CDM

Recent Progress in Bioremediation of Chlorinated Solvent DNAPL Source Areas

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Acknowledgements

- ESTCP
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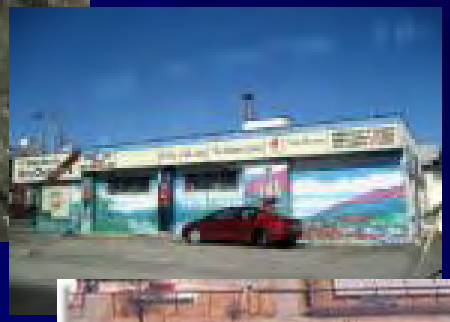
- Fred Payne (Arcadis)
- Elizabeth Edwards (University of Toronto)

Presentation Outline

- Introduction
- Mechanisms of enhanced mass transfer
- Data from selected field sites
- ITRC activities and resources

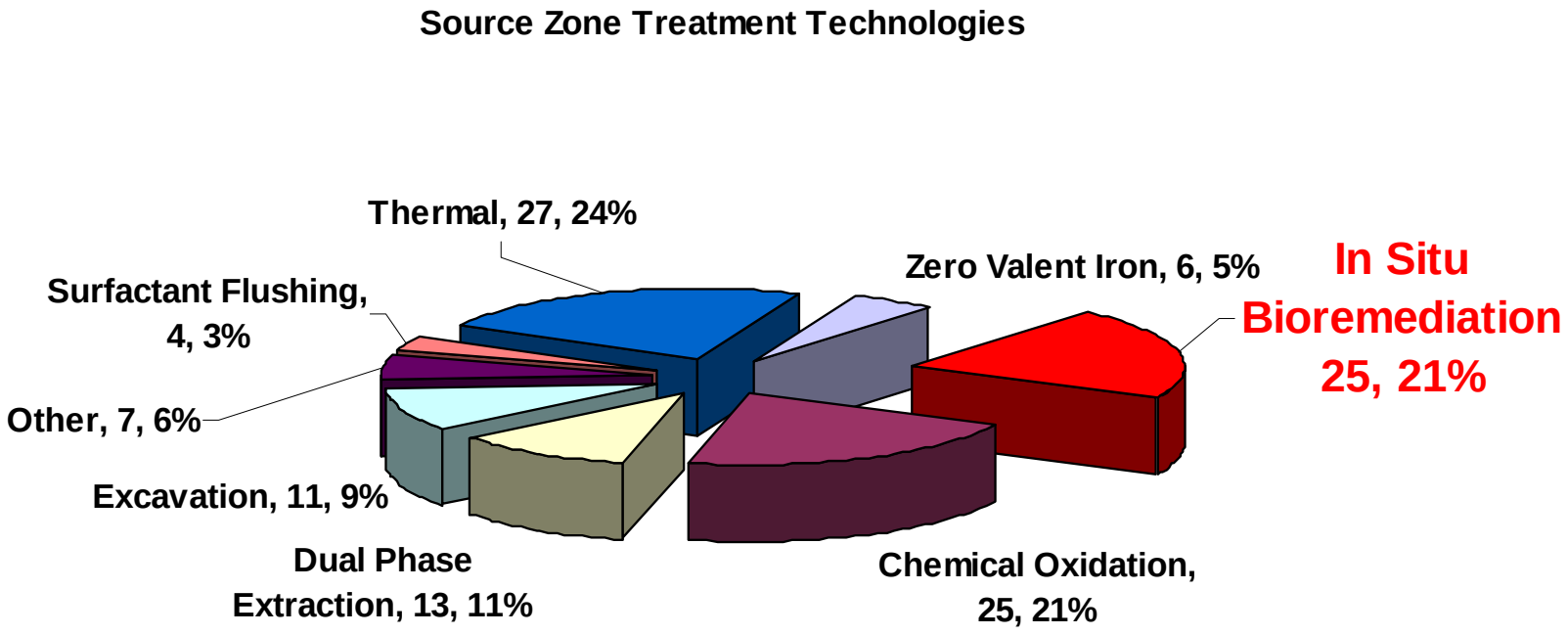
Why ISB at DNAPL Source Zones?

- Problem
  - **Over 10,000 DNAPL Sites**
  - **Sites in every state**
  - **High risk**
  - **100's of years to clean-up**
  - **Very few effective source zone clean-up technologies**
- Solution
  - ***In Situ* Bioremediation of Chlorinated Ethene DNAPL Source Zones**



Other Source Zone Technologies

(Geosyntec study for the Navy, 2005)



What to Expect of ISB at DNAPL Source Zones

- Destroys contaminant mass *in situ* i.e. less secondary wastes
- Expected to shorten the overall longevity of remediation of a DNAPL contaminated site
- Increase the rate of desorption and dissolution
- May treat mixed organic contaminants

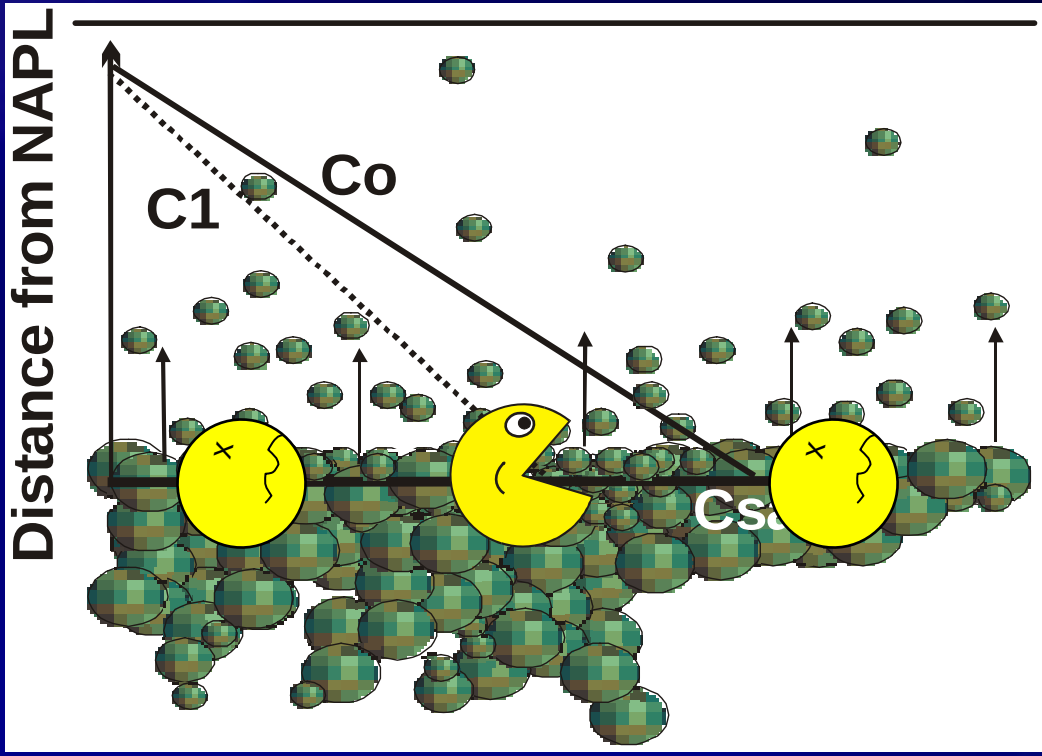
- Low maintenance
- Lower start-up cost than other source zone treatment technologies.
- The impact of BioDNAPL treatment on source longevity and restoration time frames is uncertain

A Paradigm Shift

- Conventional applications for in situ bioremediation limited to dissolved phase for two primary reasons:
  - Concerns about toxicity
  - Impact on nonaqueous sources thought to be no better than pump and treat
- New research reveals that <u>in situ bioremediation may be extremely effective for chlorinated solvent source areas</u>

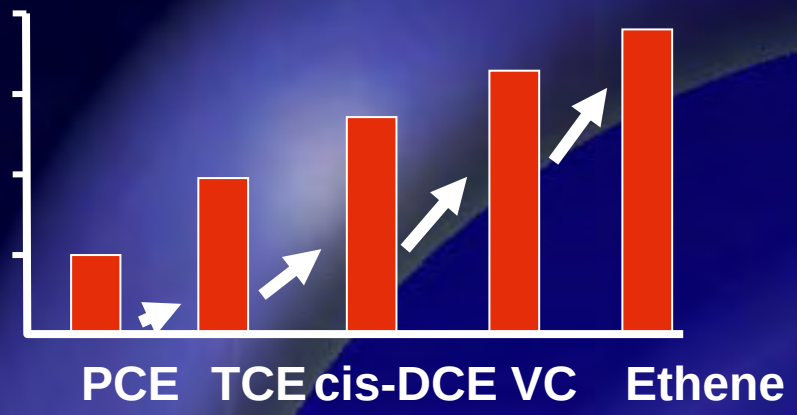
The Toxicity Issue

- Many investigators have shown that dechlorinating bacteria actually have an ecological niche in high concentration areas
- Toxicity of DCE might be a concern if formed at high enough concentrations



Mechanisms of Enhanced Mass Transfer

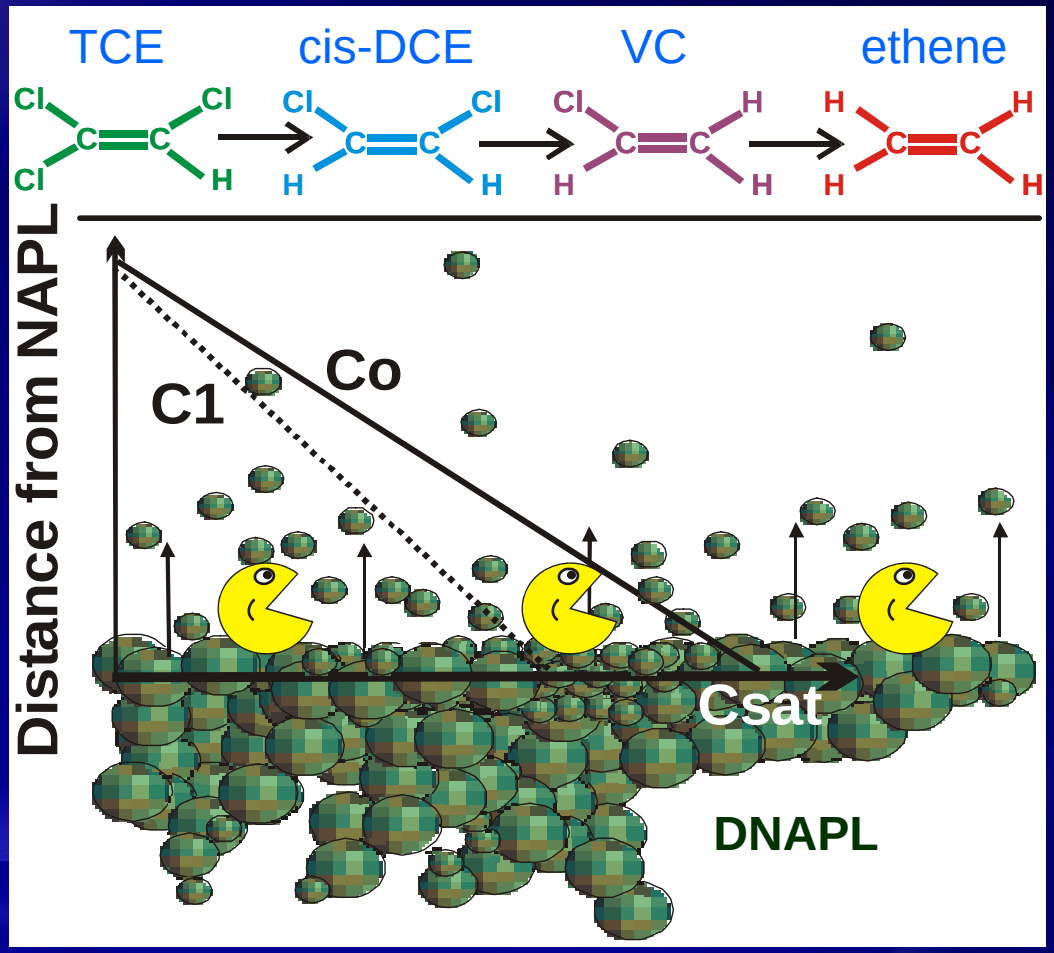
1. Bioremediation of dissolved contaminants increases the driving force for mass transfer = $k(C_s - C)$
2. Increased solubility and decreased hydrophobicity
3. Electron donor solution accelerates dissolution/desorption



