Enhanced DNAPL Dissolution and Rapid, Complete Reductive Dechlorination of Trichloroethene in a Pilot Test in a Perched Aquifer

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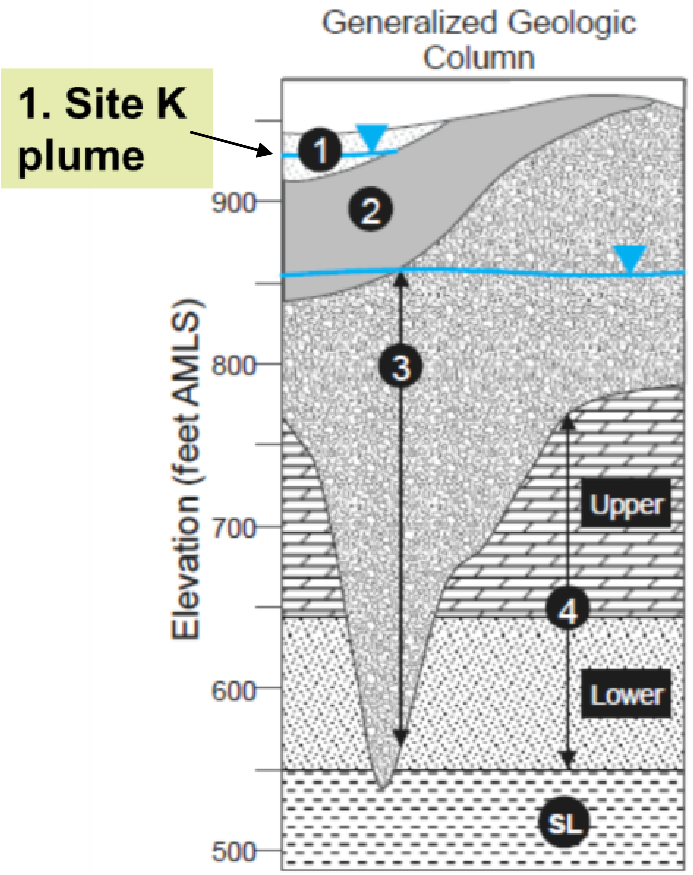
Purpose

- Improve remediation of trichloroethylene (TCE) and dichloroethylene (DCE) using *in situ* bioremediation in shallow groundwater.
  - perched aquifer
  - likely residual DNAPL



	Unit No.	Name	Aquifer Type
Unconsolidated Units	1	Fridley Formation	Perched sand aquifer
	2	Twin Cities Formation	Aquitard
	3	Hillside and Arsenal Sand Units	Sand and gravel aquifer
Bedrock Units	Upper 4	Prairie du Chien Group	Karst and fractured rock aquifer
	Lower 4	Jordan Formation	Porous fractured rock aquifer
	SL	St. Lawrence Formation	Bedrock aquitard

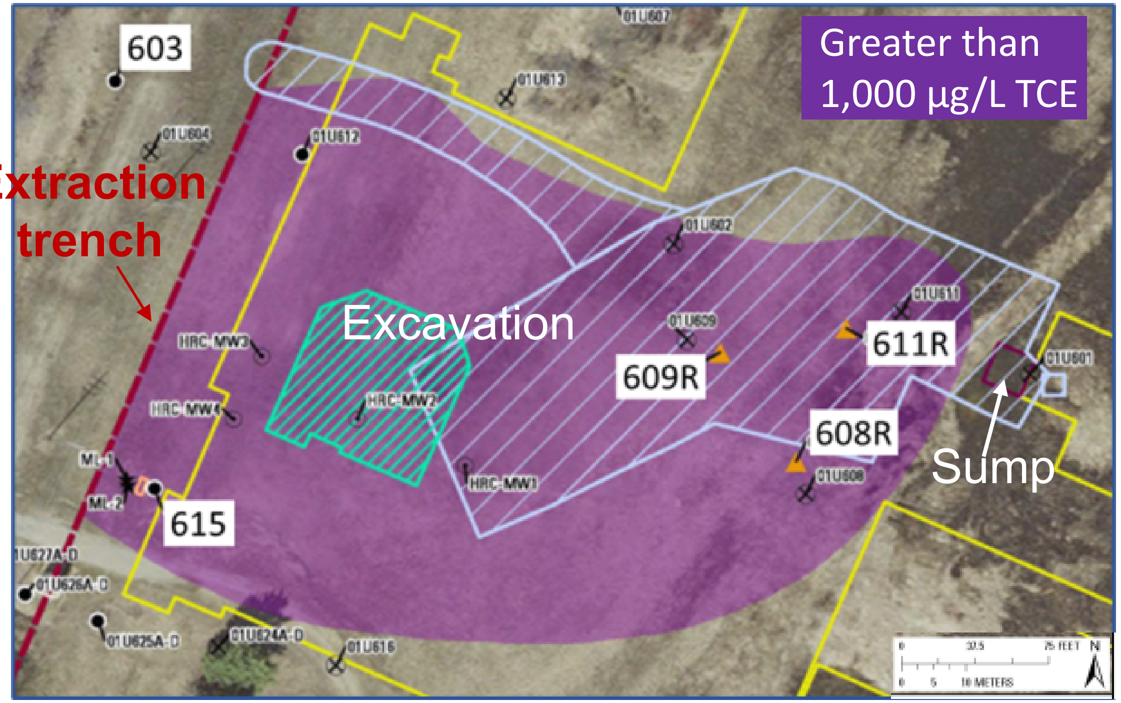
New Brighton/Arden Hills Superfund site at Former Twin Cities Army Ammunition Plant, Minnesota

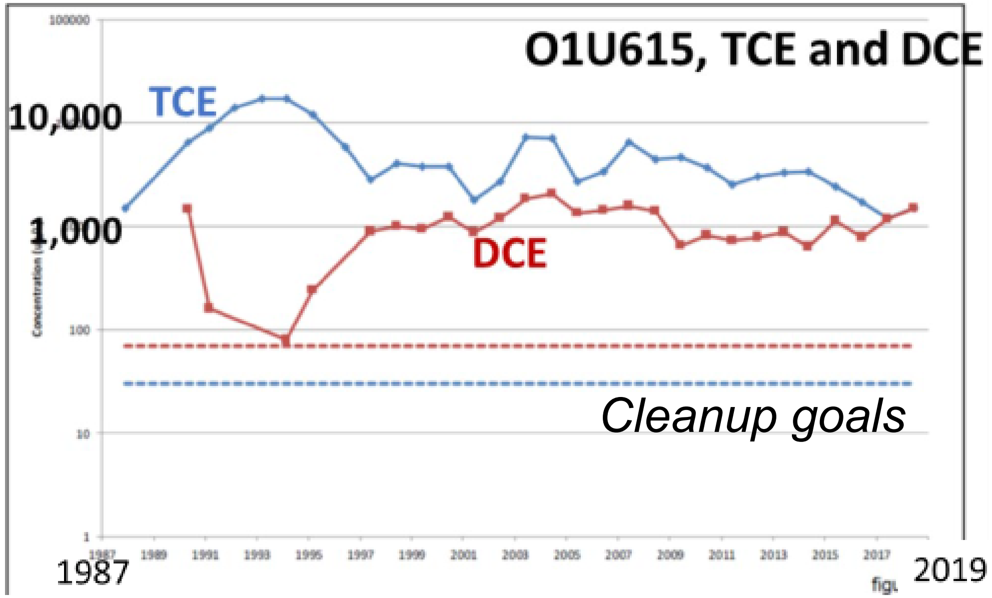
Background

- 1981 — Contamination found in groundwater
- 1986 — Groundwater extraction/air stripping begins
- 1987 — Federal Facility Agreement signed
- 1998 — Record of Decision signed (air stripping)
- 2000 — Early bioremediation pilot tests
- 2006 — Building 103 demolished
- 2009-13 — Building infrastructure removed
- 2014 — Soil excavation in former Building 103 area

2020

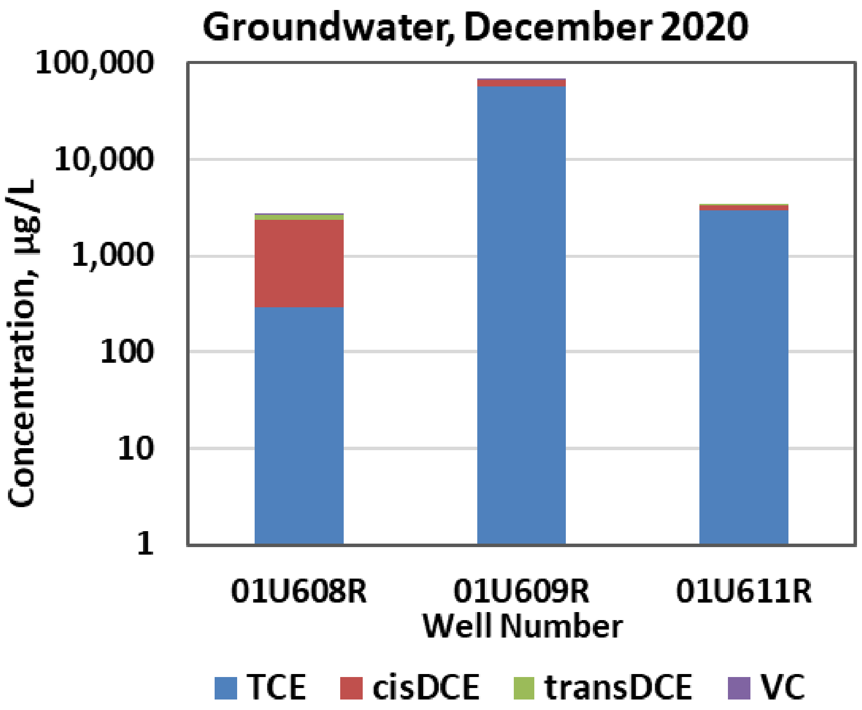
USGS study



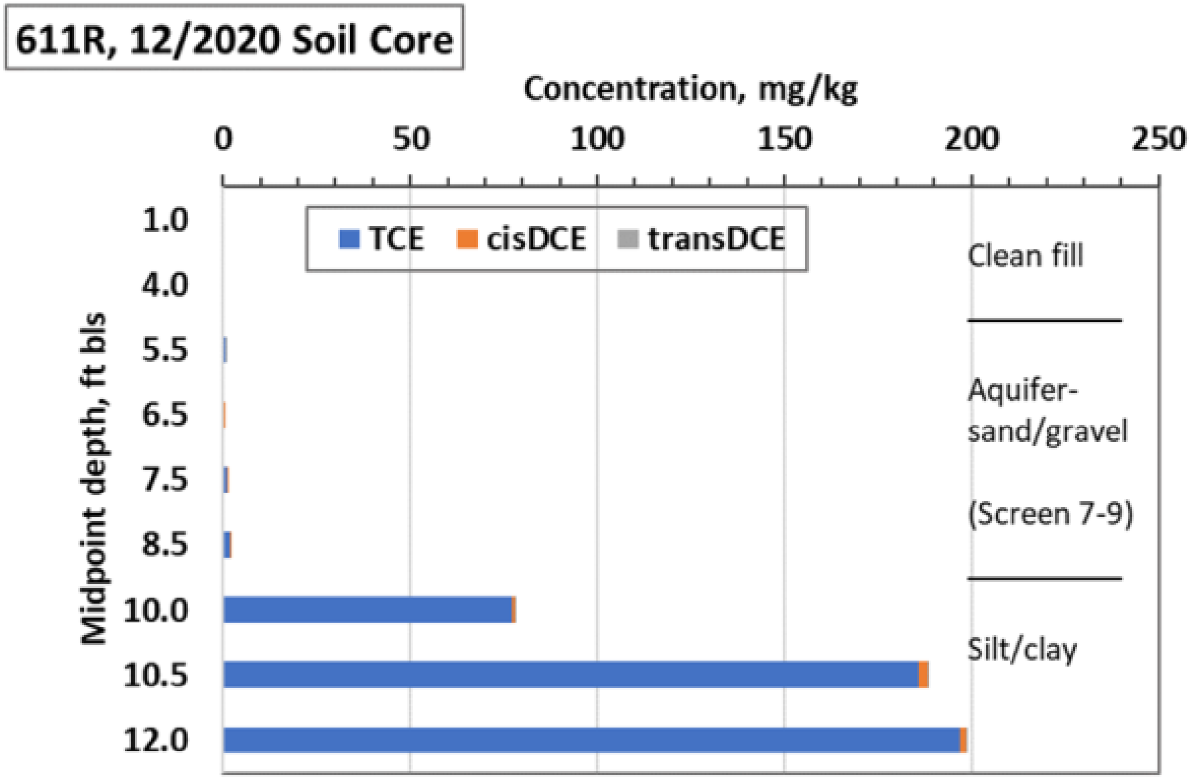


From FY 2019 Annual Performance Report, PIKA ARCADIS U.S., INC. (JV)

