Tetrachloroethene Groundwater Remediation in a Dolomitic Limestone Aquifer Using Injectable Zero Valent Iron

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Site History

- Site is located in northeastern Indiana.
- Site developed in the early 1960s.
- Operated as a dry cleaners from 1960s to early 1990s.
- Coin operated laundry and car wash operations from early 1990s to 2014.
- A Phase I Site Assessment and a 2012 Phase II Site Investigation identified chlorinated solvent soil and groundwater impacts associated with the former dry cleaners operations.

Site Investigation Activities

Detailed subsurface investigations were performed during 2014 through 2015 including:

- Further Site Investigation to determine vertical and horizontal extents of soil and groundwater impacts.
- Geophysical surveys to evaluate higher conductivity zones due to fracturing/weathering in the underlying dolomitic limestone. (See center panel for geophysics results.)
- Soil gas investigation to evaluate preferential pathways in nearby utility corridors.
- Vapor intrusion monitoring of on- and off-Site properties.
- Groundwater monitoring for VOCs.

Investigation Results:

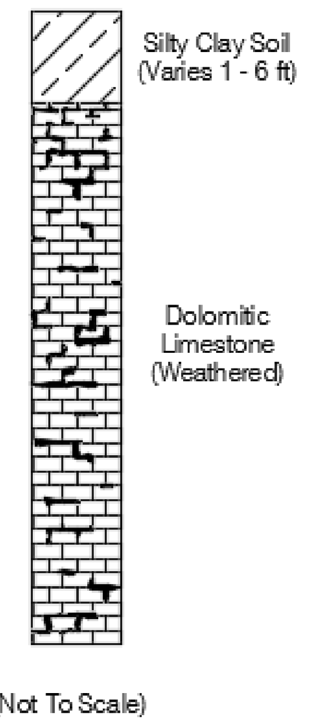
Site lithology (See illustration to the right)

Surface up to 1 ft bg - Surface cover

1 ft up to 6 ft bg - Silty/sandy clay

1 to 6 ft up to 35 ft bg - Weathered/fractured dolomitic limestone*

* - Alternating zones of bedrock weathering and consolidation were noted on boring logs with weathering observed on most fracture surfaces.



Groundwater Flow

- Depth to groundwater is approximately 5 ft bg.
- Groundwater flows to the northwest on the northern portion of the Site and to the southwest on the southern portion of the Site.

Contaminant Results

- PCE/daughter products detected in groundwater and identified in soil source areas.
- Soil impacts in proximity to former building area.
- Highest PCE shallow groundwater concentration 5,010 ug/l (ppb).
- Vertical extent of groundwater impacts is 30 ft bg.
- Approximate extents of PCE groundwater impacts above Indiana Department of Environmental Management (IDEM) Residential Tap Screening Levels are illustrated on the maps located on the right.

Proposed Plan of Action

Based upon the Site Investigation Results, the following plan of action was proposed:

- Installation of precautionary sub-slab depressurization systems to mitigate vapor intrusion issues at on- and off-Site properties.
- Excavation to remove unsaturated source area soils.
- Pilot testing and full-scale implementation of groundwater in-situ chemical reduction using injection of zero valent iron (ZVI) into the dolomitic limestone.

Soil Removal Activities

- In December 2015, 220 tons of soil were excavated from 2 interior and 2 exterior excavations to remove soil source areas associated with the former dry cleaning activities.
- Soil sampling conducted to guide excavation activities.
- Post-excavation soil sampling showed no need for further soil remedial actions.

