Overcoming a Vexing Problem of Remediation at Sites with Complex Geology :

EK-enhanced In-Situ Remediation

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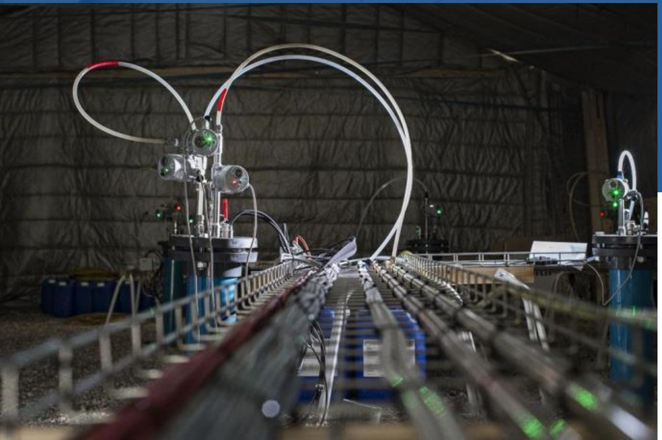

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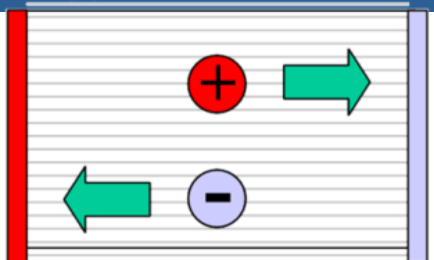

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Project Team

Geosyntec Consultants

- James Wang
- Evan Cox
- David Reynolds

USACE ERDC

- David Gent

NAVFAC SE

- Michael Singletary
- Adrienne Wilson

Funding – DoD ESTCP

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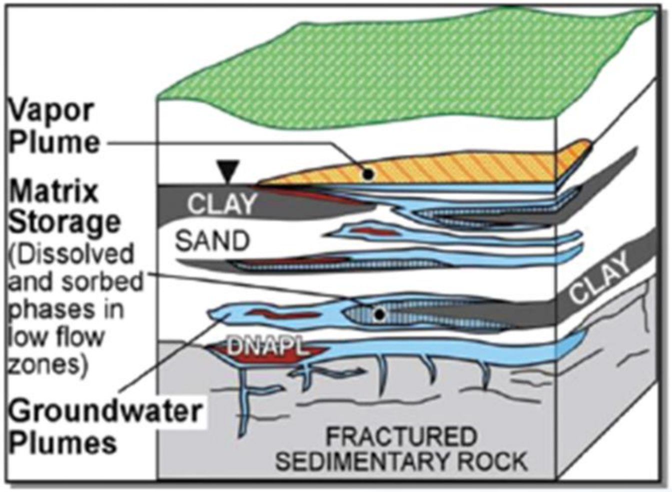
In Situ Remediation is All About Delivery and Contact

- 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
- Better amendment delivery techniques are required for low-K sites



From ESTCP, ER-200530

Electrokinetic (EK) Delivery

- 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)

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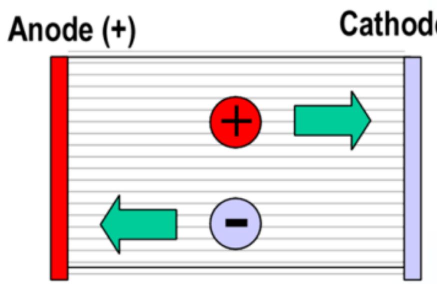
Electromigration (Ion Migration)

- **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

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

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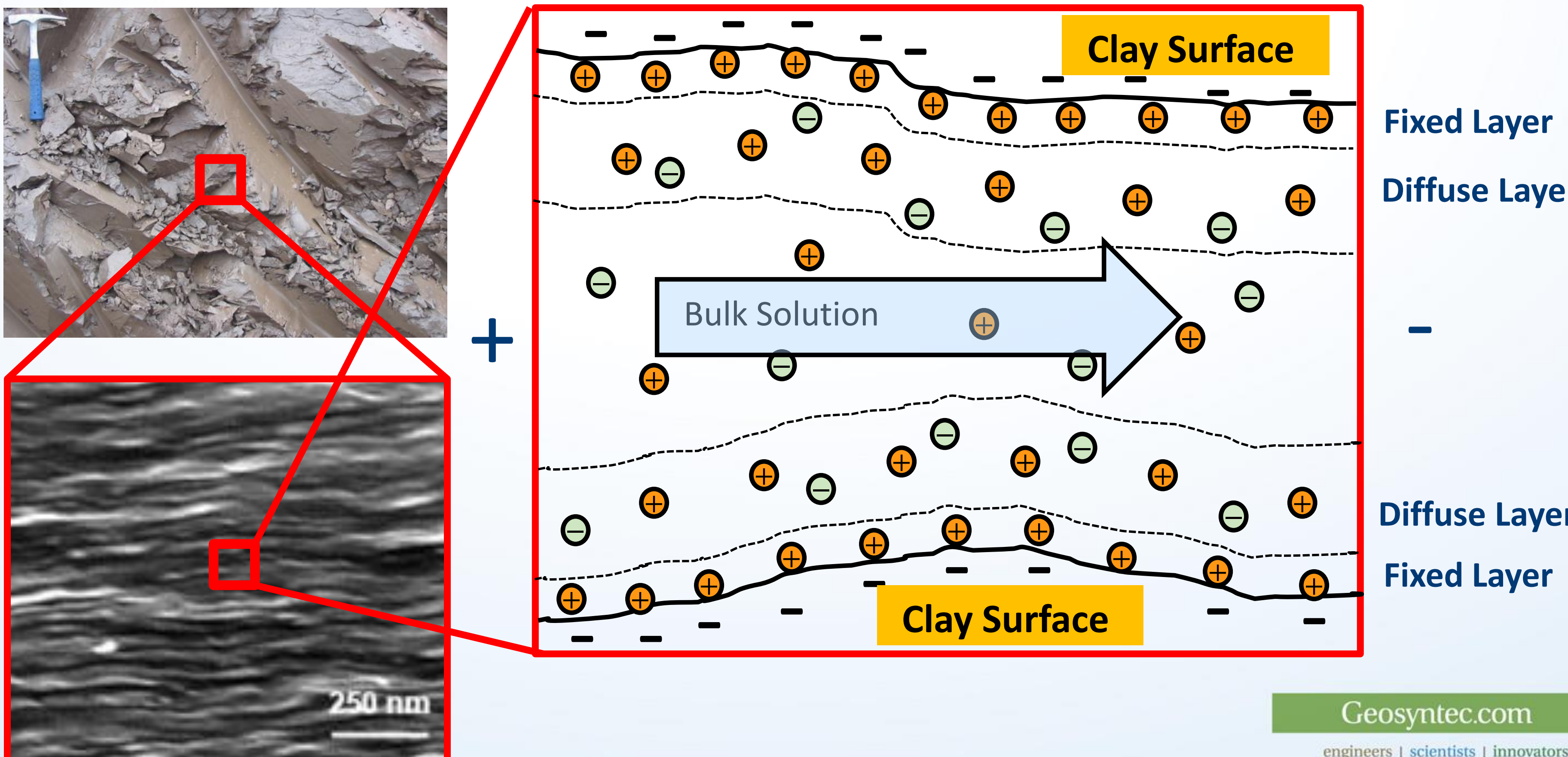
Electroosmosis (EO)

