Biological Treatment of Residual DNAPL

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President
Regenesis

In Situ Treatment of Groundwater Contaminated with Non-Aqueous Phase Liquids: Fundamentals and Case Studies

EPA TIO, EPA Region 5, ITRC

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DNAPL as a Source of Contamination

- DNAPLs—Dense Non-Aqueous Phase Liquids
  - DNAPL sinks within aquifers to provide a long-term source of contamination
  - DNAPL dissolves into the aqueous phase to directly impact groundwater
- The presence of long-term source in the form of DNAPL (60% of NPL sites) is a major complicating factor in remediation
  - "accessibility" of DNAPL to pump and treat or chemical oxidation systems is limited

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Residual DNAPL

(from: Friedrich Schwille (1988) Dense Chlorinated Solvents in Porous and Fractured Media. Lewis Publishers, Chelsea, MI)

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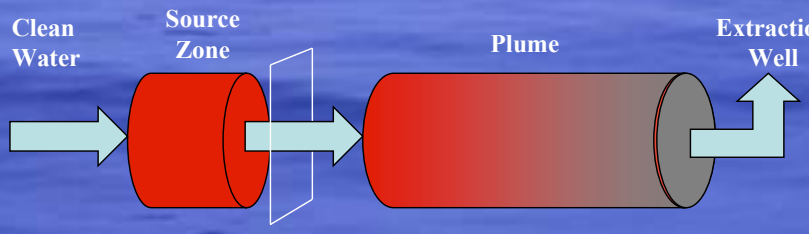
Bioremediation in Source Zones



$$\text{Remediation Time} = \frac{\text{Source Zone Mass}}{\text{Exiting Flux} \bullet (A)}$$

- Exiting Flux Observed is a function
  - velocity, dispersion
  - dissolution rate, partitioning

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DNAPL Bioremediation

- Microbial reductive dechlorination of dissolved phase contaminants increases dissolution and desorption of DNAPL/source zone contamination.
- A recent SERDP/ESTCP workshop identified *in situ* bioremediation as one of the two most promising source-zone treatment technologies (Stroo et al. (2002) article submitted to Env.Sci.&Tech.).
- Soil columns with actively dechlorinating microbes demonstrated 16x the PCE removal of abiotic columns (Cope and Hughes (2001) Env. Sci.&Tech., 35(10) p. 2014).
- Soil columns with biological substrates had 3x the DNAPL dissolution rate as no-substrate columns (Yang and McCarty (2002) Env.Sci.&Tech., 36(15) p. 3400).

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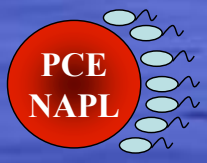
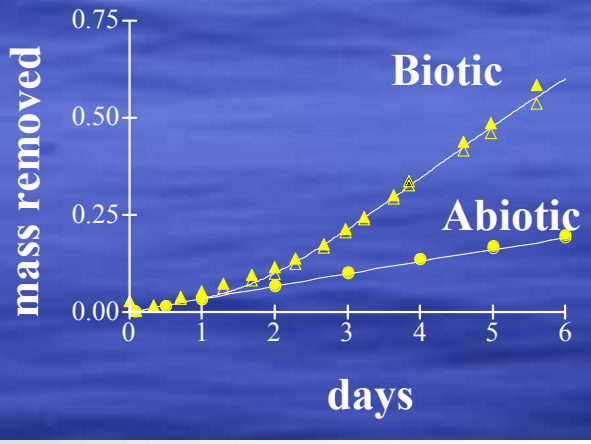
Example of Biologically Enhanced Dissolution





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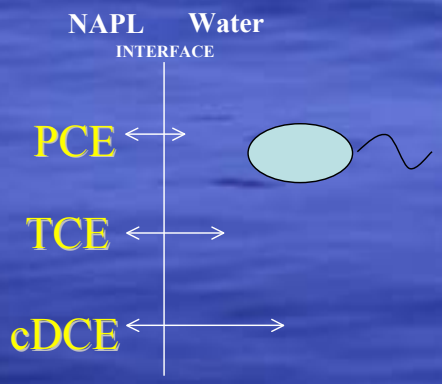
Reductive Dechlorination can Decrease Source Longevity



- Dechlorination produces increasingly hydrophilic pollutants
- At equal mole fractions to PCE:
  - $[TCE]_{aq} = 9 \bullet [PCE]_{aq}$
  - $[DCE]_{aq} = 33 \bullet [PCE]_{aq}$
  - $[VC]_{aq} = 90 \bullet [PCE]_{aq}$
- DNAPL removal rate increased

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HRC and Desorption

A visible drop of TCE (about 0.5 grams) was placed in a flask. Water from a second flask containing soil and HRC was recirculated through the flask containing the pure TCE and its disappearance was monitored.

