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Realizing the Benefits of Bioremediation in Canada

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RemTech, Virtual
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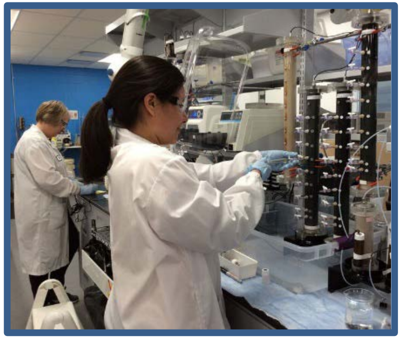
Acknowledgements

- Funding Fractured Rock Project
- Bruce Tunnicliffe –Vertex Environmental
- James Wang/ Elaine Secord
- Funding Benzene Project
- Elizabeth Edwards/Courtney Toth

Introduction to SiREM



- Located in University of Guelph, ON Research Park and Knoxville, TN
- Provide products and testing services to monitor and optimize site remediation
  - Bioaugmentation
  - Treatability Studies
  - Molecular Testing

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Some Enhanced Bioremediation Tools

- **Biostimulation**: addition of electron donors, acceptors, pH adjustment, trace nutrients etc.

- **Bioaugmentation:** addition of beneficial microorganisms to improve biodegradation. KB-1®: DGG-B bioaugmentation cultures for chlorinated ethenes/benzene
- **Treatability Studies** determine in lab if biodegradation will occur (e.g., at cold temperatures) or can be optimized
- **Molecular Tests** to track growth and spread of biodegraders

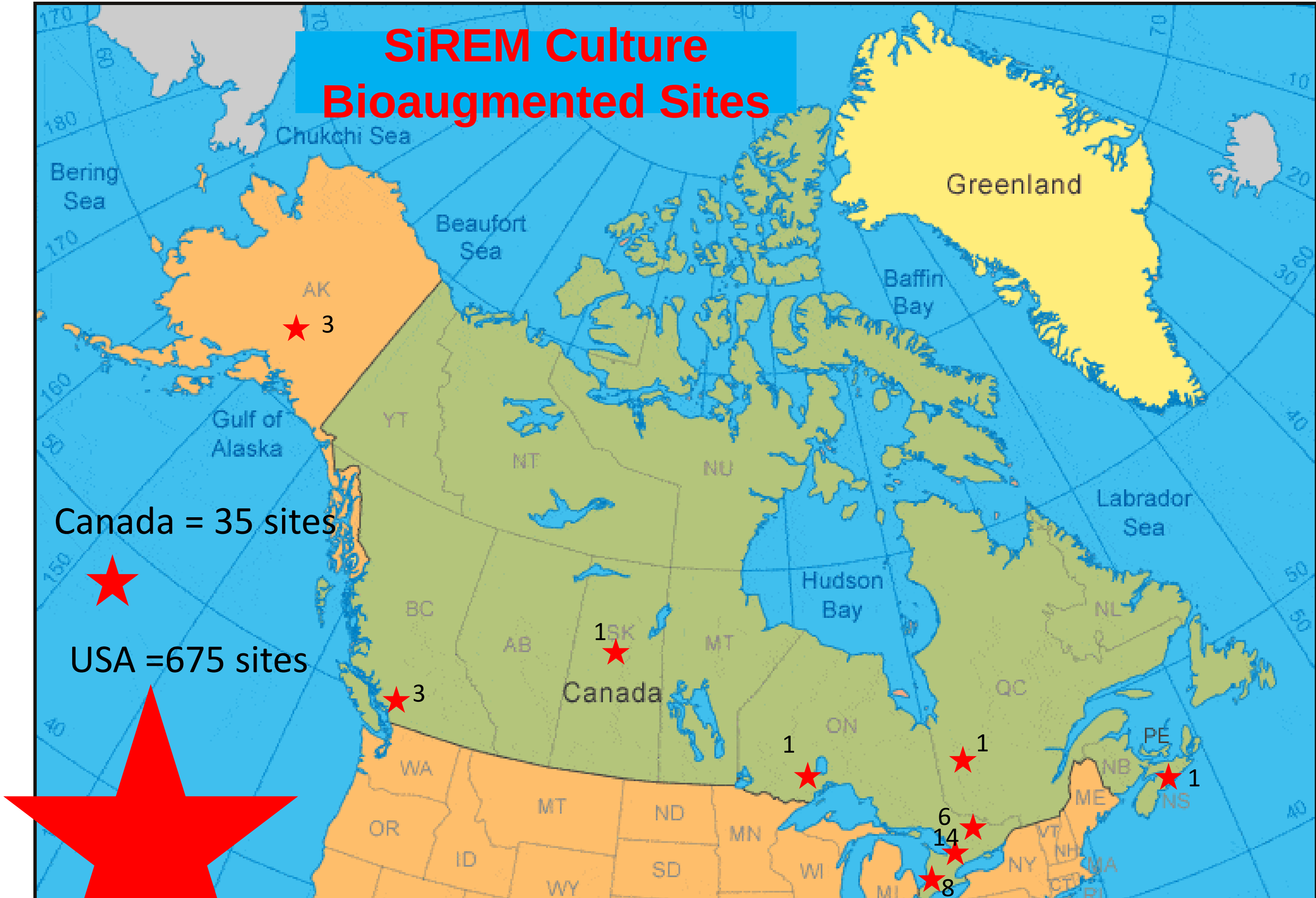
- **Enhanced Distribution**
  - Tight DPT injection grids/multiple lifts
  - Hydraulic fracturing
  - Electrokinetics
  - Groundwater recirculation systems