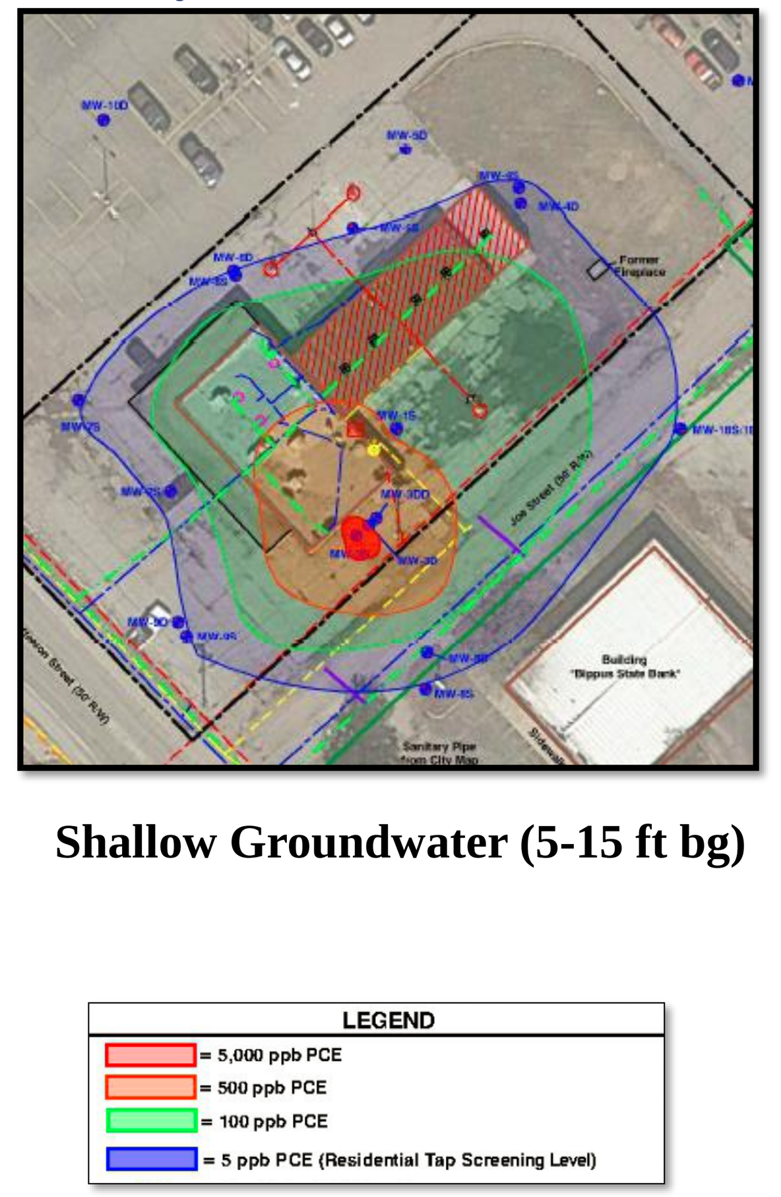
Groundwater Cleanup Objectives

Based upon the future reuse potential of the on- and off-Site properties the following proposed groundwater