

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
Chicago
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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

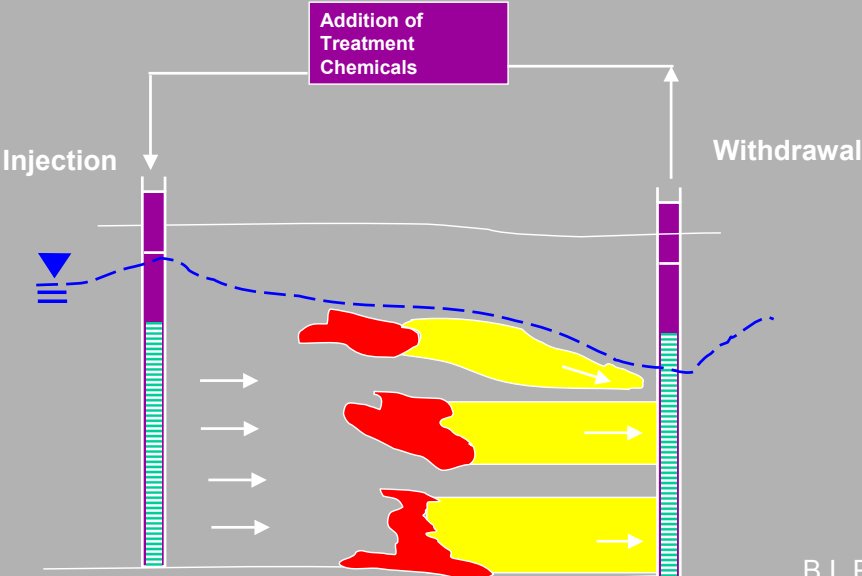
3



Two General Approaches for In Situ Oxidation

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

The Active Approach



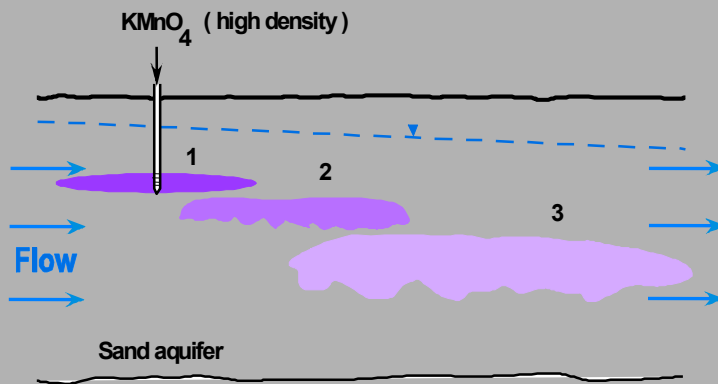
The Waterloo Passive Approach

- ➔ • 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

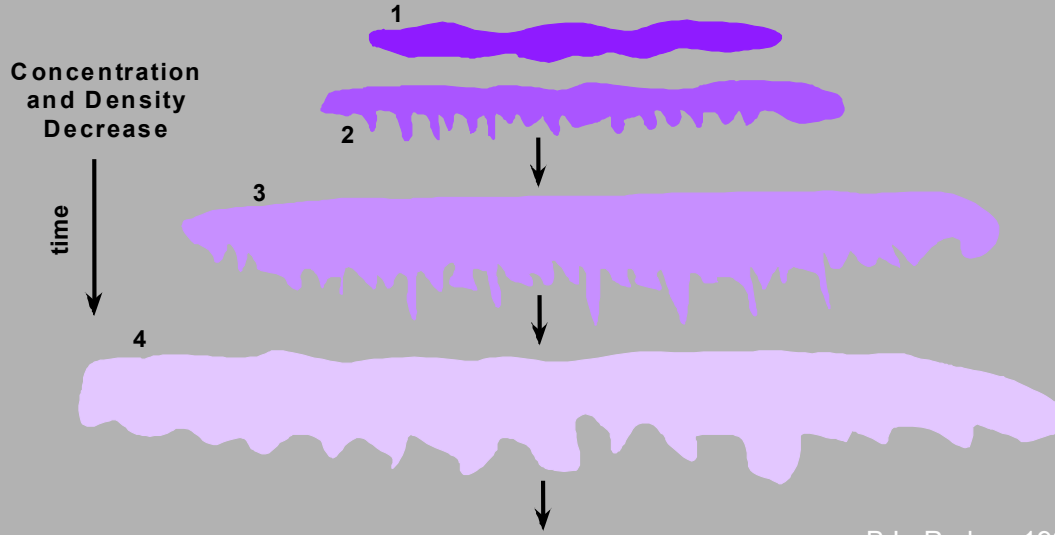


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B.L.Parker, 1997

Evolution of a Single Disc in a Sand Aquifer

no lateral groundwater flow



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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

Borden 9x9 m Sheet Pile Enclosure



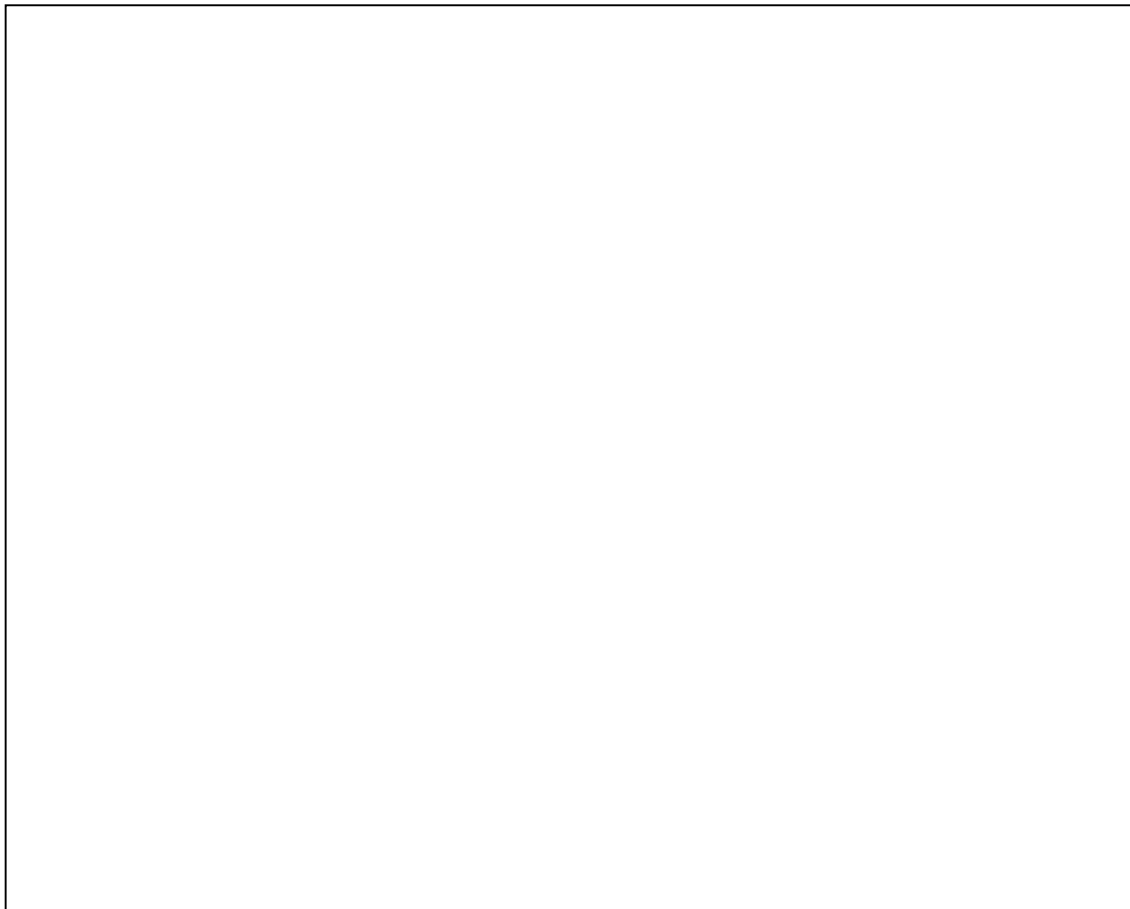
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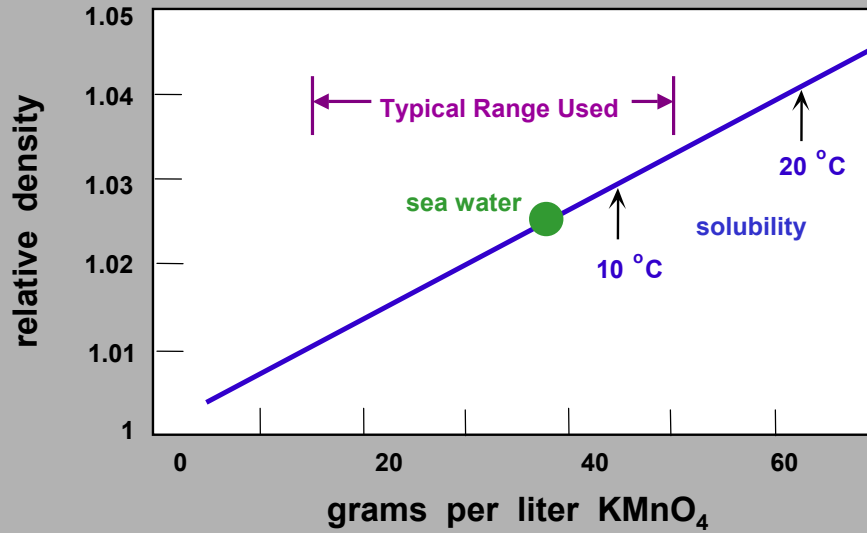
**System Set-up
at 9m Cell
Borden Site**



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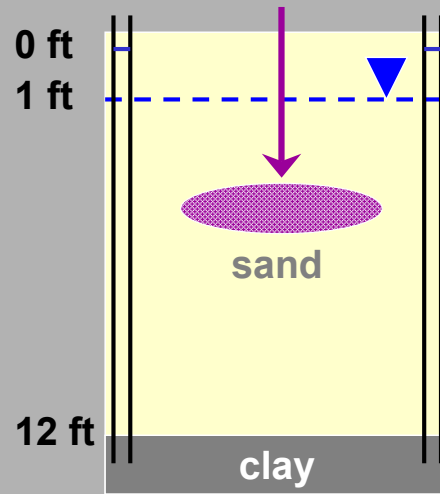


Density of Dissolved KMnO_4 in Water



12

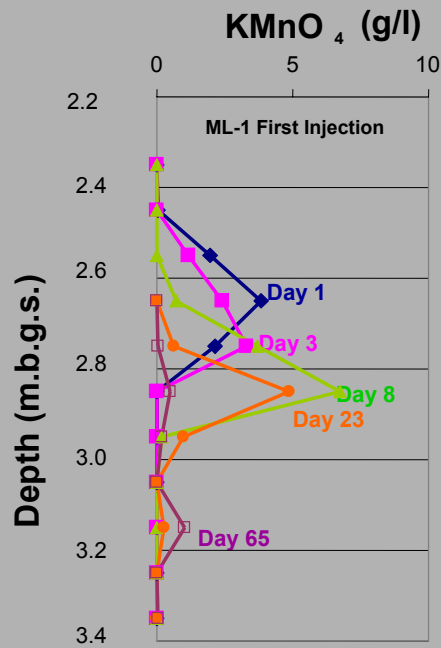
SETTING



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Evidence for Density Induced Flow



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(Nelson, 1999)

