

Enhanced Delivery of Potassium Permanganate Using Horizontal Wells

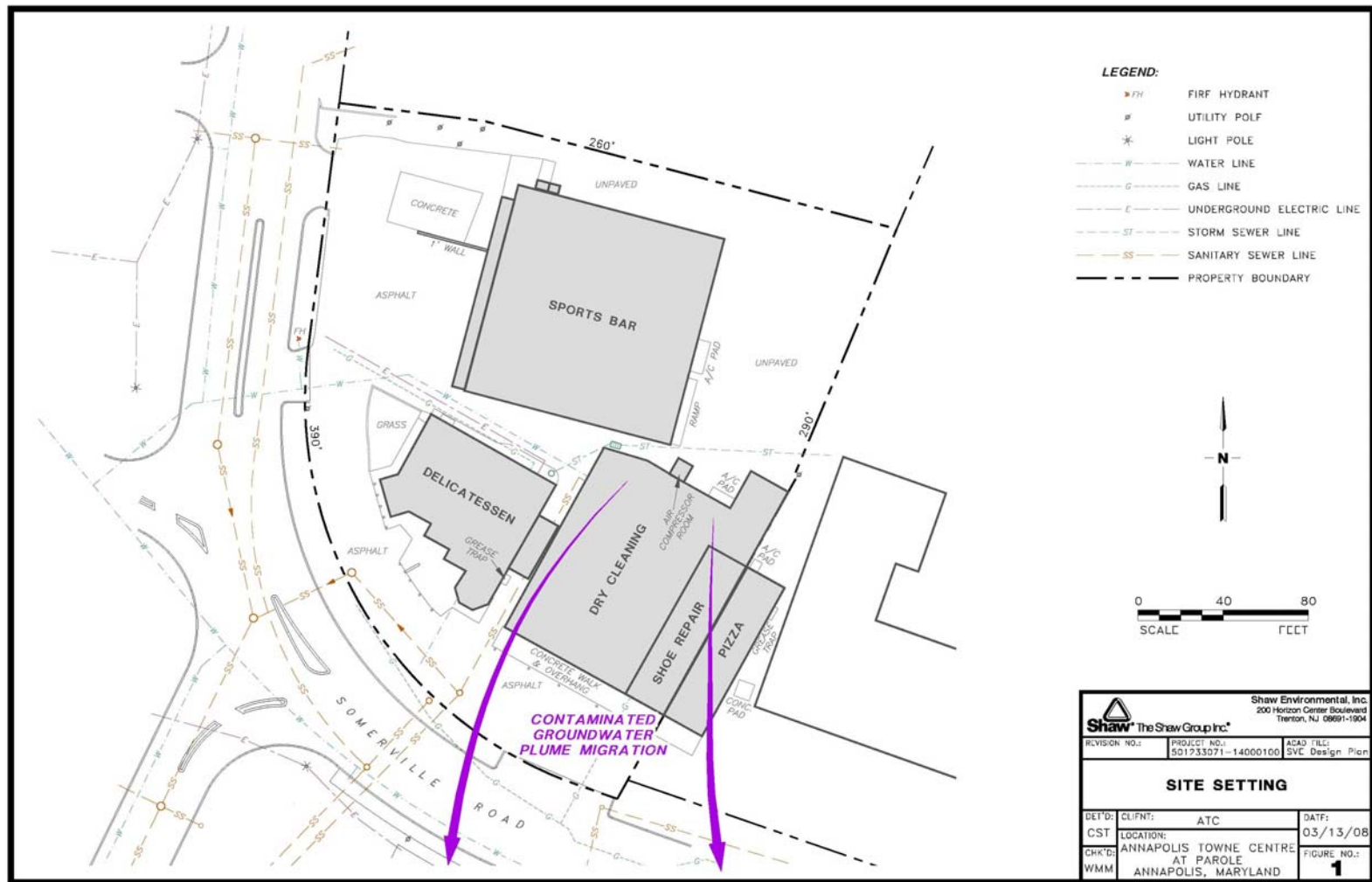
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Overview

- Contaminated Groundwater from Dry Cleaner Site.
- Groundwater Plume under Roads, Buildings, Utility Corridors.
- Limited Access for Vertical Well Injections.
- Site Remediation Takes Place on Active Construction Site.

