Dual Reactive Barrier Walls for the Remediation of CHC Contamination, Watervliet Arsenal, New York: Design and Installation of an Innovative Technology

Christopher Gaule[1], Kenneth J. Goldstein[2],and Curtis A. Heckelman[3]

Abstract

The Watervliet Arsenal (WVA) located in Albany, New York, discovered chlorinated hydrocarbons (CHCs) in its groundwater in concentrations that exceeded MCLs by several orders of magnitude. These CHCs were entering the WVA storm sewer system and discharging off-site. The U.S. Army Corps of Engineers and Malcolm Pirnie implemented an innovative remedial technology using an in-situ permeable reactive wall. This is a *passive* technology based on the use of commercially available metallic iron filings. As groundwater flows through the wall, the *zero-valent iron* reductively dehalogenates CHCs through the corrosion process into non-toxic chloride ions, ethenes and ethanes.

Bench-scale tests were performed by EnviroMetal Technologies, Inc. (ETI) to determine required residence times to degrade the CHCs to below MCLs. Two and a half days of residence time was required to degrade vinyl chloride to below the MCL (2.0 ug/l). Two reactive walls totaling approximately 285 ft. in length were installed through overburden and weathered bedrock using conventional excavation methods. Trenches were approximately 12 ft. in depth and 30 inches wide and were keyed into competent bedrock. A mixture of iron filings and sand was used to backfill the trenches. The reactive iron filings were delivered in bulk to a batch concrete manufacturing facility located in close proximity to the site. Iron and sand were weighed and mixed at the batch plant to the required proportions. The iron/sand mixture was delivered to the site using cement transit mixer trucks. One of the reactive walls was installed to intercept groundwater immediately down gradient from the source area while the second wall intercepted the leading edge of the plume before it entered the storm sewer system.

Reactive walls greatly reduce Operation and Maintenance (O&M) costs. In this case, savings are estimated at over $3 million for the 30-year life of the project. In addition, final design/build costs ($548,000) were approximately a third of the cost of a conventional remediation technology. Though groundwater velocities are slow (0.15 ft/day), samples taken one month after installation indicate CHC concentrations below detection limits within the reactive trenches. In addition, groundwater flow modeling and particle tracking revealed important design and installation measures to preclude contamination from flowing under the reactive walls.

Background

The Watervliet Arsenal (WVA) is a 140-acre government-owned installation located in the City of Watervliet, New York, which is west of the Hudson River, and five miles north of the City of Albany. A large, swampy, 14-acre area located to the west of the Main Manufacturing Area of the WVA, known as the Siberia Area, was purchased by WVA in the early 1940's and immediately filled in with debris consisting of slag, cinders, wood, brick and other debris of unknown origin. Once filled in, two areas were used for burning combustible material (i.e., scrap lumber and other solid waste) and liquids until 1967. During the period of 1994 through 1998 an RCRA Facility Investigation was conducted to assess the nature and extent of contamination in the area.

[1] Senior Project Hydrogeologist, Malcolm Pirnie, Inc., 15 Cornell Road, Latham, NY 12110, USA, Ph 518-786-7249, Fx 518-786-8645, cgaule@pirnie.com (corresponding author)
[2] Senior Associate, Malcolm Pirnie, Inc., 104 Corporate Park Dr., White Plains, NY 10602-0751, USA, Ph 914-614-2615, Fx 914-614-9286, kgoldstein@pirnie.com
[3] Design Manager, United States Army Corps of Engineers, Baltimore District, 10 South Howard Street, Baltimore, MD 21201, USA, Ph 410-962-2783, Fx 410-962-6732, Curtis.A.Heckelman@nab02.usace.army.mil

The site consists of three unconsolidated deposits overlying a shale bedrock. The unconsolidated deposits consist of an upper fill unit, approximately four feet thick, the second unit is a clayey silt, approximately two to six feet thick which extends to weathered bedrock. The third unconsolidated unit is a fluvial sand and gravel, and is found primarily in the Northwest Quadrant of the site. The majority of the unconsolidated deposits at the site are saturated and are hydraulically connected with the weathered bedrock. During the majority of the year the water table is present in the overburden deposits, but during seasonal low water table conditions the water declines into the weathered bedrock.

