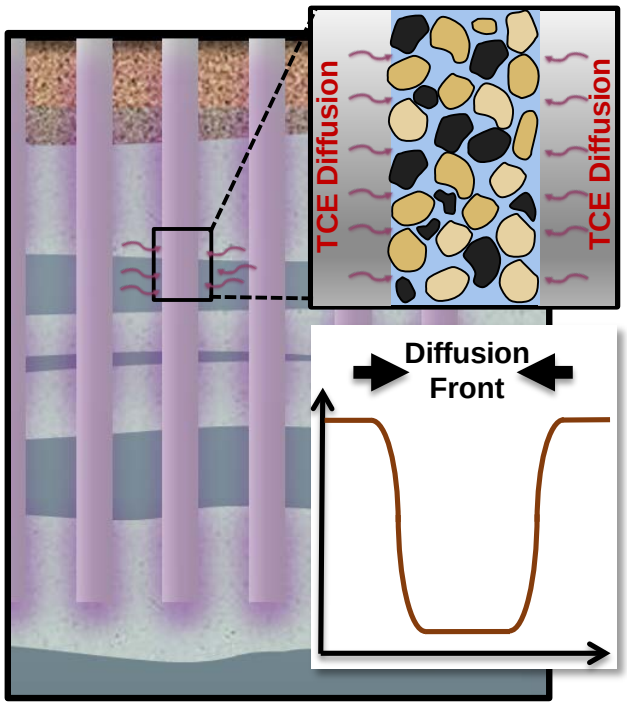


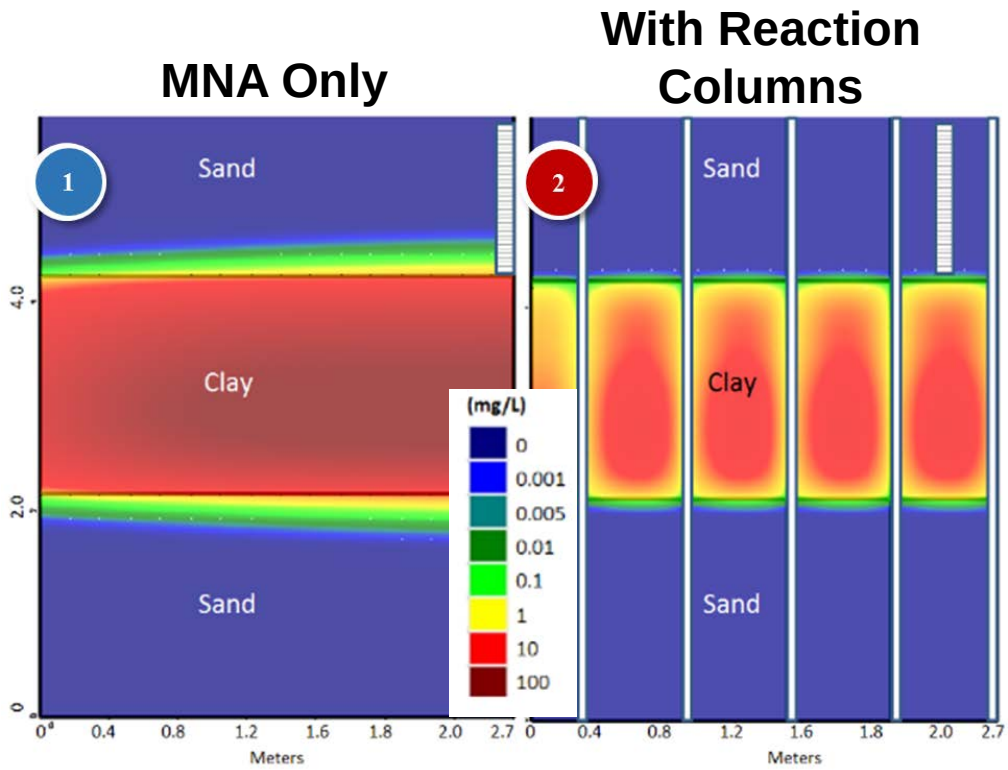
Traditional Amendment Injection



Not an injection technology; rather, it emplaces 100s of closely-spaced vertical reaction columns

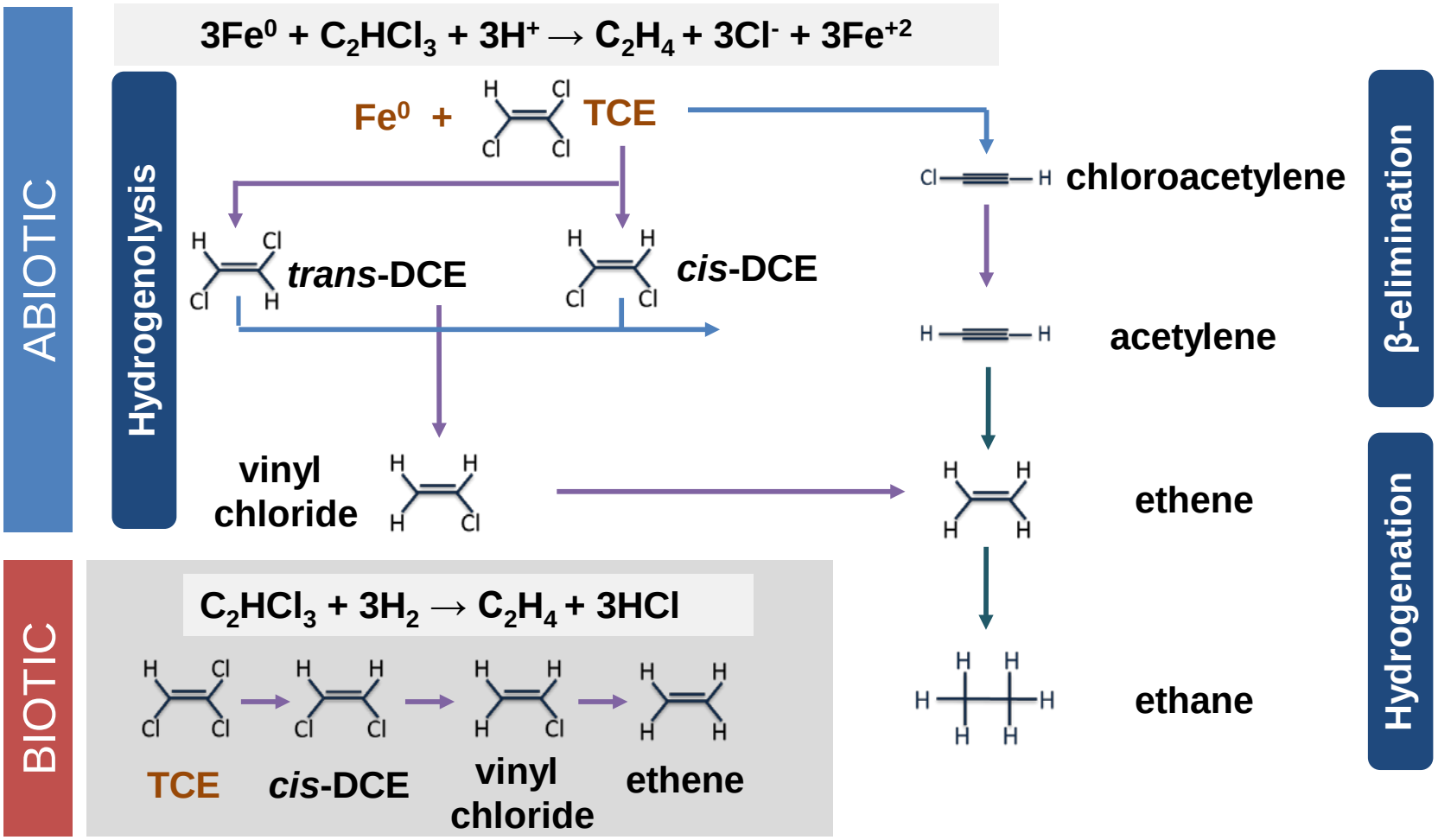
Technology Description





Generates concentration gradients that drive diffusion of contaminants into the reaction zones

