Enhanced Bioremediation for Treatment of Chlorinated Solvent Residual Source Areas – Case Study and Implications

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Bioremediation Background

- In Situ Bioremediation of chlorinated solvents:
  - Solvents utilized as electron acceptors by indigenous microorganisms
  - Chlorine atoms sequentially replaced with hydrogen through “reductive dechlorination”

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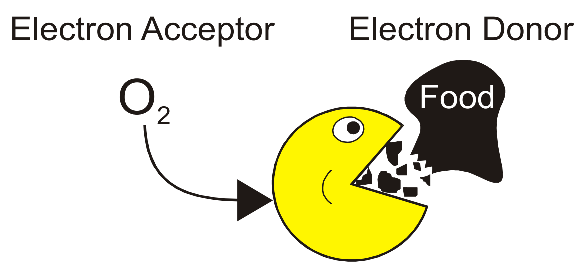
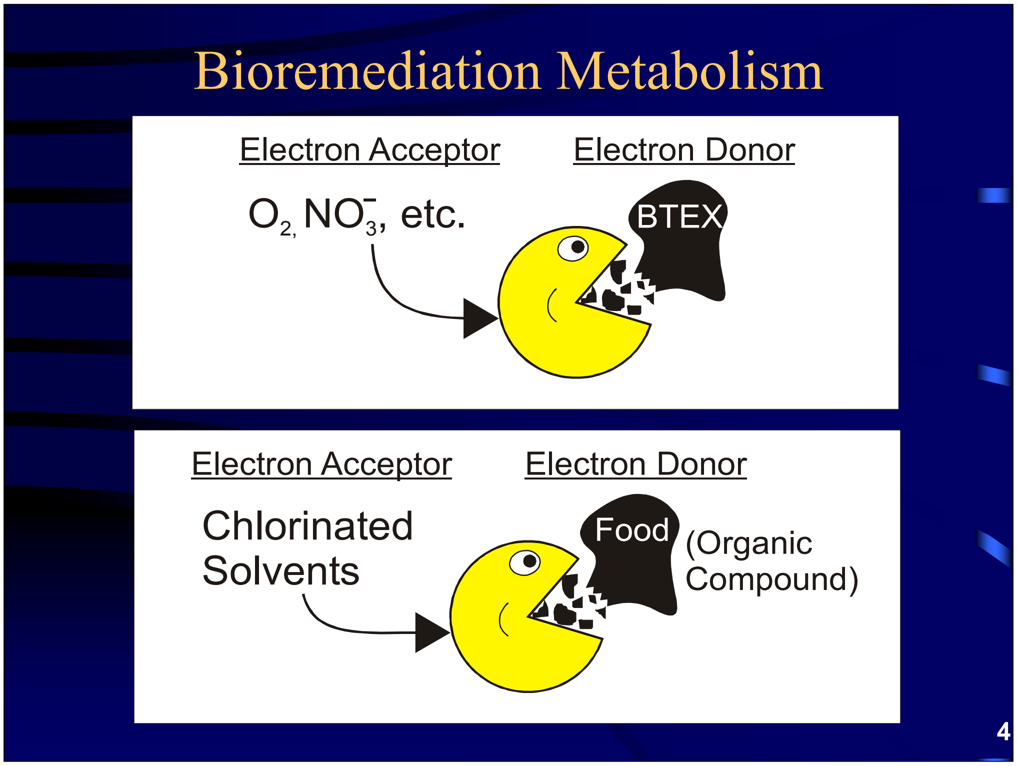
Microbial Metabolism

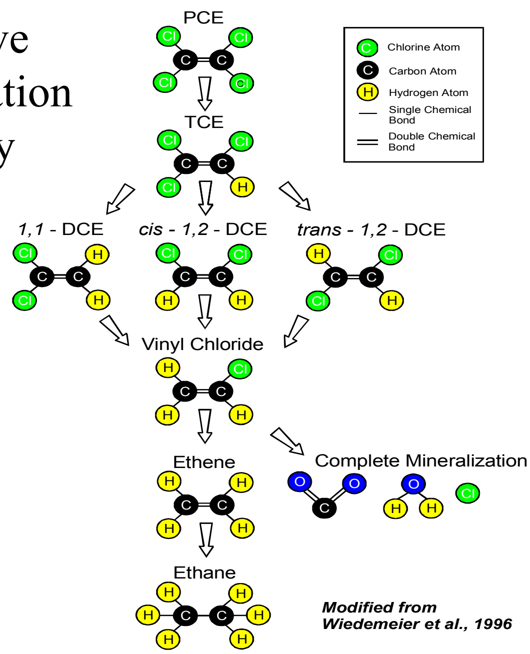


Electron Donor + Electron Acceptor $\longrightarrow$ Respiration Products + Energy

3


Bioremediation Metabolism
Electron Acceptor
Electron Donor
O_2, NO_3^-, etc.
BTEX
Electron Acceptor
Electron Donor
Chlorinated Solvents
Food
(Organic Compound)
4

Reductive Dechlorination Pathway



Modified from Wiedemeier et al., 1996

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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 in situ bioremediation may be extremely effective for chlorinated solvent source areas

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Enhanced Mass Transfer

- In situ bioremediation can enhance mass transfer, addressing the concerns previously thought to limit bioremediation applications:
  - Many investigators have shown that dechlorinating bacteria actually have an ecological niche in high concentration areas
  - Several studies have shown that in situ bioremediation enhances mass transfer of contaminants through at least three mechanisms

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Mechanisms of Enhanced Mass Transfer

- Mechanisms for enhanced mass transfer
  - Bioremediation removes contaminants from the aqueous phase, thereby increasing the driving force for mass transfer = $k(C_s\text{-}C)$
  - Increasing solubility of reductive dechlorination degradation products greatly increases the maximum aqueous contaminant loading
  - The electron donor solution can be used to decrease interfacial tension, thereby increasing the effective solubility

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Enhanced Mass Transfer: Mechanisms 1 and 2

- Enhanced mass transfer of chlorinated solvent NAPLs due to reductive dechlorination has been demonstrated in at least two laboratory batch studies:
  - Yang and McCarty (2000) showed enhanced PCE dissolution up to a factor of 5 higher than without reductive dechlorination
  - Carr et al. (2000) showed reductions in NAPL longevity of 83% due to reductive dechlorination in continuously stirred tank reactors

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Enhanced Mass Transfer: Mechanisms 1 and 2

- Enhanced mass transfer of chlorinated solvent NAPLs due to reductive dechlorination has been demonstrated in at least one laboratory column study:
  - Cope and Hughes (2001) demonstrated total chlorinated ethene removal was 5 to 6 times higher with reductive dechlorination as compared to abiotic washout

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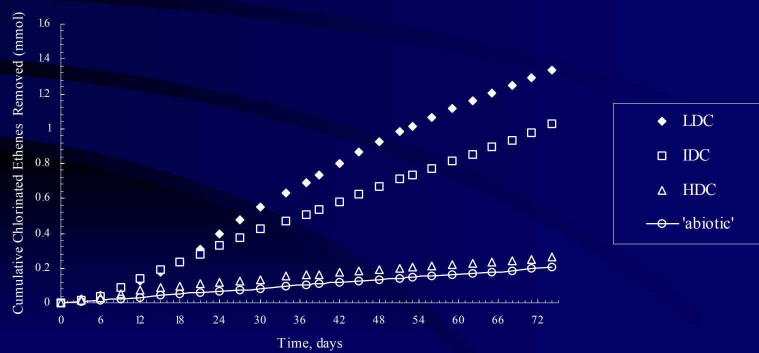
Enhanced Mass Transfer: Mechanisms 1 and 2

