

Using CSIA to Verify Effectiveness of Coupling Synthetic Iron Sulfide Injections with Bioaugmentation to Address a Trichloroethylene Plume

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Introduction / Background

A low cost, green, and sustainable remediation approach was required at a site impacted by chlorinated solvents. The site was upgradient to a river in northern New Jersey and contaminant concentrations were posing a potential health and environmental risk.

The applied site management strategy was in situ enhanced anaerobic bioremediation (EAB) and in situ chemical reduction (ISCR) of trichloroethylene (TCE), where specialized amendments are injected into the aquifer to stimulate natural processes capable of transforming TCE to innocuous end products such as ethene and carbon dioxide.

Approach

Constructing a CSM and evaluating the performance of the chosen remediation approach relied on Compound-Specific Isotope Analysis (CSIA). The measured $\delta^{13}C$ and $\delta^{37}Cl$ values for TCE, dichloroethylene (DCE), and vinyl chloride (VC) were coupled to geochemical data and results from molecular diagnostic tests such as Dhc 16S rRNA and other qPCR tests that quantify key functional genes for complete dechlorination such as *vcrA*, *tceA*, and *vbcA*. Baseline tests were performed before the amendment injections.

Activities

Eight (8) direct-push injection (DPI) points served to inject 12,000 gallons of a roughly 4% amendment solution to treat a 1,500 ft² x 12 ft source zone (from 3 to 15 feet below ground surface).

A downgradient permeable reactive front was placed to act as a barrier to mitigate further plume migration by injecting amendments through 36 points. Both areas required injecting chemicals through a twelve-foot vertical contaminant plume span.

Products used to engineer subsurface conditions included a self-emulsifying vegetable oil that acted as a source of carbon and electron donor (EDS-ER™), a nutrient rich, soluble electron donor (Nutrimens™) along with a Mackinawite-structured iron sulfide suspension replicating the mineralogy capable of abiotic reductive dechlorination of TCE (ISR™).

The injection program included inoculating with a *Dehalococcoides*-rich culture capable of complete dechlorination of chlorinated ethenes to ethene (KB-1®). The remedial injections were completed between May 11 and June 1, 2020.

Two performance monitoring points allowed evaluating the fate of chlorinated ethenes before and after ISCR and EAB.

Baseline Results

Well	Dhc cells/mL	TCE		cis-DCE		VC	
		Conc. µg/L	$\delta^{13}C$ ‰	Conc. µg/L	$\delta^{13}C$ ‰	Conc. µg/L	$\delta^{13}C$ ‰
MW-68S	1.6	14.0	-27.0	420.0	-20.6	14.0	-33.1
MW-69S	n.d.	5.6	-24.3	480	-19.3	5.6	-41.7

- In both monitoring wells, total organic carbon (TOC) and volatile fatty acids (VFAs) were non-detect (n.d.), which suggested that additional electron donors were needed in order to optimize the bioremediation approach.
- The Dhc concentrations in both wells were very low or non-detect, which suggested that site conditions were not optimal for their growth, limiting the mechanisms for natural attenuation.
- The $\delta^{13}C$ value for TCE, cis-DCE, and VC in MW-69s were more enriched (less negative) than MW-68s, indicating more degradation in MW-69s compared to MW-68s.
- The $\delta^{13}C$ value for VC in MW-69s, and the sum* of all $\delta^{13}C$ suggests VC compounds migrate off-site, as degradation is slow or now existent.

*In $\delta^{13}C$ theoretical evolution, the final ethene pool is expected to have the $\delta^{13}C$ value of the initial TCE pool, once all chlorinated compounds are completely biodegraded to ethene (see Figure 1).