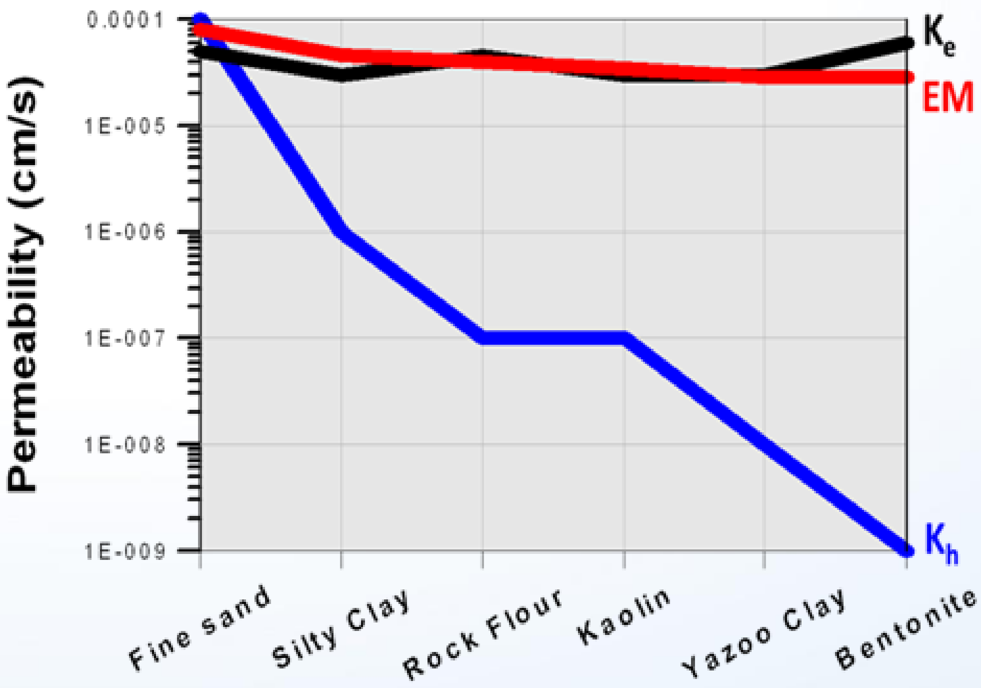
- **Electroosmotic (EO) flow** is the motion of pore fluid induced by an applied electric field across a porous material.



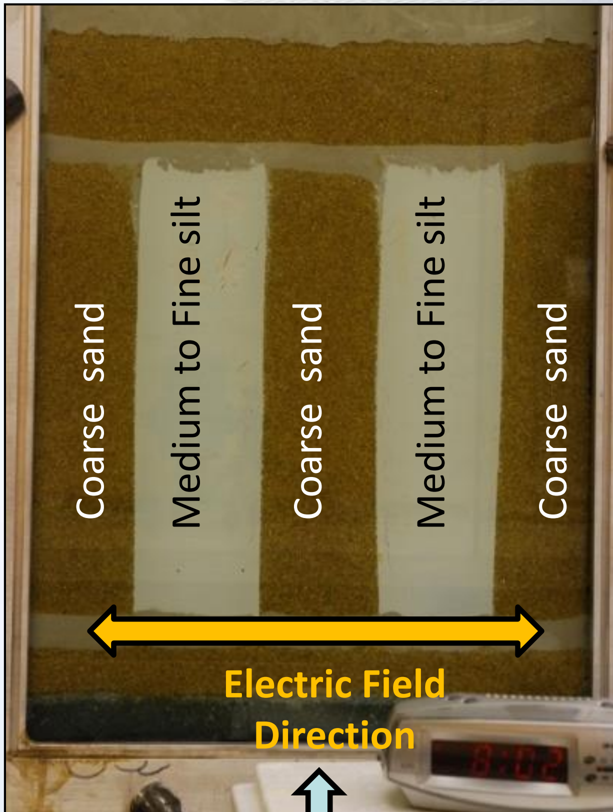
EK Represents an Innovative Solution

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 Distribution

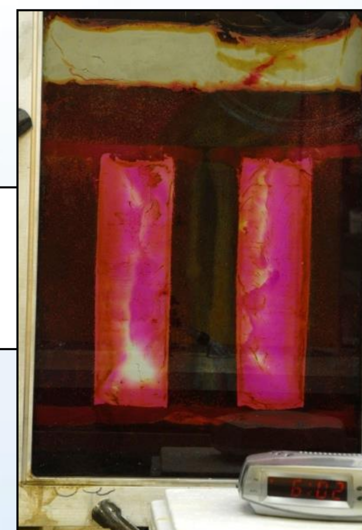


MnO_4^-
Flow Direction

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)

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 at NAS JAX
Former Building 106 Area

