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USEPA / Taiwan EPA Technical Exchange

An Innovative Solution for Sites with Low-Permeability Geology: Electrokinetic (EK) Amendment Delivery for In Situ Remediation

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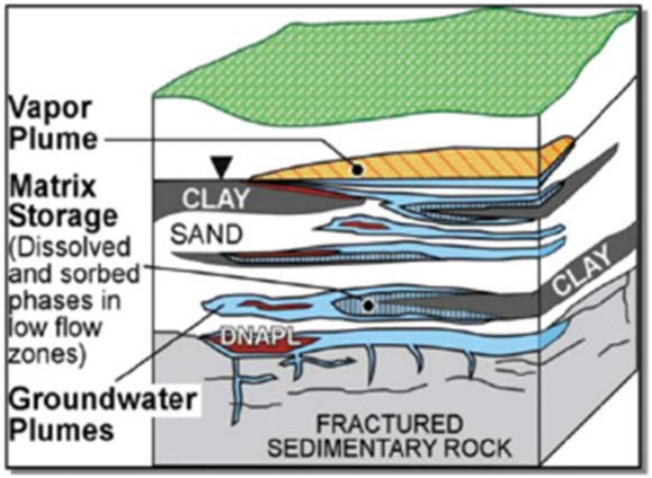
Why are we talking about this topic today ?



From ESTCP, ER-200530

Contaminants diffused into low permeability (low-K) materials serve as secondary sources 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 required for low-K sites

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Electrokinetic (EK) for Subsurface Transport

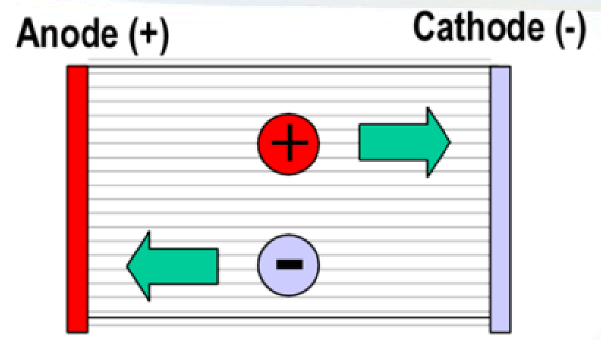
- Application of direct current (***DC***) to saturated subsurface

- 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 Subsurface Transport – Electromigration (Ion Migration)

- **Electromigration** is the movement of ions in an electric field. Ions are attracted to the electrode of opposite charge
- Electromigration occurs as long as there is a connected water pathway, and the rate is proportional to the gradient of the applied field
- Ion migration velocity related to electrical gradient (driving force)



Anions: negatively charged ions
Cations: positively charged ions

Anode: Positively charged electrode
Cathode: Negatively charged electrode

Voltage Gradient

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

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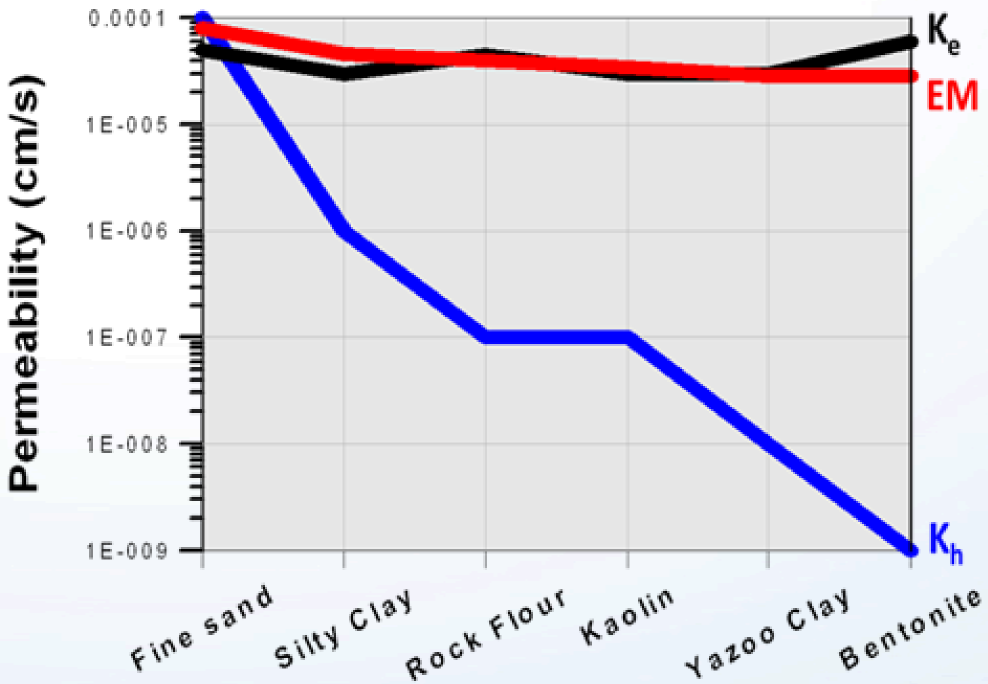
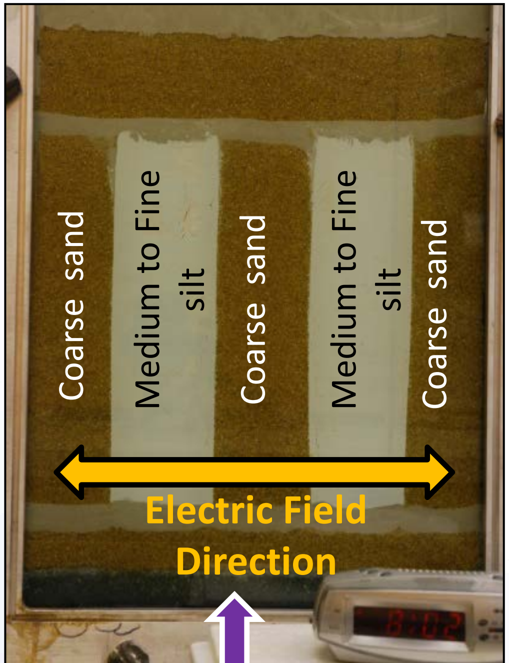
EK Transport is Fundamentally Different

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

- **EK transport relies on electrical properties of soil (not hydraulic)**
- **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)