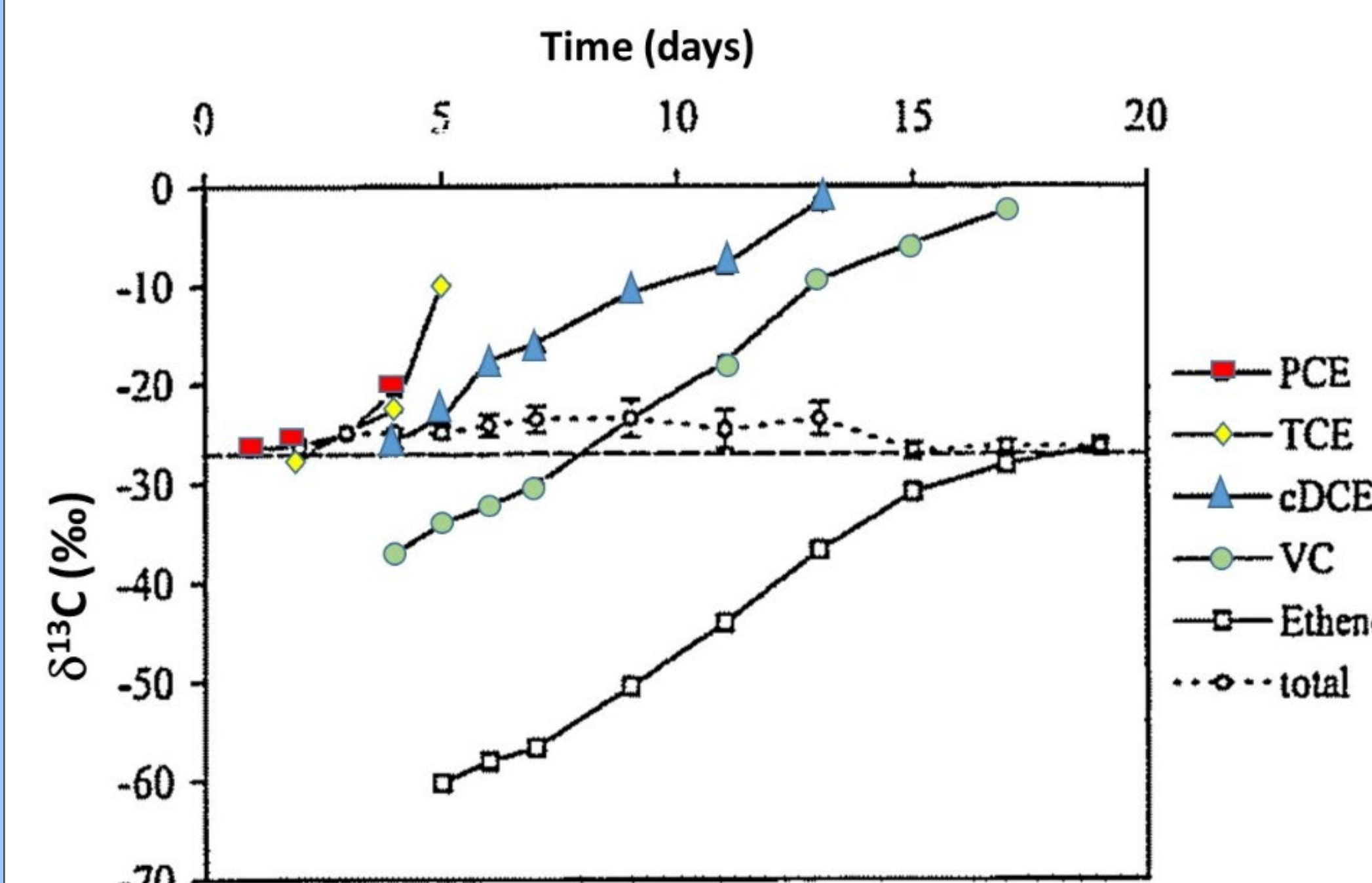
