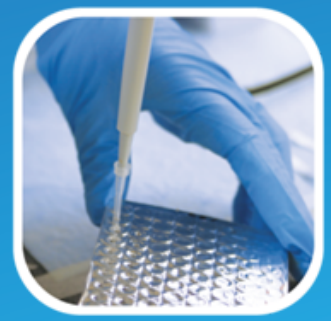
SiREM
Leading Science · Lasting Solutions

RAMBOLL

A Comparative Study of the Ability of ISCO and EISB to Treat Multiple Contaminants at a Complex Industrial Landfill Site



Sixth International Symposium on Bioremediation and Sustainable Environmental Technologies, Austin, Texas, May 9, 2023

Sandra Dworatzek, Larissa Smith, Kela Ashworth (SiREM), Mark Harkness, Robert Hornung, Jesse Vollick (Ramboll), Lew Streeter (General Electric Company), Courtney Toth, Elizabeth Edwards (University of Toronto)

Outline

Project Objectives

Background

Laboratory Study Design

SiREM Study Results

Conclusions

Project Objectives

1. Remediate mobile constituents in the soil and groundwater in the overburden soils under a Landfill cap.
    - Chlorinated ethenes
    - BTEX (benzene, toluene, ethylbenzene, and xylenes) compounds
    - Chlorobenzene
    - 1,4-dioxane

2. Conduct laboratory treatability studies to test various remedial approaches under site-specific conditions.
    - In-situ chemical oxidation (ISCO)
    - Enhanced in-situ bioremediation (EISB)
    - Post ISCO EISB

What Can Treatability Studies Tell You?

- Electron donor/acceptor/ cometabolite consumption
- Degradation intermediates/pathways
- Effect of controlling variables (e.g., pH, redox, amendment addition, inhibitory effects, oxidant demand, persulfate activators)
- Contaminant degradation rates/ lag times
- Insight into pilot–test design

Laboratory Study Objectives

Microcosm study evaluating ISCO and EISB using Landfill soil and groundwater.

Two types of soil found in the Landfill were collected and used in the laboratory studies to determine if soil type has a significant impact on technology effectiveness.

- Type 1 - glaciofluvial sand and gravel
- Type 2 - silt and clay

Key Site contaminants:

TCE – 10 mg/L, Benzene – 16 mg/L, Chlorobenzene – 6.5 mg/L, 1,4-D – 1.0 mg/L

Complex degradation mechanisms

- TCE - Reductive dechlorination
- BTEX – aerobic /anaerobic biodegradation
- Chlorobenzene - aerobic /anaerobic biodegradation (activity can be site specific)
- 1,4-D – aerobic biodegradation

All can be degraded using activated persulfate.

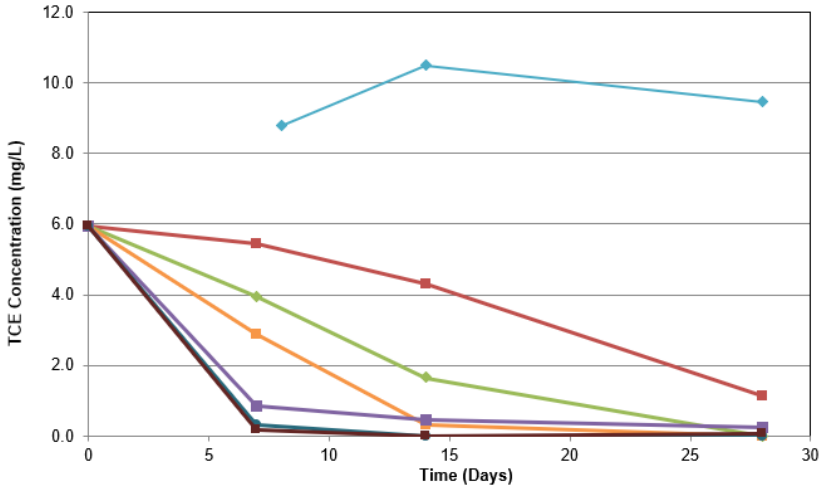
ISCO Study Design Summary

- Base titration
- Natural Oxidant Demand
- Oxidant Treatability Test

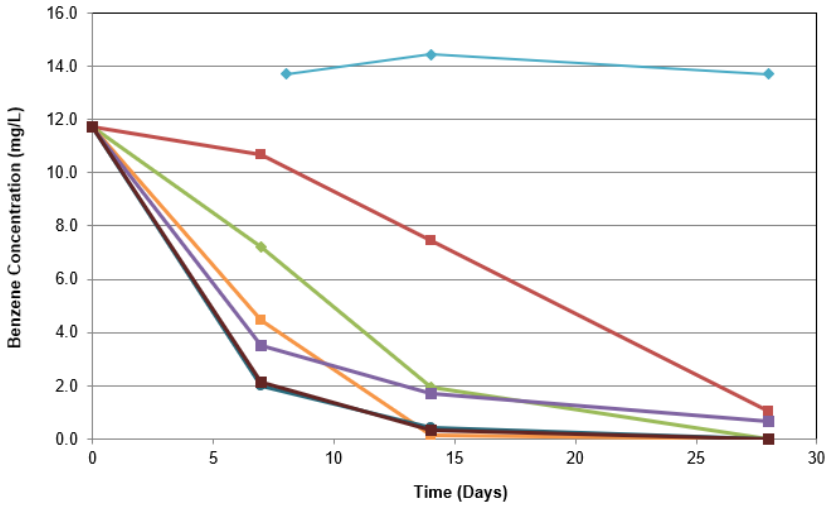
Location	Treatment/Control
Reagent Controls	Persulfate 10 g/L Reagent Control
	Persulfate 20 g/L Reagent Control
	Persulfate 40 g/L Reagent Control
Location 1/2	Sterile Control
	Unamended Control
	Chelated Iron Activated Persulfate Low Dose
	Chelated Iron Activated Persulfate Medium Dose
	Chelated Iron Activated Persulfate High Dose
	Base Activated Persulfate Low Dose
	Base Activated Persulfate Medium Dose
	Base Activated Persulfate High Dose

