Passive NAPL Barrier Design and Construction

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1. Introduction

In 2006, a "passive" non-aqueous phase liquid (NAPL) barrier was installed at New York State Electric & Gas Corporation's (NYSEG's) Court Street Former MGP Site in Binghamton, New York, USA (the Site). The term "passive" means that no pumping of groundwater is required for NAPL collection. The purpose of the NAPL barrier is to prevent on-site NAPL from migrating to the Susquehanna River, which is located less than 30 meters (m) downgradient of the site. The site had several complicating features including multiple active natural gas mains, a 170-centimeter diameter storm sewer, a major roadway, and a flood wall along the Susquehanna River.

The construction was the culmination of nine years of work involving site characterization, conceptual design development, site-specific multi-phase fluid-flow modeling, and remedial design. The design methods and techniques used to construct the NAPL barrier were innovative and selected specifically to address the complex site conditions. The NAPL barrier was constructed using a "design–build" approach where the engineer and the contractor were the same entity. The remainder of this document describes site conditions, data requirements for designing the NAPL barrier, NAPL barrier design, and construction methods.

1.1 Site History and Setting

Carburetted water gas was manufactured at the site from approximately 1888 to about 1939. At its peak, the plant produced about 300 million cubic feet of gas per year (Eng, 1984).

The site occupies a small parcel of land (approximately 1.75 hectares) in an industrial section of Binghamton, in Broome County, New York, USA and is identified as 271-291 and 293 Court Street (Figure 1). Several active gas mains were present at the site. The remaining portion of the site is now a gravel lot and used as an equipment storage and parking area for NYSEG.

To the south the site borders Court Street, a 4-lane highway that runs parallel to the Susquehanna River. East of the site is the 295 Court Street property, which contains a warehouse. Immediately north of the site is a major railroad line and yard, an asphalt works plant, and a scrap yard.

1.2 Site Geology and Hydrogeology

The general stratigraphy beneath the site consists of fill underlain by alluvial silt and clay, outwash sand and gravel, and dense basal till on top of shale bedrock (Figure 2). These units show a sequence of events specific to the site's geologic history, which include:

1. Shale bedrock deposited as clay and silt in the Devonian Period
2. Relatively impermeable, dense basal till deposited by the Pleistocene glacier(s)
3. Outwash sand and gravel (referred-to hereafter as "sand and gravel") deposited by meltwater rivers as the Pleistocene glacier(s) receded
4. Post-glacial alluvial silt and clay (referred-to hereafter as "silt and clay"), probably deposited in an abandoned river channel.
5. Fill and an assortment of man-made structures, originating from the site's industrial history

As shown on Figure 2, the water table occurs at a depth of approximately 2 meters beneath the site. Along the alignment of the NAPL barrier, the saturated units of interest are the silt and clay and the sand and gravel. The hydraulic conductivities of these two units are estimated to be 1 meter per day (silt and clay) and 23 meters per day (sand and gravel). Groundwater moves generally southward, discharging into the Susquehanna River. Some groundwater in the silt and clay also moves downward into the sand and gravel.

The average flow of the Susquehanna River near the site is approximately 100 cubic meters per second (USGS, 2001).

1.3 Distribution of Subsurface NAPL

Dense NAPL (DNAPL) released at various locations has migrated downward, through the silt and clay and distributed itself complexly in the sand and gravel, reaching the top of till in at least one location. Pooled DNAPL has been identified on top of the till in one location and near the water table at a second location. Given the large quantities of petroleum feedstocks historically used at the site, the potential exists for pooled light NAPL (LNAPL) to be present, though none has been identified. MGP-related NAPLs were also present in shallow sediments in the river; however, it could not be determined whether these impacts were the result of subsurface NAPL migration, direct discharge through sewer pipes, or a combination of these two mechanisms. Figure 2 presents a conceptual model for groundwater/NAPL interactions at the Site.

2. Passive NAPL Barrier Conceptual Design

The objective of the passive NAPL barrier was to prevent on-site NAPL from migrating to the Susquehanna River. The conceptual design of the DNAPL portion of the NAPL barrier was based on two forces that govern movement of coal-tar DNAPL:

1. Gravity (downward or upward movement due to DNAPL density or LNAPL buoyancy, respectively)
2. Hydraulic gradient (primarily horizontal, in the sand and gravel, and toward the river).