Aqueous-phase concentrations when foc = 0.002 (courtesy Arcadis)

Mechanism 2

- Reduced products can have higher Csat and lower hydrophobicity



Mechanism 1

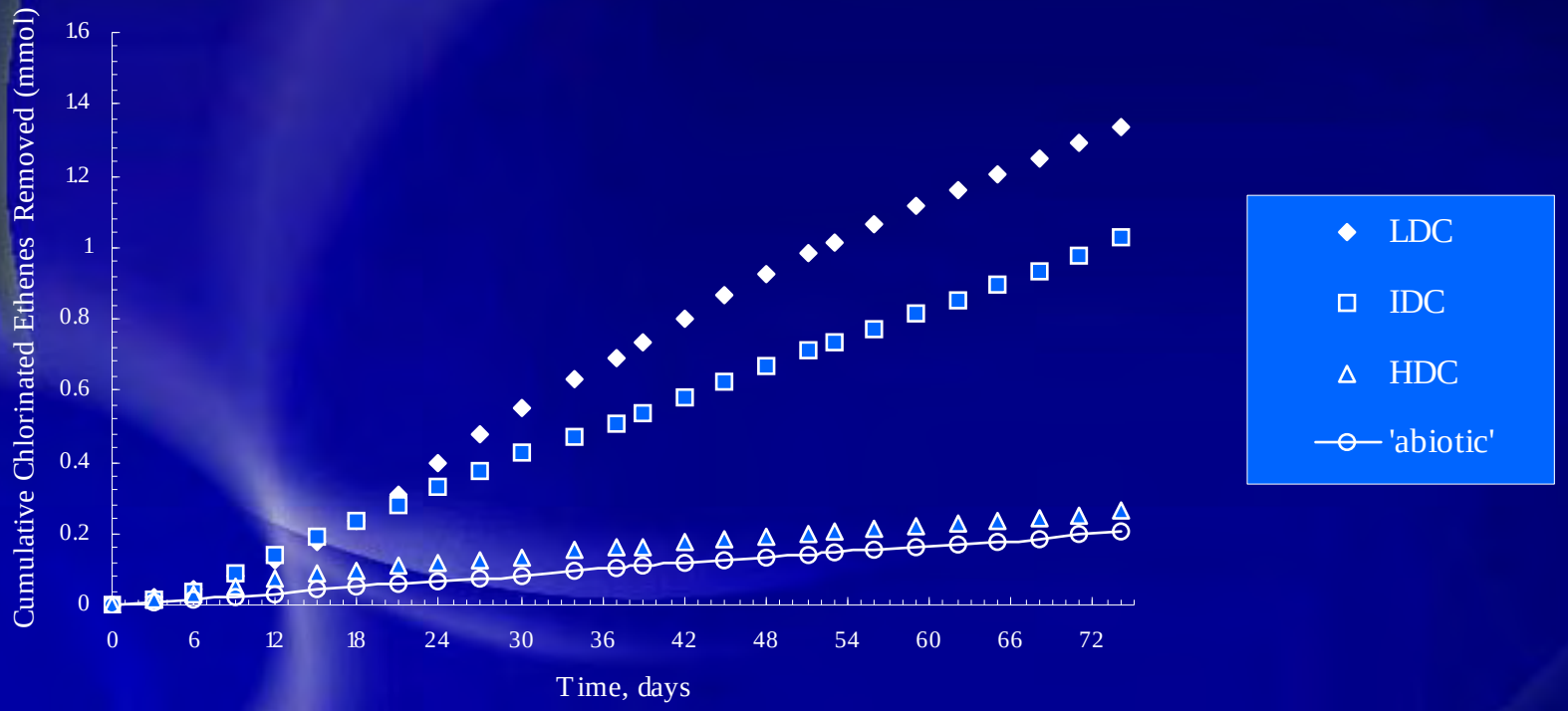
- Biodegradation near the NAPL/ water interface increases the driving force for mass transfer = k(Cs-Co); i.e., k(Cs-C1)>k(Cs-Co)

Enhanced Mass Transfer: Mechanisms 1 and 2

- Demonstrated in laboratory batch studies:
  - Yang and McCarty (2000): enhanced PCE dissolution up to a factor of 5 higher than without reductive dechlorination
  - Carr et al. (2000): reductions in NAPL longevity of 83% in continuously stirred tank reactors

Enhanced Mass Transfer: Mechanisms 1 and 2

- Demonstrated in laboratory column study:
  - Cope and Hughes (2001): PCE removal 16 times faster and total chlorinated ethene removal 5 to 6.5 times faster with reductive dechlorination



Enhanced Mass Transfer: Mechanisms 1 and 2

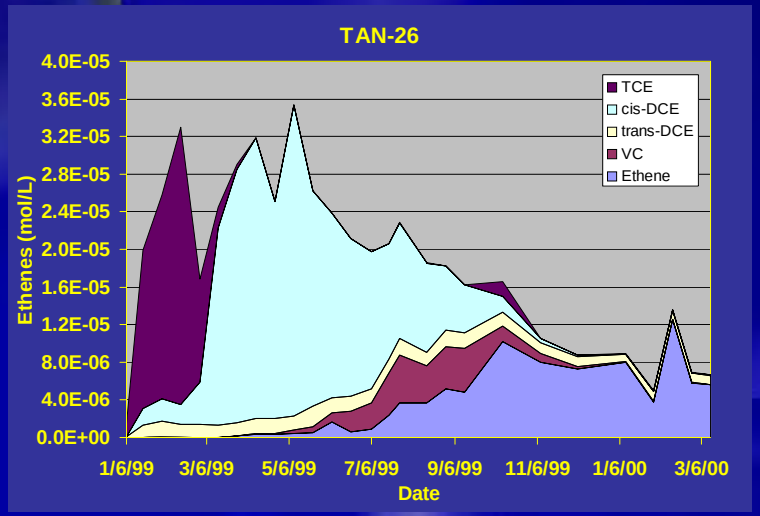
- Demonstrated in laboratory "box" study:
  - Edwards et al. (2006): Chloroethene molar flux increased by a factor of ~2 during dechlorination

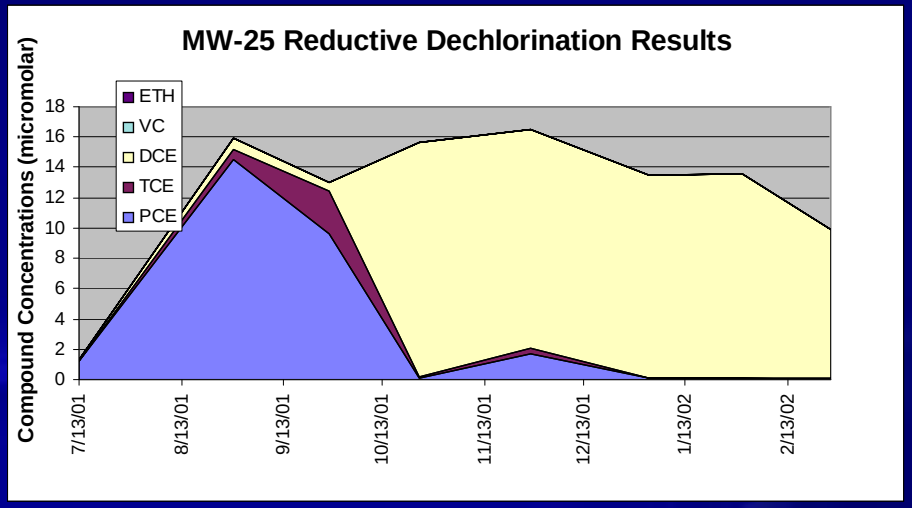
courtesy Geosyntec Consultants/University of Toronto

