Success Story at a Low-Permeability Site: Field Demonstration of Electrokinetic (EK) Enhanced Amendment Delivery for In Situ Remediation

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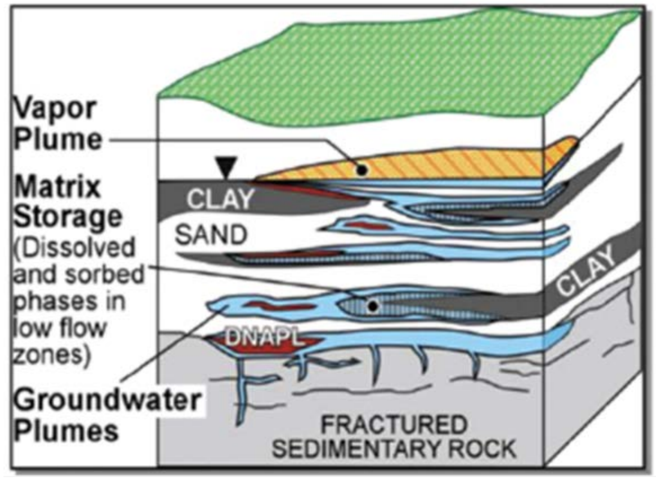
Why are we here today ?

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 amendment delivery techniques are required for low-K sites



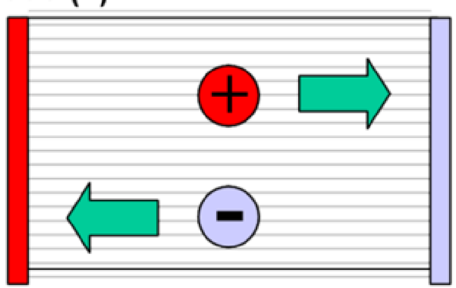
From ESTCP, ER-200530

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

- **Electromigration** is the movement of ions in a fluid due to the applied potential 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

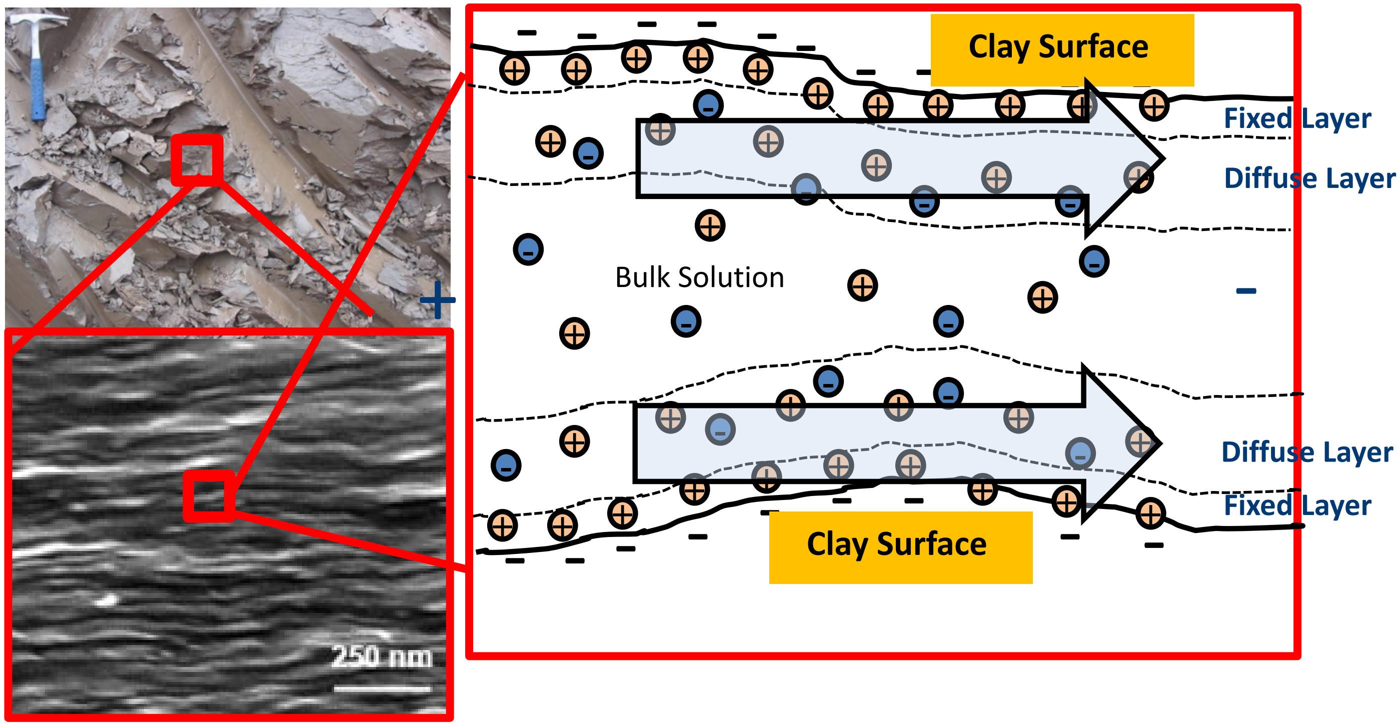
Voltage Gradient

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

Electrokinetic (EK) for Subsurface Transport - Electroosmosis

- **Electroosmotic (EO) flow** is the motion of pore fluid induced by an applied electric field across a porous material.