ISCO STUDY RESULTS – Location 1

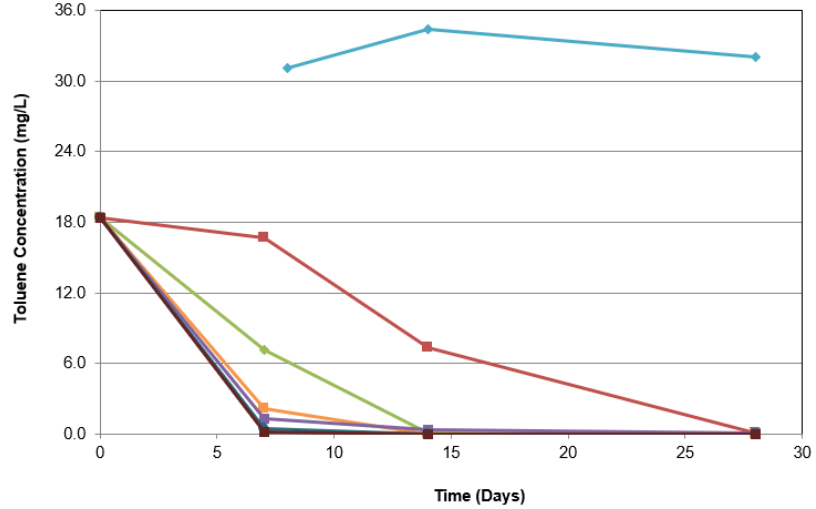
TCE



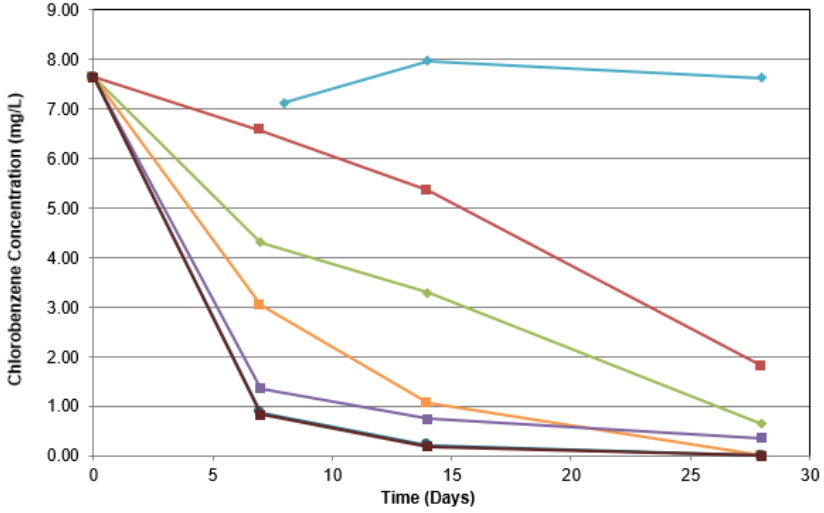
Benzene



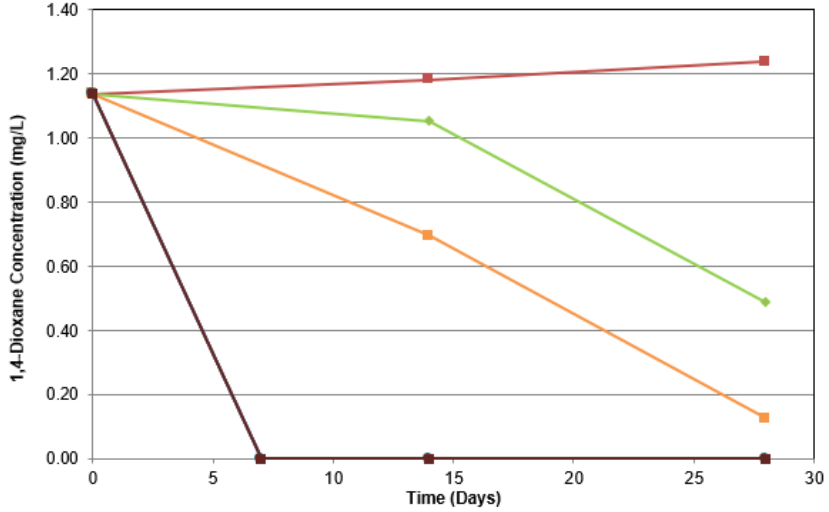
Toluene

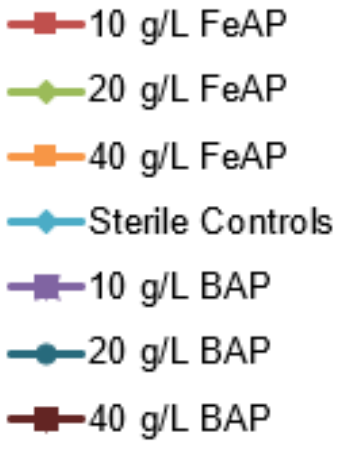


Chlorobenzene



1,4-Dioxane





ISCO Study Results – Summary

- Soil NaOH demand is ~4 g/kg in both locations to raise pH to ~11.5
- Soil NOD is lower in both locations for base-activated persulfate
- Persulfate can degrade all target contaminants regardless of activation approach
- Degradation is faster (better kinetics) for base-activated persulfate for both locations and all target contaminants
- Difference in degradation kinetics is most noticeable for 1,4-D degradation

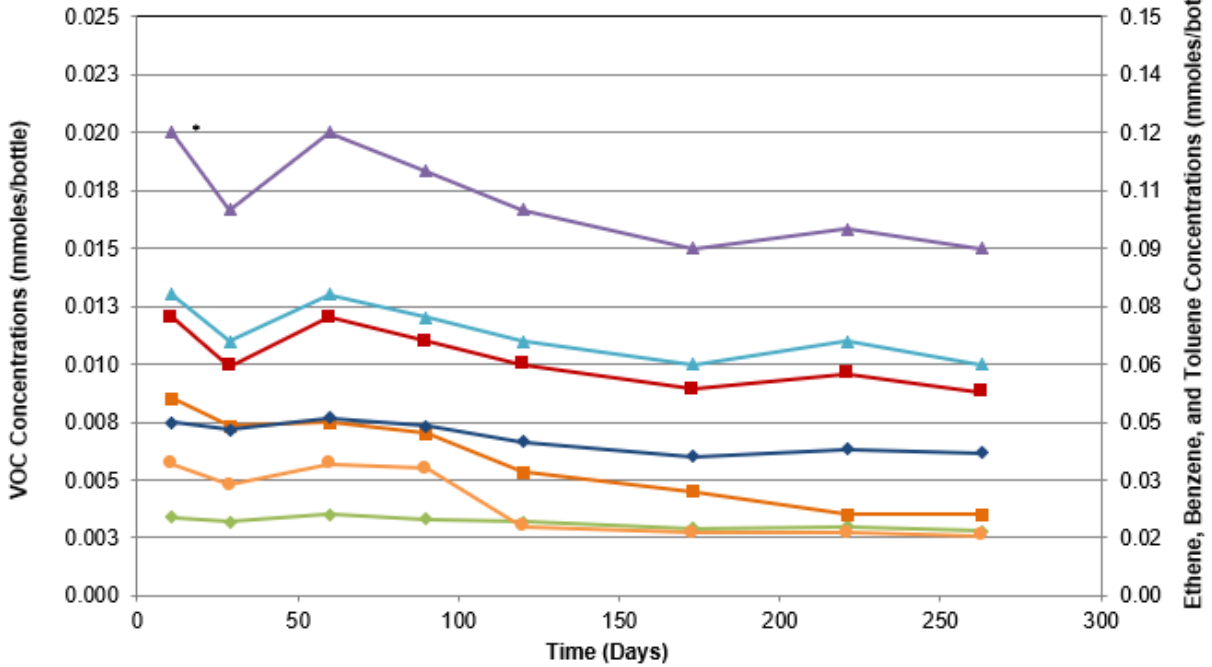
EISB Study Design Summary

Location 1 (sand and gravel)	Location 2 (silt and clay)
Anaerobic Sterile Control	Anaerobic Sterile Control
Anaerobic Intrinsic Control	Anaerobic Intrinsic Control
Sulfate Amended	Sulfate Amended/KB-1® Plus and DGG® Plus Bioaugmented
Sulfate Amended/KB-1® Plus and DGG® Plus Bioaugmented	EHC® Amended/KB-1® Plus and DGG® Plus Bioaugmented
Lactate Amended/KB-1® Plus and DGG® Plus Bioaugmented	Sulfate and EHC® Amended
Sulfate and Lactate Amended	Sulfate Amended
Sulfate and Lactate/KB-1® Plus and DGG® Plus Bioaugmented	EHC® Amended
EOS_{100} Amended/KB-1® Plus and DGG® Plus Bioaugmented	EHC® and Sulfate Amended/KB-1® Plus and DGG® Plus Bioaugmented
EOS_{100} and Sulfate Amended	
EOS_{100} and Sulfate Amended/KB-1® Plus and DGG® Plus Bioaugmented	

