PRB Installation using Edible Oil Substrate (EOS®)

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Major Contributors

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- SERDP/ESTCP
  - Cathy Vogel and Andrea Leeson
- AFCEE
  - Jim Gonzales, Jeff Cornell and Patrick Haas

Technology (Patent # 6,398,960)

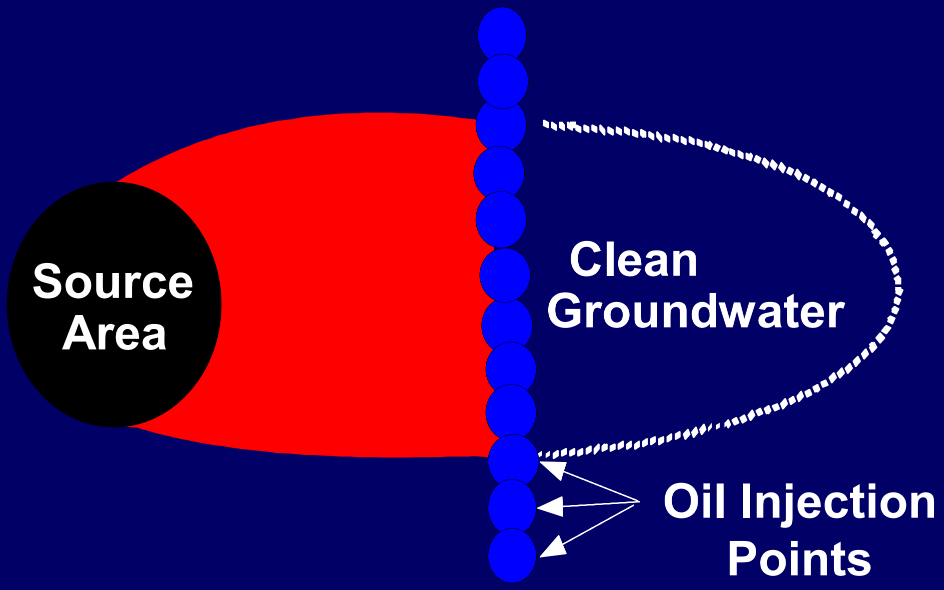
- **Enhanced Reductive Dechlorination using Slow Release Organic Substrates**
  - **Oil-in-water emulsion prepared with food grade edible oils**
  - **Use high mixing energy to achieve required droplet size**
  - **All materials are FDA Generally Recognized as Safe (GRAS)**
  - **Patent Issued June 4, 2002**

Proposed Technology

- **Application Approach**
  - Source area injected to enhance degradation of NAPLs
  - Distribution throughout plume to enhance MNA
  - Barrier to cut off plume

Barrier Approach

- **Advantages**
  - Limited source area delineation
  - Low construction cost
  - Minimal O&M cost
  - Construction to ‘any’ depth required
  - Construction in both sediments and fractured rock