Source Area Setting

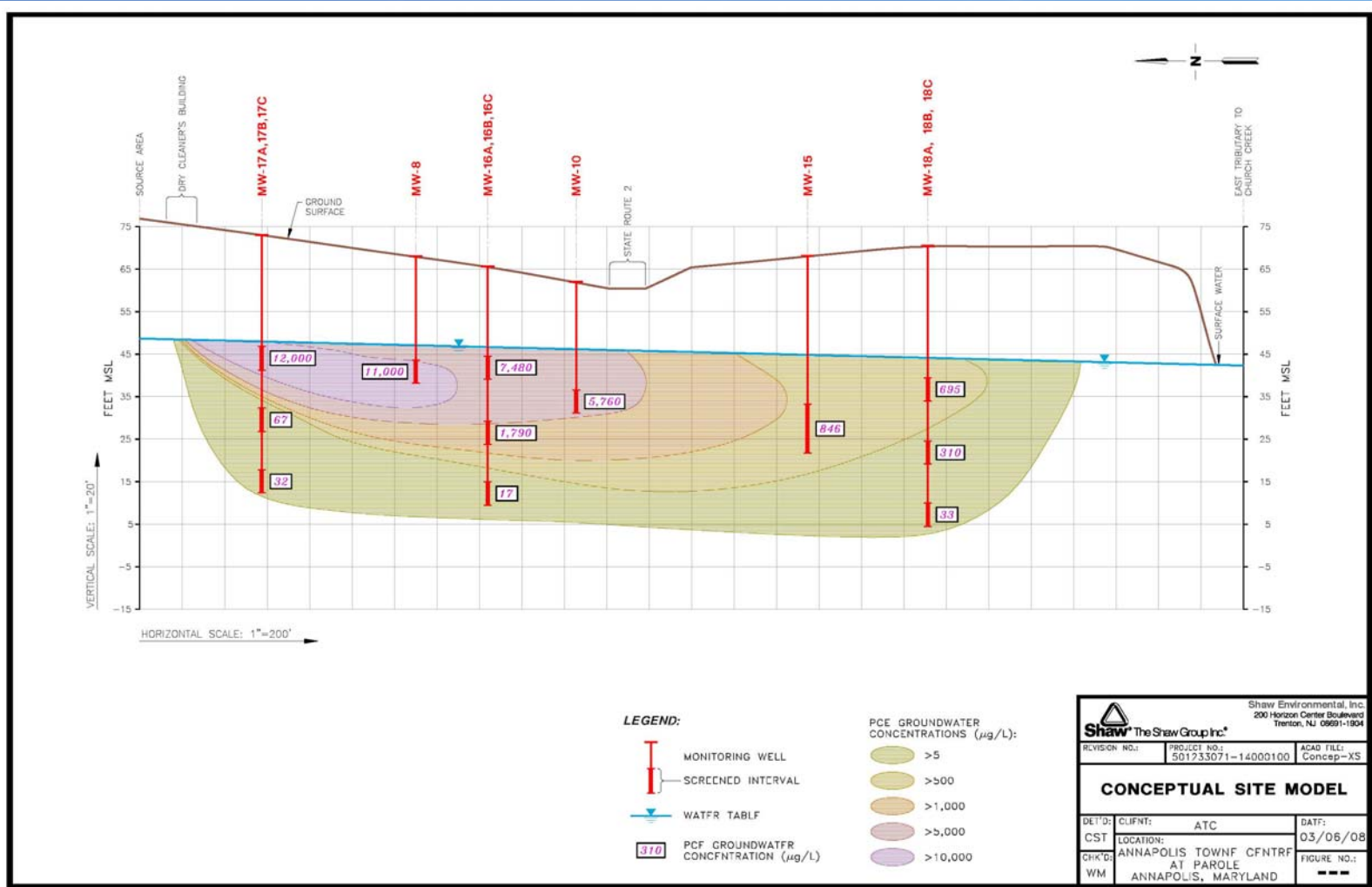


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Conceptual Site Model

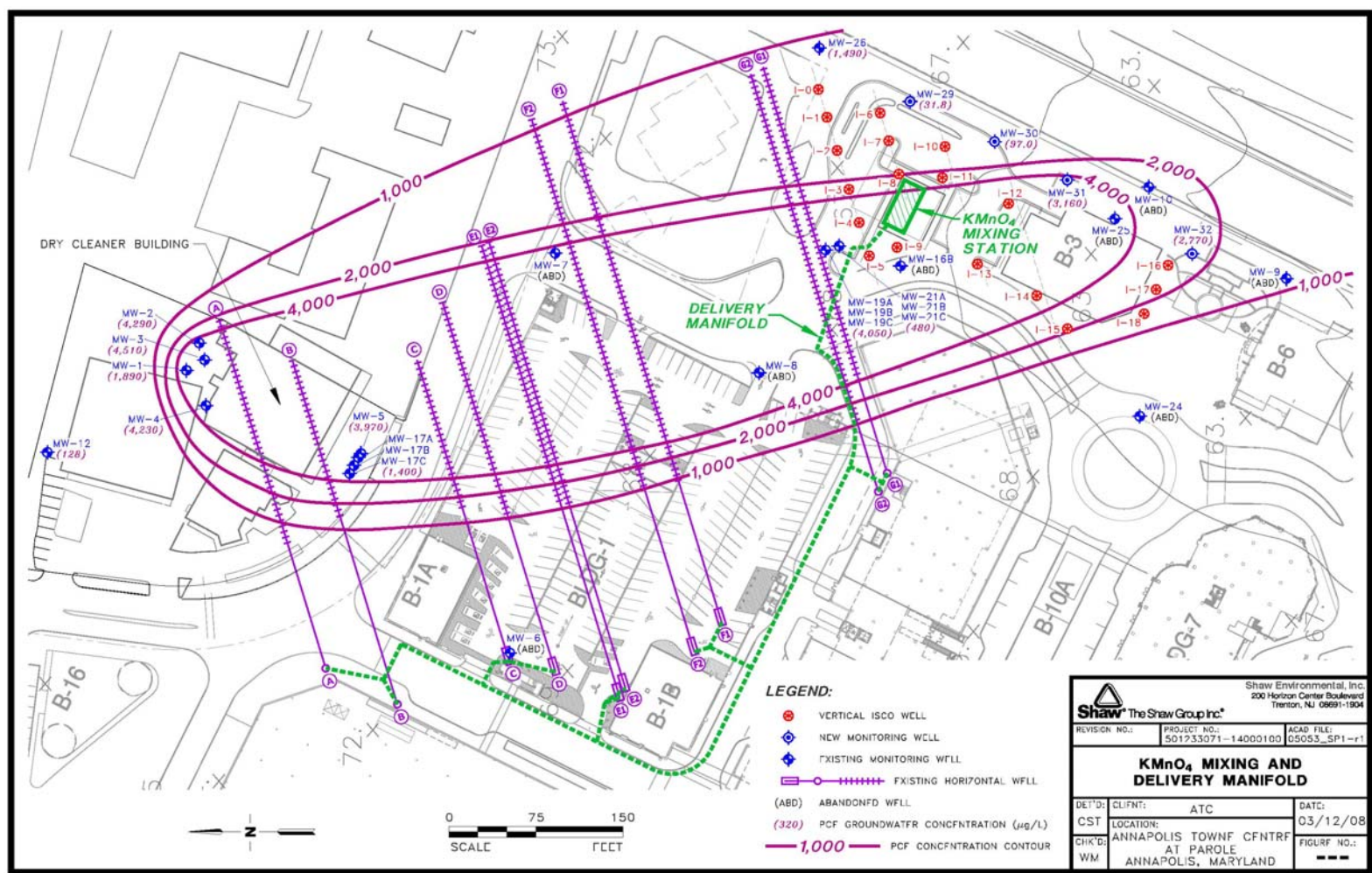
- Site Soils are Silty Sands to 65 feet.
- Groundwater Flow Rate – 0.2 to 0.4 fpd.
- Low Soil Oxidant Demand – 1.5 to 2 g/kg.
- Contaminated Groundwater Zone is 25 feet to 55 feet bgs.

Cross-Section of GW Plume



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Horizontal Well Design Layout



Horizontal Screen Design

- Modeling to Achieve Uniform Distribution of KMNO_4 through Length of Well Screen.