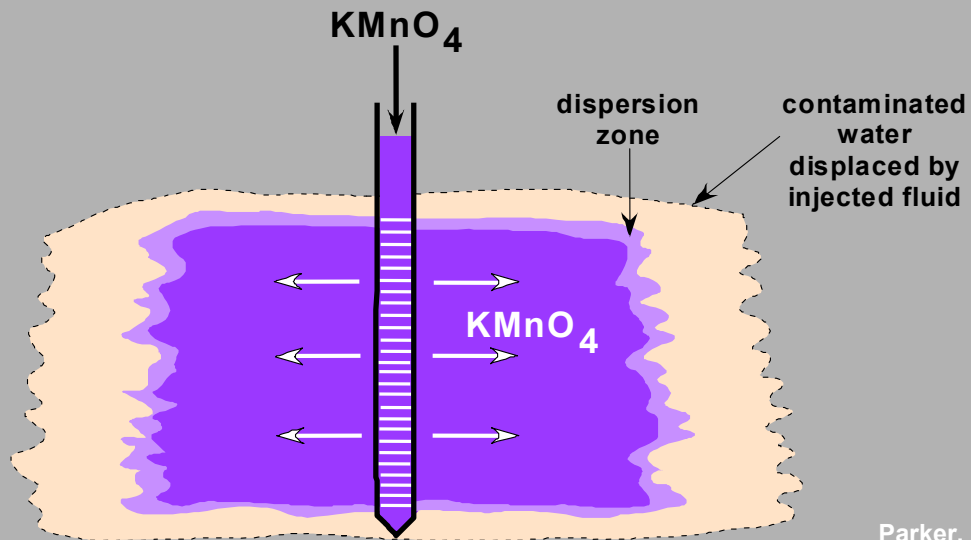
The Waterloo Passive Approach

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

15



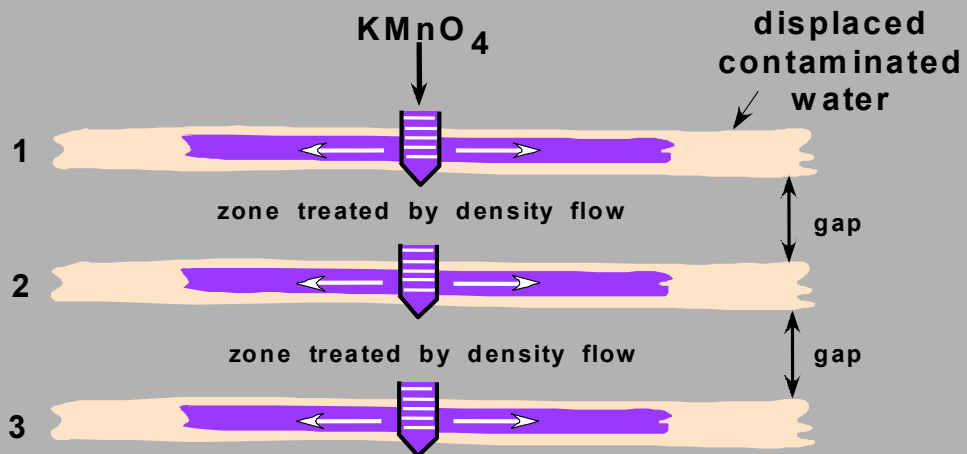
Long-Screen Injection Causes Large Displacement of Contaminated Water



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Parker, 1997

Injection of Discs Leaving Gaps Minimizes Displacement of Contaminated Water

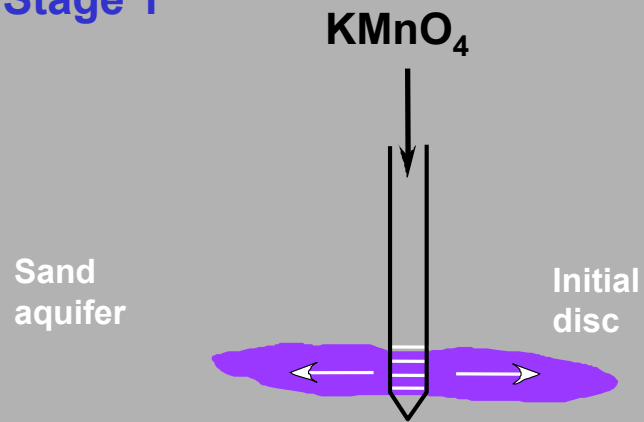


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Parker, 1997

Injection of Multiple Discs Using Direct Push Device

Stage 1

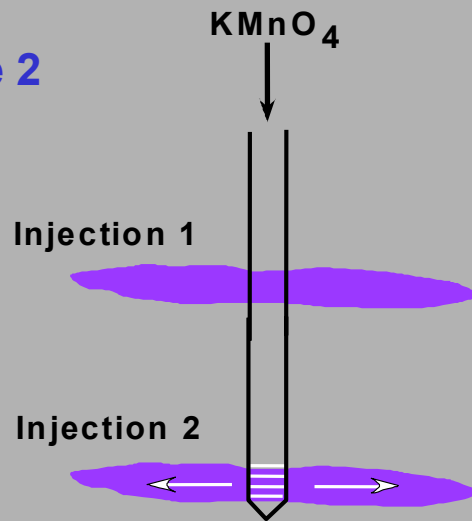


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Parker, 1997

Injection of Multiple Discs Using Direct Push Device

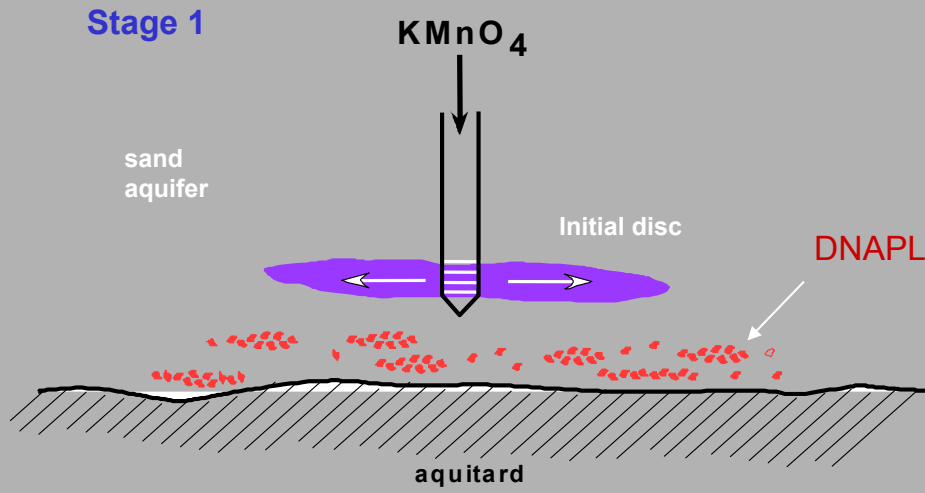
Stage 2



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Parker, 1997

Stage 1: Inject Disc Above DNAPL on Aquitard

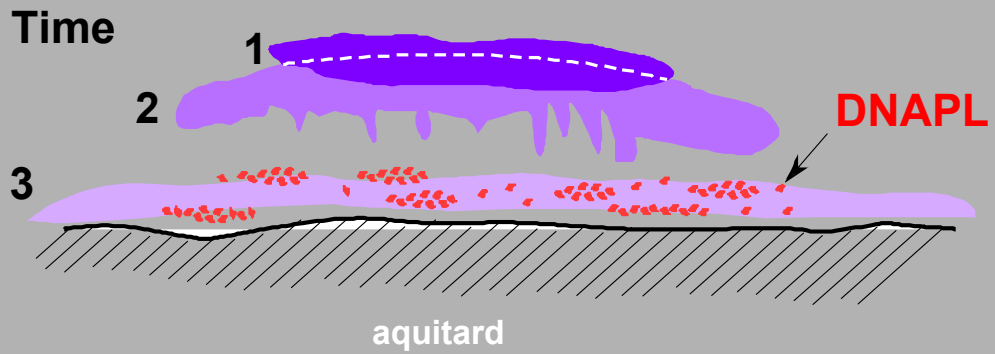


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Parker, 1997

Disc Sinks and Spreads

Injector withdrawn



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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

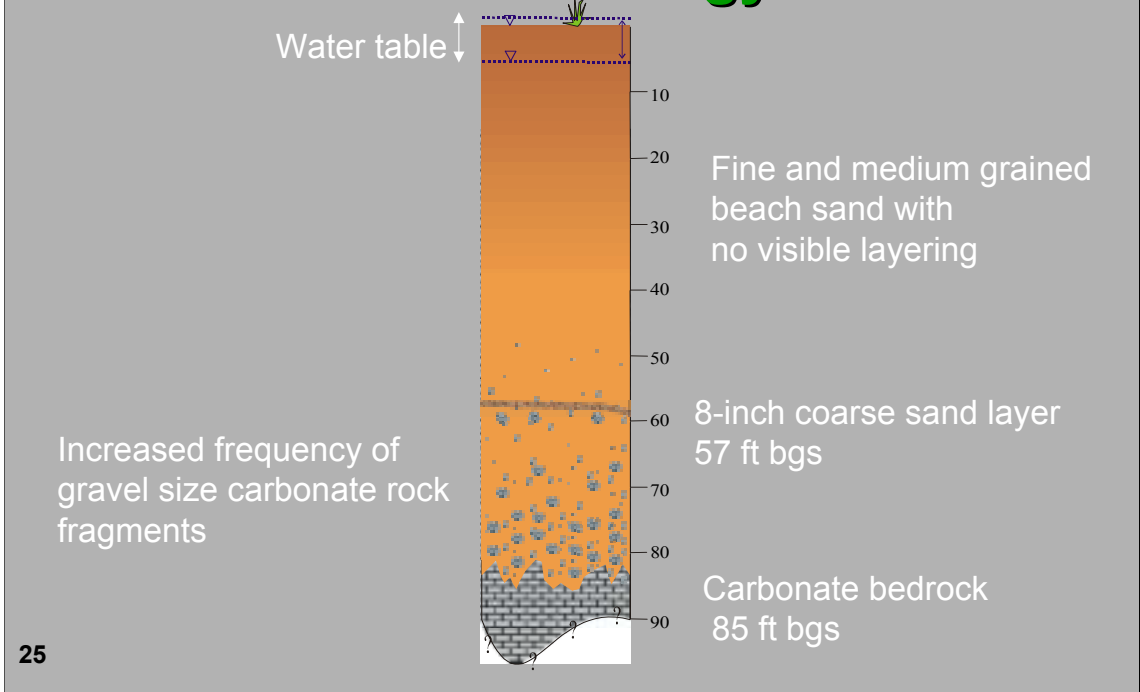
Contamination Occurred Recently late 1996 to early 1997

- 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



Monitoring Methods

Focus on depth-discrete methods

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

Core Being Removed from Piston Core Barrel

Aluminum core tube
inside core barrel



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Cutting the Aluminum Core Tube

