www.geosyntec.com

In Situ Bioremediation at FracRock Sites

Mary F. deFlaun, PhD

Geosyntec consultants

engineers | scientists | innovators

Overview

Two case studies of bioaugmentation in fractured rock:

1. Naval Air Warfare Center in NJ
   - fractured mudstones
2. Industrial facility near Nashville, TN
   - karst

Common Features:

- TCE at DNAPL concentrations
- treated using emulsified vegetable oil (EVO) as the electron donor and the anaerobic microbial consortia KB-1® (contains DHC bacteria)

- Co-author and instructor for the ITRC BioDNAPL Training
- Co-author for ITRC IDSS and Mass Flux guidance documents
- Guidance documents available at www.itrcweb.org

Collaborators:

Naval Air Warfare Center, West Trenton, NJ

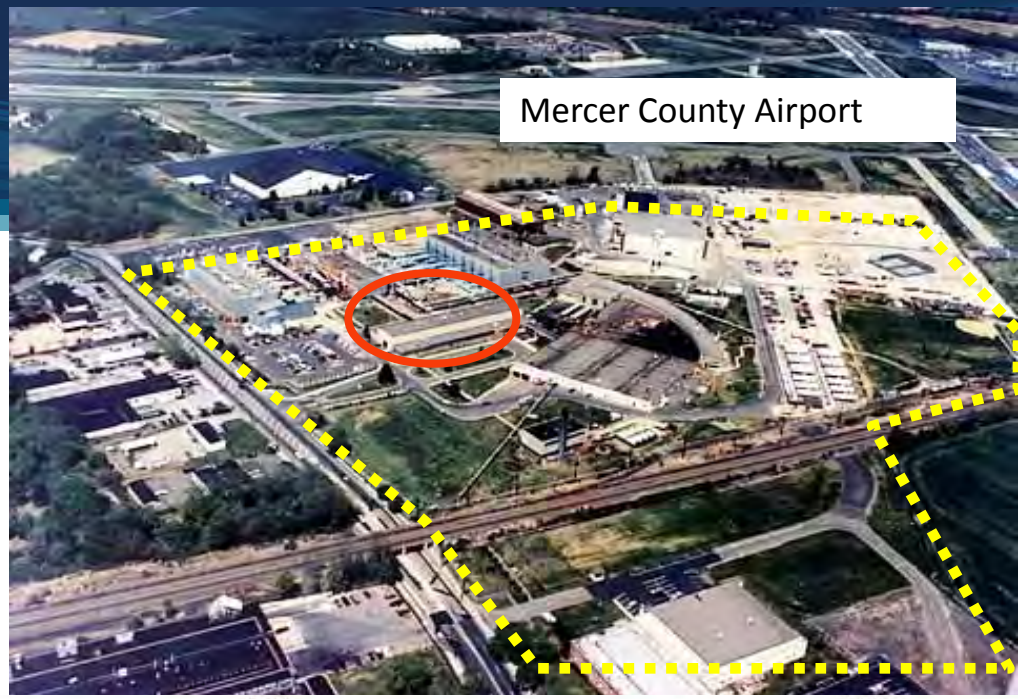
NAVFAC

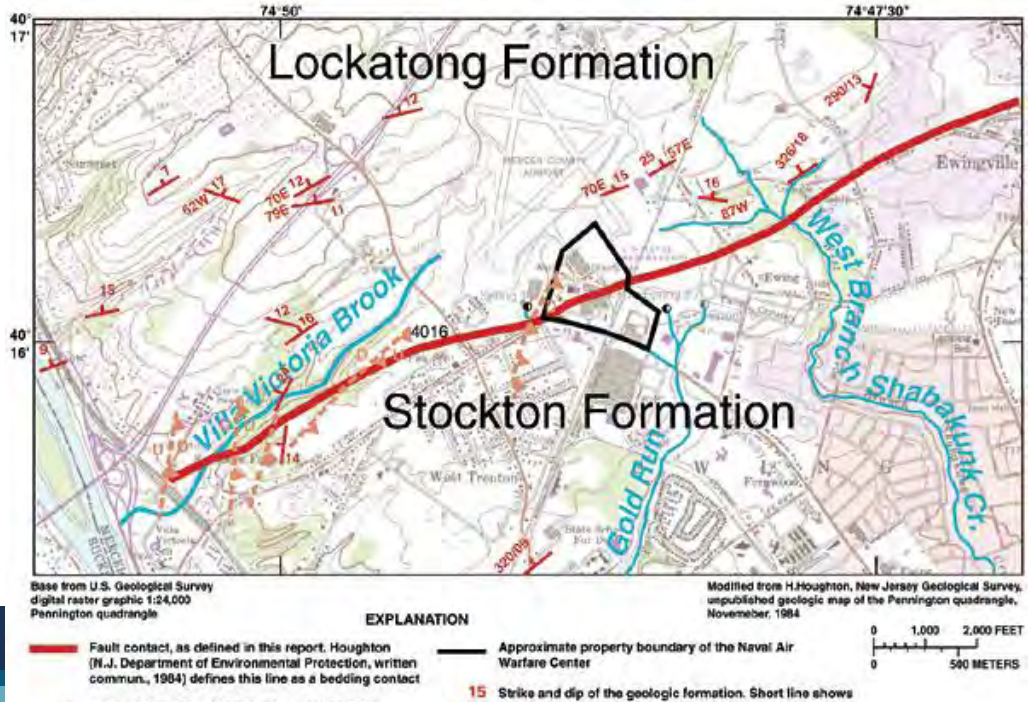
USGS
science for a changing world

ECOR Solutions, Inc.

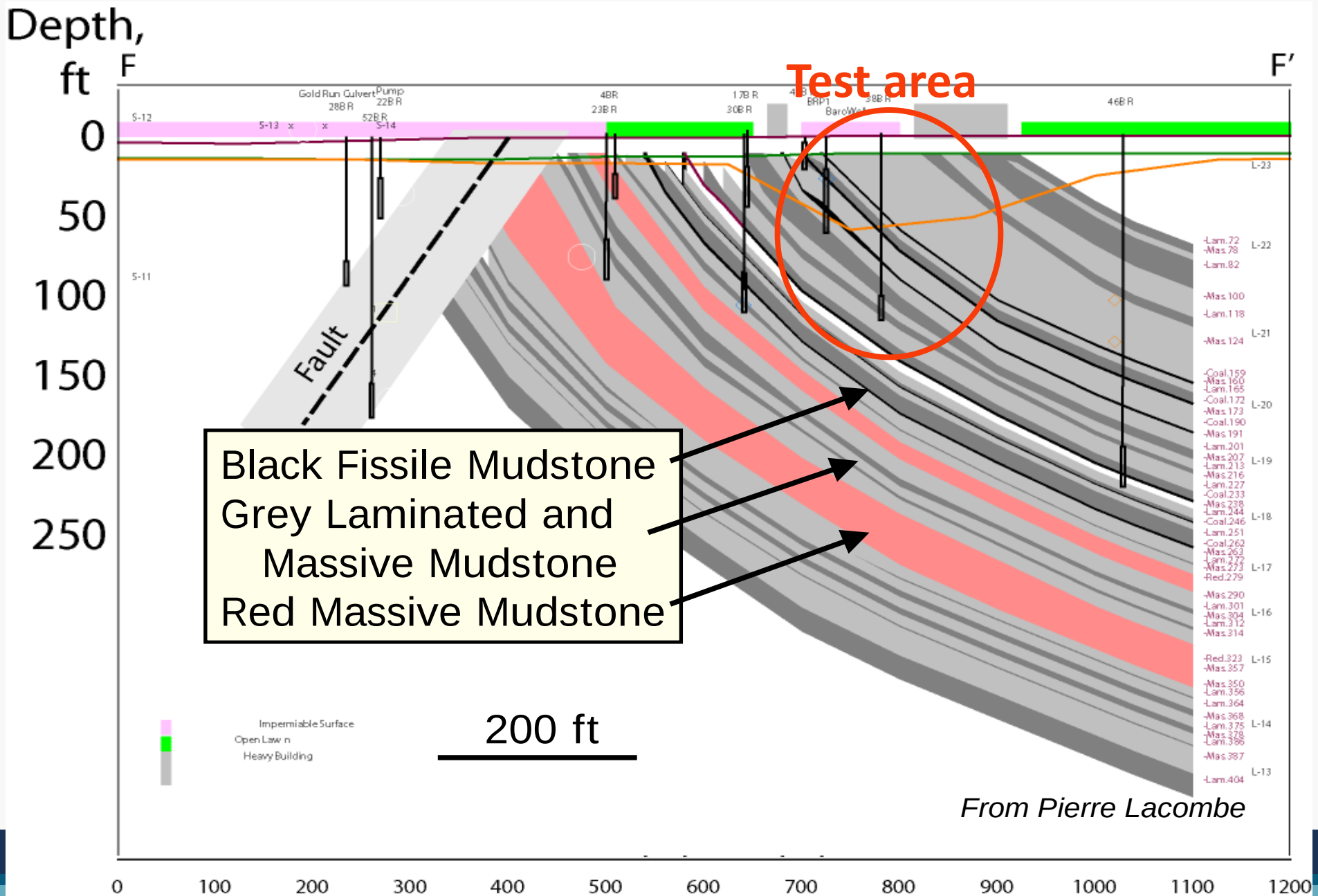
Geosyntec consultants

- Jet engine testing facility from 1950's to 1990's
- Est. 100,000 gals of TCE 'lost' from storage tanks-10,000 gals est. to gw (~200 ppm max conc.)
- Areas of coincident jet fuel contamination
- Daughter products-cis-DCE and VC present (16 & 1.2 ppm max)
- Triassic sedimentary rock – fractured sand and mudstones
- 60 gpm pump & treat system since 1993– no decrease in TCE since 1998





Dipping Bedded Lockatong Mudstones



Implementation

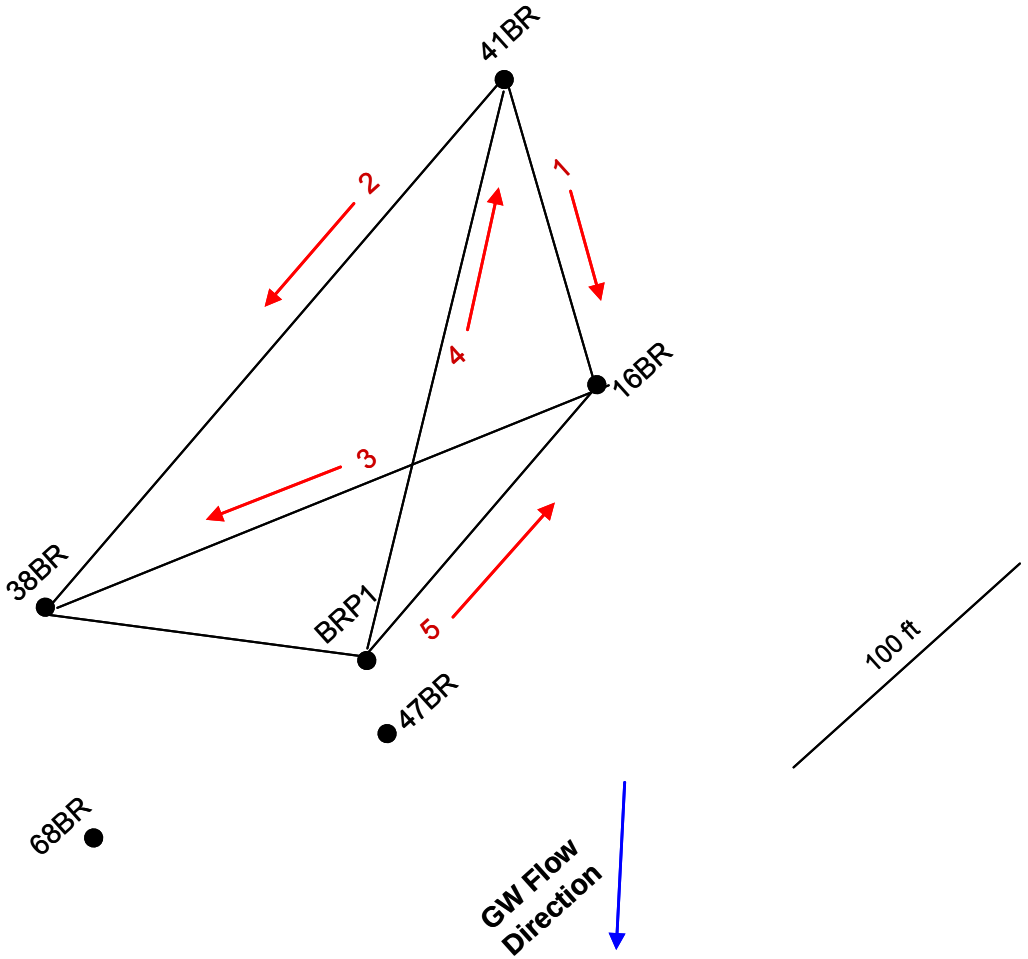
- Utilize 4 existing wells-areal extent 9,000 ft^2 up to 115’ bgs
- 4 wells form a trapezoid 230 ft on the long side
- Estimate 220 lbs TCE in pilot area (up to 16 ppm)
- Inject EVO first to retain injected bacteria