- 3-d Finite Difference Flow and Transport Model Used to Design the Screen Pattern.
- Waterloo Hydrogeologic's Visual MODFLOW, version 4.1.0.143.
- Design Specifies the Percent Open Area of the Well Screen to Generate Uniform Distribution.

Horizontal Screen Design

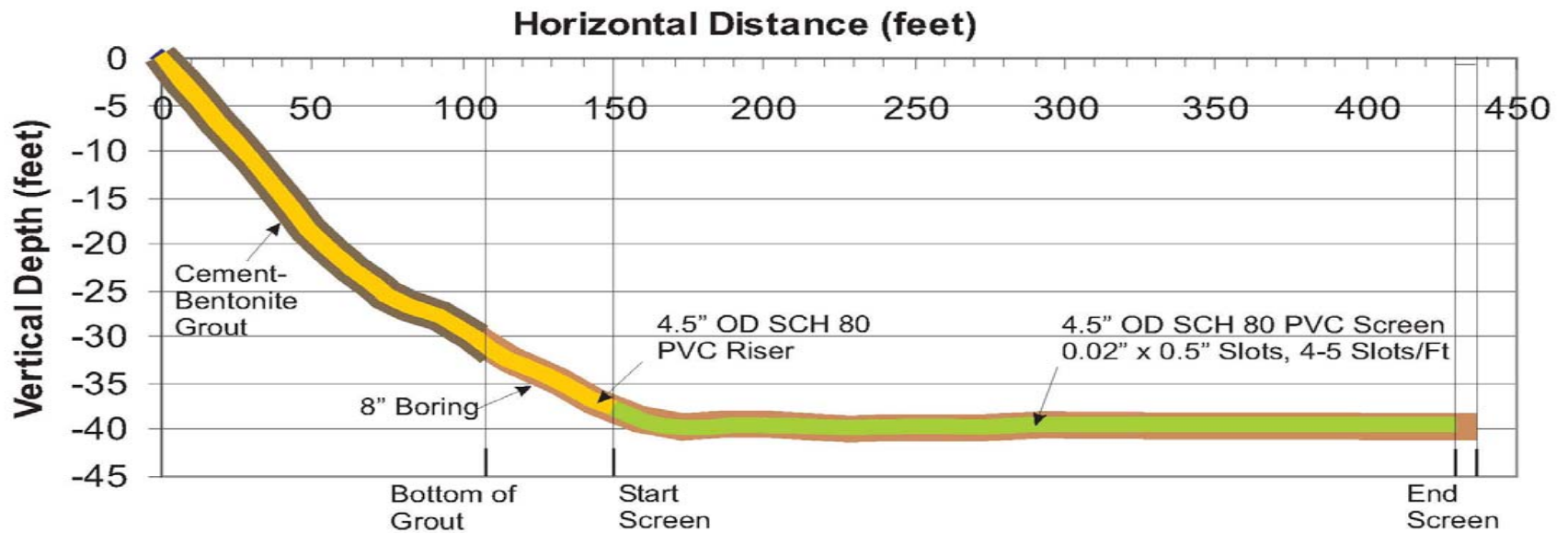
- Analysis Consists of Iterative Calculations of Pipe Flow, Slot Flow, and Formation Flow.
- Parameters Provided Are: Pressure Along Screen, Flow Through Screened Pipe, Incremental and Cumulative Injection of Fluid into the Formation.
- The Analysis Requires Definition of a Series of Pipe Specifications and Hydrogeologic Parameters.