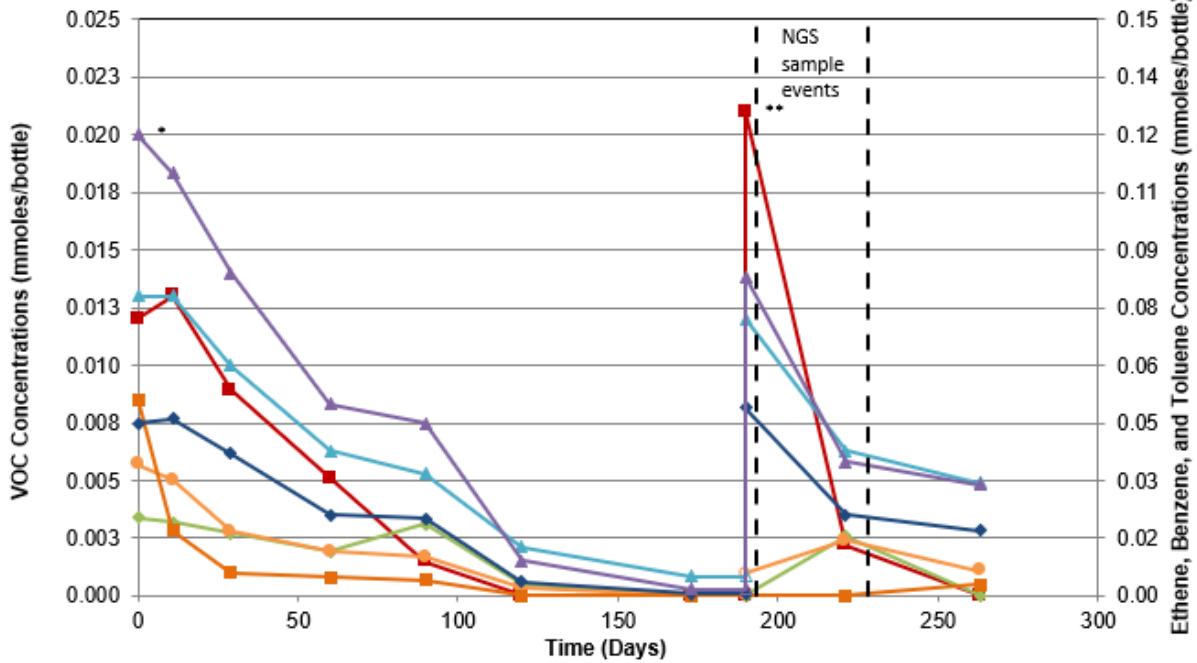
SiREM | siremlab.com

EISB Study Results – Location 1

Sterile Control



Intrinsic Control

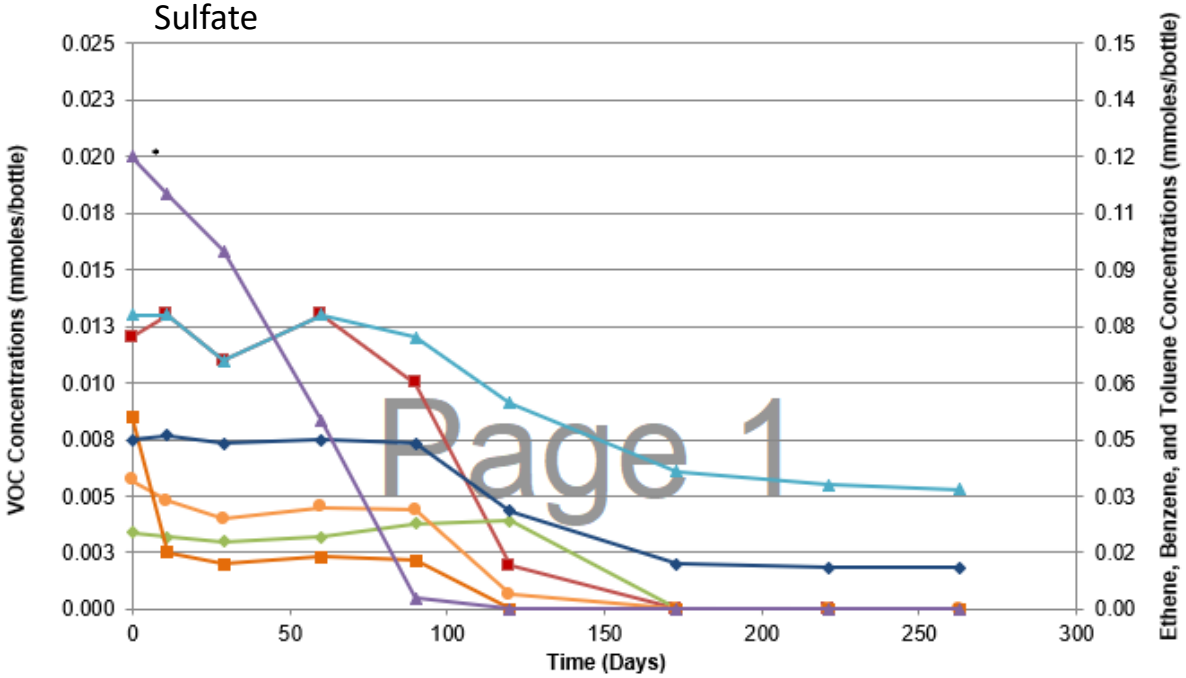


TCE
cDCE
VC
CB
Ethene
Benzene
Toluene
Sampled for NGS

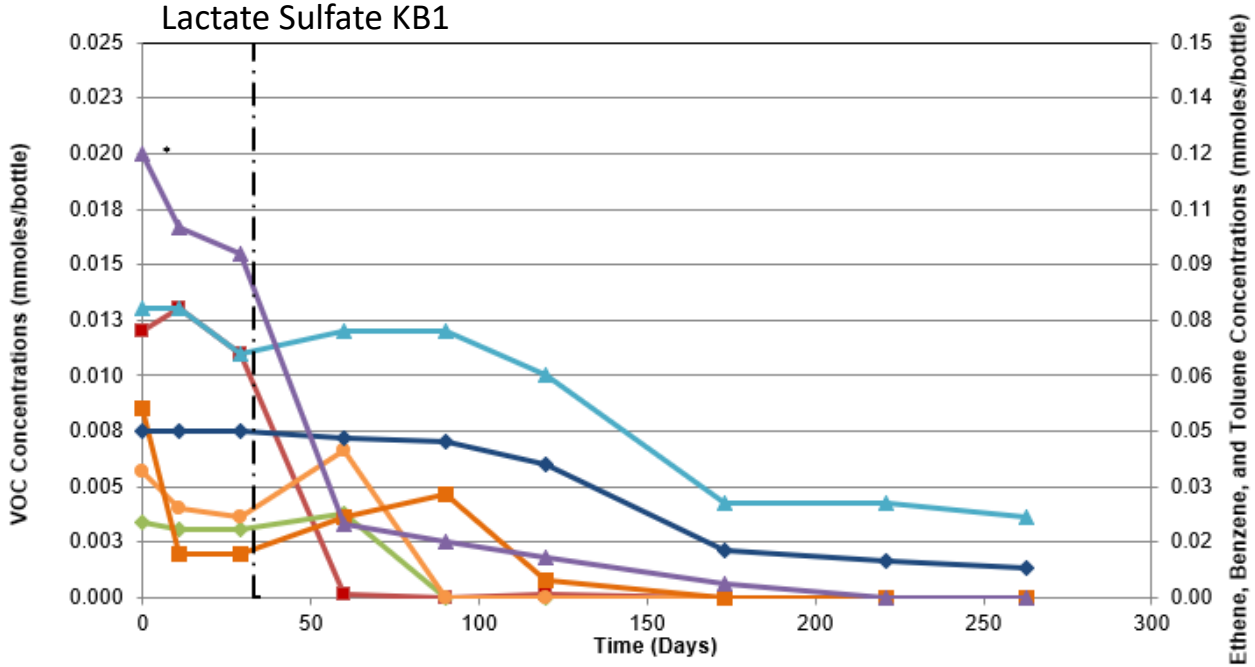
SiREM | siremlab.com

EISB Study Results – Location 1 con't

Sulfate



