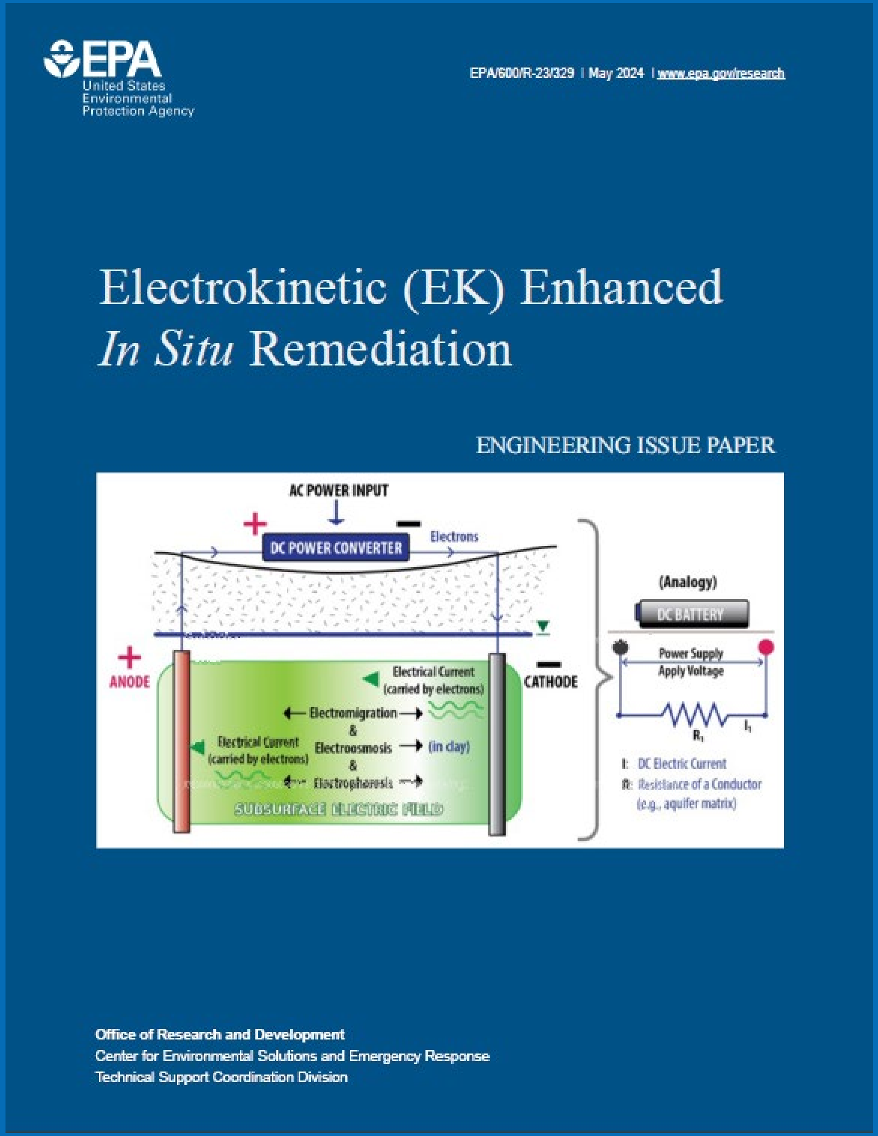
EPA United States Environmental Protection Agency

US EPA ORD's Engineering Issue Paper: Electrokinetic (EK)-Enhanced In Situ Remediation -- options for addressing contaminants in low-permeability (low-k) environments



ORD Technical Support Coordination Division
Development of the EK Enhanced Remediation EIP

EPA United States Environmental Protection Agency

EPA Technical Support Project (TSP): ORD's Technical Support for Contaminated Sites

CDR David Gwisdalla, USPHS, P.E.

Director, Engineering Technical Support Center

Presentation Overview

- EPA's Technical Support Project (TSP) Overview
- Office of Research and Development's (ORD's) role in the TSP
- Overview of ORD and its Technical Support Coordination Division (TSCD)
- How Regional offices gain access to ORD's expertise
- An Example of Relevant TSCD Technical Support – Electro Kinetic (EK) Enhanced Remediation
- TSP's Issue Papers
- Review of EK Engineering Issue Paper

United States Environmental Protection Agency

TSP: Tech. Support Sources

Regional Resources

- In-house technical expertise (e.g., hydrologists and risk assessors)
- Contractor support via regional contract vehicles
- Existing technical sources: Clu-In, TrainEx, NARPM, etc.

Regional Forums

- Act as a hub for technology transfer
- Work to ensure OSCs and RPMs are updated on the most recent policy/guidance
- Active forums: Engineering, Groundwater, Federal Facilities, Contaminated Sediments
- Led by Regional RPMs

Office of Land and Emergency Management (OLEM)

- TIFSD as a division within OLEM provides support through:
  - Environmental Response Team
  - Technology Assessment Branch
  - Technology Integration and Information Branch
  - Analytical Services Branch

Office of Research and Development (ORD)

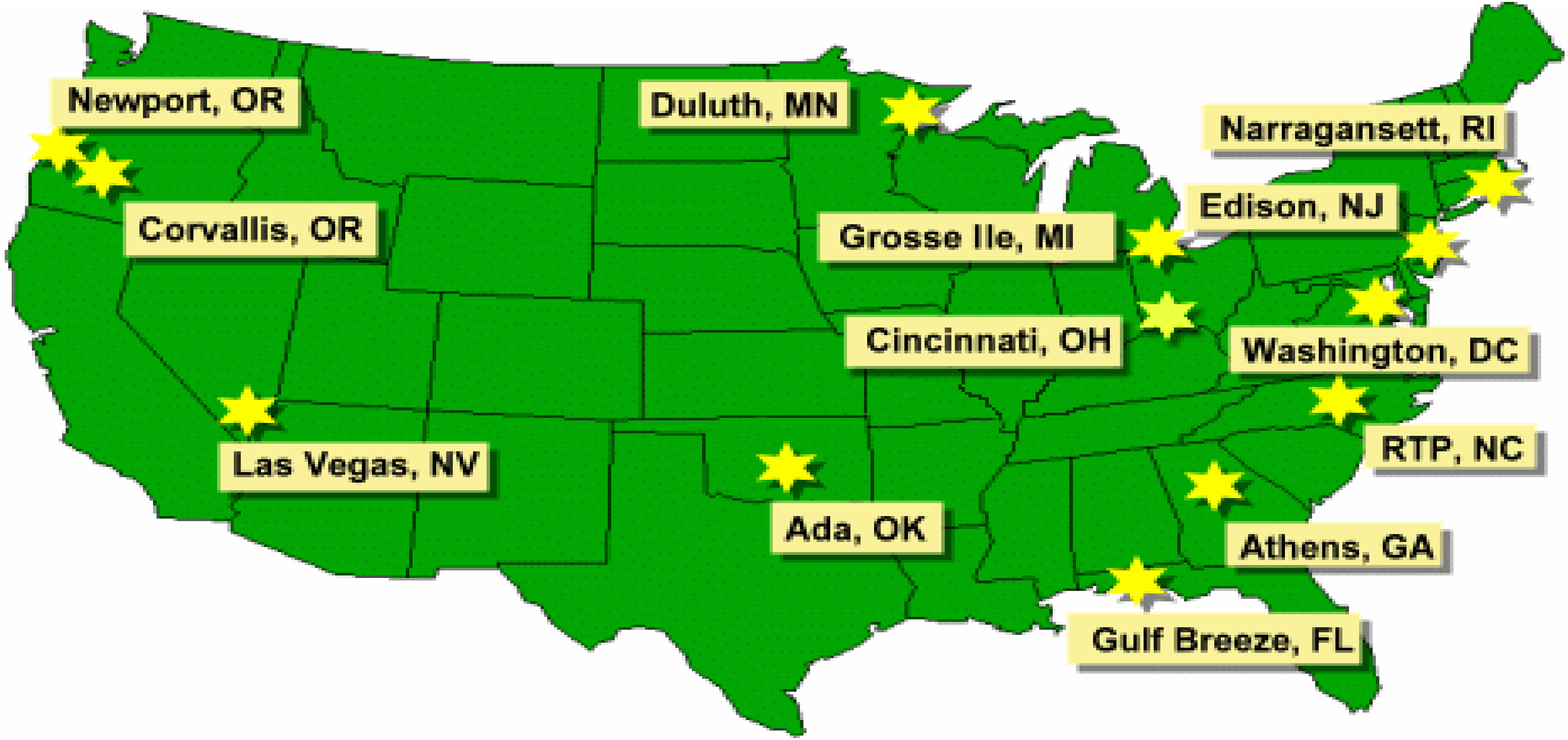
- Provides support through its Technical Support Coordination Division's (TSCD's)
  - Superfund and Technology Liaisons
  - Technical Support Centers

United States Environmental Protection Agency

OFFICE OF RESEARCH AND DEVELOPMENT (ORD)

Conducting critical research and technical support that informs and enables the safeguarding of our nation's public health and environment

ORD's Labs and Offices



EPA United States Environmental Protection Agency

ORD is Organized by Centers

Center for Computational Toxicology and Exposure (CCTE)

Center for Environmental Measurement and Modeling (CEMM)

Center for Environmental Solutions and Emergency Response (CESER)

- CESER is ORD's focal point for large-scale emergency response technical support coordination and technical support at Superfund sites
- CESER's Technical Support Coordination Division (TSCD) leads contaminated sites related technical support for ORD through its Regional Superfund Technology Liaisons (STLs) and Five Technical Support Centers (TSCs)

Center for Public Health and Environmental Assessment (CPHEA)

Technical Support Coordination Division

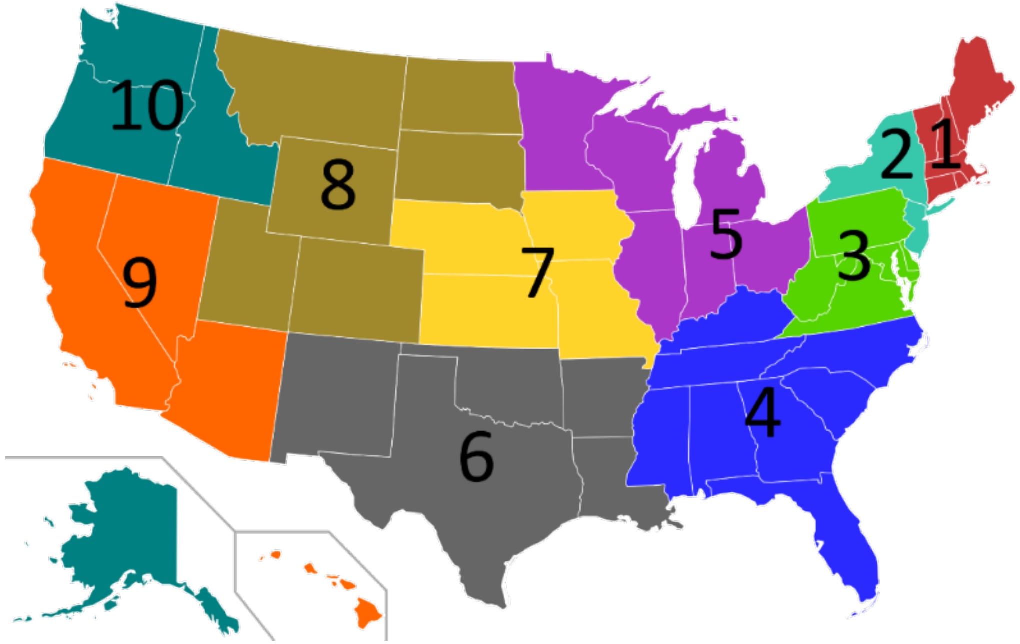
TSCD facilitates the transfer of research results into the field (site characterization, modeling, monitoring, assessment, and remediation, etc.).

- **Superfund and Technical Liaisons (STLs)**, who are regionally based, work with remedial project managers, corrective action staff, and on-scene coordinators to identify available ORD resources and specialized expertise to assist with specific clean-up sites, tasks or projects.
- ORD has **five Technical Support Centers** (TSCs) that help to integrate science and technology into contaminated site clean-up activities.

Technical Support Coordination
ORD Superfund and Technology Liaisons (STLs)

Region 10
Kim
Prestbo

Region 9
Sarah
Watson



Region 1
Dan
Burgo

Region 2
Diana
Cutt

Region 8
Stephen Dyment

Region 7
Robert Weber

Region 6
Terry Burton

Region 5
Stephanie Ross

Region 4
Felicia Barnett

Region 3
Jonathan Essoka

9

TSCD Contaminated Sites Technical Support Centers

ORD Center for Environmental Solutions and Emergency Response (CESER)
Technical Support Coordination Division (TSCD)
Director: Kelly Dipolt

