Full-Scale Permanganate Remediation of a Solvent DNAPL Source Zone in a Sand Aquifer

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In Situ Treatment of Groundwater Contaminated
With Non-Aqueous Phase Liquids
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Collaborators

- Tom Al, University of New Brunswick
  - Inorganic Geochemistry
- Ramon Aravena, University of Waterloo
  - Isotope Geochemistry
- John Cherry, University of Waterloo

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This Case Study Will Show:

- **Density driven distribution of $KMnO_4$ in sand**
- **Performance assessment with minimal uncertainty**
- **Nearly complete destruction of TCE and 1,1,1-TCA**

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Two General Approaches for In Situ Oxidation

- Inject-and-withdraw (active)
  Flushing
- Inject-and-leave (passive)
  Episodic Injection

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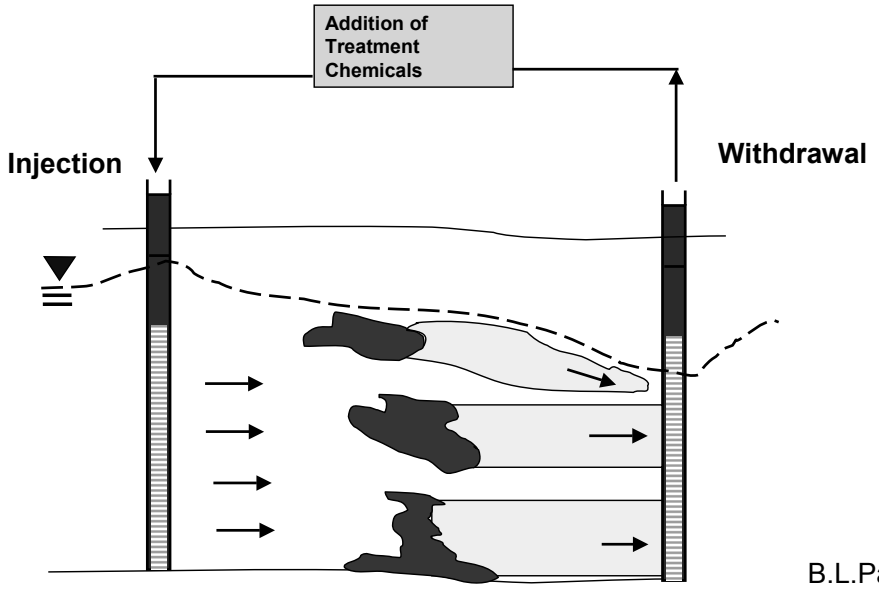
The Active Approach



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B.L.Parker

The Waterloo Passive Approach

- Use density and dispersion effects to distribute permanganate solution
- Inject in a manner that minimizes groundwater displacement

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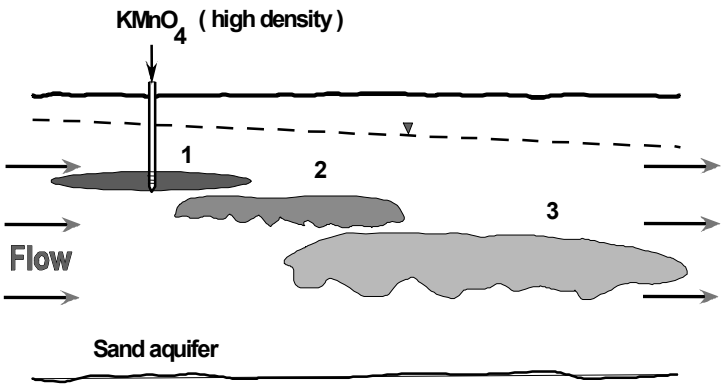
The Waterloo Passive Approach

Relies on density and dispersion effects



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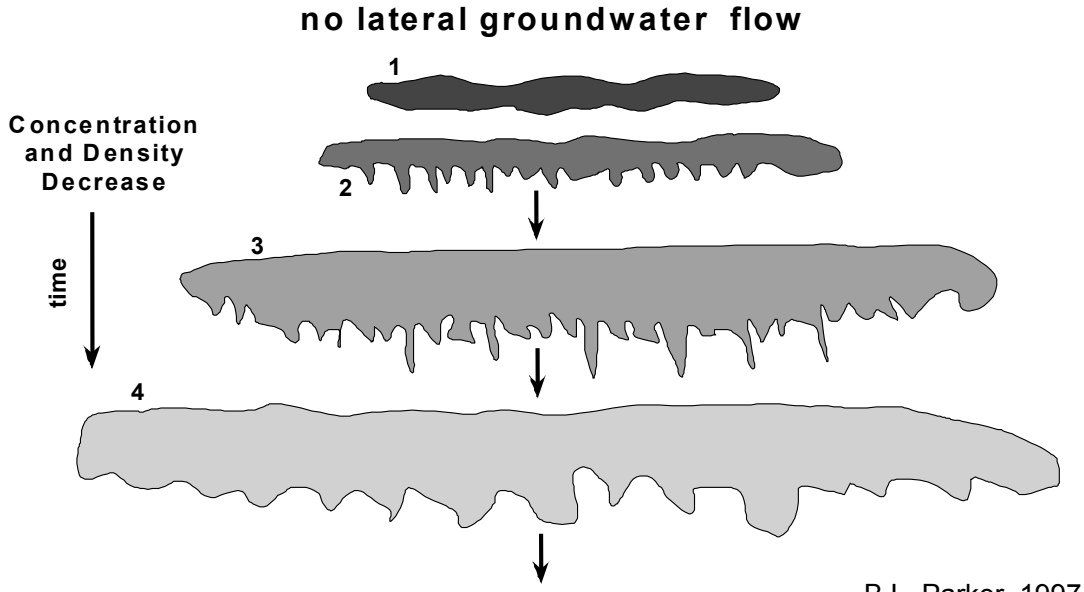
B.L.Parker, 1997

Evolution of a Single Disc in a Sand Aquifer



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B.L. Parker, 1997

Initial Proof - of - Concept

Inject-and-Leave Field Trial in Borden Aquifer

Matthew Nelson M.Sc. Thesis (1999)
Supervisors: Drs. Beth Parker and John Cherry
University of Waterloo

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Borden 9x9 m Sheet Pile Enclosure

10

System Set-up at 9m Cell Borden Site

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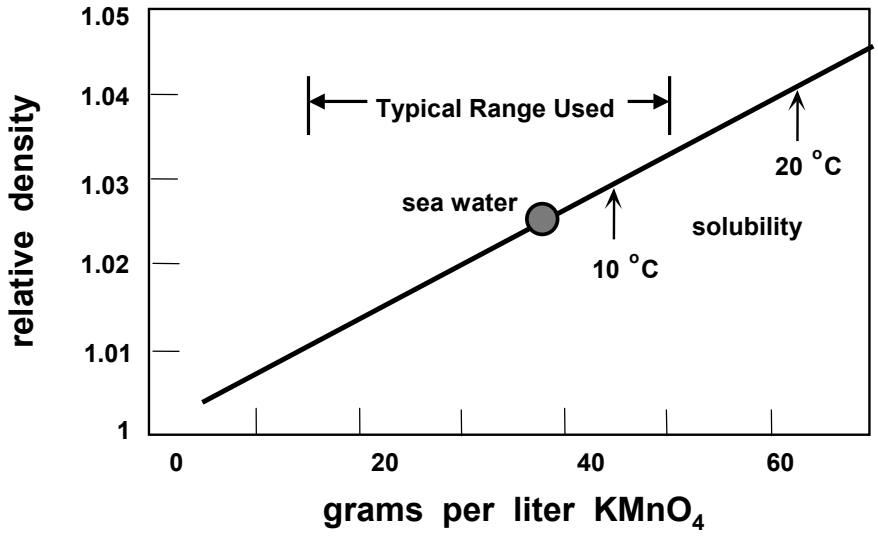
Density of Dissolved $KMnO_4$ in Water



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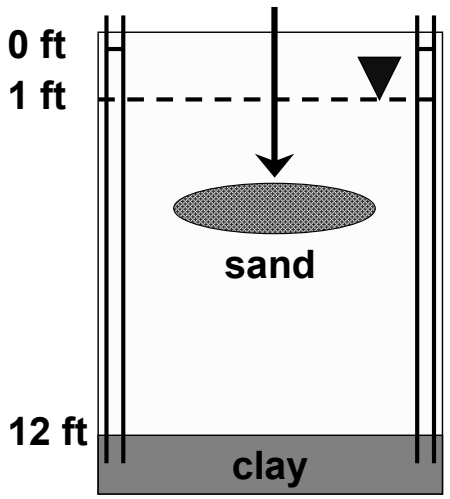
SETTING



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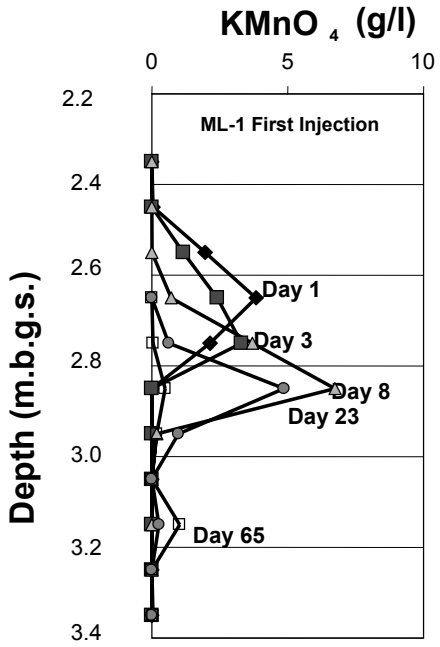
Evidence for Density Induced Flow



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(Nelson, 1999)