- Enhanced chlorinated ethene removal due to reductive dechlorination in columns with PCE DNAPL (*Courtesy of Joe Hughes*)



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Enhanced Mass Transfer: Mechanism 3

- The impact of sodium lactate and other electron donor solutions on water-TCE interfacial tension was investigated in unpublished laboratory studies
- The results supported a pending patent for the Idaho National Engineering and Environmental Laboratory
- The process is referred to as Bioavailability Enhancement Technology™ (B.E.T.™)

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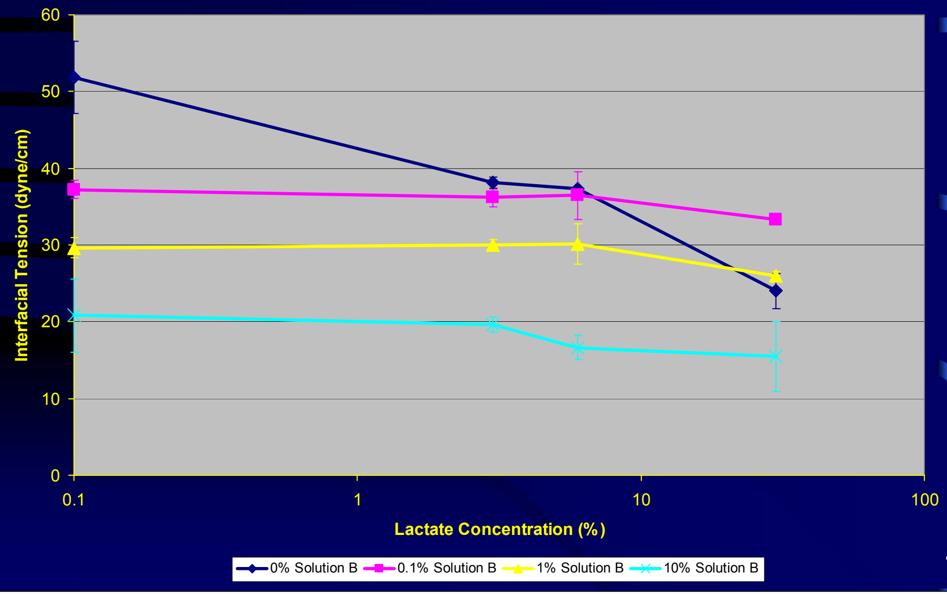
Impact of Electron Donor Solutions on Interfacial Tension



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Enhanced Mass Transfer: Mechanism 3

- Enhanced mass transfer due to electron donor solution interaction with nonaqueous TCE, followed by complete reductive dechlorination has been observed in at least one field study:
  - Sorenson (2000, in press) showed that TCE concentrations were greatly enhanced due to facilitated transport associated with the electron donor solution (high concentration sodium lactate)
  - This work will serve as our case study

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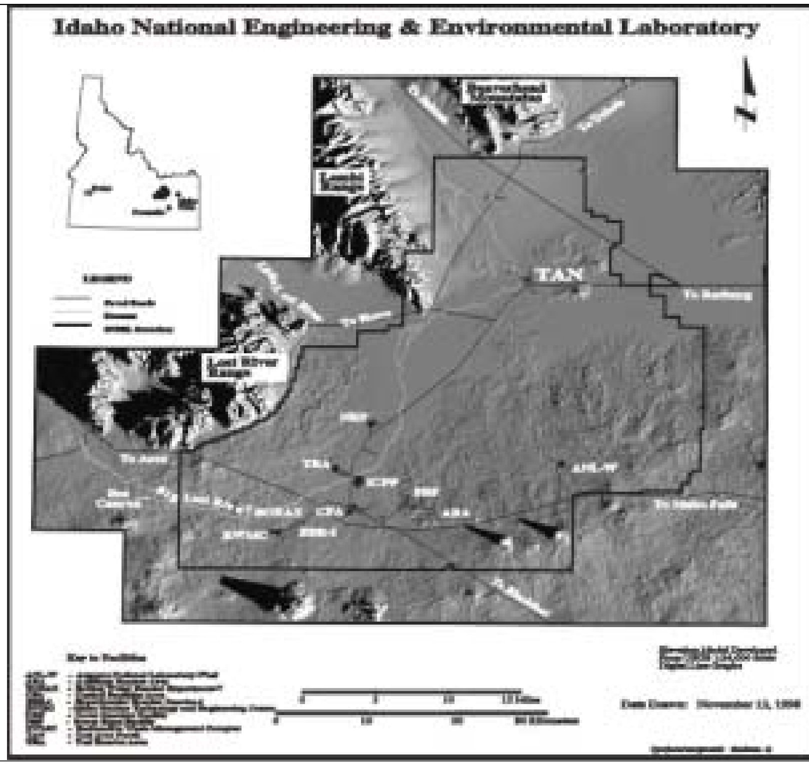
Idaho National Engineering & Environmental Laboratory
Lemhi Range
Lost River Range
TAN
TRA
ICPP
CFA
ARA
ANL-W
To Idaho Falls

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Test Area North (TAN) Background

- Industrial wastewater (including solvents), low-level radioactive wastes, and sanitary sewage were injected directly to the Snake River Plain Aquifer from the late 1950s to 1972
- TCE plume is nearly 2 miles long
- Residual source area is about 100 ft in diameter
- Contaminated aquifer is about 200-400 ft deep
- Aquifer is comprised of fractured basalt

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Approximate Plume Boundary
Groundwater Flow
Direction
Groundwater Flow
Direction
17

Record of Decision (1995)

- Pump and treat selected as default remedy
- Treatability studies established for alternative technologies:
  - zero-valent iron
  - monolithic confinement
  - in situ chemical oxidation
  - **in situ bioremediation**
  - natural attenuation
- 100-year remedial time frame

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Objectives for the 1-year In Situ Bioremediation Field Evaluation

- Primary Objective: Demonstrate that biodegradation of TCE can be significantly enhanced through electron donor addition
- Create hydraulic “treatment cell” to maintain hydraulic containment of the source area and control residence time
- Determine controls on process efficiency through extensive monitoring