$$E \approx 2$$

Enhanced Mass Transfer: Mechanism 3

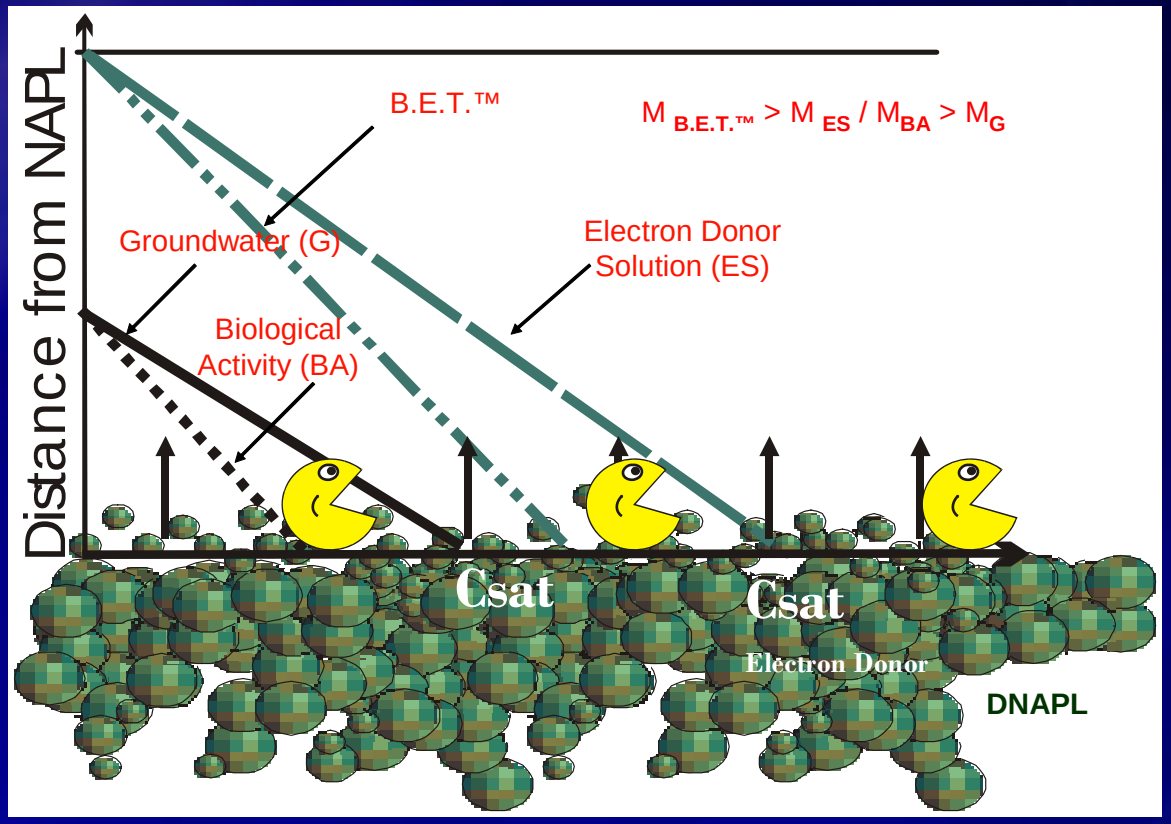
- Sorenson (2000, 2002) showed that TCE concentrations were greatly increased associated with the electron donor solution (concentrated sodium lactate)
- Similar trends were observed for PCE at a Navy site
- Patented process is referred to as Bioavailability Enhancement Technology™, or B.E.T.™





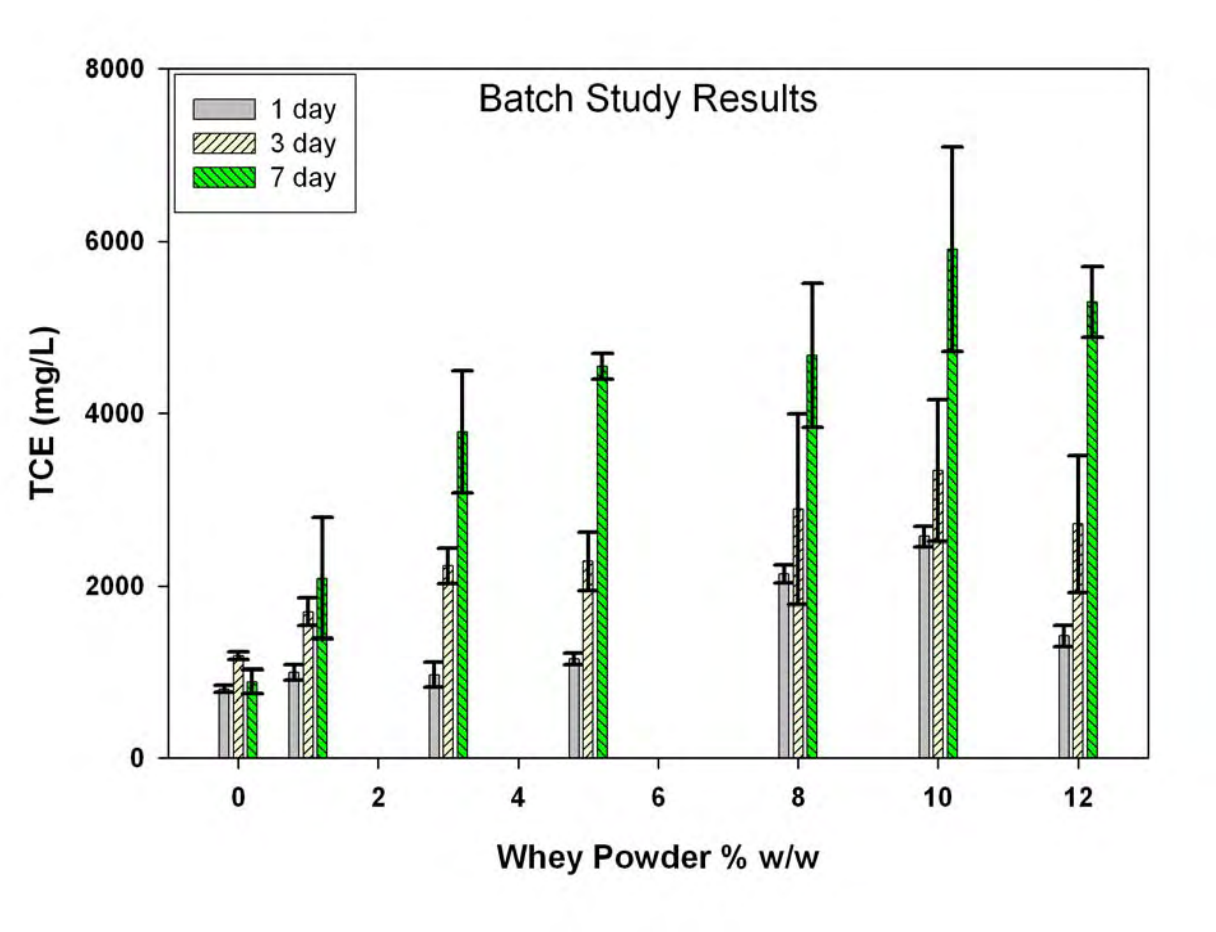
Mechanism 3

- Some electron donor solutions abiotically increase C_{sat}, and may also increase desorption



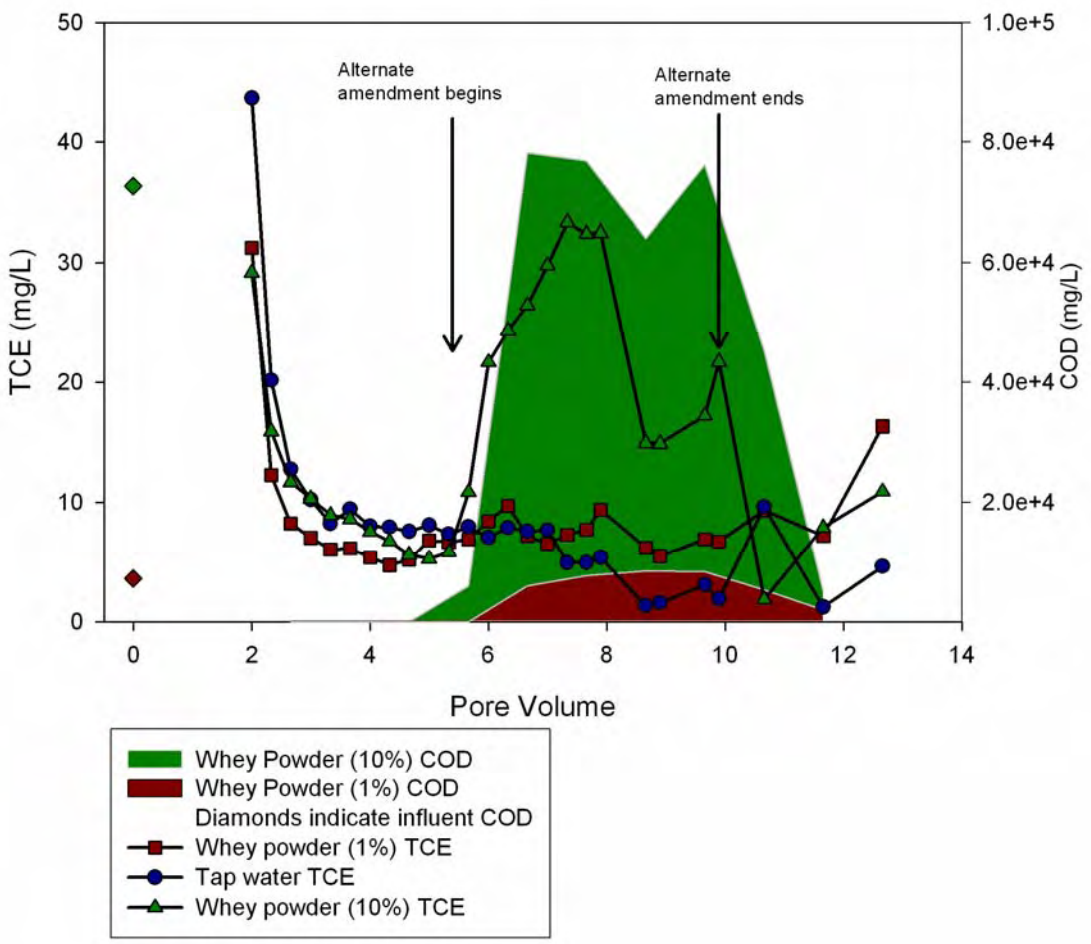
Mechanism 3 – Batch Study with Whey

- **Whey enhanced DNAPL solubility greater than a factor of 5 at high concentrations *(Macbeth et al., 2006)***