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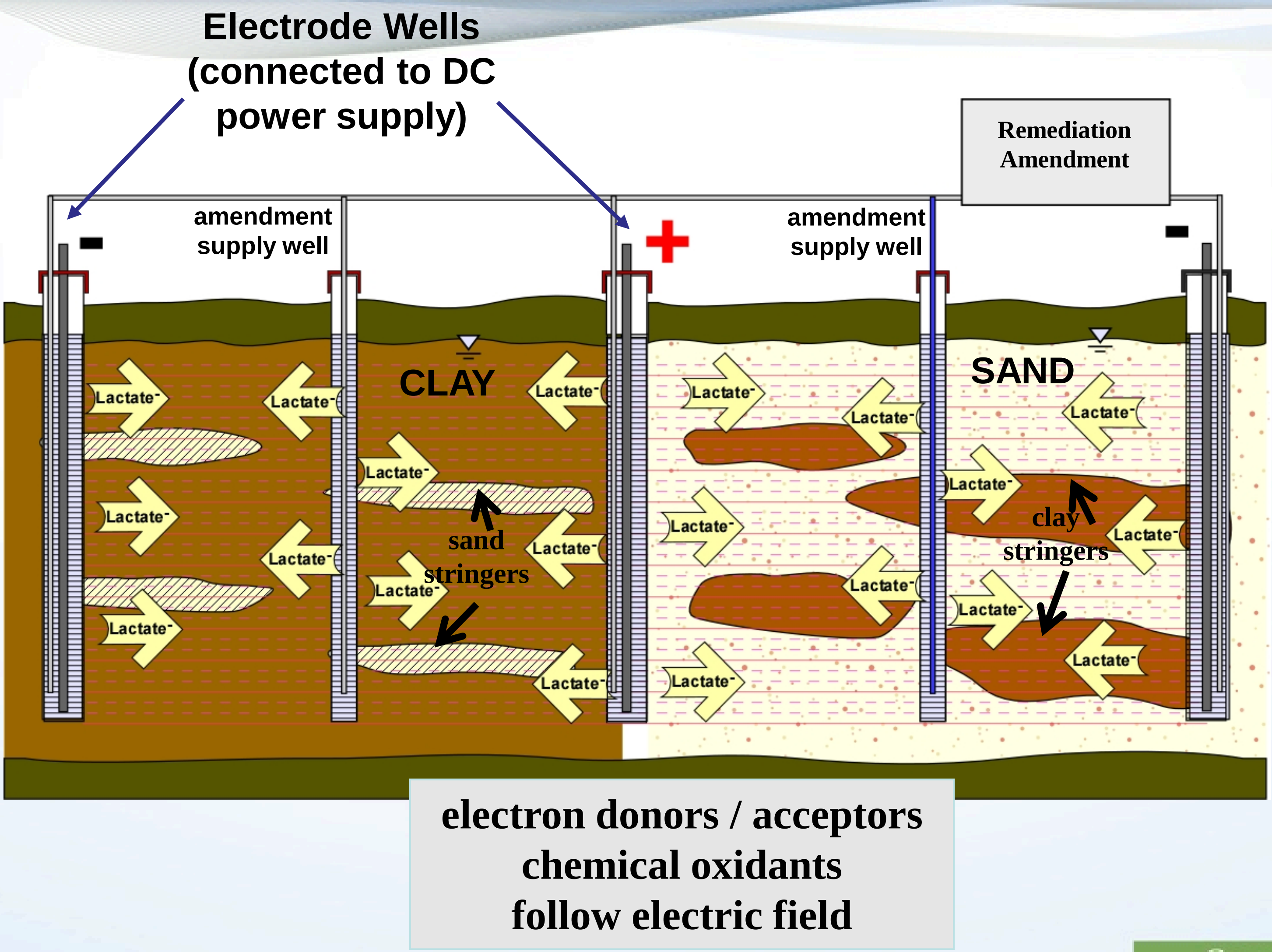
How is EK Implemented in the Field?



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

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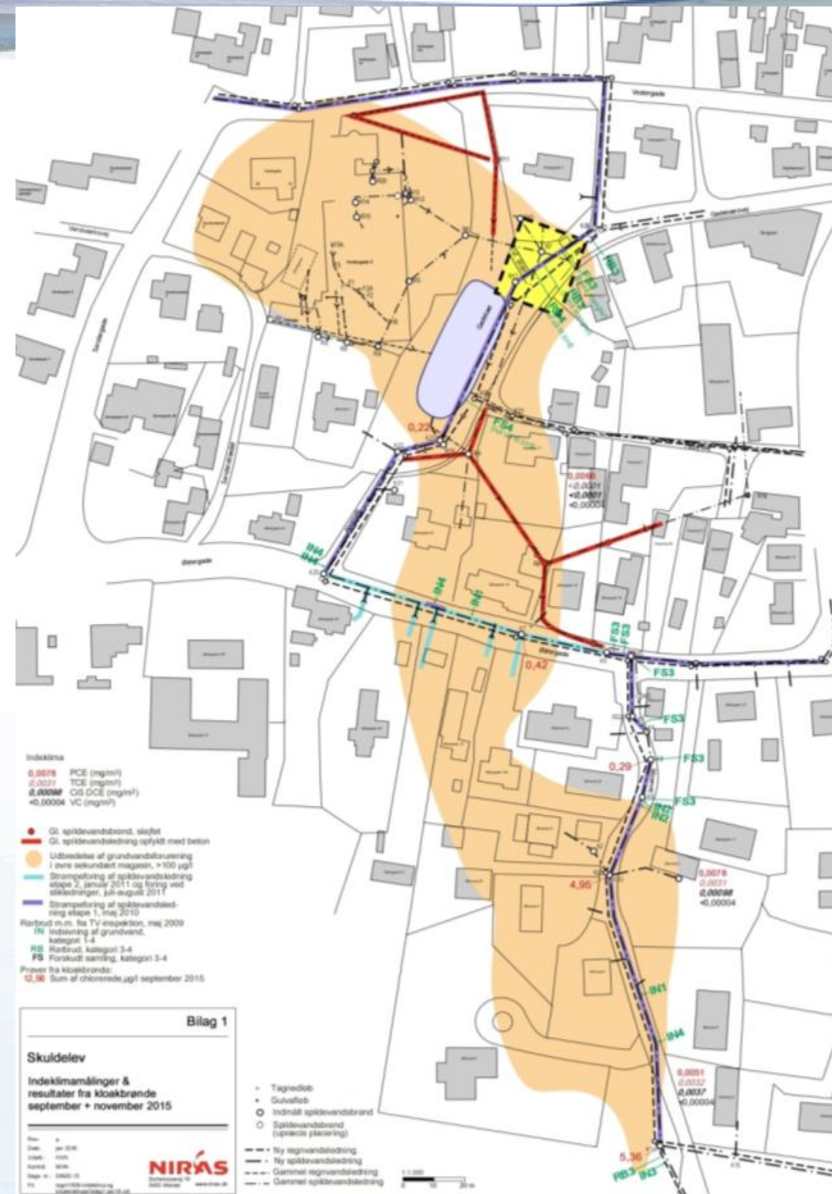
From Bench to Full-Scale EK-BIO™ Skuldelev, Denmark



