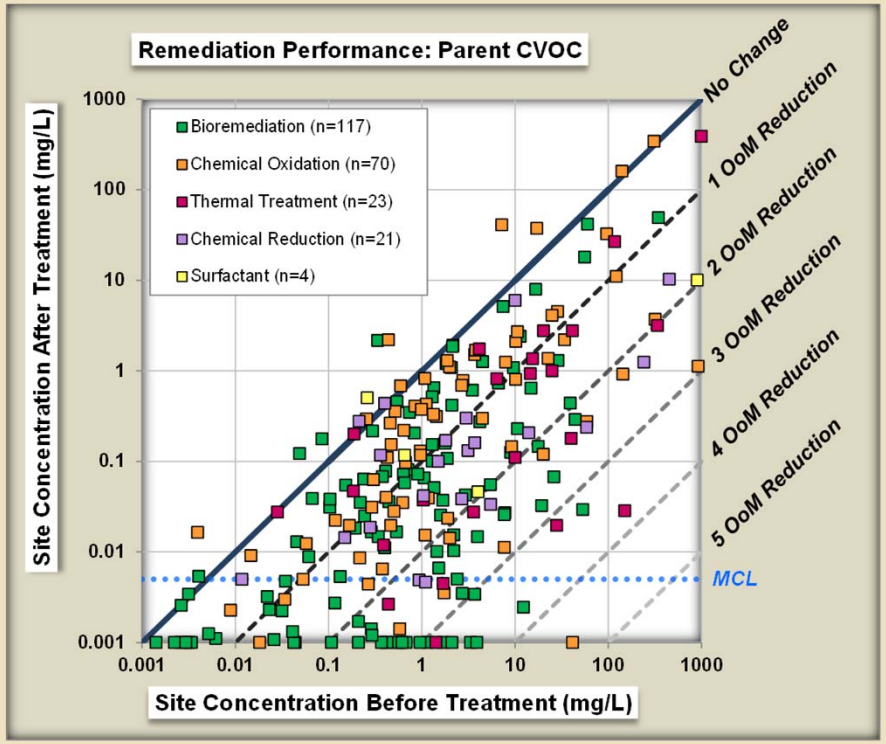
ADVANCES IN AMENDMENTS FOR REMEDIATION:
Where Are We Making Progress?
State of the Practice

David Adamson
GSI Environmental Inc., Houston, Texas

PROBLEM: *Room for Improvement Based on Observed Remediation Performance*



KEY COLLABORATORS:

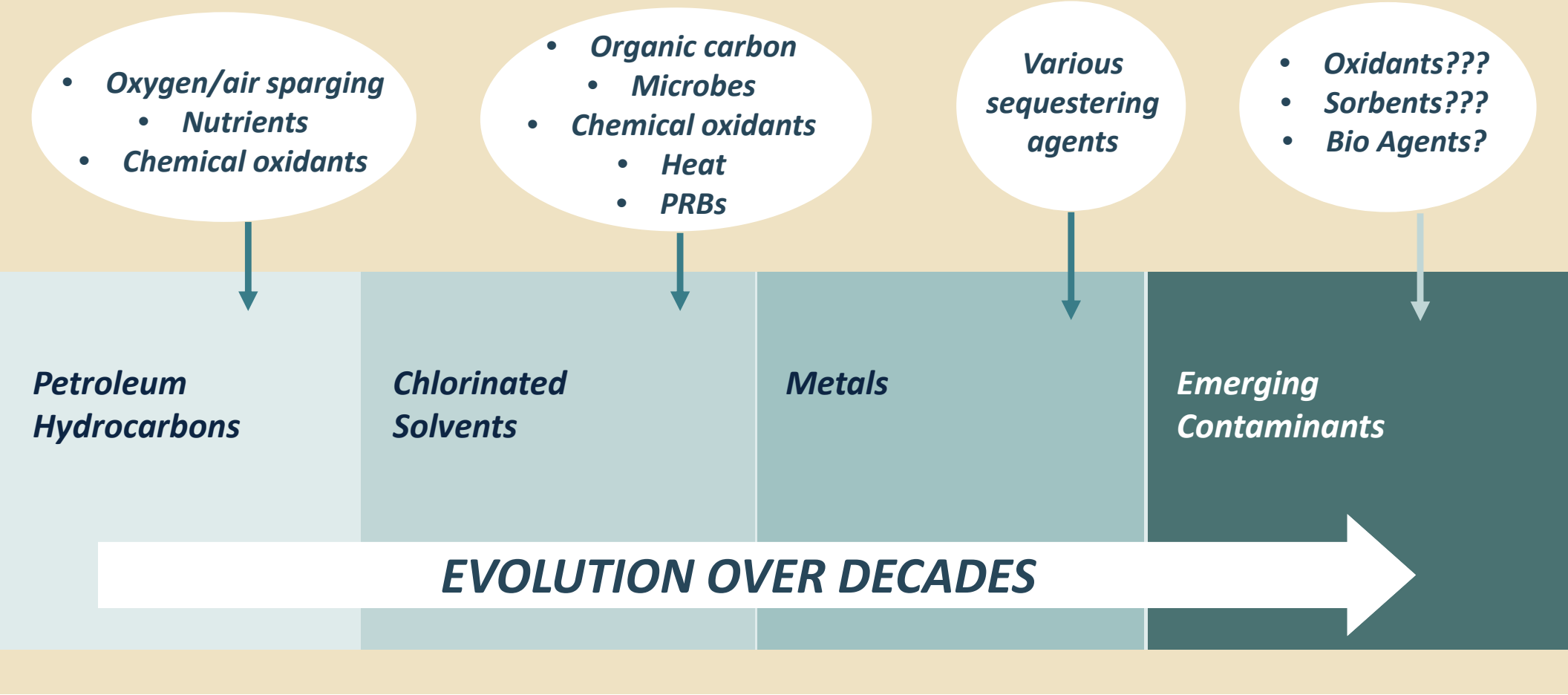
Dr. Charles Newell
Poonam Kulkarni
Travis McGuire
Dr. Stephen Richardson

GSI Environmental Inc.