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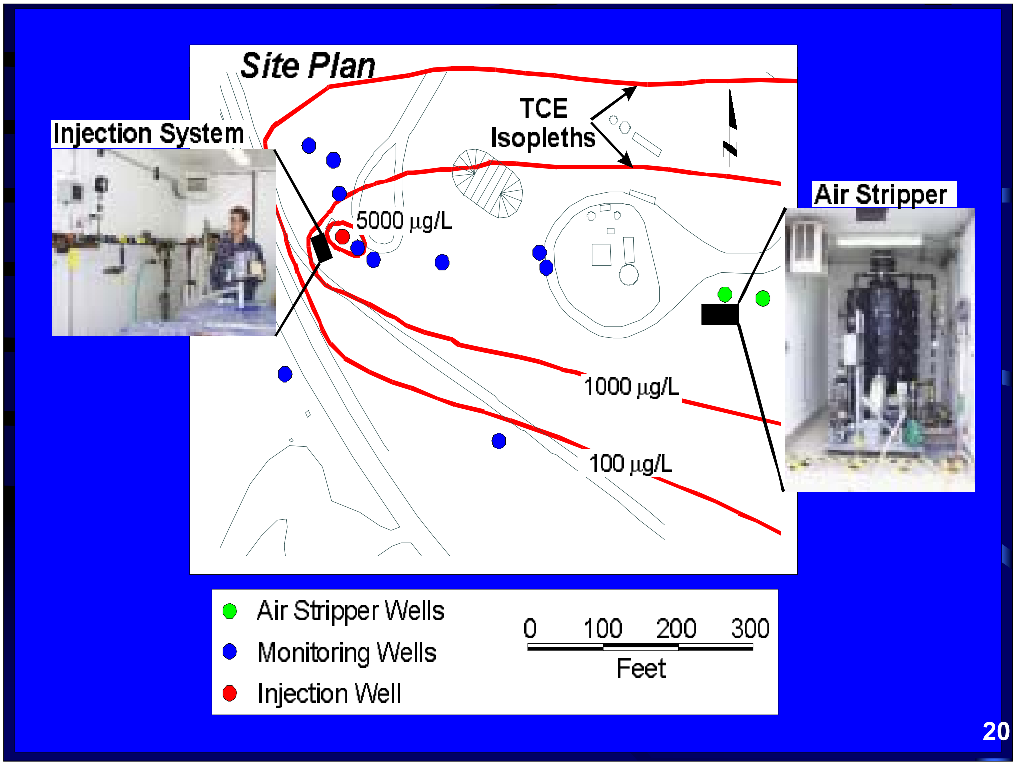
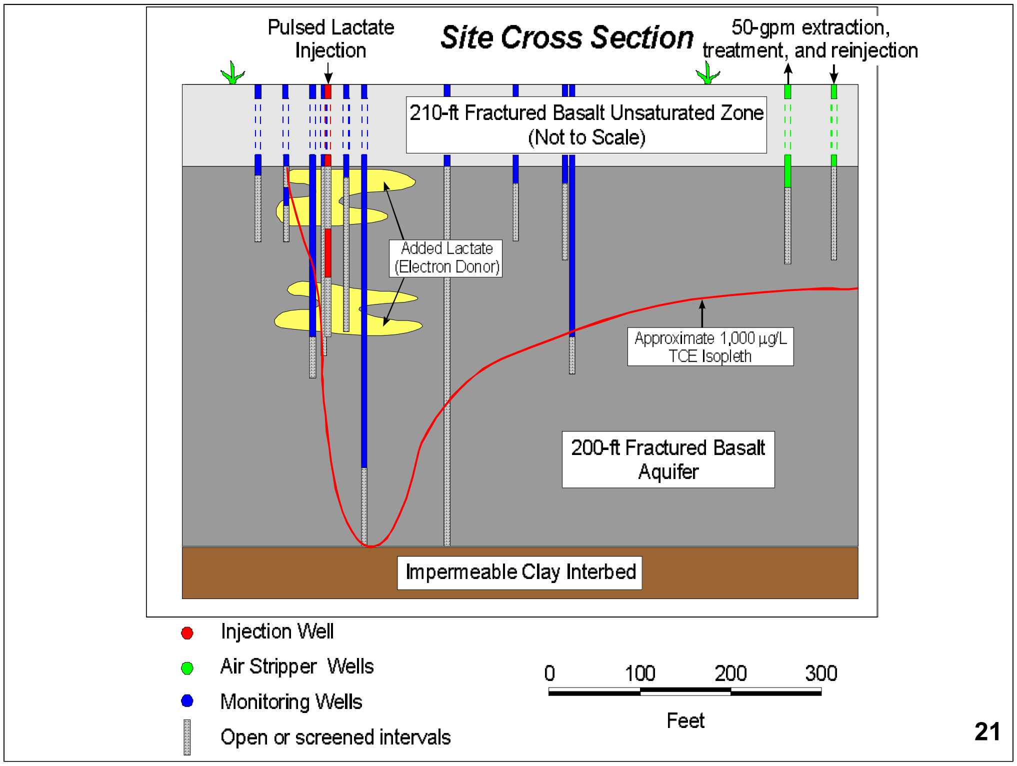
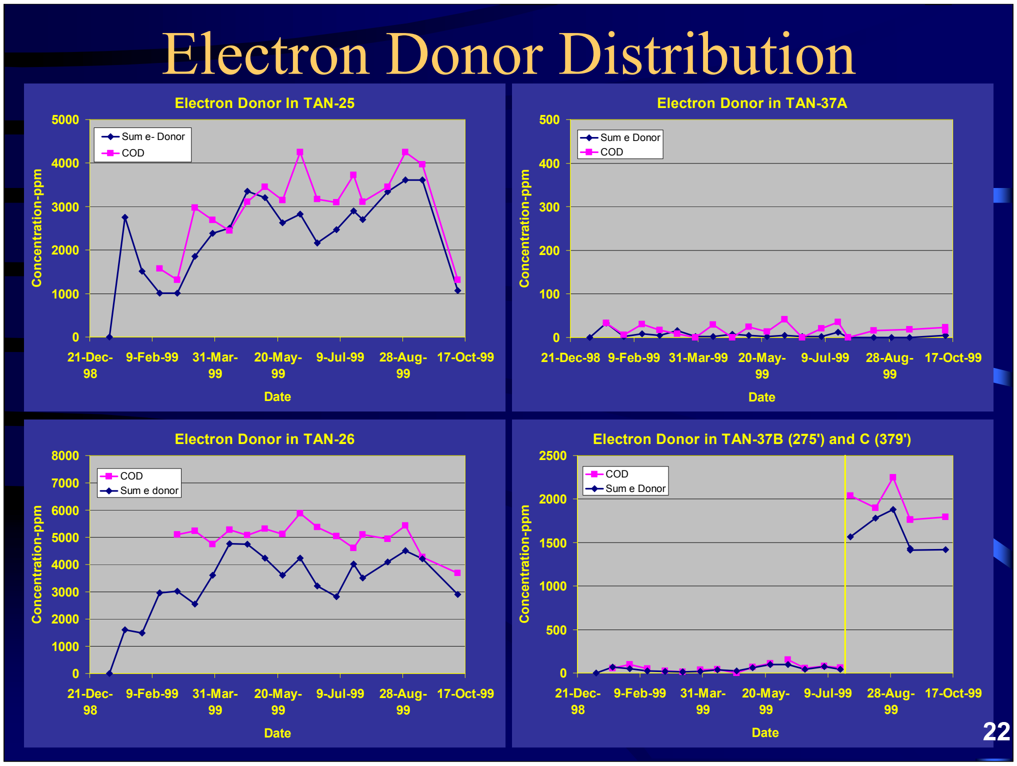
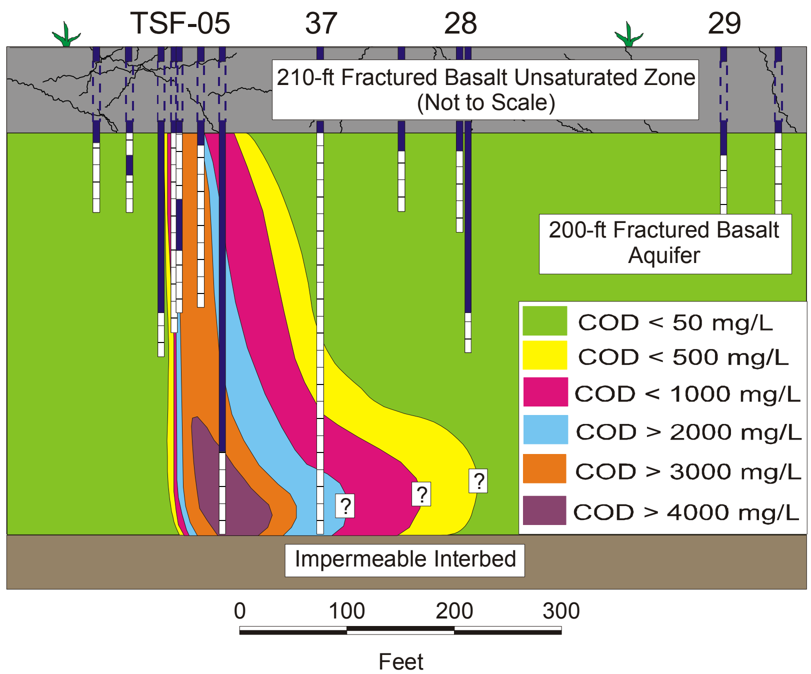

