Construction of a Tunnel/Drain Collection System to Control Contaminant Migration in Fractured Bedrock

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ABSTRACT: A tunnel drain collection system (TDCS) has been built to remediate a site contaminated with polychlorinated biphenyls (PCBs) and volatile organic compounds (VOCs).The TDCS was constructed in fractured shale beneath the Site. The primary objective of the TDCS is to prevent or minimize PCB releases to the river adjacent to the Site. A 24-foot diameter vertical access shaft was constructed to a depth of about 200 feet (elevation 24 feet National Geodetic Vertical Datum [NGVD]). Three 10-foot by 10-foot horseshoe-shaped horizontal tunnels were excavated from the access shaft beneath and adjacent to the riverbed. The total length of tunnel excavated was 1000 feet. High-angle drain wells were drilled from the tunnels to drain contaminated groundwater and DNAPL from the overlying fractured bedrock, and to create a large region of downward hydraulic gradients from the nearby river and the TDCS.

Regional groundwater flow model analyses indicated that operation of the TDCS, with a water level maintained at 40 feet NGVD, would result in Site-wide lowering of the water table including beneath the adjacent river. The model-calculated hydraulic capture zone extended beyond the area of the riverbed where DNAPL has been detected in the underlying bedrock Water level elevations, DNAPL recovery rates, and groundwater pumping rates were monitored during and after the TDCS construction to evaluate the zone of influence of the TDCS, and the zone of capture beneath the Site, changes in DNAPL distribution , and pumping rates of the existing recovery well system that resulted from the site dewatering caused by TDCS construction and operation.

This paper presents the results of the monitoring performed during and for six months following TDCS construction. Water level, pumping rate, and DNAPL recovery monitoring data were evaluated in conjunction with model-calculated hydraulic heads and pumping rates to evaluate the hydraulic capture zone created by the TDCS, and the overall effectiveness of the remedy.

INTRODUCTION

During the fabrication of electrical capacitors at an old manufacturing plant located in Hudson Falls, NY (Figure 1), there were releases of PCBs (Aroclor 1242) to the environment. Although the use of PCBs was discontinued in 1977, they have migrated as DNAPL into fractured bedrock and subsequently to the face of what is now usually a dry waterfall (Figure 2).

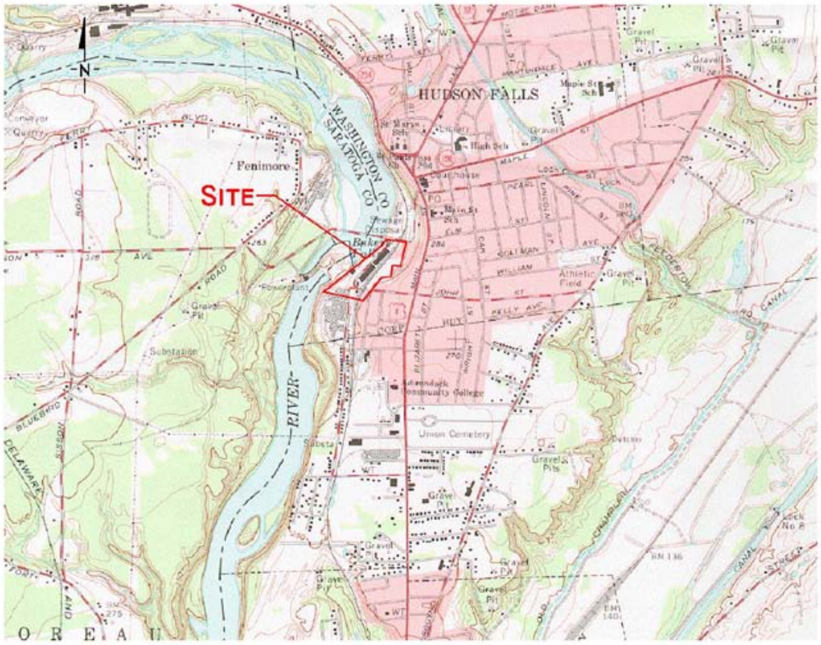

FIGURE 1 Site Location.