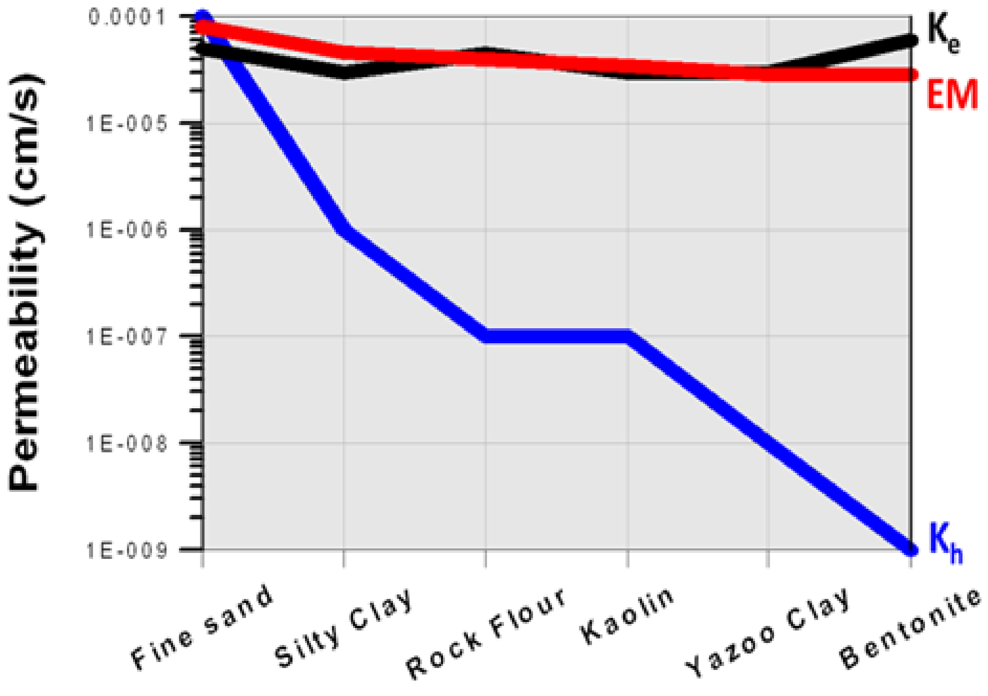
$$q_e = k_e i_e A = k_i I = \frac{k_e}{\sigma} I$$



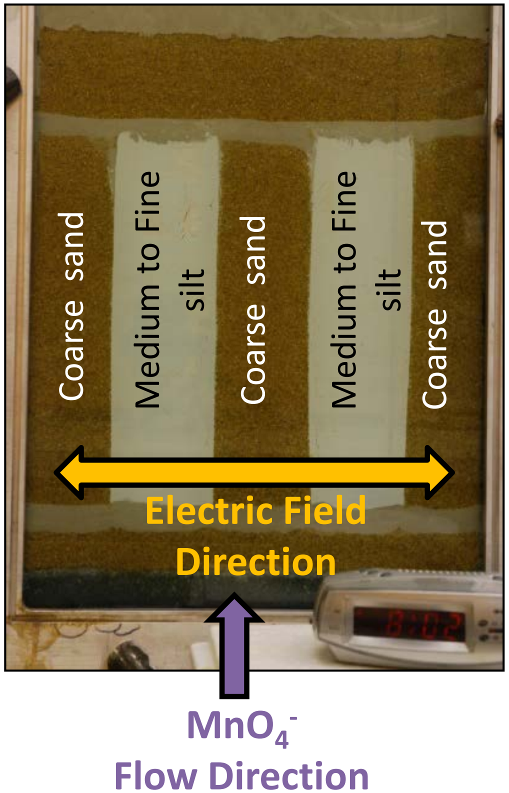
EK Transport is Fundamentally Different

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 most efficient delivery method



