Enhanced In Situ Bioremediation of a TCE Source Area in Deep, Fractured Basalt

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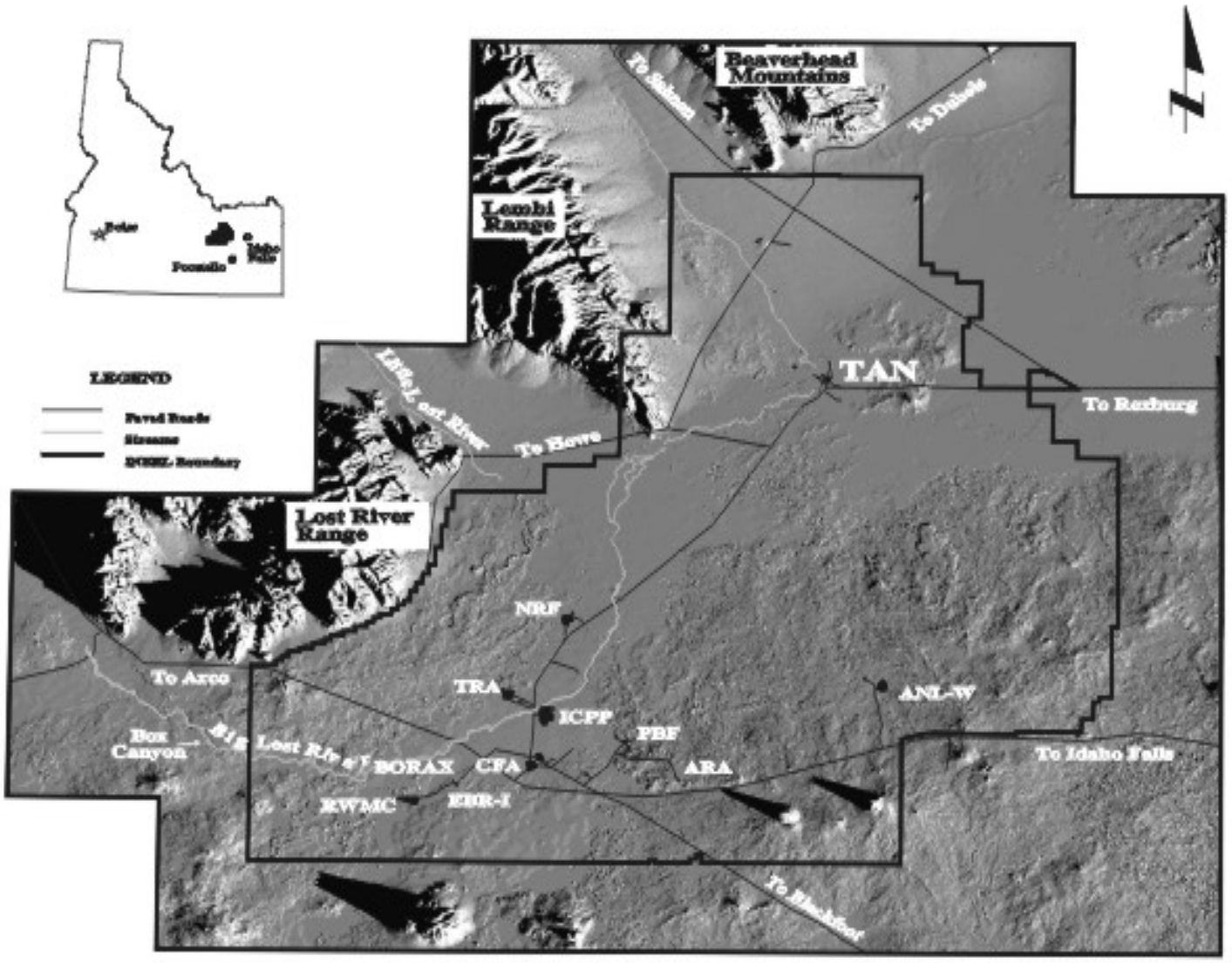


Key to Facilities

ANL-W - Argonne National Laboratory-West
ARA - Auxiliary Reactor Area
BORAX - Boiling Water Reactor Experiment-V
CFA - Central Facilities Area
EBR-I - Experimental Breeder Reactor-I
INTEC - Idaho Nuclear Technology and Engineering Center
NRF - Naval Reactors Facility
PBF - Power Burst Facility
RWMC - Radioactive Waste Management Complex
TAN - Test Area North
TRA - Test Reactor Area

0 5 10 15 Miles
0 10 20 30 Kilometers

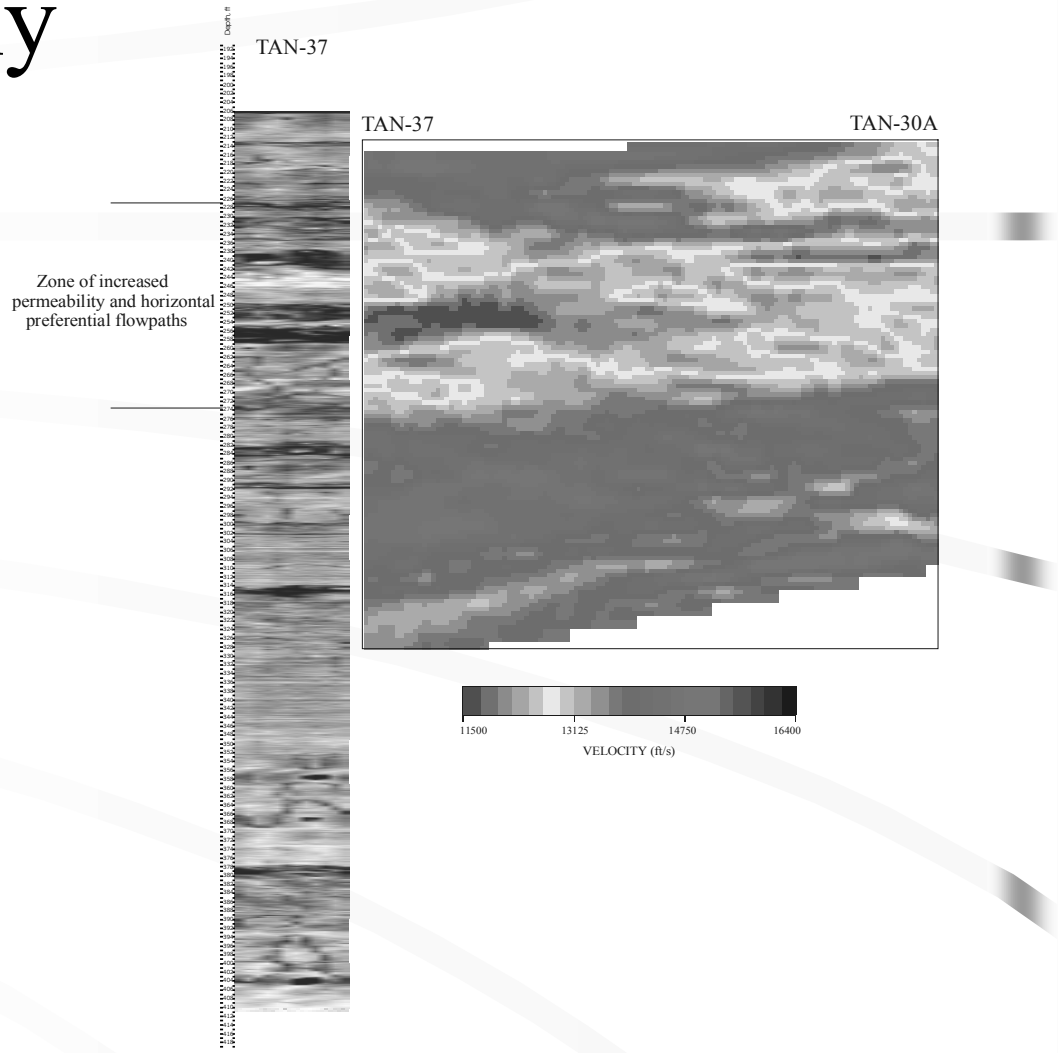
Elevation Model Developed From USGS 1:24,000 Scale Digital Line Graphs

Date Drawn: November 12, 1998

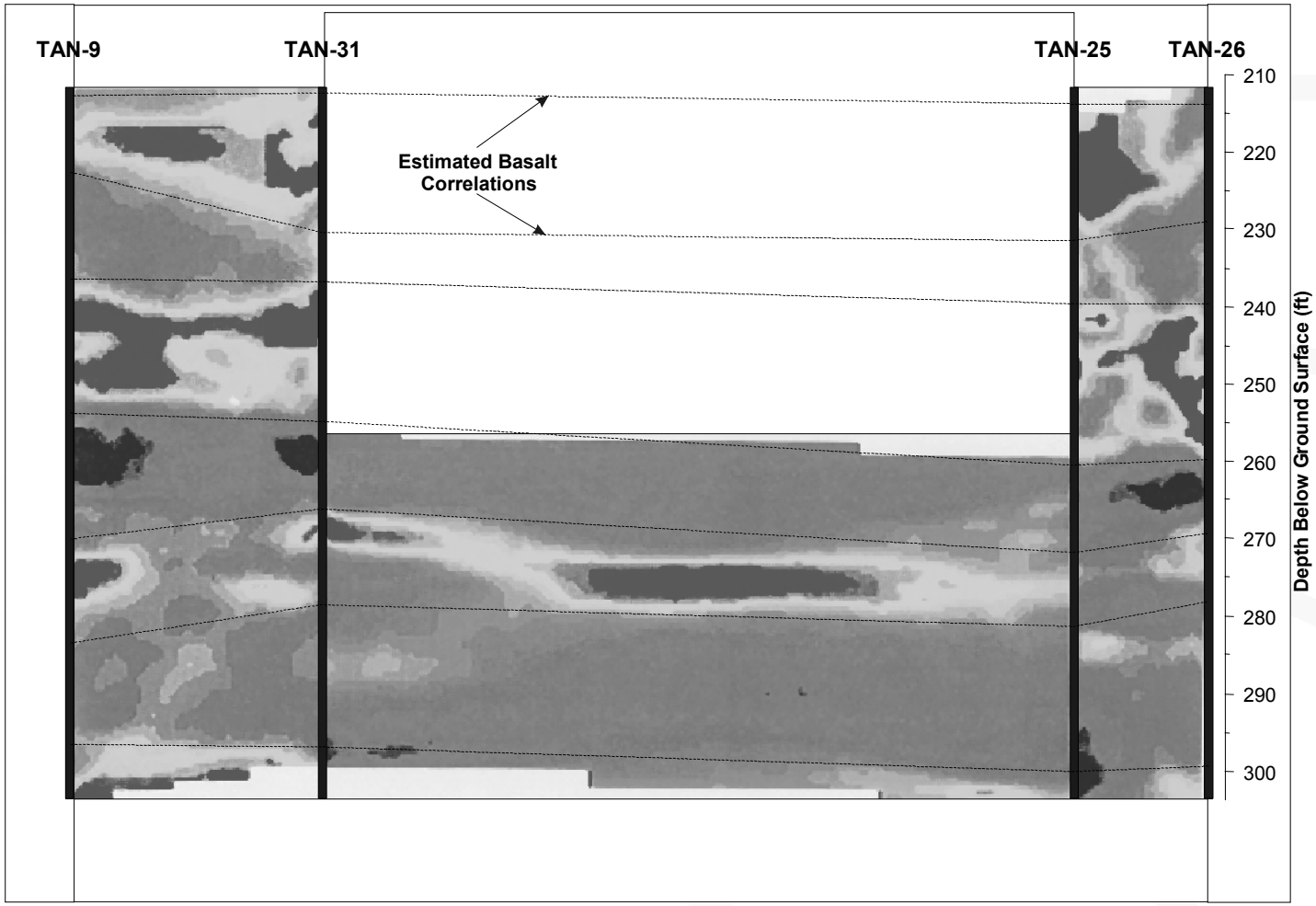
(projects/general: dialogue- s)

Hydrostratigraphy

- Groundwater flow zones occur at either high porosity, rubble contacts between two basalt flows, or at fractured horizons within the dense basalt matrix
- Frequency of flow zone occurrence is greatest in shallow aquifer
- Horizontal, preferential flowpaths - discrete heterogeneities that control flow and transport at the scale of the source area

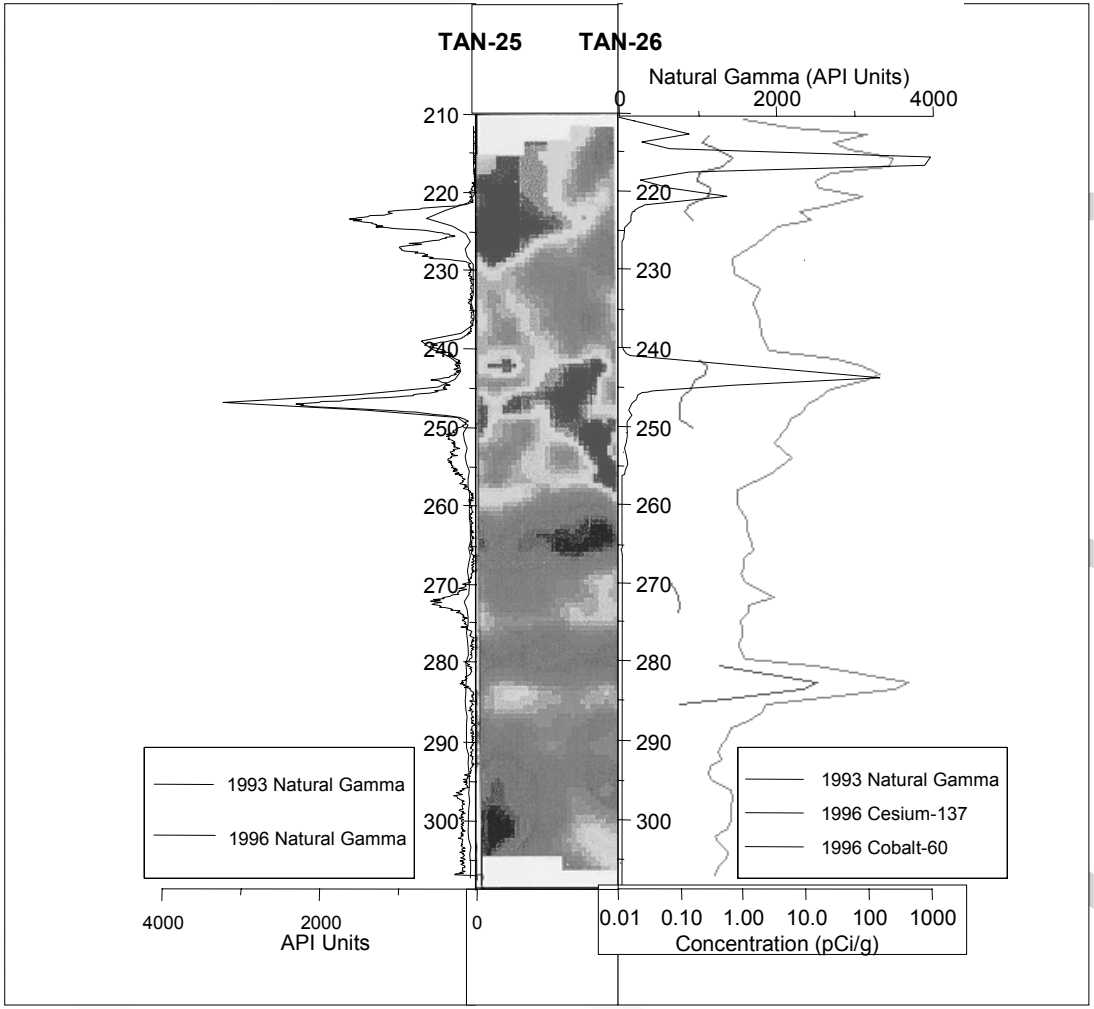


Seismic Tomography Correlations



Contaminant Distribution

- Sludge characterization identified the presence of radiological constituents including gamma emitters
- Gamma spectroscopy data demonstrate horizontal preferential flowpaths and indicate that the most significant component of gamma radiation is ^{137}Cs