Technology Description

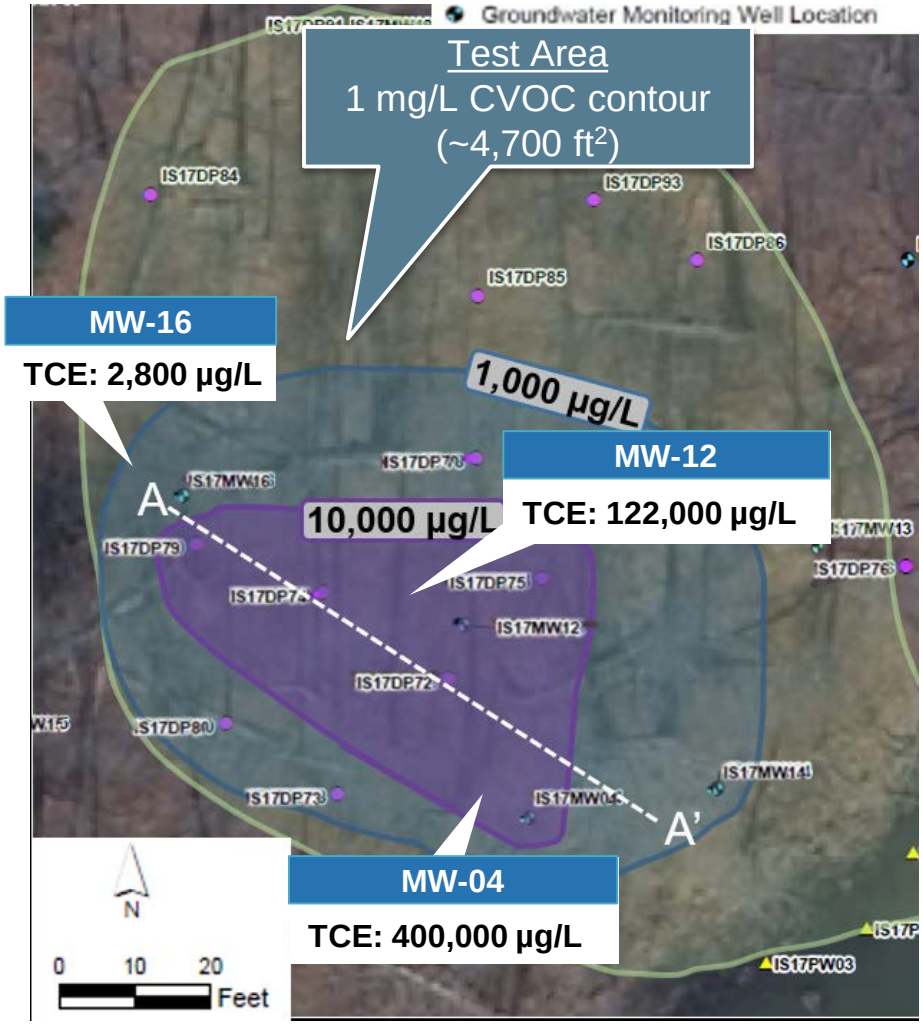


Abiotic and biotic reactions maintain concentration gradient

***Notes**: TCE = trichloroethylene; DCE = dichloroethylene; Fe = iron*

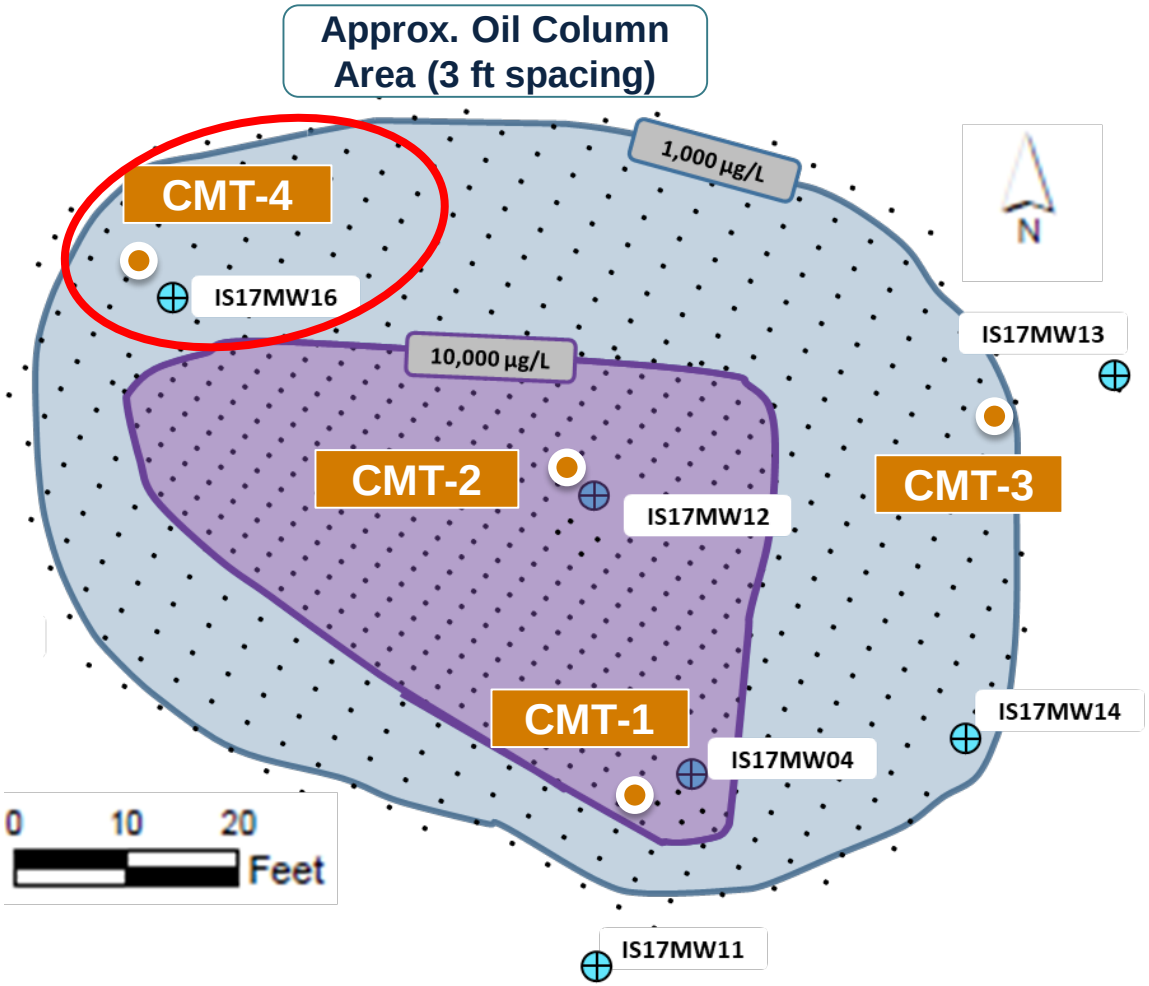
Field Demonstration

- Site 17, Naval Support Facility Indian Head, MD
- Depth to groundwater of 5 ft bgs
- Treatment area consists primarily of silts, sandy clays, and lean clays
- TCE concentrations in soil and groundwater of up to 250 mg/kg and 400 mg/L
- Treatment depth of 30 ft below ground surface (bgs)



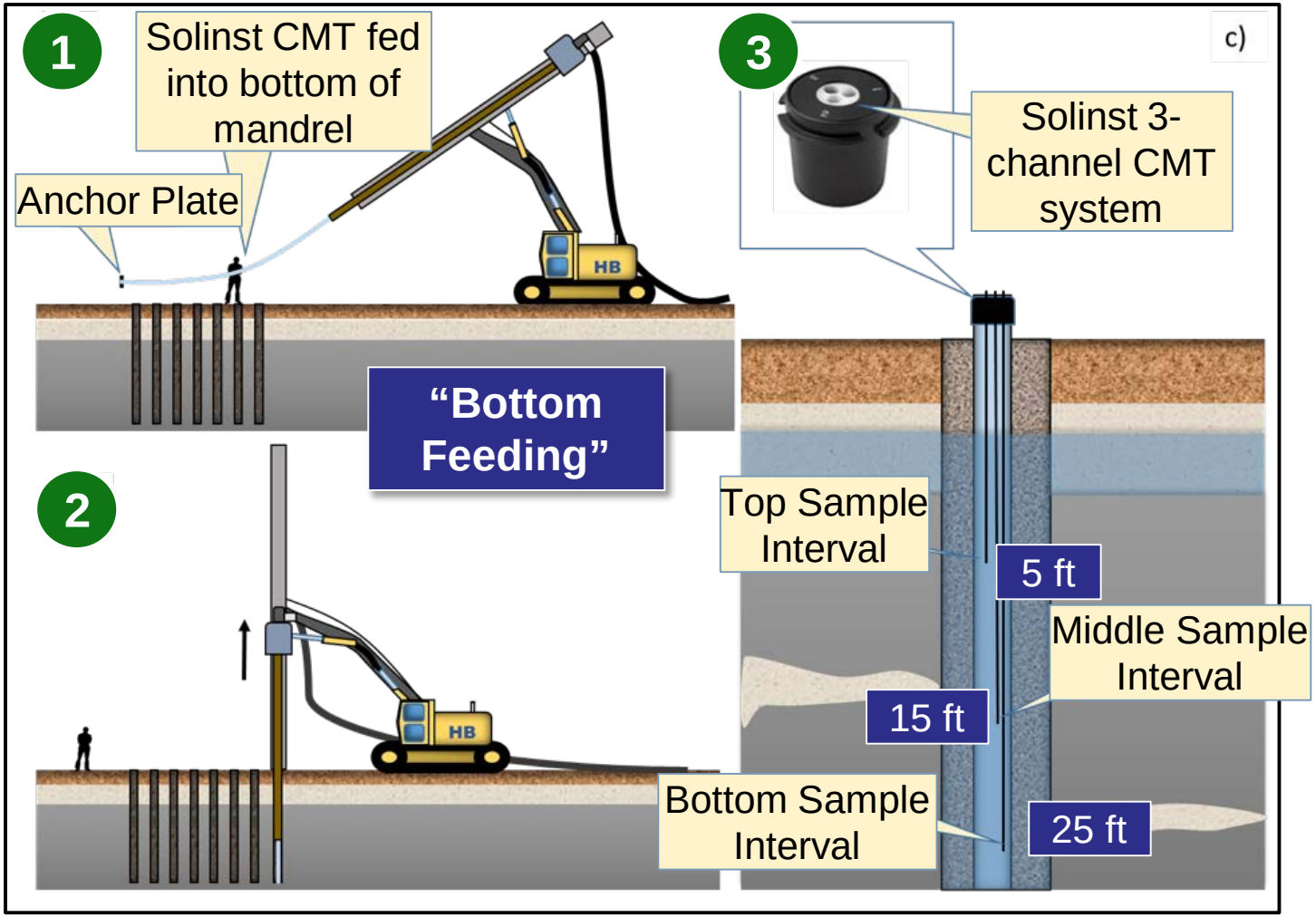
Field Demonstration

- Reaction columns (RCs)
  - 3.5” diameter
  - 2-3 ft spacing
- 700 ZVI/Sand RCs
  - 40% ZVI / 60% sand
  - Oil added to improve pumpability
- 100 Oil/sand RCs
  - 40% oil / 60% sand
  - No ZVI added



How Do We Know It's Working?

