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Remediation System Evaluation (RSE)
Moss-American Superfund Site

Milwaukee, Wisconsin

REMEDIATION SYSTEM EVALUATION
MOSS-AMERICAN SUPERFUND SITE
MILWAUKEE, WISCONSIN

Final Report
March 2011

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Table of Contents

List of Tables

List of Figures

List of Appendices

EXECUTIVE SUMMARY

This document presents the results of a Remediation System Evaluation (RSE) conducted for the Moss-American Superfund Site in Milwaukee, Wisconsin. The RSE process is designed to help site operators and managers improve effectiveness, reduce operation costs, improve technical operation, and gain site closeout. The observations and recommendations given within this RSE report are not intended to imply a deficiency in the work of either the designers or operators, but are offered as constructive suggestions to fill data gaps and optimize remedy performance.

This RSE report focuses primarily on optimizing system performance, in particular addressing the stagnant groundwater zone that is limiting flow through the treatment gates and elevated COC concentrations in the vicinity of MW-34S. Recommendations include:

- Monitoring program modifications to further delineate source and dissolved-phase contaminant extent. These modifications would result in additional costs of approximately **$22,500**. Benefits include ensuring that contaminants are not migrating through or around the sheet pile wall, as well as providing necessary information for implementing treatment enhancements, which would ultimately lead to earlier site closeout.
- Additional NAPL investigation. This investigation would cost approximately **$72,000**. Identification of source areas would allow targeted removal, thereby diminishing long-term contributions to the dissolved-phase plume and shortening time to achievement of cleanup objectives.
- Depending on results of characterization efforts, it is recommended that one of the following treatment modifications be implemented:
    1) NAPL-impacted soil excavation and enhanced dissolved-phase treatment. This option would cost roughly **$381,000** for the stagnant zone near MW-34S; costs for similar work near TG1-1 have not been developed but could be readily scaled from the estimate for the MW-34S area based on results from field investigations. Aggressive removal of identified source material (NAPL) and subsurface amendments of ORC Advanced® would greatly shorten time until achievement of cleanup objectives.
    2) Limited NAPL-impacted soil removal and installation of additional gate in NW corner. Costs for this option are estimated to be roughly **$979,000**. This option adheres closely to the original design, which included a gate in the northern portion of the sheet pile wall. Installation of a gate in the wall should improve flow and eliminate the stagnant zone, thereby resulting in more effective treatment of the dissolved-phase plume. Risk management and design considerations would determine whether the gate is installed near MW-34S or MW-7S.

1.0 INTRODUCTION

1.1 Purpose

The Remediation System Evaluation (RSE) as identified in the U.S. Army Corps of Engineers (USACE) Guidance is intended to achieve a number of goals, including:

- Assuring there is a clear system objective (an end to the project),
- Reducing costs and optimizing the system performance considering current conditions and new technologies,
- Evaluating the protectiveness of the system in accordance with the National Contingency Plan (the NCP and CERCLA requires reviews at least every five years), and
- Assuring adequate maintenance of government-owned equipment by operators. [not directly applicable to this RP-run system]

The Third Five-Year Review Report (EPA, 2010) concluded that the site is currently protective, but recommended that an optimization study be performed “to develop a solution to remediate the elevated” contaminant of concern (COC) levels found in areas within the funnel and gate system. Due to development of stagnation in groundwater flow and resulting reduction in flow through the treatment gates, these elevated COC levels persist, with consequences for long-term operations and overall costs. Because a site visit was not included in the scope for this study, the focus of this RSE was directed at optimizing system performance, with the intent of ensuring cleanup objectives can be reached within a reasonable timeframe, thereby reducing long-term costs. This report provides a brief background on the site, current operations, and recommendations for changes and additional actions. The cost impacts of the recommendations are also discussed.

1.2 Team Composition

This team conducting the RSE consisted of Mike Bailey (hydrogeologist, USACE Environmental & Munitions Center of Expertise), Mandy Michalsen (engineer, USACE Seattle District), and Sharon Gelinas (hydrogeologist, USACE Seattle District).

1.3 Documents Reviewed

Remedial Investigation Report, Moss-American Site, January 9, 1990

Superfund Record of Decision (ROD), Moss-American Co., Inc, USEPA, September 27, 1990

Explanation of Significant Differences (ESD), Moss-American Co., Inc, USEPA, April, 29, 1997

Superfund ROD Amendment, Moss-American Co., Inc, USEPA, September 30, 1998

ESD, Moss-American Co., Inc, USEPA, November 2007

Third Five-Year Review Report for Moss-American Superfund Site, USEPA, April 2010

Groundwater Monitoring Reports for the Moss-American Site from 1998-2008, Roy F. Weston, Inc (Weston)

Groundwater Remedial System Drawings, Weston , Kerr-McGee Corporation, March 1998

Response to Comments on Focused Remedial Alternatives Evaluation for Soil and Sediment, Moss-American Site, Weston, January 12, 1996

Integrated Review Comments of Soil and Groundwater Remedy, Moss-American Site, Weston, January 20, 1997

Response to Comments on Intermediate (60%) Groundwater Design, Moss-American Site, Weston, February 3, 1997

Comments on Prefinal Design – Groundwater, Moss-American Site, USEPA, October 30, 1997

Supplemental GeoProbe Soil Investigation Report, Moss-American Site, Weston, May 2, 2001

1.4 Site Location, History, and Characteristics

1.4.1 Location

The Moss-American site is located in the northwestern section of the City of Milwaukee (Figure 1). The 88-acre site is comprised of a former wood treating facility plus several miles of the Little Menomonee River and its adjacent floodplain soils. The wood treating, using creosote, was conducted on land bounded roughly by the intersection of Brown Deer and Granville Roads on the west, and Brown Deer and 91st Street on the east.

With the cessation of wood treating operations, 23 acres of site land are now owned by the Union Pacific Railroad (railroad), which, until very recently, used this land as an automobile/light truck loading and storage area. Recent business conditions curtailed most of the vehicle storage/transfer function. Industrial site zoning and usage of this portion of the site remain intact. Milwaukee County (the county) owns the remainder of the land comprising the former wood treating facility, approximately 65 acres.

The Little Menomonee River flows approximately 5 miles to its confluence with the Menomonee River. Land along the floodplain corridor is owned primarily by the City of Milwaukee, the County, and to a much lesser extent, private owners.

1.4.2 History

Wood treating operations using creosote were conducted from approximately 1921 to 1976. Past site aerial photos show that land usage patterns have changed considerably with the passage of time. Photos from the 1930s to the 1950s show the wood treating plant operating in a relatively sparsely populated setting, where several farms surrounded the manufacturing operation. From the 1960s to the present, residential and commercial use of nearby property has increased considerably, and agricultural and farming operations have been phased out almost completely. Industrial parks and multi-lane highways also traverse the site setting. County owned land along the river corridor now features recreational hiking and bicycle trails. These features have had a direct bearing on site soil cleanup standards and sediment management at the site.

In 1921, the T. J. Moss Tie Company established a wood preserving facility west of the Little Menomonee River. The plant preserved railroad ties, poles, and fence posts with creosote, a mixture of numerous chemical compounds derived from coal tar. Creosote plant operations often contain storage facilities for creosote and fuels, a boiler for making steam, heating the creosote and applying the creosote to the wood, areas for unloading and storing incoming timbers, rail cars for transporting the creosote, and a drying area for subsequent storage. Creosote is the major source of a class of contaminants called polycyclic aromatic hydrocarbons (PAHs) which are the main driver of risk at this site. Potential for release of PAHs existed throughout the storage, application, and drying processes.

From 1921 to 1971, the facility discharged wastes to settling ponds that ultimately discharged to the Little Menomonee River. These discharges ceased when the plant diverted its process water discharge to the Milwaukee sanitary sewerage system. Production at the facility ceased in 1976.

Kerr-McGee purchased the facility in 1963 and changed the facility's name to Moss-American. The name was changed again in 1974 to Kerr-McGee Chemical Corporation - Forest Products Division. In 1998, the name of this company changed to Kerr-McGee Chemical LLC (KMC). Tronox assumed ownership of the site in 2006 when it was spun off from Kerr-McGee. In January 2009, Tronox filed for Chapter 11 bankruptcy.

1.4.3 Hydrogeology Setting

The site overlies a surficial water-bearing unit and confining bed. The water-bearing unit consists of a thin mantle of fill, alluvium, and weathered till. This thin layer of material would not yield sufficient water to wells to be classified as a true aquifer. The confining bed is the unweathered till of the Oak Creek Formation.

The surficial unit comprises everything above the confining bed. It includes extensive fill deposits, alluvial deposits along the river, and the weathered upper few feet of the Oak Creek Formation. The fill is highly variable and has been added to the site at different times for different reasons. Alluvial deposits are associated with the Little Menomonee River. They consist of sand and gravel channel deposits and silt and clay flood deposits. The till is part of the Oak Creek Formation, which consists of glacial till, lacustrine clay, silt and sand, and some glaciofluvial sand and gravel. The till is fine grained, commonly containing 80 to 90 percent silt and clay. The till was generally weathered to a depth of 2 to 10 feet.

The unweathered part of the Oak Creek Formation consists of a confining bed between the surficial water-bearing unit and underlying regional aquifers. The formation is a dense, silty clay till with interbedded lacustrine units. Below the site, the glacial deposits are approximately 150 feet thick and underlain by the dolomite aquifer. The minimum thickness of the confining bed below the site is at least 40 feet. Slug tests conducted during the RI on the most permeable parts of the Oak Creek Formation indicate average hydraulic conductivities of 10^{-5} to 10^{-6} cm/s [0.03 to 0.003 feet per day (ft/day)]. The overall hydraulic conductivity of the entire unit is probably less than the values reported.

Prior to implementation of the remedy, groundwater flowed toward the low-lying areas adjacent to the river. Groundwater discharged to these areas either migrates downriver through alluvial sands, or is lost to the atmosphere by evapotranspiration. Groundwater and surface water elevation data suggest that discharge to the river may vary seasonally. During dry periods, the Little Menomonee River is probably a losing stream (the river discharges to groundwater). Conversely, during wetter conditions, it is likely a gaining stream.

Constrained and channeled by the funnel and gate system, the groundwater within the shallow groundwater-bearing zone generally flows northeastward toward the Little Menomonee River. A review of data presented in the quarterly and annual groundwater monitoring reports by Weston indicate that in the topographically higher (western) portion of the site, the horizontal hydraulic gradient is relatively steep, at approximately 0.032 feet per foot (ft/ft) to the northeast. The topography of the site levels out near the river, as does the potentiometric surface with a northerly hydraulic gradient of approximately 0.013 ft/ft. The estimated hydraulic gradients within the treatment gates ranged from 0.0007 to 0.0043 ft/ft. The hydraulic gradient is relatively flat within the treatment gate area with an overall hydraulic gradient from TG1 to TG5 of approximately 0.0026 ft/ft in an easterly direction. Lowest hydraulic gradients are found in the area encompassing monitoring wells MW-7S, MW-33S, MW-34S, and MW-38S.

The hydraulic conductivity of the deposits located on the topographically higher, western portion of the site is in the range of 10^{-5} to 10^{-6} cm/s. In contrast, the hydraulic conductivity of material used to backfill areas within the funnel and gate remedial system is approximately 10^{-3} cm/s (3 ft/day). Using a hydraulic gradient of 0.032 ft/ft, an assumed effective porosity of 0.3, and a hydraulic conductivity of 0.03 ft/day, the groundwater flow velocity in the western portion of the site is calculated to be approximately 0.0032 ft/day. Near the river, using a hydraulic gradient of 0.013 ft/ft, a porosity of 0.3, and a hydraulic conductivity of 3 ft/day, the velocity of groundwater flow is calculated to be approximately 0.13 ft/day. The groundwater flow velocities within the treatment gates are estimated to range from 0.0066 to 0.1049 ft/day.

1.4.4 Description of Groundwater Plume

Historically, non-aqueous phase liquid (NAPL) has been identified in monitoring wells MW-34S, MW-7S and TG1-1. Recent NAPL occurrences in these wells have been limited to observations of sheen. The current dissolved-phase plume boundary is primarily in an area encompassing monitoring wells MW-7S, MW-33S, MW-34S, and MW-38S (Figure 2), which coincides in large part with the groundwater stagnation zone. There are also exceedances of State groundwater standards at MW-35S and treatment gate wells TG1-1, TG2-3 and TG4-1. In general, PAH concentrations measured in groundwater samples collected from the rest of the site were at relatively low levels with only sporadic detections.

Monitoring well MW-34S exceeds cleanup standards for numerous contaminants of concern including anthracene, benzene, benzo(a)pyrene, benzo(b)fluoranthene, chrysene, fluoranthene, fluorene, naphthalene, and pyrene. Monitoring well MW-7S exceeds standards for benzene and naphthalene, although trends for both contaminants are decreasing. In addition, increasing concentrations are identified for several COCs at these, and other, wells. Statistical analysis by EPA Region 5 indicates that multiple PAH contaminant concentrations are increasing, with current concentrations higher than the period just after construction of the funnel and gate system. Monitoring well MW-33S continues to exceed standards for naphthalene. Current contaminant concentrations from well MW-33S are also higher for anthracene and fluorene than they were shortly after implementation of the remedy.

2.0 PERFORMANCE OBJECTIVES

The focus of this RSE was on the groundwater remedy; the soil and sediment remedies were not evaluated. Groundwater remediation goals were to prevent migration of contaminated site groundwater into the Little Menomonee River and to attain concentrations in NR 140 of the Wisconsin Administration Code for COCs at the site. Groundwater contaminants of concern and their associated State preventative action levels (PAL) are listed in Table 1.

The remedial action objective (RAO) for groundwater as stated in the ROD was to: *Prevent release of contaminants through the surficial groundwater aquifer to the Little Menomonee River surface water or sediment and remove contaminants from groundwater such that concentrations don't exceed applicable State groundwater standards.*

3.0 SYSTEM DESCRIPTION

The groundwater remedy consisted of a funnel and gate system to capture and treat contaminated groundwater prior to discharge to the Little Menomonee River. The following section provides a description of the groundwater treatment system and associated monitoring program.

3.1 Groundwater Treatment System

A funnel and gate system was selected as the preferred alternative in the 1997 ESD. Pre-design results indicated that the relatively fine-grained site sediments would be well suited for this type of system. Groundwater flow was relatively uniform toward the Little Menomonee River with discontinuous zones of increased permeability (i.e. gravel fill and silty sand) acting to guide the direction of the contaminant plume. In the ESD, groundwater was predicted to move slowly through the treatment gates, which would provide adequate residence time for contaminant treatment.

The funnel and gate system is constructed of Waterloo sheet piling, which has an internal cavity sealable joint. This type of joint reduces the potential for leakage of contaminants through the joints. Early designs (60%) of the funnel and gate system showed two sets of funnel and gates: two gates on an upper funnel and three gates on a lower funnel located adjacent/parallel to the river. Installation was proposed in a phased approach. The upper funnel and gates would be installed and tested for performance. The lower funnel and gates, which had a higher potential to negatively impact the river, would then be installed following verification of the upper funnel and gate performance. This phased approach was not approved by the regulators because contaminants adjacent to the river would continue to be discharged during the test performance period.

The final design of the funnel and gate system changed the lower funnel and gates to a sheet pile containment wall with two sets of funnel/treatment gates to the east. Using this design, the entire system could be installed at one time and the potential for untreated contaminants reaching the river would be reduced. In considering the design change for the final funnel and gate system, it is uncertain if this system was thought to be capable of mobilizing contaminants located in the northwest corner of the sheet pile area toward the eastern gates for treatment. A groundwater model was reportedly developed for the 60% design, but was not available for review during this RSE.

The treatment gates consist of an area backfilled with a mixture of clean sand/soil and line of injection wells. The injection wells were installed at the up-gradient edge of the gate area and were designed to distribute air or other nutrients, as necessary. NAPL collection sumps were installed up-gradient of the gates to prevent potential plugging and/or treatment performance problems.

Treatment at the gates consists of air injection to enhance biodegradation of COCs. Dissolved oxygen concentrations in the gate area have been measured at less than 1 to over 4 mg/L. Well packers were installed at Gate 5 in June 2000 to help direct the air injection; however, no discernable changes in dissolved oxygen levels were observed until 2003. Packers were also proposed at Gates 1 and 2, but could not be properly installed. Nutrients were added at Gate 1 from June 2001 through October 2002 using a solution containing potassium nitrate (KNO_3) and potassium phosphate ($KHPO_4$). Nutrient augmentation was discontinued due to inconclusive evidence that it was enhancing biodegradation. Air injection has been the only treatment since that time.