Pilot Test Injections

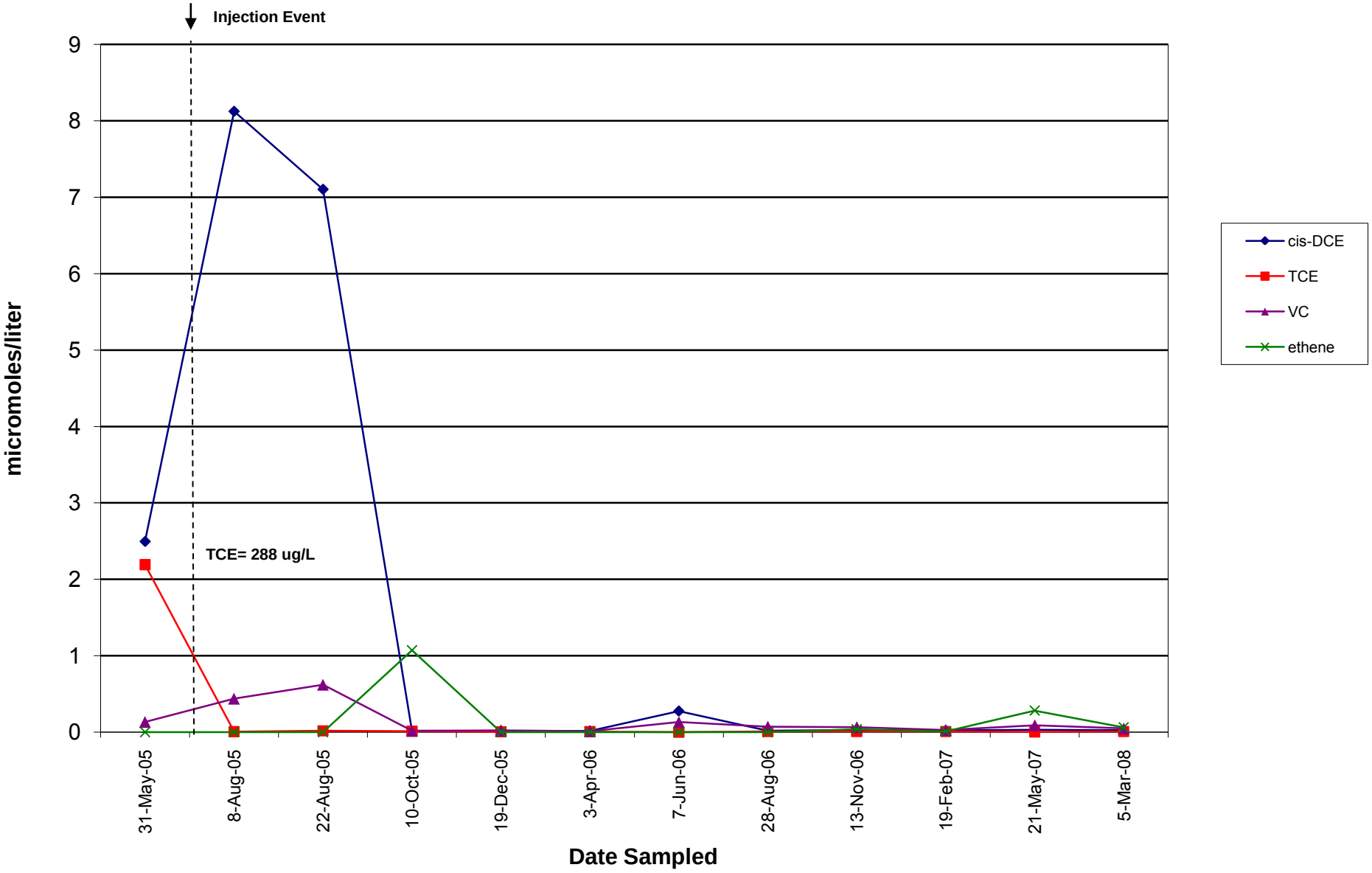
- Used the four wells as injection/extraction well pairs - extracted from one well of the pair while injecting into the other using flow proportional pump
- Pulled water from designated extraction well to make up 10% stock of EVO
- Injected the EVO stock with gw pulled from the extraction well to a final concentration of ~2%-until EVO visible in the extraction well
- Added 20 L KB-1 culture-DHC bacteria
- Injected the remainder of the EVO and flushed the well with at least 1 well volume of groundwater without amendments

USGS Toxics Research Site

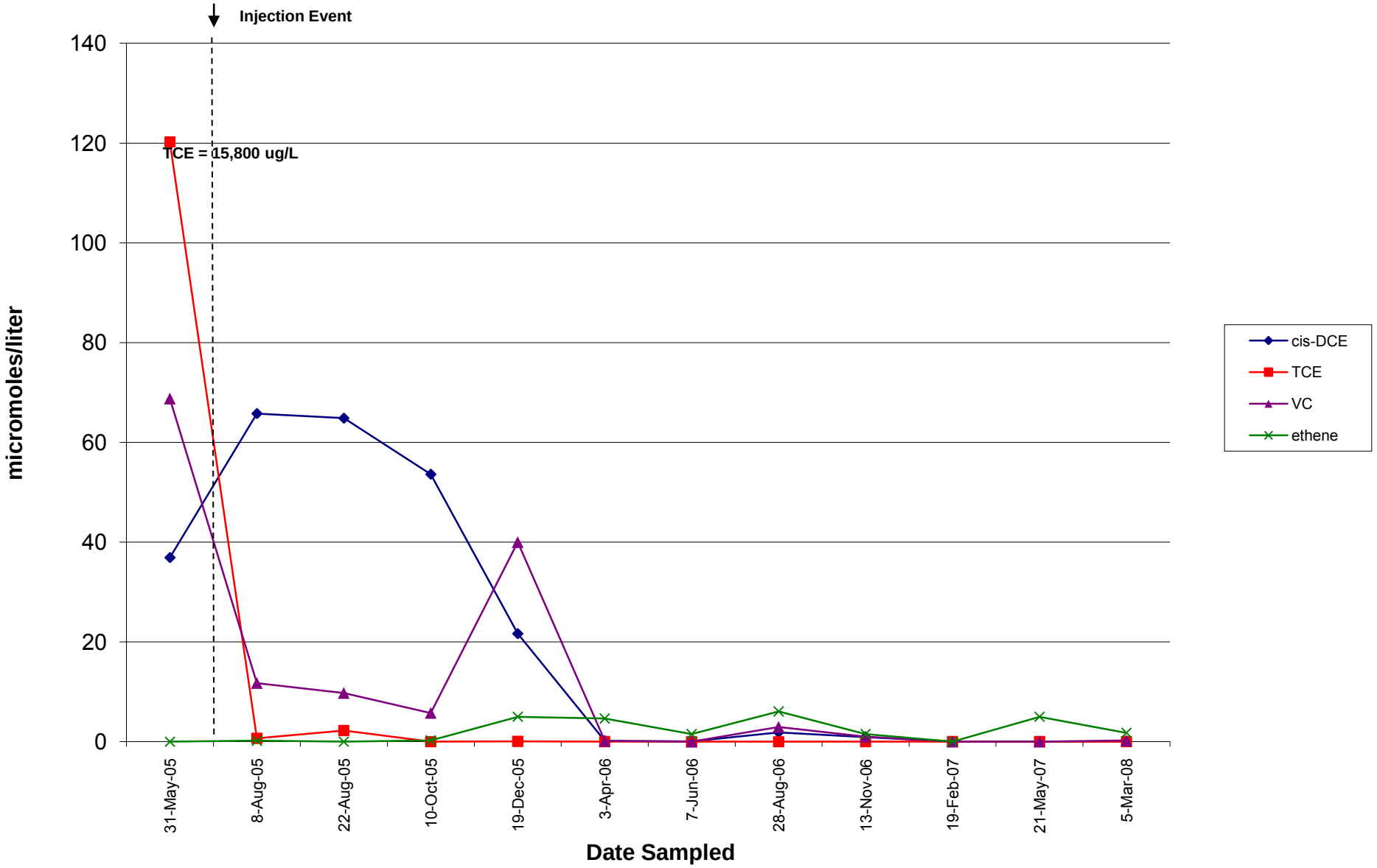
core hole 68 BR drilled downgradient



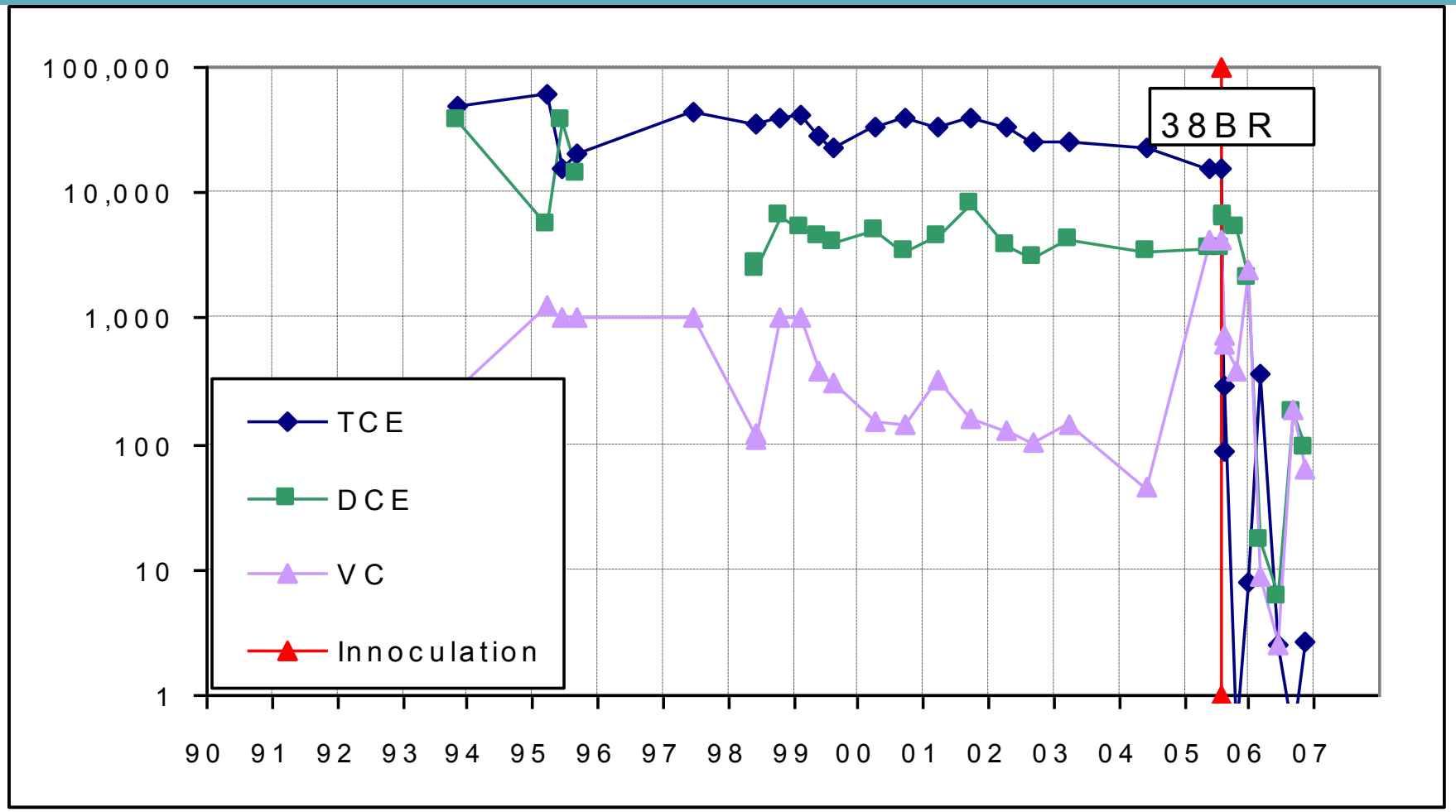
Well 16BR CVOC Molar Concentrations: May 2005-March 2008