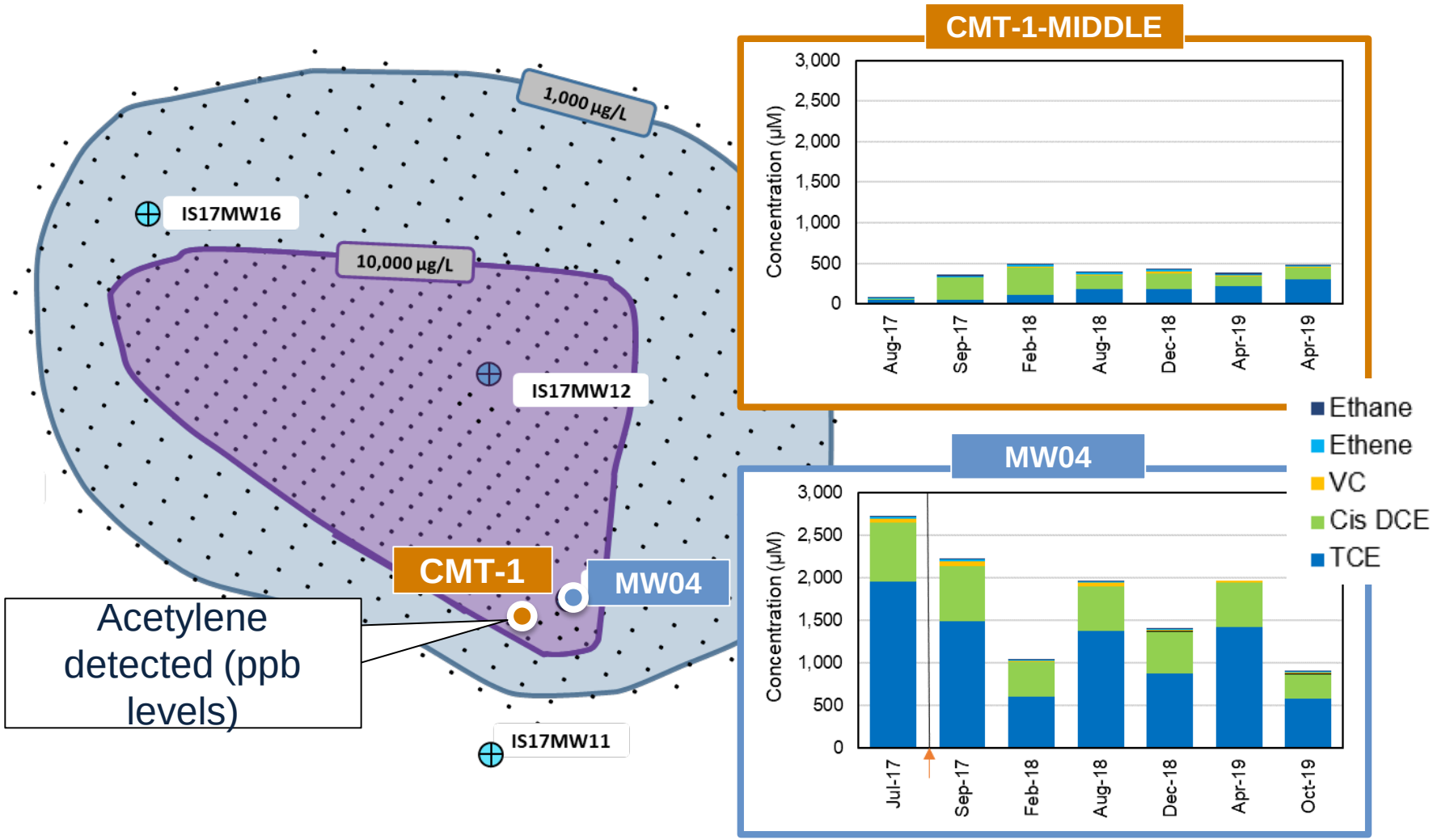
CMT Installation within the Reaction Columns



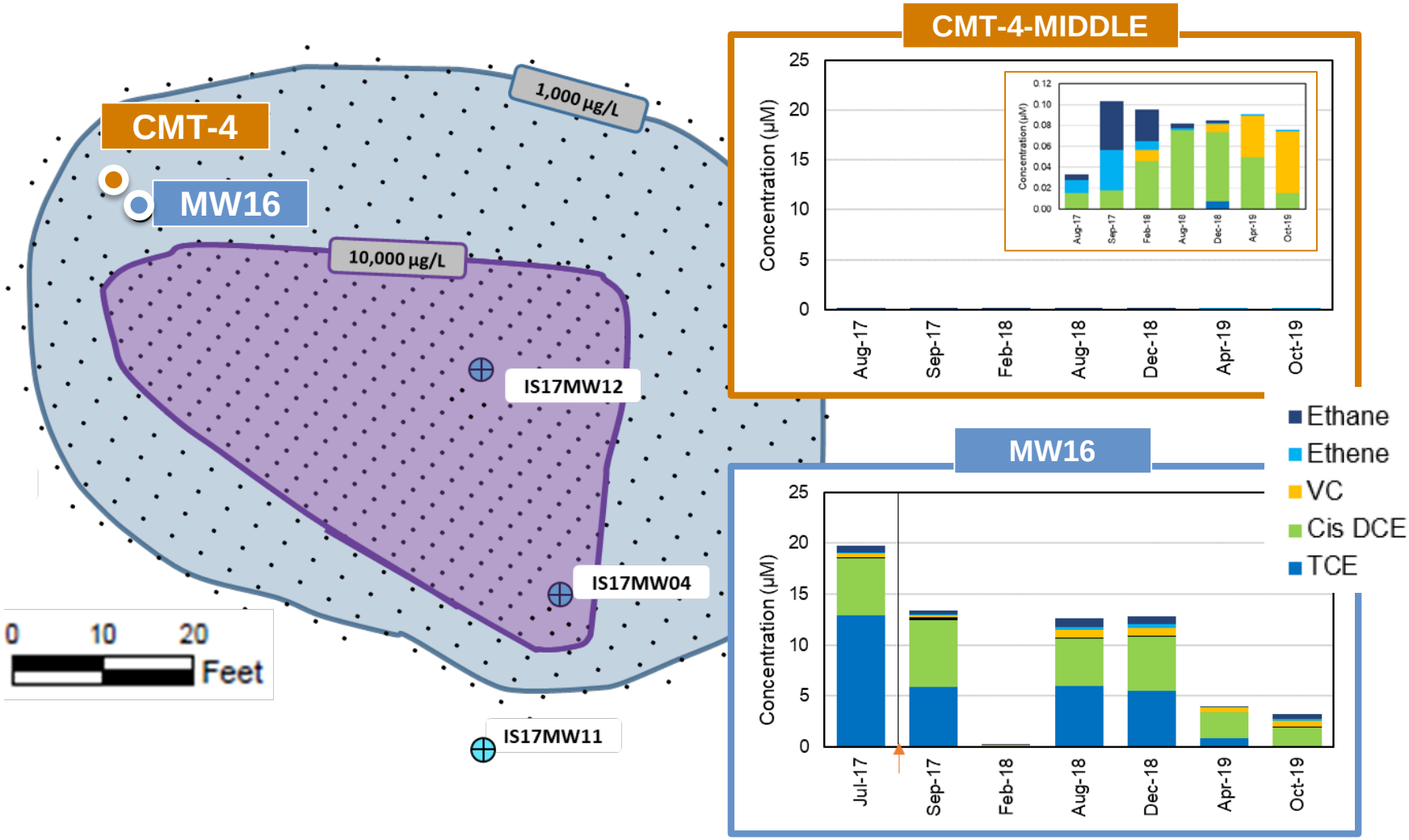
Operational Results

- 800+ reaction columns installed over 7.5 operational days
  - >100 columns/day; maximum of 180
  - 1 column installed every 2-3 minutes during peak operation
- Vegetable oil improved ZVI/sand mix pumpability
- Total emplaced
  - 77,000 pounds of ZVI
  - 650 gallons of vegetable oil
- Installation costs
  - ~$38 / cubic yard including labor, equipment, and materials