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


Approximate Plume Boundary
Groundwater Flow Direction
Groundwater Flow Direction

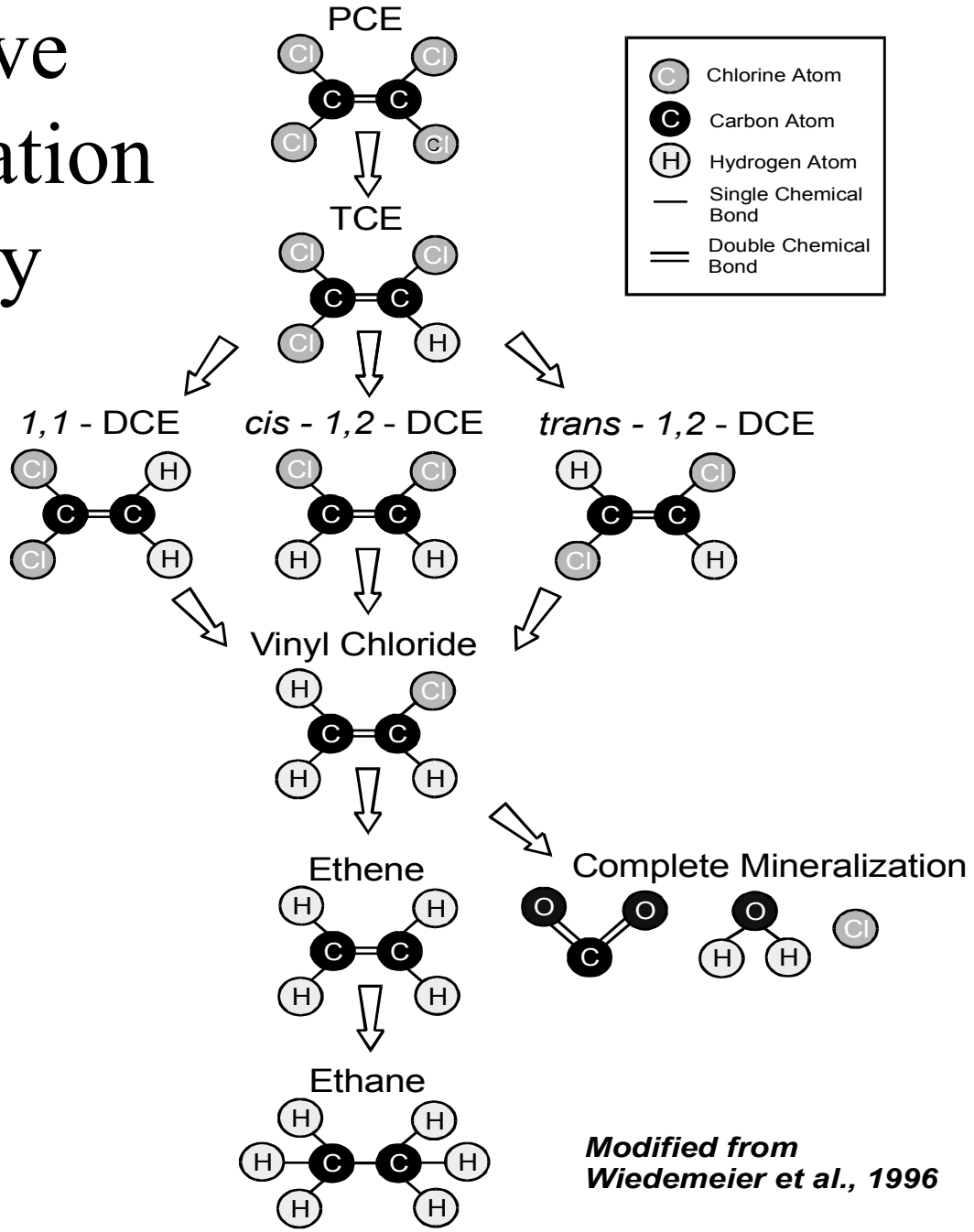
Record of Decision (1995)

- 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

Reductive Dechlorination

- Microorganisms in the subsurface use chlorinated ethenes as electron acceptors (like we use oxygen)
- An appropriate electron donor (food) is needed
- “Daughter” products are generated as chlorine atoms are sequentially replaced by hydrogen atoms
- Naturally occurring inorganic electron acceptors may “compete” with the chlorinated ethenes

