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Electrokinetic (EK) Enhanced Approaches for Remediation of Low Permeability and Heterogeneous Subsurface Materials

August 22, 2013

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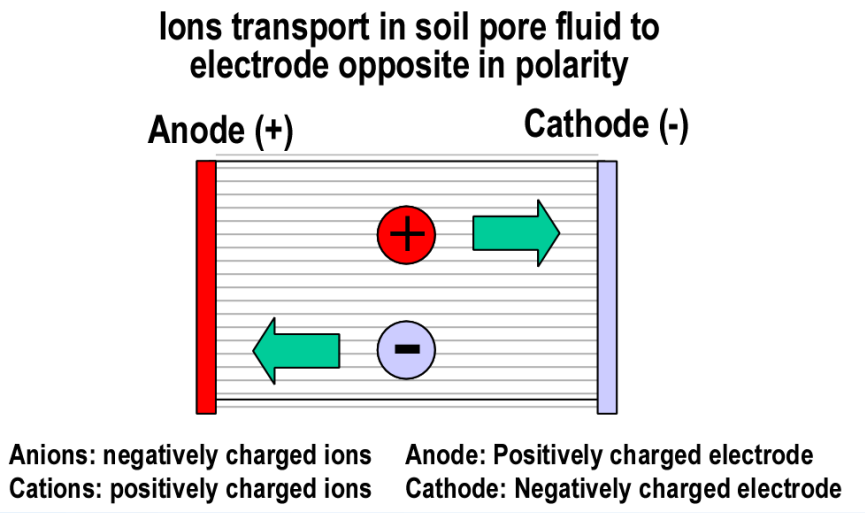
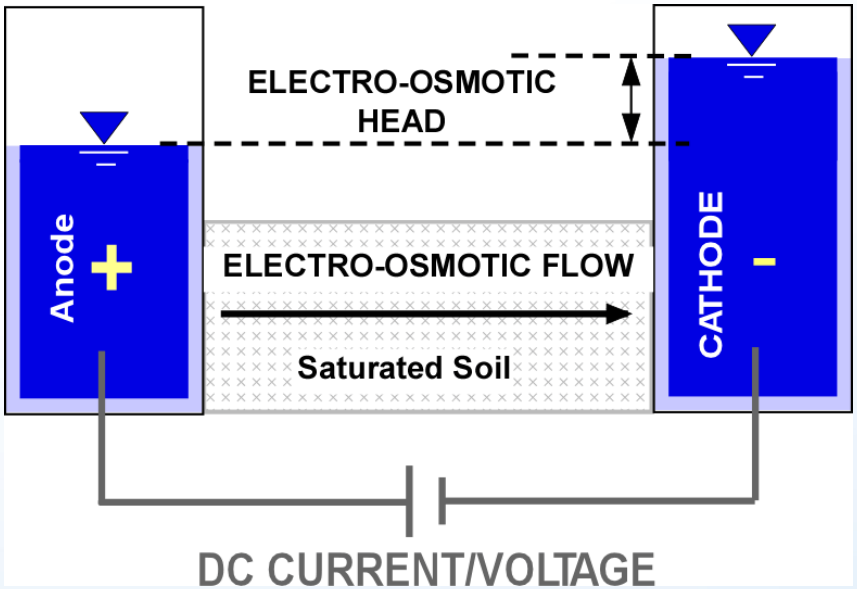
The Challenge of Low Permeability Materials

- PCE and TCE source materials migrate/diffuse into Low K materials
- Silts/clays can serve as a source for decades after accessible VOC mass is addressed
- Distribution of bioremediation and chemical oxidation amendments is poor in Low K materials
- Prolongs remediation, increases cost
- Better amendment delivery techniques required for Low K sites

Solution = Electrokinetic (EK) Migration

- Application of direct current (dc) to saturate subsurface
- Amendments move through silts and clays by:
  - Electromigration (EM) - movement of charged ions
  - Electroosmosis (EO) – bulk movement of water