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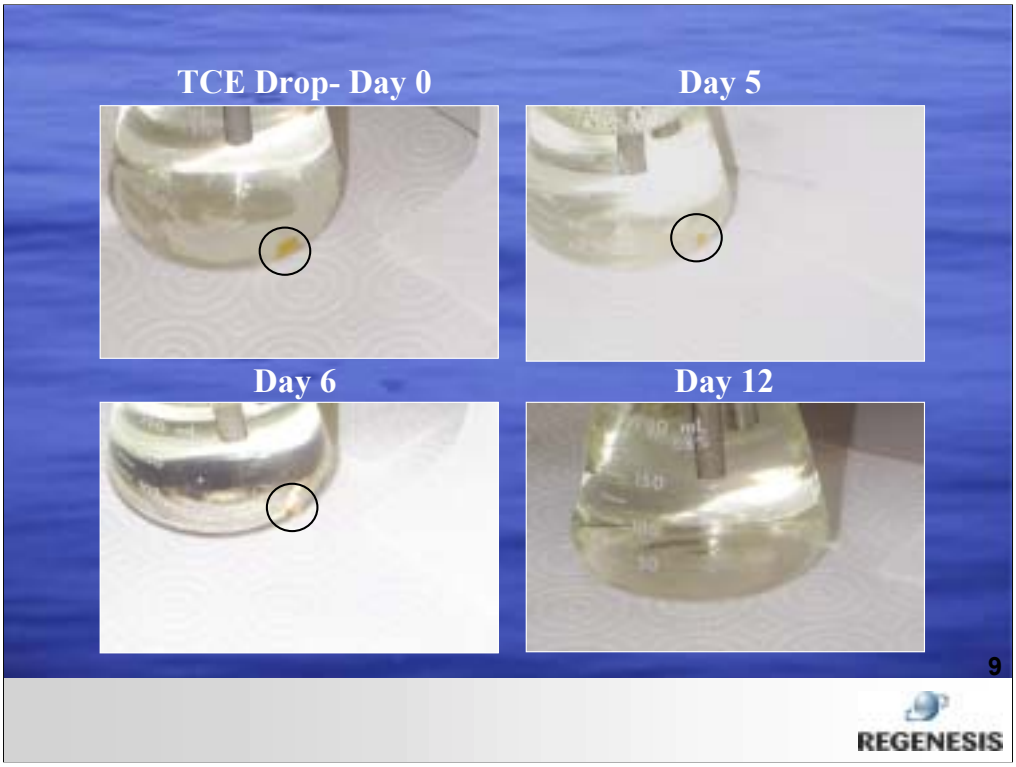
TCE Drop- Day 0
Day 5
Day 6
Day 12
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Experimental Controlled Release System (ECRS)

- ECRS is a simulated aquifer, a controlled field-scale system
- Rectangular experimentation tank (18 ft x 7 ft x 6 ft) packed with sand and fitted with stainless steel piping for sampling
- Controlled water flow (recycle or one-pass)

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ECRS Tank

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Objective and Experimental Details

Evaluate the performance of Hydrogen Release Compound (HRC®) as an electron donor delivery system for source-zone bioremediation

- 1L of PCE NAPL added to ECRS (day 0)
- lactate and acetate added to create initial anaerobic conditions (day 16)
- bioaugmentation (110 L of culture) because ECRS soil had low microbial activity (day 32)
- HRC (80 L) addition for long-term carbon and electron source (day 64)

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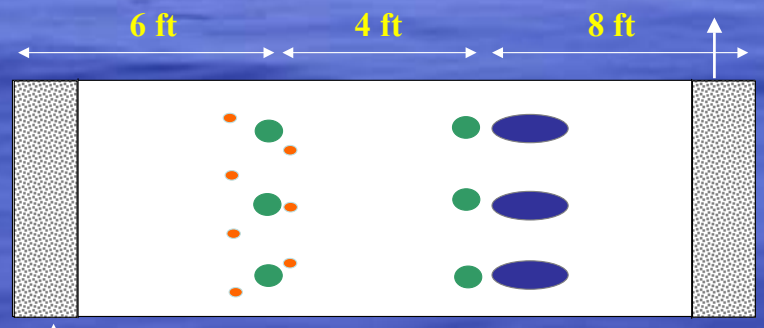
Plan View of ECRS Tank and Injection Points



