Geosyntec consultants

Success Stories at Low-Permeability Sites: Field Demonstration of Electrokinetic Enhanced Amendment Delivery for In Situ Remediation

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Project Team

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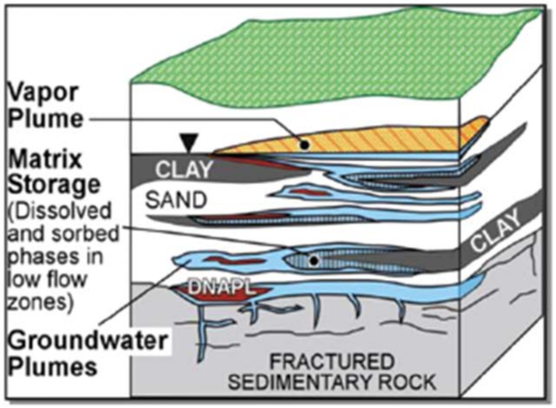
Funding – DoD ESTCP

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



From ESTCP, ER-200530

<u>Delivery</u> & **<u>Contact</u>**

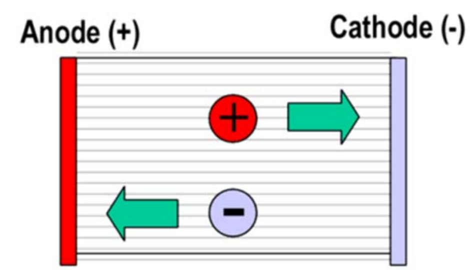
Better amendment delivery techniques are required for low-K sites