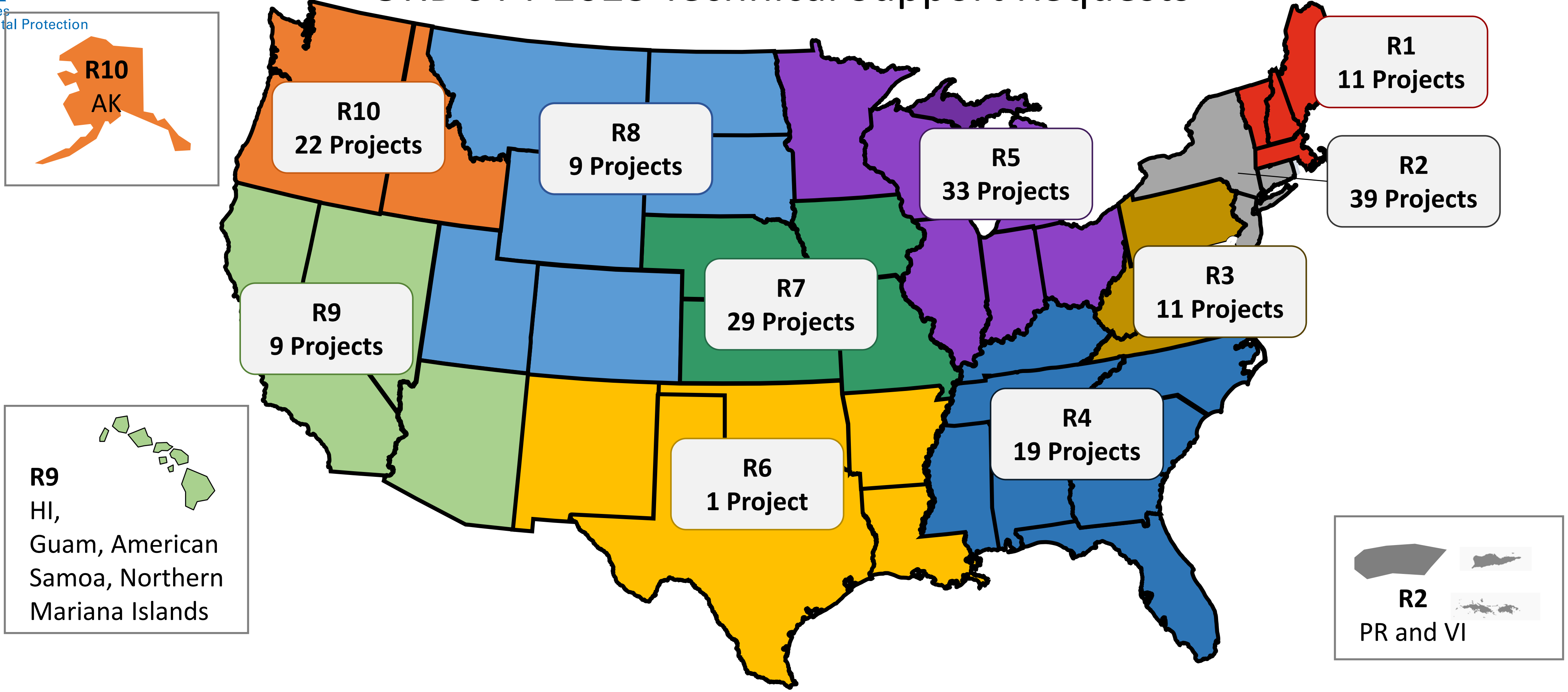
Engineering Technical Support Center (ETSC) Director: David Gwisdalla	Groundwater Technical Support Center (GWTSC) Director: Randall Ross	Ecological Risk Assessment Support Center (ERASC) Director: Michael Kravitz	Superfund Health Risk Technical Support Center (STSC) Director: Dahnish Shams A. Director: Avanti Shirke	Site Characterization and Monitoring Technical Support Center (SCMTSC) Director: Felicia Barnett A. Director: Terry Burton
• Interpret geochemical data • Evaluate remedial technologies and remediation system performance • Groundwater flow and F&T modeling • Assist with development or review of treatability or pilot studies • Remedy design & implementation assistance		• Addresses scientific questions regarding ecological risk assessment at hazardous waste sites	• Addresses exposure and toxicity risk issues • Develops new and updated provisional peer-reviewed toxicity values	• Provide statistical analysis support • Provide field support • Identification of extent of contaminants

Superfund and Technology Liaisons (STLs): Regions 1 - 10

STLs coordinate contaminated-site-related technical support requests from the Regions

United States Environmental Protection Agency

ORD's FY 2023 Technical Support Requests



188
Support Requests

Covering direct, site-specific technical assistance; document review; engineering & prototype testing; risk assessment; research & tech transfer.

124
Site-specific Projects

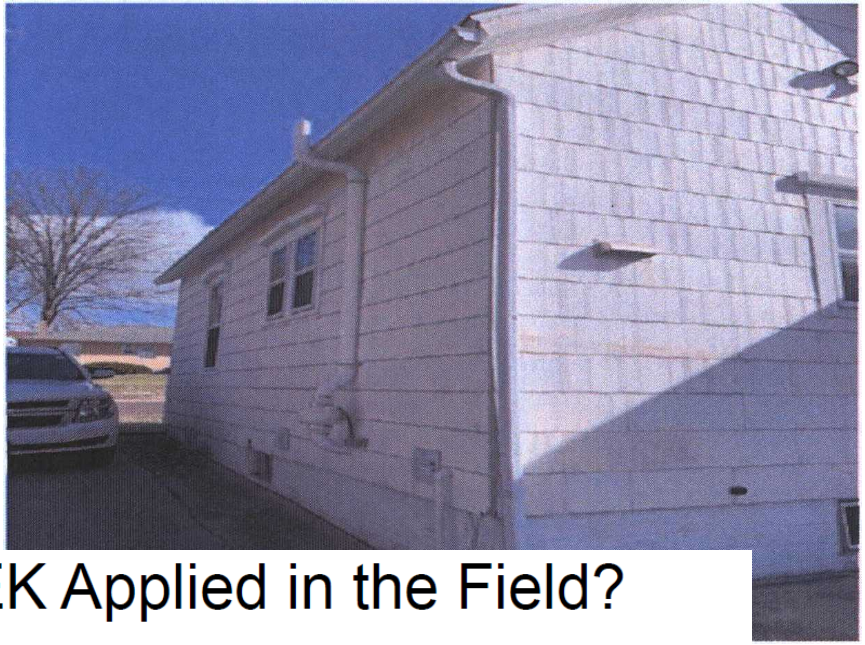
Provided direct contaminated site-specific support for Superfund, RCRA Corrective Action and Brownfields sites.

23
STLR Projects

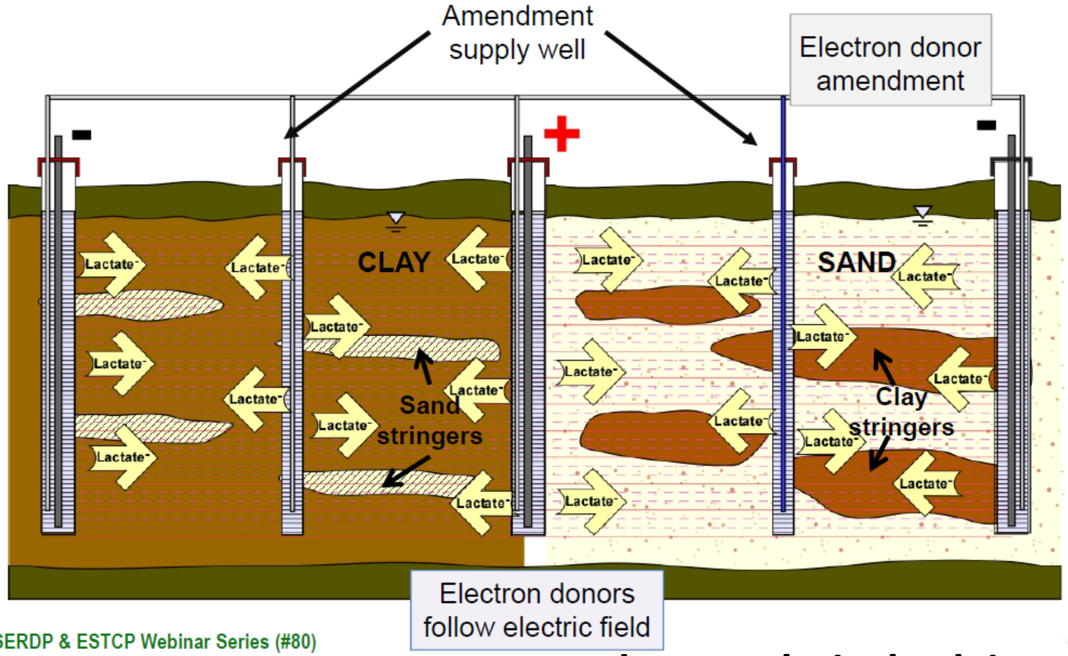
In collaboration with ORD STLs to support scientifically defensible decisions during site cleanup.

Riverfront Superfund Site: PCE Treatment Alternatives

- New Haven, Missouri – On-Scene Coordinator (OSC) sought treatment options for PCE contaminated in tight clay soils in addition to other removal action options being considered.
- Electro-Kinetic (EK) enhanced technology, called EK-BIO™ was a potential option. OSC sought insights on the feasibility of its use at the site.
- **Impact:** Informed OSC's decision making – options limited; EK-BIO™ not proven for application



How is EK Applied in the Field?



Product: Technical Advice – April 2020

United States Environmental Protection Agency

EPA Contaminated Site Related Issue Papers

- Issue Papers are a series of technology transfer documents that summarize the latest information on selected waste treatment and site remediation technologies and related issues.
- Link to TSP related Clean-up Issue Papers by ORD and others from 1989 through 2024.

A Sample of Issue Papers Available from EPA:

- Electrokinetic (EK) Enhanced In Situ (EPA-600-R-23/329)
- HazWaste Clean-up Technical Resources (EPA-542-F-09-003)
- Conducting Climate Vulnerability Assessments at Superfund Sites (EPA-542-R-23-002)
- Ecosystem Services at Contaminated Site Cleanups (EPA 542-R-17-004)

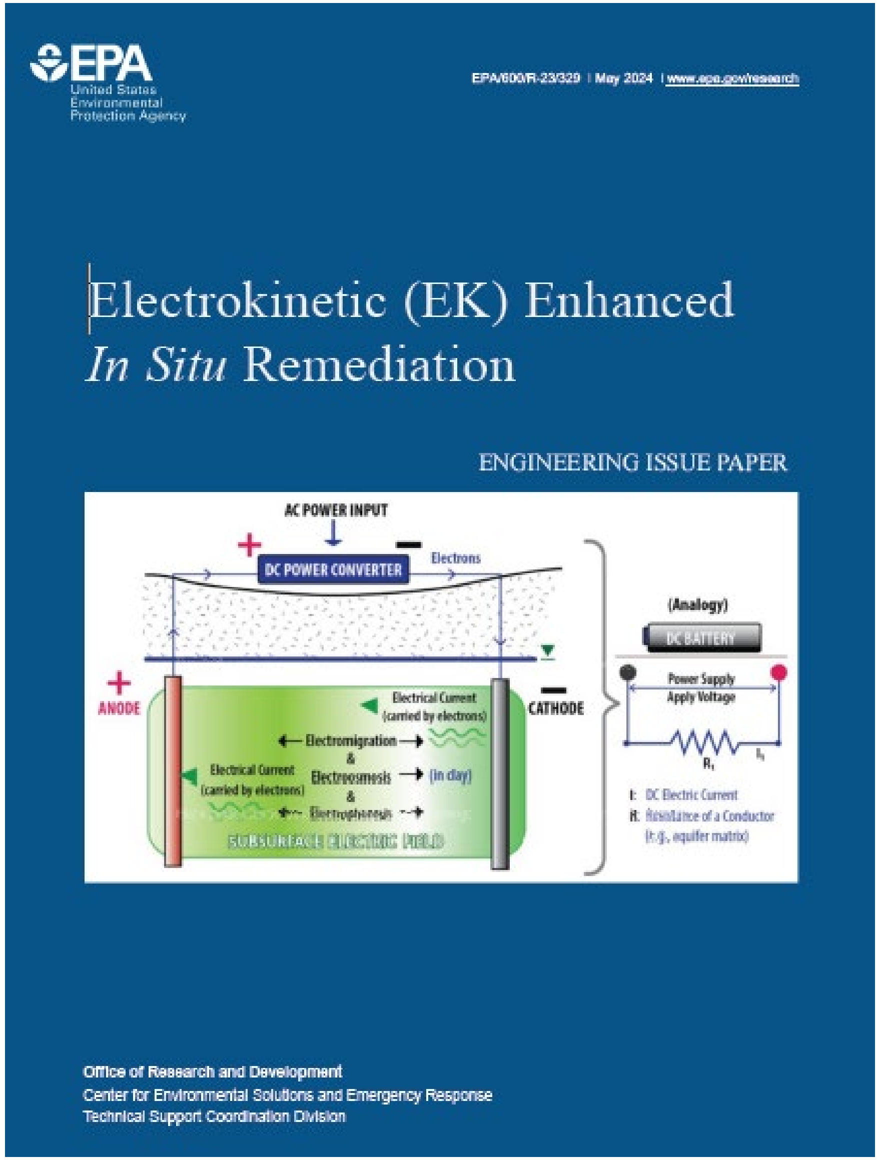
United States Environmental Protection Agency

Electrokinetic (EK) Enhanced In Situ Remediation – Issue Paper

Engineering Issue Paper developed in coordination between TSCD’s Engineering and Groundwater Technical Support Centers (ORD - ETSC & GWTSC)

EIP developed under ORD STREAMS IV Contract, with RTI International, where Geosyntec is a partner

James Wang, PhD, from Geosyntec is the primary author


EPA United States Environmental Protection Agency

EPA/600/R-23/329 | May 2024 | www.epa.gov/research

Electrokinetic (EK) Enhanced *In Situ* Remediation

ENGINEERING ISSUE PAPER

Office of Research and Development
Center for Environmental Solutions and Emergency Response
Technical Support Coordination Division

Acknowledgments

EIP's Development Co-Lead: Randall Ross, Director of Groundwater Technical Support Center (GWTSC)

Shaping this Document for Our Users:

- James Ferreira - EPA Region 4 Superfund and Emergency Management Division (SEMD)
- Daewon Rojas-Mickelson - EPA Region 9 SEMD
- James Cummings - OLEM/TIFSD
- Rohit Warrier and Katherine Bronstein – RTI International

Technical Reviews and Insights:

- James Hall - EPA Region 10 SEMD
- John McKernan - ORD/CESER's Land and Remediation Technology Division (LRTD)
- Randy Parker - ORD/CESER/TSCD
- David Gent - US Army Corps of Engineers Research and Development Center Environmental Lab (retired)
- Arvin Farid - Professor of Civil Engineering at Boise State University

EPA United States Environmental Protection Agency

ORD Tech Support Summary

- ORD's stands ready to provide technical support as part of EPA's TSP through its TSCD – including the EIP discussed today.
- ORD's expertise can be accessed through our designated Regional STLs who coordinate with TSCs
  - States and tribes can request technical support through the Regions who then work through TSP
- TSCD's 5 Technical Support Centers (TSCs) and 10 STLs support over 180 requests per year with support from our ORD staff and on-call contracts
- Further information on the TSCs, STLs and our other projects can be found in these links

For more information connect with us at:

QR Codes for TSCD

Internet Site

Intranet Site

QR Code for STLs

Intranet Site

United States
Environmental Protection
Agency

Engineering Technical Support Center (ETSC) Contact

CDR David Gwisdalla, USPHS, P.E.