cleanup criteria were established for remediation purposes based upon IDEM regulations:

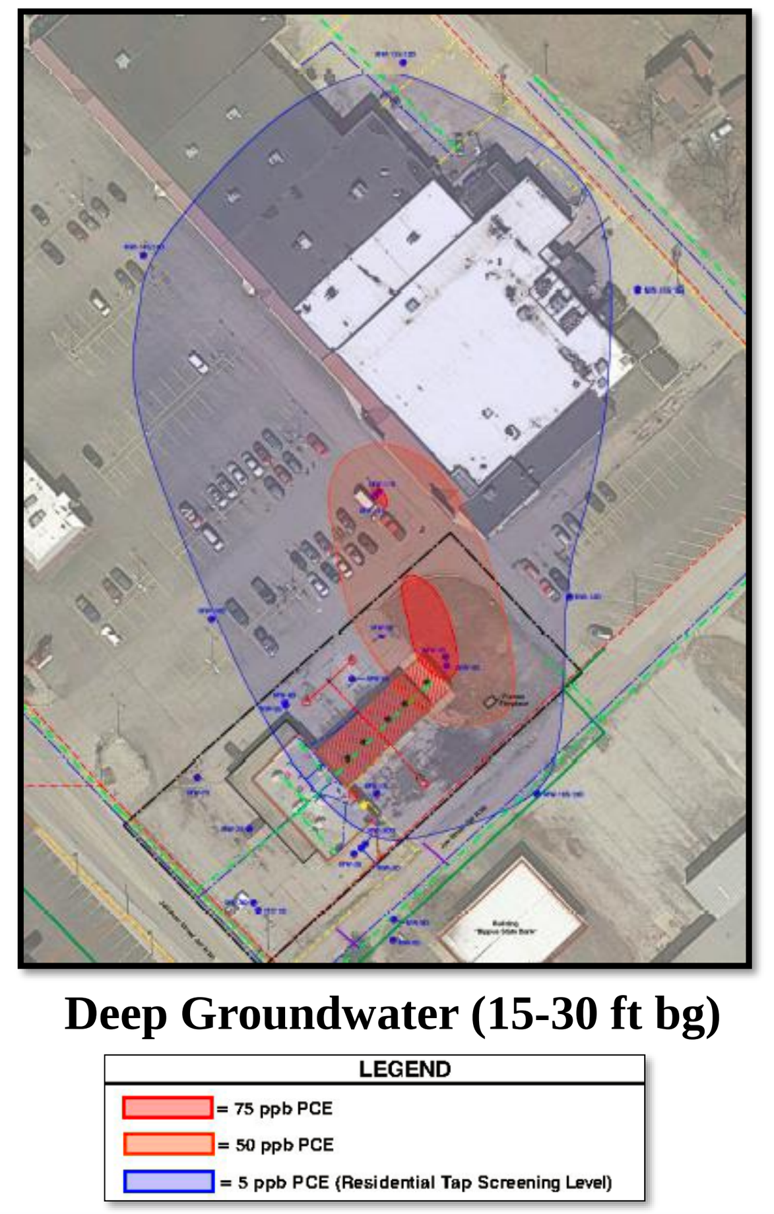
PCE and TCE – 5 ug/l   Cis-1,2-DCE – 7 ug/l