Performance Assessment



Performance Assessment



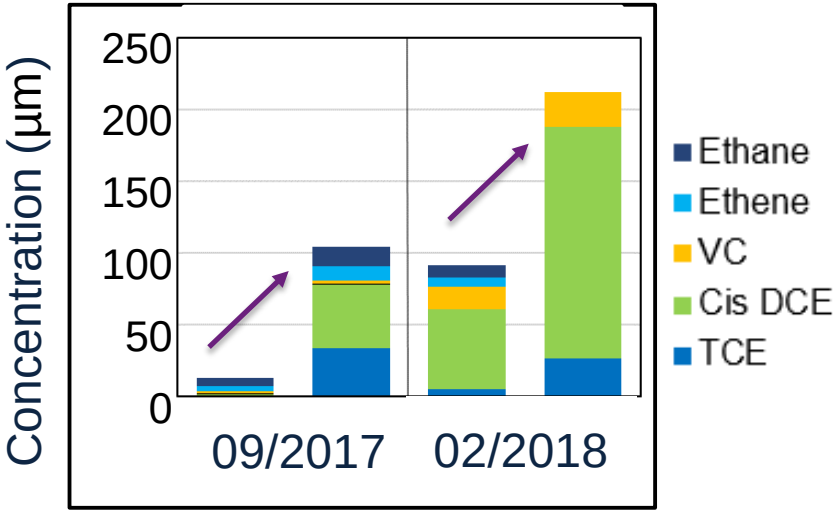
Performance Assessment

Supporting Evidence

Gas Generation

- Soil vapor probes installed within unsaturated zone of two reaction columns
- Higher coupling products detected
- Abiotic TCE degradation via β-elimination pathway

"Duplicate" Sampling

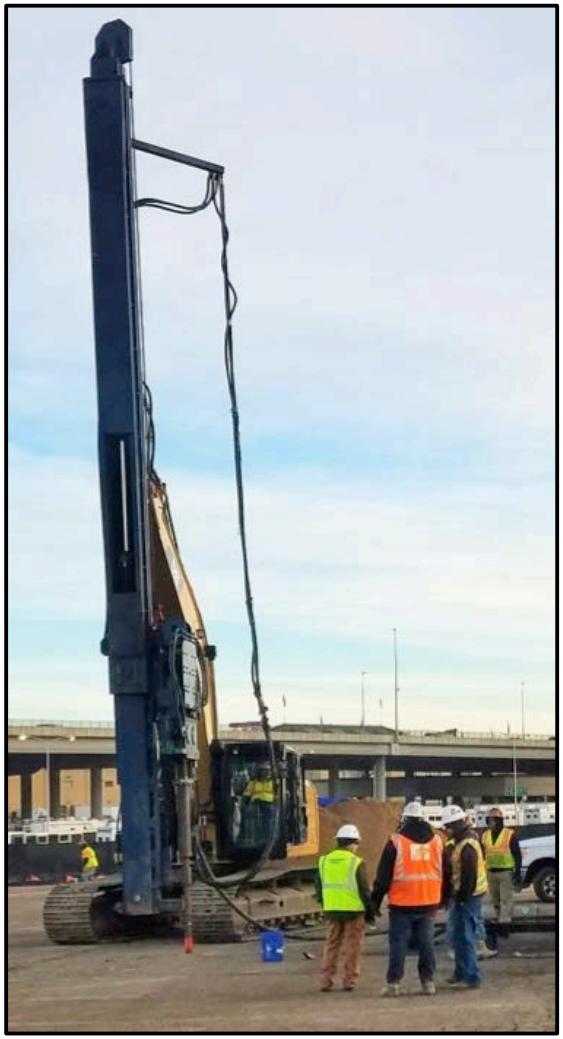


- Pore water in CMTs collected; limited purging prior to sampling
- 2nd sample collected after slow recharge
- Increase in CVOCs observed

Performance Results

- Gradual TCE decrease at monitoring wells
  - Minor fluctuations
- CVOC concentrations at CMTs
  - 10-1,000X lower than accompanying monitoring well
  - Evidence of concentration gradient
- Biotic and abiotic mechanisms
  - Acetylene
  - Increase in cis-1,2-DCE, VC, ethene
  - Production of higher coupling products in gas phase

Operational Considerations



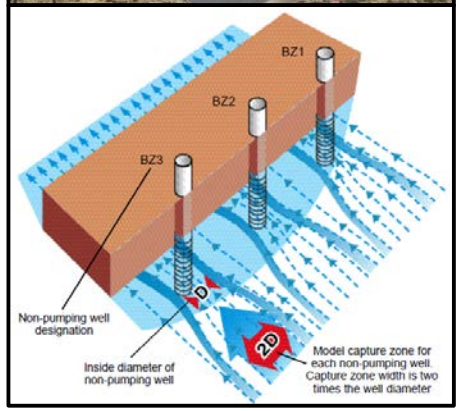
- Bomber requirements
  - Vegetation clearance and surface conditioning
  - Full day for setup
- Mast can achieve depths of 50+ ft bgs
- Appropriate for silts, clays
  - Blow counts < 35
- Potential for different remedial amendment mixtures
- Site must be well-characterized
  - Higher risk for DNAPL source zone
  - Potential for vertical contaminant migration
- Improvements are needed to emplace remedial amendments in target zone

“Take Home” Messages

- 800 reaction columns installed
  - 30-ft depth
- One reaction column every 2 minutes during peak operation
  - < 1 minute for preparation
- Biotic and abiotic degradation product detection
- Low treatment costs
  - ~$38 per cubic yard
- Promising cost-effective alternative for delivery of remedial amendments

Benefits to DoD

- Long-term treatment option for CVOCs
- Treatment option for matrix-diffusion sites
- Suitable for variety of contaminants and remedial amendments
- Other treatment applications
  - Sand columns to enhance aerobic treatment
  - Remedial amendment supply wells (e.g., electrokinetic technology)
  - Passive subsurface reactors
  - Simple permeable reactive barriers



***Sources**: USGS, 1999; DOE, 2001*

Acknowledgements

- Naval Facilities Engineering Command
  - Site 17 personnel and contractors
- Project team
  - GSI: Dylan Hart, Justin Long, Mike Schofield, Charles Newell
  - Hayward Baker: Josh Kolz (Reaction Column Installation)
  - Aestus: Stuart McDonald and Todd Halihan (Geophysics)
  - Rice University Design Kitchen

For additional information, please visit

https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-201627

Speaker Contact Information

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Q&A Session 1

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The Horizontal Reactive Media Treatment Well (HRX Well®): A New Technology for In-Situ Remediation

Craig Divine, Ph.D., P.G.
Arcadis

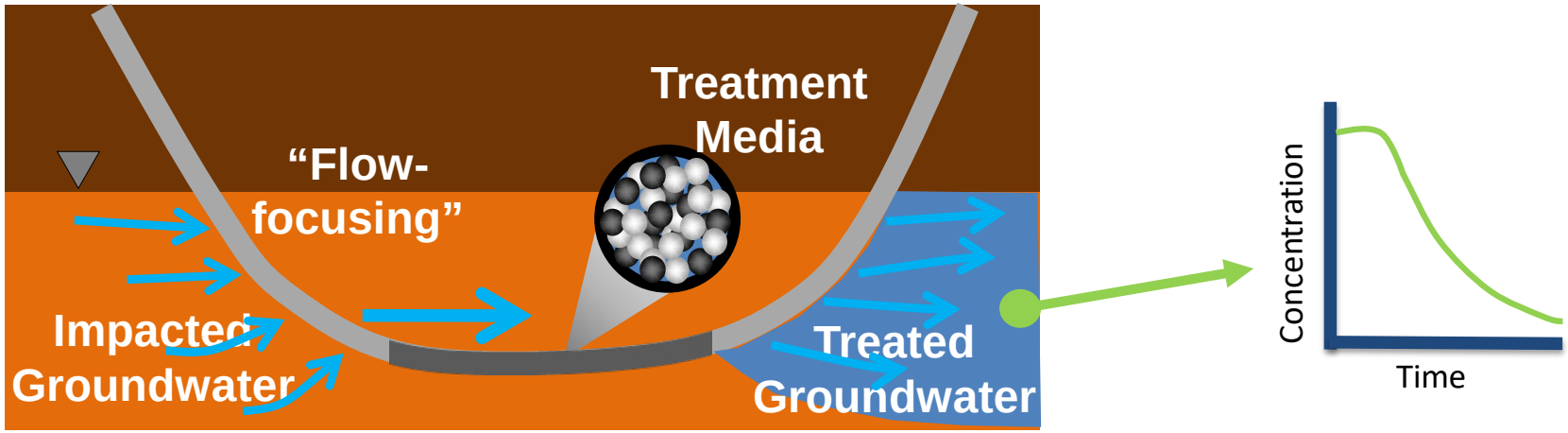
SERDP DOD • EPA • DOE | ESTCP

Agenda

- HRX Well® concept
- Field demonstration site
- Treatability testing and HRX Well® design
- Installation and performance data
- Conclusions