Well 38BR CVOC Molar Concentrations: May 2005-March 2008

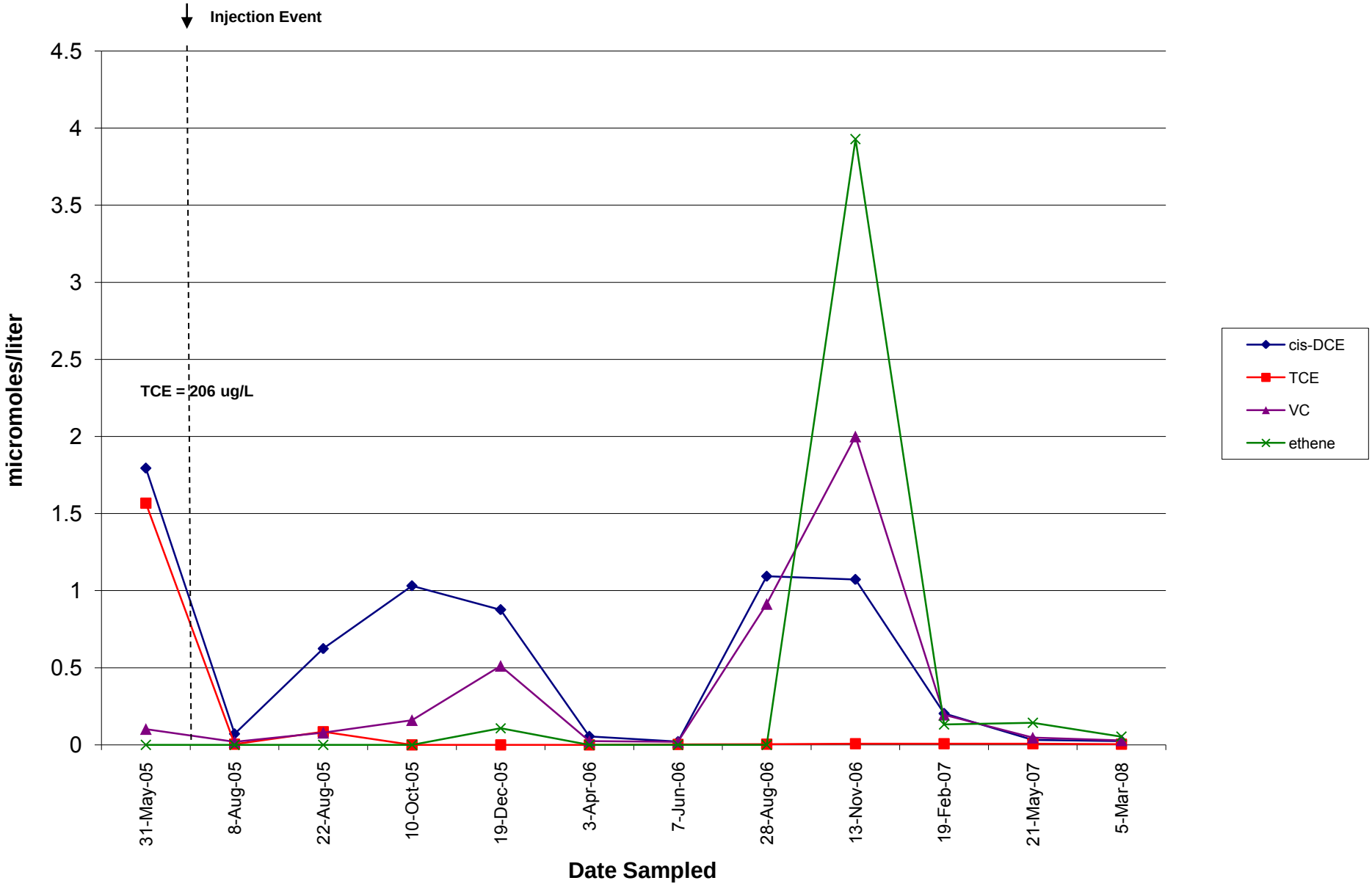


Historical Concentrations at 38BR (µg/L)

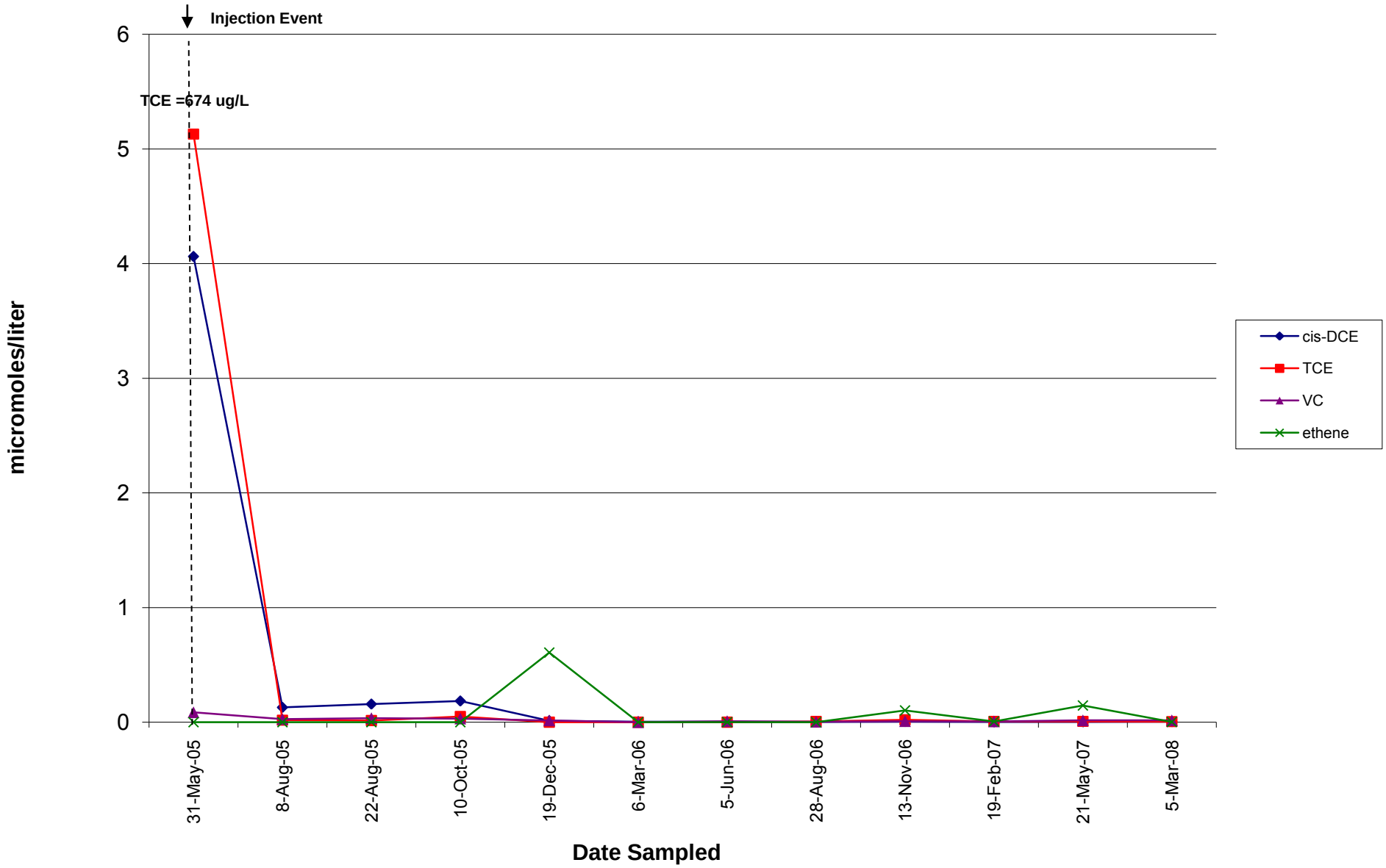


From Pierre Lacombe, USGS, Feb. 2007

Well BRP1 CVOC Molar Concentrations: May 2005-March 2008



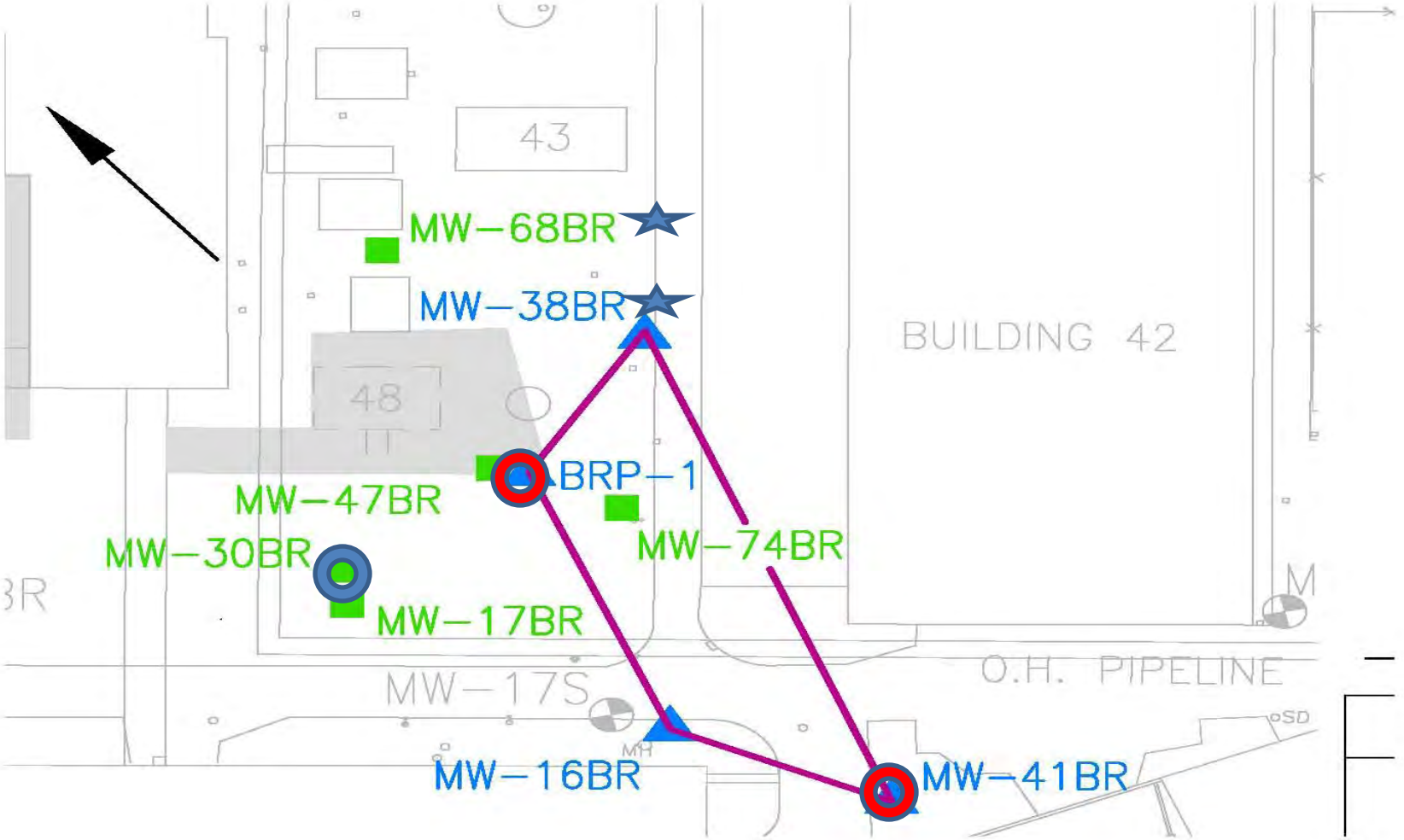
Well 41BR CVOC Molar Concentrations: May 2005-March 2008