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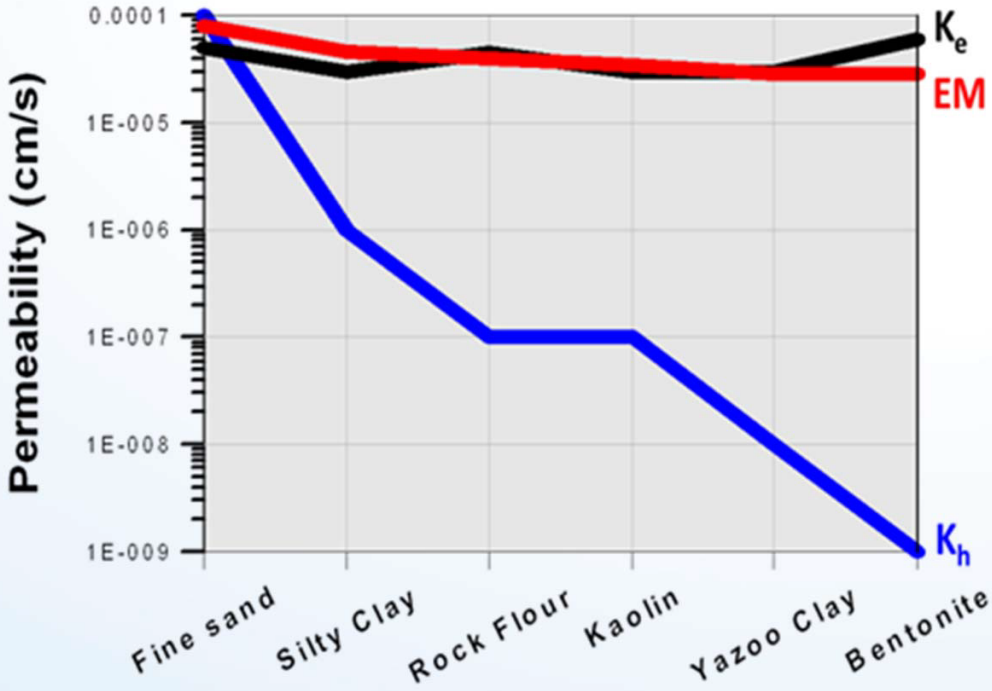
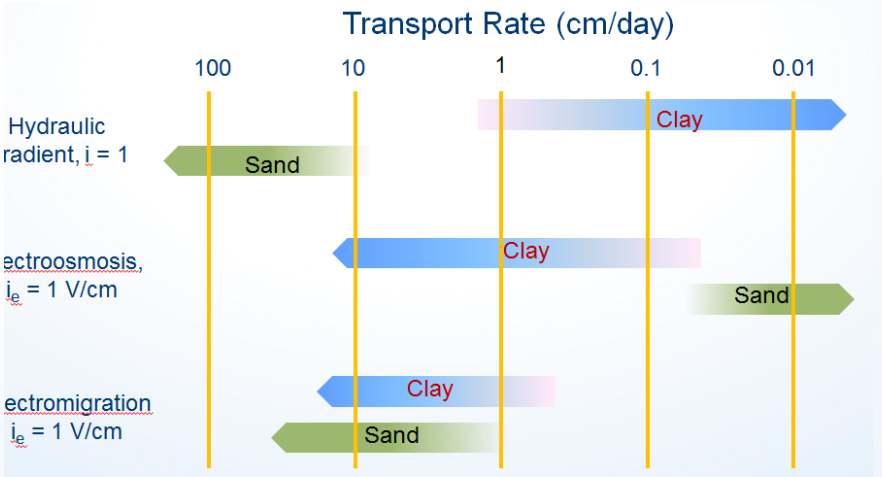
Why EK Works

Why will EK work in low K formations where conventional injection techniques commonly fail?