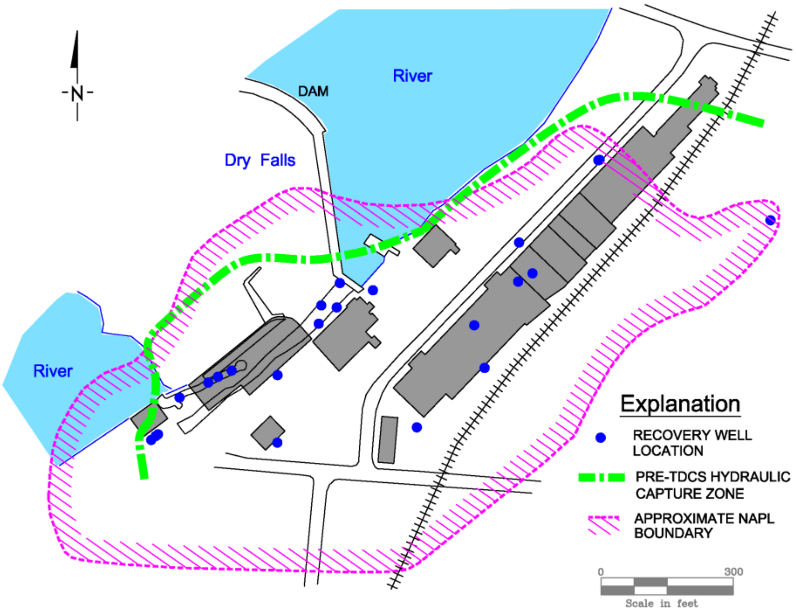

FIGURE 2 Site Contaminant Distribution Map.

Hydrogeologic Setting. Directly beneath the Site is a layer of unconsolidated deposits, up to 21 feet thick. The unconsolidated deposits are composed of glaciofluvial outwash, lacustrine clay, till, and artificial fill. Beneath the unconsolidated deposits is the fractured Snake Hill Shale, which ranges in thickness from 150 feet to 260 feet at the site. The shale overlies two distinct limestone formations, the Glens Falls Limestone and the Isle la Motte Limestone (Figure 3), which together are approximately 150 feet thick. A portion of the foundation of the main manufacturing building at the Site was excavated into the shale. Several drainage structures, tunnels, sewers, and air plenums were also excavated into the shale beneath the floor of this building. The fractured shale is exposed on cliffs and the dry waterfall immediately adjacent to the Site. The shale is divided into three hydrostratigraphic units; Upper, Middle and Lower Snake Hill Shale, separated by two major parallel sub-horizontal thrust faults, locally referred to as the upper and the lower fault planes. The two faults and the complete thickness of the Middle Snake Hill Shale are exposed on the dry waterfall. The primary pathways of DNAPL migration within the shale are the interconnected nearly vertical and approximately horizontal fractures.

A dam is located at the top of the waterfall. The dam diverts the flow of the river through a hydroelectric plant on the western side of the river. At the eastern edge of the river is a former mill. Historically, water from behind the dam was diverted through raceways and tunnels to drive the turbines in the mill. The total elevation drop from the top of the dam to the base of the falls is 67 feet. The waterfall itself drops approximately 40 feet. During much of the year, the total river flow is diverted through the hydroelectric plant and the waterfall is dry. Periodically, during routine maintenance at the hydroelectric plant and during high-river flow water spills over the dam onto the waterfall.

Nature and Extent of Contamination. PCB DNAPL is present in the bedrock as a result of releases that occurred during the manufacture of electrical equipment from the 1950s to 1977. Use of PCBs was discontinued in 1977, but the dense PCB oil migrated downward through the fractured shale, westerly toward the river, and easterly stratigraphically down dip. Figure 2 shows the lateral extent of the DNAPL beneath the Site. In the past, DNAPL has been observed to seep from the fractured shale onto the dry face of the falls below the dam. Figure 3 is a schematic cross section showing the vertical distribution of DNAPL. Samples collected from angled monitoring wells beneath the river indicate that there is DNAPL in the fractured shale beneath the river (GeoTrans, 2001a).

