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VIA ELECTRONIC MAIL

June 18, 2015

Ms. Richelle Hanson
Project Manager
Maryland Department of the Environment
1800 Washington Boulevard, Suite 625
Baltimore, Maryland 21230-1719

Re: Offsite Groundwater Monitoring Plan
Former Kop-Flex Facility, Voluntary Cleanup Program Site #31
Hanover, Maryland

Dear Richelle:

On behalf of EMERSUB 16 LLC, WSP USA Corp. is submitting two (2) copies of the Offsite Groundwater Monitoring Plan for the Kop-Flex Voluntary Cleanup Program Site #31, located in Hanover, Maryland. In addition to the enclosed hard copies, we will also send you an electronic copy of this plan for your project file. The groundwater monitoring plan comprises the proposed response action for the affected groundwater in the offsite area. The goals of the monitoring program will be to gather groundwater quality to evaluate trends in the concentrations of site-related volatile organic compounds in the aquifer system downgradient of the former Kop-Flex facility and whether additional actions are warranted to protect the potable water source in the area.

If you have any questions, please do not hesitate to contact us at 703-709-6500.

Sincerely yours,

Robert E. Johnson

Robert E. Johnson, PhD.
Senior Technical Manager - Environmental

REJ:kjb
K:\Emerson\Kop-Flex\Offsite GW Monitoring Plan\39196_Kopflex_Offsite GWMP_Transmittal_Letter 061815.docx

Enclosure

cc\encl: Mr. Erich Weissbart, USEPA Region III
Mr. Stephen Clarke, Emerson Electric Co
Ms. Sheila Harvey, Pillsbury Winthrop Shaw Pittman LLP

OFFSITE GROUNDWATER MONITORING PLAN

Kop-Flex Voluntary Cleanup Program Site #31

Hanover, Maryland

June 18, 2015

Project No. E0039196/07

OFFSITE GROUNDWATER MONITORING PLAN

Kop-Flex Voluntary Cleanup Program Site #31
Hanover, Maryland

June 18, 2015

Client

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Appendices

1 Introduction

On behalf of EMERSUB 16 LLC (Emerson), WSP USA Corp. (WSP) has prepared this Offsite Groundwater Monitoring Plan (GWMP) for the former Kop-Flex facility located at 7555 and 7565 Harmans Road in Hanover, Maryland. The former Kop-Flex facility is identified as Site #31 under the Maryland Department of the Environment (MDE) Voluntary Cleanup Program (VCP). This Offsite GWMP pertains to the response action activities to be conducted to address the groundwater impacts present in the offsite areas of the VCP Site.

The results of previous environmental investigations identified soil and groundwater impacts associated with historical releases of chlorinated solvents at the former Kop-Flex facility. The Response Action Plan submitted to MDE on June 2, 2015, describes remedial activities to be conducted to mitigate risks associated with chlorinated volatile organic compounds (VOCs) and 1,4-dioxane present in the vadose zone soil and groundwater on the Kop-Flex property (WSP 2015). Results of investigations conducted in offsite areas showed that site-related VOCs have also migrated to the south and southeast of the facility. Given the presence of VOC-affected groundwater in offsite areas, an offsite groundwater monitoring program has been developed in conjunction with the onsite response actions. The objectives of the monitoring program are to evaluate the trends in concentrations of the site-related VOCs in the aquifer system downgradient of the former Kop-Flex facility and whether additional actions are warranted to protect the drinking water source in the area.

The Offsite GWMP consists of the following sections:

- Section 2 – Site Background
- Section 3 – Previous Groundwater Quality Investigations
- Section 4 – Offsite Potable Water Sources
- Section 5 – Groundwater Monitoring Program
- Section 6 – Sampling and Analysis Plan
- Section 7 – Evaluation and Reporting of Groundwater Monitoring Data
- Section 8 – References

This Offsite GWMP was developed following the guidelines presented in the Guidance on the Content of Environmental Investigation Work Plans and Quality Assurance Project Plans Including Data Verification and Validation, which is included in the MDE *Cleanup Standards for Soil and Groundwater, Interim Final Guidance* (June 2008), and is consistent, where applicable, with information to be included in a RAP as described in Section 6 of the MDE VCP guidance.

2 Site Background

2.1 Site Description

The former Kop-Flex facility is located at 7555 and 7565 Harmans Road in Hanover, Anne Arundel County, Maryland (Figure 1). The site occupies a total area of approximately 25 acres and contains two buildings – an approximately 220,000-square-foot former manufacturing and office building and an approximately 20,000-square-foot former forge building near the eastern property boundary. The property is bordered to the north by a Verizon Communications maintenance facility; to the east by the Williams-Scotsman facility followed by railroad tracks; to the south by the Williams-Scotsman facility followed by Maryland State Route 100; and to the west by undeveloped land along Stony Run, a tributary of the Patapsco River and Harmans Road.

The former facility was constructed on previously undeveloped land in 1969 by Koppers Company, Inc., which subsequently became Kop-Flex, Inc. Emerson acquired Kop-Flex in 1996. Kop-Flex formerly manufactured flexible couplings for the mechanical power transmission industry at the site. Manufacturing operations at the facility ceased in late 2012, and all equipment and machine lines have been decommissioned and removed from the buildings. In December 2014, Emerson transferred the property to EMERSUB 16 LLC in preparation of selling the property to a third party for future redevelopment.

Land use in the vicinity of the site is primarily characterized by residential developments (single-family homes and townhouses) and undeveloped land. A small number of areas, primarily to the north and east, have been designated for commercial and light industrial/industrial park use. The greatest density of residences is located south of Maryland Route 100 and west of Harmans Road. The nearest residences are located along Harmans Road, approximately 750 feet northwest of the former manufacturing building (Figure 2). The nearest residence to the south of the facility is approximately 1,000 feet from the property boundary.

2.2 Topography and Surface Water Hydrology

Anne Arundel County is located within the Atlantic Coastal Plain Physiographic Province. The Hanover area is situated approximately five miles from the Fall Line, which marks the boundary at the ground surface between the unconsolidated deposits of the Coastal Plain and the igneous and metamorphic crystalline rocks of the Piedmont Physiographic Province. Based on the United States Geological Survey (USGS) topographic 7.5-minute series quadrangle map for Relay, Maryland (revised 1974), the site lies within an area of rolling to hilly terrain dissected by numerous perennial to intermittent streams. Overall, the highest elevations (greater than 200 feet above mean sea level [MSL]) occur in the Severn area south and west of the former Kop-Flex facility with the lowest area (approximately 90 feet above MSL) present to the north along Stony Run.

According to the USGS topographic map, the closest stream is Stony Run, which flows across the northwestern portion of the property (Figure 2). Streamflow associated with the Stony Run drainage system progresses northward and eventually discharges into the Patapsco River. Additionally, numerous small, predominately man-made pond areas have been identified and mapped in the vicinity of Stony Run and its tributaries in the Hanover-Severn area. The largest of these is a hydrologically isolated pond located approximately 0.3 mile south of the site in the Harmans Woods community (Figure 2). This surface water feature is present on the 1974 USGS topographic map of the area.

2.3 Local Geology

In Anne Arundel County, the inner portion of the Coastal Plain province is characterized by alternating layers of Cretaceous age sand and clay sediments that dip gently to the southeast (Mack and Achmad, 1986). A generalized comparison of the Cretaceous rock-stratigraphic and corresponding hydrogeologic units in the region west of the Chesapeake Bay is provided in Figure 3 (Andreasen *et al*., 2013). Evaluation of the borehole lithologic data, in light of the regional stratigraphic framework, indicates that the unconsolidated deposits in the Hanover-Severn area include units of the Lower Cretaceous Potomac Group. The most extensive lithologic information is provided by the logging of cores from offsite monitoring wells installed in 2014 and drill cuttings from deep residential well boreholes in the area (e.g., 7932 Andorick Drive and 7769 Ricker Road). Based on this data, three Cretaceous age rock-stratigraphic units were identified from the land surface to an elevation of approximately 200 feet above mean sea level (MSL). The upper-most inter-bedded sand and clay sediment on the Kop-Flex and immediately adjacent properties are interpreted to represent younger (Quarternary) alluvial lithologic units associated with the depositional processes of the Stony Run drainage system. Figure 4 shows cross-sections depicting the rock-stratigraphic units underlying the former Kop-Flex facility and offsite areas to the south.

The Quarternary alluvium consists of a complexly inter-bedded and inter-fingering sequence of predominately coarse-grained (sand with gravel and fines) and fine-grained (silt and clay) deposits. Occasional sand zones may exist as either isolated bodies within the finer grained of sediments, or inter-fingered to interbedded layers that reflect the gradational transition between the overlying and underlying sediments. Based on the boring logs, the maximum thickness of these surficial deposits is approximately 60 feet and occurs in areas proximal to Stony Run and its tributaries.

The primary Lower Cretaceous litho-stratigraphic units of interest beneath the former Kop-Flex facility and offsite area to the south include the following:

- Patapsco Formation
- Arundel Clay
- Patuxent Formation

Based on regional studies, the upper and lower portions of the Patapsco Formation are dominated by coarse-grained deposits, consisting of fine to medium sand with multiple silt and clay layers of variable thickness (Andreasen 2007 and Raffensperger *et al*., 2010). The textural heterogeneity of these predominately sand zones is exhibited by the geophysical logs in Figure 5, which are for well boreholes drilled through the lower portion of the formation (Lower Patapsco Aquifer) in western shore of the Maryland Coastal Plain (Andreasen *et al*., 2013). Unconsolidated sand deposits of the Patapsco Formation at the Kop-Flex site consist of fine to medium-grained sand that exhibits pink, yellow, and brown hues in the upper section of the formation. Deeper sand deposits display a similar sand grain size as above; however, fine gravel fragments are present and colorization of sand transitions to more gray and white with some shades of yellow and brown. Intercalated with the sand-rich zones are layers of massive, dense, predominately clayey sediments, with some layers 10's of feet in thickness. In the Hanover-Severn area, these finer grained lithologies are characterized by gray to reddish-colored clay with variable sand content.

The Patapsco Formation is underlain by the Arundel Clay in the Coastal Plain sedimentary sequence. Regionally, this litho-stratigraphic unit is comprised of variegated clay sediments containing carbonized plant remains and ironstone (siderite) nodules (Andreasen 2007 and Raffensperger *et al*., 2010). This predominately clayey unit may have occasional inter-bedded layers of coarse-grained (sand and gravel) sediments (Raffensperger *et al*., 2010). Based on correlation of the borehole lithologic data, the unconsolidated deposits classified as the Arundel Clay range from approximately 25 feet to 60 feet in thickness at the site. Lithologically, this unit consists predominately of clay that ranges in color from gray to dark gray and red to very dark brown, with rare beds of well-graded sand. Organic (plant) matter is present throughout the majority of the clayey deposits comprising this litho-stratigraphic unit in the offsite area.

The Patuxent Formation unconformably overlies the older (Mesozoic-Paleozoic) basement rocks and comprises the deepest rock-stratigraphic unit in the Coastal Plain sequence in Maryland (Andreasen 2007 and Raffensperger *et al*., 2010). Lithologically, the lower portion of this formation consists of medium to coarse-grained sand and gravelly sand with rare thin clay beds. These deposits transition upwards to generally finer grained sands in the portion of the unit underlying the Arundel Clay (Raffensperger *et al*., 2010). The evaluation of the lithologic information for the site indicates this unit has only been encountered in a small number of well boreholes in the area of interest (*e.g.*, MW-25 and residential well at 7932 Andorick Drive; Section A-A', Figure 4). The sand deposits in the upper portion of the Patuxent Formation at the Kop-Flex site consist of light gray, dense, fine-grained sand with some clay (MW-25 location). The deeper sand deposits encountered in a few residential well boreholes completed into this unit exhibit a coarser grained texture and brownish color. Since this unit has only been encountered at a limited number of drilling locations, information of the thickness and lithologic variability of this unit is uncertain for the area of interest.

2.4 Local Hydrogeology

2.4.1 Overview

The unconsolidated fine and coarse-grained deposits of the Potomac Group comprise a series of inter-layered aquifers and aquitards, or confining units, in this portion of the Maryland Coastal Plain. Regionally, the aquifer units range from several tens to hundreds of feet thick and their depth increases to the south and east (Bolton and Hayes, 1999). As indicated in Figure 3, the designated aquifer units corresponding to this part of the lithostratigraphic sequence include of the Upper and Lower Patapsco aquifers and Patuxent aquifer. The aquifers are composed of sand and gravel units with inter-fingered sand-silt-clay deposits (Andreasen, 2007). The fine-grained, low permeability sediments separating the predominately sand deposits in the upper and lower portions of the Patapsco Formation and comprising the Arundel Clay function as confining units for the more permeable aquifer units (Raffensperger et al., 2010).

In addition to the Potomac Group lithologies, the shallow, Quarternary-age sand deposits in the vicinity of the former Kop-Flex facility comprise a localized surficial water-bearing zone that overlays the more regionally-extensive hydrostratigraphic units. Contouring of the water level data from wells screened in these deposits indicates flow in a generally westward direction toward Stony Run, which is believed to be the discharge point for shallow groundwater.

Figure 6 depicts the interpreted outcrop and subcrop areas for the aquifer units associated with the Potomac Group based on information provided in Andreasen *et al*. (2013). As shown in this map and Figure 4, the former Kop-Flex facility lies within the outcrop and subcrop area for the Lower Patapsco aquifer. Although groundwater within aquifer outcrop areas typically occurs under unconfined (water table) conditions, the presence of the sand, silt and clay deposits comprising the surficial water-bearing zone and hard, low permeability materials immediately underlying these deposits has resulted in the existence of a confined condition for the aquifer in the vicinity of the property. This hydraulic condition is supported by the appreciable head difference between monitoring wells screened in the surficial sand deposits and deeper sediments at the site.

Based on the hydrogeologic framework and downward groundwater flow within the local aquifer sequence, the Lower Patapsco aquifer and the underlying Patuxent aquifer represent the primary hydrogeologic units of interest for the offsite area at the Kop-Flex site. The following sections provide a brief description of these hydrogeologic units.

2.4.2 Lower Patapsco Aquifer

The Lower Patapsco aquifer extends over the entire area of interest and ranges in thickness from approximately 90 feet at the southern boundary of the Kop-Flex property to approximately 200 feet in the Andorick Acres development south of Reece Road. Based on the borehole lithologic data, an extensive clayey layer divides the predominately sand deposits into two separate zones south of Maryland Route 100. The main recharge area for the aquifer occurs primarily where the Patapsco Formation outcrops at the ground surface (Klohe and Kay, 2007).

As part of the quarterly sampling program for the offsite monitoring wells, water level measurements are obtained during each groundwater monitoring event. Evaluation of the water level data from offsite wells MW-25 and MW-28 indicates an unconfined groundwater condition in the upper-most sand zone and confined conditions within the deeper sandy deposits. A contour map of the potentiometric surface for the deeper confined sand zone in the Lower Patapsco Aquifer based on the contouring of water level data from both on and offsite deep monitoring wells is provided in Figure 7. Evaluation of the hydraulic head data indicates a generally south-southeast flow path for groundwater in the confined portion of this aquifer.

Aquifer transmissivities obtained from the analysis of pumping test data on the deep (confined) portion of the Lower Patapsco aquifer indicated values ranging from 1,170 square feet per day (ft^2/day) to 1,620 ft^2/day. The calculated hydraulic conductivity values for the aquifer materials in the test area varied from 14.6 ft/day to 20.3 ft/day, with a geometric mean K of 17.7 ft/day. The estimated geometric mean T and K values for the Lower Patapsco aquifer are at the lower end of the range of values cited in other hydrogeologic reports for the Maryland Coastal Plain deposits. Transmissivity values determined from well tests in the northwest portion of Anne Arundel County, including the Stevenson Road well southeast of the site, are typically on the order of 2,000 ft^2/day. Regional transmissivity values cited for the Lower Patapsco aquifer range from 2,300 ft^2/day to 10,200 ft^2/day (Andreasen, 2007).

2.4.3 Patuxent Aquifer

The deepest aquifer encountered in the Severn area comprises the porous sand deposits of the Patuxent Formation underlying the Arundel Clay, and is designated as the Patuxent aquifer. Detailed information on the texture and thickness of this hydrogeologic unit is largely unknown in the area of interest due to the limited advancement of well boreholes into this aquifer. Based on regional studies, the Patuxent aquifer is believed to approach a thickness of approximately 250 feet in western Anne Arundel County. As with other Coastal Plain aquifers, the primary source of recharge is infiltration of soil moisture derived from precipitation in outcrop and subcrop areas. However, spatial variation in the permeability and thickness of materials comprising the overlying confining unit may allow for localized inter-aquifer flow to be secondary water source for this hydrogeologic unit.

No monitoring wells have been completed in the Patuxent aquifer as part of the offsite groundwater investigation activities although the deep borehole for the MW-25 well cluster was drilled to the upper-most sand deposits of this unit (see Figure 4). Therefore, site-specific head data necessary to evaluate the groundwater flow direction for this aquifer is not available. Potentiometric surface contours determined from 2004 water level data indicate a general flow direction to the east toward the Dorsey Road well field (Andreasen 2007). The regionally determined transmissivity of the Patuxent aquifer in Anne Arundel County ranges from approximately 1,000 ft^2/day to 8,700 ft^2/day (Andreasen, 2007).

3 Previous Groundwater Quality Investigations

3.1 Private Water Supply Well Sampling (2013 – 2015)

Over the past three years, water samples have been collected from a total of 174 private water supply wells during three separate sampling phases. All of these samples, except for one in the Reece Road area, were collected from residential wells to the south of the former Kop-Flex facility and Maryland Route 100. All identified water supply wells in which written access was obtained from the property owner were sampled as part of the water quality investigation, regardless of the well depth.

Evaluation of the available well information with respect to the hydrogeologic frame work shows the residential wells in the Twin Oaks Road and Minnetonka Road neighborhoods are screened in water-bearing sand deposits within the Lower Patapsco aquifer. As discussed in Section 2, the local hydrostratigraphy of the Lower Patapsco aquifer is characterized by an areally extensive clayey layer of variable thickness with overlying and underlying intervals comprised of predominately sand or inter-layered sand and clay. Those private wells completed at depths of less than approximately 160 feet in these areas obtain groundwater from transmissive zones present in the upper sand zone of the aquifer. The source of water for wells installed at greater depths is the deeper sand deposits occurring below this clayey layer and above the Arundel Clay confining unit. The sand units within the Lower Patapsco aquifer also appear to represent the primary water-bearing zones for the completion of private wells in other parts of the Severn, Maryland area, such as the Andorick Acres development along Reece Road.

The available well construction information also suggests that sand layers in other portions of the Coastal Plain aquifer system may serve as the source of potable water. For example, shallow wells completed at depths of less than 100 feet in the area east of Telegraph Road and south of Donaldson Avenue obtain groundwater from either locally extensive sand zones within the Lower Patapsco confining unit or the lower-most sand deposits of the Upper Patapsco aquifer. Alternately, wells screen at depths of greater than 350 feet below ground surface (bgs) appear to extract water from the Patuxent Aquifer underlying the Arundel Clay confining unit.

The analytical results indicated detectable levels of VOCs in 137 of the 174 water samples collected from the private wells south of the site. The majority of these detections consisted of trace to very low concentrations of methyl tertiary-butyl ether, an additive formerly used in gasoline, and/or chloroform, a common byproduct in the disinfection of wells using chlorine. Both of these VOCs are not associated with the Kop-Flex site. Site-related contaminants of concern (COCs), (i.e., chlorinated VOCs and 1.4-dioxane) were only detected in 17 of the well samples, with the majority of these wells located along Twin Oaks Road.

The highest VOC concentrations were detected in samples from the Twin Oaks Road and Old Camp Meade Road areas, with the impacted well depths ranging from 170 feet bgs in the northern portion of the Twin Oaks and 240-250 feet bgs at the south end of this road and along Old Camp Meade Road. Total site-related VOC concentrations in samples from the wells in this area range from 32.8 micrograms per liter (µg/l) to 344.1 µg/l. Typically, 1,1-DCE and 1,4-dioxane are the only site-related COCs detected at levels above the MDE comparative criteria, which consist of the numeric groundwater standards for Type I/II aquifers for the chlorinated VOCs, and the MDE-calculated risk-based standard for 1,4-dioxane. One well sample from the Twin Oaks Road area also had a TCE concentration slightly above the MDE groundwater quality standards.

Trace and very low concentrations (less than 5 µg/l total VOCs) of site-related VOCs have also been detected in the following offsite areas:

- presumed shallow (less than 150 feet bgs) residential wells along Minnetonka Road
- shallow (less than 150 feet bgs) residential wells along Reece Road
- one deep (360 feet bgs) well in the Andorick Acres community immediately south of Reece Road

The absence of VOCs concentrations exceeding the groundwater standards appears to be related to the well construction, particularly the placement of the screen interval at a depth above or below the portion of the aquifer serving as the primary zone for constituent transport. Although the constituents present in the samples from the Reece Road wells are consistent with the Kop-Flex Site, it is possible the presence of these VOCs could be associated with a separate, as of yet unidentified, source in the Severn area.

3.2 Offsite Groundwater Assessment (2014)

Based on 2013 water well sampling, additional groundwater investigation activities were conducted in the summer and fall of 2014 to further assess the offsite VOC distribution. These investigation activities focused on the Severn area south of Maryland Route 100 and involved the installation of a total of nine monitoring wells in five different areas. The locations for these offsite monitoring wells are indicated in Figure 8. Construction information for the wells is provided below.

Well ID	Well Depth (ft bgs)	Screen Interval (ft bgs)	Screen Interval (ft above mean sea level)	Hydrogeologic Unit
MW-25-40	40	30 to 40	90.6 to 100.6	Lower Patapsco Aquifer (unconfined zone)
MW-25-130	130	120 to 130	0.5 to 10.5	Lower Patapsco Aquifer (confined zone)
MW-25-192	192	182 to 192	-51.5 to -61.5	Lower Patapsco Aquifer (confined zone)
MW-28-45	45	35 to 45	105.5 to 115.5	Lower Patapsco Aquifer (unconfined zone)
MW-28-210	210	200 to 210	-49.5 to -59.5	Lower Patapsco Aquifer (confined zone)
MW-31-280	280	270 to 280	-107.5 to -117.5	Lower Patapsco Aquifer (confined zone)
MW-33-236	236	226 to 236	-47.4 to -57.4	Lower Patapsco Aquifer (confined zone)
MW-33-295	295	285 to 295	-106.7 to -116.7	Lower Patapsco Aquifer (confined zone)
MW-35-298	298	288 to 298	-110.2 to -120.2	Lower Patapsco Aquifer (confined zone)

During installation of the deep well borehole at each location, groundwater profiling was conducted to provide depth-discrete sample data to evaluate the vertical distribution of site-related VOCs and guide construction of the monitoring well(s) at each location. These groundwater samples were field screened for 1,1-DCE using compound-specific colorimetric tubes and submitted to an offsite laboratory for VOC analysis (excluding 1,4-dioxane) on an expedited (less than 24-hour) turn-around time. Overall, the highest VOC concentrations were detected in samples from depths of greater than 100 feet bgs at the MW-25 location. Traces to very low concentrations of site-related VOCs have also been detected in a limited number of samples from the MW-28 and MW-33 locations. (A summary of the analytical results for the depth-discrete groundwater samples is provided in Quarterly Status Report No. 3 for the Kop-Flex VCP Site.)

After completing the well installation activities, quarterly groundwater sampling events have been conducted to gather initial data on VOC concentrations in the Lower Patapsco Aquifer. The offsite monitoring wells have been sampled in September 2014, December 2014, and March 2015. In conjunction with each sampling event, depth to water measurements was obtained from the offsite wells and selected onsite wells to determine hydraulic heads within the aquifer system. Head values for the deeper portion of the Lower Patapsco aquifer were analyzed using geostatistical methods to interpolate the slope of the potentiometric surface in the confined zone of this hydrogeologic unit.

3.3 Site-Related Offsite VOC Distribution

The primary VOCs of concern in the groundwater system at the Kop-Flex site consist of the following chlorinated compounds:

- 1,1,1-trichloroethane (TCA)
- degradation products of 1,1,1-TCA such as 1,1-dichloroethene (1,1-DCE) and 1,1-dichloroethane (DCA)
- chlorinated ethenes such as trichloroethene (TCE) and tetrachloroethene (PCE)

In addition, the solvent additive 1,4-dioxane has been detected in samples collected from monitoring wells on and hydraulically downgradient of the former manufacturing facility. Based on the most recent groundwater quality results, no site-related VOCs have been detected in the samples from the two offsite monitoring wells – MW-25-40 and MW-28-45 – screened in the upper-most unconfined zone of the Lower Patapsco aquifer. Evaluation of the sampling data indicates the chlorinated VOCs and 1,4-dioxane associated with the Kop-Flex site are limited to the thick, predominately sand deposits present in deeper confined portions of this aquifer that overlie the Arundel Clay confining unit.

An iso-concentration map showing the total VOC distribution within the impacted interval of the Lower Patapsco aquifer in both on- and offsite areas is shown in Figure 9. The modeled iso-concentration contours were generated using the analytical results from the monitoring wells, with the sample set in the offsite area augmented with data from previously sampled residential wells screened within the affected portion of the aquifer. For samples collected from the paired monitoring well locations, the highest total VOC concentration detected in the samples was used for generating the contours. In the area south of Maryland Route 100, the highest VOC concentrations were detected in samples from the paired wells – MW-25-130 and MW-25-192 – in the Harmans Woods residential area. The degradation products 1,1-DCE and 1,2-DCA were detected above the MDE groundwater quality standards in samples collected from the deep portion of the aquifer at this well location. Additionally, the concentration of 1,4-dioxane in both well samples exceeded the MDE-calculated risk-based level of 6.7 µg/l The lower concentrations of VOCs in the sample from the deeper well at the MW-25 location (MW-25-192) is consistent with the vertical distribution of site-related constituents determined from groundwater profiling at other on- and offsite monitoring well locations. The sampling data for the deep monitoring wells located further south contained trace to very low concentrations of the site-related VOCs (Figure 9). The concentration of 1,4-dioxane detected in the March 2015 sample from MW-33-295 (8 µg/l) was just slightly above the MDE risk-based level. Overall, the areal extent of VOC-affected groundwater in the Lower Patapsco Aquifer downgradient of the former Kop-Flex facility is generally delineated by the offsite monitoring well locations. Other than the detection of 1,4-dioxane in the groundwater from well MW-33-295 sample, no site-related VOCs were detected above the comparative criteria in any of the samples from the other monitoring points.