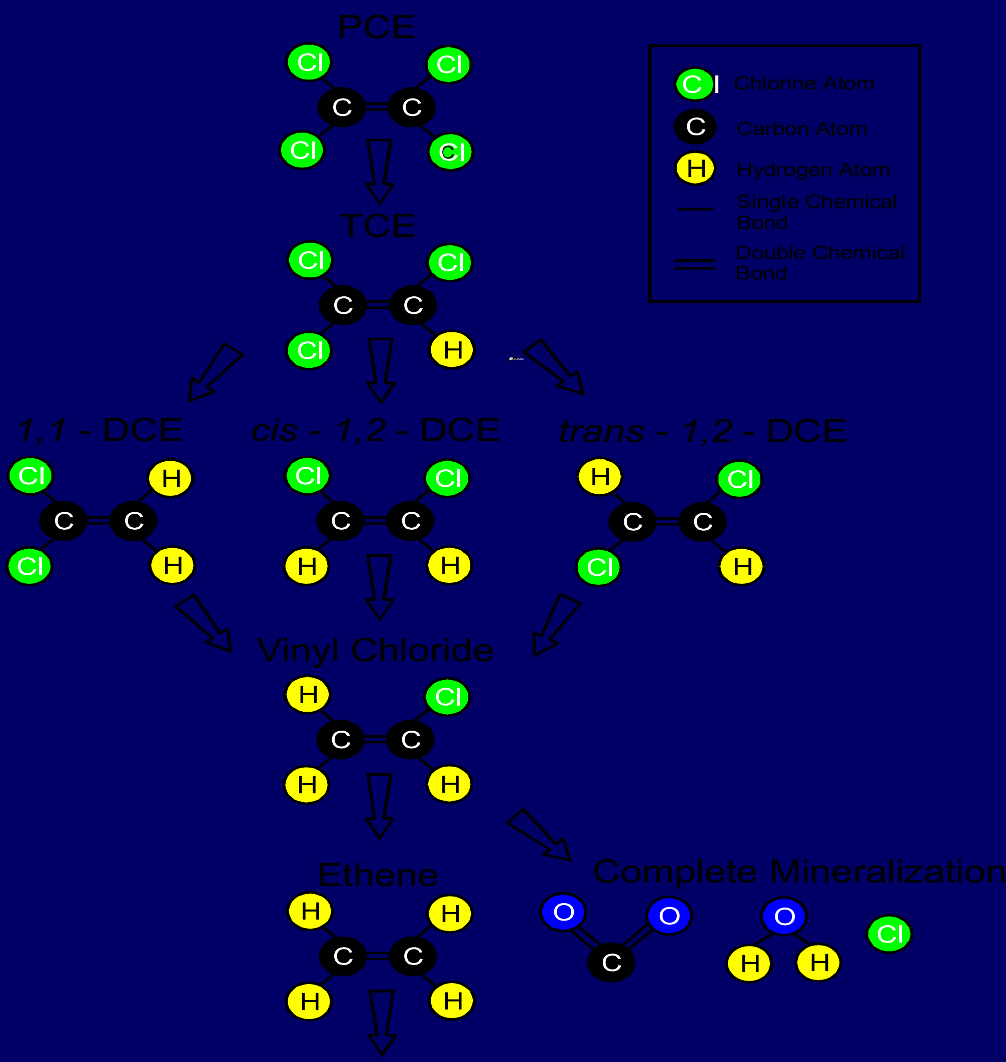
PCE Biodegradation

Reductive Dechlorination

- Soybean Oil ($C_{18}H_{32}O_2$) ferments to H_2 and simple organics

$$C_{18}H_{32}O_2 + 34\ H_2O \rightarrow$$
$$\rightarrow 18\ CO_2 + 50\ H_2$$

- H_2 and simple organics
  - Consume oxygen
  - Drive dechlorination



Possible Substrates

- Soluble Substrates
  - Lactate, molasses
  - Frequent addition required
  - Higher O&M Costs

- HRC
  - $12 per pound of organic substrate ($6/lb HRC – 50% water)
  - Lasts ~ 6 months then need to reinject
  - Very limited spread in aquifer

Possible Substrates

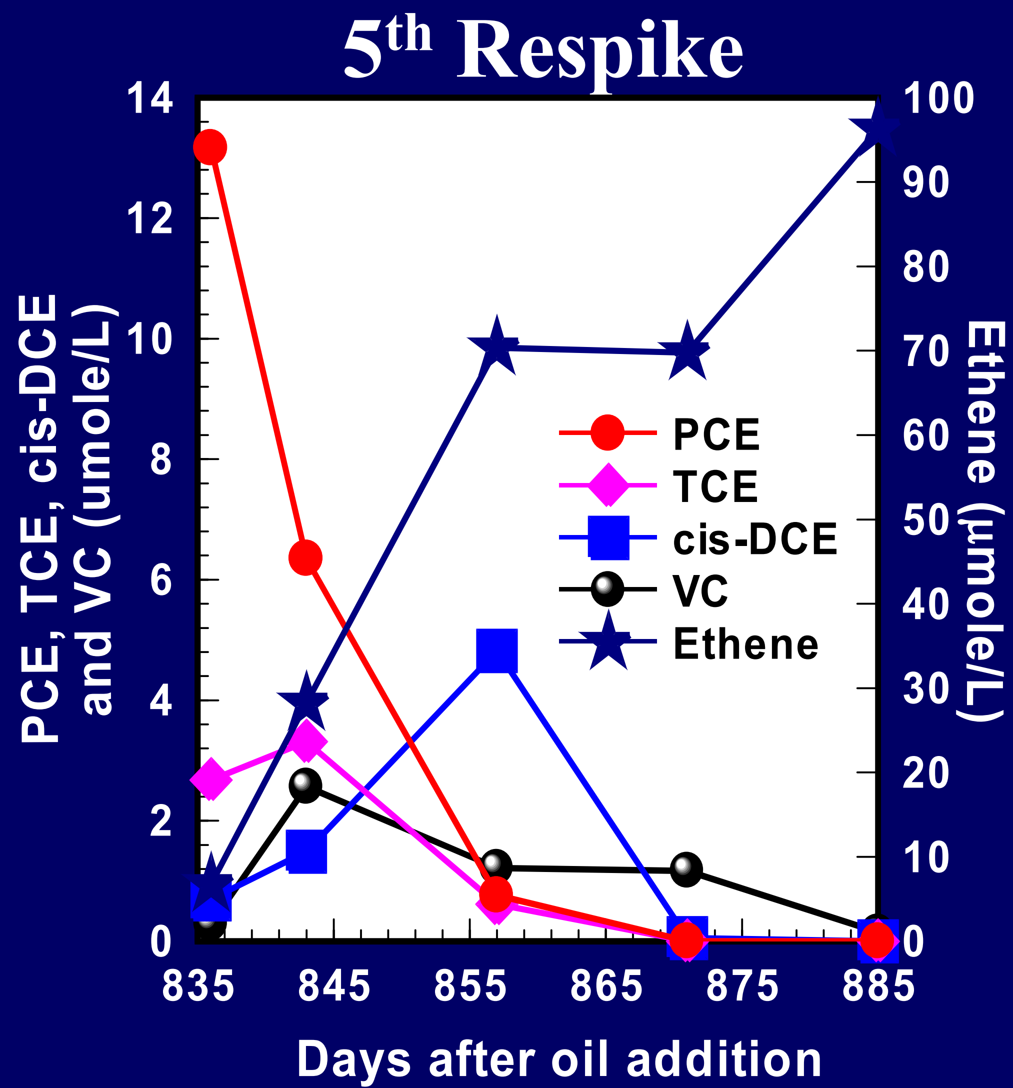
- EOS®
  - Longer lasting, lower need for reinjection
  - Effective distribution over much larger areas
  - Relatively low cost
    - Low cost substrate
    - Injection is more complicated
    - Frequent reinjection not required

Potential Concerns

- Absence of dehalogenating microorganisms
- Oil degrades too rapidly
- Limited oil distribution
- Aquifer permeability loss

How Long Will Oil Last?