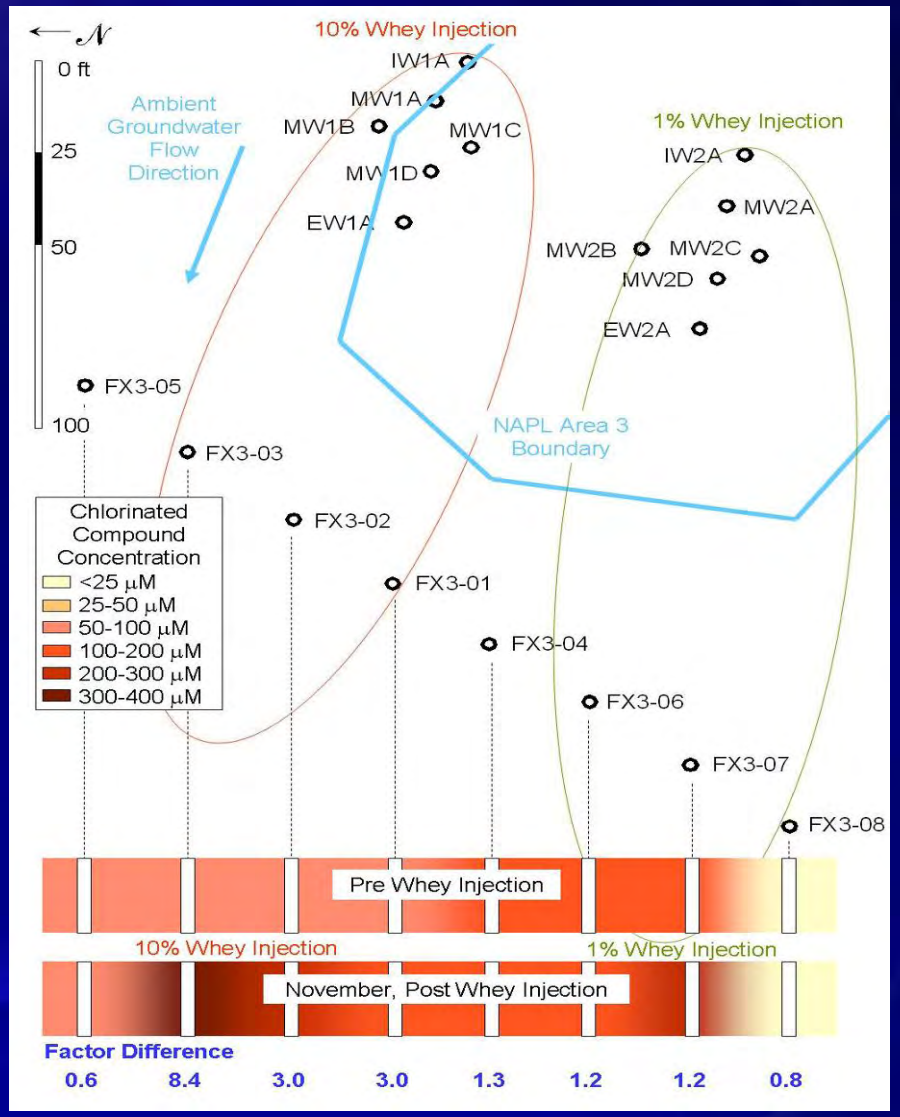
Mechanism 3 – Column Study with Whey

- High concentrations of whey solution increased mass removal by factor of ~6 *(Macbeth et al., 2006)*

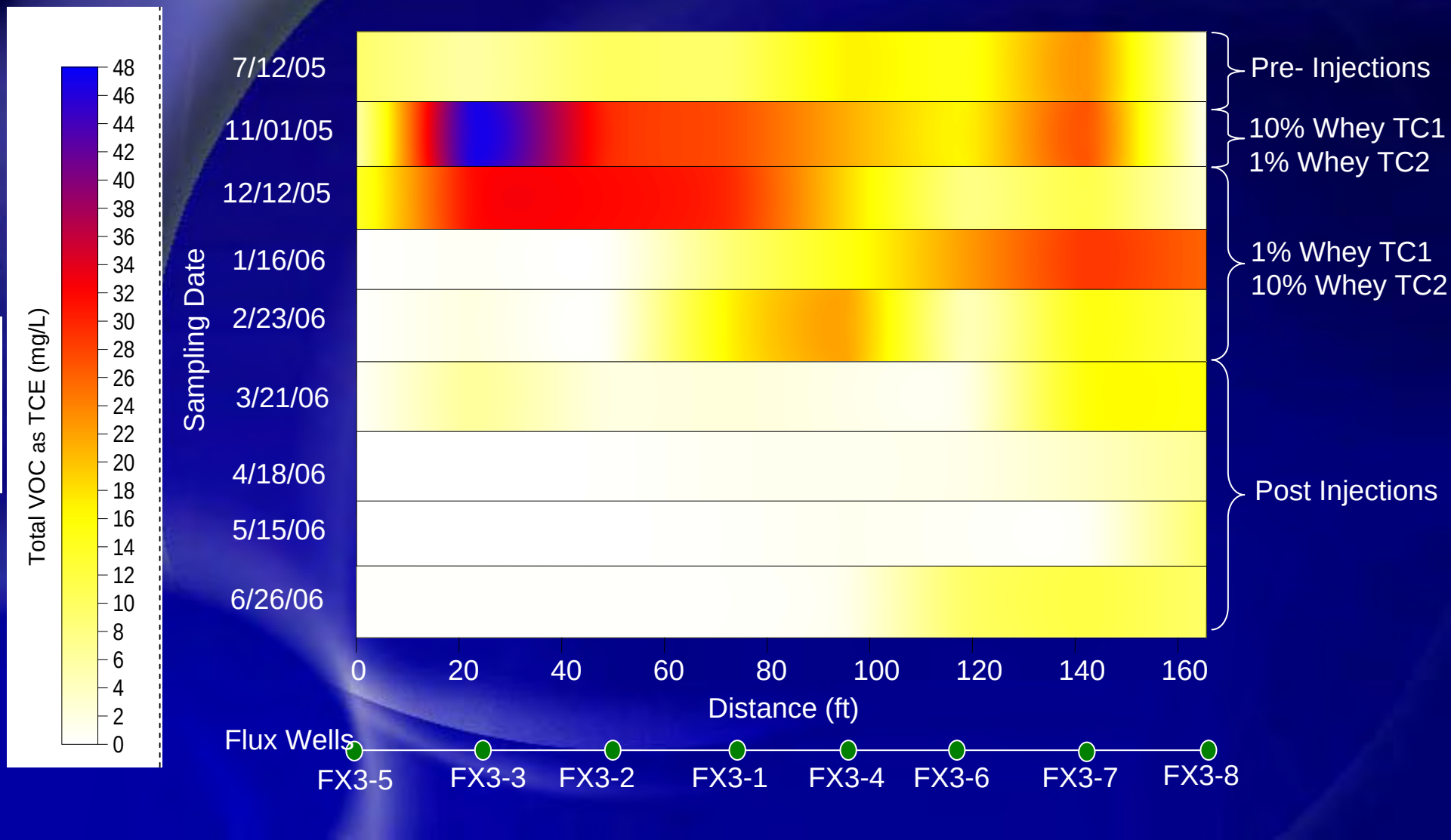


Ft. Lewis ESTCP Demonstration: Downgradient Response

- 8 wells showed downgradient impact of whey injections
- 10% whey injection increases concentrations by factor of 3 - 8

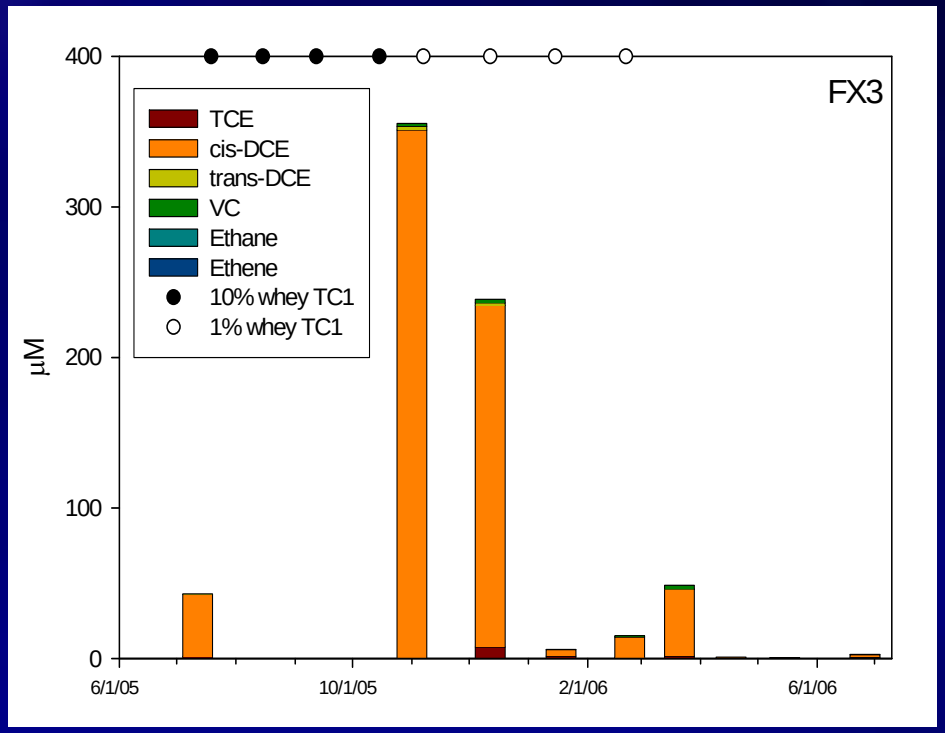


Downgradient "Flux" Results (cont/)



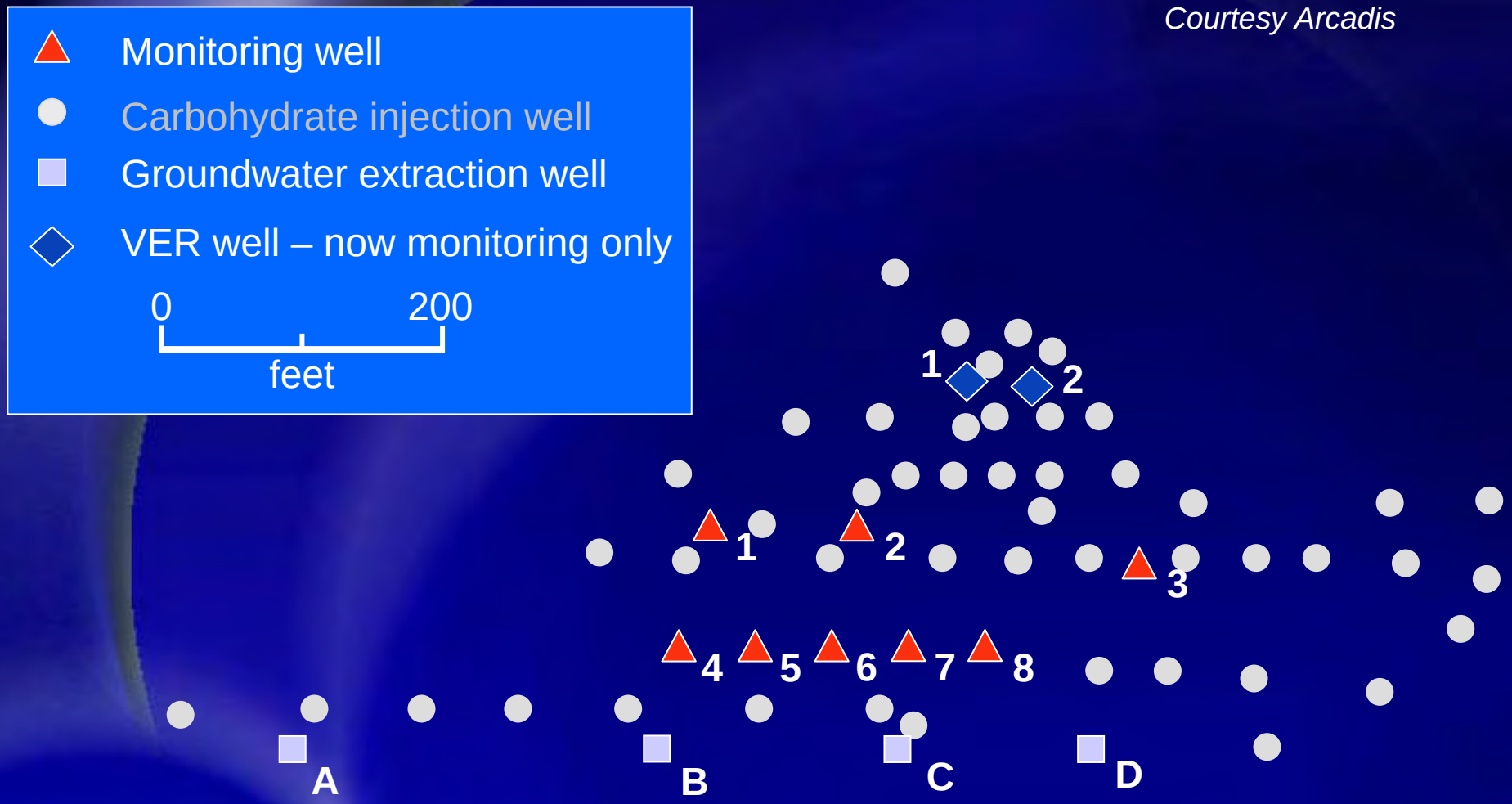
Some Conclusions of Ft. Lewis Project

- Factor of 5-6 increase in aqueous contaminant loading in the lab appears to be achieved in the field
- Extent of increase appears to be a function of the quantity of nonaqueous mass present
- ~90% decrease in downgradient aqueous contaminant loading >4 months later