HRX Well® Description

The HRX Well® is a large-diameter horizontal well installed along the groundwater flowpath that is filled with reactive or other treatment media*



- Many solid-phase reactive media options
- Efficient use of reactive media
- Treatment train approach possible
- Not limited to high-permeability aquifers
- Can be applied in relatively deep settings
- Limited above-ground footprint
- Minimal O&M and energy requirements
- Pumping can enhance treatment zone size

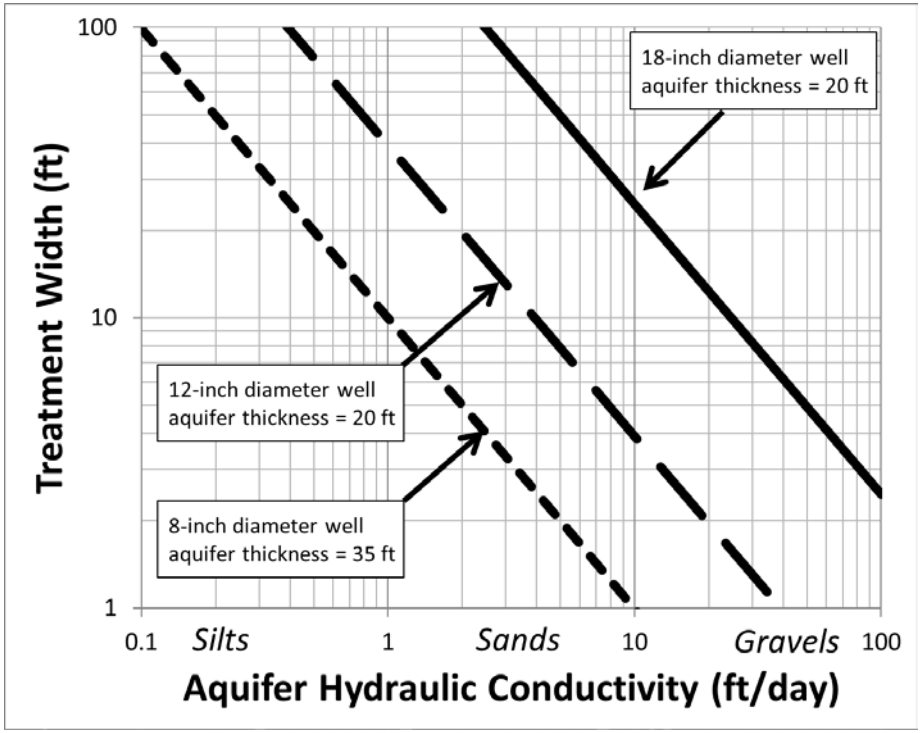
**Patent US20120261125A1*

Calculated Treatment Width

$$w_{treatment} = \frac{K_{HRX} A_{HRX} i_{HRX}}{K_A \; b_A \; i_A}$$

$w_{treatment}$	HRX Well® treatment zone width
K_{HRX}	Hydraulic conductivity of HRX Well®
A_{HRX}	x-sectional area of HRX Well®
i_{HRX}	Hydraulic gradient in HRX Well®
K_A	Hydraulic conductivity of aquifer
b_A	Aquifer thickness
i_A	Aquifer hydraulic gradient

Treatment Widths For Various Conditions



Assumes K_{HRX} = 1,000 ft/d

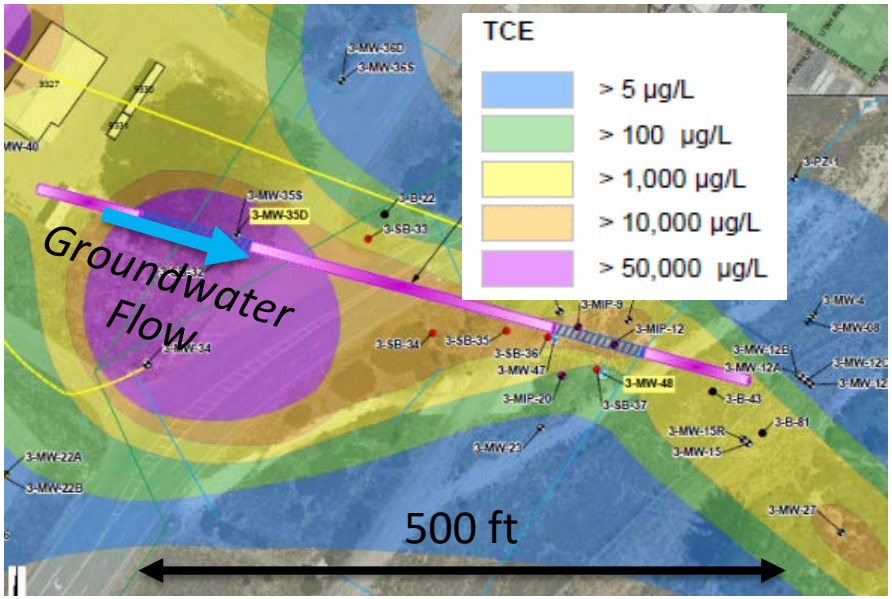
- For passive configurations, $w_{treatment}$ >50 ft may be feasible
- Larger treatment zones are possible with pumping

Potential Reactive Media and Contaminants

Reactive Media	Potential Target Groundwater Contaminants
Zero valent iron (ZVI) Bimetallics (e.g., ZVI + Pd, Pt, or Ni)	Chlorinated solvents (CVOCs), nitrate, perchlorate, energetics, chromium, arsenic
Granulated activated carbon (GAC), organosilicates	CVOCs, poly- and perfluoroalkyl substances (PFAS), hydrocarbons, halomethanes
Sustained release oxidants	CVOCs, 1,4-dioxane, hydrocarbons, polyaromatic hydrocarbons (PAHs), phenolic compounds
Biodegradable particulate organic carbon (e.g., mulch)	CVOCs, nitrate, perchlorate, energetics
Ion exchange resins	PFAS, brines
Phosphates (e.g., apatite)	Lead, uranium, other metals and radionuclides
Limestone, lime, magnesium oxide	Low pH, Acid rock drainage
Barium sulfate (barite)	Radium
Iron sulfide	Chromium, High pH
Zeolites	Ammonium, radionuclides, PFAS

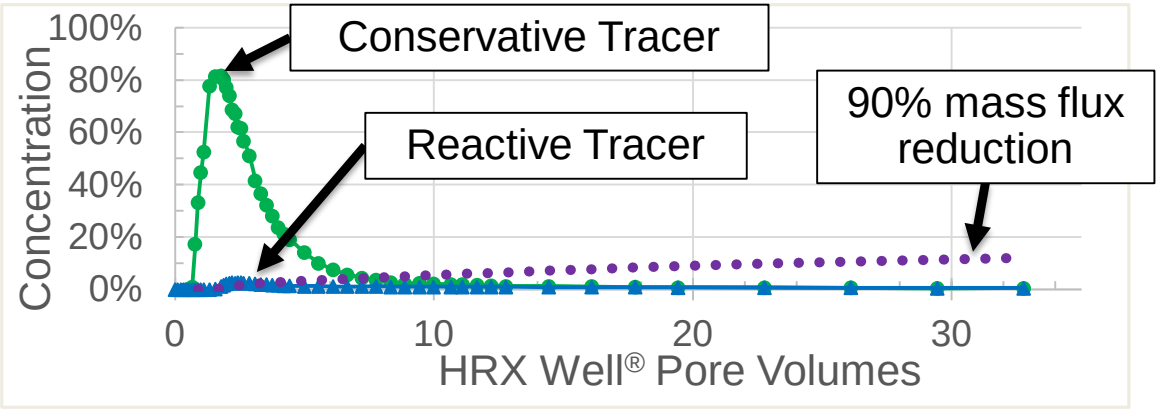
Field Demonstration Site

- Vandenberg Air Force Base (VAFB), CA
- Average aquifer thickness: 8 ft
- Depth: 20-22 ft
- Hydraulic conductivity: 0.1-0.5 ft/day
- Low hydraulic gradient: <0.001
- Average groundwater velocity: <0.1 ft/day
- Trichloroethene (TCE): 1 to 40 mg/L

