

Large-scale in situ biotic and abiotic dechlorination of groundwater impacted with commingled chlorinated ethenes and chlorinated methanes

2023 Battelle Bioremediation Symposium

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RAMBOLL

Bright ideas.
Sustainable change.



Presentation outline

1. Key site features
2. Remedial approaches
3. Remedial design and implementation
 - Modifications of remedial design based on pilot test findings
 - Post-treatment results
4. Takeaways and conclusions

Background site information

Site covers 13 acres and was used for industrial purposes from the 1940s until 2018.

Site impacts

- Investigation activities have defined the extent of CVOC impacted groundwater from historical releases of chlorinated solvents from former UST tank farm in the southwestern portion of the site.
- Two-acre area of groundwater impacted with co-mingled chlorinated ethenes and chlorinated methanes.
- Trichloroethene (3,400 µg/L), carbon tetrachloride (2,400 µg/L), and chloroform (1,100 µg/L).

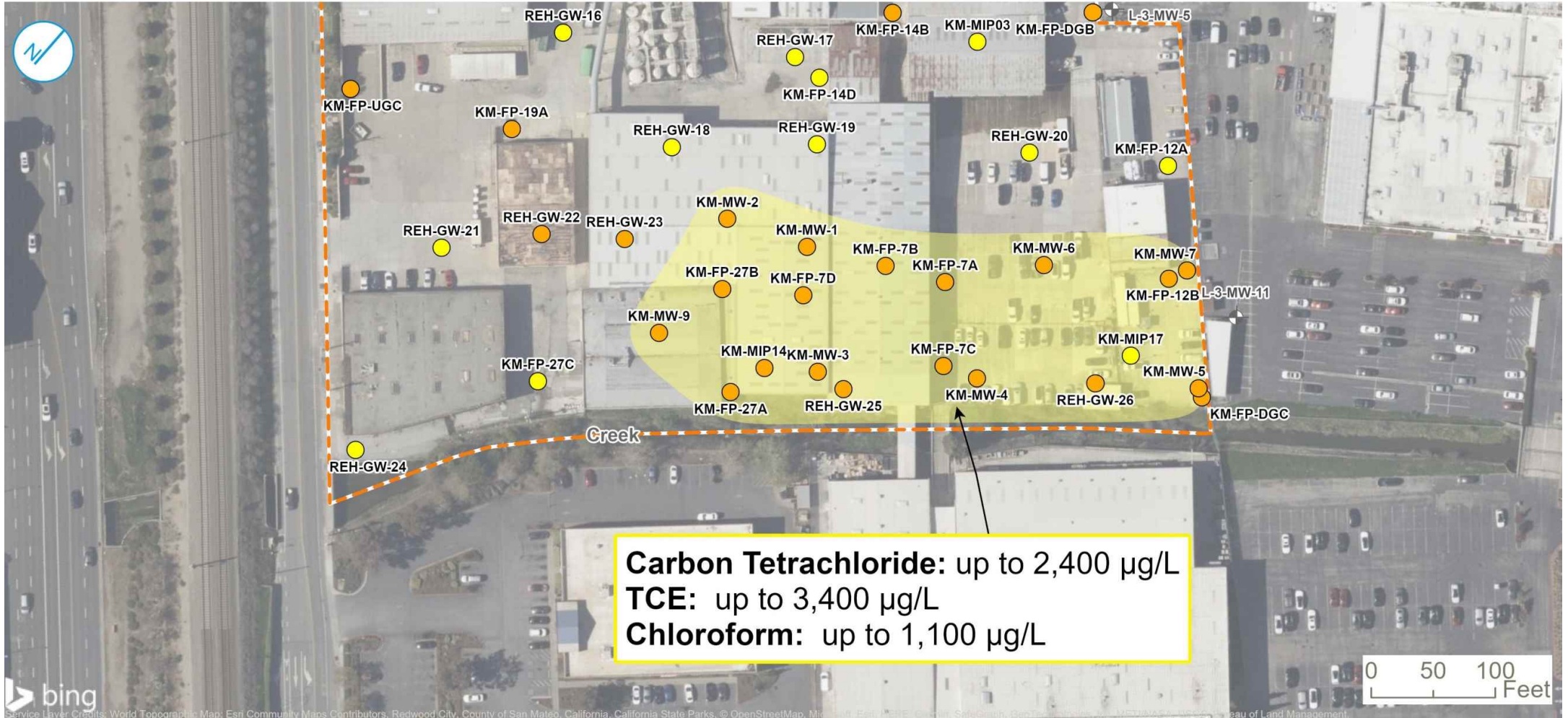
Hydrogeologic conditions

- Interbedded silty-sand and silty-clay soils, shallow water table, groundwater flow to the east.

Remedial objectives

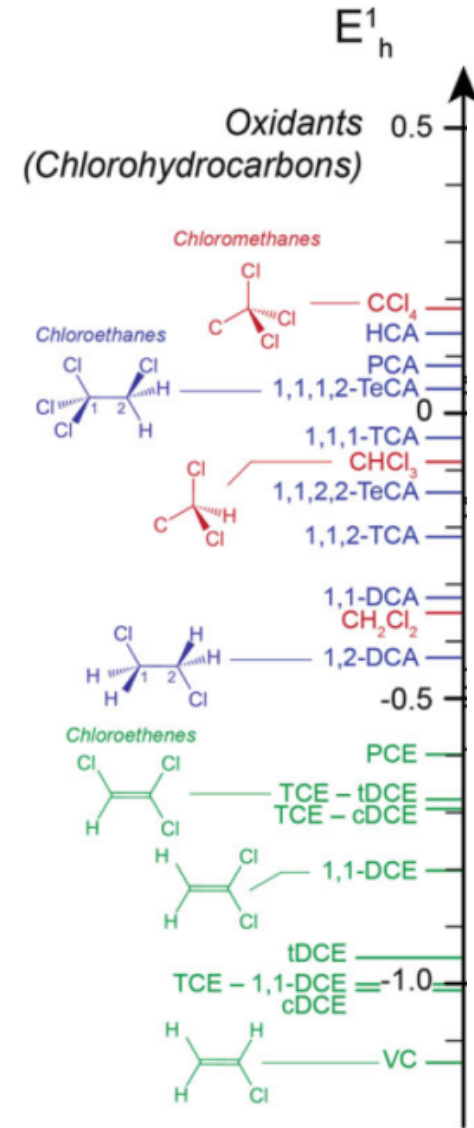
- Protect receptors from ingestion and direct contact with groundwater, and also inhalation of vapor.

Area of chlorinated-VOC-impacted groundwater



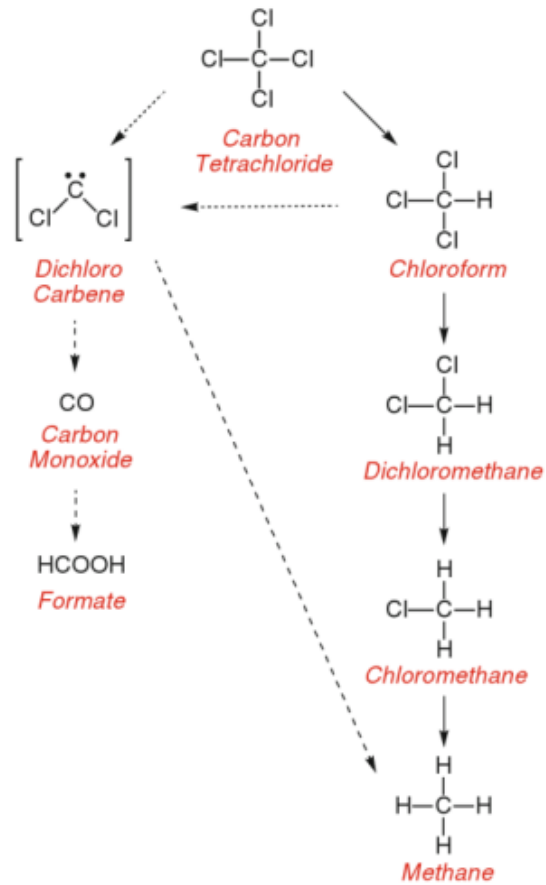
Redox ladder of reduction potentials

(Elsner and Hofstetter, 2011)