More Field Data – Related case study 1

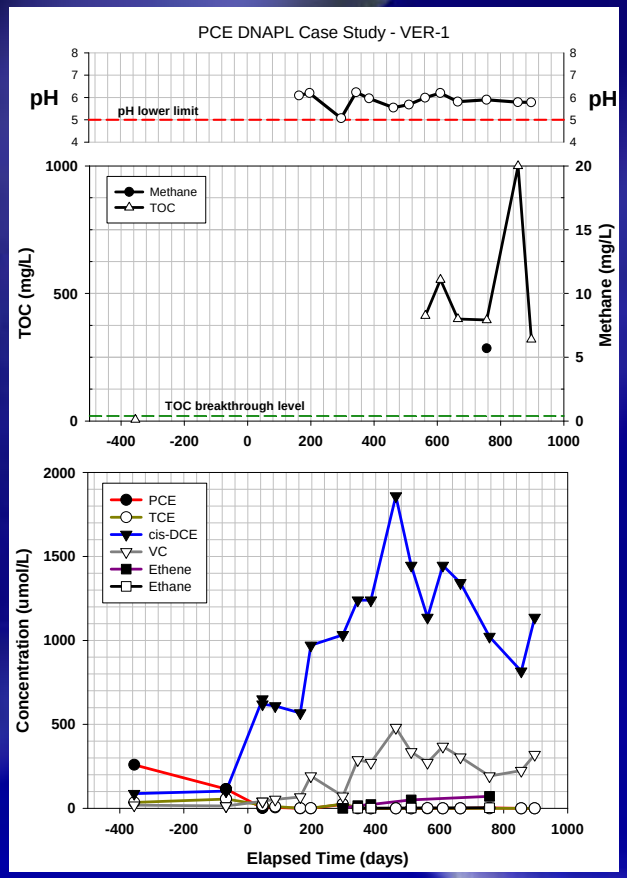
Courtesy Arcadis



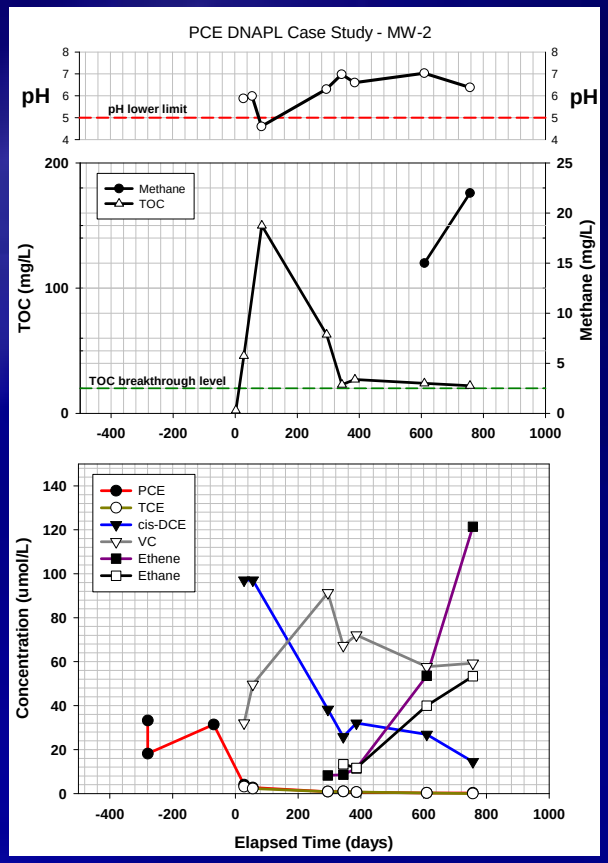
Extraction, VER and monitoring well locations