The NAPL barrier conceptual design consisted of a graved-filled trench (installed along the downgradient site boundary) keyed into the underlying till. The hydraulic conductivity of the trench gravel would be considerably higher than that of the native sand and gravel, allowing groundwater to flow freely through the trench. NAPLs entering the trench will either settle to the bottom (DNAPL) or rise to the water table (LNAPL) due to their density contrast with the groundwater, and the decrease in hydraulic gradient in the trench caused by the permeable gravel backfill. The concept of the passive NAPL barrier has been described by White, et al. (2006a, b)

To evaluate the potential efficacy of the barrier trench concept, groundwater elevation data were collected for use in a groundwater flow model, the output from which was used as input for a multi-phase flow model, as described in the following subsections.

2.1 Conceptual Design Data Collection

As part of the conceptual design, a year-long fluid-level monitoring program was implemented to gather sufficient water-level data to evaluate the groundwater flow field near the flood wall and the river, near the presumed barrier alignment, and to monitor for accumulated NAPL. Evaluating the flow field was important because the direction and magnitude of hydraulic gradients are important factors governing the movement of MGP NAPLs. To accomplish this, fluid levels were measured and recorded using a combination of pressure transducers/data loggers (referred to hereafter as “data loggers”) and manual measurements over a period of approximately one year. Water-levels were measured and recorded automatically by data loggers at one-hour intervals at eight locations, including the river, beginning in February 2004. Manual water-level measurement rounds were conducted at a larger subset of monitoring locations bimonthly through May 2004 and then monthly thereafter. Additionally, at locations where NAPL was identified in samples recovered during drilling, an interface probe was used to check for accumulated LNAPL and/or DNAPL.

Collected data were analyzed using hydrographs and comparison of calculated vertical gradients at various points behind the flood wall and beneath the river. The collected data indicated that the groundwater-level fluctuations largely mirror changes in river level, indicating good hydraulic communication between the monitored wells and the river.

2.2 Conceptual Design Modeling

To evaluate the potential efficacy of the barrier-trench concept, a numerical, 3-D groundwater flow model was constructed using MODFLOW (McDonald and Harbaugh, 1988). The calibrated model layers and groundwater head distribution were imported into a multi-phase flow model (DNAPL 3D). The multi-phase flow model is a peer-reviewed finite-difference model presented by Gerhard et al. (1998; 2001; 2003a, b, c), and represents a three-dimensional extension of the original two-phase flow model presented by Kueper and

Gerhard (1995), and Kueper and Frind (1991a, 1991b). Results of the DNAPL3D modeling performed at this site were described by Kueper, et al. (2006).

3. Passive NAPL Barrier Design

A design-build approach was selected for the NAPL barrier construction. Under the design-build process, the design and work plan are prepared by the engineer in collaboration with the construction contractor. The design is a performance-based specification (rather than detailed specifications). The turn-key aspect of this approach is that the engineer (ARCADIS) and contractor (ARCADIS BBLES) are from the same company, providing services under a single contract to the client. This approach allowed for a streamlined design and fast-tracked construction after the treatability testing was completed. In addition, this approach allowed for quick response to unforeseen field conditions, without costly delays associated with change order negotiations. The specialized treatability testing and construction technologies were provided to ARCADIS BBLES under a subcontract by Geo-Solutions Inc. of Pittsburgh, PA (Geo-Solutions).

The primary components of the passive NAPL barrier consisted of:

1. A 75-centimeter (cm) wide permeable trench, filled with pea gravel and keyed into the underlying till (located approximately 12 – 18 meters below ground surface [bgs]). To construct this trench, a biopolymer slurry was selected (as further described below).
2. Low-permeability sections, installed using jet grouting techniques in areas where the gravel trench could not be installed (in areas beneath permanent utilities, retaining walls and drainage structures).
3. A DNAPL collection system consisting of horizontal collection pipes installed in the bottom of the trench and sloped to collection sumps with vertical recovery wells at low points within the till layer. The concept of the DNAPL collection system is to convey DNAPL through the pea gravel and lateral collection piping (along the top of till) into the DNAPL collection wells.
4. An LNAPL collection system that included a low permeability HDPE geomembrane barrier installed at the downgradient side of the trench to allow LNAPL to collect and be recovered via vertical collection wells.

The general alignment of the trench, along with the width and physical characteristics of the gravel were based on model inputs used in the multi-phase model described in Section 2.