The Waterloo Passive Approach

- Use density and dispersion effects to distribute permanganate solution

➡ • Inject in a manner that minimizes groundwater displacement

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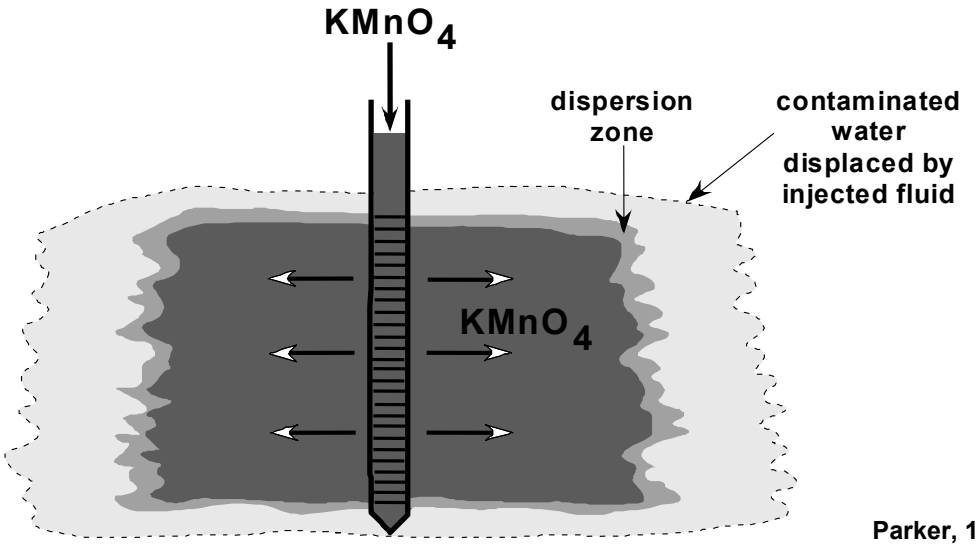
Long-Screen Injection Causes Large Displacement of Contaminated Water



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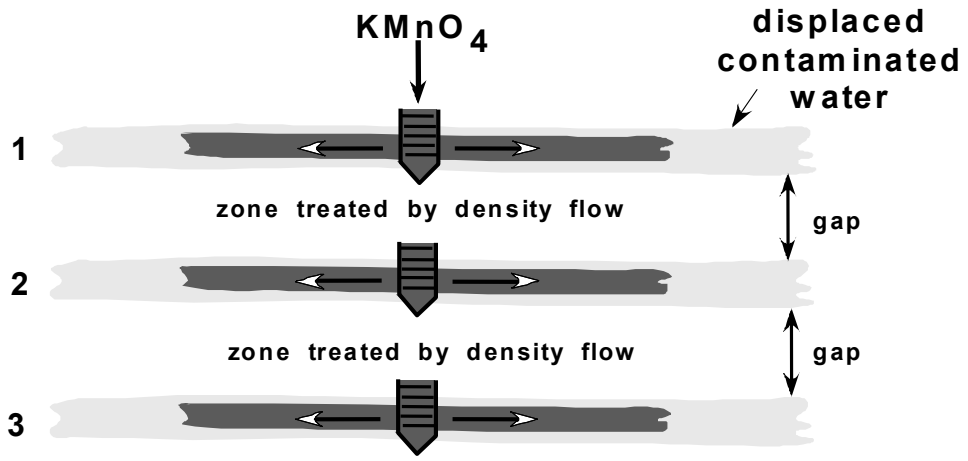
Parker, 1997

Injection of Discs Leaving Gaps Minimizes Displacement of Contaminated Water



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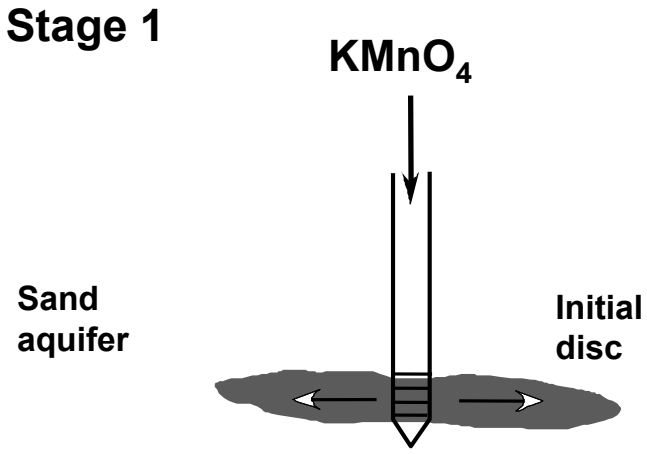
Parker, 1997

Injection of Multiple Discs Using Direct Push Device



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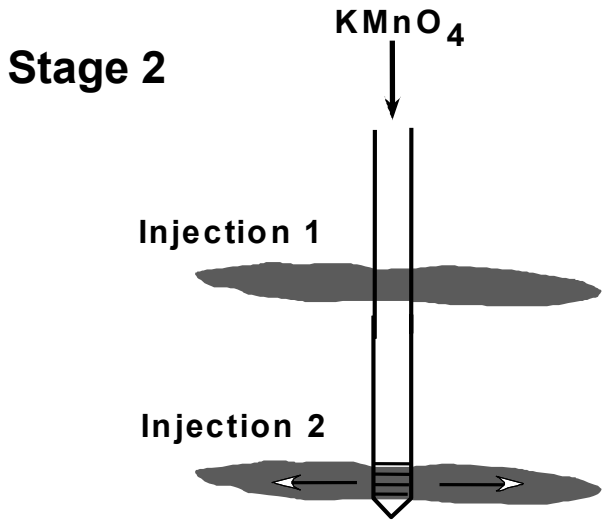
Parker, 1997

Injection of Multiple Discs Using Direct Push Device



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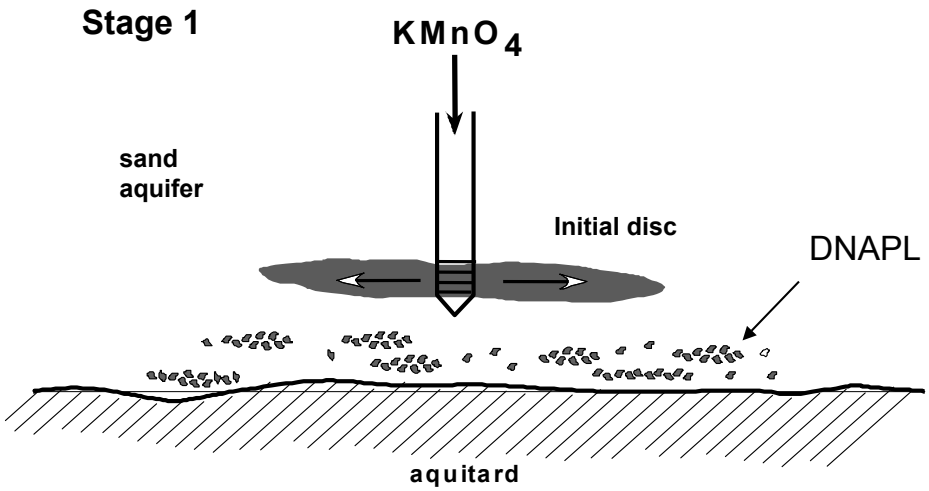
Parker, 1997

Stage 1: Inject Disc Above DNAPL on Aquitard



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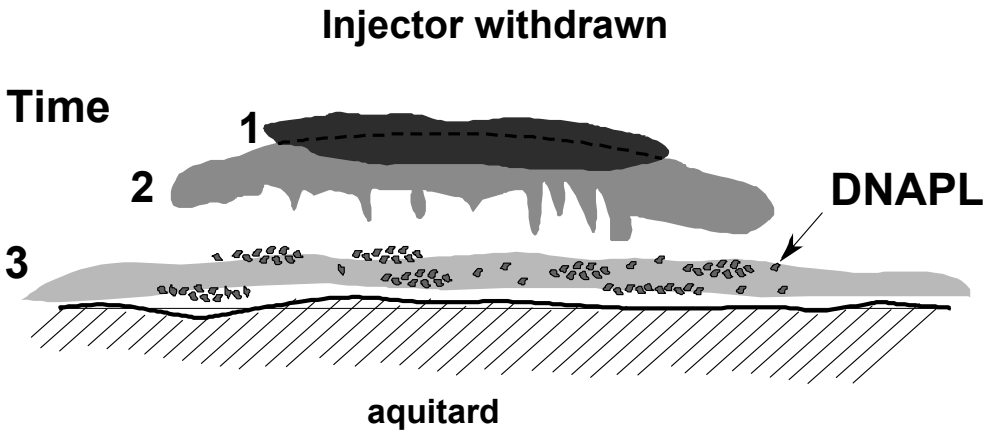
Parker, 1997

Disc Sinks and Spreads



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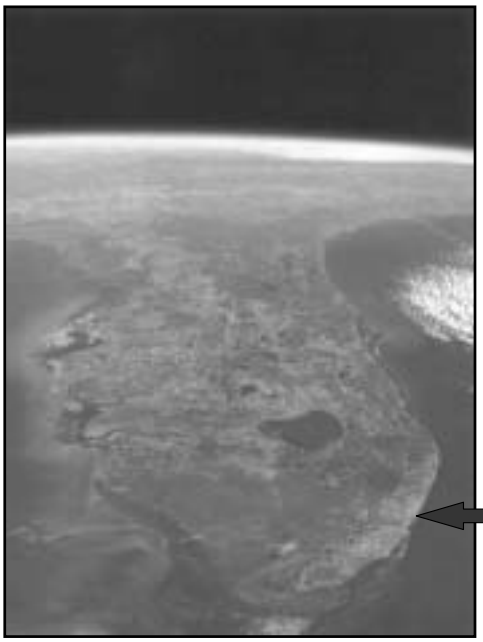
Parker, 1997