3.2 Monitoring Program

Performance monitoring for the funnel and gate system consists of an evaluation of groundwater hydraulics and groundwater chemical analyses. The groundwater monitoring program has been revised several times, most recently in 2006/2007. During this last revision, twenty-two monitoring wells and piezometers across the site that were no longer sampled were abandoned. In addition, two monitoring wells were installed within the northwest area of the sheet pile for the funnel and gate system. Monitoring wells currently sampled as part of the monitoring program are shown in Table 2. All of the wells and piezometers are screened in the shallow groundwater-bearing zone underlying the site (surficial aquifer).

Water level measurements are collected on an annual basis at all monitoring wells and piezometers at the site to evaluate groundwater hydraulics. Chemical analyses are collected annually except at monitoring wells MW-7S, MW-34S, MW-38S, and MW-39S, where samples are collected semi-annually. Piezometers installed in 2002 and the middle performance monitoring well at each gate are not included in the chemical monitoring program. In addition to the on-site monitoring wells listed in Table 2, 11 shallow groundwater monitoring wells (MW-A through MW-K) located along the Little Menomonee River are sampled to monitor groundwater chemical conditions between the old and new river channels.

Analytical parameters collected at each well include benzene, toluene, ethylbenzene, and xylene (BTEX), polycyclic aromatic hydrocarbons (PAHs), and field parameters: pH, oxidation-reduction potential, dissolved oxygen, specific conductance, temperature, and turbidity. Samples collected at the treatment performance monitoring wells at each gate also are analyzed for microbial enumeration, nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), phosphate-phosphorous (PO_4-P), orthophosphate (ORP), biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC).

4.0 SYSTEM PERFORMANCE

4.1 Groundwater Flow

Groundwater elevation data collected since the funnel and gate system was completed in 2000 were reviewed to evaluate flow through the system. Groundwater at the site generally flows from south to north toward the Little Menomonee River. Due to the presence of the sheet pile wall along the north and west portion of the system, groundwater is directed toward the eastern treatment gates.

The groundwater flow evaluation indicates that there are several areas of concern where groundwater may not be hydraulically contained or treated by the gates:

- Groundwater flow maps consistently indicate the presence of a stagnation zone in the northwest corner of the sheet pile area near MW-34S and MW-7S. Groundwater elevation data show that there is only a very slight gradient between these two wells. The boring log for MW-7S indicates the surficial aquifer in this area is composed of low permeable materials (very fine sand and silt), which, coupled with the low gradient, would result in a very low groundwater velocity. The borelog for MW-34S was not available for review.

- Groundwater elevation data at MW-33S and PZ-02 indicate that groundwater may be flowing around the end of the sheet pile wall. A head difference of about 0.5 feet is typically measured between MW-33S and PZ-02. Borelogs for these two wells were not available for review.

- Groundwater elevation data from performance wells at gates 1, 3, and 4 frequently show the gradient is reversed (flowing from down-gradient of the gate toward the up-gradient side). It should be noted that the magnitude of the calculated gradient is very low, so the possibility of measurement error (i.e water levels, top of casing survey) should also be considered.

Two monitoring wells, MW-38S and MW-39S, located near the groundwater stagnation zone, were installed in 2006 to help delineate the remaining dissolved-phase plume in the northwestern portion of the system. These wells were never surveyed and have never been used in the preparation of groundwater flow maps. These wells could be surveyed and used in future construction of groundwater flow maps to help evaluate groundwater flow across the site.

4.2 Groundwater Chemical Concentrations

Contaminants in groundwater are consistently detected above cleanup goals in two areas: 1) in the northwest section of the sheet pile area in the groundwater stagnation zone at monitoring wells MW-7S, MW-33S, MW-34S, and MW-38S, and 2) up-gradient of Gate 1 in TG1-1.

4.2.1 Contaminant Concentrations in Northwest Corner of Site

Trend analyses for the most prevalent contaminants (benzene, naphthalene, fluorene, and benzo(a)pyrene) show that there are decreasing trends or no trends for wells in the northwest corner (Appendix B). Trend testing results confirmed decreasing naphthalene concentrations in MW-7S and MW-38S and decreasing benzene concentrations in MW-7S, indicating that natural attenuation is occurring in these areas. However, these trends cannot be used in a predictive sense, because overall trends indicate that PALs should have been achieved within the past year or two. Instead, recent sampling results suggest that trends may be asymptotically “bottoming-out.”

Measurable NAPL has historically been detected at MW-34S. In 2008, 3.24 inches of NAPL was measured. Since that time measurements have decreased to trace detections, although dissolved-phase concentrations of naphthalene continue to exceed 10,000 µg/L (September 2009 data). Given high dissolved-phase PAH concentrations and typical inaccuracies with NAPL measurements, it is assumed that some NAPL remains in the vicinity of MW-34S and could be a continued source to the dissolved-phase plume. It should also be noted that the soil excavation completed during the installation of the funnel and gate system only occurred to the southeast of MW-34S and did not extend into the current dissolved-phase plume area (see Groundwater Remedial System drawings, March 1998). Presence of NAPL and the development of a stagnation zone in the funnel and gate system have the potential to greatly extend time to restoration.

Besides the extended time to restoration, there are several potential issues with the remaining dissolved-phase plume. As suggested in the 2010 Five-Year Review, the pattern of water levels near MW-7S/MW-34S could indicate that the sheet pile barrier to the north does not form a sufficiently competent barrier to groundwater flow. Thus, contaminated groundwater could be flowing through joints in the sheet pile wall near MW-34S and discharging to the river. In addition, the flow evaluation indicated that groundwater has been moving around the end of the sheet pile wall near MW-33S. Since there are no chemical samples collected north of the sheet pile wall, contamination migration along this pathway cannot be ruled out.

4.2.2 Contaminant Concentrations Up-gradient of Gate 1

Concentrations of benzene and PAHs in groundwater are typically measured above PALs at up-gradient performance monitoring well TG1-1. Trend tests show concentrations of naphthalene, fluorene, and benzo(a)pyrene have been increasing, indicating a continued source of contamination in this area (Appendix B). NAPL was historically detected in TG1-1 up to 11 inches thick; however, only trace or sheen thickness has been observed since 2003. As with MW-34S, naphthalene concentrations in TG1-1 currently exceed 10,000 µg/L (September 2009 data), which suggests that a NAPL source persists in the area. Since the extent and magnitude of the remaining contamination in soil and groundwater near Gate 1 is uncertain and contaminant concentrations continue to rise, time to restoration cannot currently be estimated. Most of the monitoring wells used to define the historical extent of the groundwater contamination near Gate 1 have been abandoned. However, there are several piezometers used only for hydraulic monitoring near Gate 1 that could be sampled to help delineate the remaining dissolved-phase plume.

4.3 Treatment Gates

With the exception of Gate 1, contaminant concentrations up-gradient and down-gradient of the treatment gates indicate that much of the historical groundwater contamination has been removed. Several PAHs (benzo(a)pyrene, benzo(f)fluorene, and chrysene) are sporadically detected above PALs in monitoring wells near Gates 3 and 4, however, concentrations are low, just above the cleanup goal of 0.02 µg/L. Even with the potential gradient reversal at Gates 3 and 4, the treatment gates appear to be functioning adequately.

The only gate area with significant remaining contamination is Gate 1. Even though groundwater concentrations are elevated at TG1-1, there are typically no detections of PAHs in the down-gradient performance monitoring well, TG1-3. Oxygen levels measured in Gate 1 are also low, signifying that the injected oxygen is being consumed, and the gate is functioning adequately.

5.0 REMEDY OPTIMIZATION OPTIONS

Previous assessments in annual reports and Five-Year Reviews determined that the existing funnel and gate remedy was having limited success in the northwest corner of the site due to development of a stagnant zone in groundwater. Investigations recommended to ensure effectiveness of the remedy and to inform decisions about ways to improve effectiveness and shorten time to site closeout are discussed below (Section 5.1). Section 5.2 evaluates three options to hasten site closeout through source removal and/or groundwater gradient enhancements.

5.1 Recommendations to Improve Effectiveness

5.1.1 Monitoring Program Modification

The primary areas of concern for the monitoring program are the lack of chemical data outside the sheet pile wall near MW-7S and MW-34S, where there is a possibility that contaminants could be passing through the joints or migrating around the end of the wall, and the extent of remaining contamination near TG1-1. A secondary area of concern is the extent of the dissolved-phase plume in the interior of the funnel and gate system. The following enhancements to the monitoring program are recommended (see Figure 2 for well locations):

- Install two monitoring wells outside the sheet pile wall to the north of MW-34S and to the west of MW-7S to determine if contaminants are migrating through the sheet pile wall.
- Develop and sample piezometer PZ-02 to determine if contaminants are migrating around the end of the sheet pile wall.
- Develop and sample piezometers PZ-07, -09, and -10 to determine the up-gradient extent of remaining contamination near TG1-1.
- Develop and sample piezometer PZ-03 to confirm the extent of the dissolved-phase plume in the interior of the funnel and gate system.
- Survey MW-38S and MW-39S and include water levels from these wells in groundwater flow maps.

Costs for modifying the monitoring program include **$13,100** for the installation and development of two monitoring wells (includes oversight and reporting) and **$5,000** for development of five existing piezometers. Prior to development of the piezometers, their construction should be verified (i.e. depth, well screen interval). Additional costs of about **$5,900** for labor and laboratory analysis would also be accrued during each sampling event. Costing assumptions are described in Table 3. If contaminants are not detected in new monitoring locations after four sampling events, the wells/piezometers could be dropped from the program.

5.1.2 NAPL Investigation

Removal of residual NAPL in areas near MW-34S and TG1-1 would eliminate this continued contaminant source to the dissolved-phase plume and shorten time to site closeout. A localized direct push soil and groundwater investigation could be implemented to spatially delineate residual NAPL contamination in these areas. NAPL is likely not uniformly distributed in site soil, which means absence of NAPL in a particular soil boring would not necessarily preclude NAPL presence in nearby soil. In order to improve NAPL delineation during the investigation, grab groundwater samples could be collected by the direct push rig during completion of soil borings. Groundwater samples with naphthalene concentrations approaching 9,100 µg/L[1] would indicate NAPL presence in the vicinity of the soil boring. A schematic of a potential NAPL investigation program is provided on Figure 3. Locations where NAPL presence, soil concentrations or groundwater naphthalene concentrations greater than 9,100 µg/L were detected would be considered for inclusion in an excavation footprint. This investigation for each area would cost an estimated **$36,000** based on assumptions described in Table 3.

5.2 Recommendations to Improve Site Closeout

Remedy optimization options were developed primarily to address the elevated COC concentrations in the vicinity of MW-34S and the stagnant groundwater zone that is limiting flow through the treatment gates. Because treatment at Gate 1 is currently effective and the remedy is functioning as intended, future work to shorten time to site closeout in that area is discretionary and of secondary importance to work in the MW-34S area. Consequently, costs for enhancements to the remedy near Gate 1 have not been developed but should be readily scalable from those for the MW-34S area. Implementation of these options would be influenced by the results of investigations discussed in Section 5.1.

Options were evaluated for effectiveness using a simplified numerical groundwater model and by considering implementability, and if applicable, cost (Table 4). It should be noted that a more robust numerical model would likely be needed if the selected remedy optimization includes significant modifications to the groundwater flow system, such as with the installation of a new gate or extraction wells. For those options which were deemed technically ineffective or for which there was insufficient site information, costs have not been developed and are not presented herein.

The groundwater model was designed to simulate groundwater flow only in the vicinity of the funnel and gate system and was calibrated to water level data collected during the 3rd quarter of 2009. Details on the model setup, calibration, and results are presented in Appendix A. The following simplifying assumptions were utilized:

- The flow system is steady state,
- The surficial unit (shallow aquifer zone) is uniformly 15-feet thick,
- The topographically higher, western portion of the site has a lower hydraulic conductivity than the topographically lower portion within the funnel and gate system, and
- The sheet pile barrier has a bulk hydraulic conductivity of 1×10^{-7} cm/s.

5.2.1 NAPL-Impacted Soil Excavation and Enhanced Dissolved-Phase Treatment

Locations identified during the NAPL investigation where NAPL presence, soil concentrations or groundwater naphthalene concentrations representing a significant percentage of the solubility level were detected could be considered for inclusion in an excavation footprint. We have assumed that an area centered around MW-34S extending 50 ft from the wall and 75 ft along the wall would be included in the excavation footprint (Figure 3). Excavation costs near TG1-1 are not included but could be scaled from MW-34S, depending on the results of field investigations. Based on current data, it is believed that excavation near TG1-1 would be less extensive than near MW-34S and costs proportionally lower.

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[1] Estimated effective naphthalene groundwater water solubility in presence of NAPL calculated assuming a typical creosote composition; calculations are included in Appendix C for reference.

Available boring logs[2] for nearby wells MW-7S and MW-39S indicate that depth to the confining clay layer is 10-12 feet bgs. An average depth of 15 feet has been assumed for the thickness of the surficial unit in the numerical groundwater model, so this excavation depth was assumed as well. A lined staging and dewatering area for excavated soil could be prepared near the excavation pit and could be sloped to allow dewatering water to collect in the excavation pit. A sump could be included to capture any product seeping from the dewatering water. Groundwater could be allowed to accumulate in the excavation pit, the bottom of which could be sloped to function as a sump as well. Any accumulated product in the excavation could be removed by pumping. Excavation, materials, handling and associated activities would cost an estimated **$202,000** based on assumptions described in Table 3.

Although the final depth of sheet pile wall installation into the clay layer is not known, preliminary design documents indicate a target final depth of 3 ft below the clay layer surface, i.e. a final sheet pile wall depth of ~ 18 ft bgs. Because the sheet pile wall will function as a retaining wall during excavation, and the engineering rule for minimum wall depth is 2x the excavation height, the wall section adjacent to the excavation area will need to be improved to safely meet depth requirements. Assuming a 15 ft excavation, the required improved sheet pile wall depth in this area would be 50 ft bgs. Materials and installation for the improved 50 ft x 75 ft section of sheet pile wall would cost an estimated **$94,000** based on assumptions described in Table 3.

Oxygen Releasing Compound Advanced (ORC Advanced®) could be incorporated into the excavation backfill to enhance biodegradation of dissolved-phase contaminants in both the excavation and groundwater. Because molecular oxygen would subsequently diffuse into groundwater surrounding the ORC Advanced® amended backfilled area, biodegradation of dissolved-phase contaminants would be enhanced in surrounding groundwater as well. The groundwater model also showed that there would be some localized groundwater flow into the ORC backfilled area (Figure A-4).

ORC Advanced® is a proprietary formulation of food-grade, calcium oxy-hydroxide that produces a controlled release of molecular oxygen for a period of up to 12 months upon hydration by groundwater[3] and has been demonstrated to enhance treatment of PAHs[4] and benzene[5] in groundwater. The recommended application rate for ORC Advanced® is 0.1-0.3 percent by weight of excavated soil. Approximately 5.2 tons of ORC Advanced® would be required for an excavated soil mass of 2,600 tons[6], which would cost an estimated **$86,000** based on assumptions described in Table 3.

Total cost for this option, assuming excavation only in the MW-34S area, would be approximately **$381,000**. In addition, limited design work not included in this estimate may be necessary for sheet pile shoring and excavation.

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[2] The MW-34S boring log was not available during our analysis.

[3] Information for ORC Advanced is available online: http://www.regenesis.com/contaminated-site-remediation-products/enhanced-aerobic-bioremediation/orc-advanced/

[4] Koenigsberg, S. and Sandefur C. The Use of Oxygen Release Compound for the Accelerated Bioremediation of Aerobically Degradable Contaminants: The Advent of Time-Release Electron Acceptors. (1999, Winter) *Remediation.* 6(4), 3-29.

[5] Bianchi-Mosquera, G. C., Allen-King, R. M., Mackay, D. M. Enhanced Degradation of Dissolved Benzene and Toluene Using a Solid Oxygen-Releasing Compound. (1994, Winter). *GWMR* X(X), 120-128.

[6] Assumes excavation volume of 2083 cy and bulk density of 1.26 ton/cy.