ETSC Director

Contact Information:

gwisdalla.david@epa.gov

513.569.7011 office

US EPA - ORD/CESER/TSCD

26 West Martin Luther King Drive

Cincinnati, Ohio 45268

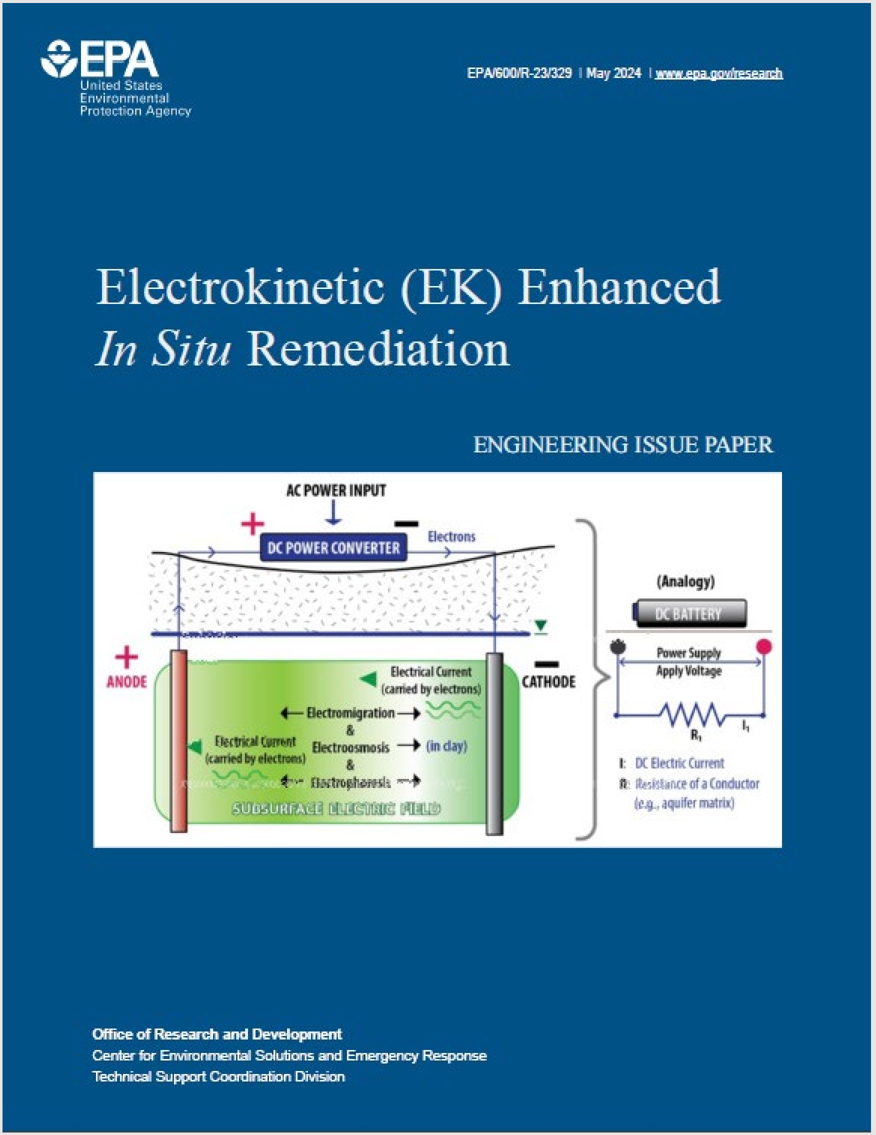
Visit us at: https://www.epa.gov/land-research/engineering-technical-support-center-etsc

ETSC QR Code

Engineering Issue Paper

Electrokinetic (EK) Enhanced In Situ Remediation

EPA/600/R-23/329   May 2024


EPA United States Environmental Protection Agency

EPA/600/R-23/329 | May 2024 | www.epa.gov/research

Electrokinetic (EK) Enhanced *In Situ* Remediation

ENGINEERING ISSUE PAPER

Office of Research and Development
Center for Environmental Solutions and Emergency Response
Technical Support Coordination Division

James Wang, Ph.D., P.E.
Geosyntec Consultants
Columbia, Maryland

EK Focused Agenda

- Challenges & Motivation
- EK Fundamentals & Applications for In Situ Remediation
- Engineering Issue Paper
- Case Studies – EK-BIO and EK-ISCO Projects
- Take Away Messages

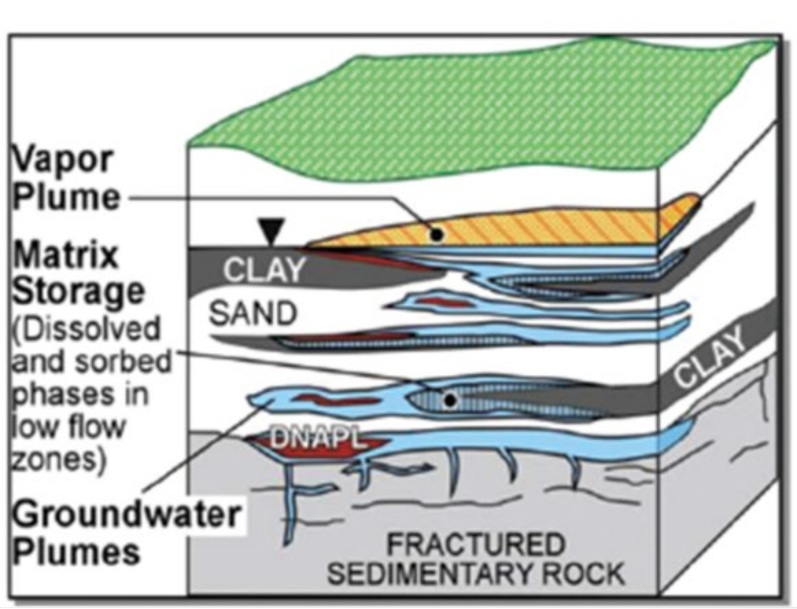
Challenges and Motivation

Contaminants diffused into low permeability (low-k) materials serve as secondary sources (back diffusion) lasting for decades

EISB and ISCO / ISCR are effective technologies, but amendment distribution is poor in low-k and heterogeneous materials

Delivery & **Contact**

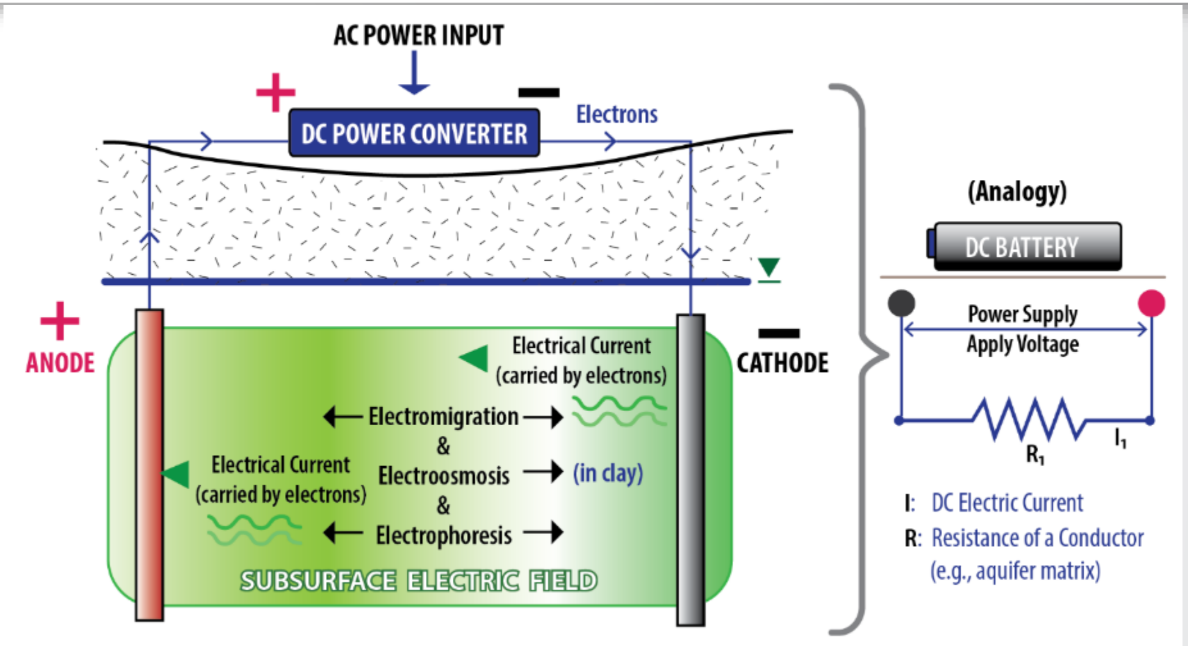
Better & fundamentally improved amendment delivery techniques are needed for low-k sites

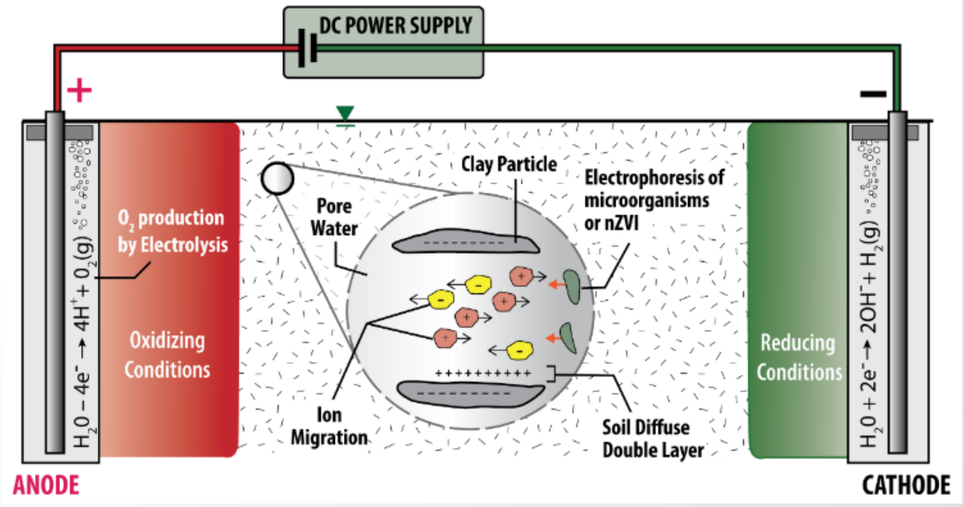


From ESTCP, ER-200530

Electrokinetic (EK) for Amendment Transport

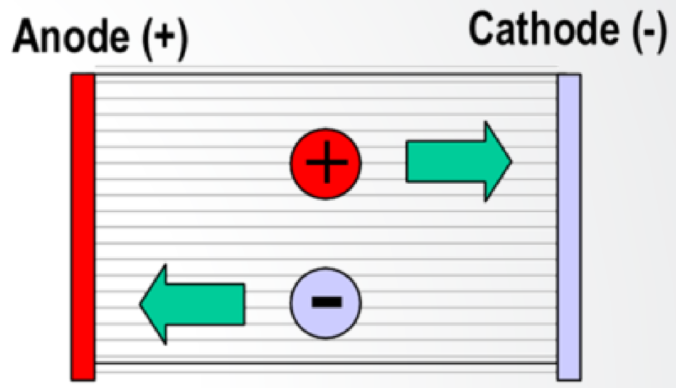
- Application of direct current (***DC***) to saturated formation
- "Powered" by the electric field, select amendments move through clays and silts via:
  - **Electro-migration (EM)** – movement of charged ions
  - Electro-osmosis (EO) – bulk movement of water
  - Electrophoresis (EP) – the movement of charged solid particles (e.g., colloids)





Electrokinetic (EK) for Amendment Transport – Electromigration (Ion Migration)

- **Electromigration** is the movement of ions in an electric field. Ions are attracted to the electrode of opposite polarity.
- Electromigration occurs in the subsurface as long as there is a connected water pathway.
- The transport rate is proportional to the electrical gradient (driving force) of the applied electric field.



Anions: negatively charged ions
Cations: positively charged ions

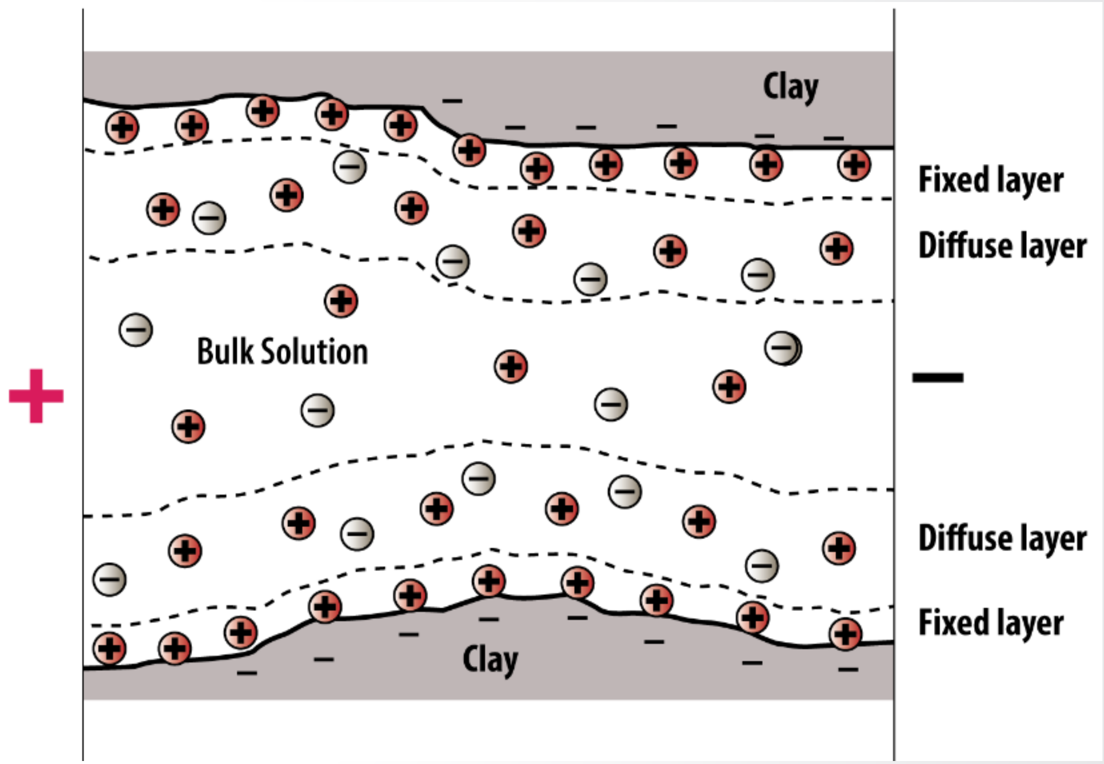
Anode: Positively charged electrode
Cathode: Negatively charged electrode

$$J_i = -D_i^* \frac{\partial c_i}{\partial x} - u_i^* c_i \frac{\partial \phi}{\partial x} + q c_i$$

