PILOT TEST OF

ELECTROKINETICALLY ENHANCED BIOREMEDIATION (EK-BIO)

AS AN INNOVATIVE REMEDIAL APPROACH FOR PCE DNAPL

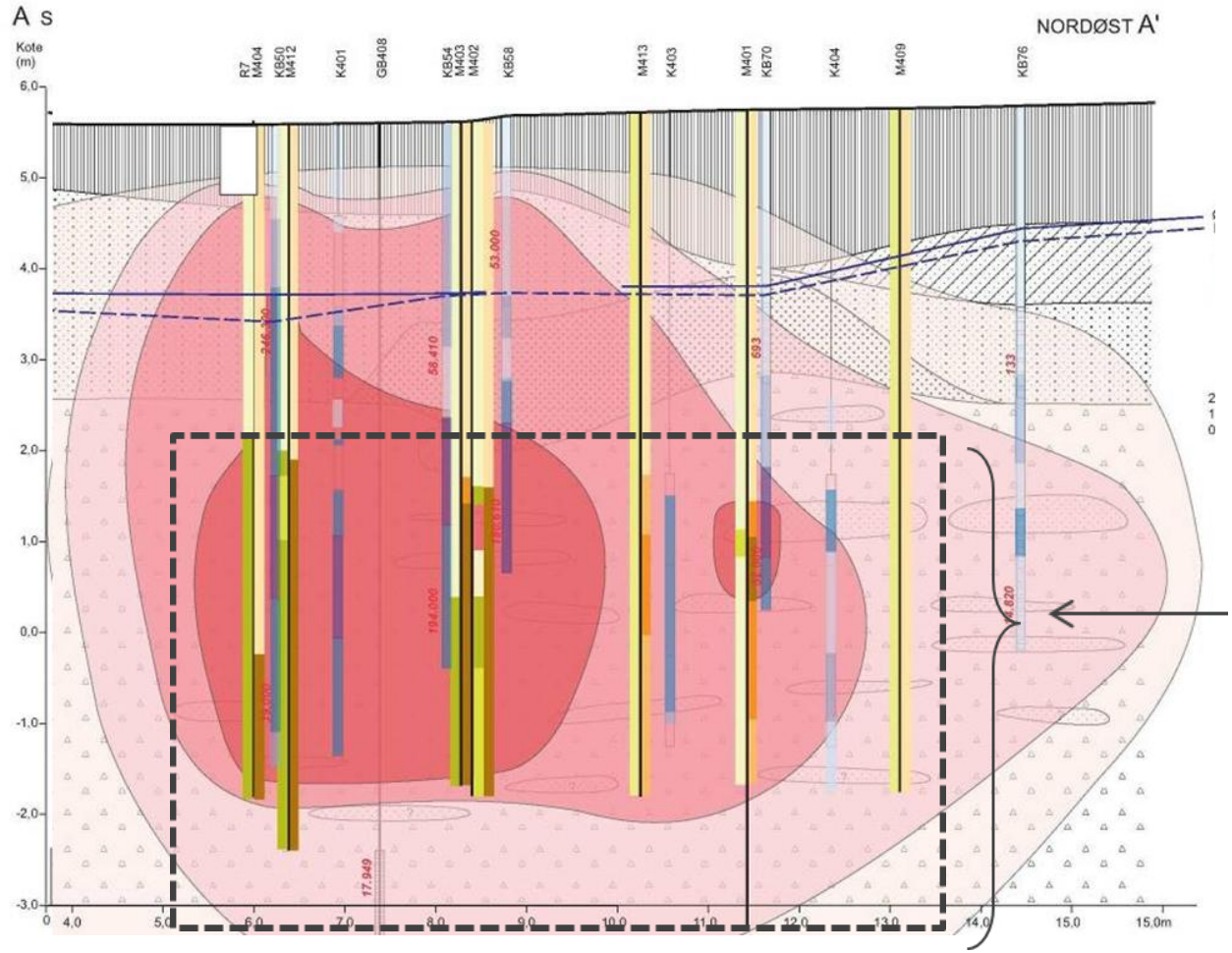
Charlotte Riis, NIRAS, Denmark

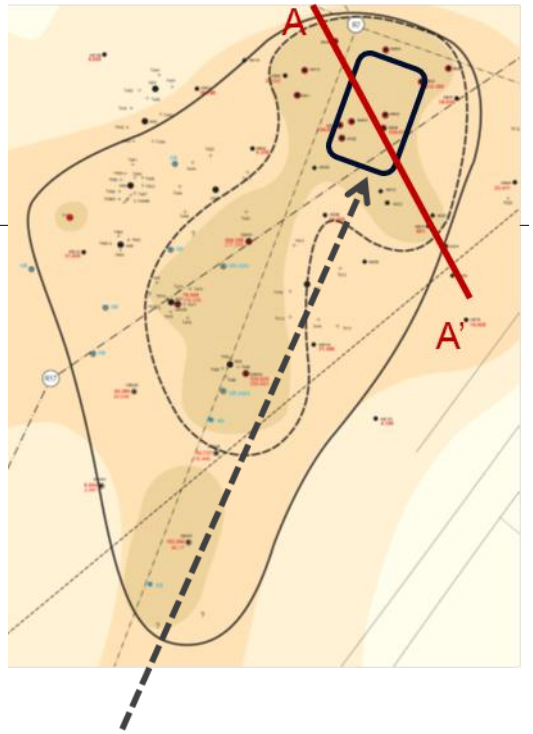
NORDROCS, September 19, 2012

EK-BIO PILOT TEST – THE TEAM

- NIRAS A/S, Denmark
  - Charlotte Riis
  - Martin Bymose
- Geosyntec Consultants, US
  - Evan Cox
  - James Wang
  - David Gent (US Army Engineer R&D Center)
- Capital Region, Denmark
  - Mads Terkelsen

PILOT TEST AREA
SKULDELEV, DENMARK





Pilot test area:

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

EK-BIO – TAKING ON THE CHALLENGE OF PCE DNAPL IN CLAY

- Why EK-BIO?

✓ 100% PCE DNAPL degradation via enhanced reductive dechlorination possible with *Dehalococcoides (Dhc)*

? Effective delivery in heterogeneous clay till?