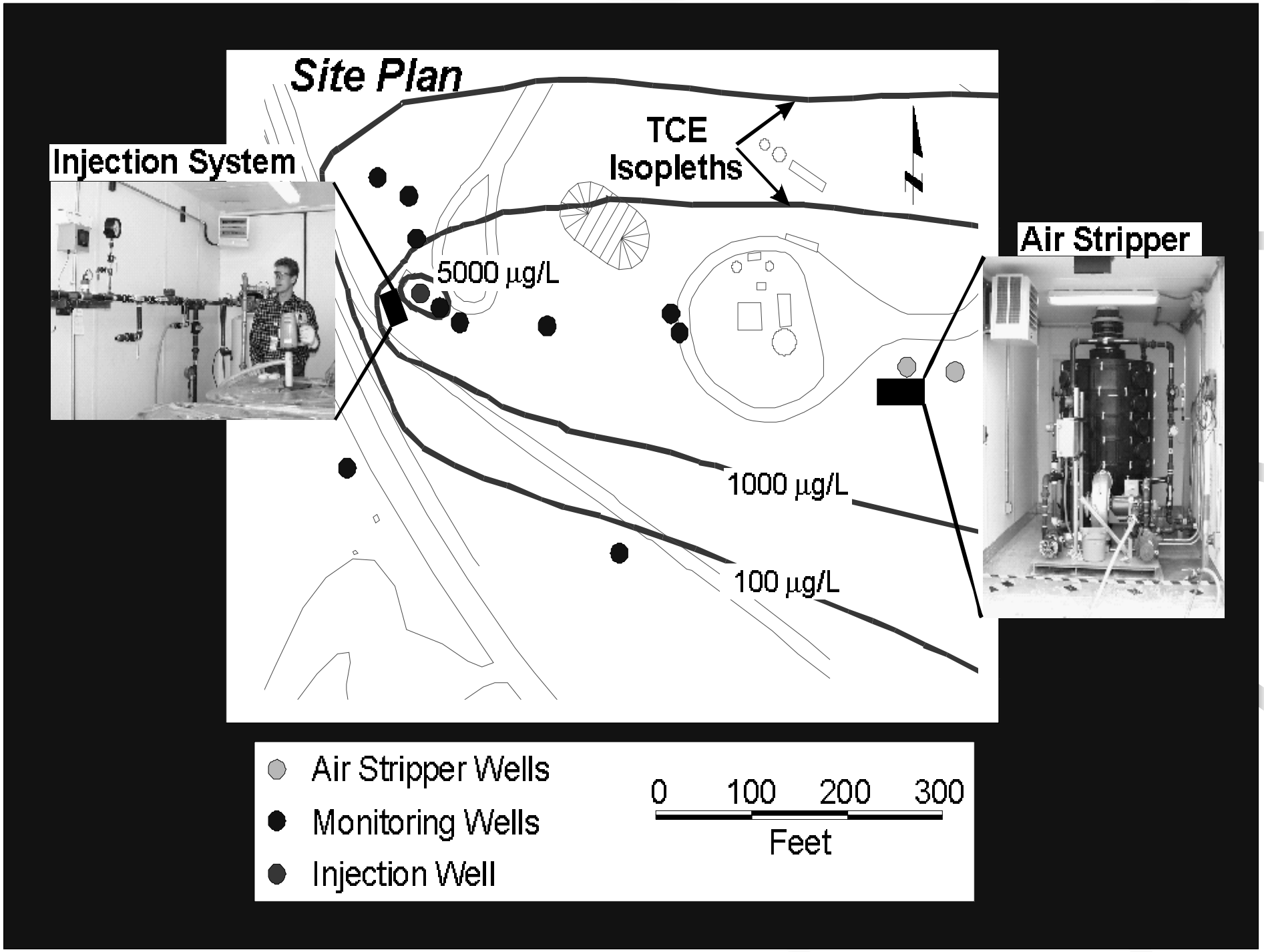
Reductive Dechlorination Pathway

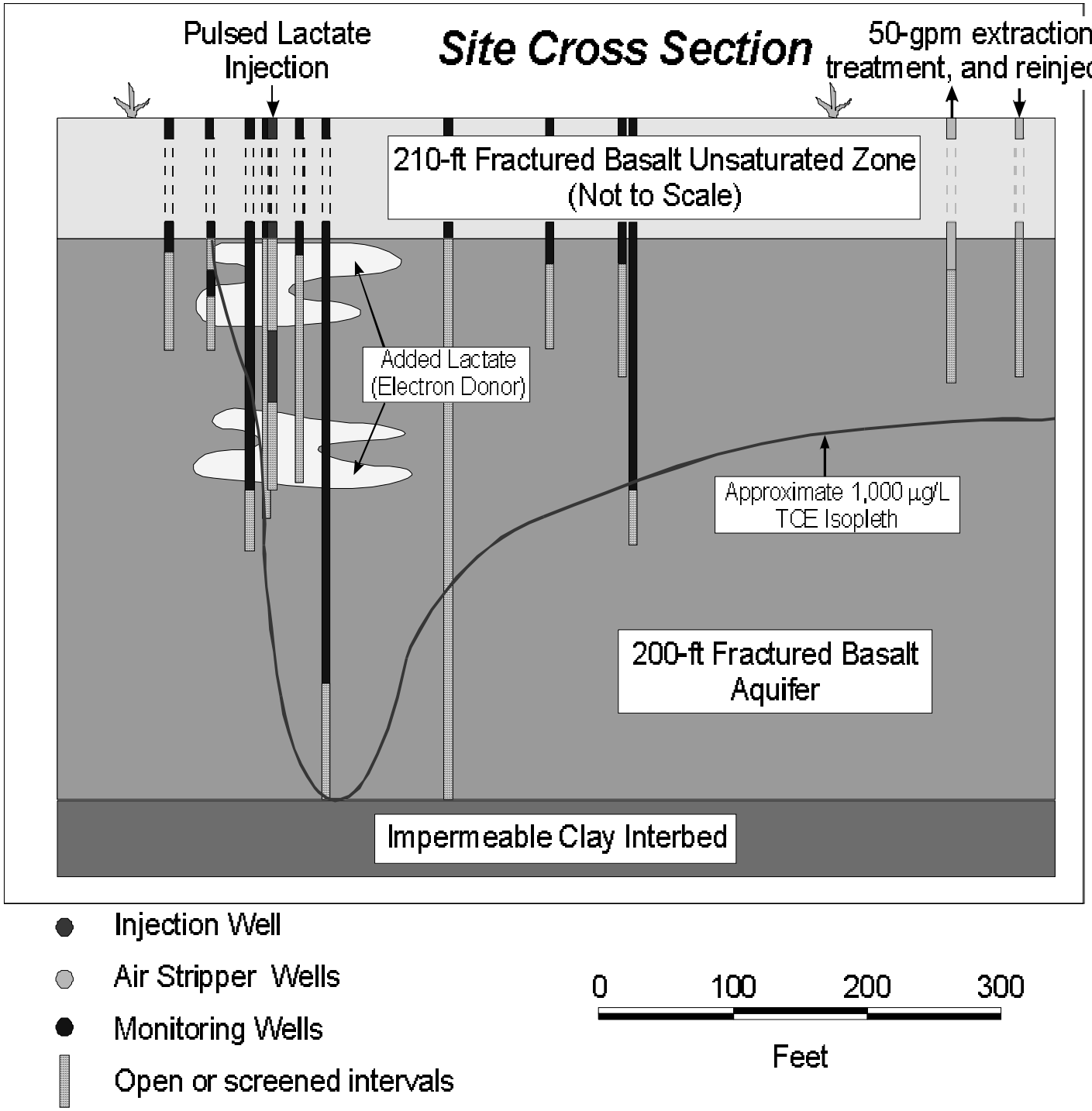


Modified from Wiedemeier et al., 1996

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


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

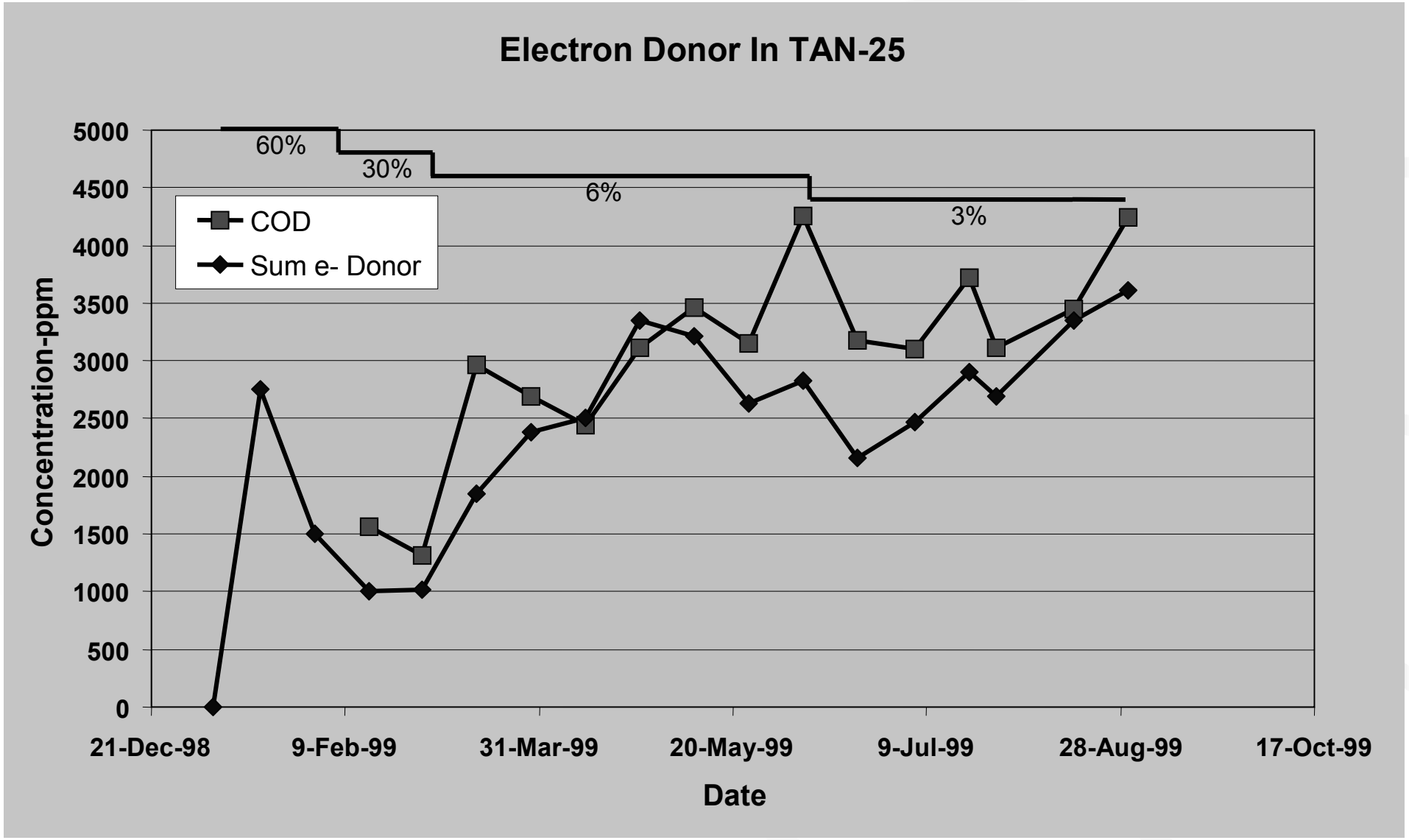

Site Cross Section
Pulsed Lactate Injection
50-gpm extraction, treatment, and reinjection
210-ft Fractured Basalt Unsaturated Zone (Not to Scale)
Added Lactate (Electron Donor)
Approximate 1,000 µg/L TCE Isopleth
200-ft Fractured Basalt Aquifer
Impermeable Clay Interbed
Injection Well
Air Stripper Wells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

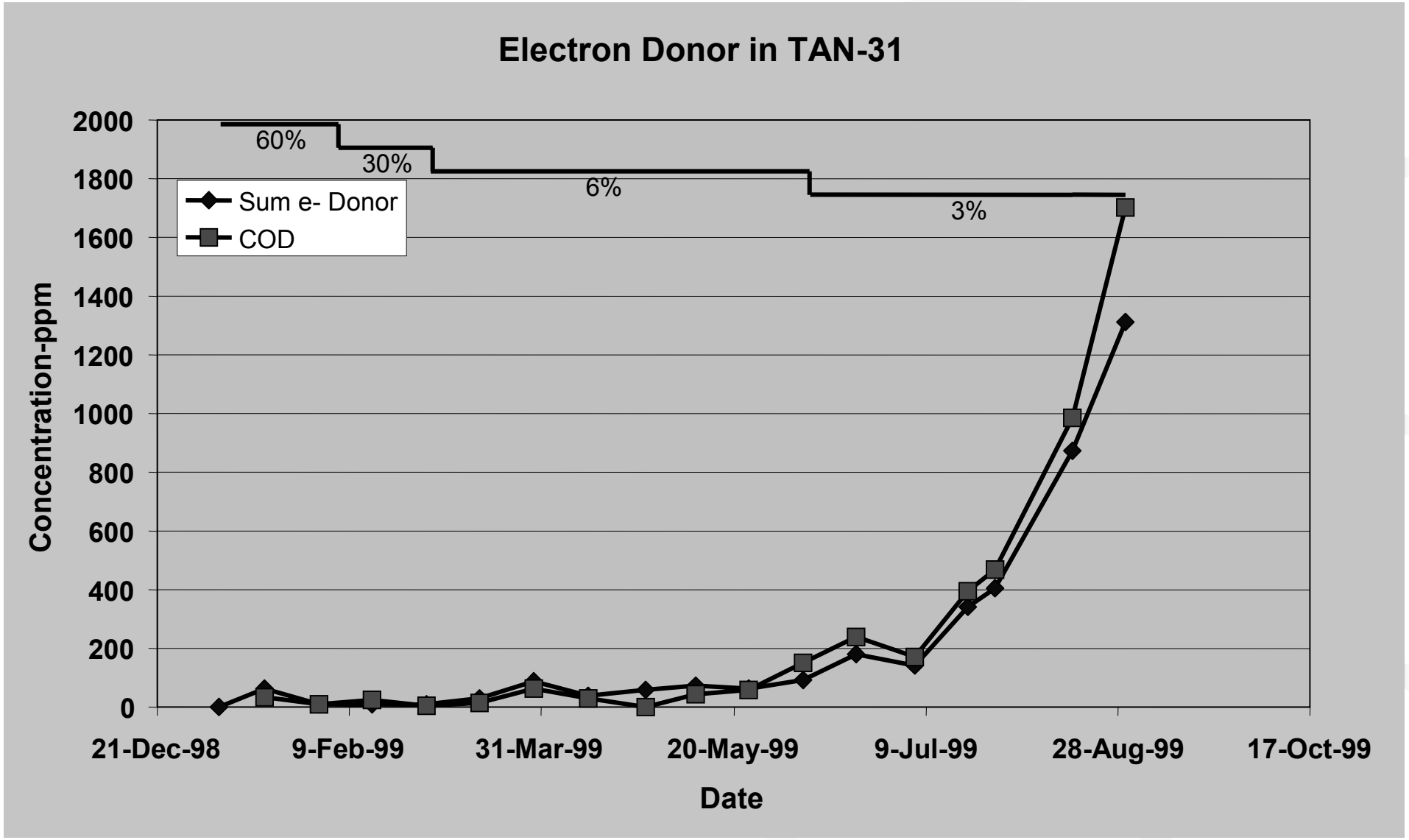
Field Evaluation Monitoring

- Biweekly sampling at 8 to 11 locations
- 19 Analyses per sample
  - Electron Donors/Nutrients: 5
  - Competing Electron Acceptors: 4
  - Biological Activity Indicators: 2
  - Contaminants and Daughter Products: 3
  - Water Quality: 4
  - Internal Tracer: 1
- Two major areas of cost savings:
  - Integration of field and in situ analyses with fixed lab analyses (only 5 fixed lab analyses)
  - Use of modified micropurging method for sampling

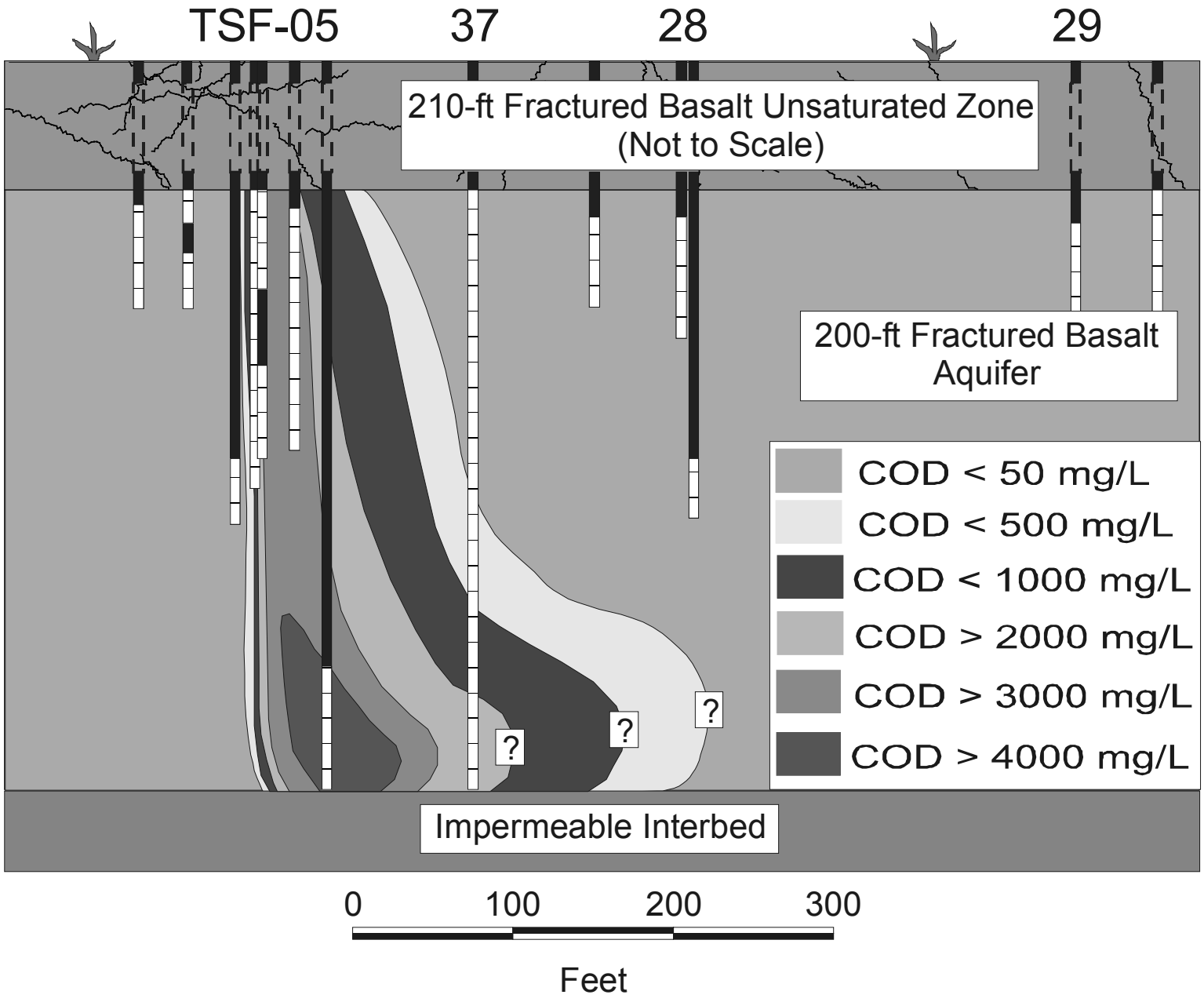
Electron Donor Addition

- Initial strategy: weekly injection of 300 gal of 60% sodium lactate solution into Well TSF-05 (January 1999)
- Potable water injected for 1 hour at 20 gpm to “flush” the injection well
- Subject to change based on monitoring
  - Feb. 2 - changed to 30%
  - Mar. 2 - changed to 6%
  - June 9 - changed to 3%
- No lactate addition after September 8, 1999