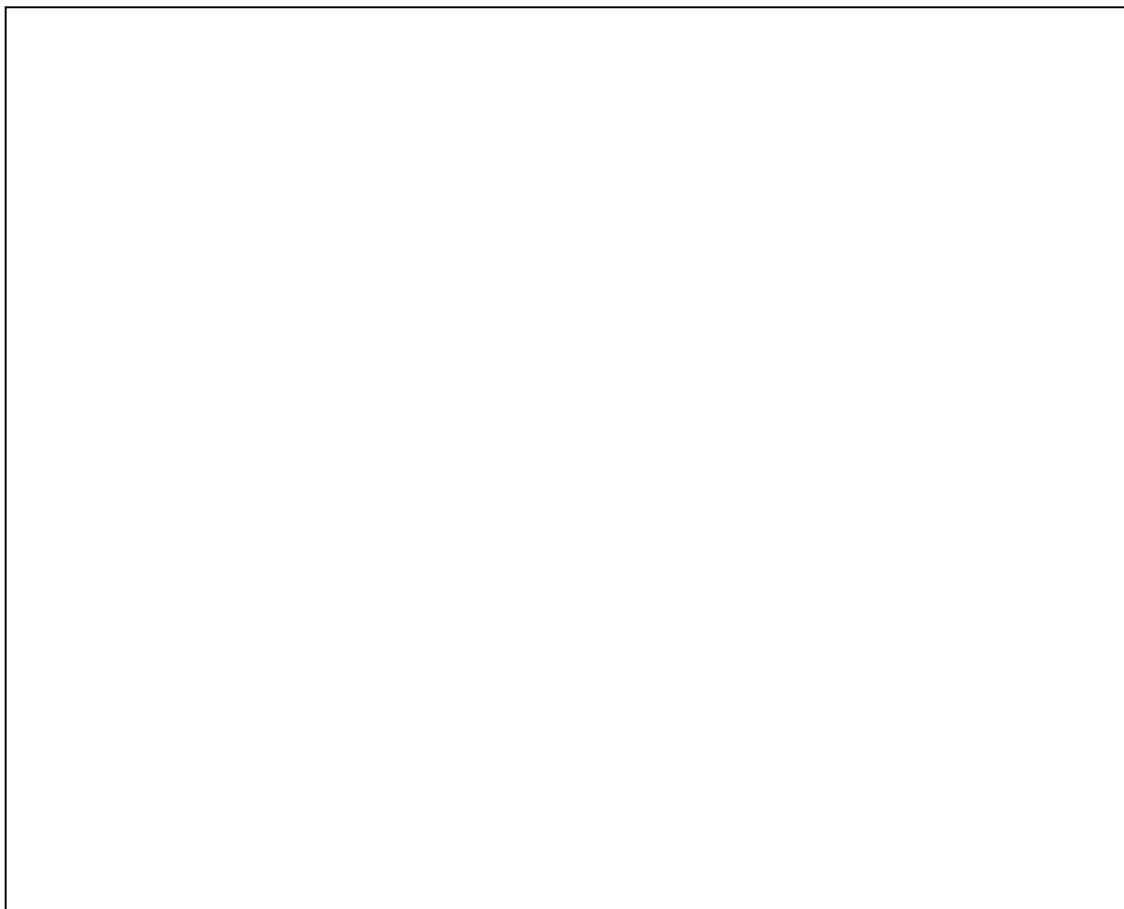


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Subsampling Sand for VOC Analysis



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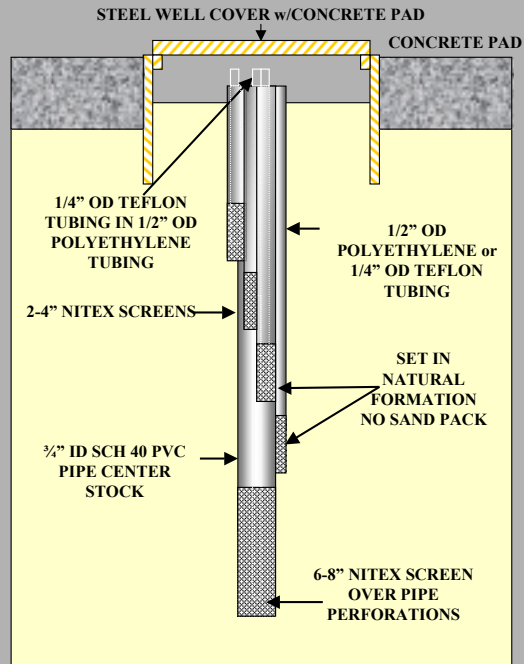
Installation of Bundle Tube Sampler: 1999



30

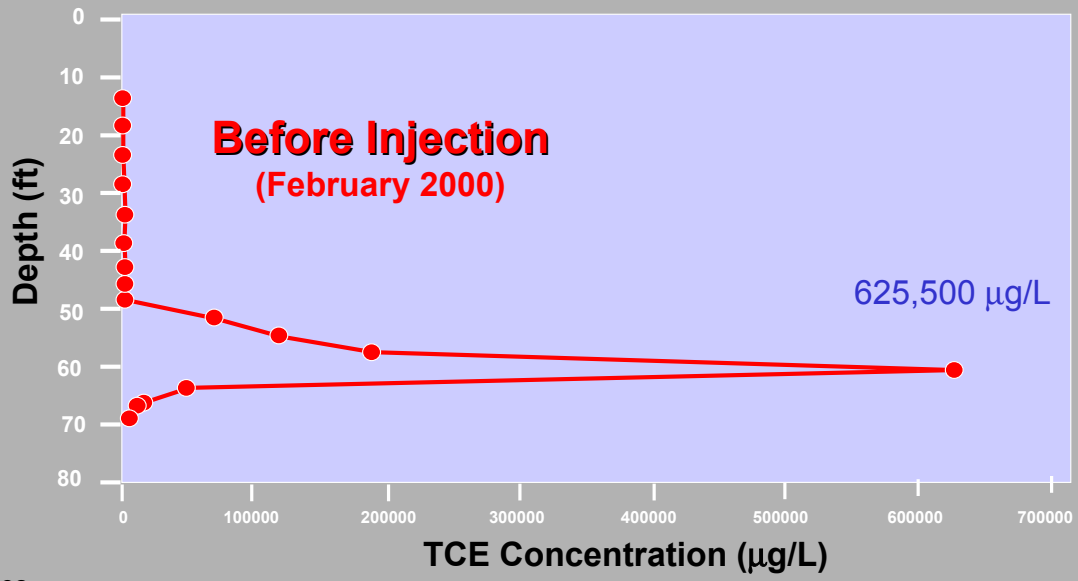


Bundle Tube Sampler



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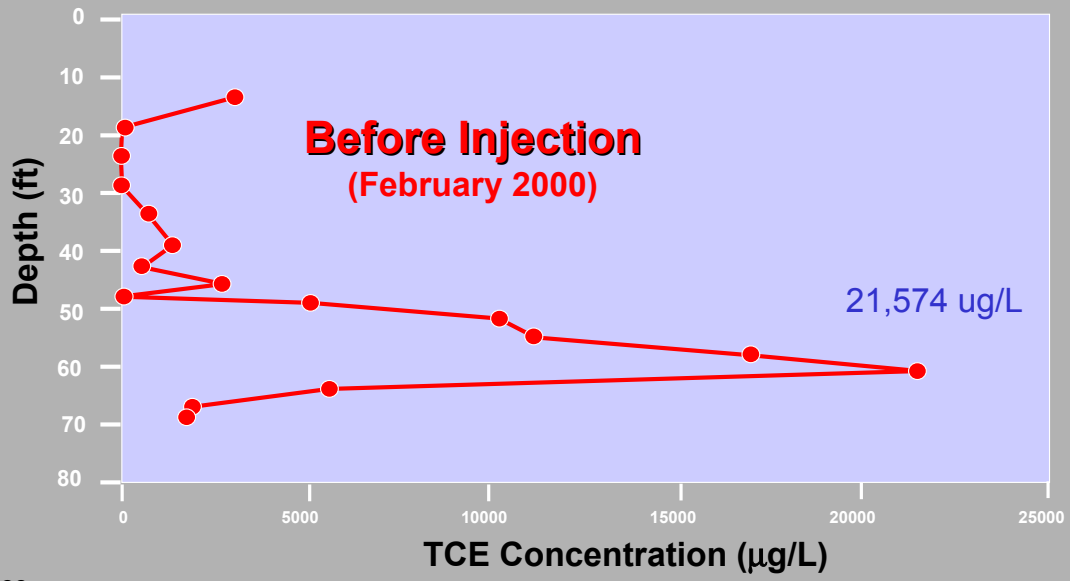
TCE Concentration Profile CW-L



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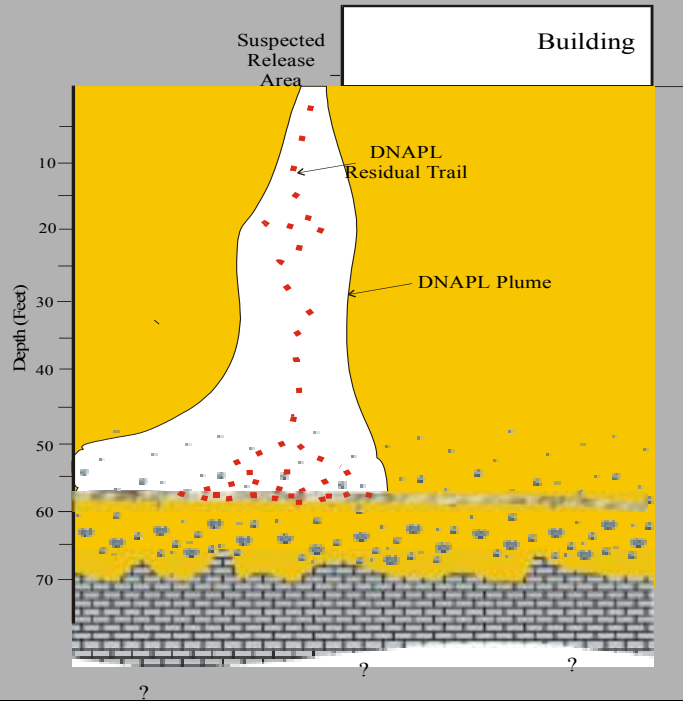
TCE Concentration Profile CW-K



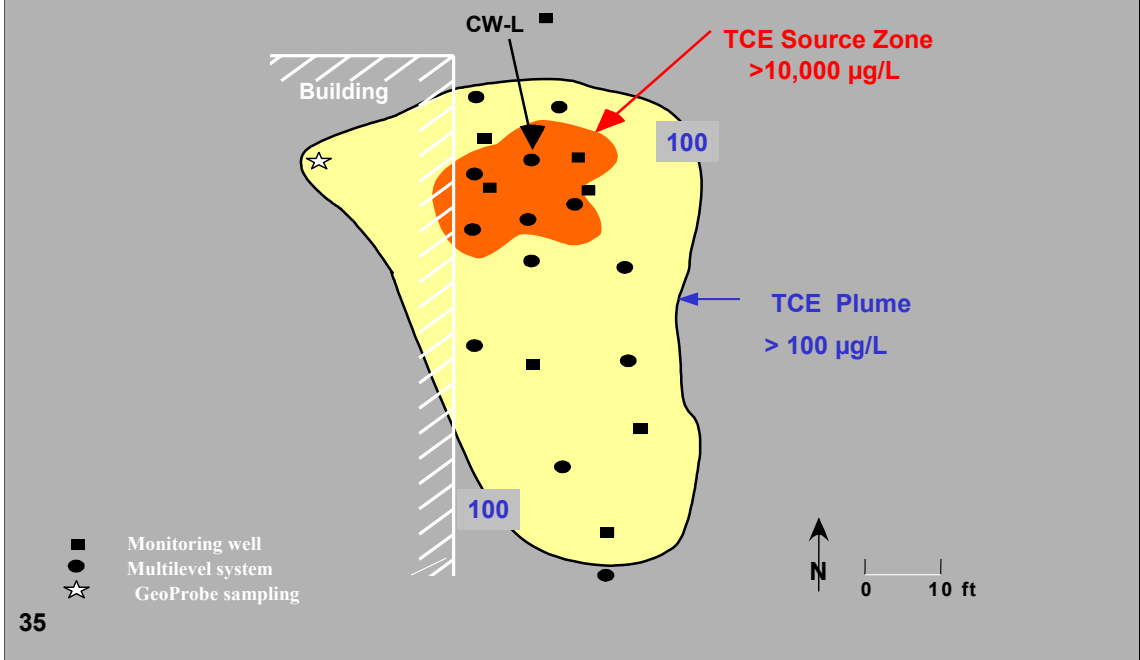
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Conceptual Model of DNAPL Distribution



