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Electrokinetic-Enhanced Bioremediation (EK–BIO)

An Innovative Bioremediation Technology for Source Area with Low Permeability Materials

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Mads Terkelsen – Capital Region, Denmark

Charlotte Riis – NIRAS A/S, Denmark

David Gent – US Army ERDC

Team Members - EK-BIO Pilot Test

- **Capital Region, Denmark**
  - **Mads Terkelsen**

- **NIRAS A/S, Denmark**
  - **Charlotte Riis**
  - **Martin Bymose**

- **Geosyntec Consultants, US**
  - **Evan Cox**
  - **James Wang**
  - **David Gent (US Army Engineer R&D Center)**

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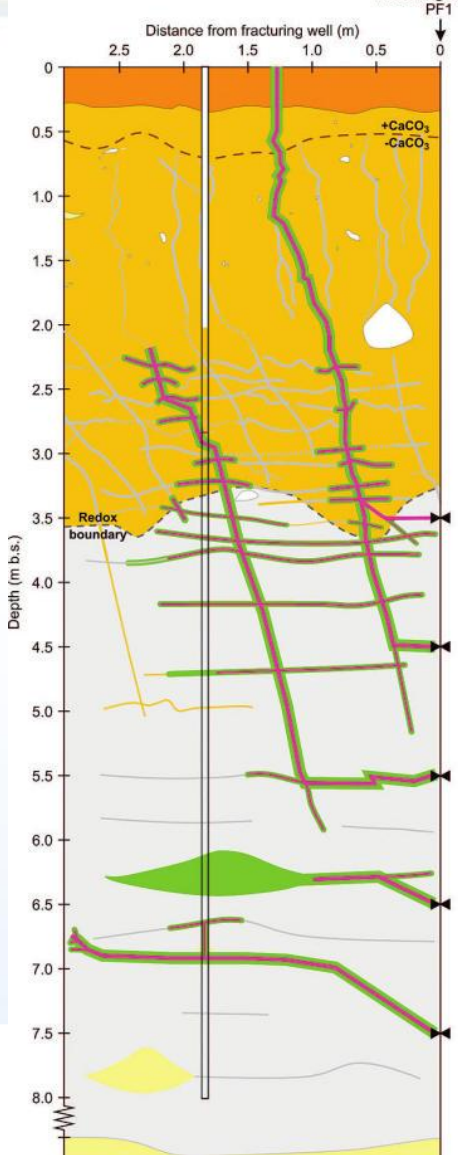
Delivery ! Delivery ! Delivery !

EISB can be cost-effective, **BUT …**

- A key challenge for EISB is **effective delivery** of remediation reagents
- Conventional hydraulic flow-based injection becomes limited in **low permeability soils and heterogeneous subsurface**

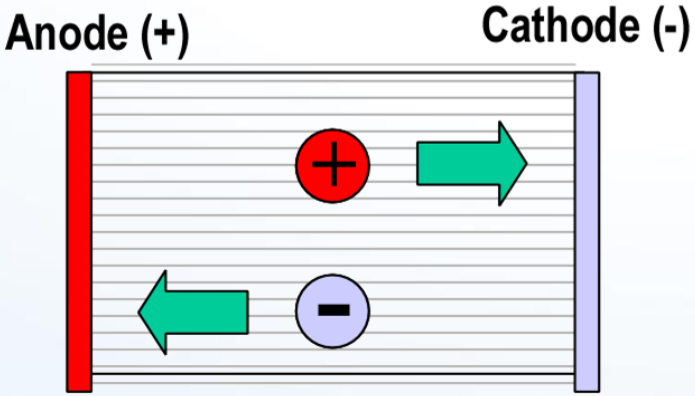


Can we overcome fundamental limitations of low-permeability materials?

Christiansen et al., ES&T 2008

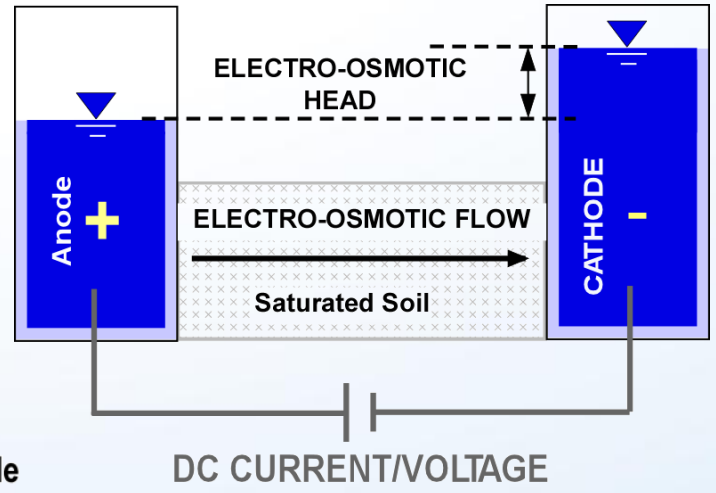
Electrokinetics (EK)–Enhanced Delivery

- EK = application of **DC electric field** to saturated subsurface system
- Primary EK transport mechanisms:
  - **Electro-migration (EM)** – movement of ions
  - **Electro-osmosis (EO)** – bulk movement of water

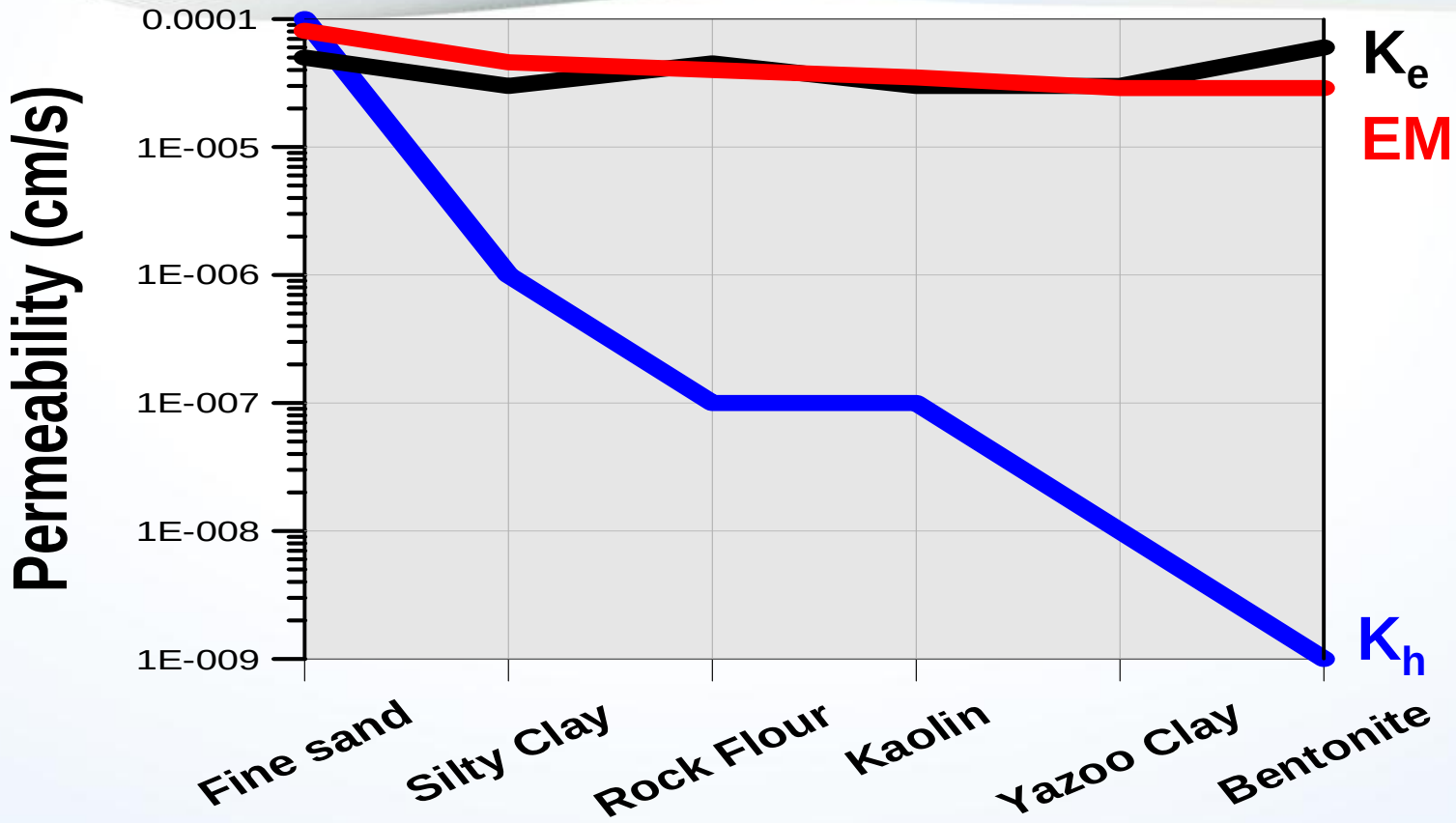


Anions: negatively charged ions
Cations: positively charged ions

Anode: Positively charged electrode
Cathode: Negatively charged electrode



Why Can EK Work in Low-K Zone ?