Case Study in Florida



TCE and TCA source zone

Site

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Ft. Lauderdale Site

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Picture 0564

Contamination Occurred Recently
late 1996 to early 1997

- TCA used: 1995-96
- Switch from TCA to TCE: Nov 1996 - April 1997
- Conventional monitoring wells installed: 1997
- Fenton's treatment pilot study: 1998-1999
- UW bundle multi-levels installed: 1999
  - Fenton's performance assessment
- Permanganate selected as source removal action for permanent remedy

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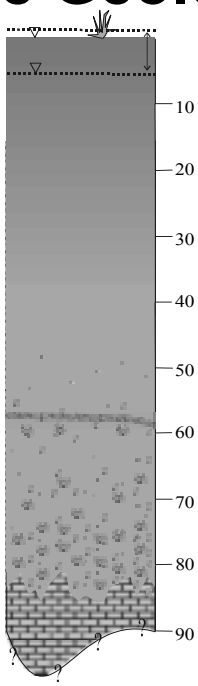
Site Geology



Fine and medium grained beach sand with no visible layering

8-inch coarse sand layer 57 ft bgs

Increased frequency of gravel size carbonate rock fragments

Carbonate bedrock 85 ft bgs

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Monitoring Methods

Focus on depth-discrete methods

- Continuous Cores
- Bundle tube samplers
- Waterloo Profiler
- Conventional Monitoring Wells
- Micro-monitoring Wells

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Core Being Removed from Piston Core Barrel

Aluminum core tube inside core barrel

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Cutting the Aluminum Core Tube

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Subsampling Sand for VOC Analysis

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Installation of Bundle Tube Sampler: 1999

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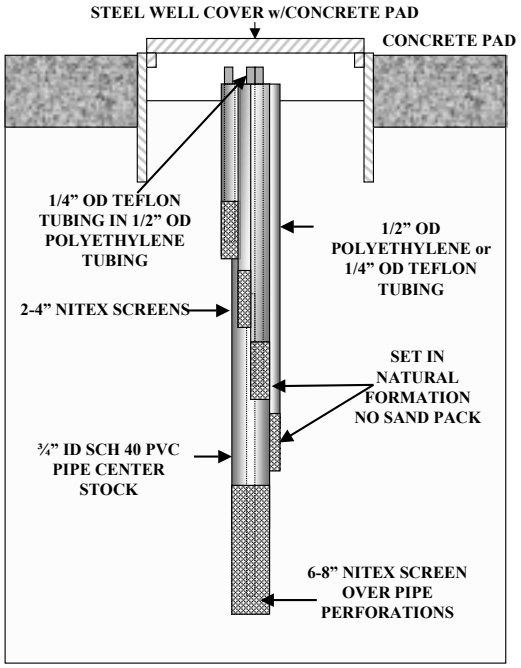
Bundle Tube Sampler



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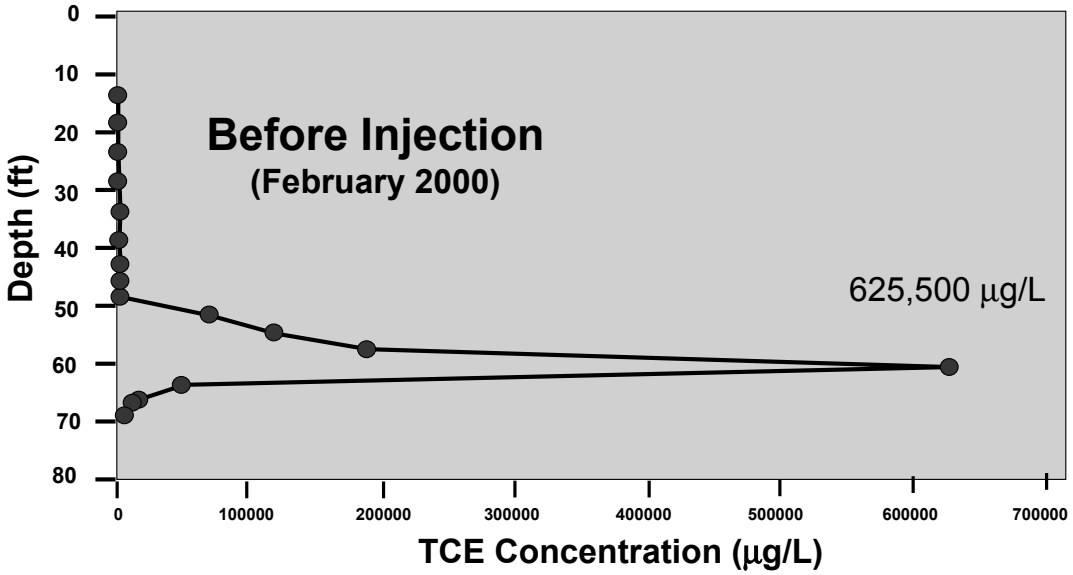
TCE Concentration Profile CW-L



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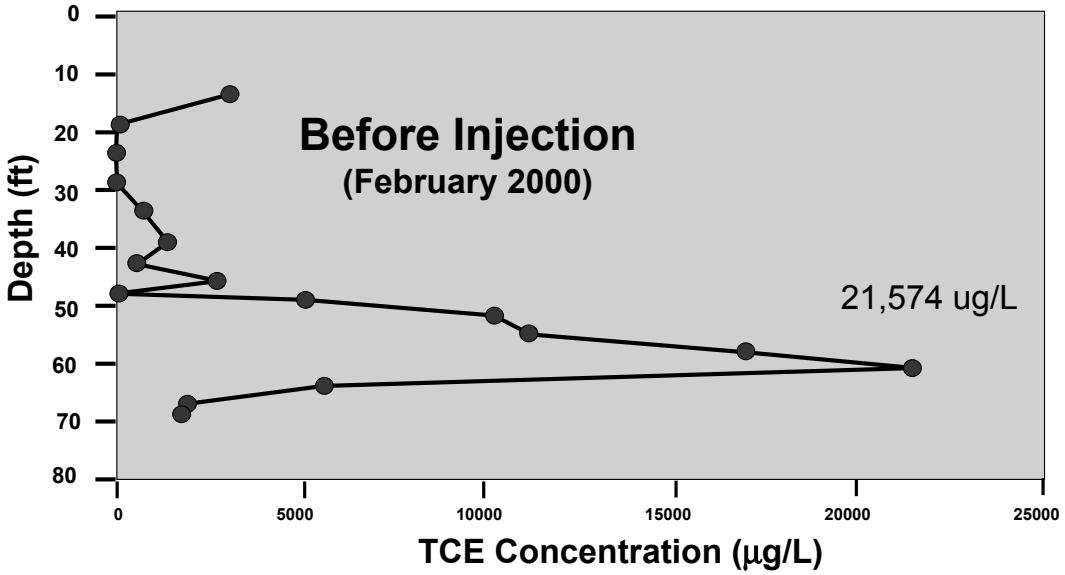
TCE Concentration Profile CW-K



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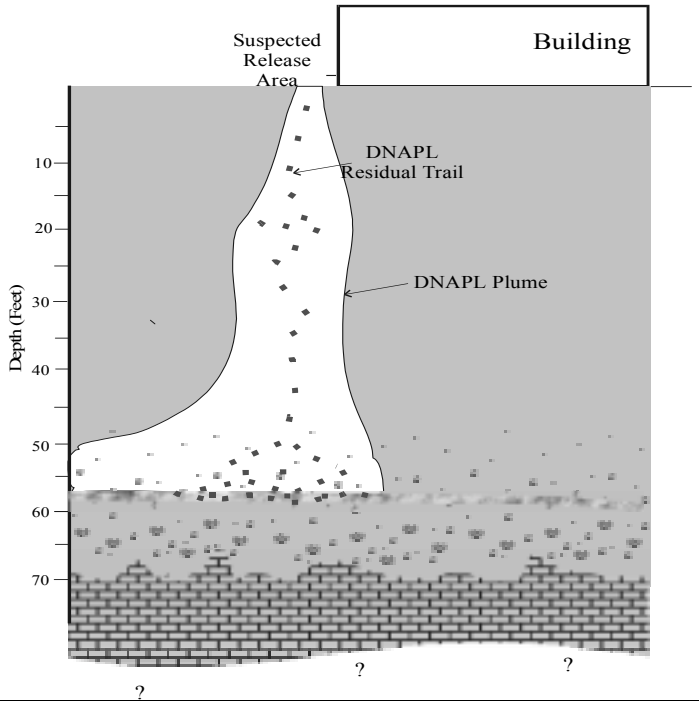
Conceptual Model of DNAPL Distribution



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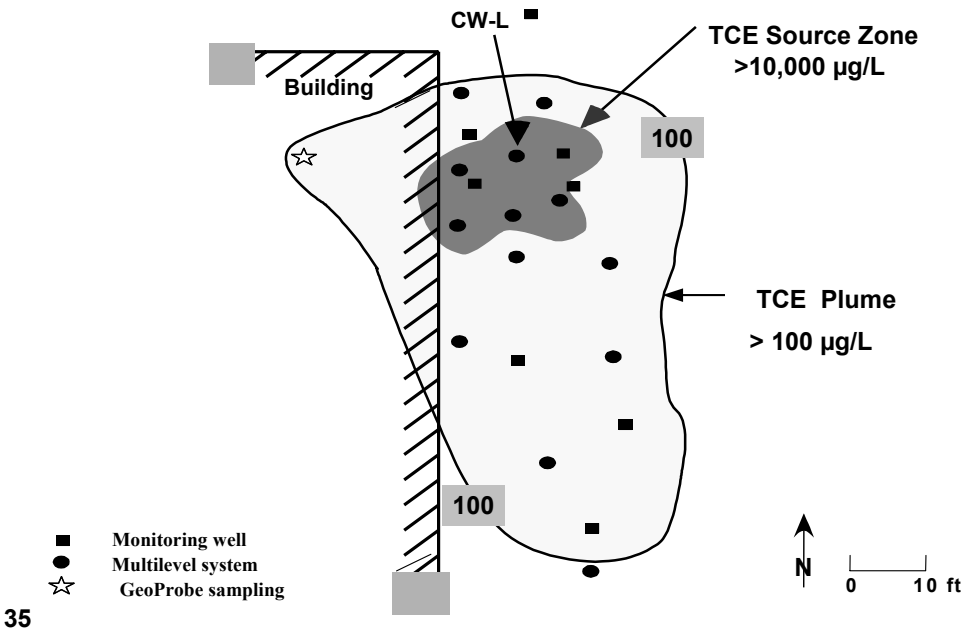
Before Remediation