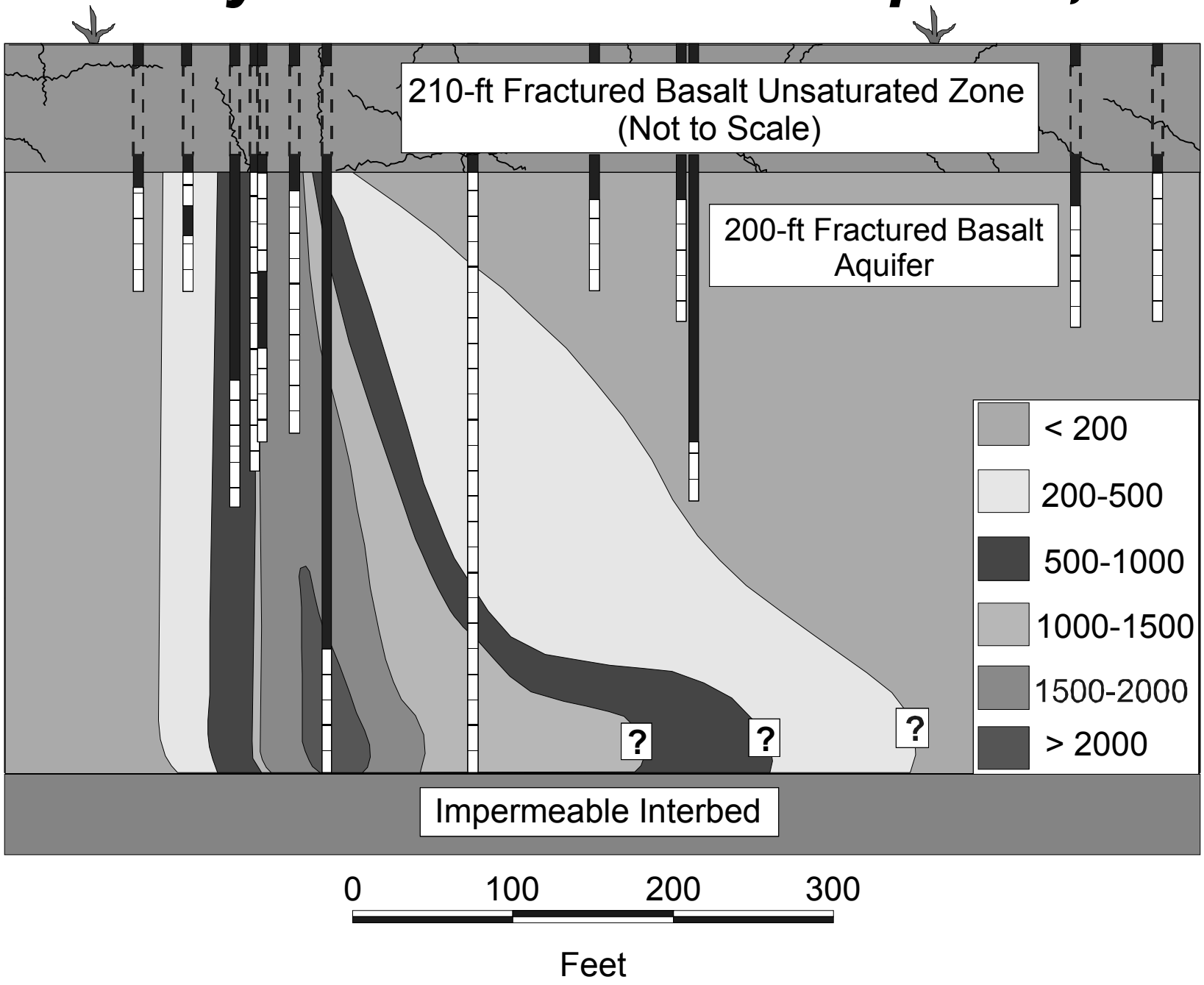

Electron Donor In TAN-25
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Concentration-ppm
60%
30%
6%
3%
COD
Sum e- Donor
21-Dec-98
9-Feb-99
31-Mar-99
20-May-99
9-Jul-99
28-Aug-99
17-Oct-99
Date

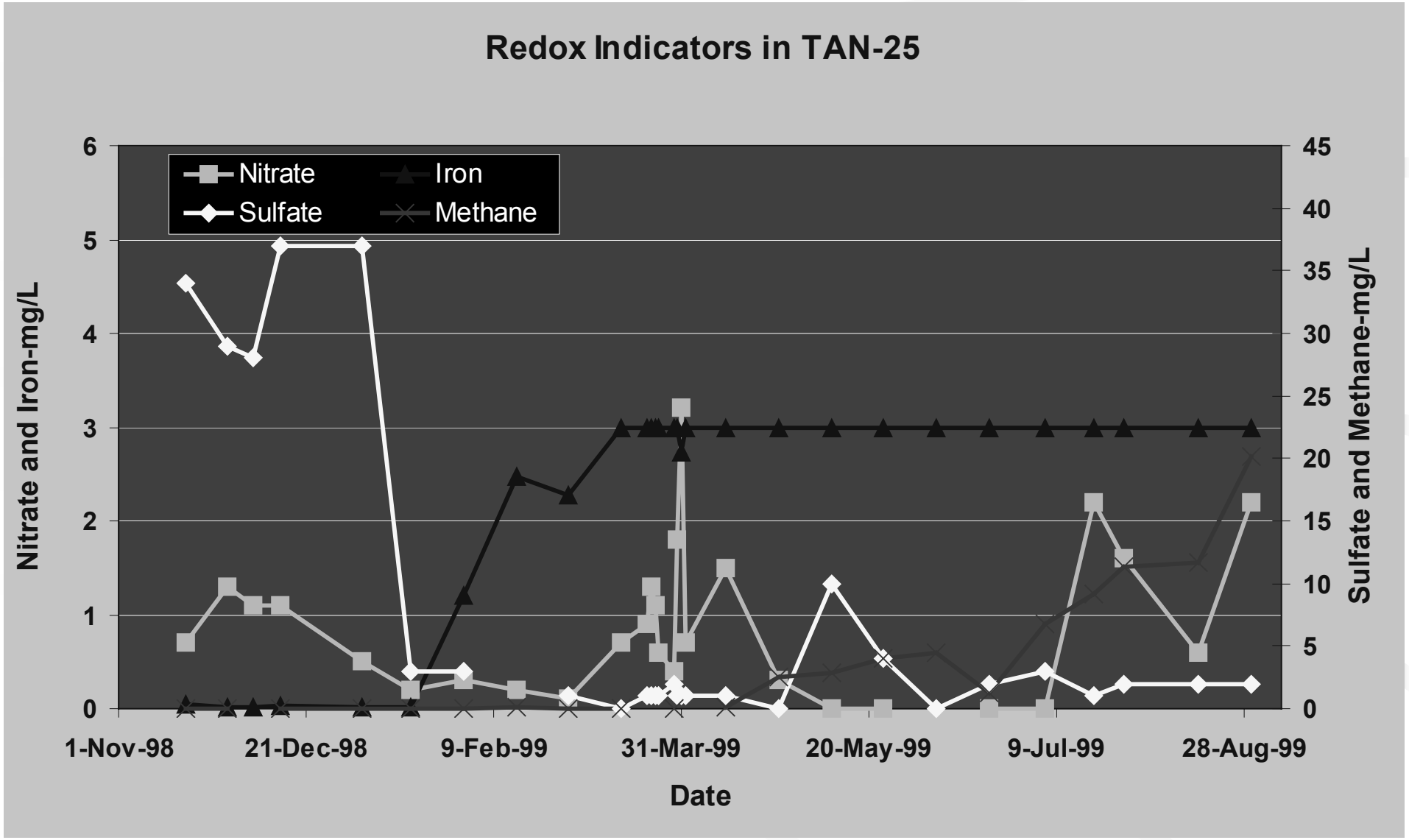

Electron Donor in TAN-31
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Concentration-ppm
60%
30%
6%
3%
Sum e- Donor
COD
21-Dec-98
9-Feb-99
31-Mar-99
20-May-99
9-Jul-99
28-Aug-99
17-Oct-99
Date

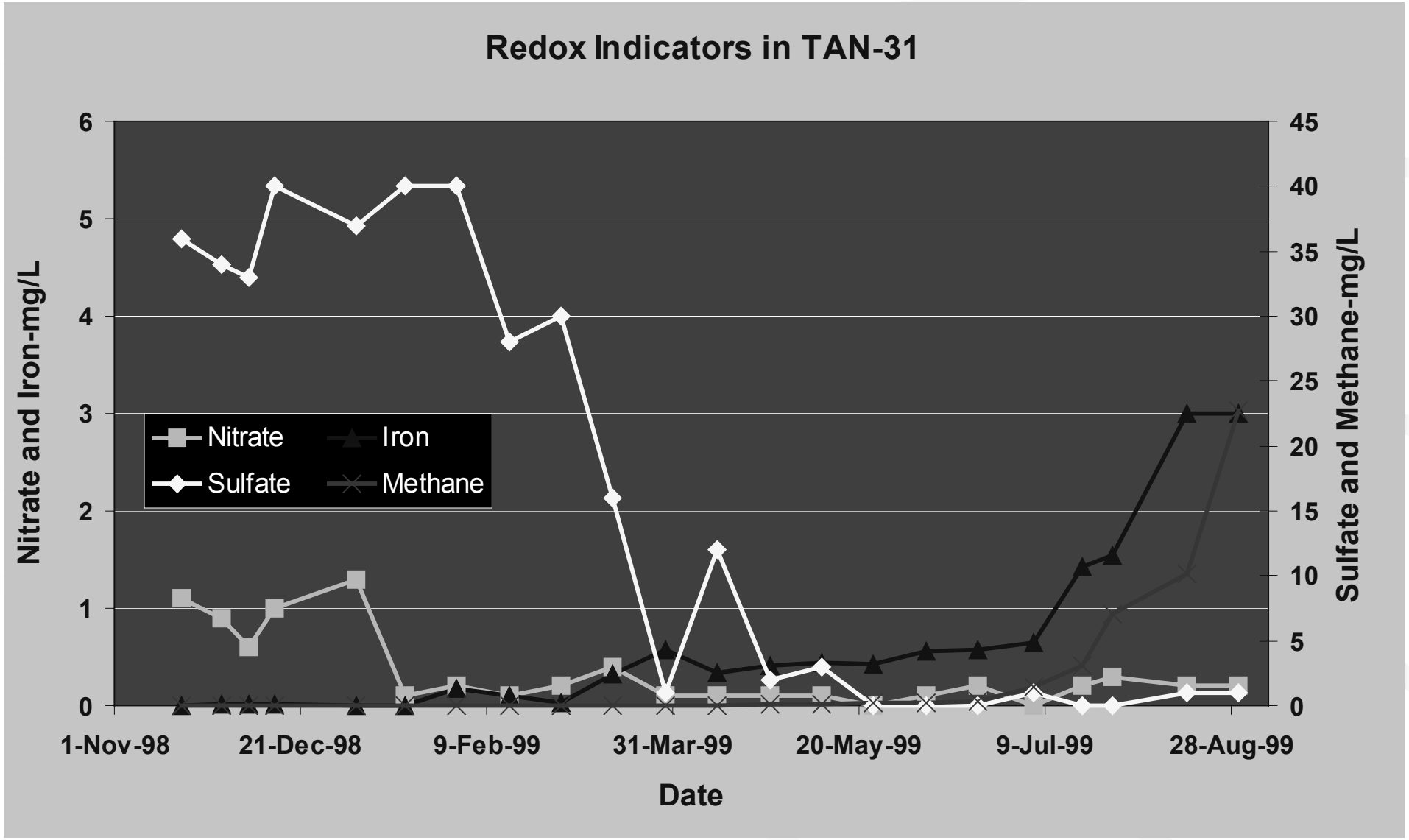
Chemical Oxygen Demand Sept. 13, 1999



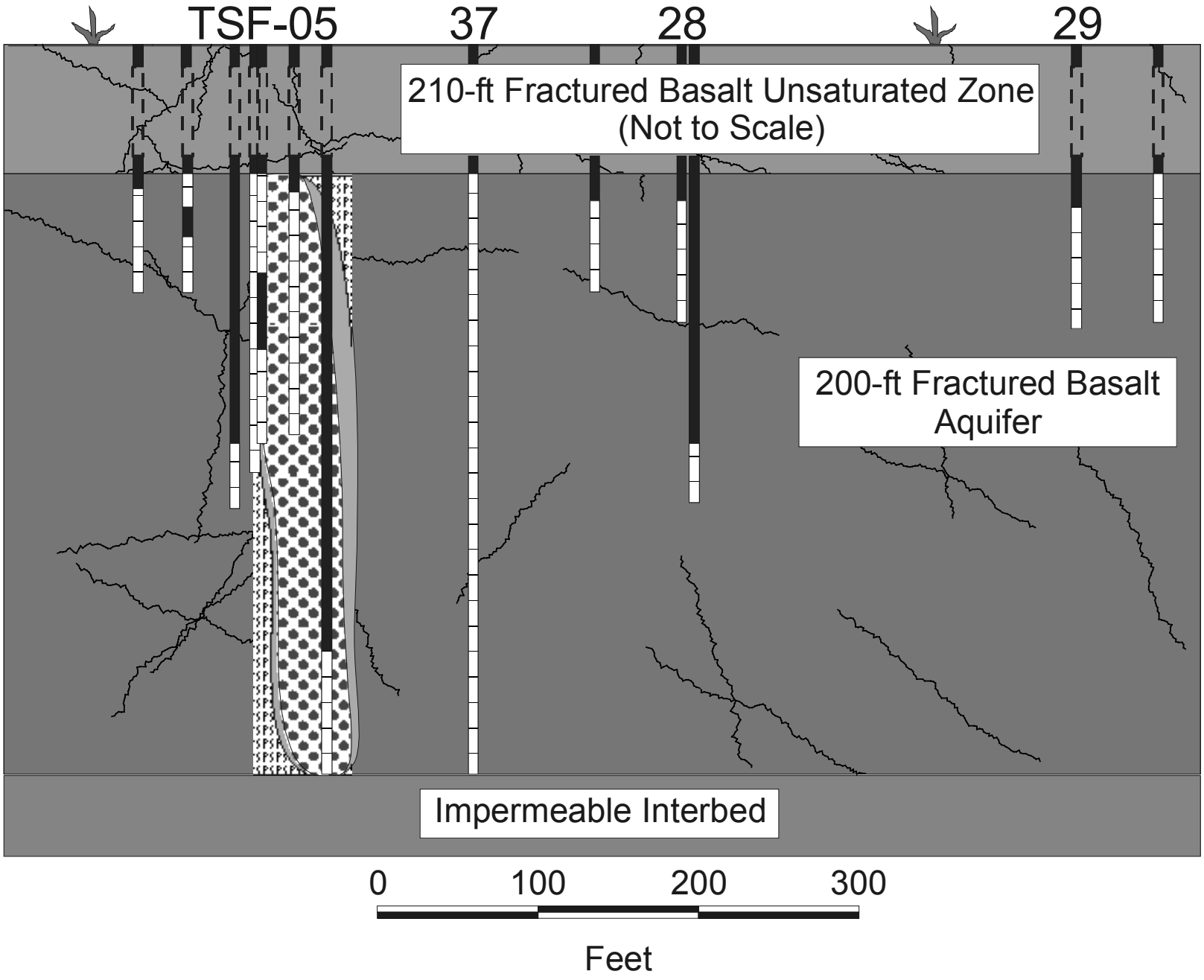
Alkalinity Concentrations Sept. 13, 1999