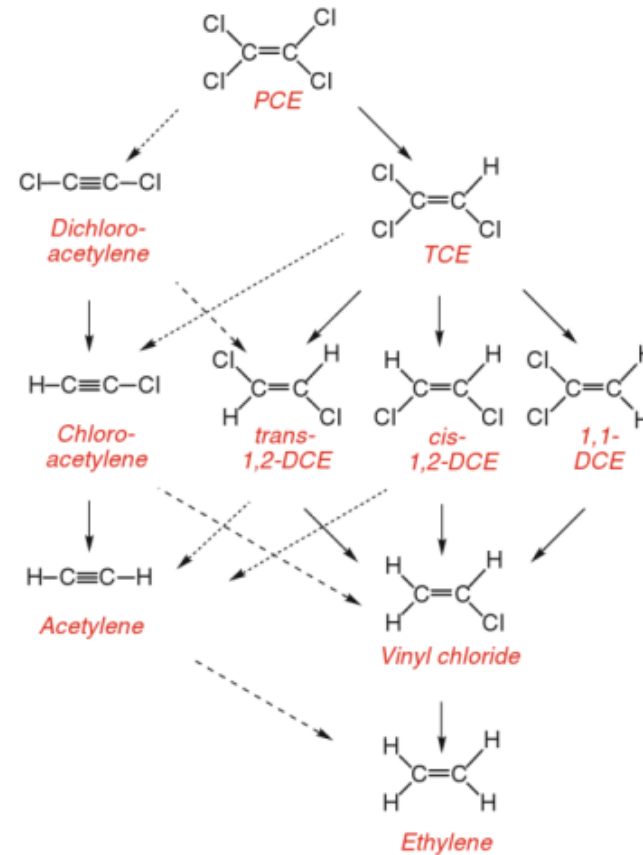


Abiotic and biotic transformation pathways

Carbon tetrachloride

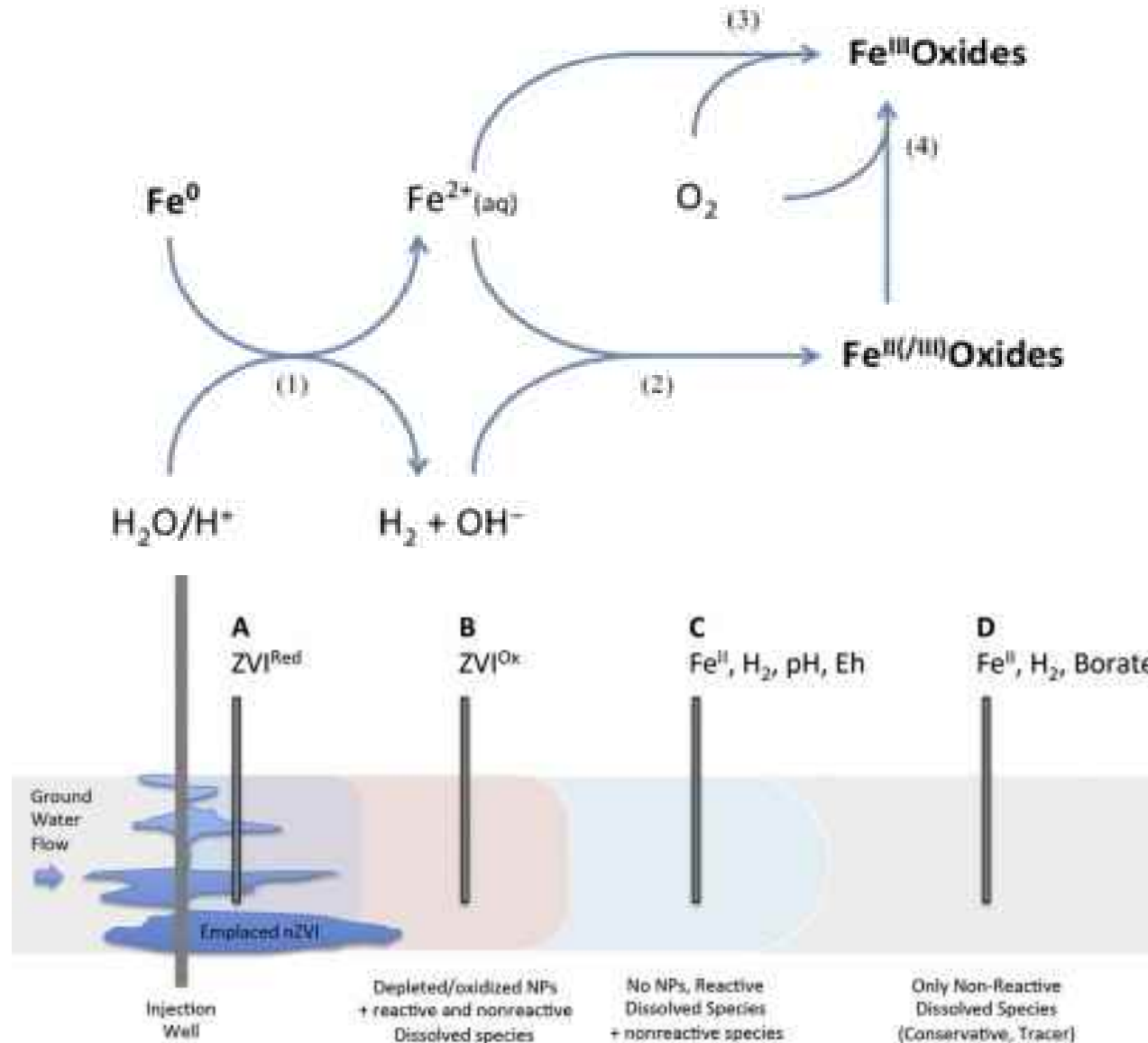


Perchloroethene

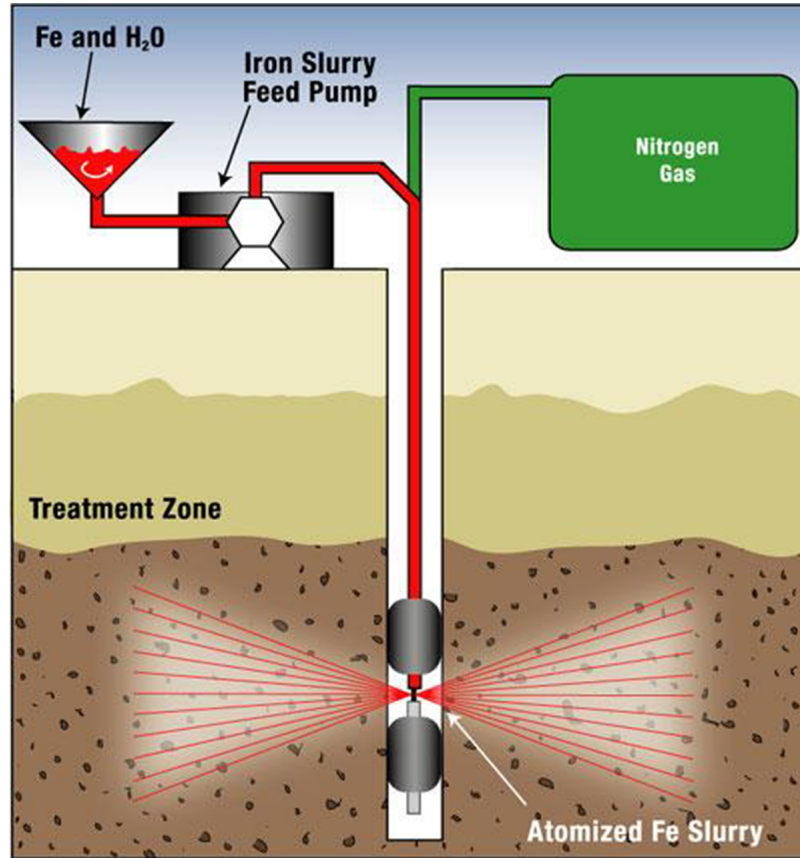


Abiotic chemical reduction

(Shi, Fan et al. 2015)