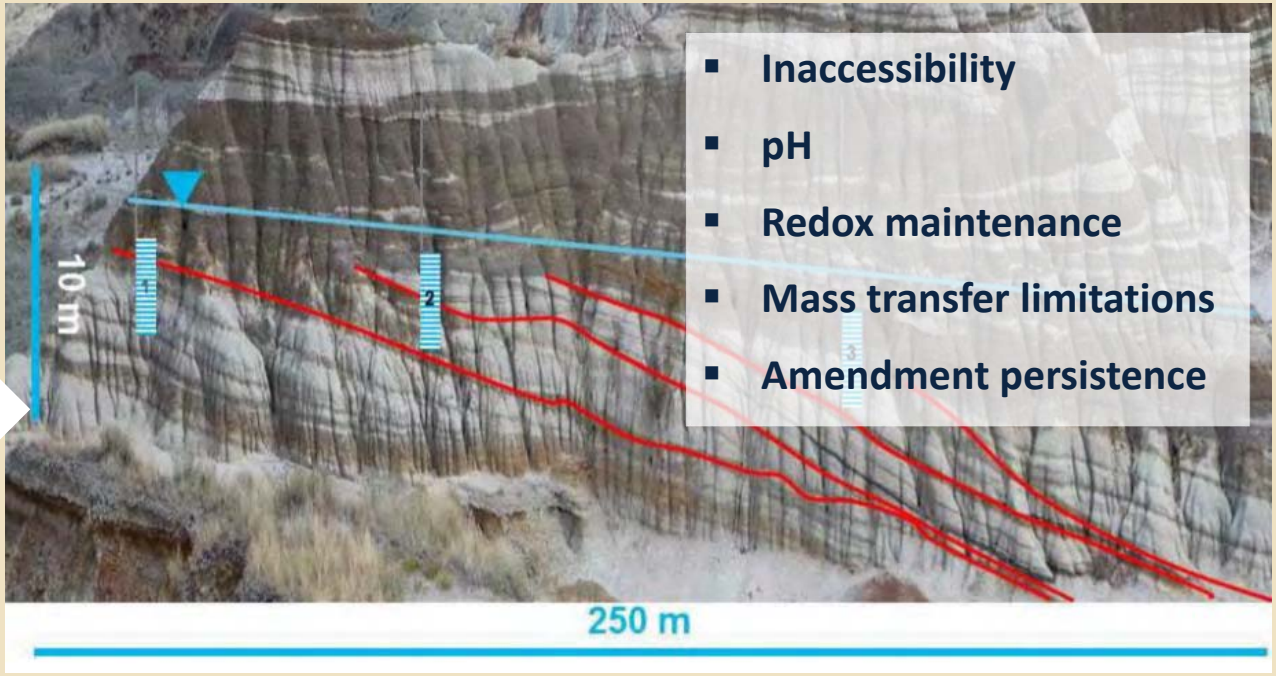
Survey of 235 sites from ESTCP ER-201120 report (2017), Travis McGuire PI

KEY POINT: ***Not just a chemistry problem looking for a solution. Requires engineered solution that acknowledges geologic complexity.***

KEY QUESTION: *Do we have the right amendments?*



BASIC CHALLENGES

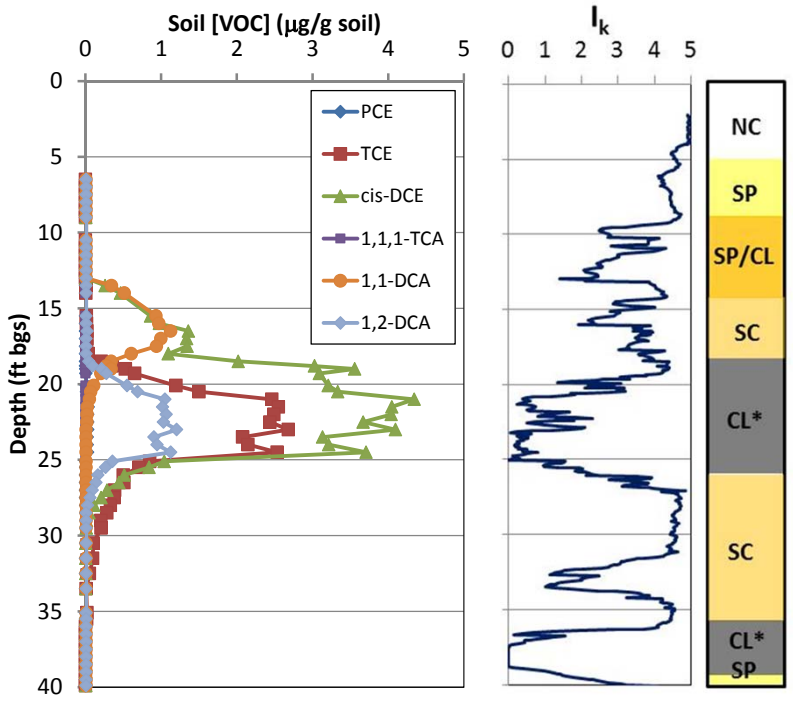


- Inaccessibility
- pH
- Redox maintenance
- Mass transfer limitations
- Amendment persistence

from USEPA, 2017

BETTER CHARACTERIZATION = BETTER DESIGN BASIS

Example of "back diffusion" concentration profile from NAS Jacksonville OU3



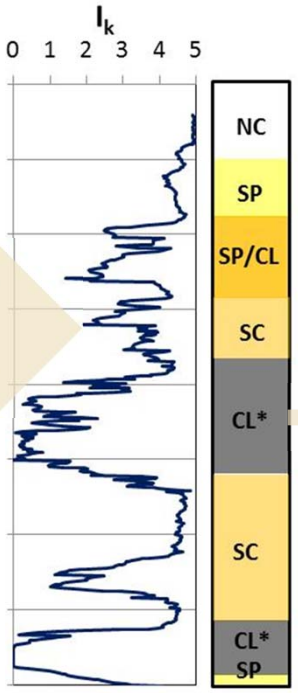
from Adamson et al., GWMR, 2015

LOTS OF AVAILABLE OPTIONS

- **MIP**
- **HPT**
- **MiHpt**
- **HPT-GW Sampler**
- **Waterloo APS**
- **High-resolution soil sub-sampling**
- **DyeLIF**
- **Focused tracer tests**
- **Geophysical tools**

BETTER CHARACTERIZATION = BETTER DESIGN BASIS

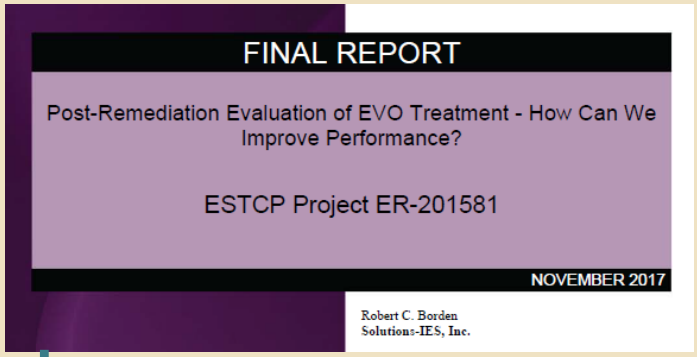
High-k zones:
small cross-sectional area may represent majority of mass discharge



Low-k zones:
much harder to access with amendments and contributes to long-term persistence

KEY POINT:
Remedy selection and amendment design are highly dependent on understanding how heterogeneity influences contaminant distribution