÷ Fracturing

÷ Direct push injections

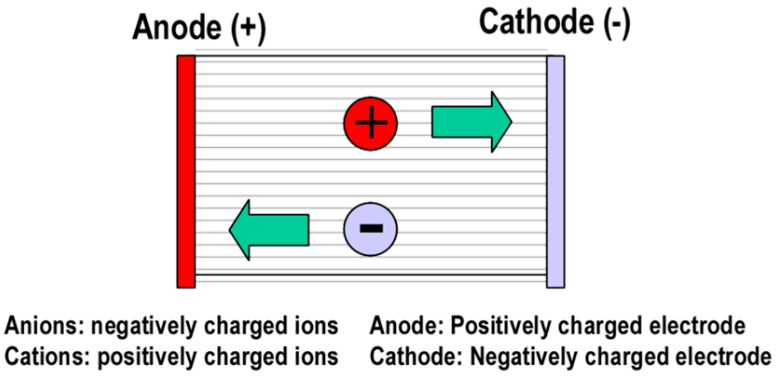
} Non-uniform distribution – back-diffusion issues and long timeframes for clean-up

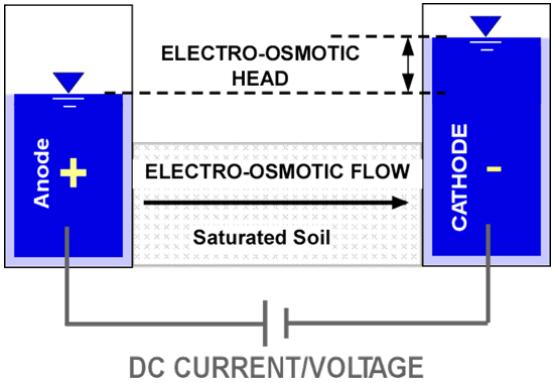
? Electrokinetics

✓ Transport drivers independent of K

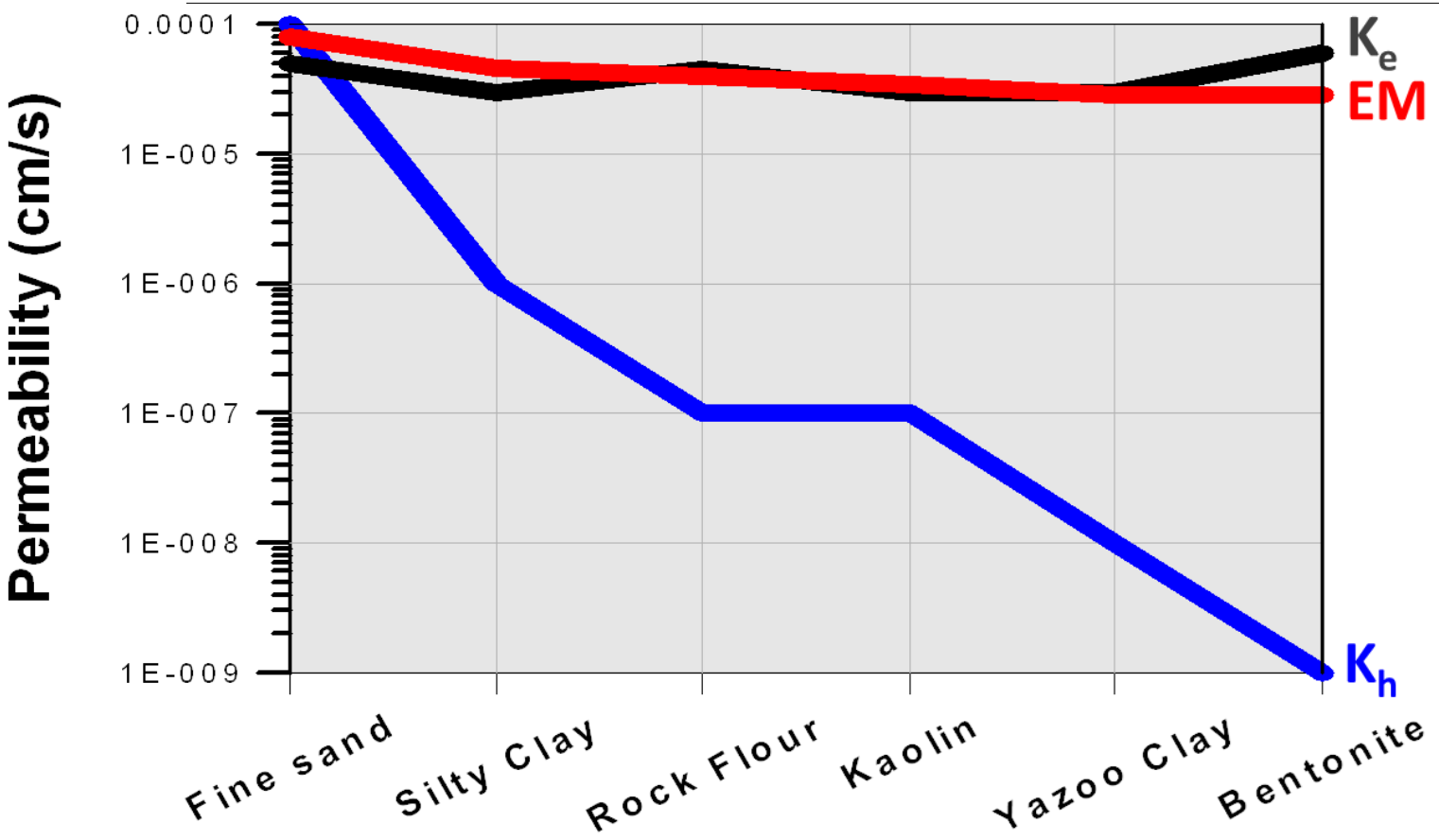
WHAT IS ELECTROKINETICS (EK)?

- EK = application of DC electric field to saturated subsurface system
- Primary EK-BIO transport drivers in clay till:
  - **Electro-migration (EM)** – movement of ions – substrate transport
  - **Electro-osmosis (EO)** – bulk movement of water – bacterial transport





EK VS. HYDRAULIC PERMEABILITY



As Kh decreases, EK becomes the most efficient delivery method

THE SKULDELEV PILOT TEST – WHAT'S NEW?

- ✓ Processes already shown to occur under EK conditions:
  - ✓ Electron donor transport (2-5 cm/day in clay)
  - ✓ Bacterial transport
  - ✓ *Dehalococcoides* viability
  - ✓ **Transport of *Dehalococcoides* under EK conditions**
    - ✓ Bench-scale EK-BIO treatability study 2010*
    - ? **Field scale yet to be shown → Until this project!**

*Test performed at Northeastern University (Akram Alshawabkeh and Xuhui Mao)

X. Mao, J.Wang, A. Ciblak, E.E. Cox, C. Riis, M. Terkelsen, D.B. Gent, A. N. Alshawabkeh (2012): Electrokinetic enhanced bioaugmentation for remediation of chlorinated solvents in contaminated clay. Journal of Hazardous Materials, Volumes 213-214, 311-317.