- Microcosms built 3.5 years ago
- Originally fed 500 mg/L soybean oil
- Periodically respiked with 20 mg/L PCE
- Now on 8th respike
- Continue to see excellent PCE → ethene



Emulsion Transport in Aquifers

- Soo and Radke ('84 – '86)
- Big droplets get removed by straining and cause large permeability loss
- Small droplets removed by sticking to solid surfaces and cause minor permeability loss

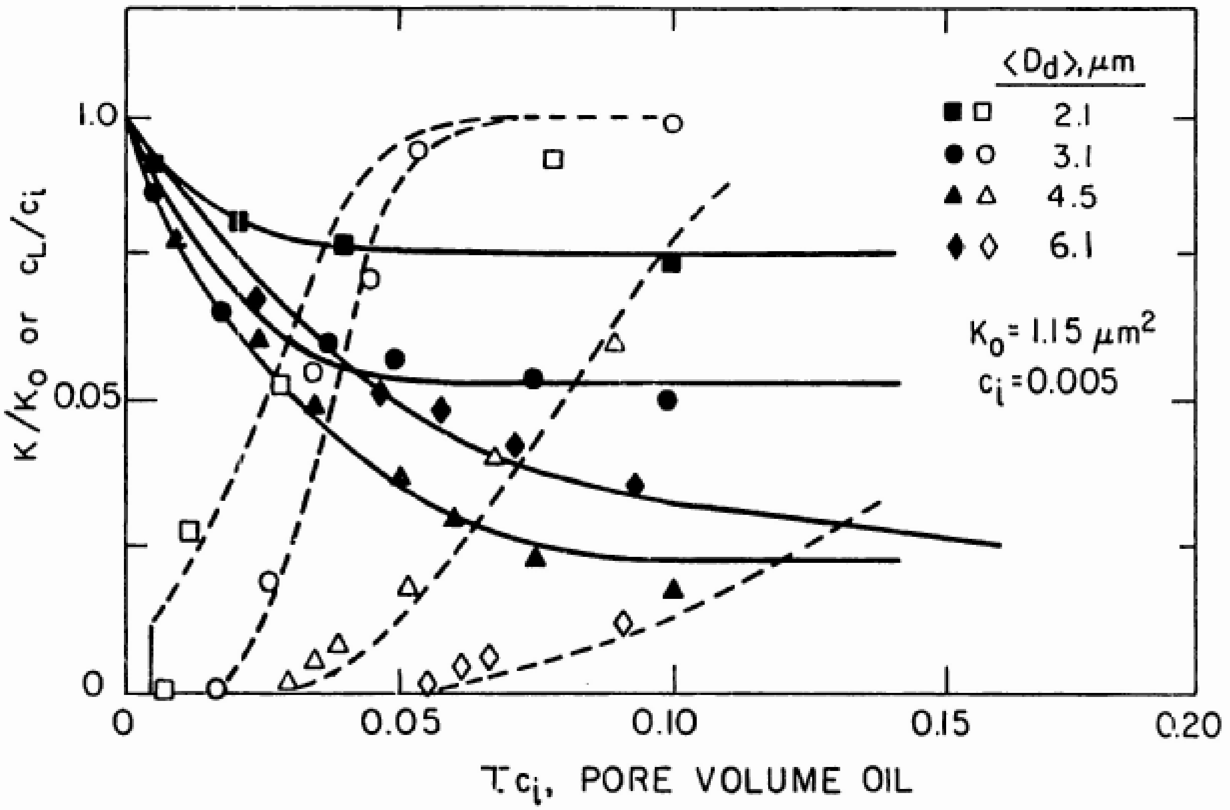
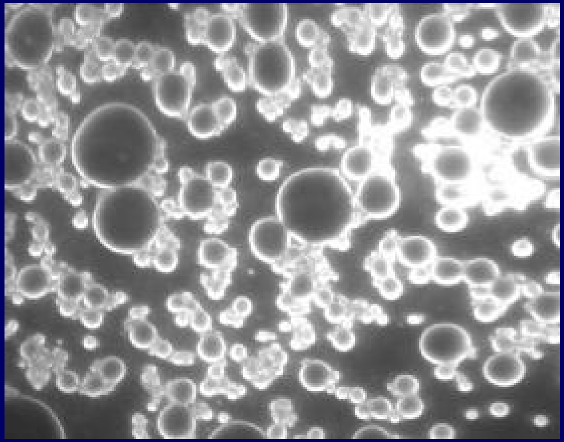
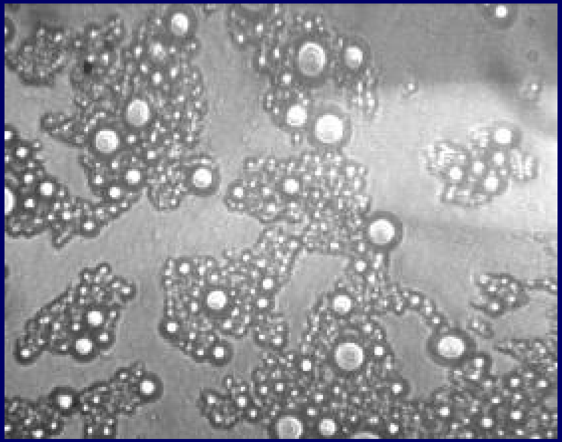


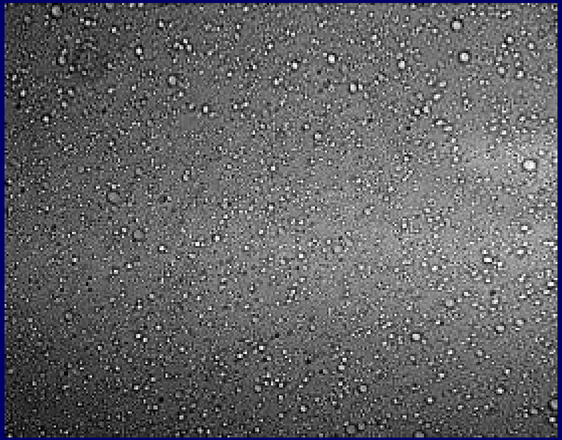
Figure 6. Experimental permeability reduction (solid symbols) and breakthrough concentration profiles (open symbols) for varying drop sizes (2.1, 3.1, 4.5 and 6.1 μm) in the 1.15 μm^2 permeability core.

