Electrolytic Reactors (e-barrier) for the In Situ Treatment of Chlorinated Compounds -*Borden Field Experiment*

Matthew Ballaban[1], Tom Sale[2], Dave Gilbert[2], Robert Gillham[1]

University of Waterloo[1] • Colorado State University[2]

Introduction

Background

Reduction

$$\mathrm{PCE} \xrightarrow{2e^- + H^+ \qquad Cl^-} \mathrm{TCE} \xrightarrow{2e^- + H^+ \qquad Cl^-} \mathrm{DCEs} \xrightarrow{2e^- + H^+ \qquad Cl^-} \cdots \; C_2H_4$$

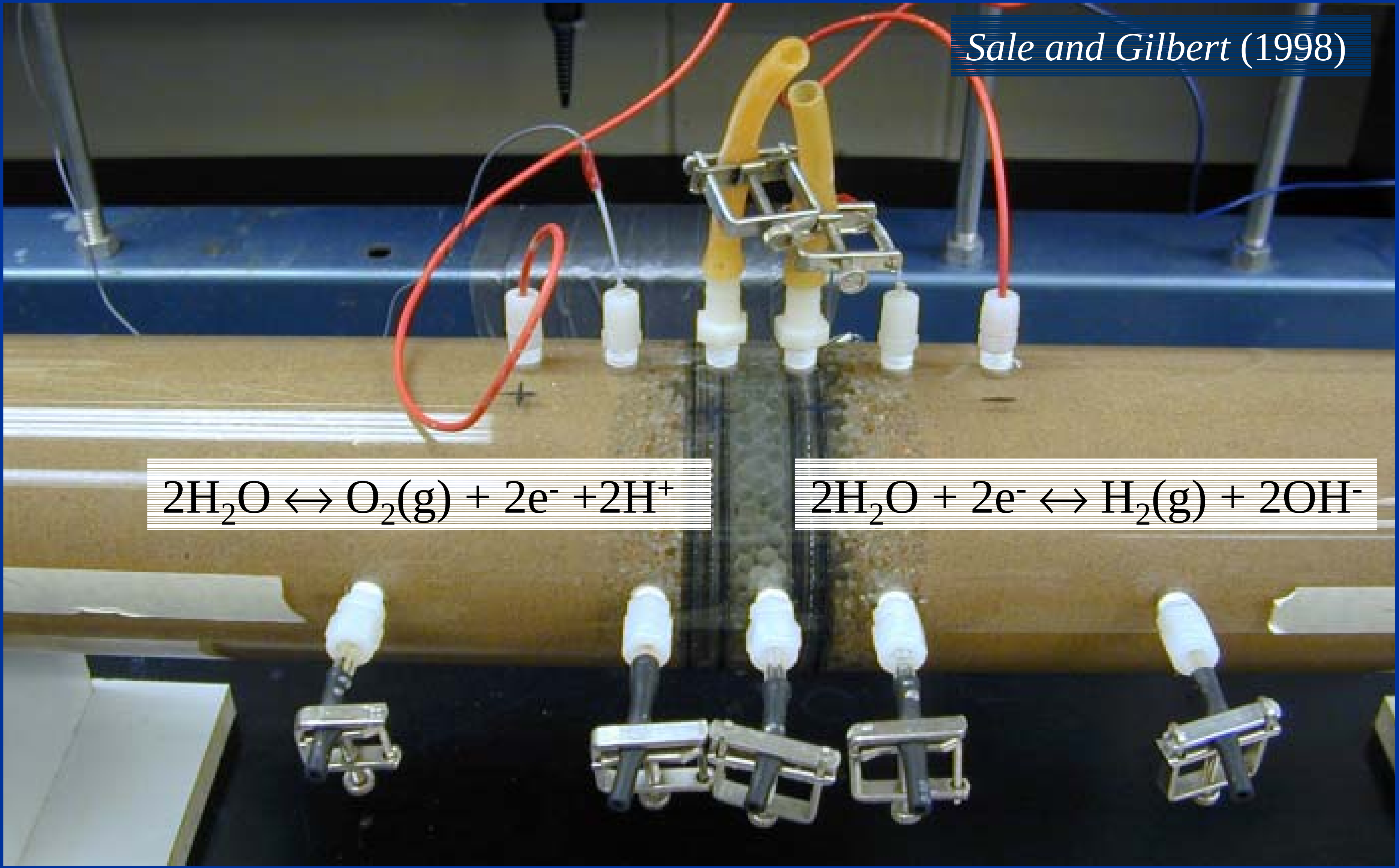
Roberts, et al. (1996)

Oxidation

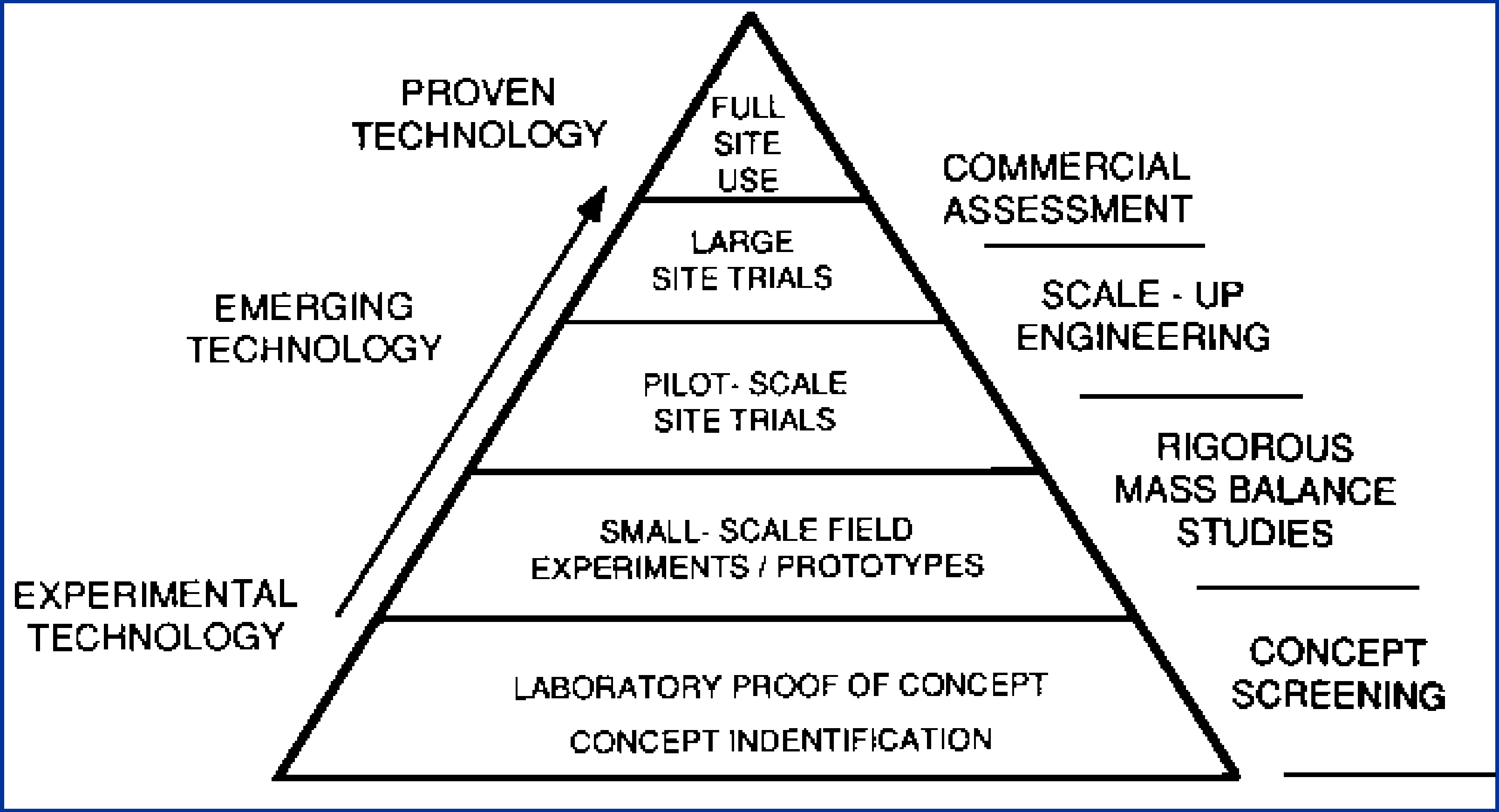
$$\mathrm{PCE} \xrightarrow{4H_2O \qquad 4e^- + 2CO_2 + \; 4Cl^- + 8H^+} CO_2$$

Huang et al. (2002)

Laboratory Experiments



Technology Evolution



Pankow and Cherry (1996)

Objectives

Performance Evaluation

1) Reference potentials sufficient for contaminant redox reactions
2) Evaluate precipitate management technique
3) Overall treatment performance including the effects of increasing applied voltage
4) Investigate possible downgradient/ upgradient treatment processes