As Kh decreases, EK becomes the most efficient delivery method

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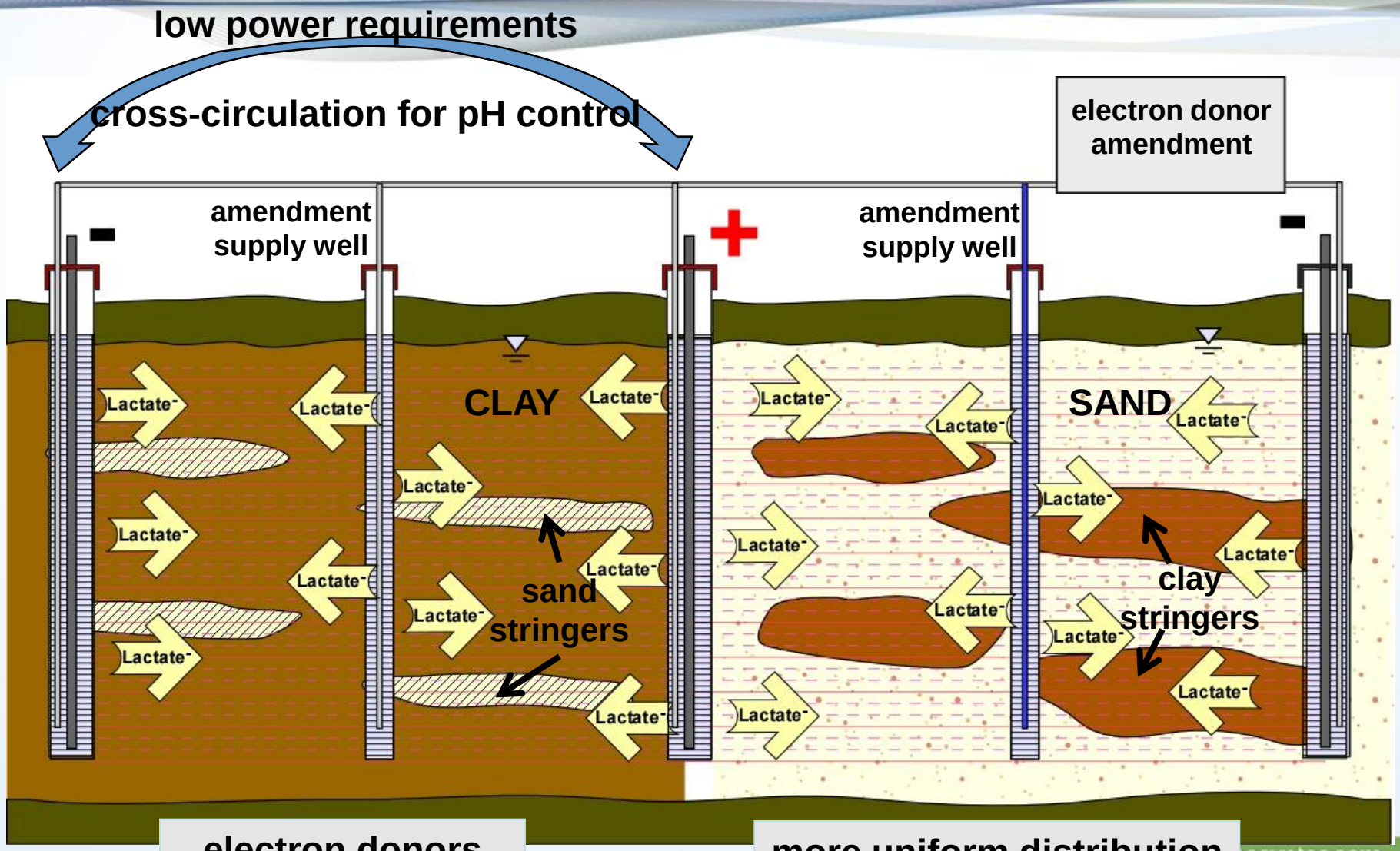
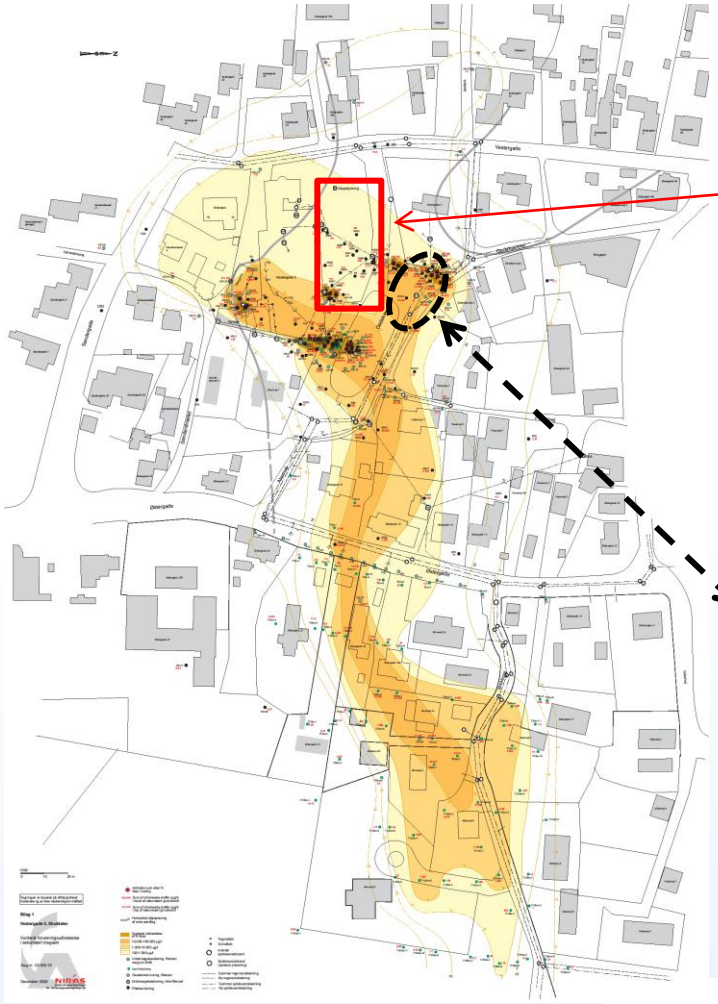
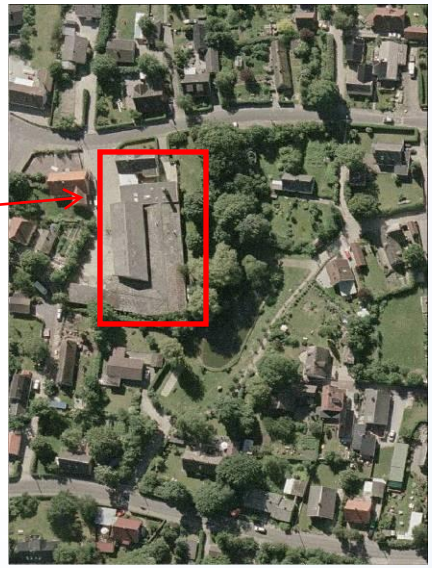
EK-Enhanced Delivery