Voltage Gradient

Electrokinetic (EK) for Amendment Transport – Electroosmosis

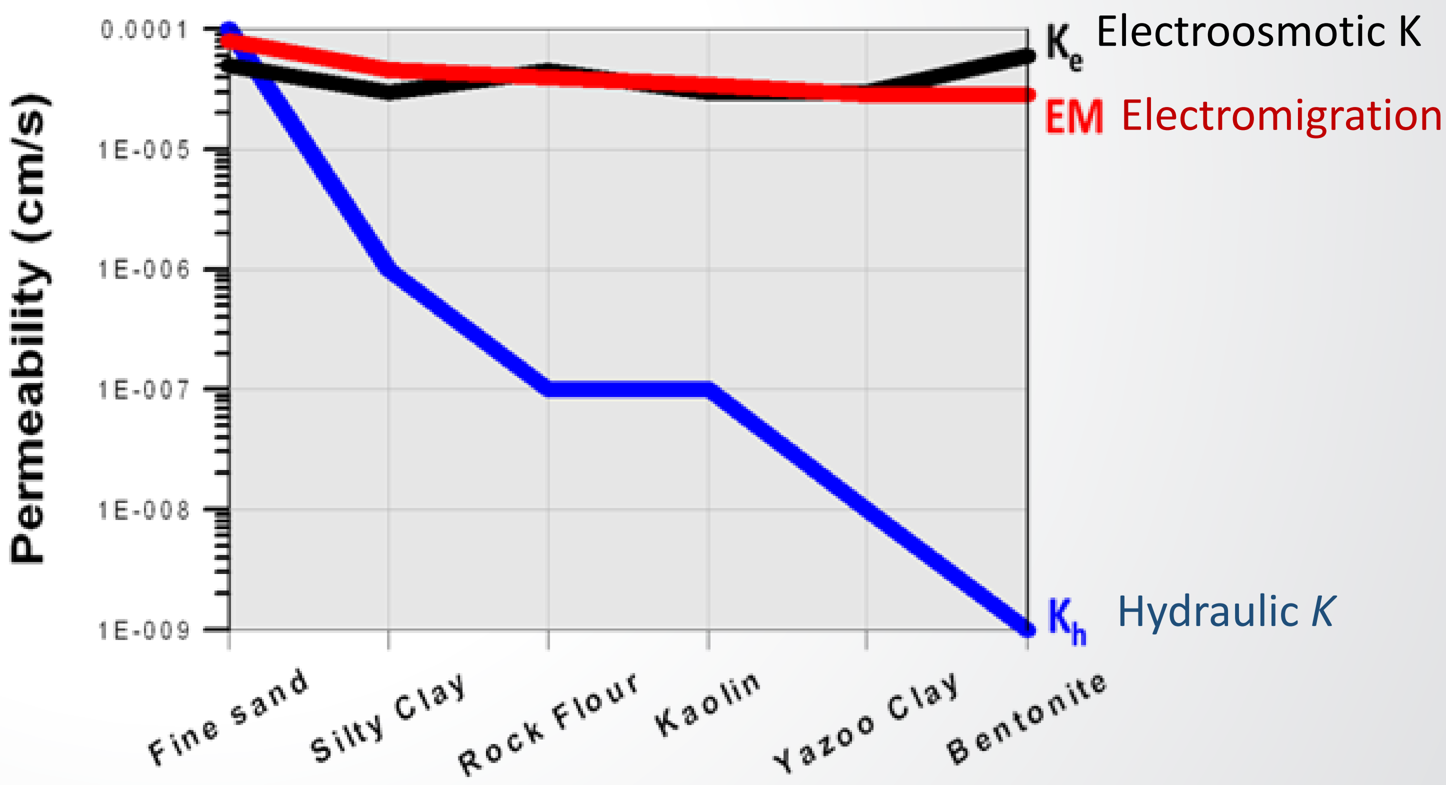
- **Electroosmosis** is the movement of pore fluid and, thus, dissolved constituents induced by a voltage gradient.
- A complex mechanism depending on electrical characteristics of solid surface, property of interstitial fluid, and the interactions between these elements.



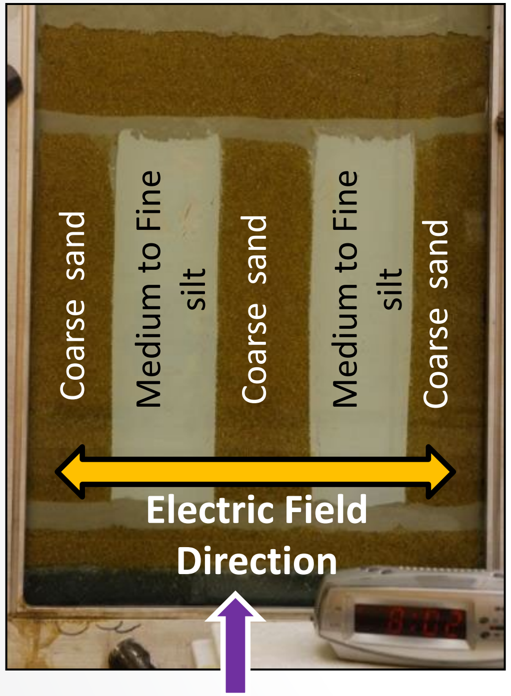
EK Transport is Fundamentally Different

Why will EK work in low-K formations where conventional hydraulic injection techniques often face challenges?

- EK transport relies on <u>electrical</u> properties of aquifer matrix (<u>not hydraulic</u>)
- Soil electrical properties ≈ between sand and clay
- As K_h decreases, EK becomes the more efficient delivery method



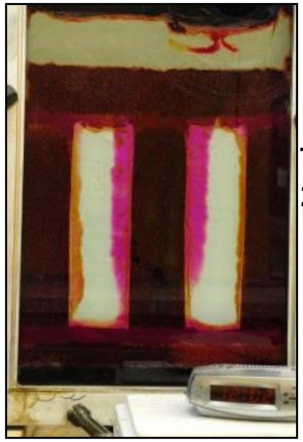
Effective and Uniform Amendment Delivery by EK



MnO_4^- Flow Direction

T = 6 hr (MnO_4^- flushing; No EK)

T = 12 hr (MnO_4^- flushing; No EK)



T = 6 hr w/ 2-hr EK (MnO_4^- flushing with EK)

T = 12 hr w/ 8-hr EK (MnO_4^- flushing with EK)

Western UNIVERSITY · CANADA

EK Applications for In Situ Remediation

- Remember – **EK is** a remediation reagent **delivery** technology

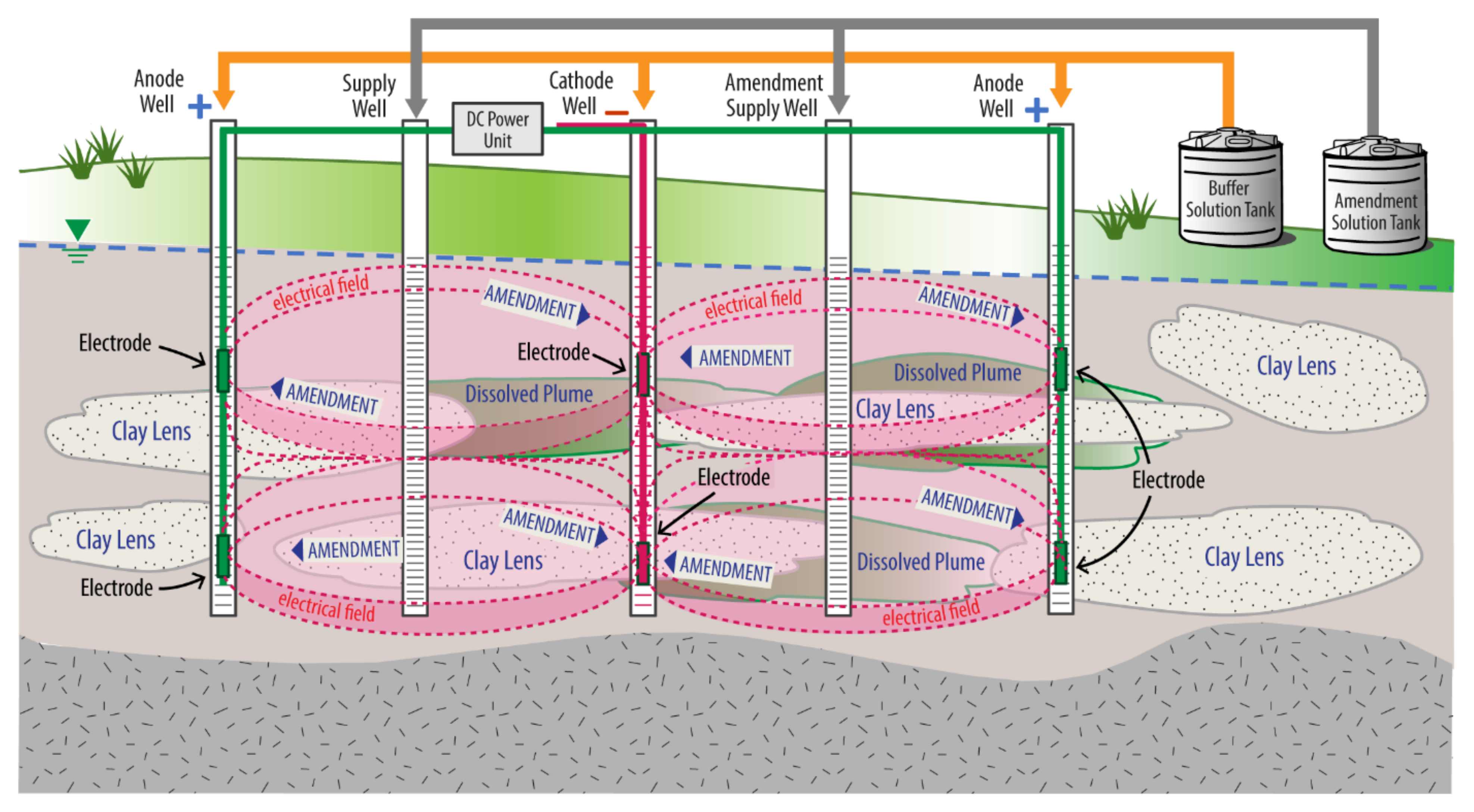
- For In Situ Bioremediation

- **EK-BIO** : Distribution of electron donors (lactate) or electron acceptors (sulfate, nitrate) and/or microorganisms (*Dehalococcoides, Dehalobacter*) to promote biodegradation

- For In Situ Chemical Oxidation Remediation

- **EK-ISCO** : Distribution of permanganate (MnO_4^-) or persulfate ($S_2O_8^{2-}$) to promote oxidation

Implement EK Enhanced In Situ Remediation



Engineering Issue Paper
EPA/600/R-23/329 (May 2024)

Table of Contents

EIP Structure –

- Introduction;
- Technology fundamentals;
- Stepwise process of feasibility screening, alternative evaluation, developing / designing / and ultimately implementing the EK technology at a site
  - generally following the CERCLA FS and RD framework;
  - enhanced usability for RPMs and remediation practitioners;
- References – over 90 peer-reviewed journal articles and technical reports;
- Also provide select case studies in appendices

Engineering Issue Paper
EPA/600/R-23/329 (May 2024)

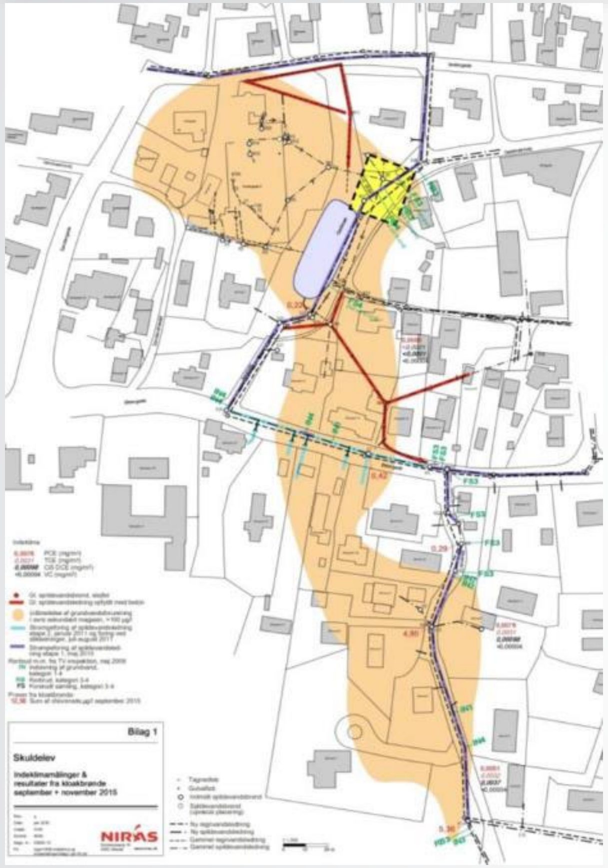
Follow the CERCLA FS and RD framework for technology screening / evaluation / selection

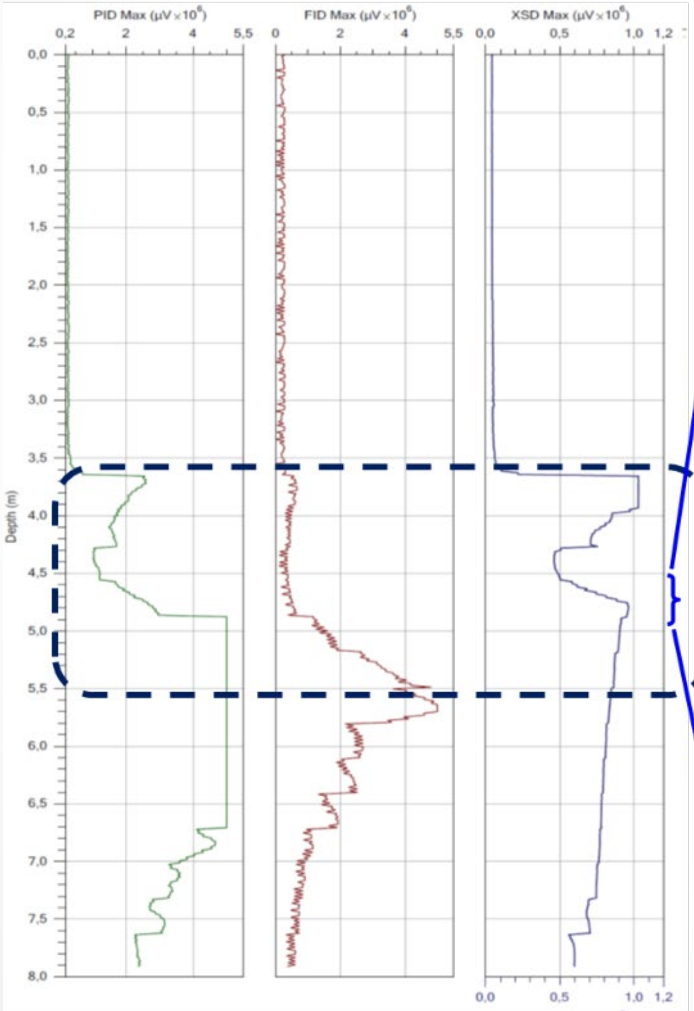
Criteria	EK-enhanced Remediation and Project-Specific Considerations
THRESHOLD CRITERIA	
BALANCING CRITERIA	
Long-Term	This criterion considers the ability of an alternative to maintain protection of human health and the environment over time.
MODIFYING CRITERIA	
State Acceptance	Acceptance will be based on regulatory stakeholder review of the proposed plan during the required community involvement period