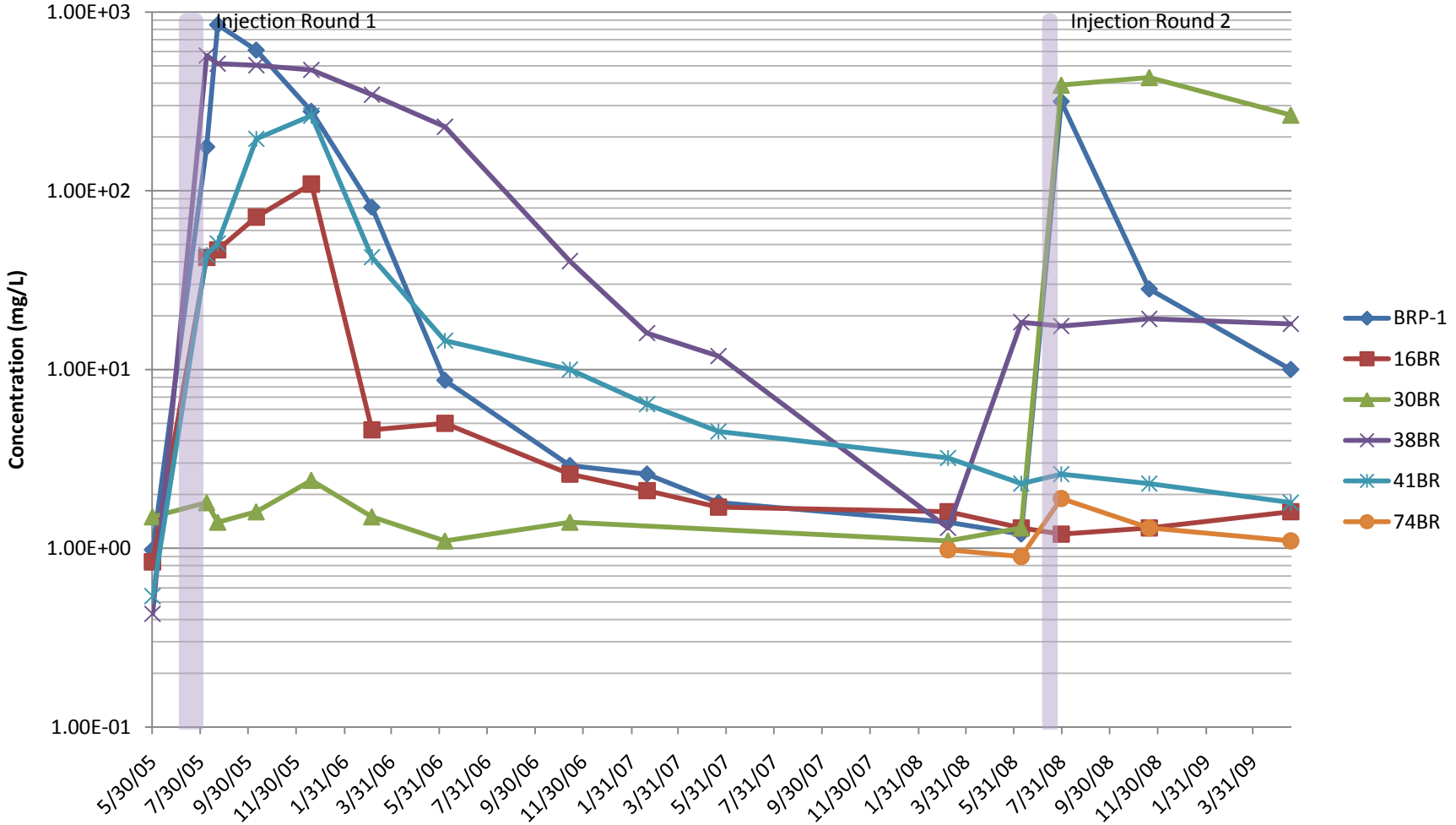
Second Donor Injection

- 3 yrs after initial injection – July 2008
- EVO added at MW-30BR by gravity injection (dg-high concentration and very tight)
- EVO added at BRP-1 using MW-41BR as the extraction well

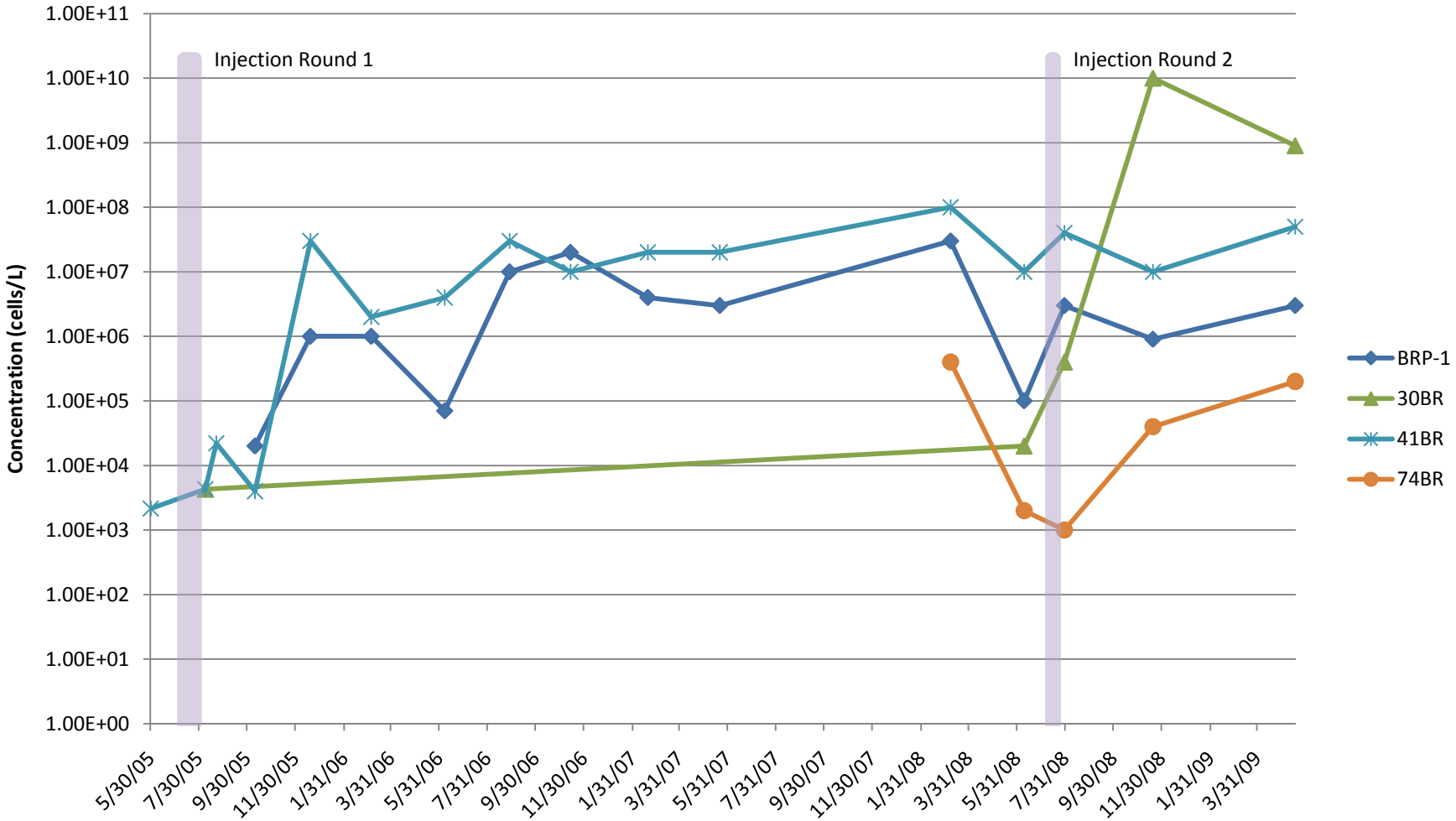
2nd Injections and Downgradient Monitoring



