Successes and Challenges of Bioaugmentation in a Low Permeability Aquifer

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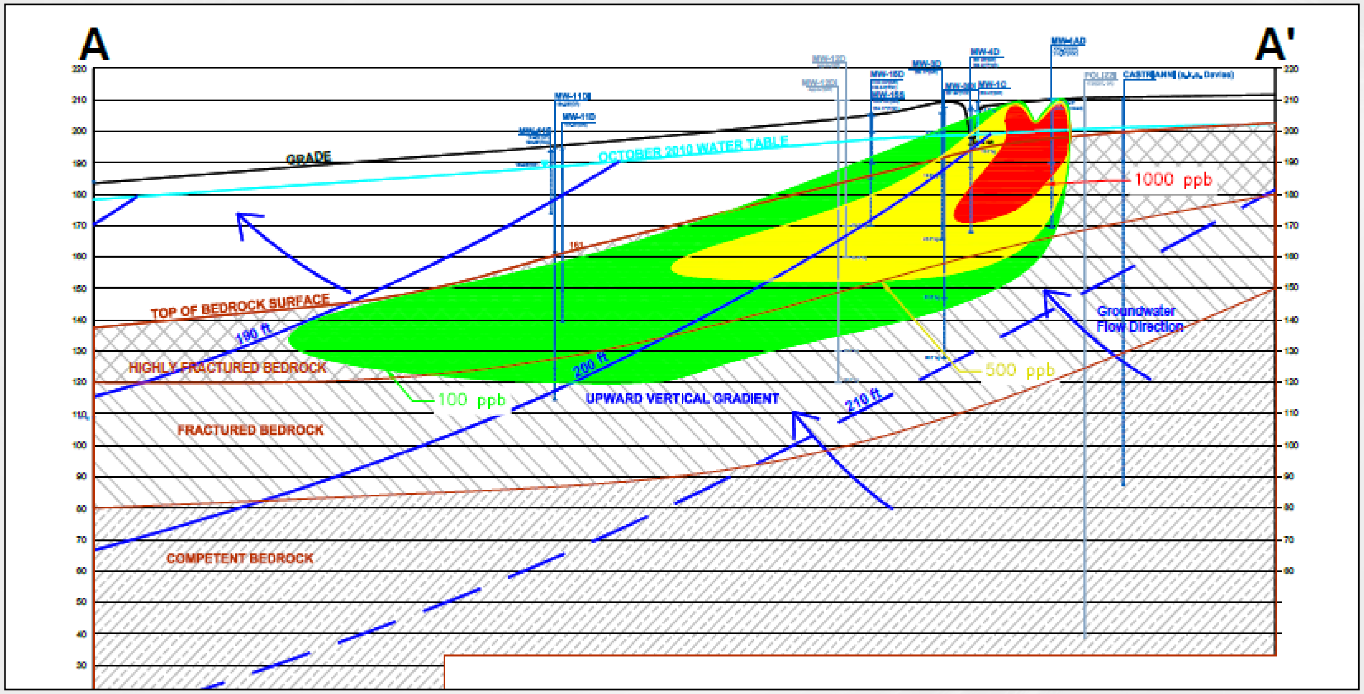
Overview

- Objective/Background
- Bioremediation Activities
- Bioremediation Results
- Lessons Learned