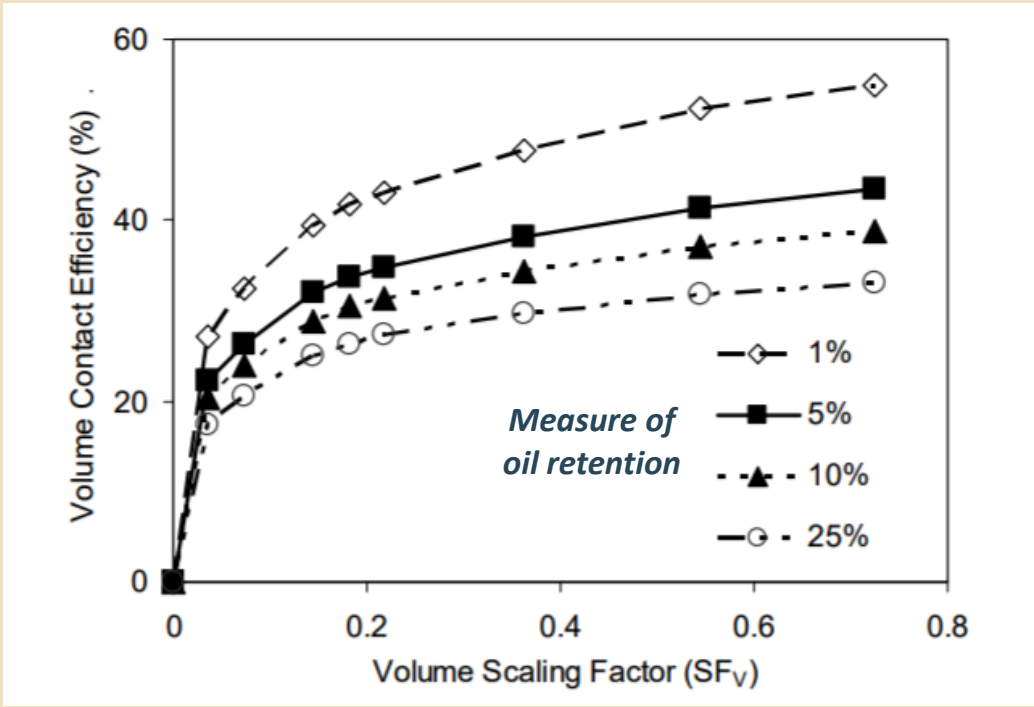
1 IMPROVED INJECTION OF BIO AMENDMENTS:
Primary focus = High-k zones



LOTS OF LESSONS

- **High injection volumes are critical for distribution**
- **Retention of less soluble amendments may be higher than anticipated**
- **Sequenced injections (rather than simultaneous) may reduce stagnation zones**
- **Importance of recirculation**

From ESTCP ER-0626 Project Report (2008)