Pre-design testing: two injection approaches evaluated



Pneumatic permeability
enhancement



Pressure activated
injection probe

July 2021 pre-design study of ISCR paired with ISB

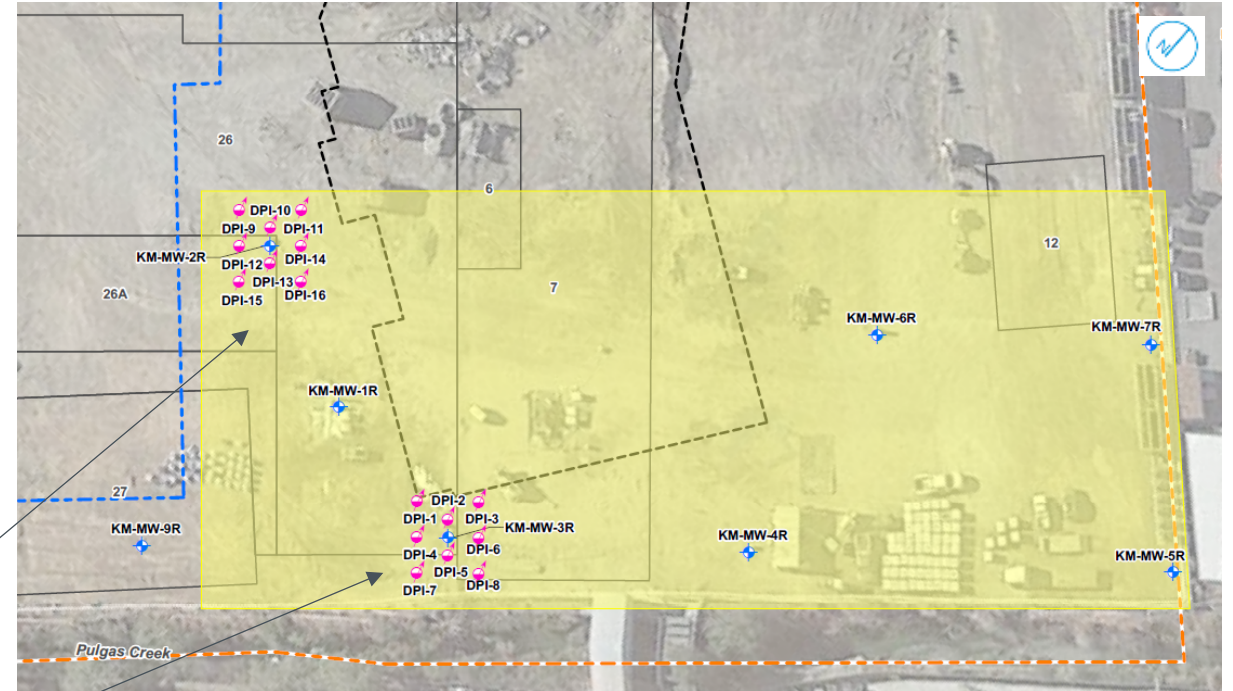
Two injection approaches evaluated

- Direct push injection (DPI)
- Pneumatic permeability enhancement (PPE) – discarded due to daylighting

Amendments injected

- Included injection of **zero-valent iron (ZVI), slow-release carbon substrate, and dechlorinating culture** to promote abiotic and biotic reduction of CVOCs in the vicinity of two monitoring wells:

- MW-2R
- MW-3R

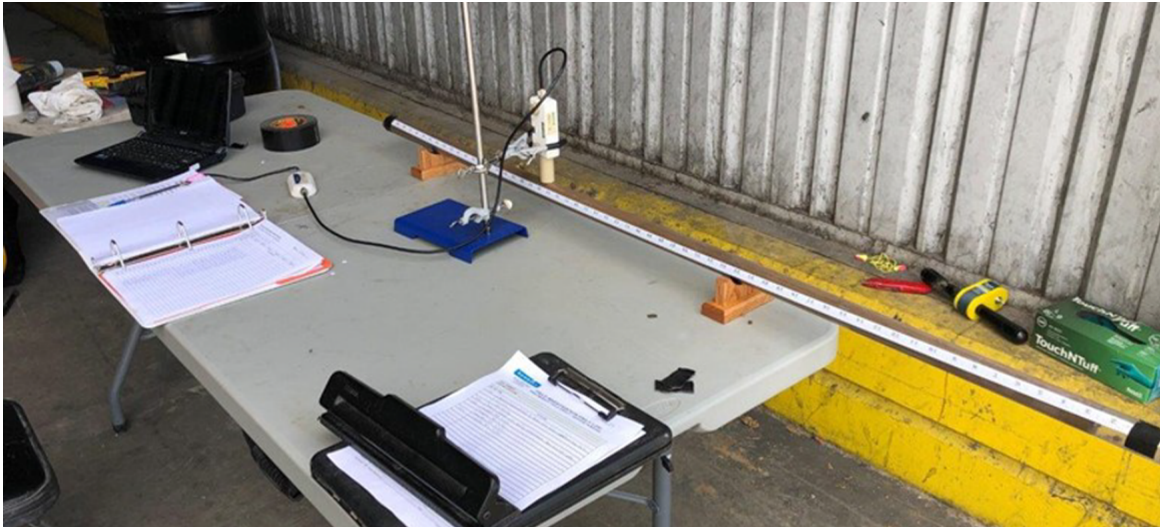


Pre-design testing – total injection quantities

ZVI (lbs)	Carbon (lbs)	Dhc culture (L)
9,000	21,000	13

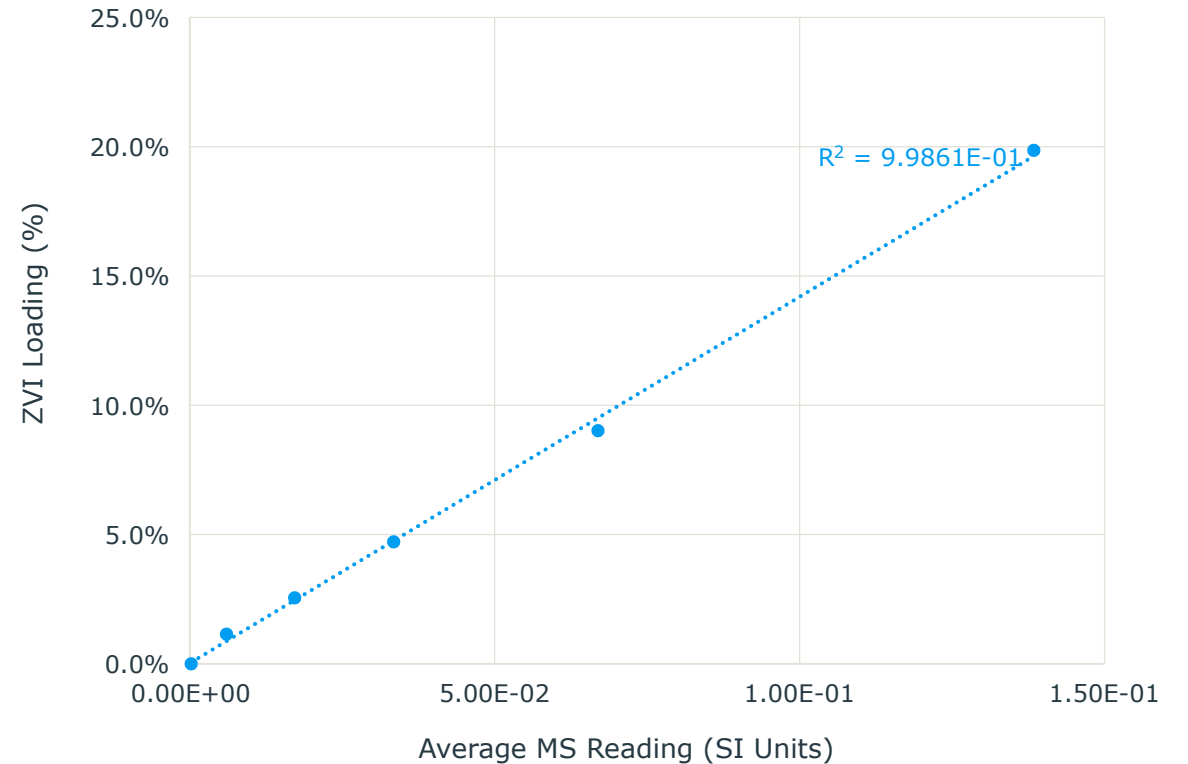
July 2021 pre-design study of ISCR paired with ISB

Magnetic susceptibility measurement set-up



- Magnetic susceptibility (MS) measurements indicated that ZVI migrated up 10 feet from DPI points
- Injection influence on monitoring wells 13 feet distant from nearest DPI locations was detected based on ORP and DO readings and visual observation of carbon substrate

Field standard MS readings



Full-scale ISB/ISCR injection layout



Groundwater remediation: full-scale injection parameters

September/October 2021 injection event

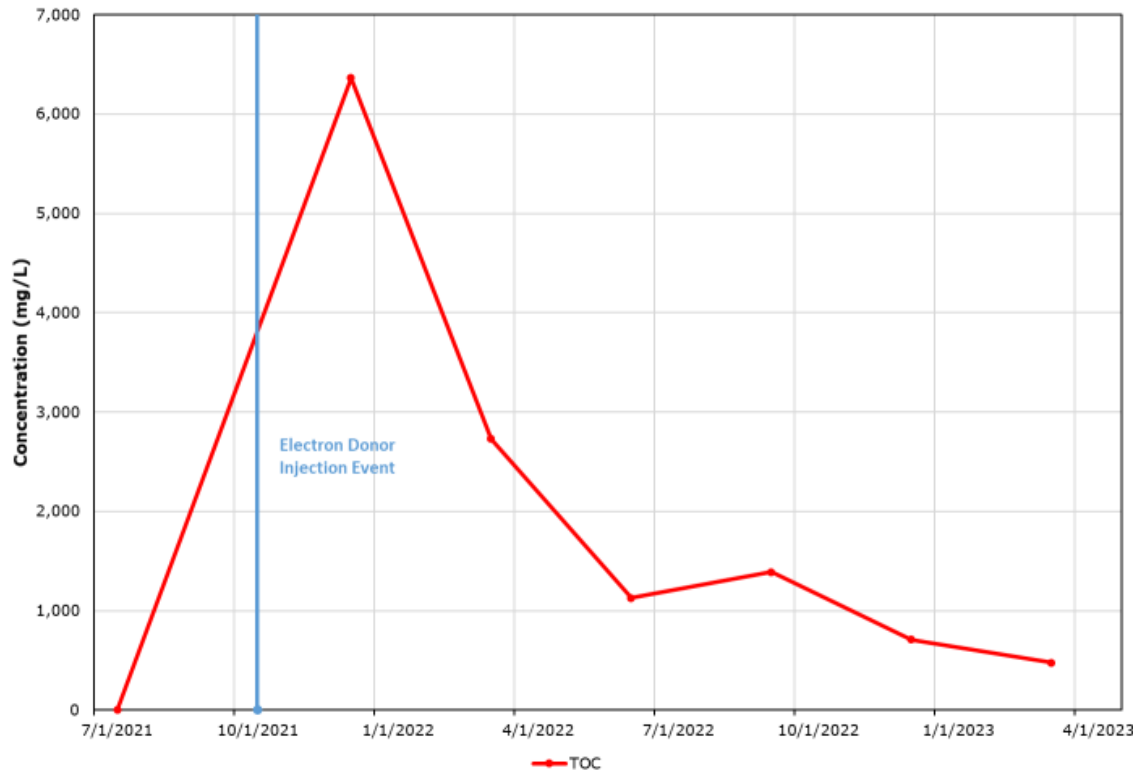
- EVO and ZVI product mass: 461,000 lbs
(0.5 lb per cubic foot of aquifer,
30% by weight ZVI)
- EVO and ZVI product slurry: 67,000 gallons
(8% of available pore volume)
- ZVI particle size: <math><125\ \mu\text{m}</math>
- Dhc and Dhb dechlorinating culture: 208 liters
(0.75 liter per injection point)
- Magnesium oxide pH buffer: 400 kg
(1.5 kg per injection point)
- Injection Pressures: 20 to 80 psi