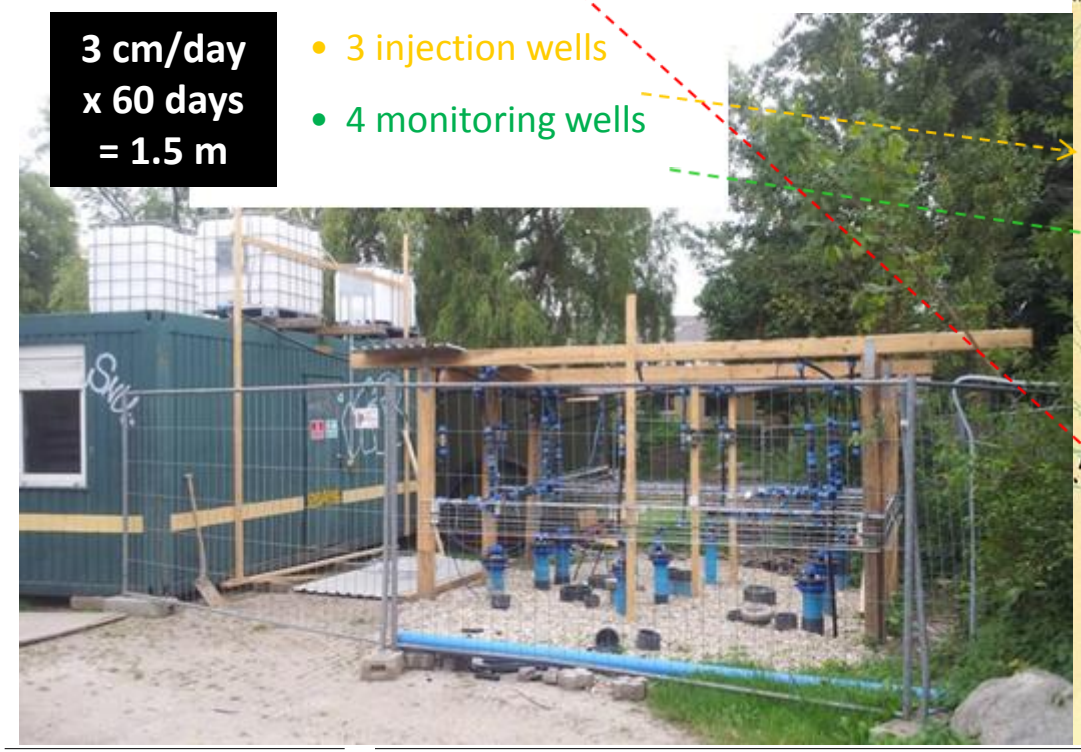
EK-BIO PILOT TEST – OBJECTIVES

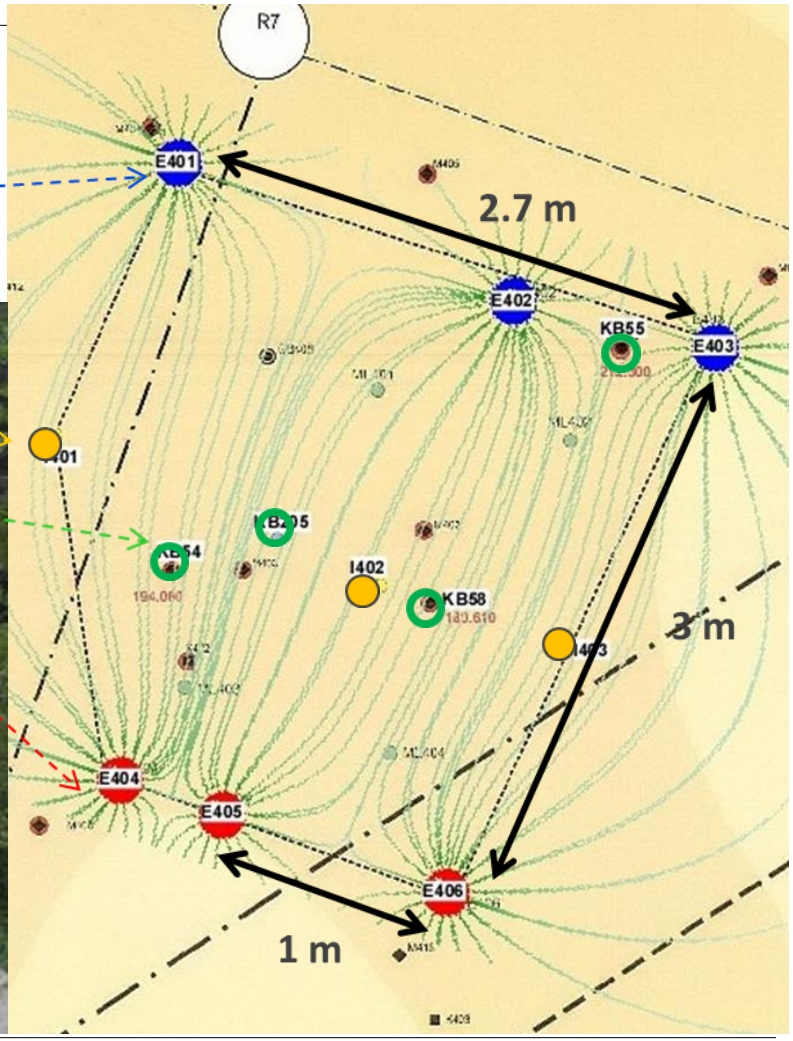
1. Evaluate and demonstrate applicability of EK-BIO
2. Evaluate lactate transport rate
3. Evaluate viability and transport of *Dhc* in clay materials
4. Evaluate degradation of PCE w/in timeframe of pilot test
5. Gather site-specific field data and operational data for full-scale EK-BIO design

EK-BIO PILOT TEST – SYSTEM LAYOUT

- Pilot test area ~3x3 m
- Pilot test infrastructure
  - 3 cathode wells
  - 3 anode wells
  - 3 injection wells
  - 4 monitoring wells

3 cm/day x 60 days = 1.5 m





EK-BIO PILOT TEST – MONITORING PROGRAM

- **Electrical system**
  - 2-3 times weekly
    - Currents of power supplies
    - Current to individual electrodes
    - Electrical potential