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The Waterloo Passive Approach for Permanganate

1. Pre-injection delineation
2. Permanganate injection in targeted zones
3. Monitor results and design subsequent injection
4. Repeat steps until attain desired endpoint

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Full-Scale Permanganate Remediation in Ft. Lauderdale, FL

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$KMnO_4$ Mixing Tank
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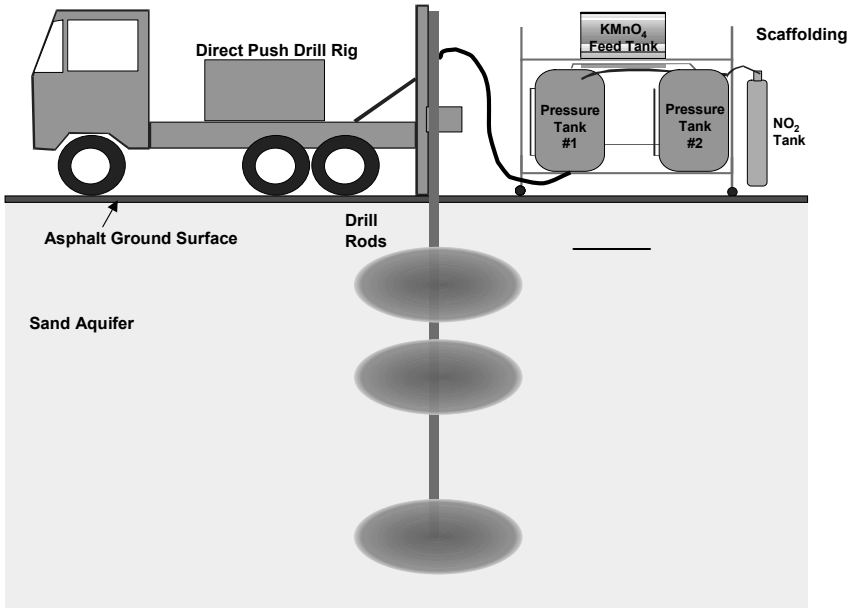
Stage 1: $KMnO_4$ Injection at Several Depths



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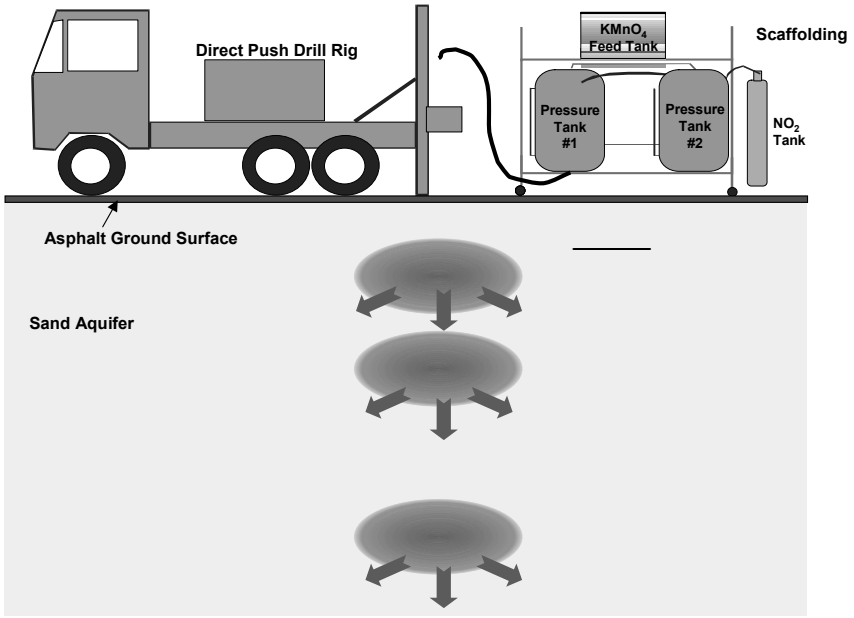
Parker, 2000

Stage 2: Spreading and Sinking by Density



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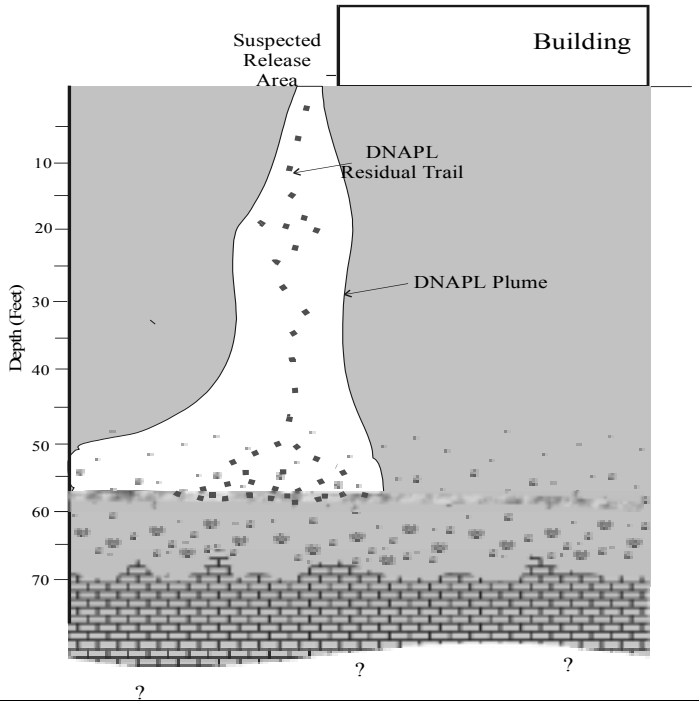
Parker, 2000

Conceptual Model of DNAPL Distribution



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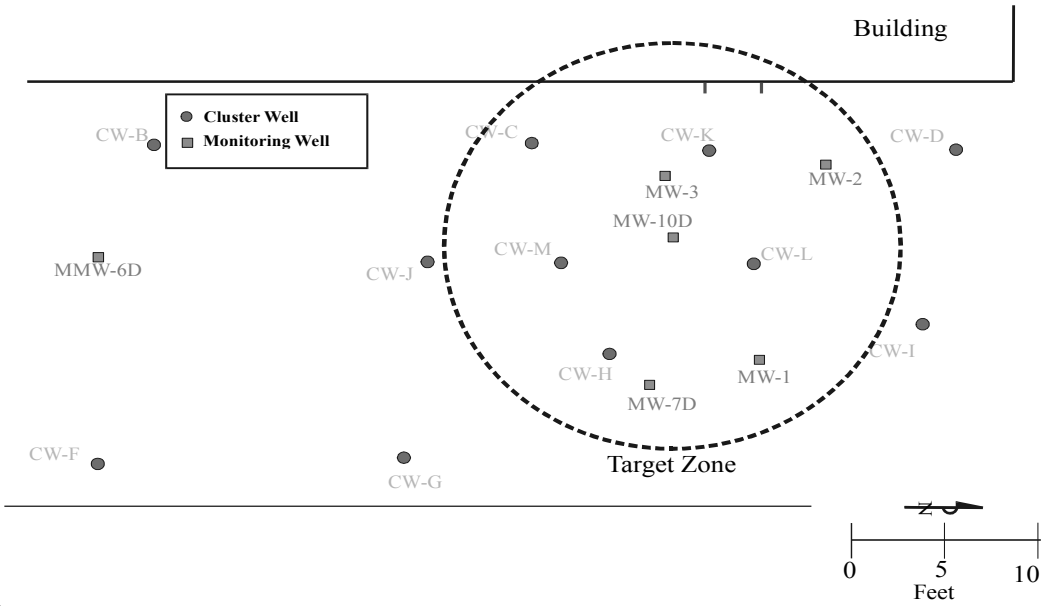
Parker, 2000

$KMnO_4$ Target Treatment Zone



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Source Zone Wells

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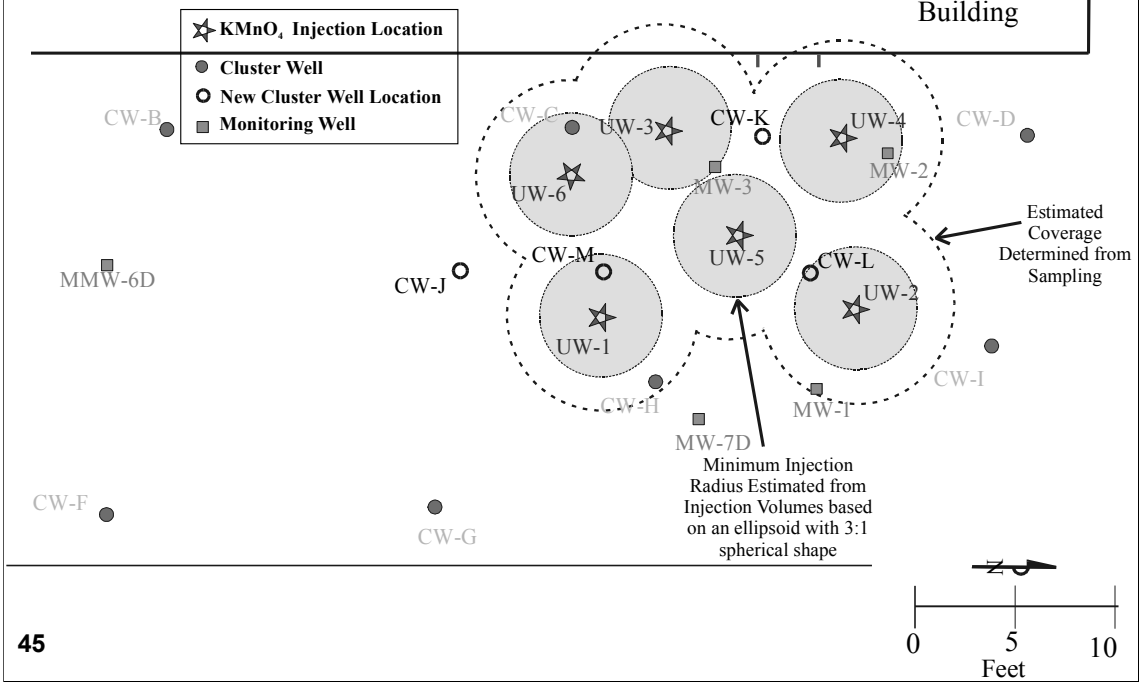
Picture 0569