As K_h decreases, EK becomes the most efficient delivery method

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EK Enhanced Remediation

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

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

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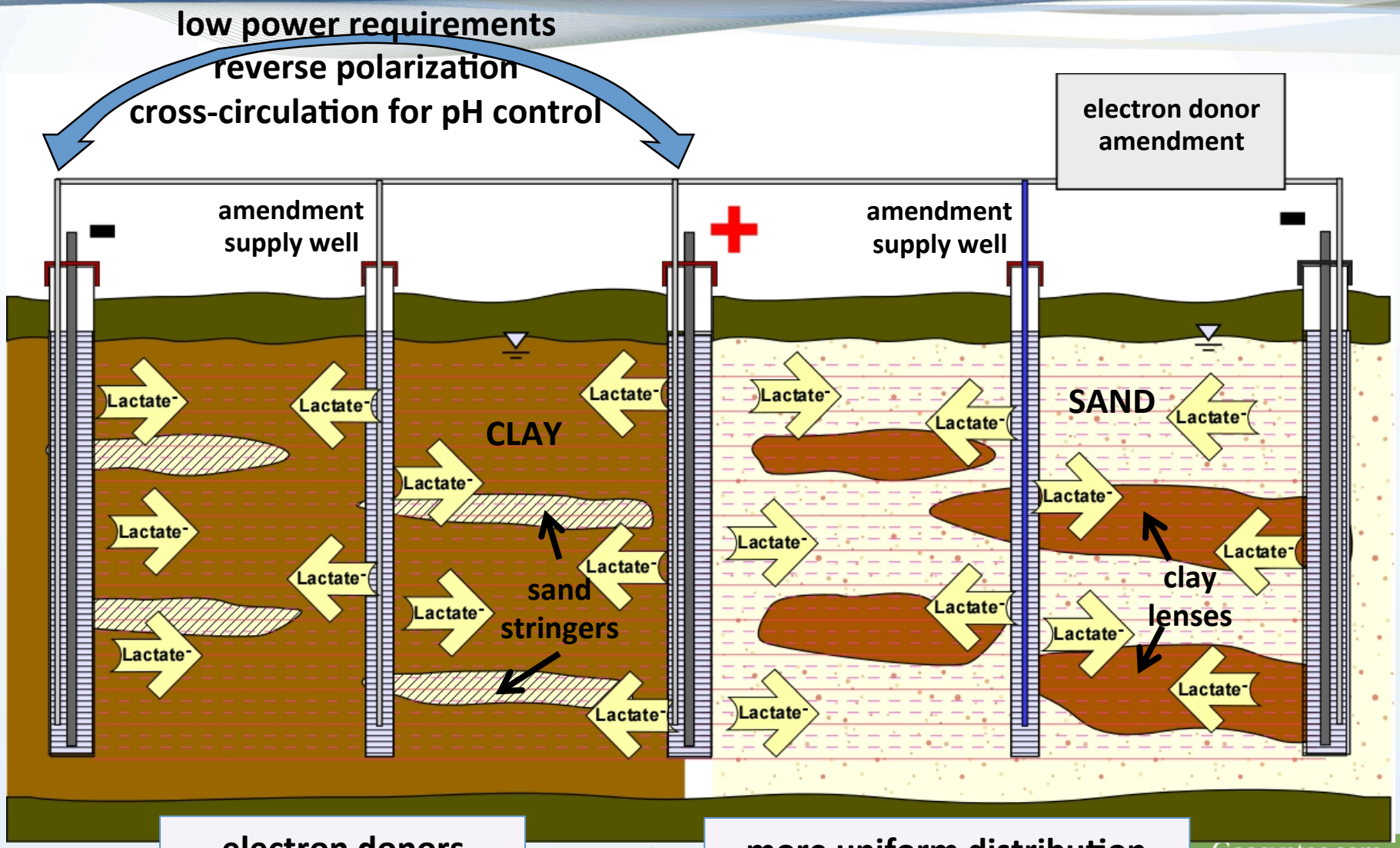
How EK-BIO is Applied in the Field

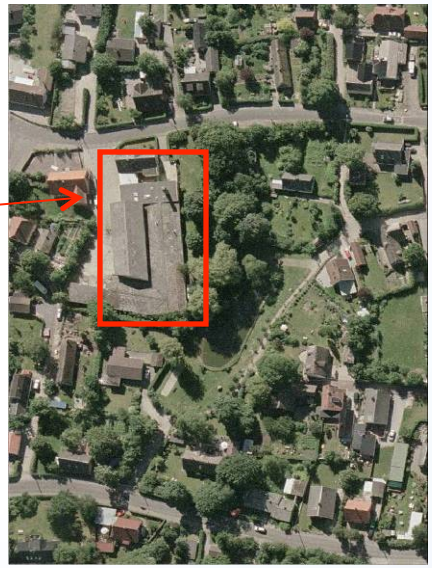


electron donors follow electric field

more uniform distribution of amendment

EK-BIO Pilot Test – Denmark

- 1969-1983 industrial facility
- PCE used for degreasing
- 7 PCE DNAPL hot spots
- 300 m long plume in sand layer 3 - 8 m bgs