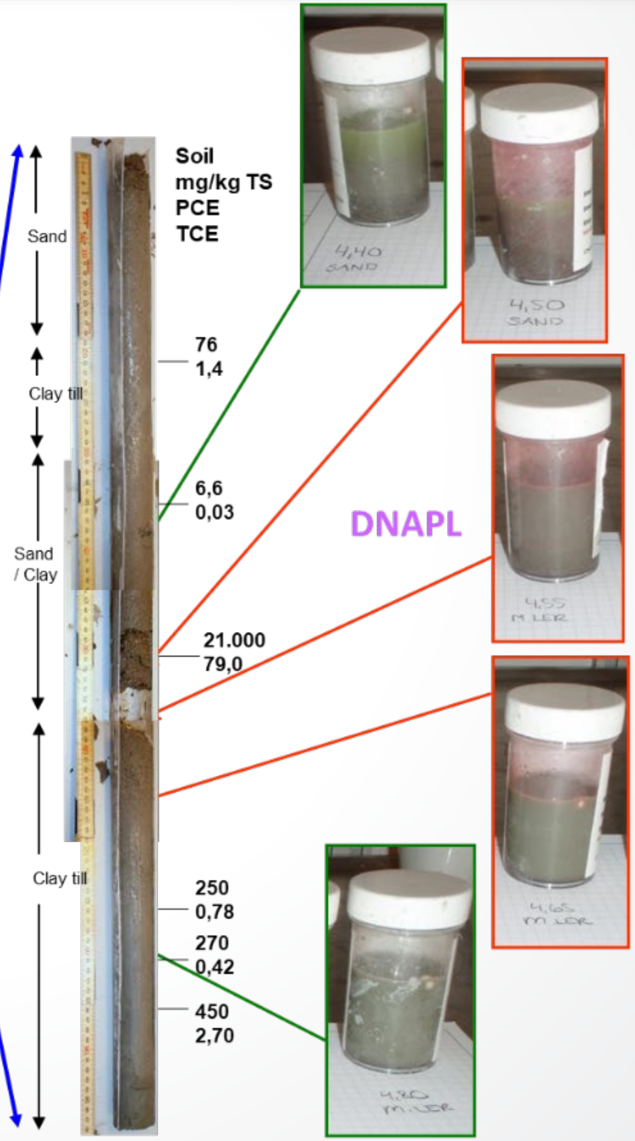
Supported with select case studies - bench-scale treatability / pilot test / full-scale implementation

APPENDICES

Case –
EK-BIO From Bench to Full-Scale, Skuldelev, DK





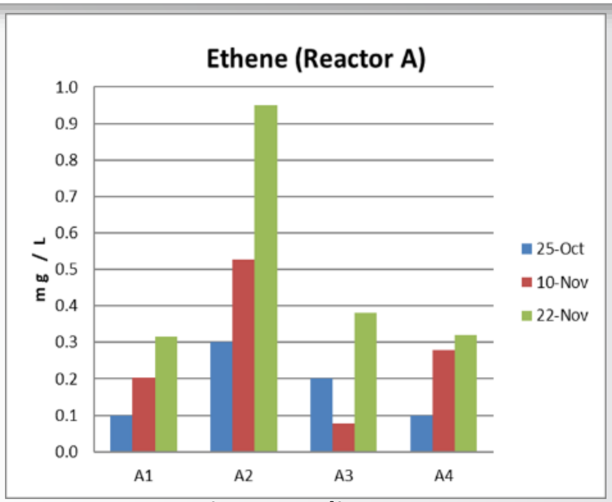


Targeting PCE DNAPL in Clay Till

Bench-Scale EK-BIO Treatability Test

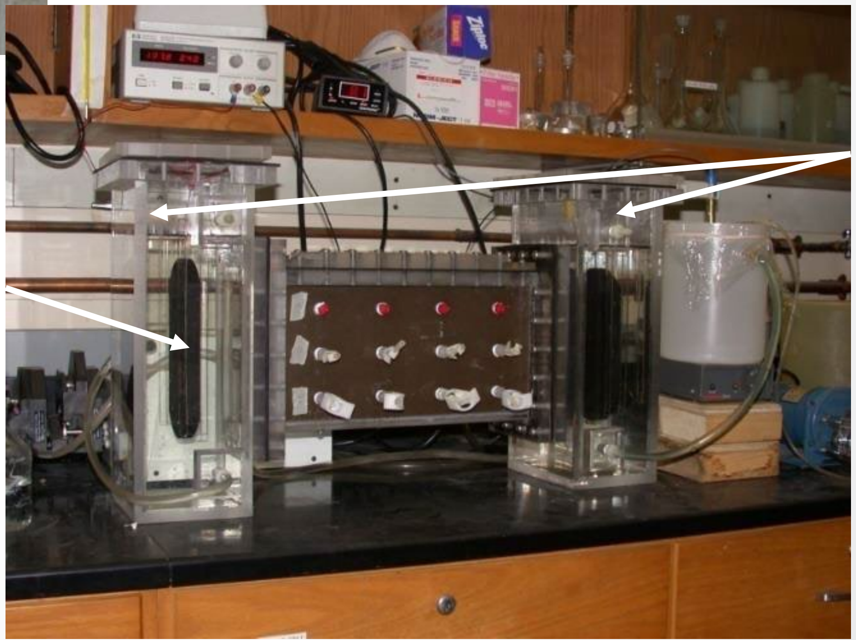
- **Bench Scale EK Reactor (40 cm x 15 cm x 5 cm test cell)**
- **DC power supply and control**
- **Interior pore-water sampling ports to track the transport progress**

Complete dechlorination to ethene



Interior Sampling Ports

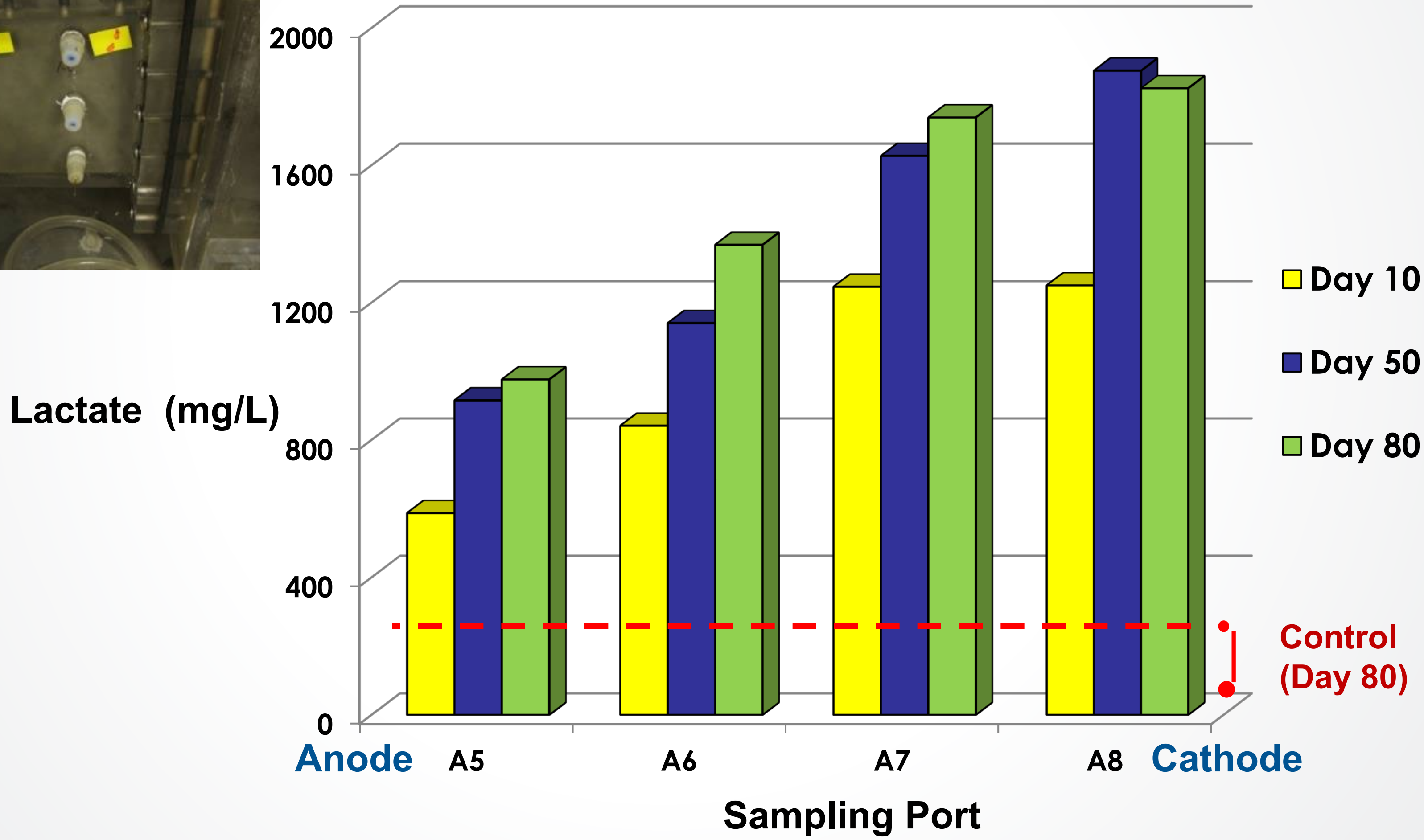
- **Electrodes : graphite plates**



- **Two 5-Liter electrode chambers; with cross-circulation & gas vent**

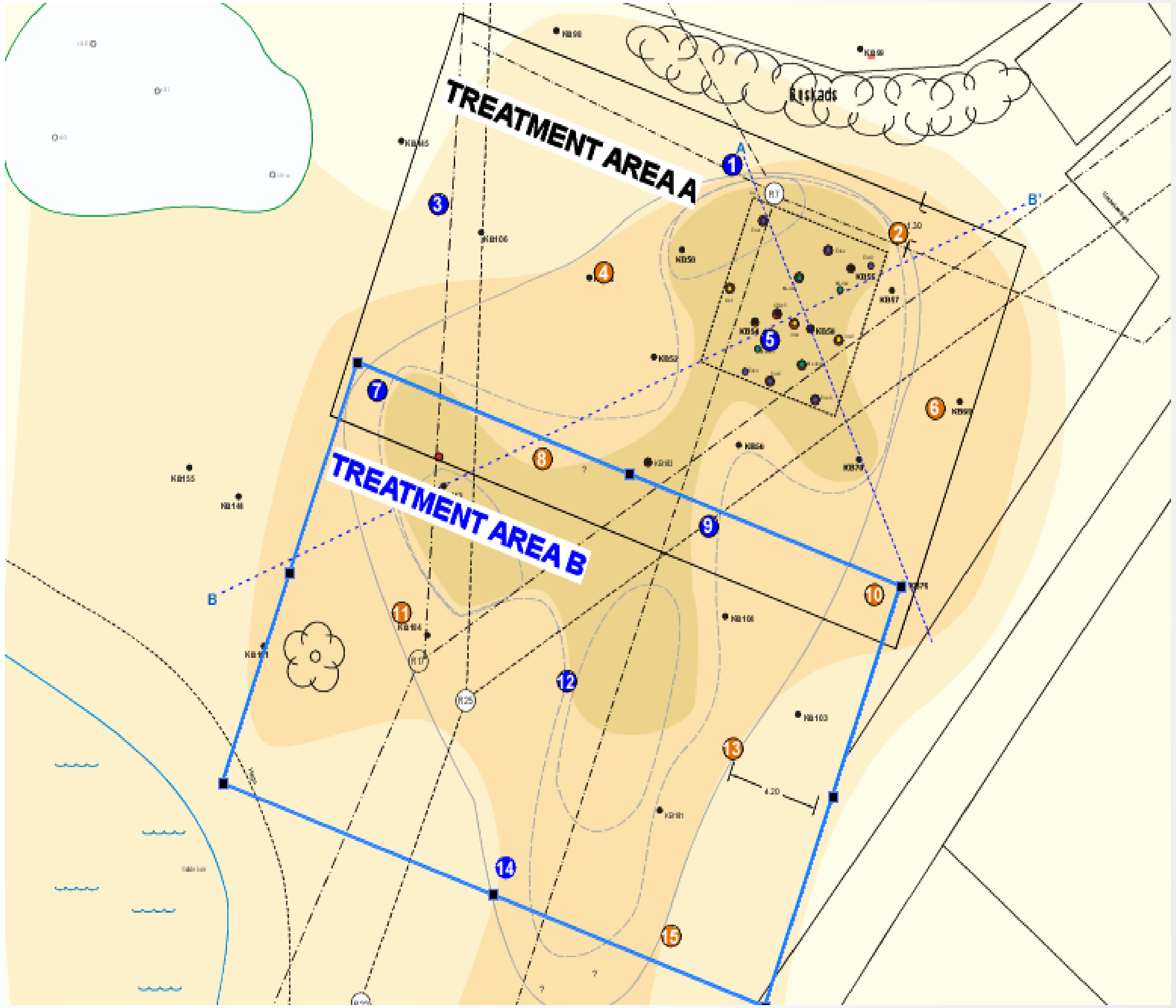
EK Transport of Lactate

Lactate "net" transport rate of 3.2 cm/day



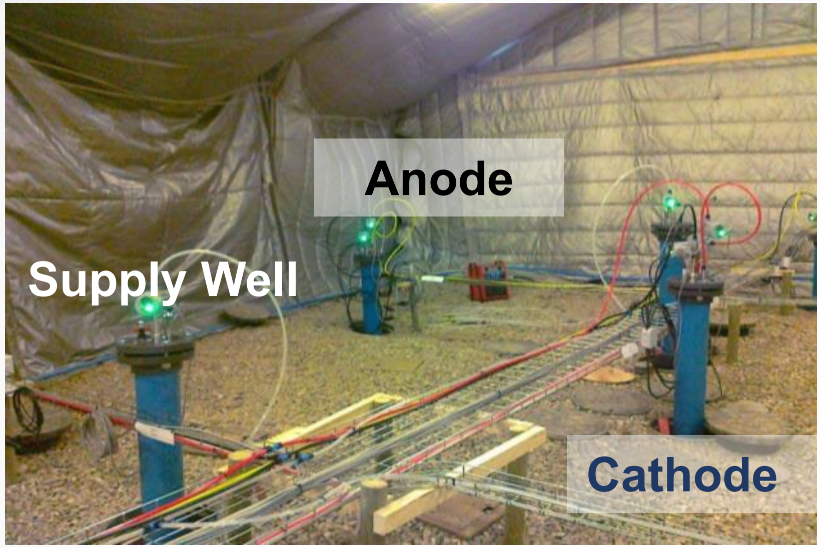
Full-Scale EK-BIO Implementation

- Following successful treatability test and pilot test
- PCE NAPL Source Area - 40 ft x 60 ft x 24 ft deep
- 15 electrode wells; ~ 14-ft electrode well spacing
- Two treatment areas; alternating active-passive phases of 90 days / phase between areas
- From December 2012 – two years implementation



Full-Scale EK-BIO Implementation

(No electrode in Supply Well)