Injection of KB-1 at a site in BC

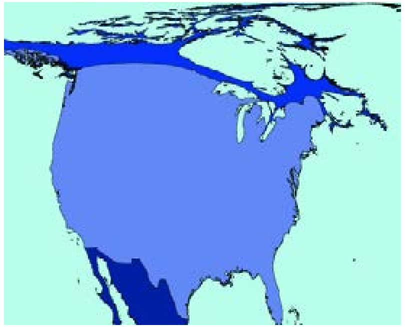
Advantages of Enhanced In Situ Bioremediation (EISB)

- Cost Effective: As little as 1/3rd the cost of other in situ remediation options
- Destroys Contaminants: doesn’t just move them
- High Concentrations Treatable: Including DNAPL/LNAPL sites
- Resistant to Rebound: Once down concentrations tend to stay down
- Sustainable: low carbon foot-print/natural process/inobtrusive
- Compatible with remote sites-no utility or maintenance requirements

SiREM Culture Bioaugmented Sites

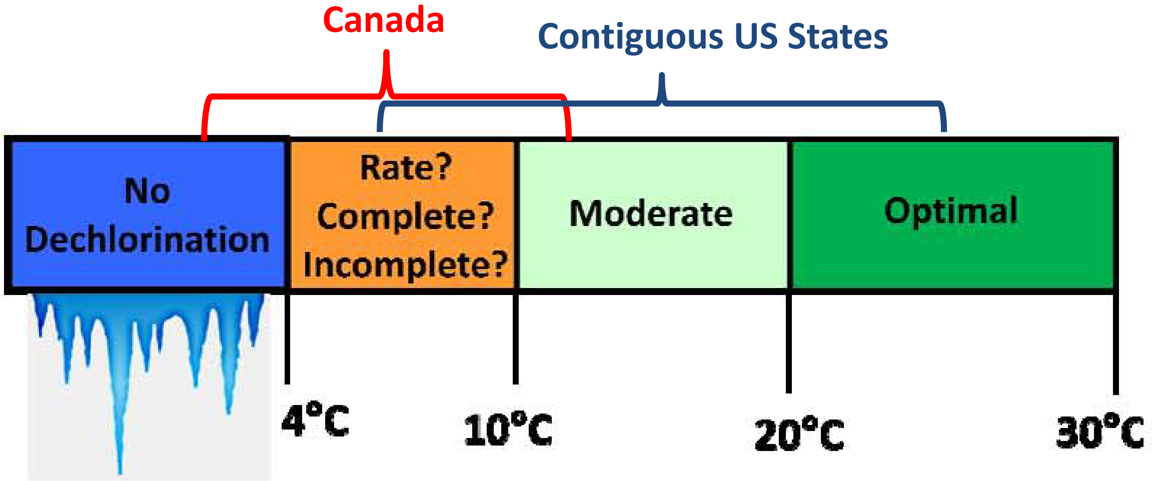


Reasons Why EISB Less Used in Canada Compared to USA?