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

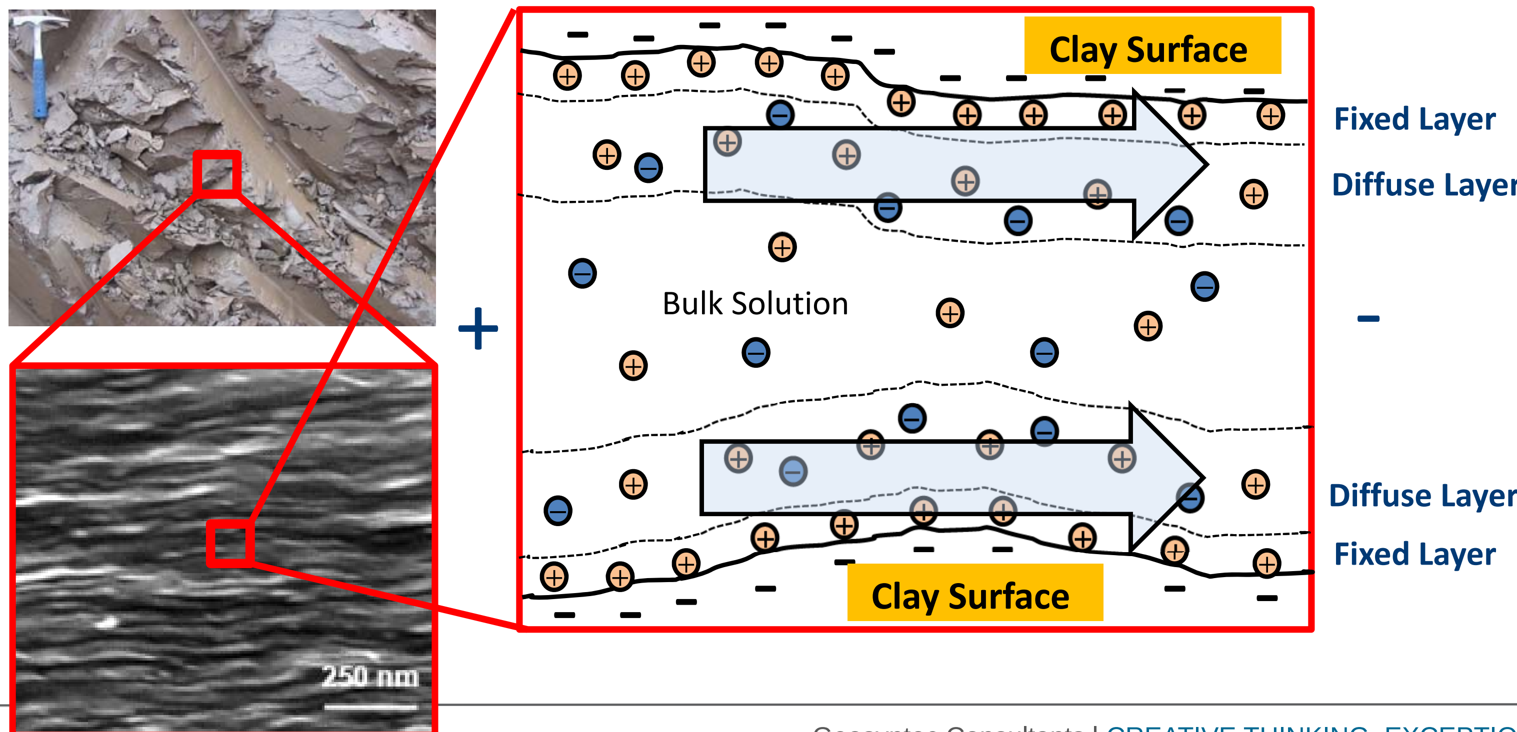
Voltage Gradient

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

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.

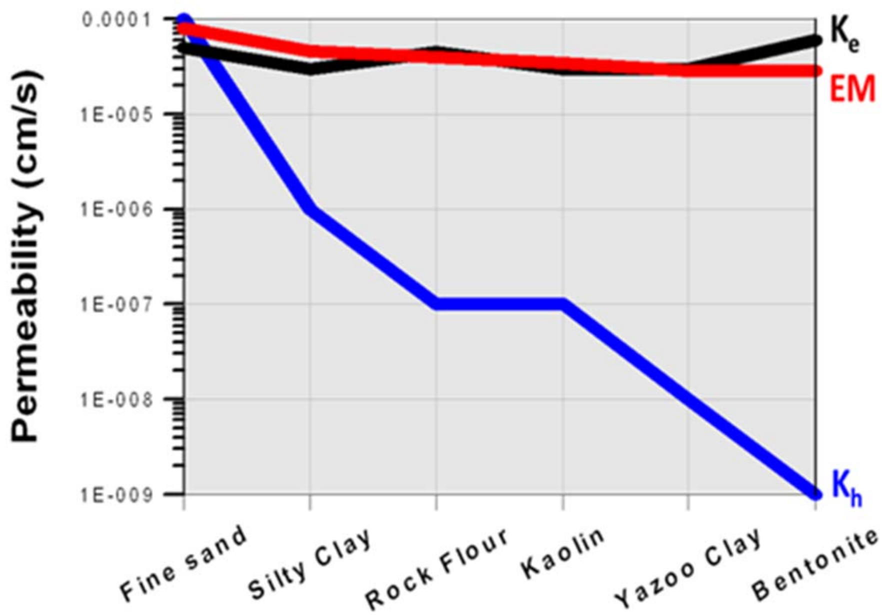
$$q_e = k_e i_e A = k_i I = \frac{k_e}{\sigma} I$$



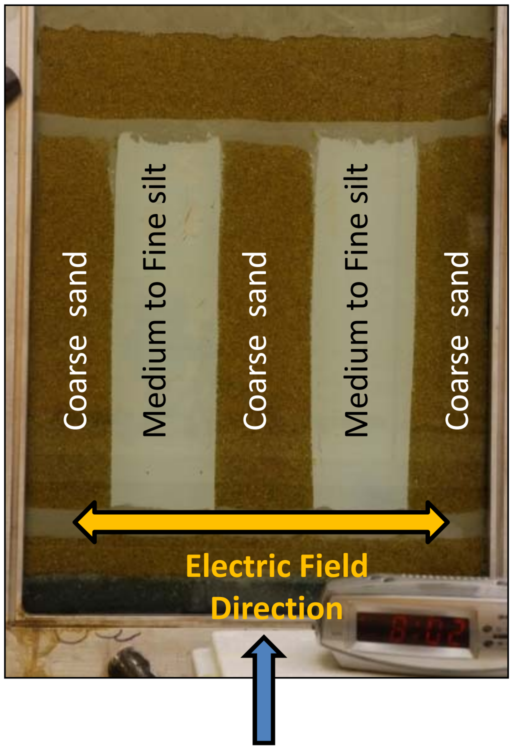
EK Transport is Fundamentally Different

Why will EK work in low-K formations where conventional hydraulic injection techniques commonly 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**



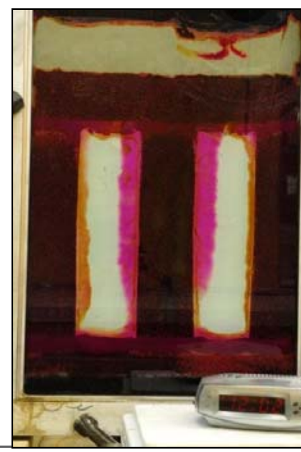
Effective and Uniform Amendment Delivery