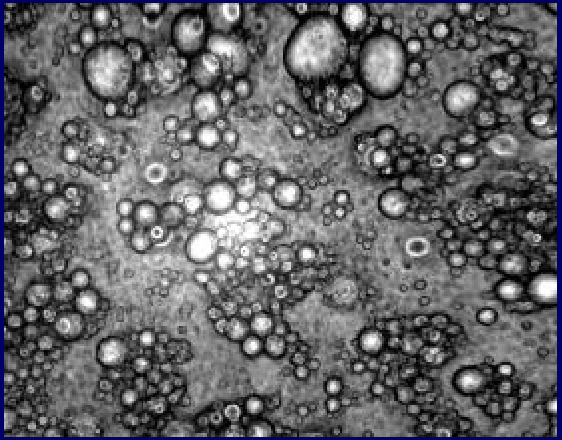
$K = 10^{-5}$ cm/s

Making Emulsions with Little Droplets


Blender

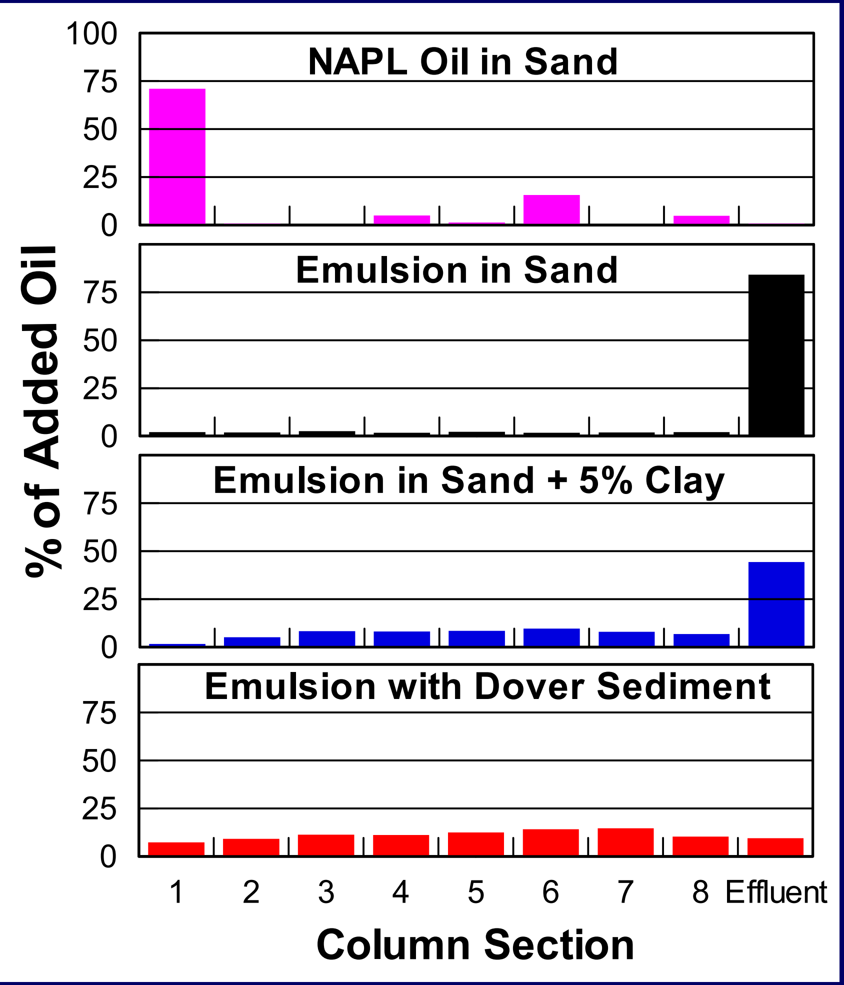

Lab Homogenizer


Dairy Homogenizer


Field Preparation

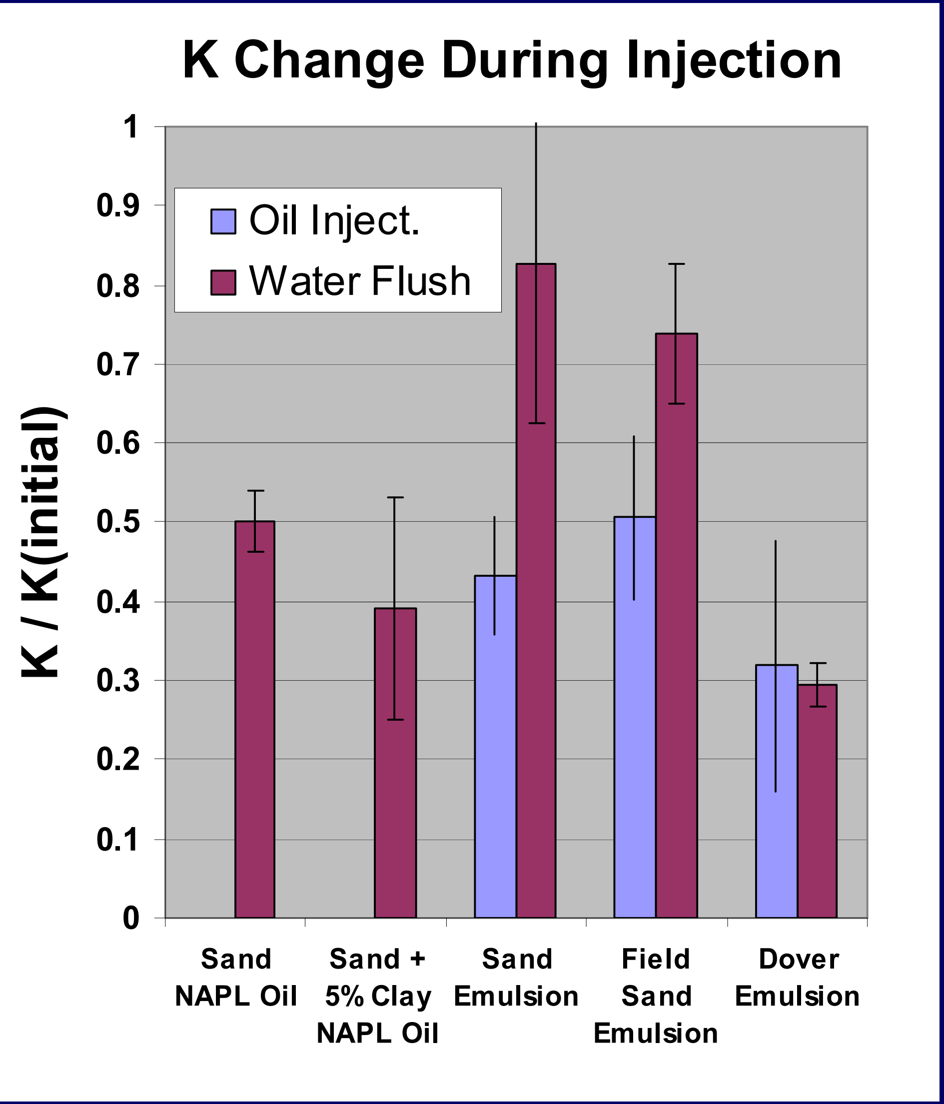
Emulsion Transport in Aquifer Material

- Column tests to evaluate oil transport
- 80 cm long x 2.5 cm dia.
- Inject 0.05 PV oil
- Chase with 3 PV water
- Sediment
  - Sand
  - Sand & 5% Clay
  - Dover AFB Sediment ($K = 4 \times 10^{-4}$ cm/s)
- Treatments
  - NAPL Soybean Oil
  - Emulsified Soybean Oil



Permeability Loss

- Columns treated with oil then flushed with water
- Sediment
  - Concrete sand ($K_{initial}$ = 0.05 cm/s)
  - Concrete sand + 5% clay ($K_{initial}$ = 0.02 cm/s)
  - Natural field sand ($K_{initial}$ = 0.01 cm/s)
  - Dover sediment ($K_{initial}$ = 0.0005 cm/s)