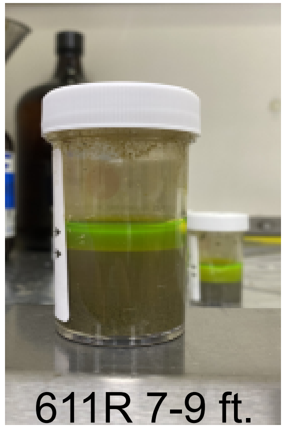
Residual DNAPL

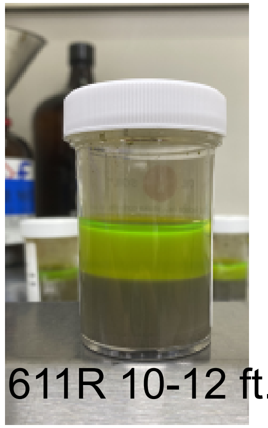


Maximum groundwater TCE concentrations in 2020 were 60 mg/L, which agreed with historical maximum and indicated presence of DNAPL.

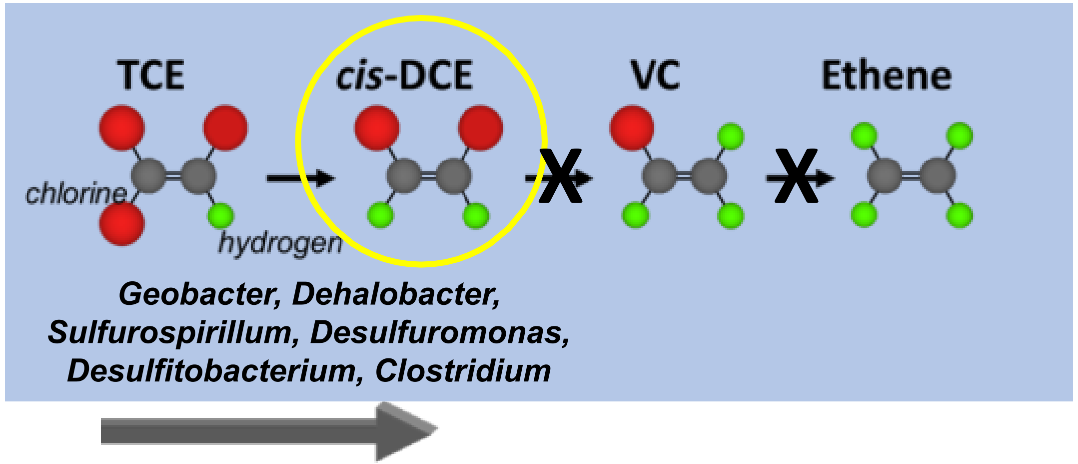


TCE concentrations indicate sorbed/residual DNAPL, but hydrophobic dye test with silt/clay at base of aquifer did not show red indicator.

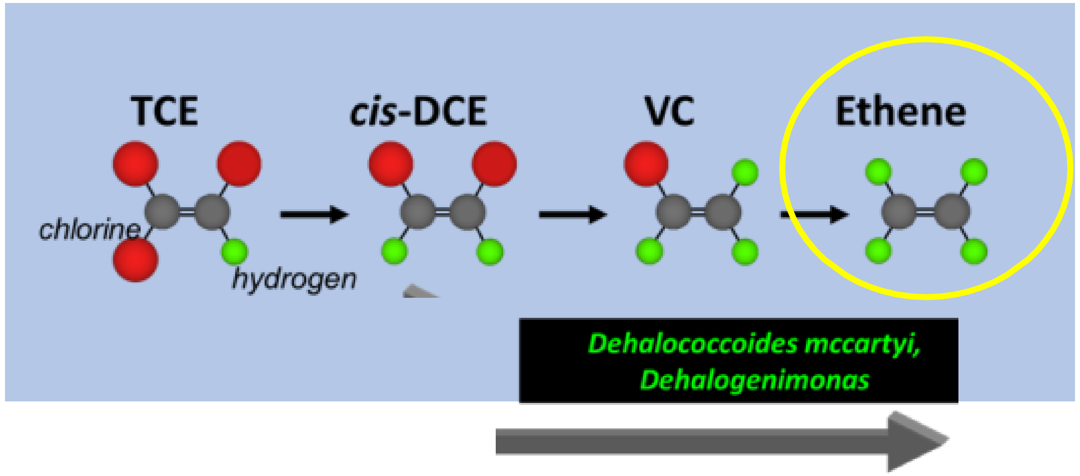




Anaerobic Biodegradation by Reductive Dechlorination



Partial degradation of TCE causes DCE to accumulate.



Complete degradation to non-chlorinated product.

Complete reductive dechlorination can be inhibited by fluctuating water levels and oxygen influx with recharge in a perched aquifer and by high concentrations associated with DNAPL.

- Dissolution/desorption of DNAPL can cause greater daughter product accumulation than the original TCE concentration in the water.
- Ethene detections are a clear indication that complete degradation is occurring.

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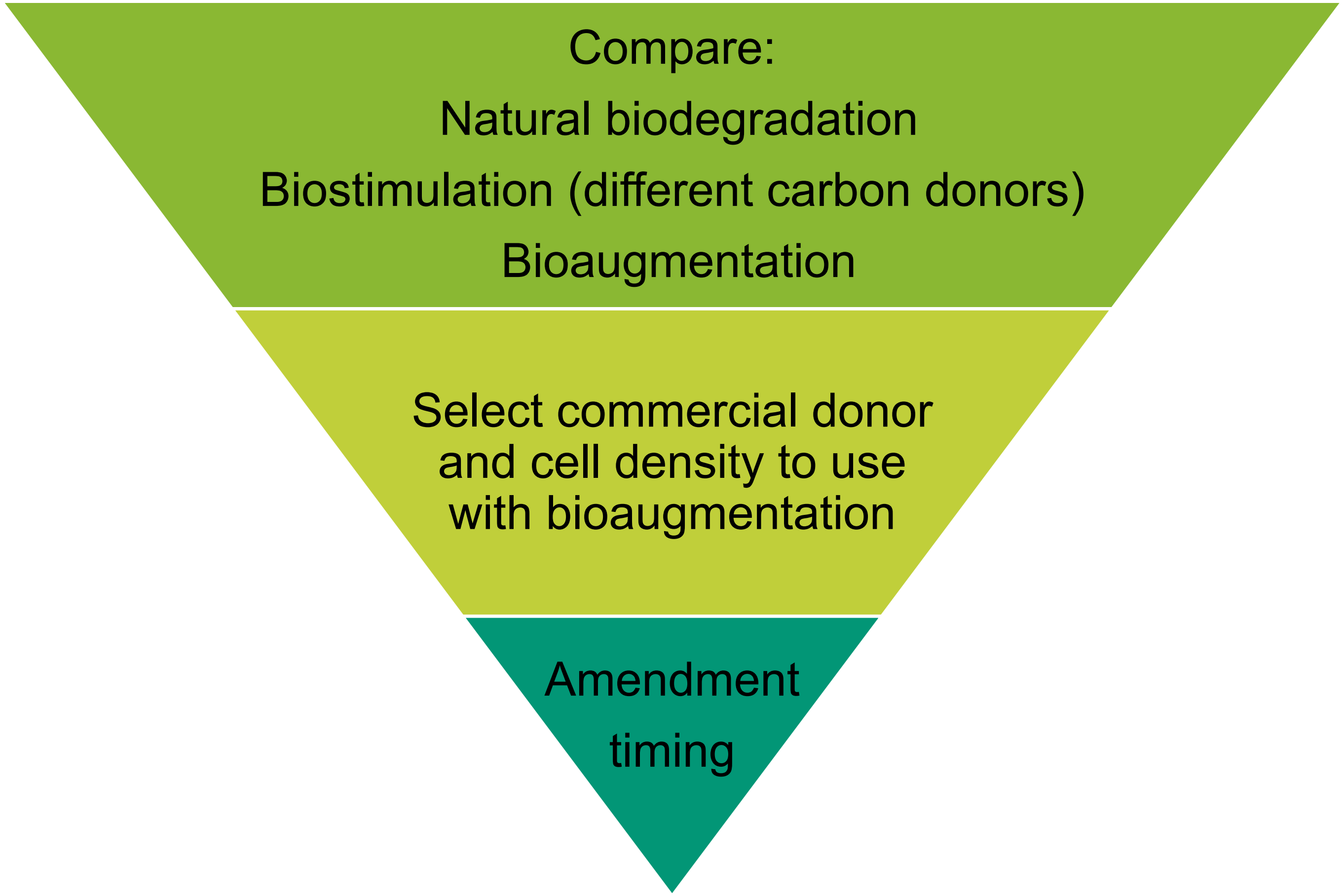
Approach: Lab Tests

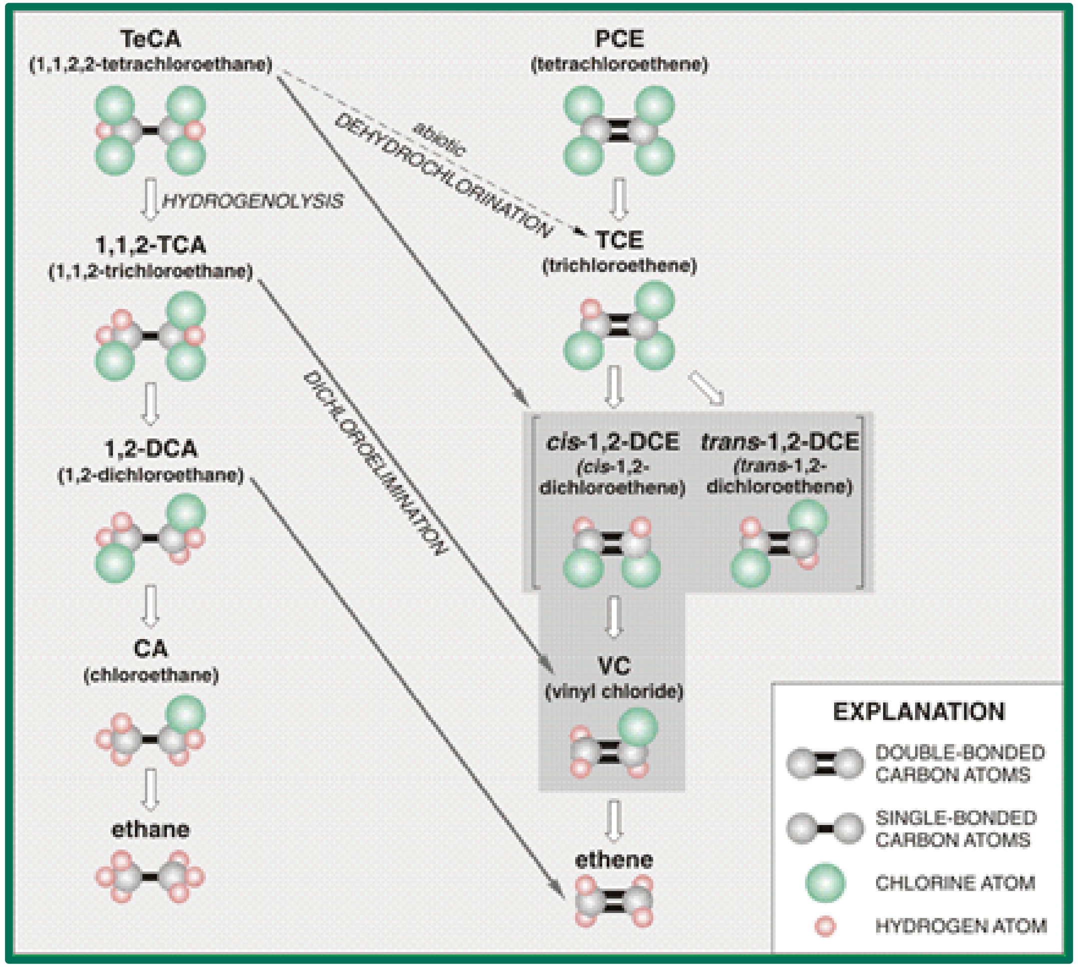
- Collected soil cores and groundwater from 3 areas of the plume (source area and downgradient) for anaerobic laboratory tests.
- Conducted tests with sand and with sand-silt-clay mix for high TCE.
- Fast-release donors: lactate, corn syrup, whey
- Slow-release donors: 3D-Microemulsion; soybean-based vegetable oil (different commercial products)
- Bioaugmentation: WBC-2 consortium
- Evaluate simultaneous and delayed addition of donor and culture.