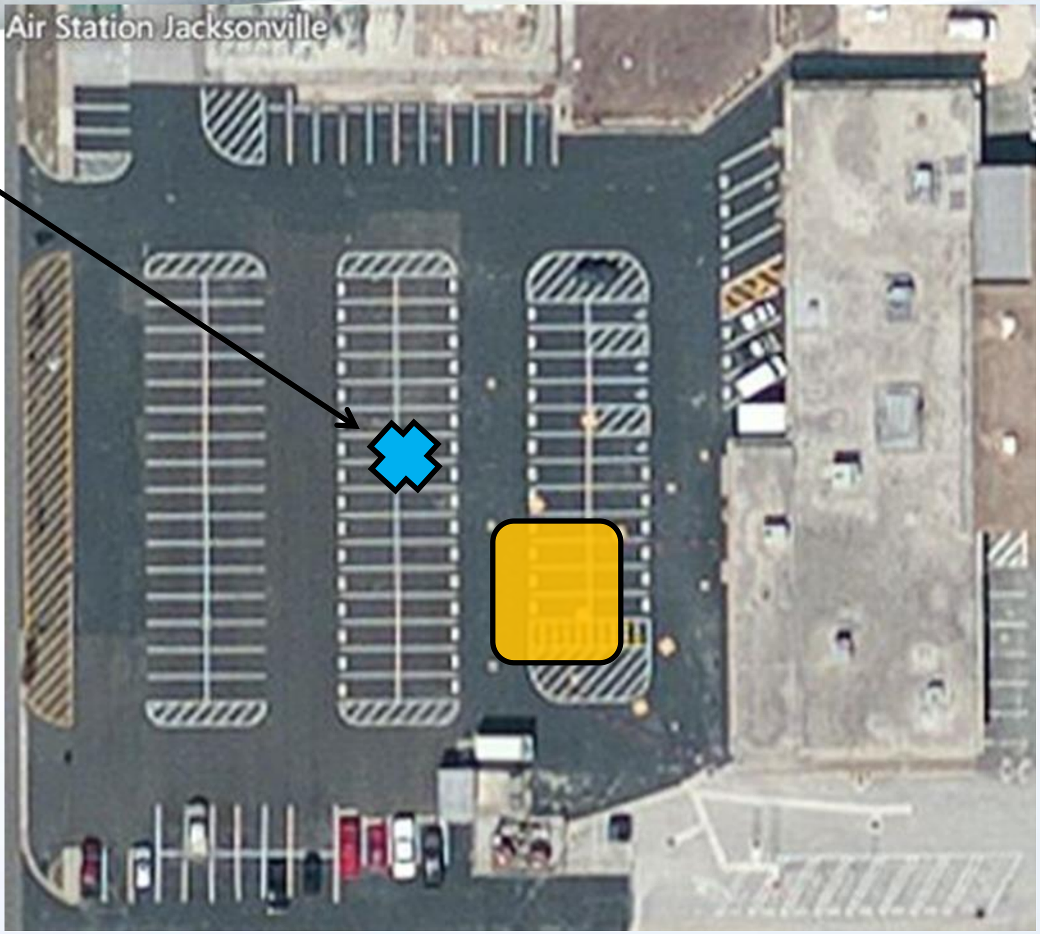
Former dry cleaner

Source for a large dissolved plume

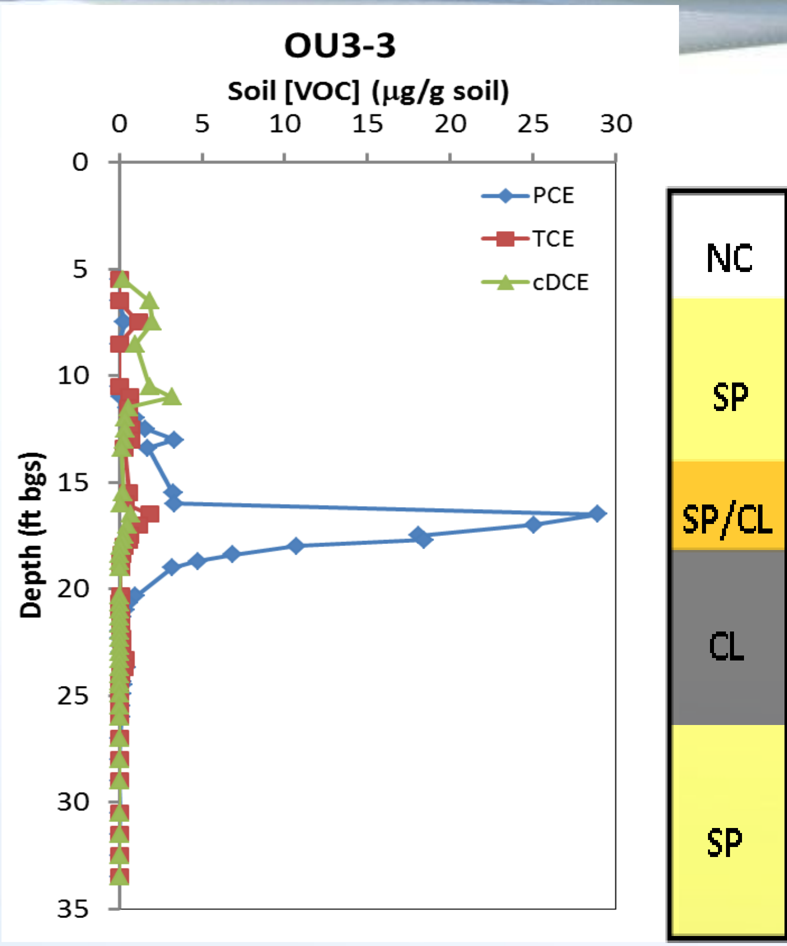
Now under an active parking lot

Many existing subsurface utilities

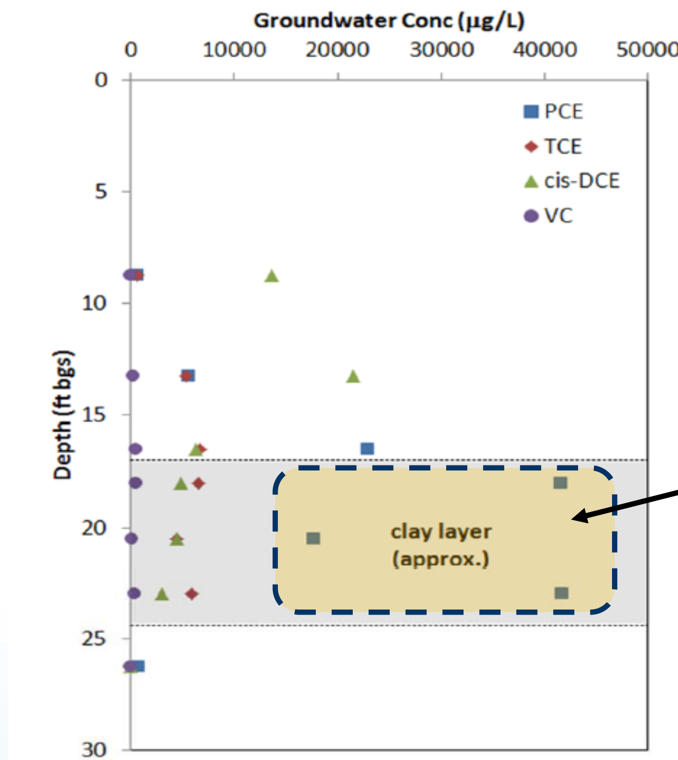
ESTCP Project ER-201325



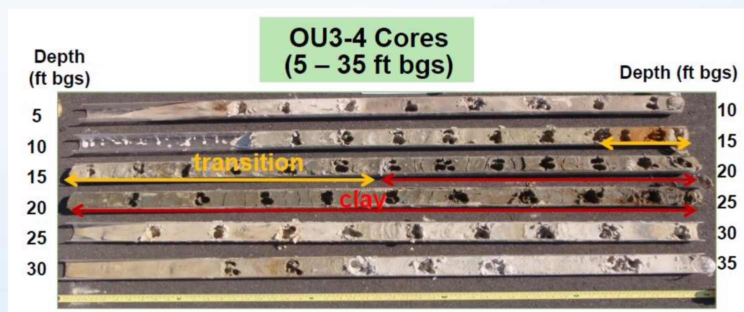
Source Area Characterization



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



PCE at
15 – 40 mg/L

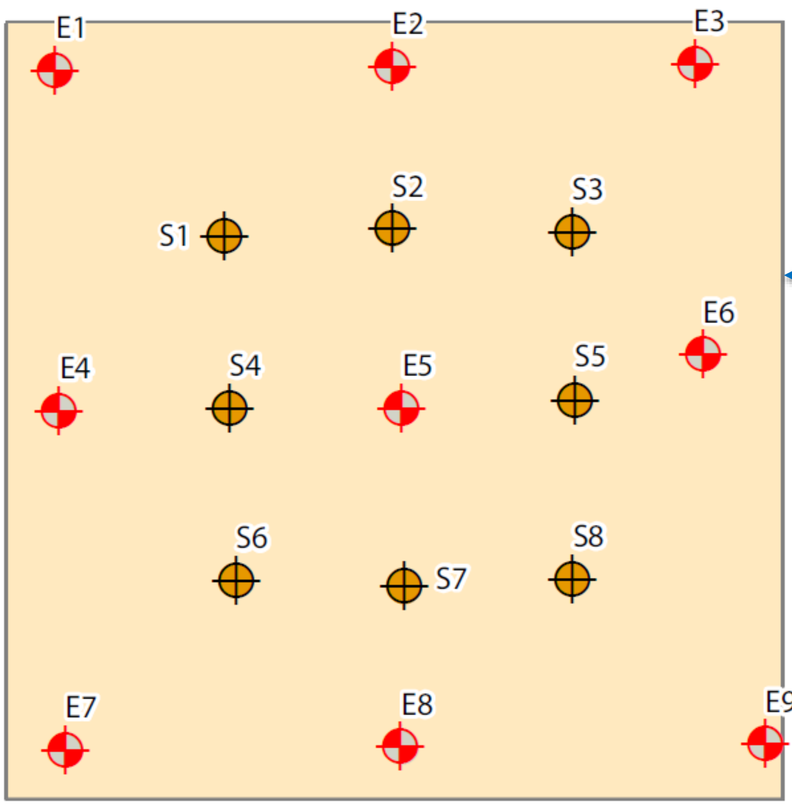


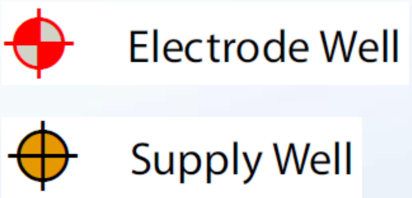