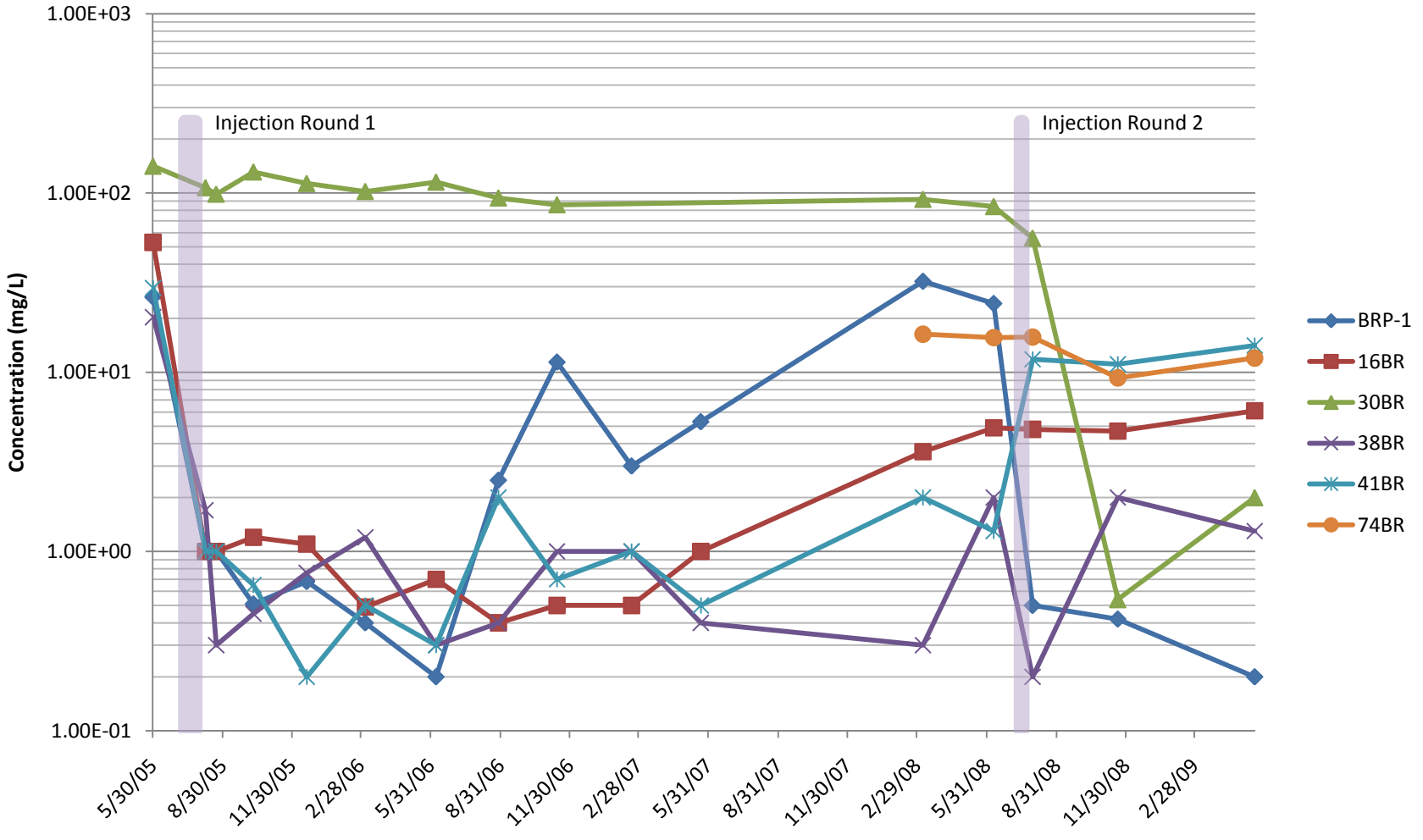
Total Organic Carbon Concentrations

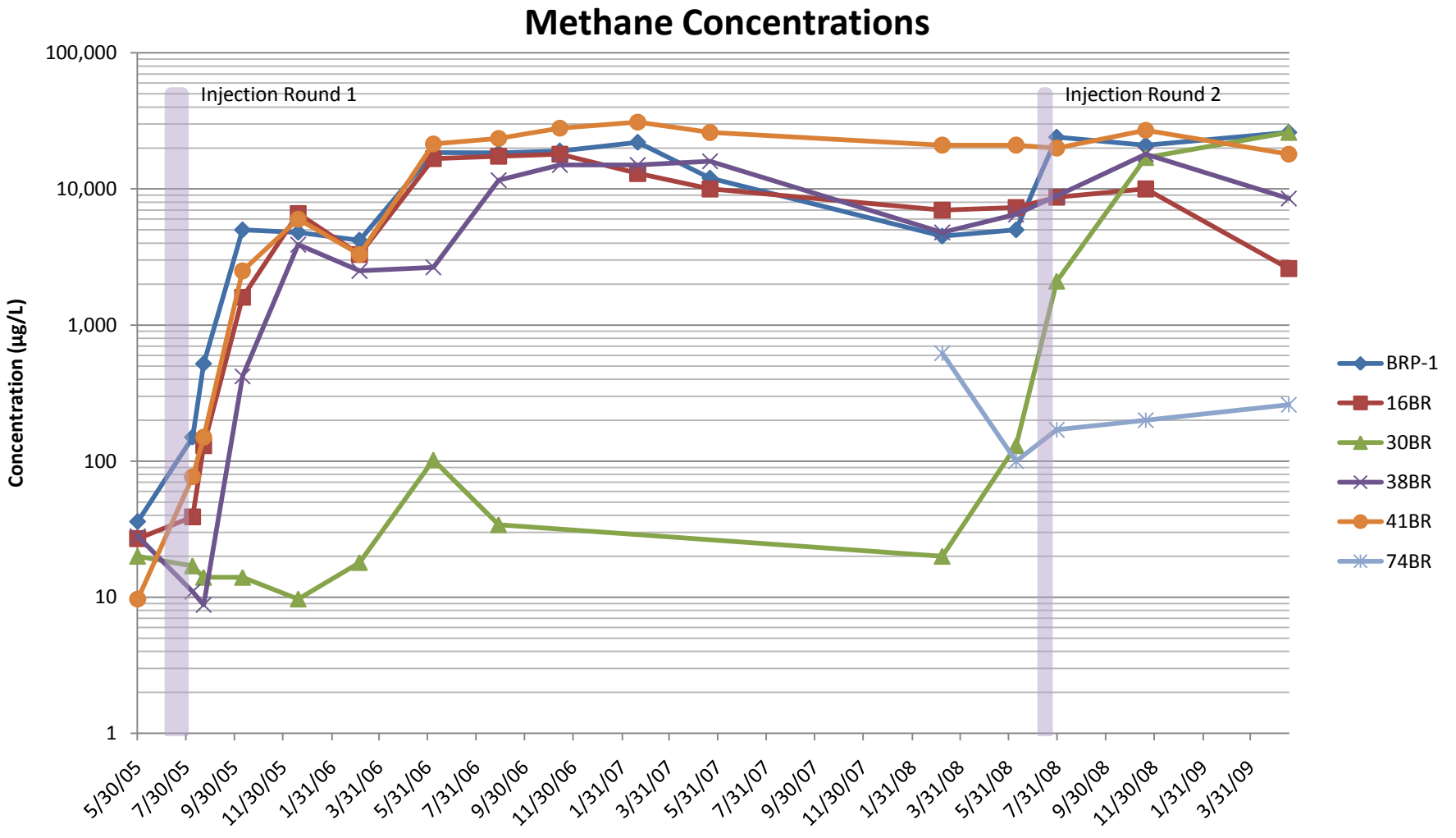


DHC Cells

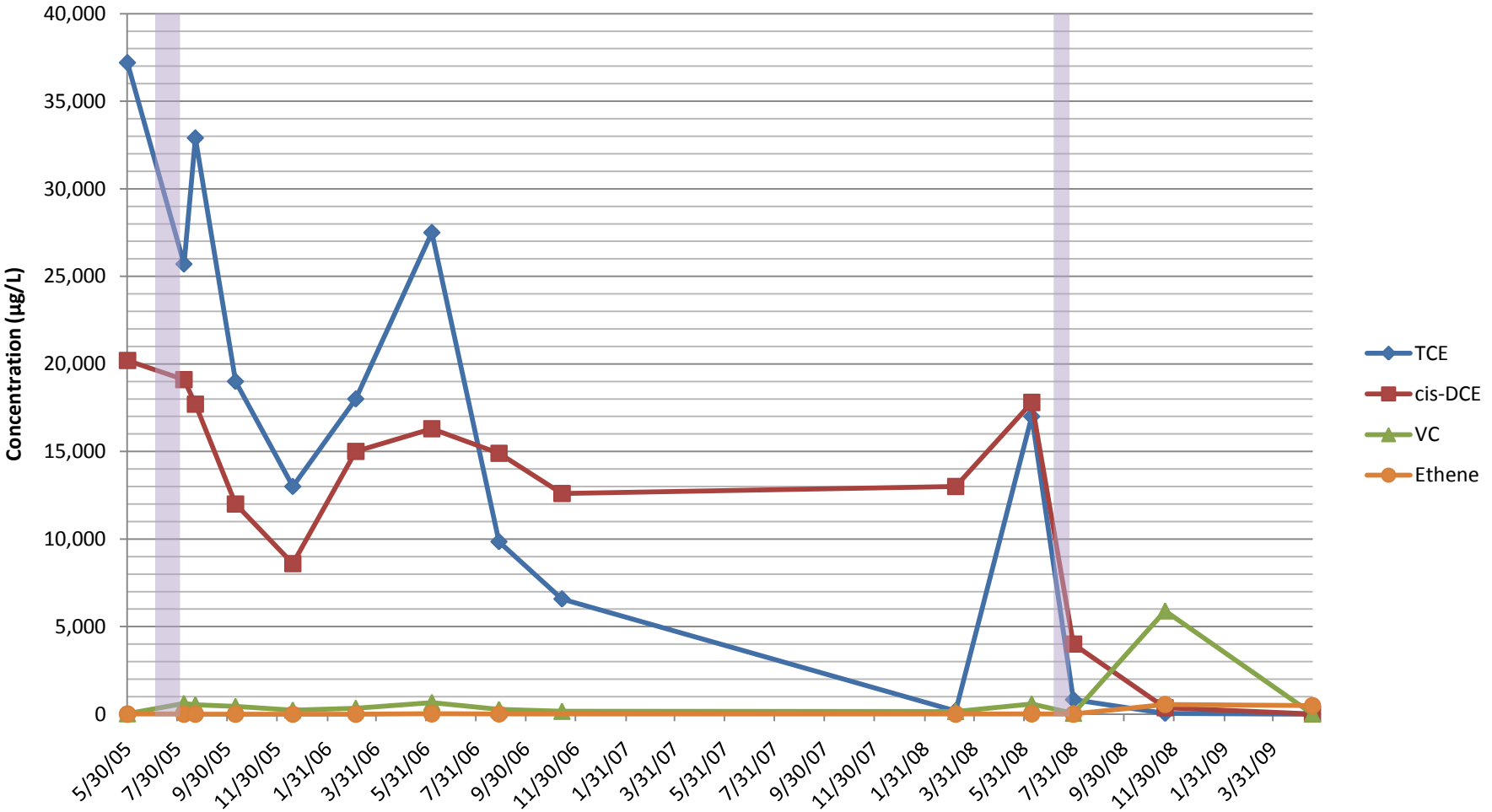

Injection Round 1
Injection Round 2
Concentration (cells/L)
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
5/30/05
7/30/05
9/30/05
11/30/05
1/31/06
3/31/06
5/31/06
7/31/06
9/30/06
11/30/06
1/31/07
3/31/07
5/31/07
7/31/07
9/30/07
11/30/07
1/31/08
3/31/08
5/31/08
7/31/08
9/30/08
11/30/08
1/31/09
3/31/09
BRP-1
30BR
41BR
74BR

Sulfate

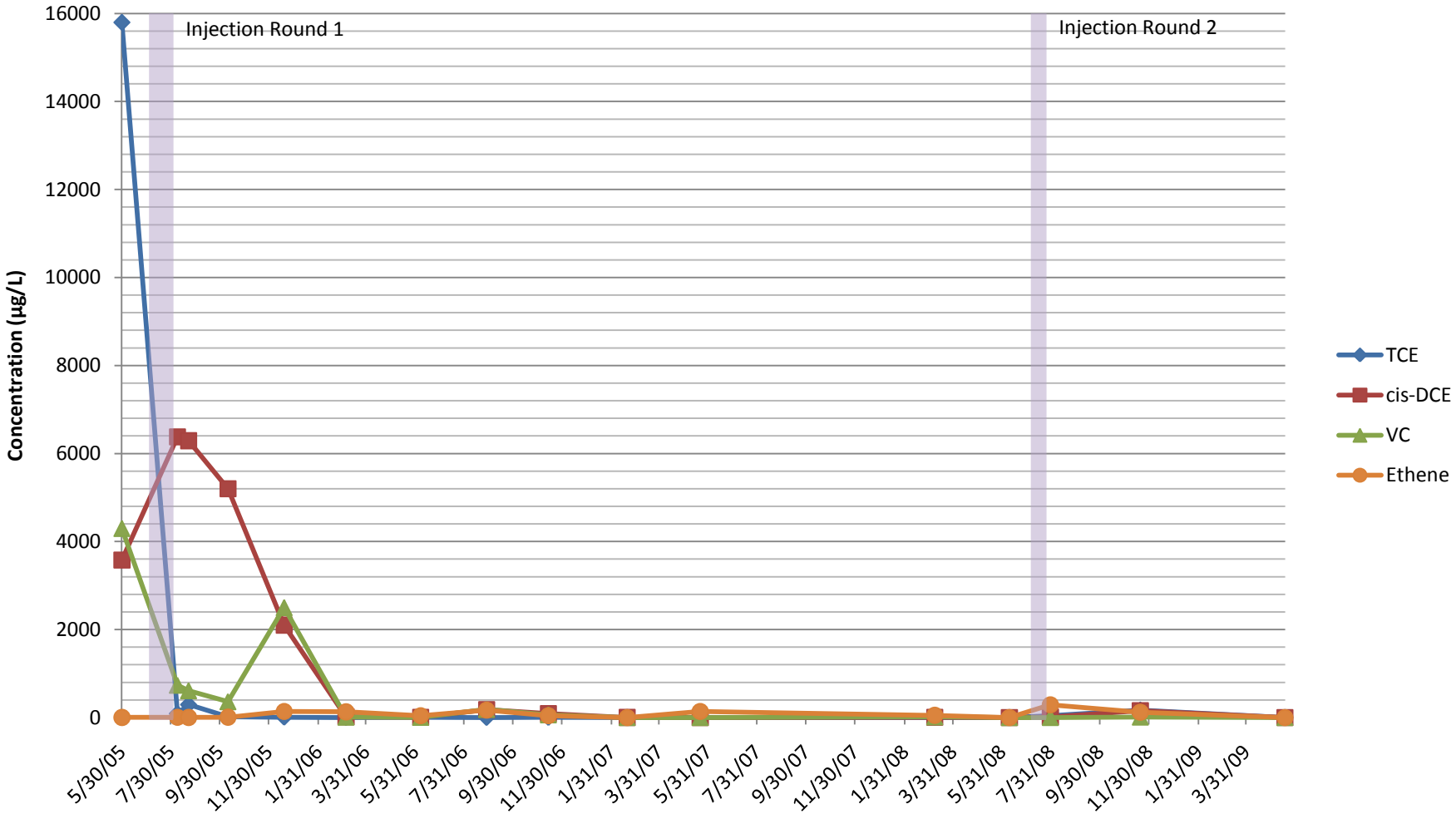

1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
Concentration (mg/L)
Injection Round 1
Injection Round 2
5/30/05
8/30/05
11/30/05
2/28/06
5/31/06
8/31/06
11/30/06
2/28/07
5/31/07
8/31/07
11/30/07
2/29/08
5/31/08
8/31/08
11/30/08
2/28/09
BRP-1
16BR
30BR
38BR
41BR
74BR


Methane Concentrations
Concentration (µg/L)
100,000
10,000
1,000
100
10
1
Injection Round 1
Injection Round 2
5/30/05
7/30/05
9/30/05
11/30/05
1/31/06
3/31/06
5/31/06
7/31/06
9/30/06
11/30/06
1/31/07
3/31/07
5/31/07
7/31/07
9/30/07
11/30/07
1/31/08
3/31/08
5/31/08
7/31/08
9/30/08
11/30/08
1/31/09
3/31/09
BRP-1
16BR
30BR
38BR
41BR
74BR