3.1 Pre-Design Investigation

A pre-design investigation (PDI) was conducted to obtain additional information required to complete the design of the NAPL barrier. The PDI activities included installing geotechnical borings along the proposed NAPL barrier alignment at approximate 100-foot intervals. The proposed borings were necessary to confirm the various soil types that would be encountered during trench installation, locate the till layer along the proposed alignment, assess the potential for obstructions to trench installation (such as large boulders), and assess the geotechnical properties of the soil materials that would be encountered during trench installation. This information was also used to determine the characteristics of the slurry to be used to install the trench. Following completion of the PDI, treatability testing of the materials to be used to support construction was conducted and the final construction documents were prepared

3.2 Jet Grout Testing and Mix Design

Jet grouting was selected to construct portions of the NAPL barrier in areas where obstructions could not be relocated or removed (such as natural gas mains and the 168-cm diameter storm sewer). Jet-grouting consists of injecting ultra high-pressure fluids or binders into the soil at high velocities (approximately 300 m/sec). Jet-grouting completely breaks down the soil structure and mixes soil particles in-situ with a binder to create a homogeneous mass, which in time solidifies and forms a low permeability barrier.

ARCADIS' geotechnical subcontractor, Geo-Solutions, Inc. (Geo-Solutions), conducted a bench-scale jet grout testing program to determine appropriate jet grout mix designs that would meet a permeability goal of less than 1×10^{-6} centimeters per second (cm/sec) and demonstrate long-term compatibility with site constituents. Based on the results of the testing program, a jet grout mix consisting of Portland cement, BFS, and bentonite was selected. The treatability test results demonstrated that this mix would meet the required permeability of 1×10^{-6} cm/sec, and was compatible with the site-related NAPL.

3.3 Biopolymer Slurry Testing and Mix Design

Slurry wall technology using biopolymer (BP) slurry was selected as the method to support the trench excavation during construction of the passive NAPL barrier. BP slurry is a mixture of water and natural (or synthetic) polymers and stabilizers that are used in place of traditional trench shoring and dewatering methods.

Geo-Solutions conducted bench-scale laboratory testing to evaluate the stability (i.e., viscosity, density, and pH) of various biopolymer slurry mixes when combined with the site groundwater, site soils, and NAPL collected from the site. Additionally, a polymer degradation agent (i.e., an “enzyme breaker”) was evaluated for compatibility with the site-specific biopolymer mix designs. The enzyme breaker is used to degrade the BP slurry following installation of the NAPL barrier components.

The bench-scale test procedures were designed to simulate potential field conditions at different stages of the NAPL barrier interim remedial measure (IRM) construction including: excavation; backfill placement; and slurry degradation (i.e. adding the enzyme breaker). A guar gum-based (carbohydrate derived from the guar bean) slurry and a polyacrymide-based slurry were tested for the stability criteria described above. The guar gum test slurry was slightly more viscous and the polyacrymide slurry was slightly less viscose than ideal; however, both slurries demonstrated stable viscosities prior to the addition of the slurry breaker. The slurries remained active (e.g., viscosity of 60 seconds or greater using the Marsh Funnel technique) during the test period and did not indicate potential incompatibility with site soil, groundwater, NAPL, or with the enzyme breakers. Following the addition of the enzyme breaker, the viscosities of both slurries decreased to that of water, demonstrating that the breaker and the slurries were compatible.

Based on the results of the bench-scale testing, a mixture of guar gum and stabilizers was selected as the biopolymer slurry. A breaker material consisting of hydrogen peroxide was chosen to degrade the slurry following installation of the gravel trench and collection system.

4. Passive NAPL Barrier Construction

4.1 Mobilization and Site Preparation

ARCADIS BBLES and its remedial subcontractor (Geo-Solutions) installed the NAPL barrier between July 10, 2006 and November 22, 2006. Mobilization and site preparation activities included:

1. Documenting existing site conditions including identifying aboveground and underground utilities, equipment, and structures, as necessary to implement the IRM activities.
2. Removing abandoned natural gas lines that interfered with the NAPL barrier alignment.
3. Relocating utilities to facilitate NAPL barrier construction.