Monitored to ensure steady electric field ⇒

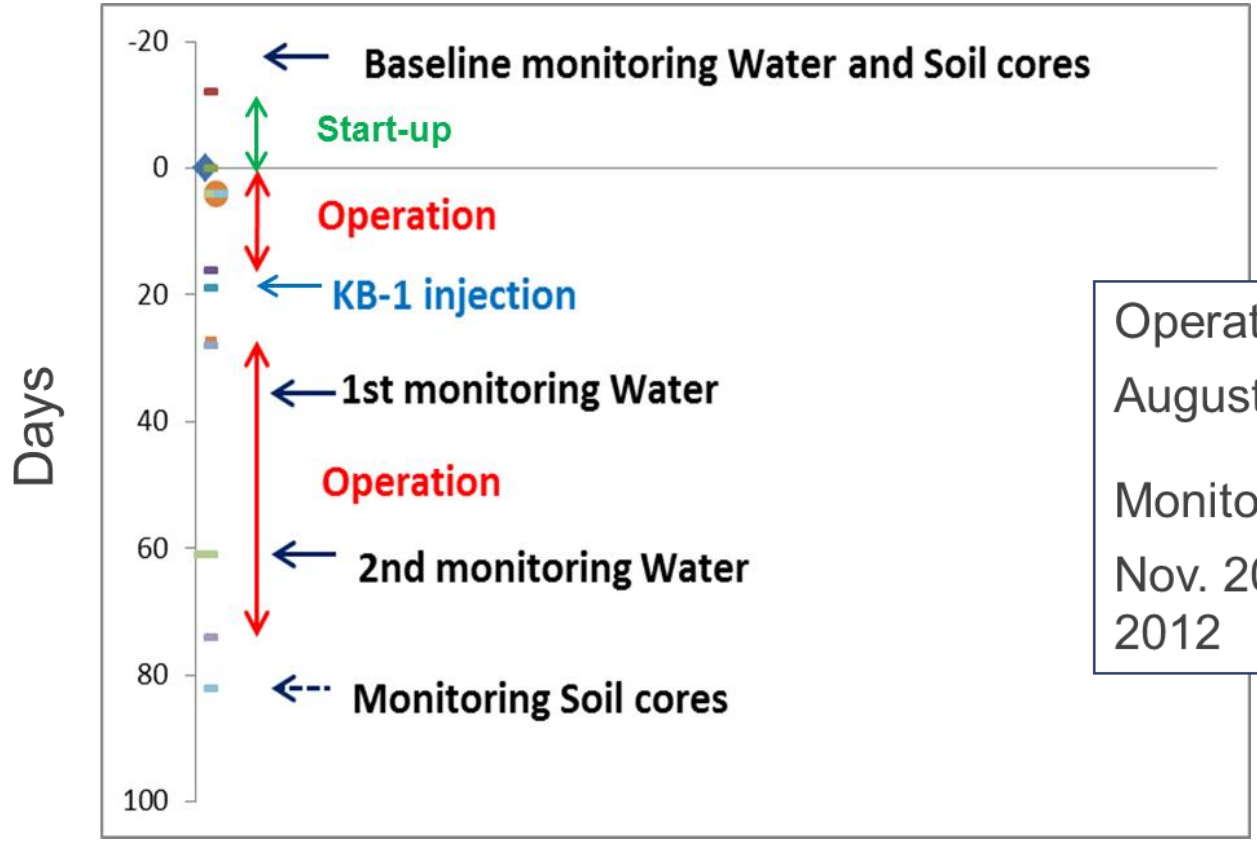
Steady amendment transport

- **Groundwater**
  - Twice weekly:
    - Field measurements (ORP, DO, EC, T)
  - Weekly:
    - VFAs
  - Baseline and monthly:
    - CVOCs, redox sensitive species (NO_3, SO_4, Fe, Mn, NVOC), dissolved gasses (incl. CH_4), *Dhc*, *vcrA*, Cl
- **Soil cores**
  - Baseline, post-test, 7 mo post-test:
    - CVOCs, TOC, *vcrA*, cations, anions