EK-BIO Pilot Test Design

~ 35 ft x 35 ft Target Test Area

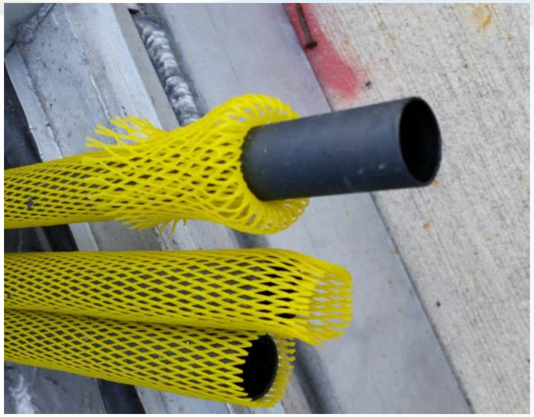
9 Electrode Wells (~ 17.5 ft spacing)

8 Supply Wells (no electrode)





Pilot Test Design



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;

  4-ft long

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

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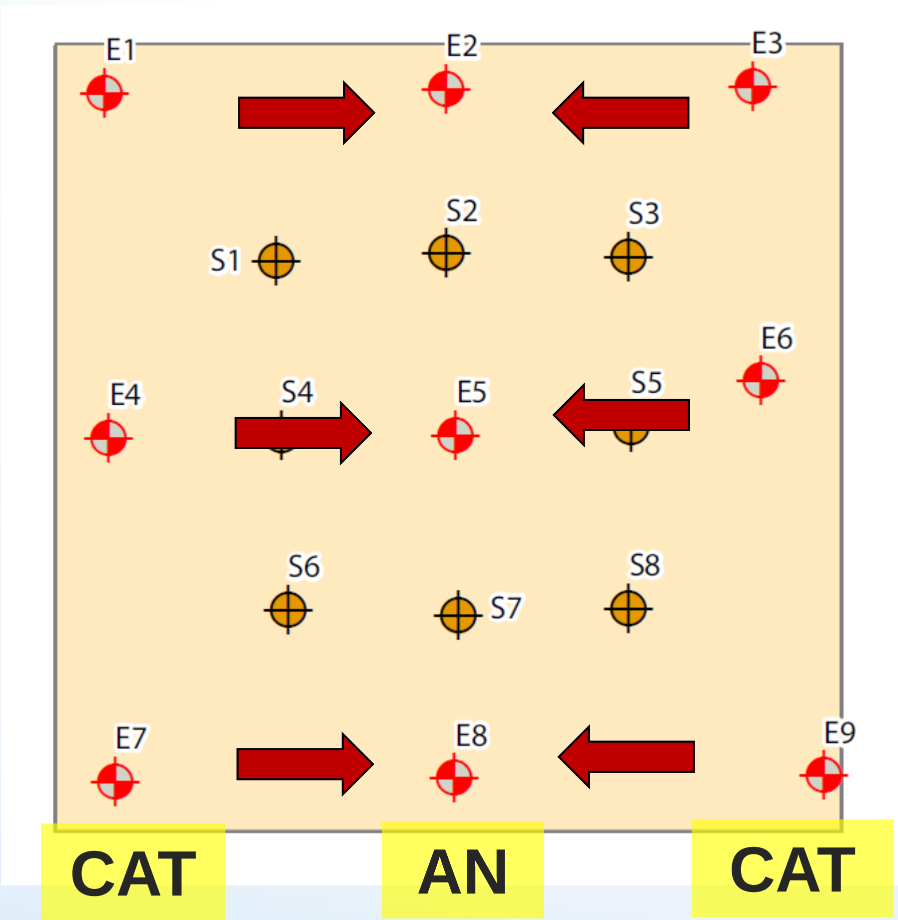
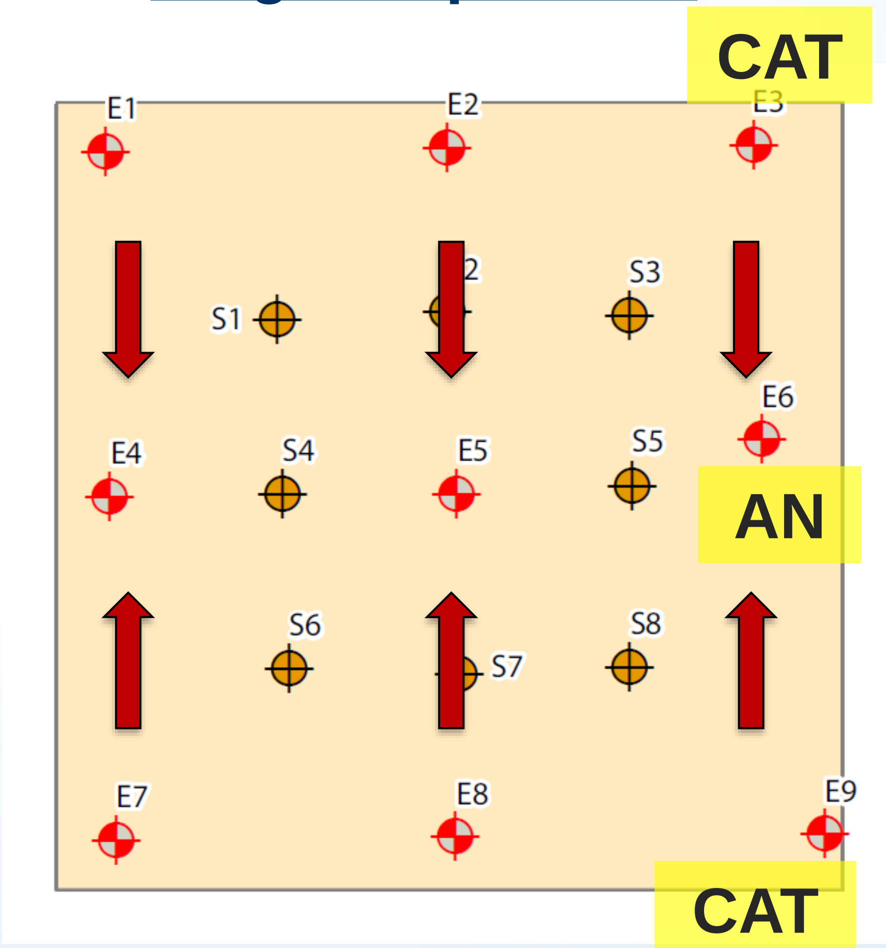
System Construction