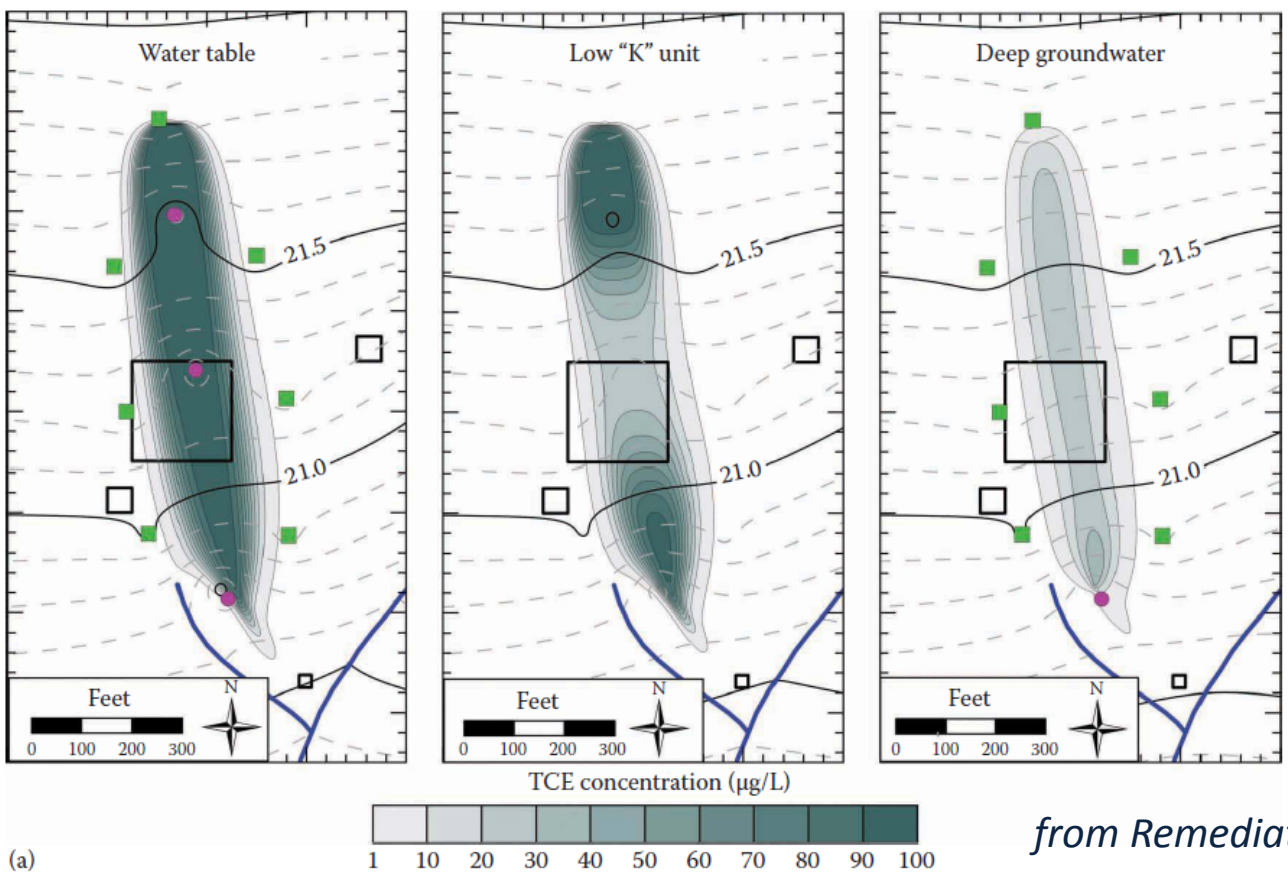


INCREASED CONTACT

INCREASED VOLUME

2 DYNAMIC GROUNDWATER RECIRCULATION (DGR):
Primary focus = High-k + Low-k zones

Before implementing DGR



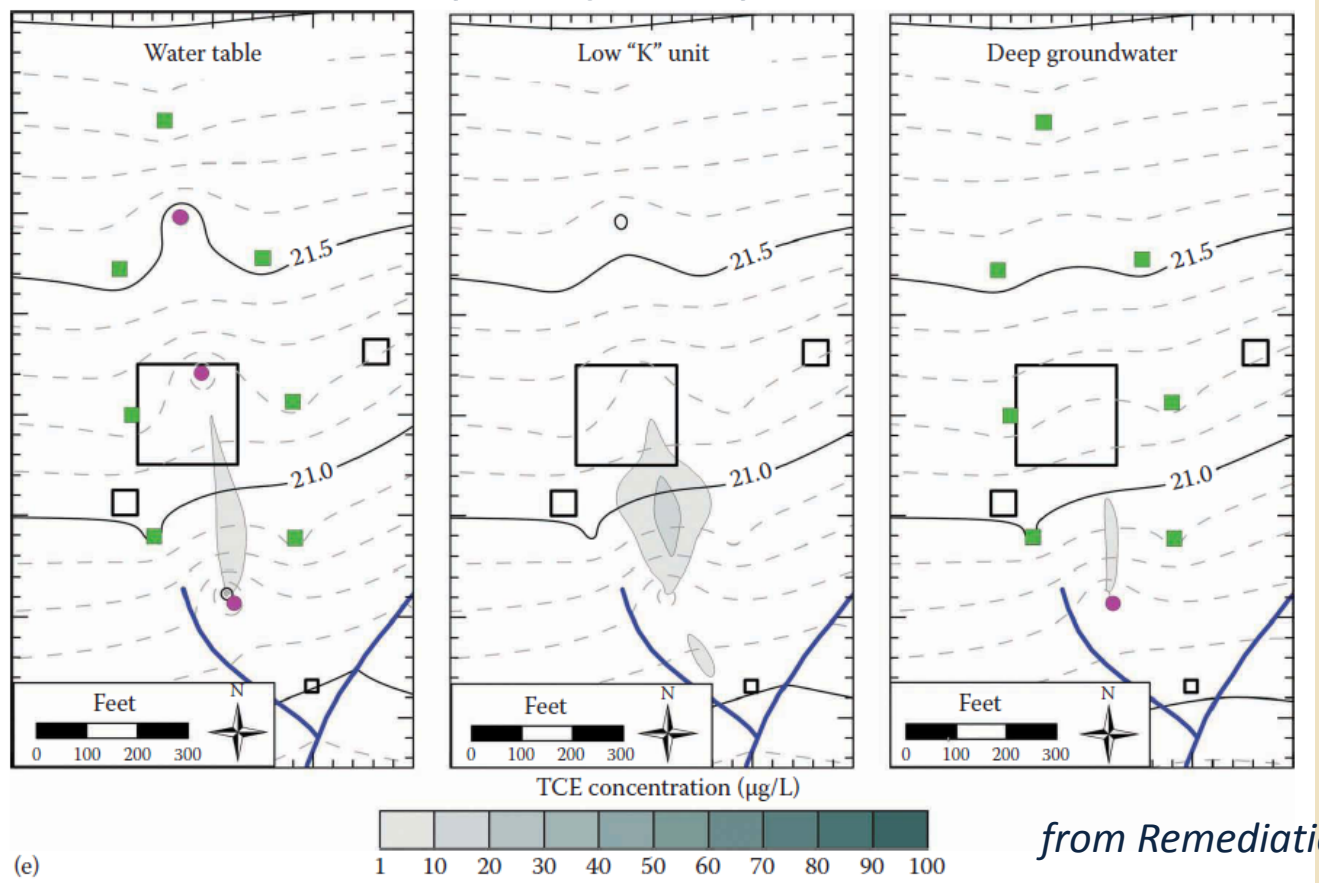
- **Increase groundwater flow rate using multiple extraction wells (along plume spine) coupled with injection at even more wells along plume edges**
- **Can use unbalanced flows to create vertical gradients that help flush out low-k zones**
- **Well network provides operational flexibility over time**

ARCADIS

from Remediation Engineering, Suthersan et al. (2017)

2 DYNAMIC GROUNDWATER RECIRCULATION (DGR):
Primary focus = High-k + Low-k zones

After 9 years of DGR

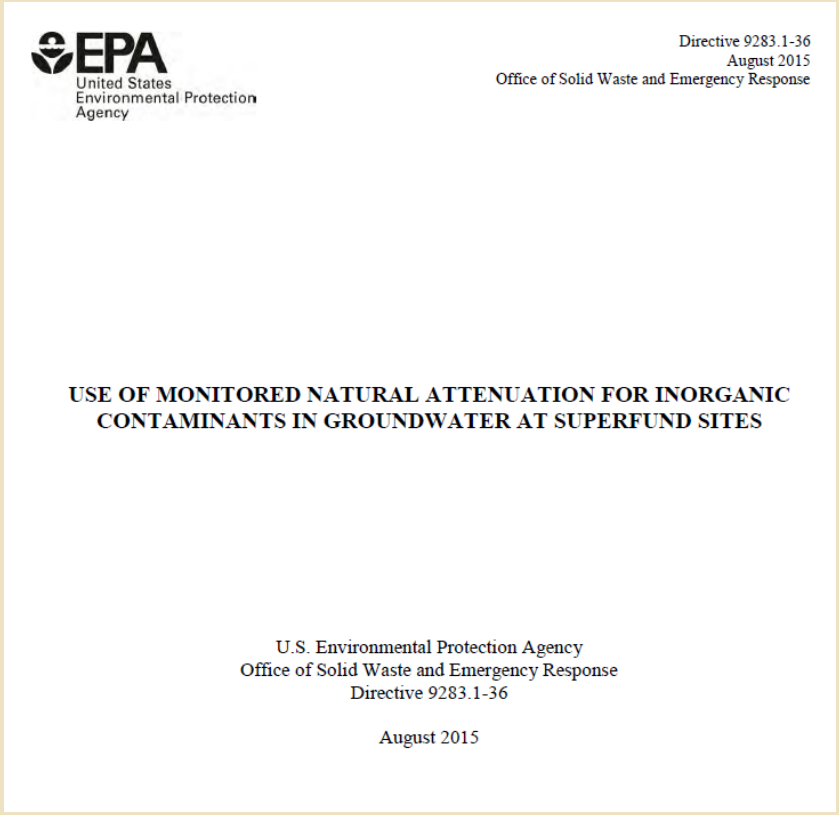


KEY POINT:
Water can be an effective "amendment" too

ARCADIS

from Remediation Engineering, Suthersan et al. (2017)

3 IN SITU BIOGEOCHEMICAL TRANSFORMATION AND SEQUESTRATION: *Primary focus = High-k zones*



EPA United States Environmental Protection Agency

Directive 9283.1-36
August 2015
Office of Solid Waste and Emergency Response

USE OF MONITORED NATURAL ATTENUATION FOR INORGANIC CONTAMINANTS IN GROUNDWATER AT SUPERFUND SITES

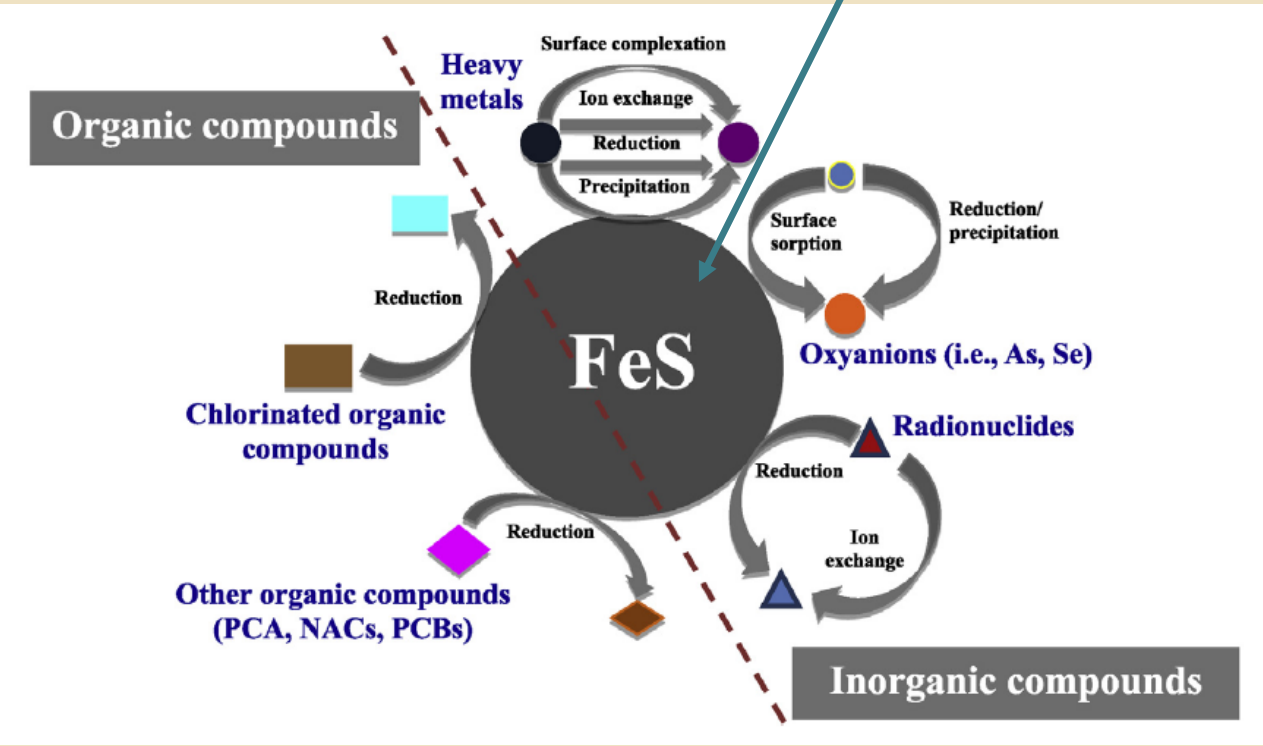
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Directive 9283.1-36