Inlet

Water Flow

Orange Circles = HRC injection points

Green Circles = Bacteria injection points

Blue Ovals = PCE addition points

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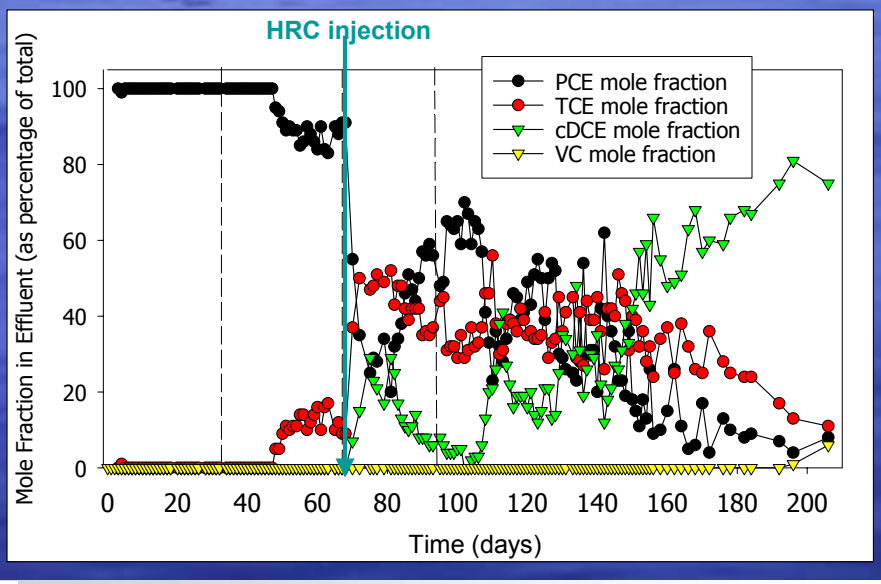
Mole Fractions in Effluent



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Conclusions of ECRS Study

- PCE in the ECRS effluent was reduced by 90% after bioaugmentation and HRC addition.
- Further results (unpublished) indicate that HRC application in conjunction with bioaugmentation was the driver for removing greater than 90% of the DNAPL in 240 days.

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HRC® Performance in Tight Clays – Cookeville, TN

- HRC chosen as effective remediation technology with cost-saving benefits
- Goal was to degrade high concentrations of dissolved PCE and TCE in the presence of residual DNAPL at a tight clay site.
- Other motivations included: no interruption to facility operations, no lengthy maintenance and operations, and no construction of unsightly/obtrusive remedial systems

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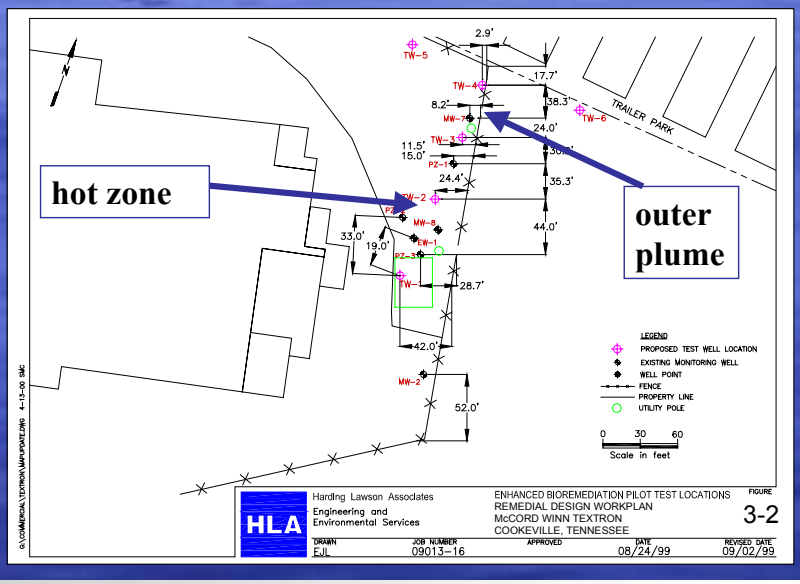
Well Locations and Site Map



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HRC warming before injection

HRC

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HRC Field Application

HRC is a viscous, injectable substance.