EK-BIO Pilot Test Site – Skuldelev, DK



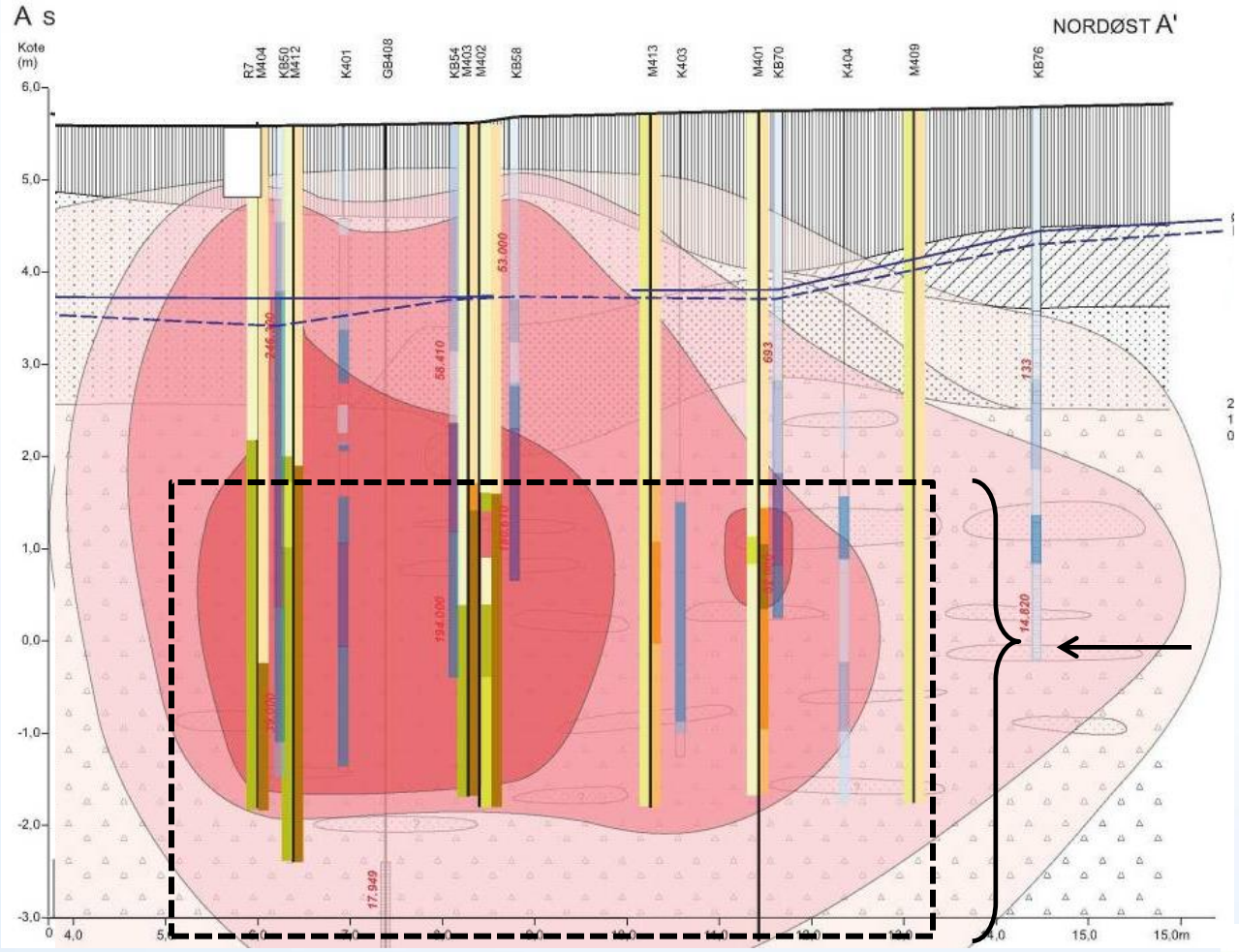


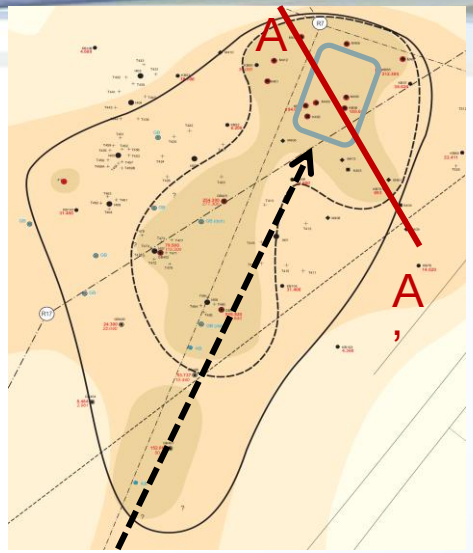
Test site: Hot Spot IV

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

- 1969-1983 industrial facility
- PCE used for degreasing
- 7 PCE DNAPL hot spots
- 300 m long plume in sand layer 2 - 6 m bgs

EK-BIO Pilot Test Area

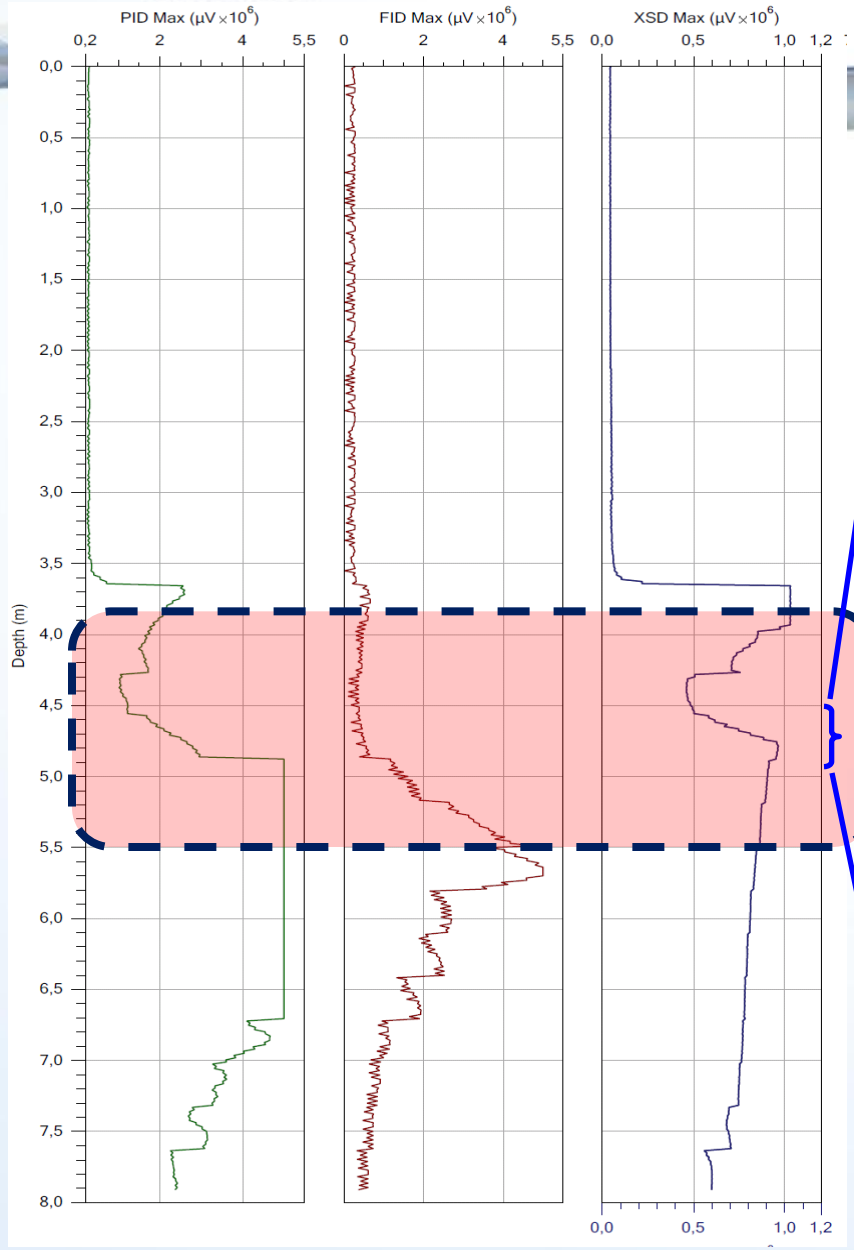


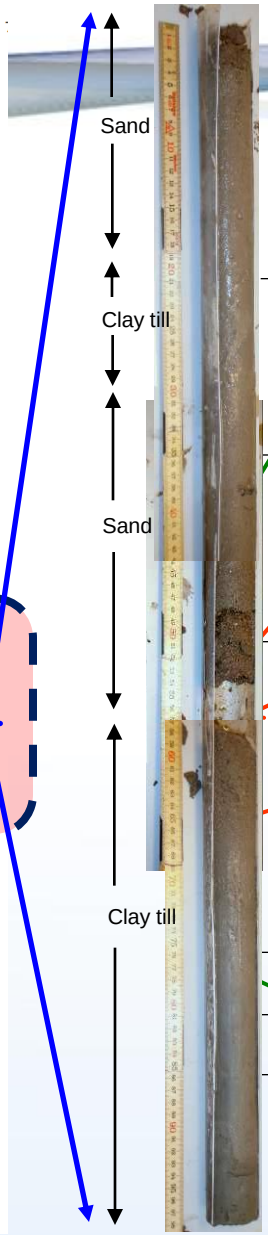


Pilot test area:

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

Distribution of PCE DNAPL





Soil
mg/kg TS
PCE
TCE

76
1.4

6.6
0.03

21,000
79.0

250
0.78

270
0.42

450
2.70

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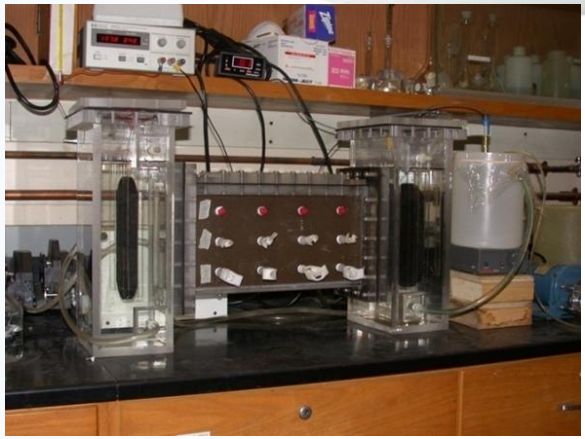
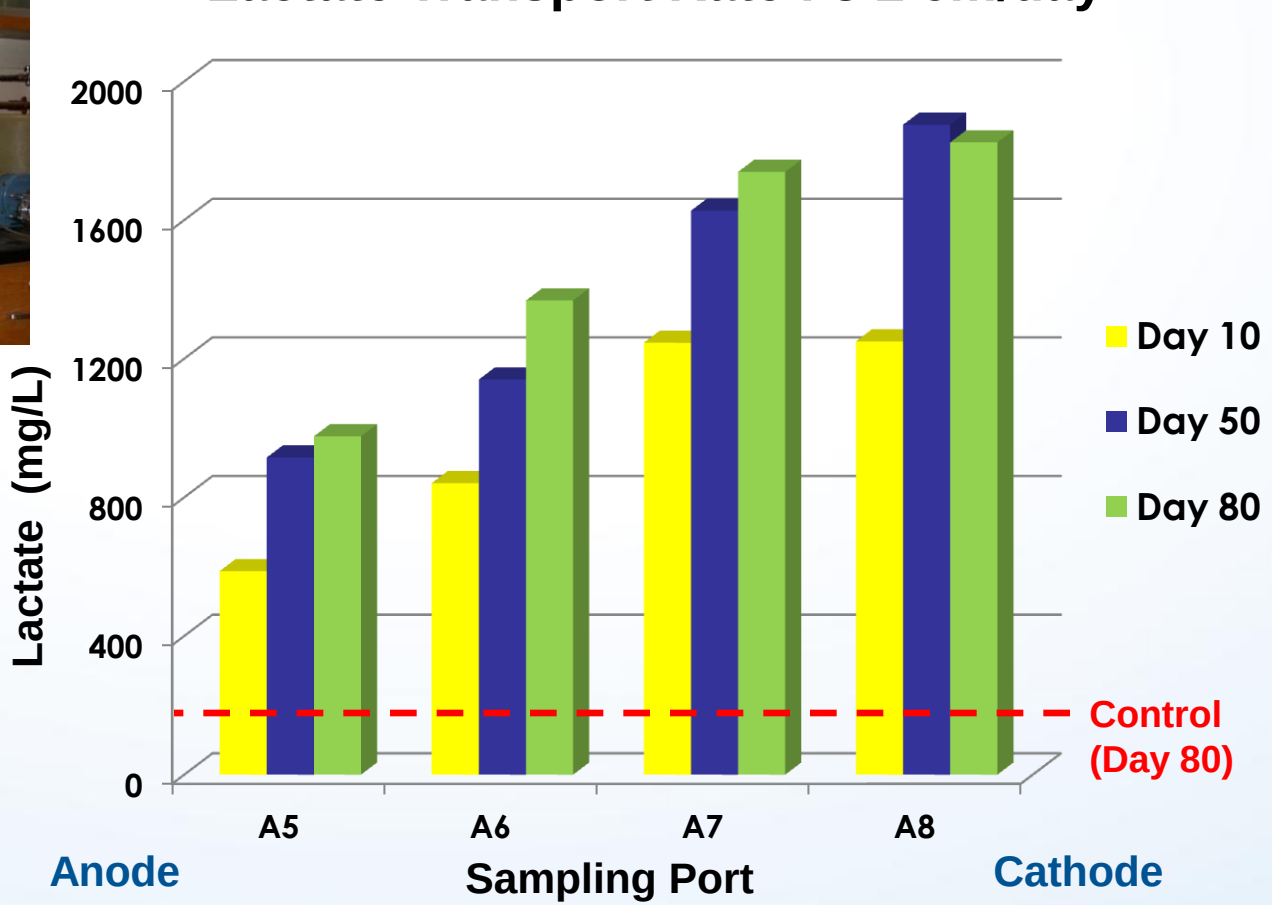
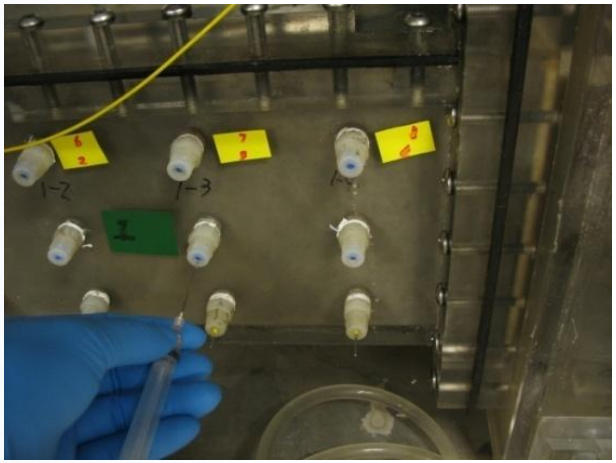
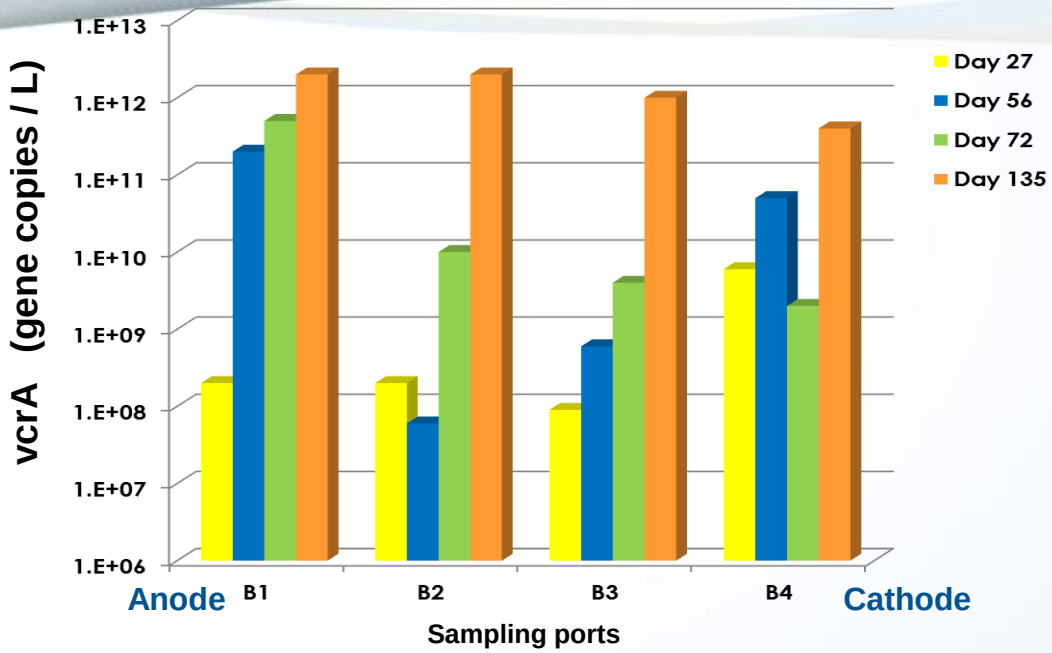
Bench-scale EK-BIO Treatability Study





Bench-scale EK-BIO Treatability Study





- ✓ Transport of *Dehalococcoides* across EK reactors (EO likely transport mechanism)
- ✓ Complete dechlorination of PCE to ethene observed via active *Dhc* population

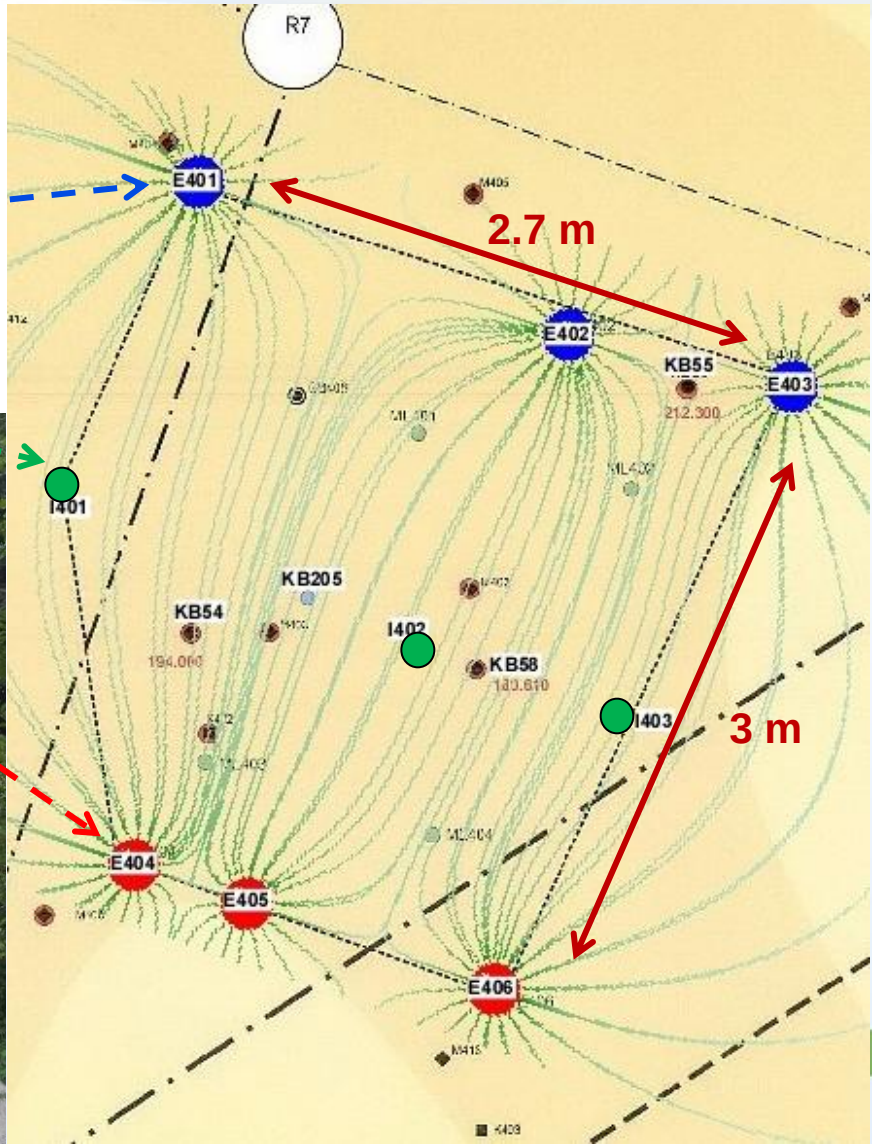
X. Mao, et al, (2012): Journal of Hazardous Materials.

