Full-Scale Electrokinetic-Enhanced Bioremediation (EK-BIO) of PCE DNAPL Source Area in Clay Till

Evan Cox
Geosyntec Consultants, Inc.

SMART Remediation
Toronto, ON
January 29, 2015

SMART is Powered by: VERTEX Environmental Inc.

www.vertexenvironmental.ca

FULL-SCALE EK-BIO™ OF PCE DNAPL SOURCE AREA IN CLAY TILL

Evan Cox
ecox@geosyntec.com

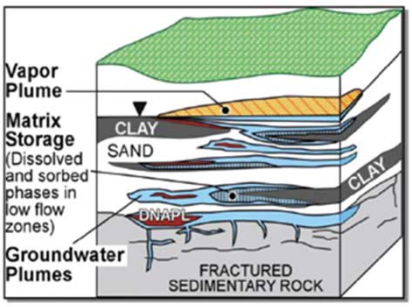
Geosyntec consultants

Geosyntec consultants

THE CHALLENGE OF LOW PERMEABILITY MATERIALS

Over time, contaminants diffuse into low permeability (low K) materials

Clays/silts serve as secondary sources for decades after cleanup of sands/gravels



From ESTCP, ER-200530

Geosyntec consultants

IN SITU REMEDIATION IS ALL ABOUT DELIVERY AND CONTACT

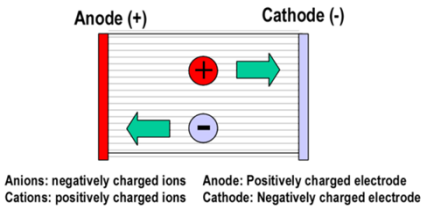
Bio and ISCO are effective technologies, but amendment distribution is poor in Low K and heterogeneous materials

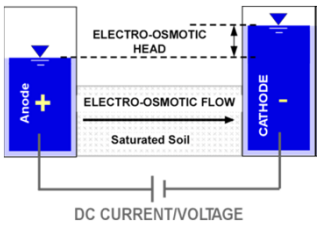
Better amendment delivery techniques are required for low K sites

Geosyntec consultants

SOLUTION = ELECTROKINETIC MIGRATION

- Application of direct current (dc) to saturated subsurface
- Amendments move through clays and silts by:
  - **Electro-migration (EM)** – movement of charged ions
  - **Electro-osmosis (EO)** – bulk movement of water

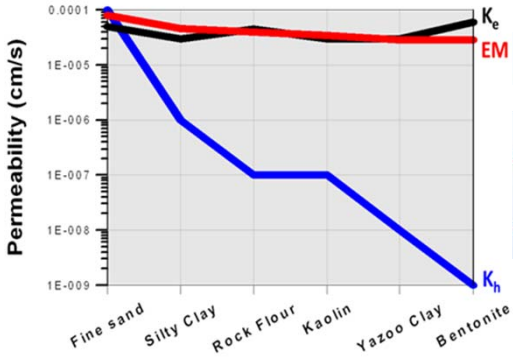


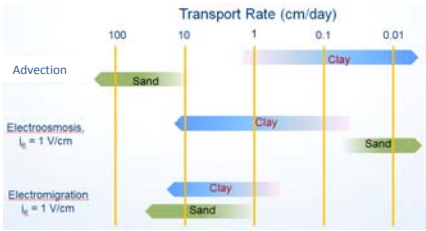


Geosyntec consultants

WHY EK WORKS?