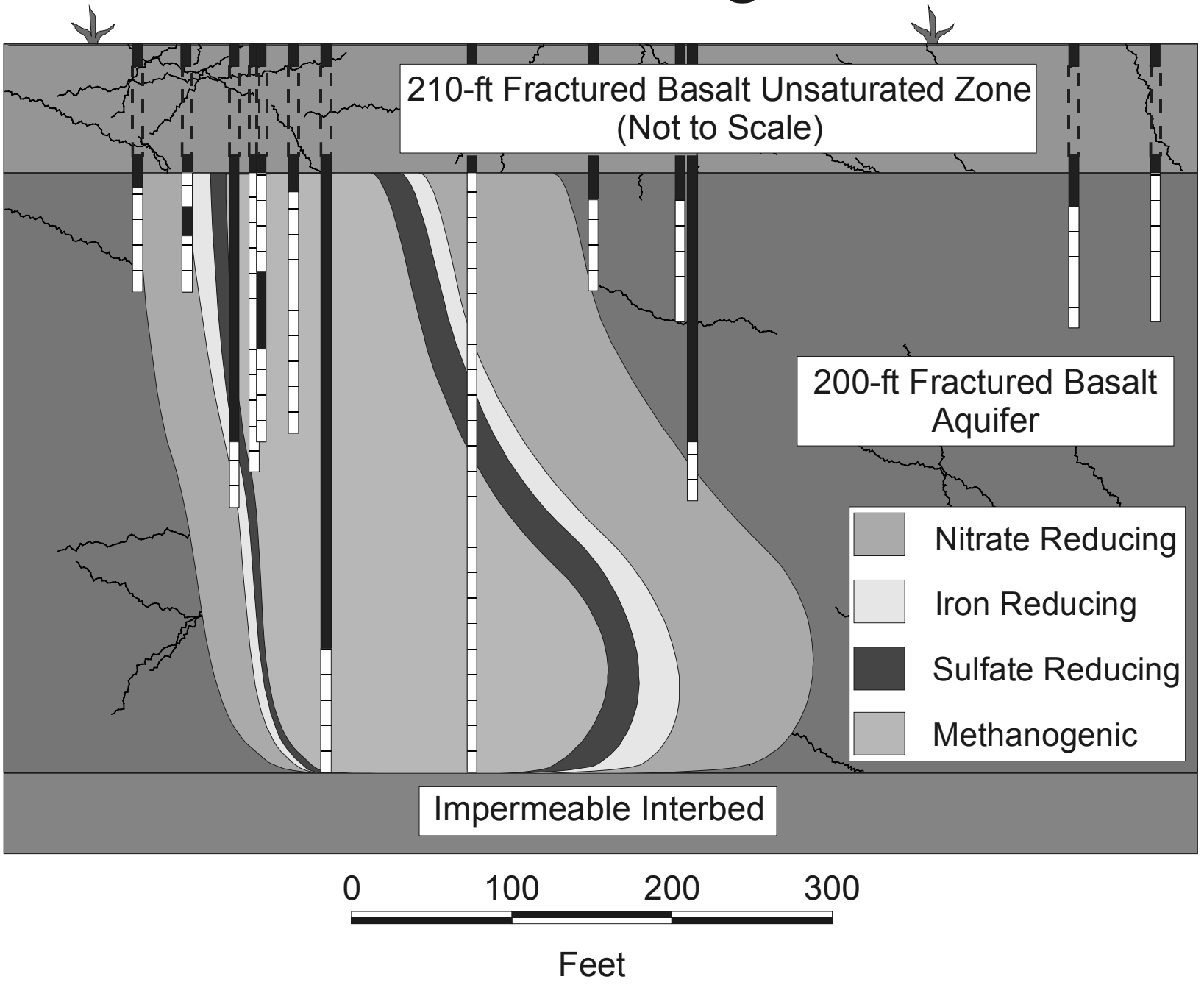

Redox Indicators in TAN-25
Nitrate
Iron
Sulfate
Methane
Nitrate and Iron-mg/L
Sulfate and Methane-mg/L
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
45
1-Nov-98
21-Dec-98
9-Feb-99
31-Mar-99
20-May-99
9-Jul-99
28-Aug-99
Date

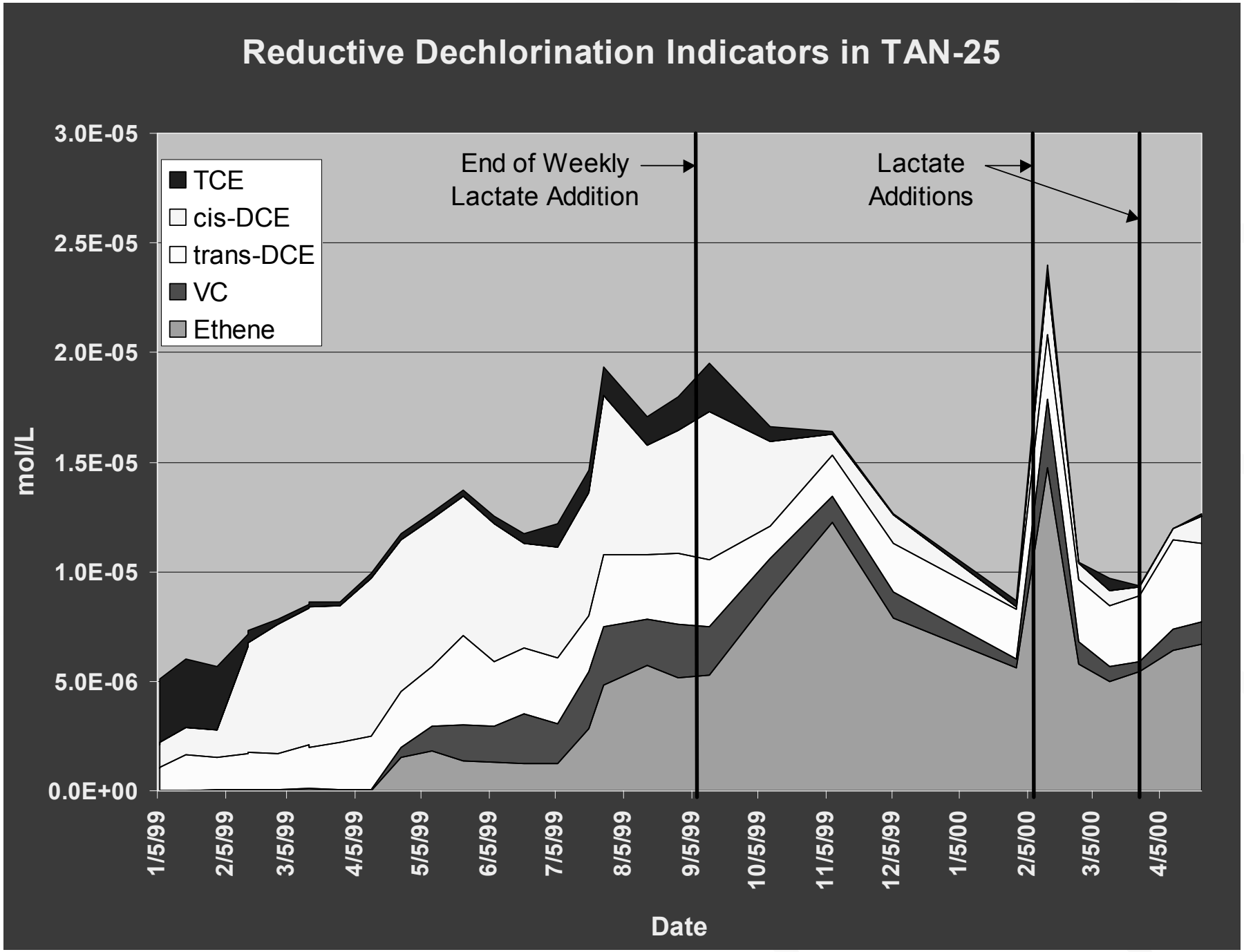

Redox Indicators in TAN-31
Nitrate and Iron-mg/L
Sulfate and Methane-mg/L
Nitrate
Iron
Sulfate
Methane
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
45
1-Nov-98
21-Dec-98
9-Feb-99
31-Mar-99
20-May-99
9-Jul-99
28-Aug-99
Date