In general, the inferred vertical distribution of site-related chemicals in the Lower Patapsco aquifer is represented by the 1,1-DCE iso-concentration contours in Figure 10, which have been overlaid on hydrogeologic cross-sections A-A’ and B-B’ in the area of interest. As with the previously discussed plume map, groundwater quality data obtained from the residential well sampling was evaluated in determining the VOC distribution within the aquifer system. In addition, the analytical results for depth-discrete samples collected during installation of both on- and offsite monitoring wells were included in assessing the vertical contaminant distribution. Based on evaluation of the sampling data, the deep confined sand zone in the Lower Patapsco Aquifer represents the primary hydrostratigraphic interval for the migration of the VOCs in the aquifer system. The regional southeastward dip of the stratigraphic units comprising the hydrogeologic framework results in a corresponding increase in the depth of the VOC plume in the downgradient direction. Another plume characteristic is the vertical extent of VOC-impacted groundwater with the highest concentrations occurring in the upper portion of the confined sand unit near the MW-25 well location and the lower portion further southeast (downgradient) at well MW-33 (Figure 10). The apparent ‘diving’ of the VOC plume core is believed to reflect the spatial variations in the permeability of the sand deposits and the presence of locally extensive clayey layers within the deep confined sand unit. The aquifer heterogeneity associated with these features would impart significant control on the pathways for dissolved VOC transport. The diving nature of the VOC plume is also reflected by the very low detections of 1,1-DCE and 1,4-dioxane in water samples collected from private wells screened in the Patuxent Aquifer in the Andorick Acres neighborhood.

4 Groundwater Monitoring Plan

4.1 Monitoring Well Network

Evaluation of the groundwater quality data for the offsite monitoring wells to the south of the former Kop-Flex facility indicates the deeper (confined) zone of the Lower Patapsco aquifer has been impacted by chlorinated VOCs and 1,4-dioxane. Based on the inferred VOC distribution, additional monitoring wells screened in this portion of the Lower Patapsco aquifer are needed to better characterize and monitor the groundwater quality in the offsite areas. The sampling data provided by the augmented offsite monitoring well network would be evaluated to assess temporal changes in constituent concentrations in the aquifer system.

Four additional wells (MW-29, MW-30, MW-32, and MW-34) are proposed for installation at four different locations to further monitor VOC concentrations in groundwater hydraulically downgradient of the Kop-Flex property. The proposed new monitoring well locations are shown on Figure 11. As with the previously installed monitoring wells, all new wells will be installed within right-of-way (ROW) areas of public roads in Severn, Maryland. Therefore, the well installation activities will commence following issuance of Right-of-Way Permits for each location by the Anne Arundel County Department of Public Works.

The proposed deep monitoring wells, together with the existing confined zone wells (MW-25-130, MW-25-192, MW-28-210, MW-31-280, MW-33-236, MW-33-295 and MW-35-298), will comprise the groundwater monitoring network for the offsite area at the Kop-Flex site. Water level data will be collected from the existing and new monitoring points and analyzed to assess head variations and flow paths within the affected portion of the aquifer. In addition, regular groundwater quality sampling will be performed to monitor VOC concentrations in the deep confined zone of Lower Patapsco Aquifer.

As discussed in Section 3.3, the analytical results for offsite wells MW-25-40 and MW-28-45 indicate site-related VOCs have not affected the shallow, unconfined portion of the Lower Patapsco aquifer in the offsite area. Based on this data and analytical data for samples from shallow residential wells in the area, the proposed monitoring activities exclude the collection of water level and water quality data from wells MW-25-40 and MW-28-45. Instead, future monitoring efforts will focus on the deeper confined zone of the aquifer where VOC-impacted groundwater has been detected based on the findings of previous investigation activities.

4.2 Monitoring Well Installation

4.2.1 Drilling and Targeted Groundwater Profiling

For each new monitoring well, the roto-sonic drilling method will be used to advance a 6-inch-diameter borehole at location in the public road ROW. During borehole advancement, continuous, 10-foot-long cores of the unconsolidated aquifer materials will be obtained using a 4-inch-diameter core barrel. The recovered material from each core run will be logged by a WSP Geologist, and the descriptive information recorded in a bound field notebook.

Based on the available groundwater quality data, WSP proposes to complete each well borehole through the entire thickness of the predominately fine to medium-grained sand sediments comprising the Lower Patapsco Aquifer and into the upper few feet of the underlying Arundel Clay confining unit. Using the hydrostratigraphic sections provided in Figure 4, the approximate borehole depths at each proposed drilling location are provided below.

Well Location	Depth of Well Borehole (feet bgs)	Depth-Discrete Groundwater Sample Interval (feet bgs)	Screen Interval for Monitoring Well (feet bgs)
MW-29	210	135 – 210	160 - 170
MW-30	265	200 – 265	235 - 245
MW-32	255	180 – 255	235 - 245
MW-34	360	260 – 360	320 - 330

The actual borehole depth will be determined in the field by the WSP Geologist based on the lithologic descriptions for the aquifer material cores samples.

Each borehole will be advanced into the sand sediments comprising the deeper confined portion of the Lower Patapsco aquifer before conducting the depth-discrete groundwater sampling. After drilling the borehole into this zone, groundwater samples will be collected at 10 to 20-foot depth intervals using a 5-foot long down-hole sampler and a suitable purge and sample pump. Based on a review of the hydrogeologic and hydrogeochemical data, the approximate borehole interval for the collection of these depth-discrete samples is provided in the above table. If a thick (i.e., greater than 10 feet) clayey unit is encountered during the profiling activities, the drilling and sampling will be temporarily suspended, and WSP will review the field data to determine whether the overlying sand deposits should be cased off before continuing with the borehole installation. If it is determined to seal off the overlying sand zone, the borehole will be over-drilled to a minimum depth of 2 feet below the top of the clayey unit using 7-inch diameter temporary steel casing. Borehole drilling and groundwater sampling will then resume and continue to the termination depth using the procedures described above.

At each sample interval, water will be continuously purged from the sampler to ensure that representative groundwater, which has not been affected by the drilling activities, is collected from the depth interval. During purging, field hydrogeochemical parameters, including temperature, pH, specific conductance, and turbidity, will be monitored at regular (3-5 minute) intervals, and the measurements recorded in the field notebook. Once the field parameters have stabilized, groundwater samples will be collected for field screening and laboratory analysis.

Groundwater samples will be screened in the field for 1,1-DCE using the Color-Tec screening procedure. Each depth-discrete sample that has a positive (i.e., measurable) detection of this chlorinated compound using the aforementioned screening procedure will be submitted to an offsite laboratory for rush (i.e., less than 24-hour turn-around time) VOC analysis. In addition, a minimum of one sample from a depth above and below the interval where positive screening detections were encountered will be submitted to the analytical laboratory to ensure the vertical delineation of the site-related COCs. If no positive detections are found for the samples, a minimum of four depth-discrete samples that bracket the inferred depth interval for dissolved constituents migrating from the Kop-Flex facility will be analyzed by the laboratory.

Groundwater samples for laboratory analysis will be submitted to the Phase Separation Science laboratory in Baltimore, Maryland. The depth-discrete samples for all well locations will be analyzed for VOCs using U.S. EPA SW-846 Test Method 8260B. Any applicable WSP standard operating procedures (SOPs) and quality assurance/quality control (QA/QC) procedures will be followed during the groundwater profiling activities.

4.2.2 Well Construction

After completing the drilling and groundwater profiling activities, the borehole will be completed as a groundwater monitoring well. The well depth and screen interval will be determined in the field based on the screening and laboratory results for the depth-discrete groundwater samples and available hydrogeologic data for the aquifer. If the well completion depth is more than 2 feet shallower than the borehole termination depth, the borehole will be backfilled with bentonite pellets or chips to allow for construction of the well at the desired depth.

A schematic diagram of the proposed monitoring well construction is provided in Figure 12. The monitoring wells will be constructed of threaded, flush-joint, 2.5-inch inside diameter, Schedule 80 polyvinyl chloride (PVC) casing. The screen will be 10 feet in length with 0.020-inch horizontal slots. Centralizers will be placed at 20-foot intervals to ensure the well casing is plumbed and aligned in the borehole during placement of the annular fill materials. A filter pack consisting of clean quartz sand (10/20 grade or equivalent) will be placed in the annular space using a tremie pipe to a minimum depth of 3 feet above the top of the screen. A 3-foot-thick bentonite seal will then be placed above the sand filter pack. The remainder of the annular space will be tremie-grouted using a cement-bentonite mixture prepared in accordance with the requirements specified in the Maryland well construction standards (COMAR 26.04.04.07.G[4][a]). Each monitoring well will be secured with a removable locking cap and covered with a traffic-rated, flush-grade protective steel cover set in a 2-foot square concrete surface pad.

The monitoring wells will be developed by removing water using a suitably sized submersible pump. Groundwater geochemical measurements (temperature, pH, and specific conductivity) and turbidity will be periodically monitored during the development activities, and the measurements recorded in a field notebook. Well pumping will continue until a relatively clear, low turbidity discharge is obtained from each well and the groundwater geochemical parameters for the well discharge exhibit generally consistent values. All development water will be contained in Department of Transportation (DOT)-compliant 55-gallon steel drums.

4.3 Surveying of Monitoring Wells

A surveyor licensed in the State of Maryland will survey the locations and elevations of the new monitoring wells installed in the offsite area. The elevation of the ground surface and top of the PVC well casing will be surveyed to the nearest 0.01 foot. The horizontal location of the borings will also be determined to the nearest 0.1 foot. Horizontal and vertical data will reference the Maryland State Plane coordinates and the NAVD1988 datum, respectively. The locations will be plotted on a scaled map showing both the former Kop-Flex facility and the surrounding area.

4.4 Management of Drilling Waste

Investigation-derived media (IDM) generated during the well installation activities will include the following:

- drill cuttings
- solid-containing drilling water
- groundwater from purging of sampler during groundwater profiling and well development
- decontamination water
- miscellaneous solid materials that come in contact with potentially contaminated soil or groundwater (e.g., personal protective equipment, plastic, tubing, etc.)

All IDM listed above will be containerized in either DOT-compliant 55-gallon steel drums or large volume (bulk) containers. The selected waste containers will be temporarily staged in a suitable area, covered, and labeled as “NON-HAZARDOUS WASTE PENDING ANALYSIS”. Drill cuttings and drilling water from the MW-30 well location will be segregated into two groups, with one comprising material from the portion of the Lower Patapsco aquifer above the zone of VOC-affected groundwater and the other consisting of material from the impacted portion of the aquifer.

Composite samples of the drill cuttings and solid-containing drilling water will be collected and analyzed to determine the appropriate management of these materials. In addition, samples of the combined wastewater streams will be collected and analyzed for subsequent management of these materials following completion of the well installation activities. All IDM will be managed in accordance with state and federal regulations.

5 Sampling and Analysis Plan

5.1 Groundwater Quality Standards for Site-Related VOCs

The cleanup criteria for all site-related COCs, excluding 1,4-dioxane, detected in the offsite area are equivalent to the promulgated MDE groundwater quality standards, which are listed below.

- 1,1,1-TCA – 200 µg/l
- 1,1-DCE – 7 µg/l
- 1,2-DCA – 5 µg/l
- 1,1-DCA – 90 µg/l
- *cis*-1,2-DCE – 70 µg/l
- TCE – 5 µg/l
- PCE – 5 µg/

These values correspond to the standards for Type I and II aquifers, and maximum contaminant levels (MCLs) and secondary MCLs developed by U.S. EPA under the Safe Drinking Water Act. Based on the site hydrogeologic and hydrogeochemical data, the Lower Patapsco aquifer meets the definition of a Type I aquifer provided in the MDE document *Cleanup Standards for Soil and Groundwater, Interim Final Guidance (Update No. 2.1)*.

At present, no groundwater quality standard has been promulgated by MDE or U.S. EPA for 1,4-dioxane. Using the current default exposure factors developed by U.S. EPA and a target cancer risk of 1E-5, the calculated risk-based criterion for 1,4-dioxane is 7.8 µg/l. Based on the known use of private wells as a potable water source in the some residential areas, the risk-based groundwater quality standard would be applicable for the offsite area.

5.2 Sampling Plan

5.2.1 First Year Baseline Sampling Activities

Given the installation of additional wells, the baseline sampling activities to be conducted during the first year of monitoring will be different for the new and existing wells comprising the offsite well network. For the new monitoring wells (MW-29, MW-30, MW-32 and MW-34), groundwater samples will be collected on a quarterly basis to characterize the hydrogeochemical conditions in the zone of interest for the Lower Patapsco aquifer and evaluate the presence of trends and/or seasonal fluctuations in VOC concentrations. Since multiple sampling events will have been conducted for the existing deep groundwater monitoring wells (MW-25 pair, MW-28, MW-31, MW-33 pair and MW-35), the monitoring of these wells during the baseline period will be conducted on a semi-annual basis.

5.2.2 Sampling Activities for Subsequent Years

Long-term groundwater quality monitoring will be implemented after completion of the baseline sampling activities. At this time, the monitoring frequency for the new offsite groundwater monitoring wells will be reduced to a semi-annual schedule to be consistent with the previously installed monitoring wells.

After collecting a sufficient number of monitoring well samples, the analytical results will be reviewed to determine whether modifications in the sampling frequency are warranted based on the groundwater quality data. If supported by the data evaluation, the sampling of groundwater wells located within the limits of the VOC plume will changed from a semi-annual to annual basis. Monitoring wells located outside and down gradient of the plume will continue to be sampled semi-annually to monitor for any changes in the VOC distribution that could potentially impact other private wells in the Severn, Maryland area. Any modification in the groundwater monitoring program will be communicated and approved by MDE and U.S. EPA, Region III before being implemented at the site.

Periodic evaluation of the groundwater quality data will continue to be conducted on a regular basis as part of the long-term monitoring activities. Optimization of the monitoring network will be assessed to determine whether additional changes in the sampling frequency can be implemented while still assuring attainment of the monitoring objectives. The optimization evaluation will use the Monitoring and Remediation Optimization System (MAROS) software package, developed by Groundwater Services, Inc., to perform qualitative and temporal statistical analyses of the groundwater sampling data from the monitoring wells (USEPA 2004). Parametric and non-parametric methods will be utilized to assess the statistical significance of temporal trends in site-related VOC concentrations. The results of the temporal-trend analyses will then be evaluated by the MAROS program to develop recommendations for optimal sampling frequency at each monitoring point using a modified Cost Effective Sampling algorithm.

5.3 Field Methods and Procedures

5.3.1 Water Level Measurements

Field measurements of the depth to standing water in monitoring wells will be obtained during each sampling event using an electronic water level indicator. For each monitoring well, measurements will be made of the static water level and well depth to determine the height of the water column and identify potential siltation problems inside the well casing. All field measurements will be recorded in a bound field notebook.

5.3.2 Field Sampling and Analysis

Groundwater samples will be collected from the monitoring wells using either the low flow purge and sample method, or a passive sampling method (HydraSleeve). The selected sampling method with be based on the findings from the field demonstration test to be performed as part of the onsite groundwater monitoring activities (WSP 2015). All field information related to the sampling activities will be documented in a bound field notebook. A description of each groundwater sampling method is provided below.

5.3.2.1 Low Flow Purge and Sample Procedure

The procedure for collecting groundwater samples using the low flow method will comply with the procedures described in the current version of the WSP Field Standard Operating Procedure (SOP) #11: Groundwater Sampling (Appendix A). Each well will be purged at a rate of less than or equal to 0.5 liter per minute using a stainless steel bladder pump equipped with a dedicated bladder and drop tube extending from the pump to the screen interval. Measurements of field hydrogeochemical parameters (pH, specific conductivity, dissolved oxygen, temperature, and oxidation-reduction potential) and turbidity will be recorded using a suitable multi-parameter field meter equipped with a flow-through cell, and the information documented in a bound field notebook. These parameters will be allowed to stabilize before sample collection.

Purge water generated during the sampling activities will be collected in 5-gallon buckets and transferred to DOT-compliant 55-gallon steel drums. The drummed water will be labeled and temporarily stored inside the treatment equipment building for the onsite remedial systems and labeled “NON-HAZARDOUS WASTE PENDING ANALYSIS”. After completing the monitoring event, a sample will be collected from each drum and analyzed for VOCs using U.S. EPA test method 8260B to characterize this material for subsequent management. All IDM will be managed in accordance with applicable state and federal regulations.

5.3.2.2 Passive Sampler Procedure

The HydraSleeve is one of several passive sampling technologies demonstrated to be capable of collecting representative groundwater samples for analysis of chlorinated VOCs and 1,4-dioxane (Parker and Clark 2002, Montgomery Watson Harza 2002, Parsons Corporation 2005, and ITRC 2006). Initially, the depth to water and total depth will be reviewed, along with the well construction information, to determine the target depth for placing the passive sampler in each well. The 2.5-foot long HydraSleeve sampler will be attached to a weighted, nylon suspension tether and set at the pre-determined depth within the screen interval. The placement of the HydraSleeve will involve first lowering the sampler to the bottom of the well and very slowly raising the sampler so the valve/opening is at the prescribed depth – termed "bottom-up deployment". The suspension line will then be secured at the well head to ensure the sampler remains at the designated depth during the two-week re-stabilization period. Following equilibration, the groundwater sample will be collected by continuously pulling upward on the HydraSleeve until full. The HydraSleeve will be carefully removed from the well, and the sample immediately collected in the appropriate containers to minimize the diffusive loss of VOCs through the polyethylene wall of the sampler. Additional information on the procedure for collecting groundwater samples using the HydrSleeve is provided in Appendix B.

5.3.2.3 Analytical Protocols

The groundwater samples will be analyzed for VOCs using U.S. EPA SW-846 Test Method 8260B. In addition, the samples will be analyzed for 1,4-dioxane using modified U.S. EPA Method 8260B with selective ion monitoring (SIM). These test methods will be used for both environmental samples and field quality control (QC) samples – *i.e*., trip blanks, duplicate samples etc.

5.3.3 Field Quality Assurance/Quality Control Procedures

5.3.3.1 Sample Custody

Documentation during all field sampling activities is essential to ensure proper sample identification. Standard sample custody procedures will be used to maintain and document sample integrity during collection, transportation, and storage. The Field Team Leader (FTL) will be responsible for ensuring proper sample management and documentation that will allow for tracing the possession and handling of individual samples from the time of collection to laboratory receipt. The following sections describe sample custody documentation and handling procedures to be followed in the field and in transporting the samples to the laboratory.

Chain-of-custody forms provide an accurate written record tracking the possession of individual samples from the time of field collection through laboratory analysis. A chain-of-custody form will be used to document the samples collected and their respective analyses. Information that field personnel will enter on the chain-of-custody form will include the following:

- project name and number
- name and signature of sampler(s)
- sample identification number
- date and time of sample collection
- destination of samples (laboratory name)
- number of containers filled
- analyses requested
- sample matrix

- signatures of individuals involved in custody transfer (including date and time of transfer)
- air-bill number, if required
- cooler number

Chain-of-custody forms completed in the field will be signed, sealed in a plastic bag, and placed inside of the shipping container used for sample transport as compliant with WSP Standard Operating Procedure (SOP) #4 (Appendix A). Signed chain-of-custody forms or air-bills will serve as evidence of sample custody transfer between the field team and courier, and the courier and laboratory. Copies of the chain-of-custody form and air-bill (if required) will be retained and filed by the FTL prior to shipment.

5.3.3.2 Sample Packaging and Shipping

General procedures for the packaging, labeling, and shipping of samples will follow the WSP SOP #3 (Appendix A) and all applicable DOT regulations. In addition, the procedures outlined below meet the EPA guidance on field operations methods.

Sample labels will be affixed to all sample containers sent to the laboratory. Each identification label will be completed with the following information:

- client
- site name
- sample identification number
- sample collection date and time
- sampler's initials
- preservatives added
- sample analysis

After labeling, each sample container will be placed in a cooler containing ice to maintain the sample temperature at 4°C.

- The cooler will be filled with sample bottles wrapped in protective material (e.g., "bubble wrap") and suitable packing material. Sufficient packing material will be used to prevent sample containers from making contact during shipment. Enough ice will be added to maintain the sample temperature at 4°C.
- The chain-of-custody form will be placed inside a sealed plastic bag. The laboratory will be notified if the field team suspects that a sample(s) contains any substance for which the laboratory personnel should take safety precautions.
- The cooler will be closed and taped shut with strapping tape (filament-type) around both ends. If there is a drain in the cooler, it will be taped shut both inside and outside of the cooler.
- Two signed custody seals will be placed on the cooler, one on the front and one on the back. Additional seals may be used if the sampler or shipper determines more seals are necessary. Wide clear tape will be placed over the seals to ensure against accidental breakage.

5.3.3.3 Equipment Calibration Procedures

Measurement equipment to be used during field activities will be calibrated at the beginning of the work day and at prescribed intervals as stated in WSP SOP #7 (Appendix A). The FTL will be responsible for ensuring that the field equipment is properly calibrated. The frequency of calibration is dependent on the type and stability of the equipment, the intended use of the equipment, and the recommendations of the manufacturer.

All field calibration information will be recorded in the field notebook. Additionally, a label specifying the date of the next manufacturer's calibration will be attached to the equipment. If this information is not legible, calibration records for the piece of equipment will be available for reference.

When a piece of equipment becomes inoperable, it will be removed from service and tagged to indicate that repair, recalibration, or replacement is needed.

5.3.3.4 Field Quality Control Samples

Field QC samples will be collected for laboratory analysis to check sampling and analytical precision, accuracy, and representativeness. The QC samples for this project include the samples described in the following sections and are compliant with WSP SOP #4 (Appendix A).

5.3.3.4.1 Equipment Rinsate Blank

One equipment rinsate blank will be collected per 10 environmental samples collected during sampling activities, if non-dedicated equipment is not used. These samples will be used as a QC check of the decontamination procedures for sampling devices. Equipment blanks will be prepared after the equipment has been used and decontaminated in the field. Equipment blanks will be prepared by filling or rinsing the cleaned equipment with analyte-free water (e.g., distilled or de-ionized water) and collecting the rinsate in the appropriate sample containers. Equipment blanks will be analyzed for all the analytes for which the environmental samples are being analyzed. Equipment blanks will be labeled, documented, and handled in the same manner as other field samples.

5.3.3.4.2 Matrix Spike/Matrix Spike Duplicate

Results from the matrix spike/matrix spike duplicate (MS/MSD) samples are used to determine accuracy by using the percent recovery of the spiked compounds, and precision by assessing the relative percent differences. Various spike recovery tests are performed at the laboratory using non-reactive compounds to determine possible matrix interferences that may affect sample reporting. An MS/MSD sample will be collected for every 20 samples collected and analyzed as a further QC check. The specific sample location that will be used for the MS/MSD sample will be selected by the FTL. MS/MSD samples will be labeled and documented as such, and handled in the same manner as other field samples.

5.3.3.4.3 Field Duplicate

Samples that are collected at the same time, from the same location, with the same apparatus, and placed into identical containers that were prepared and handled in the same manner are considered blind duplicates. These samples are laboratory-analyzed using the same methods and instruments as the field samples and provide information on the precision of the sampling and analysis. One duplicate sample will be collected for every 10 samples from the same matrix and submitted blind to the laboratory for analysis.

5.3.3.4.4 Trip Blank

Trip blanks are prepared at the laboratory and used to test for potential contamination by VOCs during roundtrip transit to/from the laboratory. Vials (40 ml) are filled with deionized water, preserved, and chilled to a temperature less than 4°C. Trip blanks remain with the sample cooler(s) at all times. One trip blank will be included with each sample cooler submitted to the laboratory. Trip blanks will be analyzed for VOCs using the aforementioned U.S. EPA test method.

In addition to a trip blank, the QC samples for assessing the data quality during the field sampling activities will consist of a field duplicate and equipment blank. The equipment blank will be used as a control sample and to identify potential biases for any target compounds. This sample will be collected by filling one, un-used sampler with deionized or distilled water, and then transferring water to the necessary sample containers in the same manner as a groundwater sample. A detail description of the field quality assurance/quality control procedures is provided in Section 5.2.2.

6 Evaluation and Reporting of Groundwater Monitoring Data

6.1 Data Tabulation and Evaluation

The analytical results for the groundwater samples collected during each monitoring event will be presented in tabular format, along with any associated data qualifiers. Non-detect results will be represented using the quantitation limit for the compound and the “U” data qualifier. Detected concentrations in any of the collected groundwater samples will be compared to the cleanup criteria discussed in Section 5.1 and other applicable groundwater quality standards. Additionally, historical data tables, which include COC concentrations for wells included in the monitoring network, will be prepared and updated in conjunction with the preparation of the sampling event data tables. Groundwater level data will be contoured using geostatistical methods to prepare potentiometric surface maps for the confined portion of the Lower Patapsco aquifer in the offsite area.

The groundwater monitoring results will be evaluated to assess if the sampling frequency is appropriate and determine relevant water quality trends. Data analysis will first involve the preparation of temporal concentration plots for selected constituents. Statistical methods (*e.g.*, Mann-Kendall test) may be used to assess the presence and significance of water quality trends and seasonal variations in the COC concentrations in groundwater. The seasonal trends analysis will be conducted on the baseline sampling data from wells MW-29, MW-30, MW-32, and MW-34 collected during the first year of monitoring.

6.2 Reporting of Monitoring Results

The water level data and groundwater sampling results will be included as part of Annual Offsite Groundwater Monitoring reports prepared for the Kop-Flex VCP Site. The information provided in the reports will include a discussion of the monitoring activities, event-specific and historical data tables, and interpretation of the water level and groundwater quality data in comparison to the applicable groundwater quality standards. The reports will also include electronic copies of the certified laboratory analytical reports for all groundwater sampling events conducted during the reporting period. The monitoring reports will be submitted to the MDE and U.S. EPA on an annual basis.