Lactate Sulfate KB1

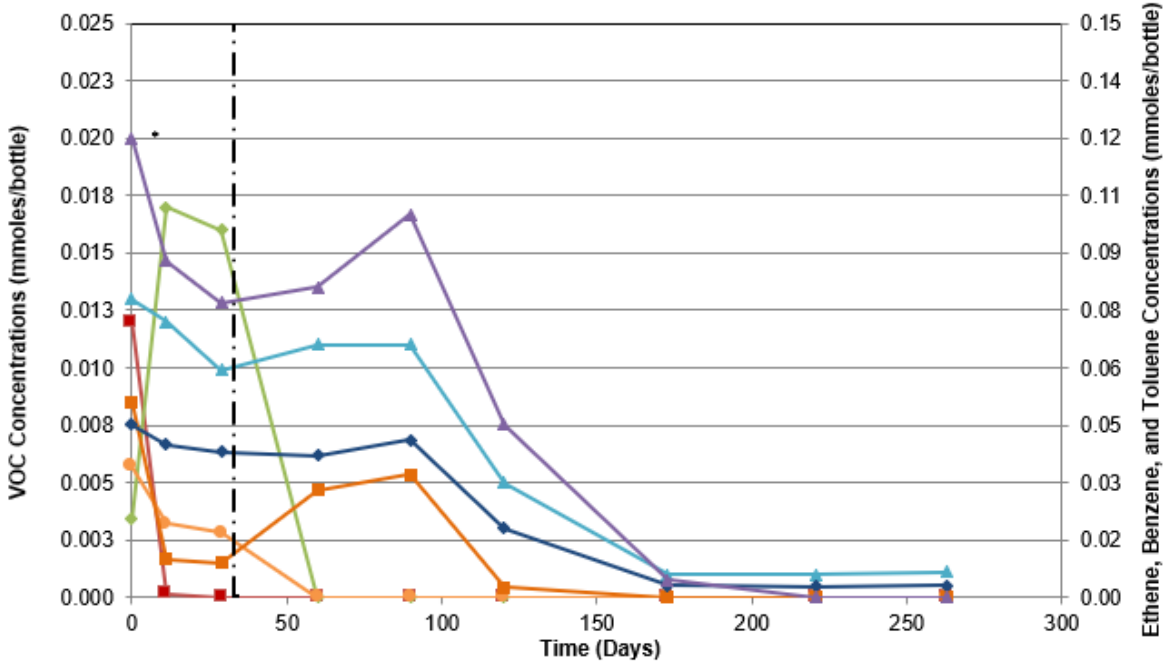


TCE
VC
Ethene
Toluene
cDCE
CB
Benzene
Bioagumented with KB-1® Plus and DGG® Plus

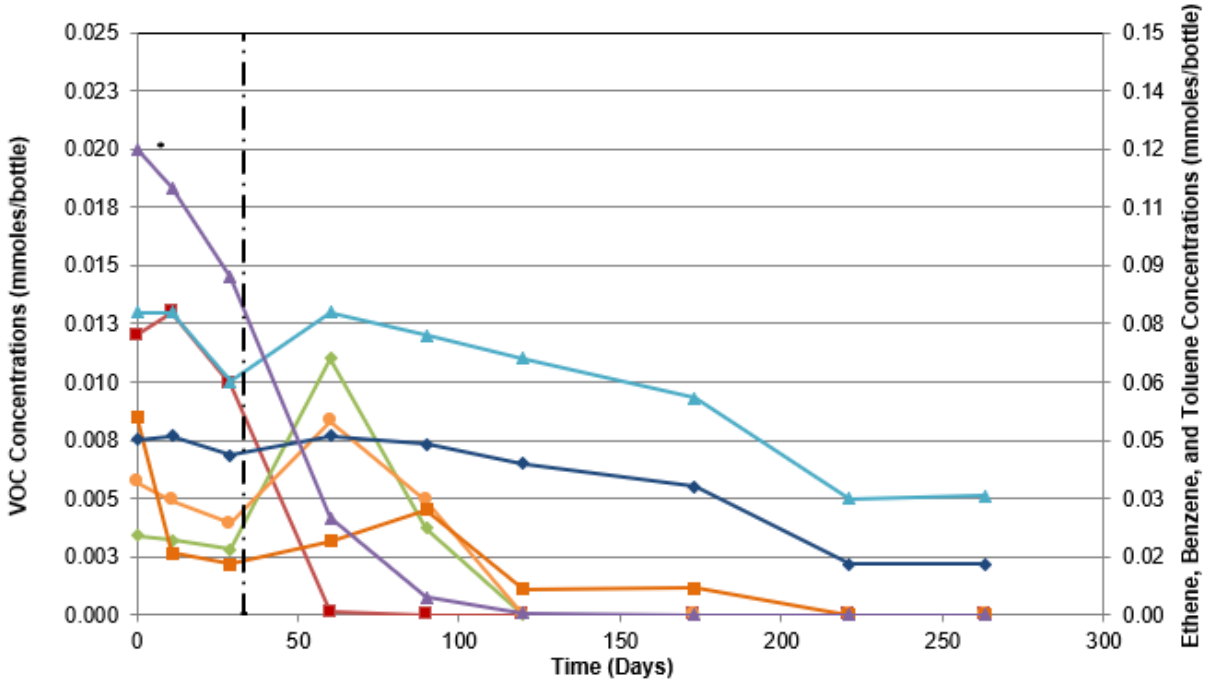
SiREM | siremlab.com

EISB Study Results – Location 1 con't

Lactate KB1



Sulfate KB1

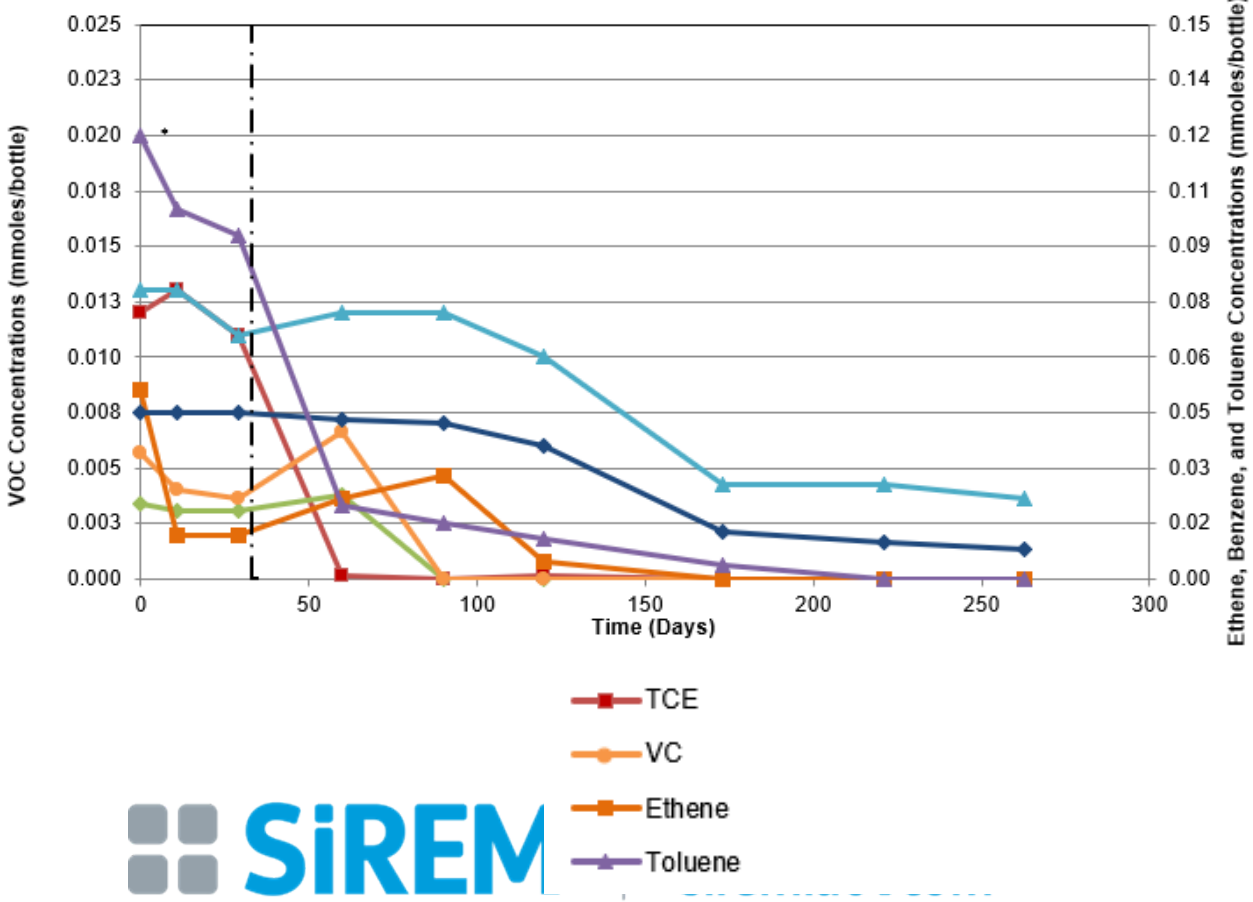


TCE
VC
Ethene