- **Use of Groundwater for Drinking water?** 30% Canada/55% USA
- **Regulatory/Legal Landscape?** Federal Approvals/Government Funding/Cleanup Regulations
- **Number of sites?** >300,000 routinely estimated in the US, in Canada 22,000 Federal Government sites alone -total number unclear
- **Climate?-** is cold climate/groundwater limiting use of bioremediation in Canada
- **Geology?**- Is Canada's geology more challenging for *in situ* remediation

Average Groundwater Temperature and Dechlorination Rates



Is complete PCE/TCE dechlorination to ethene practical below 10°C ? Yes!

Can petroleum hydrocarbons degrade below 10°C? Yes!

References Bradley *et al*., 2005; 2007 Friis *et al*., 2006; Fletcher *et al*., 2010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Bioaugmented Sites
Chukchi Sea
Bering Sea
Beaufort Sea
Greenland
Baffin Bay
Gulf of Alaska
Labrador Sea
Hudson Bay
Pacific Ocean
AK
YT
NT
NU
BC
AB
SK
MT
ON
QC
NL
PE
NB
NS
ME
WA
OR
ID
MT
WY
ND
SD
MN
WI
MI
NY
VT
NH
MA
CT
RI
Canada
3
3
1
1
1
1
6
14
8
Typically <10 °C
~10°C Groundwater

Impact of Temperature on Bioremediation Processes

- Generally lower temperature = lower growth rates/slower metabolism
  = slower biodegradation

- Psychrophiles/trophs – cold loving/tolerant microbes e.g., *Polaromonas naphthalenivorans*-degrades naphthalene at temperatures as low as 4ºC

- Mesophiles warm loving–e.g., *Dehalococcoides* degrades chlorinated solvents optimally from 20-35ºC but activity has been observed below 10°C

- Solubility of electron donors-rapidly metabolized and soluble donors (e.g., lactate ethanol) may have benefits compared to slow release donors under cold conditions

- With climate change subsurface temperatures will increase making bioremediation more feasible/effective at northern sites

Performance of Bioaugmentation for Chlorinated Solvents at Varying Groundwater Temperatures

Site	Average Groundwater Temperature °C	Time post-bioaugmentation to 1st ethene detection (or 10X pre-bioaug. ethene)	Maximum Dhc Detected/L
Florida	25	3 months	6.0E+09
California	20	2 months	2.0E+09
Denmark	10	4 months	3.0E+07
Northern Ontario	8.3	13 months	4.0E+08
Alaska	6.9	11 months	9.0E+08

- High Dhc concentrations achieved (>10^7 /L) associated with ethene production
- Ethene detected ~ 1 year after bioaugmentation at cold water sites
- VC Half lives ~ 120-44 days at 8-10 °C vs. 60-35 days at 15-20 °C
- Bioremediation below 10 °C slower but feasible