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

EK-BIO™ = Distribution of electron donors (lactate) or acceptors (oxygen, 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

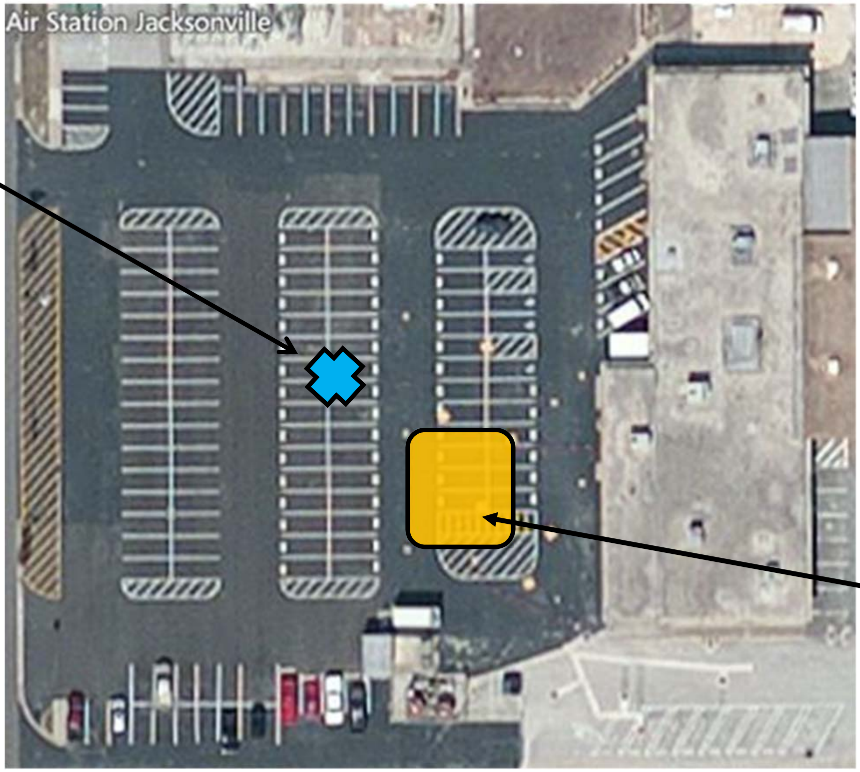
ESTCP
Project ER-201325

Former dry cleaner

Source for a large dissolved plume in shallow sandy aquifer

Source area now under an active parking lot

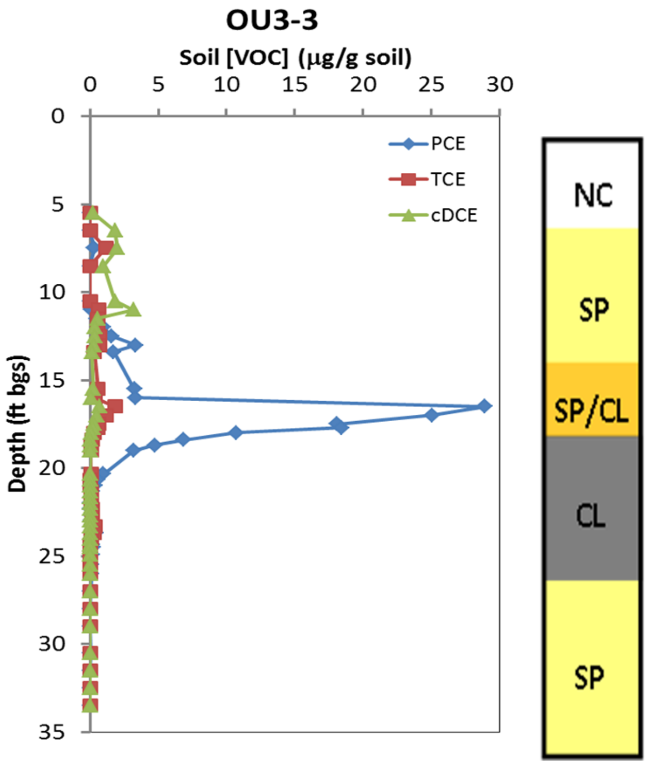
Many existing subsurface utilities



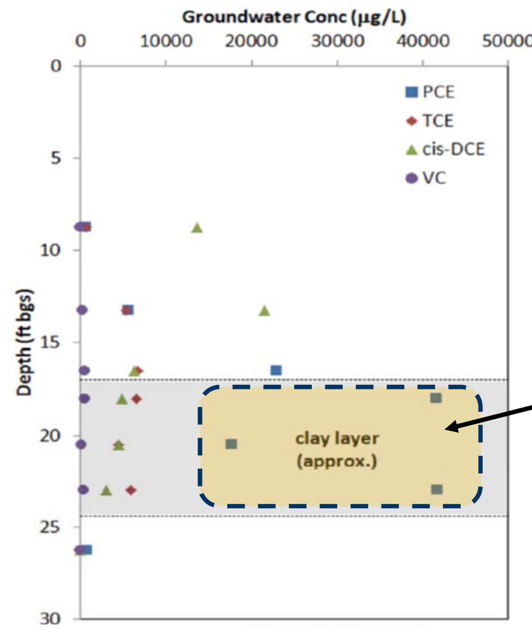
Demonstration Area

Source Area Characterization