7 References

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8 Acronym List

bgs	below ground surface
COCs	contaminates of concern
DOT	Department of Transportation
FTL	Field Team Leader
GWMP	Groundwater Monitoring Plan
IDM	Investigation-derived media
MDE	Maryland Department of the Environment
MS/MSD	matrix spike/matrix spike duplicate
MCLs	maximum contaminant levels
MSL	mean sea level
µg/l	micrograms per liter
MAROS	Monitoring and Remediation Optimization System
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
ROW	right-of-way
SIM	selective ion monitoring
SOPs	Standard Operating Procedures
ft^2/day	square feet per day
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VCP	Voluntary Cleanup Program
VOCs	volatile organic compounds

Figures

DWG Name:

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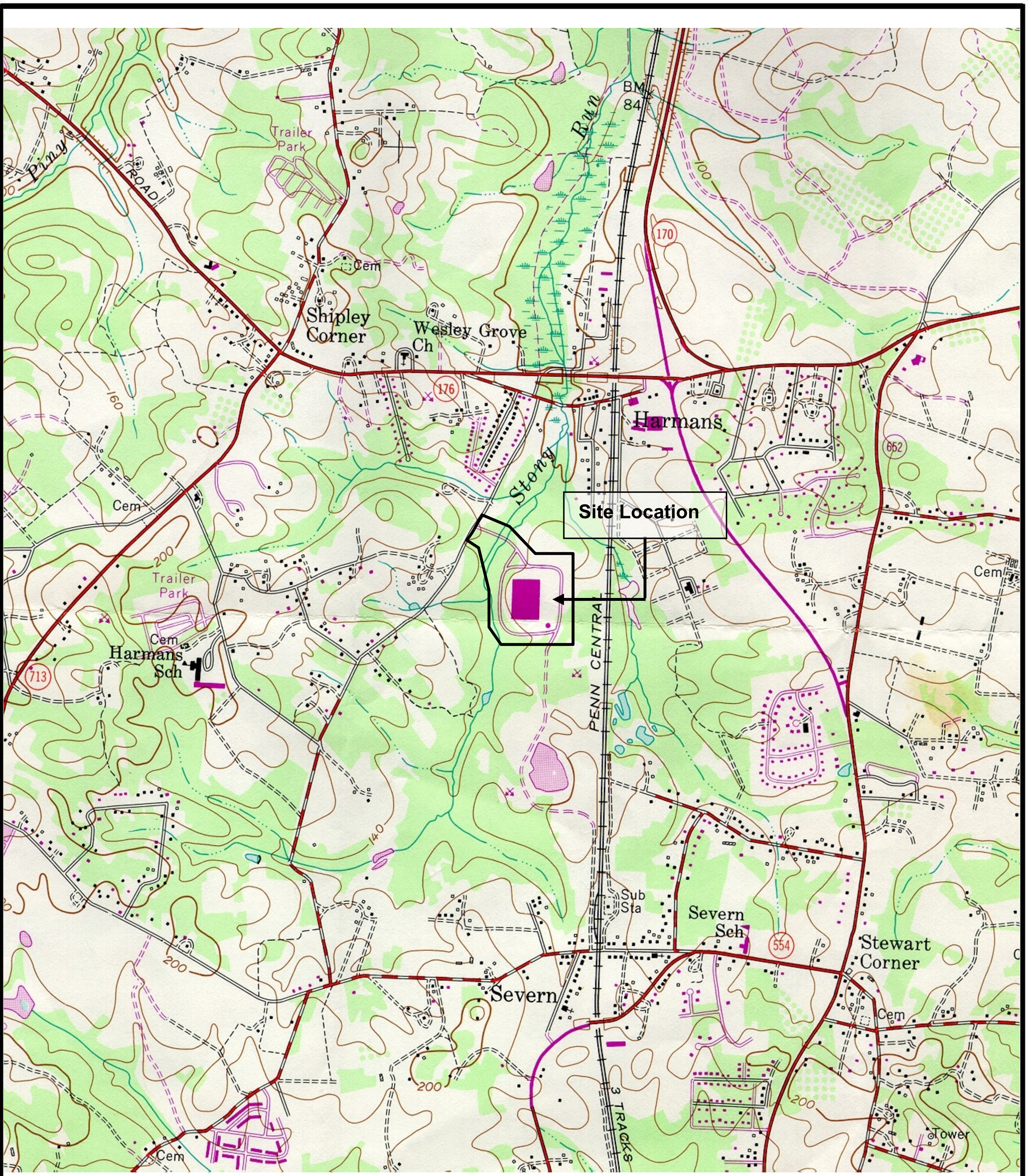

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WSP

WSP USA Corp.
11190 Sunrise Valley Drive, Suite 300
Reston, Virginia 20191
(703) 709-6500

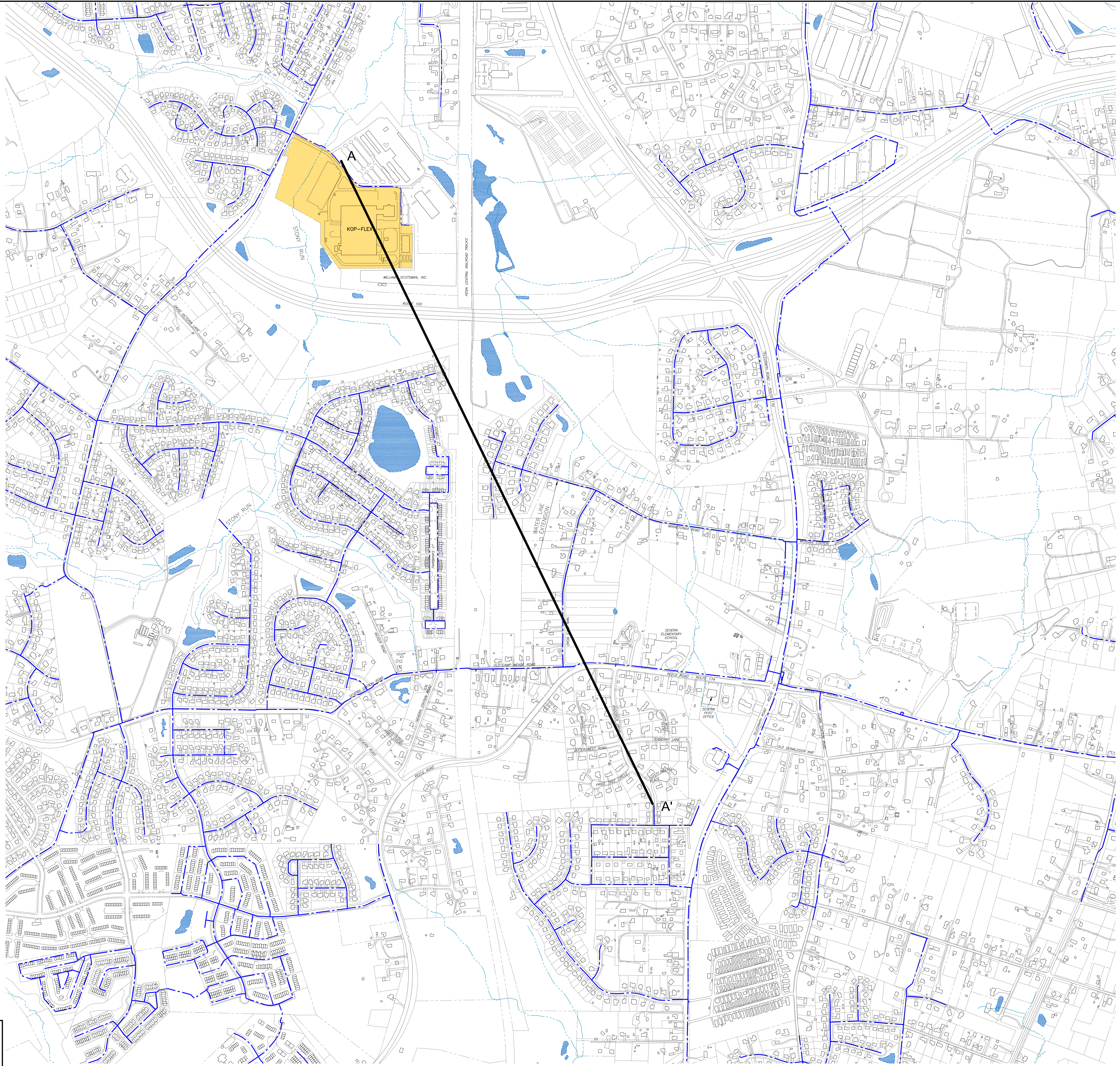
FIGURE 1

SITE LOCATION MAP

FORMER KOP-FLEX FACILITY
HANOVER, MARYLAND

PREPARED FOR

EMERSON
ST. LOUIS, MISSOURI



LEGEND

— - - —	PROPERTY LINE
— · —	WATER MAIN
— - · —	STREAM
●	WATER BODY

THE ORIGINAL VERSION OF THIS DRAWING IS IN COLOR. BLACK AND WHITE COPIES MAY NOT ACCURATELY DEPICT CERTAIN INFORMATION.

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SCALE IN FEET

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REVISIONS

REV	DESCRIPTION	
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PLAN OF FORMER KOP-FLEX FACILITY AND SURROUNDING AREAS WITH LINE OF SECTION A-A'

KOP-FLEX VCP SITE
HANOVER, MARYLAND
PREPARED FOR
EMERSON
ST. LOUIS, MISSOURI

WSP

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FIGURE 2

Drawing Number
00039196-037

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DWG Name: 00039196-039

Checked: Approved: 6/9/2015

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System	Series	Rock-stratigraphic Units		Hydrogeologic Units
Cretaceous	Upper Cretaceous	Severn Formation		Matawan confining unit
		Matawan Formation		
		Magothy Formation		Magothy aquifer
	?	Potomac Group	Patapsco Formation	Magothy-Upper Patapsco confining unit
	Lower Cretaceous			Upper Patapsco aquifer system
				Lower Patapsco confining unit
				Lower Patapsco aquifer system
			Arundel Clay	Arundel Clay confining unit
			Patuxent Formation	Patuxent aquifer system
Basement complex consisting of undifferentiated crystalline and sedimentary rocks ranging from Precambrian to Jurassic age				

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Figure 3

CRETACEOUS ROCK–STRATIGRAPHIC AND HYDROGEOLOGIC UNITS OF THE MARYLAND COASTAL PLAIN, WESTERN CHESAPEAKE BAY SHORE

KOP–FLEX VCP SITE
HANOVER, MARYLAND

PREPARED FOR
EMERSON

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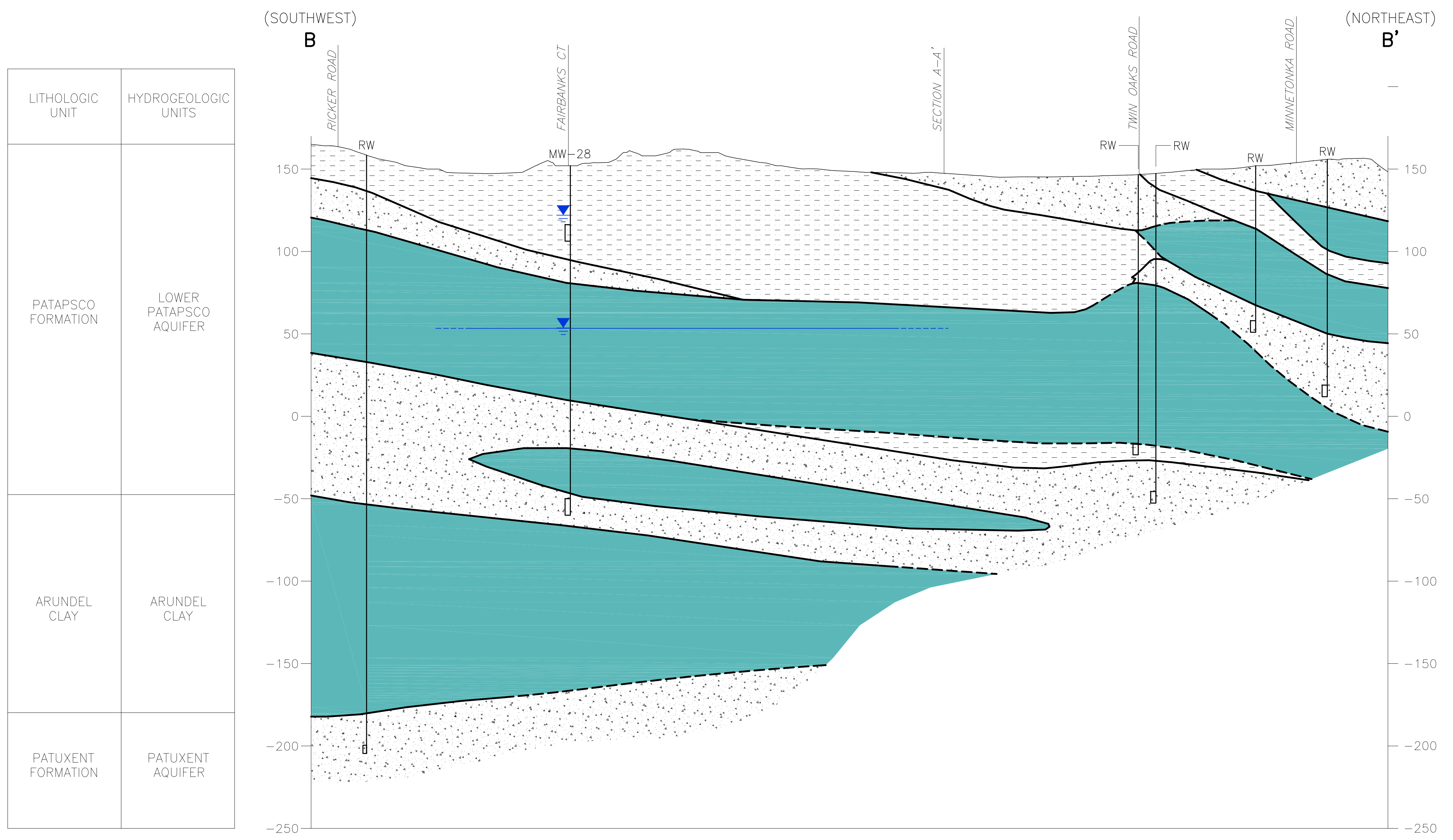
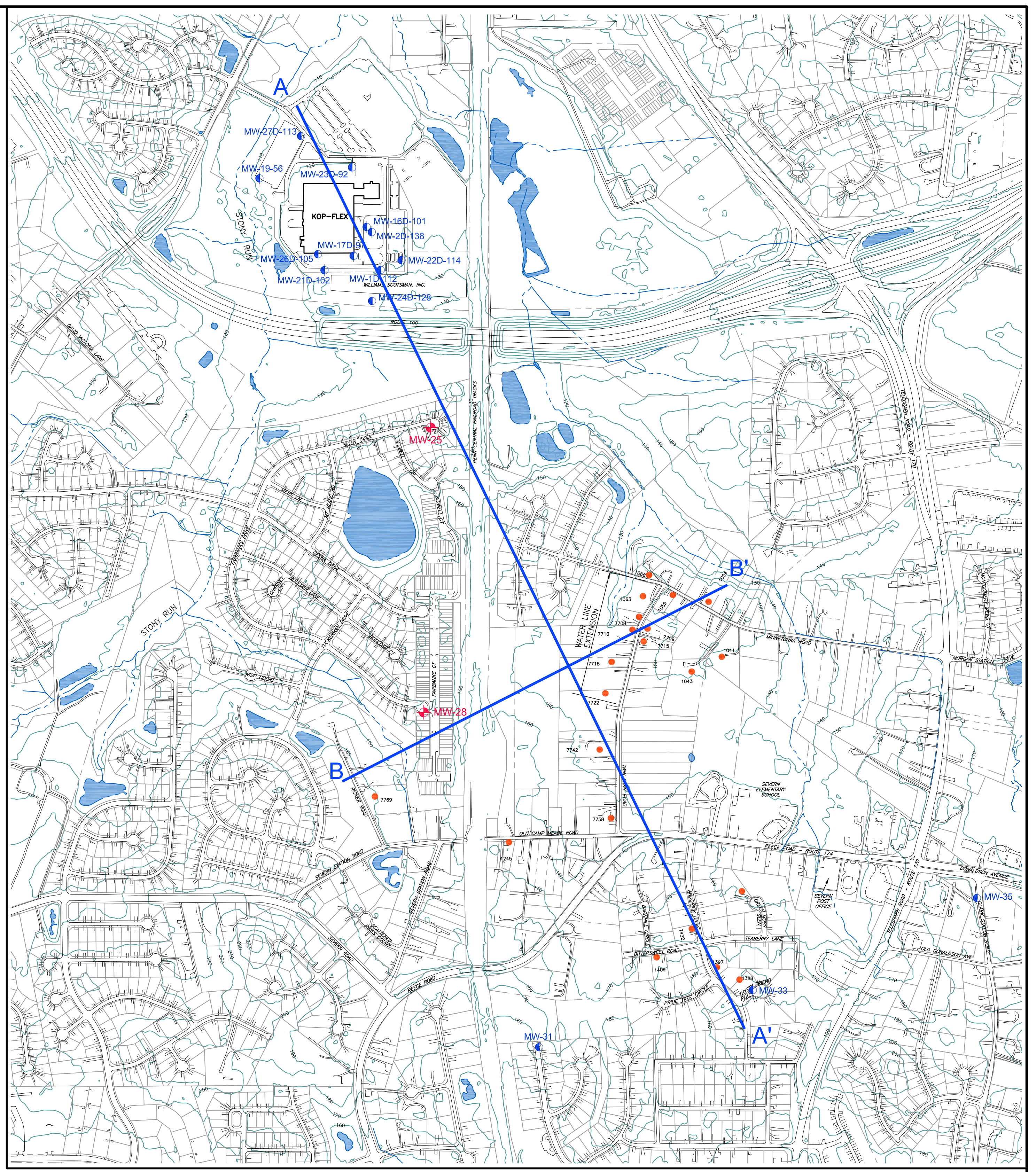


LEGEND

▨ SAND
▨ INTERLAYERED SAND AND CLAY
🟩 CLAY
▨ FILL MATERIAL
BOREHOLE
POTENTIOMETRIC HEAD IN LOWER PATAPSCO AQUIFER
SCREEN
END OF BOREHOLE
POTENTIOMETRIC SURFACE, LOWER PATAPSCO AQUIFER
RW RESIDENTIAL WELL



CROSS SECTION LOCATION MAP
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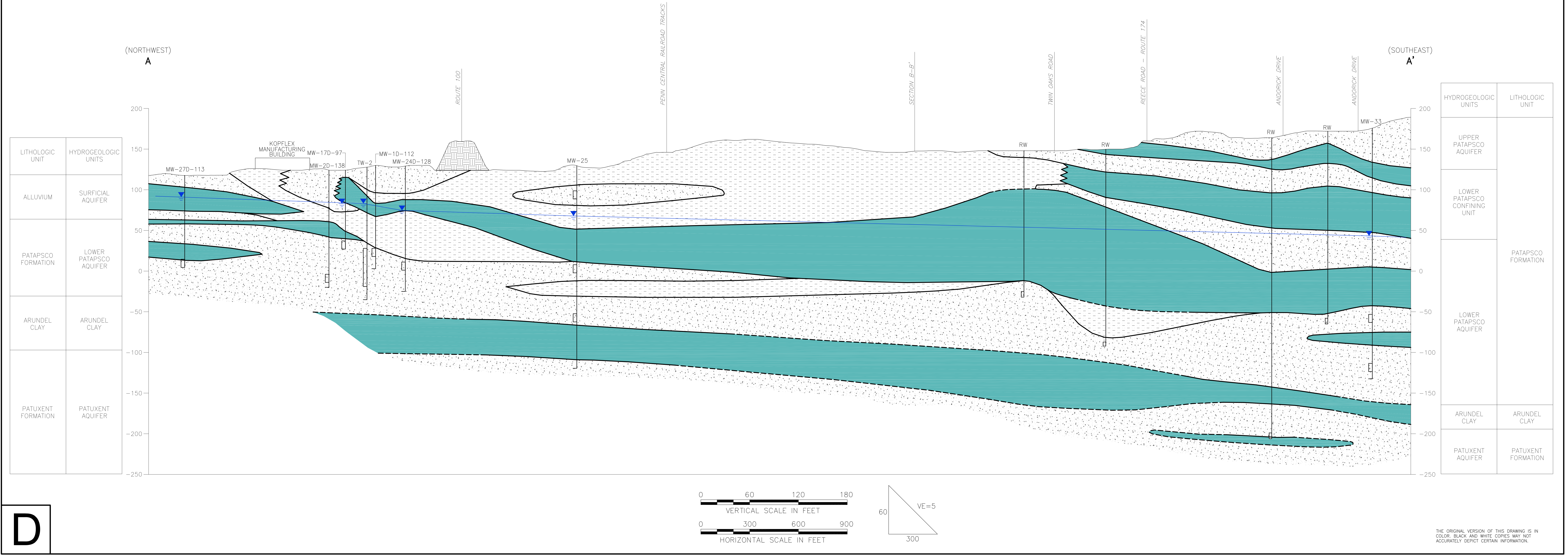

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HYDROGEOLOGIC SECTIONS INCLUDING FORMER KOP–FLEX FACILITY AND SEVERN, MARYLAND AREA

KOP–FLEX VCP SITE
HANOVER, MARYLAND
PREPARED FOR
EMERSON
ST. LOUIS, MISSOURI

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FIGURE 4

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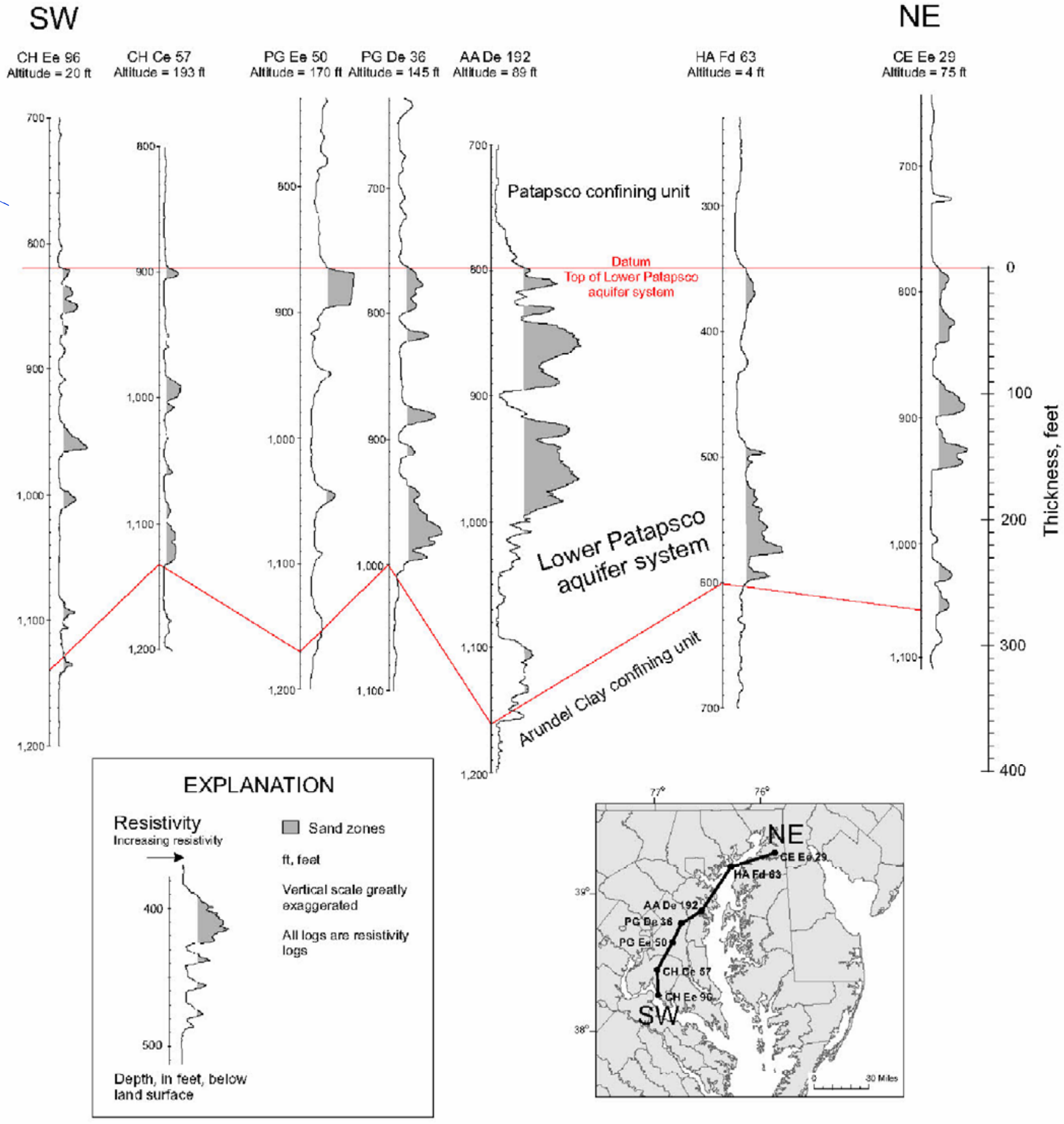

FROM: ANDREASER et al. (2013)