Before Remediation



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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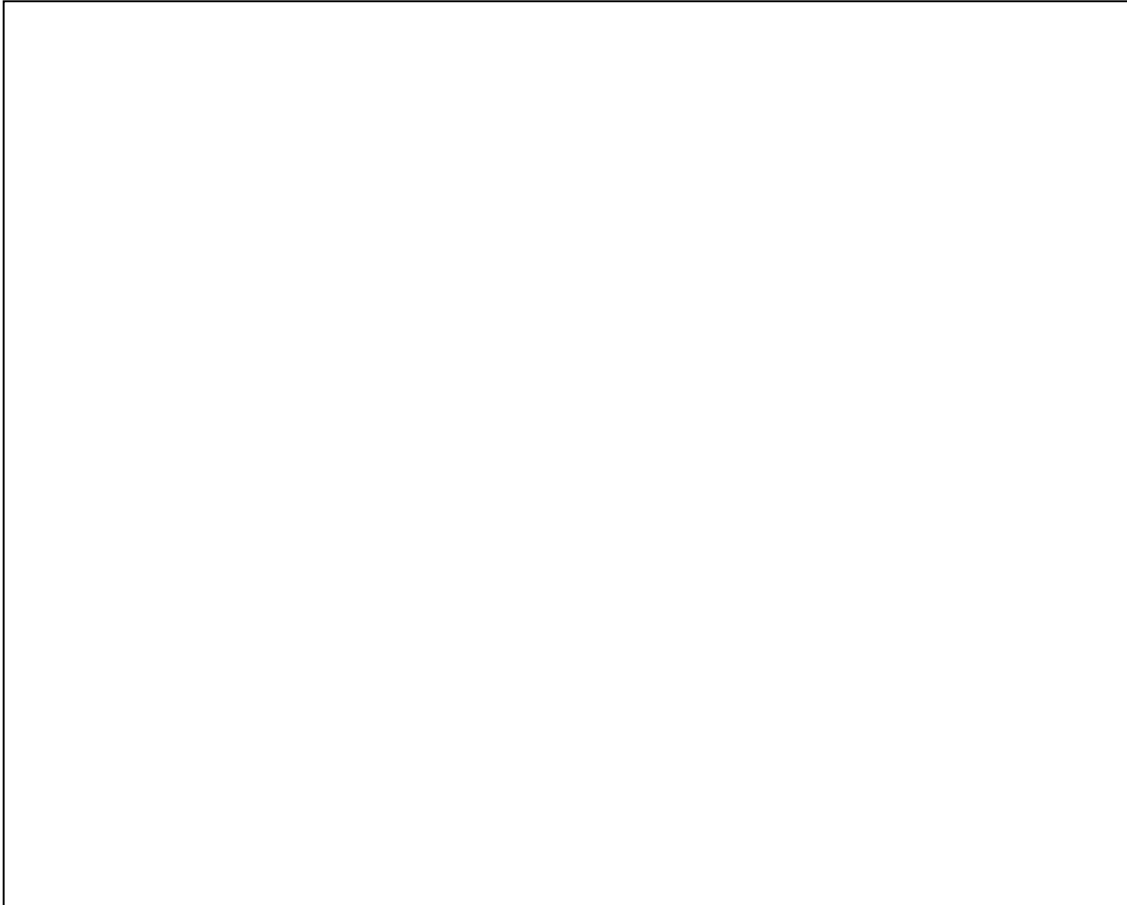
Full-Scale Permanganate Remediation in Ft. Lauderdale, FL



KMnO₄ Mixing Tank



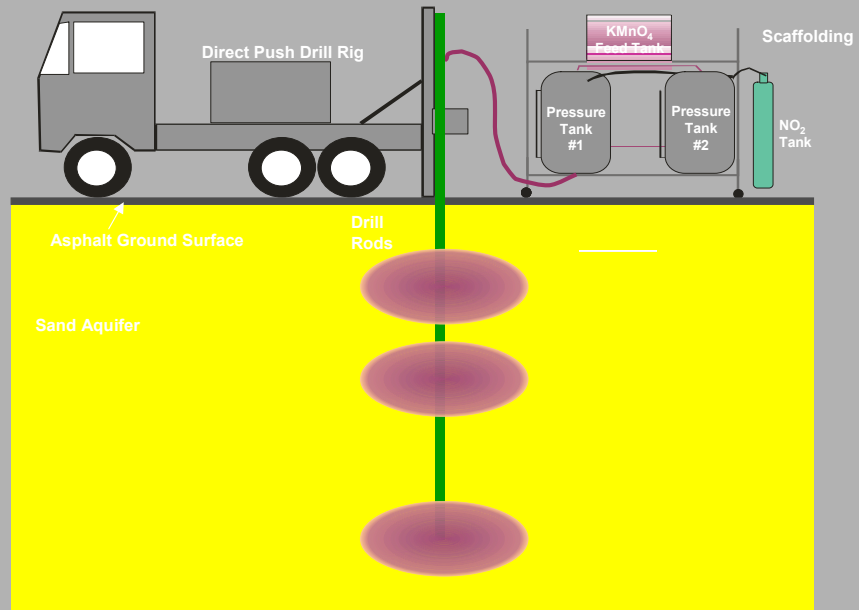
38



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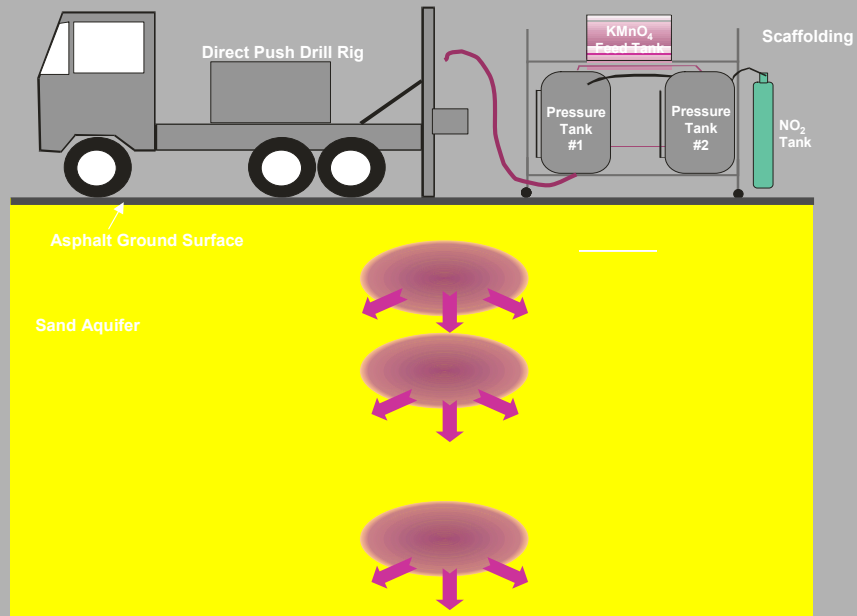
Stage 1: KMnO_4 Injection at Several Depths



40

Parker, 2000

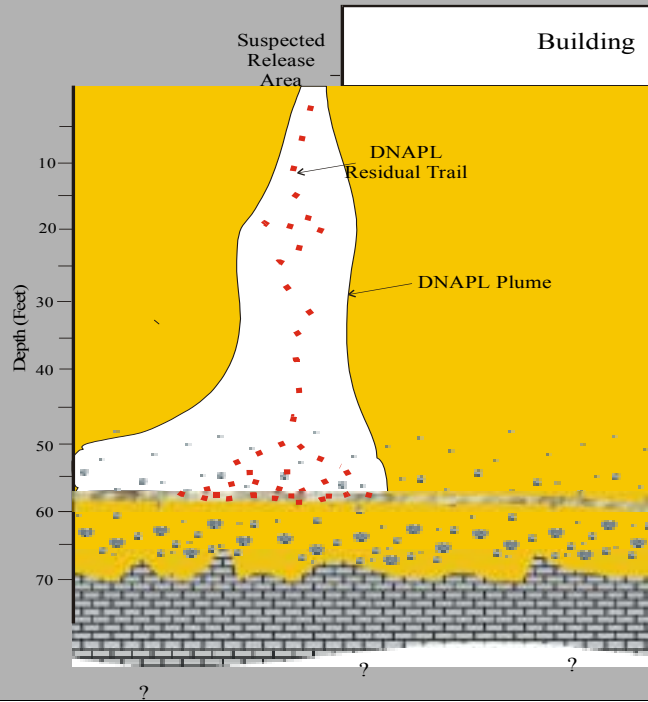
Stage 2: Spreading and Sinking by Density



41

Parker, 2000

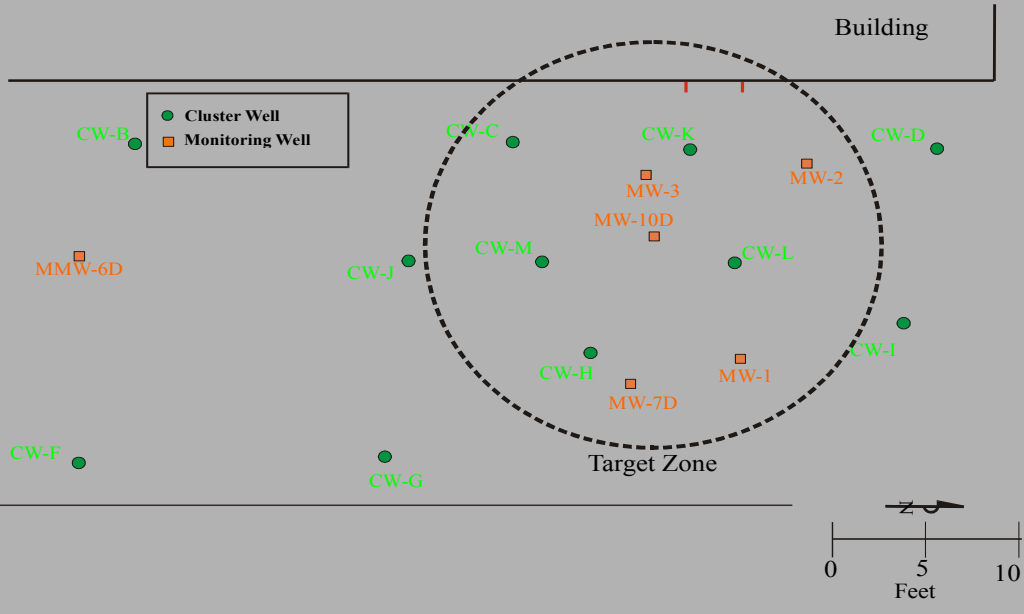
Conceptual Model of DNAPL Distribution



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Parker, 2000

KMnO₄ Target Treatment Zone



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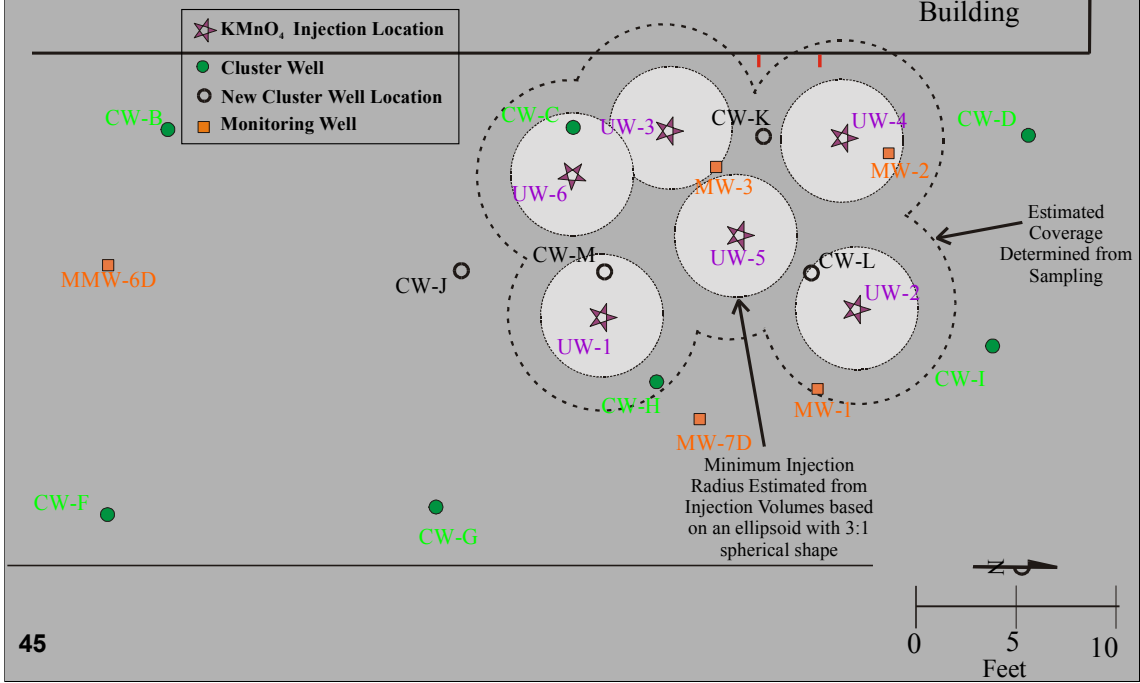
Source Zone Wells