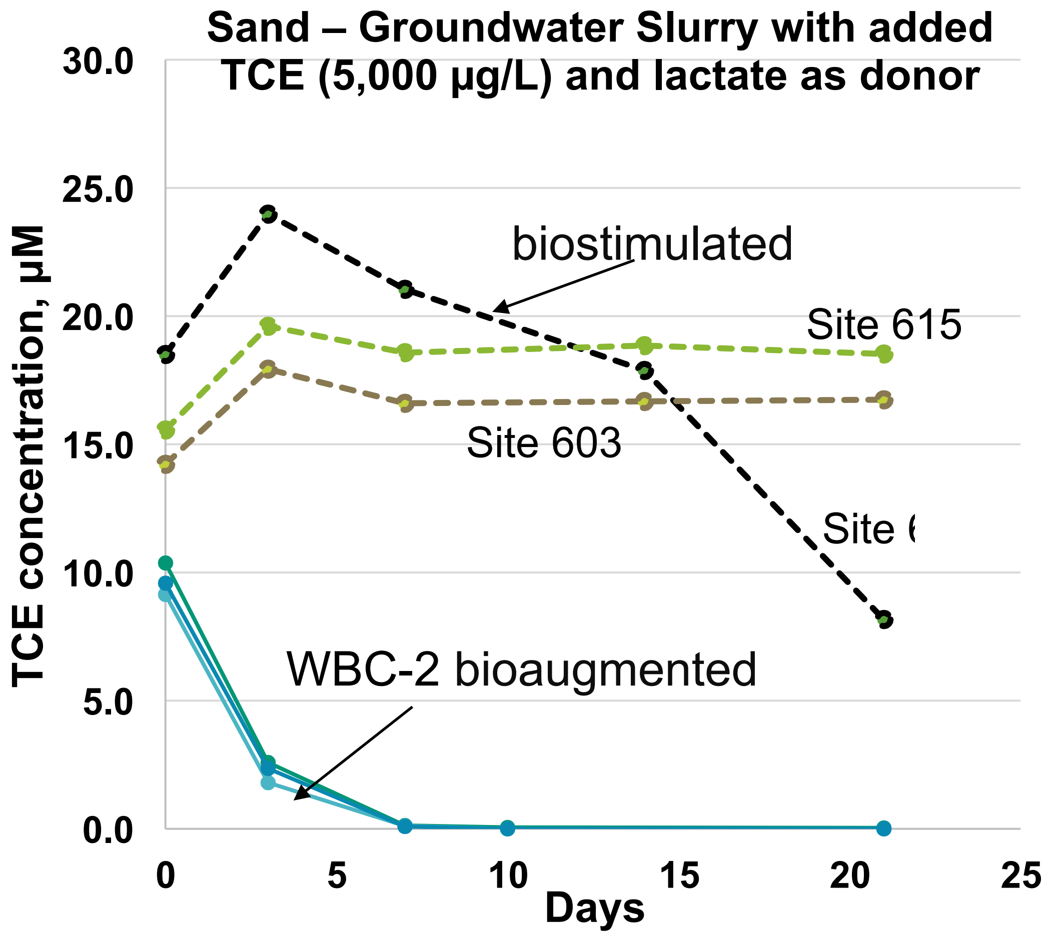
Bioaugmentation with dechlorinating consortium WBC-2

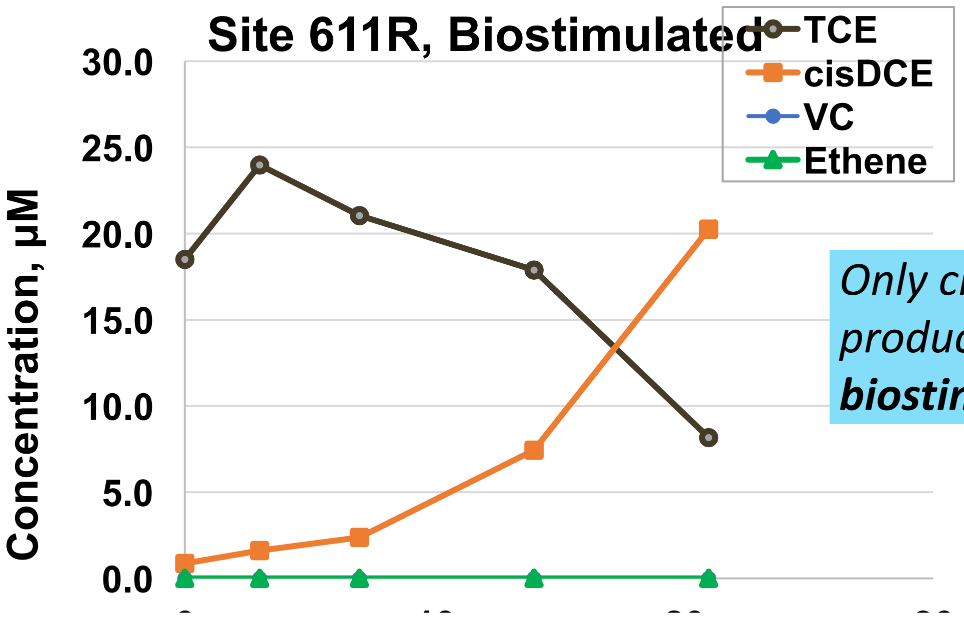
- Anaerobic microbial consortium enriched from wetland sediment at an army base in Maryland to degrade chlorinated alkanes and alkenes.
- Sediment-free, stable culture since 2003.
- Contains multiple known dehalorespirers, including *Dehalococcoides*, *Dehalobacter*, and *Dehalogenimonas*.
- Resilient to oxygen exposure.

(Jones et al., 2006; Lorah et al. 2008; Lorah, Vogler et al., 2008; Lorah et al., 2015; Majcher et al., 2009; Manchester et al., 2012, Molenda et al., 2016a,b; Chow et al. 2020; Lorah et al., 2022)