Monitored to document progress of

- amendment distribution
- contaminant degradation

EK-BIO PILOT TEST – TIMELINE



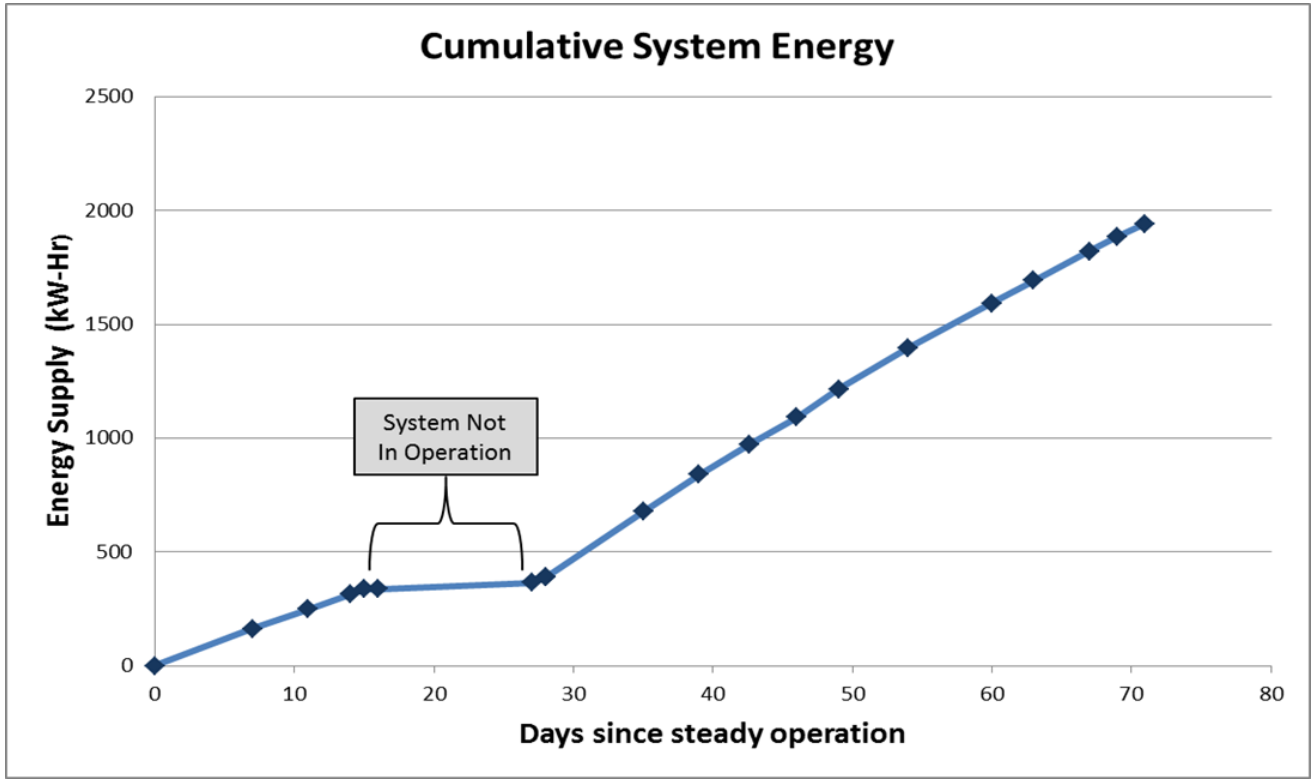
Operation:
August-Nov. 2011

Monitoring:
Nov. 2011- May 2012

+ Monitoring after operation:
  - Groundwater – 3 & 6 months post-test
  - Soil cores – 7 months post-test

EK-BIO PILOT TEST – RESULTS, OPERATIONAL PARAMETERS

- Power supplies operated w/ constant current
- Even distribution of power to all electrodes
  - 6A applied to top electrodes
  - 8A applied to lower electrodes
- Cumulative total system energy supply for the whole pilot test operation: 1950 kW-hr or 29 kW-hr per m^3 of "treated" aquifer materials

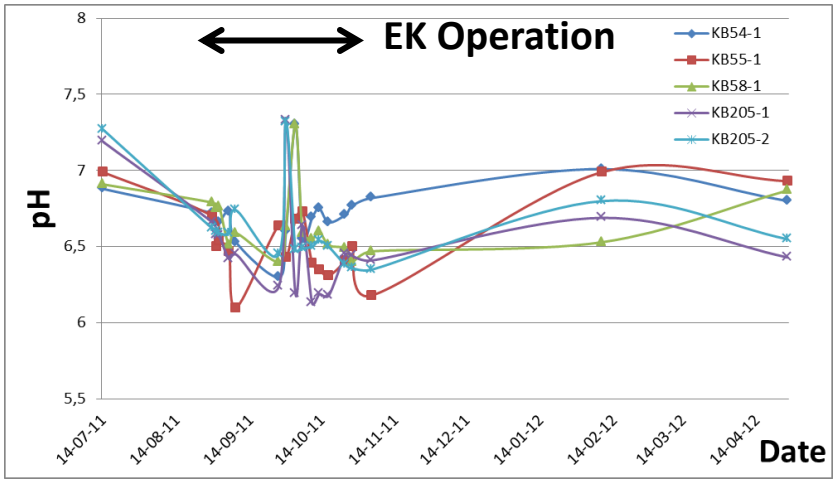


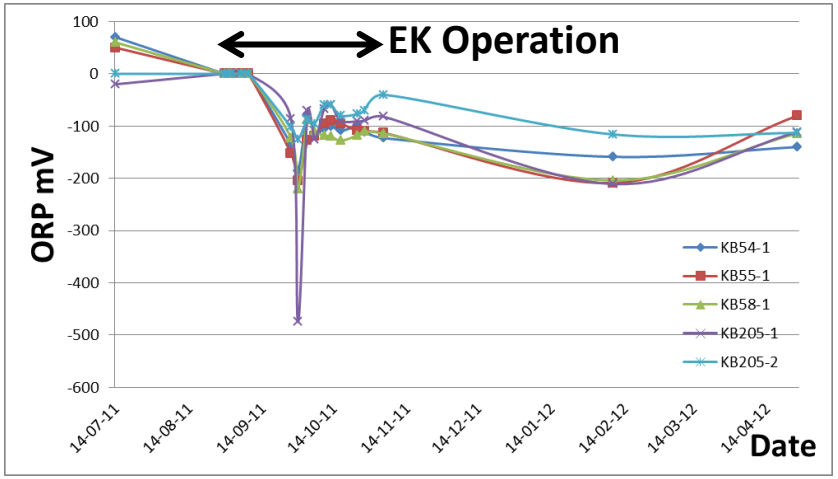
EK-BIO PILOT TEST – RESULTS, OPERATIONAL PARAMETERS

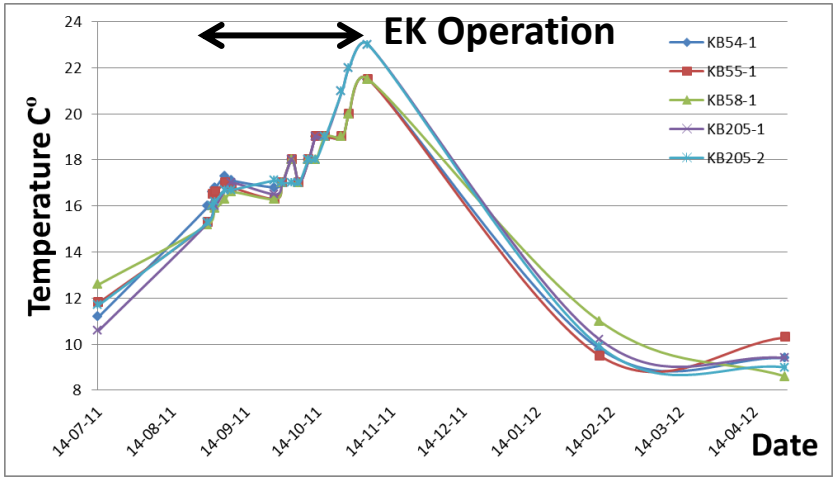
- Chemical amendment dosing:
  - Injection wells and anode wells:
    - Lactate ~ 5,900 liters total (6 g/l)
    - NaOH ~ 1,100 liters total (0,5 mol/l)
  - Cathode wells:
    - Lactic acid ~ 250 liters total (0,05 mol/l)
  - All wells:
    - KB-1~ 21 liters total

– Recirculation between cathodes and anodes for pH control in electrode wells as in treatability test