Test Site: Hot Spot IV

PCE DNAPL
10,000-100,000 µg CVOC/L
1,000-10,000 µg CVOC/L
100-1,000 µg CVOC/L

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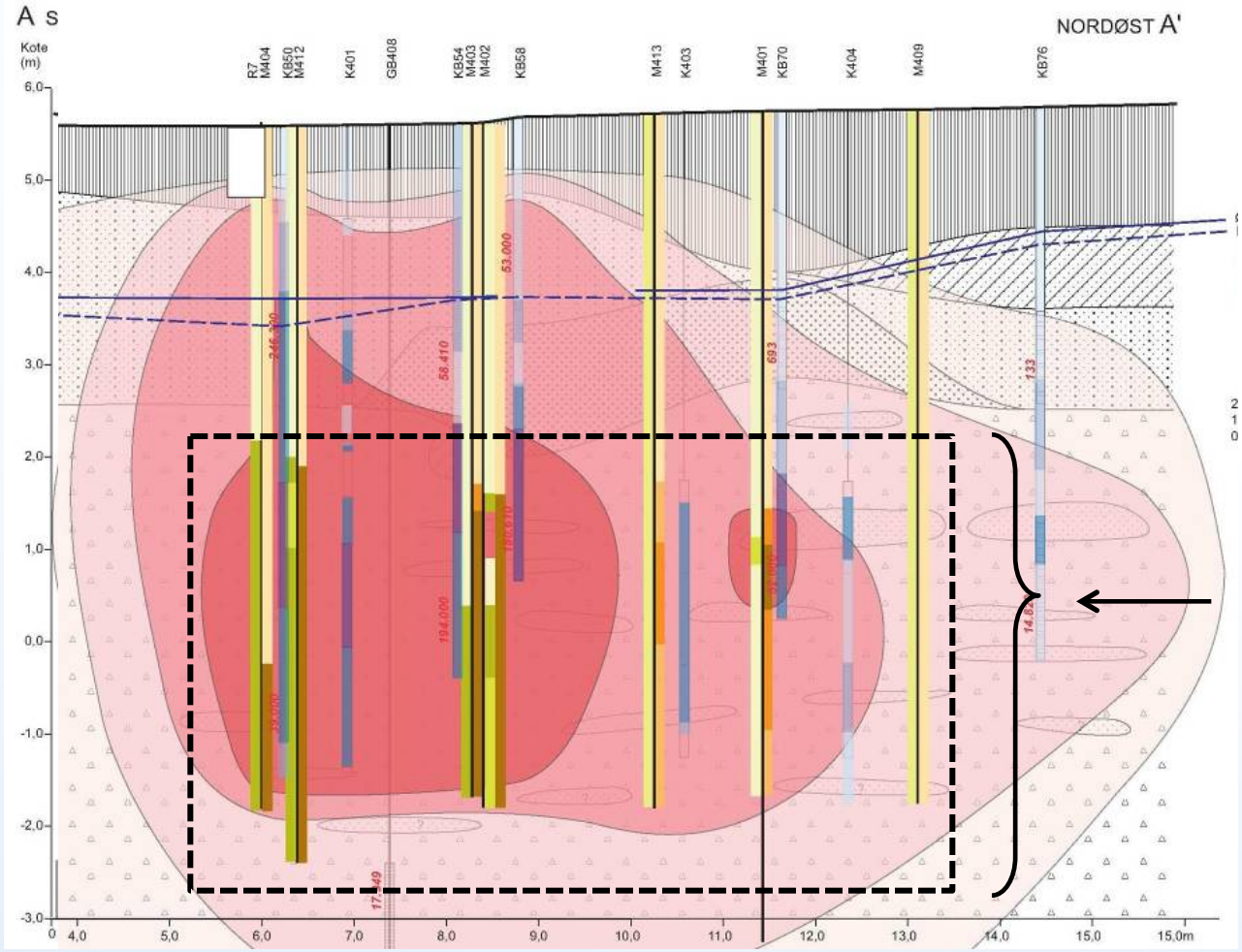
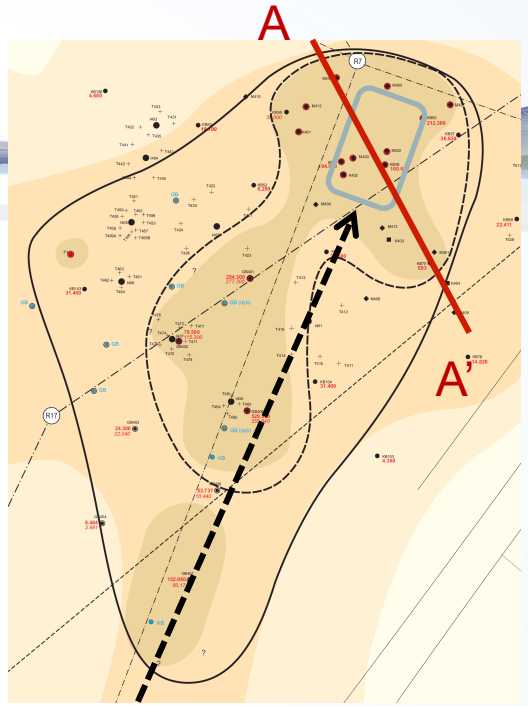
Site Background

- Tight **clay till** with sand stringers (high heterogeneity)
- **PCE DNAPL** present in soil cores (both clay and sand)
- Lab microcosm test showed **bioaugmentation required** to achieve ethene
- Field injection test - **limited distribution** within/across clays – **short-circuiting** into sands
- Conventional EISB injection approaches deemed cost-prohibitive; led to EK lab and field tests