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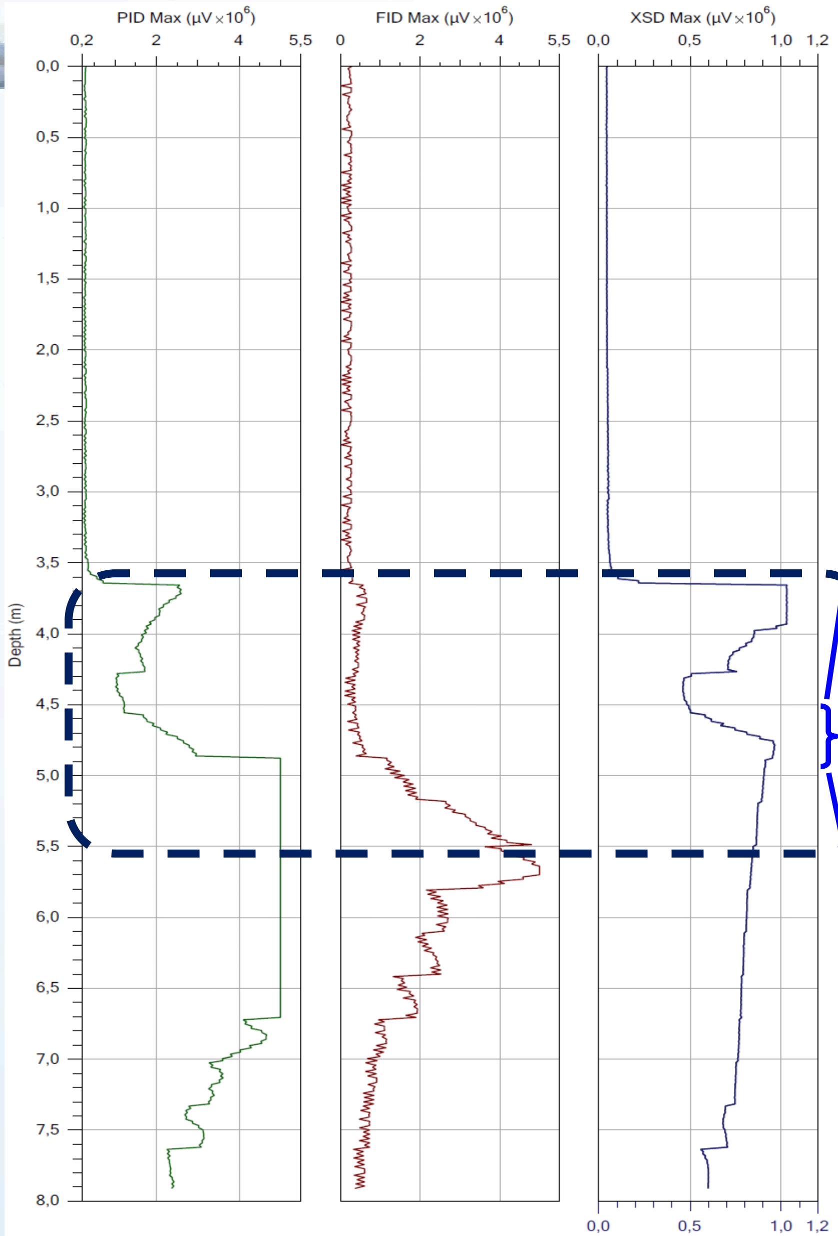
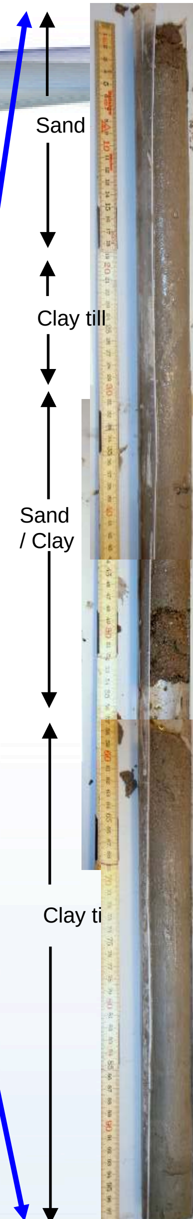
Targeting PCE DNAPL in Clay Till





Soil
mg/kg TS
PCE
TCE

76
1,4

6,6
0,03

21.000
79,0

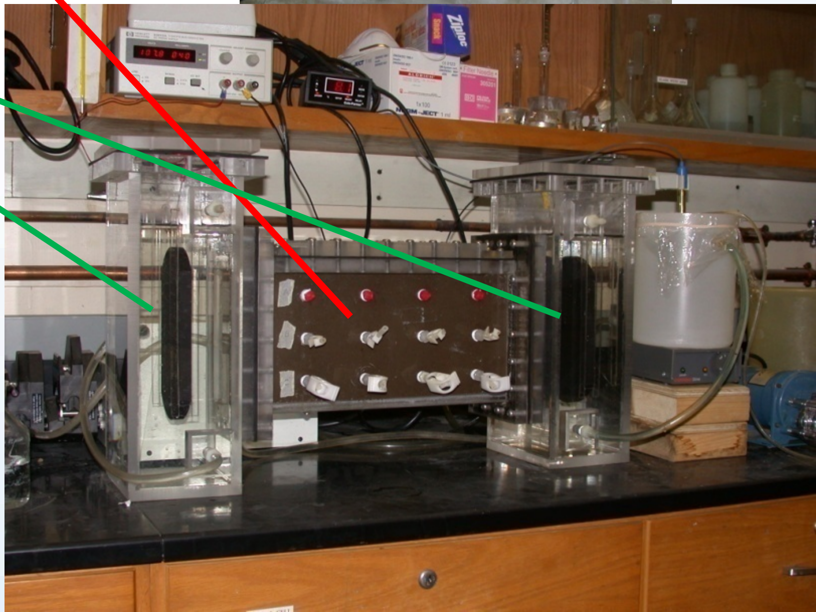
250
0,78

270
0,42

450
2,70

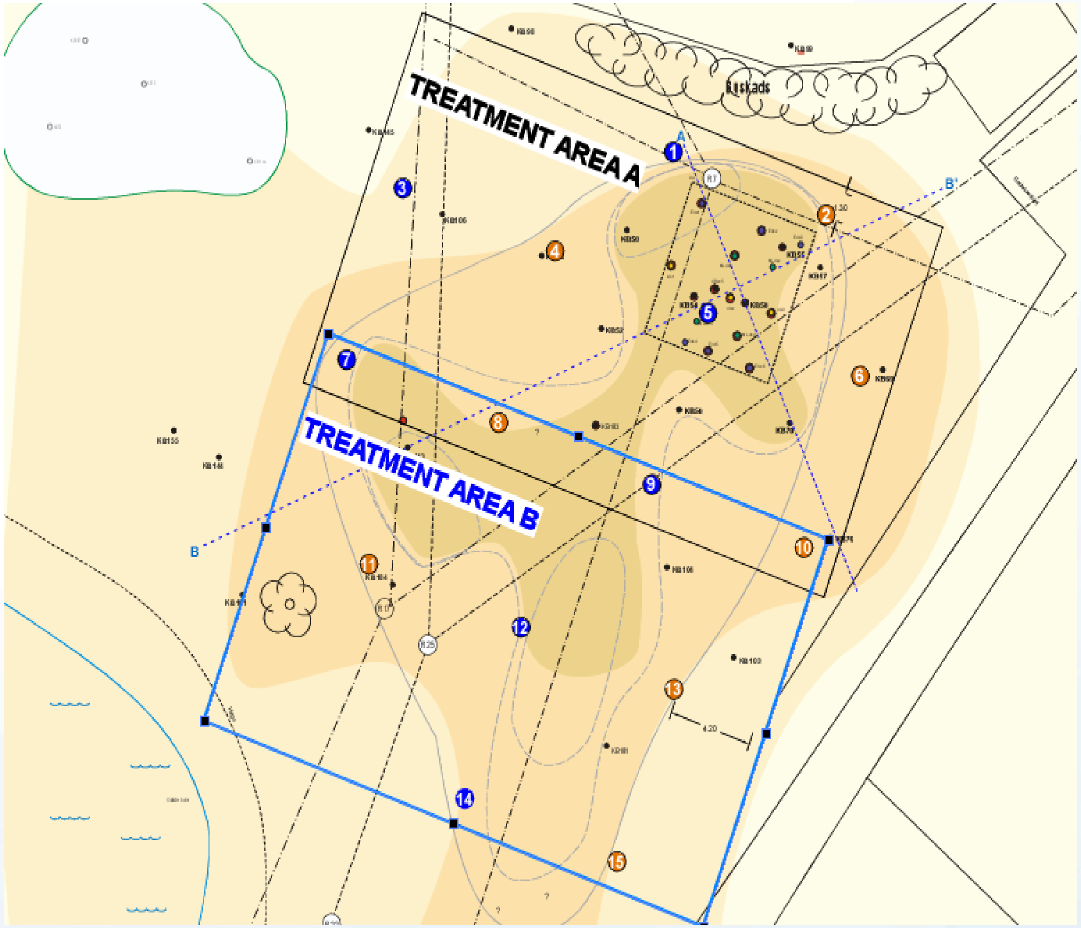
Bench-Scale EK-BIO™ Treatability Test

- **Bench Scale EK Reactor (40 cm x 15 cm x 5 cm test cell)**
- **Two 5-Liter electrode chambers; with cross-circulation & gas vent**
- **Electrodes : graphite plates**
- **DC power supply and control**
- **Compaction during setup**