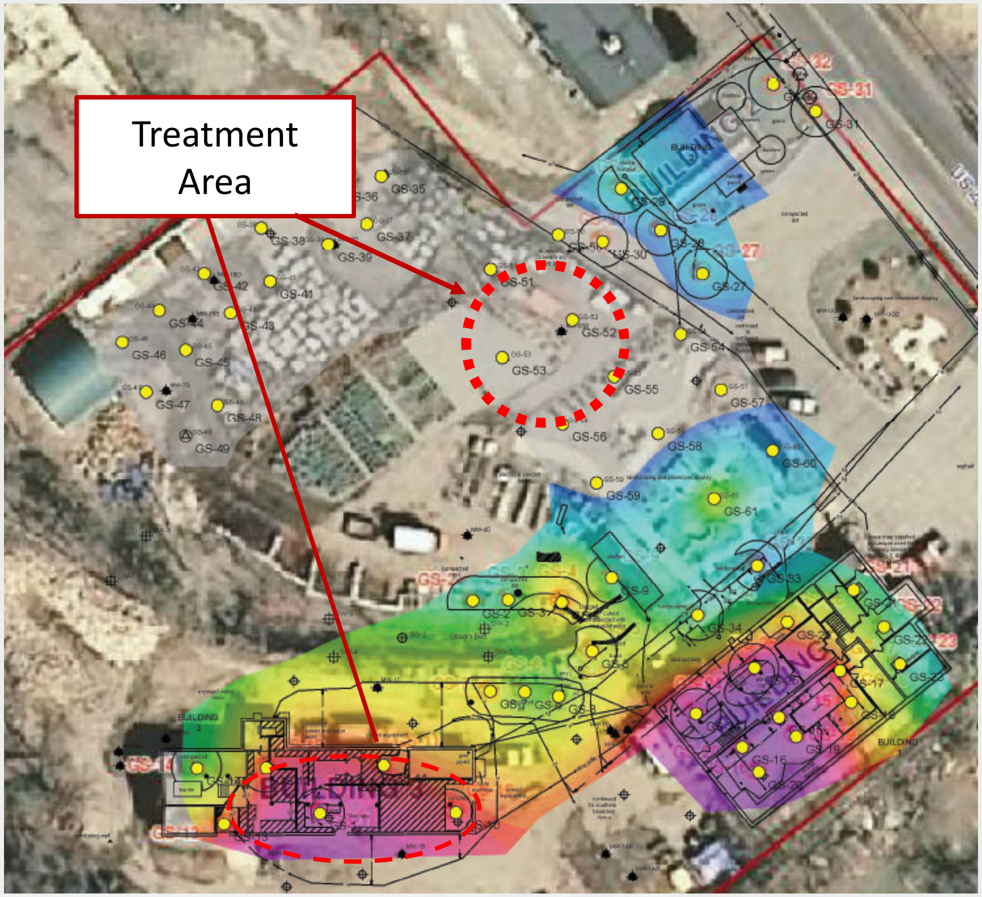
Objective/Background

- Tetrachloroethene (PCE) Source
  - 110 mg/L in groundwater
  - 3,300 mg/kg in soil
- Low permeability glacial till overburden
- Passaic formation bedrock
  - Red Shale



Remedial Challenges for Source Area

- Most impact under buildings
- Bioremediation selected remedial approach
- PCE groundwater concentration near saturation
  - Higher bioaugmentation culture dosage
  - Higher EVO dosage
- Goal is to reduce the mass, not to achieve soil or groundwater standard



Soil gas survey – GORE-SORBER®

Summary Remedial Activities

Previous Direct Push Technology (DPT) Injections did not impact the DNAPL area

- Injection #1: Hydrogen Releasing Compounds (HRC) in 2001
- Injection #2: Slow Release Substrate (SRS) as emulsified vegetable oil (EVO) in 2006

Injections focused on the Source area

- Injection #3: EVO+Bioaugmentation in 2014
  - Overburden + Bedrock + weathered bedrock
  - Successful remediation at area with CVOCs less than 2,000 μg/L.
  - PCE was converted to cis-1,2-DCE at the source area
- Injection (Supplemental) #4: EVO+Bioaugmentation + buffer + nutrient in 2018
  - Overburden + Weathered bedrock
  - Elevated DHC, $NaHCO_3$, diammonium phosphate (DAP), and yeast extract
  - Separation of DHC and EVO injection
  - Customized EVO (SRS-SD) without lactate*

* DHC culture, EVO and nutrients supplied by TerraSystems, Inc. of Wilmington, DE

Injection – 2014 and 2018

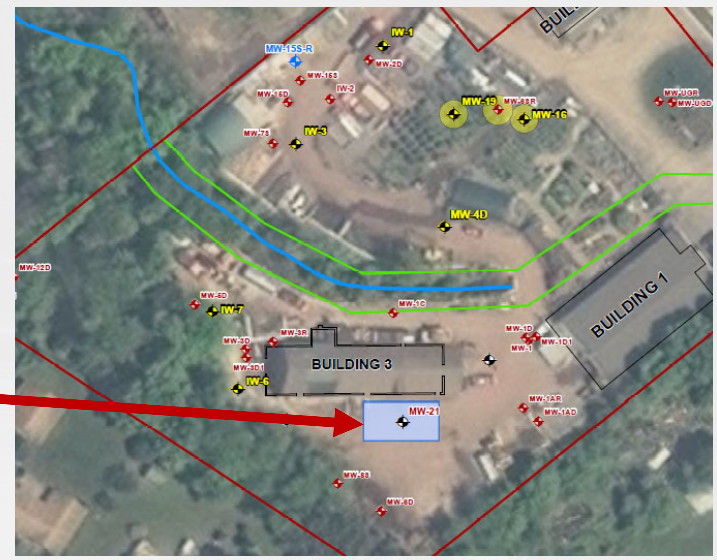
2014

- 5 bedrock wells (green), two weathered bedrock wells (yellow), and 66 DPT points (blue),
- EVO- 25,000 lbs.
- DHC culture – 78 L