Effective and Uniform Amendment Delivery by EK



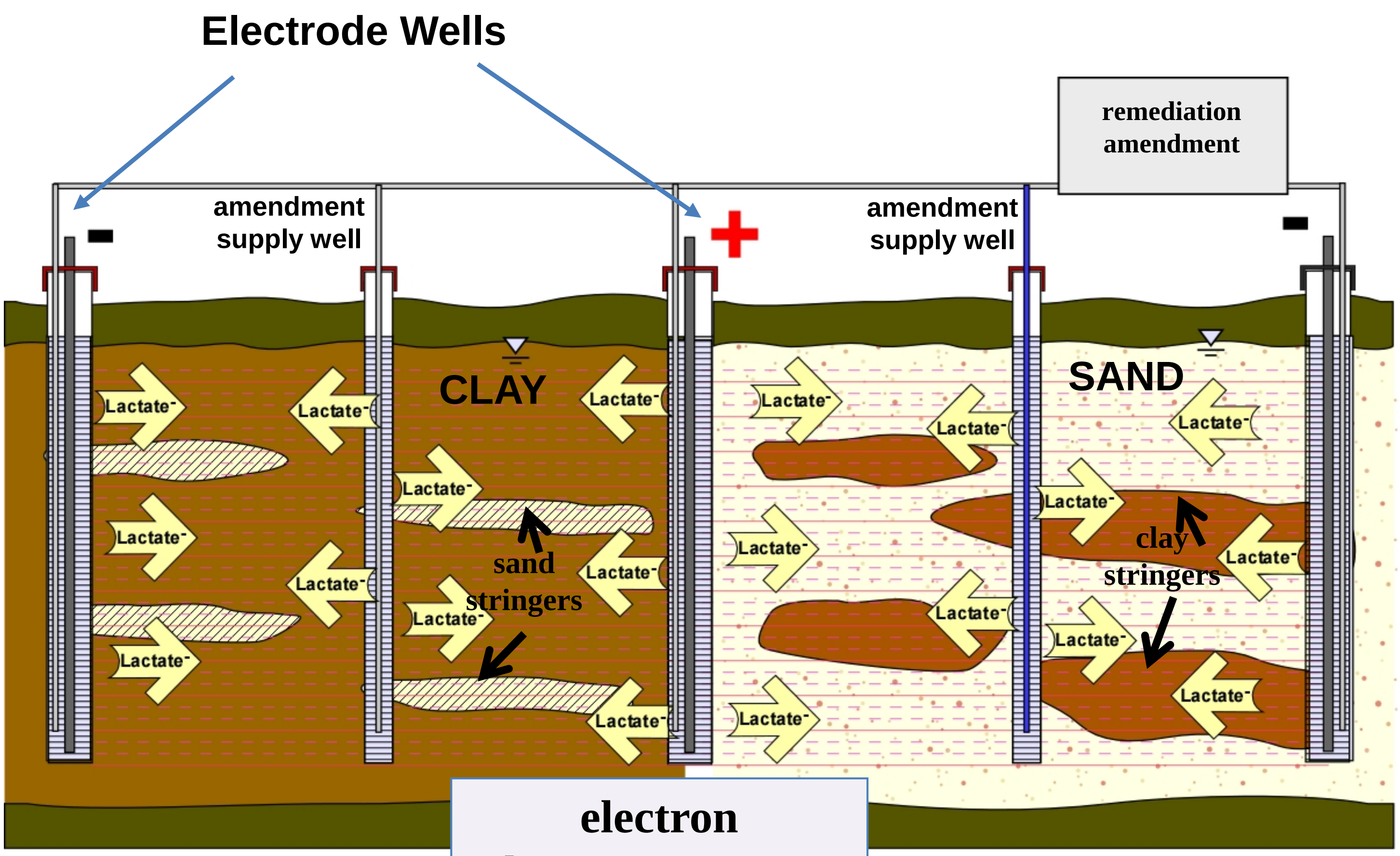
T = 6 hr (MnO_4^- flushing; No EK)

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)

How is EK Applied in the Field?



electron donors/acceptors follow electric field

EK Applications for In Situ Remediation

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

EK-ISCO™ = Distribution of permanganate (MnO_4^-) to promote oxidation

EK-TAP™ = Distribution of persulfate ($S_2O_8^{2-}$) by EK (*DC* current), followed by thermal activation of the persulfate (*AC* current)