HRC is injected into the aquifer using direct-push technologies.

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Results and Conclusions

- PCE at 110 mg/L and TCE as high as 200 mg/L were reduced, on average, 92%
- Daughter products such as cisDCE and VC have been detected and are decreasing with time
- Contaminant profiles (high concentrations of daughter products vs. PCE) suggest DNAPL is present
- The total mass of VOCs has been reduced > 86%
- A final injection of HRC is being considered for September 2002, site closure is expected in 2003

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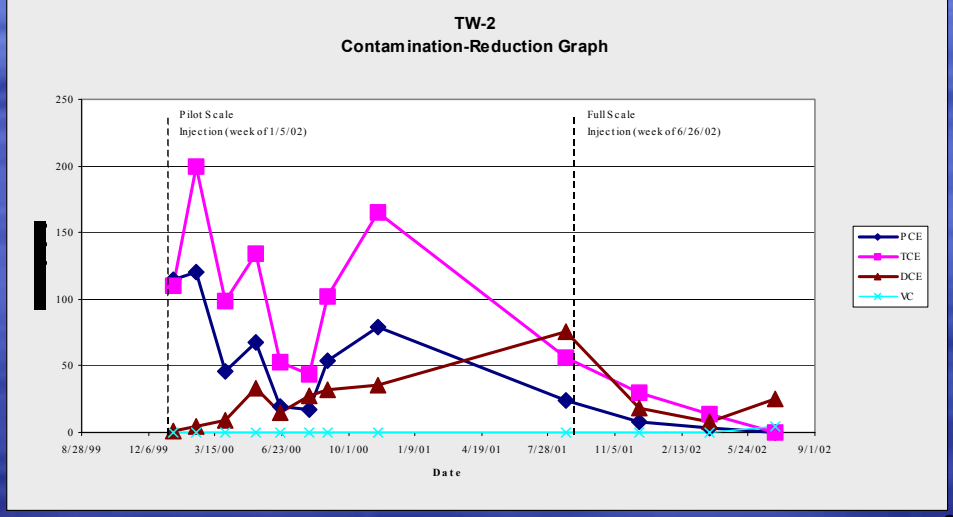
Well TW-2 in Source Area



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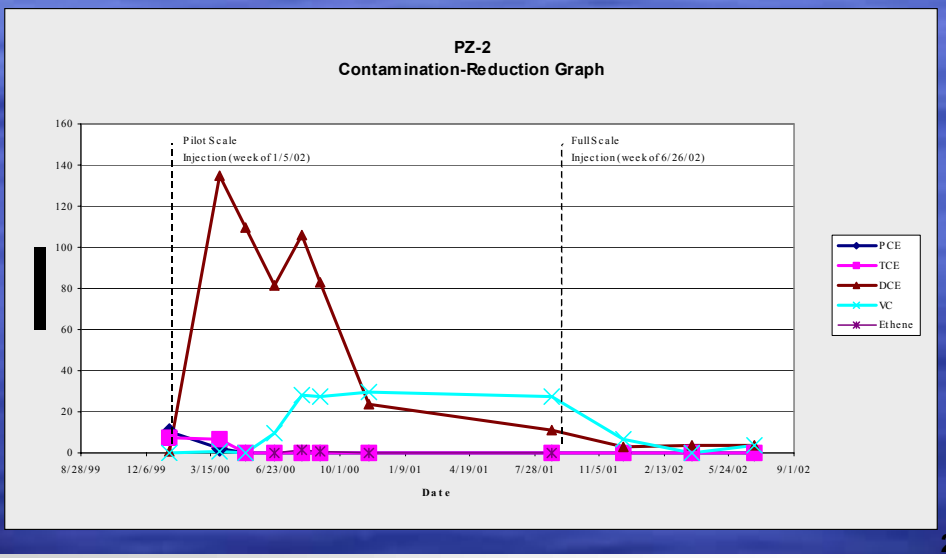
Well PZ-2 in Source Area



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Oregon Department of Environmental Quality