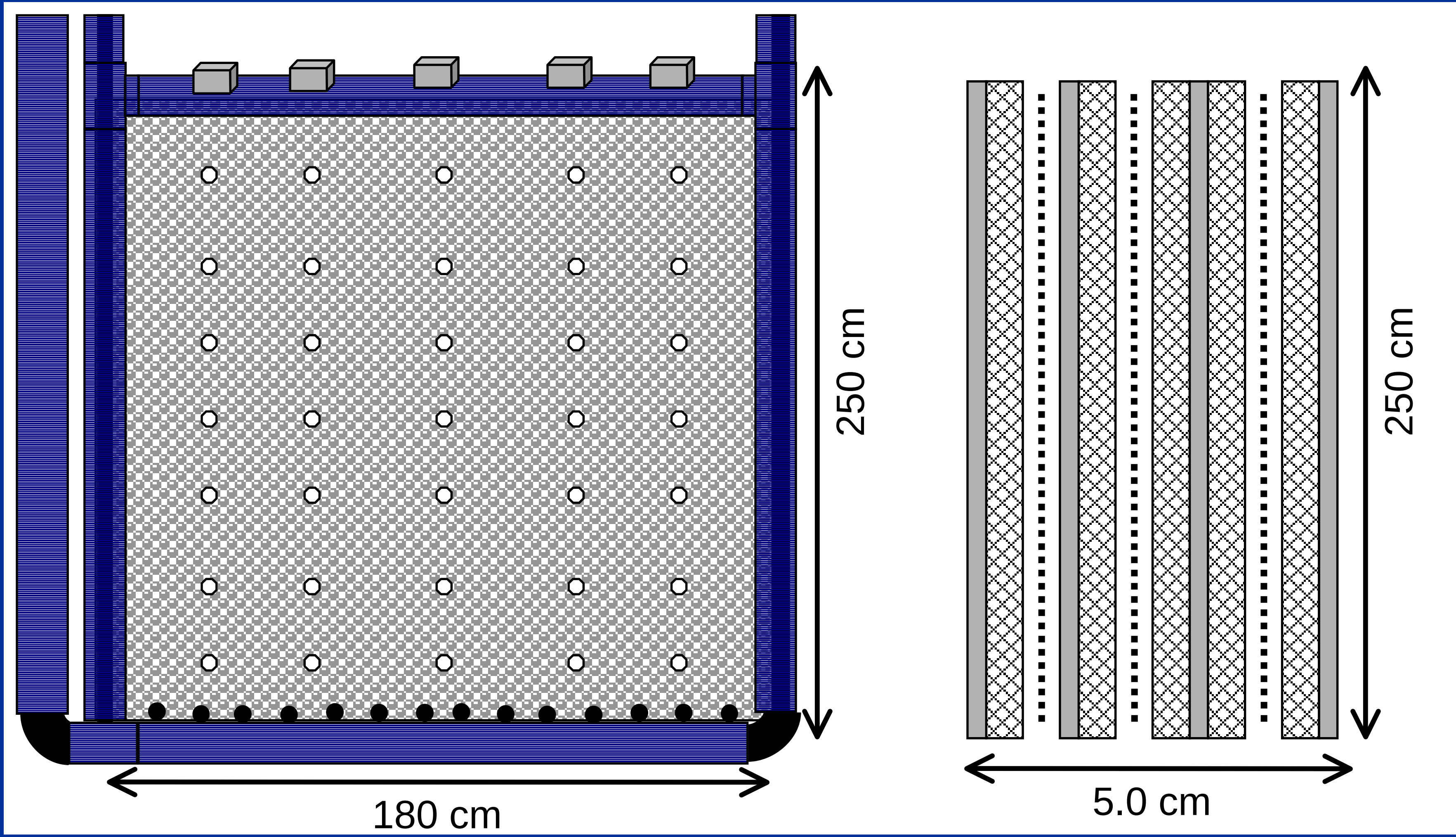
Methodology

Field Experiment

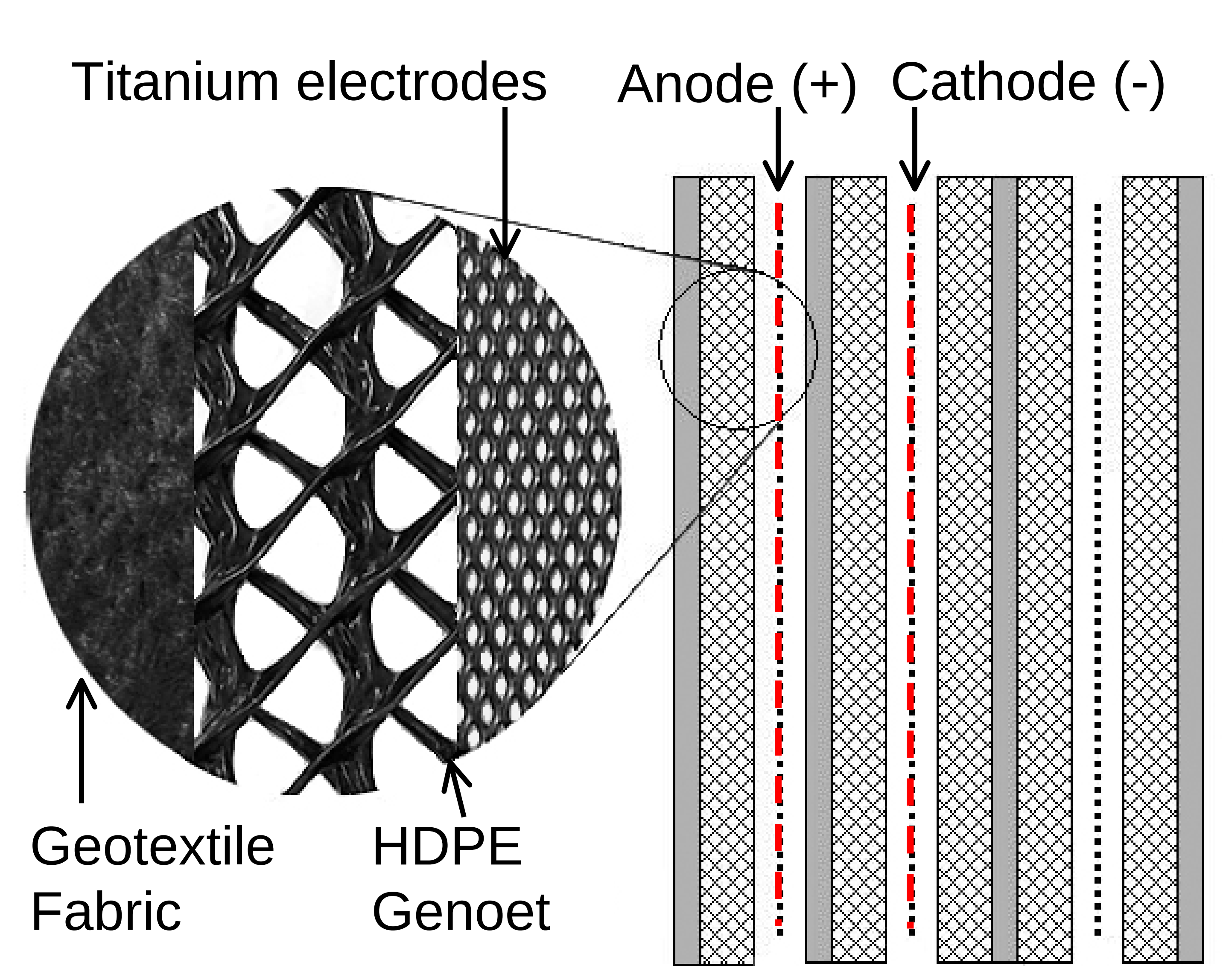
- Installed a prototype e-barrier in the field
- Collected water samples using a multilevel sampling network
- Monitored PCE, TCE and breakdown products both upgradient and downgradient from the e-barrier
- Calculated percent removals at operating voltages of 0, 5, 7 and 10 volts