More Field Data – Related case study 1

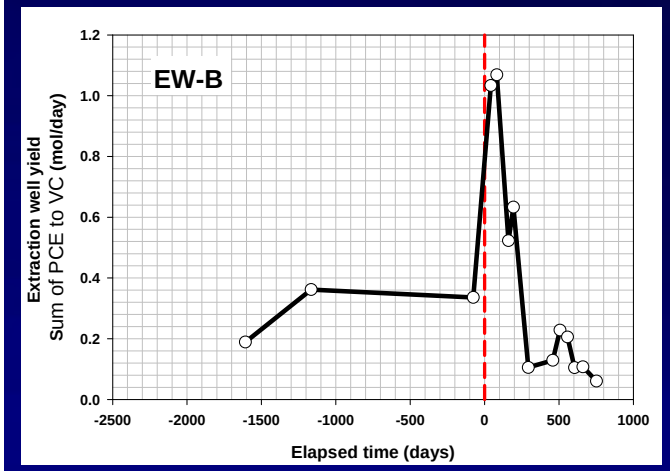
Source Zone



Intermediate Plume



Downgradient Extraction



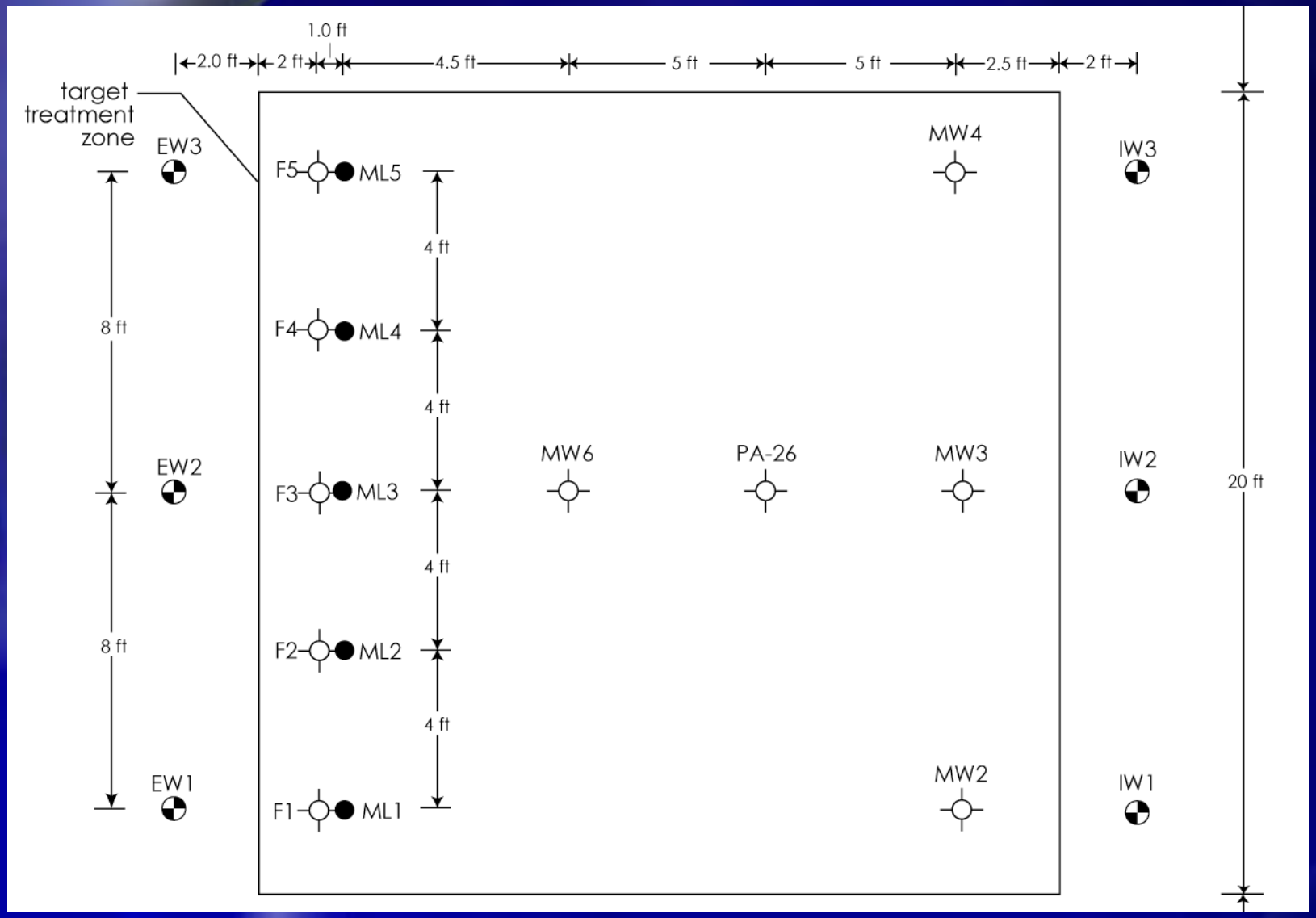
Courtesy Arcadis

5-6X mass transfer

Complete Dechlorination

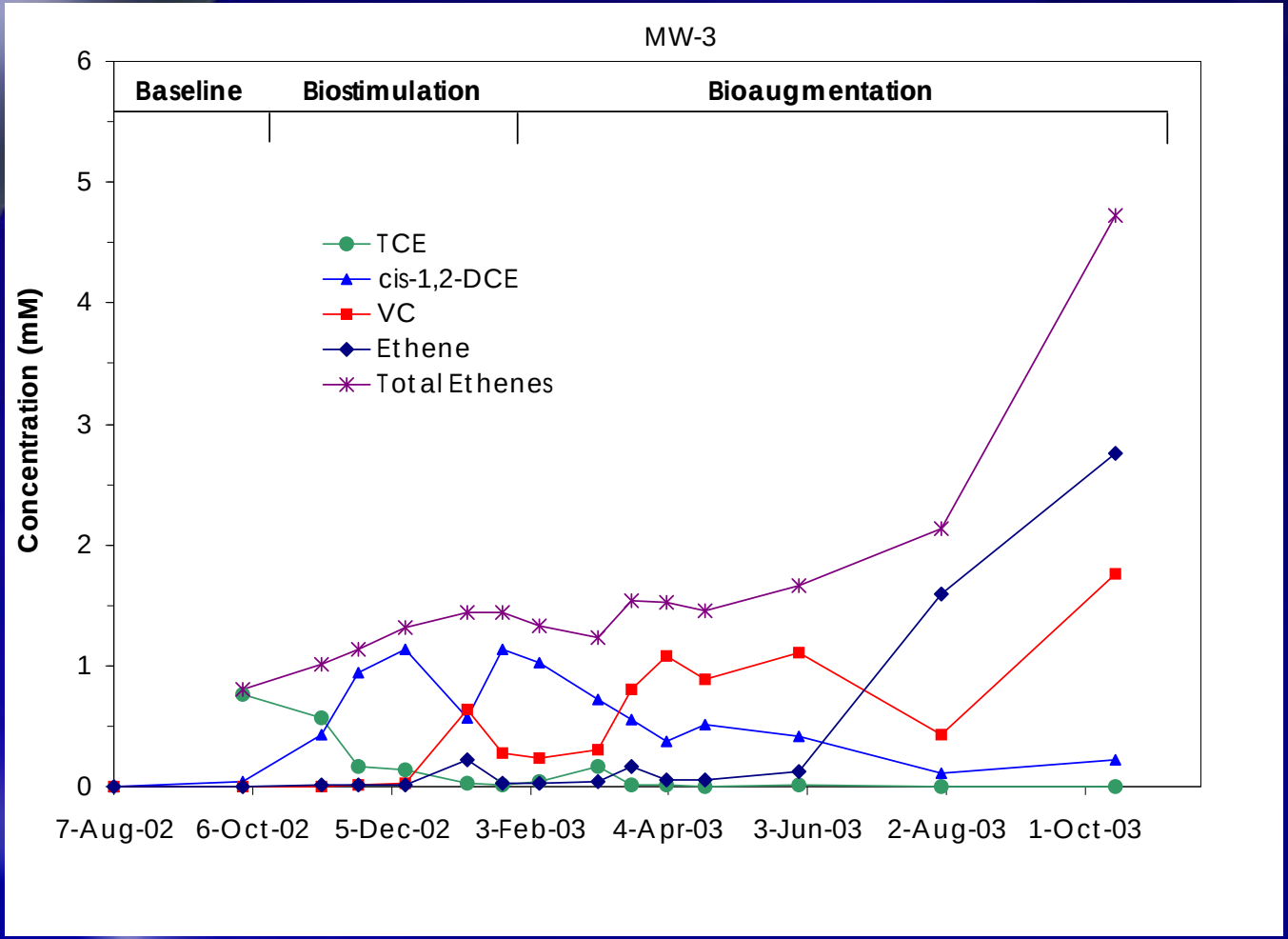
Downgradient Decrease in Mass Flux

More Field Data – Related case study 2



Courtesy Geosyntec

More Field Data – Related case study 2



Courtesy Geosyntec

- **4-5X Increase in aqueous contaminant loading**

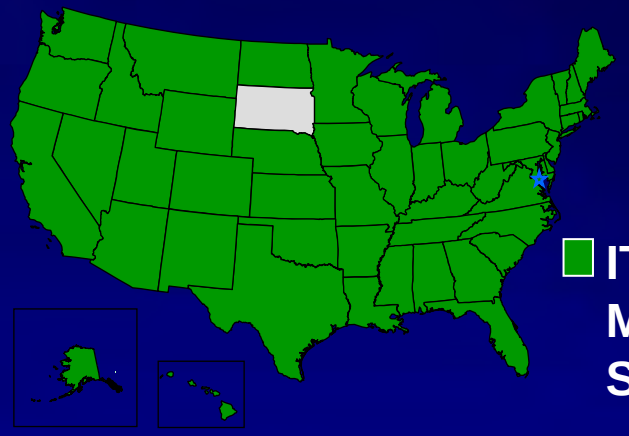
ITRC (www.itrcweb.org) – Shaping the Future of Regulatory Acceptance

- **Network**
  - **State regulators**
  - **Federal government**
  - **Industry**
  - **Consultants**
  - **Academia**
  - **Community stakeholders**
- **Documents**
  - **Technical and regulatory guidance documents**
  - **Technology overviews**
  - **Case studies**
- **Training**
  - **Internet-based**
  - **Classroom**

Host Organization

ECOS

ITRC State Members



ITRC Member States

Federal Partners

DOE **DOD** **EPA**

ITRC Industry Affiliates Program

IAP

BioDNAPL Team

- Formed in 2004 with a focus primarily on chlorinated ethenes
- Resources currently available
  - "Overview of In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones" (October 2005)
  - Resource Guide (April 2007)
  - "In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones: Case Studies" (April 2007)
- Products currently in development
  - "Technical and Regulatory Guidance for In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones" (June 2008)
  - Internet training seminars based on Tech/Reg document (mid-late 2008)

ITRC DNAPL-related products

Technical and Regulatory Guidance; Integrated DNAPL Source Zone Strategy

Technical and Regulatory Guidance; In situ Bioremediation of Chlorinated Ethenes, DNAPL Source Zones

In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones: Case Studies (April 2007)

Overview of In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones (October 2005)

Strategies for Monitoring the Performance of DNAPL Source Zone Remedies (August 2004)

An Introduction to Characterizing Sites Contaminated with DNAPLs (September 2003)

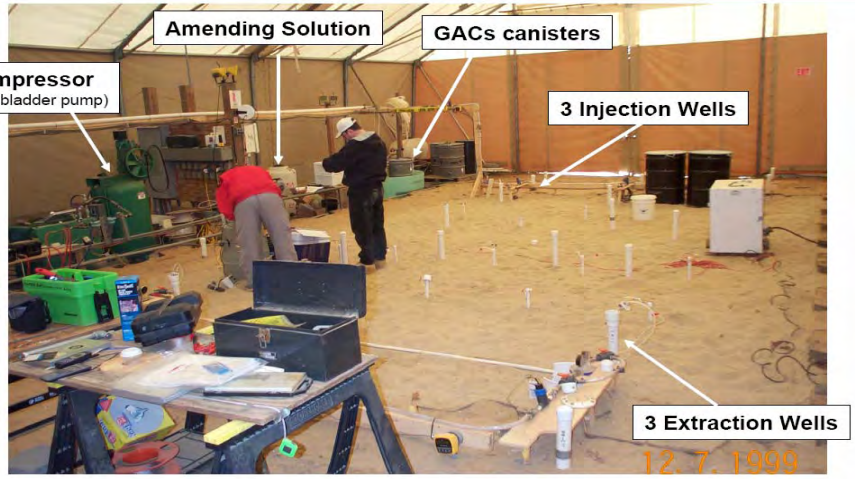
Technical and Regulatory Guidance for Surfactant/ Cosolvent Flushing of DNAPL Source Zones (April 2003)

DNAPL Source Reduction: Facing the Challenge (April 2002)

Dense Non-Aqueous Phase Liquids (DNAPLs): Review of Emerging Characterization and Remediation Technologies (June 2000)

BioDNAPL Case Study Forum

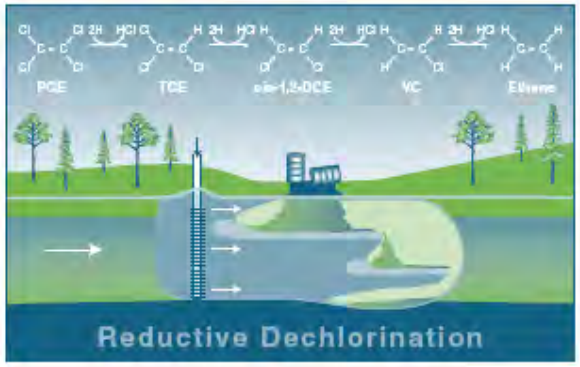
Field Work
Test Cell #1



Test Cell #1 at Dover National Test Site (DNTS) 100L PCE released

Case Study

In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones: Case Studies



April 2007

Prepared by
The Interstate Technology & Regulatory Council
Bioremediation of DNAPLs Team

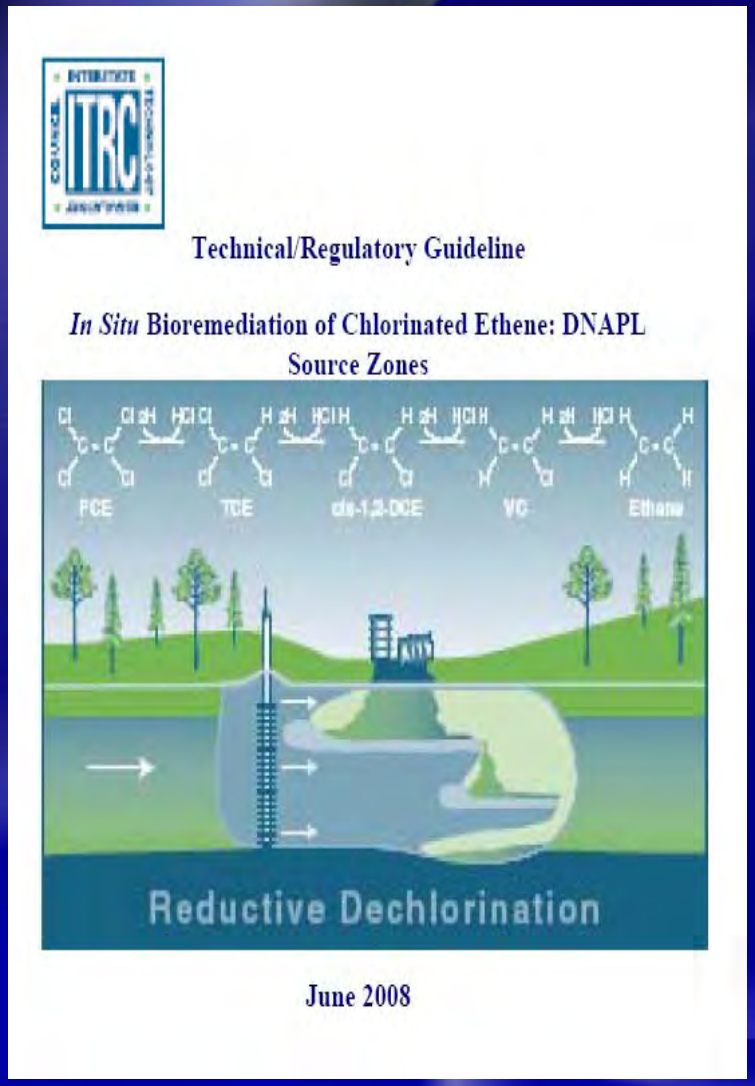
Broad Range of Conditions

- Location: East Coast to West Coast
- Donor: HRC, EOS, lactate, molasses, whey, ethanol
- Scale: Small test plot to huge full-scale
- Monitoring: Highly monitored demos – dry cleaner
- Depths: 5-300 feet
- Goal: Enhance Flushing, Contain source, Reduce Flux, Reduce Longevity
- Geology: Sands, Silts, Fractured Bedrock
- Flow: Slow to Very Fast
- DNAPL: TCE sludge, Aged TCE / PCE, Fresh PCE
- Conc: ca. 2,000 – ca. 350,000 ug/L

Case Study Forum Outcomes

- "Credible evidence for ISB of sources"
- Tentative niche definition
  - Low strength sources (no massive pools)
  - Relatively homogeneous and permeable
  - Sufficient time (slow technology) and access (for injections)
  - Hydraulic capture or sufficient downgradient buffers
  - "Where cost is a major driver"
- Concerns
  - Mobilizing DNAPL
  - Partial degradation – vapor risks?