The results of the RFI indicated that the majority of the groundwater contamination detected in the Siberia Area was confined to the Northeast Quadrant and was primarily CHCs. Figure 1 presents the limits and geometry of the CHC plume. The contamination in this area has migrated along the shallow groundwater flow paths in the overburden and weathered bedrock towards the site sewer line, which bisects the Siberia Area in a north-south direction. The maximum concentrations of volatile organic compounds detected in these units are as follows:

Vinyl chloride 1,700 µg/l
cis-1,2-Dichloroethene 4,200 µg/l
2-Butanone 11 µg/l
Trichloroethene 1,500 µg/l
Tetrachloroethene 1,100 µg/l
Xylene 43 µg/l
1,1-Dichloroethene 7 µg/l
trans-1,2-Dichloroethene 11 µg/l
Benzene 20 µg/l
Toluene 10 µg/l
Ethylbenzene 7 µg/l

Figure 1 – Extent of CHC Plume, Siberia Area, Watervliet Arsenal

Due to the location of the groundwater contamination, in WVA's primary shipping and receiving area, and the need to have unrestricted access to the Northeast Quadrant for storage, a remedial technology was required which would not compete for the valuable space. In order to meet these requirements a permeable reactive wall was considered to be the appropriate remedial technology. In order to determine the applicability of this technology to the Siberia Area groundwater contamination several, phases of study were completed. The following presents a summary of the methods utilized and their results.

Bench Scale Treatability Testing

In order to determine that the permeable reactive wall concept was suitable for treating the contaminated groundwater in the Siberia Area and to develop design parameters for such a system, bench scale treatability testing was conducted. The testing was performed by EnviroMetal Technologies, Inc., using contaminated groundwater collected from a monitoring well in the Siberia Area and zero-valent iron particles as the reactive agent. The specific goals of the bench scale treatabilty testing were to provide design parameters such as the volume of zero-valent iron required to achieve residence times, the degradation rates of the CHCs, and the effects of inorganic precipitation on the walls performance.

The test column used during the study consisted of 50-cm tube with several sampling ports along its length to collect samples throughout the testing period. The column was packed with 100% zero-valent iron. The site groundwater was then pumped through the reactive column at a flow rate of 1.0 ft/day, which was significantly higher than the site groundwater flow rates. This flow rate was used to conduct the testing in the required time frame of the project. Based on the analytical data collected from the sampling ports, and the input flow velocity, degradation rates were calculated using the first-order kinetic model. These degradation rates were later recalculated using the site specific groundwater flow velocity of 0.15 ft/day.

The longest residence time required to degrade the VOCs to the New York State MCL was associated with vinyl chloride and was estimated at 66 hours. At a flow velocity of 0.15 feet per day and a residence time of 66 hours (~2.5 days), a reactive wall, consisting of 100% reactive iron, would have to be 0.41 feet in thickness to degrade the vinyl chloride from an initial concentration of 1,700 μg/L to the MCL's of 2 μg/L. Figure 2 presents the required residence times to meet NYS MCLs. This wall thickness calculated during the testing did not account for a safety factor. Therefore, a safety factor of 2 was applied to the results of the treatability testing for the full-scale application, which resulted in a design thickness of 0.82 feet of pure reactive iron. The results of the treatability testing also indicated that precipitation of carbonates and other inorganic precipitates would be minimal.