Front View

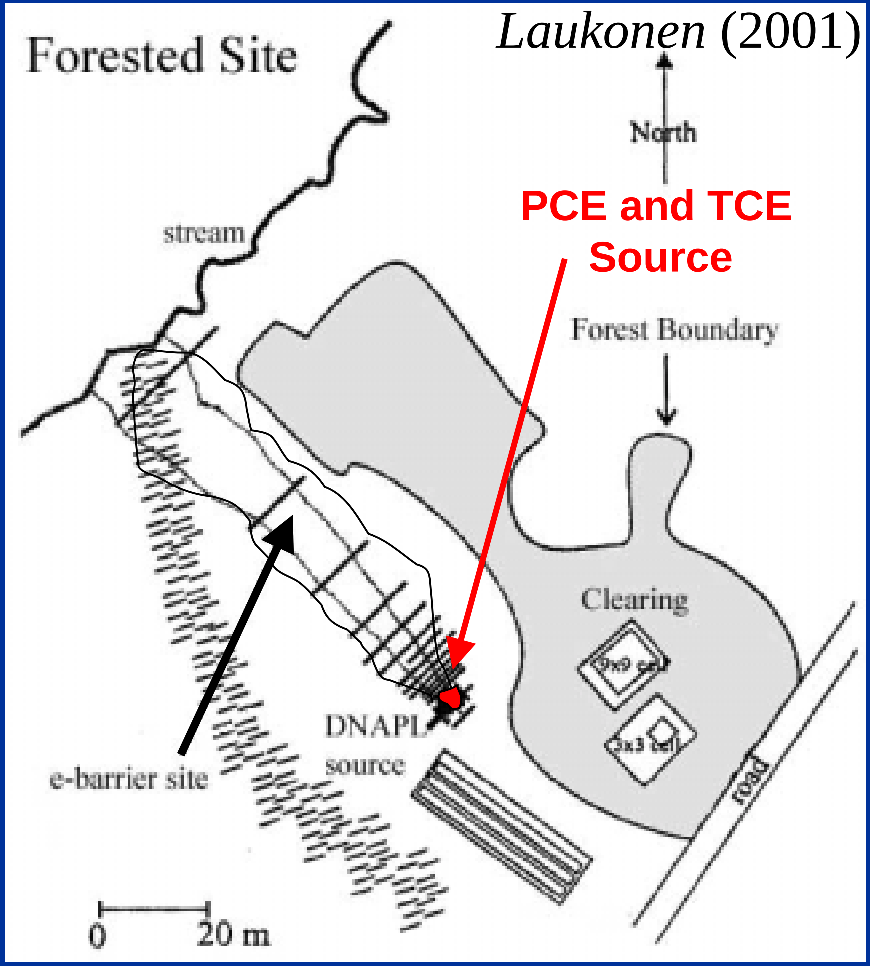
Side View



Internal Construction

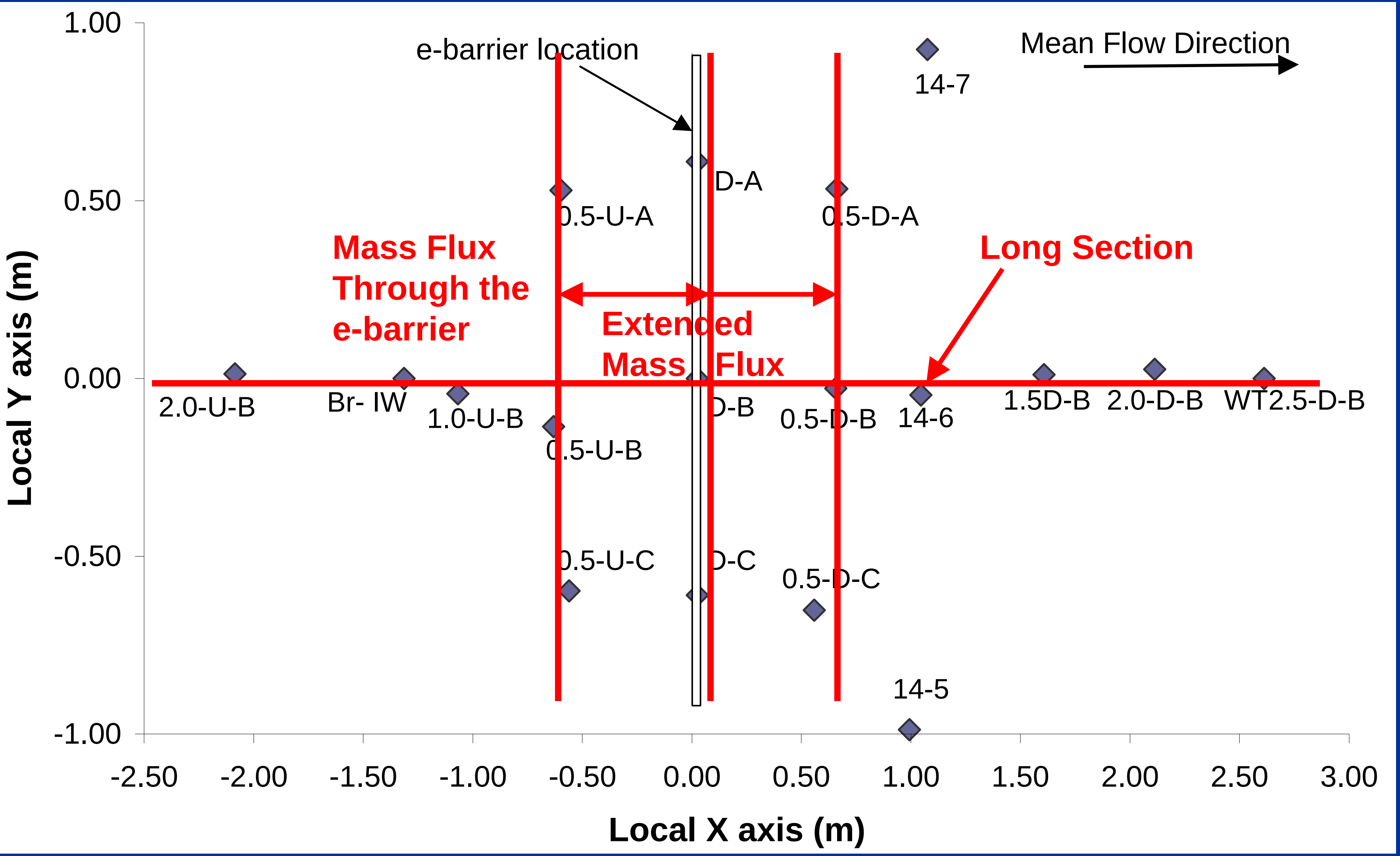


Borden Installation



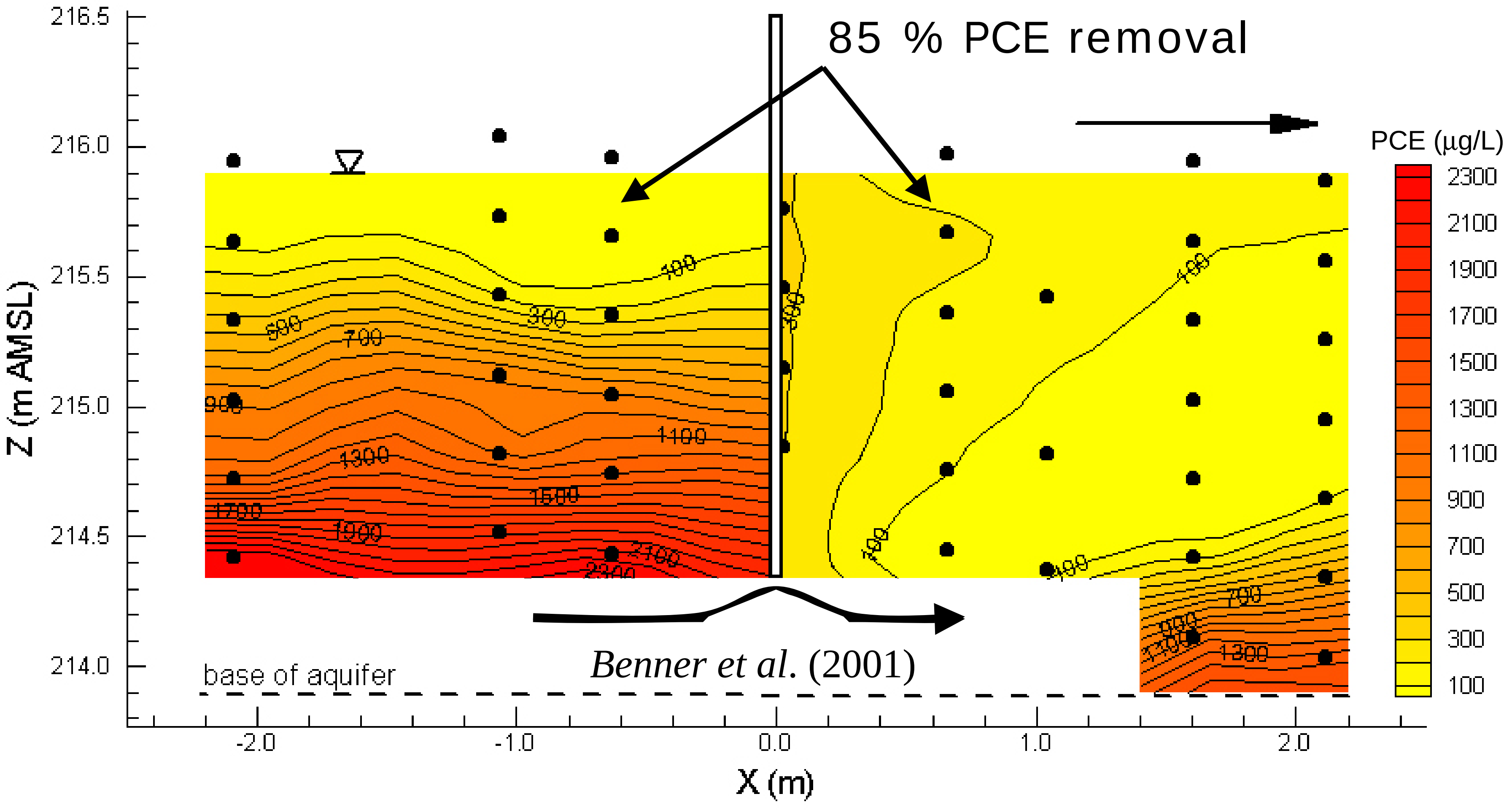
e-barrier Site Overview

Plan View –sampling network

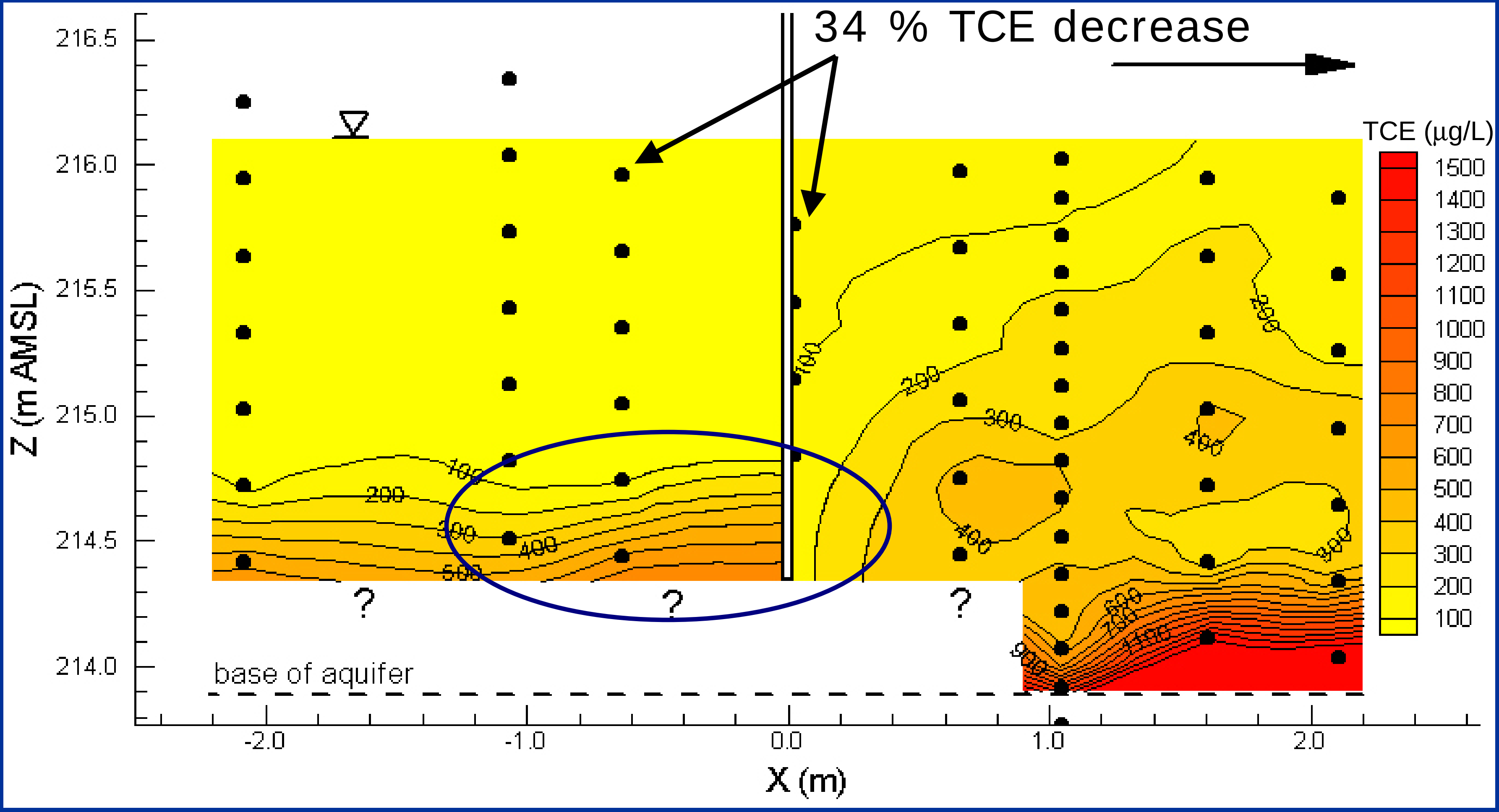


Results & Discussion

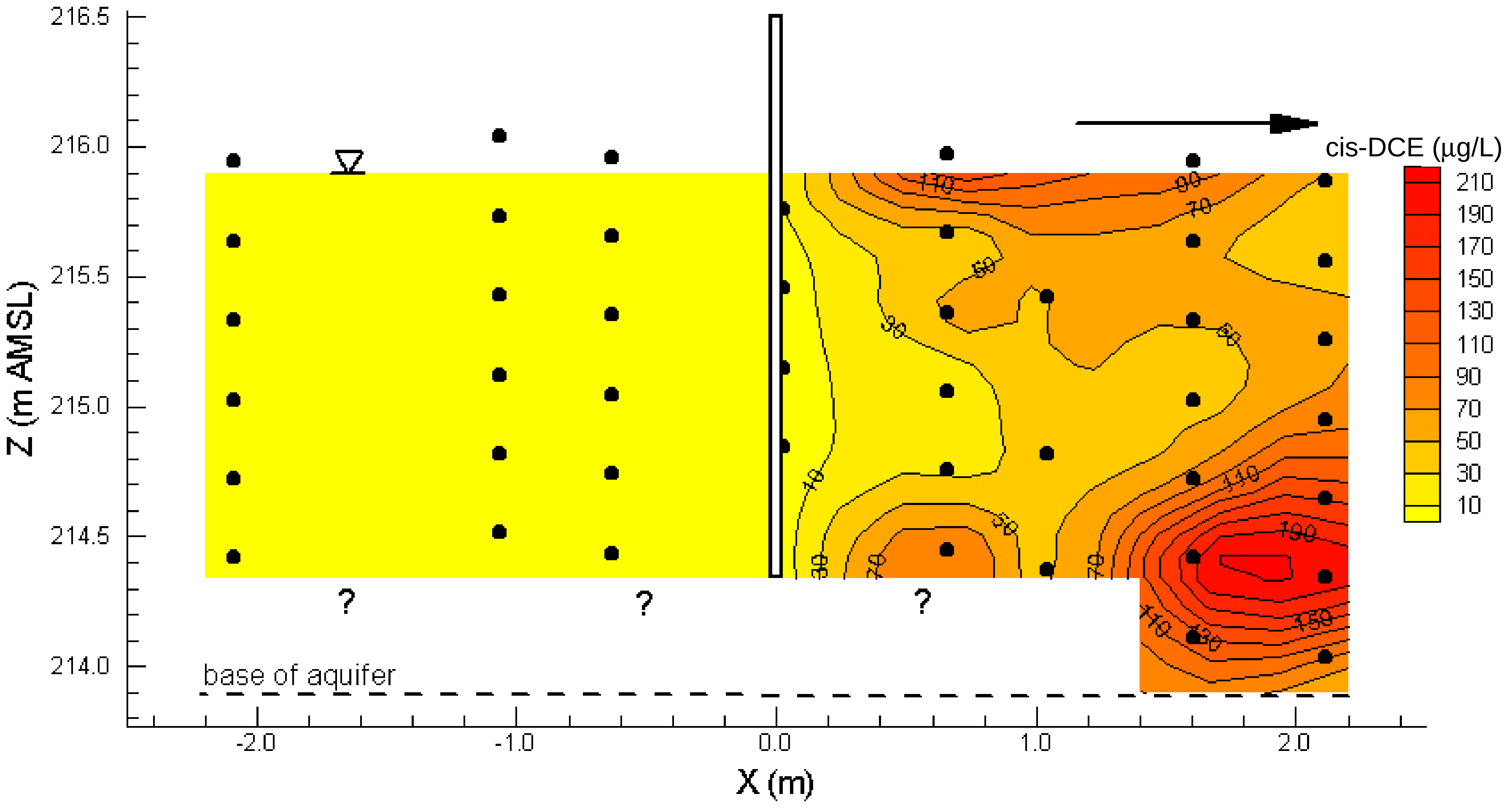
PCE Long Section