Pilot Test Area



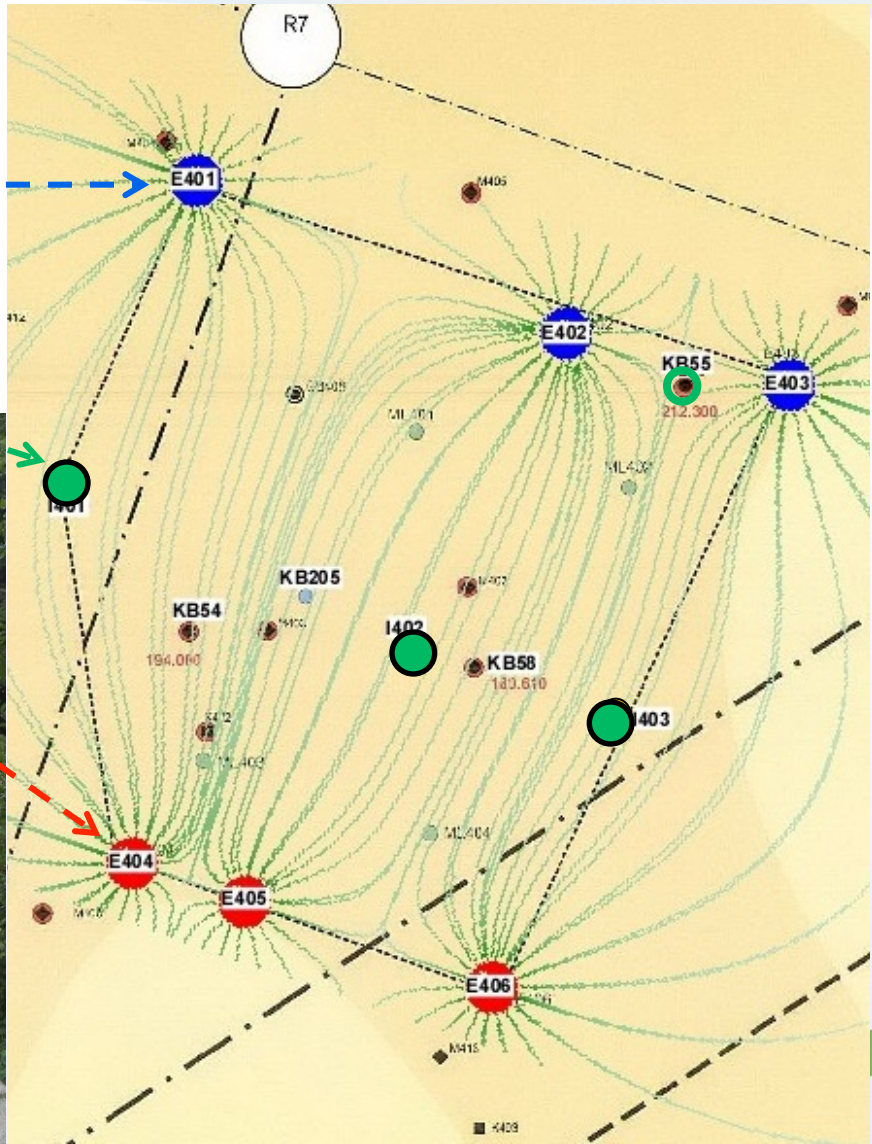


Pilot test area:

- Target depth 3-8 m bgs
- PCE DNAPL
- Tight clay till w/ sand stringers

EK-BIO Pilot Test – System Layout

- Pilot test area ~ 3 x 3 m
- Pilot test infrastructure
  - 3 cathode wells
  - 3 supply wells
  - 3 anode wells