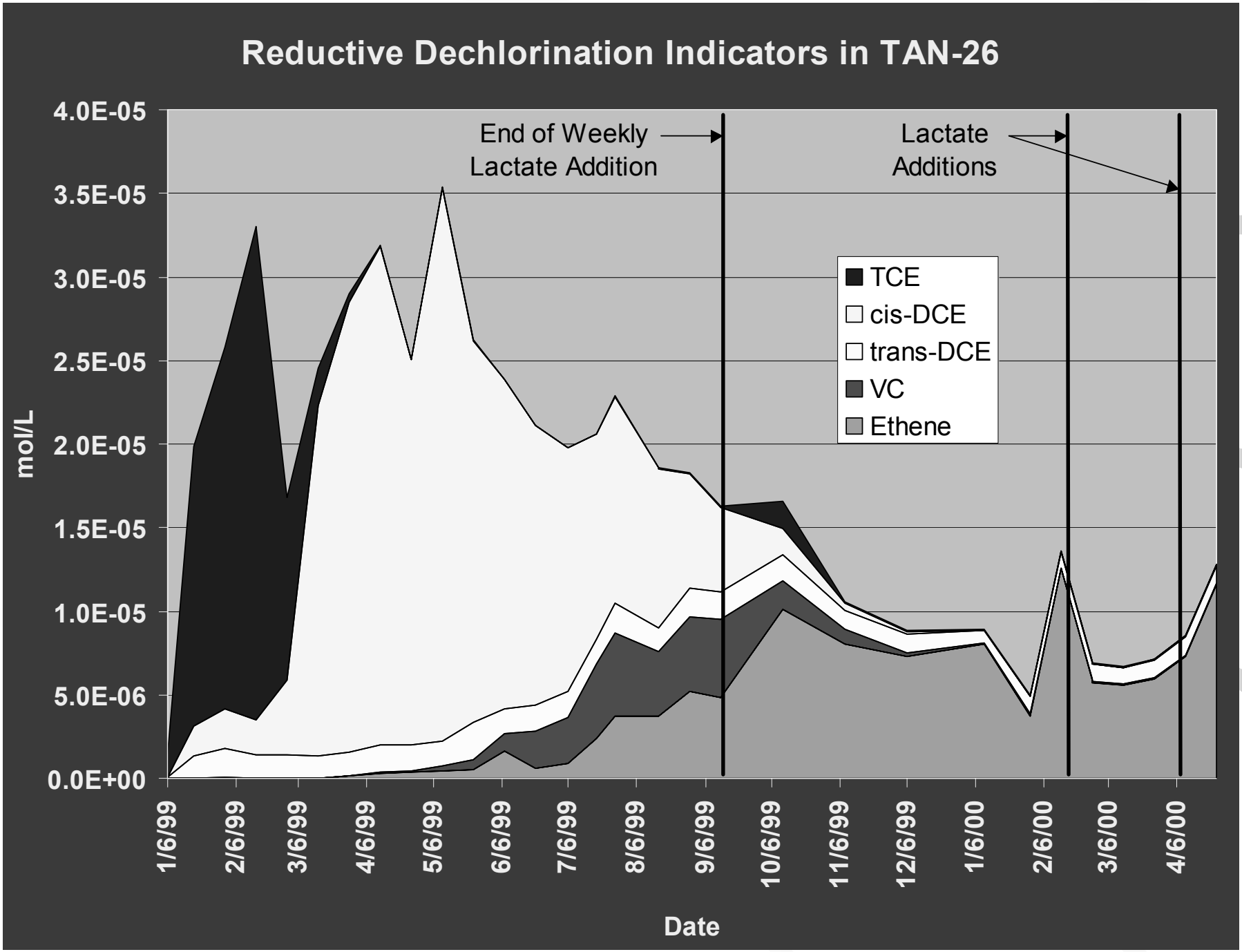
Initial Redox Conditions

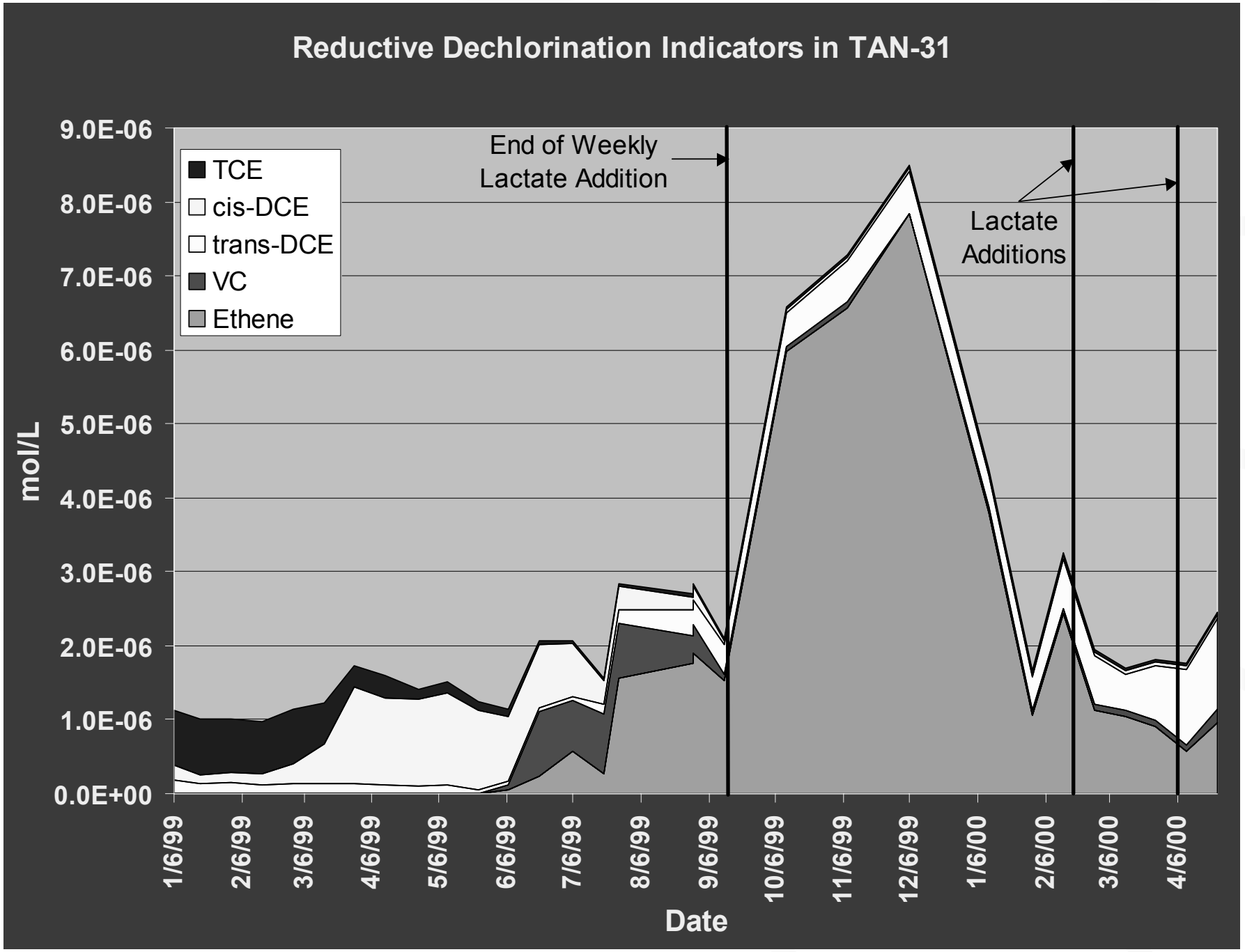


Redox Conditions August 30, 1999

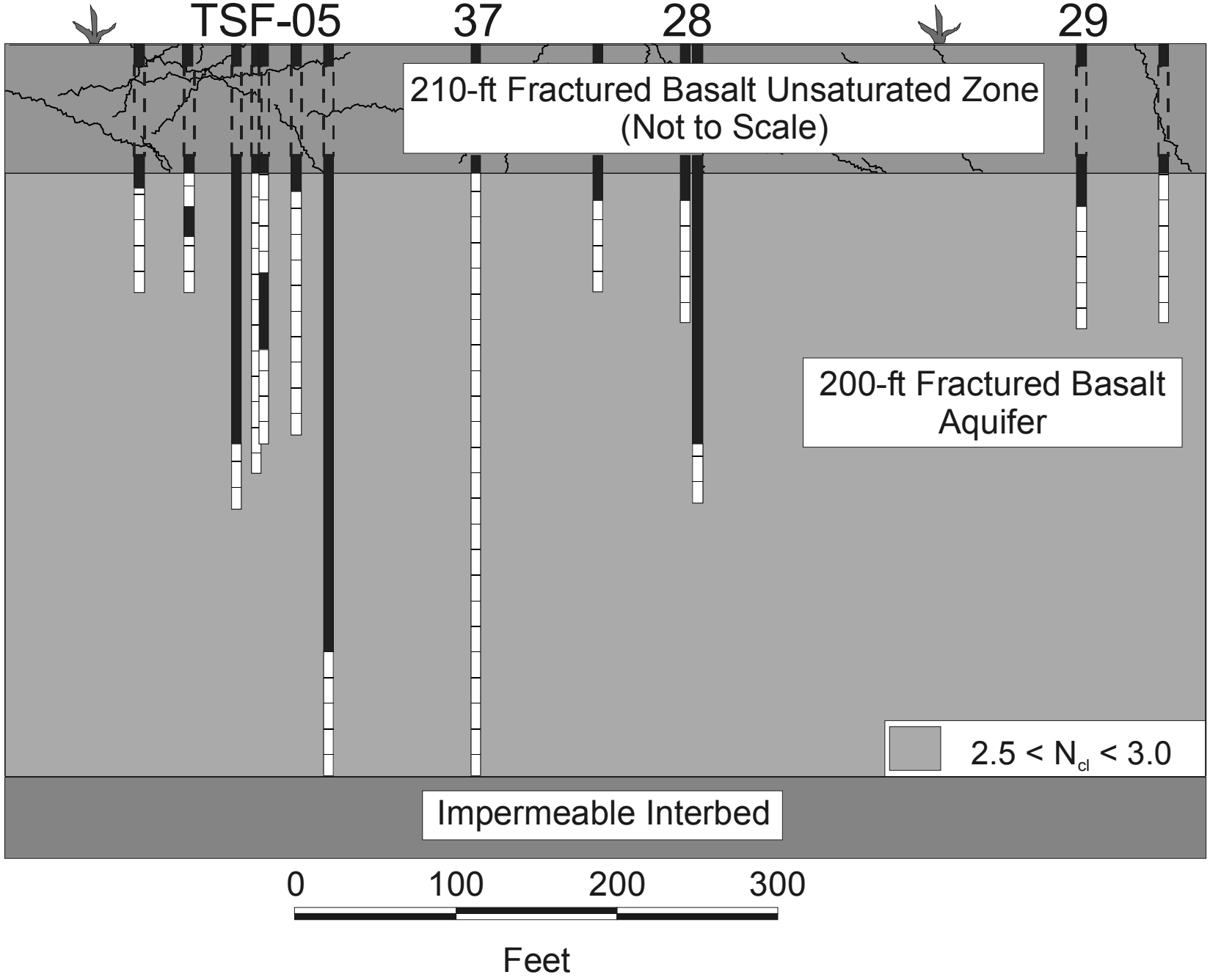



Reductive Dechlorination Indicators in TAN-25
TCE
cis-DCE
trans-DCE
VC
Ethene
End of Weekly Lactate Addition
Lactate Additions
mol/L
3.0E-05
2.5E-05
2.0E-05
1.5E-05
1.0E-05
5.0E-06
0.0E+00
1/5/99
2/5/99
3/5/99
4/5/99
5/5/99
6/5/99
7/5/99
8/5/99
9/5/99
10/5/99
11/5/99
12/5/99
1/5/00
2/5/00
3/5/00
4/5/00
Date

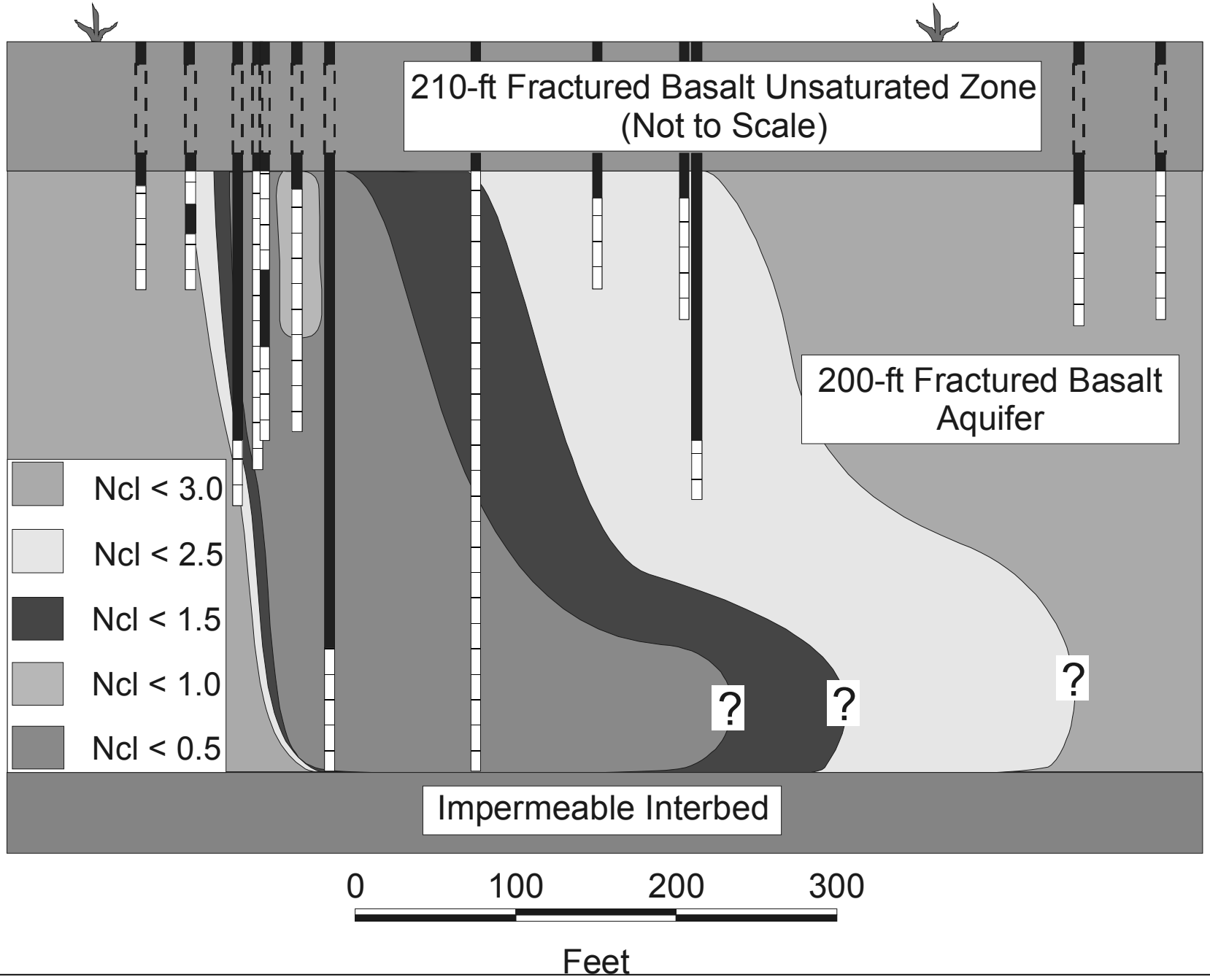

Reductive Dechlorination Indicators in TAN-26
End of Weekly Lactate Addition
Lactate Additions
TCE
cis-DCE
trans-DCE
VC
Ethene
mol/L
4.0E-05
3.5E-05
3.0E-05
2.5E-05
2.0E-05
1.5E-05
1.0E-05
5.0E-06
0.0E+00
1/6/99
2/6/99
3/6/99
4/6/99
5/6/99
6/6/99
7/6/99
8/6/99
9/6/99
10/6/99
11/6/99
12/6/99
1/6/00
2/6/00
3/6/00
4/6/00
Date


Reductive Dechlorination Indicators in TAN-31
9.0E-06
8.0E-06
7.0E-06
6.0E-06
5.0E-06
4.0E-06
3.0E-06
2.0E-06
1.0E-06
0.0E+00
mol/L
TCE
cis-DCE
trans-DCE
VC
Ethene
End of Weekly
Lactate Addition
Lactate
Additions
1/6/99
2/6/99
3/6/99
4/6/99
5/6/99
6/6/99
7/6/99
8/6/99
9/6/99
10/6/99
11/6/99
12/6/99
1/6/00
2/6/00
3/6/00
4/6/00
Date