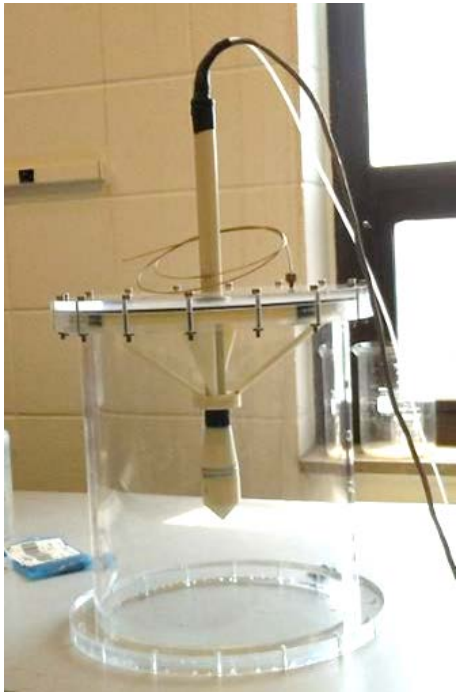


Treatability Testing

Columns Tests of Iron Types



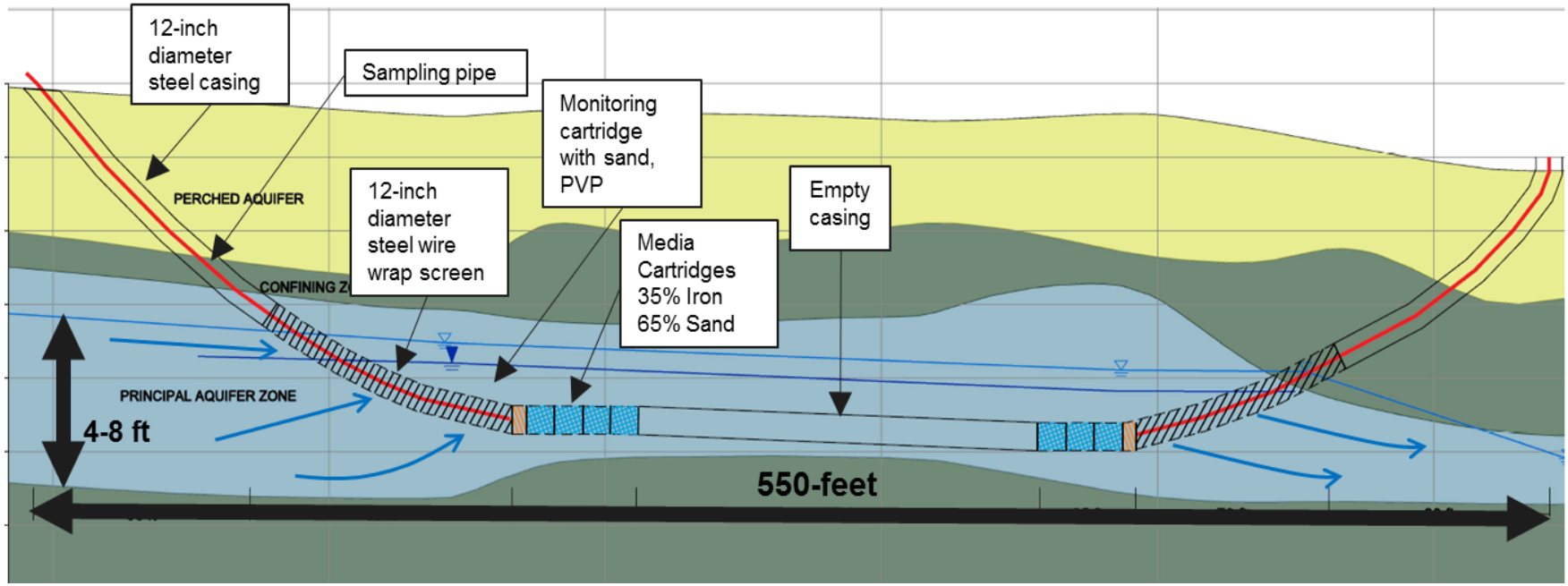
Laboratory HRX Well® Tracer Test Results



Redesigned Point Velocity Probe (PVP)

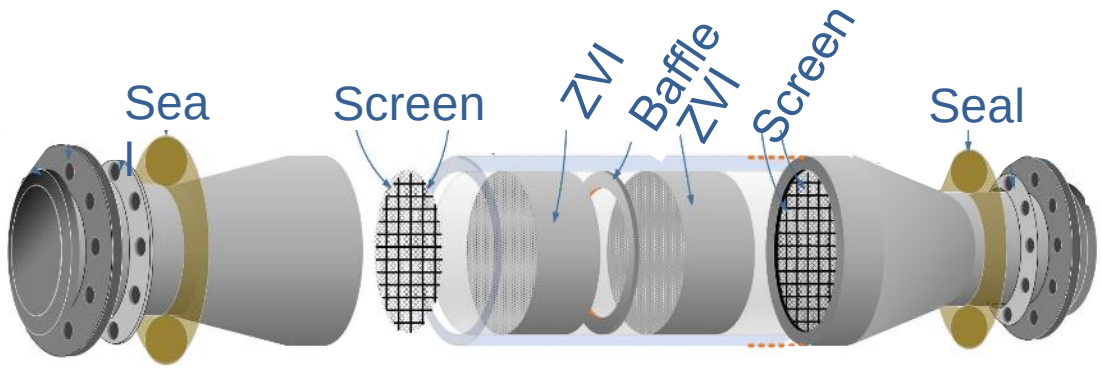
- No losses in permeability or reactivity (>1000 pore volumes)
- PVPs accurately measure in-well velocities
- Tests validate hydraulics and numerical model

Field HRX Well® Design



- Length: 550 ft; Depth: 20 ft; Diameter: 12-in
- Target treatment zone width: 40-50 ft
- Inlet and outlet PVPs to measure in-well flow
- Target residence time: 6-20 days in ZVI (35%, 70 ft), ~100 days total
- Reactive media usage: 0.7 m^3 ZVI (1,390 lbs ZVI)

Treatment Media Cartridges*

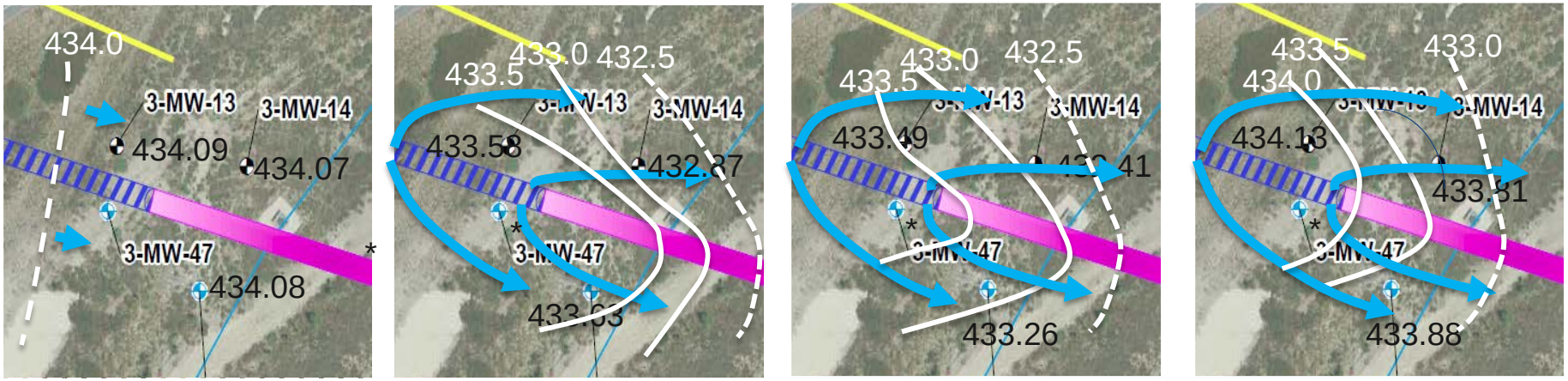


*Patent Pending

HRX Field Installation

Performance Data

Groundwater Elevations

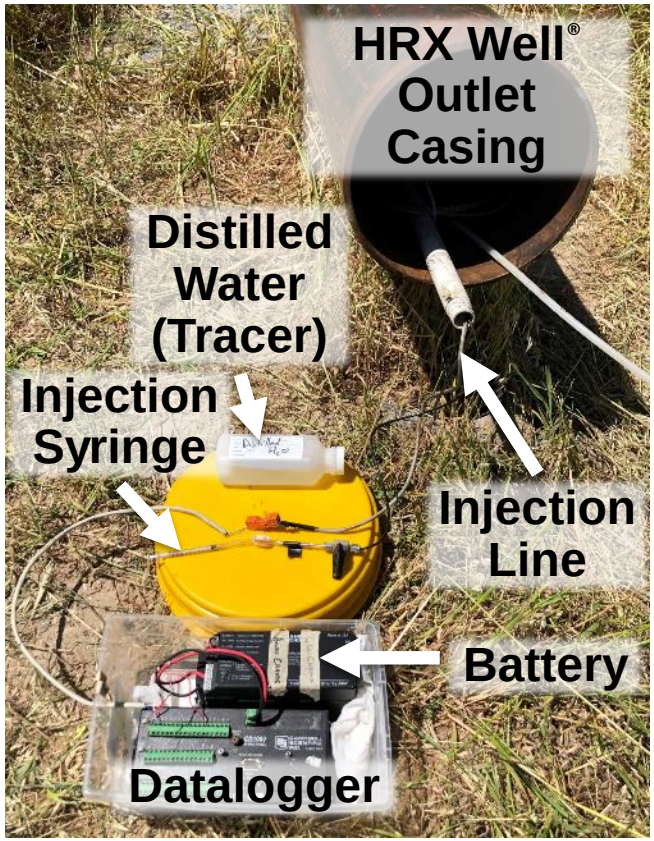


Pre-HRX Well | 134 days | 175 days | 250 days

- Gradient increased ~40x, consistent with model predictions
- Flow field clearly shows discharge from HRX Well®