Horizontal Screen Design

- Model Simulates the Injection Fluid Moving Down the Well, Through the Screen Slots, and Into and Through the Formation.
- The Necessary Open-Area Requirements for the Well Screens ranged from 0.0357 to 0.0429 Percent Open Area.
- At Standard Slot Width of 0.02-inch, the Required Number of Slots was Calculated for Each Length of Screen.

Horizontal Screen Design

Well G2 Construction Diagram



Drilled 10-12-06

End of Boring 437' Horizontal Distance, 442' Measured Depth

Horizontal ISCO Well Installation

- Directional Technologies, Inc. of Connecticut did Directional Drilling and Horizontal Well Installation.
- Installation of 10 Horizontal Wells Required 3,870 feet of drilling.
- All Horizontal Wells Installed Single-Ended.

Horizontal ISCO Well Installation

- Design: 7 Rows of Horizontal Wells.
- Some Rows Used 2 Wells at Different Depths – 30 and 40 feet bgs.
- Installation Complete in 35 Days.

Horizontal Well Installation



ISCO 1st Injection

- Injection into 10 Horizontal Wells with total of 2,330 feet of screen.
- Flow Rate = 11.7 gpm per well (avg).
- Batch Process - 10,000 Gallons per Batch.
- Injection Time = 85 Minutes per Batch.
- ISCO 1st Injection was 340,000 gallons.