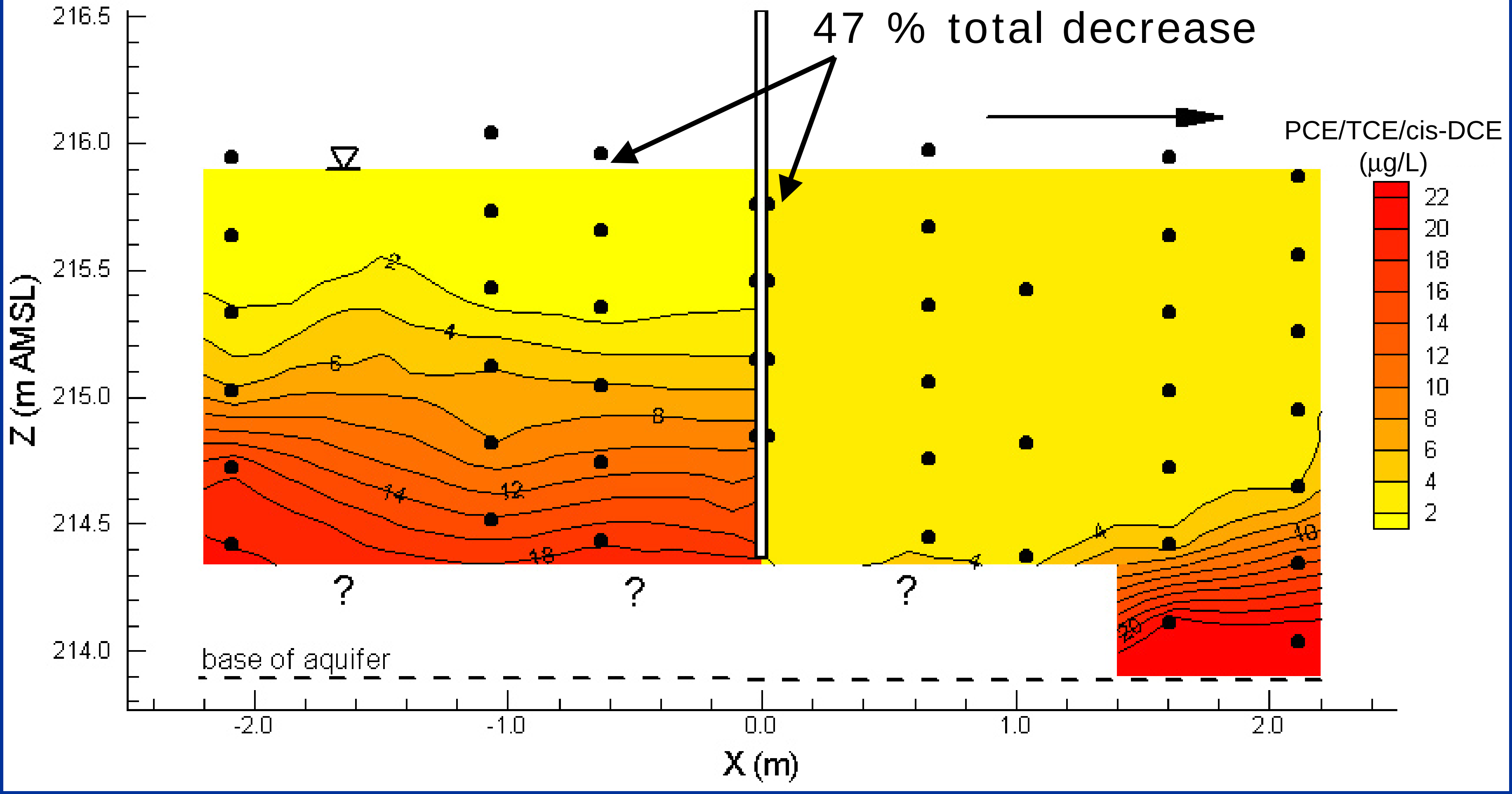
TCE Long Section



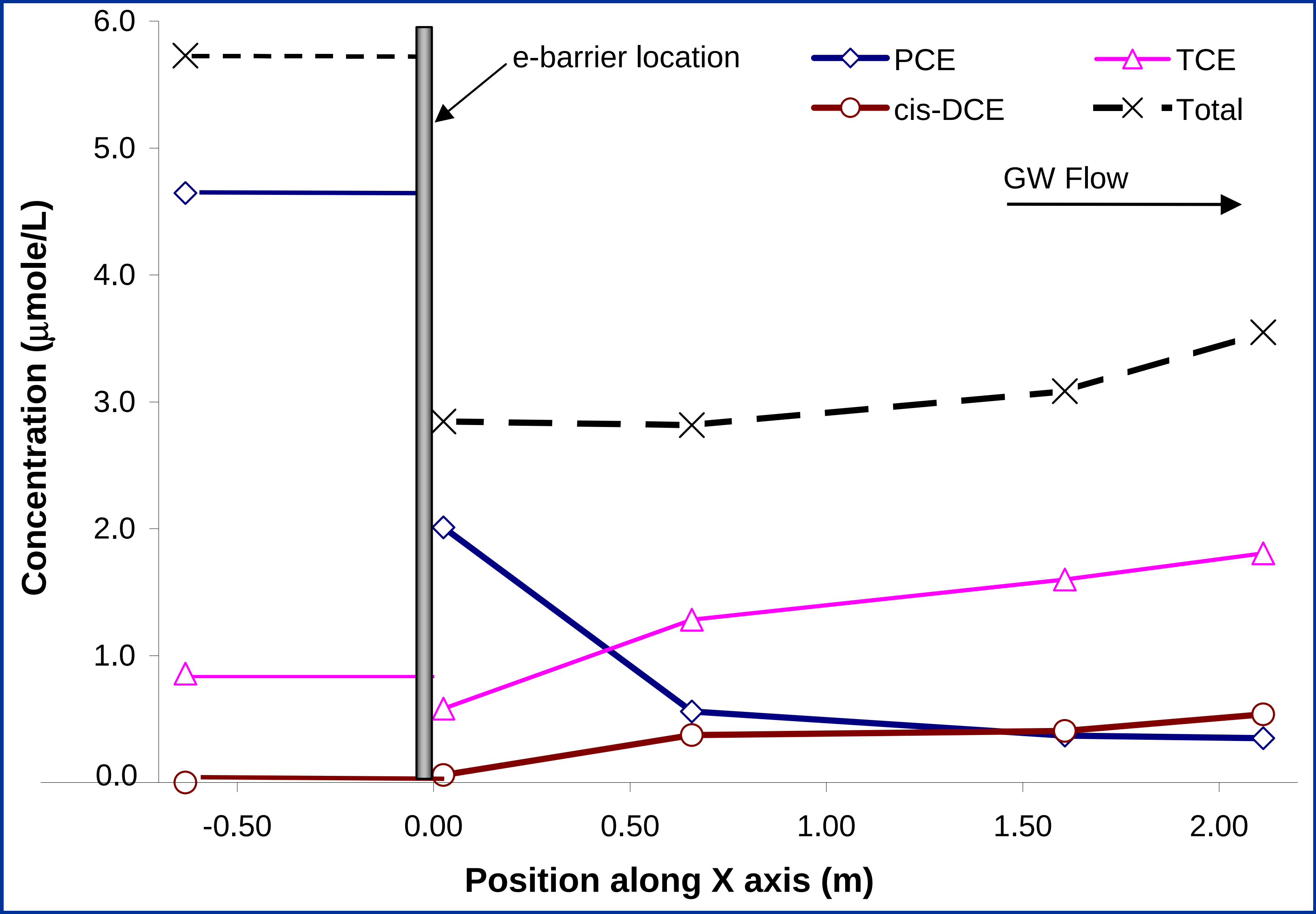
cis-DCE Long Section



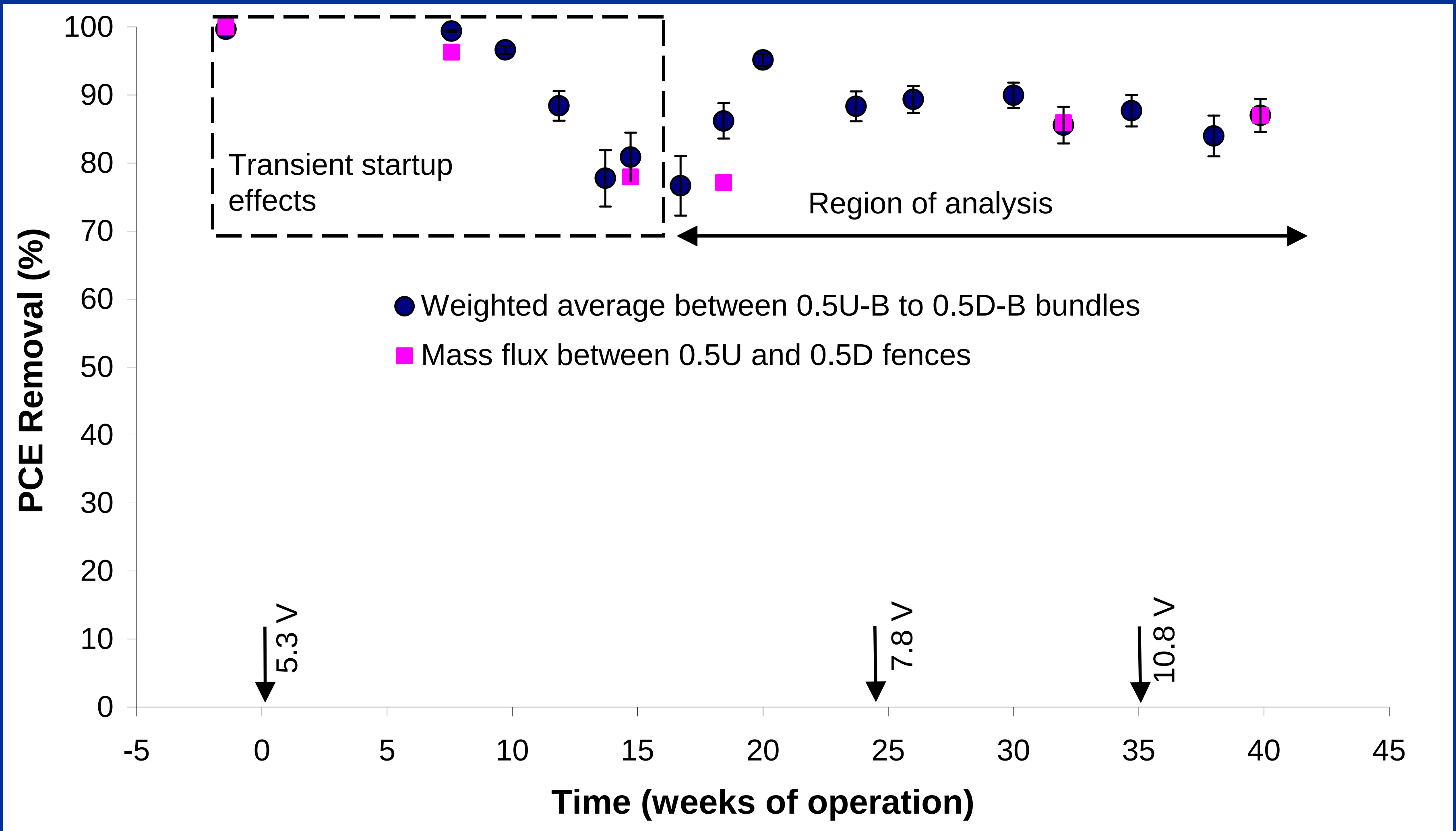
Total µmoles Long Section



Time Averaged Trends



Treatment vs. Voltage



Laboratory Experiment

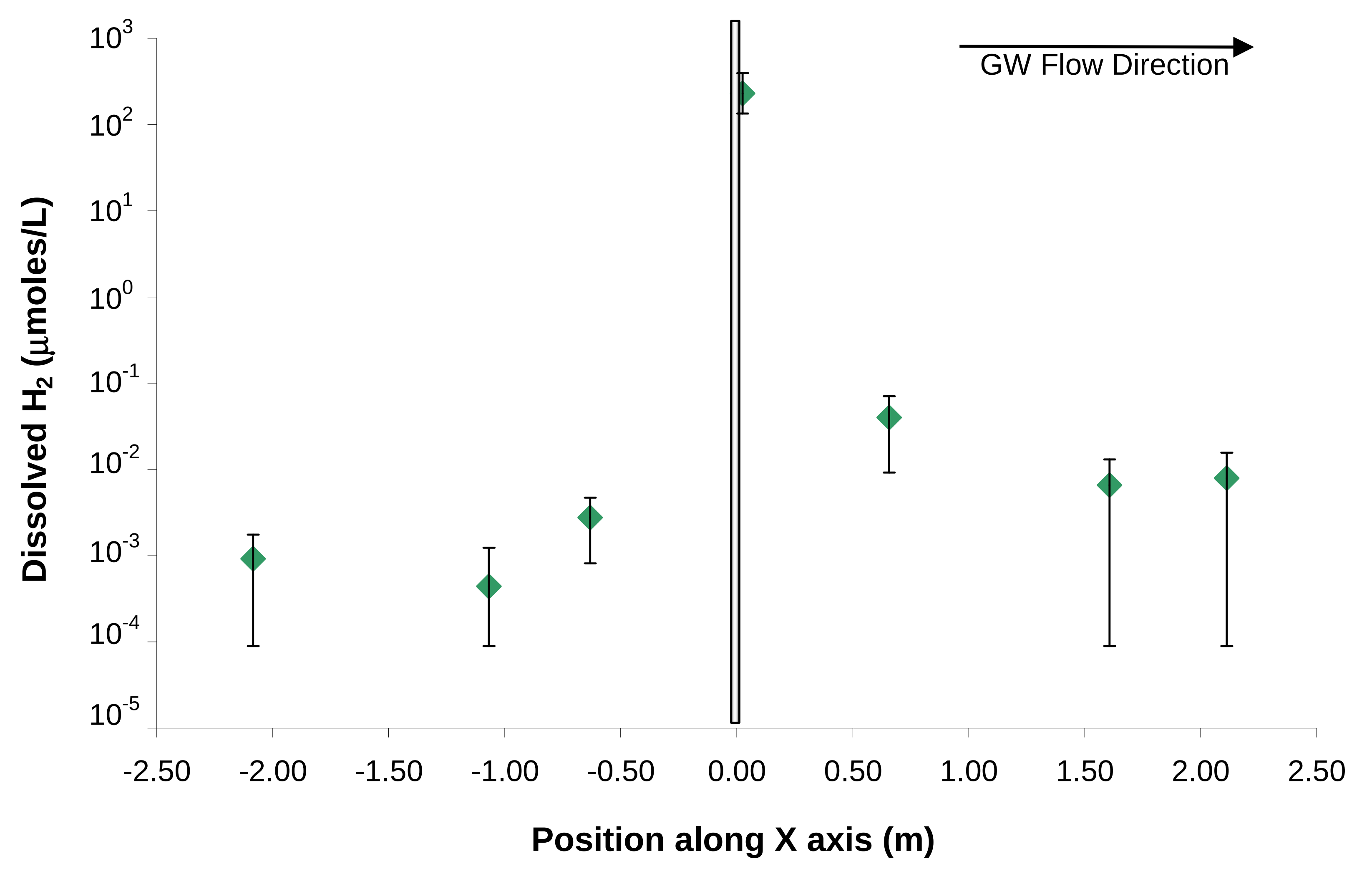
Downgradient Reactions

- Trends - Decreasing PCE
  - Increasing TCE and cis-DCE
- Microbial reductive dechlorination of PCE often ends at cis-DCE (*Chapelle*, 2001)
- Microorganisms often use H_2 as direct electron donors for reductive dechlorination (*He et al.*, 2002 and *Fennell and Gossett*, 1997)
- e-barrier produces H_2 through electrolysis

Hypothesis

- In the presence of excess H_2, indigenous Borden microorganism are able to degrade PCE to TCE to cis-DCE