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Figure 5

HYDROSTRATIGRAPHIC FENCE DIAGRAM SHOWING VARIABLILITY IN SAND CONTENT OF LOWER PATAPSCO AQUIFER

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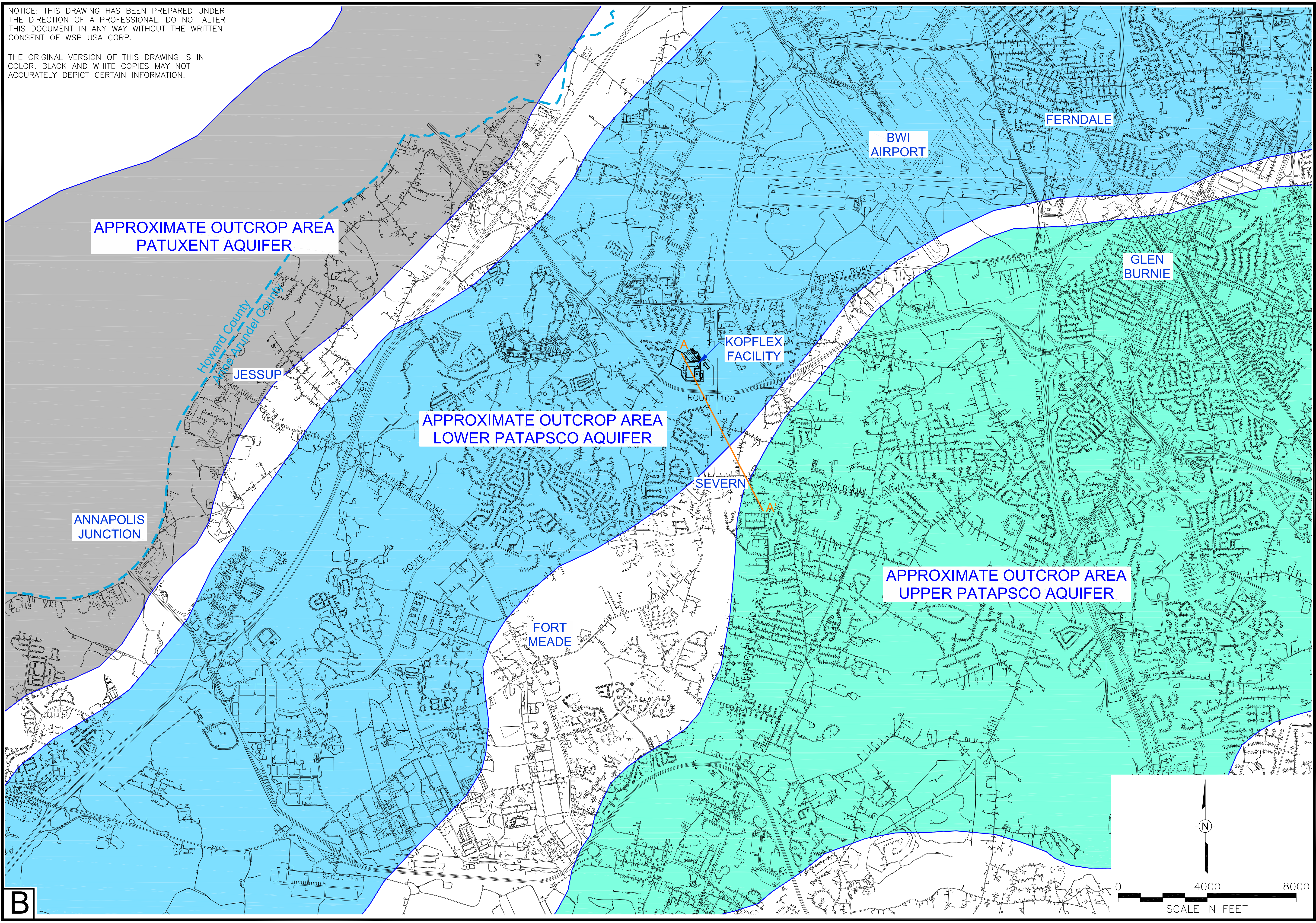

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Figure 6

APPROXIMATE OUTCROPS FOR
COASTAL PLAIN AQUIFERS
IN THE VICINITY OF KOP-FLEX SITE

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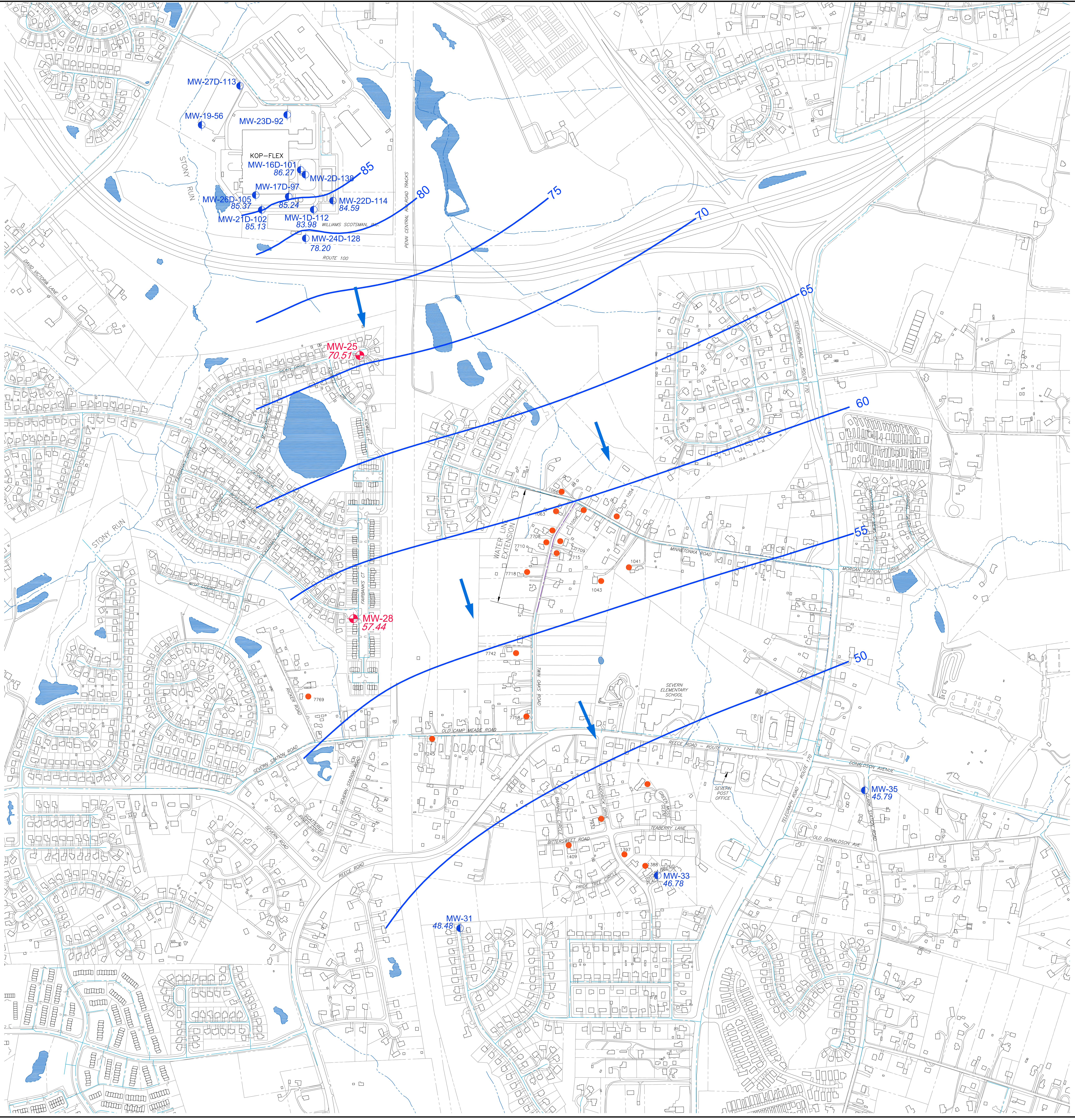

LEGEND

— - - —	PROPERTY LINE
— - —	WATER MAIN
— - — -	WATER MAIN EXTENSION
— - - - —	STREAM
▨	WATER BODY
⊕	SHALLOW AND DEEP MONITORING WELLS
◐	DEEP MONITORING WELL
●	PRIVATE WELL (APPROXIMATE LOCATION)
—	POTENTIOMETRIC SURFACE CONTOUR (FEET MSL)
←	INFERRED GROUNDWATER FLOW DIRECTION

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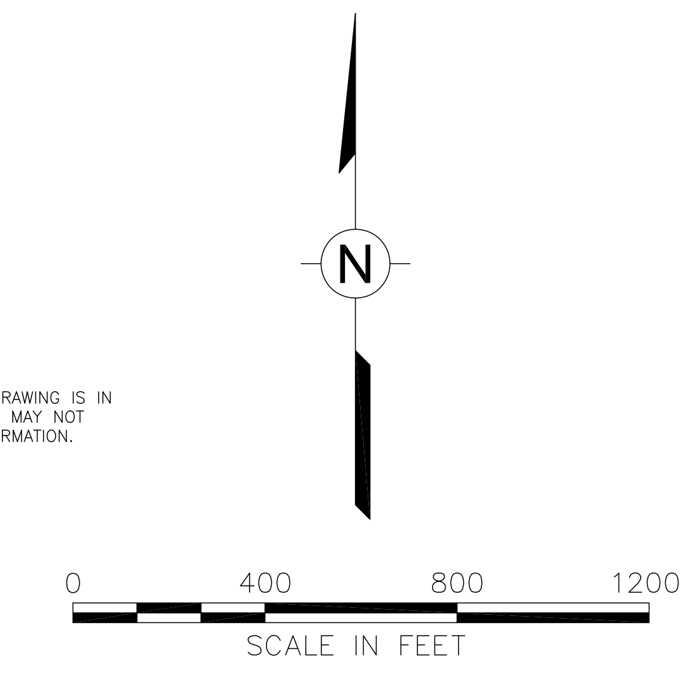

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POTENTIOMETRIC SURFACE CONTOURS FOR THE CONFINED PORTION OF THE LOWER PATAPSCO AQUIFER (MARCH 2015)

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FIGURE 7

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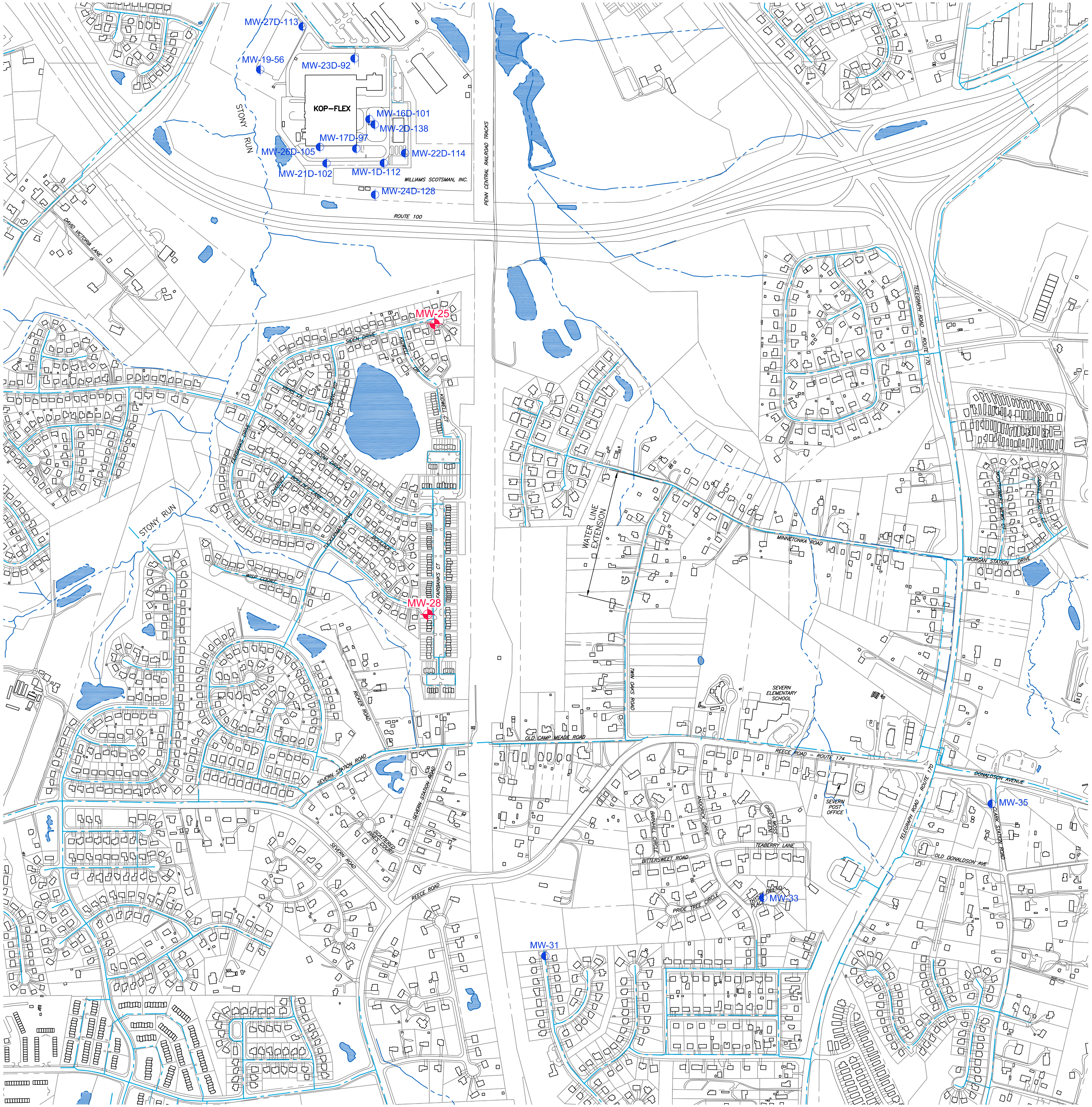

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LEGEND

— — —	PROPERTY LINE
—·—·—	WATER MAIN
———	STREAM
▨	WATER BODY
✚	SHALLOW AND DEEP MONITORING WELLS
◐	DEEP MONITORING WELL

0 800 1600
SCALE IN FEET

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Figure 8

ONSITE AND OFFSITE MONITORING WELL LOCATIONS
LOWER PATAPSCO AQUIFER

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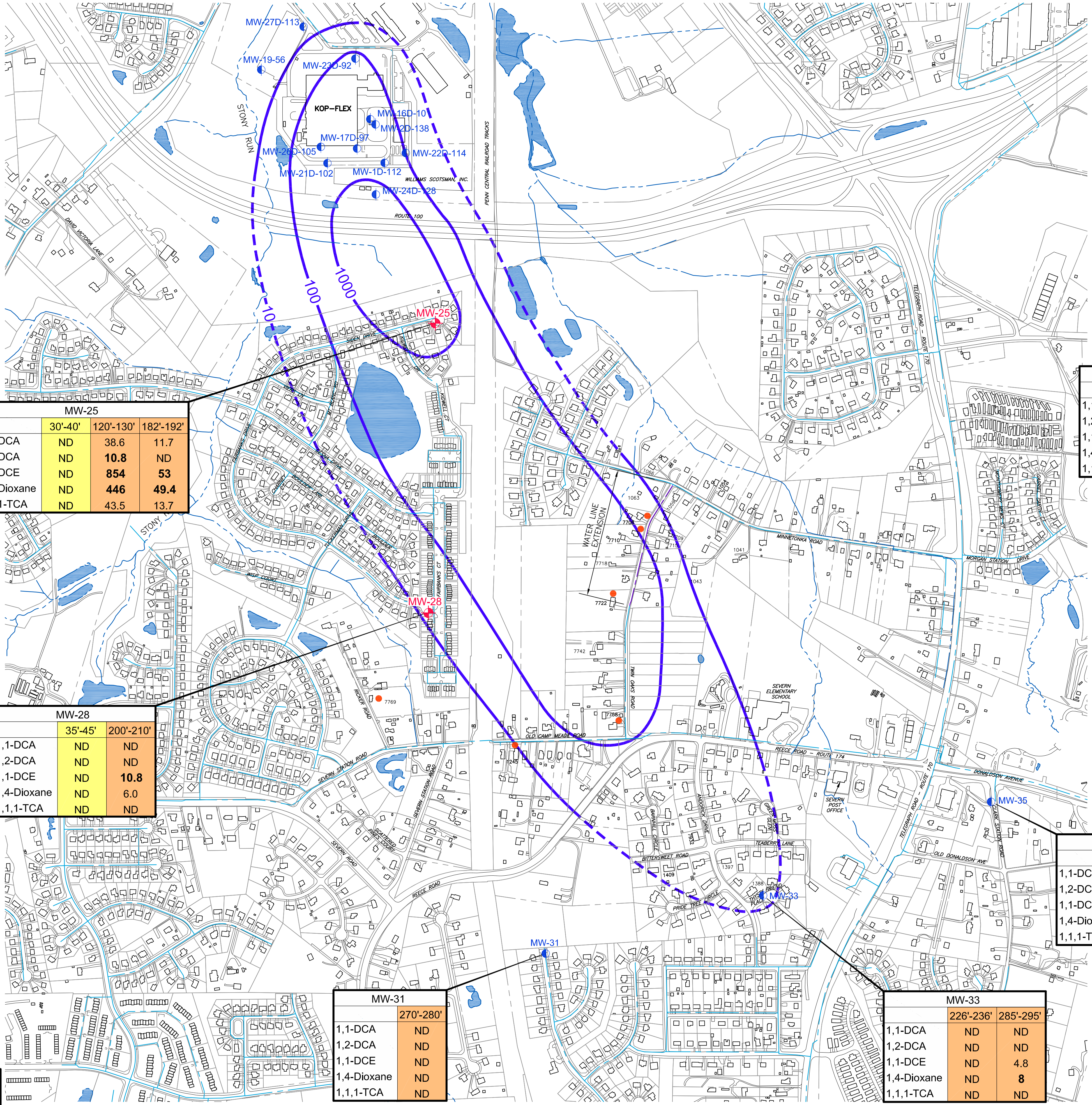

MW-25

	30'-40'	120'-130'	182'-192'
1,1-DCA	ND	38.6	11.7
1,2-DCA	ND	**10.8**	ND
1,1-DCE	ND	**854**	**53**
1,4-Dioxane	ND	**446**	**49.4**
1,1,1-TCA	ND	43.5	13.7

MW-28

	35'-45'	200'-210'
1,1-DCA	ND	ND
1,2-DCA	ND	ND
1,1-DCE	ND	**10.8**
1,4-Dioxane	ND	6.0
1,1,1-TCA	ND	ND

MW-35

	288'-298'
1,1-DCA	ND
1,2-DCA	ND
1,1-DCE	ND
1,4-Dioxane	ND
1,1,1-TCA	ND

MW-31

	270'-280'
1,1-DCA	ND
1,2-DCA	ND
1,1-DCE	ND
1,4-Dioxane	ND
1,1,1-TCA	ND

MW-33

	226'-236'	285'-295'
1,1-DCA	ND	ND
1,2-DCA	ND	ND
1,1-DCE	ND	4.8
1,4-Dioxane	ND	**8**
1,1,1-TCA	ND	ND

B

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LEGEND

- PROPERTY LINE
- WATER MAIN
- WATER MAIN EXTENSION
- STREAM
- WATER BODY
- SHALLOW AND DEEP MONITORING WELLS
- DEEP MONITORING WELL
- PRIVATE WELL (APPROXIMATE LOCATION)
- TOTAL VOC ISO-CONCENTRATION CONTOUR (ppb)

WELL ID
SCREEN INTERVAL (FEET BGS)

MW-28

	35'-45'	200'-210'
1,1-DCA	ND	ND
1,2-DCA	ND	ND
1,1-DCE	ND	**10.8**
1,4-Dioxane	ND	6.0
1,1,1-TCA	ND	ND

CONCENTRATION (ppb)
(BOLD INDICATES ABOVE COMPARATIVE CRITERIA)

CONSTITUENT

DCA	DICHLOROETHANE
DCE	DICHLOROETHENE
TCA	TRICHLOROETHANE
ND	NOT DETECTED

0 800 1600
SCALE IN FEET

N

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Figure 9

MONITORING WELL SAMPLE RESULTS AND TOTAL VOC CONCENTRATIONS IN CONFINED LOWER PATAPSCO AQUIFER (MARCH 2015)

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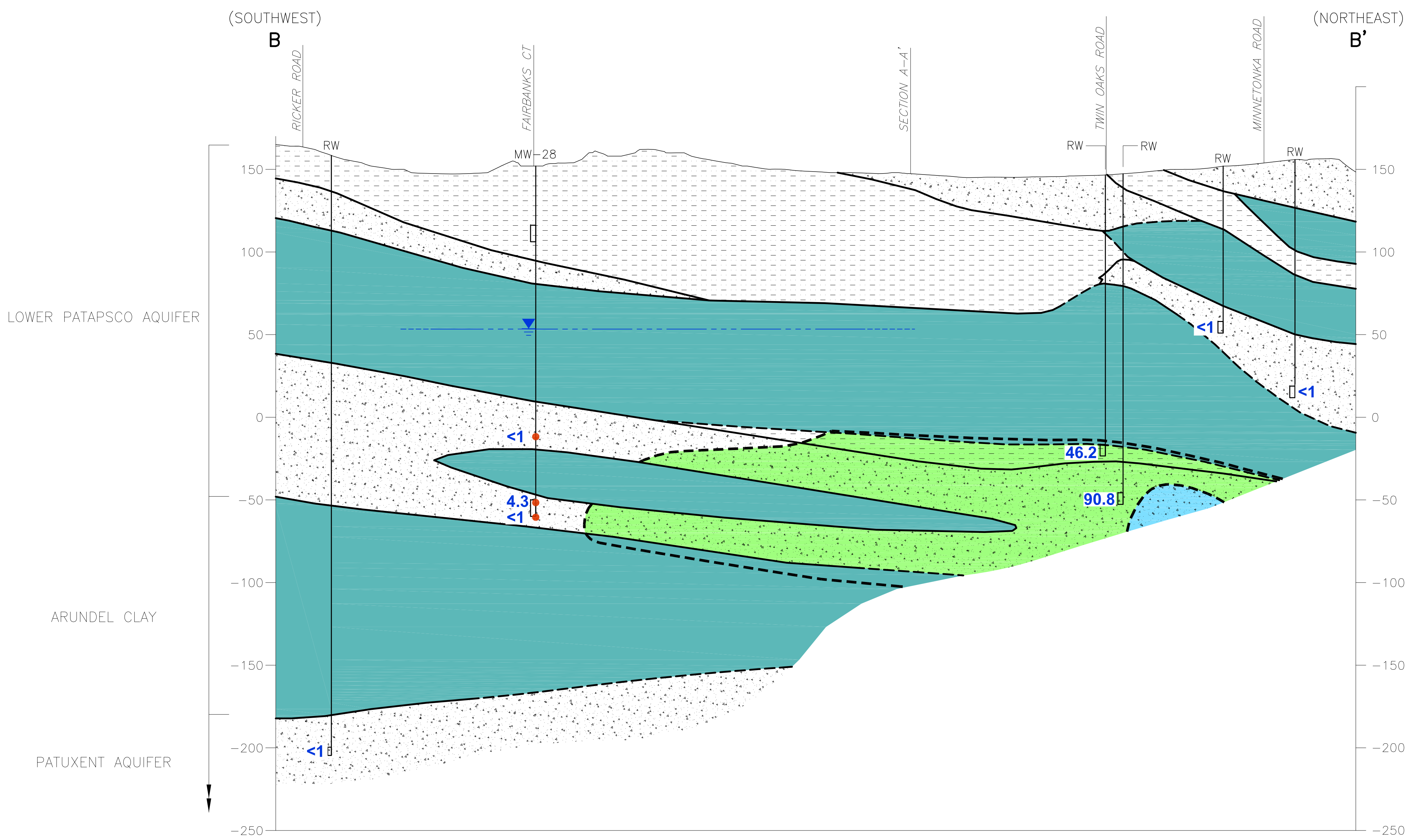
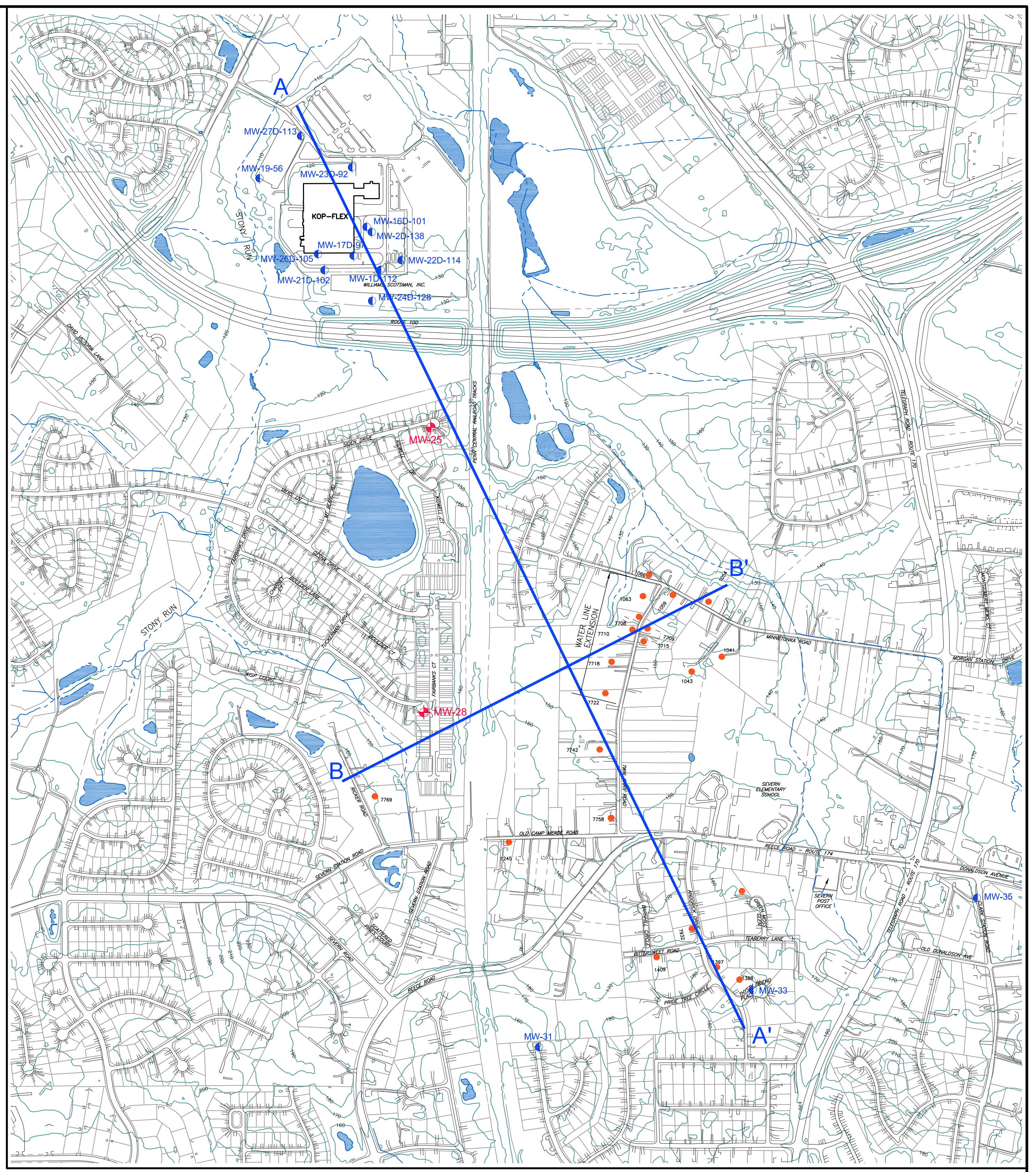
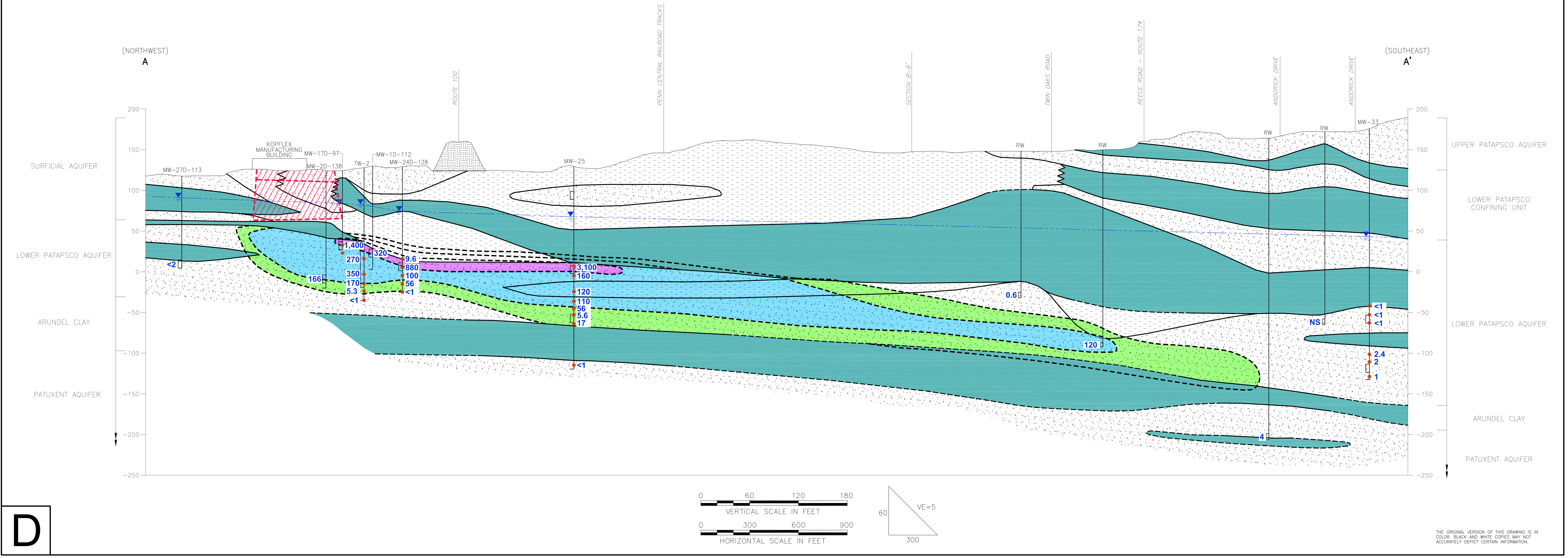