EK-BIO PILOT TEST – RESULTS, GEOCHEMISTRY



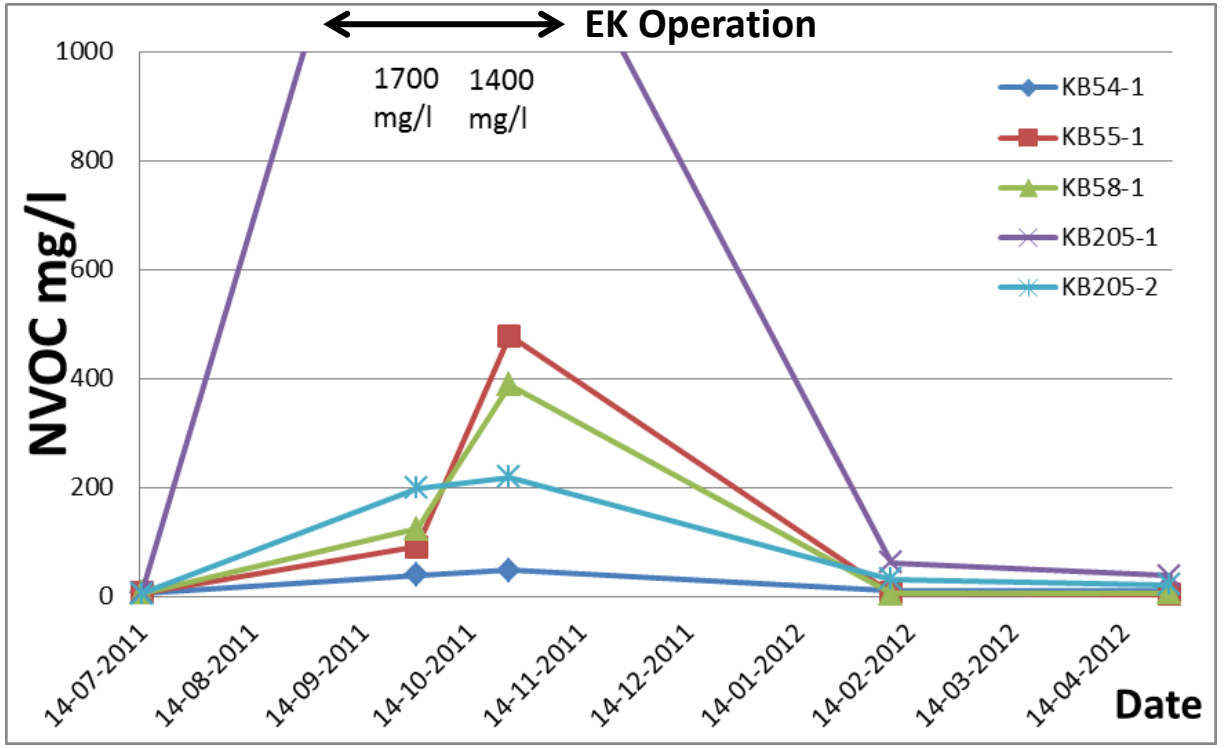




Monitoring showed:

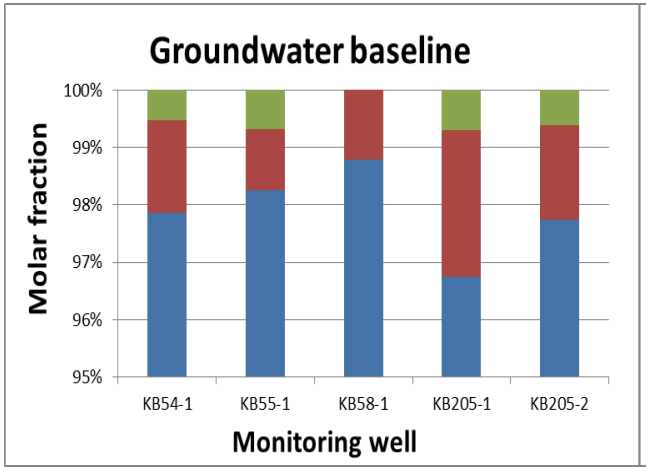
- ✓ Neutral pH
- ✓ Negative ORP
- ✓ Slight increase in temperature (~5 °C), which may benefit biological activities

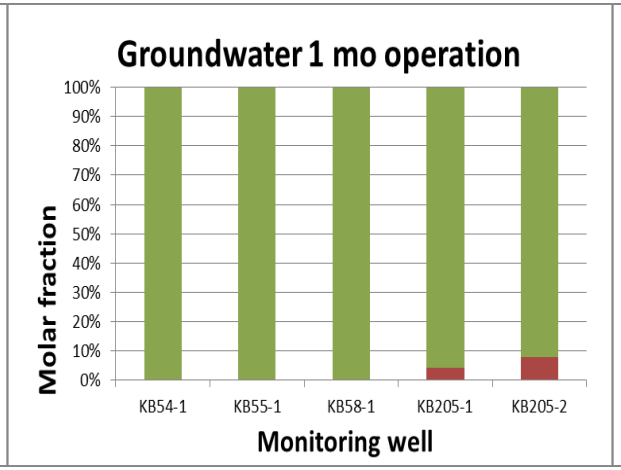
EK-BIO PILOT TEST – KEY RESULTS, SUBSTRATE TRANSPORT

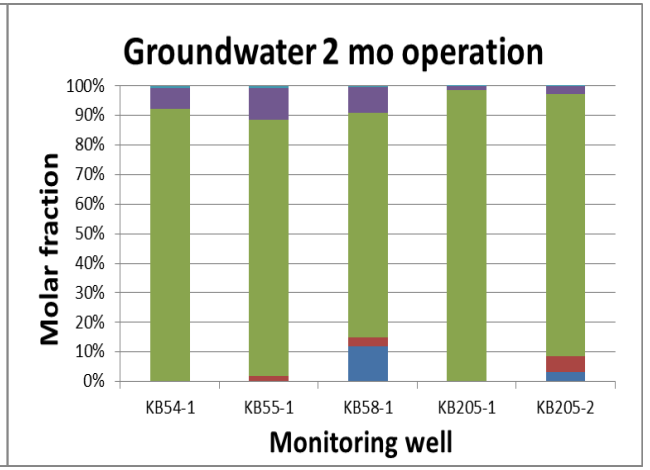


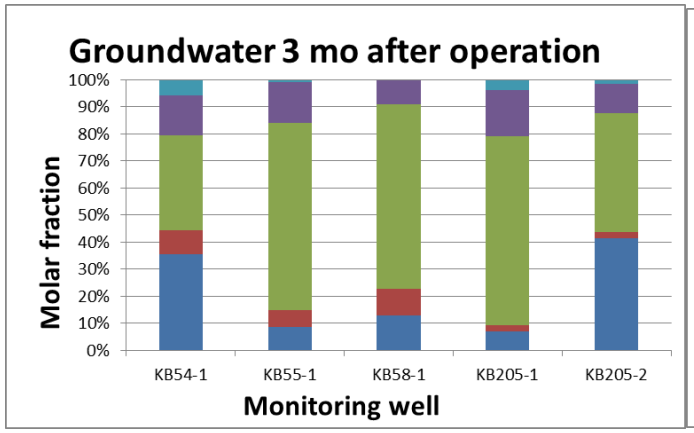
- Lactate transport rate ~ 2.5 - 5 cm/day (~ same as 3.2 cm/day found in treatability test)
- Substrate deficiency 3 months after operation