Despite evidence for decreasing trends in some wells, groundwater in the vicinity of NAPL-impacted wells MW-34S and TG1 will likely not attenuate within a reasonable timeframe. Targeted NAPL removal in these areas followed by addition of ORC Advanced® would enhance dissolved-phase attenuation in the TG1 and MW-34S areas and decrease restoration timeframes in nearby wells MW-7S and MW-38S as well.

5.2.2 Limited NAPL-Impacted Soil Removal and Installation of Additional Gate in NW Corner

The installation of a new treatment gate with air injection system in the northwest corner of the sheet pile, similar to the original design concept, could also be adopted. A new gate would increase the hydraulic gradient in the NW corner and eliminate the stagnation zone and the potential for groundwater to flow around the end of the sheet pile, as well as provide long-term treatment for any remaining dissolved-phase contaminants. Excavation of NAPL-containing soils near MW-34S could be conducted in conjunction with the installation of the gate system, thereby potentially eliminating the need for structural sheet pile during excavation as discussed in Section 5.2.1.

Two gate scenarios were evaluated: one installed to the north of MW-34S and one installed to the west of MW-7S. Both scenarios include limited excavation of NAPL-containing soil near MW-34S that is easily accessible without requiring reinforcement of the sheet pile wall. The groundwater model shows that if a new gate is installed to the north of MW-34S, the majority of groundwater flow from the upper treatment gates (Gate 1 and 2) would be directed toward the new gate (Figure A-8), eliminating the stagnation zone. Potential issues with installation of this gate include the proximity to the river, slope stability issues and a limited buffer zone between the treatment gate and the river. Concern about contaminant discharge to the river from the treatment gate should be alleviated by performance data from existing gates. Engineering complications associated with proximity of the river would have to be resolved during design.

A new gate to the west of MW-7S could also induce groundwater flow in the area of the stagnant dissolved-phase plume. The groundwater model shows that groundwater from Gates 1 and 2 would continue to flow toward the eastern treatment gates and groundwater within the dissolved-phase plume would flow toward the new gate near MW-7S. Costs for either gate scenario would total approximately **$979,000**. These costs do not include additional modeling or design work that may be necessary, especially if proximity to the river requires special design considerations.

It should be noted that a gate near NW-34S is preferred over one near MW-7S for hydraulic reasons, because it does a better job of improving flow through the stagnant zone. However, risk management and design considerations may make a gate near MW-7S preferable.

5.2.3 Groundwater Flow Modification to Enhance Treatment of Existing Funnel & Gate System

Groundwater flow modifications using the existing funnel and gate configuration could be implemented to induce a hydraulic gradient across the site and eliminate the zone of stagnation in the northwest corner. Excavation of NAPL-containing soils around MW-34S could also be conducted in conjunction with the flow modifications as described in Section 5.2.1.

Two model scenarios were evaluated: 1) installation of extraction wells down-gradient of Gates 5 and 6 and 2) installation of a large scale re-circulation cell that includes an injection well near MW-7S and an extraction well down-gradient of Gate 5. The groundwater model shows that even with extraction wells, the groundwater stagnation area may still exist (Figure A-6). The extraction wells induce a slight gradient across the site as there is a reduction in flow around the end of the sheet pile near MW-33S. Due to the low permeability soils, groundwater extraction rates were predicted to be less than 1 gpm. Since the gradient across the site would still be very low, it could take over 30 years for contaminated groundwater near the stagnation zone to reach the eastern treatment gates.

The groundwater model shows that with a large scale re-circulation cell groundwater within the stagnation zone would flow toward the eastern treatment gates; however, there could be increased flow around the end of the sheet pile near MW-33S due to mounding effects (Figure A-7). Again, the low permeability materials would limit the extraction/injection rates. When compared to the extraction well scenario, the gradient across the site is increased, but it could still take over 20 years for contaminated groundwater near the stagnation zone to reach the eastern treatment gates. In addition, such flow modification would encourage contaminated groundwater flow into areas that currently contain low-level contamination, thereby potentially increasing the volume of groundwater contaminated above cleanup levels at the site.

Planting poplar trees by the final gate pairs has also been proposed in lieu of extraction wells to induce a gradient across the site. In addition to the low gradient issues stated above, poplar trees would only have a seasonal influence on the water levels at the site. Also rejected as ineffective was extension of the sheet pile wall near MW-33S. Preliminary modeling showed no improvements to flow in the stagnant zone. Due to problems associated with persistence of the stagnation zone, sheet pile wall bypassing due to groundwater mounding, and excessive transport times to reach treatment gates, manipulations to hydraulic gradients (in the context of the existing funnel & gate system) are of questionable effectiveness. Costs were not developed for these scenarios due to perceived ineffectiveness at achieving desired results.

6.0 SUMMARY

The observations and recommendations contained in this report are not intended to imply a deficiency in the work of either the designers or operators, but are offered as constructive suggestions to fill data gaps and optimize remedy performance. These recommendations obviously have the benefit of operational data unavailable to the original designers. The RSE process is designed to help site operators and managers improve effectiveness, reduce operation cost, improve technical operation, and expedite site closeout.

Improvements to site characterization and the groundwater monitoring program were recommended in order to evaluate effectiveness and protectiveness of the system as installed and better understand subsurface conditions in advance of remedy alterations. At a minimum it is recommended that the limited monitoring program adjustments and subsurface characterization activities discussed in Sections 5.1.1 and 5.1.2 be seriously considered. These recommendations include:

- Installation of two monitoring wells outside the sheet pile wall to determine if contaminants are migrating through the wall [addresses effectiveness of the wall and evaluates protectiveness for receptors in the river]
- Conversion of PZ-02 (by developing and sampling) to a monitoring well to determine if contaminants are migrating around the end of the wall [addresses effectiveness of the wall and evaluates protectiveness for receptors in the river]
- Conversion of several piezometers (PZ-03, -07, -09, and -10) to monitoring wells to better understand residual source and dissolved-phase contaminant extent [feeds into design for system modifications leading to quicker site closeout]
- Direct push soil and groundwater investigation in the stagnant zone to delineate persistent source area [feeds into design for system modifications leading to quicker site closeout]

In addition, the following options were evaluated with the goal of improving system performance and shortening time to achievement of cleanup objectives:

- NAPL-impacted soil excavation and enhanced dissolved-phase treatment
- Limited NAPL-impacted soil removal and installation of additional gate in NW corner
- Groundwater flow modification to enhance treatment of existing funnel & gate system

Of these, the first two have the greatest potential to improve treatment efficiency and shorten time to achievement of cleanup objectives. However, the second option, which is most similar to the original design, has the potential to discharge contaminants above PALs to the Little Menomonee River. This potential is considered unlikely given a considerable record of successful treatment in the existing gates at the site. The third option was found to be ineffective or of limited benefit because of the difficulty associated with enhancing the hydraulic gradient in the low permeability soils and protracted times to site closeout.

Results from field investigations could determine the most cost-effective option for improving system performance. If minimal amounts of NAPL are encountered, the assumed need for sheet pile wall improvement and volume of soil excavation and ORC Advanced® quantities required may be reduced thereby resulting in a lower estimated cost. Likewise, institution of the original design concept of a treatment gate in the NW corner may be sufficient to flush and treat remaining dissolved-phase contaminants. If significant quantities of NAPL are found, more aggressive excavation, followed by amending the backfilled area with ORC Advanced®, may be more suitable to achieving site cleanup goals in a reasonable timeframe. A determination may have to be made whether the latter option requires an additional decision document.

TABLES AND FIGURES

Table 1. Groundwater Cleanup Goals

Constituent	**PAL (µg/L)**
Anthracene	600
Benzo(a)pyrene	0.02
Benzo(b)fluoranthene	0.02
Chrysene	0.02
Fluoranthene	80
Fluorene	80
Naphthalene	8
Pyrene	50
Benzene	0.5
Toluene	68.6
Ethylbenzene	140
Xylene	124

Notes:

PAL – Wisconsin Department of Natural Resources (WDNR) Preventative Action Level, Ch. NR 140, Wis. Adm. Code
µg/L – microgram per liter

Table 2. Monitoring Program

Well ID	Monitoring Purpose	Screened Interval (feet bgs)	Analytical Sampling	Water Level Measurements
MW-7S	Containment	10-15	Semi-Annual	Semi-Annual
MW-34S	Containment	*	Semi-Annual	Semi-Annual
MW-38S	Containment	10-15	Semi-Annual	Semi-Annual
MW-39S	Containment	10-15	Semi-Annual	Semi-Annual
MW-5S	Containment	12-17	Annual	Annual
MW-9S	Containment	8-13	Annual	Annual
MW-27S	Containment	*	Annual	Annual
MW-30S	Containment	*	Annual	Annual
MW-31S	Containment	*	Annual	Annual
MW-32S	Containment	*	Annual	Annual
MW-33S	Containment	*	Annual	Annual
MW-34S	Containment	*	Annual	Annual
MW-37S	Containment	*	Annual	Annual
MW-38S	Containment	*	Annual	Annual
MW-39S	Containment	*	Annual	Annual
TG1-1	Treatment	*	Annual	Annual
TG1-2	Treatment	*	--	Annual
TG1-3	Treatment	*	Annual	Annual
TG2-1	Treatment	*	Annual	Annual
TG2-2	Treatment	*	--	Annual
TG2-3	Treatment	*	Annual	Annual
TG3-1	Treatment	*	Annual	Annual
TG3-2	Treatment	*	--	Annual
TG3-3	Treatment	*	Annual	Annual
TG4-1	Treatment	*	Annual	Annual
TG4-2	Treatment	*	--	Annual
TG4-3	Treatment	*	Annual	Annual
TG5-1	Treatment	*	Annual	Annual
TG5-2	Treatment	*	--	Annual
TG5-3	Treatment	*	Annual	Annual
TG6-1	Treatment	*	Annual	Annual
TG6-2	Treatment	*	--	Annual
TG6-3	Treatment	*	Annual	Annual
PZ-01	Piezometer	*	--	Annual
PZ-02	Piezometer	*	--	Annual
PZ-03	Piezometer	*	--	Annual
PZ-04	Piezometer	*	--	Annual
PZ-05	Piezometer	*	--	Annual
PZ-06	Piezometer	*	--	Annual
PZ-07	Piezometer	*	--	Annual
PZ-09	Piezometer	*	--	Annual
PZ-10	Piezometer	*	--	Annual

Table 2 Notes:
Piezometer – Additional water level measurements locations to verify hydraulic containment
Containment – Shallow and Containment Performance Monitoring Wells
Treatment – Treatment Performance Monitoring Wells
Annual – Sampled during 3rd Quarter (September)
Semi-Annual – Sampled during 1st and 3rd Quarter (March and September)
-- Not sampled
* Well construction details not available, proposed construction included a 5-foot screen interval and total depth of 10-12 feet bgs.

Table 3. Cost Assumptions

REPORT SECTION, TASK	ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT	ASSUMPTIONS
5.1.1, Monitoring Program Modifications[1]						
Install and develop new monitoring wells	Mob/Demob	1	each	$2,000	$2,000	
	Drill and Install MW	30	foot	$120	$3,600	15-foot wells, 5-foot screen
	Development	8	hr	$250	$2,000	4 hours/well
	Survey	1	each	$1,500	$1,500	2 new wells, plus MW-38S and -39S
	Workplan/Oversight/Reporting	40	hr	$100	$4,000	
	Subtotal				$13,100	
Develop existing piezometers	Development	20	hr	$250	$5,000	4 hours/well
	Subtotal				$5,000	
Sampling and analysis for new monitoring locations	Sampling	16	hr	$200	$3,200	2 days, 2 people
	GW PAH Analysis, EPA 625/8270	8	each	$160	$1,280	Includes 1 duplicate
	GW BTEX Analysis, EPA 624/8260	8	each	$173	$1,384	Includes 1 duplicate
	Subtotal				$5,864	
Total Cost for Monitoring Program Modification					***$23,964***	

Table 3 Cont. Cost Assumptions

REPORT SECTION, TASK	ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT	ASSUMPTIONS
5.1.2, NAPL Investigation[1]						
MW-34S GeoProbe Investigation	Drilling (Geoprobe)	3	day	\$2,000	\$6,000	5 borings/day
	Workplan/Oversight/Reporting	150	hr	\$100	\$15,000	
	Soil BTEX Analysis EPA 624/8260	30	each	\$173	\$5,190	2 soil samples/well
	Soil PAH Analysis EPA 625/8270	30	each	\$160	\$4,800	2 soil samples/well
	GW BTEX Analysis, EPA 624/8260	15	each	\$173	\$2,595	
	GW PAH Analysis, EPA 625/8270	15	each	\$160	\$2,400	
	subtotal				\$35,985	
TG1-1 GeoProbe Investigation	Drilling (Geoprobe)	3	day	\$2,000	\$6,000	5 borings/day
	Workplan/Oversight/Reporting	150	hr	\$100	\$15,000	
	Soil BTEX Analysis EPA 624/8260	30	each	\$173	\$5,190	2 soil samples/well
	Soil PAH Analysis EPA 625/8270	30	each	\$160	\$4,800	2 soil samples/well
	GW BTEX Analysis, EPA 624/8260	15	each	\$173	\$2,595	
	GW PAH Analysis, EPA 625/8270	15	each	\$160	\$2,400	
	subtotal				\$35,985	
Total Cost for NAPL Investigation					***\$71,970***	

Table 3 Cont. Cost Assumptions

REPORT SECTION, TASK	ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT	ASSUMPTIONS
5.2.1, NAPL-Impacted Soil Excavation and Enhanced Dissolved-Phase Treatment[2]						
Excavation	Workplan/Oversight/Reporting					
	Project Manager	40	hr	$200	$8,000	
	Project Scientist	40	hr	$203	$8,136	
	QA/QC Officer	16	hr	$201	$3,216	
	Field Technician	100	hr	$120	$12,000	assumed 10, 10 hr days in field
	Clerical	8	hr	$74	$592	
	CADD	8	hr	$82	$656	
	Excavate and load, bank measure, medium material, 2 CY bucket, hydraulic excavator[1]	2084	CY	$2.5	$5,175	Labor unit cost 1.48; equipment unit cost 1.01
	12 CY Dum Truck Haul/Hour	130	BCY	$174	$ 22,742	Labor unit cost 107.4; equipment unit cost 67.54
	Backfill with crushed stone[1]	70	CY	$54	$3,768	Labor unit cost 1.91; equipment unit cost 1.1; material unit costs 1.10
	Unclassified fill, 6" lifts, off-site, includes delivery, spreading and compaction[1]	2708	CY	$15	$41,129	Labor unit cost 1.52; equipment unit cost 1.32; material unit costs 12.32; subbid unit cost 0.02
	Disposable materials per sample[1]	12	each	$15	$175	
	Soil testing for soil disposal					
	EPA 625/8270 (SVOCs)	5	each	$160	$800	
	EPA 624/8260 (BTEX)	5	each	$173	$865	
	Haul & Dispose Debris, 16.5 CY Truck, 10 mi Haul Distance, Non-hazardous Landfill[1]	2084	CY	$45	$94,269	Labor unit cost 2.62; equipment unit cost 2.01; subbid unit cost 40.6
	subtotal				**$201,523**	

Table 3 Cont. Cost Assumptions

REPORT SECTION, TASK	ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT	ASSUMPTIONS
Sheet Pile Wall Improvement	50ft x 75ft sheet pile wall installed	3750	sq ft	$25	$93,750	Ref: 2007 RS Means Building Construction Cost Data 65th Ed. Included 2x markup on unit cost.
	subtotal				**$93,750**	
Oxygen Release Compound (ORC) Advanced® Enhancement	ORC Advanced® Product	10535	lb	$8	$85,856	Does not include freight for product shipment.
	subtotal				**$85,856**	
Total Cost for NAPL Excavation					***$381,129***	

Table 3 Cont. Cost Assumptions

REPORT SECTION, TASK	ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT	ASSUMPTIONS
5.2.2, Limited NAPL-Impacted Soil Removal and Installation of Additional Gate in NW Corner						
Treatment Gate Installation[3]	Mobilization/Demobilization	1	LS	$93,729	$93,729	
	Equipment Setup/Teardown	1	LS	$18,492	$18,492	
	Steel Sheeting Removal	1080	VF	$35.00	$37,800	
	5-30’ Long Self Hardening 2’0”wide Perimeter and Internal cantilever support walls 24’ deep	3,600	SF	$38.57	$138,852	
	1-60’x30’x15’deep Biopolymer Treatment Gate Pit and Piping accessories (4- 15’x30’ pits)	1	LS	$609,444	$609,444	
	BP Breakdown and Pumping Operation	1	LS	$32,645	$32,645	
	subtotal				**$930,962**	
Soil Disposal	Gate plus limited additional soil disposal	0.5	LS	$96,109	$48,054.51	Scaled (0.5x) from disposal costs in 5.2.1
	subtotal				**$48,055**	
Total Cost for Limited NAPL-Impacted Soil Removal and Installation of Gate					**$979,017**	

Notes:

[1] Recent project experience used to prepare costs for monitoring program modifications and NAPL investigations

[2] RACER 10.3 used to prepare costs for NAPL-impacted soil excavation and enhanced dissolved-phase treatment. Costs are only for excavation and treatment near MW-34S; similar work in the TG1 area could cost as much, although it is likely investigation results would limit the scope of excavation and treatment required.