$KMnO_4$ Injection Coverage Episode 1



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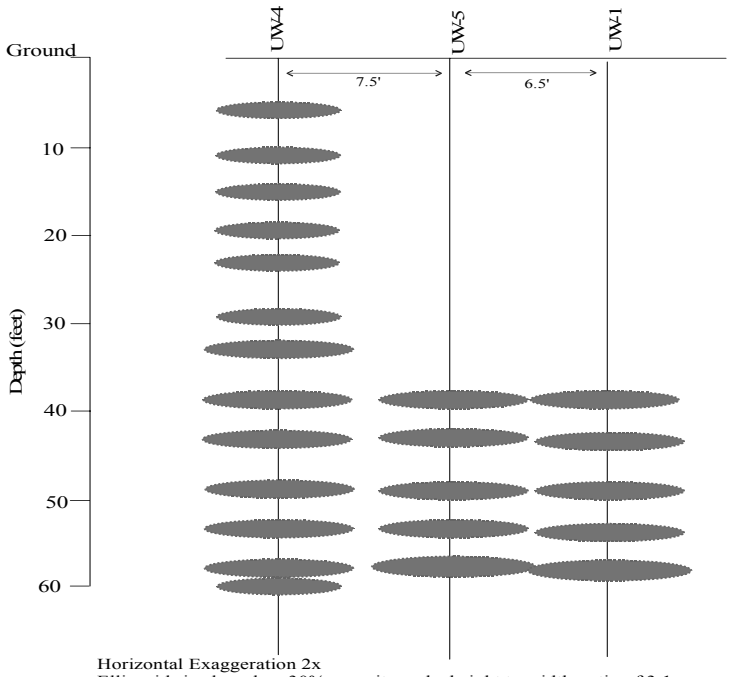
$KMnO_4$ Injection at Multiple Depths



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Horizontal Exaggeration 2x
Ellipsoid size based on 30% porosity and a height to width ratio of 3:1.


Passive Crew
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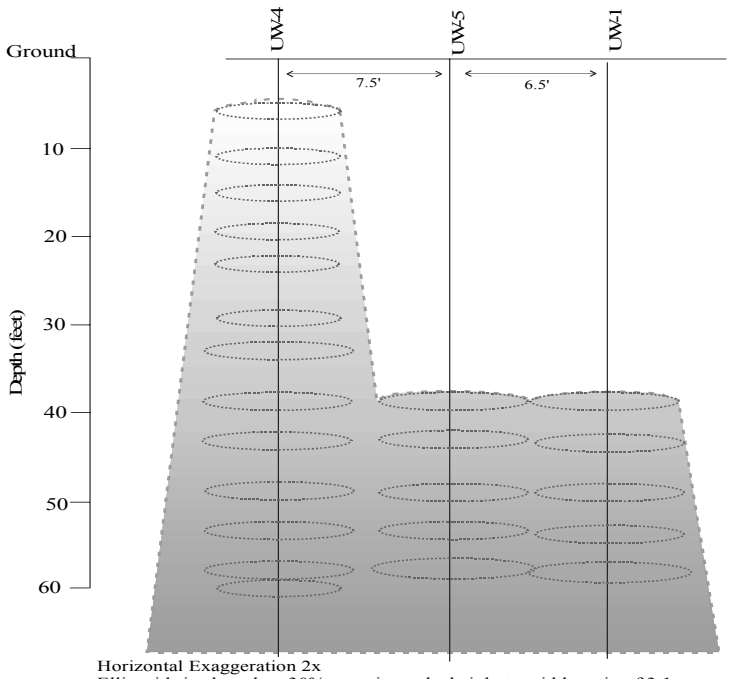
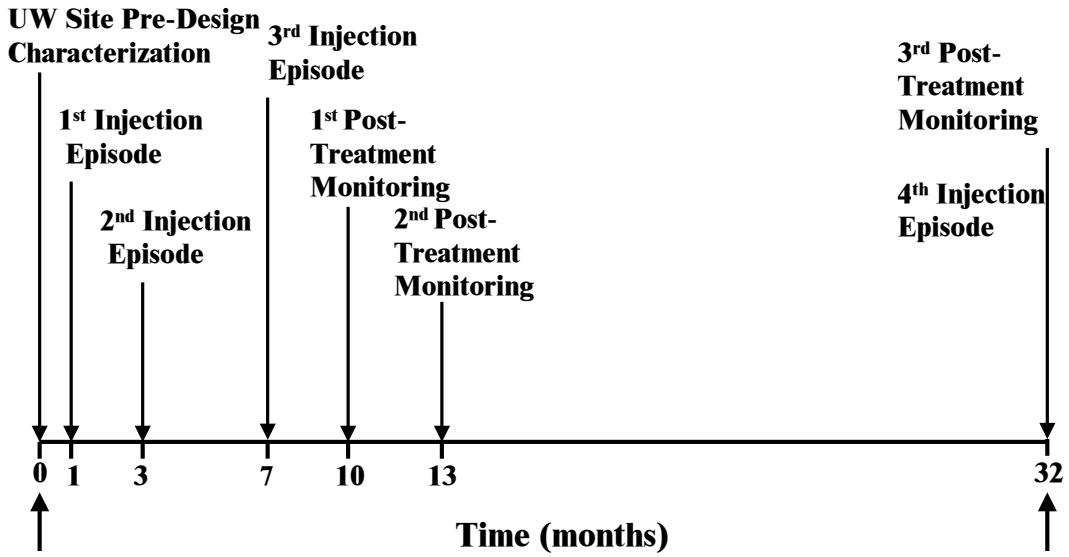
Effects of Density and Diffusion on Injected $KMnO_4$ Ellipsoids



48

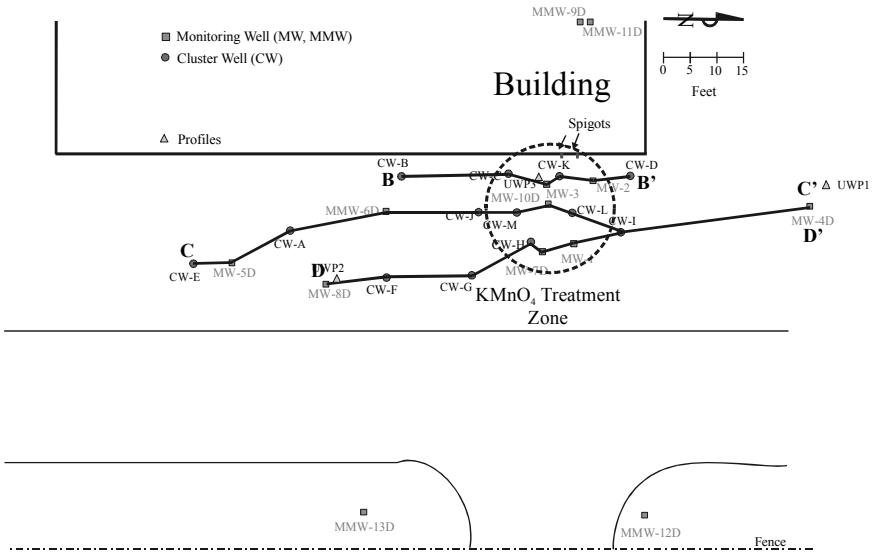
Horizontal Exaggeration 2x
Ellipsoid size based on 30% porosity and a height to width ratio of 3:1.

Project Timeline



49 February 2000 October 2002

Site Map – X Sections



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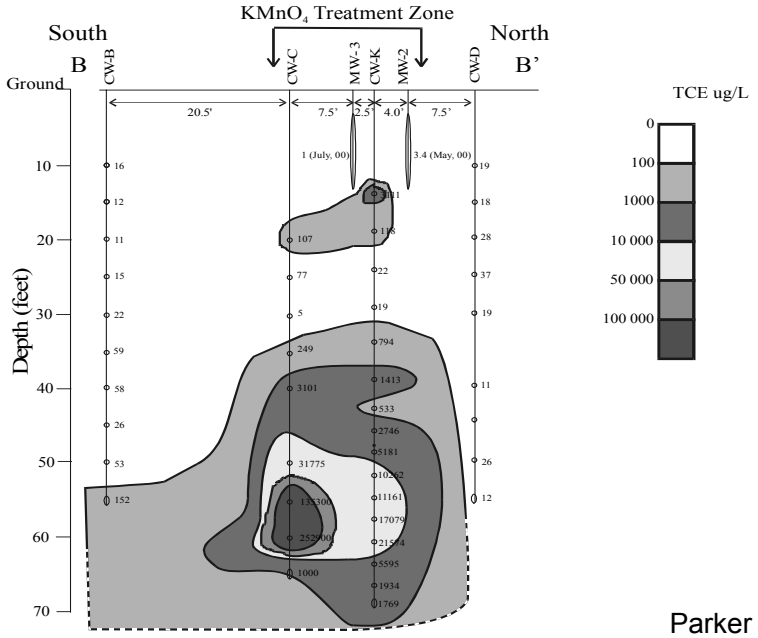
TCE Distribution on B-B' – Feb 2000