LEGEND

▨	SAND
▤	INTERLAYERED SAND AND CLAY
🟦	CLAY
▦	FILL MATERIAL
	BOREHOLE
▼	POTENTIOMETRIC HEAD IN LOWER PATAPSCO AQUIFER
120	1,1-DICHLOROETHENE CONCENTRATION (ug/l)
●	DISCRETE GROUNDWATER SAMPLE
	SCREEN
	END OF BOREHOLE
— - - —	POTENTIOMETRIC SURFACE, CONFINED PORTION OF LOWER PATAPSCO AQUIFER
NS	NO SAMPLING DATA FOR WELL
RW	RESIDENTIAL WELL
- - - -	1,1-DCE CONCENTRATION CONTOUR
🟩	>7 ug/l
🟦	>100 ug/l
🟪	>1000 ug/l
▨	AREA OF VOC-AFFECTED GROUNDWATER IN SURFICIAL AQUIFER



CROSS SECTION LOCATION MAP
SCALE: 1"=800'



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HYDROGEOLOGIC SECTIONS WITH 1,1-DICHLOROETHENE CONCENTRATIONS IN THE LOWER PATAPSCO AQUIFER

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FIGURE 10

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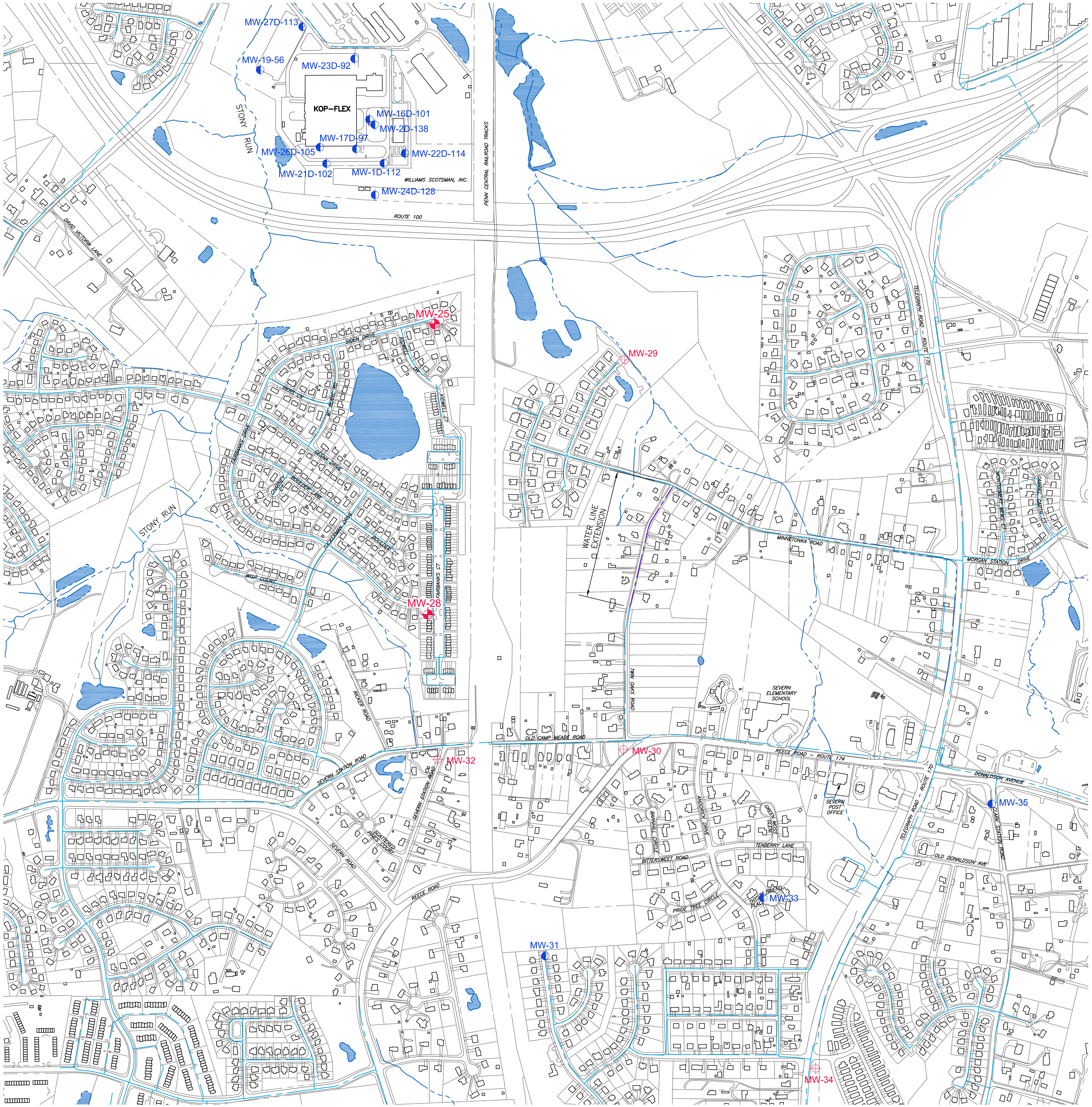

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LEGEND

— — — PROPERTY LINE
— — — WATER MAIN
— · — WATER MAIN EXTENSION
— — — STREAM
▨ WATER BODY
⊕ SHALLOW AND DEEP MONITORING WELLS
◐ DEEP MONITORING WELL
⊕ PROPOSED DEEP MONITORING WELL

0 800 1600
SCALE IN FEET

N

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Figure 11

PROPOSED DEEP OFFSITE MONITORING WELL LOCATIONS CONFINED ZONE OF LOWER PATAPSCO AQUIFER

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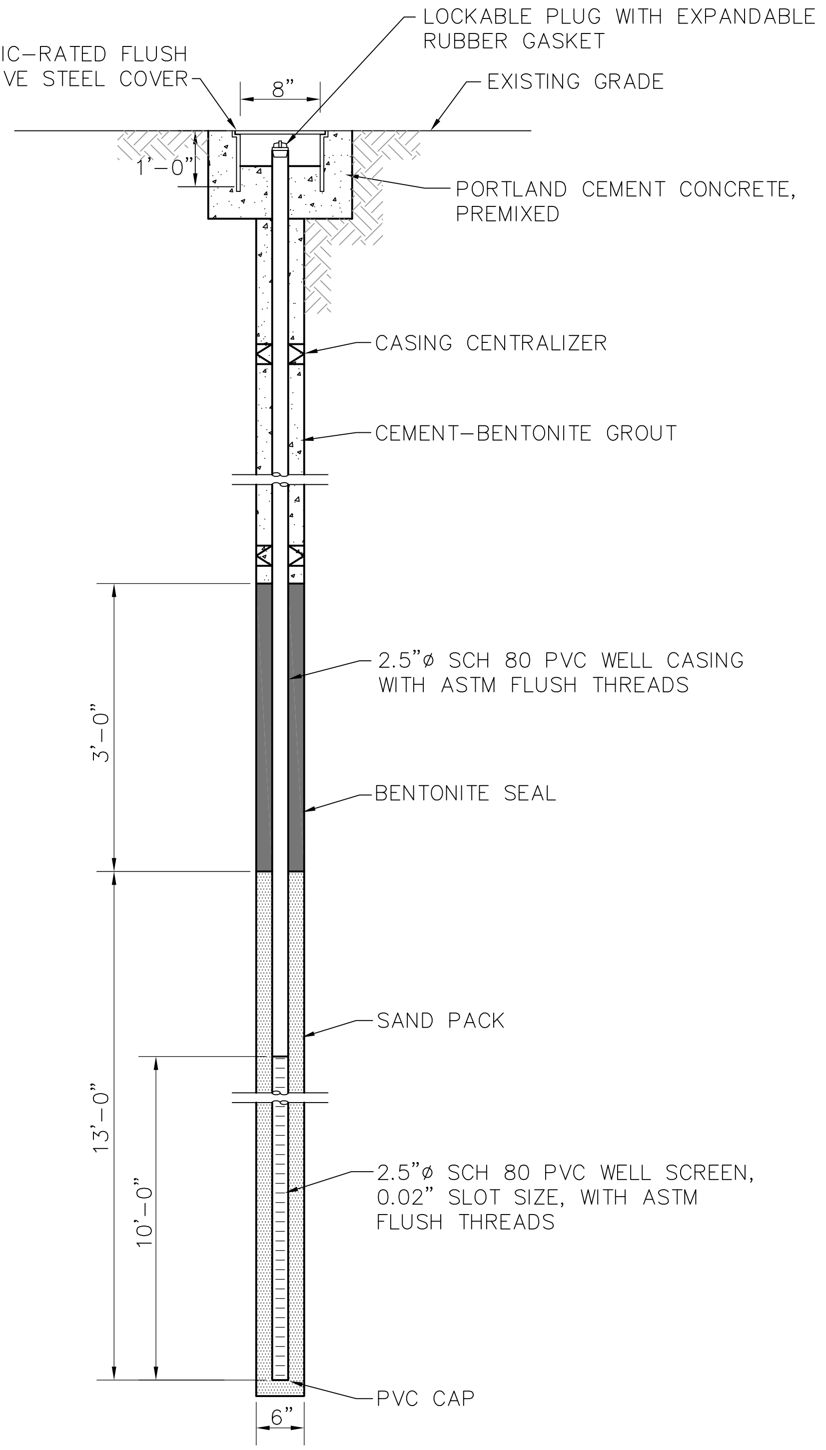

NOTE: PROPOSED WELL WILL BE INSTALLED
USING THE ROTO-SONIC DRILLING METHOD.

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Figure 12

TYPICAL CONSTRUCTION FOR PROPOSED GROUNDWATER MONITORING WELL

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Appendix A – WSP Field Standard Operating Procedures

FIELD STANDARD OPERATING PROCEDURE #3
Sample Packaging and Shipment Procedure

Shipping samples is a basic but important component of field work. Nearly all of the WSP activities include the collection of environmental samples. Proper packing and preservation of those samples is critical to ensuring the integrity of WSP's work product. The user is advised to read the entire standard operating procedure (SOP) and review the site health and safety plan (HASP) before beginning any onsite activities. In accordance with the HASP, proper personal protective equipment (PPE) must be selected and used appropriately.

3.1 Acronyms and Abbreviations

CFR	Code of Federal Regulations
DOT	U.S. Department of Transportation
IATA	International Air Transport Association
HASP	health and safety plan
PPE	personal protective equipment
SOP	standard operating procedure

3.2 Materials

- Suitable shipping container (e.g., plastic cooler or lab-supplied styrofoam-insulated cooler)
- Chain-of-custody forms
- Custody seals
- WSP mailing labels
- Tape (strapping, clear packing, or duct tape)
- Heavy-duty zipper-style plastic bags
- Knife or scissors
- Permanent marker
- PPE
- Large plastic garbage bag
- Wet ice (as necessary)
- Bubble wrap or other packing material
- Universal sorbent materials
- Sample container custody seals (if required)
- Shipping form (with account number)

3.3 Preconditions and Background

This SOP has been prepared as part of the WSP USA Corp. Environmental Quality Management Plan and is designed to provide detailed procedures for common field practices. Compliance with the methods presented in this document is mandatory for all field personnel and will ensure that the tasks are performed in a safe and consistent manner, are in accordance with federal and state guidance, and are technically defensible.

This SOP is written for the sole use of WSP employees and will be revised periodically to reflect updates to WSP policies, work practices, and the applicable state and/or federal guidance. WSP employees must verify that this document is the most recent version of the WSP SOPs. WSP employees are also strongly advised to review relevant state and/or federal guidance, which may stipulate program-specific procedures, in advance of task implementation.

This SOP is designed to provide the user with a general outline for shipping samples and assumes the user is familiar with basic field procedures, such as recording field notes (SOP 1), sample collection and quality assurance procedures (SOP 4), and investigation derived waste management procedures (SOP 5), and has a current certificate for WSP's U.S. Department of Transportation (DOT) Hazardous Materials training.

> **NOTE: WSP employees shipping samples regulated as hazardous materials or exempt hazardous materials by air must have International Air Transport Association (IATA) training. IATA training is a separate training required in addition to DOT hazardous materials training for such shipments. Most WSP employees do not have IATA training and therefore, anyone who needs to ship by air MUST consult with a WSP IATA-trained compliance professional. The remainder of Section 3.3 covers shipments regulated by DOT only.**

Environmental samples can meet the definition of DOT hazardous materials when shipped by air, ground, or rail from a project site to the laboratory. As such, field staff must work with their assigned WSP compliance professional to determine whether the sample shipment is subject to any specific requirements (e.g., packaging, marking, labeling, and documentation) under the DOT hazardous materials regulations.

Title 49 Code of Federal Regulations (CFR) Section 171.8 defines a "hazardous material" as a substance which has been determined by the Secretary of Transportation to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and which has been so designated. DOT hazardous materials are listed in the hazardous materials table at 49 CFR 172.101.

In most cases, WSP is collecting environmental samples in order to determine whether any hazardous chemicals are present in the sampled media. Therefore, we would not have the appropriate information to make a hazardous materials classification for the samples prior to shipment. 49 CFR 172.101(c)(11) allows the use of a tentative classification where the shipper is uncertain of the material's hazard class. Where WSP does not know the physical characteristics of the samples, a non-hazardous material classification may be made. Non-hazardous materials are not subject to the DOT hazardous materials regulations.

There are certain cases where the characteristics and hazard class of the samples are known (e.g., samples of free product, samples preserved with a hazardous material [TerraCore® samplers]). Contact your assigned WSP compliance professional or an internal DOT contact for guidance on shipment of these materials.

3.4 Sample Shipment Procedures

The two major concerns in shipping samples are incidental breakage during shipment and complying with applicable DOT and courier requirements for hazardous materials shipments.

> **NOTE: Many couriers, including Federal Express and UPS, have requirements that WSP register with them before shipping hazard materials. In most cases, it is the sampling location, not the WSP office address, which needs to be registered. Therefore, each project will likely have unique requirements. Please contact your WSP compliance**

professional to determine whether or not you will be required to register for your shipment.

Protecting the samples from incidental breakage can be achieved using "common sense." Pack all samples in a manner that will prevent them from moving freely about in the cooler or shipping container. Do not allow glass surfaces to contact each other. When possible, repack the sample containers in the same materials that they were originally received in from the laboratory. Cushion each sample container with plastic bubble wrap, styrofoam, or other nonreactive cushioning material. A more detailed procedure for packing environmental samples is presented below.

3.4.1 Non-Hazardous Material Environmental Samples

The first step in preparing your samples for shipment is securing an appropriate shipping container. In most cases, the analytical laboratory will supply the appropriate container for bottle shipment, which can be used to return samples once they have been collected. Be sure that the container is large enough to contain the samples plus a sufficient amount of packing materials, and if applicable, enough wet ice to maintain the samples at the preservation temperature (usually 4° Celsius). Use additional shipping containers as needed so that sample containers are protected from breakage due to overcrowding. Do not use lunch-box sized coolers or soft-sided coolers, which do not offer sufficient insulation or protection from damage.

3.4.1.1 Temperature-Preserved Samples Container Preparation

Temperature-preserved samples should be shipped to the laboratory in an insulated container (e.g., cooler). If using a plastic cooler with a drain, securely tape the inside of the drain plug with duct tape or other material to ensure that no water leaks from the cooler during shipment. Place universal sorbent materials (e.g., sorbent pads, Pig-brand absorbent blankets) in the bottom of the shipping container. The amount of sorbent material must be sufficient to absorb any condensation from the wet ice and a reasonable volume of water from melted wet ice (if a bag were to rupture) or a damaged (aqueous) sample container.

The next step is to line the shipping container with a large, heavy-duty plastic garbage bag. Place 2 to 4 inches of bubble wrap or other appropriate packing material inside the heavy-duty plastic bag in the bottom of the shipping container to form a cushion for the sample containers. Place the samples on the packing materials with sufficient space to allow for the addition of more bubble wrap or other packing material between the sample containers. Place large or heavy sample containers on the bottom of the cooler with lighter samples placed on top to minimize the potential for breakage. Place all sample containers in the shipping container right-side up. Do not overfill the cooler with samples; leave sufficient room for the wet ice if the samples are to be preserved during transit. Place wet ice to be used for sample preservation inside two sealed heavy-duty zipper-style plastic bags (1 gallon-sized, or less). Place the bags of ice on top of or between the samples. Place as much ice as possible into the cooler to ensure the samples arrive at the lab at the required preservation temperature, even if the shipment is delayed. Fill any remaining space in the container with bubble wrap or other packing material to limit the airspace and minimize the in-transit melting of ice. Securely close the top of the heavy-duty plastic bag and seal with tape.

3.4.1.2 Non-Temperature-Preserved Samples Container Preparation

Non-temperature-preserved samples should be shipped to the laboratory in a durable package (e.g., hard plastic container or cardboard box). If shipping breakable sample containers (e.g., glass), place bubble wrap or other packing materials on the bottom of the container. Place the samples on the packing materials with sufficient space to allow for the addition of more bubble wrap or other packing material between and on top of the sample containers. Place large or heavy sample containers on the bottom of the container with lighter samples placed on top to minimize the potential for breakage. Place all sample containers within the shipping container right-side up.

3.4.1.3 Container Shipment

Place the original, white top copy chain-of-custody form into a heavy-duty zipper-style plastic bag, affix the bag to the shipping container's inside lid, and then close the shipping container. Only one chain-of-custody form is required to accompany one of the shipping containers per sample shipment; the other coolers in the shipment do not need to include chain-of-custody forms. At this point, sample shipment preparations are complete if using a laboratory courier.

If sending the sample shipment through a commercial shipping vendor, place two signed and dated chain-of-custody seals on alternate sides of the shipping container lid so that it cannot be opened without breaking the seals. Securely fasten the top of the shipping container shut with clear packing tape; carefully tape over the custody seals to prevent damage during shipping. Once the shipping container is sealed, shake test the shipping container to make sure that there are no loose sample containers. If loose sample containers are detected, open the shipping container, repack the sample containers, and reseal the shipping container.

Using clear tape, affix a mailing label with WSP's return address to the top of the shipping container. Ship environmental samples to the contracted analytical laboratory using an appropriate delivery schedule. If applicable, check the appropriate box on the airbill for Saturday delivery (you need to verify with the laboratory that someone will be at the lab on a Saturday to receive the sample shipment). Declare the value of samples on the shipping form for insurance purposes, if applicable, and be sure to include the project billable number on the shipping form's internal billing reference section. When shipping samples to a lab, identify a declared value equal to the carrier's default value ($100); additional fees will be charged based on a higher value declared. Our preferred carrier, FedEx, will only reimburse for the actual value of the cooler and its contents if a sample shipment is lost; they will not reimburse for the cost of having to re-collect the samples. [Please note: if you are shipping something other than samples, such as field equipment, declare the replacement value of the contents.]

Record the tracking numbers from the shipping company forms (i.e., the airbill number) in the field book and on the chain-of-custody form and retain a copy of the shipping airbill. On the expected delivery date, confirm sample receipt by contacting the laboratory or tracking the package using the tracking number; provide this confirmation information to the WSP project manager.

> **NOTE: Most shipping carriers adhere to transit schedules with final pickup times each day; these schedules are subject to change and vary by service location. If shipping containers are dropped off at a service location after the final pickup time, transit to the laboratory will not be initiated until the following day, and samples may not be properly preserved. Therefore, confirm transit schedules in advance of each sampling event, and ensure samples are dropped off before the final pickup time of the day.**

3.4.2 Hazardous Materials Samples

WSP personnel rarely ship hazardous materials due to DOT shipping requirements. If you find that your samples could be considered a DOT hazardous material, first coordinate with the assigned WSP compliance professional and project manager to make a hazardous material classification and, if necessary, establish the necessary protocols and to receive the appropriate training/certification. **Do not ship hazardous materials samples without first consulting a WSP compliance professional.**

FIELD STANDARD OPERATING PROCEDURE #4
Sample Collection and Quality Assurance Procedure

The purpose of this procedure is to assure that sample volumes and preservatives are sufficient for analytical services required under U.S. Environmental Protection Agency (EPA) or other agency approved protocols. This operating procedure describes the ways and means of selecting the appropriate sampling containers for environmental sampling. The user is advised to read the entire standard operating procedure (SOP) and review the site health and safety plan (HASP) before beginning any onsite activities. In accordance with the HASP, proper personal protective equipment (PPE) must be selected and used appropriately.

4.1 Acronyms and Abbreviations

ºC	degrees Celsius
COC	chain-of–custody [form]
DI	deionized water
DOT	U.S. Department of Transportation
EDD	electronic data deliverable
EPA	U.S. Environmental Protection Agency
HASP	health and safety plan
MS/MSD	matrix spike and matrix spike duplicate
MSA	Master Service Agreement
PPE	personal protective equipment
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
SOP	standard operating procedure
VOCs	volatile organic compounds

4.2 Materials

- Field book
- Indelible (waterproof) markers or pens
- PPE
- Sample containers
- Sample labels
- Clear tape
- Deionized (DI) water
- Cleaned or dedicated sampling equipment

4.3 Preconditions and Background

This SOP has been prepared as part of the WSP USA Corp. Environmental Quality Management Plan and is designed to provide detailed procedures for common field practices. Compliance with the methods presented in this document is mandatory for all field personnel and will ensure that the tasks are performed in safe and consistent manner, are in accordance with federal and state guidance, and are technically defensible.

This SOP is written for the sole use of WSP employees and will be revised periodically to reflect updates to WSP policies, work practices, and the applicable state and/or federal guidance. WSP employees must verify that this document is the most recent version of the WSP SOPs. WSP employees are also strongly advised to review relevant state and/or federal guidance, which may stipulate program-specific procedures, in advance of task implementation.

This SOP is designed to provide the user with a general outline for collecting environmental and quality assurance samples and assumes the user is familiar with basic field procedures, such as recording field notes (SOP 1), sample shipment procedures (SOP 3), investigation derived waste management procedures (SOP 5), and equipment decontamination (SOP 6). This SOP does not cover investigation planning, nor does it cover the analysis of the analytical results. These topics are more appropriately addressed in a site-specific work plan or a dedicated quality assurance project plan.

4.4 Sample Identification Procedures

Information on the sample labels must contain the site/project name, project/task number, unique alpha-numeric sample identification (ID) number, sample date, time of collection using the military or 24-hour clock system (e.g., 0000 to 2400 hours), analytical parameters, preservative, and sampling personnel. WSP personnel are advised to use pre-printed waterproof mailing labels (e.g., Avery® 5xxx Waterproof Address Labels) for all sample identification. WSP templates for the labels are available in each office.

The sample identification number must, unless otherwise approved by your project manager or specified in your site-specific work plan, follow the WSP naming protocol. This protocol was developed to aid in determining the type of sample collected (e.g., soil, groundwater, vapor, etc.), the sample location, and, where appropriate, the sample depth. The protocol was also designed to ensure consistency across the company.

Construct sample IDs in the following format:

SB-10A (4-6)

Where, in this example:

SB = the first two or three characters will define the sample type (see list of approved prefixes below); in this case, a soil boring

10A = the next two or three alpha-numeric digits (separated by a dash from the sample type identifier) indicate the location of the boring on the site; in this case, boring number 10A

(4-6) = the depth the sample was collected, with the first number (including decimals, if necessary) indicating the top of the sample interval and the second number indicating the bottom of the sample interval; not all sample types will include depth information.

Additional label information may be added after the last character of the sample ID (e.g., sample date, underground storage tank number, area of concern number, “Area” number, Client Identifier, etc.). Separate any additional information from the required portion of the sample name by dash(es).