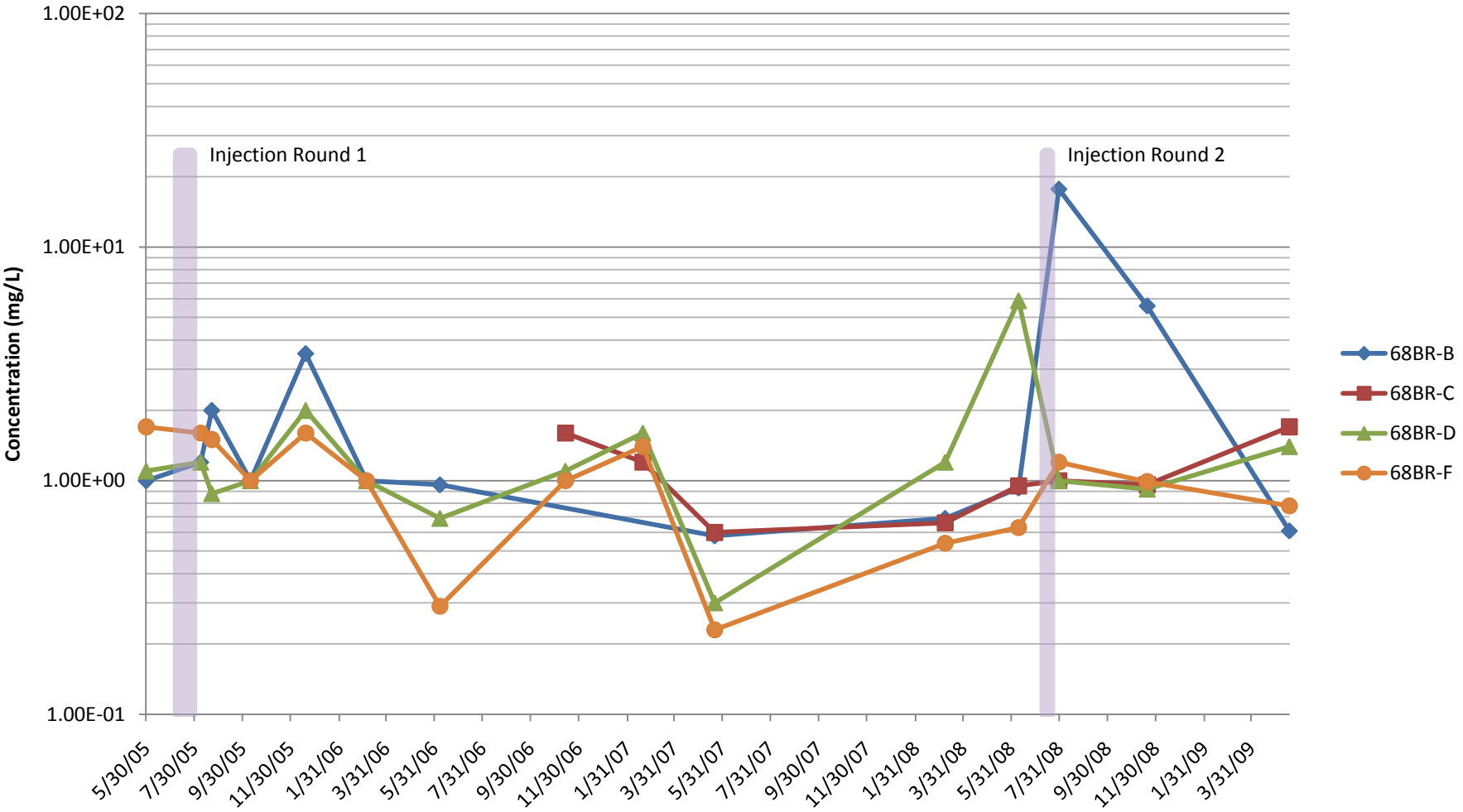
Concentrations of CVOCs at 30BR



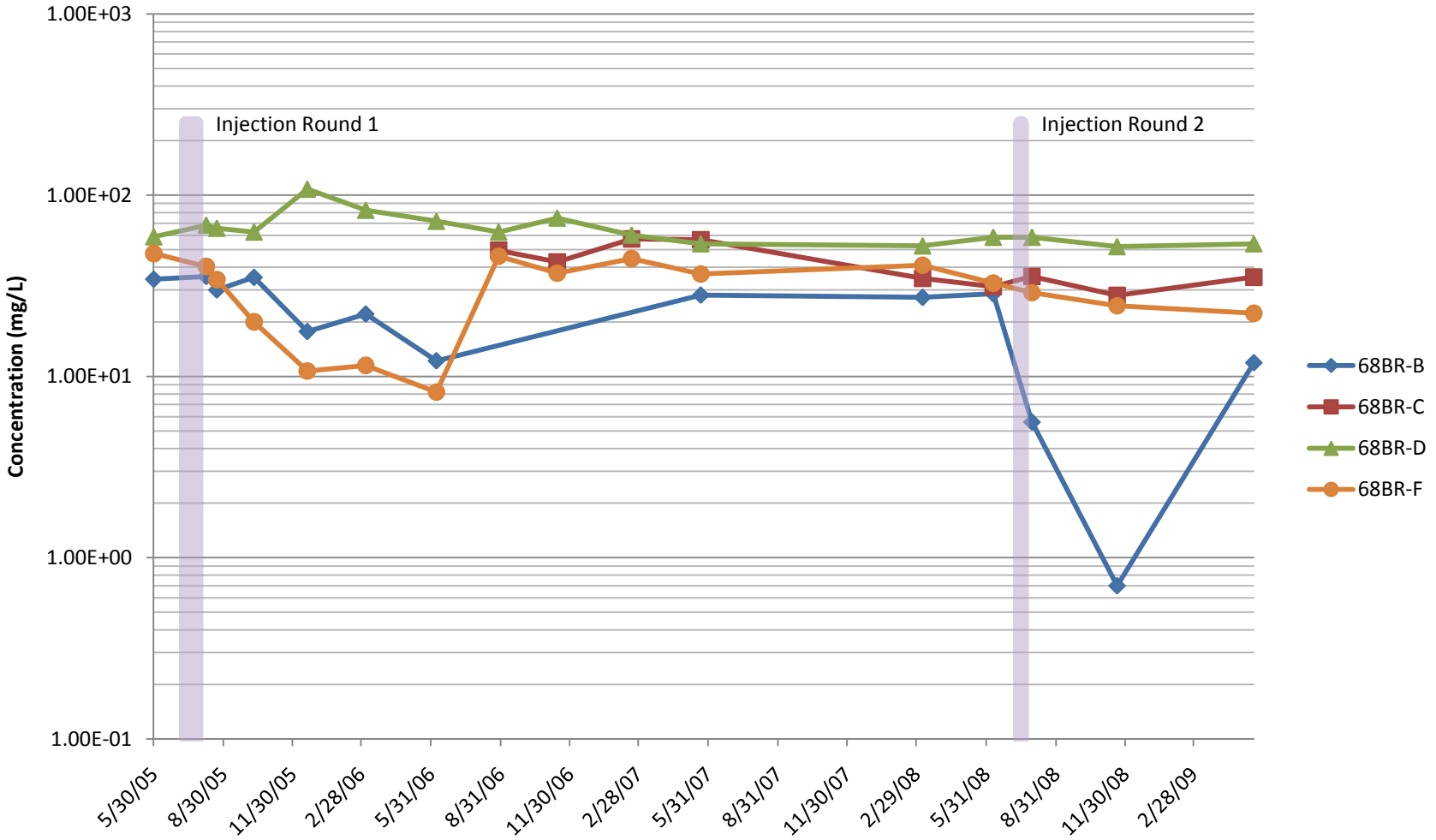
Concentrations of CVOCs at 38BR

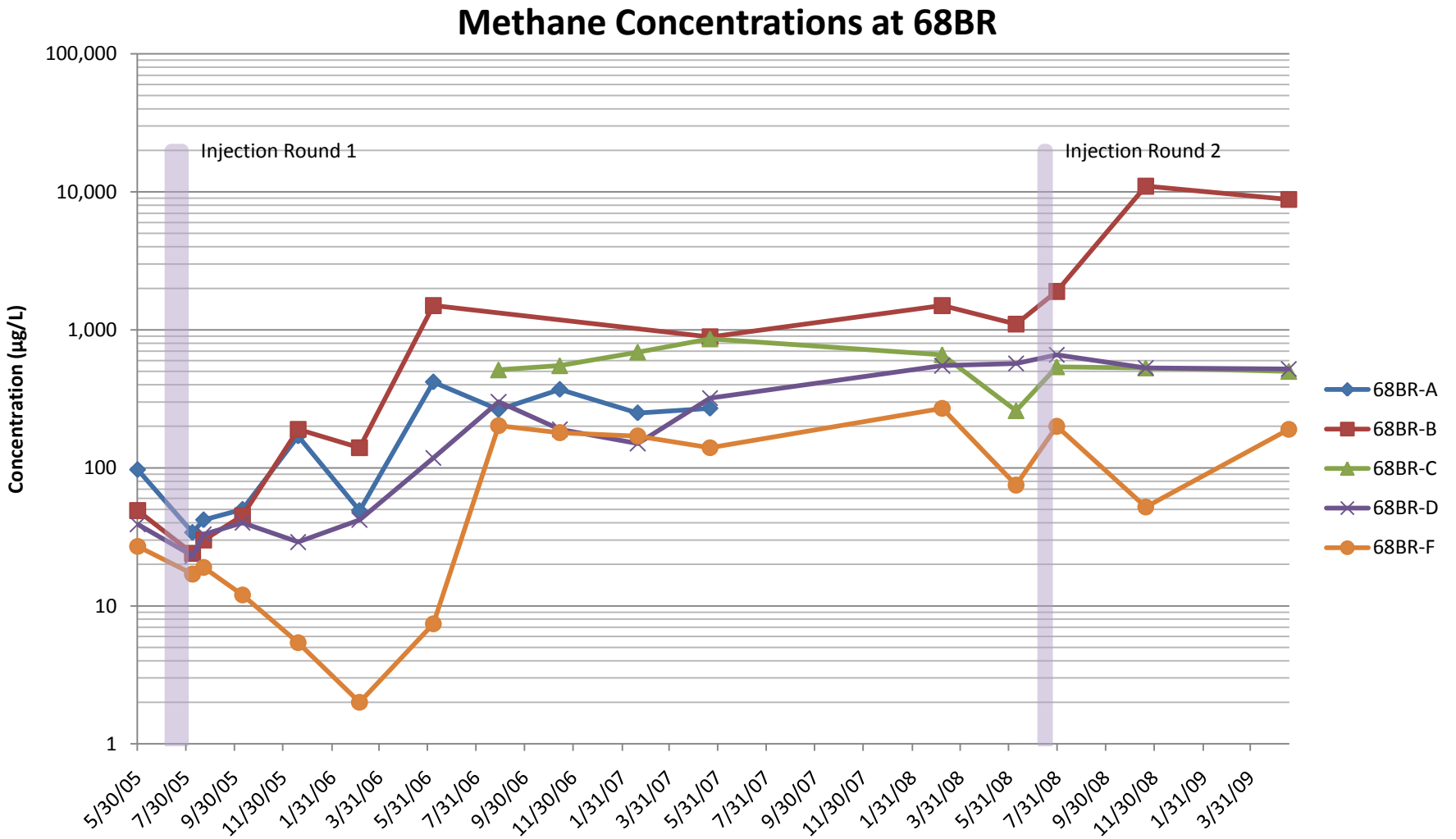


Total Organic Carbon Concentrations at 68BR

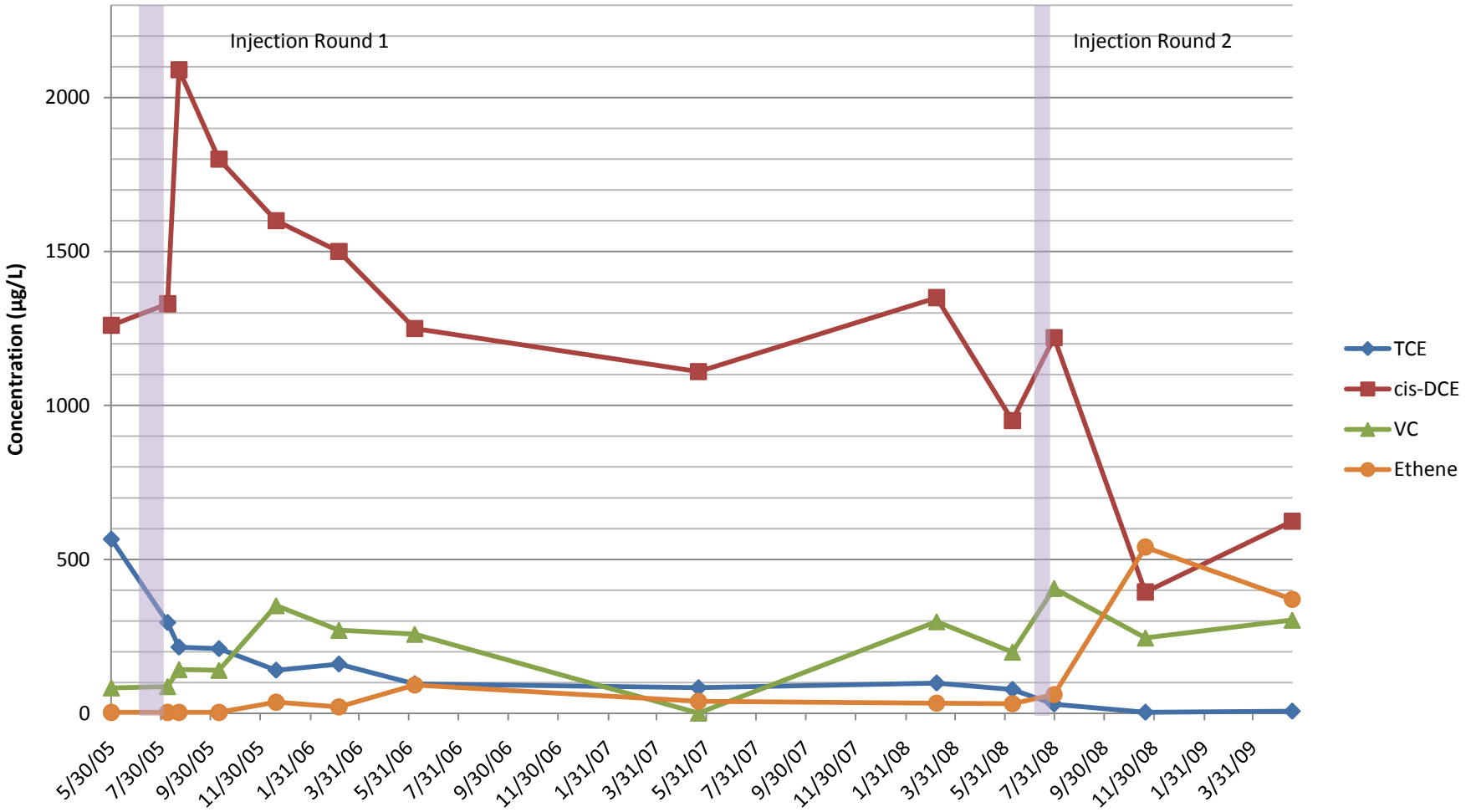


Sulfate at 68BR

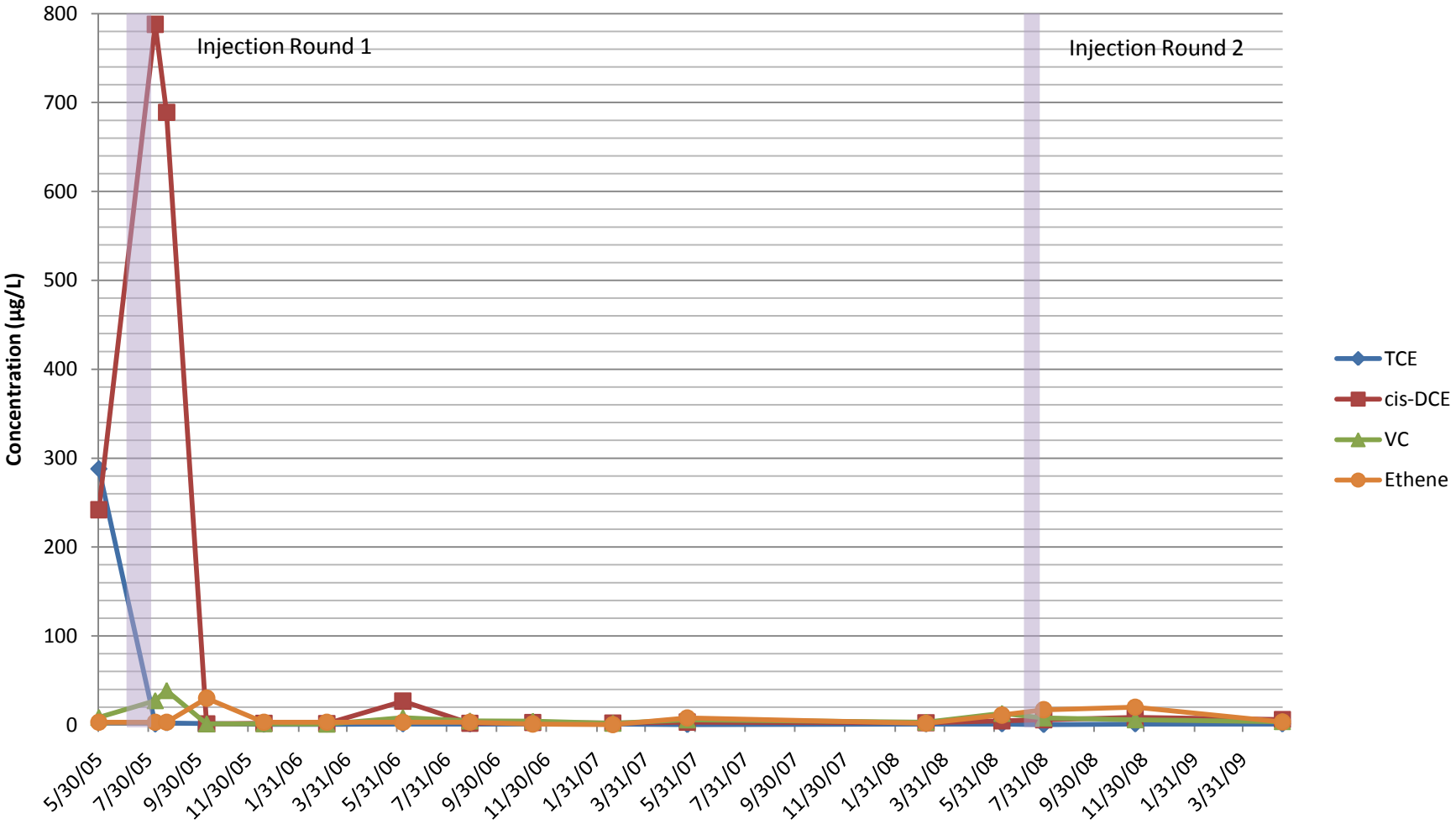



Methane Concentrations at 68BR
Concentration (µg/L)
100,000
10,000
1,000
100
10
1
Injection Round 1
Injection Round 2
5/30/05
7/30/05
9/30/05
11/30/05
1/31/06
3/31/06
5/31/06
7/31/06
9/30/06
11/30/06
1/31/07
3/31/07
5/31/07
7/31/07
9/30/07
11/30/07
1/31/08
3/31/08
5/31/08
7/31/08
9/30/08
11/30/08
1/31/09
3/31/09