Permanganate Mixing Station



Injection HDPE Manifold



HDPE Manifold With "T" Connection to Injection Well



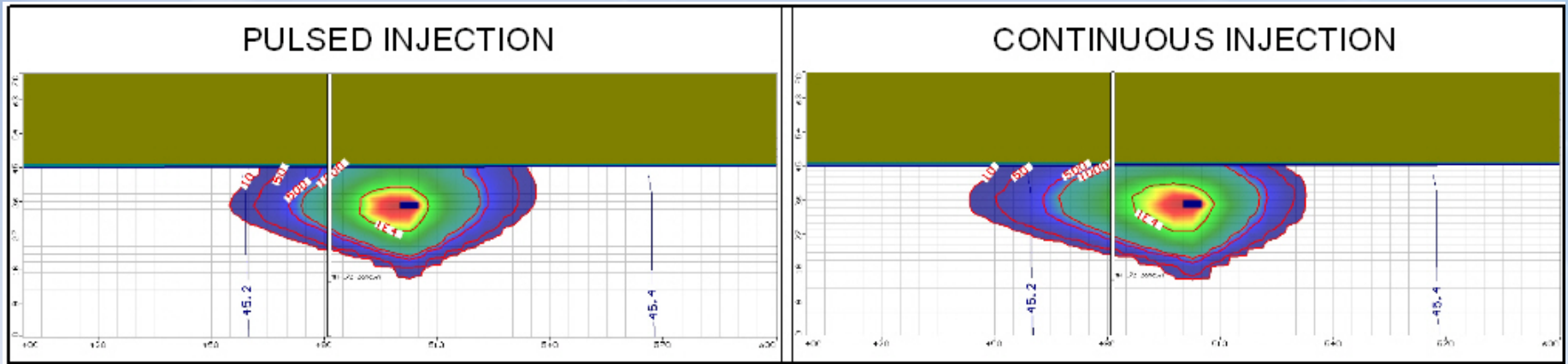
Horizontal Injection Well With Well Cap



Modeling Scenarios for Improved Delivery

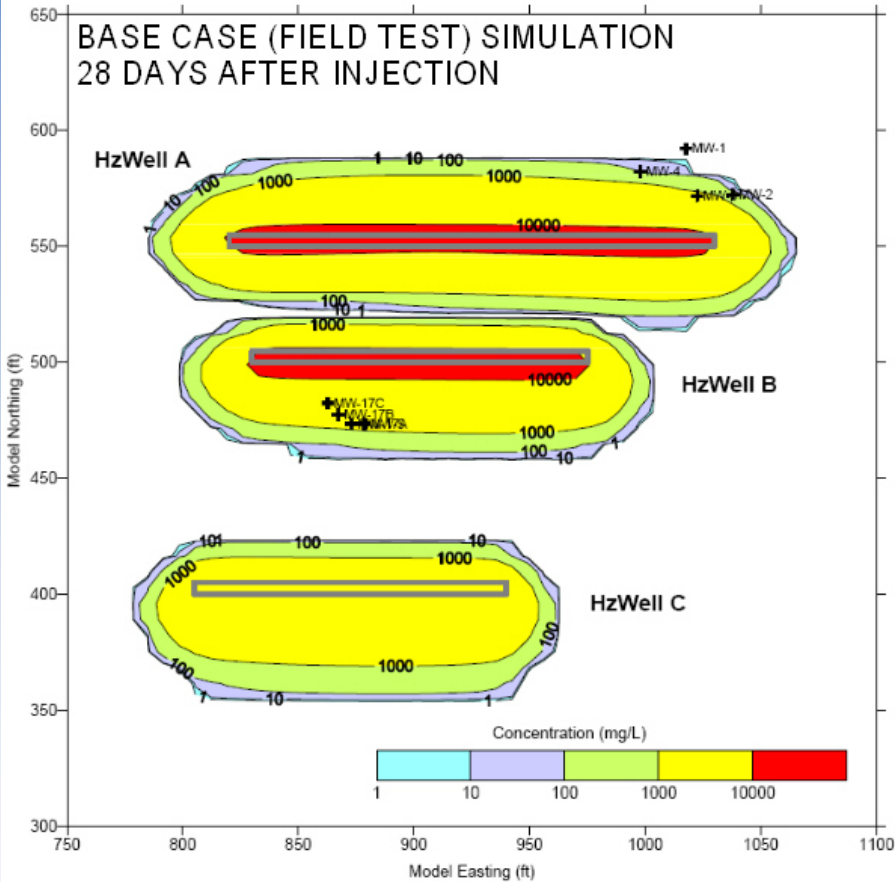
- After 1st Injection, Model was Recalibrated.
- Alternatives for Improved Delivery were Modeled.
- Pulsed Injection vs. Continuous Injection.
- Injection into Vertical Wells to Accelerate Delivery.
- Combination of Injection and Extraction.