Vinyl Chloride – 2 ug/l

Isoconcentration maps showing **PCE groundwater** analytical results obtained **February, 2015**.



Shallow Groundwater (5-15 ft bg)



Deep Groundwater (15-30 ft bg)

Pilot Testing & Goals

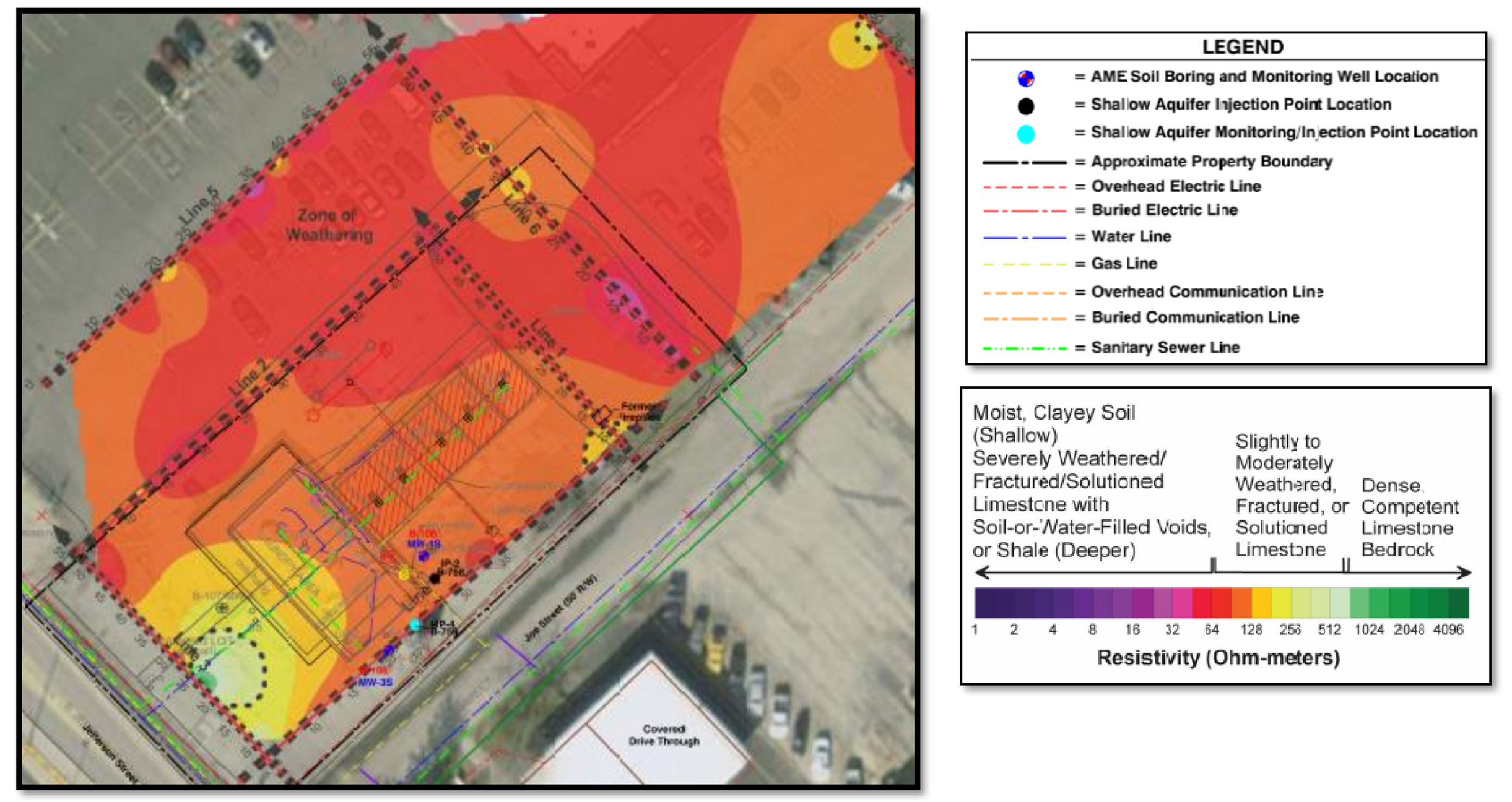
- Vet geophysical report to use discovered pathways for full-scale implementation.
- Evaluate ZVI response and migration in identified zones of weathering.
- Determine volume of injectant necessary to create a 10-20' wide radius of influence (ROI).
- Determine treatment application timeline.
- Determine full-scale remedial design costs and field application timeline.
- Monitor chlorinated solvent concentration degradation.