Amendment Supply and System Control

Injek

Flexible Electrific Field Orientations

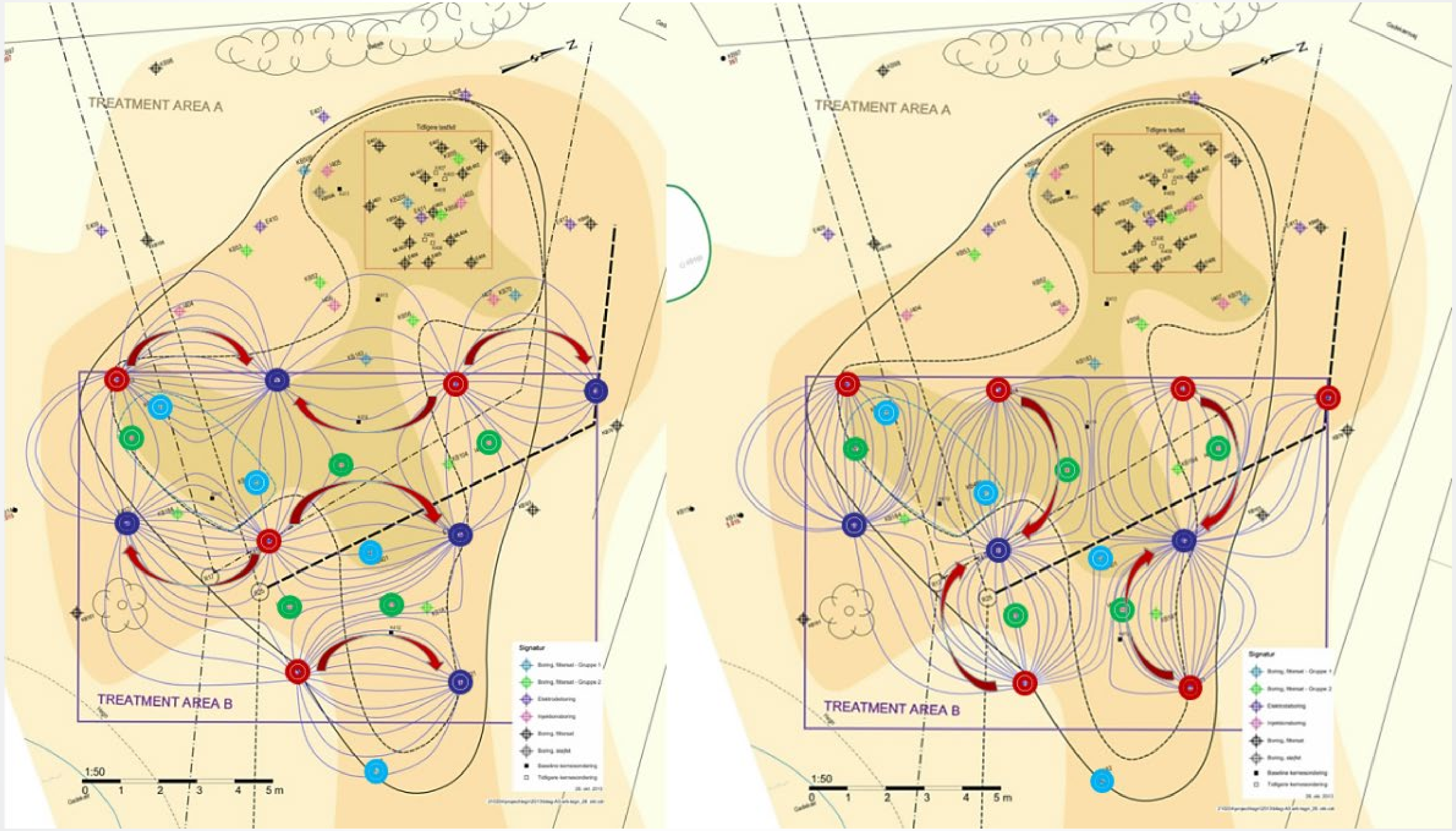
Anodes (+)

Cathodes (-)

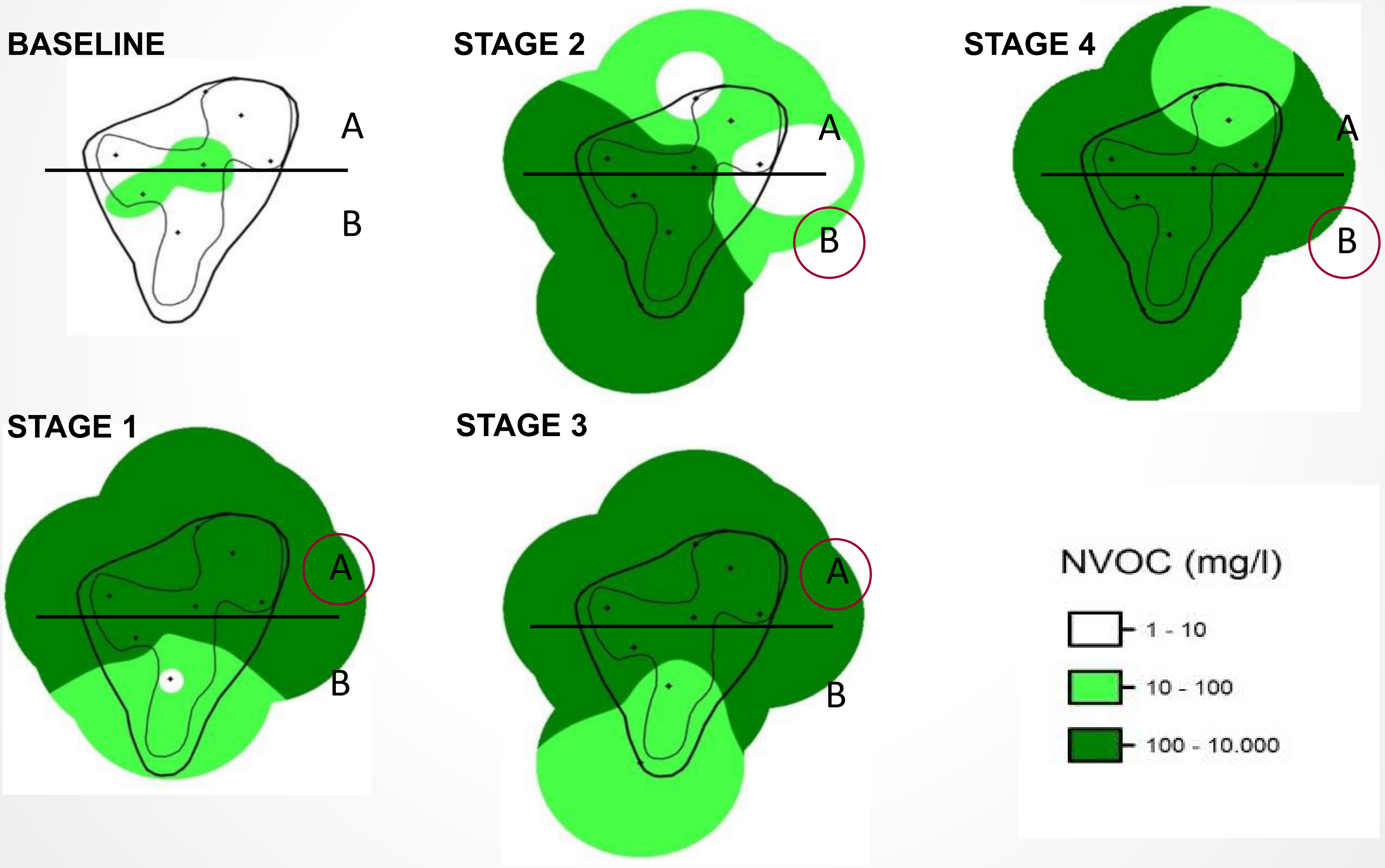
Injection wells

Monitoring wells

Electromigration: Donor transport

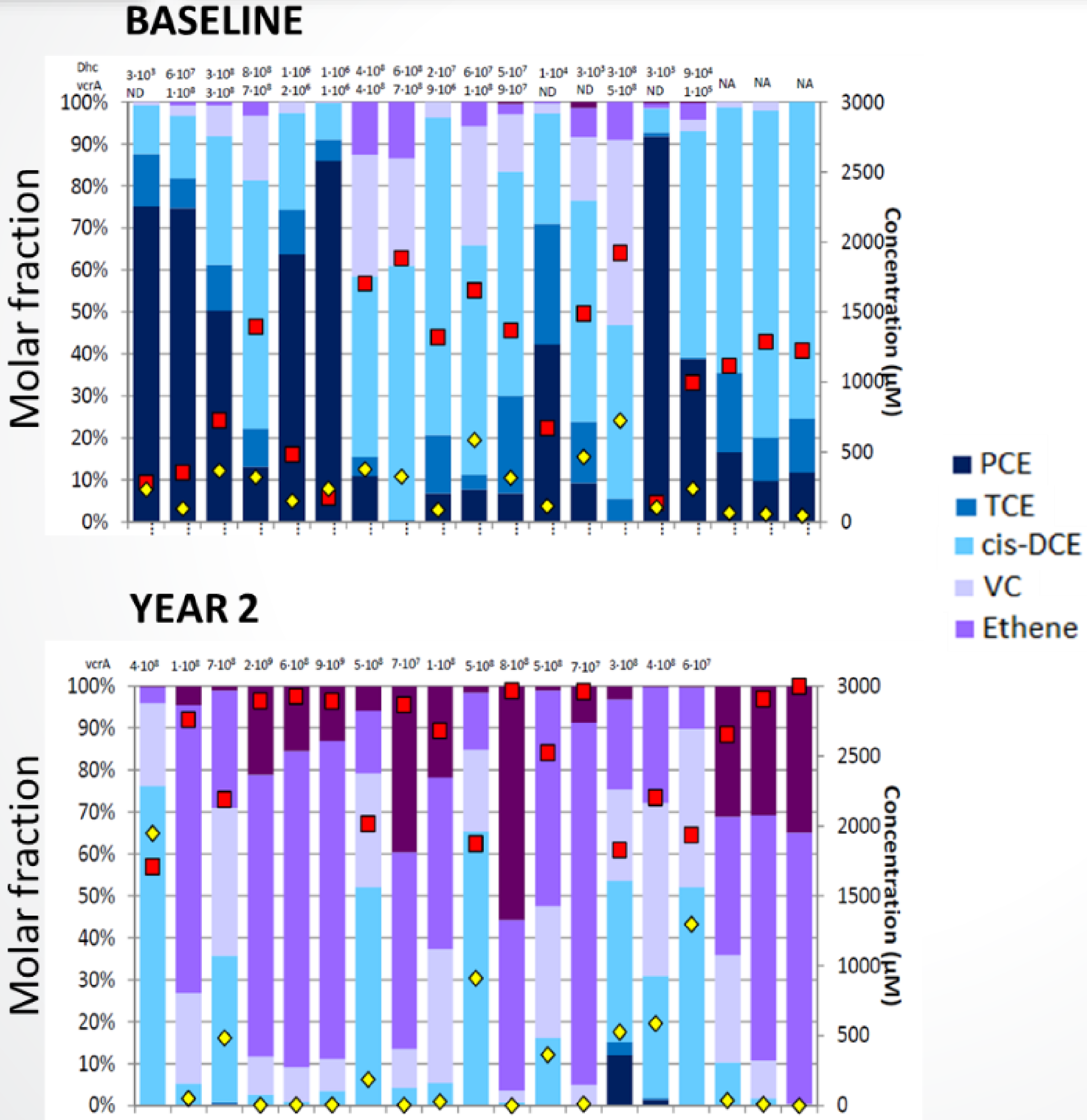


Achieved Distribution of Electron Donor



Achieved PCE Reductive Dechlorination to Ethene

GW Quality "Signature"



Biodegraded 285 kg of PCE in the treatment zone (>98% of the estimated pre-remedy total).

Rebound testing 6 months after cessation of EK-BIO operation confirmed sustained microbial dechlorination activities (degree of dechlorination increased) and compliance with the remedial goals.

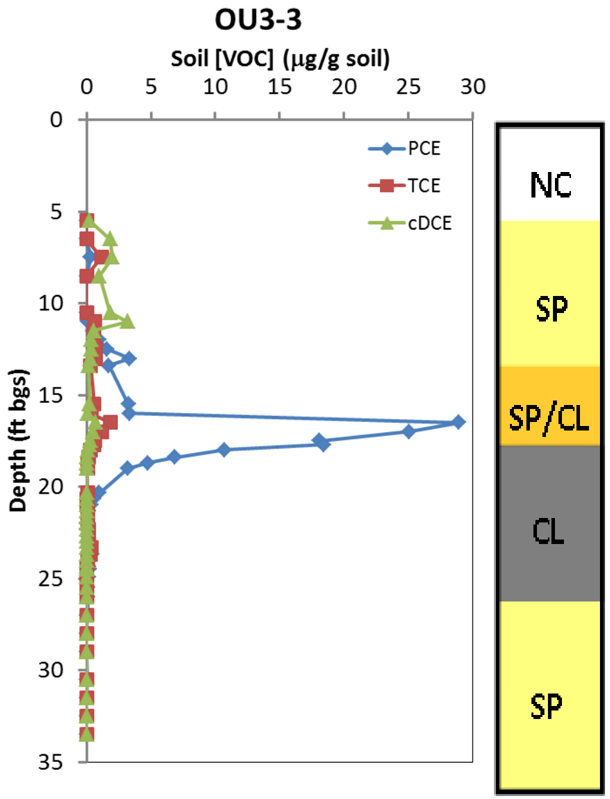
Capital Region of Denmark: No Furth Action for Source Remediation → GW MNA

Case – EK-BIO Field Demonstration at Naval Air Station Jacksonville, Florida

- Former dry cleaner
- Source for a large dissolved plume
- Source area now under an active parking lot
- Many existing subsurface utilities

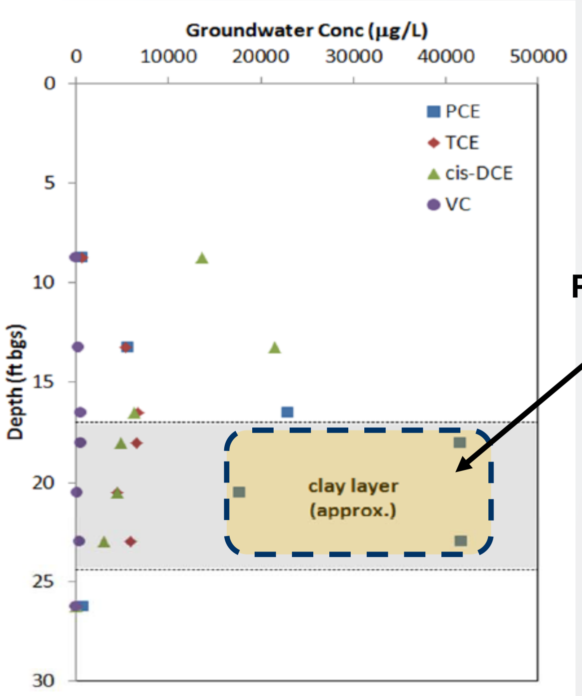
Classic example of contaminant mass diffused into low-K materials.