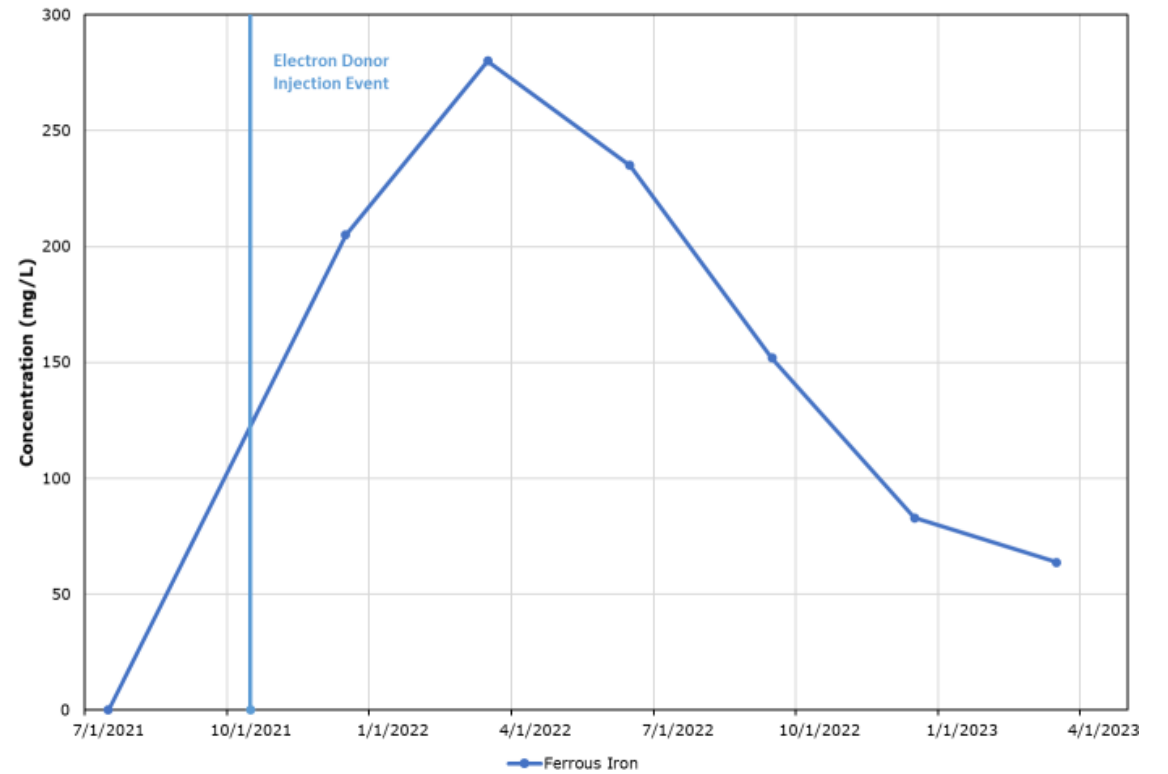
Amendment mixing operations

Groundwater remediation: geochemical data

Average total organic carbon concentrations

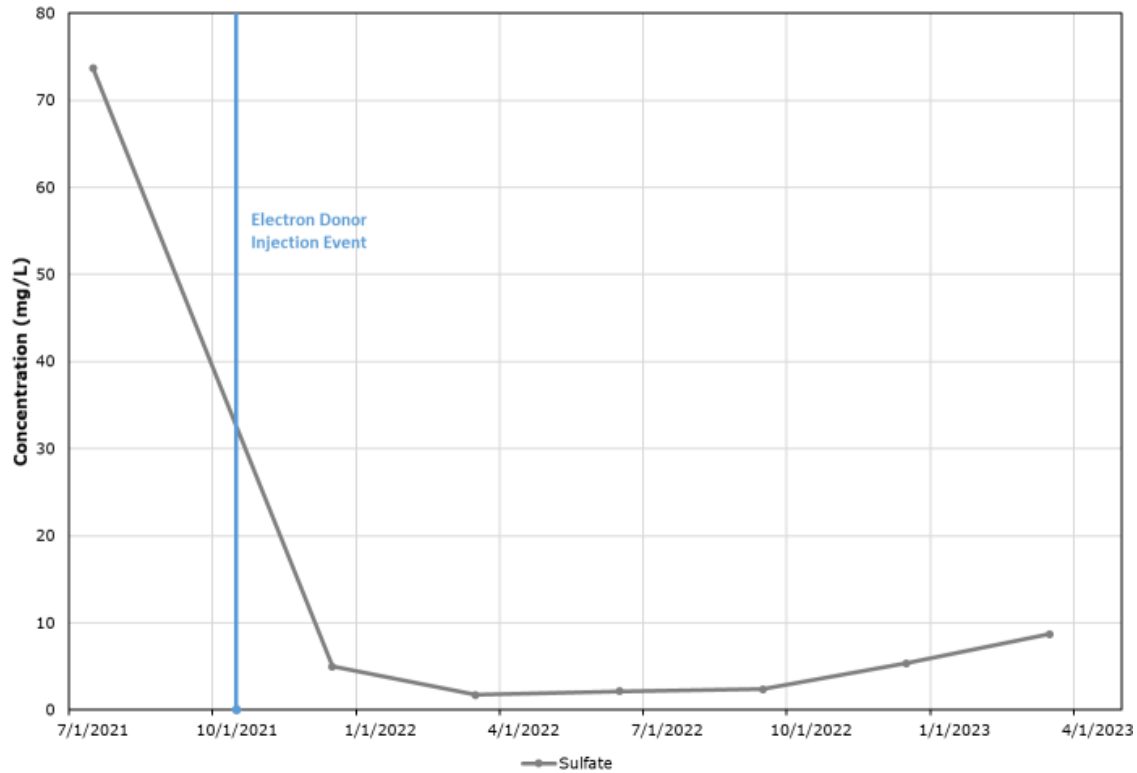


Average ferrous iron concentrations

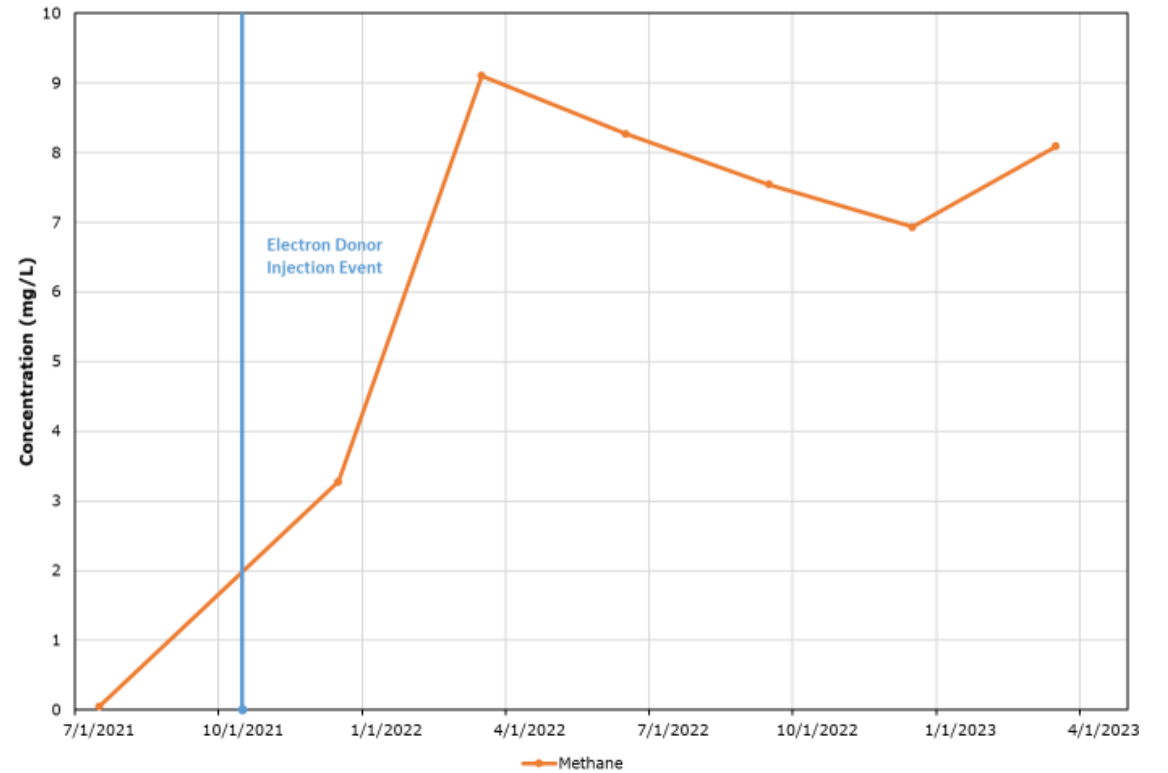