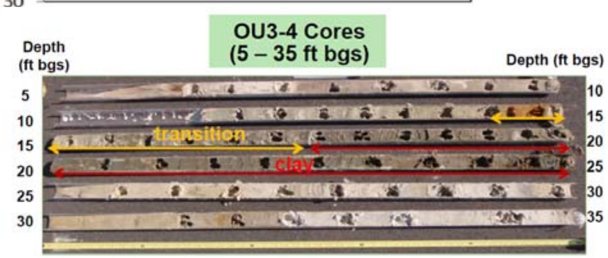
Classic case of contaminant mass diffused into low-K materials.



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



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

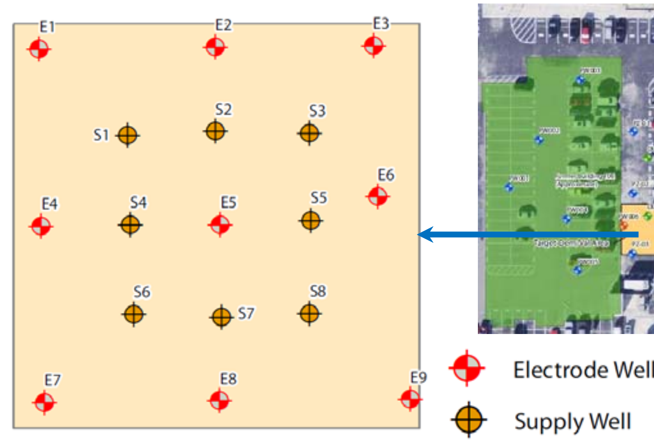


EK-BIO™ Demonstration Test Design

~ 35 ft x 35 ft Target Test Area

9 Electrode Wells (~ 17.5 ft spacing)

8 Supply Wells (no electrode)



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

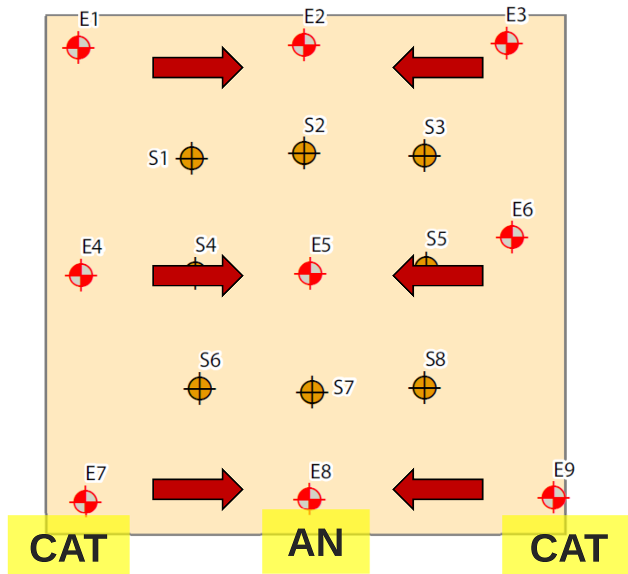
EK Remediation Construction / Installation