Performance Data

In-Well Flow

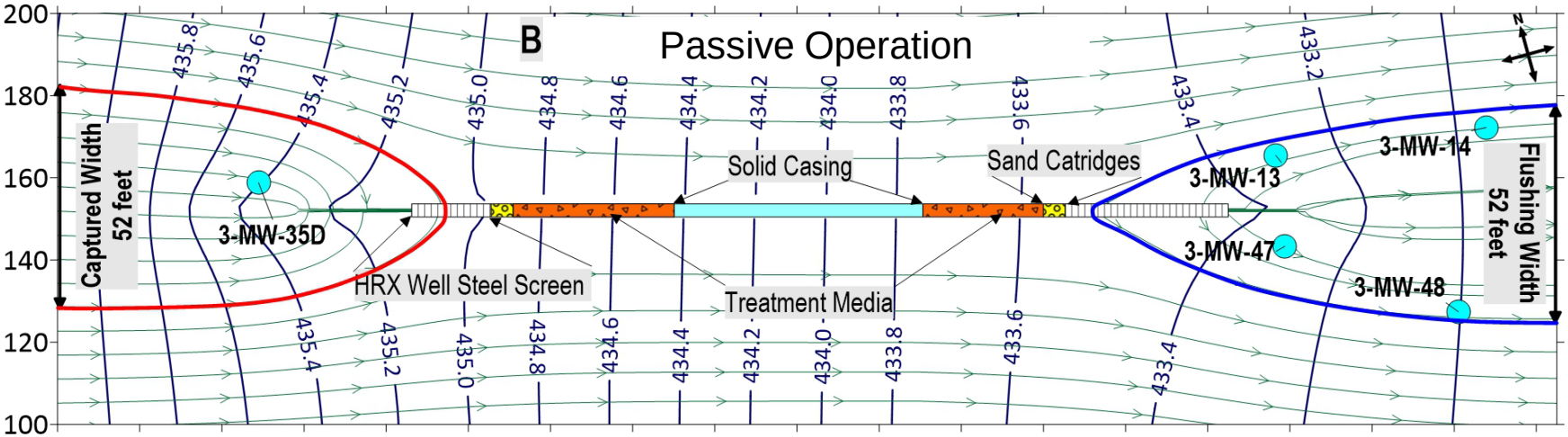


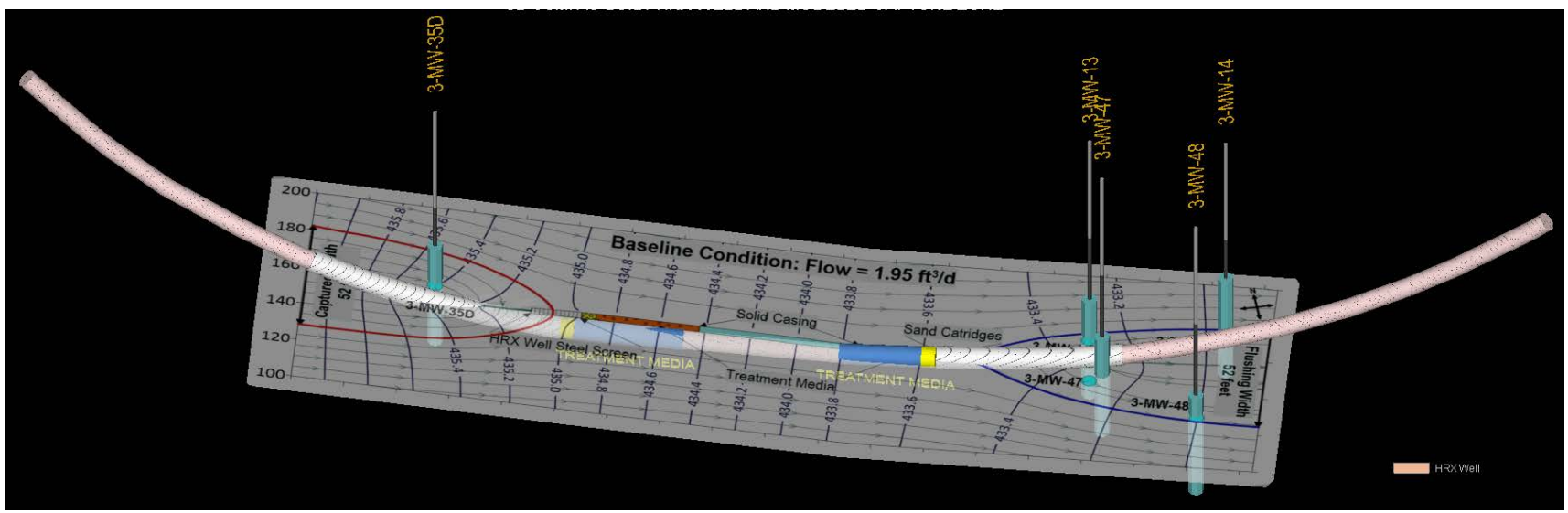
PVP Testing Equipment

- Velocity in HRX Well® = ~9.6 ft/day
  - Design Model: 7.6 ft/day
  - Velocity in aquifer: <0.1 ft/day
- Flow in HRX Well® = ~1.7 ft3/d, 100x ambient flow
- ~9 day residence time in ZVI, consistent with design model

Model-Calculated Treatment Zone

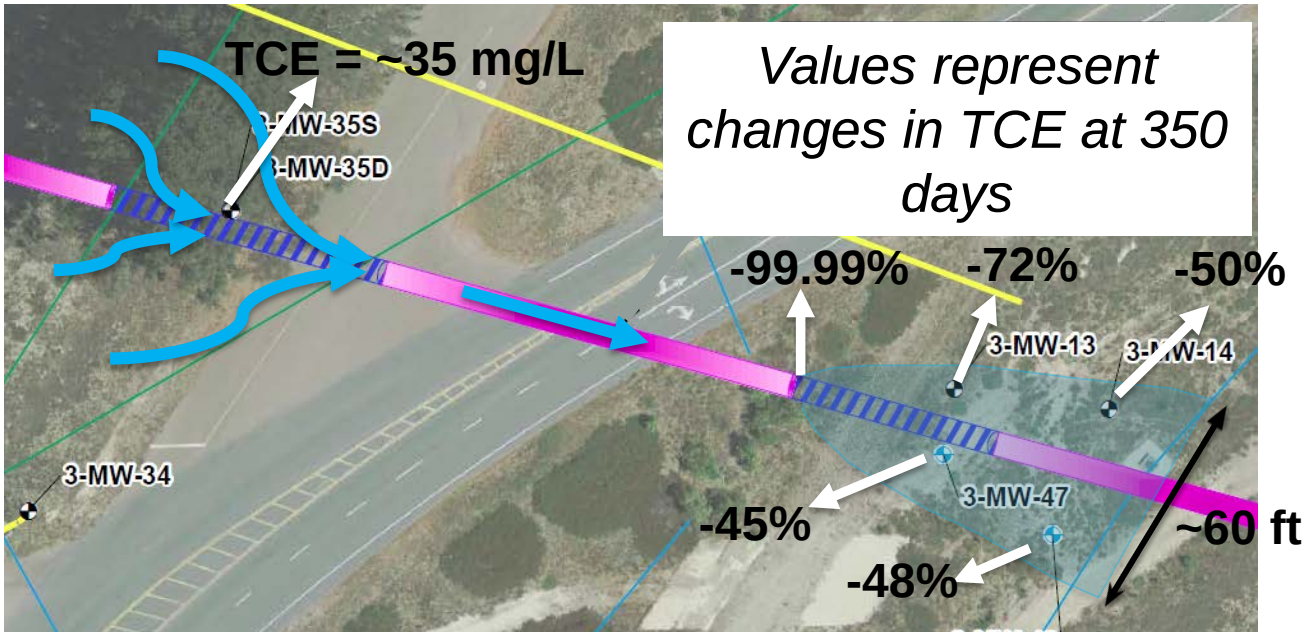
Passive Operation





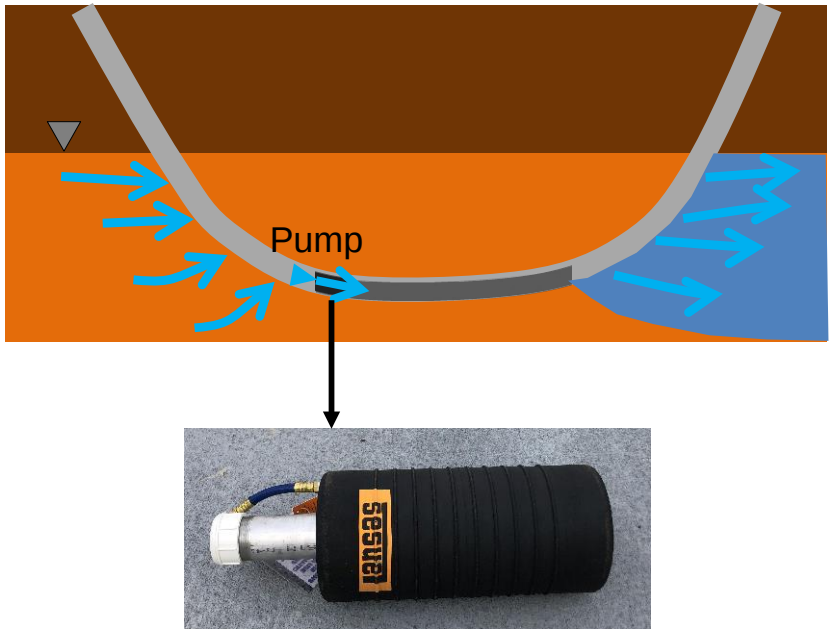
Performance Data

Concentrations



- 99.99% TCE treatment at outlet
- Mass discharge reduction ~1.7 g/day (~850 g treated to date)
- Treatment within 150 days at wells, consistent with model
- At 350 days, average TCE treatment in wells = 54%
- Residual drilling fluid promoting biodegradation