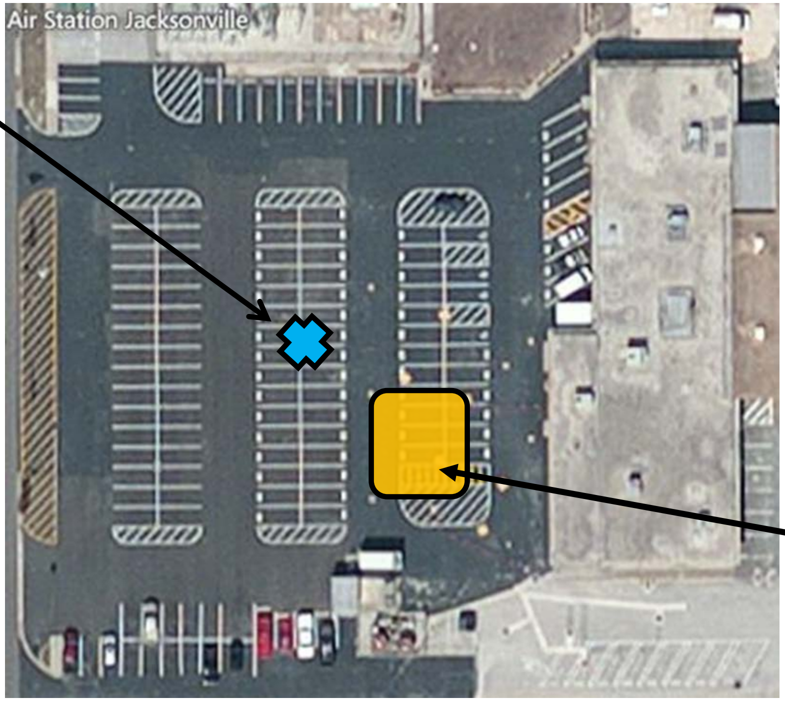
EK-BIO™ Technology Demonstration at Naval Air Station Jacksonville