Technical Approach

Stage 1 Operation



Stage 2 Operation



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EK-BIO System Operation

Stage 1 Operation : Began with 3-month initial conditioning (buffer + lactate); 10 / 2015 – bioaugmentation; 11 / 2015 through 03 / 2016 (~ 5 months)

Stage 2 Operation : 10 / 2016 through 03 / 2017 (~ 5 months)

Electrical Power – 8 A to 9 A; 22 to 31 V

Total power ~ **1,500 kW-hr** (~ one family for 4 months)

Lactate Amendment Supply

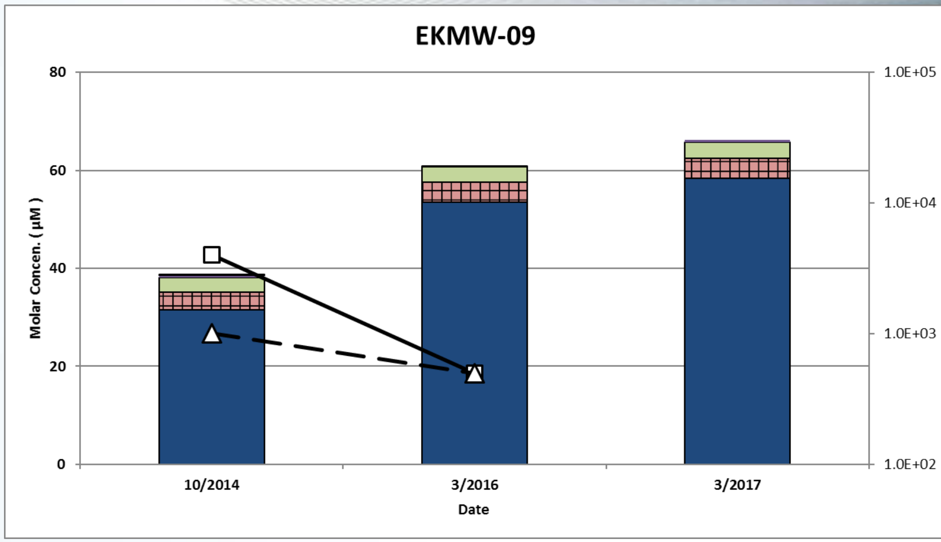
Total lactate – Stage 1 : 238 kg (1,000 gal); Stage 2 : 340 kg (1,600 gal)

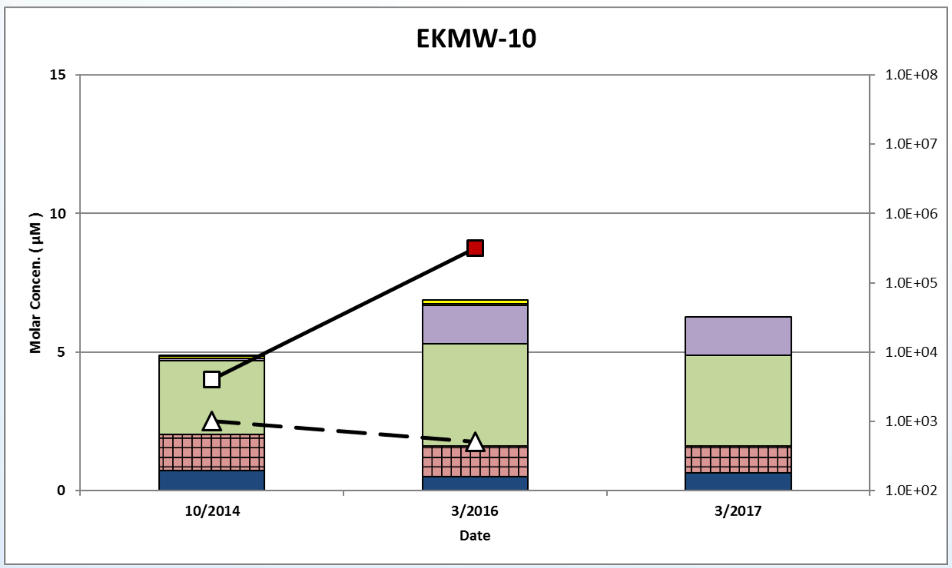
Buffer Amendment Supply : ~ 1,000 gal K-CO_3

No overpressure injection

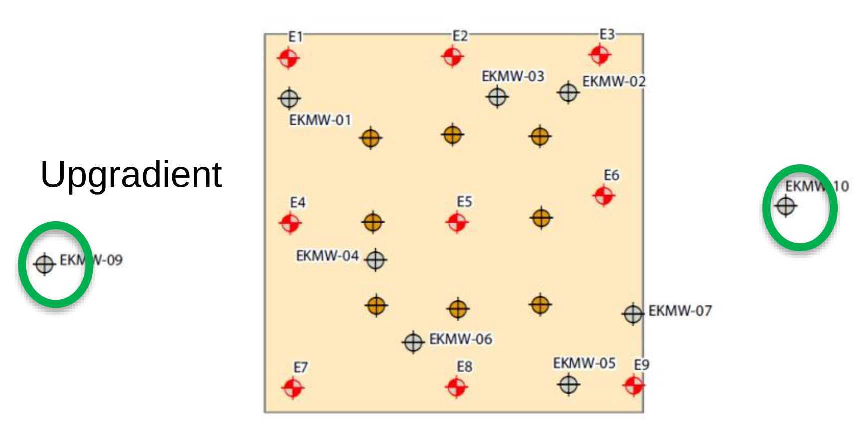
Background Wells – CVOC and Microbial Data