August 2015

- **Builds off naturally-occurring processes**

3 IN SITU BIOGEOCHEMICAL TRANSFORMATION AND SEQUESTRATION: *Primary focus = High-k zones*

OPTION 1: Add mineral directly (slurry, mixture w/ other amendments, polymer-stabilized nanoparticles)

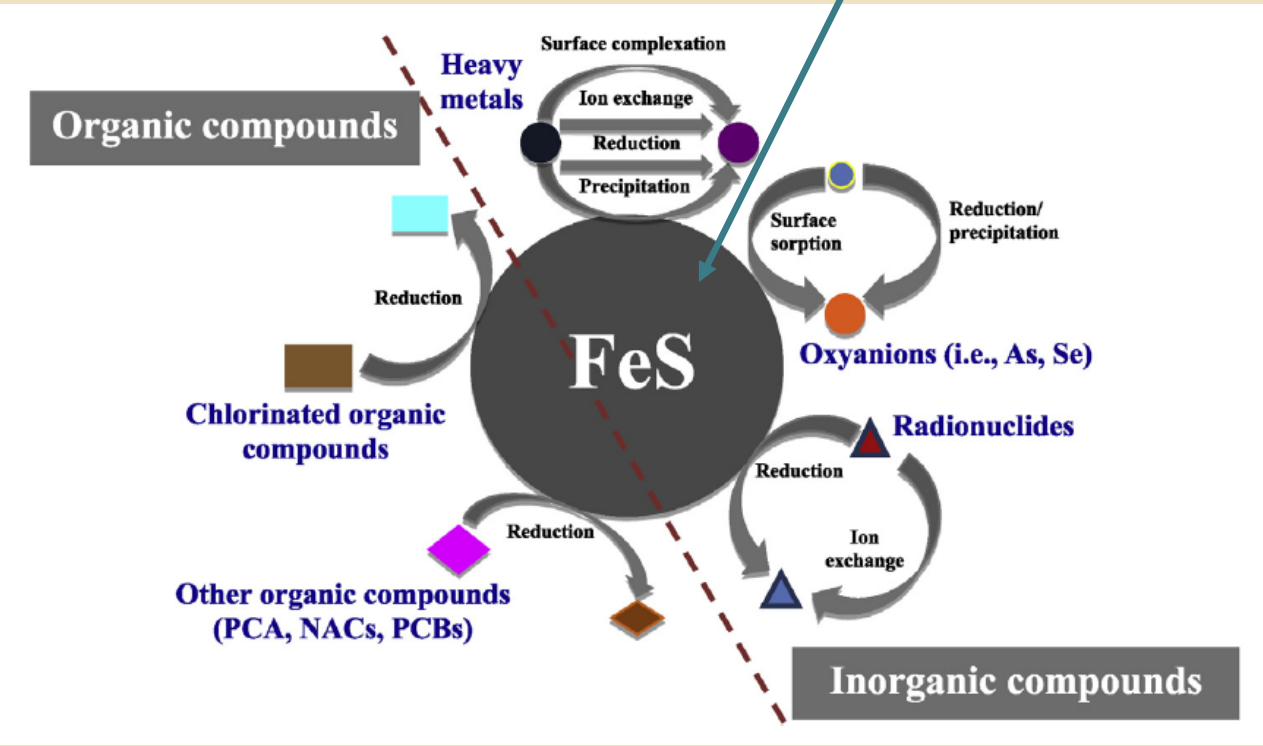


from Gong et al., Water Research, 2016

- **Builds off naturally-occurring processes**
- **Use conventional amendments or commercial products to manipulate pH and/or promote co-precipitation and other targeted (redox-sensitive) reactions**
- **Effective for Metals: As, Pb, Cd, Ni, Cu, Se, Hg…**

3 IN SITU BIOGEOCHEMICAL TRANSFORMATION AND SEQUESTRATION: *Primary focus = High-k zones*

OPTION 2: Add carbon, iron, or sulfate to promote in situ generation of mineral and co-precipitation



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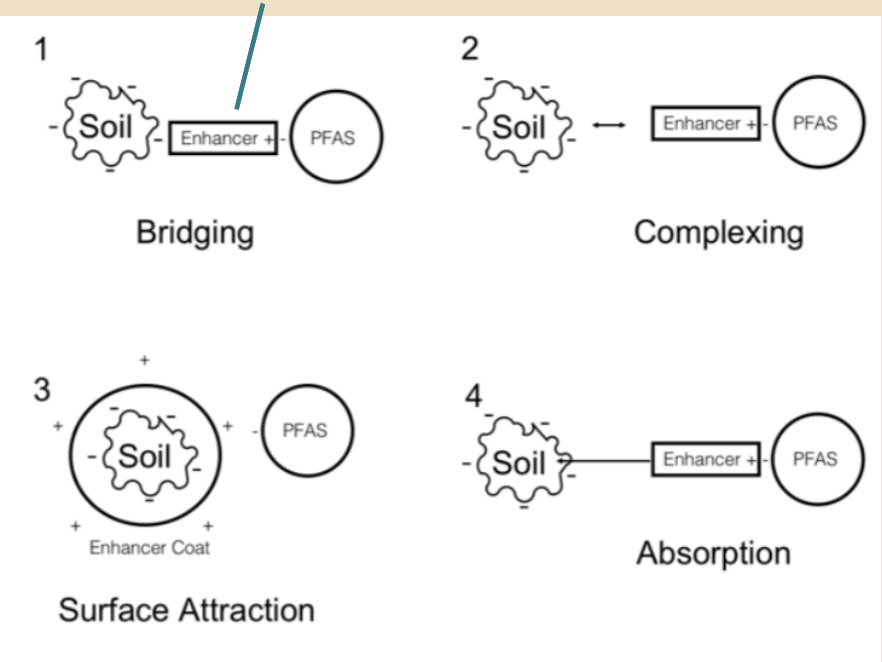
4 IN SITU SEQUESTRATION OF PFAS

Primary focus = High-k zones

- **Better sorption of PFAS is goal of lots of research and product development**
- **Most focus on ex situ applications but a few are looking at in situ applications with long-term sequestration**