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

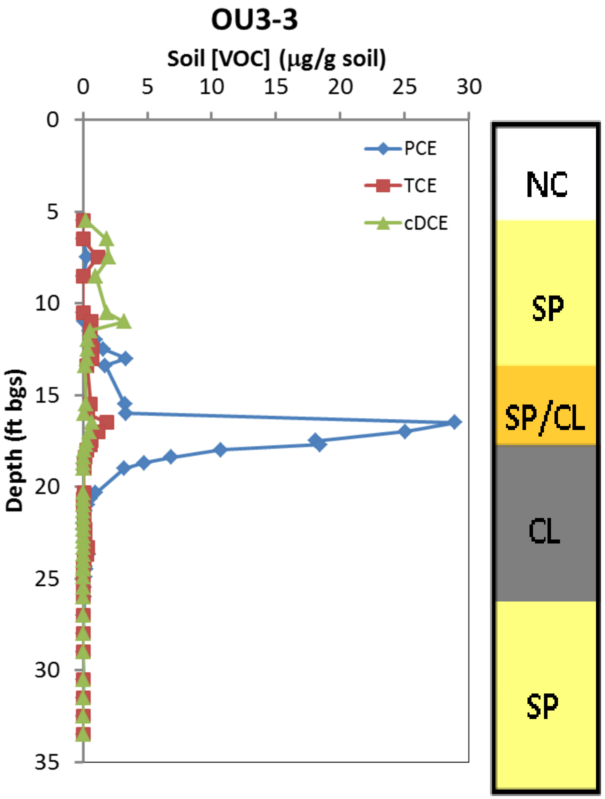


ESTCP

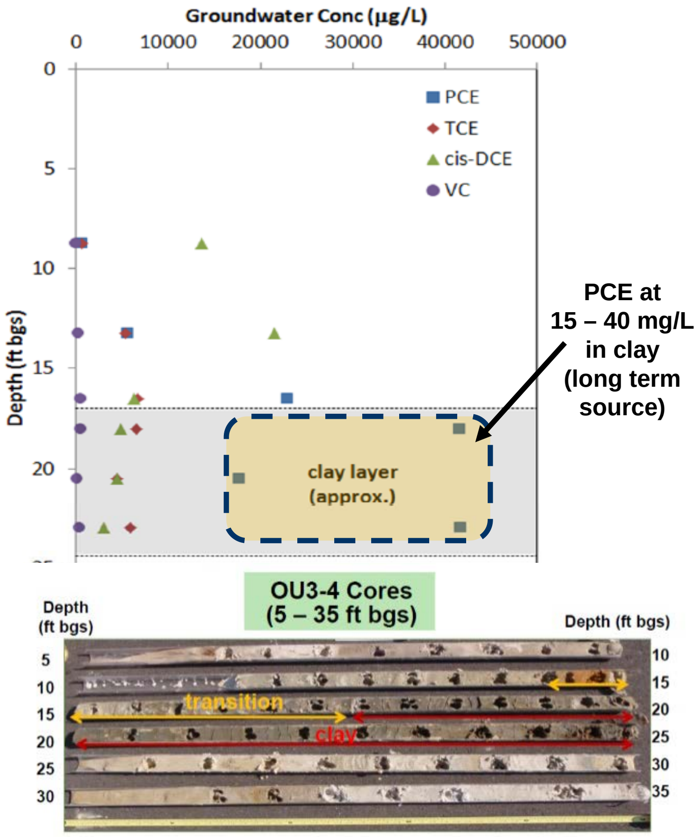
Project ER-201325

Source Area Characterization

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



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

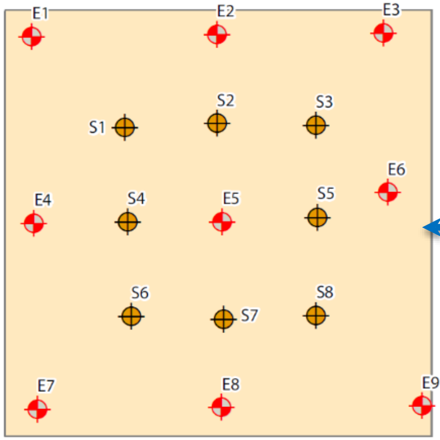


EK-BIO^{TM} Demonstration Test Design

~ 35 ft x 35 ft Target Test Area

9 Electrode Wells (~ 17.5 ft spacing)

8 Supply Wells (no electrode)



Electrode / Supply Wells

- 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

DC Power Supply Unit :

Input – 120 / 240V, 3-phase AC

Output – up to 24 A / 250V DC

Monitoring Wells : double-cased; screened in clay only

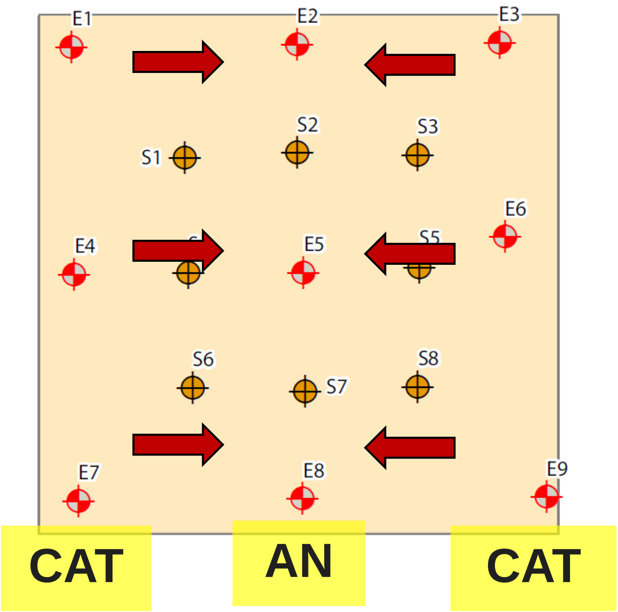
EK Remediation Construction / Installation

Bioaugmentation

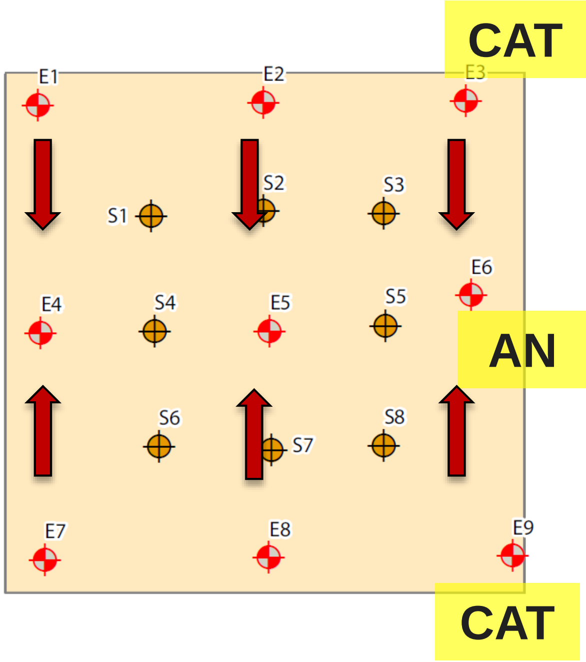
Remediation Operation

- 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 & E wells
- No overpressure injection