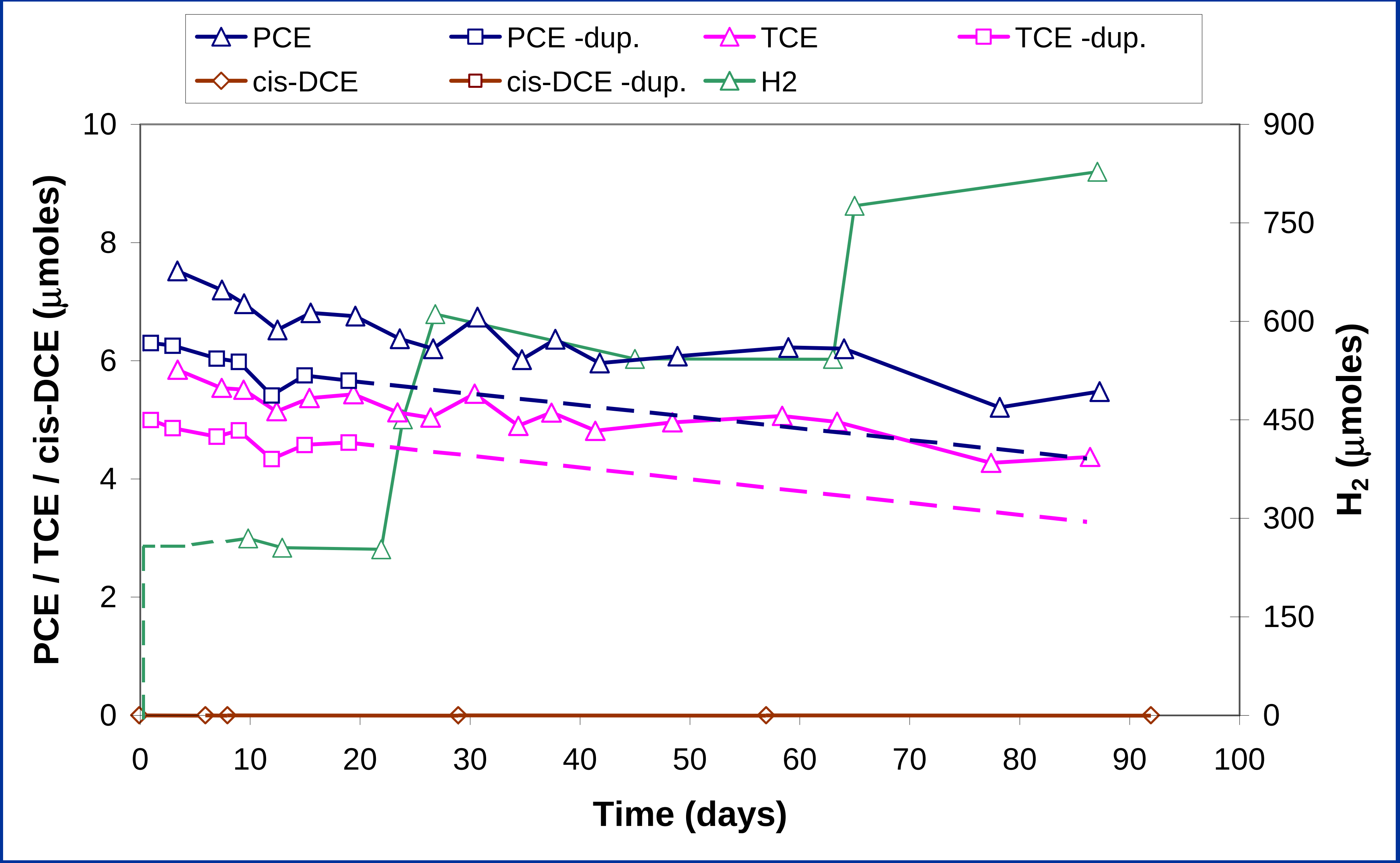
Field H_2 Measurements



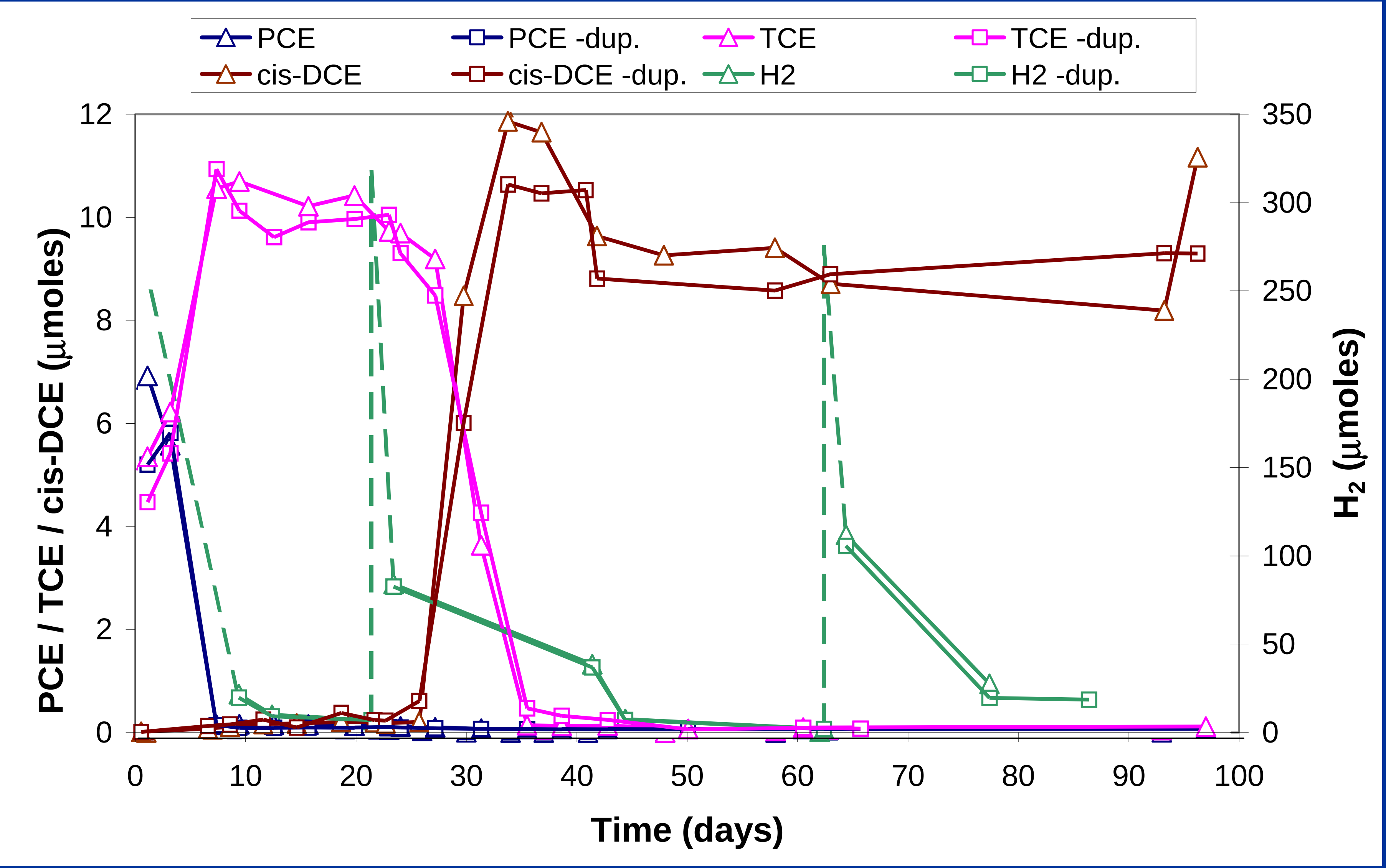
Microcosm Experiment

- Soil and GW collected from e-barrier site
- Conducted in an anaerobic chamber
- 2 Sterile controls
- 2 Active microcosms
- Aqueous samples collected over 100 days

Microcosm Sterile Controls



Microcosms, Active



Conclusions

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1) Large oxidation and reduction potentials near electrodes

   - in excess of 1.7 V and –2.8 V vs. SHE
   - operating costs of 0.93 cents day^{-1} m^{-2}

2) 1st and 3rd electrodes free from precipitate buildup

   - physical observation of 1st and 3rd electrodes
   - zero volt bromide tracer test

3) e-barrier performed as a mixing wall

   - most likely due to O_2 and H_2 gas evolution

Additional Conclusions

4) Consistent PCE, TCE and total CVC removal through the e-barrier

   - downgradient transformations of PCE to TCE ending in cis-DCE

   - no clear relation could be identified between removal and imposed potential

   - further laboratory and field experiments are warranted before full scale field applications for chlorinated compounds

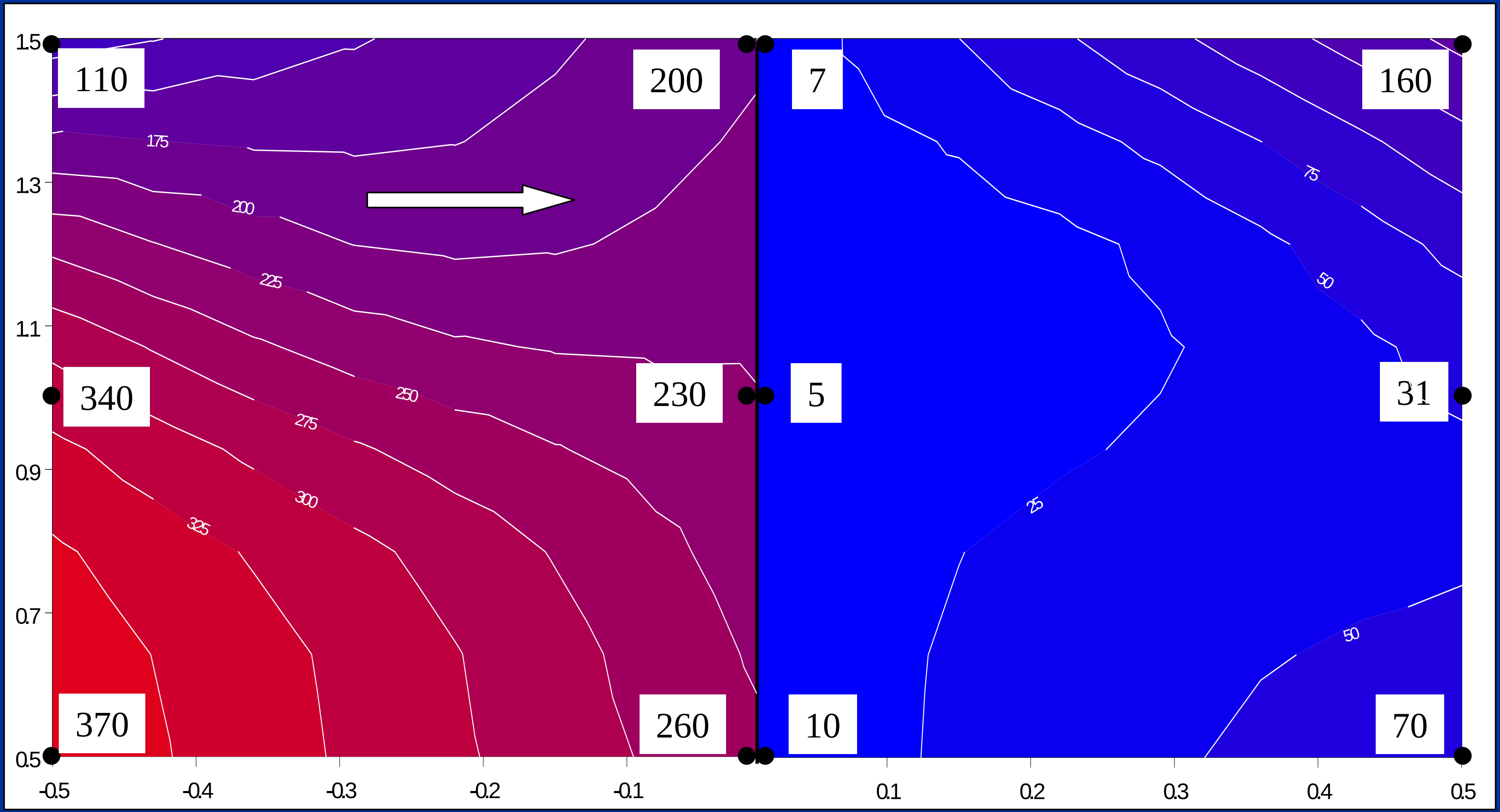
5) Downgradient reactions could be a result of electro-generated H_2 enhanced microbial dechlorination