Bioaugmentation

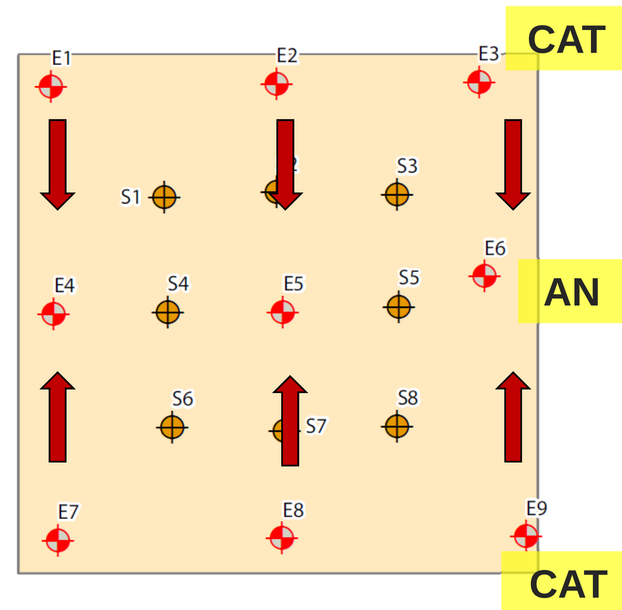
Remediation Operation

- 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

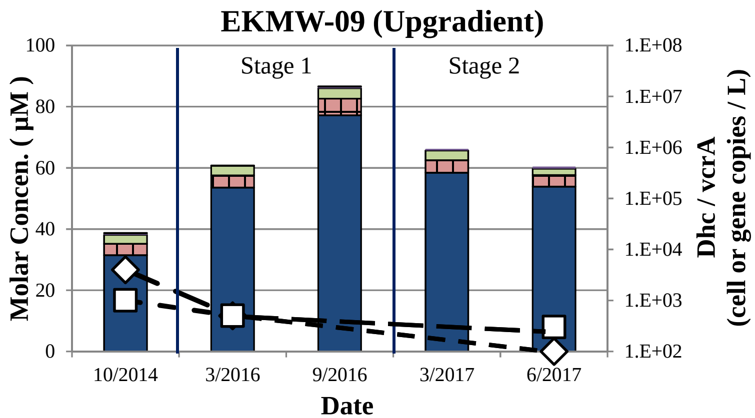
Stage 1 Operation

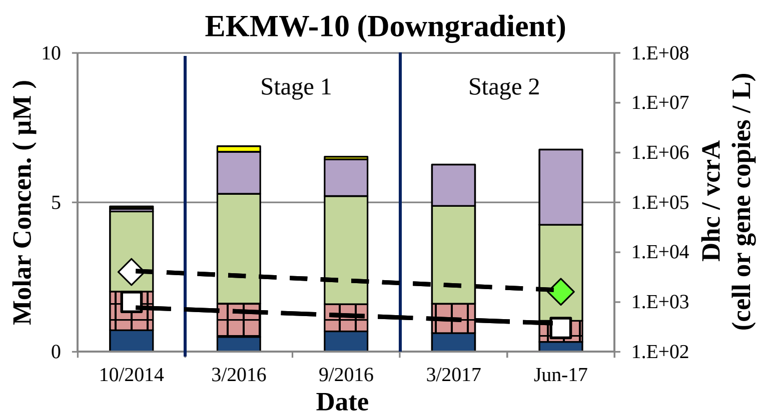


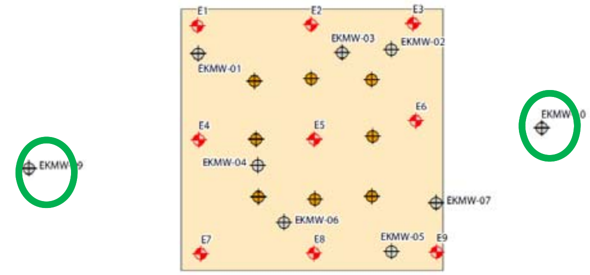
Stage 2 Operation

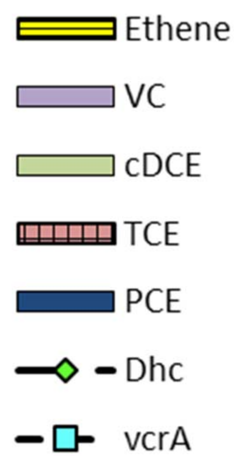


