Design of Bioaugmented Biobarriers for Remediation of a TCE Plume

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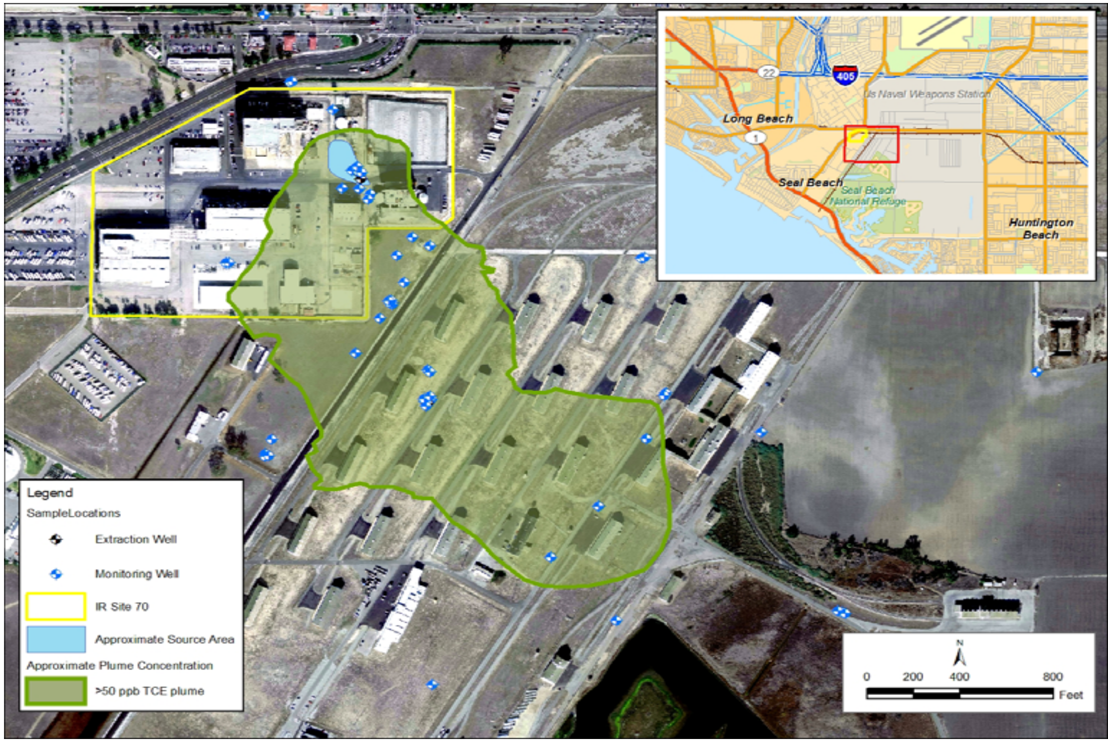
Overview

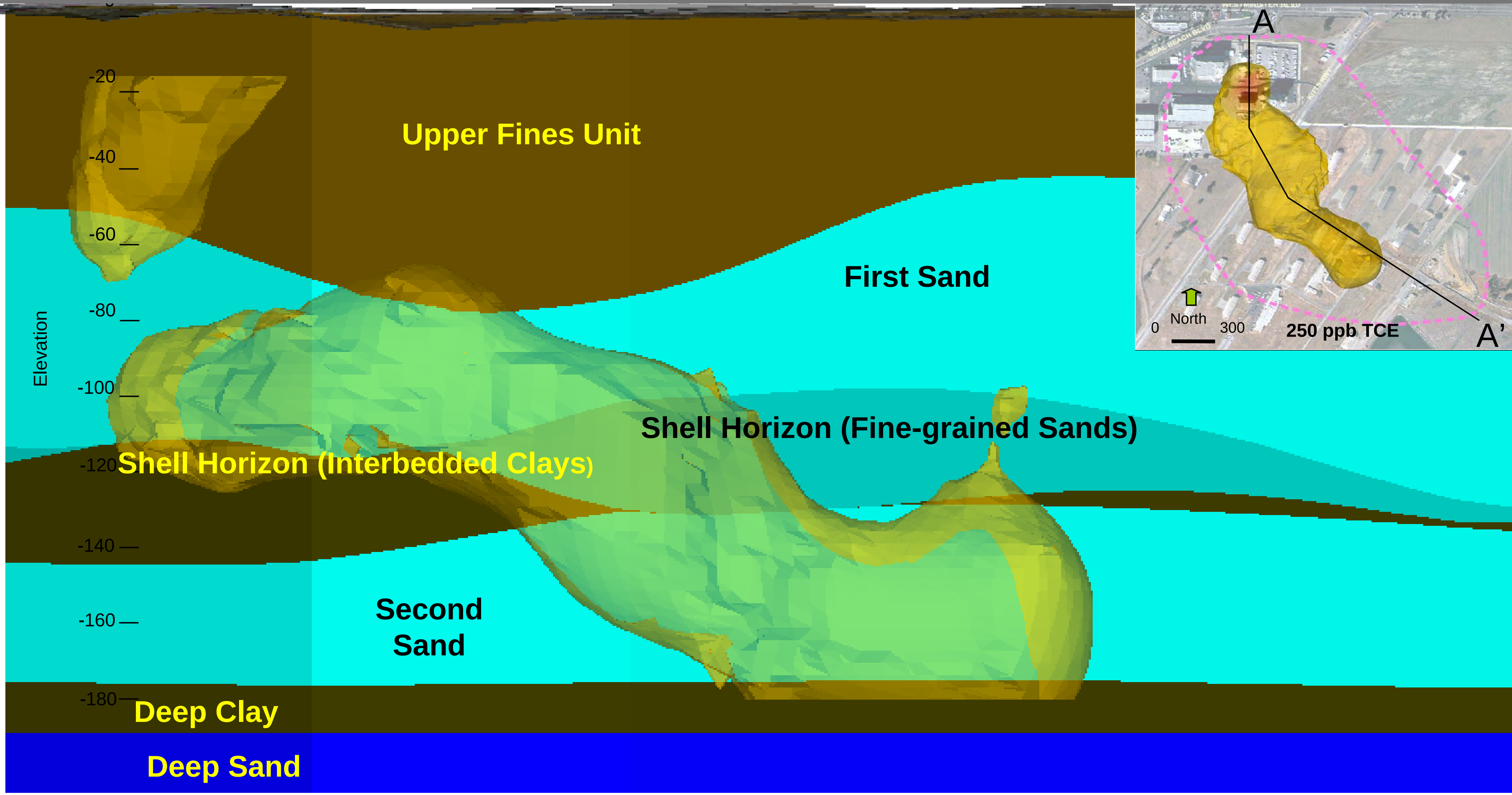
- Site Description
- General Bioremediation Approach
- Microcosm Testing
- EVO Pilot Testing
- Modeling
- Final Design