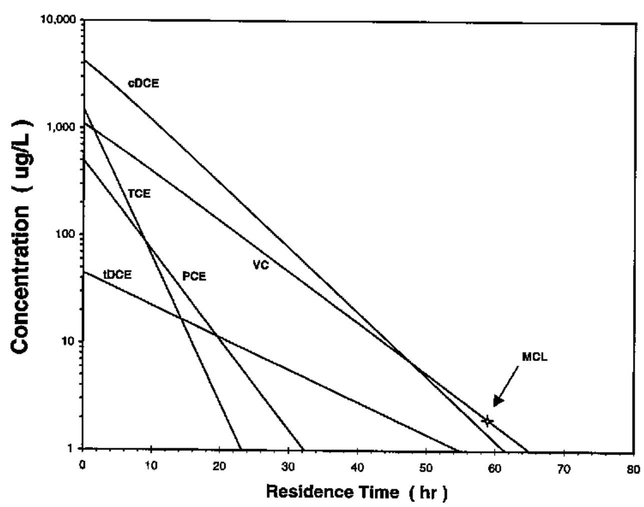

Figure 2 – Bench Scale Treatability Residence Time Results

Groundwater Modeling

Groundwater modeling was conducted to optimize the location and orientation of the reactive walls. The groundwater model simulated the groundwater flow directions (vertical and horizontal) under various reactive wall configurations. The simulations included the use of a funnel and gate scenario versus a continuous reactive wall. A total of 11 configurations of the reactive wall (continuous wall and funnel and gate) system were simulated. Particle tracking used during the modeling evaluated the wall's ability to intercept the contaminated groundwater without flow escaping treatment.

The results of the modeling indicated that the use of funnel and gate system would not be an appropriate solution. It was found that the impermeable portion of the funnel increased the hydraulic gradient at the upgradient face of the wall and forced the contaminated groundwater to pass under the wall and into the underlying bedrock, escaping treatment. As a result of the model, a continuous reactive wall was selected. In order to achieve maximum treatment of the groundwater plume it was determined that two reactive walls would be required, one at the downgradient extent of the plume and the other closer to the source area. Figure 3 presents the location of the reactive walls and particle tracking results generated during the modeling.

Figure 3 – Reactive Wall Orientations and Particle Tracking Results

Design and Construction

During the design of the system two alternate methods of construction were considered, conventional excavation and backfilling, and continuos trencher with backfilling. Both of these methods were determined to result in an excavation which would be larger than the 0.82 feet required to meet the residence time for degradation. To reduce the expense of placing additional reactive iron in the wider walls it was determined that the reactive iron would be mixed with clean washed sand in a ratio sufficient to maintain the required amount of iron. The construction width of the walls would be approximately 30 inches, resulting in a mix ratio of 1:1 by weight. The weigh ratio was controlled by mixing the iron and sand at a cement mixing batch plant. To ensure the quality control on the iron:sand mix the cement batch plant provided the weigh tickets for each truck of material delivered to the site. In addition to these controls Malcolm Pirnie also conducted magnetic segregation of grab samples throughout the construction process to confirm the mix ratio.

The final reactive walls consisted of two walls with a total length of 285 feet; each wall was keyed into the top of competent bedrock at a depth of approximately 12 feet below the ground surface. Monitoring wells were installed inside the reactive walls, at three locations per wall, to monitor the reactions occurring inside the walls and to monitor for the production of precipitates during the operational life of the walls. During the construction of the trenches a total of 326,360 pounds of sand and 330,940 pounds of reactive iron were used. Figure 4 presents the constructed profile along the length of one the walls installed. The cost of design and construction for this project was $548,000. Due to the limited operation and maintenance associated with the syste, it has been estimated that during the 30-year life of this project a total of over $3 million will be saved.

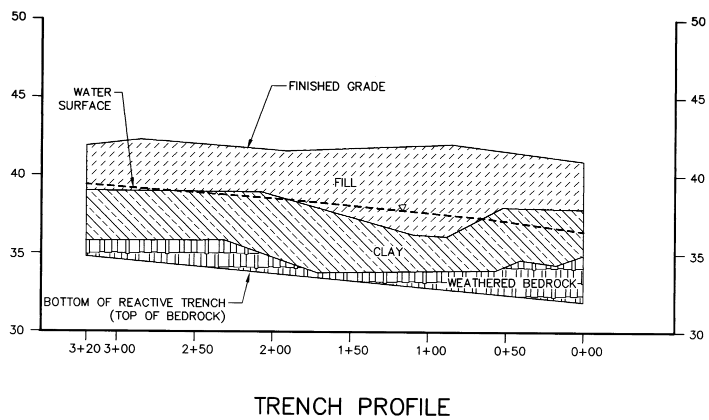

Figure 4 – Reactive Wall Profile

The results of groundwater samples collected following the completion of the construction show that the CHCs in the reactive wall are below detection limits. The system continues to be monitored, both hydraulically and analytically, on a semi-annual basis.

This project was awarded the Design Excellence Award by the Consulting Engineers Council of New York State.