*Scheutz *et al.*, 2008 note site had indigenous Dhc

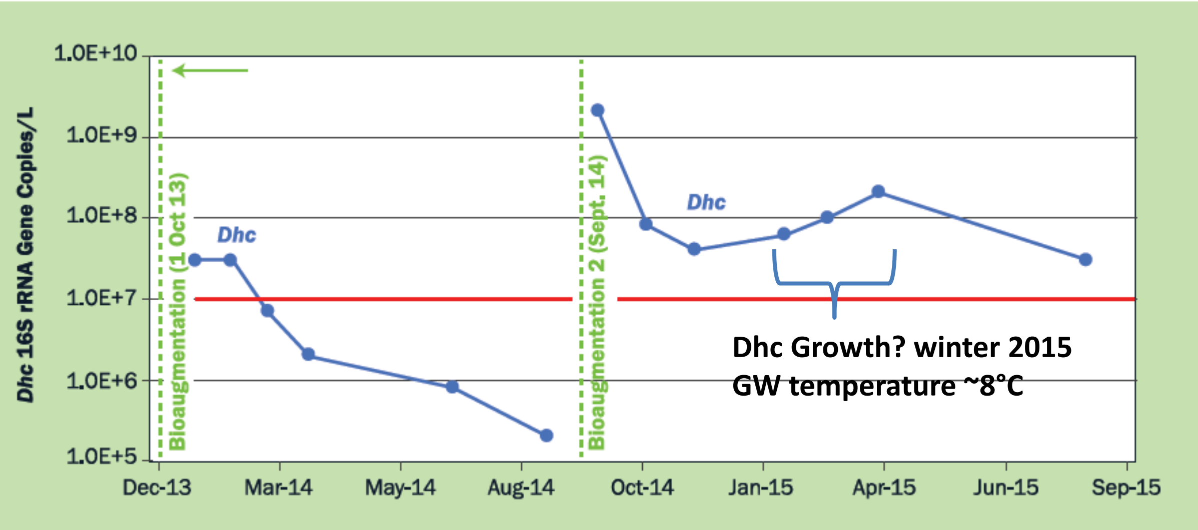
Ottawa, Federal Site

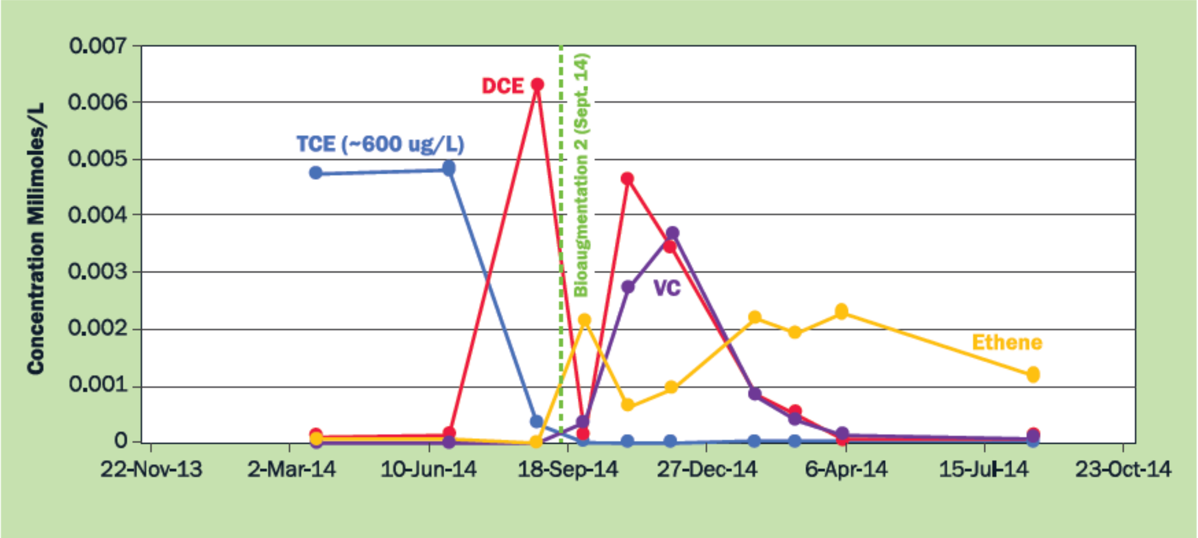
- Bioaugmentation Pilot Test at Former Gloucester Landfill– Average GW temp. 10°C

- Injection well - all chlorinated compounds 1,240 µg/L to ND/low ppb within 8 months of bioaugmentation

  vinyl chloride $t_{1/2}$ = 44 days

- Dhc spread downgradient was 9m in ~450 days =2 cm/day (6 cm/day is more typical at warmer sites)





Some Challenging Canadian Geology

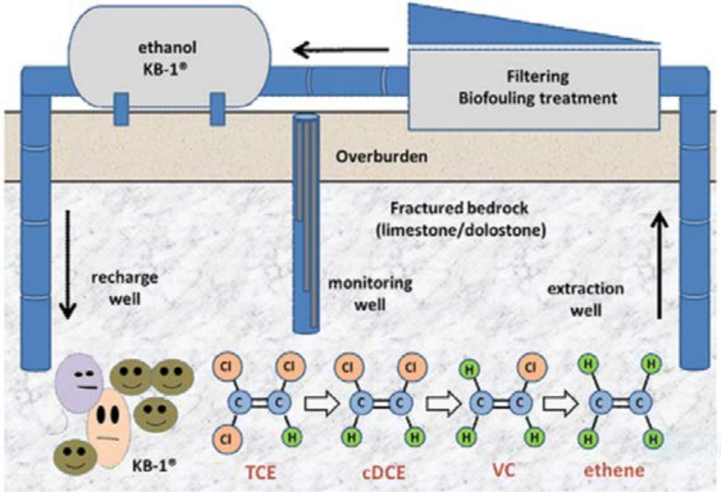
- **Fractured Rock** (Canadian Shield/Niagara Escarpment)
- **Glacial deposits/clay** (Great Lakes/St. Lawrence Lowlands)
- **Alluvial Silts and Clays**
- **Peat Lands** –anaerobic and low pH, low permeability- mainly in northern regions