2018

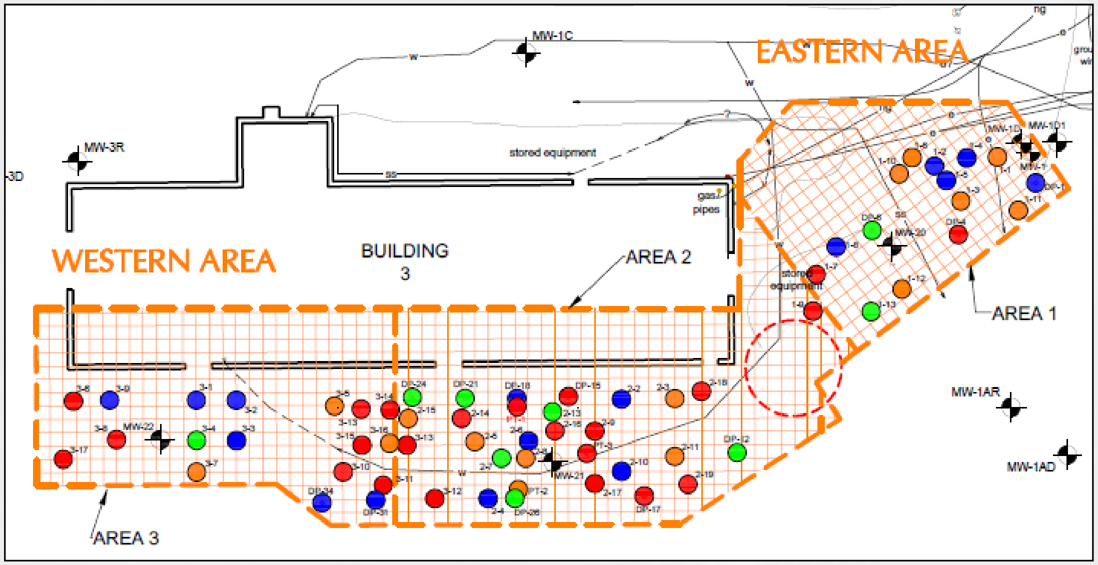
- 3 weathered bedrock wells (yellow) and 4 DPT points (blue)
- EVO- 3,950 lbs.
- $NaHCO_3$ – 300 lbs.
- DAP – 100 lbs. and Yeast Extract – 100 lbs.
- DHC culture – 50 L

Much smaller area with high nutrient and buffer dosages



Remedial Challenges for Source Area (2014)

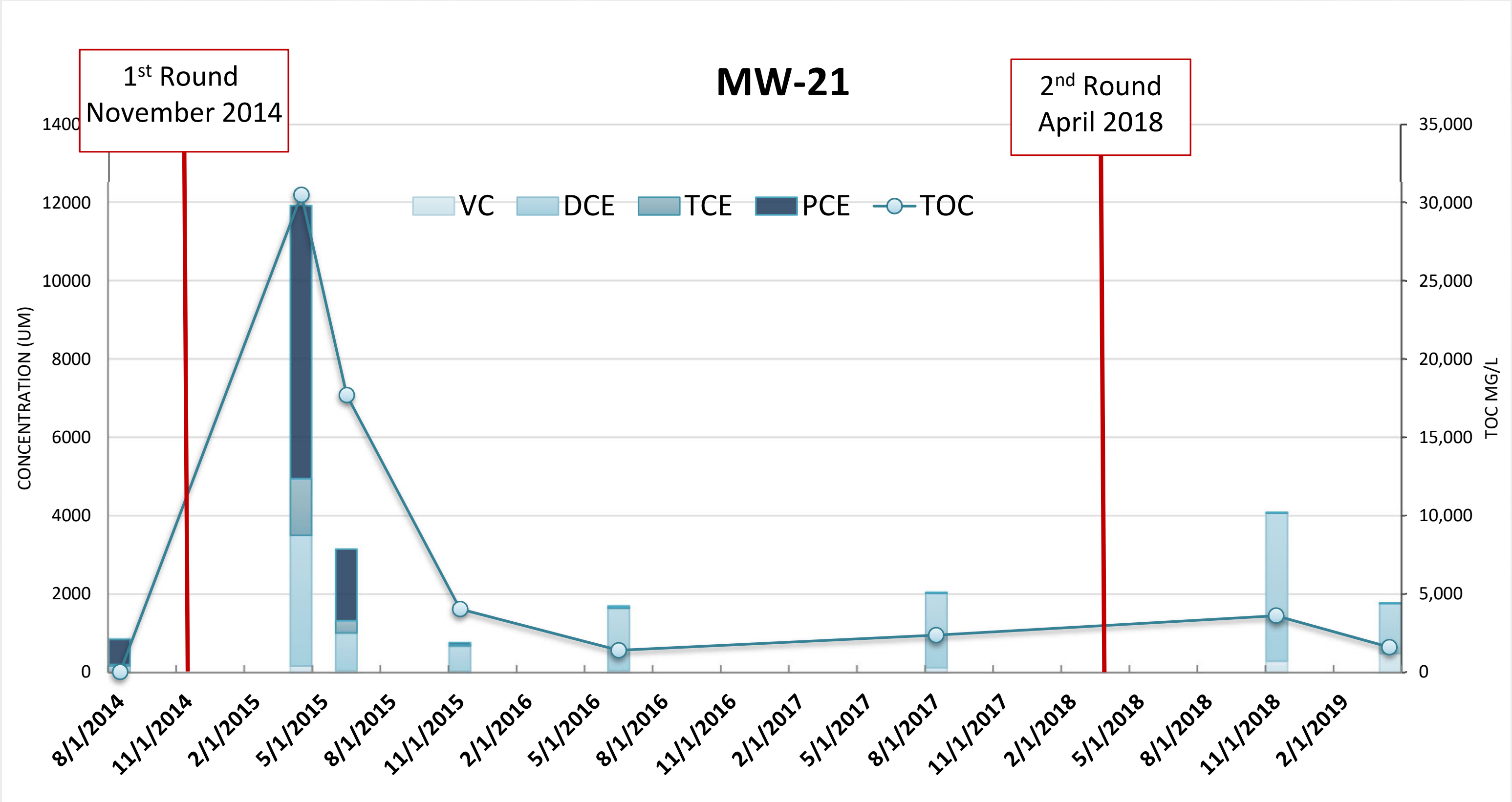
- Low permeability overburden formation obstacle to even, large volume substrate distribution
- “Push & Squirt Strategy” More points with injection volume ranging mostly between 10 to 50 gallons per point.