ISCO Distribution Modeling

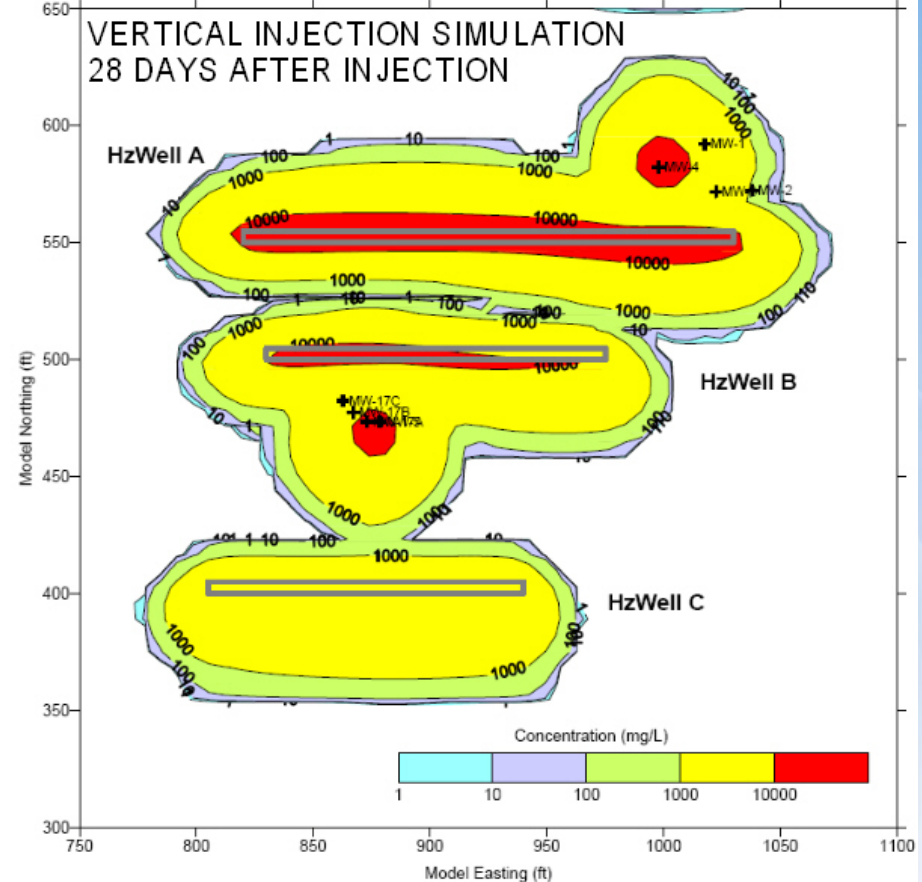


ISCO Distribution Modeling

BASE CASE (FIELD TEST) SIMULATION
28 DAYS AFTER INJECTION

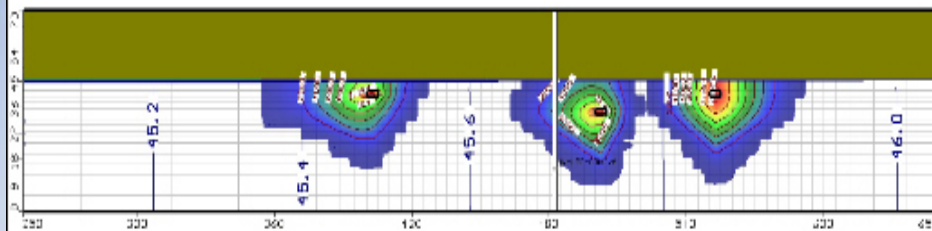


VERTICAL INJECTION SIMULATION