Site Plan
Injection System
TCE
Isopleths
5000 µg/L
1000 µg/L
100 µg/L
Air Stripper
Air Stripper Wells
Monitoring Wells
Injection Well
0 100 200 300
Feet
20



Site Cross Section
Pulsed Lactate Injection
50-gpm extraction, treatment, and reinjection
210-ft Fractured Basalt Unsaturated Zone (Not to Scale)
Added Lactate (Electron Donor)
Approximate 1,000 µg/L TCE Isopleth
200-ft Fractured Basalt Aquifer
Impermeable Clay Interbed
Injection Well
Air Stripper Wells
Monitoring Wells
Open or screened intervals
0
100
200
300
Feet
21


Electron Donor Distribution
Electron Donor In TAN-25
Electron Donor in TAN-37A
Electron Donor in TAN-26
Electron Donor in TAN-37B (275') and C (379')
Sum e- Donor
COD
Sum e Donor
Sum e donor
Concentration-ppm
Date
21-Dec-98
9-Feb-99
31-Mar-99
20-May-99
9-Jul-99
28-Aug-99
17-Oct-99
22

Chemical Oxygen Demand Sept. 13, 1999



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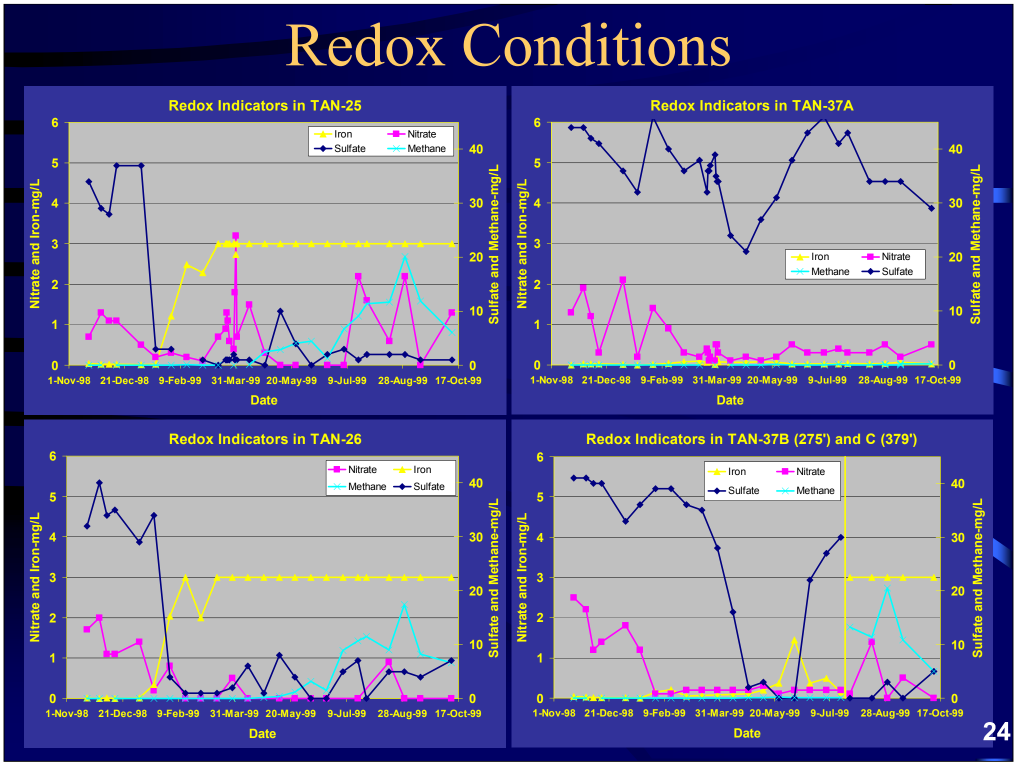
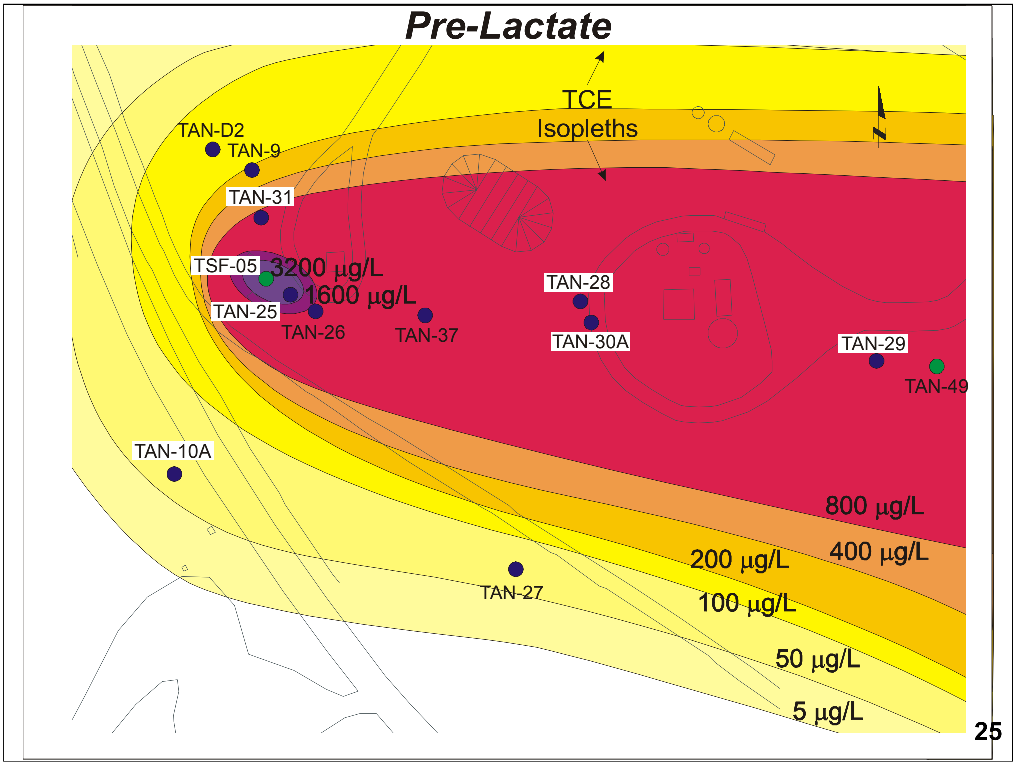
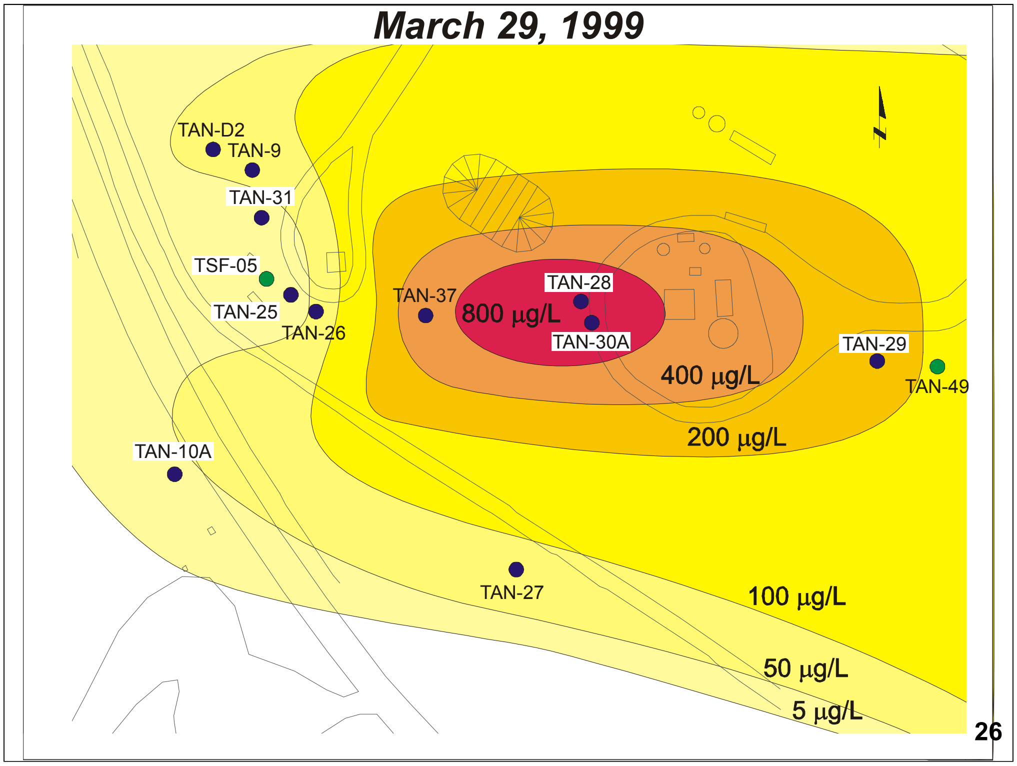
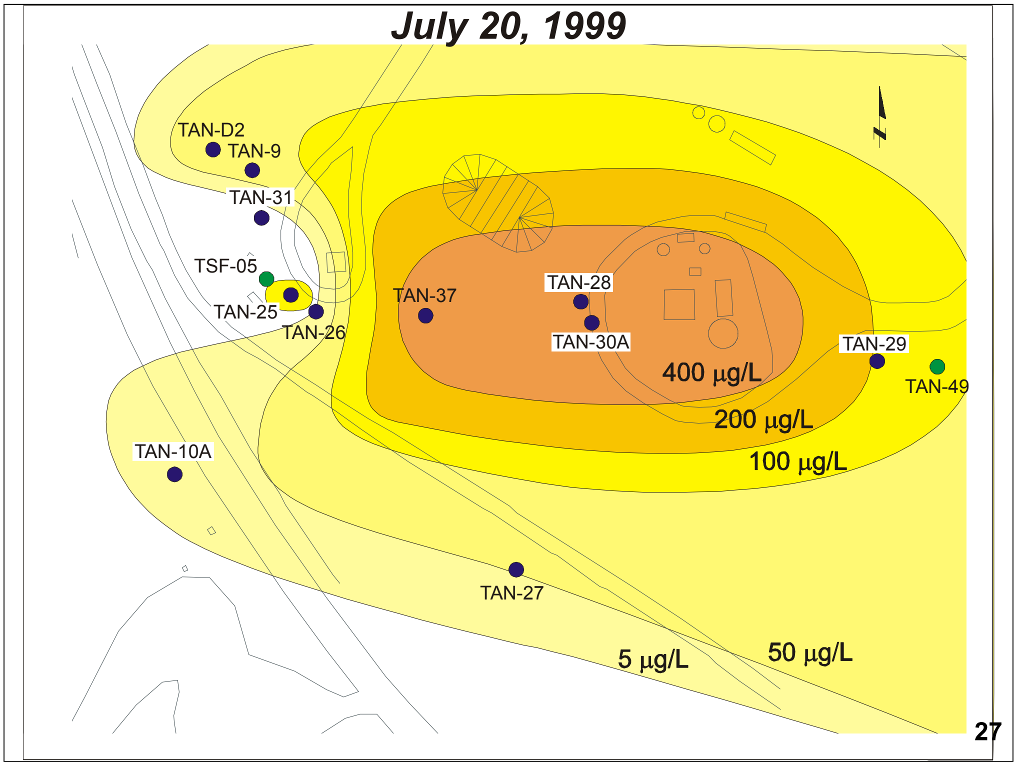
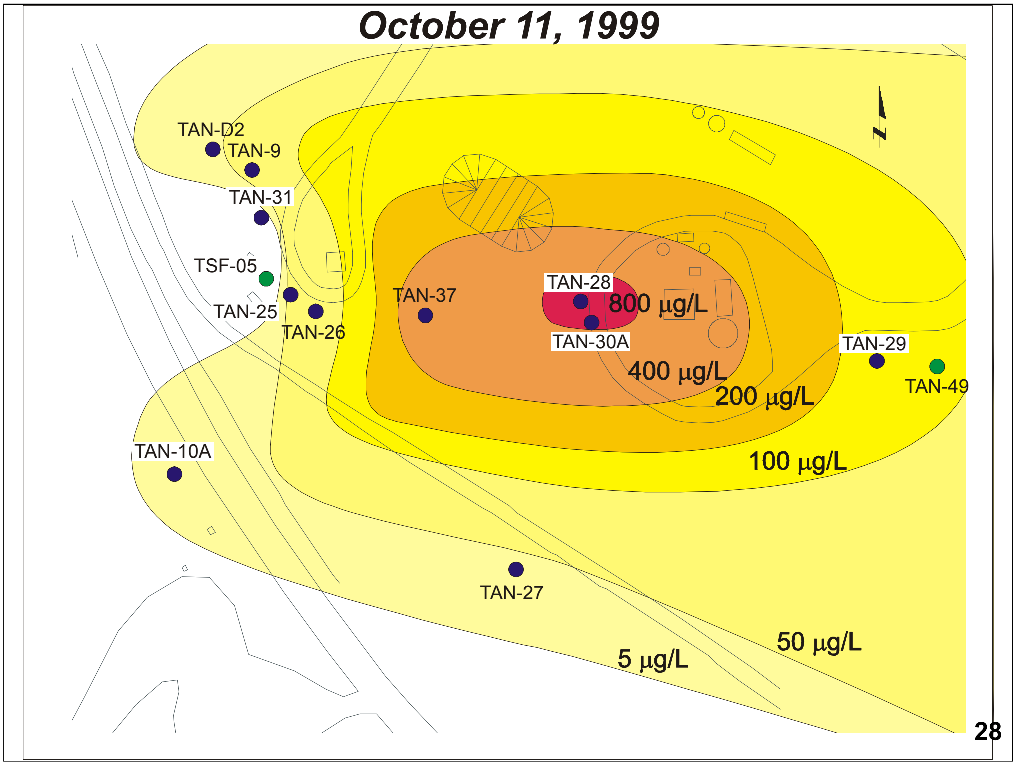

Redox Conditions
Redox Indicators in TAN-25
Redox Indicators in TAN-37A
Redox Indicators in TAN-26
Redox Indicators in TAN-37B (275') and C (379')
Iron
Nitrate
Sulfate
Methane
Nitrate and Iron-mg/L
Sulfate and Methane-mg/L
Date
1-Nov-98
21-Dec-98
9-Feb-99
31-Mar-99
20-May-99
9-Jul-99
28-Aug-99
17-Oct-99
24