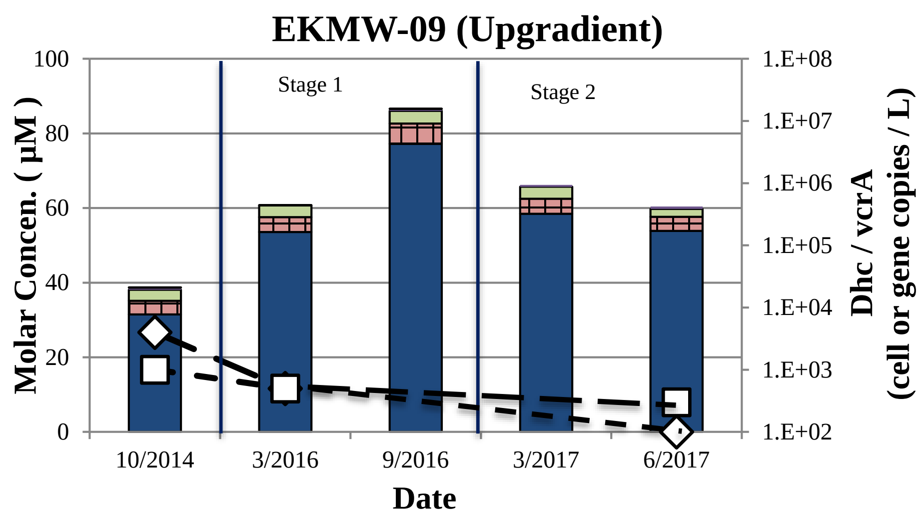
Stage 1 Operation

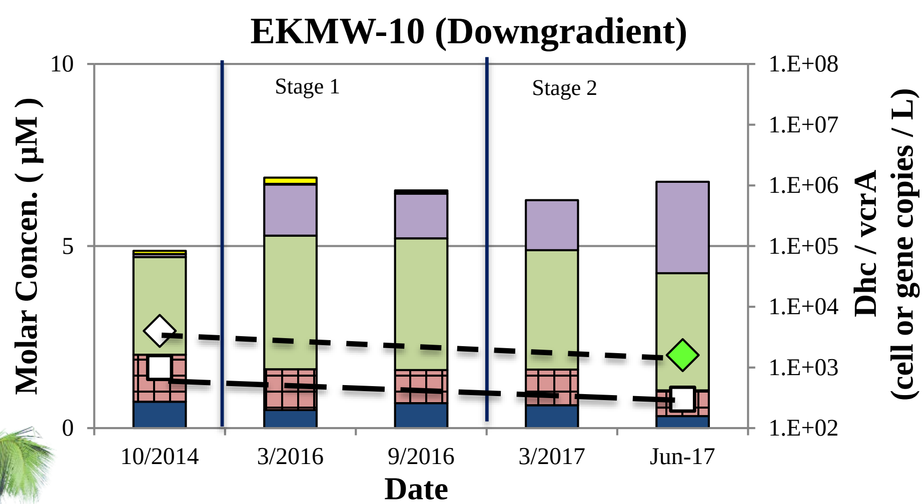


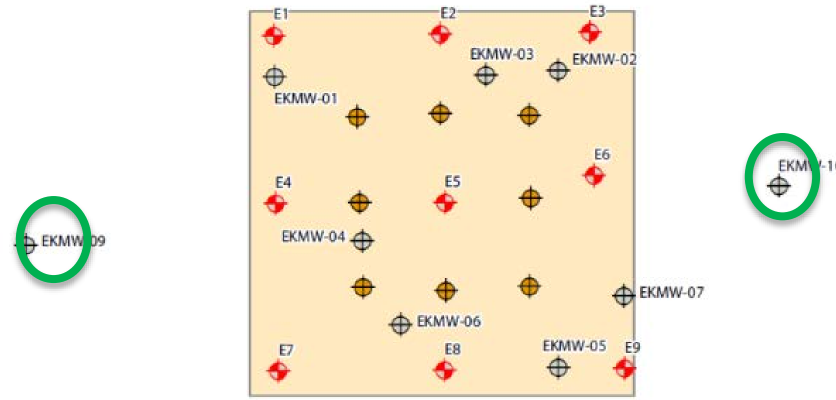
Stage 2 Operation

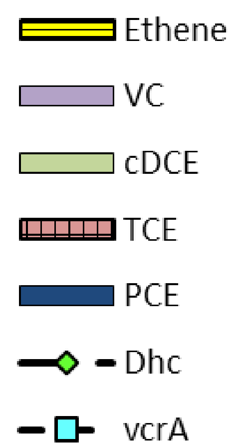


Background Wells – VOCs and Biomarkers



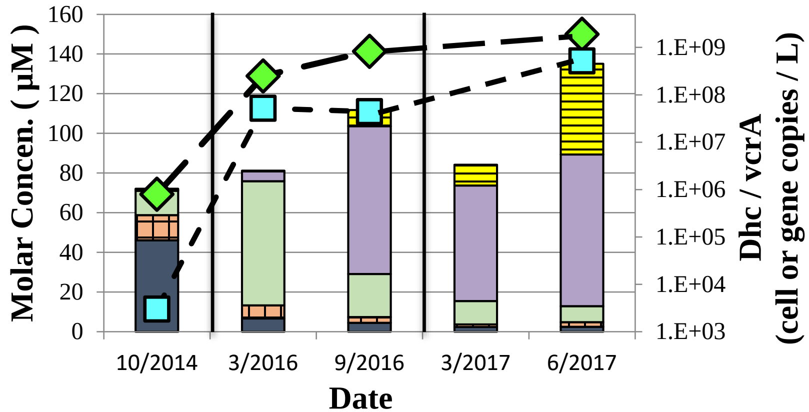


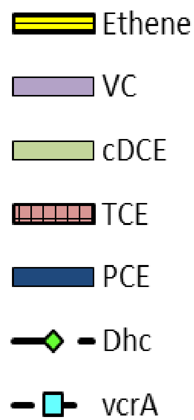


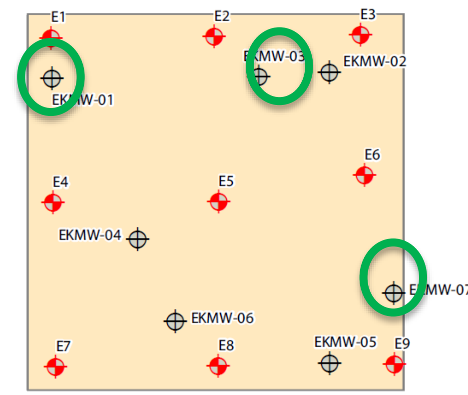


Groundwater Within Test Area – VOCs and Biomarkers

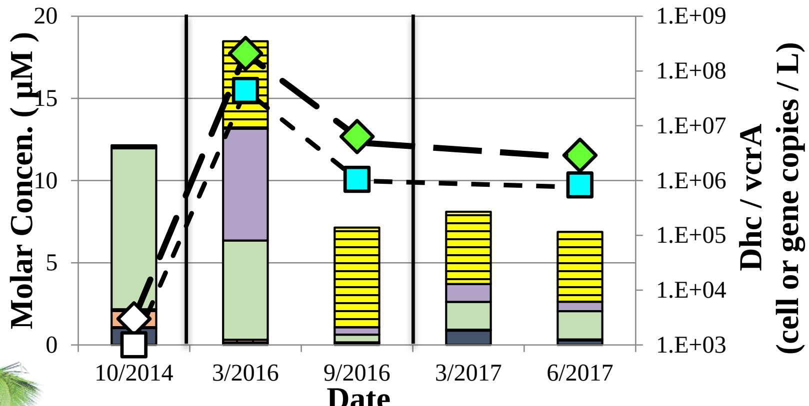
EKMW-01



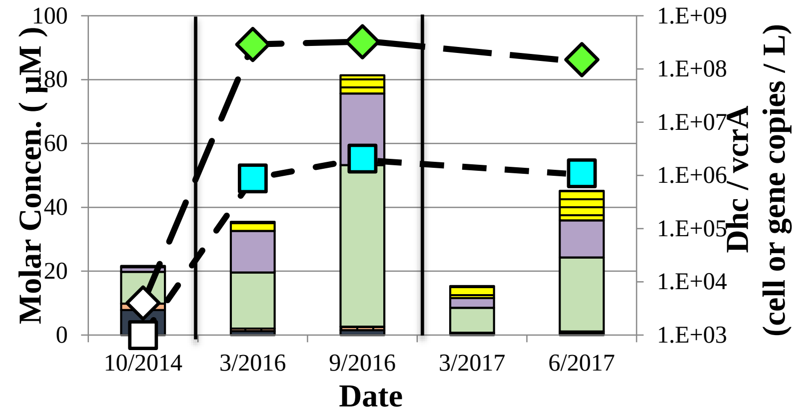