28 DAYS AFTER INJECTION

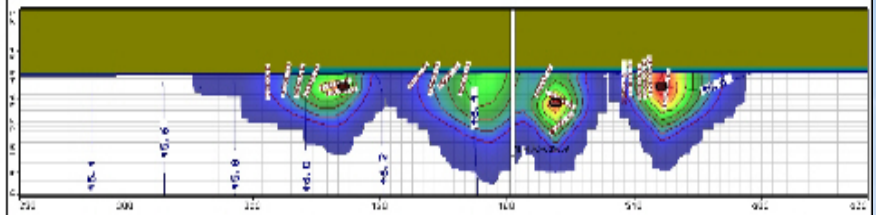


Base Case and Alternative Case Modeling

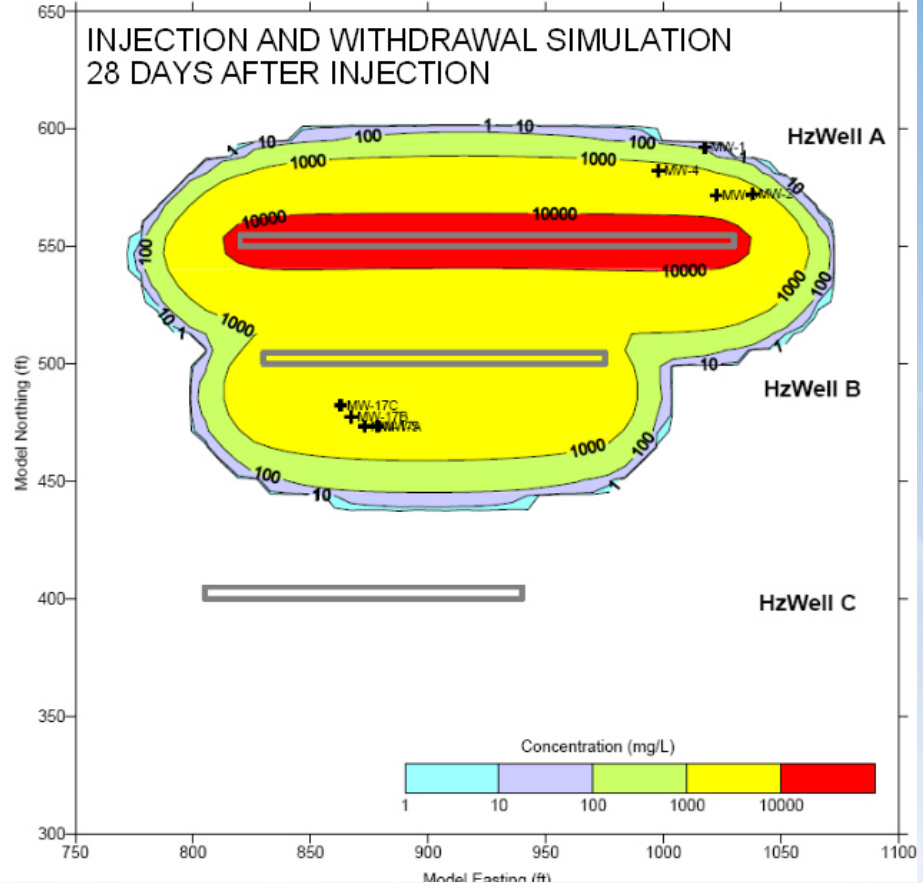
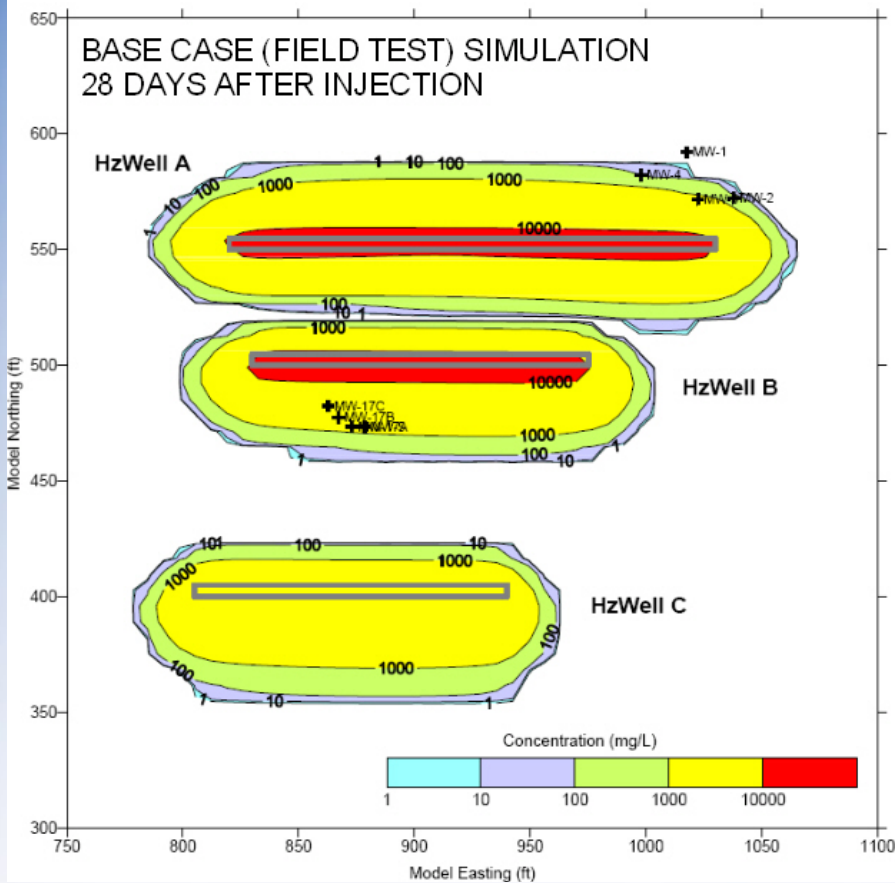
BASE CASE CROSS SECTION