[3] Industry estimate

Table 4. Remedy Optimization Options Evaluation Summary

Recommendation	Effectiveness	Implementability	Cost
5.1.1 Monitoring program modification	Evaluates effectiveness of remedy to gain site closure.	Easily implemented by installing two new wells and using existing piezometers.	$22K
5.1.2 NAPL investigation	Evaluates the extent of residual NAPL. Reduces uncertainty in the required excavation extent to gain site closeout.	Easily implemented using direct-push technology.	$72K
5.2.1 NAPL-impacted soil excavation and enhanced dissolved-phase treatment (MW-34S area only)	Removal of residual NAPL would eliminate the continued source to the dissolved-phase plume and shorten the time to site closeout. ORC will enhance bioremediation in the vicinity of the excavation.	Moderate effort to improve sheet pile wall near MW-34S prior to excavation. ORC Advanced can easily be incorporated into excavation backfill.	$381K
5.2.2a Limited NAPL-impacted soil removal and installation of additional gate in NW corner	Limited removal of residual NAPL would eliminate a continued source to the dissolved-phase plume and shorten the time to site closeout. The treatment gate near the excavation would eliminate the groundwater zone of stagnation and provide long-term treatment of any remaining dissolved-phase contaminants. More hydraulically effective than a gate near MW-7S.	Moderate effort to remove sheet pile wall, excavate residual NAPL, install gate near MW-34S and install air injection system. State no longer has concerns with a treatment gate close to the river. Proximity to river may make this more complicated than a gate near MW-7S.	$979K
5.2.2b Limited NAPL-impacted soil removal and installation of additional gate west of MW-7S	Limited removal of easily accessible residual NAPL would eliminate a continued source to the dissolved-phase plume and shorten time to site closeout. A treatment gate to the west of MW-7S would eliminate the groundwater zone of stagnation and provide long-term treatment of any remaining dissolved-phase contaminants. Less hydraulically effective than gate near MW-34S.	Moderate effort to remove sheet pile wall, excavate residual NAPL, install new gate near MW-7S and install air injection system. The State no longer has concerns with a treatment gate close to the river. Possibly easier to implement than a gate near MW-34S.	$979K

Recommendation	Effectiveness	Implementability	Cost
5.2.3a Groundwater flow modification to enhance treatment of existing funnel & gate system – install extraction wells	Installation of extraction wells down-gradient of Gates 5 & 6 would only induce a slight hydraulic gradient across the site; thus it would take years for contaminants to reach the treatment gates. Deemed ineffective.	Moderate effort to install extraction wells and treat groundwater prior to discharge. Long-term treatment of remaining dissolved-phase contaminants may not be necessary if source removed.	Not costed, ineffective
5.2.3b Groundwater flow modification to enhance treatment of existing funnel & gate system – large scale re-circulation cell	The re-circulation cell would induce flow in the groundwater zone of stagnation, however, there could be increased flow around the end of the sheet pile. Flow modification would encourage contaminated groundwater to migrate into areas that currently contain low-level contamination. Deemed ineffective.	Moderate effort to install extraction/injection wells and piping. Long-term treatment of remaining dissolved-phase contaminants may not be necessary if source removed.	Not costed, ineffective.

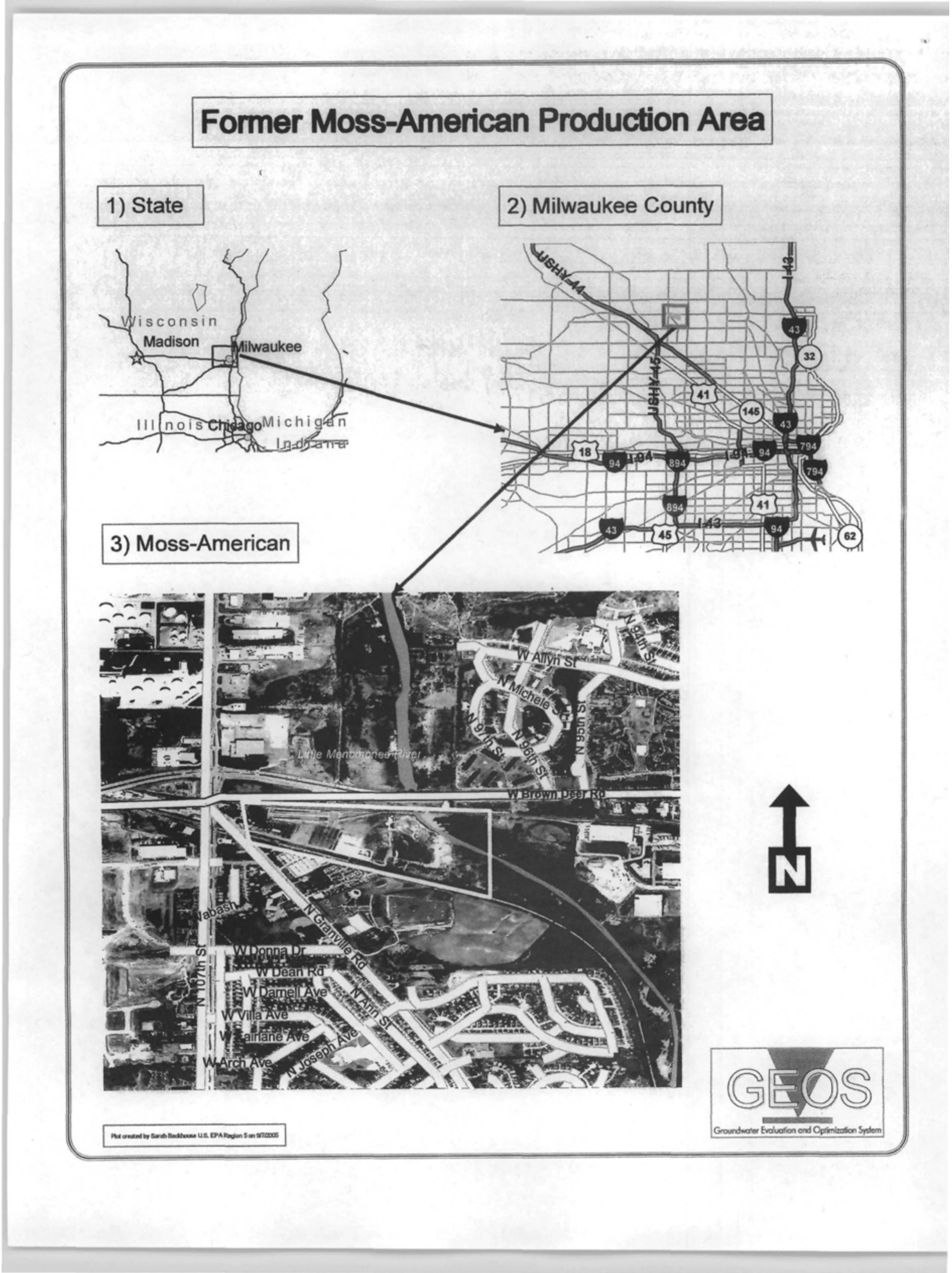


Figure 1. Site Location

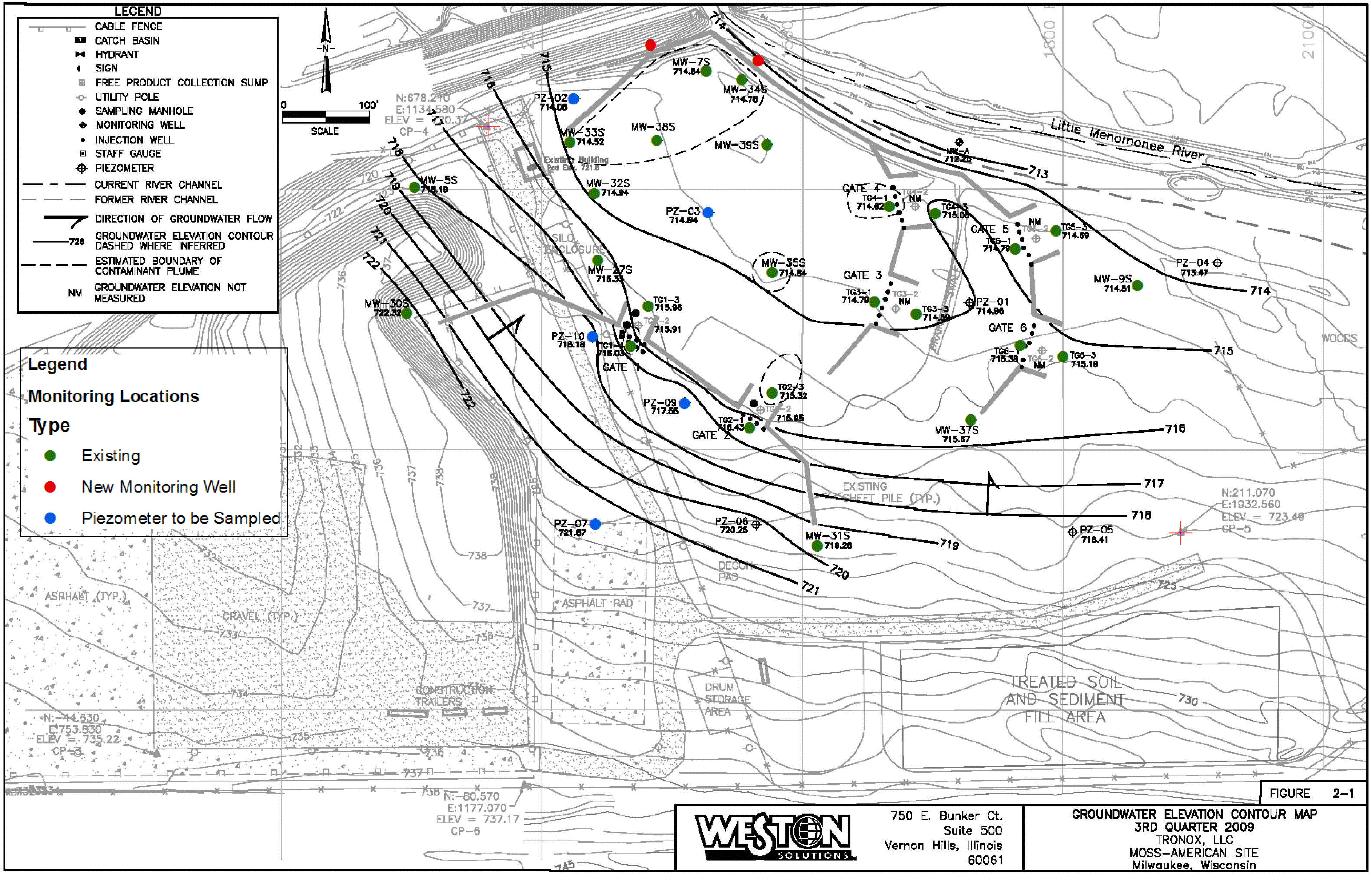


Figure 2. Proposed Additional Monitoring Locations for Chemical Analysis

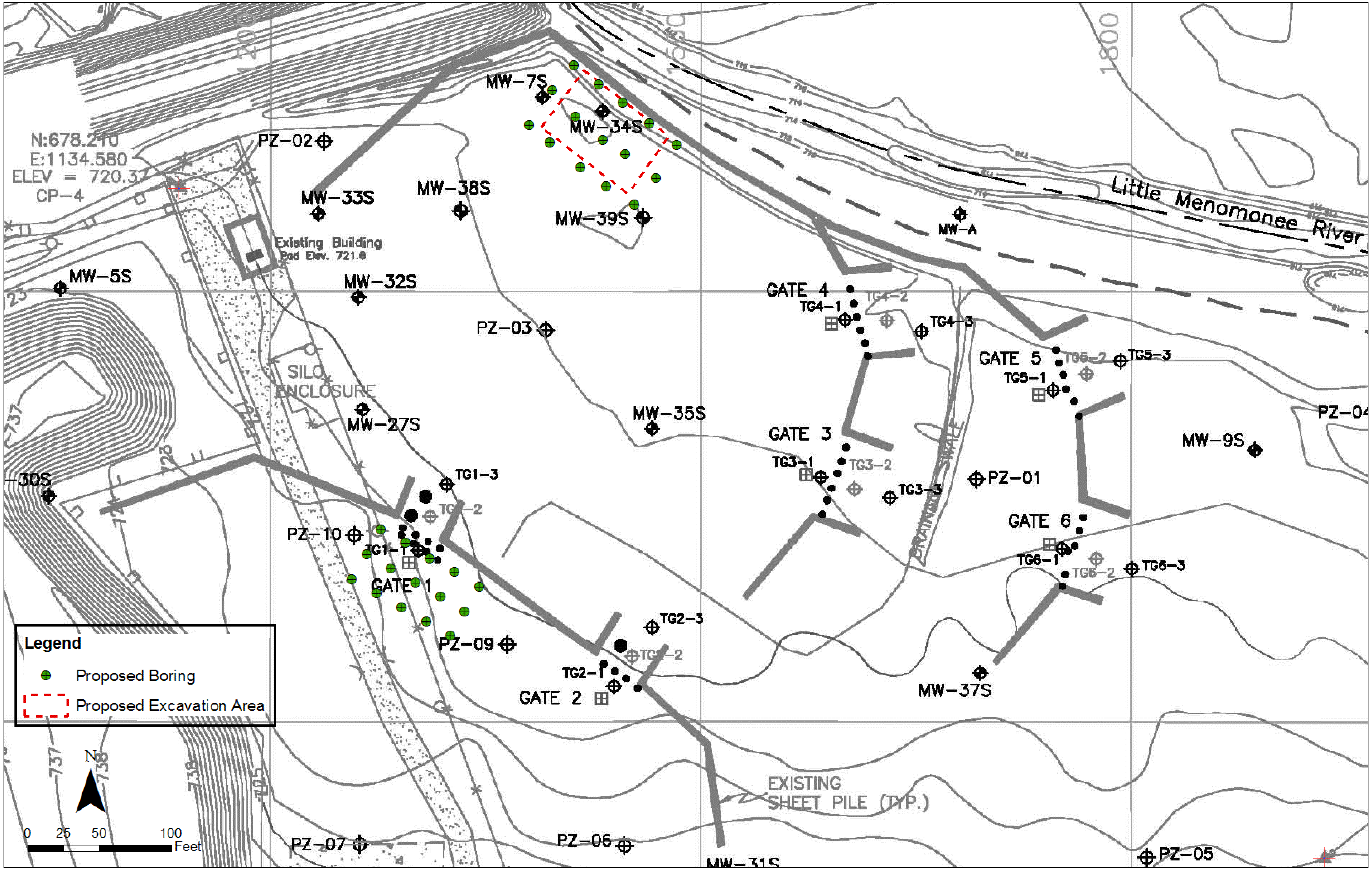


Figure 3. Potential NAPL Investigation Program

Appendix A
Groundwater Modeling Documentation

1. Computer Code

MODFLOW-2000 (Harbaugh et al., 2000) was utilized for the groundwater flow model. The Department of Defense Groundwater Modeling System (GMS) version 7.1 (EMRL, 2005) was used as the software platform and graphical-user interface for the groundwater flow model.

MODFLOW has a modular structure that allows it to be easily modified to simulate different aspects of the project. The model must use one flow and one solver package available. Those utilized for the Moss American model are:

- Layer Property Flow Package – This package defines how hydraulic properties of the model layers are defined, read, and utilized during the simulation. It differs from other flow packages in that all input data that define hydraulic properties are independent of model cell dimensions.
- Pre-conditioned Conjugate Gradient Solver Package – This package contains the information that defines the simultaneous equations that must be solved at each cell. Convergence information is output with this package if the solver fails to meet closure criteria.