Site Description

- Possible DNAPL in Source Area (2003) – TCE in EW-70-01 (10,000 ug/L) and MW-70-27 (98,000 ug/L)
- Dissolved Plume
  - *Length – 2,800 feet*
  - *Maximum Width – 1,600 feet*
  - *Depth - 30 – 170 feet bgs*
- Approx. GW Flow Direction – Southeast
- Approx. Flow Velocity = 65 ft/yr
- Some evidence of MNA occurring
- Sulfate present at several hundred mg/L



Cross-Section of Plume



Proposed Passive Bioremediation Approach

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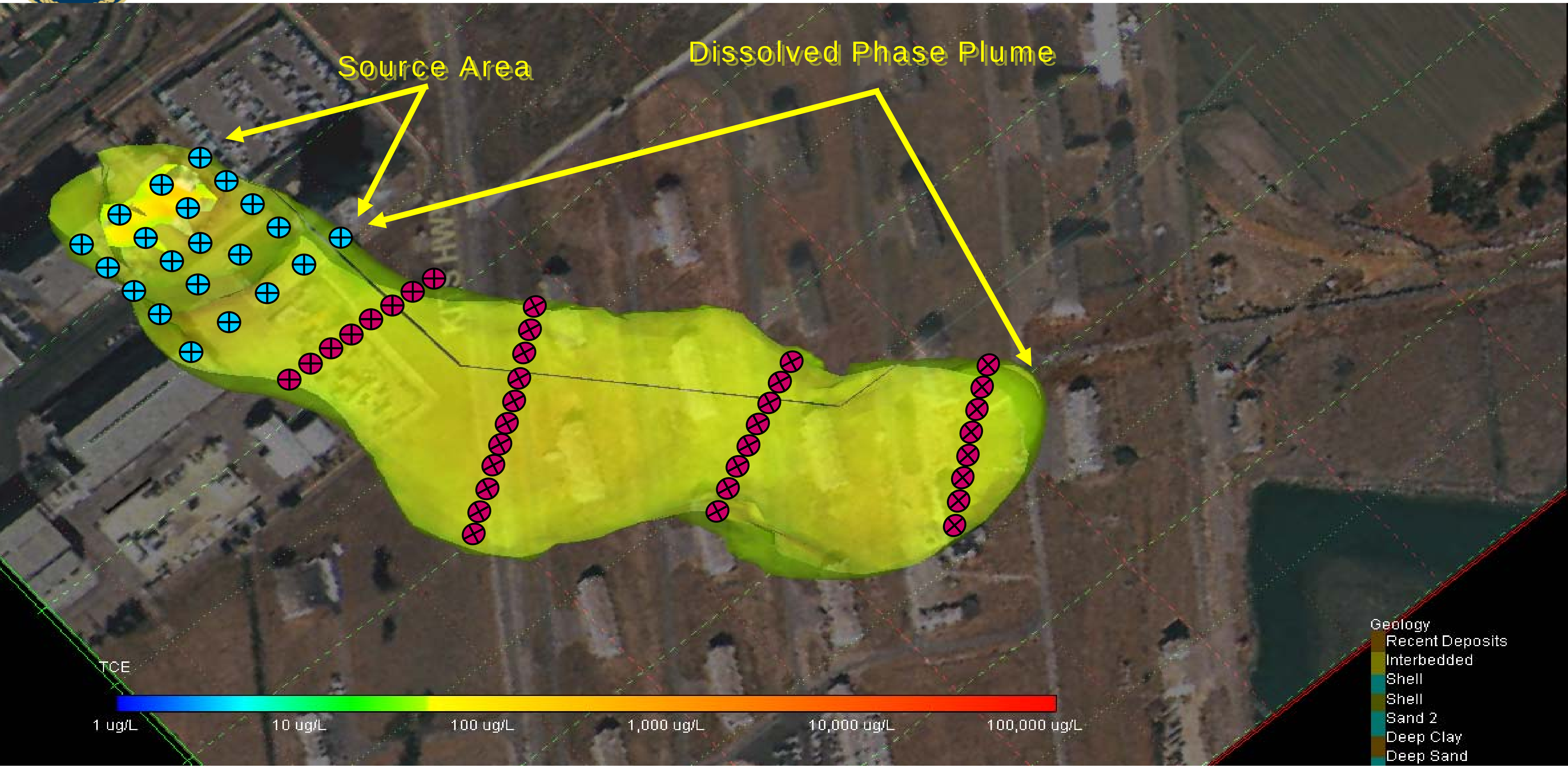
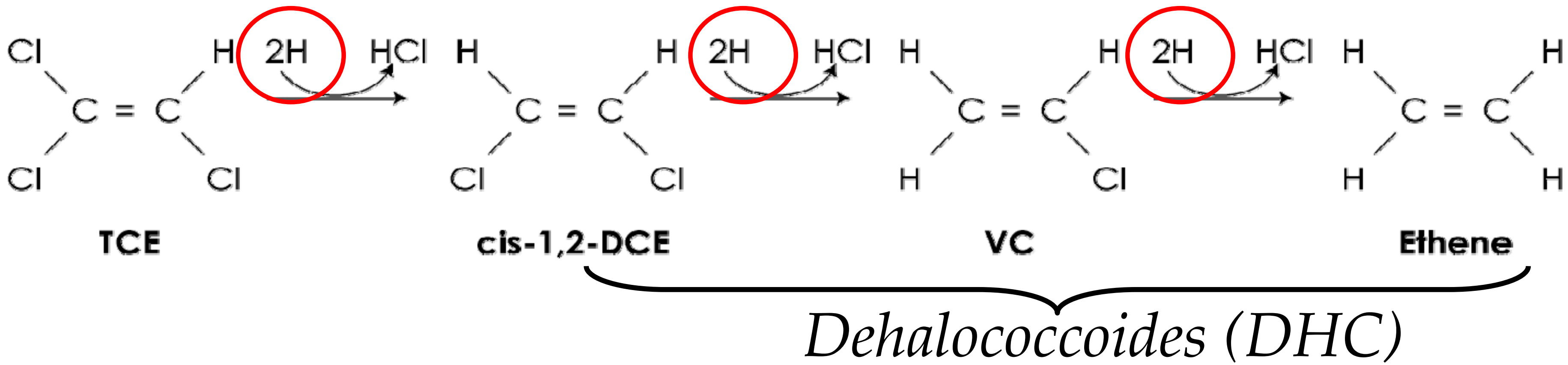