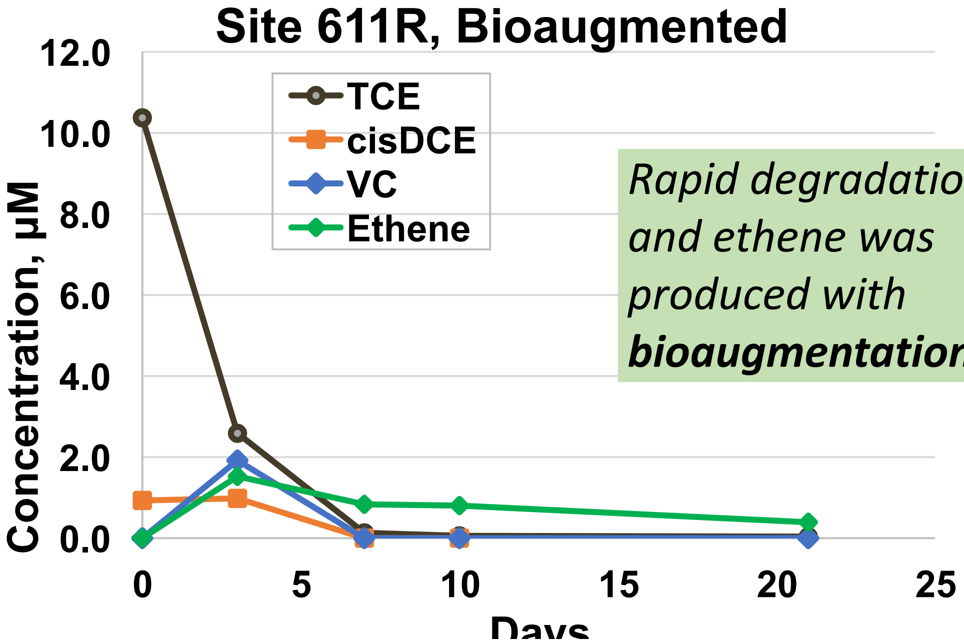


Lab Tests: Biostimulation vs. Bioaugmentation



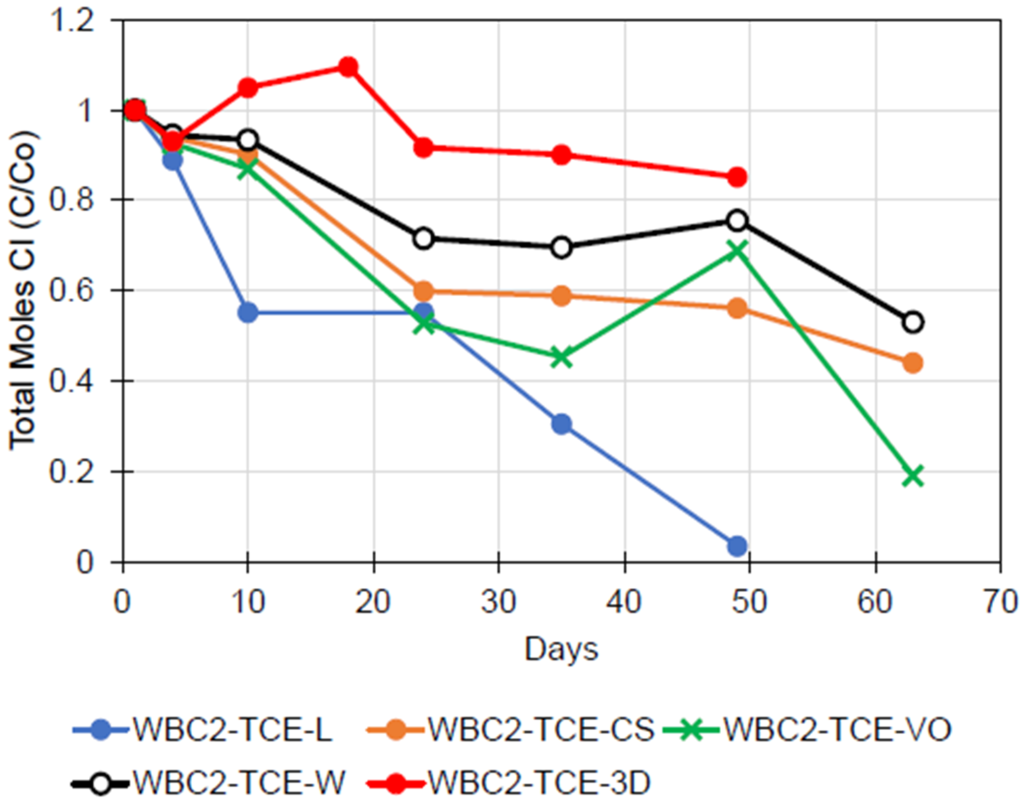


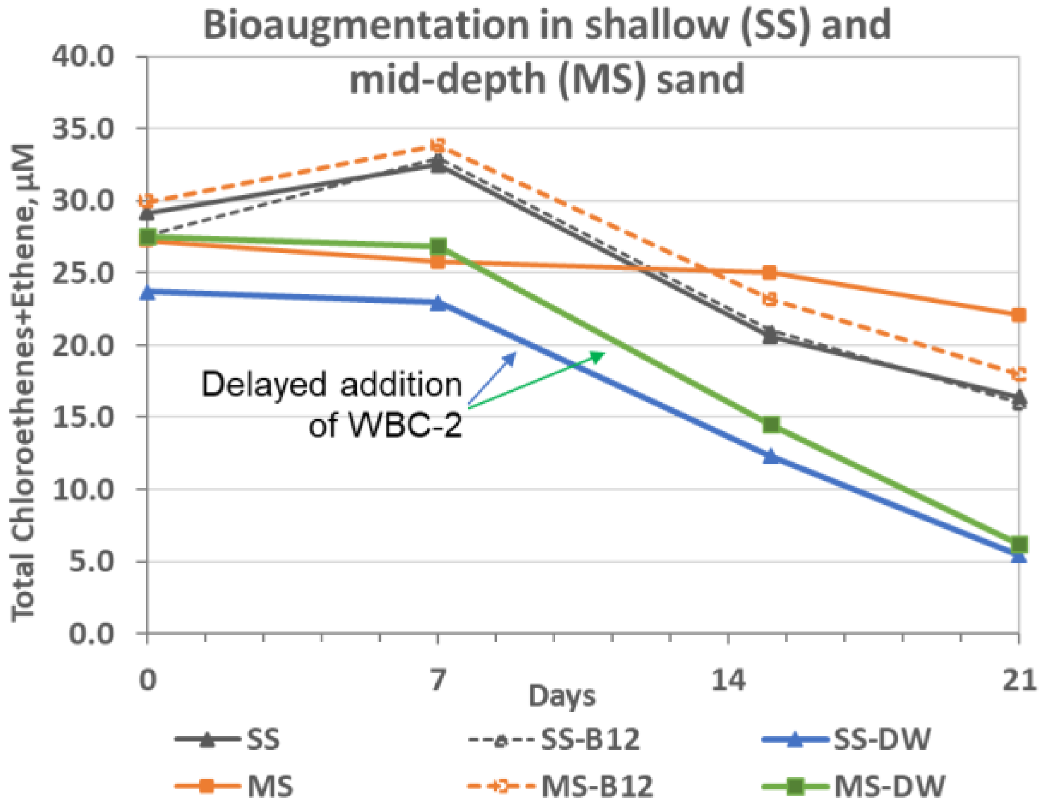
*Only cisDCE was produced with **biostimulation**.*



*Rapid degradation and ethene was produced with **bioaugmentation**.*

Lab Tests: Amendment Selection and Timing

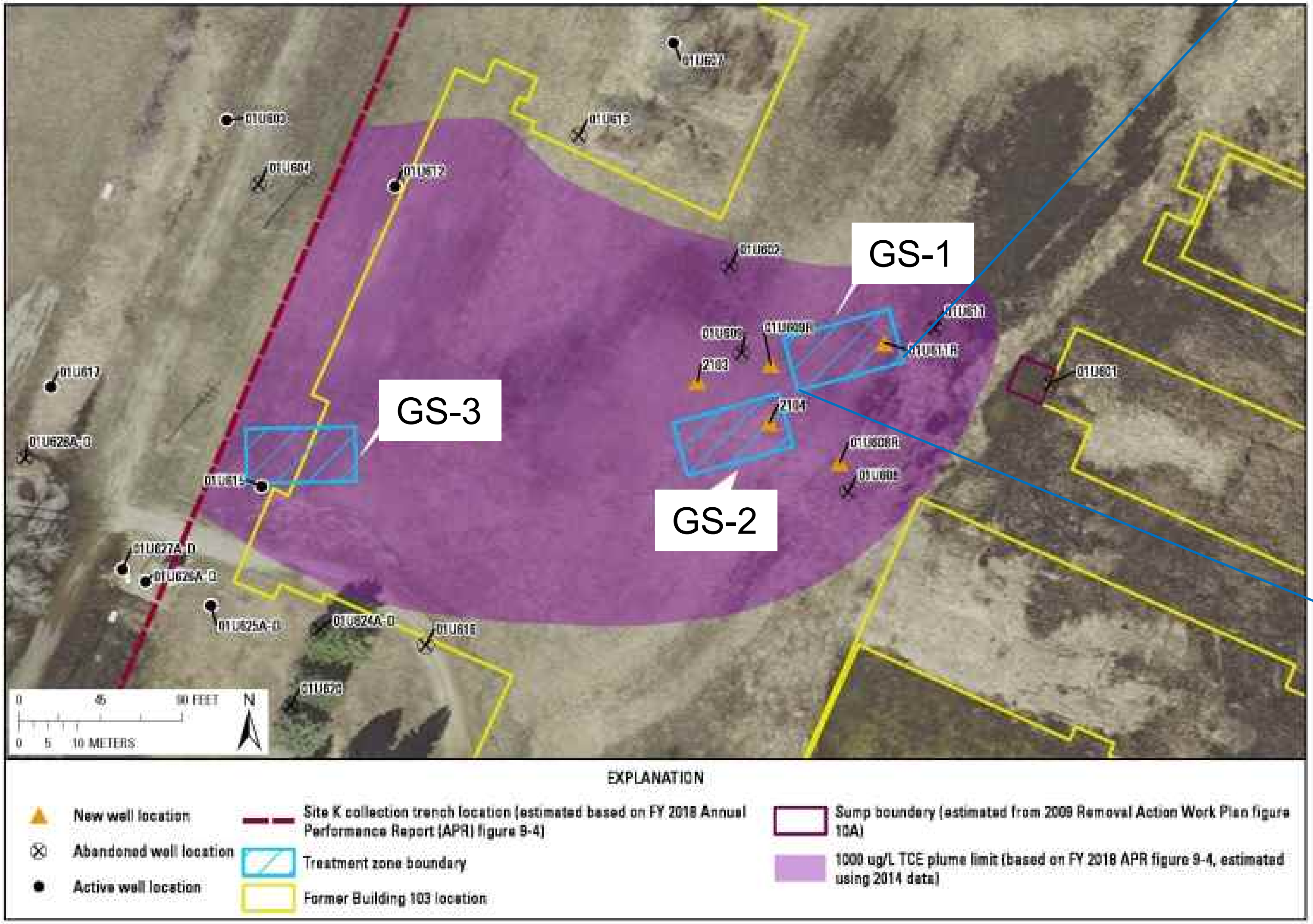


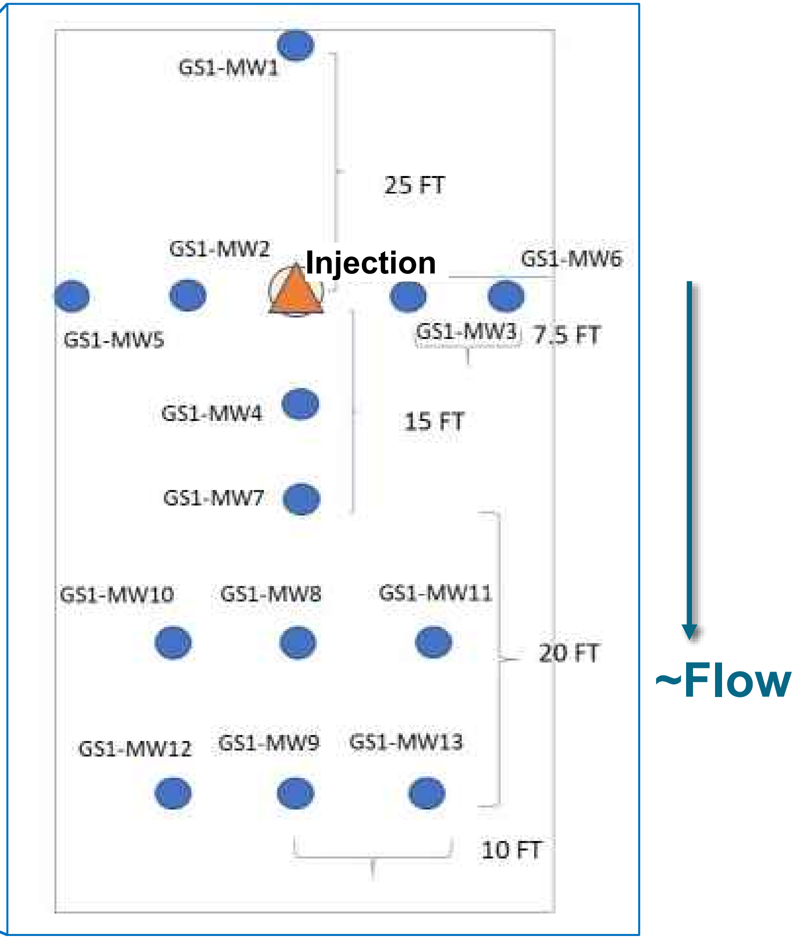


Vegetable oil (VO) worked best as slow-release donor and lactate (L) as fast release donor, in comparison to 3D-Microemulsion (3D), corn syrup (CS), or whey (W).

Delaying addition of WBC-2 (DW) worked best compared to addition at Day 0 without added vitamin B12 (SS, MS) or with added B12 (-B12) .

Site K Pilot Test Treatment Plots





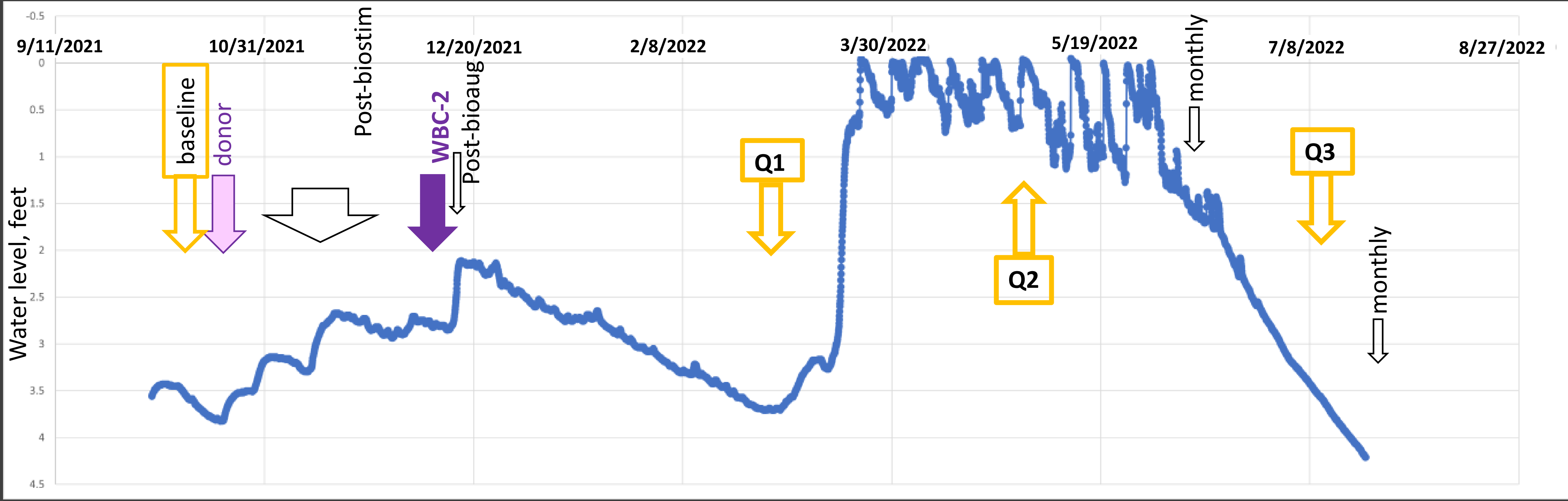
- Three treatment plots, two in source area (GS-1, GS-2) and one downgradient (GS-3).
- Each plot has an injection well and 13 monitoring points in ~ 30 x 60 ft area.