4.2 Pre-Trench Excavation

A critical component of the NAPL barrier construction was the pre-trench excavation. The pre-trench excavation was performed to locate or remove underground utilities or obstructions along the alignment of the NAPL barrier. During the performance of pretrenching, the following obstructions were observed:

1. Two underground steel structures
2. Over 20 (primarily abandoned) underground pipelines. The pipelines were exposed, removed from the trench alignment, and plugged with expandable polyurethane spray foam.
3. A large amount of construction material debris and four buried concrete foundation walls were encountered in the western portion of the site. The foundation walls were up to 1.2 m-thick and the wall bottoms were located approximately 5.2 m bgs. The fill material around these concrete foundation walls comprised primarily of masonry materials (bricks and large sections of reinforced concrete) and structural steel. There was very little soil and the fill materials had little to no cohesiveness; therefore, imported cohesive soil (saw clay) was used to backfill these pretrenched areas to facilitate excavation of the gravel-filled trench.

To install the gravel-filled trench in the area of buried debris and foundation walls, the foundation walls had to be removed from the trench alignment. Due to the integrity of the concrete foundation walls and the lack of cohesion in the surrounding fill materials, removal of the four concrete foundation walls and installation of the gravel-filled trench as originally proposed was not feasible. As a result, the design of the NAPL barrier was modified as follows:

1. A sonic drill was used to predrill areas of the barrier alignment (that were filled with debris) between 3 of the 4 foundation walls to approximately 6 m bgs, to facilitate jet grouting. In addition, a sonic drill was used to drill up to 20 boreholes through one of the existing concrete foundation walls to facilitate removal.
2. Approximately 6 m of the NAPL barrier was jet grouted to form a low permeable barrier between three of the foundation walls, and extending into the till layer. The pilot holes created using the sonic drill were used to facilitate jet grouting through the debris.
3. One of the existing concrete foundation walls was removed, following the sonic drilling without further damage to the trench sidewalls.

4.3 Jet Grout Wall Installation

The jet grout walls were installed along the NAPL barrier alignment in areas where trench excavation was not feasible due to underground obstructions (Figure 3). Jet grouting was conducted before the gravel portion of the barrier was constructed, to allow the grout adequate time to cure. The grout walls were installed using a track-mounted rotary drill rig, a grout batch plant, and jet-grout pump. Once the holes were drilled to the appropriate depth (at least 15 cm into the top of the underlying till layer), the jet-grouted columns were formed by rotating and lifting the drill string while a high pressure stream of grout was forced out of the side nozzles using pressures of at least 210 kilograms per square cm (Ksc). The jet-grouted sections were formed by installing two rows of overlapping jet grout columns.

During the performance of the jet grout wall installation activities, grout spoil material (i.e., excess grout) was collected within a trench along the alignment of the NAPL barrier. The grout spoil material was allowed to solidify within the trench and was then removed from the trench at the beginning of each day, and was stockpiled in the waste material staging area for subsequent offsite transportation and disposal.

During the jet grout wall installation, quality control testing was performed on the jet grout mixture and included the following:

1. Fresh grout slurry was tested onsite for unit weight and viscosity Marsh Funnel twice per shift in accordance with ASTM D-4380 and API RP 13B-1, respectively.
2. Insitu soilcrete (created during the jet grouting application) samples were collected using an insitu sampler (cylinder), before the soilcrete began to cure, at frequency of one sample per 300 vertical meters of (installed) jet grout column. The soilcrete samples were collected, handled, packaged, and tested for unconfined compressive strength (UCS) (in accordance with ASTM D1633) and permeability (in accordance with ASTM D5084). The testing results indicated that the permeability of the jet grout wall ranged from 7×10^{-7} to 2.4×10^{-8} cm/sec, which were approximately two orders of magnitude lower than the design objective of 1×10^{-6} cm/sec. The UCS ranged from 20 Ksc to 60 Ksc. Although UCS was not a specified performance criteria, the associated results are consistent with UCS of controlled low-strength material (e.g., flowable fill). For comparison, cohesive soils, such as clay, typically have compressive strengths in the vicinity of 1.5 Ksc.

4.4 Gravel-Filled Trench

Upon completion of the jet grout wall installation activities, the gravel-filled trench sections of the NAPL barrier were constructed. The gravel-filled trench sections of the NAPL barrier were constructed to facilitate the collection and removal of mobile or potentially mobile NAPL along the trench alignment. The trench excavation was performed using biopolymer slurry to allow for the placement of DNAPL and LNAPL collection systems and pea gravel. Upon the placement of pea gravel within the trench, the biopolymer slurry was degraded to promote the free flow of groundwater through the trench. Additional details related to the construction of the gravel-filled trench are provided below.