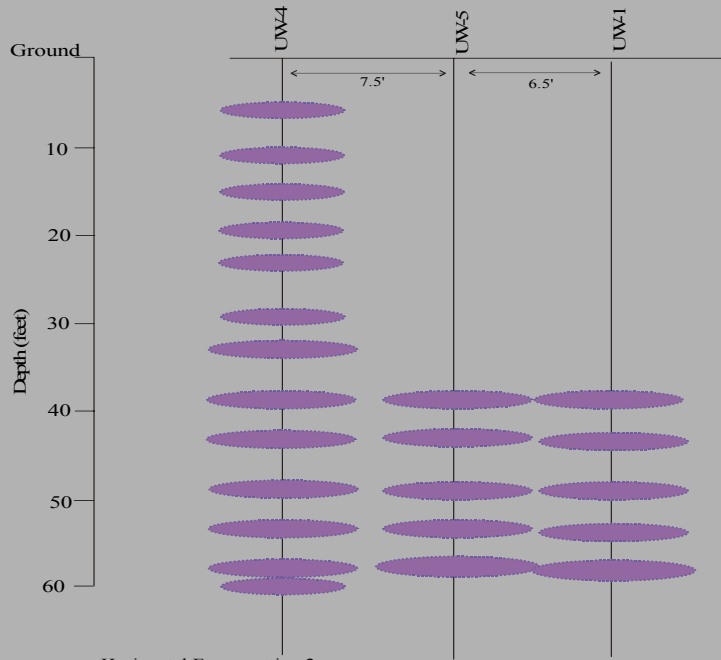
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Picture 0569

KMnO₄ Injection Coverage Episode 1



KMnO₄ Injection at Multiple Depths

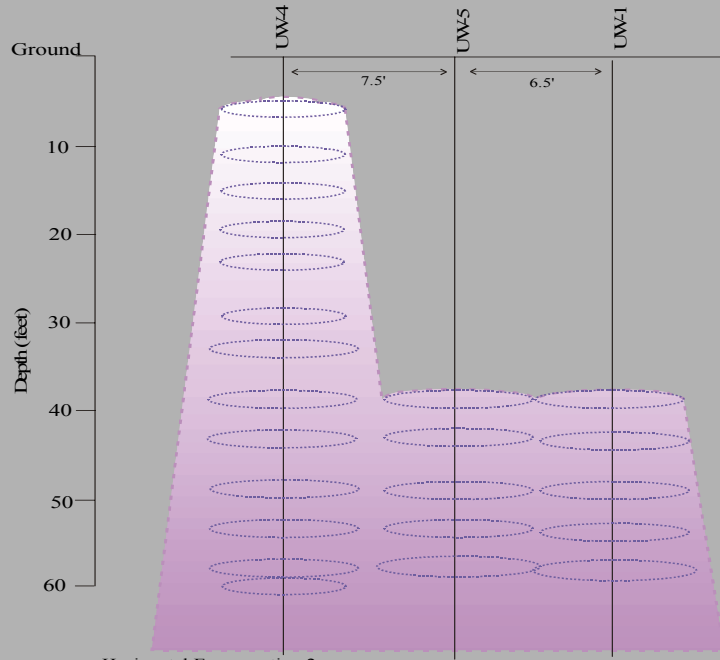


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Horizontal Exaggeration 2x
Ellipsoid size based on 30% porosity and a height to width ratio of 3:1.



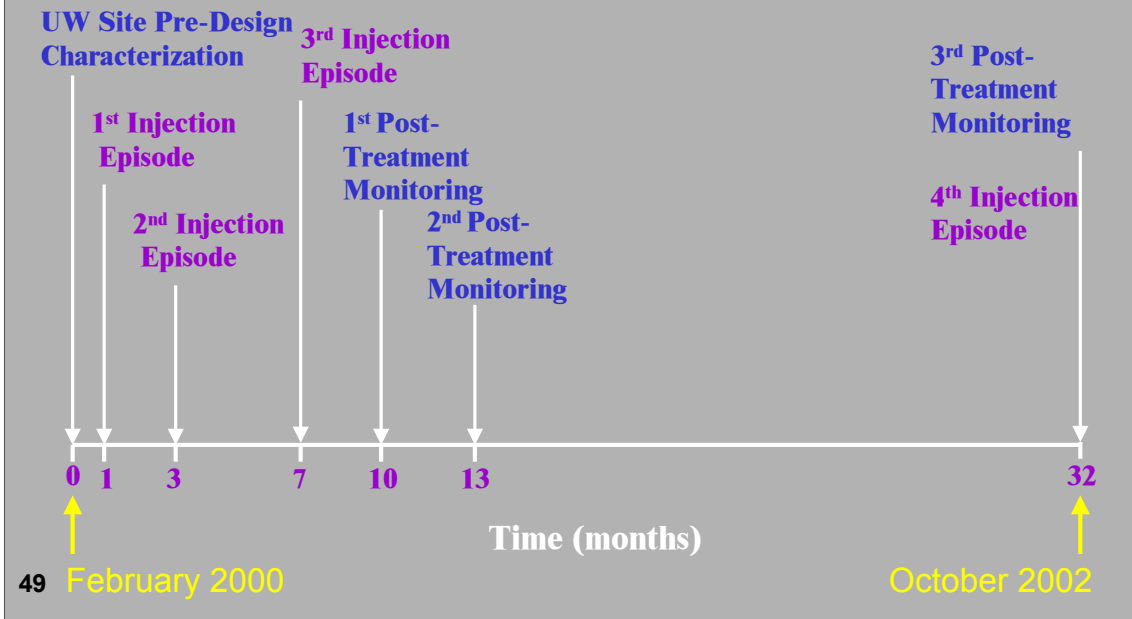
Effects of Density and Diffusion on Injected KMnO_4 Ellipsoids



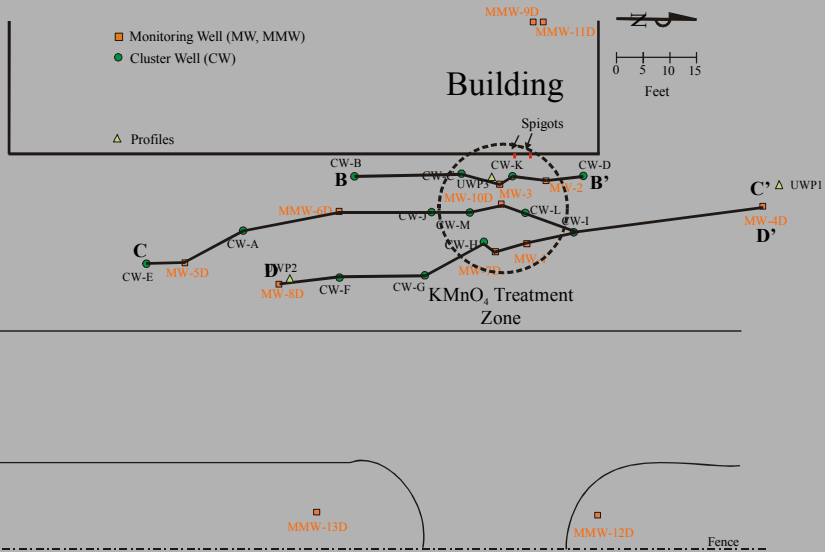
48

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

Project Timeline

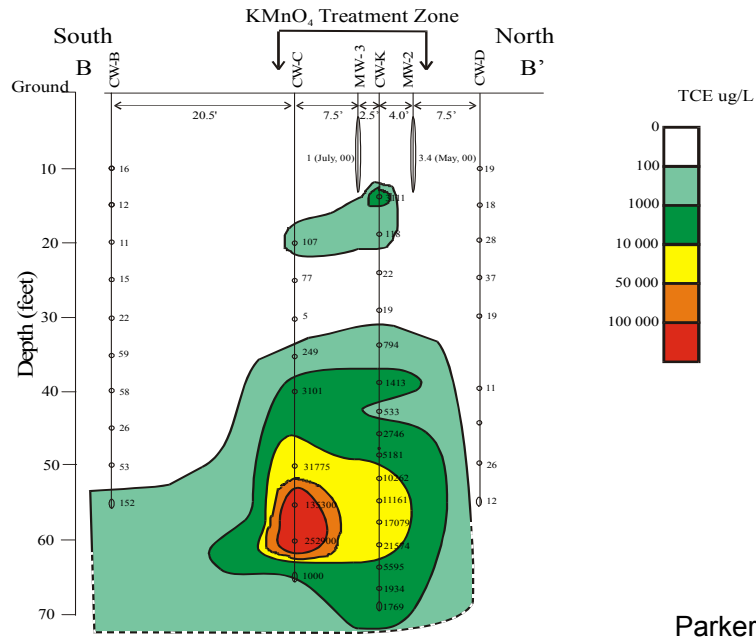


Site Map – X Sections



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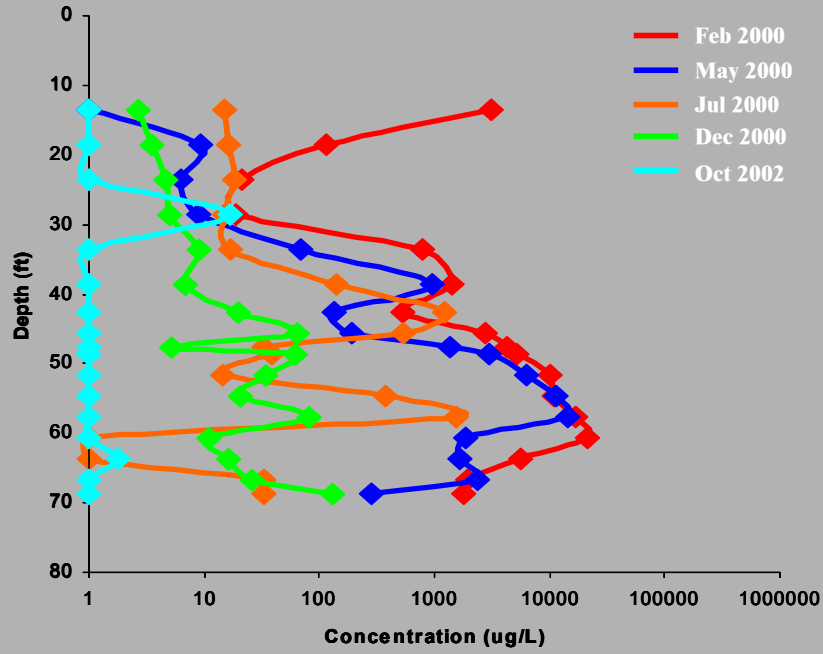
TCE Distribution on B-B' – Feb 2000