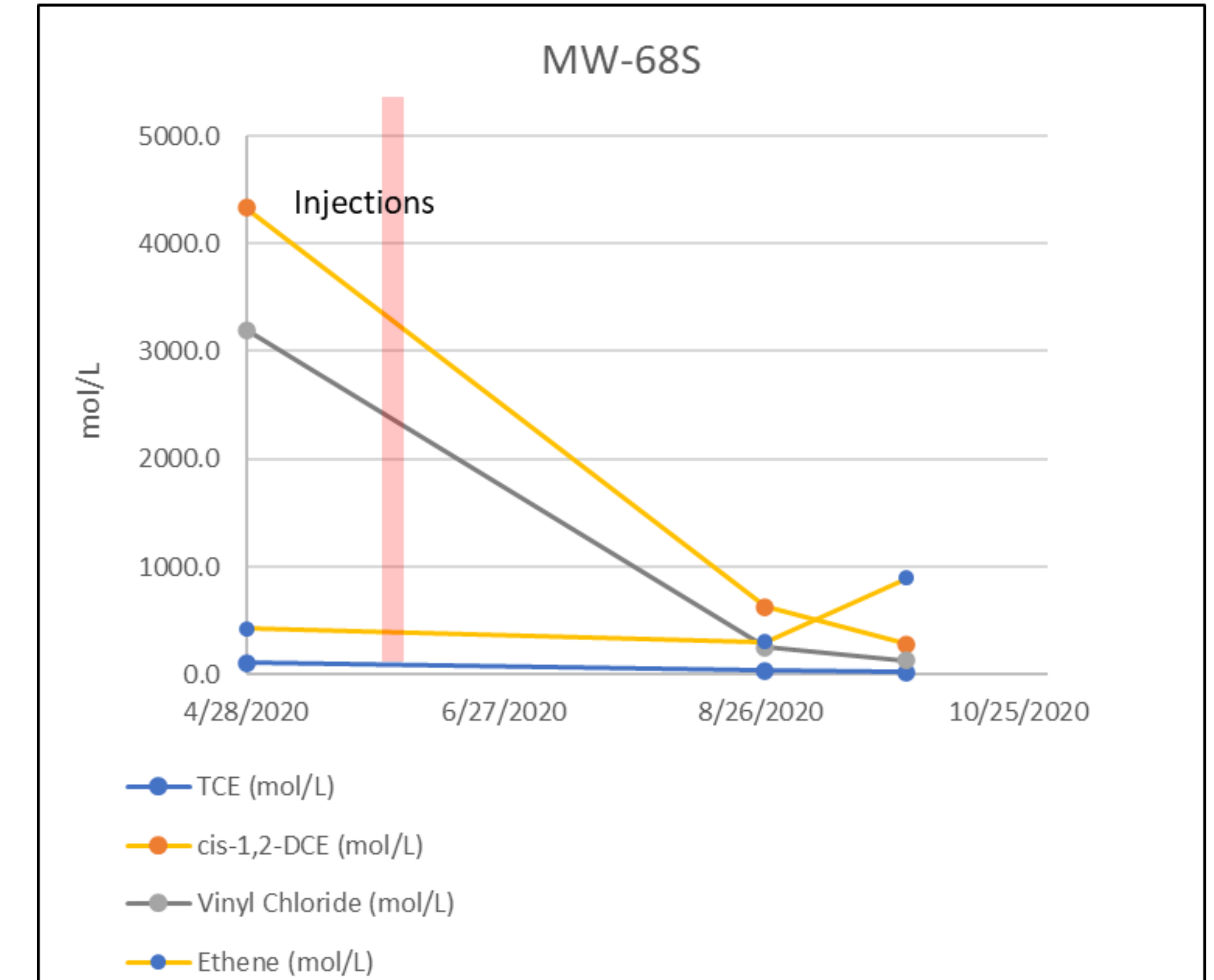