4.4.1 Trench Excavation

The trench was excavated using an extended-reach excavator and was keyed a minimum of 150 cm into the top of the till unit located approximately 12 to 18 m bgs, and the average width of the trench was approximately 75 cm. The anticipated depth of the trench was based on pre-design information and the actual top of till elevation was measured and documented during the trench excavation activities. Once the top of till elevation was measured and documented, additional till material was excavated to attain a minimum key of 15 cm into the top of the till unit to confirm the proper placement of the DNAPL collection system.

During the trench excavation, the trench stability was maintained using biopolymer slurry, which was mixed onsite using a venturi mixing device and holding tanks. As the excavation progressed, the biopolymer slurry was pumped from the onsite holding tanks to the trench, and the level of the biopolymer slurry was maintained at least 1 m above the groundwater table elevation and no more than 0.6 m bgs. During the use of biopolymer slurry, quality control testing was performed on the biopolymer slurry and included the following:

- pH testing (minimum pH of 9) and viscosity testing (minimum viscosity of 60 seconds Marsh Funnel Viscosity) was performed on the plant-mixed (i.e., slurry that had not yet been placed in the trench) biopolymer slurry a minimum of two times daily.
- pH testing (minimum pH of 8) and viscosity testing (minimum viscosity of 50 seconds Marsh Funnel Viscosity) was performed on the active biopolymer slurry (i.e., slurry in the trench excavation prior to degradation) a minimum of two times daily.

Materials excavated from the trench were drained with the excavator bucket (to remove excess biopolymer slurry/groundwater to the extent feasible) and placed in a waste material staging area either directly from the excavator bucket or by using a dump truck to transport the material from the excavation to the staging area. The excavated materials in the waste material staging area were dewatered via gravity drainage, and the collected water was placed in an onsite storage tank for subsequent offsite transportation and disposal. In addition to gravity dewatering, some excavated materials required the addition of cement to properly solidify the material for offsite transportation and disposal.

During the trench excavation on the western portion of the site (in a 30 m section of the trench), ARCADIS BBLES and its subcontractor, Geo-Solutions, observed that the biopolymer slurry level dropped significantly (approximately 2.5 to 3 m bgs) within a short time period (approximately 10 to 20 minutes). The trench was visually reviewed to determine the reason for the slurry loss, but the cause could not be determined. After the significant drop in the biopolymer slurry level, cracks began to develop in the Court Street asphalt pavement approximately 7.5 m downgradient from the excavated trench. As a result of this condition, the trench was immediately backfilled with pea gravel to prevent further damage. This effort required working around the clock to backfill the trench as quickly as feasible to prevent additional damage, as well as closing a portion of Court Street to prevent vehicular traffic from travelling over the cracked area. Once the trench was backfilled with pea gravel, the area was stabilized and no further movement of the asphalt pavement was observed.

Additional efforts were made to determine the cause of the biopolymer slurry loss; however, these efforts were unsuccessful and the cause of this biopolymer slurry loss could not be determined. These efforts included re-excavating areas along the trench to locate potential voids or pipelines, as well as observing areas along the north bank of the Susquehanna River adjacent to the site. Based on these efforts, there were no observations of voids or pipelines within the trench, and there were no observations that the biopolymer slurry drained to the river.

As a result of quickly backfilling the trench with pea gravel, various components of the DNAPL and LNAPL collection systems were not installed. In order to complete the excavation activities in this area, a 3 m long grouted plug was installed (using driven pipe and pressure grouting) for the entire depth of the trench to create a vertical wall that would retain the area backfilled with pea gravel and allow the remaining area to be excavated (thus preventing the pea gravel from sloughing into the excavated area).

Additional efforts were initiated to re-excavate the trench under slurry in this portion of the site and install the LNAPL collection system components in this area; however, this effort was unsuccessful because the trench was unable to hold the biopolymer slurry and the trench walls were collapsing at an excavation depth of 3 m bgs. Based on this condition, installing the HDPE geomembrane, LNAPL collection well, and 15 cm diameter HDPE slotted lateral collection pipe within an open excavation was not feasible and there was a risk of creating further damage to the adjacent Court Street asphalt pavement. As a result, the 15 cm diameter HDPE slotted lateral collection pipe was not installed in this area and flat steel sheeting with an Adeka sealant for the interlocking joints was installed in this area in lieu of the HDPE geomembrane. In addition, a new DNAPL and LNAPL collection well were installed using a drill rig at the east side of the grout plug as this was a low point for the underlying till unit.