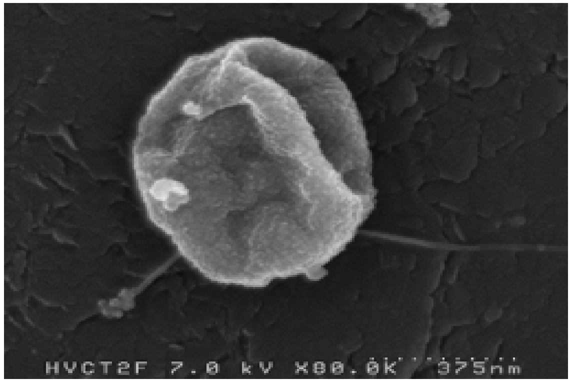
Biodegradation of TCE

- Sequential reductive dechlorination carried out by dechlorinating bacteria
- Chlorine is replaced by hydrogen atom
- Hydrogen is produced during fermentation of emulsified oil (EVO)
- *Dehalococcoides* (DHC) bacteria are the only known group capable of degrading cDCE to ethene

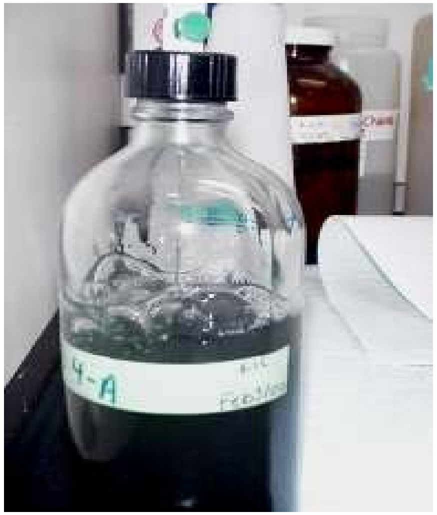


Bioaugmentation with KB-1® Culture

- Anaerobic bioaugmentation culture enriched from TCE site
- Not genetically engineered/pathogen free
- Used to introduce DHC to sites deficient in DHC-Contains ~100 billion DHC/Liter
- Applied at over 100 sites world-wide
- Recently approved by Health Canada for Canadian applications; Mobile C of A in process
- Distributed by SiREM Laboratory, Guelph, ON



***Dehalococcoides* KB-1/VC**



EVO as Long-term Electron Donor

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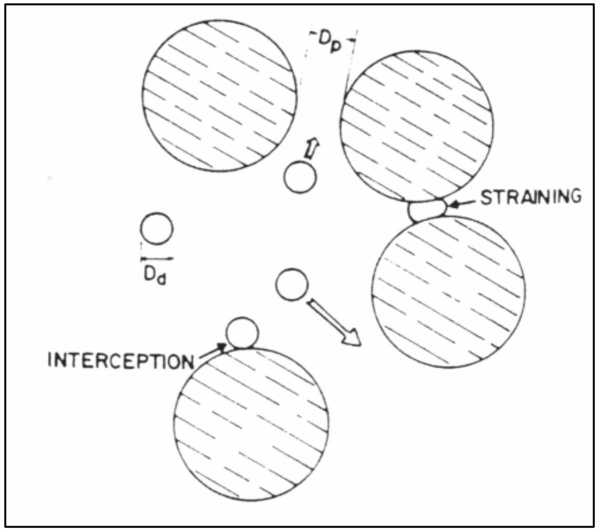
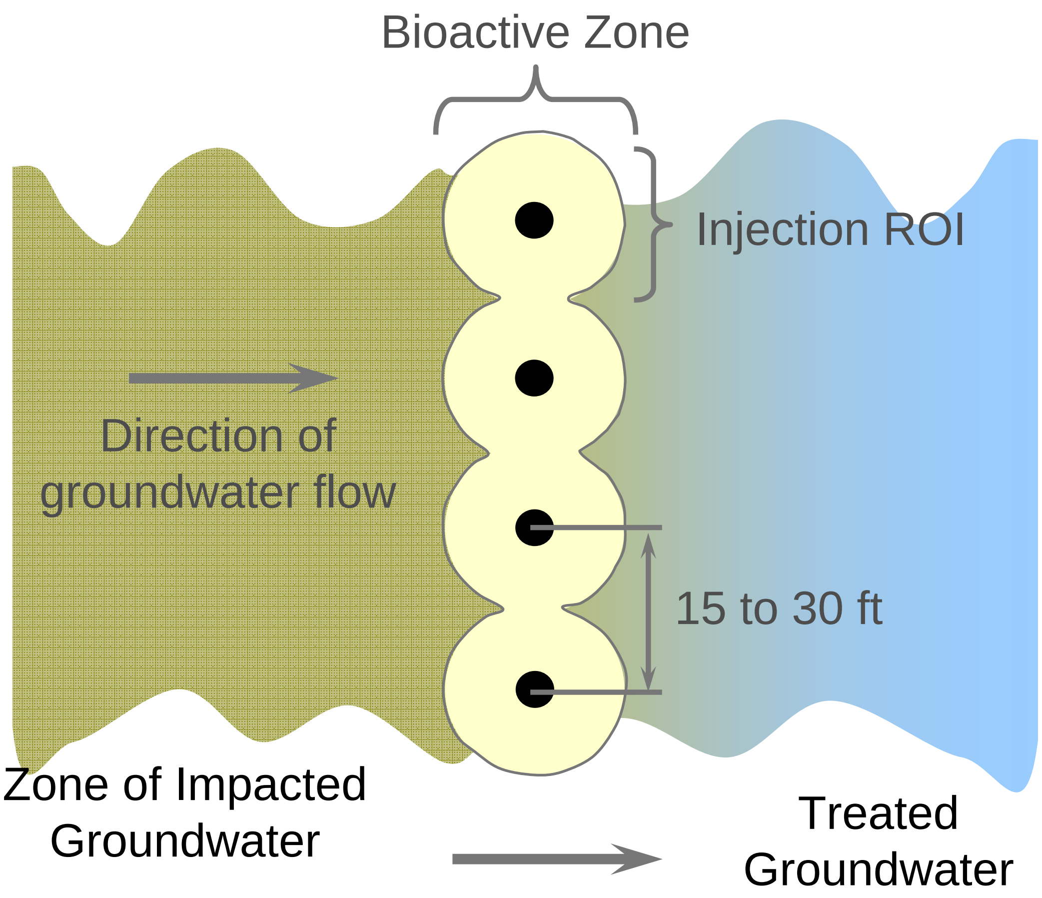
- Emulsified Vegetable Oil (EVO) - effective long-term electron donor
- EVO – mixture of fatty acids, surfactant and may contain sodium lactate
- Ferments to form hydrogen needed for reductive dechlorination
- Small oil droplets (< 1 µm) easily pass through most pores (~ 50 µm)
- EVO retention due to combination of interception and straining of droplets
- Minimizes O&M **costs** while promoting degradation