Boundary condition packages are optional packages used to simulate various site-specific features of the project. The boundary condition packages utilized for the Moss American model are:

- Horizontal Flow Barrier (HFB) – This package is used to simulate the effects of the sheet pile walls, slurry trenches, or other objects which act as a barrier (or partial barrier) to horizontal flow.
- Well – This package is used to simulate injection wells or extraction wells.

2. Groundwater Model Design

Due to the limited site information, a simplified model was developed to screen groundwater flow modification alternatives at the Moss American site.

2.1. Domain and Grid

The model domain includes the area surrounding the funnel and gate system from just up-gradient of the southern-most gate system to the river. The simplified model consists of one layer with a uniform cell size of 10 feet horizontal and 15 feet thick and is shown in Figure A-1. The top elevation of each cell was interpolated from survey data of existing wells. It was assumed that the model lower boundary (top of the confining till unit) was uniformly 15 feet below ground surface (bgs).

2.2. Boundaries

Numerical models require boundary conditions, such that the hydraulic head or groundwater flux must be specified along all the outer edges of the system and any internal cells to which conditional head values must be determined (i.e., extraction well cells, drain cells). The boundary conditions used for the Moss American model include:

- A specified head boundary was used to represent the river elevation at the north-eastern boundary.

- A specified head boundary was used to simulate groundwater flow from upgradient of the model domain. Due to the limited site information, recharge was accounted for in the upgradient specified head instead of using the recharge package.
- Groundwater flows from the south to the north toward the river; therefore the north-western and south-eastern boundaries were specified as no flow.

2.3. Material Properties

Hydrologic properties were assigned to individual grid cells based on average properties referenced in the quarterly/annual groundwater monitoring reports. Based on slug tests completed during the remedial investigation (RI), the hydraulic conductivity of material location on the topographically higher, western portion of the site ranged from 0.03 to 0.003 ft/d. Based on the laboratory-performed hydraulic conductivity analyses conducted on material used to backfill areas of the site located along the river, the hydraulic conductivity of the material on the topographically lower portion of the site within the funnel and gate system is approximately 3 ft/d.

According to design documents, the funnel and gate system was constructed using internal cavity sealable joint sheet piles. Bulk hydraulic conductivity values for Waterloo Barriers, which have a sealable joint, have been reported at less than 1×10^{-8} cm/s. A conservative estimate for the hydraulic conductivity of 1×10^{-7} cm/s (0.00028 ft/d) was used to represent the sheet pile at the Moss American site.

2.4. Calibration

The purpose of model calibration is to establish that the model can reproduce field-measured hydraulic heads and flows. During the calibration process, model input parameters are adjusted so that field-measured heads and flows are reasonably correlated and are considered to provide a good representation of actual site conditions.

The Moss American groundwater model was calibrated to water levels collected during the 3rd quarter of 2009. Hydraulic conductivity values were varied until modeled water levels provided a reasonable match to the observed values and the residuals of the modeled versus observed heads were minimized. All water level values were weighted equally. Table A-1 presents the residual calibration statistics and Figure A-2 shows the graphical representation.

Table A-1. Residual Calibration Statistics

Mean Residual (Head)	-0.076
Mean Absolute Residual (Head)	0.611
Root Mean Squared Residual (Head)	0.715
Mean Weighted Residual (Head+Flow)	-0.149
Mean Absolute Weighted Residual (Head+Flow)	1.20
Root Mean Squared Weighted Residual (Head+Flow)	1.40
Sum of Squared Weighted Residual (Head+Flow)	62.8

The final hydraulic conductivity values used for the model are shown on Figure A-1 and were:

- South/Western area – 0.2 and 0.5 ft/d
- Funnel and gate area – 3.0 ft/d

3. Predictive Simulations

The calibrated model was used to evaluate modifications to the funnel and gate system that could improve groundwater flow in the north-west section near monitoring wells MW-7S and MW-34S. MODPATH was used to depict the flow paths of fictitious contaminant particles for each scenario, which are shown in green on the Figures A-3 through A-9. Arrows along the flow paths were placed every 10-years to represent the relative time-frame for contaminant migration. It should be noted that since the model was run at steady state, particles are shown to eventually pass through the sheet pile walls if the groundwater does not flow toward the treatment gates.

3.1. Current Conditions

Figure A-3 shows the groundwater elevation contours for the current funnel and gate configuration. The model shows that there is a stagnation point area near MW-7S and MW-34S as indicated by the slow particles moving through the sheet pile wall and that groundwater near MW-33S may be moving around the end of the sheet pile wall. Particles generated at Gate 1 are shown to migrate toward the eastern gates indicating that this part of the flow system is functioning as intended.

3.2. Excavation at MW-34S

Figure A-4 shows the groundwater elevation contours for the Excavation at MW-34S scenario. This scenario includes excavation of NAPL containing soils around MW-34S (shown in red on Figure A-4) and backfill with sand and ORC. The model shows that there will still be a stagnation area near MW-7S and MW-34S, however, the presence of the higher permeability backfill material may induce localized flow toward the treated excavation area. This scenario does not impact the potential groundwater moving around the end of the sheet pile near MW-33S.

3.3. Small Scale Re-Circulation Cell, Excavation at MW-34S

Figure A-5 shows the groundwater elevation contours for the small scale re-circulation cell and excavation at MW-34S. This scenario includes excavation of NAPL containing soils around MW-34S (shown in red on Figure A-5) and backfill with sand and ORC. In addition, a small re-circulation cell would be installed in the north east portion of the system to help distribute ORC to the dissolved phase plume. An extraction well would be installed near MW-34S and an injection well would be installed near MW-38S. Due to the low permeability soils near this area, pumping/injection would be very low (0.5 gpm). The model shows that this type of circulation cell could adequately distribute ORC throughout the remaining dissolved phase plume, however, there will likely be some groundwater mounding near MW-33S that could increase the amount of flow around the end of the sheetpile wall. Additional costs may include treatment of contaminated groundwater prior to re-injection.

3.4. Groundwater Extraction near Gate 5 and 6, Excavation at MW-34S

Figure A-6 shows the groundwater elevation contours for groundwater extraction near Gates 5 and 6 and excavation at MW-34S. This scenario includes excavation of NAPL containing soils around MW-34S (shown in red on Figure A-6) and backfill with sand and ORC. Two groundwater extraction wells would be installed east of Gates 5 and 6. Due to the low permeability materials, groundwater extraction rates would only be about 0.75 gpm near Gate 5 and 0.25 near Gate 6. The model shows that the groundwater stagnation area near MW-7S and MW-34S still exists, however, flow no longer goes around the end of the sheet pile near MW-33S and groundwater near MW-38S will eventually reach the eastern treatment gates. Since the gradient is very low, it may still take over 30 years for the contaminated groundwater to reach the eastern treatment gates.

3.5. Large Scale Re-Circulation Cell, Excavation at MW-34S

Figure A-7 shows the groundwater elevation contours for the large scale re-circulation cell and excavation at MW-34S. This scenario includes excavation of NAPL containing soils around MW-34S (shown in red on Figure A-7) and backfill with sand and ORC. One extraction well would be installed near Gate 5 and one injection well would be installed near MW-7S to induce flow across the system. Due to the low permeability materials, groundwater extraction/injection rates would be very low (0.25 gpm). The model shows that groundwater near MW-7S and MW-34S would flow toward the eastern treatment gates. Groundwater mounding near MW-33S could increase the amount of flow around the end of the sheet pile wall.

3.6. New Gate North of MW-34S, Excavation at MW-34S

Figure A-8 shows the groundwater elevation contours for a new gate north of MW-34S and excavation at MW-34S. This scenario includes excavation of NAPL containing soils around MW-34S (shown in red on Figure A-8) and backfill with sand and ORC. A new gate with air injection treatment would be installed to the north of MW-34S. The model shows that flow is induced toward the gate from the up-gradient treatment gates, near the area of stagnation at MW-7S, and near MW-33S where groundwater is potentially migrating around the end of the sheet pile.

3.7. New Gate West of MW-7S, Excavation at MW-34S

Figure A-9 shows the groundwater elevation contours for a new gate west of MW-7S and excavation at MW-34S. This scenario includes excavation of NAPL containing soils around MW-34S (shown in red on Figure A-9) and backfill with sand and ORC. A new gate with air injection treatment would be installed to the west of MW-7S. The model shows that flow is induced toward the gate from the area of stagnation and near MW-33S where groundwater is potentially migration around the end of the sheet pile. This new gate configuration shows that groundwater flow from the up-gradient Gates 1 and 2 still flows toward the eastern gates.

4. References

Environmental Modeling Research Laboratory (EMRL), 2005. Groundwater Modeling System (GMS) version 6.5. Brigham Young University, Provo, UT. 2005.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000. MODFLOW-2000, the US Geological Survey modular ground-water model – User guide to modularization concepts and the ground-water flow process; USGS Open File Report 00-92, 121 p. 2000.

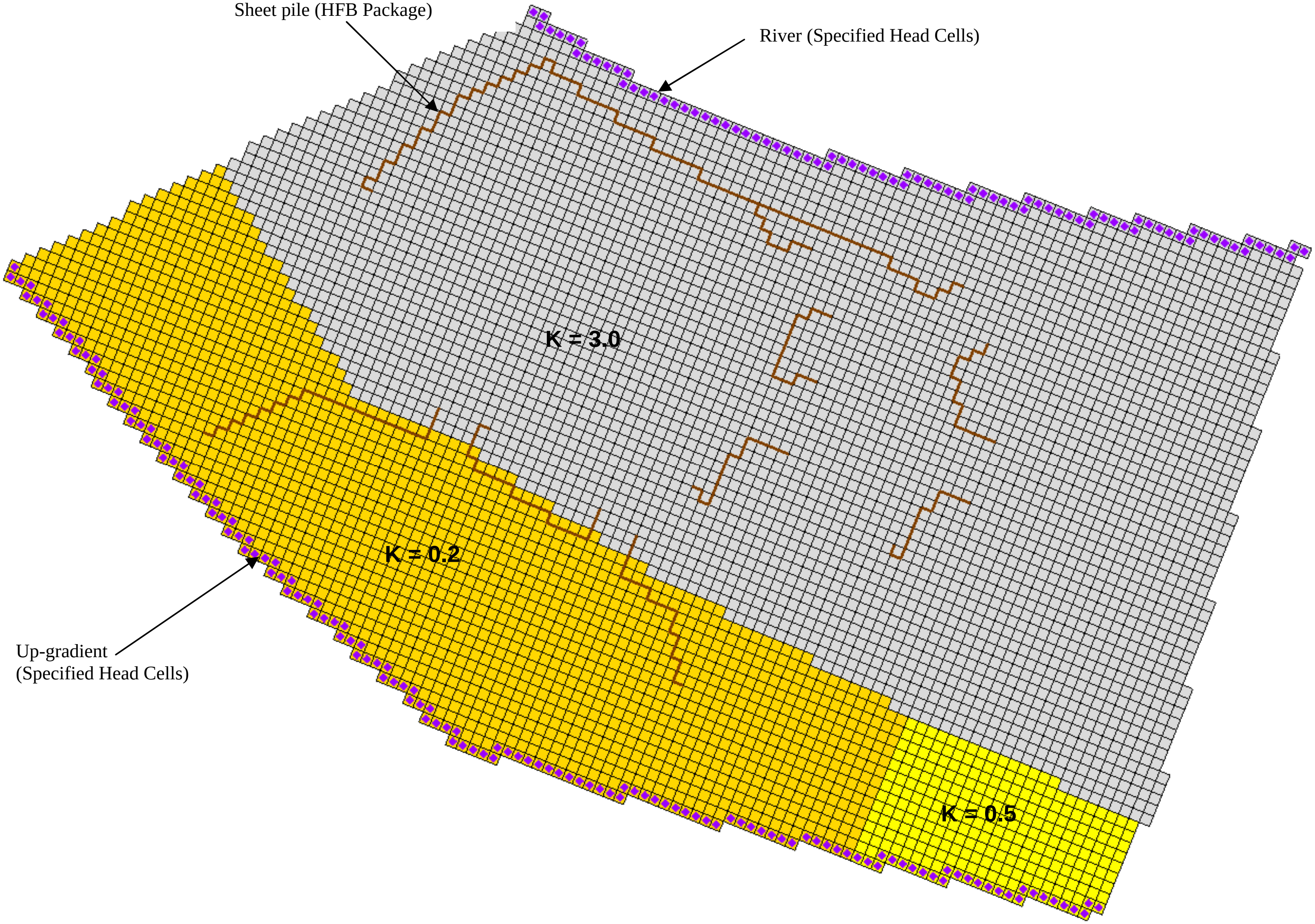


Figure A-1. Model grid and hydraulic conductivity zones.

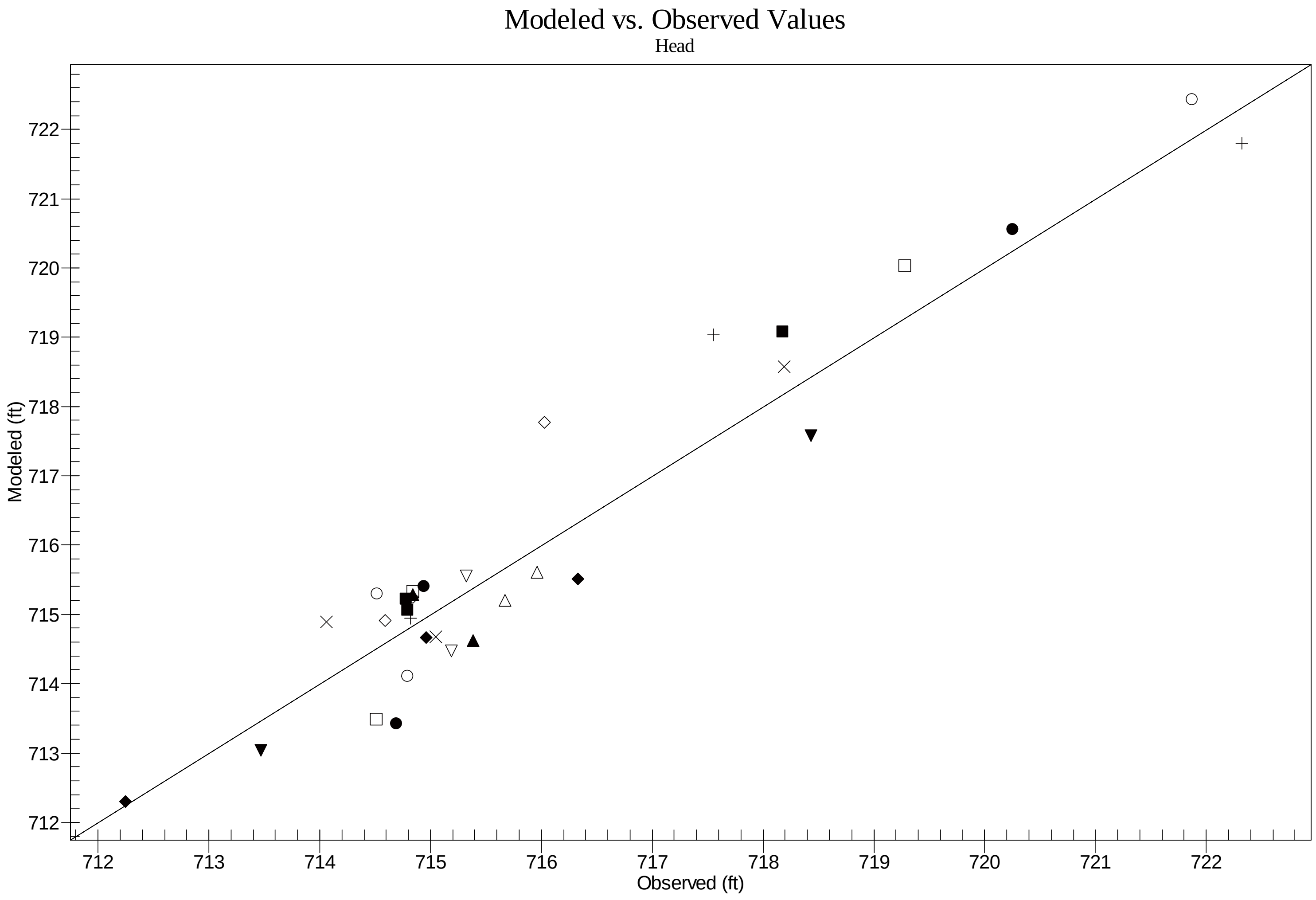


Figure A-2. Modeled versus observed heads.