Full-Scale EK-BIO™

- 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
- From December 2012 – two years operation



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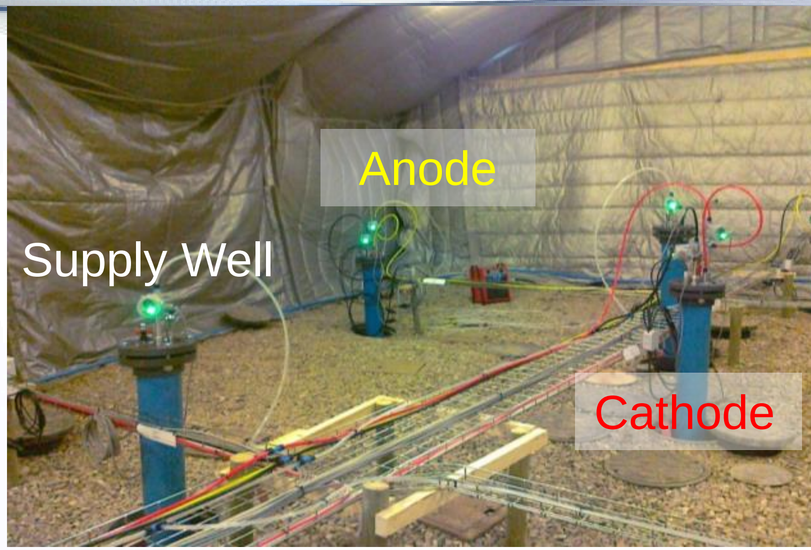
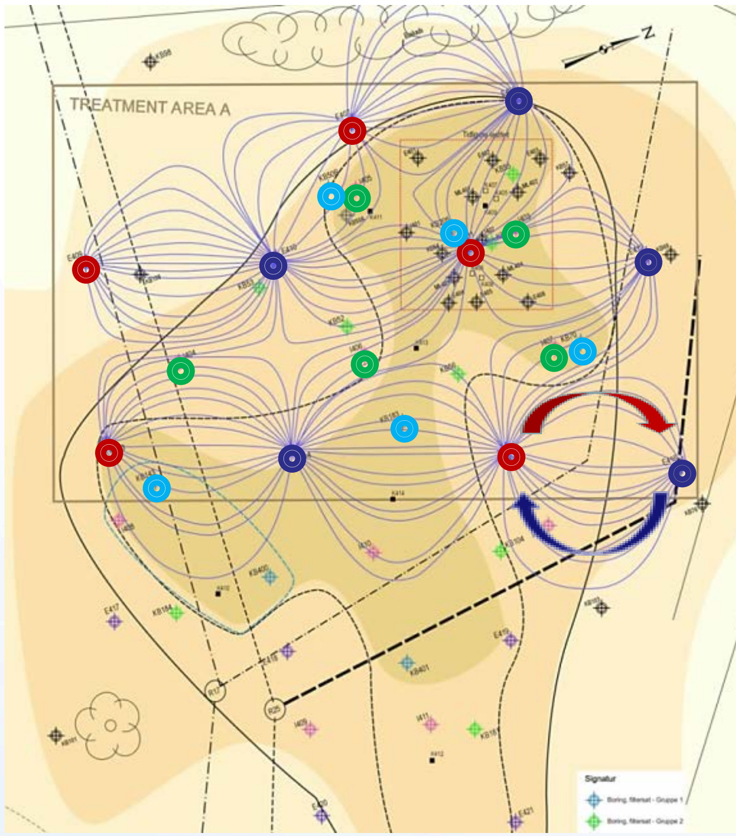
Full-Scale EK-BIO™