Sample Prefix	Permitted Use
AA -	Ambient outdoor air samples
CC -	Concrete core/chip sample
CS -	Confirmation/verification soil samples collected from an excavation
HA -	Soil samples collected with a hand auger
IAB -	Indoor air samples – basement
IAC -	Indoor air samples – crawl space
IAF -	Indoor air samples – first floor
MW -	Soil samples collected from a monitoring well borehole or a groundwater sample collected from a monitoring well
PZ -	Groundwater samples collected from a piezometer
SB -	Soil samples collected from boreholes that will not be converted to monitoring wells
SED -	Sediment samples
SG -	Soil gas samples other than sub-slab samples (e.g., samples collected from temporary or permanent PVC sample points or stainless steel screen implants)
SL -	Sludge samples
SS -	Surface soil samples collected using hand tools (e.g., trowel, spoon, etc.) and typically at depths less than 2 feet below ground surface
SSV -	Sub-slab vapor samples
SW -	Surface water samples
TC -	Tree core samples
TP -	Soil samples collected from a test pit
WC -	Waste characterization samples
WP -	Wipe samples

4.5 Sample Containers, Preservatives, and Holding Times

The first step in sample collection is to verify that the analytical laboratory has provided the correct number and type of sample containers and each contains the appropriate preservatives for the proposed project (i.e., check against the sampling plan requirements outlined in the site-specific Quality Assurance Project Plan [QAPP]). Inspect all containers and lids for flaws (cracks, chips, etc.) before use. Do not use any container with visible defects or discoloration. Report any discrepancies, or non-receipt, of specific types of sample containers to the team leader or project manager immediately. Make arrangements with the laboratory to immediately ship missing or additional sampling containers.

Take special effort to prevent cross contamination and contamination of the environment when collecting samples. Protect equipment, sample containers and supplies from accidental contamination. Wear a clean pair of new, disposable gloves each time a different sample is collected and don the gloves immediately prior to sampling. The gloves must not come in contact with the medium being sampled and must be changed any time during sample collection when their cleanliness is compromised. Sample collection must follow all appropriate SOPs and state and federal regulations, or guidance, for the collection of environmental samples; the recommended order of sample collection is:

- Geochemical measurements (e.g., temperature, pH, specific conductance)

- Volatile organic compounds (VOCs)
- Extractable organics, petroleum hydrocarbons, aggregate organics, and oil and grease
- Total metals
- Dissolved metals
- Inorganic non-metallic and physical and aggregate properties
- Microbiological samples
- Radionuclides

Collected samples that require thermal preservation must be immediately (within 15 minutes) placed in a cooler with wet ice and maintained at a preservation temperature of 4° Celsius (C).

4.6 Field Quality Assurance/Quality Control Samples

Field quality assurance/quality control (QA/QC) samples include equipment blanks, trip blanks, duplicates, and split samples. The project manager or QAPP must specify the type and frequency of QA/QC sample collection. The QA/QC sample identification number must, unless otherwise approved by your project manager or specified in your site-specific work plan, follow the WSP naming protocol as discussed in the sections below. QA/QC samples must be clearly identified on WSP's copy of the COC form and in the field book. Failure to properly collect and submit required QA/QC samples can result in invalidation of an entire sampling event.

Collect, preserve, transport and document split samples using the same protocols as the related samples.

4.6.1 Equipment Blanks

Equipment blanks are used to document contamination attributable to using non-dedicated equipment. Collect equipment blanks in the field at a rate of one per type of equipment per day, unless otherwise specified. If the site-specific work plan or QAPP indicates that an equipment blank is to be collected from dedicated sampling equipment, collect the equipment blank in the field before sampling begins. If field decontamination of sampling equipment is required, prepare the equipment blanks after the equipment has been used and field-decontaminated at least once. Prepare equipment blanks by filling or rinsing the pre-cleaned equipment with laboratory provided analyte-free water and collecting the rinsate in the appropriate sample containers. The samples must be labeled, preserved, and filtered (if required) in the same manner as the environmental samples. Record the type of sampling equipment used to prepare the blank. Have the equipment blanks analyzed for all the analytes for which the environmental samples are being analyzed, unless otherwise specified. Decontamination of the equipment following equipment blank procurement is not required. If laboratory-grade DI water is unavailable, store-grade distilled water can be used to prepare these blanks. If store-grade distilled water is used, be sure to record the source and lot number in the field book. Designate equipment blanks using "EB", followed by the date, and in the order of equipment blanks collected that day. For example, the first equipment blank collected on July 4, 2013, would be designated EB070413-1.

4.6.2 Trip Blanks

Trip blanks are used to document VOC contamination attributable to shipping and field handling procedures. Trip blanks are only required when analyzing samples for VOCs. Trip blank(s) will be prepared at the laboratory and will be sent to the facility along with sample containers. Never open trip blank sample bottles, but label them in the field and return them to the laboratory in the same shipping container in which the trip blank sample bottles arrived at the site. Keep the trip blank sample bottles in the same shipping container used to ship and store VOC sample bottles during the sampling event. To minimize the number of trip blanks needed per shipment, if possible, ship all of the VOC samples in the same shipping container with the trip blank. If laboratory-provided trip blanks are not available, DI water, or store-grade distilled water and clean, empty VOC sample bottles can be used to prepare additional trip blanks. If store-grade distilled water is used, be sure to record the source and lot number in the field book. Identify trip blanks using “TB”, followed by the date. For example, the trip blank shipped with a cooler of samples on July 4, 2013, would be designated TB070413-1. If a second trip blank is needed on that same day, the designation would be TB070413-2.

4.6.3 Temperature Blank

Temperature blanks are used to determine if proper sample thermal preservation has been maintained by measuring the temperature of the sample container upon arrival at the laboratory. A temperature blank should be included in each sample cooler used to ship and store the sample bottles during the sampling event. If laboratory-provided temperature blanks are not available, fill a clean, unpreserved sample bottle with potable, DI, or store-grade distilled water and identify the bottle as a temperature blank.

4.6.4 Duplicates

Duplicates are useful for measuring the variability and documenting the precision of the sampling process. Unless more stringent project requirements are in place, collect duplicate samples at least at a rate of 1 per 20 samples collected. Under no circumstances can equipment or trip blanks be used as duplicates. Sample locations where sufficient sample volume is available and where expected contamination is present should be selected for sample duplication.

Collect each duplicate sample at the same time, from the same sample aliquot and in the same order as the corresponding field environmental sample. When collecting aqueous duplicate samples, alternately fill sample bottle sets (i.e., the actual sample bottle and the bottle to be used for the duplicate) with aqueous samples from the same sampling device. If the sampling device does not hold enough volume to fill the sample containers, fill the first container with equal portions of the sample, and pour the remaining sample into the next sample containers. Obtain additional sample volume and pour the first portion into the last sample container, and pour the remaining portions into the first containers. Continue with these steps until all containers have been filled.

Duplicate samples will be assigned arbitrary sample ID and a false collection time so that they are not identified as duplicates by the laboratory (i.e., submit the samples blind to the lab). The blind duplicate sample "location designation" will be left up to the project manager; however, in no case will "Dup" be allowed to appear in the sample name. Have the duplicate samples analyzed for the same analytes as the original sample. Be sure to record the duplicate sample ID, the false time, and the actual time of collection in the field notebook. The duplicate should also be indicated on WSP’s carbon copy of the chain-of-custody.

4.6.5 Matrix Spike and Matrix Spike Duplicates

Matrix spike and matrix spike duplicate samples, known as MS/MSD samples, are used to determine the bias (accuracy) and precision of a method for a specific sample matrix. Many of WSPs projects require the collection of MS/MSD samples; however, laboratory generated MS/MSD samples are sufficient for some projects. As required by your QAPP or site-specific work plan, collect MS/MSD samples at the required ratio; if the sampling ratio is not specified by your QAPP or site-specific work plan, collect MS/MSD samples at a rate of 1 for every 20 samples. Clearly convey the MS/MSD identity to the laboratory by adding “MS" or "MSD” after the sample name (e.g., MW-01MS) or in the comments section of the chain-of-custody. Under no circumstances can equipment or trip blanks be used as MS/MSD samples.

4.6.6 Split Samples

Split samples may be collected as a means of determining compliance or as an added measure of quality control. Unlike duplicate samples that measure the variability of both the sample collection and laboratory procedures, split samples measure only the variability between laboratories. Therefore, the laboratory samples must be subsamples of the same parent sample and every attempt must be made to ensure sample homogeneity. Collect aqueous split samples in the same manner as a duplicate sample.

Collecting split samples of soils, sediments, wastes, and sludge is not recommended because the homogenization necessary for a true split sample in these matrices is not possible.

Spilt samples should have the same sample location (e.g., MW-01, SB-03 (4-6), but differentiated from each other by inserting the laboratory analyzing or the agency/consultant collecting the sample after the sample location (e.g., MW-01-WSP and MW-01-EPA).

4.7 Custody Documentation

Sample custody protocols are used to demonstrate that the samples and sample containers were handled and transferred in such a manner as to eliminate possible tampering. Legal chain of custody (COC) begins when the pre-cleaned sample containers are dispatched to the field from the laboratory and continues through the sample analysis and eventual disposal. Maintaining custody requires that samples must be in the actual possession or view of a person who is authorized to handle the samples (e.g., sample collector, laboratory technician), secured by the same person to prevent tampering, or stored in a designated secure area.

It is a good idea to limit, to the extent possible, the number of individuals who physically handle the samples. Samples must be placed in locked storage (e.g., locked vehicle, locked storeroom, etc.) at all times when not in the possession or view of authorized personnel. Do not leave samples in unoccupied motel or hotel rooms or other areas where access cannot be controlled by the person(s) responsible for custody without first securing samples and shipping or storage containers with tamper-indicating evidence tape or custody seals

The COC form is used to trace sample possession from the time of collection to receipt at the laboratory. Although laboratories commonly supply their own COC form, it is recommended that WSP's COC be used to ensure that all necessary data are recorded. At a minimum, the COC needs to have a unique COC number, accompany all the samples, and include the following information:

- Project number, name, and location
- Sampler's printed name(s) and signature(s)
- Sample identification number
- Date and time (military time) of collection
- Sample matrix
- Total number of containers per sample
- Parameters requested for analysis including number of containers per analyte
- Remarks (e.g., irreducible headspace, field filtered sample, expected concentration range, specific turn-around time requested, etc.)
- Signatures of all persons involved in the chain of possession in chronological order
- Requested turn-around-time
- Name and location of analytical laboratory
- Custody seal numbers
- Shipping courier name and tracking information
- Internal temperature of shipping container upon shipment to laboratory, as needed
- Internal temperature of shipping container upon delivery to laboratory

- WSP contact information

Affix tamper-indicating evidence tape or seals to all storage and shipping container closures when transferring or shipping sample container kits or samples to an off-property party. Place the seal so that the closure cannot be opened without breaking the seal. Record the time, calendar date and signatures of responsible personnel affixing and breaking all seals for each sample container and shipping container. Affix new seals every time a seal is broken until continuation of evidentiary custody is no longer required.

FIELD STANDARD OPERATING PROCEDURE #7
Water Quality Monitoring Equipment Procedure

The procedures outlined in this Standard Operating Procedure (SOP) are designed to ensure that water quality monitoring equipment is calibrated and used properly. This SOP addresses the short-term or discrete-measurement use of portable water quality monitoring equipment for the collection of physical, chemical, or biological field measurements. Common field parameters include temperature, pH, specific conductance (SC), turbidity, oxidation-reduction potential (ORP), and dissolved oxygen (DO). The user is advised to read the entire SOP and review the site health and safety plan (HASP) before beginning any onsite activities. In accordance with the HASP, proper personal protective equipment (PPE) must be selected and used appropriately.

7.1 Acronyms and Abbreviations

DI	deionized water
DO	dissolved oxygen
^{o}F	degrees Fahrenheit
HASP	health and safety plan
IDW	investigation derived waste
mg/l	milligrams per liter
mV	millivolts
NTU	nephelometric turbidity units
ORP	oxidation-reduction potential
PPE	personal protective equipment
QAPP	quality assurance project plan
SC	specific conductance
SDS	Safety Data Sheets
SOP	standard operating procedure
SU	standard units
µS/cm	microsiemens per centimeter

7.2 Materials

- Field book
- PPE
- Water quality meter
- Display/logger
- Communication cables
- Calibration cup or beaker
- Standard solutions, as appropriate

- Deionized water (DI) or distilled water
- Decontamination supplies

7.3 Preconditions and Background

This SOP has been prepared as part of the WSP USA Corp. Environmental Quality Management Plan and is designed to provide detailed procedures for common field practices. Compliance with the methods presented in this document is mandatory for all field personnel and will ensure that the tasks are performed in a safe and consistent manner, are in accordance with federal and state guidance, and are technically defensible.

This SOP is written for the sole use of WSP employees and will be revised periodically to reflect updates to WSP policies, work practices, and the applicable state and/or federal guidance. WSP employees must verify that this document is the most recent version of the WSP SOPs. WSP employees are also strongly advised to review relevant state and/or federal guidance, which may stipulate program-specific procedures, in advance of task implementation.

This SOP is designed to provide the user with a general outline for preparing water quality monitoring equipment for use and assumes the user is familiar with basic field procedures, such as recording field notes (SOP 1), investigation derived waste (IDW) management procedures (SOP 5), equipment decontamination (SOP 6), groundwater sampling (SOP 11), and surface water sampling (SOP 12). This SOP does not cover the selection of water quality monitoring equipment, nor does it cover water quality monitoring equipment-specific instructions. These topics require a significant amount of planning and are more appropriately addressed in a project-specific work plan. Be sure to review the project-specific work plan or Quality Assurance Project Plan (QAPP) and any applicable state and federal guidelines or calibration procedures. The sampler should be familiar with the use and calibration of all sampling and monitoring equipment. All sampling references must be available for consultation in the field, including:

- WSP’s SOPs
- Applicable state and federal guidelines or sampling procedures
- Manufacturer’s manuals
- Project-specific work plan, HASP, and QAPP

7.4 General Equipment Handling and Management Procedures

Generally, WSP uses multi-parameter water quality meters bundled in a single housing unit (a sonde). These types of units offer a single, convenient device that is capable of measuring most or all of the parameters monitored during a typical sampling event. Individual parameter water quality meters are available and, in some cases, offer a higher degree of accuracy, although the difficulty in deploying multiple meters for most tasks relegates them to specialty use.

Field personnel must consult their assigned WSP compliance professionals for assistance in proper use, storage, and disposal of all calibration standard solutions.

The manufacturer’s recommendations and instructions vary from one instrument to the next; however, all types of water quality monitoring equipment share common handling and management procedures designed to ensure the integrity of the measurements collected. Based on these procedures, the user should:

- Transport the water quality monitoring equipment in a padded case that is designed to protect the equipment; airtight cases need to be vented if using sensors that have flexible or semi-permeable membranes.
- Follow the manufacturer’s instructions for assembly, operation, calibration, and maintenance specific to your equipment. The manufacturer’s instructions should be followed explicitly in order to obtain accurate results.

- Follow the manufacturer's instructions for assembly, operation, calibration, and maintenance specific to your equipment. The manufacturer's instructions should be followed explicitly in order to obtain accurate results.
- Keep either the sensor guard or transportation/calibration cup installed to avoid damaging the sensors. Some sensors require a small amount of water in the transportation/calibration cup; follow the manufacturer's recommendations.
- Ensure that all equipment is in proper working condition, not damaged, and that batteries are properly charged before using the equipment for field testing measurements.
- Instruments may be sensitive to static electricity.
- Record manufacturer name and model number for each instrument used in the field book.
- Calibrate the instrument in the field, as close to the time of use as possible, and repeat at the frequency suggested by the manufacturer.
- Protect the instrument from direct sunlight, precipitation, and extremely hot or cold temperatures (e.g., do not store in vehicle).
- Store cables only after they are clean, dry, and neatly coiled – do not bend or crimp cables.
- Attach any provided storage caps. Protect cables from abrasion or unnecessary tension when in use.
- Unless otherwise instructed by the manufacturer, decontaminate water quality monitoring equipment with non-phosphate detergent solution using a small, nonabrasive brush, cotton swab or cloth, followed by a thorough DI water rinse.

7.5 Calibration Procedures

Water quality monitoring equipment must be inspected and the sensors calibrated before use. Consult the manufacturer's guidelines before beginning the calibration process and contact the manufacturer's technical support if problems or questions arise.

Conduct the following procedures to ensure proper testing and calibration and record observations in the field book:

- Inspect the sensors to be sure that they are clean, installed properly and are not damaged before calibrating and using a water quality monitoring equipment in the field.
- Complete field calibration in an area sheltered from wind, dust, and temperature/sunlight fluctuations such as inside a room or vehicle in which the ambient temperature of the standards is maintained at a temperature >40 degrees Fahrenheit (^{o}F) and < 100°F.
- Purchase appropriate, prepared standard solutions in accordance with the project-specific work plan or QAPP. Do not mix or dilute standards in the field. Allow water quality monitoring equipment to warm up for at least 10 minutes after being turned on, or for the specified time period recommended by the manufacturer.
- Record the brand, concentration, lot numbers and expiration dates of standard solutions in the field book.
- Handle standard solutions in a manner that prevents their dilution or contamination. Do not use expired standard solutions. Do not reuse standard solutions or pour solutions back into the bottle; ensure that proper chain-of-custody has been followed for standard solutions stored at a site.
- Ensure that the water quality monitoring equipment has been set to display or record the appropriate measurement unit, as available.
- Allow standard solutions to equilibrate to the temperature of the sample source, to the degree possible or as specified in the manufacturer's guidance.

- Unless otherwise instructed by the manufacturer, use the calibration cup that comes with the instrument for calibration.
- Use the recommended volume of standard solution when filling the calibration cup (e.g., the standard solution must cover the temperature sensor, as most sensors require temperature compensation).
- Be careful not to over tighten the calibration cup; many calibration cups have vents that allow their equilibration with ambient pressure.
- Rinse sensors thoroughly three times with DI water after use of each standard solution, followed by three rinses with the next standard solution to be used.
- Wait for readings to stabilize (approximately 30 seconds under normal conditions) before adjusting and saving the calibration point.
- Do not override a calibration error message without troubleshooting and correcting the cause of the error. For example, check the fluid level and check for air bubbles in the sensor. Record calibration end points and readings in the field book.
- Calibration frequency is dependent upon project specifications, instrument performance, and manufacturer's recommendations; repeat the calibration procedures as directed.
- Document the time, date, and calibration status for each instrument.
- If calibration fails to meet criteria, follow the manufacturer's instructions for corrective action to adjust instrument performance and note any indication of a substandard calibration.
- If the instrument does not start up, check out, or calibrate properly, the instrument should not be used.

7.5.1 Specific Conductance

SC, or conductivity, measures the ability of water to conduct an electric current. It is generally reported in microsiemens per centimeter (µS/cm) or millisiemens per centimeter. Natural waters, including groundwater, commonly exhibit specific conductance well below 1 µS/cm. Total dissolved solid concentrations may be approximated from specific conductance data; high readings (greater than 500 µS/cm) may indicate contamination, especially if the readings are elevated compared to background. Alternatively, elevated specific conductance may indicate inadequate well development, grout contamination, or an inadequate grout seal.

When calibrating for specific conductance:

- If not specified in the project-specific work plan, choose a SC standard solution recommended by the instrument manufacturer; otherwise, select a standard that is close in conductivity to that of the environmental water being sampled.
- The presence of air bubbles in conductivity electrodes will cause erroneous readings and incorrect calibration. Transmission lines, alternating-current electrical outlets and radio-frequency noise sources may cause interference; check with the instrument manufacturer's specifications for troubleshooting procedures.

7.5.2 Dissolved Oxygen

DO is used to assess the water quality with respect to certain metals (the amount of oxygen can control the valence state of metals) and, more typically, biological activity. Concentrations of DO in uncontaminated groundwater generally range from 1 to 4 milligrams per liter (mg/l). Erratic or elevated (greater than 4 milligrams per liter) DO readings may reflect sampling procedures that are causing excessive agitation and aeration of the water column which may affect sample results (i.e., oxidation or volatilization of dissolved compounds). Elevated DO readings may also indicate equipment maintenance issues. DO readings are sensitive to atmospheric interference and must be measured with a flow-through cell for *ex situ* measurements (i.e., those measured outside of the well itself). Select the type of DO sensor for the multi-parameter water quality meter in accordance with the project-specific work plan (i.e., the polarographic [or Clark cell] sensor or the luminescent [optical] sensor). Further discussion focuses on the more common polarographic sensor.

- Check the DO membrane for bubbles, wrinkles or tears. If necessary, install a new membrane and replace worn or stretched O-rings. Manufacturer guidance generally specifies membrane replacement should be completed at least 3 to 4 hours before use,
- Most manufacturers recommend that the sensor be allowed to equilibrate to the temperature of the water-vapor-saturated air for at least 15 minutes before calibration,
- Fill the calibration cup with less than 1/8 inch of water, or as recommended by the manufacturer.
- Remove any water droplets from the sensor without wiping the membrane. Water droplets on the sensor can cause a temperature compensation error in the DO calibration.
- Do not submerge or wet the sensor when loosely attaching the calibration cup.
- Enter the barometric pressure and wait for readings to stabilize before adjusting and saving the calibration point.

7.5.3 pH

pH is a measure of the effective concentration (or activity) of hydrogen ions and is expressed as the negative base-10 logarithm of the hydrogen-ion activity in moles per liter. Natural (uncontaminated) waters typically exhibit a pH ranging from 5 to 9 Standard Units (SU). Deviation of pH from background may indicate the presence of groundwater contamination or well construction problems.

Typically, a two-point calibration is used for pH (i.e., a zero-point and span calibration[s]):

- If not specified in the project-specific work plan, select a 7 SU buffer (zero-point) plus a second pH buffer (4 SU or 10 SU) that brackets the range of expected pH.
- If applicable, calibrate the conductivity and DO sensors before calibrating the pH sensor. This helps prevent cross-contamination of the conductivity sensor from pH buffer solutions (pH buffers have much higher conductivities than most environmental waters).
- Allow time for the pH and temperature sensors to equilibrate to the temperature of the buffer and stabilize before adjusting and saving the calibration point. Record the temperature reading and use the chart provided by the buffer manufacturer to determine the true pH of the buffer at that temperature and adjust the calibration reading to that value.
- Repeat the calibration process with the second buffer.

7.5.4 Oxidation-Reduction Potential

ORP is a numerical index of the intensity of the oxidizing or reducing conditions within an aqueous solution. Oxidizing conditions are indicated by positive potentials and reducing conditions are indicated by negative potentials; these values are frequently used when evaluating the biodegradation capacity of a system. Generally, negative potentials and low DO (less than 1 mg/l) are measured concurrently. ORP measurements are generally expressed in millivolts (mV). The ORP of natural (uncontaminated) waters typically ranges from +500 to -100 mV. ORP and reduction potential (Eh) are not equivalent. Follow the manufacturer’s instructions to calculate Eh. ORP readings are sensitive to atmospheric interference and must be measured with a flow-through cell; ORP may not be an appropriate stabilization parameter for some groundwater conditions. Avoid touching the sensors during calibration and measurement as calibration can be affected by static electricity.

A one-point calibration, at a known temperature, is used to calibrate the ORP sensor:

- Fill the calibration cup with enough standard solution (i.e., ZoBell's solution) to completely cover the temperature and ORP sensors.
- Allow time for the ORP and temperature sensors to equilibrate to the temperature of the buffer and stabilize before adjusting and saving the calibration point. Record the temperature reading and use the chart provided by the manufacturer to determine the true ORP of the solution at that temperature and adjust the calibration reading to that value.

7.5.5 Turbidity

Turbidity is the presence of suspended mineral and organic particles in a water sample. Turbid water may indicate inadequate well construction, development or improper sampling procedures, such as purging at an excessive rate that exceeds the well yield. Purging and sampling in a manner that produces low-turbidity water is particularly important when analyzing for total metals and other hydrophobic compounds, such as polychlorinated biphenyls, which may exhibit artificially elevated concentrations in high-turbidity samples due to their adsorption to colloidal material. Generally, the turbidity of *in situ* groundwater is very low (at or below 10 nephelometric turbidity units, NTUs); however, some groundwater zones may have natural turbidity higher than 10 NTUs.

Standard turbidity solutions are not necessarily interchangeable. Serious calibration errors can result from using inappropriate standards. Use only those standard turbidity solutions that are prescribed for the sensor by the instrument manufacturer.

Turbidity consists of a zero-point calibration and a span calibration(s):

- Fill the calibration cup to the reference line with DI or a zero-point standard.
- Allow time for the turbidity sensors to stabilize before adjusting and saving the calibration point. Record the temperature reading and use the chart provided by the buffer manufacturer to determine the true turbidity of the buffer and adjust the calibration reading to that value.
- Repeat the calibration process with the standard span calibration standard(s).

7.6 Equipment Use Procedures

Following calibration, use the monitoring equipment to complete the field measurement procedures directed in the project-specific work plan or QAPP.

- Charge instrument batteries per the manufacturer's instructions, as necessary.
- Ensure that instrument is warmed up and the measured value(s) on the water quality monitoring equipment are equilibrated (i.e., readings are representative of the solution, not ambient air) before recording in the field book.
- Biological growth or debris in the water can foul sensors; as possible, avoid inserting the sonde in areas that will result in having to stop and clean algae, sediment, or debris from the sensors (e.g., do not place on bottom of a well or streambed).
- If continuous monitoring is required, follow the manufacturer's instructions for performing continuous data logging events.

Monitoring should be performed at regular intervals as specified in the work plan, QAPP, and/or HASP. Record all measurements in the field book or on field forms and note any conditions that may affect the quality of the data (e.g., changes in weather or background conditions).

7.6.1 Groundwater

Field parameters are generally measured *ex situ* during well purging and development to provide an indication of when water representative of the formation is entering the well. Field parameters are typically recorded after each well volume is purged or at a periodic interval until stability criteria have been met. Field parameters may be measured *in situ* during purging by deploying a multi-parameter water quality meter downhole or lowered into a well or piezometer and collected at various depths (i.e., depth profile). Follow the instructions detailed in SOP 11 (Groundwater Sampling Procedures) for groundwater purging and sampling procedures.

7.6.1.1 Flow-through Cell Operation

A flow-through cell is used to minimize potential alteration of the water during contact with the air. A flow-through cell must be used when measuring DO or ORP under *ex situ* conditions.

- Inspect the integrity of the flow-through cell and O-rings.
- Connect the discharge tubing to the bottom of the flow-through cell using properly-sized tubing and fittings. Connect the effluent tubing to the top of the flow-through cell and secure the end of the tubing into the designated groundwater purge container.
- Shield the flow-through cell from direct sunlight to minimize changes in the temperature.
- Do not record any measurements until all the air from the flow-through cell and the effluent tubing has been displaced and the sensors have equilibrated. The presence of air bubbles in the flow-through cell will result in highly biased readings. Do not collect groundwater samples for laboratory analysis from the groundwater in the flow-through cell.