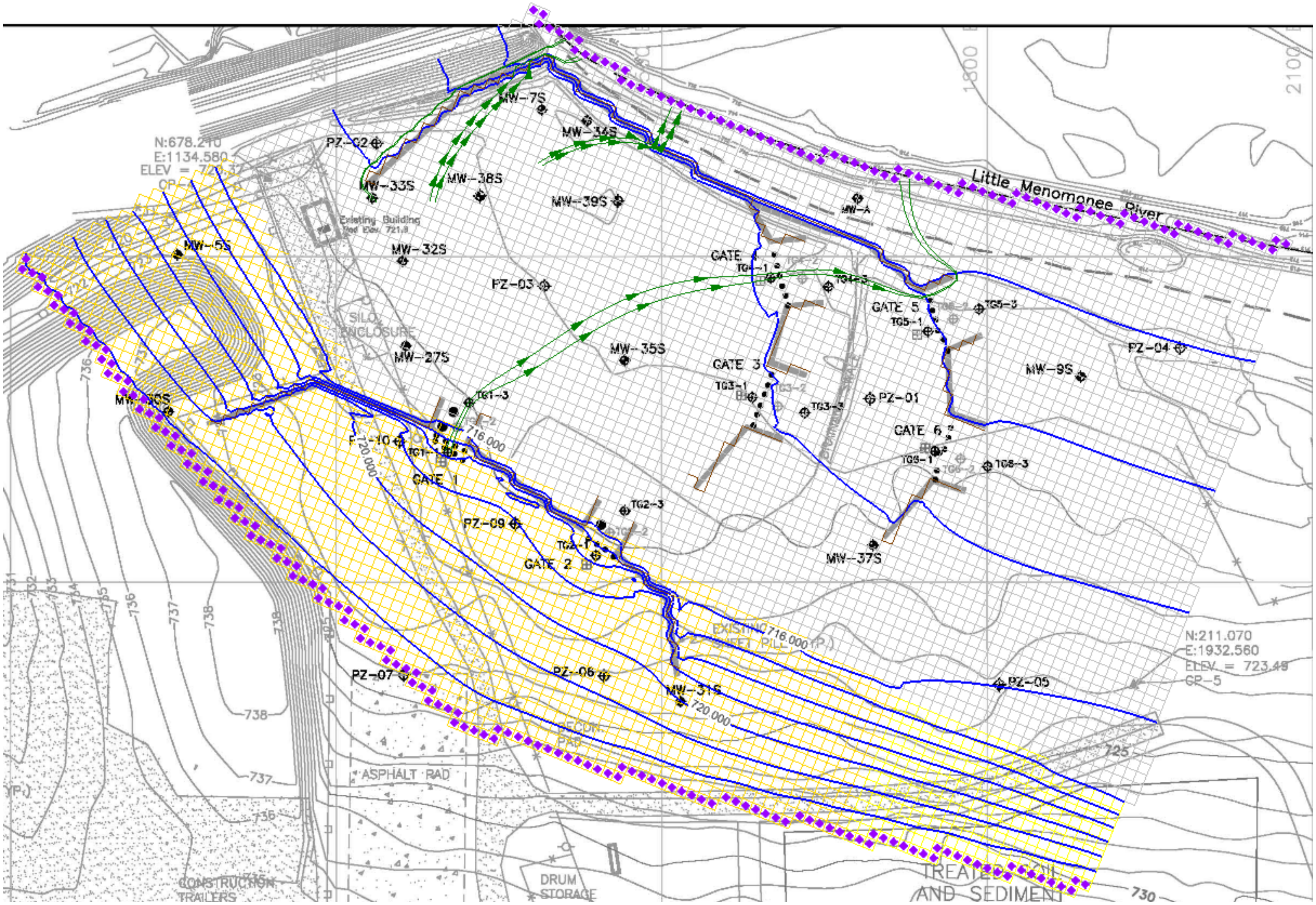


Figure A-3. Current Conditions

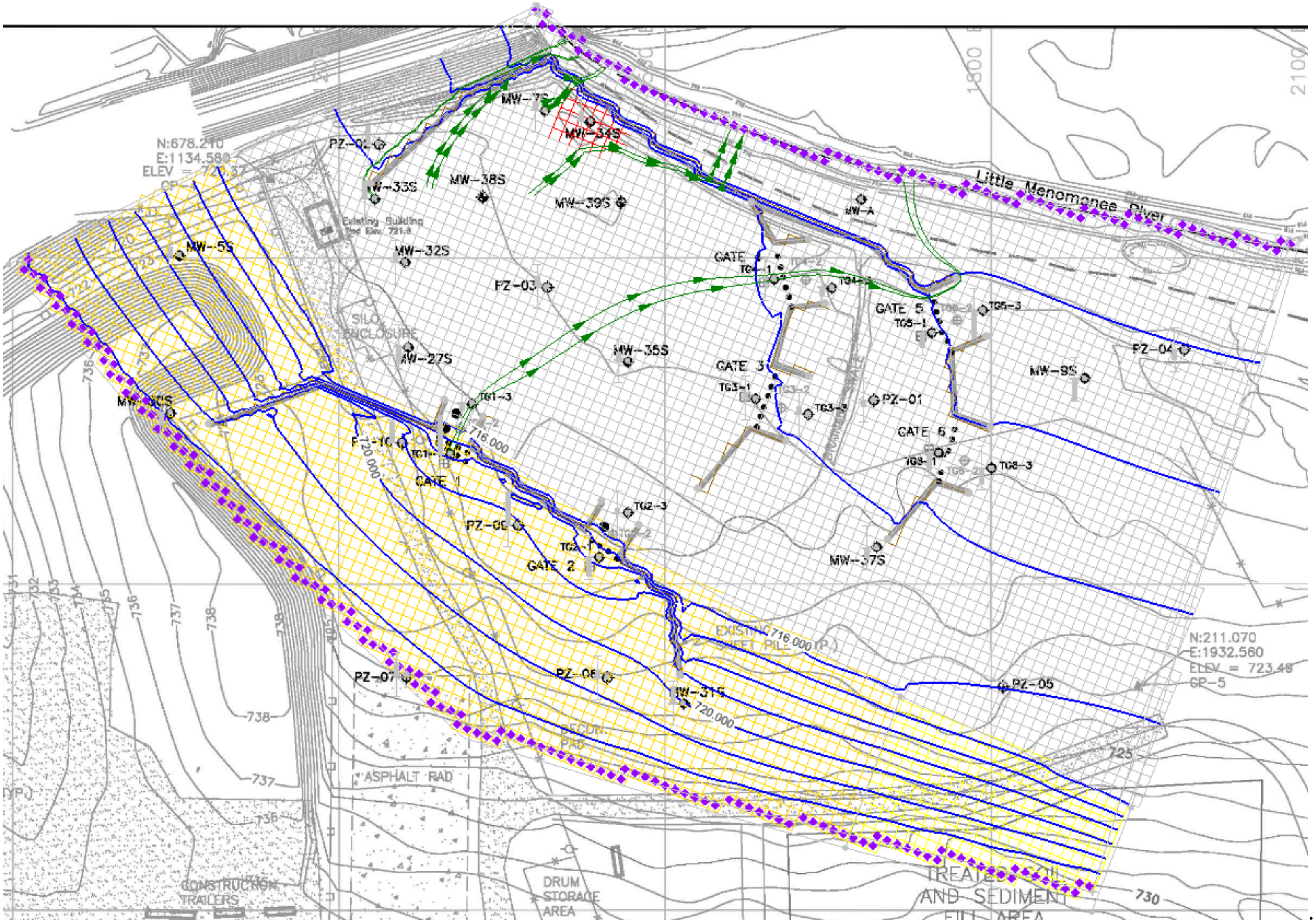


Figure A-4. Excavation at MW-34S.