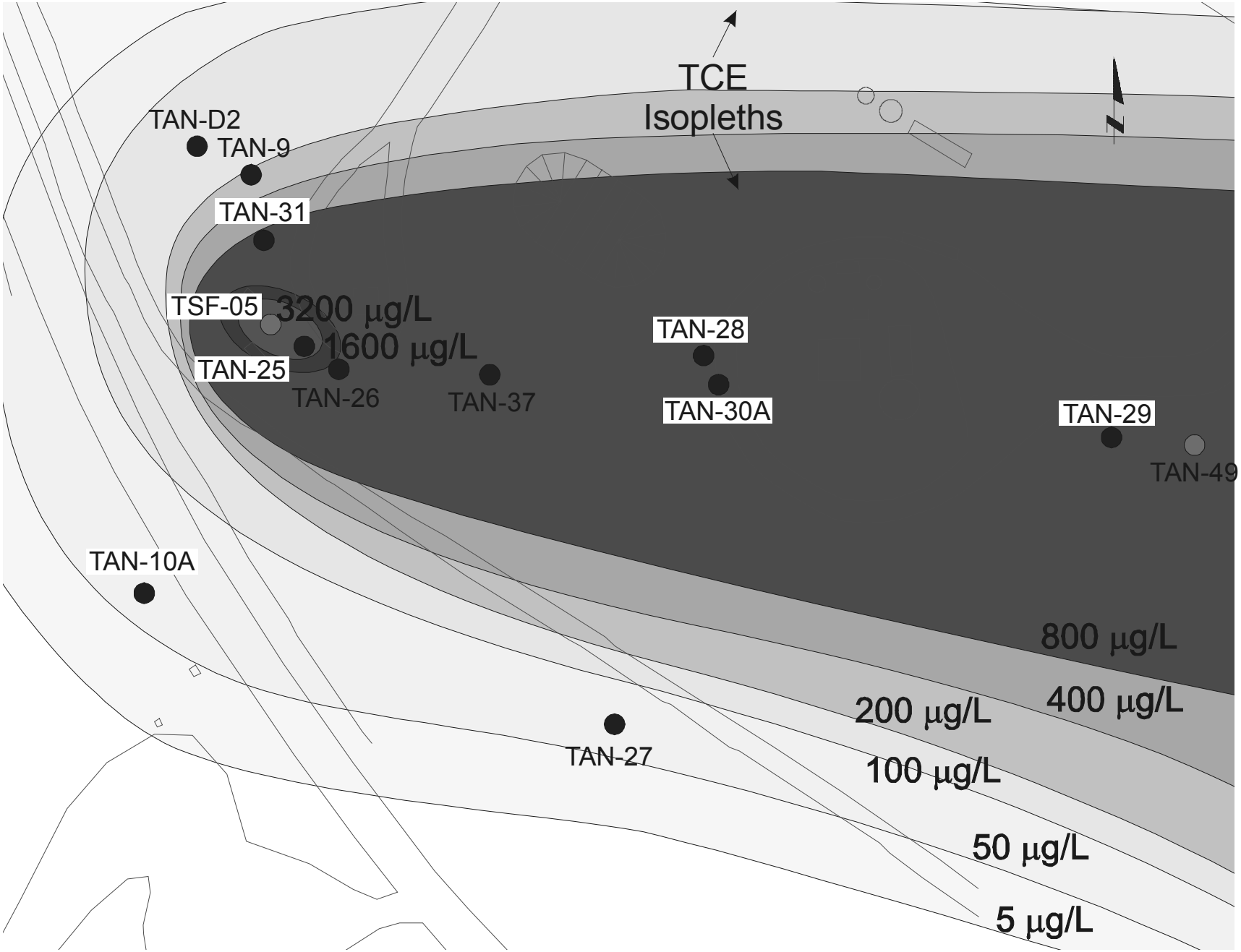
Initial Chlorine Numbers



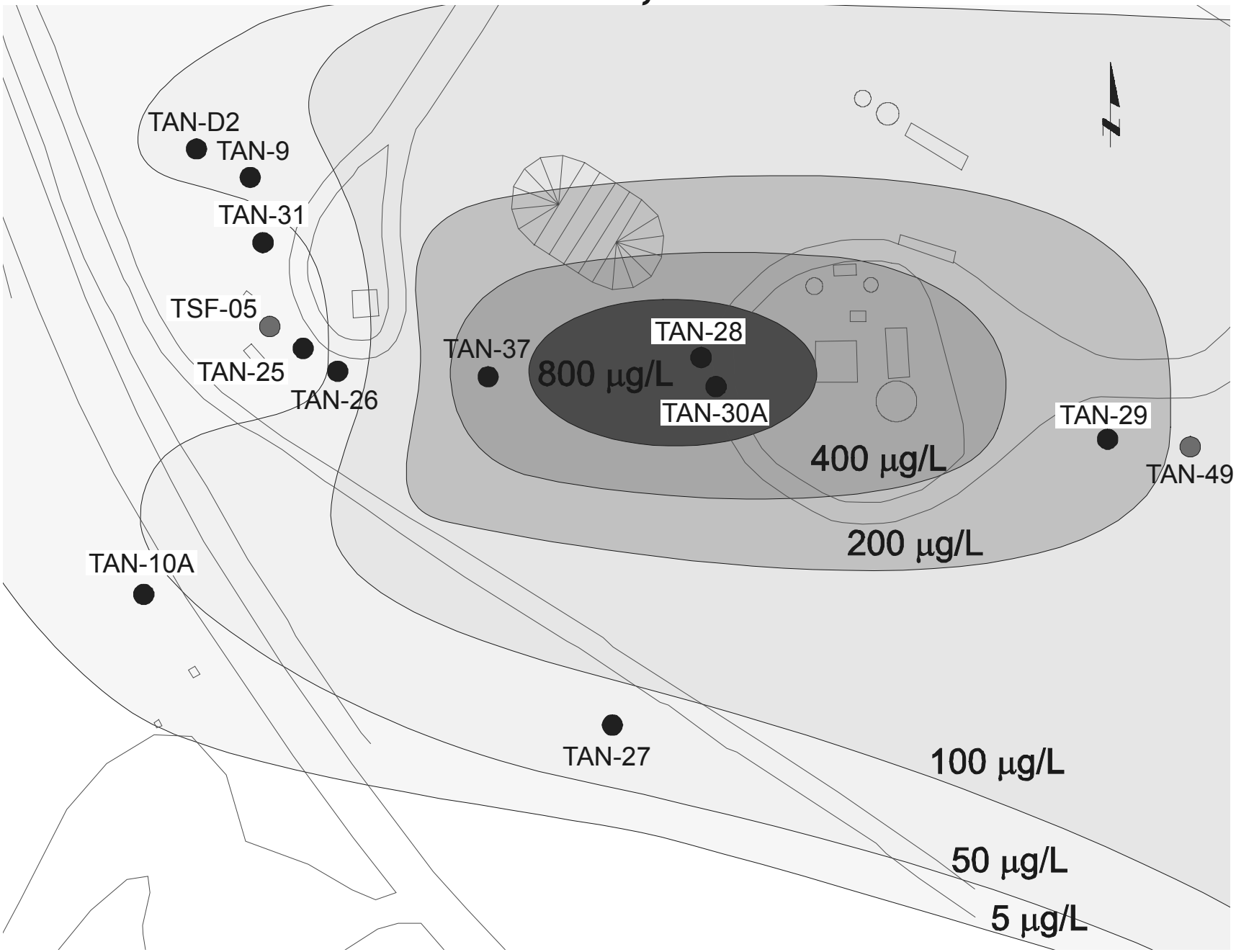
Chlorine Numbers January 10, 1999

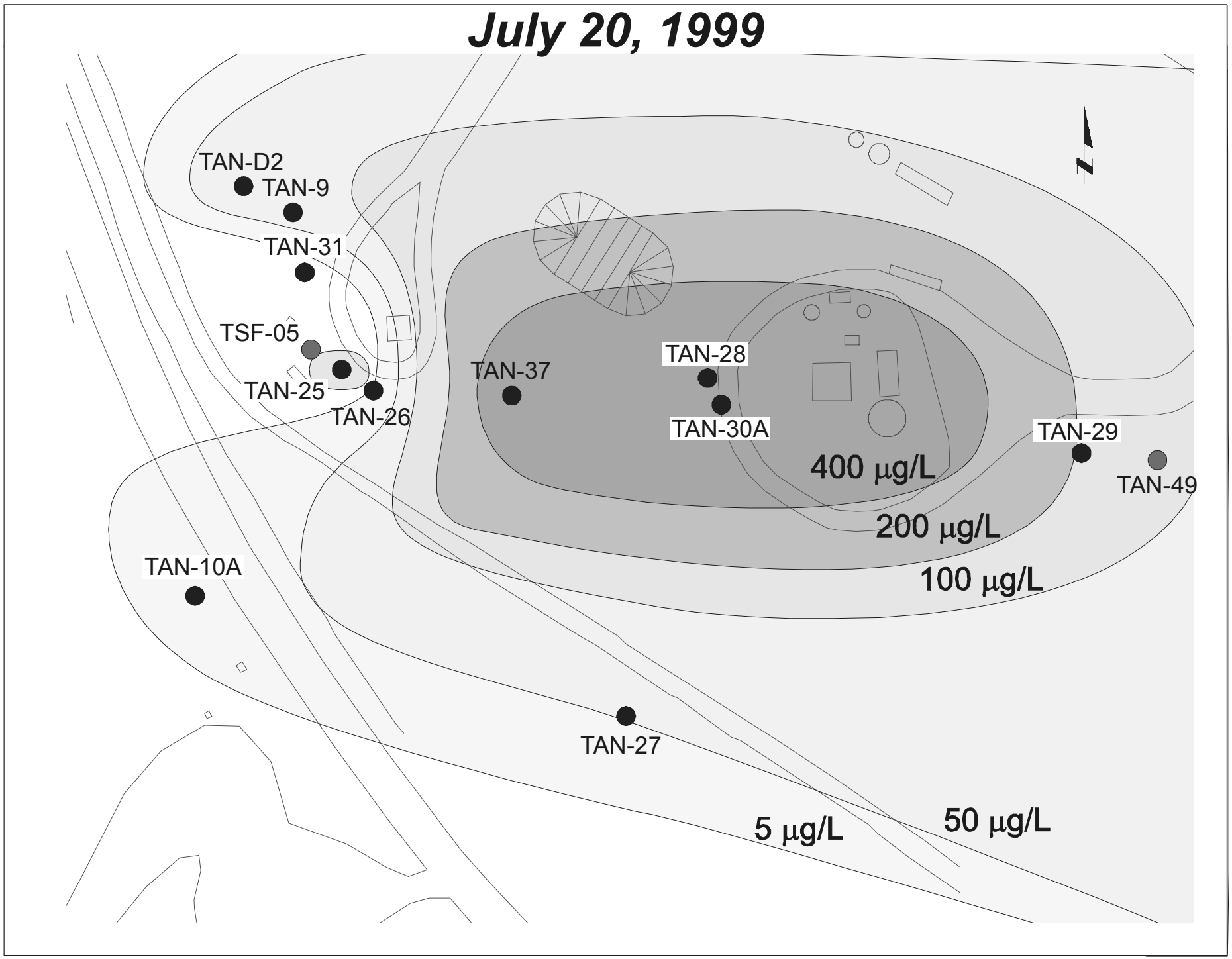


Pre-Lactate

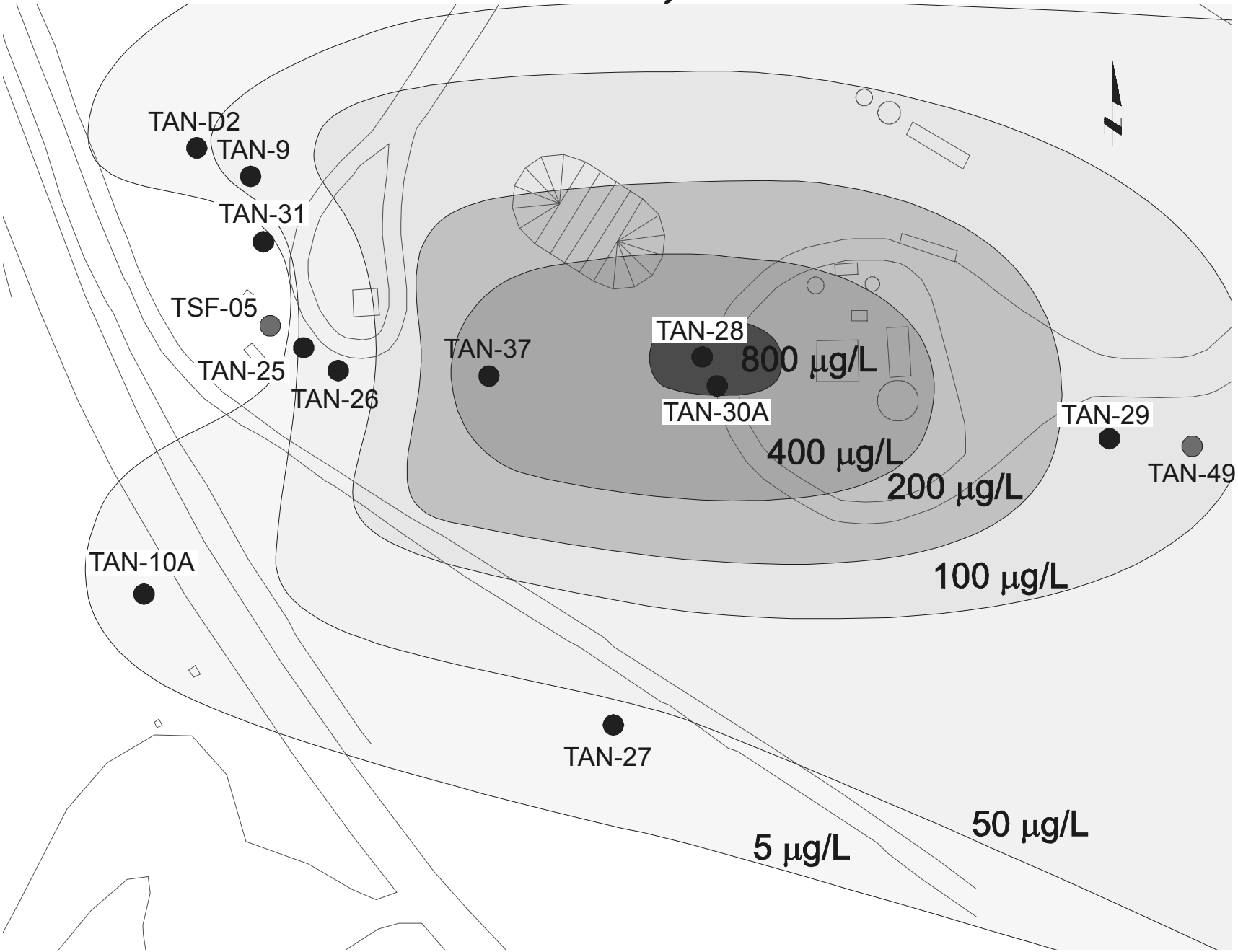

TCE
Isopleths
N
TAN-D2
TAN-9
TAN-31
TSF-05
3200 µg/L
1600 µg/L
TAN-25
TAN-26
TAN-37
TAN-28
TAN-30A
TAN-29
TAN-49
TAN-10A
TAN-27
800 µg/L
400 µg/L
200 µg/L
100 µg/L
50 µg/L
5 µg/L