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

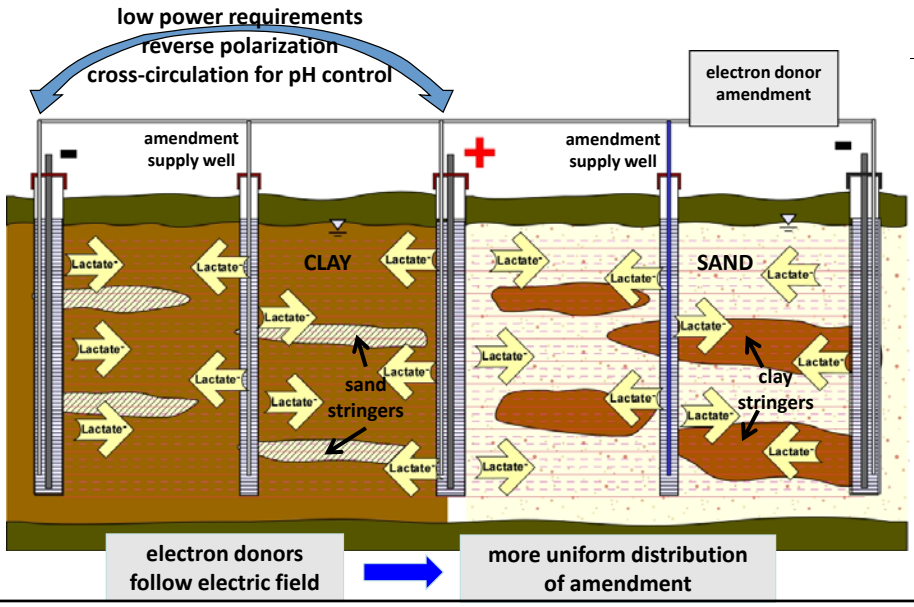




As K_h decreases, EK becomes the most efficient delivery method

Geosyntec consultants

HOW EK IS APPLIED IN THE FIELD



Geosyntec consultants

EK TERMINOLOGY

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)

Geosyntec consultants

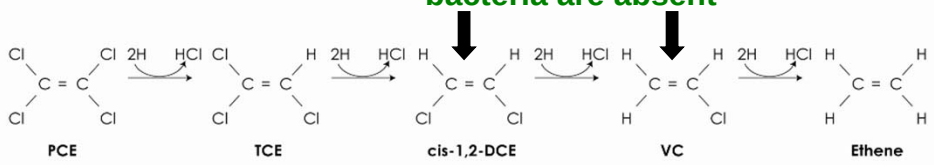
EK-BIO™

Geosyntec.com
engineers | scientists | innovators

Geosyntec consultants

Reductive Dechlorination of PCE to Ethene

Can accumulate if requisite bacteria are absent



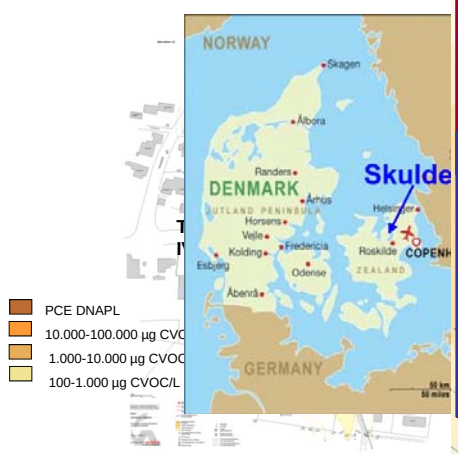
Dehalobacter
Dehalospirillum
Desulfitobacterium
Desulfuromonas
Dehalococcoides