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Parker et al., 2000

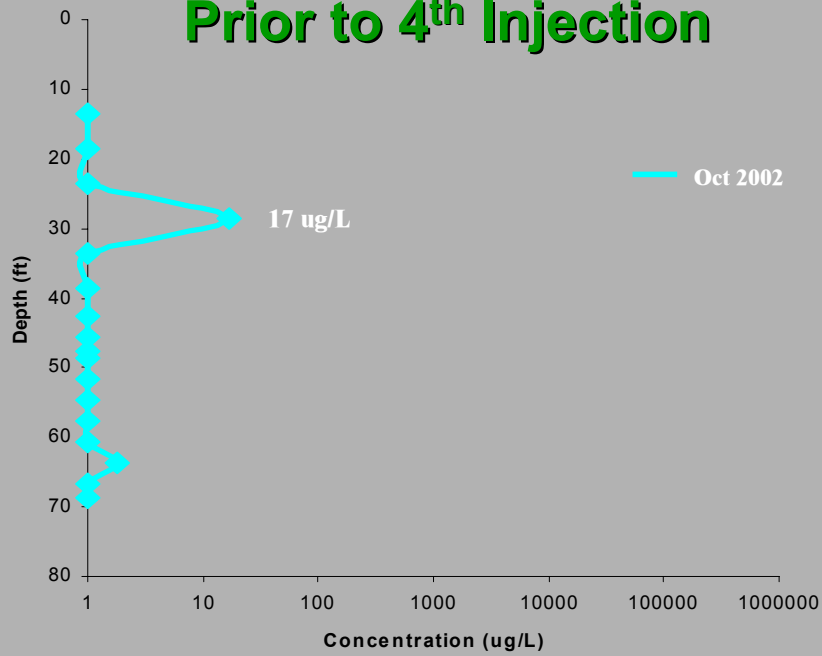
TCE Concentration Profile CW-K



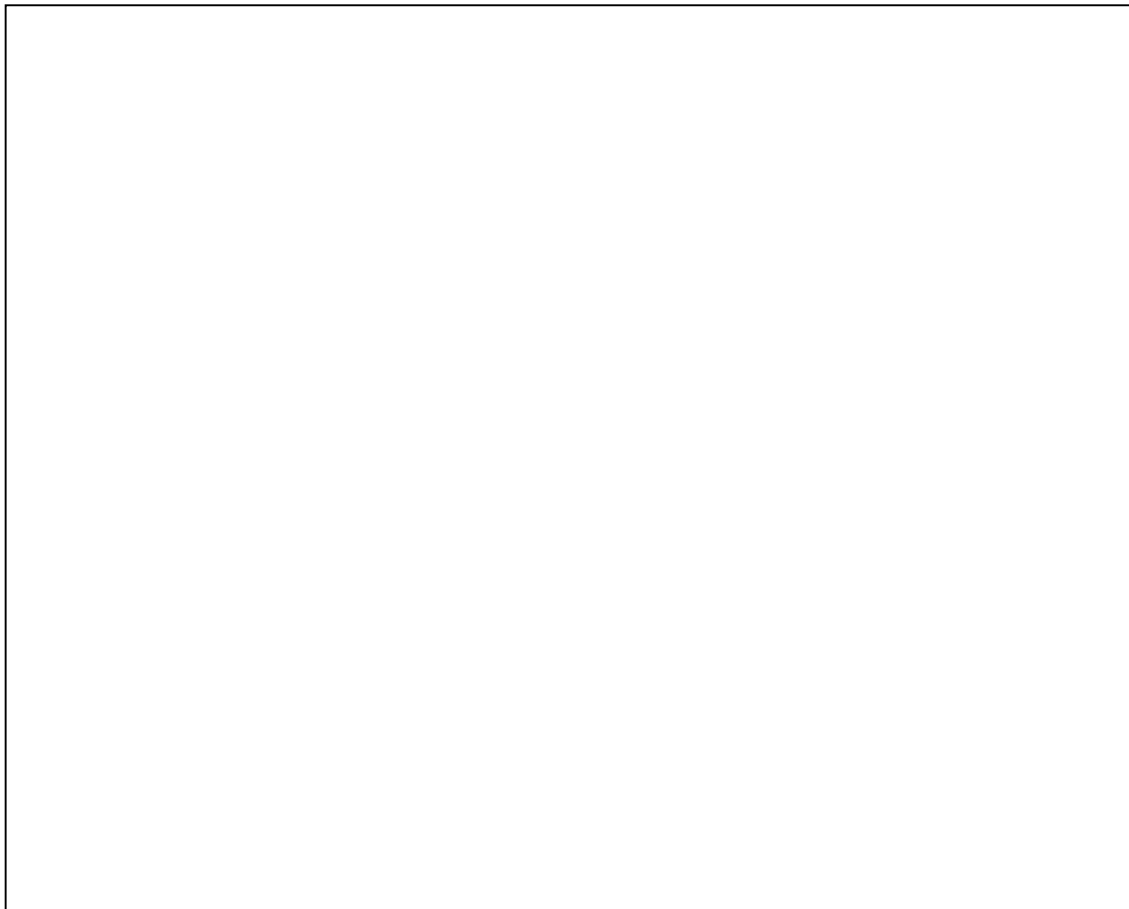
53



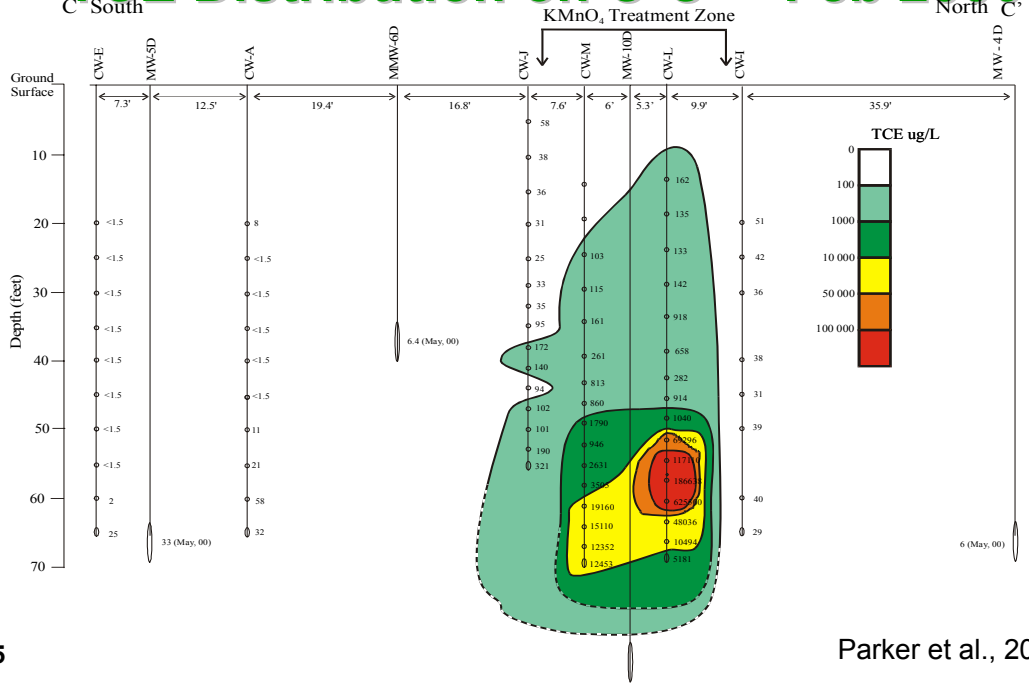
TCE Concentration Profile CW-K Prior to 4th Injection



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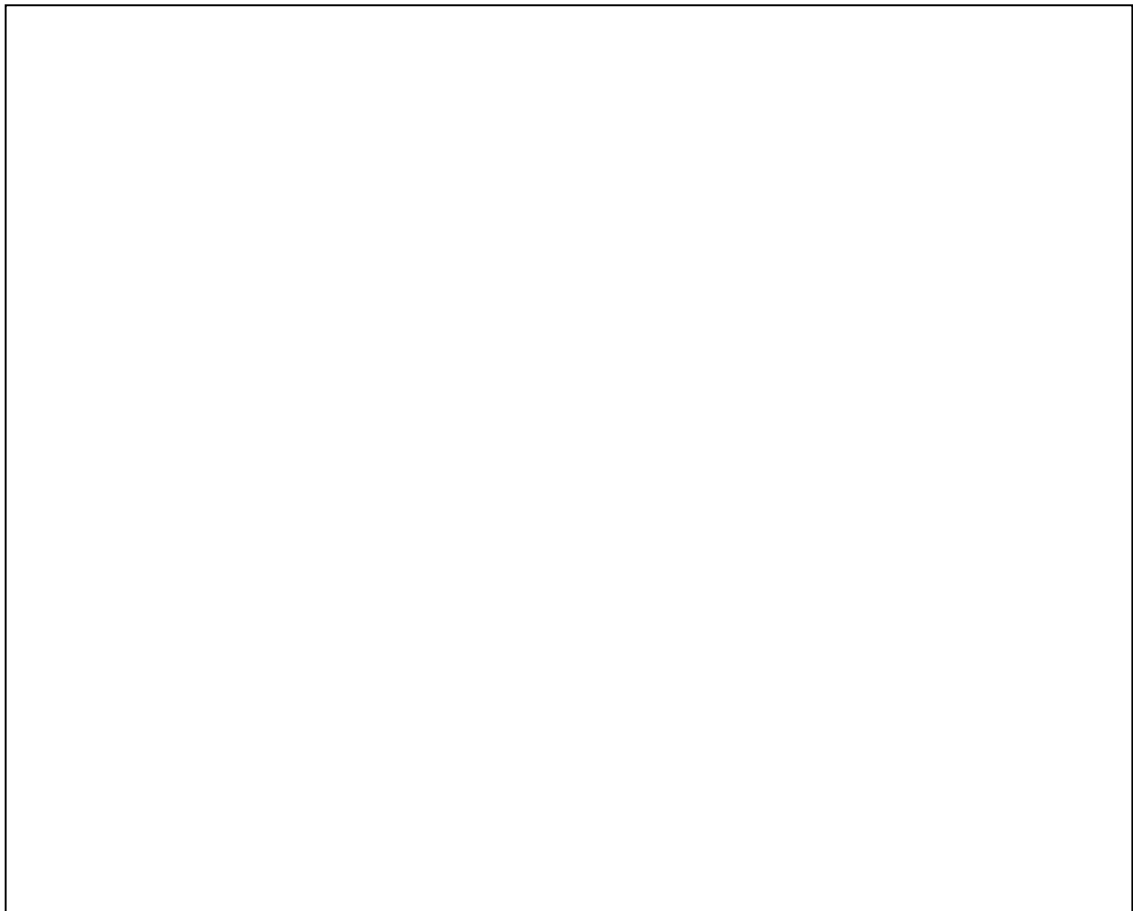
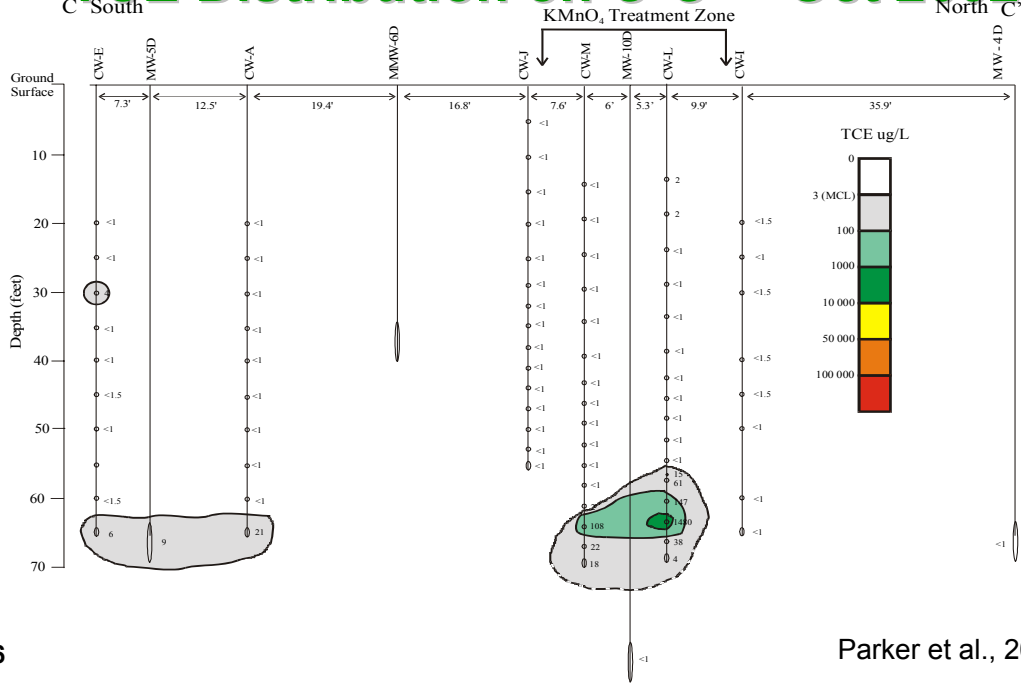
TCE Distribution on C-C' – Feb 2000