(Soo and Radke, 1986)

Passive Bioremediation Approach

Plan View of Conceptual Biobarrier Design



- No permanent infrastructure required other than injection wells
- Infrequent reinjections
- Low O&M
- Energy-efficient

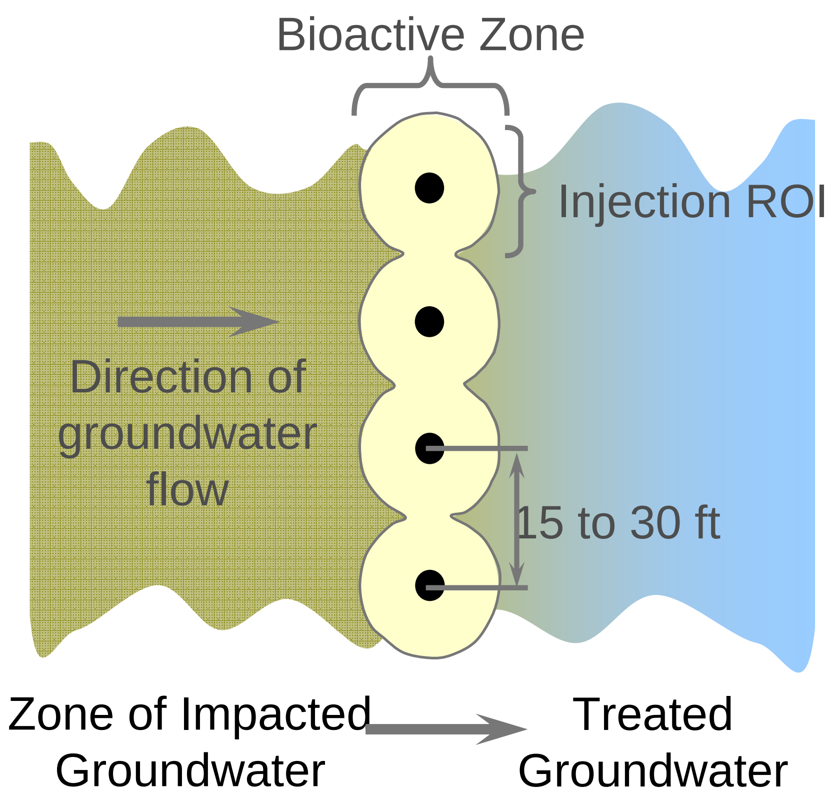
Full-Scale Design Objectives

- Remediate TCE and daughter products in plume and source within 50 years
- Use bioaugmented biobarriers to treat the TCE plume to

< 200 ug/L in <=16 years

- Use MNA to reach MCLs within 50 years
- Determine number, dimensions, and optimum placement of biobarriers
- Minimize Costs

Passive Biobarrier Approach



Key Design Parameters

✓**Injection ROI-** controls well spacing

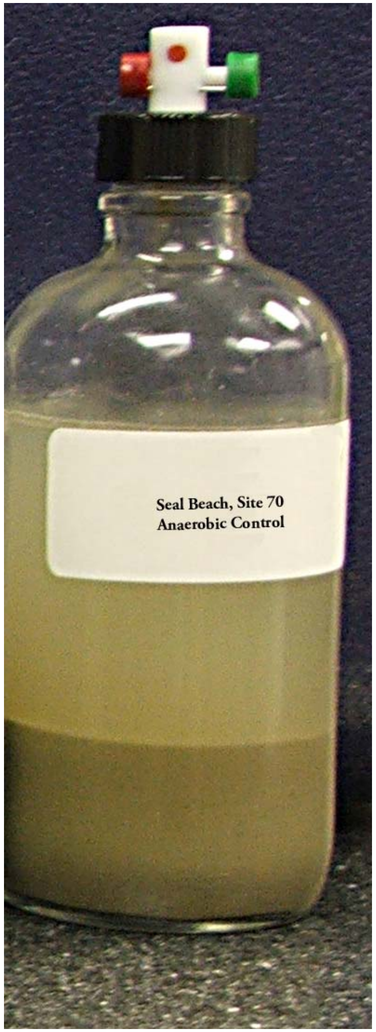
✓**Biobarrier Biodegradation Half-Life** - controls minimum thickness of biobarrier in direction of gw flow or retention time

✓**Natural Attenuation Half-life** - controls spacing and number of biobarriers

Bench-scale Study

Objectives:

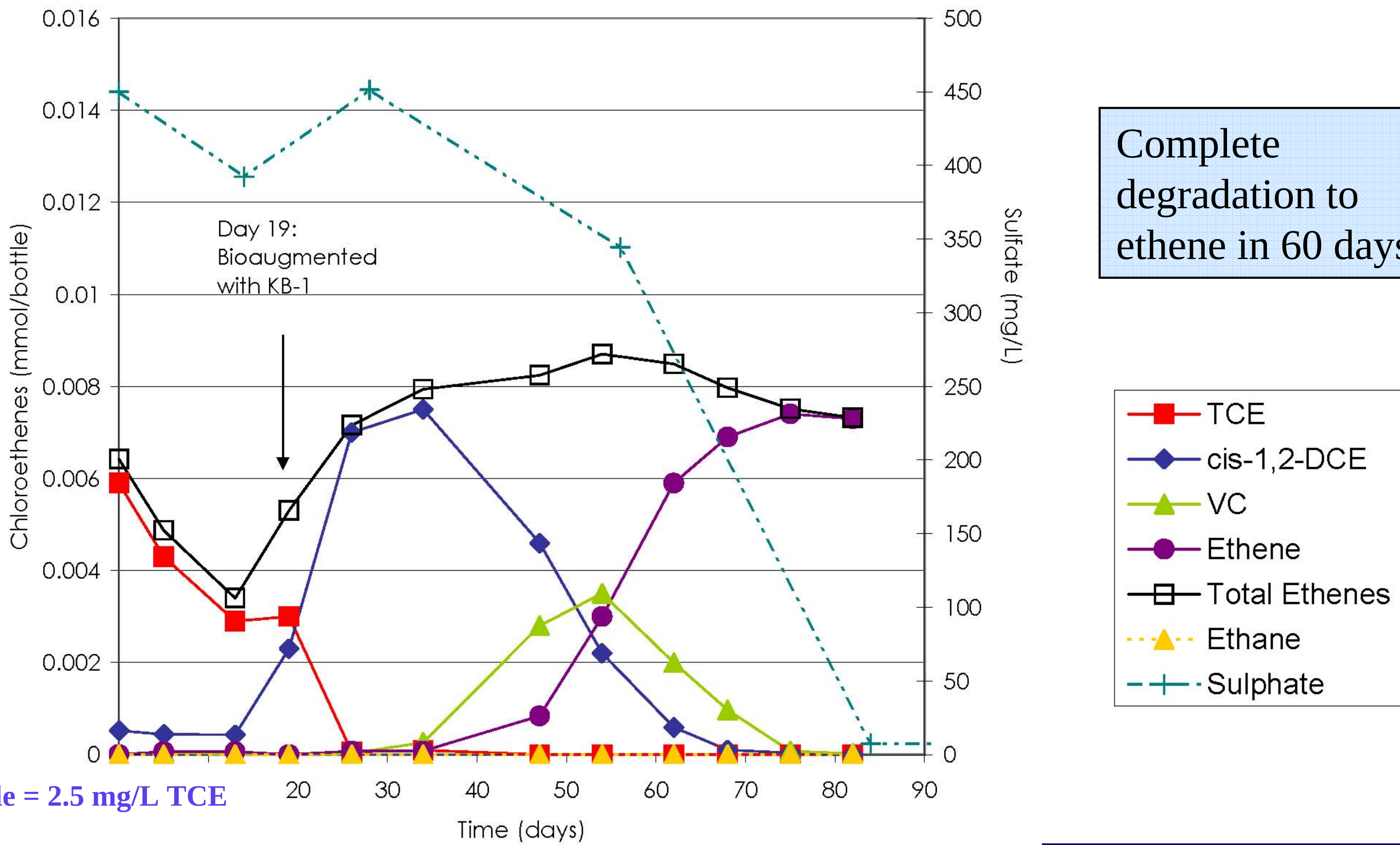
- Determine TCE, cDCE, and VC half-lives using bioaugmentation (KB-1 ®) with EVO addition
- Evaluate natural attenuation half-lives



Experimental Set-Up

- Microcosm bottles set up in triplicate
- Active treatment bottles received EVO; KB-1® after ~1 month
- Natural attenuation bottles received no amendments
- Sterile control

Microcosm Study- Bioaugmentation Results – Newman Zone EVO and KB-1®



Complete degradation to ethene in 60 days

0.006 mmol/bottle = 2.5 mg/L TCE

Half-Lives Using EVO and KB-1®

$t_{0.5,}$ TCE	5.7 days
$t_{0.5,}$ cDCE	7.6 days
$t_{0.5,}$ VC	2.0 days

$t_{0.5}$ = half-life

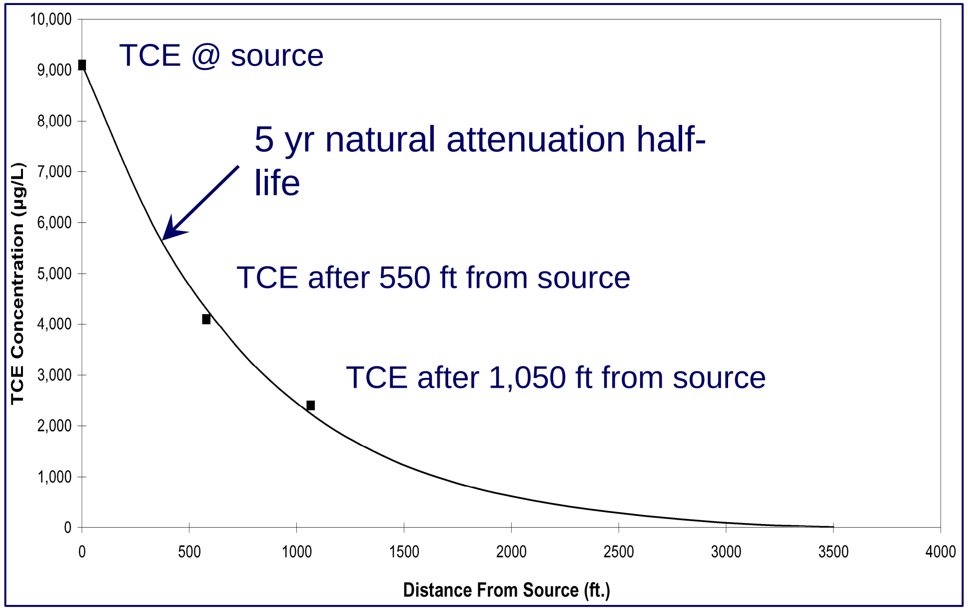
Microcosm Study- Natural Attenuation

- No substantial biodegradation observed over 160 day study period

Using Plume Data

- Rate of natural attenuation low but transformation products observed in plume
- Centerline plume data used to determine a biodegradation half-life using an analytical groundwater model
- TCE half-life estimated to be