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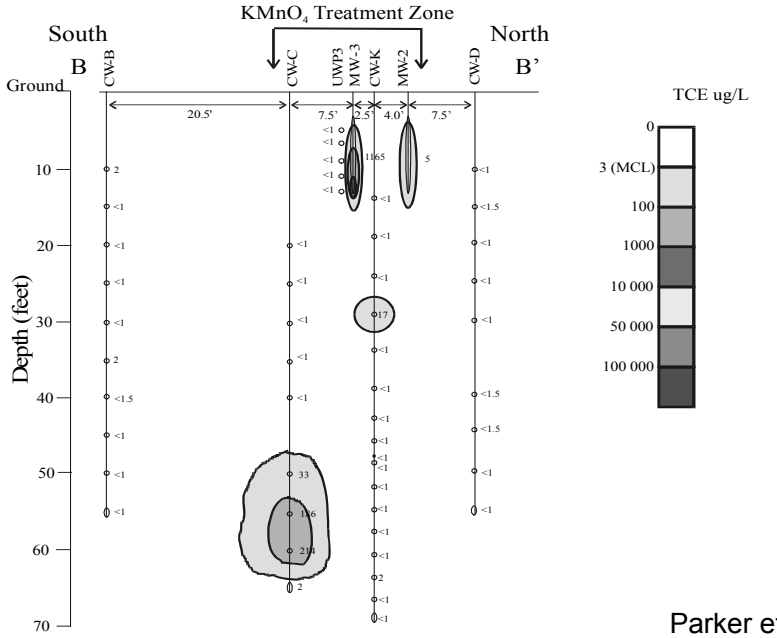
Parker et al., 2000

TCE Distribution on B-B' – Oct 2002



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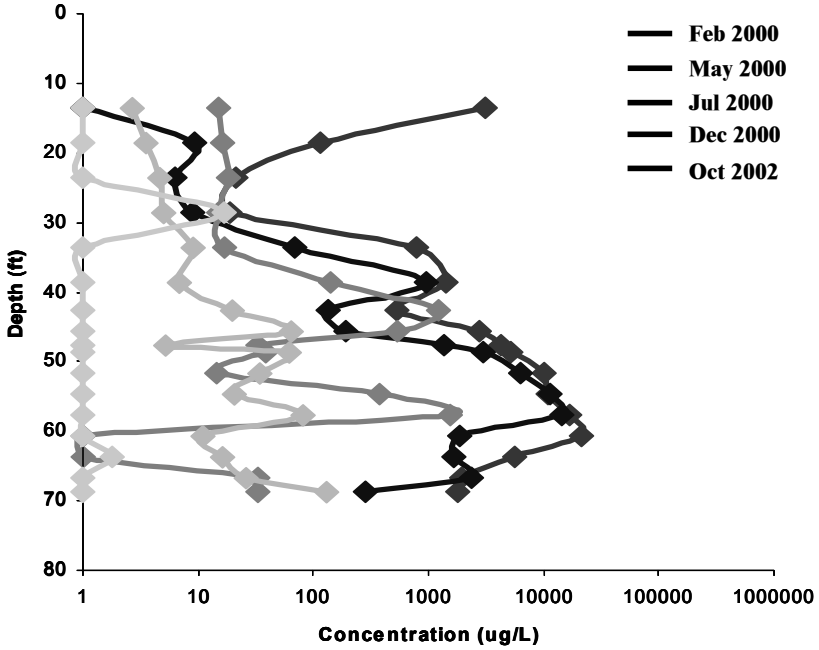
Parker et al., 2002

TCE Concentration Profile CW-K



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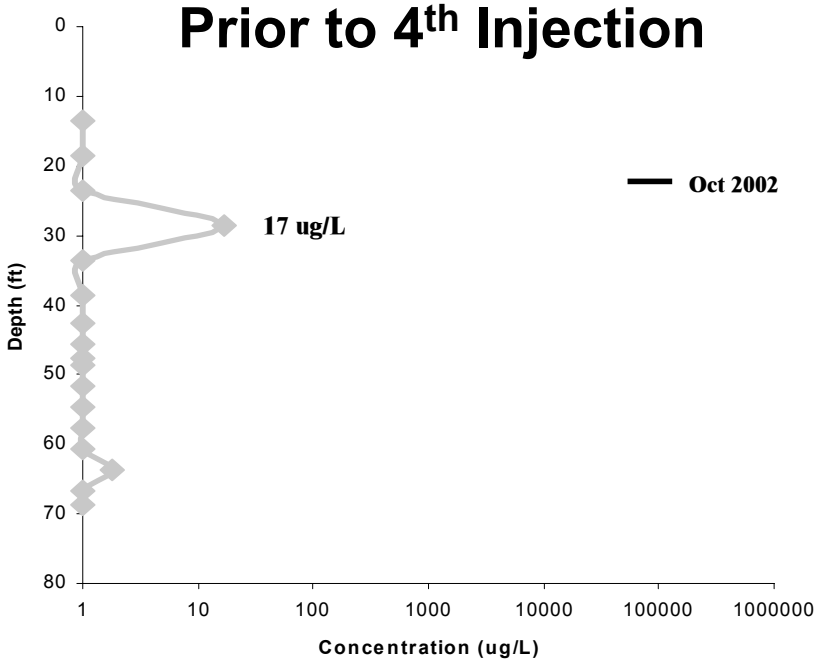
TCE Concentration Profile CW-K Prior to 4th Injection



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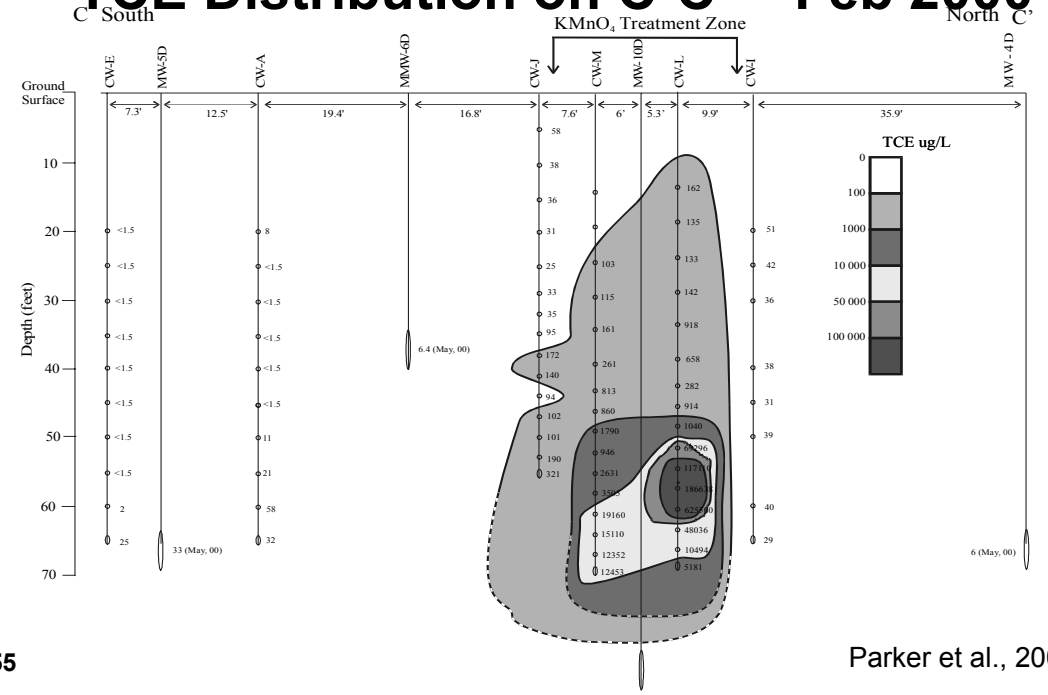
TCE Distribution on C-C' – Feb 2000



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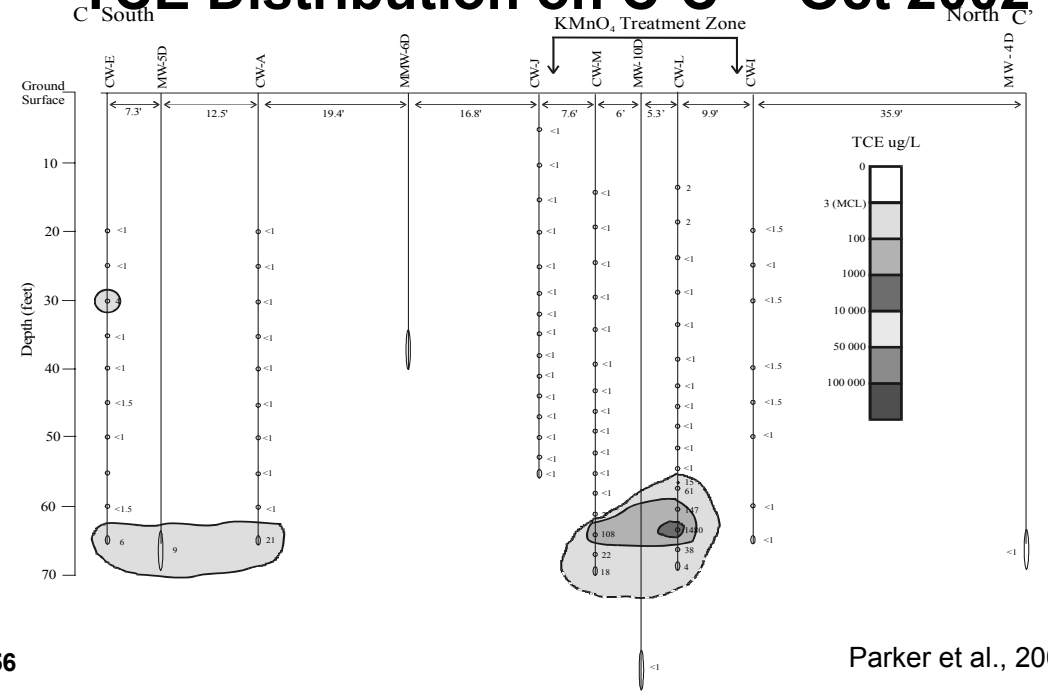
Parker et al., 2000