Pilot Test Chemical Dosing & Injection Grid

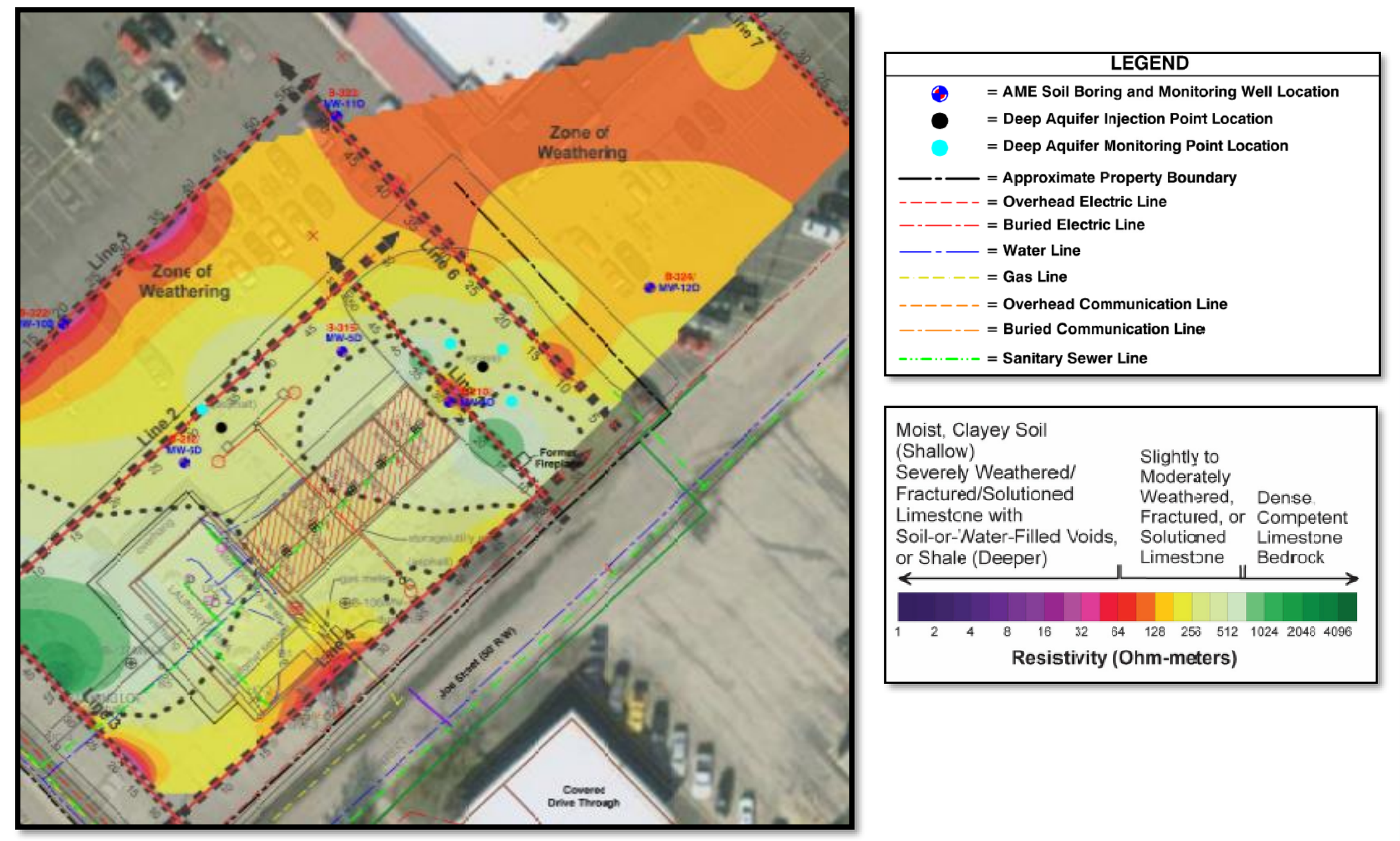
Injectant Dosing

- Engaged chemical vendors to determine an injection dosage rate.
- Based on various soil and groundwater default and site specific input values, a dosage of approximately 50 pounds per vertical foot was selected for the pilot test grid of 3 injection points.

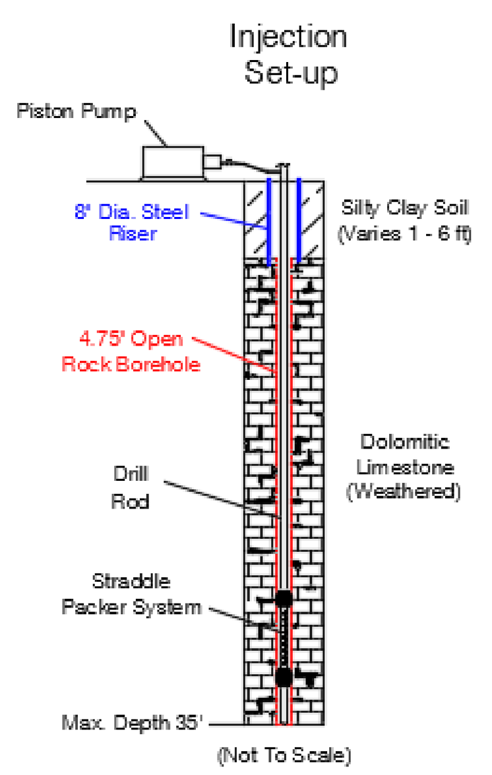
Shallow Injection Points (5-15 ft bg) Paired with Geophysical Evaluations



Deep Injection Points (15-30 ft bg) Paired with Geophysical Evaluations



Injection Point Construction



- Piston Grout Pump (pressures ranged between 50 and 350 psi depending on bedrock competency).
- Pneumatically-inflated packers (isolated 2-ft injection intervals).
- 30% solids mixture (14 gallons of water per 50 pounds of ZVI product).
- Shallow injections occurred between 5 and 15 ft bg, while deep injections occurred between 15 and 30 ft bg.