Background Wells – VOCs and Biomarkers

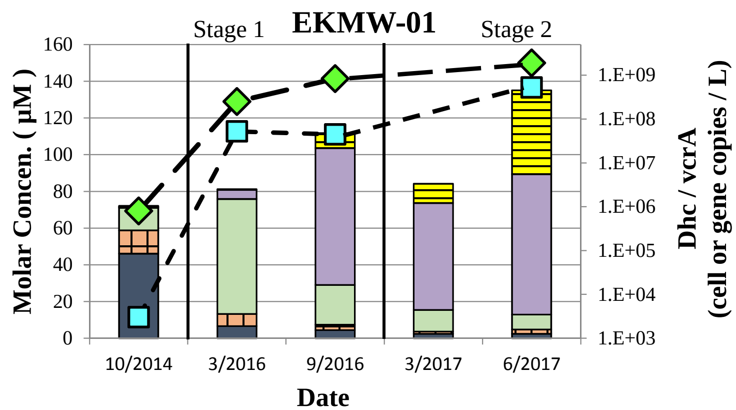


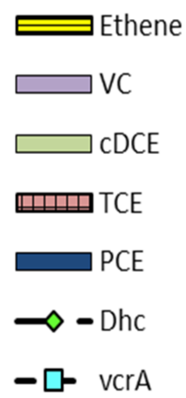


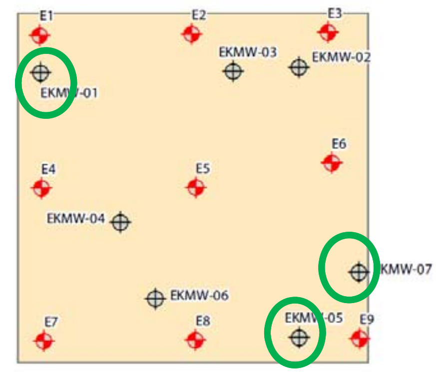


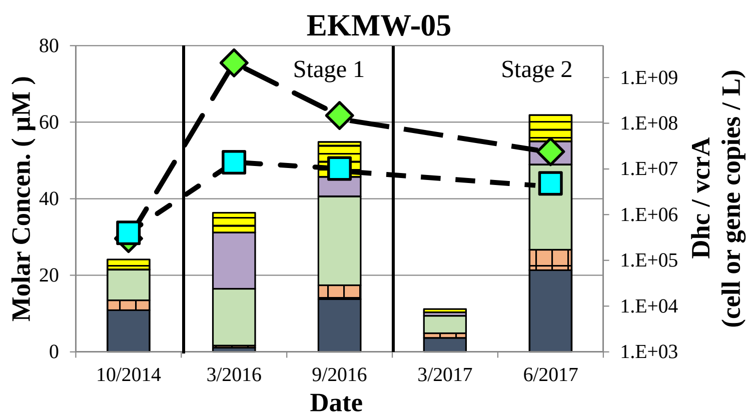


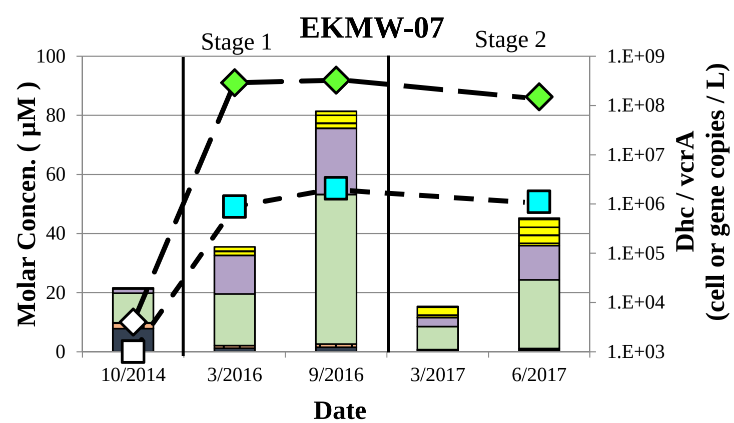
Groundwater Within Test Area – VOCs and Biomarkers











