INNOVATIVE STRATEGIES FOR DNAPL CONTAINMENT AND DEGRADATION NASHUA, NEW HAMPSHIRE

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ABSTRACT

For this former wood treating facility, simple demonstrated containment technologies were applied in combination with innovative engineering to develop a cost-effective remediation system for migration control and degradation of dense non-aqueous-phase liquid (DNAPL) in ground water.

The site, located along the banks of the Merrimack River, contains a DNAPL plume consisting largely of creosote compounds. Ground water has been impacted and DNAPL seeps occurred in the riverbank. A system of conventional screened extraction wells has had limited effectiveness and was costly to operate. The site owner and regulators needed a more effective approach that would 1) prevent the seeps, 2) allow for natural attenuation in ground water, and 3) allow for ceasing the pump and treat program. An innovative remediation system was installed in 1997 consisting of a 750-foot long sheet pile wall, with selective DNAPL extraction wells immediately up gradient of the wall. The rate of ground water seepage is designed to allow ground water and dissolved constituents of concern flux beneath the wall at a rate that can be mitigated to an acceptable level through natural attenuation. Monitoring has shown the system is functioning, and approval to cease the pump-and-treat system has been obtained. The system is providing a cost effective long-term solution.

BACKGROUND

The Nashua site, where former wood treatment activities had taken place, contained a dense non-aqueous-phase liquid (DNAPL) ground water plume consisting largely of creosote compounds. The plume impacted the underlying ground water and also resulted in creosote seeps developing along the banks of the Merrimack River, located adjacent to the site. A site remediation program consisting of ground water and DNAPL extraction through a series of conventional screened wells and treatment of the pumped water at an onsite treatment plant was operating for several years. The annual cost of this pumping and treatment was substantial. Cleanup achieved by these methods was very slow and expected to have to continue indefinitely. Futhermore, they did not control surface seeps along the riverbank. The site owner and regulators needed a better method that would 1) prevent the seeps along the riverbank, 2) allow for natural attenuation of compounds of concern in ground water, and 3) allow for ceasing of the costly and ineffective pump and treat program.

DESIGN

Initial design studies indicated that a properly designed containment system located parallel to the riverbank coupled with selective DNAPL extraction from the site behind the wall could meet the objectives. The basic concept was to construct an impermeable subsurface barrier wall along the banks of the river and extending above the ground water table. Ground water would still flow to the river but the flow largely would be under the wall. The DNAPLs however would collect behind the wall and spread downward until absorbed by the sands and silts. After that, natural degradation would occur in the long term. In the interim, while free phase DNAPLs are still present, they would be removed using onsite wells and wells located immediately behind the barrier. These would be dual phase extraction wells with the extracted water being returned to ground water after removal of the DNAPL. The wall location, length of wall, length of end "wings", depth of piling, and wall stickup distance above grade were determined from iterative design calculations including hydrologic and hydraulic modeling, conventional sheet pile geotechnical and bending stress analyses, and the practical experience of the designer and construction contractor.

Design required a field investigation of subsurface conditions at the riverbank. This was accomplished by drilling boreholes from a barge as well as on the bank. Field permeability tests (borehole packer tests) were performed in both the weathered and unweathered bedrock encountered. Permeabilities ranged from 10^{-3} cm/sec in the weathered/fractured bedrock to less than 10^{-7} cm/sec in the nonfractured areas. Borehole infiltration tests and laboratory tests on remolded samples indicated a vertical permeability of 10^{-5} cm/sec for the glacial till and a horizontal permeability of 10^{-4} cm/sec. For the silty sand alluvium above the till the corresponding permeabilities used were 10^{-4} cm/sec and 10^{-3} cm/sec. This data was used to refine the hydraulic modeling and for sheet pile design. An iterative process was used to select the barrier length, location on the bank, and depth of sheet piles. This included assessment of sheet pile drivability (i.e., a profile of depth to dense glacial till underlying alluvium, unweathered and weathered bedrock was developed from borehole data since the sheet piles could not be driven very far into the dense glacial till or weathered bedrock and could not penetrate the unweathered bedrock), evaluation of minimum required depth of sheet pile penetration to provide safe resistance to earth pressures and bending moments acting on the wall, and hydraulic modeling of the barrier. The Civil Tech Software "SHORING" program was used for sheet pile structural analyses. River dynamics were evaluated from historical flow data obtained from a nearby dam and from the Flood Insurance Study for the city to develop a range for high- and low-flow levels to be used in the hydraulic analyses and for scour assements in sheet piling design. Scour estimates were performed using the Blench Method and the 100-year-flood flow provided in the Flood Insurance Study for the city. Extensive hydraulic modeling was completed using conventional flow nets and 2-D and 3-D flow modeling with the FRACVS program to evaluate ground water flow lines at the barrier. DNAPL flow velocities were estimated based on a retardation factor developed by comparing viscosity to ground water (i.e., fluid flow in porous media is inversely proportional to dynamic viscosity). A detailed review of the flow lines and velocities was completed and the barrier adjusted to minimize the DNAPL flow velocities beneath the bottom of the wall. Drivability and the factor of safety against earth pressure and bending moment failure were then rechecked. Also, estimates were made of the build up of water behind the wall in order to establish the "stickup" of sheet piles above grade to help preclude flow over the top of the wall, particularly after a flood event that would temporarily raise the water level in the bank behind the wall. The field team was provided with the bottom and top target profile for the sheet piles.