Toluene
cDCE
CB
Benzene
Bioagumented with KB-1® Plus and DGG® Plus

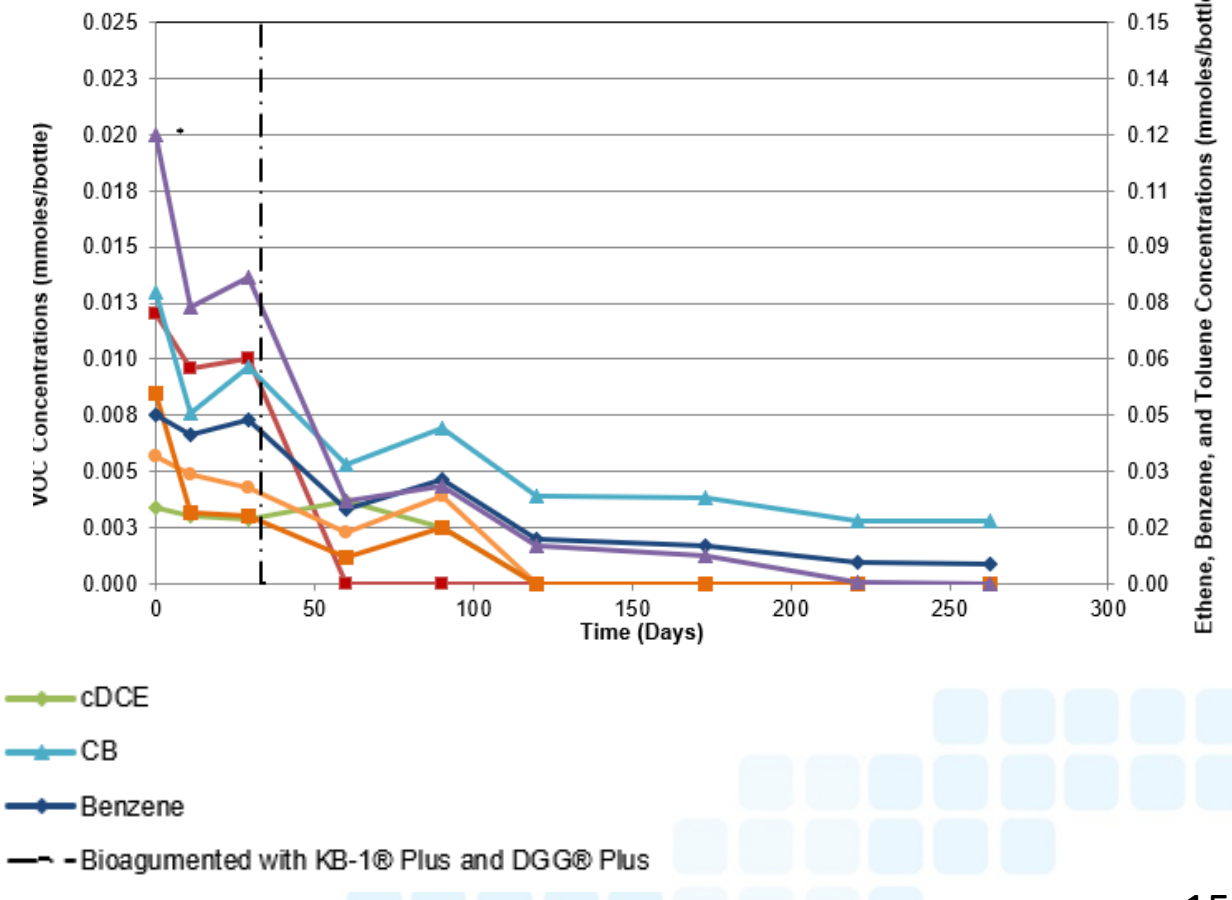
SiREM

EISB Study Results – Location 1 con't

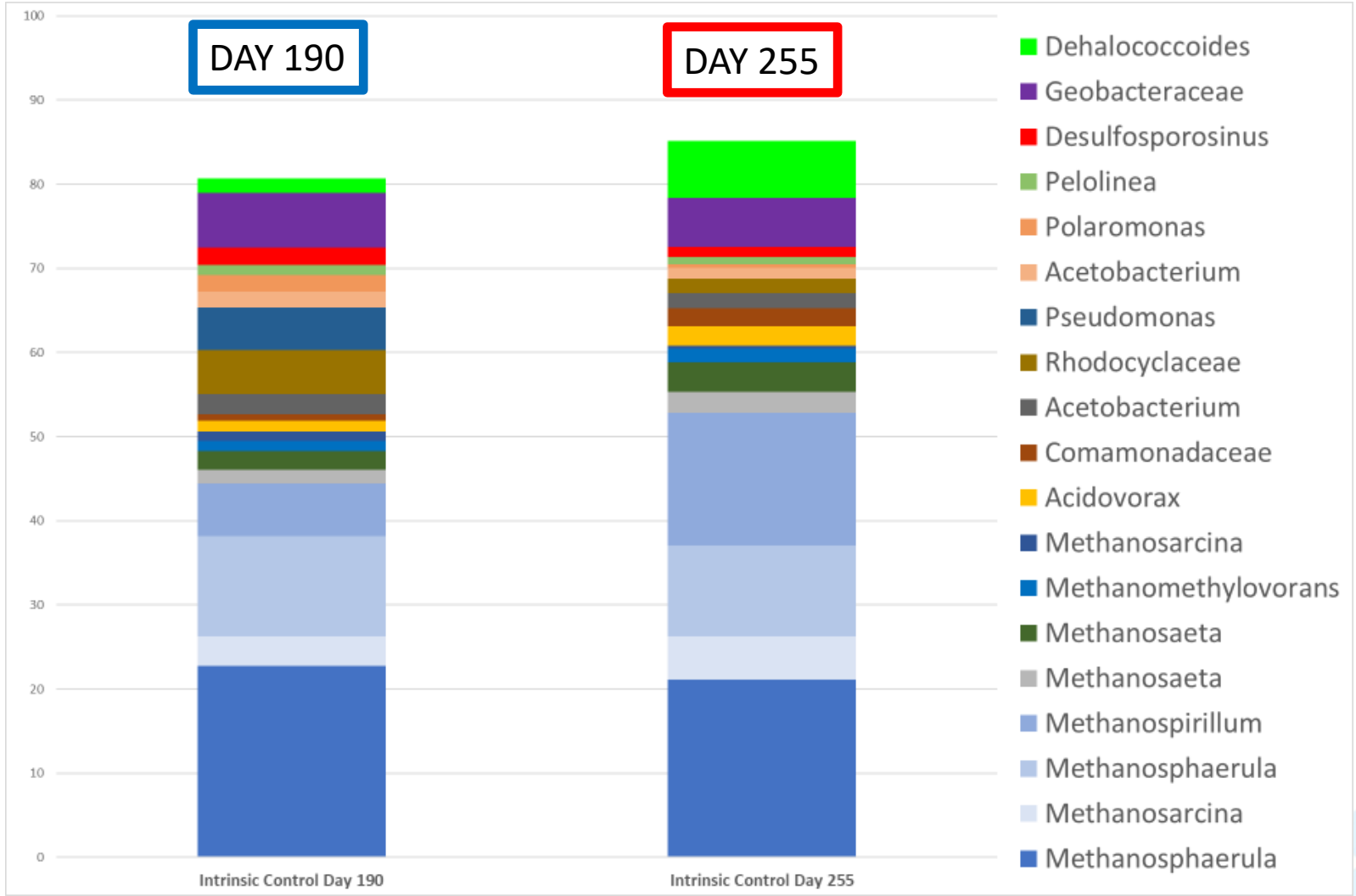
Lactate Sulfate KB1

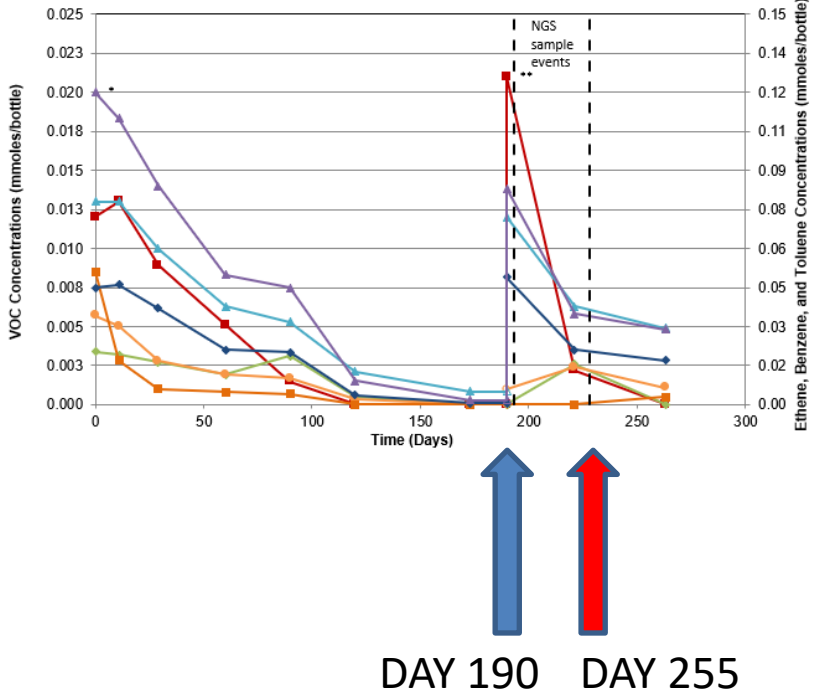


EVO Sulfate KB1

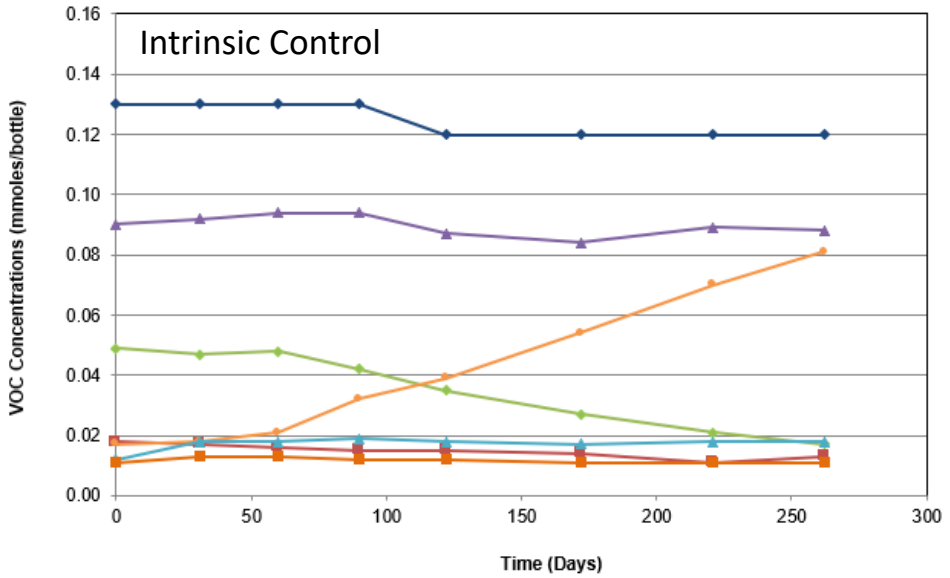


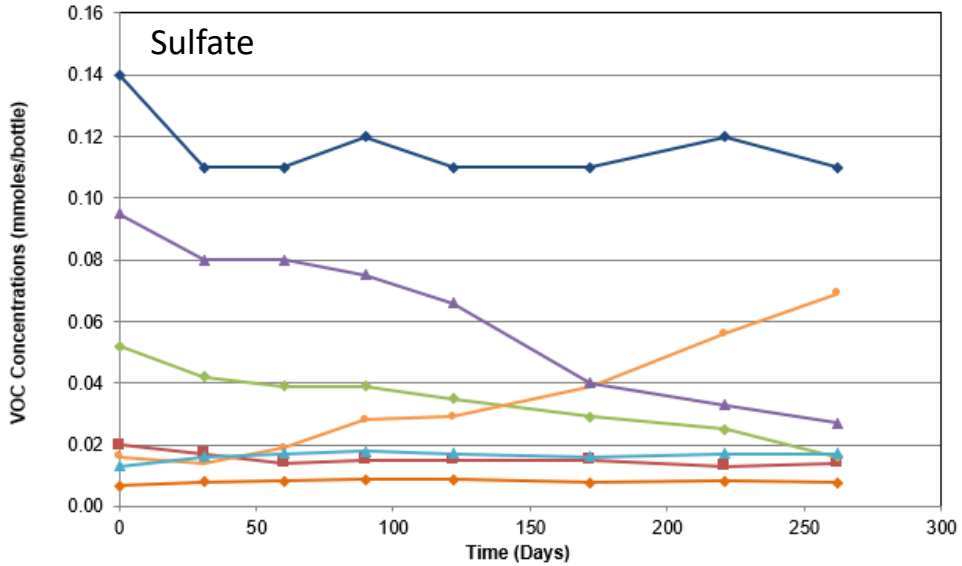