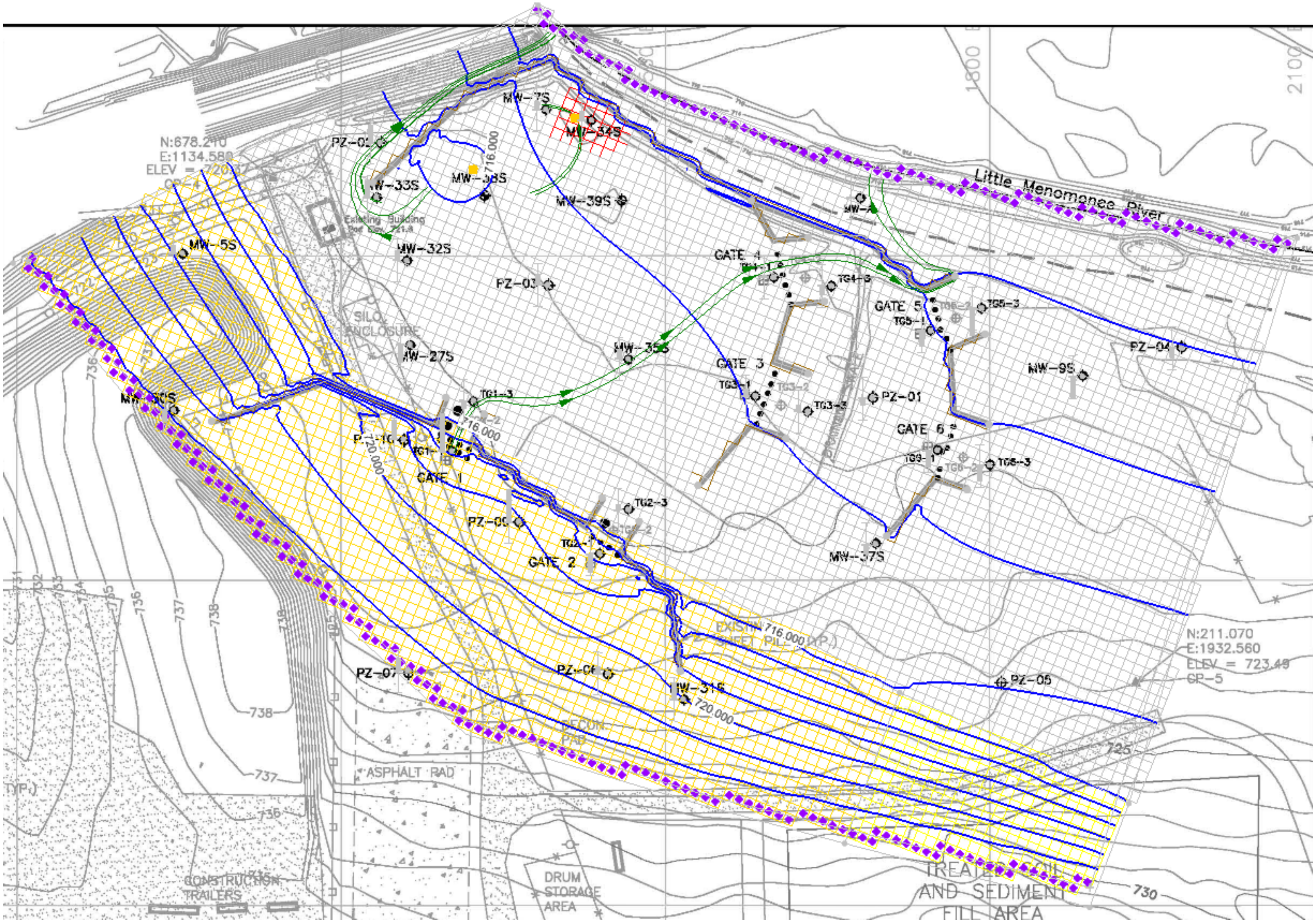


Figure A-5. Small Scale Re-Circulation Cell, Excavation at MW-34S

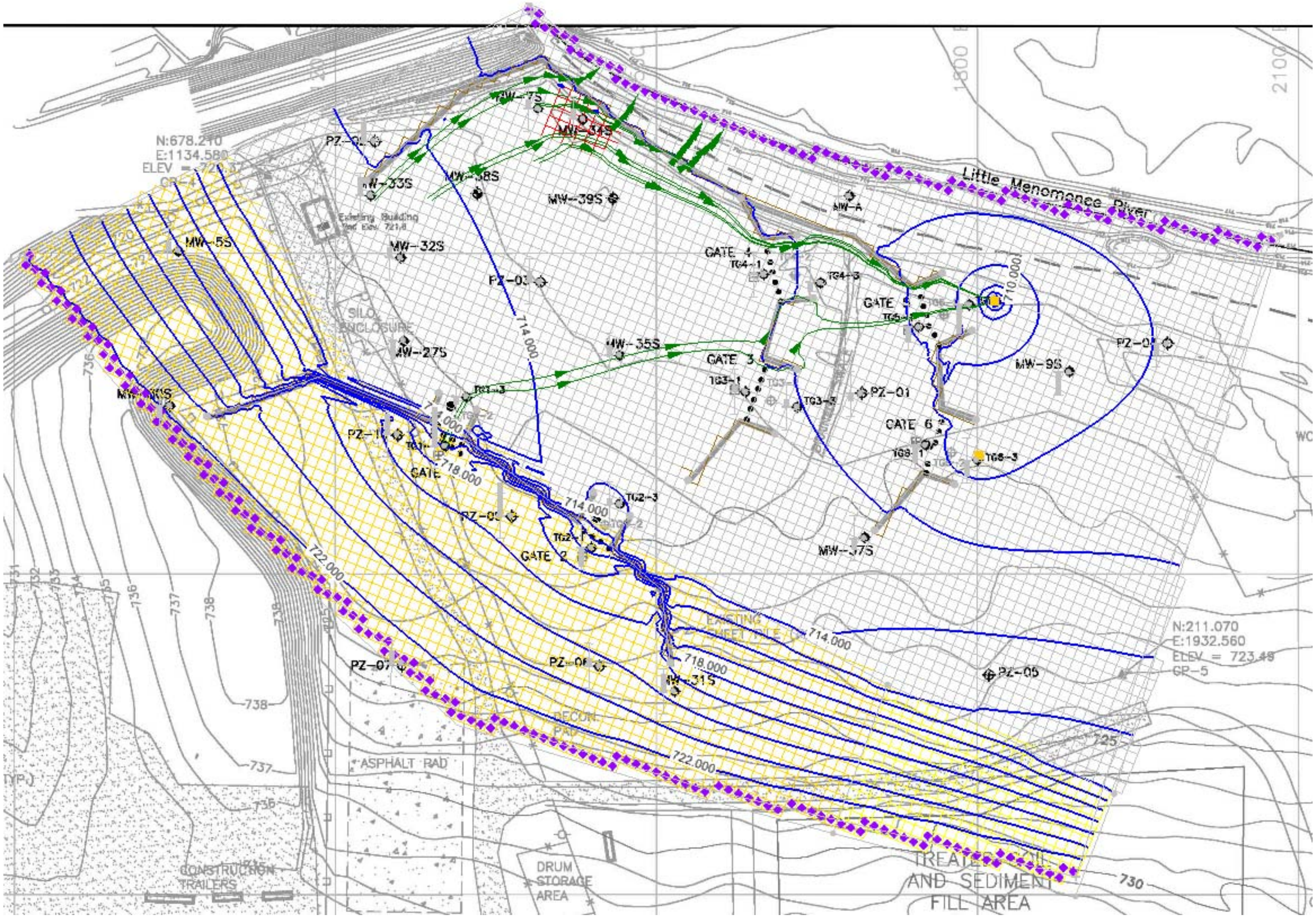


Figure A-6. Groundwater Extraction near Gate 5 and 6, Excavation at MW-34S

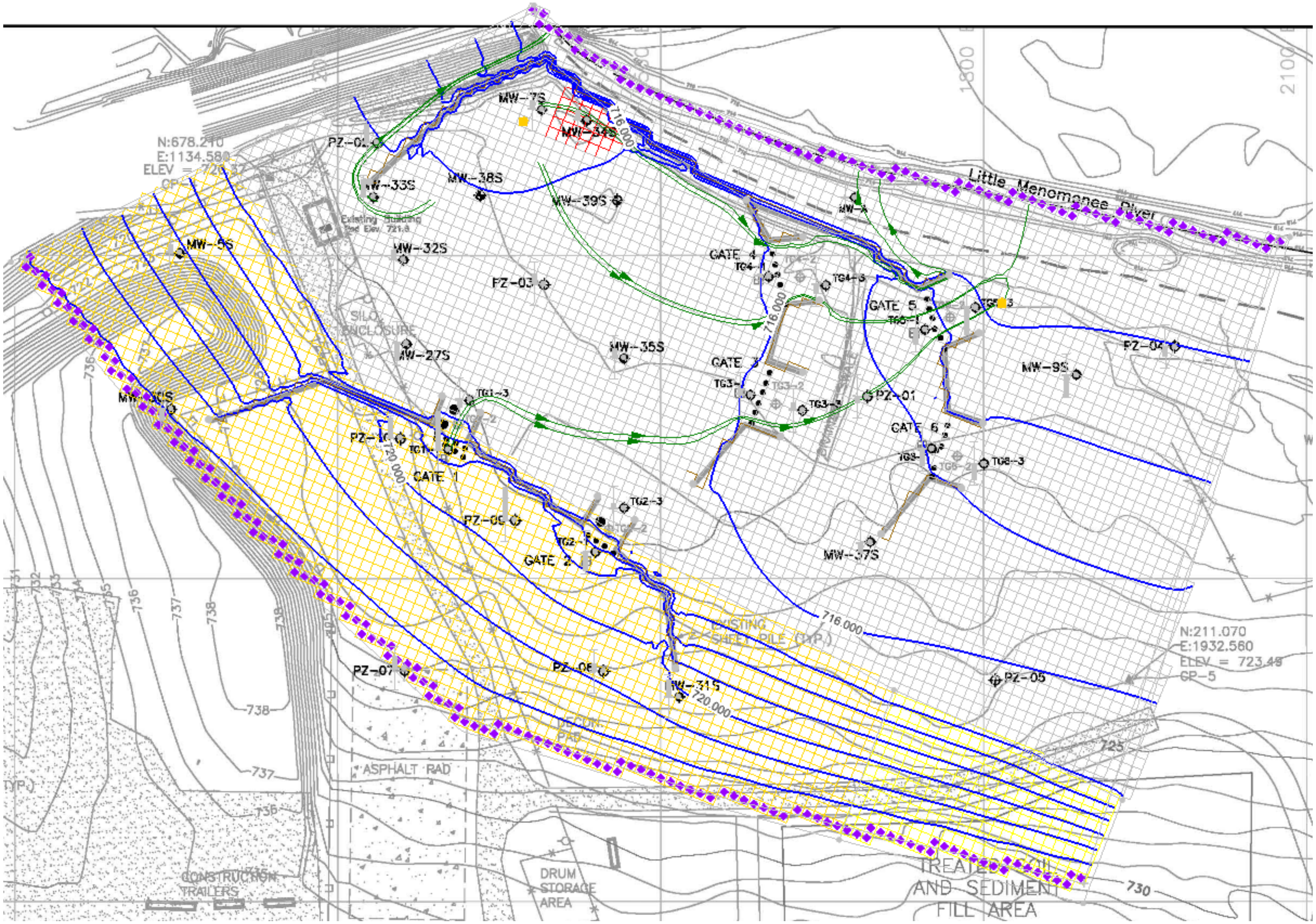


Figure A-7. Large Scale Re-Circulation Cell, Excavation at MW-34S

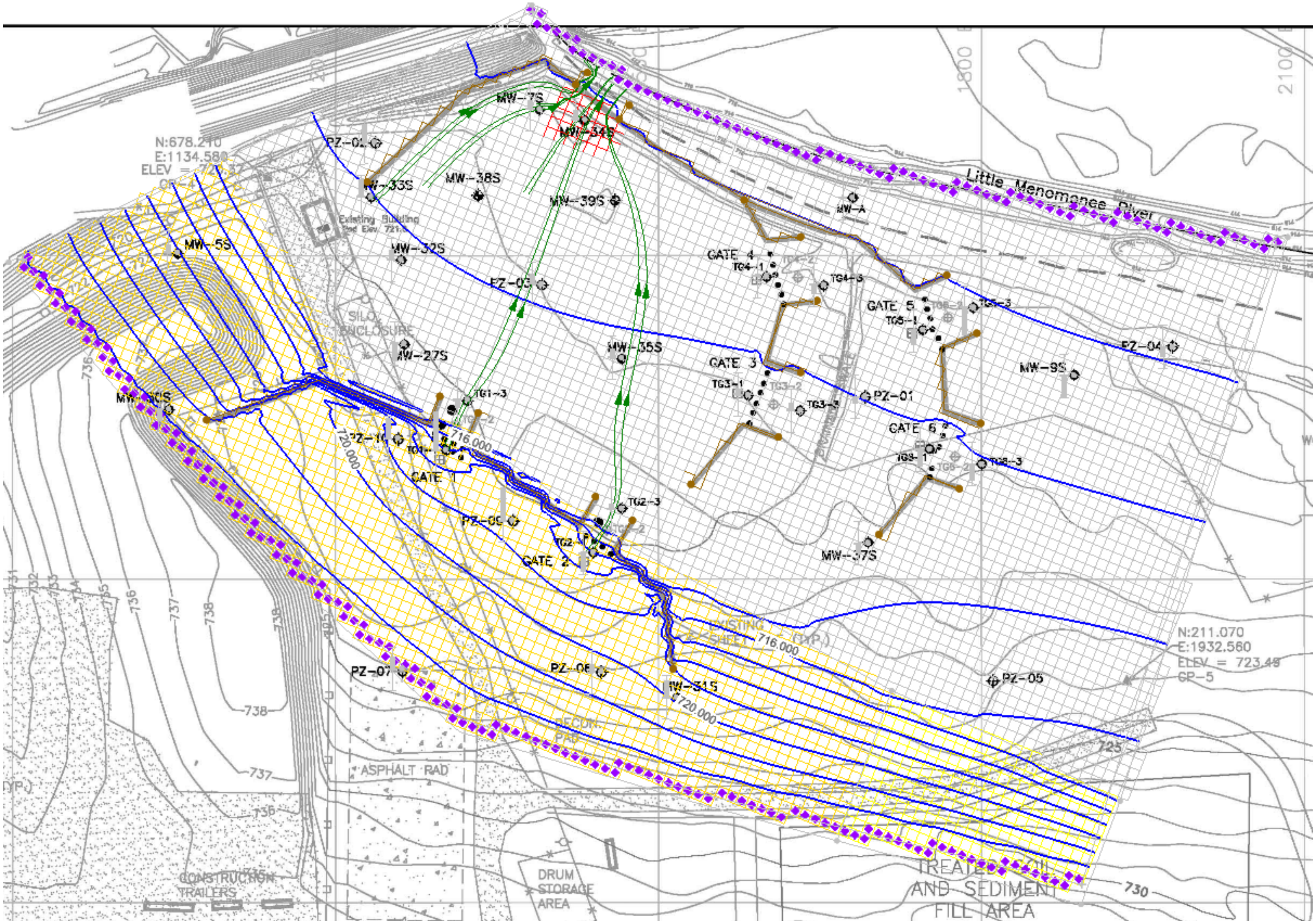


Figure A-8. New Gate North of MW-34S, Excavation at MW-34S

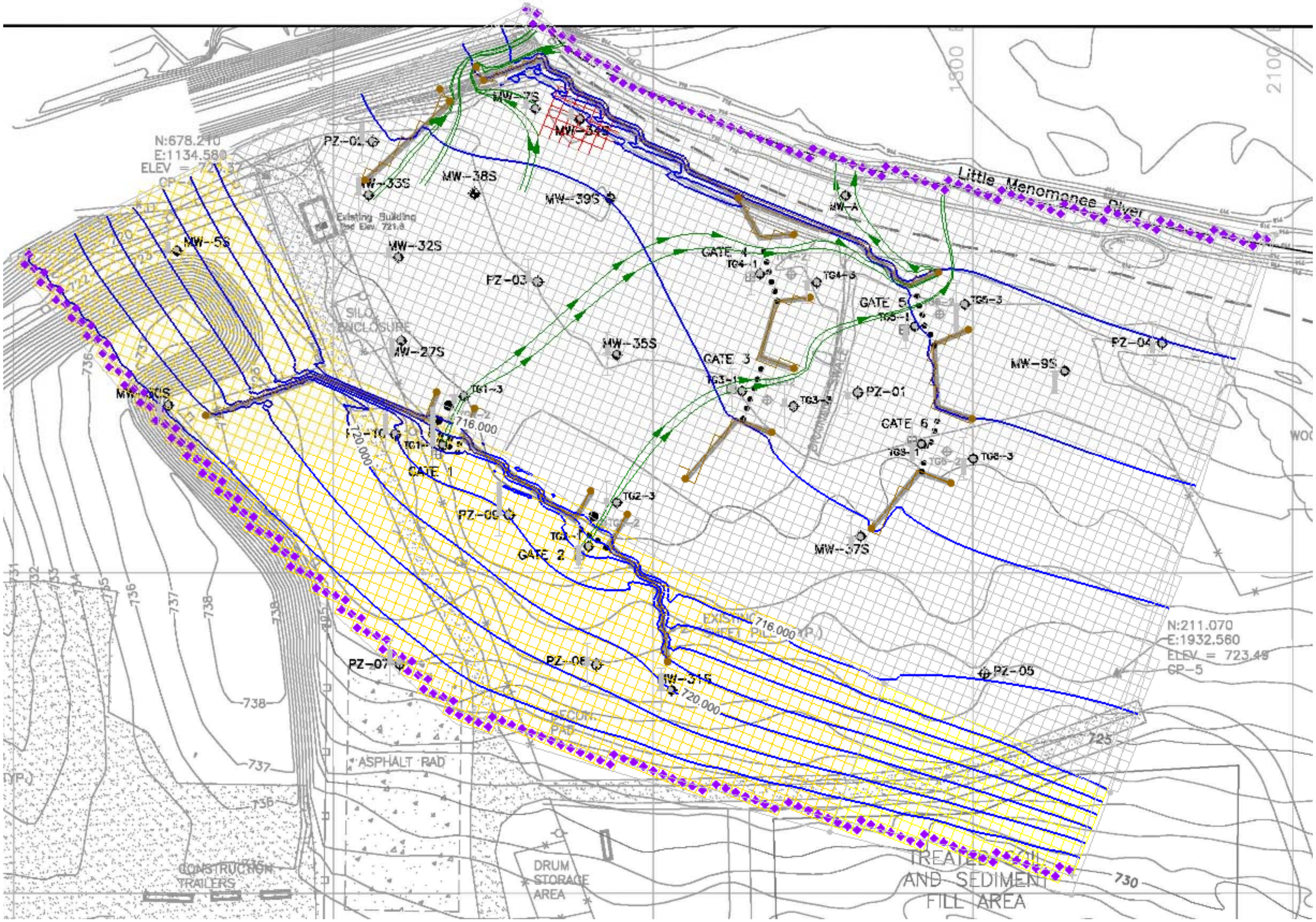


Figure A-9. New Gate West of MW-7S, Excavation at MW-34S

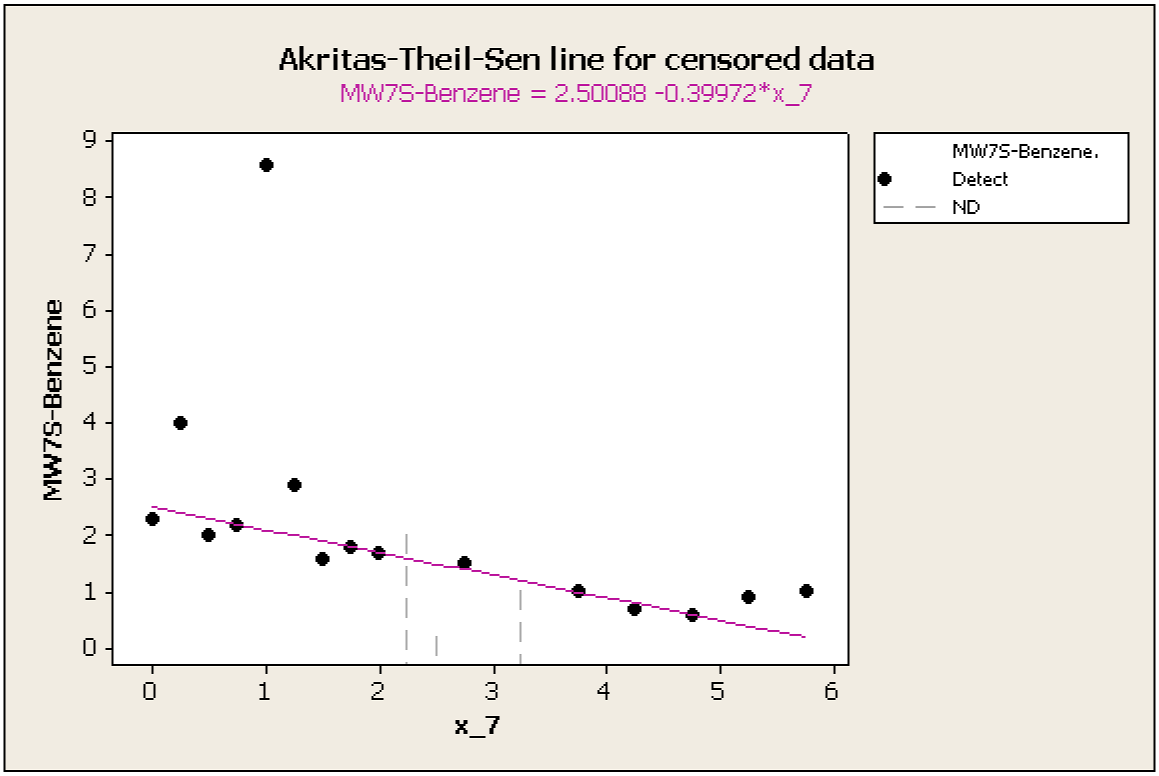
Appendix B

Trend Testing Methods.

Trend presence was determined at the 5% significance level using the censored Mann-Kendall trend test, which is a non-parametric procedure that accommodates datasets with non-detects. The censored Mann-Kendall test looks for trends in rankings of the data, rather than in absolute values of the data. If the Mann-Kendall test indicated a significant trend, the Theil-Sen slope was computed to quantify the rate of change of concentrations in each well. Both the censored Mann-Kendall and Theil-Sen computations were performed using the MiniTab statistical software program using MiniTab scripts from Helsel 2005a (available from PracticalStats.com). Trend testing was completed for wells and contaminants that had sufficient number of non-detect values over time.

Regression plots for wells where significant trends were detected are presented in this Appendix. Increasing trends were detected for naphthalene, fluorene and benzo(a)pyrene in TG1-1. Decreasing trends were detected for naphthalene and benzene in MW-7S and naphthalene in MW-38S and corresponding regression equations were used to estimate timeframes to achieve PAL levels in these wells. Caution should be applied when interpreting these predicted restoration timeframes because (a) trend testing results are based on current site conditions and conditions could change in the future resulting in a different restoration timeframes and (b) uncertainties inherent in trend testing translates into uncertainties in predicted timeframes.

Trend Testing Results.