CONSTRUCTION,QUALITY CONTROL AND FIELD DESIGN CHANGE PROCESS

The system was installed in 1997 and is comprised of a single steel sheet pile wall, with special seals at the interlocks between sheets to control leakage through the wall that extends for approximately 750 feet along the riverbank and with "wings" that extend up the bank at each end of the wall. A three-part team consisting of the owner, engineer and contractor under a successful teaming approach guided design and construction. The State and local agencies were involved very early in the project. They reviewed the work plans, field data and design, and visited the site to observe construction.

The depth of sheet piles varies (from 14 to 47.5 ft below surface grade), extends through the overlying alluvium, and penetrates either a minimum desired depth into low permeability glacial till or to the top of unweathered bedrock. Field design changes to wall alignment and sheet pile depth were made and documented based on actual sheet pile drivability, (i.e., if the original target depth could not be met, the engineer reassessed the design to check if an adequate factor of safety would still be provided considering the combined action of the interlocked sheet piles). At both ends the wall extends up the riverbank to provide a trap for DNAPL and degradation of dense non-aqueous-phase liquid (DNAPL) in ground water.

Quality control was maintained during construction through implementation of pre-established data collection formats and decision-making criteria established by the engineer and utilized by the contractor. Ongoing monitoring after construction was utilized to locate and repair any significant leaks. An as-built report was prepared and submitted to the agencies to document construction and any design changes required by field conditions. Also, a monitoring plan was prepared and implemented to evaluate performance and respond to any variances/issues.

Due to the novel design approach and the construction techniques used, issues arose during construction and the initial phases of operation that had to be resolved. In some instances the bentonite seals between pile sheets were not effective and allowed small amounts of creosote to seep through the wall. Welding on the downgradient side readily and effectively repaired these seams. The light fraction of NAPL associated with the DNAPL collected on ground water behind the wall at some locations and threatened to discharge over the wall during high ground water flow periods, (i.e., after the flood waters receded). This issue was resolved by installing additional dual phase extraction wells and "collection sumps" behind the wall. The collection sumps were constructed by excavating and replacing native materials in the upper few feet behind the wall with granular material. This allows for periodic pumping of accumulating NAPL.

MONITORING PLAN AND IMPLEMENTATION

A plan for conducting routine monitoring of the performance of the containment system was prepared and implemented. Observations related to the barrier taken during scheduled site visits include evidence of movement; scour or deposition; joint seepage; functionality of drainage outlets and sumps; and erosion, settlement, contamination, or ponding of gravel backfill. The monitoring was performed monthly for the first year and quarterly thereafter. Besides the modifications required to address seepage through some weld seams and accumulation of NAPL in the collection sumps described above there have been no other significant operational issues.

ADVANTAGES OF INNOVATIVE APPROACH

Some of the apparent advantages compared to the prior pump and treat program include:

1. Containment of DNAPL seeps into the river
2. More timely site remediation
3. Considerable O&M cost savings.

The design and construction of the containment system cost approximately $900,000 and have resulted in approval to cease pumping and treating ground water. The innovative approach resulted in both a better technical solution and a far more effective one.