Long-term source for the shallow sand aquifer plume

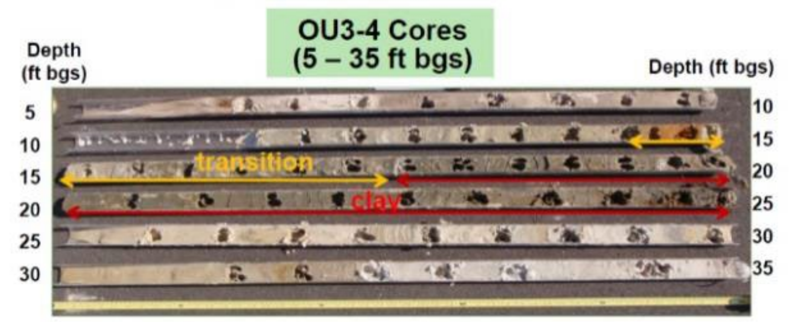


NC – not characterized; SP – sand; CL – clay

(From ESTCP ER-201032)



PCE at 15 – 40 mg/L in clay (long term source)



EK-BIO Demonstration Design

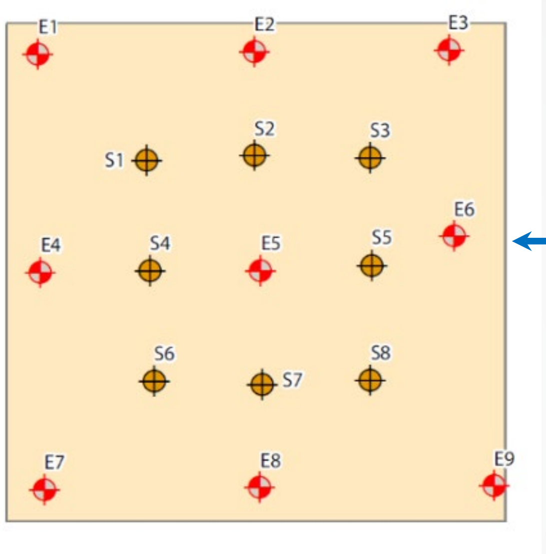
~ 35 ft x 35 ft Target Test Area

9 Electrode Wells (~ 17.5 ft spacing)

8 Supply Wells (no electrode)

<u>Electrode Wells & Supply Wells</u>

- 4-inch PVC casing; 0.01-inch slotted screen;
- Screen interval – 19 to 23 ft bgs (**all within clay**)
- Electrode – titanium rod (3/4-inch dia.) with MMO coating



Electrode Well

Supply Well

<u>DC Power Supply Unit :</u>

Input – 120 / 240V, 3-phase AC

Output – up to 24 A / 250V DC

<u>Monitoring Wells</u> : double-cased; screened in clay only

EK-BIO Remediation Construction / Installation

Parking lot in use during demonstration

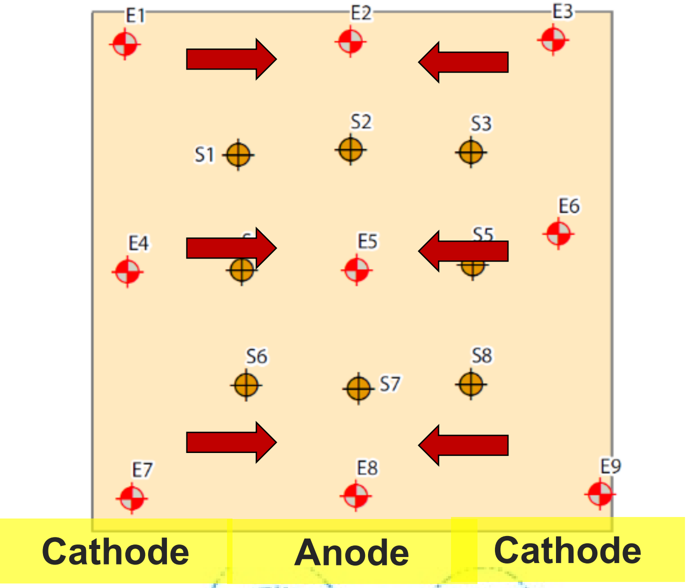
EK System Center

w/ Bioaugmentation of Dechlorination Culture

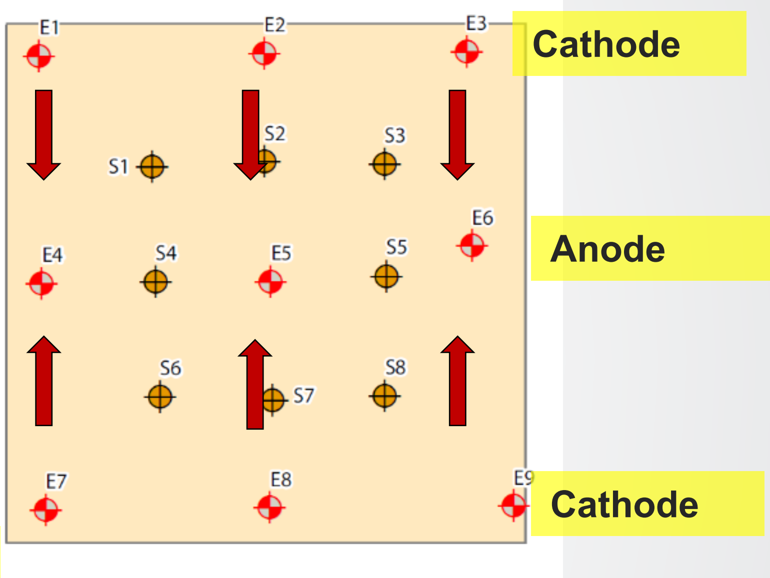
EK-BIO Remediation Operation

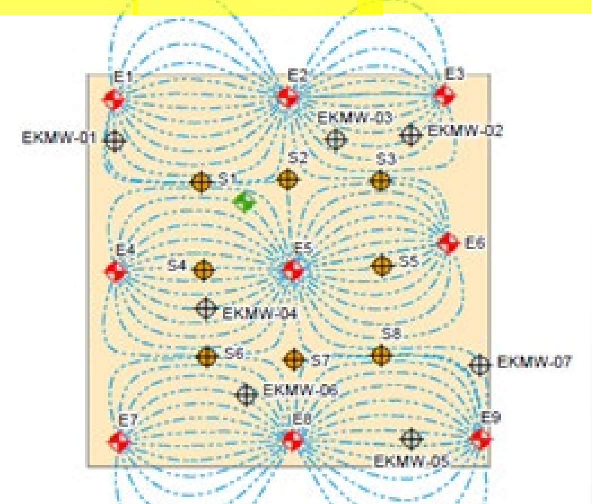
- Two stages, each stage = 5 months active operation
- Electrical Power – **8 A to 9 A; 22 to 31 V**
- Total power ~ **1,500 kW-hr** (~ **two 100-W lightbulbs** for the same duration)
- Lactate & Buffer Amendment Supply
- Bioaugmentation at Supply Wells & Electrode wells
- No overpressure injection

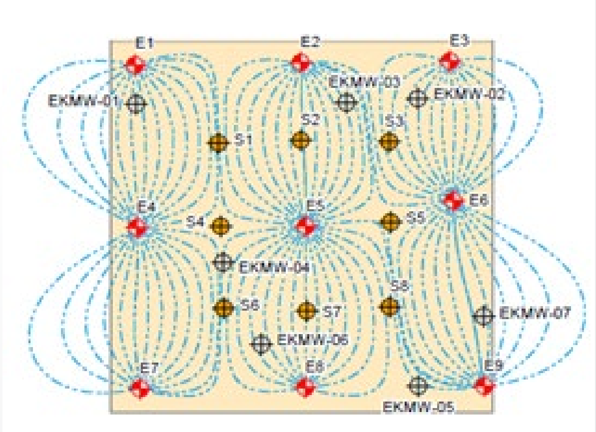
Stage 1 Operation



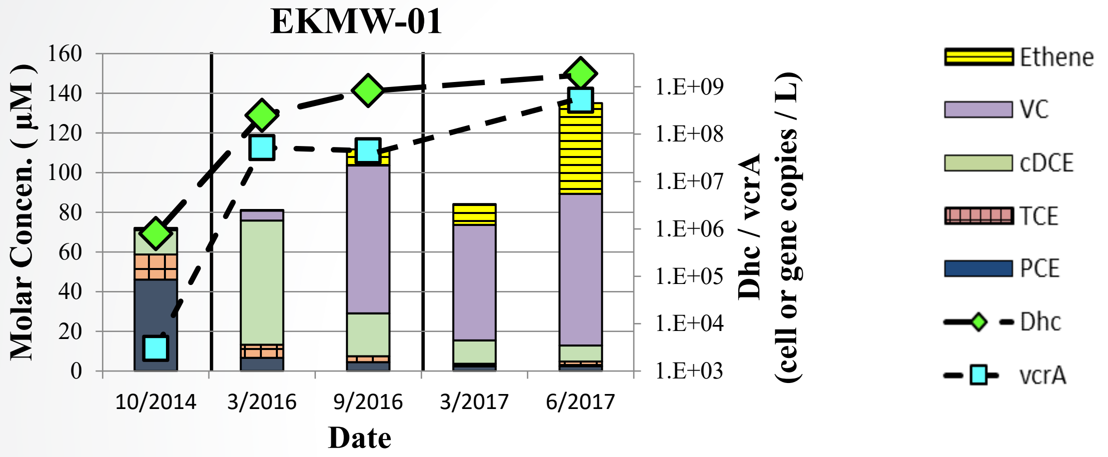
Stage 2 Operation

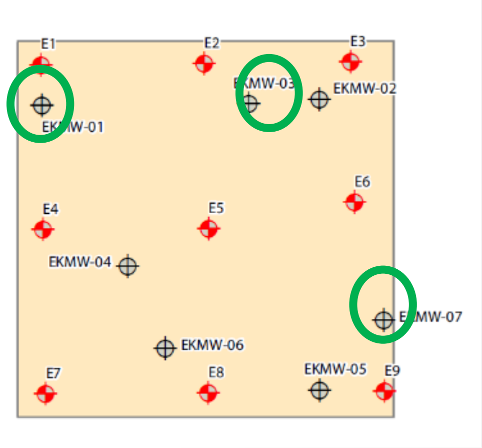




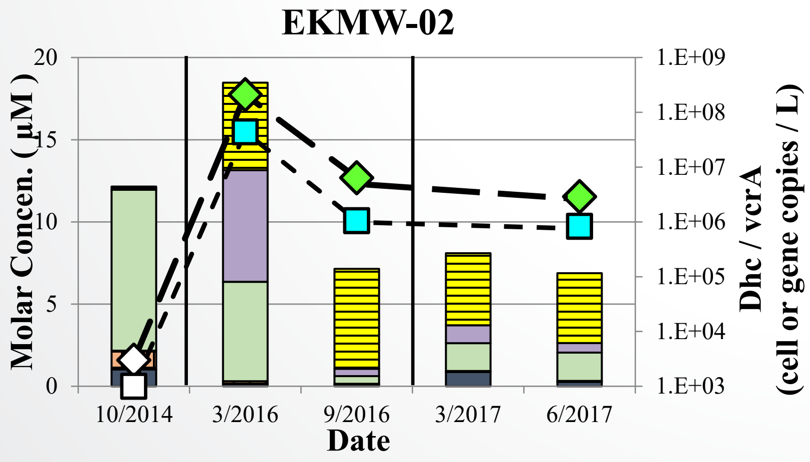


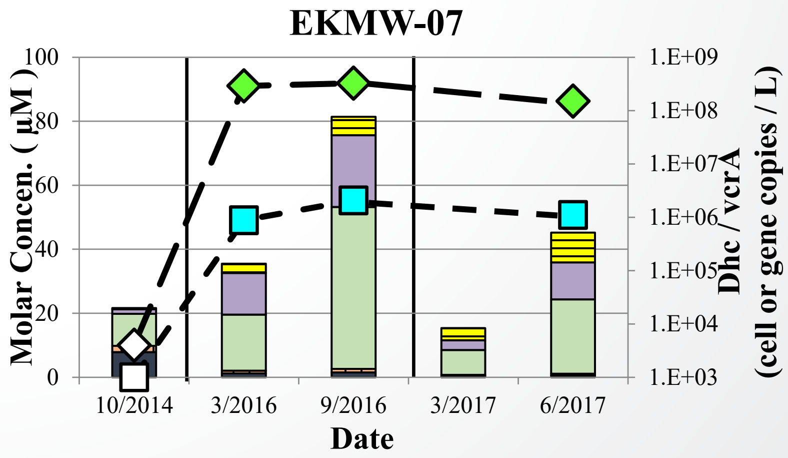
Groundwater Monitoring Within Test Area – VOCs and Biomarkers





Apparent and significant increases of dechlorination end products and genetic biomarkers of dechlorination bacteria

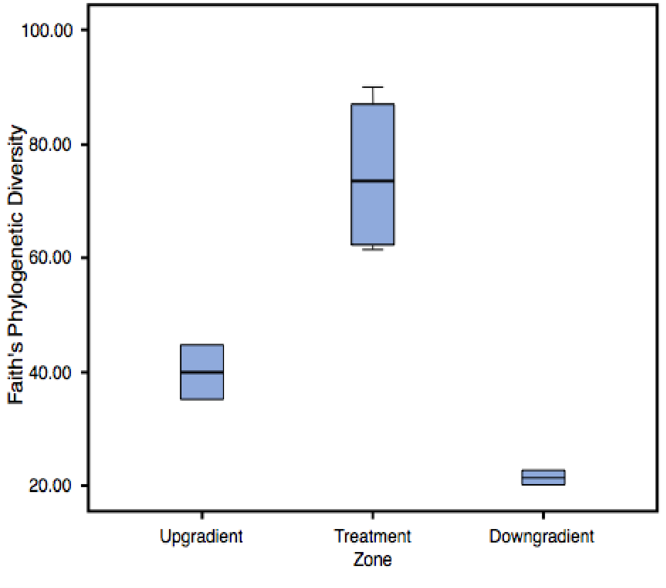




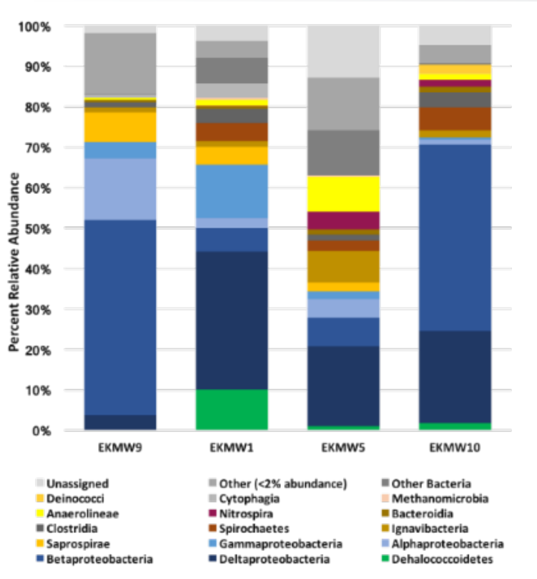
Microbial Community Structure Analysis by Next Generation Sequencing (NGS)

- **Increased biomass**: total biomass from within test area >> that in background wells

- **Increased microbial diversity within test area** : calculated Alpha diversity (mean local species diversity) in test area >> upgradient and downgradient background wells.