High Volume > 50 gallons
Moderate Volume 50 to 10 gallons
Low Volume 10 to 2 gallons
No Volume < 2 gallons

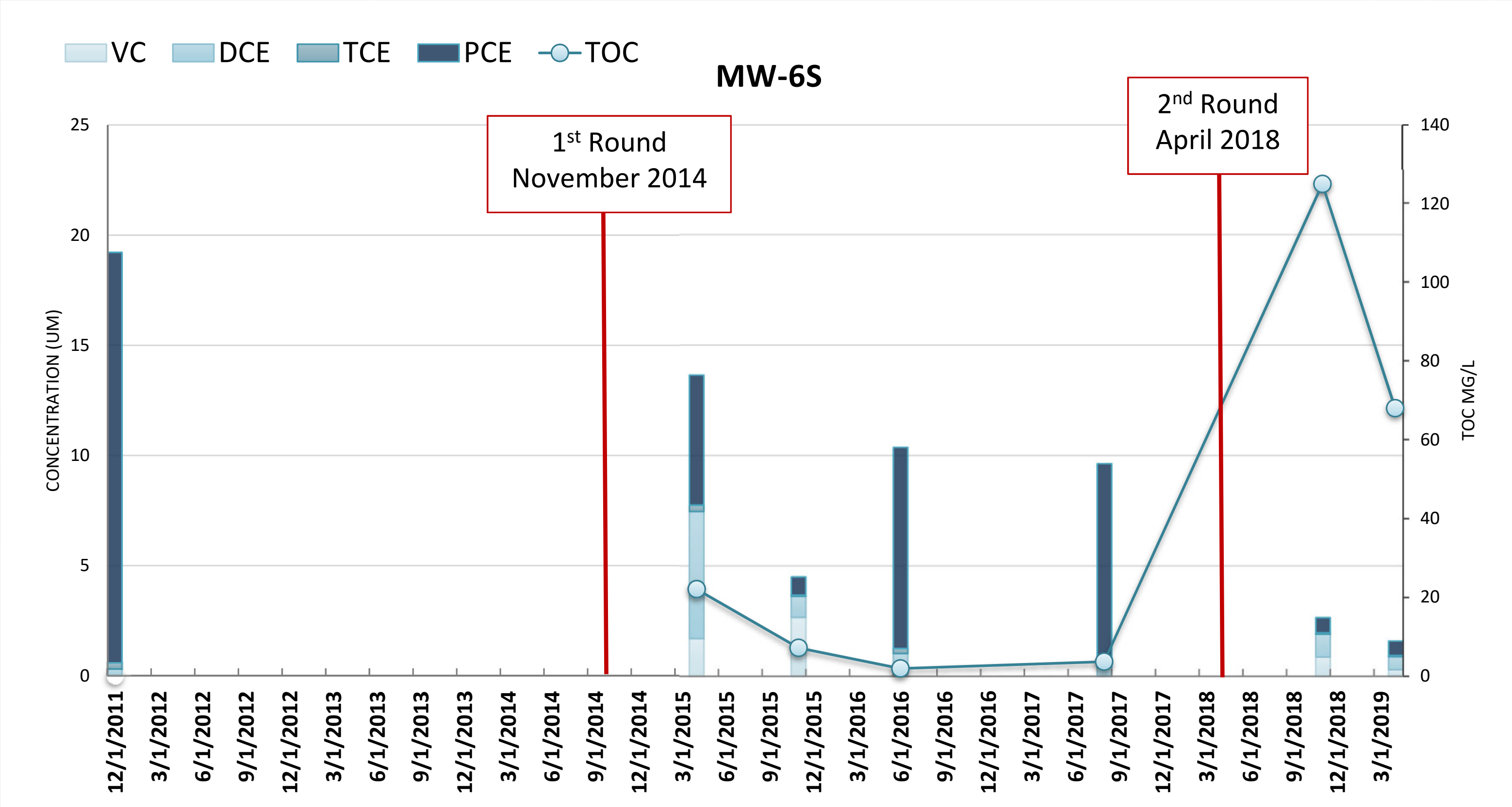
Source (Overburden) - CVOCs

- Prolonged daughter product generation
- Co-solvent effect released PCE from soil
- Elevated TOC provided sufficient electrons