EKMW-02

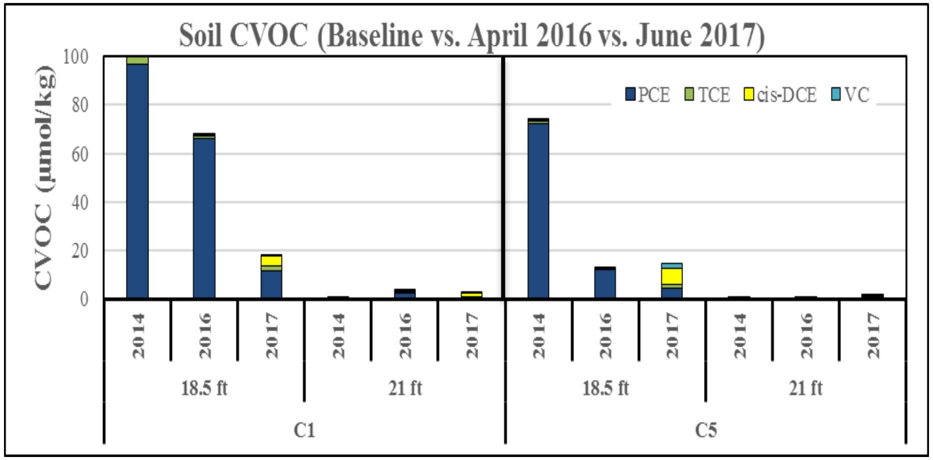


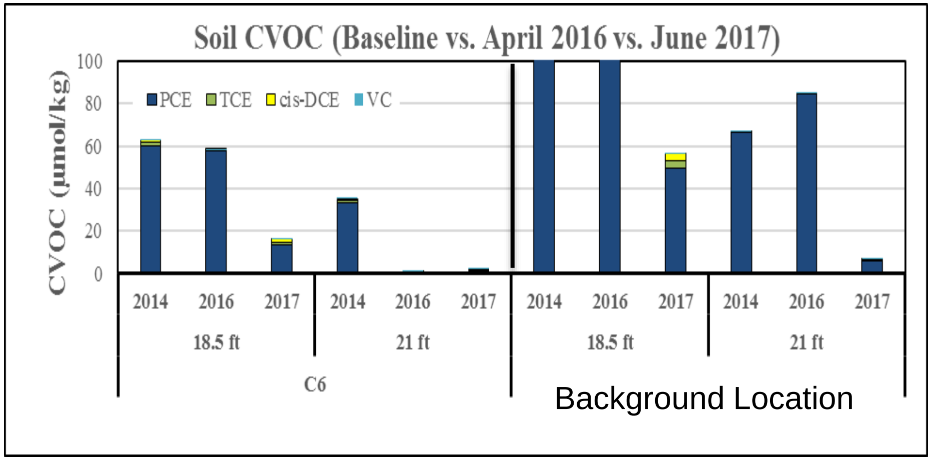
EKMW-07



Soil VOCs – Baseline / Post Stage 1 / Post Stage 2

18.5 ft and 21 ft bgs each location (in clay)





Soil PCE at 18.5 ft bgs Reduced by 78% to 99% within TTA

Average reduction – 88%

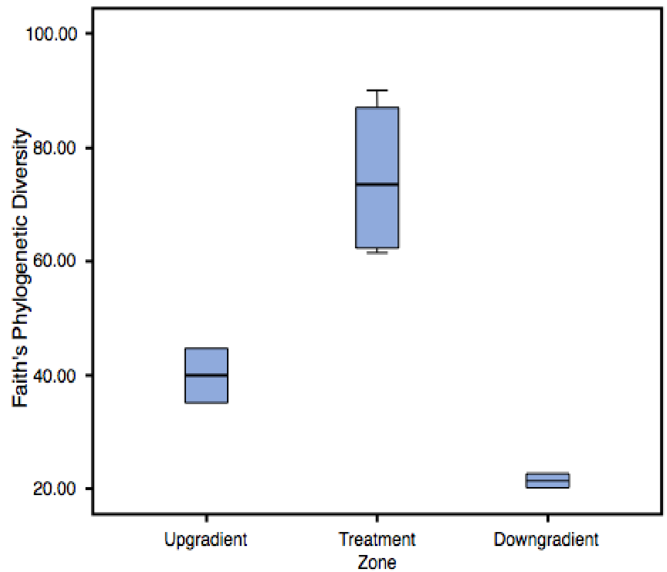
Location C6 – the only location with baseline PCE at 21 ft bgs; 96% reduction at 21 ft bgs post Stage 1

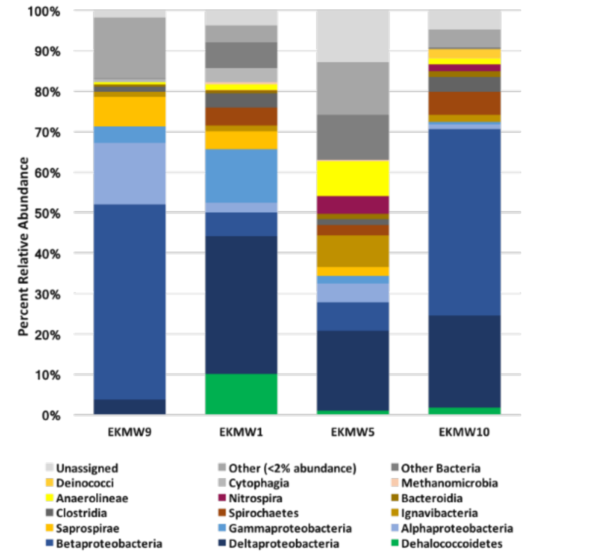
No PCE decrease at background location C10 from baseline to Post Stage 1; some decrease from Post Stage 1 to Post Stage 2

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)

Arizona State University

CBBG Center for Bio-mediated & Bio-inspired Geotechnics

Calculated Microbial Diversity

Key Takeaway Message

- **It's 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 [double-cased monitoring wells & soil sampling data]

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

THANK YOU

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