Distribution challenges

Approaches are available to implement EISB in challenging geologies

EISB at Fractured Rock Site, Fort Erie ON

Groundwater Recirculation System, Fort Erie, ON



- Recirculation system controls groundwater flow and enhances flushing of source to reduce clean up times
- Ethanol and KB-1 were injected via recirculation system
- Recirculation contains nutrients and microbes in contaminated zones

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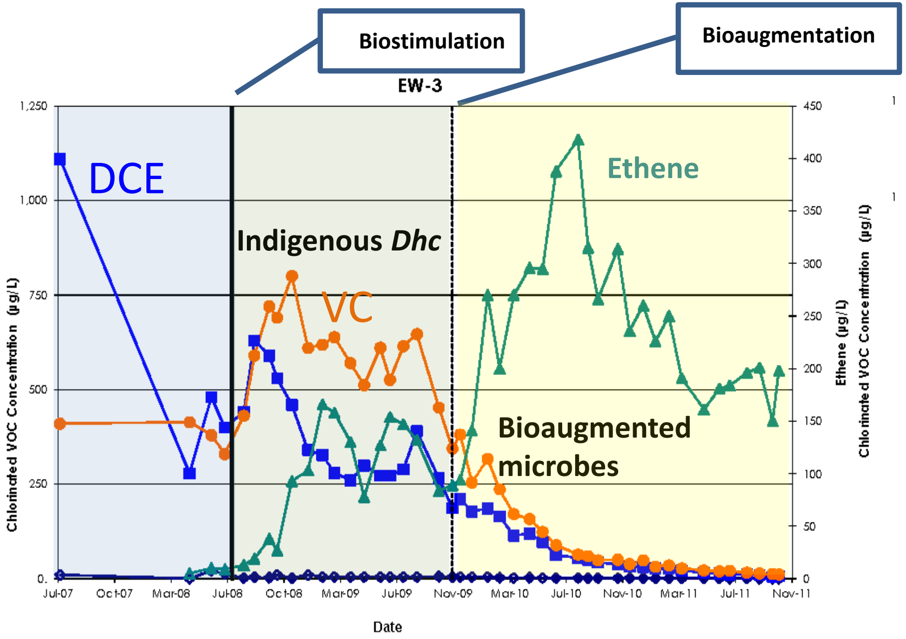
Extraction Well Results, Fractured Rock Site, Fort Erie ON



- Accelerated decrease in DCE/VC and >4-fold increase in ethene observed after bioaugmentation

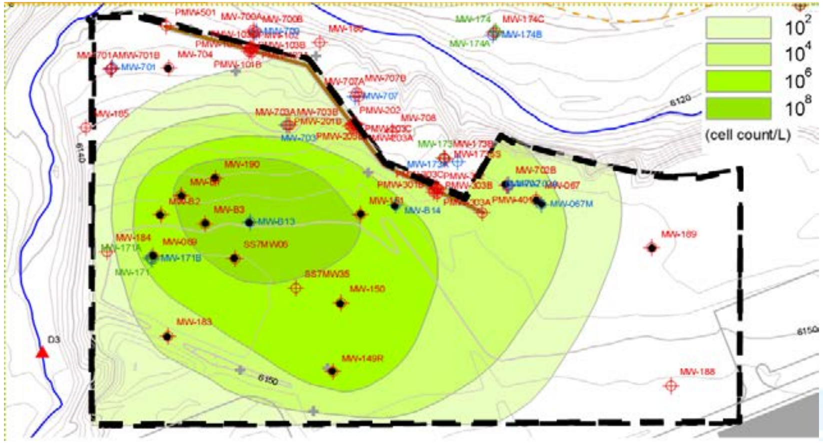
- Bioaugmentation effective at Fractured rock site even with indigenous *Dhc* at site