  5 years; cDCE and VC half-lives~ 6 years



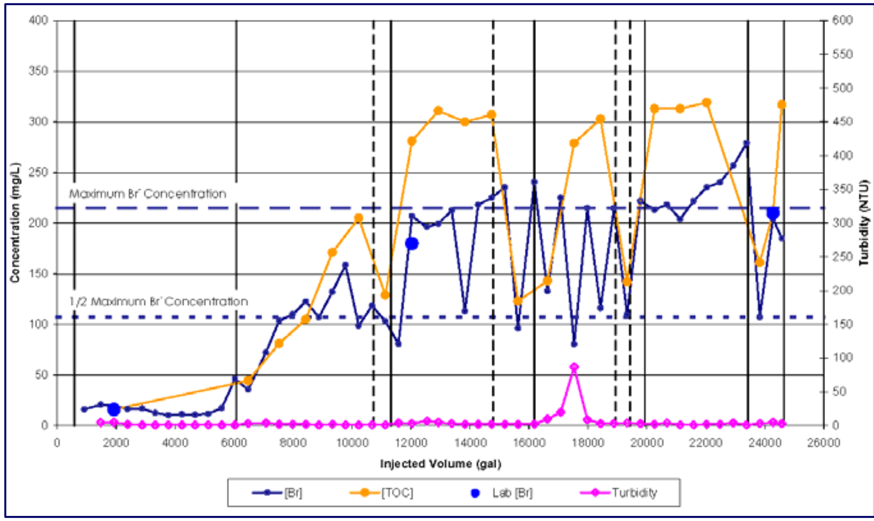
Microcosm Study- Key Conclusions

- Rapid and complete biodegradation to ethene with KB-1® and EVO addition within 60 days
- TCE, cDCE, VC half-lives of 6 days, 8 days, and 2 days, resp., for bioaugmented treatments
- Rate of natural attenuation slow (e.g., half-life of 5 years for TCE)

EVO Radius of Influence

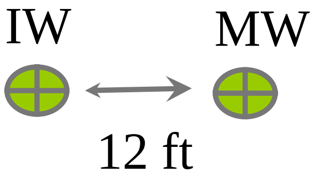
Objectives:

- Achievable injection radius of influence (ROI)
- Achievable injection rate
- Impact of soil type on EVO distribution



Approach

- Inject dilute solution of EVO to achieve 0.5% oil saturation in situ
- Use Br tracer to determine hydraulic connection
- Monitor EVO (visual, TOC, turbidity) and Br 12 ft downgradient
- Measure injection rate and pressure



ROI Pilot Test Summary

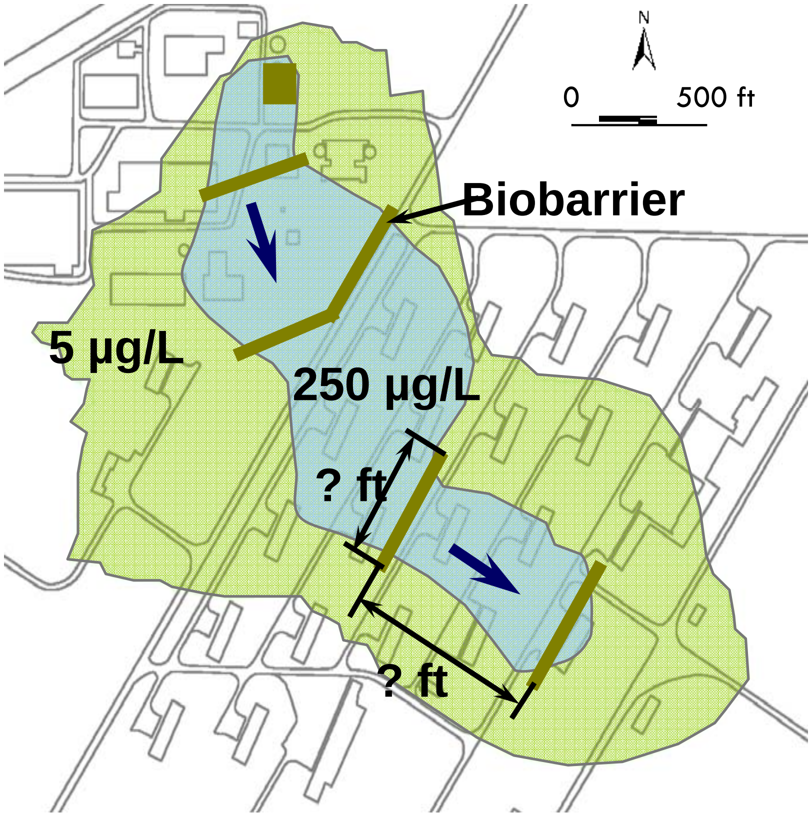
IW	Matrix	Tracer Break-through ?	EVO Observed at 12 ft ?	Well Spacing (ft)	Q (gpm)
6B	Second Sand (fine sand/gravel)	YES	YES	24	12
6A	Shell Horizon (silt/sand/clay, shells)	YES	NO	<24	5

ROI Pilot Test Conclusions

- Sandy units (First and Second Sands) – EVO injection rate of 12 gpm and ROI of 12 ft achievable – plan to use 24 ft well spacing
- Less permeable units (Shell Horizon and Upper Fines), injection rates of 5 gpm achieved; plan for 10 ft ROI or 20 ft well spacing
- 20 – 24 ft thick barrier (in direction of gw) = hydraulic residence time of at least 4 months – more than sufficient to treat chlorinated contaminants to concentrations << 200 ug/L

Design Approach for Plume Treatment – Modeling Objectives

- Determine number, dimensions, location, and operational duration of each biobarrier to remediate the TCE plume to MCLs using MNA to extent possible
- Operation of biobarriers ≤ 16 years
- MNA for remaining VOCs to MCLs within 50 years