Performance Objectives

- field parameters
- redox- Mn, Fe2+/Fe3+, ammonia, nitrate, sulfide, methane
- major ions and metals
- Bromide
- Organic carbon (TOC, DOC)
- Organic acids
- Microbial community
- Stable carbon isotope ratios

1 Year Monitoring Period

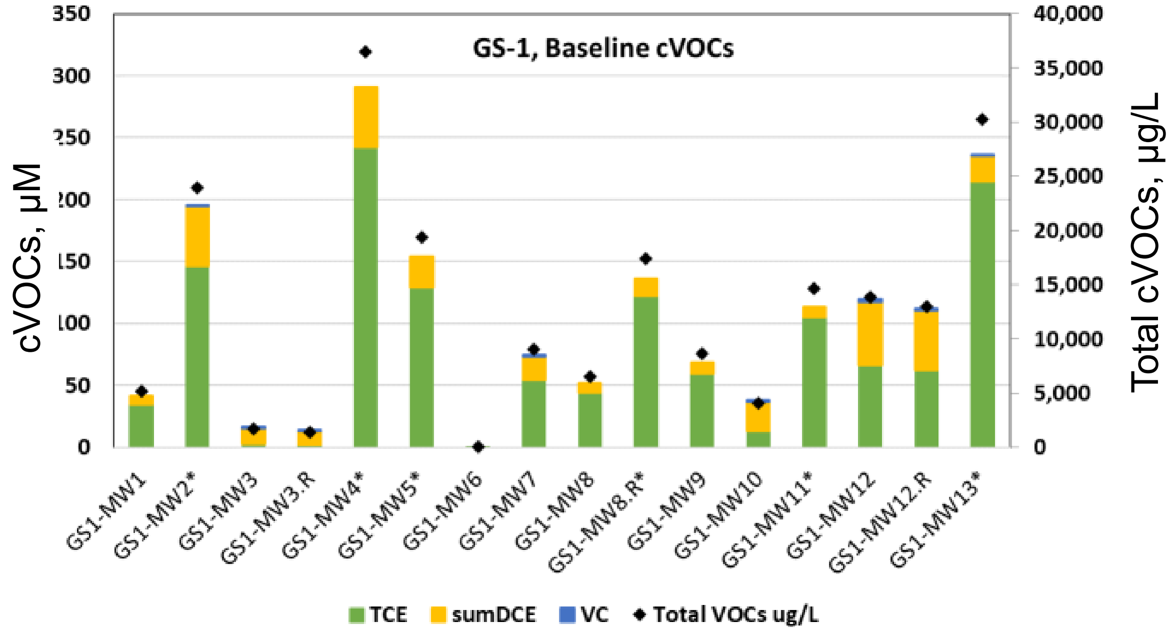
1. Induce and **maintain reducing conditions** for degradation of TCE.
2. Enhance and **maintain the degradation of TCE** following injection of microbes, without accumulation of by-products (DCE, vinyl chloride).
3. Evaluate **distribution of amendments** (carbon source and microbes) in the test area.
4. Collect data that would be needed for the **consideration of full-scale remedy**
   - radius of influence
   - optimal pumping rate for amendments
   - frequency of injections
   - hydraulic gradient
   - Potential fouling or clogging of aquifer pore space.

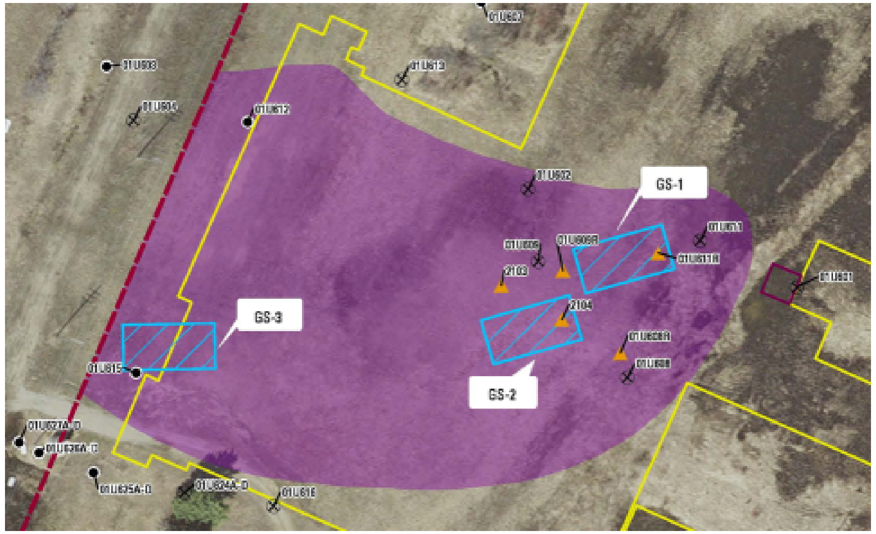


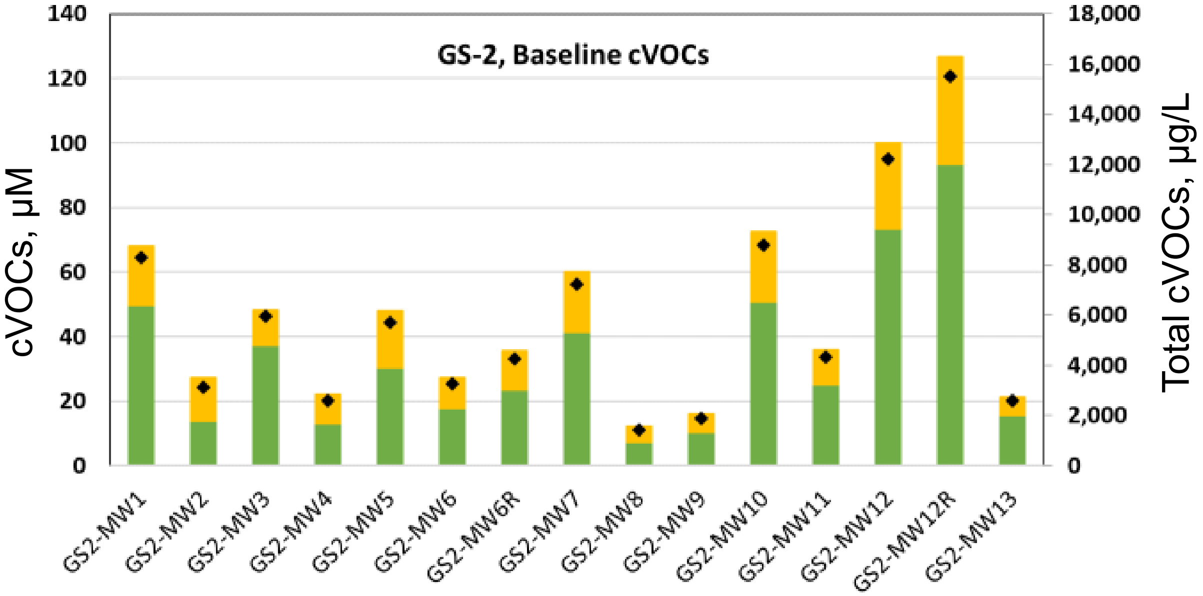
Water level depth in feet below land surface (01U609R), October 2021-August 2022, and injection and sampling events for Site K bioremediation pilot test.

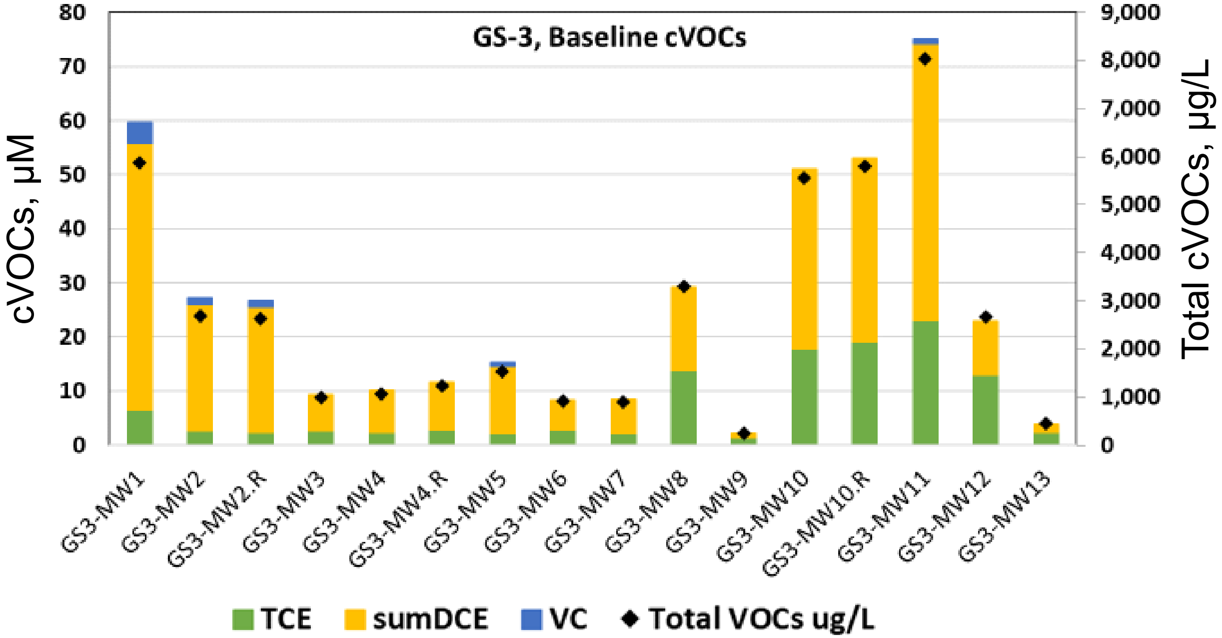
- Purple arrows: injections of donors and WBC-2
- Yellow arrows: full sampling events (baseline and Q1, Q2, Q3, quarterly events). Q4 conducted October 2022 (not shown).
- Black arrows: other sampling events in select wells and limited constituents.