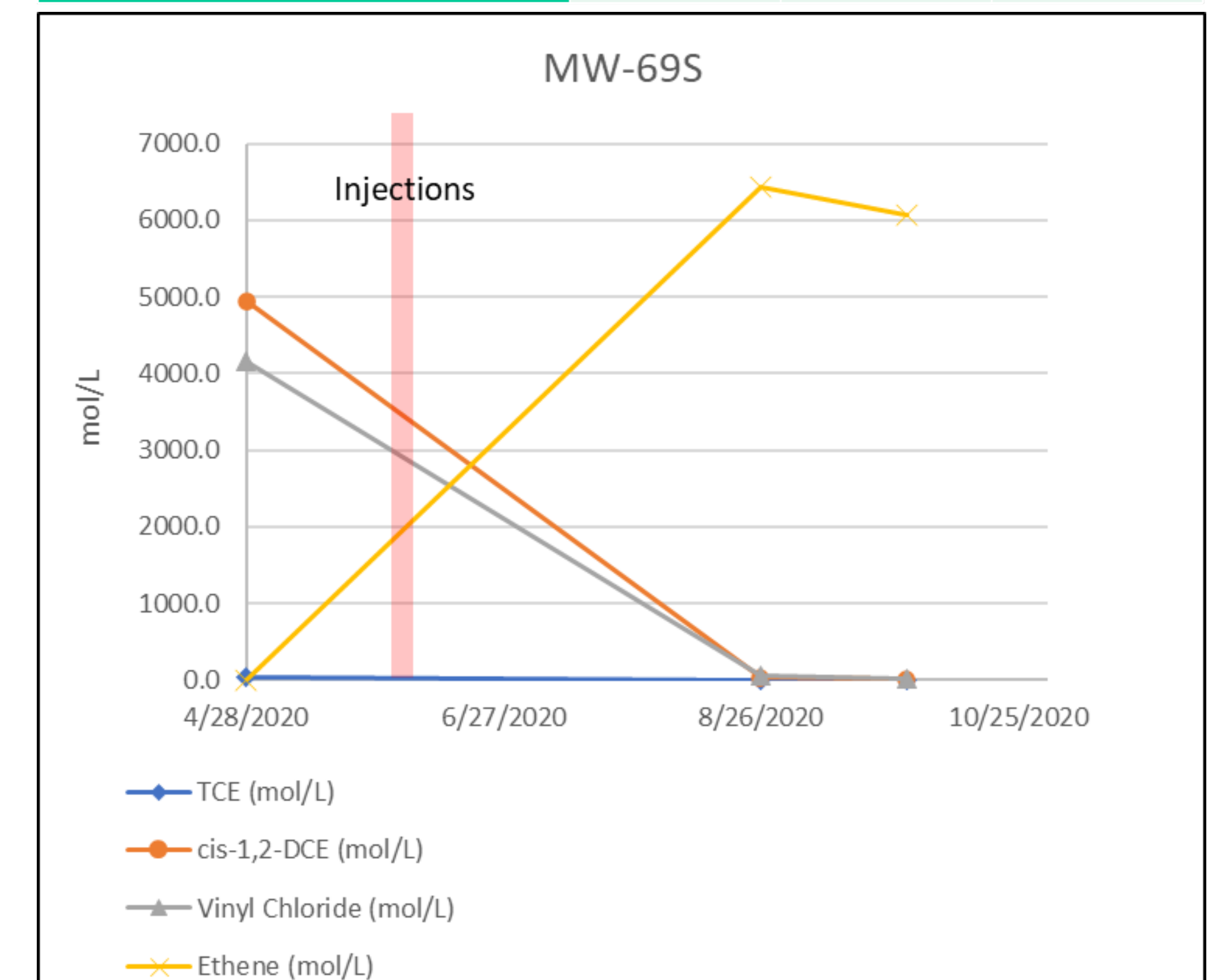