68BR-A
68BR-B
68BR-C
68BR-D
68BR-F

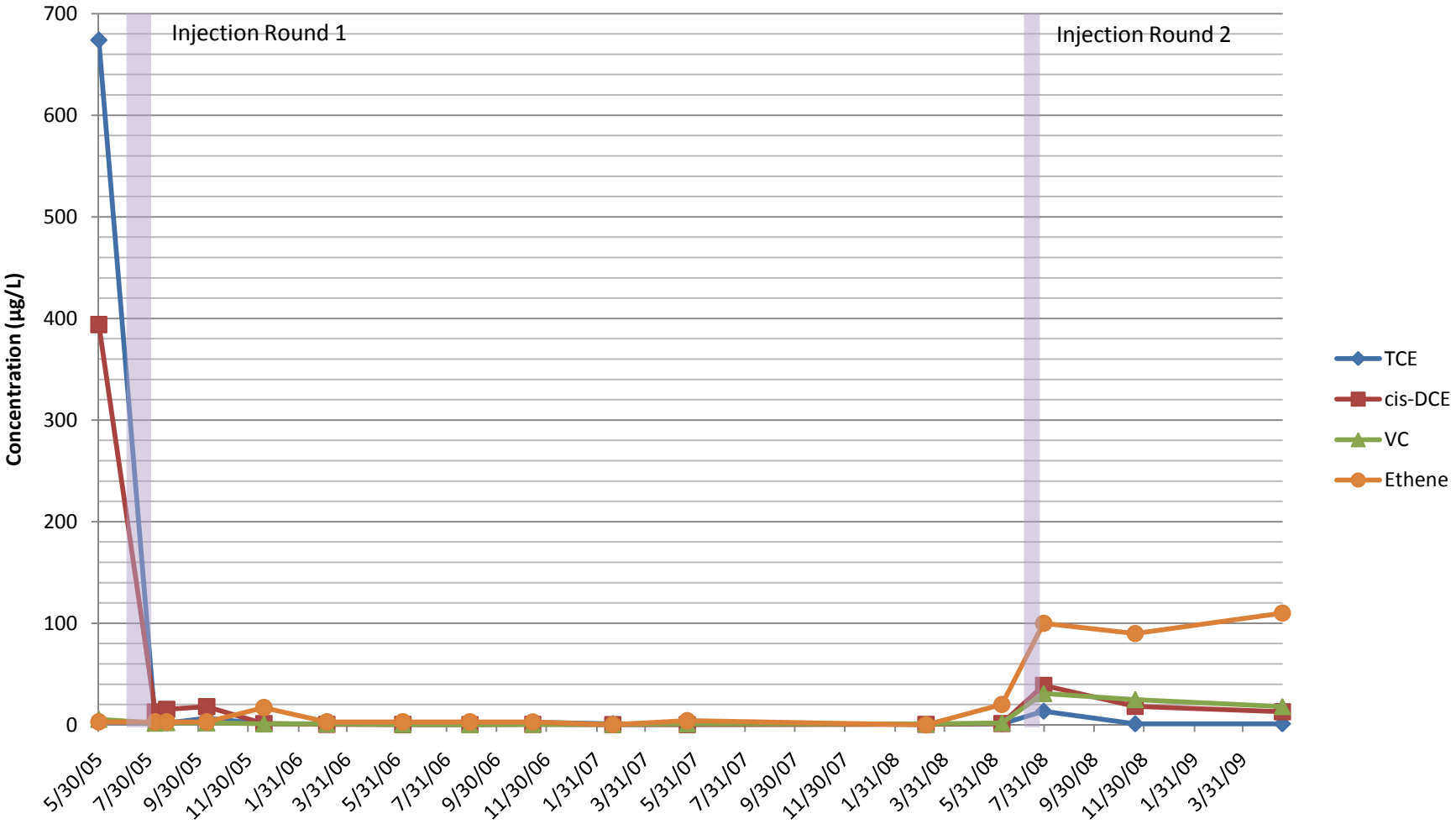
Concentrations of CVOCs at 68BR-B



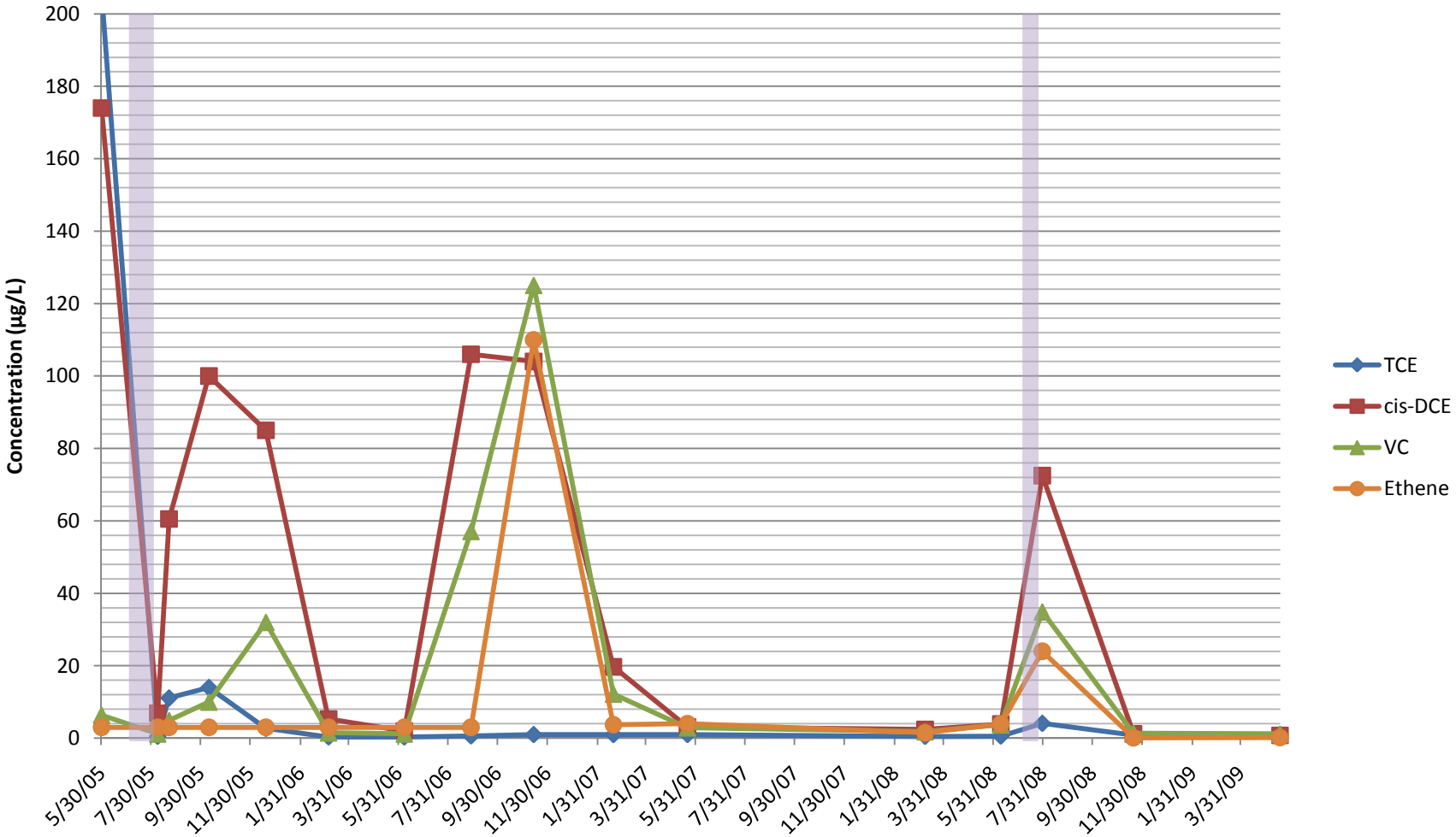
Concentrations of CVOCs at 16BR



Concentrations of CVOCs at 41BR



Concentrations of CVOCs at BRP-1



Summary

- Fracture surface coating of EVO and bacteria an effective passive approach to bioaugmentation in fractured rock
- Bioaugment only once with donor replenishment yearly or less frequently
- Temporary recirculation using well pairs an effective distribution strategy for known connections
- Several wells in the pilot test area and dg are below GWQS for the first time in decades