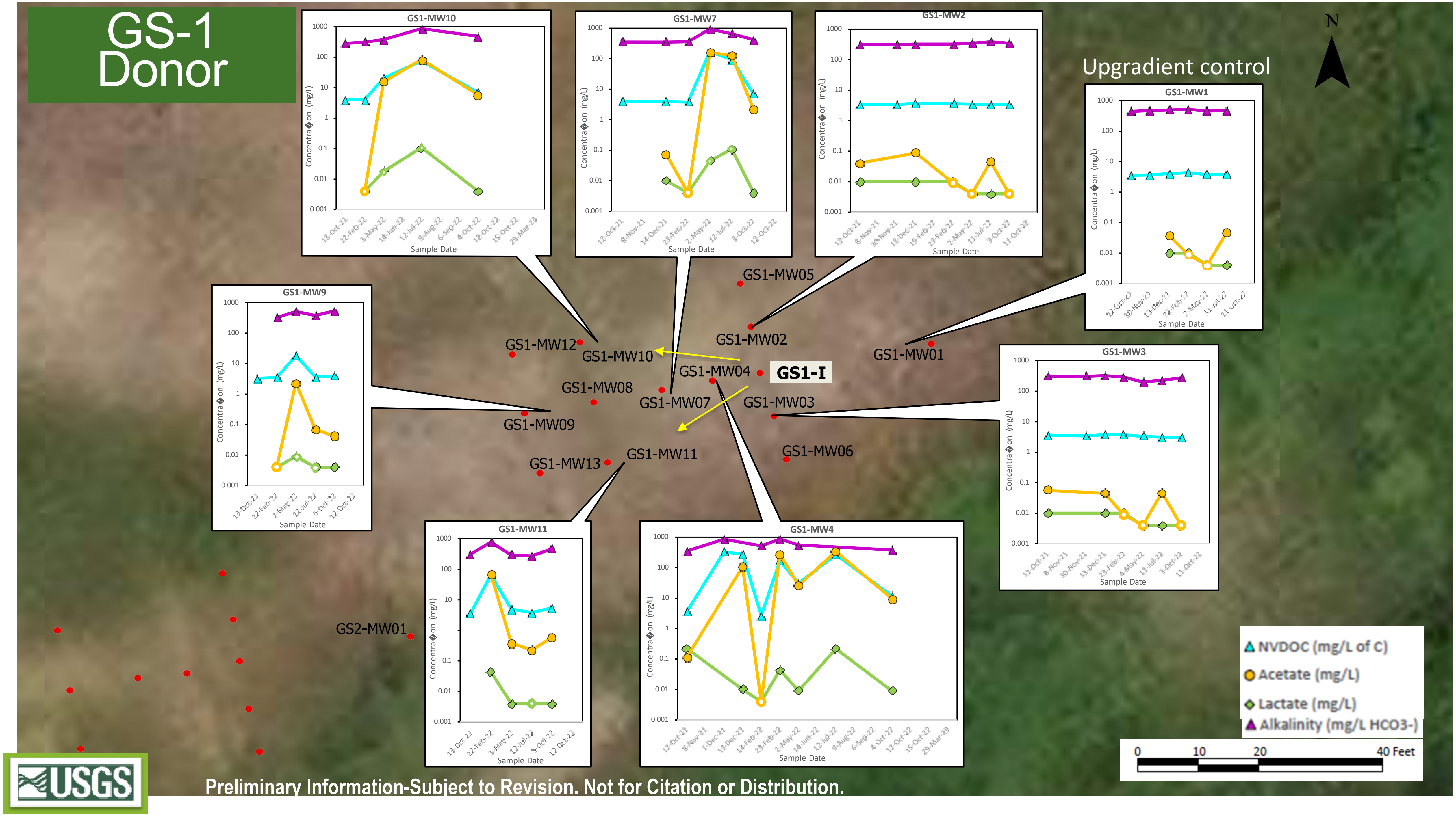
Treatment Plots Baseline VOCs

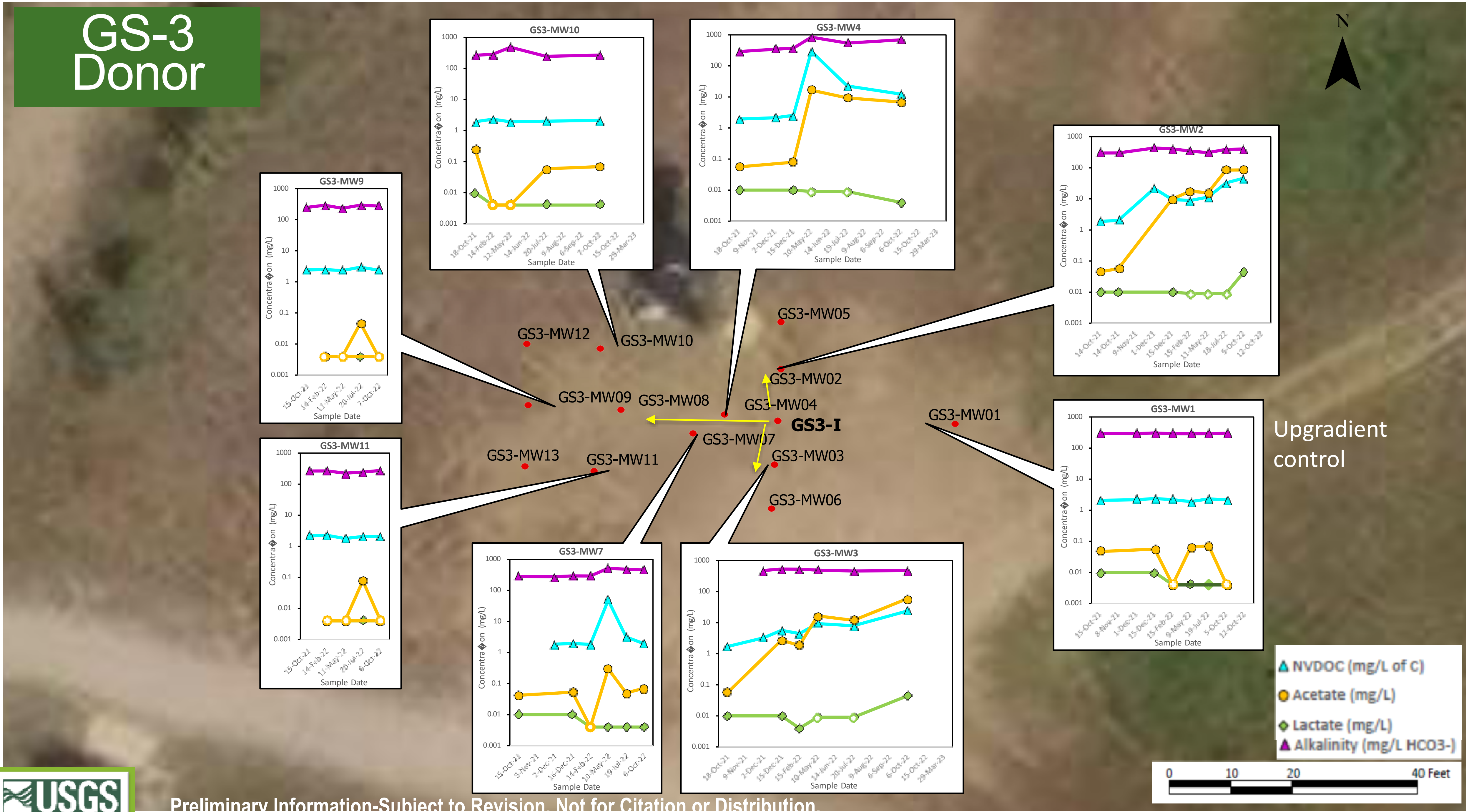




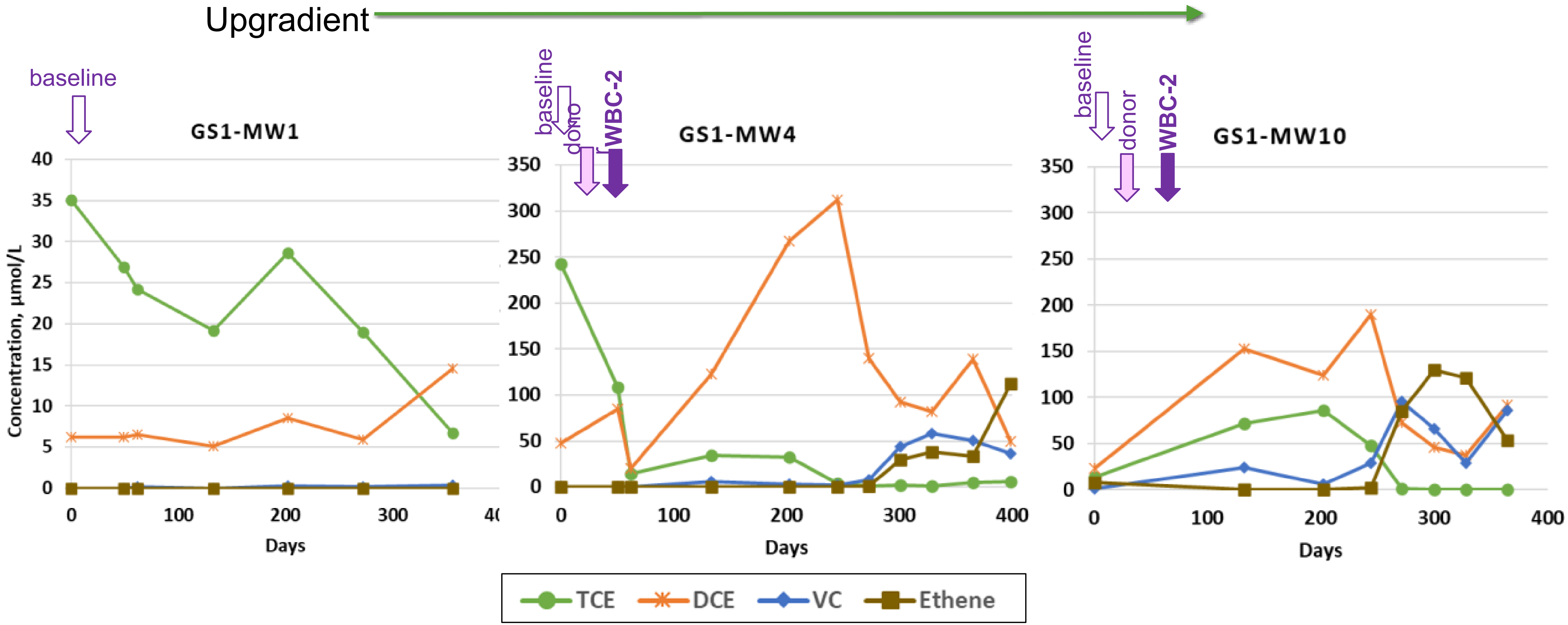





GS-1
Donor
Upgradient control
N
GS1-MW10
GS1-MW7
GS1-MW2
GS1-MW1
GS1-MW9
GS1-MW3
GS1-MW11
GS1-MW4
Concentration (mg/L)
Sample Date
GS1-MW05
GS1-MW02
GS1-MW01
GS1-MW12
GS1-MW10
GS1-MW04
GS1-I
GS1-MW08
GS1-MW07
GS1-MW03
GS1-MW09
GS1-MW06
GS1-MW13
GS1-MW11
GS2-MW01
NVDOC (mg/L of C)
Acetate (mg/L)
Lactate (mg/L)
Alkalinity (mg/L HCO3-)
0 10 20 40 Feet
USGS
Preliminary Information-Subject to Revision. Not for Citation or Distribution.

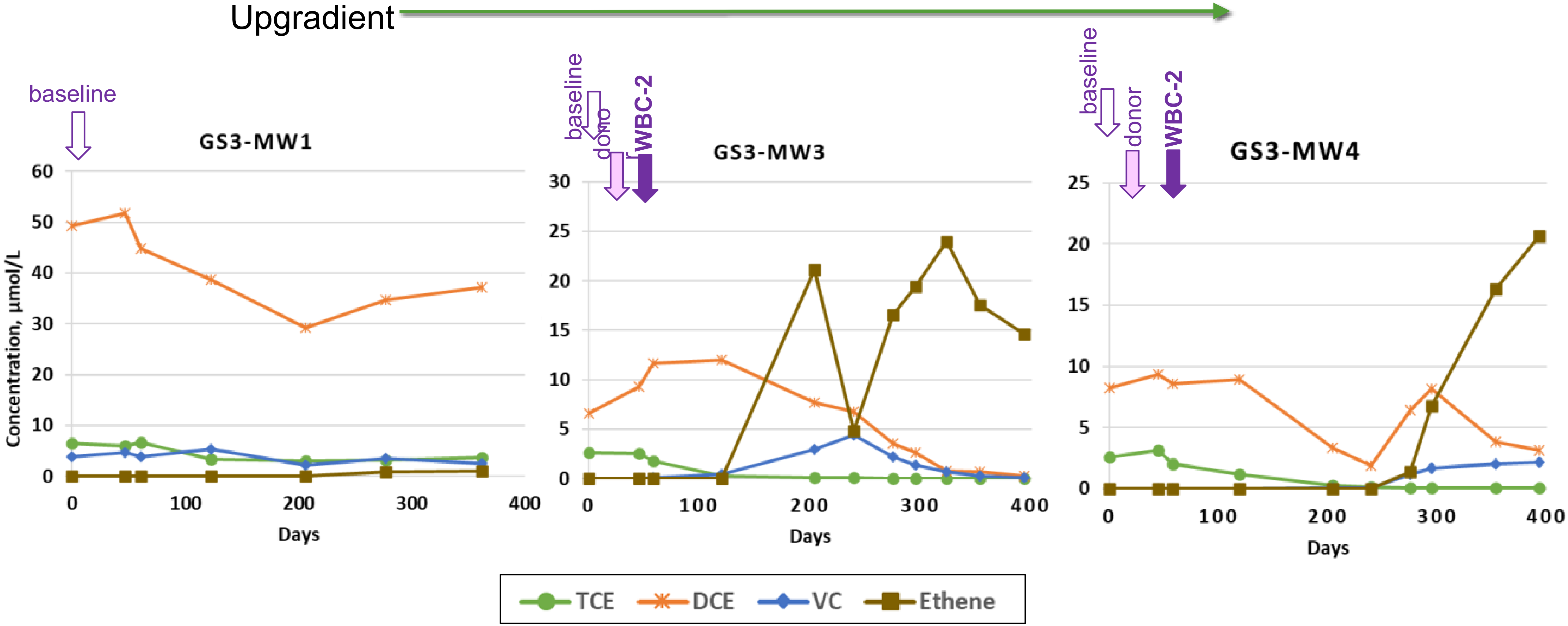

GS-3
Donor
GS3-MW10
GS3-MW4
GS3-MW9
GS3-MW2
GS3-MW11
GS3-MW1
GS3-MW7
GS3-MW3
Concentration (mg/L)
Sample Date
GS3-MW05
GS3-MW12
GS3-MW10
GS3-MW02
GS3-MW09
GS3-MW08
GS3-MW04
GS3-I
GS3-MW01
GS3-MW07
GS3-MW13
GS3-MW11
GS3-MW03
GS3-MW06
Upgradient control
N
NVDOC (mg/L of C)
Acetate (mg/L)
Lactate (mg/L)
Alkalinity (mg/L HCO3-)
0
10
20
40 Feet