NGS Results – Location 1

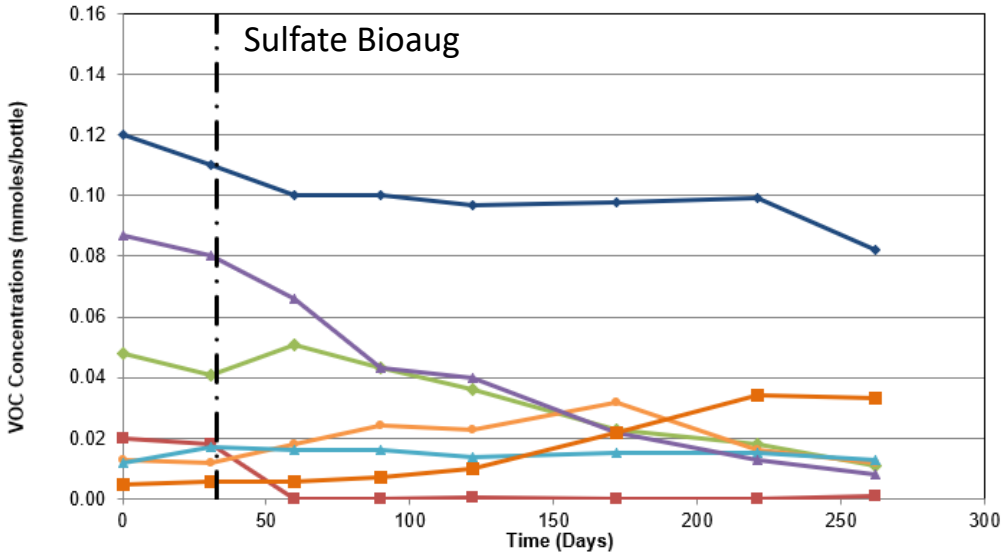


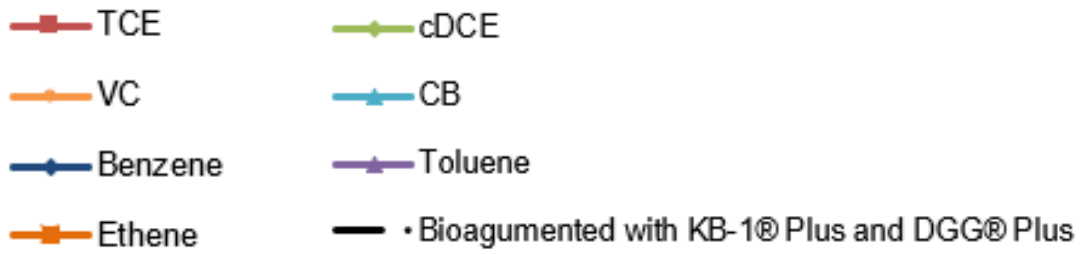


Location 2

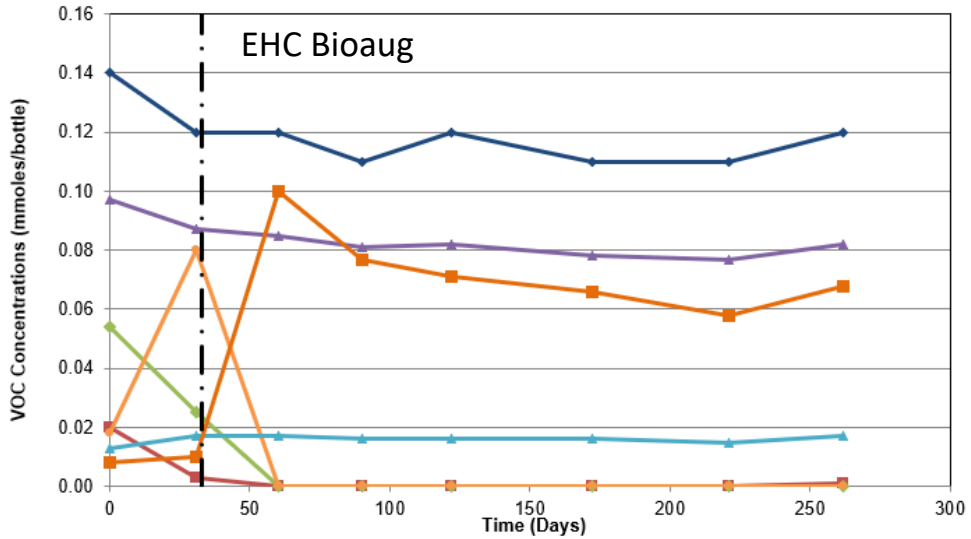

Intrinsic Control
VOC Concentrations (mmoles/bottle)
Time (Days)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
50
100
150
200
250
300