Technical/Regulatory Guidance

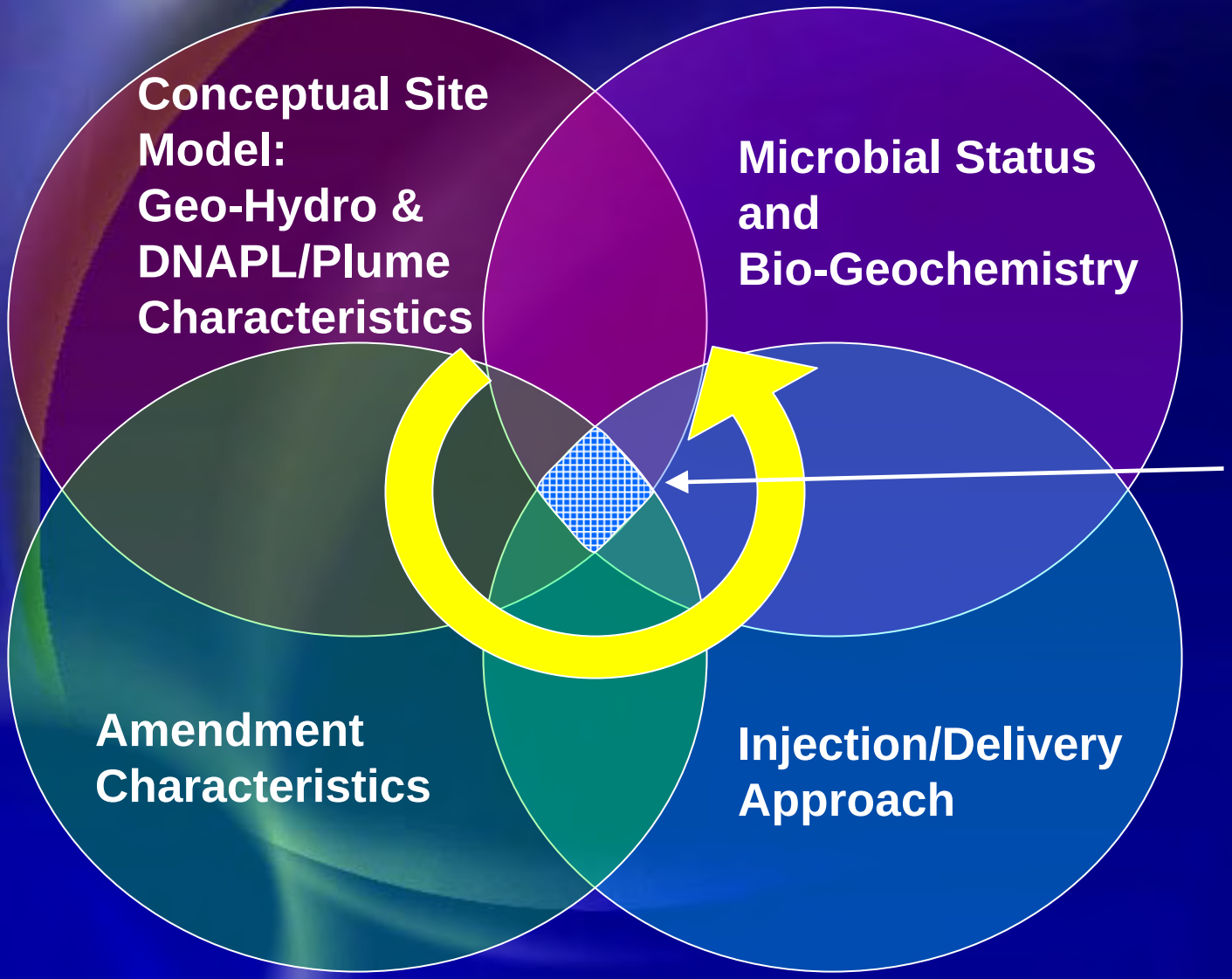

Technical/Regulatory Guideline

In Situ Bioremediation of Chlorinated Ethene: DNAPL Source Zones

June 2008

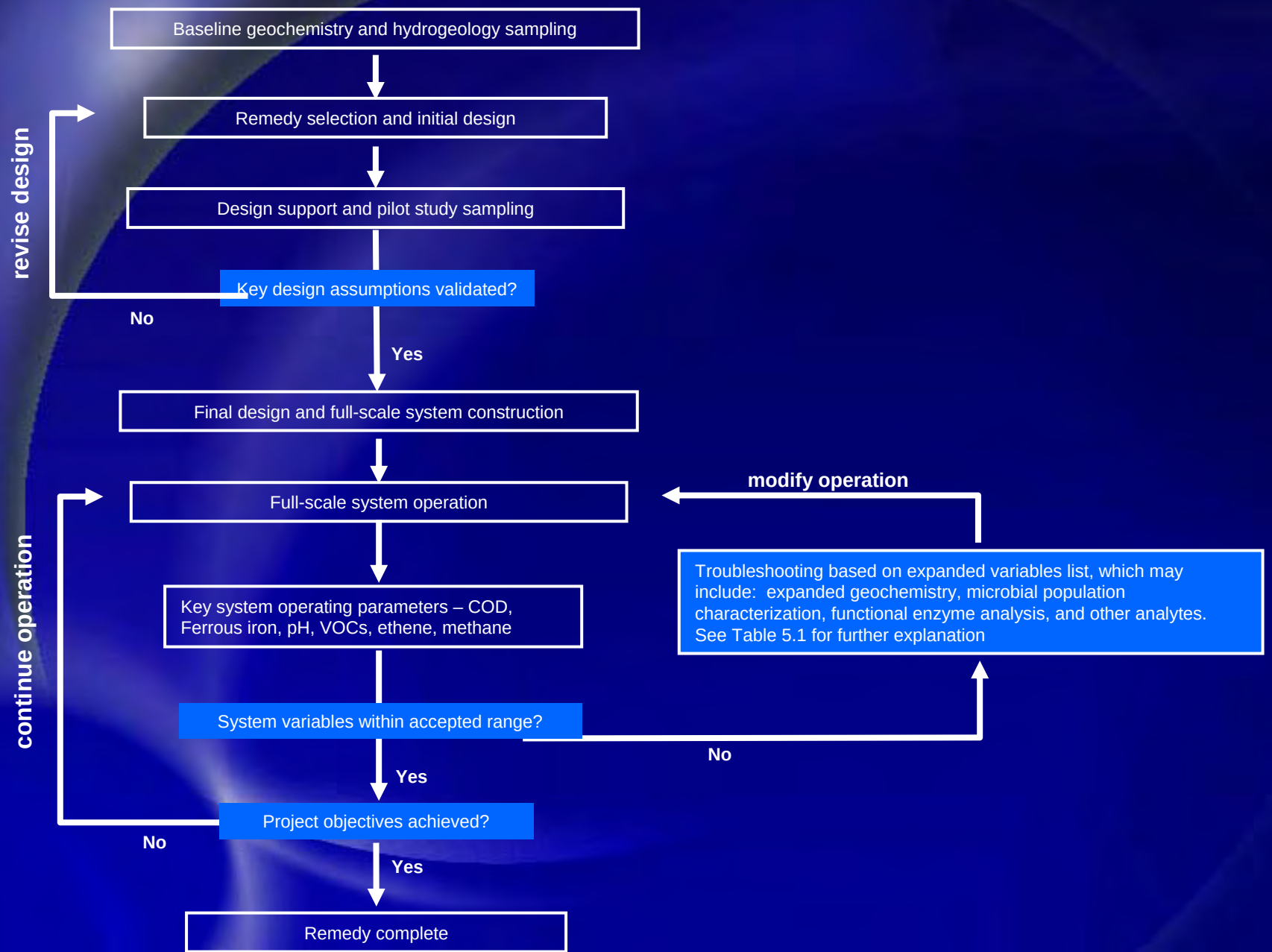
- Technology description
- Site characterization requirements
- Site assessment
- Application design
- Operations and monitoring
- Regulatory considerations
- Health and safety