GS-1, Oct. 2021—Oct. 2022

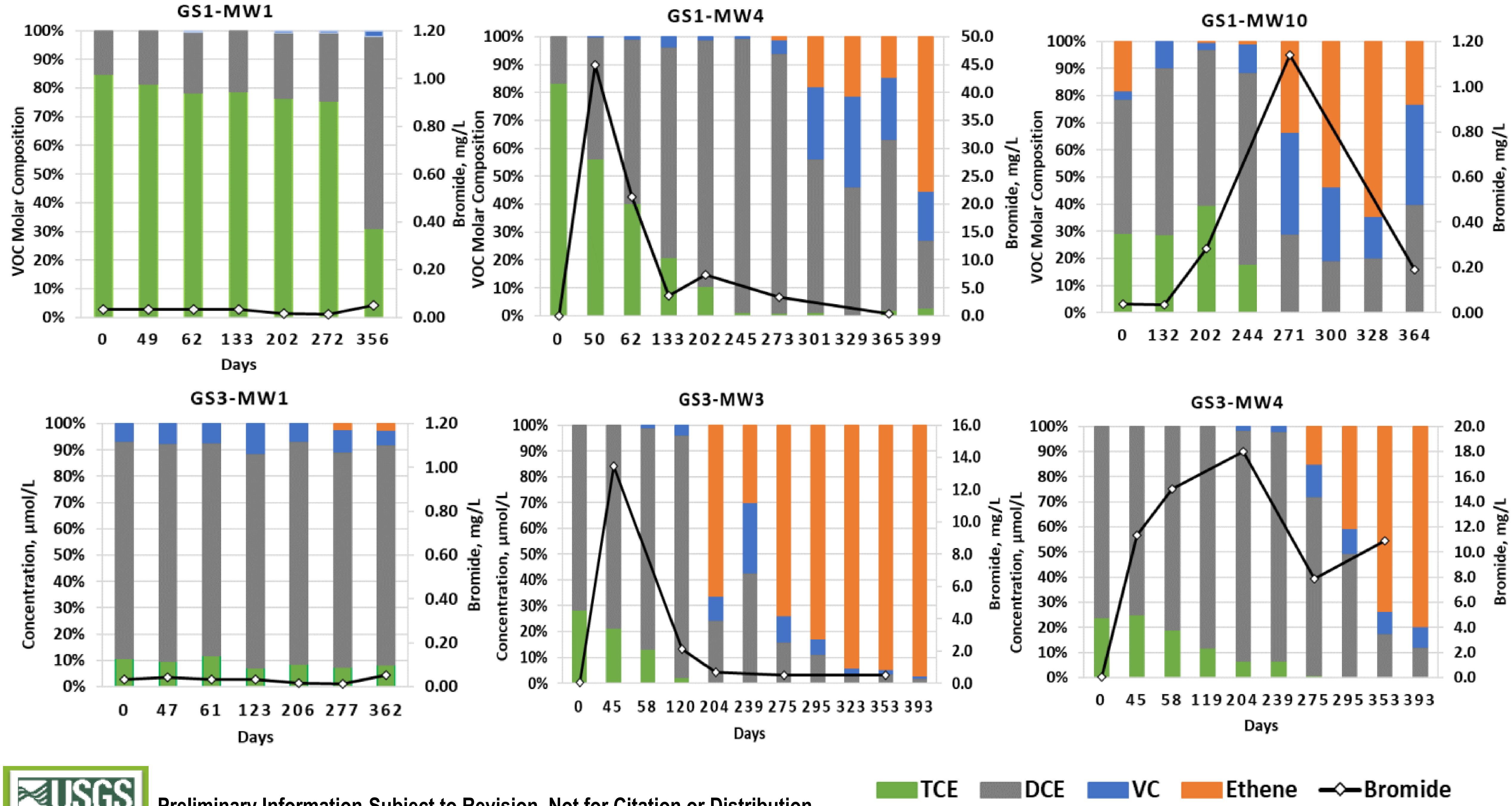


Complete reductive dechlorination is occurring at a faster rate than TCE DNAPL dissolution/desorption downgradient of injection well as evidenced by the high ethene.

GS-3, Oct. 2021—Oct. 2022

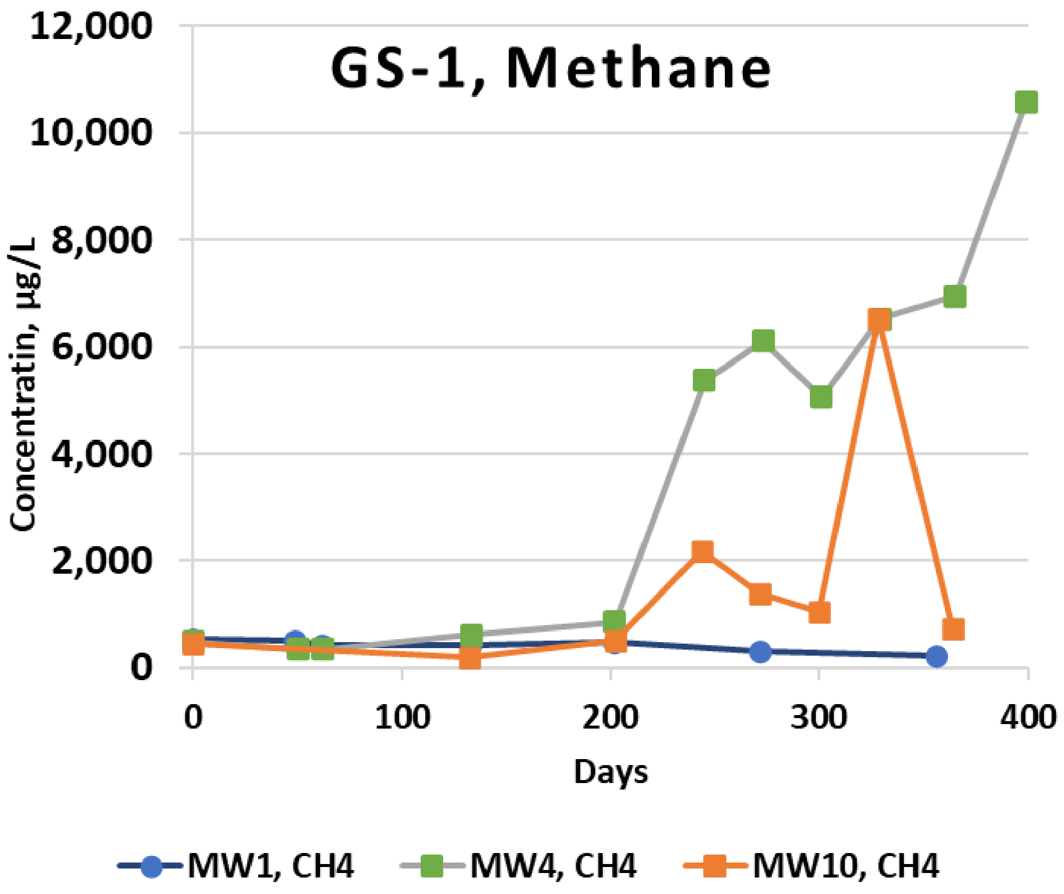


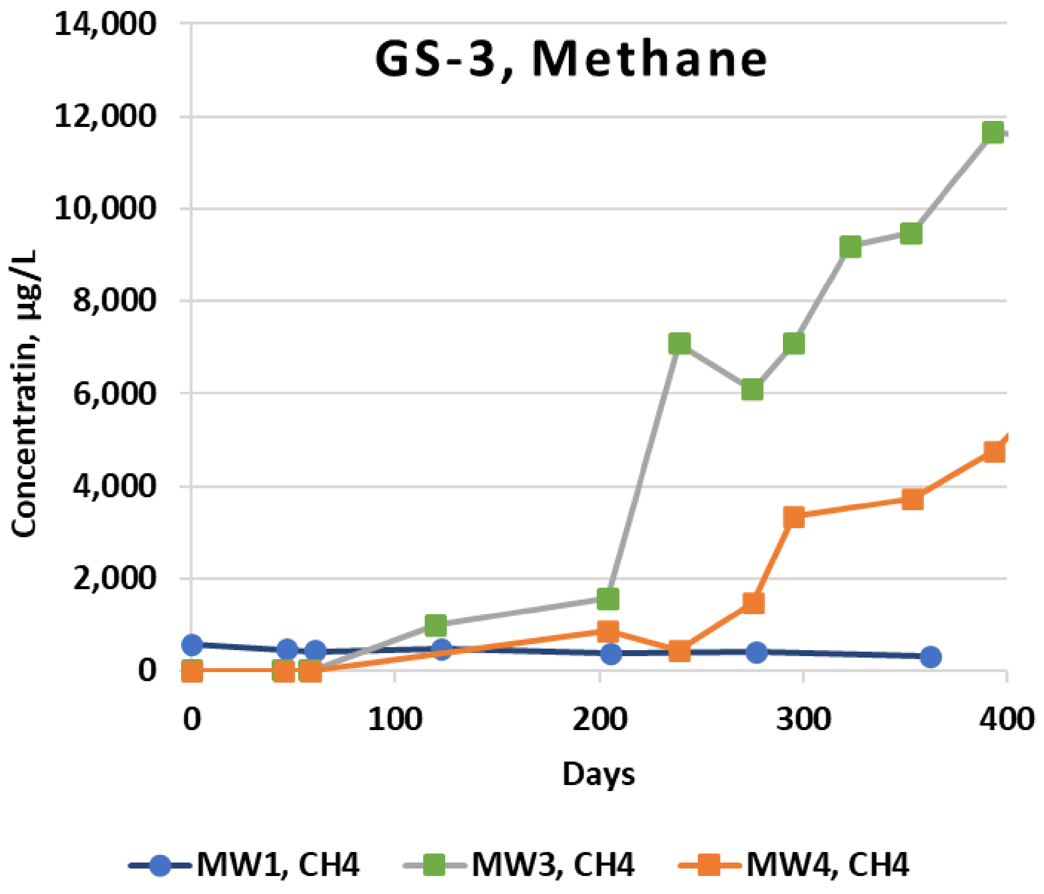
Complete reductive dechlorination is occurring without vinyl chloride accumulation. TCE decreases to below detection, and ethene has highest equimolar concentration.



Preliminary Information-Subject to Revision. Not for Citation or Distribution.