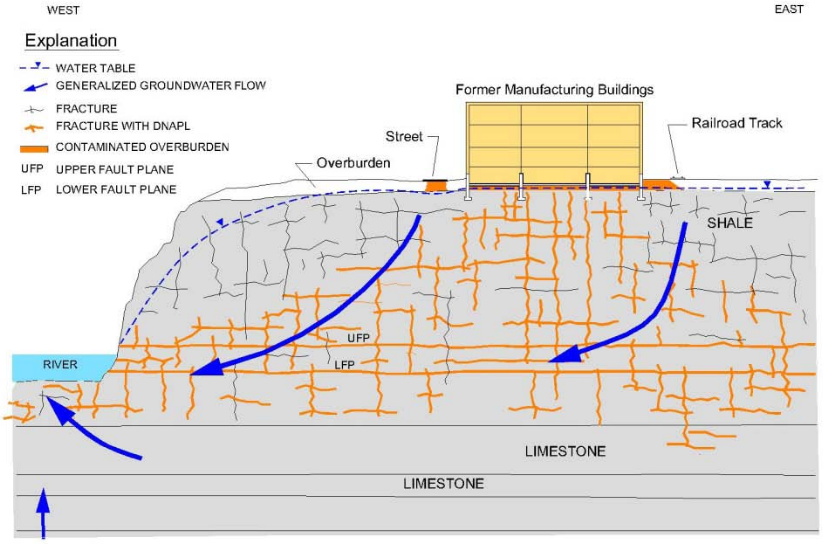

FIGURE 3 Schematic Contaminant Distribution Section.

Interim Groundwater Remedy. An interim groundwater remedy consisting of 35 recovery wells and sumps has operated at the site for approximately 14 years. Sixteen of the recovery wells are dual-phase systems. Sumps are located in the existing drainage structures excavated in the shale. The locations of recovery wells are shown on Figure 4. Water pumped from the wells and sumps is conveyed to the on-site water treatment plant. DNAPL pumped from the dual-phase extraction wells is collected in tanks located at each wellhead. In addition, surface runoff from the Site is also collected for treatment.

The interim remedy created a hydraulic capture zone that extended along the eastern river bank and beneath a portion of the dry waterfall. The downgradient boundary of the capture zone maintained by the interim remedy is shown on Figure 2. The pre-TDCS remedy did not completely contain the DNAPL zone.

TUNNEL/DRAIN SYSTEM

The principal performance criterion for the TDCS is to establish and maintain hydraulic gradients that are sufficient to prevent discharge of dissolved-phase contamination and DNAPL from the fractured bedrock to the adjacent river. To achieve this goal the TDCS must create an areally extensive region within which hydraulic gradients are directed toward the TDCS, including from the river toward the TDCS. The downstream extent of this region was designed to be beyond the lateral extent of the DNAPL zone in the bedrock. In addition, the magnitude of the hydraulic gradient in the region of fractured bedrock that is above, and on the river side of, the TDCS must be sufficient to overcome gravitational forces that might cause DNAPL migration to the river along sloping bedrock fractures. A secondary performance criterion is that the water and DNAPL inflow to the TDCS cannot cause the capacity of the on-site treatment plant to be exceeded.

Regional groundwater flow model analyses were done to evaluate the expected performance of the TDCS. The regional groundwater flow model was used to evaluate the large-scale regional hydraulic gradients, zone of hydraulic capture, and increased water flow rates that would be created by the TDCS. Figure 4 shows the estimated hydraulic capture zone for the TDCS (GeoTrans., 2010).