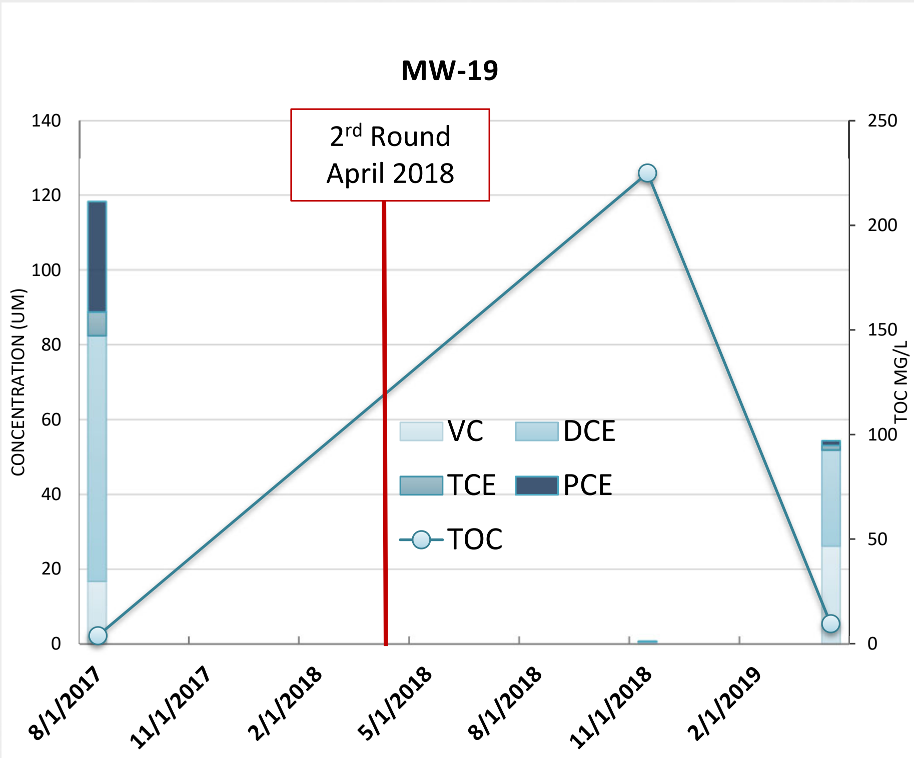


Weathered Bedrock - CVOCs

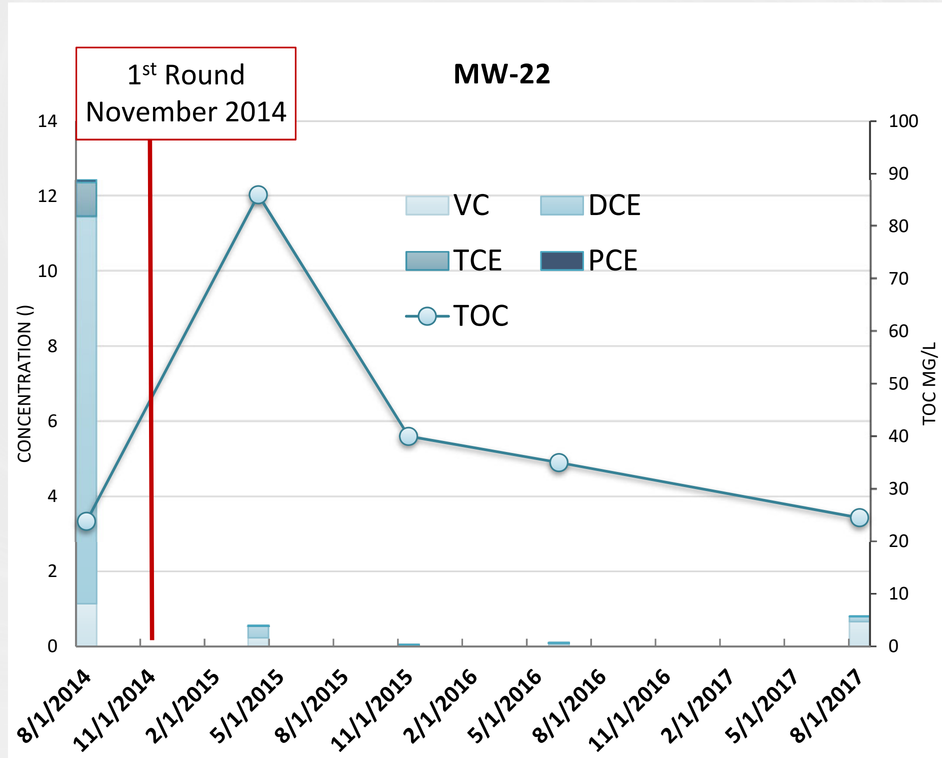
- TOC important in maintaining reducing conditions
- Both injections could not achieve elevated TOC levels (>100 mg/L) for an extended time