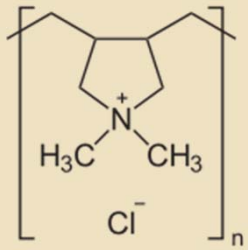
4 IN SITU SEQUESTRATION OF PFAS
Primary focus = High-k zones

Cationic polymer (e.g., PDM)



from Aly, U. of Minn. MS Thesis, 2016

- **Better sorption of PFAS is goal of lots of research and product development**
- **Most focus on ex situ applications but a few are looking at in situ applications with long-term sequestration**
- **Option: create suspension of cationic polymer plus powdered activated carbon – stable and easy to inject (but questions remain about distribution)**



Polydiallyldimethylammonium chloride (PDM)

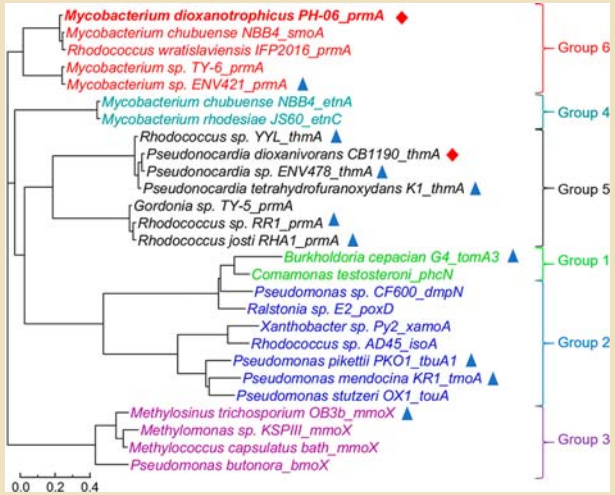
Also see:

Coagulant-enhanced Sorption for In Situ Remediation of PFAS Contaminated Groundwater Systems

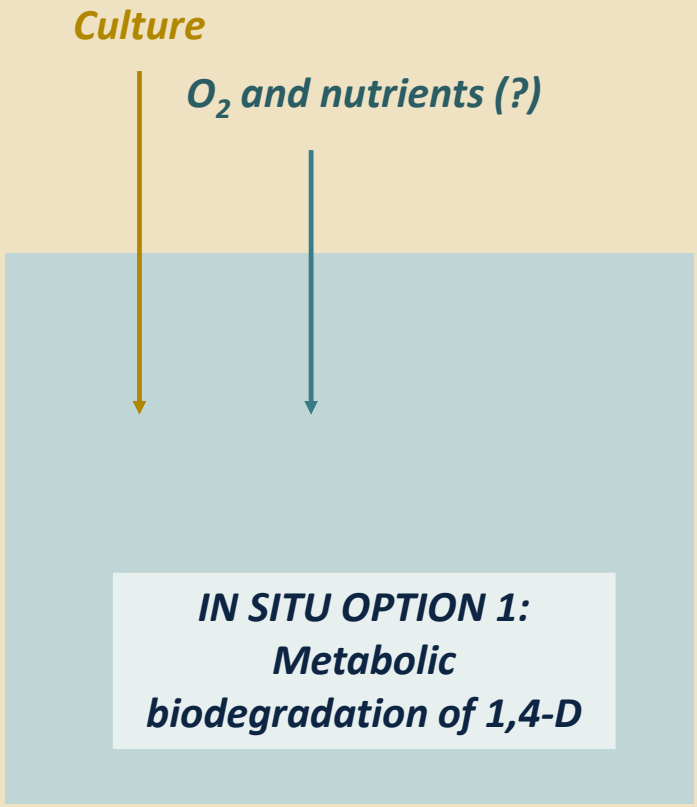
ER-2425

Objective | Approach | Benefits

5 AMENDMENTS AND CULTURES FOR IN SITU 1,4-DIOXANE BIODEGRADATION: *Primary focus = High-k zones*



from He et al., 2017



- **Rapid advancements in identifying 1,4-degraders and understanding their metabolism**
- **It's gotten people excited about cometabolism again!**
- **May require establishing different redox zones to treat both 1,4-D and co-occurring CVOCs**

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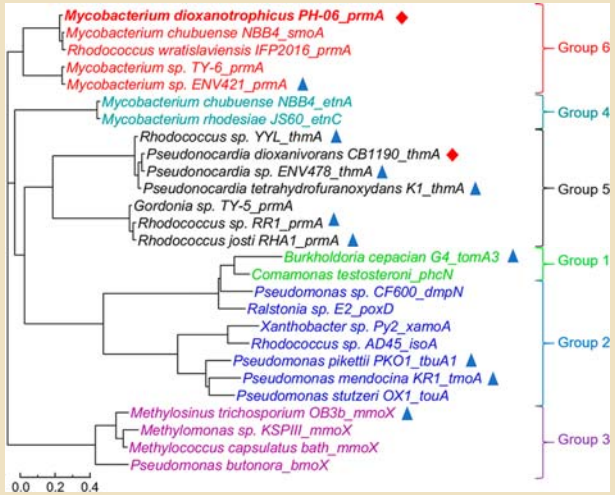

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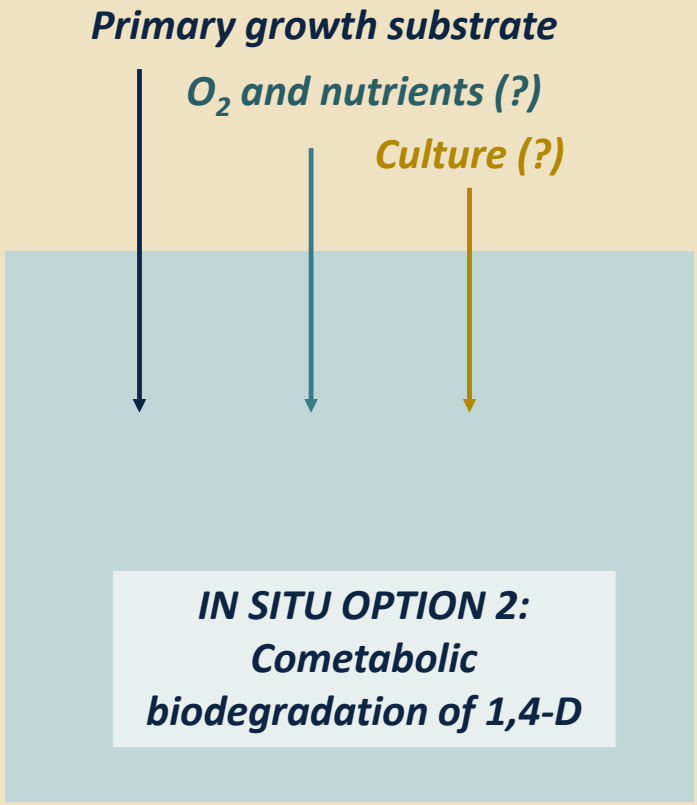