TCE Distribution on C-C' – Oct 2002



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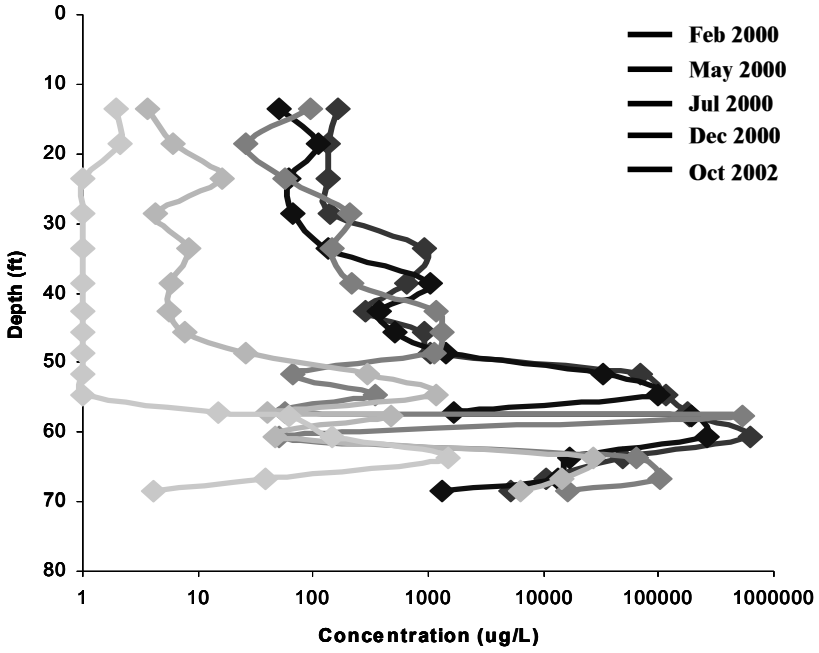
Parker et al., 2002

TCE Concentration Profile CW-L



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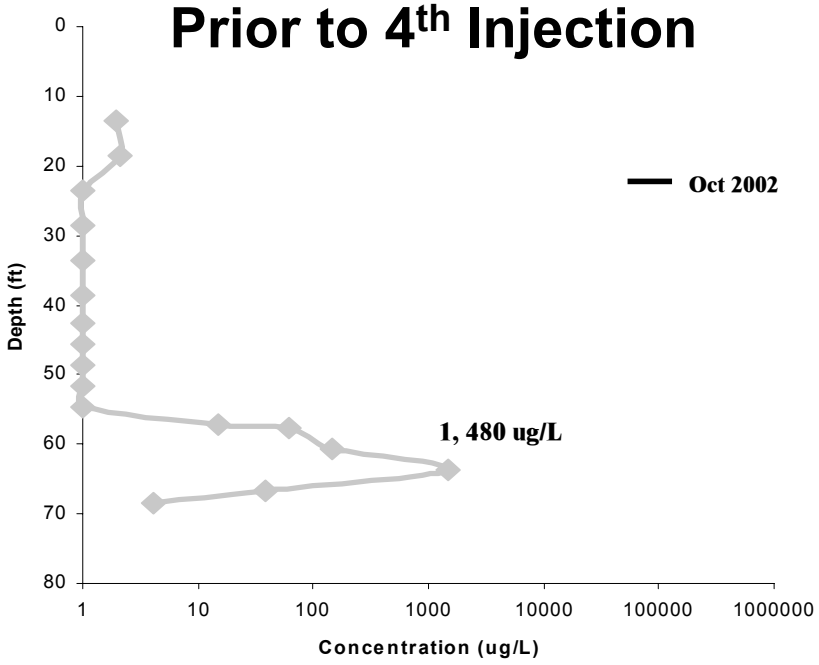
TCE Concentration Profile CW-L Prior to 4th Injection



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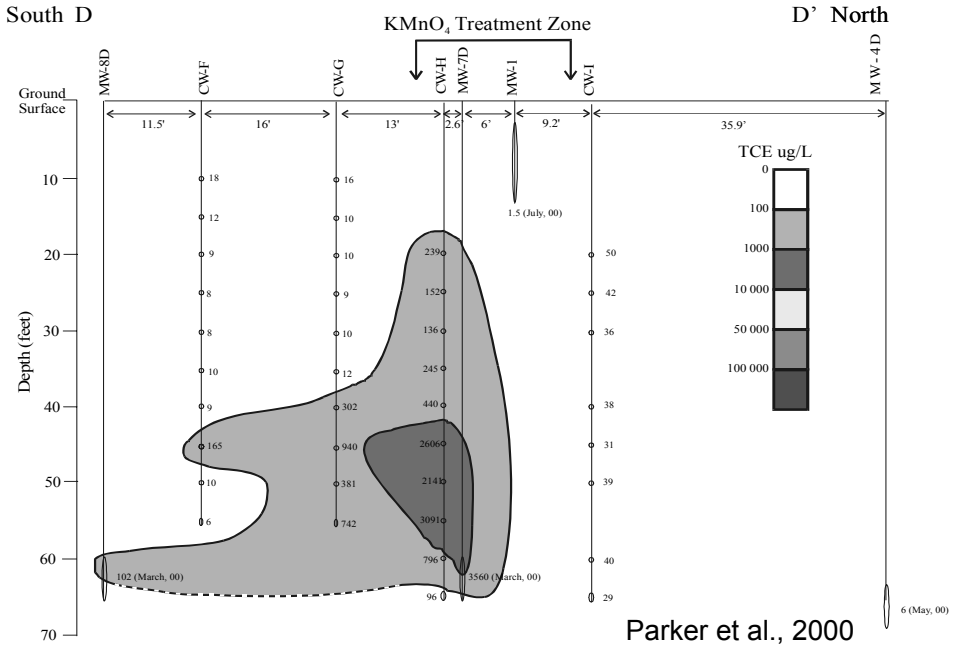
TCE Distribution on D-D' – Feb 2000



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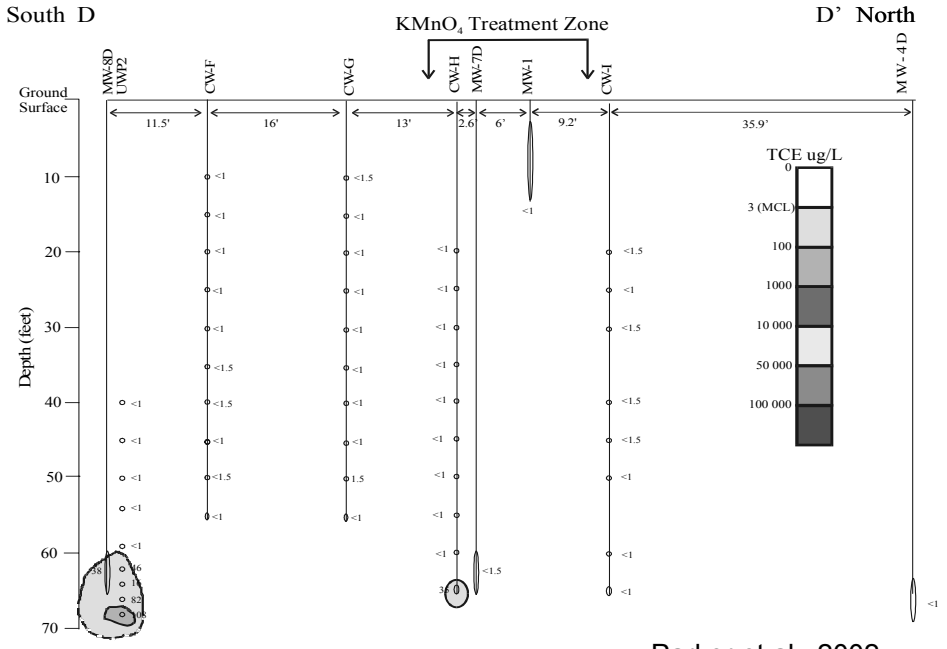
Parker et al., 2000

TCE Distribution on D-D' – Oct 2002



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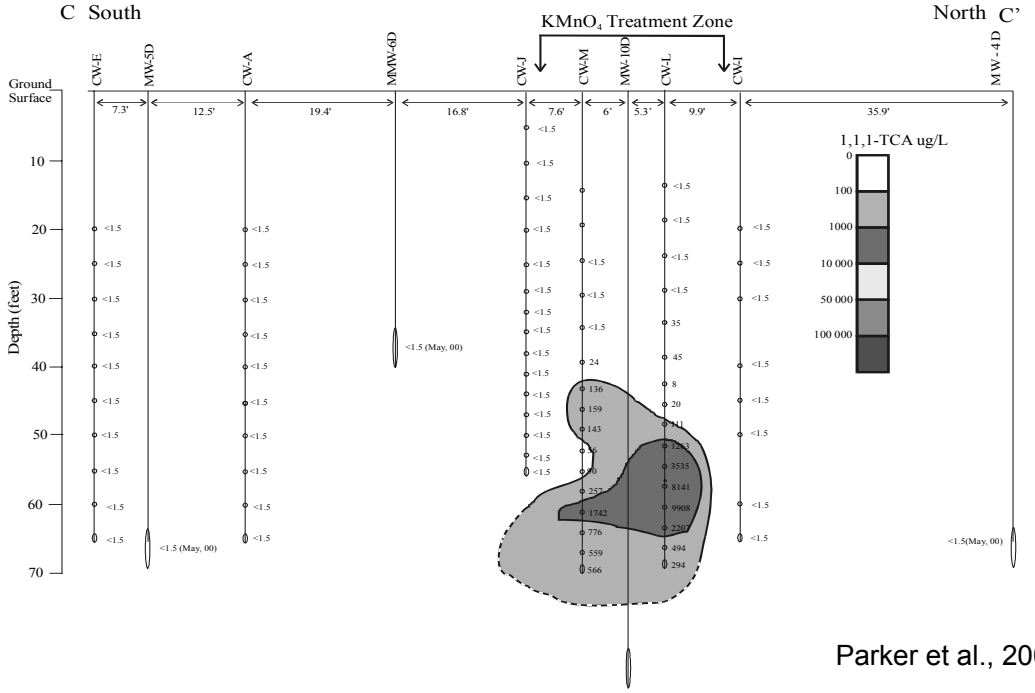
Parker et al., 2002