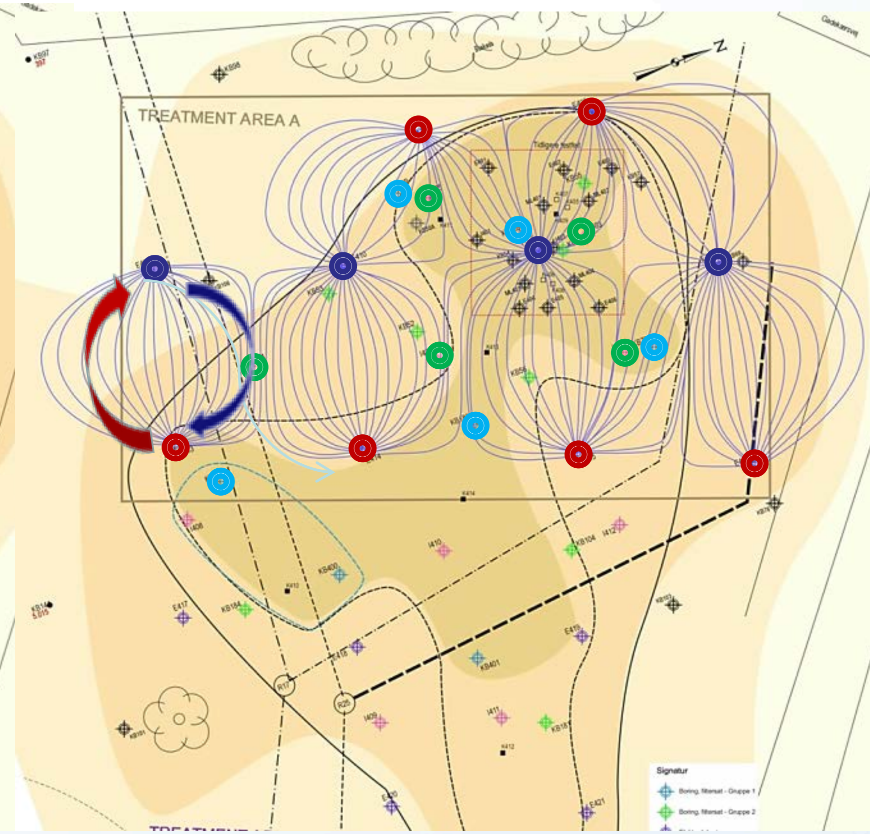
Amendment Supply and System Control

Flexible Electrific Field Orientations

- Anodes (+)
- Cathodes (-)
- Supply wells
- Monitoring wells



Stage 1: Operation period dec. 2012 – apr. 2013



Stage 3: Operation period sep. 2013 – dec. 2013

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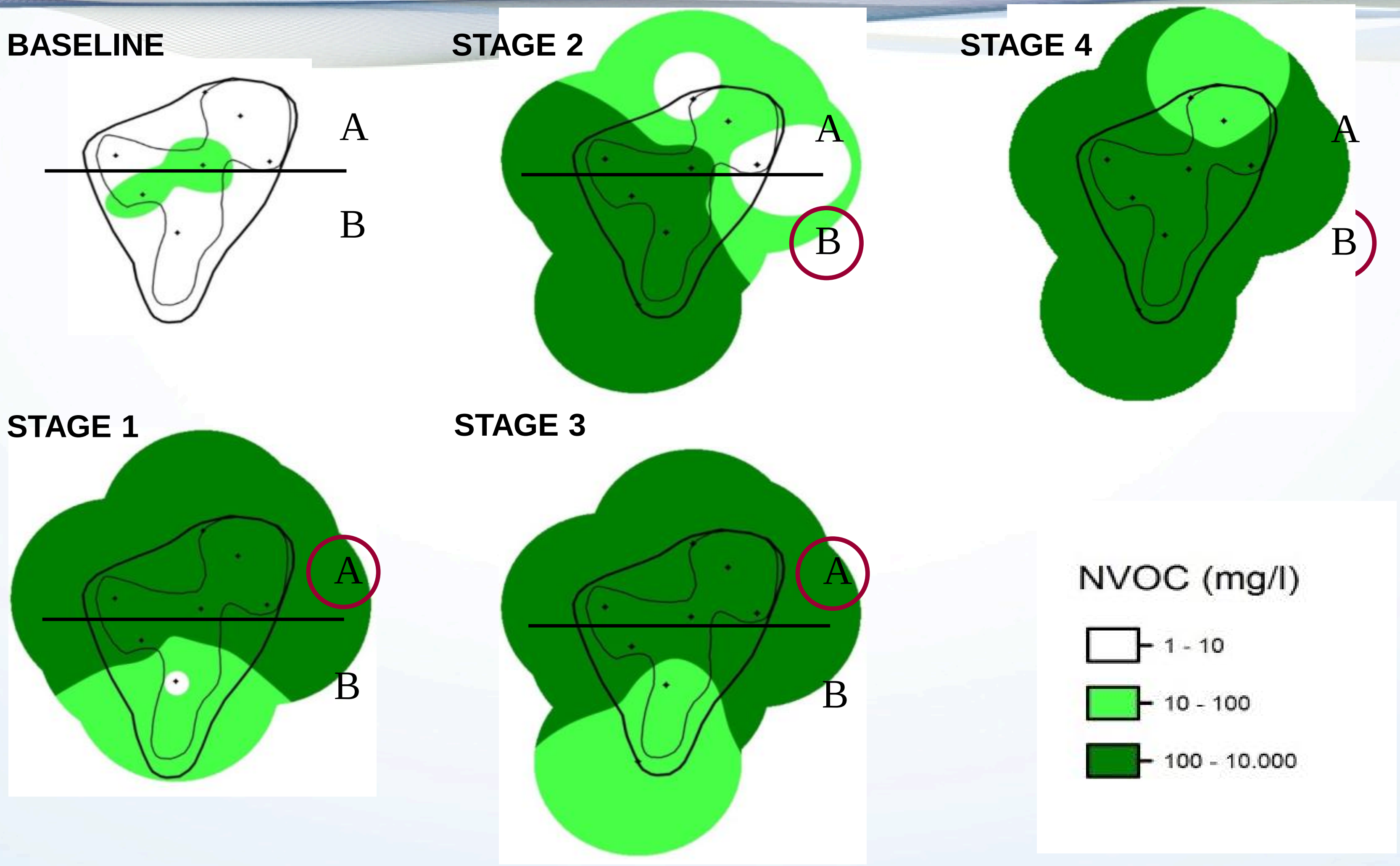
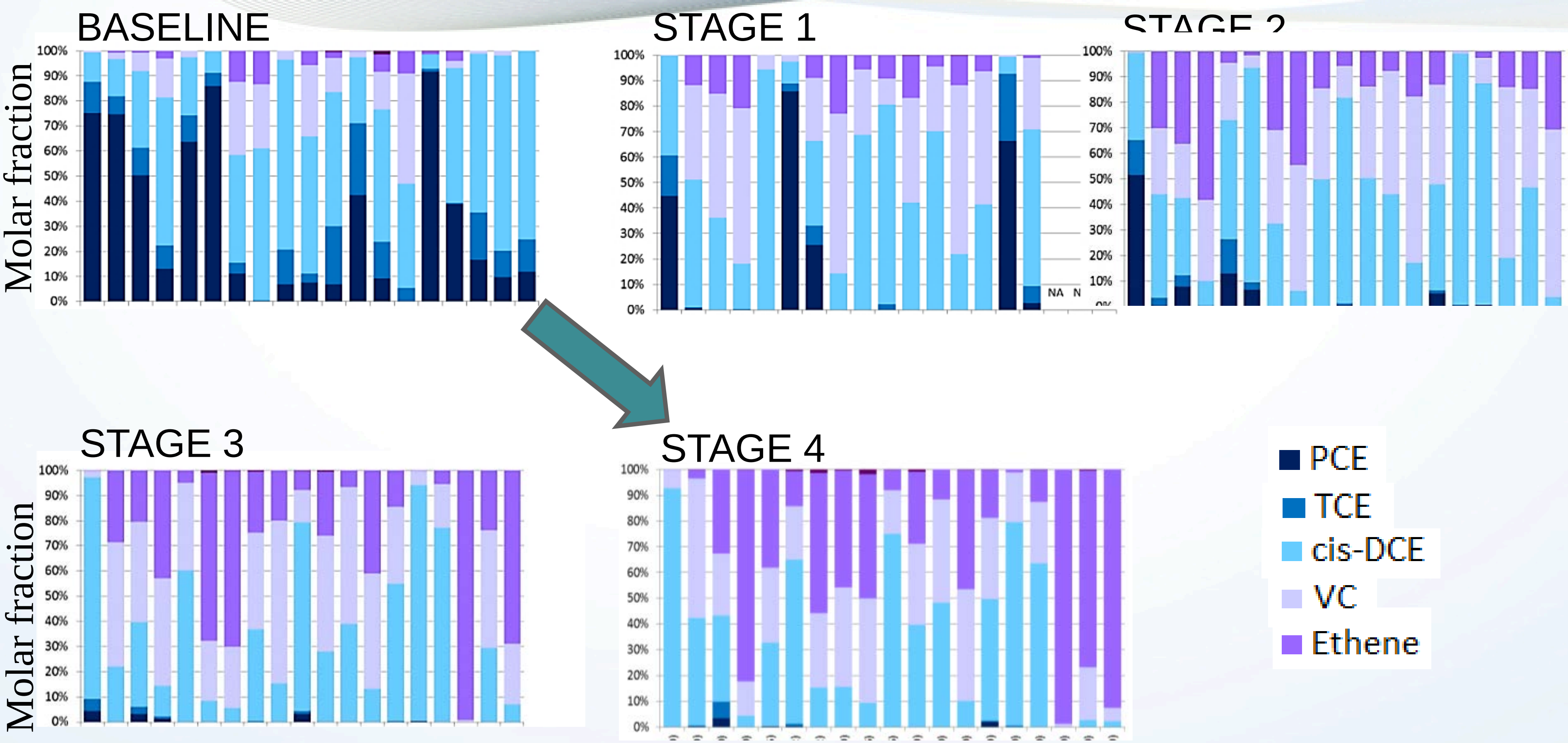
Distribution of Electron Donor



PCE Reductive Dechlorination to Ethene



Danish EPA → No Furth Action for Source Remediation

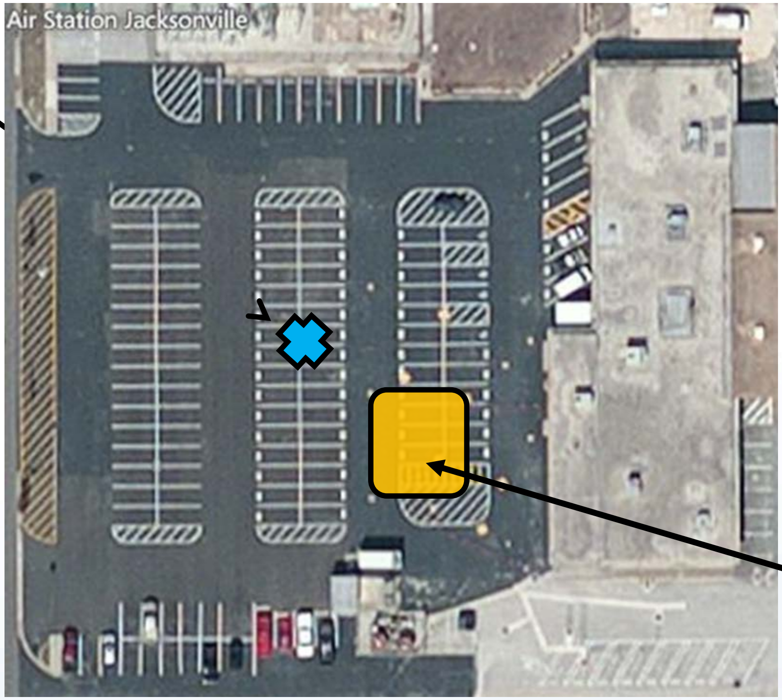
EK-BIO™ Technology Demonstration at Naval Air Station Jacksonville, Florida