EK-BIO Pilot Test – Objectives

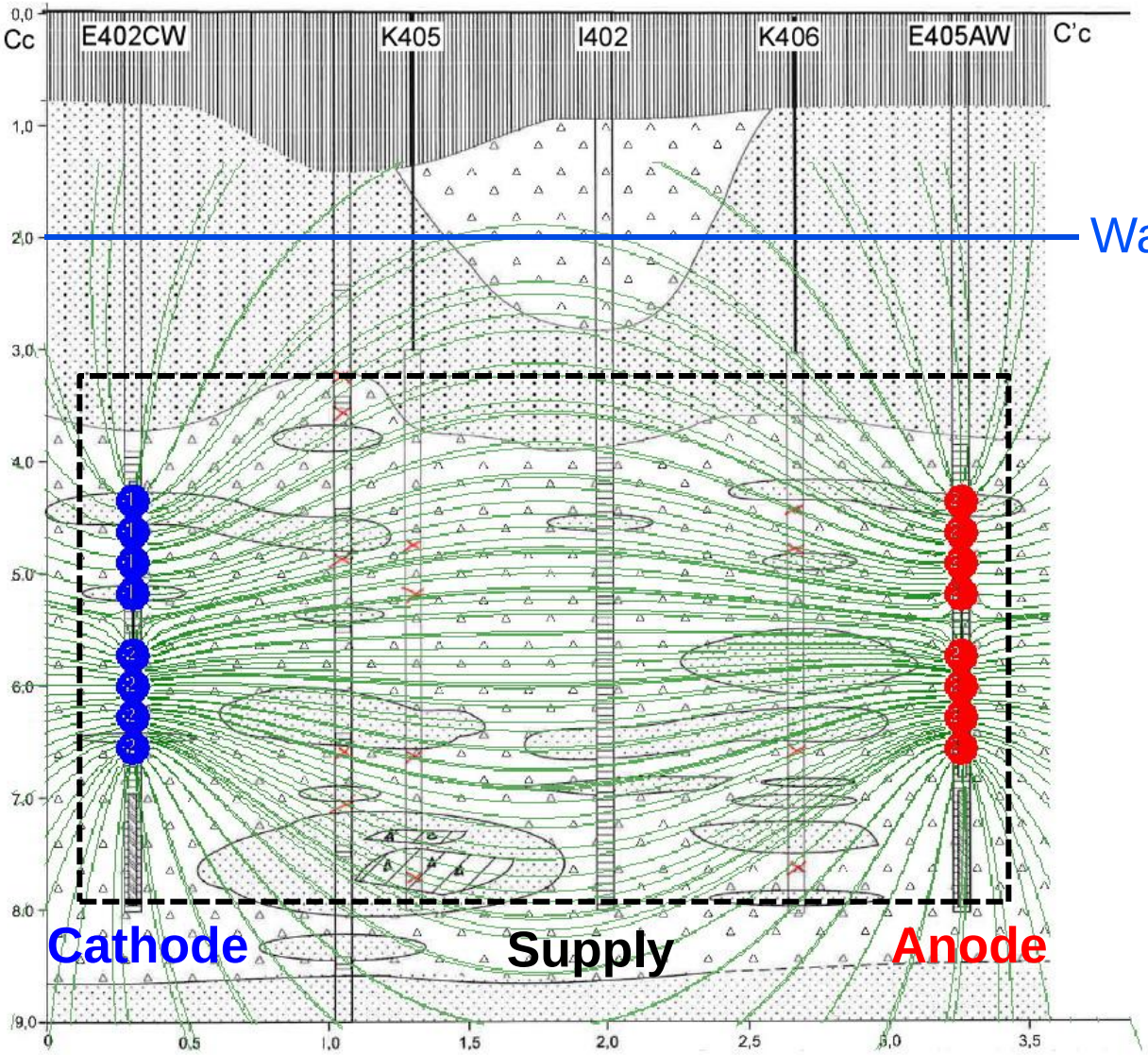
1. Evaluate and demonstrate applicability of EK-BIO
2. Evaluate lactate transport rate
3. Evaluate viability and transport of *Dhc* in clay materials
4. Evaluate degradation of PCE w/in timeframe of pilot test
5. Gather site-specific field data and operational data for full-scale EK-BIO design

EK-BIO Pilot Test – System Layout

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



EK-BIO Pilot Test – System Layout



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Amendment Supply

System Control Room

Cathode wells

Supply wells

Anode wells

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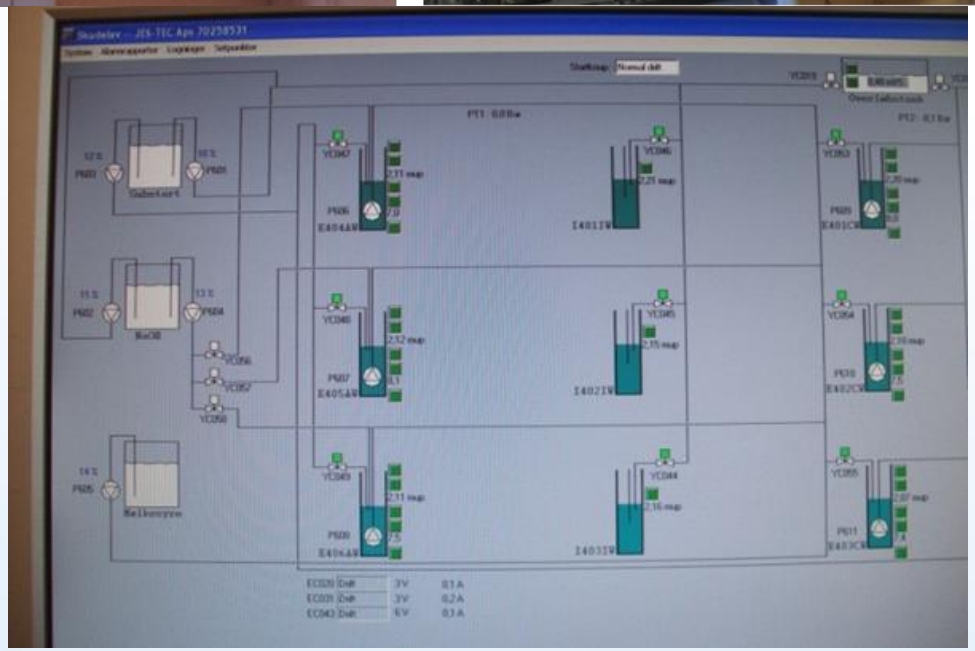
EK-BIO Pilot Test - Power and Control System

- Power supply unit : 3-phase AC input;
- Capable of 15 kW DC output for ~ 600V / 24A



- PLC-based system control

EK-BIO Pilot Test – Monitoring Program

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

Monitored to ensure steady electric field

Steady amendment supply

- **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

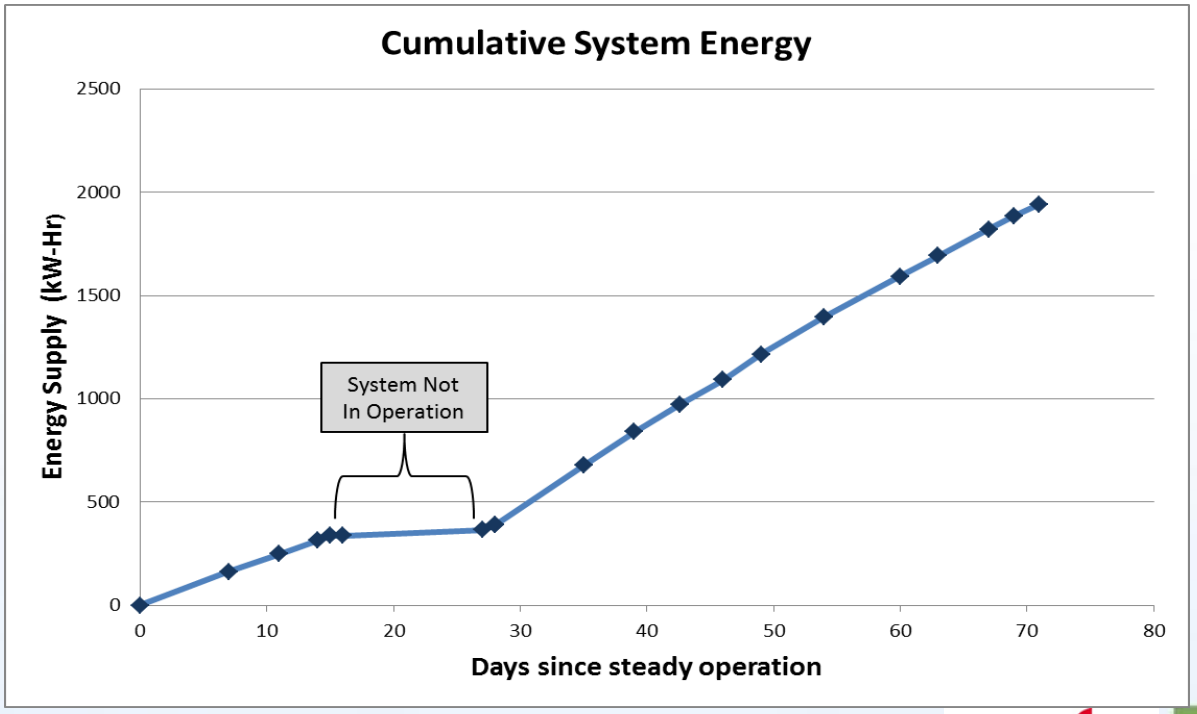
Monitored to document progress of

- **amendment distribution**
- **contaminant degradation**

EK-BIO Pilot Test Operation

- 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 Operation

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

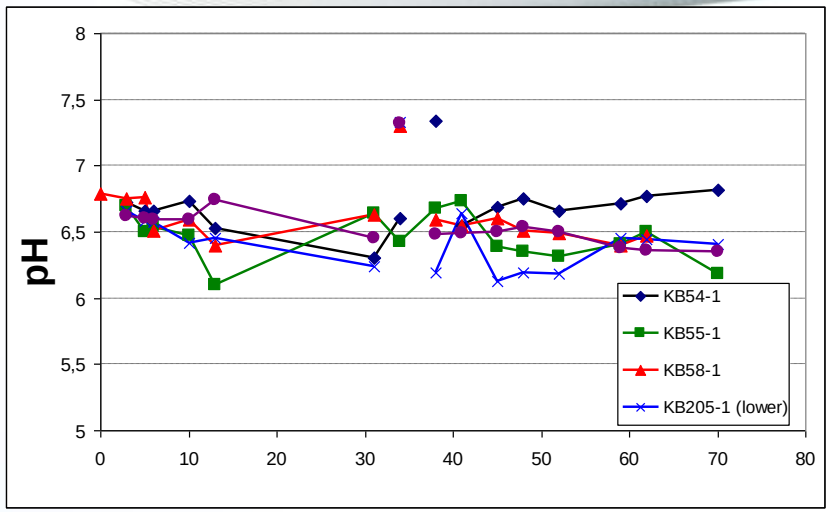
- Chemical amendment dosing:

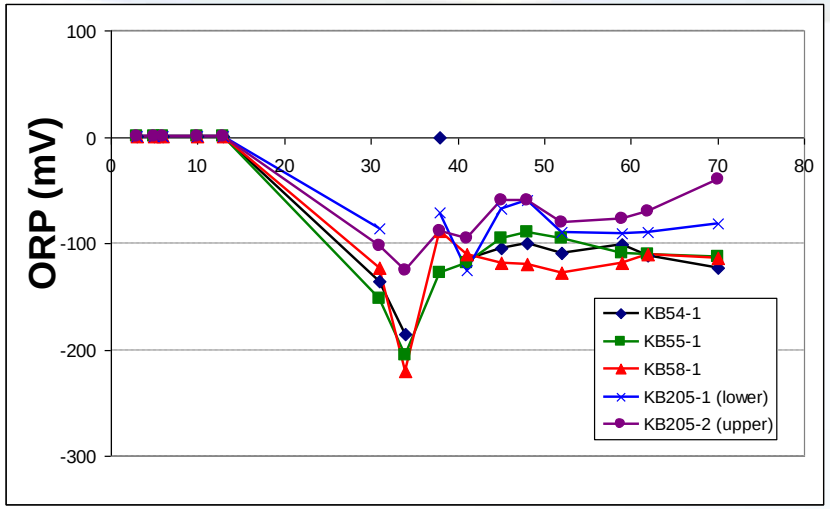
  - Injection wells and anode wells:
    - Lactate ~ 5,900 liters total
    - NaOH ~ 1,100 liters total

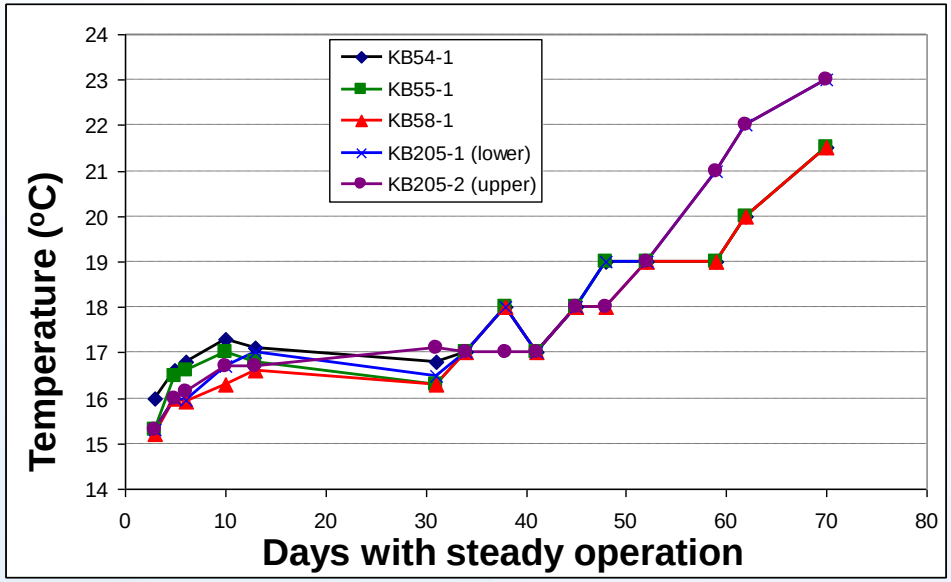
  - Cathode wells:
    - Lactic acid ~ 250 liters total

  - All wells:
    - KB-1~ 21 liters total

EK-BIO Pilot Test Results - Geochemistry



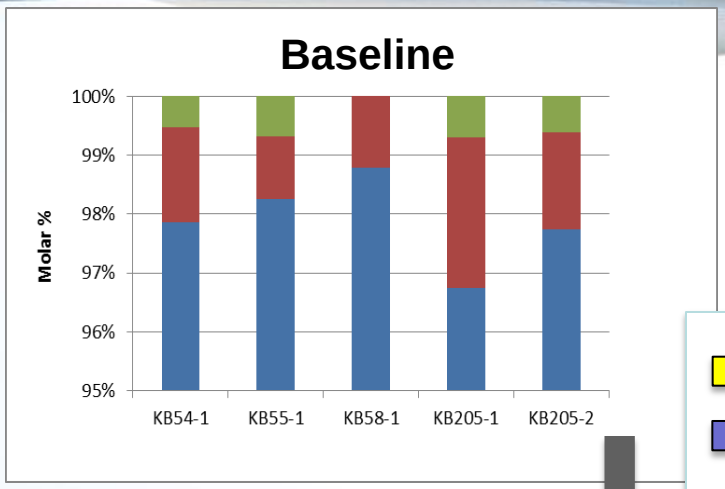


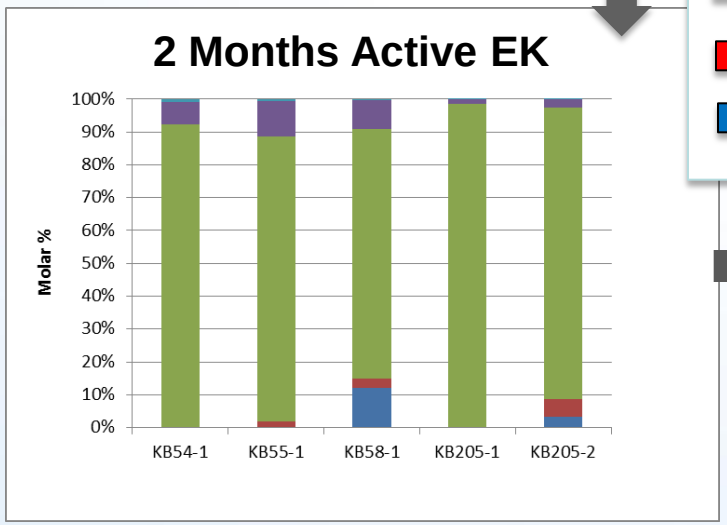


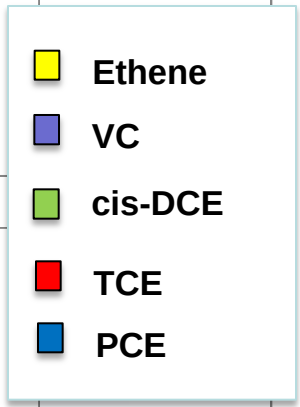
Monitoring showed:

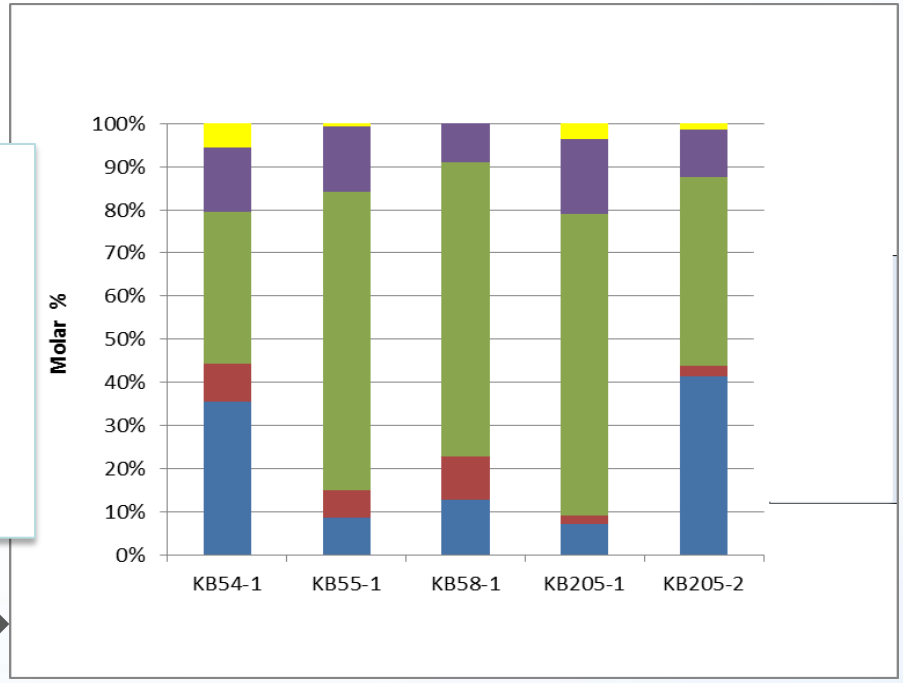
- ✓ Neutral pH
- ✓ Negative ORP
- ✓ Slight increase in temperature (~5 °C) → beneficial to Bio