Design Approach – Modeling

- Used Visual Modflow/RT3D to determine base case to meet remedial objectives
- ~15 modeling runs to meet 50 year timeframe and optimize configuration
- Emphasis on treating core of plume (250 ug/L)
- MNA to handle fringes and polish

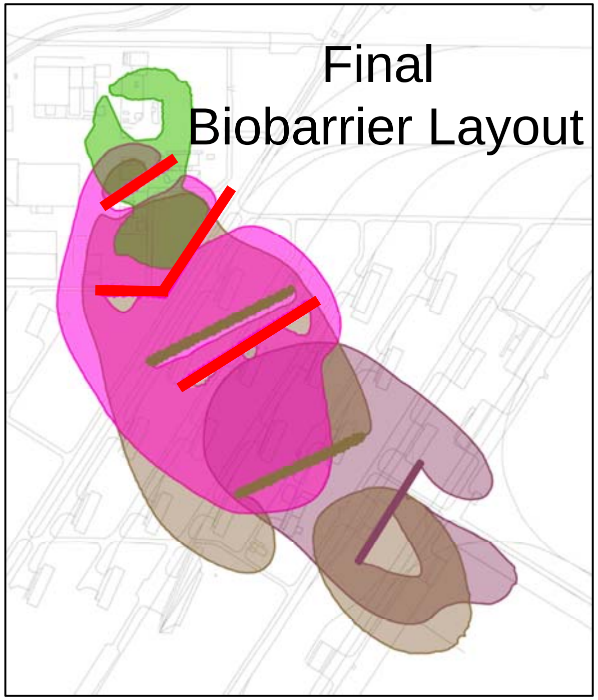
Final Biobarrier Layout – 6 biobarriers

– 3 in First Sand (FS), 2 in Shell Horizon (SH), 1 in Second Sand (SS) -range from 325 ft to 820 ft long