Groundwater remediation: geochemical data

Average sulfate concentrations

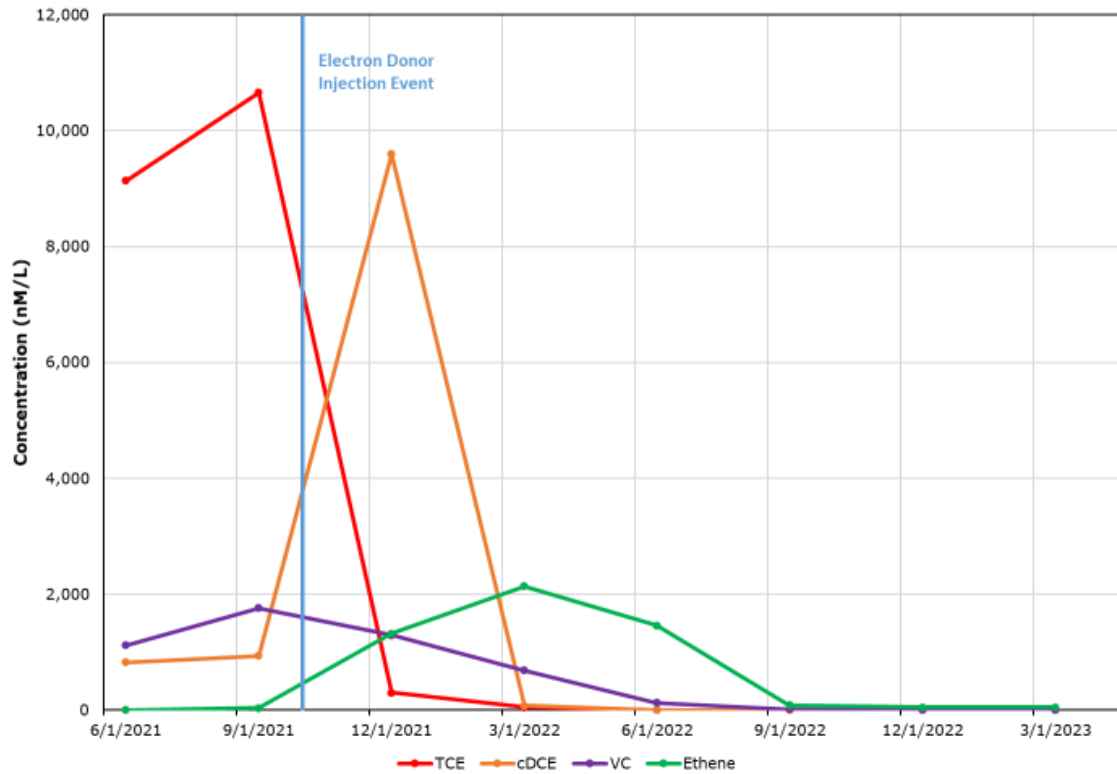


Average methane concentrations

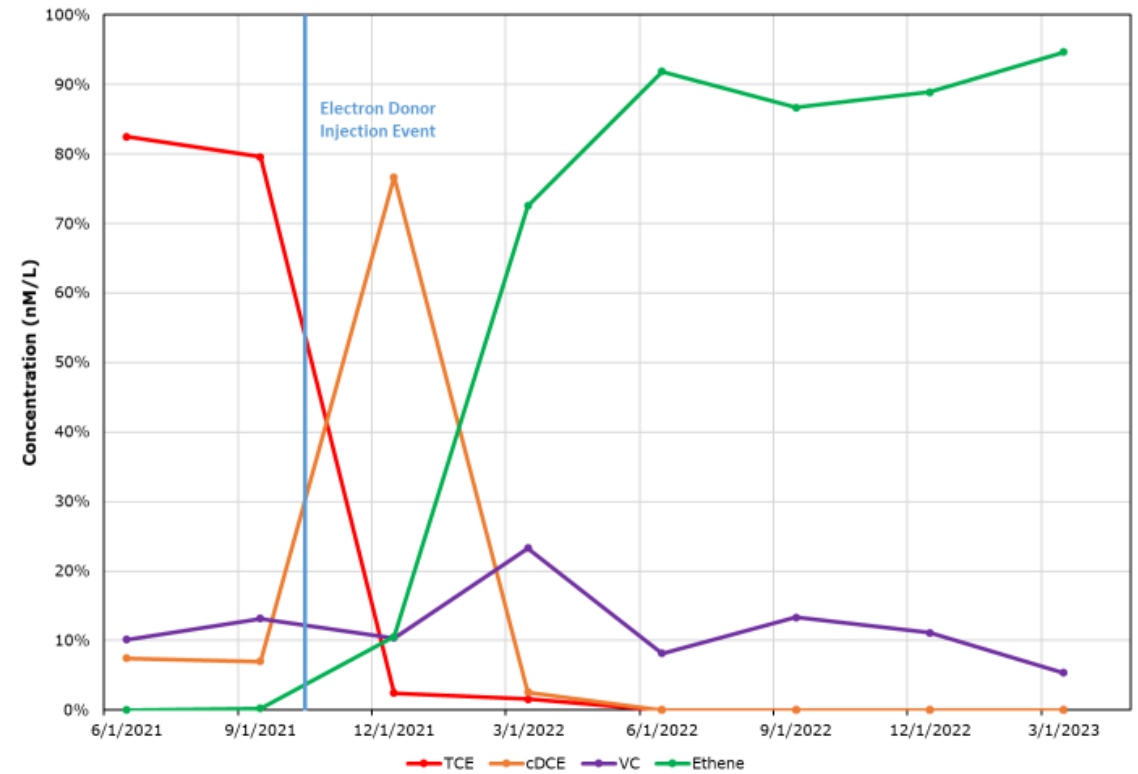


Groundwater remediation: chlorinated ethenes

Molar concentrations of VOCs at well KM-MW-4R