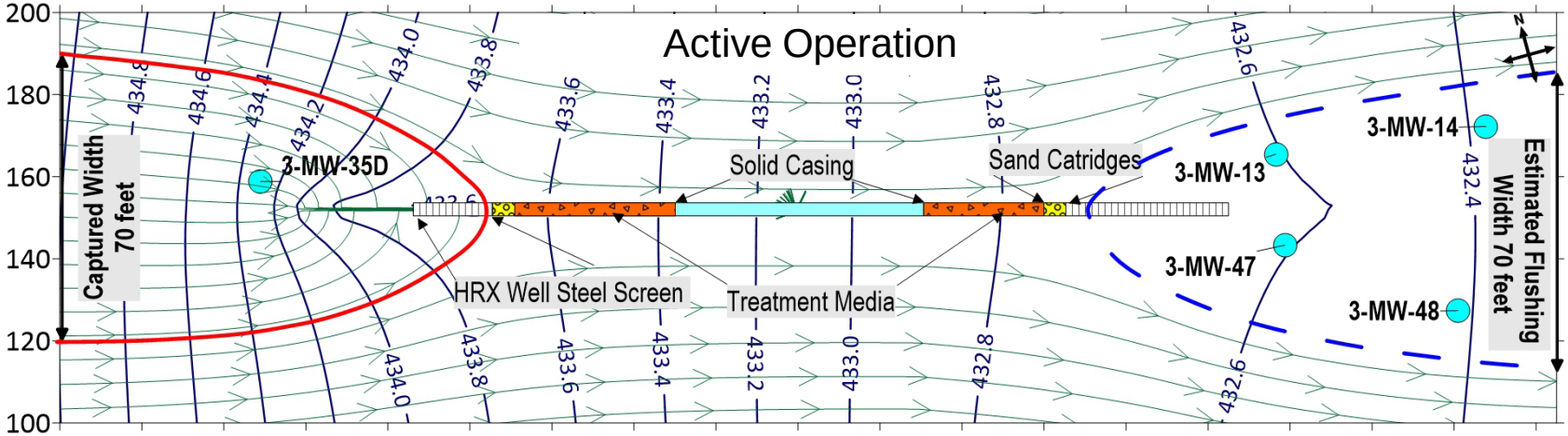
Pumping-Enhanced Capture

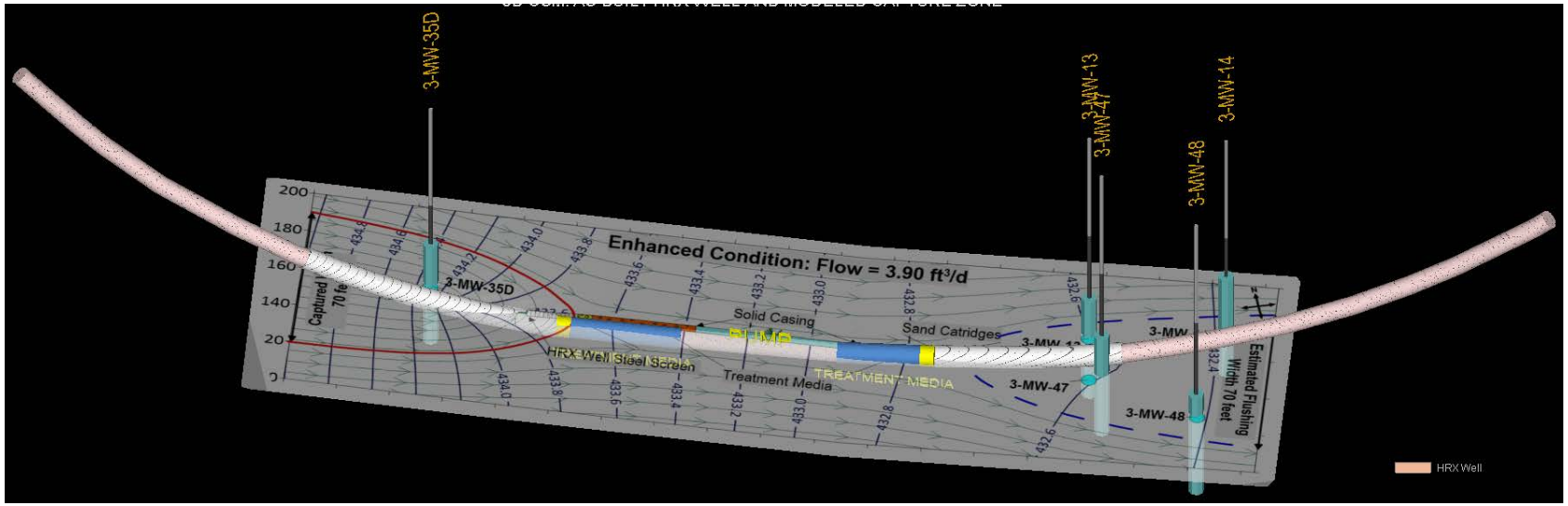


- Temporary packer and pump installed to enhance flow
- In-well flows increased ~2x
- Drawdown data used to further calibrate model

Model-Calculated Treatment Zone

Active (Pumping) Operation





Alternatives Analysis

Criterion	Alternative #1 HRX Well®	Alternative #2 Groundwater Extraction and Treatment System	Alternative #3 Funnel and Gate PRB
Overall protection of human health and environment	Yes	Yes	Yes
Effectiveness and permanence	Moderate to High	Moderate	Moderate to High
Reductions in toxicity, mobility, and volume through treatment	Moderate to High	Moderate	Moderate to High
Implementability	Moderate	Moderate	Moderate
Sustainability	High	Low to Moderate	Moderate to High
Lifecycle Cost*	Low to Moderate $2.6 - 3.4M	High $3.8 - 4.7M	Moderate $3.6 - 4.5M

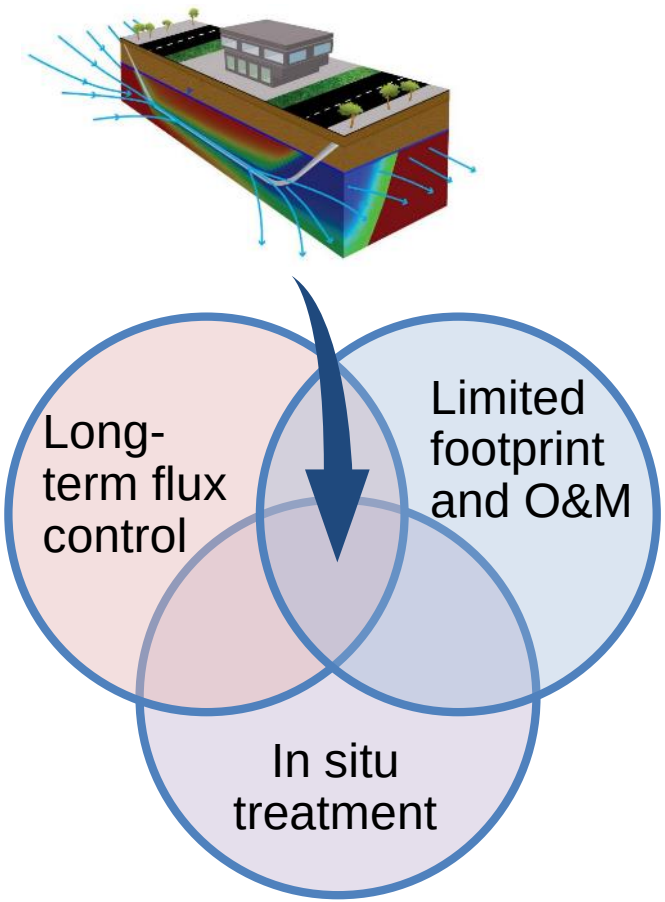
**Full-scale costs assume three HRX Wells®*

Conclusions

- Flow focusing hydraulics verified
- >50ft treatment width under passive operation
- Near-immediate >95% contaminant flux reduction
- All performance wells exhibit treatment
- Cartridge removal/replacement straightforward
- Capture can be enhanced by pumping
- Expands applicability for high-permeability sites

Benefits to DoD

- Ideally suited for long-term mass flux/discharge control
- Limited footprint, energy, water, and O&M requirements
- In situ treatment with no groundwater management
- Efficient media usage and many options applicable to challenging contaminants
- Favorable lifecycle costs



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For additional information, please visit

https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-201631

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Q&A Session 2

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The next webinar is on January 23, 2020

Battery Storage Resiliency Results from Installation Microgrid Simulations and Opportunities for Field Demonstration

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Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

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