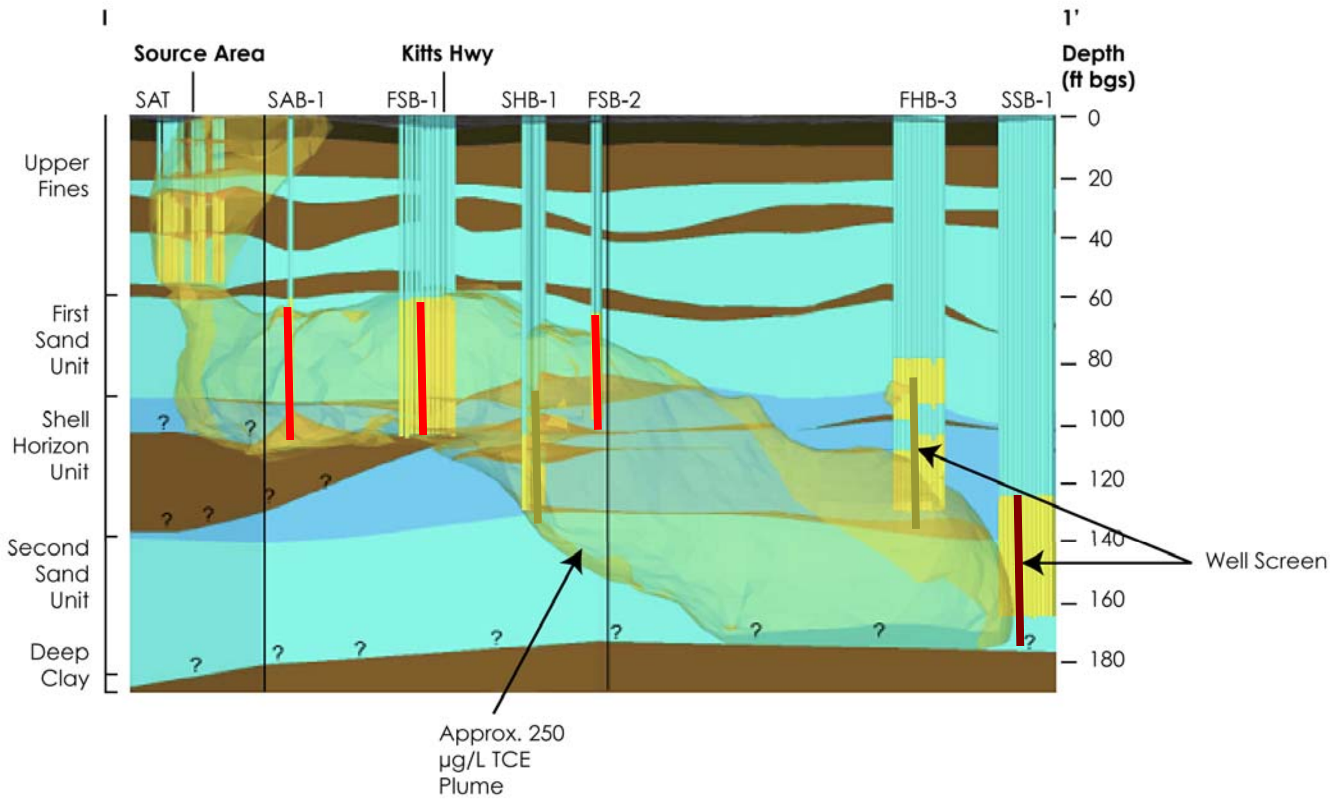
Operational : 6-16 years

MNA for 34 years

Total Treatment time = 50 years



Site 70 Design



First Sand Biobarriers

Shell Horizon Biobarriers

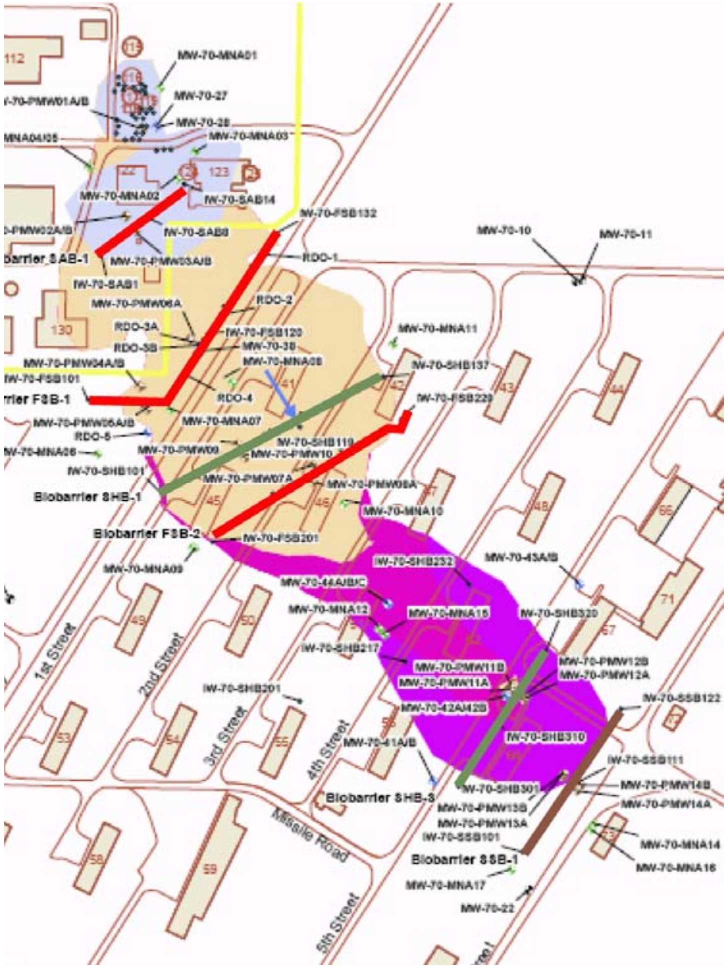
Second Sand Biobarrier

Conclusions

- Microcosm study useful for determining biodegradation half-lives for bioaugmentation/EVO treatments
- TCE rapidly and completely converted to ethene with KB-1® and EVO addition (TCE half-life of 6 days; complete conversion within 60 days)
- Natural attenuation within plume slow (TCE half-life ~ 5 years)
- Pilot tests indicated EVO ROI of 12 feet in First and Second Sand units and <12 feet in Shell Horizon
- Modeling to optimize placement and number of biobarriers to reduce cost

Epilogue - Current Status

- 214 wells installed
- Baseline sampling completed
- EVO injection and bioaugmentation planned for November



Acknowledgements

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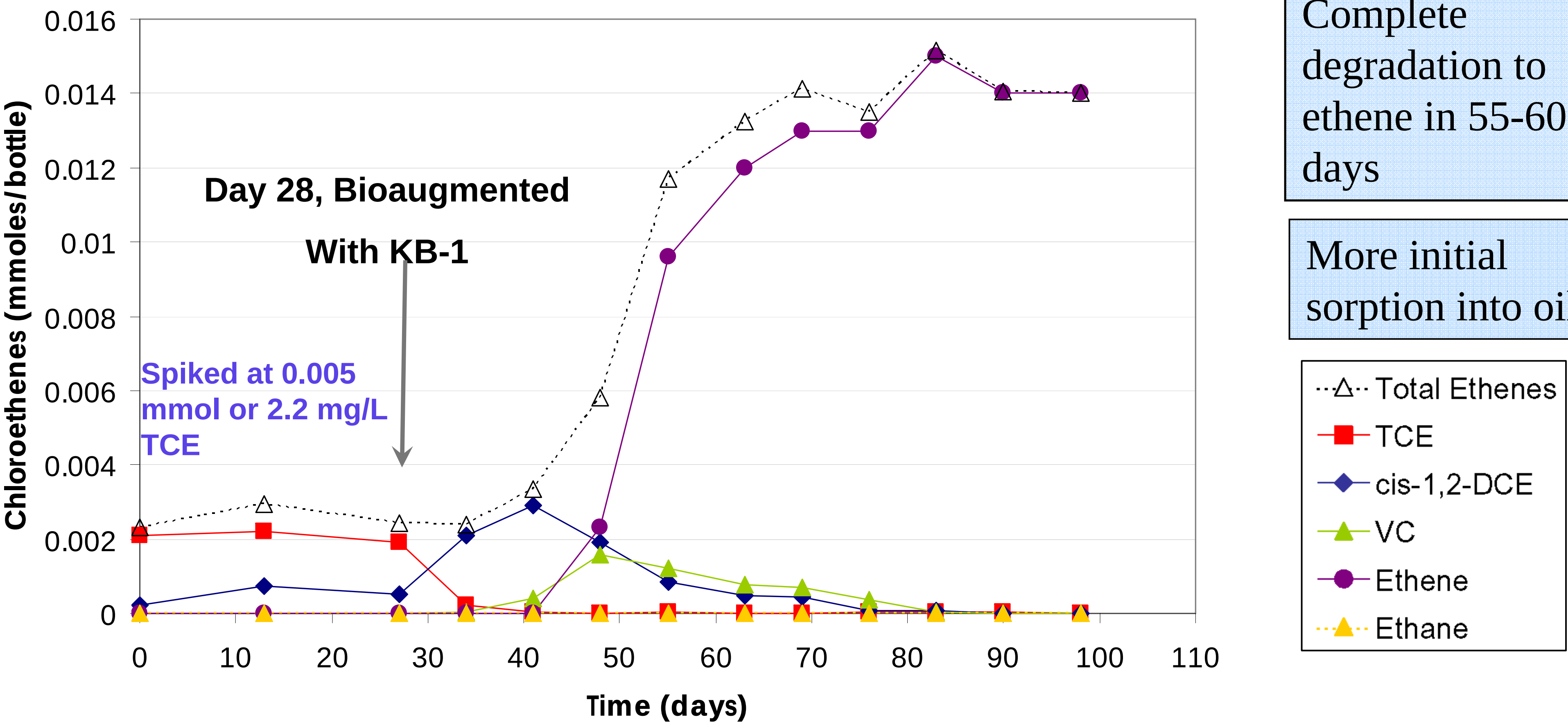
- SiREM Laboratory for conducting the microcosm studies
- Other Geosyntec team members (Huntington Beach, Inland Empire, Guelph, Knoxville offices)

Microcosm Study- Bioaugmentation Results – Plume, EOS 450 and KB-1®



Complete degradation to ethene in 55-60 days

More initial sorption into oil