Figure 1: Carbon isotope ratio ($\delta^{13}C$) of the initial PCE source and for TCE, cis-DCE, VC and ethene produced over the course of biodegradation process (by reductive dechlorination). Adapted from (Hunkeler, Aravena et al. 1999)

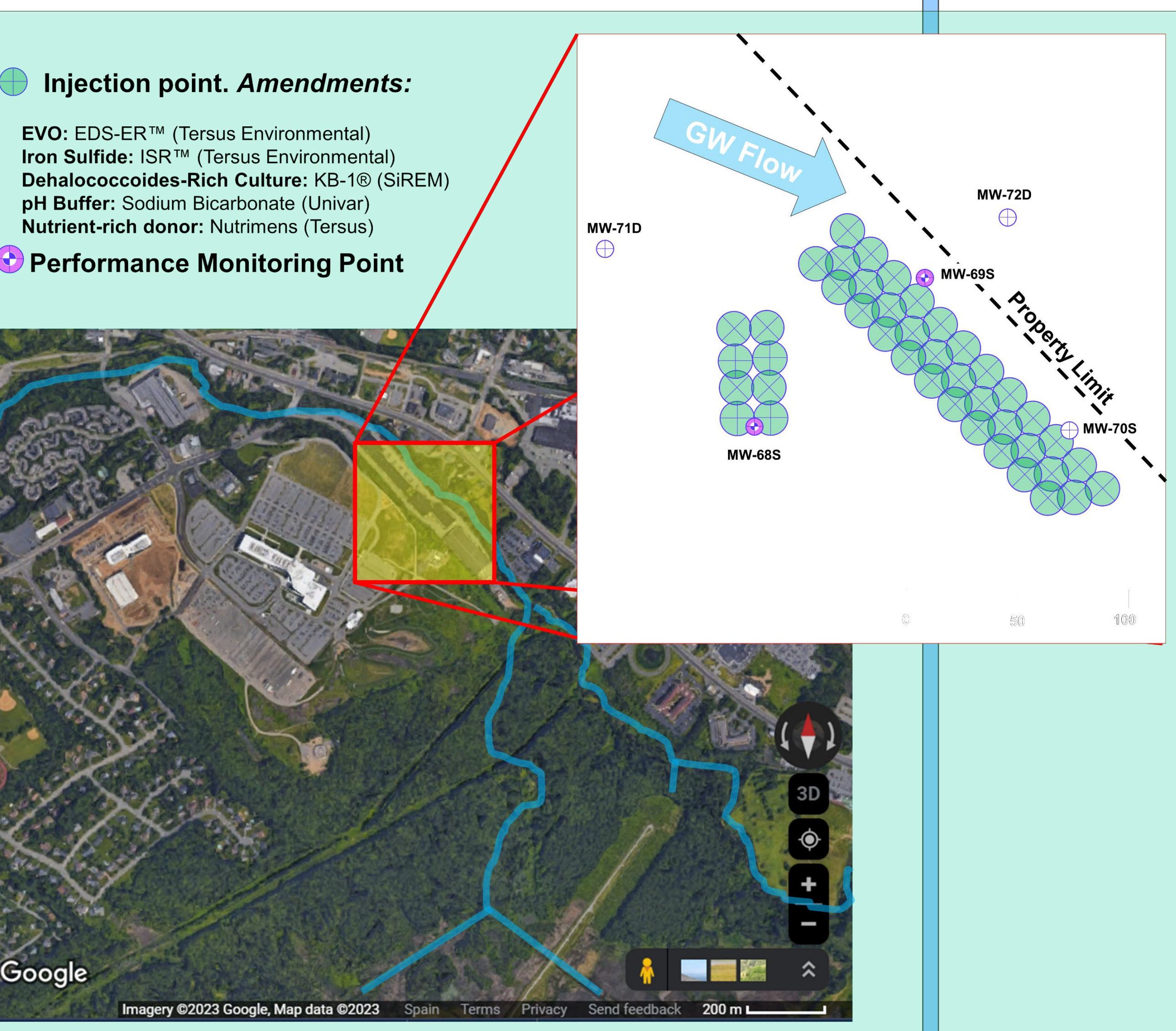
Post-Injection Results



MW-68S			
Sampling Date	04/28/2020	08/27/2020	09/29/2020
Depth to Groundwater (ft)	6.27	7.35	7.73
ORP (mV)	-66	-125	-129
Conductivity (mS/cm)	1.13	2.73	2.38
pH	6.94	6.92	7.11
Dissolved Iron (µg/L)	2,830	932	3,590
Sulfate (µg/L)	30.4	429	227
Methane (µg/L)	410	120	360
Ethane (µg/L)	3.4 J	1.2 J	1.5 J
Ethene (µg/L)	12.0	8.4	25.0



MW-69S			
Sampling Date	04/28/2020	08/26/2020	09/29/2020
Depth to Groundwater (ft)	5.22	7.15	7.47
D.O. (mg/L)	0.03	0.00	0.00
ORP (mV)	-56	-337	-334
Conductivity (mS/cm)	0.965	2.30	2.31
pH	6.41	7.01	6.81
Total Iron (µg/L)	6,350	1,510	1,110
Dissolved Iron (µg/L)	5,550	242	974
Sulfate (µg/L)	23.2	221	167
Methane (µg/L)	0.71 J	590	3,000
Ethane (µg/L)	0.71 U	3.9	5.0
Ethene (µg/L)	0.53 U	180	170



Approach

The remedial approach required constructing a conceptual site model (CSM) that incorporated subsurface geochemical and geological data that described the fate and transport mechanisms of TCE, and the suitability and performance of ISCR and EAB prior to transitioning to monitored natural attenuation (MNA).