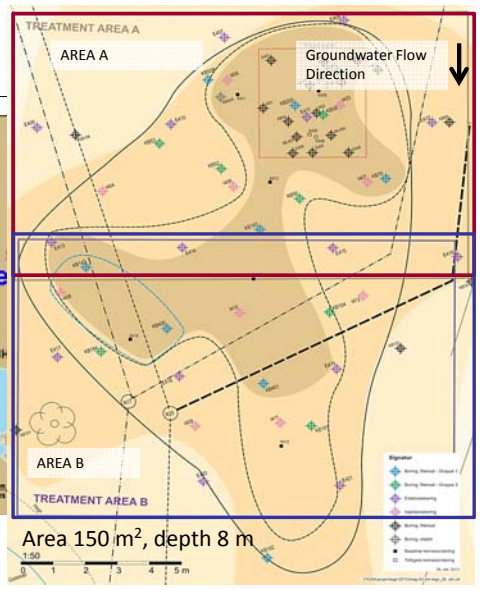
Only
Dehalococcoides &
Dehalobacter

Geosyntec.com
engineers | scientists | innovators

Geosyntec consultants

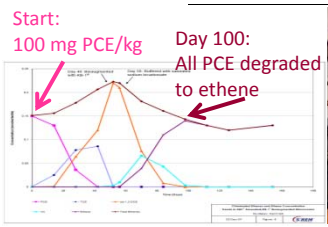
FULL-SCALE EK-BIO SITE LOCATION





Geosyntec consultants

THE ROAD TO FULL-SCALE



2009 ERD Microcosms

- 100% PCE degradation via ERD with *Dehalococcoides (Dhc)* bioaugmentation

SiREM
Leading Science · Lasting Solutions

2010 EK-BIO Lab Test

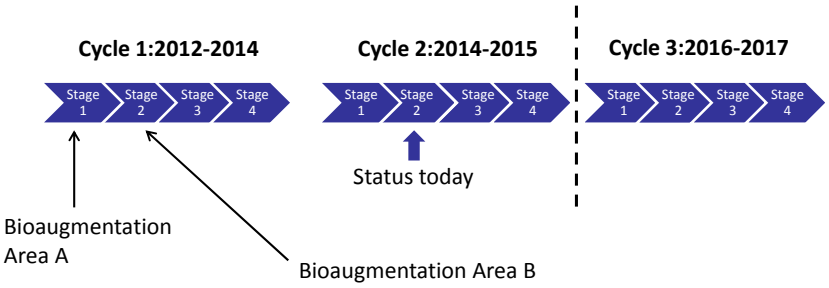
- Lactate transport rate 3.2 cm/day
- Increase in *vcrA* numbers
- PCE dechlorination to VC and ethene

2011 EK-BIO Field Pilot Test

- Lactate transport rate 2.5-5 cm/day
- Increase in *vcrA* in groundwater and clay
- PCE dechlorination to VC and ethene
- PCE desorption and dissolution

Geosyntec consultants

FULL-SCALE PROJECT SCHEDULE



- **Alternating active-passive phases of 90 days per area**
- **Full-scale remedial duration estimated at 3-5 years**

Geosyntec consultants

ELECTRICAL FIELD & LAYOUT

AREA A – STAGE 1 + 3

Anodes (+)

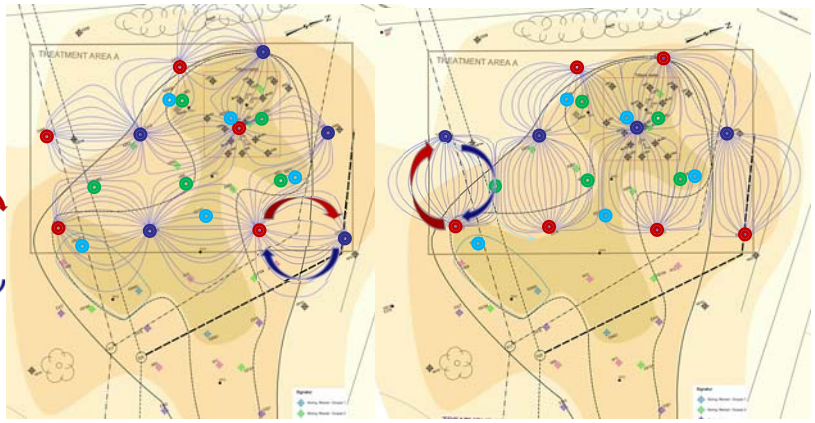
Cathodes (-)