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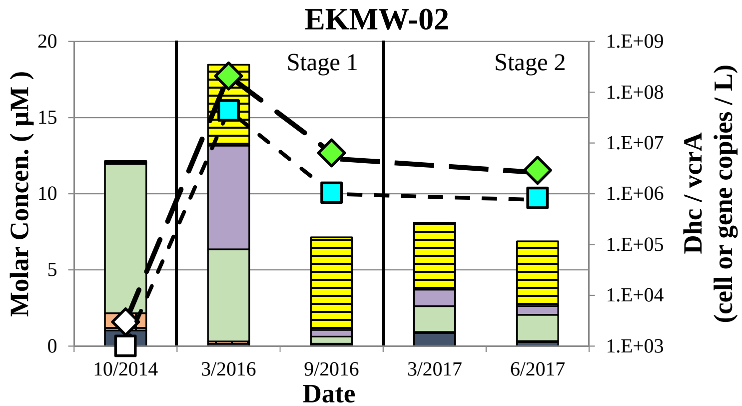
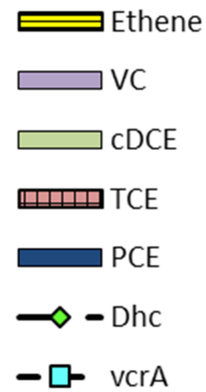
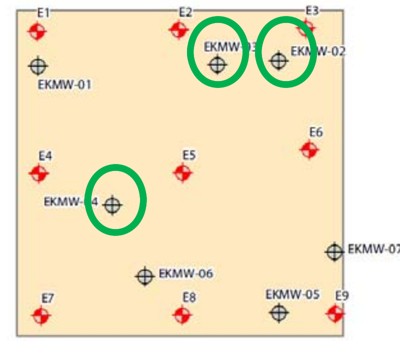
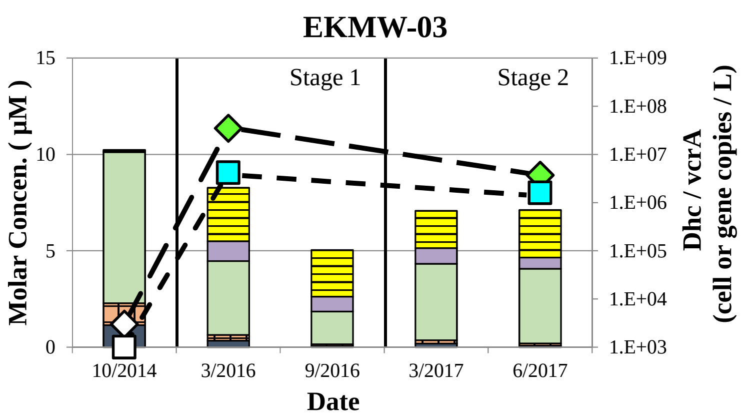
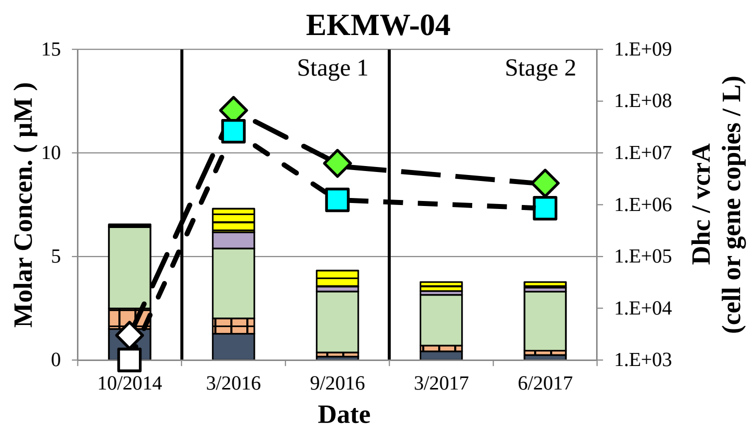