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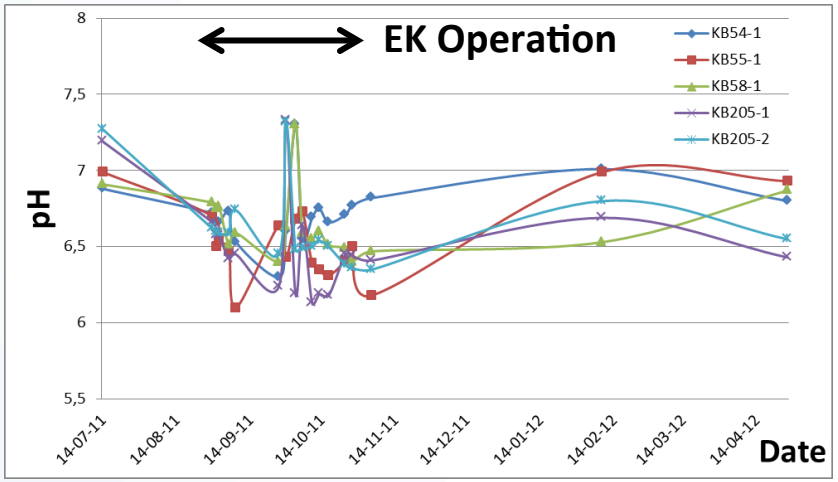
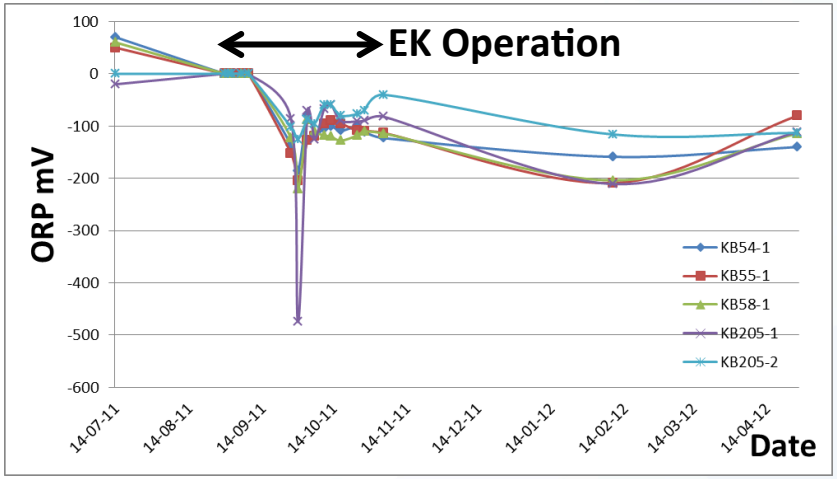
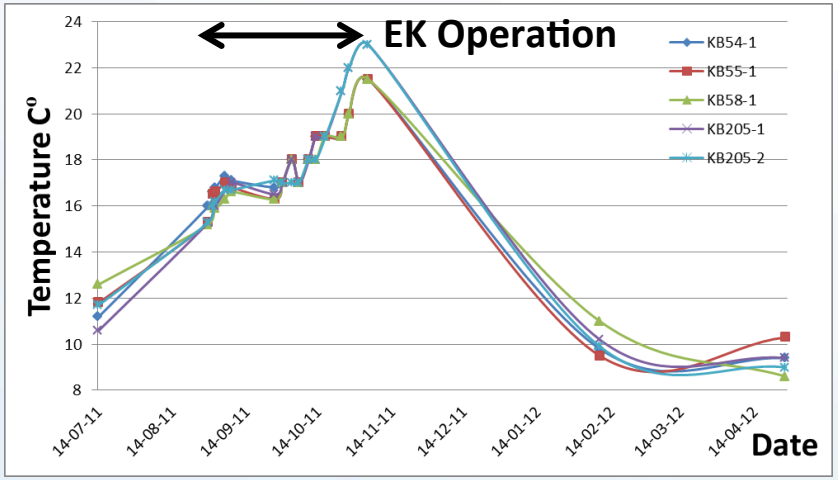
Pilot Test Highlights

- 3 x 3 network of electrode wells
- Lactate and KB-1 bioaugmentation culture added via wells (to promote PCE dechlorination to ethene)
- Direct current applied to soil for 60 days to transport lactate and KB-1 through clays
- Total energy use was ~ 1,950 kW-hr (29 kW-h/m^3) – equivalent to **10 x 100-watt light bulbs**