Contact: Kevin Parrett

Springdale Cleaners, Portland, OR

- Part of the State of Oregon Orphan Program
- PCE and daughter products present in groundwater
- Potential DNAPL and associated dissolved phase plume present
- Treated by accelerated natural attenuation with HRC-X™ and HRC®

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PCE Plume
Springdale Cleaners
SW Capital Hwy
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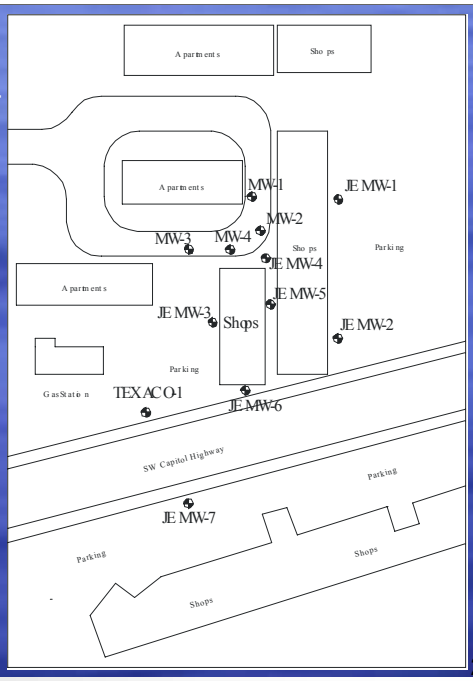
Aquifer Characteristics

- Silty sand aquifer
- Depth to groundwater ranges from 2 - 7 ft bgs
- Groundwater flow direction is to the west
- Utility trench along shopping center causes local flow to the south
- Estimated groundwater velocity is 0.3 ft/day

Contaminant Characteristics

- PCE and daughter products present
- DNAPL likely present with an associated dissolved phase plume
- PCE ranges up to 120,000 ug/L near source area
- DNAPL adjacent to and beneath the building
- Adjacent utility trench appears to be conduit for DNAPL distribution perpendicular to flow



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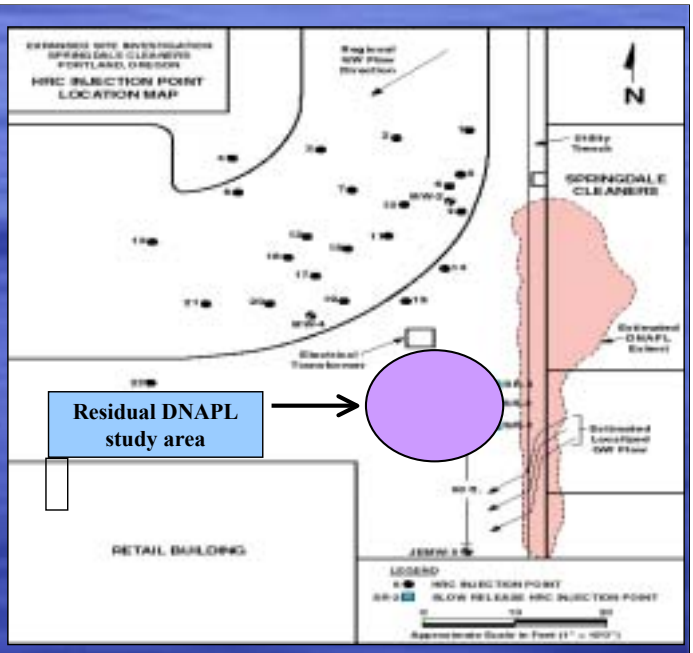
Site Map

Residual DNAPL Area

- Barrier application over 250 ft^2
- 700 lb HRC-X™ (200,000 cP)
- PCE up to 120,000 ug/L
- Depth to water = 2 – 4.5 ft bgs
- Monitored JEMW-4 and JEMW-5



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HRC-X™

- HRC-X is an extended release form of HRC that is used for treatment of residual DNAPL and source areas
- HRC-X is a high viscosity HRC (200,000 cP HRC-X vs. 20,000 cP HRC)
- HRC-X is a highly concentrated electron donor source with extreme longevity in the subsurface (3+ years)