Baseline ⟶ Post Stage 1 ⟶ Post Stage 2





Upgradient



Ethene

VC

cDCE

TCE

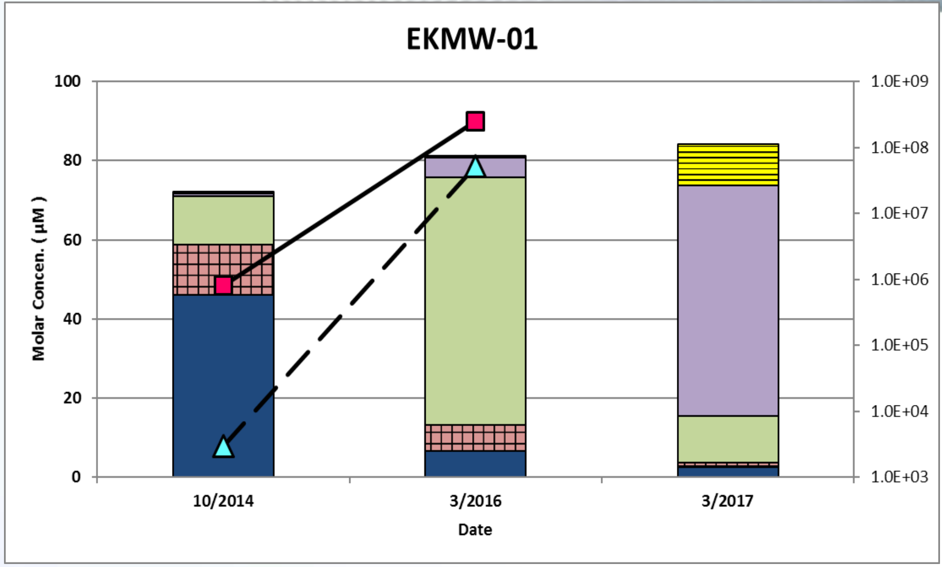
PCE

Dhc (open symbol: ND)

vcrA (open symbol: ND)

Within Test Area – CVOC and Microbial Data

Baseline → Post Stage 1 → Post Stage 2



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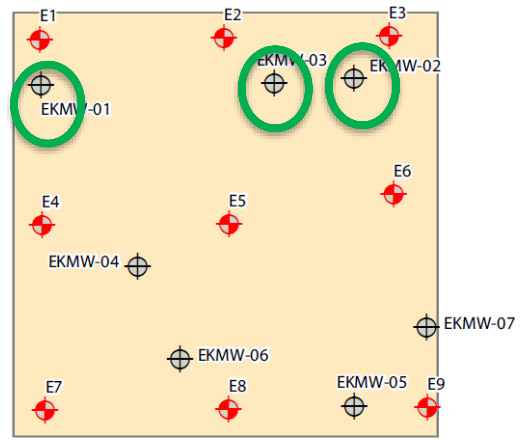
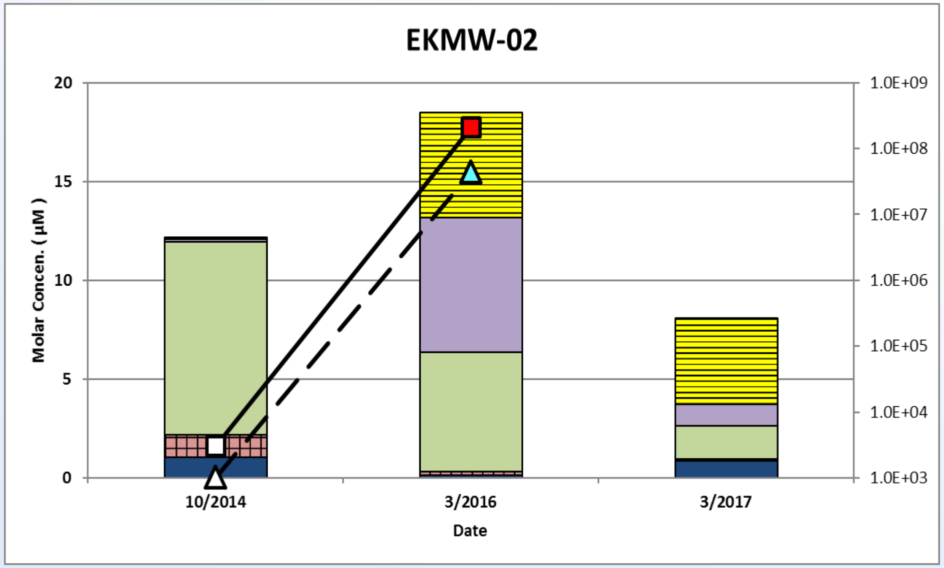
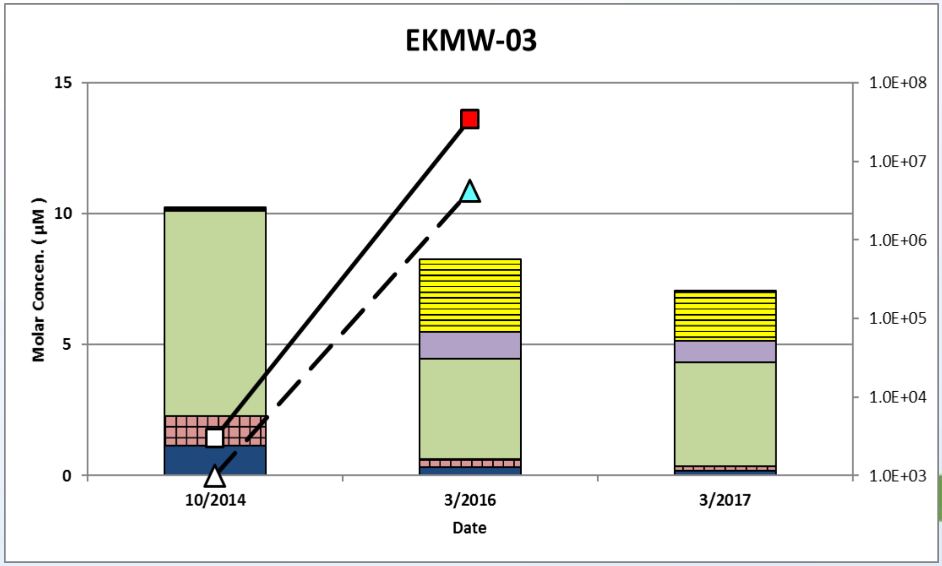
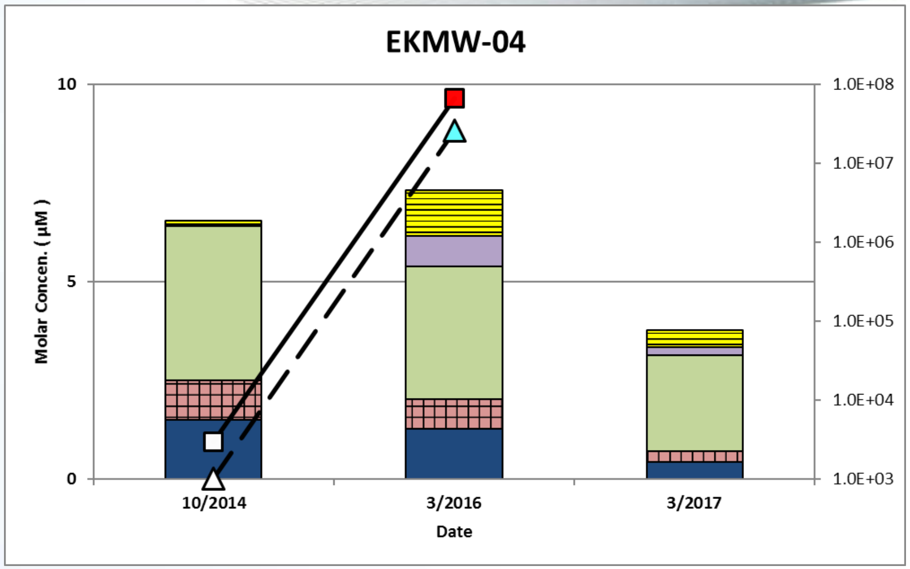