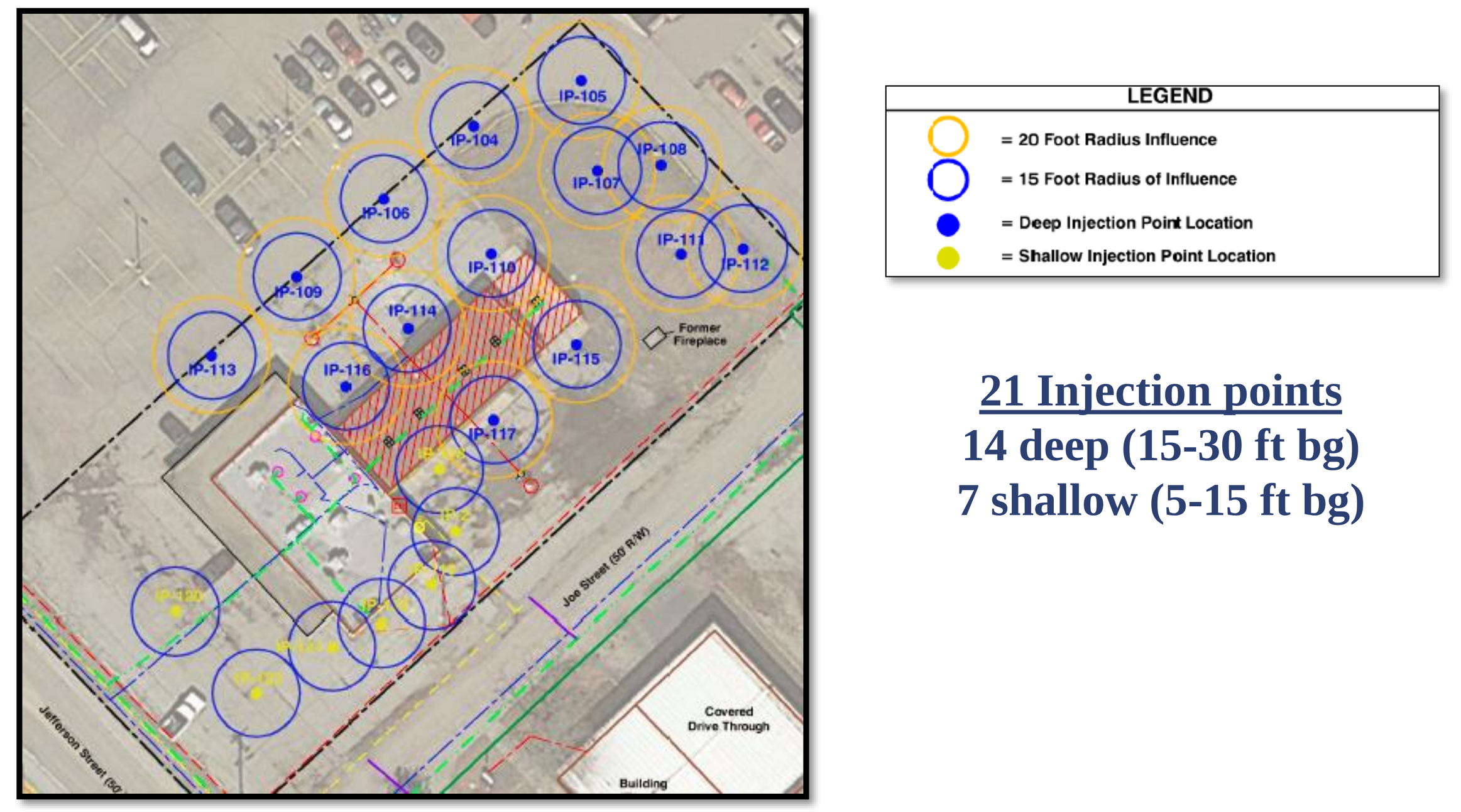
Pilot Test Results

- 64% of prescribed ZVI product was injected (1,027 pounds of 1,600 pounds).
- >20-ft injection radius observed
  - Bailer samples contained iron filings from monitoring points installed 20 feet away from injection point locations.
  - Geochemical response in monitoring wells indicated the injectant water had traveled to the observation wells due to the pilot test injections.
  - 50-100 ft radius of chemical influence observed 3-months post injection.
- Weak iron presence observed in monitoring points installed in more competent zones of bedrock.

Full-Scale Injection Design

Chemical dosage refined based on field application

- On average, approximately 32 pounds of chemical product could be injected per vertical foot.
- Highly connective aquifer - Chemical product appears to remain insoluble and active to reduce solvents up to 100 ft away from the injection point.
- Stoichiometric Demand < Physical Demand
  - Newly calculated dosage ranged between 35 and 40 pounds per vertical foot
    - August Mack selected 25 lbs/ft based on observed aquifer connectivity and chemical reductions after apply approximately 32 lbs/ft and reduced Site-wide dosage from 54,000 pounds to 7,000 pounds.