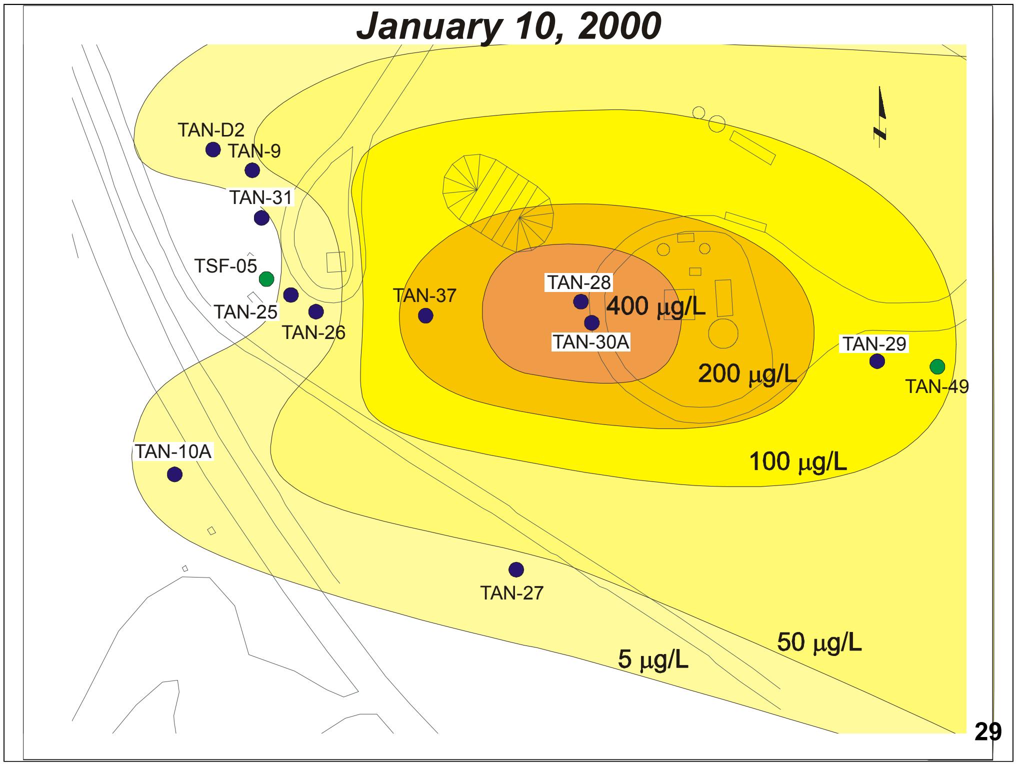


Pre-Lactate
TCE
Isopleths
TAN-D2
TAN-9
TAN-31
TSF-05
3200 µg/L
1600 µg/L
TAN-25
TAN-26
TAN-37
TAN-28
TAN-30A
TAN-29
TAN-49
TAN-10A
800 µg/L
400 µg/L
200 µg/L
100 µg/L
TAN-27
50 µg/L
5 µg/L
25


March 29, 1999
TAN-D2
TAN-9
TAN-31
TSF-05
TAN-25
TAN-26
TAN-37
TAN-28
800 µg/L
TAN-30A
TAN-29
TAN-49
400 µg/L
200 µg/L
TAN-10A
TAN-27
100 µg/L
50 µg/L
5 µg/L
26

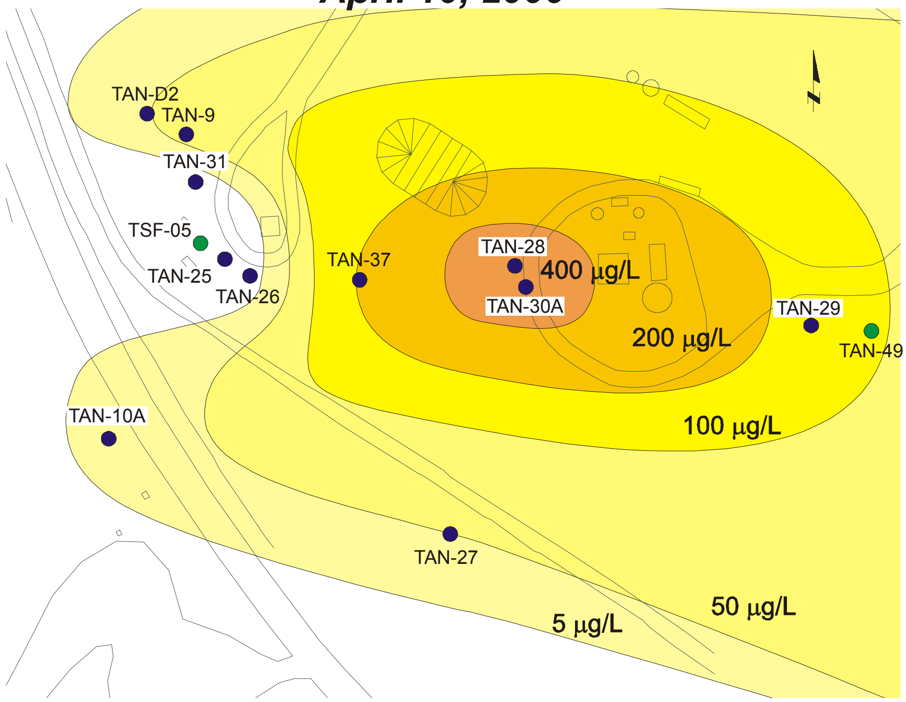

July 20, 1999
TAN-D2
TAN-9
TAN-31
TSF-05
TAN-25
TAN-26
TAN-37
TAN-28
TAN-30A
TAN-29
TAN-49
TAN-10A
TAN-27
400 µg/L
200 µg/L
100 µg/L
5 µg/L
50 µg/L
27


October 11, 1999
TAN-D2
TAN-9
TAN-31
TSF-05
TAN-25
TAN-26
TAN-37
TAN-28
800 µg/L
TAN-30A
400 µg/L
200 µg/L
TAN-29
TAN-49
TAN-10A
100 µg/L
TAN-27
5 µg/L
50 µg/L
28



January 10, 2000
TAN-D2
TAN-9
TAN-31
TSF-05
TAN-25
TAN-26
TAN-37
TAN-28
400 µg/L
TAN-30A
200 µg/L
TAN-29
TAN-49
TAN-10A
100 µg/L
TAN-27
5 µg/L
50 µg/L
29