Amendment Distribution Challenges

- E.g., low permeability glacial deposits in highly industrialized regions such as Southern Ontario, Fort McMurray, Alberta

- Spread of remediation amendments can be challenging under low permeability conditions

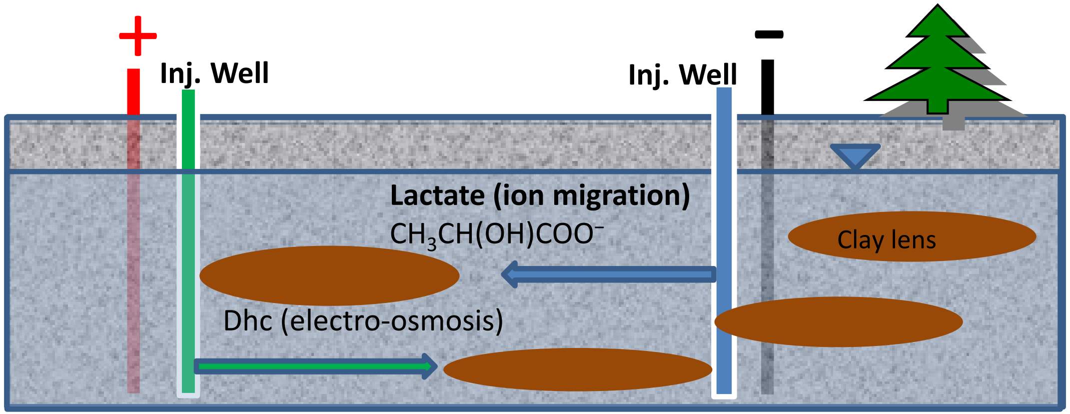
- Technical solutions include:
  - **High density direct push injection grids**
  - **Bio-barriers**–contaminants move through bioactive zone
  - **Hydraulic fracturing-** create amendment expressways
  - **Electrokinetics**- move amendments with electricity



Dehalococcoides at clay site where hydraulic fracturing was used to assist in distribution of these dechlorinators across this 4-hectare site

Electrokinetic (EK)-Bioremediation

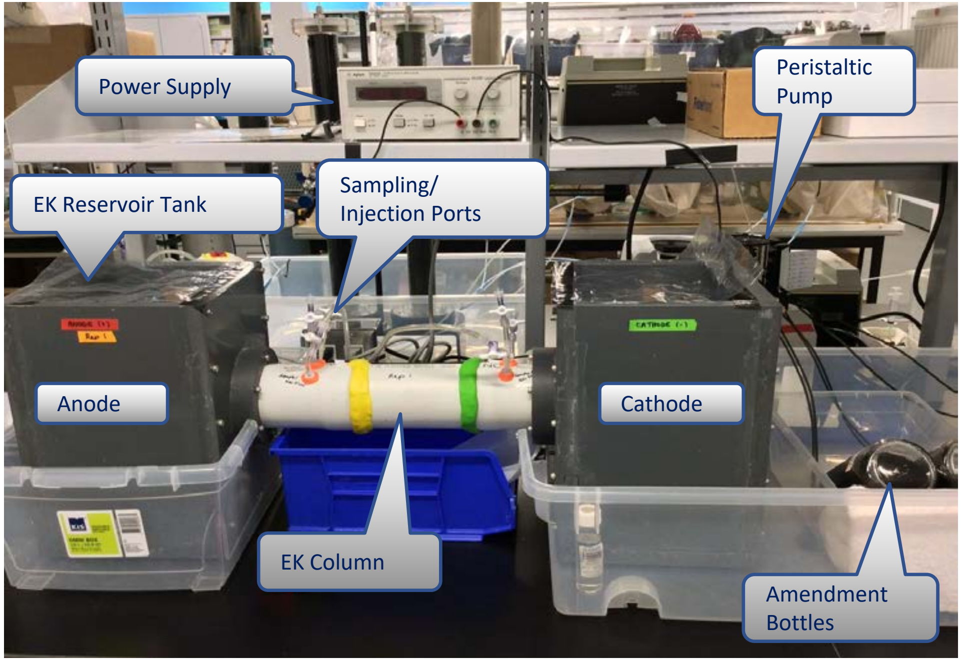
Low voltage DC current applied to subsurface to move amendments with electricity