Groundwater Results: Geochemistry

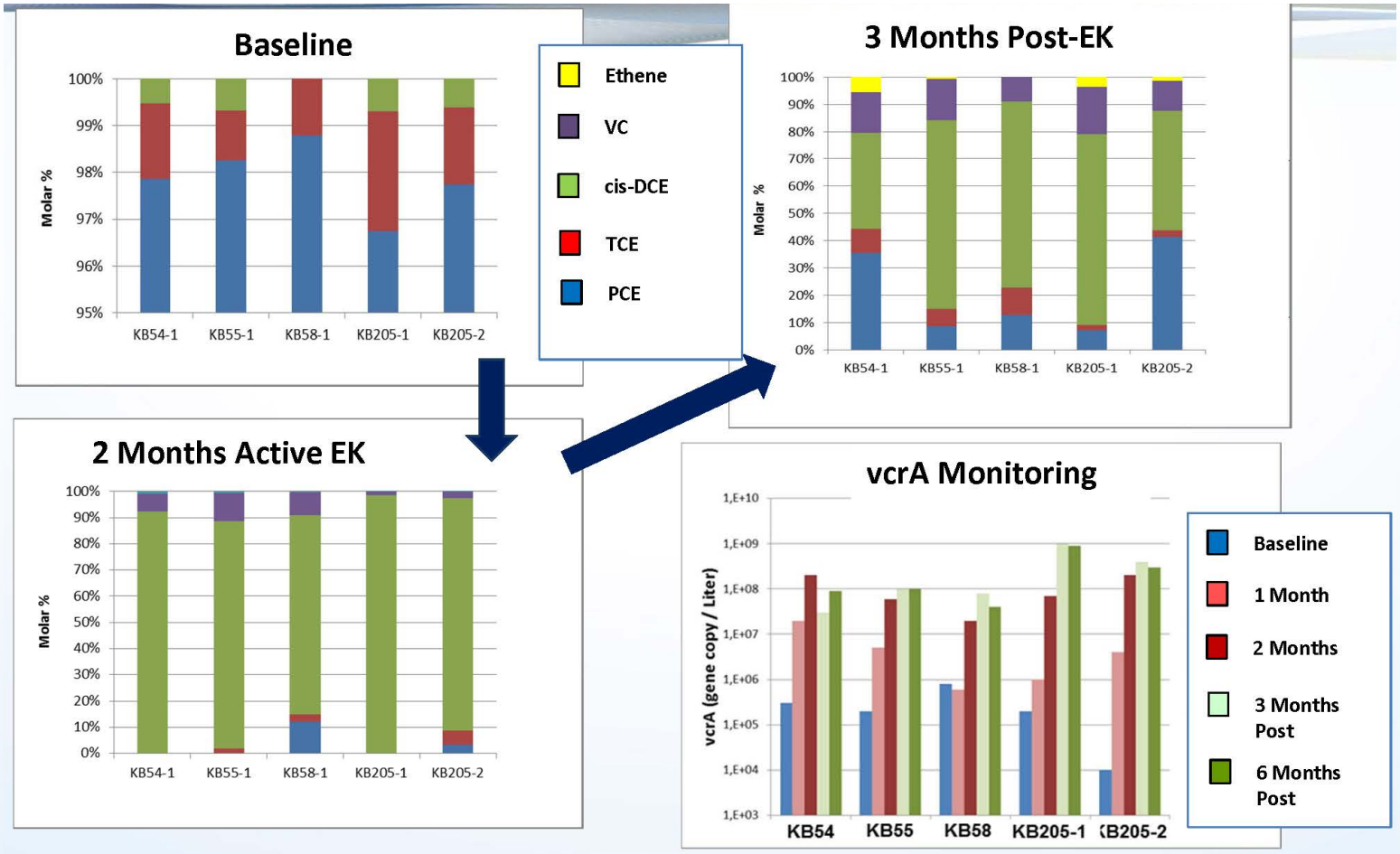






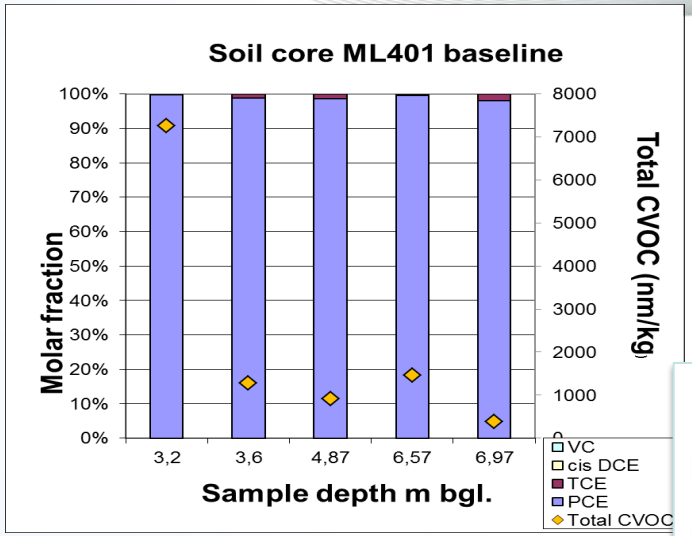
- ✓ Neutral pH
- ✓ Negative ORP
- ✓ Slight increase in temperature (~5 °C), which may benefit biological activities