April 10, 2000



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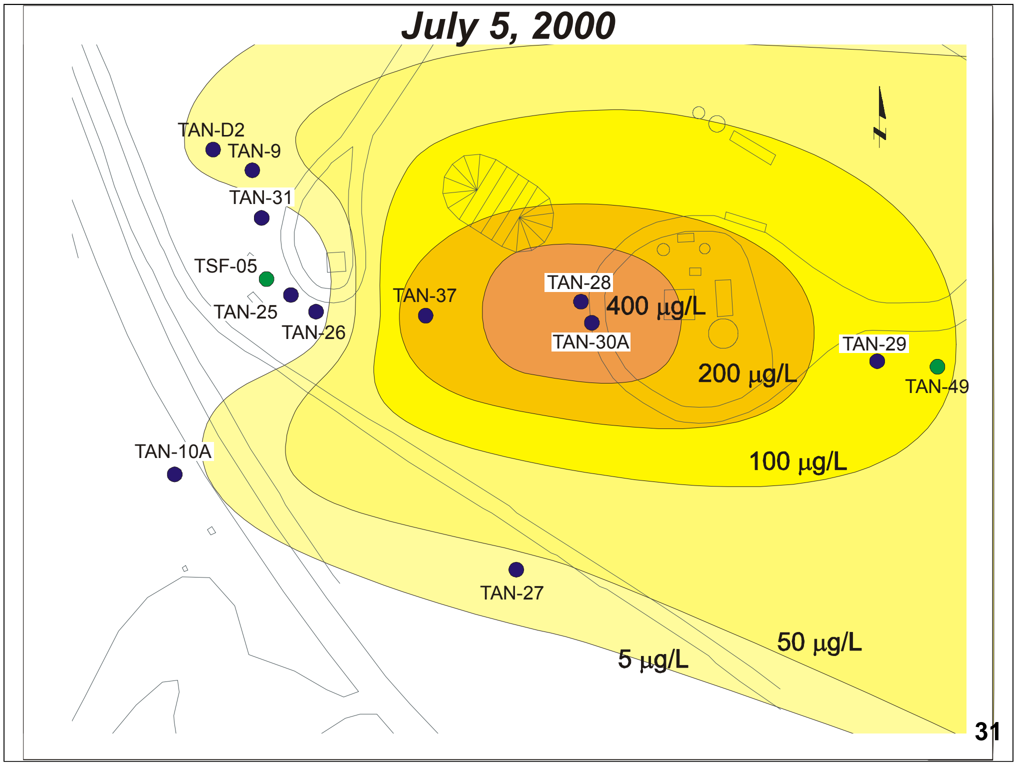
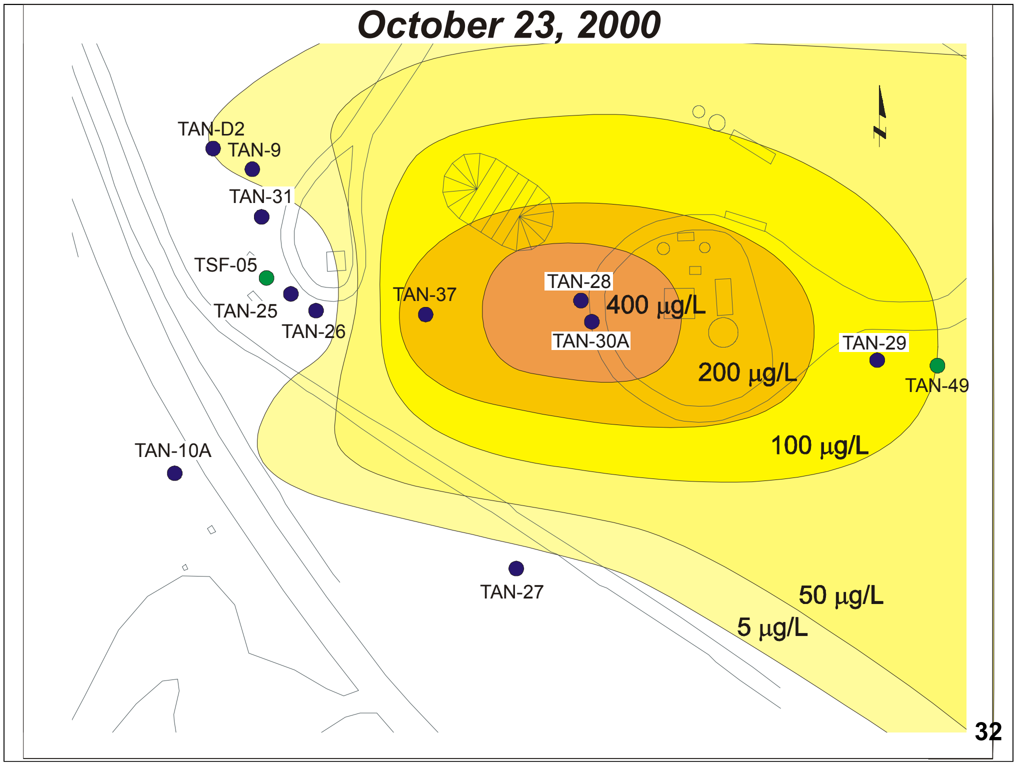
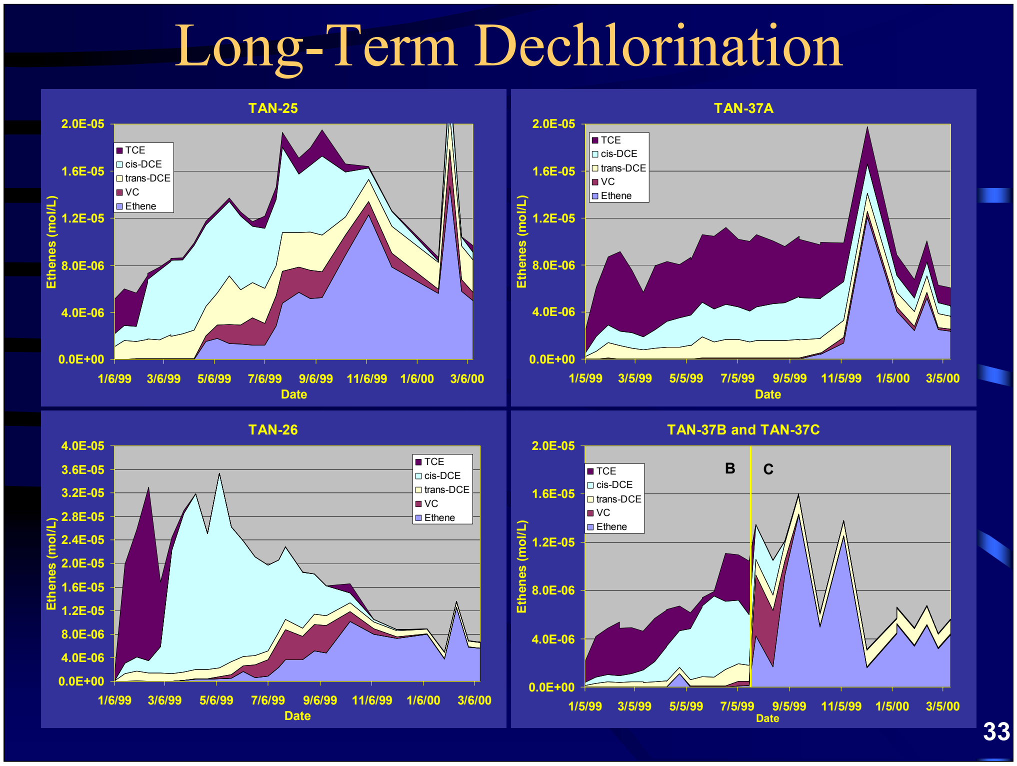
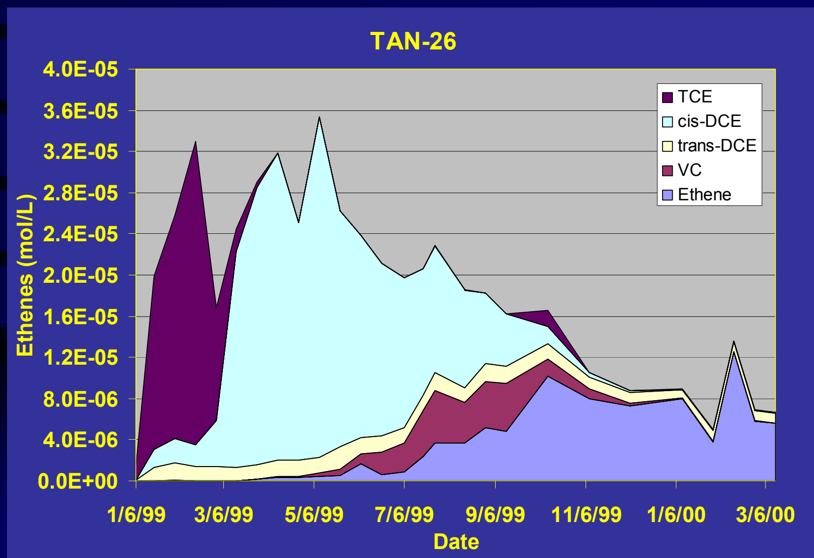

July 5, 2000
TAN-D2
TAN-9
TAN-31
TSF-05
TAN-25
TAN-26
TAN-37
TAN-28
400 µg/L
TAN-30A
200 µg/L
TAN-29
TAN-49
TAN-10A
100 µg/L
TAN-27
50 µg/L
5 µg/L
31