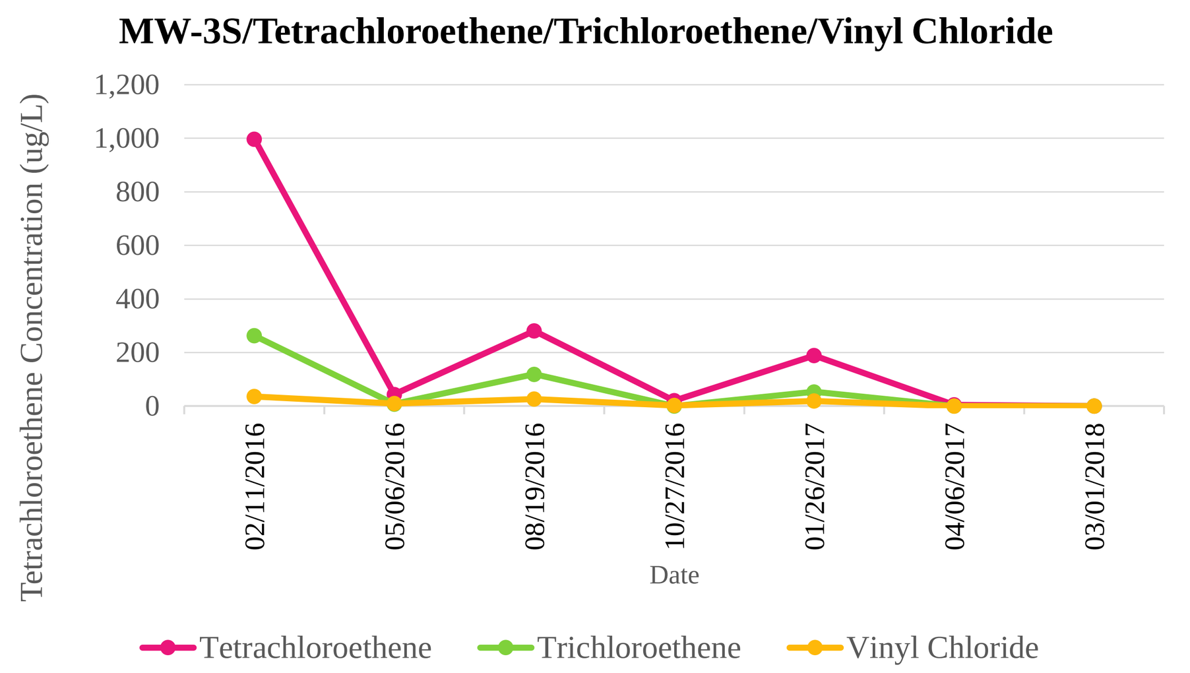


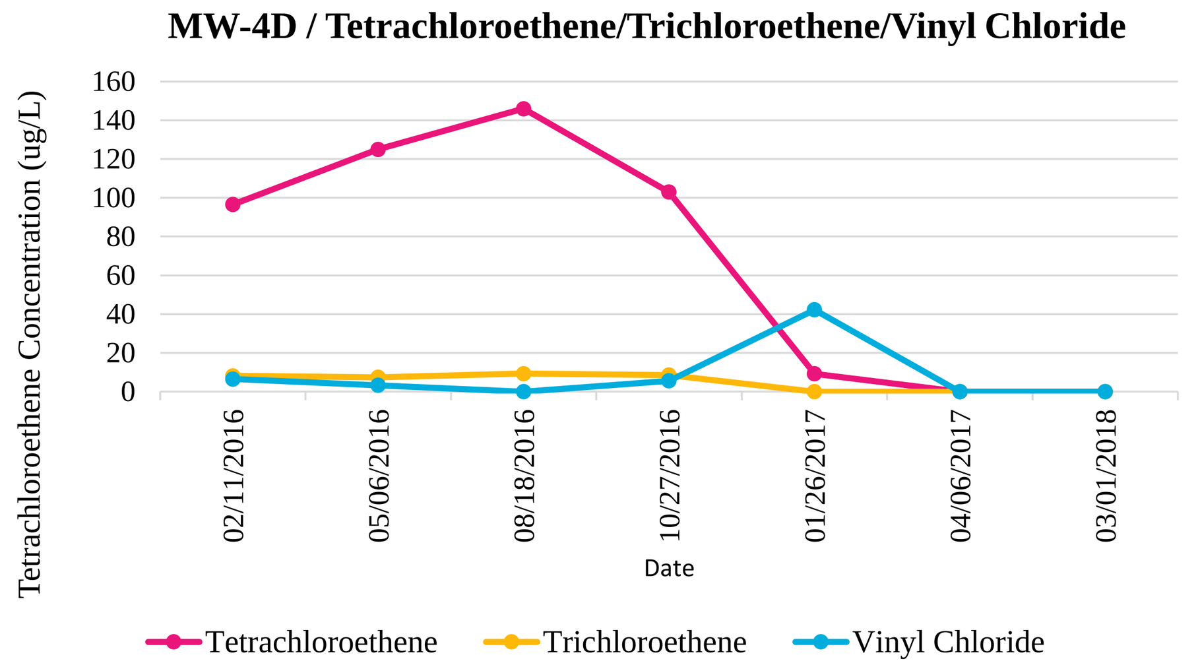
21 Injection points
14 deep (15-30 ft bg)
7 shallow (5-15 ft bg)

Results

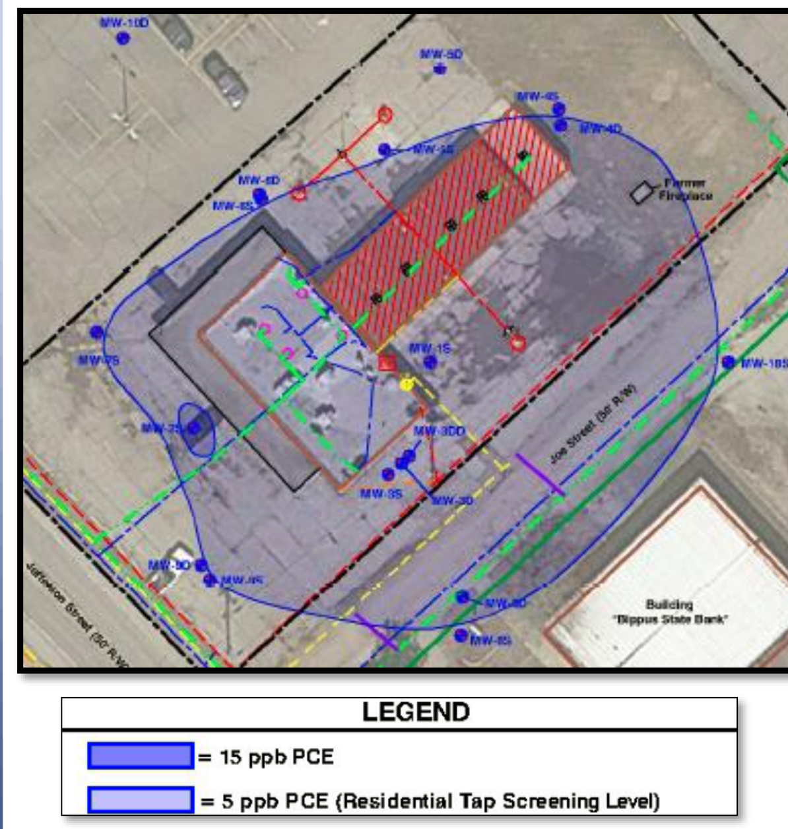
- Significant contaminant reductions (see trend graphs and figures below).
- No significant methane accumulations (between 5 and 290 ppm, 10% of LEL is 5,000 ppm).
- Varying geochemical results (ORP is generally > -100 mV, DO is generally >0.5 mg/L, pH remains neutral 6<pH<8).
- Injected approximately 7,000 pounds of chemical product (~100% injected).

Note: Reduced injection pressures allowed for more intervals to be injected due to less stress on immediate pore space within the borehole.





Shallow Groundwater (5-15 ft bg)



Deep Groundwater (15-30 ft bg)

Isoconcentration maps show **PCE groundwater** analytical results obtained during **March 2018**.