EK-BIO Pilot Test – Groundwater Data



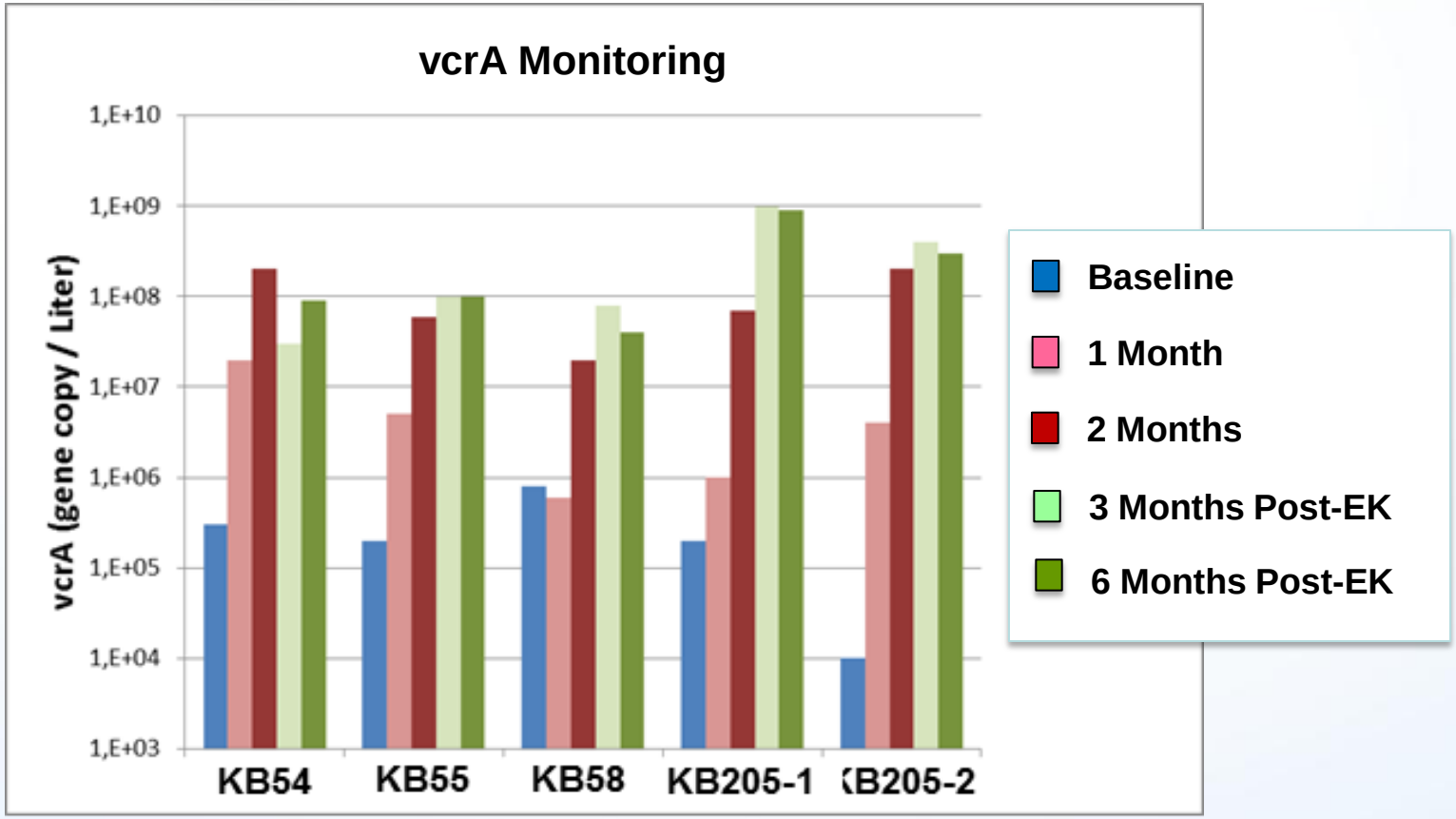






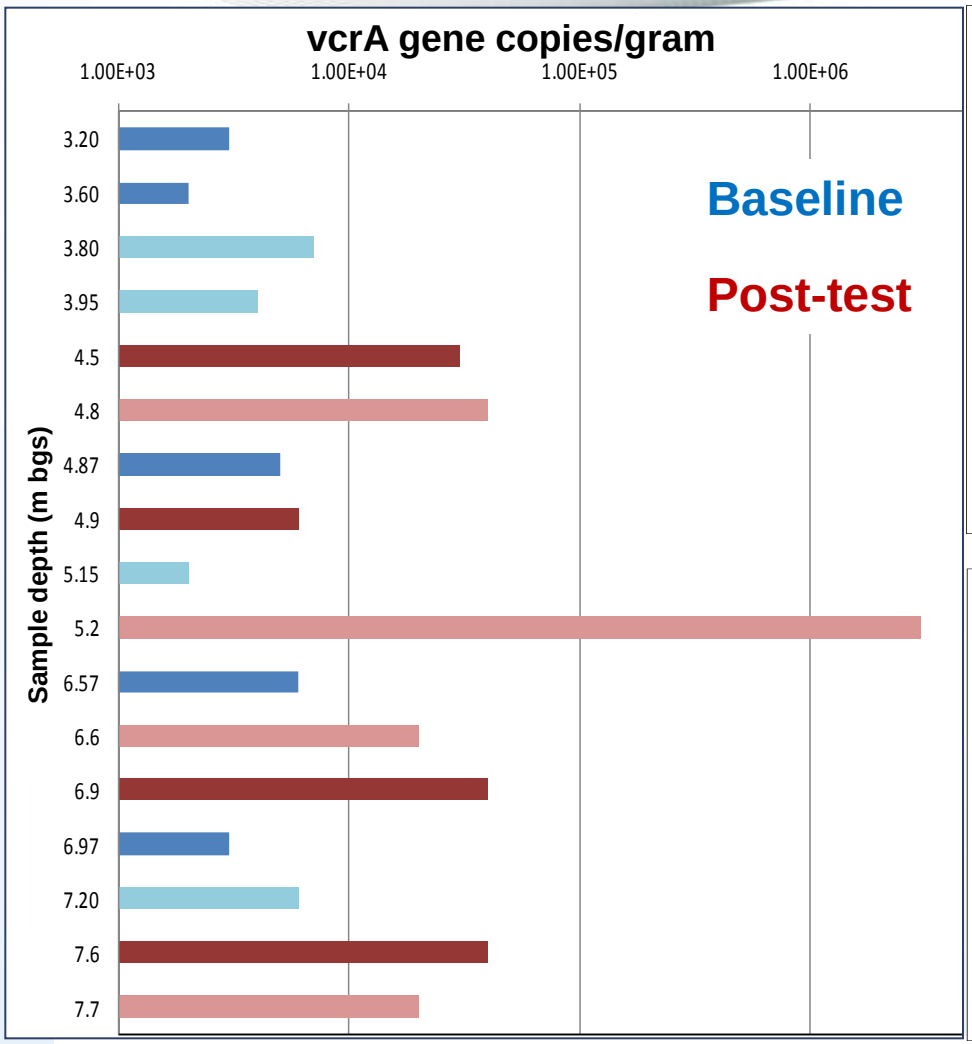
- ✓ Increase in ethene post-EK operation up to 3,700 µg/L

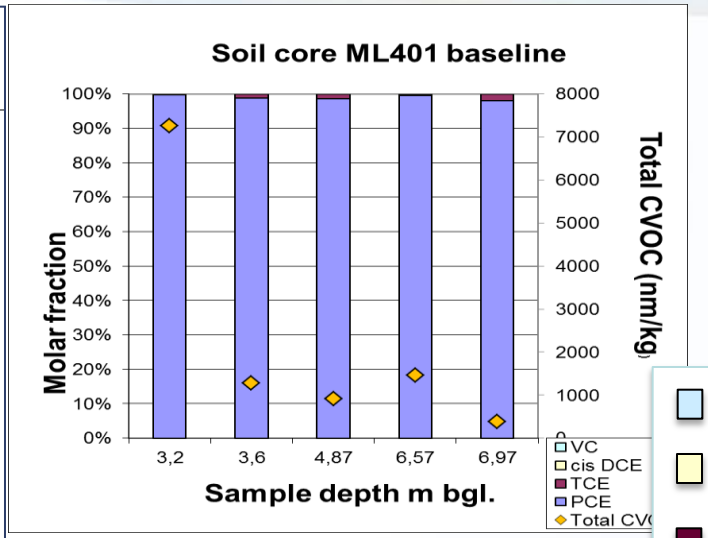
EK-BIO Pilot Test – Groundwater Biomarker

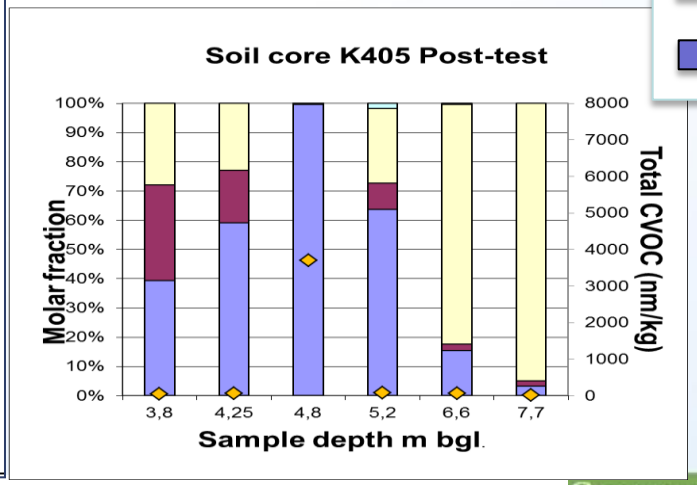


- ✓ **Confirms continuing complete reductive dechlorination by *Dehalococcoides***

EK-BIO Field Test – Soil Core Data (before vs. after)







VC
cis-DCE
TCE
PCE

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

EK-BIO Pilot Test – Key Conclusions

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 clay soil sampling show PCE dechlorination to vinyl chloride and ethene**

5. **Stable electric system - energy usage ~29 kW-hr/m^3 (the total energy used during pilot test = 10x 100-watt bulbs for the same duration)**

LET'S GO FULL-SCALE !