F.E. Warren AFB field and Laboratory Energetic e-barrier Experiments

Tom Sale

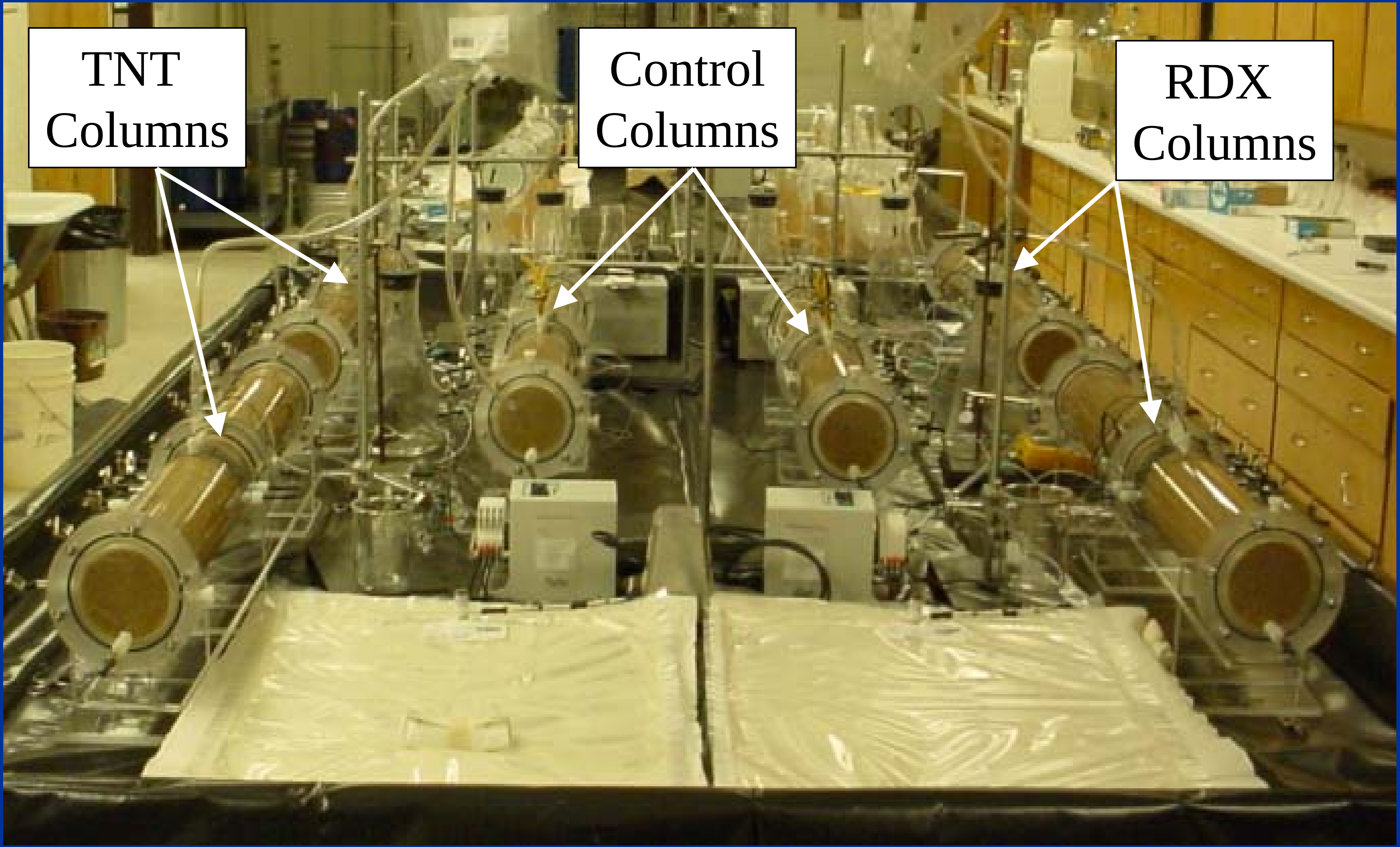
ESTCP - F.E. Warren AFB

TCE Center Transect (µg/L)

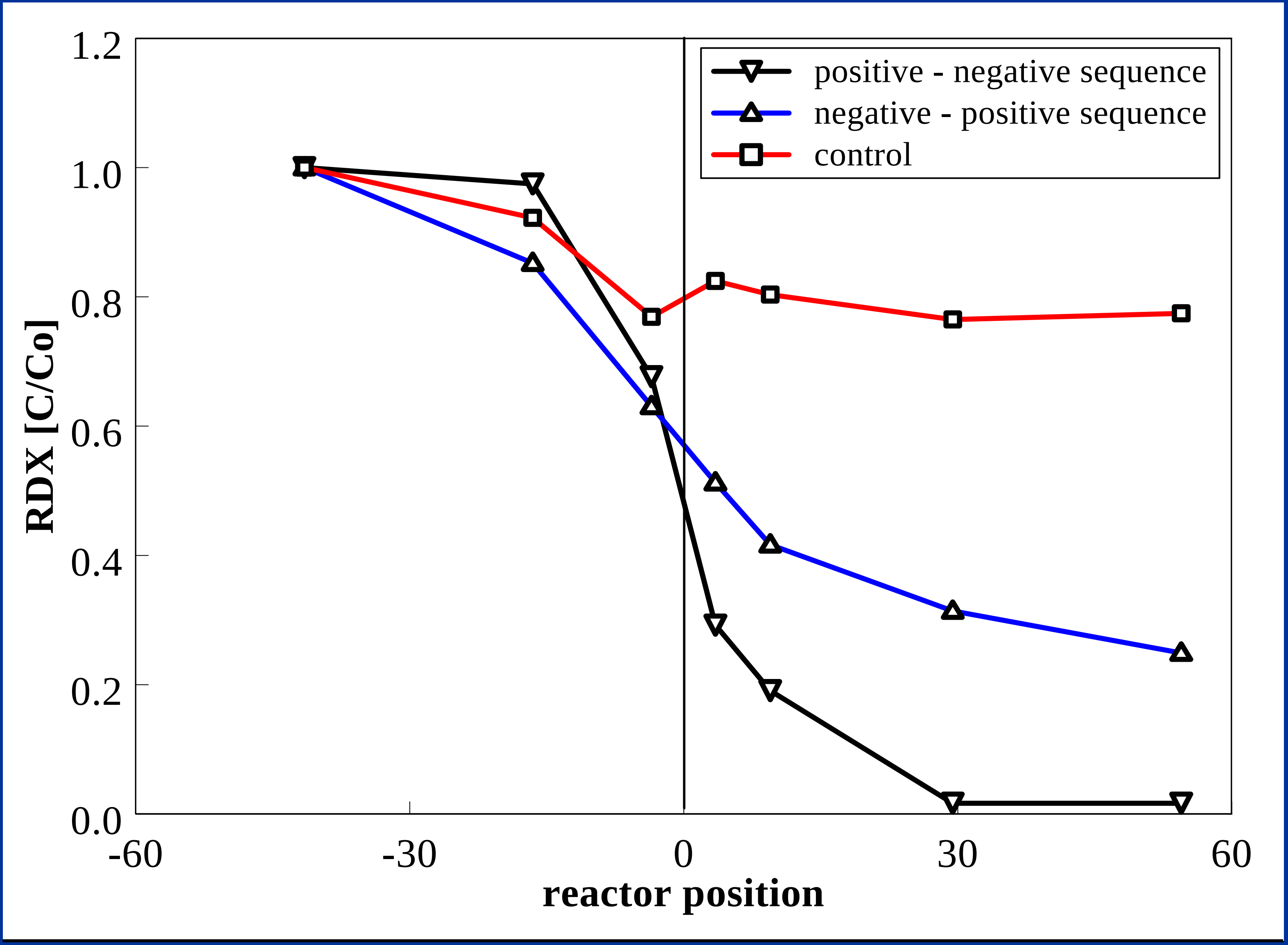


6.5 Volts on August 20, 2003 (205 days)

SERDP Energetics



RDX Results (5.0 V)



e$^-$barrier Path Forward

- Chlorinated Ethenes
  - ESTCP / F.E. Warren
    - 9V, PFLA, Inorganic
    - ESTCP Report Summer 04
- Energetics
  - SERDP/Army Corps Engineers
    - Reaction Pathways/Mass Balance
    - Screening Locations for Field Demonstration

Funding

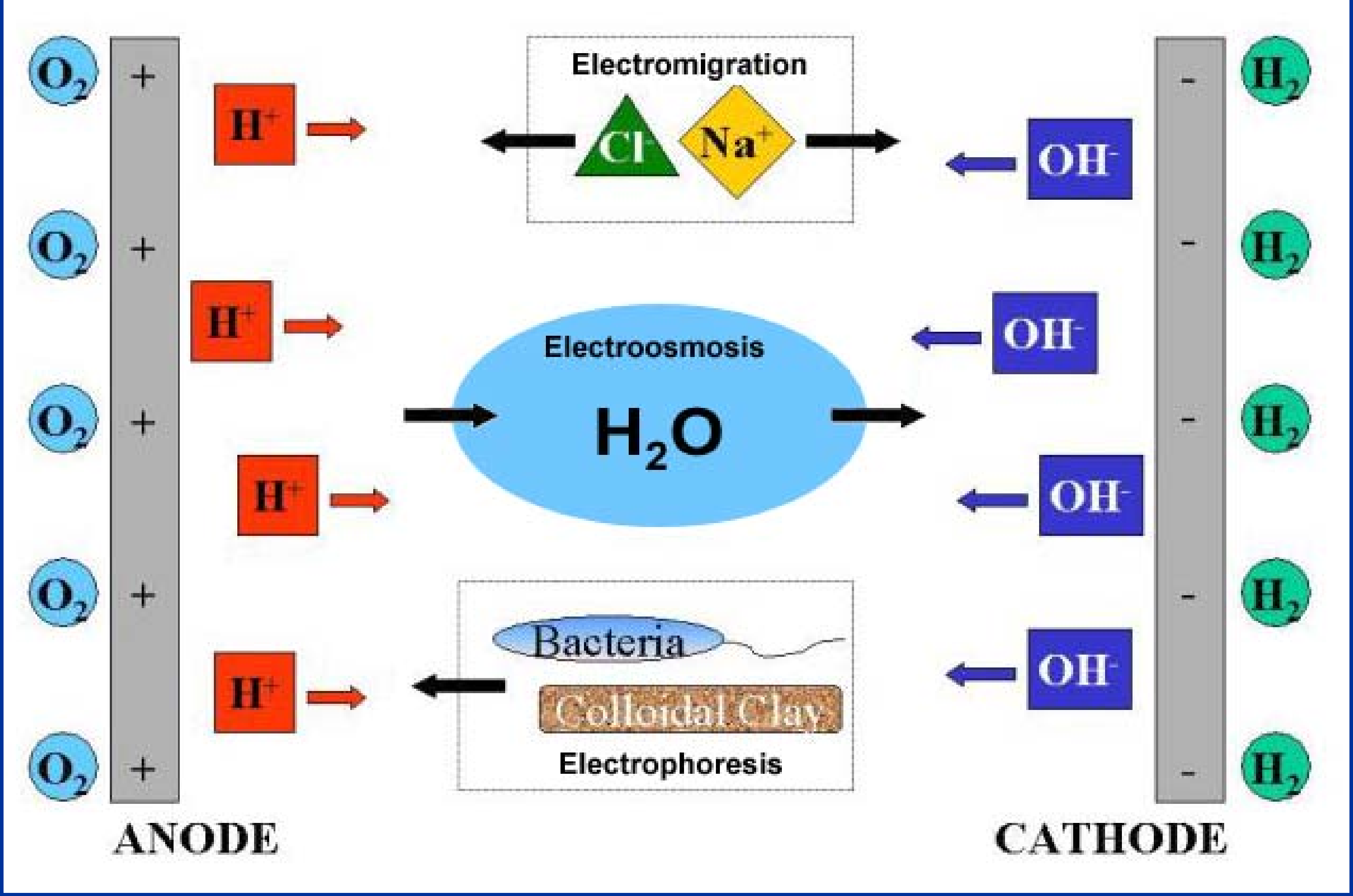
Solvents in Groundwater Research Consortium