Calculated Microbial Diversity



NGS Data
(source: ASU)

Arizona State University

CBBG
Center for Bio-mediated & Bio-inspired Geotechnics

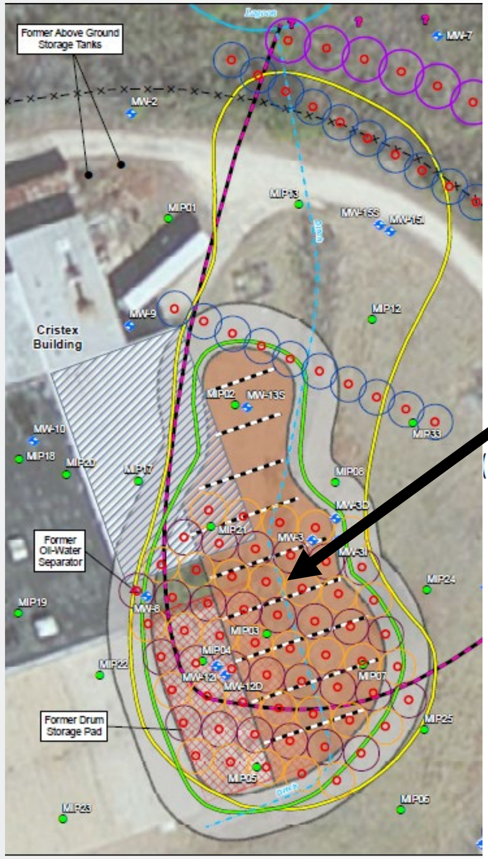
Case – EK-ISCO Pilot at Cristex Drum Superfund Site Oxford, North Carolina

- Facility operated as a textile manufacturer between 1968 and 1986

- Primary contaminants include VOCs and SVOCs, with **PCE** being the most widespread

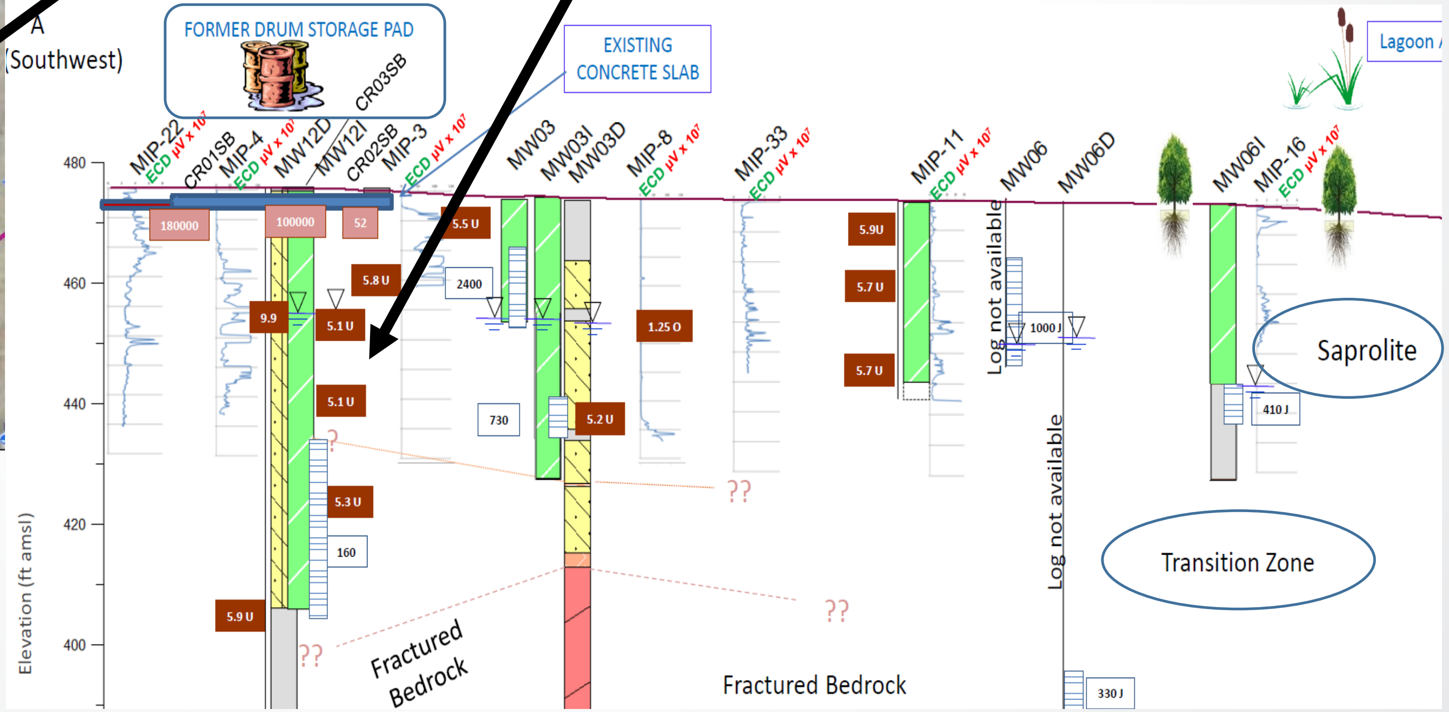
- Contaminant source – leaks/spills from former drum storage pad, oil-water separator, above-ground fuel tanks

EK-ISCO Pilot at Cristex Drum Superfund Site Oxford, North Carolina



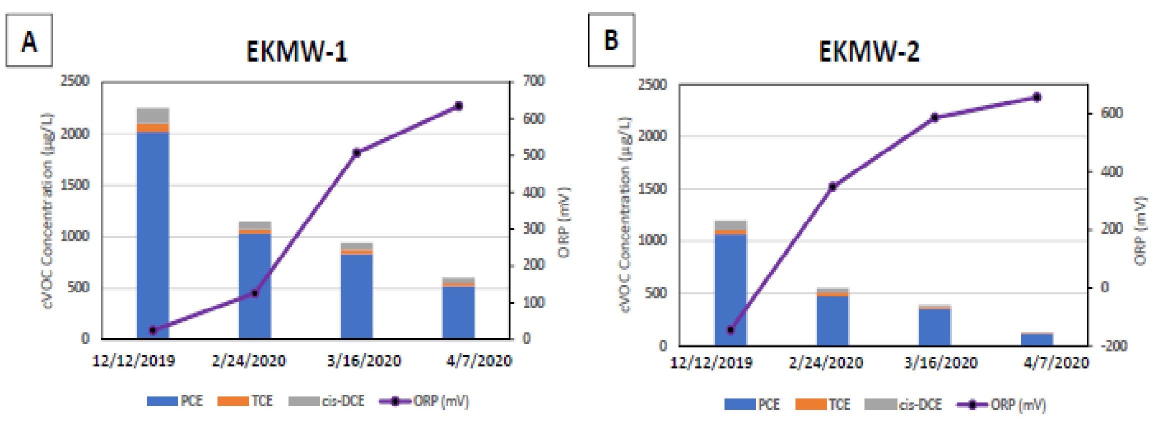
Objective – Pilot test EK-ISCO for remediation of **PCE sources in** the **saprolite** formation

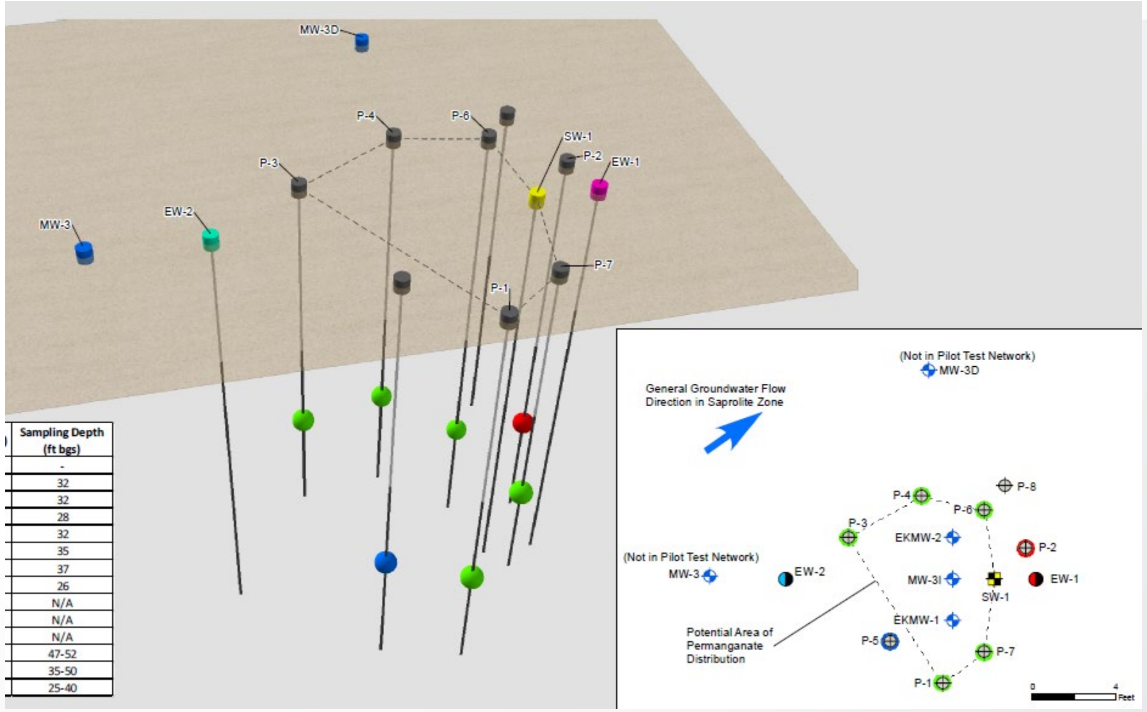
Saprolite – relatively low-permeability, highly heterogeneous



EK-ISCO Pilot at Cristex Drum Superfund Site Oxford, North Carolina

- EK Transport of **permanganate** within pilot test area (57 days; Jan. – Mar. 2020)
  - Decreases in CVOC concentrations coupled with Increases in ORP
  - Distribution detected cross-gradient and upgradient from supply well (up to 7.3 ft upgradient)
  - EK "net" transport rate for permanganate of **1.3 to 4.1 ft / month in saprolite**
  - 152 kW-hr used over 57 days (low electrical energy utilized)

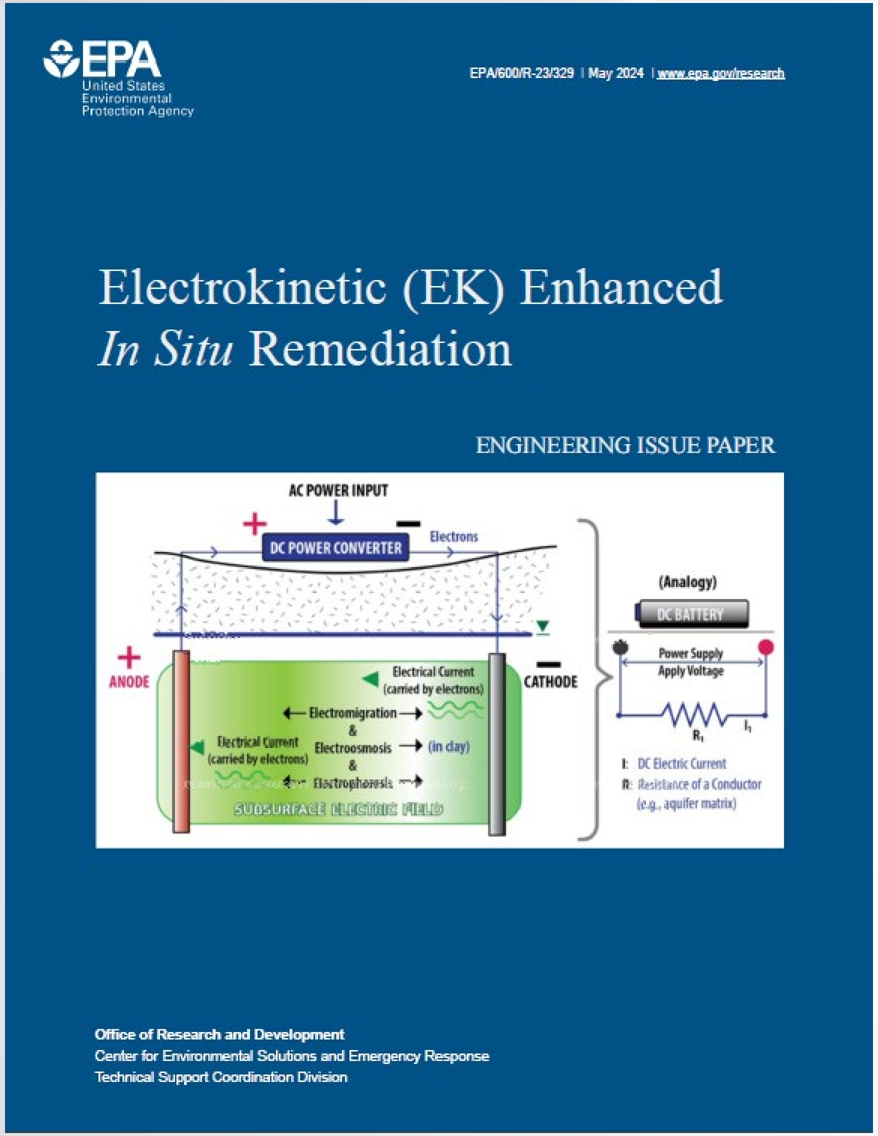




EK Pilot Test System Trailer

EK Enhanced In Situ Remediation in Low-K Geology
Key Takeaway Messages

- **In Situ Remediation Needs Effective Delivery**!
- Achieved treatment **within clay** materials
- Low energy demand [e.g., DC amperage & voltage less than 10A, 35V]
- A **fundamentally different** solution to a vexing problem
- **EIP provides stepwise approach** - technology screening / evaluation / selection through treatability study and pilot test leading to remedial design and remedy implementation
- EIP includes several **case studies** with more specifics
- More technology development ongoing


EPA United States Environmental Protection Agency

EPA/600/R-23/329 | May 2024 | www.epa.gov/research

Electrokinetic (EK) Enhanced *In Situ* Remediation

ENGINEERING ISSUE PAPER

Office of Research and Development
Center for Environmental Solutions and Emergency Response
Technical Support Coordination Division

Questions ?

James Wang
JWang@Geosyntec.com