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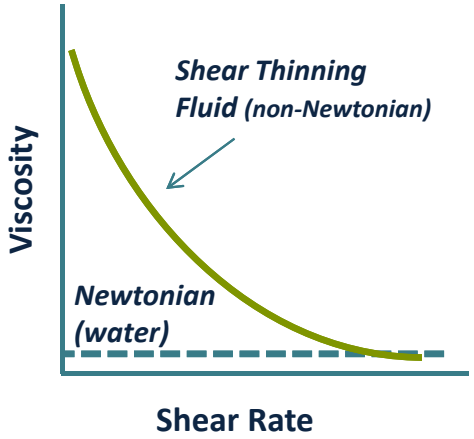
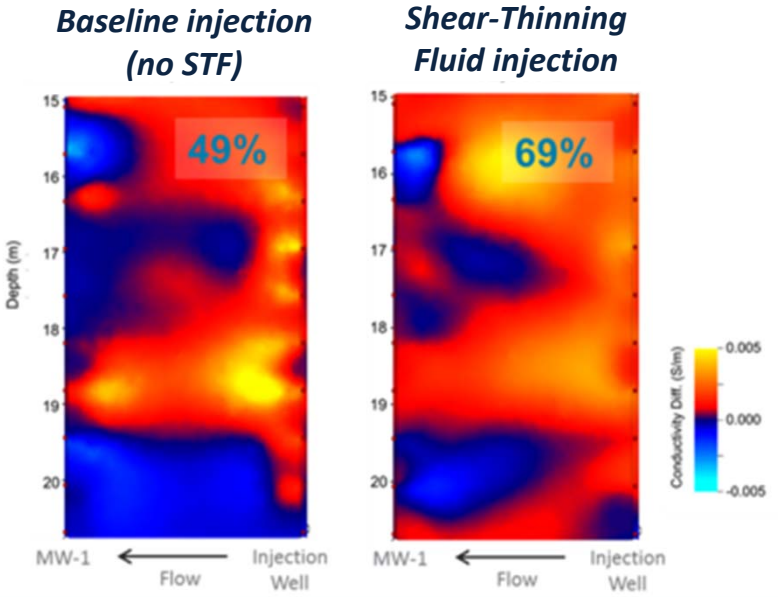
6 SHEAR-THINNING FLUIDS (STFs) AS AMENDMENTS:
Primary focus = Low-k zones

Viscosity (resistance to flow) <u>decreases</u> w/ increasing shear stress



Examples: **Xanthan gum**
Guar gum

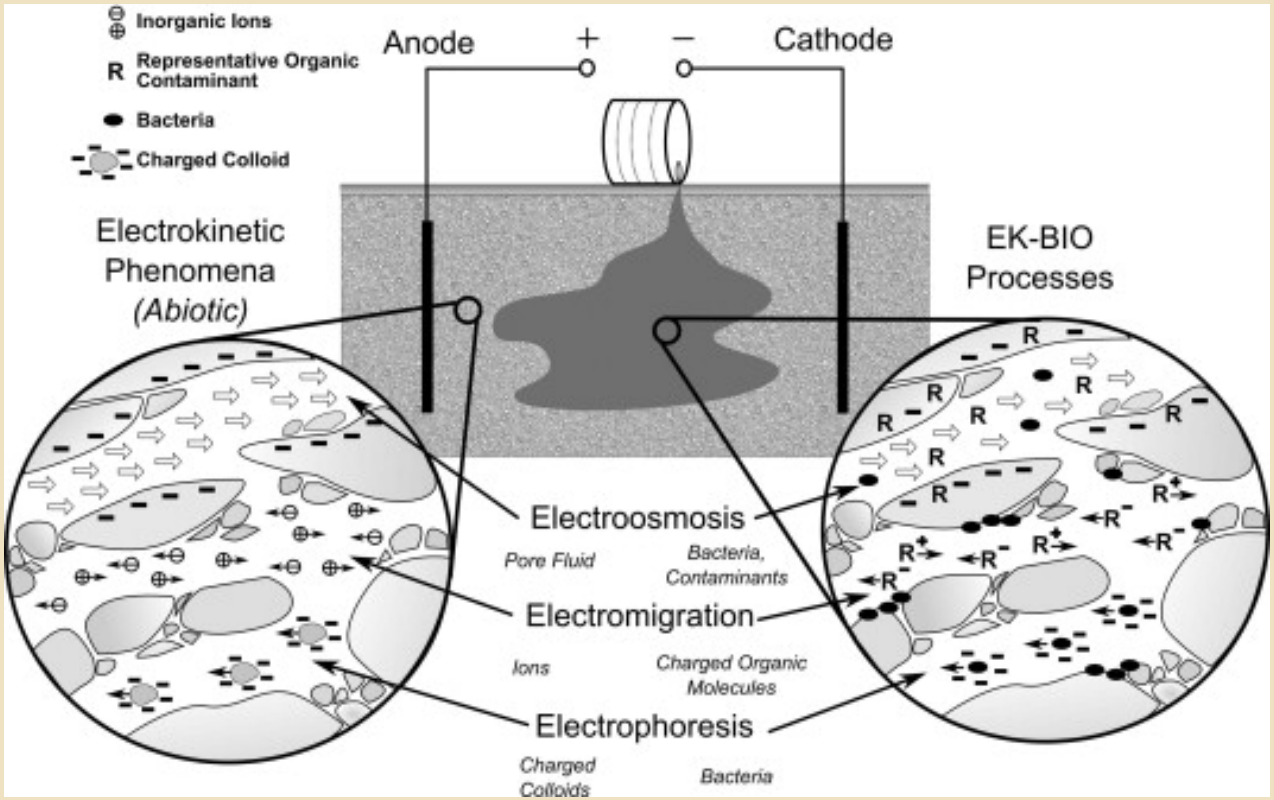
ESTCP ER-0913
GSI + PNNL Joint Project
Xantham Polymer for Improved Substrate Delivery



from Truex et al.. GWMR, 2015

- **Cross-flow is induced ahead of injection front**
- **Decreases permeability contrast near injection well**

7 ELECTROKINETICS (EK): *Primary focus = Low-k zones*



from Gill et al.. Chemosphere, 2014

- **Induced movement by applying electrical current**
- **Transport rates are generally similar or faster in clays than in sands (i.e., effective for delivering amendments into lower-k zones)**

Also see:

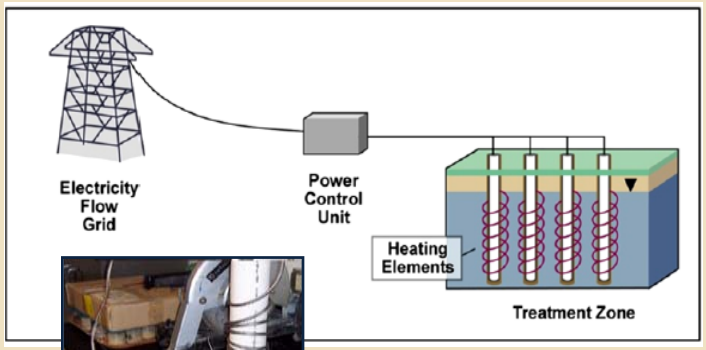
Electrokinetic-Enhanced (EK-Enhanced) Amendment Delivery for Remediation of Low Permeability and Heterogeneous Materials

ER-201325

8 LOW-LEVEL HEAT DELIVERY ("STELA"):
Primary focus = All zones

Soil Solarization with plastic sheeting

Thermal Conductance Heating



Heat Tape Used for CSU Applications

- **Raising temperature promotes faster biodegradation**
- **Variety of simple, low-cost methods**
- **5 to 10˚C temperature increases – goal is high end of naturally-occurring range (< 30 - 35˚C)**
- **Works for petroleum hydrocarbons (CSU)**
- **Should work for chlorinated solvents**

STELA = Sustainable-Thermally Enhanced LNAPL Attenuation

9 WICK DRAINS AND "GROUT BOMBERS"

Primary focus = Low-k zones

How does the "bomber" work?