March 29, 1999

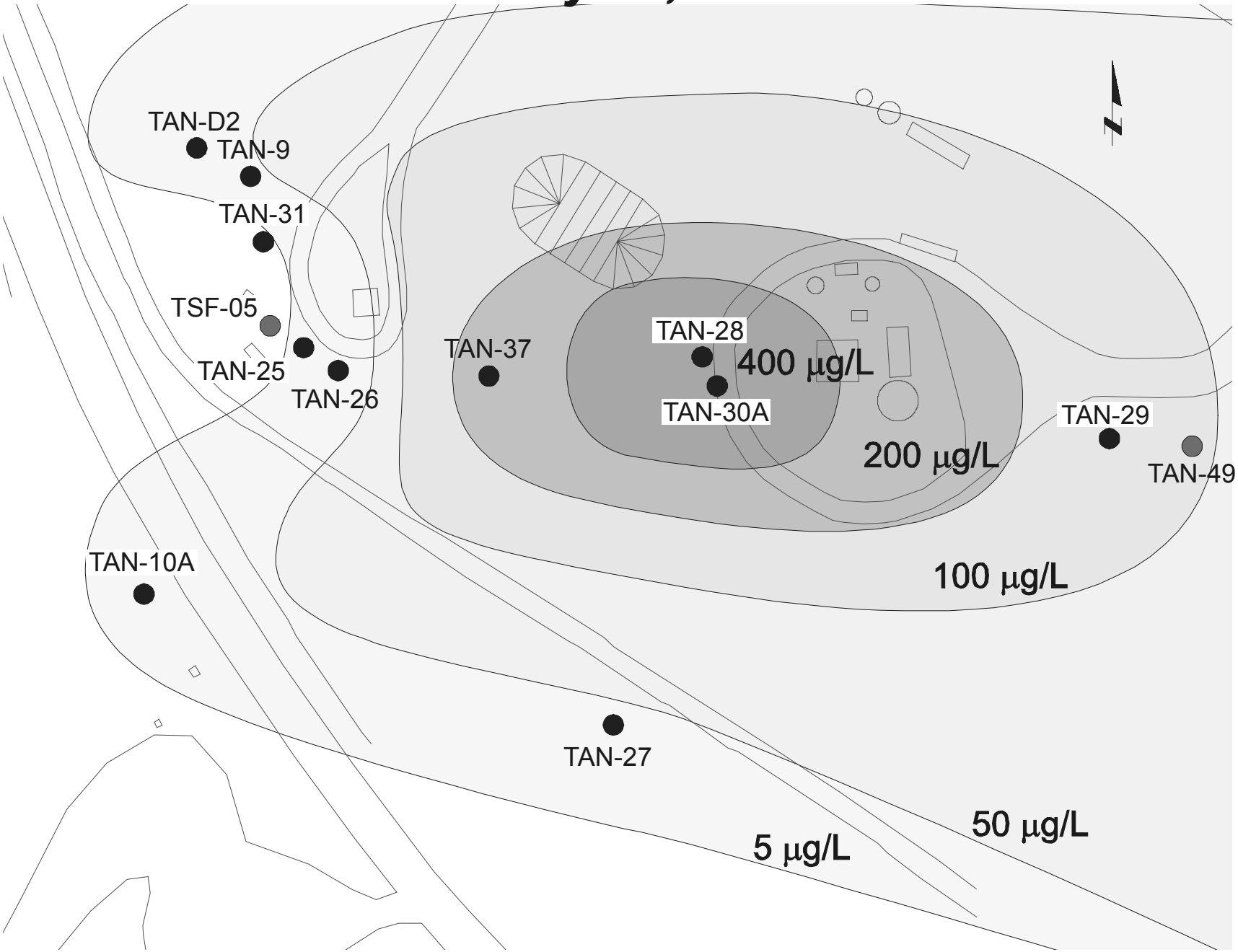


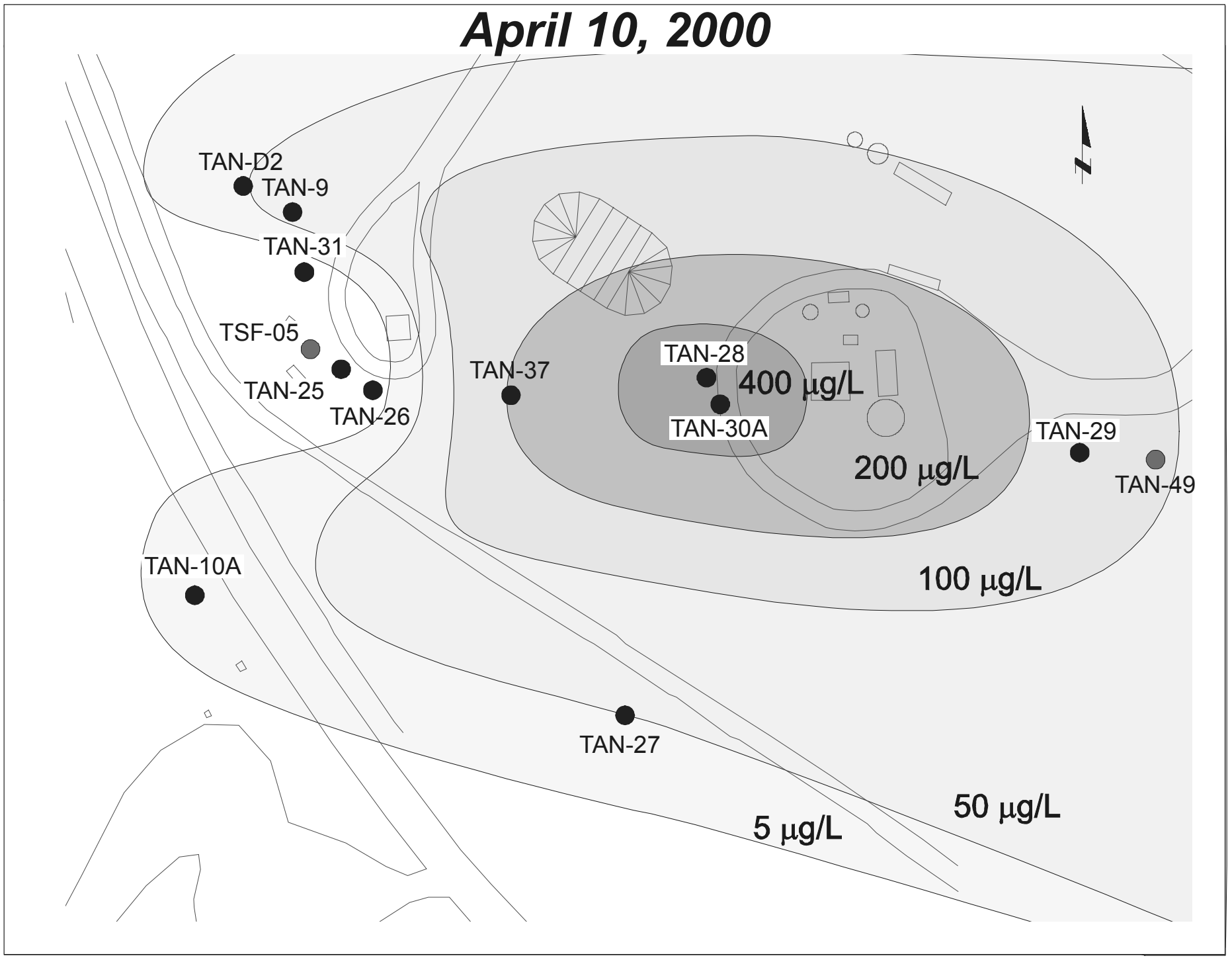

July 20, 1999
TAN-D2
TAN-9
TAN-31
TSF-05
TAN-25
TAN-26
TAN-37
TAN-28
TAN-30A
TAN-29
TAN-49
TAN-10A
TAN-27
400 µg/L
200 µg/L
100 µg/L
50 µg/L
5 µg/L
N

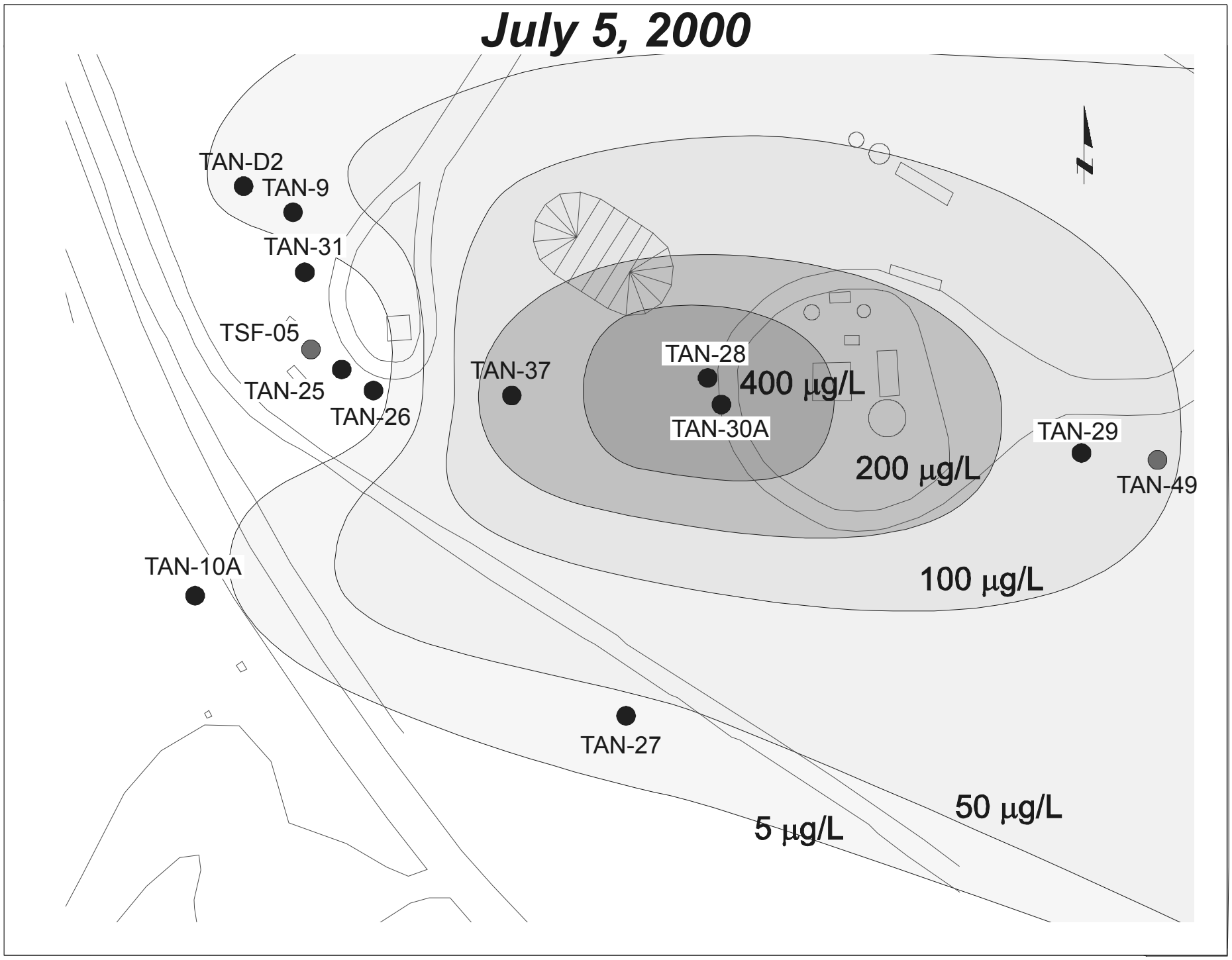
October 11, 1999



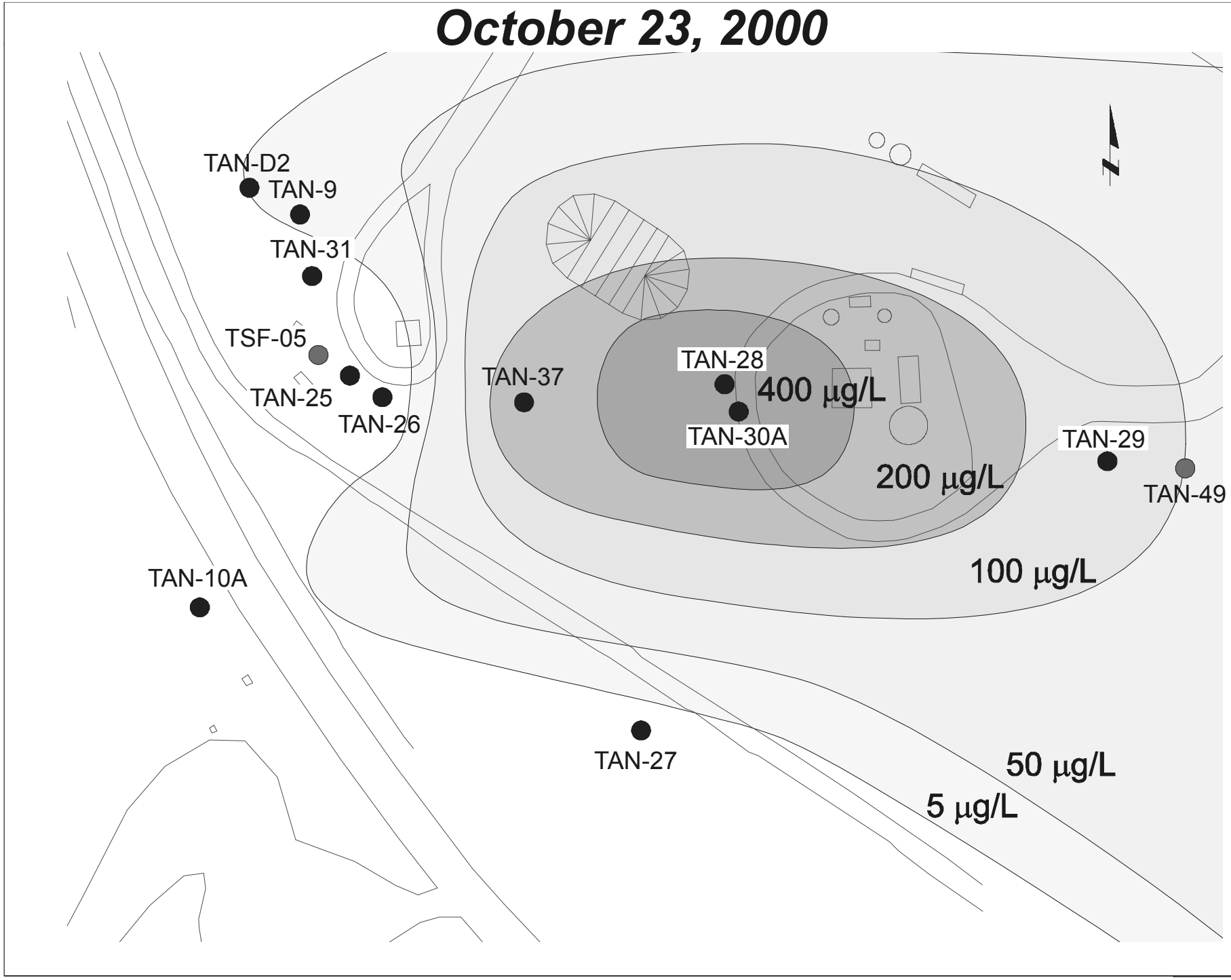
January 10, 2000




April 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
50 µg/L
5 µg/L
N


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
100 µg/L
TAN-10A
TAN-27
50 µg/L
5 µg/L

October 23, 2000



Lessons for Field Application of In Situ Bioremediation

- Dechlorination can be successful in complex settings and is strongly dependent on 2 things:
  - Redox conditions (competing electron acceptors)
  - Electron donor distribution and type

Lessons (cont.)

- Dechlorination efficiency may be affected by competition among microbial populations, the impact of which can be minimized with an appropriate addition strategy
- Field test kits are very cost-effective and provide near real-time data

Status of Enhanced In Situ Bioremediation at TAN

- Formal regulatory approval to implement bioremediation at the TAN source area as a replacement for the default remedy has been granted. A proposed plan is going out for public review and will be followed by a ROD amendment.
- Pre-design activities have begun.

Acknowledgments

- **Sampling and Analysis**: Marty Bartholomei, Jerry Batie, Heidi Bullock, Joe Lord, Jennifer Martin, Cathy Rae
- **Project Management**: Al Jantz, Joe Rothermel, Mark Shaw
- This work was performed under United States Department of Energy Idaho Operations Office Contract Number DE-AC07-94ID13223