Injection wells

Monitoring wells

Electromigra-tion: Donor transport

Elektro-Osmosis: Biomass transport

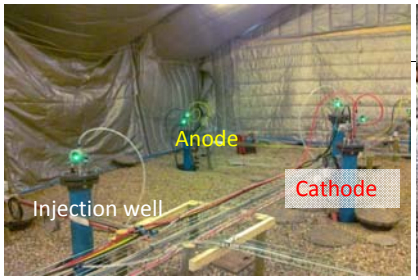


Stage 1: Operation period dec. 2012 – apr. 2013

Stage 3: Operation period sep. 2013 – dec. 2013

Geosyntec consultants

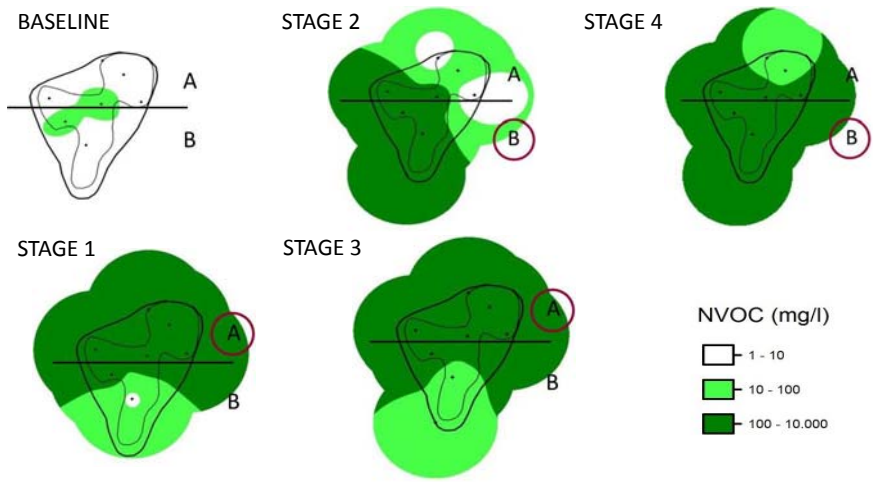
FULL-SCALE EK-BIO COMPONENTS



Geosyntec consultants

DISTRIBUTION OF DONOR (AS NVOC)

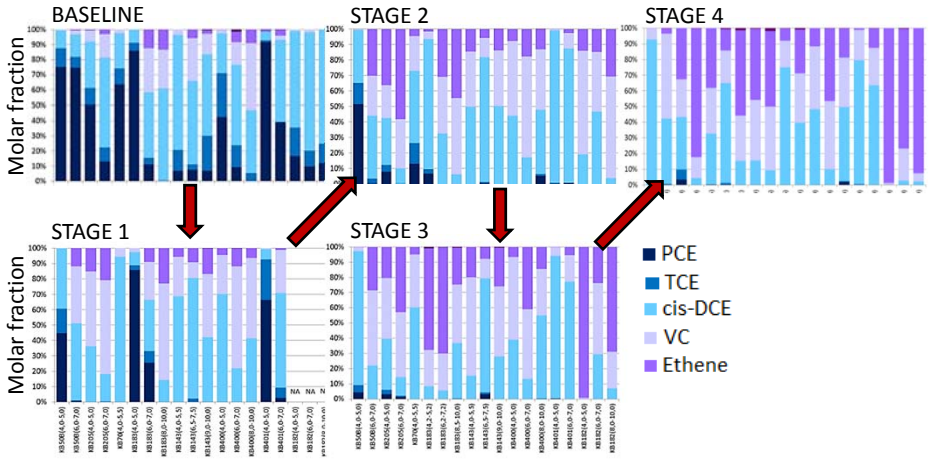
- High donor concentration in treated areas
- Partial donor depletion during passive stages



Geosyntec consultants

PCE DECHLORINATION TO ETHENE

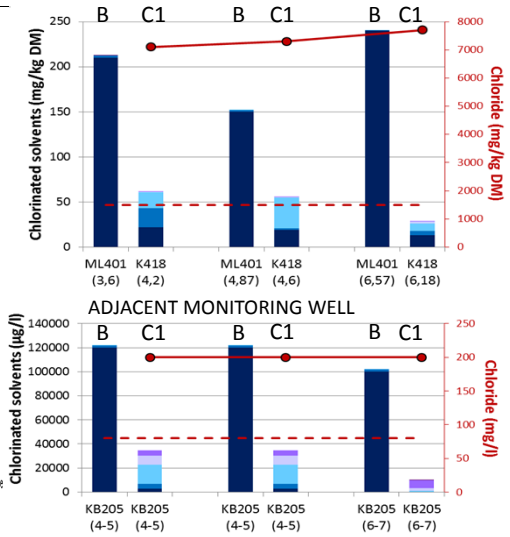
- Dechlorination to VC & ethene in all wells
- PCE only present in 2 wells after Cycle 1