EK mechanisms:

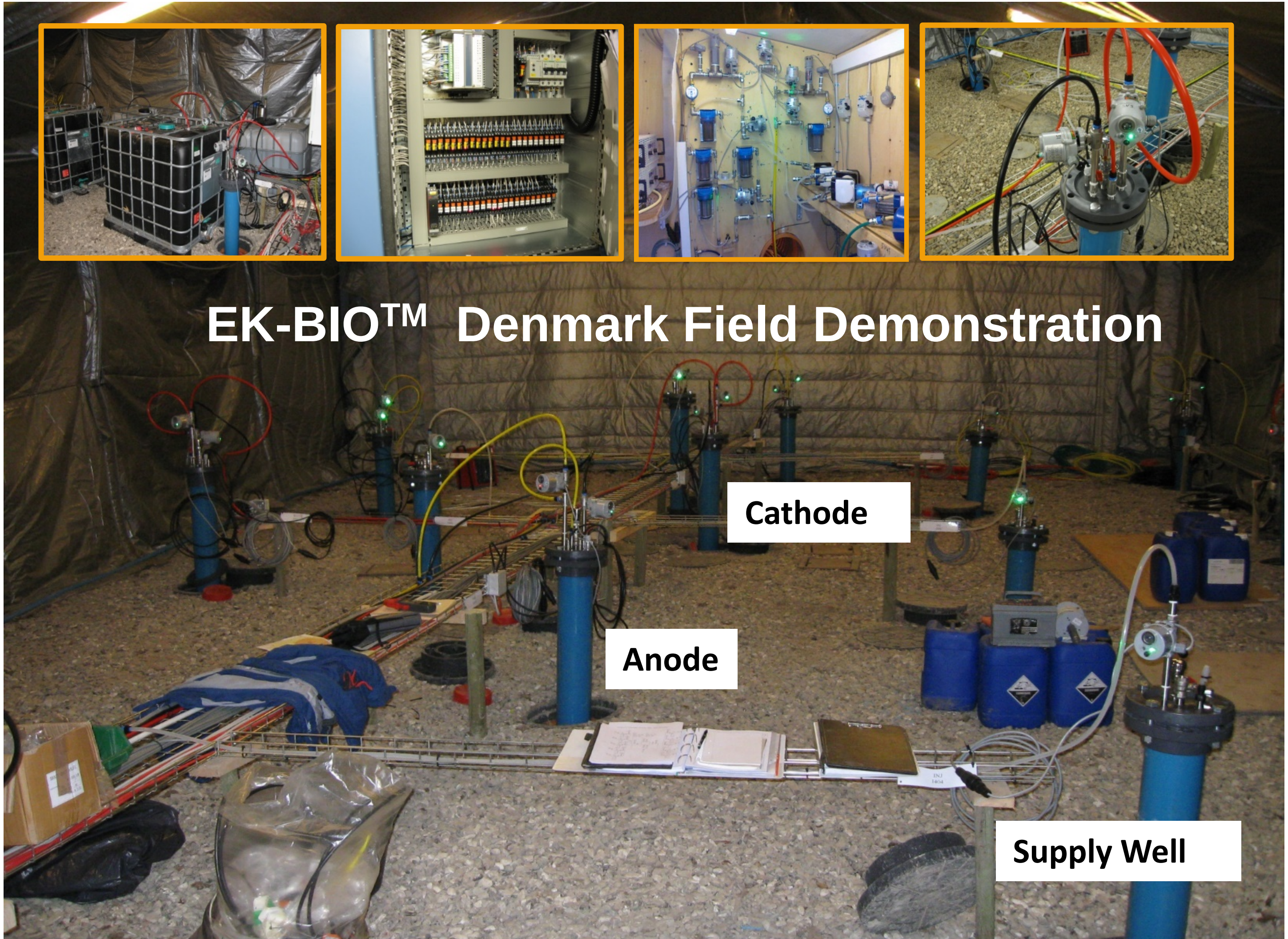
- Ion migration: charged particles move by ‘electrophoresis’
- Electro-osmosis: Charged water (H_3O+) moves to negative electrode (moves non-charged particles by advection e.g., *Dhc*)