7.6.2 Surface Water

Surface water quality measurements commonly are monitored within a cross section of the surface water body to help determine the level of stratification or mixing (if the water body is moving). Typically a multi-parameter water quality meter is lowered through the water column to collect the data *in situ*. A multi-parameter water quality meter may be paired with a pressure transducer or graduated cable to record water quality changes with depth (i.e., depth profile). If strong currents exist, it may be necessary to attach the instruments to a weighted rope. After recording multiple measurements, as possible, return to the original measurement location to confirm the initial measurement; repeat as necessary. Follow the instructions detailed in SOP 12 (Surface Water Sampling Procedures) for surface water sampling procedures.

7.7 Closing Notes

Once field activities are complete, secure the site in accordance with the project-specific work plan. Decontaminate all equipment prior to departure and properly manage all PPE and IDW in conformance with applicable regulations.

FIELD STANDARD OPERATING PROCEDURE #11
Groundwater Sampling Procedure

Groundwater sampling procedures outlined in this Standard Operating Procedure (SOP) are designed to ensure that collected groundwater samples are representative of the water-bearing zone from which they were collected and that they have not been altered or contaminated by the sampling and handling methods. These procedures can be applied to permanently or temporarily-installed monitoring wells, direct-push sample points, water supply wells with installed plumbing, extraction wells for remedial groundwater treatment systems, and excavations where groundwater is present. The user is advised to read the entire SOP and review the site health and safety plan (HASP) before beginning any onsite activities. In accordance with the HASP, proper personal protective equipment (PPE) must be selected and used appropriately.

11.1 Acronyms and Abbreviations

CID	casing inside diameter
DI	deionized
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DTW	depth to water
HASP	health and safety plan
L/min	liters per minute
LNAPL	light non-aqueous phase liquid
mg/l	milligrams per liter
mV	millivolts
NAPL	non-aqueous phase liquid
NTU	nephelometric turbidity unit
ORP	oxygen reduction potential
PID	photoionization detector
PPE	personal protective equipment
QAPP	quality assurance project plan
SOP	standard operating procedure
SU	standard units
TD	total depth
TOC	top of casing
VOCs	volatile organic compounds

11.2 Materials

- Field book

- PPE
- Groundwater monitoring data log forms
- Well key(s), as needed
- Adjustable wrench or manhole wrench
- Plastic sheeting
- Air quality monitoring equipment (e.g., photoionization detector [PID]), as needed
- Flashlight or mirror
- Electronic water level indicator or interface probe
- Pump or bailers, tubing, and associated lanyard materials
- Water quality meter(s) with calibration reagents and standards
- Field test kits, as needed
- Pocket knife or scissors
- Distilled (DI) water
- Power supply, as needed
- Buckets or drum(s) for water storage
- Sample bottles, labels, indelible markers, and clear tape

11.3 Preconditions and Background

This SOP has been prepared as part of the WSP USA Corp. Environmental Quality Management Plan and is designed to provide detailed procedures for common field practices. Compliance with the methods presented in this document is mandatory for all field personnel and will ensure that the tasks are performed in a safe and consistent manner, are in accordance with federal and state guidance, and are technically defensible.

This SOP is written for the sole use of WSP employees and will be revised periodically to reflect updates to WSP policies, work practices, and the applicable state and/or federal guidance. WSP employees must verify that this document is the most recent version of the WSP SOPs. WSP employees are also strongly advised to review relevant state and/or federal guidance, which may stipulate program-specific procedures, in advance of task implementation.

This SOP is designed to provide the user with a general outline for conducting groundwater sampling and assumes the user is familiar with basic field procedures, such as recording field notes (SOP 1), utility location (SOP 2), sample shipment procedures (SOP 3), sample collection and quality assurance procedures (SOP 4), investigation derived waste (IDW) management procedures (SOP 5), equipment decontamination (SOP 6), and use and calibration of all sampling and monitoring equipment (SOPs 7 and 8). This SOP does not cover investigation planning, nor does it cover the analysis of the analytical results. These topics are more appropriately addressed in a project-specific work plan. Before groundwater sampling, be sure to review the project-specific work plan or Quality Assurance Project Plan (QAPP) and any applicable state and federal guidelines or sampling procedures. All sampling and monitoring references must be available for consultation in the field, including:

- WSP’s SOPs
- Applicable state and federal guidelines or sampling procedures
- Manufacturer’s manuals
- Project-specific work plan and HASP

- QAPP

11.4 General Procedures

Although the techniques used to sample groundwater are varied, most sampling events can be broken down into a three-step sequence:

- Gauging: provides an indication of the height of the water column within the well under ambient (pre-sampling) conditions; these data are used to calculate the purge volume using traditional sampling techniques
- Purging: removal of stagnant water from the well bore to ensure that samples collected are representative of groundwater conditions in the water-bearing zone surrounding the well
- Sample Collection: collection of aliquots of groundwater that are representative of the conditions in the water-bearing zone surrounding the well

The procedures and equipment that are used to accomplish these steps are project-specific and should be discussed by the project team before arriving onsite. All types of groundwater sampling, however, regardless of the equipment used, share common handling and management procedures that are designed to ensure the integrity of the samples collected. These procedures include:

- The use of new, disposable, decontaminated, or dedicated sampling equipment
- The use, changing, and disposal of the appropriate PPE
- Selection of a suitable sampling location and staging area

Collect all samples using either new, disposable equipment, or properly decontaminated sampling equipment. Groundwater purging and sampling equipment should be selected based on the analytical requirements of the project and the project specific conditions (e.g., well diameter, depth to water, dissolved constituents, etc.) likely to be encountered. The equipment should be constructed of non-reactive, non-leachable materials (e.g., stainless steel, Teflon®, Teflon®-coated steel, polyethylene, polypropylene, etc.) which are compatible with the chemical constituents at the site. When choosing groundwater purging and sampling equipment, give consideration to:

- the depth of the well
- the depth to groundwater
- the volume of water to be withdrawn
- the sampling and purging technique and equipment
- the analytes of interest

Select the decontamination procedures based on the types of sampling to be performed and decontamination may require multiple steps or differing cleaning methods, depending on the sampling goals (see SOP 6 for decontamination procedures). In no case should disposable, single use materials be used to collect more than one sample.

Wear a clean pair of new, disposable gloves each time a different sample is collected and don the gloves immediately prior to collection. This limits the possibility of cross-contamination from accidental contact. The gloves must not come in contact with the medium being sampled and must be changed any time during sample collection when their cleanliness is compromised.

As possible, find a suitable purging and sampling location by selecting an area that is away from any sources of cross-contamination that could compromise the integrity of the samples. This includes positioning the sample collection area away from fuel-powered equipment, such as drill rigs or excavators, and upwind of other site activities (e.g., purging, sampling, decontamination) that could influence the sample. This is particularly important when screening for volatile organic compounds (VOCs) with a PID, but should not be limited to the active sample collection. Store samples already collected from the field for laboratory analysis in clean containers and securely stage, if possible, in uncontaminated portions of the site.

11.5 Gauging Procedures

Once you have arrived onsite and are prepared to conduct the groundwater sampling, note the following observations and measurements in the field book (and on the project-specific groundwater monitoring log, if appropriate):

- Perform a quick reconnaissance of the site to identify sampling locations
- Record the approximate ambient air temperature, precipitation, wind (direction and speed), tidal, and other field conditions that could potentially alter the groundwater samples or water level measurements in the field book
- Inspect existing wells for soundness of protective casing and surface ground seal
- Remove the well covers and all standing water around the top of the well casing, as necessary, before opening the well cap
- Place new plastic sheeting (e.g., contractor grade 55-gallon plastic trash bags) on the ground surface around existing well locations to prevent contamination (via contact with the ground surface) of the pumps, hoses, lanyards, and other equipment; keep the plastic as clean as possible and replace as necessary
- Unlock and carefully remove well cap; allow the groundwater level to equilibrate with the atmospheric pressure a minimum of 15 minutes before conducting any down-hole testing or measurements

If required by the HASP, survey the open well casing and the breathing zone around the wellhead with a PID to ensure that the level of PPE is appropriate.

11.5.1 Groundwater Level and Total Depth Measurement Procedures

Depth to water (DTW) and total depth (TD) measurements are typically collected prior to sampling and are used to determine the volume water to be purged from the well (if using techniques other than low flow sampling). The depth to groundwater measurements are also used after the sampling event is completed to establish the groundwater elevation, flow direction, and gradient. Unless otherwise directed, do not place any objects inside the casing of private water wells; accordingly, depth to water and total depth measurements should not be collected at private water wells.

Water level measurements must be collected within the shortest interval possible from all selected existing wells to be gauged during the event before beginning any purge and sampling procedures at the site. This will ensure a nearly instantaneous snapshot of the water levels before the formations are disturbed by pumping or acted upon by other outside influences, such as tides, precipitation, barometric pressure, river stage, or intermittent pumping of production, irrigation, or supply wells.

If possible, do not measure TD until after completing the sampling to avoid disturbing the bottom of the well and suspending sediment or colloidal material in the water column (i.e., increasing the turbidity and potentially biasing the water quality samples). The TD of existing wells recorded in the field book from an earlier event can be used to calculate the purge volume for the well. In instances where the TD is required to calculate the standing water height and purge volume, take care to limit the amount of bottom disturbance by the probe. TD measurement is not required for low flow applications and should not be measured before sampling the well.

Record the following observations and measurements in the field book:

- Measure the casing inside diameter (CID) and record in inches

- Measure the DTW with an electronic water level indicator (or an interface meter, if non-aqueous phase liquid [NAPL] is potentially present – see procedures below) from the top of the casing (TOC) at the surveyor's mark, if present and record the depth (to the nearest 0.01 foot) in feet below TOC
- If no mark is present, measure from the north side of the casing and mark the measuring point with a knife, metal file (if the inner casing is metal) or indelible marker for future reference
- Measure the TD from TOC at the surveyor's mark or north side of the casing, as appropriate.

Because of tape buoyancy and weight effects encountered in deep wells with long water columns, it may be difficult to determine the TD of the well with an electronic water level indicator; sediment in the bottom of the well can also make it difficult to determine total depth. Care must be taken and proper equipment selection must be used in these situations to ensure accurate measurements.

11.5.2 Gauging Wells with Non-Aqueous Phase Liquid

If NAPL is potentially present at the site, the depth to water and NAPL thickness measurements are collected using an interface meter capable of distinguishing between the NAPL and the groundwater, or a weighted tape coated with the appropriate reactive indicator paste for the suspected NAPL. Measuring the thicknesses of NAPL can be difficult and must be done with care to avoid agitating the liquids and generating an emulsion. This is particularly the case for light non-aqueous phase liquids (LNAPL; those having a density less than water), which are typically viscous oils that cling to the probe. Oil coating the probe can result in thickness measurements that are biased high (i.e., overestimate the thickness of the NAPL).

Conduct the following procedures to ensure an accurate measurement of the NAPL thickness:

- For LNAPL, slowly lower the electronic interface probe in the well casing until the electronic tone indicates the probe is at the top of the LNAPL layer; measure the depth below the TOC to the nearest 0.01 foot.
- To gauge the thickness of the LNAPL, advance the probe slowly through the layer until the electronic tone indicates you are in the water below the layer and then slowly bring the probe back up to the bottom of the LNAPL. Repeat this process several times to ensure an accurate measurement of the bottom of the LNAPL layer (which can include bubbles and an emulsion layer).
- For dense non-aqueous phase liquid (DNAPL), advance the probe through the water column until the tone indicates the top of the DNAPL layer; record the depth below TOC.
- To gauge the thickness of the DNAPL, advance the probe through the layer to the bottom of the well.
- Decontaminate all non-disposable equipment in accordance with SOP 6.

11.6 Groundwater Purging Procedures

Purging is a process whereby potentially stagnant water is removed allowing the collection of samples that are representative of groundwater conditions in the water-bearing zone. The water in a well bore that has not been purged may be different that the surrounding formation due to a number of factors, such as exposure to ambient air. There are a number of purging methods (and several no-purge methods) that may be used, depending on specific conditions encountered (e.g., depth to water, hydraulic conductivity of the formation, etc.) and the sampling requirements. Several purge/no purge options are described below.

- **Multiple Volume Purge**: traditional well purging technique that relies on the withdrawal of the volume of the well bore and the surrounding filter pack (if present); typically three to five well volumes are removed using pumps or bailers. This methodology uses equipment that is easy to obtain and use and is generally accepted in most states as an appropriate purging method.
- **Temporary Well Purge**: a variation of the multiple volume purge technique that typically uses inertia lift pumps, peristaltic pumps, or bailers to remove water from a temporary well casing or from drilling rods that are

being used to screen water quality. This is a less stringent technique that is typically done to minimize the turbidity of the samples, which can be high due to the lack of a well filter pack.

- **Private Water Well or In-Place Plumbing Purge**: another variation on the multiple volume purge technique whereby a tap or faucet is opened on a fixed water supply pipe and is allowed to remain open until the potentially stagnant water within the well casing and other components of the system (e.g., fixed piping, pressure tanks, etc.) has been removed and groundwater representative of the water-bearing zone is being discharged at the tap.
- **Low-Flow (Minimal Drawdown/Low Stress) Purge (and Sampling)**: a modified purging technique that establishes an isolated, discrete, horizontal flow zone directly adjacent to the pump intake; this method requires the pump to be placed within a screened-interval or open borehole. Pumping rates are typically 0.1 to 0.5 liters per minute (L/min) or less to minimize the stress on the surrounding formation and reduce the geochemical alteration of the groundwater caused by pumping.
- **No-Purge/Passive Sampling Techniques**: These techniques use specialized equipment, such as permeable diffusion bags or trap samplers, to sample the undisturbed water column within a screened interval or open borehole. This methodology assumes that the water in the well is representative of the surrounding formation. The approach is well suited for some VOCs and, depending on the sample device used, metals and hydrophobic compounds.

As appropriate, install the pump, tubing, or passive sampler to the depth prescribed in the project-specific work plan or QAPP. Contain and/or manage purge water in accordance with the project-specific work plan.

11.6.1 Calculating One Purge Volume

For multiple volume purging techniques, a minimum of three well volumes of water must be removed before sample collection. The actual amount of water removed may be greater than the three volumes, depending on geochemical parameter stabilization (the field measurement of these parameters is discussed below).

Calculate the volume of water in a well or boring using the following equation:

$$\text{Volume (gallons)} = (TD - DTW)*CID^2*0.041$$

Alternately, the volume of water in a well or boring may also be calculated by multiplying the water column height by the gallons per foot of water for the appropriate well or boring diameter:

CID	Gallons per foot of water	Gallons per foot; three water columns
1-inch	0.04	0.12
2-inch	0.16	0.48
3-inch	0.37	1.11
4-inch	0.65	1.98

Calculate the total volume of the pump, associated tubing and container for *in situ* measurements (flow-through cell), using the following equation:

$$\text{Volume (in gallons)} = P + ((0.0041)*D^2*L) + fc$$

where:

P = volume of pump (gallons)

D = tubing diameter (inches)

L = length of tubing (feet)

fc = volume of flow-through cell (gallons)

11.6.2 Multiple Volume Purge Procedures

Begin purging at a rate that will not cause excessive turbulence and drawdown in the well; commonly less than 1 gallon per minute for a typical 2-inch diameter monitoring well. The objective is to remove the stagnant water in the casing and surrounding filter pack or open borehole allowing water from the surrounding water-bearing zone to enter the well for sampling with as little disturbance as possible. Excessive pump rates or well dewatering can result in higher turbidity, potential volatilization, and/or geochemical alteration of dissolved parameters. If drawdown is observed on initiation of pumping, reduce the pump speed and attempt to match the drawdown of the well. Once drawdown is stabilized, measure the flow rate with a calibrated container and stopwatch.

Collect stabilization parameters at a minimum of every half well volume during the purge process. Record the stabilization measurements in the field book along with any other pertinent details, such as the visual quality of the water (e.g., color, odor, and presence of suspended particulates) and the measured withdrawal rate, as possible. After the minimum purge volume has been removed, review the geochemical measurements to ensure that readings have stabilized. Stabilization occurs when at least three consecutive measurements are within the following tolerances:

Traditional Purge Stabilization Parameters	
pH	± 0.1 standard units (SU)
Specific Conductance	± 3%
Temperature	± 3%
Dissolved Oxygen (DO)	± 0.2 milligrams per liter (mg/l) or 10% (flow-through cell only)
Turbidity	± 10% for values greater than 10 nephelometric turbidity unit (NTU)
Oxygen Reduction Potential (ORP)	± 10 millivolts (mV; flow-through cell only)

If the parameters have not stabilized within five well volumes, the project team must decide whether or not to collect a sample or to continue purging.

For wells with extremely slow recharge, purging may ultimately dewater the well before the minimum purge can be completed. If the well or borehole is purged dry before removing three well volumes, allow well or boring to recharge to a level of approximately 90% of the static pre-purge water elevation and proceed immediately to sample collection. If recovery exceeds 2 hours, sample as soon as sufficient sample volume is available.

11.6.3 Temporary Well Purge Procedures

Procedures used to purge temporary groundwater monitoring wells differ from permanent wells because temporary wells are installed for immediate sample acquisition. Wells of this type may include open bedrock boreholes, standard polyvinyl chloride well screen and riser placed in boreholes created by rotary or direct-push drilling methods, or drilling rod-based sampling devices, such as Wellpoint®, Geoprobe® Screen Point 15/16, or Hydropunch® samplers. Purging temporary wells of this type may not be necessary because stagnant water is typically not present.

Purging can minimize the turbidity in the sample, which can be significant due to the disturbance caused by the sampler installation. The exception is for groundwater profiling applications (e.g., using a Waterloo Profiler®) where a more rigorous purge is used (using the multiple volume purge techniques described above) to limit the potential for cross contamination between sample intervals.

11.6.4 Private Water Well or In-Place Plumbing Purge Procedures

The configuration and construction of private water wells varies widely, and access points for obtaining groundwater samples may be limited. WSP personnel should coordinate with the property owner/representative to access functioning ports and valves to avoid causing any inadvertent damage.

Collect the groundwater sample as close to the well as possible (e.g., port at the well head) to ensure the sample is representative, ideally upstream of the water conveyance piping and any treatment equipment (e.g., particulate filter, water softener, carbon filters, ultra-violet lights), heating unit, or storage system (e.g., holding or pressure tanks). The following potential sampling locations are presented in order of preference:

- Sampling port or spigot near the well head or piping system prior to entry into the pressure tank or holding tank
- Sampling port or spigot at pressure tank or holding tank
- Sampling port or spigot downstream of the pressure tank or holding tank but upstream of any water treatment equipment
- Tap or faucet

If purging from a tap or faucet, try to remove any aerators, filters, or other devices from the tap before purging and work with the property owner/representative to bypass any water treatment systems. Document where the sample was collected and any steps that were taken to minimize the potential alteration of the water sample in the field book.

Start to purge the system by running water from the tap or spigot. Observe and record the purge rate for the system. The minimum purge volume must be more than the combined volume of the pump, holding tanks, conveyance piping, etc., and the flow through cell (if used). After the minimum purge volume has been removed, review the geochemical measurements to ensure that readings have stabilized using the same procedures as those used for the multiple volume purge detailed above. If the minimum volume is unknown, purge the system for a minimum of 15 minutes, until the parameter readings have stabilized, and no suspended particles (e.g., iron or rust) are visible. Record the final purge volume in the field book and any water quality observations.

11.6.5 Low-Flow Purge Procedures

Low flow purging and sampling is used to obtain representative groundwater samples without removing all of the water within the well casing or the surrounding filter pack. The protocol uses low pumping rates (i.e., less than 1 L/min) to establish an isolated zone around the inlet of the pump where flow is horizontal (i.e., from the water-bearing zone) rather than from the stagnant water in the well casing above and below the pump. Selection of an appropriate pump is critical to establishing the flow zone. A pump must be selected that is suited for low pumping rates and is appropriate for the analytical samples; bailers are not appropriate.

Position the pump so that the inlet is at the specified sampling depth. Wells with longer screens may require additional samples to be collected. Slowly lower the pump into the water column to avoid agitating the water column above the screen. Avoid contacting the bottom of the well by using pre-cut tubing at the appropriate length or by lowering the pump simultaneously with an electronic water level indicator. Once the pump has been inserted, allow the water levels to return to static conditions.

The discharge tubing must be fitted with an in-line flow-through cell equipped with water quality meters that provide continuous readout displays. The flow-through cell must be used to minimize the exposure of the groundwater to ambient air which has a substantial effect on dissolved oxygen and ORP measurements.

Start the pump and maintain a steady flow rate that results in a stabilized water level (less than 0.3 feet of drawdown). If needed, reduce the pumping rate to the minimum capabilities of the pump to ensure stabilization of the water level. Record each adjustment made to the pumping rate and the water level measured immediately after each adjustment. Purging should not exceed 0.1 to 0.5 L/min.

During purging, monitor and record geochemical parameters at 30 seconds to 5 minutes intervals (depending on the hydraulic conductivity of the aquifer, diameter of the well, and pumping rate). Stabilization occurs once the following criteria have been met over three successive measurements made at least three minutes apart:

Low-Flow Purge Stabilization Parameters	
Water Level Drawdown	<0.3 feet
pH	± 0.1 SU
Specific Conductance	± 3%
Temperature	± 3%
Low-Flow Purge Stabilization Parameters	
DO	± 0.2 mg/l or 10% (flow-through cell only)
Turbidity	± 10% for values greater than 10 NTU
ORP	± 10 mV (flow-through cell only)

11.6.6 No-Purge Passive Sampling Techniques

A number of alternate sampling devices are available, including equilibrated grab samplers, passive diffusion samplers, and other *in situ* sampling devices. These devices may be particularly useful for sampling low permeability geologic materials, assuming the device is made of materials compatible with the analytical parameters, meets data quality objectives, and has been properly evaluated.

No-flow grab or trap samplers are placed in the well before sampling and typically remain closed (i.e., no water is allowed into the sampler during insertion) until the sampler is activated. This allows the sampler device to equilibrate with the surrounding groundwater (to prevent adsorption to the sampler materials) and for the groundwater to recover and re-establish the natural flow after the disturbance caused by the sampler insertion into the well. Typical equilibration times are on the order of 24 to 48 hours, depending on the well recovery rates and the type of sampler used. Samples are either transferred to containers at the well head or the sampler itself is shipped to the laboratory for analysis. Examples of equilibrated grab samplers include Hydrosleeve®, Snap Sampler™, and Kemmerer Sampler.

Equilibration time for diffusion samplers are generally dictated by the diffusion rate through the permeable membrane and, thus, are less sensitive to changes induced within the well during deployment. Most diffusion bag samplers have a minimum equilibration time of 14 days prior to sample collection. The samplers may be deployed for an extended period (e.g., three months or longer), although the continuous exchange between the sampler and the well water means that the sampler will likely reflect only the conditions in the few days preceding the sample collection.

11.7 Groundwater Sample Collection Procedures

Collect groundwater samples as soon as possible after the geochemical parameters indicate representative groundwater is present. As practically possible, reduce the pump flow rate, but maintain a flow rate high enough to deliver a smooth stream of water without splashing or undue agitation. Collect samples directly from the tubing as it exits the well bore; do not sample on the downstream side of flow through cells or any other instrumentation. If using a bailer for sample collection, lower and raise the bailer slowly and smoothly to minimize the disturbance to the water within the well.

Collect groundwater samples in order of volatilization sensitivity with organic compounds sampled first followed by inorganic compounds:

- VOCs
- Extractable organics, petroleum hydrocarbons, aggregate organics, and oil and grease
- Total metals
- Dissolved metals (see filtering procedures below)
- Inorganic non-metallic and physical and aggregate properties
- Microbiological samples
- Radionuclides

Collect quality assurance/quality control samples in accordance with SOP 4 and the project-specific work plan or QAPP.

As necessary, conduct field tests or screening in accordance with the project-specific work plan and manufacturer's specifications for field testing equipment. Field samples must be directly transferred from the sampling equipment to the container that has been specifically prepared for that given parameter; intermediate containers should be avoided.

11.7.1 Groundwater Filtration Procedures

Filtered groundwater samples are sometimes used for field kit analyses and should only be collected for laboratory analysis after approval from the appropriate regulatory agency and/or project manager. If groundwater sample filtration is necessary, the following procedures should be followed:

- Use a variable speed peristaltic, bladder, or submersible pump with the in-line filter fitted on the outlet end; pressurized bailers can also be used
- At the pump discharge end, attach a clean appropriate sized filter to the tubing
- Turn on the pump and reduce the flow rate, but maintain a flow rate high enough to deliver a smooth stream of water without splashing or undue agitation, hold the filter upright with the inlet and outlet in the vertical position and pump groundwater through the filter until all atmospheric oxygen has been removed and the minimum volume of water has been flushed through the filter, in accordance with the manufacturer's specifications
- Collect the filtered samples directly into the sample container from the pump-filter assembly
- If sediment is visible in the sample container after filtration, filter break-through has occurred and the sampling and filtering process should be repeated
- Disassemble the pump head and discard the tubing and filter appropriately

11.7.2 Non-Aqueous Phase Liquid Sampling Procedures

Non-aqueous phase liquid is typically sampled to identify the compound, usually through an analytical "fingerprint" analysis. The usefulness of this type of sampling is limited as many NAPLs weather in the subsurface making definitive identification problematic. If samples are to be collected, ensure that the NAPL is not considered to be a hazardous material for the purpose of shipping to the laboratory (SOP 3). Sampling options should be discussed with the assigned WSP compliance professional and project manager.

Samples for LNAPL are best collected using a bailer. Disposable plastic (acrylic, clear polyvinyl chloride) bailers are ideal for sampling as they provide a clear view as to what has been captured by the bailer. Disposable polyethylene and polypropylene bailers are also acceptable, but more difficult to use because of the translucent materials. Some bailer manufacturers offer a special sampling tip that can be fitted to the bailer to aid in the sample collection. Dense non-aqueous phase liquid is typically collected using a peristaltic pump, inertial pump, double check valve bailer, or polyethylene tubing equipped with a bottom check valve. Care should be used to avoid agitating the samples and creating an emulsion.

Samples of NAPL should be placed in the appropriate laboratory-supplied containers, packed on ice, and shipped to the analytical laboratory using procedures outlined in SOP 3.

11.7.3 Sample Labeling and Preparation for Shipment

Once collected, prepare the groundwater samples for offsite laboratory analysis:

- Cleaning the outside of the sample container
- Affixing a sample tag or label to each sample container and complete all required information (sample number, date, time, sampler's initials, analysis, preservatives, place of collection)
- Placing clear tape over the tag or label (if non-waterproof labels are used)
- Preserving samples immediately after collection by placing them into an insulated cooler filled with bagged wet ice to maintain a temperature of approximately 4° Celsius
- Recording the sample designation, date, time, and the sampler's initials in the field book and on a sample tracking form, if appropriate
- Completing the chain-of-custody forms with appropriate sampling information
- Securing the sample packing and shipping in accordance with proper procedures

Do not ship hazardous waste samples without first consulting a WSP compliance professional.