Geosyntec consultants

SOIL CORE RESULTS AFTER CYCLE 1

- Decrease in total CVOC
- Decrease in PCE
- Production of cDCE, VC and ethene
- Increase in vcrA in clay samples from 10^3/gram to 10^6/gram
- Production of chloride
- Soil results support gw results



B: Baseline **C1**: After Cycle 1

PCE, TCE, cis-DCE, VC, Ethene, Ethane, Cl - after stage 4, Cl - Baseline

Geosyntec consultants

CONCLUSIONS AFTER YEAR 1

- Effective distribution of lactate across treatment area in clays
- Increase in *vcrA* in groundwater and clay across treatment area
- Complete dechlorination of PCE to ethene; PCE mass declining
- PCE desorption and dissolution – should shorten remedial duration
- Soil data confirm that dechlorination is occurring in the clay till

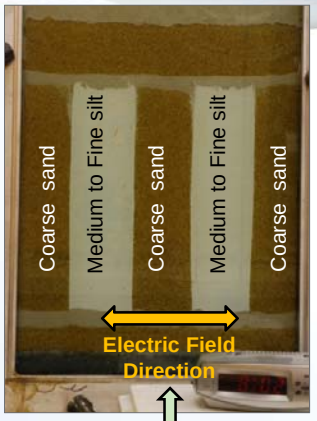
Geosyntec consultants

EK-ISCO™
EK-TAP™

Geosyntec.com
engineers | scientists | innovators

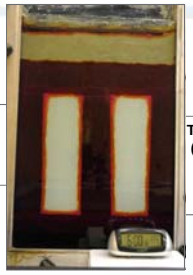
Geosyntec consultants

EK-ISCO



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)

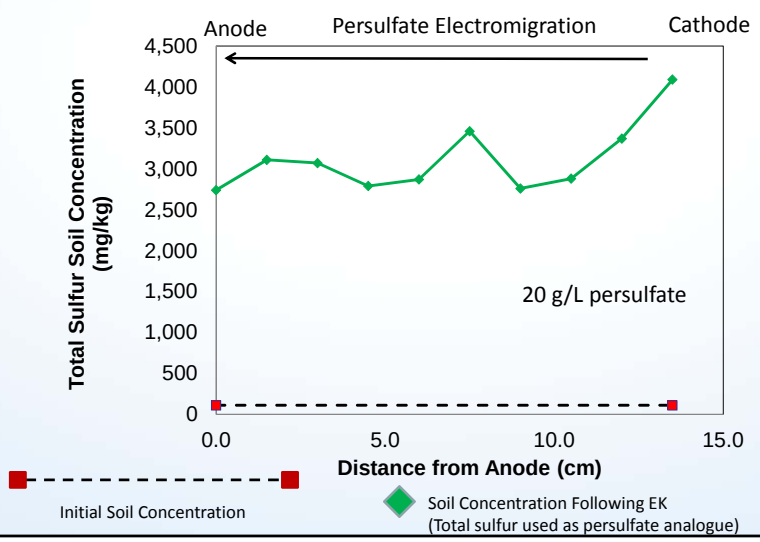
Western UNIVERSITY · CANADA

eosyntec.com
ners | scientists | innovators

EK-TAP
(Thermally-Activated Persulfate)