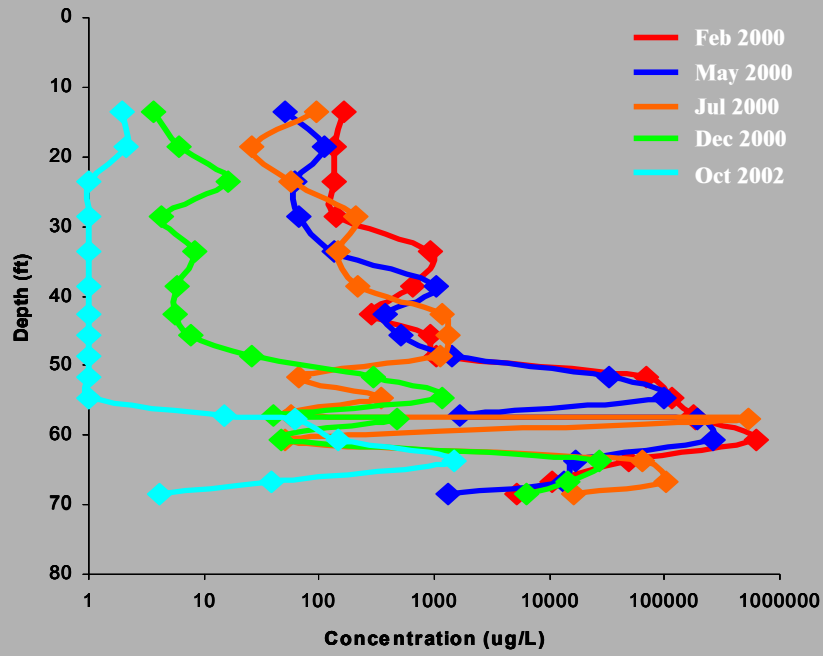
55

Parker et al., 2000

TCE Distribution on C-C' – Oct 2002



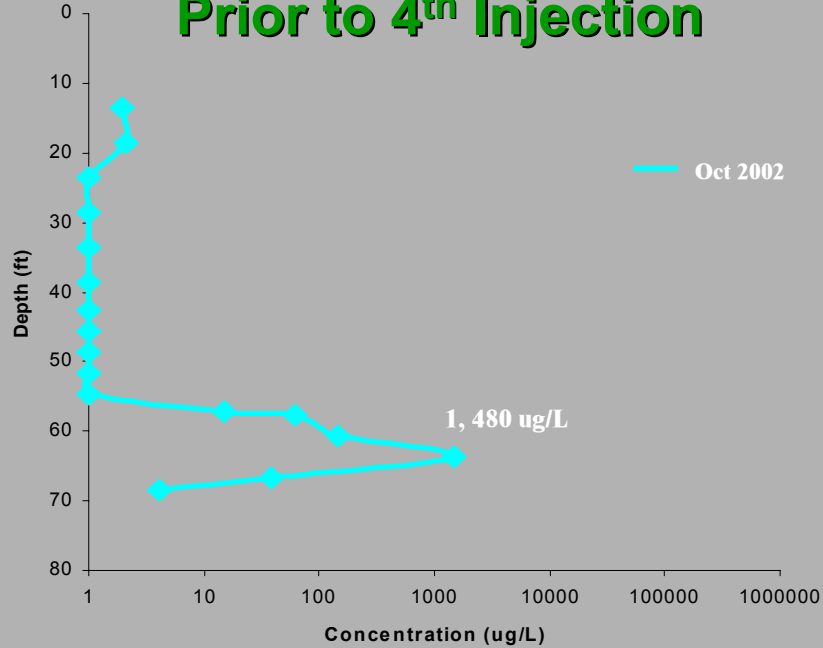
TCE Concentration Profile CW-L



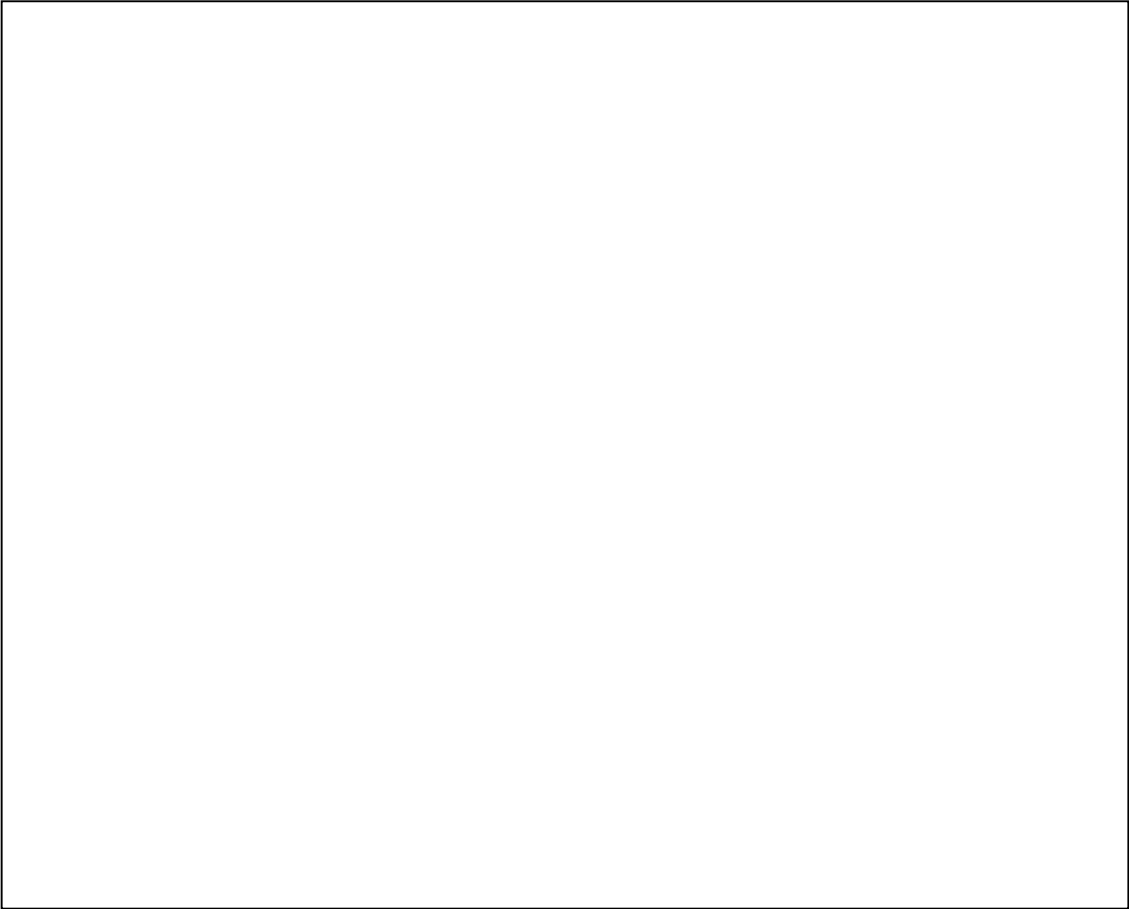
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TCE Concentration Profile CW-L Prior to 4th Injection



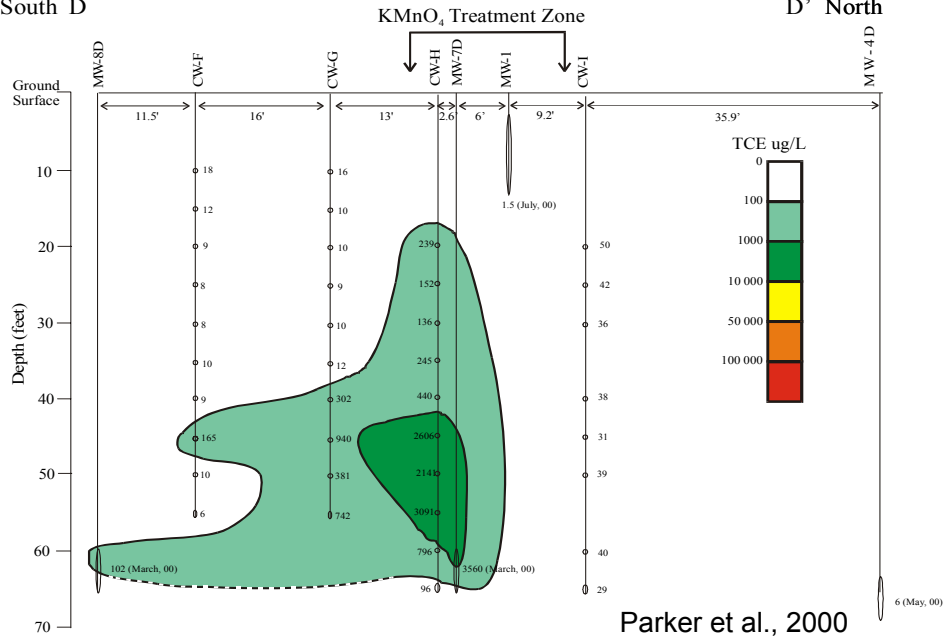
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TCE Distribution on D-D' – Feb 2000