TCA Distribution on C-C' – Feb 2000



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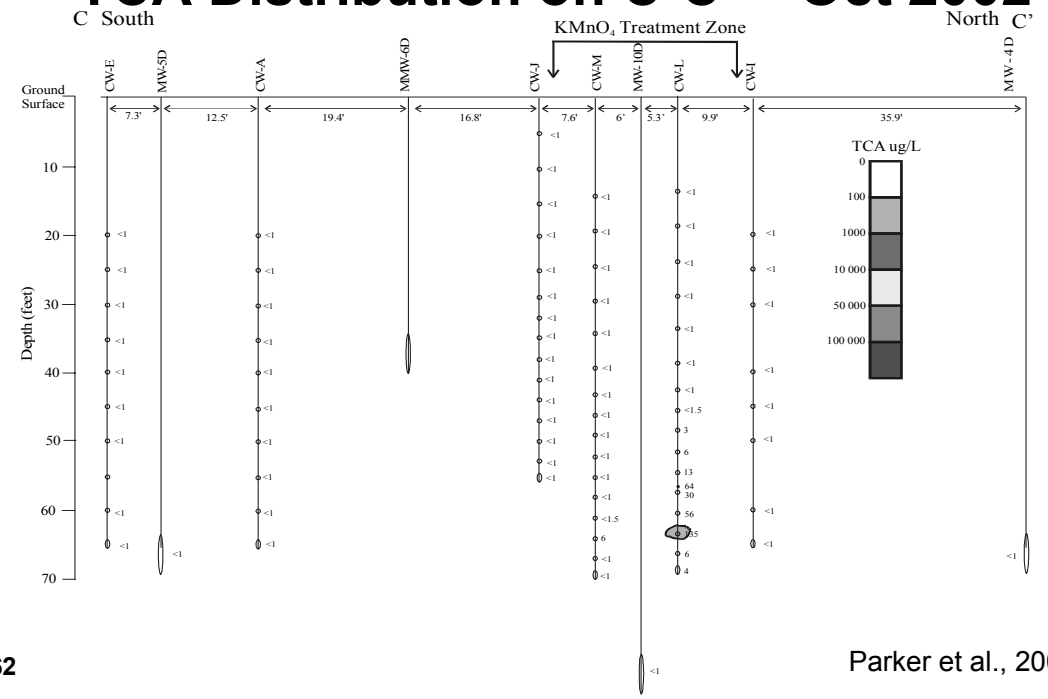
Parker et al., 2000

TCA Distribution on C-C' – Oct 2002



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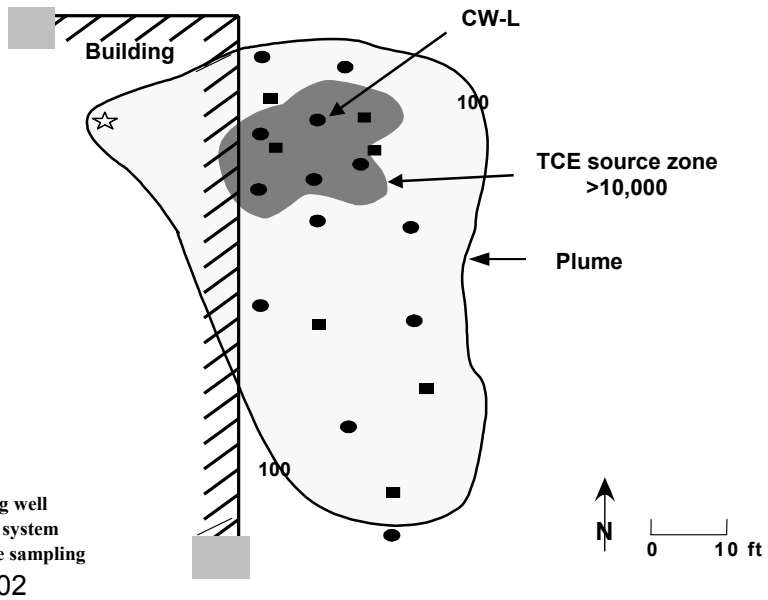
Parker et al., 2002

Before Remediation – February 2000

TCE µg/L



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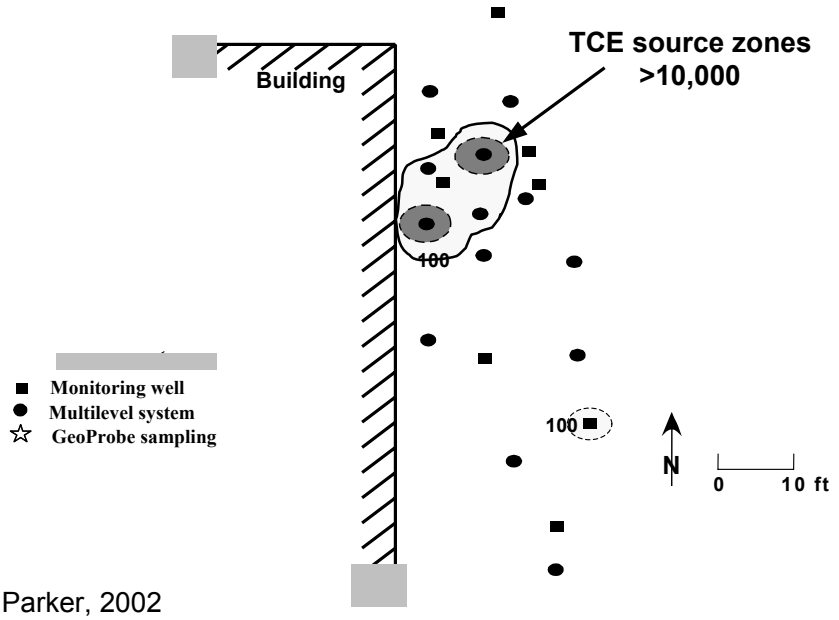
After Remediation – December 2000
TCE µg/L



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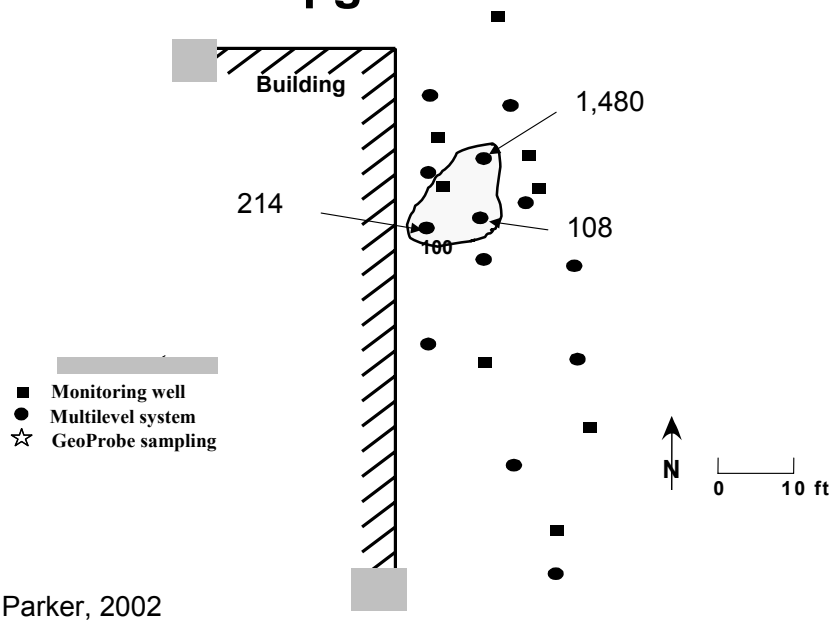
After Remediation – October 2002

TCE µg/L



65 Parker, 2002

Specific Conclusions

- 99% reduction in contaminated volume
- Displacement avoided by limiting injection to <**8%** of treatment zone pore volume for each episode
- 1,1,1-TCA also disappeared
- No TCE or TCA rebound

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General Conclusion

This case study showed that permanganate can be successful for ***complete remediation*** of the source ***if*** :

- The site conditions are suitable
- The remedial design is tailored to the site

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Final Stage

- Fourth injection occurred October 2002 to complete source zone remediation
- Performance assessment monitoring planned for February 2003

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Acknowledgements

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- University Consortium Solvents-in-Groundwater Research Program
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- Sun Belt Interplex, Inc.

Staff:

- Matthew Nelson, MSc Hydrogeologist: Project Manager
- Colin Meldrum, BASc: Field Activities and Data Display
- Bob Ingleton, Paul Johnson, BSc: Injection System Design and Field Technical Assistance
- Martin Guilbeault, MSc, Matthew Whitney, BASc: Field Assistance
- Maria Gorecka, MSc: Lab Analysis of VOC

For information on this case study:

Parker, B.L., J. A. Cherry and T. A. Al (2002).

Passive permanganate remediation of a solvent DNAPL source zone.

In proceedings for “The Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds,” Monterey, California.

Battelle 2002 Monterey Conference Proceedings

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