Predicted Time to PALs: Benzene in MW-7S

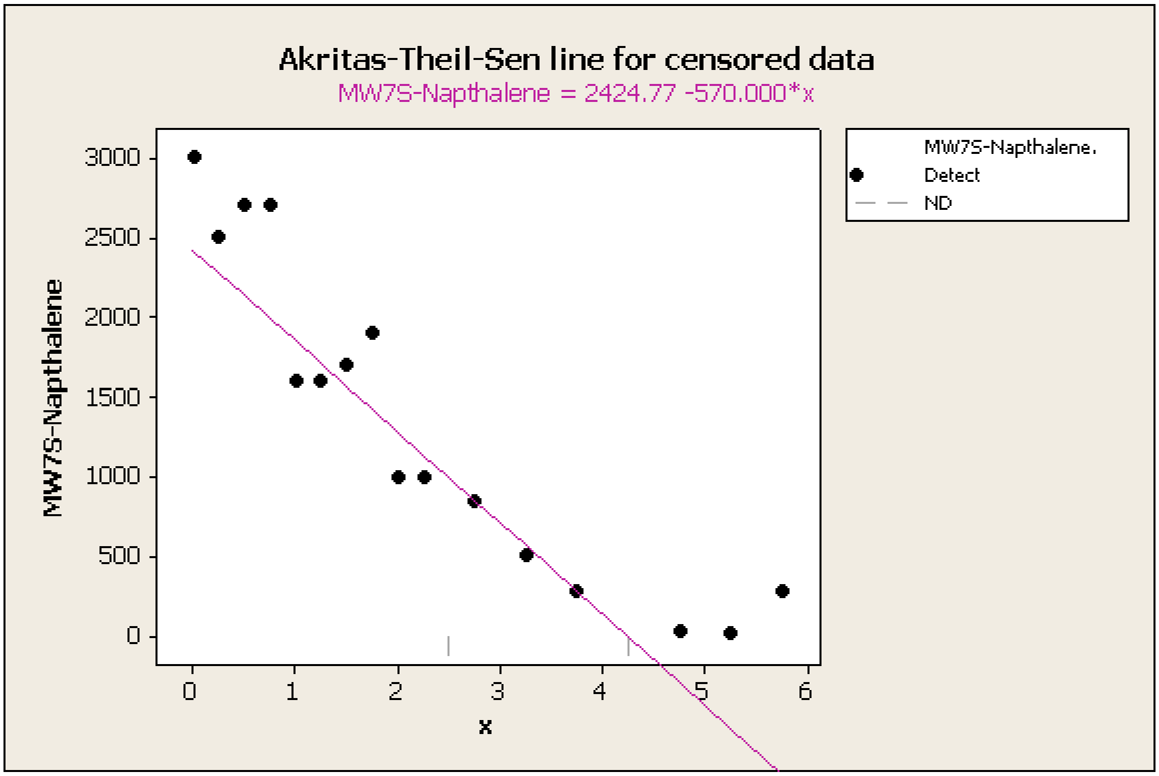
y = 2.500 – 0.3997 x

[Benzene PAL concentration, µg/L] = 2.500 – 0.3997 * [Predicted Time to PAL, years]

[0.5 µg/L] = 2.500 – 0.3997 * [Predicted Time to PAL, years]

[Predicted Time to PAL, years] = {[0.5 µg/L] – 2.500} ÷ {-0.3997}

[Predicted Time to PAL, years] = 5 years



Predicted Time to PAL: Naphthalene in MW7S

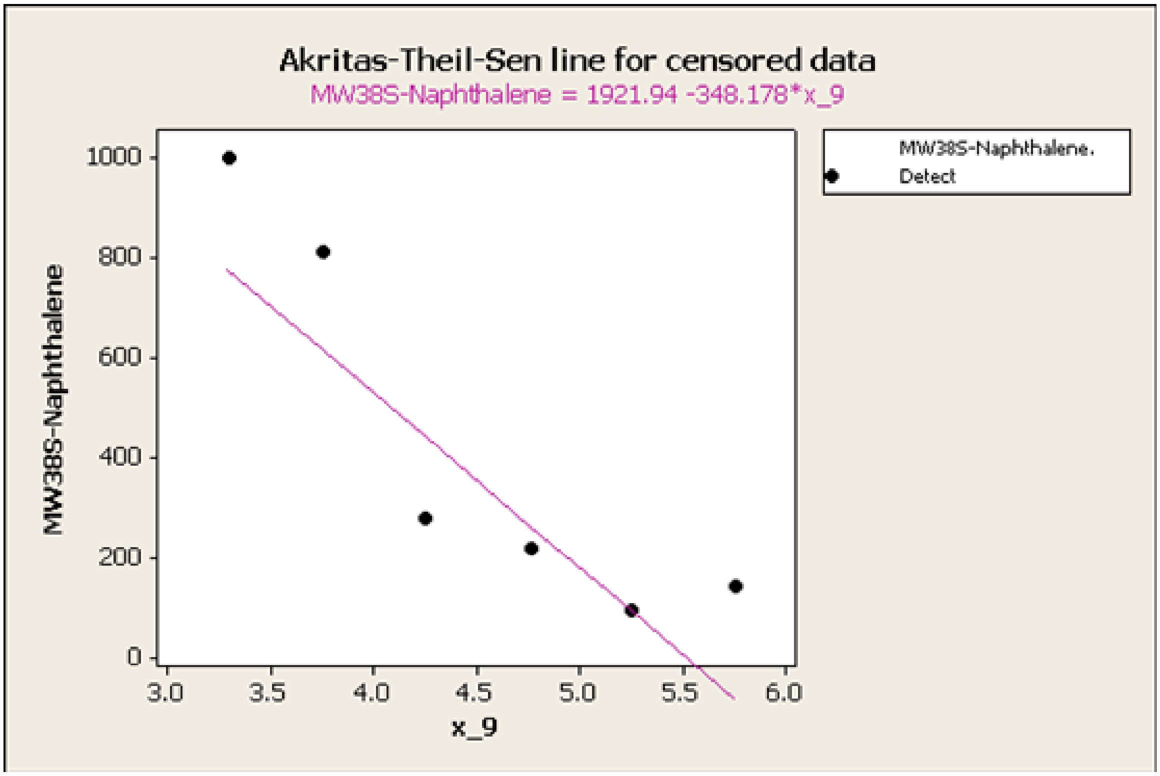
y = 2425 – 570 x

[Naphthalene PAL concentration, µg/L] = 2425 – 570 * [Predicted Time to PAL, years]

[8 µg/L] = 2425 – 570 * [Predicted Time to PAL, years]

[Predicted Time to PAL, years] = {[8 µg/L] – 2425} ÷ {-570}

[Predicted Time to PAL, years] = 4.2 years



Predicted Time to PALs: Naphthalene in MW-38S

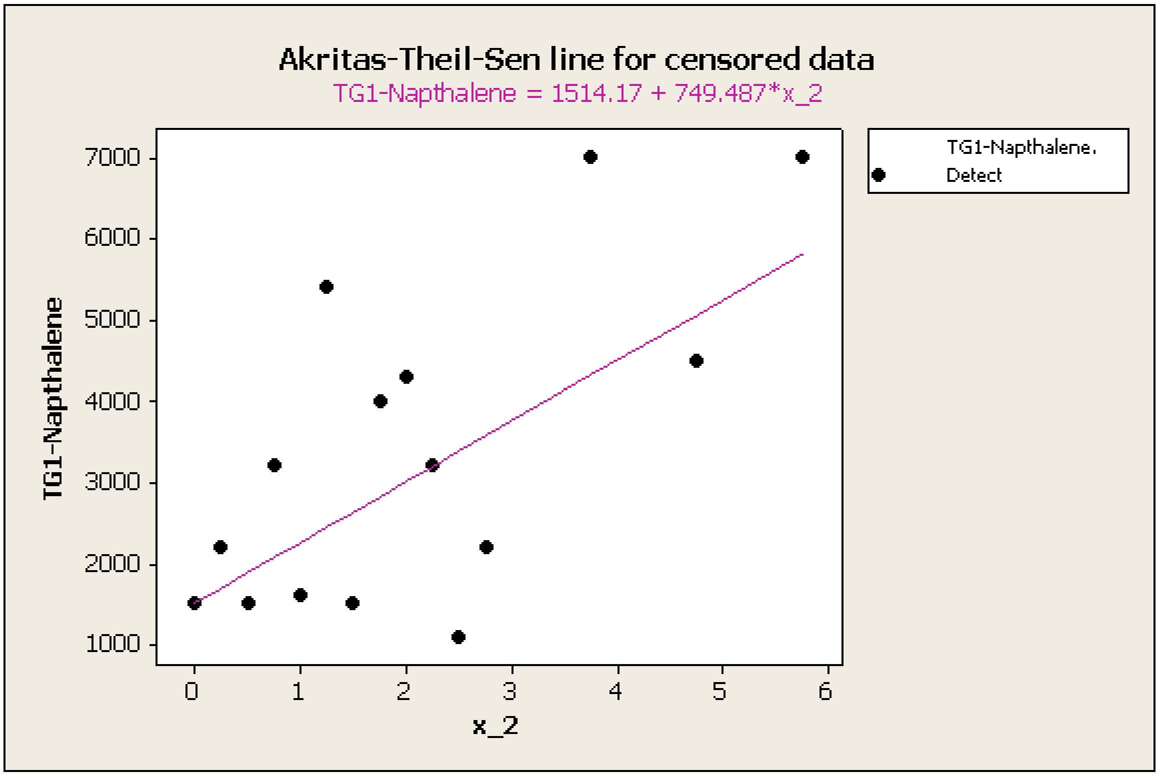
y = 1922 – 348.2 x

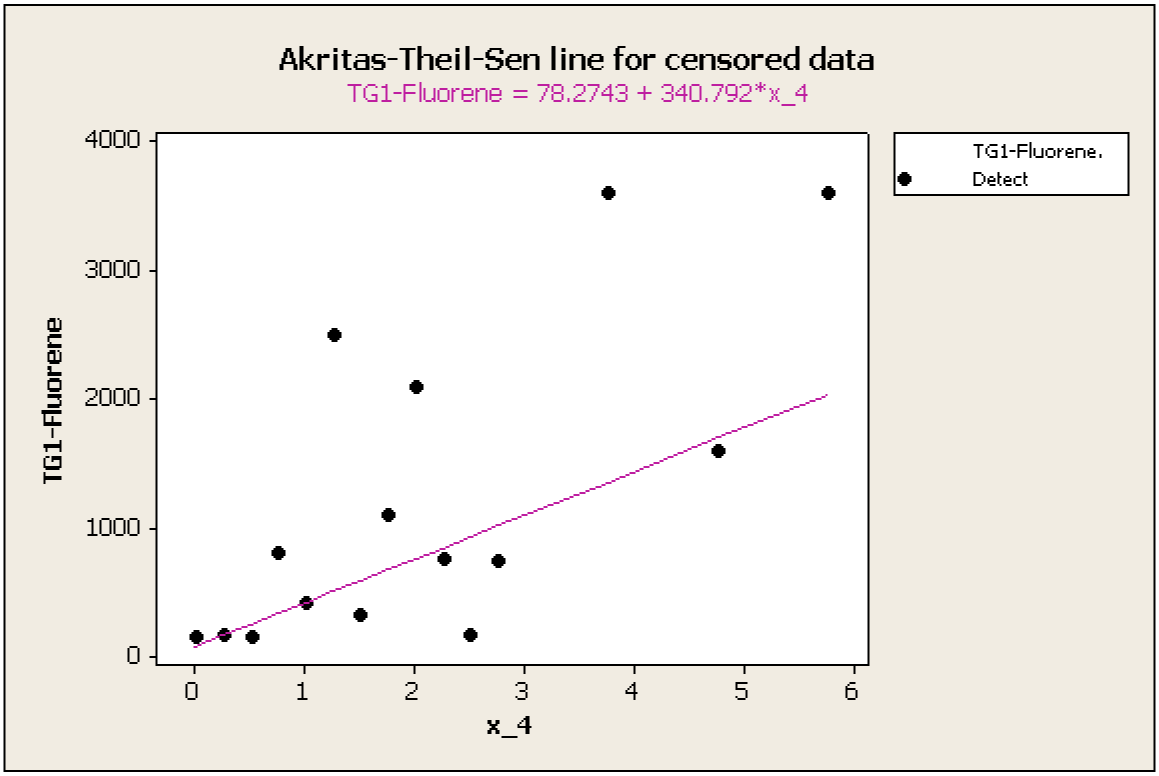
[Benzene PAL concentration, µg/L] = 1922 – 348.2 * [Predicted Time to PAL, years]

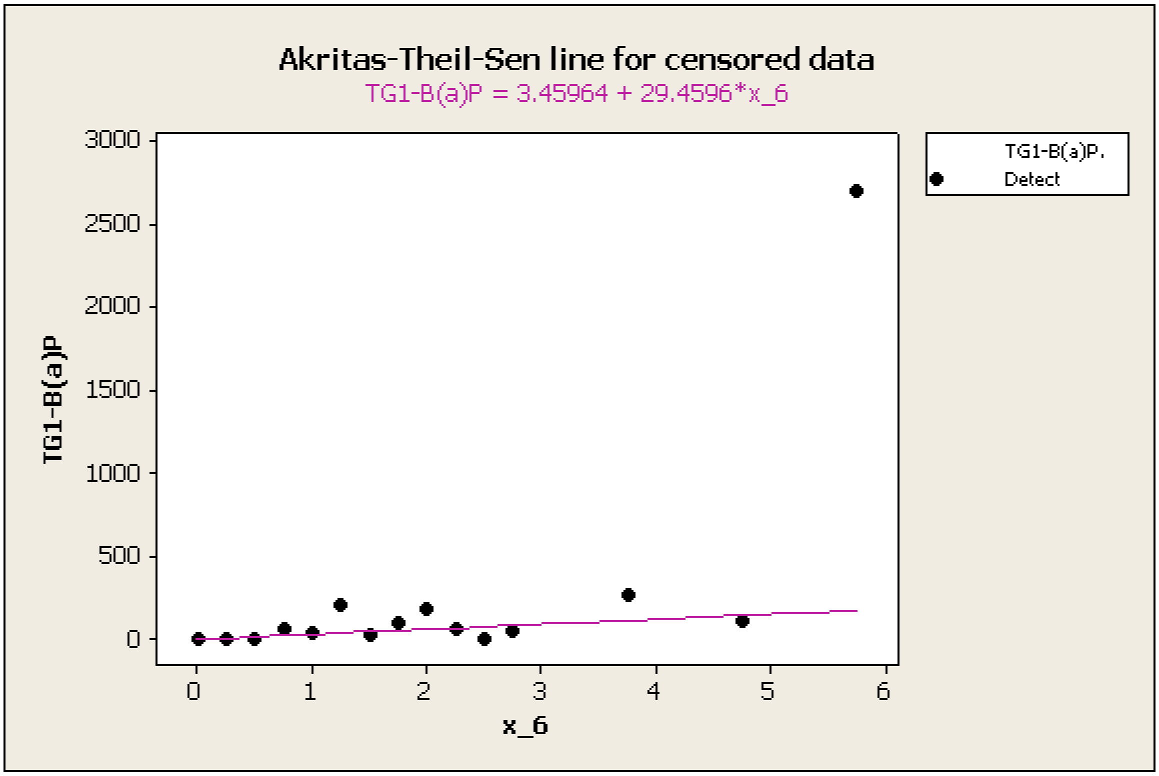
[8 µg/L] = 1922 – 348.2 * [Predicted Time to PAL, years]

[Predicted Time to PAL, years] = {[8 µg/L] – 1922 } ÷ {-348.2}

[Predicted Time to PAL, years] = 5.5 years


Akritas-Theil-Sen line for censored data
TG1-Napthalene = 1514.17 + 749.487*x_2
TG1-Napthalene
7000
6000
5000
4000
3000
2000
1000
0
1
2
3
4
5
6
x_2
TG1-Napthalene,
● Detect


Akritas-Theil-Sen line for censored data
TG1-Fluorene = 78.2743 + 340.792*x_4
TG1-Fluorene
4000
3000
2000
1000
0
0
1
2
3
4
5
6
x_4
TG1-Fluorene.
● Detect


Akritas-Theil-Sen line for censored data
TG1-B(a)P = 3.45964 + 29.4596*x_6
TG1-B(a)P
0
500
1000
1500
2000
2500
3000
0
1
2
3
4
5
6
x_6
TG1-B(a)P.
● Detect

Appendix C

constituent	weight percent NAPL	molecular weight, g/mol	mole fraction	single compound solubility in water, ug/L	effective solubility assuming γ = 1
naphthalene	25.1	128.17	0.29	31000	9094
phenanthrene	22.4	178.23	0.19		
acenaphthene	9.2	154.21	0.089		
fluoranthene	8.2	202.25	0.061		
2-methylnaphthale	7.5	142.2	0.079		
fluorene	6.7	166.22	0.060		
dibenzofuran	6.1	168.19	0.054		
pyrene	4.8	202.25	0.036		
anthracene	2.9	178.23	0.024		
benzo(a)anthracer	1.8	228.29	0.012		
check sum	*95*		*0.90*		

equivalent MWT creosote 149.80401

Estimated effective water solubiliyty of naphthalene in groundwater assuming typical creosote weight fraction, where NAPL constituents less than 2 percent were not included (Pacific Sound Resources RI/FS, 1998). A groundwater activity correction factor (gamma) of 1 was used for this estimate but the actual value is less less than 1, which means thae actual effective solublity estimate for naphthalene would be less than 9094 µg/L.