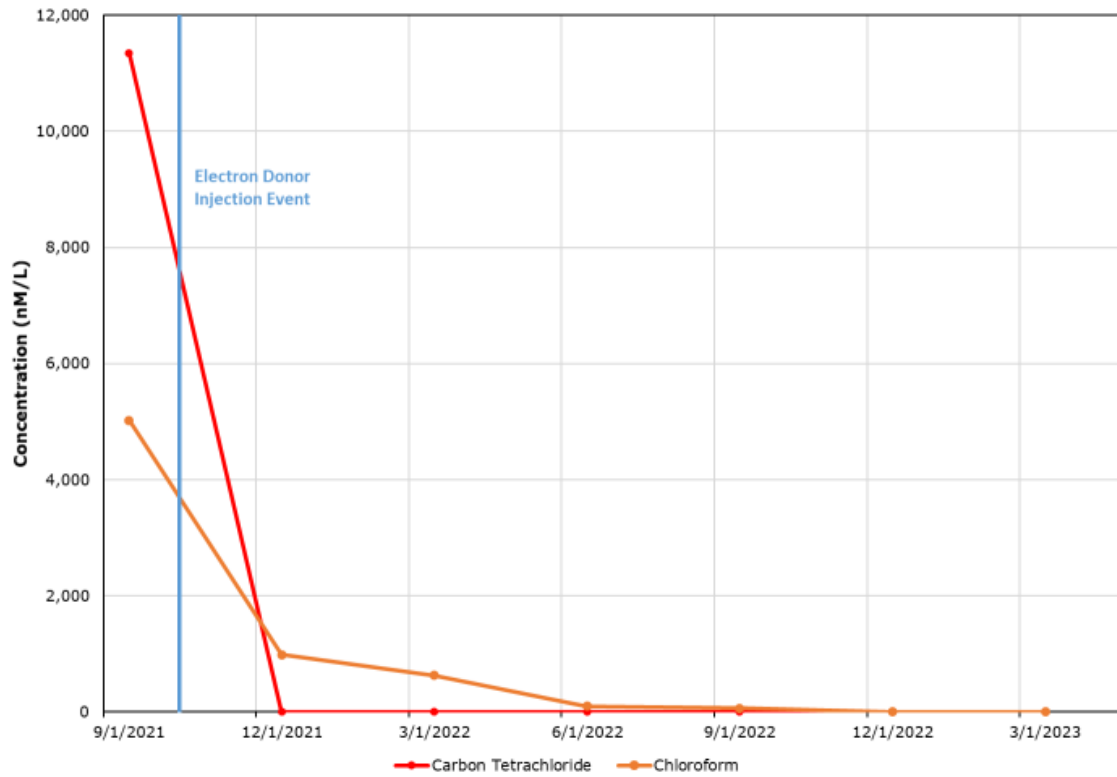


Molar fraction of VOCs at well KM-MW-4R

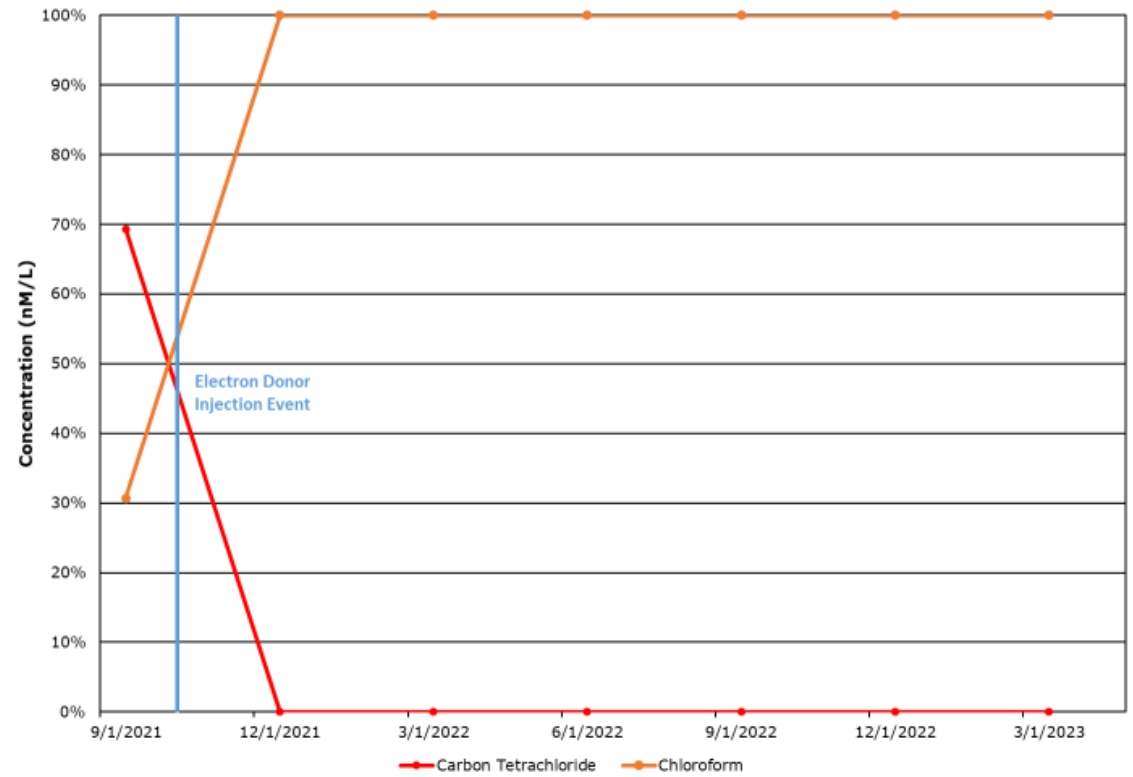


Groundwater remediation: chlorinated methanes

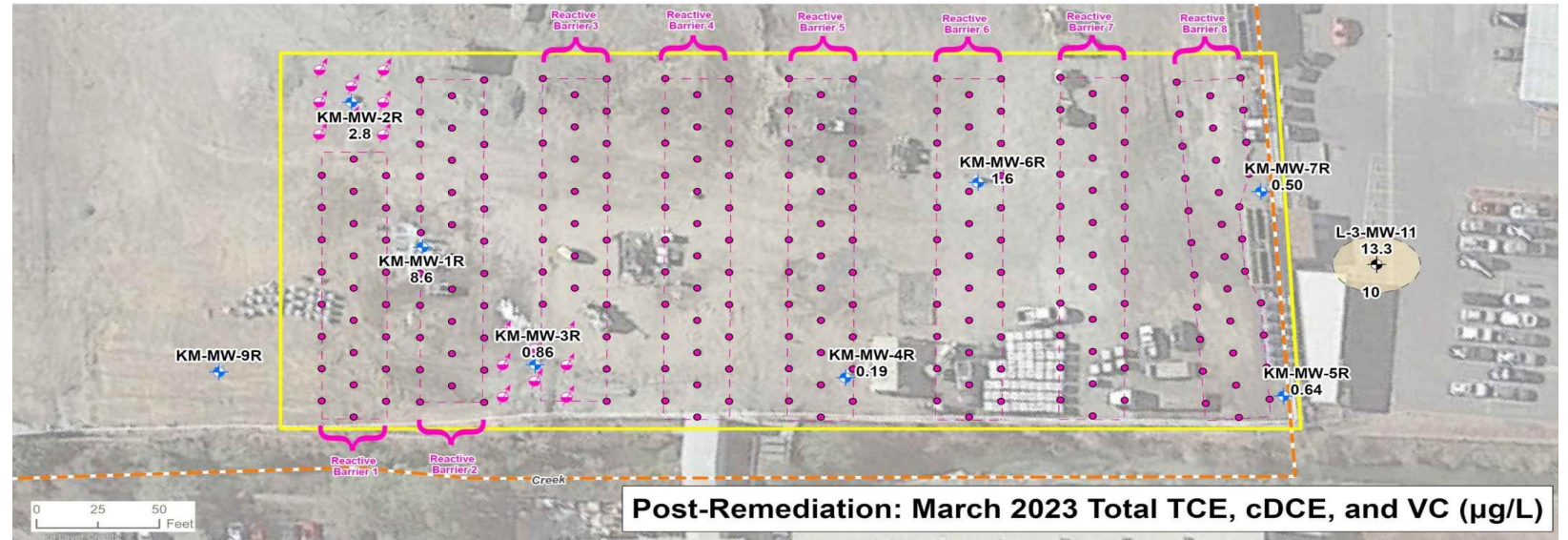
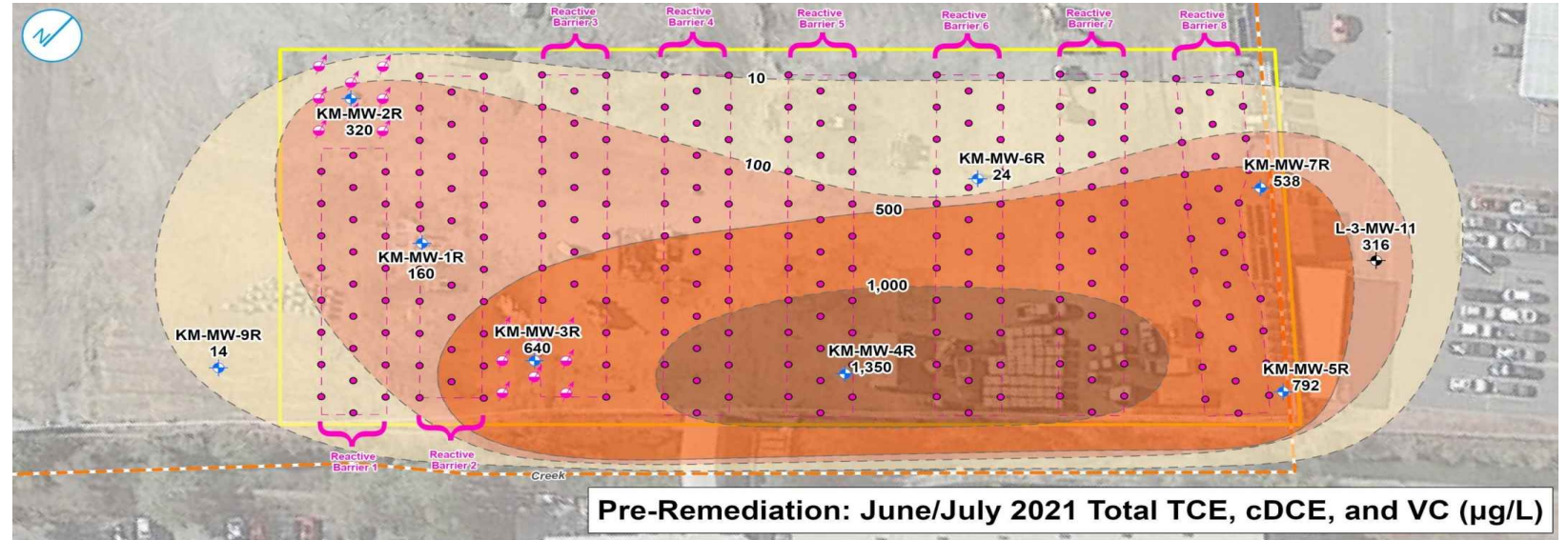
Molar concentrations of VOCs at well KM-MW-1R