Former dry cleaner

Source for a large dissolved plume in shallow sandy aquifer

Source area now under an active parking lot

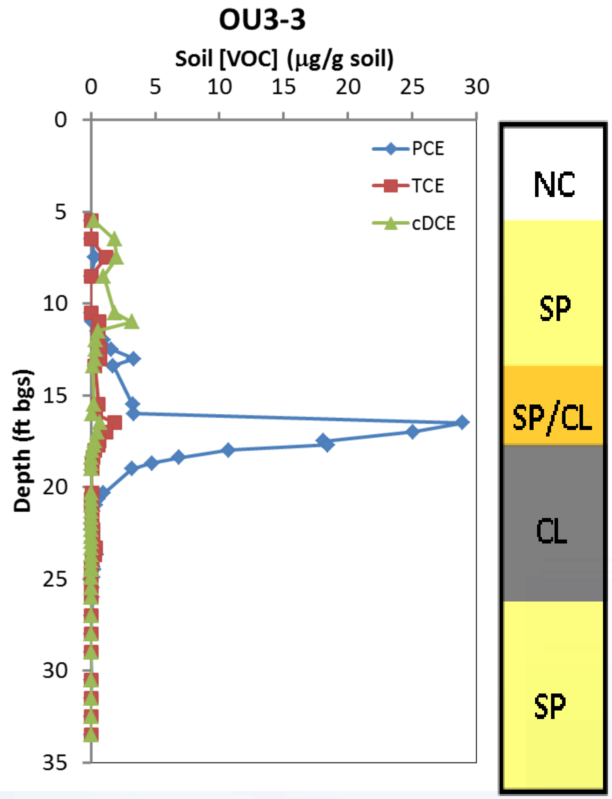
Many existing subsurface utilities



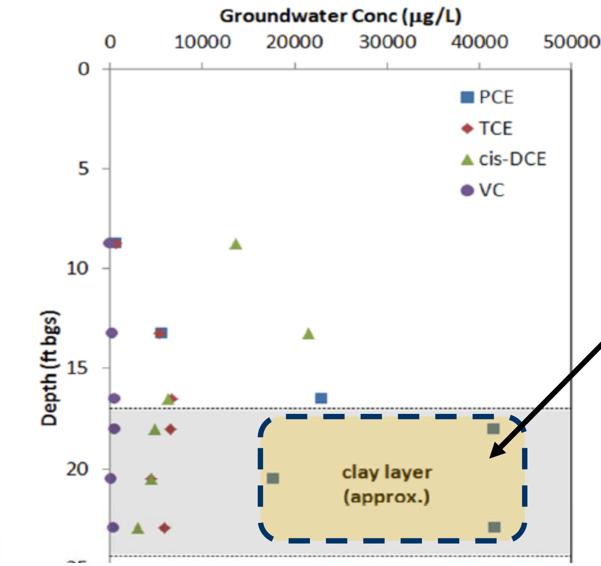
Demonstration Area

Source Area Characterization

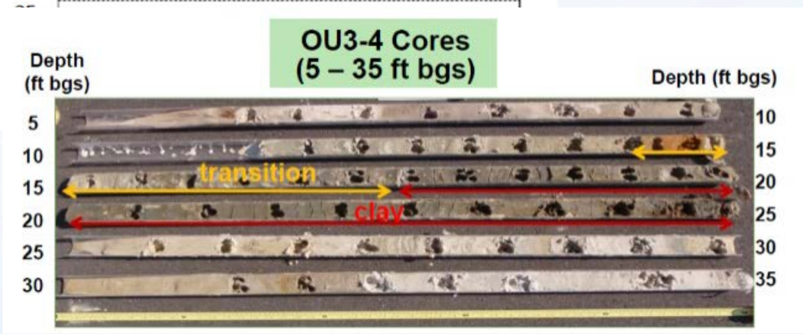
Classic example of **contaminant mass diffused into low-K** materials.



NC – not characterized; SP – sand; CL – clay
(From ESTCP ER-201032)



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



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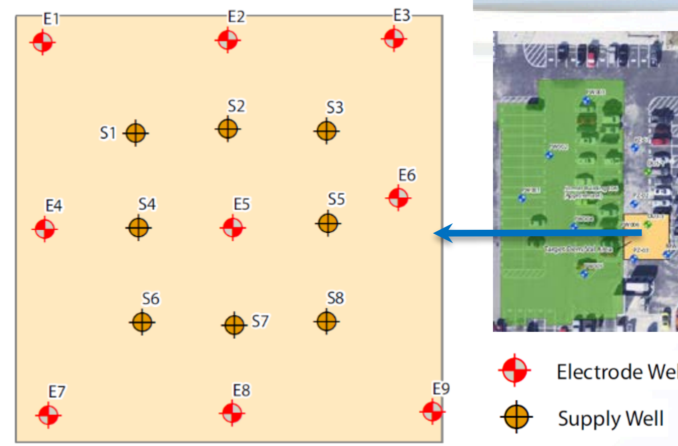
EK-BIO™ Demonstration Test Design

~ 35 ft x 35 ft Target Test Area

9 Electrode Wells (~ 17.5 ft spacing)

8 Supply Wells (no electrode)



<u>Electrode / 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

<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

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EK Remediation Construction / Installation

EK System Center

Bioaugmentation of Dechlorination Culture

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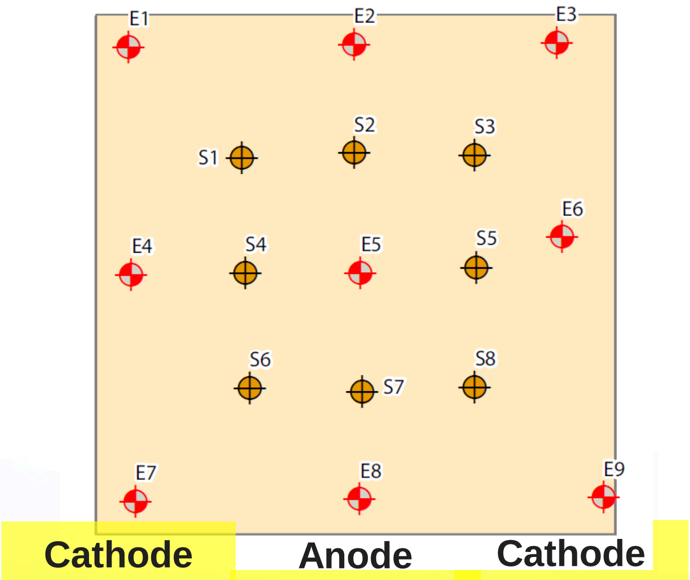
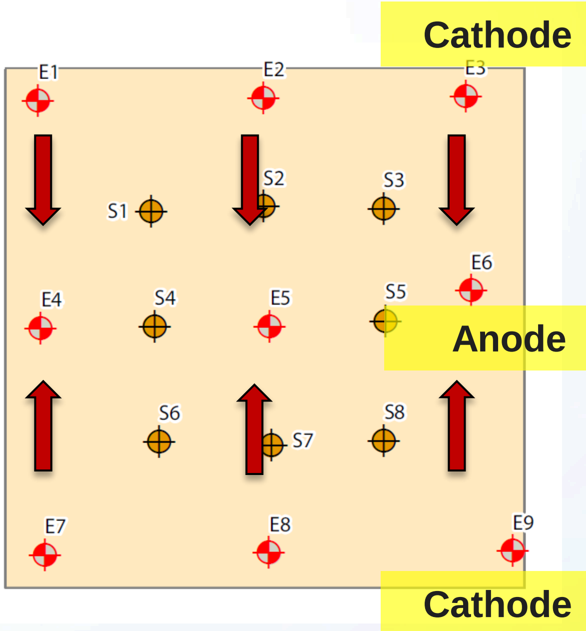
EK Remediation Operation