South D

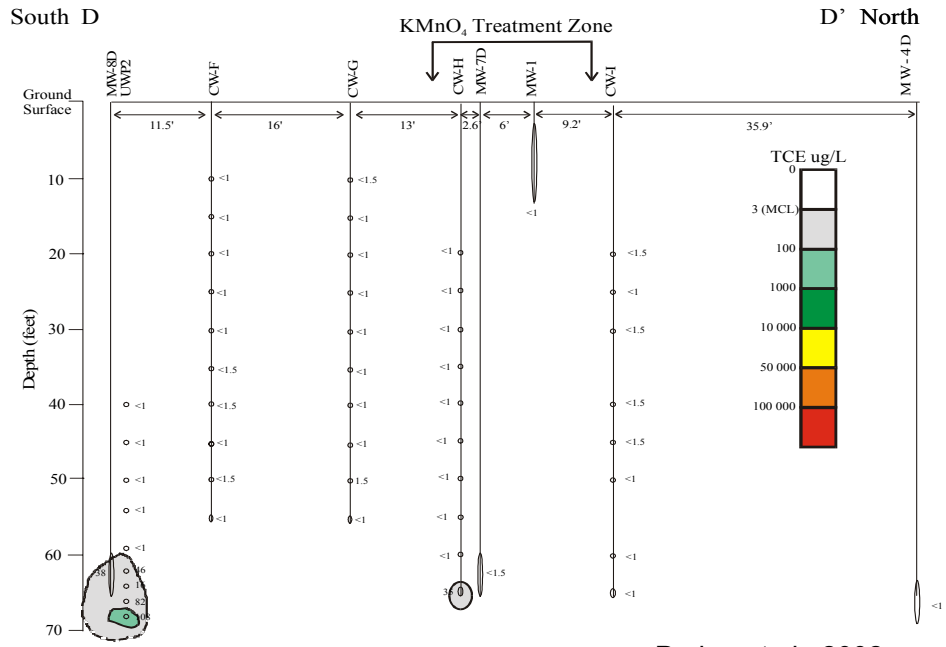
D' North



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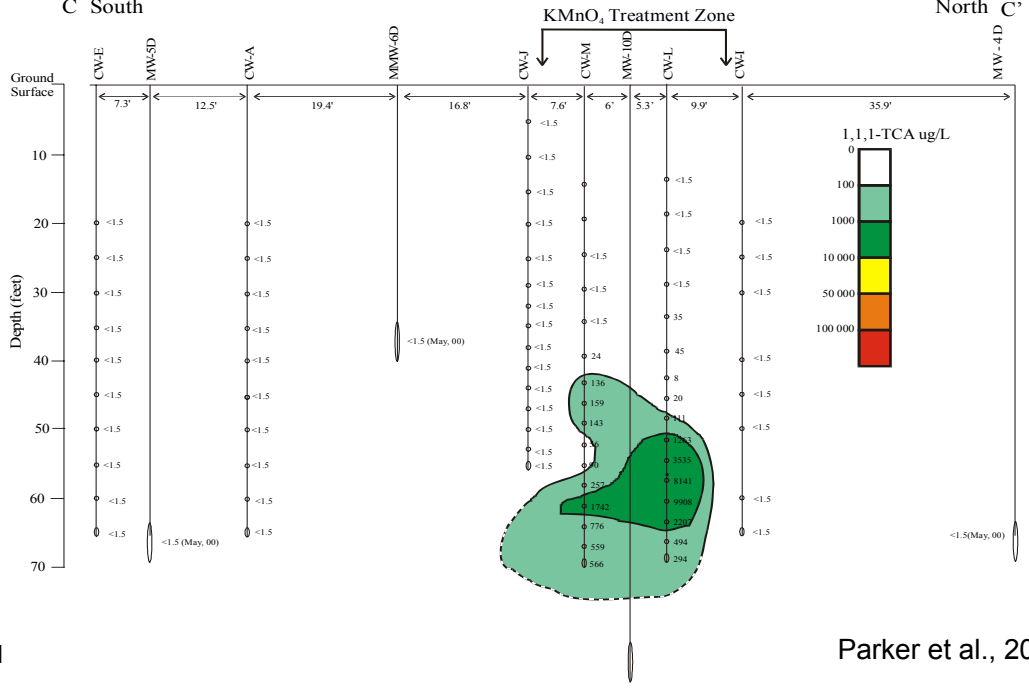
Parker et al., 2000

TCE Distribution on D-D' – Oct 2002



Parker et al., 2002

TCA Distribution on C-C' – Feb 2000

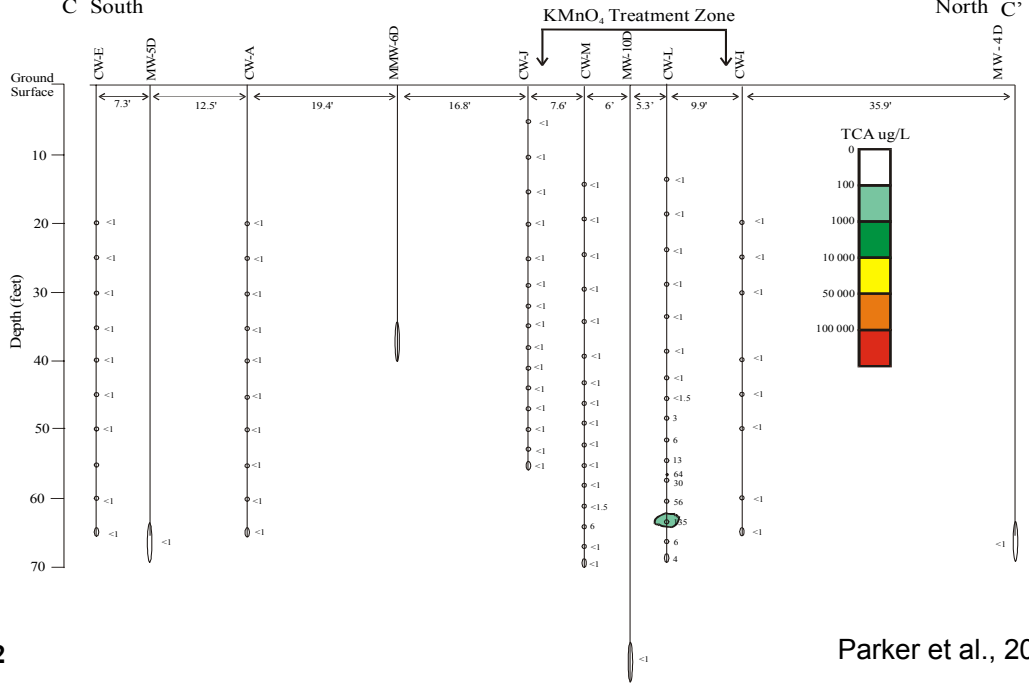


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Parker et al., 2000

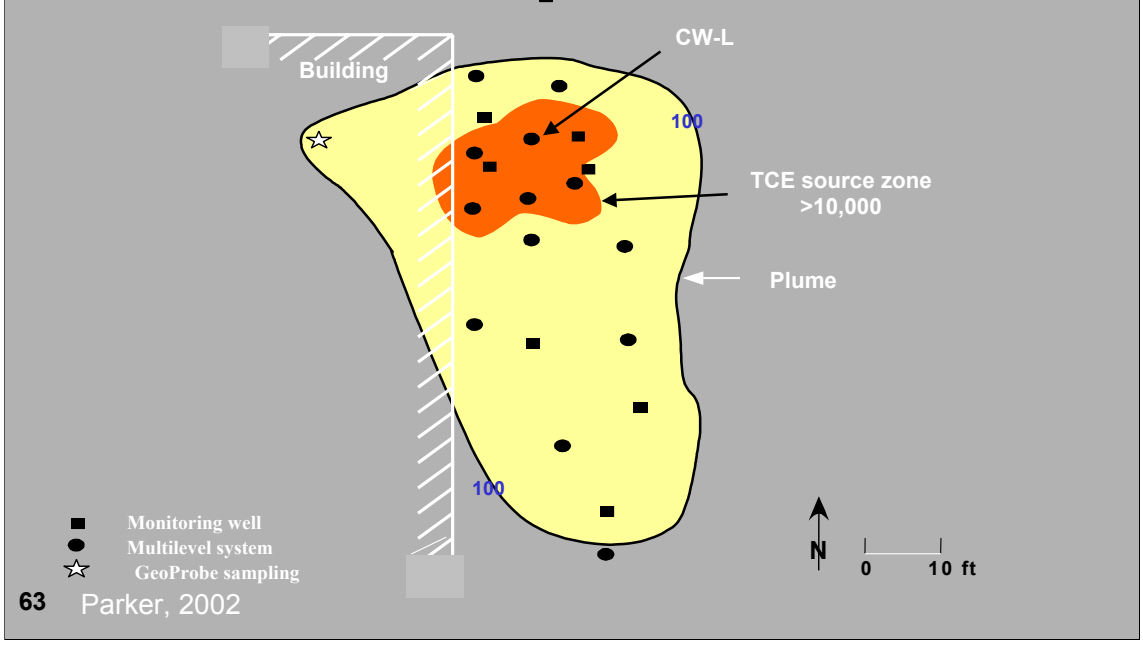


TCA Distribution on C-C' – Oct 2002



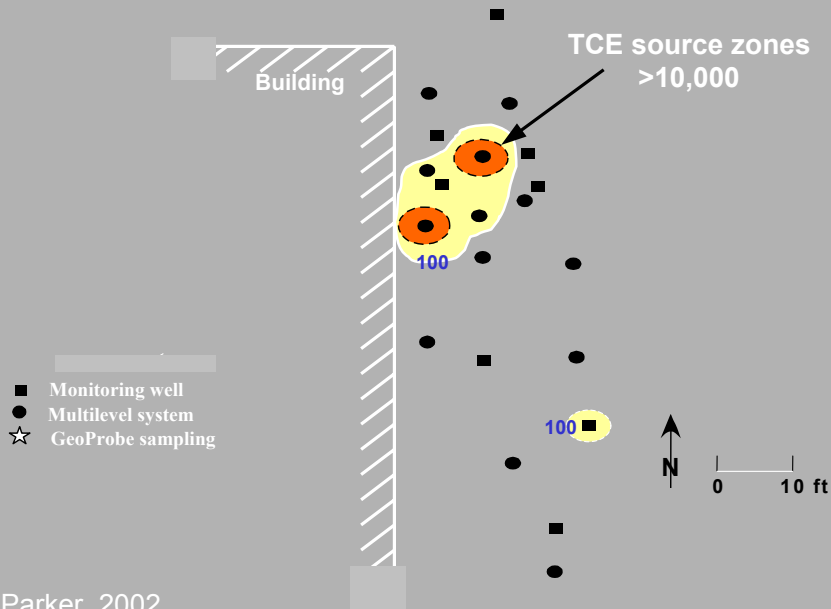
Before Remediation – February 2000

TCE $\mu\text{g/L}$



After Remediation – December 2000

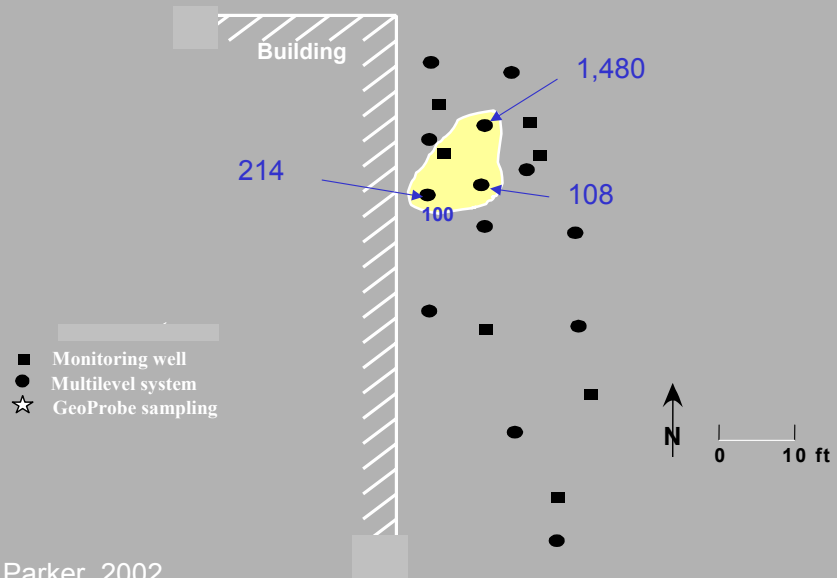
TCE $\mu\text{g/L}$



64 Parker, 2002

After Remediation – October 2002

TCE $\mu\text{g/L}$



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

Final Stage

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

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Acknowledgements

Funding:

- University Consortium Solvents-in-Groundwater Research Program
- Canadian Natural Sciences and Engineering Research Council
- 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](#)