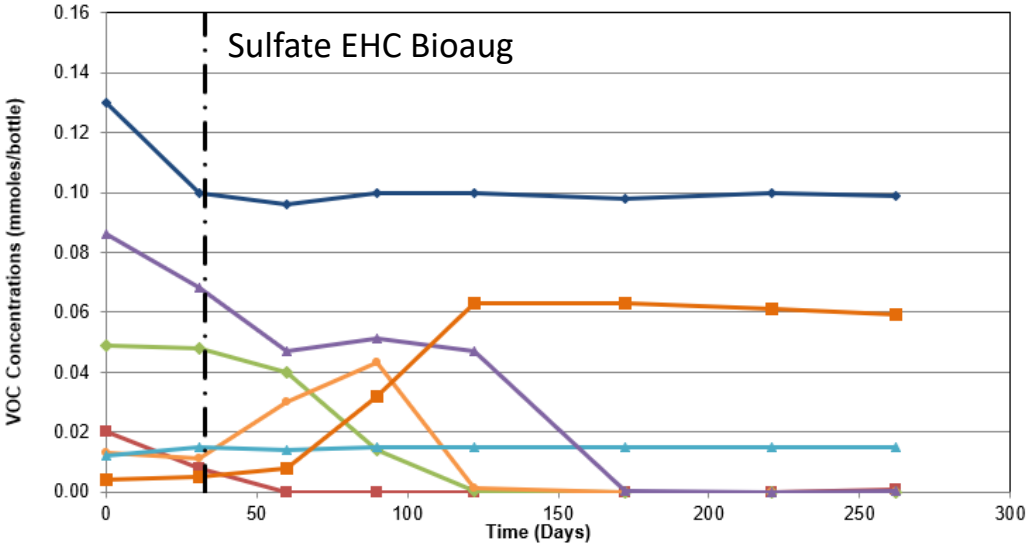

Sulfate
VOC Concentrations (mmoles/bottle)
Time (Days)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
50
100
150
200
250
300

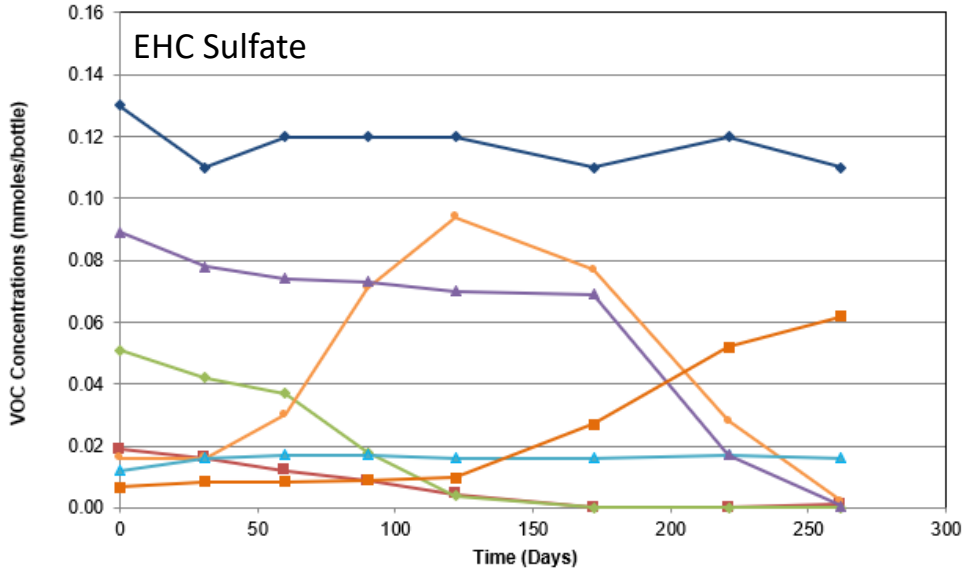

Sulfate Bioaug
VOC Concentrations (mmoles/bottle)
Time (Days)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
50
100
150
200
250
300