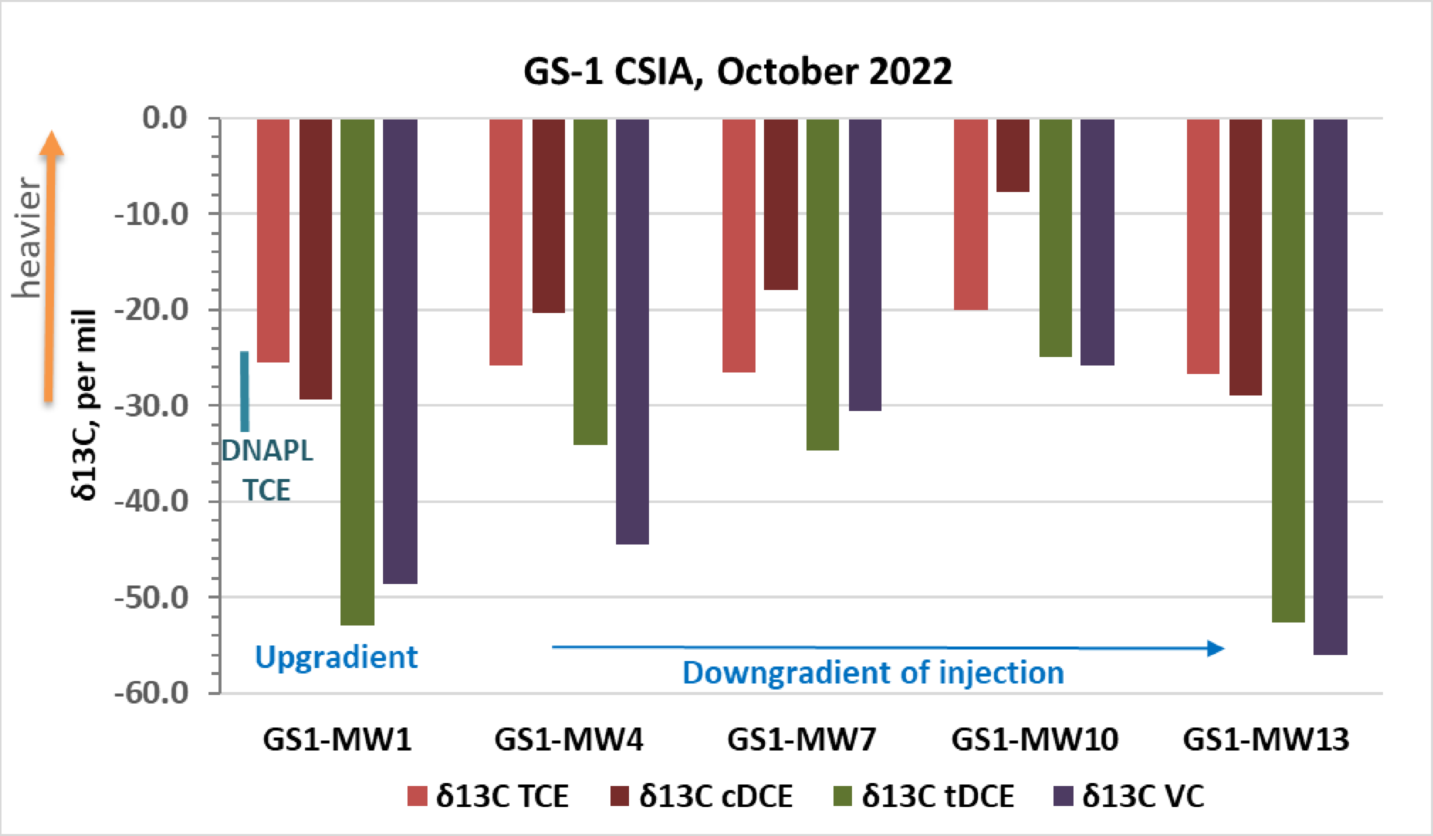
Anaerobic Conditions: Methane

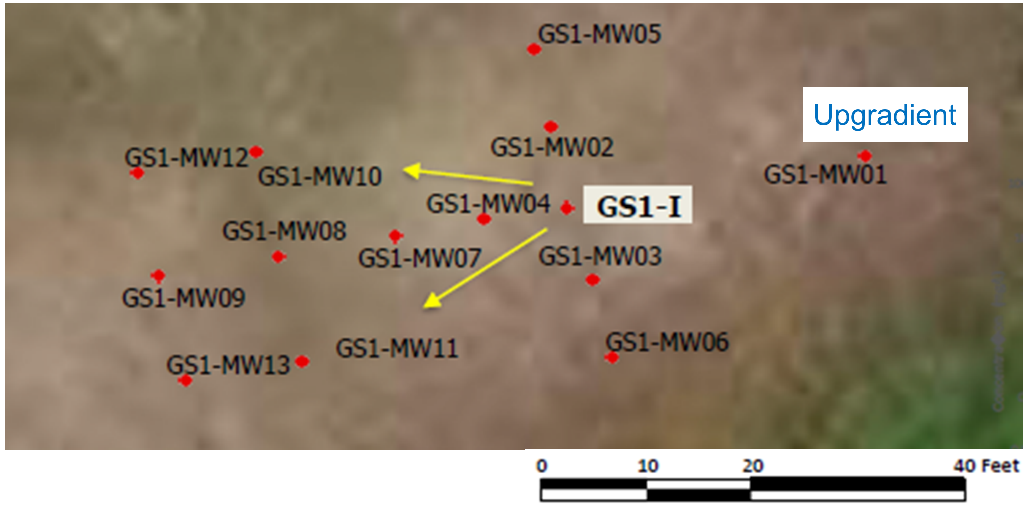




Low methane in first 200 days (until May), especially in GS-1.

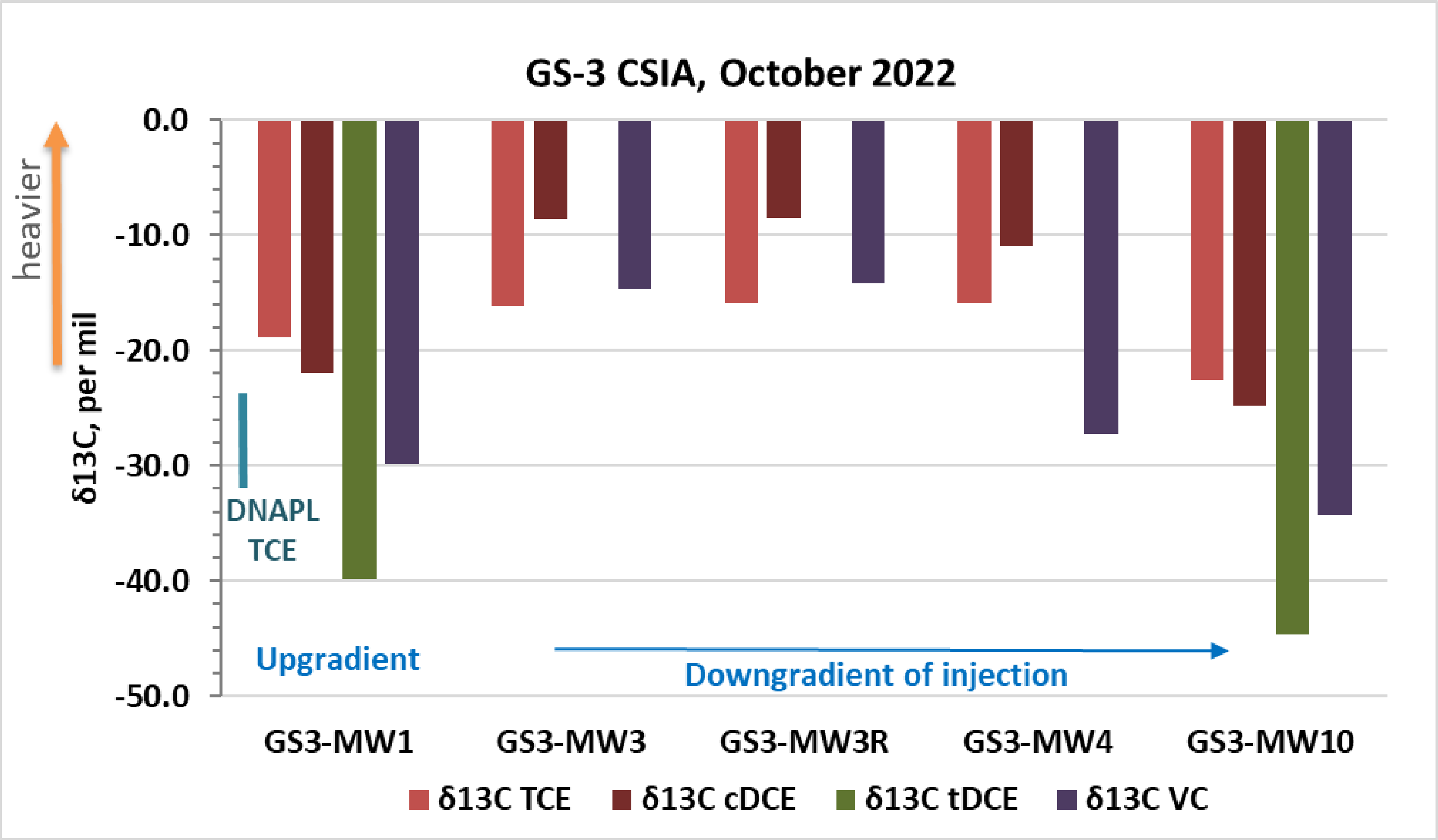
Compound Specific Isotope Analysis: GS-1

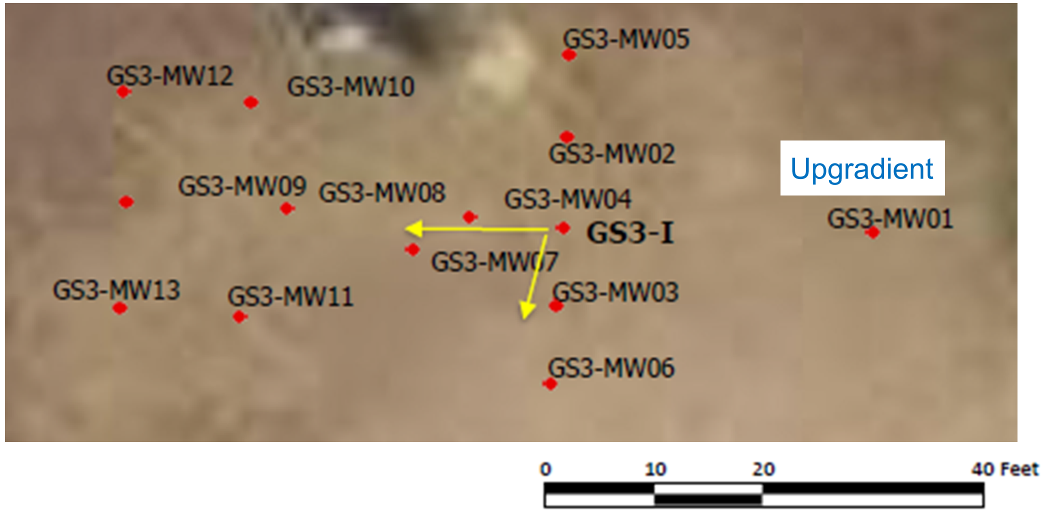




- CSIA confirmed biodegradation at 3 wells downgradient of injection well, despite ongoing DNAPL input.
- Where donor amendment had not reached (MW13), isotope signature is similar to upgradient well.

Compound Specific Isotope Analysis: GS-3





- CSIA confirmed biodegradation at 2 wells downgradient of injection well.
- Replicate analyses agree.

Conclusions

- Perched aquifer had highly variable water table and flow conditions that affected amendment distribution, but anaerobic conditions were maintained.
- Donor movement coincided with decreasing chlorinated VOC concentrations and with ethene production after short delay.
- Increase in DCE concentrations above initial TCE indicated dissolution and degradation of DNAPL in some locations.
- Complete biodegradation occurred at a faster rate than the enhanced DNAPL dissolution/desorption as evidenced by the decrease in total chlorinated VOCs and dominance of ethene in molar composition of VOCs.

More to come…Complete microbial community and hydrologic assessment of 1-year pilot test, and conduct expanded pilot test with a second donor injection and additional 1 year of monitoring.

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Pilot Test: Injections

- Adding carbon source and then microbes after a delay was best strategy to **achieve the most rapid and complete degradation** of TCE based on lab tests.
- Two separate injections for field test.
  - Carbon donor mixed with site water (1:5) collected from Site K treatment effluent: slow-release emulsified vegetable oil and fast-release lactate (SRS®-SD EVO, Terra Systems); 250 mg/L NaBr added as a tracer to donor injections
  - Microbes: 10% by volume of WBC-2 consortium (SiREM).
- Water levels and specific conductance were monitored during injection.

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