- Treatments
  - NAPL Soybean Oil
  - Emulsified Soybean Oil



Transport in a 3-D Sandbox

- Radial flow sandbox
  - 1 m x 1 m x 1 m
  - Inject in corner
  - Sample at different depths / distances
  - Core box at end to determine oil distribution
- Treatments
  - Homogeneous sand
  - Layered sands

Transport in a 3-D Sandbox

- Heterogeneous K distribution
- Top
  - field sand + 2.5% clay
- Middle
  - field sand
- Bottom
  - field sand + 5% clay

Transport in a 3-D Sandbox

- Good oil distribution throughout box
- Both high and low K layers
- No density effects

Field Evaluations of EOS™

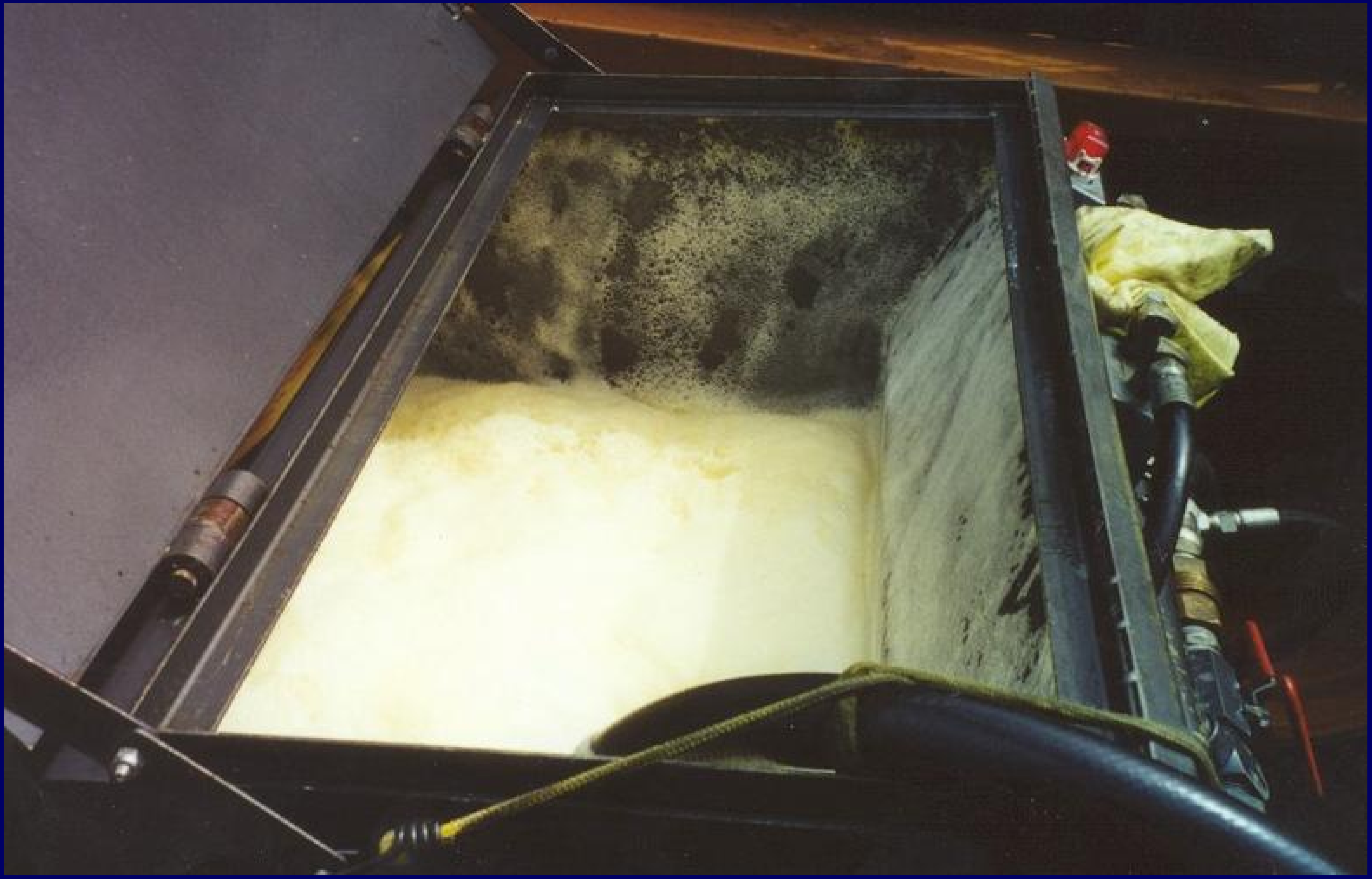
- **Dover AFB, DE – Pilot**
- **Edwards AFB, CA – Pilot**
- **Altus AFB, OK – Pilot**
- **Lumberton, NC – Full Scale**
- **Hamilton, NC – Full Scale**
- **Long Island, NY – Full Scale**