4.4.2 DNAPL Collection System Installation

The DNAPL collection system consisted of lateral collection piping and vertical collection wells. The lateral collection piping consisted of 15 cm diameter, 90-slot (2 millimeter [mm] slot size) HDPE piping, and was placed along the top of the till surface (that was keyed a minimum of 15 cm into the surrounding till). The vertical collection wells consisted of 20-cm diameter, 304 stainless steel well screen (90-slot) and solid riser pipe.

For the majority of the NAPL Barrier, the DNAPL collection system was constructed once the trench was excavated (under biopolymer slurry) a minimum of 15 cm into the top of till layer to create a positive slope. In the area of the trench collapse, as described above, the horizontal piping was not installed. At the DNAPL collection well locations, the trench was excavated at least one foot deeper below the lateral collection piping elevation to form a sump. A critical factor during the trench excavation activities was to maintain a positive slope along the top of till into the DNAPL collection well sumps. The lateral collection piping was assembled (butt fusion welded) on the ground surface and was lowered into the trench using concrete weights as ballasts to counteract the buoyancy forces of the piping. The DNAPL collection wells were assembled (thread connections) on the ground surface and were lowered into the trench within the excavated sump (Figure 4). The DNAPL collection wells contained a 3 m long well screen with end cap at the bottom of the well.

4.4.3 LNAPL Collection System Installation

The LNAPL collection system consists of 60-mil HDPE geomembrane and vertical collection wells. The LNAPL collection wells consist of 20 cm diameter, 304 stainless steel well screen (90-slot) and solid riser pipe, and were installed adjacent to each of the DNAPL collection wells. The concept of the LNAPL collection system is that the HDPE geomembrane as a barrier will prevent offsite migration of mobile NAPL, and the LNAPL collection wells will be used to facilitate monitoring and recovery of LNAPL.

The LNAPL collection system was constructed after the trench was excavated (under biopolymer slurry) and a portion of the trench was backfilled with pea gravel. The LNAPL collection wells were assembled (thread connections) on the ground surface and were lowered into the trench and positioned on top of the pea gravel at the appropriate elevation (approximate elevation 872 AMSL). The LNAPL collection wells contained a 3-m long well screen at the bottom of the well, and the remainder of the well consisted of a solid riser section.

Both the bottom of the HDPE geomembrane and LNAPL recovery wells extended approximately 0.6 m below the annual low groundwater table elevation The HDPE geomembrane was installed vertically on the downgradient side of the trench. The HDPE geomembrane was temporarily staked at the ground surface on the downgradient side of the trench and was lowered into the biopolymer slurry using weights attached to the bottom of the geomembrane to prevent the geomembrane from floating in the biopolymer slurry (Figure 5). The HDPE geomembrane panels were overlapped a minimum of 1.2 m to create a continuous LNAPL barrier on the downgradient side of the NAPL Barrier. After the HDPE geomembrane was installed, backfilling resumed within the trench using pea gravel up to approximately 1 m bgs. At this point, the temporary stakes were removed and the HDPE geomembrane was placed over the width of the trench (covering the pea gravel) for the subsequent placement of the remaining backfill and surface restoration.

4.4.4 Backfill Placement

After the installation of the DNAPL collection system, the excavated trench was backfilled with pea gravel up to approximate 2.1 m bgs. After the pea gravel was placed to approximately 2.1 m bgs (with a median diameter of approximately 12 mm), the LNAPL collection system was installed, followed by the placement of additional pea gravel up to approximately 1 m bgs. At this point, the HDPE geomembrane was placed over the top of the pea gravel, and additional backfill was placed up to approximately 30 cm bgs in areas receiving asphalt or stone surface restoration and approximately 15 cm bgs in areas receiving topsoil and grass seed (additional information related to surface restoration is included in Section 2.8).

Approximately 4,100 tonnes of pea gravel (with a median diameter of 12 mm) were used to backfill the trench for the NAPL barrier construction.

4.4.5 Biopolymer Slurry Degradation

During and following the placement of pea gravel within the trench, the biopolymer slurry was degraded to promote the free flow of groundwater through the trench. The degradation process consisted of installing a series of temporary well points at various locations within the trench and pumping the biopolymer slurry and the enzyme breaker (hydrogen peroxide) from the temporary well points on the surface of the trench. This process of recirculating the biopolymer slurry and the enzyme breaker was continued until a maximum Marsh

Funnel viscosity of 30 seconds was attained and the pH of the biopolymer was approximate 7 S.U. Upon completion of the biopolymer slurry degradation process, the temporary well points were removed from the trench.