October 23, 2000
TAN-D2
TAN-9
TAN-31
TSF-05
TAN-25
TAN-26
TAN-37
TAN-28
400 µg/L
TAN-30A
200 µg/L
TAN-29
TAN-49
100 µg/L
TAN-10A
TAN-27
50 µg/L
5 µg/L
32


Long-Term Dechlorination
TAN-25
TAN-37A
TAN-26
TAN-37B and TAN-37C
B
C
TCE
cis-DCE
trans-DCE
VC
Ethene
Ethenes (mol/L)
Date
2.0E-05
1.6E-05
1.2E-05
8.0E-06
4.0E-06
0.0E+00
4.0E-05
3.6E-05
3.2E-05
2.8E-05
2.4E-05
2.0E-05
1.6E-05
1.2E-05
8.0E-06
4.0E-06
1/6/99
3/6/99
5/6/99
7/6/99
9/6/99
11/6/99
1/6/00
3/6/00
1/5/99
3/5/99
5/5/99
7/5/99
9/5/99
11/5/99
1/5/00
3/5/00
33

Enhanced Mass Transfer from DNAPL Source Area



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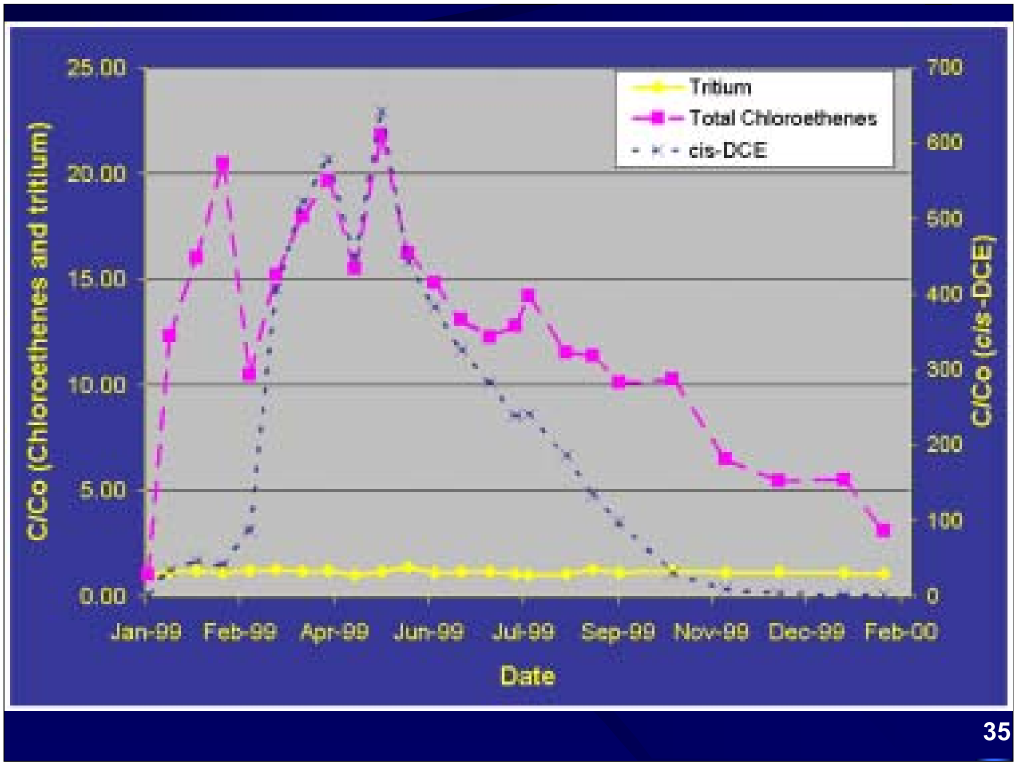
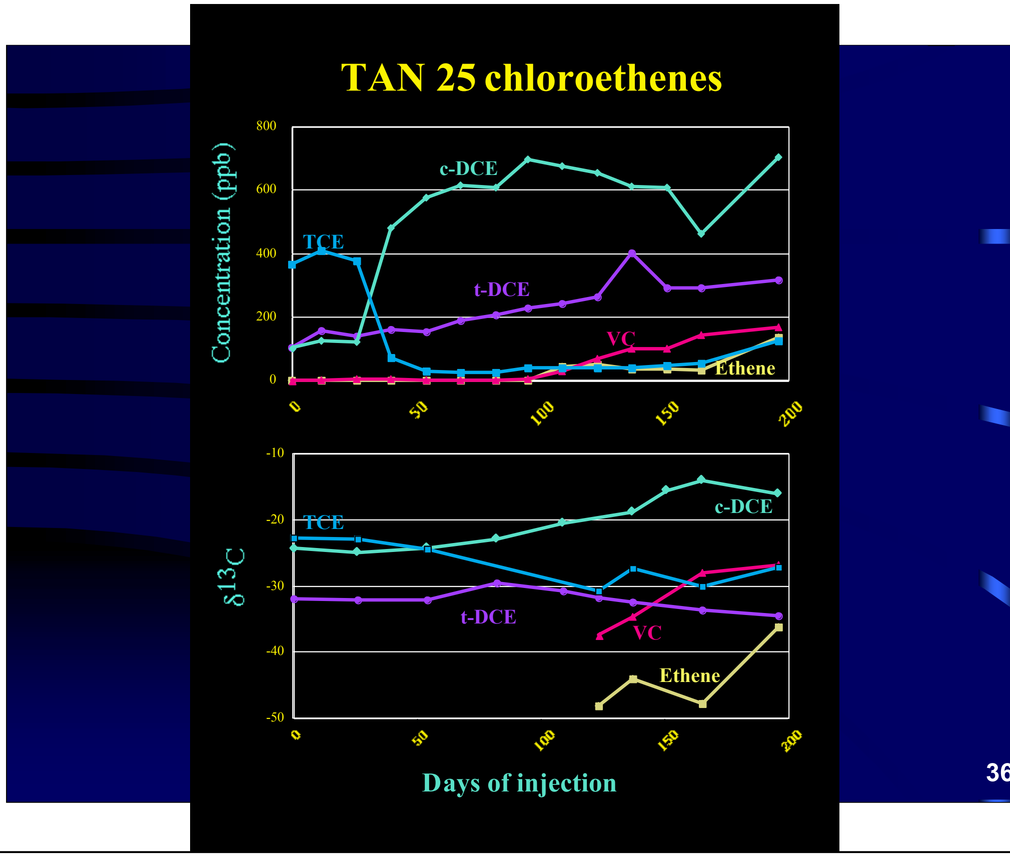


Tritium
Total Chloroethenes
cis-DCE
C/Co (Chloroethenes and tritium)
C/Co (cis-DCE)
25.00
20.00
15.00
10.00
5.00
0.00
700
600
500
400
300
200
100
0
Jan-99
Feb-99
Apr-99
Jun-99
Jul-99
Sep-99
Nov-99
Dec-99
Feb-00
Date
35



TAN 25 chloroethenes
Concentration (ppb)
800
600
400
200
0
c-DCE
TCE
t-DCE
VC
Ethene
0
50
100
150
200
δ13C
-10
-20
-30
-40
-50
c-DCE
TCE
t-DCE
VC
Ethene
0
50
100
150
200
Days of injection
36

Status of Enhanced In Situ Bioremediation at TAN

- Formal regulatory approval to implement bioremediation at the TAN DNAPL source area as a replacement for the default remedy has been granted. A ROD amendment was signed in 2001.

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Ft. Lewis ESTCP Demonstration

- The project will use two in situ treatment cells to quantitatively demonstrate the enhanced mass transfer and degradation that occurs due to in situ bioremediation in a chlorinated solvent source area
- One cell will be operated to test the first two mass transfer mechanisms, while the other will add the third mechanism
- Project planning is underway; field work is scheduled to begin in January 2003

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