Installing Injection Points

Oil Totes

Field Preparation

Emulsion Preparation

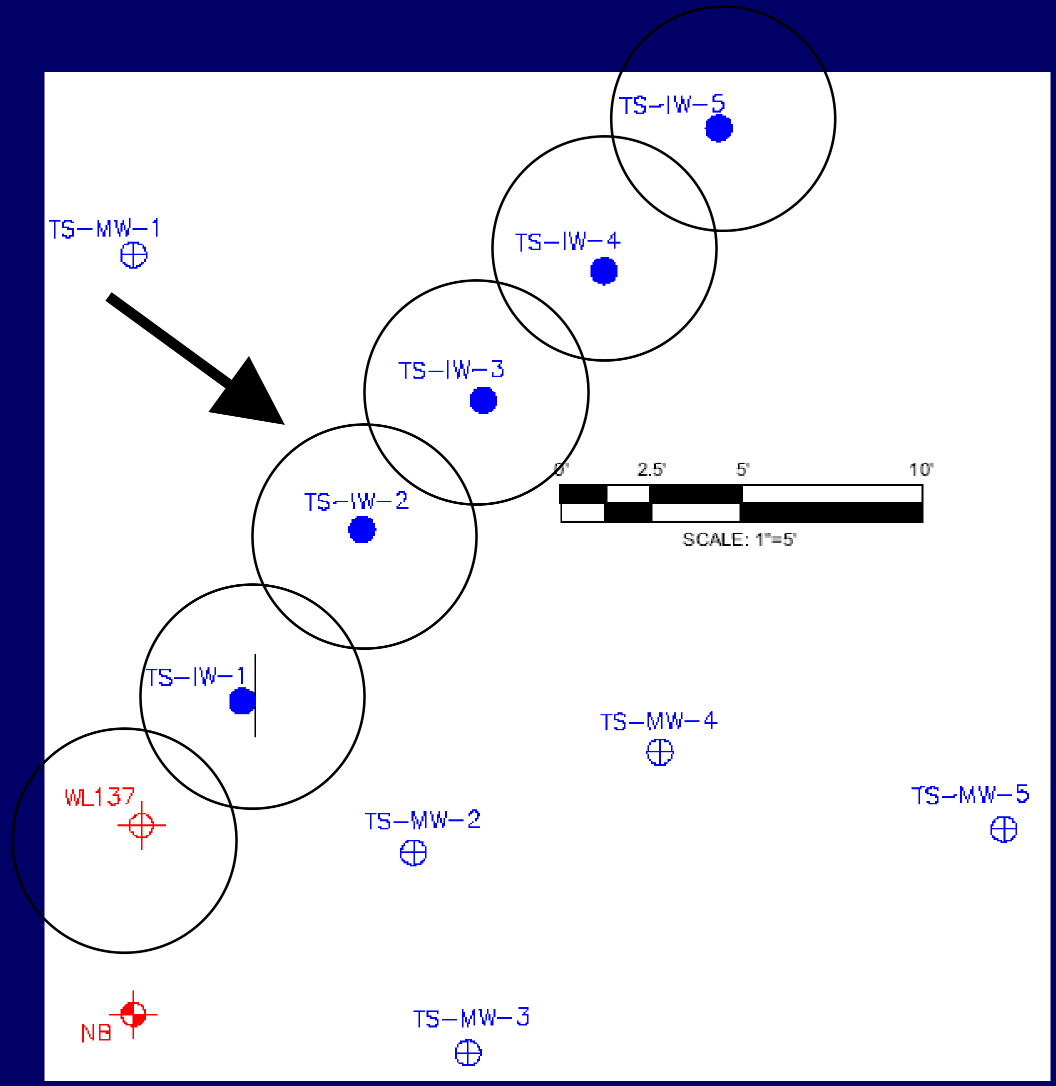


Altus AFB SS-17 Pilot

- SS-17 plume
  - Partial dechlorination of TCE to cDCE and VC
  - Plastic clay overlying weathered/fractured shale
  - Very high SO_4 (up to 2,000 mg/L)
- EOS™ injected into 6 wells
- Monitoring
  - Nov. 01 (pre-injection)
  - Dec. 02 (1 day after EOS™ injection)
  - April 02 (4 months after injection)
  - July 02 (8.5 months after injection)