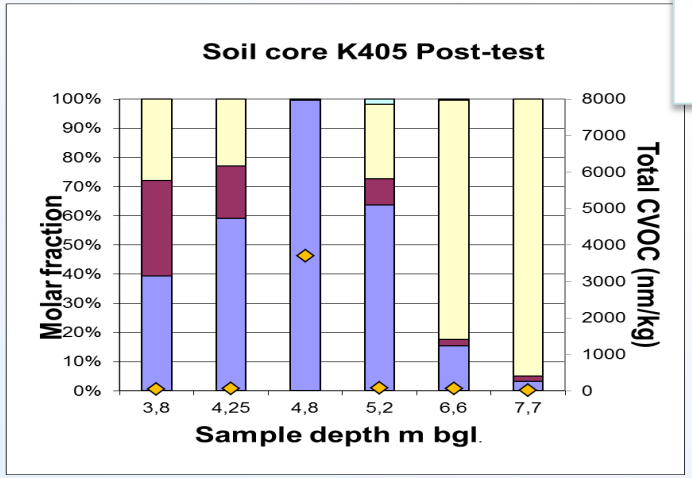
Groundwater Results - VOCs

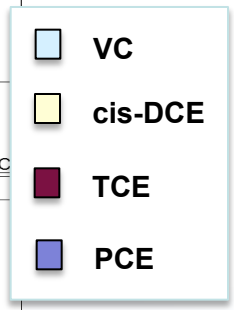


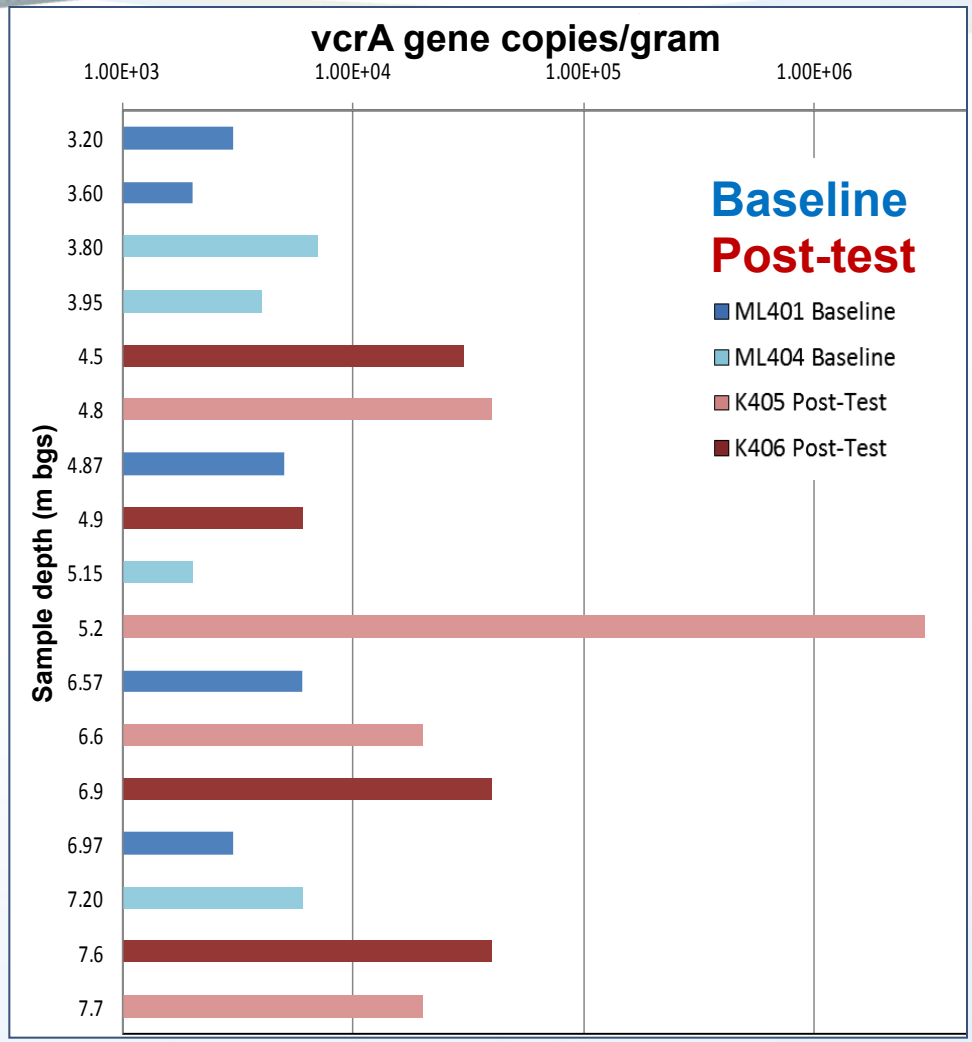
- ✓ Increase in ethene post-EK operation up to 3,700 µg/L
- ✓ Increase in Chloride represents ~190 mg/L PCE degraded

Soil Results (Before vs. After)









- **Post-test soil cores sampled 63 days after bioaugmentation**

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Key Conclusions

- EK transport of lactate through clay till ~ 2.5 to 5 cm/day
- Evident increases of *Dehalococcoides* and *vcrA* in groundwater and clay till matrix
- Groundwater and soil core data show PCE dechlorination to vinyl chloride and ethene:
  - Increasing dissolved PCE concentrations ⇔ dissolution/desorption of PCE DNAPL
  - Increasing ethene concentrations and *Dhc/vcrA* numbers ⇔ sustained Enhanced Reductive Dechlorination
- Stable electric system - energy usage ~29 kW-hr/m^3 (10x 100-W light bulbs)
- Full Scale system constructed in Nov 2012 with Startup in Dec 2012 – anticipated 16 month duration of phased “power on” operation