Weathered Bedrock and Overburden - CVOCs

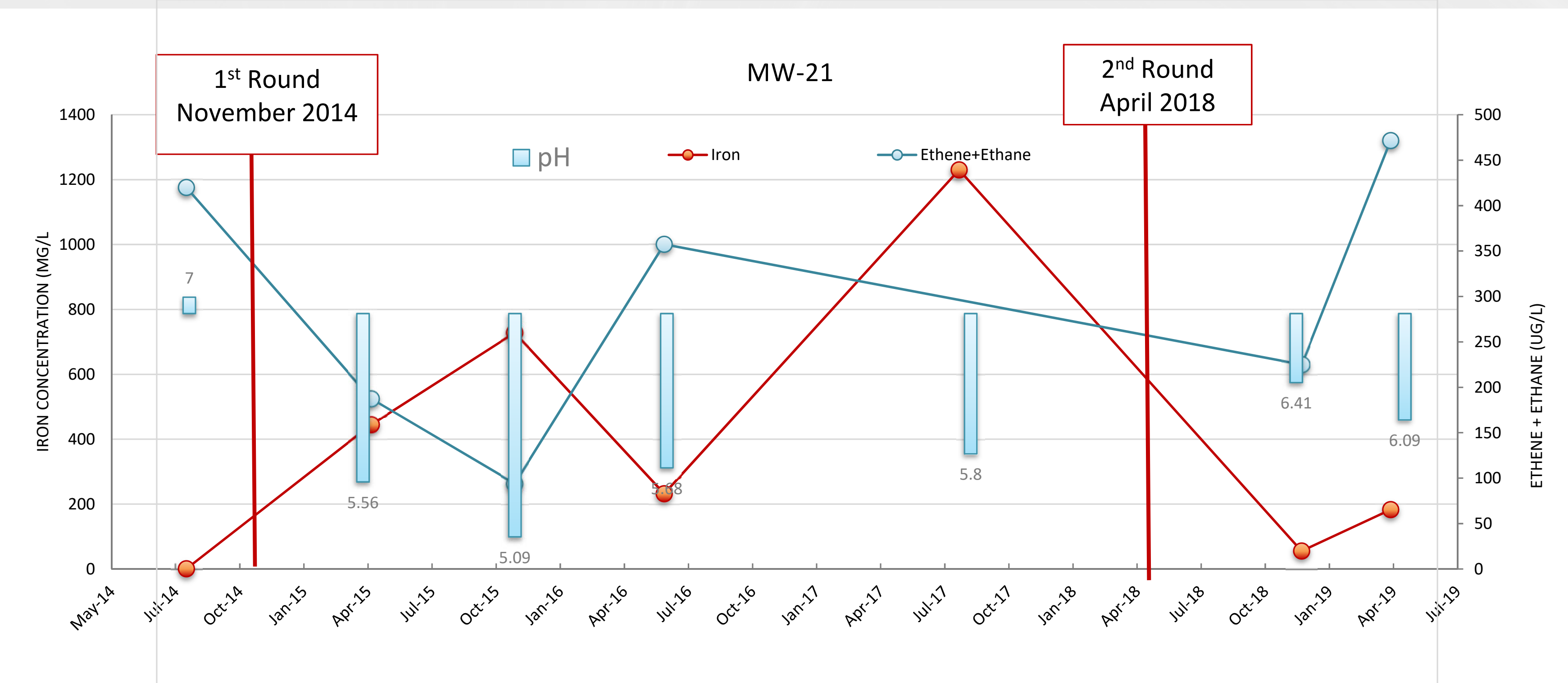


- CVOCs rebounded when TOC decreased