Successful Remediation of Solvent-Contaminated Groundwater Using a Funnel and Gate Constructed by Slurry Trench Methods

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ABSTRACT: One of the more difficult problems facing our cities is the reuse of former manufacturing facilities. In Seattle, WA, a former manufacturing site was contaminated with chlorinated solvents. Previous attempts to cleanup the site using pump and treat systems failed because the soils were heterogeneous, making it difficult to control the contamination. The owner and his consulting engineer decided that the technology with the highest probability of success for the site was a funnel and gate system using zero-valent iron to treat the groundwater. In 1999, reactive iron treatment was generally well accepted, but construction methods for its installation in deep trenches were still developing. As a result the owner, the engineer, and a slurry trench engineer developed and implemented an innovative plan to install a funnel and gate system up to 35 ft deep, using cement-bentonite (CB) slurry walls for the funnels and bio-polymer degradable slurry to install the iron-filled gates. One year after installation measured chlorinated solvent destruction efficiencies are greater than 95%. Downgradient from the gates, natural attenuation processes, including intrinsic biodegradation, are further reducing solvent concentrations to below surface water cleanup standards before reaching a public waterway less than 200 ft from the site.

INTRODUCTION: In the Ballard district of Seattle, WA, the previous operations of a defunct window manufacturer resulted in chlorinated solvents in the groundwater on a site that is now desirable for commercial and residential development. The site was used for metal anodizing, painting, and light manufacturing from the 1940's until 1989. Furthermore, the site is within 200 ft of the Lake Washington Ship Canal and adjacent to a public area that is the third most popular tourist destination in the city. Existing buildings on the site, railroad tracks, public walkways, and nearby properties preclude large excavations for the remediation. The site was also used as a path for joggers and tourists.

The groundwater plume consisted of tetrachloroethylene (PCE) and its degradation products trichloroethylene (TCE), cis-1,2-dichloroethene (cis-DCE), and vinyl chloride (VC). Two potential source areas were identified with maximum detected constituent concentrations in groundwater of 50 mg/L PCE, 23 mg/L TCE, 8 mg/L cis-DCE, and 0.8 mg/L VC. Areas of high pH (up to pH 12) were also found in the groundwater. Upper soil layers consisted of heterogeneous fill material overlying stratified estuarine deposits, forming two distinct water-bearing zones. Chlorinated solvents were found up to 32 ft deep beneath the surface where a dense, relatively impermeable till tends to prevent vertical migration of contaminants.

Prior to construction, the site was a narrow, paved parking lot and gravel alley separated by an active railroad track. From fence line to building line the site was only about 70 ft wide, including the railroad track. The alley provided access to an unloading dock with a 4 ft depressed passageway between the railroad tracks and the loading

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docks. A domestic water pipe, storm and sanitary sewers, monitoring wells, bollards, overhead wires, and underground vaults all were located on the site.

DESIGN: The combination of chlorinated solvents in the groundwater and the heterogeneous soils presented the primary challenges to the remedial design. The potential depth of DNAPL occurrences would have made excavation prohibitively difficult and expensive, while soil heterogeneities limit the effectiveness of many in-situ treatment technologies. A permeable reactive barrier (PRB) is an in-situ technology that treats chlorinated solvents in groundwater and is not limited by soil heterogeneities. This technology uses zero-valent iron, which can destroy PCE and TCE dissolved in groundwater with reductive dehalogenation. In order to determine the amount of zero-valent iron required, a bench scale test was conducted. The testing program considered the site contaminants, use of bio-polymer slurry and type of iron. The results of the test provided the recommended residence time and wall thickness.

Using the results of the bench test, the designers devised a layout for the funnel and gate. The design had to recognize the constraints of the site and the effect on construction, as well as on the final development of the site. A 330-foot-long funnel and gate, consisting of three CB cutoff walls (funnels) and two 45-foot-long permeable reactive gates, was designed to capture and treat the chlorinated solvent plume. The 3-foot wide gates were designed with a 50/50 mixture of iron filings and sand. The gates were designed to be constructed using biodegradable, guar-based slurry, which avoided the need to drive sheet piling saving significant cost. The barrier was imbedded three feet into the dense, impermeable till layer to prevent underflow.

In addition to the funnel and gate, the design considered natural attenuation and methods to enhance attenuation. In developing the final wall thickness, natural attenuation of the solvents between the wall and the ship canal was considered. The model was a numerical description of the advective/dispersion equation, using empirically derived decay rates. As a contingency, a system of wells was designed to inject oxygenating compounds downgradient of the funnel and gate, in case the funnel and gate failed to perform as expected. Finally, disposal of excess soils resulting from construction was considered. After testing and meeting acceptance criteria, excess soils could be reused as fill to level the loading dock area.

CONSTRUCTION: Construction of the funnel and gate began with a number of site preparation activities including removing asphalt, removing a guard shack, installing security fencing, setting up a slurry mixing and pumping plant, and designating soil staging areas. Due to the close proximity of the public, the owner made personal visits to many of the nearby business and carried out a concerted effort to make the public aware of the construction activities planned for the site. Once these measures were in place excavation of the slurry trench began to form the funnels. Each of the funnels was constructed by excavating under CB slurry. Within a few days the CB hardened to a clay-like material that is relatively impermeable. During the construction of the funnel various obstruction including sewer pipes, a water line, and the railroad track were crossed. Still, unexpected events kept the construction team from becoming complacent. Shortly after the railroad was crossed and the tracks replaced, the funnel was being constructed around a deep sewer that caused the trench to be nearly 10 ft wide at the surface. While the trench was being filled with CB slurry a fully loaded and unscheduled train came down the tracks and passed within 10 ft of a 30 ft deep trench supported only by slurry. Although this caused concern, the train caused no damage.

The gate sections were constructed by excavating under a bio-polymer slurry composed of guar gum, additives, and water. After excavation, two temporary wells were installed in each gate prior to backfilling with the iron/sand mixture. The iron/sand mixture was made by adding 3000# bags of granular iron into readymix trucks on site, and turning the drum to mix the sand and iron. After mixing, the iron/sand was conveyed to the trench using a truck-mounted ladder conveyor. The conveyor was equipped with a tremie pipe that deposited the iron/sand directly into the trench under the slurry. After backfilling, the temporary wells were pumped while adding breaker enzymes, and recirculating the slurry over the top of the iron/sand. This caused the slurry to degrade without the need for disposal. After a few days of recirculating, the viscosity of the bio-polymer was reduced and the trench was ready for a final cap of compacted clay.

RESULTS OF MONITORING: Monitoring wells were installed up and down gradient of the funnel and gates. In addition, there were existing wells both up- and down gradient that were used for monitoring the changes in the groundwater resulting from the remediation. The results of the monitoring are summarized in the following table.

Compound	Upgradient	Within	Downgradient
PCE (ug/L)	36,000	32	<1
TCE (ug/L)	11,000	8.9	3.4
cis-DCE (ug/L)	8,000	60	470
VC (ug/L)	610	16	110

Contamination downstream of the funnel and gate continues to improve as the plume that formerly existed in this area dissipates. Groundwater elevation data indicate that the funnel and gate system is effectively controlling the plume and contamination is not migrating above, below or around the wall.

CONCLUSIONS: The use of an innovative funnel and gate remedial technology has allowed a contaminated site to be redeveloped into a useful property. The innovative construction method was the low cost solution for barrier installation; avoided the need for shoring; eliminated dewatering and residual water management; and minimized impact to utilities.