11.8 Closing Notes

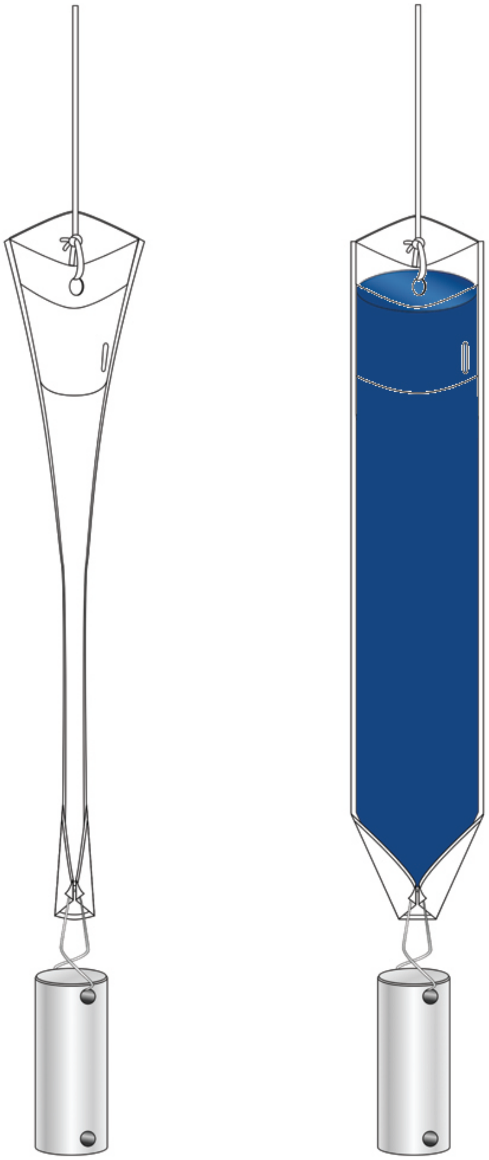
Once sampling is completed, secure the boreholes/wells/locations in accordance with the project-specific project work plan. Decontaminate all equipment prior to departure and properly manage all PPE and IDW in conformance with applicable regulations.

Appendix B – HydraSleeve Standard Operating Procedure

HYDRASleeve™

Simple by Design US Patent No. 6,481,300; No. 6,837,120 others pending

Standard Operating Procedure:
Sampling Ground Water with a HydraSleeve



This Guide should be used in addition to field manuals appropriate to sampling device (i.e., HydraSleeve or Super Sleeve).

Find the appropriate field manual on the HydraSleeve website at http://www.hydrasleeve.com.

For more information about the HydraSleeve, or if you have questions, contact:
GeoInsight, 2007 Glass Road, Las Cruces, NM 88005, 1-800-996-2225,
info@hydrasleeve.com.

Table of Contents

Introduction

The HydraSleeve is classified as a no-purge (passive) grab sampling device, meaning that it is used to collect ground-water samples directly from the screened interval of a well without having to purge the well prior to sample collection. When it is used as described in this Standard Operating Procedure (SOP), the HydraSleeve causes no drawdown in the well (until the sample is withdrawn from the water column) and only minimal disturbance of the water column, because it has a very thin cross section and it displaces very little water (<100 ml) during deployment in the well. The HydraSleeve collects a sample from within the screen only, and it excludes water from any other part of the water column in the well through the use of a self-sealing check valve at the top of the sampler. It is a single-use (disposable) sampler that is not intended for reuse, so there are no decontamination requirements for the sampler itself.

The use of no-purge sampling as a means of collecting representative ground-water samples depends on the natural movement of ground water (under ambient hydraulic head) from the formation adjacent to the well screen through the screen. Robin and Gillham (1987) demonstrated the existence of a dynamic equilibrium between the water in a formation and the water in a well screen installed in that formation, which results in formation-quality water being available in the well screen for sampling at all times. No-purge sampling devices like the HydraSleeve collect this formation-quality water as the sample, under undisturbed (non-pumping) natural flow conditions. Samples collected in this manner generally provide more conservative (i.e., higher concentration) values than samples collected using well-volume purging, and values equivalent to samples collected using low-flow purging and sampling (Parsons, 2005).

Applications of the HydraSleeve

The HydraSleeve can be used to collect representative samples of ground water for all analytes (volatile organic compounds [VOCs], semi-volatile organic compounds [SVOCs], common metals, trace metals, major cations and anions, dissolved gases, total dissolved solids, radionuclides, pesticides, PCBs, explosive compounds, and all other analytical parameters). Designs are available to collect samples from wells from 1” inside diameter and larger. The HydraSleeve can collect samples from wells of any yield, but it is especially well-suited to collecting samples from low-yield wells, where other sampling methods can’t be used reliably because their use results in dewatering of the well screen and alteration of sample chemistry (McAlary and Barker, 1987).

The HydraSleeve can collect samples from wells of any depth, and it can be used for single-event sampling or long-term ground-water monitoring programs. Because of its thin cross section and flexible construction, it can be used in narrow, constricted or damaged wells where rigid sampling devices may not fit. Using multiple HydraSleeves deployed in series along a single suspension line or tether, it is also possible to conduct in-well vertical profiling in wells in which contaminant concentrations are thought to be stratified.

As with all groundwater sampling devices, HydraSleeves should not be used to collect groundwater samples from wells in which separate (non-aqueous) phase hydrocarbons (i.e., gasoline, diesel fuel or jet fuel) are present because of the possibility of incorporating some of the separate-phase hydrocarbon into the sample.

Description of the HydraSleeve

The HydraSleeve (Figure 1) consists of the following basic components:

- A suspension line or tether (A.), attached to the spring clip or directly to the top of the sleeve to deploy the device into and recover the device from the well. Tethers with depth indicators marked in 1-foot intervals are available from the manufacturer.
- A long, flexible, 4-mil thick lay-flat polyethylene sample sleeve (C.) sealed at the bottom (this is the sample chamber), which comes in different sizes, as discussed below with a self-sealing reed-type flexible polyethylene check valve built into the top of the sleeve (B.) to prevent water from entering or exiting the sampler except during sample acquisition.
- A reusable stainless-steel weight with clip (D.), which is attached to the bottom of the sleeve to carry it down the well to its intended depth in the water column. Bottom weights available from the manufacturer are 0.75” OD and are available in three sizes: 5 oz. (2.5” long); 8 oz. (4” long); and 16 oz. (8” long). In lieu of a bottom weight, an optional top weight may be attached to the top of the HydraSleeve to carry it to depth and to compress it at the bottom of the well (not shown in Figure 1);
- A discharge tube that is used to puncture the HydraSleeve after it is recovered from the well so the sample can be decanted into sample bottles (not shown).
- Just above the self-sealing check valve at the top of the sleeve are two holes which provide attachment points for the spring clip and/or suspension line or tether. At the bottom of the sample sleeve are two holes which provide attachment points for the weight clip and weight.

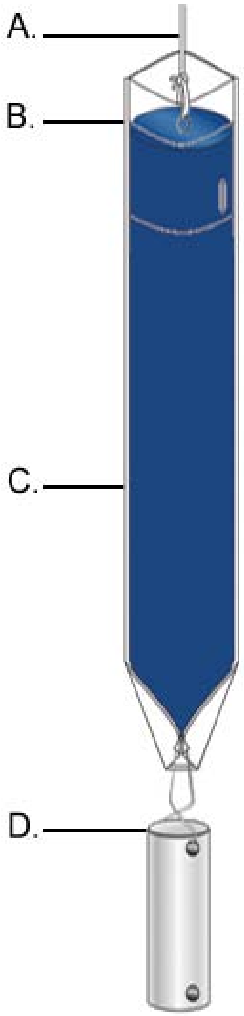


Figure 1. HydraSleeve components.

Note: The sample sleeve and the discharge tube are designed for one-time use and are disposable. The spring clip, weight and weight clip may be reused after thorough cleaning. Suspension cord is generally disposed after one use although, if it is dedicated to the well, it may be reused at the discretion of the sampling personnel.

Selecting the HydraSleeve Size to Meet Site-Specific Sampling Objectives

It is important to understand that each HydraSleeve is able to collect a finite volume of sample because, after the HydraSleeve is deployed, you only get one chance to collect an undisturbed sample. Thus, the volume of sample required to meet your site-specific sampling and analytical requirements will dictate the size of HydraSleeve you need to meet these requirements.

The volume of sample collected by the HydraSleeve varies with the diameter and length of the HydraSleeve. Dimensions and volumes of available HydraSleeve models are detailed in Table 1.

Table 1. Dimensions and volumes of HydraSleeve models.

Diameter	Volume	Length	Lay-Flat Width	Filled Dia.
2-Inch HydraSleeves				
Standard 625-ml HydraSleeve	625 ml	< 30”	2.5”	1.4”
Standard 1-Liter HydraSleeve	1 Liter	38”	3”	1.9”
1-Liter HydraSleeve SS	1 Liter	36”	3”	1.9”
2-Liter HydraSleeve SS	2 Liters	60”	3”	1.9”
4-Inch HydraSleeves				
Standard 1.6-Liter HydraSleeve	1.6 Liters	30”	3.8”	2.3”
Custom 2-Liter HydraSleeve	2 Liters	36”	4”	2.7”

HydraSleeves can be custom-fabricated by the manufacturer in varying diameters and lengths to meet specific volume requirements. HydraSleeves can also be deployed in series (i.e., multiple HydraSleeves attached to one tether) to collect additional sample to meet specific volume requirements, as described below.

If you have questions regarding the availability of sufficient volume of sample to satisfy laboratory requirements for analysis, it is recommended that you contact the laboratory to discuss the minimum volumes needed for each suite of analytes. Laboratories often require only 10% to 25% of the volume they specify to complete analysis for specific suites of analytes, so they can often work with much smaller sample volumes that can easily be supplied by a HydraSleeve.

HydraSleeve Deployment

Information Required Before Deploying a HydraSleeve

Before installing a HydraSleeve in any well, you will need to know the following:

- The inside diameter of the well
- The length of the well screen
- The water level in the well
- The position of the well screen in the well
- The total depth of the well

The inside diameter of the well is used to determine the appropriate HydraSleeve diameter for use in the well. The other information is used to determine the proper placement of the HydraSleeve in the well to collect a representative sample from the screen (see HydraSleeve Placement, below), and to determine the appropriate length of tether to attach to the HydraSleeve to deploy it at the appropriate position in the well.

Most of this information (with the exception of the water level) should be available from the well log; if not, it will have to be collected by some other means. The inside diameter of the well can be measured at the top of the well casing, and the total depth of the well can be measured by sounding the bottom of the well with a weighted tape. The position and length of the well screen may have to be determined using a down-hole camera if a well log is not available. The water level in the well can be measured using any commonly available water-level gauge.

HydraSleeve Placement

The HydraSleeve is designed to collect a sample directly from the well screen, and it fills by pulling it up through the screen a distance equivalent to 1 to 1.5 times its length. This upward motion causes the top check valve to open, which allows the device to fill. To optimize sample recovery, it is recommended that the HydraSleeve be placed in the well so that the bottom weight rests on the bottom of the well and the top of the HydraSleeve is as close to the bottom of the well screen as possible. This should allow the sampler to fill before the top of the device reaches the top of the screen as it is pulled up through the water column, and ensure that only water from the screen is collected as the sample. In short-screen wells, or wells with a short water column, it may be necessary to use a top-weight on the HydraSleeve to compress it in the bottom of the well so that, when it is recovered, it has room to fill before it reaches the top of the screen.

Example

2” ID PVC well, 50’ total depth, 10’ screen at the bottom of the well, with water level above the screen (the entire screen contains water).

Correct Placement (figure 2): Using a standard HydraSleeve for a 2” well (2.6” flat width/1.5” filled OD x 30” long, 650 ml volume), deploy the sampler so the weight (an 8 oz., 4”-long weight with a 2”-long clip) rests at the bottom of the well. The top of the sleeve is thus set at about 36” above the bottom of the well. When the sampler is recovered, it will be pulled upward approximately 30” to 45” before it is filled; therefore, it is full (and the top check valve closes) at approximately 66” (5 ½ feet) to 81” (6 ¾ feet) above the bottom of the well, which is well before the sampler reaches the top of the screen. In this example, only water from the screen is collected as a sample.

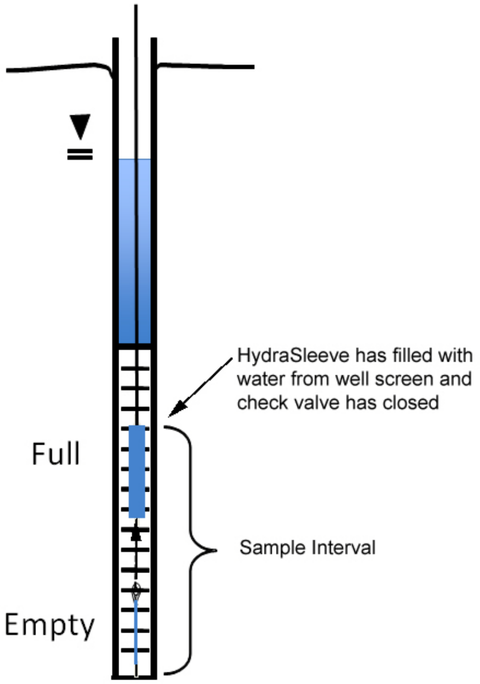


Figure 2. Correct placement of HydraSleeve.

Incorrect Placement (figure 3): If the well screen in this example was only 5' long, and the HydraSleeve was placed as above, it would not fill before the top of the device reached the top of the well screen, so the sample would include water from above the screen, which may not have the same chemistry.

The solution? Deploy the HydraSleeve with a top weight, so that it is collapsed to within 6" to 9" of the bottom of the well. When the HydraSleeve is recovered, it will fill within 39" (3 ¼ feet) to 54" (4 ½ feet) above the bottom of the well, or just before the sampler reaches the top of the screen, so it collects only water from the screen as the sample.

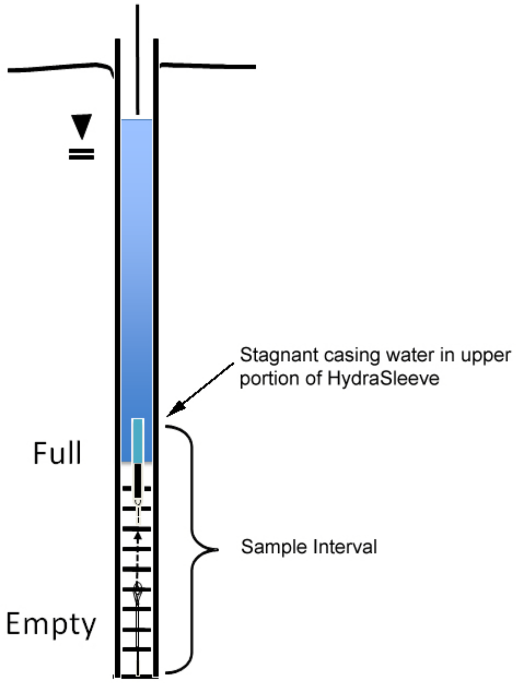


Figure 3. Incorrect placement of HydraSleeve.

This example illustrates one of many types of HydraSleeve placements. More complex placements are discussed in a later section.

Procedures for Sampling with the HydraSleeve

Collecting a ground-water sample with a HydraSleeve is a simple one-person operation.

Note: Before deploying the HydraSleeve in the well, collect the depth-to-water measurement that you will use to determine the preferred position of the HydraSleeve in the well. This measurement may also be used with measurements from other wells to create a ground-water contour map. If necessary, also measure the depth to the bottom of the well to verify actual well depth to confirm your decision on placement of the HydraSleeve in the water column.

Measure the correct amount of tether needed to suspend the HydraSleeve in the well so that the weight will rest on the bottom of the well (or at your preferred position in the well). Make sure to account for the need to leave a few feet of tether at the top of the well to allow recovery of the sleeve

Note: Always wear sterile gloves when handling and discharging the HydraSleeve.

I. Assembling the HydraSleeve

1. Remove the HydraSleeve from its packaging, unfold it, and hold it by its top.
2. Crimp the top of the HydraSleeve by folding the hard polyethylene reinforcing strips at the holes.
3. Attach the spring clip to the holes to ensure that the top will remain open until the sampler is retrieved.
4. Attach the tether to the spring clip by tying a knot in the tether.

Note: Alternatively, attach the tether to one (NOT both) of the holes at the top of the Hydrasleeve by tying a knot in the tether.

5. Fold the flaps with the two holes at the bottom of the HydraSleeve together and slide the weight clip through the holes.
6. Attach a weight to the bottom of the weight clip to ensure that the HydraSleeve will descend to the bottom of the well.

II. Deploying the HydraSleeve

1. Using the tether, carefully lower the HydraSleeve to the bottom of the well, or to your preferred depth in the water column

   During installation, hydrostatic pressure in the water column will keep the self-sealing check valve at the top of the HydraSleeve closed, and ensure that it retains its flat, empty profile for an indefinite period prior to recovery.

Note: Make sure that it is not pulled upward at any time during its descent. If the HydraSleeve is pulled upward at a rate greater than 0.5'/second at any time prior to recovery, the top check valve will open and water will enter the HydraSleeve prematurely.

2. Secure the tether at the top of the well by placing the well cap on the top of the well casing and over the tether.

Note: Alternatively, you can tie the tether to a hook on the bottom of the well cap (you will need to leave a few inches of slack in the line to avoid pulling the sampler up as the cap is removed at the next sampling event).

III. Equilibrating the Well

The equilibration time is the time it takes for conditions in the water column (primarily flow dynamics and contaminant distribution) to restabilize after vertical mixing occurs (caused by installation of a sampling device in the well).

- Situation: The HydraSleeve is deployed for the first time or for only one time in a well

  The HydraSleeve is very thin in cross section and displaces very little water (<100 ml) during deployment so, unlike most other sampling devices, it does not disturb the water column to the point at which long equilibration times are necessary to ensure recovery of a representative sample.

  In most cases, the HydraSleeve can be recovered immediately (with no equilibration time) or within a few hours. In regulatory jurisdictions that impose specific requirements for equilibration times prior to recovery of no-purge sampling devices, these requirements should be followed.

- Situation: The HydraSleeve is being deployed for recovery during a future sampling event

  In periodic (i.e., quarterly or semi-annual) sampling programs, the sampler for the current sampling event can be recovered and a new sampler (for the next sampling event) deployed immediately thereafter, so the new sampler remains in the well until the next sampling event.

Thus, a long equilibration time is ensured and, at the next sampling event, the sampler can be recovered immediately. This means that separate mobilizations, to deploy and then to recover the sampler, are not required. HydraSleeves can be left in a well for an indefinite period of time without concern.

IV. HydraSleeve Recovery and Sample Collection

1. Hold on to the tether while removing the well cap.
2. Secure the tether at the top of the well while maintaining tension on the tether (but without pulling the tether upwards)
3. Measure the water level in the well.
4. In one smooth motion, pull the tether up between 30” to 45” (36” to 54” for the longer HydraSleeve) at a rate of about 1’ per second (or faster).

   The motion will open the top check valve and allow the HydraSleeve to fill (it should fill in about 1 to 1.5 times the length of the HydraSleeve). This is analogous to coring the water column in the well from the bottom up.

   When the HydraSleeve is full, the top check valve will close. You should begin to feel the weight of the HydraSleeve on the tether and it will begin to displace water. The closed check valve prevents loss of sample and entry of water from zones above the well screen as the HydraSleeve is recovered.
5. Continue pulling the tether upward until the HydraSleeve is at the top of the well.
6. Decant and discard the small volume of water trapped in the Hydrasleeve above the check valve by turning the sleeve over.

V. Sample Collection

Note: Sample collection should be done immediately after the HydraSleeve has been brought to the surface to preserve sample integrity.

1. Remove the discharge tube from its sleeve.
2. Hold the HydraSleeve at the check valve.
3. Puncture the HydraSleeve just below the check valve with the pointed end of the discharge tube
4. Discharge water from the HydraSleeve into your sample containers.

Control the discharge from the HydraSleeve by either raising the bottom of the sleeve, by squeezing it like a tube of toothpaste, or both.

5. Continue filling sample containers until all are full.

Measurement of Field Indicator Parameters

Field indicator parameter measurement is generally done during well purging and sampling to confirm when parameters are stable and sampling can begin. Because no-purge sampling does not require purging, field indicator parameter measurement is not necessary for the purpose of confirming when purging is complete.

If field indicator parameter measurement is required to meet a specific non-purging regulatory requirement, it can be done by taking measurements from water within a HydraSleeve that is not used for collecting a sample to submit for laboratory analysis (i.e., a second HydraSleeve installed in conjunction with the primary sample collection HydraSleeve [see Multiple Sampler Deployment below]).

Alternate Deployment Strategies

Deployment in Wells with Limited Water Columns

For wells in which only a limited water column exists to be sampled, the HydraSleeve can be deployed with an optional top weight instead of a bottom weight, which collapses the HydraSleeve to a very short (approximately 6” to 9”) length, and allows the HydraSleeve to fill in a water column only 36” to 45” in height.

Multiple Sampler Deployment

Multiple sampler deployment in a single well screen can accomplish two purposes:

- It can collect additional sample volume to satisfy site or laboratory-specific sample volume requirements.
- It can accommodate the need for collecting field indicator parameter measurements.
- It can be used to collect samples from multiple intervals in the screen to allow identification of possible contaminant stratification.

It is possible to use up to 3 standard 30” HydraSleeves deployed in series along a single tether to collect samples from a 10’ long well screen without collecting water from the interval above the screen.

The samplers must be attached to the tether at both the top and bottom of the sleeve. Attach the tether at the top with a stainless-steel clip (available from the manufacturer). Attach the tether at the bottom using a cable tie. The samplers must be attached as follows (figure 4):

- The first (attached to the tether as described above, with the weight at the bottom) at the bottom of the screen
- The second attached immediately above the first
- The third (attached the same as the second) immediately above the second

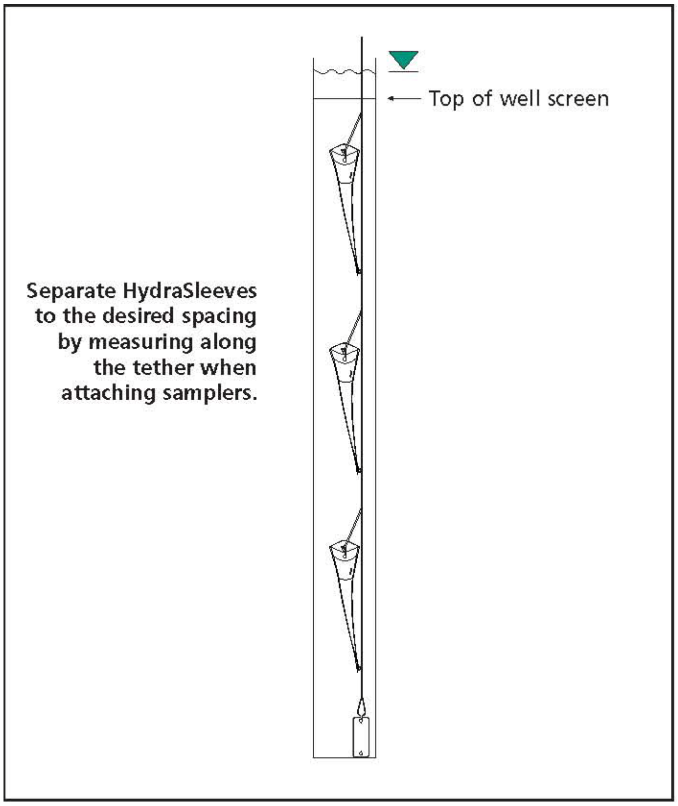


Figure 4. Multiple HydraSleeve deployment.

Alternately, the first sampler can be attached to the tether as described above, a second attached to the bottom of the first using a short length of tether (in place of the weight), and the third attached to the bottom of the second in the same manner, with the weight attached to the bottom of the third sampler (figure 5).

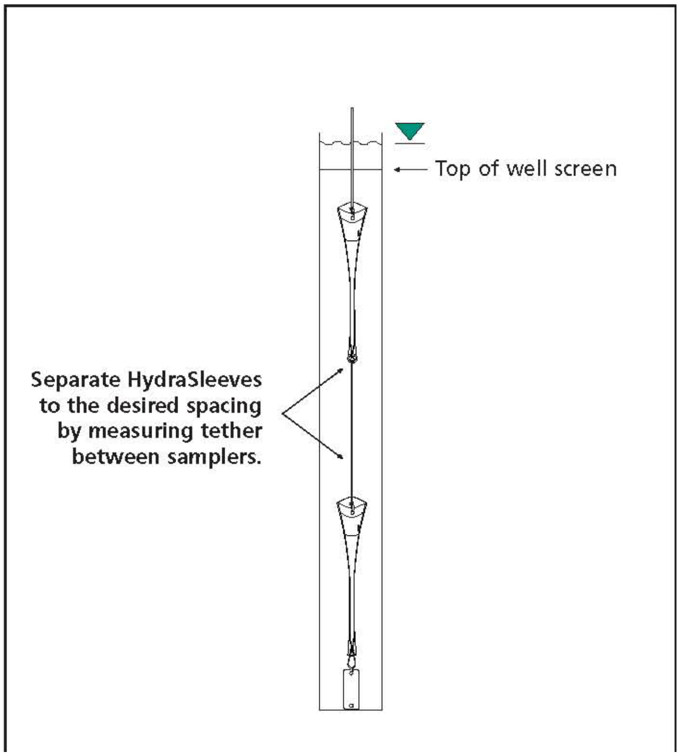


Figure 5. Alternative method for deploying multiple HydraSleeves.

In either case, when attaching multiple HydraSleeves in series, more weight may be required to hold the samplers in place in the well than would be required with a single sampler. Recovery of multiple samplers and collection of samples is done in the same manner as for single sampler deployments.

Post-Sampling Activities

The recovered HydraSleeve and the sample discharge tubing should be disposed as per the solid waste management plan for the site. To prepare for the next sampling event, a new HydraSleeve can be deployed in the well (as described previously) and left in the well until the next sampling event, at which time it can be recovered.

The weight and weight clip can be reused on this sampler after they have been thoroughly cleaned as per the site equipment decontamination plan. The tether may be dedicated to the well and reused or discarded at the discretion of sampling personnel.

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