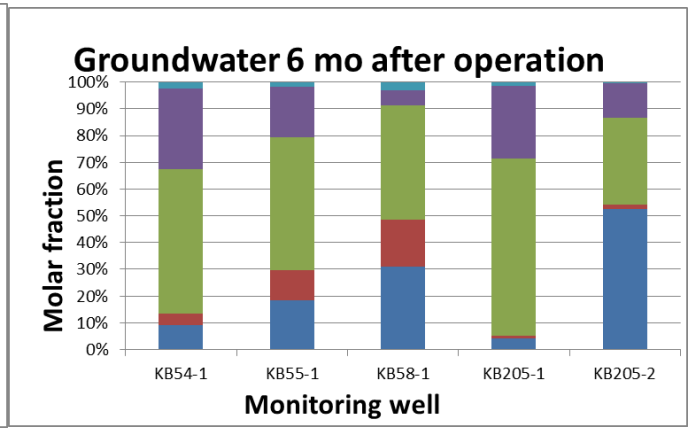
EK-BIO PILOT TEST – KEY RESULTS, REDUCTIVE DECHLORINATION



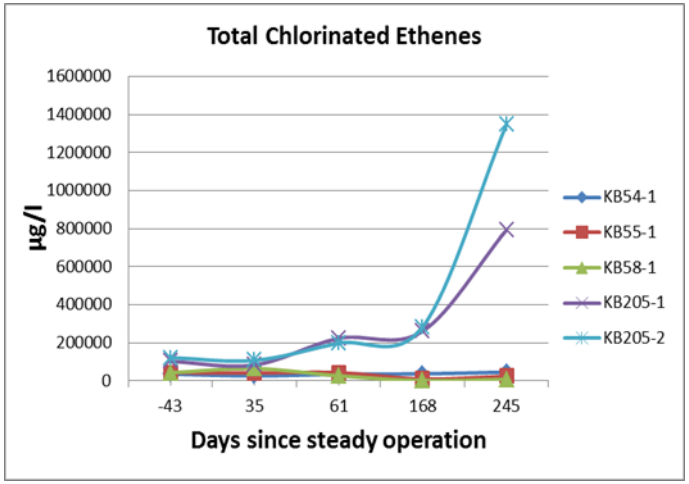


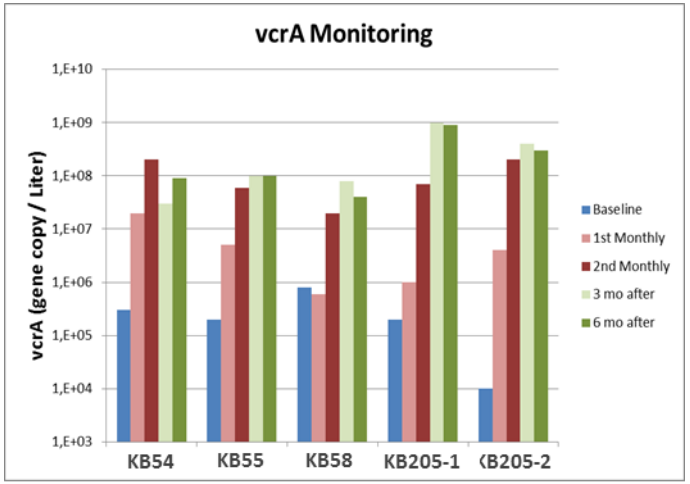






EK-BIO PILOT TEST – KEY RESULTS, REDUCTIVE DECHLORINATION





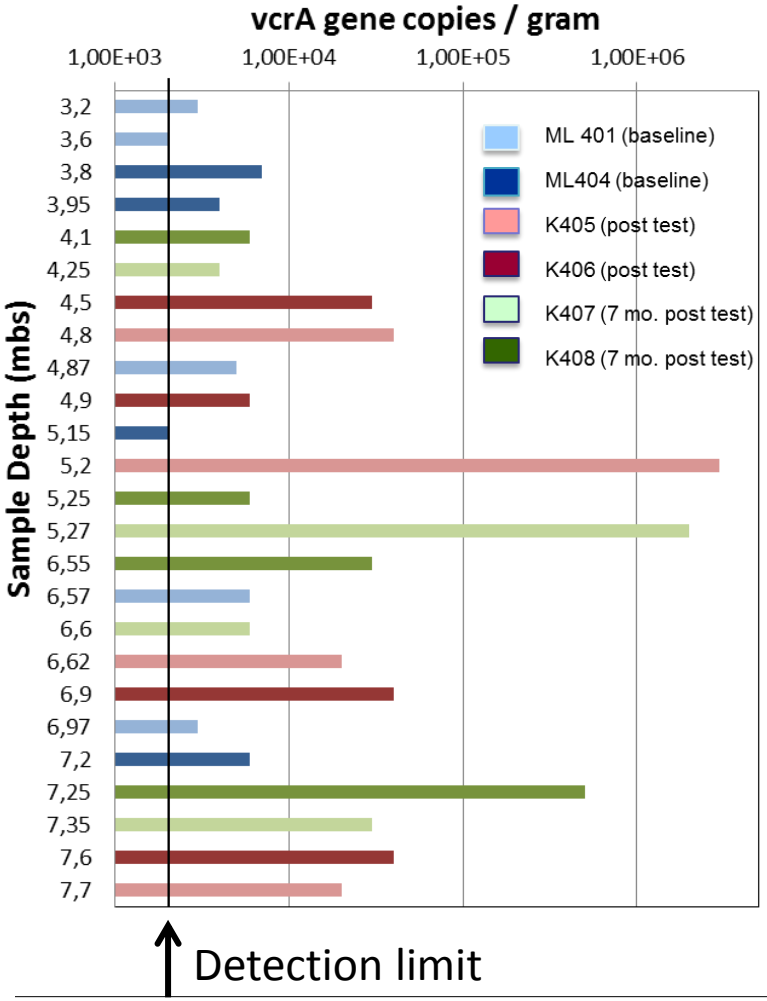
- Increase in vcrA in all wells, also post test
- Increase in ethene 3 mo and 6 mo after pilot test - max 3,700 µg/l