Site 2
Active Manufacturing Plant

Background

Site History

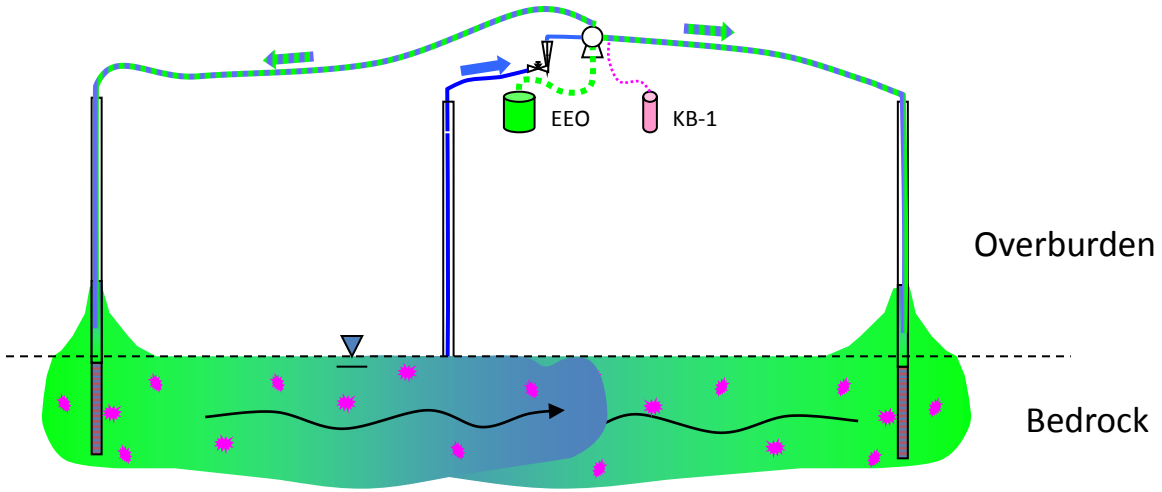
- Release of ~1500 pounds of TCE
- 5 to 10 ppm of TCE in clay overburden and bedrock at the source
- 3 ppm of TCE in DG bedrock
- Biodegradation daughter products and DHC bacteria present

Challenges

- **GEOLOGY!!**
- **TCE in clay overburden and fractured bedrock**
- **Expedited timeframe (3 months) for the initial source treatment**
- **Bedrock groundwater (and VOCs) discharge through seeps to an off-property stream; vinyl chloride discharge is unacceptable**

Approach – Full Scale

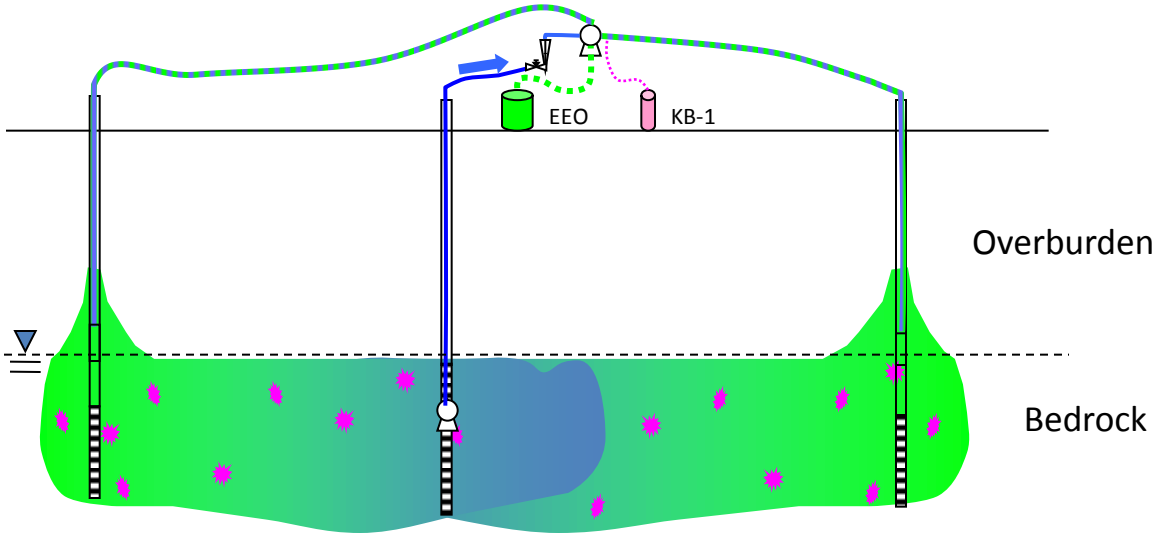
- Injections at existing wells in source area –Nov-05, Nov-06, Jul-08
  - EVO and KB-1® in Nov 05, EVO only thereafter to replenish electron donor
- Passive bioremediation as a biobarrier near the site boundary – Jun-07
  - Addition of EVO and KB-1 at 7 locations using recirculation between groups of wells



Full-Scale Biobarrier Application (Down Gradient Plume)

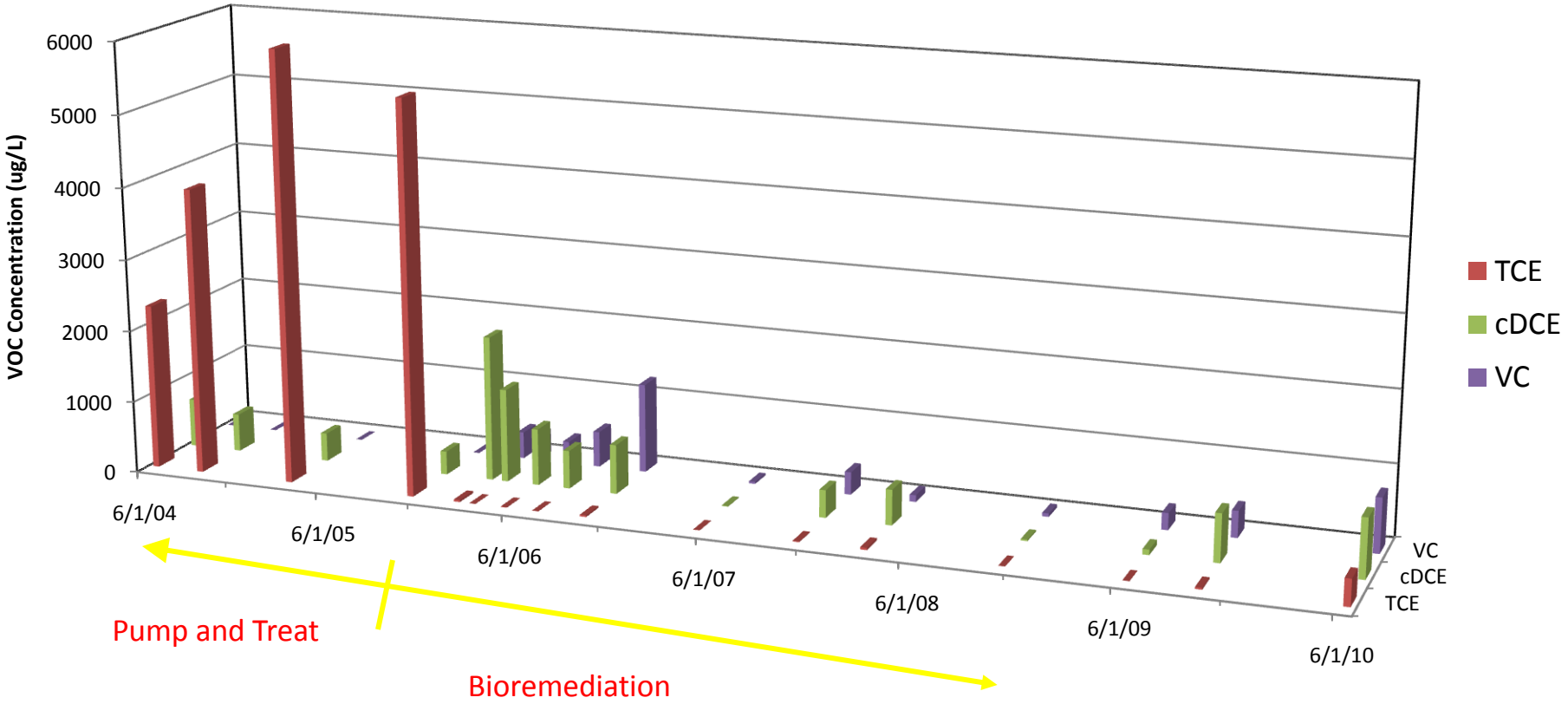
Plume Treatment

- Pump between wells at least until EVO breakthrough
- Add KB-1™ during oil injection
- In one week, a 300' biobarrier was constructed using 290 gallons of EVO and 40 liters of KB-1™

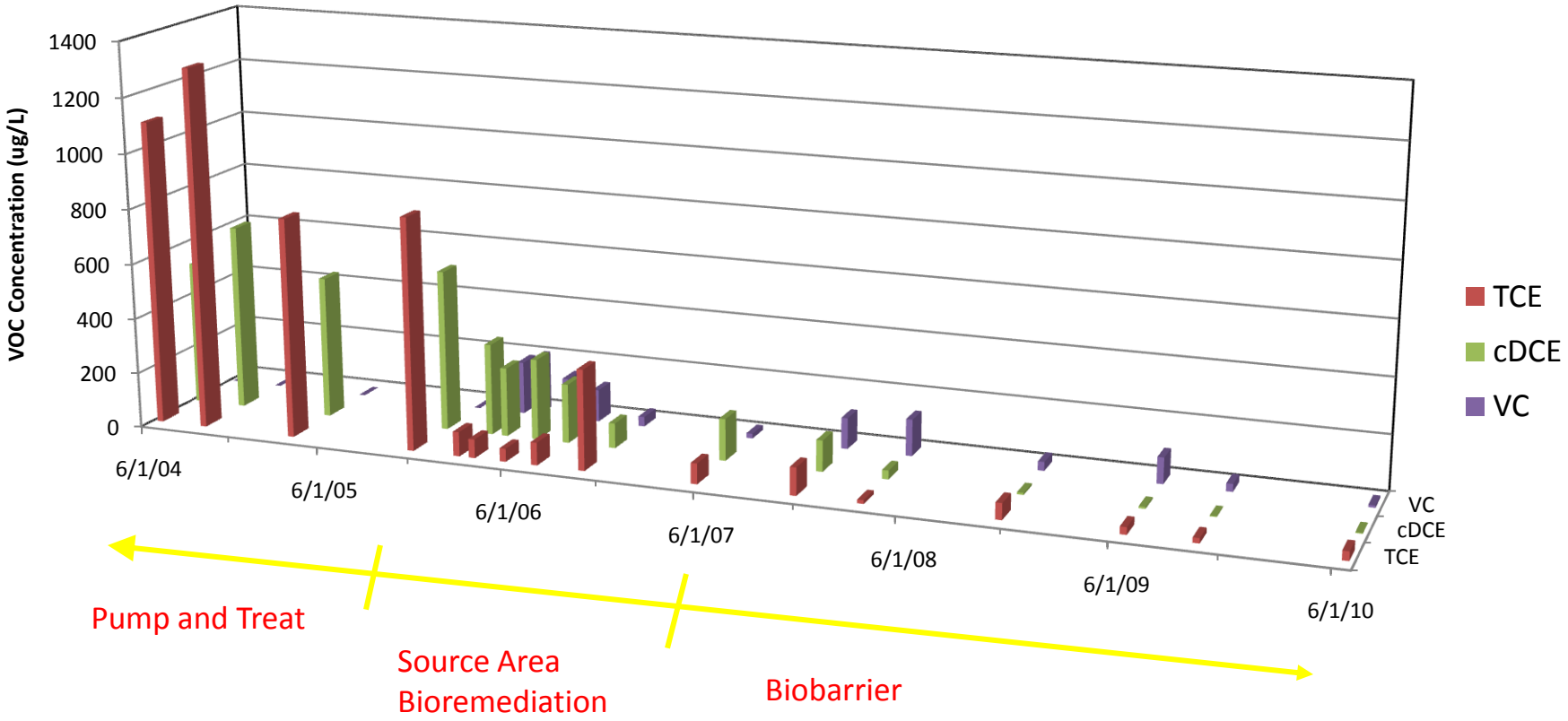


Biobarrier Results

Average Results at MW-09 Series Wells
(Source Area)



Average Results for MW-20 Series Wells
(downgradient of biobarrier)



Full-Scale Biobarrier


Questions?