4.4.6 Site Restoration

Upon the completion of backfilling the gravel-filled trench, the site surface was restored, and various underground/overhead utility lines were reactivated.

5. Post-Construction Monitoring

An initial (12-month) monitoring plan for the NAPL barrier trench was developed to determine optimal monitoring and NAPL recovery methods and frequencies. Post-construction monitoring has been conducted monthly to assess the location and amount of NAPL that enters the trench and to monitor the area between the trench and the Susquehanna River for the presence of NAPL. To date, recoverable amounts of NAPL have not accumulated within the trench, only odors, sheens and trace amounts of NAPLs.

FIGURES:

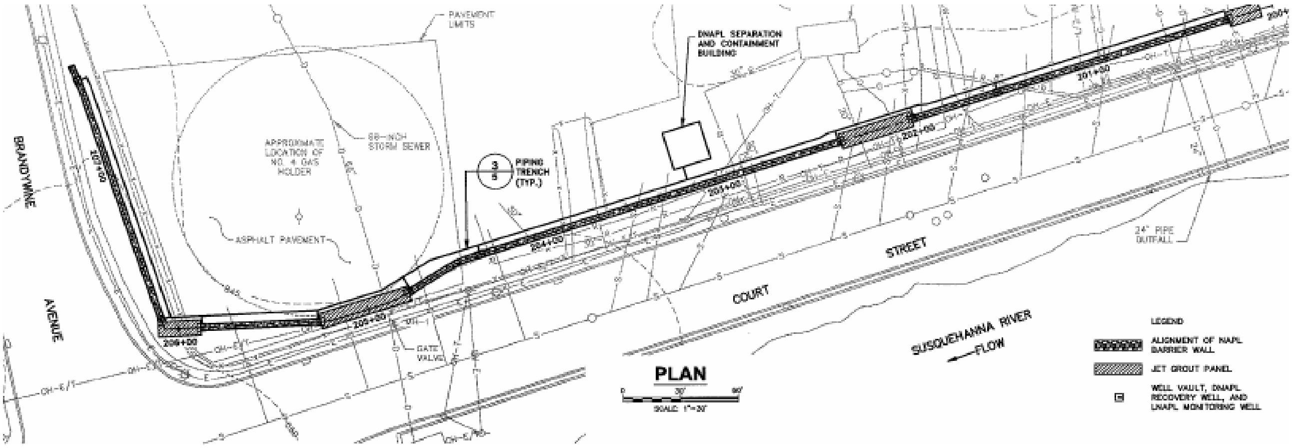

Figure 1 – Site Layout and NAPL Barrier Alignment (North is towards the top of the page)

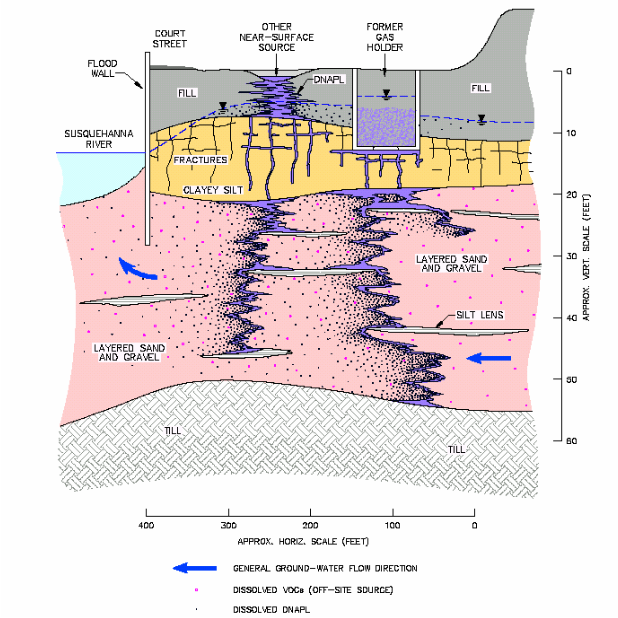

Figure 2 – Conceptual Site Model

Figure 3 – Jet Grouting

Figure 4 – Installation of DNAPL Collection Well

Figure 5 – Placement of HDPE Barrier

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