The TDCS was selected as a Site remedy because of the need for a highly reliable recovery system that would prevent the migration of PCB, in both dissolved and non-aqueous phases, to the river. The TDCS consists of a 200-foot deep, 24-foot diameter vertical access shaft, approximately 1000 feet of tunnel in three segments, and 20 drain wells drilled from the tunnels. The tunnels were excavated in three segments at the base of the Snake Hill Shale (Tetra Tech, 2006). The shaft and tunnels were excavated by the drill and blast method. Figure 4 shows the layout of the TDCS. Following excavation of the tunnels, high angle drain wells were drilled from the tunnel to about ten feet below the bedrock surface. The drain wells were oriented to intersect open fractures in the shale. Fracture orientations were mapped as the shaft tunnels were excavated. Stereo plots of the poles to the fracture planes were prepared and analyzed to assist in selecting the orientations of the drain wells. To assist monitoring the TDCS performance, six multi-level piezometers were installed in the vicinity of the tunnel. The piezometers were installed in cored boreholes beneath the river. Each multi-level piezometer includes three vibrating wire sensors grouted into the borehole. The sensors were located adjacent to hydraulically active fractures in the shale.

The flow from the drain wells is directed to a trough cast in the concrete floor of the tunnels. The collected water is directed to a pumping station at the base of the shaft.

The water is pumped to the on-site water treatment system. The operating head in the drains is at the tunnel level. This allows access to the tunnel for maintenance.

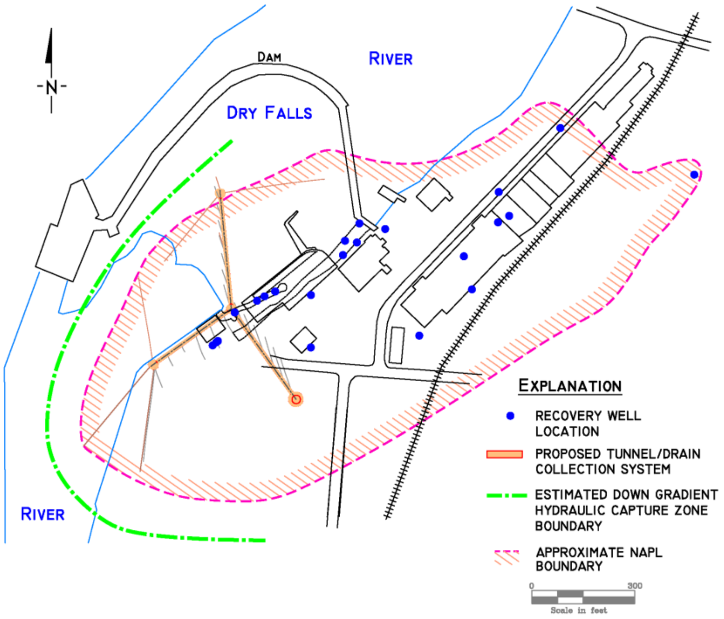

FIGURE 4 Estimated Capture Zone with Operating TDCS.

TDCS Construction. Excavation of the Shaft for the TDCS began on September 18, 2007 and was completed in January 2008. Tunnel excavation began after completion of the shaft and was completed in September 2008. In general the sequence of excavation operations was:

- Drill shot holes,
- Load explosives and blast,
- Excavate the shot rock,
- Install rock dowels, and
- Apply shotcrete (shaft and work rooms only).

Following the initial test blasts, each blasting and shot rock excavation cycle advanced the excavation approximately 10 feet. After crossing the water table, the water level in the Shaft was maintained at the bottom of the excavation by pumping. Water pumped from the TDCS was directed to the on-site water treatment plant. The flow from the TDCS was measured and recorded daily. The average groundwater inflow to the Shaft was approximately 6.4 gallons per minute (gpm). The total flow increased to about 42 gpm at the completion of the tunnels. Following each excavation cycle, the exposed wall of the Shaft and tunnels were mapped and photographed. The mapping consisted of:

- identification of the exposed rock,
- measurement of bedding, joints, and cleavage orientation
- observations of the results of the smooth-wall blasting
- observations of water inflow and the presence of NAPL.

Following completion of the tunnel excavation the concrete floor and troughs were formed and poured the piezometers were drilled and installed and the drain wells were drilled.