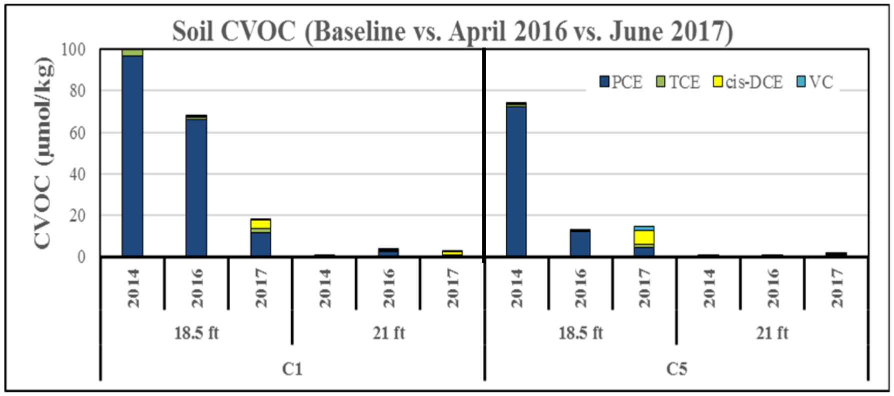


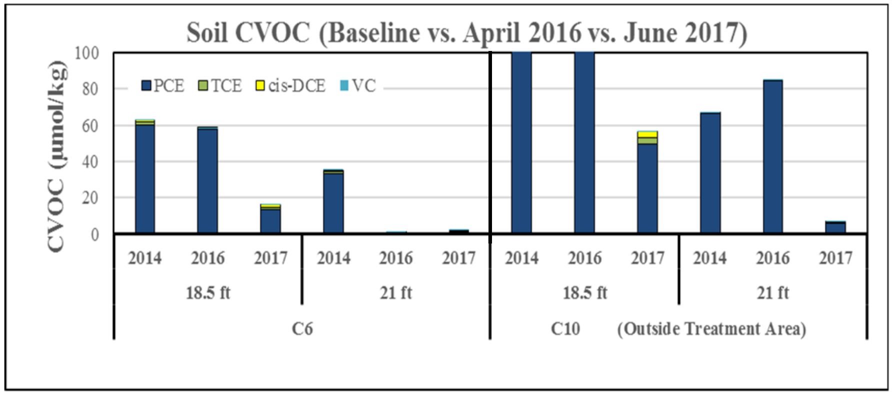




Soil cVOCs – Baseline / Post Stage 1 / Post Stage 2

18.5 ft and 21 ft bgs each location





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

Average reduction – 88%

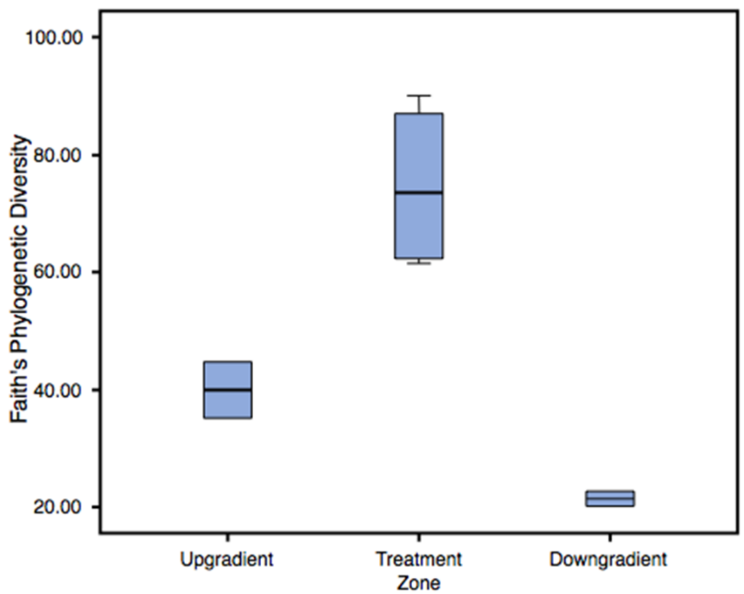
Location C6 – the only location with baseline PCE at 21 ft bgs; 96% reduction at 21 ft bgs after Stage 1

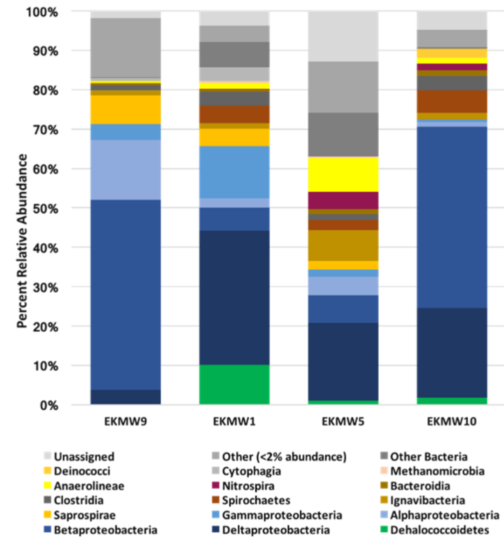
No PCE decrease at background location C10 from baseline to Post Stage 1; decrease from Post Stage 1 to Post Stage 2 may be due to offset location closer to the TTA or heterogeneity

Microbial Community Structure Analysis by Next Generation Sequencing (NGS)

- **Total biomass in groundwater samples from within test area >> that in background wells**

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





Calculated Microbial Diversity

NGS Data (source: ASU)

Arizona State University

CBBG Center for Bio-mediated & Bio-inspired Geotechnics

Key Takeaway Message

- It's all about delivery !
- Achieved complete reductive 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]
- **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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