Batch-mix amendment ingredients in Elkin Mixer

Deliver amendment into hopper and displacement pump

Pump amendment up mast and into mandrel for emplacement

- **Install closely-spaced (2-3 ft) reaction columns filled with amendments vertically through low-k zones**
- **Quick - a few minutes per column**
- **Shortens diffusion pathways to minimize long-term persistence within low-k zones**

For This Application…

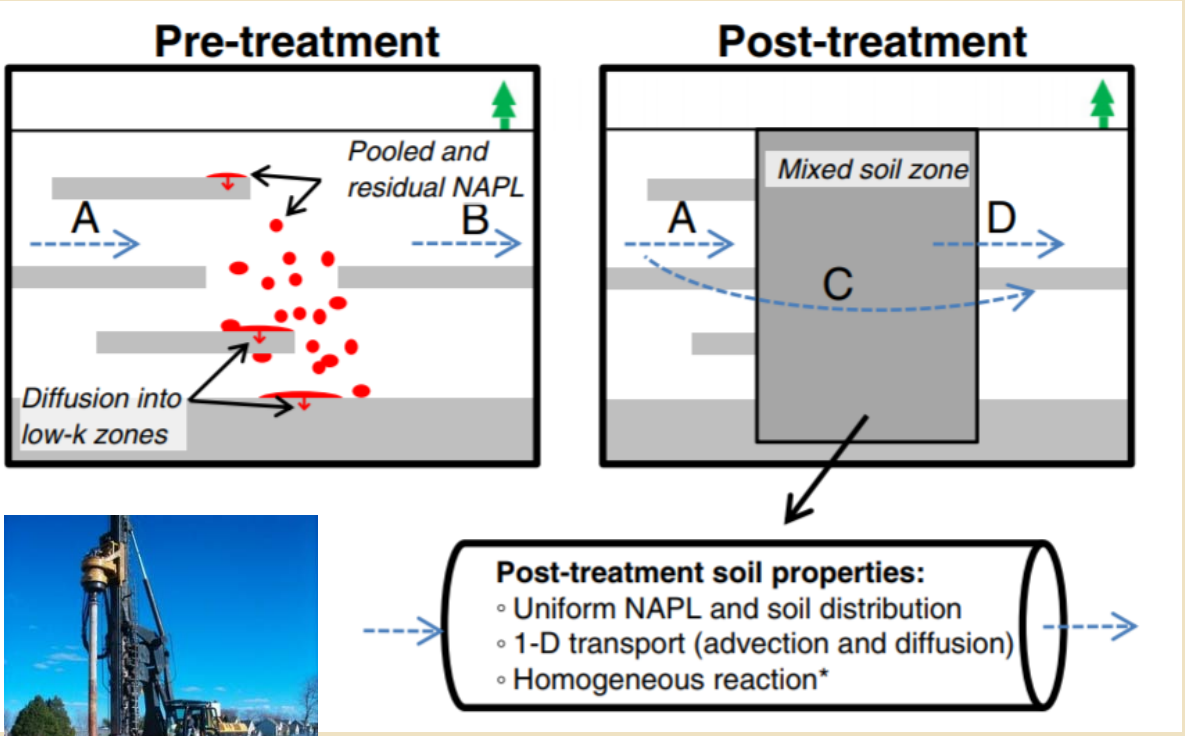
Repurpose "Grout Bomber" technology to deliver remedial amendments (ZVI and oil) in the subsurface, *not* cement grout.

New Application of Pre-Fabricated Vertical Drains to Remediate Low-Permeability Contaminated Media

ER-201627

Principal Investigator
Dr. Stephen Richardson
GSI Environmental, Inc.
Phone: 512-346-4474 x223
sdrichardson@gsi-net.com

10 DEEP SOIL MIXING
Primary focus = All zones

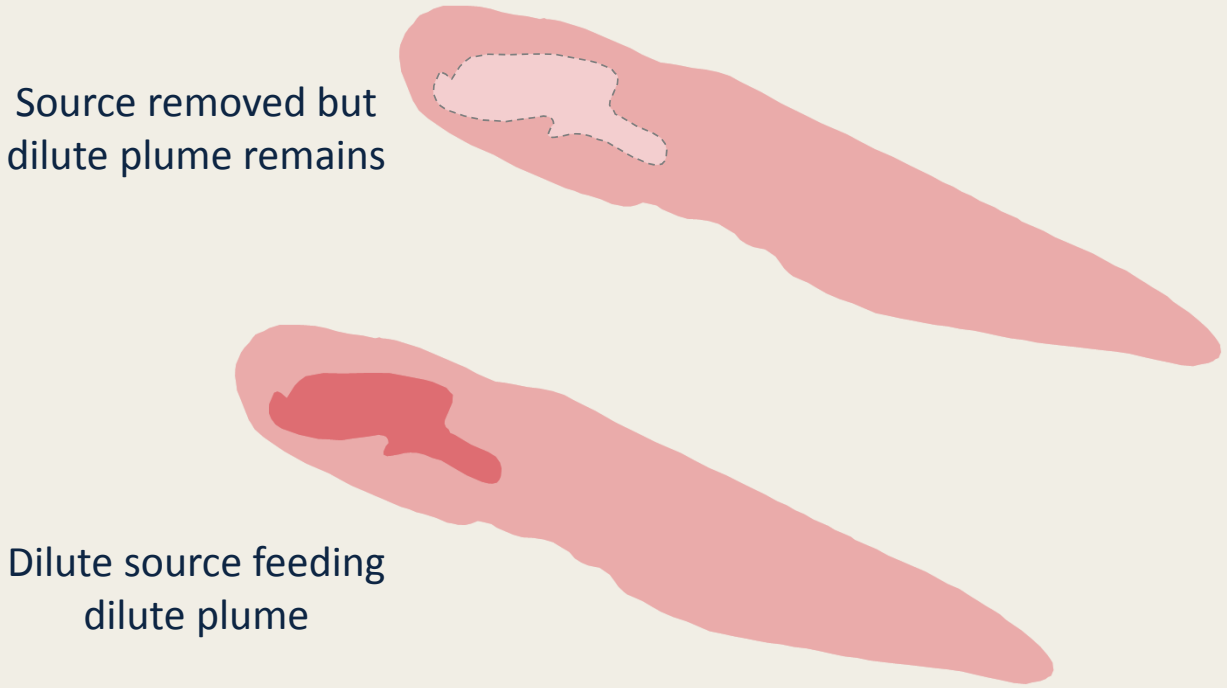


from Olson et al., J. Contam. Hydrology, 2015

- **Turning heterogeneous sites into homogeneous ones!**
- **Combination of sequestration and treatment**
  - **Reduces flux through entire treatment area zone by introducing bentonite or other agent**
  - **Treats contaminants by introducing ZVI or other reactive amendment**
- **Appropriate for all types of CONTAMINANTS but not all types of SITES**

SIGNIFICANT CHALLENGES STILL REMAIN

Different Flavors of Dilute Plumes



- **Secondary water quality issues**
- **Dilute plumes**
- **Delivering solid-phase amendments**
- **Amendments that are effective at interfaces**
- **Improving persistence**
- **Understanding persistence of long-term sequestration processes**