to less 10 mg/L



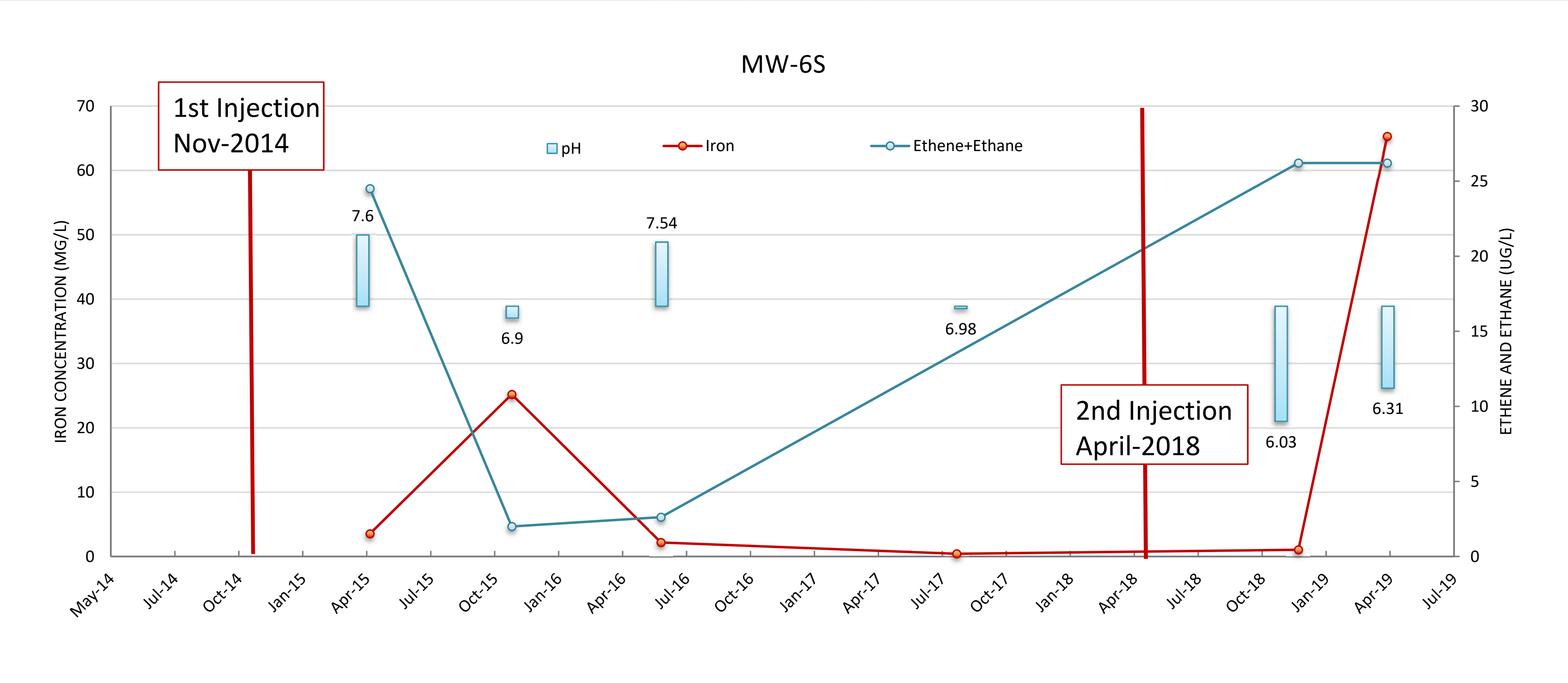
- Moderate low levels of CVOCs did not generate rebound