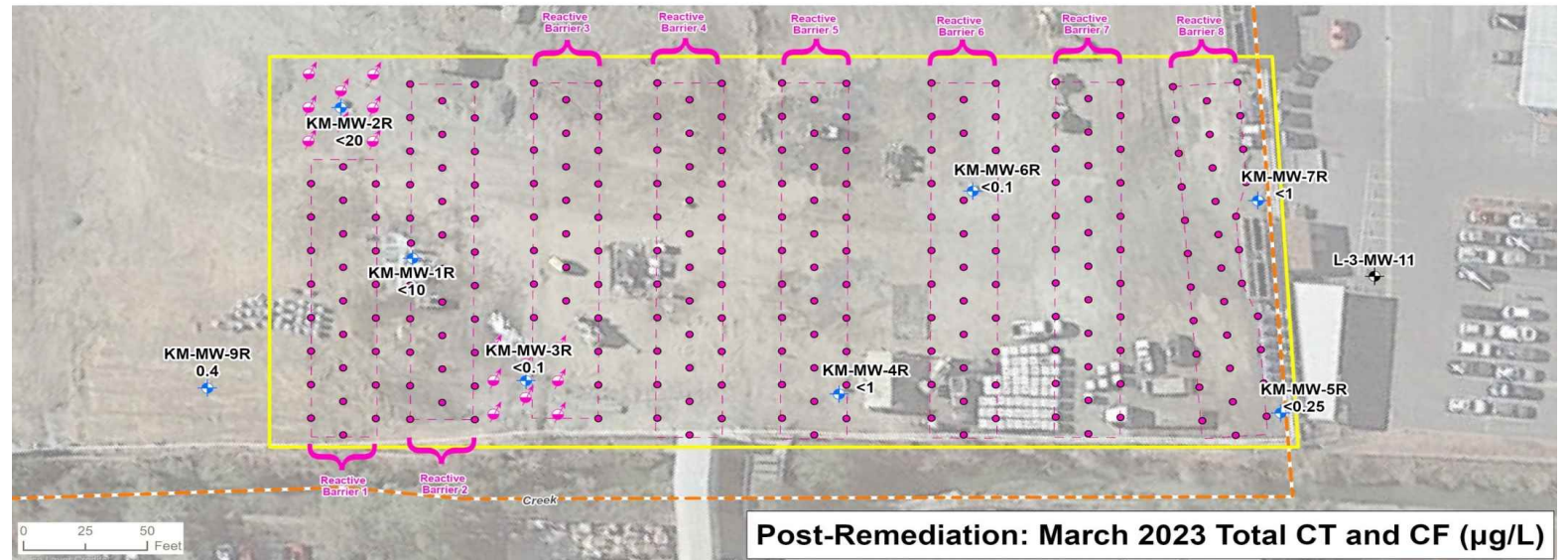
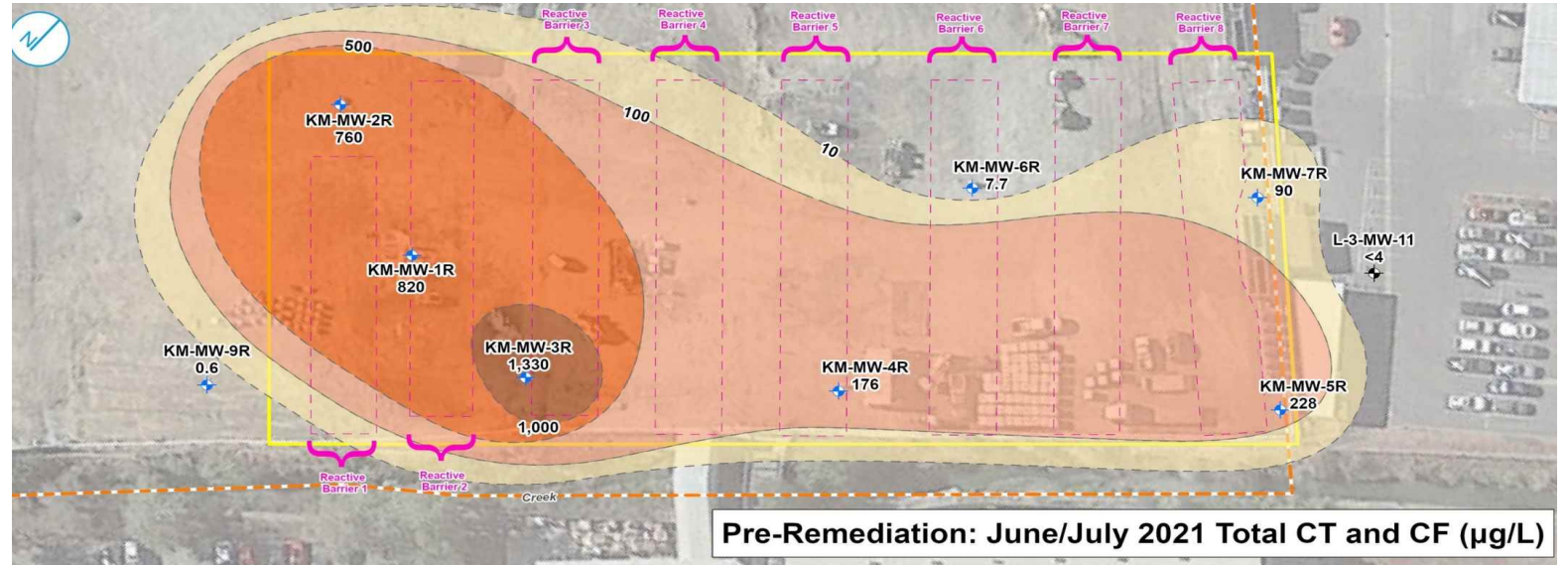
Molar fraction of VOCs at well KM-MW-1R



Groundwater remediation: chlorinated ethenes



Groundwater remediation: chlorinated methanes



Takeaways

- We applied a robust electron donor dosage in order to meet an aggressive site re-development schedule, with the goal being to minimize the need for future injections.
- Our multibarrier injection resulted in widespread anaerobic conditions at an otherwise aerobic site.
- Pre-injection, the dominant compounds of concern were trichloroethene and carbon tetrachloride.
- Total chlorinated ethene concentrations, including daughter products, declined by greater than 99% (from as high as 1,350 µg/L to <9 µg/L) between July 2021 and March 2023.
- Total chlorinated methane concentrations, including daughter products, declined from as high as 1,330 µg/L to non-detect in all site wells between July 2021 and March 2023.
- Remaining high TOC concentrations (approximately 500 mg/L) should promote further dechlorination of low residual vinyl chloride (<9 µg/L).
- Moreover, enhanced anaerobic dechlorination can result in sustained treatment, likely due to accumulation of biomass and reduced iron minerals that support future dechlorination.

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Thank you!

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