EK-Bio™ Laboratory Test Setup



EK-Bio lab demonstration indicated that TCE/electron donor and KB-1 could be moved through sandstone (*Elaine Secord,* MSc Thesis. Faculty of Science. Earth Science. UWaterloo, 2017)

EK-BIO™ Denmark Field Demonstration



Geosyntec consultants

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REGION H The Capital Region of Denmark

EK-BIO™ Denmark Field Demonstration

- PCE Source Area 13 m x 20 m
- 15 electrodes installed
- Operated 2.5 years on alternating cycles
- Low-energy demand ~10 x 100-W light bulbs

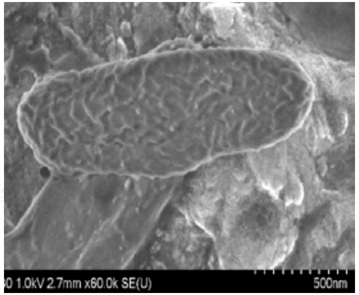
Conclusions

- EK transport of lactate through clay till ~ 2.5 to 5 cm/day
- Evident increases of *Dehalococcoides* in groundwater and clay till matrix
- Groundwater /soil core data show PCE dechlorination to vinyl chloride and ethene:
- Groundwater temperature increased from 5°C=heat enhanced bioremediation

Saskatchewan Site Benzene Culture Bioaugmentation

DGGB™ bioaugmentation culture with ORM-2

- ORM-2 Anaerobic benzene specialist derived from an oil refinery site



- ORM2 is a mesophile but may be able tolerate conditions at or below 10°C –field testing in SK in progress

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Canadian Regulatory Landscape For Bioaugmentation Cultures

- Canadian regulations for approval for bioaugmentation products are some of the most comprehensive in the world – New Substances Notification (NSN) requirement

- NSN Regulations were created to ensure the safety of products introduced into the Canadian marketplace

- KB-1 was approved and placed on the Domestic Substances List (of products approved for use in Canada) in 2008, DGG-B site specific approval 2019 –Other cultures are currently being considered for process

- Federal facilities often don’t require additional regulatory approval beyond NSN

- Provincial regulations vary but are not typically onerous

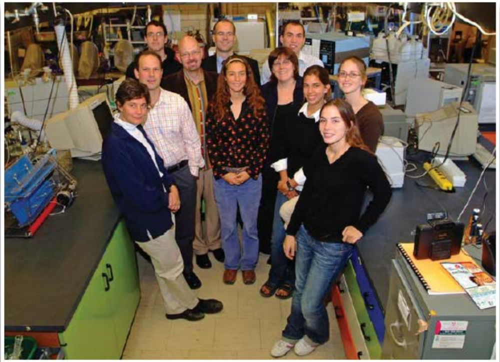
Site Remediation

New Canadian process approved to detoxify chlorinated solvents

Due to their pervasive use in industrialized countries, persistence in the environment, and poor disposal techniques prior to regulations, chlorinated solvents rank among the most severe and common groundwater contaminants in the world.

Recently, Environment Canada approved a new method, which uses micro-organisms to eradicate these toxic compounds. It is built on a sophisticated, mixed culture of naturally-occurring anaerobic bacteria. One particular species converts poisonous chlorinated solvents into benign compounds.

Known as bio-augmentation, the remediation technology was pioneered by Dr. Elizabeth Edwards, a chemical engineering professor at the University of Toronto, and her colleagues at Geosyntec Consultants. Dr. Edwards’ discoveries and innovations were funded largely



Students from Dr. Edwards’ lab visit Geosyntec in Guelph; Dr Edwards is in the front row on the left.

Conclusions

- Bioremediation has a number of financial, sustainability and logistical advantages over other remediation technologies

- In situ bioremediation is likely underutilized in Canada for variety of reasons - both regulatory and geology/climate

- There are technical solutions and growing Canadian/International expertise to many geological, technical and climatic factors that make bioremediation a viable remedial solution in the north

Thank you for your Attention!

Further Information

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