Within Test Area – CVOC and Microbial Data

Baseline ⟶ Post Stage 1 ⟶ Post Stage 2



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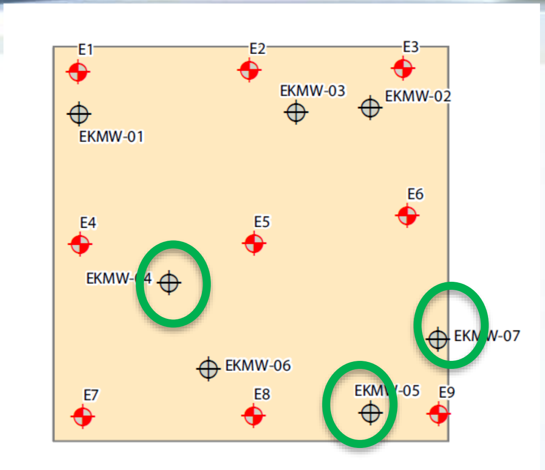
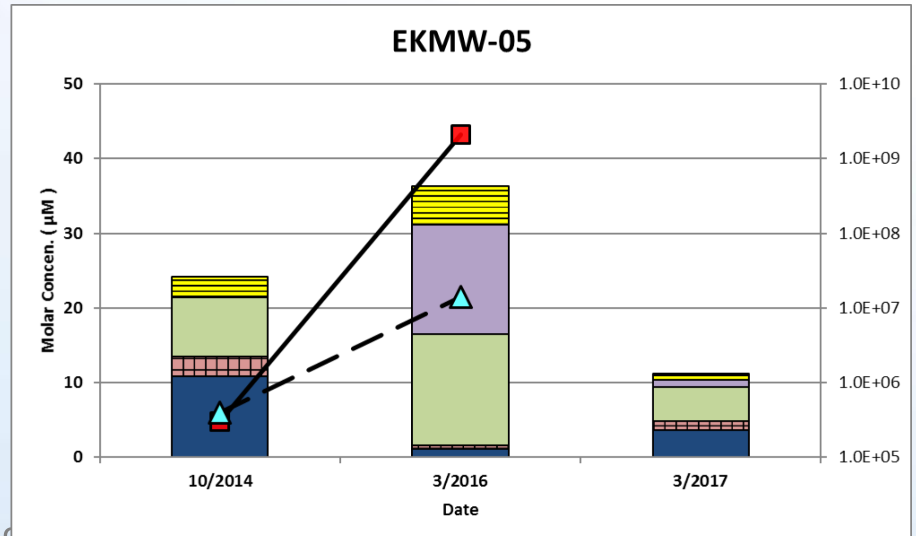
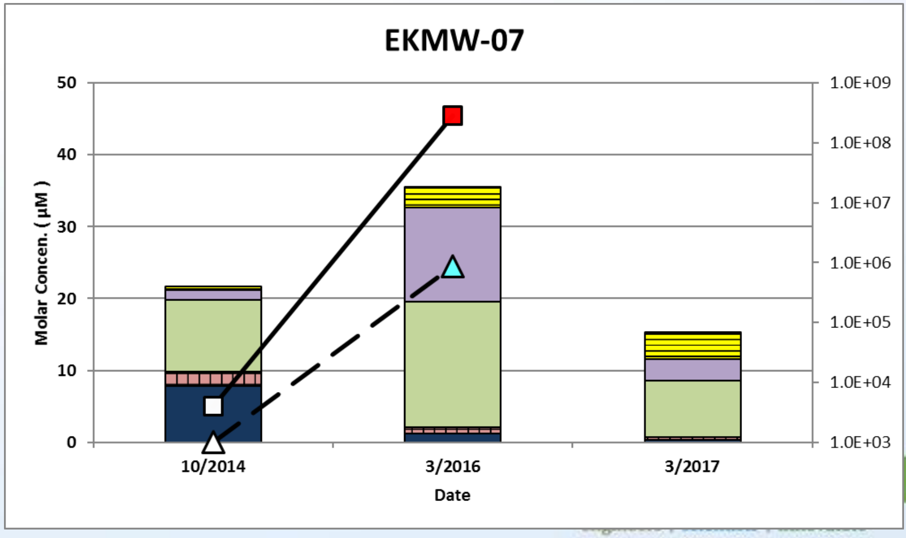


Dhc (open symbol: ND)

vcrA (open symbol: ND)