✓ confirms ongoing complete reductive dechlorination by *Dehalococcoides*

- Increase in PCE and Chloride (~190 mg/L PCE degraded)

✓ DNAPL dissolution and desorption

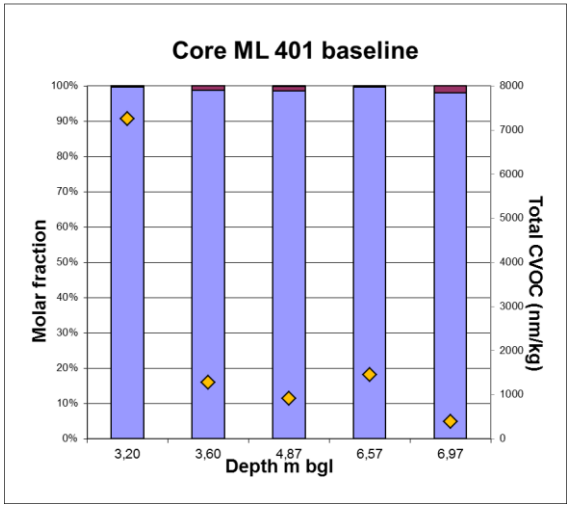
EK-BIO PILOT TEST – KEY RESULTS, REDUCTIVE DECHLORINATION

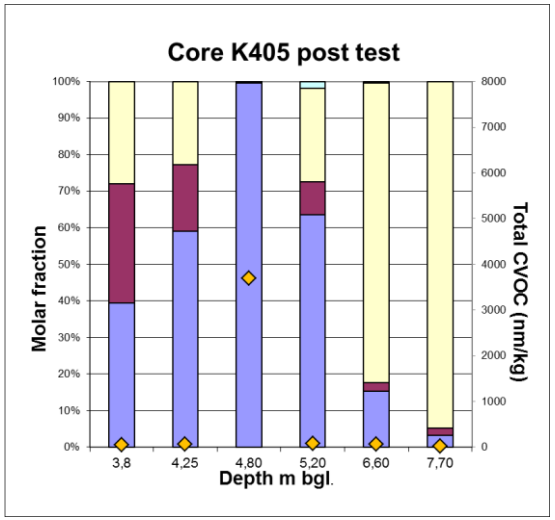


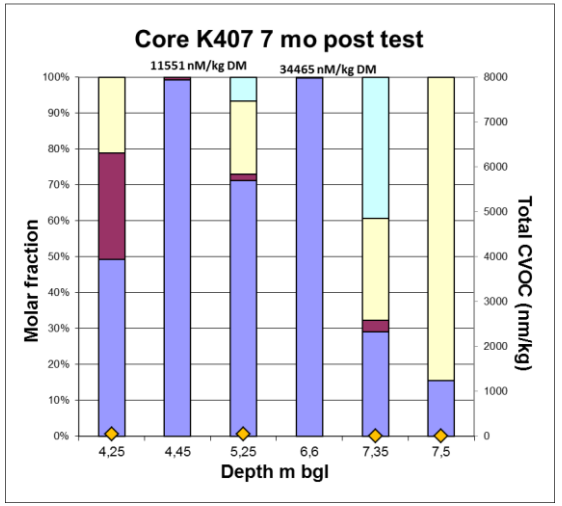
Post test soil cores sampled 63 days after bioaugmentation

High concentrations of vcrA in samples from clay till --> *Dhc* transport into clay due to EK-processes

EK-BIO PILOT TEST – KEY RESULTS, REDUCTIVE DECHLORINATION







- Reductive dechlorination in soil cores post test
- Few samples unaffected by degradation
- Degradation observed in cores w *Dehalococcoides* (vcrA)
- Decrease in total CVOC concentrations in most samples

VC
cis DCE
TCE
PCE
Total CVOC

Objectives

KEY CONCLUSIONS OF THE EK-BIO PILOT TEST

Applicability

Lactate transport

Dhc trans-port/viability

Degradation of PCE

Data for full-scale EK-BIO

1. EK-BIO works!
2. EK transport of lactate through clay till ~ 2.5 to 5 cm/day
3. Evident increases of *Dehalococcoides* and *vcrA* in groundwater and clay till matrix within pilot test area
4. Groundwater and core data show PCE dechlorination to vinyl chloride and ethene by end of pilot test
   - Increasing dissolved PCE concentrations ⇔ dissolution/desorption of PCE DNAPL
   - Increasing ethene concentrations and *Dhc/vcrA* numbers ⇔ sustained ERD
5. Stable electric field in test area

EK-BIO is an effective method for achieving good distribution of sub-strate and bacteria for the purpose of enhancing PCE dechlorination! ☺

WHAT'S NEXT?

- Full-scale implementation in Hot Spot IV starting up in December 2012
- Expected remediation time 3-5 years

QUESTIONS / COMMENTS ?
THANK YOU !

References Cited in Presentation

D. B. Gent, R. Bricka, R. Mark. D. Truax, and M. Zappi (2001), Electrokinetic Movement of Biological Amendments through Natural Soils to Enhance In-Situ Bioremediation, *In Situ and On-Site Bioremediation, Sixth International Symposium.* San Diego, CA.

S. Granade, D. B. Gent, S. Larson (2002), Electrokinetic Remediation of Contaminated Sediments, *First International Conference on Remediation of Contaminated Sediments,* Venice, Italy, October 8, 2002.

X. Wu, (2005), Tetrachloroethylene Bioremediation by Lactate Injection under Direct Electric Currents, Doctoral Dissertation, Northeastern University, Boston, MA, USA.

X. Wu, A. N. Alshawabkeh, D. B. Gent, S. L. Larson, and J. L. Davis, (2007), Lactate Transport in Soil by DC Fields, *J. Geotechnical and Geoenvironmental Engineering, V.* 133, pp. 1587-1596.

L. Y. Wick, P. A. Mattle, P. Wattiau, and H. Harms, (2004), Electrokinetic Transport of PAH-Degrading Bacteria in Model Aquifers and Soil, *Environmental Science & Technology, V38, pp. 4596-4602.*

SERDP ER-1204. Innovative Electrochemical Injection and Mixing Strategies for Stimulation of. In-Situ Bioremediation. http://www.serdp.org/research/er-chlorinatedsolvents.cfm