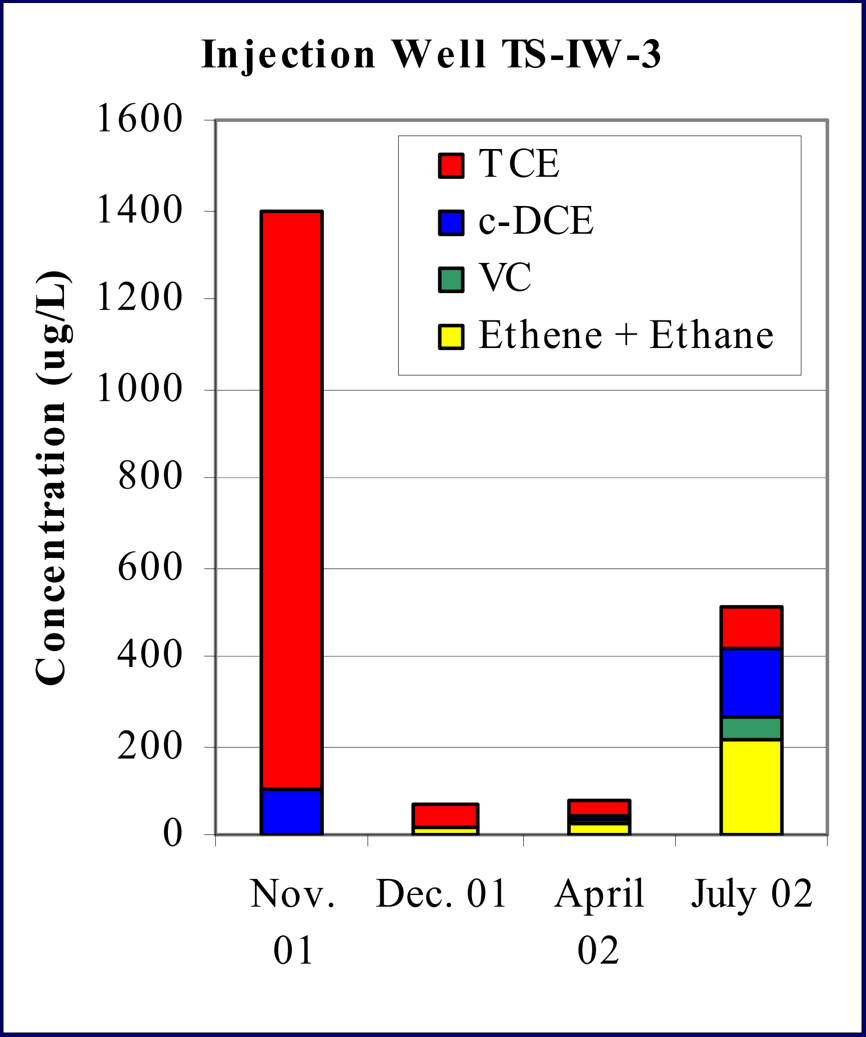
Altus AFB SS-17 Pilot

- Inject wells space 7.5 ft O.C.
- Emulsion distributed 25 ft in high K zone
- Little distribution in low K zone