Geochemical Conditions - Source



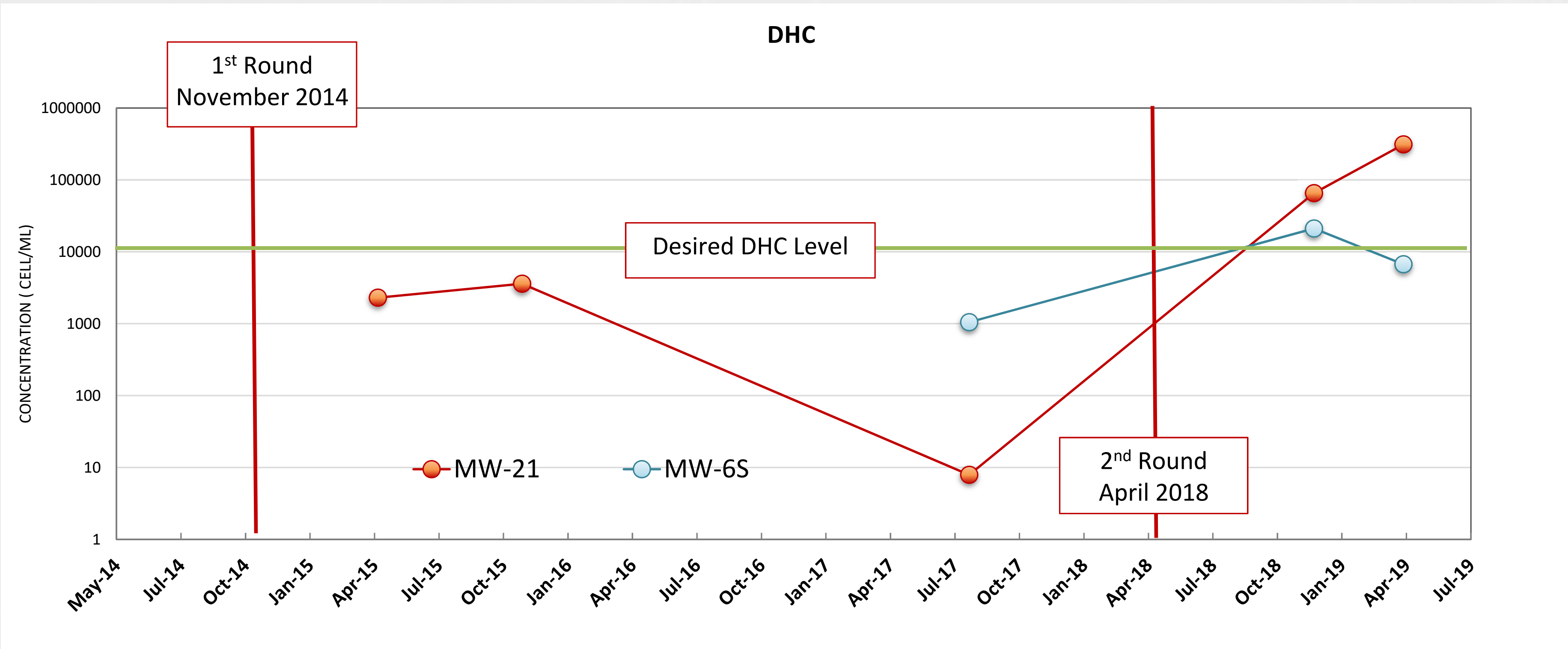
- Iron generation was correlated with a decrease of pH
- Ethene and ethane levels negatively correlate with iron and declined to the baseline level.

Geochemical Conditions – Weathered Bedrock



- Iron generation was correlated to the decrease of the pH level
- Ethene and ethane levels were low.

DHC



- DHC increased to above 10^4 cell/ml after 2nd bioaugmentation.

Lessons Learned

- Concentration limit for bioremediation
  - Generally, at < 2,000 μg/L, one injection event of EVO was able to reduce the CVOCs without rebound.
  - For source concentrations (>100 mg/L), persistent high concentration of cis-1,2-DCE and multiple injection events are needed.
- Buffer and nutrients are important
  - pH can decrease significantly within presumed DNAPL areas
  - High nitrogen nutrient content necessary

Lessons Learned

- Customize carbon substrate to meet hydrological and geochemical conditions.
  - Droplet sizes – small for low permeability and large for high permeability
  - Lactate content – high for high pH aquifer and low (to none) for low pH aquifer.
- Low pH and high TOC are both detrimental for bioremediation
  - Elevated TOC level (more than 10 g/L) and/or metabolic acids >1,000 mg/L
  - pH < 5.5 resulted in cis-1,2-DCE accumulation.
- Iron interference can prevent rapid degradation in the iron-rich and low sulfate aquifer
  - Iron concentrations up to 1 g/L after injection