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HRC injection

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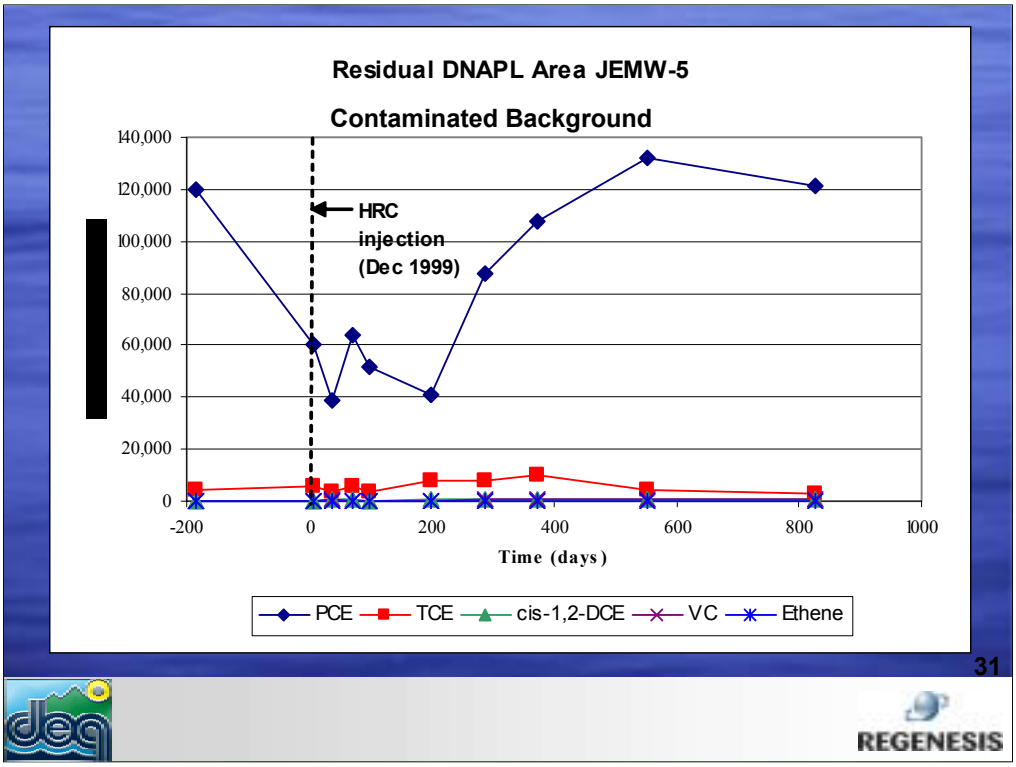
Residual DNAPL Area JEMW-5
Contaminated Background
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
HRC
injection
(Dec 1999)
-200
0
200
400
600
800
1000
Time (days)
PCE
TCE
cis-1,2-DCE
VC
Ethene
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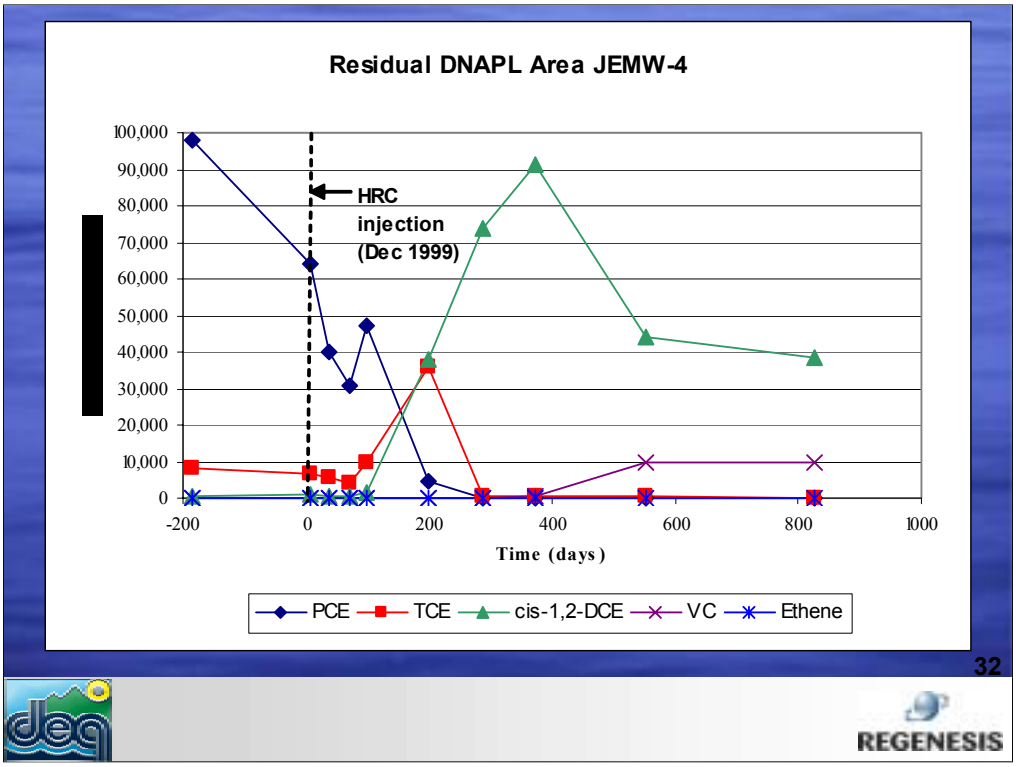
Residual DNAPL Area JEMW-4
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-200
0
200
400
600
800
1000
HRC
injection
(Dec 1999)
Time (days)
PCE
TCE
cis-1,2-DCE
VC
Ethene
32
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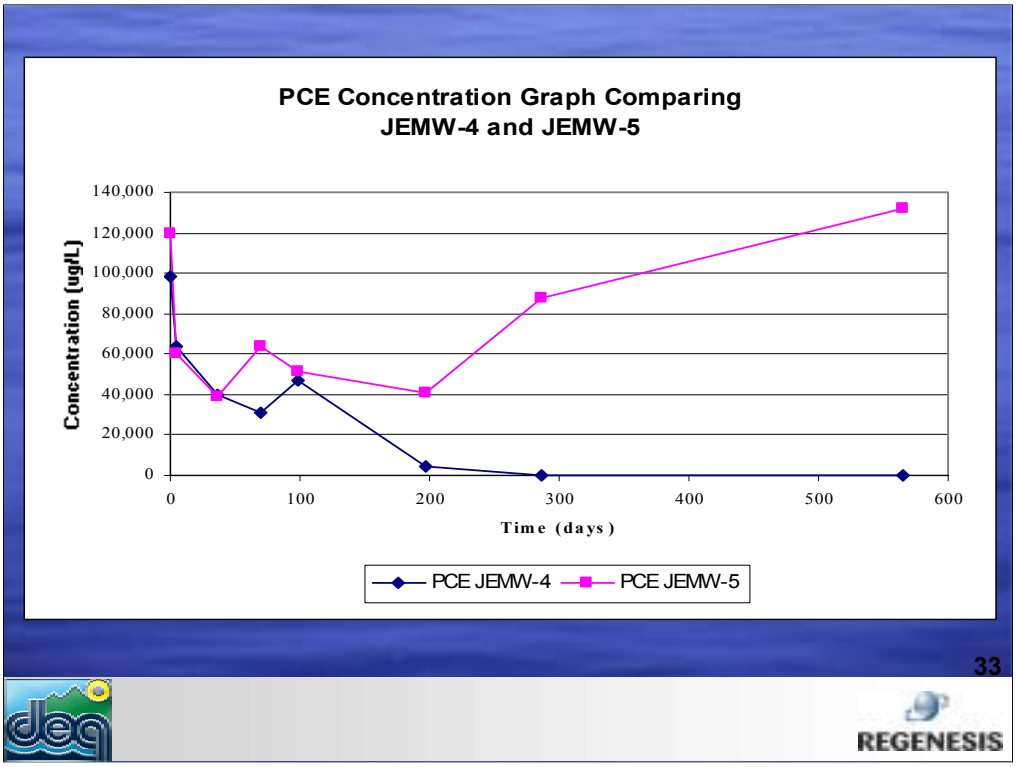
PCE Concentration Graph Comparing
JEMW-4 and JEMW-5
Concentration (ug/L)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
100
200
300
400
500
600
Time (days)
PCE JEMW-4
PCE JEMW-5
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Summary of Results for Springdale Site

- After 1.5 years, HRC-X™ reduced PCE mass by over 99% in both the residual DNAPL area and the dissolved phase plume.
- Project was very low cost: <$20,000 in HRC and about 3 days direct push application (includes cost of treating dissolved-phase plume)

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Conclusions

- Biodegradation can be used to accelerate and enhance residual DNAPL/source zone remediation
- HRC-X™ is designed to provide the longevity and high concentration electron donor necessary for DNAPL and source zone bioremediation

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