- 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



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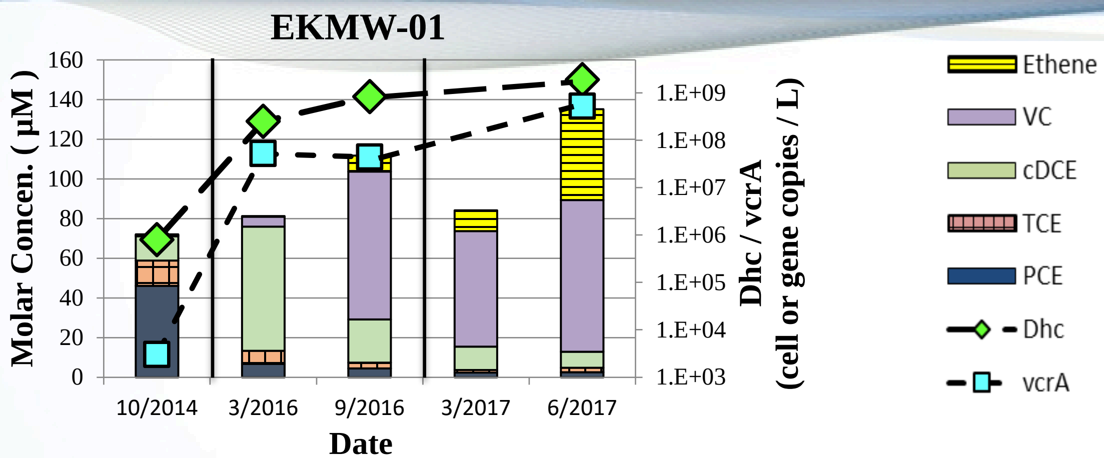
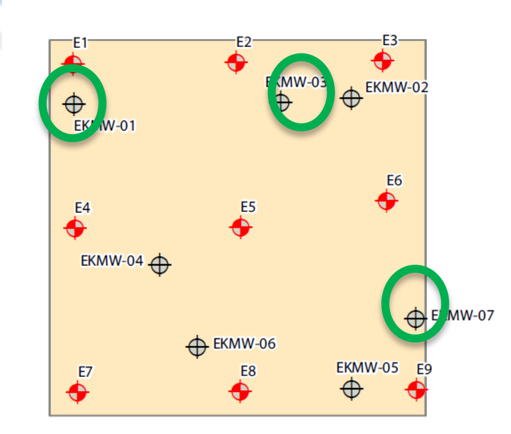
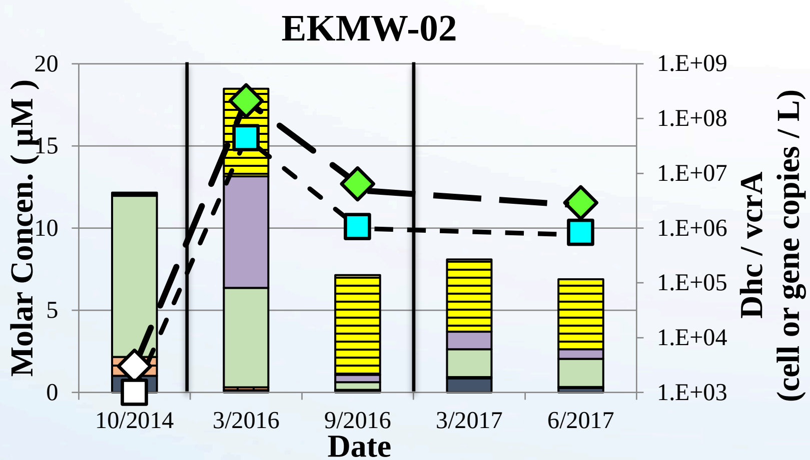
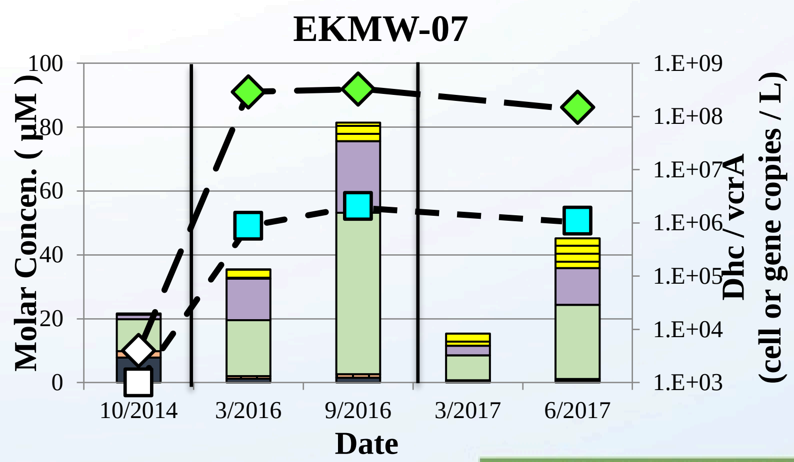
Groundwater Within Test Area – VOCs and Biomarkers





Apparent increases of dechlorination end products and microbial genetic biomarkers

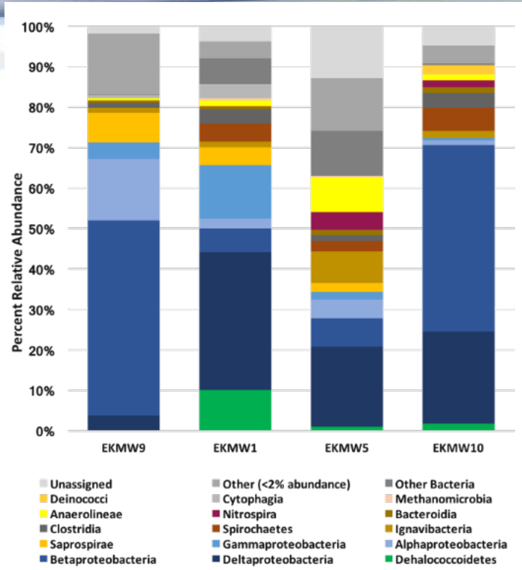




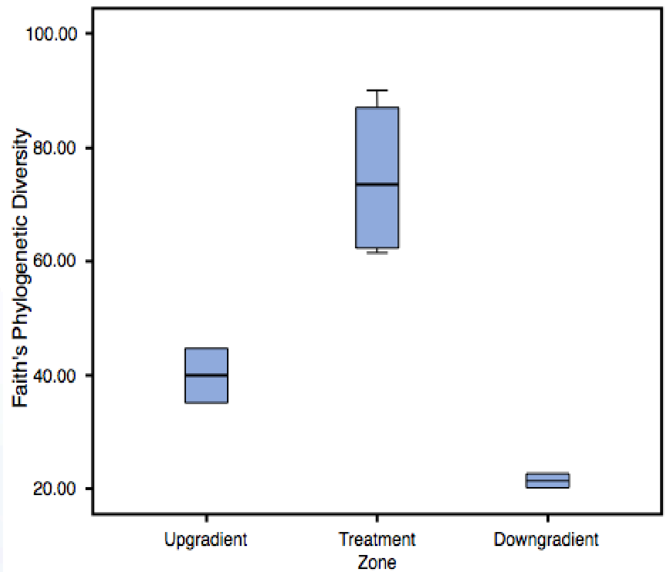
Microbial Community Structure Analysis by Next Generation Sequencing (NGS)

- **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.