NSERC Industrial Research Chair in Groundwater Remediation

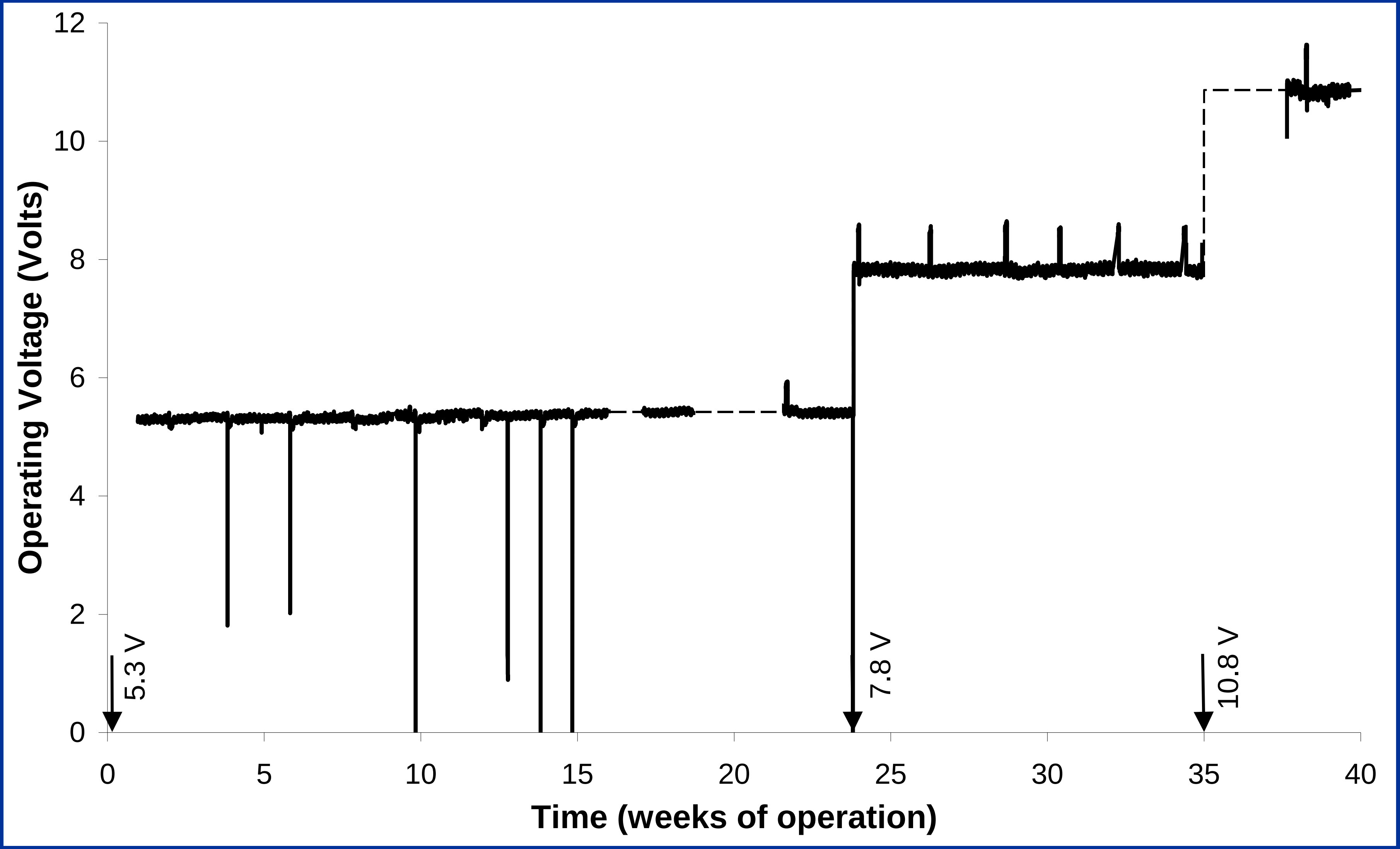
ESTCP and SERDP

Appendix

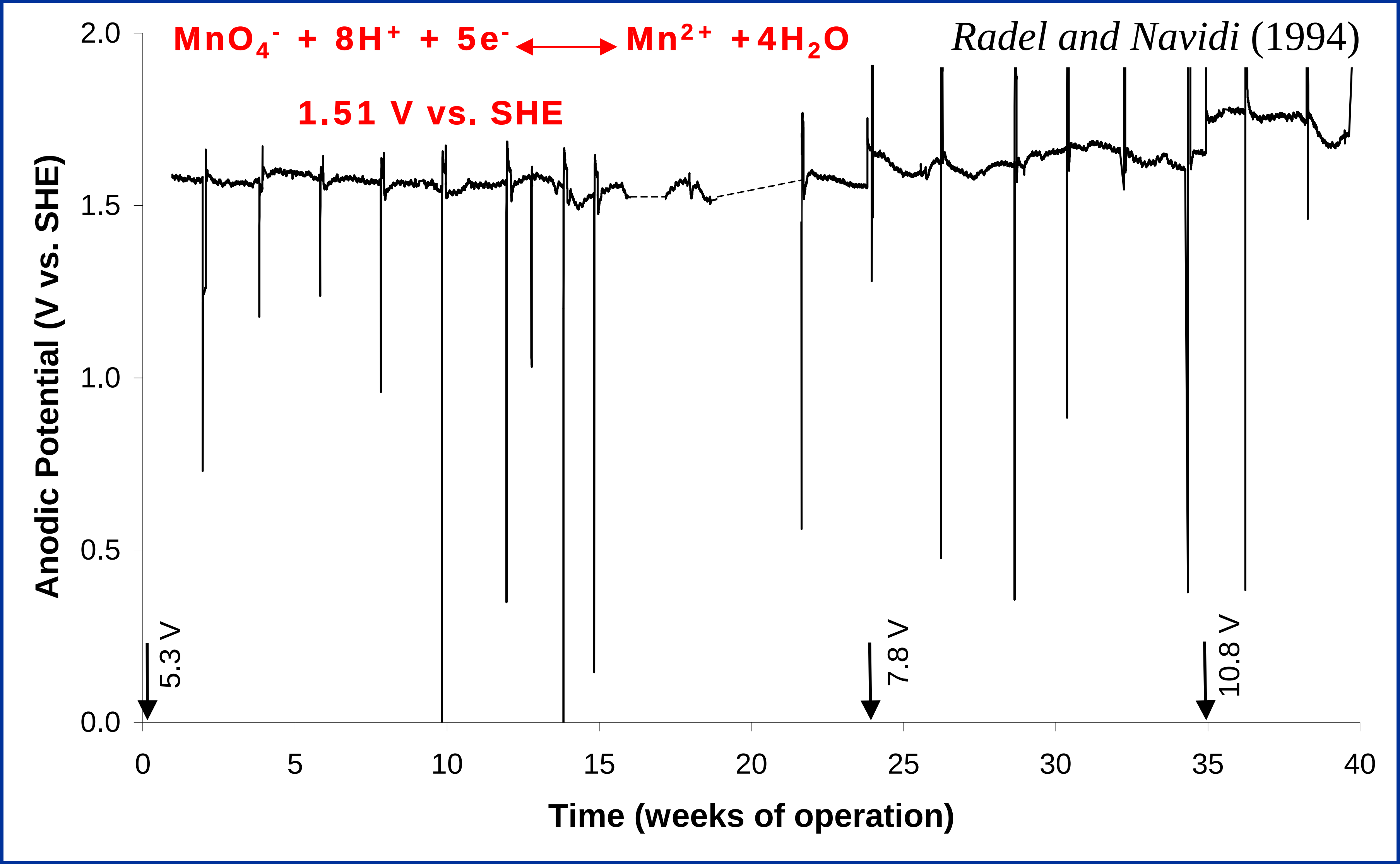
Electrokinetics



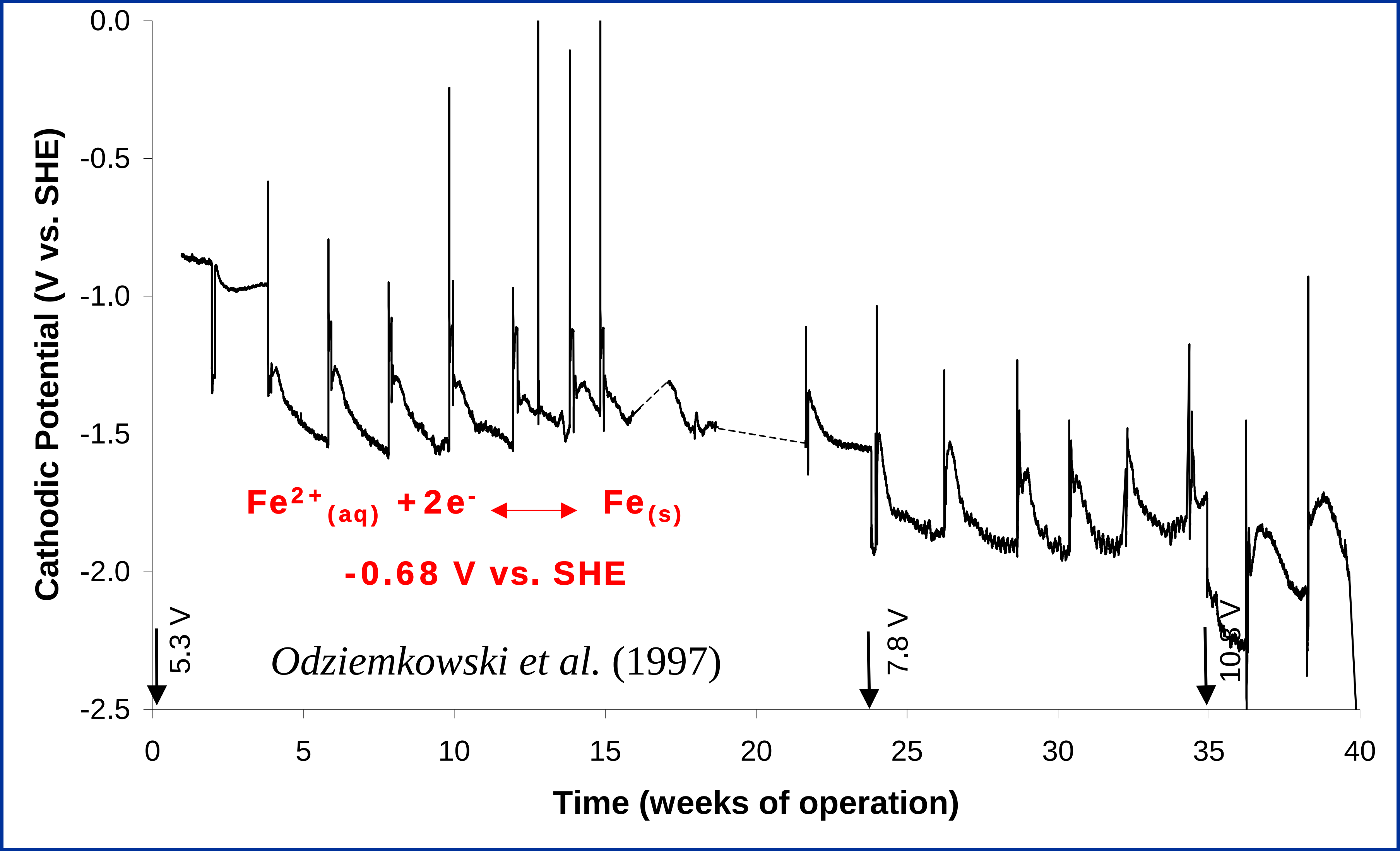
Applied System Voltage



Anode Reference Potential



Cathode Reference Potential



Eh, pH and Cond. Trends