HYDRAULIC MONITORING

For the purpose of monitoring the effects of TDCS construction on groundwater levels, continuous water level data were collected from 29 wells in three areas of the Site. Sixteen of the wells are in four well clusters located around the Shaft. Each of those four clusters consists of four wells with open intervals in the Upper, Middle, and Lower Snake Hill Shale as well as the Glens Falls Limestone. Three other wells are in one well cluster, located east of the former manufacturing buildings, with open intervals in the Upper, Middle, and Lower Snake Hill Shale. Data from this well cluster was collected to evaluate background water level changes. Five wells are angled wells with open intervals in the Snake Hill Shale beneath the Hudson River. Four of the wells are in two two-well clusters located south of the TDCS. One well is open in the Glens Falls and Ilse LaMotte limestone below the work room at the intersection of the tunnels. In addition, periodic manual water level measurements were collected from 198 wells throughout the Site. Continuous river stage data were also collected at two locations in the Hudson River, one upstream of the dam and one down stream of the dry water fall to evaluate water level changes resulting from changes in river stage (GeoTrans, 2006).

Water level variations observed in the wells located around the Shaft indicate a high degree of heterogeneity in the Snake Hill Shale. Water level decline in the wells open in the shale ranged from 0 to 25 feet. The wells open in the Glens Falls Limestone have been drawn down up to 20 feet by TDCS construction and operation.

Potentiometric maps of the three shale units and the limestone were prepared to evaluate the changes in groundwater flow directions and the combined capture zone. Figure 5 is a potentionmetic map of the Lower Snake Hill Shale, approximately six months after the TDCS began full-scale operation.

Recovery Well Flow Rates. Groundwater flow rates in existing recovery wells were monitored to identify possible effects of Shaft construction and dewatering. Groundwater flow rates during Shaft construction were compared to flow rates observed during the previous two years. With the exception of two recovery wells located closest to the TDCS, flow rates during construction and the first six months of operation for all groundwater recovery wells were within the range of observed pre-construction flow rates.

During TDCS construction the average flow rate from the two wells dropped from 7 gpm to 4 gpm and 1.4 gpm to 0.3 gpm respectively. The average groundwater flow rate into the TDCS Shaft was approximately 42 gpm at the completion of tunnel construction. The flow rate reductions from wells RW-100 and RW-104 represent about 7 percent of the rate of groundwater inflow to the Shaft and tunnels

Following completion of the drain wells, the TDCS flow rate increased to approximately 80 gpm. At that time the water level in RW-100 dropped below the low level shut off for the pump and the the well stopped pumping. In the first six months of TDCS operation the TDCS flow rate has declined from 80 gpm to about 50 gpm. The reduction in TDCS flow rate is likely due to slow drainage of low conductivity fractures and the gradual dewatering of the shale in the vicinity of the TDCS.

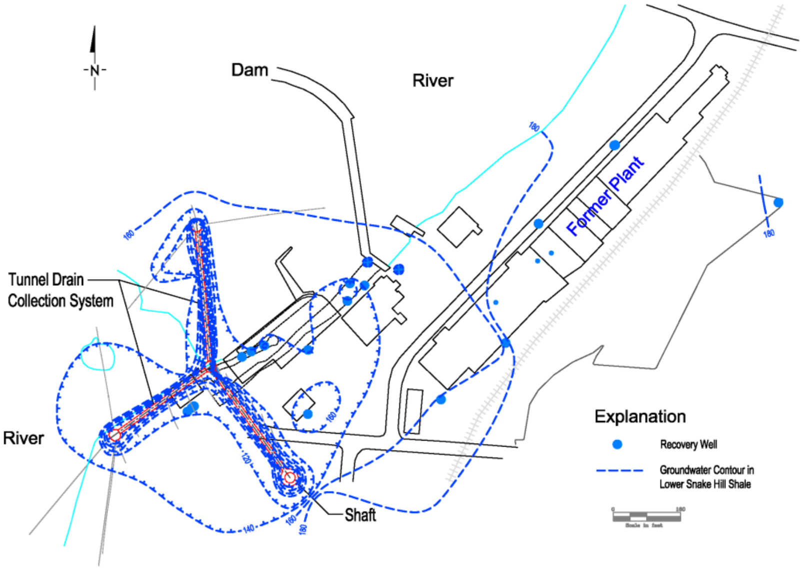

FIGURE 5 Lower Snake Hill Shale Potentiometric Map Shaft with TDCS operating.