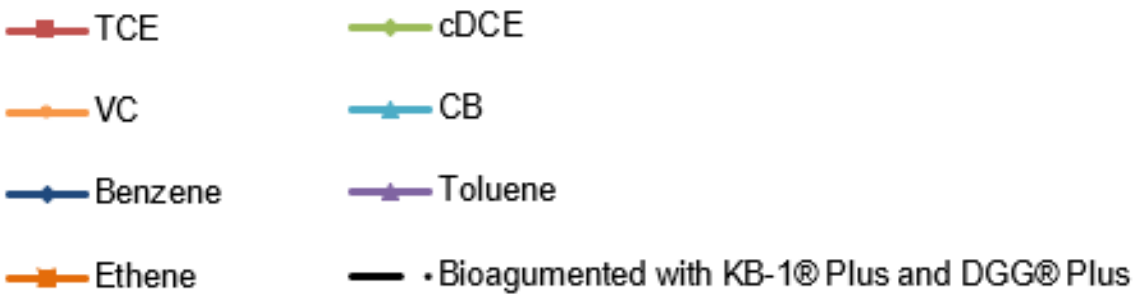

TCE
cDCE
VC
CB
Benzene
Toluene
Ethene
Bioagumented with KB-1® Plus and DGG® Plus

Location 2 EISB Con't









EISB Study Results – Summary

- All target contaminants removed in multiple location 1 treatments, with the exception of 1,4-D
- Location 1 intrinsic control performed very well without any amendment addition
- Longer-lived electron donors (e.g., EVO) appeared to have inhibited BTEX and CB degradation
- Biodegradation less robust in Location 2 bottles
- Best performance at Location 2 observed in bottles that did not receive electron donor (e.g., EHC™)

Post ISCO Bio Study Design

Location 1	Location 2
Anaerobic Sterile Control	Anaerobic Sterile Control
Anaerobic Intrinsic Control	Anaerobic Intrinsic Control
Lactate Amended/KB-1® Plus and DGG® Plus Bioaugmented (Chelated Iron Activated Persulfate)	Lactate Amended/KB-1® Plus and DGG® Plus Bioaugmented (Chelated Iron Activated Persulfate)
Lactate Amended/KB-1® Plus and DGG® Plus Bioaugmented (Base Activated Persulfate)	Lactate Amended/KB-1® Plus and DGG® Plus Bioaugmented (Base Activated Persulfate)
KB-1® Plus and DGG® Plus Bioaugmented (Chelated Iron Activated Persulfate)	KB-1® Plus and DGG® Plus Bioaugmented (Chelated Iron Activated Persulfate)
KB-1® Plus and DGG® Plus Bioaugmented (Base Activated Persulfate)	KB-1® Plus and DGG® Plus Bioaugmented (Base Activated Persulfate)

Reserved ISCO reactors were amended with L-ascorbic acid to quench 90% of the remaining persulfate.

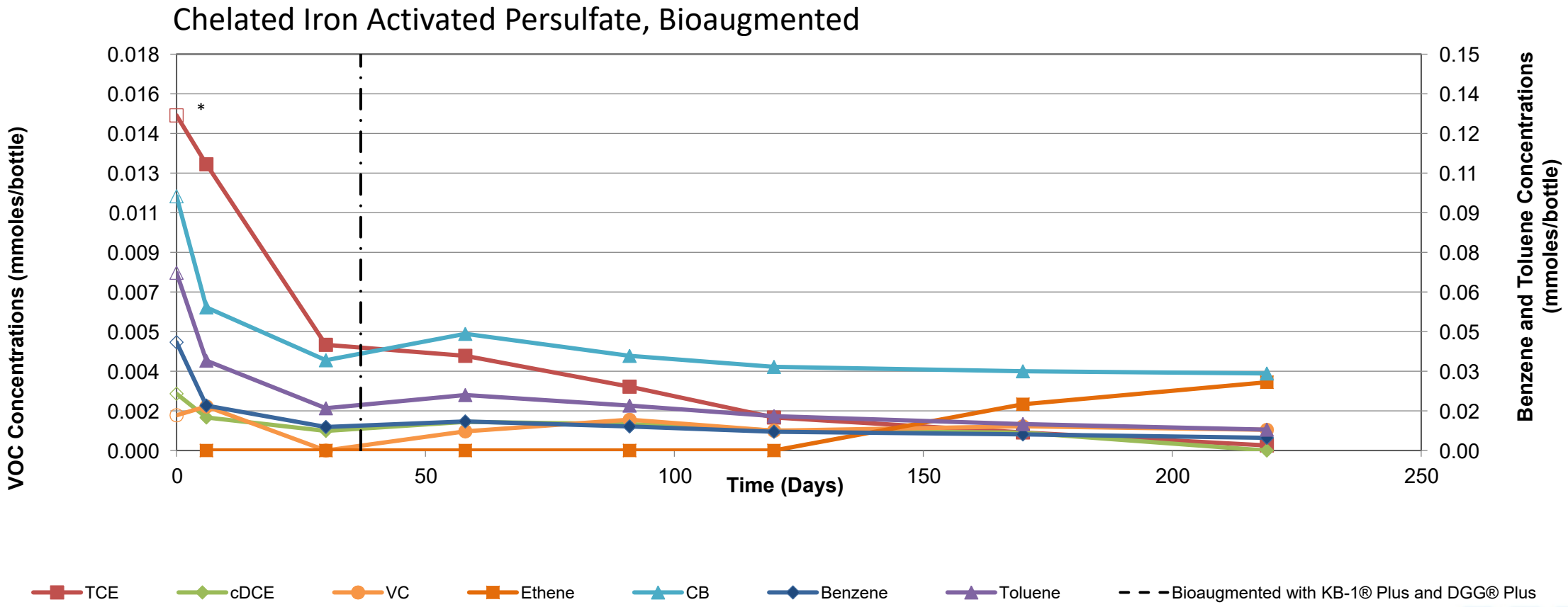
The pH was adjusted with 10 M NaOH to target between pH 6 and 7.

The bottles were respiked to the same VOC concentrations as measured in the sterile controls from the ISCO test.

All microcosms were sampled and incubated in the anaerobic chamber.

Study lasted ~220 days.

Post ISCO EISB Results



SiREM | siremlab.com

Post ISCO EISB Study Results – Summary

- It is possible to stimulate biological activity after persulfate addition
- More robust biological activity observed after iron-activated compared to base-activated persulfate treatment at both locations
- More robust biological activity observed at location 2 compared to location 1
- All target contaminants removed in two location 2 treatments, with the exception of 1,4-D

Summary and Conclusions

- The results of the ISCO treatment were straight-forward.
  - Base-activated persulfate > iron-activated persulfate.
  - The degradation rate differential was most apparent for 1,4-dioxane.
  - ISCO treatment bottles were then subjected to EISB
    - ✓ Biodegradation activity was subsequently noted, particularly in the location 2 bottles.

Summary and Conclusions Con't

- EISB treatment results were more complex
  - Complete removal in 120 days of chlorinated ethenes, BTEX, and CB in the intrinsic control
  - Removal of chlorinated ethenes, BTEX, and CB was also observed for some amended and bioaugmented bottles.
  - Slow-release donors tended to inhibit BTEX and CB biodegradation
  - Consistent with the literature, no anaerobic biodegradation of 1,4-D was observed.
  - NGS results demonstrated *Dehalococcoides* and *Geobacteraceae* as well as a *Desulfosporosinus* (known toluene degrader) were indigenous to the Location 1 area.

Questions?
siremlab.com

Sandra Dworatzek
Principal Scientist
sdworatzek@siremlab.com
519-515-0839