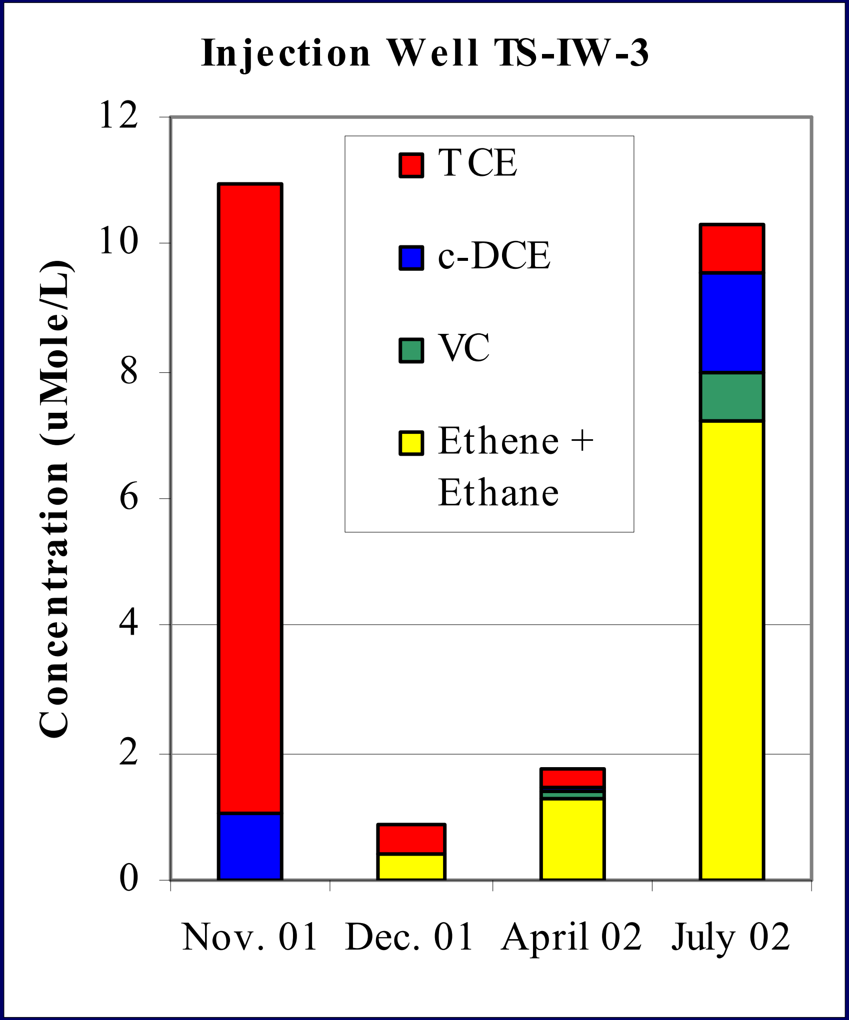
Altus AFB Injection Well 3

- Concentrations in μg/L
- TCE initially sorbs to oil
- Rebound as oil equilibrates with groundwater
- Production of ethene + ethane



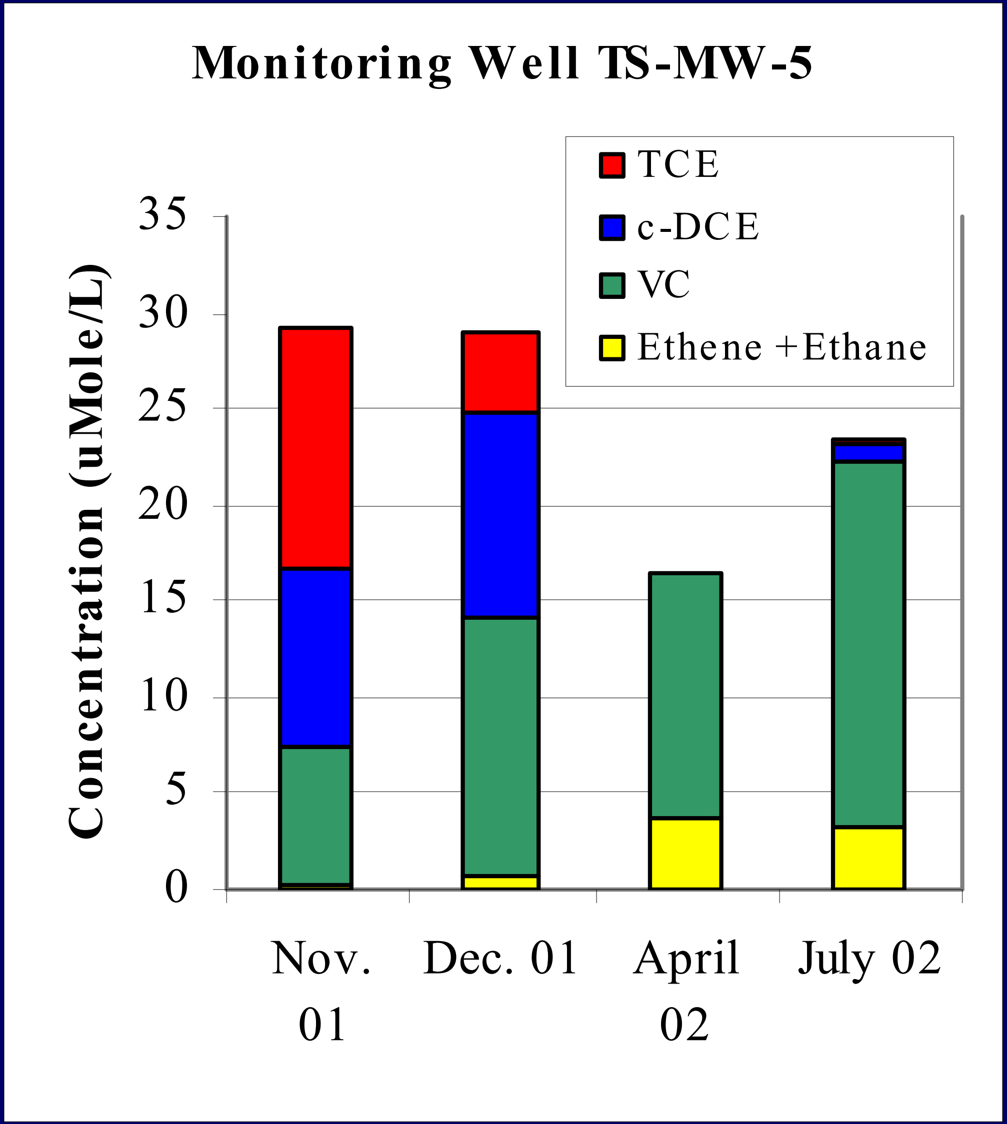
Altus AFB Injection Well 3

- Same data as previous graph – conc. in μMole/L
- By 8.5 months, sorption is not significant
- Total ethenes > 90% of initial
- 93% decline in TCE
- > 70% of initial TCE recovered as ethene + ethane



Altus AFB MW 5

- Monitor Well 5
  - 25 ft downgradient
  - high K zone
  - emulsion reached well
  - TOC above 100 mg/L after 9 months
- TCE is BDL
- VC increase from 440 to 1185 µg/L



Altus AFB Conclusions

- EOS™ moved at least 25 feet in low K weathered - fractured shale
- EOS™ injection stimulated dechlorination
  - > 90% reduction in TCE
  - Large production of ethene and ethane
  - VC produced. May degrade further downgradient
- High sulfate (500 to 2000 mg/L) not major a problem

Benefit – Lower Lifecycle Costs

- 30 yr Net Present Value (Quinton et al.)
- 600 ft wide x 80 ft deep
- Every 5 yr
  - 25% engineering
  - Reinject oil
  - Replace 25% of wells
- Monitoring same as iron PRB