Comparison of Observed and Model-Calculated Hydraulic Effects. The groundwater flow model previously developed for the Site (GeoTrans, et al., 2001b) was used to estimate the capture zone and flow rate from the TDCS prior to beginning tunnel excavation. Following the tunnel excavation the model was again used to estimate the capture zone and flow rate from the shaft and tunnels together. Comparisons of observed and model-calculated water level and flow rate data were done to determine if the model continued to be an adequate representation of Site conditions for design purposes and performance evaluation.

Prior to using the model to evaluate the hydraulic effects of the completed TDCS, several modifications were made during model recalibration which was performed following Shaft construction and again following Tunnel construction. Changes were made to constant head boundaries and to the distribution and value of some hydraulic conductivity zones to provide a better match between model-calculated water levels and water levels observed during TDCS construction. The average water levels and pumping rates observed between October 2006 and September 2007 were used for the model recalibration. This data set represents the average Site conditions for the one year period prior to initiation of construction.

The hydraulic effects of the Shaft and Tunnels were simulated using the recalibrated groundwater flow model. The Shaft was simulated as a drain in the upper three layers of the model, representing the Upper, Middle and Lower Snake Hill Shale. The conductance of the drain cells was set so that the flux into the drain in the model matched the observed flux into the Shaft. A similar process was undertaken to refine the model following the Tunnel excavation. The tunnels were simulated as constant head boundaries with the head set at the tunnel floor elevation. Comparison of the model-calculated water levels to the water levels measured on February 2008 (completion of shaft) and November 2008 (2 months after completion of the tunnels) show that the model may be overestimating the hydraulic impacts of the shaft and tunnels, as model-calculated water levels in many wells are lower than the observed water levels. Steady-state conditions were specified in the model. It is possible that water levels at the Site have not fully-equilibrated to the TDCS construction

DNAPL MONITORING

DNAPL recovery rates from monitoring and recovery wells during the TDCS construction and operation indicated that DNAPL recovery was generally within the pre-construction recovery rate range observed during the two years before construction began in all but a few wells. Well HF-108, located 220 feet southwest of the shaft, began accumulating DNAPL when the Shaft had been excavated and dewatered to elevation 147 feet NGVD. Approximately 15 liters of DNAPL have been recovered from HF-108 since construction began. Prior to beginning construction no measurable DNAPL had been recovered from HF-108 for approximately two years.

When the tunnel excavation reached workroom 1-1, at the intersection of the three tunnels, DNAPL recovery from recovery wells RW-106 through RW-107, located near workroom 1-1, increased for a period of several weeks then returned to pre-construction recovery rates. When the drain wells were opened, substantial increases in DNAPL recovery were observed in monitoring wells S-3A and HF-59BD. Well S-3A is located approximately 75 feet north of the TDCS and HF-59BD is located east of the former manufacturing building 1200 feet northeast of the TDCS. The DNAPL recovery rates subsequently declined but continue at greater than pre-construction rates.

SUMMARY

A TDCS has been constructed as part of a comprehensive remedy for a site contaminated with PCBs and VOCs. Approximately 1000 linear feet of 10 by 10-foot tunnel was mined in fractured shale at a depth of about 200 feet. The primary objective of the TDCS is to prevent or minimize PCB releases to a nearby river. The first six months of monitoring data demonstrate that A large zone of capture has been capture has been created in the shale and the direction of the hydraulic gradients beneath the river are now downward toward the TDCS. Ongoing hydraulic monitoring will continue to document the TDCS performance.

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