Application Design for ISB of DNAPL Source Zones

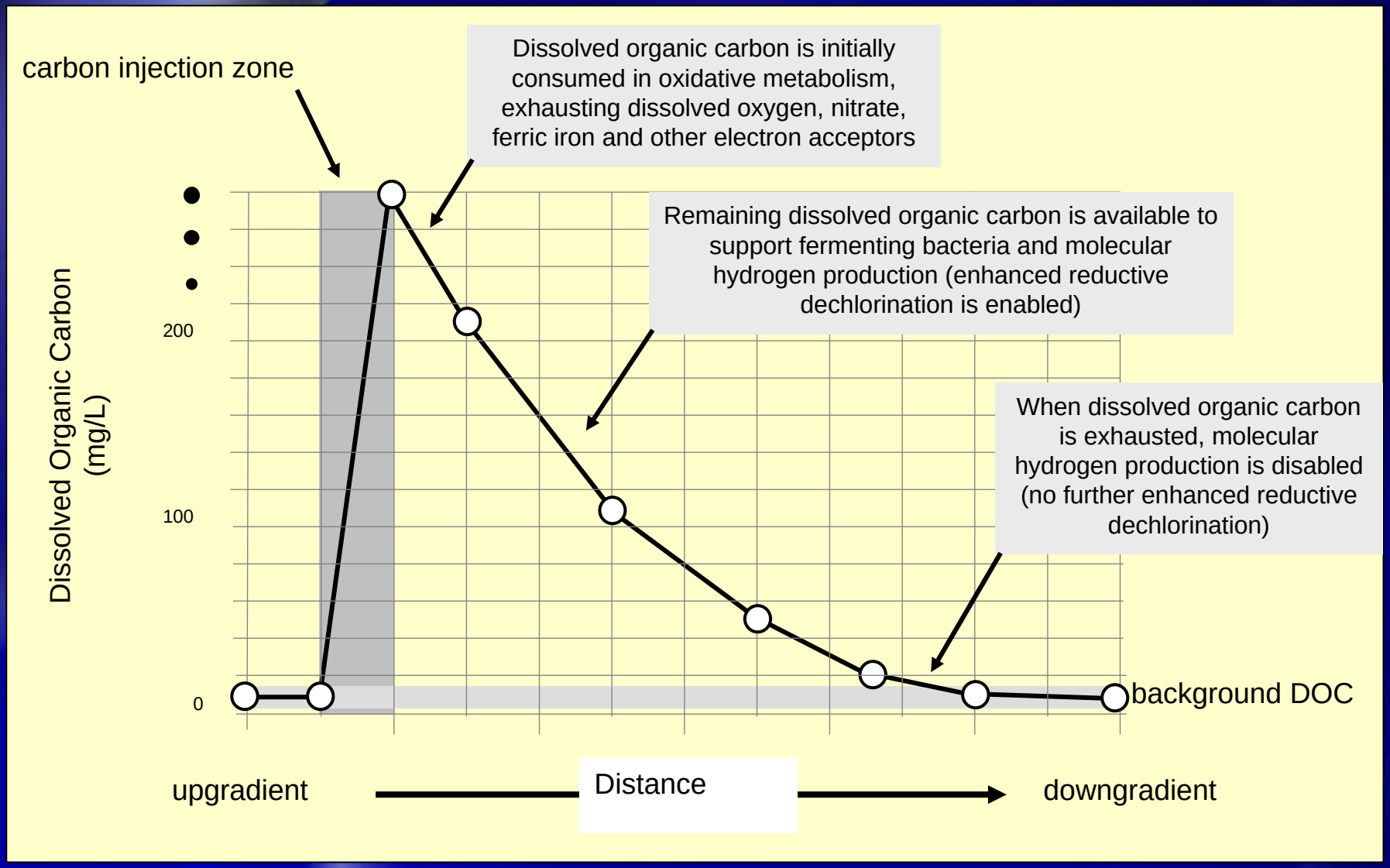


Successful Design Approach Must Be Appropriate for All These Factors

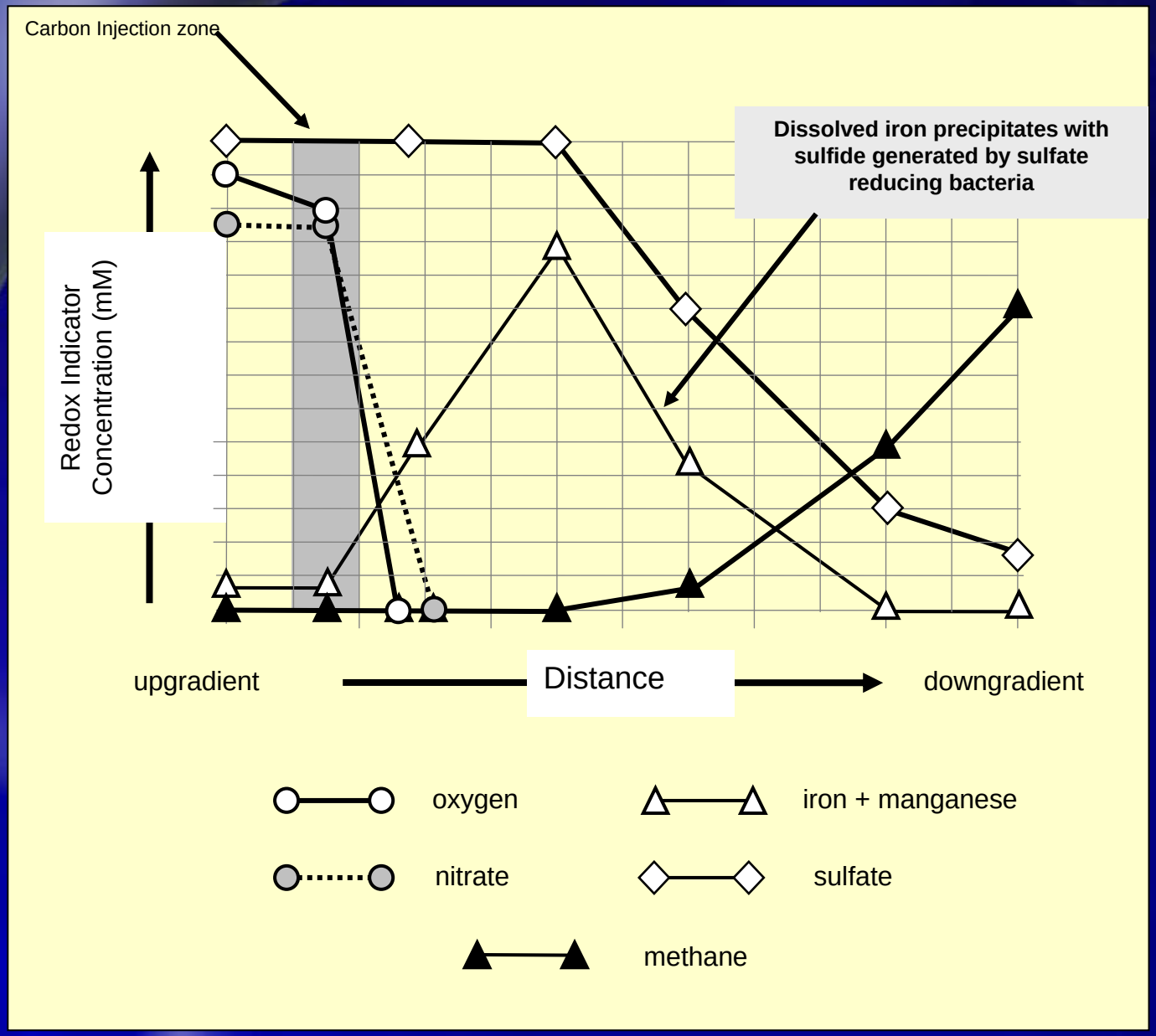
Operational Decision-Making



Data Evaluation – Electron Donor Loading



Data Evaluation – Redox Indicators



Data Evaluation – VC, Ethene/Ethane

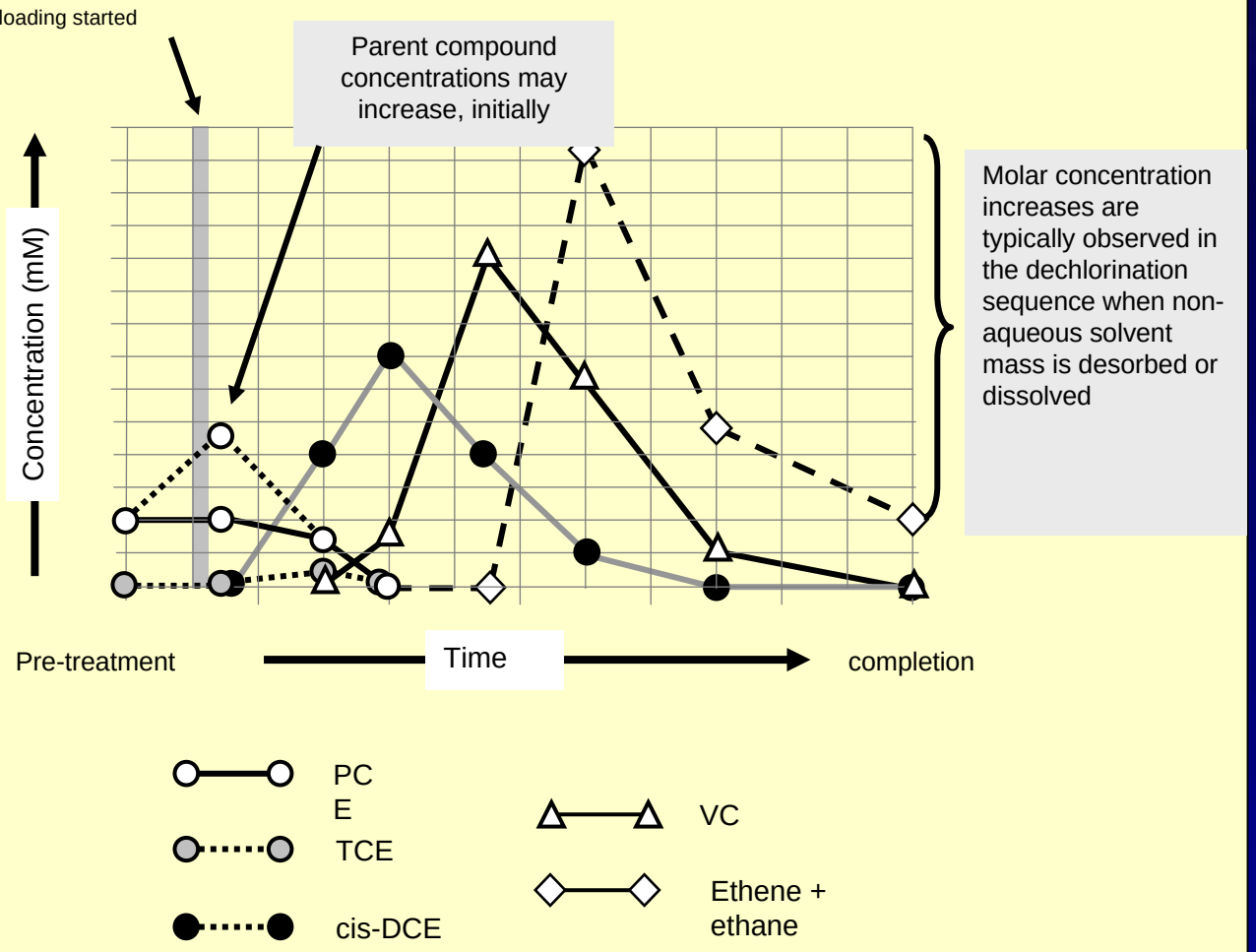


Figure 5-5 Concentration patterns in the chlorinated ethene dechlorination sequence that are typically observed when DNAPL source mass is dissolved or desorbed during enhanced reductive dechlorination.

Summary and Conclusions

Bioremediation of DNAPL source zones

- Is a viable source zone remediation technology,
  - Is not a sole site remediation technology
- Solubilizes the DNAPL at the water-DNAPL interface
- Degrades the contaminants immediately after solubilization
- Accelerates site remediation through mass removal
- Is not a fast removal technology but is an efficient removal technology