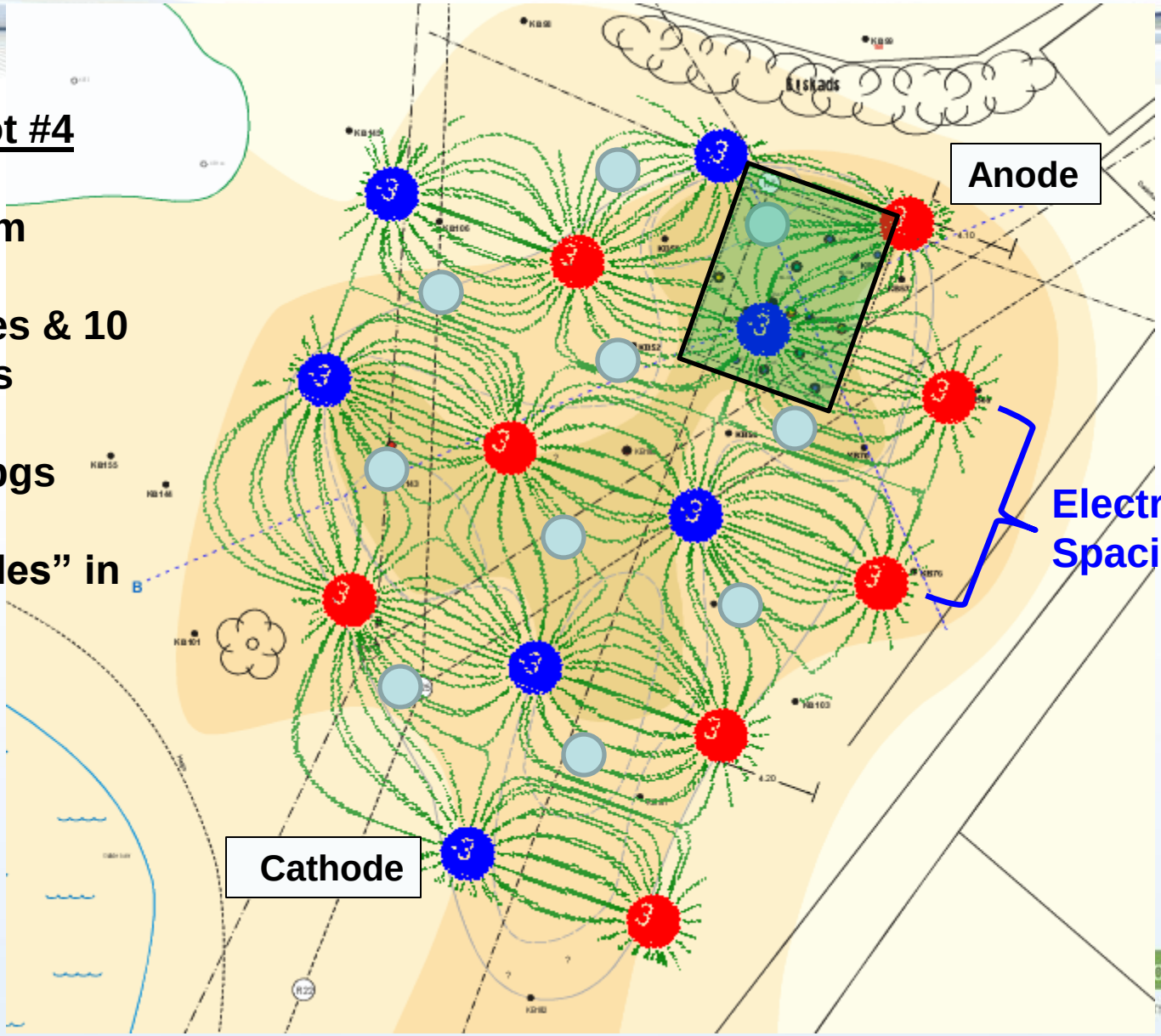
For Hot Spot #4

12 m by 18 m

15 electrodes & 10 supply wells

3 m to 8 m bgs

~ 3 EK "cycles" in ~ 4 years



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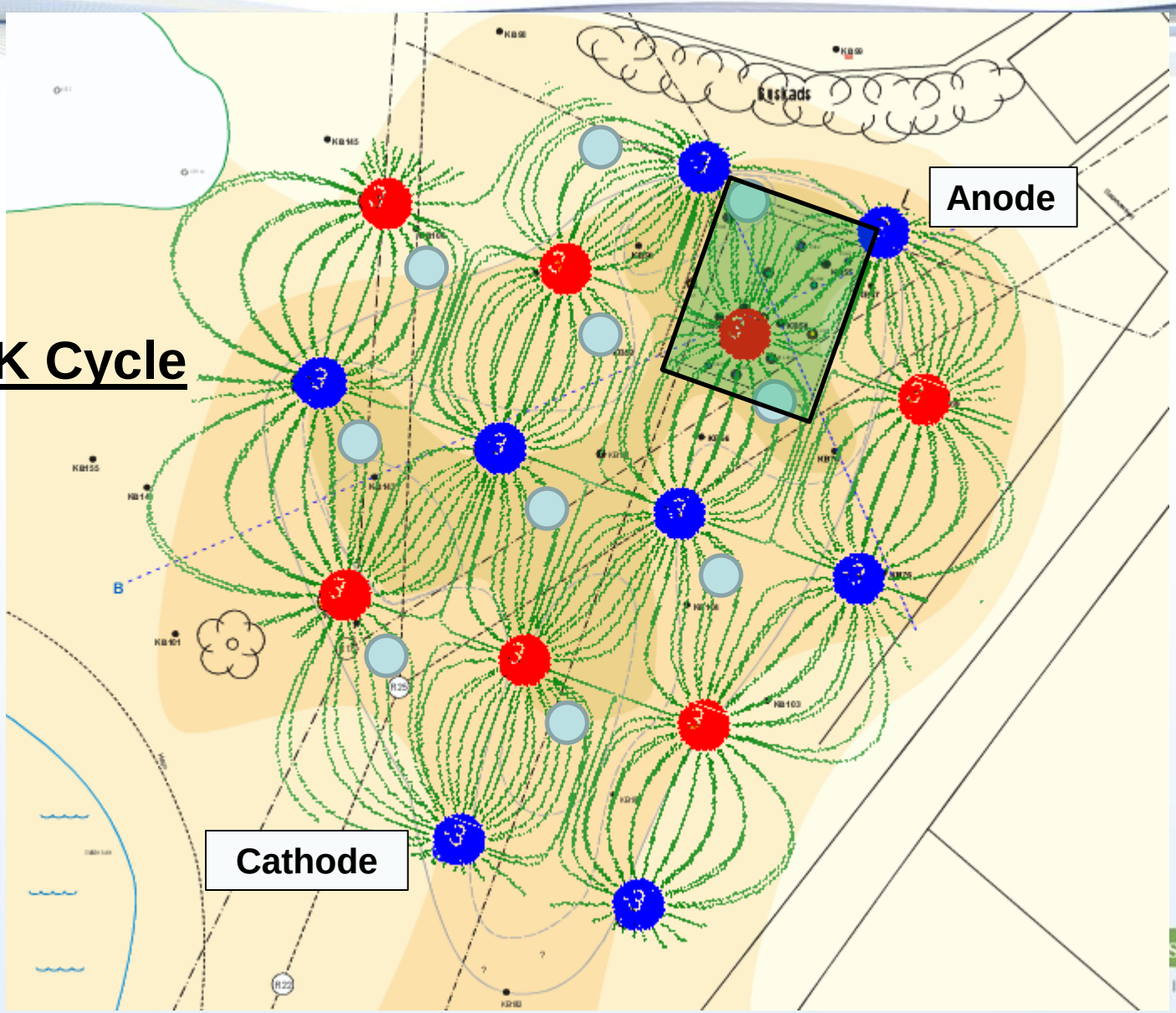
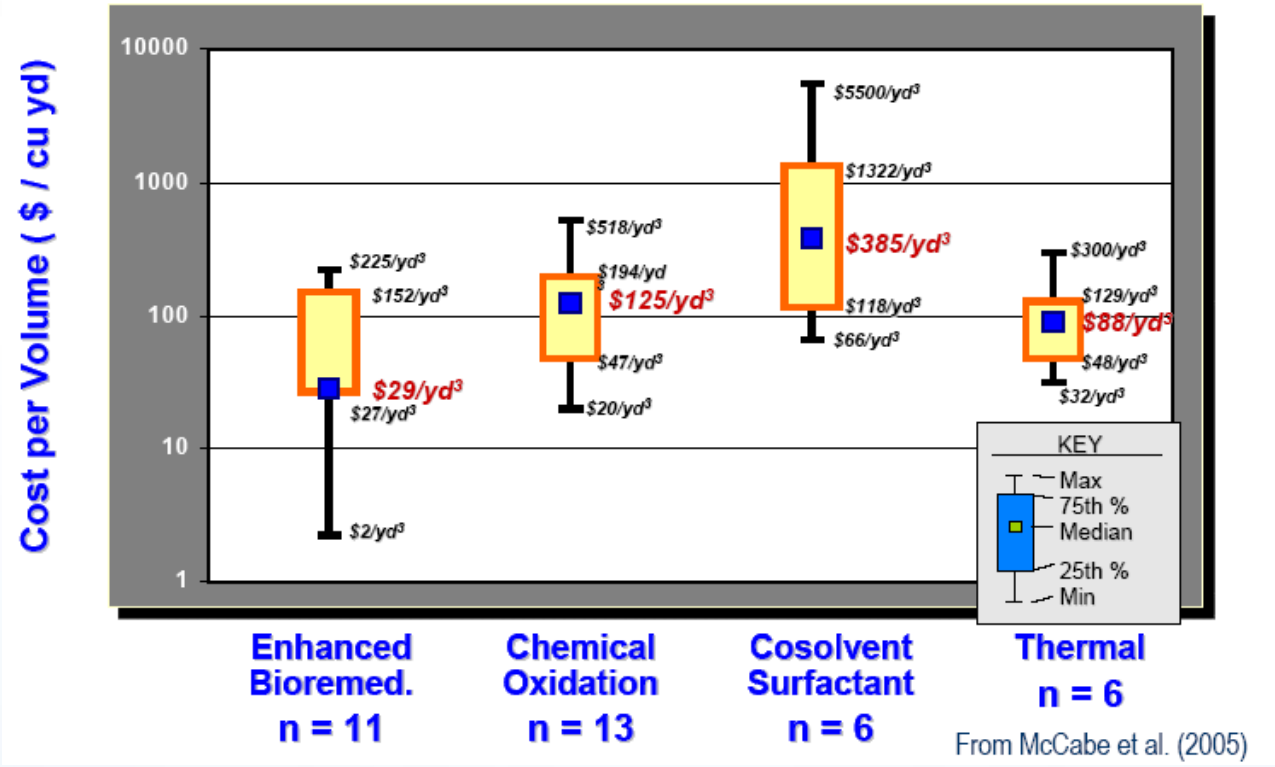
LET'S GO FULL-SCALE !

2nd EK Cycle



Cost Considerations



- For the Danish pilot test (beyond EISB costs):
  - Electricity costs ~ $7/m^3
  - Infrastructure costs ~ $40,000

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http://practices.geosyntec.com/electrokinetics/

QUESTIONS / COMMENTS ?

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NIRAS

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