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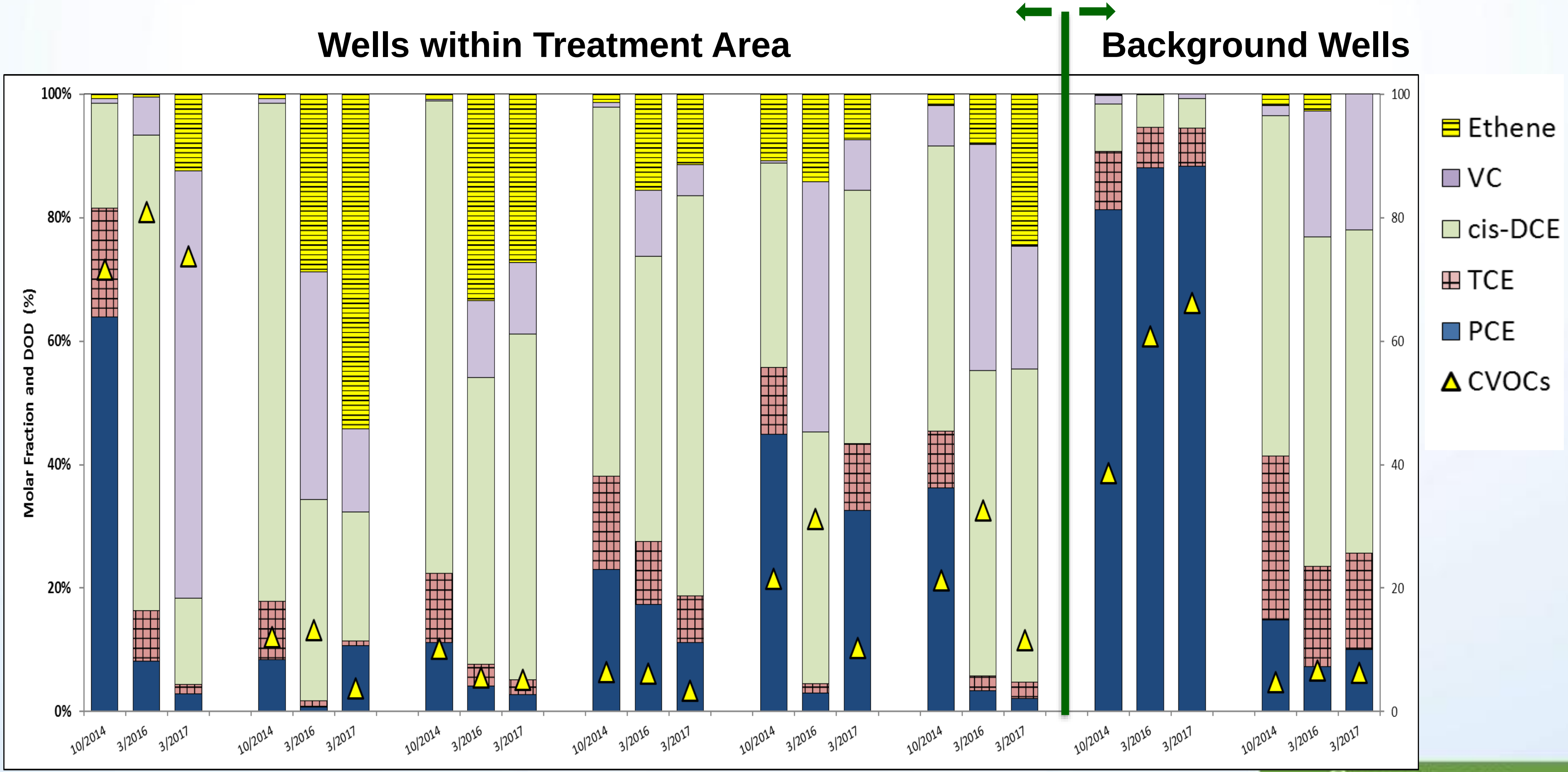
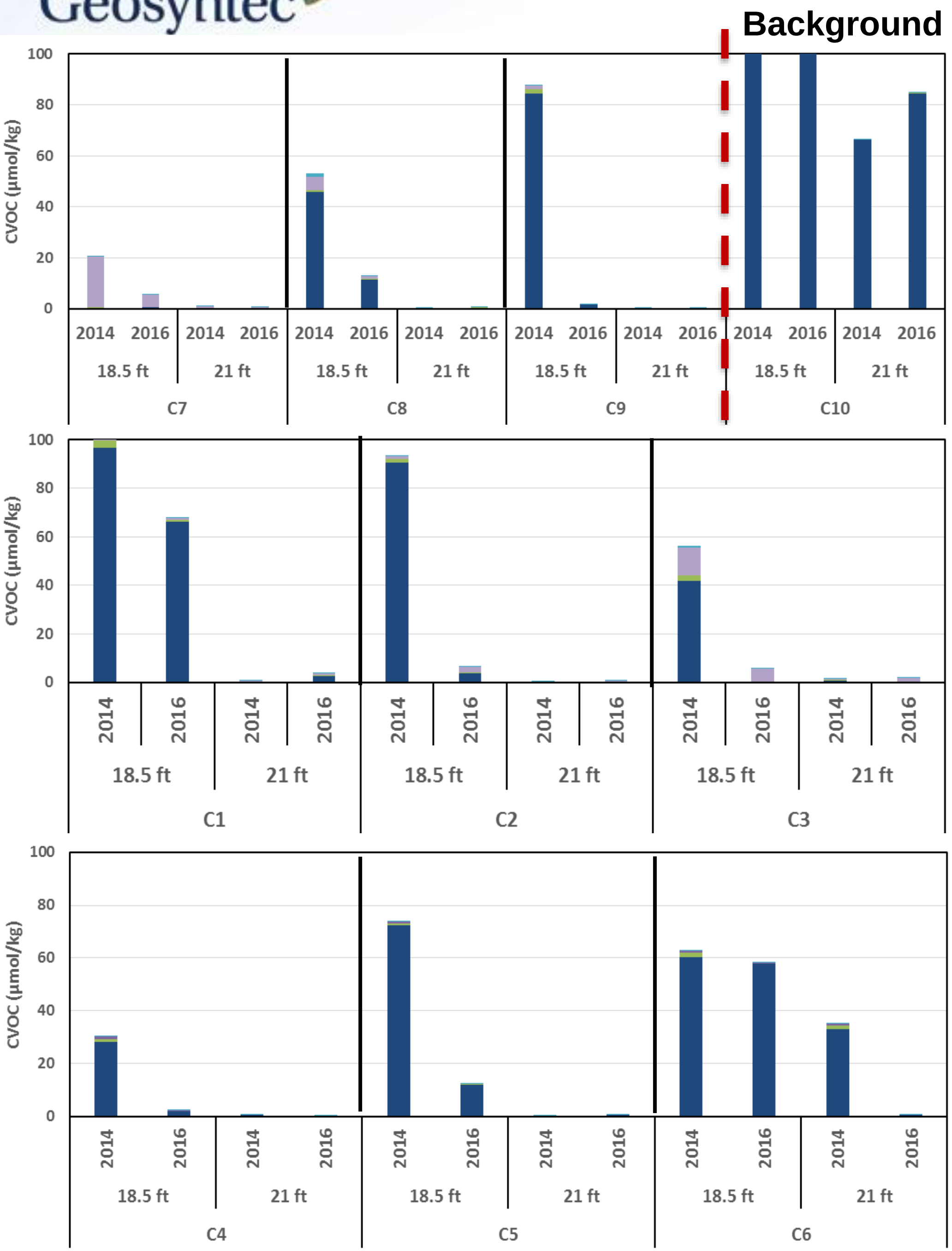
Summary
CVOC Molar Fraction % and Total CVOC

Each Well : Baseline / Post Stage 1 / Post Stage 2



Soil CVOC
(Baseline vs. Post Stage 1)



18.5 ft bgs and 21 ft bgs (clay) at each sampling location

At 18.5 ft bgs

- One location with no detectable baseline PCE
- PCE decreased by 75% ~ 99% at 6 of 7 locations in test area;
- One location with no decrease at 18.5 ft bgs, but >99% decrease at 21 ft bgs

At 21 ft bgs

- No significant baseline PCE, except one location where > 99% decrease from baseline

No PCE decrease at background location outside test area

Key Take-away Message

- 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]
- Another similar EK-BIO project recevied USACE Green Innovation Award for Sustainability
- An innovative solution to a vexing problem!

THANK YOU

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