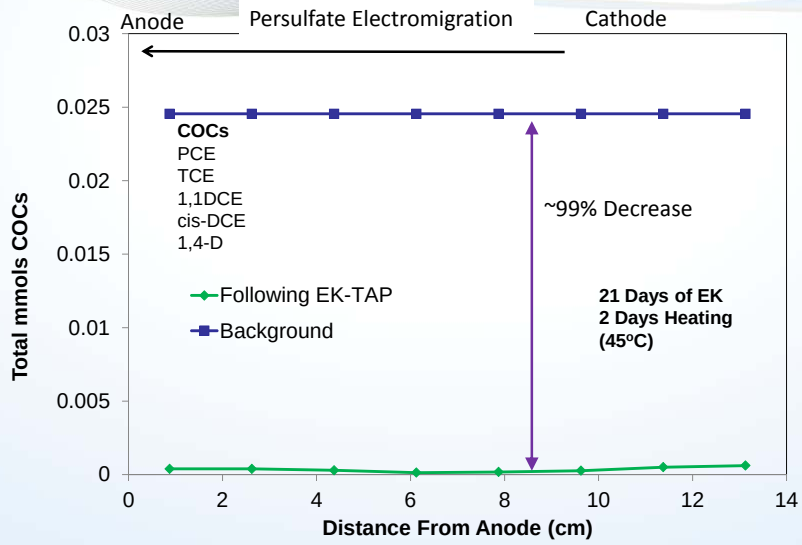
- Use of dual purpose EK-ERH electrodes
- EK uses direct current (*DC*) to inexpensively distribute persulfate through clays and silts
- ERH then uses alternating current (*AC*) to heat soils
- Contaminant (incl. 1,4-Dioxane) is oxidized in situ at ~40°C rather than boiled/volatilized at 100°C
- Less energy use, no SVE = lower remediation cost
- Patent application filed by Geosyntec

EK-TAP in Clay Soil, Northern California



Geosyntec consultants
engineers | scientists | innovators

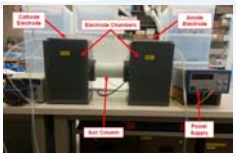
EK-TAP in Clay Soil, Northern California



Geosyntec consultants
engineers | scientists | innovators

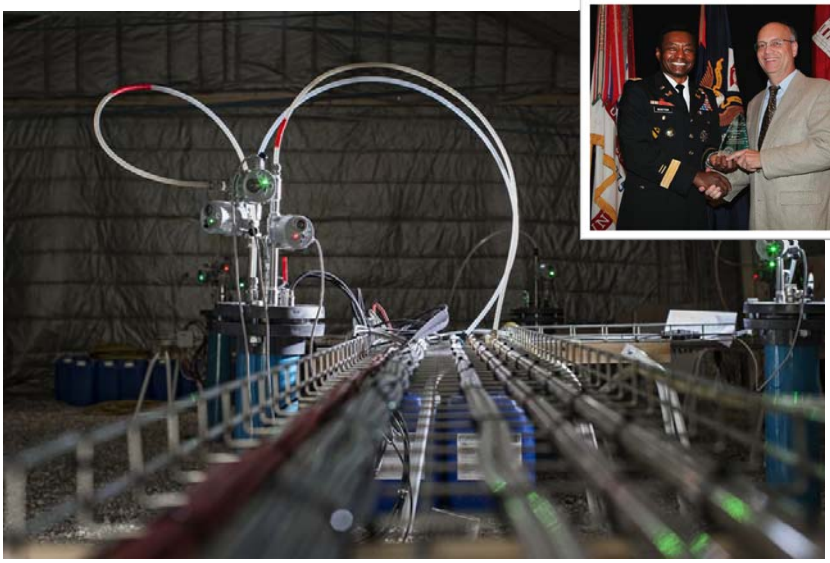
How Do I Get Me Some of That?

- Treatability Testing ($15,000 - $40,000)
  - Kinetics (NOD, batch testing)
  - Column migration experiments or 2D box reactor experiments
- Pilot test ($200,000 - $300,000, depends on scale)
- Full-scale implementation ($85/yd^3)



Acknowledgements

- **Geosyntec Consultants**
  - David Reynolds
  - James Wang
- **NIRAS A/S**
  - Charlotte Riis
  - Martin Bymose
- **US Army Engineer R&D Center**
  - David Gent
- **The Capital Region DK**
  - Mads Terkelsen
- **Western University**
  - Denis O'Carroll
  - Ahmed Chowdhury

QUESTIONS

EK-Bio Wins a Green Innovation (Sustainability) Award from US Army Corps of Engineers