VERTICAL INJECTION CROSS SECTION



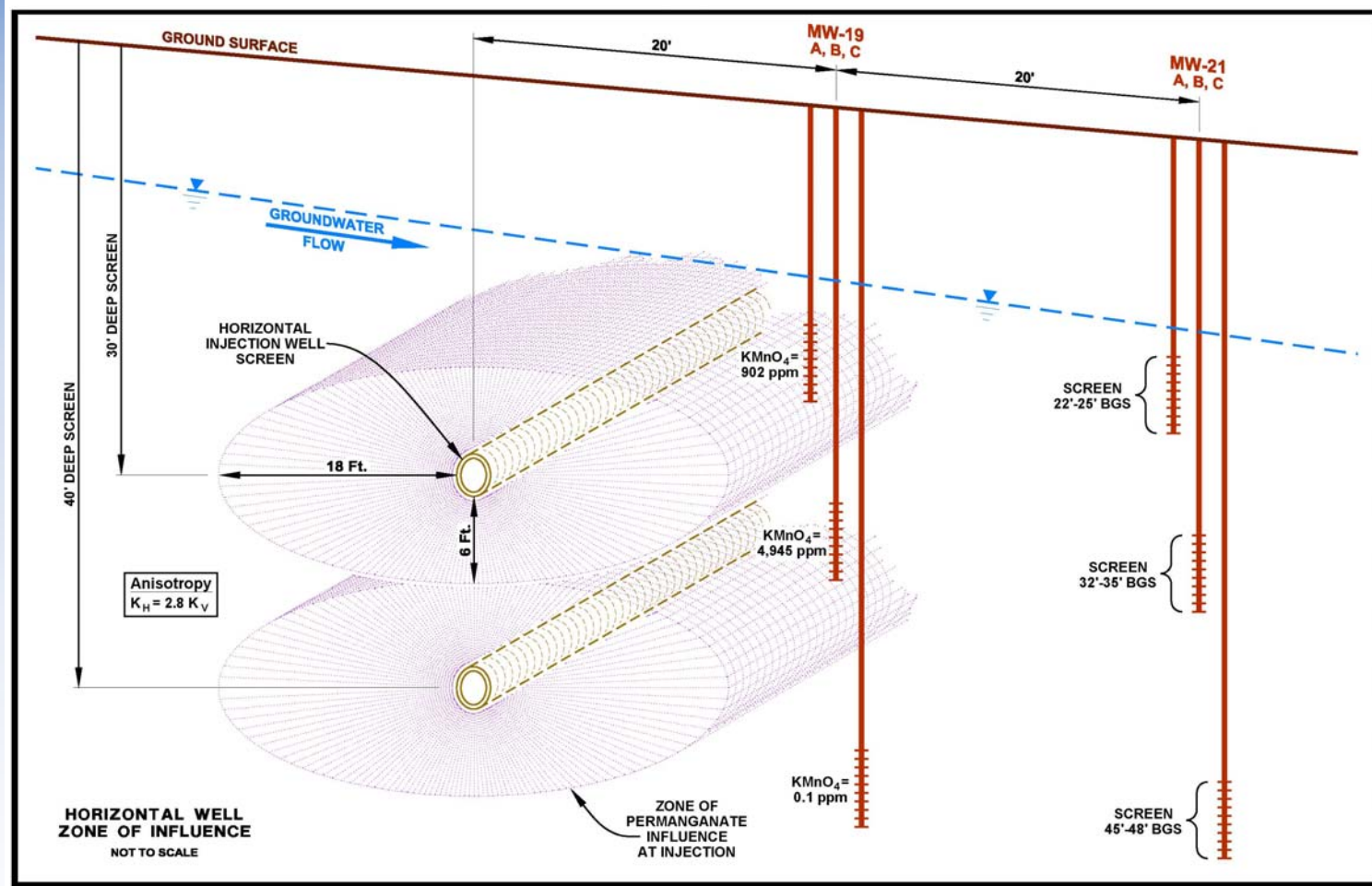
Injection and Extraction Simulation



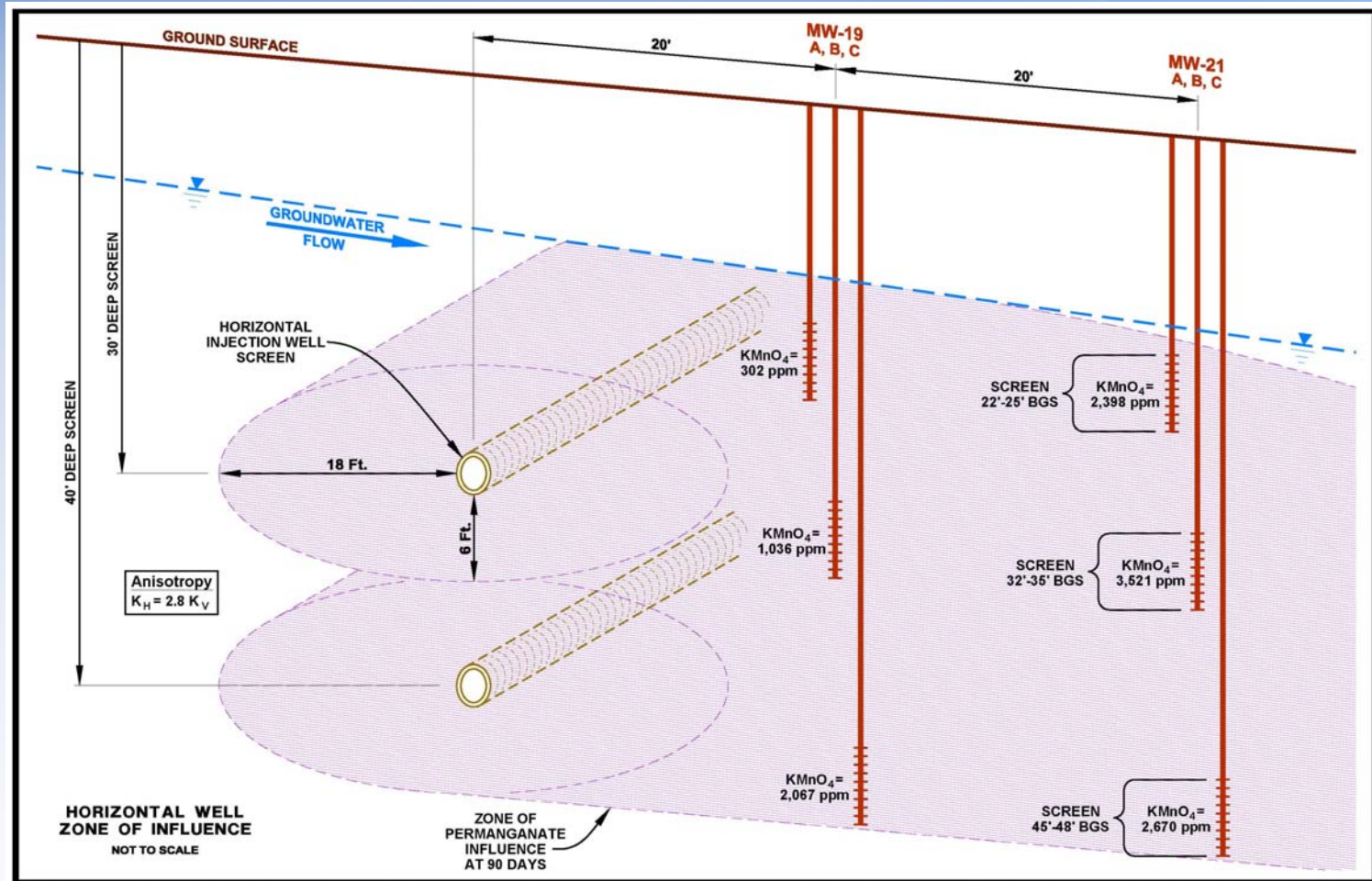
ISCO 2nd Injection

- ISCO 2nd Injection was 1,032,333 gallons.
- Average Injection Rate was 38,235 gallons per 10-Hour Shift.
- Maximum Injection Rate was 55,000 gallons in 10-Hour Shift.
- 81 Tons of KMNO_4 Injected in 26 Days.

KMnO₄ Distribution at Initiation of Injection



KMnO₄ Distribution at 90 Days After Injection



Reduction In PCE Concentrations

- Source Area MWs:
 - Pre-Treatment PCE Concentrations as high as 13,000 ppb.
 - Post-Treatment PCE Concentrations from ND to 400 ppb.
- Downgradient MWs:
 - Pre-Treatment PCE Concentrations as high as 8,000 ppb.
 - Post-Treatment PCE Concentrations from ND to 1,840 ppb.

Summary – Advantages of Horizontal Wells

- Length of Screen Allows for Higher Volume Injections – Faster, Less Costly Injection Process.
- Smaller Footprint, Less Interference with Site Activities.
- Allow injections in areas where Streets, Utilities, and Buildings interfere with Vertical Wells.
- Questions?