NGS Data (source: ASU)



Calculated Microbial Diversity

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

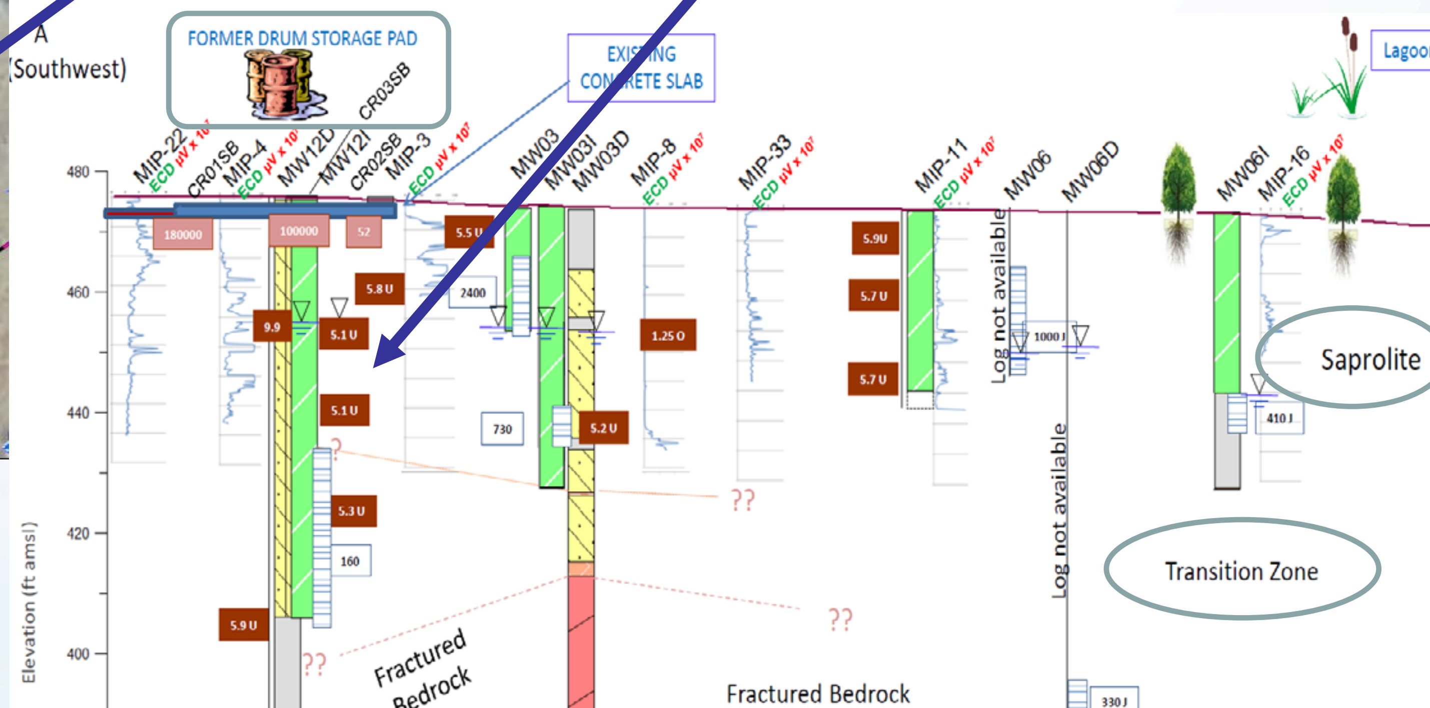
Facility operated as a textile manufacturer between 1968 and 1986

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 Test
USEPA Cristex Drum Superfund Site
Oxford, NC

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



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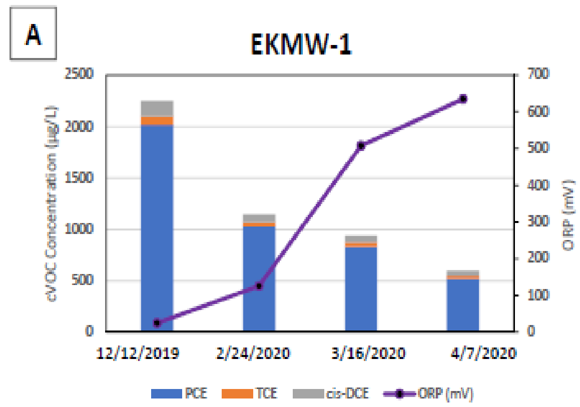
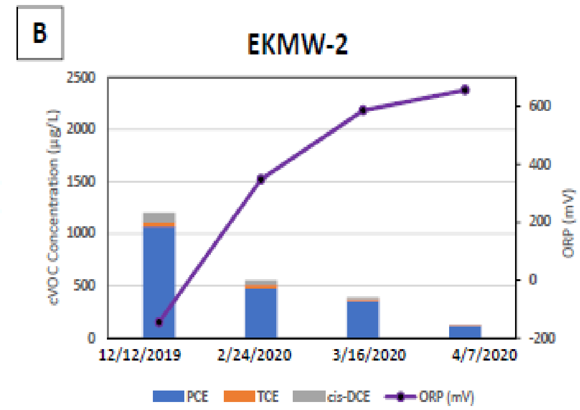
EK-ISCO Pilot Test
USEPA Cristex Drum Superfund Site
Oxford, NC

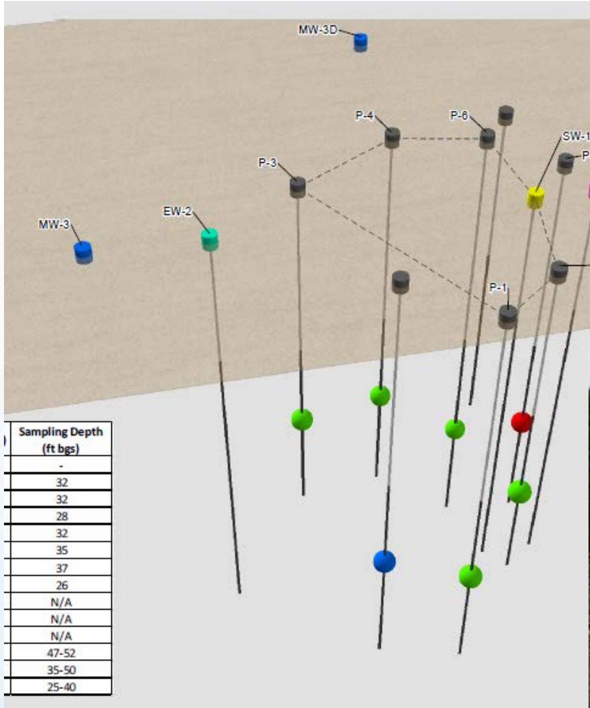
EK Transport of **permanganate** within pilot test area (57 days)

- Increased ORP ; Reduction in CVOC concentrations
- Distribution 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 (very low electrical energy utilized)

Remedial Design for Full-Scale Remedy Now Complete







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

- **In Situ Remediation is all about delivery** !
- Achieved **complete dechlorination from PCE to ethene**; confirmed with microbial genetic signature of specific dechlorination bacteria [background vs. within treatment area]
- Achieved treatment **within clay** materials

- Very **low energy** consumption [DC current & voltage less than 10A, 35V; "*two 100-W lightbulbs*"]
- **Safe implementation** underactive parking lot with many utilities [no overpressure injection]
- An **innovative, fundamentally different solution** to a vexing problem!

THANK YOU

James Wang

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